ENVI Tutorials

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Contents

Preface

The following topics are covered in this chapter.

Introducing ENVI

ENVI (the Environment for Visualizing Images) is a state-of-the-art image processing system designed to provide comprehensive analysis of satellite and aircraft remote sensing data. It provides a powerful, innovative, and user-friendly environment to display and analyze images of any size and data type on a wide range of computing platforms.

With its combined file- and band-based approach to image processing, ENVI allows you to work with entire image files, individual bands, or both. When an input file is opened, each spectral band becomes available to all system functions. With multiple input files open, you can easily select bands from different files to be processed together. ENVI also includes tools to extract spectra, use spectral libraries, and to analyze high spectral resolution image datasets such as AVIRIS, GERIS, and GEOSCAN and HyMap. In addition to its world-class hyperspectral analysis tools, ENVI provides specialized capabilities for analysis of advanced SAR data sets such as JPL's SIR-C, AIRSAR, and TOPSAR.

ENVI is written entirely in IDL, the Interactive Data Language. IDL is a powerful, array-based, structured programming language that provides integrated image processing and display capabilities and an easy to use GUI toolkit. ENVI is available as ENVI (offering full ENVI command line capabilities) and ENVI RT (the runtime version of ENVI). The only difference between ENVI and ENVI RT is that ENVI RT does not provide user access to the underlying IDL environment. You will not be able to complete the User Function tutorial provided here if you are running ENVI RT.

About These Tutorials

This document contains hands-on tutorials designed to help you become familiar with ENVI's features and capabilities. Each tutorial is formatted to clearly direct you through required tasks.

Within each tutorial, the tasks you will perform have been broken down into numbered steps, which appear in bold print. Optional steps and single-step activities are preceded by a text bullet. The following formatting conventions will help you identify the type of action required within the various steps:

- The titles of pull-down menu items appear **bold**. They are connected in order of selection by an → (arrow). For example, select **File** → **Open Image File**.
- Dialog box names are **bolded**.
- Button menus, found in many dialogs, are **bolded**; however, items selected from the pull-down menu are *italicized* like other pull-down menu selections.
- Text box names, radio buttons, spin box titles, and other buttons also appear in **bold**.
- Filenames and paths appear in courier font. For example, open the file `cuptm_rf.img`.

At the beginning of each tutorial, you will find a detailed outline of the topics covered in that tutorial. Each tutorial begins with an overview and background explaining the history and application of the functions you will be using. Also included are the names of the files required to complete the tutorial.

Finally, at the end of each tutorial, references are provided for further exploration.

ENVI Quick Start

This tutorial, which is also distributed as a small booklet with the ENVI CD-ROM is designed to get you quickly into the basics of ENVI. It allows you to start ENVI, load either a gray scale or color image, and apply contrast stretches. It demonstrates image animation (movies) and 2-dimensional scatterplots to help users determine the spectral variability of their data. Regions of interest (ROI) selection instructions allow new users to quickly move into multispectral classification. ENVI's dynamic overlay capabilities are used to compare color composites and classified images. Finally, the tutorial provides a quick introduction to ENVI's vector overlays and GIS analysis capabilities.

ENVI Tutorial #1: Introduction to ENVI (Canon City, Colorado Landsat TM)

This tutorial provides basic information about ENVI and some suggestions for your initial investigations of the software. Landsat TM data of Canon City, Colorado are used. This tutorial is designed to introduce first-time ENVI users to the basic concepts of the package and to explore some of its key features. It assumes that you are already familiar with general image-processing concepts.

ENVI Tutorial #2: Introduction to Panchromatic Data and Basic Vector Overlays (Enfidaville, Tunisia SPOT and DXF)

This tutorial provides an introduction to using ENVI with Panchromatic (SPOT) data, including display, contrast enhancement, basic information about ENVI and some suggestions for your initial investigations of the software. It is designed to introduce first-time ENVI users to the basic concepts of the package and to explore some of its key features. It assumes that you are already familiar with general image-processing concepts. This dataset is a SPOT Panchromatic image and corresponding DXF files of Enfidaville, Tunisia, courtesy of Research Systems International France. These data are Copyright CNES-Spot Image and IGN France.

ENVI Tutorial #3: Multispectral Classification (Canon City, Colorado, Landsat TM)

This tutorial leads you through typical multispectral classification procedures using Landsat TM data from Canon City, Colorado. Results of both unsupervised and supervised classifications are examined and post classification processing including clump, sieve, combine classes, and accuracy assessment are discussed. It is assumed that you are already generally familiar with multispectral classification techniques.

ENVI Tutorial #4: Image Georeferencing and Registration (Boulder, Colorado TM and SPOT)

This tutorial provides basic information about Georeferenced images in ENVI, and Image-to-Image and Image-to-Map Registration using ENVI. Landsat TM and SPOT data from Boulder, Colorado are used. The tutorial covers step-by-step procedures for successful registration, discusses how to make image-maps using ENVI and illustrates the use of multi-resolution data for image sharpening. The exercises are designed to provide a starting point to users trying to conduct image registration. They assume that you are already familiar with general image-registration and resampling concepts.

ENVI Tutorial #5: Georeferencing Images Using Input Geometry (Cuprite, Nevada HyMap)

Data from many sensors now comes with detailed acquisition (platform geometry) information that allows model-based geometric rectification and map registration. This tutorial provides basic information about Georeferenced images in ENVI and Model-Based Geometric Correction using image input geometry within ENVI. It discusses required data characteristics and covers step-by-step procedures for successful registration. It assumes that you are already familiar with general image-registration and resampling concepts. 1999 HyMap data of Cuprite, Nevada, used for the tutorial are copyright 1999 Analytical Imaging and Geophysics (AIG) and HyVista Corporation (All Rights Reserved), and may not be redistributed without explicit permission from AIG (info@aigllc.com).

ENVI Tutorial #6: Orthorectification Using ENVI (Boulder, Colorado Air Photos and SPOT)

ENVI provides basic tools for orthorectification of aerial photographs and SPOT imagery. This tutorial describes the procedures to be followed and results of the orthorectification process. Orthorectification is demonstrated using aerial photographs from Boulder, Colorado and SPOT images. Because these data sets are quite large, results only are shown, and no data are provided.

ENVI Tutorial #7: Mosaicking Using ENVI (Death Valley, Nevada AVIRIS)

This tutorial is designed to give you a working knowledge of ENVI's image mosaicking capabilities. It uses AVIRIS data from Death Valley, Nevada. Pixel-based mosaicking demonstrates ENVI’s virtual mosaic concept and easy-to-use mosaic tool. Georeferenced mosaicking shows ENVI’s automatic placement of map-referenced images and cutline feathering. The exercises assume that you are already generally familiar with mosaicking techniques.

ENVI Tutorial #8: Landsat TM and SPOT Data Fusion Using ENVI (London, UK, TM and SPOT, Brest France, SPOT)

This tutorial is designed to demonstrate selected ENVI data fusion capabilities. For additional data fusion details, please see the *ENVI User's Guide* or ENVI On-Line-Help. Two examples are provided for this tutorial. The first uses Landsat TM and SPOT data of London, UK (Data Courtesy of RSI International UK, Ltd). The TM data are Copyright, European Space Agency, and distributed by Eurimage/NRSC.

The SPOT data are Copyright CNES, 1994, distributed by Spot Image/NRSC. Both datasets are used with permission (NRSC, 1999). The second example uses SPOT XS and Panchromatic data of Brest, France (Data Courtesy of RSI International, France, Copyright CNES-Spot image., 1998. Used with permission of SPOT, 1999. These data may not be used for commercial purposes).

ENVI Tutorial #9: Landsat TM and SAR Data Fusion Using ENVI (Rome, Italy, TM and ERS)

This tutorial is designed to demonstrate selected ENVI data fusion capabilities. Landsat TM data and ERS-2 SAR data of Rome, Italy are co-registered using ENVI image-to-image registration. A Hue/Saturation/Intensity color transform is used to fuse the two datasets and the fused data are compared to the individual datasets to determine the advantages and disadvantages of data fusion. For additional data fusion details, please see the ENVI User's Guide or ENVI Online Help. ERS and LANDSAT images used in this tutorial are provided courtesy of the European Space Agency (ESA) and Eurimage (used with permission) and may not be redistributed without explicit permission from these organizations.

ENVI Tutorial #10: Vector Overlay and GIS Analysis (Gonzales, California Space Imaging Data and Shape Files)

This tutorial introduces ENVI’s vector overlay and GIS analysis capabilities. Stand-alone GIS analysis is demonstrated using ESRI-provided GIS data, including input of ArcView shapefiles and associated .dbf attribute files, display in vector windows, viewing/editing of attribute data, point-and-click spatial query, and math/logical query operations. Part 2 of this tutorial demonstrates use of ENVI’s combined image display/vector overlay and analysis capabilities using a simulated 4-meter resolution Space Imaging/EOSAT multispectral dataset of Gonzales, California, USA. Data courtesy of Space Imaging/EOSAT. The exercise includes cursor tracking with attribute information, point-and-click query, and heads-up digitizing and vector layer editing. Also demonstrated are generation of new vector layers using math/logical query operations and raster-to-vector conversion of ENVI Regions of Interest (ROI) and/or classification images. Finally, the exercise demonstrates ENVI’s vector-to-raster conversion, using vector query results to generate ROIs for extraction of image statistics and area calculations. It is assumed that the user already has a basic grasp of GIS analysis concepts.

ENVI Tutorial #11: Map Composition Using ENVI (Yellowstone, Wyoming, TM)

This tutorial is designed to give you a working knowledge of ENVI's map composition capabilities. It uses Landsat TM data of Yellowstone National Park, Wyoming, USA to show creation of an image-map with virtual borders, latitude/longitude and map coordinate grids, map key and scale, declination diagram, image insets, and text annotation using ENVI QuickMap.

ENVI Tutorial #12: Introduction to Hyperspectral Data and Analysis (Cuprite, Nevada AVIRIS)

This tutorial is designed to introduce you to the concepts of Imaging Spectrometry, hyperspectral images, and to selected spectral processing basics using ENVI. For this exercise, we use Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data of Cuprite, Nevada, USA, to familiarize you with spatial and spectral browsing of imaging spectrometer data and then compare the results of several reflectance calibration procedures.

ENVI Tutorial #13: Basic Hyperspectral Analysis (Cuprite, Nevada AVIRIS)

This tutorial is designed to introduce you to the concepts of Spectral Libraries, Region of Interest (ROI) extraction of spectra, Directed Color composites, and to the use of 2-D scatterplots for simple classification. We use 1995 Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) apparent reflectance data of Cuprite, Nevada, USA, to extract ROIs for specific minerals, compare them to library spectra, and design R, G, B color composites to best display the spectral information. You will also use 2-D scatterplots to locate unique pixels, interrogate the data distribution, and perform simple classification.

ENVI Tutorial #14: Selected Mapping Methods Using Hyperspectral Data (Cuprite, Nevada, AVIRIS)

This tutorial is designed to introduce you to advanced concepts and procedures for analysis of imaging spectrometer data or hyperspectral images. You will use the 1995 Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data from Cuprite, Nevada, USA, to investigate the unique properties of hyperspectral data and how spectral information can be used to identify mineralogy. You will evaluate Effort polished spectra vs ATREM-calibrated data, and review the Spectral Angle Mapper classification. You will compare apparent reflectance spectra and continuum-removed spectra. You will also compare apparent reflectance images and continuum-removed images and evaluate Spectral Feature Fitting results.

ENVI Tutorial #15: Advanced Hyperspectral Analysis (Cuprite, Nevada AVIRIS)

This tutorial is designed to introduce you to additional advanced concepts and procedures for analysis of imaging spectrometer data or hyperspectral images. You will use the 1995 AVIRIS data from Cuprite, Nevada, USA, to investigate sub-pixel properties of hyperspectral data and advanced techniques for identification and quantification of mineralogy. You will use Effort polished ATREM-calibrated data, and review matched filter and spectral unmixing results.

ENVI Tutorial #16: Hyperspectral Signatures and Spectral Resolution (Cuprite, Nevada, TM, GEOSCAN, GER63, AVIRIS, and HyMap)

This tutorial compares spectral resolution for several different sensors and the effect of resolution on the ability to discriminate and identify materials with distinct spectral signatures. The tutorial uses TM, GEOSCAN, GER63, AVIRIS, and HyMap data from Cuprite, Nevada, USA, for inter-comparison and comparison to materials from the USGS Spectral library.

ENVI Tutorial #17: Geology Hyperspectral Analysis Case History (Cuprite, Nevada, HyMap)

This tutorial presents a case history for use of hyperspectral techniques for geologic analysis using 1999 HyMap data from Cuprite, Nevada, USA. It is designed to be a self-directed example using ENVI’s complete end-to-end hyperspectral tools to produce image-derived endmember spectra and image maps. The processing should be done using the standard ENVI methods (**EFFORT** → **MNF** → **PPI** → **n-D Visualization** → **Spectral Mapping** → **GLT Geocorrection**). For more detail and step-by-step procedures on performing such a hyperspectral analysis, please execute the introductory through advanced ENVI hyperspectral tutorials prior to attempting this tutorial. 1999 HyMap data of Cuprite, Nevada, used for the tutorial are copyright 1999 Analytical Imaging and Geophysics (AIG) and HyVista Corporation (All Rights Reserved), and may not be redistributed without explicit permission from AIG @info.aigllc.com).

ENVI Tutorial #18: Archaeology Hyperspectral Analysis Case History (Selinunte, Italy MIVIS)

This tutorial presents a case history for use of hyperspectral techniques for archeological analysis using MIVIS data from Selinunte, Sicily, Italy. It is designed to be a self-directed example using ENVI’s complete end-to-end hyperspectral tools to produce image-derived endmember spectra and image maps. The processing should be done using the standard ENVI methods (**EFFORT** → **MNF** → **PPI** → **n-D Visualization** → **Spectral Mapping**). For more detail and step-by-step procedures on performing such a hyperspectral analysis, please execute the introductory through advanced ENVI hyperspectral tutorials prior to attempting this tutorial. The MIVIS data are courtesy of Research Systems Italia, S.R.L. and the Italian National Research Council (CNR). Used with permission.

ENVI Tutorial #19: Vegetation Hyperspectral Analysis Case History (Jasper Ridge, California HyMap)

This tutorial presents a case history for use of hyperspectral techniques for vegetation analysis using 1999 HyMap data of Jasper Ridge, California, USA. It is designed to be a self-directed example using ENVI’s complete end-to-end hyperspectral tools to produce image-derived endmember spectra and image maps. For more detail and step-by-step procedures on performing such a hyperspectral analysis, please execute the detailed hyperspectral tutorials in this booklet prior to attempting this tutorial. 1999 HyMap data of Jasper Ridge, California, used for the tutorial are copyright 1999 Analytical Imaging and Geophysics (AIG) and HyVista Corporation (All Rights Reserved), and may not be redistributed without explicit permission from AIG (info@aigllc.com).

ENVI Tutorial #20: Near-shore Marine Hyperspectral Case History (Moffett Field, California AVIRIS)

This tutorial presents a case history for use of hyperspectral techniques for analysis of near-shore marine environments using 1994 AVIRIS data from Moffett Field, California, USA. You will run through a complete example using a selection of ENVI’s available tools to produce image-derived endmember spectra and image maps.

ENVI Tutorial #21: Multispectral Processing using ENVI’s Hyperspectral Tools (Bighorn Basin, Wyoming TM)

This tutorial is designed to show you how ENVI's advanced hyperspectral tools can be used for improved analysis of multispectral data. Landsat TM data from the Bighorn Basin, Wyoming, USA, are used. You view results from a classical multispectral analysis approach, and then will run through a complete example using a selection of ENVI’s available tools to produce image-derived endmember spectra and image maps. To gain a better understanding of the hyperspectral concepts and tools, please run the ENVI hyperspectral tutorials.

ENVI Tutorial #22: Introduction to HDF Data and MSI Processing (Cuprite, Nevada MASTER)

This tutorial is designed to introduce you to HDF data and analysis of Multispectral Imagery from the MODIS/ASTER Airborne Simulator (MASTER) sensor. The exercise covers opening and reading HDF-format files, extracting spatial and spectral subsets and spectra, comparison of spectra to spectral libraries and classical multispectral processing. For additional details on specific functions, please see the *ENVI 3.5 User’s Guide* or the ENVI On-Line help. This MASTER dataset and other MASTER data are available for purchase from NASA through the EROS Data Center, Sioux Falls, SD.

ENVI Tutorial #23 Introduction to Long Wave Infrared (LWIR) Multispectral Data Analysis (Cuprite, Nevada MASTER)

This tutorial is designed to introduce you to analysis of LWIR Multispectral Imagery from the MODIS/ASTER Airborne Simulator (MASTER) sensor. The exercise covers opening and reading HDF-format files, extracting spatial and spectral subsets, examination of LWIR spectra to define key spectral bands, decorrelation stretching of color composites to enhance LWIR spectral differences, and comparison of SWIR and LWIR mapping results. For additional details on specific functions, please see the *ENVI 3.5 User’s Guide* or the ENVI On-Line help. This MASTER dataset and other MASTER data are available for purchase from NASA through the EROS Data Center, Sioux Falls, SD.

ENVI Tutorial #24: SAR Processing and Analysis (Bonn, Germany RadarSat)

This tutorial is designed to give you a working knowledge of ENVI's basic tools for processing single-band SAR data (such as RadarSat, ERS-1, JERS-1). A subset of

Radarsat data from Bonn, Germany, are used to demonstrate concepts for processing SAR with ENVI including image display and contrast stretching, removing speckle using adaptive filters, density slicing, edge enhancement and image sharpening, data fusion, and image-map output.

ENVI Tutorial #25: Polarimetric SAR Processing and Analysis (Death Valley, California SIR-C)

This tutorial demonstrates the use of ENVI's polarimetric radar data analysis functions. It uses Spaceborne Imaging Radar-C (SIR-C) data obtained over Death Valley, California, USA, during the April 1994 mission of the Space Shuttle Endeavor to demonstrate concepts such as multilooking, image synthesis from complex scattering matrix data, selection and display of polarizaton and/or multi-frequency images, slant-to-ground range conversion, adaptive filtering, and texture analysis.

ENVI Tutorial #26: Analysis of DEMs and TOPSAR (Tarrawarra, Australia TOPSAR/POLSAR)

This tutorial uses polarimetric SAR data and a Digital Elevation Model (DEM) generated from JPL's TOPSAR (interferometric SAR) data for Tarrawarra, Australia. Data Courtesy of JPL. The exercise demonstrates display and analysis of the SAR data and of the DEM using standard tools within ENVI. DEM analysis includes gray scale and color-density-sliced display; generation and overlay of elevation contours, use of ENVI's X, Y, and arbitrary profiles (transects) to generate terrain profiles; generation of slope, aspect, and shaded relief images; and 3-D perspective viewing and image overlay.

ENVI Tutorial #27: ENVI Topographic Tools (ALPS TM and DEM)

This tutorial is designed to give you a working knowledge of ENVI's Topographic Analysis Tools. Data provided include processed TM data and a 25m DEM of an area in the Swiss Alps. Selected tools reviewed include gray scale and color-density-sliced display; generation and overlay of elevation contours, use of ENVI's X, Y, and arbitrary profiles (transects) to generate terrain profiles; generation of slope, aspect, and shaded relief images; extraction of Topographic Feature Parameters (peak, ridge, pass, plane, channel, pit), and 3-D perspective viewing and image overlay. Data Courtesy of Research Systems International Ltd, UK, Digital Elevation Data © Eastern Geo Ltd 1999, Distributed by NPA Group, Edenbridge, Kent, UK, Tel: +44 1732 865023.

ENVI Tutorial #28: ENVI 3-D Surface View and Fly-through (Bighorn, Wyoming TM and DEM)

This tutorial is designed to provide a working knowledge of ENVI's 3-D SurfaceView and Fly-Through capabilities. It covers overlay of a gray scale or color composite image over a digital elevation model (DEM) as a 3-D Surface View, interactively changing the 3D visualization, and creating 3D Fly-throughs. There is also a discussion of the 3D SurfaceView function’s use as an analysis tool. Users should also be able to produce similar results with their own coregistered image and digital elevation model (DEM) data.

ENVI Tutorial #29: Introduction to ENVI User Functions

This tutorial provides basic information on programming in ENVI. It covers the basics for creating user defined band math functions and Plug-in functions, including creating compound widgets and writing data tiling operations. This tutorial assumes that you are familiar with the Interactive Data Language (IDL) and understand how to write functions and procedures in IDL. ENVI RT users cannot program in ENVI, so only the Band Math portion of this tutorial is applicable to these users.

ENVI Tutorial #30: Introduction to ENVI Plot Functions

This tutorial provides information on how to implement an ENVI Plot Function. This is a user-defined function called from the Plot Function pull-down menu on any ENVI plot window. This exercise covers the basics for creating user-defined plot functions and setting up the ENVI `useradd.txt` file to enable automatic installation of the functions in the plot menu structure.This tutorial assumes that you are familiar with the Interactive Data Language (IDL) and understand how to write functions and procedures in IDL. ENVI RunTime users cannot program in ENVI, however, the plot functions provided with this tutorial can be viewed with any text editor and installed for use with either ENVI or ENVI RunTime.

Tutorial Data Files

Data files for these tutorials are contained on two CD-ROMs in subdirectories of the `envidata` directory. Because the data sets are quite large— more than 1 GB of data are included—you may wish to load the files into ENVI directly from the CD-ROM rather than transferring the files to your hard disk. You will obtain better performance, however, if you copy the files to your disk. The specific files used by each exercise are described at the beginning of the individual tutorials.

In the tutorials, we use the term tutorial data directory to refer to the place where the tutorial data sets are stored. Depending on your system and whether you choose to copy the data sets to your hard disk, this could be the `envidata` directory on either of the *ENVI Tutorial and Data CD-ROMs*, a directory containing links to the ENVI CD-ROM (on some UNIX systems), or a place on your hard disk.

Mounting the CD-ROM for UNIX Systems

In order to have access to the ENVI tutorial data files, you must have a CD-ROM drive connected to your computer or accessible on a network.

Some platforms automatically mount the CD-ROM when you insert it into your CD-ROM drive. In most cases, the CD-ROM will be mounted as:

```
/cdrom/envidata1
```

or

```
/cdrom/envidata2
```

The following instructions work in most cases for the platform listed. Consult your operating system documentation for instructions on mounting a CD-ROM on your system.

Note

Replace *`CDROM-Dev`* with the actual name of the CD-ROM drive on your system. Type mounting commands as a single line. On most systems, you must have root permissions to mount the CD-ROM.

Platform	CD Mounting Command	Typical *CDROM-Device* Name
Compaq Tru64 UNIX	`/usr/sbin/mount -t cdfs -r -o rrip` *`CDROM-Dev`* `/cdrom`	`/dev/rz4c`
HP-UX	`mount -r -F cdfs -o cdcase` *`CDROM-Dev`* `/cdrom`	`/dev/dsk/c1t2d0`
IBM AIX	`mount -r -v cdrfs` *`CDROM-Dev`* `/cdrom`	`/dev/cd0`
Linux	`mount -o ro -t iso9660` *`CDROM-Dev`* `/mnt/cdrom`	`/dev/cdrom`
SGI IRIX	`(automatically mounted as /CDROM)`	
SUN Solaris	`(automatically mounted by volume manager as /cdrom/envi_35)`	

CD-ROM Mounting Commands

Note

We suggest that you mount the CD-ROM device in the directory `/cdrom`. If you choose to mount the CD-ROM in another directory, substitute that directory name for occurrences of `/cdrom` in these tutorials. Also, not all UNIX systems will read the CD-ROM the same way.

ENVI® Quick Start

The following topics are covered in this tutorial:

Overview of This Tutorial

This quick start tutorial is designed to give users trying ENVI for the first time a quick demo script. The following exercises briefly introduce you to ENVI's graphical user interface and basic capabilities. The exercises assume that you have downloaded and installed ENVI on your hard disk or have installed ENVI from the CD-ROM. Please contact Research Systems directly for a fully functional CD-ROM or see the ENVI download instructions to obtain the software via the Internet.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/can_tm`

File	Description
`can_tmr.img`	Boulder, CO, TM Data
`can_tmr.hdr`	ENVI Header for Above
`can_lst.evf`	List of EVF Files
`can_v1.evf`	ENVI VECTOR FILE 1
`can_v2.evf`	ENVI VECTOR FILE 2
`can_v3.evf`	ENVI VECTOR FILE 3
`can_v4.evf`	ENVI VECTOR FILE 4

Note

For instructions for mounting a CD-ROM on a UNIX system, see "Mounting the CD-ROM for UNIX Systems" on page 33.

Getting Started with ENVI

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To start ENVI on UNIX, enter `envi` at the UNIX command line.
- To start ENVI on Microsoft Windows systems, double-click on the ENVI icon or select ENVI from the Windows 98, Windows NT 4.0, or Windows 2000 Start menu.

Load a Gray Scale Image

Open a multispectral Landsat Thematic Mapper (TM) data file representing Cañon City, Colorado, USA.

Open an Image File

To open an image file:

1. Select **File** → **Open Image File**.

   An **Enter Input Data File** file selection dialog appears.

2. Navigate to the `can_tm` subdirectory of the `envidata` directory just as you would in any other application, and select the file `can_tmr.img` from the list and click **Open**.

   The **Available Bands List** dialog appears on your screen. This list allows you to select spectral bands for display and processing.

Note

You have the choice of loading either a grayscale or an RGB color image.

3. Select **TM Band 4** in the dialog by clicking on the band name in the **Available Bands List** with the left mouse button.

   The band you have chosen is displayed in the field marked **Selected Band**:

4. Click on the **Gray Scale** toggle button and then **Load Band** in the **Available Bands List** to load the image into a new display.

Band 4 will be loaded as a gray scale image.

Familiarize Yourself with the Displays

When the image loads, an ENVI image display appears on your screen. The display group consists of an Image window, a Scroll window, and a Zoom window. These three windows are intimately linked; changes to one window are mirrored in the others.

All windows can be resized by grabbing and dragging a window corner with the left mouse button.

1. Resize the Image window to be as large as possible. Note that the Scroll window disappears.
2. Now, make the Image window smaller than the full extent of the image data and the Scroll window reappears.
3. Next, try resizing the Zoom window to see how the outlining box changes in the Image window.

The basic characteristics of the ENVI display group windows are described as follows:

Scroll Window

The Scroll window displays the entire image at reduced resolution (subsampled). The subsampling factor is listed in parentheses in the window Title Bar at the top of the image. The highlighted scroll control box (red by default) indicates the area shown at full resolution in the Image window.

1. To reposition the portion of the image shown in the Image window, position the mouse cursor inside the scroll box, hold down the left mouse button, drag to the desired location, and release. The Image Window is updated automatically when the mouse button is released.
2. You can also reposition the cursor anywhere within the Scroll window and click the left mouse button to move the selected Image Window area instantly. If you click, hold, and drag the left mouse button in this fashion, the Image window will be updated as you drag (the speed depends on your computer resources).

Image Window

The Image window shows a portion of the image at full resolution. The zoom control box (the highlighted box in the Image window) indicates the region that is displayed in the Zoom window.

1. To reposition the portion of the image magnified in the Zoom window, position the mouse cursor in the zoom control box, hold down the left mouse

button, and move the mouse. The Zoom window is updated automatically when the mouse button is released.

2. Alternately, you can reposition the cursor anywhere in the Zoom window and click the left mouse button to move the magnified area instantly. If you click, hold, and drag the left mouse button in this fashion, the Zoom window is updated as you drag.

3. The Main Image window can also have optional scroll bars, which provide an alternate method for moving through the Scroll window image, allowing you to select which portion of the image appears in the Image window. To add scroll bars to the Main Image window, select **File** → **Preferences** from the Main Image window menu bar. In the second section of the dialog titled Image Window, click on the spin box control next to the **Scroll Bars** text field to toggle scroll bars on, then click **OK** at the bottom of the dialog.

   The portion of the image displayed in the Main Image window can now be controlled by clicking and dragging the scroll bars using the left mouse button.

   Scroll bars can be turned on by default for all images from the Main ENVI menu bar by selecting **File** → **Preferences** → **Display Defaults** and toggling the Main Image window **scroll bars** field as described above.

Zoom Window

The Zoom window shows a portion of the image, magnified the number of times indicated by the number in parentheses in the Title Bar of the window. The zoom area is indicated by a highlighted box (the zoom control box) in the Image window.

There is a small control graphic (red by default) in the lower left corner of the Zoom window. This controls the zoom factor and also the crosshair cursor in both the Zoom and Main Image windows.

1. Move the mouse cursor in the Zoom window and click the left mouse button to reposition the magnified area by centering the zoomed area on the selected pixel.

2. Clicking and holding the left mouse button in the Zoom window while dragging causes the Zoom window to pan within the Main Image display.

3. Clicking the left mouse button on the – (minus) graphic in the lower left corner of the Zoom window zooms down by a factor of 1. Clicking the middle mouse button on this graphic zooms down by a factor of 2. Clicking the right mouse button on the graphic returns the zoom window to the default zoom factor.

4. Clicking the left mouse button on the + (plus) graphic in the lower left corner of the Zoom window zooms up by a factor of 1. Clicking the middle mouse

button on this graphic zooms up by a factor of 2. Clicking the right mouse button on the graphic returns the Zoom window to the default zoom factor.

5. Click the left mouse button on the right (third) graphics box in the lower left corner of the Zoom window to toggle the Zoom window crosshair cursor. Click the middle mouse button on this graphic to toggle the Main Image crosshair cursor. Click the right mouse button on this graphic to toggle the Zoom box in the Main Image window on or off. Double-click the right mouse button on this graphic to toggle scroll bars on or off in the Main Image window.

Note

On Microsoft Windows systems with a two button mouse, click Ctrl-Left Mouse Button to emulate the middle mouse button.

Main Image Display Menu Bar

A menu bar at the top of the Main Image window gives you access to many ENVI features that relate directly to the images in the display group. You can select options from it as you do from any other ENVI menu.

Apply a Contrast Stretch

By default, ENVI displays images with a 2% linear contrast stretch.

1. To apply a different contrast stretch to the image, select **Enhance** from the Main Image display menu bar to display a list of six default stretching options for each of the windows (Image, Zoom, Scroll) in the display group.
2. Select an item from the list (for example **Enhance** → **[Image] Equalization** to apply a histogram equalization contrast stretch to the Image display, which also updates the Scroll and Zoom windows of the display group. Try applying several of the different available stretches.

Alternatively, you can define your contrast stretch interactively by selecting **Enhance** → **Interactive Stretching** from the Main Image display menu bar.

Apply a Color Map

By default, ENVI displays images using a grayscale color table.

1. To apply a pre-defined color table to the image, from the Main Image window menu select **Tools** → **Color Mapping** → **ENVI Color Tables** to display the **ENVI Color Tables** dialog.

2. Select a color table from the list at the bottom of the dialog to change the color mapping for the three windows in the display group.

Note

In the **ENVI Color Tables** dialog, **Options** → **Auto Apply On** is selected by default, so the color table will automatically be applied. You can turn this off by selecting **Options** → **Auto Apply Off** in which case you must select **Options** → **Apply** each time you wish to apply the color table and observe the results.

3. In the **ENVI Color Tables** dialog, select **Options** → **Reset Color Table** to return the display group to the default gray scale color mapping.
4. Select **File** → **Cancel** to dismiss the **ENVI Color Tables** dialog.

Cycle Through All Bands (Animate)

You can display all the bands in an image sequentially, creating an animation.

1. From the Main Image window menu, select **Tools** → **Animation** and click **OK** in the **Animation Input Parameters** dialog.

   Each of the six bands from the TM scene are loaded into an animation window. Once all the bands are loaded, the images are displayed sequentially creating a movie effect.
2. You can control the animation using the player controls (loop backward, loop forward, change direction, and pause buttons) at the bottom of the Animation Window, or by adjusting the value shown in the **Speed** spin box to change the speed at which the bands are displayed.
3. Select **File** → **Cancel** from the display menu bar to end the animation.

Scatter Plots and Regions of Interest

Scatter plots allow you to quickly compare the values in two spectral bands simultaneously. ENVI Scatterplots allow quick 2-band classification.

1. To display the distribution of pixel values between Band 1 and Band 4 of the image as a scatter plot, select **Tools** → **2-D Scatter Plots**.

   The **Scatter Plot Band Choice** dialog appears.
2. Under **Choose Band X:** select Band 1. Under **Choose Band Y:** select Band 4. Click **OK** to create the scatter plot.

3. Place the cursor in the Image window, then press and hold the left mouse button and move the cursor around in the window. Make sure not to press and hold the mouse cursor inside the Zoom window box.

   Notice that as you move the cursor, different pixels are highlighted in the scatter plot. This *dancing pixels* display highlights the 2-band pixel values found in a 10-pixel by 10-pixel region around the cursor.

4. Define a region of interest (ROI) in the **Scatter Plot** display by clicking the left mouse button several times in the Scatter Plot window to select points forming the vertices of a polygon, then clicking the right mouse button to close the polygon.

   Pixels in the Image and Zoom windows whose values match the values contained in the selected region of the scatter plot are highlighted.

5. To define a second class, select a second color from the Class menu of the Scatter Plot window and repeat the above steps.

6. Select **Options** → **Export All** from the Scatter Plot window menu to export the regions of interest. The **ROI Tool** dialog appears. The **ROI Tool** dialog can also be started from the Main Image Display menu bar by selecting **Overlay** → **Region of Interest**.

   By default, ENVI assigns Scatter Plot Export in the **ROI Tool** dialog, followed by the color of the region and number of points contained in the region as the name for the region of interest.

7. In the **ROI Tool** menu bar, select **File** → **Cancel** to dismiss the dialog. The region definition is saved in memory for the duration of the ENVI session. In the Scatter Plot window, close the scatter plot by selecting **File** → **Cancel**.

Load a Color Composite (RGB) Image

ENVI allows simultaneous, multiple grayscale and RGB color displays.

1. To load a color composite (RGB) image of the Cañon City area, click on the Available Bands List. If you dismissed the Available Bands List during the previous exercises, you can recall it by selecting **Window** → **Available Bands List** from the Main ENVI menu bar.

2. Click on the **RGB Color** radio button in the **Available Bands List**. Red, Green, and Blue fields appear in the center of the dialog.

3. Select Band 7, Band 4, and Band 1 sequentially from the list of bands at the top of the dialog by clicking on the band names.

The band names are automatically entered in the Red, Green, and Blue fields.

4. Click **Load RGB** to load the image into the Image window.

Classify an Image

ENVI provides two types of unsupervised classification and several types of supervised classification. The following is an example of one of the supervised classification methods.

1. From the ENVI Main menu bar, select **Classification** → **Supervised** → **Parallelepiped**. When the **Classification Input File** dialog appears, select `can_tmr.img` and click **OK**.
2. When the **Parallelepiped Parameters** dialog appears, select the regions of interest you created by clicking on the region name in the **Select Classes from Regions** list at the left of the dialog.
3. Select **Memory** in the upper right corner of the dialog to output the result to memory.
4. Click on the small arrow button in the right-center of the **Parallelepiped Parameters** dialog to toggle off Rule Image generation, and then click **OK**.

   The classification function will calculate statistics and a progress window will appear during the classification. A new entry titled *Parallel (CAN_TMR.IMG)* is added to the **Available Bands List**.
5. To load the result of the classification into a new display group, select the **New Display** by pulling down the menu button marked **Display #1** in the **Available Bands List**. Select Gray Scale for the display by clicking on the **Gray Scale** radio button in the **Available Bands List**, then click on the Parallelepiped result image name, and click on the **Load Band** button.

A new display group is created, containing the classified image.

Dynamically Overlay Images

You can link two display groups, allowing comparison of the images directly by displaying one over the other.

1. From either Image window, select **Tools** → **Link** → **Link Displays** from the Main Image display menu bar. The **Link Displays** dialog appears. Click **OK** to link at the origin.
2. In either Image window, position the cursor outside the zoom control box and hold down the left mouse button and move the cursor.

A portion of the other image is superimposed.

3. You can change the size of the superimposed area by holding down the middle mouse button and dragging until the superimposed area is the desired size.
4. Close the two image displays by selecting **File** → **Cancel** from each Image window menu bar.

Overlaying and Working with Vectors

ENVI provides a full suite of vector viewing and analysis tools, including input of ArcView Shapefiles, vector editing, and vector querying.

1. Re-display the grayscale image by clicking on TM Band 4 in the **Available Bands List**, clicking on the **Gray Scale** radio button, and then on **Load Band**.
2. Open a vector file by selecting **File** → **Open Vector File** → **ENVI Vector File** from the menu bar of the ENVI main menu. Navigate to the `can_tm` directory and choose the file `can_lst.evf` which contains a list of vector files for this area (alternatively, open each `.evf` file individually).

   The **Available Vectors List** dialog appears listing the vectors corresponding to the `can_tmr.img` display.
3. Click on one of the vector layer names and examine the information about the layer at the bottom of the **Available Vectors List**.
4. Click on the **Select All Layers** near the bottom of the dialog to choose the vectors to plot. Click on the **Load Selected** button at the bottom of the **Available Vectors List** and the **Load Vector Layer** dialog will appear. Click on **Display #1** at the top of the dialog to load the vectors.

   The vector layers are listed in the **Display #1 Vector Parameters** dialog.
5. Click on **Apply** in the **Display #1 Vector Parameters** dialog to load the vectors onto the image, then choose **Options** → **Vector Information** in the **Vector Parameters** dialog to start an information dialog about the vectors.
6. Click and drag with the left mouse button in the Main Image display to track the currently selected vector layer and list basic information about the vectors. Click on another layer name in the **Vector Parameters** dialog and then in the Main Image display to track a different layer.
7. Edit the layer display characteristics by clicking on the **Edit Layers** button in the **Vector Parameters** dialog. Change vector layer parameters as desired and click on **OK**, then **Apply** to display the changes.

Finish Up

You can finish your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then answer **Yes** to the prompt **Terminate this ENVI Session?**. All files will be closed automatically. If you are running ENVI (ENVI with IDL rather than ENVI Runtime), you may also have to exit IDL by choosing **File** → **Exit** and answering **Yes** to the prompt **Exit IDL**.

Tutorial 1:
Introduction to ENVI

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial provides basic information about ENVI and some suggestions for your initial investigations of the software. It is designed to introduce first-time ENVI users to the basic concepts of the package and to explore some of its key features. It assumes that you are already familiar with general image-processing concepts.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/can_tm`

File	Description
`can_tmr.img`	Cañon City, CO TM Data
`can_tmr.hdr`	ENVI Header for Above

Working with ENVI

ENVI uses a graphical user interface (GUI) to provide point-and-click access to image processing functions. You select menu choices and functions using a three-button mouse.

Note

If you are using *ENVI for Windows* with a two-button mouse, you can simulate a middle mouse button press by holding down the Control key and pressing the left mouse button. If you are using *ENVI for Macintosh*, hold down the Option key while pressing the mouse button to simulate a middle mouse button press, or hold down the Command key while pressing the mouse button to simulate a right mouse button press.

When you start ENVI, the **ENVI** main menu appears as a menu bar. Clicking with the left mouse button on any of the **ENVI** main menu topics brings up a menu of options, which may in turn contain submenus with further options. The choices selected from these submenus will often bring up dialog boxes that allow you to enter information or set parameters relating to the ENVI function you have selected.

ENVI File Formats

ENVI uses a generalized raster data format consisting of a simple flat binary file and a small associated ASCII (text) header file. This file format permits ENVI to use nearly any image file, including those that contain their own embedded header information.

Generalized raster data is stored as a binary stream of bytes in either Band Sequential (BSQ), Band Interleaved by Pixel (BIP), or Band Interleaved by Line (BIL) format.

- BSQ is the simplest format, with each line of data followed immediately by the next line of the same spectral band. BSQ format is optimal for spatial (X, Y) access to any part of a single spectral band.
- BIP format provides optimal spectral processing performance. Images stored in BIP format have the first pixel for all bands in sequential order, followed by the second pixel for all bands, followed by the third pixel for all bands, etc., interleaved up to the number of pixels. This format provides optimum performance for spectral (Z) access of the image data.
- BIL format provides a compromise in performance between spatial and spectral processing and is the recommended file format for most ENVI processing tasks. Images stored in BIL format have the first line of the first

band followed by the first line of the second band, followed by the first line of the third band, interleaved up to the number of bands. Subsequent lines for each band are interleaved in similar fashion.

ENVI supports a variety of data types: byte, integer, long integer, floating-point, double-precision floating-point, complex, and double-precision complex.

The separate text header file provides information to ENVI about the dimensions of the image, any embedded header that may be present, the data format, and other pertinent information. The header file is normally created (with your input) the first time a particular data file is read by ENVI. You can view and edit it at a later time by selecting **File** → **Edit ENVI Header** from the ENVI menu bar. You can also generate ENVI header files outside ENVI, using a text editor.

ENVI Windows and Displays

As you work with ENVI, a number of different windows and dialog boxes will appear on your screen. These allow you to manipulate and analyze your image. The most important of these displays is a group of three windows that display your image, allow you to move around in it, and allow you to magnify different areas. This group of windows is collectively referred to as the *Display group* (Figure 1-1). The Display group consists of:

- **The *Main Image Window*** – This window is where all or part of your image is displayed at full resolution (one screen pixel is one data pixel).
- **The *Scroll Window*** – If your entire image does not fit in the Main Image window, the Scroll window will appear. The Scroll window displays a subsampled reduced-size version of the entire image, which allows you to select the portion that is displayed in the Main Image window. A colored box in the Scroll window indicates the spatial location and coverage of the full-resolution Main Image display window. A number in the title bar of the Scroll window tells you what reduction factor has been applied to the image to display the full spatial extent within the Scroll window.
- **The *Zoom Window*** – This window displays an enlarged version of a selected portion of the Main Image window. A colored box in the Main Image display indicates the spatial location and coverage of the Zoom window. A number in the title bar of the Zoom window tells you what zoom factor has been applied to the image.

You may have any number of displays open on the screen at any time. There are a wide variety of other types of ENVI windows with which you may work, including scatter plots, spectral profiles, spectral plots, and vector windows.

Figure 1-1: An ENVI Display group: the Main Image, Scroll, and Zoom windows.

Menus in ENVI Windows

The Main Image display window has its own internal menus, which provide access to interactive display and analysis functions (Figure 1-2). These menus appear as a standard menu bar at the top of each Main Image display window. You can select options from it as you do from any other ENVI menu.

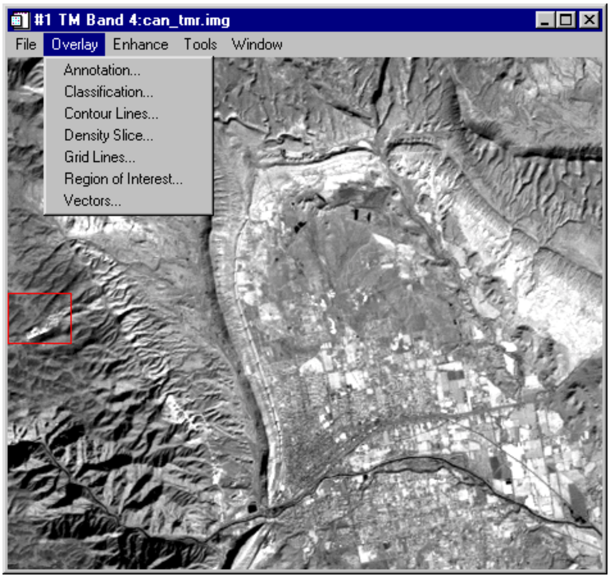


Figure 1-2: The Overlay menu in the Main Image window

The Available Bands List

ENVI provides access to both image files and to the individual spectral bands in those files. The **Available Bands List** is a special ENVI dialog that contains a list of all the available image bands in all open files (Figure 1-3).

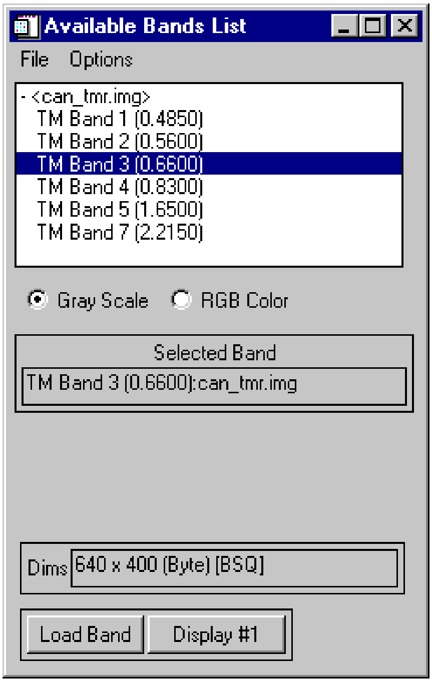


Figure 1-3: The Available Bands List dialog

Use the **Available Bands List** to load both color and gray scale images into a display by starting a new display or selecting the display number from the pull-down list of displays, clicking on the appropriate radio button, then selecting the desired bands from the list by clicking on the band name(s).

The File pull-down menu at the top of the **Available Bands List** dialog provides access to file opening and closing, file information, and the **Cancel** button. The **Options** menu provides a function to find the band closest to a specific wavelength, show the currently displayed bands, allows toggling between full and shortened band names in the list, and the capability to fold all of the bands in a single open image into just the image name. Folding and unfolding the bands into single image names or lists of bands can also be accomplished by clicking on the + (plus) or – (minus) symbols to the left of the file name in the **Available Bands List** dialog.

Basic ENVI Functions

This section of the tutorial takes you on a step-by-step tour of ENVI's basic functions.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in UNIX, enter `envi` at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Open an Image File

To open an image file:

1. Select **File** → **Open Image File**.

   Note that on some platforms you must hold the left mouse button down to display the submenus from the Main Menu.

   An **Enter Input Data File** file selection dialog appears.

2. Navigate to the `CAN_TM` subdirectory of the `envidata` directory on the ENVI *ENVI Tutorial and Data CD No. 2* just as you would in any other application and select the file `can_tmr.img` from the list and click **OK**.

   The **Available Bands List** dialog appears on your screen (Figure 1-3). This list allows you to select spectral bands for display and processing.

   You now have the choice of loading either a gray scale or an RGB color image.

3. Select one of the bands listed at the top of the dialog by clicking on the band with the left mouse button.

   The band you have chosen is displayed in the field marked **Selected Band:**.

4. Click the **Load Band** button to load the image into a new display.

Note

The Main Image window has a menu bar (Figure 1-2).

Familiarize Yourself with the Displays

When the image loads, an ENVI image display appears on your screen. The display consists of a Main Image window, a Scroll window, and a Zoom window (See Figure 1-1). These three windows are intimately linked; changes to one window are mirrored in the others. To get a feel for how the display windows interact, try the following:

Drag the Zoom Indicator Box

- Note the small red box in the center of the Main Image window. This box indicates the area of the image displayed in the Zoom window. You can drag the box from place to place in the Main Image window by clicking inside the box with the left mouse button and dragging it to a new position. The Zoom window is updated automatically to show the new area when you release the mouse button
- You can also reposition the zoom indicator box by placing the crosshair cursor in the Main Image window and clicking the left mouse button. The zoom region will be centered around the position you have chosen.
- Finally, if you click outside the zoom indicator box with the middle mouse button and hold and drag the box to a new position, the Zoom window is updated as you move the box.
- You can close either the Zoom and/or Scroll windows if you don't want to display them. They can again be displayed by selecting **Window** → **Show Scroll Window** or **Window** → **Show Zoom Window** from the Main Image window menu bar.

Zoom In and Out and Pan the Zoom Window

- Move the mouse cursor in the Zoom window and click the left mouse button to reposition the magnified area by centering the zoomed area on the selected pixel.
- Clicking and holding the left mouse button in the Zoom window while dragging causes the Zoom window to pan within the Main Image display.
- Click the right mouse button in the Zoom window to toggle the menu graphic on or off. The menu graphic is made up of three icons in the lower left corner of the Zoom window.
- Clicking the left mouse button on the – (minus) graphic zooms down by a factor of 1. Clicking the middle mouse button on this graphic zooms down by a factor of 2. Clicking the right mouse button on the graphic returns the Zoom window to the default zoom factor.

- Clicking the left mouse button on the + (plus) graphic zooms up by a factor of 1. Clicking the middle mouse button on this graphic zooms doubles the Zoom factor. Clicking the right mouse button on the graphic returns the Zoom window to the default zoom factor.
- Click the left mouse button on the right (third) graphics box to toggle the Zoom window crosshair cursor. Click the middle mouse button on this graphic to toggle the Main Image crosshair cursor. Click the right mouse button on this graphic to toggle the zoom box in the Main Image window on or off.
- Double-click the left mouse button on the right (third) graphics box to toggle interpolation in the Zoom window. Double-click the right mouse button in this graphic to toggle scroll bars on the Main Image window.

Scroll the Image

A red box in the Scroll window indicates what portion of the entire image is currently displayed in the Main Image window. You can move the selected area by clicking inside the scroll indicator box with the left mouse button and dragging the box to a new position. The displays in the Main Image and Zoom windows are updated when you release the mouse button. You can also reposition the scroll indicator box by clicking at the desired location outside of the box using the left mouse button (as for the Zoom window box above). If you click, hold and drag the left mouse button in this fashion, the Main Image window is updated as you drag (the speed depends on your computer resources).

Resize the Windows

You can resize the display windows the same way you would resize windows in other applications, by dragging any of the corners. Note, however, that you cannot make the Main Image window larger than the image size. When the Main Image window is large enough to display the entire image, the Scroll window is unnecessary and is automatically removed from your screen. The Scroll window reappears if the Main Image window is resized smaller than the full image.

Scroll Bars

The Main Image window can also have optional scroll bars, which provide an alternate method for moving through the Scroll image, allowing you to select which portion of the image appears in the Image window. To add scroll bars, select **File** → **Preferences** from the Main Image window menu bar. Click on the arrow toggle button next to the Scroll Bars text field in the dialog to toggle scroll bars on, then click **OK** at the bottom of the dialog. The portion of the image displayed in the Main Image window can now be controlled by clicking and dragging the scroll bars using the left mouse button. Scroll bars can be turned on by default for all images from the ENVI menu bar by selecting **File** → **Preferences** → **Display Defaults** and clicking on the toggle button for the **Image window scroll bars** as described above.

Use the Mouse Button Descriptions

ENVI has many interactive functions, and the mouse button combinations and actions are different for each one. The **Mouse Button Descriptions** dialog is provided to tell you what the mouse buttons do in each graphics window.

- To start the **Mouse Button Descriptions** dialog, select **Window** → **Mouse Button Descriptions** from either the Main Image window menu bar, or from the ENVI main menu bar.

Now whenever your cursor is in an ENVI display or graphics window, the mouse button assignments will be listed in this dialog. MB1 is the left mouse button, MB2 is the middle mouse button, and MB3 is the right mouse button.

Display the Cursor Location

- To display the cursor location and value, select **Window** → **Cursor Location/Value** from the ENVI main menu or the Main Image window menu bar.

  The **Cursor Location / Value** dialog box appears displaying the location of the cursor in the Main Image, Scroll, or Zoom windows (Figure 1-4). The dialog also displays the screen value (color) and the actual data value of the pixel underneath the crosshair cursor.

- To dismiss the dialog, select **Cancel** from the pull-down **File** menu at the top of the **Cursor Location /Value** dialog.
- The **Cursor Location/Value** dialog can also be started/stopped by double-clicking using the left mouse button in the Main Image window.

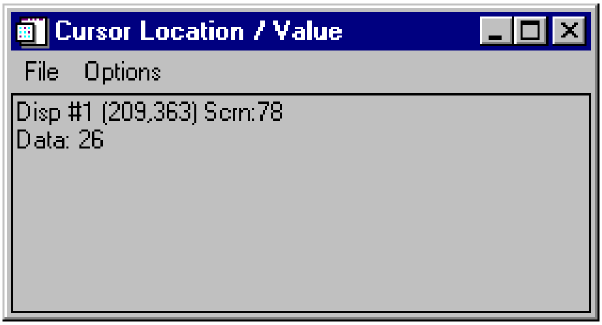


Figure 1-4: The Cursor Location/Value dialog displays the screen and data values of the selected pixel.

Display Image Profiles

X (horizontal), Y (vertical), and Z (spectral) profile plots can be selected and displayed interactively. These profiles show the data values across an image line (X), column (Y), or spectral bands (Z).

1. Select **Tools** → **Profiles** → **X Profile** from the Main Image display menu bar to display a window plotting data values versus sample number for a selected line in the image (Figure 1-5).
2. Repeat the process, selecting **Y Profile** to display a plot of data value versus line number, and selecting **Z Profile** to display a spectral plot (Figure 1-5).

Note

The **Mouse Button Descriptions** dialog contains the descriptions of the mouse button actions in the Profile displays.

3. Position the Profile plot windows so you can see all three at once.

   A red crosshair extends to the top and bottom and to the sides of the Main Image window. The red lines indicate the line or sample locations for the vertical or horizontal profiles.

4. Move the crosshair around the image (just as you move the zoom indicator box) to see how the three image profile plots are updated to display data on the new location.

5. Close the profile plots by selecting **File** → **Cancel** from within each plot window.

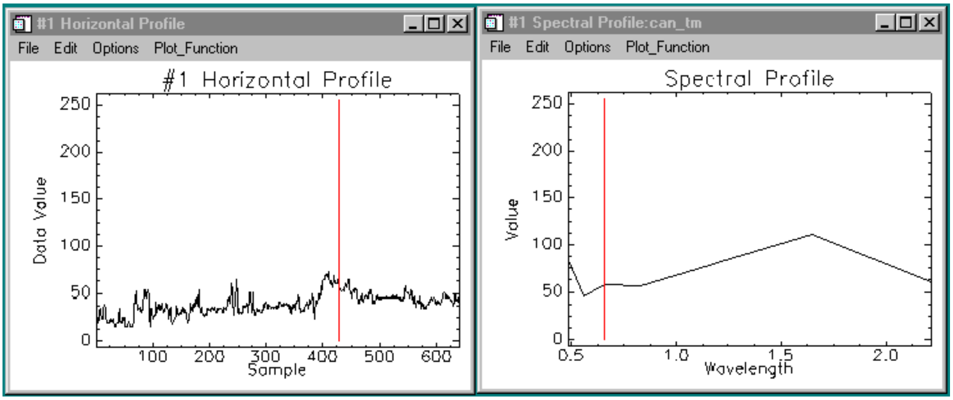


Figure 1-5: The Horizontal (X) Profile (left) and Spectral (Z) Profile (right) plots.

Perform Quick Contrast Stretching

You can perform quick contrast stretches using default parameters and data from either the Main Image window, the Zoom window, or the Scroll window. Using the **Enhance** menu from the Main Image window menu bar, you can apply various contrast stretches (Linear, Linear 0-255, Linear 2%, Gaussian, Equalization, and Square Root).

1. Try the various stretches using the Main Image, Zoom, and Scroll as the stretch data source.
2. Compare the effects of the various Linear, Gaussian, Equalization, and Square Root stretches in the Display group windows.

Display Interactive Scatter Plots

You can plot the data values of two selected image bands versus each other in a scatter plot to graphically display the overlapping values.

1. Select **Tools** → **2D Scatter Plots** from the Main Image window menu bar.

   The **Scatter Plot Band Choice** dialog appears, in which you choose the two image bands to compare.

2. Select one band for the X axis and another band for the Y axis and click **OK**.

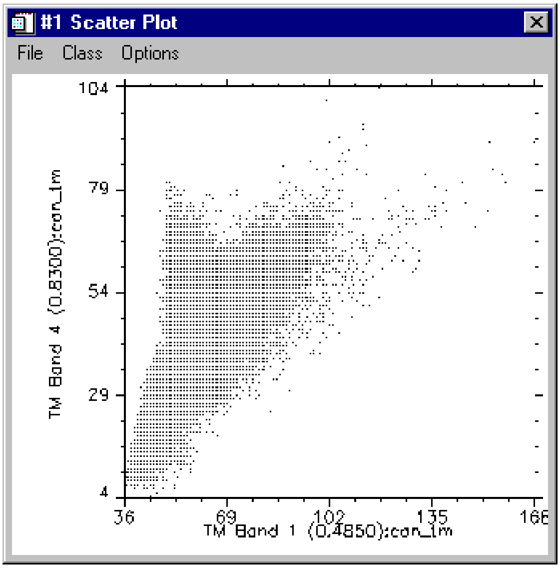


Figure 1-6: An Interactive Scatter Plot comparing band 1 values to band 4 values.

It may take a few seconds for ENVI to extract and tabulate the data values.

3. Once the scatter plot has appeared (Figure 1-6), position the mouse cursor anywhere in the Main Image window and drag with the left mouse button pressed.

   Pixel values contained in a ten-pixel by ten-pixel box surrounding the crosshair will be highlighted in red on the scatter plot.

Note

The **Mouse Button Descriptions** dialog tells you the functions of the different mouse button actions when applied in the **Scatter Plot** display.

4. Move the cursor around in the Main Image window to observe the *dancing pixels* effect.
5. You can also use the scatter plot to highlight specific data values in the Main Image window. Place the mouse cursor in the scatter plot window and click and drag with the middle mouse button.

A ten-pixel-square box will appear in red on the plot. Pixels with the values contained in the box are highlighted on the image in the Main Image window and appear to *dance*, as you drag the cursor in the **Scatter Plot** display moving the 10-by-10 pixel area.

6. From the Scatter Plot menu bar, select **File** → **Cancel** to close the **Scatter Plot** window.

Load a Color Image

1. If the **Available Bands List** dialog is not already on your screen, call it up again from the ENVI Main menu bar by selecting **Window** → **Available Bands List** (Figure 1-3).
2. Set up to load a color image in a second display by clicking on the radio button labelled **RGB Color** in the **Available Bands List** dialog.
3. Select a band for each color (red, green, blue) from the list by clicking on the band name. The radio buttons for assigning the R, G, and B colors automatically advance when you click on a band name in the list.
4. When all three colors have band names associated with them, click the **Display #1** menu button to open a **New Display** from the pull-down menu.
5. Now, click on the **Load RGB** button to load the image in the new display.

Link Two Displays

Link the two displays together for comparison. When you link two displays, any action you perform on one display (scrolling, zooming, etc.) is echoed in the linked display. To link the two displays you have on screen now do the following:

1. From either of the two Main Image menu bars, select **Tools** → **Link** → **Link Displays**. This opens the **Link Displays** dialog box.
2. Click **OK** in the **Link Displays** dialog to establish the link.
3. Now try scrolling or zooming in one display group and observe as your changes are mirrored in the second display.

Dynamic Overlays

ENVI’s multiple Dynamic Overlay feature allows you to dynamically superimpose parts of one or more linked images onto the other image. Dynamic overlays are turned on automatically when you link two displays, and may appear in either the Main Image window or the Zoom window.

1. To start, click the left mouse button to see both displays completely overlaid on one another.
2. To create a smaller overlay area, position the mouse cursor anywhere in either Main Image window (or either Zoom window) and hold down and drag with the middle mouse button. Upon button release, the smaller overlay area is set and a small portion of the linked image will be superimposed on the current image window.
3. Now click the left mouse button and drag the small overlay window around the image to see the overlay effects.
4. You can resize the overlay area at any time by clicking and dragging the middle mouse button until the overlay area is the desired size.

Select Regions Of Interest

ENVI lets you define regions of interest (ROIs) in your images. ROIs are typically used to extract statistics for classification, masking, and other operations.

1. From the Main Image window menu bar, select **Overlay** → **Region of Interest**. The **ROI Tool** dialog for that Main Image display will appear (Figure 1-7).

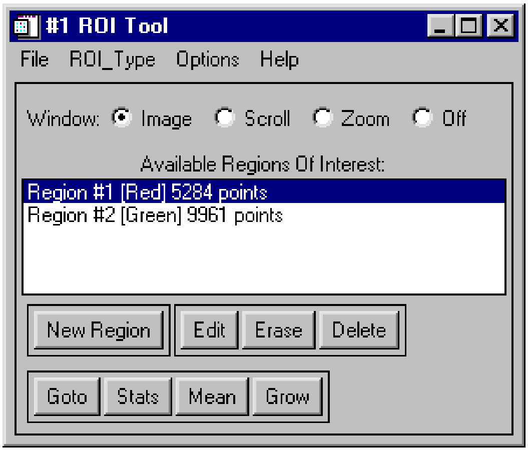


Figure 1-7: The ROI Tool dialog with two regions defined.

2. Draw a polygon that represents the region of interest.

- Click the left mouse button in the Main Image window to establish the first point of the ROI polygon.
- Select further border points in sequence by clicking the left button again, and close the polygon by clicking the right mouse button.The middle mouse button deletes the most recent point, or (if you have closed the polygon) the entire polygon. Click the right mouse button a second time to fix the polygon.
- ROIs can also be defined in the Zoom and Scroll windows by selecting the appropriate window radio button in the **ROI Tool** dialog.

When you have finished defining an ROI, it is shown in the dialog in the **Available Regions of Interest** list, with the name, region color, and number of pixels enclosed (Figure 1-7).

3. To define a new ROI, click the **New Region** button.
    - You can enter a name for the region and select the color and fill patterns for the region by clicking on the **Edit** button.

Other types of ROIs

ROIs can also be defined as polylines or as a collection of individual pixels by selecting the desired ROI type from the **ROI_Type** pull-down menu. See the *ENVI 3.5 User's Guide* or the hypertext online help for further discussion of these types of ROI.

Working with ROIs

You can define as many ROIs as you wish in any image (Figure 1-8).

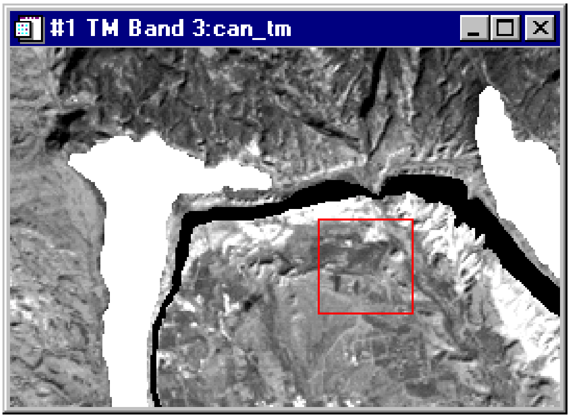


Figure 1-8: An image with two regions of interest (ROIs) defined.

1. Once you have created the ROI definitions, you can erase them from the display (leaving the definition in the list) by selecting the ROI from the **Available Regions of Interest** list and clicking on the **Erase** button.
2. Clicking on the **Stats** button allows you to view statistics about the ROI you select.
3. Clicking the **Delete** button permanently deletes the selected ROI definitions from the list.
4. The other buttons and options under the pull-down menus at the top of the **ROI Tool** dialog let you calculate ROI means, save your ROI definitions, load saved definitions, or display or delete all the definitions in the list.

Region of interest definitions are retained in memory after the **ROI Tool** dialog is closed, unless you explicitly delete them. This means the ROIs are available to other ENVI functions even if they are not displayed.

Annotate the Image

ENVI's flexible annotation features allow you to add text, polygons, color bars, and other symbols to your plots and images.

1. To annotate an image, select **Overlay** → **Annotation** from the Main Image menu bar. The **Annotation: Text** dialog for that Main Image window will appear (Figure 1-9).
2. To annotate plots, 3-D surfaces, and similar objects, select **Options** → **Annotation** from the plot window menu bar.

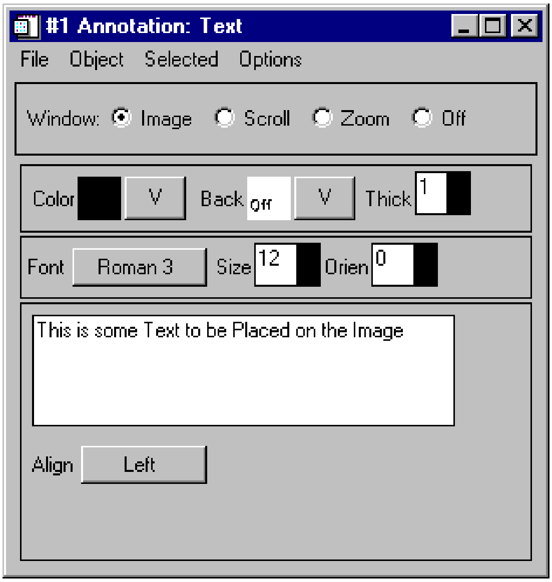


Figure 1-9: The Annotation dialog, in Text mode.

Annotation Types

The **Annotation: Text** dialog allows you to choose from a variety of annotation types. Different types are selected from the **Object** menu and include Text, Symbols, Rectangles, Ellipses, Polygons, Polylines, Arrows, Map Scale Bars and Declination Diagrams, Map Keys, Color Table Ramps, and Images. By default, the Annotation dialog starts up with *Text* selected. Other fields in the dialog let you control the size, color, placement, and angle of the annotation text. When you select different annotation types from the *Object* menu, the fields in the dialog change to display options appropriate to the new type.

Placing Annotation

Try placing a text annotation in your Main Image window:

1. Type some text in the text field of the **Annotation: Text** dialog.
2. Select a font, color, and size from the appropriate menus and parameters in the dialog, then position the mouse pointer in the Main Image window and press the left mouse button.

Note

The **Mouse Button Description** dialog describes the mouse button interactions within annotation.

Your text is displayed in the window at the point you chose (Figure 1-10).

3. Drag the handle using the left mouse button to position the text in the window.
   - You can continue to change the annotation's properties and position by changing the fields in the dialog box or dragging the text or symbol while holding down the left mouse button.
4. When you are satisfied with the annotation, press the right mouse button to fix the annotation in position.

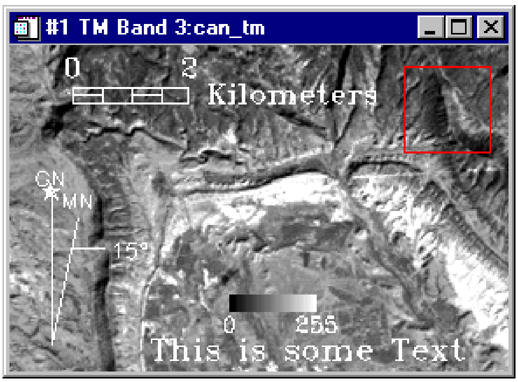


Figure 1-10: An annotated image.

Saving and Restoring Annotation

1. You can save your image annotation by selecting **File** → **Save Annotation** from the **Annotation: Text** dialog menu bar.
2. This opens the **Output Annotation Filename** dialog in which you specify a path and filename with a `.ann` extension for the saved annotation.

Note

If you do not save your annotation in a file, it will be lost when you close the **Annotation: Text** dialog (you will be prompted to save the annotation if you close without first saving).

3. You can also restore saved annotation files by selecting **File** → **Restore Annotation** in the **Annotation: Text** dialog.

Editing Previously Placed Annotation

To edit an annotation element that has already been set in the image, do the following.

1. Select **Object** → **Selection/Edit** in the **Annotation: Text** dialog.
2. Draw a box around the annotation you wish to edit by clicking and dragging with the left mouse button.
3. When the handle reappears, Click and drag the handle and annotation to move and configure the item just as you would a new annotation.

Suspending the Annotation Function Temporarily

1. To suspend annotation operations and return to normal ENVI functionality temporarily, select the **Off** radio button at the top of the **Annotation: Text** dialog.

   This allows you to use the scroll and zoom features in your display without losing your annotations.
2. To return to the annotation function, select the radio button in the **Annotation: Text** dialog for the window you are annotating.

Leave your annotation on the Main Image window as you complete this tutorial.

Add Grid Lines

Try adding a grid (Figure 1-11) to your image.

1. To overlay grid lines on your image, select **Overlay** → **Grid Lines** in the Main Image window. This brings up the **Grid Line Parameters** dialog box.

Note

An image border is automatically added when you overlay grid lines.

2. You can adjust the grid line attributes by setting the line thickness and color and the grid spacing using the **Options** → **Edit Pixel Grid Attributes** pull-down menu from the **Grid Lines Parameters** dialog. This selection brings up the **Edit Pixel Attributes** dialog box.
3. In the **Edit Pixel Attributes** dialog, you can change the color, thickness and grid spacing for the labels, lines, box and corners of the grid. When the attributes are set up to your satisfaction, click **OK** in the **Edit Pixel Attributes** dialog to apply the changes to the grid on the images.
4. When you have added a satisfactory grid, click **Apply** in the **Grid Line Parameters** dialog.

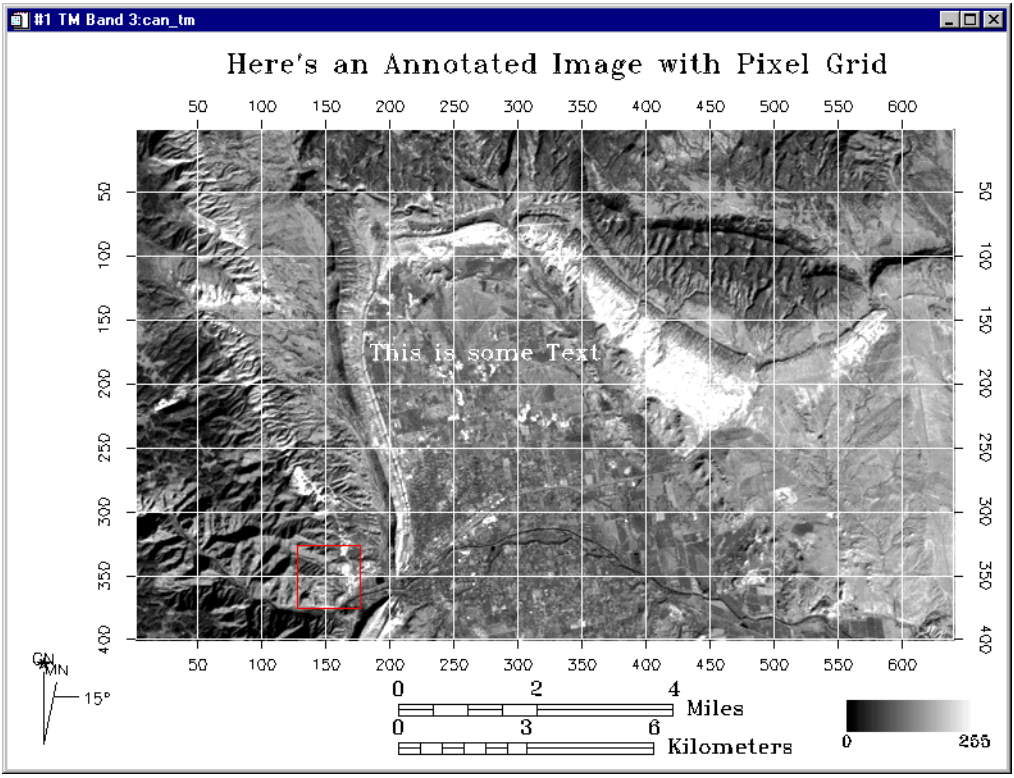


Figure 1-11: An annotated image with a grid overlaid.

Save and Output an Image

ENVI gives you several options for saving and outputting your filtered, annotated, gridded images. You can save your work in ENVI's image file format, or in several popular graphics formats (including Postscript) for printing or importing into other software packages. You can also output directly to a printer.

Saving your Image in ENVI Image Format

To save your work in ENVI's native format (as an RGB file):

1. From the Main Image window menu bar, select **File** → **Save Image As** → **Image File**. The **Output Display to Image File** dialog appears.

2. Select 24-Bit color or 8-Bit gray scale output, graphics options (including annotation and gridlines), and borders.

   If you have left your annotated and gridded color image on the display, both the annotation and grid lines will be automatically listed in the graphics options.

   You can also select other annotation files to be applied to the output image.

3. Select output to **Memory** or **File** using the desired radio button.

   - If output to **File** is selected, enter an output filename.

Note

If you select other graphics file formats from the **Output File Type** button which, by default is set to **ENVI**, your choices will be slightly different.

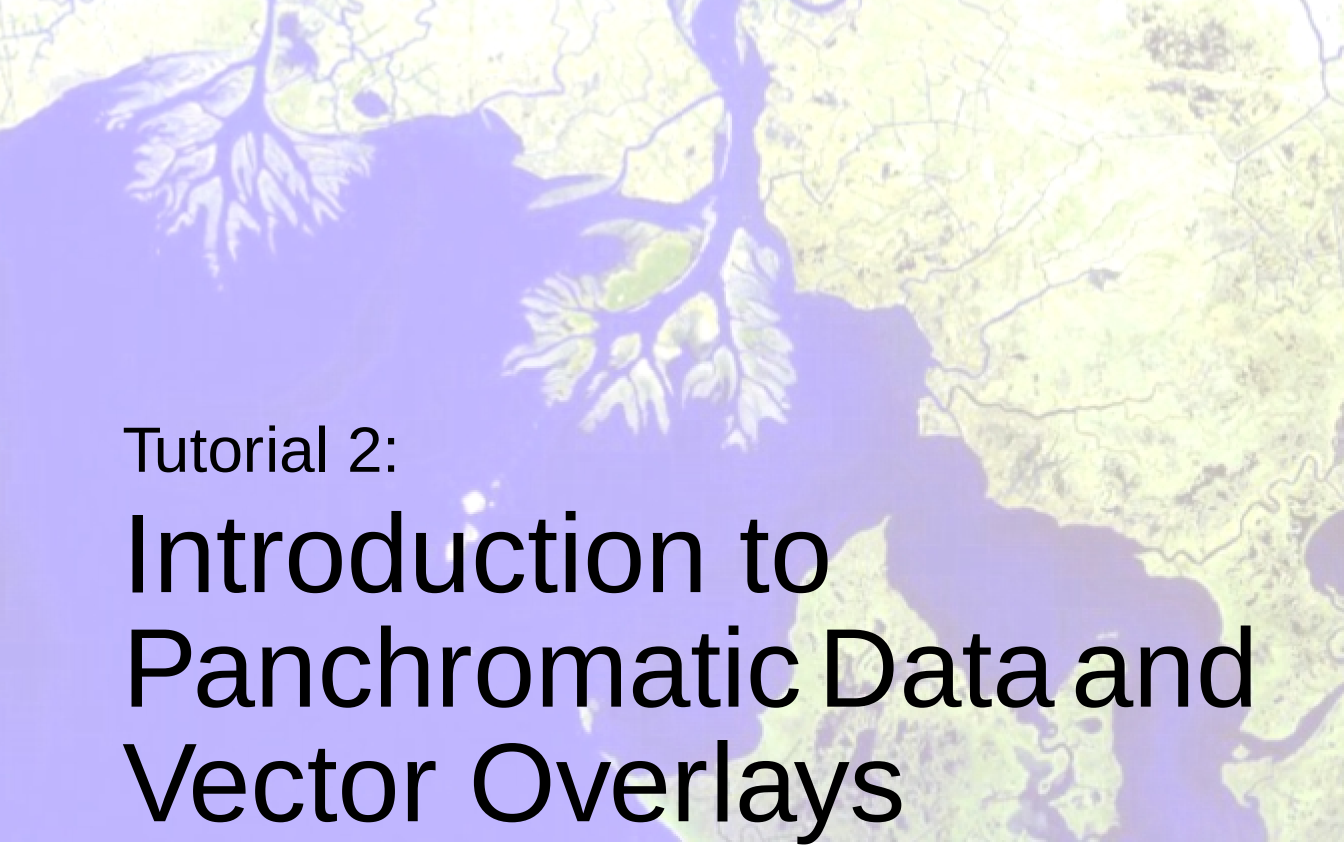
4. Click **OK** to save the image.

Note

This process saves the current display values for the image, not the actual data values.

End the ENVI Session

You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to terminate ENVI when prompted.



Tutorial 2:

Introduction to Panchromatic Data and Vector Overlays

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial provides an introduction to using ENVI with Panchromatic (SPOT) data, including display, contrast enhancement, basic information about ENVI and some suggestions for your initial investigations of the software. It is designed to introduce first-time ENVI users to the basic concepts of the package and to explore some of its key features. It assumes that you are already familiar with general image-processing concepts. This dataset is a SPOT Panchromatic image and corresponding DXF files of Enfidaville, Tunisia, courtesy of Research Systems International France. These data are Copyright CNES-Spot Image and IGN France.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/enfidavi`

File	Description
`enfidavi.bil`	SPOT Panchromatic Data, Enfidaville, Tunisia
`enfidavi.hdr`	ENVI Header for above
`enfidavi.dsc`	GeoSpot Volume Descriptor File
`enfidavi.rep`	GeoSpot report file (REP/B: GEOSPOT Structure)
`enfidavi.rsc`	GeoSpot Raster Source Description File
`dxf.txt`	DXF coding descriptor file
`alti.dxf`	Spot height DXF file
`energy.dxf`	Oil or Gas Pipeline DXF file
`hydro.dxf`	Hydrology DXF file
`industry.dxf`	Industrial Areas DXF file
`physio.dxf`	Physiographic areas DXF file
`popu.dxf`	Urban Features (Population Centers) DXF file
`transpor.dxf`	Transportation Networks DXF file
`copyrite.txt`	Data Copyright Notice

Panchromatic Data and Vector Overlays

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in UNIX, enter `envi` at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Open a Panchromatic (SPOT) Image File

To open an image file:

1. From the ENVI main menu, select **File** → **Open Image File**.

   Note that on some platforms you must hold the left mouse button down to display the submenus from the main menu.

   An **Enter Data Filenames** file selection dialog appears.

2. In the file selection dialog, navigate to the `enfidavi` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 1* just as you would in any other application and select the file `enfidavi.bil` from the list and click **Open** (on Windows) or **OK** (on UNIX).

   This is a SPOT Panchromatic image of Enfidaville, Tunisia, courtesy of RSI France. The data in this file is copyrighted as Copyright CNES-Spot Image and IGN France.

   The **Available Bands List** dialog appears on your screen. This list allows you to select spectral bands of the image for display and processing. You have the choice of loading either a gray scale or an RGB color image of the available bands.

Select and Load an Image Band

1. Select the band listed at the top of the dialog by clicking on the band with the left mouse button.

   The band you have chosen is displayed in the field marked **Selected Band:**.

2. Click the **Load Band** button to load the image into a new display.

ENVI has many interactive functions, and the mouse button combinations and actions are different for each one. The **Mouse Button Descriptions** dialog is provided to tell you what the mouse buttons do in each graphics window.

3. To bring up the **Mouse Button Descriptions** dialog, select **Window** → **Mouse Button Descriptions** from either the ENVI main menu or the Main Image display menu bar.

Spatially Browse the Image

1. Move the Scroll window indicator box around the scroll image to display different portions of the image in the Main Image display at full resolution.

   Another method for scrolling the full resolution image is to add scroll bars to the Main Image window. You can easily do this using the Zoom window controls. In Zoom window position the cursor over the right-most control in the lower left corner of the window. Double-click the right mouse button to activate scroll bars in the Main Image window.

2. Now look at the image in greater detail. To do this, click and drag the Zoom box around in the Main Image display using the left mouse button. When the Zoom box is over an area of interest, release the mouse button and you'll see the image in greater detail in the Zoom window. You can also click and release the left mouse button anywhere in the Main Image display to reposition the Zoom box.

3. Position the Zoom box at various locations in the Main Image window and examine the data.

Perform Interactive Contrast Stretching

Interactive contrast stretching plots a histogram and allows you to interactively control the contrast of the displayed image. Many different types of stretches can be applied. By default, a linear 2% stretch is applied to the data when it is first displayed.

- To access ENVI's interactive contrast stretching functions, select **Enhance** → **Interactive Stretching** from the Main Image window menu bar.

  An **Interactive Stretching** dialog for the displayed band appears. This dialog allows you to change the contrast stretch of the displayed image (Figure 2-1). Two histogram plots display the color or gray scale range of the input image (left) and the output image after contrast stretching (right). Initially, the input and output histograms reflect the default stretch applied to the data when the image was displayed.

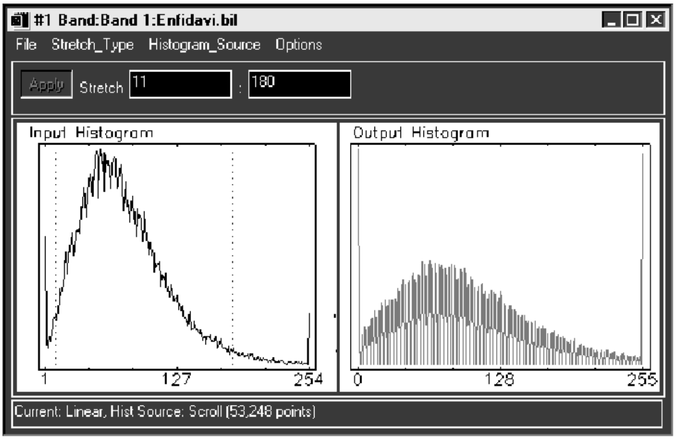


Figure 2-1: The Interactive Stretching Dialog.

- The **Stretch_Type** pull-down menu at the top of the histogram has a variety of contrast-stretching options. Try applying the methods described below and observe the results in the Main Image window.
- Also, try selecting both **Histogram_Source** → **Zoom** and **Histogram_Source** → **Scroll** from the **Interactive Stretching** menu bar and note the differences in the histograms and stretches of the Zoom window and Scroll window.

Linear

When images are loaded into the Main Image window, a 2% linear contrast stretch is applied by default.

Note

This default can be set by selecting **File** → **Preferences** → **Display Defaults** from the ENVI main menu. You can edit the **Display Default Stretch** in the **Preferences: Display Defaults** dialog which appears.

1. In the Main Image display, select **Enhance** → **Interactive Stretching**. An **Interactive Stretching** dialog appears.
2. In the menu bar of the new dialog, choose **Stretch_Type** → **Linear**.

Note

Two vertical dotted lines appear in the input histogram plot—these bars can be repositioned to control the minimum and maximum value used in the contrast stretch.

3. Position the mouse cursor on the left bar and hold down the left mouse button as you drag the bar from side to side.

   As the left mouse button is pressed and the dotted vertical bar is moved across the plot, numbers appear on the status bar of the dialog. Whenever the left mouse button is clicked over the histogram plot, the status bar displays the current data value, the number of pixels and the percentage of pixels that have that value, and the cumulative percentage of pixels with values less than or equal to the current value.

4. Since you'll be changing the stretch conditions, it may be helpful to have the changes automatically applied. To do this, select **Options** → **Auto Apply On** from the **Interactive Stretching** dialog menu bar.

   If you don't wish the changes to be made until after you're finished, then select **Options** → **Auto Apply Off**, and use the **Apply** button on the dialog to apply the stretch and observe the results.

5. Try positioning the left bar so that a cumulative percentage of pixels equaling approximately 5% is selected. Now move the right bar so that the cumulative percentage is approximately 95% of the pixels.

   You can also position the bars by entering a minimum and maximum value in the **Stretch** text fields of the dialog. You can enter either data values or percentages.

6. Enter 4% in the left text field and 96% in the right text field and press the **Enter** key.

   The % values are converted to digital numbers and the left and right bars in the display are updated with the data values at 4% and 96%, respectively.

Equalize

1. Select **Stretch_Type** → **Equalization** and note the change in the **Output Histogram** plot in the dialog.
2. Again, you can choose to have the stretch automatically applied to the image display group by ensuring the **Options** → **Auto Apply On** is selected from the **Interactive Stretching** dialog menu.

If you don’t wish the changes to be made until after you’re finished, then select **Options** → **Auto Apply Off**, and use the **Apply** button on the dialog to apply the stretch and observe the results.

Gaussian

1. From the **Interactive Stretching** dialog, select **Stretch_Type** → **Gaussian**.
2. Set the standard deviation by selecting **Options** → **Set Gaussian Stdv**.
3. The **Set Gaussian Stdv** dialog appears. You can adjust the standard deviation value and see the effect when the new setting is applied to the image display group.
4. Again, you can choose to have the stretch automatically applied to the image display group by ensuring the **Options** → **Auto Apply On** is selected from the **Interactive Stretching** dialog menu.

   If you don’t wish the changes to be made until after you’re finished, then select **Options** → **Auto Apply Off**, and use the **Apply** button on the dialog to apply the stretch and observe the results.
5. Select **File** → **Cancel** to close the contrast stretching dialog.

Color Mapping

ENVI provides tools for quickly color slicing gray scale images.

1. Select **Tools** → **Color Mapping** → **ENVI Color Tables** from the Main Image window menu bar. The **ENVI Color Tables** dialog appears.

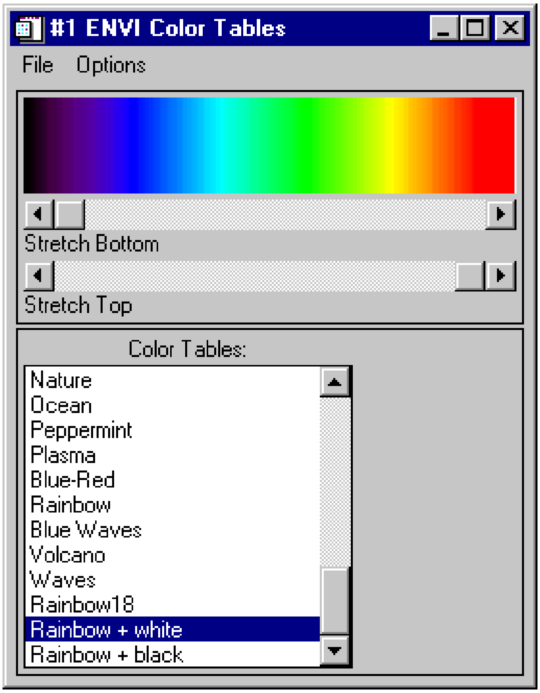


Figure 2-2: The ENVI Color Tables dialog.

2. Apply quick stretches to the displayed image by sliding the **Stretch Bottom** and **Stretch Top** sliders back and forth and observe the stretched image.
3. Click on several of the color table names in the **Color Table** list in the **ENVI Color Tables** dialog and observe the color-coded image. Change the stretch as in the previous step.
4. Select **Options** → **Reset Color Table** in the **ENVI Color Tables** dialog to return to the original stretch and gray scale color table.
5. Select **File** → **Cancel** to close the **ENVI Color Tables** dialog.

Pixel Locator

The Pixel Locator dialog allows exact positioning of the cursor and displays the screen and data values of the selected pixel.

1. Select **Tools** → **Pixel Locator** from the Main Image display menu bar to display the **Pixel Locator** dialog.

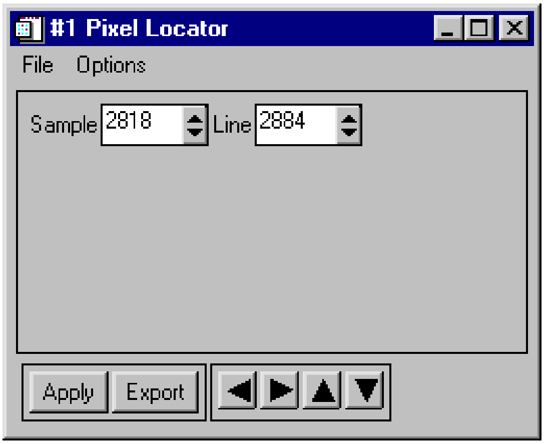


Figure 2-3: The Pixel Locator dialog allows exact positioning of the cursor and displays the screen and data values of the selected pixel.

2. Move and set the cursor in any of the three image displays to observe the dialog as it reflects the pixel location for the current pixel.
3. The **Pixel Locator** dialog shows the pixel location in pixel coordinates by default. To see the location in map coordinates, select **Options** → **Map Coordinates** from the **Pixel Locator** menu bar.
4. Use the **Proj:/Datum:** spin box controls to toggle between true map coordinates and latitude/longitude geographic coordinates. You can change the selected projection by clicking on the **Change Proj...** button.
5. Close the **Pixel Locator** dialog by selecting **File** → **Cancel** from the dialog menu.

Display the Georeferenced Cursor Location

Use ENVI's cursor location/value function to view image values and geographic location.

1. To display the cursor location and value, select **Tools** → **Cursor Location/Value** from the Main Image window menu bar. You can also display

it from the ENVI main menu by selecting **Window** → **Cursor Location/Value**.

The **Cursor Location / Value** dialog box appears displaying the location of the cursor in the Main Image, Scroll, or Zoom windows (Figure 2-4). The dialog also displays the screen value (color) and the actual data value of the pixel underneath the crosshair cursor.

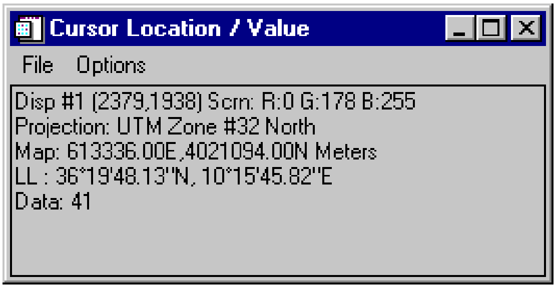


Figure 2-4: The Cursor Location dialog displays the screen and data values of the selected pixel.

2. To dismiss the dialog, select **File** → **Cancel** from the dialog pull-down menu.

Apply an Interactive Filter

ENVI gives you the ability to apply several different pre-defined or user-defined filters to a display (file-based filtering is also available and is accessed via the Filter menu on the ENVI main menu). The following example shows you how to apply a pre-defined filter to the image in the Main Image window.

Choose a Filter

1. From the Main Image window menu bar, select **Enhance** → **Filter** and choose the desired filter type from the pull-down filter menu to apply to the displayed image.
2. Try the different sharpening, smoothing, and median filters on the displayed image.

Display Image in a Second Display and Apply a Different Filter

1. From the **Available Bands List**, select the **Display #1** → **New Display** from the pull-down menu button at the bottom of the dialog to create a second display group.
2. Select the image band to be displayed in the second display group, and click **Load Band** to load the image into the second display.
3. From the Main Image window of Image #2, choose **Enhance** → **Filter** and select a filter different from that applied to Image #1 from the pull-down filter menu.

Compare Images Using Dynamic Overlays

1. Select **Tools** → **Link** → **Link Displays** from the menu bar of either of the Main Image windows and click **OK** to link the images.
2. Use the middle mouse button to resize the dynamic overlay and the left mouse button to move the region for comparison. Note that the overlay area is defined from the lower left corner of the display.

Review GeoSpot Map Information

To review the GeoSpot Map information in the ENVI Header file:

1. From the ENVI main menu, select **File** → **Edit ENVI Header**.
2. In the **Edit Header Input File** dialog, select `enfidavi.bil` as the input file, and click **OK**.

   The **Header Info** dialog appears.

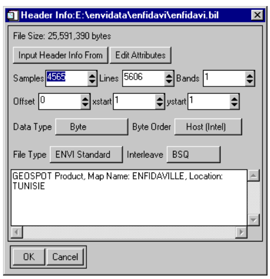


Figure 2-5: The Header Info dialog.

3. Click the **Edit Attributes** button and select **Map Info** from the pull-down menu. The **Map Information** dialog appears. Note that the data are in UTM projection, Zone 32 utilizing the NAD27 datum.
4. Click **Cancel** in the **Map Information** dialog and **Cancel** in the **Header Info** dialog.

Open and Overlay DXF Vector Files

1. From the ENVI main menu, select **File** → **Open Vector File** → **DXF**. A standard file selection dialog called **Enter DXF Filenames** appears.
2. In the file selection dialog, navigate to the *ENVI Tutorial and Data CD No. 1* `envidata/enfidavi` directory. Set the file filter to `*.dxf` and select all of the files with the `.dxf` extension. Click **Open** at the bottom of the file selection dialog on Windows and Macintosh or click **OK** on UNIX to open the **Import DXF File Parameters** dialog.
3. Midway down the **Import DXF File Parameters** dialog is the selection list of projections. Select UTM as the Output Projection. This field refers to the map units that the imported vector data is in.
4. Click the **Datum** button to bring up the **Select Geographic Datum** dialog. Highlight the **Mexico (NAD27)** datum in the list and click **OK**.
5. In the **Import DXF File Parameters** dialog enter the UTM Zone as **32 North**.
6. Click **OK** to load the DXF files and convert to `.evf` (ENVI Vector Files).
7. The **Available Vectors List** dialog appears. Click on the **Select All Layers** button. Next, click on the **Load Selected** button.
8. A **Load Vector** dialog appears which lists all of the available Main Image windows. Select **Display #1** from the list.
9. The **#1 Vector Parameters** dialog appears showing the named vector layers.
10. Click **Apply** to load the vectors onto the display.
11. Click on one of the layer names in the **#1 Vector Parameters** dialog. In the Main Image display click and drag the left mouse button to move the cursor in the image and observe map coordinates for the selected vectors in the **#1 Vector Parameters** dialog.

Basic Map Composition

Add Grid Lines

Add a grid to your image:

1. To overlay grid lines on your image, select **Overlay** → **Grid Lines** from the Main Image window menu bar. An image border is automatically added when you overlay grid lines.
2. You can adjust the grid lines by setting the line thickness and color and the grid spacing using the **Options** pull-down menu.
3. When you have added a satisfactory grid, click **Apply** in the **Grid Line Parameters** dialog.

Annotate the Image with a Map Key

ENVI's flexible annotation features allow you to add text, polygons, color bars, and other symbols to your plots and images.

1. To annotate the image, select **Overlay** → **Annotation**. The **#1 Annotation: Text** dialog appears.
2. To annotate a map key corresponding to the DXF overlays, select **Object** → **Map Key** in the **#1 Annotation: Text** dialog.
3. Edit the map key characteristics by clicking the **Edit Map Key Items** button in the dialog. The **Map Key Object Definition** dialog appears.
4. You can change the names, colors, and fill (for polygons) using the **Map Key Object Definition** dialog. Click **OK** to return to the **#1 Annotation: Text** dialog.
5. Add a background color by selecting the color pull-down menu next to the **Back** color swatch in the **#1 Annotation: Text** dialog.
6. Click the left mouse button to place the map key in the Main Image window. Reposition the map key by clicking, or by clicking and dragging with the left mouse button. Set the map key by clicking the right mouse button in the image.

Saving and Restoring Annotation

1. You can save your image annotation by selecting **File** → **Save Annotation** in the **#1 Annotation: Text** dialog.

Note

If you do not save your annotation in a file, it will be lost when you close the Annotation dialog (you will be prompted to save the annotation if you close without first saving).

2. You can also restore saved annotation files by selecting **File** → **Restore Annotation** in the dialog.

Suspending the Annotation Function Temporarily

1. To suspend annotation operations and return to normal ENVI functionality temporarily, select the **Off** radio button at the top of the **Annotation: Text** dialog.
2. This allows you to use the scroll and zoom features in your display without losing your annotations.
3. To return to the annotation function, select the radio button for the window you are annotating.

Save and Output an Image (Burn-In)

ENVI gives you several options for saving and outputting your filtered, annotated, gridded images. You can save your work in ENVI's image file format, or in several popular graphics formats (including Postscript) for printing or importing into other software packages. You can also output directly to a printer.

Save your Image in GEOTIFF Format

To save your work as a GEOTIFF:

1. Select **File** → **Save Image As** → **Image File** in the Main Image window.

   The **Output Display to Image File** dialog appears.

2. Click on the **Output File Type** button and select **TIFF/GeoTIFF** output from the pull-down menu.

   If you have left your annotated and gridded color image on the display, both the annotation and grid lines will be automatically saved.

3. If output filename shown is not the one you want, enter an output filename in the text box; otherwise, click **OK** to save the image.

   - Because this is a georeferenced image, ENVI automatically saves it as a GEOTIFF.

Note

If you select other graphics file formats from the **Output File Type** button, your choices will be slightly different.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

Tutorial 3: Multispectral Classification

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial leads you through a typical multispectral classification procedure using Landsat TM data from Canon City, Colorado. Results of both unsupervised and supervised classifications are examined and post classification processing including clump, sieve, combine classes, and accuracy assessment are discussed. It is assumed that you are already generally familiar with multispectral classification techniques.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/can_tm`

File	Description
`can_tmr.img`	Boulder Colorado TM Reflectance
`can_tmr.hdr`	ENVI Header for Above
`can_km.img`	K MEANS Classification
`can_km.hdr`	ENVI Header for Above
`can_iso.img`	ISODATA Classification
`can_iso.hdr`	ENVI Header for Above
`classes.roi`	Regions of Interest (ROI) for Supervised Classification
`can_pcls.img`	Parallelepiped Classification
`can_pcls.hdr`	ENVI Header for Above
`can_bin.img`	Binary Encoding Result
`can_bin.hdr`	ENVI Header for Above
`can_sam.img`	SAM Classification Result
`can_sam.hdr`	ENVI Header for Above
`can_rul.img`	Rule image for SAM classification
`can_rul.hdr`	ENVI Header for Above
`can_sv.img`	Sieved Image

File	Description
can_sv.hdr	ENVI Header for Above
can_clmp.img	Clump of sieved image
can_clmp.hdr	ENVI Header for Above
can_comb.img	Combined Classes image
can_comb.hdr	ENVI Header for Above
can_ovr.img	Classes overlain on gray scale image
can_ovr.hdr	ENVI Header for Above
can_v1.evf	Vector layer generated from class #1
can_v2.evf	Vector layer generated from class #2

Examine Landsat TM Color Images

This portion of the exercise will familiarize you with the spectral characteristics of Landsat TM data of Canon City, Colorado, USA. Color composite images will be used as the first step in locating and identifying unique areas for use as training sets in classification.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To start ENVI in UNIX, enter `envi` at the UNIX command line.
- To start ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Open and Display Landsat TM Data

To open an image file:

1. Select **File** → **Open Image File** on the ENVI main menu.

Note

On some platforms you must hold the left mouse button down to display the submenus from the ENVI main menu.

An **Enter Data Filenames** file selection dialog appears.

2. Navigate to the `can_tm` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 2* just as you would in any other application and select the file `can_tmr.img` from the list and click **OK**.

   The **Available Bands List** dialog appears on your screen. This list allows you to select spectral bands for display and processing.

Note

You have the choice of loading either a gray scale or an RGB color image.

3. Select the **RGB Color** radio button in the **Available Bands List**, and then click on bands 4, 3, and 2 sequentially with the left mouse button.

   The bands you have chosen are displayed in the appropriate fields in the center of the dialog.

4. Click on the **Load RGB** button to load the image into a new display.

Review Image Colors

Use the displayed color image as a guide to classification. This image is the equivalent of a false color infrared photograph. Even in a simple three-band image, it’s easy to see that there are areas that have similar spectral characteristics. Bright red areas on the image represent high infrared reflectance, usually corresponding to healthy vegetation, either under cultivation, or along rivers. Slightly darker red areas typically represent native vegetation, in this case in slightly more rugged terrain, primarily corresponding to coniferous trees. Several distinct geologic and urbanization classes are also readily apparent as is urbanization.

The following figure shows the resulting Main Image window for these bands.

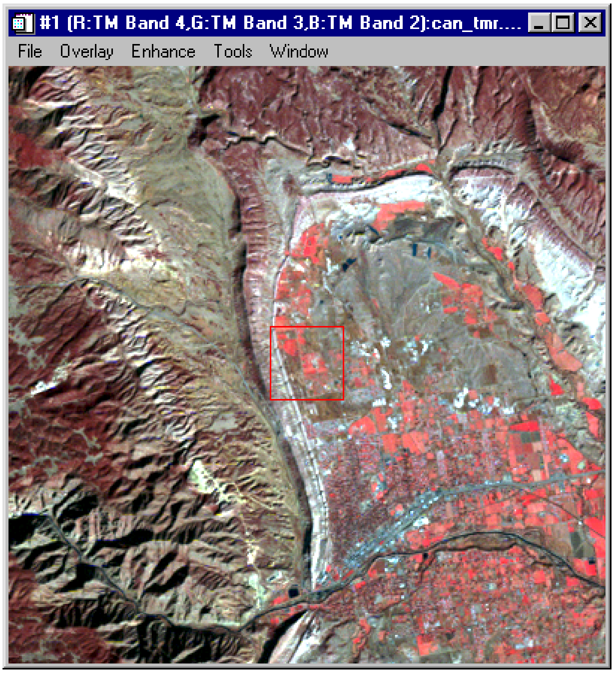


Figure 3-1: Canon City Landsat TM Data.

Cursor Location/Value

Use ENVI's **Cursor Location/Value** dialog to preview image values in the displayed spectral bands. To bring up a dialog box that displays the location of the cursor in the Main Image, Scroll, or Zoom windows.

1. Select **Tools** → **Cursor Location/Value** from the Main Image window menu bar.

   Alternatively, double-click the left mouse button in the image display to toggle the **Cursor Location/Value** dialog on and off.

2. Move the cursor around the image and examine the data values in the dialog for specific locations. Also note the relation between image color and data value.

3. Select **Files** → **Cancel** in the **Cursor Location/Value** dialog to dismiss when finished.

Examine Spectral Plots

Use ENVI's integrated spectral profiling capabilities to examine the spectral characteristics of the data.

1. Choose **Tools** → **Profiles** → **Z Profile (Spectrum)** from the Main Image window menu bar to begin extracting spectral profiles.

2. Examine the spectra for areas that you previewed above using color images and the **Cursor/Location Value** dialog by clicking the left mouse button in any of the display group windows. Note the relations between image color and spectral shape. Pay attention to the location of the image bands in the spectral profile, marked by the red, green, and blue bars in the plot.

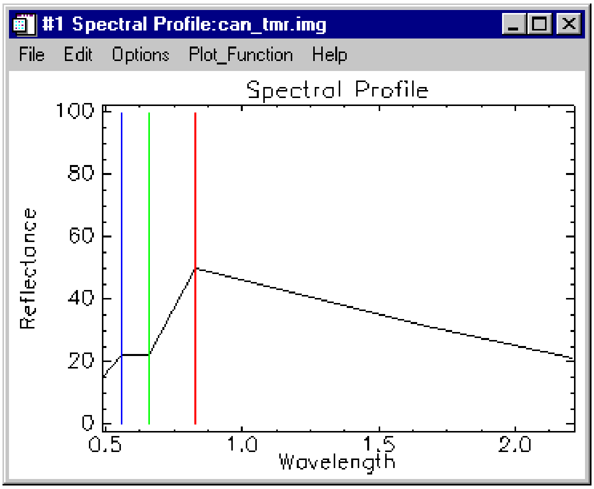


Figure 3-2: Spectral Plots from Canon City TM Data.

3. Select **File** → **Cancel** in the **Spectral Profile** dialog to dismiss it.

Unsupervised Classification

Start ENVI's unsupervised classification routines from the ENVI main menu, by choosing **Classification** → **Unsupervised** → **K-Means** or **IsoData**, or review the pre-calculated results of classifying the image in the `can_tm` directory.

K-Means

Unsupervised classification uses statistical techniques to group n-dimensional data into their natural spectral classes. The K-Means unsupervised classifier uses a cluster analysis approach which requires the analyst to select the number of clusters to be located in the data, arbitrarily locates this number of cluster centers, then iteratively repositions them until optimal spectral separability is achieved.

Choose K-Means as the method, use all of the default values and click on **OK**, or review the results contained in `can_km.img`.

1. Open the file `can_km.img`, click on the **Gray Scale** radio button in the **Available Bands List**, click on the band name at the top of the list, select **New Display** on the **Display** button pull-down menu, and then **Load Band**.

2. From the Main Image display menu, select **Tools** → **Link** → **Link Displays** and click **OK** in the dialog to link the images.
3. Compare the K-MEANS classification result to the color composite image by clicking and dragging using the left mouse button to move the dynamic overlay around the image.
4. When finished, select **Tools** → **Link** → **Unlink Display** to remove the link and dynamic overlay.

If desired, experiment with different numbers of classes, change thresholds, standard deviations, and maximum distance error values to determine their effect on the classification.

Isodata

IsoData unsupervised classification calculates class means evenly distributed in the data space and then iteratively clusters the remaining pixels using minimum distance techniques. Each iteration recalculates means and reclassifies pixels with respect to the new means. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached.

Choose **IsoData** as the method, use all of the default values and click on **OK**, or review the results contained in `can_iso.img`.

1. Open the file `can_iso.img`, click on the **Gray Scale** radio button in the **Available Bands List**, click on the band name at the top of the list, select the **Display #1** button and choose **New Display** on the pull-down menu. Then click on the **Load Band** button.
2. Select **Tools** → **Link** → **Link Displays**. Click **OK** to link this image to the color composite image and the K-MEANS result.
3. Compare the IsoData classification result to the color composite image by clicking and dragging using the left mouse button to move the dynamic overlay around the image. Toggle the dynamic overlay of the third image by holding the left mouse button down and simultaneously clicking on the middle mouse button. Compare the ISODATA and K-MEANS classifications.
4. Select **File** → **Cancel** to dismiss the two image displays.

If desired, experiment with different numbers of classes, change thresholds, standard deviations, maximum distance error, and class pixel characteristic values to determine their effect on the classification.

Supervised Classification

Supervised classification requires that the user select training areas for use as the basis for classification. Various comparison methods are then used to determine if a specific pixel qualifies as a class member. ENVI provides a broad range of different classification methods, including Parallelepiped, Minimum Distance, Mahalanobis Distance, Maximum Likelihood, Spectral Angle Mapper, Binary Encoding, and Neural Net. Examine the processing results below, or use the default classification parameters for each of these classification methods to generate your own classes and compare results.

To perform your own classifications from the ENVI main menu, select **Classification** → **Supervised** → **[*method*]**, where *[method]* is one of the supervised classification methods in the pull-down menu (**Parallelepiped**, **Minimum Distance**, **Mahalanobis Distance**, **Maximum Likelihood**, **Spectral Angle Mapper**, **Binary Encoding**, or **Neural Net**). Use one of the two methods below for selecting training areas, also known as regions of interest (ROIs).

Select Training Sets Using Regions of Interest (ROI)

As described in Tutorial 1, "Introduction to ENVI" and summarized here, ENVI lets you easily define regions of interest (ROIs) typically used to extract statistics for classification, masking, and other operations. For the purposes of this exercise, you can either use predefined ROIs, or create your own.

Restore Predefined ROIs

1. Use pre-selected regions of interest by starting the **#1 ROI Tool** dialog by choosing from the #1 Main Image menu bar **Overlay** → **Region of Interest**.
2. In the **#1 ROI Tool** dialog choose **File** → **Restore ROIs**.
3. The **Enter ROI Filename** dialog opens. Select `CLASSES.ROI` as the input file to restore.

Create Your Own ROIs

1. Select **Overlay** → **Region of Interest** from the Main Image window menu bar. The **ROI Tool** dialog for the display group appears.
2. In the Main Image window draw a polygon that represents the new region of interest. To accomplish this, do the following.
    - Click the left mouse button in the Main Image window to establish the first point of the ROI polygon.

- Select further border points in sequence by clicking the left button again, and close the polygon by clicking the right mouse button.The middle mouse button deletes the most recent point, or (if you have closed the polygon) the entire polygon. Fix the polygon by clicking the right mouse button a second time.
- ROIs can also be defined in the Zoom and Scroll windows by choosing the appropriate radio button at the top of the ROI Controls dialog.

When you have finished defining an ROI, it is shown in the dialog's list of Available Regions, with the name, region color, and number of pixels enclosed, and is available to all of ENVI's classification procedures.

3. To define a new ROI, click the **New Region** button.
   - You can enter a name for the region and select the color and fill patterns for the region by clicking on the **Edit** button to bring up the **Edit ROI Parameters** dialog. Define the new ROI as described above.

Classical Supervised Multispectral Classification

The following methods are described in most remote sensing textbooks and are commonly available in today's image processing software systems.

Parallelepiped

Parallelepiped classification uses a simple decision rule to classify multispectral data. The decision boundaries form an n-dimensional parallelepiped in the image data space. The dimensions of the parallelepiped are defined based upon a standard deviation threshold from the mean of each selected class.

1. Pre-saved results are in the file `can_pcls.img`. Examine these or perform your own classification using the `CLASSES.ROI` regions of interest described above. Try using the default parameters and various standard deviations from the mean of the ROIs.
2. Use image linking and dynamic overlay to compare this classification to the color composite image and previous unsupervised classifications.

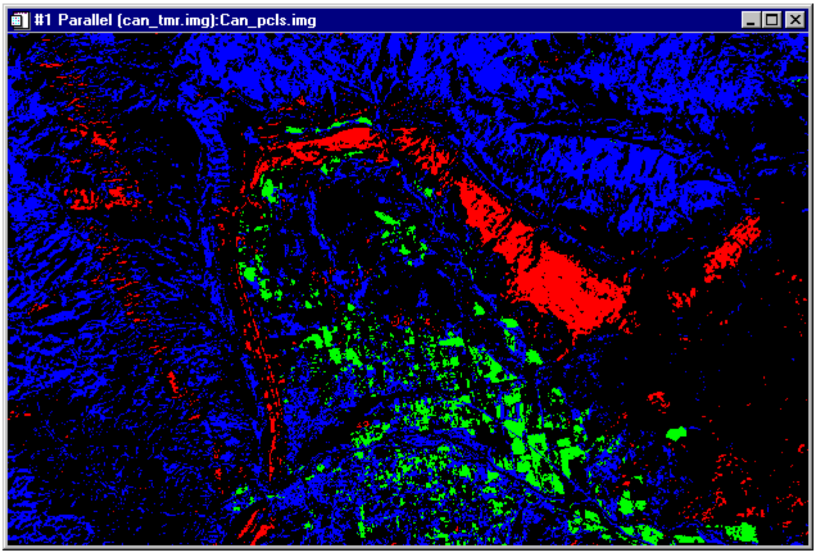


Figure 3-3: Parallelepiped Classification Image.

Maximum Likelihood

Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Unless a probability threshold is selected, all pixels are classified. Each pixel is assigned to the class that has the highest probability (i.e., the maximum likelihood).

1. Perform your own classification using the `CLASSES.ROI` regions of interest described above. Try using the default parameters and various probability thresholds.
2. Use image linking and dynamic overlay to compare this classification to the color composite image and previous unsupervised and supervised classifications.

Minimum Distance

The minimum distance classification uses the mean vectors of each ROI and calculates the Euclidean distance from each unknown pixel to the mean vector for each class. All pixels are classified to the closest ROI class unless the user specifies standard deviation or distance thresholds, in which case some pixels may be unclassified if they do not meet the selected criteria.

1. Perform your own classification using the `CLASSES.ROI` regions of interest described above. Try using the default parameters and various standard deviations and maximum distance errors.
2. Use image linking and dynamic overlay to compare this classification to the color composite image and previous unsupervised and supervised classifications.

Mahalanobis Distance

The Mahalanobis Distance classification is a direction sensitive distance classifier that uses statistics for each class. It is similar to the Maximum Likelihood classification but assumes all class covariances are equal and therefore is a faster method. All pixels are classified to the closest ROI class unless the user specifies a distance threshold, in which case some pixels may be unclassified if they do not meet the threshold.

1. Perform your own classification using the CLASSES.ROI Regions of Interest described above. Try using the default parameters and various maximum distance errors.
2. Use image linking and dynamic overlay to compare this classification to the color composite image and previous unsupervised and supervised classifications.

Spectral Classification Methods

The following methods are described in the *ENVI 3.5 User's Guide*. These were developed specifically for use on Hyperspectral data, but provide an alternative method for classifying multispectral data, often with improved results that can easily be compared to spectral properties of materials. They typically are used from the Endmember Collection dialog using image or library spectra, however, they can also be started from the classification menu, **Classification** → **Supervised** → **[*method*]**, where *[method]* represents one of the methods shown in the pull-down menu.

The Endmember Collection Dialog

The **Endmember Collection:Parallel** dialog is a standardized means of collecting spectra for supervised classification from ASCII files, regions of interest, spectral libraries, and statistics files.

1. To start the **Classification Input File** dialog from the ENVI main menu, select **Spectral** → **Mapping Methods** → **Endmember Collection**.

This dialog can also be started by choosing **Classification** → **Endmember Collection** from the ENVI main menu.

2. In the **Classification Input File** dialog, click on the **Open File** button at the bottom of the dialog.
3. A new file selection dialog appears. In the **Please Select a File** dialog, choose the input file `can_tmr.img` and click **Open** (Windows) or **OK** (UNIX). The `can_tmr.img` file will appear in the **Select Input File:** section of the **Classification Input File** dialog.
4. Click on the `can_tmr.img` file within the **Select Input File:** section of this dialog and then click **OK**.
5. This brings up the **Endmember Collection:Parallel** dialog.

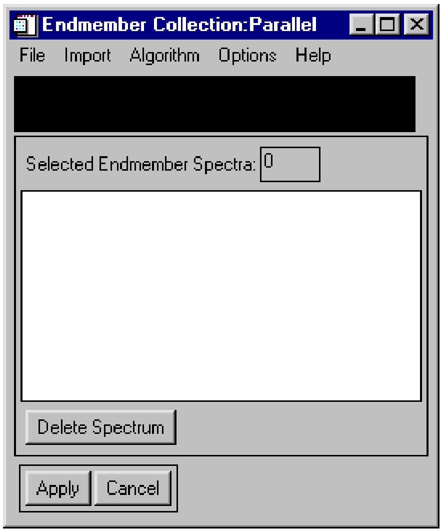


Figure 3-4: Endmember Collection dialog.

The Endmember Collection dialog appears with the Parallelepiped classification method selected by default. The available classification and mapping methods are listed by choosing **Algorithm** → **[*method*]** from the **Endmember Collection** dialog menu bar, where *[method]* represents one of the methods available: currently including **Parallelepiped**, **Minimum Distance**, **Manlanahobis Distance**, **Maximum Likelihood**, **Binary Encoding**, and the **Spectral Angle Mapper** (SAM).

Binary Encoding Classification

The binary encoding classification technique encodes the data and endmember spectra into 0s and 1s based on whether a band falls below or above the spectrum mean. An exclusive OR function is used to compare each encoded reference spectrum with the encoded data spectra and a classification image is produced. All pixels are classified to the endmember with the greatest number of bands that match unless the user specifies a minimum match threshold, in which case some pixels may be unclassified if they do not meet the criteria.

1. Pre-saved Binary Encoding results are in the file `can_bin.img`. These were created using a minimum encoding threshold of 75%. Examine these or perform your own classification using the `CLASSES.ROI` regions of interest described above. To do your own classification, select **Algorithm** → **Binary Encoding** from the menu bar.
2. Use the predefined regions of interest in the file `CLASSES.ROI`. From the **Endmember Collection** dialog menu bar, select **Import** → **from ROI from Input File**.
3. The **Input Regions of Interest** dialog appears. Click the **Select All Items** button, and click **OK**.
4. You can view the **Endmember Spectra** plots for the ROIs from the **Endmember Collections** dialog menu bar by choosing **Options** → **Plot Endmembers**.
5. In the **Endmember Collections** dialog click on **Apply**. This brings up the **Binary Encoding Parameters** dialog box.
6. In the **Binary Encoding Parameters** dialog, click the **Memory** radio button in the **Output Result to** section.
7. Click on the spin button for the **Output Rule Images** text field to change it to No and click **OK** at the bottom of the dialog to start the classification.
8. Use image linking and dynamic overlays to compare this classification to the color composite image and previous unsupervised and supervised classifications.

Spectral Angle Mapper Classification

The Spectral Angle Mapper (SAM) is a physically-based spectral classification that uses the n-dimensional angle to match pixels to reference spectra. The algorithm determines the spectral similarity between two spectra by calculating the angle between the spectra, treating them as vectors in a space with dimensionality equal to the number of bands.

1. Pre-saved SAM Classification results are in the file `can_sam.img`. Examine these or perform your own classification using the `CLASSES.ROI` Regions of Interest described above, which will be listed in the **Endmember Collection** dialog. To do your own classification, select **Algorithm** → **Spectral Angle Mapper** from the **Endmember Collection** menu bar. Click **Apply** to start the classification.
2. If performing your own classification, enter the output filename `can_tmr.sam` for the SAM classification image in the Endmember Collection dialog. Also enter the filename `can_rul.img` as the rule output image name and click **OK** at the bottom of the dialog to start the classification.
3. Use image linking and dynamic overlays to compare this classification to the color composite image and previous unsupervised and supervised classifications.

Rule Images

ENVI creates images that show the pixel values used to create the classified image. These optional images allow users to evaluate classification results and to reclassify if desired based on thresholds. These are gray scale images; one for each ROI or endmember spectrum used in the classification.

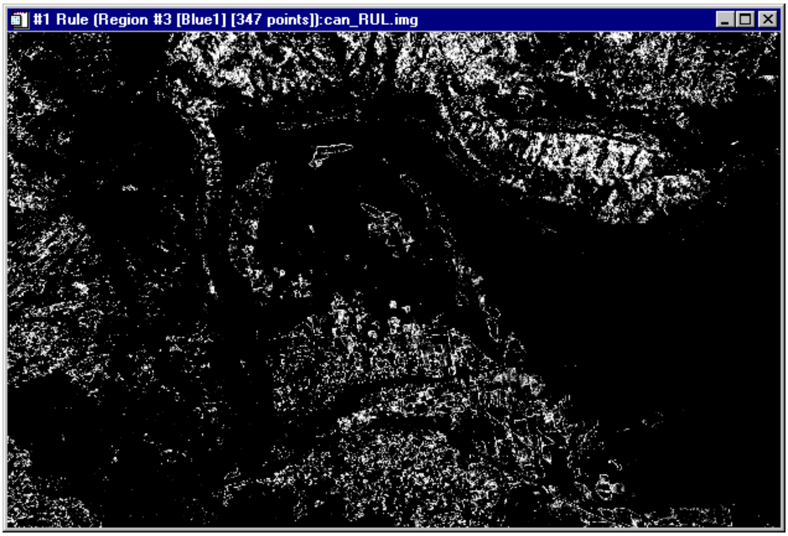


Figure 3-5: Rule Image for Canon City Landsat TM, Spectral Angle Mapper Classification. Stretched to show best matches (low spectral angles) as bright pixels.

The rule image pixel values represent different things for different types of classifications, for example:

Classification Method	Rule Image Values
Parallelepiped	Number of bands that satisfied the parallelepiped criteria.
Minimum Distance	Sum of the distances from the class means
Maximum Likelihood	Probability of pixel belonging to class
Mahalanobis Distance	Distances from the class means
Binary Encoding	Binary Match in Percent
Spectral Angle Mapper	Spectral Angle in Radians (smaller angles indicate closer match to the reference spectrum)

1. For the SAM classification above, load the classified image and the rule images into separate displays and compare using dynamic overlays. Invert the SAM rule images using **Tools** → **Color Mapping** → **ENVI Color Tables** and dragging the **Stretch Bottom** and **Stretch Top** sliders to opposite ends of the dialog. Areas with low spectral angles (more similar spectra) should appear bright.
2. Create classification and rule images using the other methods. Use dynamic overlays and **Cursor Location/Value** to determine if better thresholds could be used to obtain more spatially coherent classifications.
3. If you find better thresholds, select **Classification** → **Post Classification** → **Rule Classifier** from the ENVI main menu.
4. Double-click the `can_tmr.sam` input file to bring up the **Rule Image Classifier Tool**, enter a threshold to create a new classified image. Compare your new classification to the previous classifications.

Post Classification Processing

Classified images require post-processing to evaluate classification accuracy and to generalize classes for export to image-maps and vector GIS. ENVI provides a series of tools to satisfy these requirements

Class Statistics

This function allows you to extract statistics from the image used to produce the classification. Separate statistics consisting of basic statistics (minimum value, maximum value, mean, std deviation, and eigenvalue), histograms, and average spectra are calculated for each class selected.

1. Choose **Classification** → **Post Classification** → **Class Statistics** to start the process and select the Classification Image `can_pcls.img` and click **OK**.
2. Next select the image used to produce the classification `can_tmr.img` and click **OK**.
3. Use the **Class Selection** dialog to choose the classes for statistics. Click on **Select All Items**, then **OK**.
4. Finally, choose the statistics to be calculated in the **Compute Statistics Parameters** dialog, click **OK** at the bottom of the **Compute Statistics Parameters** dialog.

Several plots and reports will appear, depending on the statistics options selected.

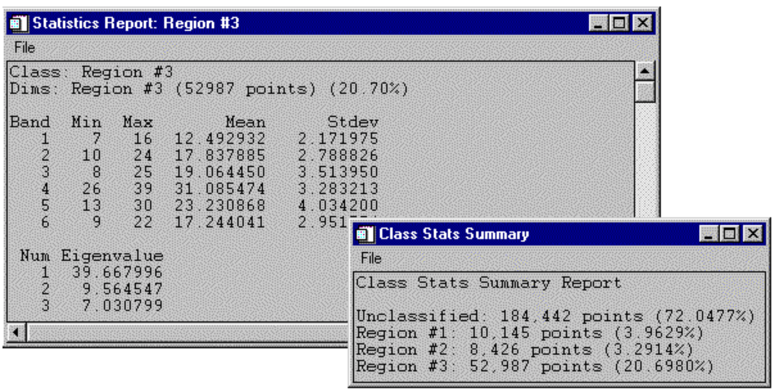
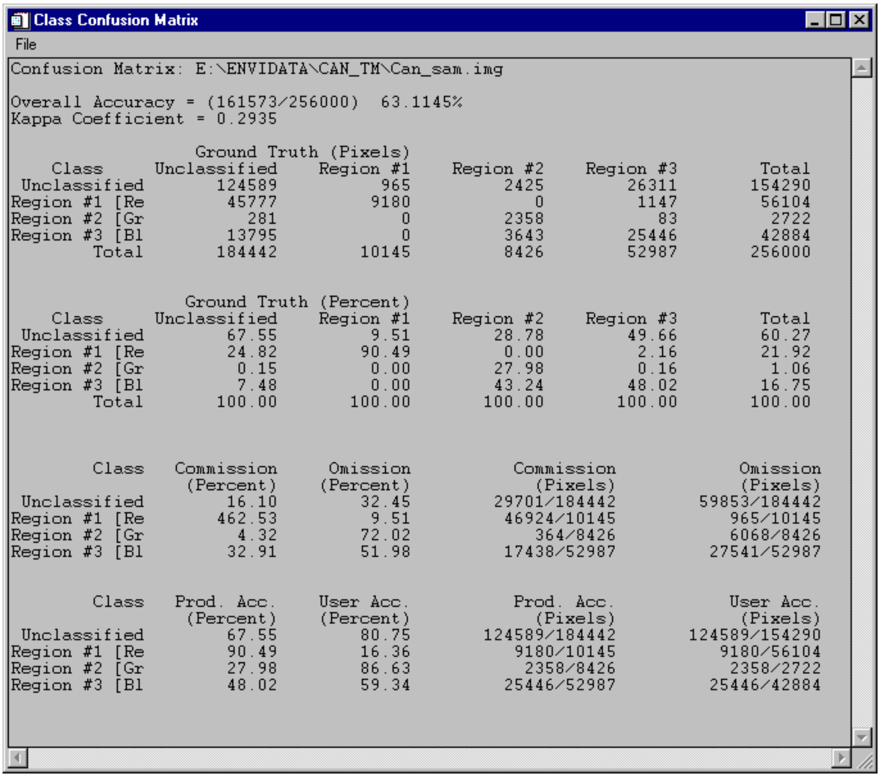


Figure 3-6: Statistics reports from Parallelepiped Classification of Canon City, CO, Thematic Mapper data.

Confusion Matrix

ENVI's confusion matrix function allows comparison of two classified images (the classification and the "truth" image), or a classified image and ROIs. The truth image can be another classified image, or an image created from actual ground truth measurements.

1. Select **Classification** → **Post Classification** → **Confusion Matrix** → **[*method*]**, where [*method*] is either **Using Ground Truth Image**, or **Using Ground Truth ROIs**.
2. For the *Ground Truth Image Method*, compare the *Parallelepiped* and *SAM* methods by entering the two filenames `can_sam.img` and `can_pcls.img` and clicking **OK** (for the purposes of this exercise, we are using the `can_pcls.img` file as the ground truth).
3. Use the **Match Classes Parameters** dialog to pair corresponding classes from the two images and click **OK**.
4. Use **Output Result to** radio button to output the result to **Memory** and then click **OK** in the **Confusion Matrix Parameters** dialog.
5. Examine the confusion matrix and confusion images. Determine sources of error by comparing the classified image to the original reflectance image using dynamic overlays, spectral profiles, and **Cursor Location/Value**.
6. For the *Using Ground Truth ROIs* method, select the classified image `can_sam.img` to be evaluated.
7. Match the image classes to the ROIs loaded from `CLASSES.ROI`, and click **OK** to calculate the confusion matrix.
8. Click OK in the **Confusion Matrix Parameters** dialog.
9. Examine the confusion matrix and determine sources of error by comparing the classified image to the ROIs in the original reflectance image using spectral profiles, and **Cursor Location/Value**.



Confusion Matrix: E:\ENVIDATA\CAN_TM\Can_sam.img

Overall Accuracy = (161573/256000) 63.1145%
Kappa Coefficient = 0.2935

	Ground Truth (Pixels)				
Class	Unclassified	Region #1	Region #2	Region #3	Total
Unclassified	124589	965	2425	26311	154290
Region #1 [Re	45777	9180	0	1147	56104
Region #2 [Gr	281	0	2358	83	2722
Region #3 [Bl	13795	0	3643	25446	42884
Total	184442	10145	8426	52987	256000

	Ground Truth (Percent)				
Class	Unclassified	Region #1	Region #2	Region #3	Total
Unclassified	67.55	9.51	28.78	49.66	60.27
Region #1 [Re	24.82	90.49	0.00	2.16	21.92
Region #2 [Gr	0.15	0.00	27.98	0.16	1.06
Region #3 [Bl	7.48	0.00	43.24	48.02	16.75
Total	100.00	100.00	100.00	100.00	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Unclassified	16.10	32.45	29701/184442	59853/184442
Region #1 [Re	462.53	9.51	46924/10145	965/10145
Region #2 [Gr	4.32	72.02	364/8426	6068/8426
Region #3 [Bl	32.91	51.98	17438/52987	27541/52987

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Unclassified	67.55	80.75	124589/184442	124589/154290
Region #1 [Re	90.49	16.36	9180/10145	9180/56104
Region #2 [Gr	27.98	86.63	2358/8426	2358/2722
Region #3 [Bl	48.02	59.34	25446/52987	25446/42884

Figure 3-7: Confusion Matrix using a second classification image as Ground Truth.

Clump and Sieve

Clump and Sieve provide means for generalizing classification images. Sieve is usually run first to remove the isolated pixels based on a size (number of pixels) threshold, and then clump is run to add spatial coherency to existing classes by combining adjacent similar classified areas. Compare the pre-calculated results in the files `can_sv.img` (sieve) and `can_clmp.img` (clump of the sieve result) to the classified image `can_pcls.img` (parallelepiped classification) or calculate your own images and compare to one of the classifications.

1. To execute the function, select **Classification** → **Post Classification** → **Sieve Classes**, choose one of the classified images, enter an output to **Memory** and click **OK**.
2. Use the output of the sieve operation as the input for clumping. Choose **Classification** → **Post Classification** → **Clump Classes**, choose the previously-made image from memory and click **OK**.
3. Output to memory and click **OK** in the **Clump Parameters** dialog.
4. Compare the three images and reiterate if necessary to produce a generalized classification image.

Combine Classes

The *Combine Classes* function provides an alternative method for classification generalization. Similar classes can be combined to form one or more generalized classes.

1. Examine the pre-computed image `can_comb.img` or perform your own combinations as described below.
2. Select **Classification** → **Post Classification** → **Combine Classes**.
3. Select the `can_sam.img` file in the **Combine Classes Input File** dialog and click **OK**.
4. Choose Region 3 to combine with Unclassified, click on **Add Combination**, and then **OK** in the **Combine Classes Parameters** dialog. Output memory and click OK.
5. Compare the combined class image to the classified images and the generalized classification image using image linking and dynamic overlays.

Edit Class Colors

When a classification image is displayed, you can change the color associated with a specific class by editing the class colors.

1. Select **Tools** → **Color Mapping** → **Class Color Mapping** in the Main Image Display window.
2. Click on one of the class names in the **Class Color Mapping** dialog and change the color by dragging the appropriate color sliders or entering the desired data values. Changes are applied to the classified image immediately. To make the changes permanent, select **Options** → **Save Changes** in the dialog.

Overlay Classes

Overlay classes allows the user to place the key elements of a classified image as a color overlay on a gray scale or RGB image.

1. Examine the pre-calculated image `can_ovr.img` or create your own overlay(s) from the `can_tmr.img` reflectance image and one of the classified images above.
2. Select **Classification** → **Post Classification** → **Overlay Classes** from the ENVI main menu.
3. Choose the current display as an input for class overly from the **Available Bands List** dialog.
4. `Select can_tmr.img` band 3 for each RGB band (band 3 for the R band, band 3 for the G band, and band 3 for the B band) in the **Input Overlay RGB Image Input Bands** dialog and click **OK**.
5. Use `can_comb.img` as the classification input in the **Classification Input File** dialog.
6. Click **OK** and then choose Region #1 and Region #2 in the **Class Overlay to RGB Parameters** dialog to overlay on the image. Output to memory and click **OK** to complete the overlay.
7. Load the overlay image into an image display and compare with the classified image and the reflectance image using linking and dynamic overlays.

Interactive Classification Overlays

In addition to the methods above for working with classified data, ENVI also provides an interactive classification overlay tool. This tool allows you to interactively toggle classes on and off as overlays on a displayed image, to edit classes, get class statistics, merge classes, and edit class colors.

1. Display band 4 of `can_tmr.img` as a gray scale image using the **Available Bands List** dialog.
2. From the Main Image window menu bar, select **Overlay** → **Classification**.
3. Choose one of the available classified images (a good choice is `can_sam.img`) in the **Interactive Class Tool Input File** dialog and click **OK**.

   The **Interactive Class Tool** dialog will appear and each class will be listed with it’s corresponding colors.

4. Click in each **On** check box to change the display of each class as an overlay on the gray scale image.
5. Try the various options for assessing the classification under the **Options** menu.
6. Choose various options under the **Edit** menu to interactively change the contents of specific classes.
7. Select **File** → **Save Image As** → ***[Device]*** in the Main Image window (where ***[Device]*** is either **Postscript** or **Image**) to burn in the classes and output to a new file.
8. Select **File** → **Cancel** to exit the interactive tool.

Classes to Vector Layers

Load the pre-calculated vector layers onto the gray scale reflectance image for comparison to raster classified images, or execute the function and convert one of the classification images to vector layers. You can use the following steps to load the pre-calculated vector layers produced from the clumped classification image above:

1. Select **Overlay** → **Vectors** in the Main Image window with the clumped image `can_clmp.img` displayed.
2. Choose **File** → **Open Vector File** → **ENVI Vector File** in the **Vector Parameters** dialog and choose the files can_v1.evf and can_v2.evf. Choose **Select All Layers** in the **Available Vectors List** dialog, then choose **Load Selected**. Select the `can_dmp.img`. From the Vector Parameters dialog, click **Apply** to load the vector layers onto the image display. The vectors derived from the classification polygons will outline the raster classified pixels.

   To complete your own classification to vector conversion:

1. Select **Classification** → **Post Classification** → **Classification to Vector** and choose the generalized image `can_clmp.img` within the **Raster to Vector Input Band** dialog.
2. Select Region #1 and Region #2 and enter the root name `canrtv` and click **OK** to begin the conversion.
3. Select the two regions in the **Available Vectors List** dialog click on **Load Selected** at the bottom of the dialog.
4. Choose the correct display number in the **Load Vector** dialog for the gray scale reflectance image and the vector layers will be loaded into the **Vector Parameters** dialog. Click **Apply** to display the vectors over the image. Use

Edit Layers to change the colors and fill of the vector layers to make them more visible.

Classification Keys Using Annotation

ENVI provides annotation tools to put classification keys on images and in map layouts. The classification keys are automatically generated.

1. Choose **Overlay** → **Annotation** from the Main Image window menu bar for either one of the classified images, or for the image with the vector overlay.
2. Select **Object** → **Map Key** to start annotating the image. You can edit the key characteristics by clicking on the **Edit Map Key Items** button in the **Annotation: Map Key** dialog and changing the desired characteristics.
3. Click and drag the map key using the left mouse button in the display to place the key.
4. Click in the display with the right mouse button to finalize the position of the key. For more information about image annotation, please see the *ENVI 3.5 User's Guide*.

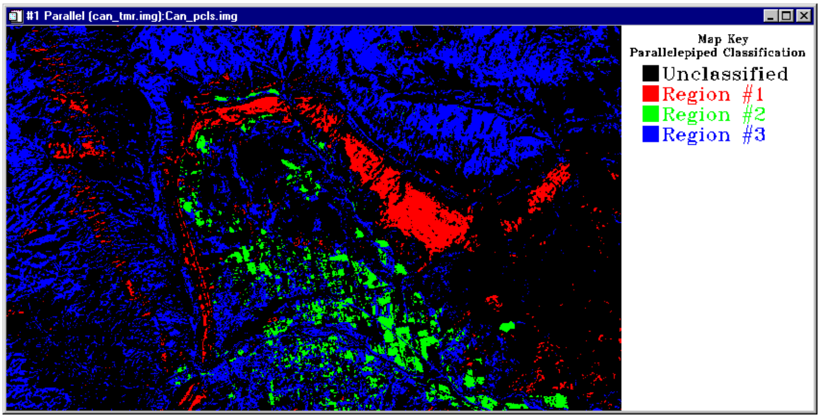


Figure 3-8: Classification image with classification key.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then clicking **OK** to exit IDL.

If you are using ENVI RT, quitting ENVI will take you back to your operating system.

Tutorial 4: Image Georeferencing and Registration

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial provides basic information about georeferenced images in ENVI and Image-to-Image and Image-to-Map Registration using ENVI. It covers step-by-step procedures for successful registration, discusses how to make image-maps using ENVI and illustrates the use of multi-resolution data for HSV Sharpening. It is designed to provide a starting point to users trying to conduct image registration. It assumes that you are already familiar with general image-registration and resampling concepts. This tutorial is designed to be completed in about 1 to 2 hours.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/bldr_reg`

File	Description
Required Files	
`bldr_sp.img`	Boulder SPOT Georeferenced Image Subset
`bldr_sp.hdr`	ENVI Header for Above
`bldr_sp.grd`	Boulder SPOT Map Grid Parameters
`bldr_sp.ann`	Boulder SPOT Map Annotation
`bldr_tm.img`	Non-Georeferenced Boulder TM Data
`bldr_tm.hdr`	ENVI Header for Above
`bldr_tm.pts`	GCPs for TM-SPOT Image-to-Image Registration
`bldrtm_m.pts`	GCPs for TM-Map Registration
`bldr_rd.dlg`	Boulder Roads DLG
`bldrtmsp.grd`	Merged TM-SPOT Map Grids
`bldrtmsp.ann`	Merged TM-SPOT Annotation
Generated Files	
`bldr_tm1.wrp`	Image-to-Image Result Using RST and Nearest Neighbor
`bldr_tm1.hdr`	ENVI Header for Above

File	Description
bldr_tm2.wrp	Image-to-Image Result Using RST and Bilinear Interpolation
bldr_tm2.hdr	ENVI Header for Above
bldr_tm3.wrp	Image-to-Image Result Using RST and Cubic Convolution
bldr_tm3.hdr	ENVI Header for Above
bldr_tm4.wrp	Image-to-Image Result Using 1st degree polynomial and Cubic Convolution
bldr_tm4.hdr	ENVI Header for Above
bldr_tm5.wrp	Image-to-Image Result Using Delaunay Triangulation and Cubic Convolution
bldr_tm5.hdr	ENVI Header for Above
bldr_tm5.hdr	ENVI Header for Above
bldrtm_m.img	Image-to-Map Result using RST and Cubic Convolution for the Boulder TM data
bldrtm_m.hdr	ENVI Header for Above
bldrtmsp.img	Boulder TM/SPOT sharpening result using HSV sharpening, 10 meter pixels
bldrtmsp.hdr	ENVI Header for Above

Georeferenced Images in ENVI

ENVI provides full support for georeferenced images in numerous predefined map projections including UTM and State Plane. In addition, ENVI's user-configurable map projections allow construction of custom map projections utilizing 6 basic projection types, over 35 different ellipsoids and more than 100 datums to suit most map requirements.

ENVI map projection parameters are stored in an ASCII text file `map_proj.txt` that can be modified by ENVI map projection utilities or edited directly by the user. The information in this file is used in the ENVI Header files associated with each image and allows simple association of a Magic Pixel location with known map projection coordinates. Selected ENVI functions can then use this information to work with the image in georeferenced data space.

ENVI's image registration and geometric correction utilities allow you to reference pixel-based images to geographic coordinates and/or correct them to match base image geometry. Ground control points (GCPs) are selected using the full resolution (Main Image) and Zoom windows for both image-to-image and image-to-map registration. Coordinates are displayed for both base and uncorrected image GCPs, along with error terms for specific warping algorithms. Next GCP point prediction allows simplified selection of GCPs.

Warping is performed using resampling, scaling and translation (RST), polynomial functions (of order 1 through *n*), or Delaunay triangulation. Resampling methods supported include nearest-neighbor, bilinear interpolation, and cubic convolution. Comparison of the base and warped images using ENVI's multiple Dynamic Overlay capabilities allows quick assessment of registration accuracy.

The following sections provide examples of some of the map-based capabilities built into ENVI. Consult the *ENVI 3.5 User's Guide* for additional information.

Georeferenced Data and Image-Map

This portion of the exercise will familiarize you with the use of georeferenced data in ENVI, allow you to construct an image-map complete with map grids and annotation, and produce an output image.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in UNIX, enter `envi` at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has loaded and executed.

Open and Display SPOT Data

To open the Georeferenced SPOT data:

1. Select **File** → **Open Image File** on the ENVI main menu.

Note

On some platforms you must hold the left mouse button down to display the submenus from the menu bar.

2. When the **Enter Data Filename** file-selection dialog appears, navigate to the `bldr_reg` subdirectory of the `envidata` directory and select the file `bldr_sp.img` from the list.
3. Click **OK**.
4. When the **Available Bands List** dialog appears, click on the **Gray Scale** radio button and select the SPOT band listed at the top of the dialog by clicking on the band with the left mouse button.

   The band you have chosen will be displayed in the field marked **Selected Band:**.
5. Click the **Load Band** button to load the image into a new display.

Edit Map Info in ENVI Header

1. From the ENVI main menu, select **File** → **Edit ENVI Header**.

2. When the **Edit Header Input File** dialog appears, select the file `bldr_sp.img` and click **OK**.
3. The **Header Info: *[filename]*** dialog opens. In this dialog, select the **Edit Attributes** button and *Map Info* from the pull-down menu to start the **Map Information** dialog.

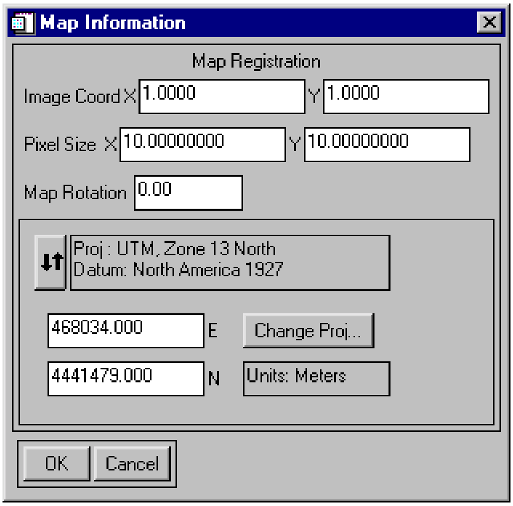


Figure 4-1: The Map Information Dialog.

This dialog lists the basic map information used by ENVI in georeferencing. The image coordinates correspond to the Magic Pixel used by ENVI as the starting point for the map coordinate system. Because ENVI knows the map projection, pixel size, and map projection parameters based on this header information and the map projection text file, it is able to calculate the geographic coordinates of any pixel in the image. Coordinates can be entered in either map coordinates or geographic coordinates.

4. Click on the spin box arrow next to the **Projection/Datum** field to see the latitude/longitude coordinates for the UTM Zone 13 North map projection.

   ENVI makes this conversion on-the-fly.
5. Click on the active **DMS** or **DDEG** button to toggle between Degrees-Minutes- Seconds, and Decimal Degrees, respectively.
6. Click **Cancel** to exit the **Map Information** dialog.

7. Click **Cancel** to exit the **Header Info: *[filename]*** dialog.

Cursor Location/Value

To open a dialog box that displays the location of the cursor in the Main Image, Scroll, or Zoom windows, do the following.

1. From the Main Image window menu bar, select **Tools** → **Cursor** *Location/Value*.

   You can also open this dialog from both the ENVI main menu and the Main Image window menu bar, by selecting **Window** → **Cursor Location/Value**.

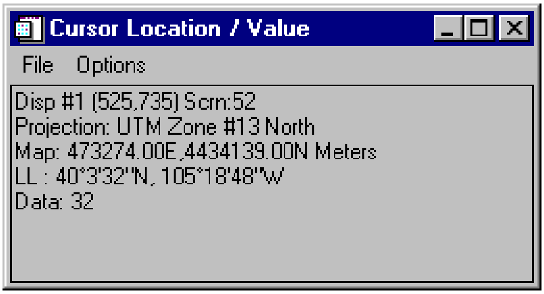


Figure 4-2: The Cursor Location dialog displays the pixel and georeferenced coordinates for georeferenced images.

   Note that the coordinates are given in both pixels and georeferenced coordinates for this georeferenced image.

2. Move the cursor around the image and examine the coordinates for specific locations and note the relation between map coordinates and latitude/longitude.
3. Select **File** → **Cancel** to dismiss the dialog when finished.

Overlay Map Grids

1. From the Main Image window menu bar, select **Overlay** → **Grid Lines**.

   The **#1 Grid Line Parameters** dialog appears and a virtual border is added to the image to allow display of map grid labels exterior to the image.

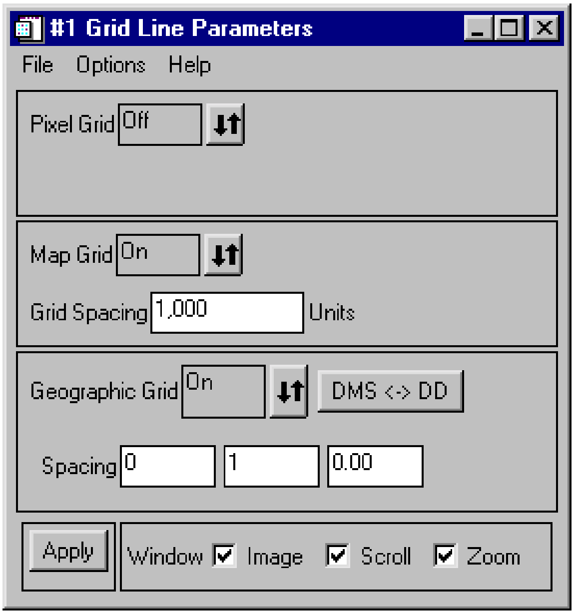


Figure 4-3: The Grid Line Parameters dialog.

2. In the new dialog, select **File** → **Restore Setup**. A file selection dialog opens.
3. In the **Enter Grid Parameters Filename** dialog, select the file `bldr_sp.grd` and click **Open**.

   Previously saved grid parameters are loaded into the dialog.
4. In the **#1 Grid Line Parameters** dialog you can examine the map parameters by selecting **Options** → **Edit Map Grid Attributes** from the dialog menu bar. An **Edit Map Attributes** dialog opens.
5. In the **Edit Map Attributes** dialog, note the grid spacing and the parameters that control the color and other characteristics of the lines, labels, corners, and the box (outlining box).
6. Click **File** → **Cancel** to close the dialog when you are finished.
7. Now in the **#1 Grid Line Parameters** dialog you can examine the geographic parameters by selecting **Options** → **Edit Geographic Grid Attributes** from the menu bar. This opens the **Edit Grid Attributes** dialog.

Note again the parameters for the geographic (latitude/longitude) grid. Click **Cancel** to close the dialog when you are finished.

8. Click **Apply** in the **Grid Line Parameters** dialog to put the grids on the image.

   ENVI allows simultaneous pixel, map, and geographic coordinate grids.

Overlay Map Annotation

1. In the Main Image display, select **Overlay** → **Annotation**. This opens the **#1 Annotation: Text** dialog.
2. In the new dialog, select **File** → **Restore Annotation**. Doing this opens a standard file selection dialog.
3. In the **Enter Annotation Filename** dialog, choose the file `bldr_sp.ann` from the file list and click **OK**.

   The pre-saved map annotation is loaded onto the image.
4. Enlarge the Scroll window by grabbing one of the corners and dragging. Reposition the resized Scroll window so you can see the Main Image window simultaneously.
5. In the resized Scroll window, move the main image indicator box using the left mouse button and examine the map elements which appear in the Main Image window.
6. In the **#1 Annotation: Text** dialog, click and hold the *Object* menu to examine the objects you can use to annotate the map.

Output to Image or Postscript

ENVI gives you several options for saving and outputting your image-maps. You can save your work in ENVI's image file format, or in several popular graphics formats (including Postscript) for printing or importing into other software packages.

Saving Your Image in ENVI Image Format

To save your work in ENVI's native format (as an RGB file) do the following.

1. In the Main Image window, select **File** → **Save Image As** → **Image File**.
2. When the **Output Display to Image File** dialog appears, select the Output File Type button pull-down menu (default file type setting is ENVI) to see the different formats available.

The **Change Graphics Overlay Selections** button opens a dialog of the same name which allows you to add or delete many graphics overlay options, including annotations and gridlines.

The **Change Image Border Size** button also opens a dialog of the same name. This dialog allows you to change the top, bottom, left, and right border widths and also the border color if desired.

If you have left your annotated and gridded color image on the display, both the annotation and grid lines will be automatically listed in the graphics options. You can also select other annotation files to be layered onto the output image.

3. You can choose whether you want your result to be saved to a file on disk or to memory by selecting either the radio button labeled **Memory**, or the **File** radio button. This time, select **Memory** and click **OK** to output the image.
4. The Available Bands List now has the new image available. Open another display by clicking on the **Display #1** button pull-down menu in the **Available Bands List** and choosing *New Display* from the menu.
5. Select the **RGB Color** radio button and load the image in from memory by selecting the **R**, **G**, and **B** (Georeferenced SPOT) data bands successively.
6. Then select the **Load RGB** button to display the results of the annotation as a raster image.

Saving your Image to Postscript

To save your work to a Postscript file perform the following.

1. In the Main Image window, select **File** → **Save Image As** → **Postscript File**.

   The **Output Display to Postscript File** dialog appears. Both the annotation and grid lines will be automatically listed in the graphics options. A graphical representation of the output page appears at the right top of the dialog.

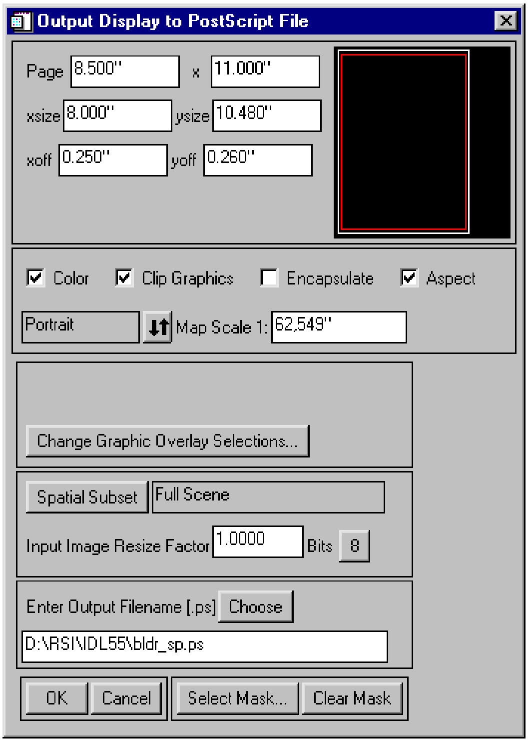


Figure 4-4: The Display to Postscript dialog for output of the above image map.

2. Enter the desired size of the output image in the **xsize** and **ysize** parameter text fields. By clicking the left mouse button in the representational graphic you can see the new image size outline and position in the graphical representation of the output page in the dialog.
3. Click the right mouse button in the graphic to center the image on the page.
   - If you'd like scaled map output, enter the desired map scale in the **Map Scale** text box, and then click the left mouse button in the graphic representation to see the result.

     If the scale makes the image larger than the available page size, ENVI automatically creates a multi-page Postscript document.

4. If you have a large-scale plotter, change the **Page** size to the plot size and the scaled image will be output to a Postscript file that can be plotted to scale directly on the plotter.

Note

Create the Postscript file only if you can print color output and print the file using your standard operating system procedures for printing Postscript output.

5. Save the postscript print settings by clicking **OK**.

   If you can't print color output, click **Cancel** to cancel the output operation.

Direct Printing

ENVI also allows direct printing to devices supported by your operating system.

1. From the Main Image window, select **File** → **Print**. This opens your operating systems standard **Print** dialog, and you can now follow your standard printing procedures.
2. Once you have selected all of the parameters in the operating system's standard **Print** dialog and clicked **OK**, ENVI opens an **Output Display to Printer** dialog to allow you to set additional basic ENVI printing parameters similar to those used for postscript output procedure (see above). Adjust these print settings as desired and click **OK** to begin printing.

Image to Image Registration

This section of the tutorial takes you step-by-step through an Image to Image registration. The georeferenced SPOT image will be used as the Base image, and a pixel-based Landsat TM image will be warped to match the SPOT.

Open and Display Landsat TM Image File

1. From the ENVI main menu, select **File** → **Open Image File**.
2. When the **Enter Data Filenames** dialog appears, navigate to the `bldr_reg` subdirectory of the `envidata` directory and select the file `bldr_tm.img` from the list.
3. Click **Open** (**OK** on UNIX) in the file selection dialog to load the TM image bands into the **Available Bands List**.
4. Click on Band 3 in the list, select the **No Display** button menu and **New Display** from the pull-down menu.
5. Then click on the **Load Band** button to load the TM band 3 image into a new display.

Display the Cursor Location/Value

To bring up a dialog box that displays the location of the cursor in the Main, Scroll, or Zoom windows do the following.

1. From the Main Image display menu bar, select **Tools** → **Cursor Location/Value**.
2. Move the cursor around the TM image in the Main Image, Scroll, and Zoom windows.

   Note that the coordinates are given in pixels since this is a pixel-based rather than georeferenced image like the SPOT data above.
3. Select **File** → **Cancel** to dismiss the **Cursor Location/Value** dialog.

Start Image Registration and Load GCPs

1. From the ENVI main menu bar, select **Map** → **Registration** → **Select GCPs: Image to Image**.

2. The **Image to Image Registration** dialog appears. For the **Base Image**, click on **Display #1** (the SPOT image) to select it. For the **Warp Image** select **Display #2** (the TM image).
3. Click **OK** to start the registration. This opens the **Ground Control Points Selection** dialog.

   Individual ground control points (GCPs) are added by positioning the cursor position in the two images to the same ground location.

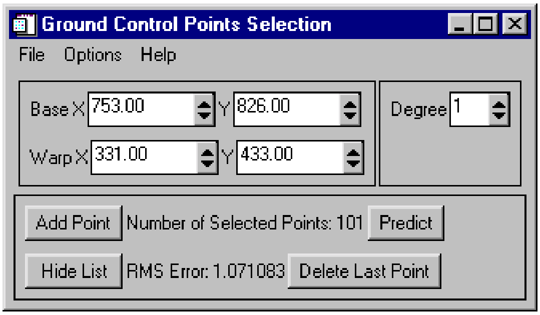


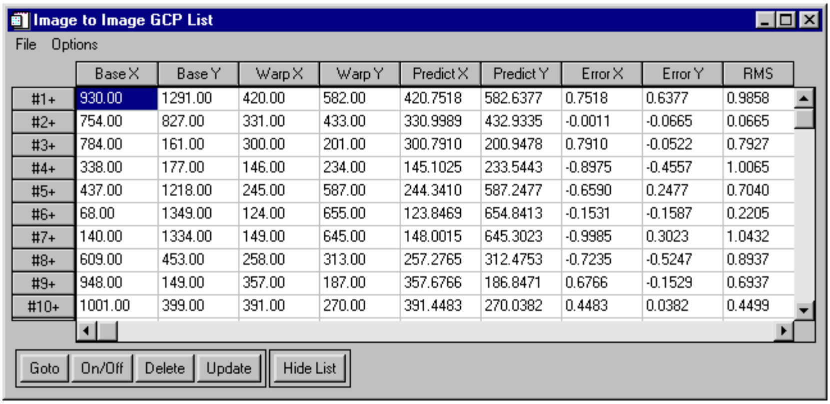
Figure 4-5: The Ground Control Points Selection dialog used for image to image registration.

4. Move the cursor in the SPOT image to 753, 826 by entering the values into the **Ground Control Points Selection** dialog in the **Base X** and **Y** text boxes.
5. Move the cursor in the TM image to 331, 433 by entering the values in the same way into the dialog in the **Warp X** and **Y** text boxes.
6. Examine the locations in the two Zoom windows and adjust the locations if necessary by clicking the left mouse button in each Zoom window at the desired locations.

   Note that sub-pixel positioning is supported in the Zoom windows. The larger the zoom factor, the finer the positioning capabilities.
7. In the **Ground Control Points Selection** dialog, click **Add Point** to add the GCP to the list. Click **Show List** to view the GCP list. Try this for a few points to get the feel of selecting GCPs.

   Note the list of actual and predicted points in the dialog. Once you have at least 4 points, the RMS error is reported.

8. In the **Ground Control Points Selection** dialog, select **Options** → **Clear All Points** to clear all of your points.
9. In the **Ground Control Points Selection** dialog, choose **File** → **Restore GCPs from ASCII**.
10. In the **Enter Ground Control Points Filename** dialog, select the file name `bldr_tm.pts`, and click **OK** to load a list of pre-saved GCPs.
11. Click on individual GCPs in the **Image to Image GCP List** dialog and examine the locations of the points in the two images, the actual and predicted coordinates, and the RMS error. Resize the dialog to observe the total RMS Error listed in the **Ground Control Points Selection** dialog.



	Base X	Base Y	Warp X	Warp Y	Predict X	Predict Y	Error X	Error Y	RMS
#1+	930.00	1291.00	420.00	582.00	420.7518	582.6377	0.7518	0.6377	0.9858
#2+	754.00	827.00	331.00	433.00	330.9989	432.9335	-0.0011	-0.0665	0.0665
#3+	784.00	161.00	300.00	201.00	300.7910	200.9478	0.7910	-0.0522	0.7927
#4+	338.00	177.00	146.00	234.00	145.1025	233.5443	-0.8975	-0.4557	1.0065
#5+	437.00	1218.00	245.00	587.00	244.3410	587.2477	-0.6590	0.2477	0.7040
#6+	68.00	1349.00	124.00	655.00	123.8469	654.8413	-0.1531	-0.1587	0.2205
#7+	140.00	1334.00	149.00	645.00	148.0015	645.3023	-0.9985	0.3023	1.0432
#8+	609.00	453.00	258.00	313.00	257.2765	312.4753	-0.7235	-0.5247	0.8937
#9+	948.00	149.00	357.00	187.00	357.6766	186.8471	0.6766	-0.1529	0.6937
#10+	1001.00	399.00	391.00	270.00	391.4483	270.0382	0.4483	0.0382	0.4499

Figure 4-6: Image to Image GCP LIst dialog for image to image registration.

Working with GCPs

The following descriptions are provided for information only. **Perform only the numbered Predict GCP button functions.**

- The position of individual GCPs can be edited by selecting the appropriate GCP in the **Image to Image GCP List** dialog and editing in the **Ground Control Points Selection** dialog. Either enter a new pixel location, or move the position pixel-by-pixel using the direction arrows in the dialog.
- Clicking on the **On/Off** button in the **Image to Image GCP List** dialog removes selected GCPs from consideration in the Warp model and RMS calculations. These GCPs aren't actually deleted, just disregarded, and can be toggled back on using the **On/Off** button.

- In the **Image to Image GCP List** dialog, clicking on the **Delete** button removes a GCP from the list.
- Positioning the cursor location in the two Zoom windows and clicking the **Update** button in the **Image to Image GCP List** dialog updates the selected GCP to the current cursor locations.
- The **Predict** button in the **Image to Image GCP List** dialog allows prediction of new GCPs based on the current warp model.

1. Try positioning the cursor at a new location in the Main Image containing the SPOT image. Click on the **Predict** button and the cursor position in the TM image will be moved to match its predicted location based on the warp model.
2. The exact position can then be interactively refined by moving the pixel location slightly in the TM data.
3. In the **Ground Control Points Selection** dialog, click **Add Point** to add the new GCP to the list.

Warp Images

Images can be warped from the displayed band, or multiband images can be warped all bands at once. We will warp only the displayed band.

1. In the **Ground Control Points Selection** dialog, select **Options** → **Warp Displayed Band**.
2. The **Registration Parameters** dialog appears. Use the **Warp Method** button menu to select *RST*, and the **Resampling** button menu to select *Nearest Neighbor* resampling.

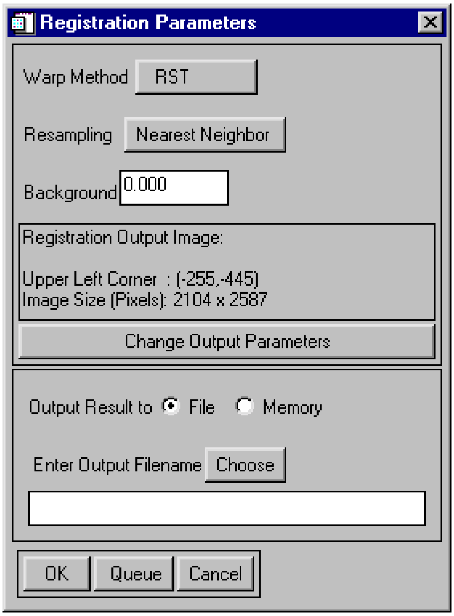


Figure 4-7: The Registration Parameters dialog.

3. Enter the filename `bldr_tm1.wrp` and click **OK**.

   The warped image will be listed in the **Available Bands List** when the warp is completed.

4. Now repeat steps 1 and 2 still using *RST* warping but with both *Bilinear*, and *Cubic Convolution* resampling methods.

5. Output the results to `bldr_tm2.wrp` and `bldr_tm3.wrp`, respectively.

6. Repeat steps 1 and 2 twice more, this time performing a 1st degree *Polynomial* warp using *Cubic Convolution* resampling, and again using a Delaunay *Triangulation* warp with *Cubic Convolution* resampling.

7. Output the results to `bldr_tm4.wrp` and `bldr_tm5.wrp`, respectively.

Compare Warp Results

Use Dynamic Overlays to compare your warp results:

1. In the **Available Bands List**, click on the original TM Band 3 image name `bldr_tm.img` and select **File** → **Close Selected File** from the menu bar.
2. In the subsequent ENVI Warning dialog, click **Yes** to close the associated image file.
3. In the **Available Bands List**, select the `BLDRTM_1.WRP` file and click on the **Display #** button pull-down menu. Select *New Display* and choose **Load Band** to load the file into the new display.
4. Click the right mouse button in the Main Image window and select **Tools** → **Link** → **Link Displays**.
5. Click **OK** in the **Link Displays** dialog to link the SPOT and the registered TM image.
6. Now compare the SPOT and the TM images using the dynamic overlay by clicking the left mouse button in the Main Image display.
7. Load `bldr_tm2.wrp` and `bldr_tm3.wrp` into new displays and use the image linking and dynamic overlays to compare the effect of the three different resampling methods: nearest neighbor, bilinear interpolation, and cubic convolution.

   Note how jagged the pixels appear in the nearest neighbor resampled image. The bilinear interpolation image looks much smoother, but the cubic convolution image is the best result, smoother, but retaining fine detail.
8. Close the displays containing `bldr_tm1.wrp` (RST warp, Nearest Neighbor resampling) and `bldr_tm2.wrp` (RST, Bilinear interpolation) by clicking the right mouse button in the appropriate Main Image display and selecting **File** → **Cancel**.
9. Load `bldr_tm4.wrp` and `bldr_tm5.wrp` into two new displays and use the image linking and dynamic overlays to compare to `bldr_tm3.wrp` (RST Warp).

   Note the effect of the three different warping methods, RST, 1st degree Polynomial, and Delaunay Triangulation on the image geometry.
10. Use dynamic overlay to compare to the georeferenced SPOT data.

Examine Map Coordinates

To bring up the **Cursor Location/Value** dialog:

1. Select **Tools** → **Cursor Location/Value** from the Main Image window menu bar.
2. Browse the georeferenced data sets and note the effect of the different resampling and warp methods on the data values.
3. Select **File** → **Cancel** to close the dialog.

Close All Files

You can close all of the data files by selecting **File** → **Close All Files** from the ENVI main menu.

Image to Map Registration

This section of the tutorial will take you step-by-step through an Image to Map registration. Many of the procedures are similar to image to image and will not be discussed in detail. The map coordinates picked from the georeferenced SPOT image and a vector Digital Line Graph (DLG) will be used as the Base, and the pixel-based Landsat TM image will be warped to match the map data.

Open and Display Landsat TM Image File

1. From the ENVI main menu, select **File** → **Open Image File**.
2. When the **Enter Data Filenames** dialog appears, navigate to the `bldr_reg` subdirectory of the `envidata` directory and select the file `bldr_tm.img` from the list.
3. Click **OK** to load the TM image bands into the **Available Bands List**.
4. Select **Gray Scale** in the **Available Bands List** and click on Band 3. Then from the **Display #1** pull-down menu button select the *New Display* button at the bottom of the dialog.
5. Click the **Load Band** button to load the TM band 3 image into a new display.

Select Image-to-Map Registration and Restore GCPs

1. From the ENVI main menu, select **Map** → **Registration** → **Select GCPS: Image to Map**. The **Image to Map Registration** dialog appears.
2. In the **Image to Map Registration** dialog select Display #1.
3. Then select **UTM** from the list of projections and enter 13 in the **Zone** text field.
4. Leave the pixel size at 30 m and click **OK** to start the registration.

   The **Ground Control Points Selection** dialog appears.

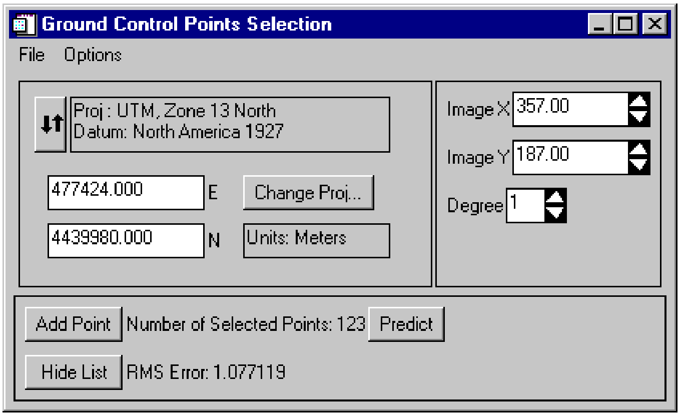
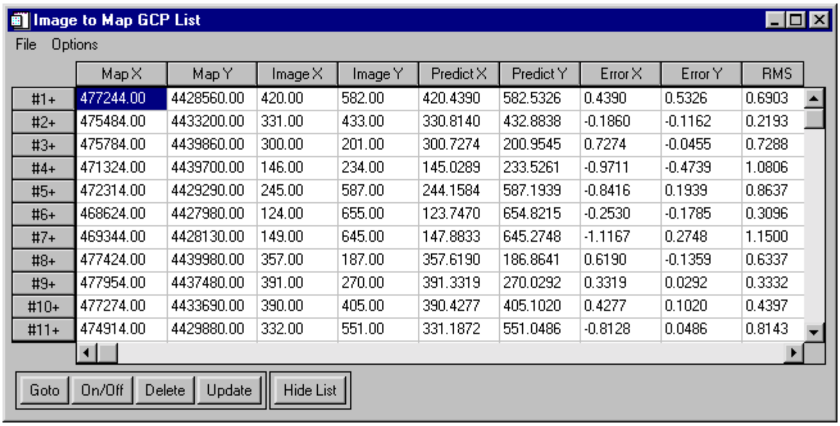


Figure 4-8: Ground Control Points Selection dialog for Image to Map Registration.

5. Add Individual GCPs by moving the cursor position in the warp image to a ground location for which you know the map coordinate (either read from a map or ENVI vector file (see below)).
6. Enter the known map coordinates manually into the **E** (Easting) and **N** (Northing) text boxes and click **Add Point** to add the new GCP.
7. Select **File** → **Restore GCPs from ASCII** in the dialog and open the file `bldrtm_m.pts`.
8. In the **Ground Control Points Selection** dialog, click the **Show List** button. The **Image to Map GCP List** dialog appears. Examine the base map coordinates, the actual and predicted image coordinates, and the RMS error. Resize the dialog to see the RMS error.



	Map X	Map Y	Image X	Image Y	Predict X	Predict Y	Error X	Error Y	RMS
#1+	477244.00	4428560.00	420.00	582.00	420.4390	582.5326	0.4390	0.5326	0.6903
#2+	475484.00	4433200.00	331.00	433.00	330.8140	432.8838	-0.1860	-0.1162	0.2193
#3+	475784.00	4439860.00	300.00	201.00	300.7274	200.9545	0.7274	-0.0455	0.7288
#4+	471324.00	4439700.00	146.00	234.00	145.0289	233.5261	-0.9711	-0.4739	1.0806
#5+	472314.00	4429290.00	245.00	587.00	244.1584	587.1939	-0.8416	0.1939	0.8637
#6+	468624.00	4427980.00	124.00	655.00	123.7470	654.8215	-0.2530	-0.1785	0.3096
#7+	469344.00	4428130.00	149.00	645.00	147.8833	645.2748	-1.1167	0.2748	1.1500
#8+	477424.00	4439980.00	357.00	187.00	357.6190	186.8641	0.6190	-0.1359	0.6337
#9+	477954.00	4437480.00	391.00	270.00	391.3319	270.0292	0.3319	0.0292	0.3332
#10+	477274.00	4433690.00	390.00	405.00	390.4277	405.1020	0.4277	0.1020	0.4397
#11+	474914.00	4429880.00	332.00	551.00	331.1872	551.0486	-0.8128	0.0486	0.8143

Figure 4-9: Image to Map GCP LIst dialog for image to map registration.

Add Map GCPs Using Vector Display of DLGs

1. From the ENVI main menu, select **File** → **Open Vector File** → **USGS DLG**.
2. In the **Enter Optional USGS DLG Filenames** dialog, choose the file `bldr_rd.dlg` and click **OK** to open the file. This opens the **Import Optional DLG File Parameters** dialog.
3. In the **Import Optional DLG File Parameters** dialog, select the **Memory** radio button and click **OK** to read the DLG data.
4. The **Available Vectors List** appears. Highlight the ROADS AND TRAILS: BOULDER, CO file in the **Available Vectors Layers:** list, and then click on the **Load Selected** button.
5. In the **Load Vector** dialog, click **New Vector Window**. This opens the **Vector Window Parameters** dialog and a new Vector Window.
6. Click **Apply** in the **Vector Window Parameters** dialog to plot the vectors in the vector window.
7. Click and drag the left mouse button in the Vector window to activate a crosshair cursor.

The map coordinates of the cursor will be listed in the **Location** field of the **Vector Window Parameters** dialog.

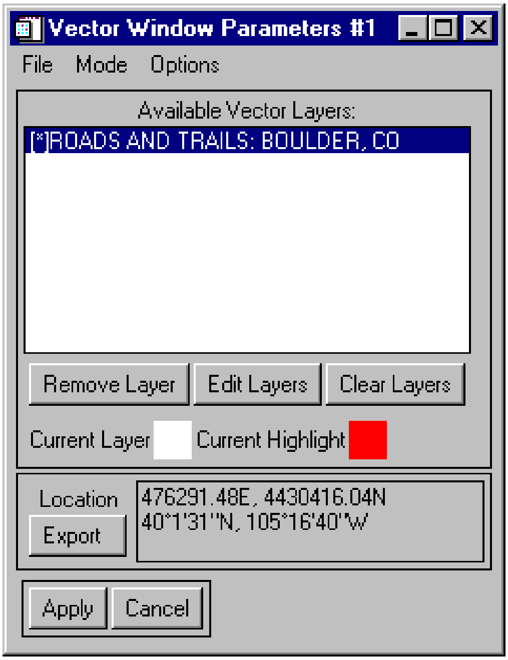


Figure 4-10: Vector Window Parameters dialog showing cursor location.

8. Position the image cursor on the road intersection at 402, 418 in the Main Image display by selecting **Tools** → **Pixel Locator**, entering the values, and clicking **Apply**.

   Note that sub-pixel positioning accuracy is again available in the Zoom window.

9. In the Vector window, position the vector cursor at the road intersection at 477593.74, 4433240.0 (40d 3m 3s N, -105d 15m 45s W) by clicking and dragging with the left mouse button and releasing when the circle at the crosshair intersection overlays the intersection of interest.

10. Click **Export** in the **Vector Window Parameters #1** dialog. The new map coordinates will appear in the **Ground Control Points Selection** dialog.

11. In the **Ground Control Points Selection** dialog, click **Add Point** to add the map-coordinate/image pixel pair and observe the change in RMS error.

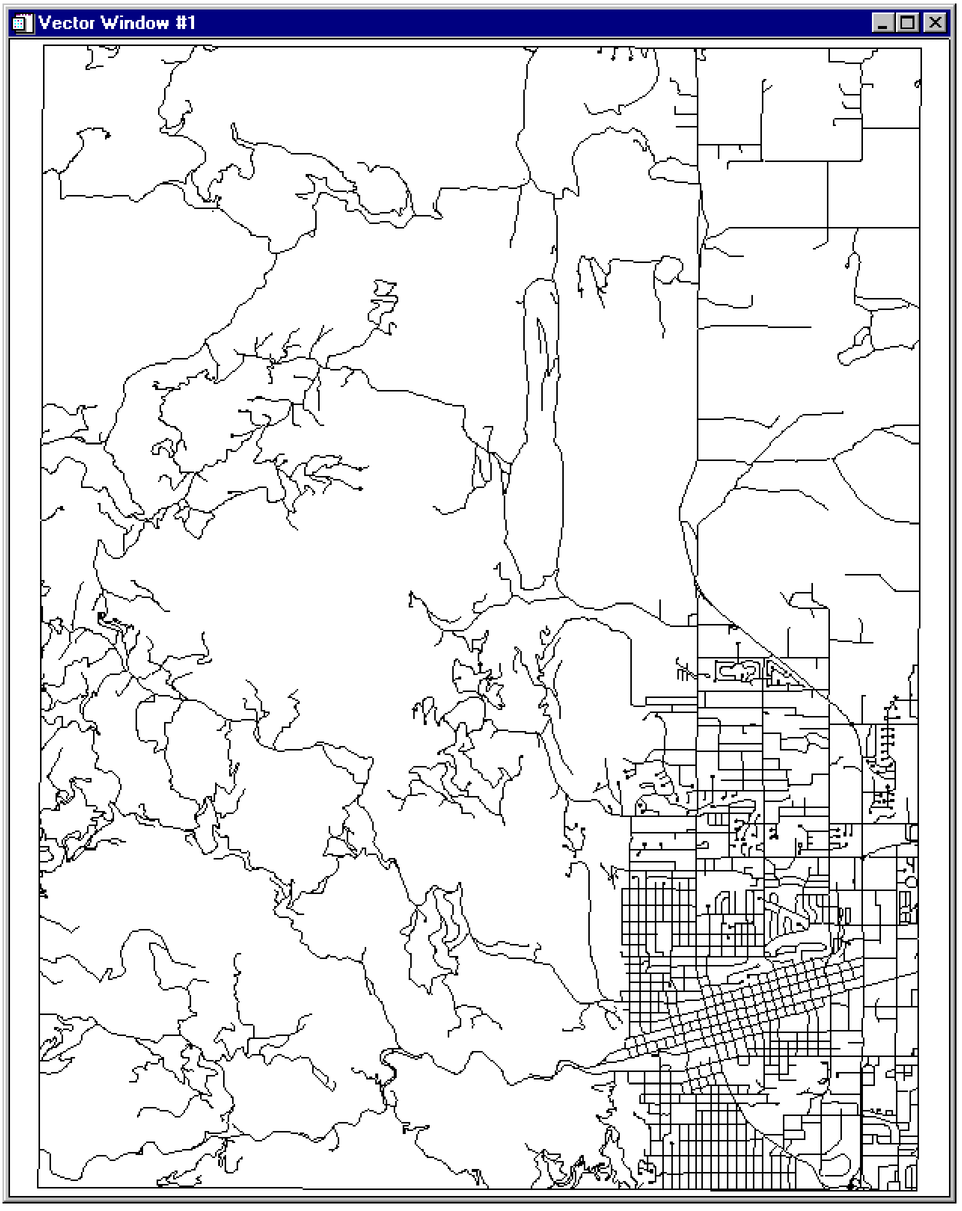


Figure 4-11: The Vector Window display.

RST and Cubic Convolution Warp

1. In the **Ground Control Points Selection** dialog, select **Options** → **Warp File**.
2. In the Input Warp Image dialog, highlight the file name `bldr_tm.img` and click **OK** to select all 6 TM bands for warping.
3. The Registration Parameters dialog appears. Choose *RST* for the **Warp Method**, and set **Resampling** to *Cubic Convolution* in the **Registration Parameters** dialog.
4. Change the background value to 255.
5. Enter the output file name `bldrtm_m.img` in the output file text box.
6. Click **OK** to start the image to map warp.

Display Result and Evaluate

Use Cursor Location/Value to evaluate the resulting warped color image.

1. Click on the RGB radio button in the **Available Bands List** followed by clicking on bands 4, 3, and 2 (RGB) of the warped image.
2. Select *New Display* from the **Display #** button pull-down menu. Click on **Load RGB** to load the TM warped color image.

   Note the skew of the image resulting from removal of the Landsat TM orbit direction. This image is georeferenced, but at 30 meter resolution versus the 10 meter resolution provided by the SPOT image.

   - If desired, load the SPOT image into a new display window and compare the image geometries and scale.

Close Selected Files

You can leave `bldrtm_m.img` and `bldr_sp.img` open as you will use these files in the next exercise.

1. Click on any other file names in the **Available Bands List** and select **File** → **Close Selected File** to close these images.
2. Click **Cancel** in the **Vector Window Parameters #1** dialog to close the Vector window.
3. Select **File** → **Cancel** in the **Available Vectors List** to close that dialog.

4. Select **File** → **Cancel** in the **Ground Control Points Selection** dialog to close that dialog. Save the GCPs if desired.

HSV Merge of Different Resolution Georeferenced Data Sets

This portion of the tutorial describes the procedures for merging two georeferenced data sets containing different pixel sizes. We will use the TM color-composite image registered above as the low-resolution color image and the georeferenced SPOT image as the high resolution image. The result is a color composite image with enhanced spatial resolution.

Display 30 m TM Color Composite

1. If you closed the registered TM image, reopen the file `bldrtm_m.img`.
2. Click on the **RGB** radio button in the **Available Bands List**, and load bands 4, 3, and 2 (R, G, and B) into a new display.

Display 10 m SPOT Data

1. If you closed the SPOT image, open the file `bldr_sp.img`.
2. Click on the **Gray Scale** radio button in the **Available Bands List**, then click the **Display #** button and select *New Display* from the pull-down menu. Click the **Load Band** button to load the SPOT data into a new display.

Compare with the TM data above and note the similar image geometry, but different spatial coverage and image scales.

Perform HVS Sharpening

1. Select **Transform** → **Image Sharpening** → **HSV** from the ENVI main menu.
2. If you have the color image displayed, choose the appropriate display in the **Select Input RGB** dialog. Otherwise, choose bands 4, 3, and 2 from the TM Image in the **Select Input RGB Input Bands** dialog and click **OK**.
3. The **High Resolution Input File** dialog opens. Choose the SPOT image in the **Select Input Band** list and click **OK**.
4. In the **HSV Sharpening Parameters** dialog, enter the output file name `bldrtmsp.img` and click **OK**.

A processing status box will appear and the new image will be listed in the **Available Bands List** when the processing is completed.

Display 10 m Color Image

1. Load the enhanced color image into a *New Display* by selecting the **RGB Color** radio button in the **Available Bands List** dialog, selecting the **R**, **G**, and **B** bands from the new file from list and clicking **Load RGB**.

   Compare the HSV sharpened color image to both the original TM color composite and to the SPOT data.

2. Try the same process using the Color Normalized (Brovey) Transform by selecting **Transforms** → **Image Sharpening** → *C***olor Normalized (Brovey)**, entering the required file information and clicking **OK**.

Overlay Map Grid

1. From the HSV Image display menu, select **Overlay** → **Grid Lines**.

   The **Grid Line Parameters** dialog appears and a virtual border is added to the image to allow display of map grid labels exterior to the image.

2. In the **Grid Line Parameters** dialog, select **File** → **Restore Setup**. In the **Enter Grid Parameters Filename** dialog which opens, select `bldrtmsp.grd`, and click **Open** (**OK** on UNIX).

   Previously saved grid parameters will be loaded into the dialog.

3. Click **Apply** to put the grids on the image.

Overlay Annotation

1. From the HSV Main Image menu bar, select Overlay → **Annotation**.

2. In the **Annotation: Text** dialog for the HSV image display, select **File** → **Restore Annotation** and choose the file `bldrtmsp.ann` from the file list that appears and click **Open** (**OK** on UNIX).

   The pre-saved map annotation will be loaded onto the image.

   - Optionally, enlarge the Scroll window by grabbing one of its corners and dragging it.

Output Image Map

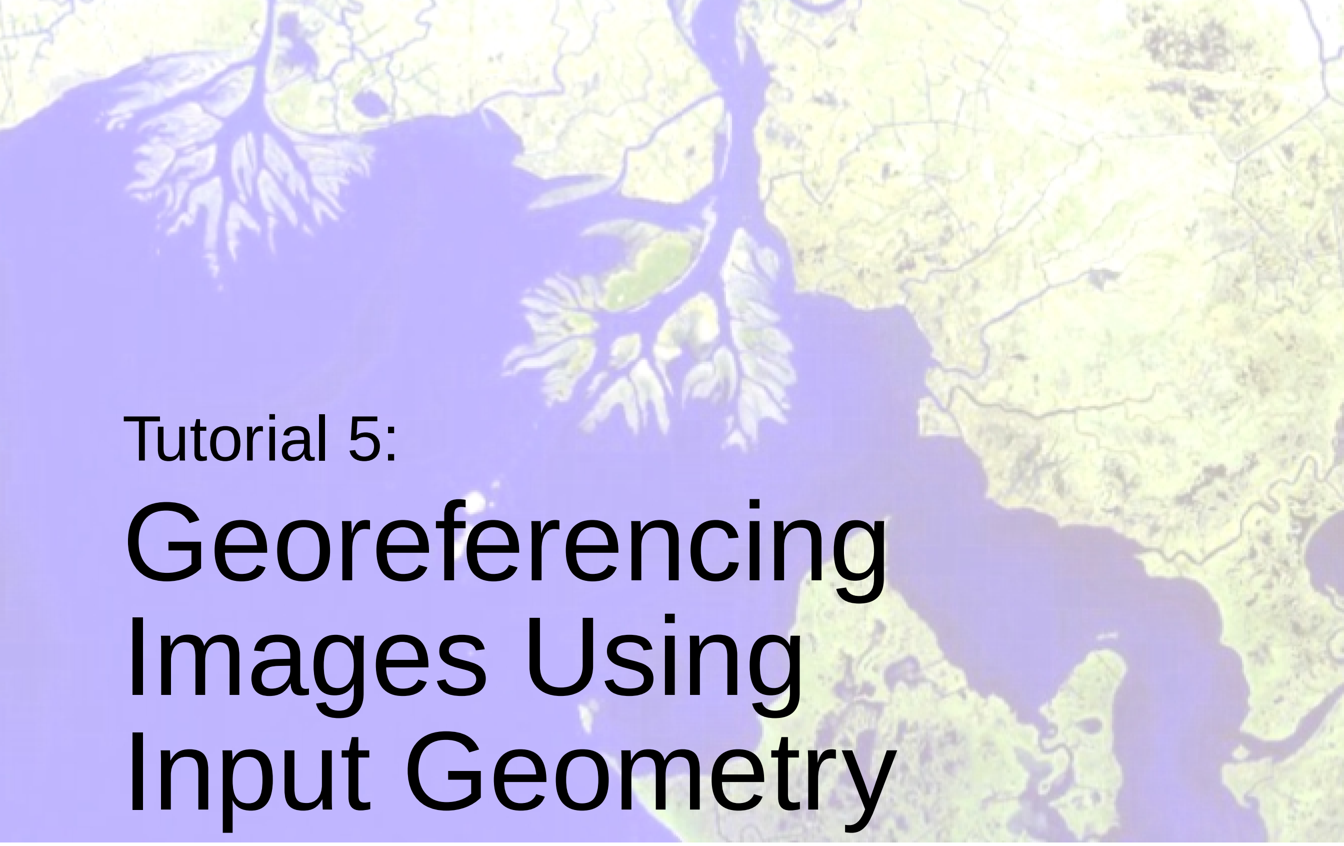
To save your work, use the procedures described in “Output to Image or Postscript” on page 121 for image output. You can:

- Create an image output file.

- Create a Postscript file.
- Print a copy of the image-map (see “Direct Printing” on page 124).

End the ENVI Session

This concludes the Registration Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.



Tutorial 5:

Georeferencing Images Using Input Geometry

The following topics are covered in this tutorial:

Overview of This Tutorial

Data from many sensors now comes with detailed acquisition (platform geometry) information that allows model-based geometric rectification and map registration. This tutorial provides basic information about Georeferenced images in ENVI and Model-Based Geometric Correction using image input geometry within ENVI. It discusses required data characteristics and covers step-by-step procedures for successful registration. It assumes that you are already familiar with general image-registration and resampling concepts. 1999 HyMap data of Cuprite, Nevada, used for the tutorial are copyright 1999 Analytical Imaging and Geophysics (AIG) and HyVista Corporation (All Rights Reserved), and may not be redistributed without explicit permission from AIG (`info@aigllc.com`).

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/cup99hym`

File	Description
`cup99hy_true.img`	True Color Composite, Cuprite 1999 HyMap Data
`cup99hy_true.hdr`	ENVI Header for above
`cup99hy_geo_glt`	Geometry Lookup File
`cup99hy_geo_glt.hdr`	ENVI Header for above
`cup99hy_geo_igm`	Input Geometry File
`cup99hy_geo_igm.hdr`	ENVI Header for above
`copyright.txt`	Description of data copyright

Georeferencing Using Input Geometry

ENVI provides full support for georeferenced images in numerous predefined map projections including UTM and State Plane. In addition, ENVI's user-configurable map projections allow construction of custom map projections utilizing 6 basic projection types, over 35 different ellipsoids, and more than 100 datums to suit most map requirements.

ENVI map projection parameters are stored in an ASCII text file `map_proj.txt` that can be modified by ENVI map projection utilities or edited directly by the user. The information in this file is used in the ENVI Header files associated with each image and allows simple association of a "Magic Pixel" location with known map projection coordinates. Selected ENVI functions can then use this information to work with the image in georeferenced data space.

Modern sensors collect ephemeris data along with their image data to allow precision georeferencing to map coordinates. ENVI provides a paradigm for storing sensor geometry information and automatically correcting image data to specified map projections/coordinates. The Input Geometry (IGM) file contains the X and Y map coordinates for a specified map projection for each pixel in the uncorrected input image. The Geometry Lookup (GLT) file contains the sample and line that each pixel in the output image came from in the input image. If the GLT value is positive, there was an exact pixel match. If the GLT value is negative, there was no exact match and the nearest neighboring pixel is used.

Three ENVI routines are provided to do the georeferencing:

- **Map** → **Georeference from Input Geometry** → **Build GLT** builds a GLT file from input geometry information.
- **Map** → **Georeference from Input Geometry** → **Georeference from GLT** performs geocorrection utilizing the Geometry Lookup images.
- **Map** → **Georeference from Input Geometry** → **Georeference from IGM** performs geocorrection utilizing the input geometry and creates the GLT file

Users must have the IGM or GLT file as a minimum to conduct this form of geocorrection. Image geometry data files are available for delivery as products from several sensors, including AVIRIS, MASTER, and HyMap. HyMap is a state-of-the-art aircraft-mounted commercial hyperspectral sensor developed by Integrated Spectronics, Sydney, Australia, and operated by HyVista Corporation.

HyMap provides unprecedented spatial, spectral, and radiometric excellence. The system is a whiskbroom scanner utilizing diffraction gratings and four 32-element detector arrays (1 Si, 3 liquid-nitrogen-cooled InSb). Data consists of 126 spectral channels covering the 0.44 - 2.5 μm range with approximately 15nm spectral resolution and 1000:1 SNR over a 512-pixel swath. Spatial resolution is 3-10 m (approximately 8 meters for the Cuprite data used here). Because the instrument utilizes a gyro-stabilized platform, the initial image geometry (prior to this correction) is quite good and corrections are minor.

While geocorrected images produced using the above methods are visually pleasing and map-correct, they do have several practical drawbacks. First, they have null values around their edges that must be masked in processing. Second, they are often inflated in size by replicated pixels as indicated in the GLT files. These two disadvantages lead to our suggestion to acquire and process the hyperspectral imagery in its raw spatial format, then apply the geocorrection to the derived final products. We do not recommend geocorrecting the entire reflectance data cube.

The following sections provide examples of the model-based geocorrection built into ENVI. Consult the *ENVI 3.5 User's Guide* for additional information.

Uncorrected HyMap Hyperspectral Data

This portion of the tutorial will familiarize you with uncorrected image geometry and characteristics.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI on UNIX, enter `envi` at the UNIX command line.
- To open ENVI on Windows or Macintosh, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Open and Display HyMap Data

To open HyMap data:

1. Select **File** → **Open Image File** from the ENVI main menu.

Note

On some platforms, you must hold down the left mouse button to display the submenus from the main menu.

2. In the **Enter Data Filenames** dialog, navigate to the `envidata/cup99hym` directory of the *ENVI Tutorial and Data CD No. 2* and select the file `cup99_hytrue.img` from the list. This is a TrueColor image extracted from the HyMap reflectance data.
3. Click **Open** and the default image bands will be loaded into a new display.

Examine Uncorrected Data

Examine the characteristics of the uncorrected data as follows:

1. Display the **Cursor Location/Value** dialog by doing one of the following:
    - Select **Tools** → **Cursor Location/Value** from the Main Image window menu.
    - Select **Window** → **Cursor Location/Value** from either the ENVI main menu or the Main Image window menu.
    - Double-click in the Main Image window.
2. A dialog box will appear displaying the location of the cursor in the Main Image, Scroll, or Zoom windows. The dialog also displays the screen value and the actual data value of the pixel underneath the crosshair cursor.
3. Move the cursor throughout the image. Examine the pixel locations and data values, and geometric relations between pixels (rotation, road curvature, etc.).
4. To dismiss the dialog, select **File** → **Cancel** from the menu at the top of the **Cursor Location/Value** dialog.

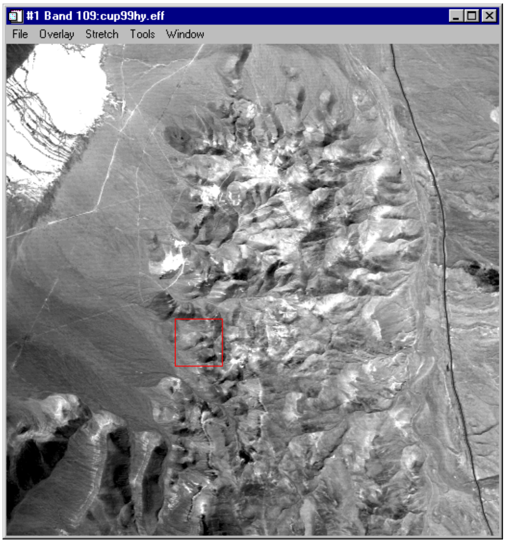


Figure 5-1: Uncorrected Cuprite HyMap Data

Examine IGM files

To open a HyMap Input Geometry data file:

1. Select **File** → **Open Image File** from the ENVI main menu.
2. In the **Enter Data Filenames** dialog, navigate to the `envidata/cup99hym` directory of the *ENVI Tutorial and Data CD No. 2*, select the Input Geometry file `cup99hy_geo_igm`, and click **Open**.
3. In the **Available Bands List** dialog, select the **Gray Scale** radio button, and select **IGM Input X Map** from the list. The band you have chosen will be displayed in the **Selected Band** field.
4. Select *New Display* from the *Display* pull-down menu at the bottom of the dialog.
5. Click the **Load Band** button to load the image into the new display.
6. Open the **Cursor Location/Value** dialog. Move the cursor throughout the image, and examine the pixel locations and data values (Map Coordinates).
7. Repeat the steps above for the **IGM Input Y Map** band.

Geocorrect Image Using IGM File

1. Select **Map** → **Georeference from Input Geometry** → **Georeference from IGM** from the ENVI main menu.
2. In the **Input Data File** dialog, click the **Open File** button.
3. In the **Please Select a File** dialog, select the file `cup99hy.eff` and click **Open**.
4. In the **Input Data File** dialog, select the file `cup99hy.eff` and click the **Spectral Subset** button.
5. In the **File Spectral Subset** dialog, select only band 109 and click **OK**.
6. In the **Input Data File** dialog, click **OK**.
7. In the **Input X Geometry Band** dialog, select the **IGM Input X Map** band and click **OK**.
8. In the **Input Y Geometry Band** dialog, select the **IGM Input Y Map** band and click **OK**.
9. In the **Geometry Projection Information** dialog, click OK. This produces an image with the same map projection as the input geometry (UTM, Zone 13, NAD27).

10. In the **Build Geometry Lookup File Parameters** dialog, enter an output filename for the GLT file, a background value of -9999, and an output filename for the georeference image. Click **OK**.

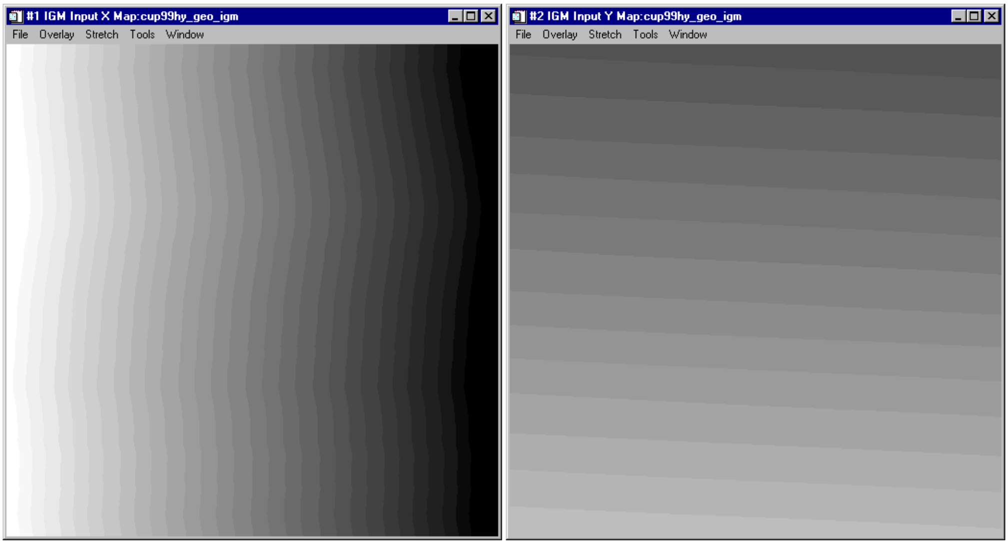


Figure 5-2: Cuprite HyMap IGM images. Left is IGM Input X Map. Right is IGM Input Y Map.

Display and Evaluate Correction Results

Use Cursor Location/Value to evaluate the correction results:

1. In the **Available Bands List** dialog, select the **Gray Scale** radio button and select the **Georef** band.
2. Click **Load Band** to load the image into a new display.
3. Open the **Cursor Location/Value** dialog. Move the cursor throughout the image, and examine the image geometry, pixel locations, map coordinates, and data values.
4. Close IGM displays when finished examining results.

Examine GLT Files

To open a HyMap Geometry Lookup file:

1. Select **File** → **Open Image File** from the ENVI main menu.

2. In the **Enter Data Filenames** dialog, navigate to the `envidata/cup99hym` directory of the *ENVI Tutorial and Data CD No. 2*, select the Geometry Lookup file `cup99hy_geo_glt` and click **Open**.
3. In the Available Bands List dialog, select the **Gray Scale** radio button and select the **GLT Sample Look-up** band.
4. Select **New Display** from the **Display** pulldown menu at the bottom of the dialog and click **Load Band** to load the image into the new display.
5. Open the **Cursor Location/Value** dialog. Move the cursor throughout the image, and examine the pixel locations and data values (input pixel locations). Pay particular attention to the negative values, which indicate use of nearest neighbor pixels.
6. Repeat the above steps for the **GLT Line Look-up** band.

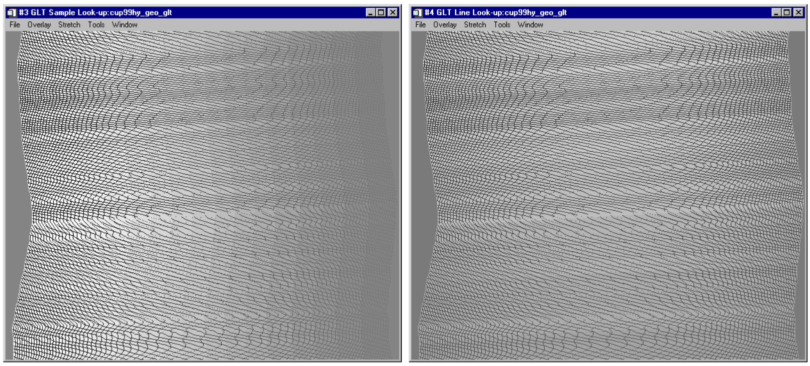


Figure 5-3: Cuprite HyMap GLT images. Left is GLT Sample Look-up. Right is GLT Line Look-up.

Geocorrect Image using GLT File

1. Select **Map** → **Georeference from Input Geometry** → **Georeference from GLT** from the ENVI main menu.
2. In the **Input Geometry Lookup File** dialog, select the file `cup99hy_geo_glt` and click **OK**.
3. In the **Input Data File** dialog, select the file `cup99hy.eff` and click the **Spectral Subset** button.
4. In the **File Spectral Subset** dialog, select only band 109 and click **OK**.

5. In the **Input Data File** dialog, click **OK**.
6. In the **Georeference from GLT Parameters** dialog, enter a background value of -9999 and an output filename for the georeferenced image, then click **OK**.

Display and Evaluate Correction Results

1. In the **Available Bands List** dialog, select the **Gray Scale** radio button and select the **Georef** band.
2. Click **Load Band** to load the image into a new display.
3. Open the **Cursor Location/Value** dialog. Move the cursor throughout the image, and examine the image geometry, pixel locations, map coordinates, and data values.
4. Close GLT displays when finished examining results.

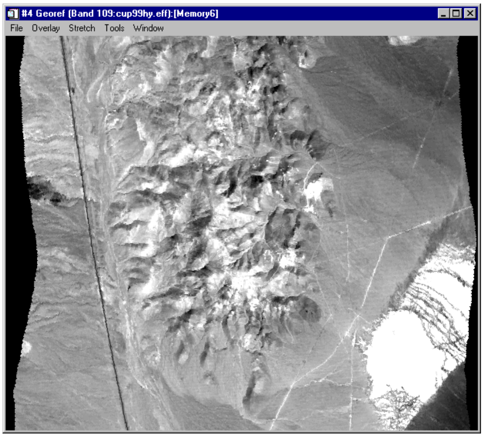


Figure 5-4: Cuprite HyMap Geocorrected Image

Using Build GLT with Map Projection

1. Select **Map** → **Georeference from Input Geometry** → **Build GLT** from the ENVI main menu.
2. If the file `cup99hy_geo_igm` is not already open, select **File** → **Open Image File** from the ENVI main menu and open the file.
3. In the **Input X Geometry Band** dialog, select the **IGM Input X Map** band and click **OK**

4. In the **Input Y Geometry Band** dialog, select the **IGM Input Y Map** band and click **OK**
5. At the bottom of the **Geometry Projection Information** dialog, select **State Plane (NAD 27)** as the Output Projection.
6. Click **Set Zone** and choose **Nevada West** (2703) as the output zone.
7. Click **OK**.
8. In the **Build Geometry Lookup File Parameters** dialog, enter an output filename for the GLT file and click **OK** to create the GLT.
9. Using the steps listed under “Geocorrect Image using GLT File” on page 151, geocorrect band 109 of the `cup99hy.eff` data and compare the resulting image to the UTM-corrected image.
10. Close all displays by selecting **Window** → **Close All Display Windows** from the ENVI main menu when finished examining results.

Overlay Map Grids

1. In the **Available Bands List** dialog, select one of the georeferenced images produced above by clicking on the appropriate name, then click **Load Band** to display the image.
2. Select **Overlay** → **Grid Lines** to start the **Grid Line Parameters** dialog. A virtual border will be added to the image to allow display of map grid labels exterior to the image.
3. Change the **Map Grid Spacing** to 1000 and the **Geographic Grid Spacing** to 1 minute and click **Apply**.
4. Utilize the **Cursor Location/Value** dialog to compare the grids to the pixel coordinates.

Output to Image

ENVI gives you several options for saving and outputting your image maps. You can save your work in ENVI’s image file format, or in several popular graphics formats (including Postscript) for printing or importing into other software packages.

Saving your Image in ENVI Image Format

To save your work in ENVI’s native format (as an RGB file):

1. In the Main Image window, select **File** → **Save Image As** → **Image File**.

2. In the **Output Display to Image File** dialog, click the **Output File Type** pull-down button and select **ENVI**.
3. Select the Memory radio button and click OK to output the image.
4. Load into another display and examine the results of the grid annotation as a raster image.

Direct Printing

ENVI also allows direct printing to devices supported by your operating system. Select **File** → **Print** and follow your standard printing procedures. For example, in Microsoft Windows, you would select the printer name from the pulldown menu, change the properties as desired, and click on OK to print the image. Once you have selected all of the parameters and clicked **OK**, a dialog appears to allow you to set additional basic ENVI printing parameters similar to those used for postscript output (see above). Set these as desired and click **OK** to begin printing.

End the ENVI Session

This concludes the tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **Yes**. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

Tutorial 6: Orthorectification Using ENVI

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to give you a working knowledge of ENVI's orthorectification capabilities. For additional details, please see the *ENVI User's Guide* or ENVI On-Line Help.

Files Used in this Tutorial

This tutorial demonstrates ENVI’s orthorectification capabilities, but because of the size of the required data sets, does not utilize any hands-on exercises. No data files are required. Users should be able to produce similar results with their own scanned aerial photographs or SPOT 1A, 1B, or SPOT CAP format data following the procedures outlined.

Orthorectification in ENVI

Orthorectification is the process by which the geometry of an image is made planimetric (map-accurate) by modeling the nature and magnitude of geometric distortions in the imagery. Camera or satellite models in conjunction with limited ground control, allow construction of correction formulae that produce accurate, geometrically correct, map-oriented imagery.

ENVI's Orthorectification function allows rectification of aerial photographs and SPOT data using a digital elevation model (DEM). The orthorectification uses geometric projections to produce geometrically correct images for mapping and measurement. See the following reference for more details:

> Wolf, R., 1974. Elements of Photogrammetry (2nd ed.), McGraw-Hill Inc., New York.

Tip

Because the orthorectification process is computationally intensive and time consuming, before beginning an orthorectification make sure you have sufficient disk space to save the resulting ortho image, as such images can be very large.

Steps for Orthorectification Using ENVI

The process of orthorectification using ENVI requires several steps that are the same regardless of the type of photograph or sensor used to collect the digital data. These include:

1. Build the Interior Orientation (aerial photographs only) — Building the interior orientation establishes the relationship between the camera and the aerial photograph. It uses tie points between the image and camera fiducial marks (at least three) and the camera focal length.
2. Build the Exterior Orientation — The exterior orientation relates points in the aerial photograph or satellite image to their known ground locations (map coordinates) and elevations. It is built by selecting ground control points and entering the corresponding map coordinates similar to an image-to-map registration.
3. Orthorectify using a Digital Elevation Model — This step does the actual orthorectification of the aerial photograph or satellite image using the orientation files or satellite location and collinearity equations generated using the above steps in conjunction with a digital elevation model (DEM).

Aerial Photo Orthorectification Example

The ENVI aerial photograph orthorectification corrects for distortions introduced by the camera geometry, look angles, and topography using a single photo. The orthorectification is done in three steps as described above. The figure below shows an original aerial photograph for Boulder, Colorado.

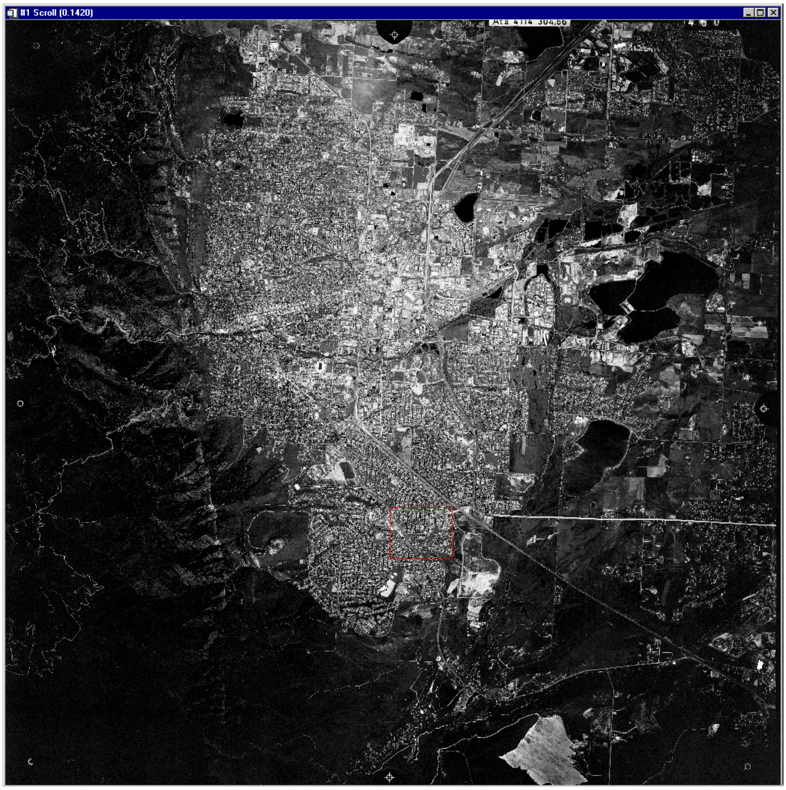


Figure 6-1: Original Aerial Photograph

Building the Interior Orientation

1. Display the aerial photograph image to allow interactive selection of fiducial marks. The figure below (Figure 6-2) shows a typical set of fiducial marks.
2. Select **Map** → **Orthorectification** → **Build Air Photo Interior Orientation**. If more than one image is displayed, select the display number containing the aerial photograph. The **Ortho: Build Interior Orientation** dialog appears.

3. Select a fiducial mark location by centering the Zoom window crosshair on the fiducial mark and entering the fiducial location in camera units (mm) in the **Fiducial X** and **Fiducial Y** text boxes (this information is obtained from the camera report). Click on **Add Point** in the the **Build Interior Orientation** dialog to add the location to the list of tie points. Continue selecting fiducial mark locations until three or more have been entered. Click on **Show List** at the bottom of the dialog to show the actual points and errors. Be sure to review the RMS error in the dialog to insure that the points were properly selected.

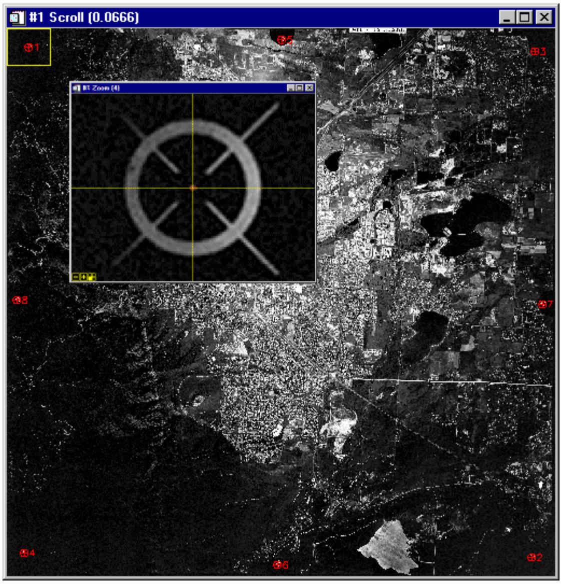


Figure 6-2: Aerial photograph showing locations of fiducial marks, and Zoom window with individual fiducial mark.

4. Select **Options** → **Build Interior Orientation** from the **Ortho: Build Interior Orientation** dialog. Enter the camera focal length in mm and enter an output filename with an `.ort` extension for consistency.

   The output `.ort` file contains the fiducial tie point locations and the affine transformation coefficients for both the camera coordinates to image pixels and image pixels to camera coordinates. The following is an example of the `.ort` file after the interior orientation has been calculated.

```
ENVI Orthorectification Parameters File
Sensor Type = Air Photo
Focal Length= 304.67100
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;
; Interior Orientation Information
; interior points = {fiducial (x,y) millimeters, image (x,y)}
Interior Points = {
 -106.0230, -105.9940, 302.33, 251.44,
 105.9780, 106.0140, 7315.45, 7359.55,
 -106.0210, 106.0100, 7364.71, 303.57,
 105.9790, -105.9940, 254.33, 7309.67,
 -110.0200, 0.0100, 3834.00, 143.80,
 109.9750, 0.0100, 3783.43, 7467.71,
 -0.0220, 110.0040, 7473.14, 3832.43,
 -0.0320, -109.9880, 146.00, 3779.57}
;Affine Transformation (Camera Coords to Image Pixels)
; a0 = 3808.86863414
; a1 = -0.22975948
; a2 = 33.30821680
; b0 = 3806.73931581
; b1 = 33.28923748
; b2 = 0.23988471
;Affine Transformation (Image Pixels to Camera Coords)
; a0 = -113.52361324
; a1 = -0.00021635
; a2 = 0.03003821
; b0 = -115.13524789
; b1 = 0.03002113
; b2 = 0.00020719
```

Building the Exterior Orientation

1. Display the aerial photograph image as above and select **Map** → **Orthorectification** → **Build Air Photo Exterior Orientation**. If more than one image is displayed, select the display number containing the aerial photograph.
2. Select the desired projection and enter a zone number if needed. The selected projection will be used as the orthorectified output projection and does not need to be the same projection as the DEM file. Click **OK**.

   The **Ortho: Build Exterior Orientation** dialog appears. This dialog is similar to the image-to-map registration **Ground Control Points Selection** dialog.

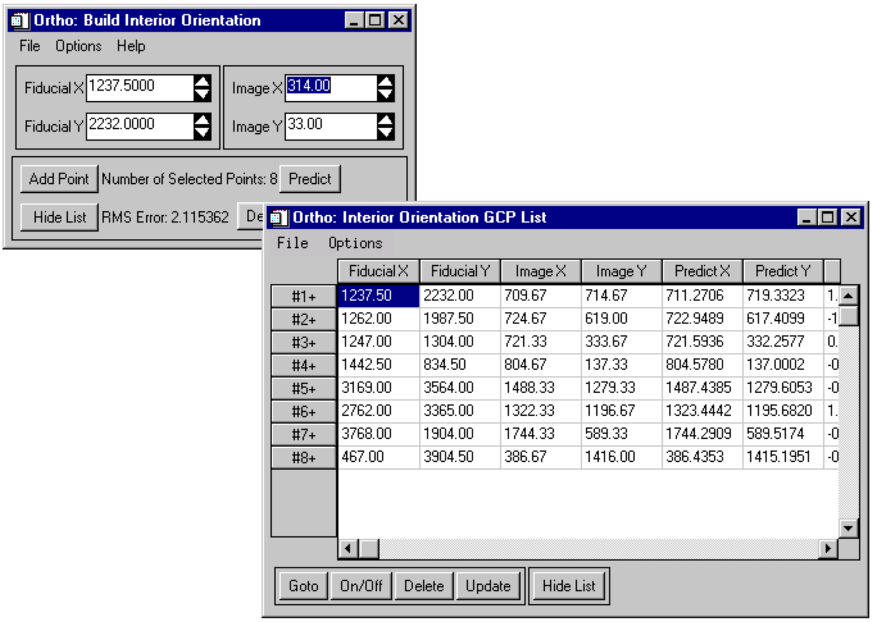


Figure 6-3: Ortho: Build Interior Orientation and GCP List Dialogs

3. Select a ground control point (GCP) by centering the Zoom window crosshair over a pixel on the aerial photograph image and entering the corresponding map coordinates in the appropriate text boxes. Enter an elevation for the selected pixel in the **Elev** text box and click on **Add Point** to add the location to the list of GCPs. Continue selecting ground control points until three or more have been entered. (Note: It is recommended that you use as many GCPs as possible spread over the image for best results). Be sure to review the RMS error in the dialog to insure that the points were properly selected.

4. Select **Options** → **Build Exterior Orientation** from the **Ortho: Build Exterior Orientation** dialog and enter the `.ort` parameters file created for the interior orientation. The GCPs from the exterior orientation are added to the selected `.ort` file. The following is an example of the exterior orientation parameters and points.

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;
; Exterior Orientation Information
; projection info = {UTM, 13, North}
; exterior points = {map (x,y,z) meters, image (x,y)}
Exterior Points = {
 476788.860, 4434052.500, 1702.040, 2993.00, 545.00,
 475174.630, 4430823.600, 1705.600, 2037.50, 2192.50,
 478404.380, 4430819.300, 1672.630, 3748.00, 2296.00,
 478602.050, 4428903.900, 1635.940, 3799.00, 3314.00,
 481632.990, 4430804.900, 1613.830, 5439.00, 2391.00,
 480787.590, 4429184.200, 1627.220, 4965.00, 3212.00,
 476789.250, 4427487.300, 1713.750, 2815.00, 3997.00,
 477837.900, 4424410.800, 1750.380, 3279.00, 5646.00,
 480272.650, 4422811.100, 1707.080, 4501.00, 6550.00,
 483949.430, 4423904.600, 1762.360, 6487.33, 6086.33}
; PHI   = 0.08065113
; OMEGA = -0.29078090
; KAPPA = -87.39367868
; Projection Center x = 478695.7071
; Projection Center y = 4428046.0844
; Projection Center z = 20962.4655
```

Orthorectifying the Air Photo

1. Select **Map** → **Orthorectification** → **Orthorectify** Air Photo.
2. Select the input aerial photograph filename and any subsetting if desired.
3. Select the input digital elevation model (DEM) filename. The DEM for the Boulder, Colorado, aerial photograph is shown in Figure 6-4.
4. Select the orientation parameters (`.ort`) filename created using the steps described above.
5. When the **Orthorectification Bounds** dialog appears, enter or calculate the approximate minimum value contained in the DEM file.

   The **Orthorectification Parameters** dialog appears. Currently, only nearest neighbor resampling is available.
6. Enter the value to ignore (missing data) in the DEM in the appropriate text box.
7. To set the Background Value (the DN value used to fill areas where no image data appears in the warped image) enter the DN value in the **Background Value** text box.

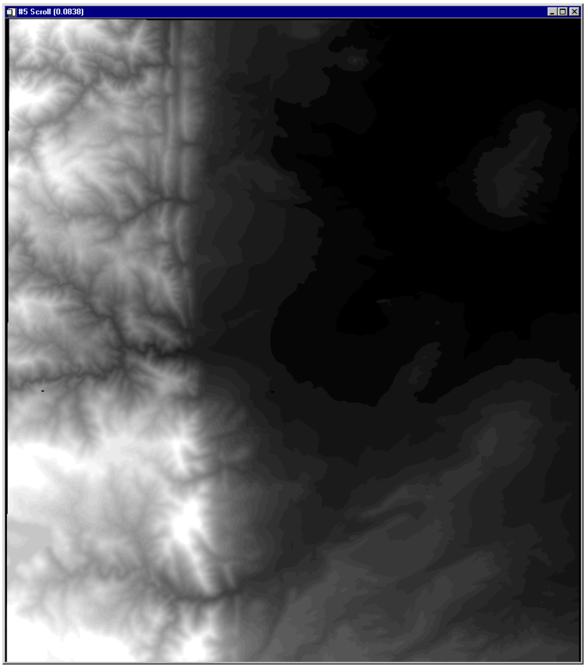


Figure 6-4: Boulder, Colorado DEM

The output image dimensions are automatically set to the size of the bounding rectangle that contains the warped input image. Therefore, the output warp image size may not be the same size as the DEM image. The output size coordinates are determined in the exterior orientation projection coordinates. If desired, change the map coordinate or latitude/longitude information for the upper left coordinate, pixel size, and image size by clicking **Change Output Parameters** and entering the desired values.

The **Change Projection** button is used to change the projection for entering the upper left coordinate only. The output projection of the image is set using the Build Exterior Orientation function.

8. Select output to **File** or **Memory** and click **OK** to start the orthorectification. The result of the orthorectification of the Boulder, Colorado, aerial photograph is shown below.

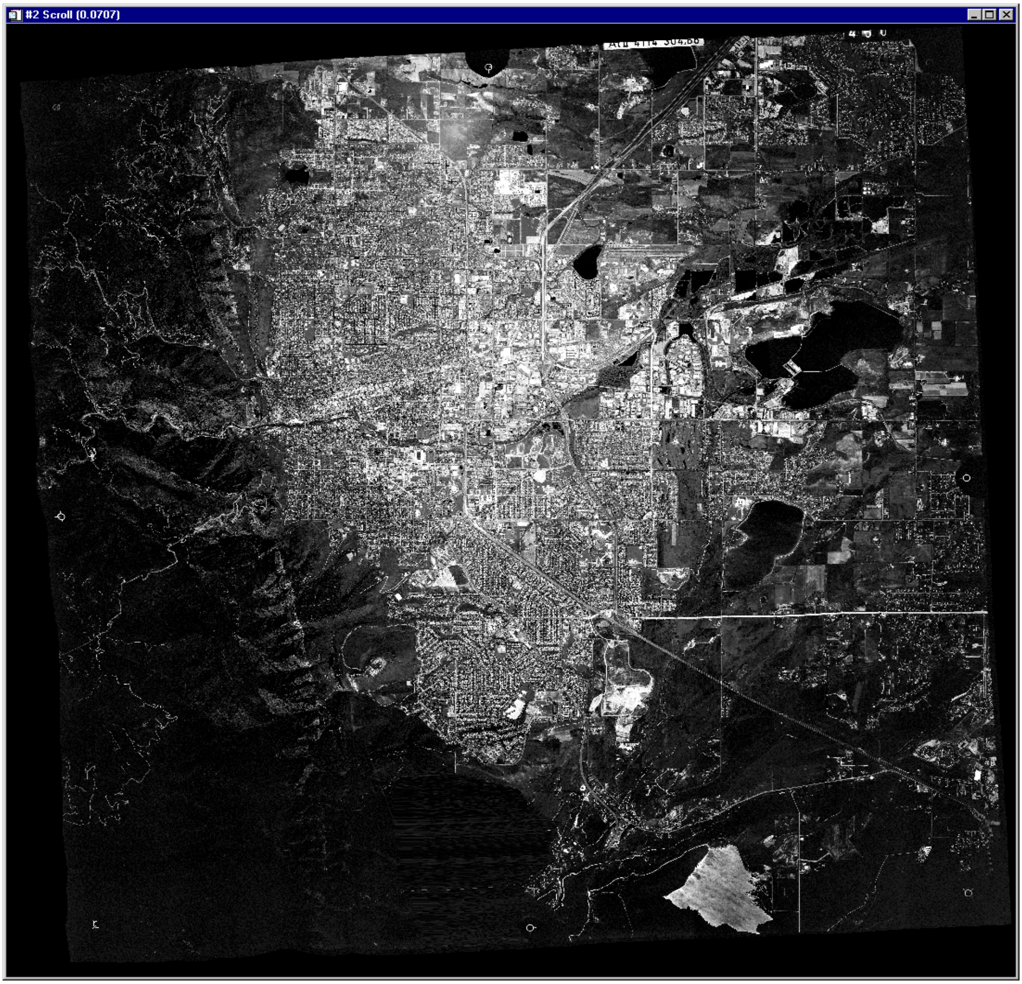


Figure 6-5: Orthorectified Aerial Photograph of Boulder, Colorado

SPOT Image Orthorectification Example

SPOT 1A, 1B and CAP data can be orthorectified using a DEM (digital elevation model). The orthorectification is done in two steps. The first step builds the exterior orientation using ground control points. The orthorectification uses satellite ephemeris information from the SPOT leader file to generate an initial orbit and view geometry model. Ground control points (GCPs) are used to optimize the orbital model by performing a non-linear inversion. The satellite position and set of collinearity equations for every line in the SPOT data are calculated and stored in a `.sot` file. The second step performs the orthorectification using the orbit model and a DEM file to correct the SPOT image pixel by pixel. See the following reference for details.

Westin, Torbjorn, 1990. Precision rectification of SPOT imagery, Photogrammetric Engineering & Remote Sensing, Vol. 56, No. 2, pp. 247-253.

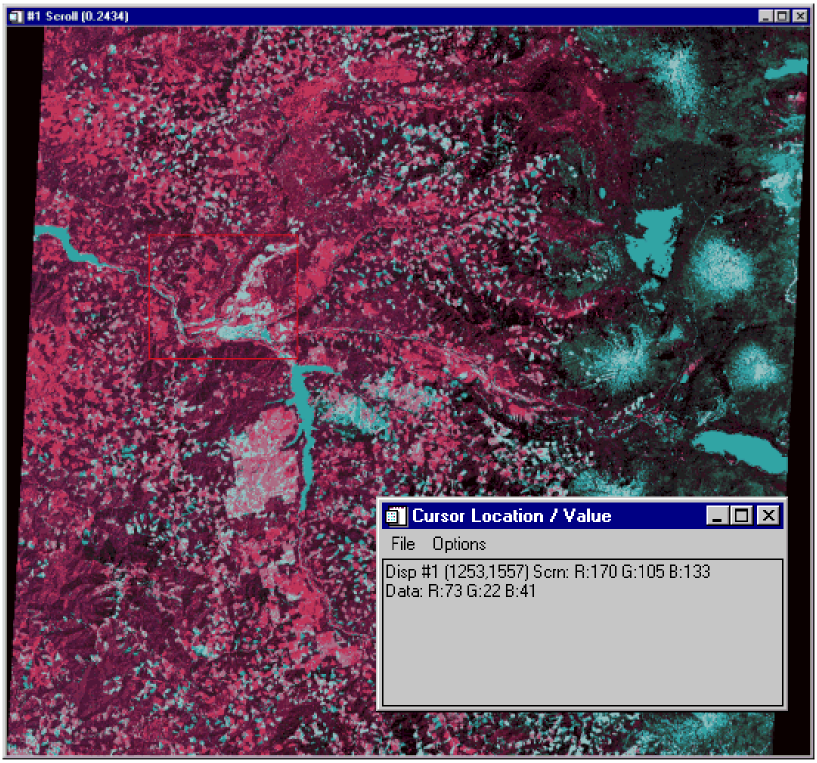


Figure 6-6: Oregon, SPOT XS Level 1B Data (Note pixel-based coordinates.)

Building the Exterior Orientation

The exterior orientation is used to optimize the satellite orbit model by relating points in the SPOT image to their known map coordinates and elevations. It is built by selecting ground control points and entering the corresponding map coordinates similar to an image-to-map registration. The SPOT image must be displayed in an image window for selection of the ground control point locations.

1. Display the SPOT image.
2. Select **Map** → **Orthorectification** → **Build SPOT Exterior Orientation**. If more than one image is displayed, select the display number containing the SPOT image.
3. Select the desired projection for the image output and enter a zone number if needed. The selected projection will be used as the orthorectified output projection and does not need to be the same projection as the DEM file. Click **OK**.

   The **Ortho: Build Exterior Orientation** dialog appears. This dialog is similar to the image-to-map registration **Ground Control Points Selection** dialog.
4. Select a ground control point (GCP) by centering the Zoom window crosshair over a pixel on the SPOT image and entering the corresponding map coordinates in the appropriate text boxes. Enter an elevation for the selected pixel in the **Elev** text box and click on **Add Point** to add the location to the list of GCPs. Continue selecting ground control points until three or more have been entered. Click on the **Show List** button to review the selected GCPs. Be sure to review the RMS error in the **Ortho: Build Exterior Orientation** dialog to ensure that the points were properly selected.

Note

It is recommended that you use as many GCPs as possible (dozens) spread over the image to stabilize the satellite orbit inversion. Although the orthorectification can be run with only 3 GCPs, it may produce instability in the satellite orbit inversion.

Once you have finished collecting GCPs, select **Options** → **Build Exterior Orientation** from the **Ortho: Build Exterior Orientation** dialog. Select the SPOT leader filename, typically `lead_xx.dat` where `xx` is the scene number.

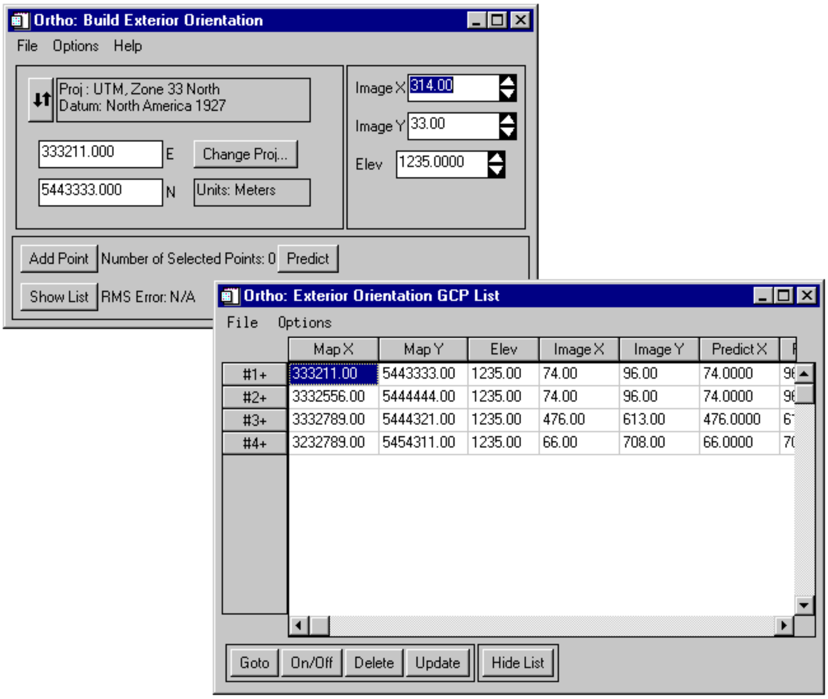


Figure 6-7: The Ortho: Build Exterior Orientation dialog.

5. Enter an output filename with a `.sot` extension for consistency. The `.sot` file is in binary format and contains the satellite location and collinearity equations for each line in the SPOT image.

Orthorectifying the SPOT Image

This section describes the orthorectification of the SPOT image using the `.sot` parameters file generated above and a digital elevation model (DEM).

1. Select **Map** → **Orthorectification** → **Orthorectify SPOT Image**.
2. Select the input SPOT image filename and any subsetting if desired.
3. Select the input digital elevation model (DEM) filename.
4. Select the ortho parameters (`.sot`) filename created above.
5. Select the SPOT leader filename.

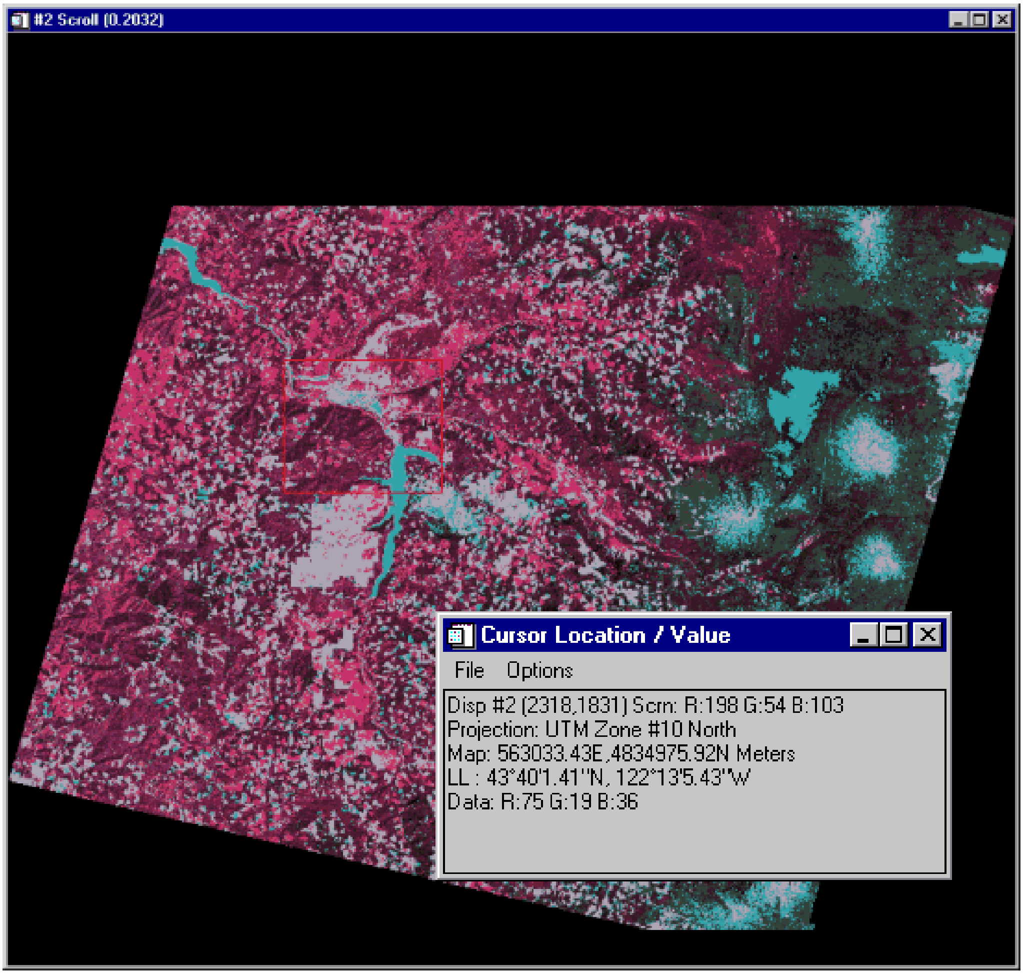


Figure 6-8: Oregon, SPOT XS Level 1B Data
Note the geographic-based coordinates and that image rectification has been cut off in the north at the edge of the DEM.

6. When the **Orthorectification Bounds** dialog appears, enter or calculate the approximate minimum value contained in the DEM file. If your DEM has a filler value for missing data, enter that value in the **DEM Value to Ignore** text box.

7. Click **OK** and the **Orthorectification Parameters** dialog appears. Enter the value to ignore (missing data) in the DEM in the appropriate text box. To set the Background Value (the DN value used to fill areas where no image data appears in the warped image) enter the DN value in the **Background Value** text box.

   The output image dimensions are automatically set to the size of the bounding rectangle that contains the warped input image. Therefore, the output warp image size may not be the same size as the DEM image. The output size coordinates are determined in the exterior orientation projection coordinates. This may be changed by modifying the map coordinate or latitude/longitude information for the upper left coordinate, pixel size, and image size by clicking **Change Output Parameters** and entering the desired values.

8. Select to output to **File** or **Memory** and click **OK** to start the orthorectification.

Tips for Successful Orthorectification

ENVI’s Orthorectification routines were designed to be as flexible as possible, so there are very few restrictions on the parameters that the user provides. While this flexibility makes the tools easy to use, it also makes it possible to set up an orthorectification incorrectly.

Spatial Resolution

Before beginning an orthorectification, it is important to consider the issue of spatial resolution, as it is handled very differently here than in ENVI's “warp” registrations. There are three key parameters:

- The pixel size of the DEM.
- The pixel size of the input image.
- The desired output pixel size for the resulting orthorectified image.

ENVI will let you proceed with any combination of pixel sizes, but these settings will have a profound effect on your results. Ideally, the pixel size of the DEM should be the same (or smaller) as that of the output ortho image you want to create. If the DEM resolution is significantly larger than the desired output resolution, you will often end up with artifacts in the ortho result that look like steps (or blocks) in the image. The steps will occur where there is a boundary between groups of pixels in the output ortho image which map back to the same DEM elevation (i.e., the same DEM pixel). So, before doing an orthorectification in ENVI, use the [**Basic Tools → Resize Images (Spatial/Spectral)**] to resample the DEM to the desired output ortho image resolution. We recommend that you use bilinear interpolation for the resampling, as cubic convolution is more likely to create features that are unrealistic; the nearest neighbor technique will not smooth out the resampled DEM.

Resampling During the Orthorectification

When producing the ortho image, the value for each pixel in the output image (i.e., the ortho image’s DNs) is determined by figuring out which pixel in the input air photo “belongs” in this position. This is accomplished by using the 2 models to trace back which air photo DN occurs at a given map coordinate. Then, this air photo DN is placed in the correct location in the output ortho image. While the map coordinate of the center of each pixel in the output ortho image will map back to a single pixel in the input air photo, the value that is used for the output ortho image is typically adjusted by resampling it based on the values of the pixels in its immediate vicinity (in the air photo). This resampling produces a smoother, more realistic looking ortho image. Bilinear interpolation uses the values of the 4 nearest neighbors, while cubic convolution uses the 16 nearest neighbors. Currently only nearest neighbor resampling is offered. Nearest neighbor resampling does not provide any smoothing effects. When using nearest neighbor resampling, and the output pixel size of the ortho image is considerably larger than that of the input air photo, you may end up with an ortho image that does not have the spatial characteristics of a typical photograph.

Consider a case where the input air photo has 1x1 meter pixels but the output ortho image has been set up to have only 5x5 meter pixels. In the ortho result, each 5x5 meter pixel will have a DN based on a 1x1 meter area in the air photo. Further, because the map location of the centers of neighboring pixels in the 5 meter ortho result are separated by 5 pixels the air photo, neighboring pixels in the ortho result will have DNs represented by pixels in the air photo that are not continuous. If you wish for your ortho result to have a pixel size that is significantly larger than the air photo, you may want to first resample the air photo to the pixel size of the desired output ortho image.

Accuracy of GCPs

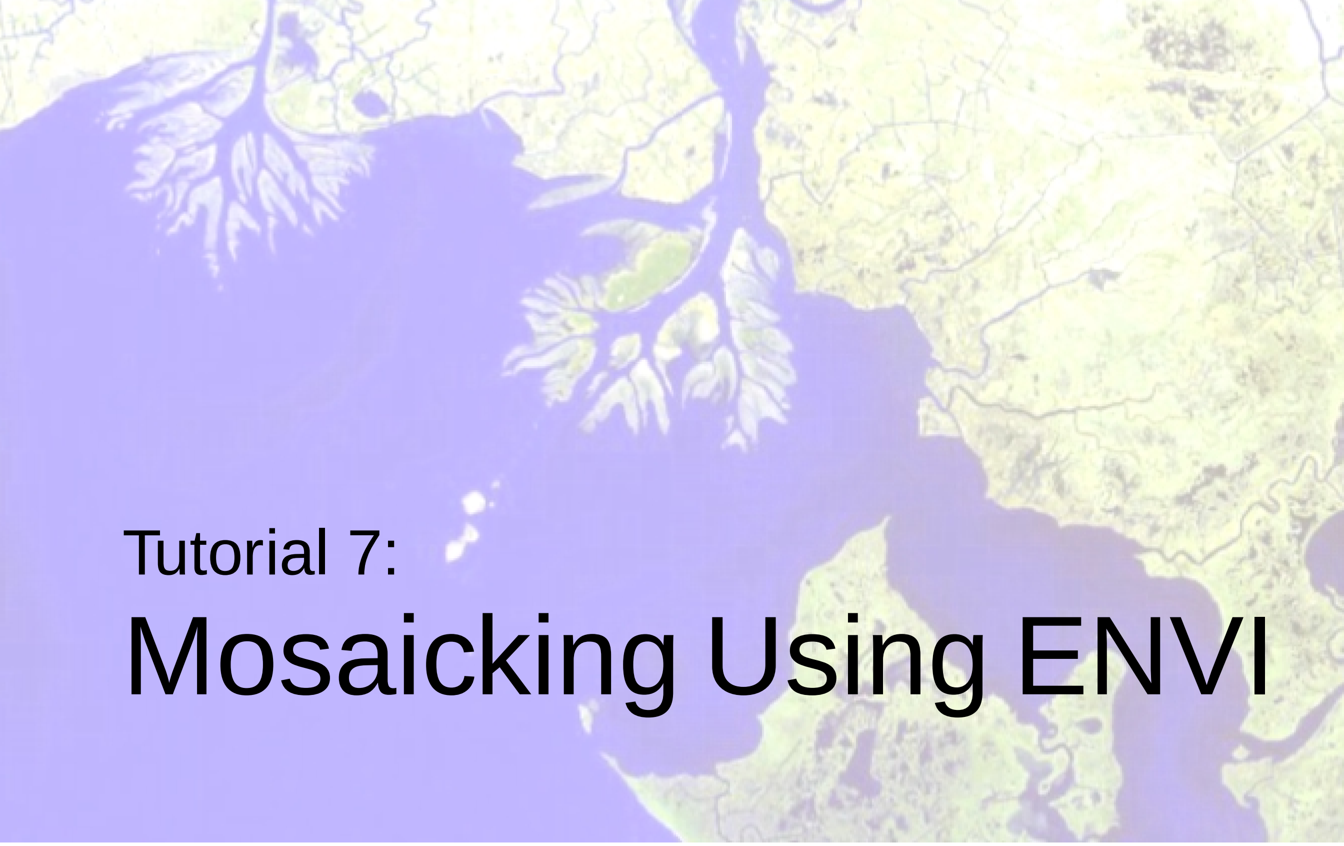
Unlike the GCPs used in “warp” registrations, the accuracy of each GCP used for the Exterior Orientation is absolutely critical for locating the position of the air photo camera. If the Exterior Orientation is not accurate, then the orthorectified image will be in error, even if the Interior Orientation is perfect. It is not uncommon for GCPs to be based on survey results and be located to sub-millimeter accuracy, especially when orthorectifying air photos with a resolution of 1 meter or less. Also, in order to optimally recover the camera position, try to spread the GCPs across the entire image. It is better to have fewer GCPs that are well distributed than to have many GCPs clustered together. Once at least 4 GCPs are entered in the Exterior Orientation, an estimate of the (x.y) position error is reported as the RMS value. This error estimate is calculated with an RST warping algorithm which is quite different than the orthorectification procedure. The RMS error is provided simply to check for large errors, such as those that might occur with a typo or a misplaced decimal point when entering the GCPs. This error does not consider the Z-values of the GCPs and is not an accurate assessment of the true error in the orthorectification.

Minimum DEM Value

After you have built the `.ort` file by defining the Interior and Exterior Orientations, and you are running the Orthorectify Air Photo procedure, you will be prompted to enter a Minimum DEM Value. For any given set of orthorectification parameters, the greater the distance between the camera and the ground, the bigger the ortho image must be. The value that is entered here is used to determine the size (in samples and lines) of the orthorectification output image. This value will not affect the DNs of the resulting ortho image, however, entering an accurate value will likely reduce the processing time and make a smaller resulting image file.

Output Pixel Size

The output pixel size for the resulting ortho image defaults to the pixel size of the DEM. If this is not the pixel size you wish for your result, you can change the pixel size in the dialog window by selecting the **Change Output Parameters** button located in the middle of the last dialog window (the **Orthorectification Parameters** dialog). Generally speaking, it is always a good idea to check the values in the Output Image Parameters window before doing any kind of registration (orthorectification, warping, converting map projections, etc.), because a quick glance at these parameters can often identify problems with input parameters.



Tutorial 7:

Mosaicking Using ENVI

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to give you a working knowledge of ENVI's image mosaicking capabilities. For additional details, please see the *ENVI 3.5 User's Guide* or the ENVI Online Help.

Files Used in this Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/avmosaic`

File	Description
Pixel-Based Mosaicking	
`dv06_2.img`	AVIRIS Scene 02
`dv06_2.hdr`	ENVI Header for above
`dv06_3.img`	AVIRIS Scene 03
`dv06_3.hdr`	ENVI Header for above
`dv06a.mos`	Mosaic Template for end-to-end AVIRIS mosaic
`dv06b.mos`	Mosaic Template for feathered overlapping AVIRIS mosaic
`dv06_fea.img`	Feathered Mosaic image
`dv06_fea.hdr`	ENVI Header for above
Georeferenced Mosaicking	
`lch_01w.img`	Warped, histogram matched image
`lch_01w.hdr`	ENVI Header for above
`lch_01w.ann`	Cut-line feathering annotation for above
`lch_02w.img`	Warped, histogram matched image
`lch_02w.hdr`	ENVI Header for above
`lch_a.mos`	Mosaic Template for Georeferenced Image Mosaicking

File	Description
lch_mos1.img	Georeferenced mosaic result
lch_mos1.hdr	ENVI Header for above

Mosaicking in ENVI

Mosaicking is the art of combining multiple images into a single composite image. It can be used to combine pixel-based images, to lay out images for publication or map composition, or as a means for combining georeferenced images into an image covering a larger geographic area. ENVI provides interactive capabilities for placing pixel-based images within a mosaic, and automated placement of georeferenced images within a georeferenced output mosaic. The software provides tools for common mosaic requirements such as blending edges (feathering), image border transparency, and histogram matching. ENVI's Virtual Mosaic capability allows users to optionally create and display mosaics without creating large output files.

General Topics

The following sections walk you through some of the preparation required to make mosaics in ENVI. The actual exercises begin with the section “Pixel-Based Mosaicking Example” on page 183 or alternatively, for georeferenced mosaics, in the section “Georeferenced Mosaicking Example” on page 187.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in UNIX, enter `envi` at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Preparing Images

Raw image data can be mosaicked together if desired (ENVI can be used to easily produce multiband mosaics of multiple data types), however, most mosaics are for output and usually require scaling (contrast stretching), and histogram matching to minimize image differences in the output mosaic.

The first step in creating a mosaic using ENVI is usually to contrast stretch the images. This is done by displaying the bands to be mosaicked and either using one of ENVI's quick (default) stretches or using ENVI's interactive contrast stretching capabilities.

Start in either of the following Pixel-Based ("Steps for Creating a Pixel-Based Mosaic" on page 180) or the Georeferenced Image Mosaic ("Create the Georeferenced Mosaic Image" on page 187) sections and open the appropriate images by navigating to the `avmosaic` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 1*, selecting the desired image file and opening it just as you would in any other application.

Open the Files

1. Select **File** → **Open Image File**. An **Enter Data Filenames** file selection dialog appears. Select the desired file.

Note

On some platforms you must hold the left mouse button down to display the submenus from the Main Menu.

2. Display the image(s) by selecting the desired bands in the **Available Bands List** and clicking **Load Band**.
3. Select **Enhance** → **[Image] Linear 2%** to stretch the displayed image, or select **Enhance** → **Interactive Stretching**.
4. Stretch the image to enhance the desired image features and output to memory or a new file by selecting **File** → **Save Image As** → **Image File** in the Main Display window.

Histogram Matching

When mosaicking two or more images that overlap, it is usually necessary to choose a base image and balance gray scale values in the rest of the images to match the base image. This is called histogram matching (Richards, 1993). ENVI provides an interactive tool to perform histogram matching. The procedure for performing the histogram matching is described below.

The following steps are provided for information and are not to be executed as part of this tutorial.

1. Display the two images to be histogram matched in two display windows. Select one of the images as the base image and stretch that image as desired using either the default stretches under the *Enhance* menu or **Enhance** → **Interactive Stretching**.
2. Identify the overlap areas, position the Zoom windows of both images within the overlap, and resize and/or reposition the Zoom window to cover exactly the same region in both images (try to cover as large an area as possible and a broad range of cover types).

3. Select **Enhance** → **Histogram Matching** from the Main Image Display menu bar of the image you want to match to the base image. The **Histogram Matching Input** dialog appears.

4. Select the display number of the base image to match, click on the **Zoom** radio button, and then click **OK**.

   The output histogram from the base image is applied to the histogram of the second image and histogram matching is complete. The two images should now have the same gray scale characteristics.

5. Save the two contrast stretched images by selecting **File** → **Save Image As** → **Image File** in both Main Displays.

6. Select to save the stretched files either to memory or to new output files.

7. Repeat for additional overlapping images as required.

You may want to try the histogram matching yourself on the input file for the "Georeferenced Mosaicking Example" on page 187. However, for the purpose of this exercise, the pre-stretched, histogram-matched images `lch_01w.img` and `lch_02w.img` are provided as input to the georeferenced mosaicking function.

Feathering

It is often desirable to blend or blur the seams between mosaicked images. ENVI provides the capability of feathering the edges of overlapping areas using either edge feathering or cutline feathering over a user specified distance. To use feathering when mosaicking images, import the bottom image without feathering. Import the overlapping images with feathering, either edge or cutline, as desired.

Edge Feathering

Edge Feathering uses the distance specified in the **Edge feathering distance (pixels)** text box in the **Mosaic Entry Input Parameters** dialog to blend the image seams along the edges of the image. The edge feathering distance specified is blended using a linear ramp that averages the two images across that distance. For example, if the specified distance is 20 pixels, 0% of the top image is used in the blending at the edge and 100% of the bottom image is used to make the

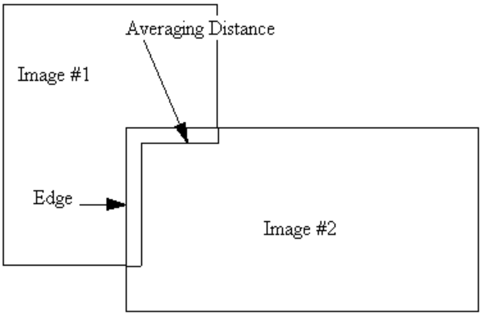


Figure 7-1: Edge Feathering

output image. At the specified distance (20 pixels) in from the edge, 100% of the top image is used to make the output image and 0% of the bottom image is used. At 10 pixels in from the edge, 50% of each image is used to make the output image.

Cut-Line Feathering

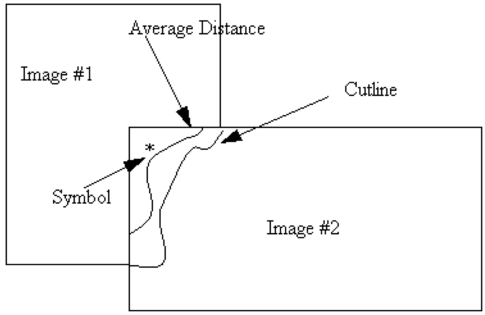


Figure 7-2: Cutline Feathering

Cut-Line Feathering uses the distance specified in the **Cutline feathering distance (pixels)** text box and the annotation file selected from **Ann File** in the **Mosaic Entry Input Parameters** dialog to blend the image boundaries. Cutlines must be defined using the annotation tools prior to mosaicking. The annotation file must contain a polyline defining the cutline that is drawn from edge-to-edge and a symbol placed in the region of the image that will be cut off. The cutline distance specified is used to create a linear ramp that averages the two images across that distance from the cutline outwards. For example, if the specified distance is 20 pixels, 100% of the top image is used in the blending at the cutline and 0% of the bottom image is used to make the output image. At the specified distance (20 pixels) out from the cutline, 0% of the top image is used to make the output image and 100% of the bottom image is used. At 10 pixels in from the cutline, 50% of each image is used to make the output image.

Virtual Mosaics

ENVI allows use of the mosaic template file as a means of constructing a “Virtual Mosaic” — a mosaic that can be displayed and used by ENVI without actually creating the mosaic output file.

1. To create a virtual mosaic, create the mosaic and save the template file using **File** → **Save Template** in the **Image Mosaicking** dialog. This creates a small text file describing the mosaic layout
2. To use the virtual mosaic, select **File** → **Open Image File** from the ENVI main menu and open the mosaic template file. All of the images used in the mosaic are opened and their bands are listed in the **Available Bands List**. Display or process any of the bands in the virtual mosaic, and ENVI treats the individual images as if they were an actual mosaic output file. The new processed file has the specified size of the mosaic and the input files are in their specified positions within the mosaic.

Steps for Creating a Pixel-Based Mosaic

The following describes the steps required to create a pixel-based image mosaic.

Set up the Mosaicking Dialog

1. Select **Map** → **Mosaicking** → **Pixel Based** from the ENVI main menu.

   The pixel-based option can also be used to place georeferenced images, where the georeferencing information will not be retained. Pixel-based images can also be placed within a georeferenced image using the **Map** → **Mosaicking** → **Georeferenced** option.

2. For pixel-based images, set the size of the output mosaic by entering the desired size in pixels in **X Size** (Samples) and **Y Size** (Line) parameters in the dialog.
3. Also set the "Snap" factor, which controls a grid to which images will be placed or snapped (for example, a snap of 5 means that pixel-based images will be placed at the nearest intersection of a pixel grid with 5 x 5 pixel spacing). Set the snap factor by selecting **Options** → **Set Snap Value**.

Import Images

Use one of the following methods to import images depending on the type of mosaic and whether the images have overlapping areas.

Importing Images Without Feathering

Images that do not overlap, or images that do not require blending should be imported using the Import file without feathering option as follows:

1. Select **Import** → **Import file without feathering** from the menu bar in the pixel-based or georeferenced **Mosaicking** dialog.
2. Open and select the desired image in the **Mosaic Input File** dialog and spectrally and/or spatially subset it if desired.

   The image description will be listed in the dialog, and a graphic representing the image and its position in the mosaic will be displayed in the draw widget within the dialog.

3. Open and import the remaining images in the mosaic in the same fashion.

Importing Images With Feathering

Images that overlap may require feathering of the overlap areas to avoid obvious seams in the final mosaic.

1. Select **Import** → **Import file with feathering** from the menu bar in the Mosaicking dialog.

   If cutline feathering is being used, the cutline must already have been drawn as a polyline annotation and saved to an annotation file as described in the section "Cut-Line Feathering" on page 179.

2. For both cutline and edge feathering, specify a distance over which to feather as described in "Feathering" on page 178.

Feathering blends adjoining images, but mosaicking with feathering is computationally intensive and requires a long time to run, especially for large mosaics.

Importing Images With a Background Value to Ignore

This option allows image transparency for overlapping images.

1. Select **Import** → **Import file with feathering** regardless of whether or not you want to feather the images. This allows you to set a background value to ignore when images overlay one another.
2. If feathering (which is used for mosaicking images with constant digital number value borders) is desired, enter the desired values, however, if feathering is not desired, leave the feathering values set to zero.
3. Enter the data value to be ignored in the labeled text box.

The overlap areas with this value will be transparent, allowing underlying images to show through. This value will also be ignored during the feathering process if selected.

Create a Virtual Mosaic or an Output Mosaic

Complete one of the following steps, either creating a template (virtual mosaic) or creating an output mosaic:

1. To create a virtual mosaic, described in "Virtual Mosaics" on page 179, select **File** → **Save Template**, enter the output filename, and click **OK**. To view this mosaic, select **File** → **Open Image File** from the ENVI main menu, choose the mosaic template file as the input file and click **Open**. Click on the mosaic band name in the **Available Bands List** and then **Load Band** to automatically

get the required images and display the virtual mosaic to the ENVI Image Display.

2. Alternatively, to actually create the mosaic as a new file, select **File** → **Apply** in the **Mosaic** dialog and enter an output filename. The output mosaic is a standard ENVI file and can be displayed using the **Available Bands List**.

Pixel-Based Mosaicking Example

This section leads you through creation of pixel-based mosaics using ENVI's mosaicking tools.

1. Start the ENVI pixel-based mosaic function by selecting **Map** → **Mosaicking** → **Pixel Based** from the ENVI main menu.
2. The **Pixel Based Image Mosaicking** dialog appears.

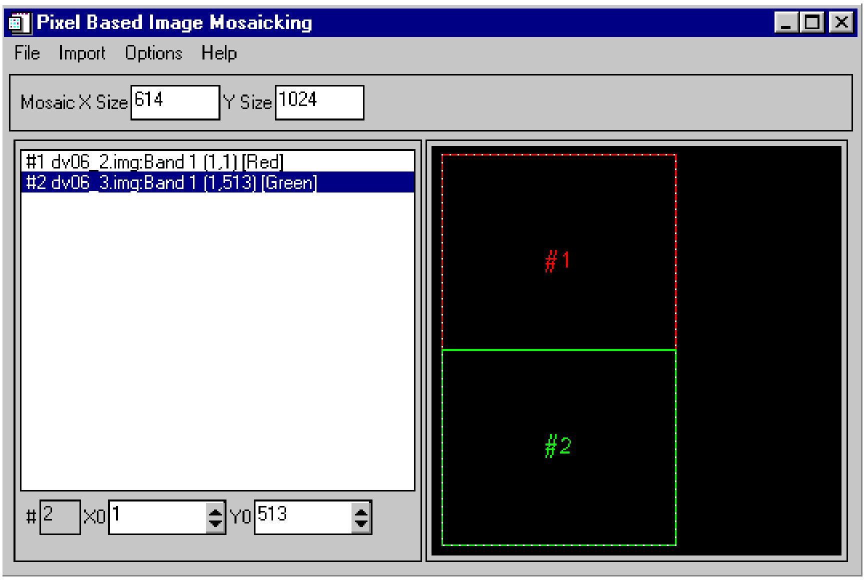


Figure 7-3: The Pixel Based Image Mosaicking Dialog

Import and Position Images

To position pixel-based images:

1. Import each of the following two images, `dv06_2.img` and `dv06_3.img`, by selecting **Import** → **Import file without feathering** from the **Pixel Based Image Mosaicking** dialog.
2. Specify the mosaic size by entering the 614 for the **X Size** and 1024 for the **Y Size** in the text boxes at the top of the **Pixel Based Image Mosaicking** dialog.
3. Click on the second image in the list of images in the dialog (`dv06_3.img`).

The current position of the image in pixels will be listed in the text box at the bottom of the dialog.

4. Change the image position by entering the desired **XO** (x offset) and **YO** (y offset) values in pixels in the corresponding text boxes. Enter a value of 513 for the **YO** for `dv06_3.img` to place it directly below `dv06_2.img`.

Note

Images can also be positioned by clicking and holding the left mouse button on the desired image in the mosaic diagram on the right side of the dialog, dragging the selected image to the desired location, and releasing the left mouse button to place the image.

5. Select **File** → **Apply** from the **Pixel Based Image Mosaicking** dialog menu and enter the output filename `dv06.img` and click **OK** to create the mosaic.
6. Choose **File** → **Save Template** from the **Pixel Based Image Mosaicking** dialog and enter the output filename `dv06a.mos`.
7. Display the mosaicked image by clicking on the `dv06a.mos` band name in the **Available Bands List** and then clicking **Load Band**.

The second part of this example shows positioning of the two images into a composite mosaic image, accomplished by either entering the **XO** and **YO** values, or dragging the images to the desired locations within the dialog. The example also includes edge feathering.

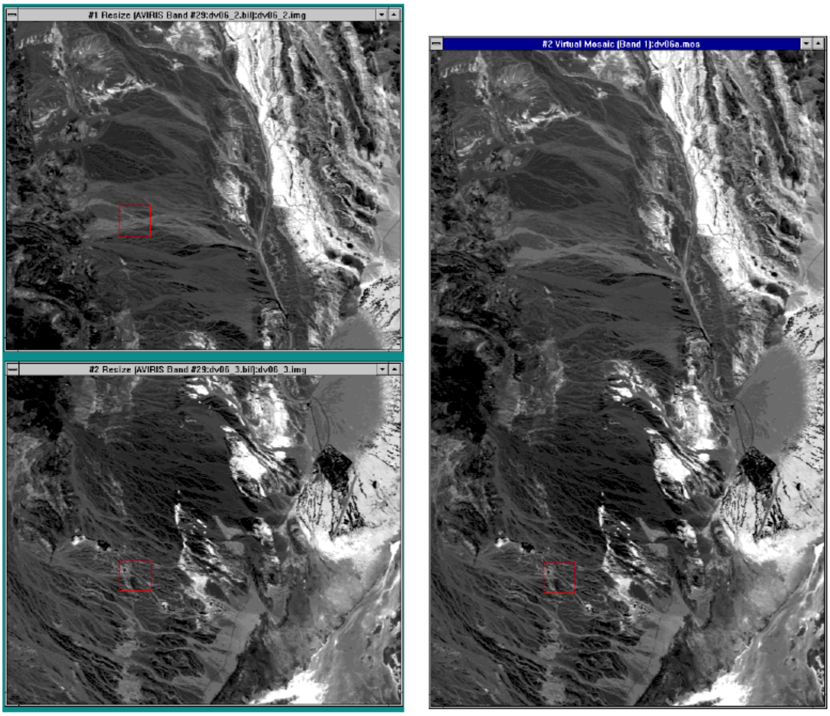


Figure 7-4: Two Single-band AVIRIS Images (left) and the Final Seamless Join of the Two (right)

1. Using the images already displayed, enter a value of 768 into both the Mosaic **X Size** and **Y Size** text boxes to change the size of the output mosaic
2. Left-click within the green graphic outline of image #2 in the **Pixel Based Image Mosaicking** dialog. Drag the #2 image to the lower right hand corner of the diagram.
3. Edit the mosaic characteristics by selecting **Options** → **Edit Entry** in the **Pixel Based Image Mosaicking** dialog. Enter a value of 25 for the **Edge Feathering Distance** and a **Background Data Value to Ignore** of 0, and click **OK**. Repeat for the second image.
4. Choose **File** → **Save Template** and enter the output filename `dv06b.mos`. Click on the mosaic template name in the **Available Bands List** and select

Load Band to display it. No feathering is performed when using virtual mosaic.

5. Now make the same image as a feathered mosaic by actually creating the output file. In the **Pixel Based Image Mosaicking** dialog, select **File** → **Apply** and click **OK**.
6. Enter an output filename, and a **Background Value** of 255, then click **OK**. Display the mosaic now listed in the Available Bands List in a new display window.
7. Compare the virtual mosaic and the feathered mosaic using image linking and dynamic overlays.

The following figure shows the feathered output mosaic produced by overlapping the two AVIRIS scenes as described above.

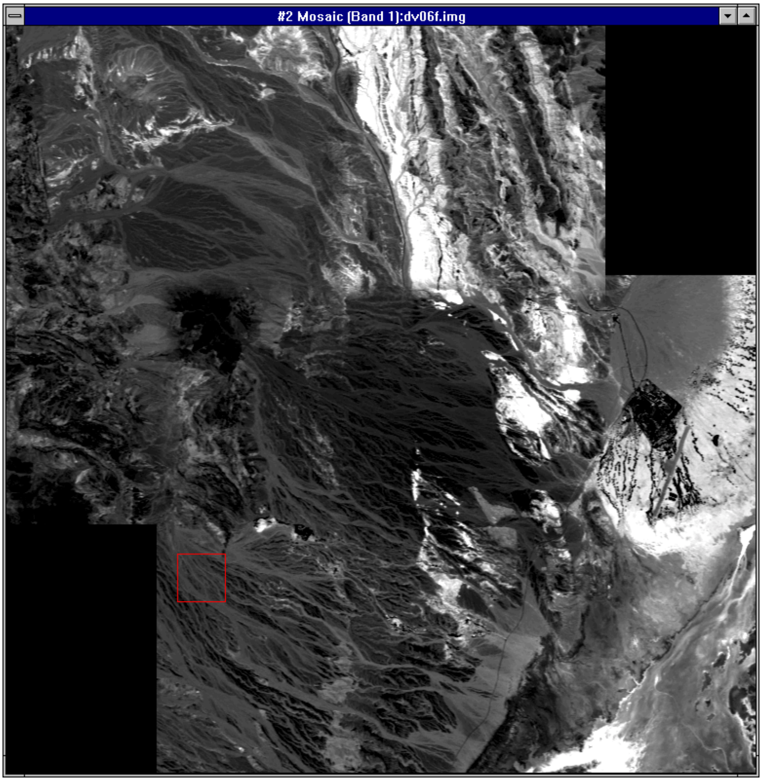


Figure 7-5: The Final Feathered Mosaic

Georeferenced Mosaicking Example

Putting together georeferenced, overlapping images requires considerable preparation, including histogram matching and usually feathering. The following sections of this tutorial describe some of the requirements and how to accomplish these using ENVI.

Create the Georeferenced Mosaic Image

1. Start the ENVI Georeferenced Mosaic function by selecting **Map** → **Mosaicking** → **Georeferenced** from the ENVI main menu.

Load the Mosaic Template

Select **File** → **Restore Template** and select the file `lch_a.mos`. This opens the files and restores the mosaic parameters necessary for a georeferenced, feathered mosaic.

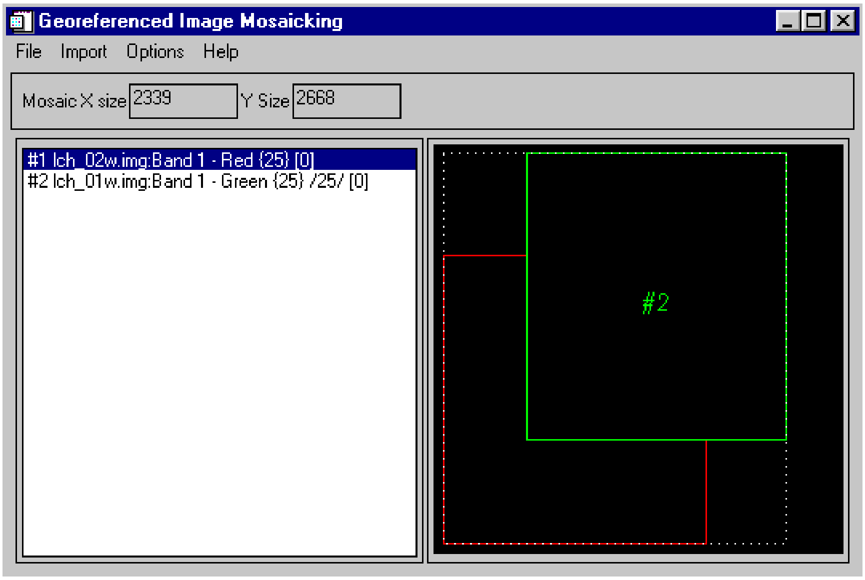


Figure 7-6: The Georeferenced Image Mosaicking Dialog

Optionally Input and Position Images

Optionally, to manually position the georeferenced images and set the feathering options, import the images individually. Images will automatically be placed in their correct geographic locations. The location and size of the georeferenced images will determine the size of the output mosaic.

View the Top Image, Cutline and Virtual, Non-Feathered Mosaic

1. In the **Available Bands List**, select the file `lch_01w.img` and display as a gray scale by clicking on the band name and then the **Load Band** button.
2. Choose **Overlay** → **Annotation** from the Main Image Display menu bar to start the Annotation dialog.
3. Select **File** → **Restore Annotation** and choose the file `lch_01w.ann` to display the cutline used to blend the two images in this mosaic.
4. Display the second image `lch_02w.img` and examine the nature of the cutline with respect to this image.
5. View the virtual, non-feathered mosaic. Select **File** → **Open Image File** from the ENVI main menu and choose `lch_a.mos` as the input file. Load this image to a new display using the **Available Bands List** and examine the non-feathered edge between the two images used to create the mosaic.

Create the Output Feathered Mosaic

1. Select **File** → **Apply** in the **Georeferenced Image Mosaicking** dialog and enter the output filename `lch_mos.img` and click **OK** to create the feathered mosaic.
2. Close the two Image Display Windows containing the individual warped images and load the mosaic image into a new display.
3. Compare the feathered mosaic to the non-feathered mosaic using image linking and dynamic overlays.

In the following figure, the left images show the warped, histogram-matched images with the cutline selected. The right image is the mosaic resulting from using cutline feathering.

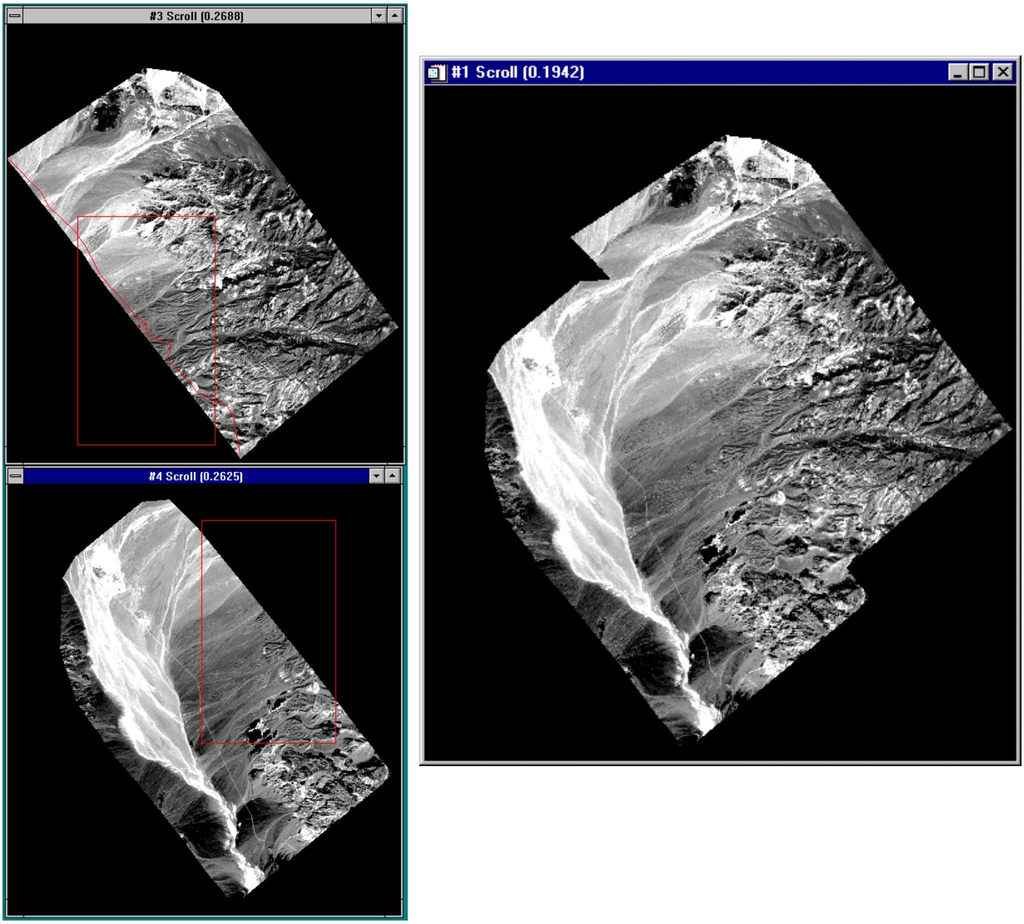


Figure 7-7: Examples of Georeferenced Image Mosaicking

Additional Options in the Pixel Based and Georeferenced Mosaicking Dialogs

The following list describes additional options when using the mosaicking dialogs:

- To edit the characteristics of an image, such as modifying feathering distances, setting the Background Data Value to Ignore (transparency), or changing the X and Y image offsets, select **Options** → **Edit Entry** and enter the desired values.
- To replace an image currently in a mosaic with another image of the same size, select the image to be replaced, and select **Options** → **Replace Entry** and select the image to use for the replacement.
- To delete the currently selected image from the mosaic, select **Options** → **Delete Entry**.
- To remove all images from the mosaic and clear the mosaic, select **Options** → **Clear All Entries**.

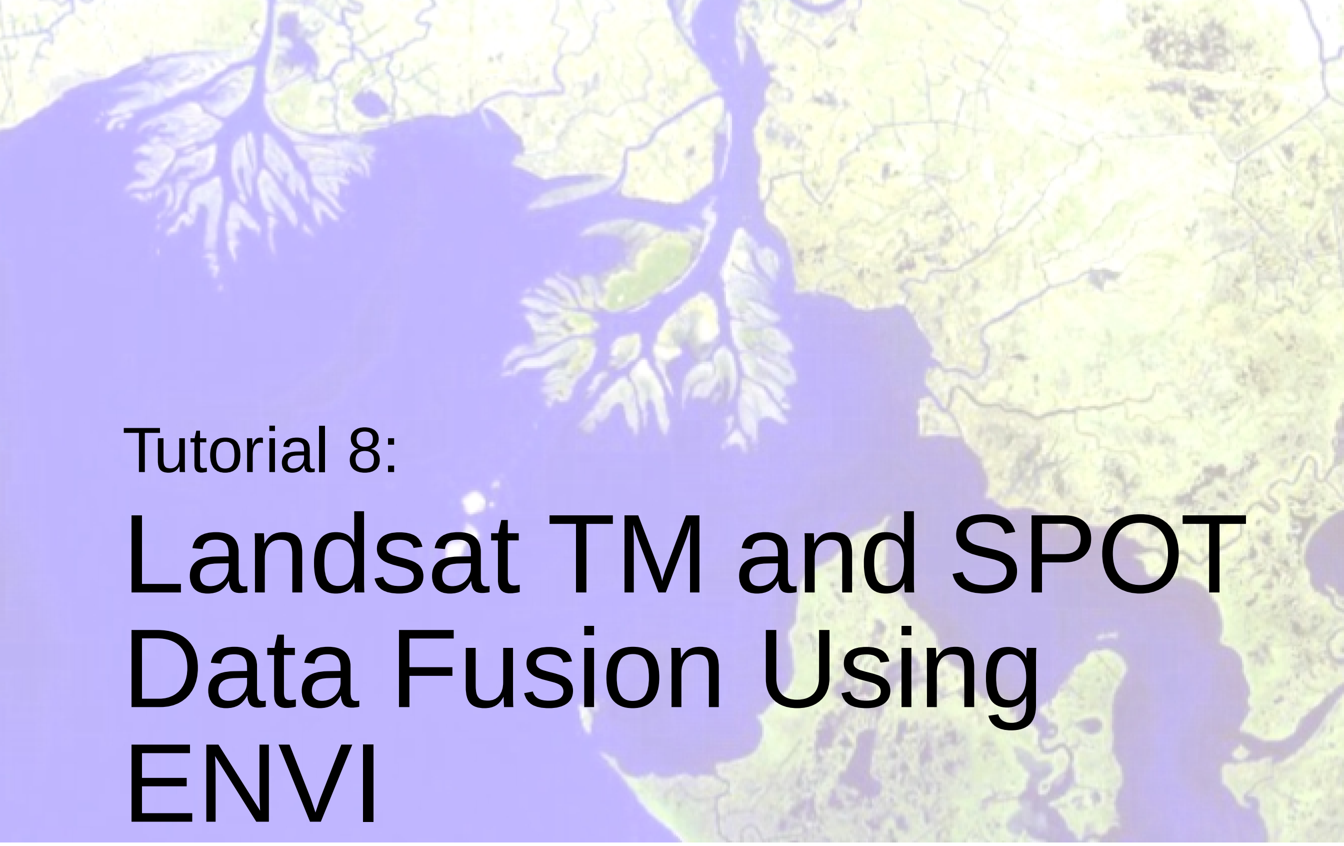
The following **Pixel Based Image Mosaicking** dialog options are available only for pixel-based images:

- To float the pixel-based image to the top of the stack of overlapping images, click on the image in the list, or the mosaic diagram, and select **Options** → **Percolate Entry**.
- To center all of the current images in the mosaic as a group, select **Options** → **Center Entries**.
- To place an image as if their upper left corner has the x, y coordinates of (1,1), select **Options** → **Do Not Use Image Offset**.

  Do this for images which were previously created as subsets from other larger images and which have an image offset value. This means that the upper left corner of the image has X and Y values corresponding to its position in the original image.
- To place images in the mosaic at the location specified by its location in the original image from which it was subset, select **Options** → **Use Image Offset**.

End the ENVI Session

You can quit your ENVI session by selecting **File** → **Exit (Quit** on UNIX) in the ENVI main menu, then click **Yes** to end the session. If you are using ENVI RT, quitting ENVI will take you back to your operating system.



Tutorial 8:

Landsat TM and SPOT Data Fusion Using ENVI

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to demonstrate selected ENVI data fusion capabilities. For additional data fusion details, please see the *ENVI User's Guide* or ENVI Online Help. Two examples are provided for this tutorial. The first uses Landsat TM and SPOT data of London, UK (Data Courtesy of RSI International UK, Ltd). The TM data are Copyright, European Space Agency, and distributed by Eurimage/NRSC. The SPOT data are Copyright CNES, 1994, distributed by Spot Image/NRSC. Both datasets are used with permission (NRSC, 1999). The second example uses SPOT XS and Panchromatic data of Brest, France (Data Courtesy of RSI International, France, Copyright CNES-Spot image, 1998. Used with permission of SPOT, 1999. These data may not be used for commercial purposes).

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/lontmsp` (London, UK TM and SPOT example)
`envidata/brestsp` (Brest, France SPOT PAN and XS example)

File	Description
London, UK TM and SPOT example	
`lon_spot`	London SPOT data
`lon_spot.ers`	ER Mapper Header for above file
`lon_tm`	London Landsat TM data
`lon_tm.ers`	ER Mapper Header for above file
Brest, France SPOT PAN and XS example	
`s_0417_1.bil`	Brest, France, SPOT panchromatic data
`s_0417_1.hdr`	ENVI Header for above file
`s_0417_2.bil`	Brest, France, SPOT multispectral data
`s_0417_2.hdr`	ENVI Header for above file
`copyright.txt`	Data copyright statement

Data Fusion

Data Fusion is the process of combining multiple image layers into a single composite image. It is commonly used to enhance the spatial resolution of multispectral datasets using higher spatial resolution panchromatic data or single-band SAR data.

The following sections walk you through some of the preparation required to fuse image datasets in ENVI and the actual data fusion process.

Preparing Images

To perform data fusion using ENVI, the files must either be georeferenced (in which case spatial resampling is performed on the fly), or if not georeferenced, cover the same geographic area, have the same pixel size, the same image size, and the same orientation. The files used in this exercise are not georeferenced, therefore the low resolution images must be resampled to have the same pixel size as the high spatial resolution image (using nearest neighbor resampling).

London, UK, Data Fusion Example

Read and Display ERMapper Images

The London data are TM and SPOT data binary files with ERMapper header files, and can be automatically read using ENVI's ERMapper reading routines.

1. Select **File** → **Open External File** → **IP Software** → **ER Mapper**, navigate to the `lontmsp` subdirectory and select the file `lon_tm.ers`.
2. Click on the **RGB Color** radio button in the **Available Bands List**, click sequentially on the Red Layer, Green Layer, and Blue Layer bands, then **Load RGB** to display a true-color Landsat TM image.

1. Select **File** → **Open External File** → **IP Software** → **ER Mapper**, navigate to the `lontmsp` subdirectory and select the file `lon_spot.ers`.
2. Click on the **Gray Scale** radio button in the **Available Bands List**, click on the **Pseudo Layer** band, select **New Display** from the pull-down **Display** menu, then click **Load Band** to display the gray scale SPOT image

Resize Images to Same Pixel Size

1. Click first on the SPOT image band in the **Available Bands List** and note its spatial dimensions (2820 x 1569) and then click on the Landsat TM and note its spatial dimensions (1007 x 560). The Landsat data have a spatial pixel size of 28 meters, while the SPOT data are 10 meter spatial resolution. The Landsat image has to be resized by a factor of 2.8 to create 10 m data that matches the SPOT data.
2. Select **Basic Tools** → **Resize Data (Spatial/Spectral)** and choose the `lon_tm` image then click **OK**. Enter a value of `2.8` into the **xfac** text box in the **Resize Data Parameters** dialog. Enter a value of `2.8009` into the **yfac** text box (the value of 2.8009 rather than 2.8 must be used to add an extra pixel to the y dimension so the images will match exactly). This difference is insignificant for the purposes of this exercise, but might be important for an actual application. Enter an output filename and click **OK** to resize the TM image.
3. Display the resized image and select **Tools** → **Link** → **Link Displays** to link the resized TM image and the SPOT Panchromatic image. Use the dynamic overlay to compare the two images.

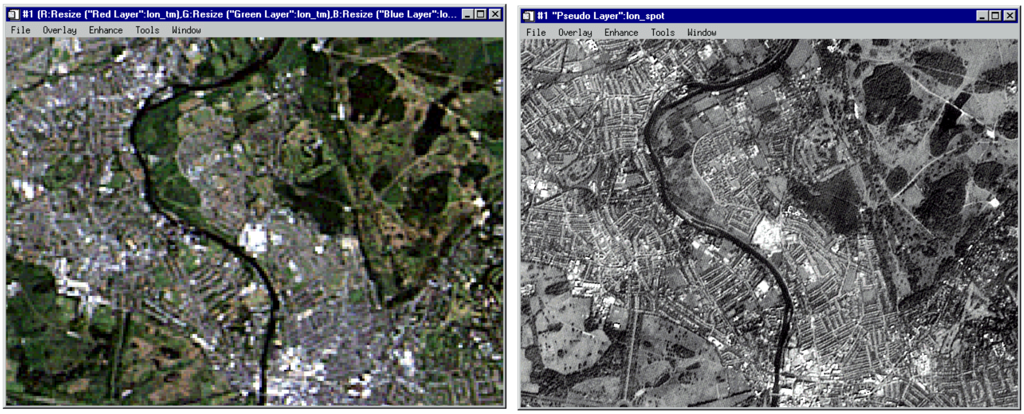


Figure 8-1: Landsat TM True-Color Composite (28 m spatial resolution, left). SPOT Panchromatic Image (10m spatial resolution, right).
Figure 8-2:

Perform Manual HSI Data Fusion

Try manually performing data fusion in order to understand the process. First, the color TM image is transformed into hue-saturation-value color space. The value band is replaced with the higher resolution SPOT data and stretched from zero to one to fill the correct data range. Then the hue and saturation from the TM data and value from the SPOT data are transformed back to red-green-blue color space. This produces an output image that contains the colors from the TM data and the spatial resolution of the SPOT data.

Forward HSV Transform

1. Select **Transform** → **Color Transforms** → **RGB to HSV** from the ENVI main menu, and select the resized TM data as the RGB image from the Display. Enter an output filename and click **OK** to perform the transform.
2. Display the Hue, Saturation, and Value images as gray scale images or an RGB.

Create a Stretched SPOT Image to Replace TM Band Value

1. Select **Basic Tools** → **Stretch Data** from the ENVI main menu, click on the `lon_spot` file and then **OK**.
2. In the **Output Data** portion of the **Data Stretching** dialog, enter the value `0` for the **Min** and `1.0` for the **Max** values, enter an output filename, and click **OK** to stretch the SPOT data to floating point data with a range of 0 to 1.0.

Inverse HSV Transform

1. Select **Transform** → **Color Transforms** → **HSV to RGB** from the ENVI main menu, and select the transformed TM **Hue** and **Saturation** bands as the **H** and **S** bands for the transformation.
2. Choose the stretched SPOT data as the **V** band for the transform, click **OK**. Enter an output filename into the **HSV to RGB Parameters** dialog and click **OK** to perform the inverse transform.

Display Results

1. Click on the **RGB Color** radio button in the **Available Bands List**, click sequentially on the transformed R, G, and B bands, then click the **Load RGB** button to display a fused true-color Landsat TM/SPOT image.
2. Display the fused image and select **Tools** → **Link** → **Link Displays** to link with the resized TM image and the SPOT Panchromatic image. Use the dynamic overlay to compare the images.

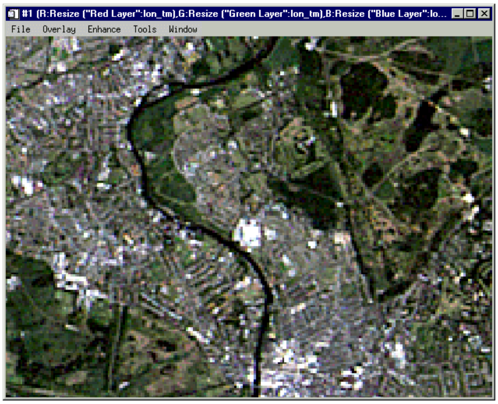
ENVI Automated HSV Fusion

1. Select **Transform** → **Image Sharpening** → **HSV** from the ENVI main menu.
2. If you have the resized TM color image displayed, choose the appropriate display in the **Select Input RGB** dialog. Otherwise, choose the **"Red Layer"**, **"Green Layer"**, and **"Blue Layer"** from the resized TM Image in the **Select Input RGB Input Bands** dialog and click **OK**.
3. Choose the SPOT image in the **High Resolution Input File** dialog and click **OK**.
4. Enter the output file name `lontmsp.img` and click **OK** in the **HSV Sharpening Parameters** dialog.

Display Results, Link and Compare

1. Load the fused color image into a new display by selecting the **RGB Color** radio button in the **Available Bands List** dialog, selecting the R, G, and B bands from the new file and clicking **Load RGB**.
2. Compare the HSV sharpened color image to the original TM color composite, to the SPOT data, and to the manual data fusion result by selecting **Tools** → **Link Displays** → **Link** from the Main Display Window menu bar.

Try the same process using the Color Normalized (Brovey) Transform by selecting **Transform** → **Image Sharpening** → **Color Normalized (Brovey)**, entering the required file information and clicking **OK**.



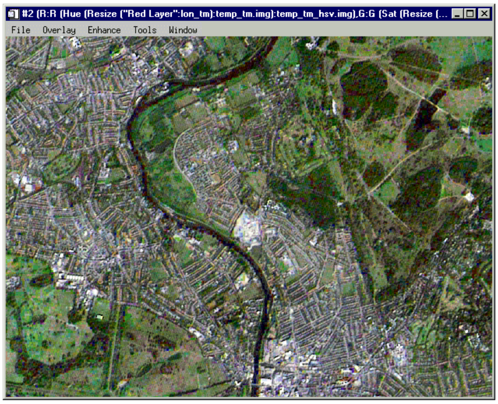


Figure 8-2: Landsat TM data (30 m spatial resolution, left). Fused Landsat TM and SPOT Panchromatic data (10 m spatial resolution, right).
Figure 8-3:

Brest, France, Data Fusion Example

Open and Display Images

The Brest data are SPOT PAN and XS format data.

1. Select **File** → **Open Image File**, navigate to the `brestsp` subdirectory and open the file `s_0417_2.bil`. This is SPOT-XS (multispectral) data. Three bands appear in the **Available Bands List**.
2. Click on the **RGB Color** radio button in the **Available Bands List**, click sequentially on bands 1, 2, and 3, then click **Load RGB** to display a false-color infrared SPOT-XS image with 20 m spatial resolution.

1. Select **File** → **Open Image File** to open the file `s_0417_1.bil`. This is SPOT Panchromatic data with 10 m spatial resolution. One band appears in the **Available Bands List**.
2. Click on the **Gray Scale** radio button in the **Available Bands List**, click on the SPOT band, then **Load Band** to display the SPOT Panchromatic data.

Resize Images to Same Pixel Size

1. Click in the **Available Bands List**, first on the SPOT Panchromatic image band and note its spatial dimensions (2835 x 2227) and then the SPOT-XS band and note its spatial dimensions (1418 x 1114). The SPOT-XS data have a spatial pixel size of 20 meters, while the SPOT Panchromatic data are 10 meter spatial resolution. The SPOT-XS image has to be resized by a factor of 2.0 to create 10 m data that matches the SPOT data.
2. Select **Basic Tools** → **Resize Data (Spatial/Spectral)** and choose the SPOT-XS image (`s_0417_2.bil`) then click **OK**. Enter a value of `1.999` into the **xfac** text box in the **Resize Data Parameters** dialog. Enter a value of `1.999` into the **yfac** text box. The value of 1.999 rather than 2.0 must be used to add an extra pixel to the x and y dimensions so the images will match exactly. This difference is insignificant for the purposes of this exercise, but might be important for an actual application. Enter an output filename and click **OK** to resize the SPOT-XS image.
3. Display the resized image and select **Tools** → **Link** → **Link Displays** to link the resized SPOT-XS image and the SPOT Panchromatic image. Use the dynamic overlay to compare the two images.

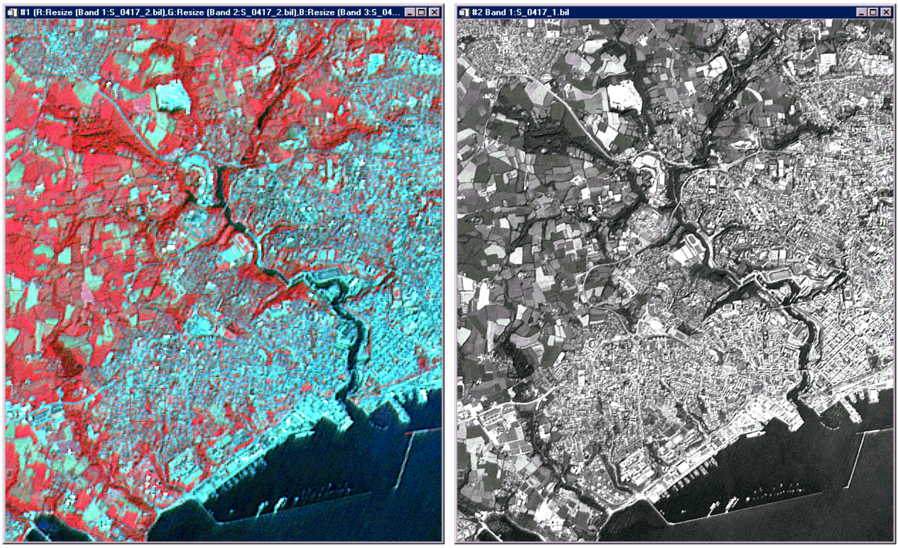


Figure 8-3: SPOT-XS data (20 m spatial resolution, left), SPOT Panchromatic data (10 m spatial resolution, right).

Fuse Using ENVI Methods

1. Select **Transform** → **Image Sharpening** → **HSV** from the ENVI main menu.
2. If you have the resized SPOT color image displayed, choose the appropriate display in the **Select Input RGB** dialog. Otherwise, choose bands 1, 2, and 3 from the resized SPOT-XS Image in the **Select Input RGB Input Bands** dialog and click **OK**.
3. Choose the SPOT Panchromatic image in the **High Resolution Input File** dialog and click **OK**.
4. Enter the output file name `brest_fused.img` and click **OK** in the **HSV Sharpening Parameters** dialog.

Display and Compare Results

1. Load the fused color image into a new display by selecting the **RGB Color** radio button in the **Available Bands List** dialog, selecting the R, G, and B bands from the new file and clicking **Load RGB**.
2. Compare the HSV sharpened color image to the original SPOT XS color composite and to the SPOT Panchromatic data by selecting **Tools** → **Link Displays** → **Link** from the Main Display Window menu bar.

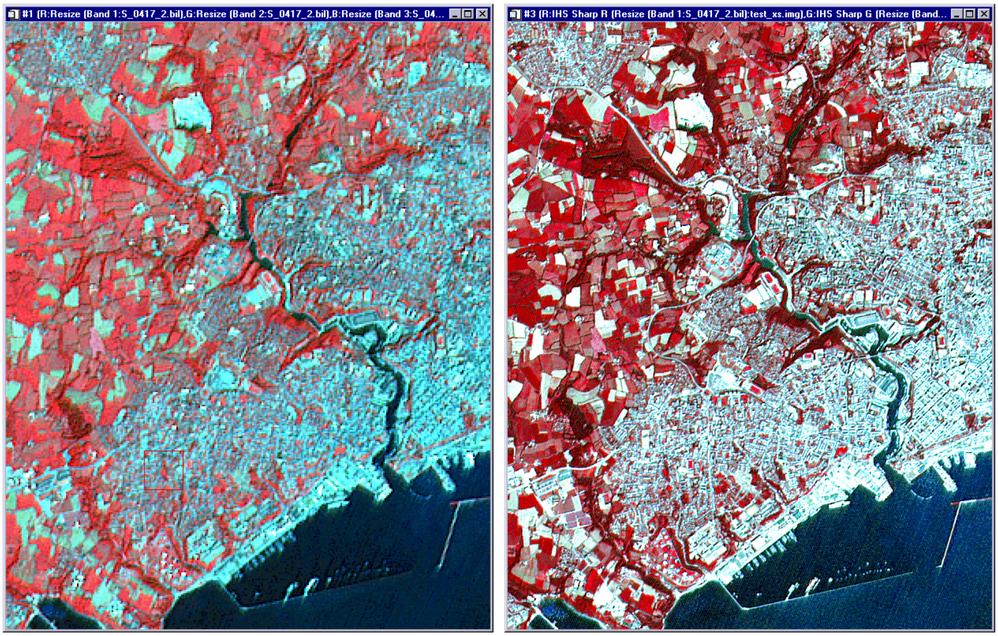
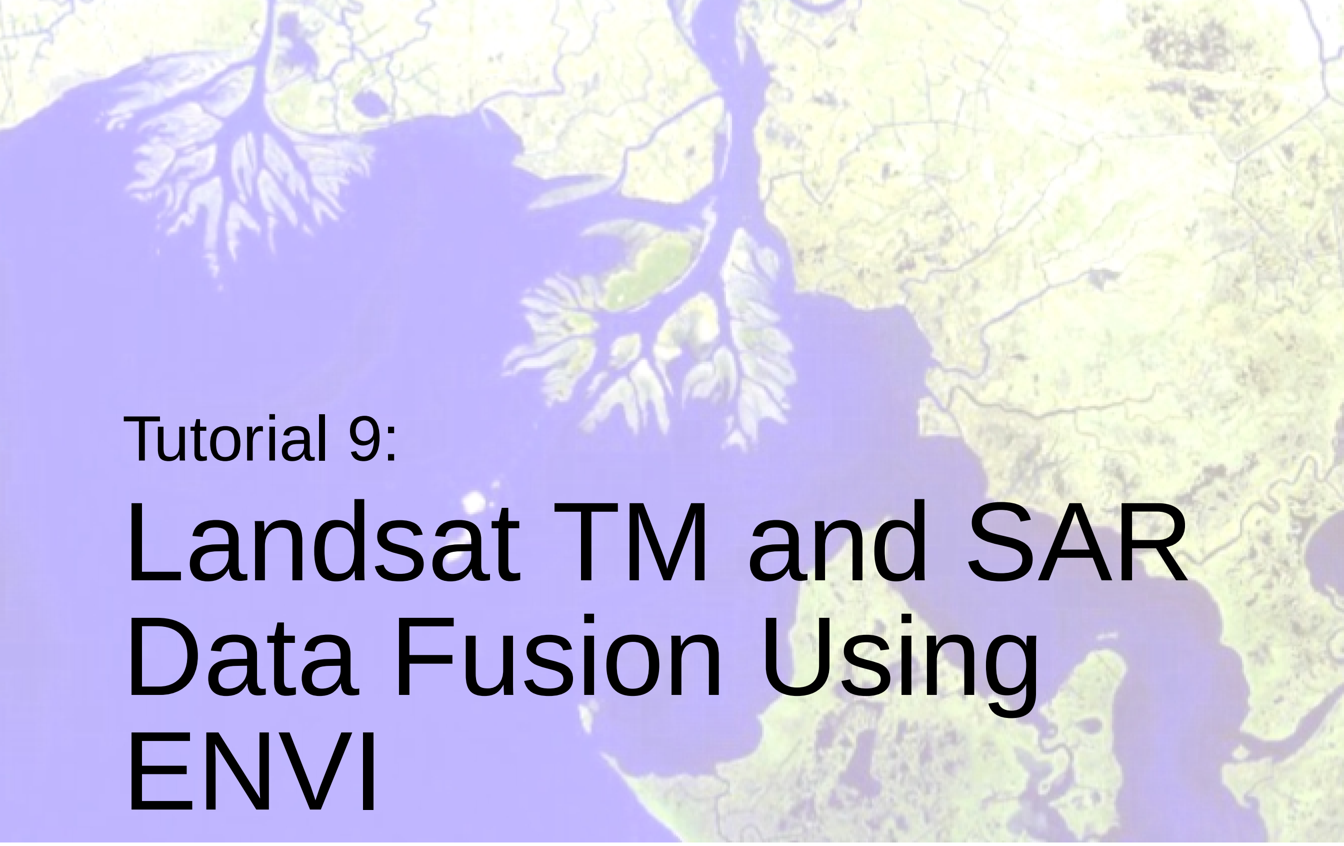


Figure 8-4: SPOT-XS data (20 m spatial resolution, left). Fused SPOT-XS and Panchromatic data (10 m spatial resolution, right).

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX**)** on the ENVI main menu, then click **Yes** to end the session. If you are using ENVI RT, quitting ENVI will take you back to your operating system.



Tutorial 9:
Landsat TM and SAR Data Fusion Using ENVI

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to demonstrate selected ENVI data fusion capabilities. Landsat TM data and ERS-2 SAR data of Rome, Italy are co-registered using ENVI image-to-image registration. A Hue/Saturation/Intensity color transform is used to fuse the two datasets and the fused data are compared to the individual datasets to determine the advantages and disadvantages of data fusion. For additional data fusion details, please see the *ENVI User's Guide* or ENVI On-Line Help. ERS and LANDSAT images used in this tutorial are provided courtesy of the European Space Agency (ESA) and Eurimage (used with permission) and may not be redistributed without explicit permission from these organizations.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/rometm_ers` (Rome, Italy TM and ERS example)

File	Description
`rome_tm`	Landsat TM Data, Rome, Italy
`rome_tm.hdr`	ENVI Header for above
`romr_tm.pts`	GCPs for image-to-image registration
`rome_ers2`	ERS SAR data, Rome, Italy
`rome_ers2.hdr`	ENVI Header for above

Data Fusion

Data Fusion is the process of combining multiple image layers into a single composite image. It is commonly used to enhance the spatial resolution of multispectral datasets using higher spatial resolution panchromatic data or single-band SAR data.

The following sections walk you through some of the preparation required to fuse image datasets in ENVI and the actual data fusion process.

Preparing Images

To perform data fusion using ENVI, the files must either be georeferenced (in which case spatial resampling is performed on the fly), or if not georeferenced, cover the same geographic area, have the same pixel size, and the same image size. The files used in this exercise are not georeferenced, therefore the low resolution images must be resampled to have the same pixel size as the high spatial resolution image (using nearest neighbor resampling).

Rome, Italy, Data Fusion Example

The Rome, Italy data are TM and ERS format data.

Read and Display Images

1. Select **File** → **Open Image File**, navigate to the `rometm_ers` subdirectory, and open the file `rome_ers2`. This is ERS-2 SAR data. One band appears in the **Available Bands List**.
2. Click on the **Gray Scale** radio button in the **Available Bands List**, click on the ERS band, then **Load Band** to display the SAR data.
3. Select **File** → **Open Image File** and open the file `rome_tm`. This is Landsat TM data. Seven bands appear in the **Available Bands List**.
4. From the **Display #1** button menu, select **New Display.**
5. Click on the **RGB Color** radio button in the **Available Bands List**, click sequentially on bands 4, 3, and 2, then **Load RGB** to display a false-color infrared Landsat TM image with 30m spatial resolution.

Register the TM images to the ERS image

1. Select **Map** → **Registration** → **Select GCPs: Image-to-Image**, choose Display #1 (the ERS data) as the **Base Image** and Display #2 (the TM data) as the **Warp Image** and click **OK**.
2. Select **File** → **Restore GCPs from ASCII** in the **Ground Control Points Selection** dialog, choose the saved GCP file `rome_tm.pts`, and click **OK**.
3. Pre-selected GCPs will be loaded onto both the TM and ERS data. Review the positions of these points in both images for accuracy and observe the total RMS Error listed at the bottom of the GCP Selection dialog. Also click on the **Show List** button at the bottom of the dialog and review the GCPs and error. These GCPs are sufficient for a quick registration, however, you may want to add more points to improve the match between images. See Chapter 4, "Image Georeferencing and Registration" for additional details about how to perform image-to-image registration.
4. Select **Options** → **Warp File** from the **Ground Control Points Selection** dialog. Choose the file `rome_tm`, and click **OK** to warp all 7 TM bands to match the ERS data.

5. Click on **Change Output Parameters** in the middle of the **Registration Parameters** dialog and enter `1` for the **Upper Left Corner (XO)**, `1` for the **Upper Left Corner (YO)**, `5134` for the **Number of Samples**, and `5549` for the **Number of Lines**, followed by **OK**.
6. Enter an output filename in the **Registration Parameters** dialog and click **OK** to perform the image-to-image registration.

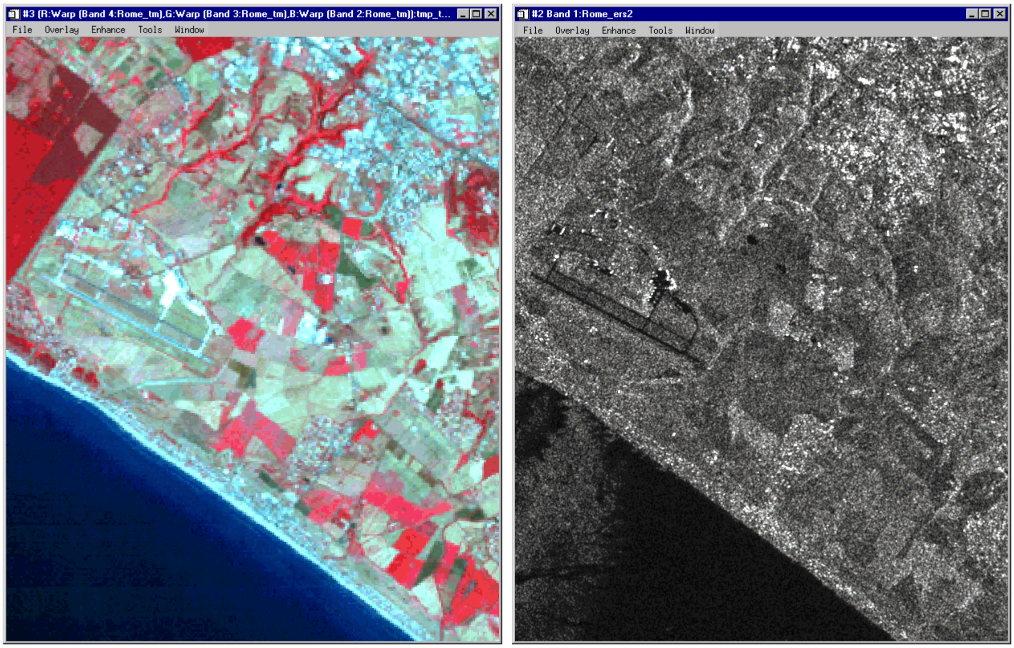


Figure 9-1: Landsat TM False-color Infrared Composite (bands 4, 3, 2 as RGB), left. ERS-2 SAR Data, right.

Perform HSI Transform to Fuse Data

1. Select **Transform** → **Image Sharpening** → **HSV** from the ENVI main menu.
2. If you have the registered TM color image displayed, choose the appropriate display in the **Select Input RGB** dialog. Otherwise, choose bands 4, 3, 2 from the TM Image in the **Select Input RGB Input Bands** dialog and click **OK**.

Note

If you select input from the **Available Bands List**, the data will be clipped to byte data. The colors in the resulting image may be unexpected.

3. Choose the ERS-2 image in the **High Resolution Input File** dialog and click **OK**.
4. Enter the output file name `rome_fused.img` and click **OK** in the **HSV Sharpening Parameters** dialog.

Display and Compare Results

1. Load the fused color image into a new display by selecting the **RGB Color** radio button in the **Available Bands List** dialog, selecting the R, G, and B bands from the new file from list and clicking **Load RGB**.
2. Compare the HSV sharpened (fused) color image to the registered Landsat TM color composite and to the ERS-2 data by selecting **Tools** → **Link Displays** → **Link** from the Main Display Window menu bar.
3. Try fusing other color composites with the ERS data as above and compare the results.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **Yes** to end the session. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

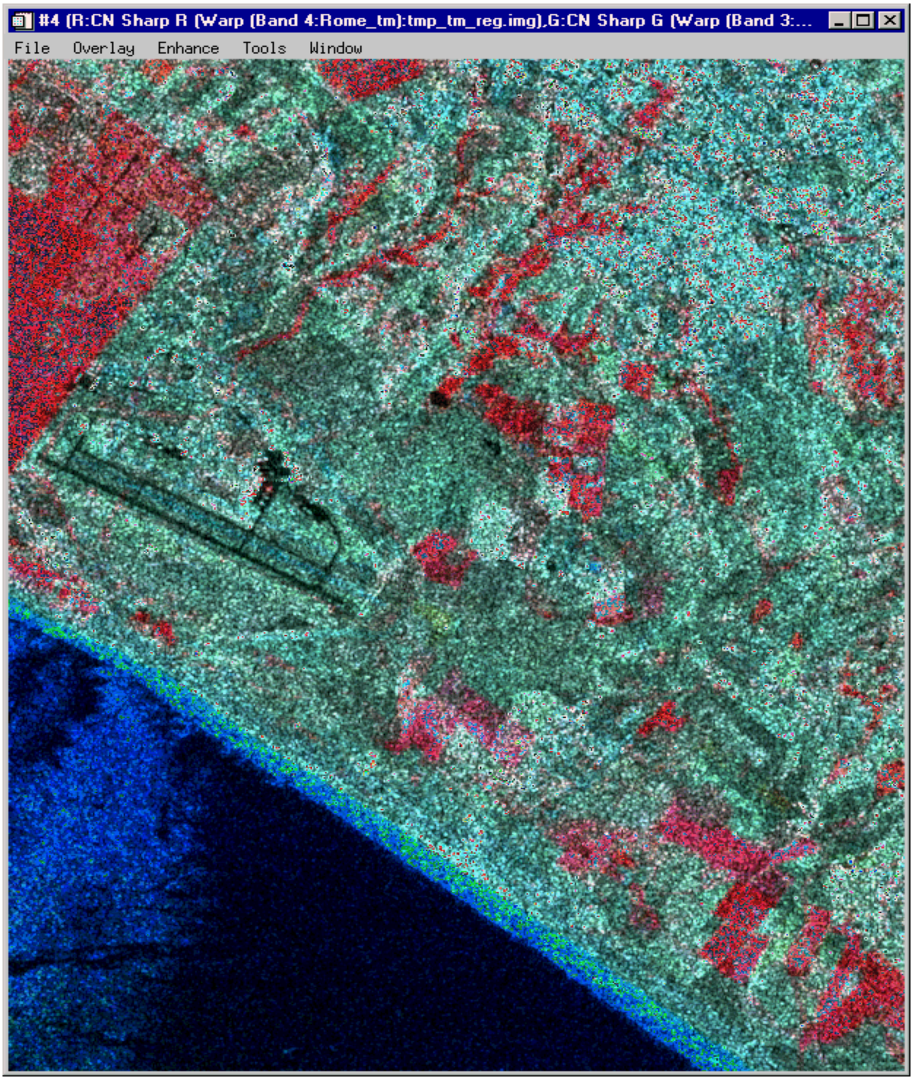
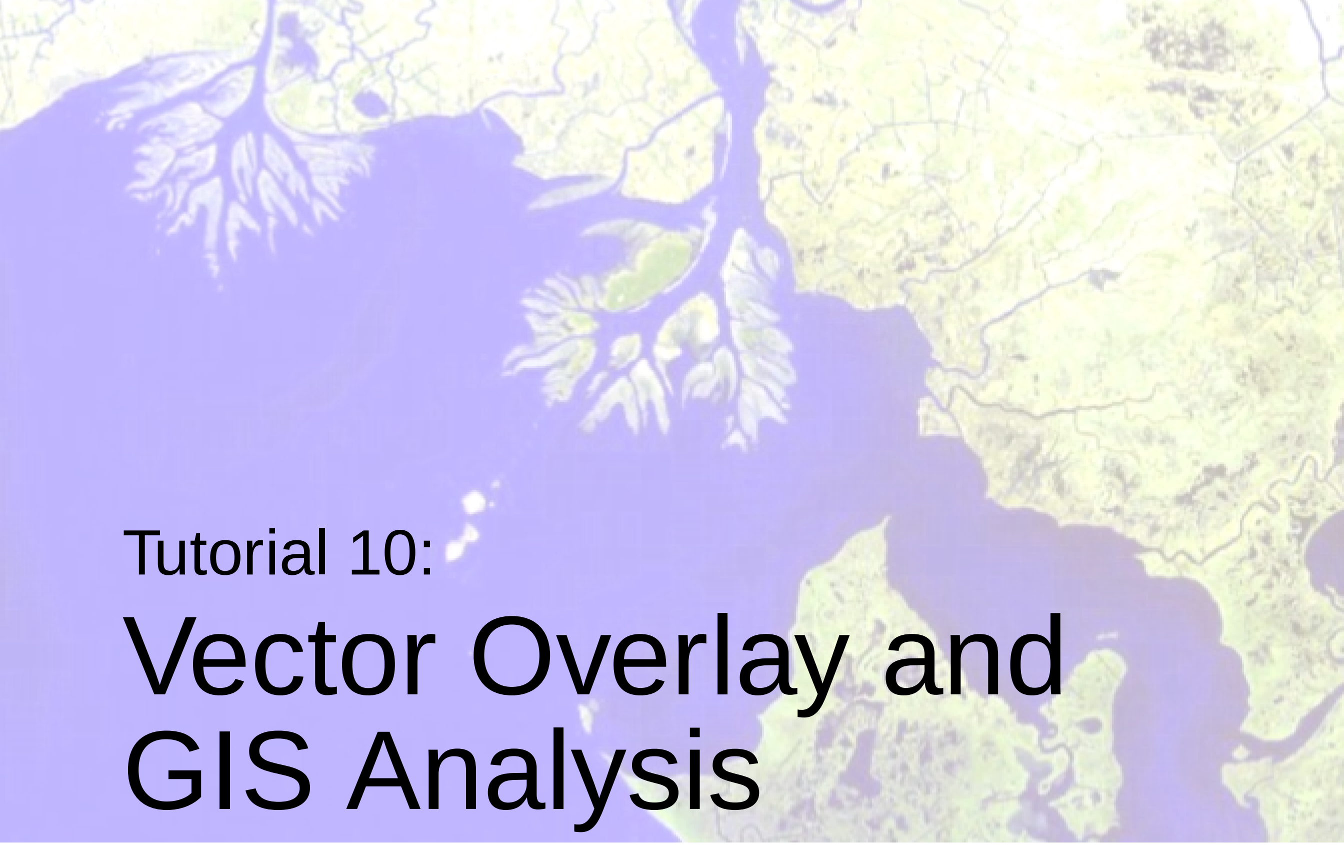


Figure 9-2: Fused Landsat CIR Image with ERS-2 Data. Note improved texture which aids in discrimination of specific land cover classes.



Tutorial 10:

Vector Overlay and GIS Analysis

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial introduces ENVI's vector overlay and GIS analysis capabilities using vector data from ESRI's Maps and Data CD-ROM and a simulated 4-meter resolution Space Imaging/EOSAT multispectral dataset and associated vector data of Gonzales, California, USA. Data courtesy of ESRI and Space Imaging/EOSAT. Part 1 of this tutorial uses ESRI's data to demonstrate stand-alone vector GIS analysis, including input of ArcView Shape Files and associated `.dbf` attribute files, display in vector windows, viewing/editing of attribute data, point-and-click spatial query, and math/logical query operations. Part 2 of this tutorial uses the Space Imaging/EOSAT data to demonstrate use of ENVI's combined image display/vector overlay and analysis capabilities, including cursor tracking with attribute information, point-and-click query, and heads-up digitizing and vector layer editing. Also demonstrated are generation of new vector layers using math/logical query operations and raster-to-vector conversion of ENVI Regions of Interest (ROI) and/or classification images. Finally, the exercise demonstrates ENVI's vector-to-raster conversion, using vector query results to generate ROIs for extraction of image statistics and area calculations. It is assumed that the user already has a basic grasp of GIS analysis concepts.

Sources and Files Used in this Tutorial

The data used in this tutorial are provided courtesy of the Environmental Systems Research Institute Inc. and Space Imaging/EOSAT and may not be redistributed without explicit permission from those organizations.

ESRI Data and Maps Version 1 CD-ROM

Example data used in Part 1 of this tutorial come from the ESRI Data and Maps Version 1 CD-ROM distributed with ARCView Version 3.0. Research Systems strives to maintain import/export compatibility with ESRI GIS products and data formats, including ARCView Shape files and ARC/INFO export files (`.e00`, non-compressed).

Space Imaging EOSAT Carterra™ Agriculture Sampler Data

Example images and vector data used in Part 2 of this tutorial are from the Space Imaging EOSAT Carterra Agriculture Sampler CD-ROM (Copyright © 1997, Space Imaging EOSAT), and are used with their explicit permission. This sample data set covers an agricultural area near Gonzales, California, USA; the north-central portion of the Palo Escrito Peak, CA USGS 7.5 minute quadrangle. The digital imagery are simulated data products designed to be similar to the space-based image data products that have been collected and distributed by Space Imaging EOSAT in early

1998. They are provided by Space Imaging EOSAT to give current users of digital imagery a look at the imagery products that they collect from orbit. These simulated data sets provide a reasonable example of the types of information extracted from the Space Imaging EOSAT imagery products. The imagery data sets were generated from digital image data collected by an air-borne multispectral scanner. The air-borne data were geometrically rectified, solar corrected and mosaicked at a spatial resolution simulating the CARTERRA data products. There are, however, both radiometric and geometric differences between these data and satellite-based products planned for delivery. Please see the Carterra Sampler `readme.txt` file included in the `si_eosat` subdirectory for additional information.

Required Files

CD-ROM: *ENVI Tutorial and Data CD No. 1*
ENVI Tutorial and Data CD No. 2

Path: `envidata/esri_gis` (On *CD No. 1* for Part 1 of this tutorial)
`envidata/si_eosat` (On *CD No. 1* for Parts 1 and 2 of this tutorial)
`envidata/can_tm` (On *CD No. 2* for Part 2 of this tutorial)

File	Description
Required Vector GIS Files for Part 1 (`envidata/esri_gis` on *CD No. 1*)	
`cities.shp (.shx, .dbf,)`	USA Cities Points
`states.shp (.shx, .dbf)`	USA States Polygons
Optional Vector GIS Files for Part 1 (`envidata/esri_gis` on *CD No. 1*)	
`counties.shp (.shx, .dbf)`	USA Counties Polygons
`drainage.shp (.shx,.dbf)`	USA Drainage Polygons
`rivers.shp (.shx, .dbf)`	USA Rivers Polylines
`roads.shp (.shx, .dbf)`	USA Roads Polylines
Required Image Files for Part 2 (`envidata/si_eosat` on *CD No. 1*)	
`0826_ms.img`	4-meter Multispectral data
`0826_ms.hdr`	ENVI Header for above
Required Image Files for Part 2 (`envidata/can_tm` on *CD No. 2*)	
`can_tmr.img`	Canon City TM data

File	Description
can_tmr.hdr	ENVI Header for above
can_sam.img	Canon City SAM Classification
can_sam.hdr	ENVI Header for above
can_pcls.img	Canon City Parallelepiped Classification
can_pcls.hdr	ENVI Header for above
can_sv.img	Sieved Classification (threshold = 5)
can_sv.hdr	ENVI Header for above
can_clmp.img	Clumped (5 x 5) after sieve
can_clmp.hdr	ENVI Header for above
can_tm1.roi	Canon City TM ROI #1
can_tm2.roi	Canon City TM ROI #2
Required Vector Files for Part 2 (envidata/si_eosat on *CD No. 1*)	
vectors.shp (.shx, .dbf, .evf)	Field outlines polygons
Optional Vector Files for Part 2 (envidata/si_eosat on *CD No. 1*)	
gloria.evf, (.dbf)	Query results polygons
lanini.evf, (.dbf)	Query results polygons
sharpe.evf, (.dbf)	Query results polygons

Vector Overlay and GIS Concepts

Capabilities

ENVI provides extensive vector overlay and GIS analysis capabilities. These include:

- Import support for industry-standard GIS file formats including ArcView Shape files and associated `.dbf` attribute files, Arc/Info Interchange (uncompressed), MapInfo vector files (`.mif`) and attributes from associated `.mid` files, Microstation DGN vector files, DXF, USGS DLG and USGS SDTS formats. ENVI uses an internal binary format (`.evf`) to maximize performance.
- Vector or Image/Vector Displays: ENVI provides a stand-alone GIS plot window for displaying vector data and composing simple vector-only maps. More importantly, ENVI provides vector overlays on standard ENVI displays including true vectorization of overlays in all windows, including the Zoom window.
- Generate world boundary vector layers including both low- and high-resolution political boundaries, coastlines, and rivers, as well as the USA state boundaries for display in vector windows or overlay on image displays.
- Heads-up (on-screen) digitizing can be performed in either the vector or raster image window. Heads-up digitizing provides an easy means of creating new vector layers by adding polygons, lines, or points.
- Image-based and vector window-based vector editing allows users to modify individual polygons, polylines, and points in vector layers using standardized editing tools, taking full advantage of the image backdrop provided by raster images in ENVI.
- Regions-of-interest, specific image contour values, classification images and other raster processing results can easily be converted to vector format for use in GIS processing.
- Track vectors in either vector or image display windows. Display latitude/longitude and map coordinate information. Export map coordinates to image-to-map registration. Open a Vector Information window and display attribute information in real-time as the cursor tracks each vector.

- ENVI supports linked vectors and attribute tables with point-and-click query for both vector and raster displays. Click on a vector in the display window, and the corresponding vector and its associated information is highlighted in the attribute table. Click on an attribute in the table, and the display scrolls to and highlights the corresponding vector.
- Scroll and pan through rows and columns of data in attribute tables. Edit existing information or replace individual attributes with constant values, or with data imported from ASCII files. Add or delete attribute columns. Sort column information in either forward or reverse order. Save attribute records to ASCII format.
- Query vector GIS database information directly to generate new layers of selected information with attributes. Allows GIS analysis of layers using simple mathematical functions and logical operators to produce new information and layers. In keeping with established ENVI processing paradigms, results can either be held in memory, or saved to file for later access.
- Edit GIS layer display characteristics: modify line-types, fill types, colors, and symbols. Use attributes to control labels and symbol sizes. Add custom vector symbols.
- Convert the vector layer from one projection to any other map projection
- Vector GIS data converted from vector to raster Regions of Interest for extraction of statistics, calculation of areas, and use in ENVI's many raster processing functions.
- Generate GIS maps using standardized ENVI annotation on either vector or image windows. Set border widths and background colors. Additional graphics colors have been added for ENVI 3.0 and are fully user-configurable. Automatically generate vector layer map keys. Insert objects such as rectangles, ellipses, lines, arrows, symbols, text, and image insets. Select and modify existing annotation objects. Save and restore annotation templates for specific map compositions.
- Create ArcView Shape Files and associated `.dbf` attribute files and indexes, or DXF files from internal ENVI `.evf` format. New vector layers generated using ENVI's robust image processing capabilities, and changes made to vector layers in ENVI are easily exported to industry standard GIS formats.
- Use ENVI's new direct printing capabilities to output to printers and plotters.

Concepts

ENVI's vector overlay and GIS analysis function generally follow the same paradigms as ENVI's raster processing routines. Standardized file opening procedures are used, as are the standard dialog boxes for selection of options and for file or memory output. The sections below describe some of the basic concepts.

ENVI Vector Files (.evf)

External vector files imported into ENVI are automatically converted to ENVI's internal vector format, which has the default file extension `.evf`. This speeds processing and optimizes data storage. It is possible to utilize external vector files without creating an `.evf` file by simply selecting **Memory** as the output option when the file is first imported. In this case, no `.evf` file is created, and it will have to be converted again the next time the file is used.

The Available Vectors List

Much like the **Available Bands List** used to list and load image bands, the **Available Vectors List** provides access to all vector files open in ENVI (Figure 10-1). It automatically appears when vector files are opened and converted, or it can be started by selecting **Window** → **Available Vectors List** on the ENVI main menu. Vectors are loaded to either vector or image displays by selecting the vectors to load in the list and clicking on **Load Selected** at the bottom of the window. If an image window is displayed, the user has the option of loading the vectors to the display, or to a new vector window. In addition to listing and loading vector layers, the **Available Vectors List** provides utilities to open vector files, to start new vector windows, to create world boundaries (see below) and new vector layers, and to export analysis results to both Regions of Interest (raster-to-vector conversion), and as ARCView Shape Files and ancillary files.

The following figure shows an example of the **Available Vectors List**.

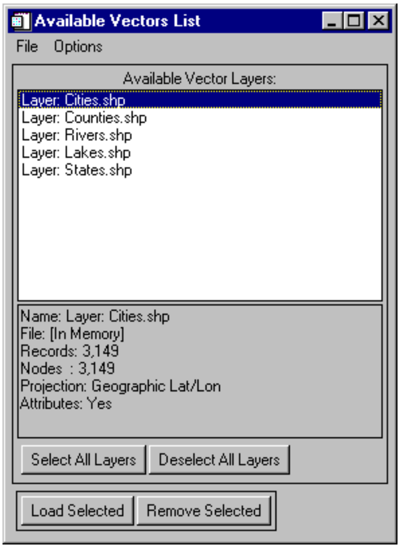


Figure 10-1: The ENVI Available Vectors List

Create World Boundaries

ENVI can utilize the IDL map sets to generate both low- and high-resolution world boundaries in ENVI `.evf` vector format. Select **Options** → **Create World Boundaries** from the **Available Vectors List**, or **Vector** → **Create World Boundaries** from the ENVI main menu. The user can create political boundaries, coastlines, rivers, and the USA state boundaries.

High-resolution format is available only if the IDL high-resolution maps are installed. If these are not currently installed on your system, you can install them using the ENVI Installation CD, modifying your installation to include the high-resolution maps.

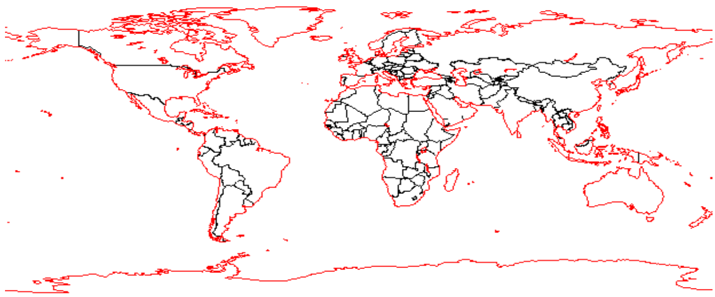


Figure 10-2: ENVI World Boundaries

The Vector Window Parameters Dialog

When vectors are loaded to a vector or image window, the **Vector Window Parameters** dialog appears to allow control of the way the vectors are displayed and the functions that are available for vector processing and analysis (Figure 10-3).

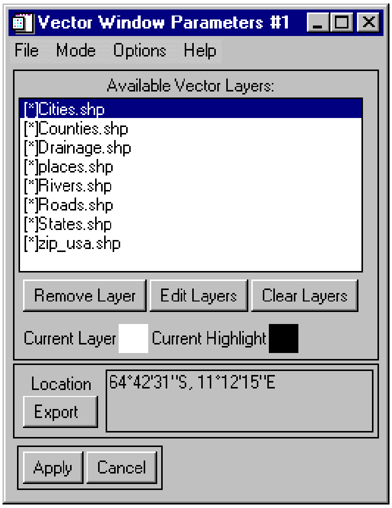


Figure 10-3: The ENVI Vector Window Parameters Dialog

The **Vector Window Parameters** dialog provides for opening vector files, importing vector layers from the **Available Vectors List**, arranging vector layer precedence, setting plot parameters and annotating plots. It also controls the mode of operation in the vector or image display toggling between cursor query versus heads-up digitizing and editing. The **Vector Window Parameters** dialog initiates ENVI's GIS analysis functions (**Options** →) including real-time vector information, attribute viewing and editing, and vector query operations. Finally, the **Vector Window Parameters** dialog provides utilities for export of analysis results to industry-standard ARCView Shape files with ancillary attribute files as well as raster conversion to ENVI's internal ROI format. The current configuration of vector overlays can also be saved to a template to allow simple reloading of the current vector overlays and overlay characteristics.

ENVI Attributes

ENVI provides access to fully attributed GIS data in the industry standard `.dbf` format associated with ARCView Shape files. Attributes are listed in an editable table, allowing point-and-click selection and editing (see Figure 10-4).

ENVI Attributes: E:\ENVIDATA\ESRI_GIS\Cities.dbf

File Options

	CITY_FIPS	CITY_NAME	STATE_FIPS	STATE_NAME
1	16750	College	02	Alaska
2	24230	Fairbanks	02	Alaska
3	03000	Anchorage	02	Alaska
4	36400	Juneau	02	Alaska
5	05280	Bellingham	53	Washington
6	35050	Havre	30	Montana
7	01990	Anacortes	53	Washington
8	47560	Mount Vernon	53	Washington
9	50360	Oak Harbor	53	Washington
10	53380	Minot	38	North Dakota
11	40075	Kalispell	30	Montana
12	86220	Williston	38	North Dakota
13	55365	Port Angeles	53	Washington
14	49992	North Marysville	53	Washington
15	43955	Marysville	53	Washington
16	77542	West Lake Stevens	53	Washington
17	22640	Everett	53	Washington
18	32060	Grand Forks	38	North Dakota
19	52765	Paine Field-Lake Stickney	53	Washington
20	64452	Silver Lake-Fircrest	53	Washington
21	37705	Lake Serene-North Lynnwood	53	Washington
22	43815	Martha Lake	53	Washington
23	40840	Lynnwood	53	Washington
24	20750	Edmonds	53	Washington
25	49670	North Creek-Canyon Park	53	Washington
26	01178	Alderwood Manor-Bothell North	53	Washington

Figure 10-4: An ENVI Attributes Table

Double-clicking in a particular cell selects that cell for editing. The table also supports full column substitution using a uniform value and replacement with values from an ASCII file. Options include adding and deleting individual columns and sorting data forward and backward based on information within a column. ENVI attributes can be saved to an ASCII output file, or to a `.dbf` file.

Point-and-click spatial query is supported in **ENVI Attribute** tables to allow location of key features on either images or in a vector window. Specific records are selected by clicking on the label at the left edge of the table for a specific row in the table.The corresponding vector is highlighted in a contrasting color in the display or vector window.

Part 1: Stand-Alone Vector GIS

This part of the tutorial demonstrates how to use ENVI as a simple stand-alone vector processing and analysis system for GIS data. The ESRI Data and Maps 1 CD-ROM data, found on the *ENVI Tutorial and Data CD No. 1* are used.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in UNIX, enter `envi` at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Open an ArcView Vector File (Shape File)

To open a vector file:

1. Select **File** → **Open Vector File** → **ArcView Shape File**.

   Note that on some platforms you must hold the left mouse button down to display the submenus from the Main Menu.

   An **Enter ArcView Shape Filenames** file selection dialog appears.

2. Navigate to the `esri_gis` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 1* just as you would in any other application and select the file `cities.shp`.

   The **Import ArcView Shape File Parameters** dialog appears on your screen. This list allows you to select either file or memory output, enter the output filename for the ENVI `.evf` file, and choose the output projection for the data.

3. Select **Memory Output** and choose the default values by simply clicking on **OK**. A status window will appear indicating the number of vector vertices being read and the **Available Vectors List** appears when the data have been converted.

4. Select the vector layer to be loaded by selecting the `cities.shp` entry in the **Available Vectors List**. Click on **Load Selected** to open a new vector window and the **Vector Window Parameters** dialog.

5. Click on **Apply** in the **Vector Window Parameters** dialog to load `cities.shp` into the vector display.

The cities of the United States will be plotted in the vector display.

Work with Vector Point Data

1. Click the left mouse button in the Vector window and hold down the button and drag the cursor around the vector window to read latitude and longitude in the **Vector Window Parameters** dialog.
2. Zoom in on just the contiguous 48 states by positioning the cursor just to the northwest of cities marked in the state of Washington and clicking and dragging using the middle mouse button to define a box covering the desired region.

   Releasing the mouse button defines the lower right corner of the area selected and causes the display to be zoomed in on just that area. Multiple levels of zoom are possible. Clicking the middle mouse button anywhere in the display zooms out one level.
3. Change the symbol used to mark the cities, by clicking on **Edit Layers** in the **Vector Window Parameters** dialog and selecting **Flag** from the pull-down **Symbol** menu. Click on **OK** at the bottom of the dialog, then **Apply** at the bottom of the **Vector Window Parameters** dialog.

Note

You can add your own symbols by defining them in the file `usersym.txt` in the `menu` directory of your ENVI installation.

4. Also experiment with changing other vector display characteristics by selecting **Edit Layers** and changing the desired characteristics (color, symbol, size) in the **Edit Vector Layers** dialog.

Create the USA State Boundaries Using IDL Map Sets

1. Select **Options** → **Create World Boundaries** in the **Available Vectors List**.

   The **Create Boundarie**s dialog appears.
2. Click in the check box next to USA States, select the **Memory** radio button, and click on **OK** to create the USA States boundaries, which is loaded into the **Available Vectors List**.
3. Highlight USA States and then click on the **Load Selected** button a the bottom of the **Available Vectors List**. In the **Load Vector** dialog, select Vector

Window #1 as the location to load the vector. Click **Apply** in the **Vector Window Parameters** dialog to plot the vectors.

Both the previously defined cities and the state boundaries appear in the vector window. The state boundaries in this case are polylines, that is, they are not true polygons (because of the way the were digitized and stored).

4. Click on USA States in the **Vector Window Parameters** dialog and choose **Edit Layers** to change parameters for the state boundaries, including color, line style, and thickness. After making any changes, click **OK** and then click the **Apply** button in the **Vector Window Parameters** dialog to plot the changes.
5. Clear the state boundaries by highlighting USA States in the **Vector Window Parameters** dialog and then on **Remove Layer**.

Work with Vector Polygon Data

1. Select **File** → **Open Vector File** → **ArcView Shape File** from the menu in the **Vector Window Parameters** dialog. Choose `states.shp` and click on **Open**. Select Memory Output and choose the default values by simply clicking on **OK**. A status window reports the number of vector vertices being read and the **Available Vectors List** appears when the data have been converted.

   This loads `states.shp` into the **Available Vectors List**.
2. Make sure that the USA States boundaries previously used are deselected in the **Available Vectors List** and select `states.shp`. Click on **Load Selected** and then choose Vector Window #1 in the **Load Vector** dialog. In the **Vector Window Parameters** dialog, click **Apply** to display the vectors.
3. Select `states.shp` in the **Vector Window Parameters** dialog and click on **Edit Layers**. Change the color to green, the fill to line and click on **OK**. In the **Vector Window Parameters** dialog, click **Apply** to re-display the vectors with changes applied.
4. Change the vector layer precedence by selecting **Options** → **Arrange Layer Order**, clicking on one of the vector layer names in the **Vector Layer Ordering** dialog and dragging it to the desired position in the stack.

Get Vector Information and Attributes

1. Select `cities.shp` in the **Vector Window Parameters** dialog and choose **Options** → **Vector Information** to open the Vector Information window. Click and drag using the left mouse button on the city flags in the Vector window to see the basic attribute information from the ArcView `.dbf` attribute file displayed in the Vector Information window.
2. Find your hometown or the nearest city by examining the CITY_NAME attribute in the Vector Information window and then find the latitude and longitude by looking in the **Vector Window Parameters** dialog.

View Attributes and Point-and-Click Query

1. Make sure that `cities.shp` is selected and choose **Options** → **View/Edit Attributes** in the **Vector Window Parameters** dialog to open an **ENVI Attributes** table.

   This is a fully editable table of the attributes for the selected layer.
2. Click in the left column to do a spatial query on the selected city. The corresponding city flag will be highlighted in the vector window. If desired, zoom in on the specific city selected by clicking and dragging a box around the highlighted city using the left mouse button. Zoom back out by clicking the middle mouse button in the window.
3. Verify that you have selected the correct city by clicking with the left mouse button on the city flag and observing the attributes in the Vector Information window.
4. Edit the elevation value for the selected city by scrolling the **ENVI Attribute** window to the right until you can view the Elevation attribute, and double clicking with the left mouse button in the corresponding elevation table cell. Enter a new value and press the **Enter** keyboard key to change the value.
5. Now do a map-based query by clicking on a city flag and observing that the corresponding record is highlighted in the **ENVI Attributes** table. Drag the vector cursor around the country from city flag to city flag and note how the **ENVI Attribute** table scrolls to follow the selected cities.

Query Attributes

1. Make sure that `cities.shp` is selected in the **Vector Window Parameters** dialog and select **Options** → **Query Attributes**. Enter a name for the layer to be generated in the **Query Layer Name** text box. For this example, enter `Where State==California`. Click on the **Start** button to begin the query.

   The **Query Condition** dialog appears.

2. Click on **CITY_FIPS** and select **STATE_NAME** from the pull-down menu. Now click the > symbol and select **==** from the list of options in the center of the dialog. Finally, enter the string `California` (be sure to match case) in the **String Value** text box.

3. When the **Layer Attribute Query** dialog appears, click the **Memory** radio button and the **OK** to begin the query.

   ENVI creates a new vector layer with associated `.dbf` file based on the results of the query and lists the new layer in the **Vector Window Parameters** and the **Available Vectors** dialogs.

4. Click **Apply** in the **Vector Window Parameters** dialog to show the selected vectors in the vector window in a new color.

5. Zoom in on the selected vectors using the middle mouse button to drag and draw an outlining box around the state of California. Open the new `.dbf` attribute file by clicking on the new layer name in the **Vector Window Parameters** dialog and then selecting **Options** → **View/Edit Attributes**. When the **ENVI Attributes** table appears, try some point-and-click query operations as described above to see the association between the selected cities, their locations in the vector window, and the attributes.

Tip

The easiest way to find a specific city is to sort the attributes and then click on the city name as described in the following step.

6. Click at the top of the **CITY_NAME** column in the **ENVI Attributes** table to highlight that complete set of attributes. Select **Options** → **Sort by selected column forward** to sort the column alphabetically. Now scroll down the column and click on **Sacramento** to highlight the location of the capital of California in a different color in the vector window.

Annotate Map Key in Vector Window

ENVI provides tools to generate a basic vector map from the Vector window. These are essentially the same as the annotation tools used for ENVI image and plot annotation, so no details are covered here. The description below demonstrates how to put a map key in the annotation window.

1. Select **Options** → **Annotate Plot** in the **Vector Windows Parameters** dialog to begin.
2. In the **Annotation** dialog, select **Object** → **Map Key** to automatically create a map key for the vector layers. Click the left mouse button in the Vector Display window to place and move the annotation.

   The characteristics of the key are controlled by clicking on the **Edit Map Key Items** button in the **Annotations** dialog and selecting the desired changes. Change the annotation characteristics by clicking **OK**.
3. Click the right mouse button in the Vector window to finalize placement of the map key. All annotation in the vector window follows the same paradigms as annotation in ENVI display windows. See the descriptions of Annotation in the *ENVI 3.5 User's Guide* for additional details.

Close all Windows and Files

1. Click on **Select All Layers** in the **Available Vectors List** and then click **Remove Selected**. Close the **Available Vectors List** by selecting **File** → **Cancel**.
2. Close the vector window and all associate dialogs and tables by selecting **File** → **Cancel** in the **Vector Window Parameters** dialog.

   This concludes Part 1 of the exercise.

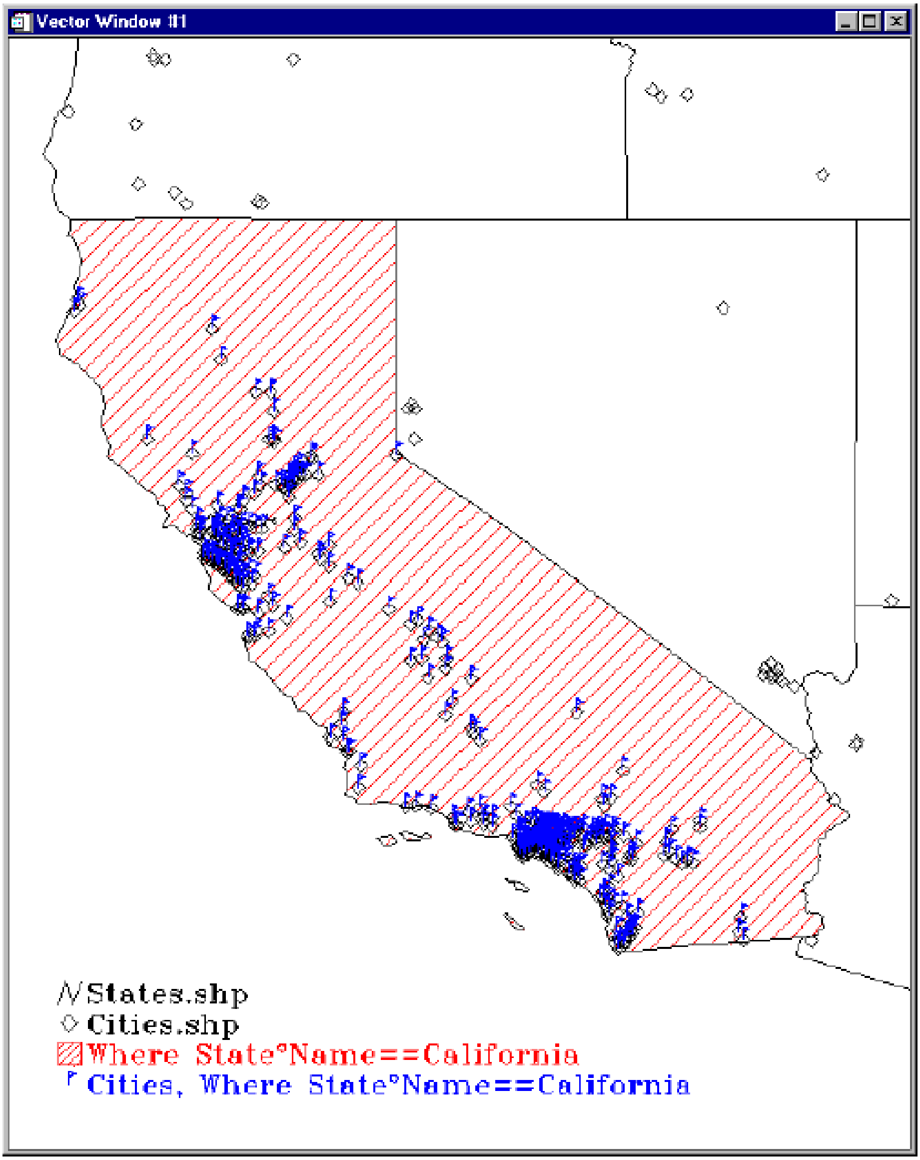


Figure 10-5: Results of GIS Attribute Queries and Annotations

Part 2: Raster and Vector Processing

This section of the tutorial demonstrates how to use Vector Overlays and GIS data and attributes in combination with raster images. Data from Space Imaging EOSAT are used.

Load Image Data to Combined Image/Vector Display

To open an image file to use as a backdrop for vector layers:

1. Select **File** → **Open Image File** from the ENVI main menu.

   Note that on some platforms you must hold the left mouse button down to display the submenus from the Main Menu.

   An **Enter Data Filenames** selection dialog appears.

2. Navigate to the `si_eosat` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 1* just as you would in any other application and select the file `0826_ms.img`.

   The **Available Bands List** appears with four spectral bands listed. These data are a simulated 4-meter Space Imaging EOSAT multispectral dataset with spectral band coverage similar to the first 4 spectral bands of Landsat Thematic Mapper data.

   The bands to load into a color composite have already been selected using ENVI default bands option in the ENVI header file, thus a true-color image has automatically been loaded into a new image display window.

Open a Vector Layer and Load to Image Display

1. Select **Overlays** → **Vectors** from the main image display to open the **Vector Parameters** dialog.

2. Select **File** → **Open Vector File** → **ArcView Shape File** from the menu bar in the **Vector Parameters** dialog. Select the file `vectors.shp` from the list.

Note

You could also have used the **File** → **Open Vector File** → **ArcView Shape File** method used above from the ENVI main menu to accomplish the same thing. ENVI provides several methods of accessing the vector overlays. Users can choose the method most consistent with their applications and approach to processing.

The **Import ArcView Shape File Parameters** dialog that appears allows you to select either file or memory output, enter the output filename for the ENVI `.evf` file, and choose the output projection for the data.

3. In the **Import ArcView Shape File Parameters** dialog, click on **State Plane (NAD 83)** as the **Output Projection**. Click on the **Set Zone** button and select **(404, 3351) California IV** in the **Select State Plane Zone** dialog. Select **Memory** output and click on **OK** in the **Import ArcView Shape File Parameters** dialog to complete the projection selection.

   Alternatively, use **File** → **Open Vector File** → **ENVI Vector File (.evf)** to open the existing ENVI vector files.

   A status window reports the number of vector vertices being read. When the data have been converted (`.shp`) or imported (`.evf`), the **Available Vectors List** displays the vector layer and automatically loads the vector layer into the **Vector Parameters** dialog.

4. Click on **Apply** in the **Vector Parameters** dialog to load the vectors into the image display as an overlay on the displayed image.
5. Choose **Edit Layers** in the **Vector Parameters** dialog and change the color of the vectors to red and click **OK**. Then click **Apply** to re-apply the modified vectors to the image.

Track Attributes with the Cursor

1. Select **Options** → **Vector Information** from the **Vector Parameters** dialog to start the Vector Information window. Click and drag using the left mouse button in the image to view the attribute information for the vectors. Also observe the latitude and longitude listed in the **Vector Parameters** dialog. Select the Scroll and Zoom radio buttons in the **Vector Parameters** dialog to allow vector tracking in the corresponding window. Select the **Off** radio button to allow normal scrolling in the Scroll and Main windows and zooming in the Zoom window. Try different zoom factors in the Zoom window to assess the accuracy of the vectors.
2. Select **Options** → **View/Edit Attributes** in the **Vector Parameters** dialog to load the **ENVI Attributes** table for these data. Utilize point-and-click query as described for the vector-only case above by clicking in the left (numbered) column of the attribute table to find and highlight specific polygons on the image.

Heads-up (On-screen) Digitizing

ENVI provides vector editing routines for adding your own vectors to an existing vector layer or for creating new vector layers. These vector editing routines function are similar in fashion to ENVI's annotation polygons, polylines, and points. ENVI heads-up vector digitizing allows creation of new polygons, polylines, points, rectangles, and ellipses.

To add new objects to a vector layer, first choose the layer name from the list in the **Vector Parameters** dialog. Then select **Mode** → **Add New [*Object*]**, where [*Object*] is one of the available object types. For the purposes of this exercise, we will create a new polygon layer as follows:

1. Create a new layer by selecting **Options** → **Create New Layer** from the **Vector Parameters** dialog. Enter a name for the layer in the **New Vector Layer Parameters** dialog, choose the **Memory** radio button, and click **OK**.
2. Click on the new layer name in the **Vector Parameters** dialog and a new `.dbf` file is initialized. Choose **Mode** → **Add New Polygon** to begin adding polygons to the layer.
3. In the image display window (or the Scroll or Zoom window if selected using the radio button in the **Vector Parameters** dialog), use the mouse to define the new polygon area as follows:
   - Click the left mouse button to draw polygon segments.
   - Click the middle mouse button to erase polygon segments.
   - Click the right mouse button to close the polygon, and a right-click a second time to accept the polygon.

   Polylines (line segments) are added in the same manner described above. However, when working with points, clicking the left mouse button places the point, the middle deletes it, and the right mouse button finalizes the placement.
4. Draw a few polygons using field outlines on the image as guides.
5. To add attributes to the newly created polygons, select **Options** → **Add Attributes** in the **Vector Parameters** dialog. In the **Attribute Initialization** dialog, Enter `Field ID` in the **Name** field and choose **Character** for the **Type** of the parameter. Click on the **Add Field** button at the bottom of the dialog and enter a second attribute called `Field Area` in the **Name** field and change the **Type** to **Numeric**. Click **OK** to create the **Attribute Table**.

6. Now edit the attribute table as previously described. Double-click on a field to make changes, enter the value, and press the **Enter** key on the keyboard. Use point-and-click query to see which attributes are associated with which fields.
7. Close the Attribute table by selecting **File** → **Cancel** from the menu bar at the top of the table.

Edit Vector Layers

1. In the **Vector Parameters** dialog, click on the new vector layer you created and select **Mode** → **Edit Existing Vectors**. In the main image display, left-click on one of the polygons you created previously.

   The polygon will be highlighted and the nodes of the polygon will be marked with a diamond. When the vector is selected, you can make the following changes:

   - Delete the entire polygon by selecting **Mode** → **Delete Vector** in the **Vector Parameters** dialog.
   - Exit the editing function without making any changes by clicking the middle mouse button.
   - Modify the vector by clicking on one of the markers with your left mouse button and dragging to a new location.
   - Finalize changes and redraw the polygon by clicking the right mouse button.
2. To finish up this section, delete any new layers you have made by selecting, those layers in the **Available Vectors List** and clicking on **Remove Selected**. Do not remove the `vectors.shp` layer.

Query Operations

1. Choose the `vectors.shp` layer in the **Vector Parameters** dialog by clicking on the layer name. Select **Options** → **View/Edit Attributes** to open an **ENVI Attributes** table. Examine the RANCH attribute and note the predominance of three owners “gloria”, “lanini”, and “sharpe”. Close the attribute table by selecting **File** → **Cancel**.
2. Select **Options** → **Query Attributes** in the **Vector Parameters** dialog. Enter the **Query Layer Name** `Gloria Ranch` in the **Layer Attribute Query** dialog and click on the **Start** button. Click **AREA** and choose **RANCH** from the pull-down menu. Set the condition to **==**, and enter `gloria` for the string value (be sure to match the case seen in the attribute table). Click **OK**.

3. Select the **Memory** radio button in the **Layer Attribute Query** dialog and click **OK** again. The new layer generated by the query is listed in the **Vector Parameters** dialog.
4. Click on the layer name in the dialog and then on the **Edit Layer** button to change layer parameters. Choose **Line** for the fill type and then click **OK**. Click **Apply** in the **Vector Parameters** dialog.

   The Gloria Ranch holdings are highlighted as a new layer.
5. Examine the attributes for this layer by selecting the layer name in the **Vector Parameters** dialog and choosing **Options** → **View/Edit Attributes**. Examine the query results.
6. Close the attribute table and repeat the query for the `lanini` and `sharp` ranches, highlighting each in a different color or pattern.
7. Try other queries on combinations of attributes by choosing one of the logical operators in the **Layer Attribute Query** dialog.

Vector-to-Raster Conversions

ENVI provides several important links between vector analysis and raster image processing. This portion of the exercise describes how to take vector processing results, create Regions of Interest for use on the images, and extract region statistics and polygon area.

1. Open the **ROI Tool** dialog by selecting **Overlay** → **Regions of Interest** in the Main Image Display window.
1. To create Regions of Interest (ROI) for use with ENVI raster processing, click on the name of the layer to be exported to ROI. Select **File** → **Export Layer to ROI** in the **Vector Parameters** dialog. Do this for several of the layers you created using the query operations above.

   The layers are listed in the **ROI Tool** dialog.
2. Click on the ROI name in the **ROI Tool** dialog and select **Options** → **Report Areas of ROIs** → **Meters^2** to generate a report of the area of the selected region.
3. Click on the ROI name in the **ROI Tool** dialog and click on the **Stats** button at the bottom of the dialog to get the image statistics for the gloria ranch polygons and multispectral data. Try the same thing for the other queries you generated in the vector analysis and compare the areas and statistics.

Now that these vector polygons are ENVI ROIs, you can use the power of all of ENVI's raster processing capabilities to analyze the image data with respect to the ROIs. This includes such activities as masking, statistics, contrast stretching, and supervised classification.

Image-Map Output

ENVI provides tools to generate image maps from the combined raster/vector data in the ENVI Main Image Display window. These are essentially the same as the annotation tools used for ENVI image and plot annotation, so no details are covered here. The description below demonstrates how to put a map key in the Main Image display window.

1. Generate a map-output image with a vector key using ENVI's image-map composition capabilities. From the Main Image Display menu bar, select **Overlay** → **Annotation**.
2. Select **Object** → **Map Key**. Use the **Annotation: Map Key** dialog to automatically create a map key for the vector layers. Click the left mouse button in the Main Image Display window to place and move the annotation.
3. The characteristics of the key are controlled by clicking on **Edit Map Key Items** and selecting the desired changes. Return to placing the annotation by clicking **OK**.
4. Click the right mouse button in the Vector window to finalize placement of the map key. All annotation in the vector window follows the same paradigms as annotation in ENVI display windows. See the descriptions of Annotation in the *ENVI 3.5 User's Guide* for additional detail.

The result of GIS vector overlay onto a raster image appears in the following figure.

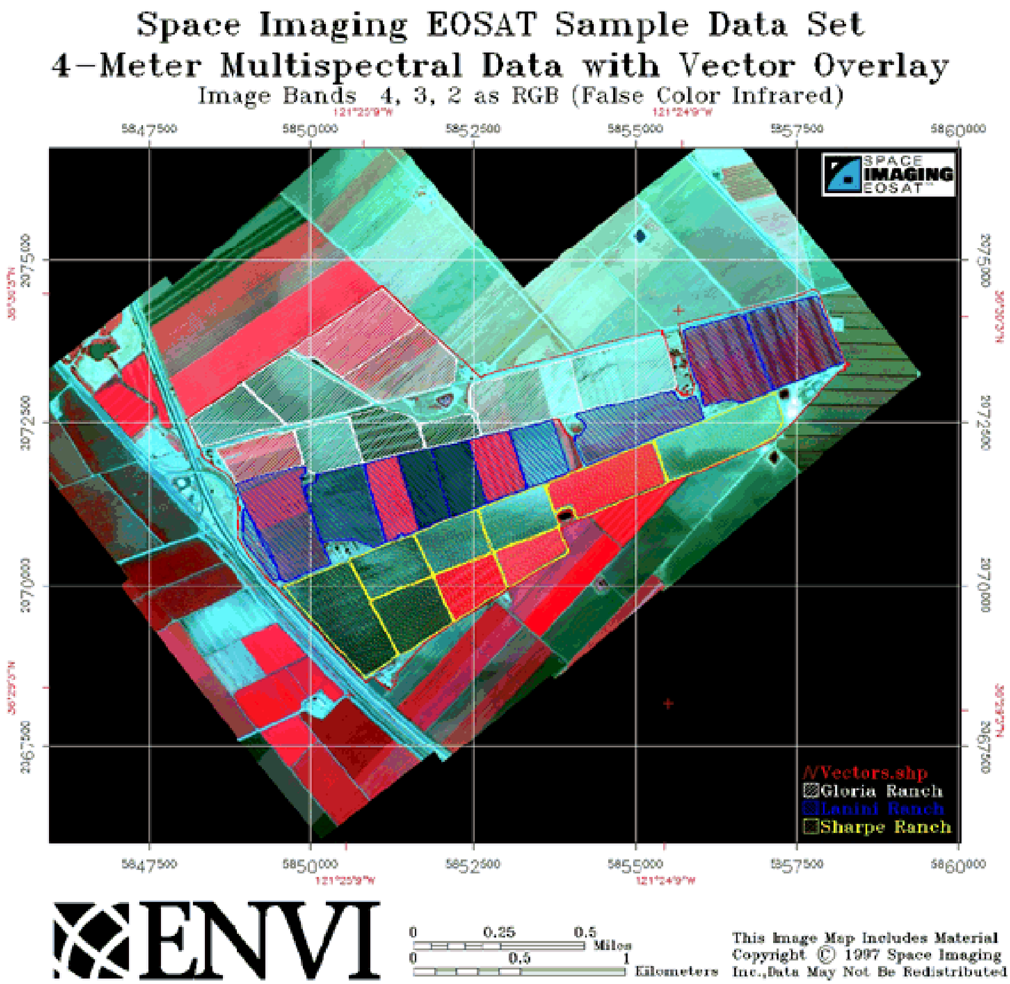


Figure 10-6: Results of GIS Vector Overlay on Raster Image

Close All Windows and Files

1. Click on **Select All Layers** in the **Available Vectors List** then click **Remove Selected**. Close the **Available Vectors List** by selecting **File** → **Cancel**.
2. Close the image window and all associated dialogs and tables by selecting **File** → **Close All Files** from the ENVI main menu.

Raster to Vector Conversions

ENVI can also easily convert raster processing results for use in ENVI vector processing and analysis, as well as for export to external GIS systems such as ArcView and ArcInfo. The last part of this tutorial illustrates the export of raster information to vector GIS.

Export ROI to Vector Layer

Regions of Interest defined using any of ENVI's standard methods can be exported to become one or more vector layers

Load Image Data to Image Display

Open an image file to use as background for ROI definition and export to vector:

1. Select **File** → **Open Image File** from the ENVI main menu.

   Note that on some platforms you must hold the left mouse button down to display the submenus from the Main Menu.

   An **Enter Data Filenames** file selection dialog appears.

2. Navigate to the `can_tm` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 2* just as you would in any other application and select the file `can_tmr.img`.

3. Click on the **Gray Scale** toggle button in the **Available Bands List**, select Band 4 in the list, then click **Load Band** to load a grayscale image of TM band into a new image display window.

Load Predefined ROIs

Some regions of interest have been predefined using ENVI's interactive ROI definition tools.

1. Select **Overlay** → **Region of Interest** in the Main Display window to open the **ROI Tool** dialog. Select **File** → **Restore ROIs** and select the ROI file `can_tm1.roi`. An **ENVI Message** dialog reports what regions have been restored. Click **OK**.

   The predefined ROI is loaded into the **ROI Tool** dialog and plotted on the image.

2. Repeat the above step for the file `can_tm2.roi`.

The ROIs are overlaid onto the TM Band 3 data.

Convert ROIs to Vectors

1. To convert these ROIs to vector polygons, select **File** → **Export ROI to EVF** in the **ROI Tool** dialog. The **Export Region to EVF** dialog appears. Choose one of the regions by highlighting the region name. Choose the **All points as one record** radio button option, enter a **Layer Name** in the appropriate text box, click on **Memory**, and then **OK** to convert the first ROI and import it into the **Available Vectors List**. Repeat the procedure for the second ROI.
2. In the **Available Vectors List**, click **Select All Layers**, then click the **Load Selected** button.
3. Select **New Vector Window** in the **Load Vector** dialog to open a new vector window and load the new vector polygons into the **Vector Window Parameters** dialog. Click **Apply** in the **Vector Window Parameters** dialog to load the polygons.
4. Choose **Options** → **Add Attributes** to add attributes to the polygons.

   These can now be used in Query and GIS analysis with other vector data or exported to ArcView Shape Files by selecting **File** → **Export Layer to ArcView** in the **Vector Window Parameters** dialog.

Close All Windows and Files

1. Click on **Select All Layers** in the **Available Vectors List** then on Remove Selected. Close the **Available Vectors List** by selecting **File** → **Cancel**.
2. Close the Vector display window by clicking on **File** → **Cancel** in the **Vector Window Parameters** dialog.
3. Close the image window and all associated dialogs and tables by selecting **File** → **Close All Files** from the ENVI main menu.

Export Classification Image to Vector Polygons

Classes defined using any of ENVI’s standard classification methods can be exported to become one or more vector layers. ENVI also allows selection of individual image brightness levels for export as a vector layer.

Load and Display a Classification Image

Open an image file to use as background for ROI definition and export to vector:

1. Select **File** → **Open Image File** from the ENVI main menu.

   Note that on some platforms you must hold the left mouse button down to display the submenus from the Main Menu.

An **Enter Data Filenames** file selection dialog appears.

2. Navigate to the `can_tm` subdirectory of the *ENVIDATA* directory on the *ENVI Tutorial and Data CD No. 2* and select `can_pcls.img`.

   This is a parallelepiped classification of the Canon City TM data with 3 classes.

3. Load this Classification into a gray scale image by clicking on the band name in the **Available Bands List** and selecting **Load Band**.

Generalize the Classification Image.

To conduct successful raster-to-vector conversions, it is usually necessary to generalize the results of raster processing. If you don't do this, you end up with vector polygons around individual pixels and small groups of pixels.

To demonstrate the results of generalization of the classification image, load and display the results of a 5 pixel sieve operation followed by a 5 x 5 clump operation as follows:

1. First open and display `can_sv.img`, the sieve results in Display #1. Next display `can_clmp.img`, the clump results in Display #1. Both files are located in the `can_tm` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 2*.

2. Convert the generalized classification image to vector polygons. Select **Classification** → **Post Classification** → **Classification to Vector** from the main ENVI menu bar. Choose the `can_clmp.img` classification for processing by clicking on the image name and then the **OK** button in the **Raster to Vector Input Band** dialog. This open the **Raster to Vector Parameters** dialog.

Create the Vector Polygons

1. Highlight Region #1 and Region #2 by clicking on each while holding down the **Shift** key in the **Raster to Vector Parameters** dialog. Toggle to select **One Layer per Class** for the **Output**. Select **Memory** output results and click **OK**. A status dialog will appear while the vectorization takes place and the new vector layers will appear in the **Available Vectors List**.

2. Select both layers by pressing **Shift** while clicking on the vector names and click on **Load Selected** and choose **Display Window #1**.

3. Change the layer characteristics by selecting **Edit Layers**. Select the color while and **Line** fill for the first layer. Highlight the second layer and select the color yellow and **Line** fill. Click **OK**. Click **Apply** in the **Vector Parameters**

dialog to display the vector outlines overlaid onto the clumped classification image.

Alternatively, you could also select **New Vector Window** in the **Load Vector** dialog to display in an ENVI vector window. Clicking on **Apply** in the **Vector Window Parameters** dialog would load the selected vectors into the vector display.

Examine the vector layer and the results of the vectorization of raster classification. You can also overlay the vectors onto a gray scale `can_tmr` band 3 if desired. This overlay is show in the following figure.

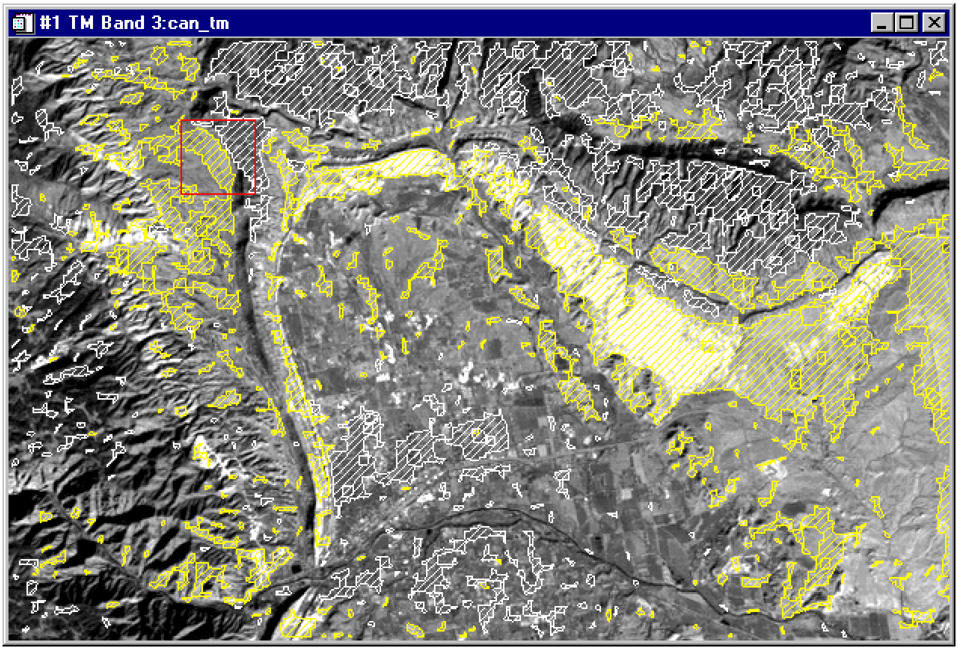


Figure 10-7: Results of Raster-to-Vector Classification Conversion Overlaid onto the Raster Image

End the ENVI Session

You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **Yes** to end the session. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

Tutorial 11: Map Composition Tutorial

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to give you a working knowledge of ENVI's map composition capabilities. ENVI's new QuickMap utility is used to generate a basic map template, then additional information is added using ENVI's annotation capabilities. For additional information please see the *ENVI User's Guide* or the ENVI Online Help.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/ys_tmsub`

File	Description
`ysratio.img`	Yellowstone National Park TM Ratio Subset Image
`ysratio.hdr`	ENVI Header for above
`ysratio.ann`	Saved Annotation Result for above
`ysratio.grd`	Saved Grid Parameters for above
`ys_loc.tif`	Location Image for above

Map Composition in ENVI

Map composition requires that you are able to easily and quickly go from an image to an image-based map by interactively inserting key map components. The map composition process usually consists of basic template generation (or restoring a saved template) using ENVI’s QuickMap utility, followed by interactive customization (if required) using ENVI annotation or other image overlays. QuickMap allows you to set the map scale and the output page size and orientation; to select the image spatial subset to use for the map; and to easily add basic map components such as map grids, scale bars, map titles, logos, projection information, and other basic map annotation. Additional custom ENVI annotation of QuickMap output allows insertion of map keys, declination diagrams, arrows, images and/or plots, and additional text. Interactive map composition using ENVI annotation and/or grid line overlays also allows modification of QuickMap default overlays and custom placement of all map elements.

Getting Started

Composing a map in ENVI is as simple as displaying the image, using ENVI’s QuickMap utility to build or restore a basic map template, and then if necessary, interactively adding to or modifying the individual map components such as annotation, map scales, gridlines, etc. The map composition can be saved as an ENVI Display Group and restored for future modification and/or printing. Additionally, ENVI annotation allows you to individually build and save templates of common map objects.

- To begin, select the image for map composition, open the file, and load as a grayscale or RGB image into one of ENVI's display windows with the desired contrast stretch as indicated in the next section.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To start ENVI in UNIX, enter `envi` at the UNIX command line.
- To start ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Open and Display Landsat TM Data

To open an image file:

1. Select **File** → **Open Image File** on the ENVI main menu.

   The Enter Input Data File file selection dialog appears.

2. Navigate to the `ys_tmsub` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 1* and select the file `ysratio.img` from the list and click **Open**.

   The file and bands are listed in the Available Bands List. The 5/7, 3/1, 3/4 ratio bands are automatically loaded into the “R,” “G,” and “B” fields by default. Note that you have the choice of loading either a grayscale or an RGB color image. Click the **RGB Color** button.

3. Click **Load RGB** to load the image into a new display.

Once the image is displayed, complete the following steps to build a QuickMap template and to add individual map components.

Build the QuickMap Template

1. From the Main Display menu, select **File** → **QuickMap** → **New QuickMap**.

   The **QuickMap Default Layout** dialog appears. This dialog allows modification of the output page size, the page orientation, and the map scale.

2. For the purposes of this tutorial, we will use all of the default values except for the map scale. Change the **Map Scale** to 200,000 then click **OK** to proceed to the image subset selection.

3. Select the image subset for the output map by positioning the red box in the **QuickMap Image Selection** dialog using the left mouse button. You can also change the portion of the image selected by resizing this box by grabbing and dragging one of the box corners. For the purposes of this tutorial, we will use the full image. Click using the left mouse button on the lower right corner of the red box and drag down so that the whole image is selected. Click **OK** and the **QuickMap Parameters** dialog appears (see Figure 11-1).

4. Click with the left mouse button in the Main Title text box in the dialog and type the text “Yellowstone National Park Image-Map.”

5. Click with the right mouse button in the Lower Left Text text box in the dialog and left-click the **Load Projection Info** menu button to load the image map projection information from the ENVI header.

6. Click with the left mouse button in the Lower Right Text text box in the dialog and type the text “Map Generated Using.” Press the Enter key and type “ENVI QuickMap.” Press the Enter key and type “Copyright 2001,” press the Enter key and type “Research Systems, Inc.”
7. For the purposes of this tutorial, we recommend using the default Distance Scale Bars, Grids, and North Arrows/Declination settings, however, if desired, modify these using the check boxes and options on the right side of the **QuickMap Parameters** dialog.
8. Select **Save Template** at the bottom of the dialog, enter the **Output Filename** `ysratio.qm`, and click **OK** to save the QuickMap results as a QuickMap template file. This template can be recalled for use on any image of the same pixel size by simply displaying the desired image and selecting **File** → **QuickMap** → **from Previous Template** to restore the saved QuickMap template.

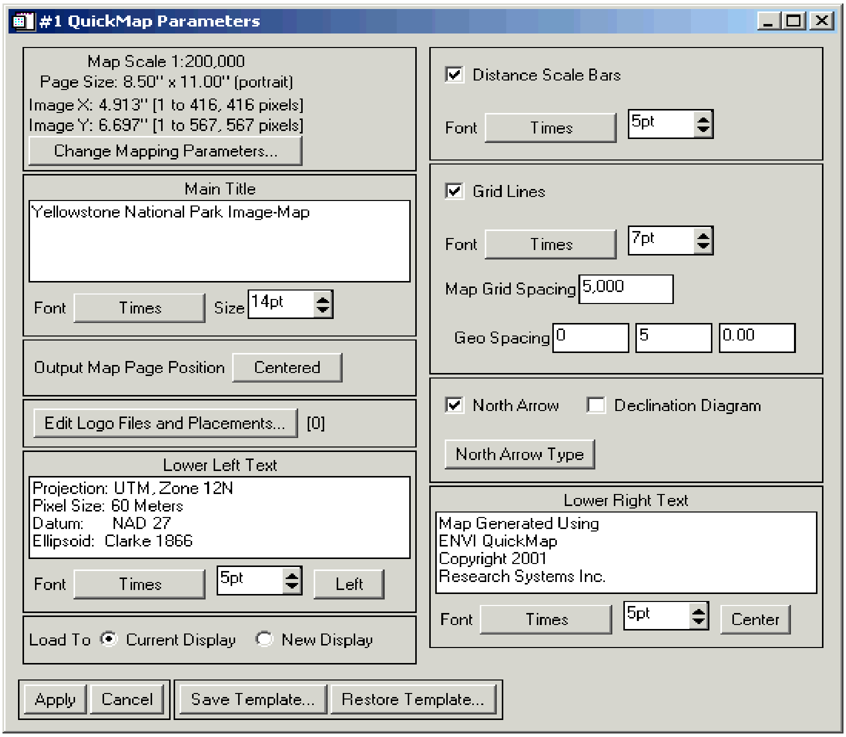


Figure 11-1: ENVI QuickMap Parameters dialog showing default settings and text added for the tutorial map composition.

9. Click **Apply** in the lower left corner of the **QuickMap Parameter** dialog to display the QuickMap results in a standard ENVI display group.

   If desired, you can modify the settings in the **QuickMap Parameters** dialog and click **Apply** to change the displayed QuickMap.

10. At this stage, you can output the QuickMap to a printer or a Postscript file. See "Save the Results" on page 259 and "Printing" on page 260 for more information. Save or print a copy if desired, otherwise, continue with Step 11.

11. Review the QuickMap results using the ENVI display group. Observe the map grids, scale bars, north arrow, and positioning of the default text.

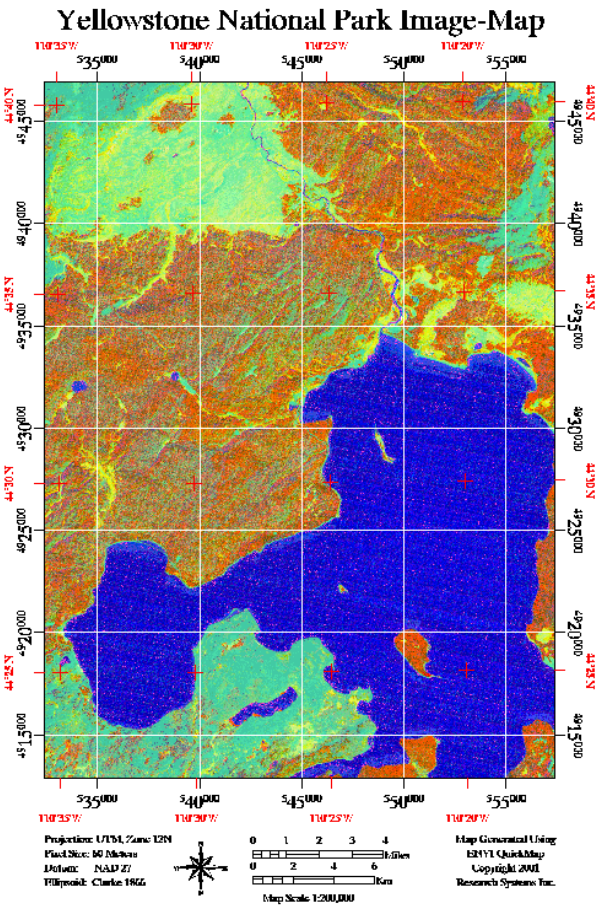


Figure 11-2: ENVI QuickMap default output.

Elements for Customizing Map Layouts

ENVI offers many options for customizing your map composition. Options include adding virtual borders, text annotation, grid lines, contour lines, plot insets, vector overlays, and classification overlays. You can use the ENVI Main Image window, Scroll window, and/or Zoom window to perform additional, custom map composition. (If you are working in the Scroll window, you may want to enlarge it by dragging one of the corners to resize the display.) The following sections describe the different elements and provide general instructions.

Adding Virtual Borders

Default ENVI displays contain only the image, with no surrounding blank space. Map composition typically requires that some map objects reside outside the image proper. ENVI provides a “Virtual Border” capability that allows annotation in the image borders without creating a new image. Virtual borders can be added to an image in several ways, which are described here:

Automatically When Using Image Grids in ENVI QuickMap

A virtual border is added to accommodate the QuickMap grid and a default grid is displayed. See the following specific grid instructions for information on modifying the grid. The required border is automatically added on all sides of the image.

1. To change from the default border, select **Overlay** → **Grid Lines** from the Main Display menu bar of the QuickMap display and when the Grid Line Parameters dialog appears, choose **Options** → **Set Display Borders** to start the Display Borders dialog.

2. For the purposes of this tutorial, enter the values “100,” “400,” “150,” and “100” as shown in Figure 11-3. Click **OK**.

   The new virtual border characteristics are applied immediately to the image. If you save the Grid Parameter File, the border information will be saved with the grid and will be restored when the grid parameters file is restored.

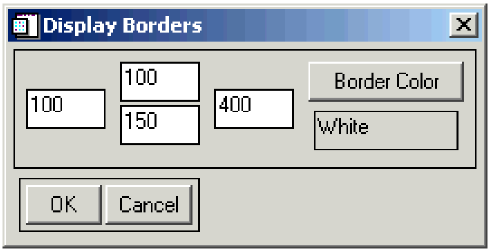


Figure 11-3: Set Display Borders dialog.

Using the Display Preferences

You can also change the Virtual Borders using the display preferences:

1. Select **File** → **Preferences** from the Main Image Display menu bar of the QuickMap display.

   The Display Parameters dialog appears, containing text boxes at the top of the dialog similar to those described previously.

2. Enter the desired values and select the desired color for the border.
3. Click **OK**.

   The new borders will be applied to the image immediately.

Using the Annotation Function

Virtual Borders are also controlled using the ENVI Annotation Function.

1. Select **Overlay** → **Annotation** from the Main Image Display menu bar of the QuickMap display.
2. When the Annotation dialog appears, select **Options** → **Set Display Borders** to start the Display Borders dialog.
3. Enter the desired border characteristics and click **OK**.

The new virtual border characteristics are applied immediately to the image. If you save the Annotation File, the border information will be saved with the annotation and will be restored when the annotation file is restored.

Adding Grid Lines

ENVI supports simultaneous pixel, map coordinate, and geographic (latitude/longitude) grids. A 100-pixel virtual border (which can be adjusted as described in "Adding Virtual Borders" on page 245) is automatically appended to the image to accommodate the grid labels when grids are applied. To add or modify image grids, follow these steps:

1. Select **Overlay** → **Grid Lines** from the Main Image Display menu bar of the QuickMap display.

   The **Grid Line Parameters** dialog appears and a default grid is displayed with default grid spacings set.

2. Change the grid spacing to 4000 meters by entering the value "4,000" in the **Grid Spacing** text box.

   If desired, choose **Options** → **Edit Pixel Grid Attributes** or **Edit Map Grid Attributes** or **Edit Geographic Grid Attributes** to edit the attributes of the selected grid, then click **OK** to apply the selected attributes.

   This allows editing of the line and label characteristics for the grid.

3. In the **Grid Line Parameters** dialog click **Apply** to post the new grid to the displayed image.

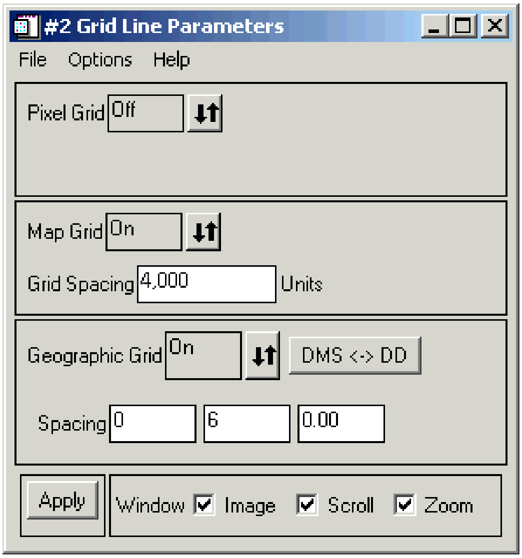


Figure 11-4: The Grid Line Parameters dialog.

- To save Grid parameters for later use, select **File** → **Save Setup** from the **Grid Parameters** menu bar and select an output file.

  This saves a template of the grid parameters, which can be recalled for use on another map composition by choosing **File** → **Restore Setup** from the **Grid Parameters** menu bar.

Working with Annotation

Annotation is used as a generalized means of inserting (and positioning) map objects in an ENVI display for map composition. Several classes of map objects are available and all are placed using ENVI's standardized annotation procedures.

1. Select **Overlay** → **Annotation** in the Main Image Display menu bar of the QuickMap display to start the **Annotation** dialog.
2. Choose the desired annotation object from the **Object** pull-down menu in the **Annotation** dialog menu bar.
3. Place the object by dragging using the left mouse button and clicking the right mouse button to lock the annotation in position.
   - All annotation objects can be reselected and then modified by choosing **Object** → **Selection/Edit** followed by selecting the object by drawing a box around it using the left mouse button. The selected object can then be moved by clicking the associated handle and dragging to a new location. The object can be deleted or duplicated by choosing the appropriate option from the selected menu.
   - Clicking the right mouse button re-locks the annotation.

The various types of annotation available in ENVI are discussed in the following sections. Please see the *ENVI User's Guide* or the ENVI Online Help for more details.

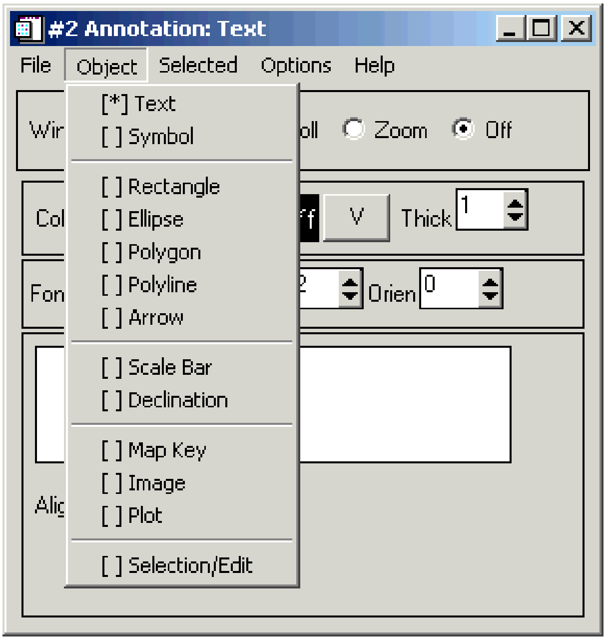


Figure 11-5: The Annotation dialog.

Text and Symbol Annotation

ENVI currently has a wide variety of text fonts and different standard symbol sets. In addition, ENVI can utilize TrueType fonts installed on your system. This provides access to a wide range of different text fonts and symbols. All of these can be interactively scaled and rotated, and different colors and thickness can be set.

Note

ENVI provides some useful symbols (including special North Arrows) as a custom TrueType font. Select **ENVI Symbols** from the **Font** pull-down button in the **Annotation** dialog for use with either Text or Symbol annotation.

1. Select **Object** → **Text** or **Object** → **Symbol** from the **Annotation** menu bar.

- For text annotation, select the font from the **Font** button menu in the left center of the dialog. Select size, color, and orientation parameters using the appropriate buttons and text boxes in the center of the dialog.

```
Landsat TM Data
Ratios 5/7, 3/1, 3/4 (RGB)
```

Figure 11-6: Text annotation.

  TrueType fonts provide more flexibility. Select one of the TrueType fonts available on your system by choosing TrueType from the **Font** button menu and selecting the desired font. Enter the character you want and place using the methods described in "Working with Annotation" on page 248.

- For symbols, select the desired symbol from the table of symbols that appears in the Annotation dialog when this object is selected.

Figure 11-7: Some TrueType font symbols.

2. Place the text or symbol on the image as described in "Working with Annotation" on page 248. Position with the left mouse button, and place by clicking the right mouse button.
3. Reselect, modify, and move the annotation as desired.

Polygon and Shape Annotation

ENVI allows you to draw rectangles, squares, ellipses, circles, and free-form polygons. These can be an outline only, or filled with a solid color or a pattern. Placement is interactive, with easy rotation and scaling.

1. Select **Object** → **Rectangle**, **Object** → **Ellipse**, or **Object** → **Polygon** in the **Annotation** dialog.

2. Drag and place the shapes as described in "Working with Annotation" on page 248.
   - For polygons, use the left mouse button to define polygon vertices and the right mouse button to close the polygon.

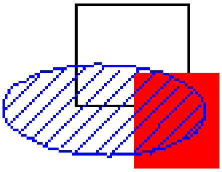


Figure 11-8: Annotation with shapes.

Line and Arrow Annotation

ENVI annotation allows the placement of polylines (lines) and arrows. You have full control over the color, thickness and linetype, and the fill and head characteristics for arrows.

1. Select **Object** → **Polyline** or **Object** → **Arrow** in the Annotation dialog.
2. Define arrows and lines by clicking with the left mouse button.
3. Click using the right mouse button to close the current line.

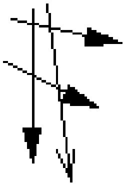


Figure 11-9: Line and arrow annotation.

Map Scale Annotation

Map Scales are automatically generated by ENVI based on the pixel size of the image being used in the map composition. Options include feet, miles, meters, and kilometers. Scales can be placed individually, or in groups. You can configure the number of divisions and minor divisions, and the font and character size.

1. Select **Object** → **Scale Bar** in the Annotation dialog.

2. Enter the desired parameters, then place the scale bar using the left mouse button.

3. Lock in the annotation using the right mouse button.

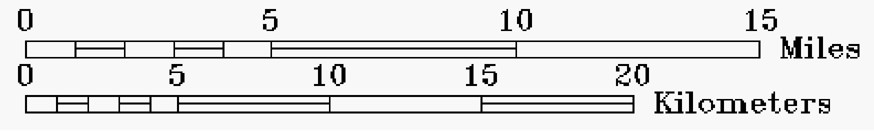


Figure 11-10: Scale Bar annotation.

Declination Diagrams

ENVI automatically generates declination diagrams based on user-provided characteristics. The size of the diagram and the azimuths for True North, Grid North, and Magnetic North are entered in decimal degrees and the diagram is placed using standard ENVI annotation procedure.

1. Select **Object** → **Declination** in the **Annotation** dialog.

2. Place the annotation using the left mouse button.

3. Lock in the annotation using the right mouse button.

Map Key Annotation

Shown in Figure 11-11 is an example of a map key built using ENVI's map key editing feature. The box around the key is a rectangle placed as a separate annotation object as is the key description at the top of the box.

1. Select **Object** → **Map Key** in the **Annotation** dialog.

2. Choose **Edit Map Key Items** to add, delete, or modify individual map key items.

3. Place the map key using the left mouse button and lock in using the right mouse button.

Figure 11-11: ENVI Map Key.

Map keys are generated automatically for classification images and vector layers.

Color Ramp Annotation

You can create grayscale ramps and color bars for grayscale and color-coded images respectively.

Note

This option is not available when an RGB image is displayed.

1. Select **Object** → **Color Ramp** in the **Annotation** dialog.
2. Enter minimum and maximum values and intervals as desired and set vertical or horizontal orientation.
3. Place the color ramp using the left mouse button.
4. Lock in the annotation using the right mouse button.

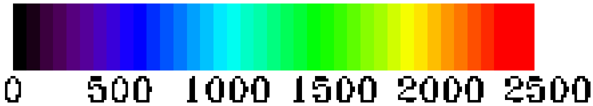


Figure 11-12: ENVI Color Ramp with labels.

Image Insets as Annotation

While many images can be inset into another image using ENVI's mosaicking capabilities, ENVI annotation provides the capability to inset images into other images during the map composition/annotation process as well.

1. Select **Object** → **Image** in the **Annotation** dialog.
2. Click **Select New Image** to choose the image to be inserted (the image must previously be opened and listed in the **Available Bands List**).
3. Pick the image from the **Available Bands List**, perform any spatial subsetting, and resize on-the-fly if desired.
4. Place the image using the left mouse button.
5. Lock the image in using the right mouse button.

Because 8-bit displays can't easily assign a new color table to the inset image, ENVI only shows a representation of the image in the display window. The actual image is placed when the image is output to a file and the annotation is "burned in."

Plot Insets as Annotation

ENVI annotation also provides the capability to inset ENVI plots into other images during the map composition/annotation process. These vector plots will maintain their vector character (will not be rasterized) on output to "Printer" or "Postscript" (note: they will not show up on output to image.)

1. Select **Object** → **Plot** from the **Annotation** dialog menu.
2. Click **Select New Plot** to choose the plot be inserted (the plot must currently be displayed). Types of plots supported include X-, Y-, spectral-, and arbitrary profiles, and spectral plots.
3. Select the plot from the **Select Plot Window** dialog, set the size of the plot by entering the desired dimensions, and click **OK**.
4. Place the plot using the left mouse button.
5. Lock the plot annotation into the image using the right mouse button.

Because 8-bit displays can't easily assign a new color table to the inset plot, ENVI only shows a representation of the plot in the display window. The actual plot is placed when the image is output directly to the printer or a postscript file and the annotation is burnt in. Again, this option does not produce a vector plot when output to "Image."

Overlaying Classification Images

ENVI Classification images can be used as overlays during map composition. First classify the image using standard ENVI classification procedures or open an existing ENVI classification image. Once the classified image is listed in the Available Bands List, then it can be used as an overlay. See the *ENVI User's Guide* or online help for additional details about image classification.

1. Select **Overlay** → **Classification** from the Display menu of the image being used for the map composition and choose the ENVI classification image in the **Interactive Class Tool Input File** dialog then click **OK**.

   The **Interactive Class Tool** dialog will appear.

2. Turn on specific classes on the map composition by clicking in the corresponding **On** box in the dialog. Multiple classes can be selected. The selected classes will appear in the appropriate color as an overlay on the image.
3. Class colors/names can be changed by choosing **Options** → **Edit class colors/names** in the **Interactive Class Tool** dialog and changing as desired.

Overlaying Contour Lines

ENVI provides the capability to contour the “Z” value of images and overlay the contour lines as vectors on an image background. Digital Elevation Models (DEMs) work best. The contours can be simply added to a map composition as follows:

1. Select **Overlay** → **Contour Lines** from the Main Display menu bar of the image being used for map composition.
2. Choose the desired image to contour in the **Contour Band Choice** dialog and click **OK**.
3. To use the default contour values click **Apply** in the **Contour Plot** dialog.
4. New contour levels can be added, levels edited, colors and line types changed, etc. using the **Contour Plot** dialog. See the *ENVI User's Guide* or online help for additional details.

Incorporating Regions of Interest

Regions of interest created using a variety of methods can be incorporated into ENVI map compositions. Generate ROIs by drawing, thresholding specific image bands, utilizing 2-D or n-D scatterplots, or vector-to-raster conversions. To display the ROI on the map composition:

1. Select **Overlay** → **Region of Interest** from the **Display** menu of the image being used for the map composition.

   Any existing Regions of Interest having the same dimensions as the displayed image will be listed in the ROI Tool and displayed on the image.

2. Add or modify ROIs as desired using standard ENVI methods. See the *ENVI User's Guide* or online help for additional details.

Overlaying Vector Layers

ENVI can import ArcShape, Arc/Info Interchange, DXF, and DLG vector formats. Vectors from these files and internal ENVI Vector Files (`.evf`) can be used in an ENVI map composition.

1. Open the files by selecting **File** → **Open Vector File** from the ENVI main menu and then select the file type.
2. Load the vectors into the map composition display, by clicking on **Apply** and adjust the attributes to obtain the desired colors, thickness, and linetypes.

   See the Vector Overlay and GIS Analysis Tutorials or see the *ENVI User's Guide* or online help for additional information.

Customize the Map Layout

In this section, several of the elements described in the previous sections are used to demonstrate some of ENVI's custom map composition capabilities. The previously created ENVI QuickMap result serves as the basis for this portion of the exercise.

If you don't already have the ENVI QuickMap result from the first part of this tutorial displayed, display the image using the following instructions.

1. Select **File** → **Open Image File** on the ENVI main menu.

   The input file selection dialog appears.
2. Navigate to the `ys_tmsub` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 1* and select the file `ysratio.img` from the list and click **Open**.

   The **Available Bands List** dialog appears. This list allows you to select spectral bands for display and processing.

   Note that you have the choice of loading either a grayscale or an RGB color image. The 5/7, 3/1, 3/4 ratio bands are loaded as the defaults in the "R," "G," and "B" fields.
3. Click **Load RGB** to load the image into a new display.

Load the QuickMap Template

Once the image is displayed, follow these steps to load the previously saved QuickMap template and to add individual map components:

1. Recall the previously saved QuickMap Template by simply displaying the desired image and selecting **File** → **QuickMap** → **from Previous Template**

to display the **Enter QuickMapTemplate Filename** dialog. Click on the saved QuickMap template `ysratio.qm` then **Open**.

2. Click **Apply** in the **QuickMap Parameters** dialog to generate the QuickMap image.
3. Restore some saved grid parameters by selecting **Overlay** → **Grid Lines** from the Main Display menu bar in the QuickMap image, selecting **File** → **Restore Setup** in the **Grid Line Parameters** dialog, choosing the saved grid parameters file `ysratio.grd` and clicking **Open**, then **Apply**. Try modifying some of the parameters and clicking **Apply** to display them on the image.

Note

Be sure to save any changes using **File** → **Save Setup**.

4. Restore some saved ENVI annotation by selecting **Overlay** → **Annotation** from the Main Display menu in the QuickMap image, selecting **File** → **Restore Annotation** in the **Annotation** dialog, choosing the saved annotation file `ysratio.ann` and clicking **Open**, then **Apply**.
5. Click on the **Image** button at the top of the annotation dialog, then try selecting **Object** → **Selection/Edit** and clicking and dragging a box around an object in the image using the left mouse button.

   A red "handle" will appear for selected object(s).
6. Move the selected object(s) by grabbing the red "handle" with the left mouse button and dragging to a new location. Try modifying some of the parameters for the selected object. Fix the selected object(s) at the new location by clicking the right mouse button in the image.

Note

Be sure to save any changes using **File** → **Save Annotation**. See the *ENVI User's Guide* or online help for additional details.

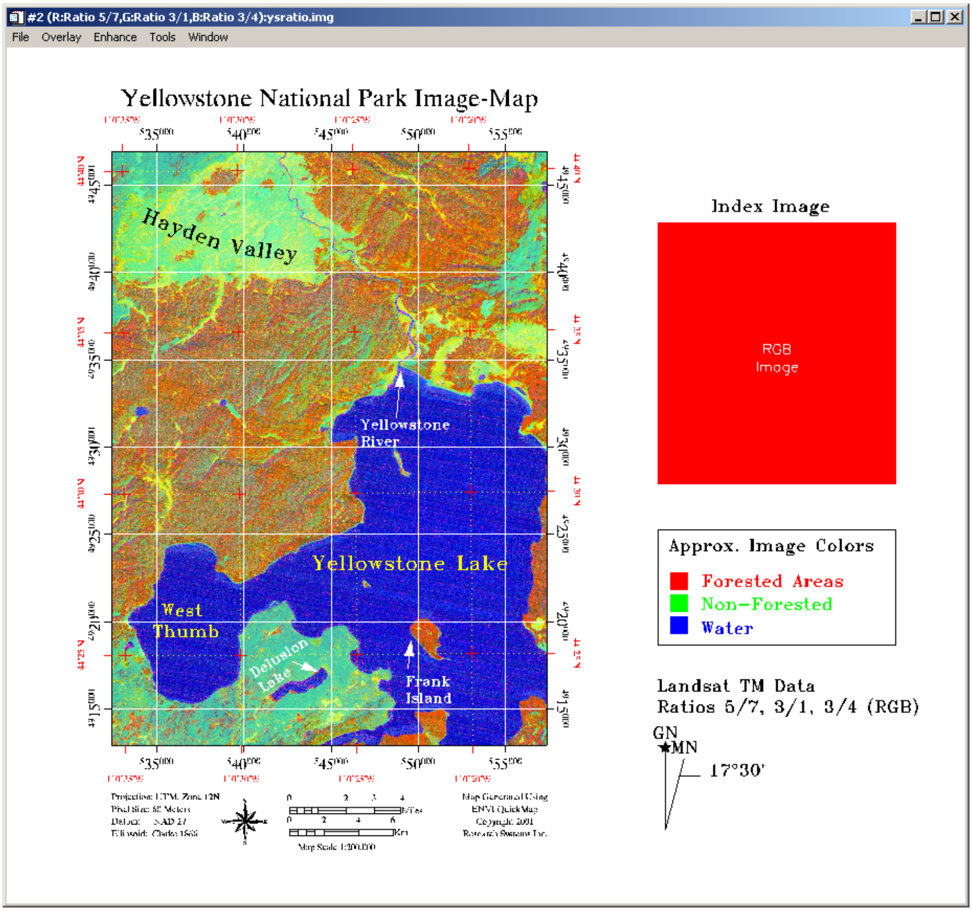


Figure 11-13: Custom map composition using ENVI annotation.

Save the Results

The image-map composition can be saved from the Main Image window either for future modification as an ENVI Display Group, or with the map composition burned-in.

Saving for Future Modification

This is the most flexible option.

1. Select **File** → **Save as Display Group** in the Main Image window.
2. Enter the output filename `ysratio.grp` and click **OK**.
3. This map composition can be restored later by choosing **File** → **Restore Display Group** from the ENVI main menu, clicking on the filename `ysratio.grp`, then clicking **Open**.

Saving as a “Burned-in” Image

1. Select **File** → **Save Image As** → **Postscript File**
   - Choose **Standard Printing** to output a postscript file with user-specified page size and scaling parameters.

     This option provides additional control, but may produce a map that doesn’t fit the originally selected QuickMap scale.
   - Choose **Output QuickMap to Postscript** to output a postscript file at the specified QuickMap page size and scaling. If your additional annotation has caused the image to be too large to be put out on the specified page size, ENVI will ask if you want to output to multiple pages. If this is the case, click **Yes**, and ENVI automatically creates multiple postscript files.

Saving as an Image File

You can save your map composition as an image file. Output formats include ENVI (binary) image, BMP, HDF, JPEG, PICT, PNG, SRF, TIFF/GeoTIFF, and XWD, as well as common image processing system formats such as ERDAS (`.lan`), ERMAPPER, PCI, and ArcView Raster.

1. Select **File** → **Save Image As** → **Image File**.
2. Set the resolution, output file type and other parameters as described in the *ENVI User's Guide* or online help, enter an output filename, and click **OK**.

Printing

You can also select direct printing of the ENVI map composition, in which case, the map composition will be printed directly to your printer using system software drivers.

1. Select **File** → **Print** and choose either **Standard Printing** or **Output QuickMap to Printer** as described previously for the Postscript option.
2. Choose your printer, then click **OK**.

In all of the output options just described, graphics and map composition objects will be burned into the image on output. Figure 11-14 shows an example of a final map composition produced in ENVI using QuickMap and custom map composition as described in this tutorial.

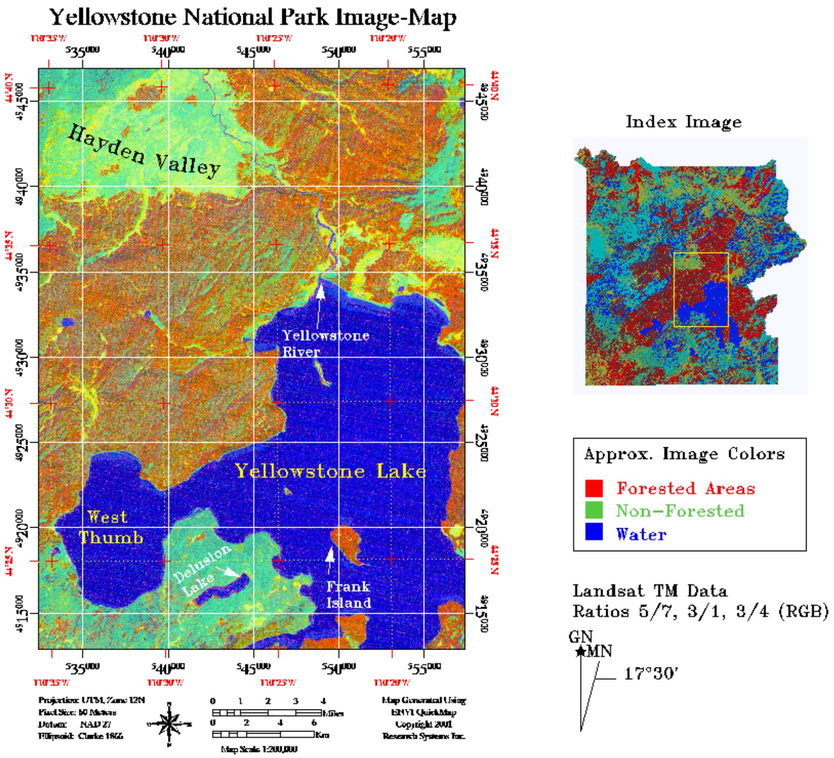
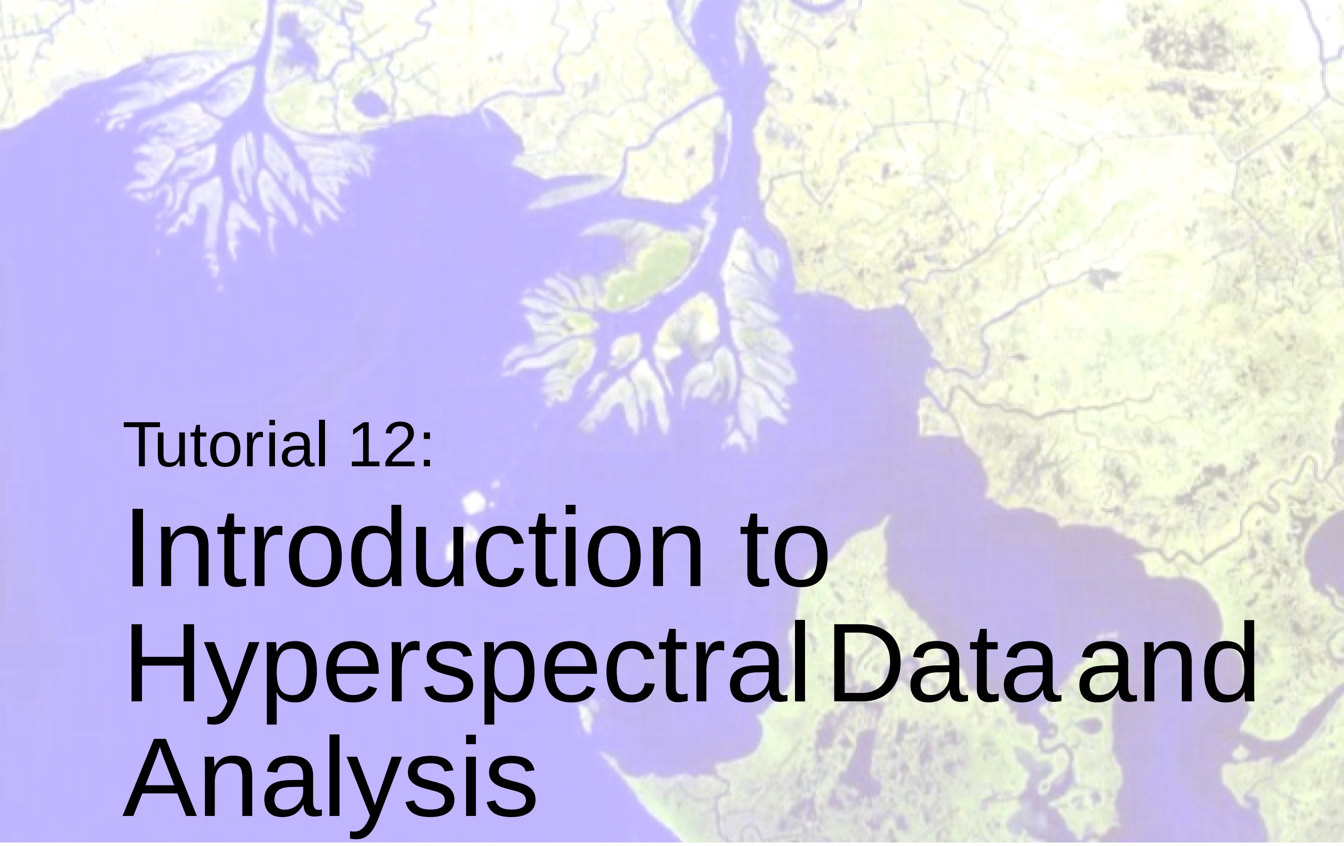


Figure 11-14: An example of the final image created using the ENVI map composition capabilities.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on Unix) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.



Tutorial 12: Introduction to Hyperspectral Data and Analysis

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to introduce you to the concepts of *Imaging Spectrometry*, *hyperspectral images*, and selected spectral processing basics using ENVI. For this exercise, we will use Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data to familiarize you with spatial and spectral browsing of imaging spectrometer data. We will start with 1995 AVIRIS radiance data for Cuprite, Nevada, USA, provided by Jet Propulsion Laboratory (JPL) and then compare the results of several reflectance calibration procedures.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/c95avsub`

File	Description
Required Files	
`cup95_rd.int`	Cuprite AVIRIS radiance data. 400 samples x 350 lines x 50 bands (Integer).
`cup95_rd.hdr`	ENVI Header for above
`cup95_at.int`	Cuprite ATREM-calibrated apparent reflectance data. 50 bands (Integer).
`cup95_at.hdr`	ENVI Header for above
`cup95cal.sli`	Spectral Library of calibration results for selected minerals (Integer).
`cup95cal.hdr`	ENVI Header for above
`jpl1sli.dat`	Spectral Library in ENVI format.
`jpl1sli.hdr`	ENVI Header for above
`usgs_sli.dat`	USGS Spectral Library in ENVI format
`usgs_sli.hdr`	ENVI Header for above

File	Description
Optional Files	
cup95_ff.int	Cuprite Flat-Field-calibrated apparent reflectance data. 50 bands (Integer).
cup95_ff.hdr	ENVI Header for above
cup95_ia.int	Cuprite Internal Average Relative Reflectance (IARR) data. 50 bands (Integer).
cup95_ia.hdr	ENVI Header for above
cup95_el.int	Cuprite Empirical Line calibrated apparent reflectance data. 50 bands (Integer).
cup95_el.hdr	ENVI Header for above

Note

Optional files listed may also be used if more detailed calibration comparisons are desired. All image data files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. A value of 1000 therefore represents apparent reflectance of 1.0.

Background: Imaging Spectrometry

Imaging spectrometers or "hyperspectral sensors" are remote sensing instruments that combine the spatial presentation of an imaging sensor with the analytical capabilities of a spectrometer. They may have up to several hundred narrow spectral bands with spectral resolution on the order of 10 nm or narrower (Goetz *et al*., 1985). Imaging Spectrometers produce a complete spectrum for every pixel of the image (Figure 12-1).

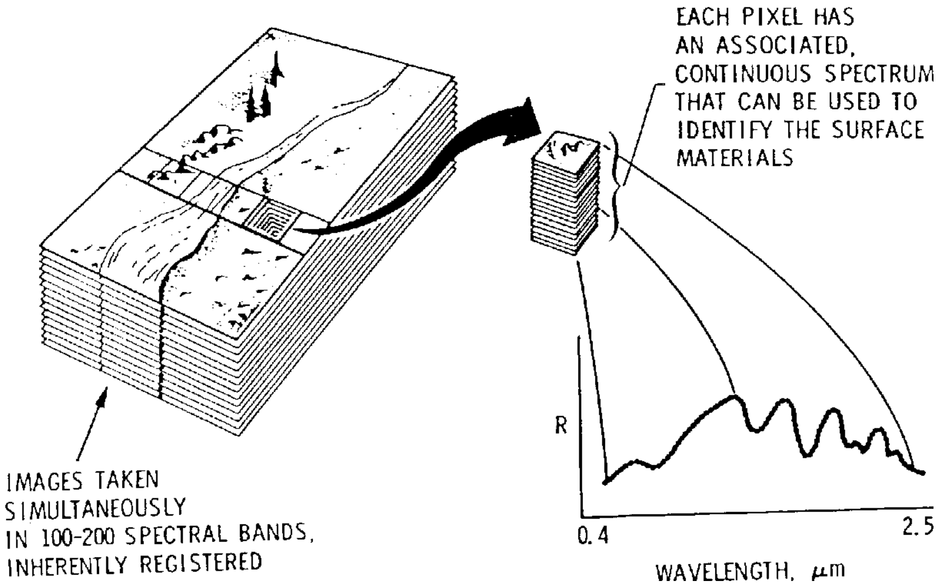


Figure 12-1: The imaging spectrometer concept; hundreds of spectral images, thousands to millions of individual spectra (from Vane, 1985).

Compare this to broad-band multispectral scanners such as Landsat Thematic Mapper (TM), which only has 6 spectral bands and spectral resolution on the order of 100 nm or greater (Figure 12-2). The end result of the high spectral resolution of imaging spectrometers is that we can identify materials, where with broad-band sensors we could previously only discriminate between materials.

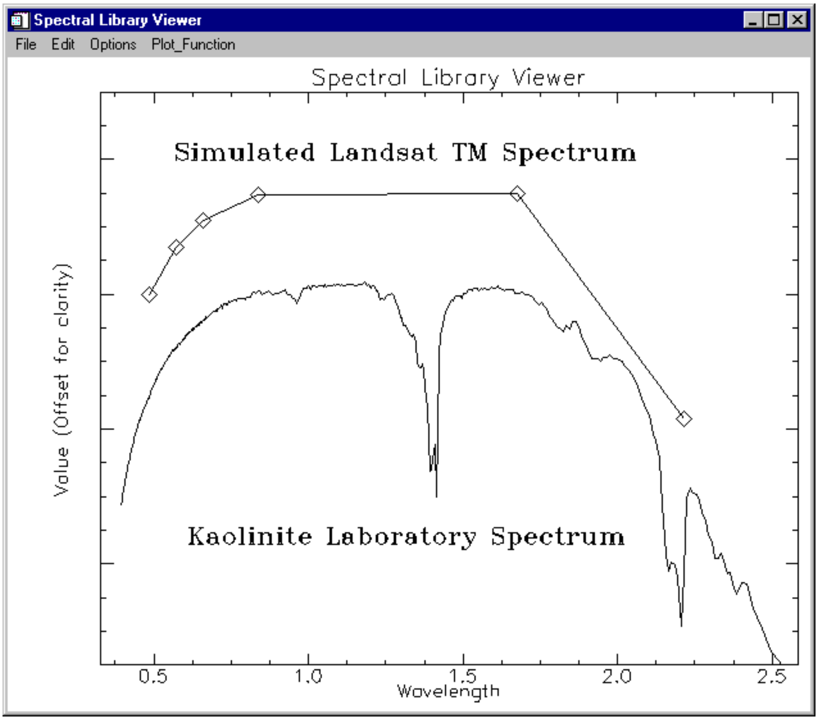


Figure 12-2: Comparison of a simulated Landsat TM spectrum to the corresponding laboratory spectrum.

Introduction to Basic ENVI Spectral Processing

This portion of the tutorial is designed to familiarize you with ENVI features that are useful for spectral processing of imaging spectrometer data.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in Unix, enter `envi` at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

1. Select **File** → **Open Image File** and navigate to the `c95avsub` subdirectory of the *ENVI Tutorial and Data CD No. 2*.
2. Choose `cup95_rd.int` as the input file name.

The file contains 50 bands (1.99 - 2.48 µm) of JPL-calibrated AVIRIS radiance for the Cuprite Mining District, Nevada, USA.

The **Available Bands List** dialog will appear, listing the 50 spectral band names.

Display a Gray Scale Image

1. Use the scroll bar on the right side of the **Available Bands List** dialog to scroll through the list until Band 193 (2.2008 µm) is displayed.
2. Click on the **Gray Scale** radio button, then select Band 193 and click on the **Load Band** button at the bottom of the dialog.

   The Main Image window containing the selected band will appear.
3. Position the red box outlining the Zoom window by clicking the left mouse button at the desired location in the Main Image window.

   The Zoom window will be automatically updated.
4. Change the zoom factor by clicking the left mouse button in **+** graphic located in the lower left hand corner of the zoom window to zoom up or on the **-** button to zoom down.

- Clicking the left mouse button in the Zoom window centers the selected pixel.
- The Zoom window can also be changed by dragging the red outlining box within the Main Image window by using the left mouse button.

Display a Color Image

1. Load a color composite image by clicking on the **RGB Color** radio button in the **Available Bands List** dialog.
2. Click sequentially on Band 183, Band 193, and Band 207 (2.10, 2.20, and 2.35 μm).
3. Select **New Display** from the **Display** pull-down button at the bottom of the dialog to start a new display.
4. Click **Load RGB** at the bottom of the dialog.

The color image will be loaded into the new (second) image display.

Link Two Displays

Images can be linked to allow simultaneous, identical user action on multiple images. Once linked, moving the zoom box, the scroll box, changing the zoom factor, or resizing any of the image windows causes the same actions to occur in the linked windows.

1. Place the cursor in the Display #1 Main Image window and select **Tools** → **Link** → **Link Displays**.

   The **Link Displays** dialog will appear (Figure 12-3).
2. Use the defaults and click **OK** to enable the link.

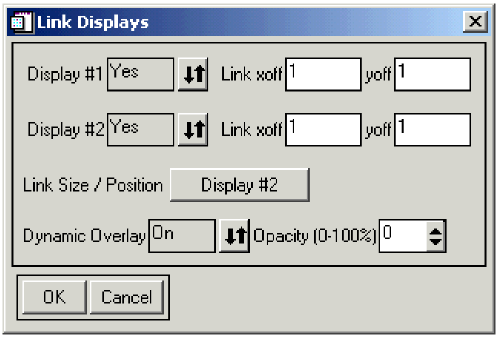


Figure 12-3: The Link Displays dialog.

3. Position the Zoom window for Display #1 by clicking the left mouse button in the red Zoom Window outlining box in the #1 Main Image Display and dragging it to a new location.

   Note how the Display #2 Zoom window updates to correspond with the first display.

   Multiple Dynamic Overlays are available when two or more images are linked, allowing real-time overlay and flicker of multiple gray scale or color images. Dynamic overlays are activated automatically when two or more windows are first linked.

4. Click the left mouse button in either of the linked images to cause the second linked image (the overlay) to appear in the first image (the base).
5. You can make a quick visual comparison of the images by repeatedly clicking and releasing the left mouse button, which causes the overlay area to flicker.
6. Change the size of the overlay by pressing the middle mouse button and dragging the corner of the overlay to the desired location.
7. After trying the different possibilities, turn off dynamic linking in the displayed color image by selecting **Tools** → **Link** → **Unlink Display**.

Extract Spectral Profiles

ENVI's Z-profile capabilities provide integrated spectral analysis. You can extract spectra from any multispectral data set including MSS, TM, and higher spectral dimension data such as GEOSCAN (24 bands), GERIS (63 bands), and AVIRIS (224 bands). From the displayed color image, you can select **Tools** → **Profiles** → **Z Profile (Spectrum)** in the Main Image window menu bar to start a spectral profile.

Current Spectrum

The spectrum for the current cursor location will be plotted in a plot window. A vertical line on the plot is used to mark the wavelength position of the currently displayed band. If a color composite image is displayed, three colored lines will appear, one for each displayed band in the band's respective color (red, green, or blue).

1. Select **Tools** → **Profiles** → **Z Profile (Spectrum)** in the Main Image window menu bar to start a spectral profile.
2. Move the cursor position in the Main Image or Zoom window.

   The spectrum will be extracted and plotted for the new location.
3. Browse the spectral profile by clicking and holding the left mouse button in the Main Image window and dragging the box across the image.

   The spectrum will be updated as the Zoom window box moves. Note that the spectra you are viewing are radiance—not reflectance—spectra, as you are currently working with Cuprite radiance data.
4. Save spectra for comparison using the **File** → **Save Plot As** option from the menu bar at the top of the plot window.

Collect Spectra

1. Select **Options** → **Collect Spectra** in the **Spectral Profile** window to accumulate spectra in this plot (Figure 12-4).

   Optionally, to collect spectra in another plot window, open a new plot window and save image spectra from the **Spectral Profile** window.
2. Select **Options** → **New Window: Blank** from the plot menu to open a new plot window to contain saved image spectra.
3. Click the right mouse button in the previous plot to display the spectrum name to the right of the plot window.
4. Click and hold the left mouse button on the first character of the spectrum name, drag the name to the new plot window, and release the mouse button.
5. Select a new spectrum from the image by moving the current pixel location in either the Main Image or Zoom window and repeat the drag-and-drop process to build a collection of spectra in the new plot window.

6. Once you have several plots in the plot window, select **Options** → **Stack Data** in new plot window. The spectra will be offset vertically to allow interpretation.

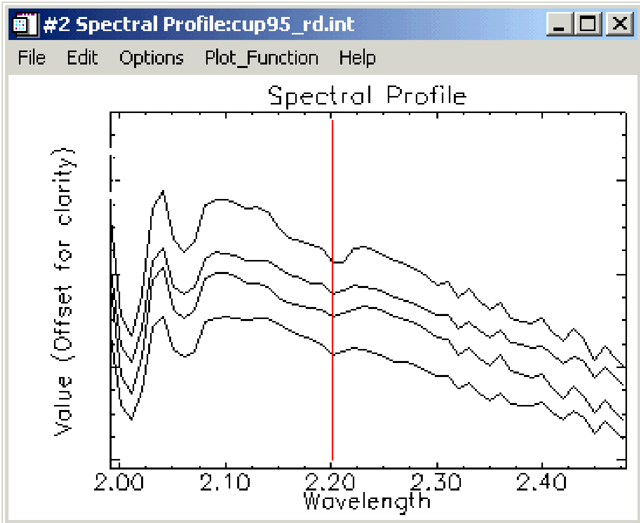


Figure 12-4: An ENVI Spectral Profile window with collected spectra.

7. To change the color and line style of the different spectra, select **Edit** → **Data Parameters** in the new plot window.

   Each spectrum is listed by name/location in the **Data Parameters** dialog.

8. Select a line and change its properties as desired.
9. When completed, click **Cancel** to close the dialog.
10. Select **File** → **Cancel** to close the plots after completing this section.

Animate the Data

You can animate gray scale images to make the spatial occurrence of spectral differences more obvious.

1. In the Main Image window of the previous gray scale image (Display #1), select **Tools** → **Animation** to create a movie using the Cuprite AVIRIS data.

The **Animation Input Parameters** dialog will appear (Figure 12-5). This dialog lists all the bands provided in the **Available Bands List.**

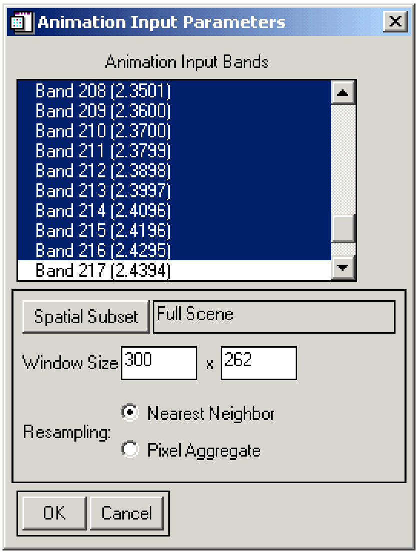


Figure 12-5: The Animation Input Parameters dialog.

2. Choose a subset of the full set of bands for animation. Click and drag to select a desired range of bands, or use Control-Click to select specific bands. For the purposes of this exercise, select bands 197 - 216 (20 bands).

3. Change the **Window Size** field to 200 x 175 to reduce the size of the image to be animated (and thus increase the speed of the animation).

4. Click **OK** to start the animation loading process.

   The **Animation Window** and the **Animation Controls** dialog will appear. The selected bands are loaded individually into the **Animation Window**. A status bar appears as each image is processed. You can cancel the animation in progress at any time by clicking **Cancel** in the status window.

   Once all of the selected images have been loaded, the animation will start automatically. Selected bands are displayed sequentially.

The **Animation Controls** dialog (Figure 12-6) are used to specify the animation characteristics. The animation speed is varied from 1 to 100 using the spin box labeled **Speed**.

Figure 12-6: The Animation Controls dialog.

5. Use the control buttons (which look like CD player buttons) to run the animation forward and reverse and to pause a specific bands. When paused, click and drag the slider to manually select the band to display.
6. Choose the **File** → **Cancel** to end the animation.

Working with Cuprite Radiance Data

Continue this exercise using the images displayed in the first section.

1. If you have quit ENVI and IDL, restart ENVI and select **File** → **Open Image File**.
2. Navigate to the `c95avsub` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 2*. Choose `cup95_rd.int` as the input file name.

Load AVIRIS Radiance Data

1. If you don't already have this image displayed, load a color composite image by clicking on the **RGB Color** radio button in the **Available Bands List** dialog.
2. Click sequentially on Band 183, Band 193, and Band 207 and then **Load RGB** at the bottom of the dialog.

The color image will be loaded into the current image display.

Extract Radiance Spectra

You can extract selected image radiance spectra for specific targets in the AVIRIS radiance data with the following steps:

1. From the Main Image window menu bar, select **Tools** → **Pixel Locator**.
2. Position the Zoom window over Stonewall Playa, centered around the pixel at sample 590 and line 570 by entering these pixel coordinates in the Pixel Locator and clicking **Apply**.
3. Extract the radiance spectrum for this location by selecting the **Tools** → **Profiles** → **Z-Profile (Spectrum)** option.
4. Select **Options** → **Collect Spectra** to extract radiance spectra for the following locations and load into the same plot window for comparison (Figure 12-7).

Location Name	Sample (with offset)	Line (with offset)
Stonewall Playa	590	570
Varnished Tuff	435	555
Silica Cap	494	514
Opalite Zone with Alunite	531	541
Strongly Argillized Zone with Kaolinite	502	589
Buddingtonite Zone	448	505
Calcite	260	613

5. Use the **Pixel Locator** dialog to obtain the spectra for the other locations.

6. Select **Options** → **Stack Data** to be able to separately view each spectrum and right-click in the plot display to show the legend for the spectra.
7. Change the colors of the individual plots if necessary by selecting **Edit** → **Data Parameters** and making the appropriate changes in the subsequent dialog.

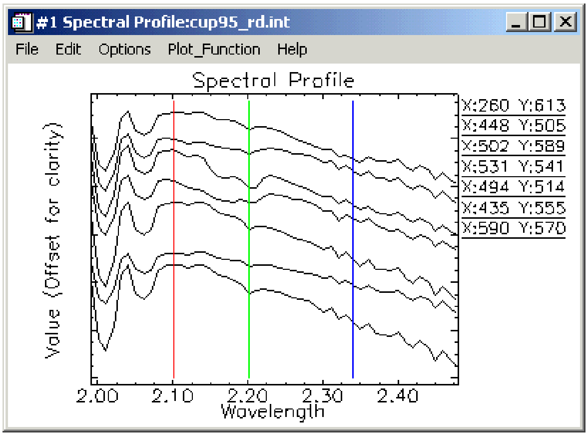


Figure 12-7: AVIRIS Radiance Spectra.

Compare the Radiance Spectra

Note how similar the radiance spectra appear. The overall shape of the spectra is caused by the typical combined solar/atmospheric response. Note small absorption features (minima) near 2.2 micrometers that may be attributable to surface mineralogy.

Load Spectral Library Reflectance Spectra

Now compare apparent reflectance spectra from the image to selected library reflectance spectra.

1. Select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer** from the ENVI main menu.
2. When the **Spectral Library Input File** dialog appears, click **Open Spec Lib** and select `jpl1.sli` from the `spec_lib/jpl_lib` subdirectory.
3. Click **OK**. The `jpl1.sli` file will appear in the **Select Input File** field of the dialog.

4. Click on the file name and click **OK** to open the **Spectral Library Viewer** dialog (Figure 12-8).

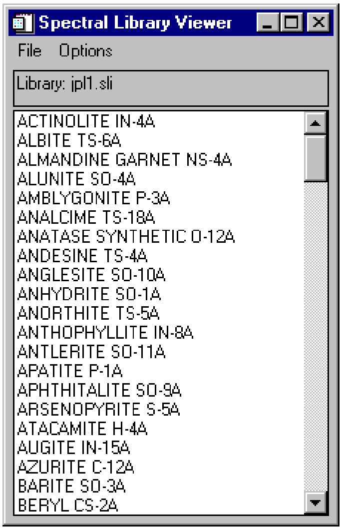


Figure 12-8: The Spectral Library Viewer dialog.

5. Plot the following spectra in the **Spectral Library Viewer** window by clicking on the appropriate mineral name in the list of spectra:
   - ALUNITE SO-4A
   - BUDDINGTONITE FELDS TS-11A
   - CALCITE C-3D
   - KAOLINITE WELL ORDERED PS-1A
   - If desired, change the X-Axis scale by choosing **Plot Parameters** from the **Edit** menu and entering the values 2.0 and 2.5 for the range.

   This allows direct visual comparison of radiance (Figure 12-7) and reflectance (Figure 12-9), though the Y-axes will not have the same scale.

6. Click **Cancel** to close the **Plot Parameters** dialog.

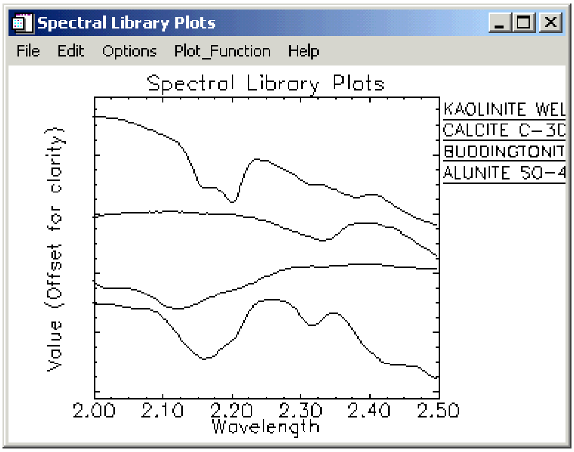


Figure 12-9: Library Spectra.

Compare Image and Library Spectra

When visually comparing and contrasting the corresponding AVIRIS radiance spectra with the laboratory measurements for alunite, buddingtonite, calcite, and kaolinite, you should notice how difficult it is to visually identify the minerals by comparing features in the radiance spectra to absorption features shown in the laboratory spectra. You should also notice the effect of the superimposed convex-upward solar-atmospheric signature in the AVIRIS radiance data on visual identification.

Close the Windows

When you are finished with this section, close all of the plot windows by choosing **Windows** → **Close All Plot Windows** from the ENVI main menu.

Compare Radiance and ATREM

In this portion of the tutorial you will extract selected image radiance spectra and compare them to ATREM apparent reflectance spectra for specific targets in the AVIRIS radiance data.

Background: ATREM Calibration

The ATmospheric REMoval Program (ATREM) is a radiative transfer model-based technique for deriving scaled surface reflectance from AVIRIS data without *a priori* knowledge of surface characteristics (Gao and Goetz, 1990, CSES, 1992). It utilizes the 0.94 and 1.1 micrometer water vapor bands to calculate water vapor on a pixel-by-pixel basis from the AVIRIS data, the solar irradiance curve above the atmosphere, and transmittance spectra for each of the atmospheric gases CO2, O_3, N_2O, CO, CH_4, and O_2. **At the time this tutorial was released, ATREM was unavailable for distribution.** Additional information is available at http://cires.colorado.edu/cses/atrem.html (Center for the Study of Earth from Space, University of Colorado). The ATREM-calibrated data used for this tutorial were reduced to apparent reflectance using ATREM 1.3.1.

Note

ATREM is not included as part of ENVI. The other calibration methods examined in this tutorial and described here are implemented within ENVI.

Continue or Restart ENVI

Continue this exercise using the images displayed in the first section.

1. If you have quit ENVI and IDL, restart ENVI and select **File** → **Open Image File** and navigate to the `c95avsub` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 2*.
2. Choose `cup95_rd.int` as the input file name.

Load Radiance Data and Start the Z-Profiler

1. If it is not already loaded, load a color composite image by clicking on the **RGB Color** radio button in the **Available Bands List** dialog.
2. Click sequentially on Band 183, Band 193, and Band 207.
3. Click **Load RGB** at the bottom of the dialog.

   The color image will be loaded into the current image display.

4. Extract the radiance spectrum by selecting **Tools** → **Profiles** → **Z Profile (Spectrum)** from the Main Image window menu bar.
5. Move the Z-Profile window to the bottom of the screen for easy access.

Load ATREM Apparent Reflectance Data and Start the Z Profiler

Now open a second AVIRIS data set.

1. Select **File** → **Open Image File** and choose `cup95_at.int` as the second input file name.

   This is 50 bands (1.99 - 2.48 μm) of AVIRIS data calibrated to apparent reflectance using the atmospheric model ATREM to process the AVIRIS radiance data. The 50 band names will be added to the **Available Bands List** dialog.
2. Use the scroll bar on the right side of the **Available Bands List** dialog to scroll through the list until Band 193 of `cup95_at.int` is listed.
3. Click on the **Gray Scale** radio button and select band 193.
4. Select **New Display** from the **Display** pull-down button at the bottom of the dialog, and then **Load Band** to start a second ENVI image display and load the selected band.
5. Extract the radiance spectrum by selecting **Tools** → **Profiles** → **Z Profile (Spectrum)** in the second Main Image window.
6. Move the Z-Profile window to the bottom of the screen next to the Z-Profile from the radiance data for easy comparison.

Link Images and Compare Spectra

1. Link the two AVIRIS images together by selecting **Tools** → **Link** → **Link Displays** from the first Main Image window and clicking **OK** in the subsequent **Link Displays** dialog.
2. Now turn the dynamic overlay off in the first Main Image window by selecting **Tools** → **Link** → **Dynamic Overlay Off**.
3. Once the images are linked and the overlay is turned off, positioning the current pixel in one image (either by clicking the left mouse button in the image, dragging the Zoom window box using the left mouse button, or by using the Pixel Locator) will also position the cursor in the second image.

The Z profiles for both images will change to show the radiance and apparent reflectance spectra at the current location.

4. Position the zoom window over Stonewall Playa, centered around the pixel at sample 590 and line 570 (use the **Pixel Locator** dialog found in the **Tools** menu of the Main Image window).

   Visually compare both radiance and apparent reflectance spectrum for this location using the two Z-Profiles. If you wish, save the radiance spectrum in one new plot window and the reflectance spectrum in a second new plot window.

5. Now extract radiance and apparent reflectance spectra for the following locations and visually compare.

Location Name	Sample (with offset)	Line (with offset)
Stonewall Playa	590	570
Varnished Tuff	435	555
Silica Cap	494	514
Opalite Zone with Alunite	531	541
Strongly Argillized Zone with Kaolinite	502	589
Buddingtonite Zone	448	505
Calcite	260	613

Note

An alternate method for getting linked spectral profiles simultaneously from two or more images is to select **Tools** → **Profiles** → **Additional Z Profile** and choose additional datasets for extraction of profiles.

6. Select **Options** → **Stack Data** to offset data vertically for comparison.

7. Load the corresponding spectral library spectra into the apparent reflectance plot window for direct comparison of image apparent reflectance spectra (Figure 12-10) with laboratory spectra.

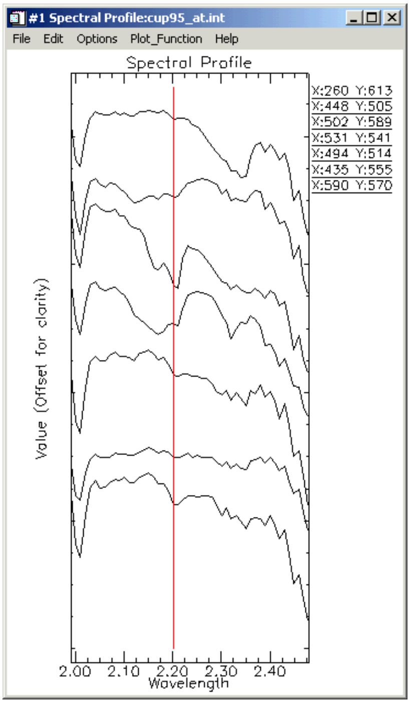


Figure 12-10: ATREM Apparent Reflectance Spectra.

Close the Windows

When you are finished with this section, you can close all of the plot windows by choosing **Windows** → **Close All Plot Windows**. Then you can close all of the image displays by choosing **Windows** → **Close all Displays**.

Compare Atmospheric Corrections

Background: Atmospheric Correction

This section of the tutorial compares several image apparent reflectance spectra. You will use a spectral library of apparent reflectance spectra generated using ENVI's Flat Field Correction, Internal Average Relative Reflectance (IARR) Correction, and Empirical Line Correction functions to compare the characteristics of the various calibration methodologies. The calibration techniques used are briefly described below.

Flat Field Correction

The Flat Field Correction technique is used to normalize images to an area of known "flat" reflectance (Goetz and Srivastava, 1985; Roberts *et al.*, 1986). The method requires that you locate a large, spectrally flat, spectrally uniform area in the AVIRIS data, usually defined as a Region of Interest (ROI). The radiance spectrum from this area is assumed to be composed of primarily atmospheric effects and the solar spectrum. The average AVIRIS radiance spectrum from the ROI is used as the reference spectrum, which is then divided into the spectrum at each pixel of the image. The result is apparent reflectance data that can be compared with laboratory spectra.

Internal Average Relative Reflectance (IARR)

The IARR calibration technique is used to normalize images to a scene average spectrum. This is particularly effective for reducing imaging spectrometer data to relative reflectance in an area where no ground measurements exist and little is known about the scene (Kruse *et al.*, 1985; Kruse, 1988). It works best for arid areas with no vegetation. The IARR calibration is performed by calculating an average spectrum for the entire AVIRIS scene and using this as the reference spectrum. Apparent reflectance is calculated for each pixel of the image by dividing the reference spectrum into the spectrum for each pixel.

Empirical Line Calibration

The Empirical Line correction technique is used to force image data to match selected field reflectance spectra (Roberts *et al.*, 1985; Conel *et al.*, 1987; Kruse *et al.*, 1990). This method requires ground measurements and/or knowledge. Two or more ground targets are identified and reflectance is measured in the field. Usually the targets consist of at least one light and one dark area. The same two targets are identified in the AVIRIS images and average spectra are extracted for Regions of

Interest. A linear regression is calculated between the field reflectance spectra and the image radiance spectra to determine a linear transform from radiance to reflectance for each band of the AVIRIS data set. Gains and offsets calculated in the regression are applied to the radiance spectra for each pixel to produce apparent reflectance on a pixel-by-pixel basis.

Continue or Restart ENVI and Select Spectral Library of Calibration Results Spectra

1. If you have quit ENVI and IDL, restart ENVI and select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer**.

   The **Spectral Library Input File** dialog will appear to allow selection of a spectral library.

2. Click **Open File** at the bottom center of the dialog to start a standard file selection dialog.

3. Navigate to the `c95avsub` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 2*, and select the file `cup95cal.sli`.

   This is the spectral library containing the results from the various calibration methods.

4. In the **Spectral Library Input File** dialog, select the open library file name and click **OK**.

The **Spectral Library Viewer** will appear with a list of the available spectra (Figure 12-11).

Select Atmospherically Corrected Spectra from Spectral Library

1. Select the ATREM, Flat Field, IARR, and Empirical Line corrected spectra for the mineral Alunite.

   The spectra are plotted in a **Spectral Library Viewer** plot (Figure 12-12). Visually compare the various calibrations and note and compare their characteristics.

2. Attempt to explain some of the differences in terms of the correction methodology used (see the above brief descriptions of the various methods).

3. When finished, select **Options** → **Clear Plots** in the menu bar at the top of the **Spectral Library Viewer** to clear the spectra.

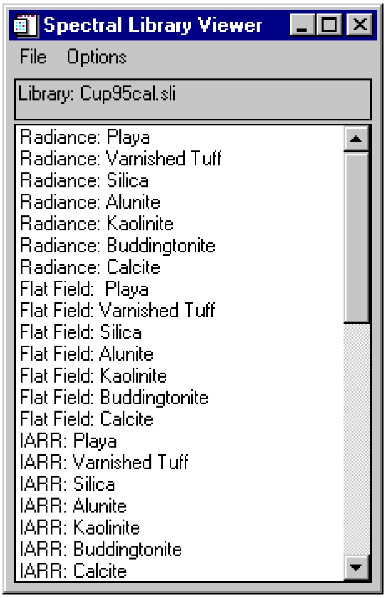


Figure 12-11: The Spectral Library Viewer dialog showing spectra from various calibrations.

Compare Corrected Spectra

Repeat the procedure for the minerals kaolinite, buddingtonite, calcite, and silica. What general conclusions can you draw about the quality of the different calibration procedures?

You can also compare the laboratory spectra for these minerals to the AVIRIS spectra by opening the `jpl1.sli` or the `usgs_sli.dat` spectral libraries, plotting the corresponding spectra, and dragging and dropping into the **Spectral Library Viewer** plot for direct comparison.

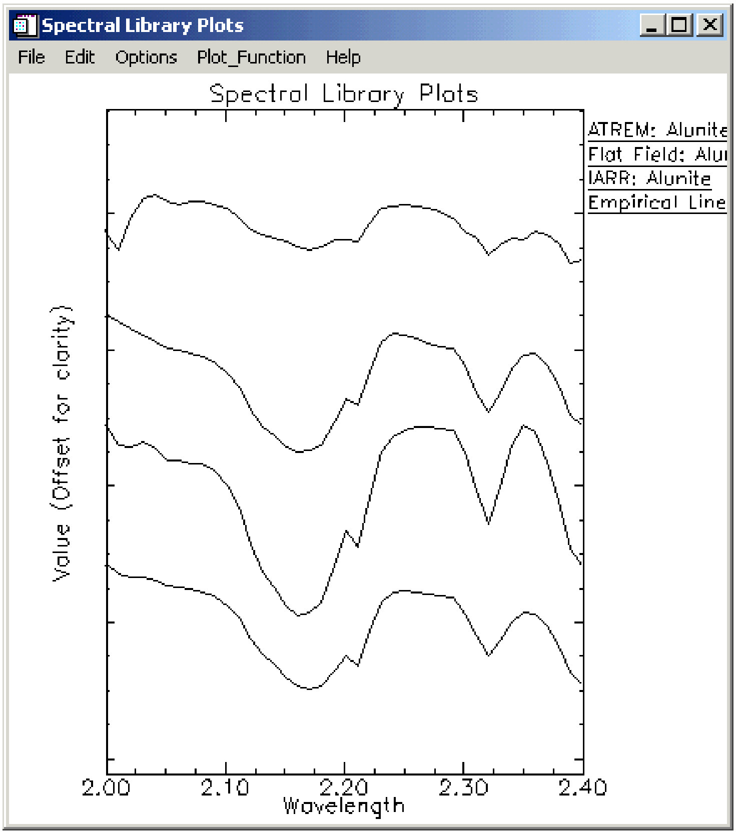


Figure 12-12: Comparison of Apparent Reflectance Spectra.

Optional: Browse Corrected Data Files

The corrected data files for all of the different corrections are available for spectral browsing if desired. All files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. Values of 1000 in the data indicate apparent reflectances of 1.0.

1. Open and load the files listed in the table below if desired.

File Type	File Name
ATREM	`cup95_at.int`
Flat Field	`cup95_ff.int`
IARR	`cup95_ia.int`
Emp. Line	`cup95_el.int`

2. Use the Z-profiling and multiple linked images to compare apparent reflectance spectra for specific areas of interest.
3. After comparison of all of the correction methods for a variety of minerals, which calibration method(s) best reproduce(s) the laboratory spectra for all minerals? Is there one best calibration method?

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

References

Conel, J. E., Green, R. O., Vane, G., Bruegge, C. J., Alley, R. E., and Curtiss, B., J., 1987, Airborne imaging spectrometer-2: radiometric spectral characteristics and comparison of ways to compensate for the atmosphere: in Proceedings, SPIE, v. 834, p. 140 - 157.

CSES (Center for the Study of Earth from Space), 1992, Atmospheric REMoval Program (ATREM), version 1.1, University of Colorado, Boulder, 24 p.

Gao, B. C., and Goetz, A. F. H., 1990, Column atmospheric water vapor and vegetation liquid water retrievals from airborne imaging spectrometer data: Journal of Geophysical Research, v. 95, no. D4, p. 3549-3564.

Goetz, A. F. H., Vane, G., Solomon, J. E., and Rock, B. N., 1985, Imaging spectrometry for Earth remote sensing: Science, v. 211, p. 1147 - 1153.

Goetz, A. F. H., and Srivastava, V., 1985, Mineralogical mapping in the Cuprite Mining District, Nevada: in Proceedings of the Airborne Imaging Spectrometer Data Analysis Workshop, JPL Publication 85-41, Jet Propulsion Laboratory, Pasadena, CA, p. 22-29.

Kruse F. A., Raines, G. l., and Watson, K., 1985, Analytical techniques for extracting geologic information from multichannel airborne spectroradiometer and airborne imaging spectrometer data: in Proceedings, 4th Thematic Conference on Remote Sensing for Exploration Geology, Environmental Research Institute of Michigan (ERIM), Ann Arbor, p. 309 - 324.

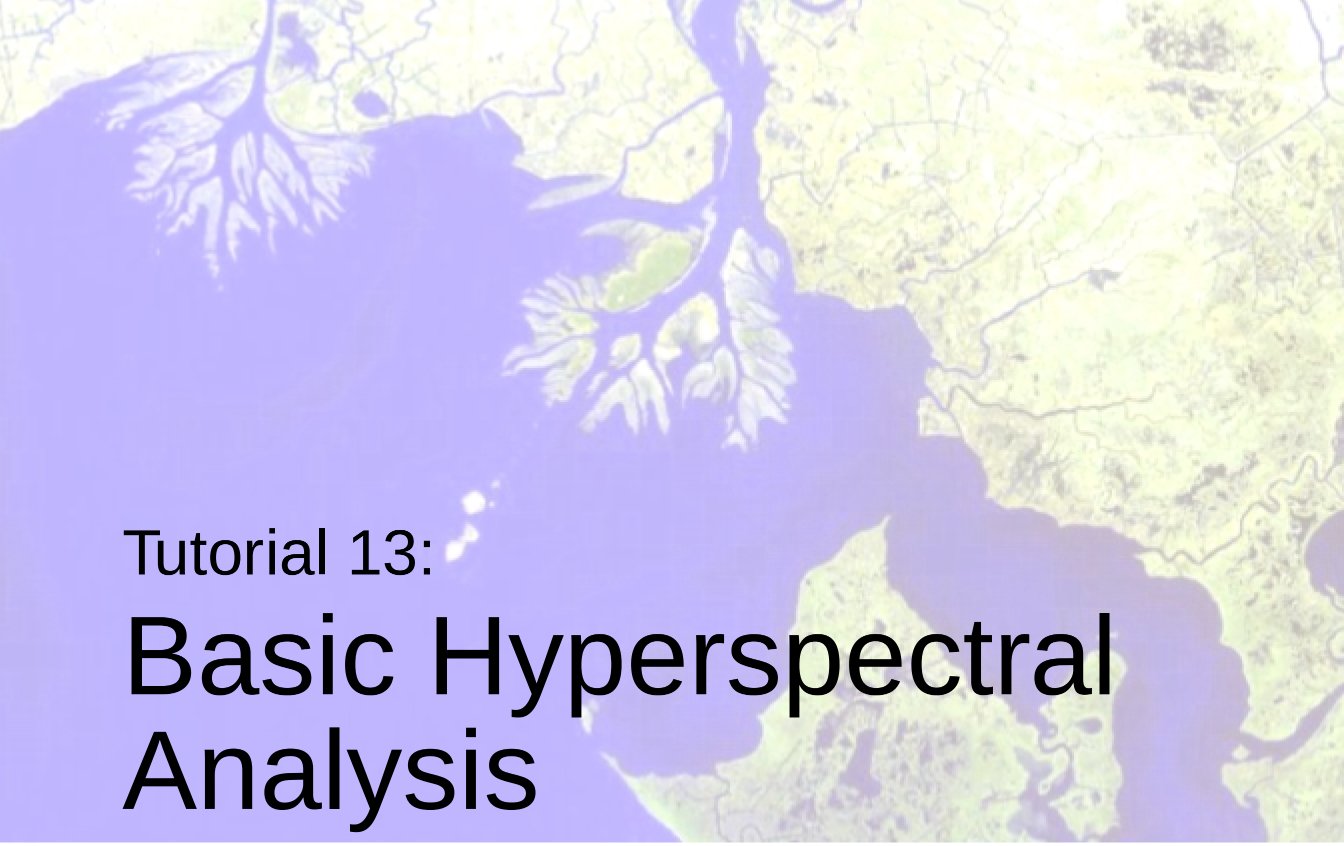
Kruse, F. A., 1988, use of Airborne Imaging Spectrometer data to map minerals associated with hydrothermally altered rocks in the northern Grapevine Mountains, Nevada and California: Remote Sensing of Environment, v. 24, no. 1, p. 31 - 51.

Kruse, F. A., Kierein-Young, K. S., and Boardman, J. W., 1990, Mineral mapping at Cuprite, Nevada with a 63 channel imaging spectrometer: Photogrammetric Engineering and Remote Sensing, v. 56, no. 1, p. 83-92.

Roberts, D. A., Yamaguchi, Y., and Lyon, R. J. P., 1985, Calibration of Airborne Imaging Spectrometer data to percent reflectance using field measurements: in Proceedings, Nineteenth International Symposium on Remote Sensing of Environment, Ann Arbor, MI, October 21-25, 1985.

Roberts, D. A., Yamaguchi, Y., and Lyon, R. J. P., 1986, Comparison of various techniques for calibration of AIS data: in Proceedings, 2nd AIS workshop, JPL Publication 86-35, Jet Propulsion Laboratory, Pasadena, CA, p. 21-30.

Vane, Gregg, and Goetz, 1985, Introduction to the proceedings of the Airborne Imaging Spectrometer (AIS) data analysis workshop: in Proceedings of the Airborne Imaging Spectrometer Data Analysis Workshop, JPL Publication 85-41, Jet Propulsion Laboratory, Pasadena, CA p. 1 - 21.



Tutorial 13:

Basic Hyperspectral Analysis

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to introduce you to the concepts of *Spectral Libraries*, *Region of Interest* (ROI) extraction of spectra, *Directed Color composites*, and to the use of 2-D scatter plots for simple classification. We will use 1995 Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) apparent reflectance data of Cuprite, Nevada, USA, calibrated using the ATREM atmospheric modeling software. The subsetted data cover the 1.99 to 2.48 µm range in 50 spectral bands approximately 10 nm wide. You will extract ROIs for specific minerals, compare them to library spectra, and design RGB color composites to best display the spectral information. You will also use 2-D scatter plots to locate unique pixels, interrogate the data distribution, and perform simple classification.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/c95avsub`

File	Description
`cup95_at.int`	Cuprite ATREM calibrated reflectance data. 50 bands (integer)
`cup95_at.hdr`	ENVI Header for above
`jpl1sli.dat`	JPL Spectral Library in ENVI format
`jpl1sli.hdr`	ENVI Header for above
`usgs_min.sli`	USGS Spectral Library in ENVI format
`usgs_min.hdr`	ENVI Header for above
`cup95_av.roi`	Saved ROI locations.

Note

The files listed are required to run this exercise. Selected data files have been converted from floating-point to integer format by multiplying by 1000 to conserve disk space. Data values of 1000 represent apparent reflectances of 1.0.

Spectral Libraries / Reflectance Spectra

This portion of the tutorial is designed to familiarize you with Spectral Libraries, browsing and extraction of image reflectance spectra, Region of Interest (ROI) definition in ENVI, and directed design of color composite images for spectral discrimination.

Start ENVI and Load AVIRIS data

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI on UNIX, enter `envi` at the UNIX command line.
- To open ENVI on Windows or Macintosh, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

1. On the ENVI main menu, select **File** → **Open Image File** and navigate to the `envidata/c95avsub` directory on the *ENVI Tutorial and Data CD No. 2*.
2. Choose `cup95_at.int` as the input file name and click **Open**. The **Available Bands List** dialog will appear, listing the 50 spectral band names.

Display a Grayscale Image

1. In the **Available Bands List** dialog, select **Band 193 (2.2008 μm)**.
2. Click the **Gray Scale** radio button and click **Load Band**. An ENVI image display containing the selected band will appear.
3. From the Main Image window menu, select **Tools** → **Profiles** → **Z Profile (Spectrum)** to extract an apparent reflectance spectrum.

Browse Image Spectra and Compare to Spectral Library

1. Move the Zoom window indicator box around the image while looking at the #1 Spectral Profile window to browse through image apparent reflectance spectra.
2. In the Main Image window, drag the box by grabbing and dragging with the left mouse button or click the middle mouse button to center the Zoom Indicator box on the selected pixel.
3. Compare apparent reflectance spectra from the image to selected library reflectance spectra.

   ENVI includes several spectral libraries. For the purposes of this exercise, you will use the JPL Spectral Library (Groves et al., 1992) and the USGS Spectral Library (Clarke et al., 1993).
4. Select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer** from the ENVI main menu.
5. In the **Spectral Library Input File** dialog, click **Open File**, select `jpl1.sli` from the `spec_lib/jpl_lib` subdirectory, and click **OK**.
6. Click on `jpl1.sli` in the **Select Input File** field and click **OK**.
7. In the **Spectral Library Viewer** dialog, select **Options** → **Edit (x, y) Scale Factors**, enter a value of 1000 into the **Y Data Multiplier** field to match the image apparent reflectance range (0 – 1000), and click **OK**.
8. Plot the following spectra by selecting the spectra names in the **Spectral Library Viewer** dialog:
   - ALUNITE SO-4A
   - BUDDINGTONITE FELDS TS-11A
   - CALCITE C-3D
   - KAOLINITE WELL ORDERED PS-1A

   The following plot is produced:

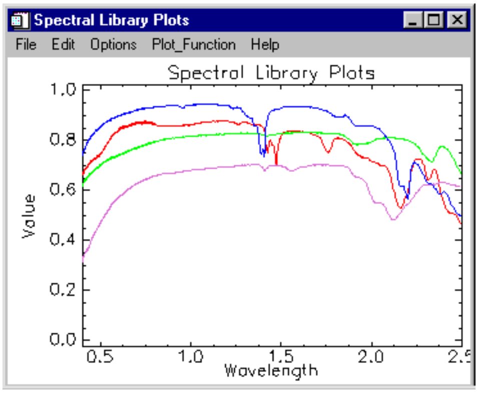


Figure 13-1: Library Spectra

9. Customize the plot by selecting **Edit** → **Plot Parameters** from the plot window menu. In the **Plot Parameter**s dialog, do the following:
   - Reduce the **Charsize** to 0.50.
   - Select the **X-Axis** radio button, and adjust the **Range** to 1.90 to 2.45.
   - With the **X-Axis** radio button selected, change the **Margin** fields until the X margins are as desired.
   - Select the **Y-Axis** radio button, and change the **Axis Title** to "Reflectance".
   - With the **Y-Axis** radio button selected, change the **Margin** fields until the Y margins are as desired.
   - Click **Apply** then **Cancel**.
10. To display a legend of the spectra names, right click in the plot window. Drag the plot window to the desired size to accommodate the spectra names.
11. In the plot window, offset the plot data by selecting **Options** → **Stack Data**. The plot now looks like the following:

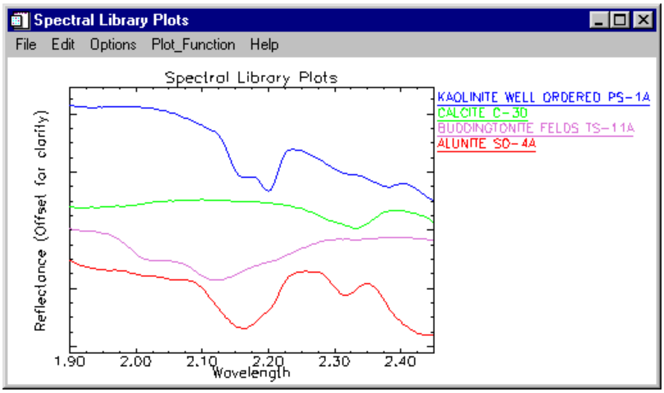


Figure 13-2: Customized Plot Parameters

12. Right click in the #1 Spectral Profile window to display a legend of X and Y pixel locations.
13. In the #1 Spectral Profile window, select **Options** → **New Window: Blank** to open a new plot window. Position the #1 Spectral Profile window and the new plot window so you can see both windows.
14. From the Main Image window menu, select **Tools** → **Pixel Locator**. We will use the **Pixel Locator** dialog to locate the exact pixels for the following locations:

Location Name	Sample (with offset)	Line (with offset)
Stonewall Playa	590	570
Varnished Tuff	435	555
Silica Cap	494	514
Opalite Zone with Alunite	531	541
Strongly Argillized Zone with Kaolinite	502	589
Buddington ZOne	448	505

Location Name	Sample (with offset)	Line (with offset)
Calcite	260	613

15. In the **Pixel Locator** dialog, enter 590 in the **Sample** field and enter 570 in the **Pixel** field to center the Zoom Indicator on pixel 590, 570 (Stonewall Playa). Click **Apply** to move to that location. The #1 Spectral Profile window updates to show the spectrum for this pixel. The legend should read “X:590 Y:570”.
16. Right click in the new plot window to display a legend of X and Y pixel locations.
17. In the #1 Spectral Profile window, click and hold the left mouse button on the legend item “X:590 Y:570”. Drag and drop this spectrum into the new plot window.
18. Repeat the previous steps for each site in the above table until the new plot window contains all 7 spectra.
19. In the new plot window, select **Options** → **Stack Data**. The new plot window should now look like the following:

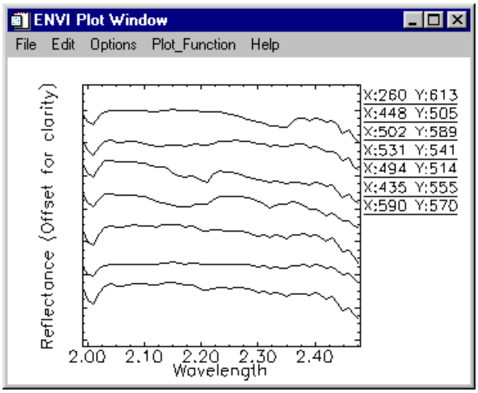


Figure 13-3: Individual ATREM Image Apparent Reflectance Spectra

20. Visually compare these spectra to the library spectra extracted previously.

    Note the similarity of shape and absorption features between the laboratory spectra and the individual image apparent reflectance spectra.

Based on these similarities, we conclude that the image spectra similar to the alunite, buddingtonite, calcite, and kaolinite laboratory spectra represent pixels predominantly of the above minerals.

21. Drag and drop spectra from the Spectral Library Plots window into the #1 Spectral Profile window for direct comparison.

Identify Spectra

Use the Spectral Analyst™ to identify spectra:

ENVI has a spectral matching tool that provides a score with respect to the library spectra. The spectral analyst uses several methods to produce a score between 0 and 1, with 1 equaling a perfect match.

1. Select **Spectral** → **Spectral Analyst** from the ENVI main menu.
2. Click on the **Open Spec Lib** button at the bottom of the **Spectral Analyst Input Spectral Library** dialog.
3. Navigate to the `usgs_min` spectral library directory, select the `usgs_min.sli` spectral library, and click **Open**.
4. The file `usgs_min.sli` should now appear in the **Spectral Analyst Input Spectral Library** dialog. Select this file and click **OK**.
5. In the **Edit Identify Methods Weighting** dialog, click **OK**.
6. From the Main Image window menu, select **Tools** → **Profiles** → **Z Profile (Spectrum)**. Right click in the #1 Spectral Profile window to display the legend of spectra.
7. From the Main Image window menu, select **Tools** → **Pixel Locator**.
8. Enter the pixel 502, 589 in the Pixel Locator dialog and click **Apply**.
9. In the Spectral Analyst dialog, select **Options** → **Edit Method Weights**.
10. In the **Edit Identify Methods Weighting** dialog, enter 0.33 in each of the **Weight** fields click **OK**. The different matching methods are described in the *ENVI 3.5 User's Guide*.
11. In the Spectral Analyst dialog, click Apply. If more than one spectrum is displayed in the #1 Spectral Profile window, a list of spectra will appear. If this

list appears, select the spectrum for pixel 502, 589. The **Spectral Analyst** dialog shows the following:

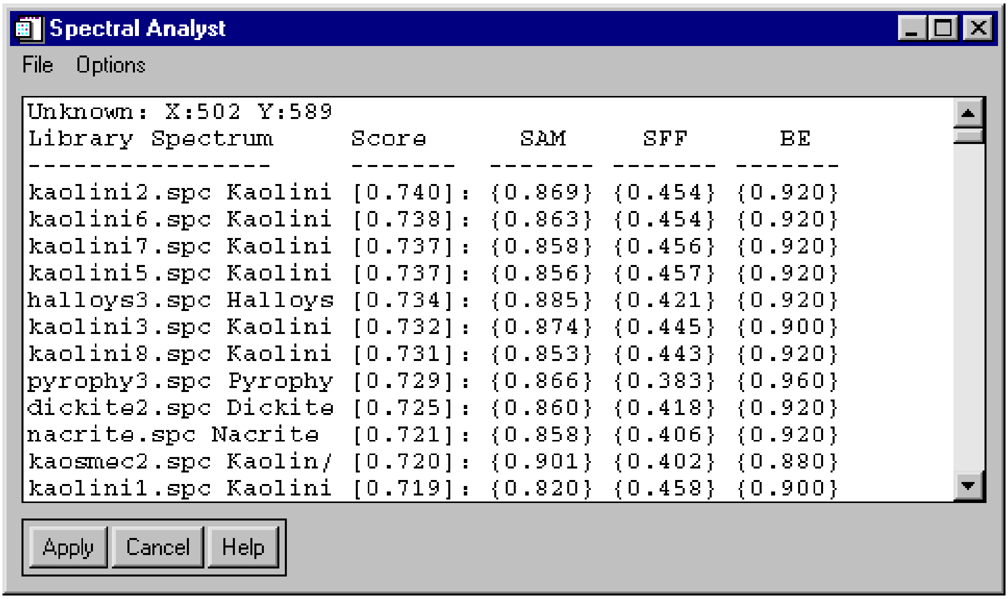


Figure 13-4: The Spectral Analyst dialog, showing a high match to the mineral kaolinite for pixel 502, 589.

The Spectral Analyst scores the unknown spectrum against the library. The previous figure shows an identification for pixel 502, 589. Note the high number of kaolinite spectra at the top of the list. This, and the relatively high scores, indicates a high likelihood of kaolinite.

12. Now double click on the first spectrum name in the list. This will plot the unknown and the library spectrum in the same plot for comparison, as shown in the following figure:

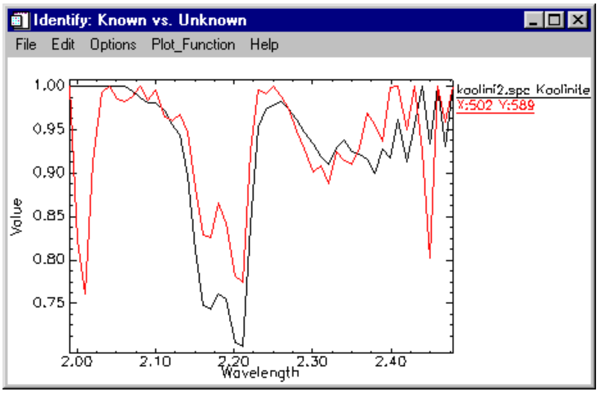


Figure 13-5: Comparison plot of the unknown against the best-match library spectrum for kaolinite showing a high degree of match.

13. Use the Spectral Analyst and the comparison plots to verify the mineralogy for the image spectra you have extracted. When you have identified several minerals, continue with the next section.
14. Optionally, compare spectra from the USGS Spectral Library `usgs_min.sli` with image spectra and the JPL Spectral library.

Close Windows and Plots

1. Close the **Spectral Library Viewer** and **Pixel Locator** dialogs.
2. Close all of the previous plot windows by selecting **Window** → **Close All Plot Windows**.

Define Regions of Interest

Regions of Interest (ROIs) are used to extract statistics and average spectra from groups of pixels. You can define as many ROIs as you wish in any displayed image. Select **Overlay** → **Region of Interest** from the Main Image window menu to start the ROI Tool.

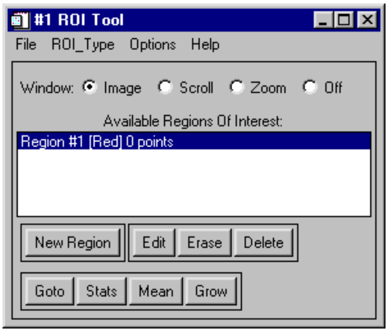


Figure 13-6: Region of Interest Tool

Create New Region of Interest

1. Click the left mouse button in the image.
2. Draw the ROI by clicking the left mouse button at the axes of a polygon, or draw continuously by clicking and dragging the left mouse button.
3. Complete the ROI by clicking the right mouse button to close the polygon and the right mouse button a second time to lock-in the ROI.
4. Click on the **Stats** button to calculate the statistics and plot a mean spectrum (white), the first standard deviation above and below the mean spectrum (green), and the Min/Max envelope containing all of the spectra in the ROI (red).
5. Select **File** → **Cancel** in the **File Statistics Report** dialog, and select **File** → **Cancel** in the Avg Spectrum plot.
6. Click **Delete** in the **ROI Tool** dialog to delete the selected ROI.

Load Previously Saved Regions of Interest

1. From the **ROI Tool** dialog menu, select **File** → **Restore ROIs**.
2. In the **Enter ROI Filename** dialog, navigate to the `envidata/c95avsub` directory, select the file `cup95_av.roi`, and click **Open**. Regions previously defined for known areas of specific minerals will be listed in an ENVI message dialog, and loaded into the **ROI Tool** dialog as shown in the following figure:

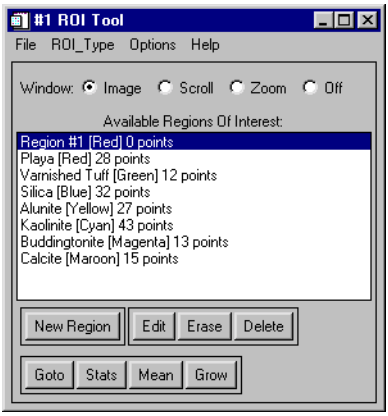


Figure 13-7: ROI Tool showing restored regions

3. Select the **Off** radio button at the top of the **ROI Tool** dialog to enable pixel positioning within the Main Image display.
4. Start a Z-Profile window by selecting **Tools** → **Profiles** → **Z-Profile (Spectrum)** in the Main Image window.
5. Move the current pixel position/cursor location into each ROI by clicking the middle mouse button on a pixel in the ROI.
6. Click on different pixels in the ROI to move the cursor position and display a new spectral profile in the Spectral Profile window.

Note that the y-axis plot range is automatically rescaled to match the spectral profile for each new ROI. Examine the spectral variability within each ROI.

Extract Mean Spectra from ROIs

1. Select an ROI name in the **ROI Tool** dialog, then click **Stats** to extract statistics and a spectral plot of the selected ROI.

2. Examine the spectral variability of each ROI by comparing the mean spectrum (white) with the 1st standard deviation spectra (green above and below the mean) and the envelope spectra (red above and below the mean).

3. Repeat for each ROI.

4. If you wish, load the corresponding library signatures from the `jpl1.sli` library into the plot window for direct comparison/identification. Don't forget to use a Y-Scaling Factor of 1000 when loading the library spectra.

5. When you have finished, close all of the **File Statistics Report** dialogs and plot windows.

6. In the **ROI Tool** dialog, select **Options** → **Mean for All Regions** to plot the average spectrum for each ROI in the same plot window.

7. In the plot window, select **Options** → **Stack Data** to offset spectra for comparison, as shown in the following figure:

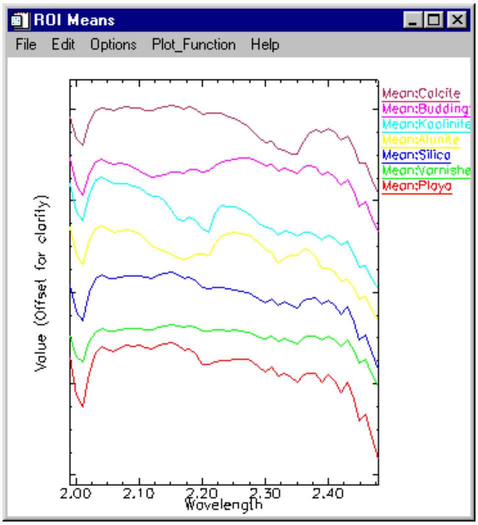


Figure 13-8: ROI Mean ATREM Image Apparent Reflectance Spectra

8. Compare the spectral features of each spectrum and note unique characteristics that might allow identification.

9. If desired, load the corresponding spectral library signatures from the `jpl1.sli` library for direct comparison of image apparent reflectance spectra

with laboratory spectra. Don't forget to use a Y Factor of 1000 when loading the library spectra.

10. Optionally, compare spectra from the USGS Spectral Library `usgs_min.sli` with image spectra and the JPL Spectral library.

Discriminate Mineralogy

Design color images to discriminate mineralogy:

1. In the **Available Bands List** dialog, select the **RGB Color** radio button, and click sequentially on Band 183, Band 193, and Band 207.
2. Click **Load RGB** to load the color image into the current image display.
3. In the Main Image window, select **Tools** → **Profiles** → **Z-Profile (Spectrum)**. Note that the positions of the bands used to make the RGB color composite image are marked in the Z-Profile with vertical red, green, and blue lines.
4. In the **ROI Tool** dialog, select the **Off** radio button and use the Z profiler accessed through the Main Image window to browse spectra at or near your ROI locations from above.

   Note where the selected RGB bands fall with respect to spectral features in the previously displayed mean spectra and how the spectral features affect the color observed in the image.
5. Change the plot bars in the spectral profile to the desired bands by clicking and dragging the plot bars with the left mouse button.

   Note

   (Note: one way to enhance specific materials is by centering one color bar in an absorption feature and the other two on opposite shoulders of the feature.)
6. Double click the left mouse button within the Z Profile plot window to load the new bands into the display window.

After inspecting a few sites, you should begin to understand how the color composite colors correspond with the spectral signature. For instance, the alunitic regions appear magenta in the RGB composite because the green band is within the alunite absorption feature, giving a low green value, while the red and blue bands are of almost equal reflectance. The combination of red and blue results in a magenta color for pixels containing alunite.

Based on the above results, try these exercises:

1. Predict how certain spectra will look, given a particular pixel's color in the RGB image.
2. Explain the colors of the training sites, in terms of their spectral features.
3. Design and test specific RGB band selections that maximize your ability to map certain minerals, like kaolinite and calcite.

Close Plot Windows and ROI Controls

1. Close all open plot windows by selecting **Window** → **Close All Plot Windows**.
2. Close the **ROI Tool** dialog by selecting **File** → **Cancel**.

2-D Scatter Plots

Examine 2-D Scatter Plots

1. In the Main Image window, select **Tools** → **2-D Scatter Plots** to start a 2-D scatter plot for the apparent reflectance image.
2. Select band 193 in the **Choose Band X** list and select band 207 in the **Choose Band Y** list.
3. Click **OK**.

The following scatter plot is displayed with a plot of the X vs. Y apparent reflectance values:

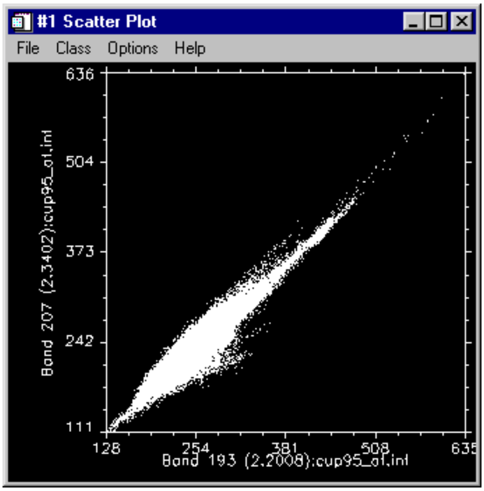


Figure 13-9: Scatter Plot of bands 193 and 207 (ATREM Apparent Reflectance)

Density Slice the Scatter Plot

1. From the scatter plot menu, select **Options** → **Density On** to automatically density-slice the scatter plot. The colors show the frequency of occurrence of specific apparent reflectance combinations for the two bands being scatter plotted. Purple is the lowest frequency, progressing through the colors blue, green, yellow, to red as the highest frequency of occurrence.
2. From the scatter plot menu, select **Options** → **Density Off** to turn off the color slice.

Scatter Plot Dancing Pixels

1. In the Main Image window, click and drag the left mouse button to toggle "Dancing Pixels" in the scatter plot. The red pixels in the scatter plot correspond to those pixels within a 10 x 10 box around the cursor in the Main Image window.
2. Try to predict the locations of certain image colors in the scatter plot, then check them. Notice the shape of the red sub-scatter plot of dancing pixels.
3. Change the box-cursor size in the scatter plot window by selecting **Options** → **Set Patch Size**, and observe the difference.

Image Dancing Pixels

1. In the scatter plot window, click and drag the middle mouse button over any portion of the white scatter plot to toggle "Dancing Pixels" in the Main Image window. The red pixels in the image correspond to those pixels within a 10 x 10 box around the cursor in the scatter plot window. Note the spatial distribution and coherency of the selected pixels.
2. Change the box-cursor size in the scatter plot window by selecting **Options** → **Set Patch Size**, and observe the difference.

Scatter Plots Linked to a Spectral Profile

1. From the scatter plot window menu, select **Options** → **Z Profile**, select an input file from which to extract the spectral profile, and click **OK**. This starts a blank ENVI spectral profile linked to the 2-D scatter plot.
2. Position the cursor in the 2-D scatter plot and click the right mouse button to extract the spectrum for the corresponding spatial pixel with those scatter plot characteristics.
3. Compare spectra from the different parts of the scatter plot and note what sorts of spectra appear at the "points" of the plot versus the center of the plot.

Scatter Plot ROIs

The scatter plot tool can also be used as a quick classifier.

1. Click the left mouse button in the scatter plot to select the first point of a Region of Interest (ROI).
2. Draw an ROI polygon in the scatter plot by selecting the desired line segments using the left mouse button.
3. Click the right mouse button to close the polygon. Image pixels with the two-band characteristics outlined by the polygon will be color-coded red in the Main Image window.
4. Choose another color from the *Class* pulldown menu in the scatter plot window.
5. Draw another polygon and the corresponding pixels will be highlighted in the selected color on the image.
6. To remove a class, select **Options** → **Clear Class**. You can also clear the current class by clicking the middle mouse button outside (below) the plot axes.
7. Use the 2-D scatter plot tool to work backwards from the scatter plot to see where certain pixels occur in the image.
8. Classes can be converted to ROIs to act as training sets for classification using all of the bands by selecting **Options** → **Export Class** or **Export All** from the scatter plot menu bar. ROIs exported in this fashion will appear in the **ROI Tool** dialog and be available for subsequent supervised classification. They can also be converted to a classification image by choosing **Classification** → **Create Class Image** from ROIs from the ENVI main menu.
9. Select **Options** → **Clear All** in the scatter plot to clear both scatter plot and image.

Image ROIs

The scatter plot tool also functions as a simple classifier from the image.

1. Choose **Options** → **Image ROI** in the scatter plot.
2. Draw polygons in the Main Image window using the left mouse button to draw lines and the right button to close and lock-in the polygon. They will be mapped to the scatter plot and highlighted in the currently selected color. After the pixels are highlighted on the scatter plot, all of the matching pixels in the image will be inverse-mapped to the Main Image window and highlighted in

the same color, as though you had drawn the scatter plot region yourself. This is the simplest form of 2-band classification, but it is still a powerful tool.

3. Draw a few image regions and note the correspondence between image color and scatter plot characteristics.

Scatter Plots and Spectral Mixing

Can you explain the overall diagonal shape of the scatter plot in terms of spectral mixing? Where do the purest pixels in the image fall on the scatter plot? Are there any secondary “projections” or “points” on the scatter plot?

1. Choose some other band combinations for scatter-plotting by selecting **Options** → **Change Bands** in the scatter plot. Try at least one pair of adjacent bands and other pairs that are far apart spectrally.

   How do the scatter plots change shape with different band combinations? Can you describe the *n*-Dimensional “shape” of the data cloud?

End the ENVI Session

This concludes the tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) from the ENVI main menu, then click **Yes**. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

References

Clark, R. N., Swayze, G. A., Gallagher, A., King, T. V. V., and Calvin, W. M., 1993, The U. S. Geological Survey Digital Spectral Library: Version 1: 0.2 to 3.0 mm: U. S. Geological Survey, Open File Report 93-592, 1340 p.

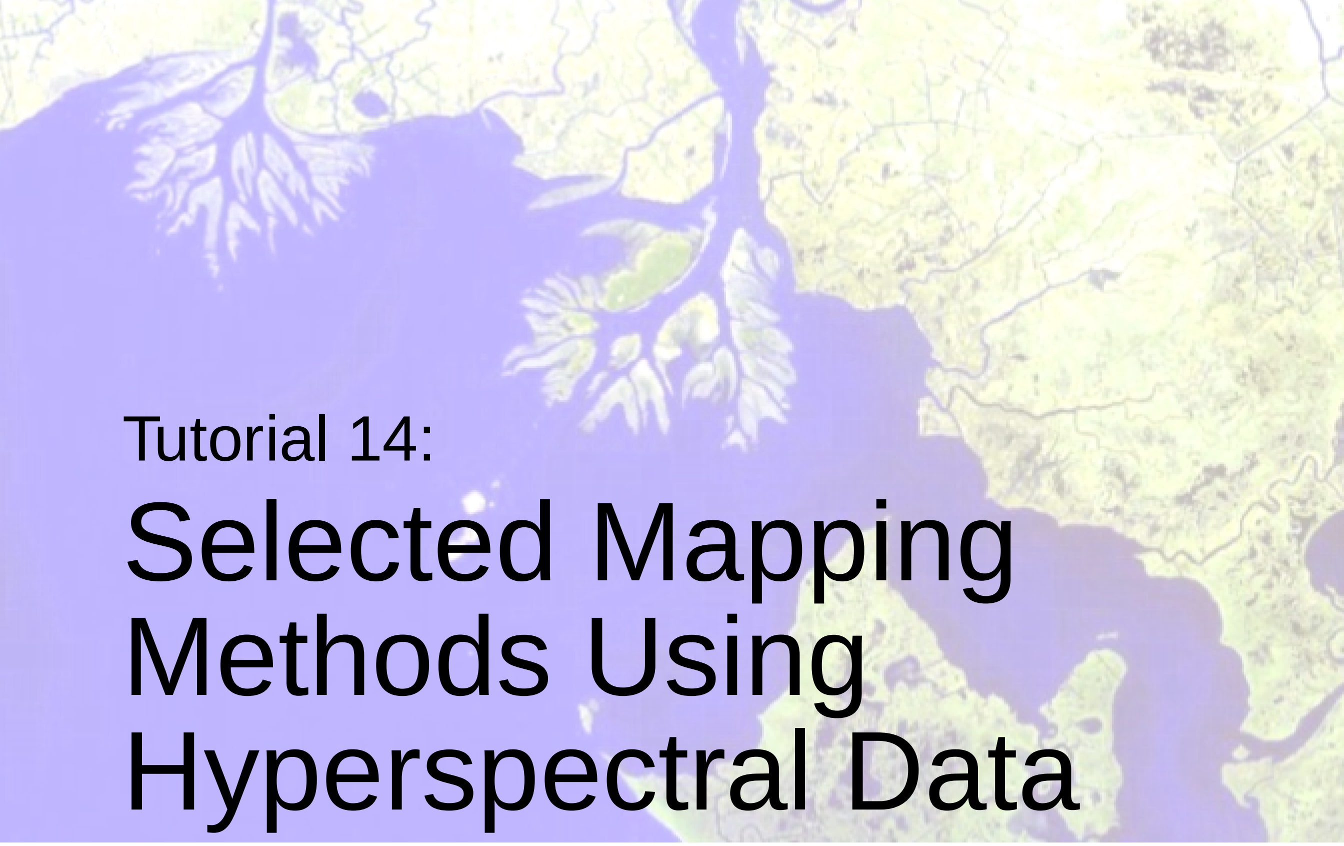
Clark, R. N., Gallagher, A. J., and Swayze, G. A., 1990, Material absorption band depth mapping of the imaging spectrometer data using a complete band shape least-squares fit with library reference spectra: in Proceedings of the Second Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Workshop, JPL Publication 90-54, p. 176 - 186.

Clark, R.N., T.V.V. King, M. Klejwa, G. Swayze, and N. Vergo, 1990, High Spectral Resolution Reflectance Spectroscopy of Minerals: J. Geophys Res. 95, 12653-12680.

Grove, C. I., Hook, S. J., and Paylor, E. D., 1992, Laboratory reflectance spectra of 160 minerals, 0.4 to 2.5 Micrometers: JPL Publication 92-2.

Kruse, F. A., Lefkoff, A. B., and Dietz, J. B., 1993, Expert System-Based Mineral Mapping in northern Death Valley, California/Nevada using the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): Remote Sensing of Environment, Special issue on AVIRIS, May-June 1993, v. 44, p. 309 - 336.

Kruse, F. A., and Lefkoff, A. B., 1993, Knowledge-based geologic mapping with imaging spectrometers: Remote Sensing Reviews, Special Issue on NASA Innovative Research Program (IRP) results, v. 8, p. 3 - 28.



Tutorial 14: Selected Mapping Methods Using Hyperspectral Data

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to introduce you to advanced concepts and procedures for analysis of imaging spectrometer data or *hyperspectral images*. We will use 1995 Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data from Cuprite, Nevada, to investigate the unique properties of hyperspectral data and how spectral information can be used to identify mineralogy. We will evaluate EFFORT "polished" spectra versus ATREM-calibrated data, and review the Spectral Angle Mapper classification. We will compare apparent reflectance spectra and continuum-removed spectra. We will also compare apparent reflectance images and continuum-removed images and evaluate Spectral Feature Fitting™ results.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/c95avsub`

File	Description
`cup95_at.int`	Cuprite ATREM calibrated apparent reflectance data. 50 bands (integer).
`cup95_at.hdr`	ENVI Header for above.
`cup95eff.int`	Cuprite EFFORT-Corrected ATREM calibrated apparent reflectance data. 50 bands (integer).
`cup95eff.hdr`	ENVI Header for above.
`jpl1sli.dat`	JPL Spectral Library in ENVI format.
`jpl1sli.hdr`	ENVI Header for above.
`usgs_min.sli`	USGS Spectral Library in ENVI format.
`usgs_min.hdr`	ENVI Header for above.
`cup95_av.roi`	Saved ROI locations.
`cupsamem.asc`	Optional file of ROI mean spectra.
`cupsam1.img`	SAM classification image using ROI image spectra endmembers.
`cupsam1.hdr`	ENVI Header for above.

File	Description
`cuprul1.img`	SAM rule image using ROI image spectra endmembers.
`cuprul1.hdr`	ENVI Header for above.
`cupsam2.img`	SAM classification image using Spectral Library EM.
`cupsam2.hdr`	ENVI Header for above.
`cuprul2.img`	SAM rule images using Spectral Library endmembers.
`cuprul2.hdr`	ENVI Header for above.
`cup95_cr.dat`	Continuum-removed data (floating point)
`cup95_cr.hdr`	ENVI Header for above.
`cup95sff.dat`	Spectral Feature Fitting Results
`cup95sff.hdr`	ENVI Header for above.
`cup95sfr.dat`	Spectral Feature Fitting Band-Math Results
`cup95sfr.hdr`	ENVI Header for above.

Note

The files listed are required to run this exercise. Optional files listed below may also be used if more detailed calibration comparisons are desired. All image data files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. A value of 1000 therefore represents apparent reflectance of 1.0.

Removal of Residual Calibration Errors

Use EFFORT (Empirical Flat Field Optimized Reflectance Transformation) to remove residual calibration errors. EFFORT is a correction used to remove residual “saw-tooth” instrument (or calibration-introduced) noise and atmospheric effects from ATREM-calibrated AVIRIS data. It is a custom correction designed to improve overall quality of spectra. It provides the best reflectance spectra available from AVIRIS data, so the EFFORT data are used in later exercises in this tutorial. EFFORT is a relatively automated improvement on the Flat-Field Calibration method (Boardman and Huntington, 1996). The EFFORT correction selects those AVIRIS spectra that match a low-order polynomial estimate in a least-squares sense as representative featureless spectra. These spectra are averaged and a mild gain factor is determined to remove systematic, coherent noise, present in every spectrum, including small residual atmospheric effects near 2.0 µm range attributable to CO_2. EFFORT is run from ENVI by selecting **Spectral** → **Effort Polishing**. We will not run this function during this exercise, but will instead compare pre-calculated EFFORT-corrected data to 1995 AVIRIS data corrected to reflectance using only ATREM without the corresponding EFFORT correction.

Open and Load the 1995 EFFORT-Corrected Data

1. Select **File** → **Open Image File** from the ENVI main menu, navigate to the `envidata/c95avsub` directory on the *ENVI Tutorial and Data CD No. 2*, select the file `cup95eff.int`, and click **Open**. This is the 1995 AVIRIS ATREM-calibrated apparent reflectance data with the EFFORT correction.
2. Select **Tools** → **Profiles** → **Z Profile (Spectrum)** from #1 Image window menu.
3. Start a new display (#2) by selecting **New Display** from the **Display** pulldown button at the bottom of the **Available Bands List** dialog.
4. Select **File** → **Open Image File** from the ENVI main menu, select the file `cup95_at.int`, and click **Open**. This is the 1995 ATREM calibrated apparent reflectance data.
5. In the **Available Bands List** dialog, select band 193 (2.20 µm), select the **Gray Scale** radio button, and click **Load Band**.
6. Select **Tools** → **Profiles** → **Z Profile (Spectrum)** from #2 Image window menu.
7. Compare the two spectral profiles.

Compare ATREM and Effort Spectra

1. From the #1 image window menu, select **Tools** → **Link** → **Link Displays**.
2. Click **OK** in the **Link Displays** dialog to activate the link.
3. From the #1 image window menu, select **Tools** → **Link** → **Dynamic Overlay Off** to enable normal mouse interaction.

   Moving the Zoom window indicator box in this image will cause the cursor location to be updated in the #2 image window. Both spectral profiles will show the spectrum for the current pixel.
4. Move the Zoom window indicator box around the image and compare the corresponding ATREM and EFFORT spectra. Note where the major differences occur.
5. In the #1 image window, select **Tools** → **Pixel Locator**, and position the cursor at 503, 581.
6. Right-click in the #1 plot window to display the plot legend.
7. Drag and drop the EFFORT spectrum in the #1 plot window by grabbing the first character of the legend name and dragging onto the #2 (ATREM-only) plot window.
8. From the #2 plot window menu, select **Edit** → **Data Parameters**.
9. In the **Data Parameters** dialog, change the color of the EFFORT spectrum and add the text “(EFFORT)” to the Name. Similarly, add the text “(ATREM-Only)” to the Name of the ATREM spectrum.
10. Stack the spectra by selecting **Options** → **Stack Data**. The plot should now resemble the following:

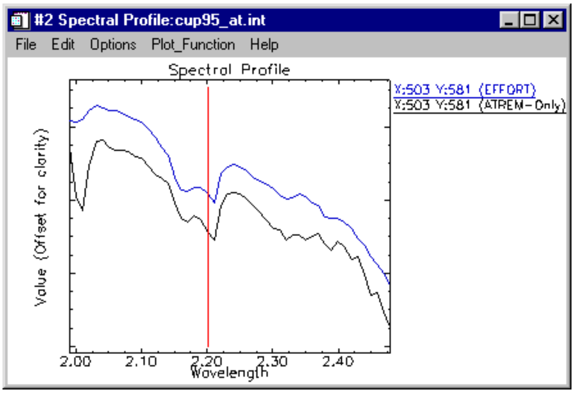


Figure 14-1: Comparison of EFFORT Apparent Reflectance (top) and ATREM-only (bottom) Spectra.

11. Compare the EFFORT-corrected spectrum to the ATREM-only spectrum. Note how similar the two spectra are, but how very small coherent noise “wiggles” have been removed from the EFFORT spectrum. Also note the correction of residual CO_2 at 2.01 µm.
12. In the #2 (ATREM) spectral profile window, delete the imported spectrum by clicking the right mouse button on the first character of the EFFORT spectrum name.
13. In the #1 image window, move the cursor location to 542, 533 using the Pixel Locator, and drag the spectrum from the #1 spectral profile window to the #2 spectral profile window. Note how EFFORT changes the spectrum.
14. Try selecting some other points in the two images using the Pixel Locator and compare the spectra. What are the major differences?

Close All Files, Displays, and Plots

Close all of the files used in the previous section by selecting **File** → **Close All Files** from the ENVI main menu and clicking **Yes**. The associated plot windows will also be closed.

Spectral Angle Mapper Classification

Next, we will use both image and laboratory spectra to classify the AVIRIS data using the “Spectral Angle Mapper” (SAM). We will go through the endmember selection process for SAM, but will not actually run the algorithm. We will examine previously calculated classification results to answer specific questions about the strengths and weaknesses of the SAM classification.

The Spectral Angle Mapper (SAM) is an automated method for comparing image spectra to individual spectra or a spectral library (Boardman, unpublished data; CSES, 1992; Kruse *et al*., 1993a). SAM assumes that the data have been reduced to apparent reflectance (true reflectance multiplied by some unknown gain factor controlled by topography and shadows). The algorithm determines the similarity between two spectra by calculating the “spectral angle” between them, treating them as vectors in a space with dimensionality equal to the number of bands (*nb*). A simplified explanation of this can be given by considering a reference spectrum and an unknown spectrum from two-band data. The two different materials will be represented in the 2-D scatter plot by a point for each given illumination, or as a line (vector) for all possible illuminations.

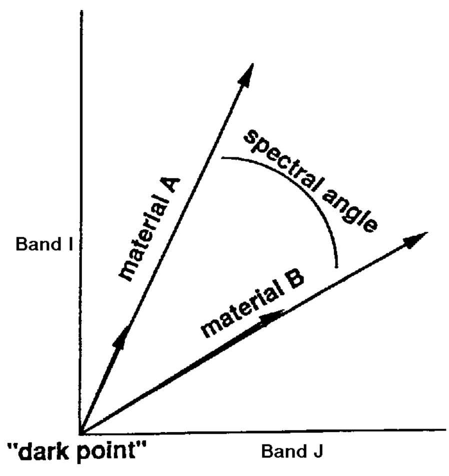


Figure 14-2: Two-dimensional example of the Spectral Angle Mapper

Because it uses only the “direction” of the spectra, and not their “length,” the method is insensitive to the unknown gain factor, and all possible illuminations are treated equally. Poorly illuminated pixels will fall closer to the origin. The “color” of a material is defined by the direction of its unit vector. Notice that the angle between the vectors is the same regardless of the length. The length of the vector relates only to how fully the pixel is illuminated.

The SAM algorithm generalizes this geometric interpretation to *nb*-dimensional space. SAM determines the similarity of an unknown spectrum *t* to a reference spectrum *r*, by applying the following equation (CSES, 1992):

$$\alpha = \cos^{-1}\left(\frac{\vec{t} \bullet \vec{r}}{\|\vec{t}\| \bullet \|\vec{r}\|}\right)$$

which also can be written as:

$$\alpha = \cos^{-1}\left(\frac{\sum_{i=1}^{nb} t_i r_i}{\left(\sum_{i=1}^{nb} t_i^2\right)^{1/2}\left(\sum_{i=1}^{nb} r_i^2\right)^{1/2}}\right)$$

where *nb* equals the number of bands in the image.

For each reference spectrum chosen in the analysis of a hyperspectral image, the spectral angle α is determined for every image spectrum (pixel). This value, in radians, is assigned to the corresponding pixel in the output SAM image, one output image for each reference spectrum. The derived spectral angle maps form a new data cube with the number of bands equal to the number of reference spectra used in the mapping. Gray-level thresholding is typically used to empirically determine those areas that most closely match the reference spectrum while retaining spatial coherence.

The SAM algorithm implemented in ENVI takes as input a number of “training classes” or reference spectra from ASCII files, ROIs, or spectral libraries. It calculates the angular distance between each spectrum in the image and the reference spectra or “endmembers” in *n*-dimensions. The result is a classification image showing the best SAM match at each pixel and a “rule” image for each endmember showing the actual angular distance in radians between each spectrum in the image and the reference spectrum. Darker pixels in the rule images represent smaller spectral angles, and thus spectra that are more similar to the reference spectrum. The rule images can be used for subsequent classifications using different thresholds to decide which pixels are included in the SAM classification image.

Select Image Endmembers

1. Open the 1995 AVIRIS ATREM-calibrated apparent reflectance data file, `cup95eff.int`. This is image window #1.
2. In the **Available Bands List** dialog, select band 193 (2.20 µm), select the **Gray Scale** radio button, and click **Load Band**.
3. From the ENVI main menu, select **Classification** → **Supervised Classification** → **Spectral Angle Mapper** (or alternatively, **Spectral** → **Mapping Methods** → **Spectral Angle Mapper**) to start the SAM endmember selection process.
4. In the Classification Input File dialog, select the file `cup95eff.int` as the input file and click **OK**.
5. In the SAM Endmember Collection dialog, select **Import** → **from ASCII file**.
6. Select the file `cup95_em.asc` and click **Open**.
7. In the **Input ASCII File** dialog, hold down the Ctrl key and deselect the spectra Dark/black, Bright/playa, Silica? (Dark), and Alunite (2.18) in the **Select Y Axis Columns** list. This will leave you with the mean spectra Zeolite, Calcite, Alunite (2.16), Kaolinite, Illite/Muscovite, Silica (Bright), and Buddingtonite.
8. Click **OK** to load all of the endmember spectra into the **Endmember Collection:SAM** dialog.
9. From the **Endmember Collection:SAM** dialog menu, select **Options** → **Plot Endmembers** to plot the endmember spectra.
10. From the Endmember Spectra plot window, select **Options** → **Stack Data** for improved comparison of spectral features, then right click in the plot window to display the legend. The result is shown in the following figure:

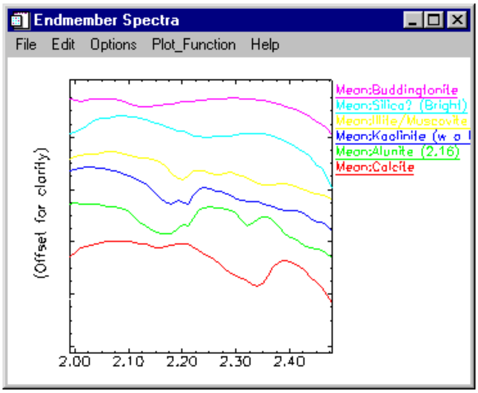


Figure 14-3: Spectral Endmembers for use with SAM.

Normally, you would click **Apply** on the **Endmember Collection:SAM** dialog to start the classification, but because classification can take some time, preprocessed results are provided for this exercise.

11. If sufficient time and resources are available, click **Apply** in the **Endmember Collection:SAM** dialog, enter output file names in the **Spectral Angle Mapper Parameters** dialog, and click **OK**.

    Or

    In the **Endmember Collection:SAM** dialog, click **Cancel** and continue by reviewing previously calculated SAM results as described below.

Execute SAM

1. Open the SAM classification image by selecting **File** → **Open Image File** and choosing `cupsam1.img` as the input file name. The classification image is one band with coded values for each class (for example, alunite is coded as “1”). When opened, the classified image will appear in the **Available Bands List** dialog.
2. In the **Available Bands List** dialog, ensure that the **Gray Scale** radio button is selected.

3. Click **Display** → **New Display**, select the SAM classification image, then click **Load Band**. This is image window #2. The classes will automatically be color coded as follows:

Mineral	Color
Zeolites	White
Calcite	Green
Alunite	Yellow
Kaolinite	Red
Illite/Muscovite	Dark Green
Silica	Blue
Buddingtonite	Maroon

Note

The number of pixels displayed as a specific class is a function of the threshold used to generate the classification. Just because a given pixel is classified as a specific mineral doesn't make it so. SAM is a similarity measure, not an identifier.

4. In the **Available Bands List** dialog, click **Display** → **New Display**. This is image window #3.
5. Select the **RGB Color** radio button, then select in sequence bands 183, 193, and 207 of the EFFORT data. Click **Load RGB**.
6. Start a spectral profile by selecting **Tools** → **Profiles** → **Z-Profile** in the #3 image window.
7. Compare the SAM classification results with the distributions shown by the color composite image.
8. Open the SAM rule image by selecting **File** → **Open Image File** and choosing `cuprul1.img` as the input file name.

   The rule image has one band for each endmember classified, with the pixel values representing the spectral angle in radians. Lower spectral angles (darker pixels) represent better spectral matches to the endmember spectrum.

   When opened, one band for each endmember will appear in the **Available Bands List** dialog.

9. In the **Available Bands List** dialog, ensure that the **Gray Scale** radio button is selected. Select **Display** → **New Display**, then click **Load Band**. This is image window #4.
10. Evaluate the image with respect to the color composite and the SAM classification image as well as the ROI means and individual spectra extracted using the Z Profiler.
11. In image window #4, select **Tools** → **Color Mapping** → **ENVI Color Tables**.
12. Use the **Stretch Bottom** and **Stretch Top** sliders to adjust the SAM rule thresholds to highlight those pixels with the greatest similarity to the selected endmember.
13. Pull the **Stretch Bottom** slider all the way to the right and the **Stretch Top** slider all the way to the left to highlight the most similar pixels in white.
14. Move the **Stretch Bottom** slider gradually to the left to reduce the number of highlighted pixels and show only the best SAM matches in white. You can use a rule image color composites or image animation if desired to compare individual rule images.
15. Repeat the process with each SAM rule image. Select **File** → **Cancel** when finished to close the **ENVI Color Tables** dialog.
16. Select **Windows** → **Close All Display Windows**.

Select Spectral Library Endmembers

In this exercise, we will once again go through the endmember selection process, but we won't actually perform the SAM classification. Previously saved SAM results will be used for comparisons. If you have time, you can perform your own SAM classification using spectral library endmembers.

1. From the ENVI main menu, select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer**.
2. Click **Open File**, select the file `envidata/spec_lib/jpl_lib/jpl1.sli` and click **Open**.
3. In the **Spectral Library Input File** dialog, select `jpl1.sli` and click **OK**.
4. In the **Spectral Library Viewer** dialog, plot the following spectra by clicking on the mineral name in the list of spectra:
   - ALUNITE SO-4A
   - BUDDINGTONITE FELDS TS-11A

- CALCITE C-3D
- CHABAZITE TS-15A (a zeolite mineral)
- ILLITE PS-11A
- KAOLINITE WELL ORDERED PS-1A

5. Start the SAM endmember selection process by selecting **Classification** → **Supervised** → **Spectral Angle Mapper** from the ENVI main menu. You can also access this function from the ENVI **Spectral** menu.
6. If the file `cup95eff.int` does not appear in the input file list in the **Classification Input File** dialog, click **Open File**, select the file `envidata/c95avsub/cup95eff.int` and click **Open**.
7. In the **Classification Input File** dialog, select the file `cup95eff.int` as the input file and click **OK**.
8. In the **Endmember Collection: SAM** dialog, select **Import** → **from Spectral Library**.
9. In the **Spectral Input Library File** dialog, select the file `jpl1.sli` and click **OK**.
10. In the **Input Spectral Library** dialog, hold down the Ctrl key and select the following spectra, then click **OK**:
    - ALUNITE SO-4A
    - BUDDINGTONITE FELDS TS-11A
    - CALCITE C-3D
    - CHABAZITE TS-15A (a zeolite mineral)
    - ILLITE PS-11A
    - KAOLINITE WELL ORDERED PS-1A
11. From the ENVI main menu, select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer**.
12. In the **Spectral Library Input File** dialog, click **Open File**.
13. In the **Please Select a File** dialog, select the file `envidata/spec_lib/usgs_min/usgs_min.sli` and click **Open**.
14. In the **Spectral Library Input File** dialog, select `usgs_min.sli` and click **OK**.

15. Select the endmember “opal2.spc Opal TM8896 (Hyalite)” from the list of spectra. Note that the spectra are automatically resampled to the AVIRIS wavelengths and resolution using the AVIRIS band positions and FWHM and listed in the **Endmember Collection** dialog.
16. Select **Options** → **Plot Endmembers** to plot the endmember spectra for these AVIRIS data.
17. Choose **Options** → **Stack Data** in the plot window to offset the spectra vertically for comparison.
18. Compare these spectra to the image spectra plotted in the previous SAM exercise.
19. Since we will not actually be performing the SAM classification because of time constraints, click **Cancel** in the **Endmember Collection** dialog to continue the exercise. If you have time, you can generate your own SAM classification by clicking **Apply**.

Review SAM Results

1. Open the pre-calculated SAM classification image generated using Spectral Library Endmembers by selecting **File** → **Open Image File**.
2. Select `envidata/c95avsub/cupsam2.img` as the input file name and click **Open**.

   The classification image is one band with coded values for each class (for example, alunite is coded as “1”). When opened, the classified image will appear in the **Available Bands List** dialog.
3. Ensure that the **Gray Scale** radio button is selected.
4. Load the SAM classification image into a new ENVI display window by clicking on the classified image name, clicking **Display** → **New Display** and then **Load Band**.

   The classes will automatically be color coded as follows:

Mineral	Color
Zeolites	White
Calcite	Green
Alunite	Yellow
Kaolinite	Red

Mineral	Color
Illite/Muscovite	Dark Green
Silica	Blue
Buddingtonite	Maroon

Note

The number of pixels displayed as a specific class is a function of the threshold used to generate the classification. Just because a given pixel is classified as a specific mineral doesn't make it so. SAM is a similarity measure, not an identifier).

5. Compare the classification results with the distributions shown by the color composite image, the previous classification using image spectra, and the library spectra. Use image linking for direct comparison if desired.
6. Load the SAM rule images by selecting **File** → **Open Image File** and selecting `envidata/c95avsub/cuprul2.img` as the input file name and clicking **Open**.

   Again, the rule image has one band for each endmember classified, with the pixel values representing the spectral angle in radians. Lower spectral angles (darker pixels) represent better spectral matches to the endmember spectrum. When opened, one band for each endmember will appear in the **Available Bands List** dialog.
7. Ensure that the **Gray Scale** radio button is selected.
8. Load a SAM rule image into a new ENVI display window by clicking on the classified image name, selecting **Display** → **New Display**, then clicking **Load Band**.
9. Evaluate the image using the ENVI Color Tables as above and with respect to the color composite and the SAM classification image as well as the ROI means and individual spectra extracted using the Z Profiler. Also use a rule image color composite or image animation if desired to compare individual rule images.
10. Repeat the process with each SAM rule image. Based upon the results of the two SAM classifications, answer the following questions:
    - What ambiguities exist in the SAM classification based on your images and spectra above?

- Why are the two classifications so different? What factors could affect how well SAM matches the endmember spectra?
- How could you determine which thresholds represent a true map of the selected endmembers?
- Can you see the topographic shading effects in the SAM data? Why or why not?
- Make a sketch map of the Cuprite surface mineralogy for all classes on a separate piece of paper. Do some classes co-occur?
- In light of some of the ambiguities in the SAM classification, how could you select better endmembers?

Optional: Generate new SAM Classified Images Using Rule Classifier

If you have extra time at the end of the exercise, try generating new classified images based on different thresholds in the rule images.

1. Display the individual bands of one of the two previously calculated rule images `cuprul1.img` or `cuprul2.img` and define the threshold for the classification by browsing using the **Cursor Location/Value** dialog. Thresholds can also be defined using ENVI’s interactive density slice tool, by selecting **Tools** → **Color Mapping** → **Density Slice** in the main image window.
2. Now select **Classification** → **Post Classification** → **Rule Classifier** and choose the rule file as viewed above for classification.
3. In the **Rule Image Classifier** dialog, select a rule file and click **OK**.
4. In the **Rule Image Classifier Tool** dialog, select “Minimum Value” in the **Classify by** field, and enter the previously defined SAM threshold.

   All of the pixels with values lower than the minimum will be classified. Lower thresholds result in fewer pixels being classified.
5. Click either **Quick Apply** or **Save to File** to begin the processing. After a short wait, the new classification image will appear.
6. Compare with previous classifications and comment on the differences and what they mean.

Close Files and Plots

- To close all of the files used in this portion of the exercise, select **File** → **Close All Files** in the **Available Bands List** dialog, then click **Yes**.
- To close all of the spectral plots, select **Window** → **Close All Plot Windows**.

Spectral Feature Fitting and Analysis

Spectral Feature Fitting™ (SFF™) is an absorption-feature-based method for matching image spectra to reference endmembers, similar to methods developed at the U. S. Geological Survey, Denver (Clark et al., 1990, 1991, 1992; Clark and Swayze, 1995).

Most methods used for analysis of hyperspectral data still do not directly identify specific materials. They only indicate how similar the material is to another known material or how unique it is with respect to other materials. Techniques for direct identification of materials, however, via extraction of specific spectral features from field and laboratory reflectance spectra have been in use for many years (Green and Craig, 1985; Kruse et al., 1985; Yamaguchi and Lyon, 1986; Clark et al., 1987). Recently, these techniques have been applied to imaging spectrometer data, primarily for geologic applications (Kruse et al., 1988; Kruse, 1988; Kruse, 1990; Clark et al., 1990, 1991, 1992; Clark and Crowley, 1992; Kruse et al. 1993b, 1993c; Kruse and Lefkoff, 1993, Swayze et al., 1995).

All of these methods require that data be reduced to reflectance and that a continuum be removed from the reflectance data prior to analysis. A continuum is a mathematical function used to isolate a particular absorption feature for analysis (Clark and Roush, 1984; Kruse et al, 1985; Green and Craig, 1985). It corresponds to a background signal unrelated to specific absorption features of interest. Spectra are normalized to a common reference using a continuum formed by defining high points of the spectrum (local maxima) and fitting straight line segments between these points. The continuum is removed by dividing it into the original spectrum.

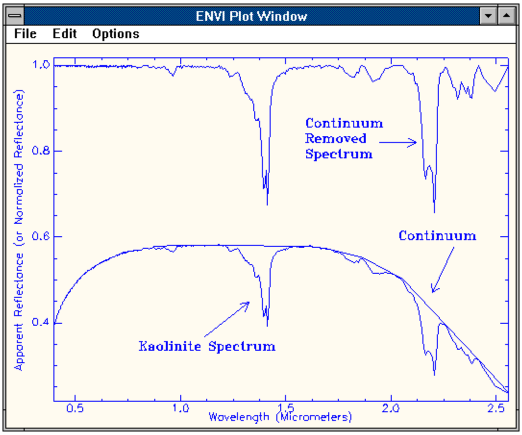


Figure 14-4: Example of a fitted continuum and a continuum-removed spectrum for the mineral kaolinite.

Spectral feature fitting requires that reference endmembers be selected from either the image or a spectral library, that both the reference and unknown spectra have the continuum removed, and that each reference endmember spectrum be scaled to match the unknown spectrum. A “Scale” image is produced for each endmember selected for analysis by first subtracting the continuum-removed spectra from one, thus inverting them and making the continuum zero. A single multiplicative scaling factor is then determined that makes the reference spectrum match the unknown spectrum. Assuming that a reasonable spectral range has been selected, a large scaling factor is equivalent to a deep spectral feature, while a small scaling factor indicates a weak spectral feature.

A least-squares-fit is then calculated band-by-band between each reference endmember and the unknown spectrum. The total root-mean-square (RMS) error is used to form an RMS error image for each endmember. An optional ratio image of Scale/RMS provides a “Fit” image that is a measure of how well the unknown spectrum matches the reference spectrum on a pixel-by-pixel basis.

Open and Load the Continuum-Removed Data

For the purposes of this exercise, you can use pre-calculated data if you do not wish to create your own continuum-removed data. If you want to use pre-calculated data, you can skip to the To Use Pre-Calculated Data section.

To Create Your Own Data

1. Open the file `cup95eff.int` and select **Spectral** → **Mapping Methods** → **Continuum Removal**.
2. In the **Continuum Removal Input File** dialog, select the file `cup95eff.int`, perform spectral subsetting if desired to limit the spectral range for continuum removal, and click **OK**.
3. Enter the continuum-removed output file name (`cup95cr.dat` for example) in the Continuum Removal Parameters dialog and click **OK** to create the continuum-removed image.

   This image will have the same number of spectral bands as the input image if no spectral subsetting was done.

To Use Pre-Calculated Data

1. Open the file `cup95_cr.dat`.

   This is the continuum-removed data (floating point 0 - 1.0 range) derived from the 1995 AVIRIS Effort-calibrated apparent reflectance as described above.

2. In the **Available Bands List** dialog, select band 193 (2.20 µm), select the **Gray Scale** button, and click **Load Band**.
3. Start a Z-Profile by selecting **Tools** → **Profile** → **Z-profile (Spectrum)** in the Main Image window.
4. In the Spectral Profile window, select **Options** → **Auto-scale Y-axis: Off**.
5. Choose **Edit** → **Plot Parameters** in the Spectral Profile window, select the **Y-Axis** radio button, and enter the range 0.5 - 1.0, and click **Apply** to apply the new Y-axis range.
6. Click **Cancel** to close the **Plot Parameters** dialog.
7. Move the Spectral Profile window to the bottom of the screen for comparison with the EFFORT data.

Open and Load the 1995 EFFORT-Corrected Data

1. Open the file `cup95eff.int`.

   This is the 1995 AVIRIS ATREM-calibrated apparent reflectance data with the EFFORT correction applied.
2. In the **Available Bands List** dialog, start a new display by selecting **Display** → **New Display**.
3. Select band 193 (2.20 µm), select the **Gray Scale** button, and click **Load Band**.
4. Start a Z-Profile by selecting **Tools** → **Profile** → **Z-profile (Spectrum)** in the Main Image window.
5. In the Spectral Profile window, select **Options** → **Auto-scale Y-axis Off**.
6. Choose **Edit** → **Plot Parameters** in the Spectral Profile window, select the **Y-Axis** radio button, enter the range 0 - 500, and click **Apply** to apply the new Y-axis range.
7. Click **Cancel** to close the **Plot Parameters** dialog.
8. Move the Spectral Profile window to the bottom of the screen for comparison with the continuum-removed data.

Compare Continuum-removed spectra and EFFORT Spectra

1. Link the two displays by selecting **Tools** → **Link** → **Link Displays** in the continuum-removed image window.

2. Click **OK** in the **Link Displays** dialog to activate the link.
3. In the Continuum-Removed image window, select **Dynamic Overlay Off** in the **Tools** → **Link** menu in order to enable normal mouse interaction.

   (Alternatively, select **Tools** → **Profiles** → **Additional Z-Profile** and select the EFFORT data to link a second Z-profile to the spatial location in the continuum-removed image).

   Moving the Zoom Window indicator box in this image will cause the cursor location to be updated in the EFFORT Main Display window. Both spectral profiles will show the spectrum for the current pixel.
4. Move the Zoom window indicator box around the image and compare the corresponding Continuum-Removed and EFFORT spectra.

   Note how the continuum-removed spectrum normalizes and enhances spectral features.
5. Now position the cursor at (503, 581) by selecting **Tools** → **Pixel Locator** in the image display and **Apply**. Compare the continuum-removed spectrum to the EFFORT spectrum.

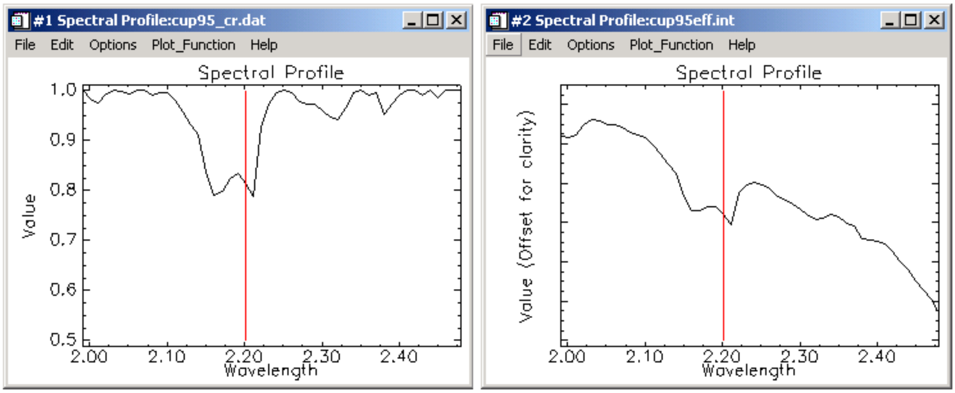


Figure 14-5: Comparison of continuum-removed (left) and EFFORT Apparent Reflectance (right) Spectra.

6. Move the cursor location to (542, 533) using the Pixel Locator and repeat the comparison. Note how continuum-removal affects the spectrum.
7. Try selecting some other points in the two images using the Pixel Locator and compare the spectra. What are the major differences? What improvements in visual analysis does the continuum-removal procedure allow?

Compare Continuum-Removed and Effort Images

1. Load a color composite image consisting of EFFORT bands 183, 193, and 207 (2.10, 2.20, and 2.34 µm) into RGB.
2. Click the left mouse button in the EFFORT image window to activate the dynamic overlay.
3. Compare the continuum-removed image for band 193 (2.20 µm) to the color composite image.

   Note the correspondence between dark areas on the continuum-removed image and red-to-purple areas on the color composite. The dark areas are areas with absorption bands near 2.2 µm.
4. Move the Zoom window indicator box to some of these dark areas by dragging with the left mouse button or by clicking in the desired location with the left mouse button in the Main Image window.
5. Compare the corresponding spectral profiles for both the continuum-removed data and the EFFORT data and note the image colors.
6. Load continuum-removed band 207 (2.34 µm) in the appropriate display.

   Note by moving the Zoom window to the dark areas and examining the spectra that these correspond to absorption features near 2.34 µm in both the continuum-removed and Effort spectra.

Close the Effort Display and Spectral Profile

Click on one of the EFFORT bands in the **Available Bands List** dialog, then select **File** → **Close Selected File**. The associated display windows and spectral plot will also be closed. ENVI will warn you that it will need to close out the display windows. You can confirm this by clicking on the **Yes** button.

Open and Load the SFF Scale and RMS Images

For the purposes of this exercise, you can use pre-calculated data if you do not wish to create your own Spectral Feature Fitting Scale or RMS data. If you do not want to create your own data, you can skip to the To Use Pre-Calculated Data section.

To Create Your Own Data

1. Open the file `cup95_cr.dat` and select **Spectral** → **Mapping Methods** → **Spectral Feature Fitting**.

2. Select the `cup95_cr.dat` file, perform spectral subsetting if desired to limit the spectral range for fitting, and click **OK**.
3. Use ENVI's standardized Endmember Collection dialog to import image or library spectra to use as endmembers in the SFF and click **Apply** in the **Endmember Collection** dialog.
4. Choose "Output separate Scale and RMS Images" in the Spectral Feature Fitting Parameters dialog, enter an output file name, and click **OK** to create the Scale and RMS error images.

   The output image will have two images for each endmember, a Scale image and an RMS error image.

To Use Pre-Calculated Data

1. Open the file `cup95sff.dat`.

   This contains the Scale and RMS images derived from spectral feature fitting of a library of image endmember spectra from the 1995 AVIRIS EFFORT-calibrated apparent reflectance data. Library spectra could also have been used, but the image spectra were used to allow direct comparison with other methods that use image spectra.
2. In the **Available Bands List** dialog, select **Display** → **New Display**, select the band "Scale (Mean: Kaolinite...)", select the **Gray Scale** radio button, and click **Load Band**.
3. In the **Available Bands List** dialog, select **Display** → **New Display**, select the band "Scale (Mean: Alunite 2.16...)", select the **Gray Scale** radio button, and click **Load Band**.
4. Link the two Scale and the Continuum-Removed displays by selecting **Tools** → **Link** → **Link Displays**.
5. In the **Link Displays** dialog, click **OK**.
6. Use the dynamic overlay function to compare the images.
7. Select **Tools** → **Cursor Location/Value**, move the cursor around one of the images, and compare the actual values for the two Scale images.

   Note that although similar as stretched images, the values for the two images are very different.
8. Load the "RMS (Mean: Kaolinite...)" image as a gray scale image into the display that contains the Kaolinite Scale Image.

9. Load the "RMS (Mean: Alunite 2.16...)" image as a gray scale image into the display that contains the Alunite Scale Image.
10. Again, use the dynamic overlay function to compare the images and the Cursor Location/Value functions to compare the actual values for the two RMS images.

    Low RMS values correspond to good spectral matches.

2-D Scatterplots of SFF Results

1. Start 2-D Scatter plots from the RMS (Mean: Kaolinite...) image by selecting **Tools** → **2-D Scatter plots**.
2. In the **Scatter Plot Band Choice** dialog, select Kaolinite Scale for band X and Kaolinite RMS for band Y, then click **OK**.
3. Draw a Region of Interest (ROI) on the scatterplot at low RMS values for all ranges of Scale by clicking the left mouse button to draw lines connecting the vertices of a polygon and the right mouse button to close the polygon.

   Note the highlighted pixels in the RMS Kaolinite.
4. Select **Options** → **Change Bands** in the Scatter Plot window.
5. Load other combinations of Scale and RMS for the various endmembers.
6. Close the 2-D scatter plot by selecting **File** → **Cancel** in the Scatter Plot window.
7. Select **Window** → **Close All Plot Windows**.

Spectral Feature Fitting Ratios — "Fit" Images

For the purposes of this exercise, you can use pre-calculated data if you do not wish to create your own SFF Fit Images. If you do not want to create your own data, you can skip to the To Use Pre-Calculated Data section.

To Create Your Own Data

1. Open the file `cup95_cr.dat` and select **Spectral** → **Mapping Methods** → **Spectral Feature Fitting**.
2. Select the `cup95_cr.dat` file, perform spectral subsetting (if desired) to limit the spectral range for fitting, and click **OK**.
3. Use ENVI's standardized **Endmember Collection** dialog to import image or library spectra to use as endmembers in the SFF and click **Apply**.

4. Use the toggle arrows in the **Spectral Feature Fitting Parameters** dialog to select **Output combined (Scale/RMS) images**, enter an output file name, and click **OK** to create the fit images.

   The output image will have one fit image for each endmember.

To Use Pre-Calculated Data

1. Open the file `cup95sfr.dat`. This contains the images that are the ratio of Scale/RMS for each of the endmembers.
2. In the **Available Bands List** dialog, select the “Fit (Mean: Kaolinite...)” band, select the **Gray Scale** button, and click **Load Band** to load the band into the existing display containing the continuum-removed data.

   The bright pixels represent the best fit to the reference endmember spectrum of Kaolinite.
3. Load the “Scale (Mean: Kaolinite...)” and “RMS (Mean: Kaolinite...)” images into the other two displays if not already loaded.
4. Link the image displays and compare the Fit, Scale, and RMS images.

   Note how the Scale and RMS image interact to produce the Fit result.
5. Load the EFFORT data again and extract spectral profiles for the bright pixels in the Fit image.
6. Compare the Fit, Scale, and RMS images as well as the spectral profiles for the other endmembers.
7. Make one or more color composite images by loading Fit images for different endmembers as RGB. What conclusions can you draw regarding the effectiveness of spectral feature fitting for identifying specific endmembers?

End the ENVI Session

This concludes the tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) from the ENVI main menu, then click **Yes**. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

References

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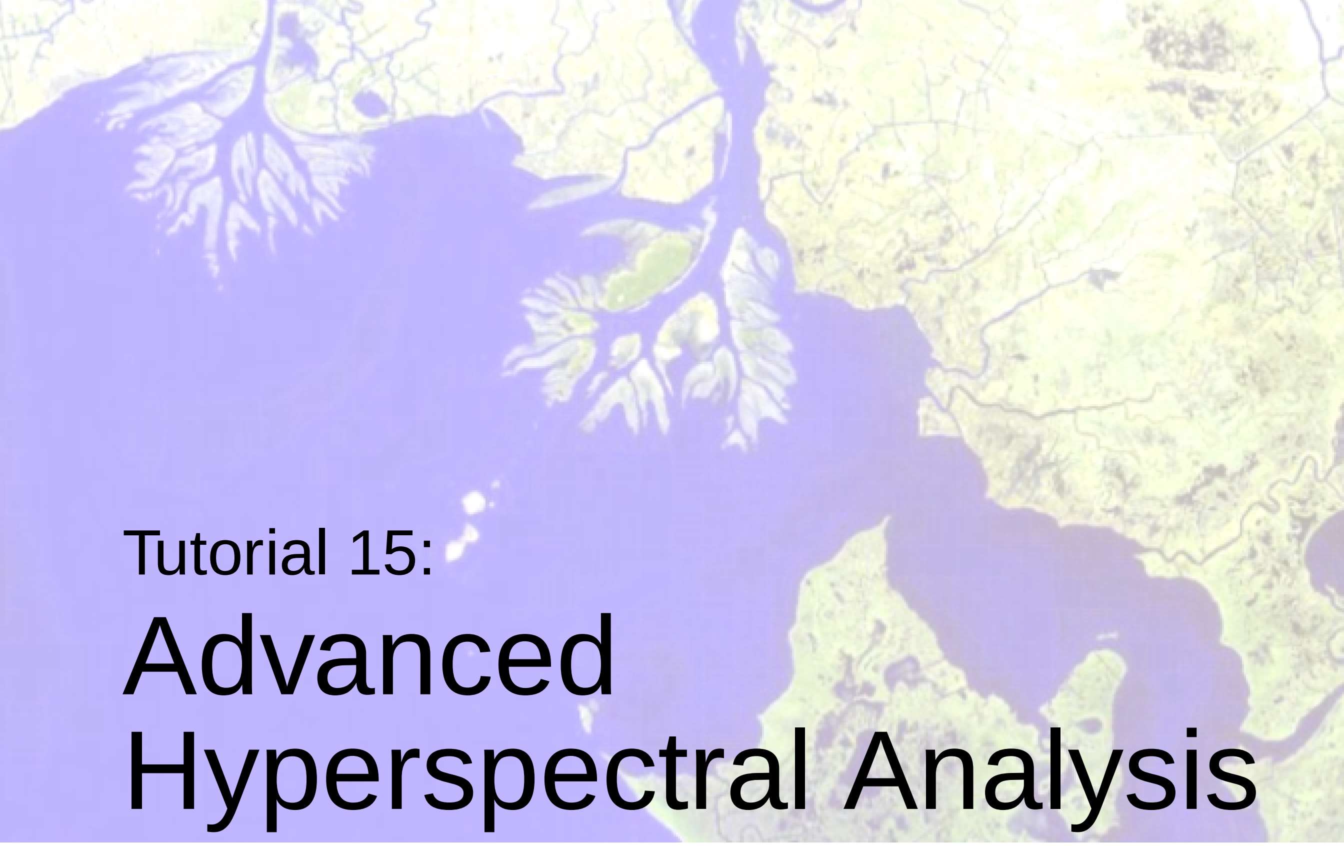


Tutorial 15: Advanced Hyperspectral Analysis

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to introduce you to advanced concepts and procedures for analysis of imaging spectrometer data or *hyperspectral images*. We will use 1995 Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data from Cuprite, Nevada, to investigate sub-pixel properties of hyperspectral data and advanced techniques for identification and quantification of mineralogy. We will use EFFORT polished ATREM-calibrated data, and review matched filter and spectral unmixing results. This tutorial is designed to be completed in two to four hours.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/c95avsub`

File	Description
Required Files	
`cup95eff.int`	Effort" corrected ATREM apparent reflectance data, 50 bands, 1.96 - 2.51 mm.
`cup95eff.hdr`	ENVI Header for above
`cup95mnf.dat`	First 25 MNF bands
`cup95mnf.hdr`	ENVI Header for above
`cup95mnf.asc`	MNF eigenvalue spectrum
`cup95mnf.sta`	MNF statistics
`cup95ns.sta`	Noise statistics from Shift Difference
`cup95ppi.dat`	Pixel Purity Index (PPI) Image
`cup95ppi.hdr`	ENVI Header for above
`cup95ppi.roi`	Region of Interest for PPI values greater than 1750
`cup95ppi.ndv`	N-D Visualizer Saved State File.
`cup95ndv.roi`	ROI endmembers corresponding to the N-D Visualizer Saved State File

File	Description
cup95_em.asc	EFFORT ASCII file of 11 spectral endmembers selected using the PPI threshold, MNF images, and n-Matched Filtering and Unmixing
cup95_mnfem.asc	MNF ASCII file of 11 spectral endmembers elected using the PPI threshold, MNF images, and n-D Visualization - used in Matched Filtering and Unmixing
cup95unm.dat	Unmixing Results—Fractional Abundance images
Optional Files	
jpl1sli.dat	JPL Spectral Library in ENVI format
jpl1sli.hdr	ENVI Header for above
usgs_sli.dat	USGS Spectral Library in ENVI format
usgs_sli.hdr	ENVI Header for above

Note

The files listed are required to run this exercise. Optional spectral library files listed below may also be used if more detailed comparisons are desired. Selected data files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. Values of 1000 in the files represent reflectance values of 1.0.

Open the 1995 Effort-Corrected Data

1. Open the file `cup95eff.int`. This is the 1995 AVIRIS ATREM-calibrated apparent reflectance data with the Effort correction applied.
2. Load band 193 as a gray scale image in the new image display by clicking on the **Gray Scale** radio button, selecting the band, and clicking on the **Load Band** button.

These data will be used for comparison with MNF bands and to extract spectral endmembers for PPI results.

MNF Transform Data, Endmembers, and Spectral Unmixing

Background: Minimum Noise Fraction

The minimum noise fraction (MNF) transformation is used to determine the inherent dimensionality of image data, to segregate noise in the data, and to reduce the computational requirements for subsequent processing (See Boardman and Kruse, 1994). The MNF transform as modified from Green *et al*. (1988) and implemented in ENVI is essentially two cascaded Principal Components transformations. The first transformation, based on an estimated noise covariance matrix, decorrelates and rescales the noise in the data. This first step results in transformed data in which the noise has unit variance and no band-to-band correlations. The second step is a standard Principal Components transformation of the noise-whitened data. For the purposes of further spectral processing, the inherent dimensionality of the data is determined by examination of the final eigenvalues and the associated images. The data space can be divided into two parts: one part associated with large eigenvalues and coherent eigenimages, and a complementary part with near-unity eigenvalues and noise-dominated images. By using only the coherent portions, the noise is separated from the data, thus improving spectral processing results.

Figure 15-1 summarizes the MNF procedure in ENVI. The noise estimate can come from one of three sources; from the dark current image acquired with the data (for example AVIRIS), from noise statistics calculated from the data themselves, or from statistics saved from a previous transform. Both the eigenvalues and the MNF images (eigenimages) are used to evaluate the dimensionality of the data. Eigenvalues for bands that contain information will be an order of magnitude larger than those that contain only noise. The corresponding images will be spatially coherent, while the noise images will not contain any spatial information.

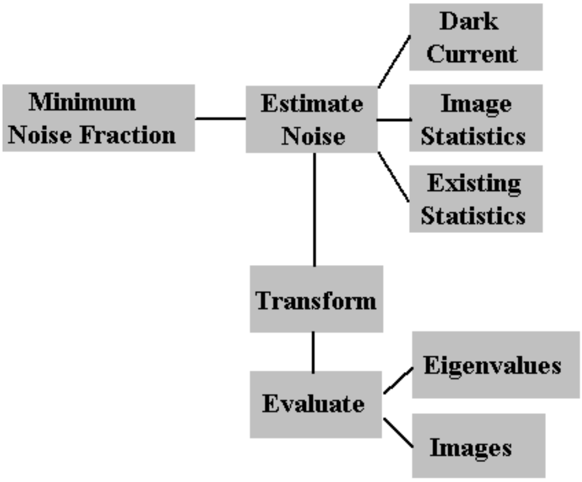


Figure 15-1: MNF Procedures in ENVI.

Open and Load MNF Image

1. Open the file `cup95mnf.dat`.

   This dataset contains the first 25 MNF bands (floating point) from the 1995 Cuprite Effort data.

2. Load the first MNF band as a gray scale image in a new image display by clicking on the **Gray Scale** radio button, selecting the band, and clicking on **Load Band** in the **Available Bands List** dialog.

Compare MNF Images

1. Load several other MNF bands, either one at a time for individual examination or in RGB composites for intercomparison.
2. Use the Z-Profile, image linking, and dynamic overlay to compare MNF-spectra with Apparent Reflectance spectra from the Effort image.
3. Try to determine the relation(s) between the MNF image and the apparent reflectance images. Relate MNF band number to MNF image quality.

Examine MNF Scatter Plots

1. Use **Tools** → **2-D Scatter Plots** in the Main Image window for forward and inverse mapping modes to understand the MNF images.
2. Be sure to examine the high variance (low band number) MNF bands. Also be sure to examine at least one scatter plot of a low variance (high band number) MNF band (change the bands by selecting **Options** → **Change Bands** in the Scatter Plot window).

   Notice the corners (pointed edges) on some MNF scatter plots (Figure 15-2).

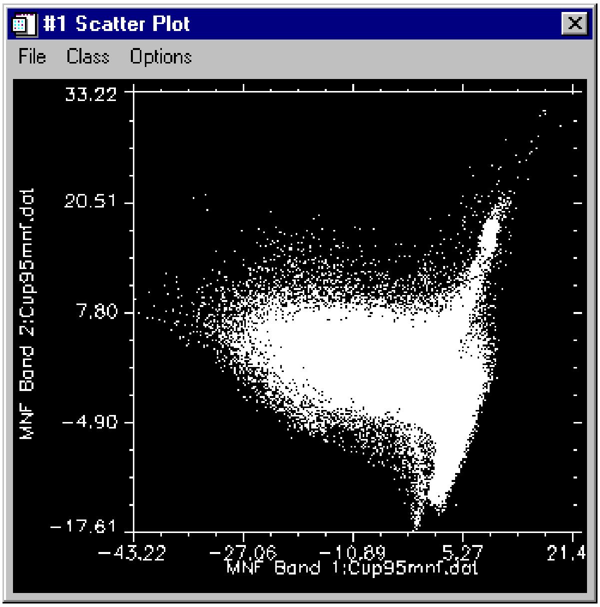


Figure 15-2: MNF 2-D Scatter Plot.

3. Use linked windows, overlays, and Z-profiles to understand the reflectance spectra of the MNF corner pixels.

   Look for areas where the MNF data stops being “pointy” and begins being “fuzzy”. Also notice the relationship between scatter plot pixel location and spectral mixing as determined from image color and individual reflectance spectra.

   How do you explain these patterns? How can you exploit them?

Use Scatter Plots to Select Endmembers

We will now investigate the possibilities of deriving unmixing endmembers from the data using MNF images and the 2-D scatter plot tools.

1. Load a scatter plot of MNF bands 1 and 2.
2. In the scatter plot, use the ROI drawing functions to circle the extreme few pixels in one or more of the corners or arms of the data cloud.

   These will be mapped into the image as colored pixels.
3. Use different colors for several classes by selecting the desired color from the *Class* pull-down menu in the Scatter Plot window.
4. Use image and scatter plot dancing pixels (double-click and drag with the middle mouse button) to help identify unique areas.
5. Select **Options** → **Export All** in the **Options** pull-down menu of the scatter plot to export these lists of pixels as ENVI Regions of Interest (ROI).
6. Load these ROIs into the window displaying the apparent reflectance data by choosing selecting **Overlay** → **Region of Interest** in the Main Image window menu bar.
7. Continue to select MNF-corner ROIs using different combinations of the first several MNF bands.
8. Use the **Mean for All Regions** menu item in the **Options** pull-down menu of the **ROI Tool** to extract the mean apparent reflectance spectra of the ROIs.
9. Use the linked windows and Z-profiles to examine the relations between the MNF and reflectance spectra.

Note

Corner pixels on the scatter plots generally make good endmember estimates. However, note also the occurrence of overlapping or repeat ROIs. This is a limitation of examining the data in a pairwise fashion (2-D).

10. Close the 2-D scatter plot by selecting **File** → **Cancel** in the **Scatter Plot** window.

Pixel Purity Index

In this portion of the exercise, you will examine the role of convex geometry in determining the relative purity of pixels. Separating purer from more mixed pixels reduces the number of pixels to be analyzed for endmember determination and makes separation and identification of endmembers easier.

The Pixel-Purity-Index™ (PPI™) is a means of finding the most “spectrally pure,” or extreme, pixels in multispectral and hyperspectral images. See Boardman *et al*. (1995). The most spectrally pure pixels typically correspond to mixing endmembers. The Pixel Purity Index is computed by repeatedly projecting *n*-dimensional scatter plots onto a random unit vector. The extreme pixels in each projection are recorded and the total number of times each pixel is marked as extreme is noted. A Pixel Purity Index (PPI) image is created in which the DN of each pixel corresponds to the number of times that pixel was recorded as extreme. Figure 15-3 summarizes the use of PPI in ENVI.

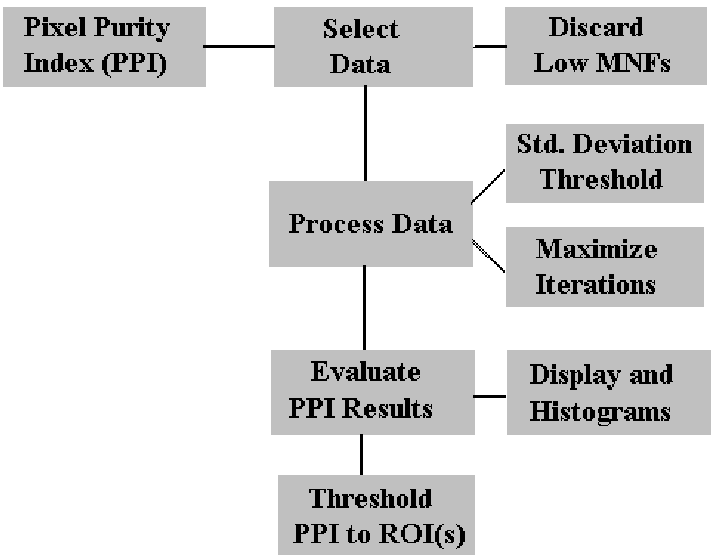


Figure 15-3: Pixel Purity Index procedures in ENVI.

Display and Analyze the Pixel Purity Index

1. Open the file `cup95ppi.dat` and display it as a gray scale image.

   Brighter pixels represent more spectrally extreme finds (hits) and indicate pixels that are more spectrally pure. Darker pixels are less spectrally pure.

2. Try various interactive stretches from the **Enhance** pull-down menu on the Main Image window menu bar to understand the PPI image's histogram and data distribution.

   Why is the histogram skewed to the low values. What does this mean from a mixing point of view?

3. If it is not already open and displayed, open the MNF (`cup95mnf.dat`) and Effort apparent reflectance (`cup95eff.int`) files and load bands from each of these two into two new windows.

   The PPI image is the result of several thousand iterations of the PPI algorithm discussed above on the MNF data. The values in the image indicate the number of times each pixel was discovered as extreme in some projection. These numbers then indicate the degree of local convexity of the data cloud near each pixel and the proximity of each pixel to the convex hull of the data. In short, the higher values indicate pixels that are nearer to corners of the *n*-Dimensional data cloud, and are thus relatively purer than pixels with lower values. Pixels with values of zero were never found to be extreme.

4. Link all three windows using **Tools** → **Link** → **Link Displays** and create Z-profiles in the MNF and reflectance image displays.

   In this configuration, you can examine the spectral profiles of certain pixels as they are selected in the PPI display.

5. To determine the range of values present in the image, use the **Cursor Location/Value** dialog (by selecting **Tools** → **Cursor Location/Value** from the Main Image window menu bar.

6. Move around the image using the Z-profiles and dynamic overlay tools to examine the purest pixels both spatially and spectrally.

   Do any of the high PPI values fall in the regions of the image corresponding to the 2-D scatter plot corners you picked in the previous exercise? Why?

Threshold PPI to Regions of Interest

1. Restore the file `cup95ppi.roi` by selecting **Tools** → **ROI Tool** from the Main Image window using **File** → **Restore ROIs** in the **ROI Tool** dialog.

   This is a list of pixels where the PPI value is over 1000.

   How many high PPI pixels are there?

   Now try making some of your own thresholded PPI Regions of Interest.

2. Select **Enhance** → **Interactive Stretching** in the PPI image.
3. Determine a threshold to use for choosing only the purest pixels by using the left mouse button to read values off the histogram.
4. Click the middle mouse button in the histogram to zoom in on the lower end of the distribution.
5. Select a value on the high tail of the histogram as the minimum threshold (if you have difficulty with this try a value of 2000 as a starting point).
6. Start the ROI Tool by choosing **Overlay** → **Region of Interest** from the Main Image window menu bar. Choose **Options** → **Band Threshold to ROI** in the **ROI Tool** dialog to create an ROI containing only the pixels with high PPI values.
7. Choose the PPI file for thresholding and click **OK**
8. Enter the value selected above for the minimum threshold into the **Band Threshold to ROI Parameters** dialog and click **OK**.

   ENVI will determine the number of pixels that meet the selected criteria and post a message.

Note

For the purposes of this exercise, if your threshold results in more than 2000 pixels being selected, you should select a higher minimum threshold.

9. Click **OK** in the **ENVI Question** dialog and a standard ENVI ROI will be created and listed in the **ROI Tool** dialog.

   Only those pixels with values greater than the selected minimum will be included in the ROI built from the PPI image.

10. Select and display the ROI by clicking on the name in the **ROI Tool** dialog.

    This ROI contains the pixel locations of the purest pixels in the image regardless of the endmember to which they correspond. The *n*-Dimensional

Visualizer will be used in the next portion of the exercise to isolate the specific pure endmembers.

n-Dimensional Visualization

Spectra can be thought of as points in an *n*-dimensional scatter plot, where *n* is the number of bands. See Boardman *et al*. (1995). The coordinates of the points in *n*-space consist of "n" values that are simply the spectral radiance or reflectance values in each band for a given pixel. The distribution of these points in *n*-space can be used to estimate the number of spectral endmembers and their pure spectral signatures.

ENVI's *n*-Dimensional Visualizer™ provides an interactive tool for selecting the endmembers in *n*-space. In this section, you will examine a Grand Tour of the *n*-dimensional data. Because the computer method is computer intensive, it only operates well with no more than a few thousand pixels in a few dozen bands. From a theoretical standpoint, it makes little sense to view all the mixed pixels. The most important pixels, those that best suggest the endmember materials, are the purest pixels, previously selected using the PPI thresholding. Figure 15-4 summarizes the steps involved in using the *n*-Dimensional Visualizer to select endmember spectra.

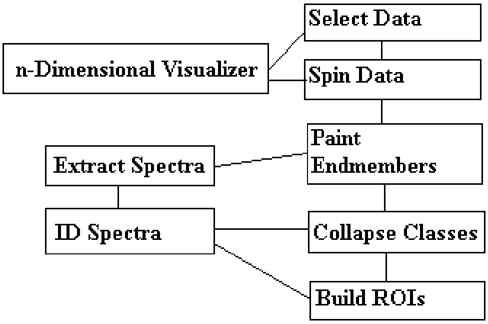


Figure 15-4: Steps used in the n-Dimensional Visualizer.

Compare n-D Data Visualization with 2-D Scatter Plot

1. Select **Spectral** → **n-Dimensional Visualizer** → **Visualize with New Data** from the ENVI main menu,
2. Select the MNF file `cup95mnf.dat` for visualization using the first 10 MNF bands (click **Spectral Subset** to specify only the first 10 bands) and click **OK**.

   Remember that these bands encompass almost all the signal variability and limiting the number of bands will improve the interactive visualization performance. The other, higher-order MNF bands have already been discarded as primarily noise.

If you only have one valid ROI listed in the **ROI Tools** dialog, that ROI data will automatically be loaded into the ***n*-Dimensional Visualizer**. If you have more than one ROI, choose the ROI derived using the PPI threshold when queried.

After a short wait, the *n*-D scatter plotting window and controls will appear. The numbers 1 through 10 on the *n*-D Controls dialog refer to the ten spectral bands chosen.

3. Click on **1** and **2** to create a 2-D scatter plot of the purest pixels of band 1 and 2 (Figure 15-5).

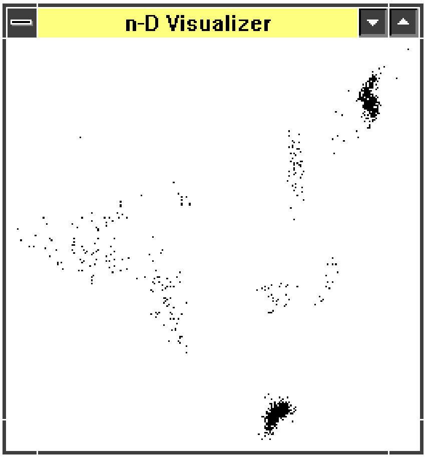


Figure 15-5: MNF 2-D Scatter Plot "thinned" using the PPI.

4. Meanwhile, also start a standard 2-D scatter plot of MNF bands 1 and 2 (Figure 15-6) for comparison by selecting **Tools** → **2-D Scatter Plot** in the Main window.

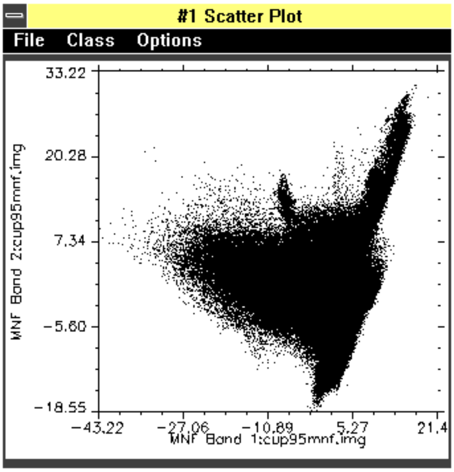


Figure 15-6: MNF 2-D Scatter Plot.

5. Compare the two scatter plots.

   Can you see how pixels were excluded from the *n*-D scatter plot based on pixel purity? Why is this important?

Use the n-D Visualizer

1. Close the 2-D scatter plot and try several different 2-band combinations in the ***n*-D Visualizer**.

   Note the shape of the data clouds. Be sure to examine some of the higher order MNF bands.

2. Now try several three-band combinations by clicking on three of the band numbers.

3. When only 3 bands are selected, you can change the view of the projection by selecting **Options** → **3D: Drive Axes** in the ***n*-D Controls** dialog.

4. Subsequently clicking and dragging with the left mouse button in the ***n*-D Visualizer** rotates the projection.

   Again, note the shape of the data clouds. Be sure to examine some of the higher order MNF bands. Turn on the axes by selecting **Options** → **Axes: On**.

5. Change back to **Options** → **3D: ROI Definition** when finished with the 3-D visualization; we will use the ROIs in higher dimensional rotations.
6. Click on the **Start** button to start the many various rotations.

   This is an animation of random projections of *n*-Dimensional space into the scatter plot. In this mode, any number of bands can be examined simultaneously.
7. Click on bands 1, 2, 3, 4, and 5 to view a projection of 5-D data.
8. Click on bands again to deselect them.
9. Try a few different combinations of 2, 3, and more different bands to get a feeling for the *n*-D data. Stop the rotation by clicking on the **Stop** button and then use the arrow buttons next to the **Step** text label to step forward and backward through the projections. The **New** button loads a new random projection. Enter lower or higher values in the **Speed** spin box to slow down or speed up the rotation.
10. Try MNF band 9 versus MNF band 10 to see how they compare to 1 versus 2.
11. Select the **Options** → **Axes: On** option to display the axes for the various bands in the n-Dimensional projection.

    Notice how the rotations seem different when more than three bands are included. This is the result of dimensions greater than 3 being folded in upon themselves in the projection. This should convince you that the data is truly high dimensional and why 2-D scatter plots are inadequate for dealing with hyperspectral data.

Paint Your Own Endmembers

1. Go back to the **n-D Controls** and restart the rotation using the **Start** button.
2. When you see an interesting projection (one with points or corners), stop the rotation, select a color from the list under the ***Class*** pull-down menu, and use the cursor to circle the points at one or more of the corners (Figure 15-7).

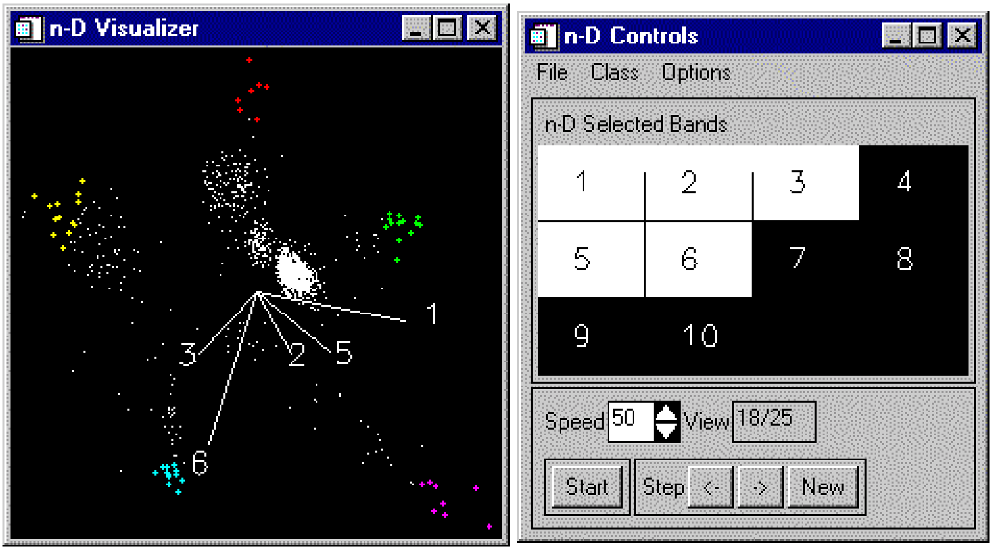


Figure 15-7: The n-Dimensional Visualizer and Controls with selected pixels highlighted.

3. Use the left mouse button to define the segments of a ROI in the scatter plot, and the right mouse button to complete the ROI.
4. Continue spinning the data and update classes as needed as they split up in further projections.

Use the n-D Class Controls

1. Select **Options** → **Class Controls** to start the **n-D Class Controls** dialog.

   This is used to change class colors, turn classes on and off, and control clipping of class values.
2. Click on one of the colored class boxes to make that class the active class.
3. Select a **Symbol** to display in the **n-D Visualizer** for the selected class from the pull-down list for pixels in the active class.

4. Calculate statistics (**Stats**), a mean spectrum (**Mean**), plot the class (**Plot**), clear (**Clear**), or export (**Export**) by selecting the corresponding button in the **n-D Class Controls** dialog.
5. Try turning classes on and off by clicking on the check box next to a class.

Link the n-D Visualizer to Spectral Profiles

You can view reflectance spectra for specific endmembers while you're painting endmembers and rotating the scatter plot. This allows you to preview spectra before finalizing spectral classes

1. Select **Options** → **Z-Profile** in the **n-D Controls** dialog. Choose the reflectance data `cup95eff.int` from the list and click **OK**. A blank spectral plot appears.
2. Click the middle mouse button in the **n-D Visualizer**, and a spectrum will appear for the current pixel in the **n-D Profile** window. Dragging the cursor around the image with the middle mouse button depressed allows real-time spectral browsing. When the cursor is in an n-D-defined class, the plotted spectrum will match the color of that class.
3. Click the right mouse button in the **n-D Profile** window, then right-click and drag in the **n-D Visualizer** to turn on spectrum collection. Each subsequent spectrum will be retained in the one plot, without erasing the previous spectrum. Click in the **n-D Visualizer** using the middle mouse button to clear the plot and return to single spectrum mode.

Link the Spectral Analyst to the n-D Visualizer Spectra

The **Spectral Analyst**™ matches unknown spectra to library spectra and provides a score with respect to the library spectra. The spectral analyst uses several methods to produce a score between 0 and 1, with 1 equaling a perfect match. Linking the **Spectral Analyst** to the **n-D Visualizer** profile provides a means of identifying endmember spectra on-the-fly.

1. Select **Spectral** → **Spectral Analyst** from the ENVI main menu.
2. Click on the **Open Spectral Library** button at the bottom of the **Spectral Analyst Input Spectral Library** dialog.
3. Navigate to the `usgs_min` spectral library directory in the `spec_lib` directory of the main ENVI distribution and select and open the `usgs_min.sli` spectral library.

4. When the E**dit Identify Methods Weighting** dialog appears, click **OK**. The different matching methods are described in the ENVI User's Guide.
5. Select **Options** → **Auto Input via-Z Profile** in the **Spectral Analyst** dialog and click on the **n-D Profile** in the list of available profiles. Click the middle mouse button on one of the painted classes in the **n-D visualizer** and the **Spectral Analyst** scores the unknown spectrum against the library. High scores indicates a high likelihood of match.
6. Double-click on the spectrum name at the top of the list to plot the unknown and the library spectrum in the same plot for comparison. Use the **Spectral Analyst** and the comparison plots to determine the mineralogy for the **n-D Visualizer** spectra you have extracted. When you have identified several minerals, continue with the next section.

Load Individual Spectra Into the n-D Visualizer

1. Make sure that ROI drawing is turned off in the displayed image (Select the **Off** radio button in the **ROI Tool** dialog).
2. Select **Tools** → **Profiles** → **Z Profile** to display an EFFORT spectrum from the Cuprite data.
3. Select **Tools** → **Profiles** → **Additional Z Profile** and select the MNF data for the second associated spectral profile.

   Because the data in the **n-D Visualizer** are in MNF space, you must import the MNF spectra that represent the materials of interest.
4. Select **Options** → **Import Library Spectra** from the **n-D Controls** dialog. The **n-D Visualizer Import Spectra** dialog appears (a standard ENVI **Endmember Collection** dialog).
5. To import the single spectrum from the **Additional Z Profile** window, first move the cursor in the image until the desired reflectance spectrum is displayed in the primary spectral profile. The additional spectral profile spectrum is linked and will show the corresponding MNF spectrum.
6. Drag and drop by clicking the right mouse button in the plot window to show the spectrum name, selecting the spectrum name with the left mouse button and dragging and dropping in the black draw window at the top of the **Endmember Collection** dialog.
7. The spectrum will be plotted in the **n-Dimensional Visualizer** window with a flag marking its position. Repeat for as many spectra as desired.

8. These spectra can be rotated along with the PPI-derived data in the **n-D Visualizer**.

Collapse Classes in the n-D Visualizer

Once you have identified a few endmembers, it may be difficult to find additional endmembers, even though you run the rotations or many different 2-D projections of the n-Dimensional data.

Class Collapsing in ENVI is a means of simplifying this endmember determination problem by allowing you to group the endmembers you have already found into one group representing the background. The net result is that mixing features that were previously hidden become visible, and can be selected using ENVI's ROI drawing in the **n-D Visualizer** window.

You can collapse on means by selecting **Options** → **Collapse Classes by Means** from the **n-D Controls** menu bar to geometrically project the selected data according to their class mean values. You can also alternatively select **Options** → **Collapse Classes by Variance**. The Z-profile can be used to verify that you are choosing homogeneous endmember classes.

Notice that the bands selected are now listed in red and only two are chosen. Additionally, a MNF plot appears, estimating the dimensionality of the data, and the number of endmembers remaining to be found. Repeat the endmember selection and class collapsing process until there are no new endmembers found.

Export Your Own ROIs

You can also export mean spectra for the selected endmembers.

1. Delete all of the previous ROIs by selecting **Options** → **Delete All Regions** in the **ROI Tool** dialog.
2. Export your best set of classes to ROIs by selecting **Options** → **Export All** in the **n-D Control** dialog. You can also export individual classes from the **n-D Class Controls** dialog (access with **Options** → **Class Controls**). Examine the ROI spatial locations.
3. Extract the average spectra for the different ROIs using either the **Stats** or **Mean** buttons in the **n-D Control** dialog. Compare these endmembers to endmembers extracted using the 2-D scatter plots and those used in the previous exercises.
4. Use **Options** → **Z-Profile** in the **n-D Controls** dialog to compare single spectra with average spectra.

Save Your n-D Visualizer State

1. Select **File** → **Save State** in the **n-D Controls** dialog, enter an output filename `cup95.ndv` and click **OK**. This saved state can be restored for later use.

Restore n-D Visualizer Saved State

1. Start another **n-D Visualizer** session using previously saved parameters and painted endmembers by selecting **Spectral** → **n-D Visualizer** → **Visualize with Previously Saved Data**.

1. Select the file `cup95ppi.ndv`.
2. Click on the **Start** button to start rotating the data.

   The colored pixels in the visualizer represent previously selected endmembers.
3. Examine different projections and numbers of bands in the visualizer.
4. Click on **Stop** to stop the rotation.
5. Select **Options** → **Delete All Regions** in the **ROI Tool** dialog to remove all previous regions of interest.
6. Now select Options → **Export All** in the **n-D Controls** dialog.
7. In the **ROI Tool** dialog, make sure that the display is set to the Effort apparent reflectance image and then select **Options** → **Mean for All Regions** to extract average reflectance spectra for all of the endmembers (Figure 15-8).

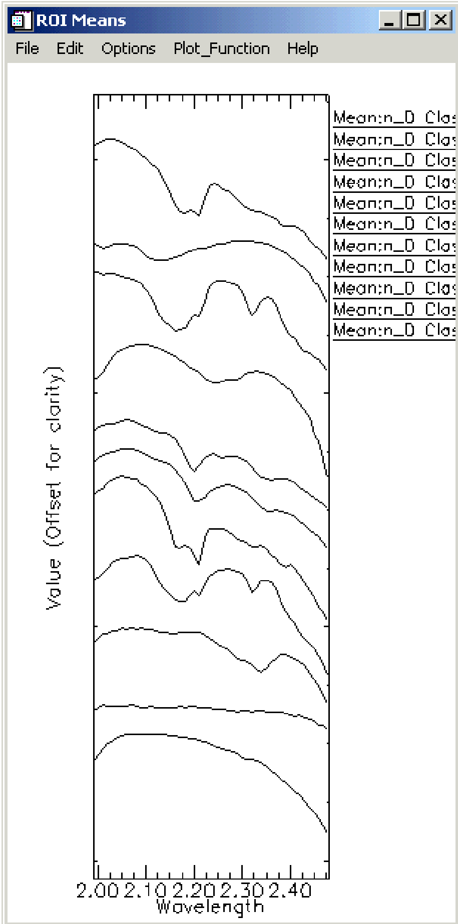


Figure 15-8: Endmember Spectra extracted using the n-D Visualizer.

8. Examine the relations between reflectance spectra and the painted pixels in the **n-D Visualizer**.
9. Pay particular attention to similar spectra and the positions of painted clusters.

Close all Displays and Other Windows

1. Select **File** → **Close All Files** from the **Available Bands List** dialog to close all open files and their associated displays.
2. Select **File** → **Cancel** in the **n-D Controls** to close those windows and the **n-D Visualizers**.

Spectral Mapping

ENVI provides a variety of mapping methods, but their success depends on the data type and quality, and the desired results. These include the Spectral Angle Mapper (SAM) Classification, Spectral Unmixing, Matched Filtering, and Mixture-Tuned Matched Filtering.

SAM is an automated method for comparing image spectra to individual spectra that determines the similarity between two spectra by calculating the “spectral angle” between them, treating them as vectors in a space with dimensionality equal to the number of bands. This provides a good first cut at spectral mapping of the predominant spectrally active material present in a pixel, however, natural surfaces are rarely composed of a single uniform material. Spectral mixing occurs when materials with different spectral properties are represented by a single image pixel. Several researchers have investigated mixing scales and linearity. Singer and McCord (1979) found that if the scale of the mixing is large (macroscopic), mixing occurs in a linear fashion (Figure 15-9) For microscopic or intimate mixtures, the mixing is generally nonlinear (Nash and Conel, 1974; Singer, 1981).

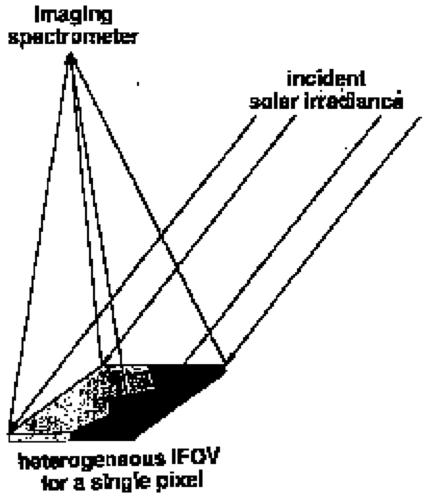


Figure 15-9: Macroscopic (linear) mixing.

The linear model assumes no interaction between materials. If each photon only sees one material, these signals add (a linear process). Multiple scattering involving several materials can be thought of as cascaded multiplications (a non-linear process). The spatial scale of the mixing and the physical distribution of the materials governs the degree of non-linearity. Large-scale aerial mixing is very linear. Small-scale intimate mixtures are slightly non-linear. In most cases, the non-linear mixing is a second order effect. Many surface materials mix in non-linear fashions but linear unmixing techniques, while at best an approximation, appear to work well in many circumstances (Boardman and Kruse, 1994). While abundance determined using the linear techniques are not as accurate as those determined using non-linear techniques, to the first order they appear to adequately represent conditions at the surface.

What Causes Spectral Mixing

A variety of factors interact to produce the signal received by the imaging spectrometer:

- A very thin volume of material interacts with incident sunlight. All the materials present in this volume contribute to the total reflected signal.
- Spatial mixing of materials in the area represented by a single pixel result in spectrally mixed reflected signals.
- Variable illumination due to topography (shade) and actual shadow in the area represented by the pixel further modify the reflected signal, basically mixing with a black endmember.
- The imaging spectrometer integrates the reflected light from each pixel.

Modeling Mixed Spectra

The simplest model of a mixed spectrum is a linear one, in which the spectrum is a linear combination of the pure spectra of the materials located in the pixel area, weighted by their fractional abundance (Figure 15-10).

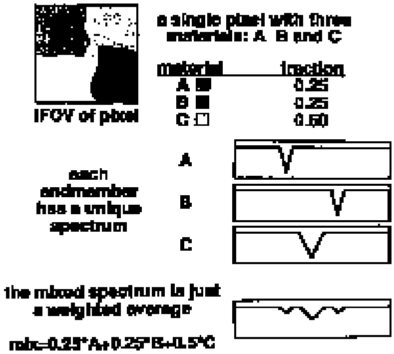


Figure 15-10: Linear mixing for a single pixel.

This simple model can be formalized in three ways: a physical model a mathematical model, and a geometric model. The physical model as discussed above includes the Ground Instantaneous Field of View (GIFOV) of the pixels, the incoming irradiance, the photon-material interactions, and the resulting mixed spectra. A more abstract mathematical model is required to simplify the problem and to allow inversion, or *unmixing* (Figure 15-11).

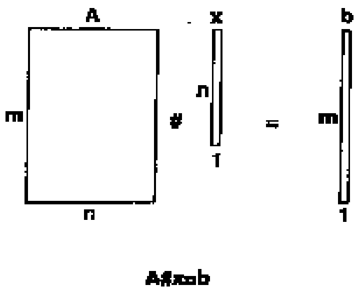


Figure 15-11: The linear algebra model of spectral mixing. A (m x n) columns are the endmember spectra, x (n x 1) is a vector of unknown abundance, and b (m x 1) is the observed spectrum where m is the # bands, n is the # endmembers and all x values are positive and sum to unity.

A spectral library forms the initial data matrix for the analysis. The ideal spectral library contains endmembers that when linearly combined can form all other spectra. The mathematical model is a simple one. The observed spectrum (a vector) is considered to be the product of multiplying the mixing library of pure endmember spectra (a matrix) by the endmember abundance (a vector). An inverse of the original spectral library matrix is formed by multiplying together the transposes of the orthogonal matrices and the reciprocal values of the diagonal matrix (Boardman, 1989). A simple vector-matrix multiplication between the inverse library matrix and an observed mixed spectrum gives an estimate of the abundance of the library endmembers for the unknown spectrum

The geometric mixing model provides an alternate, intuitive means to understand spectral mixing. Mixed pixels are visualized as points in *n*-dimensional scatter-plot space (spectral space), where *n* is the number of bands. In two dimensions, if only two endmembers mix, then the mixed pixels will fall in a line (Figure 15-12A). The pure endmembers will fall at the two ends of the mixing line. If three endmembers mix, then the mixed pixels will fall inside a triangle (Figure 15-12B). Mixtures of endmembers fill in between the endmembers.

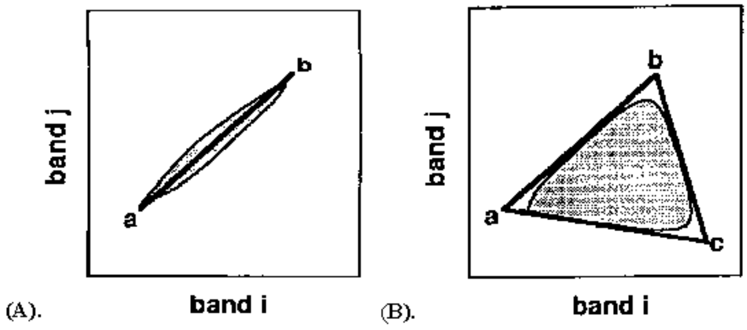


Figure 15-12: Geometric mixing model.(A). two dimensional mixing (two endmembers). (B). three dimensional mixing (three endmembers). Higher dimensions of mixing are represented by higher dimension geometric figures (eg: four endmembers mix within a tetrahedron, etc.).

All mixed spectra are interior to the pure endmembers, inside the simplex formed by the endmember vertices, because all the abundance are positive and sum to unity. This convex set of mixed pixels can be used to determine how many endmembers are present and to estimate their spectra. The geometric model is extensible to higher dimensions where the number of mixing endmembers is one more than the inherent dimensionality of the mixed data.

Practical Unmixing Methods

Two very different types of unmixing are typically used: Using known endmembers and using derived endmembers.

Using known endmembers, one seeks to derive the apparent fractional abundance of each endmember material in each pixel, given a set of known or assumed spectral endmembers. These known endmembers can be drawn from the data (averages of regions picked using previous knowledge), drawn from a library of pure materials by interactively browsing through the imaging spectrometer data to determine what pure materials exist in the image, or determined using expert systems as described above or other routines to identify materials.

The mixing endmember matrix is made up of spectra from the image or a reference library. The problem can be cast in terms of an over-determined linear least squares problem. The mixing matrix is inverted and multiplied by the observed spectra to get least-squares estimates of the unknown endmember abundance fractions. Constraints can be placed on the solutions to give positive fractions that sum to unity. Shade and shadow are included either implicitly (fractions sum to 1 or less) or explicitly as an endmember (fractions sum to 1).

The second unmixing method uses the imaging spectrometer data themselves to “derive” the mixing endmembers (Boardman and Kruse, 1994). The inherent dimensionality of the data is determined using a special orthogonalization procedure related to principal components:

- A linear sub-space (flat) that spans the entire signal in the data is derived.
- The data are projected onto this subspace, lowering the dimensionality of the unmixing and removing most of the noise.
- The convex hull of these projected data is found.
- The data are shrink-wrapped by a simplex of *n*-dimensions, giving estimates of the pure endmembers.
- These derived endmembers must give feasible abundance estimates (positive fractions that sum to unity).

Spectral unmixing is one of the most promising hyperspectral analysis research areas. Analysis procedures using the convex geometry approach already developed for AVIRIS data have produced quantitative mapping results for a a variety of materials (geology, vegetation, oceanography) without a priori knowledge. Combination of the unmixing approach with model-based data calibration and expert system identification capabilities could potentially result in an end-to-end quantitative yet automated analysis methodology.

Unmixing Results

In this section, you will examine the results of unmixing using the means of the ROIs restored above and applied to the first ten MNF bands. You will then run your own unmixing using endmember suites of your own choosing.

Open and Display the Unmixing Results

1. Open the file `cup95unm.dat`.
2. Load the Kaolinite abundance image by clicking on the Kaolinite band name and then **Load Band** in the **Available Bands List** dialog.

   Brighter areas correspond to higher abundances.

   Use contrast stretching, if necessary, to show only the higher values (larger apparent abundances).
3. Load the other fractional abundance images into one or more displays and compare the distribution of endmembers.

Determine Abundance

1. Select **Tools** → **Cursor Location/Value** and investigate the values at specific pixels.
2. Open the EFFORT data `cup95eff.int` and create spectral Z profiles of the reflectance data to reconcile absorption band strength with apparent abundance of the various endmembers.

Display a Color Composite

1. Choose three good unmixing result images and make an RGB color composite.
2. Use spatial and spectral clues to evaluate the results of the unmixing.
3. Explain the colors in the RGB composite of fraction endmembers in terms of mixing.

   Notice the occurrence of non-primary colors (not R, G, or B).

   Are all of the fractions feasible?

Notice areas where unreasonable results were obtained (e.g., fractions greater than one or less than zero).

4. Examine the RMS Error image and look for areas with high errors (bright areas in the image).

   Are there other endmembers that could be used for iterative unmixing? How do you reconcile these results if the RMS Error image doesn't have any high errors yet there are negative abundance or abundance greater than 1.0?

Mixture-Tuned Matched Filtering

Matched Filtering removes the requirement of knowing all of the endmembers by maximizing the response of a known endmember and suppressing the response of the composite unknown background, thus matching the known signature (Chen and Reed, 1987; Stocker et al., 1990; Yu et al., 1993; Harsanyi and Chang, 1994). It provides a rapid means of detecting specific minerals based on matches to specific library or image endmember spectra. This technique produces images similar to the unmixing, but with significantly less computation and without the requirement to know all the endmembers. It does, however, suffer from high false alarm rates, where materials may be randomly matched if they are rare in a pixel (thus not contributing to the background covariance).

Mixture-Tuned Matched Filtering™ (MTMF™) is a hybrid method based on the combination of well-known signal processing methodologies and linear mixture theory (Boardman, 1998). This method combines the strength of the Matched Filter method above (no requirement to know all the endmembers) with physical constraints imposed by mixing theory (the signature at any given pixel is a linear combination of the individual components contained in that pixel). Mixture-Tuning uses linear spectral mixing theory to constrain the result to feasible mixtures and reduce false alarm rates (Boardman, 1998). Mixture-Tuned Matched filter results are presented as two sets of images, the MF score (Matched Filter image), presented as gray-scale images with values from 0 to 1.0, which provide a means of estimating relative degree of match to the reference spectrum (where 1.0 is a perfect match) and the Infeasibility image, where highly infeasible numbers indicate that mixing between the composite background and the target is not feasible. The best match to a target is obtained when the Matched Filter Score is high (near 1) and the infeasibility score is low (near 0).

Perform Your Own Mixture-Tuned Matched Filtering

Display and compare the EFFORT and MNF Data

1. Display the MNF-transformed data (MTMF requires these). Select **File** → **Open Image File** and choose `cup95mnf.dat` as the input file. In the **Available Bands List**, click on the **RGB** radio button, then sequentially choose MNF bands 1, 2, and 3, then click on **Load RGB**.
2. Display a color composite of the EFFORT data. Select **File** → **Open Image File** and choose `cup95eff.int`. In the **Available Bands List**, click on the **RGB** radio button, then sequentially choose bands 183, 193, and 207, then select **New Display** from the **Display** pull-down menu and click **Load RGB**.

3. Link the two images using **Tools** → **Link** → **Link Displays**. Turn the dynamic overlay off in the EFFORT color image by choosing **Tools** → **Link** → **Dynamic Overlay off**.
4. Start a spectral profile for each dataset using **Tools** → **Profiles** → **Z Profile (Spectrum)**. Move the cursor in the EFFORT image and observe the two sets of spectral profiles. Note that the MNF spectra don't make it possible to identify the materials.

Collect the MNF Endmember Spectra for Use in MTMF

1. Select **Window** → **Start New Plot Window** in the Main Image window. Select **File** → **Input Data** → **ASCII**, in the plot window and choose the file `cup95_em.asc`. Click **OK** in the **Input ASCII File** dialog to plot the EFFORT spectra.
2. Select **Window** → **Start New Plot Window**. Select **File** → **Input Data** → **ASCII**, in the plot window and choose the file `cup95_mnfem.asc`. Click **OK** in the **Input ASCII File** dialog to plot the MNF spectra.
3. Compare the EFFORT and MNF spectra. The MNF spectra will be used with the MNF data to do the MTMF mapping.

Calculate MTMF Images

1. Choose **Spectral** → **Mapping Methods** → **Mixture Tuned Matched Filtering**. Click on the file `cup95mnf.dat` then click **OK**.
2. In the Endmember Collection dialog, select **Import** → **From ASCII File** and choose `cup95_mnfem.ascii` as the input file (these are the MNF-transformed endmember spectra). Click **OK** to load the endmembers.
3. Click **Apply** at the bottom of the **Endmember Collection** dialog. In the **MTMF Parameters** dialog, enter an output file name for the MTMF statistics and for the MTMF image, then click **OK**. (For ease of comparison, these results are also pre-calculated on the *ENVI Tutorial and Data CD No. 2* in the file `cup95_mtmf.img`).

Display MTMF Results

1. Load **Matched Filter** score bands as gray scale images. Stretch using interactive stretching from 0.0 to 0.25 abundances and look at the pixel distributions for the various endmembers.Try other stretches to minimize false alarms (scattered pixels).

2. Click on the **RGB** radio in the **Available Bands List** dialog, then sequentially on the Kaolinite, Alunite, and Buddingtonite MF images and click **Load RGB** to display a color composite of MF scores (Figure 15-13).

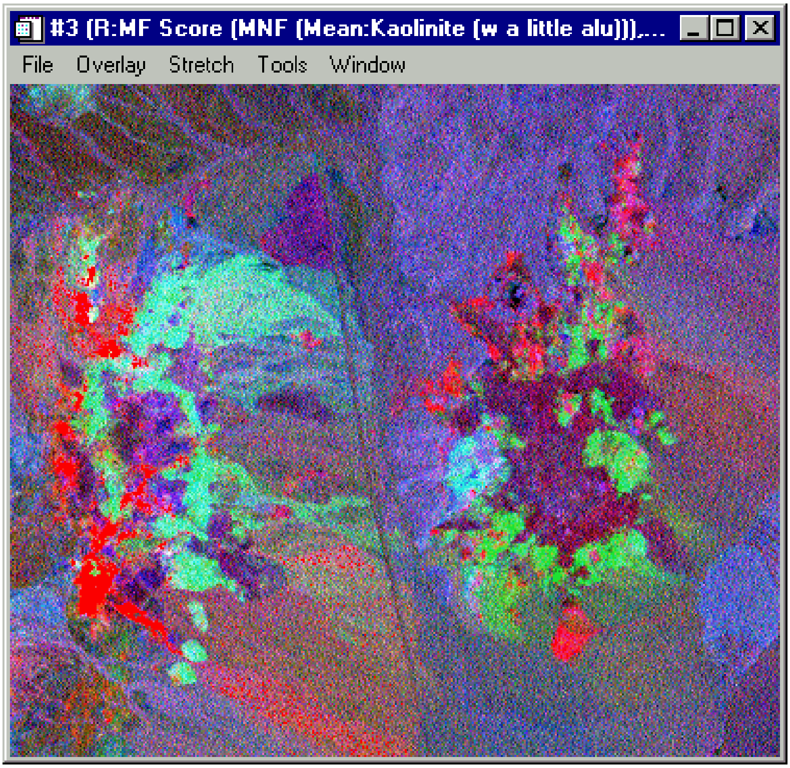
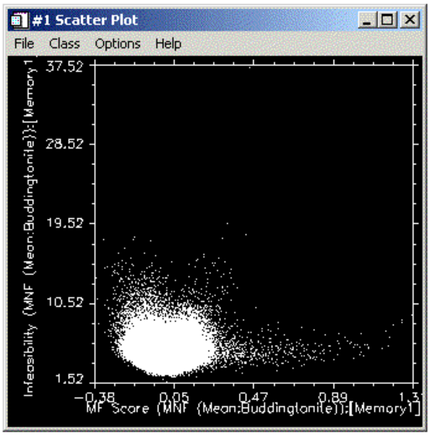


Figure 15-13: MTMF Results image (MF Score Only) for Kaolinite, Alunite, Buddingtonite (RGB).

In this color composite, using only MF, kaolinite appears red, alunite green, and buddingtonite blue. This is a pretty good looking image map, but has many obvious false alarms (every pixel has a color).

Display Scatter Plots of MF Score versus Infeasibility

1. Display a gray scale of EFFORT band 193 by **Gray Scale** radio button, selecting the appropriate band, then clicking **Load Band**.
2. Select **Tools** → **2-D Scatter Plot** from the Main Image window menu bar and scatter plot Buddingtonite MF Score versus Buddingtonite Infeasibility. Circle all the pixels that have a high MF score and low infeasibilities (Figure 15-14).



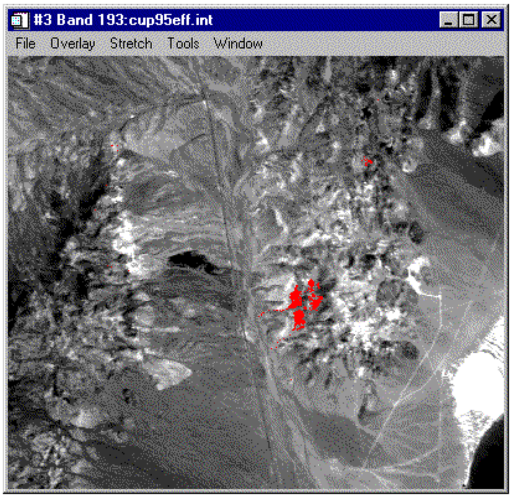


Figure 15-14: 2-D Scatter Plot of MF Score versus Infeasibility for the Buddingtonite endmember.

Notice the highly selective nature of the MTMF. The selection of the desired endmember is very selective and there are very few false alarms when using this method.

3. Start scatter plots for the other endmembers using **File** → **New Scatter Plot** from the existing scatter plot window. Select **Options** → **Export Class** in each scatter plot to build ROIs showing the individual minerals (Figure 15-15).

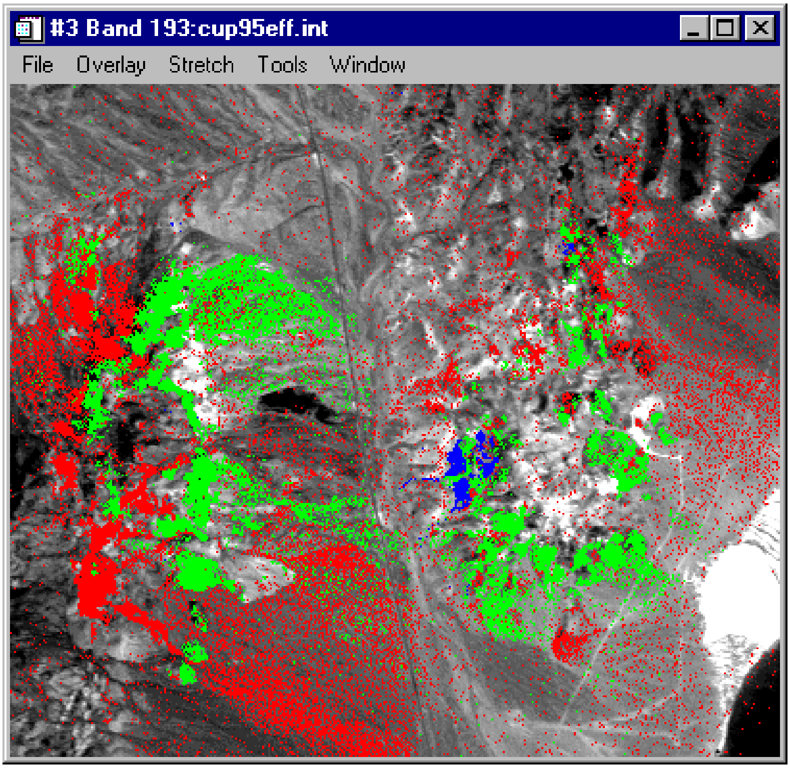


Figure 15-15: Kaolinite, Alunite, and Buddingtonite MTMF mapping results overlain on AVIRIS band 193.

4. Compare your MTMF results to the MF color composite, to the MNF data, and to the EFFORT data. Compare to the Linear Spectral Unmixing results.
5. Link the MTMF results window with the EFFORT image window to browse spectra and compare them to the endmember spectra, MTMF images, ROIs and scatter plots. Extract spectra from the EFFORT data and verify the sensitivity of the MTMF mapping.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

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Tutorial 16:

Hyperspectral Signatures and Spectral Resolution

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial compares spectral resolution for several different sensors and the effect of resolution on the ability to discriminate and identify materials with distinct spectral signatures. The tutorial uses TM, GEOSCAN, GER63, AVIRIS, and HyMap data from Cuprite, Nevada, USA, for intercomparison and comparison to materials from the USGS Spectral library.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/cup_comp`
`envidata/cup99hym`
`envidata/c95avsub`

File	Description
Required Files (`envidata/cup_comp`)	
`usgs_em.sli`	Subset of USGS Spectral Library
`usgs_em.hdr`	ENVI Header for Above
`cuptm_rf.img`	Cuprite TM reflectance subset
`cuptm_rf.hdr`	ENVI Header for Above
`cuptm_em.txt`	Kaolinite and Alunite average spectra from above
`cupgs_sb.img`	Cuprite Geoscan Reflectance Image Subset
`cupgs_sb.hdr`	ENVI Header for above
`cupgs_em.txt`	Kaolinite and Alunite average spectra from above
`cupgersb.img`	Cuprite GER64 Reflectance Image Subset
`cupgersb.hdr`	ENVI Header for above
`cupgerem.txt`	Kaolinite and Alunite average spectra from above
Required Files (`envidata/cup99hym`)	
`cup99hy.eff`	Cuprite 1999 HyMap EFFORT Data
`cup99hy.hdr`	ENVI Header for above

File	Description
cup99hy_em.txt	Kaolinite and Alunite average spectra from above
Required Files (envidata/c95avsub)	
cup95eff.int	Cuprite 1995 AVIRIS Reflectance Image Subset (in the c95avsub directory)
cup95eff.hdr	ENVI Header from above (in the c95avsub directory)
cup95eff.txt	Kaolinite and Alunite average spectra from above in the c95avsub directory
Optional Files (envidata/c95avsub)	
usgs_sli.dat	USGS Spectral Library
usgs_sli.hdr	ENVI Header for Above

Note

The files listed, along with their associated .hdr files, are required to run this exercise. Optional spectral library files listed below may also be used if more detailed comparisons are desired. Selected data files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. Values of 1000 in the files represent reflectance values of 1.0.

Background

Spectral resolution determines the way we see individual spectral features in materials measured using imaging spectrometry. Many people confuse the terms spectral resolution with spectral sampling. These are very different. Spectral resolution refers to the width of an instrument response (band-pass) at half of the band depth (the Full Width Half Max [FWHM]). Spectral sampling usually refers to the band spacing - the quantization of the spectrum at discrete steps - and may be very different from the spectral resolution. Quality spectrometers are usually designed so that the band spacing is about equal to the band FWHM, which is why band spacing is often thought of as equal to spectral resolution. These are two different things, however, so be careful in the use of terms.

This exercise compares the effect of the spectral resolution of different sensors on the spectral signatures of minerals.

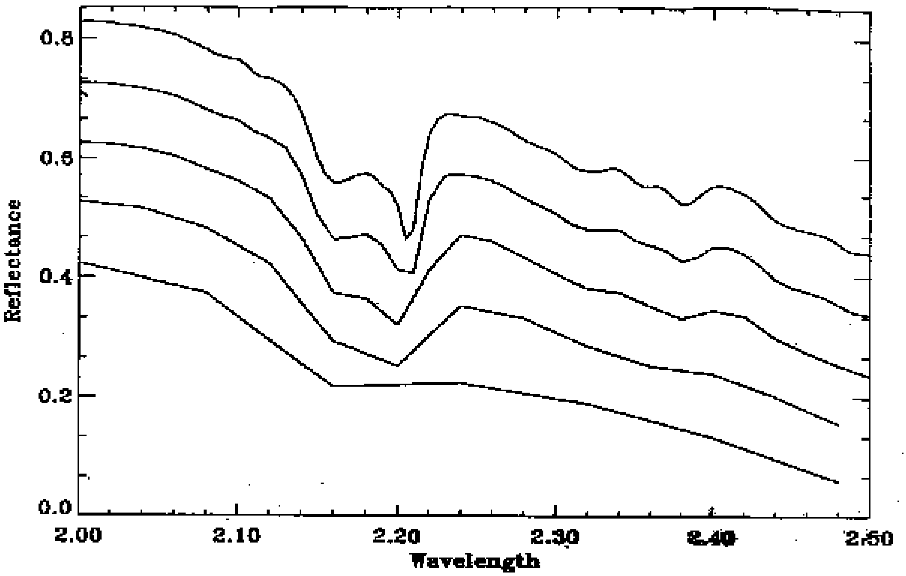

Figure 16-1: Modeled effect of spectral resolution on the appearance of spectral features of kaolinite. Spectral resolution from top to bottom: 5, 10, 20, 40, and 80 nm resolution

Spectral Modeling and Resolution

Spectral modeling shows that spectral resolution requirements for imaging spectrometers depend upon the character of the material being measured. For example, for the mineral kaolinite, shown in the plot below, we are still able to distinguish the characteristic doublet near 2.2 μm at 20 nm resolution. Even at 40 nm resolution, the asymmetrical shape of the band may be enough to identify the mineral, even though the spectral features have not been fully resolved.

The spectral resolution required for a specific sensor is a direct function of the material you are trying to identify, and the contrast between that material and the background materials. The following figure shows modeled spectra for the mineral kaolinite for several different sensors.

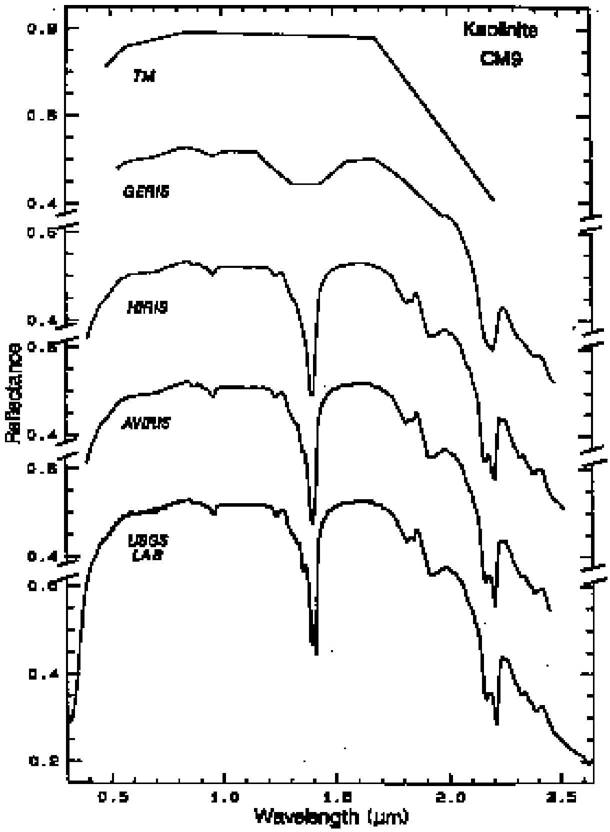

Figure 16-2: Modeled signatures of different hyperspectral sensors for the mineral kaolinite. From Swayze, 1997.

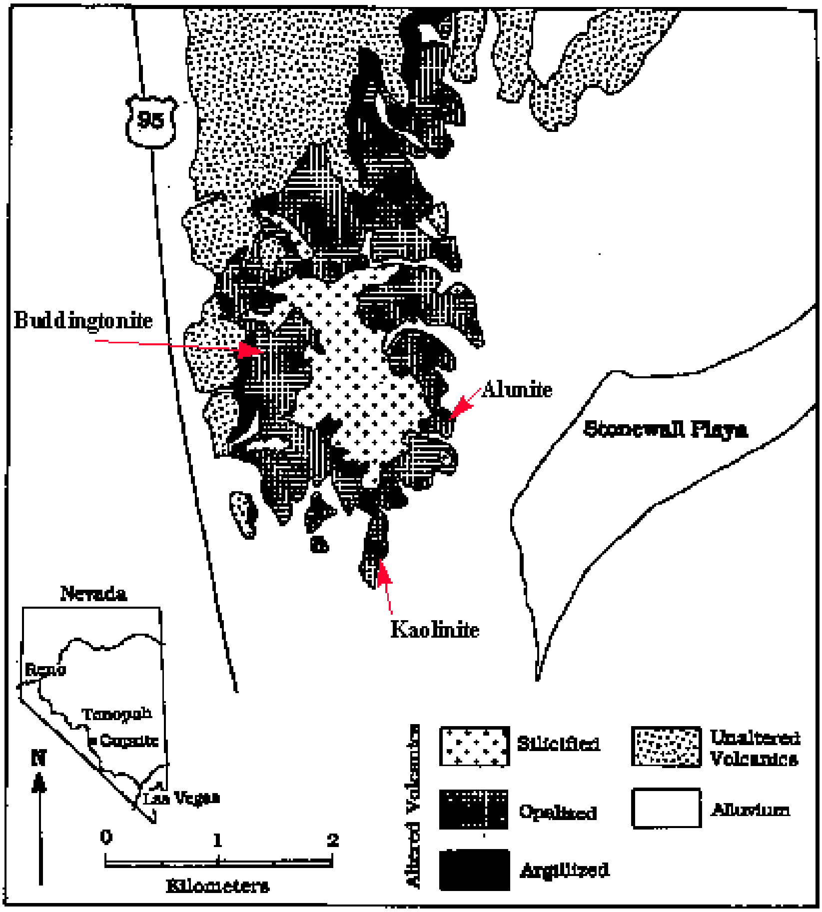

Figure 16-3: Alteration map for Cuprite, Nevada.

Case History: Cuprite, Nevada, USA

This example is provided to illustrate the effects of spatial and spectral resolution on information extraction from multispectral/hyperspectral data. Several images of the Cuprite, Nevada, USA, area acquired with a variety of spectral and spatial resolutions serve as the basis for discussions on the effect of these parameters on mineralogic mapping using remote sensing techniques. These images have not been georeferenced, but image subsets covering approximately the same spatial areas are shown. Cuprite has been used extensively as a test site for remote sensing instrument validation (Abrams et al., 1978; Kahle and Goetz, 1983; Kruse et al., 1990; Hook et al., 1991). A generalized alteration map is provided for comparison with the images. Examples from Landsat TM, GEOSCAN MkII, GER63, HyMap and AVIRIS illustrate both spatial and spectral aspects.

All of these data sets have been calibrated to reflectance. Only three of the numerous materials present at the Cuprite site were used for the purposes of this comparison. Average kaolinite, alunite, and buddingtonite image spectra were selected from known occurrences at Cuprite. Laboratory spectra from the USGS Spectral Library (Clark et al., 1990) of the three selected minerals are provided for comparison to the image spectra. The following is a synopsis of selected instrument characteristics and a discussion of the images and spectra obtained with each sensor

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the *Installing and Licensing ENVI* manual.

- To start ENVI for UNIX, enter `envi` at the UNIX command line.
- To start ENVI for Windows or Macintosh, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Open a Spectral Library File

To open a spectral library:

1. Select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer**. Click the **Open Spec Lib** button to display the file selection dialog.
2. Navigate to the `cup_comp` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 2* and select the file `usgs_em.sli` from the list and on Windows and Macintosh click **Open** and on UNIX click **OK**.

3. Double-click the `usgs_em.sli` file in the Select Input File section of the Spectral Library Input File dialog. The **Spectral Library Viewer** dialog displays with four laboratory spectra for the Cuprite site listed.

View Library Spectra

This step uses library Spectra (approximately 10 nm Spectral Resolution) from the USGS Spectral Library.

1. Plot each of the four spectra from the spectral library in an ENVI spectral plot by clicking on the spectrum name in the **Spectral Library Viewer** window.
2. Examine the detail available in the library spectral plots paying special attention to the absorption feature positions, depths, and shapes near 2.2 - 2.4 μm. You may want to select **Edit** → **Plot Parameters** and change the X-Axis range to 2.0 - 2.5 μm to accomplish this comparison or click and drag a box outlining the desired subset using the middle mouse button.
3. Place this plot window to one side of the screen for use with data from the hyperspectral sensors.

View Landsat TM Image and Spectra

This dataset is Landsat Thematic Mapper data with spatial resolution of 30 meters and spectral resolution of up to 100nm. The Cuprite TM data were acquired on 4 October 1984 and are in the public domain.

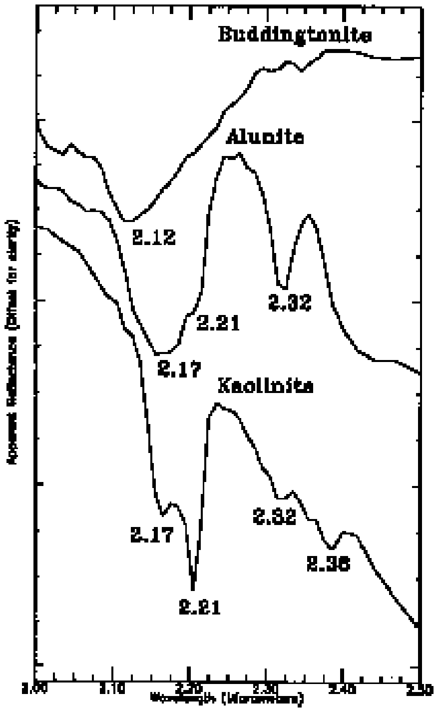

Figure 16-4: Laboratory measurements for the minerals kaolinite, alunite, and buddingtonite measured on the USGS Denver Beckman Spectrometer.

The figure below (Figure 16-5) is a plot of the Region of Interest (ROI) average spectra for the three materials shown in the library spectra above (Figure 16-4). The small squares indicate the TM band 7 (2.21 µm) center point. The lines indicate the slope from TM band 5 (1.65 µm). Note the similarity of all of the “spectra” and how it is not possible to discriminate between the three endmembers.

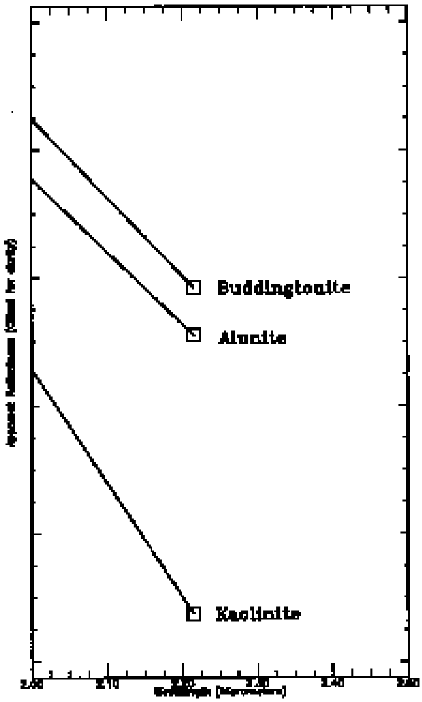

Figure 16-5: Landsat TM Measurements for TM Band 7.

1. Select **File** → **Open Image File** from the ENVI main menu, navigate to the `cup_comp` directory, and open the file `cuptm_rf.img`.

   This is the Landsat TM reflectance data for Cuprite, Nevada, produced using ENVI's Landsat TM calibration Utility.

2. Load TM band 3 as a grayscale image in a new image display by choosing the **Gray Scale** radio button in the **Available Bands List** dialog, clicking on Band 3, clicking "New Display" on the **Display** pulldown button, and then click **Load Band**.

3. Start a Z-Profile by selecting **Tools** → **Profiles** → **Z-Profile** in the Main Image Display window and use to examine apparent reflectance spectra.

4. Start a new plot window from the **Window** → **Start New Plot Window** option in the ENVI main menu and load the ASCII file `cuptm_em.txt`. Compare the

two spectra to the library spectra in the Spectral Library Viewer. Drag and drop spectra from the Spectral Library Viewer plot window into this new plot window by clicking the right mouse button in the plot to toggle on the spectra names, then clicking and dragging using the left mouse button on the beginning of the spectrum name and releasing the left mouse button when the spectrum name appears in the second plot window.

5. Select **Tools** → **Pixel Locator** and use the Pixel Locator to locate and browse around the location of the Kaolinite (248, 351) and the Alunite (260, 330) and examine the spectral variability. Examine spectra near 202, 295 (Buddingtonite) and near 251, 297 (Silica or Opal) and compare to the library spectra. Drag-and-drop spectra for best comparison. Answer questions pertaining to the TM data in "Draw Conclusions" on page 395.

6. Place this plot window to one side of the screen for comparison with data from the other sensors.

View GEOSCAN Data

This dataset is Cuprite GEOSCAN imagery with approximately 60 nm Resolution with 44 nm sampling converted to apparent reflectance using a flat field correction. The GEOSCAN MkII sensor, flown on a light aircraft during the late 1980s was a commercial aircraft system that acquired up to 24 spectral channels selected from 46 available bands. GEOSCAN covered the range from 0.45 to 12.0 µm using grating dispersive optics and three sets of linear array detectors (Lyon and Honey, 1989). A typical data acquisition for geology resulted in 10 bands in the visible/near infrared (VNIR, 0.52 - 0.96 µm), 8 bands in the shortwave infrared (SWIR, 2.04 - 2.35 µm), and thermal infrared (TIR, 8.64 - 11.28 µm) regions (Lyon and Honey, 1990). The GEOSCAN data were acquired in June 1989. The figure below (Figure 16-6) is a plot of the ROI average spectra for the three materials shown in the library spectral plot above. Compare these to library spectra and the Landsat TM spectra and note that the three minerals appear quite different in the GEOSCAN data, even with the relatively widely spaced spectral bands.

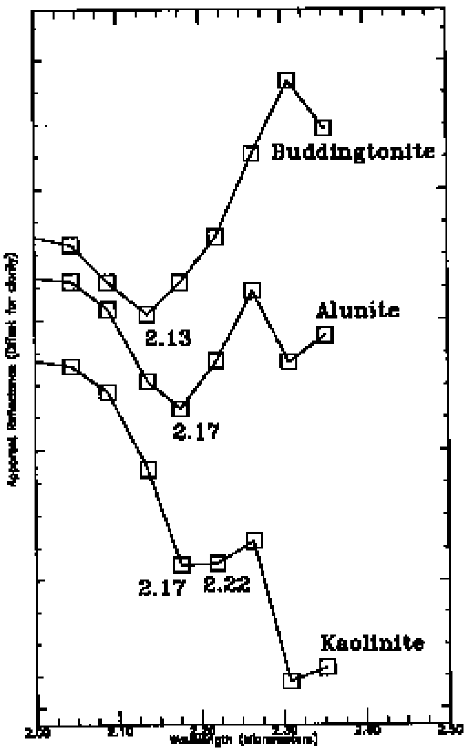

Figure 16-6: Geoscan SWIR spectra.

GEOSCAN is high spatial resolution makes it suitable for detailed geologic mapping (Hook et al., 1991). The relatively low number of spectral bands and, low spectral resolution limit mineralogic mapping capabilities to a few groups of minerals in the absence of ground information. Strategic placement of the SWIR bands, however, does provide more mineralogic information than would intuitively be expected based on the spectral resolution limitations.

1. Select **File** → **Open Image File** from the ENVI main menu and open the Cuprite GEOSCAN data `cupgs_sb.img`.
2. Click on the **Gray Scale** radio button in the **Available Bands List**, Band 15 in the list, and then click **Load Band** to display the image.
3. Start a Z-Profile by selecting **Tools** → **Profiles** → **Z-Profile** in the Main Image Display window and use to browse through some of the apparent reflectance spectra.
4. Load a color composite image of bands 13, 15, and 18 (RGB) to enhance mineralogical differences.
5. Start a new plot window from the **Window** → **Start New Plot Window** menu and load the ASCII file `cupgs_em.txt`. Compare the two spectra to the library spectra in the **Spectral Library Viewer**, and to the spectra from the other sensors. Drag and drop spectra as described above for direct comparison.
6. Select **Tools** → **Pixel Locator** and use the **Pixel Locator** to locate and browse around the location of the Kaolinite (275, 761) and the Alunite (435, 551) and examine the spectral variability. Examine spectra near 168, 475 (Buddingtonite) and near 371, 592 (Silica or Opal) and compare to the library spectra and spectra from the other sensors. Answer questions pertaining to the GEOSCAN data in “Draw Conclusions” on page 395.
7. Place this plot window to one side of the screen for comparison with data from the other sensors.

View GER63 Data

This dataset is Cuprite Geophysical and Environmental Research 63-band scanner data (GER63). It has an advertised spectral resolution of 17.5 nm, but comparison with other sensors and laboratory spectra suggests that 35 nm resolution with 17.5 nm sampling is more likely. Four bad bands have been dropped so that only 59 spectral bands are available. The GER63 data described here were acquired during August 1987. Selected analysis results were previously published in Kruse et al. (1990). The figure below (Figure 16-7) is a plot of the ROI average spectra for the three materials shown in the library spectra above. Note that the GER63 data adequately discriminate the alunite and buddingtonite, but do not fully resolve the kaolinite “doublet” near 2.2 μm shown in the laboratory.

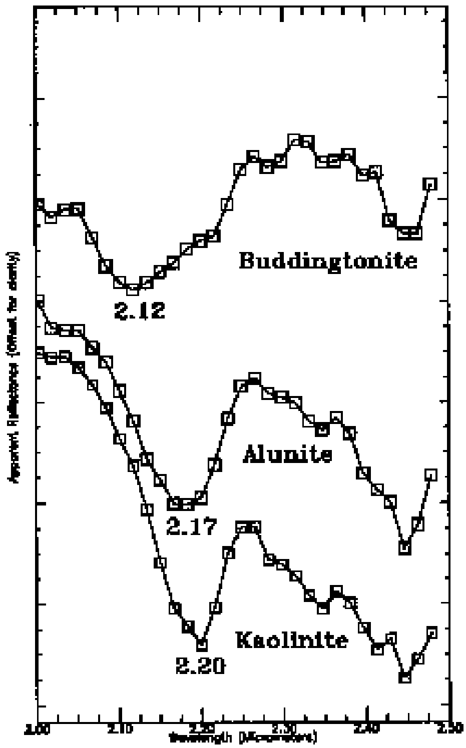

Figure 16-7: GER-63 SWIR spectra.

1. Select **File** → **Open Image File** from the ENVI main menu and open the Cuprite GER64 data `cupgersb.img`.
2. Click on the **Gray Scale** radio button in the **Available Bands List**, Band 42 in the list, and then click **Load Band** to display the image.
3. Start a Z-Profile by selecting **Tools** → **Profiles** → **Z-Profile** in the Main Image Display window and use to browse through some of the apparent reflectance spectra.
4. Load a color composite image of bands 36, 42, and 50 (RGB) to enhance mineralogical differences.

5. Start a new plot window from the **Window** → **Start New Plot Window** menu and load the ASCII file `cupgerem.txt`. Compare the two spectra to the library spectra in the **Spectral Library Viewer**, and to the spectra from the other sensors. Drag and drop spectra as described above for direct comparison.
6. Select **Tools** → **Pixel Locator**. Use the **Pixel Locator** to locate and browse around the location of the Kaolinite (235, 322) and the Alunite (303, 240) and examine the spectral variability. Examine spectra near 185, 233 (Buddingtonite) and near 289, 253 (Silica or Opal) and compare to the library spectra and spectra from the other sensors. Drag-and-drop spectra for best comparison. Answer questions pertaining to the GER63 data in "Draw Conclusions" on page 395.
7. Place this plot window to one side of the screen for comparison with data from the other sensors.

View HyMap Data

HyMap is a state-of-the-art aircraft-mounted commercial hyperspectral sensor developed by Integrated Spectronics, Sydney, Australia, and operated by HyVista Corporation. HyMap provides unprecedented spatial, spectral and radiometric excellence (Cocks et al., 1998). The system is a whiskbroom scanner utilizing diffraction gratings and four 32-element detector arrays (1 Si, 3 liquid-nitrogen-cooled InSb) to provide 126 spectral channels covering the 0.44 - 2.5 µm range over a 512-pixel swath. Spectral resolution varies from 10 - 20 nm with 3-10m spatial resolution and SNR over 1000:1. The HyMap data described here were acquired on September 11, 1999. Selected analysis results were have been published in Kruse et al. (1999). The figure below (Figure 16-8) is a plot of the ROI average spectra for the three materials shown in the library spectra above (Figure 16-4).

1. Select **File** → **Open Image File** from the ENVI main menu, navigate to the `cup99hym` directory, and open the file `cup99hy.eff`.

   This is the HyMap reflectance data for Cuprite, Nevada, produced by running calibrated radiance data through the ATREM atmospheric correction followed by EFFORT polishing (Kruse et al., 1999). The data is rotated 180 degrees from north (north is towards the bottom of the image).

2. Load HyMap band 109 as a grayscale image in a new image display by choosing the **Gray Scale** radio button in the **Available Bands List**, clicking on the band name, clicking **New Display** in the pulldown **Display** menu, and then clicking **Load Band**.
3. Start a Z-Profile by selecting **Tools** → **Profiles** → **Z-Profile** in the Main Image Display window and use to examine apparent reflectance spectra.

4. Start a new plot window from the **Window** → **Start New Plot Window** menu and load the ASCII file `cup99hy_em.txt`. Compare the two spectra to the library spectra in the Spectral Library Viewer. Drag and drop spectra from the **Spectral Library Viewer** plot window into this new plot window by clicking the right mouse button in the plot to toggle on the spectra names, then clicking and dragging using the left mouse button on the beginning of the spectrum name and releasing the left mouse button when the spectrum name appears in the second plot window.

5. Load a color composite image of bands 104, 109, 117 (RGB) to enhance mineralogical differences.

6. Select **Tools** → **Pixel Locator** and use the **Pixel Locator** to locate and browse around the location of the Kaolinite (248, 401) and the Alunite (184, 568) and examine the spectral variability. Examine spectra near 370, 594 (Buddingtonite) and near 172, 629 (Silica or Opal) and compare to the library spectra. Drag-and-drop spectra for best comparison. Answer questions pertaining to the GER63 data in "Draw Conclusions" on page 395 pertaining to the 1999 HyMap data in Figure 16-8.

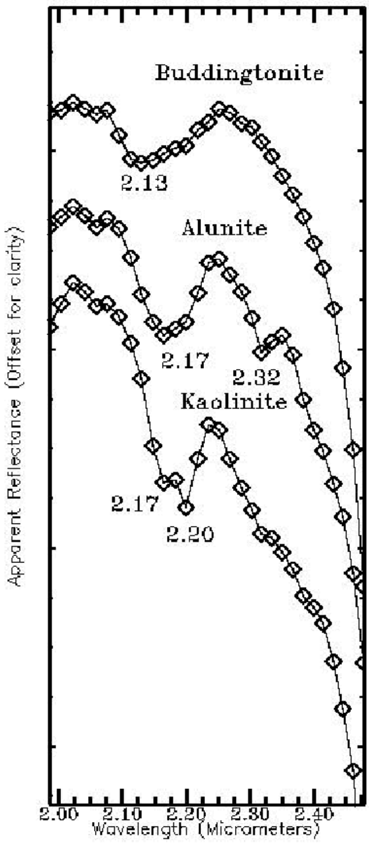

Figure 16-8: HyMap SWIR spectra.

7. Place this plot window to one side of the screen for comparison with data from the other sensors.

View AVIRIS Data

These data are Cuprite 1995 Airborne Visible Infrared Imaging Spectrometer (AVIRIS), which have approximately 10 nm spectral resolution and 20 m spatial resolution. The AVIRIS data shown here were acquired during July 1995 as part of an AVIRIS Group Shoot (Kruse and Huntington, 1996). The data were corrected to reflectance using the ATREM method and residual noise was removed using the EFFORT procedure. The figure below (Figure 16-9) is a plot of the ROI average spectra for the three materials shown in the library spectral plot. Compare these to the laboratory spectra above and note the high quality and nearly identical signatures.

1. Select **File** → **Open Image File** and navigate to the `c95avsub` subdirectory and select the file `cup95eff.int` from the list and click **OK**.
2. Display a grayscale image and then start a Z-Profile by selecting **Tools** → **Profiles** → **Z-Profile** in the Main Image Display window and use to browse through some of the apparent reflectance spectra.
3. Load a color composite image of bands 183, 193, and 207 (RGB) to enhance mineralogical differences.
4. Start a new plot window from the **Window** → **Start New Plot** Window menu and load the ASCII file `cup95eff.txt`. Compare the two spectra to the library spectra in the **Spectral Library Viewer**, and to the spectra from the other sensors. Drag and drop spectra as described above for direct comparison.
5. Select **Tools** → **Pixel Locator**. Use the **Pixel Locator** to locate and browse around the location of the Kaolinite (500, 581) and the Alunite (538, 536) and examine the spectral variability. Examine spectra near 447, 484 (Buddingtonite) and 525, 505 (Silica or Opal) and compare to the library spectra and spectra from the other sensors. Drag-and-drop spectra for best comparison. Answer questions pertaining to the GER63 data in “Draw Conclusions” on page 395 pertaining to the 1995 AVIRIS data in Figure 16-9.

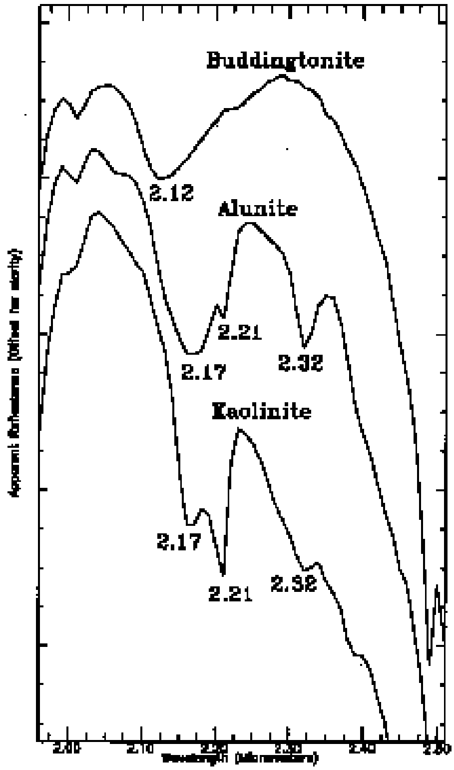

Figure 16-9: AVIRIS SWIR spectra.

Evaluate Sensor Capabilities

These four sensors and the library spectra represent a broad range of spectral resolutions.

1. Using the Library Spectra as the ground truth, evaluate how well each of the sensors is able to represent the ground truth information. Consider what it means to discriminate between materials versus identification of materials.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

Draw Conclusions

1. Using the selected library spectra provided, what is the minimum spacing of absorption features in the 2.0 - 2.5 µm range?
2. The TM data obviously dramatically undersample the 2.0 - 2.5 µm range, as only TM band 7 is available. What evidence do you see for absorption features in this range? What differences are apparent in the TM spectra of minerals with absorption features in this range?
3. The GEOSCAN data also undersample the 2.0 - 2.5 µm range, however, the bands are strategically placed. What differences are there between the GEOSCAN spectra for the different minerals? Could some of the bands have been placed differently to provide better mapping of specific minerals?
4. The GER63 data provide improved spectral resolution over the GEOSCAN data and individual features can be observed. The advertised spectral resolution of the GER63 between 2.0 - 2.5 µm is 17.5 nm. Examine the GER-63 kaolinite spectrum and defend or refute this resolution specification. Do the more closely spaced spectral bands of the GER63 sensor provide a significant advantage over the GEOSCAN data in mapping and identifying these reference minerals?
5. What are the main differences between mineral spectra at Cuprite caused by the change from 10nm spectral resolution for AVIRIS to the 17nm spectral resolution of HyMap?
6. The AVIRIS data provide the best spectral resolution of the sensors examined here. How do the AVIRIS and laboratory spectra compare? What are the major similarities and differences? What factors affect the comparison of the two data types?
7. Examine all of the images and spectra. What role does spatial resolution play in the comparison?
8. Based on the Library spectra, provide sensor spectral and spatial resolution design specifications as well as recommendations on placement of spectral bands for mineral mapping. Examine the trade-offs between continuous high-spectral resolution bands and strategically placed, lower resolution bands.

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Tutorial 17: Geologic Hyperspectral Analysis Case History

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial presents a case history for use of hyperspectral techniques for geologic analysis using 1999 HyMap data from Cuprite, Nevada, USA. It is designed to be a self-directed example using ENVI's complete end-to-end hyperspectral tools to produce image-derived endmember spectra and image maps. The processing should be done using the standard ENVI methods (**EFFORT** → **MNF** → **PPI** → **n-D Visualization** → **Spectral Mapping** → **GLT Geocorrection**). For more detail and step-by-step procedures on performing such a hyperspectral analysis, please execute the introductory through advanced ENVI hyperspectral tutorials prior to attempting this tutorial. 1999 HyMap data of Cuprite, Nevada, used for the tutorial are copyright 1999 Analytical Imaging and Geophysics (AIG) and HyVista Corporation (All Rights Reserved), and may not be redistributed without explicit permission from AIG @info.aigllc.com).

Objectives

1. To examine application of ENVI end-to-end hyperspectral processing methodology to a geology case study.
2. To give students hands-on experience in actually running the procedures rather than reviewing pre-calculated results (preprocessed results are provided for comparison).
3. To provide students with guidance to perform data exploration in a loosely structured framework.
4. To compare analysis results with known ground information.

Tasks

1. Evaluate Atmospherically Corrected (ATREM) EFFORT-corrected data.
2. Conduct Spatial/Spectral browsing to evaluate data, determine presence and nature of spectral variability, and to select wavelength range (s) for further analysis.
3. Reduce data dimensionality using MNF transform.
4. Select spectral endmember candidates using PPI.
5. Evaluate and select endmembers using n-D Visualizer.
6. Map endmember distribution and abundance using ENVI mapping methods. Compare and contrast results.

7. Reconcile image and lab spectra/ground information.
8. Optionally geocorrect the data.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/cup99hym`
`envidata/c95avsub`

File	Description
Required Files (`envidata/cup99hym`)	
`cup99hy.eff`	EFFORT-corrected HyMap data
`cup99hy.hdr`	ENVI Header for above
`cup99hy_geo_glt`	ENVI Geometry Lookup file
`cup99hy_geo_glt.hdr`	ENVI Header for above
`cup99hy_geo_igm`	ENVI Input Geometry file
`cup99hy_geo_igm.hdr`	ENVI Header for above
`cup99hy_mnf`	MNF results of 32 SWIR bands, using data to estimate noise covariance
`cup99hy_mnf.hdr`	ENVI Header for above
`cup99hy_mnf.sta`	MNF stats from MNF run
`cup99hy_mnfevs.txt`	ASCII file of MNF Eigenvalues
`cup99hy_mtmf`	MTMF results using endmembers from mtmf.roi mean
`cup99hy_mtmf.hdr`	ENVI Header for above
`cup99hy_mtmf.roi`	ROIs of classes picked in n-d visualizer
`cup99hy_mtmfems.txt`	ASCII file of MTMF endmember spectra
`cup99hy_noi.sta`	Noise statistics from MNF run
`cup99hy_ppi`	PPI image
`cup99hy_ppi.hdr`	ENVI Header for above

File	Description
cup99hy_ppi.cnt	PPI count file
cup99hy_true.img	True-Color Image
cup99hy_true.hdr	ENVI Header for above
Required Files (envidata/c95avsub)	
usgs_sli.dat	USGS Spectral Library
usgs_sli.hdr	ENVI Header for above

Note

The files listed are required to run this exercise. Miscellaneous files listed below provide additional information that may be useful. Selected data files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. Values of 1000 in the files represent reflectance values of 1.0.

Cuprite Background Materials

The Cuprite site has been used as a remote sensing test site by JPL and others since the early 1980s. A generalized alteration map is provided in Tutorial 16, "Hyperspectral Signatures and Spectral Resolution" ENVI tutorial for comparison with processing results derived during this analysis. AVIRIS Standard Datasets are available from JPL for 1992-2000.

HyMap Processing Flow

The Figure 17-1 illustrates an approach for analysis of hyperspectral data that is implemented with ENVI.

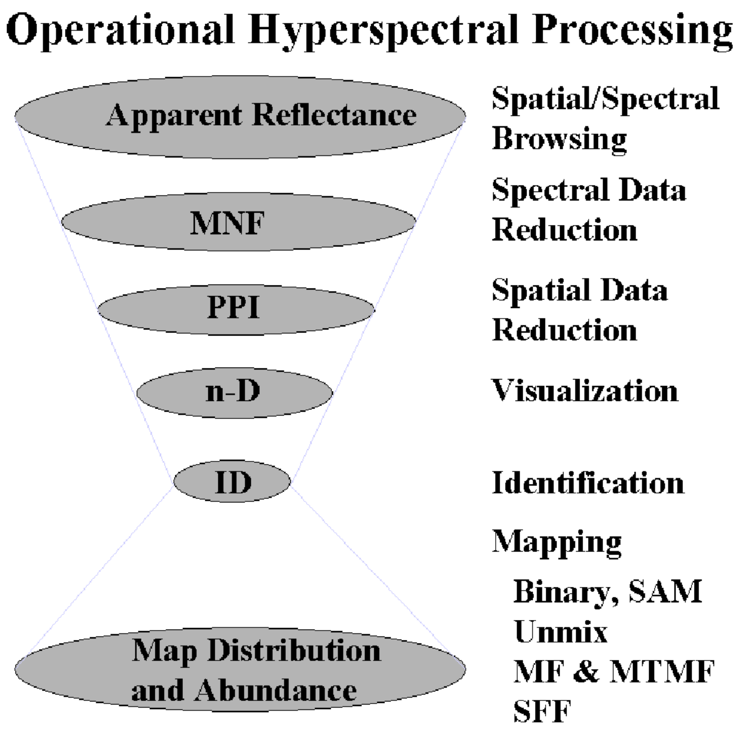


Figure 17-1: End-to-End Hyperspectral Processing with ENVI.

The following outlines in general terms the implementation of this approach. The student is expected to follow the procedures below, referring to previous tutorials and the *ENVI User's Guide* for guidance in performing specific tasks where required. The purpose of this tutorial isn't to teach you how to run the ENVI tools, but how to apply the methodology and tools to a general hyperspectral remote sensing problem.

Geologic Hyperspectral Analysis

1. Examine HyMap EFFORT apparent reflectance data: Load a gray scale and/or color composite images. Start a spectral profile and examine spectra for residual atmospheric absorption features (CO2 bands near 2.0 micrometers).

File	Description
`cup99hy.eff`	EFFORT-corrected HyMap data
`cup99hy.hdr`	ENVI Header for above

2. Conduct spatial/spectral browsing. Display a gray scale image. Extract reflectance signatures and examine for mineral spectral features. Animate the data and extract spectra for areas of high variability. Determine bad spectral bands. Load color composite images designed to enhance spectral contrast. Determine spectral subset(s) to use for mineral mapping. Extract reflectance signatures for vegetation and geologic materials. Compare to spectral libraries.

File	Description
`cup99hy.eff`	EFFORT-corrected HyMap data
`cup99hy.hdr`	ENVI Header for above

3. Apply MNF Transform to the EFFORT data to find the data's inherent dimensionality. Review MNF eigenvalue plot to determine break-in-slope and relate to spatial coherency in MNF eigenimages. Determine MNF cut-off between signal and noise for further analysis.

   Make your own MNF-Transformed dataset or review the results in the files below:

File	Description
`cup99hy_mnf.sta`	MNF stats from MNF run
`cup99hy_ppi`	PPI image
`cup99hy_ppi.hdr`	ENVI Header for above
`cup99hy_ppi.cnt`	PPI count file
`cup99hy_mtmf.roi`	ROIs of classes picked in n-D visualizer

File	Description
cup99hy_mtmfems.txt	ASCII file of MTMF endmember spectra

4. Apply PPI Analysis to the MNF output to rank the pixels based on relative purity and spectral extremity. Use the FAST PPI option to perform calculations quickly in system memory, creating the PPI image. Display the PPI image, examine the histogram, and threshold to create a list of the purest pixels, spatially compressing the data.

   Generate your own PPI results and ROIs or review the results in the files below:

File	Description
cup99hy_ppi	PPI image
cup99hy_ppi.hdr	ENVI Header for above
cup99hy_ppi.cnt	PPI count file

5. Perform n-Dimensional Visualization of the high PPI value pixels, using the high signal MNF data bands to cluster the purest pixels into image-derived endmembers. Rotate the MNF data interactively in 3-D, or spin in 3-or-more dimensions and paint pixels that occur on the points (extremities) of the scatterplot. Use Z-Profiles connected to the EFFORT apparent reflectance data and the **n-D Visualizer** to evaluate spectral classes. Use class collapsing to iteratively find all of the endmembers. Evaluate mixing and endmembers. Save your n-D results to a save state file (.ndv). Export classes to ROIs and extract mean spectra. Compare mean spectra to spectral libraries. Use spectral/spatial browsing to compare image spectra to ROI means.

   Extract endmembers and make your own ROIs or review the results below:

File	Description
cup99hy_mnf	MNF results of 32 SWIR bands, using data to estimate noise covariance
cup99hy_mnf.hdr	ENVI Header for above
cup99hy_mnf.sta	MNF stats from MNF run
cup99hy_ppi	PPI image

File	Description
cup99hy_ppi.hdr	ENVI Header for above
cup99hy_ppi.cnt	PPI count file
cup99hy_mtmf.roi	ROIs of classes picked in n-D visualizer
cup99hy_mtmfems.txt	ASCII file of MTMF endmember spectra

6. Use ENVI's wide variety of mapping methods to map the spatial occurrence and abundance of materials at Cuprite. As a minimum, try the Spectral Angle Mapper (SAM) and MTMF. Use SAM to determine spectral similarity to image endmember spectra. If time and space permit, try a SAM classification using one of the Spectral Libraries. Be sure to evaluate the Rule Images. Use the MTMF mapping method to determine material abundance. Be sure to use both the MF and Infeasibility images in a 2-D scatterplot to select the best matches (high MF and low Infeasibility Score). Compare abundance image results to the endmember spectra and spectral libraries using spatial/spectral browsing.

File	Description
cup99hy_mnf	MNF results of 32 SWIR bands, using data to estimate noise covariance
cup99hy_mnf.hdr	ENVI Header for above
cup99hy_mnf.sta	MNF stats from MNF run
cup99hy_mtmf	MTMF results using endmembers fromtmf.roi mean
cup99hy_mtmf.hdr	ENVI Header for above
cup99hy_mtmf.roi	ROIs of classes picked in n-D visualizer
cup99hy_mtmfems.txt	ASCII file of MTMF endmember spectra

Use the provided GLT and/or IGM files to produce geocorrected output images of the MTMF processing. Follow the procedures described in Tutorial 5, "Georeferencing Images Using Input Geometry" ENVI tutorial "Georeferencing Images Using Input

Geometry” to geocorrect mineral maps. Add map grids and annotation and produce a final map produce.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

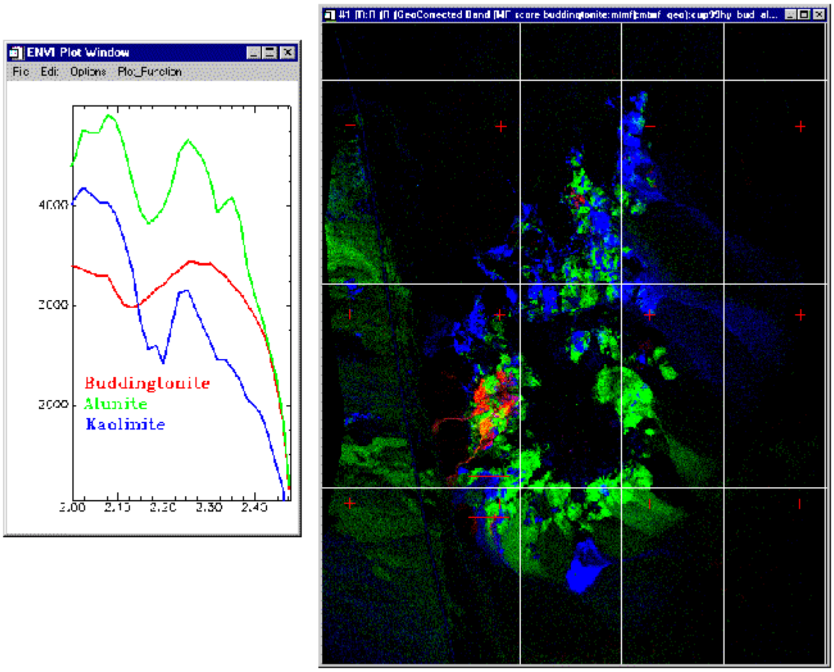


Figure 17-2: Selected endmember spectra and portion of geocorrected image-map result for Cuprite, Nevada 1999 HyMap data.

Tutorial 18: Archaeology Hyperspectral Analysis Case History

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial presents a case history for use of hyperspectral techniques for archeological analysis using MIVIS data from Selinunte, Sicily, Italy. It is designed to be a self-directed example using ENVI's complete end-to-end hyperspectral tools to produce image-derived endmember spectra and image maps. The processing should be done using the standard ENVI methods (**EFFORT** → **MNF** → **PPI** → n-**D Visualization** → **Spectral Mapping**). For more detail and step-by-step procedures on performing such a hyperspectral analysis, please execute the introductory through advanced ENVI hyperspectral tutorials prior to attempting this tutorial. The MIVIS data are courtesy of Research Systems Italia, S.R.L. and the Italian National Research Council (CNR). Used with permission.

Objectives

1. To examine application of ENVI end-to-end hyperspectral processing methodology to an archaeology case study.
2. To give students hands-on experience in actually running the procedures rather than reviewing pre-calculated results (preprocessed results are provided for comparison).
3. To provide students with guidance to perform data exploration in a loosely structured framework.
4. To compare analysis results with known ground information.

Tasks

1. Evaluate Radiance Data.
2. Perform empirical (Flat-Field) Atmospheric Correction.
3. Evaluate Atmospherically Corrected data.
4. Conduct Spatial/Spectral browsing to evaluate data, determine presence and nature of spectral variability, and to select wavelength range (s) for further analysis.
5. Reduce data dimensionality using MNF transform.
6. Select spectral endmember candidates using PPI.
7. Evaluate and select endmembers using n-D Visualizer.

8. Map endmember distribution and abundance using ENVI mapping methods. Compare and contrast results.
9. Reconcile image and field spectra/ground information.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/selmivis`

File	Description
Required Files	
`selinunte_rad.bil`	MIVIS 92 band radiance subset
`selinunte_rad.hdr`	ENVI Header for above
`selinunte.ann`	ENVI annotation for above
`mivis_waves.txt`	Text Wavelength file for MIVIS
`selinunte_ff.roi`	ROI used for Flat Field correction
Generated Files	
`selinunte_ff.bil`	MIVIS Flat Field Apparent Reflectance Data
`selinunte_ff.hdr`	ENVI Header for above
`selinunte_mnf.bil`	MNF for 91 MIVIS bands
`selinunte_mnf.hdr`	ENVI Header for above
`selinunte_mnf.txt`	ASCII file of MNF Eigenvalues
`selinunte_mnf.sta`	MNF Statistics
`selinunte_ns.sta`	Noise Statistics
`selinunte_ppi.img`	Pixel Purity Index Image
`selinunte_ppi.hdr`	ENVI Header for above
`selinunte_ppi.cnt`	PPI count file
`selinunte_ppi.roi`	Thresholded PPI ROI
`selinunte_ppi.ndv`	Saved n-D Visualizer state

File	Description
selinunte_ndv.roi	n-D Visualizer regions of interest
selinunte_ndvems.txt	n-D Visualizer endmember
selinunte_sam.img	Spectral Angle Mapper result
selinunte_sam.hdr	ENVI Header for above
selinunte_mtmf.img	MTMF results images
selinunte_mtmf.hdr	ENVI Header for above

Selinunte/MIVIS Background Materials

Selinunte is an abandoned ancient Greek city with ruins of an acropolis and numerous temples (Figure 18-1), located on the southwest coast of Sicily, Italy, in the province of Trapani. The city was founded between 650 and 630 BC, and effectively destroyed by the Carthaginians in 409 BC.

The city of Selinunte, the Acropolis, is situated on high ground overlooking the Mediterranean. Selinunte is surrounded by a park (Parco Archeologico di Selinunte) extending approximately 1,300 meters east to west. There are five temples within the Acropolis, some of which have been excavated. Others are essentially jumbled piles of stones. The entire Acropolis has never been completely excavated, but the surrounding walls were mostly reconstructed by archaeologists in 1927. See http://www.bestofsicily.com/selinunte.htm for additional information.

Daedalus AA5000 MIVIS data were flown over the Selinunte Park during 1996 with approximately 3-meter spatial resolution. MIVIS, the Multispectral Infrared and Visible Imaging Spectrometer, owned and operated by the Italian National Research Council (CNR), is a 102 channel scanner with 92 bands covering the approximately 0.4 to 2.5 micrometer (VNIR-SWIR) range and 10 bands over the 8-14 micrometer (LWIR) range. For the purposes of this tutorial, we will use 90 of the 92 VNIR-SWIR bands (excluding bands 63 and 87 as bad bands). MIVIS data are courtesy of RSI Italy and CNR.

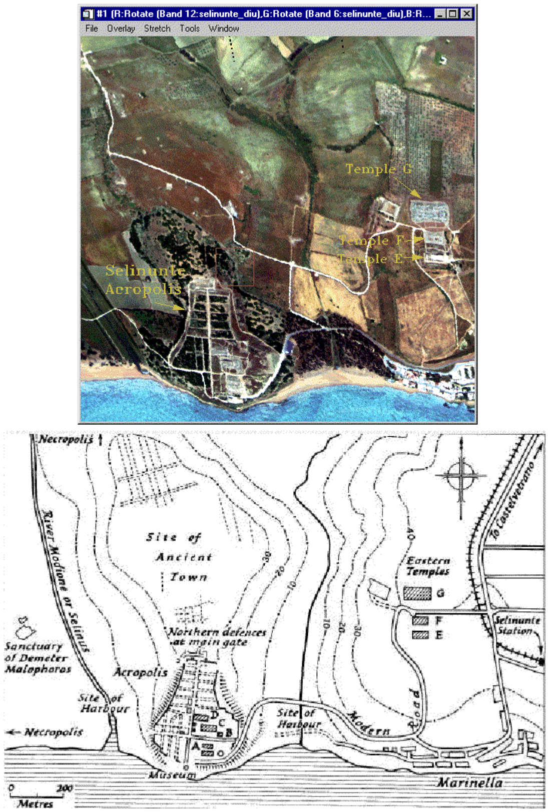


Figure 18-1: Reference map and selected archaeological features annotated on a MIVIS true-color image.

MIVIS Processing Flow

The Figure 18-2 illustrates an approach for analysis of hyperspectral data that is implemented with ENVI.

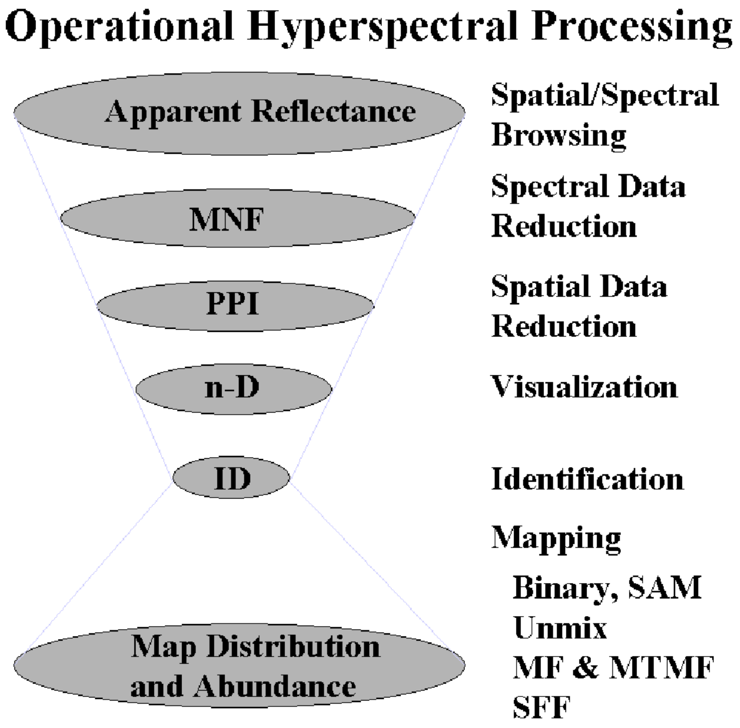


Figure 18-2: End-to-End Hyperspectral Processing with ENVI.

The following outlines in general terms the implementation of this approach. The student is expected to follow the procedures below, referring to previous tutorials and the *ENVI User's Guide* for guidance in performing specific tasks where required. The purpose of this tutorial isn't to teach you how to run the ENVI tools, but how to apply the methodology and tools to a general hyperspectral remote sensing problem

Hyperspectral Techniques for Archeological Analysis

1. Examine MIVIS radiance data: Load selected MIVIS bands as gray scale images. Perform animation. Extract radiance signatures for areas of high variability. Examine radiance spectra for evidence of absorption features. Determine bad spectral bands. Load color composite images designed to enhance spectral contrast. Determine spectral subset(s) to use for materials mapping.

File	Description
`selinunte_rad.bil`	MIVIS 92 band radiance subset
`selinunte_rad.hdr`	ENVI Header for above
`mivis_waves.txt`	Text Wavelength file for MIVIS

2. Correct MIVIS data to apparent reflectance using the Flat Field method. Use the file `selinunte_ff.roi` as the Region of Interest for the flat field. (Generate the output file `selinunte_ff.bil`). Examine MIVIS apparent reflectance data: Load gray scale images. Perform animation. Extract reflectance signatures for areas of high variability. Examine reflectance spectra for evidence of absorption features. Determine bad spectral bands. Load color composite images designed to enhance spectral contrast. Determine spectral subset(s) to use for mineral mapping. Extract reflectance signatures for vegetation and geologic materials. Compare to spectral libraries.

File	Description
`selinunte_ff.roi`	ROI used for Flat Field correction
`selinunte_ff.bil`	User Generated MIVIS Flat Field Apparent Reflectance Data
`selinunte_ff.hdr`	ENVI Header for above

3. Apply MNF Transform to a spectral subset of the apparent reflectance data to find the data’s inherent dimensionality (Generate the output file `selinunte_mnf.bil`). Review MNF eigenvalue plot(s) to determine break-in-slope and relate to spatial coherency in MNF eigenimages. Determine MNF cut-off between “signal” and “noise” for further analysis.

Make your own MNF-Transformed dataset using the file naming convention below:

File	Description
`selinunte_mnf.bil`	MNF for 90 MIVIS bands
`selinunte_mnf.hdr`	ENVI Header for above
`selinunte_mnf.txt`	ASCII file of MNF Eigenvalues
`selinunte_mnf.sta`	MNF Statistics
`selinunte_ns.sta`	Noise Statistics

4. Apply PPI Analysis to the MNF output to rank the pixels based on relative purity and spectral extremity. Use the FAST PPI option to perform calculations quickly in system memory, creating the PPI image. Display the PPI image, examine the histogram, and threshold to create a list of the purest pixels, spatially compressing the data.

   Generate your own PPI results using the file naming convention below:

File	Description
`selinunte_ppi.img`	Pixel Purity Index Image
`selinunte_ppi.hdr`	ENVI Header for above
`selinunte_ppi.cnt`	PPI count file
`selinunte_ppi.roi`	Thresholded PPI ROI

5. Perform n-Dimensional Visualization of the high PPI value pixels, using the high signal MNF data bands to cluster the purest pixels into image-derived endmembers. Rotate the MNF data interactively in 3-D, or spin in 3-or-more dimensions and "paint" pixels that occur on the points (extremities) of the scatterplot. Use Z-Profiles connected to the apparent reflectance data and the **n-D Visualizer** to evaluate spectral classes. Use class collapsing to iteratively find all of the endmembers. Evaluate mixing and endmembers. Save your n-D results to a save state file (.ndv). Export classes to ROIs and extract mean spectra. Compare mean spectra to spectral libraries. Use spectral/spatial browsing to compare image spectra to ROI means.

Extract endmembers and make your own ROI results using the file naming convention below:

File	Description
`selinunte_ppi.ndv`	Saved n-D Visualizer state
`selinunte_ndv.roi`	n-D Visualizer regions of interest
`selinunte_ndvems.txt`	n-D Visualizer endmember

6. Use ENVI's wide variety of mapping methods to map the spatial occurrence and abundance of materials at Selinunte. Hint: the temples and portions of the Acropolis are built of Calcarenite and/or Limestone, which have distinct spectral signatures (See Figure 18-3).

   As a minimum, try the Spectral Angle Mapper (SAM) and MTMF. Use SAM to determine spectral similarity of image pixels to image endmember spectra. If time and space permit, try a SAM classification using one of the Spectral Libraries. Be sure to evaluate the Rule Images. Use the MTMF mapping method to determine material abundances. Be sure to use both the MF and Infeasibility images in a 2-D scatter plot to select the best matches (high MF and low Infeasibility Score). Compare abundance image results to the endmember spectra and spectral libraries using spatial/spectral browsing.

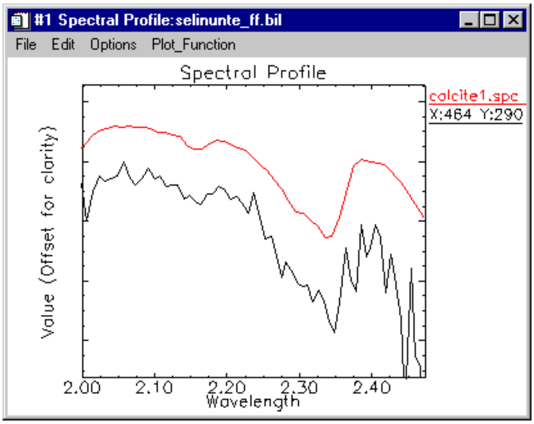


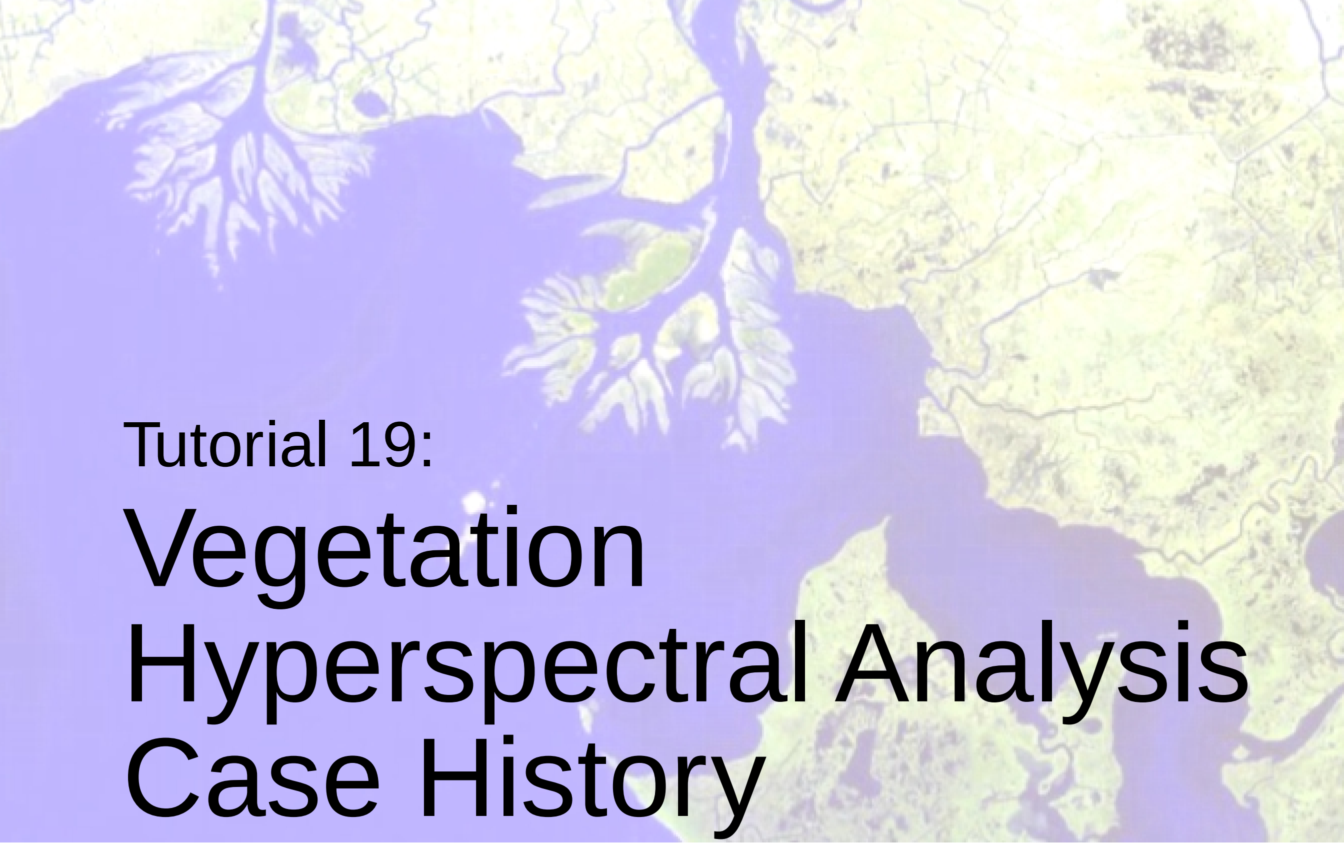
Figure 18-3: MIVIS Flat Field apparent reflectance spectrum from "Temple E", compared to a library spectrum of Calcite (Limestone).

Generate your own mapping results using the naming convention below:

File	Description
selinunte_sam.img	Spectral Angle Mapper result
selinunte_sam.hdr	ENVI Header for above
selinunte_mtmf.img	MTMF results images
selinunte_mtmf.hdr	ENVI Header for above

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.



Tutorial 19: Vegetation Hyperspectral Analysis Case History

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial presents a case history for use of hyperspectral techniques for vegetation analysis using 1999 HyMap data of Jasper Ridge, California, USA. It is designed to be a self-directed example using ENVI's complete end-to-end hyperspectral tools to produce image-derived endmember spectra and image maps. For more detail and step-by-step procedures on performing such a hyperspectral analysis, please execute the detailed hyperspectral tutorials in this booklet prior to attempting this tutorial.

Objectives

1. To examine application of ENVI end-to-end hyperspectral processing methodology to a vegetation case study.
2. To give students hands-on experience in actually running the procedures rather than reviewing pre-calculated results (preprocessed results are provided for comparison).
3. To provide students with guidance to perform data exploration in a loosely structured framework.
4. To compare analysis results with known ground information.

Tasks

1. Examine HyMap radiance data and evaluate data characteristics and quality.
2. Evaluate Atmospherically Corrected (ATREM), EFFORT-corrected HyMap data and compare to radiance data.
3. Conduct Spatial/Spectral browsing to evaluate data, determine presence and nature of spectral variability, and to select wavelength range (s) for further analysis.
4. Reduce data dimensionality using MNF transform
5. Select spectral endmember candidates using PPI.
6. Evaluate linearity and select endmembers using **n-D Visualizer**.
7. Map endmember distribution and abundance using ENVI mapping methods. Compare and contrast results.

8. Reconcile image and field spectra/ground information.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/spec_lib/veg_lib`
`envidata/spec_lib/usgs_min`
`envidata/jsp99hym`

File	Description
Required Files (`envidata/spec_lib/veg_lib`)	
`usgs_veg.sli`	USGS Vegetation Spectral Library
`usgs_veg.hdr`	ENVI Header for Above
`veg_2grn.sli`	Jasper Ridge, Spectral Library
`veg_2grn.hdr`	ENVI Header for Above
Required Files (`envidata/spec_lib/usgs_min`)	
`usgs_min.sli`	USGS Mineral Spectral Library
`usgs_min.hdr`	ENVI Header for Above
Required Files (`envidata/jsp99hym`)	
`jsp99hym_rad.bil`	HyMap Radiance, VNIR (60 bands)
`jsp99hym_rad.hdr`	ENVI Header for Above
`jsp99hym.eff`	HyMap ATREM with EFFORT Correction Applied
`jsp99hym.hdr`	ENVI Header for Above
`jsp99hym_mnf.bil`	VNIR MNF Transformed data (60 Bands)
`jsp99hym_mnf.hdr`	ENVI Header for Above
`jsp99hym_mnf_ns.sta`	VNIR MNF Noise Statistics
`jsp99hym_mnf.txt`	ASCII file of MNF Eigenvalues
`jsp99hym_ppi.img`	VNIR PPI image
`jsp99hym_ppi.hdr`	ENVI Header for Above
`jsp99hym_ppi.cnt`	PPI Count file

File	Description
jsp99hym_ppi.roi	ENVI PPI ROI file for use with n-D Visualizer
jsp99hym_ppi.ndv	n-D Visualizer Save State from PPI
jsp99hym_ndv_em.roi	VNIR ROI File of n-D Visualizer Endmember locations
jsp99hym_ndv_em.txt	VNIR ASCII File of Endmember Spectra
jsp99hym_sam.img	VNIR SAM Classes
jsp99hym_sam.hdr	ENVI Header for Above
jsp99hym_rul.img	VNIR SAM Rules
jsp99hym_rul.hdr	ENVI Header for Above
jsp99hym_glt.img	Geometry Lookup file for HyMap geocorrection
jsp99hym_glt.hdr	ENVI Header for Above
copyright.txt	HyMap Copyright Statement

Note

The files listed are required to run this exercise. Miscellaneous files listed provide additional information that may be useful. Selected data files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. Values of 1000 in the files represent reflectance values of 1.0.

Jasper Ridge Background Materials

Jasper Ridge Biological Preserve is a 1200 acre natural area owned by Stanford University. For additional information on the site, please see the Jasper Ridge homepage at http://jasper1.stanford.edu/.

Figure 19-1: Jasper Ridge Homepage Banner. (Copyright 2000, Jasper Ridge Biological Preserve, Used With Permission)

The Jasper Ridge site has been used as a remote sensing test site by JPL and others since the early 1980s. AVIRIS standard datasets are available from JPL for the years of 1992-98. Detailed maps and ground spectra have been published and are available from Standford University (see below). This remote sensing test site has been used by JPL and others since early 1980s.

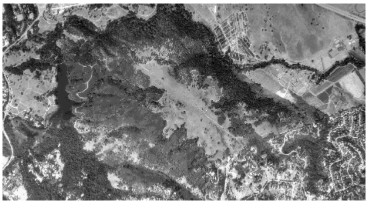


Figure 19-2: Jasper Ridge - Portion of USGS Digital Orthophoto Quad. Copyright 1997, Center for Conservation Biology and JRPB, Stanford University (Used with Permission).

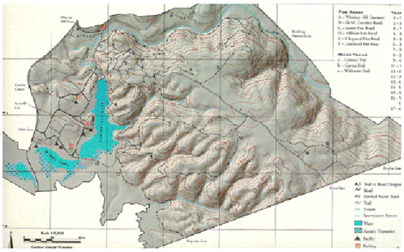


Figure 19-3: Jasper Ridge Trail Map and Shaded Relief Map. Copyright 1996, Center for Conservation Biology and JRPB, Stanford University (Used with Permission).

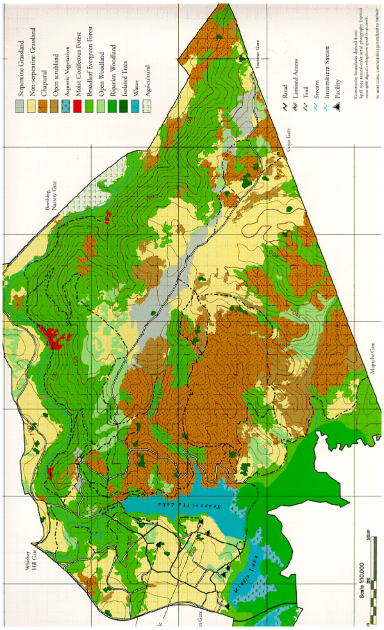


Figure 19-4: Jasper Ridge Vegetation Map. Copyright 1996, Center for Conservation Biology and JRPB, Stanford University (Used with Permission).

HyMap Processing Flow

Figure 19-5 illustrates an approach for analysis of hyperspectral data that is implemented with ENVI.

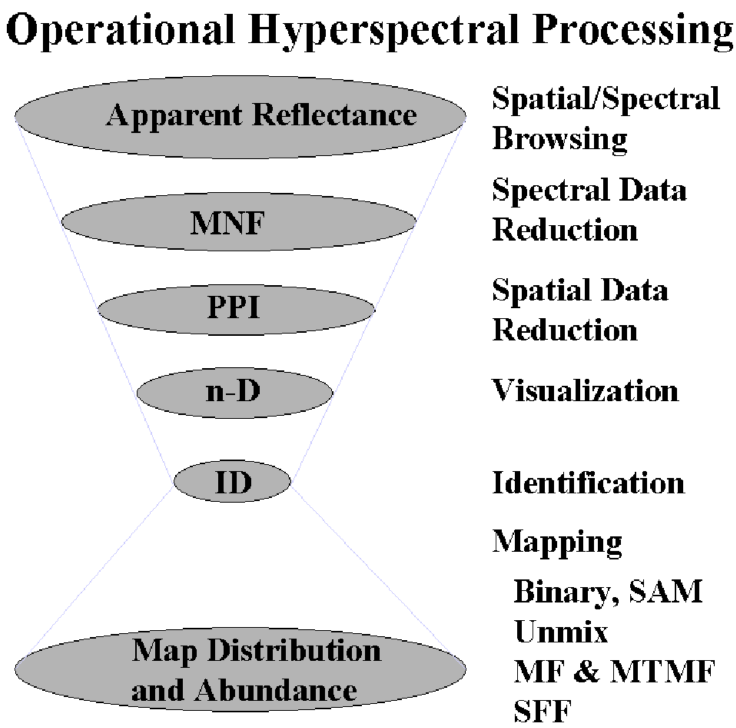


Figure 19-5: End-to-End Hyperspectral Processing with ENVI.

The following procedures outline, in general terms, the implementation of this approach. The student is expected to follow the procedures, referring to previous tutorials and the *ENVI User's Guide* for guidance in performing specific tasks where required. The purpose of this tutorial isn't to teach you how to run the ENVI tools, but how to apply the methodology and tools to a general hyperspectral remote sensing problem.

Vegetation Hyperspectral Analysis

1. Examine the Jasper Ridge HyMap radiance data: Load HyMap data as gray scale images. Perform animation. Extract radiance signatures for areas of high variability. Examine radiance spectra for evidence of absorption features. Determine bad spectral bands. Load color composite images designed to enhance spectral contrast. Determine spectral subset(s) to use for materials mapping for vegetation and/or minerals.

File	Description
jsp99hym_rad.bil	HyMap Radiance, VNIR (60 bands)

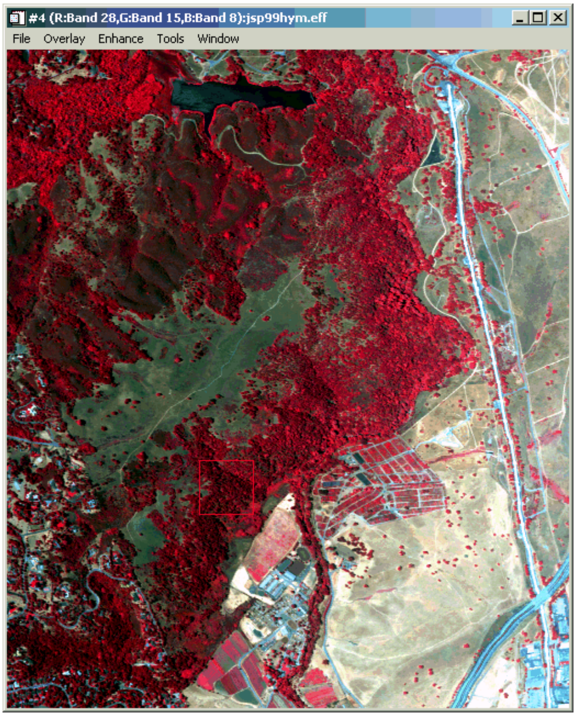


Figure 19-6: Jasper Ridge HyMap False Color Infrared Composite Image.

2. Evaluate ATREM Correction (with EFFORT) applied to the HyMap spectral radiance to remove the bulk of the solar and atmospheric effects, transforming the data from radiance to apparent surface reflectance. Examine the data using spectral/spatial browsing and color composites to characterize spectral variability and determine residual errors. Extract reflectance signatures for vegetation and geologic materials. Compare to spectral libraries.

File	Description
`jsp99hym.eff`	HyMap ATREM with EFFORT Correction Applied
`jsp99hym.hdr`	ENVI Header for Above
`usgs_veg.sli`	Vegetation Spectral Library
`usgs_min.sli`	Mineral Spectral Library
`veg_2grn.sl`	Jasper Ridge, Spectral Library
`veg_2grn.hdr`	ENVI Header for Above

3. Apply MNF Transform to the EFFORT data to find the data's inherent dimensionality. Review MNF eigenvalue images to determine break-in-slope and relate to spatial coherency in MNF eigenimages. Determine MNF cut-off between "signal" and "noise" for further analysis.

   Make your own MNF-Transformed dataset or review the results in the files below:

File	Description
`jsp99hym_mnf.bil`	VNIR MNF Transformed data (60 Bands)
`jsp99hym_mnf.hdr`	ENVI Header for Above
`jsp99hym_mnf.txt`	ASCII file of MNF Eigenvalues
`jsp99hym_mnf_ns.sta`	VNIR MNF Noise Statistics

4. Apply PPI Analysis to the MNF output to rank the pixels based on relative purity and spectral extremity. Use the FAST PPI option to perform calculations quickly in system memory, creating the PPI image. Display the PPI image, examine the histogram, and threshold to create a list of the purest pixels, spatially compressing the data.

Generate your own PPI results and ROIs or review the results in the files below:

File	Description
`jsp99hym_ppi.img`	VNIR PPI image
`jsp99hym_ppi.hdr`	ENVI Header for Above
`jsp99hym_ppi.cnt`	PPI Count file
`jsp99hym_ppi.roi`	ENVI PPI ROI file for use with n-D Visualizer

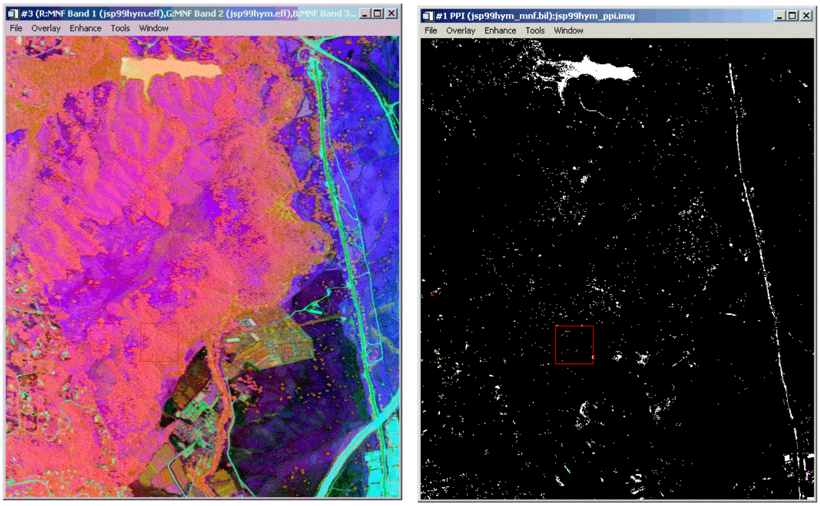


Figure 19-7: Jasper Ridge HyMap MNF Bands 1, 2, 3 as RGB image (left) and Jasper Ridge PPI image (right).

5. Perform n-Dimensional Visualization of the high PPI value pixels, using the high signal MNF data bands to cluster the purest pixels into image-derived endmembers. Rotate the MNF data interactively in 3-D, or spin in 3-or-more dimensions and “paint” pixels that occur on the “points” (extremities) of the scatterplot. Use Z-Profiles connected to the EFFORT apparent reflectance data and the n-D Visualizer to evaluate spectral classes. Use class collapsing to

iteratively find all of the endmembers. Evaluate the linearity of vegetation mixing and endmembers. Save your n-D results to a save state file (.ndv). Export classes to ROIs and extract mean spectra. Compare mean spectra to spectral libraries. Use spectral/spatial browsing to compare image spectra to ROI means.

Extract endmembers and make your own ROIs or review the results below:

File	Description
`jsp99hym.eff`	HyMap ATREM with EFFORT Correction Applied
`jsp99hym.hdr`	ENVI Header for Above
`jsp99hym_mnf.bil`	VNIR MNF Transformed data (60 Bands)
`jsp99hym_mnf.hdr`	ENVI Header for Above
`jsp99hym_ppi.ndv`	n-D Visualizer Save State from PPI
`jsp99hym_ndv_em.roi`	VNIR ROI File of n-D Visualizer Endmember locations
`jsp99hym_ndv_em.txt`	VNIR ASCII File of Endmember Spectra
`usgs_veg.sli`	Vegetation Spectral Library
`usgs_min.sli`	Mineral Spectral Library
`veg_2grn.sli`	Jasper Ridge, Spectral Library
`veg_2grn.hdr`	ENVI Header for Above

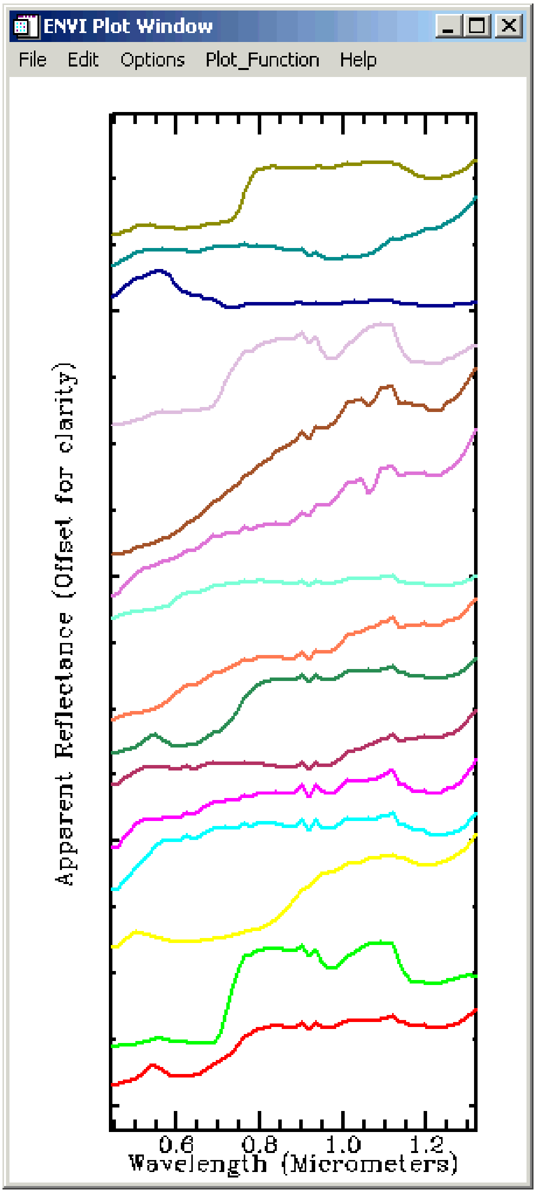


Figure 19-8: Jasper Ridge HyMap Spectral Endmembers from the n-D Visualizer.

6. Use ENVI's wide variety of mapping methods to map the spatial occurrence and abundance of materials at Jasper Ridge. As a minimum, try the Spectral Angle Mapper (SAM) and Unconstrained Linear Unmixing. Use SAM to determine spectral similarity of image spectra to endmember spectra. Perform your own SAM Classification or review the results below. If time and space permit, try a SAM classification using one of the Spectral Libraries. Be sure to evaluate the Rule Images. Use the Unconstrained Linear Unmixing to determine material abundances. Be sure to examine the RMS error image and evaluate whether the physical constraints of non-negative and sum to unity (1) or less have been satisfied. Iterate if time and space permit. Compare abundance image results to the endmember spectra and spectral libraries using spatial/spectral browsing. If time and space permit, try running Mixture-Tuned Matched filtering.

File	Description
`jsp99hym.eff`	HyMap ATREM with EFFORT Correction Applied
`jsp99hym.hdr`	ENVI Header for Above
`jsp99hym_mnf.bil`	VNIR MNF Transformed data (60 Bands)
`jsp99hym_mnf.hdr`	ENVI Header for Above
`jsp99hym_ndv_em.txt`	VNIR ASCII File of Endmember Spectra
`jsp99hym_sam.img`	VNIR SAM Classes
`jsp99hym_sam.hdr`	ENVI Header for Above
`jsp99hym_rul.img`	VNIR SAM Rules
`jsp99hym_rul.hdr`	ENVI Header for Above

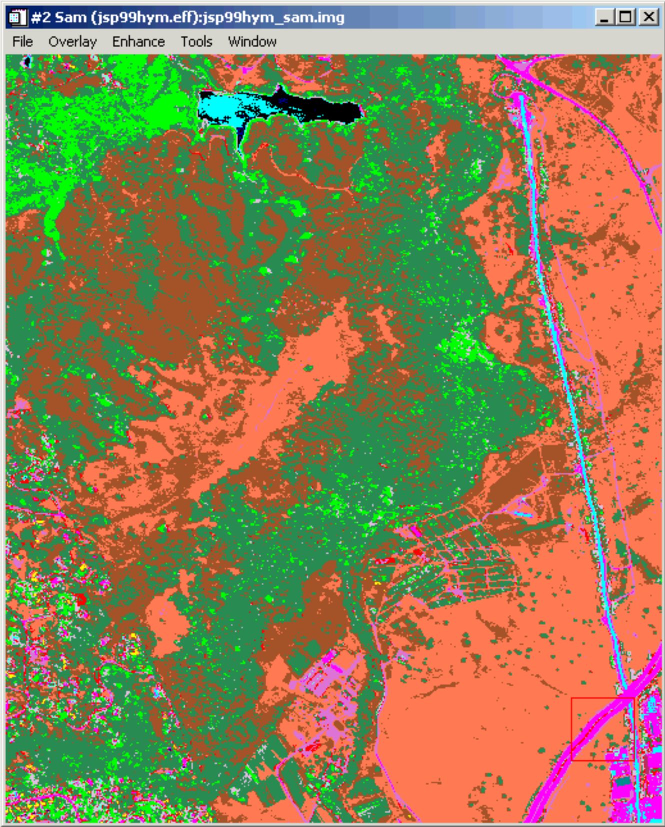


Figure 19-9: Jasper Ridge SAM classification result using n-D Visualizer endmembers.

7. Use ENVI's Georeference from the Input Geometry function to geocorrect the processed images of the Jasper Ridge to map coordinates. Compare geocorrected images to image maps of conventional vegetation mapping at Jasper Ridge.

File	Description
`jsp99hym.eff`	Bands from HyMap ATREM with EFFORT Correction Applied or HyMap output products

File	Description
jsp99hym.hdr	ENVI Header for Above
jsp99hym_glt.img	Geometry Lookup file for HyMap geocorrection
jsp99hym_glt.hdr	ENVI Header for Above

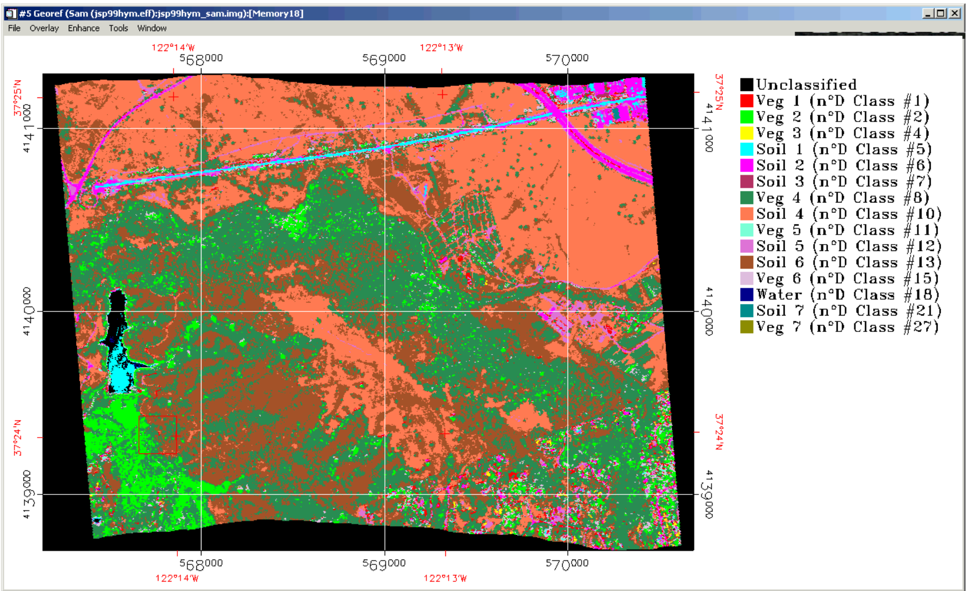
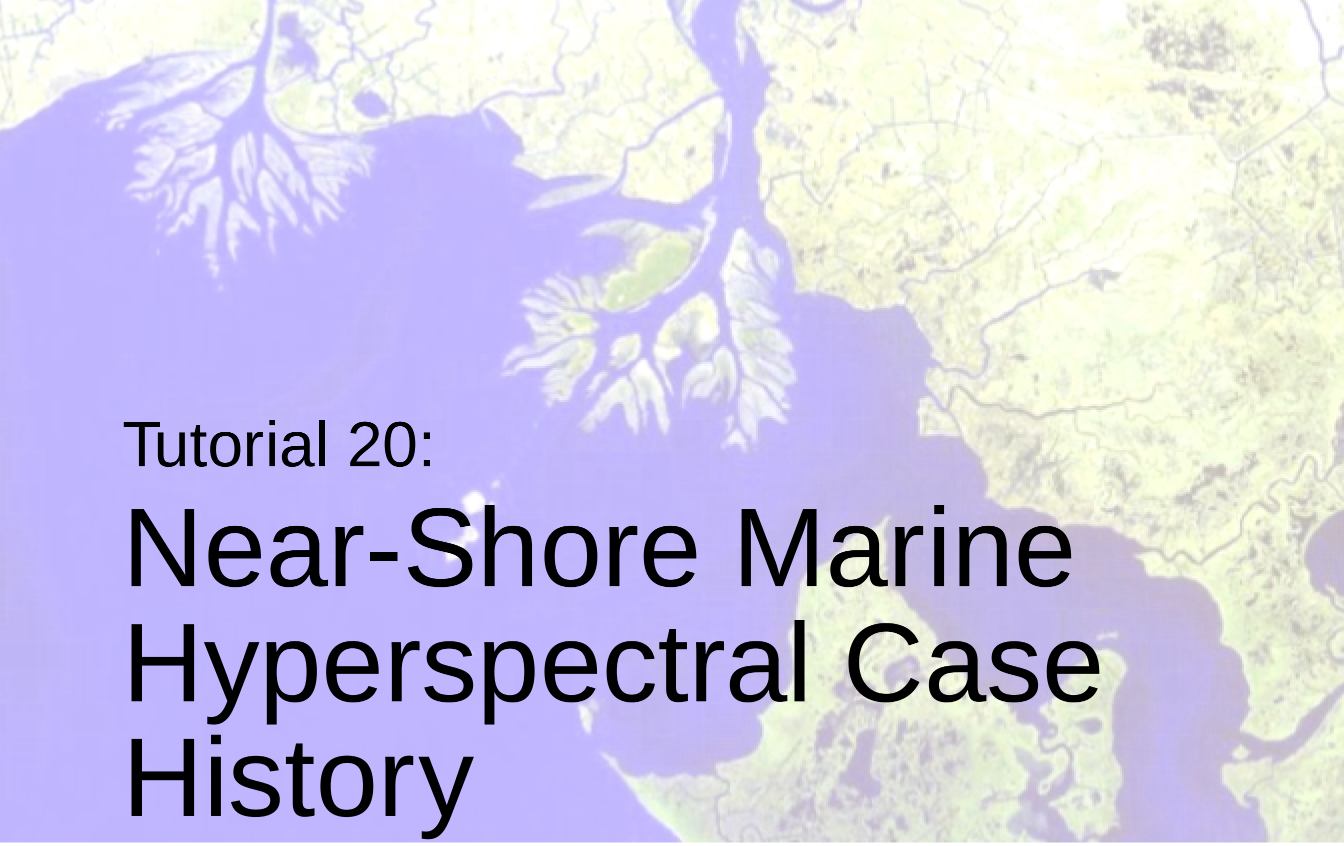


Figure 19-10: Jasper Ridge HyMap geocorrected SAM Classification Image.



Tutorial 20: Near-Shore Marine Hyperspectral Case History

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial presents a case history for use of hyperspectral techniques for vegetation analysis using 1994 AVIRIS data from Moffett Field, California, USA. It is designed to be a self-directed example using ENVI's complete end-to-end hyperspectral tools to produce image-derived endmember spectra and image maps. For more detail and step-by-step procedures on performing such a hyperspectral analysis, please execute the hyperspectral tutorials in this booklet prior to attempting this tutorial.

Objectives

1. To examine the application of ENVI end-to-end hyperspectral processing methodology to a near-shore marine case study.
2. To give students hands-on experience in actually running the procedures rather than reviewing pre-calculated results (preprocessed results are provided for comparison).
3. To provide students with guidance to perform data exploration in a loosely structured framework.
4. To compare analysis results with known ground information.

Tasks

1. Examine ATREM-corrected apparent reflectance data and evaluate data characteristics and quality.
2. Conduct Spatial/Spectral browsing to evaluate data, determine presence and nature of spectral variability, determine linearity of mixing, and to select wavelength range (s) for further analysis.
3. Reduce data dimensionality using MNF transform.
4. Select spectral endmember candidates using PPI.
5. Evaluate linearity and select endmembers using n-D Visualizer.
6. Map endmember distribution and abundance using ENVI mapping methods.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/spec_lib/veg_lib`
`envidata/spec_lib/usgs_min`
`envidata/m94avsub`

File	Description
Required Files (`envidata/spec_lib/veg_lib`)	
`usgs_veg.sli`	USGS Vegetation Spectral Library
`usgs_veg.hdr`	ENVI Header for Above
Required Files (`envidata/spec_lib/usgs_min`)	
`usgs_min.sli`	USGS Mineral Spectral Library
`usgs_min.hdr`	ENVI Header for Above
Required Files (`envidata/m94avsub`)	
`mof94av.bil`	AVIRIS ATREM Corrected Data, 500 x 350 x 56 bands
`mof94av.hdr`	ENVI Header for Above
`m94mnf.img`	VNIR MNF Transformed data
`m94mnf.hdr`	ENVI Header for Above
`m94mnf.asc`	VNIR Eigenvalue plot data
`m94ppi.img`	VNIR PPI image
`m94ppi.hdr`	ENVI Header for Above
`m94ppi.roi`	ROI of VNIR PPI threshold
`m94_em.asc`	VNIR ASCII File of Endmember Spectra - all EM
`m94_em.roi`	VNIR ROI File of Endmember Spectra - all EM
`m94_ema.asc`	VNIR ASCII File of Endmember Locations - selected EM
`m94_sam1.img`	VNIR SAM Classes using M94EM1A.ASC

File	Description
`m94_sam1.hdr`	ENVI Header for Above
`m94_rul1.img`	VNIR SAM Rules
`m94_rul1.hdr`	ENVI Header for Above
`m94_unm1.img`	VNIR Unmixing image using M94EM1A.ASC
`m94_unm1.hdr`	ENVI Header for above

Note

The files listed are required to run this exercise. Selected data files have been converted to integer format by multiplying the reflectance values by 1000 because of disk space considerations. Values of 1000 in the files represent reflectance values of 1.0.

Moffett Field Site Background

- Launch site for AVIRIS at Moffett Field.
- Remote Sensing Test Site Used By JPL and others since launch of AVIRIS in 1987.
- AVIRIS Standard Datasets for 1992-97.
- Study area for water variability (salt evaporation ponds with algae), urban studies, vegetation.

The salt ponds are highly colored and contain a dense biomass of algae and/or photosynthetic bacteria (Richardson et al., 1994). Accessory bacterial pigments cause distinct spectral signatures that can be detected using AVIRIS data (Figure 20-1). These include carotenoids, phycocyanin, and chlorophyll *a* and *b*. Application of the standardized AVIRIS analysis methods described below should lead to the extraction of endmembers from the data and spatial mapping of their distribution and abundance. There are obvious mixing non-linearities in the data, however, and care must be taken to recognize these.

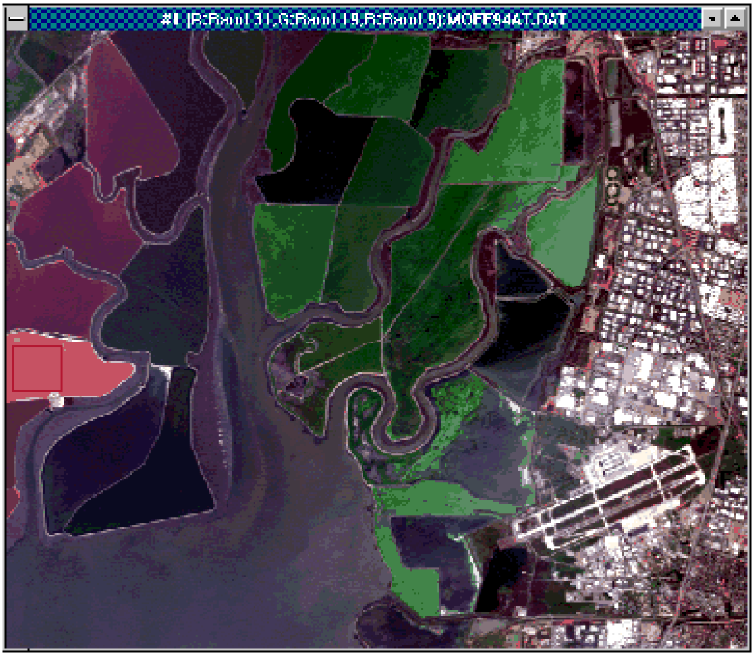


Figure 20-1: 1994 Moffett Field AVIRIS Data.

AVIRIS Processing Flow

The following diagram illustrates an approach for analysis of hyperspectral data that is implemented with ENVI.

The following outlines in general terms the implementation of this approach. The student is expected to follow the procedures below, referring to previous tutorials and the *ENVI User's Guide* for guidance in performing specific tasks where required. The purpose of this tutorial is not to teach you how to run the ENVI tools, but how to apply the methodology and tools to a general hyperspectral remote sensing problem.

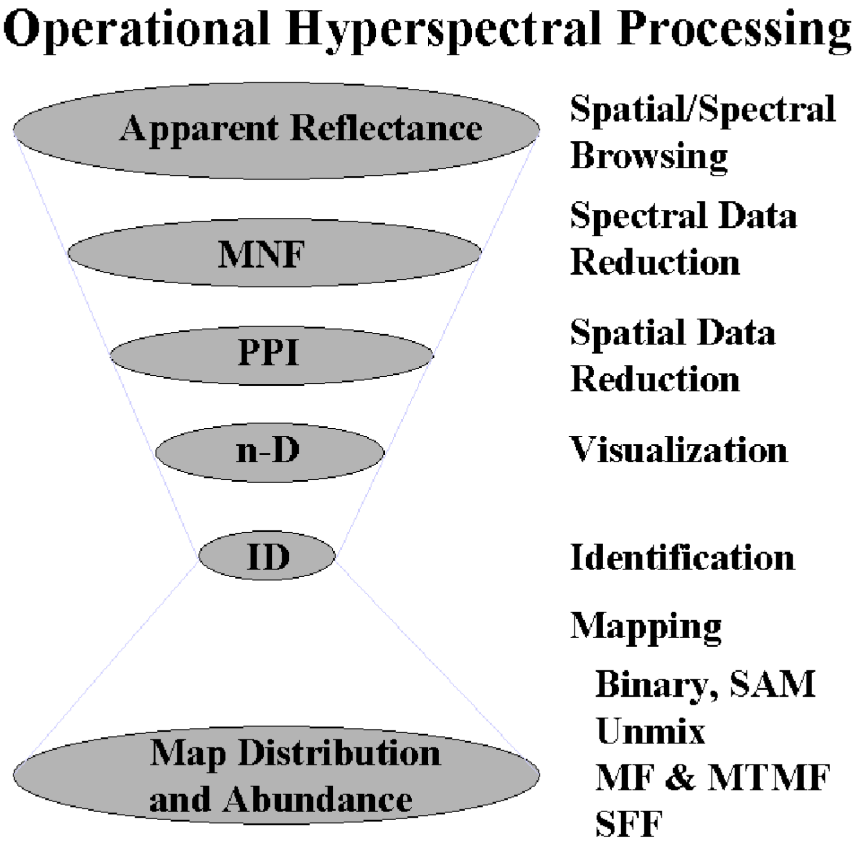


Figure 20-2: End-to-End Hyperspectral Processing with ENVI.

Hyperspectral Techniques for Vegetation Analysis

1. Evaluate the ATREM Correction applied to the JPL-provided AVIRIS spectral radiance to remove the bulk of the solar and atmospheric effects, transforming the data from radiance to apparent surface reflectance. Examine the data using spectral/spatial browsing and color composites to characterize spectral variability and determine residual errors. Extract reflectance signatures for water, vegetation, urban areas, and geologic materials. Compare to spectral libraries.

File	Description
`mof94av.bil`	ATREM Apparent Reflectance
`usgs_veg.sli`	Vegetation Spectral Library
`usgs_min.sli`	Mineral Spectral Library

2. Apply the MNF Transform to the ATREM data to find the data's inherent dimensionality. Review MNF eigenvalue plot(s) to determine break-in-slope and relate to spatial coherency in MNF eigenimages. Determine MNF cut-off between "signal" and "noise" for further analysis.

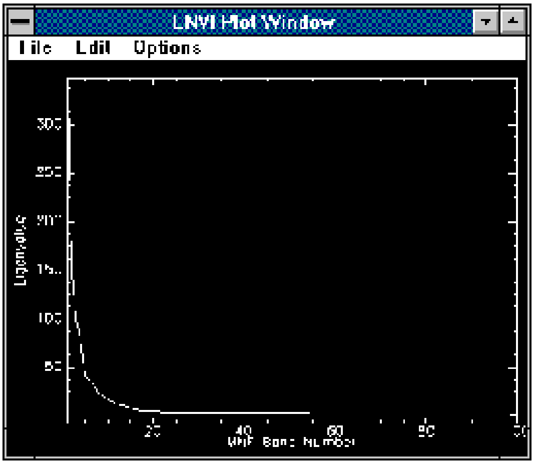


Figure 20-3: MNF Eigenvalues.

Make your own MNF-Transformed dataset or review the results in the files below:

File	Description
`m94av.bil`	ATREM Apparent Reflectance
`m94mnf.asc`	VNIR Eigenvalue ASCII Data
`m94mnf.img`	VNIR MNF Eigenimages

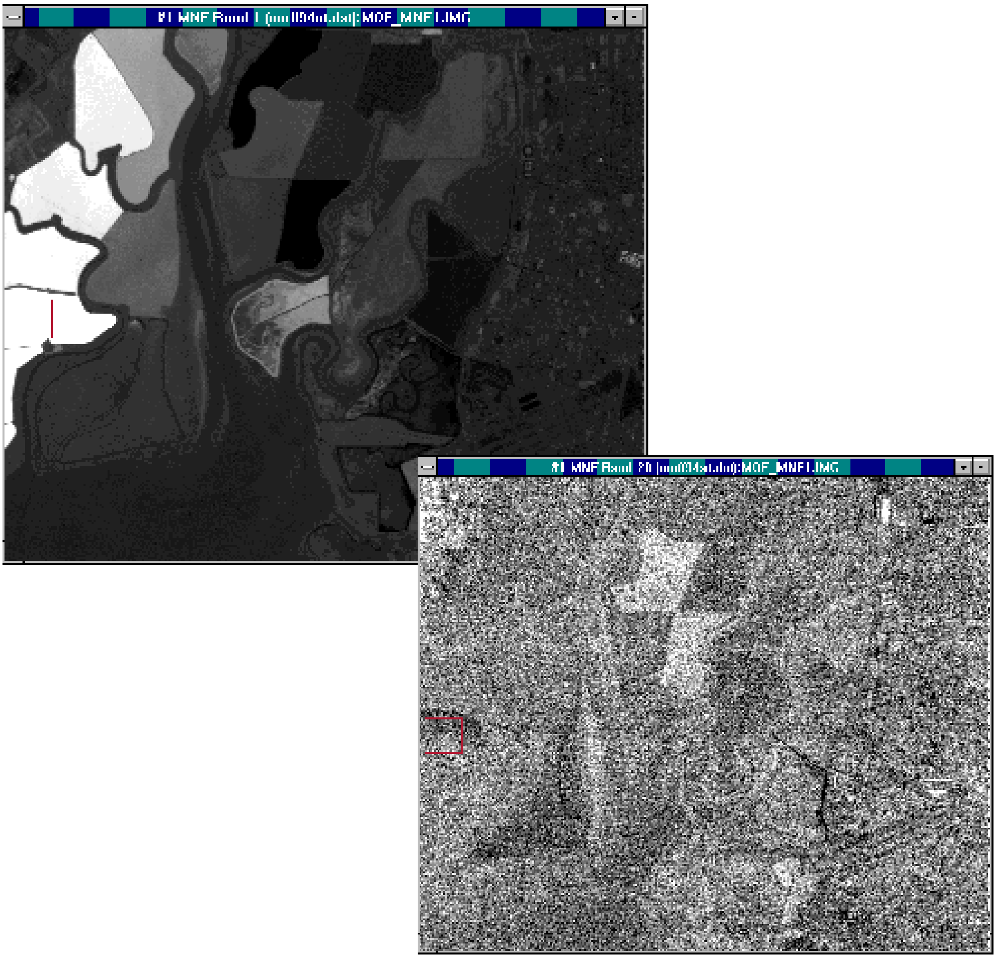


Figure 20-4: MNF Bands 1 (upper left) and 20 (lower right)

3. Apply PPI Analysis to the MNF output to rank the pixels based on relative purity and spectral extremity. Use the FAST PPI option to perform calculations quickly in system memory, creating the PPI image. Display the PPI image, examine the histogram, and threshold to create a list of the purest pixels, spatially compressing the data.

Figure 20-5: Pixel Purity Index (PPI) Image

Generate your own PPI results and ROIs or review the results in the files below:

File	Description
`m94mnf.img`	VNIR MNF Eigenimages
`m94ppi.img`	VNIR PPI Image
`m94ppi.roi`	VNIR PPI Threshold Results

4. Perform n-Dimensional Visualization of the high PPI value pixels, using the high signal MNF data bands to cluster the purest pixels into image-derived endmembers. Rotate the MNF data interactively in 3-D, or spin in 3-or-more dimensions and “paint” pixels that occur on the “points” (extremities) of the

scatterplot. Use Z-Profiles connected to the ATREM apparent reflectance data and the n-D Visualizer to evaluate spectral classes. Use class collapsing to iteratively find all of the endmembers. Pay particular attention to the linearity of water mixtures, variability, and endmembers. Save your n-D results to a save state file (.ndv). Export classes to ROIs and extract mean spectra. Compare mean spectra to spectral libraries. Use spectral/spatial browsing to compare image spectra to ROI means.

Extract endmembers and make your own ROIs or review the results below:

File	Description
`m94mnf.img`	VNIR MNF Eigenimages
`m94ppi.roi`	VNIR PPI Threshhold Results
`m94av.bil`	ATREM Apparent Reflectance
`m94_em.asc`	VNIR Saved ASCII Endmember Spectra (all)
`m94_ema.asc`	Selected VNIR Saved ASCII Endmembers
`usgs_veg.sli`	Vegetation Spectral Library
`usgs_min.sli`	Mineral Spectral Library

5. Use ENVI's wide variety of mapping methods to map the spatial occurrence and abundance of materials in the Moffett Field scene. As a minimum, try the Spectral Angle Mapper (SAM) and Unconstrained Linear Unmixing. Use SAM to determine spectral similarity to image endmember spectra Perform your own SAM Classification or review the results below. If time and space permit, try a SAM classification using one of the Spectral Libraries. Be sure to evaluate the Rule Images. Use the Unconstrained Linear Unmixing to determine material abundances or review the results below. Be sure to examine the RMS error image and evaluate linearity and whether the physical constrains of non-negative and sum to unity (1) or less have been satisfied. Iterate if time and space permit. Compare abundance image results to the endmember spectra and spectral libraries using spatial/spectral browsing. If time and space permit, try running Mixture-Tuned Matched filtering and/or Spectral Feature Fitting.

File	Description
`m94_em.asc`	VNIR Saved ASCII Endmember Spectra

File	Description
m94_ema.asc	Selected Saved ASCII Endmembers
mof94av.bil	ATREM Apparent Reflectance
m94_sam1.img	VNIR SAM Classes
m94_rul1.img	VNIR SAM Rules
m94_unm1.img	VNIR Linear Spectral Unmixing Results
usgs_veg.sli	Vegetation Spectral Library
usgs_min.sli	Mineral Spectral Library

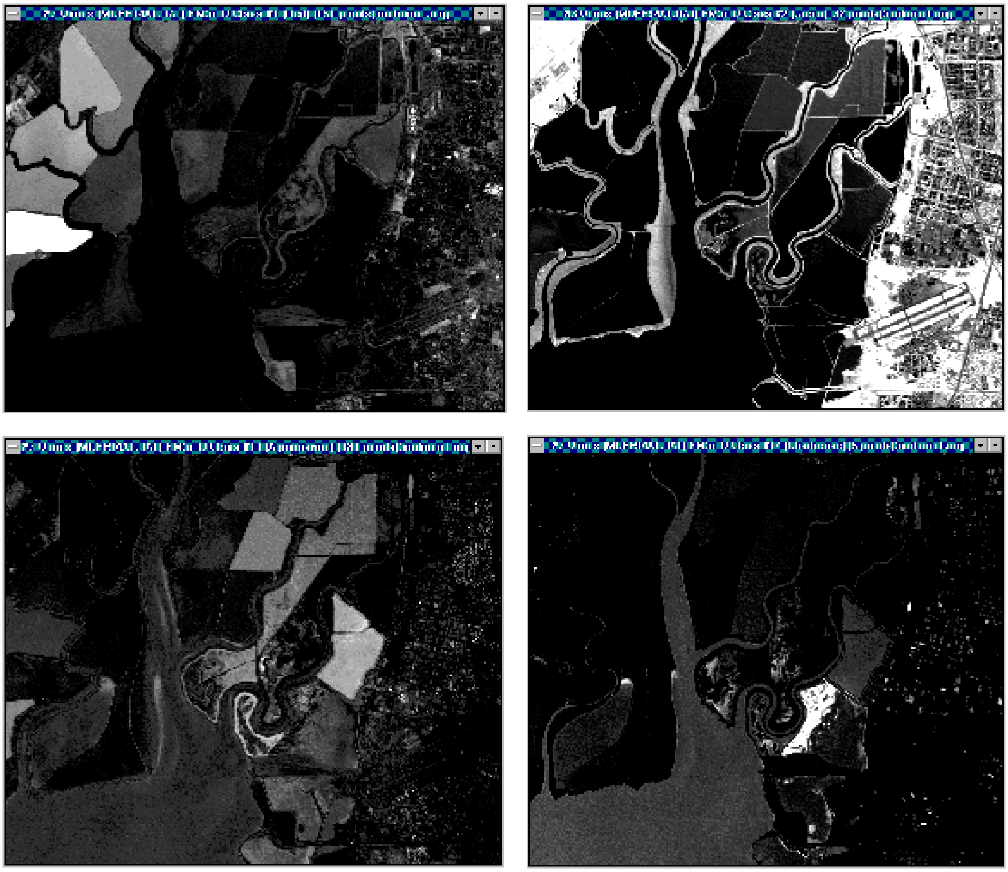


Figure 20-6: Spectral Unmixing Results: Red Pigment (UL), Green Pigment (LL), Vegetation 1(UR), Vegetation 2(LR)

References

Richardson, L.L., 1996, Remote Sensing of Algal Bloom Dynamics: BioScience, V. 46, No. 7, p. 492 - 501.

Richardson, L.L, Buison, D., Lui, C.J., and Ambrosia, V., 1994, The detection of algal photosynthetic accessory pigments using Airborne Visible-Infrared imaging Spectrometer (AVIRIS) Spectral Data: Marine Technology Society Journal, V. 28, p. 10-21.

Tutorial 21:

Multispectral Processing Using ENVI's Hyperspectral Tools

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to show you how ENVI's advanced hyperspectral tools can be used for analysis of multispectral data. To gain a better understanding of the hyperspectral concepts and tools, please see the ENVI hyperspectral tutorials. For additional details, please see the *ENVI 3.5 User's Guide* or the ENVI On-Line help.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/bh_tmsub`
`envidata/spec_lib/usgs_min`

File	Description
Required Files (`envidata/bh_tmsub`)	
`bhtmref.img`	Bighorn Basin, Wyoming Landsat TM Reflectance
`bhtmref.hdr`	ENVI Header for Above
`bh_rats.img`	Band Ratio Image 5/7, 3/1, 3/4 (RGB)
`bh_rats.hdr`	ENVI Header for Above
`bhtmiso.img`	Isodata Classification
`bhtmiso.hdr`	ENVI Header for Above
`bhisiev.img`	Sieve Image of Isodata Classification
`bhisiev.hdr`	ENVI Header for Above
`bhiclmp.img`	Clump Image of the Sieved Classification
`bhiclmp.hdr`	ENVI Header for Above
`bhtm.grd`	Saved Grid for Bighorn TM data
`bhtmiso.ann`	Map Annotation for Bighorn TM data
`bhtm_mnf.asc`	ACII Eigenvalue data for MNF Transform
`bhtm_mnf.img`	MNF Transform Data
`bhtm_mnf.hdr`	ENVI Header for Above

File	Description
bhtm_mnf.sta	ENVI Statistics File for above
bhtm_ns.sta	ENVI Noise statistics for above
bhtm_ppi.img	Pixel Purity Index Image
bhtm_ppi.hdr	ENVI Header for Above
bhtm_ppi.cnt	Counter for PPI analysis
bhtm_ppi.roi	Regions of Interest threshold from the PPI
bhtmppi.ndv	n-D Visualizer Save State file
bhtm_nd.roi	ROIs from n-D Visualizer Analysis
bhtm_em.asc	ASCII Spectral Endmembers from n-D
bhtm_sam.img	SAM Classification
bhtm_sam.hdr	ENVI Header for Above
bhtm_sam.ann	Map Annotation for the SAM images
bhtm_rul.img	ENVI SAM Rule Images
bhtm_rul.hdr	ENVI Header for Above
bhtm_unm.img	Linear Spectral Unmixing Result
bhtm_unm.hdr	ENVI Header for Above
bhunm_em.asc	Endmembers used for Spectral Unmixing
Required Files (envidata/spec_lib/usgs_min)	
usgs_min.sli	USGS Spectral Library in ENVI format
usgs_min.hdr	ENVI Header for above

Background

ENVI was not designed solely as a hyperspectral image processing system. The decision was made in 1992 to develop a general purpose image processing software package with a full suite of standard tools in response to the general lack of powerful yet flexible commercial products capable of handling a wide variety of scientific image data formats. This included support for panchromatic, multispectral, hyperspectral, and both basic and advanced radar systems. ENVI presently contains the same basic capabilities as other major image processing systems such as ERDAS, ERMapper, and PCI. Where ENVI differs is in the many advanced, state-of-the-art algorithms resulting from active leading-edge remote sensing research. While many of these features were developed specifically to deal with imaging spectrometer data or hyperspectral data having up to hundreds of spectral bands, many of these techniques are applicable to multispectral data and other standard data types. This tutorial presents a scenario for use of some of these methods for analysis of Landsat Thematic Mapper data.

This example is broken into two separate parts: 1) a typical multispectral analysis of TM data using standard or classical multispectral analysis techniques, and 2) analysis of the same data set using ENVI's hyperspectral tools.

Standard Multispectral Image Processing

A standard, or classical, Landsat TM analysis scenario might consist of the following (though many other variations are available within ENVI. See Sabins, 1987 for other examples):

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To start ENVI in UNIX, enter envi at the UNIX command line.
- To start ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Read TM Tape or CD

ENVI provides the tools to read standard Landsat Thematic Mapper data from both tape and CD/disk.

- To read from tape, select **File** → **Tape Utilities** → **Read Known Tape Formats** → **Landsat TM** (or **NLAPS** for new EDC-format tapes) from the ENVI main menu.
- To read from disk, select **File** → **Open External File** → **Landsat** → **Fast**, or for NLAPS data select **File** → **Open External File** → **Landsat** → **NLAPS**.
- For the purposes of this exercise, the data have already been read in and made into subsets and the file `bh_tmref.img` is provided for analysis. This image has been corrected to reflectance using ENVI’s TM Calibration Utility, accessed using **Basic Tools** → **Data Specific Utilities** → **Landsat TM** → **Landsat TM Calibration**.

Open and Display Landsat TM Data

To open an image file:

1. Select **File** → **Open Image File** on the ENVI main menu.

   Note that on some platforms you must hold the left mouse button down to display the submenus from the Main Menu.

   An **Enter Data Filenames** file selection dialog appears.

2. Navigate to the `bh_tmsub` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 1* just as you would in any other application and select the file `bhtmref.img` from the list and click **OK**.

   The **Available Bands List** dialog appears on your screen. This list allows you to select spectral bands for display and processing.

   Note that you have the choice of loading either a gray scale or an RGB color image.

3. Select bands 4, 3, and 2 listed at the top of the dialog by first selecting the **RGB Color** radio button in the **Available Bands List**, then clicking on the bands sequentially with the left mouse button.

Display and Examine a Color Composite Image

1. To load the image, click **Load RGB**.
2. Once the image is displayed, select and execute some of the available functions from the Main Image window menu bar.
3. Resize the image display windows by grabbing one of the corners with the left mouse button and dragging. Scroll and pan the image by grabbing and dragging the red outline boxes in the Scroll and Zoom windows. Zoom the image by clicking with the left mouse button in the + (plus) or – (minus) graphic in the lower left corner of the Zoom window. The left mouse button centers the cursor on the clicked pixel.
4. From the Main Image menu bar, select **Tools** → **Cursor Location/Value** and use the interactive cursor to determine location and pixel value.
5. Contrast stretch the images by selecting **Enhance** → **[Image] Stretch Type**, where **Stretch Type** is **Linear**, **Linear 0-255**, **Linear 2%**, **Gaussian**, **Equalization**, **Square Root**. In this instance, choose the **[Image] Equalization** stretch.

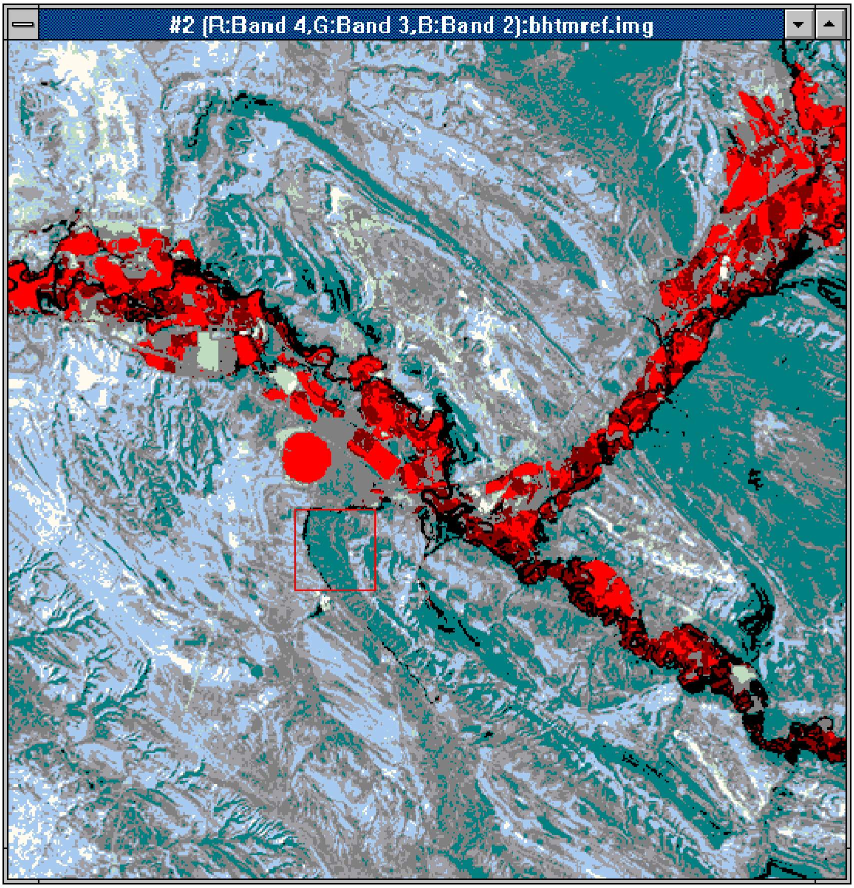


Figure 21-1: A Color Composite Image showing Landsat TM Bands 4, 3, 2 (RGB)

Conduct a Ratio Analysis

Here you will create Color-Ratio-Composite (CRC) images using standard TM band-ratio images. This method tries to get around the limitations of relatively broad spectral bands in Landsat TM data by using ratios of bands to determine relative spectral slope between bands and thus the approximate shape of the spectral signature for each pixel. Common band-ratios include: Band-Ratio 5/7 for clays, carbonates, vegetation; band-ratio 3/1 for iron oxide; band-ratios 2/4 or 3/4 for vegetation; and band-ratio 5/4 also for vegetation.

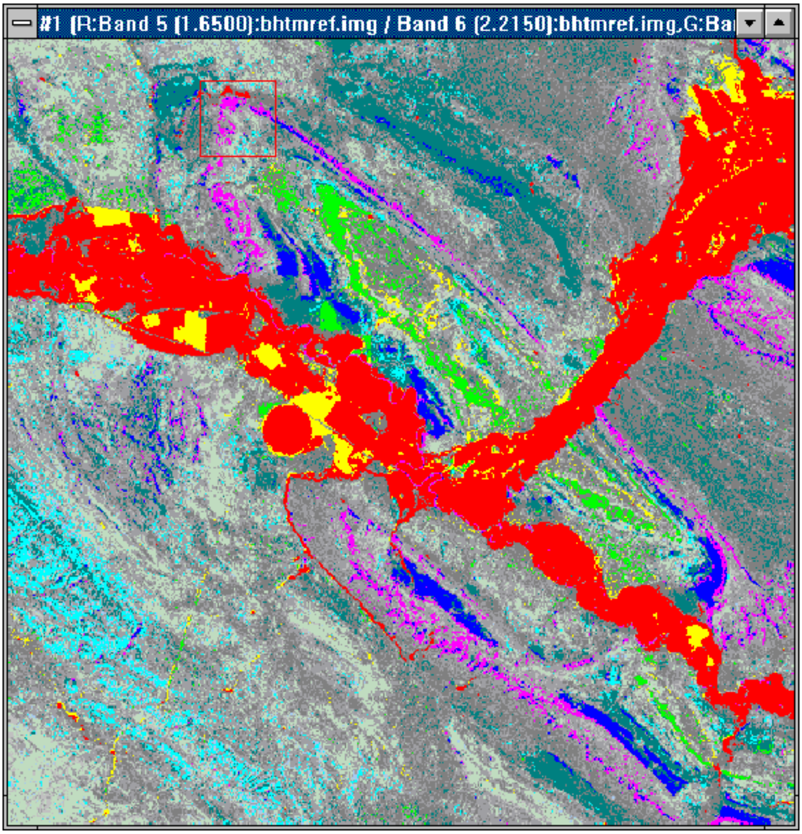


Figure 21-2: A Color-Ratio Composite Image of ratios 5/7, 3/1, and 2/4 (RGB).

To create a band-ratio image:

1. Select **Transform** → **Band Ratios** from the ENVI main menu.
2. In the **Band Ratio Input Bands** dialog, select the following **Numerator** and **Denominator** band pairs from the Available Bands list in the dialog (5/7, 3/1, 2/4). Click **Enter Pair** after each Numerator/Denominator set is chosen, and repeat for as many band-ratios as desired.
3. Click **OK** in the **Band Ratio Input Bands** dialog to calculate the ratios.

4. In the **Band Ratios Parameters** dialog, select the **Memory** radio button to save the ratios to memory, and click **OK**.
5. The band ratios now appear in the **Available Bands List** when complete.

   The combination of 5/7, 3/1, 2/4 (RGB) results in an image in which clays/carbonates are magenta, iron oxides are green, and vegetation is red. Other ratio combinations and color schemes can be designed to highlight specific materials.
6. In the **Available Bands List**, select the 5/7 ratio for **R**, 3/1 for **G**, and 2/4 for **B**. Select **Display #1** → **New Display** to load and display your CRC image.
7. You can also select **File** → **Open Image File** from the ENVI main menu and choose the CRC image `bh_rats.img` from the file selection dialog. Display the result in a **New Display** from the **Available Bands List**.
8. In **Display #2**, use a histogram equalization stretch by selecting **Enhance** → **[Image] Equalization**.
9. Compare the CRC image in Display #3 to the false CIR image in Display #2 above using image linking and dynamic overlays by selecting **Tools** → **Link** → **Link Displays**, and then clicking and dragging using the left mouse button in one of the images to display the dynamic overlay. The overlay area can be resized by clicking and dragging the middle mouse button in the image.

Run Unsupervised Classification (IsoData)

Unsupervised classification provides a simple way to segment multispectral data using the data statistics. IsoData calculates class means evenly distributed in the data space and then iteratively clusters the remaining pixels using minimum distance techniques. Each iteration recalculates means and reclassifies pixels with respect to the new means. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached.

1. From the ENVI main menu, select **File** → **Open Image File** and choose the file `bhtmiso.img` and load as a **Gray Scale** image using the **Available Bands List**. Open the image in a **New Display**.
2. To perform an IsoData classification, from the ENVI main menu select **Classification** → **Unsupervised** → **IsoData**. Choose the image `bhtmiso.img` and use the default settings in the **Classification Input File** dialog.

3. In the **ISODATA Parameters** dialog, select the **Memory** radio button and click **OK** to create the IsoData classified image.
4. In the **Available Bands List**, load the ISODATA image into a **New Display**.
5. Compare the IsoData classification image to the CRC image and the false CIR image above using image linking and dynamic overlays by selecting **Tools** → **Link** → **Link Displays**, and then clicking and dragging using the left mouse button in one of the images to display the dynamic overlay.

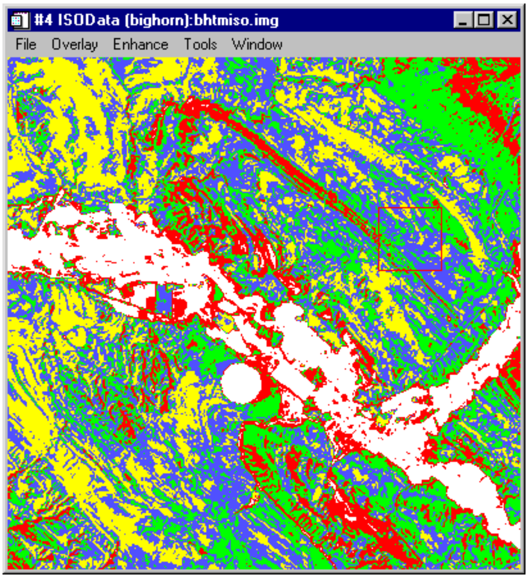


Figure 21-3: An IsoData Image.

Clump and Sieve, Combine Classes

Once the classification is complete, because classified images often suffer from a lack of spatial coherency (speckle or holes in classified areas), it is often desirable to generalize the classes to generalize the classification for operational use. Low pass filtering could be used to smooth these images, however, the class information would be contaminated by adjacent class codes. The Sieve Class and Clump Class operators have been designed to avoid this problem by removing isolated pixels and clumping together adjacent similar classified areas respectively using morphological operators.

- To sieve classes, select **Classification** → **Post Classification** → **Sieve Classes** from the ENVI main menu.

- To clump classes, select **Classification** → **Post Classification** → **Clump Classes** from the ENVI main menu.

1. Load and examine the sieve and clump classes images by selecting **File** → **Open Image File** and choosing `bhisiev.img` and `bhiclmp.img` respectively.
2. In the **Available Bands List**, load the Sieve and Clump images into **New Displays**.
3. Compare the generalized classification images to the ISODATA image using image linking and dynamic overlays by selecting **Tools** → **Link** → **Link Displays**, and then clicking and dragging using the left mouse button in one of the images to display the dynamic overlay.

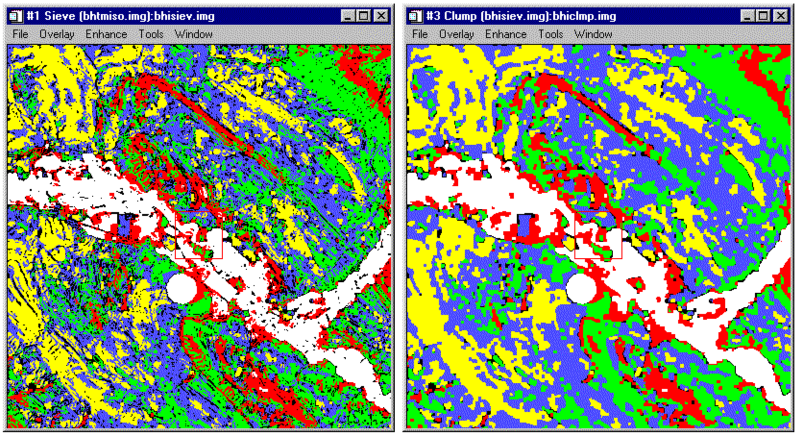


Figure 21-4: Sieve and Clump Classification Generalization. Sieve is on the left, Clump of the Sieved image on the right.

Annotate and Output Map

The final output from any image processing within ENVI is usually a map-oriented, scaled image-map for presentation or visual analysis and interpretation. In this case, the TM data were already geographically referenced, however, ENVI includes full image-to-image and image-to-map registration capabilities. Please see the Registration Tutorial or the *ENVI 3.5 User's Guide* and on-line tutorials.

ENVI also provides all of the tools to produce fully annotated publication-quality maps. This includes pixel, map, and geographic (latitude/longitude) grids; scale-bars;

declination diagrams and north arrows; text and symbols; polygons, polylines, and geometric shapes (circles, rectangles); map keys and legends; and image insets. For additional information on map composition, please see the Map Composition Tutorial or the *ENVI 3.5 User's Guide* and on-line tutorials.

1. To add a grid to the displayed IsoData classification, select **Overlay** → **Grid Lines** from the Main Image window menu bar.
2. In the **Grid Lines Parameters** dialog, choose **File** → **Restore Setup**.
3. In the **Enter Grid Parameters Filename** dialog, click on the file `bhtm.grd` and **Open** it.
4. To add the grid to the image, click **Apply** in the **Grid Line Parameters** dialog.
5. To add map annotation to the displayed IsoData classification, select **Overlay** → **Annotation** from the Main Image window.
6. In the **Annotation: Text** dialog, choose F**ile** → **Restore Annotation**.
7. In the **Enter Annotation Filename** dialog, pick the file `bhtmiso.ann` and click on **Open**. The map annotation is loaded onto the image.

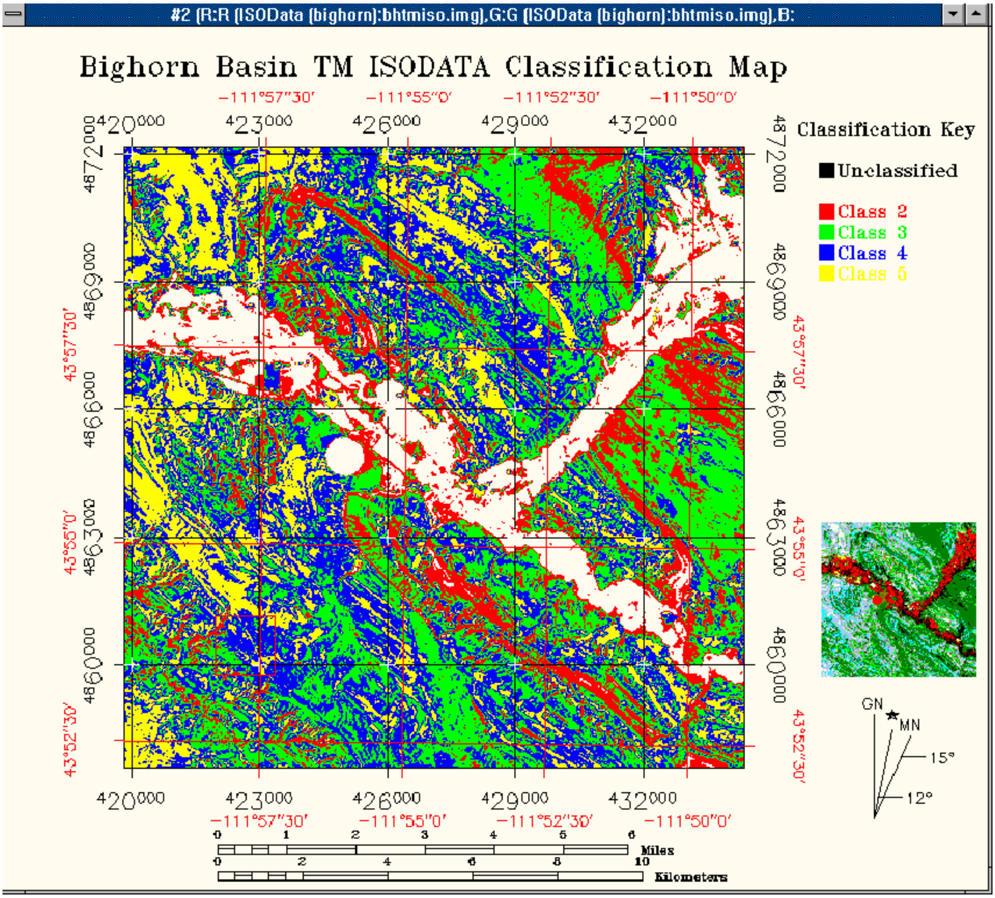


Figure 21-5: IsoData Classification annotated image-map.

8. Now from the ENVI main menu, close all windows to clean up the work space by selecting **Window** → **Close All Display Windows**.

Analyze Multispectral Data with ENVI's Hyperspectral Tools

Read TM Tape or CD

As described above, ENVI provides the tools to read standard Landsat Thematic Mapper data from both tape and CD/disk.

- To read from tape, select **File** → **Tape Utilities** → **Read Known Tape Formats** → **Landsat TM** (or **NLAPS** for new EDC-format tapes) from the ENVI main menu.
- To read from disk, either select **File** → **Open External File** → **Landsat** → **Fast** or for NLAPS data select **File** → **Open External File** → **Landsat** → **NLAPS**.
- For the purposes of this exercise, the data have already been read in and made into subsets and the file `bh_tmref.img` is provided for analysis. This image has been corrected to reflectance using ENVI's TM Calibration Utility, accessed using **Basic Tools** → **Data Specific Utilities** → **Landsat TM** → **Landsat TM Calibration** (see below).

Calibrate TM to Reflectance

A reflectance calibration is required for Landsat TM data to compare image spectra to library reflectance spectra and to run some of ENVI's hyperspectral routines. ENVI provides TM calibration through the use of pre-launch gains and offsets calculated for the Landsat Sensors (Markham and Barker, 1986).

1. From the ENVI main menu bar, select **Basic Tools** → **Data Specific Utilities** → **Landsat TM** → **Landsat TM Calibration**.
2. When the **TM Calibration Input File** dialog appears, choose `bhtmref.img` as the image to be calibrated. Click **OK**.
3. In the **TM Calibration Parameters** dialog you can enter the calibration parameters, including the **Landsat Satellite** (5), the month (August), day (12), and year of acquisition (1984), and the sun elevation (40). At this time, simply select the **Memory** radio button.
4. Choose the **Reflectance** calibration type and click **OK**.

The resulting image approximates reflectance.

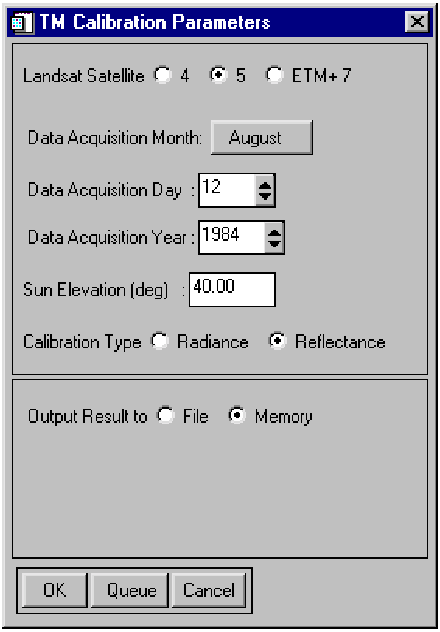


Figure 21-6: TM Calibration Parameters

Display a Color Composite Image and Extract Spectra

1. In the **Available Bands List**, click on the **RGB Color** radio button. Next, select bands 3, 2, 1 (RGB - True Color) or 4, 3, 2 RGB (Color Infrared) of the `bh_tmref.img` open image file. Open a **New Display**, and click on **Load RGB**.
2. Once the image is displayed, select and execute some of the available functions on the Main Image window menu bar.
3. Scroll the image and zoom the image.
4. Use the interactive cursor to determine location and values.
5. Contrast stretch and/or density slice the images.
6. Extract Z-profiles (reflectance spectra) from the data by selecting **Tools** → **Profiles** → **Z Profile** in the Main Image window and browse around

the image by clicking and dragging the red Zoom window box using the left mouse button.

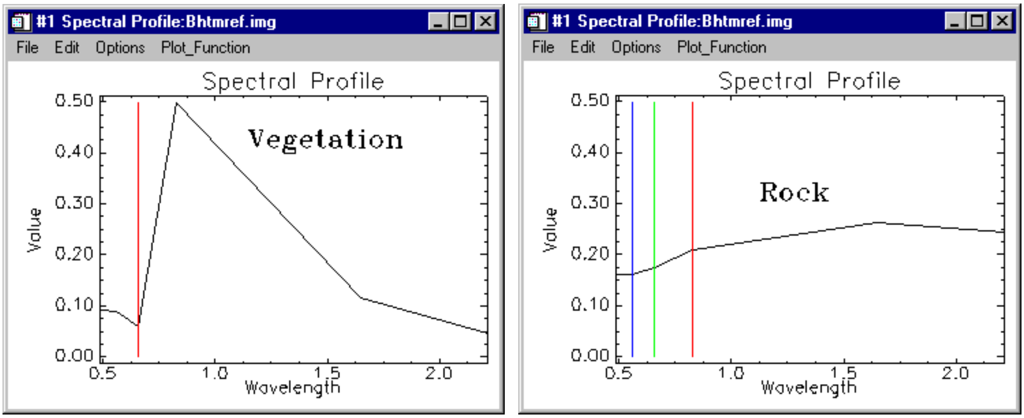


Figure 21-7: Landsat TM reflectance spectra.

7. Now from the ENVI main menu, close all windows to clean up the work space by selecting **Window** → **Close All Display Windows**.

Run Minimum Noise Fraction (MNF) Transformation

MNF Transform is a method similar to Principal Components used to segregate noise in the data, determine inherent data dimensionality, and reduce computational requirements for subsequent processing (Green et al., 1988; Boardman and Kruse, 1994). For hyperspectral data (less-so for multispectral data), the MNF divides data space into two parts; one with large eigenvalues and coherent eigenimages and the second with near-unity eigenvalues and noise-dominated images. It is used as a preparatory transformation to put most of the interesting information into just a few spectral bands and to order those bands from most interesting to least interesting.

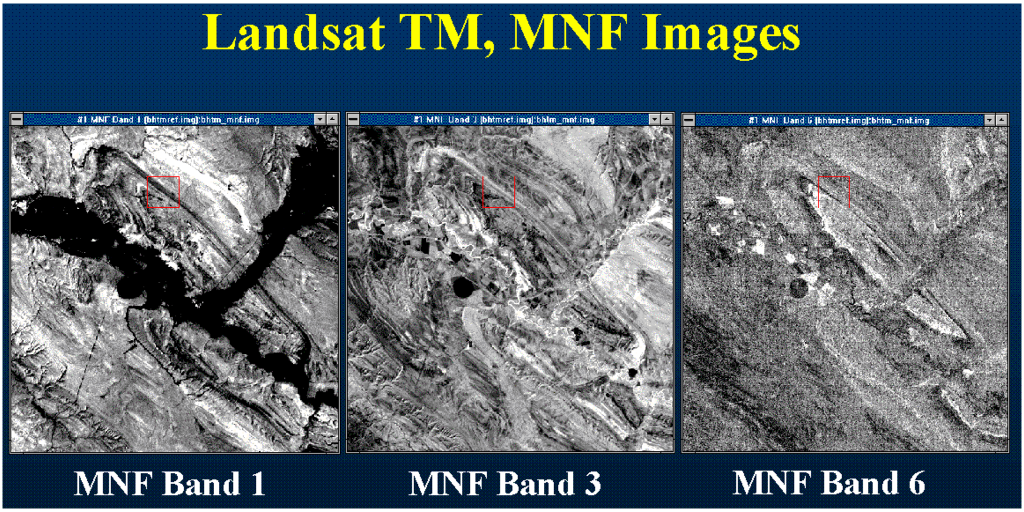


Figure 21-8: MNF Transformation Results.

See the Hyperspectral Tutorials for additional background information and examples. To calculate the MNF transformation from the TM reflectance data:

1. Examine the pre-calculated MNF Eigenvalue plot `bhtm_mnf.asc` by selecting **Window** → **Start New Plot Window** from the ENVI main menu bar.
2. Load the `bhtm_mnf.asc` ASCII file using **File** → **Input Data** → **ASCII** from the plot window menu bar.
3. The **Input ASCII File** dialog appears. Click **OK** to plot the input.

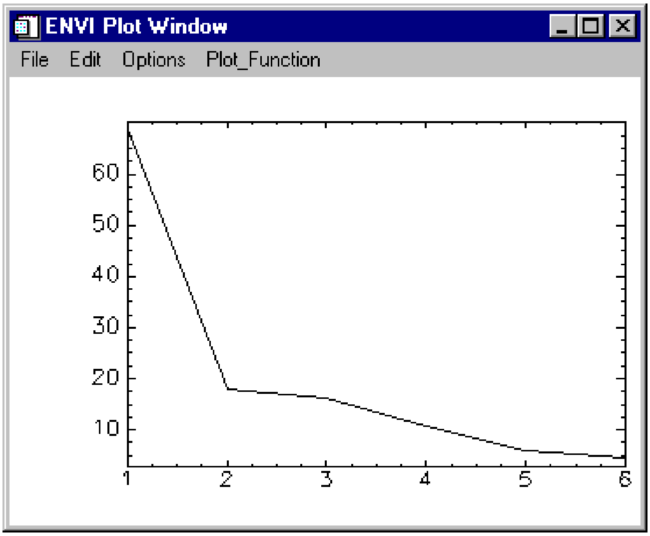


Figure 21-9: MNF Eigenvalue Plot

4. In the **Available Bands List**, select **File** → **Open Image File** to load and examine the MNF image file `bhtm_mnf.img`. Be sure to examine both the low and high MNF bands. In the **Available Bands List**, open a **New Display** and load MNF Band 1.
5. Next, in the **Available Bands List**, open another **New Display** and load MNF Band 6. Look at the two different MNF Bands and note the decrease in spatial coherency with increasing MNF Band number.

The decreasing eigenvalue with increasing MNF band shown in the eigenvalue plot above shows how noise is segregated in the higher number MNF bands.

Run PPI to Find Endmembers

The Pixel Purity Index™ (PPI™) function finds the most spectrally pure or extreme pixels in multispectral and hyperspectral data (Boardman and Kruse, 1994). These correspond to the materials with spectra that combine linearly to produce all of the spectra in the image. The PPI is computed by using projections of n-dimensional scatterplots to 2-D space and marking the extreme pixels in each projection. The output is an image (the PPI Image) in which the digital number (DN) of each pixel in the image corresponds to the number of times that pixel was recorded as extreme.

Thus bright pixels in the image show the spatial location of spectral endmembers. Image thresholding is used to select several thousand pixels for further analysis, thus significantly reducing the number of pixels to be examined. See the Hyperspectral Tutorials for additional PPI background information and examples.

1. To start the PPI analysis, select **Spectral** → **Pixel Purity Index** → **[FAST] New Output Band** from the ENVI main menu.

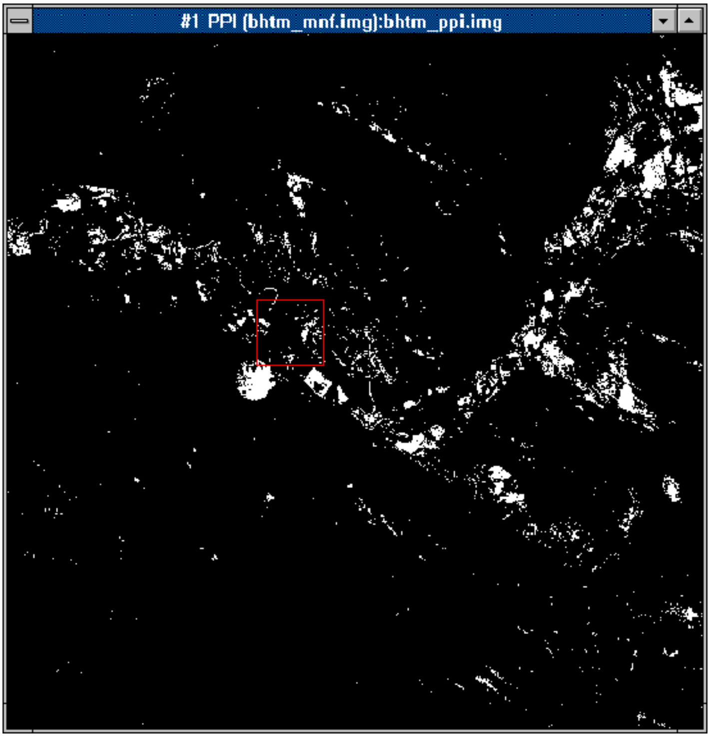


Figure 21-10: The PPI Image.

This calculates the PPI in memory.

Note

If not enough RAM is available in your hardware, you may need to choose **Spectral** → **Pixel Purity Index** → **New Output Band**, which will execute several orders of magnitude more slowly.

2. In the **Available Bands List**, select **File** → **Open Image File**. In the **Enter Data Filenames** dialog select the pre-calculated PPI image, `bhtm_ppi.img`.
3. Select the PPI file and load it into a **New Display**.

   Alternatively, you can choose the `bhtm_mnf.img` data as the input file, spectrally subset to include only those coherent MNF bands (the lower band number images as determined above).

   In the **Fast Pixel Purity Index Parameters** dialog, enter several thousand (4000 for instance) as the number of iterations and enter a **Threshold Factor** of 3. Click **OK**.

   The PPI image will appear in the **Available Bands List** when processing has completed.
4. From the Main Image window menu, select **Tools** → **Region of Interest** → **ROI Tool** to load the ROI file `bhtm_ppi.roi` into the ROI Tool.

   Alternatively, display the PPI image and select **Tools** → **Region of Interest** → **Band Threshold to ROI** in the Main Image window to extract a Region of Interest by thresholding the image.

   Choose the PPI image as the input file, and enter a minimum threshold value of 5, and click **OK**.

   The selected pixels will be entered into ENVI's **ROI Tools** dialog.

n-D Visualization and Extract Endmembers

Though both the MNF and PPI operations above effectively reduce the data volume to be analyzed interactively, the high dimensionality of hyperspectral data requires advanced visualization techniques. ENVI's N-Dimensional Visualizer is an interactive n-dimensional scatterplotting paradigm that allows real-time rotation of scatterplots in n-dimensions (Boardman et al., 1995). This is accomplished by casting the scatterplots from n-D to 2-D to simplify analysis. Animation of the scatterplots then provides the capability to simultaneously use all bands for interactive analysis. The scientist's visual skills and scatterplot geometry are used to locate image spectral endmembers. See the Hyperspectral Tutorials and the *ENVI 3.5 User’s Guide* and Online Help for additional background information and examples.

1. From the ENVI main menu, select **Spectral** → **n-Dimensional Visualizer** → **Visualize With Previously Saved Data**. In the **Enter n-D State Filename** dialog, choose the file `bhtmppi.ndv` to use this in the visualization.

Alternatively, Select **Spectral** → **n-Dimensional Visualizer** → **Visualize With New Data** and use the ROI created from the PPI image as described above and the MNF images as the input data file.

When the **n-D Visualizer** window and **n-D Controls** dialog and appear, select the first three MNF bands by clicking on the band numbers (1, 2, 3) in the dialog.

Click on the **Start**/**Stop** button to start and stop the animation.

2. Look for corners on the scatterplot and then use ENVI's ROI definition paradigm to draw ROIs encompassing the corner pixels.
3. Select **Options** → **Z Profile** from the menu bar at the top of the **n-D Controls** dialog and choose the TM reflectance image as the file from which to get the reflectance spectra.
4. Click the middle mouse button in the **n-D Visualizer** window to extract spectra for specific scatterplot locations.

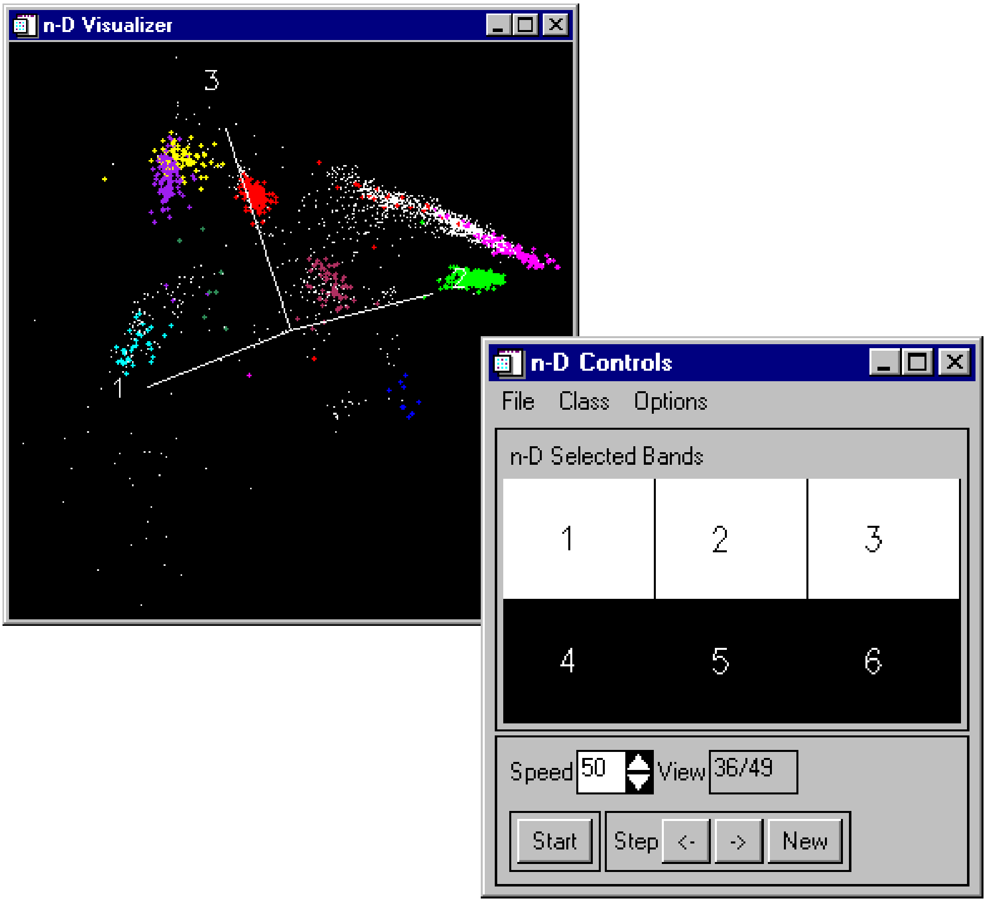


Figure 21-11: The n-Dimensional Visualizer.

5. Click the right mouse button in the **n-D Visualizer** window to extract multiple spectra.

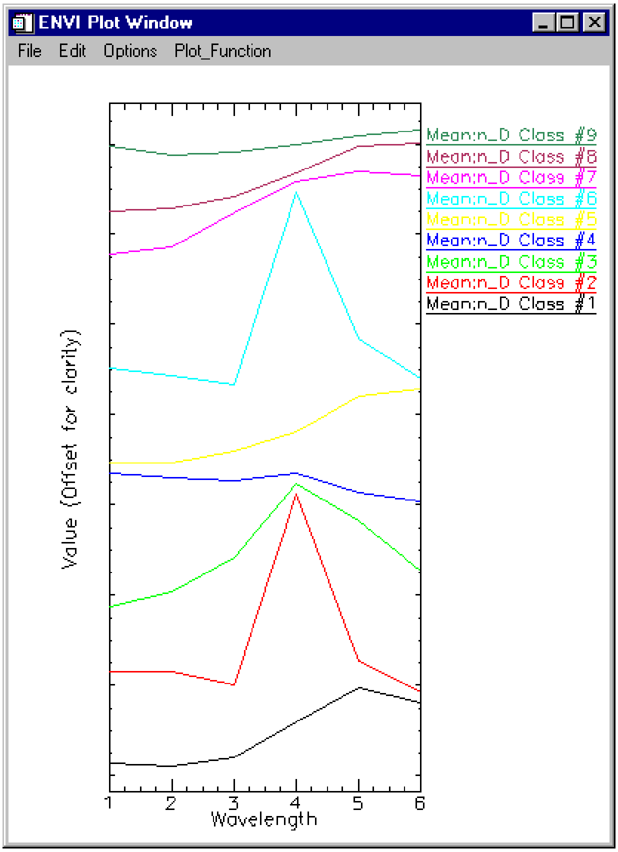


Figure 21-12: n-Dimensional Visualizer-extracted endmember spectra.

6. Export the spectral endmembers you have selected in the **n-D Visualizer** to the **ROI Tool** dialog.

   Alternatively, instead of collecting your own spectra, load and view the spectra in the file `bhtm_em.asc` from the **File** → **Input Data** → **ASCII** option in the **n-D Profile** plot window.

   Do this in the **n-D Controls** dialog by selecting **Options** → **Export All** from the dialog menu bar.

7. Plot these spectra by choosing **Options** → **Mean for All Regions** in the **ROI Tool** dialog.

Compare Image Spectra to Spectral Library

ENVI allows comparison of image spectra to spectra measured in the laboratory and saved in spectral libraries. Several relatively high spectral resolution spectral libraries are provided with ENVI.

1. From the ENVI main menu, select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer**.
2. The **Spectral Library Viewer** dialog opens. Click on several of the mineral and/or vegetation spectra names in the list.

   The selected spectra will be plotted in a **Spectral Library Plots** display window.
3. Open the ENVI spectral library `usgs_min.sli` from the *ENVI Tutorial and Data CD No. 1* directory `envidata\spec_lib\usgs_min` with the **Open Spec Lib** button in the **Spectral Library Input File** dialog, then click **OK**.
4. Compare these high resolution spectra to the TM spectral endmembers.
5. Resample the entire library to the Landsat wavelengths and resolution using ENVI's spectral tools.
6. Select **Spectral** → **Spectral Libraries** → **Spectral Library Resampling** from the ENVI main menu.
7. Select the `usgs_min.sli` spectral library and choose resampling to Landsat TM5.
8. Click OK and the library will be resampled and placed in the Available Bands List.
9. Select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer** from the ENVI main menu.
10. Choose the library you just created and click on several of the mineral and vegetation spectra to display their resampled spectra.
11. Compare these spectra to the Landsat TM image spectra.

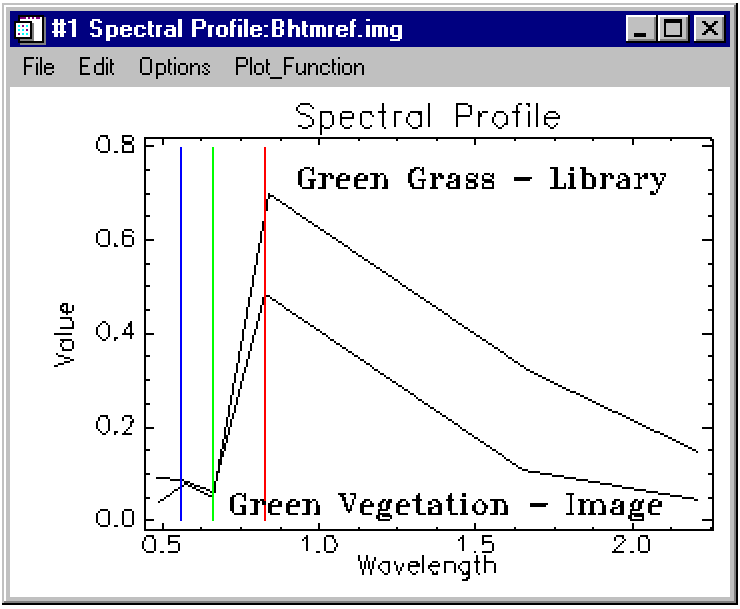


Figure 21-13: Comparison of image and library spectra.

Spectral Angle Mapper Classification

The Spectral Angle Mapper (SAM) measures the similarity of unknown and reference spectra in n-dimensions. The angle between the spectra treated as vectors in n-space is the spectral angle, this is illustrated in 2-dimensions in Figure 21-14 below. This method assumes that the data have been reduced to apparent reflectance and uses only the direction of the spectra, and not their length. Thus the SAM classification is insensitive to illumination effects. See the Hyperspectral Tutorials and the *ENVI 3.5 User's Guide* and on-line help for additional background information and examples.

To start SAM:

1. From the Main Image window, select **Tools** → **Region of Interest** → **ROI Tool**. Use **File** → **Restore ROIs** to load the ROIs from the file `bhtm_em.asc`.

   Alternatively, select **Classification** → **Supervised** → **Spectral Angle Mapper**.

   Enter the Landsat TM reflectance data `bhtmref.img` as the input file.

When the **Endmember Collection:SAM** dialog appears, select **Import → from ROI from Input File** and choose the ROIs you created in the **n-D Visualizer** window.

2. In the **Endmember Collection:SAM** dialog, click **Apply** and enter the output file names to start the classification.

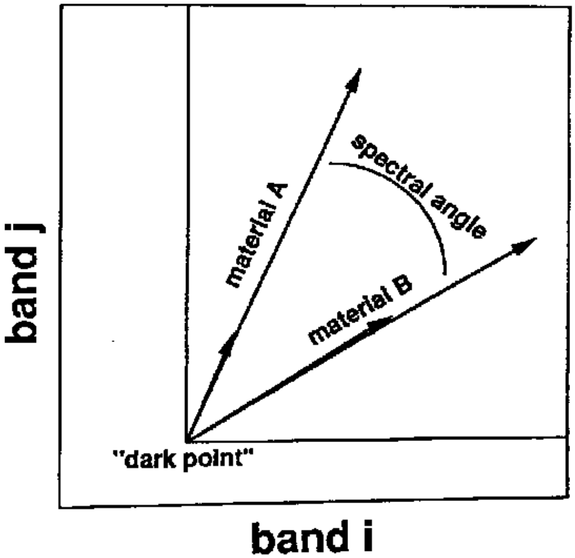


Figure 21-14: 2-D SAM Classification Schematic.

The results of the classification will be a set of rule images corresponding to the number of endmembers you selected and a SAM Classification Image. The rule images show the best matches in black when first displayed, however, these are typically inverted to better show the matches as bright pixels in the displayed rule images, select **Tools → Color Mapping → ENVI Color Tables** from the Main Image window menu bar and reverse the Stretch Bottom and Stretch Top slider bars to invert the image.

The following figure (Figure 21-15) shows the best match for each pixel (within the default threshold of 0.10 radians) color coded for each endmember.

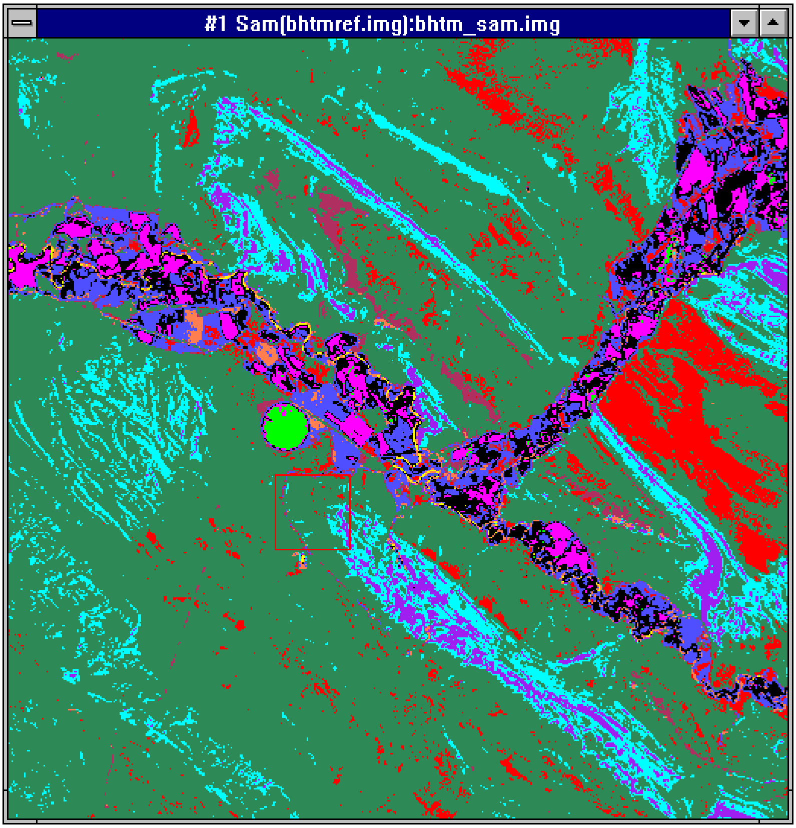


Figure 21-15: SAM Classification Result.

Linear Spectral Unmixing

Image pixels typically represent areas of from 1 to several square meters. Within these pixels, the Earth's surface is composed of mixtures of materials; pure pixels are extremely rare (Boardman). The mixed spectrum received by most imaging systems is a linear combination of the pure or endmember spectra, each weighted by their fractional abundance of area. Mixed pixels can be analyzed using a mathematical model where the observed spectrum is the result of multiplication of the mixing library of pure endmember spectra by the endmember abundances. Mixing can also be visualized, however, using a geometric model; this is the basis of ENVI's 2-D Projections of n-dimensional scatterplots. See ENVI’s Hyperspectral Tutorials and the *ENVI 3.5 User's Guide* and on-line tutorials for additional unmixing background information and examples.

To perform linear spectral unmixing using ENVI:

1. Display the pre-calculated results in `bhtm_unm.img`.

   Alternatively, use the endmember spectra from the **n-D Visualizer** above.

   Select **Spectral** → **Mapping Methods** → **Linear Spectral Unmixing** and choose the TM calibrated reflectance data as the input file.

   Select **Import** → **from ROI from Input File** from the menu bar at the top of the **Endmember Collection:Unmixing** dialog, choose the ROIs you created in the **n-D Visualizer** window, and then click **Apply**.

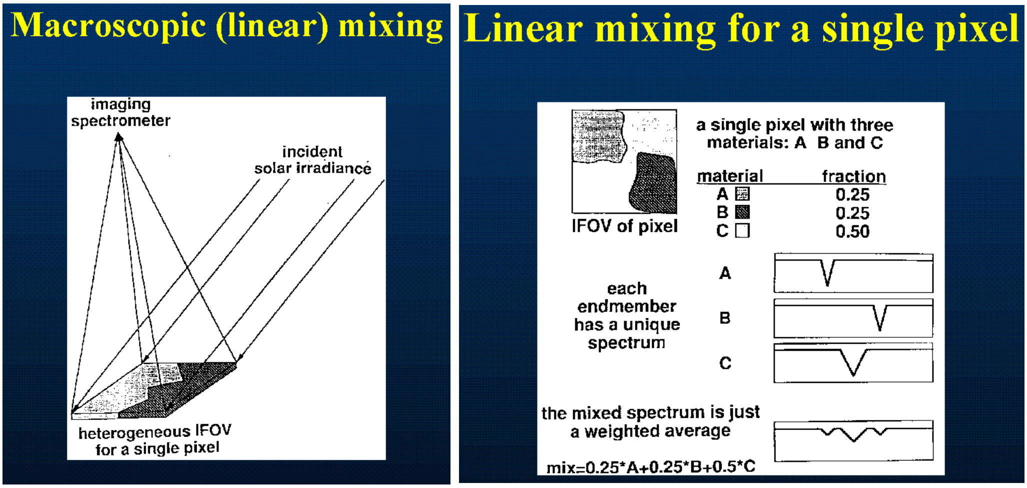


Figure 21-16: Aerial Mixing=Linear Mixing (Left) and Linear Spectral Mixing (Right).

   When complete, the spectral unmixing endmember image will appear in the **Available Bands List**.

2. Display these images from the **Available Bands List**, and the RMS (error) image generated during the analysis.

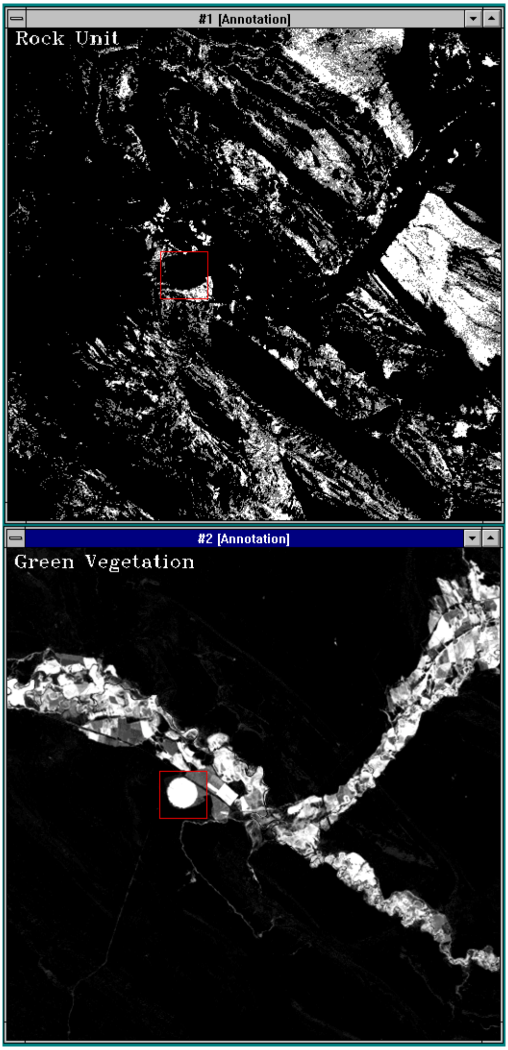


Figure 21-17: Linear Spectral Unmixing Abundance images

Bright values in the abundance images represent high abundances; the Cursor Value/Location function can be used to examine the actual values.

- By default ENVI utilizes an unconstrained unmixing algorithm. This means if you don't select the correct endmembers, the results will not be quantitatively correct. If you observe negative abundances for any of the endmembers, or the abundances for all of the endmembers for the same pixel sum to a quantity greater than 1, then the unmixing doesn't make any physical sense. The best way to correct this is to run ENVI's unmixing iteratively and to examine the abundance images and RMS error image.

- Look for high errors in the RMS image, extract the spectra for these areas and re-run the unmixing with the new endmember set.

When the RMS image doesn't have any more high errors, and all of the abundance images are non-negative and sum to less than one, then the unmixing is completed. This iterative method is much more accurate than trying to artificially constrain the mixing, and even after extensive iteration, also effectively reduces the compute time by several orders of magnitude compared to the constrained method.

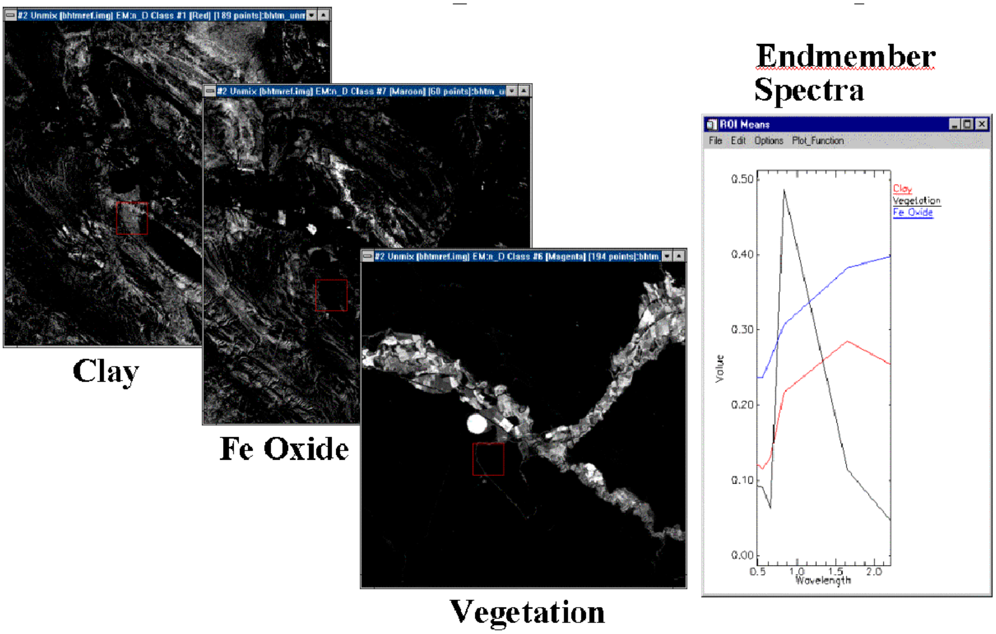


Figure 21-18: Linear Spectral Unmixing Results.

- Optionally, if you are confident that you have all of the endmembers, run the unmixing again and click on **Apply a unit sum constraint**.

Annotate and Output Map

As previously described, the final output from any image processing within ENVI is usually a map-oriented, scaled image-map for presentation or visual analysis and interpretation. In this case, the TM data were already geographically referenced, however, ENVI includes full image-to-image and image-to-map registration capabilities. Please see the Registration Tutorial in this volume or the *ENVI 3.5 User's Guide* and on-line help. ENVI also provides all of the tools to produce fully annotated publication-quality maps. This includes pixel, map, and geographic (latitude/longitude) grids; scale-bars; declination diagrams and north arrows; text and symbols; polygons, polylines, and geometric shapes (circles, rectangles); map keys and legends; and image insets. For additional information on map composition, please see the Map Composition Tutorial or the *ENVI 3.5 User's Guide* or on-line help.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to confirm your exit from IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

Summary

A wide variety of advanced tools have been developed for analysis of imaging spectrometer (hyperspectral data). These tools are mature and are being used operationally for analysis of AVIRIS and other data sets. We don't have hyperspectral data for many of the areas we would like to investigate, however, widely available multispectral data can be analyzed using some of the hyperspectral tools. ENVI allows users to use approaches developed for analysis of hyperspectral data to provide new insight to the use and analysis of multispectral data sets.

References

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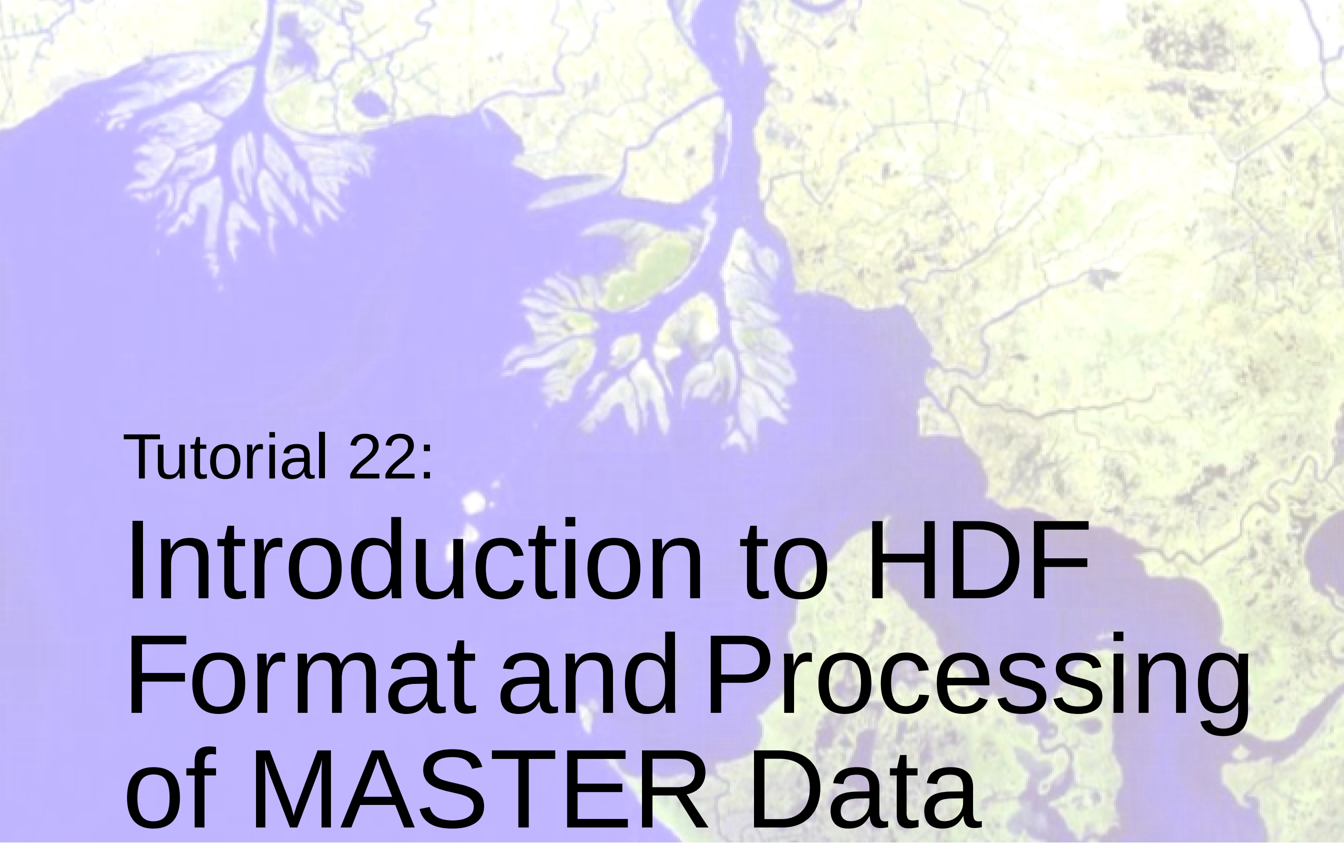
Boardman, J. W., 1993, Automated spectral unmixing of AVIRIS data using convex geometry concepts: in Summaries, Fourth JPL Airborne Geoscience Workshop, JPL Publication 93-26, v. 1, p. 11 - 14.

Green, A. A., Berman, M., Switzer, P, and Craig, M. D., 1988, A transformation for ordering multispectral data in terms of image quality with implications for noise removal: IEEE Transactions on Geoscience and Remote Sensing, v. 26, no. 1, p. 65-74.

Markham, B. L., and Barker, J. L.,1986, Landsat MSS and TM post-calibration dynamic ranges, exoatmospheric reflectances and at-satellite temperatures: EOSAT Landsat Technical Notes, No. 1, August 1996.

Research Systems Inc, 1997, ENVI User's Guide, Chapter 10.

Sabins, F. F. Jr., 1986, Remote Sensing Principles and Interpretation: W. H. Freeman and Company, New York, 449 p.



Tutorial 22: Introduction to HDF Format and Processing of MASTER Data

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to introduce you to HDF data and analysis of Multispectral Imagery from the MODIS/ASTER Airborne Simulator (MASTER) sensor. The exercise covers opening and reading HDF-format files, extracting spatial and spectral subsets and spectra, comparison of spectra to spectral libraries and classical multispectral processing. For additional details on specific functions, please see the *ENVI User's Guide* or the ENVI On-Line help. This MASTER dataset and other MASTER data are available for purchase from NASA through the EROS Data Center, Sioux Falls, SD.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/cup99mas`

File	Description
`9900511f.hdf`	MASTER date, Cuprite, Nevada
`header.txt`	Text Header with data information

Background

MASTER is designed to collect simulation data in support of the ASTER and MODIS instrument teams in the areas of algorithm development, calibration, and validation. Operated by NASA (see http://masterweb.jpl.nasa.gov/), MASTER is a 50-band scanner covering approximately the 0.4 - 14 micrometer range. The instrument operates on the NASA Beachcraft B200, DC-8 or ER-2 aircraft to produce spatial resolutions of 5-50m. Spectral band positions are designed to simulate both ASTER and MODIS.

MASTER data are delivered via EROS Data Center in Hierarchical Data Format (HDF). HDF is a multi-object file format for the transfer of graphical and numerical data between machines, and allows the user to create, access, and share scientific data in a form that is self-describing and network-transparent. “Self-describing” means that a file includes information defining the data it contains. “Network-transparent” means that a file is represented in a form that can be accessed by computers with different ways of storing integers, characters, and floating-point numbers. HDF data supported in ENVI include raster format images, images stored in 2 or 3-D scientific data format, and plots stored in 1-D scientific data format.

The HDF Format and Processing of MASTER Data

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To start ENVI in Unix, enter `envi` at the UNIX command line.
- To start ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Open a HDF File and Review Data Items

1. Select **File** → **Open External File** → **Generic Formats** → **HDF**. Click on `990051f.hdf` and **Open**. The **HDF Dataset Selection** dialog will appear listing the available HDF data contained in the file.

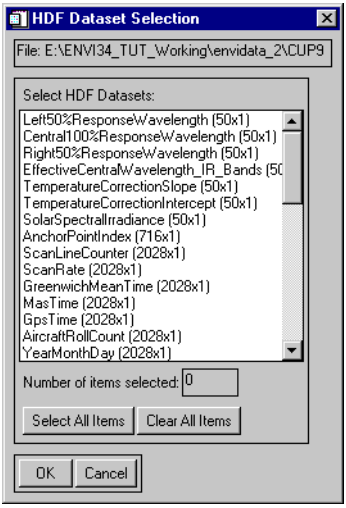


Figure 22-1: HDF Dataset Selection dialog

2. Click on the HDF dataset labeled `(50x1):Left50%ResponseWavelength` in the **Select HDF Datasets:** list and then click **OK** to plot the data. This dataset contains the center wavelengths for the MASTER HDF data.
3. Select **Edit** → **Data Parameter** from the plot window and add symbols to the plot by selecting a symbol name from the **Symbol** pull-down button in the **Data Parameters** dialog. Enlarge the plot 2 or 3 times its initial size by dragging one of the corners so that you can see the markers for the individual band centers.
4. Use the interactive plot cursor to read the wavelength values by clicking and dragging with the left mouse button on the plot. The values for the band centers are listed at the bottom of the plot as you move the cursor. The far right number represents the band center of the selected band in micrometers. Note the MASTER coverage from approximately 0.4 - 14 micrometers.

Open the HDF File and Load image

1. Select **File** → **Open External File** → **Generic Formats** → **HDF**. Click on `990051f.hdf` and **Open**. The **HDF Dataset Selection** dialog will appear listing the available HDF data contained in the file.
2. Scroll to the bottom of the **Select HDF Datasets:** list in the **HDF Dataset Selection** dialog and click on the HDF dataset labeled `(716x50x2028):CalibratedData` and then click **OK**. Select the **BIL** radio button in the **HDF Data Set Storage Order** dialog and click **OK** to load the image data into the **Available Band List** dialog. This dataset contains the image data for the Cuprite, Nevada, MASTER HDF data.
3. Click on Band 4 in the **Available Bands List** and **Load Band** to display the image. ENVI directly reads the HDF data.
4. Examine the displayed data, then select **File** → **Close All Files** in the main ENVI menu to close the display and data.

Open and Display MASTER HDF File

Use ENVI’s MASTER HDF reading capability to open a MASTER HDF file.

1. Select **File** → **Open External File** → **Thermal** → **MASTER**, click on the `990051f.hdf` and **Open**. Alternatively, select **File** → **Open Image File** and double click on `990051f.hdf` and ENVI will automatically recognize the file format. The 50 MASTER bands and their associated wavelengths will appear in the **Available Bands List** dialog.

2. Click on the **RGB** radio button in the **Available Bands List** dialog, then sequentially on Bands 5, 3, 1 and **Load RGB** to display a MASTER true-color image.

Spatially/Spectrally Subset VNIR/SWIR

1. Resize the Main Image window to cover a small area of interest centered on Cuprite, Nevada by clicking and dragging one of the window corners to the desired size. Cuprite is in the lower right corner of the displayed image.
2. Perform simultaneous spatial and spectral subsetting by selecting **Basic Tools** → **Resize Data (Spatial/Spectral)** from the ENVI main menu and clicking on the `9900511f.hdr` file in the **Resize Data Input File** dialog.
3. Click on the **Spatial Subset** button in the **Resize Data Input File** dialog, then **Subset by Image** in the Select Spatial Subset dialog. Move the red box in the **Subset Function** dialog using the left mouse button until an appropriate subset is outlined, then click **OK** and then **OK** in the **Select Spatial Subset** dialog.
4. Click on the **Spectral Subset** button in the **Resize Data Input Fil**e dialog, then **Clear** in the **File Spectral Subset** dialog. Select bands 1-25 by clicking and dragging on the names using the left mouse button, or by entering the 1-25 range at the bottom of the dialog, then clicking **Add Range**. Click **OK** to return to the **Resize Data Input File** dialog and click **OK** again.
5. Enter an output filename (`resizedimage` for example) in the **Resize Data Parameters** dialog, then click **OK** to spatially and spectrally resize the data.

Empirical Reflectance Calibration

1. Click on the **RGB** radio button in the **Available Bands List** dialog, then sequentially on Bands 5, 3, 1 and **Load RGB** to display a the resized MASTER true-color image.
2. Choose **Tools** → **Profiles** → **Z Profile (Spectrum)** from the Main Image window menu bar to display a spectrum of MASTER bands 1-25 (0.46 - 2.396 micrometers). Note the shape of the spectrum, corresponding to the shape of the solar irradiance spectrum modified by atmospheric absorption.

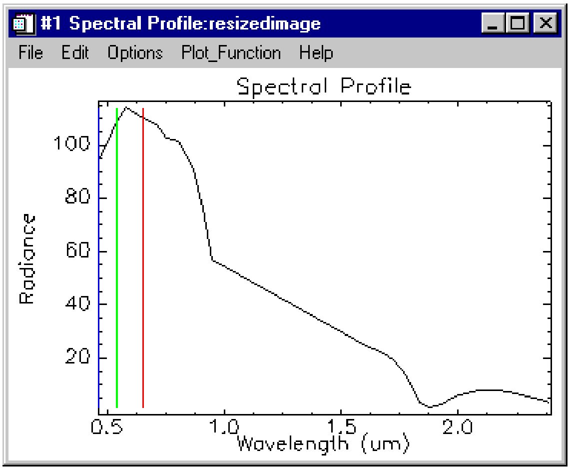


Figure 22-2: MASTER radiance spectrum

Perform a quick (rough) atmospheric correction using the empirical Flat Field Correction by choosing a spectrally flat region of interest and then dividing the average spectrum for that region into the spectrum for each pixel in the image.

3. Double-click in the Main Image window to start the **Cursor Location/Value** dialog and move the cursor around the image to locate Stonewall Playa (a bright area in the lower right corner of the image) in the vicinity of 565 and 1622.

4. Select **Overlay** → **Region of Interest** to start the **ROI Tool**, then draw a region of interest in the Playa by clicking with the left mouse button, closing with the right mouse button and fixing with a second right mouse button click. Be sure to click the **Off** radio button in the **ROI Tool** when finished to turn off ROI mouse control.

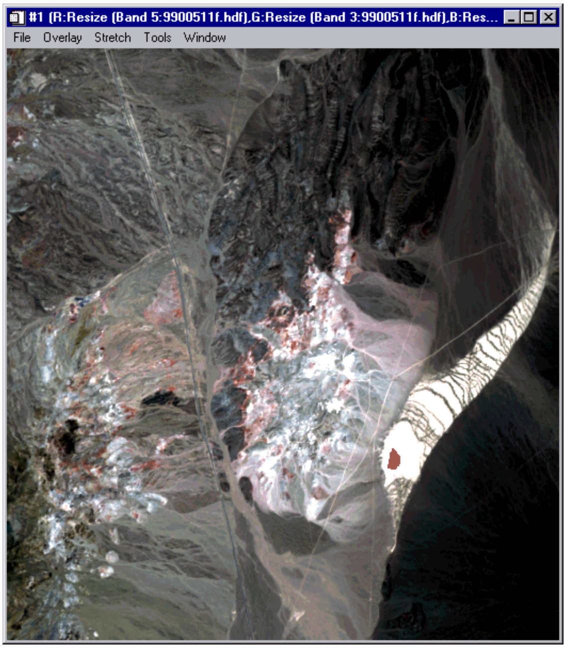


Figure 22-3: MASTER true-color composite for Cuprite Nevada with Flat-Field ROI marked in red.

5. Select **Basic Tools** → **Calibration Utilities** → **Flat Field** from the ENVI main menu, select the spatially/spectrally subsetted file you created, and click **OK**.
6. Click on `Region #1` in the **Select ROI for Calibration:** field of the **Flat field Calibration Parameters** dialog, enter an output filename (`calibration` for example), and click **OK** to start the Flat Field correction.

Display a Color Composite Image and Extract Spectra

1. As in the steps above, select bands 5, 3, 1 (RGB - True Color) from the **Available Bands List** dialog and click on **Load RGB**.
2. Once the image is displayed, start a spectral profile by choosing **Tools** → **Profiles** → **Z Profile (Spectrum)** from the Main Image window menu bar to display a spectrum of MASTER bands 1-25 (0.46 - 2.396

micrometers). Note the corrected spectrum, corresponding to apparent reflectance or relative reflectance (relative to the flat-field spectrum).

3. Use the interactive cursor to examine spectra for pixels throughout the image. Look at areas that appear red on the true-color image for Fe+3 absorption features near 0.87 micrometers (Band 9). Also zoom in on the 2.0 - 2.4 micrometer portion of the spectrum using the middle mouse button in the plot and observe absorption features near 2.2 and 2.3 micrometers caused by clays and carbonates respectively.

Compare Image Spectra

Compare the image spectra to spectra in the spectral library:

1. Select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer** from the ENVI main menu, click on **Open Spectral Library** at the bottom of the **Spectral Library Input File** dialog and open the file `usgs_min.sli` and click **OK** in the **Spectral Library Input File** dialog. Click on the spectrum name `alunite1.spc` in the main list of the **Spectral Library Viewer** dialog to display a spectrum for the mineral alunite. Click on `budding1.spc` to display a spectrum of buddingtonite, `calcite1.spc` for calcite, and `kaolini1.spc` for the mineral kaolinite. Stack the spectra by choosing **Options** → **Stack Data** in the **Spectral Library Plot**s window.
2. Use the image spectral profile to select MASTER spectra for the same minerals. Browse through the data and examine the spectra for features near 2.2 and 2.3 micrometers. Extract a spectrum for 521:1587 (alunite), 424:1578 (buddingtonite), 239:1775 (calcite), and 483:1674 (kaolinite).
3. Select **Options** → **New Window: Blank** in the plot window to start a new plot and use ENVI's spectral drag-and-drop capabilities to drag spectra into the window for comparison. Click using the right mouse button in the spectral profile to display spectra names, click and drag using the left mouse button on the spectral name to drag-and-drop the spectra into the window. Compare the image spectra to the library spectra and the differences between the image spectra.

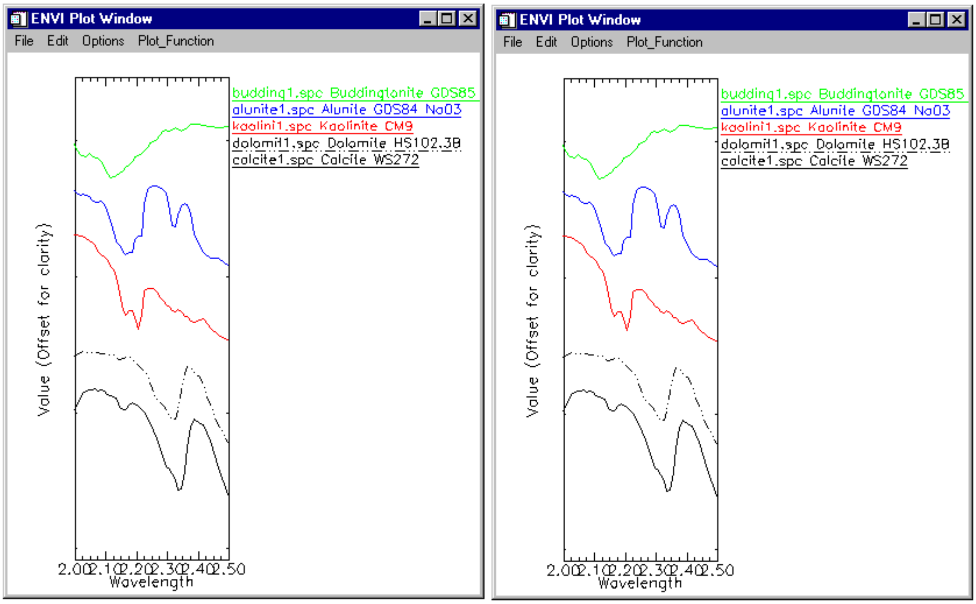


Figure 22-4: Spectral library reflectance spectra for selected minerals (left) and MASTER reflectance spectra thought to be characteristic of the same materials in the image.

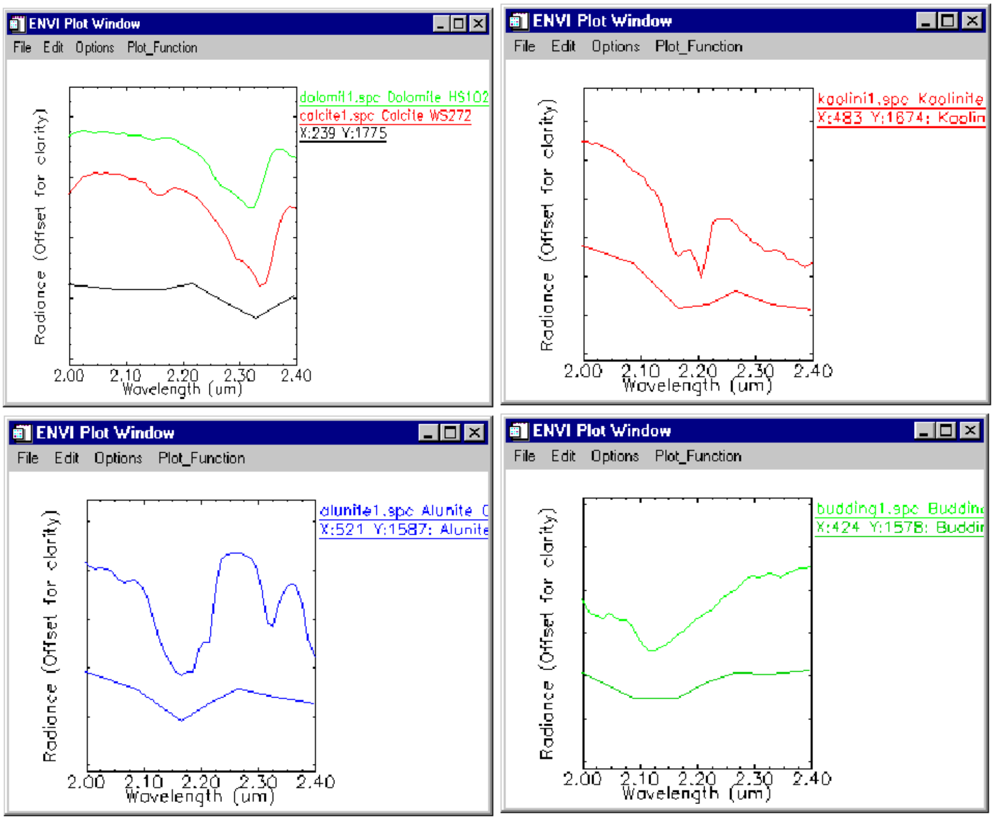


Figure 22-5: Comparison of Spectral library reflectance spectra for selected minerals and their corresponding MASTER apparent reflectance spectra from the image.

Image Processing with SAM

Use the image spectra to perform a Spectral Angle Mapper (SAM) classification of the MASTER data. SAM measures the similarity of unknown and reference spectra in n-dimensions. The angle between the spectra treated as vectors in n-space is the *spectral angle*. This method assumes that the data have been reduced to apparent reflectance and uses only the direction of the spectra, and not their length. Thus the SAM classification is insensitive to illumination effects. See the *Hyperspectral*

Tutorials and the *ENVI User's Guide* and on-line help for additional background information and examples.

To perform the SAM Classification:

1. Select **Classification** → **Supervised** → **Spectral Angle Mapper** or **Spectral** → **Mapping Methods** → **Spectral Angle Mapper** from the ENVI main menu.
2. Choose the MASTER apparent reflectance (flat field) data you created as the input file in the **Spectral Angle Mapper Input File** dialog and subset to only bands 20-25 by clicking on **Spectral Subset** and either entering the range or clicking on the desired bands then clicking **OK**.
3. From the spectral plot containing the MASTER spectra you extracted from the data, click the right mouse button to display the spectra names. Now click using the left mouse button on each of the spectra names and drag into the small black draw window at the top of the **Endmember Collection: SAM** dialog. The spectrum name will be listed in the dialog. Select **Options** → **Plot Endmembers** to confirm that you have the right endmember spectra.
4. Click **Apply** in the **Endmember Collection: Sam** dialog, enter the output file names (`spectralmapping` for example), and click **OK** to start the classification. The results of the classification will be a set of rule images corresponding to the number of endmembers you selected and a SAM Classification Image.
5. Display the SAM image by selecting the image in the **Available Bands List**, clicking on the **Gray Scale** radio button and then **Load Band**. Compare the SAM map to the color composite image. Select **Tools** → **Link Displays** → **Link** and use the dynamic overlay to look at the spatial locations of specific mapped minerals. Use the spectral profile tool to verify the spectral match.
6. You can also use the rule images to evaluate the spectral matches. The rule images show the best matches in black when first displayed, however, these are typically inverted to better show the matches as bright pixels in the displayed rule images. Display each of the rule images and select **Tools** → **Color Mapping** → **ENVI Color Tables** from the Main Display window menu bar and reverse the **Stretch Bottom** and **Stretch Top** slider bars to invert the image. Select **Tools** → **Link Displays** → **Link** and use the

dynamic overlay to look at the spatial locations of specific mapped minerals. Use the spectral profile tool to verify the spectral match.

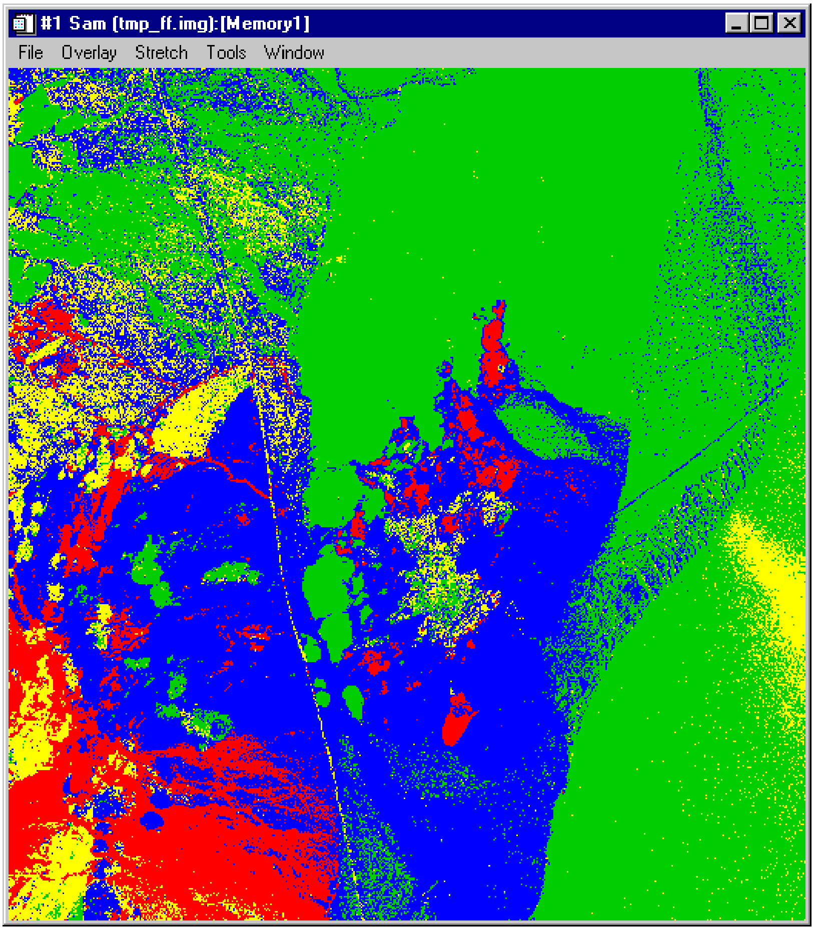
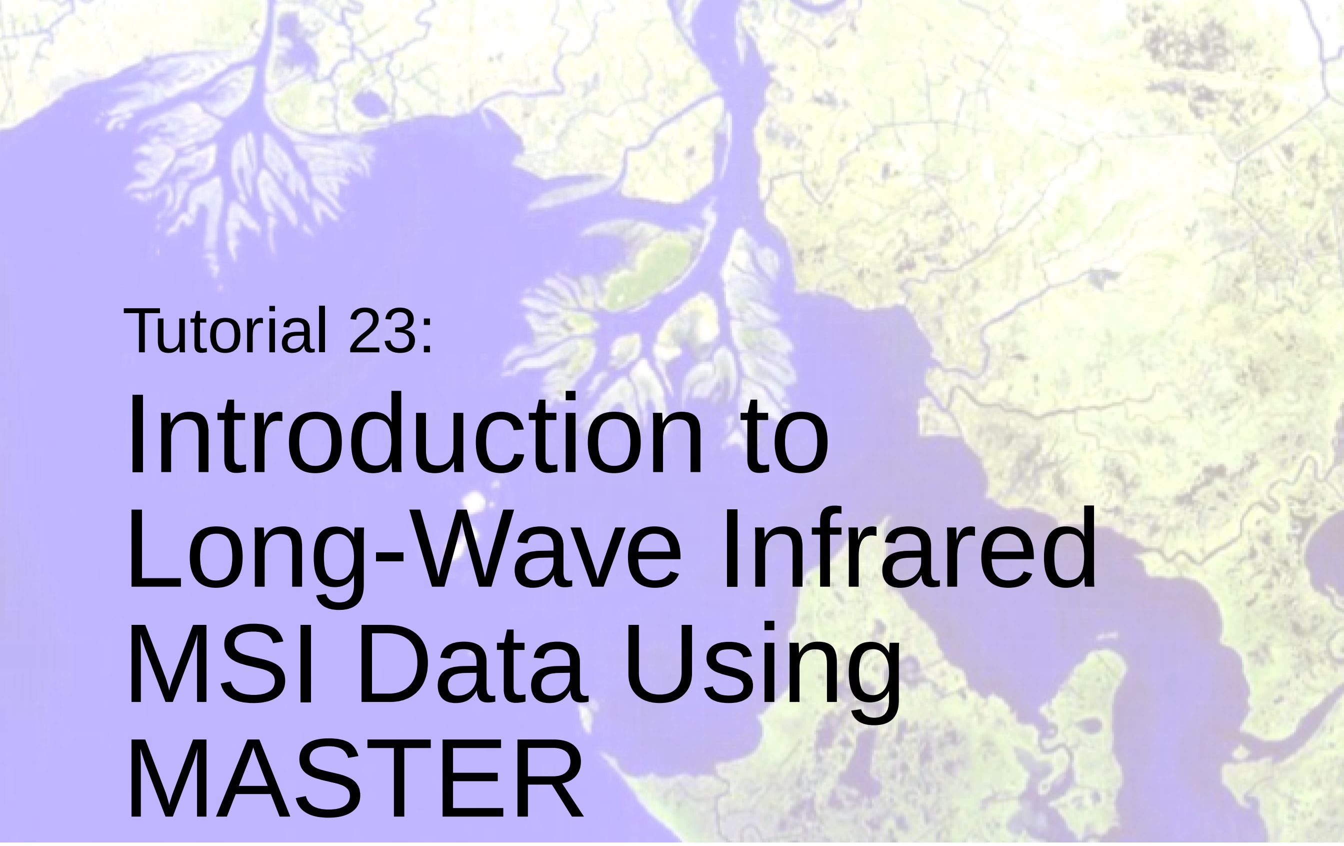


Figure 22-6: MASTER Spectral Angle Mapper result for Cuprite Nevada. Colors correspond to colors of endmember spectra in previous figures.



Tutorial 23:

Introduction to Long-Wave Infrared MSI Data Using MASTER

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to introduce you to analysis of Long-Wave Infrared (LWIR) Multispectral Imagery from the MODIS/ASTER Airborne Simulator (MASTER) sensor. The exercise covers opening and reading HDF-format files, extracting spatial and spectral subsets, examination of LWIR spectra to define key spectral bands, decorrelation stretching of color composites to enhance LWIR spectral differences, and comparison of SWIR and LWIR mapping results. For additional details on specific functions, please see the *ENVI 3.5 User's Guide* or the ENVI On-Line Help. This MASTER dataset and other MASTER data are available for purchase from NASA through the EROS Data Center, Sioux Falls, SD.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 2*

Path: `envidata/cup99mas`

File	Description
`9900511f.hdf`	Cuprite MASTER data in HDF format
`header.txt`	MASTER ASCII Header file

Background

MASTER is designed to collect simulation data in support of the ASTER and MODIS instrument teams in the areas of algorithm development, calibration, and validation. Operated by NASA (see http://masterweb.jpl.nasa.gov/), MASTER is a 50-band scanner covering approximately the 0.4 - 14 micrometer range. The instrument operates on the NASA Beachcraft B200, DC-8 or ER-2 aircraft to produce spatial resolutions of 5-50m. Spectral band positions are designed to simulate both ASTER and MODIS.

MASTER data are delivered via EROS Data Center in Hierarchical Data Format (`.hdf`). HDF is a multi-object file format for the transfer of graphical and numerical data between machines, and allows the user to create, access, and share scientific data in a form that is self-describing and network-transparent. “Self-describing” means that a file includes information defining the data it contains. “Network-transparent” means that a file is represented in a form that can be accessed by computers with different ways of storing integers, characters, and floating-point numbers. HDF data supported in ENVI include raster format images, images stored in 2 or 3-D scientific data format, and plots stored in 1-D scientific data format.

In the longwave infrared (LWIR, 8-14 micrometers), emission spectra of typical rocks indicate that this region is best suited for determining rock types based on shifts of the emissivity minimum from around 8.5 µm for framework silicates (quartz and feldspars) to progressively longer wavelengths for sheet and chain silicates, and isolated SiO4. The MASTER sensor is unique in that it provides full coverage of the 0.4 - 14 µm region in 50 spectral bands.

Long-Wave Infrared MSI Data Using MASTER

Open and Display MASTER HDF File

Use ENVI's MASTER HDF capabilities to open the MASTER HDF file.

1. Select **File** → **Open External File** → **Thermal** → **MASTER**. Select `990051f.hdf` in the `cup99mas` subdirectory. Alternatively, select **File** → **Open Image File** and double click on `990051f.hdf` and ENVI will automatically recognize the file format. The 50 MASTER bands and their associated wavelengths appear in the **Available Bands List**.
2. Click on the RGB radio button in the **Available Bands List**, then sequentially on Bands 46, 44, 41. Click **Load RGB** to display a MASTER LWIR color composite image.

Spatially/Spectrally Subset LWIR Data

1. Resize the Main Image window to cover a small area of interest centered on Cuprite, Nevada by clicking and dragging one of the window corners to the desired size. Cuprite is in the lower right corner of the displayed image.

Note

If you plan to perform the final comparison of SWIR and LWIR results at the end of this tutorial, you should run the MASTER HDF/SWIR analysis (in the previous tutorial) first and make sure that you extract the same spatial subset for this tutorial.

2. Perform simultaneous spatial and spectral subsetting by selecting **Basic Tools** → **Resize Data (Spatial/Spectral)** from the ENVI main menu and clicking on the `9900511f.hdr` file in the **Resize Data Input File** dialog.
3. Click on the **Spatial Subset** button, then **Subset by Image** in the **Spatial Subset** dialog. Move the red box in the **Subset Function** dialog using the left mouse button until an appropriate subset is outlined, and click **OK**. Then click **OK** in the **Spatial Subset** dialog.
4. Click on the **Spectral Subset** button in the **Resize Data Input File** dialog, then select **Clear** in the **File Spectral Subset** dialog. Select bands 41-50 (7.8 - 12.8 micrometers) by clicking and dragging on the names using the left mouse button, or by entering the `41` and `50` for the range at the bottom of the dialog. Clicking **Add Range** and **OK** to return to the **Resize Data Input File** dialog. Click **OK** again.

5. Enter an output filename in the **Resize Data Parameters** dialog, then click **OK** to spatially and spectrally resize the data.

Display Various Bands

1. Select Band 41 in the **Available Bands List**, click on the **Gray Scale** radio button, and **Load Band** to display a gray scale image.
2. Animate all of the resized LWIR bands to look at variability by choosing **Tools** → **Animation** from the Main Image Window menu bar and clicking **OK** in the **Animation Image Parameters** dialog. The 10 MASTER LWIR bands will be loaded and ENVI will cycle through them. Note that most of the variability displayed is caused by differential heating, not by between-band spectral differences. Ideally these data should be atmospherically corrected, then converted to emissivity to enhance spectral differences, however, to simplify this tutorial, we will substitute selection of key image bands using LWIR spectra, and enhancement using decorrelation stretching.
3. Change the animation speed and review individual frames to compare the images, and select **File** → **Cancel** when finished. If desired, display individual bands of interest using the **Available Bands List** and compare in different displays using image linking and dynamic overlays.

Review LWIR Spectra/Spectral Features

ENVI includes spectral libraries from Johns Hopkins University containing spectra for selected materials from 0.4 to 14 micrometers. The apparently seamless reflectance spectra over this region of rocks and soils were generated using two different instruments, both equipped with integrating spheres for measurement of directional hemispherical reflectance. Under most conditions, the infrared portion of these data can be used to calculate emissivity using Kirchhoff's Law (E = 1 - R).

For the purposes of this tutorial, however, highs in the reflectance spectra from the JHU spectral library can be considered equivalent to lows expected in emissivity spectra.

1. Select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer** from the main ENVI menu bar. Click on the **Open Spec Lib...** button, navigate to the `jhu_lib` directory, and choose the spectral library `minerals.sli`. Click **OK**.
2. Click on the first Quartz (Si02) and the second Calcite CaCO3 (calcite 1) in the **Spectral Library Viewer** to display reflectance spectra of quartz and calcite respectively. Select Edit Æ Plot Parameters to change the range of the wavelength axis to be in between 8 and 13. Notice the maxima for quart

(silica) near 9 micrometers (indicated by the dotted red line in the following figure), and the lack of such a feature in Calcite. We can use this information to help find all of the silica-rich areas imaged by the MASTER data.

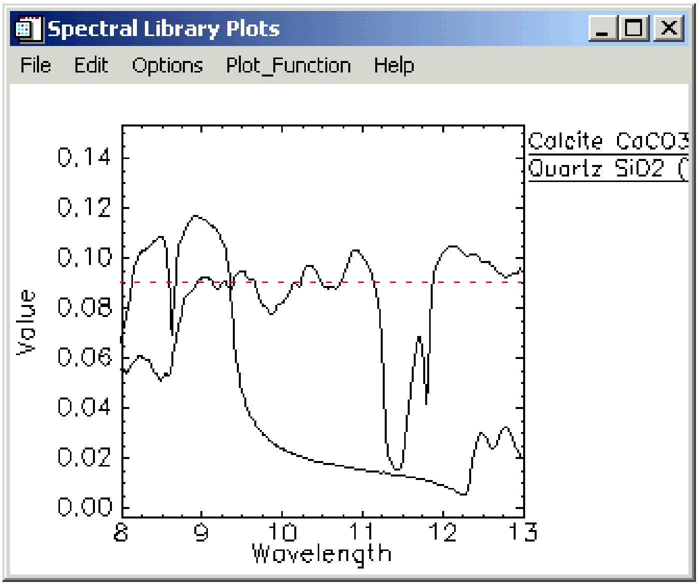


Figure 23-1: LWIR Reflectance Spectra

Design and Display Color Composites

Based on spectra, use these steps to design and display color composites.

1. Use the left mouse button in the Spectral Library Plots window to examine the nature of the two spectra. Look for contrasts between the two in the 8-14 micrometer range and equate contrasting wavelength positions to the MASTER LWIR spectral bands.
2. Bands 46, 44, and 41 (10.085, 9.054, and 7.793 micrometers) bracket the prominent silica feature near 9.0 micrometers. Click on the **RGB Color** radio button in the **Available Bands List** and sequentially select these three bands for display.

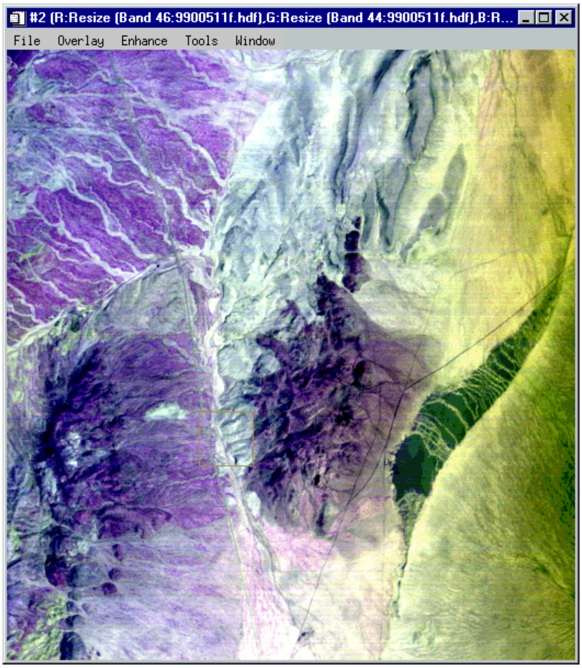


Figure 23-2: MASTER Color Composite image of Bands 46, 44, 41 (RGB)

3. Observe the image colors and relate to the expected relative contributions based on the LWIR library spectra. Note that the colors don't match the expected colors very well. This is because the effect of temperature overwhelms the spectral differences. The bands are highly correlated because of differential heating of the rocks and soils.

Perform Decorrelation Stretch

Use Decorrelation stretch to enhance color differences. Decorrelation stretching provides a means of removing the high correlation commonly found in LWIR multispectral data.

Note

While ENVI provides a specific decorrelation routine, similar results can be obtained by using a sequence of forward PCA, contrast stretching, and inverse PCA transforms.

Decorrelation stretching requires three bands (a stretched color composite) for input.

1. If you don't have a color image displayed, load bands 46, 44, and 41 for the RGB bands as described above.
2. Select **Transform** → **Decorrelation Stretch** from the ENVI main menu and click on the Display # of the displayed color composite in the **Decorrelation Stretch Input File** dialog.
3. Enter an output filename and click **OK** to produce the decorrelated image.
4. Click on the **RGB Color** radio button in the **Available Bands List** and sequentially choose the R DS, G DS, and B DS bands then click on **Load RGB** to display the decorrelated image as shown in Figure 23-3. Try other color combinations as well.

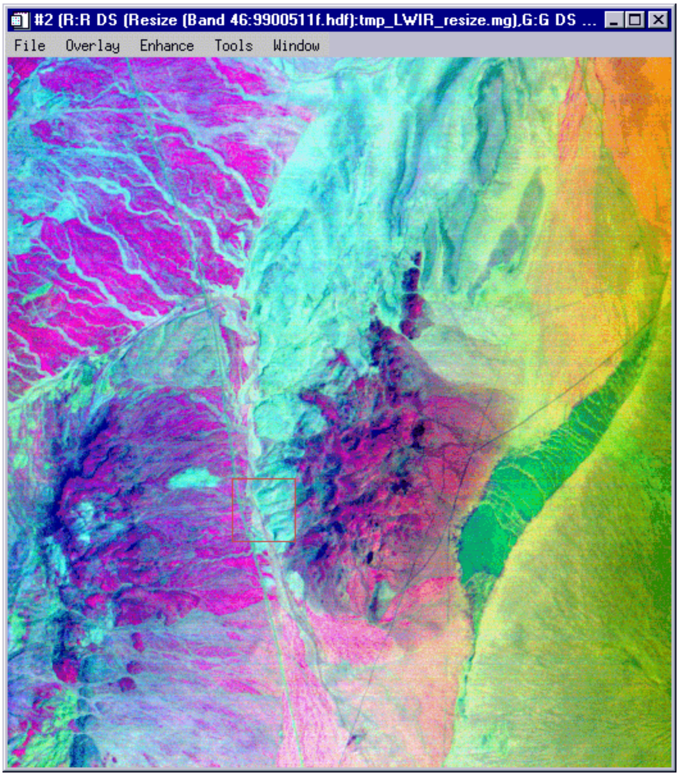


Figure 23-3: MASTER Decorrelated Color Composite Image of Bands 46, 44, 41 (RGB)

Compare LWIR and SWIR Results

Compare the Spectral Angle Mapper (SAM) result from the previous MASTER exercise with the decorrelated LWIR image.

1. Load the SAM result in one display and the decorrelated image in a second display.
2. Select **Tools** → **Link Displays** → **Link** and use the dynamic overlay to compare the distribution of minerals mapped using the SWIR data versus the distribution of silica (red areas) on the decorrelated image.

The following figure shows the MASTER decorrelated color composite image (left) and the SAM classification image (right). In the following image, using SAM color coding, red represents kaolnite, green represents buddingtonite, blue represents alunite, and yellow represents carbonate.

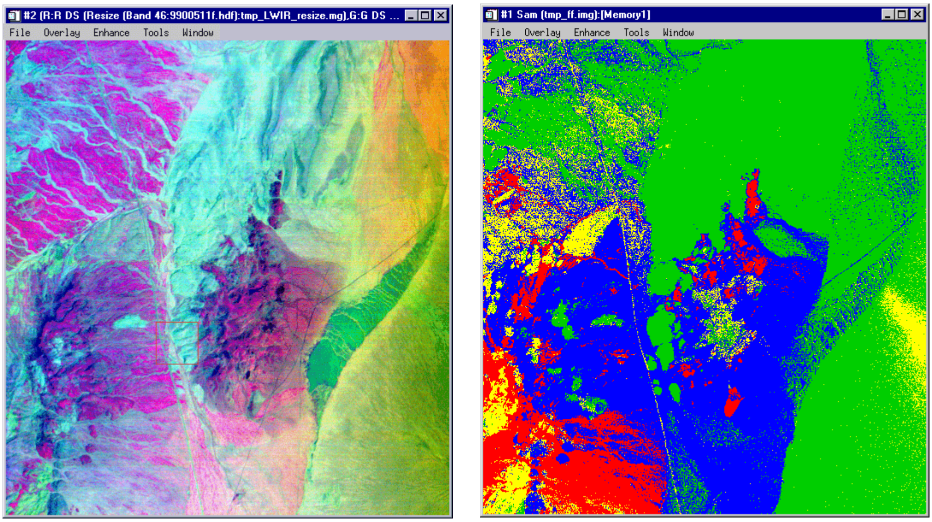
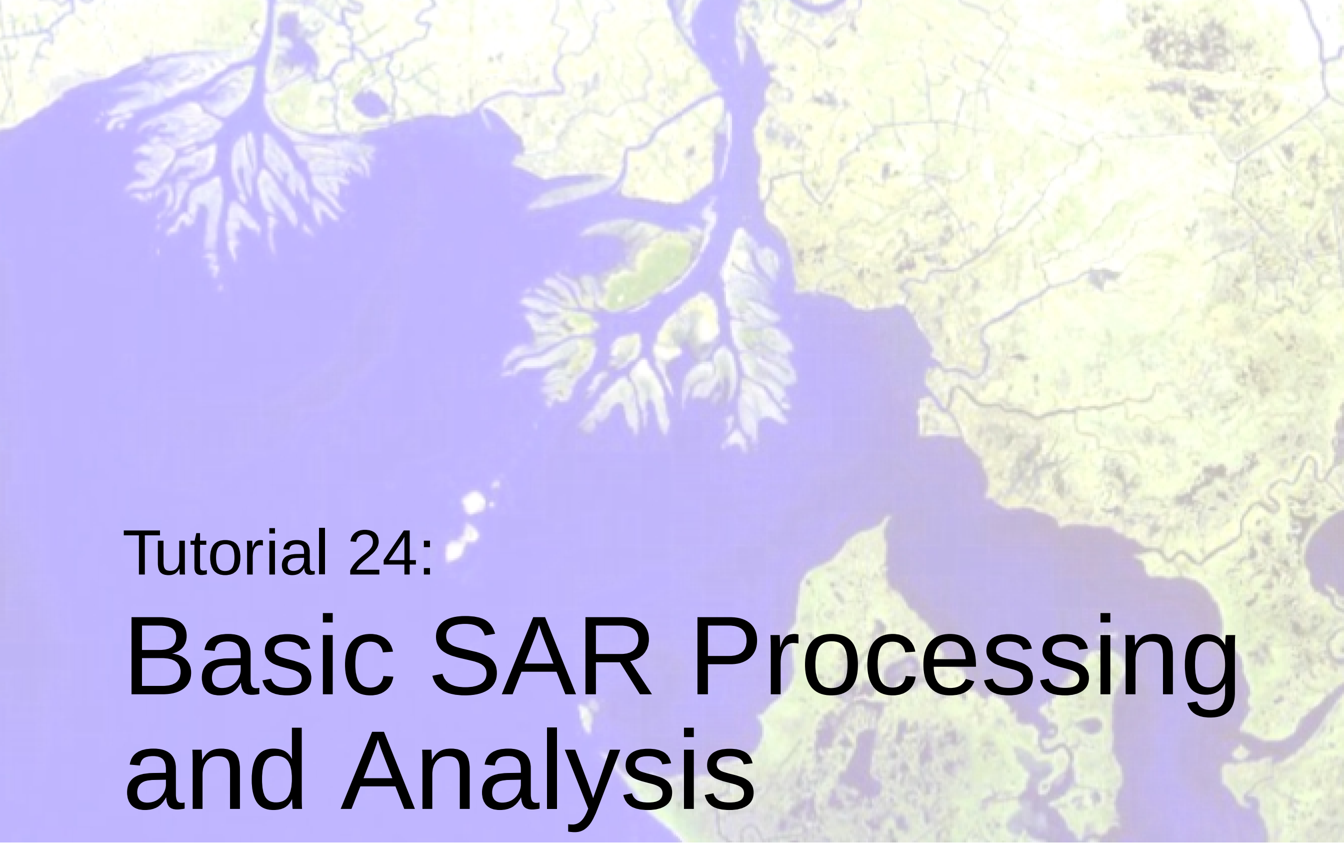


Figure 23-4: MASTER Decorrelated Color Composite Image of Bands 46, 44, 41 (RGB), Left, and SAM Classification of MASTER SWIR Data, Right

Perform Combined SWIR/LWIR Analysis

Utilize the MASTER data in a combined analysis by following the methodology described in the hyperspectral tutorials. Try utilizing bands 1-25 and bands 41-50 together in a combined hyperspectral analysis. Use the following steps as a guide.

1. Open the Cuprite MASTER HDF file, extract the SWIR and LWIR bands using spectral and spatial subsetting to build a combined data cube.
2. Select **Transform** → **MNF Rotation** → **Forward MNF**, create a MNF output file, perform the MNF analysis by looking at the spectral bands and the eigenvalue plots, then choose a reduced number of MNF bands for further analysis.
3. Choose **Spectral** → **Pixel Purity Index** → **[FAST New Output Band]** and run for around 10,000 iterations to find the key endmember spectra thus reducing the spectral dimensionality. Threshold the PPI to a ROI with around 5000 pixels.
4. Select **Spectral** → **N-Dimensional Visualizer** → **Visualize with New data** and choose the PPI region of interest for input. Rotate the n-dimensional scatterplot in high-dimensions and select extreme pixels by drawing ROIs in the n-D visualizer and exporting to Image ROIs.
5. Use ENVI’s spectral mapping methods (**Spectral** → **Mapping Methods** → ***Desired Method*** to produce image maps utilizing the combined datasets. Compare these results to the SWIR and LWIR results above.



Tutorial 24:
Basic SAR Processing and Analysis

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to give you a working knowledge of ENVI's basic tools for processing single-band SAR data (such as RadarSat, ERS-1, JERS-1).

Files Used in this Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/rsat_sub`

File	Description
`lea_01.001`	Radarsat Leader file
`bonnrsat.img`	Radarsat image subset
`bonnrsat.hdr`	ENVI Header for above
`rsi_f1.img`	Frost filter result
`rsi_f1.hdr`	ENVI Header for above
`dslice.dsr`	Density Slice level save file
`rsi_f2.img`	Laplacian filter result
`rsi_f2.hdr`	ENVI Header for above
`rsi_f3.img`	Laplacian Filter result with 0.9 addback
`rsi_f3.hdr`	ENVI Header for above
`rsi_fus.img`	Simulated Fused TM and Radarsat
`rsi_fus.hdr`	ENVI Header for above
`rsi_map.jpg`	Radarsat map composition example

Background

Concepts for processing SAR with ENVI

Most standard ENVI processing functions are inherently radar capable including all display capabilities, stretching, color manipulations, classification, registration, filters, geometric rectification, etc. Specific Radar menu items are also included under the Radar menu for specific ENVI routines that are particularly useful for radar processing. Many of these can also be accessed from their functional areas on the ENVI main menu. ENVI provides standard and advanced tools for analysis of detected radar images as well as advanced SAR systems such as JPL's fully polarimetric AIRSAR and SIR-C systems. ENVI can process ERS-1/ERS-2, JERS-1, RADARSAT, SIR-C, X-SAR, and AIRSAR data as well as any other detected SAR data set. In addition, ENVI is designed to handle radar data distributed in the CEOS format, and should be able to handle data from other radar systems that distribute their data in this format.

RadarSat Data

The ENVI software completed a RADARSAT Endorsement Review on 02/29/95. ENVI's Radarsat capabilities were demonstrated using ENVI 2.5 on a Pentium 133 running Microsoft Windows NT 3.51. All ENVI SAR capabilities are fully cross-platform portable, running identically on supported UNIX, Intel PC, and Macintosh/Power Macintosh systems. The demonstration consisted of the following components:

- CEOS Header Browsing
- Ingest Verification
- Path Image (SGF) from CD-ROM
- Path Image - ScanSAR (SCN) from CD-ROM
- Sample Point Target Grid (Beam 51, SGF) from 8mm Tape
- ENVI Features Demonstration - histograms, contrast stretching, band math, filters, display, hard copy output, etc.
- Radiometric Enhancements
- Speckle Reduction
- Texture Analysis
- Edge Enhancement
- Registrations - Image-to-image, Vector, Map
- IHS Data Merge

Radarsat's review showed that ENVI already had most of the RADARSAT Level 1 and Level 2 capabilities including the following:

Level 1

- Existing features are all radar capable

- Specific required features are already available in ENVI 2.0 at no extra cost
- Speckle reduction filters - Lee, Local Sigma, Bit Errors
- Texture Analysis - Data Range, First Moment, Second Moment, RMS
- Edge Enhancements - high pass, laplacian, directional
- Radiometric enhancements - linear, piecewise linear, gaussian, arbitrary, LUTs
- Handling of 16 bit data files

Level 2

- Image-to-Image registration
- Image-to-Vector registration
- Image-to- Map registration
- Mosaicking
- RGB to HIS conversion and data merging

Radarsat-Specific Routines Added Starting with ENVI 2.5

ENVI RADARSAT-specific ingest routines and other modifications were added for ENVI version 2.5 including:

- RADARSAT CEOS Reader for CD-ROM, Disk, and Tape with 16 bit or 8 bit ingest
- Compression on ingest
- RADARSAT CEOS Header/Trailer Browser
- Support for the following Platforms: UNIX (SUN, SGI, HP, IBM, DEC), Intel PC (Windows 3.1, Windows NT, Windows 95), Macintosh and Power Macintosh

ENVI Version 2.5 was certified as Radarsat Compatible on 02/29/95 and SAR support has subsequently been improved with every version upgrade.

Single-Band SAR Processing Scenario

This section of the tutorial describes a typical single-band SAR processing scenario from data input through processing and analysis, to publication-quality and/or map output. Data used for the example are a subset of a Radarsat 1 Path Image, Fine Beam 2, December 17, 1995, Bonn, Germany.

Read CEOS Data, Display Data, and Review Quality

ENVI provides the tools to read Generic CEOS data tapes and Radarsat Data from both Tape and CD-ROM.

- For tape reading, select **File** → **Tape Utilities** → **Read Known Tape Formats** → **Radarsat CEOS**
- To read original RadarSat data from disk or CD select **Radar** → **Open/Prepare Radar File** → **Radarsat**

1. For the purposes of this tutorial, a Radarsat image subset has already been extracted. From the ENVI main menu, select **File** → **Open Image File** and choose the file `bonnrsat.img` from the `rsat_sub` directory.
2. Load the image into an ENVI display window by choosing the band name in the **Available Bands List** and clicking on **Load Image** at the bottom of the dialog.

Figure 24-1 shows the image subset of the Radarsat Image of Bonn, Germany, with a 2% Linear Stretch applied. These data were acquired during the Radarsat commissioning phase and should not be used for scientific analysis or interpretation. Data are copyright, Radarsat, 1995.

Figure 24-1: Radarsat Subset of Bonn, Germany with 2% Linear Stretch Applied

Review CEOS Header

Many SAR data sets are distributed in CEOS format. ENVI provides generic tools to read CEOS headers and display CEOS header information on-screen. ENVI also has tools specifically designed to read Radarsat CEOS headers, which contain additional information.

1. Select **Radar** → **Open/Prepare Radar File** → **View RADARSAT Header**.
2. Choose the RadarSat leader file `lea_01.001` or one of the other files to extract the CEOS information and display on-screen.

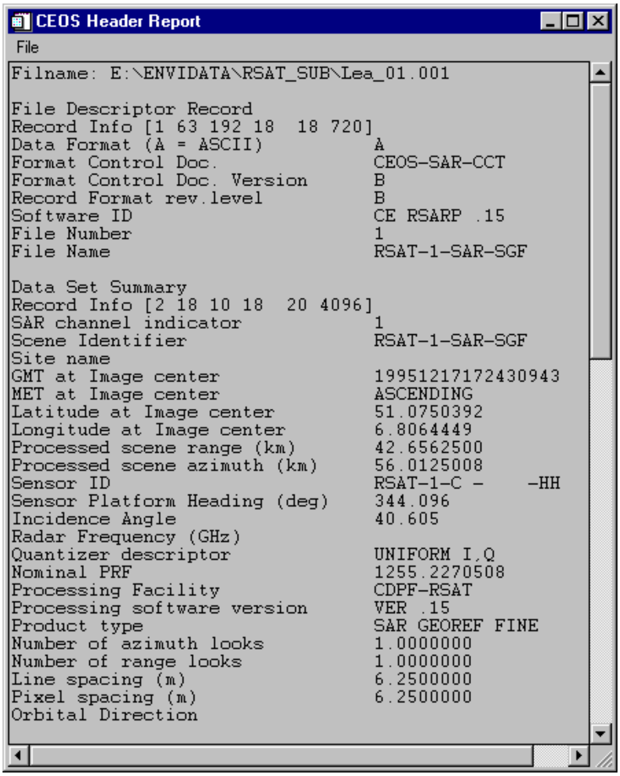


Figure 24-2: Radarsat CEOS Header Information From the Leader File

Contrast Stretching (Square Root)

Radar data typically cover a large range of data values. As seen above, default linear stretches do not do a very good job of contrast enhancing most radar images. ENVI's square-root stretch provides a means of spreading radar data out better over a given range of gray scales than other types of stretches, thus permitting improved display of Radar images. Figure 24-3 shows a square-root stretch of the Radarsat image of Bonn Germany. Compare to the linear contrast stretch above.

1. To perform a square-root stretch with ENVI, display the image to be stretched and select
2. **Enhance** → **[Image] Square-Root**.

The stretch will be applied to the data based on the statistics of the data in the Main Display window.

3. Display the image in a new window and select **Tools → Link → Link Displays** to link the square-root image back to the 2% linear stretch image. Click and drag using the left mouse button to compare the two images using the dynamic overlay.

Figure 24-3: Radarsat Image with Square Root Contrast Stretch Applied

Remove Speckle using Adaptive Filters

Adaptive filters provide a means of removing radar speckle from images without seriously affecting the spatial characteristics of the data. The Frost filtered image shown below is a considerable improvement over the unfiltered data. The Frost filter, an exponentially damped, circularly symmetric filter that uses local statistics, is used to reduce speckle while preserving edges in the data. The pixel being filtered is replaced with a value calculated based on the distance from the filter center, the damping factor, and the local variance. Compare to the images above and to the dynamic overlay image below. To perform the Frost Filter on the Radarsat data:

1. Select **Radar** → **Adaptive Filters** → **Frost**.
2. Choose `bonnrsat.img` as the input image and use the default filter size (3x3) and Damping factor (1.0). Enter an output filename and click **OK**, or load the pre-saved file `rsi_f1.img` to a second display using a square root stretch.
3. Select **Tools** → **Link** → **Link Displays** to link the Frost filtered image back to the 2% linear stretch image. Click and drag using the left mouse button to compare the two images using the dynamic overlay.

Figure 24-4: Frost Filter Result

Density Slice

Density slicing provides a means of visually enhancing radar differences based on image brightness. The density sliced image below has four levels, with higher radar backscatter in the warmer colors.

1. In the Frost Filtered image display choose **Tools** → **Color Mapping** → **Density Slice**.
2. Enter the desired ranges and colors in the **Density Slice** dialog by choosing **File** → **Restore Ranges** and selecting the file `dslice.dsr`. Then click **Apply** in the **Density Slice** dialog to density slice the image.
3. Use dynamic overlays to compare to the gray scale images above.

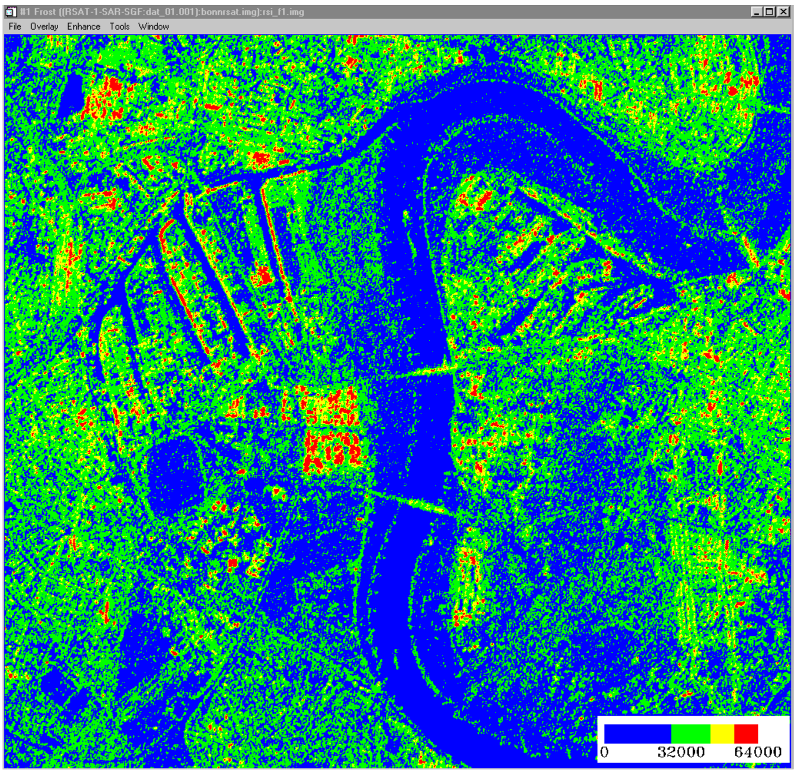


Figure 24-5: Density sliced Radarsat Image

Edge Enhancement

A Laplacian Filter can be used to enhance edges in SAR data and other data types. This is a convolution filter with a kernel (for a 5 x 5 filter) of:

0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	16	-2	-1
0	-1	-2	-1	0
0	0	-1	0	0

1. From the ENVI main menu, select **Filter** → **Convolutions** to open the **Convolutions and Morphology Tool**. Click **Convolutions** → **Laplacian**.
2. Set the **Kernel Size** to 5 x 5 and click **Quick Apply** to select the `bonnrsat.img` and click **OK**. Alternately, view the pre-saved file `rsi_f2.dat`.

   Applying the kernel in this fashion strongly enhances the edges and causes loss of most of the radiometric information.
3. Choose the filter as above, but enter the value of `90` for the **Image Add Back** value. Use `bonnrsat.img` and the default parameters to create a new output file or view the pre-saved file `rsi_f3.dat`. (See Figure 24-6).
4. Compare the result to the filtered image and to the original data using dynamic overlays.

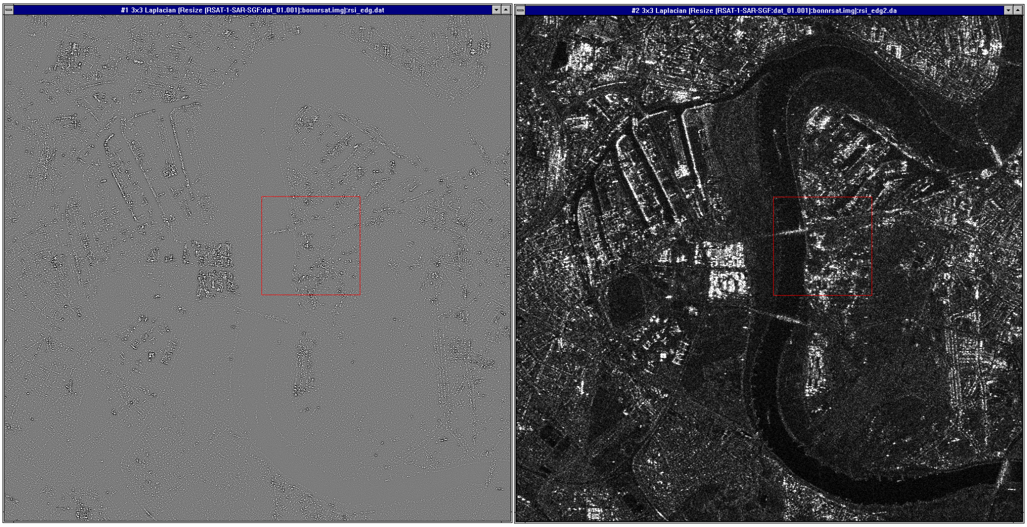


Figure 24-6: Edge Enhancement Results; Left Image is Laplacian, Right is with 90% Add Back

Data Fusion

One of the strengths of SAR data is its highly complementary nature with respect to other data sets. Radar data provides a wealth of spatial information that isn't present in many other types of image data. Conversely, however, SAR data doesn't have much compositional information, which is typically expressed in multispectral optical data sets. This situation leads naturally to the use of combined SAR/Optical data.

The most common means of combining data sets is the use of Intensity, Hue, Saturation (IHS) transforms to combine a multispectral, color-composite image with a monochromatic SAR sharpening band. ENVI provides a simple tool to conduct data merging using IHS.

No optical data set was available that corresponded to the Bonn Radarsat data so you are not able to perform this function with these data. The example and figure below, however, illustrate a simulated image showing IHS-Merged Data of an unrelated Landsat Thematic Mapper data set. This image is designed to give you an idea of how a merged SAR/Optical dataset might appear. ENVI also provides a Color Normalization (Brovey) transform for data fusion.

Figure 24-7: Simulated TM-Radarsat Data Fusion Result

1. Given 3-band color composite image, select **Transform** → **Image Sharpening** → **HSV** and then enter the three bands for the color composite into the **Select Input RGB Input Bands** dialog.
2. Select the single band SAR image.

If the two images have the same spatial dimension, ENVI goes ahead with the fusion. If the two data sets are both georeferenced, but with different pixel sizes, ENVI resamples low resolution image to match the high resolution image, then fuses the two data sets.

Image-Map Output

The final output from any image processing within ENVI is usually a map-oriented, scaled image-map for presentation or visual analysis and interpretation. Radar data can be used in map composition like any other data set. If map registration is desired, ENVI includes full image-to-image and image-to-map registration capabilities. Please see the Map Registration tutorial or the *ENVI 3.5 User's Guide* or On-line Help for more information.

ENVI also provides all of the tools to produce fully annotated publication-quality maps. This includes pixel, map, and geographic (latitude/longitude) grids; scale-bars; declination diagrams and north arrows; text and symbols; polygons, polylines, and geometric shapes (circles, rectangles); map keys and legends; and image insets. For additional information on map composition, please see the Map Composition tutorial in this volume, or the *ENVI 3.5 User's Guide* or On-line Help.

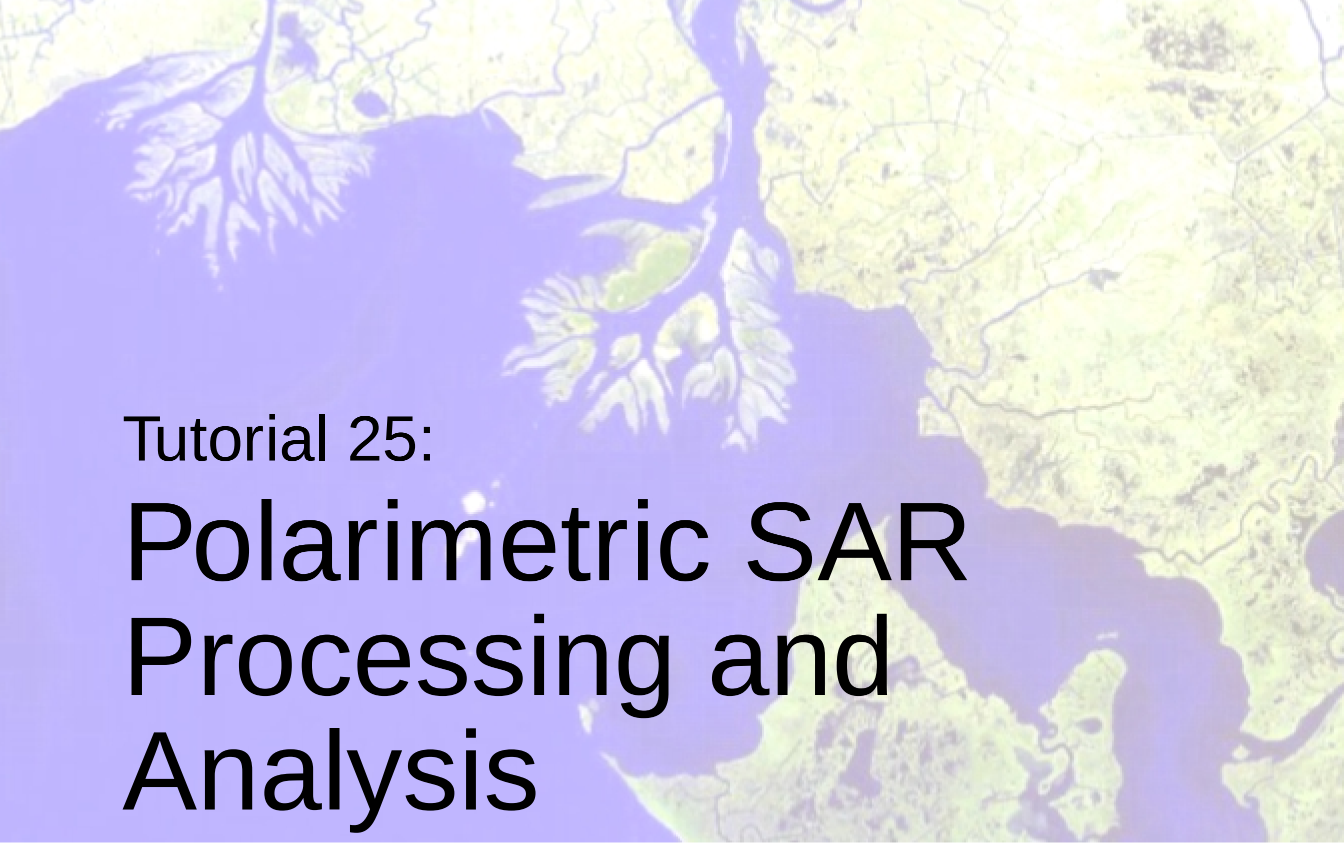
Figure 24-8: Radarsat Image-Map Composition

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **Yes** to end the session. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

Summary

ENVI is fully radar capable (Radarsat Level 2 Certified); most of ENVI's routines work transparently with SAR data. ENVI also provides a series of specialized tools for analysis of both single-band and polarimetric, multifrequency Radar data. A typical scenario might consist of Reviewing the CEOS header, reading the CEOS data, displaying and contrast stretching, removing speckle using an adaptive filter, density slicing, edge enhancement, data fusion, and map composition. These tools provide end-to-end SAR processing capabilities, including tape/CD-ROM input, processing, analysis, and publication output within a single software system.



Tutorial 25:

Polarimetric SAR Processing and Analysis

The following topics are covered in this tutorial:

Overview of This Tutorial

The following tutorial demonstrates the use of ENVI's radar data analysis functions. Data from the Spaceborne Imaging Radar-C (SIR-C) for Death Valley, California are used in this example. The data were obtained by SIR-C onboard the Space Shuttle Endeavor in April 1994.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/ndv_sirc`

File	Description
Required Files	
`ndv_l.cdp`	L-band SIR-C subset in ENVI Compressed Data Product .cdp format.
`pol_sig.roi`	Saved Regions of Interest (ROI).
`texture.dsr`	Saved Density Slice Range .dsr file.
Generated Files	
`ndv_l.syn`	Synthesized images (~2.5 Mb, also generates .hdr file).
`ndv_l2.syn`	Synthesized images in dB (~5 Mb, also generates .hdr file).
`ndv_gam.img`	Gamma filter result (~0.6 Mb, also generates .hdr file).
`ndv_gr.img`	Slant to ground range result (~0.9 Mb, also generates .hdr file).
`ndv_hh.tex`	Texture filter result (~2.5 Mb, also generates .hdr file).
`envi.ps`	Output ENVI postscript file (~3.8 Mb).

Background: SIR-C/SAR

SIR-C is a polarimetric synthetic aperture radar that uses two microwave wavelengths: L-band (24 cm) and C-band (6 cm). The SIR-C radar system was flown as a science experiment on the Space Shuttle Endeavor in April (SRL-1) and October

1994 (SRL-2), collecting high quality SAR data over many sites around the world (a second radar system—“X-SAR”—was also flown on this mission, but these data are not discussed or processed here). Additional information about SIR-C is available on the NASA/JPL Imaging Radar Home Page on the World Wide Web at http://southport.jpl.nasa.gov/.

Analyzing SIR-C Data

The data used in this tutorial are a subset of L-band “Single Look Complex” (SLC) SIR-C data that cover the northern part of Death Valley, including Stovepipe Wells, a site of active sand dunes and extensive alluvial fans at the base of mountains. These data have been pre-processed by reading/subsetting from tape and multilooking (averaging) to 13 m square pixels. The data are provided in a special ENVI “Compressed Data Product (.cdp) format. This is a non-image format similar to the tape format and can not be viewed until images are “synthesized” for specific polarizations.

The first two functions described in this example—reading the data tape and “multilooking”— have been pre-applied to the SIR-C data. We include the sections here for completeness in dealing with SIR-C data. Skip to the section “Synthesize images - Start The Actual Work Here” if you are not interested in reading about data input and preparation.

Read a SIR-C CEOS Data Tape

Note

The file used for this exercise has already been read from tape and saved in a file. Instructions on reading a SIR-C tape are included here only for completeness.

---

1. Select **File** → **Tape Utilities** → **Read Known Tape Formats** → **SIR-C CEOS** to read a SIR-C CEOS data tape into ENVI.

   The **SIRC Format - Load Tape** dialog will appear. See the Tape Reading section of the *ENVI User’s Guide* for details on the SIR-C tape-reading function. To read a tape:

2. Enter the tape device name and let the record size default to 65,536.
3. Click **OK**.

   The tape will be scanned to determine what SIR-C files it contains and a dialog will appear, allowing you to select the desired data sets. By default, ENVI will read all of the data files on the tape.

4. If you do not want to read all of the data files, click **Clear** and then click on the box next to each desired file. When the files are selected, click **OK**.

5. The selected data files can be subset and multilooked independently as they are being read from tape. We recommend, however, that multilooking be performed on disk files unless insufficient disk space is available, as this function is extremely slow from tape.
6. Click on a filename, then click on **Spatial Subset** or **Multi-Look** to enter parameters for the data file and enter an output filename.

Each input file must have an output filename. By convention, the output filenames should take the form `*filename*_c.cdp` and `*filename*_l.cdp` for the C- and L-bands, respectively.

The SIR-C data will be read from the tape and one compressed scattering matrix output file created for each data set selected.

Multilook SIR-C Data

Multilooking is a method for reducing speckle noise in SAR data and for changing the size of a SAR file. SIR-C data can be multilooked to a specified number of looks, number of lines and samples, or azimuth and range resolutions.

Note

The SIR-C file used in this tutorial was a single look dataset that had a range resolution of 13 m and an azimuth size of 5 m. Multilooking has already been performed in the azimuth direction to make 13 m square pixel sizes. Instructions on Multilooking are included here only for completeness in dealing with SIR-C data. To multilook a dataset:

1. Select **Radar** → **Polarimetric Tools** → **Multilook Compressed Data** → **SIR-C Multilook**.
2. When the **Input Data Product Files** dialog appears, click **Open File** and select the input file.

   ENVI will detect whether the file contains L- or C- band data and display the file name in the appropriate field of the dialog.
3. Click **OK**.
4. Select the file to multilook by selecting the box next to the name. You can select multiple files.
5. Enter any one of three values—number of looks, number of pixels, or pixel size—and the other two will be calculated automatically. Both integer and floating point number of looks are supported.

6. Enter the desired values in the appropriate box for both **Samples (range)** and **Lines (azimuth)**.
7. Enter the base file name in the appropriate text box and click **OK**.

Synthesize Images

Note

Begin the tutorial exercises here.

The SIR-C quad-polarization data provided with this tutorial and available on tape from JPL are in a non-image, compressed format. Accordingly, images of the SIR-C data must be mathematically synthesized from the compressed scattering matrix data. You can synthesize images of any transmit and receive polarization combinations desired.

1. Select **Radar** → **Polarimetric Tools** → **Synthesize SIR-C Data**.
2. When the **Input Product Data Files** dialog appears, click **Open File** to display a standard file selection dialog and navigate to the `envidata/ndv_sirc` directory.
3. Select the file `ndv_l.cdp` from the list. When the filename appears in the **Selected Files L:** field, click **OK**.

   The **Synthesize Parameters** dialog appears.

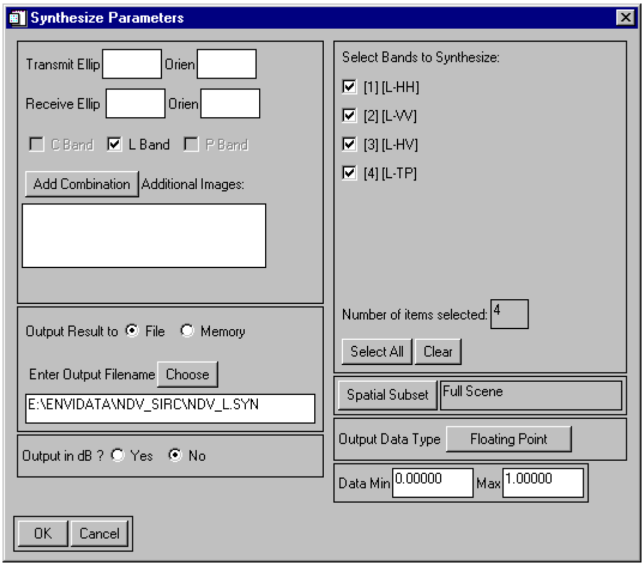


Figure 25-1: Synthesize Parameters Dialog.

Default Polarization Combinations

Four standard transmit/receive polarization combinations—HH, VV, HV, and TP—will be listed in the “Select Bands to Synthesize” list in the Synthesize Parameters dialog. By default, these bands are selected to be synthesized.

1. Enter the output filename `ndv_l.syn` with its correct path in the **Enter Output Filename** field.
2. Select **Byte** from the **Output Data Type** pulldown menu. This will scale the output data to byte values. Make the appropriate selections and click **OK**.

Note

If you will be doing quantitative analysis, the output should remain in floating point format.

An ENVI Status Window will appear and after a short wait, the file NDV_L.SYN will be created, and four bands corresponding to the four polarization combinations will be added to the Available Bands List, which appears automatically.

Other Polarization Combinations

The transmit and receive ellipticity and orientation angles determine the polarization of the radar wave used to synthesize an image. The ellipticity angle falls between -45 and 45 degrees and determines the “fatness” of the ellipse. The orientation angle is measured with respect to horizontal and ranges from 0 to 180 degrees.

You can synthesize images of non-default polarization combinations by entering the desired parameters as follows.

1. Select **Radar** → **Polarimetric Tools** → **Synthesize SIR-C Data**. The file `ndv_l.cdp` should still appear in the **Selected Files** field.
2. Click **OK**.
3. Enter -45 and 135 in the **Transmit Ellip** and **Orien** fields respectively and -45 and 135 in the **Receive Ellip** and **Orien** fields respectively.
4. Click the **Add Combination** button. This will produce a right hand circular polarization image.
5. Enter 0 in both the **Transmit Ellip** and **Receive Ellip** fields and 30 in both the **Orien** fields for both Transmit and Receive.

6. Click the **Add Combination** button. This will produce a linear polarization with an orientation angle of 30 degrees.
7. Click **Clear** under the list of standard polarization combinations to turn off synthesis of the standard polarization bands which have already been generated.
8. Select **Yes** radio button for **Output in dB?**. This will produce images that are in decibels and therefore have values typically between -50 and 0.
9. Enter the output filename `ndv_l2.syn` and click **OK**.

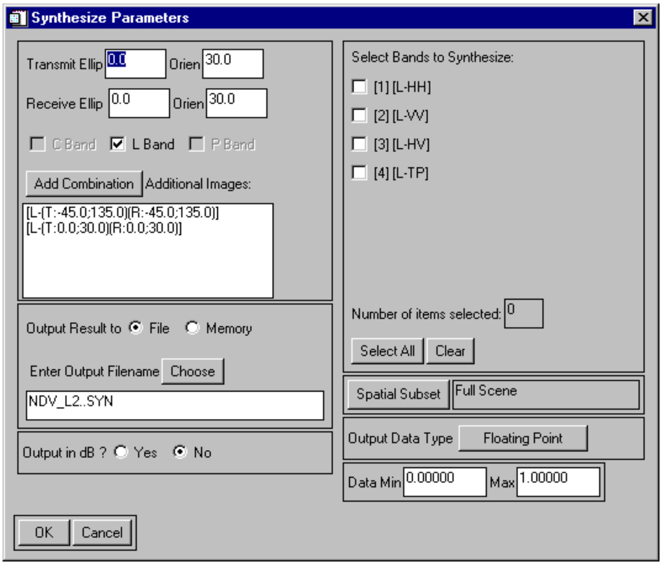


Figure 25-2: Synthesize Parameters Dialog with non-standard orientation and ellipticity angles.

The file `ndv_l2.syn` will be created, and two bands corresponding to the two polarization combinations will be added to the **Available Bands List**.

Display Images

1. Click on the band named [L-TP]: ndv_l.syn in the **Available Bands List**, and click **Load Band**. The SIR-C L-band total power image will be displayed in a new window.

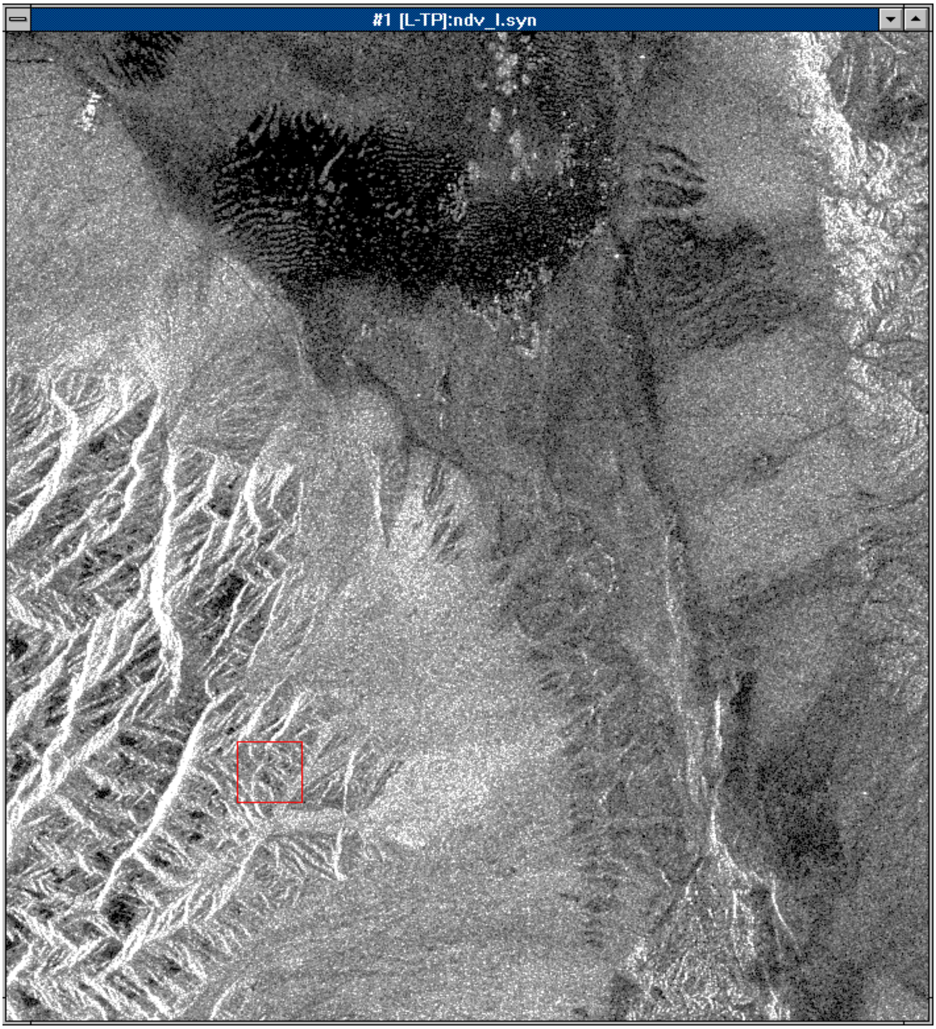


Figure 25-3: L-Band SIR-C Total Power Image with Gaussian stretch applied.

2. Investigate the image using the **Scroll** and **Zoom** windows.

3. Select **Enhance** → **Interactive Stretching** from the Main Image Display window menu bar. A window containing a histogram plot of the data in the image window appears.

   The histogram plot shows the current stretch with (between the vertical dotted lines) on the input histogram and the corresponding DN values in the text boxes.

4. Click the left mouse button on and drag the dotted vertical lines to change the stretch or enter the desired DN values into the appropriate fields.
5. Enter 5% in the left text box in the dialog and enter 95% in the right text box.
6. Select **Stretch Type** → **Gaussian** (initially set to **Linear**) and the stretch will be automatically applied This will perform a gaussian stretch with a 5% low and high cut-off.
7. Also try to compare the linear and square-root stretches.
8. To display a color composite image, select the **RGB Color** radio button in the **Available Bands List**.
9. Click on the [L-HH]: ndv_l.syn, [L-VV]: ndv_l.syn, and [L-HV]: ndv_l.syn bands.
10. Select **New Display** from the **Display** pulldown menu in the **Available Bands List**. to start a new display window.
11. Click **Load RGB** to display the HH band in red, VV in green, and HV in blue.
12. Adjust the stretch as desired (Gaussian and Square Root both work well on all three bands).
13. Display the other synthesized bands as desired.

The color variations in the images are caused by variations in the radar reflectivity of the surfaces. The bright areas in the sand dunes are caused by scattering of the radar waves by vegetation (mesquite bushes). The alluvial fans show variations in surface texture due to age and composition of the rock materials.

Define ROIs for Polarization Signatures

Polarization signatures can be extracted from the SIR-C compressed scattering matrix for a Region of Interest (ROI) or a single pixel in a polarimetric radar image. ROIs are defined by selecting pixels or by drawing lines or polygons within an image.

1. Select **Overlay** → **Region of Interest** in the window containing the grayscale L-TP image. The **ROI Tool** dialog appears.

2. Four ROIs were previously defined and saved for use in extracting polarization signatures for the purposes of this tutorial. Restore the pre-saved ROIs by selecting **File** → **Restore ROIs** and selecting the filename `pol_sig.roi`.

   A dialog box will appear stating that the regions were restored. Click OK.

3. Regions named `veg`, `fan`, `sand`, and `desert pvt` will appear in the **Available Regions of Interest** list box and will be drawn in the image window.

   Regions can be drawn in both the image and zoom windows and can consist of any combination of polygons, lines, and pixels.

   You can also draw your own Regions of Interest using ENVI's standardized ROI tools.

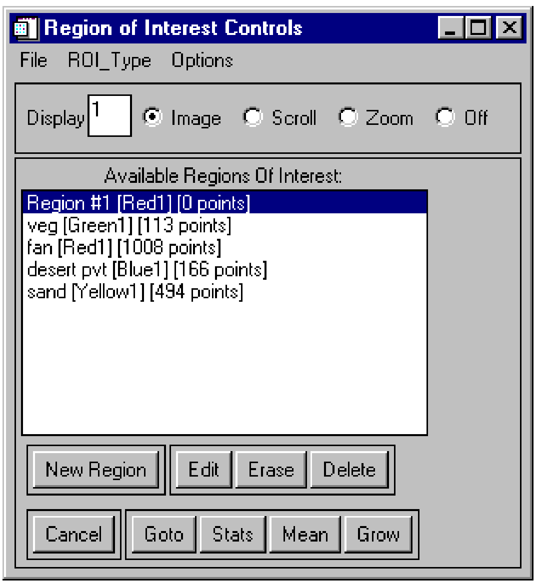


Figure 25-4: Predefined ROIs for Polarization Signatures

4. Select the type of region to draw by clicking in the box next to **ROI_TYPE** → and then **Polygon**, **Polyline**, or **Point**.

   - Draw polygons by clicking the left mouse button to select the endpoints of line segments or holding down the mouse button and moving the cursor for continuous drawing. Click the right mouse button once to close the polygon and a second time to accept the polygon
   - Draw polylines in the same manner as polygons. Click the left mouse button to define the line endpoints and click the right button to end the polyline and again to accept the polyline
   - Point mode is used to select individual pixels. Click the left mouse button to add the pixel currently under the cursor to the ROI.

   Multiple polygons, lines, and pixels may be selected for each ROI.

5. Click **New Region** to define another ROI, enter a name, and choose a color.
6. Draw a second ROI.

ROIs can be saved to a file and restored at a later time by choosing **File** → **Save ROI** in the **ROI Tool** dialog.

Extract Polarization Signatures

Polarization signatures are 3-D representations of the complete radar scattering characteristics of the surface for a pixel or average of pixels. They show the backscatter response at all combinations of transmit and receive polarizations and are represented as either co-polarized or cross-polarized. Co-polarized signatures have the same transmit and receive polarizations. Cross-polarized signatures have orthogonal transmit and receive polarizations. Polarization signatures are extracted from the compressed scattering matrix data using the ROIs for pixel locations. Polarization signatures are displayed in viewer windows; the figure below shows an example.

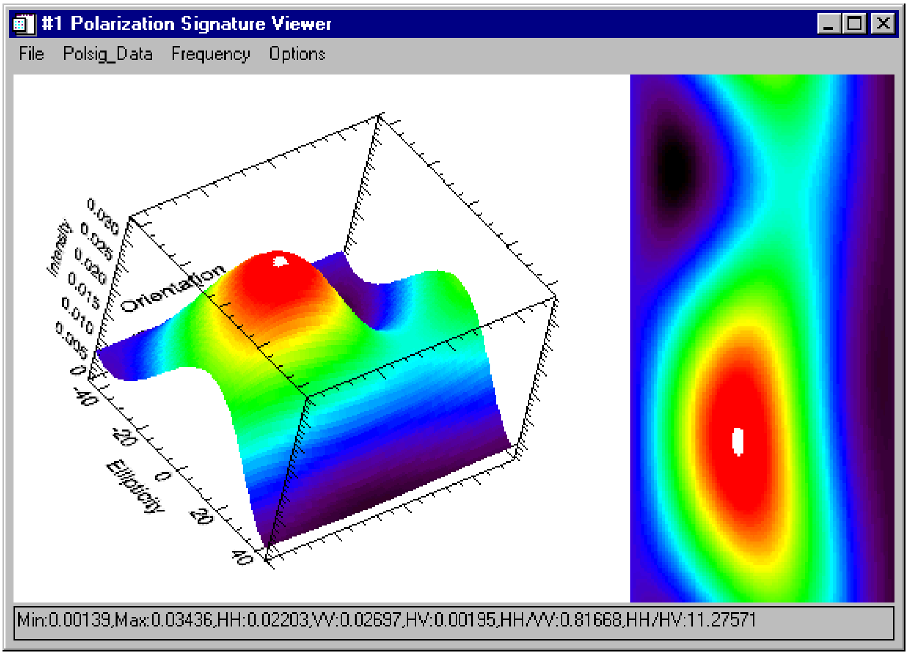


Figure 25-5: Polarization Signature Viewer.

To extract your own polarization signatures:

1. Select **Radar** → **Polarimetric Tools** → **Extract polarization Signatures** → **SIR-C**. The filename `ndv_l.cdp` should appear in the **Input Data Product Files** dialog. If not, click **Open File** and select this file.
2. Click **OK**. The **Polsig Parameters** dialog will appear.
3. Select the four ROIs (`veg`, `fan`, `sand`, and `desert pvt`) by clicking **Select All**.
4. Select the **Memory** radio button and then click **OK**.

   Four Polarization Signature Viewer dialogs will appear, one for each ROI. The polarization signatures are displayed as both 3-D wire mesh surface plots and as 2-D gray scale images.

The X and Y axes represent ellipticity and orientation angles and the vertical axis can be selectively plotted as intensity, normalized intensity, or dB by selecting the desired option from the **Polsig_Data** pulldown menu.

5. Polarization signature statistics are displayed at the bottom of the **Polarization Signature Viewer** window.

   Notice the range of intensity values for the different surfaces. The smoother surfaces — sand and desert pvt — have low Z values. The rough surfaces — fan and veg — have higher Z values. The minimum intensity indicates the "pedestal height" of the polarization signature. The rougher surfaces have more multiple scattering and therefore have higher pedestal heights than the smoother surfaces. The shape of the signature also indicates the scattering characteristics. Signatures with a peak in the middle show a Bragg-type (resonance) scattering mechanism.

6. Change the Z axis by selecting **Polsig_Data** → **Normalized** from the pulldown menu.

   This normalizes the signature by dividing by its maximum and plots it between 0 and 1. This representation shows the difference in pedestal heights and shapes better, but removes the absolute intensity differences.

   Alternately select **Polsig_Data** → **Co-Pol** and **Cross-Pol** to toggle between co-polarized and cross-polarized signatures.

7. Use the left mouse button to drag a 2-D cursor on the polarization signature image on the right side of the plot. Note the corresponding "3-D" Cursor in the polarization plot.

8. Click the left mouse button and drag on one of the axes to rotate the polarization signature in real time.

9. The signatures can be output by selecting **File** → **Save Plot As** in the **Polarization Signature Viewer** window or directly to a printer using **File** → **Print**

10. When you have finished examining the polarization signatures, select **File** → **Cancel** to close the **Polarization Signature Viewer** window.

Use Adaptive Filters

Adaptive filters are used to reduce the speckle noise in a radar image while preserving the texture information. Statistics are calculated for each kernel and used as input into the filter allowing it to adapt to different textures within the image.

1. Select **Radar** → **Adaptive Filters** → **Gamma**. The **Gamma Filter Input File** dialog will appear with a list of open files. The filters can be run on an entire file or an individual band.
2. Click on the arrow toggle button next to the **Select By File** field to toggle to **Select By Band** and list the bands in the files.
3. Select the band `[L-HH]:NDV_L.SYN` and click **OK**. The **Gamma Filter Parameters** dialog will appear.
4. Specify a **Filter Size (NxN)** of 3 and the **Number of Looks** to 1.000 and output the result to memory by selecting the **Memory** radio button.
5. Click **OK**. The resulting image name will appear in the **Available Bands List** as `Gamma ([L-HH]: NDV_L.SYN)`.

Display the Filter Result

1. Select the **Gray Scale** radio button and then select the band name in the **Available Bands List**.
2. Select **New Display**” from the pulldown **Display** button at the bottom of the **Available Bands List** to start a new display window, then click **Load Band**.
3. Select **Enhance** → **[Image] Square Root** in the Main window to perform a Square Root stretch on the image.

   You can use dynamic overlays to compare the results of the Gamma filter to the original image.
4. Display the original band by selecting `[L-HH]: NDV_L.SYN` in the **Available Bands List**, starting a new display and clicking **Load Band**.
5. Perform a quick Square Root stretch on this image as well.
6. Select **Tools** → **Link** → **Link Displays**. The **Link Displays** dialog will appear.
7. Make sure that **Yes** appears only next to the names of the two displays that contain the Gamma filtered and original images and click **OK**.

   Dynamic overlay is activated automatically when the windows are linked.
8. Click the left mouse button in either image to cause a small portion of the second linked image (the overlay) to appear in the first image (the base).

   The overlay is active in both windows simultaneously and in the **Zoom** window.

9. Move the overlay by clicking and holding the left mouse button and moving the cursor.
10. Change the size of the overlay by pressing the middle mouse button and dragging the corner of the overlay to the desired location.
11. Compare the Gamma Filter image to the original data.
12. Turn the dynamic overlay feature off by selecting **Tools** → **Link** → **Unlink Displays** or **Dynamic Overlay Off** in the Main window.

Slant-to-Ground Range Transformation

Slant range radar data have a geometric distortion in the range direction. The true or ground range pixel sizes vary across the range direction because of the changing incidence angles. This geometric distortion is corrected by resampling the slant range data to create ground range pixels that are a fixed size. The slant-to-ground range transformation requires information about the instrument orientation. For SIR-C data, the necessary information is found in the CEOS header.

Preview the CEOS header using **Radar** → **Open/Prepare Radar File** → **View Generic CEOS Header** and selecting the file `ndv_l.cdp`. Scroll down the CEOS Header Report and note that the line spacing (azimuth direction) is 5.2 meters while the pixel spacing (slant range direction) is 13.32 meters. The Slant-to-Ground-Range function will be used to resample the output image to a square 13.32 m pixel, thus removing slant-range geometric distortion.

1. Select **Radar** → **Slant to Ground Range** → **SIR-C**.
2. When the **Enter SIR-C Parameters Filename** dialog appears, select the file `ndv_l.cdp`. The **Slant Range Correction Input File** dialog will appear.
3. Select the file `ndv_l.syn` and click **OK**. The **Slant to Ground Range Correction Dialog** will appear and all of the pertinent information will be filled in from the CEOS header in the `.cdp` file.
4. Enter 13.32 in the **Output pixel size** field to generate square ground-range pixels.
5. Select **Bilinear** as the **Resampling Method**, enter `ndv_gr.img` as the output filename, and click **OK**. The input image is resampled to 1152 13.32m sized square pixels.
6. Display this image and compare it with the slant range image.

Use Texture Analysis

Texture is the measure of the spatial variation in the grey levels in the image as a function of scale. It is calculated within a processing window of user-selected size. The texture measures demonstrated in this tutorial are Occurrence Measures, including Data Range, Mean, Variance, Entropy, and Skewness. These terms are explained in the *ENVI User's Guide* and on-line help. Texture is best calculated for radar data that has not had any resampling or filtering applied.

1. Select **Radar** → **Texture Filters** → **Occurrence Measures**.
2. When the **Texture Input File dialog appears**, click the **Select By** toggle button and select **Band** and then select the band `[L-HH]: ndv_l.syn` and click **OK**.
3. In the **Occurrence Texture Parameters** dialog, deselect all of the **Textures to Compute** except for **Data Range**, change the **Processing Window: Rows** and **Cols** to 7 x 7, enter an output filename `ndv_hh.tex`, and click OK.

   An ENVI Status Window will appear and after a short wait the new band will be listed in the Available Bands List.

Create Color-coded Texture Map

Display the resulting Data Range texture image by clicking on the band name `Data Range:[L-HH]` in the **Available Bands List** and clicking **Load Band**.

1. Perform a quick square root stretch on the image.
2. Select **Tools** → **Color Mapping** → **Density Slice** in the Main Image display.
3. Select the `Data Range:[L-HH]` band in the **Density Slice Band Choice** dialog and click **OK**.
4. In the **Density Slice** dialog, apply the default ranges by clicking on **Apply**. Examine this image with respect to the original data using image linking and dynamic overlays.
5. Now select **Tools** → **Cursor Location/Value** in the Main window and look at the Data Range values while roaming around the image.
6. Try creating your own density sliced image or use the predetermined color-coded density slice TEXTURE.DSR saved for your use by selecting **File** → **Restore Ranges** in the **Density Slice** dialog, selecting the file `texture.dsr` and clicking **Open**, and then **Apply**.

   This density slice shows the various textures in the image in distinct colors.

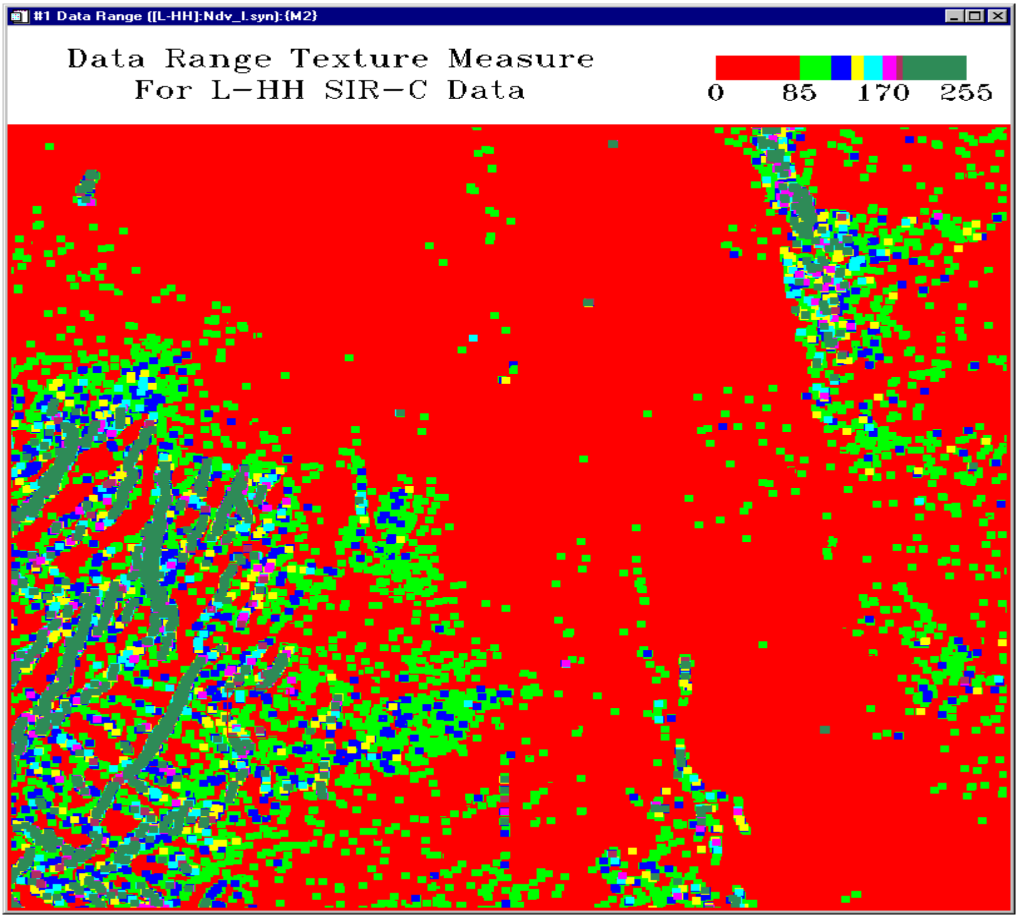
Display and density slice some of the other texture measures and use dynamic overlays to compare to each other and the original data.

Create an Image-Map for Output

1. With the Data Range texture measure displayed, add a border around the image to place a key and text annotation.
2. Select **Overlay** → **Annotation** in the main window.
3. When the **Annotation** dialog appears, select **Options** → **Set Display Borders**.
4. Enter 100 in the upper text box, select a **Border Color** of **White**, and click **OK**. This will make a 100 pixel white border at the top of the image.
5. Position the Main Image indicator box in the Scroll window at the top of the image to display the portion of the image with border.
6. Place a title at the top of the image by entering a title into the text field in the center of the dialog.
7. Enter 16 in the **Size** field to change the font size and change the **Color** to **Black**.
8. Place the title on the image by using the left mouse button to position it and clicking the right button to fix the location.

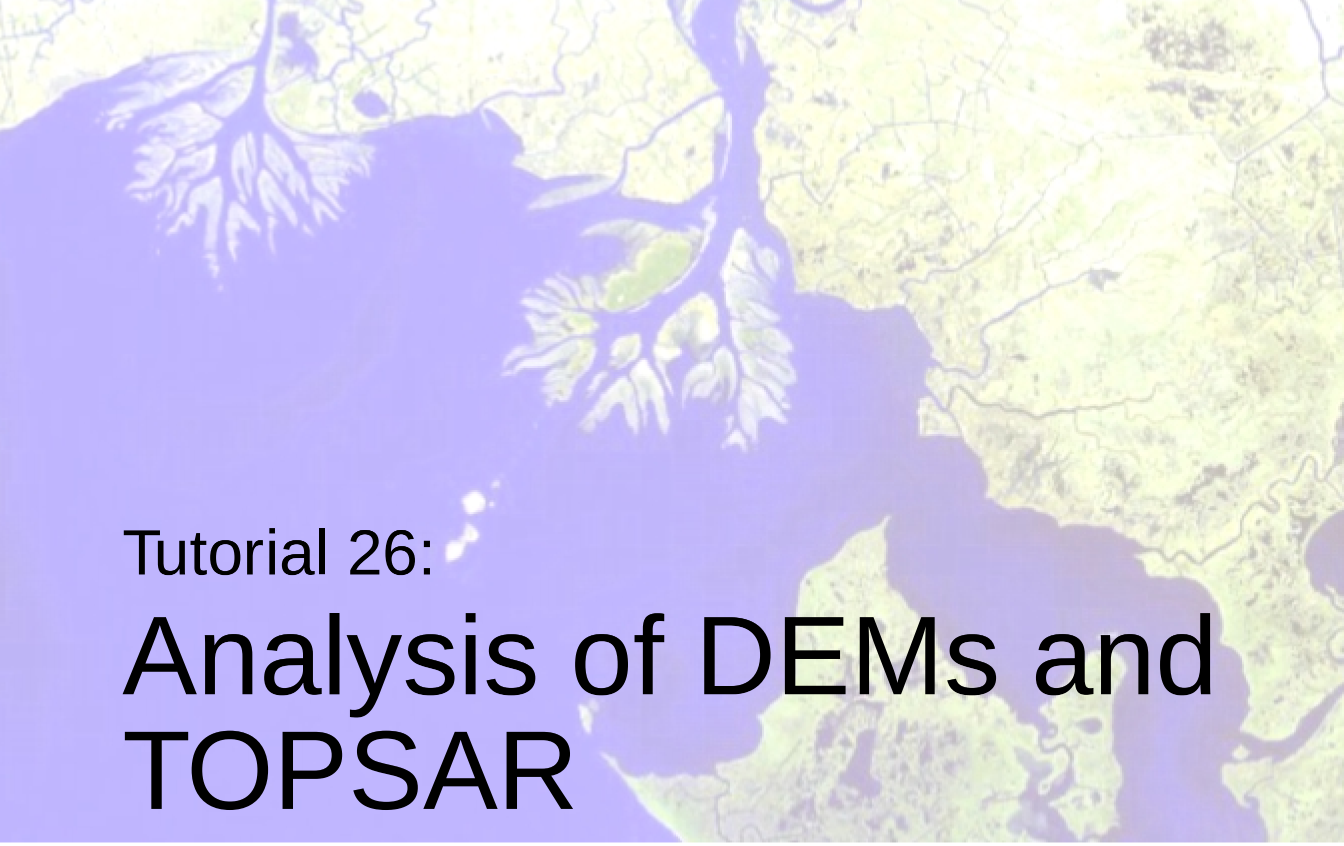
   Multiple text items can be placed on the image in this manner and the font size, type, color, and thickness can be changed.
9. Put a color table ramp in the top border of the image for a color-code key by selecting **Object** → **Color Ramp** in the **Annotation** dialog.
10. Enter **Min** and **Max** values of 0 and 255 respectively, set **Inc** to 4, and the font **Size** to 14 to annotate the color ramp.
11. Position the color ramp using the left mouse button and fix the location by clicking the right mouse button.
12. Add any other objects desired to the image using the annotation dialog.
13. Save the image to a PostScript file by selecting **File** → **Save Image As** → **Postscript File**.
14. Enter an output filename or let the name default to `ndv_hh.ps`. and click OK.

15. Optionally, output directly to your printer by selecting **File** → **Print**.



End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.



Tutorial 26: Analysis of DEMs and TOPSAR

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial uses Polarimetric SAR data and a Digital Elevation Model (DEM) generated from JPL's TOPSAR (interferometric SAR) data for Tarrawarra, Australia. Data Courtesy of JPL. The exercise demonstrates input and display of the SAR data and display and analysis of the DEM using standard tools within ENVI. For the DEM, these include data input; grayscale and color-density-sliced display; generation and overlay of elevation contours, use of ENVI's X, Y, and arbitrary profiles (transects) to generate terrain profiles; generation of slope, aspect, and shaded relief images; and 3-D perspective viewing and image overlay.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/topsar`

File	Description
Required Files	
`ts0218_c.vvi`	C-Band VV-polarization image, integer format. Original name `ts0218_c.vvi2`
`ts0218_c.cor`	C-Band Correlation image: original name `ts0218_c.corgr`
`ts0218_c.dem`	C-Band-Derived, integer-scaled DEM: original name `ts0218_c.demi2`
`ts0218_c.inc`	C-Band incidence angle image: original name `ts0218_c.incgr`
`ts0218_l.dat`	L-Band stokes matrix data
`ts0218_p.dat`	P-Band stokes matrix data
Generated Files	
`ts0218lp.syn`	L- and P-Band Synthesized data
`ts0218lp.hdr`	Generated ENVI Header for above
`ts_cgam.img`	Generated Gamma filtered image
`ts_cgam.hdr`	Generated ENVI Header file for above

File	Description
ts_ped.img	Generated Pedestal Height image
ts_ped.hdr	Generated ENVI Header for above
topsar.img	Generated DEM image scaled to meters, C-VV scaled to Sigma Zero, and incidence angle and correlation images
topsar.hdr	Generated ENVI Header for above

Note

This dataset includes all of the typical files provided by JPL for a TOPSAR distribution tape or CD. Some of the filenames have been changed from JPL's standard naming convention because they would have non-unique ENVI header names using DOS 8.3 filenames, and thus could not be used directly by systems supporting only the DOS convention (Windows 3.1). The original filenames are indicated in the file descriptions.

Background - TOPSAR and DEMs

TOPSAR data are a polarimetric Synthetic Aperture Radar (SAR) dataset generated by an airborne SAR system flown by Jet Propulsion Laboratory (JPL).

Description of the Dataset

The data consist of fully polarimetric (quad polarized) data for both P- and L-band and a C-Band VV-polarization image. The Digital Elevation Model (DEM) provided is generated by JPL using SAR interferometry using the C-Band antenna. Also provided are the correlation image and an incidence angle image generated from the C-band data.

Display and Convert the Data

In this section of the tutorial, you will display the data and convert them to physical parameters. JPL provides several images for display including the C-Band VV, C-Band correlation image, and C-Band Incidence Angle image, which are easily displayed using ENVI TOPSAR routines. The P- and L-Band data are provided as non-viewable Stokes Matrix data and images must be synthesized as described below.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To start ENVI in UNIX, enter `envi` at the UNIX command line.
- To start ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

View the TOPSAR Headers

1. Select **Radar** → **Open/Prepare Radar File** → **View AIRSAR/TOPSAR Header**.

   Note

   Note that on some platforms you must hold the left mouse button down to display the submenus from the Main Menu.

   An **AIRSAR/TOPSAR Input File** selection dialog appears.

2. Navigate to the `topsar` subdirectory of the `envidata` directory on the *ENVI Tutorial and Data CD No. 1* just as you would in any other application and select `ts0218_c.vvi`.

   The **AIRSAR File Information** dialog appears listing information from the embedded AIRSAR Integrated Processor headers.

3. Review the New Header, Parameter Header, and the Calibration Header sections.

4. Repeat the above for the DEM file `ts0218_c.dem`, viewing the New Header, Parameter Header, and the TOPSAR DEM Header, in place of the above Calibration Header.

Load and Display the Raw C-Band image

1. Select **Radar** → **TOPSAR Tools** → **Open TOPSAR File** and choose the file `ts0218_c.vvi`.

   This opens the TOPSAR C-Band data and displays without converting the data to physical units (Sigma Zero), utilizing the embedded AIRSAR/TOPSAR header to get the required file information. This also loads the image into the **Available Bands List**.

   Note

   This file can also be opened from **File** → **Open External File** → **Radar** → **TOPSAR**. You could also open this file using the generic file opening procedure, **File** → **Open Image File**, but you would have to manually enter the file parameters.

2. Make sure that the **Gray Scale** radio button is selected, choose the image at the top of the dialog, and click on **Load Band** to load the image.
3. Examine the geometry and characteristics of the image. Start the **Cursor Location/Value** dialog by selecting **Tools** → **Cursor Location/Value** from the Main Image Display menu bar.

   This is a ground-range C-Band VV-polarization image scaled to integer format. A scaling factor must be applied to the data to convert to Sigma Zero (radar backscatter coefficient).
4. Review the image pixel values, observing the general magnitude of the numbers (integer values).

Load and Display the Raw DEM image

1. Select **Radar** → **TOPSAR Tools** → **Open TOPSAR File** and choose the file `ts0218_c.dem`.

   This opens the TOPSAR DEM data, utilizing the embedded AIRSAR/TOPSAR header to get the required file information and loads the image into the **Available Bands List**. You could also open this file using **File** → **Open Image File**, but you would have to manually enter the file parameters.

2. Display the image by clicking on the band name in the **Available Bands List**, select **New Display** and then on **Load Band**. Select **Tools** → **Cursor Location/Value** and review the image pixel values, observing the general magnitude of the numbers (integer values).

   The image displayed is in RAW Digital Number, as stored in the DEM file.

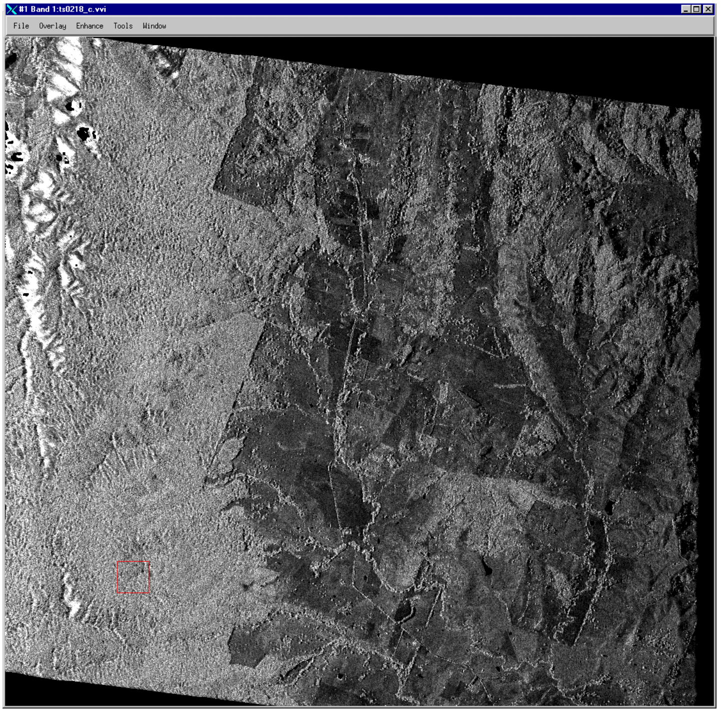


Figure 26-1: TOPSAR C-Band VV Image.

3. Select **Tools** → **Link** → **Link Displays** and use ENVI's dynamic overlay capabilities to compare the two images.

Convert the C-Band Data to Sigma Zero and DEM to Meters

1. Select **Radar** → **TOPSAR Tools** → **Convert TOPSAR Data** and choose the file `ts0218_c.vvi`. This opens the **TOPSAR Conversion Parameters** dialog. ENVI automatically identifies all of the TOPSAR data present in this dataset based on the TOPSAR file naming convention. The VV Polarization, Correlation, Incidence Angle, and DEM images will be opened. The C-VV

data will automatically be converted to Sigma Zero and the DEM to meters based upon values present in the TOPSAR headers.

2. Subset the number of lines in the **TOPSAR Conversion Parameters** dialog to 1061 by clicking on the **Spatial Subset** button and changing the **To** parameter for **Line** from the ending line value of 1140 to `1061`. This will match the size of the C-band data and DEM to the P- and L-band data. Click **OK**.
3. Enter the output filename `topsar.img` and click **OK** to start the conversion. The four images are placed in the **Available Bands List**.
4. Display the C-VV Sigma Zero image by clicking on the VV Polarization band name in the **Available Bands List**, selecting a **New Display**, and then clicking on **Load Band**. Select **Tools** → **Cursor Location/Value** and review the image pixel values, observing the general magnitude of the numbers (Sigma Zero).
5. Select **Tools** → **Link** → **Link Displays** and use ENVI's dynamic overlay capabilities to compare the two C-VV images (Raw vs Sigma Zero).
6. Display the DEM (meters) image by clicking on the DEM (m) band name in the **Available Bands List**, selecting a **New Display**, and then clicking **Load Band**. From the Display menu in the Main Image window, select **Tools** → **Cursor Location/Value** and review the image pixel values, observing the general magnitude of the numbers (Elevation in meters).

   Note the large negative number (approximately -2911) associated with holes in the DEM and the image border. These are not valid elevations and these areas should be excluded from analysis using ENVI's masking functions.

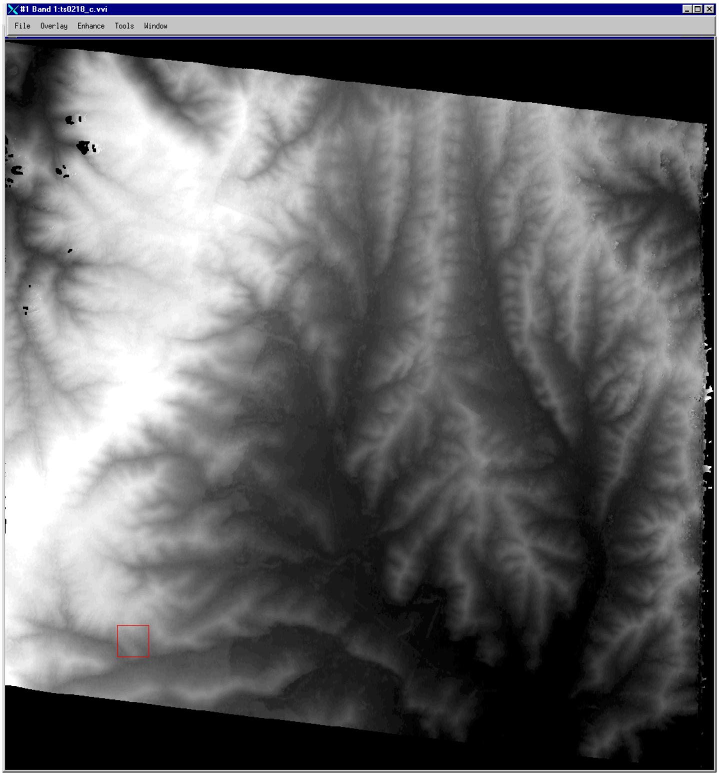


Figure 26-2: TOPSAR DEM Image

7. Select **Tools** → **Link** → **Link Displays** and use ENVI's dynamic overlay capabilities to compare the two DEM images (Raw vs Elevation in meters).

Synthesizing the P- and L-band Data

Both the L-Band and P-Band data are distributed by JPL in compressed Stokes Matrix format. These data can not be displayed directly by most image processing systems. ENVI provides utilities to decompress the data and synthesize to image format.

1. Select **Radar** → **Open/Prepare Radar File** → **Synthesize AIRSAR Data** from the ENVI main menu.

2. Click on **Open File** in the **Input Stokes Matrix Files** dialog, select the file `ts0218_l.dat` in the **Enter Compressed Stokes Matrix Filename** dialog. Both the L and P band Stokes Matrix file names will be entered into the dialog.

3. Click **OK** to open the **Synthesize Parameters** dialog. The “standard” polarization bands, L-HH, L-VV, L-HV, L-TP (total power), P-HH, P-VV, P-HV, and P-TP (total power) are automatically entered into the dialog.

   If additional polarizations are desired, enter the Transmit and Receive Ellipticity and Orientation angles into the appropriate text boxes in the upper left part of the dialog and click on **Add Combination**.

4. Select **Byte** as the **Output Data Type** from the pull-down menu originally labeled **Floating Point**, enter the output filename `ts0218lp.syn` with its correct path, and click **OK** to synthesize the images.

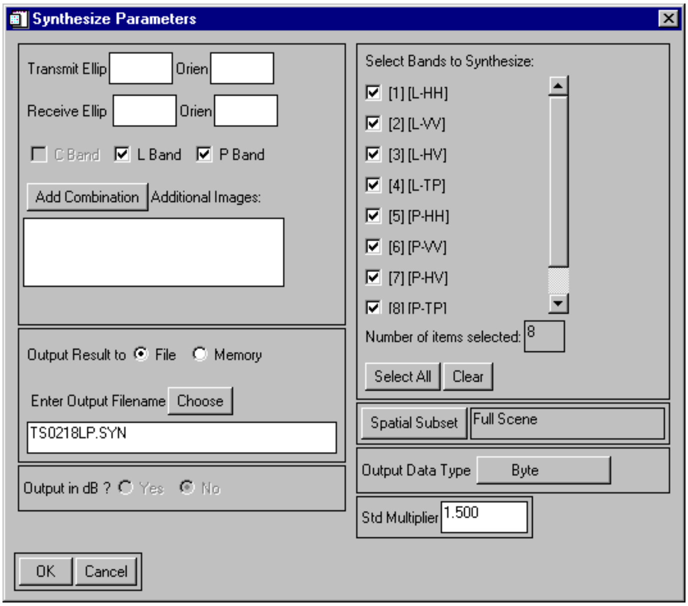


Figure 26-3: Synthesize Parameters Dialog

5. Select one or more of the synthesized bands to display as a gray scale or an RGB image using the **Available Bands List**, and display the image in a **New Display**.

6. Compare the L-Band and C-Band VV data to the C-Band VV data using image linking and dynamic overlays.

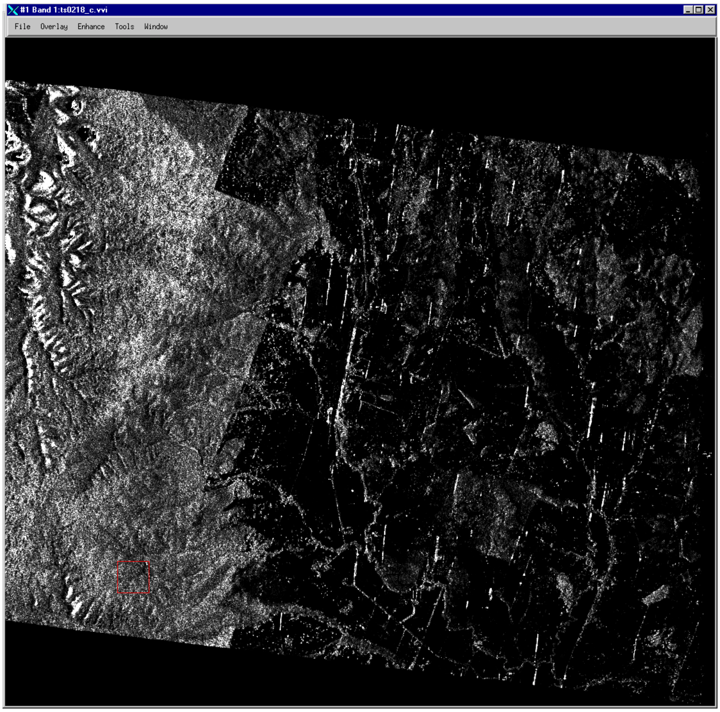


Figure 26-4: TOPSAR P-Band VV Image

Analysis of JPL Polarimetric SAR Data

This section of the tutorial describes some of the analysis options for general analysis of SAR data as well as selected polarimetric analysis capabilities. For additional SAR processing information see the *ENVI 3.5 User's Guide*.

General Concepts for processing SAR with ENVI

Most standard ENVI processing functions are inherently radar capable including all display capabilities, stretching, color manipulations, classification, registration, filters, geometric rectification, etc. Specific Radar menu items are also included under the Radar menu for specific ENVI routines that are particularly useful for radar processing. Many of these can also be accessed from their functional areas on the ENVI main menu. ENVI provides standard and advanced tools for analysis of detected radar images as well as advanced SAR systems such as JPL's fully polarimetric AIRSAR and SIR-C systems. ENVI can process ERS-1/ERS-2, JERS-1, RADARSAT, SIR-C, X-SAR, and AIRSAR data as well as any other detected SAR data set. In addition, ENVI is designed to handle radar data distributed in the CEOS format, and should be able to handle data from other radar systems that distribute their data in this format.

Remove Speckle using Adaptive Filters

Adaptive filters provide a means of removing radar speckle from images without seriously affecting the spatial characteristics of the data. The Gamma Filter and other adaptive filters provide considerable improvement over the unfiltered data. To perform the Gamma Filter on the AIRSAR data:

1. Select **Radar** → **Adaptive Filters** → **Gamma**, and select the input image `ts0218_c.vvi`. Click **OK**. This opens the **Gamma Filter Parameters** dialog.

2. Use the default filter size (3) and Number of Looks (1.000). Enter the output filename `ts_cgam.img`, and click **OK**.

Edge Enhancement

A Laplacian Filter can be used to enhance edges in SAR data and other data types. This is a convolution filter with a kernel (for a 5 x 5 filter) of:

0	0	-1	0	0
0	-1	-2	-1	0
-1	-2	16	-2	-1
0	-1	-2	-1	0
0	0	-1	0	0

Of course, applying the kernel in this fashion strongly enhances the edges and causes loss of most of the radiometric information.

1. From the ENVI main menu, select **Filter** → **Convolutions**. Then select **Convolutions** → **Laplacian**. Enter a kernel size of 5x5. To avoid loss of the radiometric information, select to add back part of the original image as follows.
2. Apply add-back to a filtered image, enter a percentage of the original image to to added back (between 0 and 100%) in the **Convolution and Morphology Tool**. Click **Quick Apply** and select Band 1 of the `ts0218_c.vii` image. This displays the image in a new Display window. If desired, change the **Image Add Back** value and redisplay.

Compare Images using Linked Images and Dynamic Overlay

Compare images generated above to each other and the original data using ENVI's dynamic overlay capabilities. To compare the images using Dynamic Overlay:

1. Display the two images in separate displays and contrast stretch as described above.
2. Select **Tools** → **Link** → **Link Displays**.
3. Select the appropriate display numbers and click **OK** to link the two images. Compare them by dragging the dynamic overlay with the left mouse button.

Polarimetric Analysis

ENVI provides a full suite of tools for analyzing Polarimetric SAR data. These include generation and display of specific polarization images, a phase image, and pedestal height image as well as extraction of polarization signatures and generation of a scattering classification image.

Display Multifrequency, Polarimetric SAR Images

The synthesized images produced above form the basis for image analysis of polarimetric data.

1. Display one of the synthesized images by selecting the [L-HH] band of `ts0218lp.syn` in the **Available Bands List** and clicking on **Load Band**.
2. Start an animation by choosing **Tools** → **Animation** from the Image Display menu. In the Animation Input Parameters dialog, hold down the **Ctrl** key and click on the two total power image ([L-TP] and [P-TP]) to deselect them. Click **OK** to start the animation. Observe the different frequencies and polarizations and compare the SAR response for various materials to determine a 3-band combination that will maximize spectral contrast.
3. When finished, select **File** → **Cancel** to end the animation.
4. Load a multifrequency, multipolarization AIRSAR image into the display as an RGB image using your selected bands from above, or load the P-HH, L-HH, and the C-VV image as RGB and observe the color differences associated with various materials. Experiment with different contrast stretches using both the Main Display and the Zoom windows to maximize color differences in the image.

Examine Polarization Signatures

Polarization signatures are 3D representations of the complete scattering characteristics for a single pixel or ROI in terms of the orientation angle and ellipticity angle of the transmitted and received radar waves. These signatures can be used to observe the scattering characteristics of materials and surfaces and to determine what polarization images to generate to maximize image contrast between materials as viewed in the SAR data.

1. Position the cursor over an area that appeared to change significantly in the animation by clicking at the desired location in the Main Image Display window using the left mouse button.
2. Choose **Tools** → **Polarization Signatures** → **AIRSAR**, click on the **Open File** button, and choose the L-Band Stokes Matrix data `ts0218_l.dat.`Both the L-Band and P-Band Stokes Matrix filenames will be entered into the **Input Stokes Matrix Files** dialog. Click **OK** to start the Polarization Signature Viewer window.

3. Choose **Options** → **Extract Current Pixel** to extract an L-Band polarization signature for the current pixel. Choose **Frequency** → [ ]**P** to display the corresponding P-Band polarization signature. Select the **Polsig_Data** menu item to see the different surface plotting options. Select **Polsig_Data** → **Cross-Pol** to display and compare the cross-polarized signature.
4. Click and drag using the left mouse button in the image on the right side of the plot to display the interactive 2D, 3D cursor. Read the cursor values in the lower left corner of the plot. Observe the maximum contrast orientation and ellipticity angles in the plot and optionally synthesize and display an image with these parameters as described above.
5. Click on one of the polsig plot axes and drag to rotate the 3-D polsig in real time.
6. Select **File** → **Cancel** to exit the function.

Pedestal Height Image

1. Generate a pedestal height image for the AIRSAR data by choosing **Radar** → **Polarimetric Tools** → **Pedestal Height Image** → **AIRSAR**, clicking **OK** in the **Input Stokes Matrix Files** dialog, entering the output filename `ts_ped.img` and clicking **OK**.
2. Display the image by clicking on the band name in the **Available Bands List** and clicking on **Load Band**.

   This image provides a measure of the amount of multiple scatter of the radar wave for every pixel by averaging the following four polarization combinations:

   - Orientation 0 degrees, Ellipticity -45 degrees
   - Orientation 90 degrees, Ellipticity -45 degrees
   - Orientation 0 degrees, Ellipticity 45 degrees
   - Orientation 90 degrees, Ellipticity 45 degrees.

   A higher pedestal height value in the image indicates greater multiple scattering, generally a rougher surface.
3. Select **Tools** → **Cursor Location/Value** from the Main Image Display menu bar to start the Cursor Location/Value window and examine the pedestal height values for this image.

Displaying and Analyzing DEMs

This portion of the tutorial describes ENVI's tools for processing and analyzing Digital Elevation Models. While this tutorial refers specifically to the TOPSAR DEM, all of these methods and tools are fully applicable to any DEM data set.

Display the DEM Converted to Meters

1. If not already displayed, display the band DEM (m) from the generated file `topsar.img` (created using the steps described in the section "Convert the C-Band Data to Sigma Zero and DEM to Meters" on page 546).
2. Select **Tools** → **Cursor Location/Value** and examine the pixel values of the DEM.

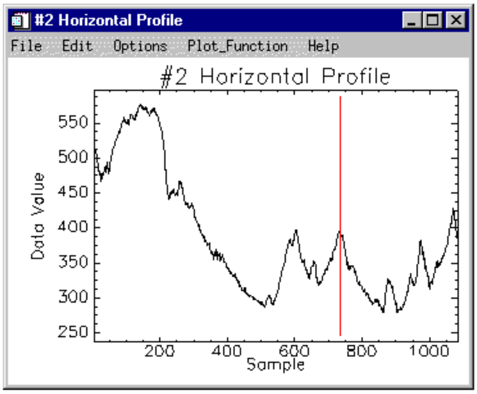
This DEM has had a scaling function applied to convert these data to physical parameters; the elevation in meters. The formula for this conversion is on page 21 of the AIRSAR Integrated Processor Documentation, version 0.01, May 1995. The required information for this conversion is obtained from the TOPSAR DEM header, in this case, consisting of an ELEVATION INCREMENT of 0.1 and the ELEVATION OFFSET of 365.6. Also note that after this conversion, bad pixels (borders, radar shadows in the DEM, etc.) will have the value -2911.099. You probably will want to generate a mask for these areas using ENVI masking capabilities to set these values to zero (see the *ENVI 3.5 User's Guide* for details).

X and Y Elevation Profiles

ENVI provides tools for extracting elevation profiles along either the X or Y directions.

1. From the DEM (m) image display menu, select **Tools** → **Profiles** → **X Profile** and then **Tools** → **Profiles** → **Y Profile** to extract the profiles for the two directions.

Move these two plots off to the side of the DEM (m) image display so you can see them while moving the cursor in the display.



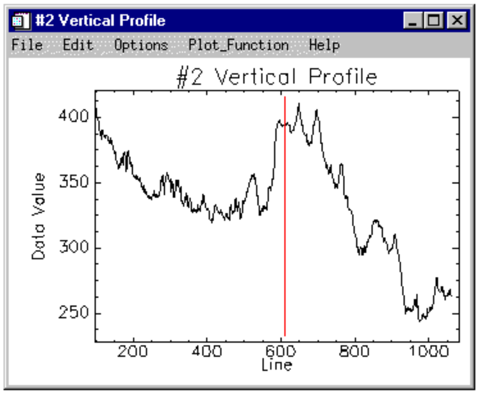


Figure 26-5: TOPSAR Horizontal and Vertical DEM Topographic Profiles

2. Click and drag using the left mouse button in the image display window to generate new elevation profiles when the left mouse button is released. The position of the red bar in the X and Y profiles marks the position of the center of the Zoom window along the profile. Click and drag in the Zoom window using the left mouse button for continuous updating.
3. Close the two profiles by choosing **File** → **Cancel** from each plot window.

Arbitrary Elevation Transect

ENVI also allows extraction of elevation profiles along multiple arbitrary transects.

1. Select **Tools** → **Profiles** → **Arbitrary Profile (Transect)** to extract a profile along an arbitrary transect.
2. Click using the left mouse button in the Main Display Window to draw each segment of the desired transect. You can hold down the left mouse button and draw if desired.
3. Click the right mouse button once to close the last line segment and a second time to extract the profile. Draw one or more profiles using the Arbitrary Profile tool. Each additional profile will be assigned a new color and number.

Note

Profiles can also be drawn in the Scroll or Zoom windows by selecting the appropriate window in the Spatial Profile Tool dialog.

ENVI's standard plot controls can be used to read the elevation off of the plot.

4. Click the left mouse button in the Plot window and drag along the profile. The Zoom Window tracks the profile in the Main Image Display.
5. Zoom in on portions of the plot using the middle mouse button to draw a box and zoom back out by clicking the middle mouse button below the plot axis.
6. Close the profiles by selecting **File** → **Cancel** in the **Spatial Profile Tool** dialog.

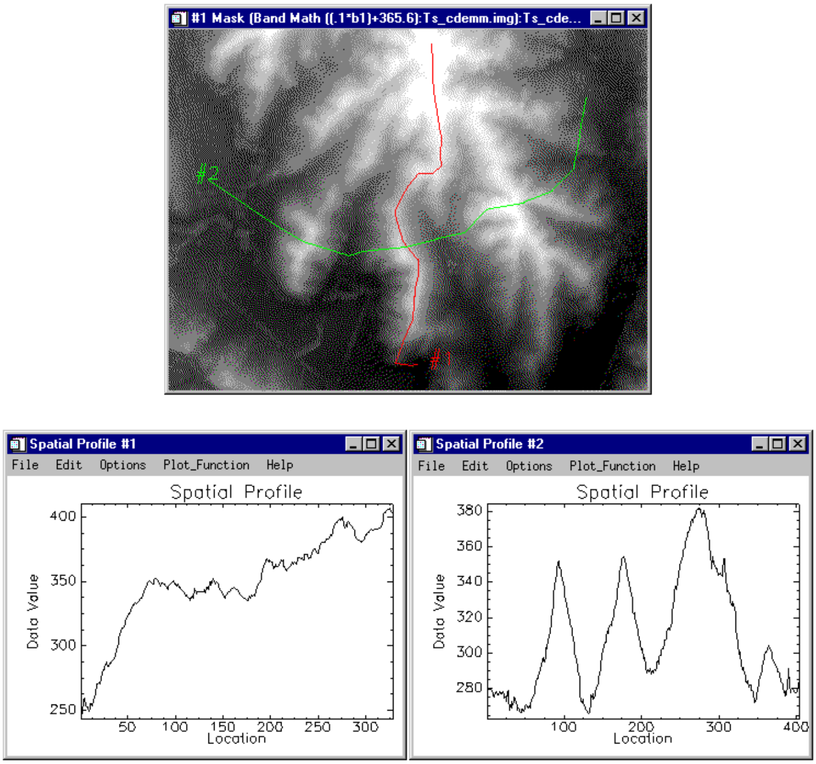


Figure 26-6: TOPSAR DEM Arbitrary Transects (top) and Profiles (bottom)

Color Density Slice the DEM

Density slicing provides a means of visually enhancing radar differences based on image brightness.

1. Select **Tools** → **Color Mapping** → **Density Slice** in the Main Image display containing the DEM in meters. Choose the DEM file data and click **OK**.
2. Click **Clear Ranges** in the **Density Slice** dialog to clear the default ranges (necessary because of the holes and mask values).
3. Enter the value `0` in the **Min** text box. Select **Options** → **Add New Ranges** to open the **Add Density Slice Ranges** dialog.
4. Enter `0.0` for the **Range Start**, `700.00` for the **Range End**, and `10` for **# of Ranges**, then click **OK**. Click **Apply** in the **Density Slice** dialog to density slice the image.
5. Load the gray scale DEM into a second image by clicking on the band name, selecting a **New Display** and **Load Band** in the **Available Bands List**.
6. Use Dynamic Overlays to compare to the gray scale density sliced images.

Overlay of Elevation Contours

ENVI can generate elevation contours from the DEM data and overlay either on the DEM itself, or on another co-registered image.

1. If the DEM image is still displayed, and the Color Density Slice is turned on, turn it off by selecting **File** → **Cancel** in the **Density Slice** dialog. If the DEM is not displayed, display the DEM (m) band as a gray scale image by clicking on the band name for the meters DEM in the **Available Bands List** followed by **Load Band**.
2. Choose **Overlay** → **Contour Lines** in the Main Image Display window and choose DEM (m) as the input contour band.
3. Click on **Clear Levels** in the **Contour Plot** dialog, enter `0.0` in the **Min** text box, and choose **Options** → **Add New Levels**. Enter `0` for the **Level Start**, `50` for the level increment, and `15` for the number of levels, then click **OK**.
4. Click **Apply** in the **Contour Plot** dialog to plot the DEM contours on the DEM image. Examine the relation between contour lines and image brightness.

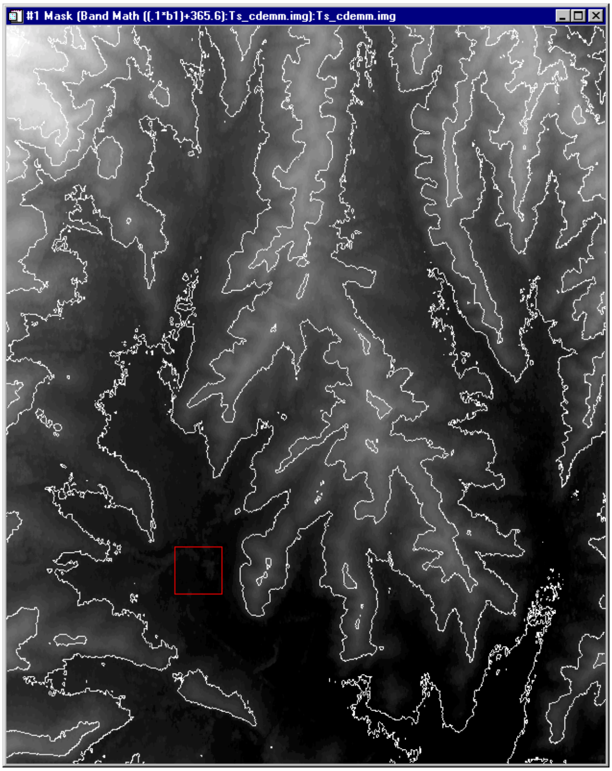


Figure 26-7: TOPSAR DEM with Generated Elevation Contours

5. Now display one of the synthesized images by selecting the [L-HH] band of `ts0218lp.syn` in the **Available Bands List** and clicking on **Load Band**.

   The contour lines will be overlain on the SAR band data.

6. Select **File** → **Cancel** from the **Contour Plot** dialog to remove the contour lines.

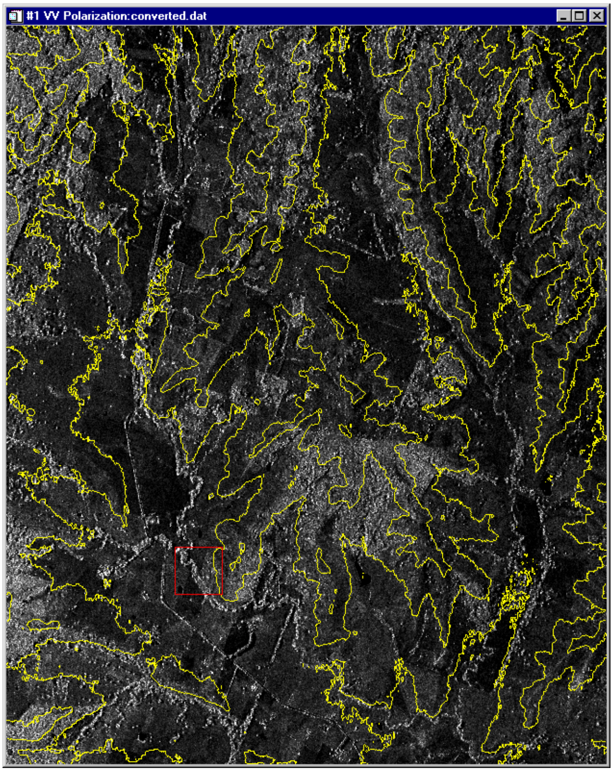


Figure 26-8: TOPSAR C-Band Data with DEM-Generated Elevation Contours

Basic 3-D Perspective Viewing and Image Overlay

ENVI can generate interactive 3-D perspective views from DEM data and also overlay co-registered image data (Note: this requires that your display be set for at least 32k colors). TOPSAR provides the ideal data for this procedure because the standard dataset includes registered DEM and SAR data.

1. To start this option, display either the DEM or the image to be overlain on the 3-D SurfaceView. Redisplay the meters DEM image DEM (m) by clicking on the band name and then the **Load Band** button in the **Available Band List** and/or redisplay the L-HH SAR band by clicking on the band name, selecting **New Display**, and then **Load Band** at the bottom of the **Available Band List**.

2. Select **Topographic** → **3D SurfaceView** from the ENVI main menu to start the 3-D SurfaceView function and choose the display to use for the overlain image. Choose the display containing the DEM (m) image.
3. Choose the TOPSAR DEM image as the associated DEM input file and click **OK**.
4. In the **3D SurfaceView Input Parameters** dialog, Enter a value of `0` into the **DEM min plot value text box**, change the vertical exaggeration to `20`, the image resolution to **Full**, and click **OK**.
5. The 3-D perspective will be displayed with a gray-scale overlay. A wire-mesh can be displayed by selecting **Surface** → **Wire** in the **3D SurfaceView** window. The left mouse button controls image rotation, the middle mouse button panning, and the right mouse button zooming.

See the 3D SurfaceView and Fly-through tutorial or *ENVI 3.5 User's Guide* for additional details on how to run this function.

Generation of Slope, Aspect, and Shaded Relief

ENVI provides tools for processing DEMs to extract parametric information including slope and aspect, and to generate lambertian (shaded relief) surfaces. A plane is fit to a 3-pixel by 3-pixel box centered over each pixel and the slope and aspect of the plane calculated. The slope is measured in degrees, from 0 to 90. Aspect angle is measured with 0 degrees to the north with increasing angles in a clockwise direction. A root mean square (rms) error image is also generated indicating the planarity of the 9 pixel box.

1. Select **Topographic** → **Topographic Modeling** from the ENVI main menu. Click on the meters DEM band name DEM (m) in the **Topo Model Input DEM** dialog and click **OK**.
2. Click on the **Compute Sun Elevation and Azimuth** button in the **Topo Model Parameters** dialog and select November 11, 1996, 12:00:00 hours as the time and enter -37 degrees, 21 minutes, 0 seconds and 145 degrees 17 minutes, 0 seconds respectively for the latitude and longitude. Click **OK** to return to the **Topo Model Parameters** dialog.
3. Enter a X and Y pixel size of `10` meters, and the output filename `ts_model.img` and click **OK** to generate the slope, aspect, shaded relief, and RMS images.

4. Click sequentially on each of the band names in the new image, start a **New Display**, and then **Load Band** to display the parameter images in separate image windows. Use ENVI's dynamic overlays and the **Cursor Location/Value** dialog to examine the relations between the DEM and the parameter images.

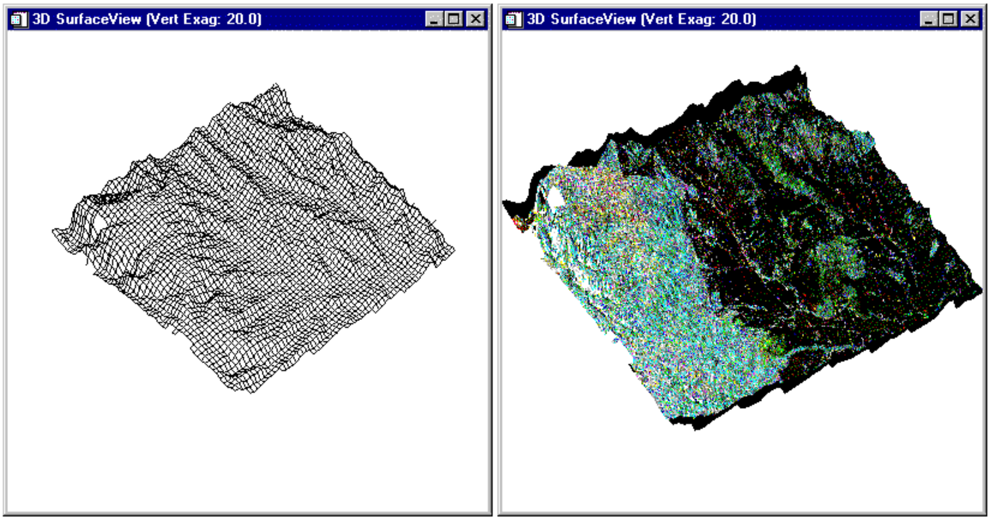


Figure 26-9: Wire-Mesh Perspective View of TOPSAR DEM (left), and L-HH, LHV, PHV Data Draped on TOPSAR-generated Perspective View (right)

Image-Map Output

The final output from any image processing within ENVI is usually a map-oriented, scaled image-map for presentation or visual analysis and interpretation. Radar data can be used in map composition like any other data set. The TOPSAR data are inherently map-registered, so creating an output map is simply a matter of adding all of the standard map composition elements such as pixel, map, and geographic (latitude/longitude) grids; scale-bars; declination diagrams and north arrows; text and symbols; polygons, polylines, and geometric shapes (circles, rectangles); map keys and legends; and image insets.

For additional information on map composition, see the Map Composition tutorial or the *ENVI 3.5 User's Guide*. An example of a TOPSAR map composition is shown below.

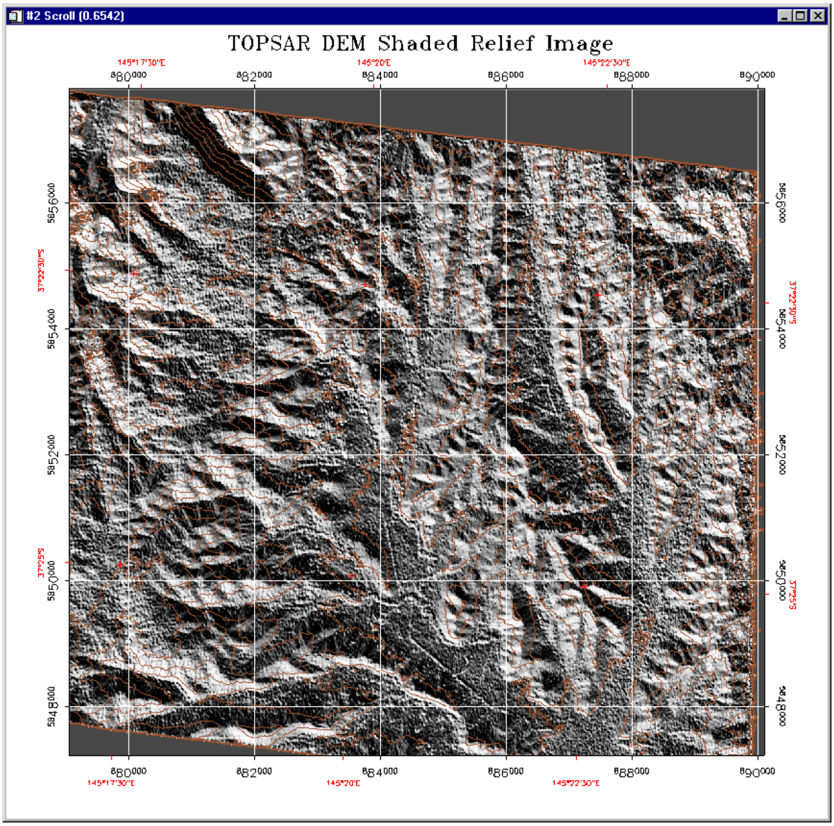


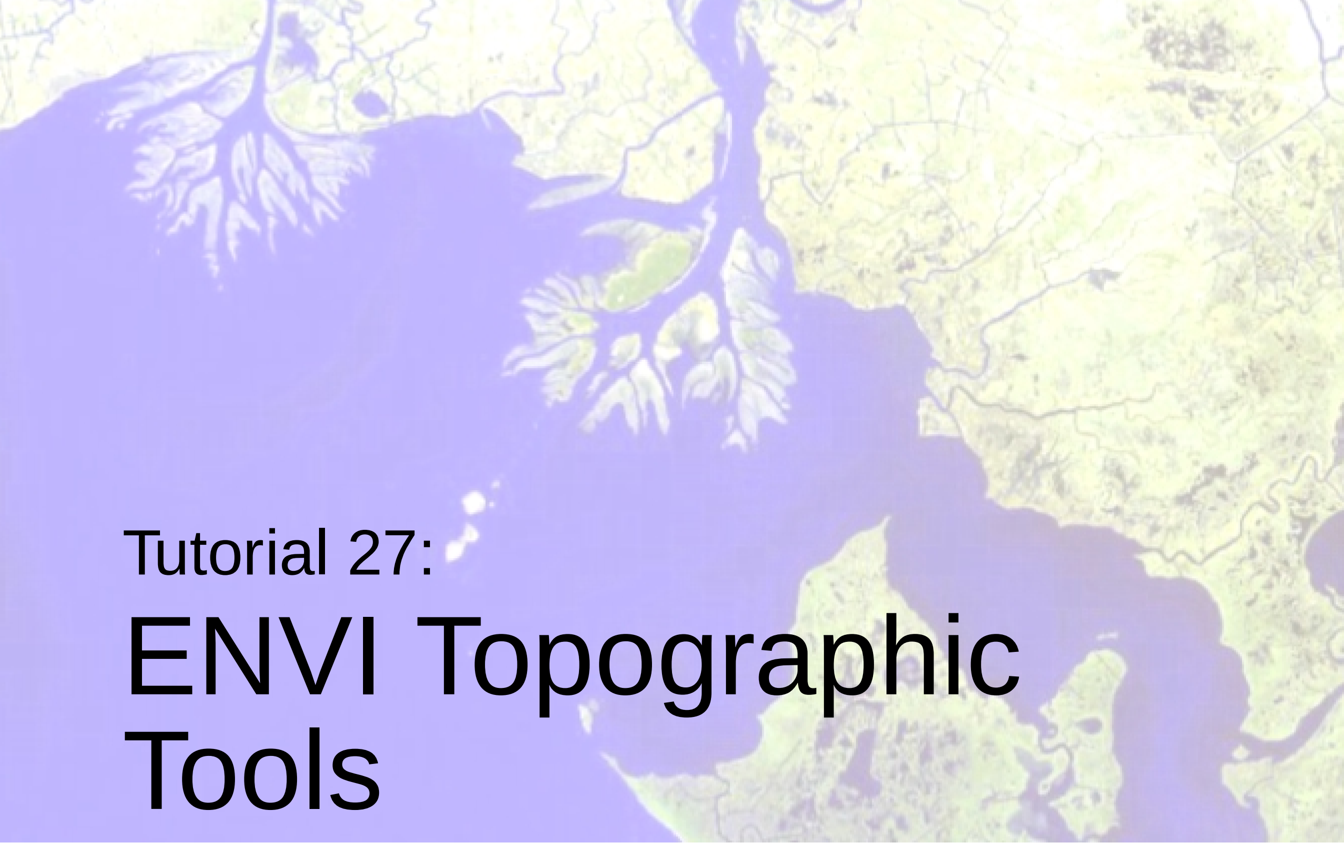
Figure 26-10: TOPSAR Shaded Relief Image with Map and Geographic Coordinates Superimposed.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **Yes** to end the session. If you are using ENVI RT, quitting ENVI will take you back to your operating system.

Summary

ENVI provides tools for end-to-end polarimetric SAR processing as well as a suite of tools for working with standard DEMs and DEMS generated from interferometric SAR data. These are fully integrated into the ENVI processing environment and may be utilized along with other non-SAR-specific routines to provide optimized analysis and map output.



Tutorial 27: ENVI Topographic Tools

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to give you a working knowledge of ENVI's Topographic Analysis Tools. Data provided include processed TM data and a 25m DEM of an area in the Austrian Alps. Selected tools reviewed include grayscale and color-density-sliced display; generation and overlay of elevation contours, use of ENVI's X, Y, and arbitrary profiles (transects) to generate terrain profiles; generation of slope, aspect, and shaded relief images; extraction of Topographic Feature Parameters (peak, ridge, pass, plane, channel, pit), and 3-D perspective viewing and image overlay.

The TM image used is Landsat 5 acquired 21-Mar-87 (192-27). The scene is centered on the “Hohe Tauern” area just south of Salzburg, Austria. The river Salzach runs from W-E. The town of “Zell am See” lies near the distinctive cross of 2 valleys. This is a “pseudo-true color” image made from a combination of VNIR bands. Data Courtesy of Research Systems International Ltd, UK, Digital Elevation Data © Eastern Geo Ltd 1999, Distributed by NPA Group, Edenbridge, Kent, UK, Tel: +44 1732 865023.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/alptmdem`

File	Description
`alps_tm.img`	Landsat TM data, Swiss Alps
`alps_tm.hdr`	ENVI Header for above
`alps_dem25m.img`	25m spatial resolution digital elevation model (DEM)
`alps_dem25m.hdr`	ENVI header for above

Note

The files listed are required to run this exercise. You should also be able to produce similar results with their own coregistered image and digital elevation model (DEM) data.

ENVI Topographic Tools

ENVI provides general tools that can be used for analysis of topographic data. These include image display; color slicing; image contouring; X, Y, and arbitrary profiles; and Georeferenced Cursor Location/Value. A variety of DEM-specific tools are also provided for processing digital elevation data (DEM) to generate geomorphic measures. These include Slope, Aspect, Shaded Relief, Profile Convexity, Plan Convexity, Longitudinal Convexity, Cross Sectional Convexity, Minimum Curvature, Maximum Curvature, and RMS Error. Other Topographic feature parameters that can be calculated include Peak, Ridge, Pass, Plane, Channel, and Pit. Finally, ENVI provides 3-D visualization and analysis tools (the ENVI 3-D SurfaceView). For additional details about ENVI's Topographic Tools, please see the *ENVI 3.5 User's Guide* or ENVI On-Line-Help.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in UNIX, enter `ENVI` at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Select and Display the DEM

Display Grayscale Image

1. Select **File** → **Open Image File**.

   An **Enter Data Filenames** file selection dialog appears.

2. Select the DEM `alps_dem25m.img` from the list and click **Open**.
3. First select the gray scale display option by clicking on the **Gray Scale** radio button in the **Available Bands List**.
4. Select the DEM band name in the dialog by clicking on the name in the **Available Bands List** with the left mouse button.

   The band you have chosen is displayed in the field marked **Selected Band:**.

5. Click on the **Load Band** button in the **Available Bands List** to load the image into a new display. Open, load, and display the `alps_tm.img` TM data in a second display.
6. Double-click in the image to start ENVI’s **Cursor Location/Value** dialog and browse spatially to familiarize yourself with the data (elevation values are meters).

Color-Code the DEM

- Select **Tools** → **Color Mapping** → **ENVI Color Tables** from the Main Image window, scroll to the bottom of the list of **Color Tables:**, and select `Rainbow + White`. The DEM will be color coded from black, purple, blue, green yellow, red, to white (low elevation to high elevation). Try applying various available color tables and select one that best shows the elevation differences.

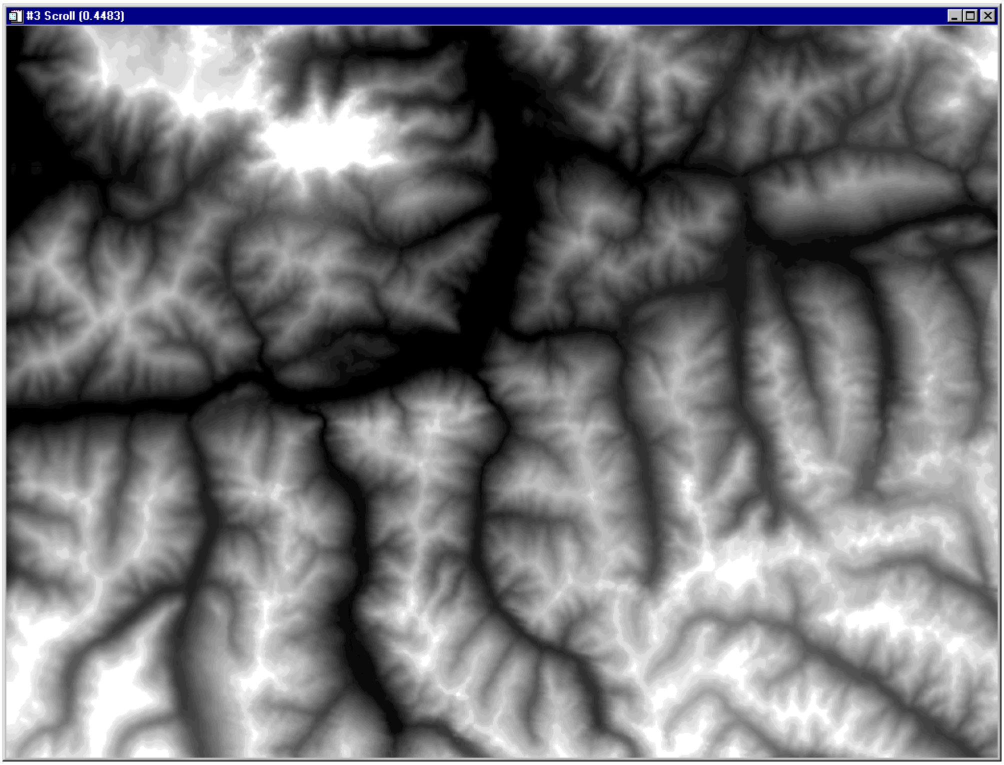


Figure 27-1: Gray scale DEM image, Austrian Alps.

DEM Contour Overlays

1. Select **Overlay** → **Contour Lines** from the Main Image window, choose the 25m DEM as the source of the contour information by clicking on the band name in the **Contour Band Choice** dialog and then clicking **OK**. Click on the **Apply** button to plot the default contour lines on the DEM image.
2. Experiment with your own contour lines by clicking **Clear Levels** in the dialog, then choosing **Options** → **Add New Levels** from the **Contour Plot** dialog and entering your desired **Level Start**, **Level Inc** (increment), and **# of Levels** in the appropriate text boxes in the **Add Contour Levels** dialog.
3. Compare the Landsat and the DEM using **Tools** → **Link** → **Link Displays**.

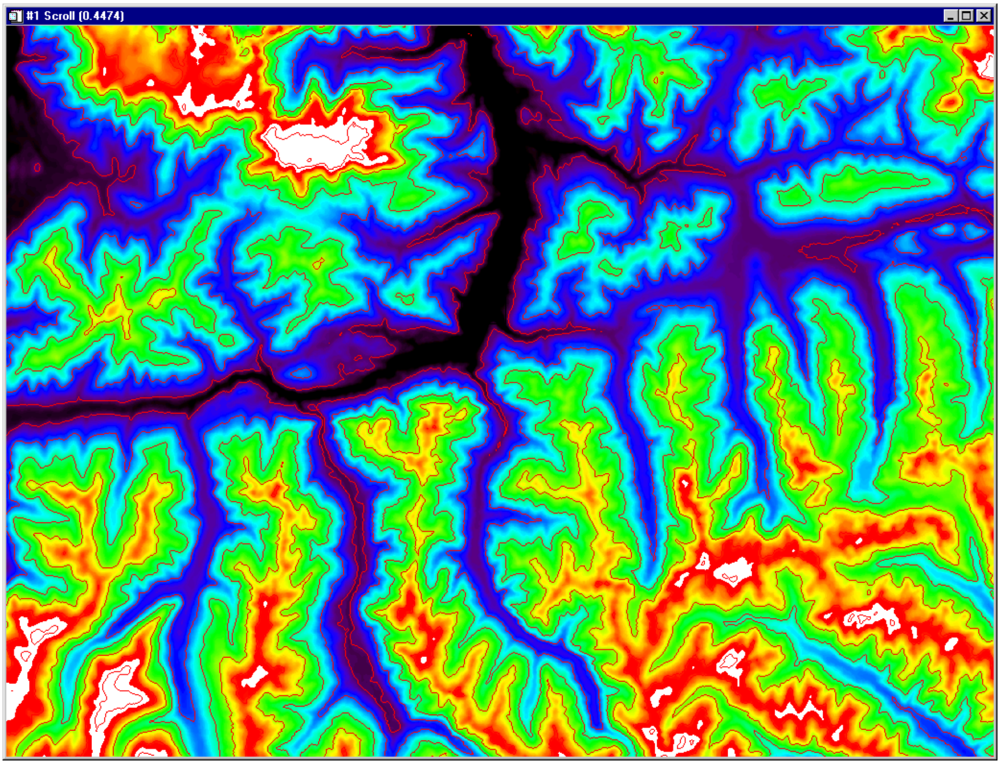


Figure 27-2: Color-coded, contoured DEM image, Austrian Alps.

Terrain Profiles

ENVI provides tools for extracting elevation profiles along either the X or Y directions, or along an arbitrary transect.

1. Select **Tools** → **Profiles** → **X Profile** and then **Tools** → **Profiles** → **Y Profile** in the Main Image window menu bar to extract profiles for the two directions.
2. Click and drag using the left mouse button to generate new elevation profiles when the left mouse button is released. The position of the red bar in the X and Y profiles marks the position of the center of the Zoom window along the profile. For continuous updating, click and drag using the left mouse button.
3. Close the two profiles by choosing **Window** → **Close All Plot Windows** from the ENVI main menu.
4. Select **Tools** → **Profiles** → **Arbitrary Profile (Transect)** from the Main Image window menu bar to extract a profile along an arbitrary transect.
5. Click using the left mouse button in the Main Image window to draw each segment of the desired transect. You can hold down the left mouse button and draw if desired.
6. Click the right mouse button once to close the last line segment and a second time to extract the profile. Draw one or more profiles using the **Arbitrary Profile** tool. Each additional profile will be assigned a new color and numbered.

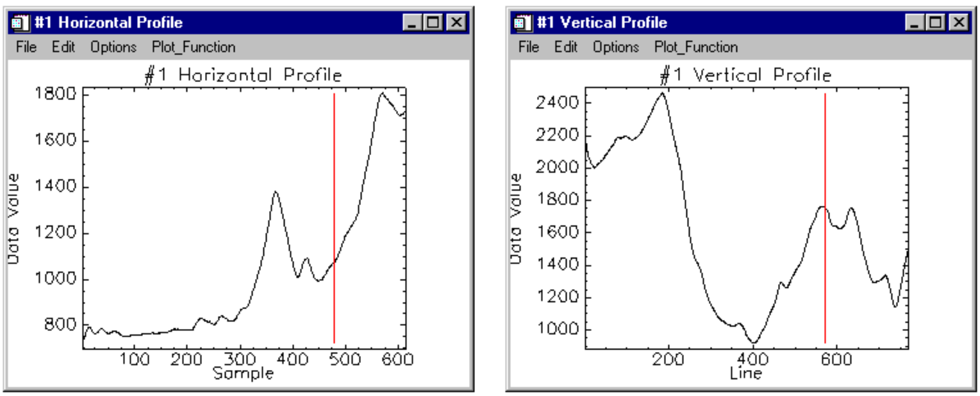


Figure 27-3: X- and Y-spatial profiles, Austrian Alps DEM.

7. Profiles can also be drawn in the Scroll or Zoom windows by selecting the appropriate window in the **Spatial Profiler Tool** dialog.

   ENVI's standard plot controls can be used to read the elevation off of the plot.

8. Click the left mouse button in the plot and drag along the profile. The Zoom window will track the profile in the Main Image window.
9. Zoom in on portions of the plot using the middle mouse button to draw a box and zoom back out by clicking the middle mouse button below the plot axis.
10. Close the profiles by selecting **File** → **Cancel** in the **Spatial Profiler Tool** dialog.

Topographic Modeling

ENVI can be used to generate geomorphic measures including Slope, Aspect, Shaded Relief, Profile Convexity, Plan Convexity, Longitudinal Convexity, Cross Sectional Convexity, Minimum Curvature, Maximum Curvature, and RMS Error.

1. Select **Topographic** → **Topographic Modeling** from the ENVI main menu, click on the 25m DEM file name in the **Topo Model Input DEM** dialog, and click **OK**.
2. Choose the measures desired in the **Topo Model Parameters** dialog by clicking on the appropriate parameter names (See the *ENVI User's Guide* and On-Line Help for details about the specific measures).
3. Click on the **Compute Sun Elevation and Azimuth** button and enter today's date, GMT of 10:0:0, and Lat (latitude of) 47 degrees and Lon (longitude) of 13 degrees. Click **OK** and ENVI will automatically calculate and enter the sun elevation and azimuth
4. Enter an output name (`topomodel` for example) and click **OK** to generate the parameter images.
5. Examine the Topographic Model images. Note that there are artifacts and patterns in these apparently associated with processes used to generate the DEM (see in particular the Shaded Relief Image). This is not apparent in the contrast-stretched DEM itself, but is enhanced and is a problem in the product images. Try minimizing these effects in the product images by selecting **Enhance** → **Filter** → **Smooth** or **Enhance** → **Filter** → **Median** and observing the results on the displayed image. Try other filters if desired.

6. Go back and smooth the original DEM image and re-calculate the geomorphic measures. Select **Filter** → **Convolutions** or **Morphology** from the ENVI main menu, then choose **Convolutions** → **Median**. Change the **Kernel Size** to 7 using the spin box and click on **Apply to File**, select the 25m DEM, click **OK**, enter the output filename (`medianfilter` for example) and click **OK** in the **Convolution Parameters** dialog to generate the filtered image. Select **File** → **Cancel** to close the **Convolutions and Morphology Tool** dialog.
7. Recalculate the Topographic Model by selecting **Topographic** → **Topographic Modeling** from the ENVI main menu, using the smoothed 25m DEM file as the input file in the **Topo Model Input DEM** dialog, and clicking **OK**.
8. Choose the measures desired in the **Topo Model Parameters** dialog by clicking on the appropriate parameter names.
9. Click on the **Compute Sun Elevation and Azimuth** button and enter today's date, GMT of 10:0:0, and Lat (latitude of) 47 degrees and Lon (longitude) of 13 degrees. Click **OK** and ENVI will automatically calculate and enter the sun elevation and azimuth
10. Display the Topographic Model images derived from the smoothed DEM and compare to the original and smoothed DEM images and the Topographic Model images derived from the original DEM using **Tools** → **Link** → **Link Displays**.

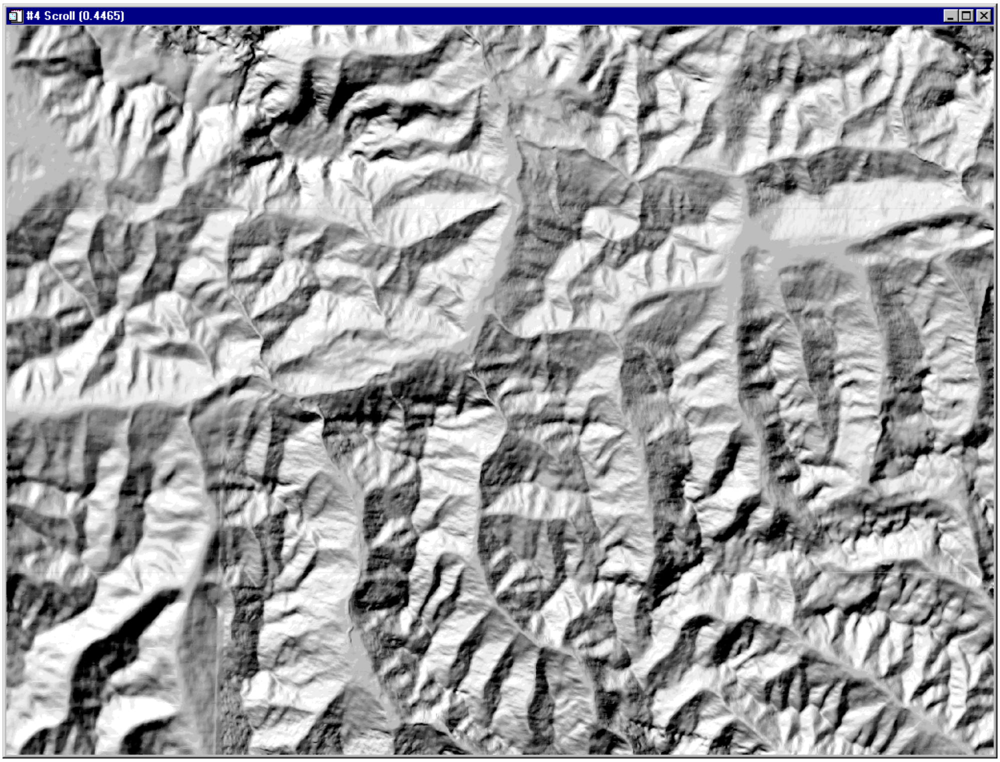


Figure 27-4: Shaded Relief image, Austrian Alps.

Topographic Feature Parameters

ENVI can be used to produce additional topographic feature parameters (Peak, Ridge, Pass, Plane, Channel, and Pit) that help characterize the terrain.

1. Select **Topographic** → **Topographic Features** from the ENVI main menu, choose the smoothed 25m DEM data file in the **Topographic Feature Input DEM** dialog and click **OK**.
2. Change the **Kernel Size** to 7, enter an output filename (`topofeature` for example), and click **OK** to start the processing.
3. Display the feature image in a new display by first clicking the **Gray Scale** radio button in the **Available Bands List**, clicking on the image name in the

Available Bands List, then clicking **Load Band**. (The feature image is actually a classification image, which is automatically color-coded according to feature).

4. Select **Overlay** → **Annotation** from the Main Image window menu bar and choose **Object** → **Map Key** from the menu bar in the **Annotation** dialog.

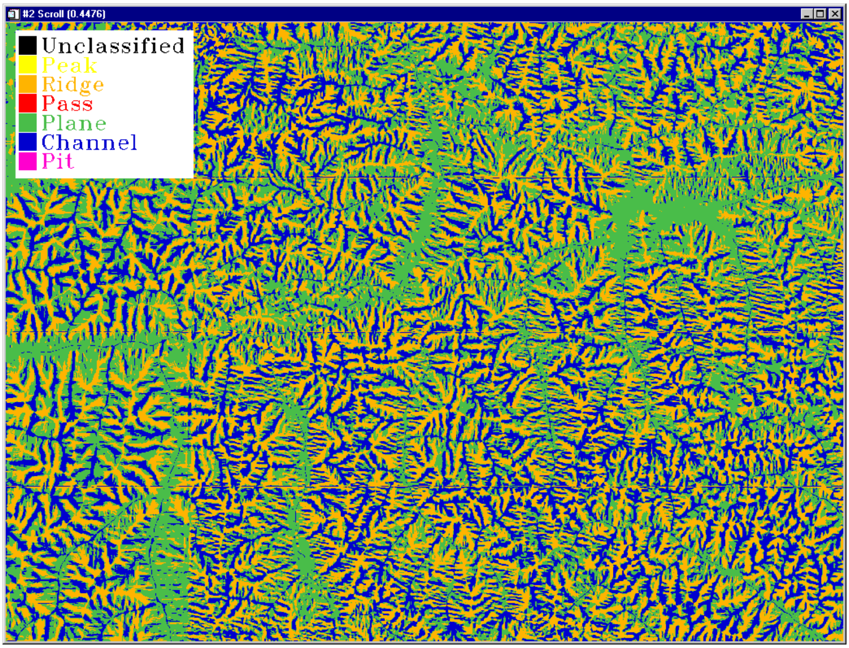


Figure 27-5: Topographic Feature Classified image, Austrian Alps.

5. Select a foreground color of black using the **Color** selection pull-down menu and a background color of white using the **Back** selection pull-down menu in the **Annotation** dialog.
6. Click the left mouse button in the image to display the map key in the image, the right mouse button to place the annotation.
7. Compare the feature image classification to the DEM and to the Topographic Model images using **Tools** → **Link** → **Link Displays** and dynamic overlays and evaluate the success of the feature classification procedure.

3D Visualization

If you are running ENVI on a Windows system, you must set the display to 16 bit or 24 bit color mode before starting ENVI.

Start the ENVI 3D SurfaceView Function

1. Select **Topographic** → **3D SurfaceView** from the ENVI main menu to start the function.
2. If more than one display window is open, select the display window that contains the desired image (try both the Landsat TM image and the color-coded DEM) in the **3D SurfaceView:Select Input Display** dialog.
3. Select the digital elevation model (DEM) input file from the **Associated DEM Input File** dialog by clicking on the DEM band name. Click on **OK** to start the **3D SurfaceView Input Parameters** dialog.

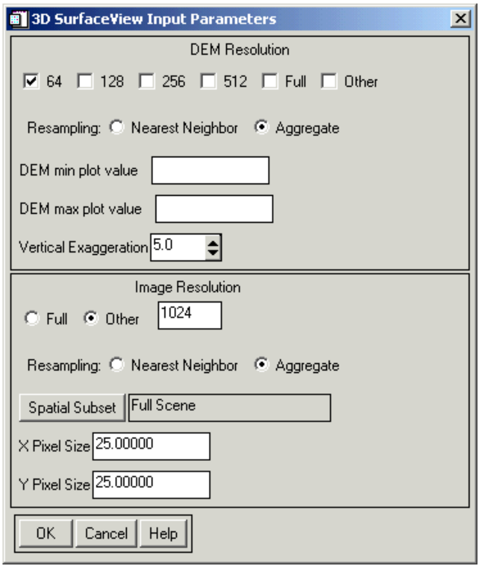


Figure 27-6: 3-D SurfaceView Input Parameters dialog.

4. Select the desired DEM Resolution (number of pixels) check box(es) used for the 3D plot. The DEM will be resampled to the selected resolution.

Note

Using higher DEM resolutions will significantly slow the visualization and should only be used when sufficient computing power is available. More than one resolution can be selected. Typically you will want to use the lowest resolution (64) while you are determining the best flight path. Then a higher resolution can be used to display your final fly-through sequence.

5. Enter a value for the **Vertical Exaggeration**. Increasing the number increases the amount of exaggeration.
6. Click **OK** to start the visualization.

Interactive 3-D Visualization Controls

The mouse cursor and buttons are used to interactively rotate, translate (pan), and scale the 3D surface. Try this for your -D SurfaceView as described below.

1. Clicking and dragging with the left mouse button in a horizontal direction in the **3D SurfaceView** rotates the surface around the Z axis. Clicking and dragging with the left mouse button in a vertical direction rotates the surface around the X axis.
2. Clicking and dragging with the middle mouse button in the **3D SurfaceView** translates (pans the image) in the corresponding direction.
3. Clicking and dragging to the right with the right mouse button in the **3D SurfaceView** increases the zoom factor. Clicking and dragging to the left with the right mouse button decreases the zoom factor.
4. Double-clicking with the left mouse button on a pixel in the **3D SurfaceView** moves the Zoom window to that pixel in the Main Image window containing the draped image. Selected functions that are active in the display window can be linked to the 3D cursor location by double-clicking using the left mouse button (see **3D SurfaceView** as an Analysis Tool below).

   The rotation, translation, and zoom factor can also be controlled, and the surface plot can be reset to its original position from the Options pull-down menu in **3D SurfaceView** window (see below).

Additional details on using the **3D SurfaceView** controls are described in the ENVI 3D Surface View and Fly-Through tutorial.

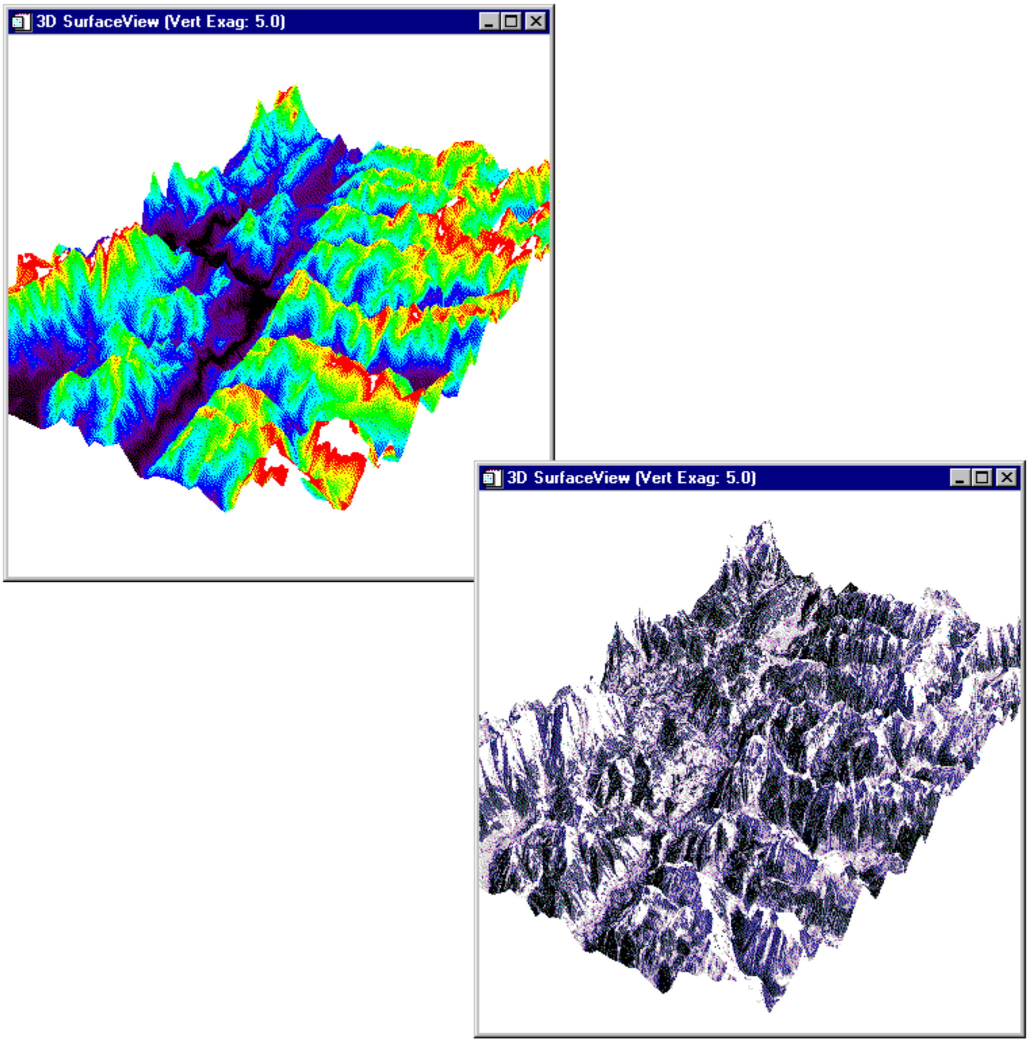
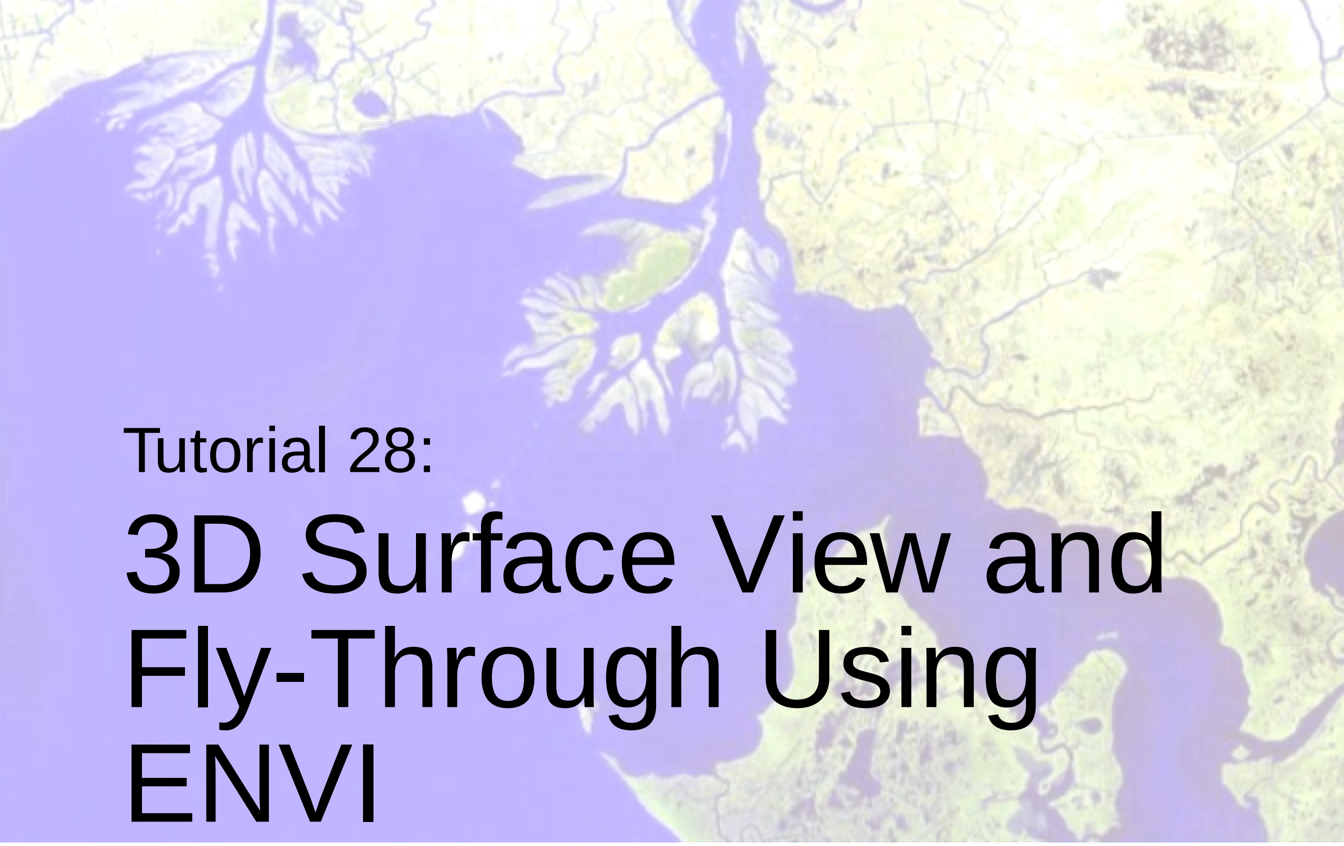


Figure 27-7: 3-D SurfaceView. Top view shows DEM, bottom view is Landsat TM on DEM.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.



Tutorial 28:

3D Surface View and Fly-Through Using ENVI

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to give you a working knowledge of ENVI's **3D SurfaceView** and Fly-Through capabilities. This function allows you to overlay a gray scale or color composite image over a digital elevation model (DEM) as a 3D Surface View, interactively change the 3D visualization, and create a 3D Fly-through. The **3D SurfaceView** function also provides limited analysis capabilities. For additional details, please see the *ENVI User's Guide* or ENVI On-Line-Help.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/bh_3d`

File	Description
`bhtmsat.img`	Bighorn Basin Landsat TM bands 3, 2, 1 (Saturation Enhanced)
`bhtmsat.hdr`	ENVI Header for Above
`bhdemsub.img`	30-meter resolution USGS digital elevation model (DEM)
`bhdemsub.hdr`	ENVI Header for Above
`bhdemsub.pat`	Fly-through path file
`bhdemsub.ann`	Fly-through path annotation file

Note

The files listed are required to run this exercise. You should also be able to produce similar results with their own coregistered image and digital elevation model (DEM) data.

3D Visualization Using ENVI

ENVI provides comprehensive capabilities for viewing and analyzing image data in 2 dimensions. The ENVI **3D SurfaceView**™ tool is the first step towards extending these capabilities into 3 dimensions.

ENVI's three-dimensional surface viewing function allows display of a digital elevation model (DEM) as a wire frame, ruled grid or points, or with a gray scale or color image draped over it. The 3D surface can be rotated, translated, and zoomed in or out in real-time using the mouse cursor. Each 3D "view" can be added to a list to be used later for animation. A "fly-through" of the three-dimensional datasets is achieved using the saved views or a predefined flight path drawn interactively using ENVI's annotation tool. The vertical exaggeration, vertical and horizontal view angles, and altitude are controlled via user selectable parameters. The cursor is also linked to the draped 3D image allowing extraction of profiles in the X, Y, and spectral directions as well as cursor locations and values utilizing the 3D projection.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in UNIX, enter `envi` at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu appears when the program has successfully loaded and executed.

Loading a 3D SurfaceView

If you are running ENVI on a Windows system, you must set the display to 16 bit or 24 bit color mode before starting ENVI.

To start ENVI's **3D SurfaceView** function:

Open and Display the Landsat TM Data

To open the image file:

1. Select **File** → **Open Image File** on the ENVI main menu.

   An **Enter Data Filenames** file selection dialog appears.

2. Select the file `bhtmsat.img` from the list and click **OK**.

The **Available Bands List** dialog will appear on your screen. This list allows you to select spectral bands for display and processing.

Note

ENVI 3.5 will automatically perform Steps 3 and 4.

3. Select bands 1, 2, and 3 listed at the top of the dialog by first selecting the **RGB Color** radio button in the **Available Bands List**, then clicking on the bands sequentially with the left mouse button.

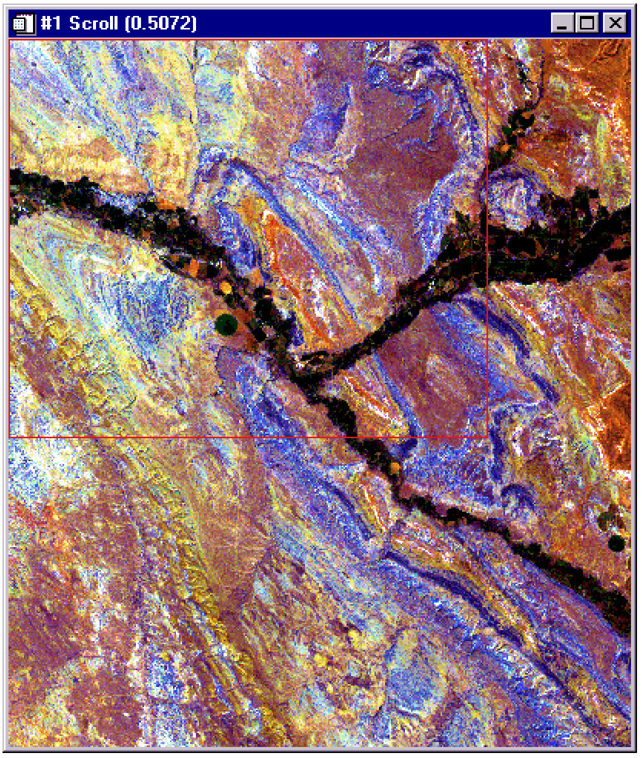


Figure 28-1: Bighorn Basin, Wyoming Saturation Enhanced Landsat TM Data.

The bands you have chosen are displayed in the appropriate fields in the center of the dialog.

4. Click **Load RGB** to load the image into a new display.

You can adjust the displayed contrast stretch using ENVI's contrast enhancement tools accessed from the **Enhance** menu in the Main Image window.

Open and Display the DEM as a Gray Scale Image

While the DEM data should be opened prior to starting the **3D SurfaceView** function, displaying the DEM image is not required. It is a good idea, however, to do this routinely when starting the **3D SurfaceView** function to ensure that you have a matched DEM/Image pair.

To open the DEM image file:

1. Select **File** → **Open Image File**.

   An **Data Filenames** dialog appears.

2. Select the file `bhdemsub.img` from the list and click **Open**.

Note

ENVI 3.5 will automatically perform Steps 3, 4, and 5.

3. First select the Gray Scale display option by clicking on the **Gray Scale** radio button in the **Available Bands List**.

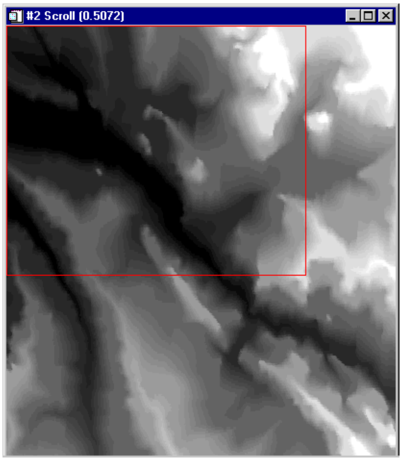


Figure 28-2: Bighorn Basin, Wyoming DEM.

4. Select the DEM band name in the dialog by clicking on the name in the **Available Bands List** with the left mouse button.

The band you have chosen is displayed in the field marked **Selected Band:**.

5. Click **New Display** then click **Load Band** in the **Available Bands List** to load the image into a new display.

The DEM will be loaded as a gray scale image.

Start the ENVI 3D SurfaceView Function

1. Select **Topographic** → **3D SurfaceView** to start the function.
2. If more than one display window is open, select the display window that contains the desired image in the **3D SurfaceView: Select Input Display** dialog.
3. Select the digital elevation model (DEM) input file (or other 3D data set) from the **Associated DEM Input File** dialog by clicking on the DEM band name. Perform any spatial subsetting as desired and click on **OK** to start the **3D SurfaceView Input Parameters** dialog.

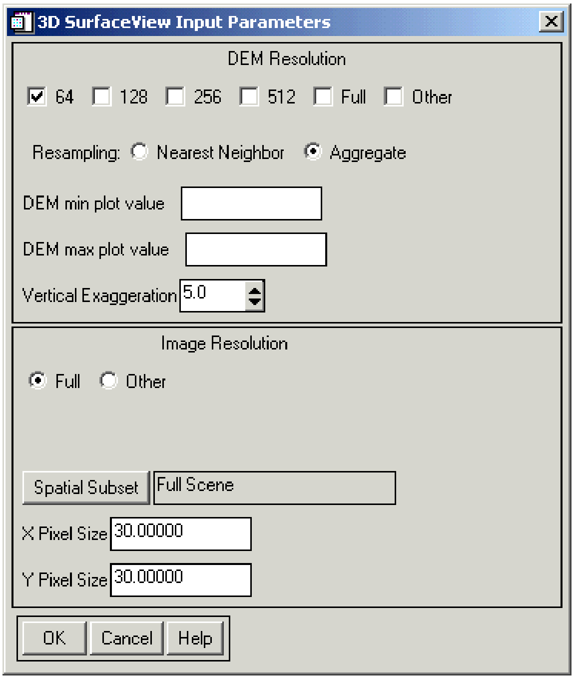


Figure 28-3: 3D SurfaceView Input

4. Select the desired DEM Resolution (number of pixels) check box(es) used for the 3D plot. The DEM will be resampled to the selected resolution.

Note

Using higher DEM resolutions will significantly slow the visualization and should only be used when sufficient computing power is available. More than one resolution can be selected. Typically you will want to use the lowest resolution (64) while you are determining the best flight path. Then a higher resolution can be used to display your final fly-through sequence.

5. Enter the DEM minimum and maximum plot values if desired to clip values from the displayed DEM. (this can be used to cut out background pixels or limit the elevation range of the DEM). DEM values lower than the minimum value and higher than the max value will not be plotted in the 3D views.
6. Enter a value for the **Vertical Exaggeration**. Increasing the number increases the amount of exaggeration.
7. Select either **Full** or **Other** image resolution. If **Other** is selected, the image is resampled to the number of pixels selected for the DEM.
8. Click on the **Spatial Subset** button and select a spatial subset of the image, if desired.
9. Use the defaults or enter the desired pixel size in the **X Pixel Size** and **Y Pixel Size** text boxes.
10. Click **OK** to start the visualization.

Interactive Control of 3D Visualization

The mouse cursor and buttons are used to interactively rotate, translate (pan), and scale the 3D surface. Try this for your **3D SurfaceView** as described below.

Clicking and dragging with the left mouse button in a horizontal direction in the **3D SurfaceView** rotates the surface around the Z axis. Clicking and dragging with the left mouse button in a vertical direction rotates the surface around the X axis.

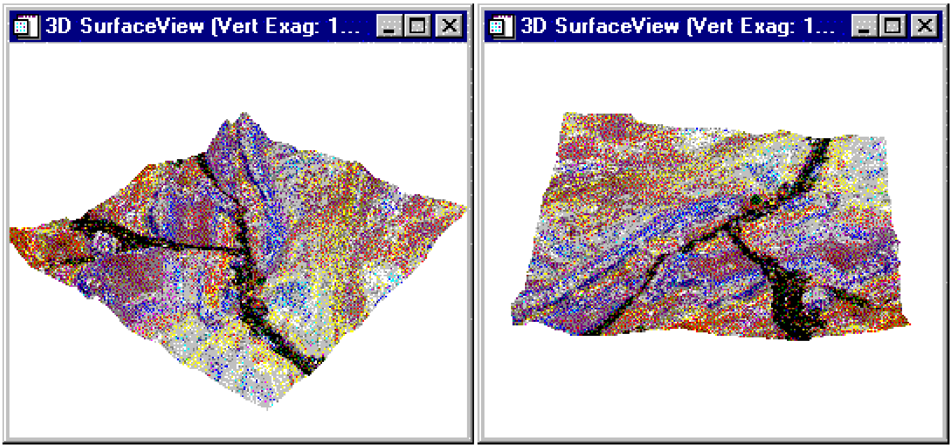


Figure 28-4: Two 3D SurfaceViews rotated using the left mouse button.

Clicking and dragging with the middle mouse button in the **3D SurfaceView** translates (pans the image) in the corresponding direction.

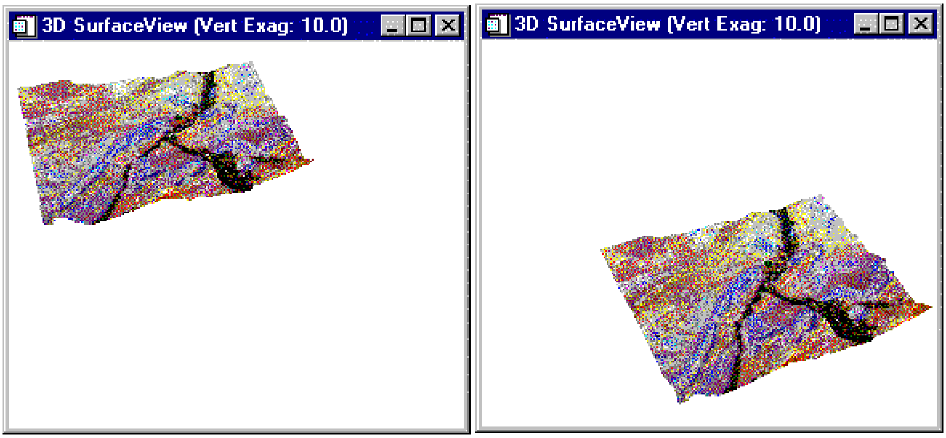


Figure 28-5: Two 3D SurfaceViews translated (panned) using the middle mouse button.

Clicking and dragging to the right with the right mouse button in the **3D SurfaceView** increases the zoom factor. Clicking and dragging to the left with the right mouse button decreases the zoom factor.

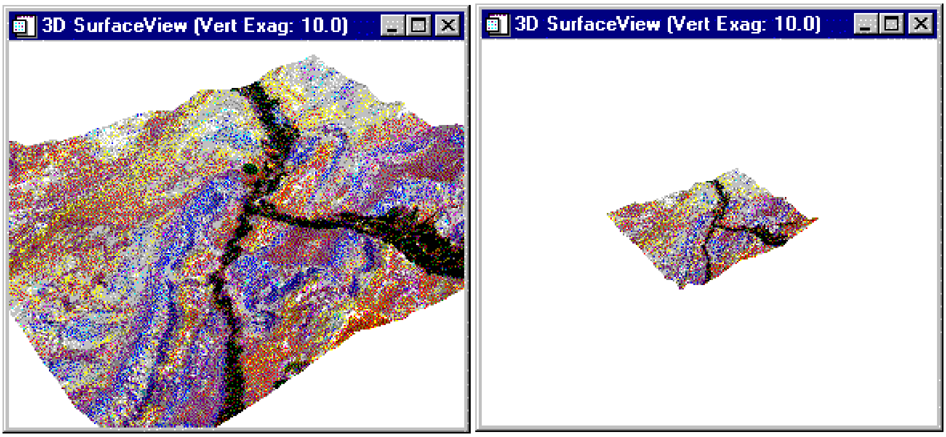


Figure 28-6: Two 3D SurfaceViews with different zoom factors set using the right mouse button.

Double-clicking with the left mouse button on a pixel in the **3D SurfaceView** moves the ENVI Zoom Window to that pixel in the Main Image window containing the draped image. Selected functions that are active in the display window can be linked to the 3D cursor location by double-clicking using the left mouse button (see "3D SurfaceView as an Analysis Tool" on page 595 for more information).

Note

The rotation, translation, and zoom factor can also be controlled, and the surface plot can be reset to its original position by from the **SurfaceView Controls** dialogs (see Figure 28-7 and Figure 28-8).

The 3D SurfaceView Control Dialogs

The 3D SurfaceView Control dialogs are accessed by selecting **Options** → **Controls Dialog** from the **3D SurfaceView** window, where a control dialog is either **Rotate/Scale/Trans Controls** or **Motion Controls**. These controls determine what kind of 3D surface is displayed; how the surface is displayed; fine control over rotation, translation, and zoom factor; animation of the surface; and image, printer, or VRML output.

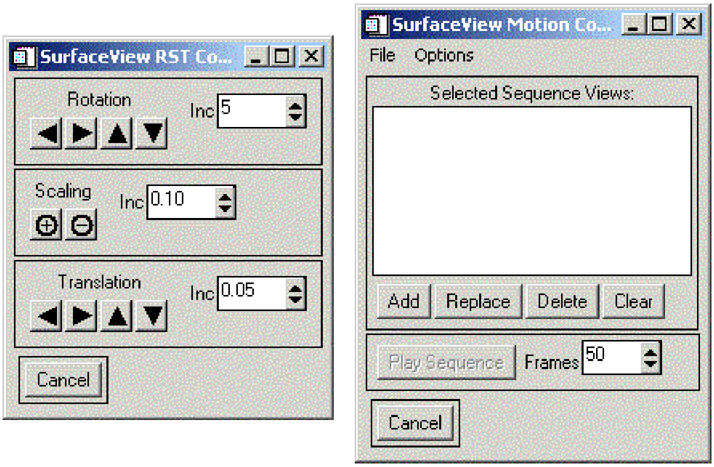


Figure 28-7: The 3D SurfaceView Control dialogs.

Type of Visualization

Several options are available for the **3D SurfaceView**. The surface can be displayed as an image overlay (draped image), as a wireframe surface, as a ruled XZ wireframe, as a ruled YZ wireframe, or as individual points.

1. To view the 3D surface as a draped image, select **Surface** → **Texture** in the **3D SurfaceView** dialog. Try displaying with and without interpolation by selecting **Options** → **Interpolation:None** or **Options** → **Interpolation:Bilinear**. No interpolation is the default.
2. Try the different wireframe options by selecting the desired option from the **Surface** and **Option** menus. Examples are shown below.

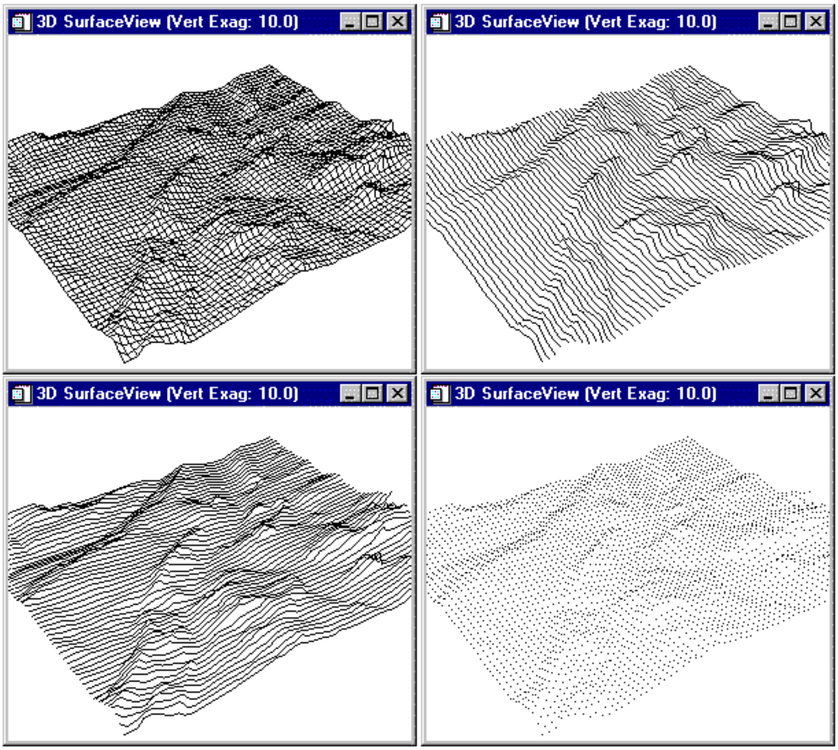


Figure 28-8: Examples of the different types of wireframe options for the 3D SurfaceView: Upper left, wireframe; Upper right, ruled XZ; Lower left, ruled YZ; Lower right, Points.

Visualization Fine Controls

The **3D SurfaceView RST Controls** dialog (select **Options** → **Rotate/Scale/Trans Controls**) provides the means to make fine adjustments to the visualization.

To change the rotation of the surface plot:

1. Enter a value, in degrees, in the **Rotation Inc** spin box to change the rotation increment.
2. Click on the arrows next to the **Rotation** text label to rotate in a specific direction. The left arrow rotates clockwise around the Z axis, the right arrow counter clockwise around the Z axis, the up arrow away from the viewer around the X axis, and the down arrow towards the viewer around the X axis.

To translate the surface plot:

1. Enter a value in the **Translation Inc** text box to change the translation increment.
2. Click on the arrows next to the **Trans** text label to move the image in the direction shown by the arrows.

To zoom in and out of the image:

1. Enter a value in the **Scaling Inc** text box to change the zoom increment.
2. Click on the plus and minus buttons next to the **Scaling** text label to respectively increase or decrease the zoom factor.

Other Visualization Controls

To change the color of the background from the **3D SurfaceView** dialog, select **Options** → **Change Background Color**.

To change the vertical exaggeration from the **3D SurfaceView** dialog, select **Options** → **Change Vertical Exaggeration** and enter the desired value. Higher factors increase the vertical exaggeration.

To reset the surface view to the default view from the **3D SurfaceView** dialog, select **Options** → **Reset View**.

To set the view to a specific position and viewing direction/angle, select **Options** → **Position Controls** (see section below).

To animate the current flight path, select **Options** → **Motion Controls**.(see section below).

To turn the annotation flight line trace off and on, select **Options** → **Annotation Trace: Off** or **On**.(see section below).

The SurfaceView Positioning Dialog

The **3D SurfaceView** can also be controlled by setting the view to a specific position and viewing direction/angle.

1. Select **Options** → **Position Controls** from the **3D SurfaceView** window and the **SurfaceView Position Controls** dialog will appear.

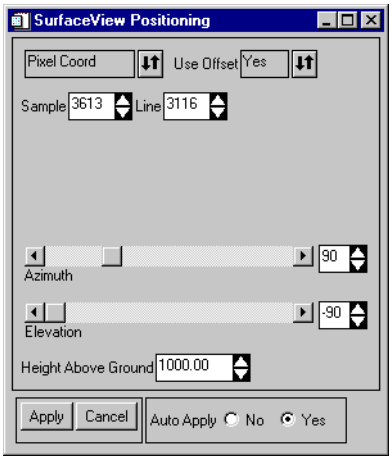


Figure 28-9: The SurfaceView Positioning dialog.

2. Select a viewing position by starting the **Cursor Location/Value** dialog in the Main Image window (**Tools** → **Cursor Location/Value**) and reading either the pixel or map coordinates for the desired location. Enter these coordinates into the SurfaceView Positioning dialog. A good starting point is Sample 3600 and Line 3000.
3. Try varying the **Azimuth**, **Elevation**, and **Height Above Ground** parameters to see how they change the **3D SurfaceView**. Start with an **Azimuth** (look direction) of 90, an Elevation (look angle) of -90 (looking straight down), and a height above ground of 2000 m. Change the height from 2000 to 1000 to 500.
4. Use the interactive rotation and zooming to see the **3D SurfaceView** from the selected viewpoint.

Building and Playing a User-Defined Visualization Sequence

ENVI's **3D SurfaceView** function can be used to build an animation sequence or 3D "Fly-Through" of the 3D visualization.

Try restoring a previously saved flight path and playing the animation sequence.

1. Select **Options** → **Motion Controls** to display the **SurfaceView Motion Controls** dialog.
2. Select **File** → **Restore Sequence from File** in the **SurfaceView Motion Controls** dialog and choose `bhdemsub.pat` as the flight path to be restored.
3. Enter a value of 500 into the **Frames** spin box and click on the **Play Sequence** button to play the flight path. Click **Stop Sequence** to stop the fly-through.

Now try interactively defining your own flight path and flying through the data:

1. Clear the current path by clicking on the **Clear** button in the **SurfaceView Motion Controls** dialog. Use the mouse or arrow buttons to select the starting **3D SurfaceView** and click the **Add** button in the **SurfaceView Motion Controls** dialog to add this projection as the starting point of the flight path.
2. Use the mouse or arrow buttons to select another 3D view and click the **Add** button to add this view to the flight path. Repeat this step until you have selected as many visualization steps as desired (2 minimum are required). When the visualization is played, the flight path will be smoothly interpolated between the different views.

   Click on the path view number and click **Replace** to replace a projection in the flight path list. Click on the path view number and click **Delete** to delete a projection in the flight path list. Click on **Clear** to clear the flight path list.
3. Enter the number of frames to be used in the "fly-through" animation and the flight path will be smoothly interpolated. A larger number of frames will be smoother, but slow down the animation.
4. Click the **Play Sequence** button to animate the fly-through.

Use the **Options** → **Animate Sequence** from the **SurfaceView Motion Controls** dialog to build a full animation and control the speed and direction of the fly-through (see "Animate Sequence" below).

Using ENVI Annotation to Build a Visualization Sequence

1. Select **Options** → **Motion:Annotation Flight Path** from the **SurfaceView Motion Controls** dialog to use a flight path drawn on the image in the display window using ENVI annotation. A polyline, polygon, rectangle, or ellipse annotation object can be used to define the flight path. Saved annotation files can also be input.
2. Select the flight path from a saved annotation file option by choosing the **Input Annotation from File** radio button, selecting `bhdemsub.ann` and choosing the 1st annotation object (a green polyline). The selected annotation file and number of nodes are shown in the middle of the dialog and the flight path plotted on the surface. Enter **Frames** of 500. To smooth the flight path using a running average of points along the line, enter a **Flight Smooth Factor** of 1000. Enter a **Flight Clearance** of 1000. Set the **Up/Down** look angle to -60. A vertical look angle of -90 degrees looks straight down at the surface. A look angle of 0 degrees looks straight ahead (horizontal). Leave the **Right/Left** look angle at 0. A horizontal look angle of -90 degrees looks to the left, a look angle of 0 degrees looks straight ahead, and a look angle of 90 degrees looks to the right. Click on **Play Sequence** to animate the fly-through. Try different values in each of the parameters and observe the effect they have on the visualization. Also try flying over the surface at a constant elevation by clicking the arrow radio button until **Flight Clearance** appears and entering the desired elevation above sea level.
3. Next select the flight path from the saved annotation file by choosing **File** → **Input Annotation from File** from the **SurfaceView Motion Controls** dialog, select `bhdemsub.ann` and choosing the 2nd annotation object (a red ellipse). Enter **Frames** of 100, a **Flight Smooth Factor** of 10000 and a **Flight Clearance** of 1000. Set the **Up/Down** look angle to -60 and leave the **Left/Right** look angle at 0. Click on **Play Sequence** to animate the fly-through. Try different values in each of the parameters and observe the effect they have on the visualization.
4. Now try creating your own annotation objects and doing the fly-through by selecting **Overlay** → **Annotation** in the Main Image window, selecting **File** → **Input Annotation from Display**, and clicking on **Play Sequence**.

The Animate Sequence Option

The Animate Sequence option allows control of the speed and direction of the **3D SurfaceView** animation.

1. Set up the flight path from the ellipse in the saved annotation file as described above, set **Frames** to 100, then select **Options** → **Animate Sequence** from the **SurfaceView Motion Controls** dialog to load the individual frames into the animation.

   The **3D SurfaceView** Controls dialog changes to show an interactive tool for controlling the animation (See Figure 28-10).

2. Control the speed of the fly-through by increasing the value in the **Speed** spin box. Higher values result in faster animation.
3. Control the direction of the fly-through by clicking on the appropriate bitmap button at the bottom of the dialog. The buttons are from left to right: reverse animation, forward animation, continuous forward/reverse animation, pause animation.
4. When the animation is paused, clicking and dragging the slider steps through the animation one or more frames at a time.

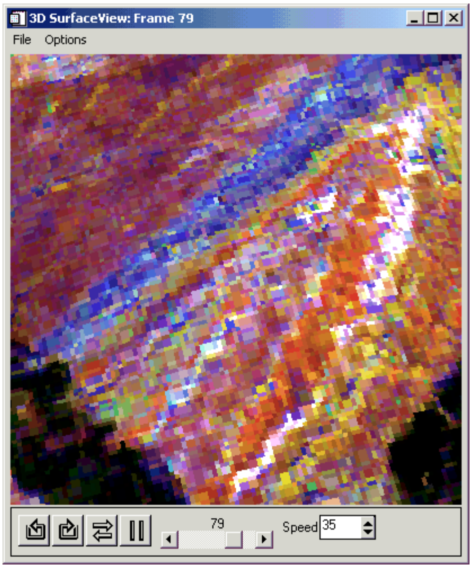


Figure 28-10: The SurfaceView Control dialog when Animate Sequence is selected.

5. Select **File** → **Cancel** to return to the **SurfaceView Motion Controls** dialog.

Saving Visualizations and Output

The ENVI **3D SurfaceView** function also offers several options to save the visualization results and/or path.

- Click **File** → **Save Sequence to File** in the **SurfaceView Motion Controls** dialog to save the current path to an ENVI path (.pat) file that can be restored to a 3D visualization session.
- Click **File** → **Restore Sequence Path from File** from the **SurfaceView Motion Controls** dialog to restore a saved flight path when the visualization is in the User Defined mode.
- Click **File** → **Input Annotation from Display** from the **SurfaceView Motion Controls** dialog to get annotation from the current display when the visualization is in the Annotation mode.
- Click **File** → **Input Annotation from File** from the **SurfaceView Motion Controls** dialog to get annotation from an ENVI annotation file when the visualization is in the Annotation mode.
- Select **File** → **Save Surface As** → **Image File** from the **3D SurfaceView** to output the currently displayed view to an ENVI image.
- Select **File** → **Print** from the **3D SurfaceView** to perform direct printing of the currently displayed view.
- Select **File** → **Save Surface As** → **VRML** from the **3D SurfaceView** to output the 3D visualization to a VRML file that can be viewed using programs such as Netscape Navigator.

3D SurfaceView as an Analysis Tool

ENVI's **3D SurfaceView** tool provides powerful visualization capabilities for viewing images draped on digital elevation models. Because of the way ENVI's windows and dialogs can be dynamically linked, this function also provides the capability to do analysis using the **3D SurfaceView** in conjunction with other ENVI capabilities. Currently support is provided for:

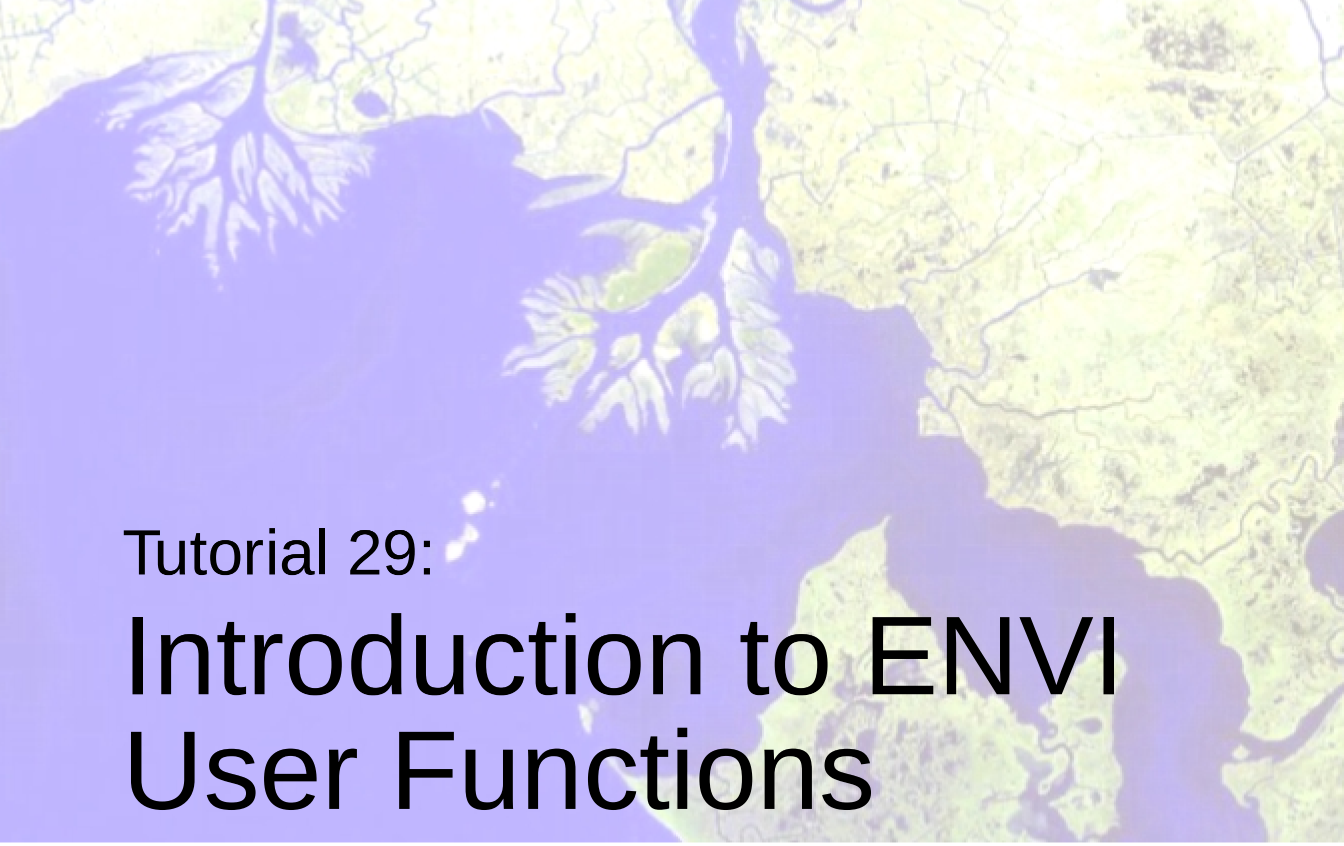
- Cursor Tracking/Pixel Locator
- The Spatial and Spectral Pixel editors
- X and Y Profiles
- Z-Profiles (Spectral Profiles) and the Spectral Analyst

To utilize the **3D SurfaceView** for analysis:

1. Display the desired 3D surface using the methods described above and start one of the ENVI interactive functions above from the displayed image to be analyzed.
2. Cursor Location: Select **Tools** → **Cursor Location/Value** in the Main Image window. Read the cursor location (pixel and map coordinates) and value by moving the cursor in the **3D SurfaceView** window.
3. Spatial and Spectral Pixel Editors: Select **Tools** → **Spatial Pixel Editor** or **Tools** → **Spectral Pixel Editor** in the Main Image window. Double-click using the left mouse button on the desired pixel in the **3D SurfaceView** window to position the cursor in the ENVI display windows to the appropriate location. Edit the desired pixel values.
4. X and Y Profiles: Select **Tools** → **Profiles** → **X Profile** or **Tools** → **Profiles** → **Y Profile** in the Main Image window. Double-click using the left mouse button on the desired pixel in the **3D SurfaceView** window to position the cursor in the ENVI display windows to the appropriate location. The X and/or Y Profiles will be updated to match the selected cursor location and the location will be marked with a red vertical line in the selected profile.
5. Z-Profile (Spectral Profile): Select **Tools** → **Z Profile** or **Tools** → **Profiles** → **Additional Z Profile** in the Main Image window. Double-click using the left mouse button on the desired pixel in the **3D SurfaceView** window to position the cursor in the ENVI display windows to the appropriate location. The Z Profile(s) spectrum will be extracted from the data to match the selected cursor location.
6. Spectral Analyst: Display a Z profile, then select **Spectral** → **Spectral Analyst** from the ENVI main menu. Open the desired spectral library by clicking on the Open Spectral Library button in the Spectral Analyst Input Spectral Library dialog and choosing the library name. Click on **OK** in the Edit Identify Methods Weighting dialog that appears. Select **Options** → **Auto Input via Z-Profile** in the Spectral Analyst dialog to link the Spectral Analyst to a specific spectral profile. Once the Spectral Analyst is set up, double click using the left mouse button on the desired pixel in the **3D SurfaceView** window to position the cursor in the ENVI display windows to the appropriate location. The Z Profile(s) spectrum will be extracted from the data to match the selected cursor location and the Spectral Analyst will calculate a match to the library spectrum.

End the ENVI Session

This concludes the Tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.



Tutorial 29:

Introduction to ENVI User Functions

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial provides basic information on programming in ENVI. It covers the basics for creating user-defined band math functions and User Functions, including creating compound widgets and writing data-tiling operations. This tutorial assumes that you are familiar with the Interactive Data Language (IDL) and that you understand how to write functions and procedures in IDL. ENVI Runtime users cannot program in ENVI.

Files Used in This Tutorial

CD-ROM: *ENVI Tutorial and Data CD No. 1*

Path: `envidata/user_fun`
`envidata/bldr_reg`

File	Description
Required Files (`envidata/user_fun`)	
`bm_divz1.pro`	Simple Band Math™ Function
`bm_divz2.pro`	Revised Band Math™ Function
`tp_divz1.pro`	ENVI User Function
`tp_divz2.pro`	Revised ENVI User Function
Required Files (`envidata/bldr_reg`)	
`bldr_tm.img`	Boulder Thematic Mapper Data
`bldr_tm.hdr`	ENVI Header for above

Programming in ENVI

ENVI provides a variety of interfaces for executing user-written routines. User routines are written in the Interactive Data Language (IDL). IDL routines are written as functions or procedures and named with a `.pro` extension. This tutorial shows examples of two of these techniques — Band Math and User Functions. For descriptions of the ENVI programming functions used in this tutorial, see the *ENVI 3.5 User's Guide* or online help.

ENVI processes data spatially or spectrally depending on the requirements of the function and on the input file storage format. If a function only operates either spatially or spectrally, then the data must be accessed accordingly. If a process can be performed either spatially or spectrally, however, then ENVI operates on the data based on the file storage format. The three file storage formats that ENVI uses are Band Sequential (BSQ), Band Interleave by Line (BIL), or Band Interleave by Pixel (BIP). See the *ENVI 3.5 User's Guide*, online help, or ENVI Tutorials.

ENVI allows processing of image data larger than available memory. This is accomplished by breaking the data up into usable pieces or "tiles," processing the tiles separately, then reassembling the tiles into the output image. A tile is a piece of data processed in memory by ENVI. The size of a spatial tile is determined by the ENVI configuration item *image tile size* and is set by the user to optimize memory usage without exceeding the computer's physical memory size. Spatial tiles always include all the samples being processed and as many lines as possible. Spectral tiles on the other hand, are defined by the number of samples (ns) and the number of bands (nb) being processed. A BIL spectral tile is (ns, nb) and a BIP spectral tile is (nb, ns). Spectral tiles will always be this size and are unrelated to the set *image tile size*.

The basic process for a tiling operation in ENVI is as follows:

> Initialize the ENVI tiles
>
> Loop on the number of tiles
>
> > request the tile
> >
> > process the tile
> >
> > [write result of the processing to disk or memory]
>
> end loop
>
> [Enter the data into Available Bands List]

User Defined Band Math Routines

This portion of the exercise will familiarize you with editing and compiling a `.pro` file (an IDL program). The compiled function is executed using ENVI's Band Math routine. Band math uses ENVI's tiling capabilities for handling large images. You will create a simple band math function that performs a mathematical expression using two bands. The optional keyword CHECK will enable divide-by-zero checking and the keyword DIV_ZERO will be used to set divide by zeros to another value.

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI on UNIX, enter `envi` at the UNIX command line.
- To open ENVI on Windows or Macintosh, double-click on the ENVI icon.

The ENVI main menu will appear when the program has successfully loaded and executed.

Open TM Data

To open the Boulder, Colorado Thematic Mapper (TM) data:

1. Select **File** → **Open Image File** from the ENVI main menu.

Note

On some platforms you must hold the left mouse button down to display the submenus from the main menu.

2. Select the file `envidata/bldr_reg/bldr_tm.img` and click **Open**.

The **Available Bands List** dialog will appear on your screen with the 6 available TM bands listed. This list allows you to select spectral bands for display and processing.

Edit the Band Math Function

Normally, you would open an editor and type the following IDL function, however, this function has already been saved in the `envidata/user_fun` directory as `bm_divz2.pro`.

If you choose to enter the function yourself, use IDL's text editor or your favorite editor, enter the text below, and save the function as `bm_divz2.pro`.

```
function bm_divz2, b1, b2, check=check, div_zero=div_zero
  if (keyword_set(check)) then begin
    ; If div_zero is set then use it otherwise use zero
    if (n_elements(div_zero) gt 0) then $
      temp_value = div_zero $
    else $
      temp_value = 0.0
    ; Find all the locations where the band is zero
    temp = float(b1) - b2
    ptr = where(temp eq 0, count)
    ; Temporarly set the divide by zero cases to divide by 1
    if (count gt 0) then $
      temp(ptr) = 1
    ; Perform the ratio
    result = (float(b1) + b2) / temp
    ; If any divide by zeros then set the output
    if (count gt 0) then $
      result(ptr) = temp_value
  endif else begin
    ; Just do the ratio and ignore divide by zeros
    result = (float(b1) + b2) / (float(b1) - b2)
  endelse
  return, result
end
```

Compile the Band Math Function

To compile the updated function:

1. Select **File** → **Compile IDL Module** from the ENVI main menu.
2. In the **Enter Module Filename** dialog, navigate to the `envidata/user_fun` directory (or the directory where you saved the file if you created it manually), select the file `bm_divz2.pro`, and click **Open**.
3. To make sure that the function compiled, look in the IDL output log window.

   On Windows and Macintosh, this is the output log window. On UNIX, it is the shell window from which ENVI was started. The following line will appear if the module compiled successfully:

   ```
   % Compiled module BM_DIVZ2
   ```

4. Edit and fix any errors for modules that did not compile successfully.

Run the Band Math Function

The new function can now check for divide by zeros and can set them to an error value. To run the compiled function:

1. Select **Basic Tools** → **Band Math**.
2. When the **Band Math** dialog appears, enter the following in the “Enter an expression:” input text box:

```
bm_divz2(b1,b2, /check, div_zero=1.0)
```

3. Click **OK**.
4. When the **Variables to Band Pairings** dialog appears, select “B1” in the “Variables used in expression” field.
5. In the “Available Bands List field, select “Band 2”.
6. Select “B2” in the “Variables used in expression” field.
7. In the “Available Bands List” field, select “Band 3”. The “Variables used in expression” field should contain the following:

```
B1 - Band 2(0.5600):bldr_tm.img
B2 - Band 3(0.6600):bldr_tm.img
```

8. Select the File radio button, enter an output filename, and click **OK**.

Display the Result

1. In the **Available Bands List** dialog, click the **Display** button and select **New Display**.
2. Select the band math result we just created, “Band Math (bm_divz2(b1,b2, /check, div_zero=1.0))”, and click **Load Band**.

   Any pixels that caused a divide be zero now have the value 1.0.

Creating a User Function

The process of creating an ENVI User Function consists of adding a menu item, creating an event handler that defines the widget interface, using data tiling for accessing the data, and adding the output bands to the Available Bands List. The User Function you will create performs the same mathematical expression as the band math example above. The code has been saved in the file `tp_divz1.pro`.

Editing envi.men

User functions can be added to the `envi.men` file and run from the menu like the rest of the ENVI routines.

1. Copy the `envi.men` file from the ENVI installation `menu` subdirectory to another directory and filename.

2. Select **File** → **Preferences** from the ENVI main menu. The **System Pereferences** dialog will appear. Select **User Defined Files** in this dialog.
3. Enter the new filename (including its directory path) in the **Default ENVI Menu File** field of the **Preferences: User Defined Files** dialog.

   Exit ENVI so that you can update the `envi.men` file to include your new routine.
4. To quit your ENVI session, select **File** → **Exit** or **Quit** from the ENVI main menu and click **Yes**.
5. Edit your new ENVI menu file and add the lines:

```
0 {User Functions}
   1{User Band Ratio1} {user ratio} {tp_divz1}
   1{User Band Ratio2} {user ratio} {tp_divz2}
```

   where 1 indicates the menu level, {User Band Ratio} is the menu item name, {user ratio} is the name of the uvalue, and {tp_divz1} or {tp_divz2} is the name of the event handler.
6. Save and close the new ENVI menu file.

Creating an Event Handler

This portion of the exercise will familiarize you with creating ENVI event handlers for user-defined functions. You will use the ENVI file selection function and ENVI's compound widgets.

Edit the Event Handler

Enter the following code using your text editor or use the file included in the `user_fun` directory under the filename `tp_divz1.pro`.

The first thing to do in the routine is to extract the UVALUE and compare it the UVALUE in the ENVI menu file.

After receiving the uvalue the event handler selects the input file. ENVI_SELECT is used for file selection and spatial and spectral subsetting. Returned from ENVI_SELECT are the input file id (FID), the band dimensions (DIMS), and the selected bands (POS). If the returned FID equals –1, then the "Cancel" button was selected and the event handler must exit.

Since the processing routine is performing the same mathematical expression as the band math example, we need to make sure that at lease two bands are selected. If the improper number of bands are selected then ENVI_ERROR is used to give a warning message and the event handler exits.

Input parameters entered on the command line in the Band Math exercise are now entered using ENVI compound widgets.

- Use WIDGET_AUTO_BASE to create a widget base which allows auto-management of widget events.
- Use row and column bases for positioning the compound widgets WIDGET_MENU and WIDGET_PARAM to replace the keywords in the Band Math example.
- WIDGET_MENU creates the “Check for divide by 0?” using an exclusive list to make a “Yes/No” button.
- WIDGET_PARAM accepts an input value that is used as the replacement for the divide by zero.
- WIDGET_PARAM accepts a floating point number (DT=4) with three digits past the decimal points (FIELDS=3) with a default value of zero (DEFAULT=0.0).
- Finally, WIDGET_OUTFM is used to prompt for the output filename or memory option.
- Each of the compound widgets sets the keyword /AUTO, giving AUTO_WID_MNG the responsibility of managing the compound widgets.
- AUTO_WID_MNG returns a structure with the tag names defined by the uvalue of each compound widget.
- In addition, the structure contains the tag *accept*, which is set to one if the you select “OK” and zero if the “Cancel” button is selected.

In this example, we print the selections for “Check for divide by 0?” and the “Divide by zero value”. The next exercise will use the same event handler but pass the arguments to the tile processing routine.

```
pro tp_divz1, ev
  widget_control, ev.id, get_uvalue=uvalue

  if (uvalue eq 'user ratio') then begin

    envi_select, title='Ratio Input File', fid=fid, dims=dims, $
      pos=pos
    if (fid eq -1) then return
    ; We will just do a ratio of the first two band
    ; from the pos array so make sure there are at
    ; least two bands are selected
    if (n_elements(pos) lt 2) then begin
      mstr = 'You must select two bands to ratio.'
```

```
          envi_error, mstr, /warning
          return
        endif
        ; Create a compound widget for the input parameters
        base = widget_auto_base(title='Ratio Parameters')
        sb  = widget_base(base, /column, /frame)
        sb1  = widget_base(sb, /row)
        mw   = widget_menu(sb1, prompt='Check for divide by 0 ? ', $
          list=['Yes','No'], /excl, default_ptr=0, rows=0, $
            uvalue='check', /auto)
        sb1  = widget_base(sb, /row)
        wp   = widget_param(sb1, prompt='Divide by zero value', $
          dt=4, field=3, xs=6, uvalue='div_zero', default=0.0, /auto)
        sb   = widget_base(base, /column, /frame)
        ofw  = widget_outfm(sb, func='envi_out_check', $
          uvalue='outf', /auto)

        ; Automanage the widget
        result = auto_wid_mng(base)
        if (result.accept eq 0) then return
        check = (result.check eq 0)
        div_zero = result.div_zero
        help, result.outf, /st
        print, check
        print, div_zero
      endif
    end
```

If you are creating your own file, save this routine as `tp_divz1.pro` in the same directory as the new envi menu file or use the `tp_divz1.pro` in the `user_fun` directory.

Running the User Function

Follow the procedures below to compile and run the User Function from within ENVI.

Start ENVI

- To open ENVI on UNIX, enter `envi` at the UNIX command line.
- To open ENVI on Windows or Macintosh, double-click on the ENVI icon.

The ENVI main menu will appear when the program has successfully loaded and executed.

Open TM Data

To open the TM data:

1. Select **File** → **Open Image File**.

Note

On some platforms, you must hold the left mouse button down to display the submenus from the main menu.

2. In the **Enter Data Filenames** dialog, navigate to the `envidata/bldr_reg` directory, select the file `bldr_tm.img`, and click **OK** or **Open** depending on your operating system.

Compile the Event Handler

To compile the newly created event handler:

1. Select **File** → **Compile IDL Module** from the ENVI main menu.
2. When the **Enter Module Filename** dialog appears, navigate to the location of the saved function, `tp_divz1.pro`, and select the file.
3. To make sure that the function compiled, look in the IDL command window.

   On Windows and Macintosh, this is the output log window. On UNIX, it is the shell window from which ENVI was started. The following line will appear if the module compiled successfully:

   ```
   % Compiled module TP_DIVZ1
   ```
4. Edit and fix any errors for modules that did not compile successfully.

Run the Event Handler

1. Select **User Functions** → **User Band Ratio1**.
2. In the **Ratio Input File** selection dialog, select the file `bldr_tm.img` and click **OK**. The **Ratio Exercise Parameters** dialog will appear and allow the selection of divide by zero checking, the divide by zero value, and an output filename.
3. Select the **No** button for “Check for divide by 0”.
4. Enter 1.0 for the “Divide by zero value”.
5. Enter `tp_divz1.img` as the output filename.
6. Click **OK**.
7. Look in the IDL command log window to see the values printed at the bottom of the event handler.

Write the Tiling Routines

Follow the procedures below to create the tiling routines that allow ENVI to process large image files.

Creating the Tiling Routine

This portion of the exercise will familiarize you with creating ENVI tile processing routines. You will use the band math example and convert it to a tiling routine which uses the newly created event handler.

Updating the Event Handler

The first thing to do in the processing routine sets up the IO error handling. Next, ENVI_FILE_QUERY is used to get the filename (FNAME) and X and Y starting pixel (XSTART and YSTART). The filename is used for the processing status report and XSTART and YSTART are just used in the output image header.

The tile processing routine allows both output to file and memory, file operations open the output file for writing and memory output allocates a float array. Next, the ENVI tiles are initialized using ENVI_INIT_TILE. Since the processing routine uses two bands simultaneously the MATCH_ID is used on the second ENVI_INIT_TILE forcing processing tiles from the two bands to be the same size. ENVI_REPORT_INIT and ENVI_REPORT_INC set up a processing status widget and the report increment respectively.

Now that everything is initialized the processing routine can just loop over the number of tiles. At the start of each loop the processing status is updated and a check is made to see if the “Cancel” button was selected. The calls to ENVI_GET_TILE with the TILE_IDs return the data to process. Each tile is processed with the mathematical expression from the Band Math exercise. After processing the data memory items are written to the variable mem_res otherwise the result is written to a file.

Now that the processing is completed, ENVI_ENTER_DATA or ENVI_SETUP_HEAD enter the new image into ENVI. Memory items use ENVI_ENTER_DATA while output to disk uses ENVI_SETUP_HEAD to open the file and write the ENVI header file (`.hdr`). Finally, the tile pointers and report are cleaned up using ENVI_TILE_DONE and ENVI_REPORT_INIT.

In the event handler replace the print statements with the call to the processing routine show below.

```
tp_divz_doit, fid=fid, pos=pos, dims=dims, check=check, $
  out_name=result.outf.name, div_zero=div_zero, $
  in_memory=result.outf.in_memory
```

Here is the new code for tp_divz2.pro. You can enter this using your favorite editor or use the file tp_divz2.pro saved in the user_fun directory.

```
pro tp_divz_doit, fid=fid, pos=pos, dims=dims,check=check,$
  out_name=out_name, in_memory=in_memory, $
  div_zero=div_zero, r_fid=r_fid
  ; Set up the error catching and initialize optional keywords
  !error = 0
  on_ioerror, trouble
  in_memory = keyword_set(in_memory)

  ; Get the file xstart and ystart and calculate ns and nl
  envi_file_query, fid, fname=fname, xstart=xstart, $
    ystart=ystart
  ns = dims(2) - dims(1) + 1
  nl = dims(4) - dims(3) + 1

  ; Either alloate a memory array or open the output file
  get_lun, unit
  if (in_memory) then $
    mem_res = fltarr(ns, nl) $
  else $
    openw, unit, out_name

  ; Initialize the data tiles
  tile_id1 = envi_init_tile(fid, pos(0), $
    num_tiles=num_tiles, xs=dims(1), xe=dims(2), $
    ys=dims(3), ye=dims(4), interleave=0)
  tile_id2 = envi_init_tile(fid, pos(1), match_id=tile_id1)

  ; Setup the processing status report
  if (in_memory) then tstr = ‘Output to Memory’ $
  else tstr = ‘Output File: ‘ + out_name
  envi_report_init, [‘Input File: ‘ + fname, tstr], $
    title=’Ratio Processing’, base=rbase, /interupt

  envi_report_inc, rbase, num_tiles

  ; Loop over each processing tile
  for i=0, num_tiles-1 do begin
    envi_report_stat, rbase, i, num_tiles, cancel=cancel
    if (cancel) then begin
      !error = envi_cancel_val()
      goto, trouble
    endif

    ; Retrieve the tile data
    data1 = envi_get_tile(tile_id1, i, ys=ys, ye=ye)
    data2 = envi_get_tile(tile_id2, i)
```

```
      ; Perform the ratio
      if (keyword_set(check)) then begin
        ; Find all the locations where the band is zero
        temp = float(data1) - data2
        ptr = where(temp eq 0.0, count)

        ; Temporarly set the divide by zero cases to divide
        ; by 1, do the ratio, and then set the divide by zero
        ; to div_zero
        if (count gt 0) then $
          temp(ptr) = 1

        result = (float(data1) + data2) / temp

        if (count gt 0) then $
          result(ptr) = div_zero

      endif else begin

        ; Just do the ratio and ignore divide by zeros
        result = (float(data1) + data2) / $
          (float(data1) - data2)
      endelse

      if (in_memory) then $
        mem_res(0,ys-dims(3)) = result $
      else $
        writeu, unit, result

    endfor

    ; Process error messages
    !error = 0
  trouble: if (!error ne 0) then $
    envi_io_error, 'Ratio Processing', unit=unit
    free_lun, unit

    if (!error eq 0) then begin
      descrip = 'Ratio Processing'
      if (in_memory) then $
        envi_enter_data, mem_res, descrip=descrip, $
        xstart=xstart+dims(1), ystart=ystart+dims(3), $
        r_fid=r_fid $
      else $
        envi_setup_head, fname=out_name, ns=ns, nl=nl, nb=1, $
          data_type=4,interleave=0, xstart=xstart+dims(1), $
          ystart=ystart+dims(3), /write, /open, r_fid=r_fid, $
          descrip=descrip
```

```
  endif

  ; Clean up the tile pointer and the status report
  envi_tile_done, tile_id1
  envi_tile_done, tile_id2
  envi_report_init, base=rbase, /finish
end

pro tp_divz2, ev
  widget_control, ev.id, get_uvalue=uvalue

  if (uvalue eq 'user ratio') then begin

    envi_select, title='Ratio Input File', fid=fid, dims=dims, $
      pos=pos
    if (fid eq -1) then return

    ; We will just do a ratio of the first two band
    ; from the pos array so make sure there are at
    ; least two bands are selected
    if (n_elements(pos) lt 2) then begin
      mstr = 'You must select two bands to ratio.'
      envi_error, mstr, /warning
      return
    endif

    ; Create a compound widget for the input parameters
    base = widget_auto_base(title='Ratio Parameters')
    sb  = widget_base(base, /column, /frame)
    sb1  = widget_base(sb, /row)
    mw   = widget_menu(sb1, prompt='Check for divide by 0 ? ', $
      list=['Yes','No'], /excl, default_ptr=0, rows=0, $
        uvalue='check', /auto)
    sb1  = widget_base(sb, /row)
    wp   = widget_param(sb1, prompt='Divide by zero value', $
      dt=4, field=3, xs=6, uvalue='div_zero', default=0.0, /auto)

    sb   = widget_base(base, /column, /frame)
    ofw  = widget_outfm(sb, func='envi_out_check', $
      uvalue='outf', /auto)

    ; Automanage the widget
    result = auto_wid_mng(base)
    if (result.accept eq 0) then return
    check = (result.check eq 0)
    div_zero = result.div_zero

    tp_divz_doit, fid=fid, pos=pos, dims=dims, check=check, $
      out_name=result.outf.name, div_zero=div_zero, $
```

```
        in_memory=result.outf.in_memory
    endif
  end
```

Compile the Tile Processing Routine

To compile the updated tile processing routine:

1. Select **File** → **Compile IDL Module** from the ENVI main menu.
2. In the **Enter Module Filename** dialog, navigate to the location of the saved function, `tp_divz2.pro`, and select the file.
3. To make sure that the function compiled, look in the IDL command window.

   On Windows and Macintosh, this is the output log window. On UNIX, it is the shell window from which ENVI was started. The following line will appear if the module compiled successfully:

   ```
   % Compiled module TP_DIVZ2
   ```
4. Edit and fix any errors for modules that did not compile successfully.

Run the Tile Processing Routine

1. Select **User Functions** → **User Band Ratio2**.
2. When the **Ratio Input File** selection dialog appears, select `bldr_tm.img` in the “Select Input File” field.
3. Click the **Spectral Subset** button.
4. In the **File Spectral Subset** dialog, select only bands 2 and 3 (hold the **Shift** key down while clicking make more than one selection), and click **OK**.
5. In the **Ratio Input File** selection dialog, click **OK**. The **Ratio Exercise Parameters** dialog will appear and allow the selection of divide by zero checking, replacement value, and output to memory or file.
6. Select the **Yes** button for “Check for divide by 0”.
7. Enter 1.0 for “Divide by zero value”.
8. Select the **File** button, enter a filename, and click **OK**.

The resulting image will be placed into the **Available Bands List** dialog.

Display the Result

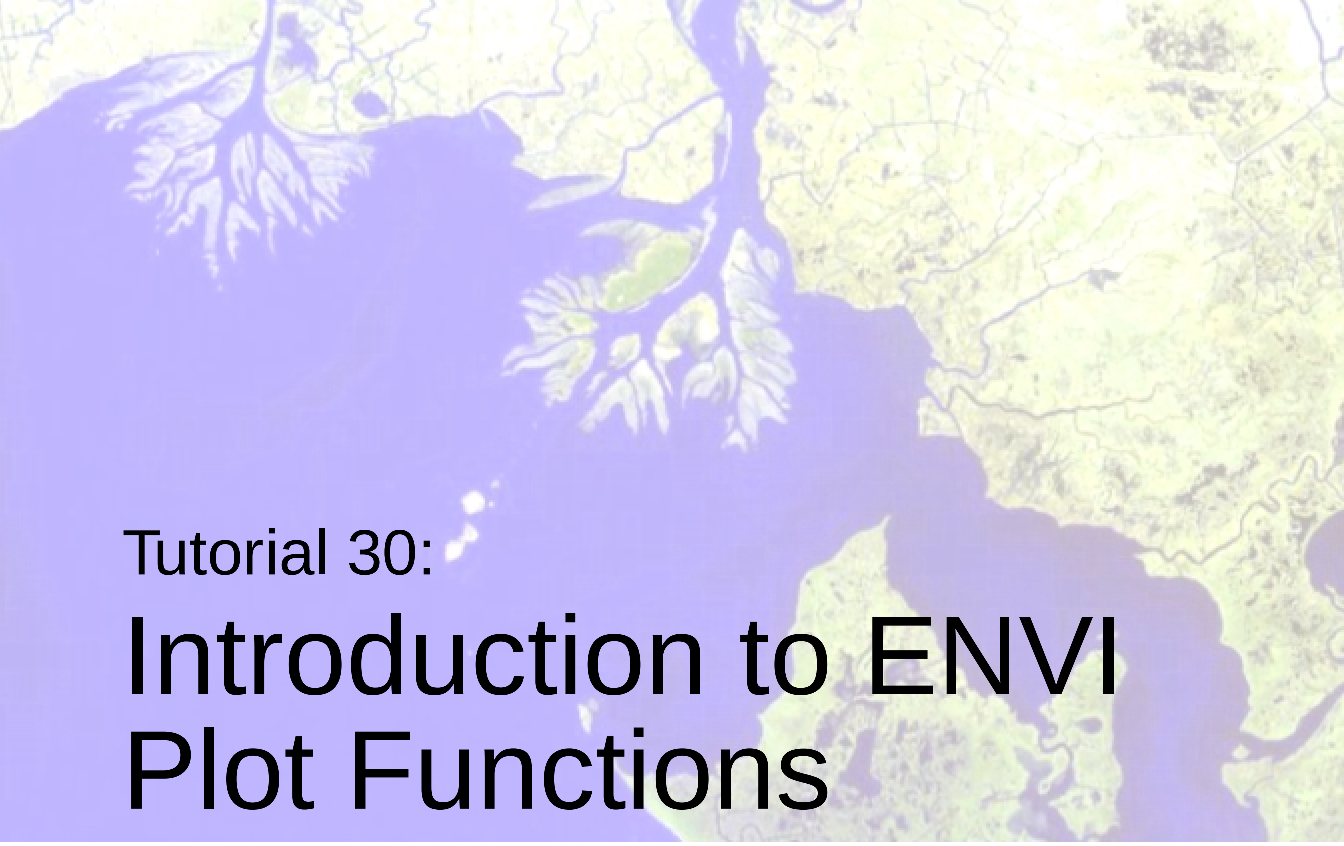
Select the newly created band in the **Available Bands List** dialog and click **Load Band** to display the image. This image should be the same as the Band Math example for the case that checked for divide by zero values.

Notes on Autocompiling

The two routines created in this tutorial can be set up to autocompile for future ENVI sessions. To autocompile, place the two `.pro` files in the `save_add` directory of the ENVI installation and restart ENVI. They will be compiled whenever ENVI is started.

End the ENVI Session

This concludes the tutorial. You can quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) from the ENVI main menu, then click **Yes**.



Tutorial 30: Introduction to ENVI Plot Functions

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial provides information on how to implement an ENVI "Plot Function". This is a user-defined function called from the "Plot Function" pulldown menu on any ENVI plot window. This exercise covers the basics for creating user-defined plot functions and setting up the ENVI "useradd.txt" file to enable automatic installation of the functions in the plot menu structure.This tutorial assumes that you are familiar with the "Interactive Data Language (IDL)" and understand how to write functions and procedures in IDL. ENVI Runtime users cannot program in IDL, however, the plot functions provided with this tutorial can be viewed with any text editor and installed for use with either ENVI or ENVI Runtime.

Files Used in This Tutorial

CD-ROM: *ENVI 3.5 Tutorial and Data CD No. 2*

Path: `envidata/user_fun`
`envidata/cup95avsub`
`envidata/spec_lib`

File	Description
Required Files (`envidata/user_fun`)	
`pf_1st_derivative.pro`	Plot function to take the 1st derivative of a spectrum
`pf_2nd_derivative.pro`	Plot function to take the 2nd derivative of a spectrum
`useradd.txt`	Modified (replacement) version of useradd.txt
Required Files (`envidata/cup95avsub`)	
`cup95eff.int`	Cuprite Effort-Corrected ATREM calibrated apparent reflectance data 50 bands (integer).
Required Files (`envidata/spec_lib`)	
`usgs_min.sli`	USGS mineral spectral library
`usgs_min.hdr`	ENVI Header for above

ENVI Plot Functions

ENVI Plot Functions provide a method for applying algorithms to data in any plot window. When a plot function is selected, “normal” plot data (all the spectra in the plot window) are passed to the user-defined function. The plot function is applied to the data, and the results data are returned to the plot window where they are displayed. Once the plot function is selected, the function is applied to every spectrum placed in that window until a different plot function is selected.

ENVI provides a standard set of plot functions and also allows users to define custom plot functions. Custom plot functions are added to ENVI by entering the menu name and function into the `useradd.txt` file in the `menu` directory of the ENVI installation.

Creating a Plot Function

Plot functions can be created using the IDL editor, or any other text editor.

1. If you are running ENVI, select **File** → **Open** in the main IDL window. If you are using ENVI Runtime, start your text editor.
2. Navigate to the `envidata/user_fun` directory and open the file `pf_1st_derivative.pro`. You should see the following code:

   ```
   function pf_1st_derivative, x, y, bbl, bbl_list, _extra=_extra
   ptr= where (bbl_list eq 1, count)
   result = fltarr(n_elements(y))
   if (count ge 3) then $
      result(ptr) = deriv (x[ptr], y[ptr])
   return, result
   end
   ```

   This function accepts the X and Y data, a list of bad bands, and excluding the bad bands takes the first derivative of the Y value and returns it to the plot window. For additional information on specific function parameters, see “plot function” in the *ENVI User’s Guide* or On-Line Help.
3. Follow the same procedure to open the file `pf_2nd_derivtive.pro`. When you are satisfied that you understand how the functions work, close the files and continue.

Adding the Plot Function

Add the plot function by editing the `useradd.txt` file:

1. If you are running ENVI, select **File** → **Open** in the main IDL window. If you are using ENVI Runtime, start your text editor.
2. Navigate to the USER_FUN directory and open the file “useradd.txt”. You should see the following:

```
{plot} {Normal} {sp_normal} {type=0}
{plot} {Continuum Removed} {sp_continuum_removed} {type=1}
{plot} {Binary Encoding} {sp_binary_encoding} {type=0}
{plot} {1st Derivative} {pf_1st_derivative} {type=0}
{plot} {2nd Derivative} {pf_2nd_derivative} {type=0}

{identify} {Spectral Angle Mapper} {SAM} {envi_identify_sam} {0,.78539816}
{identify} {Spectral Feature Fitting} {SFF} {envi_identify_sff} {0,.1}
{identify} {Binary Encoding} {BE} {envi_identify_be} {0,1.}
```

   Plot functions use the {plot} tag to differentiate them from other functions. The format for a plot function is:

   {plot} {Button Name} {function_name} {type=n}

   where

   {plot} = Tag to indicate the following definition is a plot function.

   {Button Name} = Menu button name for the Plot Functions pulldown menu.

   {function_name} = Name of the plot function to call.

   {type=n} = Type of plot function updates. Set type=0 to call the plot function only when new data is available. Set type=1 to call the plot function when new data is available or the plot is zoomed.

3. Observe the plot function calls for the `pf_1st_derivative` and `pf_2nd_derivative` functions. When you are satisfied you understand the calls, close the editor and continue.

Set up ENVI to Run the Plot Functions

ENVI requires that IDL functions be located in the ENVI `save_add` directory. The `useradd.txt` file should be in the ENVI `menu` directory.

Use the appropriate operating system routines (eg: “cp” on UNIX, or Windows Explorer on Microsoft Windows) to copy these files to the appropriate directories.

Running the Plot Function

Start ENVI

Before attempting to start the program, ensure that ENVI is properly installed as described in the installation guide.

- To open ENVI in UNIX, enter `envi` at the UNIX command line.
- To open ENVI from a Windows or Macintosh system, double-click on the ENVI icon.

The ENVI main menu will appear when the program has successfully loaded and executed.

Open a Spectral Library and Plot Spectra

1. Select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer** from the ENVI main menu and click **Open Spectral Library** at the bottom of the **Spectral Library Input File** dialog.
2. Navigate to the `usgs_min` directory, and open the Spectral Library file `usgs_min.sli`. Click **OK** at the bottom of the **Spectral Library Input File** dialog to display the **Spectral Library Viewer** dialog.
3. Click on one or more spectra in **Spectral Library Viewer** dialog to display library spectra in a **Spectral Library Plots** window.

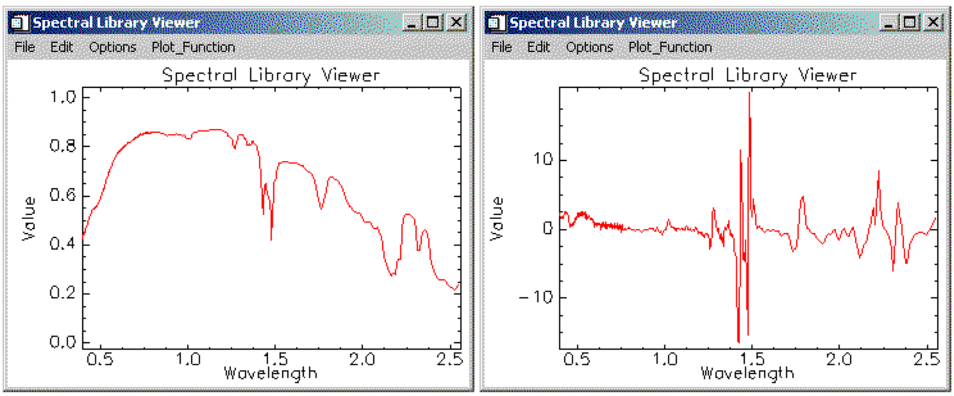


Figure 30-1: “Normal “spectrum (left), and 1st Derivative spectrum (right)

4. Select **Plot Function** → **1st Derivative** from the pulldown menu at the top of the Plot Window to utilize the Plot Function `pf_1st_deriv.pro`. The 1st derivative spectra of all plots will calculated and be displayed in the plot window.
5. Select **Plot Function** → **2nd Derivative** from the pulldown menu at the top of the Plot Window to utilize the Plot Function `pf_2nd_deriv.pro`. The 2nd derivative spectra of all plots will calculated and be displayed in the plot window.
6. Select **Plot Function** → **Normal** to return to the standard reflectance spectrum.

End the ENVI Session

This concludes the Plot Function Tutorial. You quit your ENVI session by selecting **File** → **Exit** (**Quit** on UNIX) on the ENVI main menu, then click **OK** to exit IDL. If you are using ENVI RT, quitting ENVI will take you back to your operating system.