ERS 186L

Environmental Remote Sensing

Lab Spring 2011

University of California Davis

Instructor: Susan L. Ustin

TAs: Paul Haverkamp & Sean Hogan

ERS186L – Environmental Remote Sensing Lab

Spring 2011

Location: 1137 PES
Hours: 10:00-11:50, T, Th
Door code and computer access information will be provided to registered students on the first day of lab.

Base Directory: My Documents\ERS_186\Lab_Data
Your Directory: My Documents\ERS_186\[*your name*]

Schedule

Date	Lab*	Topic
March 29	L1	Introduction to ENVI
March 31	L1, A1	Fieldwork Exercise, Introduction to ENVI, Image Exploration Assignment
April 5	A1	Fieldwork Exercise, Image Exploration Assignment
April 7	L2	Georegistration & Mosaicking
April 12	L3, A2	Vector Data, Georegistration Assignment
April 14	A2	Georegistration Assignment, cont.
April 19	L4	Data Reduction I: Indexes
April 21	L5	Data Reduction II: Principal Components
April 26	L6	Unsupervised and Supervised Classification
April 28	A3	Classification & Data Reduction Assignment
May 3	A3	Classification & Data Reduction Assignment, cont.
May 5	A3	Classification & Data Reduction Assignment, cont.
May 10	L7, A4	Change Detection Lab, Change Detection Assignment
May 12	L8, A4	Map Composition Lab, Change Detection Assignment, cont.
May 17	A4	Change Detection Assignment, cont.
May 19	A4	Change Detection Assignment, cont.
May 24	L9	Wildfire Exercise Lab
May 26	L10,A5	Spectral Mapping and Unmixing Lab & Assignment
May 31	L11,A5	LIDAR Lab Exercise, Spectral Mapping and Unmixing Assignment, cont.
June 2	A6	LIDAR Assignment

* LX = Lab exercise #X; AX = Lab Assignment #X.

Lab Exercises
You will complete 11 lab exercise tutorials in ERS186L. These tutorials have been designed to familiarize you with common image processing tools and will provide you with the background and skills necessary to complete your assignments. In addition, there will be two days of fieldwork exercises to introduce you the data collection techniques corresponding to remote sensing research.

Assignments
There will be 5 lab assignments in ERS186L and each of these assignments will be worth 20% of your grade for the quarter. If you are unable to complete an assignment during the time provided in the lab sessions, check the computer lab's schedule and return to work on it when no classes are meeting. All assignments should be submitted by 8am on the day it is due to the ERS186L Smartsite page at smartsite.ucdavis.edu. Late work will be penalized.

All assignments must be submitted electronically in Microsoft word format. Please remember that your homework assignments must be clear, well-written, and of professional quality (include your name, titles/numbering, etc). You will be required to include screen shots of your work in your lab write-ups. These MUST be inserted into your Word document as JPEGs.

When submitting your assignments, please use the following file naming convention:
Last name, First name, Lab#, and the date submitted **(**i.e. **Doe_John_Lab4_05242011).**

Date	Lecture #	Lecture homework assigned or due	Lab homework assigned or due
29-Mar	Lecture 1	Homework 1 assigned	
31-Mar	Lecture 2		Homework 1 assigned
5-Apr	Lecture 3		
7-Apr	Lecture 4	**Homework 1 due**; HW 2 assigned	
12-Apr	Lecture 5		**Homework 1 due;** HW 2 assigned
14-Apr	Lecture 6		
19-Apr	Lecture 7	**Homework 2 due**	
21-Apr	1st midterm		
26-Apr	Lecture 9	Homework 3 assigned	**Homework 2 due;** HW 3 assigned
28-Apr	Lecture 10		
3-May	Lecture 11		
5-May	Lecture 12	**Homework 3 due;** HW 4 assigned	
10-May	Lecture 13		**Homework 3 due;** HW 4 assigned
12-May	Lecture 14		
17-May	Lecture 15	**Homework 4 due**	
19-May	2nd midterm		
24-May	Lecture 17	Homework 5 assigned	**Homework 4 due**
26-May	Lecture 18		HW 5 assigned
31-May	Lecture 19		
2-Jun	Lecture 20	**Homework 5 due**	Lab 6 - in class exercise
3-Jun			**Homework 5 due**
8-Jun	**Final: 1:00pm**		

ADAPTED FROM …

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ENVI Tutorials

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Tutorial 1: Getting Started with ENVI

The following topics are covered in this tutorial:

Overview of This Tutorial

Getting Started with ENVI

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 you to the basic concepts of the software and to explore some of its key features. If you are new to ENVI, this quick-start tutorial is designed to provide a quick demonstration of the product. The following exercises briefly introduce you to the graphical user interface and basic capabilities of ENVI.

Files Used in This Tutorial

Path: My Documents\ERS_186\Lab_Data\Multispectral\Landsat

File	Description
`Delta_LandsatTM_2008.img`	SF Bay-Delta, CA, TM Data
`Delta_LandsatTM_2008.hdr`	ENVI Header for Above
`Delta_classes_vector.evf`	ENVI Vector File

Working with ENVI

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

Note: In Windows, using a two-button mouse, you can simulate a middle mouse button click by holding down the Ctrl key and pressing the left mouse button. On a Macintosh with a one-button mouse, hold down the Option key while pressing the mouse button to simulate a right mouse button click. To simulate a middle mouse button click, hold down the Command key while pressing the mouse button.

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 also supports a variety of data types: byte, integer, unsigned integer, long integer, unsigned long integer, floating-point, double-precision floating-point, complex, double-precision complex, 64-bit integer, and unsigned 64-bit integer.

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 (sometimes 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 main menu bar, or by right-clicking on a file in the **Available Bands List** and selecting **Edit Header**. You can also generate ENVI header files outside ENVI, using a text editor.

Getting Started with ENVI

Starting ENVI

Select **Start → All Programs → ENVI 4.7 → ENVI**.

Loading a Grayscale Image

Open the multispectral Landsat Thematic Mapper (TM) data file of the San Francisco Bay and Sacramento-San Joaquin Delta, California, USA.

Open an Image File

To open an image file:

1. Select **File → Open Image File**.

   The Enter Data Filenames file selection dialog appears.

2. Navigate to C:\My Documents\Lab_Data\Multispectral\Landsat and select the file `Delta_LandsatTM_2008.img` from the input directory and click Open. The **Available Bands List** dialog that appears on your screen will allow you to select spectral bands for display and processing (Figure 1-1).

The Available Bands List

ENVI provides access to both image files and to the individual spectral bands in these files. The Available Bands List is a special ENVI dialog containing a list of all the available image bands in all open files, as well as any associated map information.

You can use the Available Bands List to load both color and grayscale images into a display by starting a new display or selecting the display number from the Display #N button menu at the bottom of the dialog, clicking on the Gray Scale or RGB radio button, then selecting the desired bands from the list by clicking on the band names.

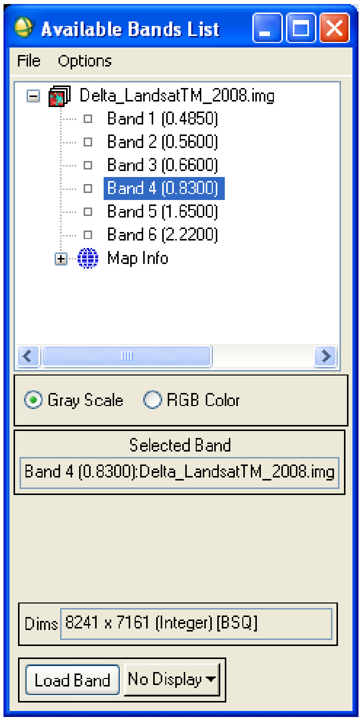


Figure 1-1: The Available Bands List

Tip: To load a single-band image, simply double-click on the band.

The File menu at the top of the Available Bands List dialog provides access to file opening and closing, file information, and canceling the Available Bands List. The Options menu provides a function to find the band closest to a specific wavelength, shows the currently displayed bands, allows toggling between full and shortened band names in the list, and provides 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.

Using the Available Bands List Shortcut Menus

Right-clicking in the Available Bands List displays a shortcut menu with access to different functions. The shortcut menu selections will differ depending on what item is currently selected (highlighted) in the Available Bands List. For example, right-clicking on the **Map Info** icon under a filename displays a shortcut menu for accessing map information in that file's header, whereas right-clicking on the filename displays a shortcut menu with selections to load the image or close the file.

1. Select **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:
2. 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.

Familiarizing Yourself with the Displays

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

Tip: You can choose which combination of windows appear on the screen by right-clicking in any image window to display the shortcut menu and selecting a style from the Display Window Style submenu.

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

1. Resize the **Main Image** window. Note how the size of the Image window affects the outlining box in the Scroll window.
2. 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 in the following sections.

The 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 Main Image window.

- To reposition the portion of the image shown in the Main Image window, position the mouse cursor inside the scroll control box, hold down the left mouse button, drag to the desired location, and release. The Main Image window is updated automatically when the mouse button is released.
- You can also reposition the cursor anywhere within the Scroll window and click the left mouse button to instantly move the selected Main Image window area. 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).
- Finally, you can reposition the image by clicking in the Scroll window and pressing the arrow keys on your keyboard. To move the image in larger increments, hold down the Shift key while using the arrow keys.

The Main Image Window

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

- 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.
- Alternately, you can reposition the cursor anywhere in the Main Image 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.
- Finally, you can move the Zoom indicator by clicking in the box and using the arrow keys on your keyboard. To move several pixels at a time, hold down the Shift key while using the arrow keys.
- 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, right-click in the image to display the shortcut menu and select **Toggle → Display Scroll Bars**.

> Tip: To have scroll bars always appear in the Main Image window by default, select **File → Preferences** from the ENVI main menu. Select the **Display Defaults** tab in the System Preferences dialog, and set the Image Window Scroll Bars toggle to **Yes**.

The Zoom Window

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

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

- 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.

- Move the Zoom window by clicking in it and using the arrow keys on your keyboard. To move several pixels at a time, hold down the Shift key while using the arrow keys.
- Clicking and holding the left mouse button in the Zoom window while dragging causes the Zoom window to pan within the Main Image display.
- Clicking the left mouse button on the – (minus) graphic in the lower left corner of the Zoom window zooms out by a factor of 1. Clicking the middle mouse button on this graphic zooms out to half the current magnification. 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 in the lower left corner of the Zoom window zooms in by a factor of 1. Clicking the middle mouse button doubles the current magnification. 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 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 control box in the Main Image window on or off.

Note: On Microsoft Windows systems with a two button mouse, click the Ctrl key and the left mouse button simultaneously to emulate the middle mouse button.

- The Zoom window can also have optional scroll bars, which provide an alternate method for moving through the Zoom window. To add scroll bars to the Zoom window, right-click in the Zoom window to display the shortcut menu and select **Toggle → Zoom Scroll Bars**.

Tip: To have scroll bars appear on the Zoom window by default, select **File → Preferences** from the ENVI main menu. Select the Display Defaults tab, and set the Zoom Window Scroll Bars toggle to **Yes**.

The Display Group Menu Bar

The 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. If you have chosen to display only the Scroll and Zoom windows or simply the Zoom window, the menu bar will appear at the top of the Zoom window.

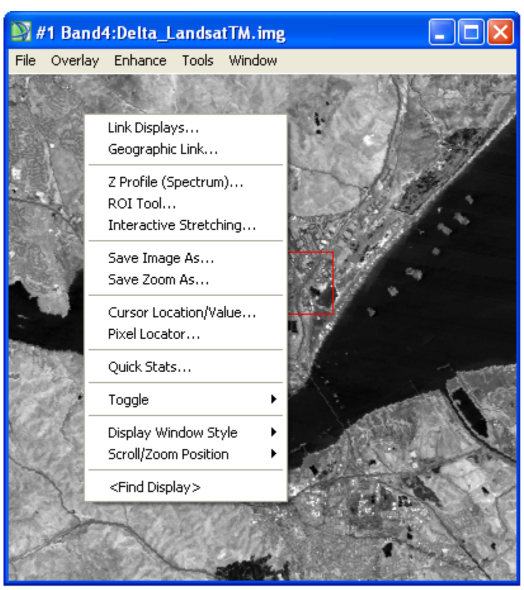


Figure 1-2: Image Display Shortcut Menu

Image Display Shortcut Menus

Each of the three display windows has a shortcut menu for accessing general display settings and some interactive functions.

To access the shortcut menu in any display window, right-click in the window (Figure 1-2).

Displaying the Cursor Location and Value

The cursor location and value can be obtained simply by passing the cursor over the Main Image, Scroll, or Zoom windows (Figure 1-3). The **Cursor Location/Value** dialog displays the location of the cursor in pixels starting from an origin in the upper-left corner of the Main Image window; and it also shows the RGB color values associated with that location. When the Cursor Location/Value dialog display is open, it shows the Main Image display number, cursor position, screen value (RGB color), and the actual data value of the pixel underneath the crosshair cursor. If your image has map information associated with it, the geographic position of your cursor location is also displayed. When several Main Image displays are open, the dialog specifies which display's location and value are being reported.

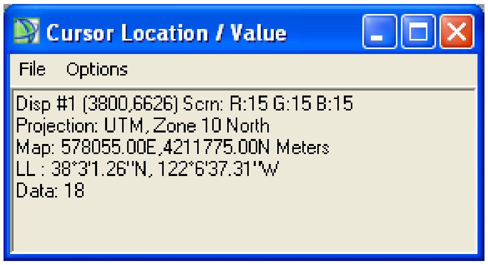


Figure 1-3: the Cursor Location/Value Dialog

- To display the cursor location and value, select **Window → Cursor Location/Value** from the ENVI main menu or the Main Image window menu bar, or right-click in the image window to display the shortcut menu and select **Cursor Location/Value** (Figure 1-3).
- To dismiss the dialog, select **File → Cancel** from the menu at the top of the Cursor Location /Value dialog.
- To hide/unhide the Cursor Location/Value dialog once it has been displayed, double-click using the left mouse button in the Main Image window.

Using the Pixel Locator

The Pixel Locator allows exact positioning of the cursor. You can manually enter a sample and line location to position the cursor in the center of the Zoom window. If an image contains georeferenced data, you can optionally locate pixels using map coordinates. If the image contains an associated DEM, elevation information displays. The Pixel Locator pertains to the display group from which it was opened. You can open a Pixel Locator for each display group shown on your screen.

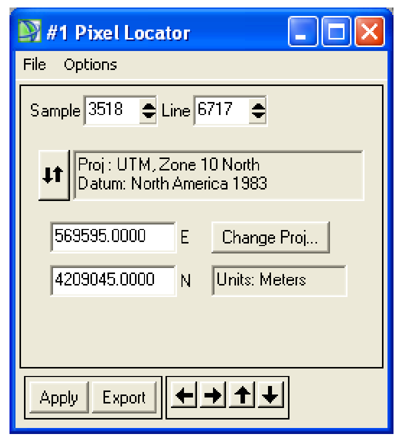


Figure 1-4: Pixel Locator Window

1. From the Image window menu bar, select **Tools → Pixel Locator** to open the Pixel Locator dialog (Figure 1-4).
2. Place the cursor in any of the three windows of the image display group and click the left mouse button. Notice that the Pixel Locator provides the pixel location for the selected pixel.
3. Skip around in the image by entering the X (sample) and Y (line) coordinates you wish to visit and click Apply.
4. Click the toggle button next to the projection field to toggle between true map coordinates and latitude/longitude geographic coordinates. You can also choose to change the selected projection by clicking the **Change Proj** button.
5. From the Pixel Locator dialog menu bar, select **File → Cancel** to close the Pixel Locator dialog.

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).

To display these profiles, perform the following steps.

6. 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).
7. 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).

Tip: You can also open a Z profile from the shortcut menu in any image window.

8. Select **Window** → **Mouse Button Descriptions** to view the descriptions of the mouse button actions in the Profile displays.
9. 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.
10. 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.
11. Close the profile plots by selecting **File** → **Cancel** from within each plot window.

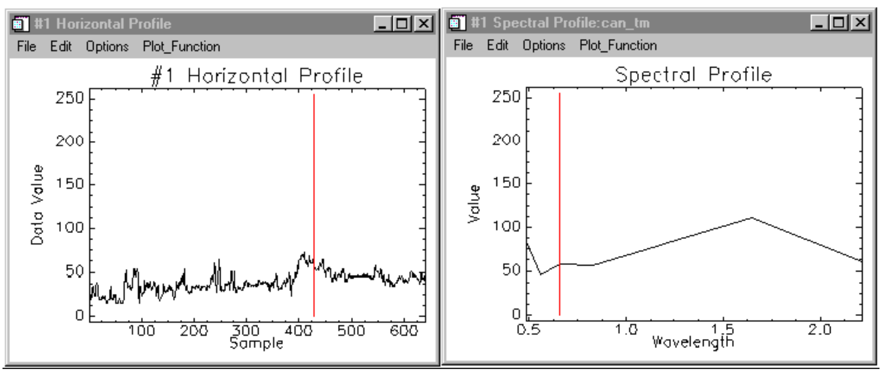


Figure 1-5: The Horizontal (X) Profile (left) and Spectral (Z) Profile (right) Plots

Collecting Spectra

When collecting spectral profiles in your image, you can "drag and drop" spectra from the z profile window into a new ENVI plot window.

1. In the Spectral Profile window, select **Options** → **Plot Key**. Or you can right click on the window and select plot key from the shortcut menu. The plot key default name is the x,y coordinates of the pixel you selected (Figure 1-6).
2. To collect spectra in the Spectral Profile window, select **Options** → **Collect Spectra**. Now navigate through your image. Each pixel you select will be plotted in the Spectral profile Window.

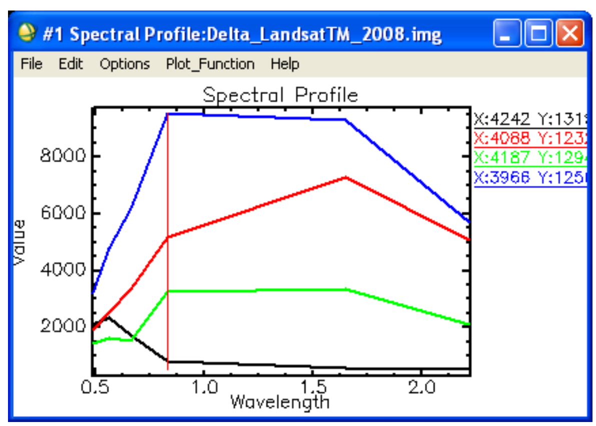


Figure 1-6: The Spectral Profile Window

3. To edit plot parameters, select **Edit**→ **Plot Parameters…** You can edit the x- and y-axis scale, names, and appearance of the plot.
4. To open a new ENVI plot window, select **Options** → **New Window: Blank…** to open a new window without plots, or **Options** → **New Window: With Plots…**

5. Drag the plot key of a spectrum from the Spectral Profile window to the new blank ENVI Plot Window.
6. To rename a spectrum, select **Edit→ Data Parameters**. You can change the name, and appearance of the line in this dialog.
7. To save a spectral plot as a spectral library (or an image file), select **File→ Save Plot As → Spectral library → Select All Items → OK →** Check Output Result to **Memory.** The spectral library will show up in your Available Bands List, and will be refered to later in this exercise.

Applying 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). This action 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.

Loading an RGB Image

ENVI allows you to simultaneously display multiple grayscale and/or RGB color composite images.

1. To load a color composite (RGB) image of the delta area, click on the Available Bands List.

> Note: If you dismissed the Available Bands List during the previous exercises, you can recall it by selecting **Window → Available Bands List** from the ENVI main menu bar.

2. Click on the **RGB Color** radio button in the Available Bands List. Red, Green, and Blue fields appear in the middle of the dialog.
3. Select Band 4, Band 3, and Band 2 sequentially from the list of bands at the top of the dialog by left-clicking on the band names. The band names are automatically entered in the Red, Green, and Blue fields.
4. Click on the **Display #** button at the bottom of the Available Bands List to open a New Display in which to load the RGB image.
5. Click **Load RGB** to load the image into a Main Image window.

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 the Main Image Display menu, select **Tools → Link → Link Displays**, or right-click in the image to display the shortcut menu and select **Link Displays**. The Link Displays dialog opens.
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.

You can turn off the dynamic overlay by right clicking in the image window and choosing **Dynamic Overlay Off**.

Mouse Button Functions with Dynamic Overlays Off

The following table specifies the mouse button functions for linked images when dynamic overlay is off.

Table 1-1: Mouse Button Functions – Linked Images without Dynamic Overlays

Mouse Button	Function
Left	Clicking and dragging inside the Zoom box causes repositioning of the selected Zoom window. The portion of the image displayed in the Zoom window is updated when released.
Middle	Position the current pixel at the center of the Zoom window.
Right	Click to display the right-click menu.

Linking Multi-Resolution Georeferenced Images

Use Geographic Link to link display groups and Vector windows containing georeferenced data. When linked, all displayed georeferenced images and Vector windows update to the current cursor map location when you move the cursor. This function works regardless of the projection, pixel size, and rotation factor of each data set. Geographic Link does not provide any on-the-fly reprojection, resampling, or dynamic overlay. To reproject and resample data sets to the same projection and resolution, see Layer Stacking.

To create a geographic link:

1. From the Display group menu bar, select **Tools →Link →Geographic Link**. The Geographic Link dialog displays.
2. Select the displays to link and click the associated toggle buttons to **On** to link the displays. Click OK.
3. When you move the cursor in one georeferenced Image or Vector window, the cursor in all other georeferenced images and vector windows will move to the same map location.

To turn a geographic link off:

1. From the Display group menu bar, select **Tools →Link →Geographic Link**. The Geographic Link dialog displays.
2. Click the toggle buttons beside the display names to select **Off** for the displays to unlink.
3. Click OK.

Editing ENVI Headers

Use Edit ENVI Header to edit existing header files. See Editing Header Files in ENVI Online Help for steps to open the Header Info dialog and edit required header information. See the next section for details about editing optional header information.

Entering Optional Header Information

ENVI headers may have associated ancillary information (band names, spectral library names, wavelengths, bad bands list, FWHM) depending on the image data type. In the Header Info dialog, click Edit Attributes and select the desired option to edit optional header information.

Editing Band Names or Spectral Library Names

You can edit the default names of bands or spectral libraries. The dialog to perform either of these functions is similar, so both are described here.

1. In the Header Info dialog, click **Edit Attributes** and select either:
    a. **Band Names** — The Edit Band Name values dialog appears.
    OR
    b. **Spectral Library Names** — The Edit Spectral Library Names values dialog appears.
2. Select the band name or spectral library name to change in the list. The name appears in the Edit Selected Item field.
3. Type the new name and press Enter. Click OK

Setting Default Bands to Load

You can identify bands to automatically load into the a new display group when you open the file. You can select either a gray scale image or a color image.

1. In the Header Info dialog, click **Edit Attributes** and select **Default Bands to Load**. The Default Bands to Load dialog appears with a list of all the bands in the file.
2. Select the band names to load in the red (R), green (G), and blue (B) options. If you select only one band, it is loaded as a gray scale image.
3. Click Reset to clear the bands. Click OK.

The Header Info dialog appears. When you open the file, ENVI automatically loads the bands into a new display group.

Editing Wavelengths or FWHM

1. In the Header Info dialog, click Edit Attributes and select either:
    a. **Wavelengths** — The Edit Wavelength values dialog appears.
    OR
    b. **FWHM** — The Edit FWHM values dialog appears.
2. Select the value to change in the list. The value appears in the Edit Selected Item field. Type the new value and press Enter.

In the **Wavelength/FWHM Units** drop-down list, select the units to use with your wavelength and FWHM values. The wavelength units are used to scale correctly between different wavelength units in ENVI's Endmember Collection dialog. For more information, see Collecting Endmember Spectra.

3. Click OK.

Selecting Bad Bands

Use Bad Bands List to select bands to exclude from plotting or optionally omit during processing. The Bad Bands list is often used to omit the water vapor bands in hyperspectral data sets.

1. In the Header Info dialog, click **Edit Attributes** and select **Bad Bands List**. The Edit Bad Bands List values dialog appears.
2. All bands in the list are highlighted by default as good. Deselect any desired bands in order to designate them as bad bands.
3. To designate a range of bands, enter the beginning and ending band numbers in the fields next to the **Add Range** button. Click **Add Range**.
4. Click OK.

Changing Z Plot Information

Use Z Plot Information to change Z profiles, set axes titles, set a Z Plot box size, or specify an additional Z profile filename.

1. In the Header Info dialog, click **Edit Attributes** and select **Z Plot Information**. The Edit Z Plot Information dialog appears.
2. Enter the minimum range value in the left and maximum value in the Z Plot Range fields.
3. Enter the desired axes titles in the X Axis Title and Y Axis Title fields.
4. To specify the size (in pixels) of the box used to calculate an average spectrum, enter the parameters into the Z Plot Average Box fields.
5. To specify an additional filename from which to extract Z profiles, click **Default Additional Z Profiles**. The Default Additional Z Profiles dialog appears.
6. Click **Add New File**.
7. Select the desired filename and click OK. The filename appears in the list.
8. To remove a filename from the list, select the filename and click **Remove Selected File**.
9. Click OK, then click OK again.

Entering a Reflectance Scale Factor

Use Reflectance Scale Factor to enter a reflectance scale factor that is used in ENVI's Endmember Collection to correctly scale library data or other reflectance data to match the image data. If one of the files used in the Endmember Collection does not have a reflectance scale factor defined, then no scaling is done.

1. In the Header Info dialog, click **Edit Attributes** and select **Reflectance Scale Factor**.
2. Enter the value that, when divided into your data, would scale it from 0 to 1. For example, if the value of 10,000 in your data represents a reflectance value of 1.0, enter a reflectance scale factor of 10,000.
3. Click OK. The Header Info dialog appears.

Entering Sensor Types

1. In the Header Info dialog, click **Edit Attributes** and select **Sensor Type**.
2. From the list, select a sensor type.

Setting the Default Stretch

Use Default Stretch to set the default stretch to use when displaying a band from the file.

1. In the Header Info dialog, click **Edit Attributes** and select **Default Stretch**.
2. From the Default Stretch menu, select the stretch type. Your choices include: linear, linear range, gaussian, equalize, square root, or none.
3. Some of the stretches require you to enter additional information: For the % Linear stretch, enter the percentage of the data to clip (for example. 5%).
4. For Linear Range stretching, enter the minimum and maximum DN values to use in the stretch.
5. For Gaussian stretching, enter the number of standard deviations to use in the stretch.

6. Click OK. ENVI saves the stretch setting in the .hdr file. Whenever you display this image, this stretch setting overrides the global default stretch given in the envi.cfg file.

Note: If the Default Stretch is set to None, ENVI uses the Default Stretch set in your ENVI preferences.

Applying a Color Map

By default, ENVI displays images using a gray scale 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** to uncheck this feature. If the auto apply is off, 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 dialog.

Animating Your Image

You can animate a multiband image by cycling through the bands of the image sequentially.

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 is 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 Animation window menu bar to end the animation.

Using Scatter Plots and Regions of Interest

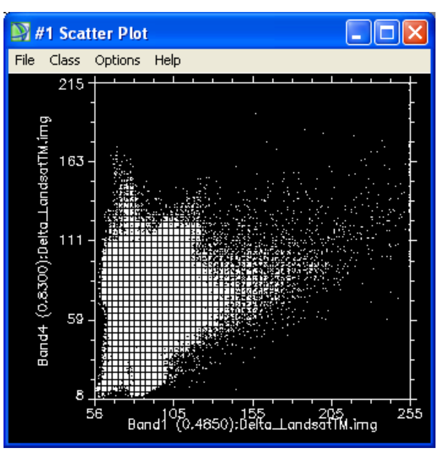


Figure 1-7: 2-d scatter plot of Landsat TM bands 1(x-axis) and band 4 (y-axis)

Scatter plots allow you to quickly compare the values in two spectral bands simultaneously. ENVI scatter plots enable a 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→ 2D Scatter Plots** from the Main Image window. 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 (Figure 1-7).

3. Place the cursor in the Main Image window, then click and drag the left mouse button, moving the cursor around in the window. Be sure not to click and drag the mouse cursor inside the zoom box in the

window. As you move the cursor, you will notice different pixels are highlighted in the scatter plot, making the pixels appear to "dance." The dancing pixels in the display are the highlighted 2-band pixel values found in a 10-pixel by 10-pixel region centered on the cursor.

4. Define a region of interest (ROI) in the Scatter Plot window. To do this, click the left mouse button several times in different areas in the Scatter Plot window. Doing this selects points to be the vertices of a polygon. Click the right mouse button when you are done selecting vertices. This closes the polygon. Pixels in the Main 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 ROI class, do one of the following:
   - Select **Class → New** from the Scatter Plot menu and repeat the actions described in the step 4. By default, the new ROI class is assigned the next unused color sequentially in the Items 1:20 color list.

   OR

   - Select **Class → Items #:#** from the Scatter Plot menu. Choose the color for your next class and repeat the actions described in the step 4.
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 window by selecting **Overlay → Region of Interest** from the menu bar. 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.
8. In the Scatter Plot window, close the scatter plot by selecting **File → Cancel**.

Classifying an Image

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

1. From the ENVI main menu bar, select **Classification → Supervised → Parallelepiped**.
2. In the Classification Input File dialog, select `Delta_LandsatTM_2008.img` and click OK.
3. When the Parallelepiped Parameters dialog appears, select the regions of interest (ROIs) you just created above, by clicking on the region name in the **Select Classes from Regions** list at the left of the dialog.
4. Select **Memory** in the upper right corner of the dialog to output the result to memory.
5. 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 then calculates statistics and a progress window appears during the classification. A new entry titled, `Parallel(Delta_LandsatTM_2008.img)` is added to the Available Bands List.
6. Select **New Display** from the Display #1 menu button in the Available Bands List.
7. In the Available Bands List, select the Gray Scale radio button, click on `Parallel (Delta_LandsatTM_2008.img),` and select Load Band. A new display group is created, containing the classified image.

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 Display menu, select **Overlay → Region of Interest**, or right-click in the image to display the shortcut menu and select ROI Tool.

   The ROI Tool dialog for that display will appear (Figure 1-8).

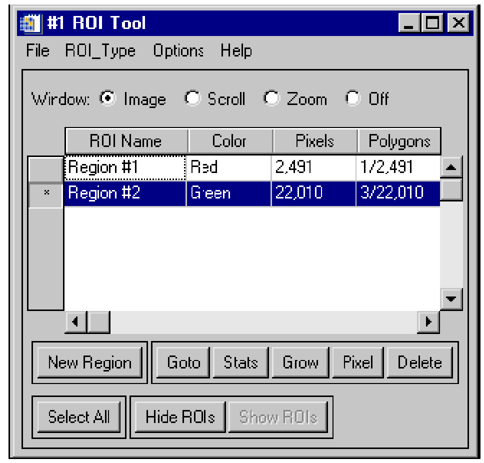


Figure 1-8: ROI Tool

2. To 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 table, with the name, region color, number of pixels enclosed, and other ROI properties (Figure 1-8).

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 editing the values in the cells of the table.

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 User's Guide or the hypertext online help for further discussion of these types of ROIs.

Working with ROIs

You can define as many ROIs as you wish in any image.

Once you have created the ROIs, their definitions are listed in the ROI Tool table. The table allows you to perform the following tasks.

- Select an ROI by clicking in a cell of the far left column (also known as the Current Selection column) of the table. An ROI is selected when its entire row is highlighted. An asterisk in this column also signifies the currently active ROI. Multiple ROIs can be selected by using a Shift-click or Ctrl-click. All the ROIs can be selected by clicking the Select All button.
- Hide ROIs by selecting them in the table and then clicking the **Hide ROIs** button. Use the **Show ROIs** button to re-display these hidden ROIs.
- Go to an ROI in the ENVI display by selecting it and then clicking the **Goto** button.
- View the statistics for one or more ROIs by selecting them in the table and then clicking the **Stats** button.

- Grow an ROI to its neighboring pixels within a specified threshold by selecting it and then clicking the **Grow** button.
- Pixelate polygon and polyline ROIs by selecting them in the table and then clicking the **Pixel** button. Pixelated objects become a collection of editable points.
- Delete ROIs by selecting them in the table and then clicking the **Delete** button.

The table also allows you to view and edit various ROI properties, such as name, color, and fill pattern. The other options under the pull-down menus at the top of the ROI Tool dialog let you perform various other tasks, such as calculate ROI means, save your ROI definitions, and load saved definitions.

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

Overlaying and Working with Vectors

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

1. Re-display the grayscale image by clicking on 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** from the menu bar of the ENVI main menu. In the Select Vector Filenames dialog, navigate to the My Documents\ERS_186\Lab_Data\Multispectral directory and open `Delta_classes_vector.evf` file. The Available Vectors List dialog appears listing the file you selected.
3. Click on the vector layer name and examine the information about the layer at the bottom of the Available Vectors List.
4. Click on **Select All Layers** near the bottom of the dialog to select all of the listed vectors to plot. Click on the Load Selected button to load all the layers to the image display.
5. When the Load Vector Layer dialog appears, click on Display #1 to load the vectors into the first display. The vector layers are listed in the #1 Vector Parameters dialog.
6. In the **Display #1 Vector Parameters** dialog, click **Apply** 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.
7. To display the currently selected vector layer and list basic information about the vectors, click and drag using the left mouse button in the Main Image window.
   - When other layers are present, you can click on another layer name in the Vector Parameters dialog and then click and drag in the Main Image display to track a different layer.
8. Edit the layer display characteristics by clicking on the **Edit → Edit Layer Properties** button in the Vector Parameters dialog.
   - Change vector layer parameters as desired and click OK.

   Note: You may right click on the color option boxes to select your color preference from a drop down menu.

   - In the #1 Vector Parameters dialog, click **Apply** to display the changes.

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):

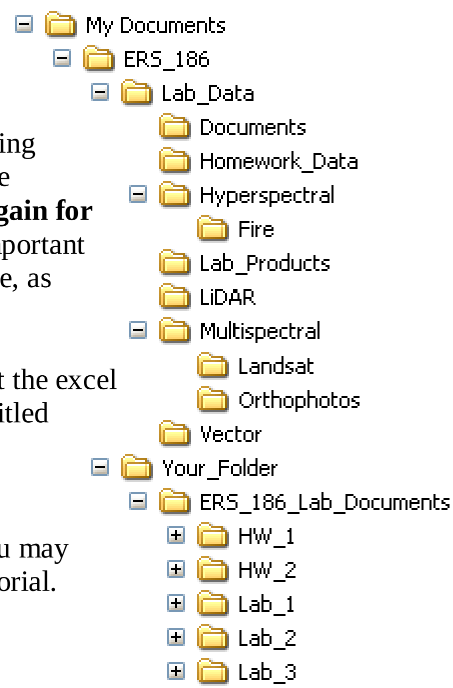
1. From the Main Image window menu bar, select **File → Save Image As → Image File**. The Output Display to Image File dialog appears.
2. Select 24-Bit color or 8-Bit grayscale output, graphics options (including annotation and gridlines), and borders. If you have left your annotated and gridded color 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.

Keeping track of your data products



When performing remote sensing analyses, you often create multiple data products from a single (or multiple) input. Being able to keep track of your work, and link inputs to outputs can help further your understanding of the flow of the analysis, as well as inform your interpretation of remote sensing results. And, of course, **this will help you find your products again for later use** (as you will be required to do in this course). Therefore, it is important to have a file-structure that is well organized, and easy for you to navigate, as well as to carefully document your inputs and outputs.

For the remainder of this course, we **strongly recomend** that you fill out the excel spreadsheets located in MyDocuments\ERS_186\Lab_Data\Documents titled

- `Data_products_record_example.xls` and
- `Georeg_tracking_info_example.xls`

These spreadsheets have been partially filled out as examples of how you may record your input and output files during or after completing each lab/tutorial.

End the ENVI Session

Tutorial 2.1: 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 User's Guide or the ENVI Online Help.

Files Used in this Tutorial

Input Path: My Documents\ERS_186\Lab_Data\Multispectral\Orthophotos

Output Path: My Documents\ERS_186\your_folder\lab_2

Input Files	Description
`Delta_orthophoto01.tif`	
`Delta_orthophoto02.tif`	
`Delta_orthophoto03.tif`	
`Delta_orthophoto04.tif`	
`Delta_orthophoto05.tif`	
`Delta_orthophoto06.tif`	
`Delta_orthophoto07.tif`	
`Delta_orthophoto08.tif`	Delta, CA, Digital Ortho Photos
`Delta_orthophoto09.tif`	
`Delta_orthophoto10.tif`	
`Delta_orthophoto11.tif`	
`Delta_orthophoto12.tif`	
`Delta_orthophoto13.tif`	
`Delta_orthophoto14.tif`	

Output Files	Description
`Delta_ortho_mos`	Georeferenced virtual mosaic

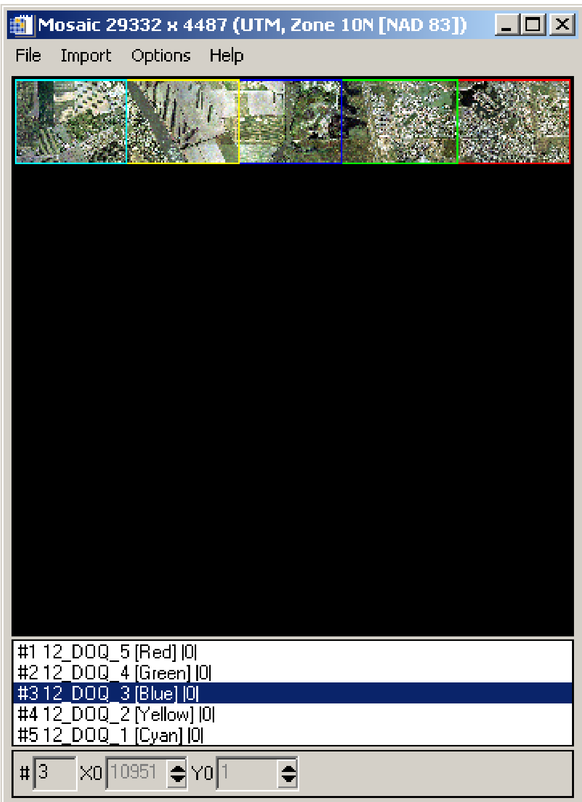
Mosaicking in ENVI

Use mosaicking to overlay two or more images that have overlapping areas (typically georeferenced) or to put together a variety of non-overlapping images and/or plots for presentation output (typically pixel-based). For more information on pixel-based mosaicking, see ENVI Online help. You can mosaic individual bands, entire files, and multi-resolution georeferenced images. You can use your mouse or pixel- or map-based coordinates to place images in mosaics and you can apply a feathering technique to blend image boundaries. You can save the mosaicked images as a virtual mosaic to avoid having to save an additional copy of the data to a disk file. Mosaic templates can also be saved and restored for other input files.

Virtual Mosaics

ENVI allows the 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).

Note: Feathering cannot be performed when creating a virtual mosaic in ENVI.



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.

Map Based Mosaicking Example

Putting together a mosaic of georeferenced images can take a lot of computing time. This section leads you through creation of georeferenced virtual mosaic of some orthophotos which can later be used as a base image to georeference your HyMap data.

Create the Map Based Mosaic Image

1. Open the orthophotos for this lab section in ENVI →**File** →**Open Image File** → My Documents\ERS_186\Lab_Data\Multispectral\Orthophotos. Note: You can open all of the orthophotos (`Delta_orthophoto01-14)` at once by holding down the shift key and selecting all of the files. Click Open.
2. Start the ENVI Georeferenced Mosaic function by selecting **Map → Mosaicking → Georeferenced** from the ENVI main menu. The Map Based Mosaic dialog appears.
3. Input and Position Images: To manually input the georeferenced images and set the background, import the images individually. Import -> Import Files and Edit Properties select input files, specifying the background value to ignore[1] (0) and the feathering distance (0). 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 (Figure 2-1).

[1] Use the Cursor Location/Value indicator in an image display to determine what the background value is.

Create the Output Virtual Mosiac

1. In the Mosaic widget, select **File → Save Template**. In the Output Mosaic Template dialog, select the appropriate output folder, and enter the output filename `Delta_ortho_mos`. Make sure the "Open Template as Virtual Mosaic?" is turned to "yes". Click OK to create the virtual mosaic.
2. Explore your mosaic and check for errors

Complete Your Data Products Spreadsheet

You have created one data product, `Delta_ortho_mos,` from the input files `Delta_orthophoto01-14.` Record this information, including file pathways, in your `your_name_data_products.xls` spreadsheet.

Tutorial 2.2.: 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 Registration using ENVI. It covers step-by-step procedures for successful registration. 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.

Files Used in this Tutorial

Input Path: My Documents\ERS_186\Lab_Data\Hyperspectral\

Output Path: My Documents\ERS_186\your_folder\lab_2

Input Files	Description
`Delta_HyMap_2008.img`	Delta, CA, HyMap Data for 2008
`Delta_ortho_mos.mos`	The virtual mosaic you created above

Output Files	Description
`Delta_HyMap_2008_geo.img`	Georeferenced Hymap File for 2008
`Delta_HyMap_2008_gcp.pts`	GCP file for Hymap File for 2008

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 User's Guide for additional information.

Georeferenced Data

Open and Display HyMap and Reference Data

1. Open the orthophoto virtual mosaic file that will be used as the base or reference image, `Delta_ortho_mos` and load it into display 1.
2. Open the Hymap file: `Delta_HyMap_2008.img` from My Documents\ERS_186\Lab_Data\Hyperspectral\ and load a true color image into display 2.

> Reminder: To load this image in true color: In the available bands list → click on the RGB Color radial button, then select bands 3, 2 and 1 consecuatively (so R is band 3, G is band 2, and B is band 1).

Edit Map Info in ENVI Header

1. In the Available Bands List, right click on the Map Info icon under the `Delta_Hymap_2008.img` filename and select Edit Map Information from the shortcut menu. The Edit Map Information dialog appears. 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 (latitude/longitude) coordinates.
2. Click on the arrow next to the **Projection/Datum** field to display the latitude/longitude coordinates for the UTM Zone 10 North map projection. ENVI makes this conversion on-the-fly.
3. Click on the active **DMS** or **DDEG** button to toggle between Degrees- Minutes- Seconds, and Decimal Degrees, respectively.
4. Click **Cancel** to exit the Edit Map Information 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.

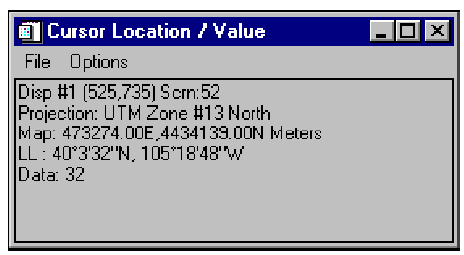


Figure 2-2: The Cursor Location Dialog Displaying Pixel and Georeferenced Coordinates

1. From the Main Image window menu bar, select **Tools → Cursor Location/Value**. You can also open this dialog from both the Main Image window menu bar, by selecting **Window → Cursor Location/Value,** or by right clicking the image itself and choosing Cursor Location/Value from the drop down menu. 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 (Figure 2-2).
3. Select **File → Cancel** to dismiss the dialog when finished.

Image to Image Registration

This section of the tutorial takes you step-by-step through an Image to Image registration. The georeferenced virtual mosaic of the orthophotos, **`Delta_ortho_mos`, will be used as the Base image**, and the coarsely georeferenced Hymap Delta images will be warped to match the orthophoto mosaic. Registration of multiple images can take several days. Often you will need to re-use gcps to register later image products. Therefore, in order to keep your work organized, **create a spreadsheet that records your work.**

Create Registration Spreadsheet

1. In My Documents\ERS_186\Lab_Data\Documents\ there is a file titled `Georeg_tracking_info_example.xls.` Open it and save it in My Documents\ERS_186\your_folder. Name it `your_name_georegistration.xls` and begin modifying it as you work.

Open and Display the Base and Warp Image Files

1. Open the base image, `Delta_ortho_mos` as a RGB into display 1.
2. If not already loaded, open the warp image, `Delta_Hymap_2008.img` as a True Color image in display 2 (by right clicking it in the Availible Bands List).

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 the Display containing the orthophoto virtual mosaic to select it. For the Warp Image select the Display containing the Hymap image.
3. Click OK to start the registration. This opens the Ground Control Points Selection dialog (Figure 2-3). Individual ground control points (GCPs) are added by positioning the cursor position in the two zoom images to the same ground location.
4. Navigate to a point in the base image and the warp image that show the exact same location (e.g. the end of a bridge) –Hint: You can right click on any of your images to use a Geographic Link for navigating to roughly the same location in your images, then unlink before fine-scale navigation. ***You must UNLINK before you begin your fine scale navigation!***
5. 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.
6. 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 (Figure 2-4). 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 5 points, the RMS error is reported.
7. Choose 20 pairs of points in your warp image subset (Hymap image) and the base image (orthophoto virtual mosaic) in the same manner that you chose the first pair. In order to achieve a good registration, it is extremely important to place your GCPs evenly throughout the image.

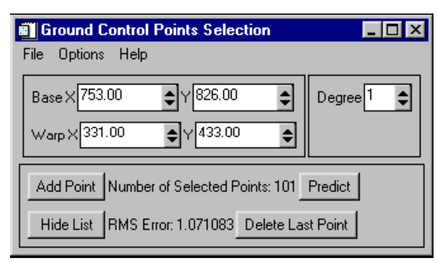
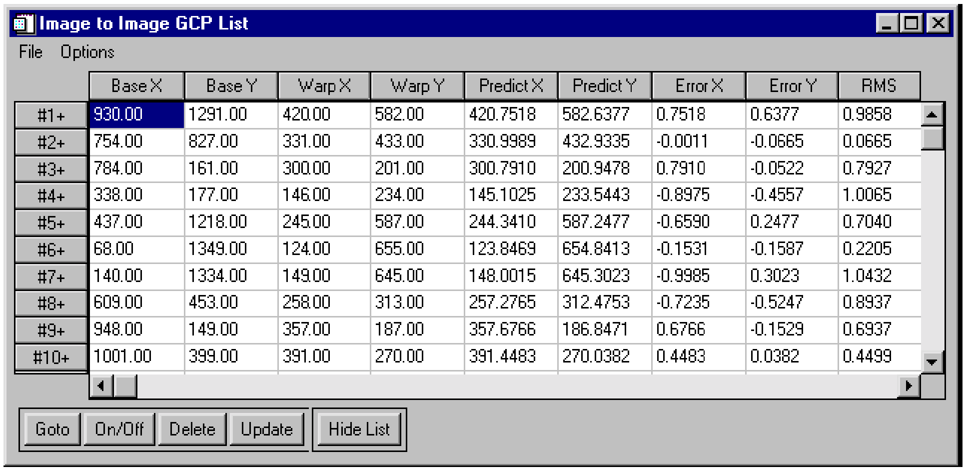


Figure 2-3: The Ground Control Points Selection Dialog for Image to Image Registration

8. After you are done selecting the 20 pairs, 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. In the GCP list you can order points by error (**Options→Order Points by Error**) to see which GCPs are contributing the most to your RMSE.



	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 2-4: Image to Image GCP List Dialog

Working with GCPs

- 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 base image (orthophoto). Click on the Predict button and the cursor position in the warp image (Hymap 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 warp image window.
3. In the Ground Control Points Selection dialog, click Add Point to add the new GCP to the list.
4. In the Image to Image GCP list dialog, select **Options → Order points by error**. Click on the pairs with maximum RMS error and try to refine their positions reducing the overall RMS error.
5. Once 20 pairs are selected, save your GCP points by selecting, **File → Save GCPs** to ASCII. Choose your output folder and give the name `Delta_Hymap_2008_gcp.pts` to the points file. Record the name of this file, where it is saved, how many points there are, and what the RMSE is in your `georeg_tracking_info.xls` spreadsheet.

Warp Images

Images can be warped from the displayed band, or all bands of multiband images can be warped at once. We will warp only 3 bands to reduce computing demand.

1. In the Ground Control Points Selection dialog, select **Options → Warp File (as image to map…).** Select warp image as `Delta_Hymap_2008`. Select a spectral subset with bands, 14, 8 and 2.
2. The Registration Parameters dialog appears (Figure 2-5). Use the Warp Method pulldown menu to select RST, and the Resampling button menu to select Nearest Neighbor resampling.
3. Change the X and Y pixel size to 3 m. **Press enter after changing each pixel size** to make sure that the output X and Y sizes are adjusted.
4. Choose **your** output folder, enter the filename `Delta_Hymap_2008_geo` and click OK. The warped image will be listed in the Available Bands List when the warp is completed.

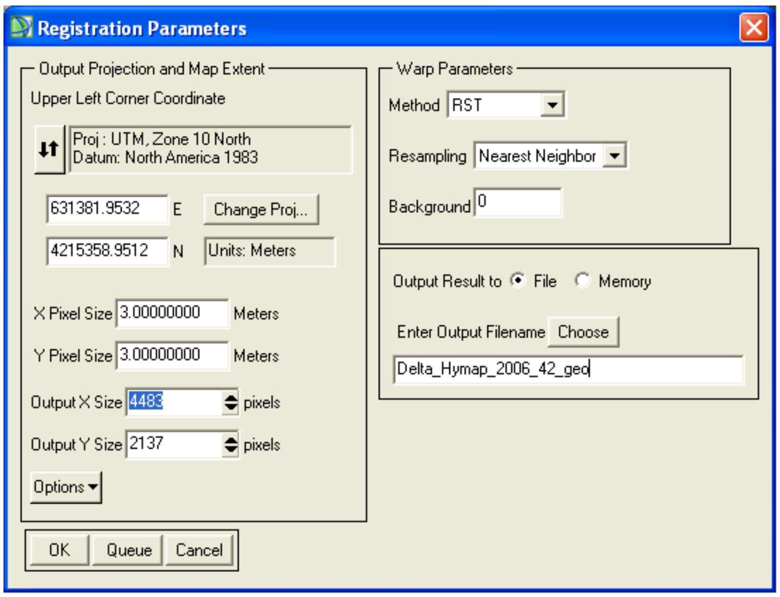


Figure 2-5: The Registration Parameters Dialog

Load the warped file to a new image window. Connect the orthophoto, original image, and warped image using the geographic link (Right-click in the Main Image Window and select Geographic Link). Toggle on the cursor crosshairs in each zoom window and click around the images. With the geographic link, pixels with the same geographic coordinates should be centered in each zoom window. Do the different images all line up? Has your georegistration improved the correspondence of the Hymap image to the orthophoto?

Complete Your Data Products Spreadsheet

You have created two data products, `Delta_Hymap_2008_gcp.pts` and `Delta_HyMap_2008_geo`, from the input files `Delta_orthophoto01-14`, and `Delta_HyMap_2008`. Record this information, including file pathways, in your `your_name_data_products.xls` spreadsheet.

Tutorial 3.1: Vector Overlay & GIS Analysis

The following topics are covered in this tutorial:

Stand alone vector GIS analysis, including input of shapefiles and associated DBF attribute files

Display in vector windows

Viewing and editing attribute data

Point and click spatial query

Overview of This Tutorial

This tutorial introduces ENVI's vector overlay and GIS analysis capabilities using vector data.

Part 1 of this tutorial demonstrates the following:

Stand-alone vector GIS analysis, including input of shapefiles and associated DBF attribute files
Display in vector windows
Viewing and editing attribute data
Point-and-click spatial query
Math and logical query operations

Part 2 of this tutorial demonstrates the following:

ENVI's combined image display/vector overlay and analysis capabilities

- Cursor tracking with attribute information
- Point-and-click spatial query
- Heads-up digitizing and vector layer editing

Generation of new vector layers using math and logical query operations
Raster-to-vector conversion of ENVI regions of interest (ROIs) and classification images
ENVI's vector-to-raster conversion, using vector query results to generate ROIs for extraction of image statistics and area calculation.

Files Used in This Tutorial

Path: MyDocuments\ERS_186\Lab_Data\vector, MyDocuments\ERS_186\Lab_Data\Multispectral

File	Description
`Bay_Delta_Preserves.shp`	Delta, CA, Vector data-polygons of Natural preserve boundaries
`2008_field_points.shp`	Delta, CA, Vector data-points of field data collected June 2006
`Delta_LandsatTM_2008.img`	Delta, CA, TM Data
`Delta_LandsatTM_2008.hdr`	ENVI Header for Above

Vector Overlay and GIS Concepts

Capabilities

ENVI provides extensive vector overlay and GIS analysis capabilities. These include the following:

Import support for industry-standard GIS file formats, including shapefiles and associated DBF attribute files, ArcInfo interchange files (.e00, uncompressed), MapInfo vector files (.mif) and attributes from associated .mid files, Microstation DGN vector files, DXF, and USGS DLG and SDTS formats. ENVI uses an internal ENVI Vector Format (EVF) to maximize performance.

Vector and image/vector display groups provide a stand-alone vector plot window for displaying vector data and composing vector maps. More importantly, ENVI provides vector overlays in display groups (Image windows, Scroll windows, and Zoom windows).

You can generate world boundary vector layers, including low- and high-resolution political boundaries, coastlines, and rivers, and USA state boundaries. You can display all of these in vector windows or overlay them in image display groups.

You can perform heads-up (on-screen) digitizing in a vector or raster display group. Heads-up digitizing provides an easy means of creating new vector layers by adding polygons, lines, or points.

Image- and vector window-based vector editing allows you to modify individual polygons, polylines, and points in vector layers using standard editing tools, taking full advantage of the image backdrop provided by raster images in ENVI.

ROIs, specific image contour values, classification images, and other raster processing results can be converted to vector format for use in GIS analysis.

Latitude/longitude and map coordinate information can be displayed and exported for image-to-map registration. Attribute information can be displayed in real-time as each vector is selected.

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 group, 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 vector attribute data. Edit existing information or replace 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. Export attribute records as ASCII text.

Query vector database attributes directly to extract information that meets specific search criteria. You can perform GIS analysis using simple mathematical functions and logical operators to produce new information and layers. Results can either be output to memory or to a file for later access.

You can set vector layer display characteristics and modify line types, fill types, colors, and symbols. Use attributes to control labels and symbol sizes. Add custom vector symbols.

You can reproject vector data from any map projection to another.

You can convert vector data to raster ROIs for extraction of statistics, calculation of areas, and use in ENVI's many raster analysis functions.

Generate maps using ENVI annotation in either vector or image windows. Set border widths and background colors, and configure graphics colors. 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 shapefiles and associated DBF attribute files and indices, or DXF files, from the internal ENVI Vector Format (EVF). New vector layers generated using ENVI's robust image processing capabilities, and changes made to vector layers in ENVI are exported to industry-standard GIS formats.

Concepts

ENVI's vector overlay and GIS analysis functions generally follow the same paradigms as ENVI's raster processing routines, including the same procedures for opening files and the use of standard dialogs for output to memory or file. The following sections describe some of the basic concepts.

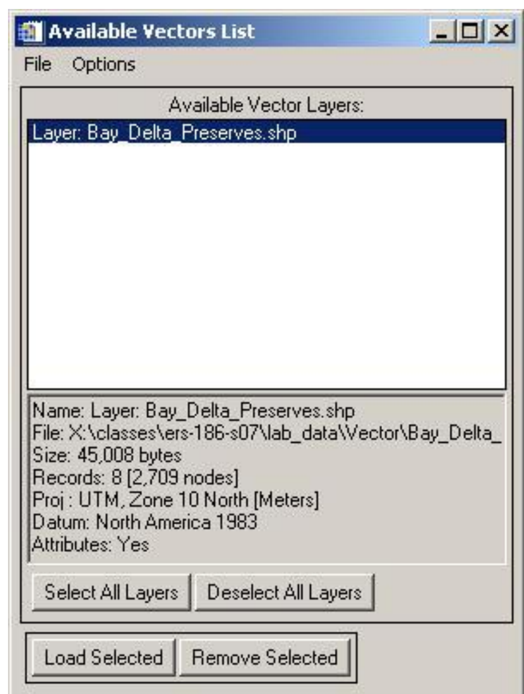


Figure 3-1: The Available Vectors List

ENVI Vector Files (.evf)

External vector files imported into ENVI are automatically converted into EVF, with the default file extension .evf. The EVF format speeds processing and optimizes data storage. When you select output to memory (instead of to a file), ENVI retains the external vector format without creating an EVF file.

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. It appears when needed, or you can invoke it by selecting **Window → Available Vectors List** from the ENVI main menu bar (Figure 3-1). Vectors are loaded to either vector or image display groups when you select them from the Available Vectors List and click Load Selected. If you have an image display group open, you can load the vectors to that display group, 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 and new vector layers, and to export analysis results to ROIs (through raster-to-vector conversion), shapefiles, and ancillary files.

Create World Boundaries

ENVI uses IDL map sets to generate low- and high-resolution world boundaries in EVF. Select **Options → Create World Boundaries** from the Available Vectors List, **or Vector → Create World Boundaries** from the ENVI main menu bar. You can also generate political boundaries, coastlines, rivers, and 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.

The Vector Parameters Dialog and Vector Window Menu

When vectors are overlaid on an image, the Vector Parameters dialog appears to let you control the way vectors are displayed and the functions that are available for vector processing and analysis.

When vectors are loaded into a vector window (not in an image display group), the vector window has the same menu functions available in the Vector Parameters dialog.
The Vector Parameters dialog and the vector window menu bar allow you to open vector files, import vector layers from the Available Vectors List, arrange vector layer precedence, set plot parameters, and annotate plots. They also control the mode of operation in the vector window or image display group, toggling between cursor query and heads-up digitizing and editing. The Vector Parameters dialog or the vector window menu initiate ENVI's GIS analysis functions, including real-time vector information, attribute viewing and editing, and vector query operations. Finally, the Vector Parameters dialog and the vector window menu bar provide utilities for exporting analysis results to shapefiles and ancillary attribute files, or to ROIs (through vector-to-raster conversion). You can also save the current configuration of vector overlays to a template, so you can later restore them.

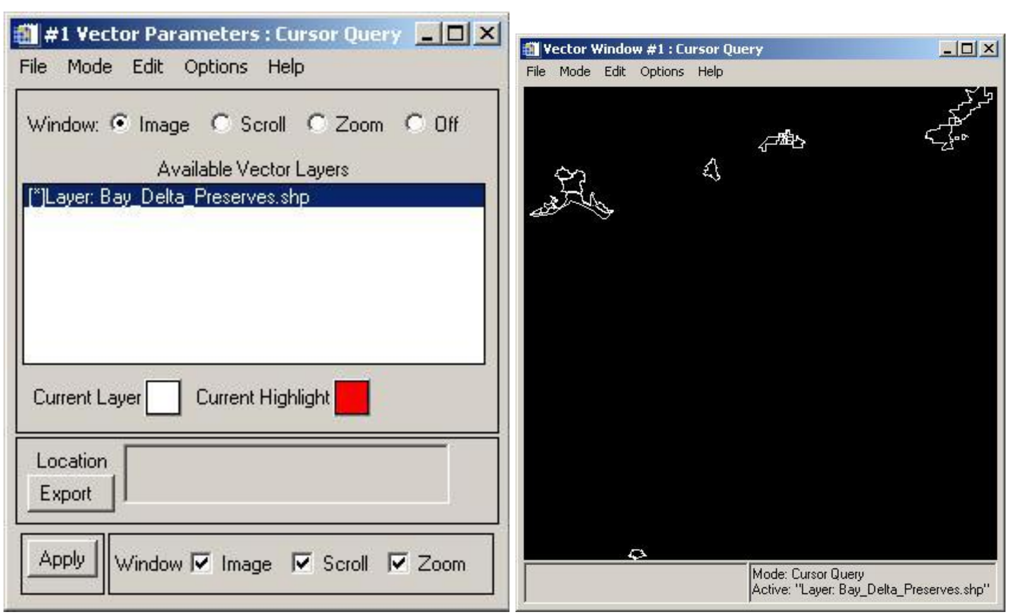
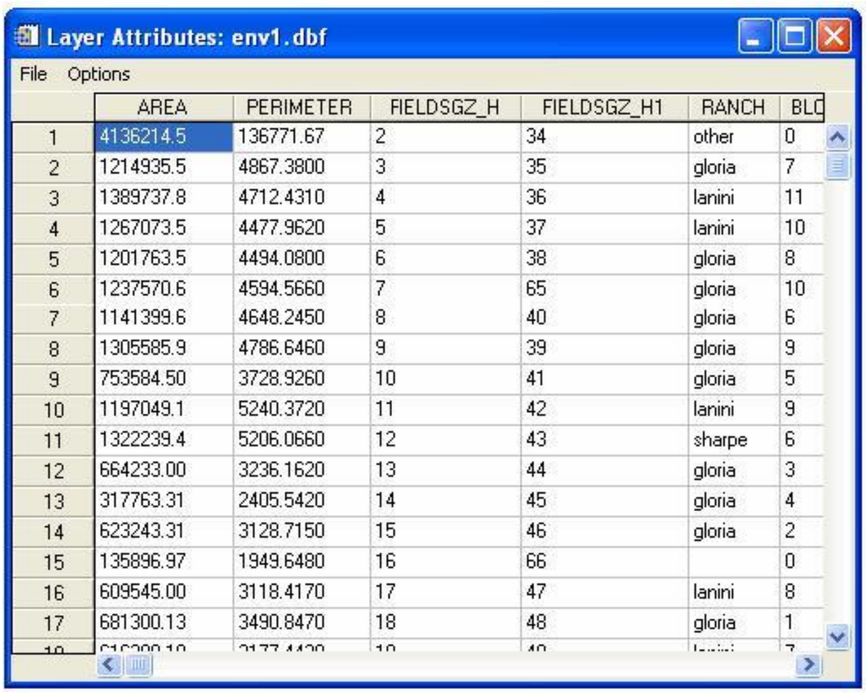


Figure 3-2: The Vector Parameters Window and New Vector Window

ENVI Attributes

ENVI provides access to fully attributed GIS data in a shapefile DBF format. Attributes are listed in an editable table, allowing point-and-click selection and editing.

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. You can save attributes to an ASCII file or to a DBF file. Point-and-click spatial query is supported in ENVI attribute tables to help you locate key features in images or in a vector window. Select specific records by clicking 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 image display group or vector window. You can select multiple records, including non-adjacent records, by holding down the <Ctrl> key as you click the additional row labels.



	AREA	PERIMETER	FIELDSGZ_H	FIELDSGZ_H1	RANCH	BLC
1	4136214.5	136771.67	2	34	other	0
2	1214935.5	4867.3800	3	35	gloria	7
3	1389737.8	4712.4310	4	36	lanini	11
4	1267073.5	4477.9620	5	37	lanini	10
5	1201763.5	4494.0800	6	38	gloria	8
6	1237570.6	4594.5660	7	65	gloria	10
7	1141399.6	4648.2450	8	40	gloria	6
8	1305585.9	4786.6460	9	39	gloria	9
9	753584.50	3728.9260	10	41	gloria	5
10	1197049.1	5240.3720	11	42	lanini	9
11	1322239.4	5206.0660	12	43	sharpe	6
12	664233.00	3236.1620	13	44	gloria	3
13	317763.31	2405.5420	14	45	gloria	4
14	623243.31	3128.7150	15	46	gloria	2
15	135896.97	1949.6480	16	66		0
16	609545.00	3118.4170	17	47	lanini	8
17	681300.13	3490.8470	18	48	gloria	1

Figure 3-3: ENVI Vector Attribute Table

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.

Open a Shapefile

1. From the ENVI main menu bar, select **File → Open Vector File**. A Select Vector Filenames dialog appears.
2. Navigate to Lab_Data\vector. Click the Files of type drop-down list in the **Select Vector Filenames** dialog, and select Shapefile (at the bottom right hand corner).
3. **Select `Bay_Delta_Preserves.shp`**. **Click Open**. The Import Vector Files Parameters dialog appears. This dialog allows you to select file or memory output, enter an output filename for the ENVI .evf file, and enter projection information if ENVI is unable to find the projection information automatically.
4. Click the Output Results to file button. **Accept the default values by clicking OK**. A status window indicates the number of vector vertices being read, and the Available Vectors List appears when the data have been converted.

5. Select `Bay_Delta_Preserves` in the Available Vectors List and click Load Selected. The Vector Window #1 dialog appears with regional Bay Delta preserves plotted. The default mode (shown in the title bar or in the lower-right corner of the dialog) is Cursor Query.

Work with Vector Polygon Data

1. Click and drag the cursor around in Vector Window #1. Latitudes and longitudes are displayed in the lower-left corner of the dialog.
2. Zoom into the file by positioning the cursor at the bottom corner of one of the polygons delineating the boundaries of a preserve and clicking and dragging the middle mouse button to define a box covering the desired region. Release the middle mouse button.
3. Multiple levels of zoom are possible. Click the middle mouse button while holding the <Shift> key to zoom into the display centered on the cursor. Right click in the Vector Window #1 dialog and select Previous Range to step backward through the previous zoom levels. Right-click and select Reset Range, or click the middle mouse button in the Vector Window #1 dialog to reset the zoom level and to set the vector display back to the original range.
4. Change the symbol used to mark the cities. From the Vector Window #1 menu bar, select **Edit → Edit Layer Properties**. An Edit Vector Layers dialog appears. Click the Line attributes drop-down list and select Dotted. Click OK. You can add your own symbols by defining them in the file usersym.txt in the menu directory of your ENVI installation. E
5. Experiment with changing the color, fill, and size. Click Preview to view your changes as you go.

Retrieve Vector Information and Attributes

1. Right-click in the Vector Window #1 dialog and select **Select Active Layer → Layer: Bay_Delta_Preserves.shp**. From the Vector Window #1 dialog menu bar, select **Options → Vector Information** to open the Vector Information dialog.
2. Click and drag over the Vector Window #1 dialog to see the basic attribute information at the bottom of the Vector Information dialog.

View Attributes and Use Point-and-Click Query

1. While B`ay_Delta_Preserve.shp` is still the active layer and Cursor Query is the active mode, select **Edit → View/Edit/Query Attributes** from the Vector Window #1 dialog menu bar. A Layer Attributes table appears. This is a fully editable table of the attributes for the selected layer.
2. Click in the Site column (on the record number) to do a spatial query on a selected preserve. The corresponding preserve polygon is highlighted in the Vector Window #1 dialog. If desired, zoom to the selected city by clicking and dragging a box around it with the middle mouse button. Zoom back out by clicking the middle mouse button in the Vector Window #1 dialog.
3. Verify that you have selected the correct preserve by clicking the highlighted polygon in the Vector Window #1 dialog and observing the attributes in the Vector Information window.

Query Attributes

1. Ensure that `Bay_Delta_Preserves.shp` is still the active layer. From the Vector Window #1 dialog menu bar, select **Options → Select Active Layer → Layer: Bay_Delta_Preserves.**
2. From the Vector Window #1 dialog menu bar, select **Edit → Query Attributes**. A Layer Attribute Query dialog appears.

3. Click **Start**. A Query Expression section appears at the top of the Layer Attribute Query dialog.
4. Click the SITE drop-down list and select Site.
5. Click the > drop-down list and select = =.
6. In the String field, enter "Jasper Ridge Biological Preserve" (be sure to match this case).
7. Click the Memory radio button and click OK. ENVI creates a new vector layer and associated DBF file based on the results of the query. The new layer appears in the Available Vectors List and is loaded into Vector Window #1. Zoom to the selected vectors using the middle mouse button to draw a box around Jasper Ridge Biological Preserve.

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 from the Landsat TM scene of the Bay Delta.

Load Image Data to Combined Image/Vector Display

Open an image file to use as a backdrop for vector layers.

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears.
2. Navigate to MyDocuments\ERS_186\ Lab_Data\Multispectral and select `Delta_LandsatTM_2008.img`. Click Open.

The Available Bands List appears with four spectral bands listed. Right click the file and load a true-color image into a new display group.

1. From the Display group menu bar, select **Overlay → Vectors.** A Vector Parameters dialog appears.
2. From the Vector Parameters dialog menu bar, select **File → Open Vector File**. This menu option is also accessible from the ENVI main menu bar. A Select Vector Filenames dialog appears.
3. Click the Files of type: drop-down list and **select Shapefile** (at the bottom right corner). Navigate to Lab_Data/vector and select both `Bay_Delta_Preserves.shp` and `2008_field_points.shp` by holding down the shift key and selecting the files. Click Open. An Import Vector Files Parameters dialog appears.
4. Select File or Memory output, and enter an output filename for the ENVI .evf file if you selected File.
5. In the Native Projection list, select UTM (or ensure that it is already selected). Click Datum.
6. A Select Geographic Datum dialog appears. Select North America 1983 and click OK. Do the same for the next vector file.
7. Select Memory output and click OK. A status window reports the number of vector vertices being read. When the data have been converted, they are automatically loaded into the Vector Parameters dialog and displayed in white on the image. The vectors.shp layer should be highlighted in the Vector Parameters dialog.
8. Right click the Current Layer colored box to select a more visible color for the vector layer or right-click on the box and select from the menu. Click Apply to update the vector color.

Track Attributes with the Cursor

1. In the Vector Parameters dialog, select **Options → Vector Information**. A Vector Information dialog appears.
2. Click and drag inside 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

or Zoom radio button 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. You can only view attribute information for the vector file highlighted in the Vector Parameters dialog.

3. Ensure that you are in Cursor Query mode by selecting Mode from the Vector Parameter dialog menu bar.
4. From the Vector Parameters dialog menu bar, select **Edit → View/Edit/Query Attributes**. A Layer Attributes table appears. Select random records by clicking the numbered columns to highlight specific polygons on the image. You may want to change the Current Highlight color in the Vector Parameters dialog to something that is more visible in your display group.

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 are similar in function to ENVI's annotation polygons, polylines, and points. ENVI heads-up vector digitizing allows you to create new polygons, polylines, points, rectangles, and ellipses.

1. Create a new vector layer by selecting **File → Create New Layer** from the Vector Parameters dialog. A New Vector Layer Parameters dialog appears.
2. Enter a Layer Name. Click the Memory radio button, and click OK.
3. In the Vector Parameters dialog, click the new layer name to initialize a new DBF file.
4. From the Vector Parameters dialog menu bar, select **Mode → Add New Vectors**.
5. For this exercise, you will create a polygon vector. From the Vector Parameters dialog menu bar, select **Mode → Polygon**.
6. Since the Image radio button is selected by default in the Vector Parameters dialog, you will define the new polygon in the Image window. You can specify which display group window you want to edit your vectors in, by selecting the appropriate radio button in the Vector Parameters dialog.

You may want to change the new vector layer color from white to something more visible before drawing new polygons.

7. Draw a few polygons using field outlines on the image as guides. In the Image window, 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 fix the polygon. Right-click again and select Accept New Polygon to accept the polygon.
8. To move the Image box in the Scroll window to a new location, you must click the Off radio button in the Vector Parameters dialog. When you are finished moving around the image, click the Image radio button to resume adding new vectors.
9. To add attributes to the new polygons, select **Edit → Add Attributes from the Vector Parameters** dialog menu bar. An Add Attributes Choice dialog appears.
10. Select Define new attributes interactively. Click OK. An Attribute Initialization dialog appears. In the Name field, type Field_ID. Click the Type drop-down list and select Character. Click Add Field.
11. For the second attribute, type Field_Area in the Name field. Click the Type drop-down list and select Numeric. Click OK to create the attribute table. A Layer Attributes table appears.
12. Double-click in a field, enter the value, and press the <Enter> key. To see which rows are associated with which fields, select **Mode → Cursor Query** from the Vector

Parameters dialog, and click the row labels in the Layer Attributes table. The corresponding polygon is highlighted in the Image window.

13. From the Layer Attributes dialog menu bar, select **File → Cancel**. When you are prompted to save the attribute table, click No.

Edit Vector Layers

1. In the Vector Parameters dialog, select the new vector layer and select **Mode → Edit Existing Vectors.**
2. In the Image window, click one of the polygons you created in the last section. The polygon is highlighted and its nodes are marked with diamonds. When the vector is selected, you can make the following changes:
    a. Delete the entire polygon by right-clicking it and selecting Delete Selected Vector.
    b. To move a node, click and drag it to a new location.
    c. After making changes to a polygon, right-click it and select Accept Changes
    d. Exit the editing function without making any changes by clicking the middle mouse button, or right-click and select Clear Selection.
    e. To add or remove nodes from a polygon, right-click to display the shortcut menu and select from the following options:
        - To add a node, right-click and select Add Node, then drag the node to a new location.
        - To remove a node, right-click it and select Delete Node from the shortcut menu.
        - To change the number of nodes added at one time, right-click and select Number of Nodes to Add. Enter the number of nodes in the dialog that appears.
        - To remove a range of nodes, right-click on the first node and select Mark Node. Right-click on the last node and select Mark Node again. Right-click again and select Delete Marked Nodes.

To finish this section, select **Window → Available Vectors** List from the ENVI main menu bar to display the Available Vectors List. Delete any new layers you have created by selecting them in the Available Vectors List and clicking Remove Selected. **Do not remove the** `Bay_Delta_Preserves.shp` or `2008_field_points.shp layer`.

Query Operations

1. From the Vector Parameters dialog menu bar, select **Mode → Cursor Query**.
2. In the Vector Parameters dialog, highlight `2008_field_points.shp`. **Select Edit → View/Edit/Query Attributes**. A Layer Attributes table appears.
3. Examine the land_cover column and note the different land cover classes, including several types of vegetation, soil, water, and non-photosynthetic vegetation (npv). Close the attribute table by selecting **File → Cancel.**
4. From the Vector Parameters dialog menu bar, select **Edit → Query Attributes**. A Layer Attribute Query dialog appears.
5. In the Query Layer Name field check that field_points is entered in the field. Click Start.
6. In the Query Expression section that appears at the top of the Vector Parameters dialog, click the drop-down list and select land_cover.
7. Click the ID drop down list and select land_cover. Then click the > drop-down list and select = =.

8. In the String field, type “water”. (Be sure to match the case in the attribute table).
9. Select the Memory radio button and click OK. The selected layer (called a subset) generated by the query appears in the Vector Parameters dialog.
10. In the Vector Parameters dialog, select the new subset[Layer: 2008_field_points.shp] layer and select Edit → Edit Layer Properties from the menu bar to change layer parameters. An Edit Vector Layers dialog appears.
11. Click the Point Symbol drop-down list and select Flag. Click OK. The water field points as flags are highlighted as a new layer.
12. To examine the attributes for this layer, select subset[Layer: Delta_field_points.shp]in the Vector Parameters dialog, and select **Edit → View/Edit/Query Attributes** from the menu bar. A Layer Attributes table appears. Examine the query results.
13. Close the Layer Attributes table and repeat the query for the "levee_herbaceous" land cover, highlighting it in a different color or symbol.
14. Try other queries on combinations of attributes by choosing one of the logical operators in the Layer Attribute Query dialog.

Convert Vectors to ROIs

1. ENVI provides several important links between vector analysis and raster image processing. This portion of the exercise describes how to create ROIs from vector processing results and extract ROI statistics.
2. From the Display group menu bar, select **Overlay → Region of Interest**. The ROI Tool dialog appears.
3. In the Vector Parameters dialog, highlight the Bay_Delta_Preserves.shp layer and select **File → Export Active Layer to ROIs**. An Export EVF Layers to ROI dialog appears.
4. Select Convert all records of an EVF layer to one ROI, and click OK.
5. Repeat Steps 2-3 for each layer you created earlier from the query operations. The layers appear in the ROI Tool dialog.
6. In the ROI Tool dialog, select the `Bay_Delta_Preserves` ROI by clicking in the far left column of its row. Click Stats. An ROI Statistics Results dialog appears with image statistics for the Preserves and multispectral data.
7. Save ROI in **File → Save ROI.**
8. Now that you have converted these vector polygons to ROIs, you can use ENVI’s raster processing capabilities to analyze the image data, with respect to the ROIs. This includes masking, statistics, contrast stretching, and supervised classification.

Export ROI to Vector Layer

ENVI can convert raster processing results (such as ROIs) for use in ENVI vector processing and analysis and for export to external GIS software such as ArcGIS. The following exercises illustrate the export of raster information to vector GIS.

Open and Display an Image

Re-Open the Landsat TM 2008 image of the Bay Delta to use as background for ROI definition and export to vector:

1. From the ENVI main menu bar, select **File → Open Image File**. A file selection dialog appears.
2. In the Available Bands List, select Band 4, select the Gray Scale radio button, and click Load Band.

Load Predefined ROIs

1. From the Display group menu bar, select **Overlay → Region of Interest**. An ROI Tool dialog appears.
2. Your ROIs from the above exercise should reload. If not, from the ROI Tool dialog menu bar, select **File → Restore ROIs**.
3. Navigate to your saved ROI file. Click Open. 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.

Convert ROIs to Vectors

1. To convert these ROIs to vector polygons, select **File → Export ROIs to EVF** from the ROI Tool dialog menu bar. An Export Region to EVF dialog appears.
2. Select a region from the Select ROIs to Export field.
3. **Select All** points as one record.
4. Enter an Output Layer Name, click Memory, and click OK to convert the first ROI.
5. In the Available Vectors List, click to select your new layer, followed by Load Selected. A Load Vector dialog appears.
6. Select New Vector Window and click OK. The vectors are loaded as polygons into the Vector Window #1 dialog.
7. From the Vector Window #1 dialog menu bar, select **Edit → View/Edit/Query Attributes**.
8. Practice editing and/or adding to your attributes as you desire (the paragraph at the beginning of page 34 may be a useful reference).
9. Repeat Steps 1-8 for the second ROI. The layers appear in the Available Vectors List.

You can now use these polygons with query operations and GIS analysis with other vector data, or you can export them to shapefiles by selecting **File → Export Active Layer to Shapefile** from the Vector Window Parameters dialog.

Close All Windows and Files

1. In the Available Vectors List, click **Select All Layers**, followed by **Remove Selected**.
2. From the Available Vectors List menu bar, select **File → Cancel**.
3. From the Vector Window #1 dialog menu bar, select **File → Cancel**.
4. From the ENVI main menu bar, select **File → Close All Files**.

Tutorial 4.1: The n-D Visualizer

The following topics are covered in this tutorial:

Exploration of feature space and land cover classes

Multispectral data

Overview of This Tutorial

Remote sensing data is comprised of data layers (bands) that complete the data set. Each of these layers can be considered a feature or a dimension of the data. It is helpful to sometimes think of spectra in your image as points in an n-D scatter plot, where *n* is the number of bands. The coordinates of the points in n-D space consist of *n* spectral reflectance values in each band for a given pixel. The n-D visualizer can help you visualize the shape of a data cloud that results from plotting image data in feature space (sometimes called spectral space), with the image bands as plot axes. The n-D visualizer is commonly used to examine the distribution of points in n-D space in order to select spectral endmembers in your image (pixels that are pure, containing a unique type of material). It can also be used to examine the separability of your classes when you use ROIs as input into supervised classifications. When using the n-D visualize, you can actively rotate data in n-D space.

Files Used in this Tutorial

Input Path: My Documents\ERS_186\Lab_Data\Multispectral\Landsat\

Output Path: My Documents\ERS_186\your_folder\lab4

Input Files	Description
`Delta_LandsatTM_2008.img`	Delta, CA TM Data
`Delta_classes_2008.roi`	ENVI regions of interest file

Launching & using the n-D Visualizer

1. Start ENVI and open the image file `Delta_LandsatTM_2008.img.` Load the image file to a true-color RGB display.
2. Overlay the `Delta_classes_2008.roi` regions of interest file on the image.
3. In the ROI Tool dialog, select **File → Export ROIs to n-D visualizer** Select `Delta_LandsatTM_2008.img.`
4. In the n-D Visualizer Input ROIs, Select All Items and click OK. The n-D visualizer and n-D controls dialogs appear (Figure 4-1).
    - Clicking on an individual band number in the n-D Controls dialog turns the band number white and displays the corresponding band pixel data in the n-D scatter plot. You must select at least two bands to view a scatter plot.
    - Clicking the same band number again turns it black and turns off the band pixel data in the n-D scatter plot.
    - Selecting two bands in the n-D Controls dialog produces a 2-D scatter plot; selecting three bands produces a 3-D scatter plot, and so on. You can select any combination of bands at once.

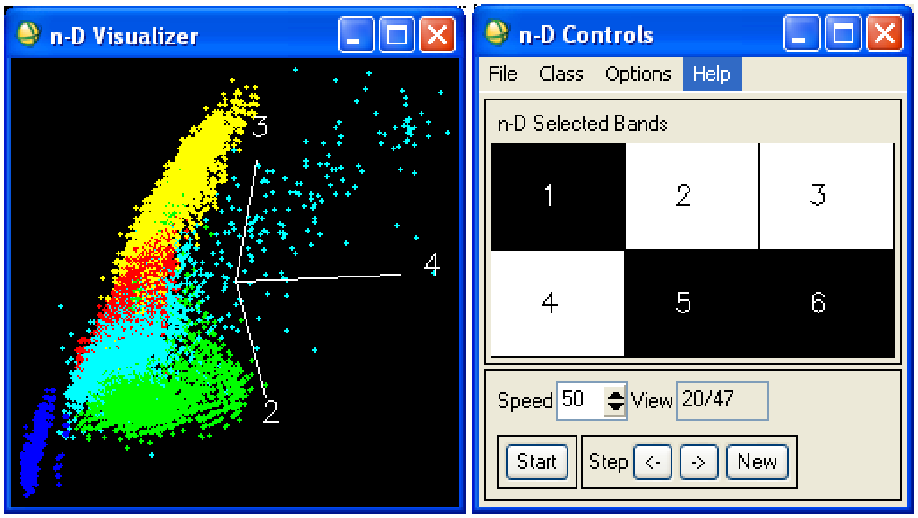


Figure 4-1: n-D Visualizer (left) and n-D Controls dialog (right)

Selecting Dimensions and Rotating Data

Rotate data points by stepping between random projection views. You can control the speed and stop the rotation at any time. You can move forward and backward step-by step through the projection views, which allows you to step back to a desired projection view after passing it.

1. In the n-D Controls dialog, click the band numbers (thus the number of dimensions) you want to project in the n-D Visualizer. If you select only two dimensions, rotation is not possible. If you select 3-D, you have the option of driving the axes, or initiating automatic rotation. If you select more than 3-D, only automatic random rotation is available.

2. Select from the following options:

    2. To drive the axes, select **Options** → **3D: Drive Axes** from the n-D Controls menu bar. Click and drag in the n-D Visualizer to manually spin the axes of the 3D scatter plot.

    3. To display the axes themselves, select **Options** → **Show Axes** from the n-D Controls menu bar.

    4. To start or stop rotation, click **Start** or **Stop** in the n-D Controls dialog.

    5. To control the rotation speed, enter a **Speed** value in the n-D Controls dialog. Higher values cause faster rotation with fewer steps between views.

    6. To move step-by-step through the projection views, click < to go backward and > to go forward.

    7. To display a new random projection view, click **New** in the n-D Controls dialog.

Interacting with Classes

Use the n-D Class Controls dialog to interact with individual classes. The dialog lists the number of points in each defined class and the class color. You can change the symbol, turn individual classes on and off, and select classes to collapse. You can also plot the minimum, maximum, mean, and standard deviation spectra for a class, plot the mean for a single class, and plot all the spectra within a class. Also, you can clear a class and export a class to an ROI.

From the n-D Controls menu bar, select **Options → Class Controls**.

All of the defined classes appear in the dialog. The white class contains all of the unclustered or unassigned points. The number of points in each class is shown in the fields next to the colored squares.

Turning Classes On/Off

To turn a class off in the n-D Visualizer, de-select the **On** check box for that class in the n-D Class Controls dialog. Click again to turn it back on.

To turn all but one of the classes off in the n-D Visualizer, double-click the colored box at the bottom of the n-D Class Controls dialog representing the class that you want to remain displayed. Double-click again to turn the other classes back on.

Selecting the Active Class

To designate a class as the active class, click once on the colored square (at the bottom of the n-D Class Controls dialog) corresponding to that class.

The color appears next to the **Active Class** label in the n-D Class Controls dialog, and any functions you execute from the n-D Class Controls dialog affect only that class.

You may designate a class as the active class even though it is not enabled in the n-D Visualizer.

Producing Spectral Plots

To produce spectral plots for the active class:

1. Click the **Stats**, **Mean**, or **Plot** button on the n-D Class Controls dialog. The Input File Associated with n-D Data dialog appears.
    - **Stats**: Display the mean, minimum, maximum, and standard deviation spectra of the current class in one plot. These should be derived from the original reflectance or radiance data file.
    - **Mean**: Display the mean spectrum of the current class alone. This should be derived from the original reflectance or radiance data file.
    - **Plot**: Display the spectrum of each pixel in the class together in one plot. This should be derived from the original reflectance or radiance data file.
2. Select the input file that you want to calculate the spectra from.

    If you select a file with different spatial dimensions than the file you used as input into the n-D visualizer, enter the x and y offset values for the n-D subset when prompted.

Note: If you select **Plot** for a class that contains hundreds of points, the spectra for all the points will be plotted and the plot may be unreadable.

Clearing Classes

To remove all points from a class, click **Clear** on the n-D Class Controls Options dialog, or right-click in the n-D Visualizer and select **Clear Class** or **Clear All**.

Designating Classes to Collapse

To include the statistics from a class when calculating the projection used to collapse the data, select the **Clp** check box next to that class name in the n-D Class Controls dialog.

If the data are in a collapsed state, they will be recollapsed using the selected classes when you select any of the **Clp** check boxes.

Collapsing Classes

You can collapse the classes by means or by variance to make class definition easier when the dimensionality of a dataset is higher than four or five. With more than four or five dimensions, interactively identifying and defining many classes becomes difficult. Both methods iteratively collapse the data cloud based on the defined classes.

To collapse the data, calculate a projection (based either on class means or covariance) to minimize or hide the space spanned by the pre-defined classes and to maximize or enhance the remaining variation in the dataset. The data are subjected to this special projection and replace the original data in the n-D Visualizer.

Additionally, an eigenvalue plot displays the residual spectral dimension of the collapsed data. The collapsed classes should form a tight cluster so you can more readily examine the remaining pixels. The dimensionality of the data, shown by the eigenvalue plot, should decrease with each collapse.

1. From the n-D Controls menu bar, select **Options → Collapse Classes by Means** or **Collapse Classes by Variance** (see the descriptions in the following sections).

   An eigenvalue plot displays, showing the remaining dimensionality of the data and suggesting the number of remaining classes to define. The **n-D Selected Bands** widget changes color to red to indicate that collapsed data are displayed in the n-D Visualizer.

2. Use the low-numbered bands to rotate and to select additional classes.

3. From the n-D Controls menu bar, select **Options → Collapse Classes by Means** or **Collapse Classes by Variance** again to collapse all of the defined classes.

4. Repeat these steps until you select all of the desired classes.

Collapsing Classes by Means

You must define at least two classes before using this collapsing method. The space spanned by the spectral mean of each class is derived through a modified Gram-Schmidt process. The complementary, or null, space is also calculated. The dataset is projected onto the null space, and the means of all classes are forced to have the same location in the scatter plot. For example, if you have identified two classes in the data cloud and you collapse the classes by their mean values, ENVI arranges the data cloud so that the two means of the identified classes appear on top of each other in one place. As the scatter plot rotates, ENVI only uses the orientations where these two corners appear to be on top of each other.

Collapsing Classes by Variance

With this method, ENVI calculates the band-by-band covariance matrix of the classified pixels (lumped together regardless of class), along with eigenvectors and eigenvalues. A standard principal components transformation is performed, packing the remaining unexplained variance into the low-numbered bands of the collapsed data. At each iterative collapsing, this process is repeated using all of the defined classes. The eigenvalue plot shows the dimensionality of the transformed data, suggesting the number of remaining classes to define.

The full dataset is projected onto the eigenvectors of the classified pixels. Each of these projected bands is divided by the square root of the associated eigenvalue. This transforms the classified data into a space where they have no covariance and one standard deviation.

You should have at least *nb* * *nb*/2 pixels (where *nb* is the number of bands in the dataset) classified so that ENVI can calculate the *nb***nb* covariance matrix.

ENVI calculates a *whitening* transform from the covariance matrix of the classified pixels, and it applies the transform to all of the pixels. Whitening collapses the colored pixels into a fuzzy ball in the center of the scatter plot, thereby hiding any corners they may form. If any of the unclassified pixels contain mixtures of the endmembers included among the classified pixels, those unclassified pixels also collapse to the center of the data cloud. Any unclassified pixels that do not contain mixtures of endmembers defined so far will stick out of the data cloud much better after class collapsing, making them easier to distinguish.

Collapsing by variance is often used for partial unmixing work. For example, if you are trying to distinguish very similar (but distinct) endmembers, you can put all of the other pixels of the data cloud into one class and collapse this class by variance. The subtle distinctions between the unclassified pixels are greatly enhanced in the resulting scatter plot.

UnCollapsing Classes

To uncollapse the data and return to the original dataset, select **Options → UnCollapse** from the n-D Controls menu bar.

All defined classes are shown in the n-D Visualizer, and the band numbers return to a white color in the n-D Controls menu bar.

n-D Visualizer/Controls Options

Select **Options** from the n-D Controls menu bar to access the n-D Class Controls dialog, to annotate the n-D Visualizer, to start a Z Profile window, to import, delete, and edit library spectra, to collapse classes, to clear classes, to export classes to ROIs, to calculate mean spectra, and to turn the axes graphics on or off.

Opening the Class Controls Dialog

To access the n-D Class Controls dialog, select **Options → Class Controls** from the n-D Controls menu bar. For details, see Interacting with Classes.

Adding Annotation

To add an annotation to the n-D Visualizer window, select **Options → Annotate Plot** from the n-D Controls menu bar. See Annotating Images and Plots for further details. You cannot add borders to the n-D Visualizer.

Plotting Z Profiles

To open a plot window containing the spectrum of a point selected in the n-D Visualizer:

1. Select **Options → Z Profile** from the n-D Controls menu bar. The Input File Associated with n-D Data dialog appears.
2. Select the data file associated with the n-D data. Typically, this file is the reflectance or original data. If you select an input file with different spatial dimensions than the file used for input into the n-D Visualizer, you will be prompted to enter the x and y offsets that point to the n-D subset.

   The Z Profile plot window appears.

3. Select from the following options:
   - To plot the Z Profile for the point nearest the cursor, middle-click in the n-D Visualizer plot window.
   - To add plots to the Z Profile plot window, right-click in the n-D Visualizer plot window. The Z Profile corresponding to the point you selected is added to the Z Profile plot window.

   When the Z Profile plot window is open, the selected file is automatically used to calculate the mean spectra when you select **Options → Mean Class** or **Mean All** from the n-D Controls menu bar.

Managing n-D Visualizer States

Select **File** from the n-D Controls menu bar to save and restore the state of the n-D Visualizer, including the highlighted groups of pixels.

Exporting the n-D Visualizer

Select **File → Save Plot As → PostScript** or **Image** from the n-D Controls menu bar.

To print the n-D Visualizer window, select **File → Print** (see Printing in ENVI for details).

Saving States

To save the n-D Visualizer state, select **File → Save State** from the n-D Controls menu bar and enter an output filename with the extension .ndv for consistency.

Restoring Saved States

To restore a previously saved state, select **File → Restore State** and select the appropriate file.

You can also restore a previously saved state by selecting **Spectral → n-Dimensional Visualizer → Visualize with Previously Saved Data** from the ENVI main menu bar.

Tutorial 4.2: Data Reduction 1 - Indexes

The following topics are covered in this tutorial:

Band-Math for Calculating Narrow-band Indexes

Continuum Removal

Overview of This Tutorial

A disadvantage of the statistical data reduction tools (that you will practice in Lab 5) is that they are not readily interpretable. An MNF composite image might highlight that two materials are spectrally different, but do not easily allow you to determine the spectral or physical basis for that difference. This effectively ignores the amazing capability of hyperspectral data to provide physiological measurements by detecting specific narrow-band absorptions. Since specific materials absorb at specific wavelengths, the relative depth of an absorption feature can quantify how much of that material is present. Spectral physiological indexes and continuum removal are two methods for quantifying absorption features. These products can then be used for further analyses in the place of the original reflectance data, thereby reducing data dimensionality. This tutorial is designed to give you a working knowledge of ENVI's data reduction capabilities. For additional details, please see the ENVI User's Guide or the ENVI Online Help.

Files Used in this Tutorial

Input Path: My Documents\ERS_186\Lab_Data\Hyperspectral\

Output Path: My Documents\ERS_186\your_folder\lab4

Input Files	Description
`Delta_Hymap_2008`	Delta, CA, HyMap Data

Output Files	Description
`Delta_Hymap_2008_cr_carb`	Continuum Removal of soil carbonate
`Delta_Hymap_2008_cr_water`	Continuum Removal of vegetation water
`Delta_Hymap_2008_XXXX.img`	Image file of the index XXXX (12 total)
`Delta_Hymap_2008_index_mask.img`	Mask file
`Delta_Hymap_2008_indexstack.img`	Band stacked file

Data Reduction

Because of the enormous volume of data contained in a hyperspectral data set, data reduction techniques are an important aspect of hyperspectral data analysis. Reducing the volume of data, while maintaining the information content, is the goal of the data reduction techniques covered in this section. The images created by the data reduction techniques can be used as inputs to classification.

Narrow Band Indexes

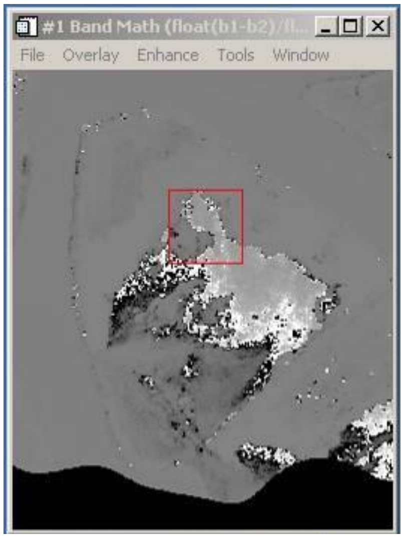


Figure 4-1: Grey-scale image of PRI

Band Math

Here you will calculate vegetation indexes, covariance statistics, and correlation matrices with ENVI's Band Math function.

The first vegetation index we will calculate, shown to the left, the Photochemical Reflectance Index (PRI), is a measure of photosynthetic efficiency. The formula for PRI is

$$\frac{R_{531} - R_{570}}{R_{531} + R_{570}}$$

where R_{531} and R_{570} are the reflectance values at 531nm and 570nm, respectively. Since Hymap does not sample at exactly these wavelengths, we will calculate PRI using the bands closest to 531 and 570nm.

Calculate PRI following these steps:

1. In ENVI's main menu, select **File → Open Image File** → `Delta_Hymap_2008.img` from My Documents\ERS_186\Lab_Data\Hyperspectral\and load a true color display.
2. Select **Basic Tools → Band Math**.
3. In the Band Math Expression dialog, enter **float(b1-b2)/float(b1+b2)**.
   In case you wonder about the "float" term, this is because the raw image is saved as an integer data type. Unless told otherwise, the computer will set the type of the output band math image to integer as well. This results in the truncation of decimal places. An index that ranges between -1 and 1, which many of them are normalized to do, will therefore be saved as 0. When entering your band math expressions, you must convert the input bands to decimals (or floating point values, in computer speak) by calling the "float()" function.
4. Click OK.
5. In the Variables to Bands Pairing dialog, click on B1 (undefined).
6. Select Band 6 (526nm) for B1.
7. Click on B2 (undefined).
8. Select Band 9 (570.4 nm).
9. Choose your output file path as: My Documents\ERS_186\Lab_Data\Lab_Products.
10. Name the output file `Delta_Hymap_2008_PRI.img and click Open`
11. Click OK
12. Display your newly calculated index and inspect it with the Cursor Location/Value Tool.
13. Repeat steps 3 - 12 using the 11 remaining vegetation indexes listed in Table 4-1. For example, band math expressions you will need include:

- NDWI, Normalized Difference Water Index: **float(b1-b2)/float(b1+b2)**. Here you can also click on the previous Band Math expression and assign different band pairings.

- SR, Simple Ratio, **float(b1)/float(b2)**.
- CAI, Cellulose Absorption Index: **0.5*float((b1+b2) – b3)**
- NDNI, Normalized Difference Nitrogen Index: **(alog10(float(b1)/float(b2)))/(alog10(1/(float(b1)*float(b2))))**
- To take the sum of a set of bands, a shortcut is to go to **Basic Tools → Statistics → Sum Data Bands**, and choose the bands you wish to sum as a spectral subset.

  This is just a sample of the many physiological indexes that have been developed to estimate a wide variety of properties including, pigment contents and ratios between pigments, foliar water content, and foliar dry matter content.

Table 4-1: Physiological indexes used in vegetation mapping

Index	formula	details	citation
Pigment indexes			
SR, Simple Ratio	$\frac{R_{NIR}}{R_R}$	Index of green vegetation cover. Various wavelengths used, depending on sensor.(eg: NIR=845nm, R=665nm)	Tucker (1979)
NDVI, Normalized Difference Vegetation Index	$\frac{R_{NIR} - R_R}{R_{NIR} + R_R}$	Index of green vegetation cover. Various wavelengths used, depending on sensor.(eg: NIR=845nm, R=665nm)	Tucker (1979)
mNDVI, modified NDVI	$\frac{R_{750} - R_{705}}{R_{750} + R_{705}}$	leaf chlorophyll content	Fuentes et al. (2001)
Summed green reflectance	$\sum_{500}^{599} R_i$	Index of green vegetation cover.	Fuentes et al. (2001)
PRI, Photochemical Reflectance Index	$\frac{R_{531} - R_{570}}{R_{531} + R_{570}}$	Xanthophyll response to light ~ photosynthetic efficiency. Also sensitive to carotenoid/chlorophyll ratio	Rahman et al. (2001)
Red/Green ratio	$\sum_{600}^{699} R_i \Big/ \sum_{500}^{599} R_i$	anthocyanins/chlorophyll	Fuentes et al. (2001)

Table 4-1: Physiological indexes used in vegetation mapping (continued)

PI2, Pigment Index 2	$\frac{R_{695}}{R_{760}}$	plant stress status	Zarco-Tejada (1998)
Water indexes			
NDWI, Normalized Difference Water Index	$\frac{R_{860} - R_{1240}}{R_{860} + R_{1240}}$	leaf water content	Gao (1996)
WBI, Water Band Index	$\frac{R_{900}}{R_{970}}$	leaf water content	Peñuelas et al. (1997)
Foliar chemistry indexes			
NDNI, Normalized Difference Nitrogen Index	$\frac{\log\left(R_{1680}/R_{1510}\right)}{\log\left(1/R_{1680}R_{1510}\right)}$	foliar nitrogen concentration	Serrano et al. (2002)
NDLI, Normalized Difference Lignin Index	$\frac{\log\left(R_{1680}/R_{1754}\right)}{\log\left(1/R_{1680}R_{1754}\right)}$	foliar lignin concentration	Serrano et al. (2002)
CAI, Cellulose Absorption Index	$0.5 * (R_{2020}+R_{2220}) - R_{2100}$	based upon cellulose & lignin absorption features, used to discriminate plant litter from soils	Nagler et al. (2000)

Checking for Independence of Calculated Indexes

Calculating a correlation matrix is a fairly simple method for verifying the additional information content of each index. Not all indexes are independent of each other. For example, many are designed to estimate chlorophyll content; so these will necessarily be correlated. Additionally, many variables are correlated with overall plant vigor. For example, more robust vegetation will tend to have higher chlorophyll, water, and nitrogen contents and thus have higher NDVI, NDWI, and NDNI values than stressed vegetation, and these indexes will thus be correlated. When calculating the correlation matrix, mask out zero, NaN, and infinite values to ensure that useful values are generated.

Combine Bands into a Single Image

Combine all bands into a single image to calculate covariance statistics and a correlation matrix.

1. In ENVI's main menu, select **File → Save File As → ENVI Standard**.
2. Click Import and, holding down the Ctrl button, select all 12 of the `Delta_Hymap_2008_XXXX.img` index files that you calculated. Click OK.

> Note: **Write down the order of the bands as you import them**, you will need to enter this information in Step 9.

3. Choose a file path to My Documents\ERS_186\Lab_Data\Lab_Products.
4. Name the file `Delta_Hymap_2008_indexstack.img` and click Open.
5. Click OK.
6. In ENVI's main menu, select **File → Edit ENVI Header**.
7. Select `Delta_Hymap_2008_indexstack.img`.
8. Click Edit Attributes and select Band Names. Change the band names to the appropriate index names you just wrote down.
9. Click the Display button and select New Display. Click Load RGB and select three indexes from the New Stacked Layer into a new display.

Masking

- Masking reduces the spatial extent of the analysis by masking out areas of the image which do not contain data of interest. Masking reduces processing times by reducing the number of pixels an analysis must consider. Masking may also improve results by removing extraneous, confounding variation from the analysis. It is common for analysts to mask out hydrologic features (streams, rivers, lakes), roads, or nonvegetated pixels, for example, depending on the project goals.
- During the masking process, the user compares the mask carefully to the original image to verify that only non-essential data is removed. If there is any doubt whether data is important, it is left in the data set.

Build the Mask

1. Select **Basic Tools → Masking → Build Mask.**
2. Select the display corresponding to your index stack image.

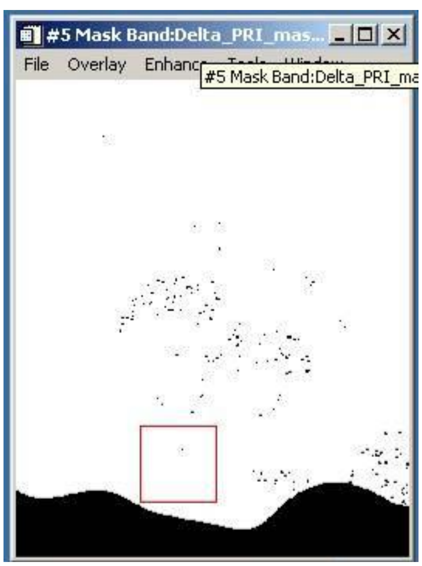


Figure 4-2: NaN Mask

3. In the Mask Definition dialog, select **Options → Selected Areas Off**.
4. Select **Options → Mask NaN values**. These are the pixels with nonreal index values that resulted from having a zero in the denominator.
5. Select the file `Delta_Hymap_2008_indexstack.img` and click OK.
6. Choose the option "Mask pixel if ANY band matches NaN".
7. Name the file `Delta_Hymap_2008_index_mask.img`, click Apply.
8. Close the Mask Definition dialog.

Calculate Statistics and Covariance Image

1. In ENVI's main window, select **Basic Tools → Statistics → Compute Statistics**.
2. Select `Delta_Hymap_2008_indexstack.img` as the input file, click "Select Mask Band", choose `Delta_Hymap_2008_index_mask.img`, and click OK.
3. Check Covariance in the Compute Statistics Parameters dialog and click OK.
4. Maximize the Statistics Results and scroll (if necessary) to the correlation matrix. A high absolute value (close to 1 or negative 1) indicates that the two indexes are highly correlated. What clusters of highly correlated indexes fall out? Which indexes are not correlated to any others? If your correlation matrix contains many nonsensical values, you did not successfully mask the image. See the troubleshooting guide on page 6.

You may use physiological indexes (instead of reflectance data) as the input to any classification algorithm. Choose indexes to include as classification inputs using the following rules of thumb:

- Inspect each of your index images. Indexes that are very noisy (i.e., those with a lot of speckle and low spatial coherence) should be excluded from further analyses.
- Use only one index from a set of highly correlated indexes (i.e., $|r| > 0.9$).

Continuum Removal

Many hyperspectral mapping and classification 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 the original spectrum by the continuum. In this way, the spectrum is normalized for albedo in order to quantify the absorption feature.

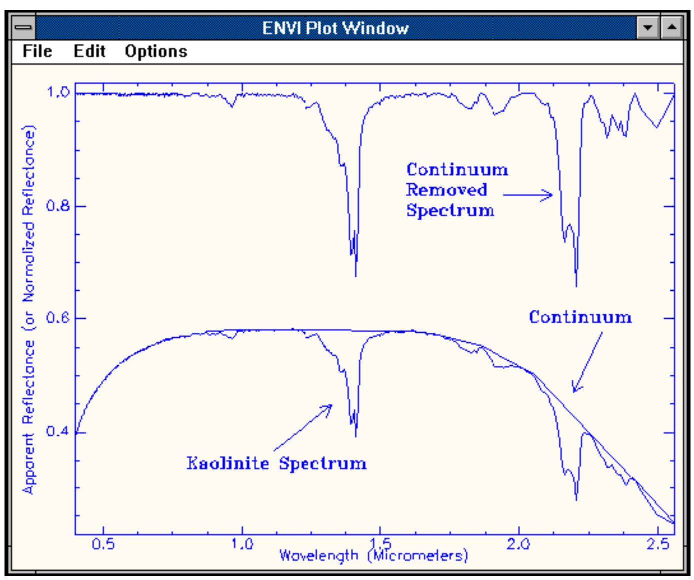


Figure 4-3: Fitted Continuum and a Continuum-Removed Spectrum for the Mineral Kaolinite

Create Continuum-Removed Data

Continuum Removal in ENVI Plot Windows

1. Open the file `Delta_Hymap_2008.img` and display it as a color infrared by right clicking it in the Availible Bands List and selecting Load CIR….
2. Right-click in the Image window and select Z Profile (Spectrum…)
3. Make sure that **Options → Auto-scale Y Axis** is checked in the Spectral Profile window.
4. Select **Edit → Plot parameters…**
5. Edit Range to display wavelengths from 2.0 µm to 2.41 µm and close the Plot Parameter dialog.
6. Select **Plot Function → Continuum Removed**. The spectrum will be displayed after continuum removal.

Navigate to soil pixels in your image and observe the spectra. Note the absorption at 2.2 µm for clay, 2.3 µm for carbonates and if the pixel has dry vegetation, the spectra will also show a cellulose absorption at 2.1 µm. Click back and forth between Normal and Continuum Removed in the Plot_Function menu so that you can see how the shape of the reflectance spectrum corresponds to the shape of the continuum removed spectrum. Can you see the absorption features in both?

To Map the Continuum Removal for all pixels

1. Open the file `Delta_Hymap_2008.img` and select **Spectral → Mapping Methods → Continuum Removal.**
2. In the Continuum Removal Input File dialog, select the file `Delta_Hymap_2008`, perform spectral subsetting by clicking **Spectral Subset** and choosing bands from 2.0 µm to 2.41 µm to limit the spectral range for continuum removal, and click OK.
3. Choose the Lab_Products output folder, enter the continuum-removed output file name, `Delta_Hymap_2008_cr_carb.img` 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 number of bands chosen in the spectral subset.
4. Load the central band of this file (band 110) as a gray scale and link it to your CIR display. Observe the Z profile from both displays for soil and dry vegetation pixels. (You will probably need to check **Options → Autoscale Y axis** for your continuum removed profile.)

Repeat the above steps choosing as your spectral subset, bands from 0.87 µm to 1.08 µm. This range contains the liquid water absorption bands for vegetation. Output the file as `Delta_Hymap_2008_cr_water.img`. Once the process is complete, the file will show up in the Available Bands List dialog. Load the central band as a gray scale. Navigate to vegetation pixels, display the Z profile and observe the spectra.

Look at full spectra of soil, litter, and green vegetation pixels in your Hymap image. Inspect the regions used for the continuum removals. Can you see the cellulose and water absorptions? Can you tell soil and litter pixels apart? Look at band pairs that were used in the physiological indexes you calculated earlier. Can you see what spectral features they're taking advantage of?

Complete Your Data Products Spreadsheet

You have created several data products from the input file `Delta_HyMap_2008.img`. Record this information, including file pathways, in your `your_name_data_products.xls` spreadsheet.

> Note: You may wish to organize your Lab_Products folder using subfolders to appropriately group your files together (i.e. index files vs continuum removal images), or transfer your files to your appropriate personal lab folder(s).

Tutorial 5: Data Reduction 2 - Principal Components

The following topics are covered in this tutorial:

Masking

Principal Components Analysis

Minimum Noise Fraction Transform

Overview of This Tutorial

The large number of spectral bands and high dimensionality of hyperspectral data overwhelm classical multispectral processing techniques. Moreover, contiguous bands tend to be highly correlated. Since not all bands provide new information, they may be unnecessary for subsequent analyses. Researchers have devised many strategies to reduce the dimensionality and remove the redundant information in hyperspectral data, including statistical transforms, feature selection, and the calculation of narrowband indexes. This tutorial goes through the process of creating and interpreting PCA and MNF transforms on Hyperspectral Images. Both of these transforms are statistical tools that use the variance-covariance structure of a hyperspectral dataset.

Files Used in This Tutorial

Input Path: C:\My Documents\ERS_186\Lab_Data\Hyperspectral\

Output Path: C:\My Documents\ERS_186\your_folder\lab5

Input Files	Description
`Delta_HyMap_2008.img`	Delta, CA, HyMap Data

Output Files	Description
`Delta_Hymap_2008_pca.img`	Principal Components Analysis file
`Delta_Hymap_2008_mnf.img`	Minimum Noise Transform file

Principal Component Analysis

Principal Components produces uncorrelated output bands, segregates noise components, and can be used to reduce the dimensionality of data sets. Because hyperspectral data bands are often highly correlated, the Principal Component (PC) Transformation is used to produce uncorrelated output bands. This is done by finding a new set of orthogonal axes that have their origin at the data mean and that are rotated so the data variance explained by each axis is maximized. As a result, the first PC band contains the largest percentage of data variance and the second PC band contains the second largest data variance, and so on. The last PC bands appear noisy because they contain very little variance, much of which is due to noise in the original spectral data.

Since PCA is a simple rotation and translation of the coordinate axes, PC bands are linear combinations of the original spectral bands. You can calculate the same number of output PC bands as input spectral bands. To reduce dimensionality using PCA, simply exclude those last PC bands that contain very little variance and appear noisy. Unlike the original bands, PC bands are uncorrelated to each other. Principal Component bands produce more colorful color composite images than spectral color composite images because the data is uncorrelated. ENVI can complete forward and inverse PC rotations.

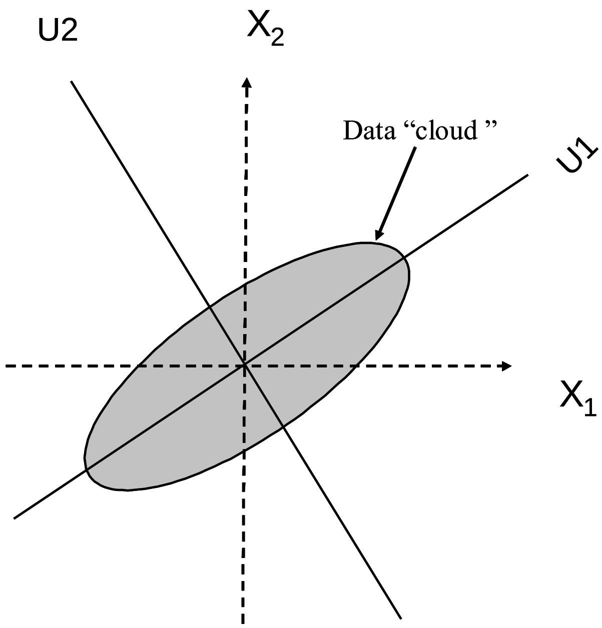


Figure 5-1: Schematic representation of the first two eigenvectors (U1 and U2) from a PCA decomposition of a hypothetical data set

Richards, J.A., 1999. Remote Sensing Digital Image Analysis: An Introduction, Springer-Verlag, Berlin, Germany, p. 240.

Start ENVI and Load Hymap Data

Start ENVI by double-clicking on the ENVI icon. The ENVI main menu appears when the program has successfully loaded and executed. Open the file, `Delta_Hymap_2008.img` and load it into a display as a CIR.

Calculating Forward PC Rotations

The forward PC rotation uses a linear transform to maximize the variance of the data contained by each successive axis. When you use forward PC rotation, ENVI allows you to calculate new statistics or to rotate from existing statistics. The output of either can be saved as byte, floating point, integer, long integer, or double precision values. You also have the option to subset the output of the PC rotation based on eigenvalues, and to generate output of only the PC bands that you need.

Computing New Statistics and Rotating

1. We will use Compute New Statistics and Rotate to calculate the eigenvalue and covariance or correlation statistics for your data and to calculate the forward PC rotation transform.
2. Select **Transforms → Principal Components → Forward PC Rotation → Compute New Statistics and Rotate**.
3. When the Principal Components Input File dialog appears, select and subset your input file using standard ENVI file selection procedures (choose a spectral subset of the first 93 bands) and click OK. You can perform a PCA on any subset of bands or all bands within an image. We are limiting our analysis here to the first 93 bands to reduce processing times. The Forward PC Rotation Parameters dialog appears.

> Note: You can click Stats Subset to calculate the variance-covariance statistics based on a spatial subset such as an area under an ROI. However, the default is for the statistics to be calculated from the entire image.

4. Enter resize factors less than 1 in the Stats X/Y Resize Factor text boxes to sub-sample the data when calculating the statistics. For example, using a resize factor of 0.1 will use every 10th pixel in the statistics calculations. This will increase the speed of the statistics calculations.
5. Output your statistics file to your Lab_Products folder using the filename: `Delta_Hymap_2008_pcastats.sta`.
6. Select to calculate the PCs based on the Covariance Matrix using the arrow toggle button.

> Note: Typically, use the covariance matrix when calculating the principal components. Use the correlation matrix when the data range differs greatly between bands and normalization is needed.

7. Save your PCA file to the Lab_Products folder, using the file name `Delta_Hymap_2008_pca.img`.
8. From the Output Data Type menu, select the desired data type of the output file (we'll stick with Floating Point).
9. Select the number of output PC bands as 30. You can limit the number of output PC bands, by entering the desired number of output bands in the text box or by using the arrow increment button next to the Number of Output PC Bands label. The default number of output bands is equal to the number of input bands. Reducing the number of output bands will increase processing speed and also reduce disk space requirements. It is unlikely that PC bands past 30 will contain much variance.
10. Alternatively, you can choose to select the number of output PC bands using the eigenvalues to ensure that you don't omit useful information. To do this, perform the following steps.
    - Click the arrow toggle button next to the **Select Subset from Eigenvalues** label to select **Yes**. Once the statistics are calculated the Select Output PC Bands dialog appears with each band listed with its corresponding eigenvalue. Also listed is the cumulative percentage of data variance contained in each PC band for all PC bands.
    - Select the number of bands to output by entering the desired number into the **Number of Output PC Bands** box or by clicking on the arrow buttons. PC Bands with large eigenvalues contain the largest amounts of data variance. Bands with lower eigenvalues contain less data information and more noise. Sometimes, it is best to output only those bands with large eigenvalues to save disk space.
    - Click OK in the Select Output PC Bands dialog. The output PC rotation will contain only the number of bands that you selected. For example, if you chose "30" as the number of output bands, only the first 30 PC bands will appear in your output file.
11. In the Forward PC Rotation Parameters dialog, click OK.
12. The PCA will take a few minutes. When ENVI has finished processing, the PC Eigenvalues plot window appears and the PC bands are loaded into the Available Bands List where you may access them for display. For information on editing and other options in the eigenvalue plot window, see Using Interactive Plot Functions in ENVI Help.

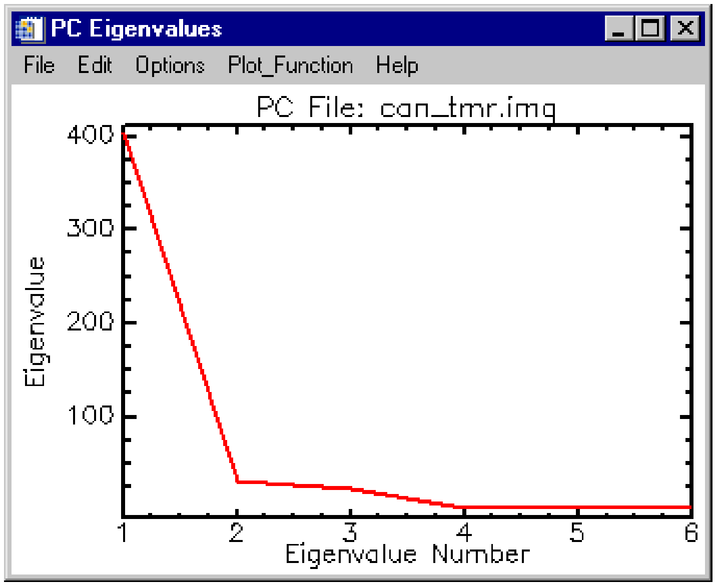


Figure 5-2: PC Eigenvalues Plot Window

13. Load an RGB image of the top 3 PCA bands. Inspect the z-profile of the PCA image. Link the PCA image to your CIR reflectance image. Are any features more readily apparent in the PCA-transformed data? Are different land cover classes more distinctly colored than in the CIR?

14. Load band 30 as a gray scale. How does it differ from the reflectance image and the top 3 PCA bands?

15. Inspect the variance structure of the image. Open the statistics file: **Basic Tools → Statistics → View Statistics File**. In the Enter Statistics Filename dialog, find your file `Delta_Hymap_2008_pcastats.sta` and click OK. Output the statistics to a text file by selecting **File → Save** results to text file in the Stats File window. Use the filename `Delta_Hymap_2008_pcastats.txt`.

    You can now open this text file in Microsoft Excel. Specify that the file type is delimited and that Excel should start import at line 4. Click Next and then Finish. Excel should open a spreadsheet with the PC bands as the rows. For each PC band it includes the minimum, maximum, and mean values, the standard deviation, and the eigenvalue. If you scroll down further, you will see the variance-covariance matrix and the eigenvectors.

    Calculate the sum of all the eigenvalues. This is the total amount of variance in your image. Now, next to your eigenvalue column make a new column entitled "% variation". Calculate this as 100 * the eigenvalue of each band divided by the sum of all the eigenvalues you just calculated. How well distributed is the variation in your PCA bands?

    You may close your PCA files.

Minimum Noise Fraction Transformation

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 variance equal to one 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 5-3 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.

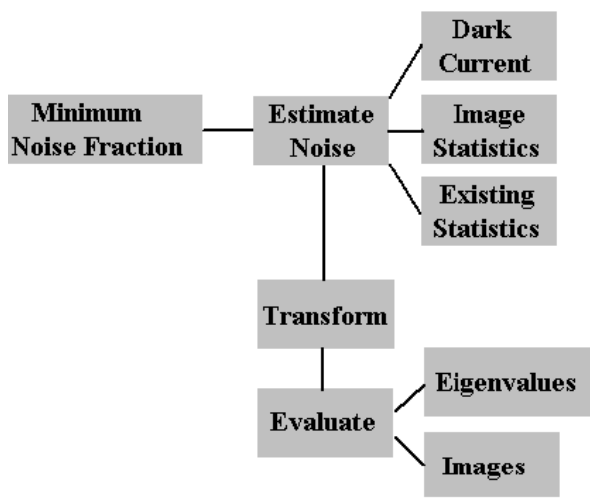


Figure 5-3: MNF Procedures in ENVI

Calculating Forward MNF Transforms

Perform your MNF transform using the Estimate Noise Statistics From Data option when you have no dark current image for your data, which is usually the case. ENVI assumes that each pixel contains both signal and noise, and that adjacent pixels contain the same signal but different noise. A shift difference is performed on the data by differencing adjacent pixels to the right and above each pixel and averaging the results to obtain the "noise" value to assign to the pixel being processed. The best noise estimate is gathered using the shift-difference statistics from a homogeneous area rather than from the whole image. ENVI allows you to select the subset for statistics extraction.

1. Select **Transforms → MNF Rotation → Forward MNF → Estimate Noise Statistics From Data** or **Spectral → MNF Rotation → Forward MNF → Estimate Noise Statistics From Data.**
2. When the MNF Transform Input File dialog appears, select and subset your input file using the standard ENVI file selection procedures (choose a spectral subset of the first 93 bands) and click OK.

   You can perform an MNF on any subset of bands or all bands within an image. We are limiting our analysis here to the first 93 bands to reduce processing times. The Forward MNF Transform Parameters dialog appears.

   > Note: Click Shift Diff Subset if you wish to select a spatial subset or an area under an ROI on which to calculate the statistics. You can then apply the calculated results to the entire file (or to the file subset if you selected one when you selected the input file). For instructions, see Using Statistics Subsetting. The default is for the statistics to be calculated from the entire image.

Saving your MNF files to the Lab_Products folder:

3. In the Enter Output Noise Stats Filename [.sta] text box, enter a filename for the noise statistics (e.g., `Delta_Hymap_2008_mnf_noisestats.sta`).
4. In the Enter Output MNF Stats Filename [.sta] text box, enter an output file for the MNF statistics (e.g., `Delta_Hymap_2008_mnf_stats.sta`).

   > Note: Be sure that the MNF and noise statistics files have different names.

5. Select File output and give it the filename `Delta_Hymap_2008_mnf.img`.
6. Select the number of output MNF bands by using one of the following options:
   A. Enter "40" in the Number of Output MNF Bands box, or
   B. To select the number of output MNF bands by examining the eigenvalues, click the arrow toggle button next to the **Select Subset from Eigenvalues** label to select Yes.
   Click OK to calculate the noise statistics and perform the first rotation. Once the statistics are calculated the Select Output MNF Bands dialog appears, with each band listed with its corresponding eigenvalue. Also listed is the cumulative percentage of data variance contained in each MNF band for all bands.

   Click the arrow buttons next to the Number of Output MNF Bands label to set number of output bands to the desired number, or enter the number into the box. Choose to include only bands with large eigenvalues that contain nontrivial proportions of variation. As you can see, by band 30, most of the variation is explained and the addition of each successive band only adds additional information in very small increments.
   Click OK in the Select Output MNF Bands dialog to complete the rotation.

   > Note: For the best results, and to save disk space, output only those bands with high eigenvalues-bands with eigenvalues close to 1 are mostly noise.

7. The MNF transform will take a few minutes. When ENVI has finished processing, it loads the MNF bands into the Available Bands List and displays the MNF Eigenvalues Plot Window. The output only contains the number of bands you selected for output. For example, if your input data contained 224 bands, but you selected only 50 bands for output, your output will only contain the first 50 calculated MNF bands from your input.

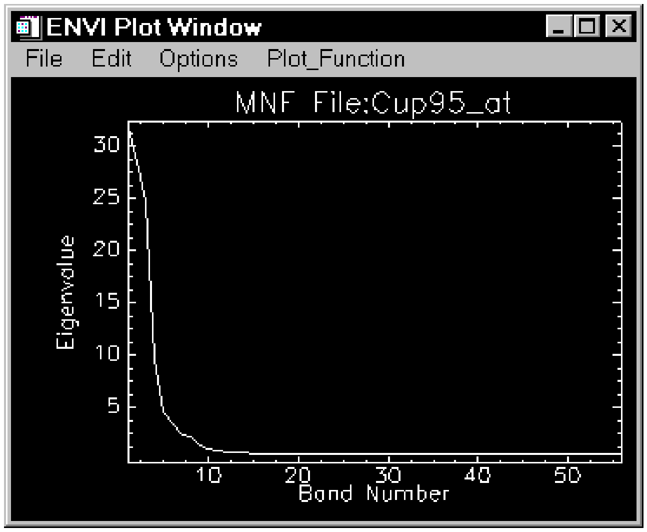


Figure 5-4: MNF Eigenvalues Plot Window

8. Load an RGB image of the top 3 MNF bands. Inspect the z-profile of the MNF image. Link the MNF image to your CIR reflectance image (by right clicking an image and selecting Geographic Link). Are any features more readily apparent in the MNF-transformed data? Are different land cover classes more distinctly colored than in the CIR?

9. Load band 30 as a gray scale. How does it differ from the reflectance image and the top 3 MNF bands?

10. Inspect the variance structure of the image. Open the statistics file: **Basic Tools → Statistics → View Statistics File.** In the Enter Statistics Filename dialog, find your file `Delta_Hymap_2008_mnf_stats.sta` and click OK. Output the statistics to a text file in the Lab_Products folder by selecting **File → Save** results to text file in the Stats File window. Use the filename `Delta_Hymap_2008_mnf_stats.txt.`

You can now open this text file in Microsoft Excel. Specify that the file type is delimited and that Excel should start import at line 4. Click Next and then Finish. Excel should open a spreadsheet with the PC bands as the rows. For each MNF band it includes the minimum, maximum, and mean values, the standard deviation, and the eigenvalue. If you scroll down further, you will see the variance-covariance matrix and the eigenvectors.

Calculate the sum of all the eigenvalues. This is the total amount of variance in your image. Now, next to your eigenvalue column make a new column entitled "% variation". Calculate this as 100 * the eigenvalue of each band divided by the sum of all the eigenvalues you just calculated. How well distributed is the variation in your MNF bands?

Now create another new column entitled "cumulative variation" and calculate the values. (A quick way to do this is to set the cumulative variation for the first band equal to its %

variation. For the second band, enter the formula "= the cell with the % variation for that band + the cell with the cumulative variation for the preceding band". Now copy that formula and paste it into the remaining rows.)

11. To perform dimensionality reduction of MNF (or PCA) bands, common rules of thumb are to:
    a. Exclude all bands occurring after a threshold of 80% cumulative variation.
    b. Exclude all bands whose eigenvalue is less than the average eigenvalue.
    c. Plot the eigenvalues vs. band number. This is called a "Scree plot". Identify the band at which a kink occurs and the scree plot flattens out and exlude all bands occurring after this one.
    d. View the individual MNF bands and exclude those that are dominated by noise and are not spatially coherent.
    e. If you performed the MNF transform on a mosaic of several images, you should inspect each MNF output band and discard those that show dramatic differences between the individual images that make up the mosaic.

Examine MNF Scatter Plots

1. Use **Tools → 2D Scatter Plots** in the Main Image window to understand the MNF images.
2. Choose MNF band 1 as your X and MNF band 2 as your Y.
3. Now plot 2 reflectance bands against each other (e.g., bands 18 and 28). Can you see from the plots that the 2 reflectance bands are much more tightly correlated to each other than the 2 MNF bands are?
4. Now plot a reflectance band (e.g., band 28) against a high variance (low band number) MNF band (e.g., band 1). Remember that MNF bands are linear combinations of the original reflectance bands. The degree to which these bands are correlated depends on the contribution of that reflectance band to that MNF band.
5. Plot a reflectance band (e.g., band 28) against a low variance (high band number) MNF band (e.g., band 30). Can you see from the nebulous point cloud that the reflectance band makes a much lower contribution to this MNF band, which is dominated by noise.
6. Notice the corners (pointed edges) on some MNF scatter plots (Figure 5-5). Pixels occurring in these regions are generally interpreted as being spectrally pure, composed of a single land cover while pixels that fall within these corners on the scatter plots are expected to be mixtures of the materials at the corners. Pixels that fall in the pointed edges may be good choices as training data for classifications or other analyses. We will discuss the idea of pure and mixed pixels in more depth in the unmixing labs.

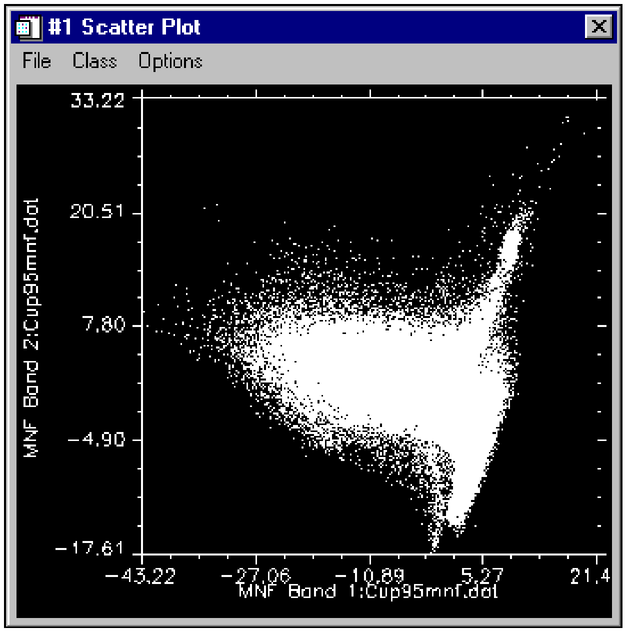


Figure 5-5: MNF Scatter Plot

7. Use linked windows, overlays, “dancing pixels”, 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.

Complete Your Data Products Spreadsheet

You have created several data products from the input file `Delta_HyMap_2008.img`, including `Delta_HyMap_2008_pca.img`, and `Delta_HyMap_2008_mnf`. Record this information, including file pathways, in your `your_name_data_products.xls` spreadsheet.

You may wish to reorganize your Lab_Products folder using subfolders to appropriately group your files together (i.e. index files vs continuum removal images), or transfer your files to your appropriate personal lab folder(s).

Tutorial 6: Unsupervised and Supervised Classification

The following topics are covered in this tutorial:

Overview of This Tutorial

Classification is the process of assigning class membership to a set of samples. In the case of remote sensing, the samples are the pixels of an image. Pixels are classified on the basis of spectral similarity, using a variety of statistical techniques. Classes may be defined a priori, using ground reference data and knowledge of the site, or may be specified from the natural spectral groupings within an image. This tutorial leads you through a typical multispectral classification procedure using Landsat TM data from the Delta, California. Results of both unsupervised and supervised classifications are examined and post classification processing including clump, sieve, combine classes, and accuracy assessment are discussed.

Files Used in This Tutorial

Input Path: My Documents\ERS_186\Lab_Data\Multispectral\Landsat\

Output Path: My Documents\ERS_186\your_folder\lab6

Input Files	Description
`Delta_LandsatTM_2008.img`	Delta, CA, TM Data
`Delta_classes_2008.roi`	ENVI regions of interest file

Output Files	Description
`Delta_2008_class_km.img`	K-means classification file
`Delta_2008_class_id.img`	Isodata classification file
`Delta_2008_class_pp.img`	Parallelepiped classification file
`Delta_2008_class_mahd.img`	Mahalanobis Distance classification file

`Delta_2008_class_mahdr.img`	Mahalanobis Distance rules file
`Delta_2008_class_mahd2.img`	Optimized Mahalanobis Distance classification file.
`Delta_2008_class_mind.img`	Minimum Distance classification file
`Delta_2008_class_ml.img`	Maximum Likelihood classification file
`Delta_2008_class_mahd2_sieve.img`	Mahalanobis Distance sieved file
`Delta_2008_class_mahd2_clump.img`	Mahalanobis Distance clumped file
`Delta_2008_class_mahd2_comb.img`	Combined classes file

Examine Landsat TM Color Images

This portion of the exercise will familiarize you with the spectral characteristics of the Landsat TM data of the Delta, California, 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

Start ENVI by double-clicking 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 C:\My Documents\ERS_186\Lab_Data\Multispectral\Landsat\ directory and select the file `Delta_LandsatTM_2008.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. A false-color infrared (CIR) display should appear.

Review Image Colors

Use the displayed color image as a guide to classification. 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 have high infrared reflectance and low reflectance in the red and green, which is characteristic of healthy vegetation, especially that under cultivation. Slightly darker red areas typically represent native vegetation; in this area, it tends to occur on the hills and in wetlands. Urbanization is also readily apparent. The following figure shows the resulting Main Image window for these bands.

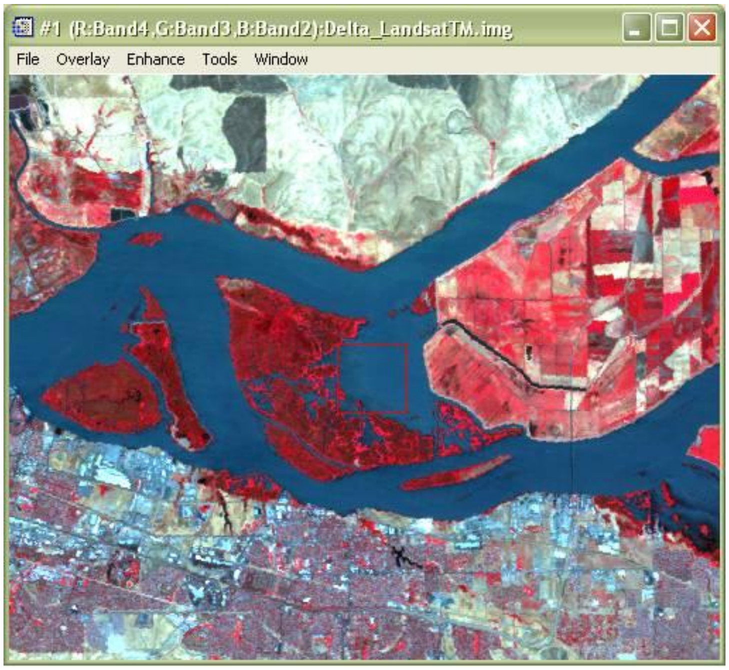


Figure 6-1: Delta, California Landsat TM Data

Cursor Location/Value

Use ENVI's Cursor Location/Value dialog to preview image values in the displayed spectral bands and the location of the cursor.

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. Or you can right click in any window of the display and choose Cursor Location/Value.

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

3. Select **File → Cance**l in the Cursor Location/Value dialog to dismiss it 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 or right click in any display window and choose Z Profile (Spectrum).

2. Examine the spectra for areas that you previewed above using the Cursor/Location Value dialog by

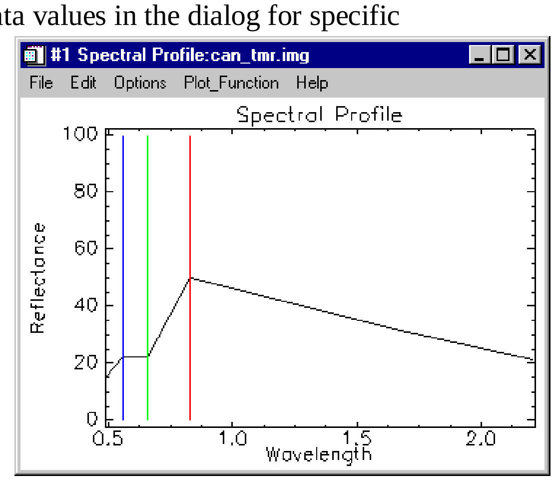


Figure 6-2: Spectral Plots from Canon City TM Data

clicking the left mouse button in any of the display group windows. The Spectral Profile window will display the spectrum for the pixel you selected. Note the relations between image color and spectral shape. Pay attention to the location of the displayed image bands in the spectral profile, marked by the red, green, and blue bars in the plot.

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**.

K-Means

Unsupervised classifications use 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. The classifier arbitrarily locates this number of cluster centers, then iteratively repositions them until optimal spectral separability is achieved.

Choose **Classification → Unsupervised → K-Means**, use all of the default values, choose the Lab_Products output directory, give the name, `Delta_2008_class_km.img` and click OK.

1. Load the file, `Delta_2008_class_km.img`. Highlight the band name for this classification image in the available bands list, click on the Gray Scale radio button, 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. You can resize the portion of the image using the dynamic overlay by clicking the center mouse button and defining a rectangle. Move the dynamic overlay around the image by clicking and dragging with the left mouse button.
4. Try to indentify the land cover associated with each class and write this down.
5. 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 **Classification → Unsupervised → IsoData**, use all of the default values, choose your output directory, give the name, `Delta_2008_class_id.img` and click on OK.

1. Load the file `Delta_2008_class_id.img`. Highlight the band name for this classification image in the available bands list, click on the Gray Scale radio button, select New Display on the Display button pull-down menu, and then Load Band.
2. In the main image window, select **Tools → Link→ Link Displays**. Click OK to link this image to the false-color CIR and the K-Means classification.
3. Compare the IsoData classification result to the color composite image using the dynamic overlay as you did for the K-Means classification. Change the image that is displayed by the dynamic overlay by holding the left mouse button down in an image window and simultaneously clicking on the middle mouse button.
4. Try to identify the land cover associated with each class and write this down.
5. Compare the IsoData and K-Means classifications. Note that these two classifiers will have assigned different colors to similar spectral classes. Do class boundaries generally agree spatially between the two techniques? Look at your land cover interpretations for the 2 classifications. Do they split the spectral data into similar classes?

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.

You may close your K-Means and IsoData classification images.

Supervised Classification

Supervised classifications require that the user select training areas to define each class. Pixels are then compared to the training data and assigned to the most appropriate class. 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, in 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 Lab 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. Open the ROI Tool dialog by choosing **Overlay → Region of Interest** in the main image window.
2. In the ROI Tool dialog, choose **File → Restore ROIs**.

3. The Enter ROI Filename dialog opens. Select `Delta_classes_2008.roi` as the input file to restore.

You can check out these regions by selecting one in the ROI Tool dialog and clicking **Goto.**

Create Your Own ROIs

If you are using the predefined ROIs, skip ahead to the Classical Supervised Multispectral Classification section.

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 creating an ROI, its definition is shown in the table of the ROI Tool dialog. The definition includes the name, region color, number of pixels enclosed, and other ROI properties.
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 editing the values in the cells of the table. 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. Pixels are assigned to a class when they occur within that class's parallelepiped. If they are outside all parallelepipeds, they are left unclassified.

1. Perform a parallelepiped classification (**Classification → Supervised→ Parallelepiped**) on the image `Delta_LandsatTM_2008.img` using the `Delta_classes_2008.roi` regions of interest or the ROIs you defined. Run the classification using the default parameters. Save your results in the Lab_Products folder as `Delta_2008_class_pp.img`. You may also output

a rules image if you like. Use the toggle switch to choose whether or not a rules image is generated.

2. Use image linking and the dynamic overlay to compare this classification to the color composite image. Do you see any pixels that are obviously misclassified? (e.g., vegetated pixels assigned to the urban class, etc..)

Minimum Distance

The minimum distance classification (**Classification → Supervised→ Minimum Distance**) uses the centroids (i.e., the mean spectral values) of each ROI and calculates the Euclidean distance from each unknown pixel to the centroid 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 a minimum distance classification of the Landsat scene using the `Delta_classes_2008.roi` regions of interest or the ROIs you defined. Run the classification using the default parameters. Save results as `Delta_2008_class_mind.img`. You may also output a rules image if you like. Use the toggle switch to choose whether or not a rules image is generated.
2. Use image linking and the dynamic overlay to compare this classification to the color composite image and the parallelepiped classification. Do you see any pixels that are obviously misclassified? How do the parallelepiped and minimum distance results differ? Note especially the Aquatic Vegetation class if you used the predefined ROIs.

Mahalanobis Distance

The Mahalanobis Distance classification (**Classification → Supervised→ Mahalanobis Distance**) is a direction sensitive distance classifier that uses covariance statistics in addition to class means and standard deviations. 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 a Mahalanobis distance classification using the `Delta_classes_2008.roi` regions of interest or the ROIs you defined. Run the classification using the default parameters. Save results as `Delta_2008_class_mahd.img`. Choose to output a rules file and name it `Delta_2008_class_mahdr.img.`
2. Use image linking and the dynamic overlay to compare this classification to the color composite image and previous supervised classifications. Do you see any pixels that are obviously misclassified? How do Mahalanobis results differ from the other 2 supervised classifications? Note especially the Aquatic Vegetation class if you used the predefined ROIs.
3. Load a band from the rule image and link it to the classification. The values in the rule image are the calculated Mahalanobis distances from that pixel to the training data for each class. Display the z-profile for the rule image. Notice the relationship between the relative values of the rule bands and the classification

result. The pixel is assigned to the class for which it has the minimum Mahalanobis distance.

Maximum Likelihood

Maximum likelihood classification (**Classification → Supervised→ Maximum Likelihood)** assumes that the reflectance values for each class in each band are normally distributed and calculates the probability that a given pixel belongs to each class. Unless a probability threshold is selected, all pixels are classified. Each pixel is assigned to the class for which it has the highest probability of membership (i.e., the maximum likelihood).

1. Perform a maximum likelihood classification using the `Delta_classes_2008.roi` regions of interest or the ROIs you defined. Run the classification using the default parameters. Save results as `Delta_2008_class_ml.img.` You may also output a rules image if you like. Use the toggle switch to choose whether or not a rules image is generated.
2. Use image linking and the dynamic overlay to compare this classification to the color composite image and previous supervised classifications. Do you see any pixels that are obviously misclassified? How do Mahalanobis results differ from the other 2 supervised classifications? Note especially the Urban class if you used the predefined ROIs.
3. You may now close all of your classification displays.

The Endmember Collection Dialog

The Endmember Collection dialog is an alternative method to import training data into your classifiers. It is a standardized means of collecting spectra for supervised classification from ASCII files, regions of interest, spectral libraries, and statistics files. You do not need to perform any classifications via this pathway as the results would be identical to those you have already generated, but the procedure, for future reference, is:

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, select `Delta_LandsatTM_2008.img` and click OK.
3. This brings up the 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, including Parallelepiped, Minimum Distance, Manlanahobis Distance, Maximum Likelihood, Binary Encoding, and the Spectral Angle Mapper (SAM).

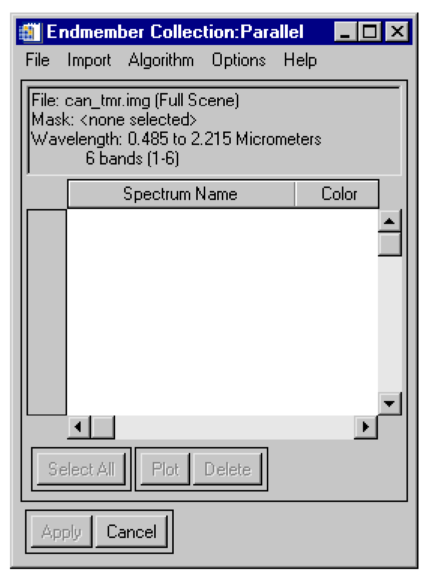


Figure 6-3: Endmember Collection Dialog

Note: You must select the algorithm BEFORE importing endmembers in order for ENVI to calculate the correct statistics.

4. Close the Endmember Collection dialog.

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 as necessary using different thresholds. These are gray scale images; one for each class in the classification. The rule image pixel values represent different things for different types of classifications, for example:

Classification Method	Rule Image Values
Parallelepiped	Number of bands satisfying the parallelepiped criteria
Minimum Distance	Euclidean distance from the class mean
Maximum Likelihood	Probability of pixel belonging to class (rescaled)
Mahalanobis Distance	Mahalanobis distance from the class mean

1. For the Mahalanobis Distance classification above, load the classified image and the rule image for one class into separate displays. Invert the rule images using **Tools → Color Mapping → ENVI Color Tables** and drag the **Stretch Bottom** and **Stretch Top** sliders to opposite ends of the dialog. Pixels closer to class means (i.e., those with spectra more similar to the training ROI and thus shorter Mahalanobis distances) now appear bright.

2. Link the classification and rule image displays. Use Z-profiles and the Cursor Location/Value tool to determine if better thresholds could be used to obtain more spatially coherent classifications. In particular, identify a better threshold value for the Aquatic Vegetation class so that classified pixels include aquatic vegetation, but exclude the Pacific Ocean and upland green and nonphotosynthetic vegetation. To do so, find a Mahalanobis distance value is greater than those exhibited by most pixels that truly contain aquatic vegetation, but it lower than pixels that are erroneously classified as Aquatic Vegetation.

3. If you **find better thresholds, select Classification**→ Post Classification → Rule Classifier from the ENVI main menu.

4. Choose the `Delta_2008_class_mahdr.img` input file as the rule image and click OK to bring up the Rule Image Classifier Tool, then enter a threshold to create a new classified image. Click on the radio button to classify by Minimum Value. This lets ENVI know that smaller rule values represent better matches.

5. Click Quick Apply to have your reclassified image displayed in a new window.

6. Compare your new classification to the previous classifications. Since you have set thresholds where there were none originally, you should now have some unclassified pixels, displayed as black.

7. You may continue to adjust the rule classifier until you are satisfied with the results. Click Save To File when you are happy with the results, and choose the filename `Delta_2008_class_mahd2.img.`

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, histograms, and average spectra are calculated for each class selected.

1. Choose **Classification→ Post Classification → Class Statistics** to start the process and select a Classification Image (e.g.: `Delta_2008_class_mahd2.img`) and click OK.

2. Select the image used to produce the classification (`Delta_LandsatTM_2008.img`) and click OK.

3. Click **Select All Items** and then OK in the Class Selection dialog.

4. Click the Histograms and Covariance check boxes in the Compute Statistics Parameters dialog to calculate all the possible statistics.

5. Click OK at the bottom of the Compute Statistics Parameters dialog. The Class Statistics Results dialog appears. The top of this window displays the mean spectra for each class. Do the mean spectra correspond to expected reflectance profiles for these land cover classes? Summary statistics for each class by band are displayed in the Statistics Results dialog. You may close this window.

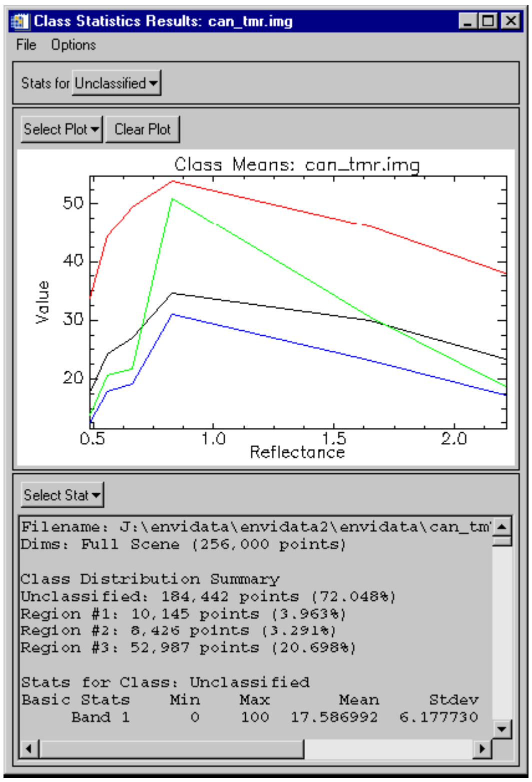


Figure 6-4: Sample Class Statistics Report

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. We do not have ground reference data for this scene, so you will be comparing two of your classifications to each other. You will also compare a classification to the training ROIs, although this will not provide an unbiased measure of accuracy.

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 Maximum Likelihood images you previously created by choosing the two files,

Delta_2008_class_ml.img and Delta_2008_class_pp.img and clicking OK (for the purposes of this exercise, we are using the Delta_2008_class_pp.img file as the ground truth).

3. Use the Match Classes Parameters dialog to pair corresponding classes from the two images and click OK. (If the classes have the same name in each image, ENVI will pair them automatically.)

4. Answer "**No**" in the Confusion Matrix Parameters where it asks "**Output Error Images**?".

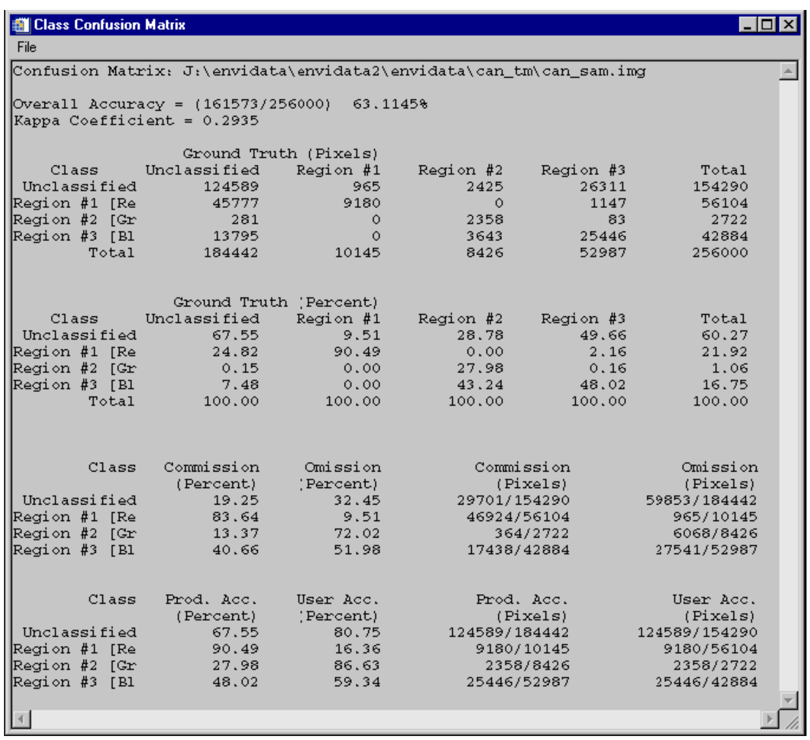
5. Examine the confusion matrix. For which class do the classifiers agree the most? On which do they disagree the most? Determine sources of error by comparing the classified images to the original reflectance image using dynamic overlays, spectral profiles, and Cursor Location/Value.

6. For the Using Ground Truth ROIs method, select the classified image Delta_2008_class_ml.img to be evaluated.

7. Match the image classes to the ROIs loaded from Delta_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. According to the confusion matrix, which classes have the lowest commission and omission errors? Is this supported by your inspection of the images?



Class Confusion Matrix

File

Confusion Matrix: J:\envidata\envidata2\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	19.25	32.45	29701/154290	59853/184442
Region #1 [Re	83.64	9.51	46924/56104	965/10145
Region #2 [Gr	13.37	72.02	364/2722	6068/8426
Region #3 [Bl	40.66	51.98	17438/42884	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 6-5: Confusion Matrix using a Second Classification Image as Ground Truth

Clump and Sieve

Clump and Sieve provide methods 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. Illustrate what each of these tools does by performing the following operations and comparing the results to your original classification.

1. To sieve, select **Classification→ Post Classification → Sieve Classes**, choose `Delta_2008_class_mahd2.img`, choose your output folder, give filename `Delta_2008_class_mahd2_sieve.img` and click OK.
2. Use the output of the sieve operation as the input for clumping. Choose **Classification → Post Classification → Clump Classes,** choose `Delta_2008_class_mahd2_sieve.img` and click OK.
3. Output as `Delta_2008_class_mahd2_clump.img` and click OK in the Clump Parameters dialog.
4. Compare the three images. Do you see the effect of both sieving and clumping? Reiterate if necessary with different thresholds to produce a generalized classification image.

Combine Classes

The Combine Classes function provides an alternative method for classification generalization. Similar classes can be combined into a single more generalized class.

1. Perform your own combinations as described below.
2. Select **Classification→ Post Classification → Combine Classes**.
3. Select the `Delta_2008_class_mahd2.img` file in the Combine Classes Input File dialog and click OK.
4. Choose Urban (as the input class) to combine with Unclassified (as the output class), click on Add Combination, and then OK in the Combine Classes Parameters dialog. Choose "**Yes**" in response to the question "Remove Empty Classes?". Output as `Delta_class_mahd2_comb.img` and click OK.
5. Compare the combined class image to the classified images and the sieved and clumped 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 of the classification image.
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. You may choose from a pulldown menu of color options by clicking on the "Color" menu. Changes are applied to the classified image immediately. To make the changes permanent, select **Options → Save Changes** in the dialog. You can also edit the names assigned to classes in this dialog.

Classes to Vector Layers

Execute the function and convert one of the classification images to vector layers which you can use in a GIS.

1. Select **Classification→ Post Classification → Classification to Vector** and choose the generalized image `Delta_2008_class_mahd2_clump.img` within the Raster to Vector Input Band dialog. (It is wise to output sieved & clumped classifications rather than the raw class outputs to vector. Sieved & clumped maps are more generalized and less complex. This reduces computing time and the complexity of the resulting polygons.)
2. In the Raster to Vector Parameters, you can choose which classes you wish to convert to vectors and also whether you would like all classes to be in a single vector file or for a separate vector file to be created for each class.
3. We will not convert our classification results to vectors because it can be very time consuming, so click Cancel.

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 one of the classified images.
2. Select **Object → Map Key** to add a legend to 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. You should shorten the class names that will be displayed.
3. Click in the image display to place the key. In the Annotation dialog, turn on the background and choose a background color that will allow your legend to be legible.
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 User's Guide.

Complete Your Data Products Spreadsheet

You have created several data products from the input file `Delta_LandsatTM_2008.img`. You may wish to reorganize your Lab_Products folder using subfolders to appropriately group your files, or transfer your files to your appropriate personal lab folder(s). Record this information, including file pathways, in your `your_name_data_products.xls` spreadsheet.

End the ENVI Session

Tutorial 7: Change Detection

The following topics are covered in this tutorial:

Image Differencing

Principal Components Analysis

Post-Classification Change Detection

Overview of This Tutorial

This tutorial is designed to introduce you to several common remote sensing change detection techniques.

Files Used in This Tutorial

Input Path: C:\My Documents\ERS_186\Lab_Data\Multispectral\Landsat\

Output Path: C:\My Documents\ERS_186\your_folder\lab7

Input Files	Description
`Delta_LandsatTM_2008.img`	Delta, CA, Landsat Data, 2008
`Delta_LandsatTM_1998.img`	Delta, CA, Landsat Data, 1998
`Delta_LandsatTM_mahdopt.img`	Optimized 2008 Mahalanobis Distance Classification from assignment 3
`Delta_classes_opt.roi`	ROI of classification training data, 2008

Output Files	Description
`Delta_LandsatTM_2date.img`	Multidate Landsat image
`Delta_LandsatTM_2date_msk.img`	Mask of overlap between 1998 and 2008
`Delta_LandsatTM_1998_NDVI.img`	1998 NDVI
`Delta_LandsatTM_2008_NDVI.img`	2008 NDVI
`Delta_LandsatTM_NDVI_diff.img`	NDVI difference, 1998-2008
`Delta_LandsatTM_2date_PCA.img`	Multidate principal components analysis
`Delta_LandsatTM_2date_PCAstats.sta`	PCA stats
`Delta_LandsatTM_1998_msk.img`	1998 edge mask
`Delta_LandsatTM_1998_mahd.img`	Mahalanobis Distance Classification, 1998

Change Detection

Change detection is a major remote sensing application. A change detection analyzes two or more images acquired on different dates to identify regions that have undergone change and to interpret the types and causes of change. Several common methods are:

Image differencing – Image differencing change detection subtracts a reflectance band or reflectance product of one image date from another. For example:

$$NDVI_{diff} = NDVI_{t+1} - NDVI_t$$

"Change" pixels are those with a large difference (positive or negative). They are typically identified by setting thresholds. For example, pixels with values more than 3 standard deviations from the average difference might be "change" pixels. Image differencing that has been generalized to multiband situations is known as Change Vector Analysis (CVA). In these cases, the magnitude of differences indicates whether or not change has occurred and the direction of differences in multiband space provides information as to the type of change. For example, CVA may be performed using indexes or linear spectral unmixixing (LSU) fractions as inputs.

Principal components analysis (PCA) – Another change detection method is to stack image dates into a single file and perform a PCA on the multidate image. The first few PC bands typically represent unchanged areas (since change generally happens over only a small portion of a scene). Higher order PC bands highlight change. As with the statistical data reduction techniques, PCA change detections may be difficult to interpret. Furthermore, they merely identify change but provide no information as to the type of change. Users must interpret the change themselves by inspecting the original images.

Post-classification change detection – In this method, the two image dates are classified independently. The change detection then determines whether and how the class membership of each pixel changed between the image dates. This technique provides detailed "from – to" information about the type of change. However, it is hampered by the accuracy of the input classifications. The accuracy of a post-classification change detection can never be higher than the product of the individual classification accuracies.

Preparing a Multidate Image

1. Open the files `Delta_LandsatTM_2008.img` and `Delta_LandsatTM_1998.img` and load CIR displays of each. These are Landsat Thematic Mapper images of the San Francisco Bay/Sacramento-San Joaquin Delta acquired in June 1998 and June 2008. As you can see, these 2 images have different extents. You will create and apply a mask including just the areas covered by both images later in this exercise, to limit our change detection to this region.
2. Geographically link the two images. Toggle on the zoom-window crosshairs for each display and click around the images to assess the georegistration. Accurate co-registration is crucial for a change detection. If the image dates are sloppily registered, areas of false change will be identified where features fail to line up.
3. Combine the two files into a multidate image.
   Go to **Basic Tools → Layer Stacking**. The Layer Stacking Parameters dialog will appear.
4. Click **Import File…,** choose your files `Delta_LandsatTM_2008.img` and `Delta_LandsatTM_1998.img` and click OK.
5. Click Reorder Files and drag 1998 upward so this image is first (if necessary).
6. In the Output File Range section choose the "**Exclusive: range encompasses file overlap**" option.

The information on the right half of the dialog has been imported from the input files and should be correct.

7. Save your multi-date image to the Lab_Products folder and name your output file `Delta_LandsatTM_2date.img`. Click OK. This will take a few minutes for ENVI to process.

8. Load an RGB of the multidate image with **2008 Band 4 in both the red and the green** and **1998 Band 4 in the blue** and geographically link it to the two single date images.

   In this multidate composite display, pixels that have brighter NIR reflectance in 2008 will appear yellow. Pixels that have brighter NIR reflectance in 1998 will appear blue. Pixels with similar NIR reflectance in the two images will be displayed in shades of gray.

   Right click in your multidate image and **select the "Pixel Locator" tool**, then Click around in the linked images to find areas of change.

   Go to the following pixel coordinates, press apply after entering each pair:
   Sample: 3333, Line: 2301 – Changed water levels in the Los Vaqueros Reservoir show up as blue in the multidate image because the reservoir had higher water levels in 2008, which is darker in the NIR, than in 1998.
   Sample: 2081, Line: 3527 – This area of the South Bay show up as yellow in the multidate image because it appears to have been developed more in 2008, and flooded in 1998, showing brighter NIR in this area in 2008.

   Find a few more instances of change and see if you can intuit the cause.

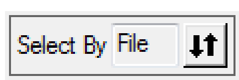
   You will notice that there is a blue fringe along the entire northern edge of the image area. This is due to the fact that the 1998 LandsatTM image extends further north than the 2008 image.

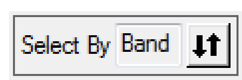
9. Create a mask for the area of overlap from the two image dates:

   Go to **Basic Tools → Masking → Build Mask** and choose the display number that corresponds to your multidate image.

   In the Mask Definition dialog choose **Options → Selected Areas "Off**". Then choose **Options → Import Data Range.**

   Select the input file **`Delta_LandsatTM_2date.img`**

   Click the up and down arrows in 

 to read 

   Select the LandsatTM_2008 Band 4 and click OK

   In the Input for Data Range Mask dialog,
   enter **-9999 for the Data Min Value** and **0 for the Data Max Value** and click OK.

   Save your mask file in the Lab_Products folder as
   `Delta_LandsatTM_2date_msk.img` and click Apply.

10. Apply the mask to constrain the extents to have the same limited area of overlap.

Go to **Basic Tools → Masking → Apply Mask** and choose `Delta_LandsatTM_2date.img`.

Click **Select Mask Band → Mask Band** (under `Delta_LandsatTM_2date_msk.img`)

Save your output file to the Lab_Products folder and name it **`Delta_LandsatTM_2date_masked.img`.** Click OK.

Calculating an NDVI Difference Image

1. Use the masked multidate image you just completed to calculate NDVI for the 1998 and 2008 image dates, since this file has been resampled to a common geographic extent.
2. Open Band Math (under Basic Tools) and enter the expression: (float(b1)-float(b2))/(float(b1)+float(b2)).
3. Pair b1 to the 1998 band 4 and b2 to the 1998 band 3 and enter the output file name `Delta_LandsatTM_NDVI_1998.img`.
4. Repeat step 2 using the 2008 bands and save as `Delta_LandsatTM_NDVI_2008.img`.
5. Load a multidate composite NDVI display as an RGB by selecting `Delta_LandsatTM_NDVI_2008` in the red and green displays and `Delta_LandsatTM_NDVI_1998` in the blue.

   Pixels that have higher NDVI in 2008 will appear yellow. Pixels that have higher NDVI in 1998 will appear blue. Pixels with similar NDVI in the two images will be displayed in shades of gray
6. Calculate an NDVI difference image:
   Use the band math expression b1-b2. Pair b1 to the 2008 NDVI and b2 to the 1998 NDVI. Save the file with the output filename `Delta_LandsatTM_NDVI_diff.img`.
7. View your NDVI difference image. Geographically link it to the CIR displays of each image date. Pixels that have increased vegetation ($NDVI_{2008} > NDVI_{1998}$) should appear bright, pixels with reduced vegetation should appear dark ($NDVI_{2008} < NDVI_{1998}$). Confirm this interpretation with comparisons to the CIRs.

   Where in this scene has most of the change in NDVI occurred? Where has remained relatively constant?
8. Calculate NDVI change statistics. Go to **Basic Tools → Statistics → Compute Statistics**. Choose the input file `Delta_LandsatTM_NDVI_diff.img`. Click OK and Click OK again in the Compute Statistics Parameters dialog.
9. A Statistics Results window will open displaying the minimum, maximum, mean, and standard deviations of the NDVI difference image. Write down these values. You will need them to choose thresholds for identifying changed pixels.
10. Calculate threshold values of mean ± 2*st.dev. Load the NDVI difference image into Display #1 and create ROIs of positive and negative change using these threshold values.

    Starting in the image window, select **Overlay → Region of Interest → Options → Band Threshold to ROI** → Delta_LandsatTM_NDVI_diff **Band Math (b1-b2)** and click OK.

    In the Band Threshold to ROI Parameters dialog:

For areas that showed an increase inNDVI greater than 2 standard deviations, enter a minimum threshold value of -9999 and a maximum threshold of your recorded mean minus a value of 2 standard deviation.

For areas that showed a decrease in NDVI, starting in your ROI Tool box, repeat the steps **Options → Band Threshold to ROI →** Delta_LandsatTM_NDVI_diff **Band Math (b1-b2) → OK,** except this time enter a value of 2 standard deviations above your recorded mean for your minimum threshold value, and 9999 for your maximum threshold value.

11. Do you think these thresholds do a good job of identifying changed pixels?

Perform a Multidate PCA

1. Go to **Transform → Principal Components → Forward PC Rotation → Compute New Statistics and Rotate.**
2. Choose the input file `Delta_LandsatTM_2date_masked.img` and click OK.
3. Save your output stats file as `Delta_LandsatTM_2date_PCAstats.sta` and your image file as `Delta_LandsatTM_2date_PCA.img` (in Lab_Products). Click OK. This will take a few minutes.
4. Open the PC bands individually in one display and geographically link them to CIRs loaded in another display (from your masked image bands 4, 3, and 2 sequentially loaded as RGB). Try to interpret what each PC band displays.

   For example, PC band 1 seems to be highlighting areas that weren't vegetated in both images, PC band 2 seems to highlight areas that were vegetated in both images, and PC band 3 has bright values in areas with a change in vegetation cover.

   Look at other PC bands and identify what they're telling you. What other PC bands are sensitive to change?

   Does the PCA change detection have similar results to the NDVI difference?

Post-Classification Change Detection

1. In the CIR display of the 2008 bands (from the masked multidate image file), open the refined ROIs you used to improve the Mahalanobis classification in Assignment 3. (If you did not save your ROIs, open the original `Delta_classes_2008.roi` file found in the Multispectral\Landsat folder).
2. If not already loaded, load a CIR image of the 1998 bands (from the masked multidate image file). In the ROI Tool, choose **Options → Reconcile ROIs via Map…** Select your ROIs and click OK.

   Choose the destination file as `Delta_LandsatTM_2date_masked.img` and click OK.

   This will translate your ROIs which were defined relative to the 2008 image to the image extent of the multidate composite image. If not already open, open the ROI tool in the 1998 display and the ROIs should now be present.

Note: You can change the colors of your ROIs by right clicking them in the ROI Tool box. If you which to hide specific ROIs, select them individually (on the left border) and click Hide ROIs.

3. Click through each of the ROIs over the 1998 CIR display several times using the Goto button of the ROI tool to make sure that they still contain the correct classes. If any have changed, delete them by clicking on them with the center mouse button in the active window.

4. Perform a Mahalanobis Distance classification on the 1998 bands from the `Delta_LandsatTM_2date_masked.img` (selecting the appropriate spectral subset of just the 1998 bands). Save your classification as `Delta_LandsatTM_1998_mahd.img`. Do not output a rule image.

NOTE: When doing a post-classification change detection, it is important that the identical classification procedure be performed on each image date. Different classifications might have different biases, which would falsely identify change.

5. Load both the 1998 classification you just created and the optimized Mahalanobis classification from the 3rd homework assignment. (If you used the original ROIs, open the original Mahalanobis classification from lab 4 instead of the improved one.)

6. Navigate to **Classification → Post Classification → Change Detection Statistics**. Select `Delta_LandsatTM_1998_mahd.img` as the Initial State Image and click OK. Select the 2008 classification as the Final State Image and click OK.

7. Pair the classes with their counterparts from each image date in the Define Equivalent Classes dialog. (Leave unclassified and masked pixels unpaired.) Click OK. In the **Change Detection Statistics Output** toggle "No" for both "**Output Classification Mask Images**?" and "**Save Auto-Coregistered Input Images**?" and click OK.

8. A Change Detection Statistics window will open tabulating the amount of change that has occurred between each class pair. Click on the tabs to see this output in terms of pixel counts, %, and area in square meters. Go back to the pixel count display.

   The "Class total" row gives the total number of pixels assigned to that class in the 1998 image within the shared extent. The "Row Total" column gives the total number of pixels assigned to that class in the 2008 image within the shared extent. (Row Total and Class Total columns differ by the number of pixels in the edge pixels of the 1998 image.)

   The "Class Changes" column is the number of pixels for a class in 1998 that were no longer that class in 2008. I.e., it is the sum of off-diagonal elements of that column.

   The "Image Difference" is the difference between the Class total in 2008 and the Class total in 1998 for a class. It is thus an index of average change across the scene, but not pixel-by-pixel change. Image Difference differs from Class Changes because change is occurring in both directions throughout the image. This will tend to balance out over the image, as measured by the Image Difference, despite large numbers of individually changing pixels.

NOTE: If you choose to look at the change detection matrix in terms of percents, the cells are calculated as the % of the pixels classified to the class in the columns in the initial state (the 1998 image) that were classified to the class in the rows in the final state (the 2008 image).

9. Click around your classifications using the geographic link and find areas that have changed. Are these true changes or were the pixels wrongly classified in one image but correctly classified in the other?

Compare the results of the three change detection techniques. How do the products differ? What are the strengths and weaknesses of each? Which do you prefer?

Complete Your Data Products Spreadsheet

You have created several data products in this tutorial. You may wish to reorganize your Lab_Products folder using subfolders to appropriately group your files together, or transfer your files to your appropriate personal lab folder(s). Record this information, including file pathways, in your `your_name_data_products.xls` spreadsheet. You may wish to reorganize your files into subfolders or transfer them to your appropriate personal lab folders.

Tutorial 8: Map Composition in ENVI

The following topics are covered in this tutorial:

Map Elements

Customizing Map Layout

Saving Results

Overview of This Tutorial

This tutorial will give you working knowledge of ENVI's map composition capabilities. You can use ENVI's QucikMap utility to generate a basic map template and add more information using ENVI's annotation capabilities.

Files Used in This Tutorial

Input Path: My Documents\ERS_186\Lab_Data\Multispectral\Landsat,

My Documents\ERS_186\Lab_Data\Hyperspectral

Output Path: My Documents\ERS_186\YourFolder\lab8

Input Files	Description
`Delta_LandsatTM_2008.img`	SF Bay Delta, CA Landsat TM Mulitspectral data
`Delta_HyMap_2008.img`	2008 HyMap flightline

Output Files	Description
`Delta_LandsatTM_2008_map.qm`	Saved QuickMap Parameters for Above
`Delta_LandsatTM_2008_map.ann`	Saved annotation result for above
`Delta_LandsatTM_2008_map.grd`	Saved grid parameters for above
`Delta_LandsatTM_2008_loc.tif`	Location Image for above

Map Composition in ENVI

Map composition should be an efficient process of creating an image-based map from a remote sensing image and interactively adding key map components. In ENVI, the map composition process usually consists of basic template generation (or restoring a saved template) using the 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 add basic map components such as map grids, scale bars, map titles, logos, projection information, and other basic map annotation. Other custom annotation types include map keys, declination diagrams, arrows, images or plots, and additional text. Using annotation or grid line overlays means you can modify QuickMap default overlays and place all map elements in a custom manner.

You can save your map composition in a display group and restore it for future modification or printing. Using annotation, you can build and save individual templates of common map objects.

Open and Display Landsat TM Data

1. From the ENVI main menu bar, select File → **Open Image File**. A file selection dialog appears. Open and load a true color image (RGB) of `Delta_LandsatTM_2008.img` (from the Multispectral folder)

Build the QuickMap Template

1. From the Display group menu bar, select **File → QuickMap → New QuickMap**. The QuickMap Default Layout dialog appears. This dialog allows you modify the output page size, page orientation, and map scale.
2. For this exercise, accept the default values but change the Orientation to Landscape, and the Map Scale to 1,000,000. Click OK. A QuickMap Image Selection dialog appears.
3. Use the full image for this exercise. Click and drag the lower-right corner of the red box downward so that the whole image is selected. Click OK. The QuickMap Parameters dialog appears.
4. Click inside the Main Title field and type San Francisco Bay-Delta Landsat Map.
5. Right-click inside the Lower Left Text field and select Load Projection Info to load the image map projection information from the ENVI header.
6. For this exercise, you should leave the Scale Bars, Grid Lines, and North Arrow check boxes selected.
7. Click the Declination Diagram check box to select it.

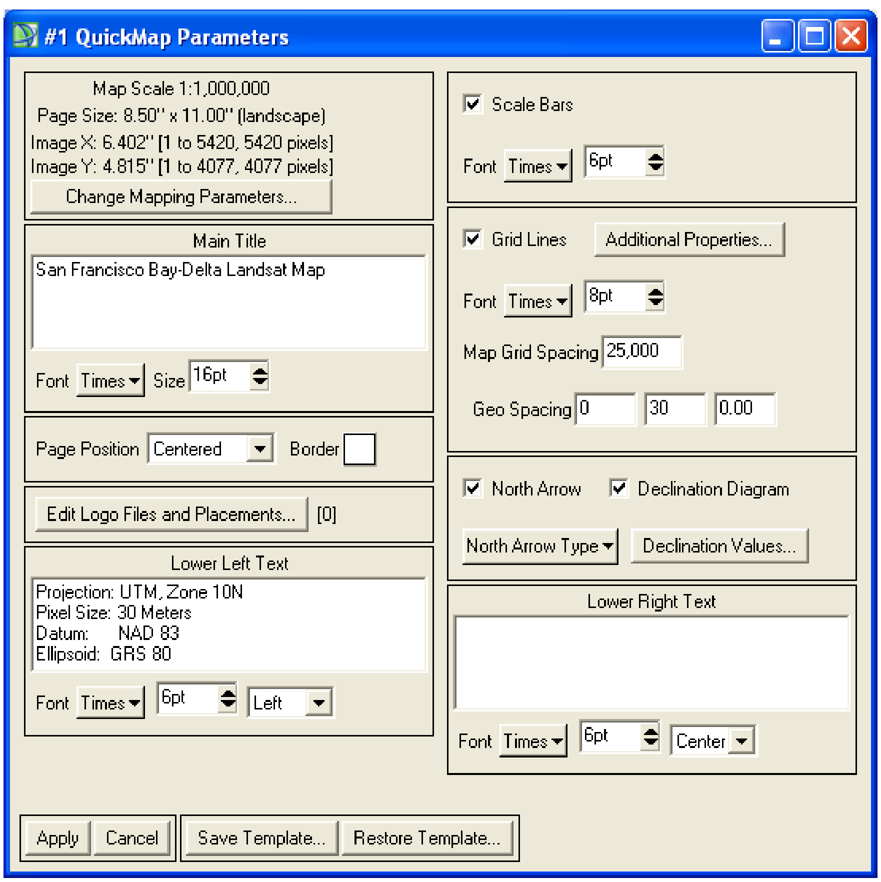


Figure 8-1: The QuickMap Parameters Dialog

8. Click Save Template at the bottom of the dialog. A Save QuickMap Template to File dialog appears.
9. In the Enter Output Filename field, enter `Delta_LandsatTM_2008_map.qm`. Click OK to save the QuickMap results as a QuickMap template file. You can recall this template later and use it with any image of the same pixel size by displaying the desired image and selecting **File → QuickMap → from Previous Template** from the Display group menu bar.
10. Click Apply in the QuickMap Parameter dialog to display the QuickMap results in a display group. If desired, you can modify the settings in the QuickMap Parameters dialog and click Apply to change the displayed QuickMap.
11. At this stage, you can output the QuickMap to a printer or a Postscript file. Save or print a copy if desired. Otherwise, continue with the next step.
12. Review the QuickMap results and observe the map grids, scale bars, north arrow, and positioning of the default text.

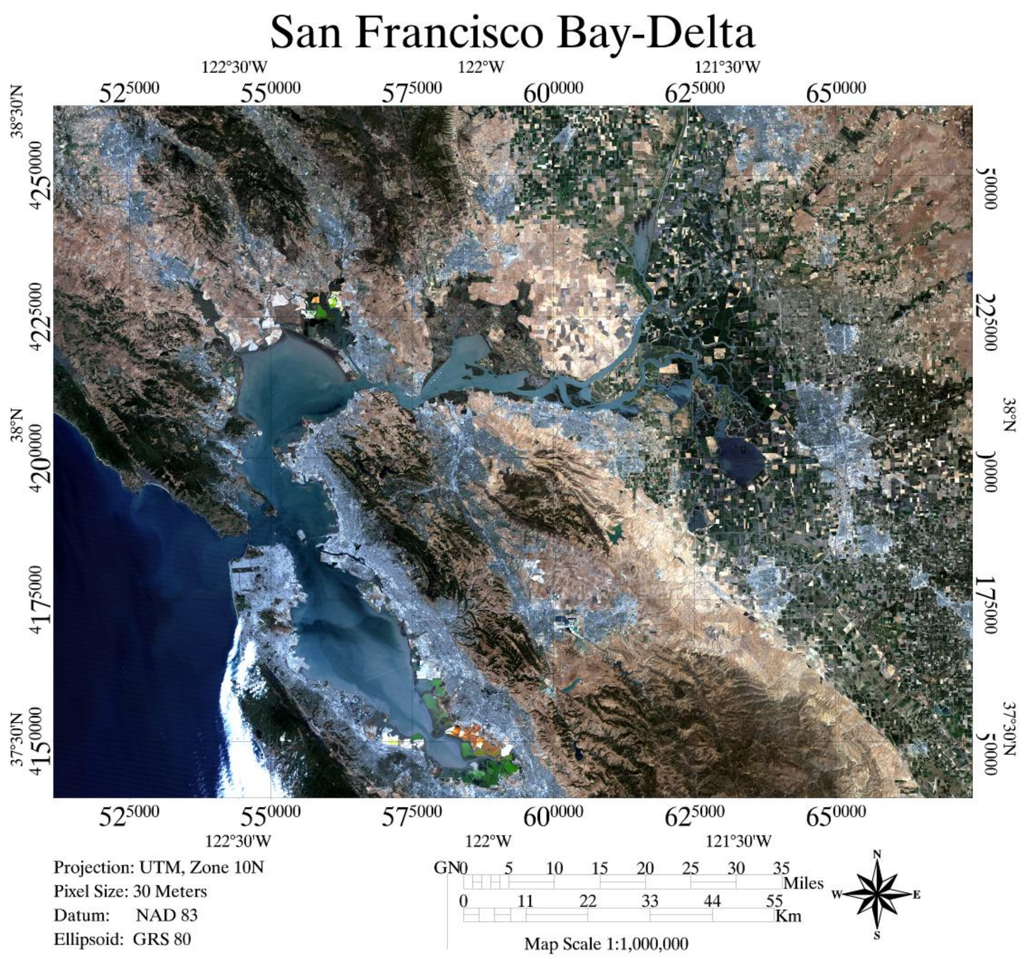


Figure 8-2: QuickMap Results of the San Francisco Bay-Delta

Map Elements

ENVI offers many options for customizing your map composition. Options include virtual borders, text annotation, grid lines, contour lines, plot insets, vector overlays, and classification overlays. You can use the display group (Image window, Scroll window, 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 display groups contain only the image, with no surrounding blank space. Map composition typically requires some map objects to reside outside the image. ENVI provides a virtual border capability that allows annotation in the image borders without creating a new image. You can add virtual borders to an image in several ways, which are described in the following sections.

When you generate a QuickMap, ENVI automatically adds a virtual border to all sides of the image to accommodate the QuickMap grid, and it displays a default grid.

1. To change the default border, select **Overlay** → **Grid Lines** from the Display group menu bar associated with the QuickMap. A Grid Line Parameters dialog appears.

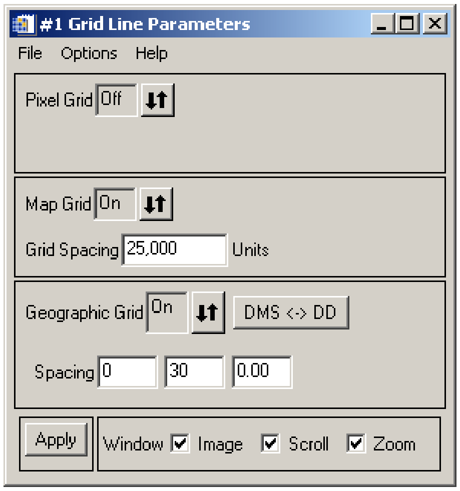


Figure 8-3: The Grid Line Parameters Dialog

2. From the Grid Line Parameters dialog menu bar, select **Options** → **Set Display Borders.** A Display Borders dialog appears.
3. Enter values as shown in the following figure.

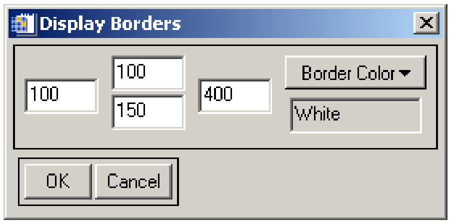


Figure 8-4: The Display Borders Dialog

4. Click OK. The new virtual border characteristics are immediately applied to the image. If you select File → Save Setup from the Grid Line Parameters dialog menu bar, the border information will be saved with the grid and will be restored when you restore the grid parameters file later. Save the border information as `Delta_LandsatTM_2008_map.grd`

Using the Display Preferences

1. You can change virtual borders and other display settings using the Display Preferences dialog.
2. From the Display group menu bar associated with the QuickMap, select **File → Preferences**. A Display Parameters dialog appears with a Display Border section similar to the above figure.
3. Enter the desired values and select the desired color for the border.
4. Click OK. The new borders are immediately applied to the image.

Using the Annotation Function

1. You can control virtual borders in the Annotation dialog.
2. From the Display group menu bar associated with the QuickMap, select **Overlay → Annotation**. An Annotation dialog appears.
3. From the Annotation dialog menu bar, select **Options → Set Display Borders**. A Display Borders dialog appears.
4. Enter the desired border characteristics and click OK. The new virtual border characteristics are immediately applied to the image. If you save an annotation to a file, the border information is also saved and restored when you restore the annotation file later.

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 6) is automatically appended to the image to accommodate grid labels when grids are applied. To add or modify image grids, follow these steps:

1. From the Display group menu bar associated with the QuickMap, select **Overlay → Grid Lines.** A Grid Line Parameters dialog appears and a default grid is displayed with default grid spacings.
2. In the Grid Spacing field, enter 4000.
3. To change line and label characteristics for the grid, select **Options → Edit Map Grid Attributes** or **Edit Geographic Grid Attributes** from the Grid Line Parameters dialog menu bar. Alternatively, you can access grid line parameters by clicking Additional Properties in the QuickMap Parameters dialog.
4. Click OK to apply the selected attributes.
5. In the Grid Line Parameters dialog, click Apply to post the new grid to the displayed image.
6. To save grid parameters for later use, select **File → Save Setup** from the Grid Parameters dialog menu bar and select an output file. `Delta_LandsatTM_2008_map.grd`. This saves a template of the grid parameters, which you can recall later and use with another map composition (select **File → Restore Setup** from the Grid Parameters dialog menu bar).

Working with Annotation

1. ENVI's annotation utility provides a way to insert and position map objects in an ENVI display group for map composition. Several classes of map objects are available.
2. From the Display group menu bar associated with the QuickMap, select **Overlay → Annotation**. An Annotation dialog appears.

3. From the Annotation dialog menu bar, select Object and choose the desired annotation object.
4. In the Annotation dialog, select the Image, Scroll, or Zoom radio button to indicate where the annotation will appear.
5. Drag the object to a preferred location, then right-click to lock it in place.
6. To reselect and modify an existing annotation object, select **Object → Selection/Edit** from the Annotation dialog menu bar. Then select the object by drawing a box around it. You can move the selected object by clicking the associated handle and dragging the object to a new location. You can delete or duplicate an object by choosing the appropriate option from the selected menu. Right-click to relock the annotation in place.
7. Remember to select the Off radio button in the Annotation dialog before attempting non-annotation mouse functions in the display group.
8. Keep the Annotation dialog open for the following exercises.

Text and Symbol Annotation

ENVI currently has a wide variety of text fonts and different standard symbol sets. In addition, ENVI can use TrueType fonts installed on your system. This provides access to a wide range of different text fonts and symbols. You can interactively scale and rotate these fonts and symbols, and you can set different colors and thickness.

ENVI provides some useful symbols (including special north arrows) as a custom TrueType font. To modify the font characteristics, click Font and select ENVI Symbols in the Annotation dialog. Following are some examples of ENVI Symbols:

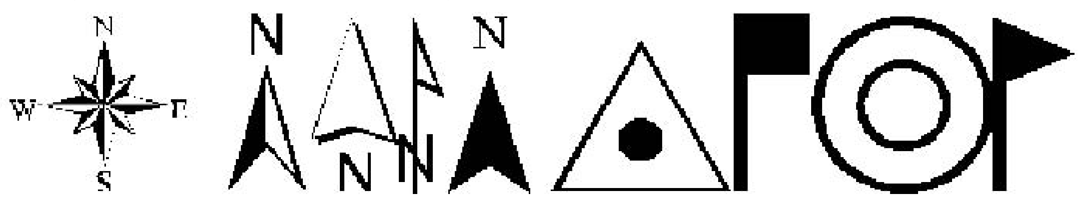


Figure 8-5: Examples of some symbols available in ENVI

Text:

1. Select **Object → Text** from the Annotation dialog menu bar.
2. Click Font and select a font.
3. Select the font size, color, and orientation using the appropriate buttons and fields in the Annotation dialog. For information on adding additional fonts, see "Using Other TrueType Fonts with ENVI" in ENVI Help. TrueType fonts provide more flexibility. Select one of the TrueType fonts available on your system by clicking Font, selecting a True Type option, and selecting the desired font.
4. Type your text in the empty field in the Annotation dialog.
5. Drag the text object to a preferred location in the image and right-click to lock it in place.

Symbols:

1. Select **Object → Symbol** from the Annotation dialog menu bar.
2. Select the desired symbol from the table of symbols that appears in the Annotation dialog.
3. Drag the text object to a preferred location in the image and right-click to lock it in place.

Polygon and Shape Annotation

You can draw rectangles, squares, ellipses, circles, and free-form polygons in an image. 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**, Ellipse, or Polygon from the Annotation dialog menu bar.
2. Enter object parameters as desired in the Annotation dialog.
3. Drag the shapes to a preferred location in the image and right-click to lock them in place. For polygons, use the left mouse button to define polygon vertices and the right mouse button to close the polygon.

Line and Arrow Annotation

You can draw polylines (lines) and arrows in an image. You have full control over the color, thickness and line type, and the fill and head characteristics for arrows.

Arrows:

1. Select **Object → Arrow** from the Annotation dialog menu bar.
2. Enter object parameters as desired in the Annotation dialog.
3. To draw an arrow, click and hold the left mouse button and drag the cursor in the image to define the length and orientation of the arrow. Release the left mouse button to complete the arrow. You can move it by dragging the red diamond handle. Right-click to lock the arrow in place.

Lines:

1. Select **Object → Polyline** from the Annotation dialog menu bar.
2. Enter object parameters as desired in the Annotation dialog.
3. To draw a free-form line, click and hold the left mouse button as you are drawing. To draw a straight line, click repeatedly (without holding the left mouse button) to define the vertices. Right-click to complete the line. You can move it by dragging the red diamond handle. Right-click again to lock the line in place.

Scale Bar Annotation

ENVI automatically generates map scales based on the pixel size of the image in the map composition. Units include feet, miles, meters, or kilometers. You can place map scales individually, or in groups. You can configure the number of major and minor divisions, and the font and character size.

1. Select **Object → Scale Bar** from the Annotation dialog menu bar.
2. Enter object parameters as desired in the Annotation dialog.
3. Click once in the image to show the scale bar. Move it to a preferred location by dragging the red diamond handle. Right-click to lock the scale bar in place.

Declination Diagrams

ENVI generates declination diagrams based on your preferences. You can specify the size of the diagram and enter azimuths for true north, grid north, and magnetic north in decimal degrees.

1. Select **Object → Declination** from the Annotation dialog menu bar.
2. Enter object parameters as desired in the Annotation dialog.
3. Click once in the image to show the declination diagram. Move it to a preferred location by dragging the red diamond handle. Right-click to lock the diagram.

Map Key Annotation

Map keys are automatically generated for classification images and vector layers, but you can manually add them for all other images. Following is an example of a map key:

1. Select **Object → Map Key** from the Annotation dialog menu bar.
2. Click Edit Map Key Items to add, delete, or modify individual map key items.
3. Click once in the image to show the map key. Move it to a preferred location by dragging the red diamond handle. Right-click to lock the map key in place.
4. If you want a border and title for the map key, you must add these separately as polygon and text annotations, respectively:

Color Ramp Annotation

You can create gray scale ramps and color bars for gray scale and color-coded images, respectively. This option is not available with RGB images.

1. Select **Object → Color Ramp** from the Annotation dialog menu bar.

2. In the Annotation dialog, enter minimum and maximum values and intervals as desired. Also set vertical or horizontal orientation.

3. Click once in the image to show the color ramp. Move it to a preferred location by dragging the red diamond handle. Right-click to lock the color ramp in place.

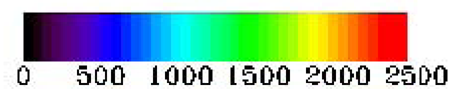


Image Insets as Annotation

While mosaicking provides one way to inset an image into another, you can also inset images while composing and annotating maps. Your image must be in byte data in order for this to work.

1. Ensure that the image to be inset is listed in the Available Bands List.
2. Select **Object → Image** from the Annotation dialog menu bar.
3. Click Select New Image. An Annotation Image Input Bands dialog appears.
4. Select the image from the Available Bands List in the Annotation Image Input Bands dialog and perform optional spatial subsetting. Click OK.
5. Click once in the image to show the inset. Drag the green diamond handle to resize the inset as desired. Right-click to lock the inset in place.

Because 8-bit displays cannot easily assign a new color table to the inset image, ENVI only shows a gray scale image in the display group. If your display has 24-bit color, a color image will be displayed.

Plot Insets as Annotation

You can easily inset ENVI plots into an image during the map composition/annotation process. These vector plots maintain their vector character (meaning they will not be rasterized) when output to the printer or to a Postscript file. They will not appear when output to an image.
You must have a plot window open, such as an X Profile, Y Profile, Z Profile, spectral plot, or arbitrary profile.

1. Select **Object → Plot** from the Annotation dialog menu bar.
2. Click Select New Plot. A Select Plot Window dialog appears.
3. Select the plot and enter the desired dimensions to set the plot size. Click OK.
4. Click once in the image to show the plot. Right-click to lock the plot in place.

Because 8-bit displays cannot easily assign a new color table to the inset plot, ENVI only shows a representation of the plot in the display group. The actual plot is placed when the image is output directly to the printer or to a Postscript file, and the annotation is burned 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 (see ENVI Help for procedures) or open an existing ENVI classification image. Once the classified image is listed in the Available Bands List, then you can use it as an overlay.

1. From the Display group menu bar associated with the map composition, select **Overlay → Classification**. A file selection dialog appears.
2. Select an ENVI classification image and click OK. An Interactive Class Tool dialog appears.
3. Turn on specific classes to appear in the map composition by selecting the corresponding On check boxes. The selected classes will appear in the appropriate color as an overlay on the image.
4. You can change class colors and names by selecting **Options → Edit class colors/names** from the Interactive Class Tool dialog menu bar.

Overlaying Contour Lines

You can contour Z values of images and overlay the contour lines as vectors on an image background. Digital elevation models (DEMs) work best. Add contours to a map composition as follows:

1. From the Display group menu bar associated with the map composition, select **Overlay → Contour Lines**. A Contour Band Choice dialog appears.
2. Select the desired image to contour and click OK. A Contour Plot dialog appears.
3. To use the default contour values, click Apply. Otherwise, you can add new contour levels, edit contours, and change colors and line types using the Contour Plot dialog. See ENVI Help for details.

Incorporating Regions of Interest

You can incorporate Regions of interest (ROIs) into ENVI map compositions. Generate ROIs by drawing them, by thresholding specific image bands, by utilizing 2D or n-D scatter plots, or by performing vector-to-raster conversions. See ENVI Help for details. Display an ROI in a map composition as follows:

1. From the Display group menu bar associated with the map composition, select **Overlay → Region of Interest**. An ROI Tool dialog appears, listing any existing ROIs having the same dimensions as the displayed image. These ROIs appear in the image.
2. Add or modify ROIs as desired. See ENVI Help for further details.

Overlaying Vector Layers

ENVI can import shapefiles, MapInfo files, Microstation DGN files, DXF files, ArcInfo interchange files, USGS DLG files, or ENVI vector files (.evf).

1. From the Display group menu bar associated with the map composition, select **Overlay → Vectors**. A Vector Parameters dialog appears.
2. From the Vector Parameters dialog menu bar, select File → Open Vector File. A file selection dialog appears.
3. Select a file and click Open. An Import Vector Files Parameters dialog appears.
4. Select the appropriate map projection, datum, and units for the vector layer.
5. Click OK. ENVI converts the input vectors into an ENVI vector format (.evf).
6. Load the vectors into the map composition by clicking Apply in the Vector Parameters dialog.
7. In the Vector Parameters dialog, adjust the vector attributes to obtain the desired colors, thickness, and line types. See the Vector Overlay and GIS Analysis tutorial or see ENVI Help for additional information.

Customize the Map Layout

This section uses several map elements described in the previous sections to demonstrate some of ENVI's custom map composition capabilities.

The QuickMap you created earlier for your Lab Assignment will be used in the following exercises. If you already closed `Delta_LandsatTM_2008.img`, redisplay it as a true color image.

1. Load the QuickMap Template
2. Once the image is displayed, follow these steps to load the previously saved QuickMap template and to add individual map components:
3. From the Display group menu bar, select **File → QuickMap → from Previous Template**. The Enter QuickMapTemplate Filename dialog appears.
4. Navigate to your output directory, select `Delta_LandsatTM_2008map.qm`, and click Open. A QuickMap Parameters dialog appears.
5. Click Apply to generate the QuickMap image. The Load To: Current Display button is selected by default, so the QuickMap parameters are applied to the display group from which you started QuickMap.
6. Restore saved grid parameters by selecting **Overlay → Grid Lines** from the Display group menu bar associated with the QuickMap. A Grid Line Parameters dialog appears.
7. From the Grid Line Parameters dialog menu bar, select **File → Restore Setup**. A file selection dialog appears.
8. Navigate to your output directory and select the saved grid parameters file Delta_LandsatTM_2008_map.grd Click Open, followed by Apply.
9. Modify some of the grid line parameters and make them aesthetically pleasing and appropriate, click Apply to show your changes on the image. Be sure to save any changes by selecting **File → Save Setup** from the Grid Line Parameters dialog menu bar.
10. Create some map annotation. Select **Overlay → Annotation** from the Display group menu bar associated with the QuickMap. The Annotation dialog appears.

11. Create a scale bar, and an object (your choice) indicating where `Delta_HyMap_2008.img` is in the LandsatTM scene. Create text that indicates what this object is referring to.
12. Click and drag the handles to move the annotation objects. Modify some parameters for the selected objects. Right-click the objects to lock them in place. Be sure to save any changes by selecting **File → Save Annotation** from the Annotation dialog menu bar. See ENVI Help for further details.

Save the Results

You can save a map composition for future modification as a display group, or with the map composition "burned in" to an image.

Saving for Future Modification

This is the most flexible option.

1. From the Display group menu bar associated with the map composition, select **File → Save as Display Group.**
2. Enter an output filename and click OK.
3. To restore this map composition, select **File → Restore Display Group** from the ENVI main menu bar.

Saving as a "Burned-in" Image

1. From the Display group menu bar associated with the map composition, select **File → Save Image As → Postscript File**. An ENVI QuickMap Print Option dialog appears.
2. Select Standard Printing and click OK to output a Postscript file. An Output Display to Postscript File dialog appears. Change the page size and scaling parameters as desired. This option provides additional control, but it may produce a map that does not fit well with the originally selected QuickMap scale.
3. Select Output QuickMap to Postscript, select an output filename, and click OK to output a Postscript file with the specified QuickMap page size and scaling. If your additional annotation enlarged the image so it will not fit in the specified page size, ENVI asks if you want to output to multiple pages. If so, 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. From the Display group menu bar associated with the map composition, select File → Save Image As → Image File.
2. Set the resolution, output file type, and other parameters as described in ENVI 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.

In all of the output options listed above, graphics and map composition objects are burned into the image on output.

Tutorial 9: Wildfire Detection Exercise

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to give you hands on experience analyzing hyperspectral imagery of wildfires.

Files Used in this Tutorial

Input Path: C:\My Documents\ERS_186\Lab_Data\Hyperspectral\Fire\

Output Path: C:\My Documents\ERS_186\your_folder\lab9

Input Files	Description
`AVIRIS_simi_fire_geo_img_crop_masked.img`	Simi Fire, CA, AVIRIS data

Output Files	Description
`AVIRIS_simi_fire_Kindex.img`	Index of potassium emission
`AVIRIS_simi_fire_CO2index.img`	Index of atmospheric CO_2 absorption

Examine AVIRIS Imagery of the Simi Fire

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) image data of the Simi Fire in Southern California was acquired on October 27, 2003. The Simi Fire was part of a large complex of seven wildfires throughout Southern California in October 2003 that was promoted by high fuel load, low fuel moisture, and Santa Ana winds. From ignition on October 25, 2003 to containment on November 3, 2003, the Simi Fire burned 315 structures and 44,000 ha in the Santa Susana Mountains and cost approximately $10 million to contain (Dennison et al. 2006).

1. Start ENVI and open the image file `AVIRIS_simi_fire_geo_img_crop_masked.img`.
2. Load the image file to a true-color RGB display.

   Observe that smoke from the fire is readily obvious and obscures the underlying ground cover. Flames are visible only in the areas burning most brightly that are not covered by smoke. There is little contrast between vegetated areas and charred areas.
3. Load a false-color CIR display of the image.

Smoke plumes are still obvious, but flames stand out more and vegetation is more clearly distinguished in this display.

4. Load gray-scale displays of individual bands in the VIS through NIR to determine the wavelength at which smoke penetration begins to occur. (No need to inspect all of them, every 5th band should suffice.)

   What spectral regions penetrate the smoke? Why is the ability to penetrate smoke dependent on wavelength?

5. Now load a false-color RGB display using the 1682, 1107, and 655 nm channels of the AVIRIS scene (displayed as red, green, and blue, respectively).

   In this display, vegetated areas appear green and burned areas appear dark gray. Smoke appears bright blue due to high reflectance in the 655 nm channel. Fire varies from red (cooler fires) to yellow (hotter fires). Now that smoke is not completely obscuring the display, a much greater burn area is visible. You should be able to see both flaming and smoldering fires.

6. Display the spectral (Z) profile (right clicking the image) and inspect reflected radiance of pixels that a) have been burned, b) contain green vegetation, and c) that are currently burning in the imagery. Note that this scene is of radiance data. It has not been corrected to reflectance (can you think why not?). The shape of non-burning spectra will be dominated by the solar emission spectrum and influenced by land-cover and atmospheric absorptions.

7. In your false-color RGB, find a pixel of vegetation covered by smoke and view its spectrum. In the Spectral Profile plot, choose **Options → New Window: with Plots**.

   Now navigate to a nearby pixel of green vegetation that is not obscured by smoke. Right click in the Spectral Profile plot and select Plot Key. Left-click on the name of spectrum in the plot key, drag it into the new plot window with your smoky vegetation, and release the mouse button. Now both spectra are plotted in the same plot window. You can change the colors and names of these spectra in **Edit → Data Parameters**.

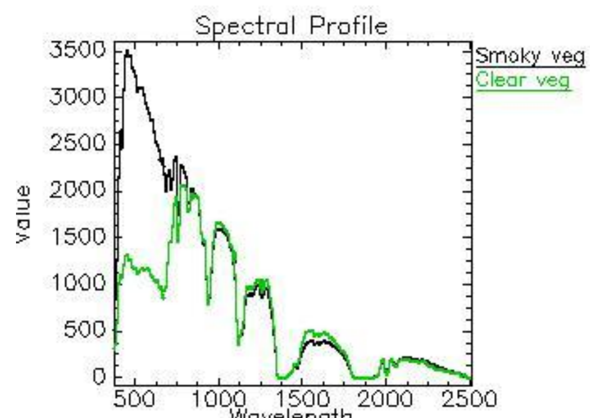


Figure 9-1: Spectral Profile of Smoky Vegetation & Clear Vegetation

   Can you see the influence of the smoke on the vegetation spectrum? How does this relate to what you learned about the penetration of smoke by different wavelengths in step 3?

8. Create another new plot window, this time leaving it blank to start with. Navigate to burning pixels and collect a sample of burning spectra in your new plot window using the same drag and drop technique as before.

How does fire temperature influence the spectral profile? Is this caused by reflected radiation or emitted radiation?

Display spectra burning at different temperatures in the same plot window and color-code them by temperature:

For example, in the plot above the black spectrum is not burning. All other spectra are of pixels that are on fire. Spectra are colored so that cooler colors represent cooler pixels. As fire temperature increases, radiance in the SWIR increases. As pixels become even hotter and more dominated by fire, the AVIRIS sensor is saturated. Even saturated pixels provide some indication of fire temperature, however. Hotter pixels saturate more wavelengths. For example, the orange spectrum above saturates only in the SWIR 2 region, the red spectrum saturates both SWIR 1 and SWIR 2, the magenta spectrum saturates into the NIR, and the maroon spectrum saturates throughout the NIR.

Continue to click around your image and investigate the effects of smoke and burning on radiance spectra. Using sophisticated unmixing techniques (which you will learn in a few weeks), it is possible to model the fire temperature of each pixel, but here we will assess temperature only qualitatively.

9. You can now close the true-color, false-color CIR, and any gray-scale displays you have open.

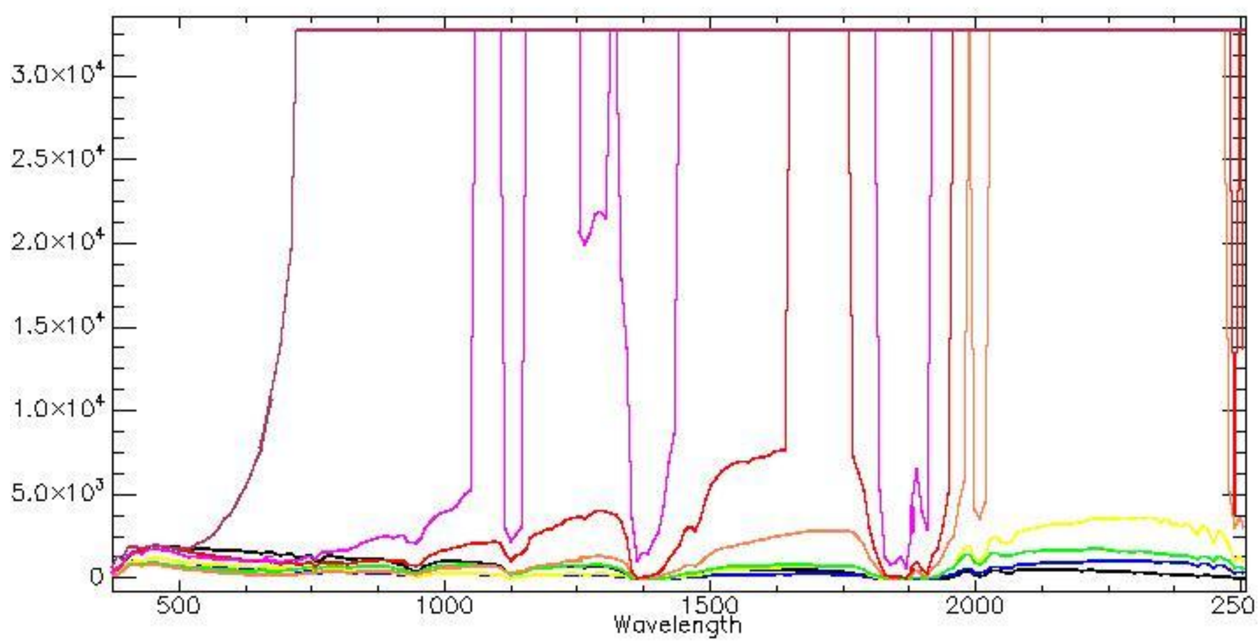


Figure 9-2: Spectral Profile of several different pixels. Notice the saturation of the sensor at high temperatures.

Calculate Hyperspectral Indexes to Detect Fire

Hyperspectral sensors such as AVIRIS and HyMap are also known as imaging spectrometers. That is, they detect the full reflectance spectra of materials and are sensitive to narrow-band spectral features, just as a lab spectrometer is. Here we will use two narrow spectral features (one emission and one absorption) to detect burning pixels. We will calculate indexes based on these features using ENVI's Band Math capabilities.

Potassium emission

Flaming combustion thermally excites potassium (K) at relatively low excitation energies; the

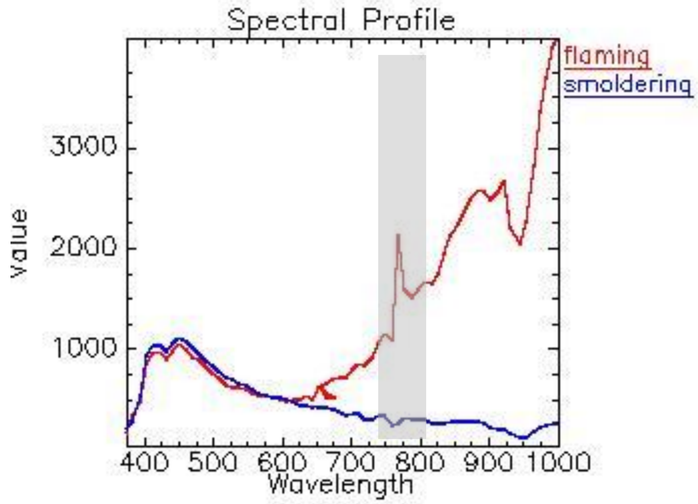


Figure 9-3: Spectral profile of flaming and smoldering pixels. Note the potassium emission.

excited potassium then emits at the NIR wavelengths 766.5 and 769.9 nm. Potassium is an essential mineral nutrient to plants and is present at detectable levels in soils and plants. Potassium emission can be detected in hyperspectral data and can be used to identify actively burning pixels (Vodacek et al. 2002).

1. Load a false-color RGB of band 45 (769 nm) in red and band 46 (779 nm) in both blue and green. These are the bands that we will use in our K emission index. Pixels that are not undergoing flaming combustion will appear in shades of gray. Flaming pixels will display as red to bright white. (You may need to adjust the display using a predefined stretch or interactive stretching in Enhance.)
2. Inspect the spectral profile of flaming and non-flaming pixels. Focus on the region of the K emission around 770 nm. Zoom into this spectral region either by drawing a box around it in the Spectral Profile window while holding down the center mouse button or by adjusting the axis ranges in **Options → Plot Parameters**. Plot flaming and non-flaming spectra in the same window. Can you see the K emission feature?
3. Calculate the K emission index using band math (**Basic Tools → Band Math** in the ENVI main menu), enter the expression: float(b1)/float(b2) and press OK.

   In the Variables to Bands Pairing Dialog define band 1 to correspond with AVIRIS band 45 (769 nm) and band 2 to correspond with AVIRIS band 46 (779 nm). Enter the output filename AVIRIS_simi_fire_Kindex.img , save it to the correct directory, and click OK.

4. Load the K emission index to a new display and link it to the false-color RGB of bands 45 and 46 and also the false-color RGB of the 1682, 1107, and 655 nm bands. You may need to adjust the display using a predefined stretch or interactive stretching in Enhance (a good approach would be to place the zoom window to contain flaming pixels and select **Enhance → [Zoom] Linear 2%**).

Do you see how the K emission index highlights burning pixels, which should appear bright white? Toggle on the cursor location/value. What range of K index values do flaming, smoldering, smoky, and not burning pixels exhibit?

Atmospheric CO_2 Absorption

This method of fire detection takes advantage of atmospheric absorptions. Reflected radiance travels through the atmosphere twice (i.e., once on its way from the sun to the ground and once again from the ground to the sensor) while emitted radiance, such as from fires, travels through the atmosphere only once (i.e., from the ground to the sensor). Burning pixels should therefore have shallower atmospheric absorption features, including the CO_2 absorption at 2000 nm, than pixels that are not burning and are dominated by reflected radiance (Dennison 2006).

1. Load a false-color RGB of band 173 (2000 nm) in red and bands 171 (1980 nm) and 177 (2041 nm) in blue and green. These are the bands that we will use in our CO_2 absorption index. Pixels that are not burning will appear in shades of gray. Burning pixels will display as red to bright white. (You may need to adjust the display using a predefined stretch or interactive stretching in Enhance.)
2. Inspect the spectral profile of burning and non-burning pixels. Focus on the region of the atmospheric CO_2 absorption around 2000 nm. Zoom into this spectral region either by drawing a box around it in the Spectral Profile window while holding down the center mouse button or by adjusting the axis ranges in Options → Plot Parameters. Plot burning and non-burning spectra in the same window. Can you see the CO_2 absorption feature?

   Note that the CO_2 absorption appears deeper in burning pixels, but relative to the amount of total radiation, it is a smaller absorption. One of the benefits of calculating indexes is that they normalize for the amount of radiation and provide a less biased estimate of absorption.

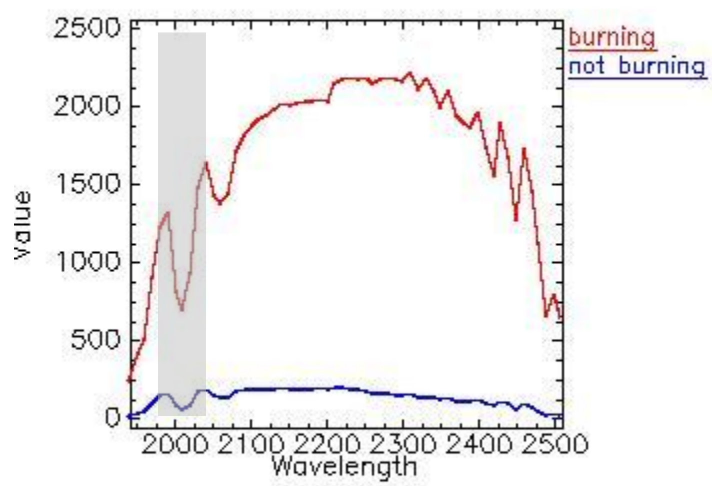


Figure 9-4: Spectral Profile of burning and not-burning pixels. Note the absorption feature at 2000nm

3. Calculate the CO_2 absorption index using band math (**Basic Tools → Band Math** in the ENVI main menu), enter the expression: float(b1)/(0.666*float(b2)+0.334*float(b3)) and press OK.

   In the Variables to Bands Pairing Dialog define band 1 to correspond with AVIRIS band 173 (2000 nm), band 2 to correspond with AVIRIS band 171 (1980 nm), and band 3 to correspond with AVIRIS band 177 (2041 nm). Enter the output filename `AVIRIS_simi_fire_CO2index.img`, save it to the correct directory, and click OK.

   (Note that our index is formulated such that pixels with less absorption by CO_2 will have higher index values.)

4. Load the CO_2 absorption index to a new display and link it to the K emission index and also the false-color RGB of the 1682, 1107, and 655 nm bands. You may need to adjust the

display using a predefined stretch or interactive stretching.

Do you see how the CO_2 absorption index highlights burning pixels, which should appear bright white? Toggle on the cursor location/value. What range of CO_2 index values do flaming, smoldering, smoky, and not burning pixels exhibit?

Compare the false-color RGB, K emission index, and CO_2 absorption index. What are the strengths and weaknesses of each? Is one able to detect fires that the others cannot and vice versa? How are each of them influenced by sensor saturation by the brightest fires?

References

Dennison, P.E., Charoensiri, K., Roberts, D.A., Peterson, S.H., & Green, R.O. (2006). Wildfire temperature and land cover modeling using hyperspectral data. Remote Sensing of Environment. 100: 212-222.

Dennison, P.E. (2006). Fire detection in imaging spectrometer data using atmospheric carbon dioxide absorption. International Journal of Remote Sensing. 27: 3049-3055.

Vodacek, A., Kremens, R.L., Fordham, A.J., Vangorden, S.C., Luisi, D., Schott, J.R., & Latham, D.J. (2002). Remote optical detection of biomass burning using a potassium emission signature. International Journal of Remote Sensing. 23: 2721-2726.

Tutorial 10.1: Spectral Mapping Methods

The following topics are covered in this tutorial:

Spectral Libraries

Spectral Angle Mapper

Overview of This Tutorial

As you have discovered, hyperspectral data provides a great deal of information about your target. Data reduction techniques such as band indexes and continuum removal can highlight specific, narrow absorption features that can provide physiological measurements, or even quantify the amount of target material in a given pixel. We can also use the spectral shape, or the color of a pixel to classify an image. Spectral Angle Mapper (SAM) is an automated algorithm in ENVI that compares image spectra to reference spectra (endmembers) from ASCII files, ROIs, or spectral libraries. It calculates the angular distance between each spectrum in the image and endmember in n-dimensions, where n is the number of bands in the image. Two images result: the first is a classification image which shows the best SAM match for each pixel, and the second is a rule image for each endmember showing the actual angular distance in radians between the image spectrum and the endmember. The rule images can be used for subsequent classifications using different thresholds to decide which pixels are included in the SAM classification image. This tutorial goes through the building of spectral libraries, the process of classifying hyperspectral images based on methods that are sensitive to spectral shape, and introduces decision trees in ENVI. Decision trees in ENVI are a type of multistage classifier that can be used to implement decision rules including statistical rules, data reduction techniques, and classification results. It is made up of a series of binary decisions that are used to determine the correct category for each pixel; each decision divides the data into one of two possible classes or groups or classes.

Files Used in This Tutorial

Input Path: My Documents\ERS_186\Lab_Data\hyperspectral

Output Path: My Documents\ERS_186\YourFolder\lab10

Input Files	Description
`Delta_HyMap_2008.img`	Delta, CA, HyMap Data
`yourname_homework1_2008.roi`	Region of interests with 6 land cover classes created and submitted for lab assignment #1.

Output Files	Description
`Delta_HyMap_2008_spec_lib.sli`	Spectral Library created from ROIs
`Delta_Hymap_2006_sam.img`	Spectral Angle Mapper Class file
`Delta_Hymap_2006_samr.img`	Spectral Angle Mapper Rule file

Spectral Libraries

Spectral Libraries are used to build and maintain personalized libraries of material spectra, and to access several public-domain spectral libraries. ENVI provides spectral libraries developed at the Jet Propulsion Laboratory for three different grain sizes of approximately 160 "pure" minerals from 0.4 to 2.5 mm. ENVI also provides public-domain U.S. Geological Survey (USGS) spectral libraries with nearly 500 spectra of well-characterized minerals and a few vegetation spectra, from a range of 0.4 to 2.5 mm. Spectral libraries from Johns Hopkins University contain spectra for materials from 0.4 to 14 mm. The IGCP 264 spectral libraries were collected as part of IGCP Project 264 during 1990. They consist of five libraries measured on five different spectrometers for 26 well-characterized samples. Spectral libraries of vegetation spectra were provided by Chris Elvidge, measured from 0.4 to 2.5 mm.

ENVI spectral libraries are stored in ENVI's image format, with each line of the image corresponding to an individual spectrum and each sample of the image corresponding to an individual spectral measurement at a specific wavelength (see ENVI Spectral Libraries). You can display and enhance ENVI spectral libraries.

Building Spectral Libraries

Use the Spectral Library Builder to create ENVI spectral libraries from a variety of spectra sources, including ASCII files, spectral files produced by field handheld spectrometers, other spectral libraries, ROI means, and spectral profiles and plots.

1. Open `Delta_HyMap_2008.img` (from the Hyperspectral folder) and load it in CIR. Overlay the 2008 region of interest (ROI) file you created for your first lab assignment.
2. From the ENVI main menu bar, select **Spectral → Spectral Libraries → Spectral Library Builder**. The Spectral Library Builder dialog appears. In the Input Spectral Wavelength From: select the Data File… radio button.
3. In the File Containing Output Wavelength dialog, select `Delta_HyMap_2008.img` and click OK.
4. In the Spectral Library Builder window, click **Import → from ROI/EVF** from input file. In the Input File of Associated ROI/EVF menu, select `Delta_HyMap_2008.img` and click OK. This will detect the ROI associated with your input file above.
5. In the Select Regions for Stats Calculation window, click Select All Items and then click OK. ENVI will calculate the mean reflectance of the pixels in each of your polygons for each land cover type. This may take a few minutes.
6. When the Stats Calculation is complete, all six landcover types will appear in the Spectral Library Builder window. Click Select All and then click Plot. Your endmembers, or training data, will be displayed in an ENVI Spectral Plot window.

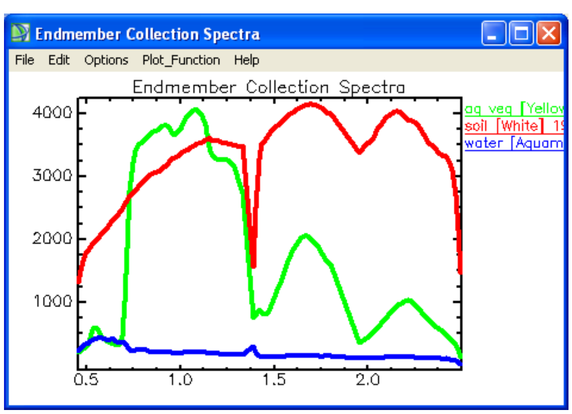


Figure 10-1: Three of the six land-cover class endmembers

7. Save your spectral library. **Click File → Save Spectra as → Spectral library file**.
8. In the Output Spectral Library window, select Z plot range 0-5000, x-axis Title Wavelength y-axis title Value, Reflectance Scale Factor 10,000, Wavelength Units Micrometers. Save your spectral library as `Delta_HyMap_2008_spec_lib.sli` in your folder. Click OK.

Spectral Angle Mapper 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 two-dimensional scatter plot by a point for each given illumination, or as a line (vector) for all possible illuminations.

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.

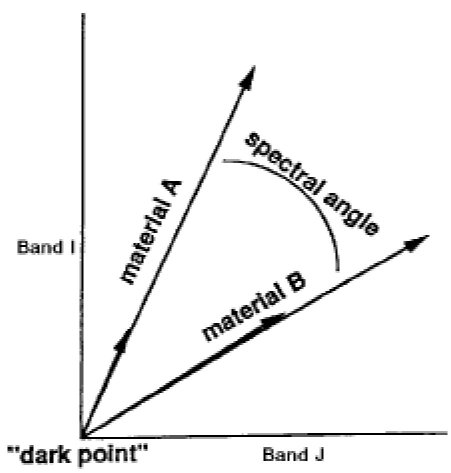


Figure 10-2: Two-Dimensional Example of the Spectral Angle Mapper

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.

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 rule image, one output image for each reference spectrum. The derived spectral angle rule 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.

Create the SAM classification

1. Click **Spectral → Mapping Methods → Spectral Angle Mapper**. In the Classification Input File dialog, select `Delta_HyMap_2008.img`. Click OK.
2. The Endmember Collection: SAM dialog window will appear. Click Import→ from Spectral Library. Select `Delta_HyMap_2008_spec_lib.sli`. Click Select All Items and then click OK.
3. In the Endmember Collection: SAM window your 6 landcover types will appear. To view them, click Select All, and the click Plot.
4. To apply the training data to the SAM classification, click Select All, and then click Apply. The Spectral Angle Mapper Parameters dialog appears. Set the Maximum Angle (radians) to 0.10 , enter output file names for both the classification image `Delta_Hymap_2008_sam.img` and rule image `Delta_Hymap_2008_samr.img` in the Spectral Angle Mapper Parameters dialog, and click OK.

Evaluate the SAM image

1. Load the SAM classification image. The classification image is one band with coded values for each class. 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. The classes will automatically be color coded.

> 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 land cover doesn't make it so. SAM is a similarity measure, not an identifier.

4. Load the SAM rule image. 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.
5. In the Available Bands List dialog, ensure that the Gray Scale radio button is selected. **Select Display → New Display**, select the band labeled Water and click Load Band.
6. Evaluate the image with respect to the SAM classification image.
7. In the image window displaying the SAM rule band, select T**ools → Color Mapping→ ENVI Color Tables.**

8. 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.
9. Pull the Stretch Bottom slider all the way to the right and the Stretch Top slider all the way to the left. Now pixels most similar to the endmember appear bright.
10. 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 composite or image animation if desired to compare individual rule images.
11. Repeat the process with each SAM rule image. Select **File → Cancel** when finished to close the ENVI Color Tables dialog.
12. Select **Window → Close All Display Windows** from the ENVI main menu to close all open displays.

Generate new SAM Classified Images Using Rule Classifier

Try generating new classified images based on different thresholds in the rule images.

1. Display the individual bands of the SAM rule image and choose a threshold for the classification by browsing using the Cursor Location/Value dialog.
2. Now select **Classification → Post Classification→ Rule Classifier**.
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 SAM threshold you decided on in step 1 (for instance, maybe 0.6 is a better threshold for Clear Water"). 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 observe the differences.

Consider the following questions:

What ambiguities exist in the SAM classification based on the two different class results and input spectra? Are there many areas that were not classified? Can you speculate why?

What factors could affect how well SAM matches the endmember spectra?

How could you determine which thresholds represent a true map of selected endmembers?

Tutorial 10.2: Spectral Mixture Analysis

The following topics are covered in this tutorial:

Linear Spectral Unmixing

Overview of This Tutorial

Spectral Angle Mapper is an effective classification method, but only woks with spectrally pure pixels. If a pixel is mixed, it is unlikely that the SAM classifier will successfully identify the pixel. In the environment, natural surfaces are rarely composed of a single, uniform material. When materials with different spectral properties are represented in an image with a single pixel, spectral mixing occurs. If the scale of the mixing is macroscopic, or the materials are not interacting, the mixing is assumed to be linear. That is, each photon strikes only one material, so the signals the sensors receive are added together (a linear process).

Sometimes instead of classifying an image into land cover types you want to know the proportion of plant cover or bare earth in each pixel or some other general information (like paved roads) about the environment. This can be done by determining the fractional composition of these general categories of materials in each pixel. In order to decompose a pixel into its constituent parts, a simple linear model can be used to describe the liner combination of the pure spectra of the materials located in the pixel, weighted by their fractional abundance. A spectral library composed of endmembers of pure pixels is the input for linear spectral unmixing (LSU). The ideal spectral library contains endmembers that when linearly combined can form all other spectra in your image. Known endmembers are often drawn from the image data (such as your ROIs), or drawn from a library of pure materials. A matrix is created from the endmembers, inverted, and multiplied by the observed spectra to obtain least-squares estimates of the unknown endmember abundance fractions. The fraction estimate for each endmember is derived from the best fit from the estimate from all bands (that is the fraction of endmember 1in the pixel is the same fraction in all bands). Constraints can be placed on the solutions to give positive fractions that sum to 1. If you do not use this constraint and you find the computed fractions are much greater than 1 or less than 0, this tells you that your endmember is not the best choice for your image since we know that in the real world, these things can't be outside the physical range (0-1). Shadows and shade are accounted for in one of two ways: implicitly (allowing the fractions to sum to 1 or less), or explicitly by including a shadow endmember (requiring fractions to sum to 1).

Files Used in This Tutorial

Input Path: MyDocuments\ERS_186\Lab_Data\hyperspectral

MyDocuments\ERS_186\Lab_Data\Multispectral\Landsat

Output Path: MyDocuments\ERS_186\YourFolder\lab10

Input Files	Description
`Delta_HyMap_2008.img`	Delta, CA, HyMap Data from 2008
`Delta_HyMap_2008_mnf.img`	Minimum Noise Fraction HyMap image from 2008
`Delta_HyMap_2008_lsu_library.sli`	Spectral library created from image spectra for HyMap 2008 image
`Delta_LandsatTM_2008.img`	SF Bay-Delta Landsat TM image from 2008

Output Files	Description
Delta_HyMap_2008_lsu.img	LSU fraction image of HyMap data
Delta_LandsatTM_2008_subset.img	Landsat TM image spatially subset to the extent of Delta_HyMap_12.img
Delta_LandsatTM_2008_subset_lsu	LSU fraction image of Landsat data

Linear Spectral Unmixing

Linear Spectral Unmixing on Hymap data

1. To perform linear spectral unmixing in ENVI select **Spectral → Mapping Methods → Linear Spectral Unmixing** and choose the `Delta_HyMap_2008.img` as the input file. The Click OK.
2. In the Endmember Collection:Unmixing window menu bar, select **Import→ from Spectral Library**. Choose `Delta_HyMap_2008_lsu_library.sli` and then click OK. Note you can also use ROIS, .evf files, and other data sources as your endmembers. Select all items from the Input Spectral Library and click OK. Select All endmembers listed and Plot them. Examine the endmembers. How many are there? What are they? Do they look like pure spectra to you? De-select the shadow endmember (in this case an artificially created spectrum with reflectance at all bands = 0), and click Apply. Toggle the constraint button to No. What the sum constraint does is apply a unit weight (usually many times more than the variance of the image) that is added to the system of simultaneous equations in the unmixing inversion process. Larger weights in relation to the variance of the data cause the unmixing to honor the unit-sum constraint more closely. To strictly honor the constraint, the weight should be many more times the spectral variance of the data. Supply an output filename `Delta_Hymap_2008_lsu.img`, and click OK.

   When complete, the linear spectral unmixing image will appear in the Available Bands List. Notice that there is a band for each endmember that you provided. The values of this image are the proportions of a given pixel that are estimated to be filled with a given target material.
3. Display these images from the Available Bands List, and the RMS (error) image generated during the analysis. Bright values in the fraction images represent high abundances; the Cursor Location / Value function can be used to examine the actual values. Z profiles can be used to compare the abundances estimated for different endmembers. For instance, if you're pretty sure a pixel is composed of mostly vegetation, hopefully the vegetation endmember will have received the greatest fraction.
4. Choose three good unmixing result images (veg, water, and npv or soil) and create a RGB color composite of them. Link this image to a CIR display of the image.
5. Use spatial and spectral clues to evaluate the results of the unmixing.
6. Explain the colors of the fractional endmembers in terms of mixing. Notice the occurrence of non-primary colors (not R,G,B). Are all of the fractions feasible? Note areas where unreasonable results were obtained (e.g. fractions greater than one or less than zero).

7. Load the RMS Error band into a new, single band display. 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

> Note – refining your LSU: In order to improve your unmixing, you can extract spectra from regions with high RMS error. Use these as new endmembers to replace old ones or possibly add a new one if it is spectrally distinct and repeat the unmixing. If you get too many endmembers that look similar to each other, the algorithm will make mistakes in the unmixing. So it is best to keep the total number less than 6.
>
> When the RMS image doesn't have any more high errors, and all of the fraction values range from zero to one (or not much outside), 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 computation time by several orders of magnitude compared to the constrained method. Optionally, if you are confident that you have all of the endmembers, run the unmixing again and click on **Apply a unit sum constraint**, click **OK**, select a filename to save the file, look at the results and compare to a unconstrained LSU.

Error image does not have any high errors, yet there are negative abundances or abundances greater than 1.0?

Linear Spectral Unmixing on Landsat TM data

When a pixel size is increased, the likelihood of having more than one land cover type present in a pixel also increases. Without spectral mixture analysis the classification of each pixel is limited to a membership to only one thematic class, and the result is that you lose the ability to represent combinations of land covers at spatial scales below your sensor resolution.

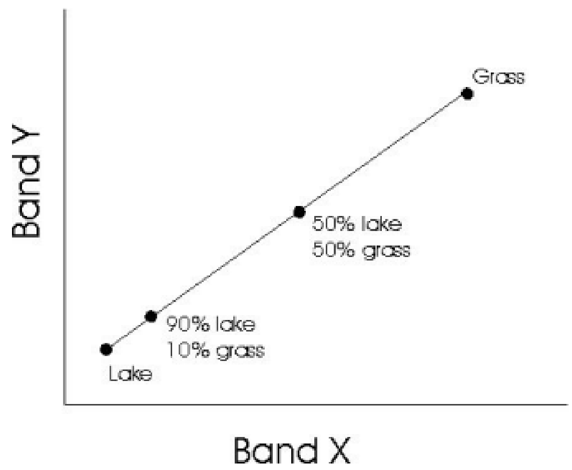
1. Resize the Landsat TM image to the spatial extent of the HyMap image. Click on **Basic Tools→ Resize Data (Spatial/Spectral).** In the Resize Data Input File window, navigate to and open `Delta_LandsatTM_2008.img`. Click on **Spatial Subset** and in the Select Spatial Subset Window, click on **Subset Using File**.
2. In the Subset by File Input File window, select `Delta_HyMap_2008.img`. Click OK. In the Select Spatial Subset window click OK. In the Resize Data Input File click OK.
3. Supply an output file name `Delta_LandsatTM_2008_subset.img` in the Resize Data Parameters dialog. Click OK.
4. Apply Linear Spectral Unmixing to the file following the steps above. Your Unmixing Input file is `Delta_LandsatTM_2008_subset.img.` Do not select any bad bands. The spectral library file used will be the same from before `Delta_HyMap_2008_lsu_library.sli.` Select all of the endmembers except for shadow. DO NOT apply a sum-unit constraint. Supply an output file name `Delta_LandsatTM_2008_subset_lsu.img`.
5. Create a RGB color composite of the three bands. Link this image to a CIR display of the image. Use spatial and spectral clues to evaluate the results of the unmixing. Load the RMS Error band into a new, single band display. Examine the RMS Error image and look for areas with high errors (bright areas in the image). How do the fraction values compare to the HyMap fractions? How does the RMS error of the Landsat unmixing result compare to the HyMap unmixing result? What affect would using fewer endmembers have on the mixing result? What about all of the endmembers?

Locating Endmembers in a Spectral Data Cloud

When pixel data are plotted in a scatter plot that uses image bands as plot axes, the spectrally purest pixels always occur in the corners of the data cloud, while spectrally mixed pixels always occur on the inside of the data cloud.

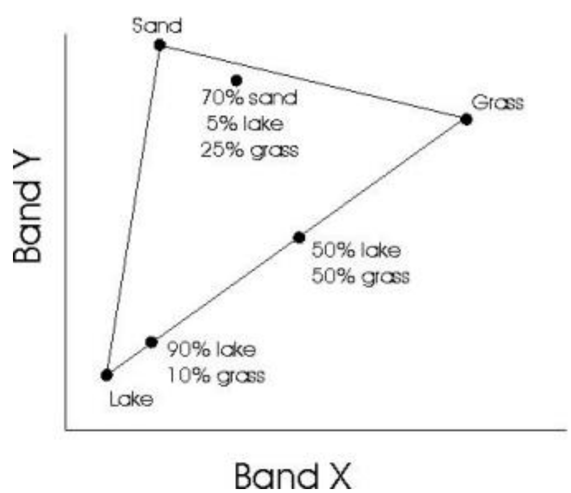
Consider two pixels, where one is in a park with uniform grass, and the other is in a lake. Now, consider another pixel that consists of 50 percent each of grass and lake. This pixel will plot exactly between the previous two pixels. Now, if a pixel is 10 percent filled with grass and 90 percent filled with lake, the pixel should plot much closer to the pixel containing 100 percent lake. This is shown in the following figure.

Figure 10-3: Scatter Plot Showing Pure Pixels and Mixing Endmembers



Now consider a third pixel that is 100 percent filled with sand. This pixel creates a third corner to the data cloud. Any pixel that contains a mixture of sand, water, and grass, will fall inside the triangle defined by connecting the three pure pixels together:

Figure 10-4: Pure Pixels Defining the Corners of the Scatter Plot



Any pixel that contains only two of the three materials falls on the edge of the triangle, but only the pure pixels fall in the corners of the triangle. In this example, the data cloud forms a triangle. This example considers only a 2D scatter plot with three endmembers, but even in scatter plots using any number of dimensions with data containing any number of endmembers, pure pixels always plot in the corners of the data cloud, and mixed pixels will fall within the shape defined by these corners.

Create ROIs from spectral library

1. Open a true-color display of `Delta_HyMap_2008.img in Display #1` and bands 2, 3, and 4 of `Delta_HyMap_2008_mnf.img` as RGB image in Display #2. Geographically link the two displays.

2. Open `Delta_HyMap_2008_lsu_library.sli` in your spectral library viewer. Each of the endmembers in `Delta_HyMap_2008_lsu_library.sli` except for "shadow" has an x and y location. Use the pixel locator to find those locations in your true color HyMap image and your MNF image. Turn the cross hairs on in the Zoom window.

3. Create an ROI at each of the pixel locations, and name each ROI the corresponding class represented by the endmemnber (e.g. "soil", "non-photosynthetic vegetation", "water"). In Display #1 go to **Overlay → Regions of Interest…** and toggle the ROI radio button to **"Off"**. Once you have navigated to the corresponding pixel location of the endmember, in the ROI Tool dialog, select **ROI Type → Point.** Toggle the radio button to **"Zoom"** and click on that pixel in the zoom window. You will have created one ROI. Change the ROI Name to the corresponding class name. Repeat this for all endmembers, creating a new ROI for each endmember.

4. In the MNF image (Display #2), go to **Tools→2D Scatter Plots** and create a scatter plot with MNF band 1 and MNF band 3.

5. In the ROI Tool dialog, Toggle the **Image** on, and Go To your first ROI. Hold your right mouse button down over the ROI in the **Zoom** window. In the scatter plot, the corresponding pixel, and pixels highly similar to that one will be highlighted in red. Repeat this for all of the ROIs. Where are the endmembers in the data cloud? Are they at the edges or the center?

6. In the Scatter Plot window, go to **Options → Change Bands…** and plot two different MNF bands. Highlight the endmembers and look to see where they fall in the data cloud. Do this for several combinations of the first 10 MNF bands. What can you conclude about the appropriateness of the endmembers used for the linear spectral unmixing? Were they spectrally pure? Do the positions of the endmembers explain some of the non-sensical results abundance image? How could you use the data cloud to improve your spectral unmixing results?

Tutorial 11: LiDAR

The following topics are covered in this tutorial:

Overview of This Tutorial

This tutorial is designed to introduce you to standard lidar data products.

Files Used in this Tutorial

Input Path: My Documents\ERS_186\Lab_Data\Hyperspectral\, My Documents\ERS_186\Lab_Data\LiDAR\
Output Path: My Documents\ERS_186\your_folder\lab11

Input Files	Description
`Delta_Hymap_12.img`	Hyperspectral data of Delta, CA
`Delta_Hymap_12_mnf.img`	MNF transform of above
`Delta_Hymap_12_ROIs.roi`	Regions of interest for above file
`Delta_12_fusion_mask.img`	Mask to exclude no-data regions
`Delta_12_bareearth_lidar_geo.img`	Lidar-derived digital ground model
`Delta_12_firstreturn_lidar_geo.img`	Lidar-derived top-of-canopy model
Output Files	**Description**
`Delta_12_bareearth_watermask.img`	Mask file to exclude water pixels
`Delta_12_lidar_heights.img`	Object heights estimated from lidar data
`Delta_12_mnf_class.img`	Classification of MNF image
`Delta_12_fusion.img`	Data fusion of MNF and lidar data
`Delta_12_fusion_class.img`	Classification using MNF and lidar data

Examine gridded LiDAR products

LiDAR (light detection and ranging) is a form of active remote sensing. The sensor emits a pulse of EMR and measures the time it takes for that pulse to reflect off the surface and return to the sensor, allowing the elevation of objects to be determined. Lidar sensors provide either full-waveform or discrete return data. Full-waveform sensors record the intensity of pulse returns over all heights present, creating a complete vertical profile of the land cover. They typically have large footprints. Discrete return sensors bin returns into two or more classes; the most common are first returns, which are the first reflected signals received by a sensor from a footprint (i.e., signals reflected off of the top of trees), and last returns, or the last reflected signals received from a footprint (i.e., signals reflected from the ground). Lidar data is usually analyzed as the raw point clouds, which requires specialized software such as Terrascan. These points can be classified, interpolated, and gridded to produce surface models such as digital elevation models or top-of-canopy models. We will be exploring gridded lidar products today, since these data can be processed in ENVI.

1. Open the file `Delta_12_bareearth_lidar_geo.img`. This is a digital ground model derived from discrete-return lidar data. The value at each pixel is the elevation in meters. Explore this image using the Cursor Location/Value tool and various stretches or color tables.

   Note: The elevation of water-covered areas was not modeled; these pixels contain the default value '************************'. This is interfering with the histogram stretch applied when displaying this data. Try centering your image or zoom windows in areas that contain no water and then choosing **Enhance → [Image] Linear 2%** or **Enhance → [Zoom] Linear 2%** to produce a more meaningful display.

2. Calculate statistics for this file (under Basic Tools) to determine the highest, lowest, and mean elevations in the scene. Where do pixels with these elevations occur?

   You will first need to create a mask to exclude all the ************************ values.

   Open the ROI tool and choose **Options → Band Threshold to ROI**. Select the ground model file and click **OK**. Enter "************************" as both the min and max values (you can copy that text from this tutorial and paste it into the Band Threshold to ROI Parameters dialog) and click **OK**.

   Go to **Basic Tools → Masking → Build Mask** and choose the correct display for your mask to be associated with. Choose **Options → Selected areas "off"**. Then define your mask by going to **Options → Import ROIs**, select the ROI you just created and click **OK**. Save your mask as `Delta_12_bareearth_watermask.img`.

   Now calculate your statistics (**Basic Tools → Statistics → Compute Statistics → Select Mask Band**) while applying this mask band. Click OK three times.

3. Open the file `Delta_12_firstreturn_lidar_geo.img` and load it into a new display. This is a top-of-canopy model derived from the lidar first returns. The value at each pixel is the elevation in meters. Link this display to your ground model. Explore it using the Cursor Location/Value tool and various stretches or color tables. Notice that trees and buildings are evident in the canopy model but have been removed from the ground model.

4. Calculate statistics for this file to determine the highest, lowest, and mean elevations of the top of objects in the scene. How do these values compare to those for the ground model?

5. Open the file `Delta_Hymap_12.img`, load a CIR to a new display, and geographically link it to the lidar displays. Explore the hyperspectral and lidar data together.

6. Calculate the height of objects using the band math (**Basic Tools → Band Math**) function "b1-b2". You should subtract the ground model (set as b2) from the top-of-canopy model (set as b1). Save this file as `Delta_12_lidar_heights.img`. Display your results and geographically link it to the other displays. Compute statistics for this file to determine the minimum, maximum, and mean object heights. You will need to apply the bare earth watermask band again when you calculate statistics.

Compare hyperspectral and data-fusion classifications

1. Open the files `Delta_Hymap_12_mnf.img` and `Delta_12_fusion_mask.img`.

2. Create a data fusion file with both the MNF bands and the lidar heights: Go to **Basic Tools → Layer Stacking**. Click the "Import File…" button and choose the file `Delta_Hymap_12_mnf` with a spectral subset of the first 5 MNF bands only. Repeat this process to import `Delta_12_lidar_heights.img`. Make sure the radio button for "Exclusive: range encompasses file overlap" is selected. Leave all the other entries as they are, enter the output file name `Delta_12_fusion.img`, and click **OK**.

3. Load a display with your fusion image and restore the ROI file `Delta_12_fusion_ROIs.roi`.

4. Perform a maximum likelihood classification on the input file `Delta_12_fusion` using a spectral subset of just the first 5 MNF bands and applying the mask band `Delta_12_fusion_mask.img`. (If this mask is not available for you, it means you haven't opened it yet or you did not select the "Exclusive" option when you created your fused file.)

   Train your classification with the ROIs you restored. Do not output a rule image. Save your classification as `Delta_12_mnf_class.img`.

5. View the output classification file. Note where it performs well and where it performs poorly. What classes are especially poor?

6. Determine the average object height for each class. Go to **Classification → Post Classification → Class Statistics**. Choose your classification file, `Delta_12_mnf_class.img`; click **OK**. Now choose your Statistics Input File, `Delta_12_fusion.img` and spectrally subset it to the lidar heights band. Click "Select Mask Band" and choose the mask band `Delta_12_fusion_mask.img`. Click **OK**. In the Class Selection window, choose all classes but "Unclassified" and "Masked Pixels" and click **OK**. Click **OK** once more in the Compute Statistics Parameters dialog.

7. The Class Statistics Results window will appear, displaying a plot with the class means in the top, and in the bottom the number of pixels classified to each class and the basic stats for an individual class. Write down the min, max, mean and standard deviation of heights for each class. To change the class that is displayed, click on the pulldown menu underneath the toolbar of the statistics results window that is labeled as “Stats for XXX”, where XXX is the class that is displayed.

   Do these heights make sense for these classes?

8. Now we will repeat the classification including the lidar height data with the MNF bands as a classification input.

   Perform a maximum likelihood classification on the file `Delta_12_fusion.img`, but this time using all bands. Again, use the mask file `Delta_12_fusion_mask.img`. Select all ROIs. Do not output a rules image. Give your output classification file the name `Delta_12_fusion_class.img`.

9. View the output classification file. Link it to the classification created with spectral data only. Note where the classifier performs poorly and where it performs well. Does including the lidar height data improve your classification? Have the problem classes from the original spectral classification been improved?

10. Repeat steps 6 and 7 to determine the min, max, mean and standard devation of class heights for the data fusion classification. Do these heights make sense for these classes? Are they more reasonable than the mean and max class heights from the classification using only spectral data?

11. Compare the two classifications using a confusion matrix to see which classes were changed the most by inclusion of the lidar information. Go to **Classification → Post Classification → Confusion Matrix → Using Ground Truth Image**.

    Choose `Delta_12_mnf_class.img` as your Classification Input Image, click **OK**, and `Delta_12_fusion_class.img` as your Ground Truth Input File, click **OK**. ENVI should automatically pair all your classes since they are named the same. Click **OK**.

    Select “No” for “Output Error Images?” and click **OK**.

    A confusion matrix displaying the classes from the fusion classification in the columns and from the spectral-only classification in the rows should appear. Inspect this confusion matrix. Which classes were relatively uninfluenced by the inclusion of structural (lidar) data? Which classes lost many pixels when structural information was included? What were those pixels classified as instead? Which classes gained many pixels when structural information was included? What classes had those pixels been classified as?