ENVI Tutorial: Multispectral Analysis of MASTER HDF Data

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Overview of This Tutorial

This tutorial introduces you to the Hierarchical Data Format (HDF) and analysis of multispectral imagery from the MODIS/ASTER Airborne Simulator (MASTER) sensor. The first part of the tutorial shows you how to open and read HDF files, extract spatial and spectral subsets of MASTER shortwave infrared (SWIR) data, compare spectra to spectral libraries, and how to perform classic multispectral processing.

The second half of the tutorial explains the analysis of longwave infrared (LWIR) MASTER data, including how to examine LWIR spectra to define key spectral bands, how to perform decorrelation stretching of color composites to enhance LWIR spectral differences, and how to compare SWIR and LWIR mapping results

For additional details on specific functions, please see ENVI Help.

Files Used in This Tutorial
CD-ROM: Tutorial Data CD #2
Path: `envidata/cup99mas`

File	Description
`9900511f.hdf`	MASTER data of Cuprite, Nevada, USA
`header.txt`	Text Header with data information

These and other MASTER data are available for purchase from NASA through the EROS Data Center, Sioux Falls, SD.

Background

MASTER is designed to collect simulation data in support of the ASTER and MODIS instrument teams for algorithm development, calibration, and validation. See http://masterweb.jpl.nasa.gov/ for more information. MASTER is a 50-band scanner, operated by NASA, that covers approximately 0.4 to 14 µm. The instrument operates on the NASA Beechcraft B200, DC-8, or ER-2 aircraft to produce spatial resolutions of 5 to 50 m. Spectral band positions are designed to simulate both ASTER and MODIS. MASTER data are delivered via EROS Data Center as HDF files.

HDF is a multi-object file format for the transfer of graphical and numerical data between machines. This format allows you to create, access, and share scientific data in a form that is self-describing and network-transparent. "Self-describing" means that a file includes information defining the data it contains. "Network-transparent" means that a file is represented in a form that can be accessed by computers with different ways of storing integers, characters, and floating-point numbers. HDF data supported in ENVI include raster format images, images stored in 2D or 3D scientific data format, and plots stored in 1D scientific data format.

Shortwave Infrared (SWIR) Analysis

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

Open HDF File and Select a Dataset to Plot

Using ENVI's HDF reader to open the MASTER HDF file, you can select individual datasets to view and plot from the HDF Dataset Selection dialog.

1. From the ENVI main menu bar, select **File** → **Open External File** → **Generic Formats** → **HDF**. A file selection dialog appears.

2. Navigate to `envidata\cup99mas` and select `990051f.hdf`. Click **Open**. An HDF Dataset Selection dialog appears with a list of the available HDF datasets in the file.

3. Select the HDF dataset labeled **(50x1):Left50%ResponseWavelength** and click **OK** to plot the data in an HDF 1-D Data Sets window. This dataset contains the center wavelengths for the MASTER HDF data.

4. Select **Edit** → **Data Parameters** from the HDF 1-D Data Sets plot window menu bar. A Data Parameters dialog appears.

5. Select a symbol from the **Symbol** drop-down list. Enlarge the plot two or three times its initial size by dragging one of the corners so that you can see the markers for the individual band centers.

6. Click and drag inside the plot window to read the wavelength values. The band center values appear at the bottom of the plot as you move the cursor. The right number represents the band center of the selected band in micrometers. The range of the MASTER data is approximately 0.4 to 14 µm.

7. Close the plot window when you are finished.

Open HDF File and Load Image

1. Repeat Steps 1-2 above.

2. In the HDF Dataset Selection dialog, select **(716x50x2028):CalibratedData** and click **OK**. An HDF Data Set Storage Order dialog appears.

3. Select the **BIL** radio button and click **OK** to load the image data into the Available Band List dialog. This dataset contains the image data for the Cuprite, Nevada, MASTER HDF data.

4. In the Available Bands List, select **(716x50x2028):CalibratedData: Band 4** and click **Load Band**. ENVI automatically reads the HDF data.

5. Examine the image and select **File** → **Close All Files** from the ENVI main menu bar when you are finished.

Open HDF File with ENVI's MASTER Reader

The following method of opening an HDF file is different from the previous steps because a HDF Dataset Selection dialog does not appear.

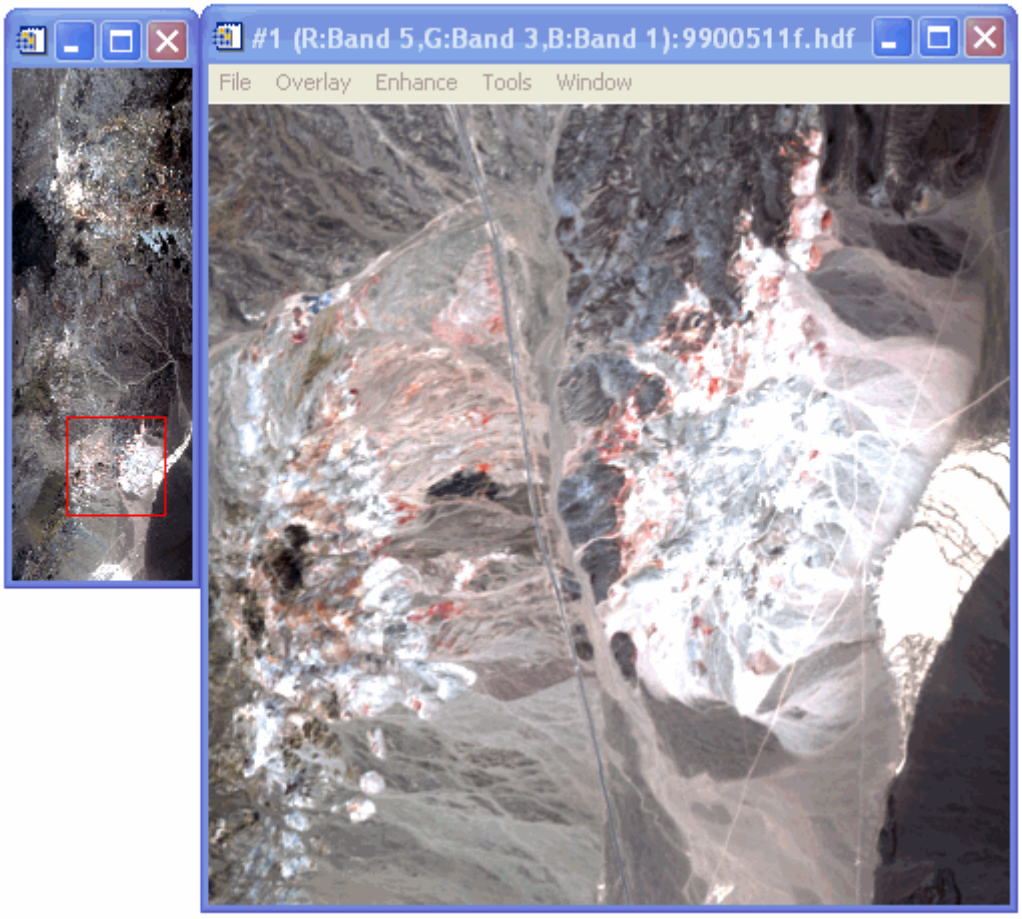
1. From the ENVI main menu bar, select **File** → **Open External File** → **Thermal** → **MASTER**. A file selection dialog appears. Select `990051f.hdf` and click **Open**.

    - Or, select **File** → **Open Image File** and double-click on `990051f.hdf`. ENVI automatically recognizes the file format. The 50 MASTER bands and their associated wavelengths appear in the Available Bands List dialog.

2. Select the **RGB Color** radio button in the Available Bands List dialog, then select **Band 5**, **Band 3**, and **Band 1**. Click **Load RGB** to display a true-color image.

Spatially/Spectrally Subset Data

1. Move the Image box in the Scroll window to the Cuprite area. Refer to the following figure:



2. Perform simultaneous spatial and spectral subsetting. From the ENVI main menu bar, select **Basic Tools** → **Resize Data (Spatial/Spectral)**. A Resize Data Input File dialog appears. Select `9900511f.hdr`, but do not click OK yet.

3. Click **Spatial Subset**. A Select Spatial Subset dialog appears.

4. Click **Image**. A Subset by Image dialog appears.

5. The red box shows the area currently viewed in the Image window. To subset this area, click **OK**, followed by **OK** in the Select Spatial Subset dialog.

6. In the Resize Data Input File dialog, click **Spectral Subset**. A File Spectral Subset dialog appears.

7. Click **Clear**. Select **Band 1**, hold down the **<Shift>** key, then select **Band 25**. Click **OK**, followed by **OK** in the Resize Data Input File dialog. A Resize Data Parameters dialog appears.

8. In the **Enter Output Filename** field, enter `resized_image` and click **OK**.

Empirical Reflectance Calibration

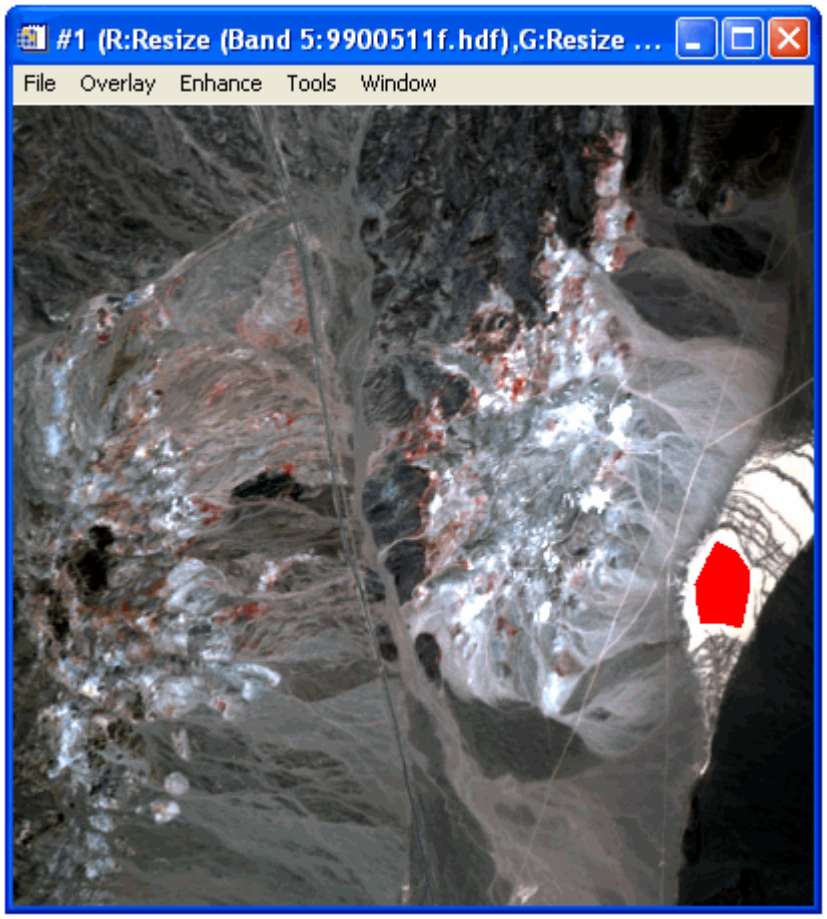
1. In the Available Bands List, select the **RGB Color** radio button. Select **Band 5**, **Band 3**, and **Band 1** under `resized_image`, and click **Load RGB**.

2. From the Display group menu bar, select **Tools** → **Profiles** → **Z Profile (Spectrum)**. A Spectral Profile plot window appears, showing a spectrum of MASTER bands 1-25 (0.46 - 2.396 µm). Note the shape of the spectrum, corresponding to the shape of the solar irradiance spectrum modified by atmospheric absorption. Select **File** → **Cancel** from the Spectral Profile menu bar.

   Perform a rough atmospheric correction using the empirical Flat Field method, by choosing a spectrally flat region of interest (ROI) and dividing the average spectrum for that ROI into the spectrum for each pixel in the image.

3. From the Display Group menu bar, select **Overlay** → **Region of Interest**. An ROI Tool dialog appears.

4. Draw a polygon ROI inside of Stonewall Playa, the white area near the bottom-center of the image. Click the left mouse button to define polygon segments, then right-click to close the polygon. Right-click again to accept the polygon ROI.



5. In the ROI Tool dialog, select the **Off** radio button to turn off ROI mouse control.

6. From the ENVI main menu bar, select **Basic Tools** → **Preprocessing** → **Calibration Utilities** → **Flat Field**. A Calibration Input File dialog appears.

7. Select `resized_image` and click **OK**. A Flat Field Calibration Parameters dialog appears.

8. Select **Region #1...** In the **Enter Output Filename** field, enter `calibration`. Click **OK** to start the Flat Field correction.

Display a Color Composite and Extract Spectra

1. In the Available Bands List, select the **RGB Color** radio button. Select **Band 5**, **Band 3**, and **Band 1** under `calibration`. Click **Load RGB**.

2. From the Display group menu bar, select **Tools** → **Profiles** → **Z Profile (Spectrum)**. A Spectral Profile plot window appears, showing a spectrum of MASTER bands 1-25 (0.46 - 2.396 µm). Note the corrected spectrum, corresponding to apparent reflectance or relative reflectance (relative to the Flat Field spectrum).

3. Drag the cursor throughout the Image window and examine the spectra. Move the cursor to some of the red areas in the image, which correspond to Fe^{+3} absorption features near 0.87 µm (Band 9), and examine their spectra.

4. Click-and-hold the middle mouse button in the Spectral Profile window, and draw a box around the 2.0 - 2.4 µm range. Drag the cursor throughout the Image window, and observe the absorption features near 2.2 and 2.3 µm caused by clays and carbonates, respectively.

Compare Image Spectra to Spectral Library

1. From the ENVI main menu bar, select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer**. A Spectral Library Input File dialog appears.

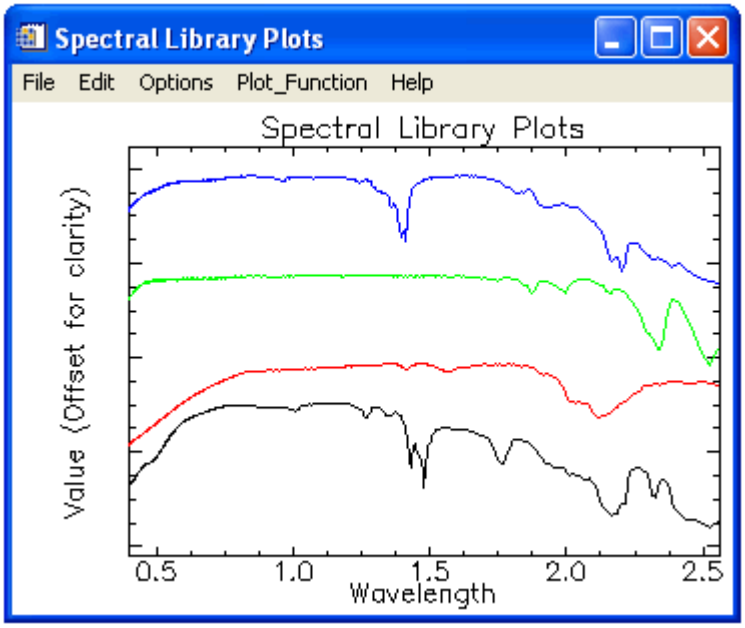
2. Click **Open** and select **Spectral Library**. A file selection dialog appears. Navigate to `spec_lib\usgs_min` and select `usgs_min.sli`. Click **Open**.

3. Select `usgs_min.sli` in the Spectral Library Input File and click **OK**. A Spectral Library Viewer dialog appears.

4. Select **alunite1.spc Alunite GDS84 Na03**. A Spectral Library Plots window appears, showing the spectrum for alunite. Then, select the following spectra:

    - **budding1.spc Buddingtonite GDS85 D-206**
    - **calcite1.spc Calcite WS272**
    - **kaolini1.spc Kaolinite CM9**

5. Right-click in the Spectral Library Plots window and select **Stack Plots**.



6. Select MASTER spectra for the same minerals. From the Display group menu bar, select **Tools** → **Pixel Locator**.

7. In the Pixel Locator dialog, enter the pixel location (**521, 1587**), which is an alunite feature. Click **Apply**.

8. Right-click in the Spectral Profile and select **Collect Spectra**.

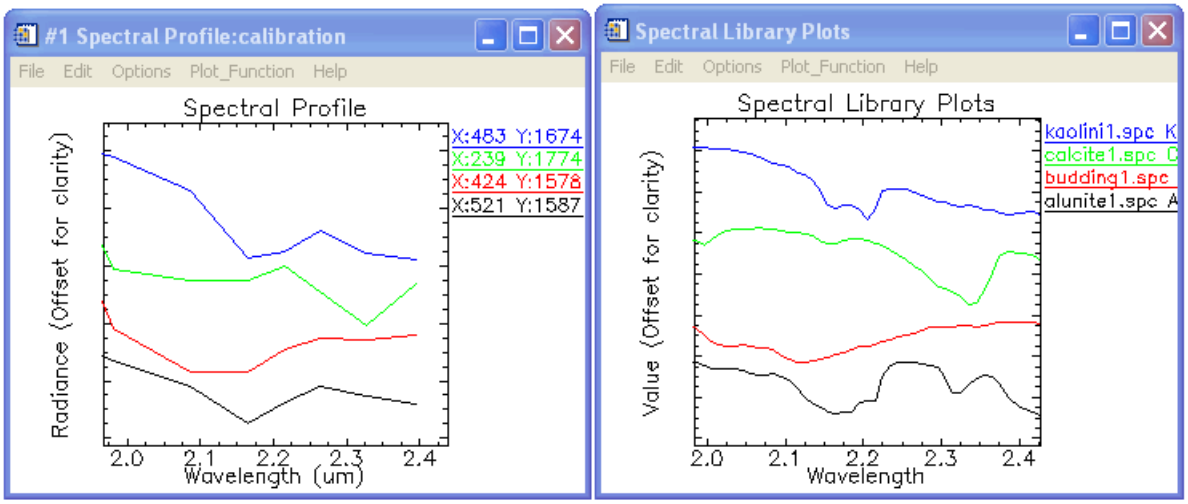
9. Enter the following pixel locations in the Pixel Locator dialog, and click **Apply** each time:

    - (**424, 1578**) - Buddingtonite
    - (**239, 1775**) - Calcite
    - (**483, 1674**) - Kaolinite

10. Right-click in the Spectral Profile window and select **Stack Plots**. Right-click again and select **Plot Key**.

11. In the Spectral Profile and Spectral Library Plots windows, zoom to a range of 2.0 to 2.4 µm, using the middle mouse button to draw a box around the range.

12. Compare the image spectra to the library spectra. Again, note the absorption features near 2.2 and 2.3 µm.



13. For a more direct comparison, select **Options** → **New Window: Blank** from the Spectral Profile menu bar. Click-and-drag a spectrum name from the Spectral Profile window into the ENVI Plot Window. Then, click-and-drag the corresponding spectrum name from the Spectral Library Plots window into the ENVI Plot Window. Following is an example for kaolinite:

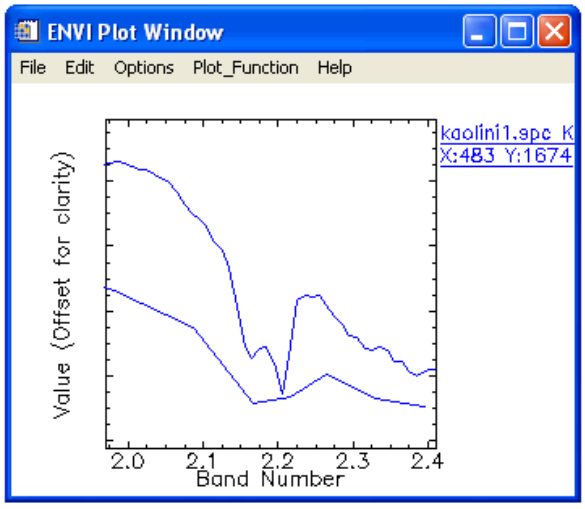


Image Processing with SAM

Use spectra collected from the image to perform a Spectral Angle Mapper (SAM) classification of the MASTER data. SAM measures the similarity of unknown and reference spectra in n-dimensions. The spectral angle is the angle between the spectra (represented as vectors) in n-D space. This method assumes that the data have been reduced to apparent reflectance and uses only the direction of the spectra, not their length. Thus, the SAM classification is insensitive to illumination effects. See the *Selected Hyperspectral Mapping Methods* tutorial and ENVI Help for more information and examples.

1. From the ENVI main menu bar, select **Classification** → **Supervised** → **Spectral Angle Mapper**. A Classification Input File dialog appears.

2. Select `calibration` and click **OK**. An Endmember Collection:SAM dialog appears.

3. Click-and-drag the spectra names from the Spectral Profiles window to the Endmember Collection:SAM dialog.

4. Click **Select All** and **Plot** to confirm that you have the correct endmember spectra.

5. Click **Apply**. A Spectral Angle Mapper Parameters dialog appears.

6. In the **Enter Output Filename** field, enter `sam_class_out`. This is the SAM classification image that will be created.

7. In the **Enter Output Rule Filename** field, enter `sam_rule_out`. Click **OK**. This is the set of SAM rule images that will be created.

8. In the Available Bands List, click **Display #1** and select **New Display**.

9. Select **Sam** under `sam_class_out`. Select the **Gray Scale** radio button, and click **Load Band**. The classes are color-coded the same as the spectrum plot colors:

Mineral	Color
Kaolinite	Blue
Calcite	Green
Alunite	White
Buddingtonite	Red

10. Compare the classification map to the true-color image. From a Display group menu bar, select **Tools** → **Link** → **Link Displays**. Click in an Image window to toggle between the true-color image and the classification map.

11. From a Display group menu bar, select **Tools** → **Profiles** → **Z Profile (Spectrum)**. Verify the spectral match.

12. You can also use the rule images to evaluate the spectral matches. The rule images show the best matches (small angles) in black when first displayed. Since it is more intuitive to show the best matches as brighter values, you can invert the colors in the rule images. Steps 13-15 explain this process.

13. In the Available Bands List, click **Display #2** and select **Display #1**. Select a rule band under `sam_rule_out` and click **Load Band**.

14. From the Display group menu bar, select **Tools** → **Color Mapping** → **ENVI Color Tables**.

15. Move the **Stretch Bottom** slider all the way to the right, and move the **Stretch Top** slider all the way to the left.

16. From a Display group menu bar, select **Tools** → **Link** → **Link Displays**. A Link Displays dialog appears. Click **OK** to link Display #1 (rule image) and Display #2 (classification image).

17. Click in an Image window to toggle between the rule image and classification image. Examine the spatial locations of specific mapped minerals.

18. When you are finished, select **Window** → **Close All Display Windows** from the ENVI main menu bar.

Longwave Infrared (LWIR) Analysis

Emission spectra of typical rocks indicate that the LWIR region (8 to 14 µm) is best suited for determining rock types. The emissivity minimum shifts from around 8.5 µm for framework silicates (quartz and feldspars) to progressively longer wavelengths for sheet and chain silicates, and isolated SiO_4.

View LWIR Color Composite and Subset Data

1. In the Available Bands List, select the **RGB Color** radio button in the Available Bands List dialog, then select **Band 46**, **Band 44**, and **Band 41**. Click **Load RGB** to display a true-color image.

2. In the Available Bands List, click **Display #1** and select **New Display**.

3. In the Available Bands List, select any band under `resized_image` (the subset you created earlier), select the **Gray Scale** radio button, and click **Load Band**.

4. From the ENVI main menu bar, select **Basic Tools** → **Resize Data (Spatial/Spectral)**. A Resize Data Input File dialog appears. Select `9900511f.hdf`, but do not click OK yet.

5. Click **Spatial Subset**. A Select Spatial Subset dialog appears. You will use the same spatial subset you created earlier, but with a different spectral subset.

6. Click **File**. A file selection dialog appears.

7. Select `resized_image` and click **OK**, followed by **OK** in the Select Spatial Subset dialog.

8. In the Resize Data Input File dialog, click **Spectral Subset**. A File Spectral Subset dialog appears.

9. Click **Clear**. Select **Band 41**, hold down the **<Shift>** key, then select **Band 50**. Click **OK**, followed by **OK** in the Resize Data Input File dialog. A Resize Data Parameters dialog appears.

10. In the **Enter Output Filename** field, enter `resized_image_lwir` and click **OK**.

11. Close Display #2.

Animate LWIR Bands

1. In the Available Bands List, select **Band 41** under `resized_image_lwir`, select the **Gray Scale** radio button, and and click **Load Band**.

2. Animate all of the subsetted LWIR bands and examine their variability. From the Display group menu bar, select **Tools** → **Animation**. The Animation Image Parameters dialog appears. Click **OK** to accept the default values. Ten LWIR bands are loaded and animated.

   Most of the variability is caused by differential heating, not by spectral differences between bands. Ideally, these data should be atmospherically corrected and converted to emissivity to enhance spectral differences. However, for this tutorial, you will substitute selection of key image bands using LWIR spectra, and enhance them using a Decorrelation Stretch.

3. From the Resize (animation) menu bar, select **File** → **Cancel**.

4. If desired, display individual bands of interest in new display groups, and use image linking and dynamic overlays to compare them.

Review LWIR Spectral Features

ENVI includes spectral libraries from Johns Hopkins University, which contain spectra for selected materials from 0.4 to 14 µm. The apparently seamless reflectance spectra over this region of rocks and soils were generated using two different instruments, both equipped with integrating spheres for measuring directional hemispherical reflectance.

Under most conditions, the infrared portion of these data can be used to calculate emissivity using Kirchhoff's Law. For this tutorial, however, highs in the reflectance spectra from the spectral library can be considered equivalent to lows expected in emissivity spectra.

1. From the ENVI main menu bar, select **Spectral** → **Spectral Libraries** → **Spectral Library Viewer**. A Spectral Library Input File dialog appears.

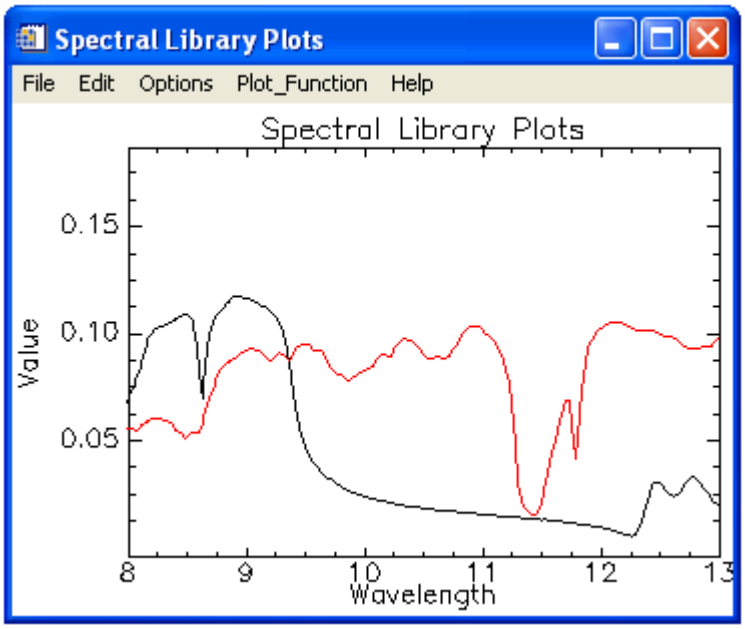
2. Click **Open** and select **Spectral Library**. A file selection dialog appears. Navigate to `spec_lib\jhu_lib` and select `minerals.sli`. Click **Open**.

3. Select `minerals.sli` in the Spectral Library Input File and click **OK**. A Spectral Library Viewer dialog appears.

4. Select the first **Quartz** option. A Spectral Library Plots window appears, showing the spectrum for quartz. Then, select the second **Calcite** option.

5. From the Spectral Library Plots window menu bar, select **Edit** → **Plot Parameters**.

6. Enter **Range** values from **8** to **13** and click **Apply**. Quartz (silica) shows a maximum near 9 µm, while Calcite does not. You can use this information to help find all of the silica-rich areas imaged by the MASTER data.



Design and Display Color Composites

1. Click in the Spectral Library Plots window to examine the nature of the two spectra. Look for contrasts between 8 to 14 µm, and relate them to the MASTER LWIR spectral bands.

2. Bands 46, 44, and 41 (10.085, 9.054, and 7.793 µm, respectively) bracket the prominent silica feature near 9.0 µm. In the Available Bands List, select the **RGB Color** radio button, select **Band 46**, **Band 44**, and **Band 41** under `resized_image_lwir`, and click **Load RGB**.

3. Relate the image colors to the expected relative contributions, based on the library spectra. The colors do not match the expected colors very well because the effect of temperature overwhelms the spectral differences. The bands are highly correlated because of differential heating of the rocks and soils.

Perform Decorrelation Stretch

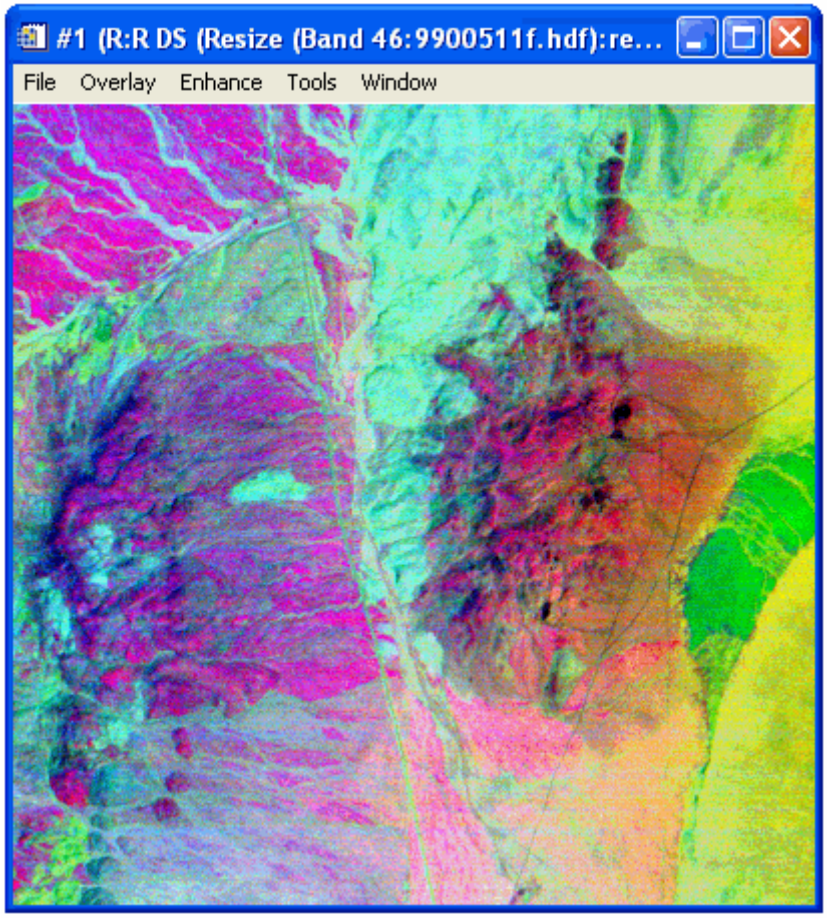
Use Decorrelation Stretch to enhance color differences, by removing the high correlation commonly found in LWIR multispectral data. ENVI provides a Decorrelation Stretch tool, but you can obtain similar results by computing a forward principal components (PC) analysis, performing contrast stretching, and computing an inverse PC analysis.

1. Decorrelation stretching requires three bands (a stretched color composite) for input. You will use the currently displayed color composite.

2. From the ENVI main menu bar, select **Transform** → **Decorrelation Stretch**. A Decorrelation Stretch Input File dialog appears. Select **Display #1** and click **OK**. A Decorrelation Stretch Parameters dialog appears.

3. In the **Enter Output Filename** field, enter `lwir_stretched` and click **OK**.

4. In the Available Bands List, select the **RGB Color** radio button. Select **R DS**, **G DS**, and **B DS**, and click **Load RGB**. Try other color combinations.



Compare LWIR and SWIR Results

Compare the SAM results from the first half of this tutorial with the decorrelated LWIR image.

1. In the Available Bands List, click **Display #1** and select **New Display**.

2. Select **Sam** under `sam_class_out`. Select the **Gray Scale** radio button, and click **Load Band**. As a reminder, the classes are color-coded as follows:

Mineral	Color
Kaolinite	Blue
Calcite	Green
Alunite	White
Buddingtonite	Red

3. From a Display group menu bar, select **Tools** → **Link** → **Link Displays** and click **OK** to link the two images.

4. Click in an Image window to toggle between the two images. Compare the distribution of minerals mapped from the SWIR data versus the distribution of silica (red areas) on the decorrelated image.

Optional: Perform Combined SWIR/LWIR Analysis

Use the MASTER data in a combined SWIR/LWIR analysis (using bands 1-25 and bands 41-50, respectively) that follows ENVI's hyperspectral processing flow. Refer to the tutorials *Advanced Hyperspectral Analysis* and *Geologic Hyperspectral Analysis Case History* for more information. Use the following steps as a general methodology.

1. From the file `990051f.hdf`, extract the SWIR and LWIR bands using spectral and spatial subsetting to build a combined data cube.

2. Create a Minimum Noise Transform (MNF) output file, and perform MNF analysis by looking at the spectral bands and the eigenvalue plots. Select a reduced number of MNF bands for further analysis.

3. Run a Fast Pixel Purity Index (PPI) analysis with 10,000 iterations to find the key endmember spectra, thus reducing the spectral dimensionality. Threshold the PPI to a ROI with around 5,000 pixels.

4. Use the n-D Visualizer to select endmembers. Rotate the scatter plot in many dimensions, and select extreme pixels by drawing ROIs in the n-D Visualizer and exporting them to image ROIs.

5. Use an ENVI spectral mapping method with the combined datasets. Compare these results to the SWIR and LWIR results above.