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Detecting Cheatgrass on the Colorado Plateau Using Landsat Data: A Tutorial for the DESI Software

By Raymond F. Kokaly

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Detecting Cheatgrass on the Colorado Plateau Using Landsat Data: A Tutorial for the DESI Software

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Abstract

Invasive plant species disrupt native ecosystems and cause economic harm to public lands. In this report, an example of applying the Detection of Early Season Invasives software to mapping cheatgrass infestations is given. A discussion of each step of the DESI process is given, including selection of Landsat images. Tutorial data, covering a semi-arid area in southern Utah, are distributed with this report. Tips on deriving the inputs required to run DESI are provided. An approach for evaluating and adjusting detection parameters by examining interim products of DESI is discussed.

Introduction

This report describes the use of DESI (Detection of Early Season Invasives) software with Landsat remote sensing data to detect early season invasive species, such as cheatgrass (*Bromus tectorum*) over an area in southern Utah. This report gives greater detail on the selection and processing of Landsat data to detect cheatgrass than is reported in the DESI User's Guide

(Kokaly, 2010). DESI is comprised of programs written in IDL (Interactive Data Language) that run within the ENVI (ENvironment for Visualizing Images) image processing system (ITT Visual Information Solutions, 2009). For a detailed explanation of how to download and install DESI, see Kokaly (2011).

The DESI software modules were developed using Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (ETM) data for semiarid regions of southern Utah. Therefore, the default values in the Landsat masking module (for detection of cloud/snow, water and other materials) and in the cheatgrass mapping module will work best for Landsat scenes of southern Utah and, more broadly, the Colorado Plateau eco-region. For other ecosystems, the programs are flexible enough to allow the user to change the detection parameters to work best for their study area. The Landsat data used in the examples in this report are included in the compressed distribution archive available online at *http://pubs.usgs.gov/of/2010/1327/downloads/*.

Satellite remote sensing data from the Landsat sensors have been used to detect infestations of the invasive plant cheatgrass (for example, Bradley and Mustard, 2006). In the spring, cheatgrass starts growing earlier than native grasses. In other words, it greens- up earlier than other plants. By midsummer, cheatgrass has reached a state of senescence, in which it becomes brown and dry. Therefore, areas containing cheatgrass can be identified by detecting areas that follow this seasonal greenness trend.

The normalized difference vegetation index (NDVI) calculated from the reflectance (R) values in red and near-infrared (NIR) bands of the Landsat TM and ETM sensors is one measure of greenness that can be calculated from satellite remote sensing data.

$$NDVI = (R_{NIR} - R_{red}) / (R_{NIR} + R_{red})$$

High NDVI values indicate the presence of abundant green vegetation. Low NDVI values indicate a low fraction of or absence of green plants on the surface. The band positions of Landsat sensors in the reflected solar portion of the electromagnetic spectrum are shown in table 1. Landsat bands three and four are the red and near-infrared bands, respectively, used in the NDVI calculation.

Table 1. Wavelength regions of Landsat bands.

Band	Landsat 5 TM center wavelength (µm)	Landsat 7 ETM center wavelength (µm)	Wavelength region
1	0.485	0.483	Blue
2	0.569	0.560	Green
3	0.660	0.662	Red
4	0.840	0.835	Near-infrared
5	1.676	1.648	Shortwave-infrared
7	2.223	2.206	Shortwave-infrared

In order to identify areas that have the cheatgrass greenness pattern and to produce a map of potential cheatgrass infestation, NDVI computed from Landsat data in midsummer is subtracted from an early-season NDVI computation to calculate a difference NDVI (dNDVI) parameter:

$$dNDVI = NDVI_{early\text{-}season} - NDVI_{mid\text{-}summer}$$

High values of dNDVI indicate areas that have the vegetation growth cycle of cheatgrass or other early season plants.

This report describes how to acquire and process Landsat imagery to compute dNDVI and detect cheatgrass for an area in southern Utah. Discussions of how to apply the DESI software modules and standard functions of ENVI to Landsat data are given. In addition, options for customizing the DESI analysis are given. Methods of evaluating intermediate products and the cheatgrass maps are presented.

Recommended Image Dates for Cheatgrass Detection

Trends in dNDVI for areas of cheatgrass compared to noncheatgrass areas in Canyonlands National Park (CNP), on the Colorado Plateau, suggest the optimum dates for Landsat image acquisition to be between March 30th and April 23rd for the early-season image and between June 18th and July 12th for the midsummer image (fig. 1). Difference NDVI and cheatgrass maps calculated from Landsat and MODIS (MODerate resolution Imaging Spectrometer) images acquired in these date ranges in 2001 and 2006 were compared to field plot data and showed good contrast between cheatgrass-infested areas and other vegetation cover and greater accuracy in cheatgrass detection as compared to images collected outside these data ranges. Since long- and short-term precipitation and temperature patterns can affect the green up and senescence of vegetation, these date ranges should serve as a general guide to selecting imagery. When image selection is supported by field observations of vegetation trends, cheatgrass detection could be attempted with images acquired beyond these dates.

General data ranges are given since optimum image dates are difficult to determine because of year-to-year variations in plant greenness, as affected by precipitation and temperature patterns, as well as, scene-to-scene variations in surface elevations. In the CNP area, a March 30, 2001, Landsat image in the early part of the early-season date range was found to be slightly better for detecting cheatgrass in lower elevation areas within the park. For cheatgrass at cooler, higher elevations, a Landsat image from April 23, 2001, was found to be better for detecting cheatgrass.

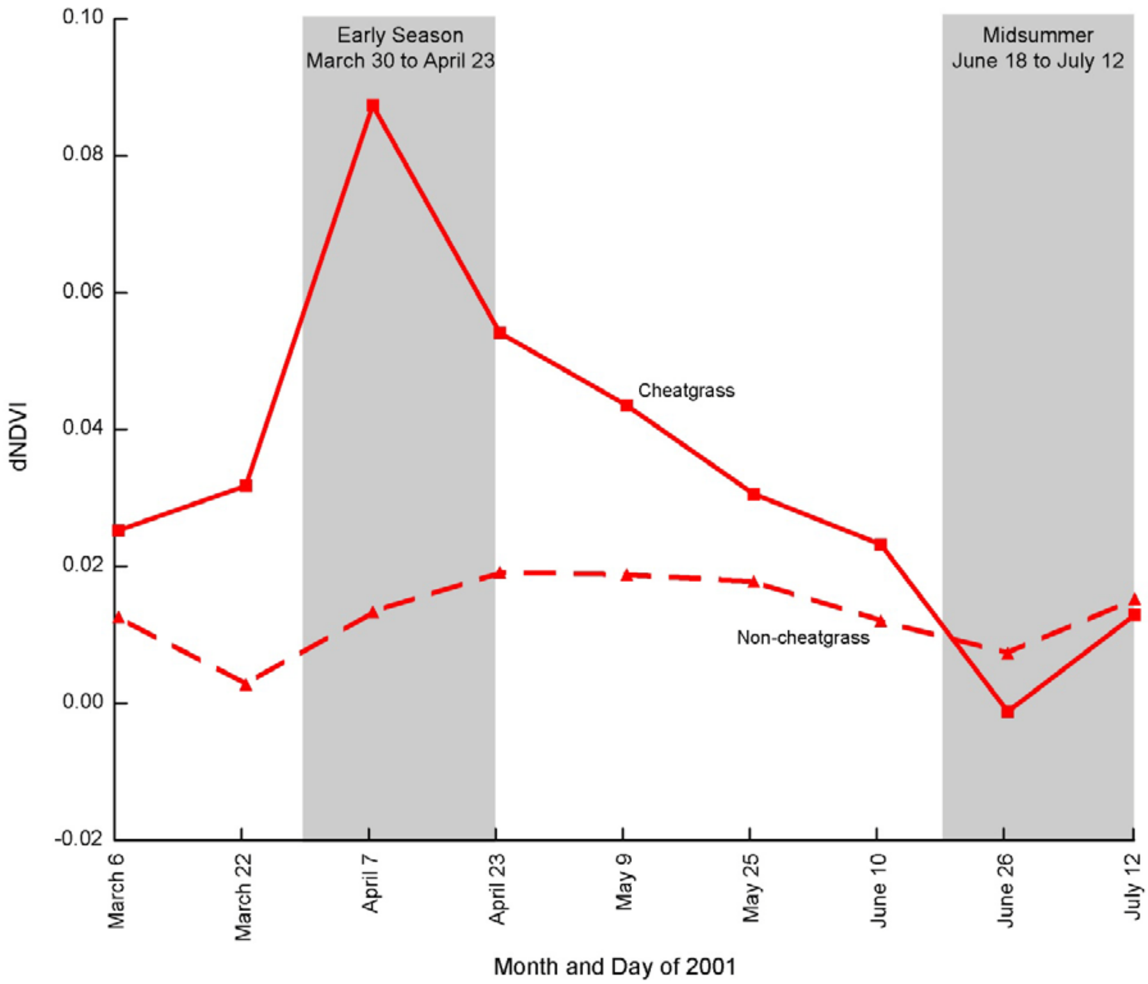

Figure 1. Seasonal trends of dNDVI for plots in Canyonlands National Park in 2001 for MODIS data.

Cloud cover can be a limiting factor in selecting images, forcing the selection of images acquired at nonoptimum dates. Cheatgrass mapping still can be attempted with such data, but, as the time between the date of the early-season image and the date of peak cheatgrass greenness increases, there is a greater likelihood that the default cheatgrass detection parameters will need to be adjusted. The accuracy of cheatgrass detection could be reduced and the likelihood of misidentifying native vegetation as cheatgrass could increase. Similar problems can occur if the date of the midsummer image falls outside the suggested date range.

Acquisition of Landsat Images

1. The USGS Earth Explorer Web site (*http://edcsns17.cr.usgs.gov/EarthExplorer/*) can be used to search for Landsat data over the area of interest (fig 2).

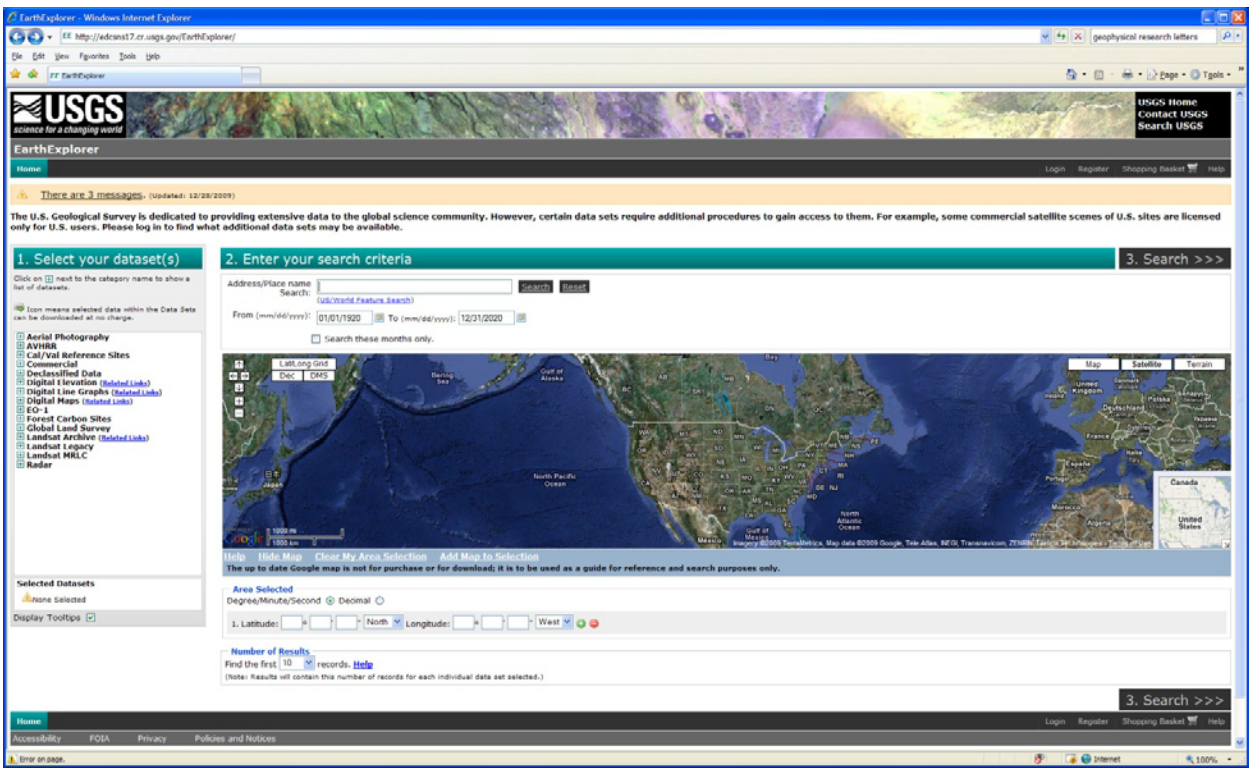

Figure 2. USGS Earth Explorer Web site.

2. On the site, the user can enter their data set and search parameters. Select the “Landsat Archive” item in the data set list, located on the left side of the window, and click on the “L7” and “L4-5” items (fig. 3).

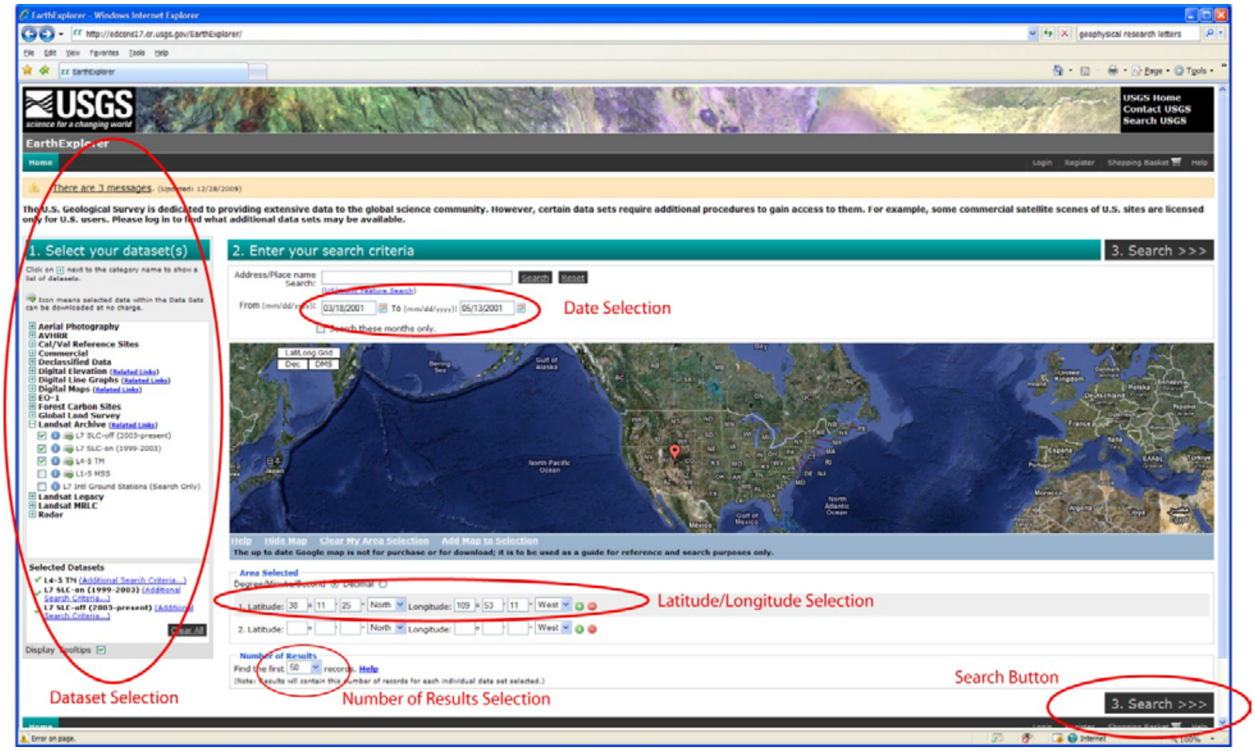

Figure 3. Selecting the Landsat data sets.

3. Enter the early-season search dates and the central latitude and longitude for the area of interest in the search criteria boxes (fig. 3). Press the green "+" button to the right of the coordinates to add the location to the search criteria. Change the "Number of Results" from the first 10 to a value of 50 using the drop-down list.

4. Press the "Search" button in the bottom right corner of the window to start the search. When the search is complete, the results for each data set are reported to the user (fig. 4). The user can click on each of the highlighted data sets to see the detailed results (fig. 5). The selection of the data should be guided by several criteria, including cloud-free imagery over the target area of interest, the image date, and Landsat sensor considerations. Several Landsat images may have been collected over the target area from the Landsat platforms, gap-free Landsat 7

SLC-on and Landsat 5 data being preferable to Landsat 7 data collected with the scan line corrector off (that is, the "L7 SLC-off" data set). The L7 SLC-off data suffers from data gaps within the image. In the middle of the image, along the path of the satellite, the images are complete. However, gaps in the coverage arise and increase towards the edges of the image (see http://landsat.usgs.gov/products_slcoffbackground.php).

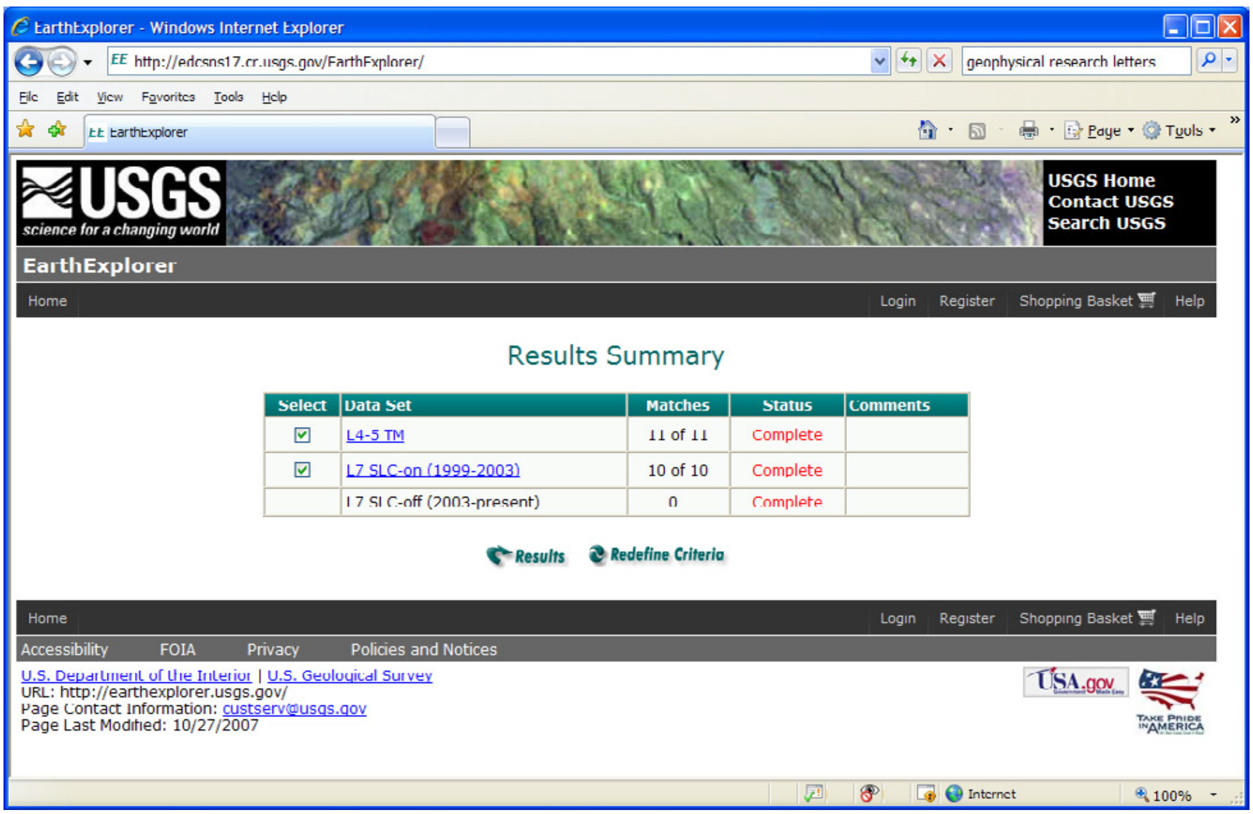

Figure 4. Search results for the Landsat data sets.

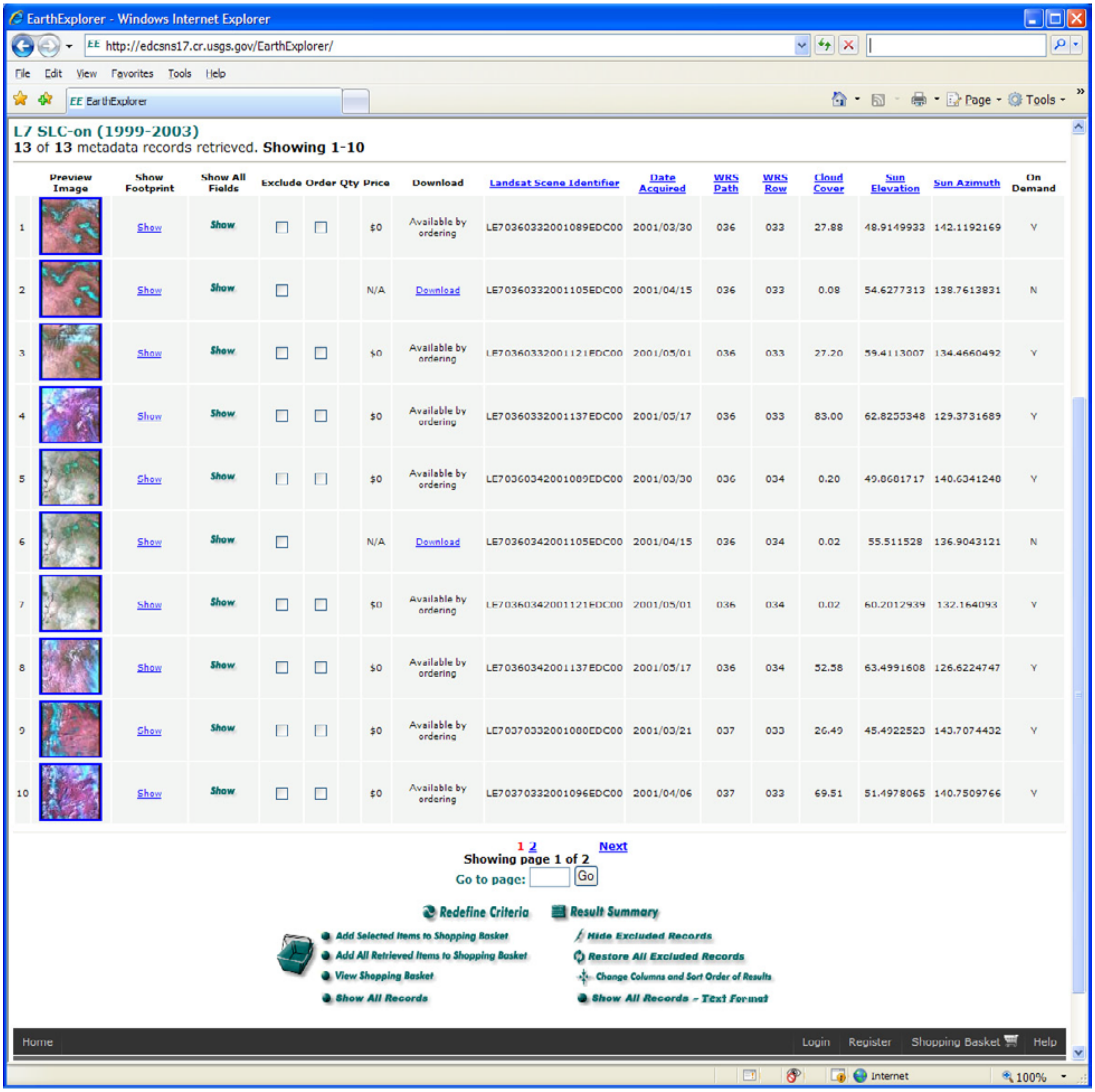

Figure 5. Search results for the Landsat 7 SLC-on data set.

The user can see the preview images of the data by clicking on the icon images in the left-hand column, clouds and snow often appear as white or light blue (fig. 6 for the preview image of April 15, 2001). Landsat coverage is divided into areas covered by Worldwide Reference System (WRS) paths and rows (see the *Landsat 7 User's Handbook*). This tutorial uses Landsat data for path 36, row 34.

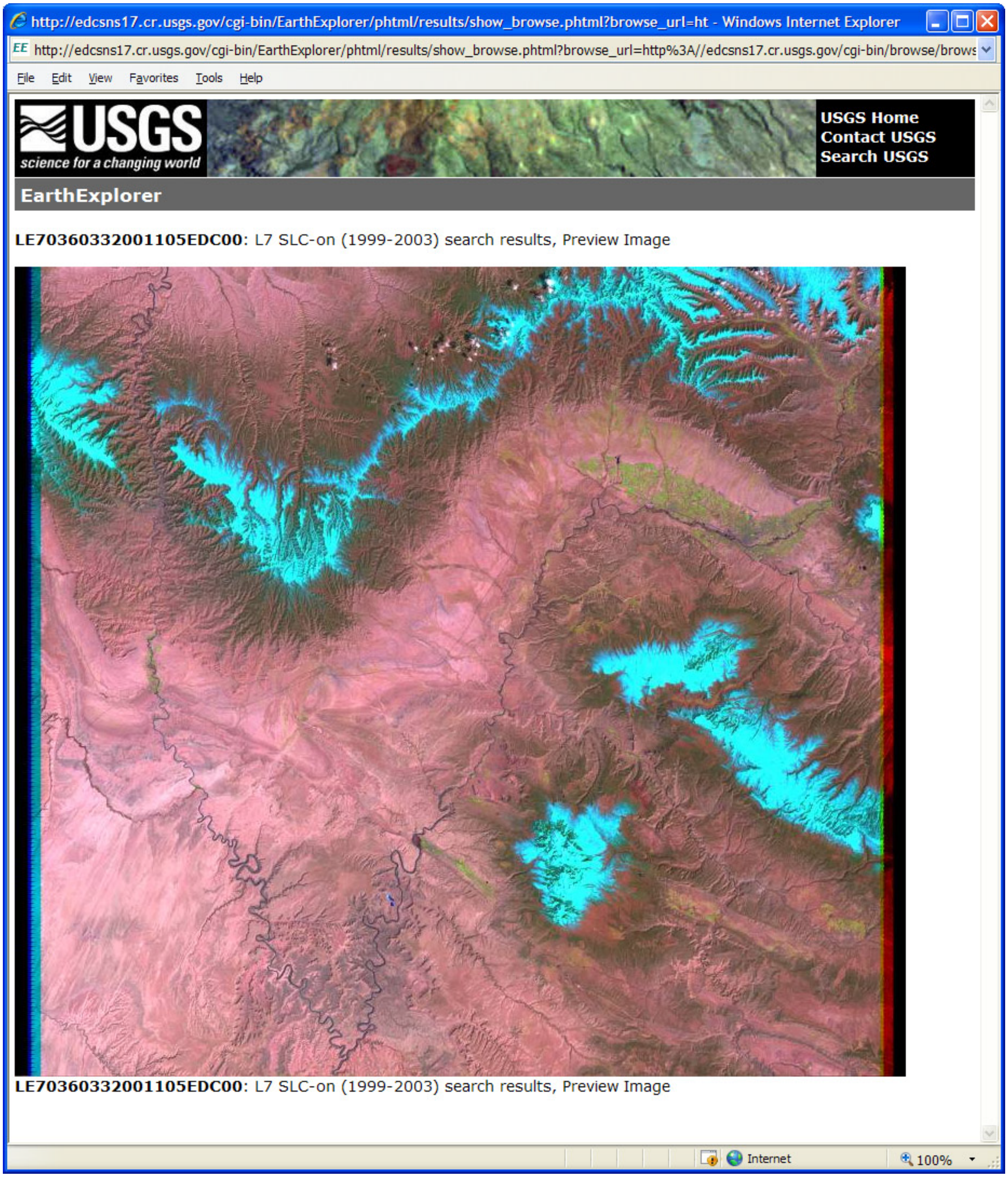

Figure 6. Preview image.

After finding a cloud free image, the user can check on the order box in the row of that image. Click on the “Add selected item to shopping basket” near the bottom of the results window (fig. 5). After you have added all the desired images to your shopping basket, click on the “View shopping basket” link near the bottom of the window. The user can then “sign-in” or “register” using the links at the top right to enter their information to obtain the data. Currently (give year), the data from the Landsat archive are available free of charge to all users. After ordering the data, the user will receive a message from USGS EROSDC acknowledging their order. When the images are ready for FTP download, the user will receive another email. In some instances the data may be directly available from the search results window, in such cases there will be a highlighted “download” link listed in the “Download” column (fig. 5). Click on the link to download the file.

The downloaded file is a compressed archive of the Landsat band images and metadata. The user needs to uncompress and unpack the files from the gzip compression and the tar archive format. Freeware and shareware utilities, such as winzip and winRAR, can be purchased/downloaded to uncompress these archives. Figure 7 shows a listing of the extracted contents of the April 15, 2001, Landsat 7 data for WRS path 36 row 34. The “TIF” files contain the images measured by each band of the sensor. The extensions, “_B10.TIF”, “_B20.TIF”, and so on, indicate bands 1, 2, and so on. The metadata file has the “_MTL.txt” extension at the end of the filename and contains detailed information about the radiometric and geometric attributes of the Landsat data. This file and the information it contains is used by the DESI software to process the Landsat imagery from the raw digital number (DN) format of the downloaded file to units of radiance and, further, to reflectance.

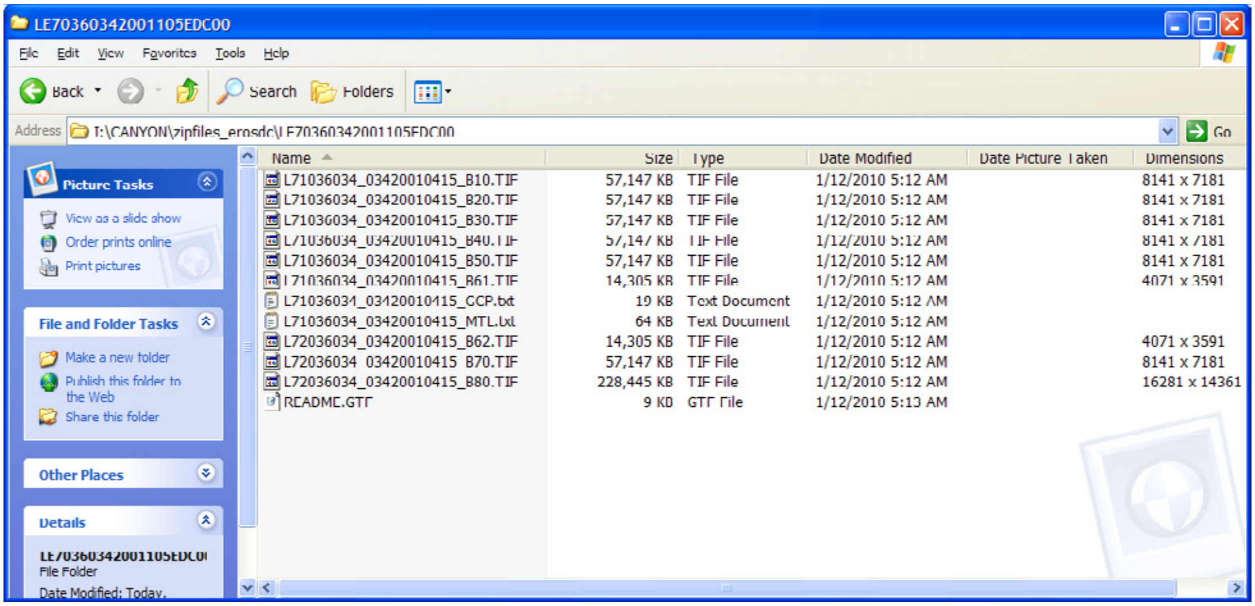

Figure 7. Listing of downloaded Landsat files.

Processing Landsat Data to Map Cheatgrass

This section of this report discusses the processing of Landsat data to detect cheatgrass using the DESI software. This report, in comparison to the DESI software installation and user's guide (Kokaly, 2011), gives additional details on the evaluation of results and customization of detection threshold values. The simple steps of running each DESI software module, shown in figure 8, are given in the DESI User's Guide (Kokaly, 2011).

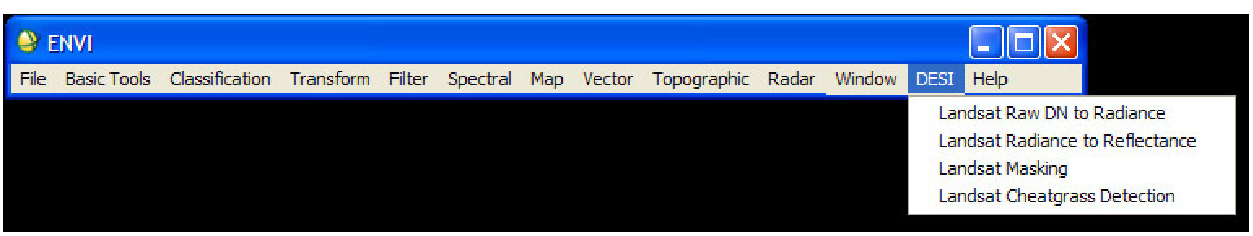

Figure 8. ENVI menu bar with DESI modules.

Converting Data from Raw Digital Number to Radiance

In DESI, the algorithm for detecting cheatgrass and other early-season invasive plants relies on the computation of NDVI from Landsat data that have been converted to reflectance. The reliance on reflectance data, as opposed to radiance data or the raw Landsat DN, arises from the fact that reflectance is primarily a function of the chemical and biochemical composition of materials. In the case of reflectance derived from Landsat data over vegetated areas, the variation in reflectance as a function of wavelength (for example, the different reflectance levels in the red and near-infrared bands) is caused by the biochemical composition of plants on the Earth's surface, the chemical composition and exposed area of the background soils, and the physical arrangement of plants on the surface. Thus, variations in the reflectance data over time (which result in variations in NDVI over time) are primarily a result of the biochemical changes in foliage and physical cover of plants.

In contrast, radiance data are a function of not only the reflectance of the surface but also of the illumination and the absorption of radiation by atmospheric gases, which vary through the year. Furthermore, atmospheric scattering of sunlight due to suspended dust and other aerosols in the atmosphere significantly changes radiance received by a satellite sensor. The atmospheric scattering varies in a non-linear fashion as a function of wavelength. The DESI software includes modules for converting Landsat data from raw DN to reflectance, in order to remove the atmospheric and illumination effects from the remotely sensed data. As a result, the DESI algorithm for detecting cheatgrass and other early-season invasive plants is based on variations in plant biochemistry and fractional canopy cover.

Landsat data from Earth Explorer are delivered as scaled radiance values, that is, digital numbers (DN). Scaling factors must be applied to the data to compute the at-sensor radiance, which is a measure of the amount of light reflected from the surface of the Earth and the atmosphere into the field of view of the satellite-borne sensor. DESI uses the equations described in Chander and others (2009) and the scaling factors contained in the Landsat metadata file to compute at-sensor radiance for each band of the sensor.

The DESI module "Landsat Raw DN to Radiance" reads the DN data, calculates radiance values in units of Watts/m^2/steradian/micrometer, applies a scaling factor of 100 to the radiance values, stores the output image in 2-byte, signed integer format, and creates an ENVI header file. Nondata pixels in the input image are set to a value of -1 in the output radiance image. Image parameters that are needed for further conversion of the radiance data to reflectance are extracted from the metadata file and encoded in the ENVI header of the output radiance image, including, the solar elevation, day, month, and year of the image acquisition, and the sensor type, Landsat 5 or Landsat 7.

During the execution of the module, a log file containing information about selected files and parameters used in the conversion of the data is created by the program. Initially, the log file is written to the user's IDL temporary directory (users of full ENVI+IDL licenses can determine the name of the directory by entering the following on the IDL command line:

```
ENVI> print, getenv('IDLTMPDIR')
```

After completion of the program, the file is copied to the directory containing the output radiance image.

This module's processing steps are described in the DESI User's Guide (Kokaly, 2011). The example data shown for this module are included in the compressed distribution archive available online at *http://pubs.usgs.gov/of/2010/1327/downloads/*.

During the processing, the data in the individual geo-tif files for each band are converted to radiance and combined into a single file that contains the six bands of the Landsat sensor that fall in the reflected solar portion of the electromagnetic spectrum. At the end of the processing, this file appears at the top of the listing of the available bands in ENVI (fig. 9).

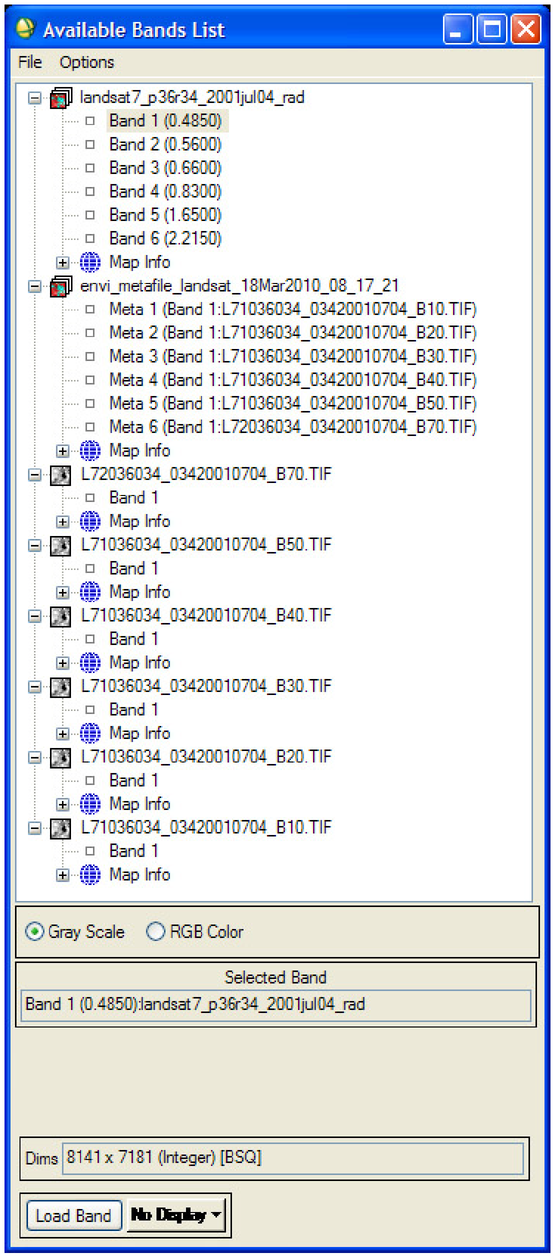

Figure 9. ENVI available bands list after converting data to radiance.

Any single band from the data can be displayed by clicking on the desired band and then pressing the "Load Band" button in the bottom left corner of the window (fig. 9). An example of displaying the first band from the Landsat radiance file is shown in figure 10.

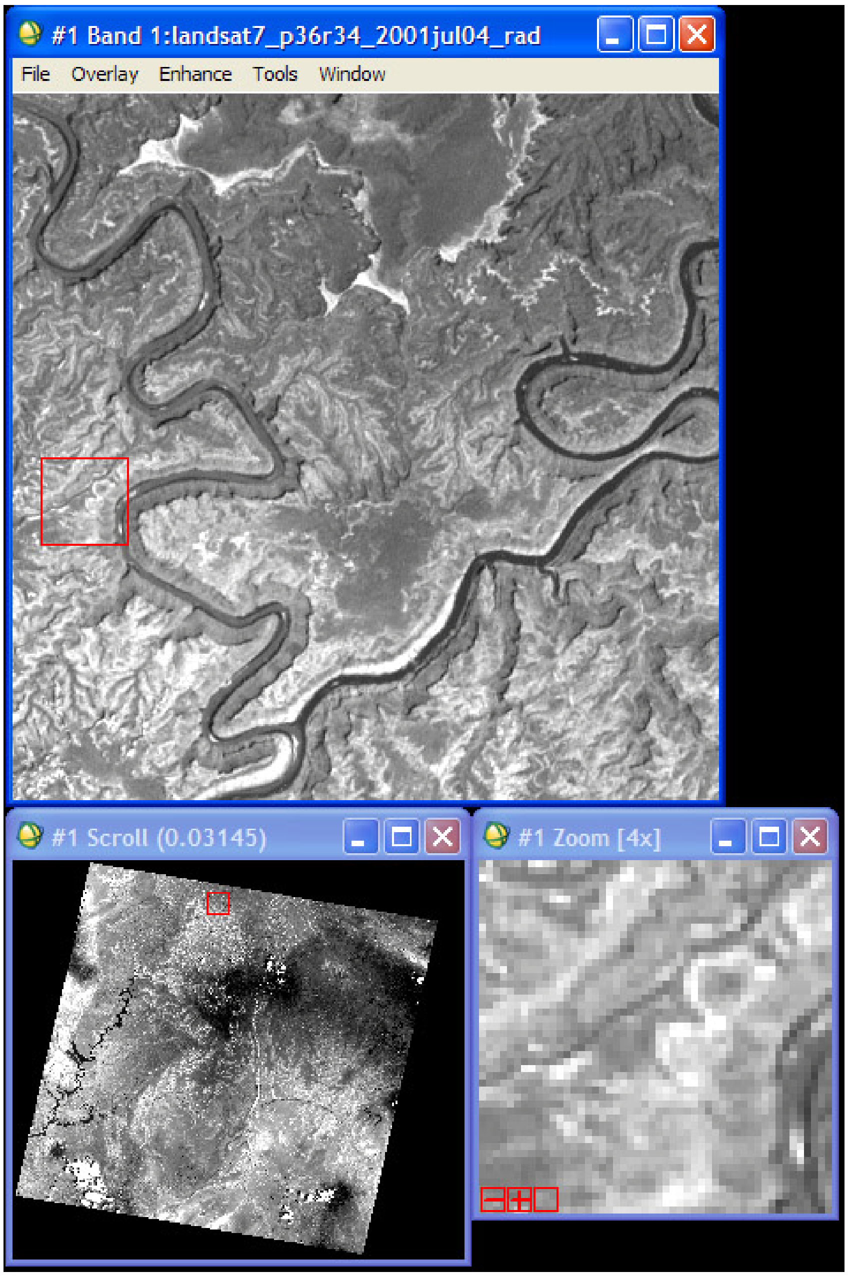

Figure 10. Example of displaying a single band from the radiance file.

ENVI displays the data in three windows, a “Band” window, a “Scroll” window, and a “Zoom” window. The scroll window shows a subsampled representation of the full extent of the data. The red box in the scroll window shows the area that is displayed in the band window. In a similar fashion, the red box in the band window shows the area that is displayed at a magnified scale in the zoom window. The area shown in the band window can be changed by left-clicking in the scroll window, subsequently the data for that selected area are read from the file and displayed in the band window.

Several bands can be combined into a color combination, by assigning bands to display as red (R), green (G), and blue (B) colors. To do this in ENVI, select the “RGB Color” option instead of the “Gray Scale” option below the listed bands (fig. 9). Typical color combinations for Landsat TM/ETM data are “true-color” composites with bands 3, 2, and 1 assigned to red, green, and blue, respectively (fig. 11) and a “false-color” composite of bands 4, 3, and 2, assigned to red, green, and blue, respectively (fig. 12). The band 3-2-1 true-color composite approximates the colors seen by the human eye. The band 4-3-2 false-color composite highlights the presence of growing vegetation in a vivid red color. In the scroll window, the black areas around the image are non-data pixels which are assigned a value of -1 by DESI.

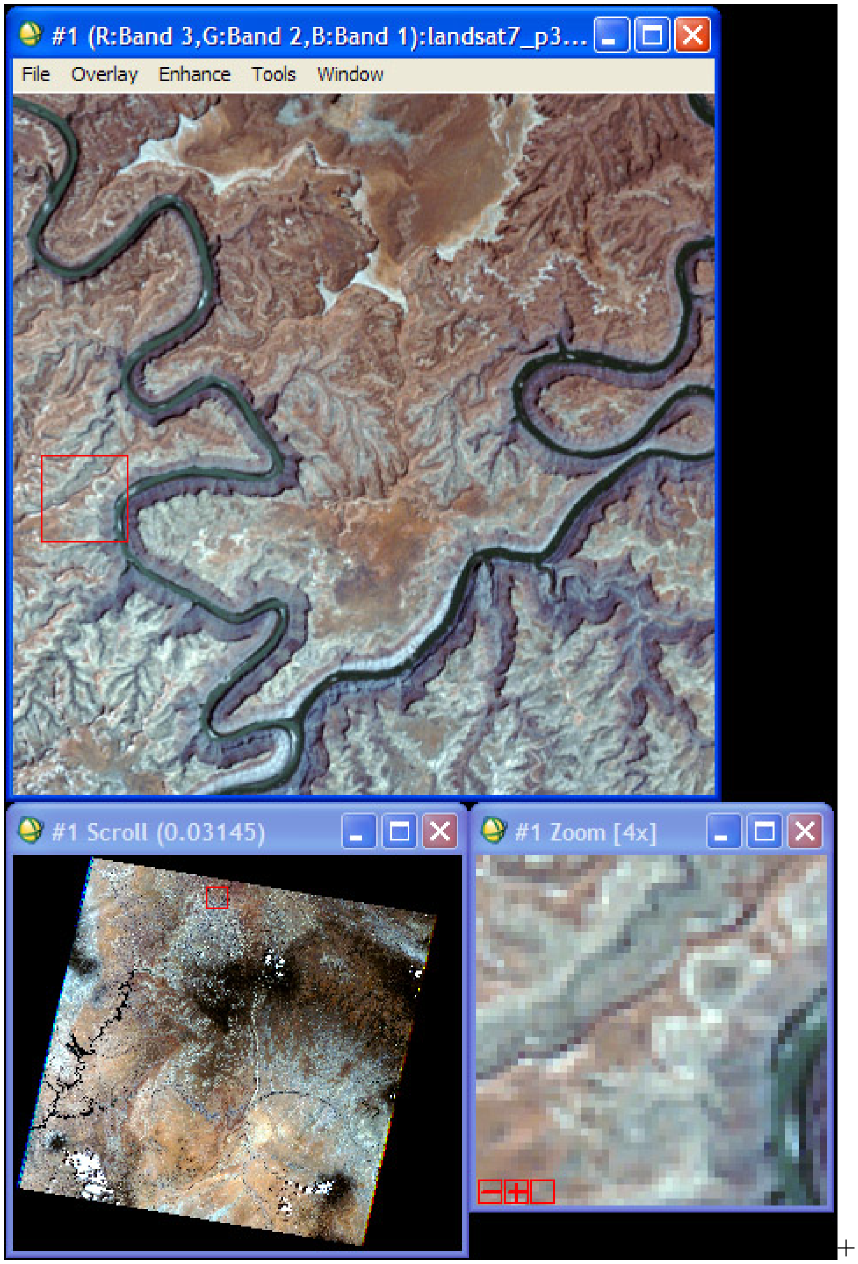

Figure 11. Example of displaying a true-color composite of bands 3-2-1 from the radiance file.

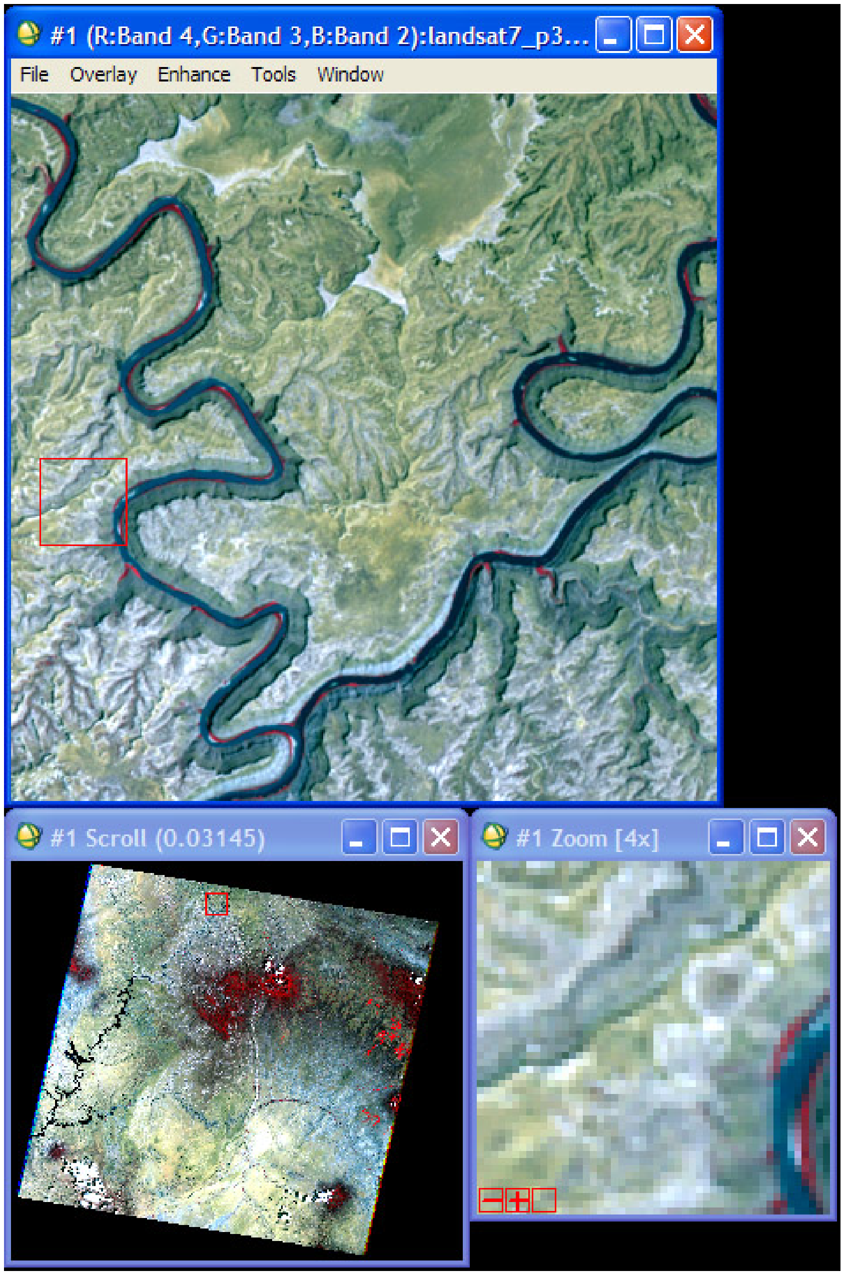

Figure 12. Example of displaying a false-color composite of bands 4-3-2 from the radiance file.

The radiance spectrum of a pixel in the Landsat image can be plotted by right-clicking in the band window and selecting the "Z-Profile (Spectrum)…" option (fig. 13). A window titled "Spectral Profile" appears (see the bottom window in fig. 13), showing the spectrum of the pixel at the center of the zoom window (designated by the red crosshairs which appear in the zoom window). The spectrum is a plot of the radiance values on the y-axis at the wavelength positions (x-axis) of the Landsat bands.

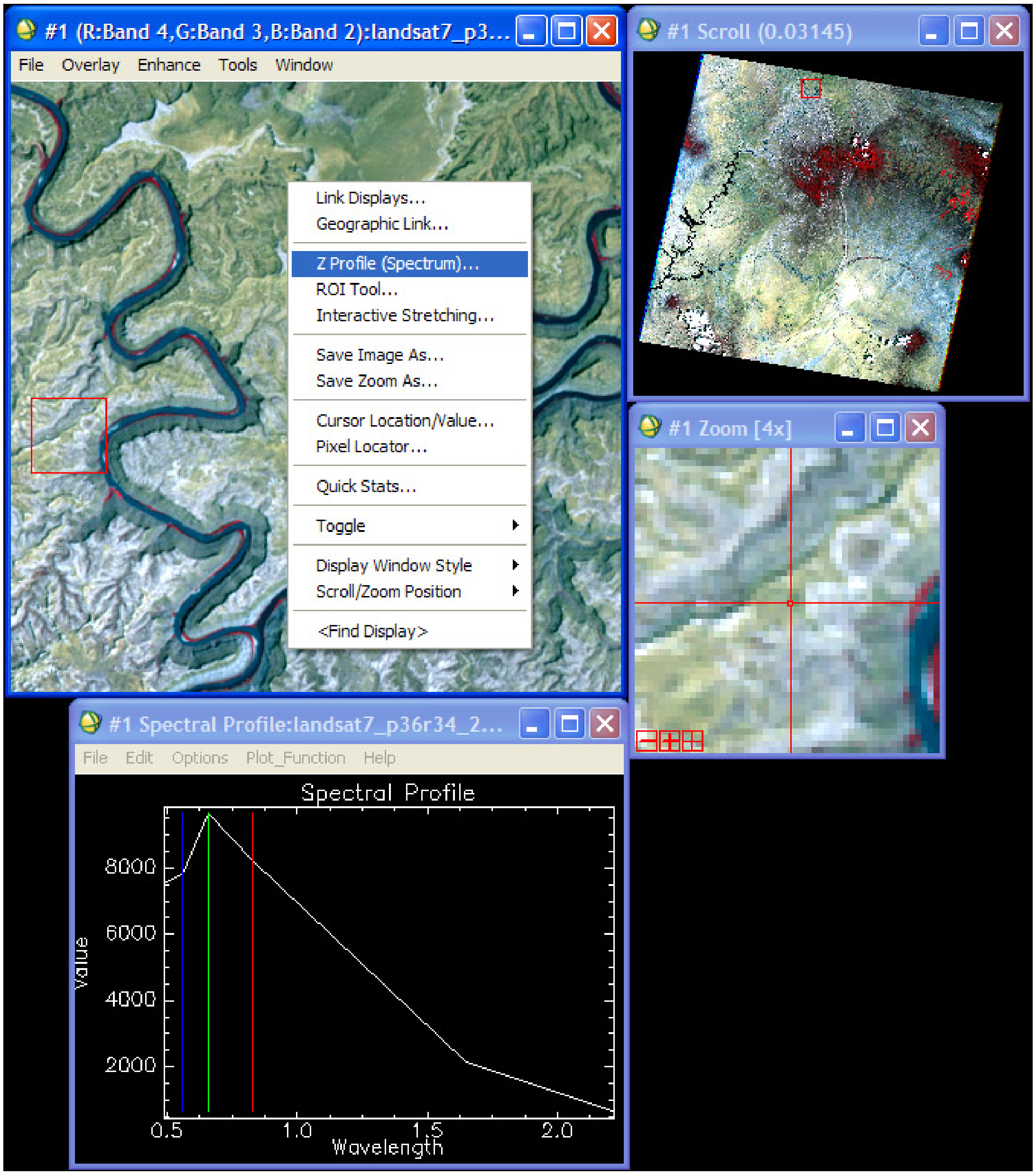

Figure 13. Displaying the Z-Profile (spectrum) for a radiance image.

The radiance spectra for areas of water, rock/soil, green riparian vegetation, dry vegetation, sparse vegetation, shadowed terrain, and cloud are shown in figure 14.

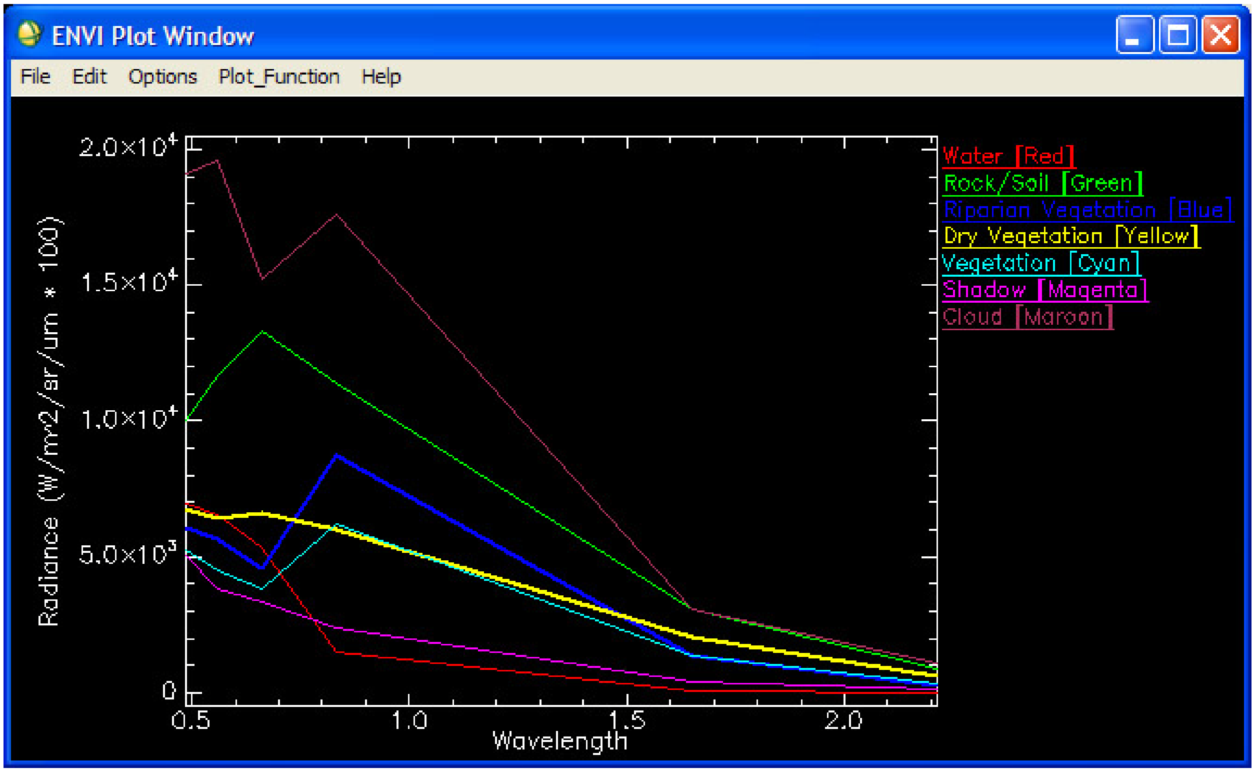

Figure 14. Radiance spectra.

The ENVI header of the output radiance image contains image parameters, extracted from the metadata file, that are needed for further conversion of the radiance data to reflectance, including, the solar elevation, day, month, and year of the image acquisition, and the sensor type, Landsat 5 or Landsat 7. Appendix A shows an example listing of the information contained in an ENVI header produced by DESI for a radiance file.

Converting Data from Radiance to Reflectance

Reflectance is the ratio of the electromagnetic radiation coming off a surface to the radiation falling onto that surface. For Landsat data, the surface reflectance in each pixel is the ratio of the at-sensor radiance measured for the pixel to the solar irradiance, accounting for the atmospheric absorption and scattering. The conversion from radiance to reflectance results in a value that is a function of the chemical and physical properties of the materials on the surface of a pixel. Reflectance varies across wavelength as a result of the absorption and scattering of light by the surface materials. Reflectance is less dependent on the viewing and illumination geometry of a surface as compared to radiance which is a function of both the reflectance properties of a surface and the irradiance that illuminates the surface. Therefore, changes in reflectance over time are more directly attributable to changes in a surface's physical composition (for example, the amount of vegetation) and the chemical composition of the material present on the surface (for example, the chlorophyll content of vegetation).

The DESI module "Landsat Radiance to Reflectance" (fig. 8) converts data to reflectance according the equations in Chander and others (2009). The program requires input data in units of radiance, in Watts/m^2/steradian/micrometer, scaled by a multiplicative factor of 100 (as produced by Module 1 of DESI). Constant values required for converting the data from radiance to reflectance as specified in Chander and others (2009) are hard coded in the program. Additional scene-specific information is needed to convert radiance data to reflectance. If Module 1 was used to produce the radiance data, the scene-specific information required for the conversion is encoded in the description field of the radiance image's ENVI header (see Appendix A). If the program cannot extract these values from the header file, the user will be prompted to set the required parameters (the solar elevation, day, month, and year of the image acquisition, and the sensor type, Landsat 5 or Landsat 7).

Accurate conversion to reflectance requires the removal of path radiance, that is, radiant energy from the sun that has been scattered by the atmosphere back to the satellite sensor. Path radiance arises from the scattering of sunlight by molecules and aerosols in the atmosphere.

Scattering by molecules (Rayleigh scattering) is greater at shorter wavelengths and decreases with increasing wavelength. A simple estimate for path radiance may be made using the at sensor radiance values over areas which are very dark (near zero reflectance). The following steps illustrate how the darkest pixels in Landsat bands one and four of the radiance image may be displayed, selected, and used to generate a path radiance estimate.

Step 1: Display band one as a gray scale image (fig. 10).

Step 2: Click on the "Enhance" menu item at the top of the band window and select the "Interactive Stretching…" option (fig. 15). This brings up a window in which the user can adjust the displayed gray scale values of the pixels in band one (fig. 16).

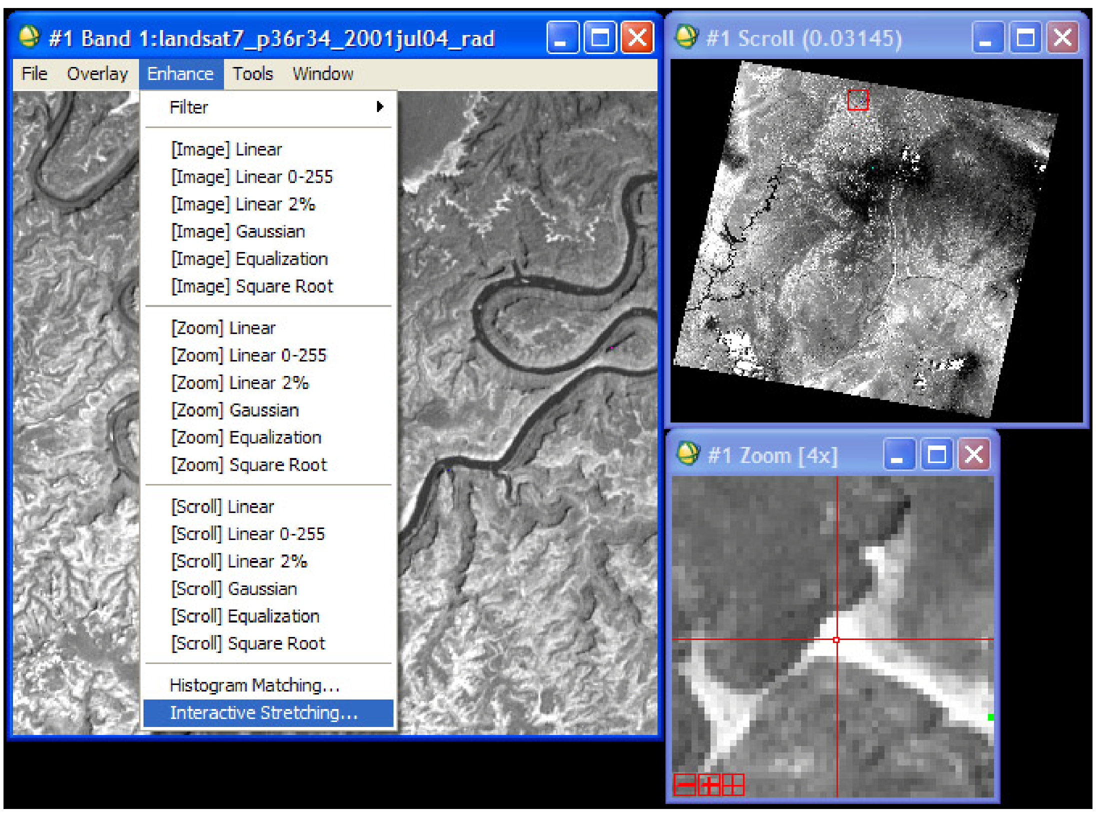

Figure 15. Selecting the interactive stretching tool.

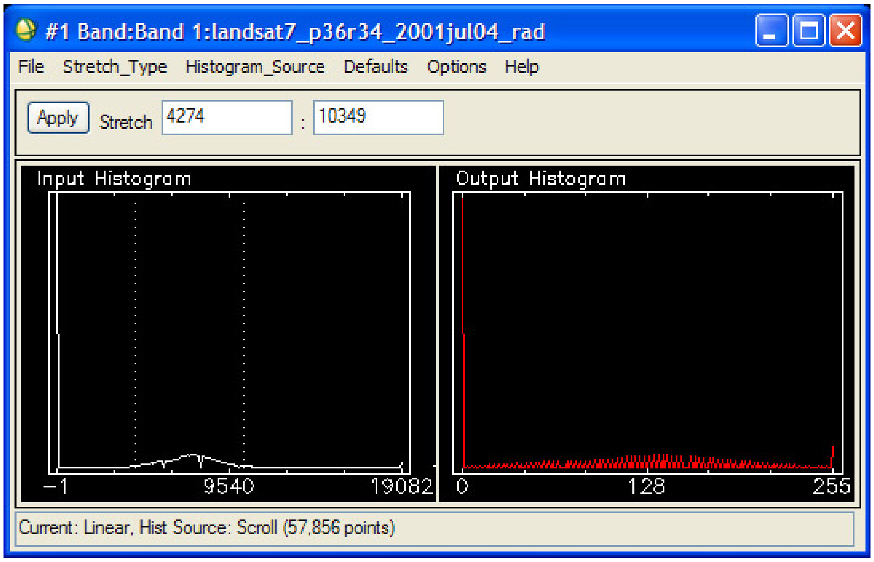

Figure 16. The interactive stretching window.

Step 3: Click on the "Histogram Source" menu item at the top of the interactive stretching window and select the "Band" option (fig. 17). The plot on the left side of the window, labeled as Input Histogram, shows the histogram of pixels that fall between the minimum and maximum values in the band. The user may click on the vertical dashed lines at the left and right edges of the plot to alter the "stretch" of the image. The stretch refers to how the data values are mapped to display values of 0 to 255 (the plot on the right, labeled as Output Histogram). As the right-most dashed line in the Input Histogram is moved, the data values to the right of that line are displayed at maximum brightness value of 255 (white). As the left-most dashed line in the Input Histogram is moved, the data values to the left of that line are displayed at minimum brightness of 0 (black). The data values in between these lines are displayed as levels of gray between black and white.

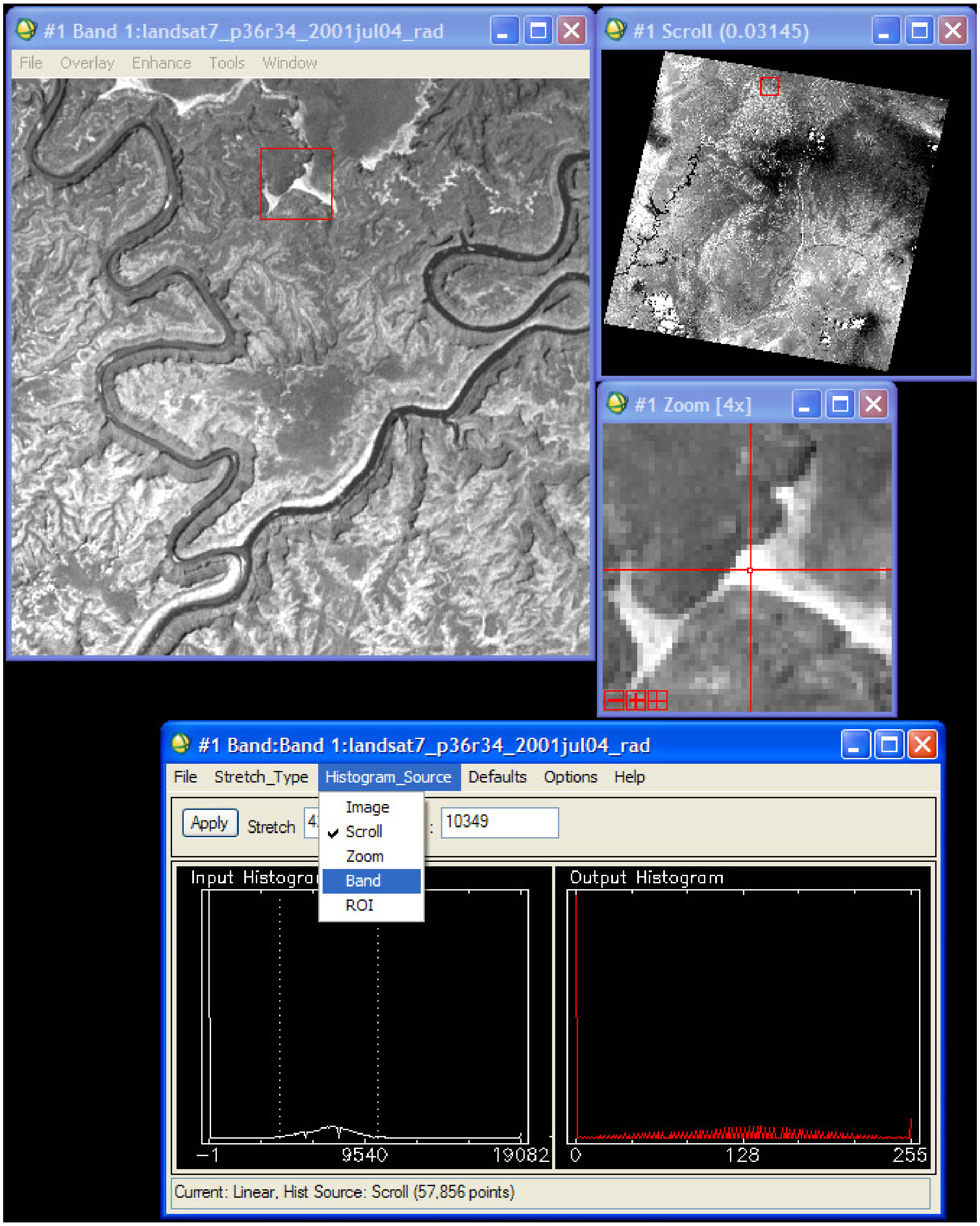

Figure 17. Assigning the band as the histogram source.

Step 4: Adjust the dashed lines to display the darkest pixels (fig. 18). It is useful to maximize the scroll window (fig. 19). As the right-most slider is moved to the left, the darkest pixels are shown in black (fig. 20).

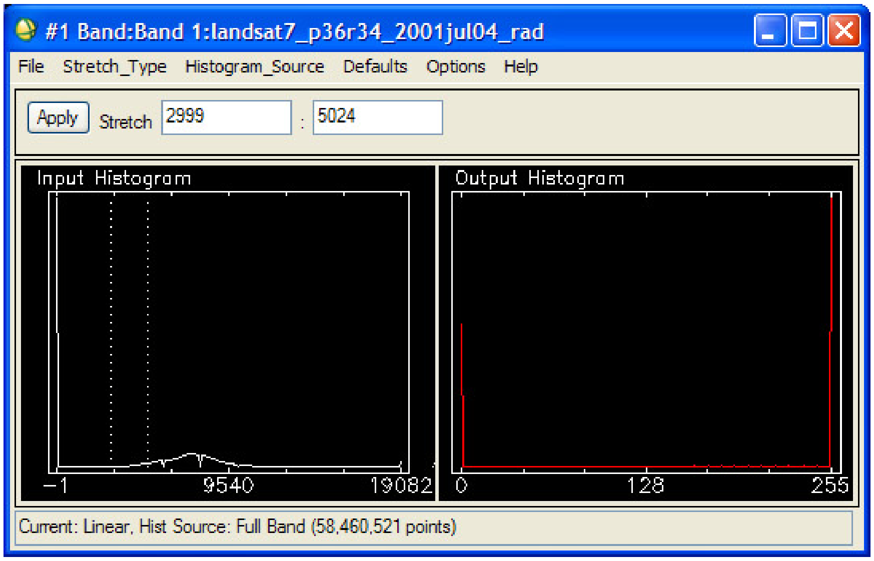

Figure 18. Adjusting the interactive stretch.

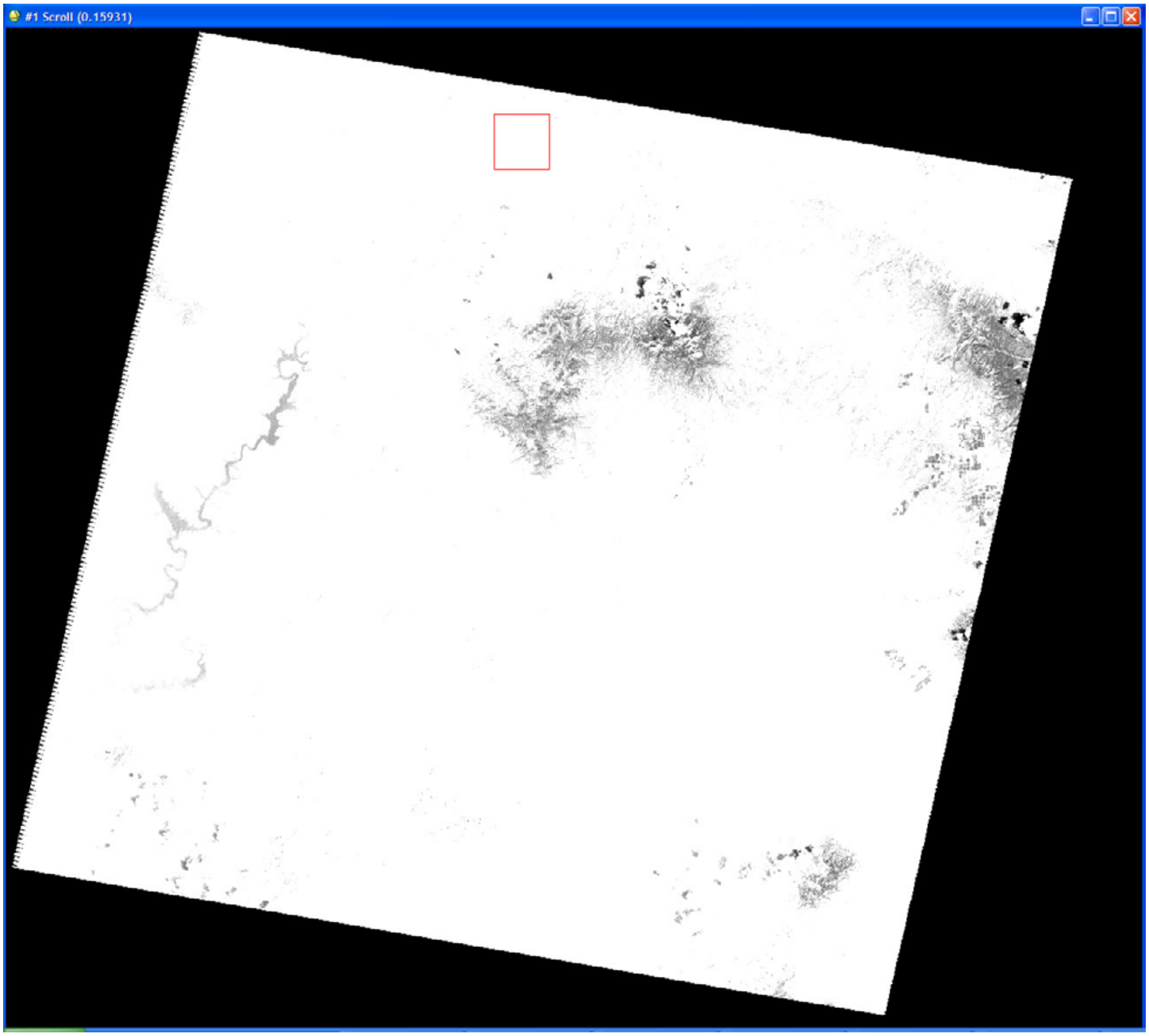

Figure 19. Dark pixels in the scroll window.

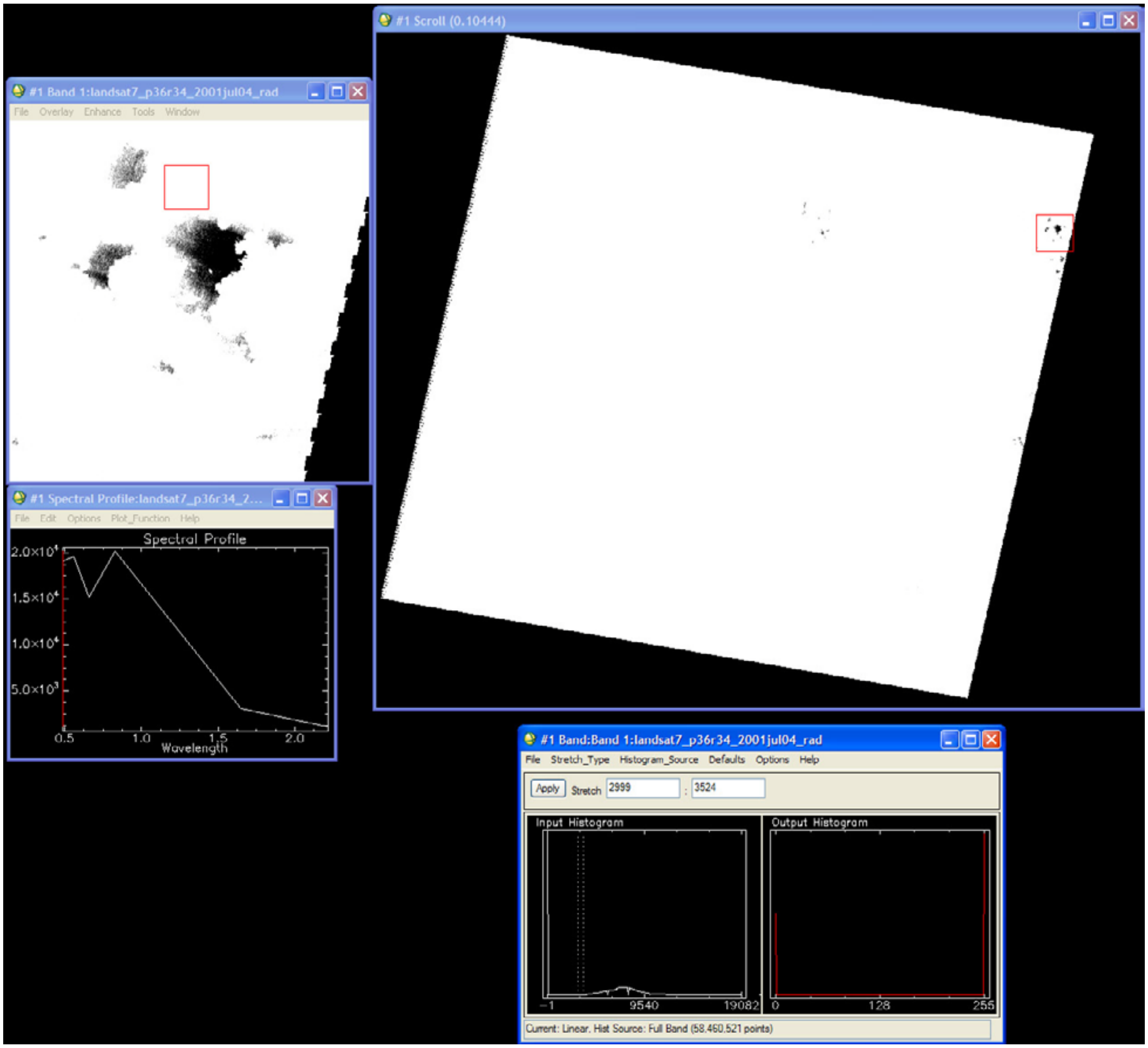

Figure 20. Displaying the darkest pixels of band 1 of the radiance image.

Step 5: Click on the “Tools” menu item at the top of the band window and select the “Region Of Interest” item. In the menu that appears, choose the “ROI Tool…” (fig. 21). The ROI Tool window will appear (fig. 22).

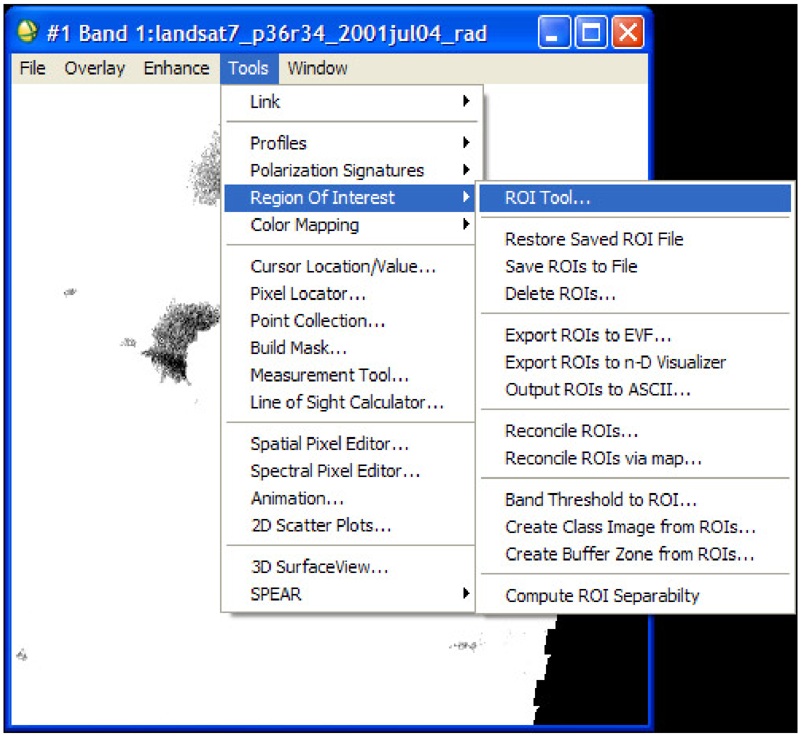

Figure 21. Selecting the ROI Tool.

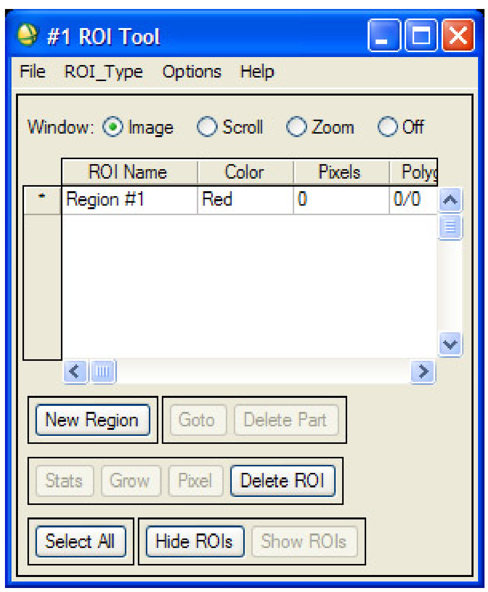

Figure 22 . ROI Tool window.

Step 6: The user can then draw a polygon around the dark pixels in the image window by left clicking at each desired vertex of the polygon (see the unfilled polygon in fig. 23). Right-click to “close” the polygon. Right-click a second time to fill the polygon. This selects all the pixels in the polygon (see the filled polygon in fig. 23).

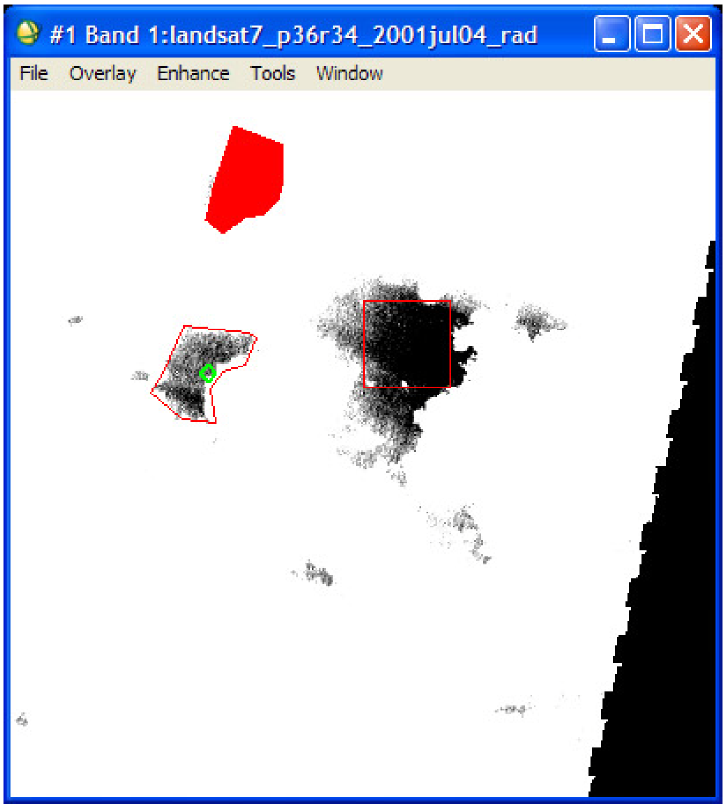

Figure 23. Defining ROIs for the darkest pixels of band 1.

Step 7: When the user has drawn polygons around all the desired dark pixels in band 1, click on “New Region” in the ROI Tool window (fig. 22).

Step 8: In the ENVI Available Bands window, select band 4 from the radiance image and click on the “Load Band” button. This will update the display windows and histogram windows with the data from band 4. The user should repeat steps 3-6 to assign the darkest pixels in band 4 to the new ROI (fig. 24). Typically, the darkest pixels in band 1 fall in topographic and/or cloud shadows and the darkest pixels in band 4 fall in deep water bodies.

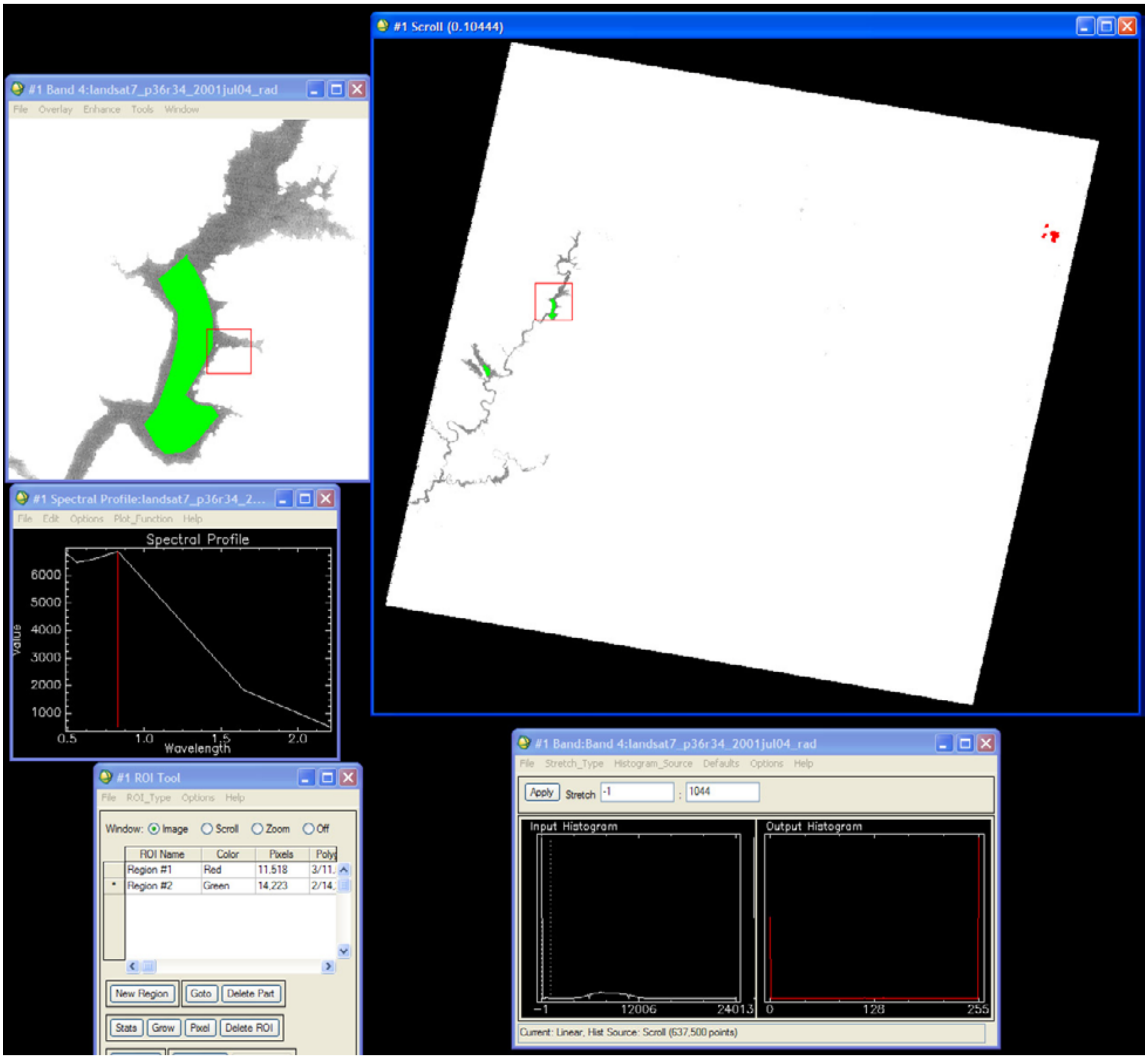

Figure 24. Defining the ROI for the darkest pixels of band 4.

Step 9: The ROIs should be stored by selecting the "Save ROIs" option under the "File" menu item at the top of the ROI Tool window (fig. 25). Save them to the same directory as the radiance image.

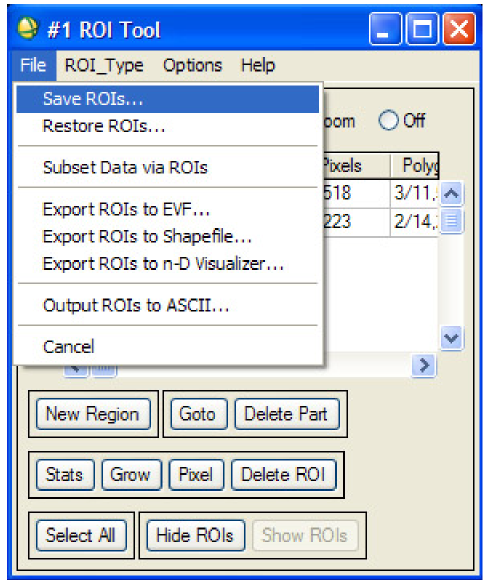

Figure 25. Saving ROIs.

Step 10: Next, merge the ROIs by selecting the "Merge Regions…" item under the "Options" menu item at the top of the ROI Tool window (fig. 26).

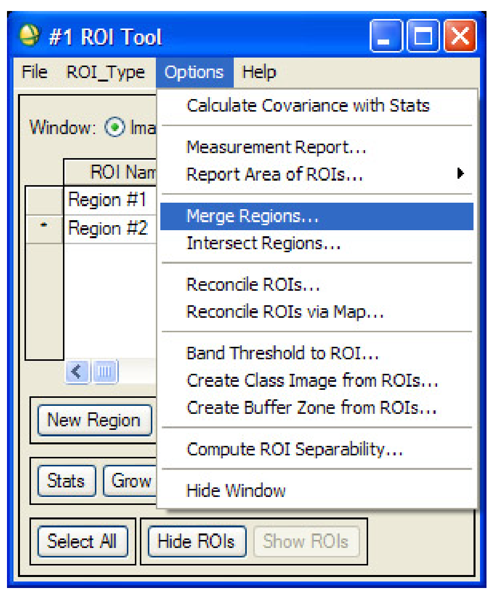

Figure 26. Merging ROIs.

Step 11: In the “Merge ROIs” window, press on the “Select All Items” button and press “OK” to merge the regions (fig. 27). A single ROI will remain in the ROI Tool window (fig. 28).

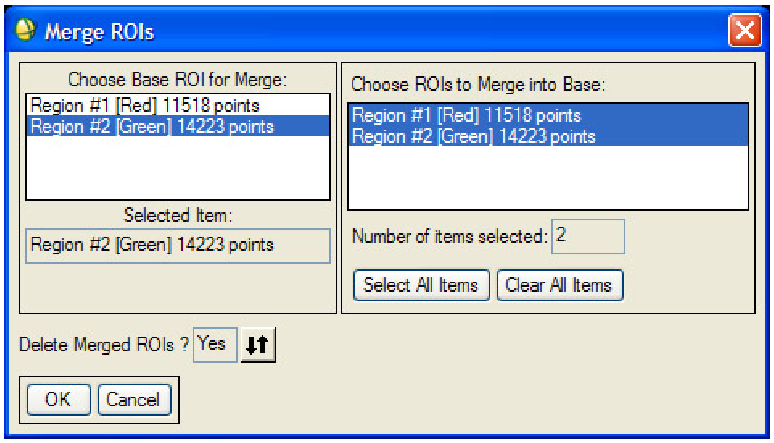

Figure 27. Selecting the ROIs to merge.

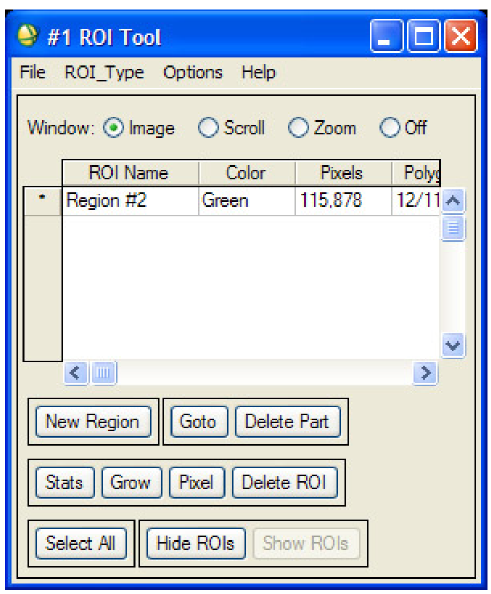

Figure 28. Merged ROI.

Step 12: Press the “Stats” button in the ROI Tool window (fig. 28).

Step 13: A new window appears with the ROI statistics, including the minimum values in each band (fig. 29). The minimum values of bands 5and 6 should be zero or near zero. Band 1 should have the highest value and each subsequent band should be approximately half of the previous value.

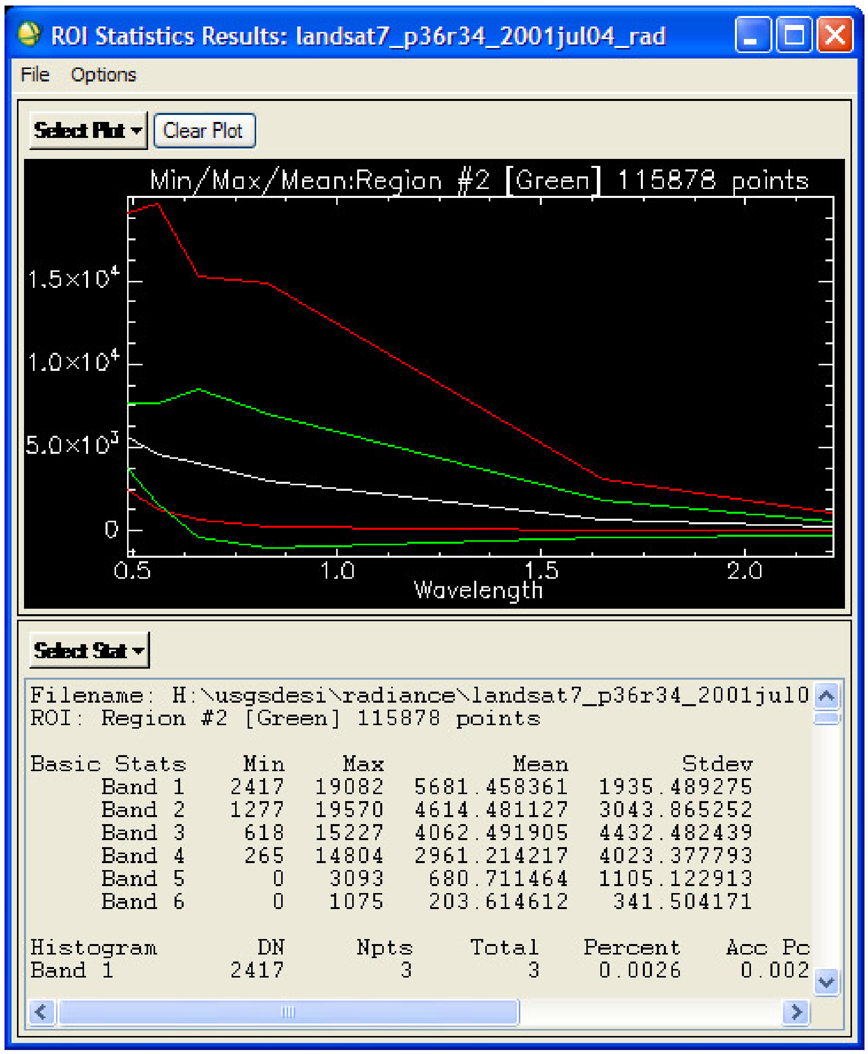

Figure 29. ROI statistics.

Step 14: Save the minimum values to a text file, by right clicking within the plot, choosing the "File" item, selecting the "Save Plot As" item, and clicking on the "ASCII" item (fig. 30). In the window that appears (fig. 31), select the "Min" item and then set the output directory and filename using the “Choose” button. Choose the output directory to be the same directory as the radiance file and use the “.txt” file extension. Click “OK” to save the text file.

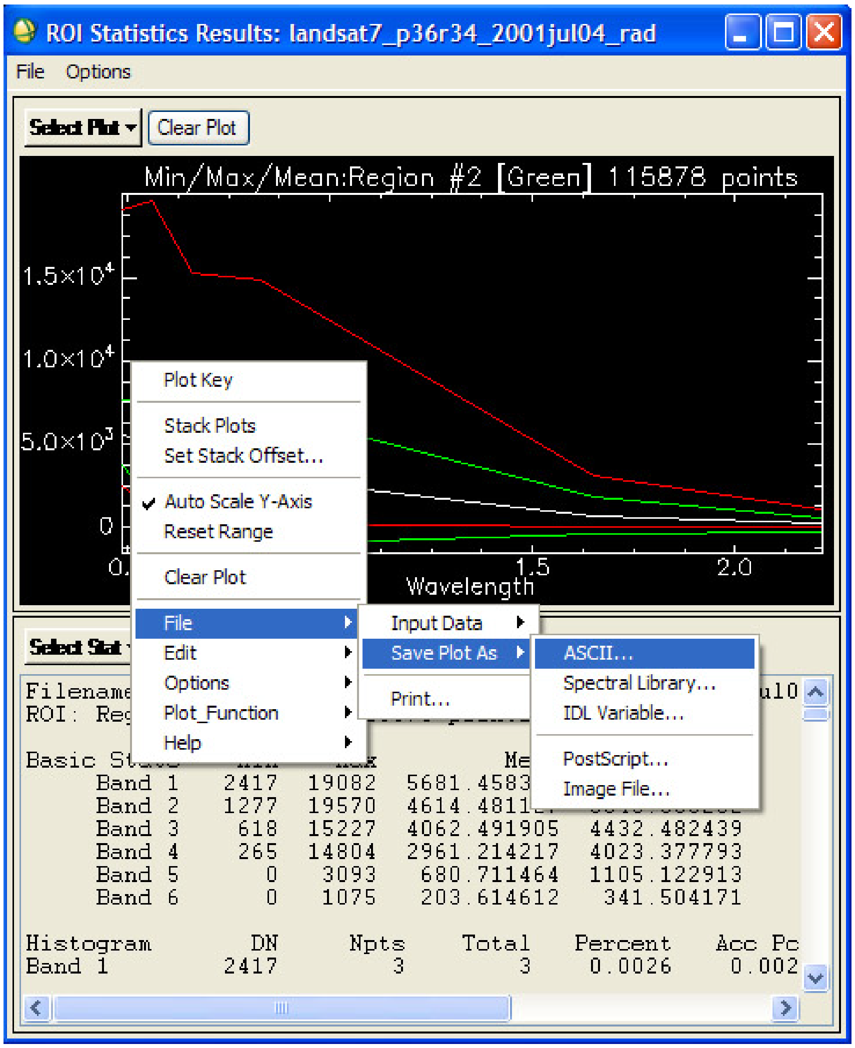

Figure 30. Selecting the save plot to a text file option.

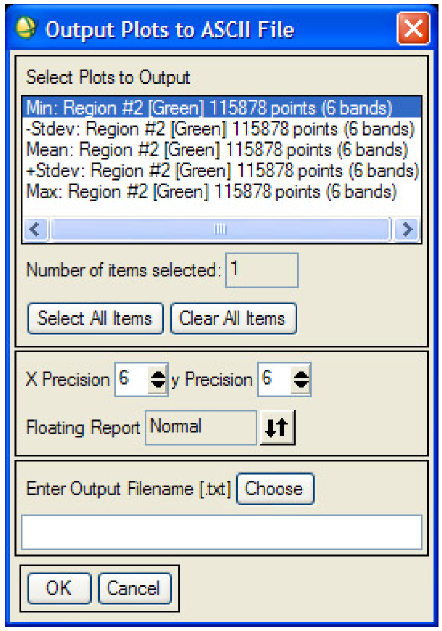

Figure 31. Saving the minimum radiance values to a text file.

Step 15: Open the text file with a text editor (fig. 32). Edit the text to remove the first three lines of text and the first column of values, leaving only the minimum radiance values (fig. 33). Save the text file.

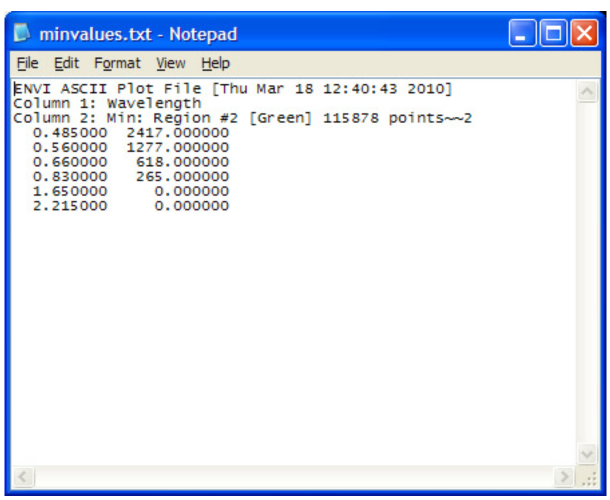

Figure 32. Text file containing the minimum radiance values.

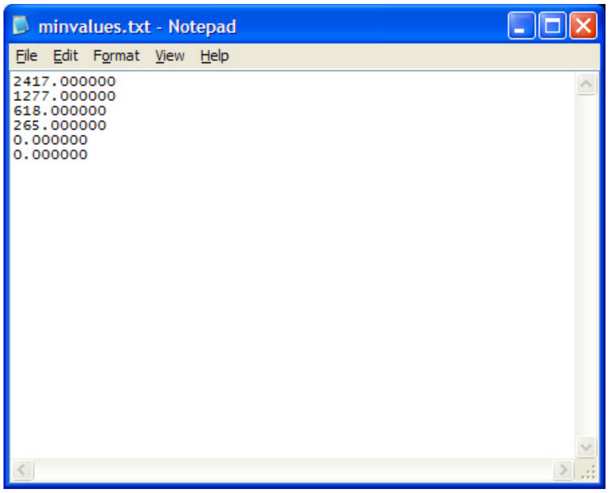

Figure 33. Edited text file containing the path radiance estimate.

This edited text file, containing the minimum radiance values found in the selection of the darkest pixels in bands 1 and 4, will be used as the path radiance estimate when converting the radiance to reflectance, see the description of Module 2 in the DESI User's Guide in (Kokaly, 2011).

The output reflectance values are scaled by a factor of 10,000 before being stored in the output image. As a result, a reflectance of 1.0 is scaled to a value of 10,000. The program expects that nondata pixels in the input radiance image are set to a value of -1. These same pixels are set to a value of -1 in the output reflectance image. A log file containing information about selected files and parameters used in the conversion of the data is created by the program. Initially, the log file is written to the user's IDL temporary directory. After completion of the program, the file is copied to the directory containing the output reflectance image.

The ENVI header of the output reflectance image contains image parameters, extracted from the metadata file, that were used in conversion of the radiance data to reflectance, including, the solar elevation, day, month, and year of the image acquisition, and the sensor type, Landsat 5 or Landsat 7. Appendix B shows an example listing of the information contained in an ENVI header produced by DESI for a reflectance file.

The reflectance spectra for areas of water, rock/soil, green riparian vegetation, dry vegetation, sparse vegetation, shadowed terrain, and cloud are shown in figure 34. These are the same areas for which radiance spectra are shown in figure 14.

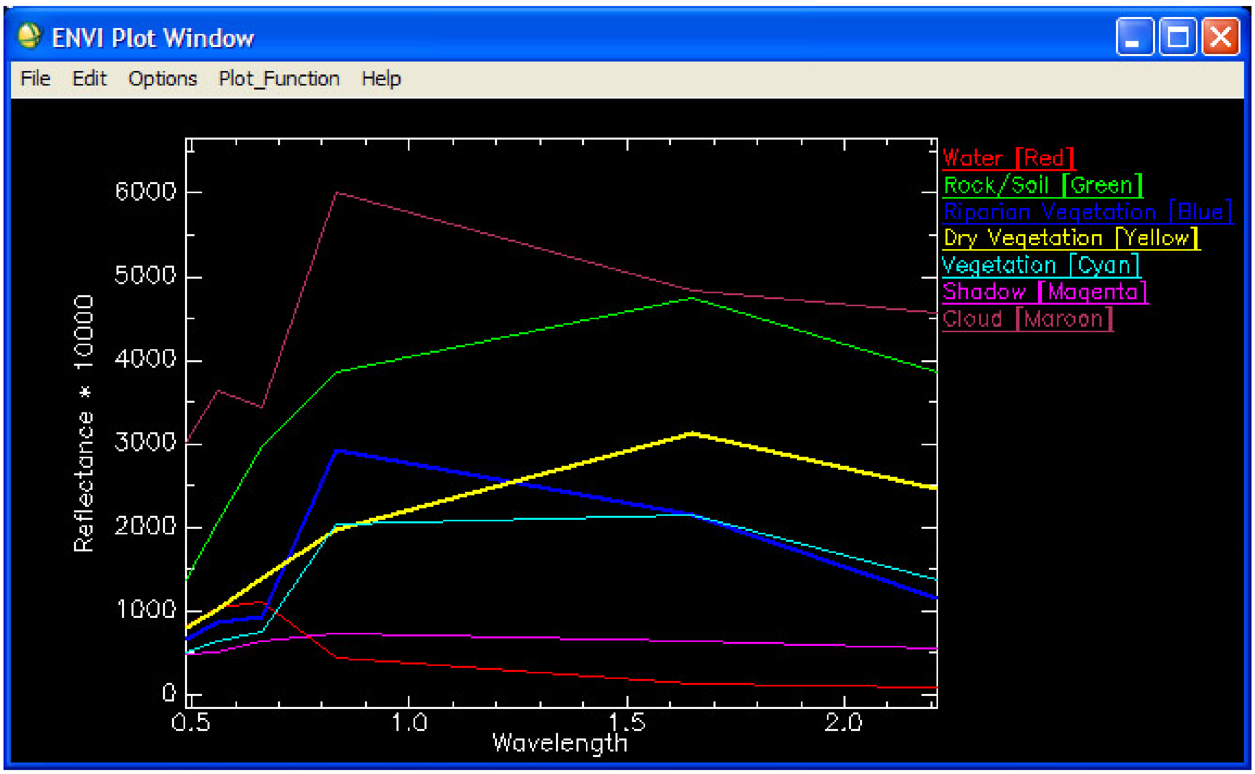

Figure 34. Reflectance spectra.

Generating a Mask for Clouds/Snow, Water, Shadows, and Burned Areas

DESI identifies area of potential cheatgrass infestation by identifying pixels with high dNDVI, computed as NDVI in a midsummer image subtracted from an early-season NDVI image. Generally, increasing NDVI values indicate a greater amount of green vegetation is present in a pixel. However, some nonvegetation materials can affect the computed NDVI value and, thus, affect the dNDVI value. In order to remove pixels that contain these materials from the final map of potential cheatgrass infestation, DESI includes a module to generate a mask of pixels that are substantially covered by cloud/snow or water, may be shadowed by steep terrain or clouds, and may contain a large amount of ash/char left on the surface by wildland fires. These materials have been found to affect NDVI values in a way that can lead to false-positive detections of cheatgrass.

Module 3 of DESI "Landsat Masking" (fig. 8) creates the mask for pixels containing cloud/snow, water, burned areas, and deep shadows (from clouds or steep terrain). The program uses both the radiance and reflectance images of Landsat data to identify the pixels containing these materials (see Kokaly, 2011). The output file is an ENVI classification image.

The masking program uses simple thresholds on band values and ratios of band values as criteria for detecting the mask materials. First, the user is shown a list of the default threshold values used in detecting the materials to mask (fig. 35). It is suggested that the defaults be used initially. In general, these parameters are maximum-allowable values of scaled reflectance. The parameter name contains both the material for which the parameter is used and the Landsat band(s) to which the threshold is applied. For example, the first parameter listed is THRESHOLD_WATER_BAND5_REFL, indicating that only pixels with scaled reflectance value less than or equal to 700 in band 5 will considered as covered by water. However, THRESHOLD_BURN_BAND5_REFL_MIN is a threshold for the minimum allowable value for band 5. Cloud and snow detection thresholds are applied to scaled radiance values, and are all minimum allowable values. In other words, the scaled radiance for a pixel must exceed these thresholds in order to be masked as a cloud/snow pixel.

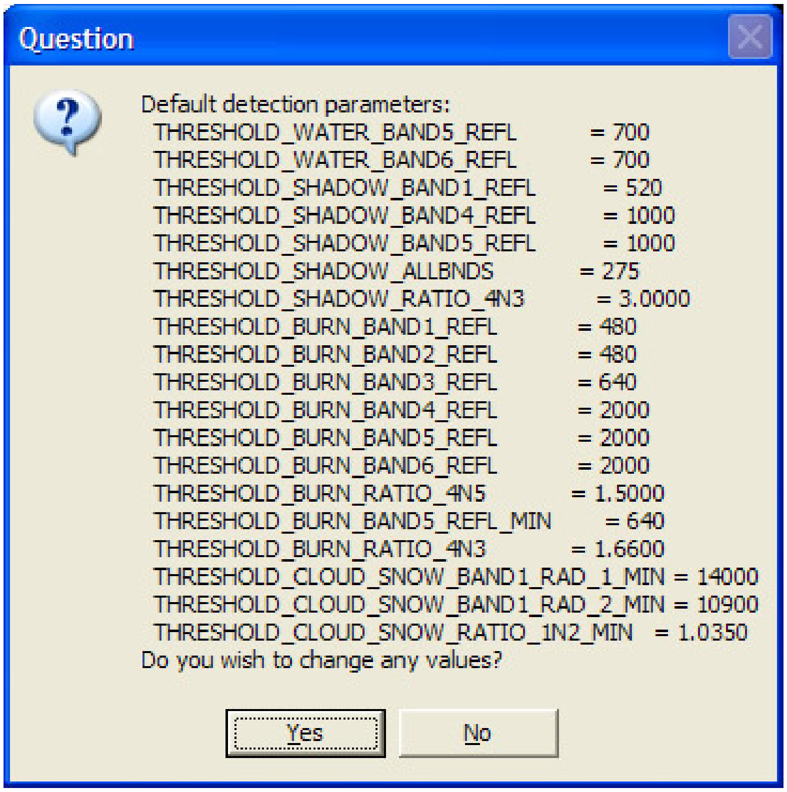

Figure 35. Material detection parameters.

In a few cases, thresholds on ratios of Landsat bands are used to detect materials, for example, THRESHOLD_SHADOW_RATIO_4N3. In this case, a pixel must have the ratio of reflectance in band 4 divided by reflectance in band 3 less than or equal to the listed value of 3.0 in order to be considered as a shadow pixel.

In the detection of water, a pixel must meet all the detection criteria, a band 5 reflectance lower than the value of the THRESHOLD_WATER_BAND5_REFL parameter and a band 6 reflectance lower than the THRESHOLD_WATER_BAND6_REFL parameter. In a similar manner, the burn class detection parameters are applied. A pixel must meet all criteria shown in figure 35. The application of the shadow detection parameters is done with two different checks of pixel values. In the first check, a pixel with reflectance values in all bands that are less than the THRESHOLD_SHADOW_ALLBNDS threshold is classified as shadow. In addition, a pixel is classified if shadow if it has reflectance values in bands 1, 4, and 5 that are below the default or user-defined thresholds, respectively, and a ratio of reflectance in bands 4 and 3 lower than the default or user-defined threshold.

The parameters for cloud and snow detection are used in two distinct detection algorithms. The first is a simple check for pixels that have radiance in band 1 that is greater than or equal to the value of the THRESHOLD_CLOUD_SNOW_BAND_1_RAD_1_MIN. If a pixel meets this criterion it is classified as a cloud/snow pixel. A separate check is done with the other cloud and snow thresholds in combination. A pixel that has a radiance in band 1 that is greater than or equal to the value of the THRESHOLD_CLOUD_SNOW_BAND_1_RAD_2_MIN detection parameter **and** a ratio of the of their band 1 divided by band 2 radiance values greater than or equal to THRESHOLD_CLOUD_SNOW_RATIO_1N2_MIN are also classified as cloud/snow. In practical terms, the THRESHOLD_CLOUD_SNOW_BAND_1_RAD_1_MIN parameter should be a value for which the user is very confident defines a radiance value that only captures cloud and snow pixels. A lower value for band 1 radiance can be set for the THRESHOLD_CLOUD_SNOW_BAND_1_RAD_2_MIN that mostly captures cloud/snow pixels, but may capture bright soils or other materials. The third parameter, the ratio of the band 1 and 2 radiance values assists in the screening of these other bright materials from being included in the cloud/snow class.

If a pixel passes all the detection criteria listed for it (fig. 35), then the mask will be set to a value identifying it as that material. Cloud/snow pixels are assigned the value of 1. Shadow pixels are given the value of 2. Water is indicated by a value of 3. Burned areas are given a value of 4 in the output mask image. If a pixel meets the criteria for more than one material, the following hierarchy is followed in assigning it a material class value, listed highest priority to lowest: cloud/snow, water, shadow, and burn area. Thus, if a pixel meets the criteria for both water and shadow, it is assigned the value of the water class because that material has priority over the shadow class. In addition, the program checks for pixels that have a no-data value of -1 in bands 3 or 4. If DESI Module 2 "Landsat Radiance to Reflectance" was used to generate the reflectance image, then no-data pixels are set properly to this value. In the output mask image, the no-data pixels are given a class value of 5. Valid Landsat pixels for which no material was detected are assigned a value 0 (zero).

Figure 36 shows an example mask file. In the ENVI classification image different colors are assigned to the different classes: cloud/snow is yellow, shadows are light blue (cyan), water is blue, burned areas are red, and no-data pixels are green. The Landsat image pixels which do not contain any mask materials are gray.

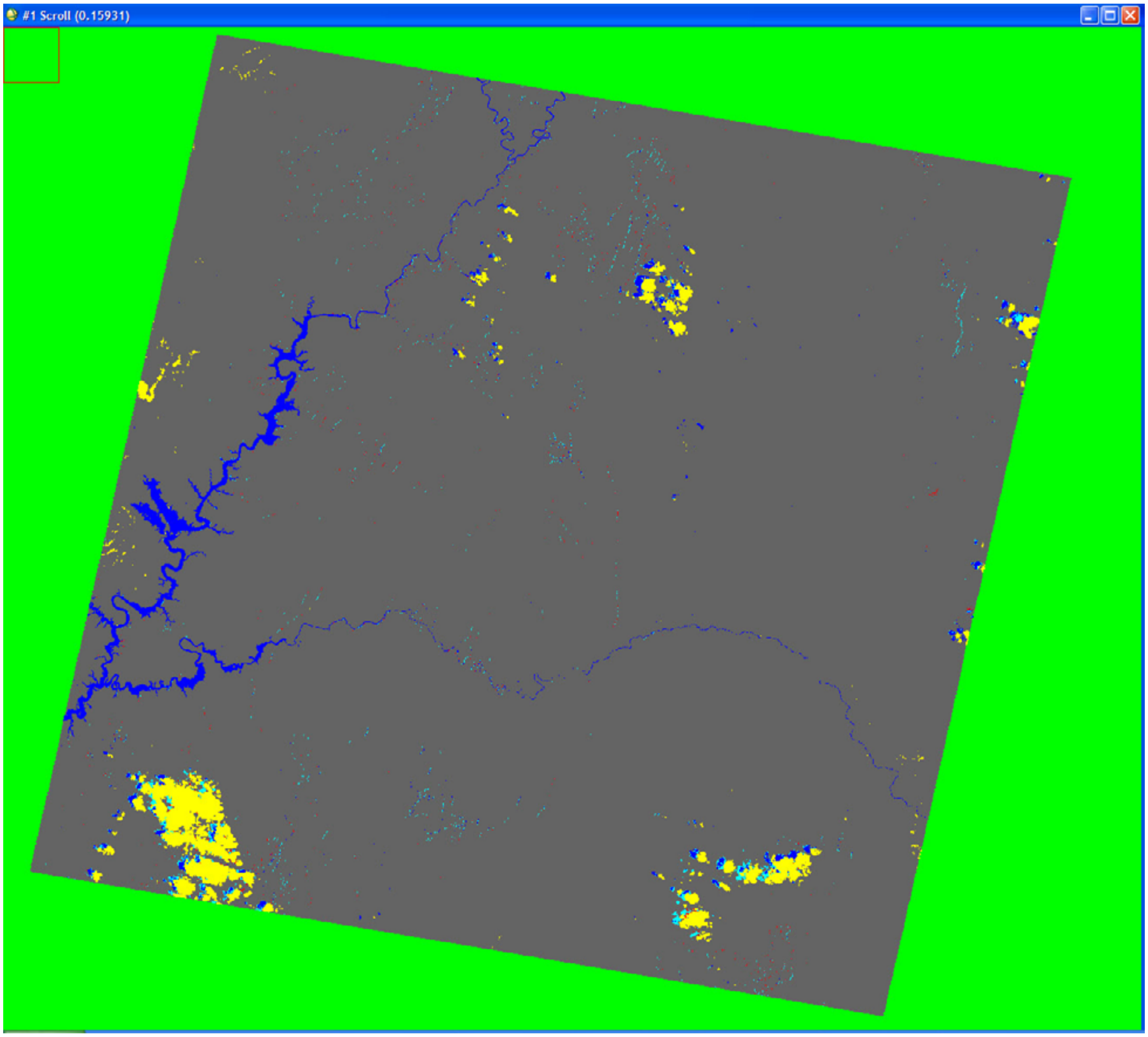

Figure 36. Material mask.

In order to assess the mask results, the user can overlay the mask classification image on the reflectance data. For example, with band 1 of the reflectance displayed (fig. 37 shows the maximized scroll window for that band), the user can click the “Overlay” menu item at the top of the band window and select the “Classification” item from the drop-down list (fig. 38).

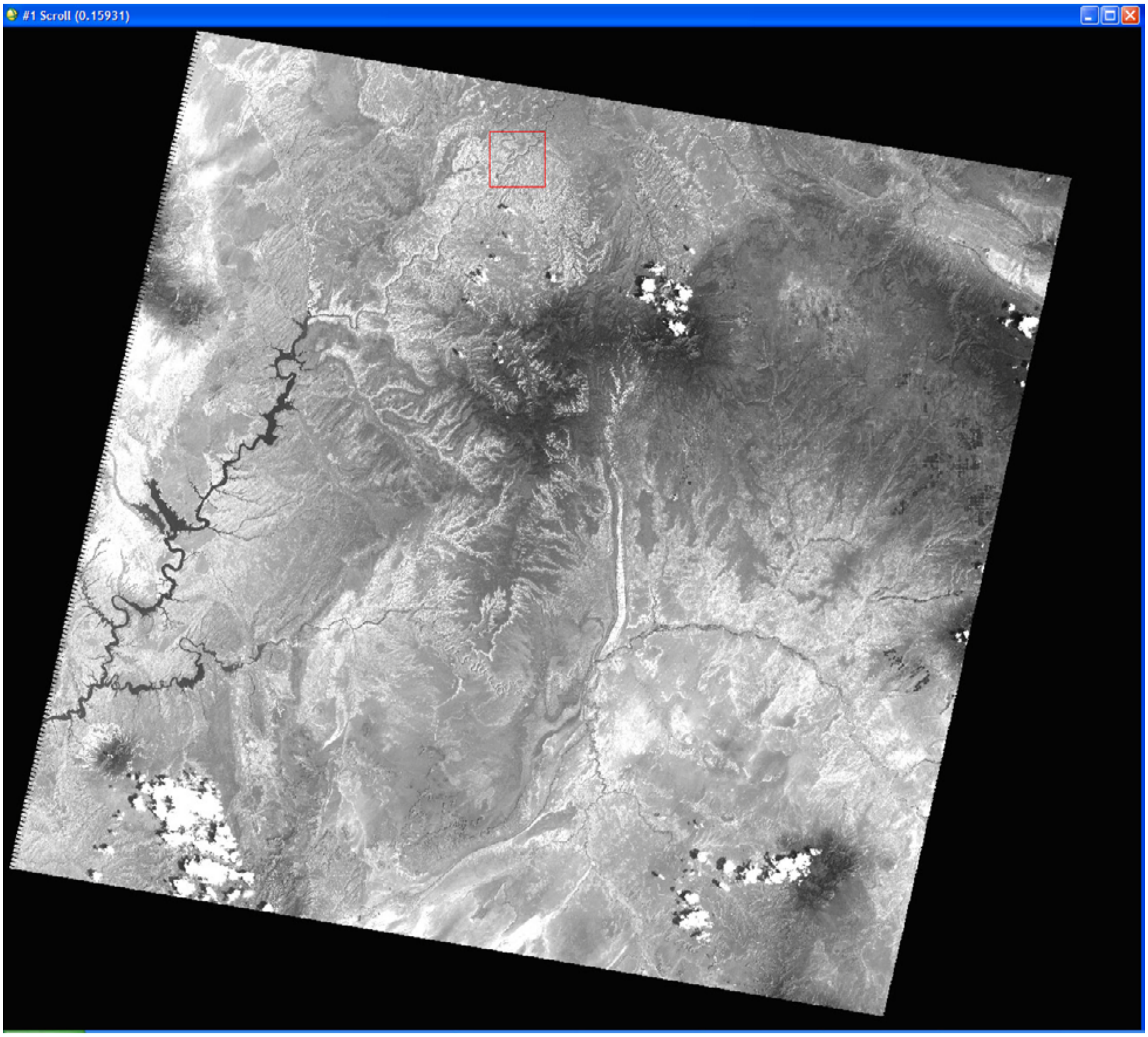

Figure 37. Band 1 of the reflectance image, scroll window.

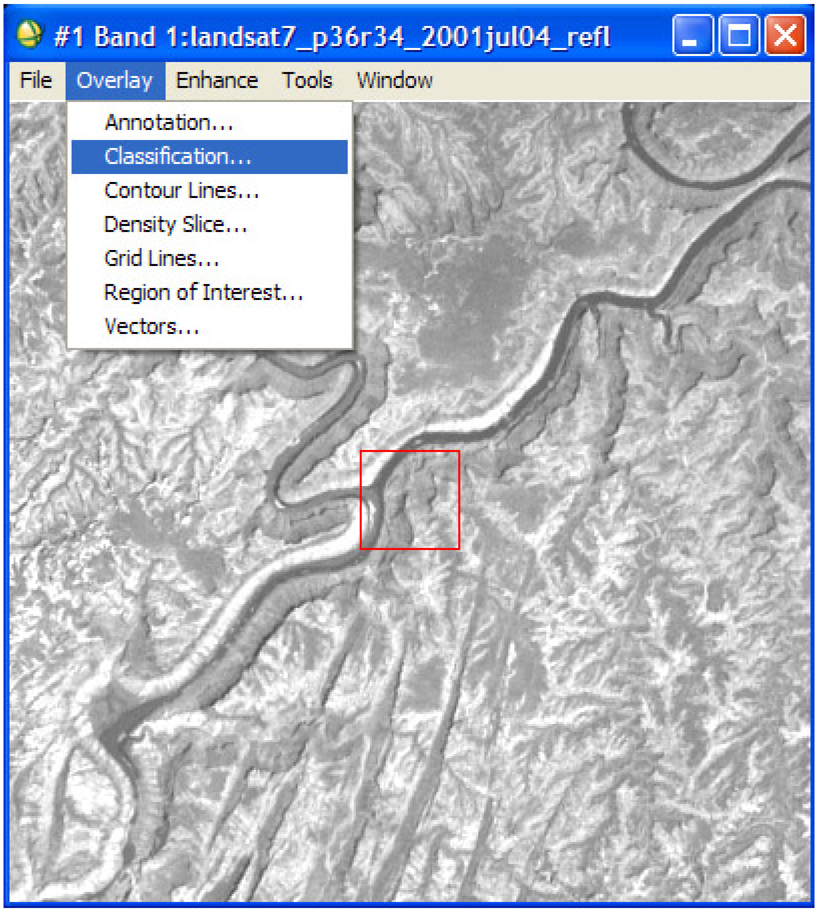

Figure 38. Overlaying the mask classification from the band window.

The user is prompted then to select the mask classification file (fig. 39). After clicking on the file, press "OK." The Interactive Class Tool window appears (fig. 40) showing the class names and colors that can be overlaid on the band image. Clicking in the check box to the left of the class color/name will toggle the class between on (overlaid on the band image) and off states.

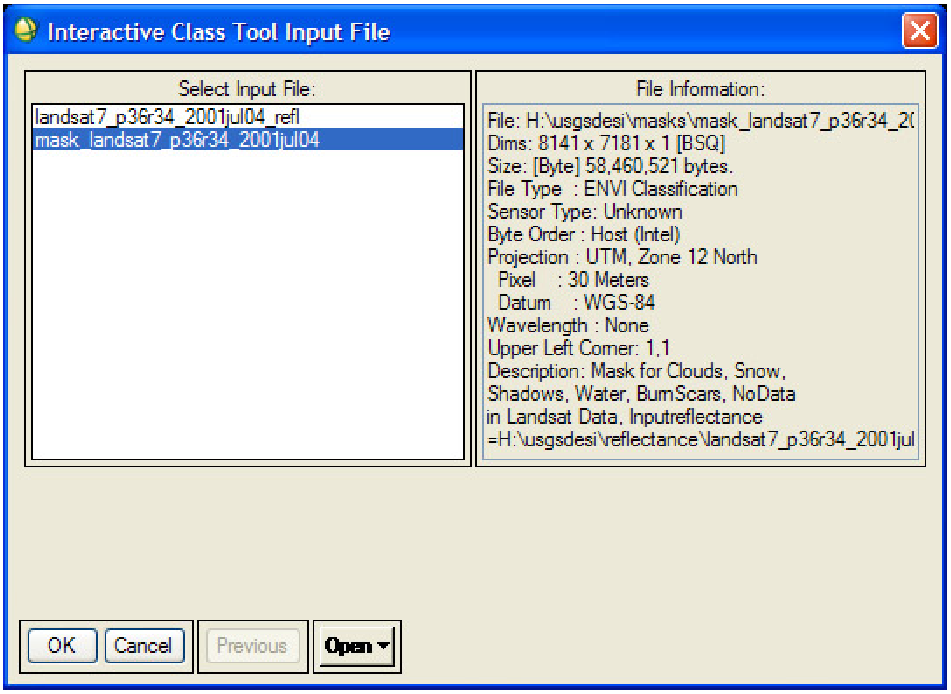

Figure 39. Selecting the mask classification file to overlay on the band.

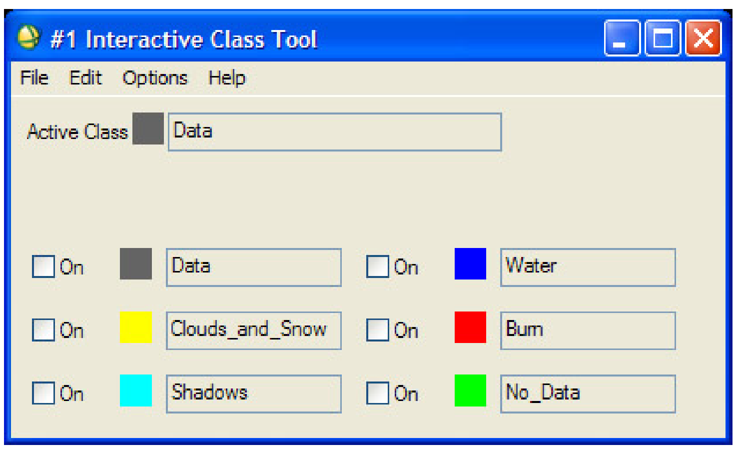

Figure 40. Interactive class tool for the mask.

Figure 41 shows the scroll window with clouds and snow, shadows, water, and burn classes overlaid on band 1 of the reflectance image.

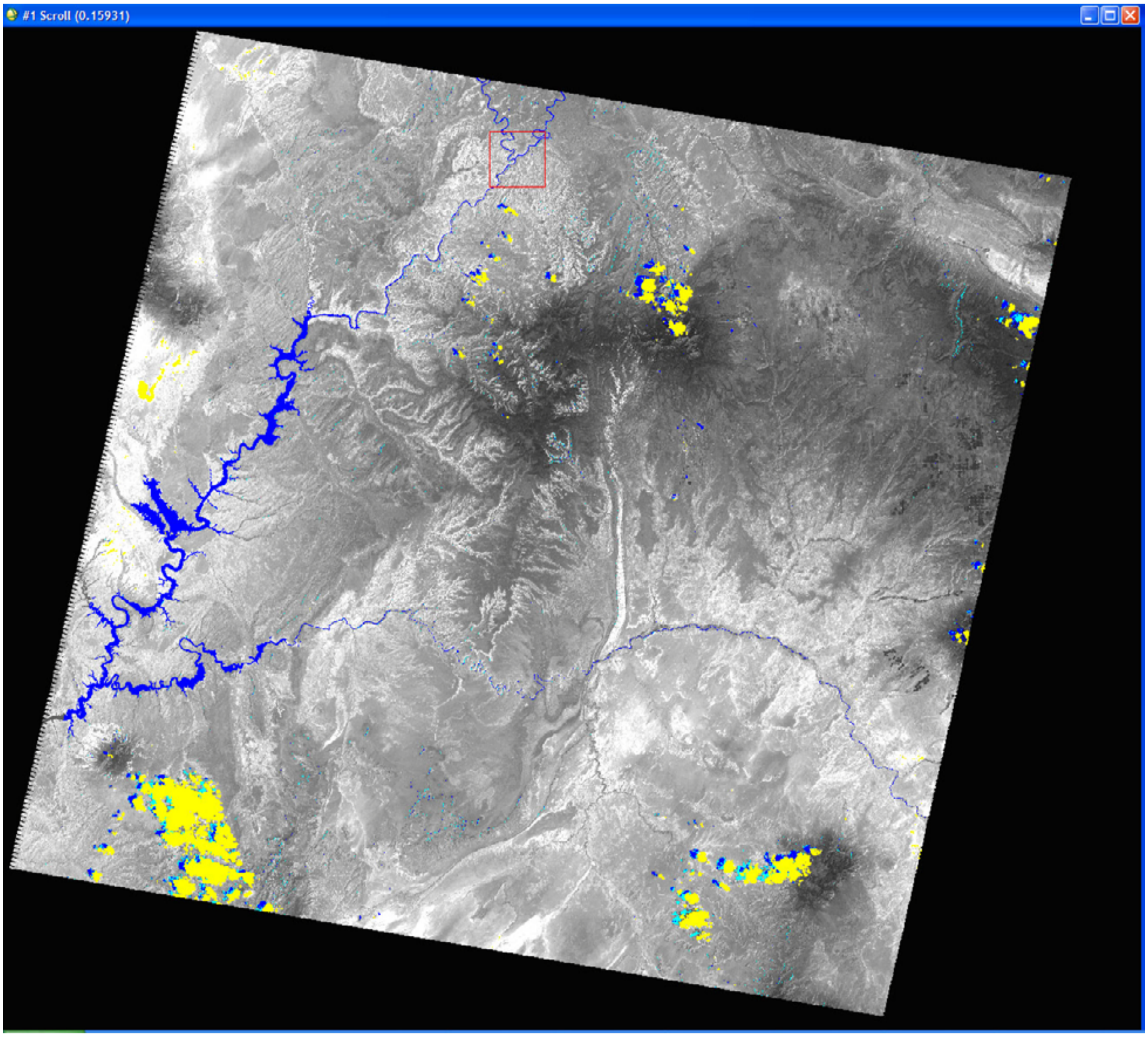

Figure 41. Scroll window showing the mask classes overlaid on the band image.

The user can use the Z-profile (spectrum) function of ENVI to examine the spectral plots and band values of pixels masked as the different materials and adjacent areas to assess the success of the mask materials (fig. 42). If materials are not detected by the mask program or many false-positive detections are made, the user can examine the spectra to determine how band thresholds should be adjusted to better capture the materials. If the user finds that resultant mask image contains errors, they can run this module again, adjusting the threshold values to work best with their Landsat imagery, see the DESI User's Guide (Kokaly, 2011) for details on entering custom threshold values.

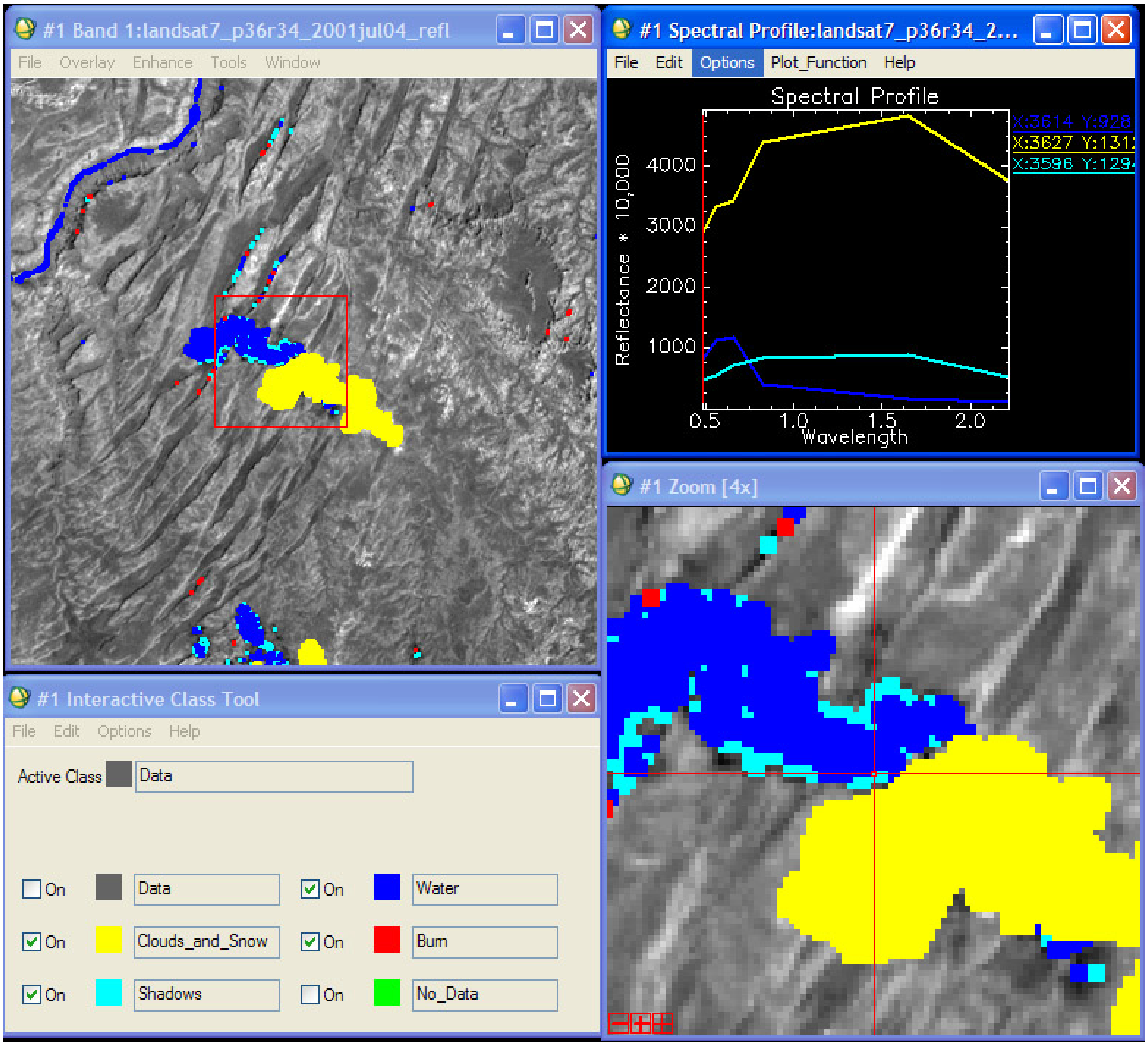

Figure 42. Spectra of pixels identified as containing mask materials.

In shadows, other dark materials often are classified (water and burn). The mask will be used to reduce false-positive detections of cheatgrass and, therefore, these misclassifications will not negatively impact the results of the cheatgrass mapping. Bright soils may be misclassified as clouds. If the Landsat early-season image shows vegetation in these areas, or cheatgrass is suspected to occur in these areas, refinement of thresholds used to detect cloud/snow is warranted. Usually, burn area pixels are sparsely classified in and around shadows. However, large clusters of pixels of the burn class, away from clouds and topographic features that would cast shadows, likely are to indicate a previously burned area (fig. 43).

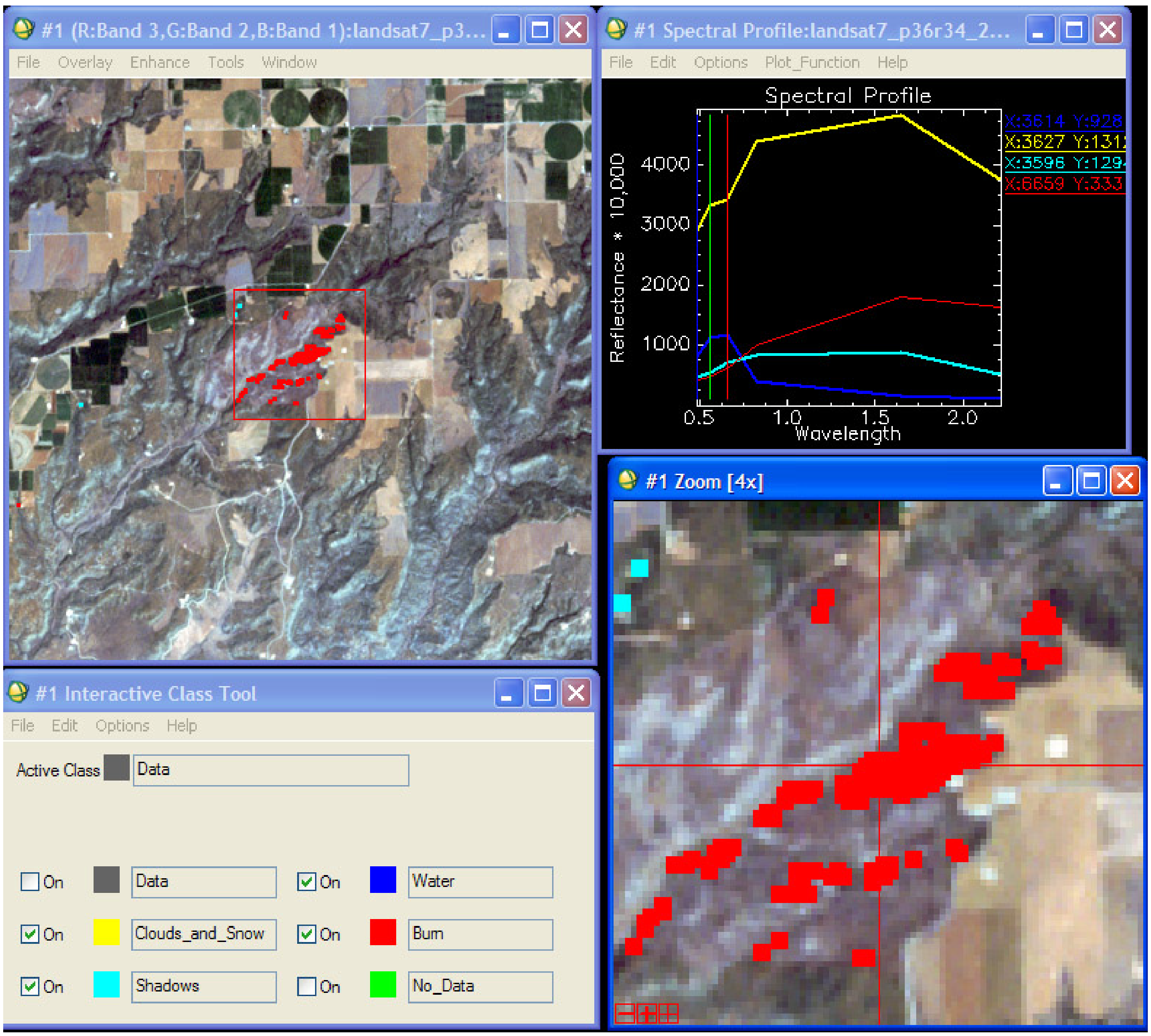

Figure 43. Pixels containing the burn class.

A log file containing information about selected files and parameters used in the creation of the mask is created by the program. Initially, the log file is written to the user's IDL temporary directory. After completion of the program, the file is copied to the directory containing the output mask image.

The ENVI header of the output mask image contains information on the input files and the threshold parameters. Appendix C shows an example listing of the information contained in an ENVI header produced by DESI for a mask file.

Checking Geographic Agreement Between Early-Season and Midsummer Images

Because DESI identifies area of potential cheatgrass infestation by differencing the mid-summer NDVI image from an early-season NDVI image, it is critical that the midsummer and early-season Landsat images geographically are consistent. In current distributions of Landsat data, the geometric correction and geodetic location of pixels are most accurate for Standard Terrain Correction (Level 1T) products. Generally, if early-season and midsummer images are Level 1T corrected, the pixels are located to within one pixel (30 meters) of one another. If one or more of the images have been processed at lesser levels of correction (Systematic Terrain Correction, Level 1Gt, and Systematic Correction, Level 1G), the user should examine the geometric agreement in the images.

The geometric consistency between early-season and midsummer images may be checked by displaying the true-color composite for both and doing a geographic link. To display both images, press the "Display #1" button to the right of the "Load RGB" button after displaying bands 3, 2, and 1 from first image (as R, G, B, respectively) and select the "New Display" item (fig. 44). Then, select the three bands to display from the second image and press the “Load Band” button. The second image appears in new band, scroll, and zoom windows (fig. 45).

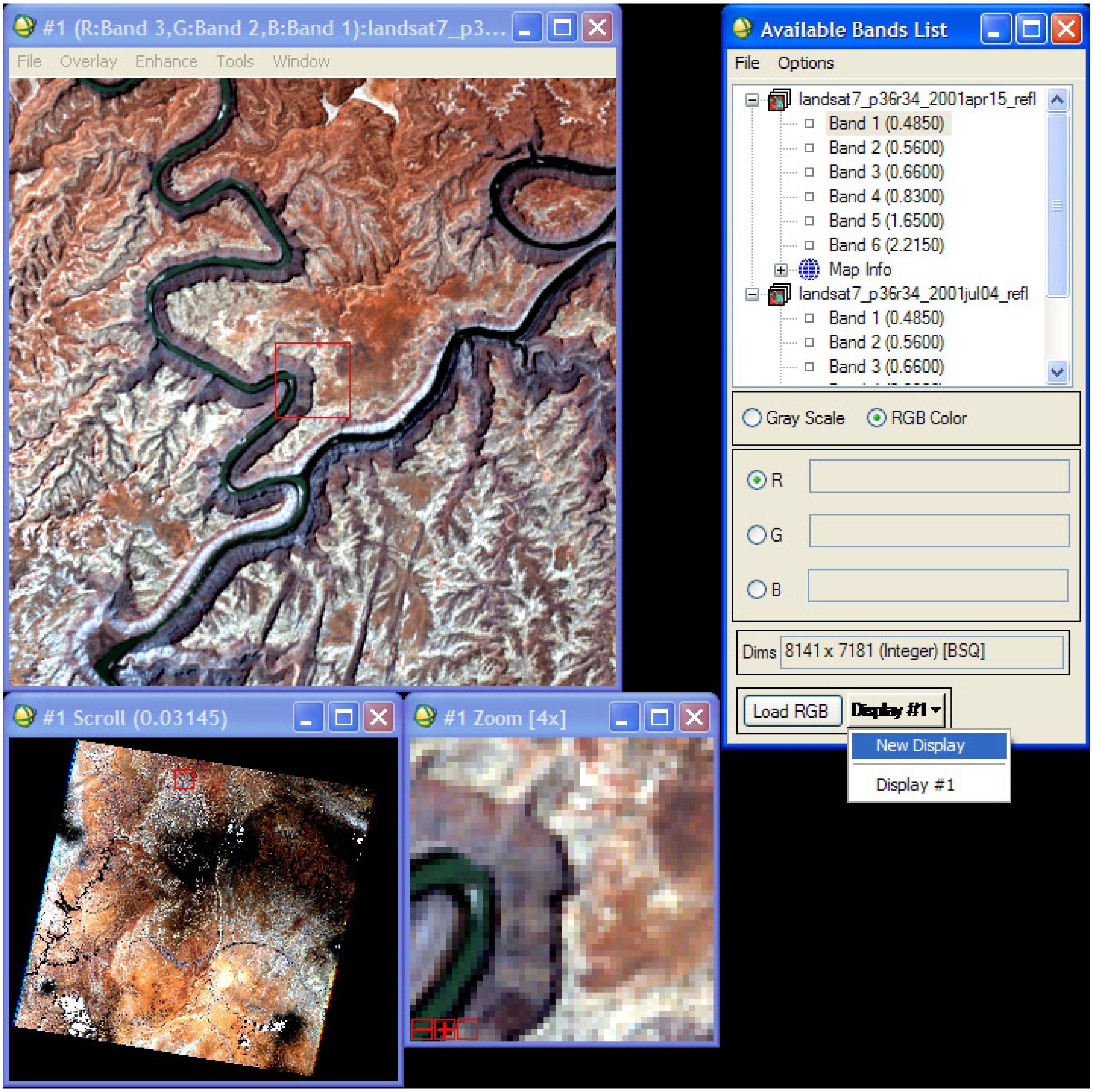

Figure 44. Selecting a new display for the second image.

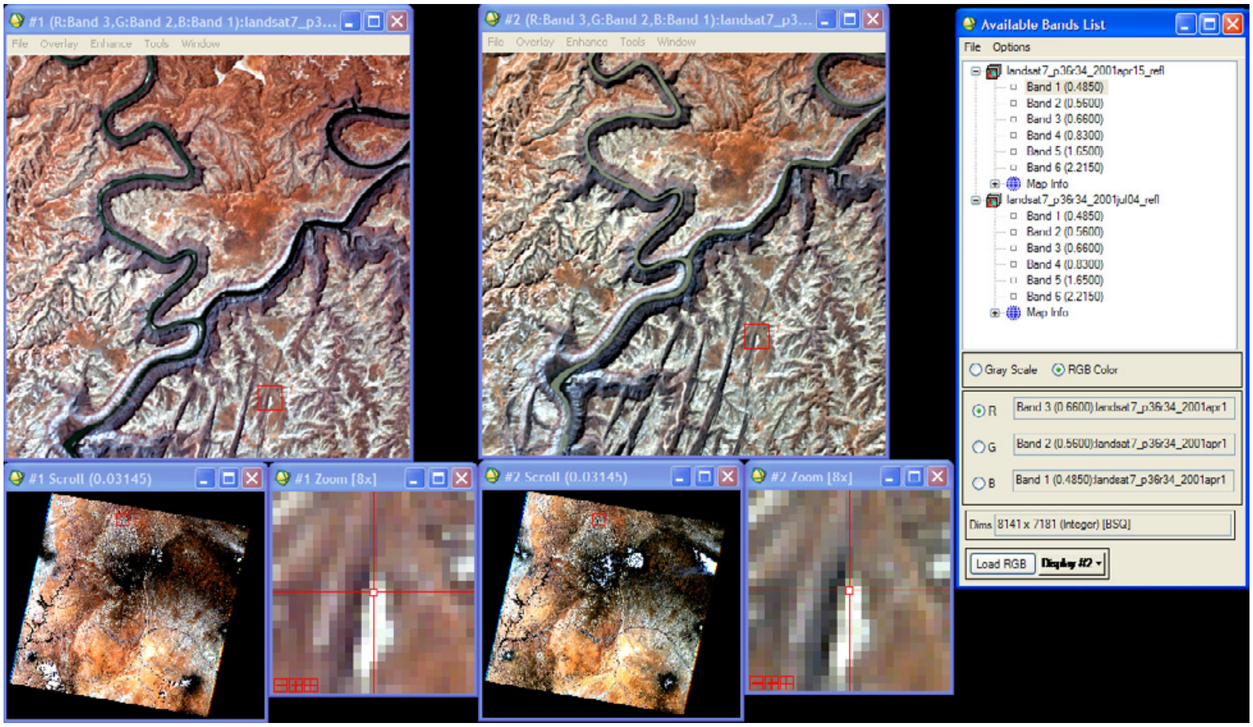

Figure 45. Midsummer and early-season Landsat images displayed in ENVI.

The images can be linked by selecting the “Tools” menu item in one of the band windows and choosing the “Link” option and then clicking on the “Geographic Link” item in the drop-down list (fig. 46).

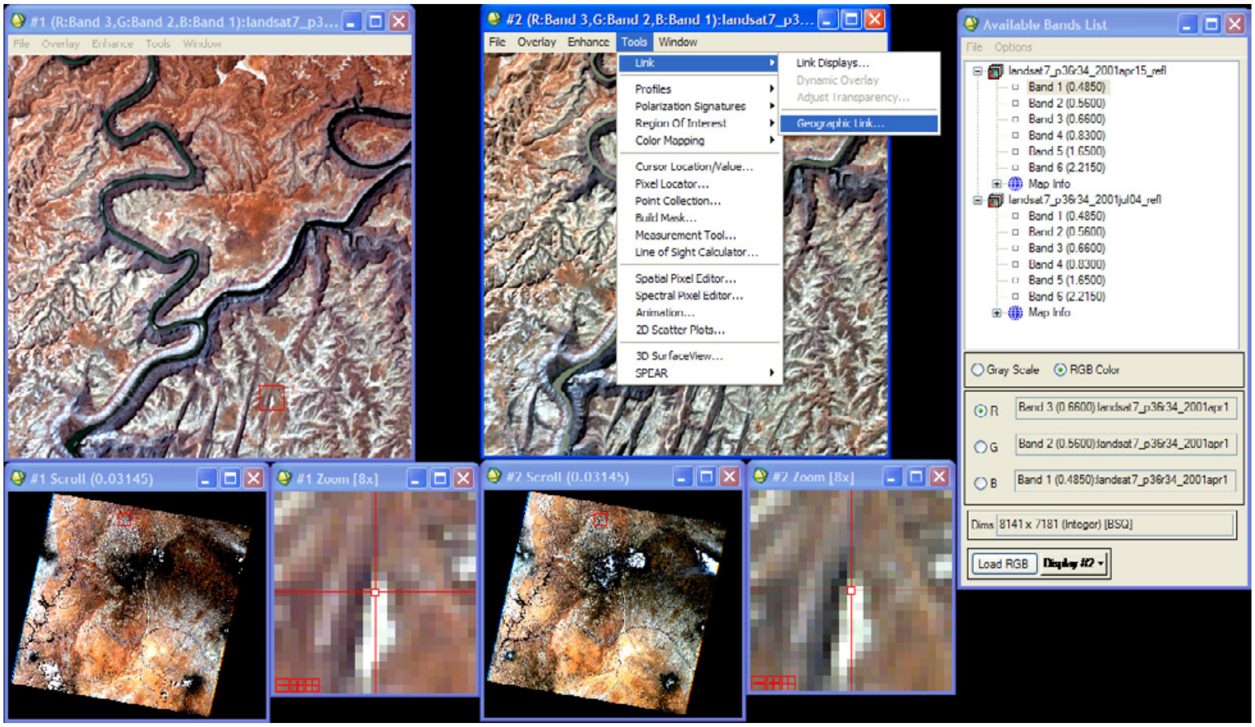

Figure 46. Initiating the geographic link.

A window appears in which the user can toggle on and off the displays which will be linked, turn both on (fig. 47). Click "OK" after the displays are turned on.

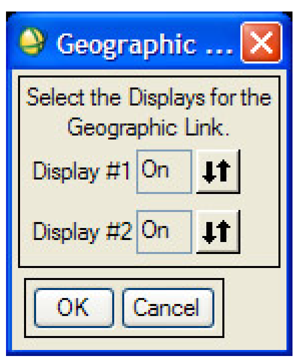

Figure 47. Turning on the geographic link.

With the images linked, the user can display different parts of the Landsat images and examine the zoom images to see that the pixels match in the two windows. To display red crosshairs on the central pixel in the zoom window, click on the red open square in the bottom left of each zoom window. To magnify the image in the zoom window, click on the red plus-sign (+) in the window. For Level 1T data, the pixels usually will appear to match exactly in the two zoom windows, unless clouds, snow, or vegetation has changed between the dates of the imagery. It is best to check the geographic agreement using roads, geologic features, or other static items.

If the images show disagreement in the pixel locations, the user should warp one image to match the other. ENVI has tools to perform simple 1st order polynomial warps by selecting ground control points in the two images, see the ENVI User's Manual for details (ITT Visual Information Solutions, 2009). The radiance and reflectance images of the midsummer data should be warped to the early-season imagery, using the nearest-neighbor resampling method. All subsequent steps of the DESI procedures for cheatgrass mapping, including the calculation of NDVI, the generation of masks, and so on, should be derived from the warped radiance and reflectance data.

The user should be aware that although there might appear to be good visual correspondence, there could be some offset at the subpixel level (less than the 30-m pixel size) which causes the midsummer image to be measuring slightly different area of ground compared to the early-season image. The effect of subpixel offsets could be large in heterogeneous terrain, such as semiarid regions where vegetation and rock outcrops are patchy. To account for any slight mismatch, the cheatgrass detection module performs a spatial filtering so that single pixel detections are removed and two pixel detections are characterized with a different value, allowing the user to apply the cheatgrass maps in a manner consistent with their evaluation of the geometric agreement in the two image dates.

Calculating NDVI

The normalized difference vegetation index (NDVI) can be calculated from the reflectance (R) values in red and near-infrared (NIR) bands of the Landsat TM and ETM sensors.

$$NDVI = (R_{NIR} - R_{red}) / (R_{NIR} + R_{red})$$

High NDVI values indicate the presence of abundant green vegetation. Low NDVI values indicate a low fraction of or absence of green plants on the surface. The band positions of Landsat sensors in the reflected solar portion of the electromagnetic spectrum are shown in table 1. Landsat bands 3 and 4 are the red and near-infrared bands, respectively, used in the NDVI calculation.

$$NDVI = (R_{Band4} - R_{Band3}) / (R_{Band4} + R_{Band3})$$

Because NDVI is a commonly computed index, ENVI includes a function for computing NDVI using Landsat data. The user should first open the reflectance image from which the NDVI image will be computed. A file can be opened from the ENVI Available Bands List window (fig. 9) by clicking the “File” item on the window’s menu bar and selecting the “Open Image File” item from the drop-down list. A selection window appears in which the user can select the file(s) to open. Click the “Open” button after selecting the file(s).

After opening the reflectance file, the filename and the bands contained in it will appear in the Available Bands window. The NDVI calculation can be started by clicking on the “Transform” item on the main ENVI menu bar. Select the “NDVI” item from the drop-down list (fig. 48).

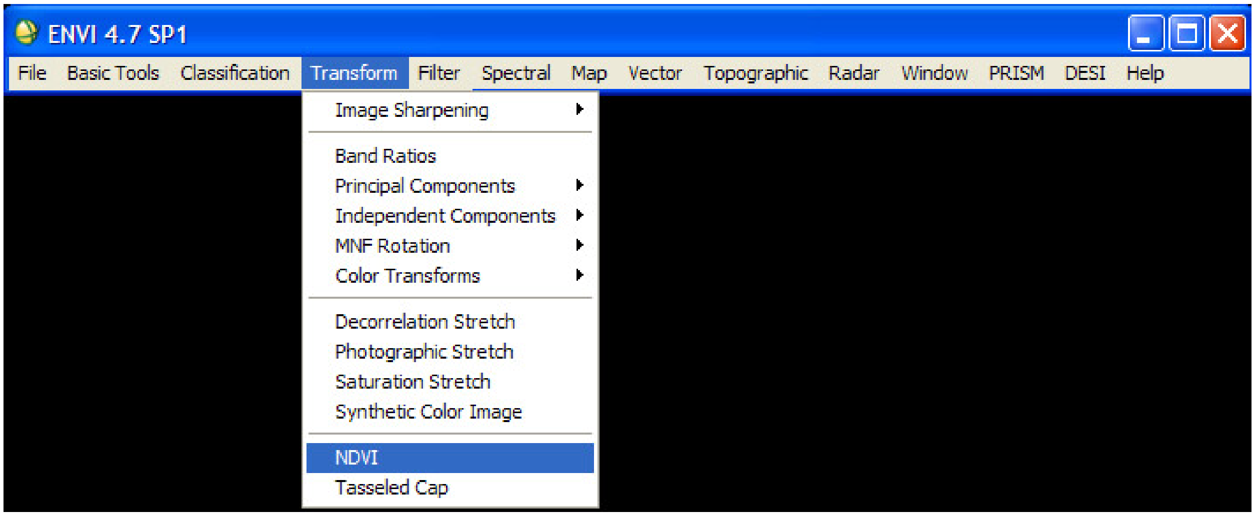

Figure 48. Starting the NDVI calculation.

A window appears asking the user to select the file on which to perform the NDVI calculation (fig. 49). Select the appropriate reflectance image and click "OK" to continue the program.

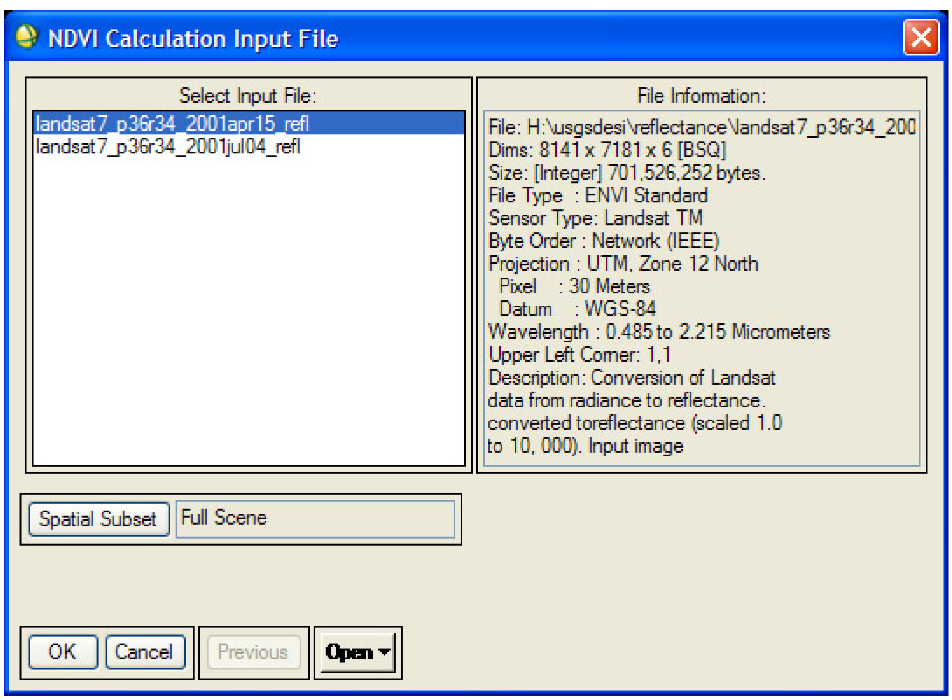

Figure 49. Selecting the file on which to perform the NDVI calculation.

Next, the user is prompted to set the calculation parameters and the output filename (fig. 50). The reflectance image computed by DESI encodes the sensor type as "Landsat TM" in the header and, as a result, the red and NIR bands are set correctly to bands 3 and 4, respectively. The output data type should be floating point. The user should set the output filename and click "OK" to continue the program.

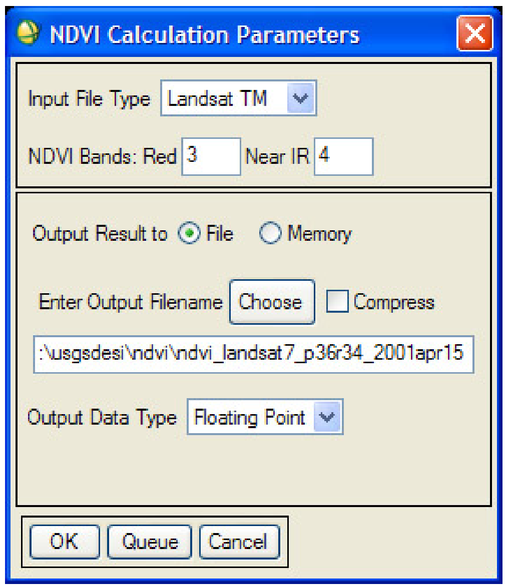

Figure 50. Selecting the file on which to perform the NDVI calculation.

The NDVI calculation will be performed and the NDVI image will be listed in the available bands list (fig. 51). The user should calculate NDVI for both the early-season and the midsummer image.

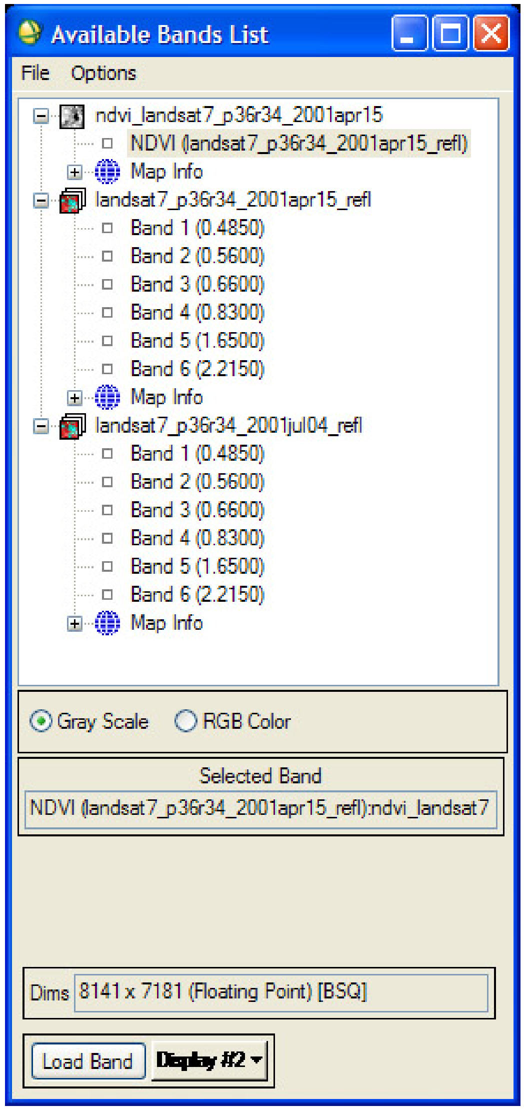

Figure 51. Available bands list showing the NDVI image.

Table 2 shows the NDVI values for pixels of water, rock/soil, green riparian vegetation, dry vegetation, sparse vegetation, shadowed terrain, and clouds that were shown in figure 34.

Table 2. NDVI values for different materials.

Material	NDVI value
Water	-0.435
Rock/soil	0.129
Green riparian vegetation	0.521
Dry vegetation	0.171
Sparse vegetation	0.467
Cloud	0.273

Calculating dNDVI

To calculate dNDVI from the early-season and midsummer images, the user must first reconcile the images to the same pixel dimensions and geographic locations. In other words, the images must be resampled to a common image grid. This can be done using the ENVI "Layer stack" function. To start the layer stack process, press the "Map" item on the main ENVI menu bar. Select the "Layer stacking" item from the drop-down list (fig. 52).

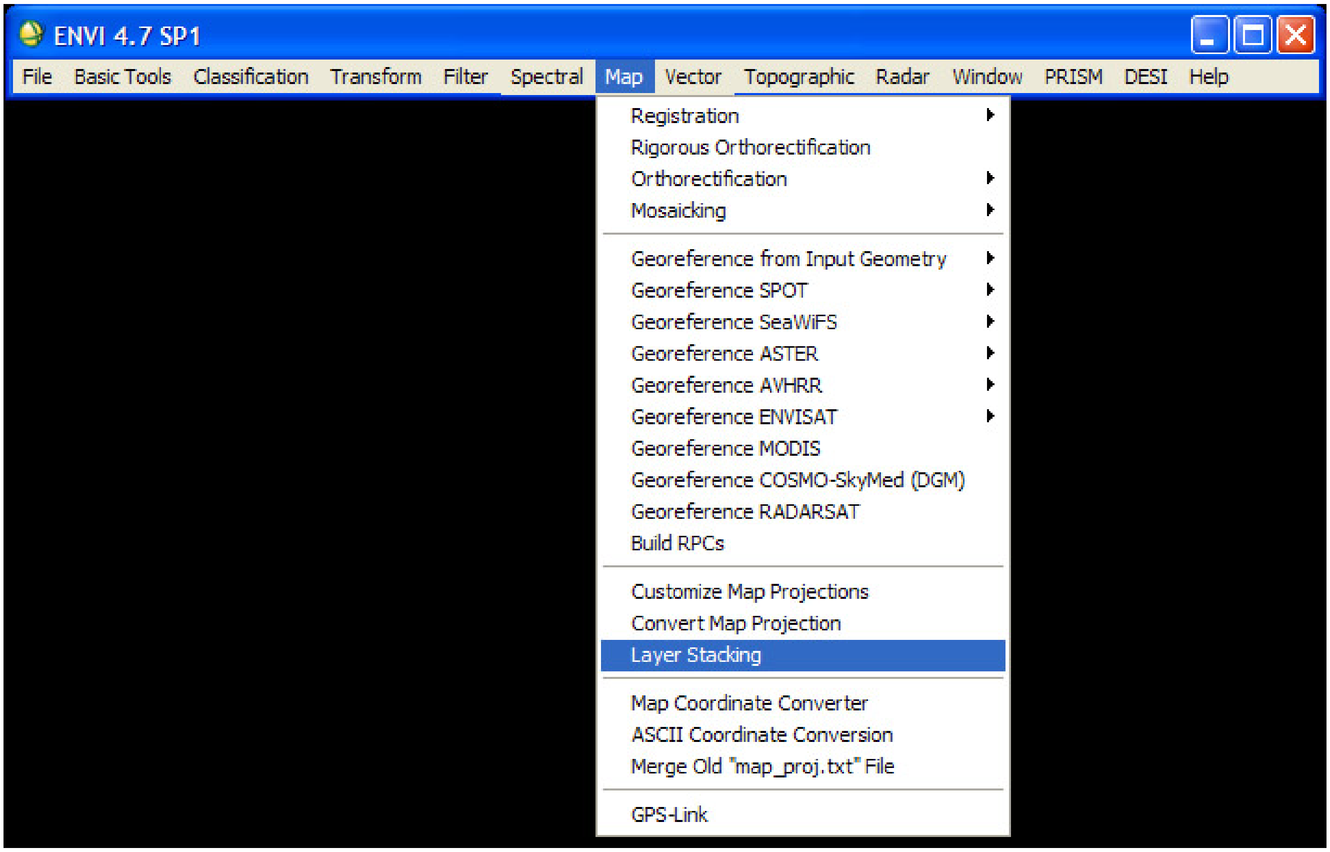

Figure 52. Starting the ENVI layer stack function.

The "Layer Stacking Parameters" window appears (fig. 53). To add the NDVI images, press the "Import File…" button on the left side of the window. A list of the files already opened in ENVI will appear (fig. 54). Choose the early-season NDVI image. Click "OK" to continue. The file will appear in the Layer Stacking Parameters window.

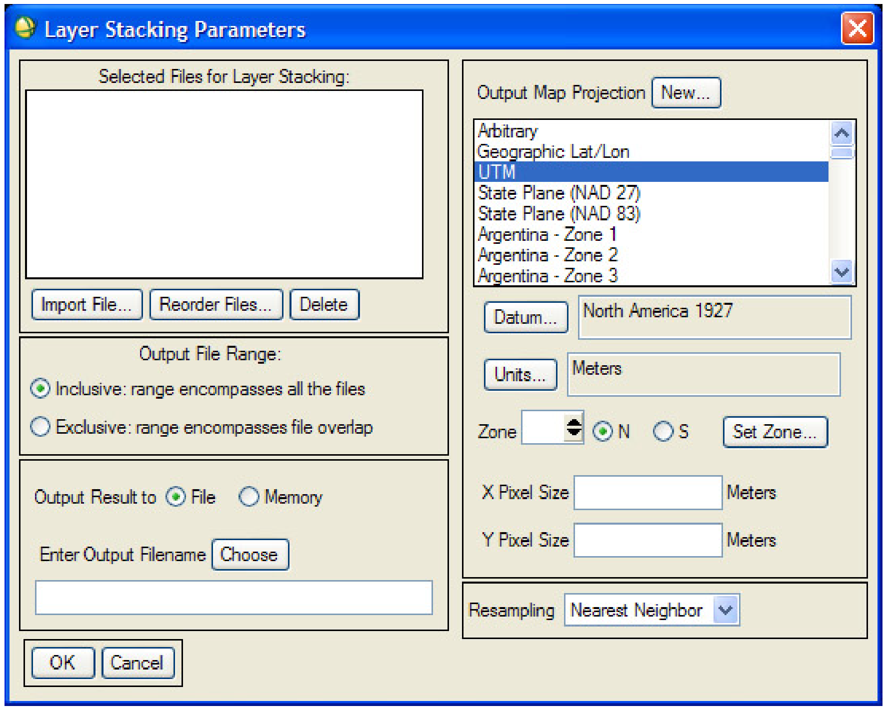

Figure 53. The Layer Stacking Parameters window.

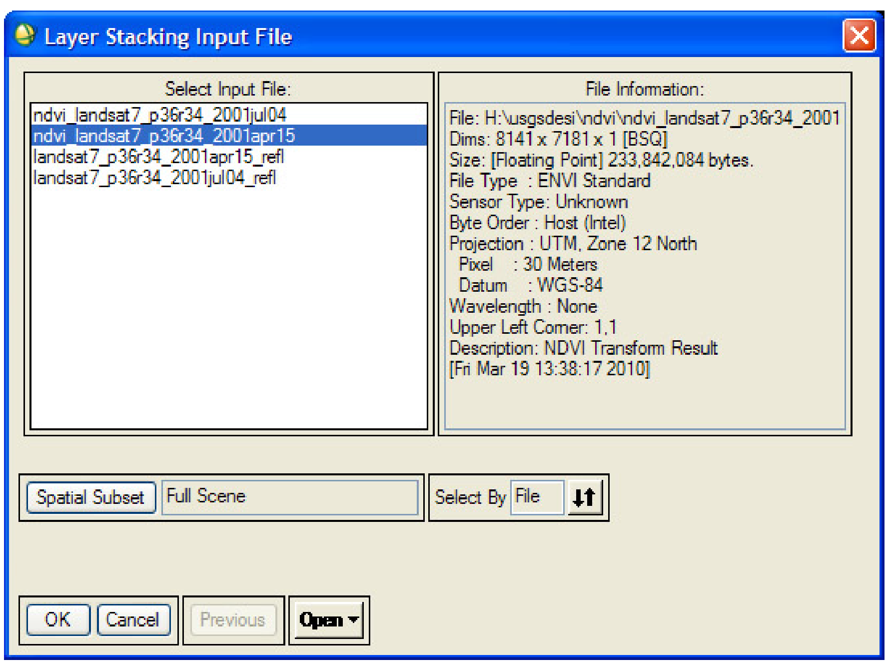

Figure 54. Selecting an input file for the layer stack.

Click the “Import File…” button again. Choose the midsummer NDVI image from the file list and click “OK” to continue. Both images will appear in the Layer Stacking Parameters window (fig. 55).

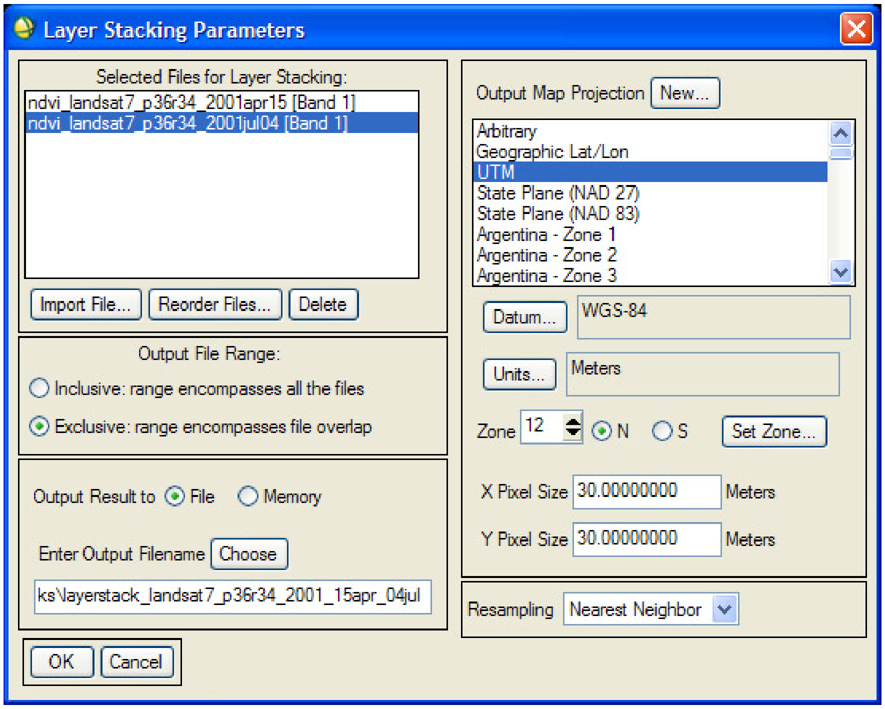

Figure 55. Layer stacking parameters for the NDVI layer stack.

Select the “Exclusive: range encompasses file overlap” button on the left side of the window, below the file list (fig. 55). Set the output file directory and filename for the layer stack file. Press “OK” to perform the layer stacking.

The ENVI band math function will be used to calculate the dNDVI image, using the NDVI bands in the layer stack. To start the band math function, click on the “Basic Tools” option on the main ENVI tool bar and click on the Band Math item (fig. 56).

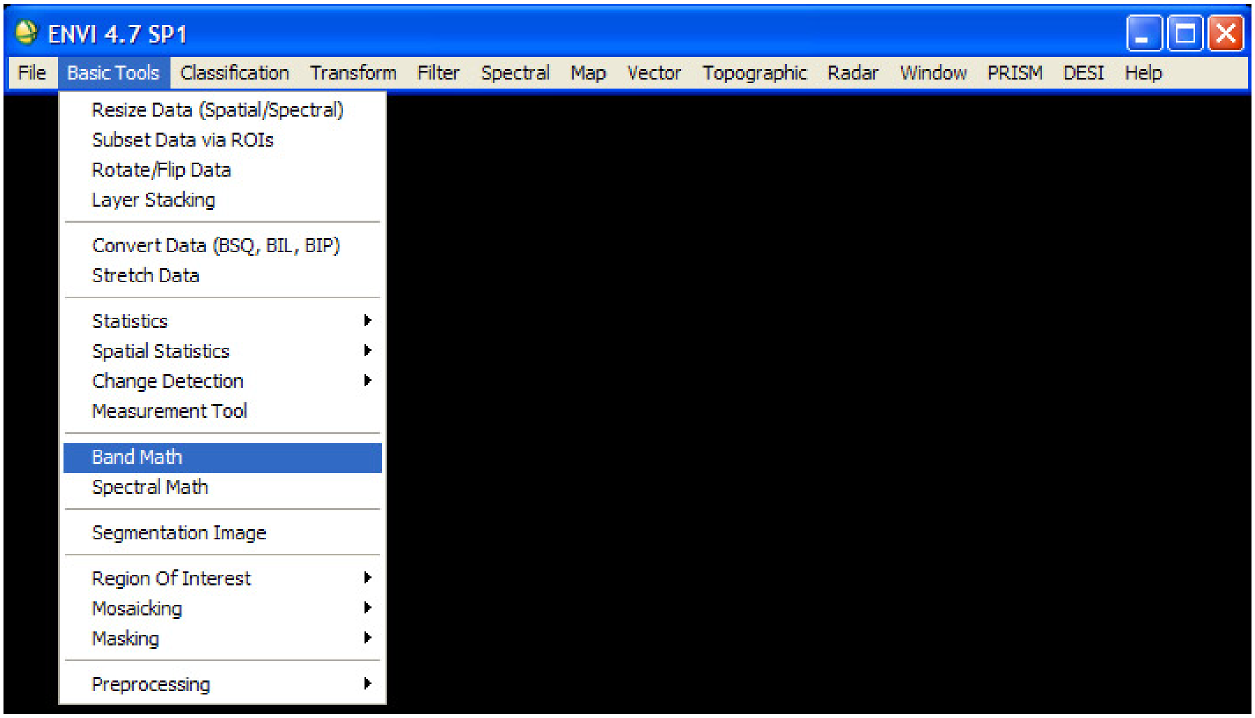

Figure 56. Starting the ENVI band math function.

The user is prompted to enter a math expression (fig. 57). Simple mathematical operators are represented with +, -, *, and / symbols for addition, subtraction, multiplication and division, respectively. Bands to be used in the expression are designated with the letter “b” followed by a number, for example, “b1” for the first band to use in the expression, “b2” for the second band, and so on. An expression to subtract one band from another is entered as “b1-b2” as shown in Figure 57. The user may press the “Add to List” button to store the expression for later use in the ENVI session. Press “OK” to continue the function and assign bands to the b1 and b2 designators.

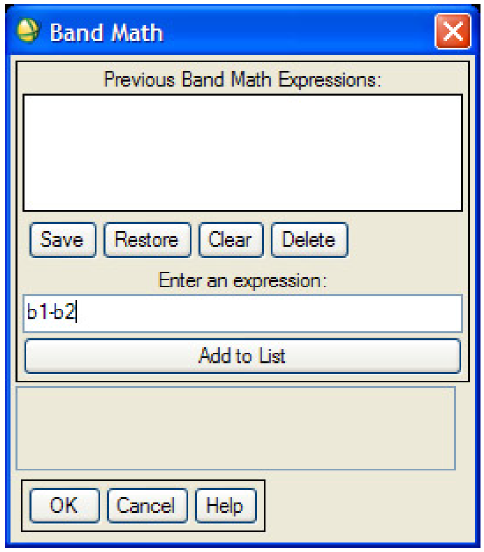

Figure 57. Entering the band math expression for the difference NDVI.

A window appears in which the user can assign bands from files opened in ENVI to the band designators in the entered expression (fig. 58). Assign the early-season NDVI image to "b1" by clicking on "B1 – [undefined]" in the "Variables used in expression" list at the top of the window. Proceed by clicking on the early-season NDVI image, which is the first band of the layer stack file, in the "Available Bands List."

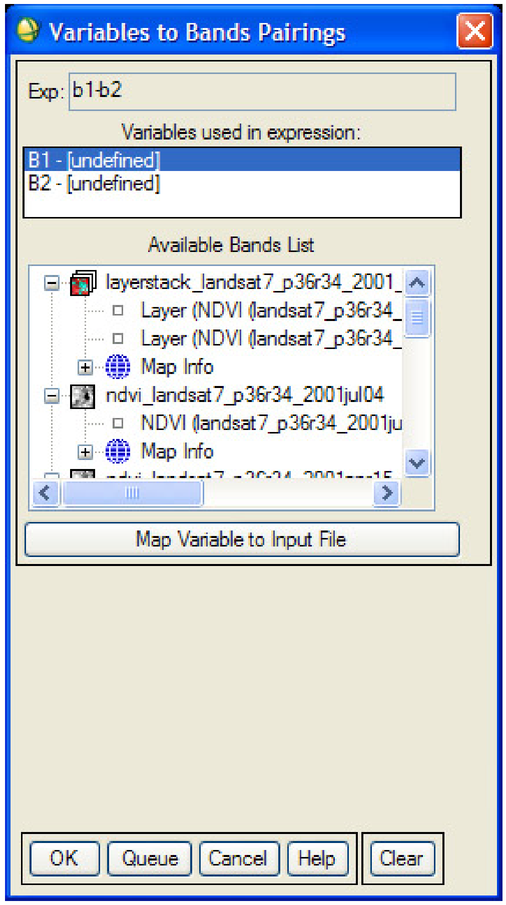

Figure 58. The Variable to Band Pairings window.

The Available Bands List area will update and only show the files that have the same pixel dimensions (lines and samples) as the B1 band (fig. 59). Assign the midsummer NDVI image to “b2” by clicking on “B2 – [undefined]” in the “Variables used in expression” list. Then, click on the midsummer NDVI image, which is the second band of the layer stack file, in the “Available Bands List.”

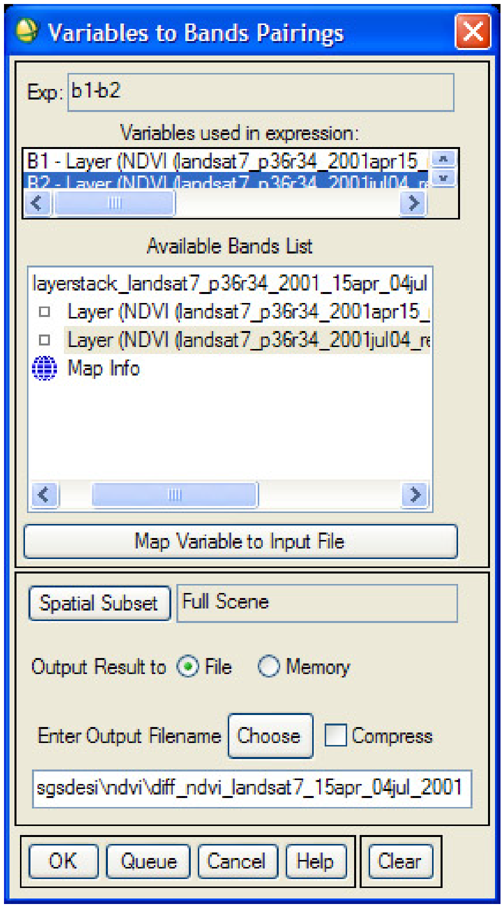

Figure 59. Parameters for the band math to calculate the dNDVI image.

Press "OK" to continue the program. The dNDVI image will be calculated and stored into the output file.

Creating and Evaluating the Cheatgrass Maps

The DESI "Landsat Cheatgrass Detection" module identifies pixels which likely are to contain cheatgrass and/or other early-season invasive plants. The detection module processes an input layer stack file containing five bands including the early-season and midsummer Landsat NDVI images, the difference NDVI image, and the early-season and midsummer masks, as shown in table 3.

Table 3. Description of layer stack file contents.

Layer stack band	Description of band contents
1	NDVI image calculated from the early-season imagery
2	NDVI image calculated from the midsummer imagery
3	dNDVI (early-season – midsummer)
4	Mask created from the early-season imagery
5	Mask created from the midsummer imagery

To create the layer stack file, open the five files listed in table 3. A file can be opened from the ENVI Available Bands List window by clicking the “File” item on the window’s menu bar and selecting the “Open Image File” item from the drop-down list. A selection window appears in which the user can select the file(s) to open. After the five files have been opened, the ENVI layer stacking function can be used to composite all files into a single file, with pixels rectified to the same geographic locations. The layer stacking procedure detailed in section “Calculating difference NDVI” of this report can be used as a guide in creating the layer stack for the five files in table 3.

For step-by-step instructions on how to run the module, see the DESI User’s Guide (Kokaly, 2011). During the execution of the cheatgrass detection module, the user is shown a list of the threshold values used in detecting cheatgrass (fig. 60).

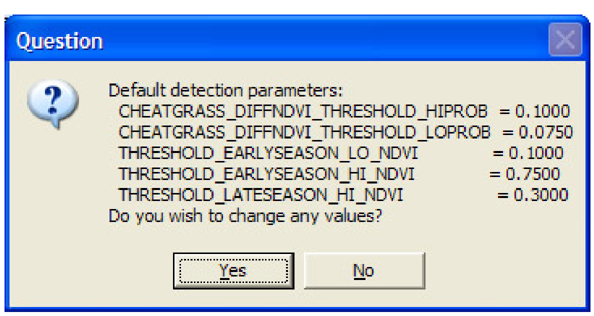

Figure 60. Cheatgrass detection parameters.

The window prompts the user whether they wish to change any of the detection parameters (fig. 60). If they press “No” these default values will be used. It is suggested that the defaults be used initially. For details on how to change the thresholds, see the DESI User’s Guide (Kokaly, 2011).

If after running the DESI cheatgrass module with the default thresholds, the user finds that the resultant cheatgrass map needs adjustment, they can run the module again, adjusting the thresholds to work best with their Landsat imagery. The DESI User’s Guide (see Kokaly, 2011) explains each parameter and how to set custom values. The threshold values are stored in the headers of the cheatgrass maps (see Appendix D).

The remainder of this section of this report discusses the output images of the DESI cheatgrass module. Furthermore, it describes how the user can examine and link the Landsat data, NDVI images, and outputs of the DESI cheatgrass module in order to evaluate the cheatgrass map and determine threshold adjustments.

The cheatgrass detection module initially produces two output files, a segmented classification version of the dNDVI band, and an initial cheatgrass map. To remove false-positive detections of cheatgrass that might arise from spatial disagreement in the location of pixels between the early-season and mid-summer images, the two spectral classes of cheatgrass in the initial map are combined and spatially filtered at several levels (using the ENVI sieve functions, see ITT Visual Information Solutions, 2009). Next, a summary map of the spatially-filtered cheatgrass is created with four classes of cheatgrass detection. A final map is produced by applying the early-season and midsummer masks to make a spatially-filtered and masked map of cheatgrass. Table 4 lists the various output files created by the DESI cheatgrass module. The program prompts the user to define the filenames of the dNDVI classification image and the initial map of cheatgrass. The other filenames are automatically derived from the filename of the initial cheatgrass map (see table 4).

Table 4. Files created by the DESI cheatgrass module.

Filename	Example filename	Description of file contents
User-set	index_diff_ndvi_l7_2001	Classification image of difference NDVI
User-set	cheatgrass_l7_2001	Initial map of cheatgrass detection (two classes, high and low "spectral-probability" cheatgrass)
User-set cheatgrass + "_combined"	cheatgrass_l7_2001_combined	Cheatgrass map with two classes combined into a single class
User-set cheatgrass + "combined_sieve2-8"	cheatgrass_l7_2001_combined_sieve2-8	Combined classes, sieved 2-8. Any pixel for which none of the 8 adjacent pixels are classified as cheatgrass is removed.
User-set cheatgrass + "combined_sieve3-8"	cheatgrass_l7_2001_combined_sieve3-8	Combined classes, sieved 3-8. Any pixel for which only 1 of the 8 adjacent pixel is classified as cheatgrass is removed.
User-set cheatgrass + "_filtered"	cheatgrass_l7_2001_filtered	Spatially-filtered map of cheatgrass detection. Five classes (see classes 1-5 in table 5).
User-set cheatgrass + "_filtered_masked"	cheatgrass_l7_2001_filtered_masked	Masked, spatially-filtered map of cheatgrass detection. Six classes (see table 5).

The final, filtered and masked, cheatgrass map is an ENVI classification image with six classes (see table 5).

Table 5. Classes in spatially-filtered and masked cheatgrass map.

Pixel value[1]	Class color	Class name (explanatory comments)
0	Black	Pixel_not_valid (masked pixels)
1	Gray	Not_classified_as_cheatgrass (pixel in which cheatgrass was not detected or in which cheatgrass was detected but none of the 8 neighboring pixels contains cheatgrass; note that this class is colored black in the spatially-filtered cheatgrass map)
2	Blue	Cheatgrass_Lower_Probability_Spectral_and_Spatial (pixels which have a dNDVI above the low probability threshold but below the high probability threshold and only 1 of the 8 neighboring pixels contains cheatgrass)
3	Green	Cheatgrass_Lower_Probability_Spatial (pixels which have a dNDVI above the high probability threshold and only 1 of the 8 neighboring pixels contains cheatgrass)
4	Orange	Cheatgrass_Lower_Probability_Spectral (pixels which have a dNDVI above the low probability threshold but below the high probability threshold and more than 1 of the 8 neighboring pixels contains cheatgrass)
5	Red	Cheatgrass_High_Probability (pixels which have a dNDVI above the high probability threshold and more than 1 of the 8 neighboring pixels contains cheatgrass)

[*] Note: in the spatially-filtered cheatgrass map, the first class is not included and classes 1 to 5 have pixel values of 0 to 4.

Figure 61 shows how the initial cheatgrass map compares to the filtered and filtered/masked cheatgrass maps in relation to the same area of the early-season Landsat image. In the spatially-filtered cheatgrass map, single-pixel detections of cheatgrass (pixels in the high and low spectral probability classes) are reclassified to the “Not Classified as Cheatgrass” class. This can be observed in the zoom windows of figure 61. In the spatially-filtered and masked cheatgrass map, the mask pixels, those containing cloud/snow, water, shadow, or burned areas in either the early-season or midsummer images, and pixels that did not contain data in either image, remain colored black with a pixel value of zero. The nonmasked image pixels in which cheatgrass was not detected are assigned to the pixel value of one and colored gray. The unmasked pixels containing cheatgrass retain the same class names and colors and have the pixel values specified in table 5.

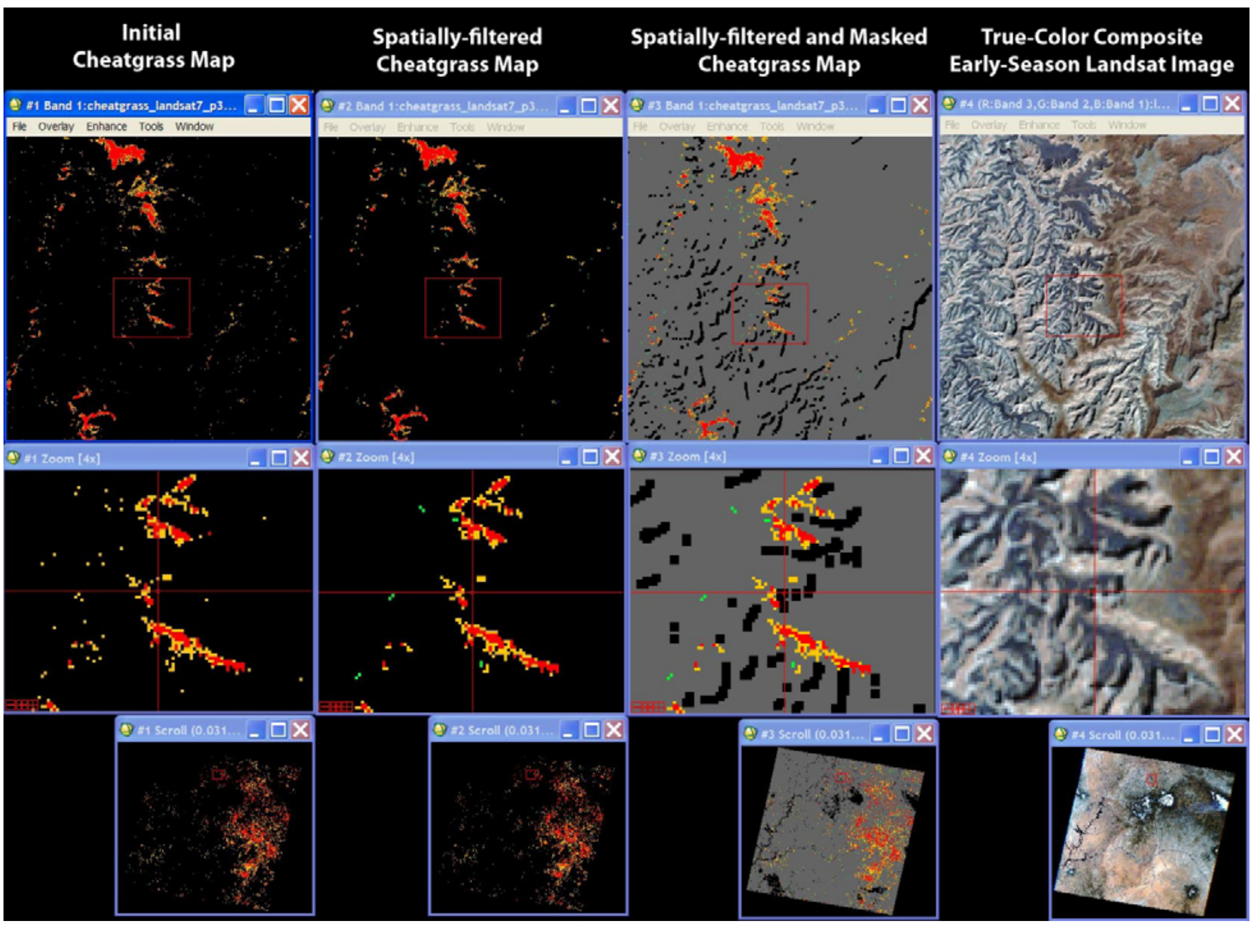

Figure 61. Cheatgrass maps and early-season Landsat image.

The displays shown in figure 61 were linked in ENVI using the “geographic link” function. The geographic link ensures that the central pixels in the crosshairs of the zoom window are those with the same geographic coordinates in the linked displays. To link displays using this function, right-click in any of the band windows and select the “Geographic Link…” item (fig. 62).

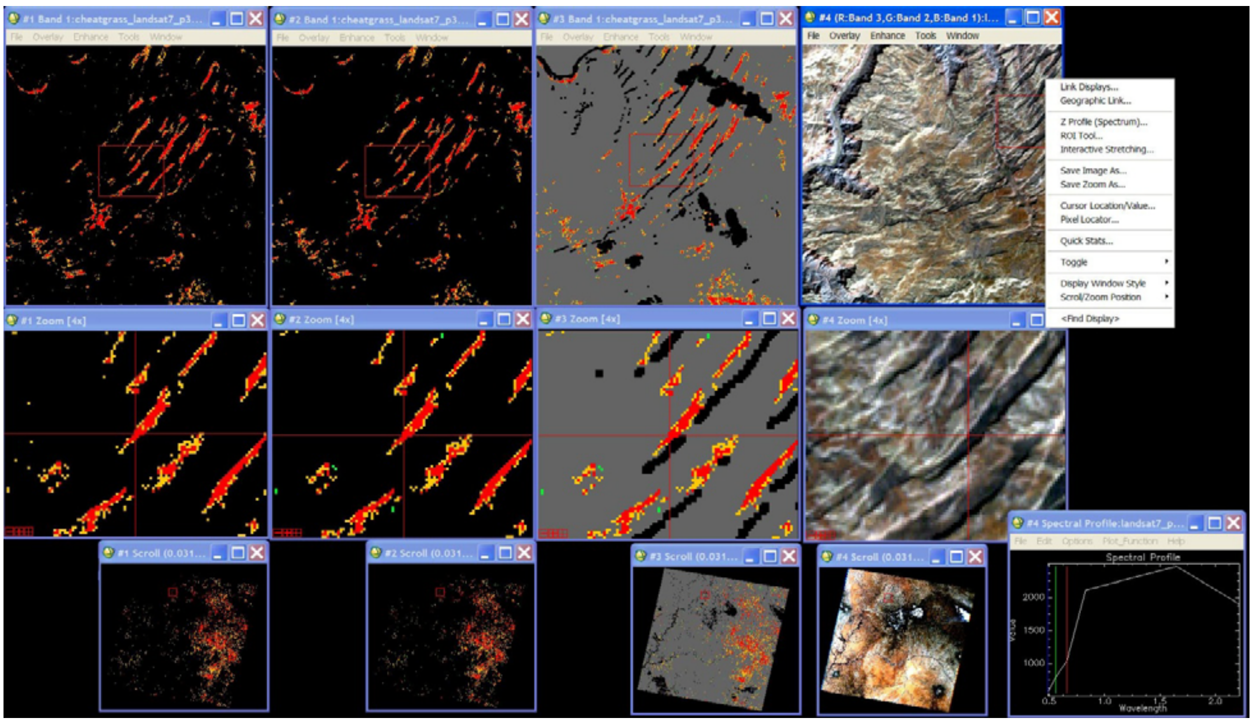

Figure 62. Initiating the geographic link function.

A window appears in which the user can define which displays to include in the geographic link (fig. 63).

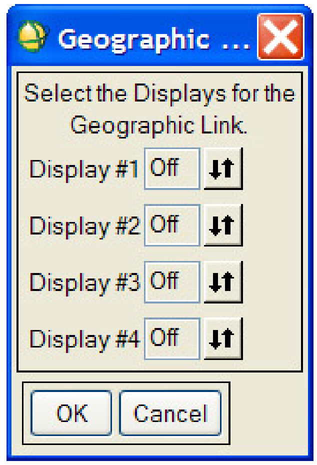

Figure 63. Assigning the displays to include in the geographic link.

Figure 64 shows the geographic linking of the initial cheatgrass map with the filtered and filtered/masked cheatgrass maps in relation to the midsummer Landsat image. In these displays, the masking of clouds and cloud shadows that were present in the midsummer Landsat image is apparent in the band and zoom windows.

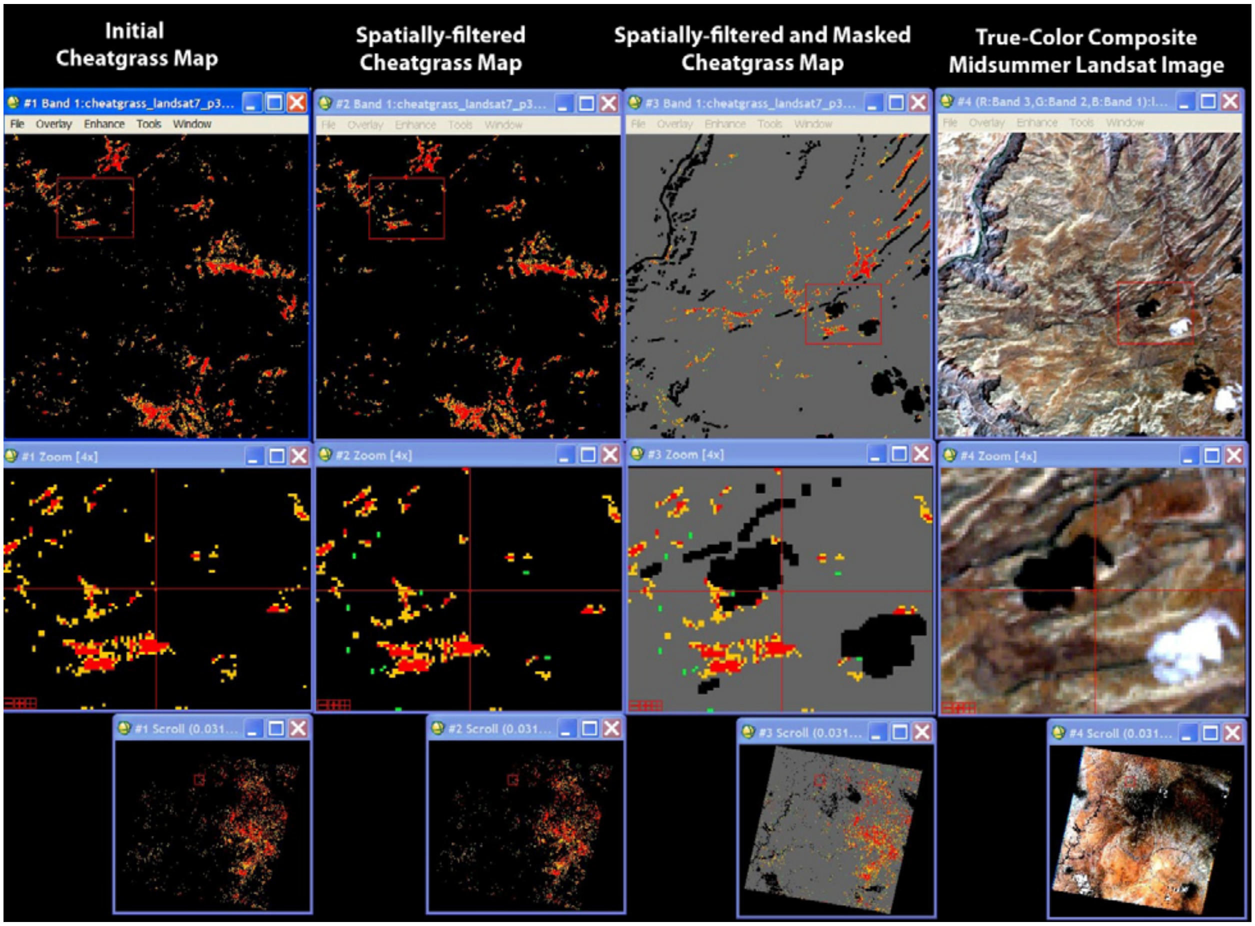

Figure 64. Cheatgrass maps and midsummer Landsat image.

Linking of the cheatgrass maps with the dNDVI image allows the user to examine the dNDVI values of pixels mapped as cheatgrass. Figure 65 shows the initial cheatgrass map linked with the spatially-filtered and masked cheatgrass map and the dNDVI image (from band three of the layer stack file). The dNDVI classification image created during the execution of the DESI cheatgrass module can be overlaid on the dNDVI image allowing the user to see a color indexed representation of the dNDVI values as well. To start the overlay of the classification image, select the "Overlay" menu item from the band window's menu bar and select the "Classification…" item (fig. 65).

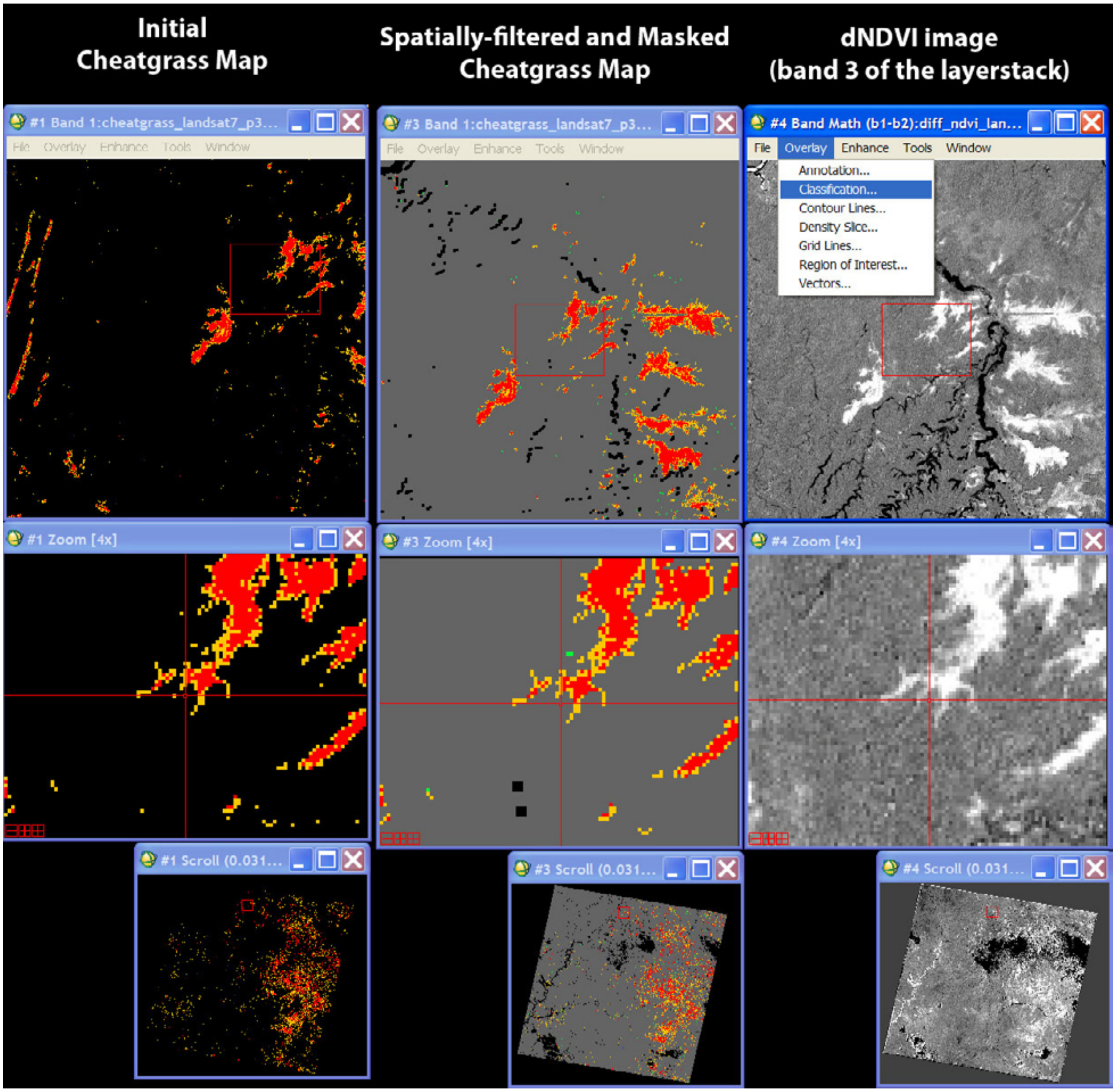

Figure 65. Cheatgrass maps and the dNDVI image.

The user is prompted to select the classification image to overlay in the display (fig. 66). After selecting the file, press "OK" to continue.

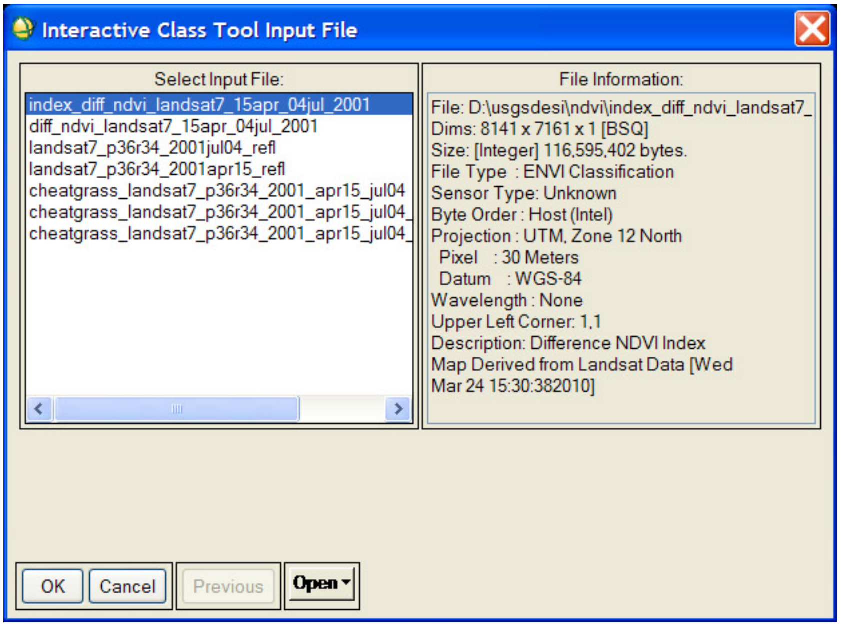

Figure 66. Selecting the classification image for overlay.

The interactive class tool appears, showing the class names and colors (fig. 67). Each class can be turned on and overlaid on the display by clicking on the box to the left of the class name.

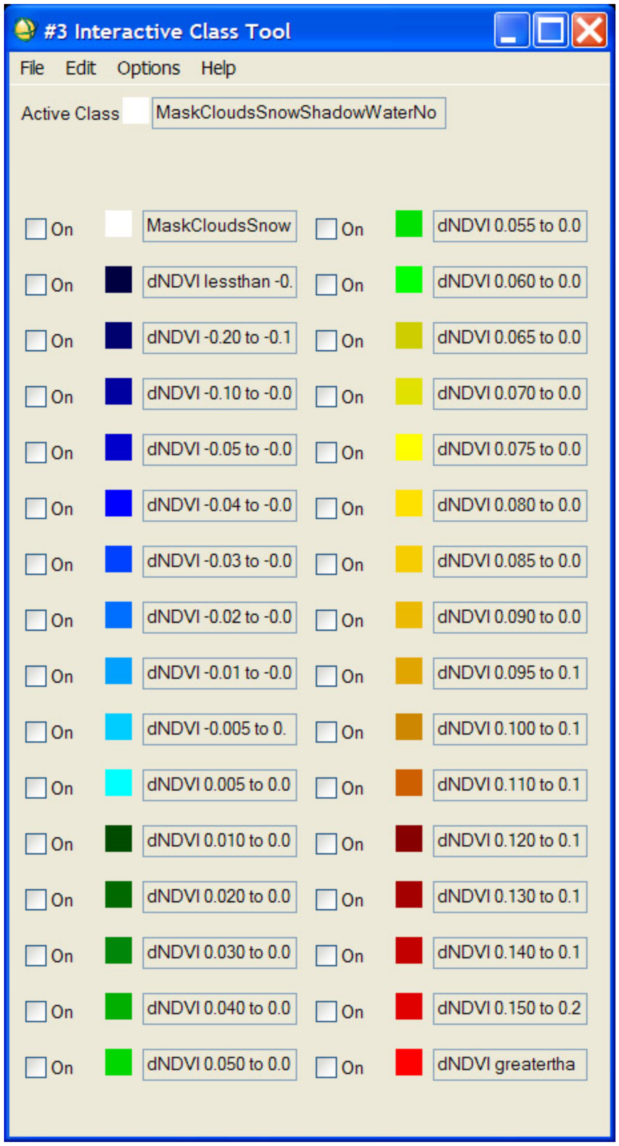

Figure 67. The interactive class tool.

Figure 68 shows several of the classes turned on in the class tool window and overlaid on the dNDVI window.

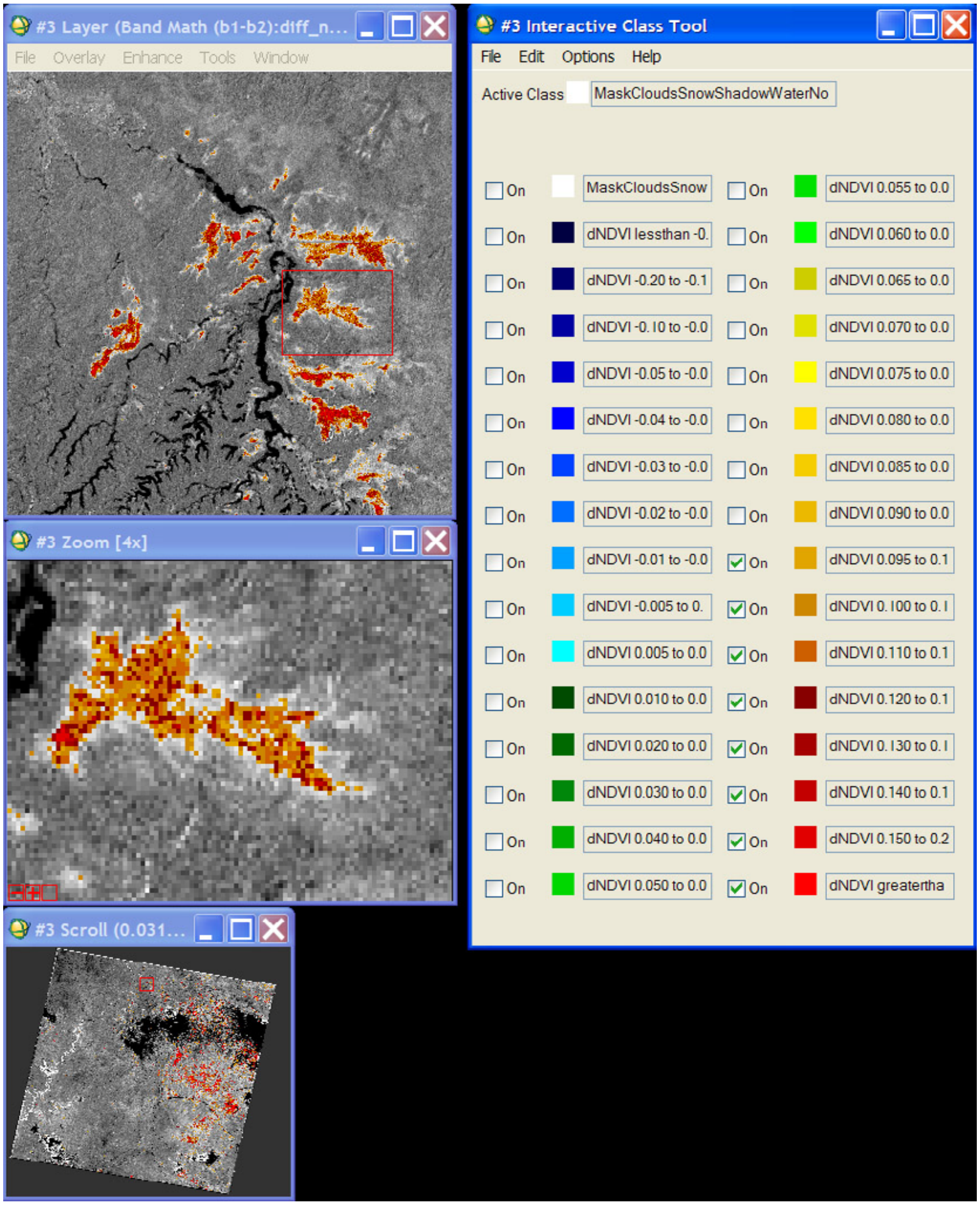

Figure 68. The dNDVI classes overlaid on the continuous-value dNDVI image.

Figure 69 shows additional classes of lower dNDVI values overlaid on the dNDVI continuous-value image. The dNDVI values of individual pixels can be displayed by using the ENVI “Cursor Location/Value” function. To start this function, right-click in the band window and choose the “Cursor Location/Value…” item from the drop-down list. A new window appears showing the image value and geographic and map location of the pixel under the cursor (see the bottom-center window in fig. 69).

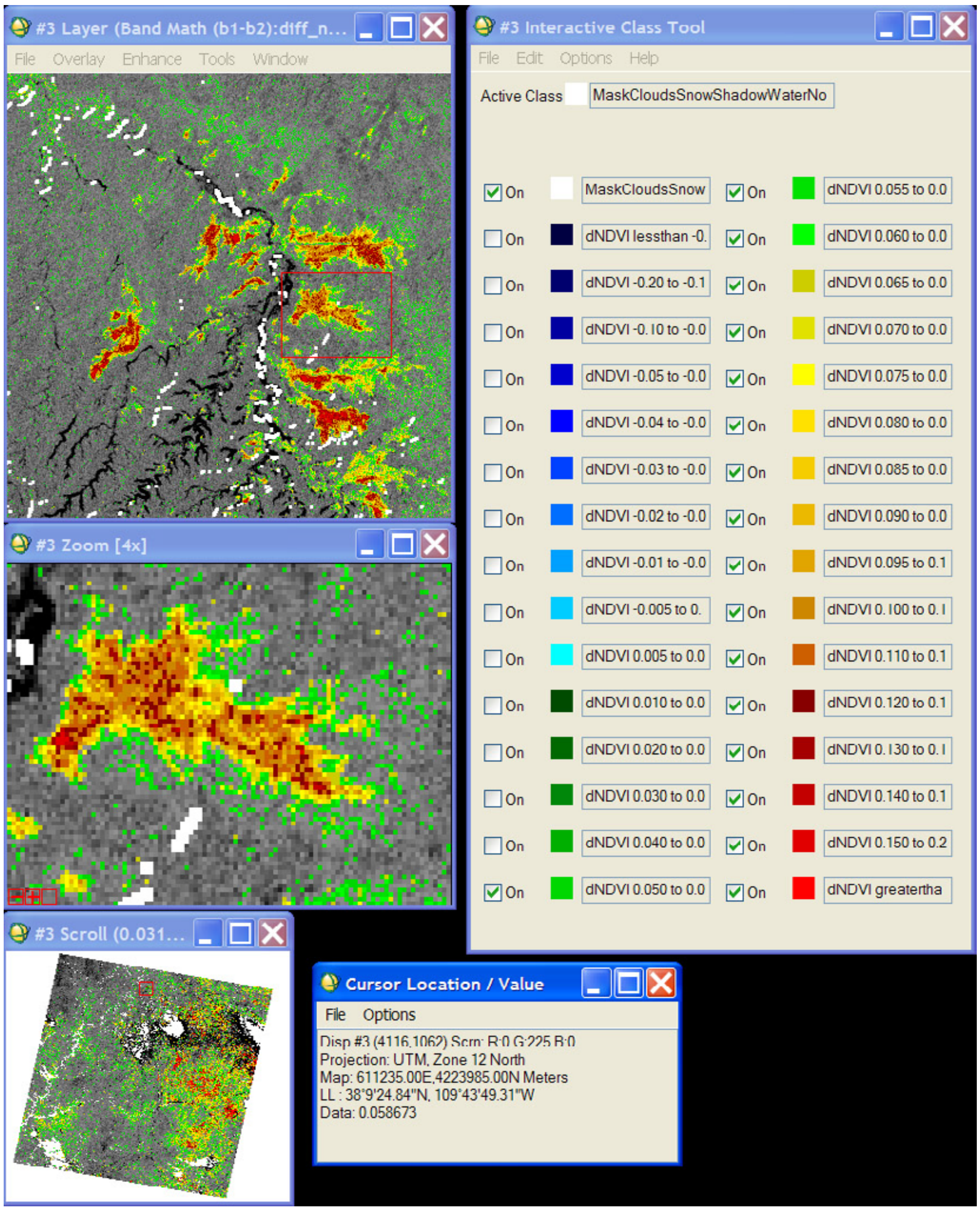

Figure 69. Classes of dNDVI with the cursor location/value window.

By comparing the cheatgrass maps to the classes of dNDVI and pixel dNDVI values (fig. 70), the user can examine whether the default thresholds should be changed to better capture areas of known cheatgrass occurrence. If the user has vector files of known cheatgrass occurrences from field surveys, ENVI has functions that allow these vectors to be overlaid in the display windows (see ITT Visual Information Solutions, 2009). For the semiarid region of the Colorado Plateau, the lower dNDVI classes become less spatially-consistent and appear in a speckled pattern in the image (see the classes in green in fig. 70). The dNDVI value at which the dNDVI classes go from spatially-consistent to a noisy pattern can be a good indicator of the lower probability threshold value for cheatgrass.

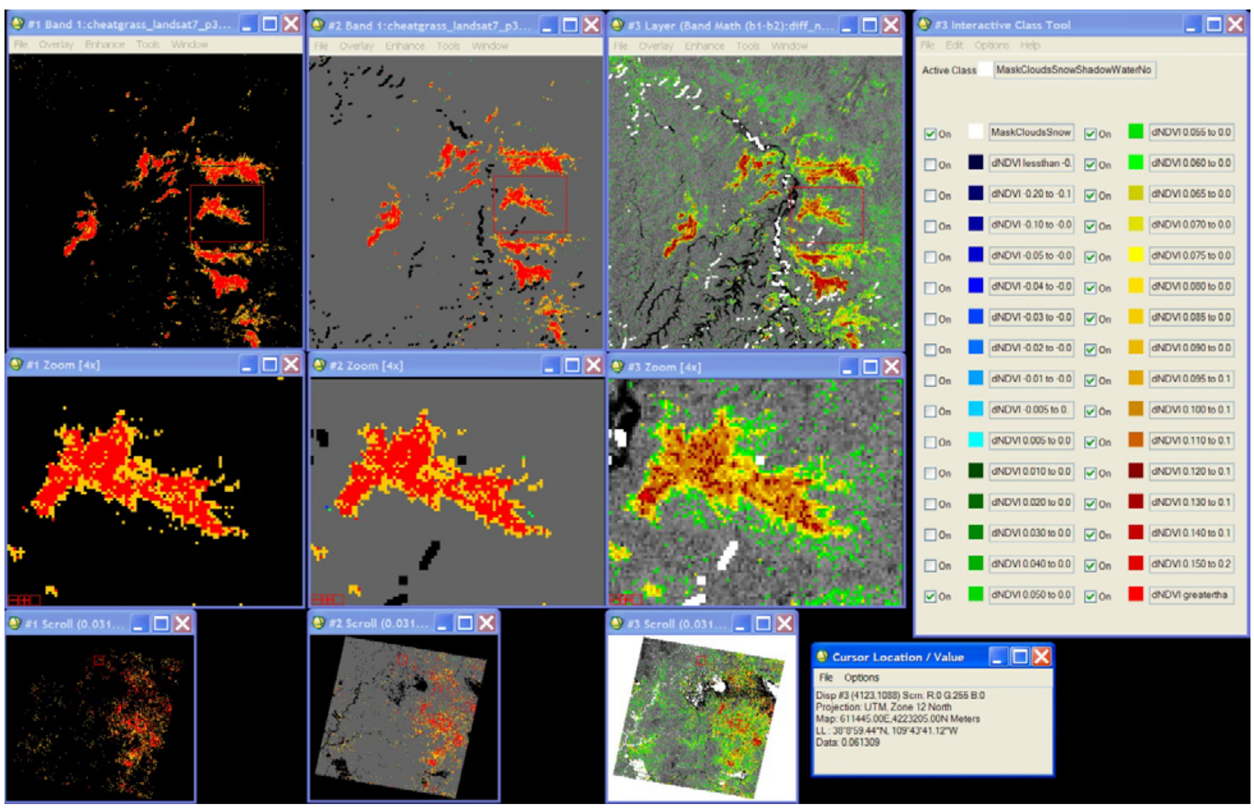

Figure 70. Cheatgrass maps and classes of dNDVI with the cursor location/value window.

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Release Notes

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Appendix A

Example header file created by DESI for a radiance image generated using "Module 1. Landsat Raw DN to Rad."

```
ENVI description = {
  Sensor=Landsat7 SolarElevation= 64.4128 Year= 2001 Month= 7 Day= 4 Input
  file=Q:\usgsdesi\rawdata\envi_metafile_landsat_21Nov2010_16_31_36 Output
  file=Q:\usgsdesi\radiance\landsat7_p36r34_2001jul04\landsat7_p36r34_2001jul04_rad
  WRS_PATH=36 WRS_ROW=34 VALUES USED TO CONVERT TO RADIANCE:
  LMIN=-6.2000,-6.4000,-5.0000,-5.1000,-1.0000,-0.3500,
  LMAX=191.6000,196.5000,152.9000,241.1000,31.0600,10.8000,
  QCALMIN=1.0000,1.0000,1.0000,1.0000,1.0000,1.0000,
  QCALMAX=255.0000,255.0000,255.0000,255.0000,255.0000,255.0000,
  GAINS=0.7787,0.7988,0.6217,0.9693,0.1262,0.0439,
  OFFSETS=-6.9787,-7.1988,-5.6217,-6.0693,-1.1262,-0.3939,Conversion of
  Landsat data from raw to radiance. Raw(DN) converted to radiance
  (Watts/m^2/sr/micron * 100 (scalefactor=100) [Sun Nov 21 16:32:35 2010]}
samples = 8141
lines   = 7181
bands   = 6
header offset = 0
file type = ENVI Standard
data type = 2
interleave = bsq
sensor type = Landsat TM
byte order = 1
map info = {UTM, 1.000, 1.000, 487785.000, 4255815.000, 3.0000000000e+001, 3.0000000000e+001, 12, North, WGS-84, units=Meters}
coordinate system string =
{PROJCS["UTM_Zone_12N",GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],
UNIT["Degree",0.0174532925199433]],PROJECTION["Transverse_Mercator"],PARAMETER["False_Easting",500000.0],PARAMETER["False_Northing",0.
0],PARAMETER["Central_Meridian",-111.0],PARAMETER["Scale_Factor",0.9996],PARAMETER["Latitude_Of_Origin",0.0],UNIT["Meter",1.0]]}
wavelength units = Micrometers
pixel size = {3.00000000e+001, 3.00000000e+001, units=Meters}
wavelength = {0.485000, 0.560000, 0.660000, 0.830000, 1.650000, 2.215000}
original rawdata keyword group = UTM_PARAMETERS
original rawdata keyword origin = "Image courtesy of the U.S. Geological Survey"
original rawdata keyword request_id = "0100912225220_00069"
original rawdata keyword product_creation_time = 2009-12-31T05:10:11Z
original rawdata keyword station_id = "EDC"
original rawdata keyword landsat7_xband = "2"
original rawdata keyword ground_station = "EDC"
original rawdata keyword lps_processor_number = 8
original rawdata keyword datehour_contact_period = "0118517"
original rawdata keyword subinterval_number = "04"
original rawdata keyword end_group = L1_METADATA_FILE
original rawdata keyword product_type = "L1T"
```

```
original rawdata keyword elevation_source = "GLS2000"
original rawdata keyword processing_software = "LPGS_10.1.2"
original rawdata keyword ephemeris_type = "DEFINITIVE"
original rawdata keyword spacecraft_id = "Landsat7"
original rawdata keyword sensor_id = "ETM+"
original rawdata keyword sensor_mode = "SAM"
original rawdata keyword acquisition_date = 2001-07-04
original rawdata keyword scene_center_scan_time = 17:46:00.0832307Z
original rawdata keyword wrs_path = 36
original rawdata keyword starting_row = 34
original rawdata keyword ending_row = 34
original rawdata keyword band_combination = "123456678"
original rawdata keyword product_ul_corner_lat = 38.4504089
original rawdata keyword product_ul_corner_lon = -111.1398158
original rawdata keyword product_ur_corner_lat = 38.4203483
original rawdata keyword product_ur_corner_lon = -108.3425280
original rawdata keyword product_ll_corner_lat = 36.5088645
original rawdata keyword product_ll_corner_lon = -111.1362442
original rawdata keyword product_lr_corner_lat = 36.4808286
original rawdata keyword product_lr_corner_lon = -108.4103198
original rawdata keyword product_ul_corner_mapx = 487800.000
original rawdata keyword product_ul_corner_mapy = 4255800.000
original rawdata keyword product_ur_corner_mapx = 732000.000
original rawdata keyword product_ur_corner_mapy = 4255800.000
original rawdata keyword product_ll_corner_mapx = 487800.000
original rawdata keyword product_ll_corner_mapy = 4040400.000
original rawdata keyword product_lr_corner_mapx = 732000.000
original rawdata keyword product_lr_corner_mapy = 4040400.000
original rawdata keyword product_samples_pan = 16281
original rawdata keyword product_lines_pan = 14361
original rawdata keyword product_samples_ref = 8141
original rawdata keyword product_lines_ref = 7181
original rawdata keyword product_samples_thm = 4071
original rawdata keyword product_lines_thm = 3591
original rawdata keyword band1_file_name = "L71036034_03420010704_B10.TIF"
original rawdata keyword band2_file_name = "L71036034_03420010704_B20.TIF"
original rawdata keyword band3_file_name = "L71036034_03420010704_B30.TIF"
original rawdata keyword band4_file_name = "L71036034_03420010704_B40.TIF"
original rawdata keyword band5_file_name = "L71036034_03420010704_B50.TIF"
original rawdata keyword band61_file_name = "L71036034_03420010704_B61.TIF"
original rawdata keyword band62_file_name = "L72036034_03420010704_B62.TIF"
original rawdata keyword band7_file_name = "L72036034_03420010704_B70.TIF"
original rawdata keyword band8_file_name = "L72036034_03420010704_B80.TIF"
original rawdata keyword gcp_file_name = "L71036034_03420010704_GCP.txt"
original rawdata keyword metadata_l1_file_name = "L71036034_03420010704_MTL.txt"
original rawdata keyword cpf_file_name = "L7CPF20010701_20010930_08"
original rawdata keyword lmax_band1 = 191.600
original rawdata keyword lmin_band1 = -6.200
original rawdata keyword lmax_band2 = 196.500
original rawdata keyword lmin_band2 = -6.400
original rawdata keyword lmax_band3 = 152.900
```

```
original rawdata keyword lmin_band3 = -5.000
original rawdata keyword lmax_band4 = 241.100
original rawdata keyword lmin_band4 = -5.100
original rawdata keyword lmax_band5 = 31.060
original rawdata keyword lmin_band5 = -1.000
original rawdata keyword lmax_band61 = 17.040
original rawdata keyword lmin_band61 = 0.000
original rawdata keyword lmax_band62 = 12.650
original rawdata keyword lmin_band62 = 3.200
original rawdata keyword lmax_band7 = 10.800
original rawdata keyword lmin_band7 = -0.350
original rawdata keyword lmax_band8 = 243.100
original rawdata keyword lmin_band8 = -4.700
original rawdata keyword qcalmax_band1 = 255.0
original rawdata keyword qcalmin_band1 = 1.0
original rawdata keyword qcalmax_band2 = 255.0
original rawdata keyword qcalmin_band2 = 1.0
original rawdata keyword qcalmax_band3 = 255.0
original rawdata keyword qcalmin_band3 = 1.0
original rawdata keyword qcalmax_band4 = 255.0
original rawdata keyword qcalmin_band4 = 1.0
original rawdata keyword qcalmax_band5 = 255.0
original rawdata keyword qcalmin_band5 = 1.0
original rawdata keyword qcalmax_band61 = 255.0
original rawdata keyword qcalmin_band61 = 1.0
original rawdata keyword qcalmax_band62 = 255.0
original rawdata keyword qcalmin_band62 = 1.0
original rawdata keyword qcalmax_band7 = 255.0
original rawdata keyword qcalmin_band7 = 1.0
original rawdata keyword qcalmax_band8 = 255.0
original rawdata keyword qcalmin_band8 = 1.0
original rawdata keyword correction_method_gain_band1 = "CPF"
original rawdata keyword correction_method_gain_band2 = "CPF"
original rawdata keyword correction_method_gain_band3 = "CPF"
original rawdata keyword correction_method_gain_band4 = "CPF"
original rawdata keyword correction_method_gain_band5 = "CPF"
original rawdata keyword correction_method_gain_band61 = "CPF"
original rawdata keyword correction_method_gain_band62 = "CPF"
original rawdata keyword correction_method_gain_band7 = "CPF"
original rawdata keyword correction_method_gain_band8 = "CPF"
original rawdata keyword correction_method_bias = "IC"
original rawdata keyword band1_gain = "H"
original rawdata keyword band2_gain = "H"
original rawdata keyword band3_gain = "H"
original rawdata keyword band4_gain = "L"
original rawdata keyword band5_gain = "H"
original rawdata keyword band6_gain1 = "L"
original rawdata keyword band6_gain2 = "H"
original rawdata keyword band7_gain = "H"
original rawdata keyword band8_gain = "L"
original rawdata keyword band1_gain_change = "0"
```

original rawdata keyword band2_gain_change = "0"
original rawdata keyword band3_gain_change = "0"
original rawdata keyword band4_gain_change = "0"
original rawdata keyword band5_gain_change = "0"
original rawdata keyword band6_gain_change1 = "0"
original rawdata keyword band6_gain_change2 = "0"
original rawdata keyword band7_gain_change = "0"
original rawdata keyword band8_gain_change = "0"
original rawdata keyword band1_sl_gain_change = 0
original rawdata keyword band2_sl_gain_change = 0
original rawdata keyword band3_sl_gain_change = 0
original rawdata keyword band4_sl_gain_change = 0
original rawdata keyword band5_sl_gain_change = 0
original rawdata keyword band6_sl_gain_change1 = 0
original rawdata keyword band6_sl_gain_change2 = 0
original rawdata keyword band7_sl_gain_change = 0
original rawdata keyword band8_sl_gain_change = 0
original rawdata keyword sun_azimuth = 117.9910568
original rawdata keyword sun_elevation = 64.4128406
original rawdata keyword output_format = "GEOTIFF"
original rawdata keyword striping_band1 = "NONE"
original rawdata keyword striping_band2 = "NONE"
original rawdata keyword striping_band3 = "NONE"
original rawdata keyword striping_band4 = "NONE"
original rawdata keyword striping_band5 = "NONE"
original rawdata keyword striping_band61 = "NONE"
original rawdata keyword striping_band62 = "NONE"
original rawdata keyword striping_band7 = "NONE"
original rawdata keyword striping_band8 = "NONE"
original rawdata keyword banding = "N"
original rawdata keyword coherent_noise = "Y"
original rawdata keyword memory_effect = "N"
original rawdata keyword scan_correlated_shift = "N"
original rawdata keyword inoperable_detectors = "N"
original rawdata keyword dropped_lines = "N"
original rawdata keyword reference_datum = "WGS84"
original rawdata keyword reference_ellipsoid = "WGS84"
original rawdata keyword grid_cell_size_pan = 15.000
original rawdata keyword grid_cell_size_thm = 60.000
original rawdata keyword grid_cell_size_ref = 30.000
original rawdata keyword orientation = "NUP"
original rawdata keyword resampling_option = "CC"
original rawdata keyword map_projection = "UTM"
original rawdata keyword zone_number = 12

Appendix B

Example header file created by DESI for a reflectance image generated using "Module 2. Landsat Radiance to Reflectance."

```
ENVI description = {
  Conversion of Landsat data from radiance to reflectance. converted to
  reflectance (scaled 1.0 to 10,000). Input image parameters: Solar_elev =
  64.4128 Year = 2001 Month = 7 Day = 4 Sensor = Landsat7 , Input Pathrad file
  = Q:\usgsdesi\radiance\landsat7_p36r34_2001jul04\minvalues_edited.txt , Path
  Radiance Values in Watts/m^2/sr/micron * 100.0: 2417.00000, 1277.00000,
  618.00000, 265.00000, 0.00000, 0.00000, Irradiance factors: Band 1 factor =
  1997.0, Band 2 factor = 1812.0, Band 3 factor = 1533.0, Band 4 factor =
  1039.0, Band 5 factor = 230.8, Band 6 factor = 84.9, , Earth-Sun Distance
  Parameters: Day of Year = 185 Earth-sun adjustment factor = 1.01670Gain
  Values applied to path radiance corrected Landsat scaled radiance:
  1.802956e-005, 1.987033e-005, 2.348665e-005, 3.465355e-005, 1.560010e-004,
  4.240875e-004 RADIANCE HISTORY: Sensor=Landsat7 SolarElevation= 64.4128
  Year= 2001 Month= 7 Day= 4
  Inputfile=Q:\usgsdesi\rawdata\envi_metafile_landsat_21Nov2010_16_31_36
  Outputfile=Q:\usgsdesi\radiance\landsat7_p36r34_2001jul04\landsat7_p36r34_2001jul04_radWRS_PATH=36
  WRS_ROW=34 VALUES USED TO CONVERT TO RADIANCE:LMIN=-6.2000, -6.4000,
  -5.0000, -5.1000, -1.0000, -0.3500, LMAX=191.6000, 196.5000, 152.9000,
  241.1000, 31.0600, 10.8000, QCALMIN=1.0000, 1.0000, 1.0000, 1.0000, 1.0000,
  1.0000, QCALMAX=255.0000, 255.0000, 255.0000, 255.0000, 255.0000, 255.0000,
  GAINS=0.7787, 0.7988, 0.6217, 0.9693, 0.1262, 0.0439, OFFSETS=-6.9787,
  -7.1988, -5.6217, -6.0693, -1.1262, -0.3939, Conversion ofLandsat data from
  raw to radiance. Raw(DN) converted to radiance(Watts/m^2/sr/micron * 100
  (scalefactor=100) [Sun Nov 21 16:32:35 2010] [Sun Nov 21 18:36:26 2010]}
samples = 8141
lines   = 7181
bands   = 6
header offset = 0
file type = ENVI Standard
data type = 2
interleave = bsq
sensor type = Landsat TM
byte order = 1
map info = {UTM, 1.000, 1.000, 487785.000, 4255815.000, 3.0000000000e+001, 3.0000000000e+001, 12, North, WGS-84, units=Meters}
coordinate system string =
{PROJCS["UTM_Zone_12N",GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],
UNIT["Degree",0.0174532925199433]],PROJECTION["Transverse_Mercator"],PARAMETER["False_Easting",500000.0],PARAMETER["False_Northing",0.
0],PARAMETER["Central_Meridian",-111.0],PARAMETER["Scale_Factor",0.9996],PARAMETER["Latitude_Of_Origin",0.0],UNIT["Meter",1.0]]}
wavelength units = Micrometers
pixel size = {3.00000000e+001, 3.00000000e+001, units=Meters}
wavelength = {0.485000, 0.560000, 0.660000, 0.830000, 1.650000, 2.215000}
```

Appendix C

Example header file created by DESI for a mask image generated using "Module 3. Landsat Masking."

```
ENVI description = {
  Mask for Clouds,Snow,Shadows,Water,BurnScars,NoData in Landsat Data, Input
  reflectance =
  Q:\usgsdesi\reflectance\landsat7_p36r34_2001jul04\landsat7_p36r34_2001jul04_refl,
  Input radiance =
  Q:\usgsdesi\radiance\landsat7_p36r34_2001jul04\landsat7_p36r34_2001jul04_rad,
  Output mask =
  Q:\usgsdesi\masks\landsat7_p36r34_2001jul04\landsat7_p36r34_2001jul04_mask,
  PARAMETERS: THRESHOLD_WATER_BAND5_REFL=700, THRESHOLD_WATER_BAND6_REFL=700,
  THRESHOLD_SHADOW_BAND1_REFL=520, THRESHOLD_SHADOW_BAND4_REFL=1000,
  THRESHOLD_SHADOW_BAND5_REFL=1000, THRESHOLD_SHADOW_ALLBNDS=275,
  THRESHOLD_SHADOW_RATIO_4N3=3.00000, THRESHOLD_BURN_BAND1_REFL=600.000,
  THRESHOLD_BURN_BAND2_REFL=600.000, THRESHOLD_BURN_BAND3_REFL=800.000,
  THRESHOLD_BURN_BAND4_REFL=2500.00, THRESHOLD_BURN_BAND5_REFL=2500.00,
  THRESHOLD_BURN_BAND6_REFL=2500.00, THRESHOLD_BURN_RATIO_4N5=1.50000,
  THRESHOLD_BURN_BAND5_REFL_MIN=800.000, THRESHOLD_BURN_RATIO_4N3=1.66000,
  THRESHOLD_CLOUD_SNOW_BAND1_RAD_1_MIN=14000,
  THRESHOLD_CLOUD_SNOW_BAND1_RAD_2_MIN=10900,
  THRESHOLD_CLOUD_SNOW_RATIO_1N2_MIN=1.03500 [Sun Nov 21 19:07:18 2010]}
samples = 8141
lines   = 7181
bands   = 1
header offset = 0
file type = ENVI Classification
data type = 1
interleave = bsq
sensor type = Unknown
classes = 6
class lookup = {
 100, 100, 100, 255, 255,   0,   0, 255, 255,   0,   0, 255, 255,   0,   0,
   0, 255,   0}
class names = {
 Data, Clouds_and_Snow, Shadows, Water, Burn, No_Data}
byte order = 0
map info = {UTM, 1.000, 1.000, 487785.000, 4255815.000, 3.0000000000e+001, 3.0000000000e+001, 12, North, WGS-84, units=Meters}
coordinate system string =
{PROJCS["UTM_Zone_12N",GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],
UNIT["Degree",0.0174532925199433]],PROJECTION["Transverse_Mercator"],PARAMETER["False_Easting",500000.0],PARAMETER["False_Northing",0.
0],PARAMETER["Central_Meridian",-111.0],PARAMETER["Scale_Factor",0.9996],PARAMETER["Latitude_Of_Origin",0.0],UNIT["Meter",1.0]]}
wavelength units = Unknown
pixel size = {3.00000000e+001, 3.00000000e+001, units=Meters}
```

Appendix D

Example header file created by DESI for the spatially-filtered and masked cheatgrass map using “Module 4. Landsat Cheatgrass Detection.”

```
ENVI description = {
  Cheatgrass Map, Spatially-Filtered and Masked, Derived from Landsat Data,
  Initial map history = THRESHOLD_EARLYSEASON_LO_NDVI=0.100000,
  THRESHOLD_EARLYSEASON_HI_NDVI=0.750000,
  THRESHOLD_LATESEASON_HI_NDVI=0.300000,
  CHEATGRASS_DIFFNDVI_THRESHOLD_LOPROB=0.0750000,
  CHEATGRASS_DIFFNDVI_THRESHOLD_HIPROB=0.100000 [Sun Nov 21 19:22:56 2010]}
samples = 8141
lines   = 7161
bands   = 1
header offset = 0
file type = ENVI Classification
data type = 1
interleave = bsq
sensor type = Unknown
classes = 6
class lookup = {
   0,   0,   0, 100, 100, 100,   0,  50, 255,   0, 255,  50, 255, 200,   0,
 255,   0,   0}
class names = {
 Pixel_not_valid, Not_classified_as_cheatgrass,
 Cheatgrass_Lower_Probability_Spectral_and_Spatial,
 Cheatgrass_Lower_Probability_Spatial,
 Cheatgrass_Lower_Probability_Spectral, Cheatgrass_High_Probability}
byte order = 0
map info = {UTM, 1.000, 1.000, 487785.000, 4255815.000, 3.0000000000e+001, 3.0000000000e+001, 12, North, WGS-84, units=Meters}
coordinate system string =
{PROJCS["UTM_Zone_12N",GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],
UNIT["Degree",0.0174532925199433]],PROJECTION["Transverse_Mercator"],PARAMETER["False_Easting",500000.0],PARAMETER["False_Northing",0.
0],PARAMETER["Central_Meridian",-111.0],PARAMETER["Scale_Factor",0.9996],PARAMETER["Latitude_Of_Origin",0.0],UNIT["Meter",1.0]]}
wavelength units = Unknown
pixel size = {3.00000000e+001, 3.00000000e+001, units=Meters}
```