Burn Indices Tutorial

This tutorial shows how to create various burn index images from Landsat 8 imagery, using the May 2014 San Diego County wildfires as a case study. You will learn how to perform the following tasks:

- Create binary masks to exclude water pixels
- Calibrate multispectral data to top-of-atmosphere reflectance
- Calibrate thermal data to brightness temperatures
- Create a layer-stacked image that includes the corrected multispectral and thermal bands
- Create burn index images using ENVI's **Spectral Index** tool

See the following sections:

Files Used in this Tutorial

Tutorial files are available from our ENVI Tutorials web page. Click the **Landsat Case Studies** link to download the .zip file to your machine, then unzip the files. You will use these files located in the `BurnIndices` folder the for the tutorial:

File	Description
`PostFireOLISubset.dat (and .hdr)`	Landsat 8 OLI bands (seven total), acquired on May 25, 2014, saved to ENVI raster format.
`PostFireTIRSubset.dat (and .hdr)`	Landsat 8 TIR thermal bands (two total), acquired on May 25, 2014, saved to ENVI raster format.
`PreFireNBR.dat (and .hdr)`	Normalized Burn Ratio image from May 9, 2014

Data are available from the U.S. Geological Survey.

Case Study: San Diego County Wildfires in 2014

In May of 2014, close to 20 different wildfires erupted in San Diego County, triggered by Santa Ana winds and a heat wave. The first fire started on May 5, and the last remaining fires were extinguished by May 22. By May 18, the fires had burned more than 27,000 acres (42 square miles) of land (Figueroa and Winkley, 2014). Some of the communities affected by the fire included Camp Pendleton, Carlsbad, San Marcos, and Escondido.

Reference:

Figueroa, T., and L. Winkley. "Fires in North County closer to being out." San Diego Union Tribune, updated 19 May 2014. http://www.utsandiego.com/news/2014/may/18/Regions-wildfires-closer-to-out-as-weather-shifts/. Accessed June 2014.

Background on Burn Indices

Land resource managers and fire officials use burn severity maps from remote sensing instruments to predict areas of potential fire hazards, to map fire perimeters, and to study areas of vegetation regrowth after fires. Landsat imagery has traditionally been used to create indices that indicate burn severity because of its repeated coverage, ease of access, and spectral wavelengths.

In this tutorial, you will create burn severity images using a variety of different indices.

Burn Area Index

The Burn Area Index (BAI) highlights burned land in the red to near-infrared (NIR) spectrum, by emphasizing the charcoal signal in post-fire images. The index is computed from the spectral distance from each pixel to a reference spectral point, where recently burned areas converge. Brighter pixels indicate burned areas. BAI is computed as follows (Martín, 1998):

$$BAI = \frac{1}{(0.1 - Red)^2 + (0.06 - NIR)^2}$$

Normalized Burn Ratio

This index highlights burned areas in large fire zones greater than 500 acres. The formula is similar to a normalized difference vegetation index (NDVI), except that it uses near-infrared (NIR) and shortwave-infrared (SWIR) wavelengths (Lopez, 1991; Key and Benson, 1995).

$$NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)}$$

The NBR was originally developed for use with Landsat TM and ETM+ bands 4 and 7, but it will work with any multispectral sensor (including Landsat 8) with a NIR band between 0.76-0.9 µm and a SWIR band between 2.08-2.35 µm.

Normalized Burn Ratio - Thermal

This index uses a thermal band to enhance the NBR. It results in a better separability between burned and unburned land (Holden et al., 2005).

$$NBRT = \frac{(NIR - SWIR\left(\frac{Thermal}{1000}\right))}{(NIR + SWIR\left(\frac{Thermal}{1000}\right))}$$

NBRT1 was originally developed for use with Landsat TM and ETM+ bands 4, 7, and 6. However, it will work with any multispectral sensor (including Landsat 8) with bands that fall within the following ranges:

- NIR: 0.76 to 0.9 µm
- SWIR: 2.08 to 2.35 µm
- Thermal: 10.4 to 12.5 µm

References

Holden, Z., et al. "Evaluation of Novel Thermally Enhanced Spectral Indices for Mapping Fire Perimeters and Comparisons with Fire Atlas Data." *International Journal of Remote Sensing* 26 (2005): 4801-4808.

Key, C. and N. Benson. "Landscape Assessment: Remote sensing of severity, the Normalized Burn Ratio; and ground measure of severity, the Composite Burn Index." In *FIREMON: Fire Effects Monitoring and Inventory System*, RMRS-GTR, Ogden, UT: USDA Forest Service, Rocky Mountain Research Station (2005).

Lopez Garcia, M.J., and Caselles, V. "Mapping Burns and Natural Reforestation using Thematic Mapper Data. *Geocarto International* 6 (1991): 31-37.

Martín, M. *Cartografía e inventario de incendios forestales en la Península Iberica a partir de imágenes NOAA AVHRR*. Doctoral thesis, Universidad de Alcalá, Alcalá de Henares (1998).

Set Preferences and Display the Post-Fire Image

Follow these steps to begin:

1. From the menu bar, select **File > Preferences**.
2. Click the **Directories** item on the left side of the Preferences window.
3. Click in the white space next to **Output Directory**.
4. Click the right-facing arrow.
5. Choose a folder where you want to save the various files that will be created in this tutorial.
6. Click **OK** in the Preferences dialog.
7. From the menu bar, select **File > Open**.
8. Select the file `PostFireOLISubset.dat`, and click **Open**.
9. Right-click on the layer name in the Layer Manager and select **Zoom to Layer Extent**. This multispectral image shows the California coastline from San Clemente in the north to Del Mar in the south. You can see some of the larger burn scars near Camp Pendleton in the upper-left part of the image; they have a distinct gray color. If you cannot clearly see them, choose a different stretch type from the drop-down list in the toolbar:

Tip: This image is a spatial subset of a full Landsat 8 scene. To open full scenes distributed by the U.S. Geological Survey, select the `*MTL.txt` metadata file. The seven OLI bands are grouped separately from the two TIR thermal bands, Cirrus band, and Quality band. This particular image was created by selecting **File > Save As** from the menu bar, selecting the OLI band group, defining a spatial subset, and saving the result to ENVI raster format. The thermal bands were similarly saved to a separate file for use with the Calibrate Thermal Bands section of this tutorial.

Preprocessing

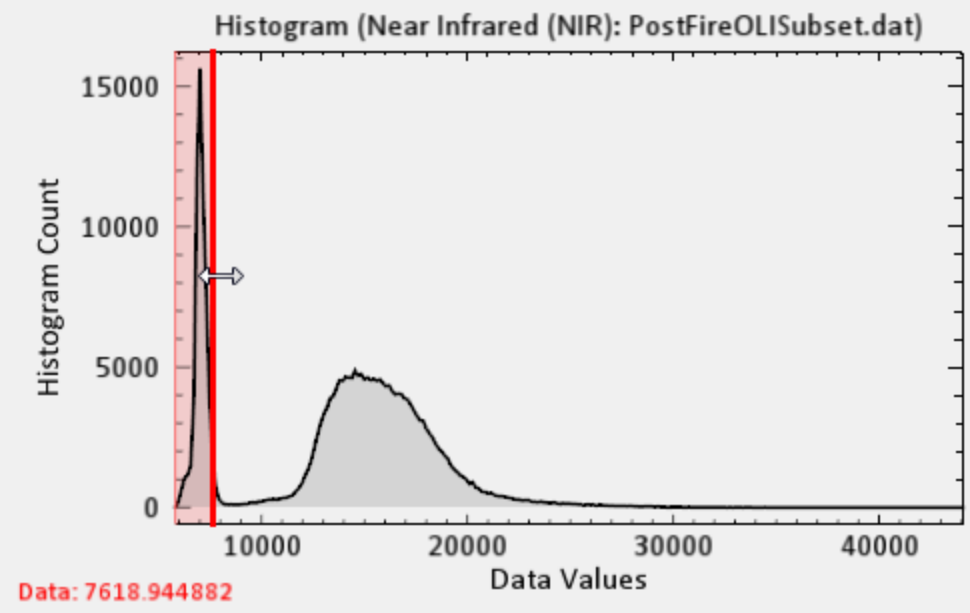
The following preprocessing steps ensure that the images are properly masked and calibrated before computing burn indices. Not all of these steps are required in every case study; exceptions are noted below.

Create a Water Mask

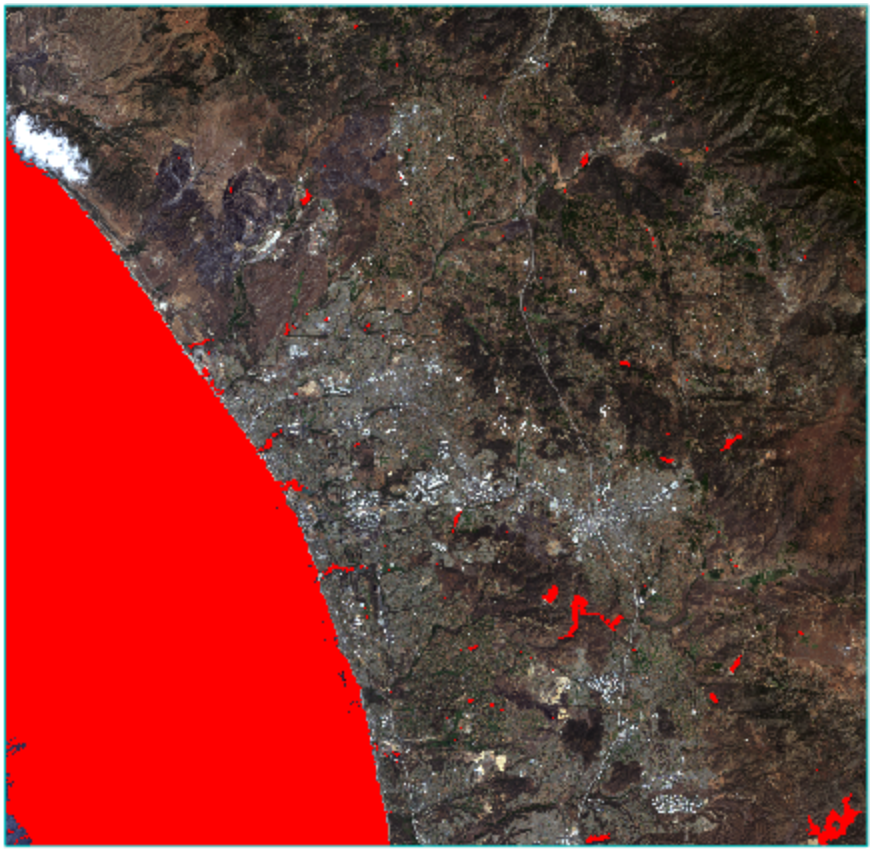
Scenes that contain oceans or other large water bodies should be masked to exclude these pixels, as they can interfere with calibration and atmospheric correction. Full Landsat 8 scenes also contain black background pixels that ENVI automatically sets to values of 'NoData'. The sample images you will use in this tutorial have already been spatially subsetted and do not include any background pixels.

An effective way to create a water mask is to create a band-thresholded region of interest (ROI), using the near-infrared (NIR) band. Water has an extremely low reflectance in the NIR region, so those pixels are nearly black. You can isolate those pixels with the ROI Tool.

1. Right-click on the `PostFireOLISubset.dat` layer name in the Layer Manager, and select **New Region of Interest**.
2. In the Region of Interest (ROI) Tool, change the **ROI Name** to **Water**.
3. Click the **Threshold** tab.
4. Click the **Add New Threshold Rule** button .
5. In the Data Selection dialog, select the **Near Infrared (NIR)** band and click **OK**. A histogram of the NIR band is displayed in the Choose Threshold Parameters dialog. You will identify the water pixels by selecting the range of low pixel values in the histogram.
6. Click and drag the red line on the left edge of the plot toward the right, covering the data values from 0 to approximately 7,618:

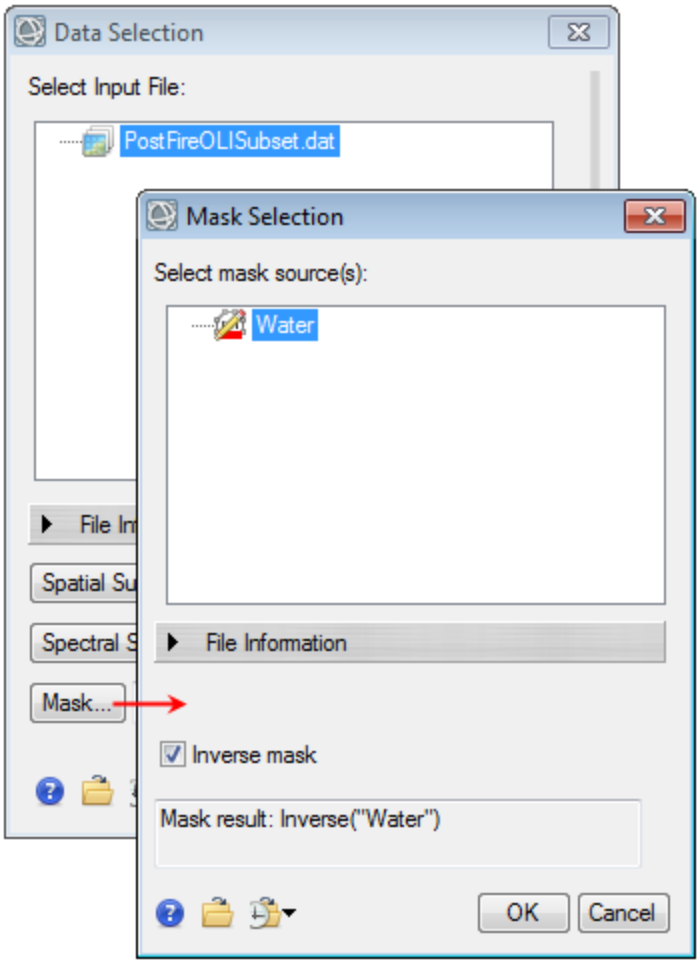


7. Enable the **Preview** checkbox. The pixels that fall within this range are highlighted in red.

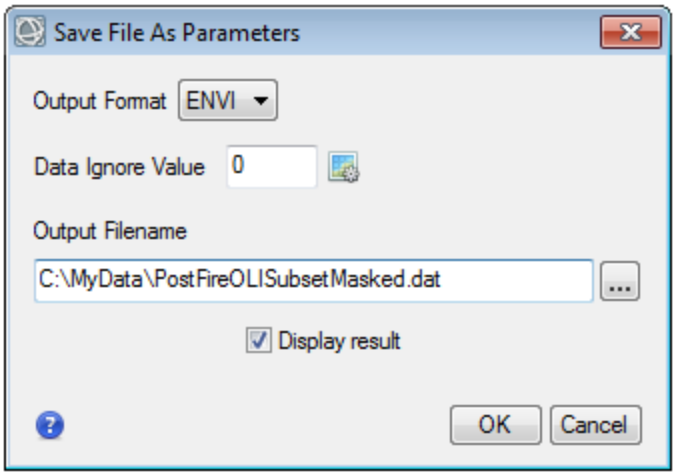


Tip: You can also use ROI thresholds to highlight clouds, using the highest data values in the histogram. However, you will ignore the sporadic cloud cover for this tutorial.

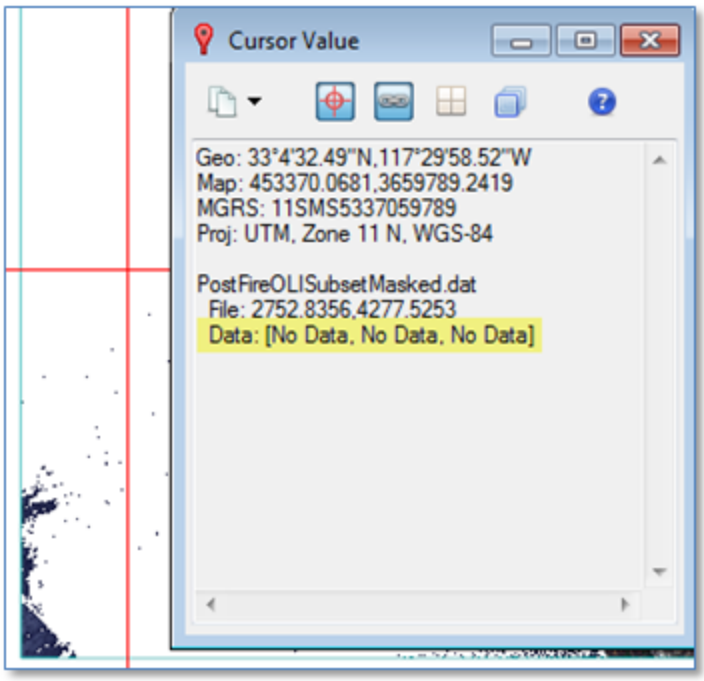
8. Click **OK** in the Choose Threshold Parameters dialog. Next, you will mask out the water pixels.
9. From the ENVI menu bar, select **File > Save As > Save As (ENVI, NITF, TIFF, DTED)**.
10. In the Data Selection dialog, highlight `PostFireOLISubset.dat`.
11. Click the **Mask** button.
12. In the Mask Selection dialog, select **Water**.
13. Enable the **Inverse** mask option, then click **OK**.



14. Click **OK** in the Data Selection dialog.
15. In the Save File As Parameters dialog, enter **0** for the **Data Ignore Value**.
16. Enter an output filename of **`PostFireOLISubsetMasked.dat`**.
17. Enable the **Display result** option.



18. After processing is complete, uncheck the **PostFireOLISubset.dat** layer in the Layer Manager so that only PostFireOLISubsetMasked.dat is visible in the display.
19. Click the **Cursor Value** icon in the ENVI toolbar.
20. Move the red crosshairs over the white ocean pixels, and verify that the Cursor Value dialog reports `NoData` values for those pixels:



21. Close the Cursor Value dialog.
22. Right-click on the **View** entry in the Layer Manager and select **Remove All Layers**.

Calibrate OLI Bands to Reflectance

To create spectral index images such as Burn Area Index and Normalized Burn Ratio, the source images should be calibrated to top-of-atmosphere (TOA) reflectance, where pixel values range from 0 to 1.0 or 0 to 100.

Tip: Using rigorous, model-based atmospheric correction methods such as FLAASH and QUAC to create apparent surface reflectance images is usually unnecessary when creating burn index images from multispectral imagery. If you wish to create a surface reflectance images, tools such as Dark Subtraction, Flat Field, or IARR are often sufficient.

1. In the search window of the Toolbox, type **calibration**. Double-click the Radiometric Calibration tool name that appears.
2. In the Data Selection dialog, select the file **`PostFireOLISubsetMasked.dat`**, and click **OK**.
3. In the Radiometric Calibration dialog, select **Reflectance** from the **Calibration Type** drop-down list.
4. Keep the default selections for all other settings. Do not click the **Apply FLAASH Settings** button.
5. Enter an output filename of **`PostFireReflectance.dat`**, and click **OK**.
6. Wait for the RadiometricCalibration process to complete in the Process Manager (in the lower-right corner of the interface):

Calibrate Thermal Bands to Brightness Temperatures

This step is only required for creating a "Normalized Burn Ratio - Thermal" image, which this tutorial covers. Since Landsat thermal bands are not used for Burn Area Index or Normalized Burn Ratio spectral indices, you do not need to calibrate the thermal bands or perform layer stacking for these indices. You do not need to create a water mask for the thermal bands.

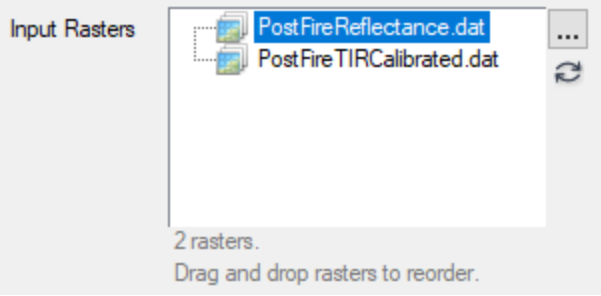
Perform these steps to calibrate the thermal bands to brightness temperatures (in Kelvins):

1. From the menu bar, select **File > Open**.
2. Select the file **`PostFireTIRSubset.dat`**, and click **Open**. The Thermal Infrared 1 band appears in the display.
3. In the search window of the Toolbox, type **calibration**. Double-click the **Radiometric Calibration** tool name that appears.
4. In the Data Selection dialog, select the file **`PostFireTIRSubset.dat`**, and click **OK**.
5. In the Radiometric Calibration dialog, select **Brightness Temperature** from the **Calibration Type** drop-down list.
6. Keep the default selections for all other settings. Do not click the **Apply FLAASH Settings** button.
7. Enter an output filename of **`PostFireTIRCalibrated.dat`**, and click **OK**.

Create a Layer-Stacked Image

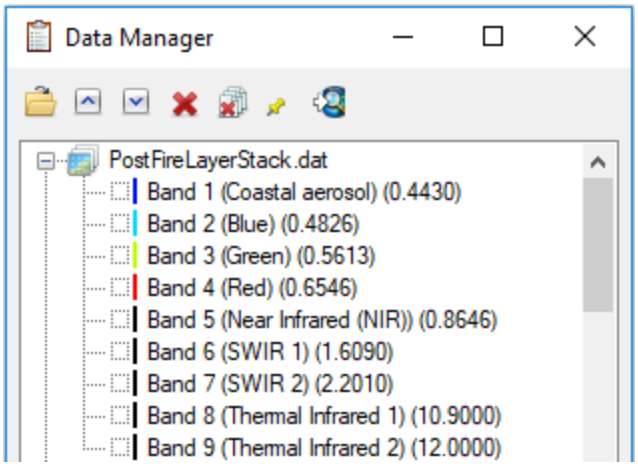
This step will combine the calibrated thermal and OLI bands into one file so that you can use the **Spectral Indices** and **Band Math** tools later to create a "Normalized Burn Ratio - Thermal" image. You do not need to build layer stacks to compute Burn Area Index or Normalized Burn Ratio spectral indices.

1. In the search window of the Toolbox, type **layer stack**. Double-click the **Build Layer Stack** tool name that appears.
2. In the Build Layer Stack dialog, click the **Browse** button ... next to **Input Rasters**.
3. In the Data Selection dialog, use the **Ctrl** key on your keyboard to select both **`PostFireReflectance.dat`** and **`PostFireTIRCalibrated.dat`**. Click **OK**.
4. In the **Input Rasters** field, drag **`PostFireReflectance.dat`** above **`PostFireTIRCalibrated.dat`**.



5. From the **Resampling** drop-down list, select **Cubic Convolution**.

6. Keep the remaining parameters at their default settings.
7. Enter an output filename of **`PostFireLayerStack.dat`**, and click **OK**.
8. When processing is complete, click the **Data Manager** icon in the toolbar.
9. Verify that the layer stack includes seven OLI bands and two TIR bands.

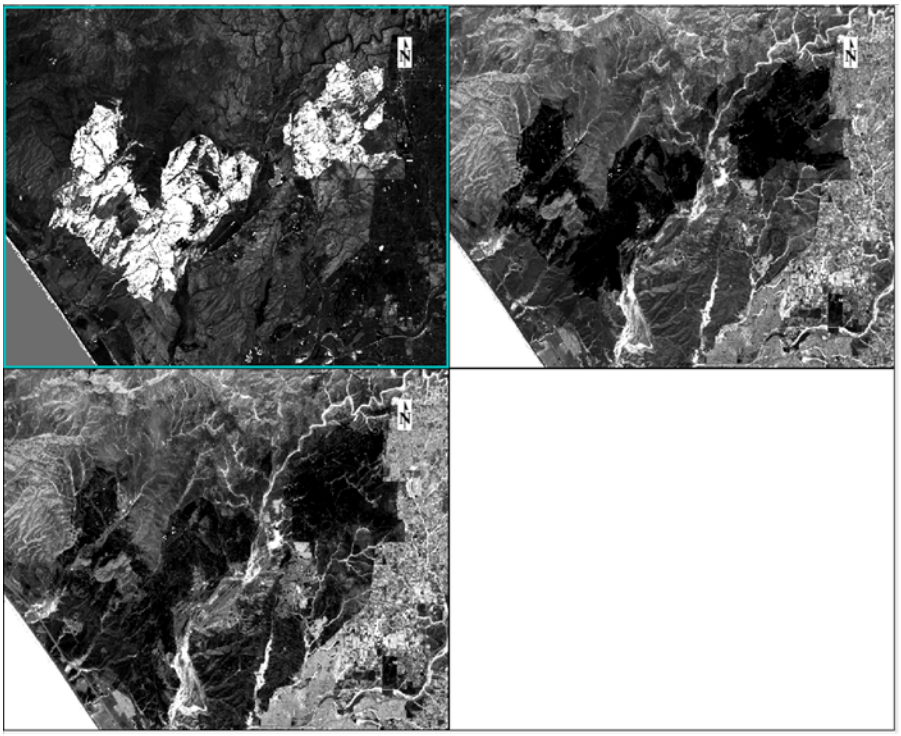


Create Burn Index Images

ENVI's **Spectral Index** tool creates images that represent different indices such as vegetation, burned areas, geologic, and built-up features. You must run this tool each time you create an index image. Follow these steps to compute burn indices:

1. In the search window of the toolbox, type **spectral indices**. Double-click the **Spectral Indices** tool name that appears.
2. In the Data Selection dialog, select the file **`PostFireLayerStack.dat`**, and click **OK**.
3. In the **Index** list, select **Burn Area Index**.
4. In the **Output Raster** field, enter a filename of **`BAI.dat`** and click **OK**.
5. Repeat Steps 1-4 for the following indices:
   - **Normalized Burn Ratio** (output filename: **`PostFireNBR.dat`**)
   - **Normalized Burn Ratio Thermal 1** (output filename: **`NBRT1.dat`**)
6. From the menu bar, select **Views > 2x2 Views**. Four empty views appear in the display.

7. Drag and drop the **Burn Area Index** band name from the Data Manager to the upper-left view.
8. Drag and drop the **Normalized Burn Ratio** band name from the Data Manager to the upper-right view.
9. Drag and drop the **Normalized Burn Ratio Thermal 1** band name from the Data Manager to the lower-left view.
10. From the menu bar, select **Views > Link Views**.
11. With the **Geo Link** option already selected, click **Link All**. Then click **OK**. All three views center over the same geographic location.
12. In the **Go To** field of the toolbar, type the pixel coordinates **631, 472** and press the **Enter** key. The views center over the burned region near Camp Pendleton.



Notice that the brighter pixels in the Burn Area Index image (upper-left view) indicate burned areas, while darker pixels indicate burned areas in the Normalized Burn Ratio images.

1. Enter the following pixel coordinates in the **Go To** field to explore other burned areas:
   - **1214, 530** (Fallbrook)
   - **1263, 1669** and **873, 1260** (Carlsbad)
   - **1246, 1253** (San Marcos)
   - **58, 123** (Camp Pendleton)
2. Use the navigation, zoom, and stretch tools in the toolbar to further explore the images. How are the Normalized Burn Ratio and its thermal version different from each other? Does one separate burned areas better than the other?
3. When you are finished, right-click on each **View** item in the Layer Manager and select **Remove View**.

Differenced Normalized Burn Ratio

A differenced normalized burn ratio (ΔNBR) is another burn-severity product that measures absolute change in the NBR. You can easily create a ΔNBR image by performing these steps:

1. Create an NBR image immediately before the fire.
2. Create an NBR image during, or after the fire.
3. Subtract the post-fire NBR image from the pre-fire NBR image.

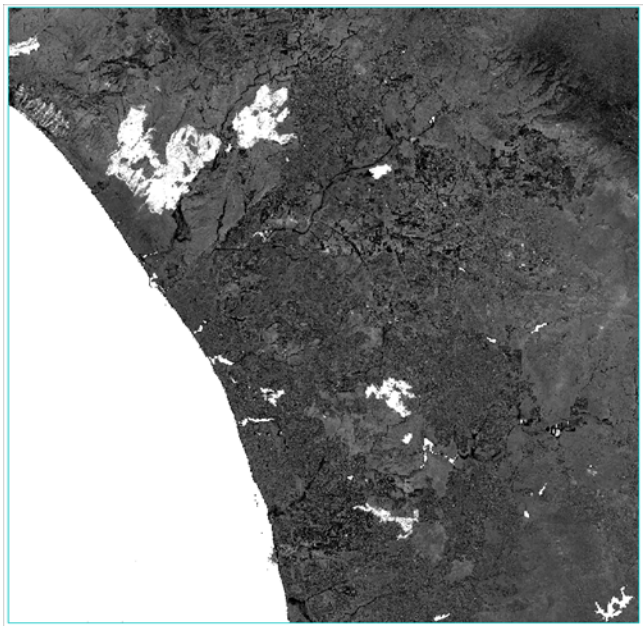
Brighter pixels indicate higher levels of burn severity.

Normally you would have to perform all of the pre-processing steps for the pre-fire image that you did for the post-fire image in this tutorial, except for thermal band calibration and layer stacking. We have done all of these steps for you for the pre-fire image.

Follow these steps to create a ΔNBR image:

1. From the menu bar, select **File > Open**.
2. Select the file **`PreFireNBR.dat`**, and click **OK**. The pre-fire NBR image is displayed.
3. Type **band math** in the Search window of the Toolbox, and double-click the **Band Math** tool name.
4. In the **Enter an expression** field, enter **float(b2 - b1)**.
5. Click **Add to List**, then click **OK**.
6. With **B1 - [undefined]** selected in the Variables to Band Pairings dialog, click the **Normalized Burn Ratio** band under **PostFireNBR.dat**.
7. Select **B2 - [undefined]**.

8. Click the **Normalized Burn Ratio** band under **PreFireNBR.dat**.
9. Enter an output filename of **`DifferencedNBR.dat`** and click **OK**. The following image appears, with the white pixels indicating burned areas. (The masked ocean pixels are also colored white.)



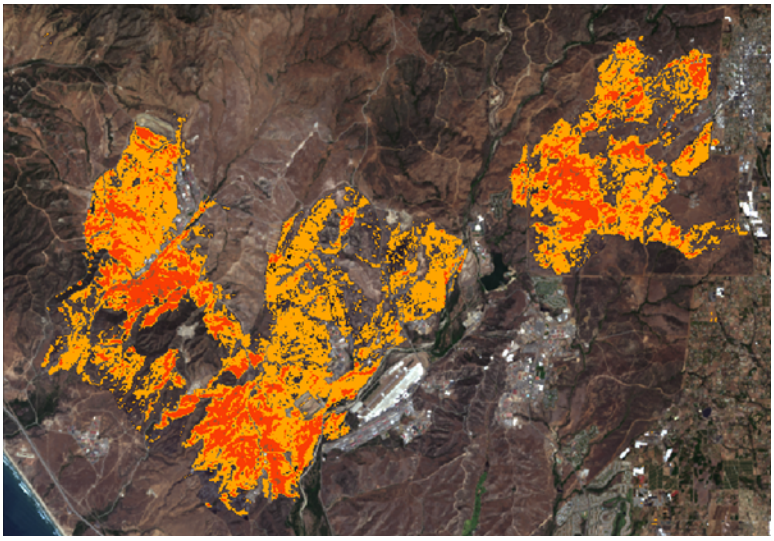
The U.S. Geological Survey FIREMON program (Key and Benson, 2005) published categories of burn severity, based on pixel values that have been scaled accordingly:

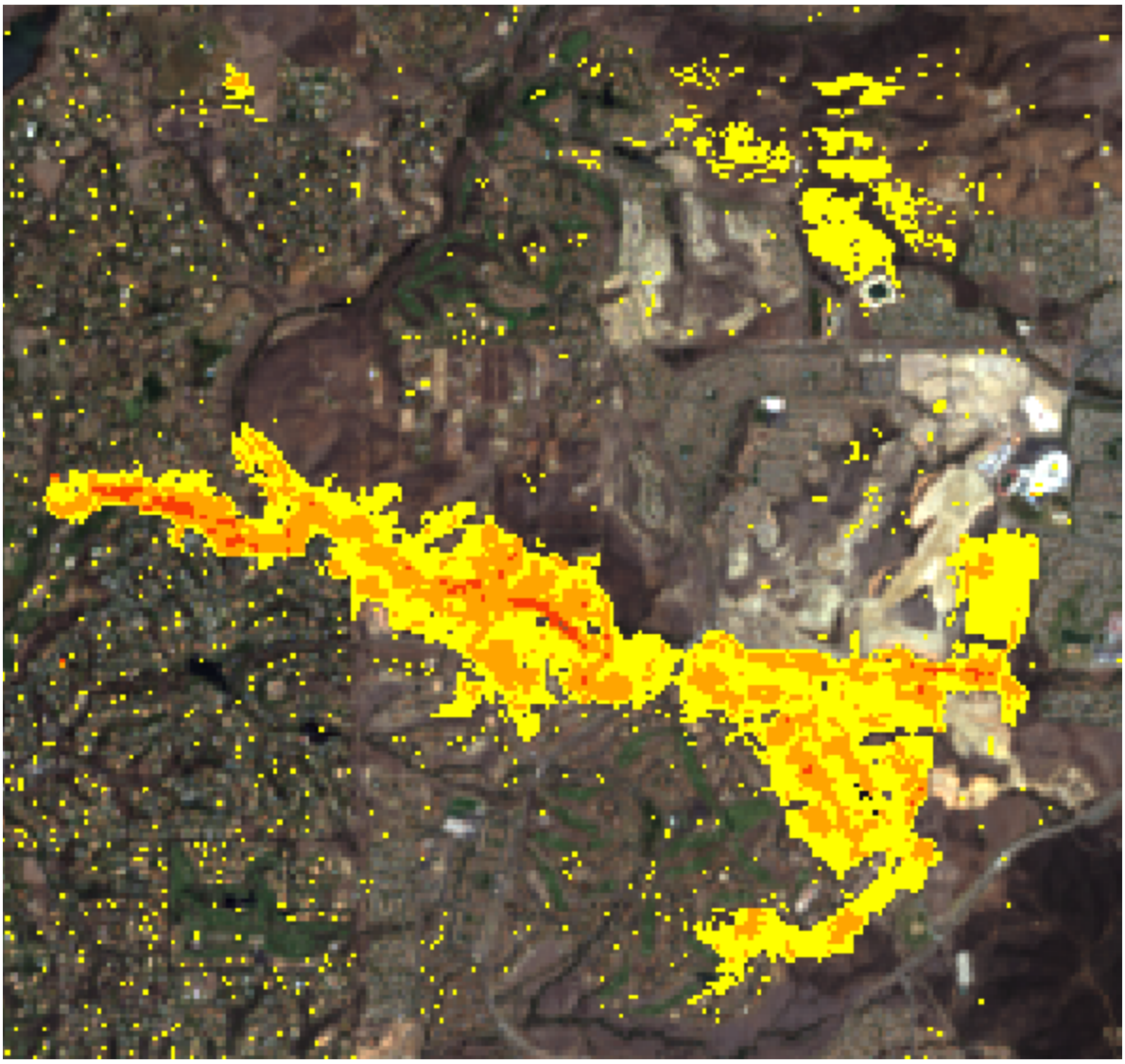
ΔNBR Values	Burn Severity
< -0.25	High post-fire regrowth
-0.25 to -0.1	Low post-fire regrowth
-0.1 to 0.1	Unburned
0.1 to 0.27	Low-severity burn
0.27 to 0.44	Moderate- to low- severity burn
0.44 to 0.66	Moderate- to high-severity burn
> 0.66	High-severity burn

We created a density color slice file that you can overlay on the ΔNBR image.

1. Right-click on the **`DifferencedNBR.dat`** layer in the Layer Manager and select **New Raster Color Slice**.
2. Select the **Band Math** band name under `DifferencedNBR.dat`, and click **OK**.

3. Click the **Clear Color Slices** button .
4. Click the **Open** button and select the file `DNBRColorSlice.dsr`. Click **Open**. The image is divided into different colors as defined by this color slice.
5. Click **OK**.
6. Uncheck the grey-colored box in the Layer Manager that represents the range of pixel values from -0.1 to 0.1.
7. In the **Go To** field of the toolbar, type the pixel coordinates **631p,472p** and press the **Enter** key.
8. In the **Zoom To** drop-down menu in the toolbar, enter **125** (%). The display centers over the Camp Pendleton burn area.
9. In the Layer Manager, click to deselect the purple, blue, and grey boxes. Only the highest levels of burn severity are displayed. The following images show examples of different levels of burn severity overlaid on the post-fire Landsat image:





This concludes the Burn Indices tutorial.