Multispectral Imaging

⇦ Overview

Learning Goals

- List the spectral band designations for the Landsat 8 satellite.
- Load and display single band images.
- Use metadata to rescale a spectral band.
- Create an RGB image from spectral bands.

Table of Contents

Earth Observation

Historical data illustrates that global temperatures have risen over the last 40 years. Continued global temperature increase has been projected to result in increased drought, wildfires, hurricanes, and rising sea levels [1].

To evaluate whether such changes are occurring and to what extent, you can explore additional data. Remote sensors, such as satellites, offer vast quantities of data useful for characterizing regional climate and weather.

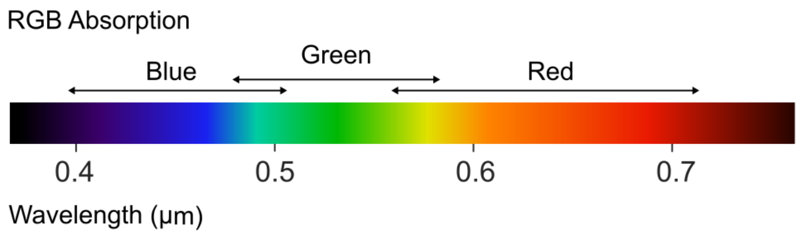
Drought conditions shown at the Alto Rabagão Reservoir in the Iberian Peninsula. Data acquired on March 6, 2021 (left) and February 5, 2022 (right). Images courtesy of NASA [2]. *These images were created using Landsat 8 data.*

Fire in the Colorado Rockies on October 22, 2020. Image courtesy of NASA [3]. *This image was created using Landsat 8 data.*

Hurricane Isabel viewed from the International Space Station on September 13, 2003. Image courtesy of NASA [4].

Multispectral Imaging

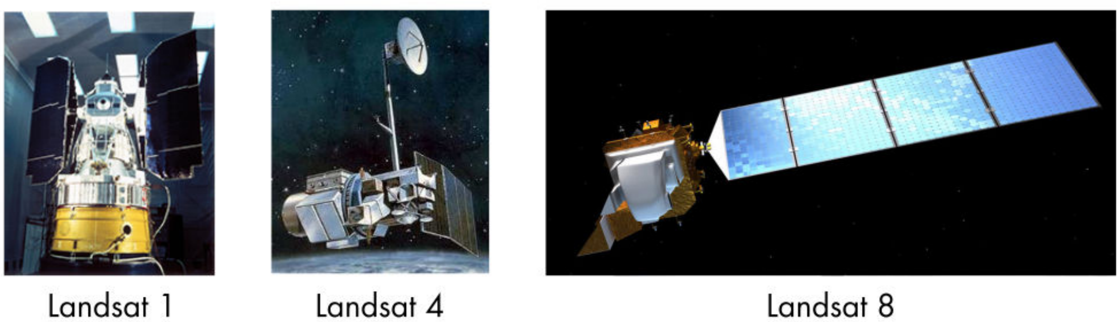
A typical DSLR camera absorbs three bands in the visible spectrum, illustrated below.



RGB color band absorption range illustration.

Each pixel recorded by the sensor contains three values: red, green, and blue. Together, they determine the display color of that pixel. This implies that an $n \times m$ RGB image is an array with size $n \times m \times 3$. Such a color image array can be thought of as a stack of three $n \times m$ matrices: one associated with each color channel (red, green, and blue).

Multispectral images differ from standard RGB images in that they absorb light from additional wavelengths besides red, green, and blue. Satellites that observe the Earth's surface typically absorb in the visible and infrared bands. The first satellite to take multispectral images of the Earth was Landsat 1, launched in 1972. Since then, there have been 8 other Landsat satellites. The most recent satellite, Landsat 9, was launched on September 27, 2021.

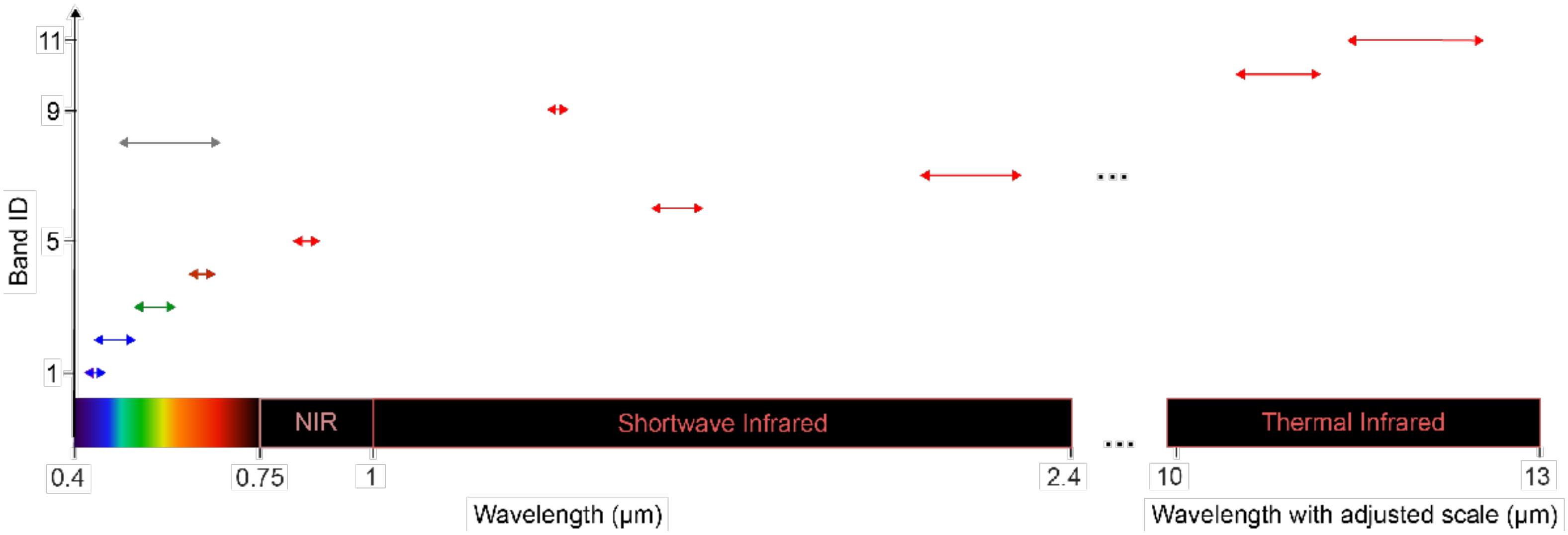


The Landsat 1 satellite and artistic renderings of the Landsat 4 and 8 satellites. Images courtesy of USGS [6-8].

In this live script, you will work with data from the Landsat 8 satellite. Landsat 8 is equipped with an Operational Land Imager (OLI) and a Thermal Infrared Sensor (TIRS). These sensors absorb several bands (illustrated below) [5]:

- Band 1 - Coastal aerosol (0.43-0.45 microns)
- Band 2 - Blue (0.45-0.51 microns)
- Band 3 - Green (0.53-0.59 microns)
- Band 4 - Red (0.64-0.67 microns)
- Band 5 - Near Infrared (NIR) (0.85-0.88 microns)
- Band 6 - Short wave infrared SWIR 1 (1.57-1.65 microns)
- Band 7 - Short wave infrared SWIR 2 (2.11-2.29 microns)

- Band 8 - Panchromatic PAN (0.50 - 0.68 microns)
- Band 9 - Cirrus (1.36 - 1.38 microns)
- Band 10 - Thermal Infrared TIRS 1 (10.6-11.19 microns)
- Band 11 - Thermal Infrared TIRS 2 (11.5-12.51 microns)



Landsat 8 spectral bands. The bands are plotted on a linear scale. The thermal infrared band scale has been adjusted to fit in the window.

What advantage does multispectral imaging have over traditional RGB images? The additional bands allow you to characterize vegetation, water, and other features more easily. This is often accomplished by computing indices that consider the absorption spectra of the species under inquiry. In the following sections, you will visually analyze indices to characterize how the conditions on the Earth's surface have changed over time.

Displaying Multispectral Bands

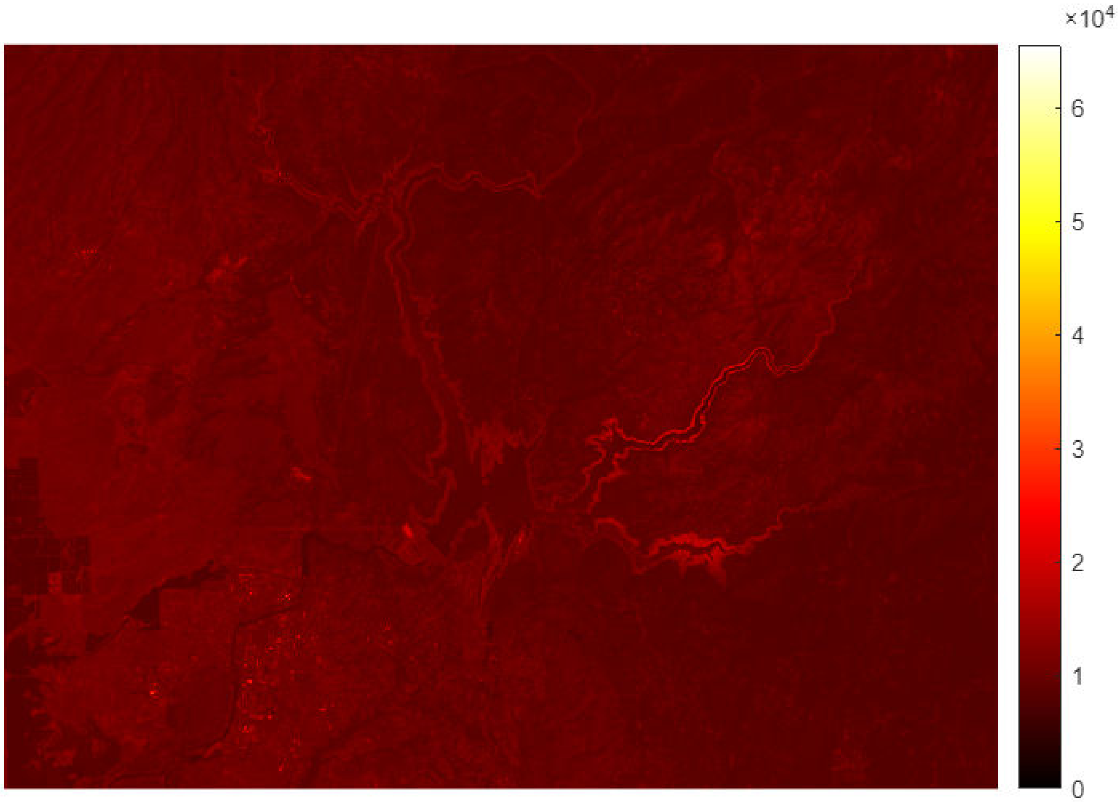
Individual spectral bands can be displayed as an image. However, because they contain only one channel, you will observe only a grayscale image.

Activity. In this activity, you will load and display single bands of multispectral image data of Lake Oroville (in northern California, USA) in 2021. This data is provided courtesy of the United States Geological Survey (USGS) [9]. Note that the data files have been cropped and their names simplified. Otherwise, the data is identical to the raw data. The files are included in this repository in:

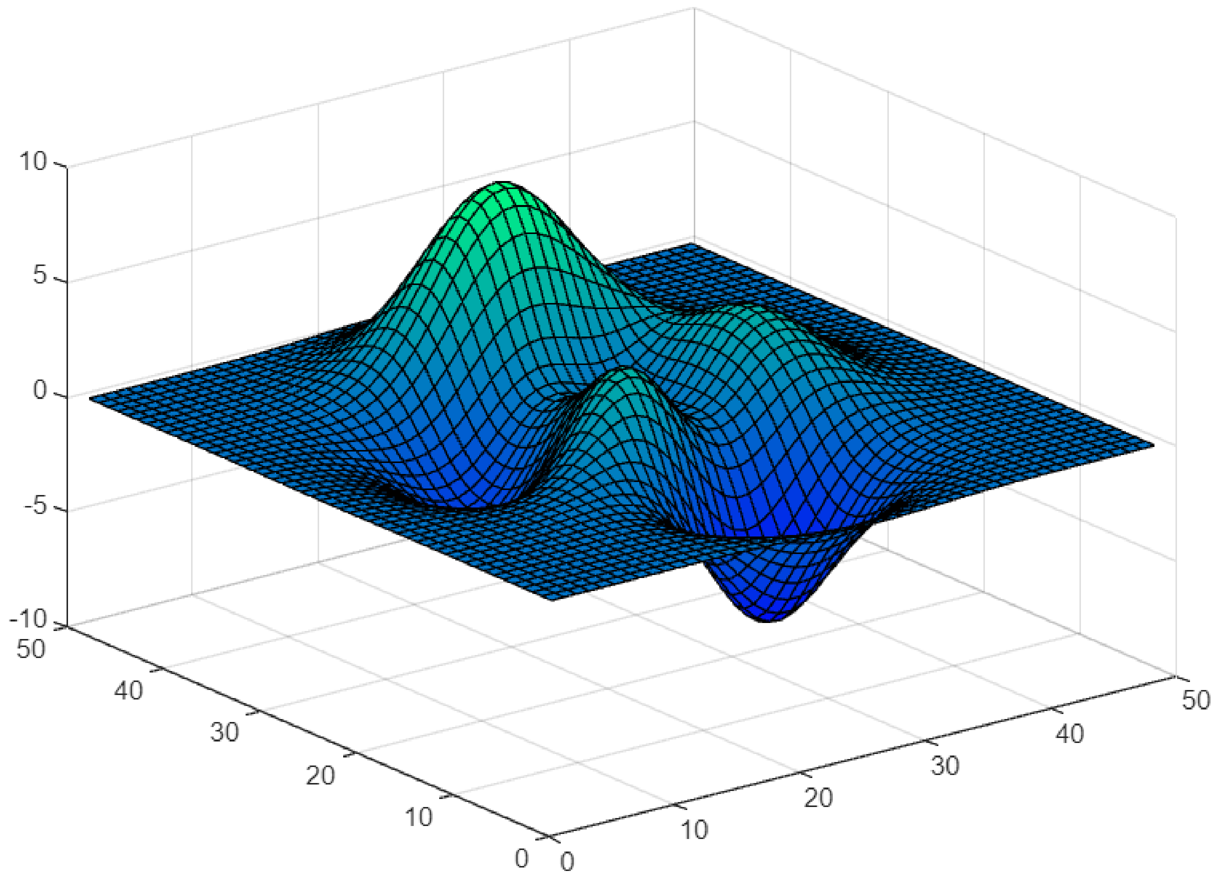
```
Data/LandsatLakeOroville_2021-06-25
```

Task 1. Run this section to load and display a single band of Landsat 8 data.

```
dataFile = "044033_20210625_B3.tif";
I = imread(dataFile);
imshow(I)
colormap hot
colorbar
```




```
surf(peaks)
colormap winter
```



Task 2. Each band is contained in a different image file: `044033_20210625_B$.tif`, where the $ is replaced with the band number (e.g., 5 or 11). Adjust the call to `imread` in the code above to select and display the near-infrared (NIR) band (refer to this list of Landsat 8 bands). What feature stands out most in this band?

Task 3. The default colormap for displaying a single band is grayscale. You can change the colormap using the command `colormap`. Use the `hot` colormap by adding the command

```
colormap hot
```

to the code above.

Task 4. You can identify the measured intensity of each pixel by adding a colorbar using the command: `colorbar`. You should notice that one region has substantially lower intensity values. Does this imply that more or less NIR radiation was absorbed by that region (compared to the rest of the image)?

Task 5. Try a few other bands. Do you notice other features standing out in particular bands?

Creating an RGB Image

Viewing individual bands of multispectral images can feel unsatisfying, since most images are in color. You can create a color image from bands 2, 3, and 4 of the Landsat 8 data, which record visible blue, green, and red radiation, respectively. This won't appear exactly the same as a typical true color image, but can be tweaked to create an informative color image.

Activity. In this activity, you will create an RGB image from the Landsat 8 data of Lake Oroville in 2021.

Task 1. Read bands 2, 3, and 4 of the Landsat 8 data using `imread` and store the result in variables named `B`, `G`, and `R`, respectively. Recall that the images are named : `044033_20210625_B$.tif`, where the $ is replaced with the band number.

```
B = imread("044033_20210625_B2.tif")
```

```
B = 1013×1352 uint16 matrix
     9499    9875   10160   10270   10068   10074   10291   10269   10210   10343 ···
     9518   10014   10250   10123   10109   10180   10324   10391   10405   10315
     9476    9969   10198   10131   10152   10281   10327   10309   10354   10396
     9550    9877   10217   10423   10394   10394   10181   10137   10394   10430
     9574    9946   10294   10383   10398   10193    9955    9820    9965   10171
     9523   10016   10340   10680   10067    9838    9996    9901    9913   10082
     9672    9992   10609   10810    9916    9903    9859    9892    9987   10263
     9839   10067   10659   10225    9977    9956    9907    9961    9966    9995
     9918   10237   10388   10007    9902    9996    9953    9966   10045    9848
    10003   10150   10215   10131   10050    9959    9991   10258   10492   10217
      ⋮
```

```
G = imread("044033_20210625_B3.tif")
```

```
G = 1013×1352 uint16 matrix
     9136    9456    9812    9999    9764    9687   10139   10171   10064   10203 ···
     9134    9661   10062    9885    9762    9866   10120   10262   10183   10244
     9092    9426    9934    9885    9943   10142   10099   10036   10168   10239
     9095    9456    9868   10230   10209   10258    9877    9716   10051   10184
     9118    9517    9947   10311   10186   10002    9868    9695    9796    9929
     9128    9580    9996   10519    9962    9693    9862    9695    9647    9983
     9228    9553   10243   10598    9717    9728    9612    9622    9752   10025
     9387    9552   10466   10056    9806    9731    9650    9706    9699    9769
     9454    9883   10285    9914    9762    9783    9758    9763    9811    9654
     9704    9858   10131    9954    9864    9738    9692   10028   10196    9847
      ⋮
```

```
R = imread("044033_20210625_B4.tif")
```

```
R = 1013×1352 uint16 matrix
     9094   10158   10998   11190   10994   10938   11566   11600   11225   11258 ···
     8933   10570   11201   11139   11043   11103   11504   11612   11321   11459
     8891    9978   11034   11092   11081   11237   11387   11252   11436   11507
     9022    9971   11025   11394   11534   11478   10616   10091   10835   10982
     9091   10122   11103   11682   11574   10807   10377    9979   10364   10492
     9070   10097   10928   11781   10432    9949   10446    9960    9905   10587
     9365    9875   11139   11429   10000   10179    9986    9997   10161   10545
     9796    9781   11241   10485   10319   10276   10151   10161    9984   10257
     9847   10321   10922   10491   10371   10366   10256   10106   10322   10092
    10185   10288   10909   10543   10501   10251   10101   10691   10925   10161
      ⋮
```

Task 2. To make a color image, you need to stack the three individual bands (which have size $n \times m$) along a third dimension. This will create an RGB image of size $n \times m \times 3$. Use the `cat` function to create the RGB image, and store the result in `Irgb`. Use the syntax

```
cat(N, A1, A2, A3)
```

where `N` is the dimension along which the arrays will be concatenated (use `N = 3`), and `A1`, `A2`, and `A3` are the arrays to be concatenated. You should concatenate the matrices in the order: R, G, B.

```
Irgb = cat(3,R,G,B)
```

```
Irgb = 1013×1352×3 uint16 array
Irgb(:,:,1) =

    9094   10158   10998   11190   10994   10938   11566   11600   11225   11258   11368   11220   11712   11271
      ⋮
```

Task 3. Display the image you created using `imshow`.

```
imshow(Irgb)
```

Rescaling Image Data

You probably noticed that the RGB image appeared quite dim. The raw TIF files are recorded as digital numbers (DN), which aren't scaled well for image display. A clearer image can be created by rescaling the bands using coefficients provided in the metadata file. Rescaling the image using the coefficients provided in the metadata also has other benefits for comparing Landsat images taken in different years and/or by different satellites.

Activity. In this activity, you will rescale the Landsat data to top of atmosphere (TOA) reflectance (following [10]) and display the result.

Task 1. Open the text metadata file associated with the data: LC08_L1TP_044033_20210625_20210707_02_T1_MTL.txt. Inside, find the value of REFLECTANCE_ADD_BAND_2 and REFLECTANCE_MULT_BAND_2. Store the additive value in a new variable called `Arho` and the multiplicative factor in `Mrho`. These values are the same for all the bands, so you only need to record them once.

```
% Replace the NaNs with the correct values
Arho = -0.100000;
Mrho = 2.0000E-05;
```

Task 2. In the previous activity, you created an RGB matrix `Irgb` that contains the digital number (DN) data. `Irgb` is stored as integer data (`uint16`). In order to perform the necessary operations, you need to convert the data to a floating-point type. Use the `double` function to convert `Irgb` to double-precision data and store the result in `Id`.

```
Id = double(Irgb);
```

Task 3. Rescale the image that was converted to doubles (`Id`) using the formula for TOA reflectance [10]:

$$\rho = M_\rho Q + A_\rho$$

where Q represents the DN data, and `Mrho` and `Arho` are the values you identified in **Task 1**. Store the result in `Irho`.

```
Irho = Mrho * Id + Arho;
```

Task 4. The image created in the previous task contains raw reflectance values in the range of `[0,1]`. To create an image from this, multiply `Irho` by `255` and then convert it to `uint8` data (which is the most common image data type) using the `uint8` function. Store the result in `Ilake` and display it with `imshow`.

```
Ilake = uint8(Irho * 800)
```

```
Ilake = 1013×1352×3 uint8 array
Ilake(:,:,1) =

    66    83    96    99    96    95   105   106   100   100   102   100   107   100    84    84    76    70    89
     ⋮
```

```
imshow(Ilake)
```

[⇦ Overview]

Task 5. Even though the image has been rescaled, it is still quite dark. Use the command `imhist` to show an intensity histogram of the `Ilake`. The histogram illustrates the distribution of pixel value (i.e., how light or dark the pixels are). Notice that most of the pixels have low brightness.

```
imhist(Ilake);
```

Task 6. Because the pixels have intensities distributed close to zero, multiplying the image by a larger positive number will brighten the image without much washout. In the code for **Task 4**, increase the multiplier to 800. Then, display the image and the histogram.

Task 7. Tweak the brightness multiplier three times. What value do you prefer?

⇦ Overview

References

[1] The Effects of Climate Change. Global Climate Change, Vital Signs of the Planet. NASA. Accessed March 8, 2022 from https://climate.nasa.gov/effects/.

[2] NASA Earth Observatory images by Lauren Dauphin, using Landsat data from the U.S. Geological Survey. https://visibleearth.nasa.gov/images/149469/iberian-peninsula-drought/149471w

[3] NASA Earth Observatory images by Lauren Dauphin, using Landsat data from the U.S. Geological Survey. Story by Kasha Patel. https://visibleearth.nasa.gov/images/147452/east-troublesome-fire-spreads-to-the-rockies/147454w

[4] Image courtesy of Mike Trenchard, Earth Sciences & Image Analysis Laboratory, Johnson Space Center. https://visibleearth.nasa.gov/images/12132/hurricane-isabel/12133l

[5] Landsat 8, United States Geological Survey website. https://www.usgs.gov/landsat-missions/landsat-8. Accessed March 9, 2022.

[6] The Landsat 1 Satellite, United States Geological Survey website. https://www.usgs.gov/media/images/landsat-1-satellite. Accessed March 9, 2022.

[7] Rendering of Landsat 4 and Landsat 5, United States Geological Survey website. https://www.usgs.gov/media/images/rendering-landsat-4-and-landsat-5. Accessed March 9, 2022.

[8] Landsat 8 illustration above Earth. Earth Resources Observation and Science (EROS) Center. United States Geological Survey website. https://www.usgs.gov/media/images/landsat-8-illustration-above-earth. Accessed March 9, 2022.

[9] Landsat 8 Collection 1 Level-1, United States Geological Survey, Accessed March 9, 2022 at https://earthexplorer.usgs.gov/.

[10] Using the USGS Landsat Level-1 Data Product. United States Geological Survey, Accessed March 9, 2022 at https://www.usgs.gov/landsat-missions/using-usgs-landsat-level-1-data-product.