Lesson 5: Radiometric Correction

Lesson Description
This lesson will demonstrate the various preprocessing levels of remote sensing imagery. Preprocessing is essential when working with multiple images because it can remove differences in images that result from the time of day the images were captured, sensor differences, and atmospheric effects such as haze. This lesson will use Landsat data to demonstrate the differences in corrected vs uncorrected data and outline how to acquire high level products that have already been preprocessed.

Objectives:
The student will:
1) Learn the basic levels of preprocessing and how they differ
2) Understand how to acquire high level products

Keywords:
Digital Number, Top-of-Atmosphere Reflectance, Surface Reflectance, Landsat CDR

Resources Required:
ArcMap

Data Used:
- DN_Mar_169051.tif: 3 band RGB March Landsat image Path 169 Row 051 in Digital Number units
- DN_Nov_169051.tif: 3 band RGB November Landsat image Path 169 Row 051 in Digital Number units
- TOA_Mar_169051.tif: 3 band RGB March Landsat image Path 169 Row 051 in TOA Reflectance units derived in ENVI software
- TOA_Nov_169051.tif: 3 band RGB November Landsat image Path 169 Row 051 TOA Reflectance units derived in ENVI software
- SR_Mar_169051.tif: 3 band RGB March Landsat image Path 169 Row 051 Surface Reflectance units acquired from USGS Climate Data Records (CDR)
- SR_Nov_169051.tif: 3 band RGB November Landsat image Path 169 Row 051 Surface Reflectance units acquired from USGS CDR
- PIF.shp: Pseudo-invariant features point shapefile

Background:
Images collected by remote sensing satellites are affected by a number of distortions that result from differences in sensor calibration, solar, and atmospheric effects on the signal received by the satellite sensor. When working with multiple images, these effects should be minimized using absolute radiometric correction to ensure the most accurate results. While the exact methods used to correct these distortions will vary sensor to sensor, the general principles and units of measurement described here are consistent across most remotely sensed data.
Lesson:
Step 1. Understanding Levels of Preprocessing

Converting raw imagery into absolute values is a complex process requiring multiple levels of correction. Each correction type is designed to minimize different types of distortions within the image (Figure 1). The amount of preprocessing required and the units you decide to use depend on the extent (both spatially and temporally) and purpose of your analysis. The types of imagery correction are as follows:

**Sensor Calibration** (Radiance units)
- Corrects for differences in sensor calibration and sensor degradation over time

**Solar Correction** (Top-of-Atmosphere Reflectance units)
- Corrects for solar effects such as Earth-Sun distance and solar elevation

**Atmospheric Correction** (Surface Reflectance units)
- Corrects for atmospheric gases and aerosols; atmospheric scattering; haze

**Topographic Correction**
- Not covered in this lesson, but is only required in some situations (typically very rugged terrain)
- Corrects for differences in observed brightness/darkness due to sun location; slope and aspect that would otherwise not be present on a horizontal geometry

![Figure 1. Common corrections and units for preprocessing remotely sensed imagery adapted from Young et al. (2017)](image-url)
Each of the corrections above are represented using different units of measurement (Digital number, radiance, reflectance). Figure 2 shows the sequential workflow of potential preprocessing steps. Each step is not required for all analyses. Preprocessing units are displayed in bold text in Figure 2 and are described as follows:

**Digital Number**

The most commonly downloaded Landsat data is the Standard Terrain Corrected (L1T) product. The values within these images are stored as digital numbers (DN). The DNs are ‘raw pixel values’ that represent the electromagnetic radiation captured by the satellite sensor. Digital numbers do not have actual physical units, instead, they are simply scaled representations of radiance. As such, DNs should only be used for analysis when you are comparing relative values within a single image. That is, the data must be preprocessed to a higher level product if you plan to use multiple images in an analysis or need absolute physical values (e.g., surface albedo, leaf-area index, etc.).

**Radiance**

The most basic form of correction is a sensor calibration to units of radiance. Separate satellite sensors are not perfectly calibrated to one another and individual sensors also degrade over time. As such, digital number values can be calibrated to radiance to reduce these sensor effects. Radiance is the amount of radiation observed by the satellite sensor, measured in watts per steradian per square meter and is calculated using gains and offsets found in the image metadata, which can then be applied to convert digital number to radiance. Radiance is typically only used in rare circumstances where watts per square meter is needed.

**Reflectance (Top-of-Atmosphere)**

All remote sensing data are affected by solar and atmospheric influences. To eliminate solar effects, the data can be converted to top-of-atmosphere (TOA) reflectance. Reflectance, as a general unit of measurement, is the ratio of radiation reflected by an object proportional to the radiation incident upon the object. This means that reflectance is a unitless property of the object being measured, meaning if the same object is measured multiple times, the reflectance value should always be the same (this is different from radiance, which measures the actual energy emitted by the object, which is affected by the quantity of sunlight at that point in time). The conversion to top-of-atmosphere reflectance minimizes solar effects, including the Earth-Sun distance and the solar elevation angle at the date, time, and location of image acquisition. Conversion to TOA reflectance requires knowledge of the Earth-Sun.
distance and solar elevation, which is found in the metadata of the imagery. Most remote sensing software packages (ENVI, Erdas, R packages) have tools to convert to TOA reflectance.

**Reflectance (Surface)**
After converting to top-of-atmosphere reflectance, the reflectance values are still influenced by effects from the atmosphere (e.g., haze, atmospheric scattering.). If you are working with multiple images in your analysis (through time or space), it is often recommended to use surface reflectance to ensure the images are as similar as possible. However, removing atmospheric effects is much more complex than the other conversions presented in this lesson. While algorithms do exist to manually convert to surface reflectance, it is not recommended for novice users to attempt their own correction. Ancillary datasets with atmospheric and haze information are typically required to perform these corrections and the complexity of these algorithms often means additional error may be added to the imagery data. Fortunately, the United State Geological Survey (USGS) provides global high level Landsat surface reflectance products directly for download, which will be covered in this lesson.

![Example of atmospheric correction using LEDAPS](https://daac.ornl.gov/MODELS/guides/LEDAPS.html)

Every remote sensing analysis is unique and the required preprocessing level is often dependent on the characteristics of the analysis, expertise of the user, and data availability. However, as a general rule, it is best to not modify the data beyond the level of preprocessing that is necessary, as each and every preprocessing step has the potential to inject an additional layer of error into the data.

Typically, if you are working with only a single image, and do not need physical unit measurements (e.g., energy, albedo, leaf-area index, etc.), it is best to work with your data as raw digital number units. If you are working with multiple images, surface reflectance is often the best option. If surface reflectance is not available, the images should be corrected as much as possible (TOA reflectance) or a relative correction should be used.
Step 2. Exploring Preprocessed Data

2.1 Copy the lesson 5 data folder into your local directory.

2.2 Add `DN_Nov_169051.tif` (digital number) to the map viewer. These images values are raw digital numbers that you will receive with most downloaded Landsat products.

We will begin by comparing these values to top-of-atmosphere reflectance, and surface reflectance values derived from the same product. While many software packages include functionality to perform these conversions, unfortunately ArcGIS does not have these features by default. As such, these datasets have already been preprocessed for this lesson. Later in this lesson, we will show you how to acquire higher level Landsat products without needing to perform your own calculations.

**NOTE:** External toolboxes can be added to ArcGIS to convert from Digital Number to top-of-atmosphere reflectance, such as the LandsatToolbox: https://www.arcgis.com/home/item.html?id=a60b0120a79f45ae990bb85f4d12edee

2.3 Add `TOA_Nov_169051.tif` (top-of-atmosphere reflectance) and `SR_Nov_169051.tif` (surface reflectance) to the map viewer. These are the same image as the digital number image, though preprocessed to different levels. Examine these three images. Visually, do you notice any differences? Use the Identify Tool to examine the pixel values for each image, how do they differ? Note that while the TOA and surface reflectance images both use the same units (reflectance), the TOA uses float values (e.g. 0.1114) while the SR image uses integer values (e.g., 1114). These values are interchangeable and are both a ratio (of radiation reflected by an object proportional to the radiation incident upon the object), but the surface reflectance values have simply been scaled to integer values because they take up less storage space than float values.

2.4 Turn off all the layers except for the November surface reflectance layer, `SR_Nov_169051.tif`. Click the Go To XY button, and go to X: 430,000 Y: 1,460,000. Examine this area. What do you think is going on in the area of black horizontal striping (Figure 4)? What are the values in those locations? This location is likely an artifact from the surface reflectance correction method. Sometimes errors can occur when correcting to surface reflectance. As such, you should always pay close attention to your data when using surface reflectance products. Accuracy may be further reduced in areas of:

- Hyper arid or snow-covered regions

![Figure 4. Areas of black horizontal stripes show artifact of surface reflectance algorithm](image)
• Areas with low sun angle conditions (> 65 degrees North or South)
• Coastal regions with small land area
• Areas with extensive cloud cover

One method to assess the accuracy of these products is by analyzing pseudo-invariant features (PIFs) within the imagery. These are features that have a reflectance that, in theory, will not change over time. Examples of PIFs include most manmade objects (asphalt, rooftops, etc.) and some natural features (large rock features, dense coniferous forest, dark/still water, etc.). In this case, we can assess the effect of each level of preprocessing by evaluating how different the spectral values between the March and November images are for the PIFs.

2.5 Add the PIFs that have already been created for you, PIF.shp. Examine the locations of the PIFs, do you think these are reasonable features that are unlikely to change through time? Are they representative of the whole scene? Examine the image, what other objects could be used as PIFs?

![Graph showing average percent difference between pixel values between the March and November images at the PIF locations.](image)

**Figure 5.** Shows the average percent difference between pixel values between the March and November images at the PIF locations

The average percent change in pixel values across these PIFs between March and November is illustrated in Figure 5.

In theory, the digital number product should have the highest difference in pixel values. Conversion to TOA reflectance should then result in less difference than DN as solar effects are removed.
Finally, surface reflectance should have the lowest percent difference, as it is the physical measurement of the surface without any atmospheric effects.

The Digital numbers had an average difference of 5.94%; TOA 4.82%; and SR 8.75%. This means the surface reflectance images actually have the highest amount of difference between the pixels. While the USGS surface reflectance products have been shown to be, in general, valid with good accuracy (Vuolo et al. 2015), there is always the potential these corrections can introduce additional error (Schroeder et al. 2006). This is why it is always important to examine your data products and to not preprocess your data if it is not necessary.

A possible explanation for the higher error in the surface reflectance product is that both images originally have minimal atmospheric effects (no visible haze, etc., TOA reflectance images had relatively minor differences in pixel values (average 4.8%)), as such, when the images are atmospherically corrected, additional error is injected with little benefit. However, in situations where atmospheric effects are more prevalent, any added error to the dataset would be offset by the benefit of removing the atmospheric effects.

Step 3. Acquiring High Level Datasets

As ArcGIS does not contain a built in function to preprocess remote sensing imagery, it is important to know how to acquire high level data products that have already been preprocessed for you. Fortunately, the USGS provides Landsat and MODIS imagery as high level products through its Earth Resource Observation and Science (EROS) Center Science Processing Architecture (ESPA) online interface (https://espa.cr.usgs.gov/), shown in Figure 6.

**NOTE:** Surface Reflectance products can also be downloaded using USGS EarthExplorer (https://earthexplorer.usgs.gov/)

Available products through the ESPA for Landsat imagery are:

- Raw Imagery (Level 1 product)
- Top of Atmosphere Reflectance
- Surface Reflectance
- Band 6 Brightness Temperature
- Surface Reflectance-based Spectral Indices (NDVI, NDMI, NBR, SAVI, EVI)
- Comparison between images and product statistics plotting

As well as output options for the imagery (file format, projection, cell size, image extent).
3.1 To order products from ESPA, you first need to create an account with USGS (https://espa.cr.usgs.gov/)

3.2 Next, create a text file (right click in Windows explorer > New > Text Document) that contains one scene identifier (filename) on each line. You can use EarthExplorer (https://earthexplorer.usgs.gov/ - see Lesson 1 – Downloading Data) to find the appropriate scene identifiers. The text file should contain only scene identifiers and have exactly one identifier per line, as such:

LT50340322011271PAC01
LT50340322010268PAC01

3.3 Save this text file and within the on-demand interface, select “Choose File” and upload your text file. Then check the products you would like to request and customize any options (format, projection, cell size, extent, etc.).

**NOTE:** If you select the option to reproject your data to Albers Equal Area, the Latitude of Origin and Central Meridian define where the map x,y units originate, these can be set to 0 to maintain true coordinates (only change these if you want x,y to be relative to your scene).

The Plot Output Product Statistics box can also be checked to generate a statistical comparison between surface reflectance products. This is particularly useful for comparing images from disparate sensors.
3.4 Finish by submitting your order, data processing can take up to 5 days (though it is often much faster). A link to the processed data will be sent to the supplied email address. When you receive the email, click your order ID to access and download the datasets.

The following links provide further information and useful links for USGS high level products:

**Landsat Higher-Level Data Products**

**Landsat Surface Reflectance Products**

**Landsat Surface Reflectance Derived Spectral Indices**
Exercise Questions

1. What is the best preprocessing unit (Digital Number, Radiance, Top of Atmosphere Reflectance, Surface Reflectance) to use for each of the following applications?

   a) Calculating relative soil moisture values between multiple locations within a single image

   ______________________________________________________

   b) Performing a change detection of vegetation density on multiple images through time

   ______________________________________________________

   c) Measuring surface albedo for a single scene

   ______________________________________________________

   d) Measuring surface energy, where watts/m² are required

   ______________________________________________________

2. Which preprocessing units minimize solar effects on the imagery? Which units for atmospheric effects?

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3. True/False: Imagery should be preprocessed as much as possible to ensure the best accuracy for all remote sensing applications.

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Works Cited


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