Converting Digital Numbers to Top of Atmosphere (ToA) Reflectance

The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors acquire temperature data and store this information as a digital number (DN) with a range between 0 and 255. It is possible to convert these DNs to ToA Reflectance using a two step process. The first step is to convert the DNs to radiance values using the bias and gain values specific to the individual scene you are working with. The second step converts the radiance data to ToA reflectance.

If you are working with Landsat data from the USGS in the “USGS GeoTIFF with Metadata” format, ENVI can easily convert these data in a single step. This process is described in Section 1 of this document. For all other Landsat data, you will need to apply the two-step process described in Section 2 of this document.

1. USGS GeoTIFF with Metadata format data:

The USGS now provides data in the GeoTIFF with Metadata format. Using ENVI software you can easily convert the optical band data to ToA reflectance values. Open the file that ends with “_MTL.TXT”. From the ENVI main menu bar, select **File ➔ Open Image File**. ENVI will automatically open the Landsat image as multiple files; the 6 bands of optical data as one file, and the thermal band as another. In the case of ETM images the thermal file will have two bands and there will also be a single band file for the panchromatic band.

To create a reflectance data file, from the ENVI main menu bar, select **Basic Tools ➔ Preprocessing ➔ Calibration Utilities ➔ Landsat Calibration**. Select the optical data file (it has six bands) and the *ENVI Landsat Calibration* dialog should open with all of the calibration parameters filled in (Figure 1). Click on the *Reflectance* radio button and enter an output file name. As a reminder, reflectance values range from 0.0 to 1.0 and are stored in floating point data format.

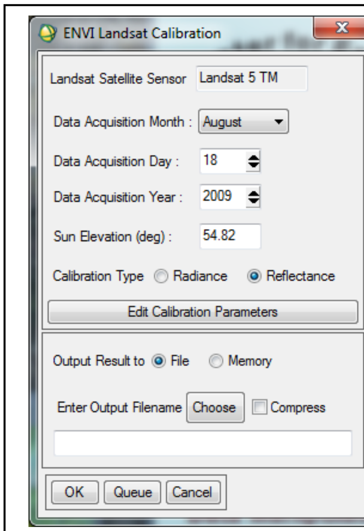

Figure 1

2. Converting other Landsat data to Reflectance:

As stated above, this is a two-step process. First you must convert DNs to radiance values. Then you need to convert these radiance values to reflectance values. For each scene you need to know the distance between the sun and earth in astronomical units, the day of the year (Julian date), and solar zenith angle. This information can also be found in Chapter 11 of the [Landsat 7 Users Handbook](). Sections of the Landsat 7 Users Handbook have been included in this document to guide you.

2.1. DN to Radiance

There are two formulas that can be used to convert DNs to radiance; the method you use depends on the scene calibration data available in the header file(s). One method uses the **Gain** and **Bias** (or Offset) values from the header file. The longer method uses the **LMin** and **LMax** spectral radiance scaling factors.   Look for a file name such as LT5171034009024510.WO, or a file with **.met** or **.txt** as the file extension. For ETM+ images this information may be in a file name such as L71171035_03520000905_htm.fst.

Appropriate calibration parameter files are available on the [Landsat Calibration]() page at the USGS.

2.1.1. Gain and Bias Method

The formula to convert DN to radiance using gain and bias values is:

$$L_\lambda = gain * DN + bias$$

Where:

L_λ is the cell value as radiance
DN is the cell value digital number
gain is the gain value for a specific band
bias is the bias value for a specific band

The ENVI formula in Band Math will look like:

0.05518 * (B1) + 1.2378

using a scene specific gain value of 0.05518 and an offset value of 1.2378. In the Band Pairing dialog you should match B1 with the appropriate optical band.

2.1.2. Spectral Radiance Scaling Method

The formula used in this process is as follows:

$$L_\lambda = \left(\left(LMAX_\lambda - LMIN_\lambda\right) / \left(QCALMAX - QCALMIN\right)\right) * \left(QCAL - QCALMIN\right) + LMIN_\lambda$$

Where:

L_λ is the cell value as radiance
QCAL = digital number
$LMIN_\lambda$ = spectral radiance scales to QCALMIN
$LMAX_\lambda$ = spectral radiance scales to QCALMAX
QCALMIN = the minimum quantized calibrated pixel value
(typically = 1)
QCALMAX = the maximum quantized calibrated pixel value
(typically = 255)

2.2. Radiance to ToA Reflectance

From the Landsat 7 Users Handbook – Chapter 11:

$$\rho_\lambda = \pi * L_\lambda * d^2 / ESUN_\lambda * \cos\theta_s$$

Where:

ρ_λ = Unitless plantary reflectance

L_λ= spectral radiance (from earlier step)

d = Earth-Sun distance in astronmoical units

$ESUN_\lambda$ = mean solar exoatmospheric irradiances

θ_s = solar zenith angle

The solar zenith angle can be calculated using the University of Oregon [Solar Poistion Calulator](#).

The following tables are from the Landsat & Users Handbook – Chapter 11

http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter11/chapter11.html

Table 11.3 ETM+ Solar Spectral Irradiances

Band	watts/(meter squared * µm)
1	1969.000
2	1840.000
3	1551.000
4	1044.000
5	225.700
7	82.07
8	1368.000

Table 11.4 Earth-Sun Distance in Astronomical Units									
Julian Day	Distance	Julian Day	Distance	Julian Day	Distance	Julian Day	Distance	Julian Day	Distance
1	.9832	74	.9945	152	1.0140	227	1.0128	305	.9925
15	.9836	91	.9993	166	1.0158	242	1.0092	319	.9892
32	.9853	106	1.0033	182	1.0167	258	1.0057	335	.9860
46	.9878	121	1.0076	196	1.0165	274	1.0011	349	.9843
60	.9909	135	1.0109	213	1.0149	288	.9972	365	.9833