

Converting Landsat TM and ETM+ thermal bands to temperature

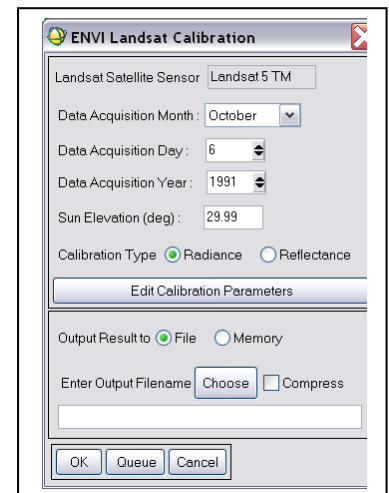
The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors acquire temperature data and store this information as a digital number (DN) with a range between 0 and 255. It is possible to convert these DNs to degrees Kelvin using a two (or optionally three) step process. The first step is to convert the DNs to radiance values using the bias and gain values specific to the individual scene you are working with. An optional second step would apply an atmospheric correction using appropriate local values for several parameters, resulting in more accurate surface temperatures. The final step converts radiance data from step one, or the optional step two, into degrees Kelvin.

1. Convert DN to Radiance:

1.1. Landsat images in the USGS GeoTIFF with Metadata format:

The USGS now provides data in the GeoTIFF with Metadata format. Using ENVI software you can easily convert the thermal band to radiance. Open the file that ends with “_MTL.TXT”. 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 radiance data layer, from the ENVI main menu bar, select **Basic Tools** → **Preprocessing** → **Calibration Utilities** → **Landsat Calibration**. Select the thermal file and the *ENVI Landsat Calibration* dialog should open with all of the calibration parameters filled in. Click on the *Radiance* radio button and direct the output result to *Memory*. After creating this file you can proceed to the optional Section 2 *Apply Atmospheric Correction* or directly to Section 3 *Convert Radiance to Kelvin* to generate a new data layer of brightness-temperature in degrees Kelvin.



1.2. Other Landsat data

For Landsat images that are not in the original USGS “GeoTIFF with Metadata” format you will need to manually convert these data to radiance. There are two formulas that can be used to convert DNs to radiance; the method you will 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. The following formulas have been adapted from the USGS Landsat Users handbook. 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.

You can also locate appropriate values from the USGS page of [Landsat Calibration](#) values.

Gain and Bias Method

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

$$CV_{RI} = gain * DN + bias \quad (1a)$$

Where:

CV_{RI} 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 thermal band.

Spectral Radiance Scaling Method

The formula used in this process is as follows: (1b)

$$CV_{RI} = ((LMAX_{\lambda} - LMIN_{\lambda}) / (QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN_{\lambda}$$

Where:

CV_{RI} 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)

The ENVI formula in Band Math will look like:

$$((15.303 - 1.238) / 254) * (B1-1) + 1.2378$$

using scene specific values for LMax of 15.303 and LMin of 1.2378. In the Band Pairing dialog you should match B1 with the thermal band.

2. Apply Atmospheric Correction (Optional):

An atmospheric correction can be applied to Landsat data if you have local values for several meteorological parameters. NASA has a web page that provides local values for Transmittance, Upwelling Radiance, and Downwelling Radiance. Data are currently

available from 2000 to the present. As older meteorological data become available this dataset will expand

<http://atmcorr.gsfc.nasa.gov/>

Using these values you can apply formula 2 to produce a new data layer of radiance that can be used in the next section. Note that this step accounts for emissivity so formula four is Section 3.2 must be used.

From Coll *et al* 2010, the formula to apply scene-specific atmospheric correction is:

$$CV_{R2} = \frac{CV_{R1} - L\uparrow}{\varepsilon\tau} - \frac{1-\varepsilon}{\varepsilon} L\downarrow \quad (2)$$

Where:

- CV_{R2} is the atmospherically corrected cell value as radiance
- CV_{R1} is the cell value as radiance from Section 1
- L \uparrow is upwelling Radiance
- L \downarrow is downwelling Radiance
- τ is transmittance
- ε is emissivity (typically **0.95**)

The ENVI formula in Band Math will look like:

$$((B1 - 0.50) / (0.95 * 0.93)) - (0.05263 * 0.84)$$

using the standard emissivity value of 0.95 and scene specific values of 0.93 for τ , 0.50 for L \uparrow and 0.84 for L \downarrow . In the Band Pairing dialog you would match B1 to the radiance band calculated in Section 1.

3. Convert Radiance to Kelvin:

Once the DN's for the thermal bands have been converted to radiance values, it is simply a matter of applying the inverse of the Planck function to derive temperature values.

3.1. For Data Without Atmospheric Correction

The formula to convert radiance to temperature *without* atmospheric correction is:

$$T = \frac{K_2}{\ln\left(\frac{K_1 * \varepsilon}{CV_{R1}} + 1\right)} \quad (3)$$

Where:

- T is degrees Kelvin
- CV_{R1} is cell value as radiance (from Section 1)

ε is emissivity (typically **0.95**)

	Landsat TM	Landsat ETM
K ₁	607.76	666.09
K ₂	1260.56	1282.71

The ENVI formula in Band Math for a TM scene will look like:

$$1260.56 / \log (((607.76 * 0.95) / B1) +1)$$

In the Band Pairing dialog match B1 with the radiance band created in Section 1.

3.2. For Atmospherically Corrected Data

For **atmospherically corrected** data the formula to convert radiance to temperature is:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{CV_{R2}} + 1\right)} \quad (4)$$

Where:

T is degrees Kelvin

CV_{R2} is the atmospherically corrected cell value as radiance (from Section 2)

	Landsat TM	Landsat ETM
K ₁	607.76	666.09
K ₂	1260.56	1282.71

The ENVI formula in Band Math for a TM scene will look like:

$$1260.56 / \log (607.76 / B1 +1)$$

In the Band Pairing dialog match B1 with the atmospherically corrected radiance band created in Section 2.

Reference:

C. Coll, J. M. Galve, J. M. Sánchez, and V. Caselles, “Validation of Landsat-7/ETM+ Thermal-Band Calibration and Atmospheric Correction With Ground-Based Measurements”, IEEE Trans. Geosci. Remote Sens., vol. 48, no. 1, pp. 547–555, Jan. 2010.