Calculating surface temperature using Landsat thermal imagery

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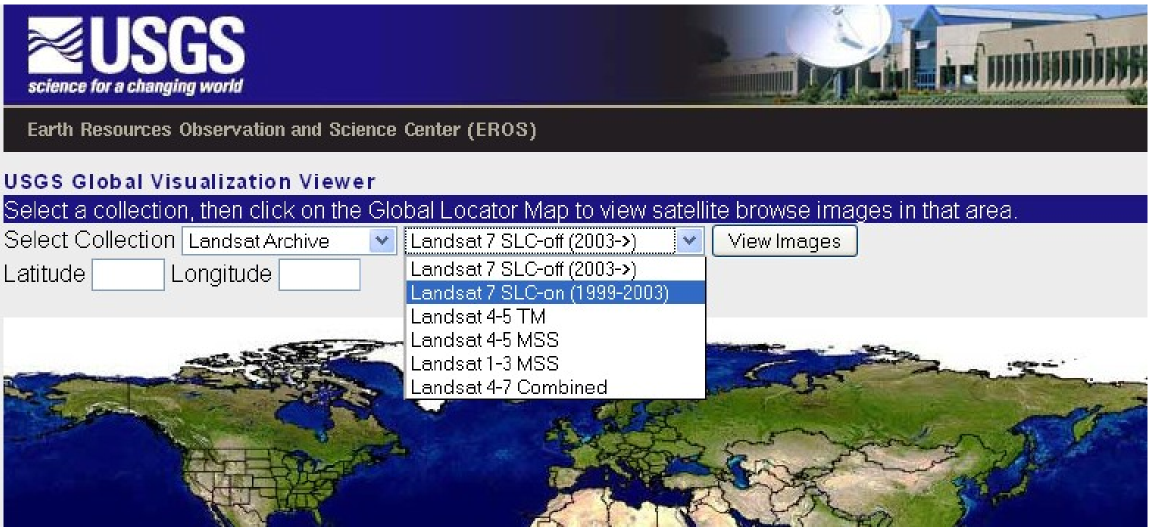
Summary

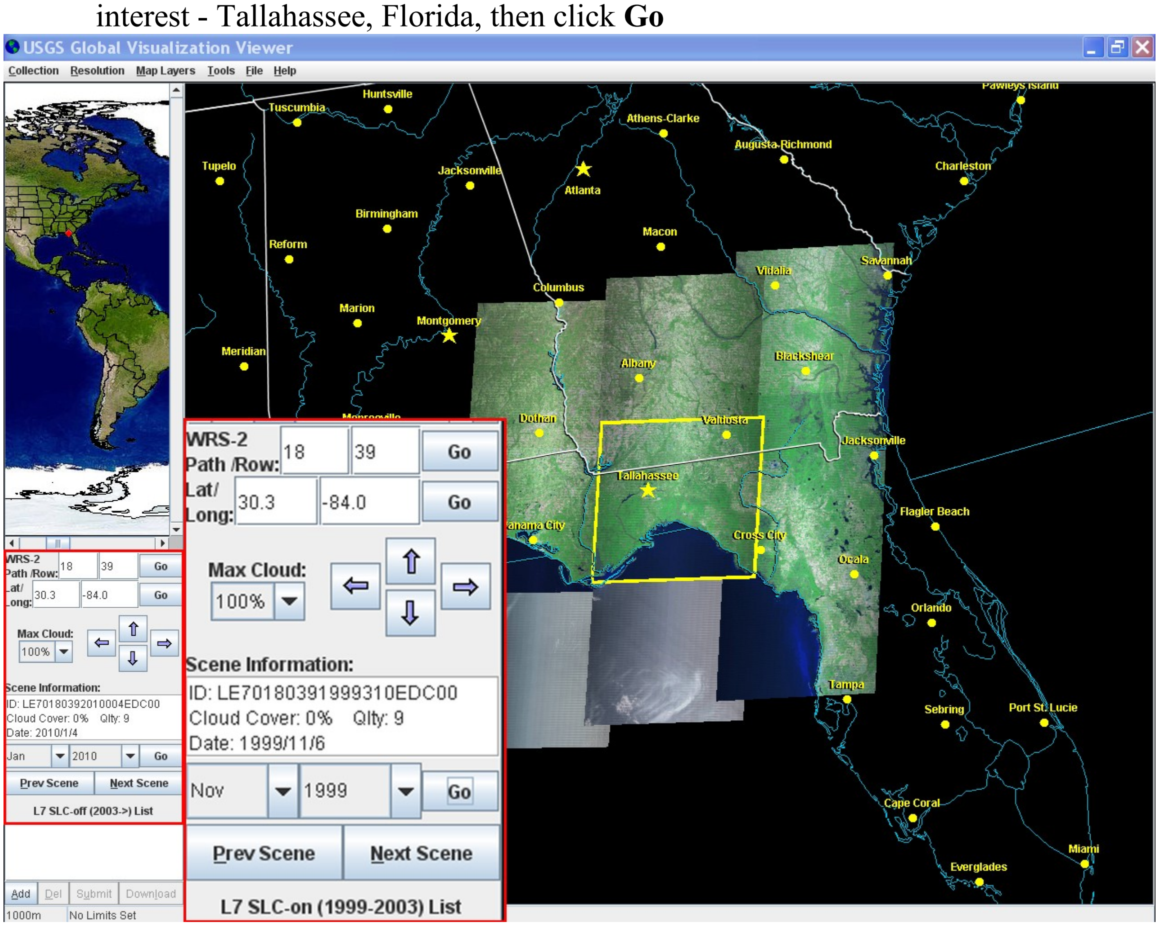
In this lab, students are walked through a hands-on exercise using Level 1B Landsat ETM+ thermal imagery acquired over Tallahassee, Florida, USA on November 06, 1999. There are known locations of submarine springs in the study area (http://www.dep.state.fl.us/).

How to get the data?

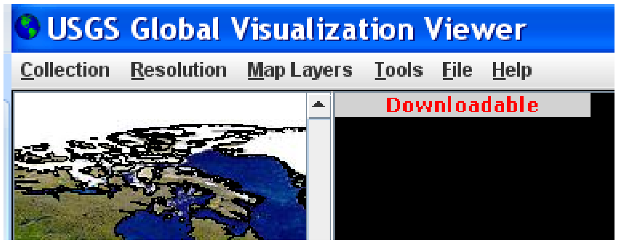
1. go to USGS website http://glovis.usgs.gov/
2. Select the Landsat Archive – **Landsat 7 SLC-on (1999-2003)** as shown in the following figure, and click **View Images**



3. In the bottom-left panel, enter the ***18/39*** for **Path/Row** references of the area of interest - Tallahassee, Florida, then click **Go**

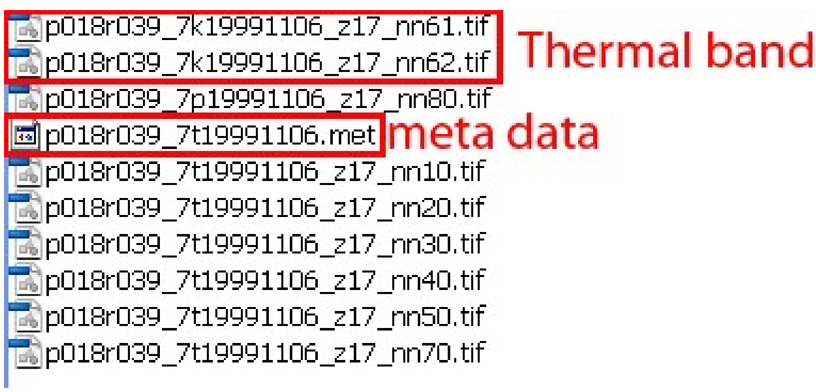


4. Click the **Downloadable** button to download the data to your local driver



5. After the “zip” file is downloaded you will need to uncompress it. The open source software 7-Zip (http://www.7-zip.org) can be downloaded and installed if other software such as WinZip or WinRAR is not available to you. Unzipped directory contains all of the ETM+ band files and metadata. Each band is noted by ".nn#" where "#" is the band number. The metadata contains all of the ancillary data required to calibrate the data to radiances.

   You may wonder why there are two files/bands for ETM+ band 6. Which one should I use for my study area? Band 61 and 62 use exactly the same detector, same wavelength and bandwidth, but the gain is set differently, i.e., 61 is set to 'low' gain, and 62 is set to 'high' gain to maximize the instrument's 8 bit radiometric resolution without saturating the detectors. It makes sense, therefore, to use the band 61 (low gain mode) when surface brightness is high (e.g., desert), and band 62 (high gain mode) when surface brightness is lower (e.g., vegetated areas).



Converting thermal DN values to temperature

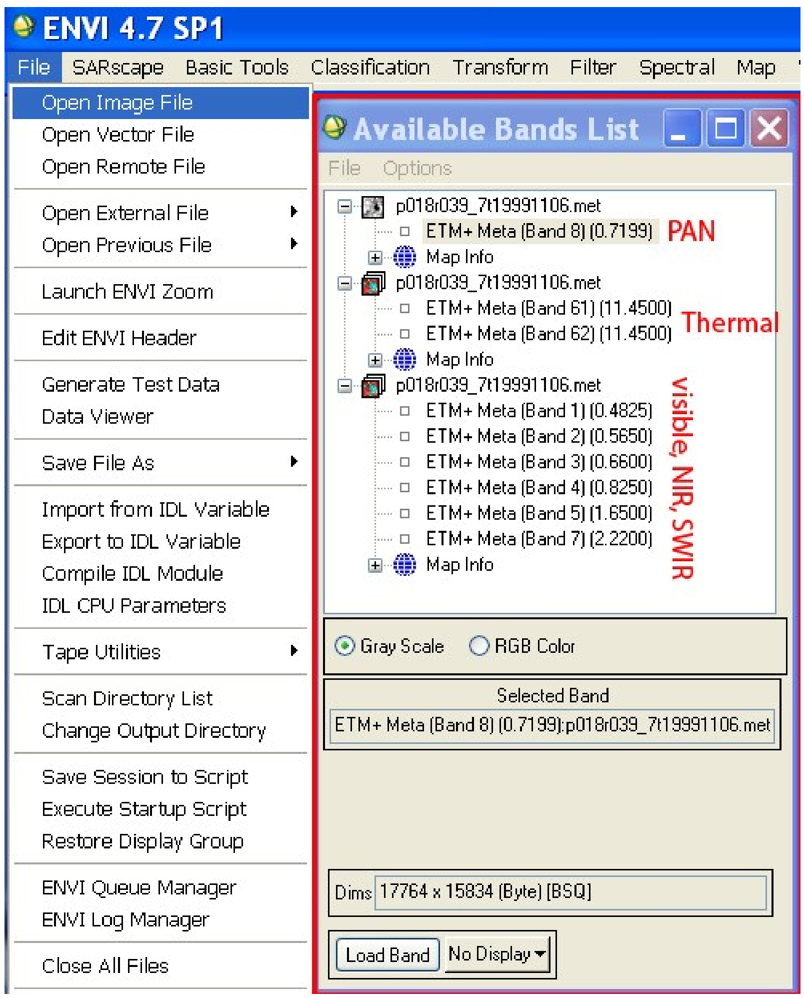
At-sensor radiances measured at a wavelength region is generally stored in Digital Numbers (DNs) converted using a quantification system for the convenience of data storage. DN values have no unit and any physical connotation, therefore, need to be converted to radiance, then to at-sensor (top-of-atmosphere) brightness temperature and, further, to land surface temperature (LST) in order to draw quantitative analysis from thermal remote sensing data.

Digital Numbers to at-sensor radiance/reflectance

The data downloaded from USGS website is in the GeoTIFF with Metadata format. ENVI can read the GeoTIFF data and automatically convert to at-sensor radiance or brightness temperature (at sensor reflectance if reflective bands used).

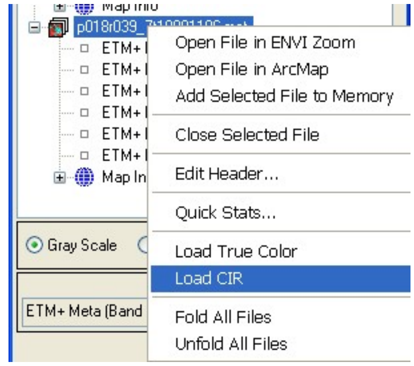
1. Open the metadata file that ends with "_.met".
   From ENVI main menu, **File → Open Image File**, and navigate to
   `p018r039_7t19991106.met`

   ENVI will automatically load the Landsat image as multiple files; the 6 bands of optical data as one file, and the thermal band as another. As mentioned above, the ETM+ thermal file has two bands and there also be a single band file for the panchromatic band.



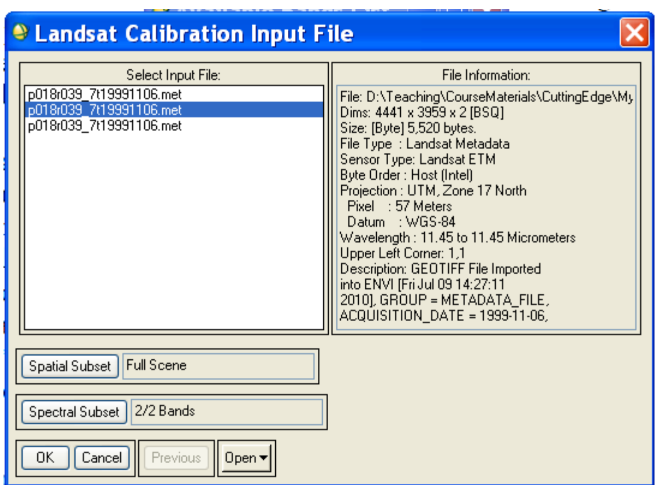
2. Examine the area using single band and color composite images
   Click on the PAN band, then **Load Band**, then load the thermal bands to have an idea of the study area.

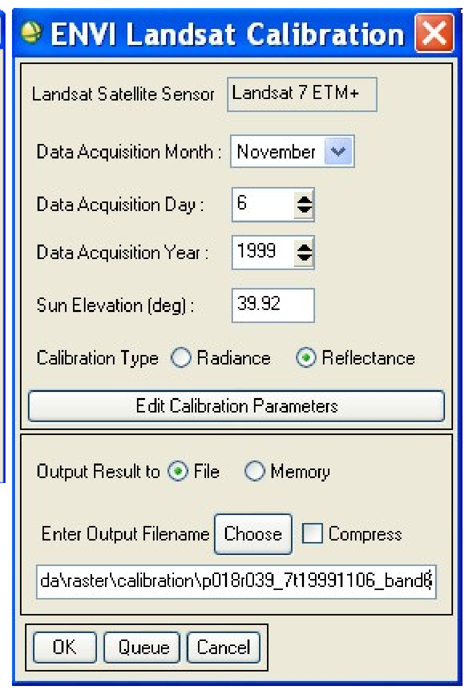
3. Click on the visible, NIR, SWIR bands file → right click → **Load CIR** to create a color infrared (CIR) composite image.



4. DN to radiance/brightness temperature conversion

From the ENVI main menu bar, select **Basic Tools → Preprocessing → Calibration Utilities → Landsat Calibration**. Select the thermal file (in the left figure) and the ENVI Landsat Calibration dialog should open with all of the calibration parameters filled in (figure to the right). Click on the ***Reflectance*** radio button and enter an output file name. The output file is the at-sensor brightness temperature in Kelvin.





Notes:

- If you choose the ***Radiance*** radio button, the output file will be at-sensor radiance. You need an additional step using ENVI band math to covert the radiance to temperature in Kelvin, as outlined in the **5. Theoretical Background Section** of this manual.
- One needs to manually convert DNs to radiance, then to at-sensor brightness temperature for Landsat data that are not in the original USGS "GeoTIFF with Metadata" format. This can be done using ENVI band math operation accessed through **ENVI → Basic Tools → Band Math.** The gain and bias values required to perform the calibration can be found from the header file. The header file is

included in the data folder either .TXT, .MET, .HTM.fst or .WO as the file extension.

Theoretical Background

These steps attempt to introduce the theoretical background of thermal remote sensing. Digital numbers are manually converted to at-sensor radiances, then to brightness temperatures using ENVI band math tool.

DN → Radiance

The ETM+ DN values range between 0 and 255.

$$\boldsymbol{L_\lambda = \frac{(LMAX_\lambda - LMIN_\lambda)}{QCALMAX - QCALMIN} \times (DN - QCALMIN) + LMIN_\lambda}$$

where the LMIN and LMAX are the spectral radiances for each band at digital numbers 1 and 255. DN is the pixel DN value, λ is the wavelength. One gets LMIN and LMAX values from the header file. Open the `.MET` file using Word Pad or any text editor. Look for the following lines.

```
CPF_FILE_NAME = "L7CPF19991001_19991123_12"
            GROUP = MIN_MAX_RADIANCE
                  LMAX_BAND1 = 191.600
                  LMIN_BAND1 = -6.200
                  LMAX_BAND2 = 196.500
                  LMIN_BAND2 = -6.400
                  LMAX_BAND3 = 152.900
                  LMIN_BAND3 = -5.000
                  LMAX_BAND4 = 157.400
                  LMIN_BAND4 = -5.100
                  LMAX_BAND5 = 31.060
                  LMIN_BAND5 = -1.000
                  LMAX_BAND61 = 17.040
                  LMIN_BAND61 = 0.000
                  LMAX_BAND62 = 12.650
                  LMIN_BAND62 = 3.200
                  LMAX_BAND7 = 10.800
                  LMIN_BAND7 = -0.350
                  LMAX_BAND8 = 243.100
                  LMIN_BAND8 = -4.700
            END_GROUP = MIN_MAX_RADIANCE
            GROUP = MIN_MAX_PIXEL_VALUE
                  QCALMAX_BAND1 = 255.0
                  QCALMIN_BAND1 = 1.0
                  QCALMAX_BAND2 = 255.0
                  QCALMIN_BAND2 = 1.0
                  QCALMAX_BAND3 = 255.0
                  QCALMIN_BAND3 = 1.0
```

```
        QCALMAX_BAND4 = 255.0
        QCALMIN_BAND4 = 1.0
        QCALMAX_BAND5 = 255.0
        QCALMIN_BAND5 = 1.0
        QCALMAX_BAND61 = 255.0
        QCALMIN_BAND61 = 1.0
        QCALMAX_BAND62 = 255.0
        QCALMIN_BAND62 = 1.0
        QCALMAX_BAND7 = 255.0
        QCALMIN_BAND7 = 1.0
        QCALMAX_BAND8 = 255.0
        QCALMIN_BAND8 = 1.0
    END_GROUP = MIN_MAX_PIXEL_VALUE
```

Implementing in ENVI

For thermal band 62, go to **Basic Tools → Band Math**, and type (copy and paste) the following expression
((12.650-3.200)/(255.0-1.0))*(B6-1.0)+3.200

Radiance → Brightness Temperature

Planck's Radiance Function

$$B_\lambda(T) = \frac{C_1}{\lambda^5\left(e^{\frac{C_2}{\lambda T}} - 1\right)}$$

Where, C_1=1.19104356×10^{-16} W m^2; C_2=1.43876869×10^{-2} m K

In the absence of atmospheric effects, T of a ground object can be theoretically determined by inverting the Planck's function as follows:

$$T = \frac{C_2}{\lambda \cdot \ln\left[\frac{C_1}{\lambda^5 B_\lambda(T)} + 1\right]}$$

This equation can be reformed as

$$T = \frac{\frac{C_2}{\lambda}}{\ln\left[\frac{C_1}{\lambda^5}\frac{1}{B_\lambda(T)} + 1\right]}$$

Let $K_1 = C_1/\lambda^5$, and $K_2 = C_2/\lambda$, and satellite measured radiant intensity $B_\lambda(T) = L_\lambda$, then above mentioned equation is collapsed into an equation similar to the one used to

calculate brightness temperature from Landsat TM image
(http://landsathandbook.gsfc.nasa.gov/handbook/handbook_htmls/chapter11/chapter11.html)

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

Therefore, K_1 and K_2 become a coefficient determined by effective wavelength of a satellite sensor.

ETM+ and TM Thermal Band Calibration Constants

	K_1 (W m^{-2} sr^{-1} μm^{-1})	K_2 (Kelvin)
Landsat 7 – ETM+	666.09	1282.71
Landsat 5 – TM	607.76	1260.56

Implementing in ENVI

For ETM+ thermal band data, go to **Basic Tools → Band Math**, and type (copy and paste) the following expression
1282.71D/(alog(666.09D/B6+1D))

where *D* after each number forces your data to double precision, and B6 is the at-sensor radiance data (not the DN values).

At this point, students can use brightness temperature from TM/ETM+ thermal band to detect thermal anomalies given the fact that retrieval of land surface temperature is complicated and sometime frustrating for someone who is not a remote sensing "expert".

The following step is provided for further reading as an advanced level of lab training in thermal remote sensing.

Brightness temperature to land surface temperature

At common terrestrial temperatures (~300 K), the peak emission occurs in the 8-to 10-µm range of wavelength. It is fortuitous that this peak occurs in a wavelength region where the atmosphere is relatively transparent compared to adjacent wavelengths.

While the peak in atmospheric transmission is in the 8- to 12- µm range, there is still significant attenuation due primarily to water vapor. As a result, the magnitude of the atmospheric effect will depend on the water vapor content of the intervening atmosphere. This unknown or uncertain atmospheric contribution is one of the problems for the remote sensing of surface temperature at infrared wavelengths. This, of course, is in addition to clouds that will totally obscure the surface at visible and infrared wavelengths (Schmugge, et al., 2002).

It is clear now that resulting brightness temperature without atmospheric correction is a rough approximation of kinetic surface temperature, and therefore, quantitative measurements based on it are arguable.

Land surface temperature can be calculate using radiative transfer simulations, e.g. LOWTRAN or MODTRAN codes, or simpler quasi-physical algorithms including ***the mono-window algorithm (MWA)*** (Qin et al., 2001), ***The generalised single-channel method (GSC)*** (Jiménez-Muñoz and Sobrino, 2003).

References and Resources

JIMÉNEZ-MUÑOZ, J.C., SOBRINO, J.A. 2003. A generalized single-channel method for retrieving land surface temperature from remote sensing data. Journal of Geophysical Research, 108, doi: 10.1029/2003JD003480

QIN, Z., KARNIELI, A., BERLINER, P. 2001. A mono-window algorithm for retrieving land surface temperature from Landsat TM data and its application to the Israel-Egypt border region. International Journal of Remote Sensing, 22, pp.3719-3746.

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

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