Chapter 3

LST CALCULATION

The plug-in uses thermal band/s of Landsat 8, Landsat 7, Landsat 5 and Landsat 4 satellite for the retrieval of LST map.

3.1 Top of atmosphere radiance calculation

The digital number representation of the signals received by the thermal sensors on board is converted to top of atmosphere radiance (L_λ) in $W/(m^2 * ster * \mu m)$ using following equations [Eq. 3.1, 3.2]:

3.1.1 For Landsat 8 thermal bands (Band 10 and Band 11) (Landsat 8 (L8) data user's handbook)

$$L_\lambda = ML_\lambda * Qcal + AL_\lambda \tag{3.1}$$

Where: Qcal is the quantized calibrated pixel value in DN; ML_λ is radiance multiplicative scaling factor for the corresponding band; AL_λ is radiance additive scaling factor for the corresponding band. Here Qcal is the individual pixel value; ML_λ, AL_λ values for the individual bands can be found in the metadata file provided with the raw data.

3.1.2 For Landsat 7 thermal bands (Band 6_VCID_1 and Band 6_VCID_2) and Landsat 4 and 5 thermal band (Band 6) (Landsat 7 Science Data User's handbook)

$$L_\lambda = \left(\frac{Lmax_\lambda - Lmin_\lambda}{Qcal_{max} - Qcal_{min}} * (Qcal - Qcal_{min}) \right) + Lmin_\lambda \tag{3.2}$$

Where: Qcal is the quantized calibrated pixel value in DN; $Qcal_{max}$ is the maximum quantized calibrated pixel value (corresponding to $Lmax_\lambda$) in DN; $Qcal_{min}$ is the minimum quantized calibrated pixel value (corresponding to $Lmin_\lambda$) in DN; $Lmax_\lambda$ is the spectral radiance that is scaled to $Qcal_{max}$ in $W/(m^2 * ster * \mu m)$; $Lmin_\lambda$ is the spectral radiance that is scaled to $Qcal_{min}$ in $W/(m^2 * ster * \mu m)$.

Here Qcal is the individual pixel value; $Qcal_{max}$, $Qcal_{min}$, $Lmax_{\lambda}$ and $Lmin_{\lambda}$ are available in the metadata file provided with the raw data.

3.2 Top of atmosphere reflectance calculation

The digital number representation of the signals received by the thermal sensors on board is converted to top of atmosphere reflectance (R_{λ}) (unitless) using following equations [Eq. 3.3, 3.4]:

3.2.1 For Landsat 8 Red band (Band 4) and NIR band (Band 5) (Landsat 8 (L8) data user's handbook)

$$R_{\lambda} = MR_{\lambda} * Qcal + AR_{\lambda} \tag{3.3}$$

Where: Qcal is the quantized calibrated pixel value in DN; MR_{λ} is reflectance multiplicative scaling factor for the corresponding band; AR_{λ} is reflectance additive scaling factor for the corresponding band. Here Qcal is the individual pixel value; MR_{λ}, AR_{λ} values for the individual bands can be found in the metadata file provided with the raw data.

3.2.2 For Landsat 7, 5 (TM), 4 (TM) Red band (Band 3) and NIR band (Band 4) (Landsat 7 Science Data User's Handbook)

$$R_{\lambda} = \frac{\pi * L_{\lambda} * d^2}{ESUN_{\lambda} * sin(\theta_{SE})} \tag{3.4}$$

Where: L_{λ} is at-satellite radiance in $W/(m^2 * ster * \mu m)$; d is Earth-Sun distance in astronomical units; $ESUN_{\lambda}$ is mean solar exo-atmospheric irradiances; θ_{SE} is solar elevation angle. Here L_{λ} is calculated as shown in Eq. 3.2. d i.e. Earth-Sun distance in astronomical units varies with the day of the year (DoY i.e. Julian day of the date on which data is acquired). d is interpolated from the values listed in Table 3.2. $ESUN_{\lambda}$ is taken from Table 3.1. θ_{SE} is available in metadata file provided with the raw satellite data.

Table 3.1: ESUN values in $W/(m^2 * \mu m)$ for the corresponding bands (Landsat 7 Science Data User's Handbook, (Gyanesh Chander et al. 2003))

Band	Landsat 7	Landsat 5	Landsat 4
1	1997	1957	1957
2	1812	1825	1826
3	1533	1557	1554
4	1039	1033	1036
5	230.8	214.9	215.0
7	84.9	80.72	80.67
8	1362	NA	NA

Table 3.2: Julian day (DY) and earth to sun distance (d) in astronomical units (Landsat 7 Science Data User's Handbook)

DY	d	DY	d	DY	d	DY	d	DY	d
1	0.98331	74	0.99446	152	1.01403	227	1.01281	305	0.99253
15	0.98365	91	0.99926	166	1.01577	242	1.00969	319	0.98916
32	0.98536	106	1.00353	182	1.01667	258	1.00566	335	0.98608
46	0.98774	121	1.00756	196	1.01646	274	1.00119	349	0.98426
60	0.99084	135	1.01087	213	1.01497	288	0.99718	365	0.98333

3.3 At-satellite brightness temperature calculation

Radiance values of the thermal band are then converted to at-satellite brightness temperature using Eq. 3.5 (Landsat 8 (L8) data user's handbook).

$$T_\lambda = \frac{K_2}{ln(\frac{K_1}{L_\lambda + 1})} - 273.15 \tag{3.5}$$

Where: T_λ is at-satellite brightness temperature in degree Celsius; L_λ is at-satellite radiance in $W/(m^2 * ster * \mu m)$; K_1 and K_2 are prelaunch calibration constants and are given in the metadata file. The temperature calculated by Eq. 3.5 is not the actual LST.

3.4 LST calculation

To obtain a fairly reliable LST from at-satellite brightness temperature calculated by Eq. 3.5, four steps of correction process may be required as mentioned by (J. A. Voogt et al. 2003): (1) top of atmosphere radiance conversion to at-satellite brightness temperature, (2) correction for atmospheric absorption and re-emission, (3) correction for surface emissivity, (4) correction for surface roughness. The first step is just the calculation process as shown in Eq. 3.5. The second to fourth steps of correction process are usually very complicated (Jinqu Zhang et al. 2006). These steps can be simplified and LST can be calculated using the following Eq. 3.6 (D. A. Artis et al. 1982).

$$LST = \frac{T_\lambda}{1 + \left(\frac{\lambda * T_\lambda}{\rho}\right) lne} \tag{3.6}$$

Where: T_λ is at-satellite brightness temperature in degree Celsius; λ = wavelength of emitted radiance in μm; ρ=h*c/j ($1.438x10^{-2}mK$), j= Boltzmann constant ($1.38x10^{-23}J/K$), h = Planck's constant ($6.626x10^{-34}Js$), and c = velocity of light ($2.998x10^{8}m/s$); e is land surface emissivity.

3.5 Emissivity calculation

In the above Eq. 3.6 to calculate LST, only unknown is the ground surface emissivity. Emissivity can be calculated using several ways, some of them are (1) method based on classification image; (2) method based on NDVI image and (3) method based on the ratio values of vegetation and bare ground. (Jinqu Zhang et al. 2006)

Using the classification image is the theoretically simplest way to calculate emissivity. In this method, every LU/LC class is assigned to its corresponding emissivity value. Therefore, classified image and the corresponding emissivity values are the key parameters of this method. Here, the classification accuracy of the classified image has a direct impact on the LST calculated. Moreover, determination of the emissivity values for every LU/LC class is a critical process. As single pixel of satellite data is comprised of several land features having different emissivity values, this makes field measurement of emissivity values a complex process. Also, we need a good knowledge of the study area for the accurate measurements of the emissivity of the required LU/LC classes at the time of satellite overpass which makes this method practically tough. An easy alternative is to obtain the emissivity image from the NDVI image (José A. Sobrino et al. 2004).

$$e = 0.004Pv + 0.986 \tag{3.7}$$

Where: Pv is the vegetation proportion which is calculated by Eq. 3.8 (T. N.Carlson et al. 1997)

$$Pv = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right]^2 \tag{3.8}$$

Where: NDVI is normalized difference vegetation index which is used to evaluate the content of vegetation present in an area. The at-satellite reflectance of NIR and Red band are used to construct NDVI image using the Eq. 3.9.

$$NDVI = (R_{NIR} - R_{Red})/(R_{NIR} + R_{Red}) \tag{3.9}$$