How to calculate reflectance and temperature using ASTER data

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This instructions walk you through the calculation of top-of-the-atmosphere (TOA) reflectance at sensor and brightness temperature (also called radiometric temperature) and true kinetic temperature (also called land surface temperature, LST).

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

Part 1: Calculating spectral reflectance

Step 1: DN to spectral radiance

Data used here, as an example, is ASTER L1B data (version 3.0), radiometrically re-calibrated digital numbers, 8bit (1-255) for visible and near-infrared bands and 12bit (1-4095) for thermal infrared (TIR) bands (see the table 1).

$$L_{rad,j} = (DN_j - 1) \times UCC_j$$

Where, $L_{rad,j}$ is ASTER spectral radiance at the sensor's aperture measured in a wavelength j; j is the ASTER band number; DN_j is the unitless DN values for an individual band j; UCC_j is the Unit Conversion Coefficient (W m^{-2} sr^{-1} μm^{-1}) from ASTER Users Handbook.

Table 1: Calculated Unit Conversion Coefficients				
Band#	Unit Conversion Coefficient (W m^{-2} sr^{-1} μm^{-1})			
	High gain	Normal Gain	Low Gain 1	Low gain 2
1	0.676	1.688	2.25	N/A
2	0.708	1.415	1.89	
3N	0.423	0.862	1.15	
3B	0.423	0.862	1.15	
4	0.1087	0.2174	0.290	0.290
5	0.0348	0.0696	0.0925	0.409
6	0.0313	0.0625	0.0830	0.390
7	0.0299	0.0597	0.0795	0.332
8	0.0209	0.0417	0.0556	0.245
9	0.0159	0.0318	0.0424	0.265
10	N/A	0.006822	N/A	N/A
11		0.006780		
12		0.006590		
13		0.005693		
14		0.005225		

Notes:

It is worth noting that the re-calibration aimed to correct for temporal decline of the detectors responsivity between consecutive changes in the radiometric calibration coefficient (RCC) has been applied for RCC versions of 3.x or higher. ASTER TIR products with RCC versions 1.x and 2.x (2.17, 2.18 and 2.20, respectively) need to be re-calibrated for this matter using the linear function below

$$L_{rad,j}(c) = A_j \times L_{rad,j} + B_j$$

Where, $L_{rad,j}$ (c) refers to the re-calibrated spectral radiance, ***A*** and ***B*** are re-calibration coefficients for a band ***j*** found at http://www.science.aster.ersdac.or.jp/RECAL

Table 2: Maximum Radiance Values for ASTER Bands and Gains

Band #	Muximum Radiance (W m^{-2} sr^{-1} μm^{-1})			
	High gain	Normal Gain	Low Gain 1	Low gain 2
1	170.8	427	569	N/A
2	179.0	358	477	
3N	106.8	218	290	
3B	106.8	218	290	
4	27.5	55.0	73.3	73.3
5	8.8	17.6	23.4	103.5
6	7.9	15.8	21.0	98.7
7	7.55	15.1	20.1	83.8
8	5.27	10.55	14.06	62.0
9	4.02	8.04	10.72	67.0
10	N/A	28.17	N/A	N/A
11		27.75		
12		26.97		
13		23.30		
14		21.38		

Step 2: Spectral radiance to TOA reflectance

ASTER at-sensor reflectance (ρ_{TOA}, also called as planetary reflectance or apparent reflectance or TOA reflectance) for a specific band *j* is calcualted using the standard Landsat equation as:

$$\rho_{TOA,\lambda} = \frac{\pi \cdot L_{rad,\lambda} \cdot d^2}{E_{SUN,\lambda} \cdot cos(\theta_s)}$$

Where:

ρ_{TOA} = Unitless planetary reflectance

L_{rad} = Spectral radiance at the sensor's aperture

d = Earth-Sun distance in astronomical units from an Excel file which is calculated using the below EXCEL equation (Achard and D’Souza 1994; Eva and Lambin, 1998) or interpolated from values listed in Table 3

E_{SUN} = Mean solar exoatmospheric irradiances from Table 4

λ = Wavelength, corresponds to the band number j

θ_s = Solar zenith angle in degrees (zenith angle = 90 – solar elevation angle), which is found in the ASTER header file

Table 3 Earth-Sun Distance in Astronomical Units

Day of Year	Distance	Day of Year	Distance	Day of Year	Distance	Day of Year	Distance	Day of Year	Distance
1	.98331	74	.99446	152	1.01403	227	1.01281	305	.99253
15	.98365	91	.99926	166	1.01577	242	1.00969	319	.98916
32	.98536	106	1.00353	182	1.01667	258	1.00566	335	.98608
46	.98774	121	1.00756	196	1.01646	274	1.00119	349	.98426
60	.99084	135	1.01087	213	1.01497	288	.99718	365	.98333

Referenced from Landsat 7 ETM+ Data User’s Handbook

The calculation of **E_{SUN}** is the same for whatever sensor you are using, as it is simply the convolution of the band's spectral response function (A) with the Extraterrestrial Solar Spectral Irradiance function (B).

A for each ASTER band can be obtained from:
http://www.science.aster.ersdac.or.jp/en/about_aster/sensor/ or download here

B can be obtained from:

http://staff.aist.go.jp/s.tsuchida/aster/cal/info/solar/ or download here

Using this standard approach the calculated **E_{SUN}** for each ASTER band is given in Table 4:

Table 4: ASTER Solar Spectral Irradiances (W m^{-2} μm^{-1})

Band#	Smith: $\mathbf{E}_{\mathbf{SUN}}$	Thome et al (A): $\mathbf{E}_{\mathbf{SUN}}$	Thome et al (B): $\mathbf{E}_{\mathbf{SUN}}$
1	1845.99	1847	1848
2	1555.74	1553	1549
3N	1119.47	1118	1114
3B			
4	231.25	232.5	225.4
5	79.81	80.32	86.63
6	74.99	74.92	81.85
7	68.66	69.20	74.85
8	59.74	59.82	66.49
9	56.92	57.32	59.85
10	N/A	N/A	N/A
11			
12			
13			
14			

Notes:

Smith: Calculated by interpolating the ASTER spectral response functions to 1nm and convolving them with the 1nm step WRC data

Thome et al (A): Calcualted by convolving the ASTER spectral response functions them with the WRC data [Unknown whether these where both interpolated to 1nm or whether a subsample of WRC data values at the ASTER spectral response function step intervals were used in the convolution]

Thome et al (B): Calculated using spectral irradiance values dervied using MODTRAN.

Step 3: TOA reflectance to surface reflectance

Surface reflectance is calculated using empirical methods when ground truthing is available by correlating the field measured surface reflectance with synchronous pixel value, or radiative transfer models such as MODTRAN , 6S (Second Simulation of the Satellite Signal in the Solar Spectrum, Vermote, et al., 1997), etc.

It is recommended to use surface reflectance products for quantitative remote sensing analysis, however, TOA reflectance based outcome is also acceptable due to the fact that land surface reflectance retrieval is complicated.

Part 2: Calculating temperature

Step 1: DNs to radiance

Refer to Part1 Step1 to convert DNs to radiance for thermal bands. There is no difference between converting DNs to radiance of thermal or optical data.

Step 2: Spectral radiance to TOA brightness temperature

Planck's Radiance Function

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

Where, $C_1=1.19104356\times10^{-16}$ W m^2; $C_2=1.43876869\times10^{-2}$ 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 (detailes here)

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

Therefore, K_1 and K_2 become a coefficient determined by effective wavelength of a satellite sensor. For example, effective wavelength of ASTER band 10, λ=8.291

μm = 8.291×10^{-6} m, we can have $K_1 = C_1/\lambda^5 = 1.19104356\times10^{-16}$ W $m^2/(8.291\times10^{-6}\ m)^5$ = 3040136402 W m^{-2} m^{-1} = 3040.136402 W m^{-2} μm^{-1}

$K_2 = C_2/\lambda = 1.43876869\times10^{-2}$ m K / 8.291×10^{-6} m = 1735.337945K

The method may be extended to the rest the ASTER thermal bands as shown in the following table.

* Unit for Unit Conversion Coefficients (UCC) is W m^{-2} sr^{-1} μm^{-1})

Table 5 ASTER thermal bands (referenced ASTER L1B Manual Ver.3.0)

Bands	Bandpass (μm)	Effective Wavelength (μm)	UCC	K_1 (W m^{-2} μm^{-1})	K_2 (K)
10	8.125-8.475	8.291	0.006882	3040.136402	1735.337945
11	8.475-8.825	8.634	0.006780	2482.375199	1666.398761
12	8.925-9.275	9.075	0.006590	1935.060183	1585.420044
13	10.25-10.95	10.657	0.005693	866.468575	1350.069147
14	10.95-11.65	11.318	0.005225	641.326517	1271.221673