A Straight Forward Guide for Processing Radiance and Reflectance for EO-1 ALI, Landsat 5 TM, Landsat 7 ETM+, and ASTER

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Introduction

To begin performing scientific analysis on multiple remote sensors there is a need to have spectral data in the same units for radiance, from which reflectance can be calculated. The necessary information to put Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced TM (ETM+), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and Earth Observing (EO)-1 Advanced Land Imager (ALI) into comparable measures of radiance and reflectance has been compiled into this document in an effort to assist an end user in adjusting their raw sensor data to a common starting point. This is not new information; rather it is compiled from many existing sources into a single document.

Satellite data comes in several formats: digital numbers (DN) calibrated DNs, and at-sensor radiance, to name a few. To be able to work with multiple sensors that come in varied data formats, it is necessary to make them all the same units and values.

Units

Radiance data will usually come in one of two units, W/m^2 SRμm or mW/cm^2Srμm.

W	= Watts
mW	= micro Watts
m^2	= meter square
cm^2	= centimeter square
SR	= Steradian
μm	= micrometers

To convert from mW/cm^2 to W/m^2, divide by 0.1; to convert W/m^2 to mW/cm^2, multiply by 0.1.

Header Files

Print out the header files for Landsat, HDF for ASTER and the *.met for ALI. There is information in these files that will be needed to get the radiance and reflectance. Also for ALI go to the USGS EarthExplorer http://earthexplorer.usgs.gov/ or USGS Global Visualization Viewer http://glovis.usgs.gov/ and locate the image and get the Metadata.

Radiance

Landsat

Use the following formula to convert the DN values to at-satellite radiance values (Chander and others, 2003). The formula is applied to each band of Landsat ETM+/TM bands 1-5, 7:

$L_{\lambda} = G_{rescale} \times DN_{\lambda} + B_{rescale}$ (Radiance = Band-specific rescaling gain factor x DN + Band-specific rescaling bias factor)

-where Band-specific rescaling gain factor is found in the header records, per specific band

-where DN is the pixel value resident in the specific band

-where Band-specific rescaling bias factor is found in the header records, per specific band

Landsat 7 scenes, gain and bias rescaling factors must come from the header file since they change for every scene.

For **Landsat 5** scenes, the gain and bias rescaling factors are usually constant. See Table 1.

Table 1: L-5 TM Postcalibration Dynamic Ranges for U.S. Processed NLAPS Data.

(Modified from Chander and others, 2007; Chander and others, 2009)

Spectral Radiances, $LMIN_{\lambda}$ and $LMAX_{\lambda}$ in W/(m^2.sr.□ m)								
Processing Date	From March 1, 1984 To May 4, 2003				From May 5, 2003 To April 1, 2007			
Band	$LMIN_{\lambda}$	$LMAX_{\lambda}$	$G_{rescale}$	$B_{rescale}$	$LMIN_{\lambda}$	$LMAX_{\lambda}$	$G_{rescale}$	$B_{rescale}$
1	-1.52	152.10	0.602431	-1.52	-1.52	193.0	0.762824	-1.52
2	-2.84	296.81	1.175098	-2.84	-2.84	365.0	1.442510	-2.84
3	-1.17	204.30	0.805765	-1.17	-1.17	264.0	1.039880	-1.17
4	-1.51	206.20	0.814549	-1.51	-1.51	221.0	0.872588	-1.51
5	-0.37	27.19	0.108078	-0.37	-0.37	30.2	0.119882	-0.37
6	1.2378	15.3032	0.055158	1.2378	1.2378	15.303	0.055158	1.2378
7	-0.15	14.38	0.056980	-0.15	-0.15	16.5	0.065294	-0.15

Spectral Radiances, $LMIN_{\lambda}$ and $LMAX_{\lambda}$ in W/(m^2.sr.□ m)				
Processing Date	From April 2, 2007			
Band	$LMIN_{\lambda}$	$LMAX_{\lambda}$	$G_{rescale}$	$B_{rescale}$
1*	-1.52	169.0	0.671339	-2.19
1	-1.52	193.0	0.765827	-2.29
2*	-2.84	333.0	1.322205	-4.16
2	-2.84	365.0	1.448189	-4.29
3	-1.17	264.0	1.043976	-2.21
4	-1.51	221.0	0.876024	-2.39
5	-0.37	30.2	0.120354	-0.49
6	1.2378	15.303	0.055376	1.18
7	-0.15	16.5	0.065551	-0.22

*For scenes acquired from March 1, 1984 to December 31, 1991

ASTER

L_λ = (DN–1) x Unit conversion coefficient (Abrams, 1991)

ASTER gain is determined from the header file, GAIN*Band#* = HGH or NOR. Usually bands 1 & 2 are High and bands 3 - 9 are normal. Bands 10 through 14 are normal. See Table 2 below.

Table 2: Calculated Unit Conversion Coefficients.
(Abrams, 1991)

Band No.	Coefficient (W/(m^2*sr*µm)/DN)			
	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	6.822×10^{-3}	N/A	N/A
11		6.780×10^{-3}		
12		6.590×10^{-3}		
13		5.693×10^{-3}		
14		5.225×10^{-3}		

ALI

For Level 1 data processed prior to December 21, 2004:

L = DN / 300

For Level 1 data processed after December 21, 2004:

L = (DN * scaling factor) + offset

Table 3: ALI Scaling Factor and Offset
(Modified from Chander and others, 2009; USGS EO-1 (2011))

band	scaling factor	offset
2 (MS-1')	.045	-3.4
3 (MS-1)	.043	-4.4
4 (MS-2)	.028	-1.9
5 (MS-3)	.018	-1.3
6 (MS-4)	.011	-0.85

7 (MS-4’)	.0091	-0.65
8 (MS-5’)	.0083	-1.3
9 (MS-5)	.0028	-0.6
10 (MS-6)	.00091	-0.21

Reflectance

The following formula and Earth- Sun distance table will be used for all sensors.

P_{λ} = (PIE x Radiance x d^2) / (Irradiance x sin (PIE x sun elevation angle / 180))

The Earth-Sun distance is derived by taking the Calendar date of the scene and converting it to a Julian date and then calculating the distance from Chart 4 below. Calendar date to Julian date conversion website: http://www.fs.fed.us/fire/partners/fepp/juliandate.htm

Table 4: Earth – Sun Distance in Astronomical Units
(Chander and others, 2003) (For a complete list of dates, see Chander and others, 2009)

DOY	Distance	DOY	Distance	DOY	Distance
1	0.9832	121	1.0076	242	1.0092
15	0.9836	135	1.0109	258	1.0057
32	0.9853	152	1.0140	274	1.0011
46	0.9878	166	1.0158	288	0.9972
60	0.9909	182	1.0167	305	0.9925
74	0.9945	196	1.0165	319	0.9892
91	0.9993	213	1.0149	335	0.9860
106	1.0033	227	1.0128	349	0.9843
DOY- Day of Year (Julian Day)				365	0.9833

Landsat

There is an attribute called "SUN_ELEVATION" in the header file. It defines the sun direction as seen from the scene center. For example:

SUN_ELEVATION= 65.49;

The value (65.49) is the Elevation angle in degrees (values can range between <= -90.0 to <= 90.0).

Table 5: Landsat Solar Exoatmospheric Solar Irradiances
(modified from Chander and others, 2009). ESUN derived from CHKUR.

Table		
Units: ESUN = $W/(m^2 . \mu m)$		
Model:	Chance Spectrum CHKUR	
Band	Landsat 5	Landsat 7
1	1983	1997
2	1796	1812
3	1536	1533
4	1031	1039
5	220	230.8
7	83.44	84.90

ASTER

There is an attribute called "SOLARDIRECTION" in the ProductMetadata.0 group in the embedded HDF metadata. It defines the sun direction as seen from the scene center. For example:

```
OBJECT          = SOLARDIRECTION
NUM_VAL         = 2
VALUE           = (177.154016, 32.061355)
END_OBJECT      = SOLARDIRECTION
```

The second value (32.061355) is the Elevation angle in degrees (values can range between <= -90.0 to <= 90.0).

Table 6: ASTER Solar Exoatmospheric Solar Irradiances
(modified from Thome and others, 2001)

ASTER Band	**Spectral Irradiance: Modtran-Based ($W/m^2/\mu m$)**
1	1848
2	1549
3	1114
4	225.4
5	86.63
6	81.85
7	74.85
8	66.49
9	59.85

ALI

Go to the USGS EarthExplorer - http://earthexplorer.usgs.gov/

Or
USGS Global Visualization Viewer - http://glovis.usgs.gov/

Once the desired scenes are located, display the metadata. This will provide you with the Acquisition Date and Sun Elevation.

Table 7: ALI Solar Exoatmospheric Solar Irradiances
(Modified from Chander and others, 2009)

ALI Solar Spectral Irradiances	
Band	Spectral Irradiances (W/m^2*um)
1 Pan	1724
2 (MS -1’)	1857
3 (MS -1’)	1996
4 (MS -1’)	1807
5 (MS -1’)	1536
6 (MS -1’)	1145
7 (MS -1’)	955.8
8 (MS -1’)	452.3
9 (MS -1’)	235.1
10 (MS -1’)	82.38

References

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