LAB EXERCISE NO. 02 **DUE DATE: 9/22/2015**

Total Points: 4

TOPIC: TOA REFLECTANCE COMPUTATION FROM LANDSAT IMAGES

You are asked to perform a radiometric conversion from raw digital numbers to reflectance at the top of atmosphere (TOA reflectance, or apparent reflectance). The objective of this lab exercise is to learn how to use the MODELER module of the software Erdas Imagine to build a script that allows you to compute TOA reflectance of Landsat 7 images.

Image Data:

Most Landsat 5 or 7 images are Level 1G, Level 1-T or data that have been radiometrically and geometrically corrected (systematic) to user-specified parameters including output map projection, image orientation, and pixel size. The correction algorithms model the spacecraft and sensor using data generated by onboard computers during imaging. Sensor, focal plane, and detector alignment information provided by the Image Assessment System (IAS) in the Calibration Parameter File (CPF) is also used to improve the overall geometric fidelity. The resulting product is free from distortions related to the sensor (e.g., jitter, view angle effect), satellite (e.g., attitude deviations from nominal), and Earth (e.g., rotation, curvature). Residual error in the systematic L1G product is less than 250 meters (1 sigma) in flat areas at sea level.

The systematic L1G correction process does not employ ground control or relief models to attain absolute geodetic accuracy. The Level 1T (L1T) data product provides systematic radiometric accuracy, geometric accuracy by incorporating ground control points, while also employing a Digital Elevation Model (DEM) for topographic accuracy. Geodetic accuracy of the product depends on the accuracy of the ground control points and the resolution of the DEM used.

Currently, all 36 years of archived Landsat scenes at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center are freely available to the public through EarthExplorer at http://earthexplorer.usgs.gov or the Global Visualization Viewer at http://glovis.usgs.gov (Chander et al. 2009). When a Landsat image is downloaded from the web it is in the form of a .tar file that contains each band separately. After the .tar file is unzipped using winzip or winrar, each band must be stacked using the "stack layers" function in Erdas. You can also use the "manage data/import" module and "raster/spectral/layerstack" method.

Data to be used for this exercise can be found in the "data folder"on dropbox which has Landsat bands 1-5 and 7 already stacked: LT50210302001168XXX02

<u>TOA Reflectance Computation:</u>

In this exercise, you are asked to build a model to convert digital numbers to TOA reflectance. The procedure to convert digital numbers (DN) to TOA reflectance of Landsat ETM + Level 1G or TM L1T product is described below. (Tables and equations from Chander et al. 2009; MSS and TM reference values can be found in this paper also).

Step 1: Digital Numbers to Radiance

During 1G product rendering image pixels are converted to units of absolute radiance using *32 bit floating point* calculations. Pixel values are then scaled to byte values prior to media output. The following equation is used to convert DN's in a 1G product back to radiance units:

$$L_\lambda = G_{rescale} * Q_{cal} + B_{rescale}$$

where:

$$G_{rescale} = \frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax} - Q_{calmin}}$$

$$B_{rescale} = LMIN_\lambda - \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax} - Q_{calmin}}\right) Q_{calmin}$$

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax} - Q_{calmin}}\right)(Q_{cal} - Q_{calmin}) + LMIN_\lambda$$

$L_\lambda =$ Spectral radiance at the sensor's aperture [W/(m^2 sr µm)]

$Q_{cal} =$ Quantized calibrated pixel value [DN]

$Q_{calmin} =$ Minimum quantized calibrated pixel value corresponding to $LMIN_\lambda$ [DN]

$Q_{calmax} =$ Maximum quantized calibrated pixel value corresponding to $LMAX_\lambda$ [DN]

$LMIN_\lambda =$ Spectral at-sensor radiance that is scaled to Q_{calmin} [W/(m^2 sr µm)]

$LMAX_\lambda =$ Spectral at-sensor radiance that is scaled to Q_{calmax} [W/(m^2 sr µm)]

The LMIN and LMAX values are the spectral radiances for each band at digital numbers 1 and 255, respectively. One set exists for each gain state (i.e., high and low gain). The low-gain setting is used for bright surfaces (higher dynamic range with low sensitivity) and the high-gain is used for darker surfaces (lower dynamic range but higher sensitivity). The variables needed for the equation above can be found in the tables below.

Refer to the following webpage: (http://landsat.usgs.gov/how_is_radiance_calculated.php)

ETM+ spectral range, post-calibration dynamic ranges, and mean exoatmospheric solar irradiance ($ESUN_\lambda$):

L7 ETM+ Sensor ($Q_{calmin} = 1$ and $Q_{calmax} = 255$)					
Band	Spectral range	Center wavelength	$LMIN_\lambda$	$LMAX_\lambda$	$ESUN_\lambda$
Units	μm		$W/(m^2\ sr\ \mu m)$		$W/(m^2\ \mu m)$
Low gain (LPGS)					
1	0.452–0.514	0.483	−6.2	293.7	1997
2	0.519–0.601	0.560	−6.4	300.9	1812
3	0.631–0.692	0.662	−5.0	234.4	1533
4	0.772–0.898	0.835	−5.1	241.1	1039
5	1.547–1.748	1.648	−1.0	47.57	230.8
6	10.31–12.36	11.335	0.0	17.04	N/A
7	2.065–2.346	2.206	−0.35	16.54	84.90
PAN	0.515–0.896	0.706	−4.7	243.1	1362
High Gain (LPGS)					
1	0.452–0.514	0.483	−6.2	191.6	1997
2	0.519–0.601	0.560	−6.4	196.5	1812
3	0.631–0.692	0.662	−5.0	152.9	1533
4	0.772–0.898	0.835	−5.1	157.4	1039
5	1.547–1.748	1.648	−1.0	31.06	230.8
6	10.31–12.36	11.335	3.2	12.65	N/A
7	2.065–2.346	2.206	−0.35	10.80	84.90
PAN	0.515–0.896	0.706	−4.7	158.3	1362

Step 2: Radiance to TOA Reflectance

For relatively clear Landsat scenes, a reduction in between-scene variability can be achieved through a normalization for solar irradiance by converting spectral radiance, as calculated above, to planetary reflectance or albedo. This combined surface and atmospheric reflectance of the Earth is computed with the following formula:

Note:

Earth-sun distance can be determined from "esun_dist.xls". E_{sun} exo-atmospheric irradiance can be obtained from Chander et al. 2009 (Landsat_Calibration_Summary_RSE). A solved example "toa_ref.gmd has been uploaded for you to get an idea. However, the numbers in the look up table (LUT) might be different from thse in .MTL file specific to your landsat scene. So please font blindly run this model. Use as it as an example. All these files are on "data" folder on Dropbox.

$$\rho_\lambda = \frac{\pi \cdot L_\lambda \cdot d^2}{\mathrm{ESUN}_\lambda \cdot \cos\theta_s}$$

where:

$\rho_\lambda=$	Planetary TOA reflectance [unitless]
$\pi=$	Mathematical constant equal to ~3.14159 [unitless]
$L_\lambda=$	Spectral radiance at the sensor's aperture [$W/(m^2$ sr μm)]
$d=$	Earth–Sun distance [astronomical units]
$\mathrm{ESUN}_\lambda=$	Mean exoatmospheric solar irradiance [$W/(m^2$ μm)]
$\theta_s=$	Solar zenith angle [degrees[9]]

NOTES:

θ_s = 90° - Sun elevation angle (which can be found in the metadata file)

ERDAS EXPECTS ANGLES IN RADIANS!!! You must convert degrees to radians when using Erdas modeler (multiply degrees by pi/180)

L_λ**=** radiance values for each band that you calculated in step 1

d is provided in the table on the next page but can also be calculated using this equation:

d = 1.00014 - 0.01671 cos g - 0.000 14 cos 2g

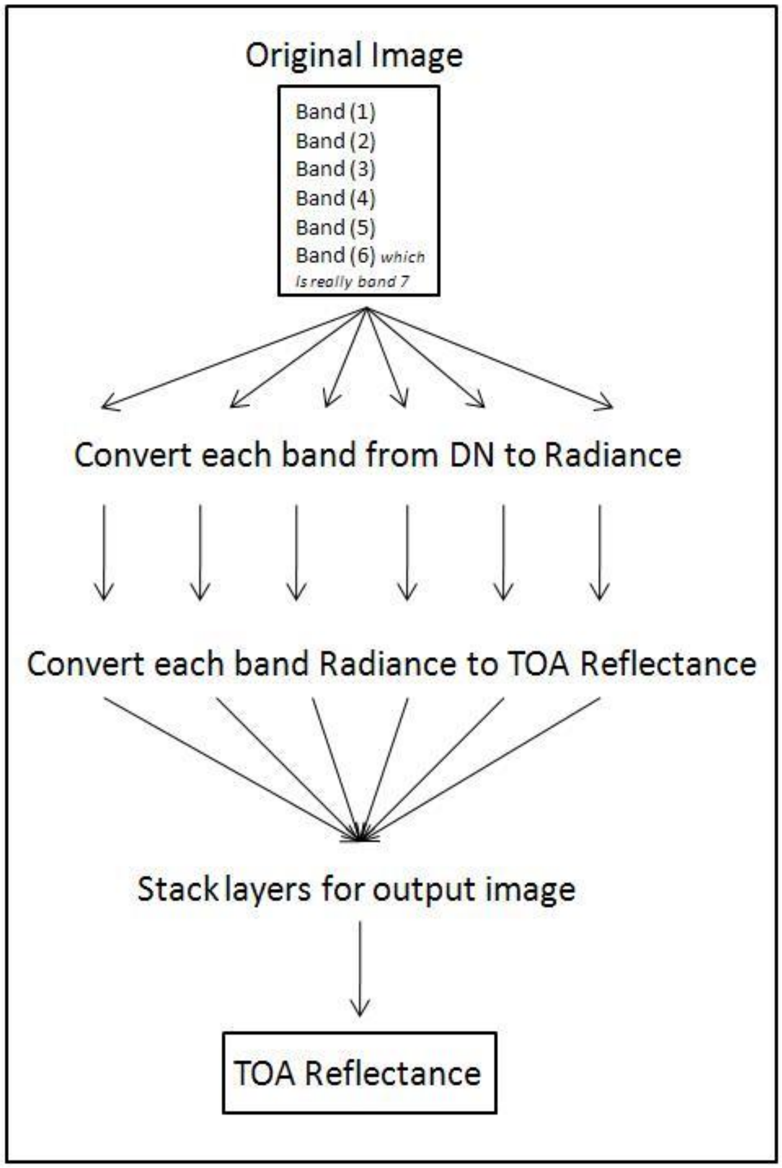
where in degrees g = 357.528 + 0.9856003 N (N = Days of the year and you can assume N=1 on January 1)

Earth–Sun distance (d) in astronomical units for Day of the Year (DOY).

DOY	d	DOY	d	DOY	d
1	0.98331	61	0.99108	121	1.00756
2	0.98330	62	0.99133	122	1.00781
3	0.98330	63	0.99158	123	1.00806
4	0.98330	64	0.99183	124	1.00831
5	0.98330	65	0.99208	125	1.00856
6	0.98332	66	0.99234	126	1.00880
7	0.98333	67	0.99260	127	1.00904
8	0.98335	68	0.99286	128	1.00928
9	0.98338	69	0.99312	129	1.00952
10	0.98341	70	0.99339	130	1.00975
11	0.98345	71	0.99365	131	1.00998
12	0.98349	72	0.99392	132	1.01020
13	0.98354	73	0.99419	133	1.01043
14	0.98359	74	0.99446	134	1.01065
15	0.98365	75	0.99474	135	1.01087
16	0.98371	76	0.99501	136	1.01108
17	0.98378	77	0.99529	137	1.01129
18	0.98385	78	0.99556	138	1.01150
19	0.98393	79	0.99584	139	1.01170
20	0.98401	80	0.99612	140	1.01191
21	0.98410	81	0.99640	141	1.01210
22	0.98419	82	0.99669	142	1.01230
23	0.98428	83	0.99697	143	1.01249
24	0.98439	84	0.99725	144	1.01267
25	0.98449	85	0.99754	145	1.01286
26	0.98460	86	0.99782	146	1.01304
27	0.98472	87	0.99811	147	1.01321
28	0.98484	88	0.99840	148	1.01338
29	0.98496	89	0.99868	149	1.01355
30	0.98509	90	0.99897	150	1.01371
31	0.98523	91	0.99926	151	1.01387
32	0.98536	92	0.99954	152	1.01403
33	0.98551	93	0.99983	153	1.01418
34	0.98565	94	1.00012	154	1.01433
35	0.98580	95	1.00041	155	1.01447
36	0.98596	96	1.00069	156	1.01461
37	0.98612	97	1.00098	157	1.01475
38	0.98628	98	1.00127	158	1.01488
39	0.98645	99	1.00155	159	1.01500
40	0.98662	100	1.00184	160	1.01513
41	0.98680	101	1.00212	161	1.01524
42	0.98698	102	1.00240	162	1.01536
43	0.98717	103	1.00269	163	1.01547
44	0.98735	104	1.00297	164	1.01557
45	0.98755	105	1.00325	165	1.01567
46	0.98774	106	1.00353	166	1.01577
47	0.98794	107	1.00381	167	1.01586
48	0.98814	108	1.00409	168	1.01595
49	0.98835	109	1.00437	169	1.01603
50	0.98856	110	1.00464	170	1.01610
51	0.98877	111	1.00492	171	1.01618
52	0.98899	112	1.00519	172	1.01625
53	0.98921	113	1.00546	173	1.01631
54	0.98944	114	1.00573	174	1.01637
55	0.98966	115	1.00600	175	1.01642
56	0.98989	116	1.00626	176	1.01647
57	0.99012	117	1.00653	177	1.01652
58	0.99036	118	1.00679	178	1.01656
59	0.99060	119	1.00705	179	1.01659
60	0.99084	120	1.00731	180	1.01662

DOY	d	DOY	d	DOY	d
181	1.01665	241	1.00992	301	0.99359
182	1.01667	242	1.00969	302	0.99332
183	1.01668	243	1.00946	303	0.99306
184	1.01670	244	1.00922	304	0.99279
185	1.01670	245	1.00898	305	0.99253
186	1.01670	246	1.00874	306	0.99228
187	1.01670	247	1.00850	307	0.99202
188	1.01669	248	1.00825	308	0.99177
189	1.01668	249	1.00800	309	0.99152
190	1.01666	250	1.00775	310	0.99127
191	1.01664	251	1.00750	311	0.99102
192	1.01661	252	1.00724	312	0.99078
193	1.01658	253	1.00698	313	0.99054
194	1.01655	254	1.00672	314	0.99030
195	1.01650	255	1.00646	315	0.99007
196	1.01646	256	1.00620	316	0.98983
197	1.01641	257	1.00593	317	0.98961
198	1.01635	258	1.00566	318	0.98938
199	1.01629	259	1.00539	319	0.98916
200	1.01623	260	1.00512	320	0.98894
201	1.01616	261	1.00485	321	0.98872
202	1.01609	262	1.00457	322	0.98851
203	1.01601	263	1.00430	323	0.98830
204	1.01592	264	1.00402	324	0.98809
205	1.01584	265	1.00374	325	0.98789
206	1.01575	266	1.00346	326	0.98769
207	1.01565	267	1.00318	327	0.98750
208	1.01555	268	1.00290	328	0.98731
209	1.01544	269	1.00262	329	0.98712
210	1.01533	270	1.00234	330	0.98694
211	1.01522	271	1.00205	331	0.98676
212	1.01510	272	1.00177	332	0.98658
213	1.01497	273	1.00148	333	0.98641
214	1.01485	274	1.00119	334	0.98624
215	1.01471	275	1.00091	335	0.98608
216	1.01458	276	1.00062	336	0.98592
217	1.01444	277	1.00033	337	0.98577
218	1.01429	278	1.00005	338	0.98562
219	1.01414	279	0.99976	339	0.98547
220	1.01399	280	0.99947	340	0.98533
221	1.01383	281	0.99918	341	0.98519
222	1.01367	282	0.99890	342	0.98506
223	1.01351	283	0.99861	343	0.98493
224	1.01334	284	0.99832	344	0.98481
225	1.01317	285	0.99804	345	0.98469
226	1.01299	286	0.99775	346	0.98457
227	1.01281	287	0.99747	347	0.98446
228	1.01263	288	0.99718	348	0.98436
229	1.01244	289	0.99690	349	0.98426
230	1.01225	290	0.99662	350	0.98416
231	1.01205	291	0.99634	351	0.98407
232	1.01186	292	0.99605	352	0.98399
233	1.01165	293	0.99577	353	0.98391
234	1.01145	294	0.99550	354	0.98383
235	1.01124	295	0.99522	355	0.98376
236	1.01103	296	0.99494	356	0.98370
237	1.01081	297	0.99467	357	0.98363
238	1.01060	298	0.99440	358	0.98358
239	1.01037	299	0.99412	359	0.98353
240	1.01015	300	0.99385	360	0.98348
				361	0.98344
				362	0.98340
				363	0.98337
				364	0.98335
				365	0.98333
				366	0.98331

General Model Format Using ERDAS Modeler:

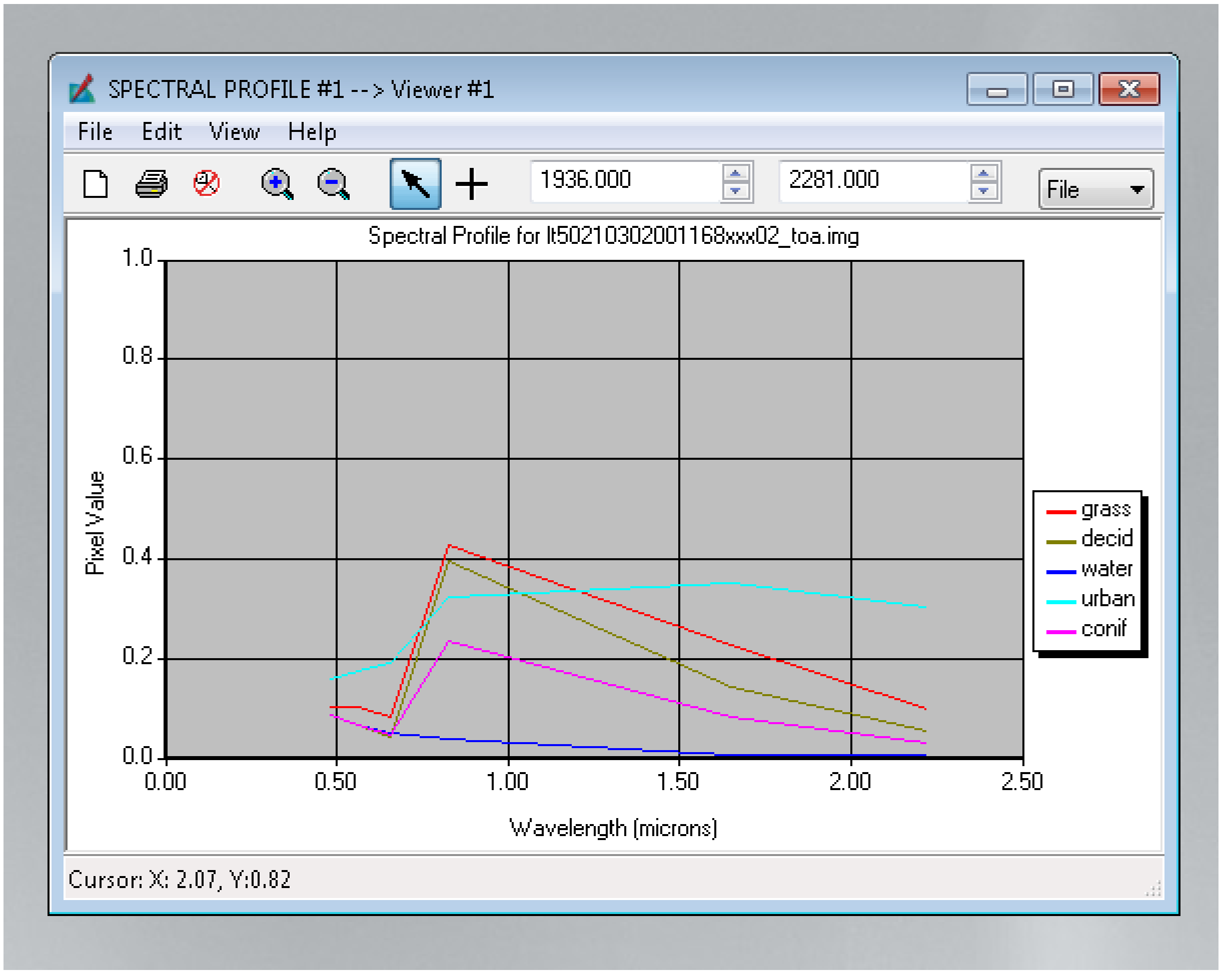


LAB REPORT TO TURN IN - Imagery Analysis:

a. Examine the histograms of before and after correction. Are they different and why?

b. Visually compare the spectral profile of a "vegetated" pixel using DN and TOA reflectance image. Which one represents a "typical" vegetation spectral curve? Why?

c. Which spectral band(s) have changed the most and why?



TM spectral range, post-calibration dynamic ranges, and mean exoatmospheric solar irradiance ($ESUN_\lambda$).

TM Sensors (Q_{calmin} = 1 and Q_{calmax} = 255)							
Band	Spectral range	Center wavelength	$LMIN_\lambda$	$LMAX_\lambda$	$G_{rescale}$	$B_{rescale}$	$ESUN_\lambda$
Units	μm		W/(m^2 sr m)		(W/m^2 sr m)/DN	W/(m^2 sr m)	W/(m^2 r
L4 TM (NLAPS)							
1	0.452 – 0.518	0.485	-1.52	152.10	0.602431	-1.52	1983
2	0.529 – 0.609	0.569	-2.84	296.81	1.175098	-2.84	1795
3	0.624 – 0.693	0.659	-1.17	204.30	0.805765	-1.17	1539
4	0.776 – 0.905	0.841	-1.51	206.20	0.814549	-1.51	1028
5	1.568 – 1.784	1.676	-0.37	27.19	0.108078	-0.37	219.8
6	10.42 – 11.66	11.040	1.2378	15.3032	0.055158	1.2378	N/A
7	2.097 – 2.347	2.222	-0.15	14.38	0.056980	-0.15	83.49
L4 TM (LPGS)							
1	0.452 – 0.518	0.485	-1.52	163	0.647717	-2.17	1983
			-1.52	171	0.679213	-2.20	
2	0.529 – 0.609	0.569	-2.84	336	1.334016	-4.17	1795
3	0.624 – 0.693	0.659	-1.17	254	1.004606	-2.17	1539
4	0.776 – 0.905	0.841	-1.51	221	0.876024	-2.39	1028
5	1.568 – 1.784	1.676	-0.37	31.4	0.125079	-0.50	219.8
6	10.42 – 11.66	11.040	1.2378	15.3032	0.055376	1.2378	N/A
7	2.097 – 2.347	2.222	-0.15	16.6	0.065945	-0.22	83.49
L5 TM (LPGS)							
1	0.452 – 0.518	0.485	-1.52	169	0.671339	-2.19	1983
			-1.52	193	0.765827	-2.29	
2	0.528 – 0.609	0.569	-2.84	333	1.322205	-4.16	1796
			-2.84	365	1.448189	-4.29	
3	0.626 – 0.693	0.660	-1.17	264	1.043976	-2.21	1536
4	0.776 – 0.904	0.840	-1.51	221	0.876024	-2.39	1031
5	1.567 – 1.784	1.676	-0.37	30.2	0.120354	-0.49	220.0
6	10.45 – 12.42	11.435	1.2378	15.3032	0.055376	1.18	N/A
7	2.097 – 2.349	2.223	-0.15	16.5	0.065551	-0.22	83.44