DN to Reflectance

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Contents

Definition of NDVI

$$\mathrm{NDVI} = \frac{\rho_{NIR} - \rho_{VR}}{\rho_{NIR} + \rho_{VR}}$$

ρ_{NIR} : Reflectance at Near Infrared

ρ_{VR} : Reflectance at Visible Red

Reflectance

- Ratio of Radiant Energy Reflected to Incident Energy
- Radiant Energy = Integral of vertical components of Radiance Measured (by satellite to be scaled back from DN)

$$\rho_\lambda = \frac{\pi L_\lambda}{G_\lambda} = \frac{\pi L_\lambda}{\mu_s E_{s\lambda}}$$

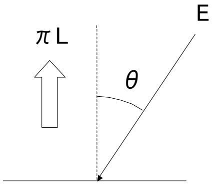
ρ_λ : Spectral Reflectance

L_λ : Spectral Radiance of the Surface $W/m^2 \cdot sr \cdot \mu m$

G : Spectral Irradiance $W/m^2 \cdot \mu m$

$E_{s\lambda}$: Spectral Solar Irradiance $W/m^2 \cdot \mu m$

$\mu_s = \cos(\theta_s), \theta_s$: Solar zenith angle

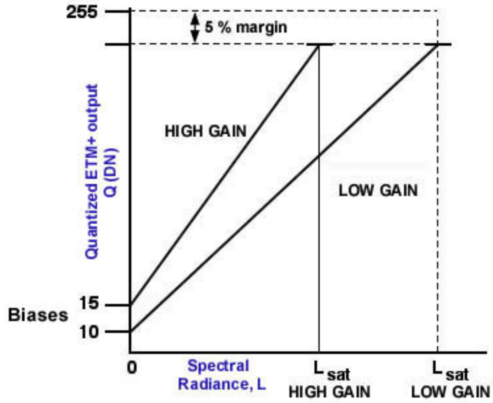


DN ?

- DN (Digital Number) you can see in the RS image files is not Reflectance.
- So you have to derive Reflectance from the DN
- Then what is DN ?

DN is a scaled Radiance

- DN is scaled from Radiance measured by sensors



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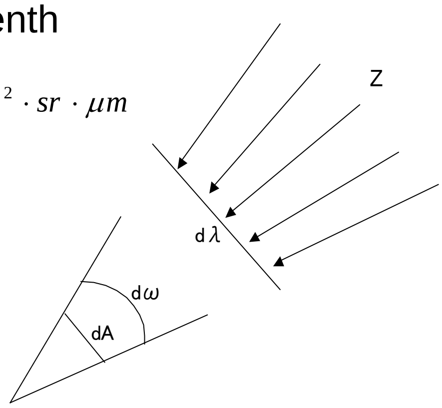
Radiance

- Energy in unit time, unit solid angle, unit wavelenth

unit $: J/s \cdot m^2 \cdot sr \cdot \mu m = W/m^2 \cdot sr \cdot \mu m$

$$L_\lambda = \frac{Energy_{received}}{dtdAd\omega d\lambda}$$



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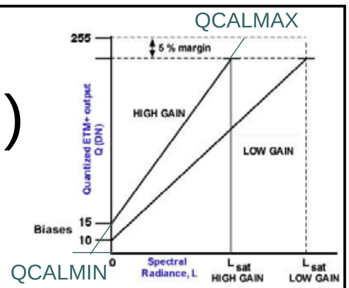
DN to Radiance (L λ)



$L_\lambda = gain \times DN + offset$

or

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

$$gain = \frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN}$$

$$offset = -\frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN} + LMIN_\lambda$$

$DN = QCAL, offset = bias$

- Have to find out LMAX, LMIN, QCALMAX, QCALMIN

L_λ = Spectral Radiance at the sensor's aperture in **watts/(meter squared * ster * µm)**

"gain" = Rescaled gain (the data product "gain" contained in the Level 1 product header or ancillary data record) in **watts/(meter squared * ster * µm)**

"offset" = Rescaled bias (the data product "offset" contained in the Level 1 product header or ancillary data record) in **watts/(meter squared * ster * µm)**

QCAL = the quantized calibrated pixel value in DN

$LMIN_\lambda$ = the spectral radiance that is scaled to QCALMIN in **watts/(meter squared * ster * µm)**

$LMAX_\lambda$ = the spectral radiance that is scaled to QCALMAX in **watts/(meter squared * ster * µm)**

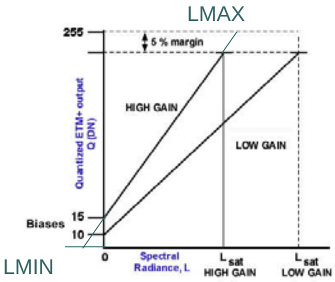
QCALMIN = the minimum quantized calibrated pixel value (corresponding to $LMIN_\lambda$) in DN
= 1 (LPGS Products)
= 0 (NLAPS Products)

QCALMAX = the maximum quantized calibrated pixel value (corresponding to $LMAX_\lambda$) in DN
= 255

LMIN, LMAX of LANDSAT7

- LMIN, LMAX List

Table 11.2 ETM+ Spectral Radiance Range watts/(meter squared * ster * µm)								
Band Number	Before July 1, 2000				After July 1, 2000			
	Low Gain		High Gain		Low Gain		High Gain	
	LMIN	LMAX	LMIN	LMAX	LMIN	LMAX	LMIN	LMAX
1	-6.2	297.5	-6.2	194.3	-6.2	293.7	-6.2	191.6
2	-6.0	303.4	-6.0	202.4	-6.4	300.9	-6.4	196.5
3	-4.5	235.5	-4.5	158.6	-5.0	234.4	-5.0	152.9
4	-4.5	235.0	-4.5	157.5	-5.1	241.1	-5.1	157.4
5	-1.0	47.70	-1.0	31.76	-1.0	47.57	-1.0	31.06
6	0.0	17.04	3.2	12.65	0.0	17.04	3.2	12.65
7	-0.35	16.60	-0.35	10.932	-0.35	16.54	-0.35	10.80
8	-5.0	244.00	-5.0	158.40	-4.7	243.1	-4.7	158.3



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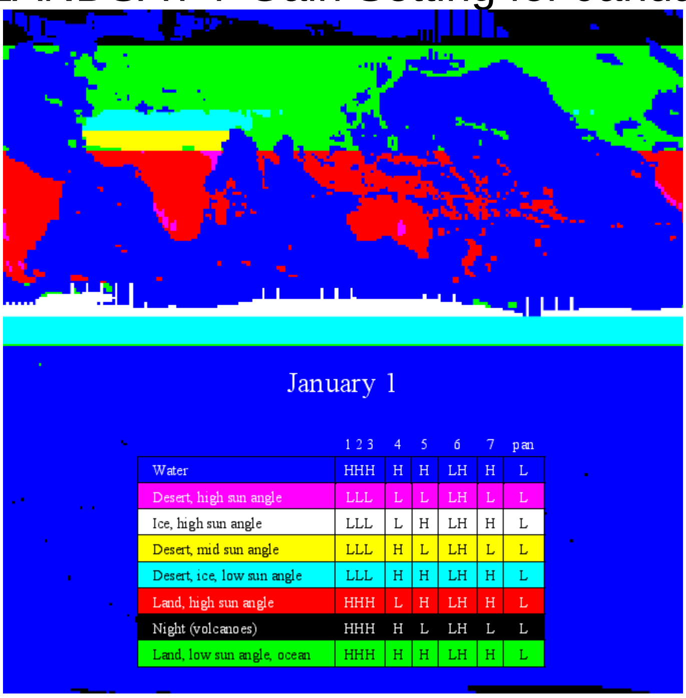
LANDSAT 7 Gain Setting for January



http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter6/htmls/january_gains.html

How to Find the Constants for Scaling factor of Radiance

- Metadata file .met
  - Sample ftp://cgceopush3.geo.msu.edu/push3_2/137/043/p137r43_7x000228/p137r043_7x20000228.met
- Identify Hi-Gain or Low Gain
  - EROS Data Center Gateway
    - http://edcimswww.cr.usgs.gov/pub/imswelcome/
- Obtain Hi-Gain and Low-Gain parameters
  - USGS LANDSAT Page
    - http://landsat7.usgs.gov/technical_details/calibration_files/
- Header file/record
- Data Handling Manuals
  - Processed in Japan, China, Thailand ….

How to obtain TOA Irradiance

- Spectral Exo-atmospheric Irradiance

$$\rho_\lambda = \frac{\pi L_\lambda}{G_\lambda} = \frac{\pi L_\lambda}{\mu_s E_{s\lambda}}$$

$$E_{s\lambda} = \frac{ESUN_\lambda}{d_s{}^2}$$

$E_{s\lambda}$: Exo-atmospheric Solar Spectral Irradiance $W/m^2 \cdot \mu m$

$ESUN_\lambda$: Average Exo-atmospheric Solor Spectral Irradiance $W/m^2 \cdot \mu m$

d_s : Earth-Sun distance in astronomical units

$\mu_s = \cos(\theta_s), \theta_s$: Solar zenith angle

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Average Solar Spectral Irradiance ESUNλ

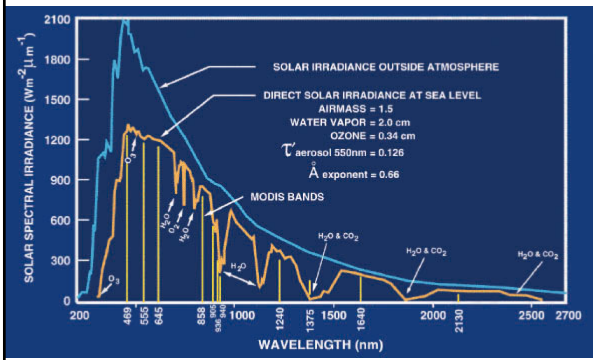
- Average Solor Spectral Exo-atmospheric Irradiance

$$\rho_\lambda = \frac{\pi L_\lambda}{G_\lambda} = \frac{\pi L_\lambda}{\mu_s E_{s\lambda}}$$

$$E_{s\lambda} = \frac{ESUN_\lambda}{d_s^{\,2}}$$

$E_{s\lambda}$: Exo-stomospheric Solar Spectral Irradiance $W/m^2 \cdot \mu m$

$ESUN_\lambda$: Average Exo-atmospheric Spectral Irradiance $W/m^2 \cdot \mu m$



ESUNλ for ETM+

Table 11.3 ETM+ Solar Spectral Irradiances

Band	watts/(meter squared * µm)
1	1969.000
2	1840.000
3	1551.000
4	1044.000
5	225.700
7	82.07
8	1368.000

http://modarch.gsfc.nasa.gov/MODIS/ATM/solar.html

http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter11/chapter11.html

Sun Earth Distance ds

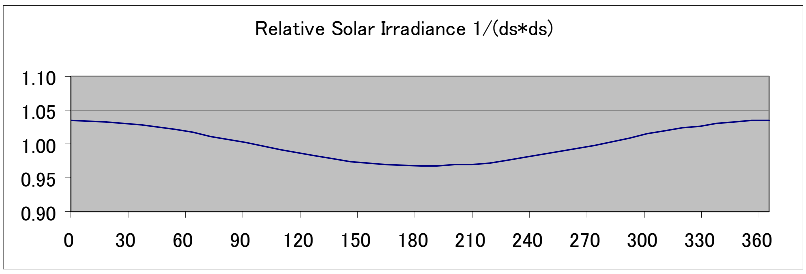
$$E_{s\lambda} = \frac{1}{d_s^{\,2}} ESUN_\lambda$$

d_s : Earth-Sun distance in astronomical units

$$d_s = 1 + 0.01672 \times \sin\left(\frac{2\pi(J-93.5)}{365}\right)$$

Table 11.4 Earth-Sun Distance in Astronomical Units

Julian Day	Distance	Julian Day	Distance	Julian Day	Distance	Julian Day	Distance	Julian Day	Distance
1	.9832	74	.9945	152	1.0140	227	1.0128	305	.9925
15	.9836	91	.9993	166	1.0158	242	1.0092	319	.9892
32	.9853	106	1.0033	182	1.0167	258	1.0057	335	.9860
46	.9878	121	1.0076	196	1.0165	274	1.0011	349	.9843
60	.9909	135	1.0109	213	1.0149	288	.9972	365	.9833



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Solar Zenith Angle

- LANDSAT: Use Zenith Angle (90deg – Sun Elevation) at the centre of the image for the whole image
  - 180km -> +- 0.81 deg
  - If Zenith Angle < 20deg, difference < 1%

Or

- Calculate the angle from Lat, Lon, Julian day and time (i.e POSSOL of 6S).

http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter11/chapter11.html

Atmospheric Correction

- The reflectance we have obtained here is Apparent Reflectance or Reflectance at TOA
- Atmospheric correction is needed to obtain Reflectance at Ground Level
- You may run 6S with appropriate parameters
- Some products are Reflectance at Ground Surface, such as MODIS, SPOT VEGETAION…

References

- Landsat 7 Science Data Users Handbook
  - Chapter6
    - http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter6/chapter6.html
  - Chapter 11
    - http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter11/chapter11.html
- Dr. Kawamura's page DN->Refelctance for Landsat (Japanese)
  - http://www.geocities.jp/kensuke_kawamura/Others/LandsatCalibration/LandsatCalibration.html
- 6S Manual