Today's lecture will cover

- Terms often used in image processing
  - Physical variables in remote sensing
- Fundamental concepts
  - Resolutions
  - Images

Terms Used in Image Processing

Lecture 02

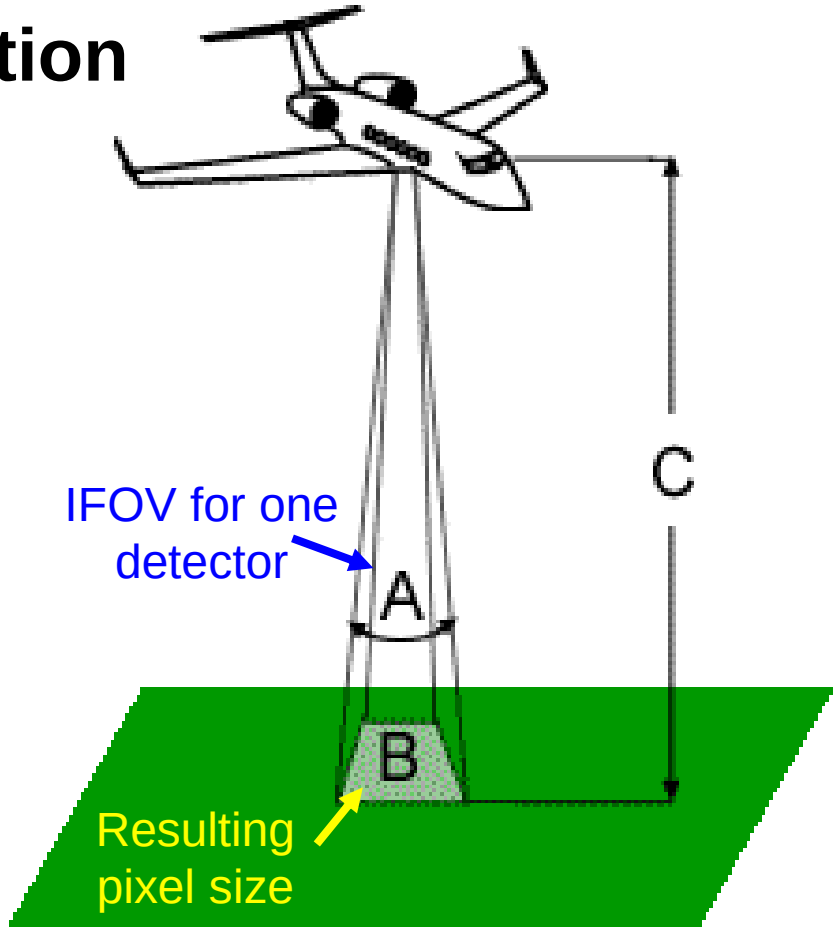
9/8/2015

Terms and Functions in DIPA

- **Important Terms**
  - ***Spatial Resolution***
  - ***Radiometric Resolution***
  - ***Temporal Resolution***
  - ***Spectral Resolution***
- **Processing**
  - ***Radiometric Correction***
  - ***Geometric Correction***
  - ***Display & Enhancement***
  - ***Information Extraction***

Spatial Resolution

- The **IFOV** is the angular cone of visibility of one detector in the sensor (A) and determines the area on the Earth's surface which is "seen" from a given altitude at one particular moment in time (B). The size of the area viewed (i.e. pixel size) is determined by multiplying the IFOV by the distance from the ground to the sensor (C).



Coarse or low resolution

Spatial resolution and pixel size are related. The question remains:
The finer the resolution the better an image is?

Fine or high resolution

Radiometric Resolution

- The radiometric resolution of an imaging system describes its ability to discriminate very slight differences in energy The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

- The maximum number of brightness levels available depends on the number of bits used in representing the energy recorded. Thus, if a sensor used 8 bits to record the data, there would be $2^8 = 256$ digital values available, ranging from 0 to 255. However, if only 4 bits were used, then only $2^4 = 16$ values ranging from 0 to 15 would be available.

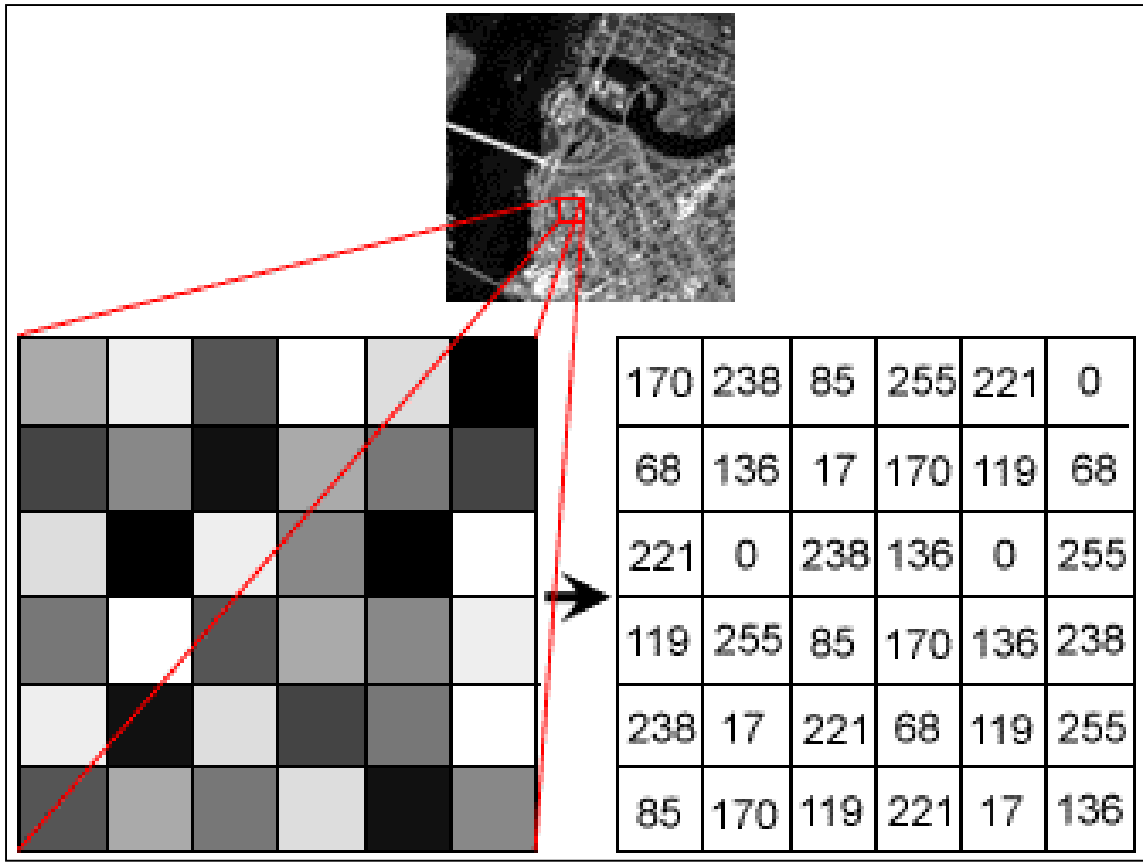
Radiometric Resolution

- 4 bit 2^4 = 16 gray levels
- 6 bit 2^6 = 64 gray levels
- 8 bit 2^8 = 256 gray levels (byte)
- 10 bit 2^{10} = 1024 gray levels
- 11 bit 2^{11} = 2048 gray levels
- 12 bit 2^{12} = 4096 gray levels
- 14 bit 2^{14} = 16384 gray levels
- 16 bit 2^{16} = 65563 gray levels (2 bytes)

Exercise 01: When you save a file or a picture, you can choose the the resolution or type of format. Use Erdas Imagine software to find out the differences in bytes and their value ranges among a) single char, b) unsigned char, c) float, d) double float, etc.

Radiometric Resolution & Pixels

- **Pixels** – Picture Element: Representing the brightness of each area with an integer value or ***digital number or DN***.



170	238	85	255	221	0
68	136	17	170	119	68
221	0	238	136	0	255
119	255	85	170	136	238
238	17	221	68	119	255
85	170	119	221	17	136

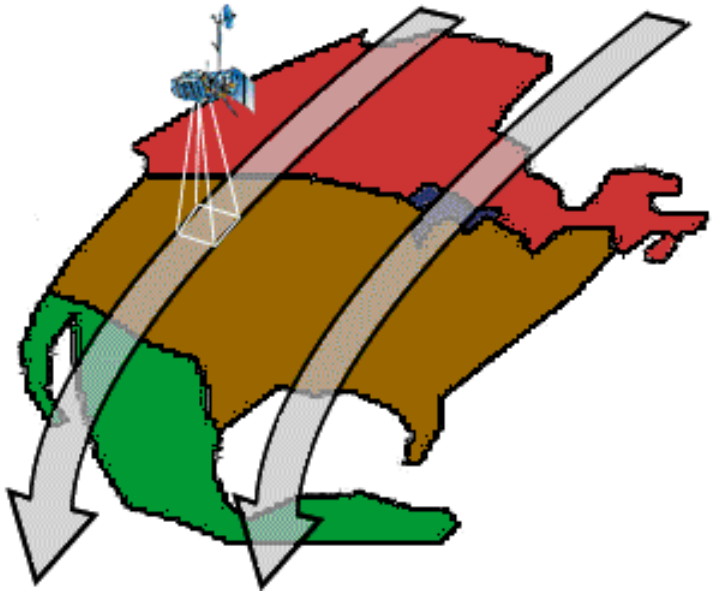
Radiometric Resolution

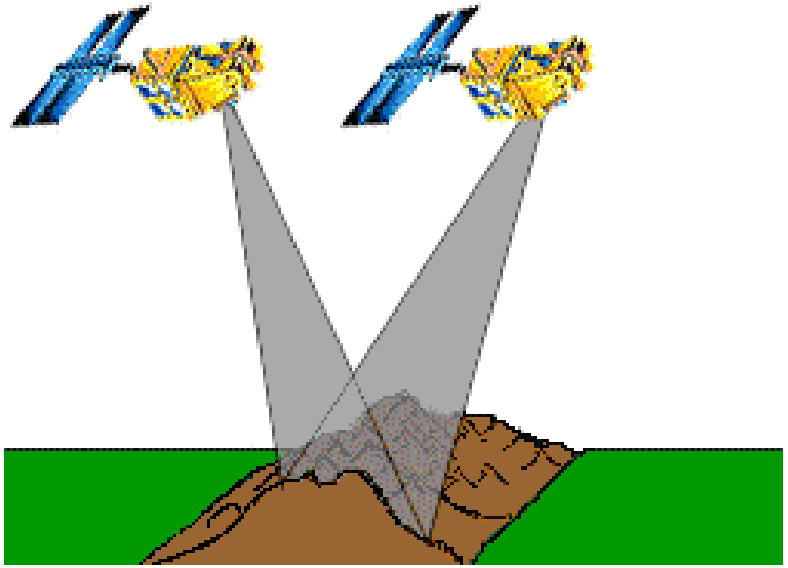
2 bit image

8 bit image

Temporal Resolution

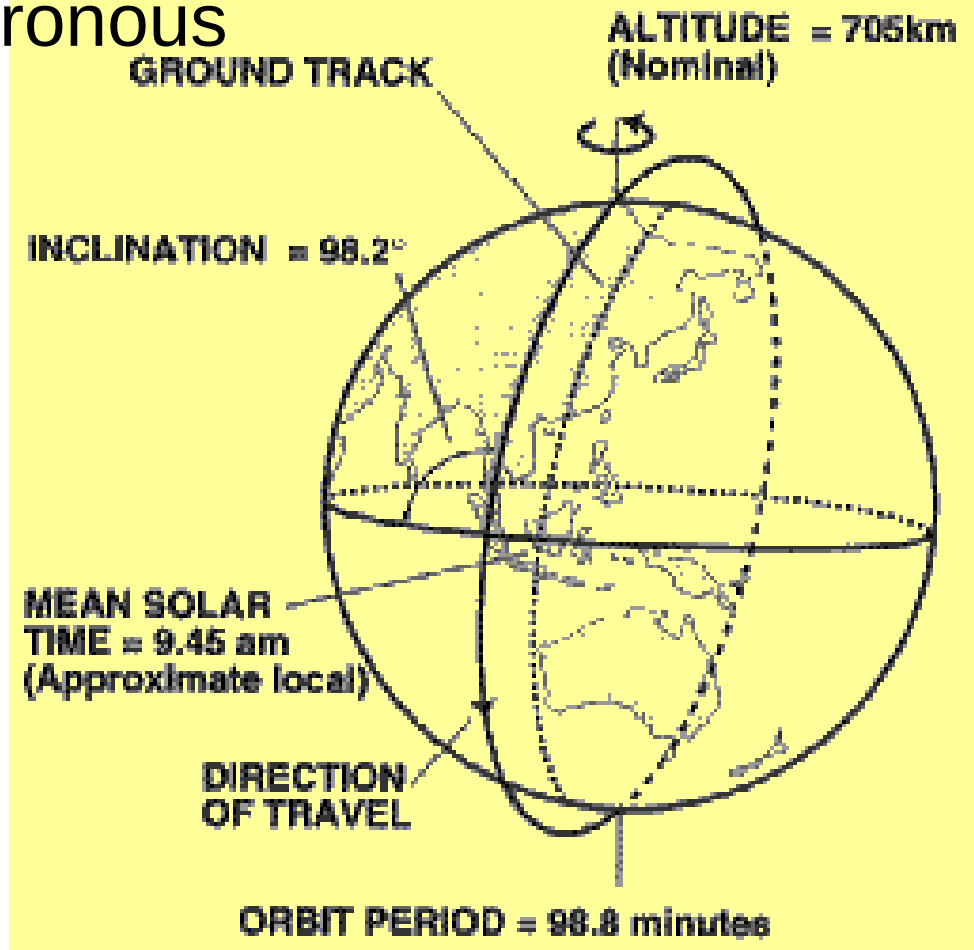
- Refers to the length of time it takes for a satellite to complete one entire orbit cycle. However, due to possible overlaps of adjacent swaths, the repeat cycle may change.
- If a satellite has a pointing capability, the temporal resolution could be higher.





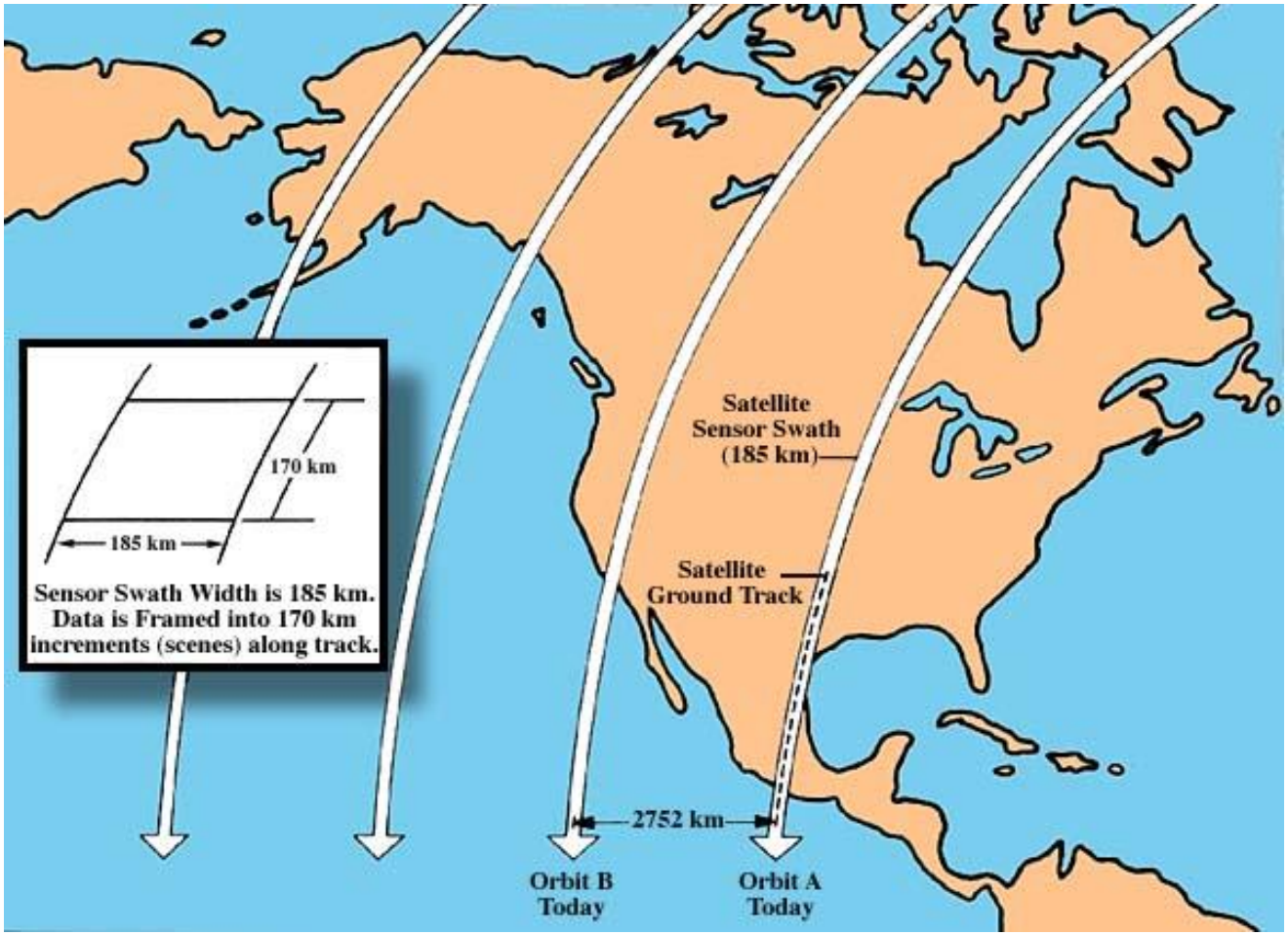
Temporal Resolution

- Orbit – Circular, Near-Polar, Sun-Synchronous



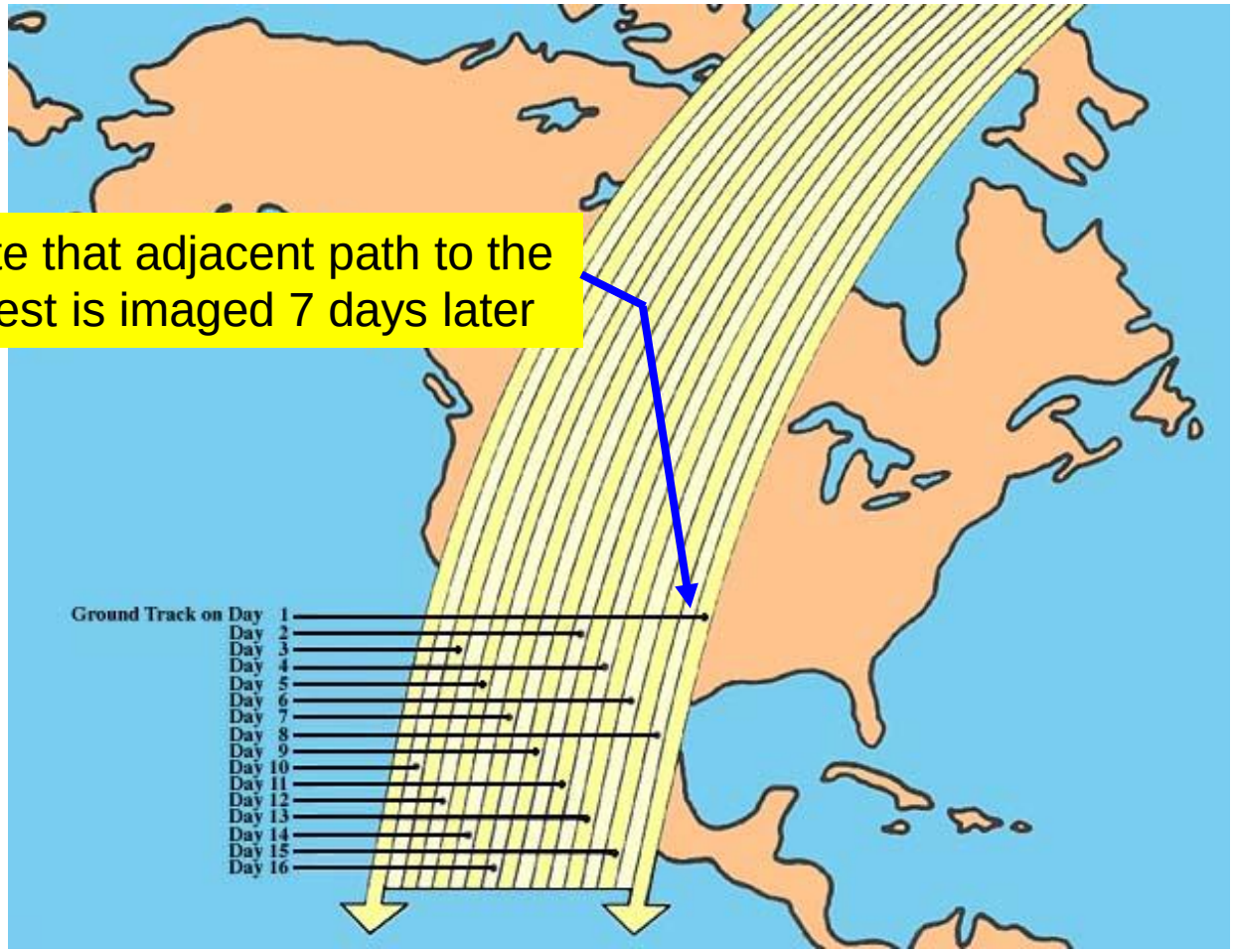
Temporal Resolution

- Orbit – Swath Width = 185 km (Landsat)

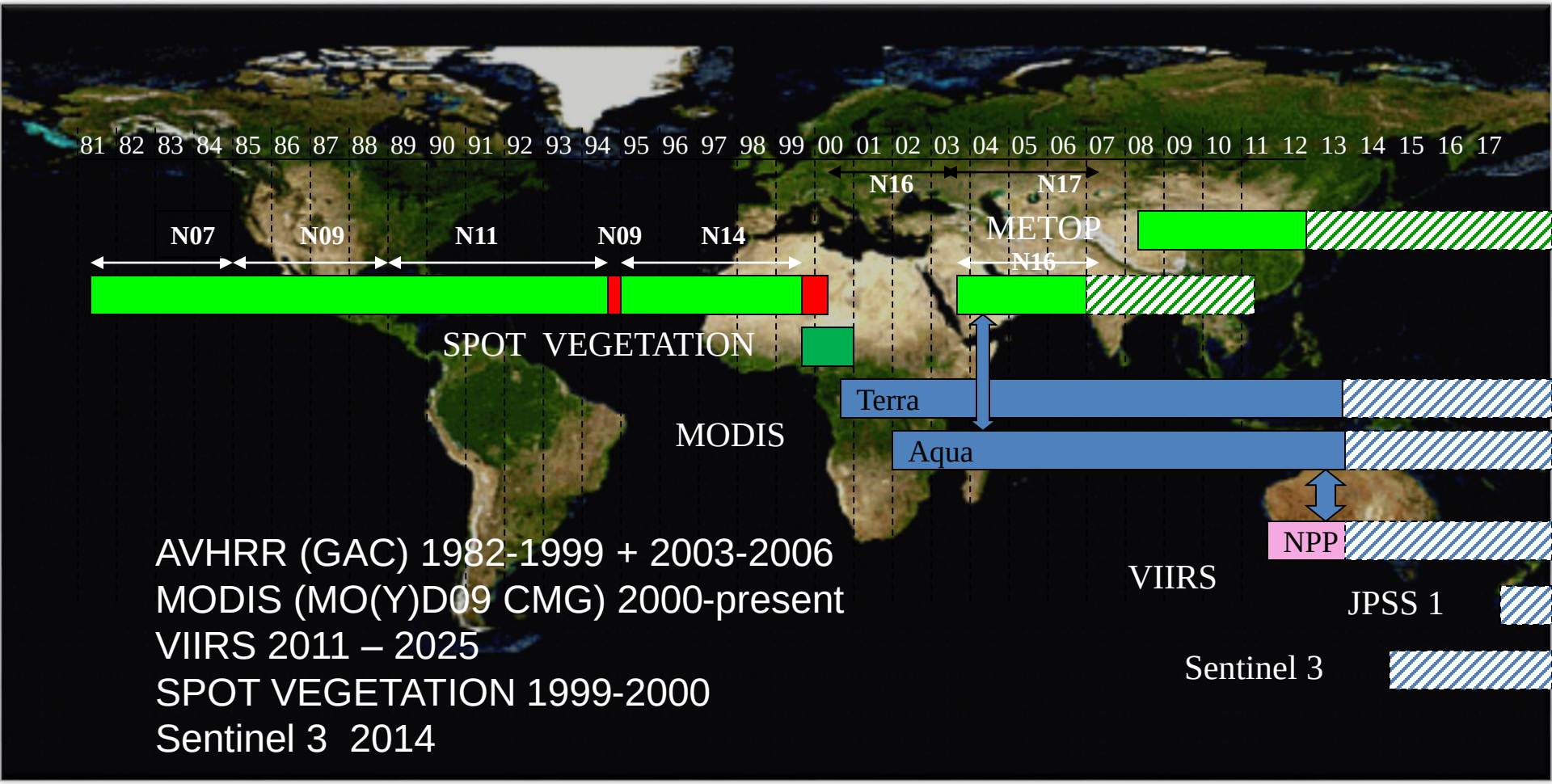


Temporal Resolution

- Orbit – Repeat cycle = 16 days

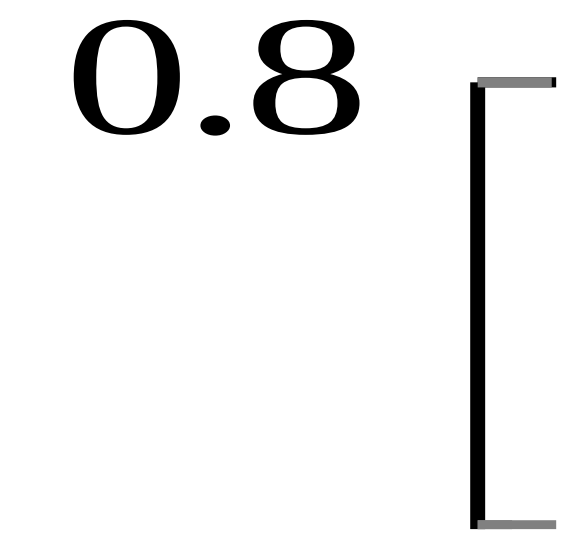


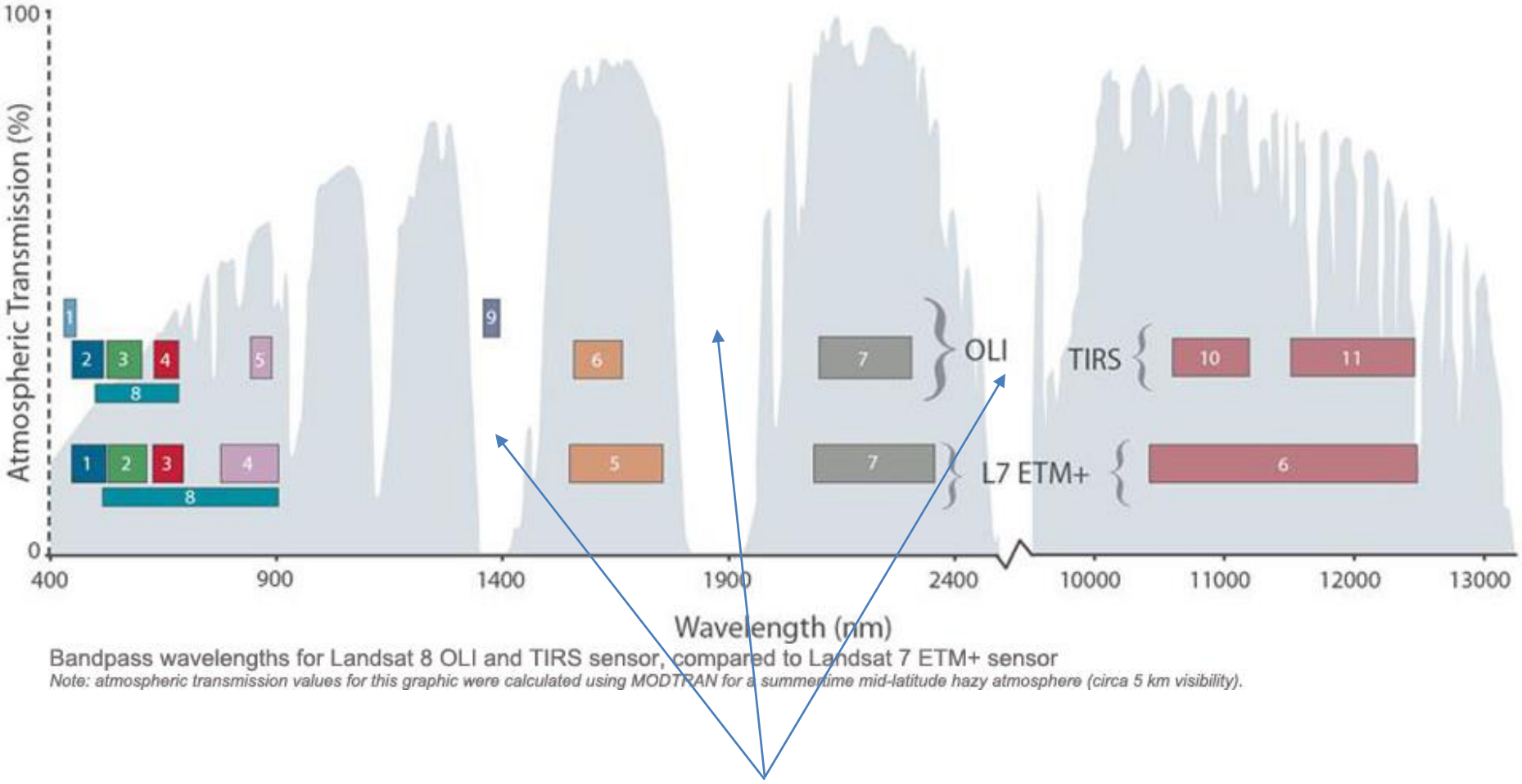
Long term data records



Spectral Resolution

- Describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band.



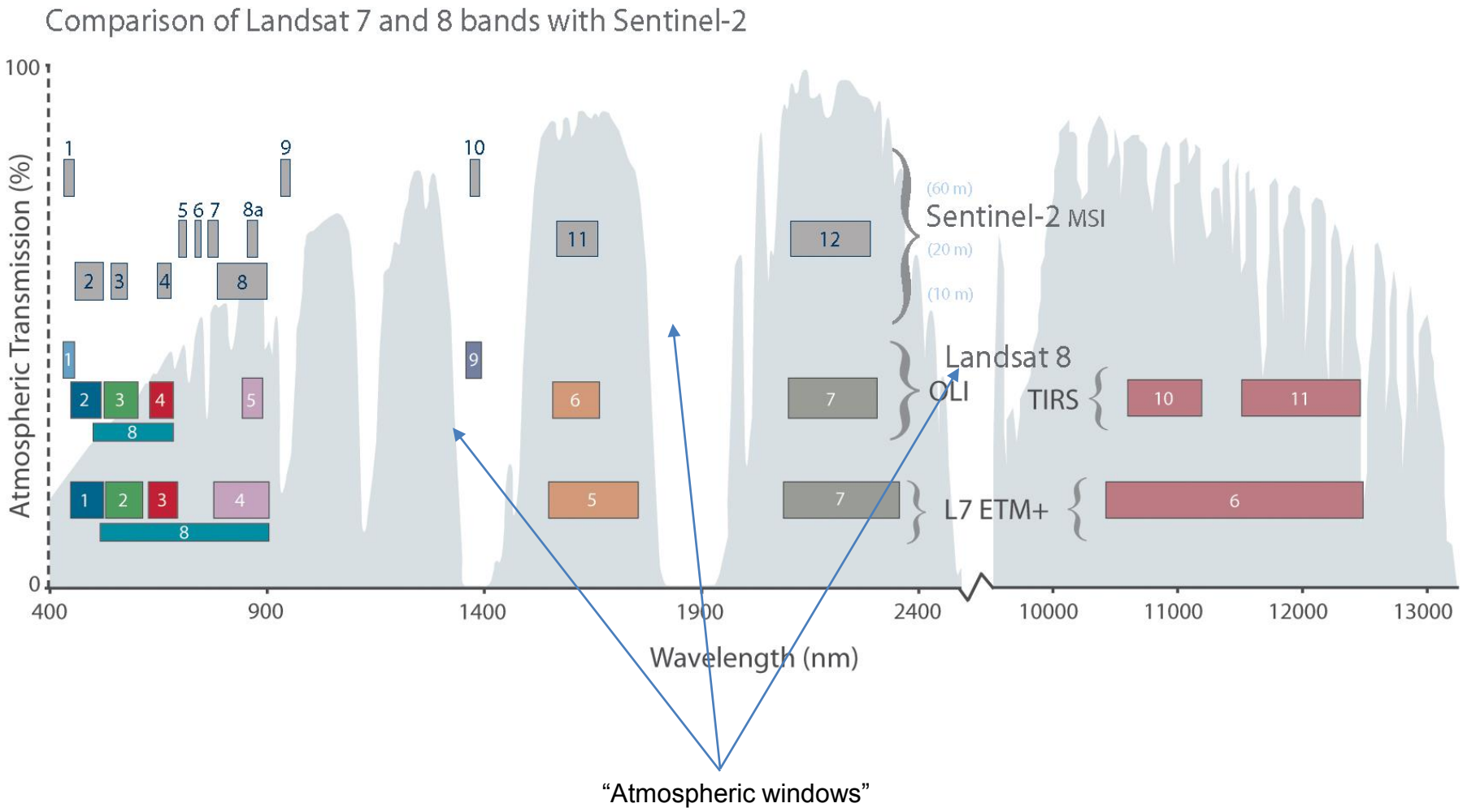


Bandpass wavelengths for Landsat 8 OLI and TIRS sensor, compared to Landsat 7 ETM+ sensor

Note: atmospheric transmission values for this graphic were calculated using MODTRAN for a summertime mid-latitude hazy atmosphere (circa 5 km visibility).

"Atmospheric windows"

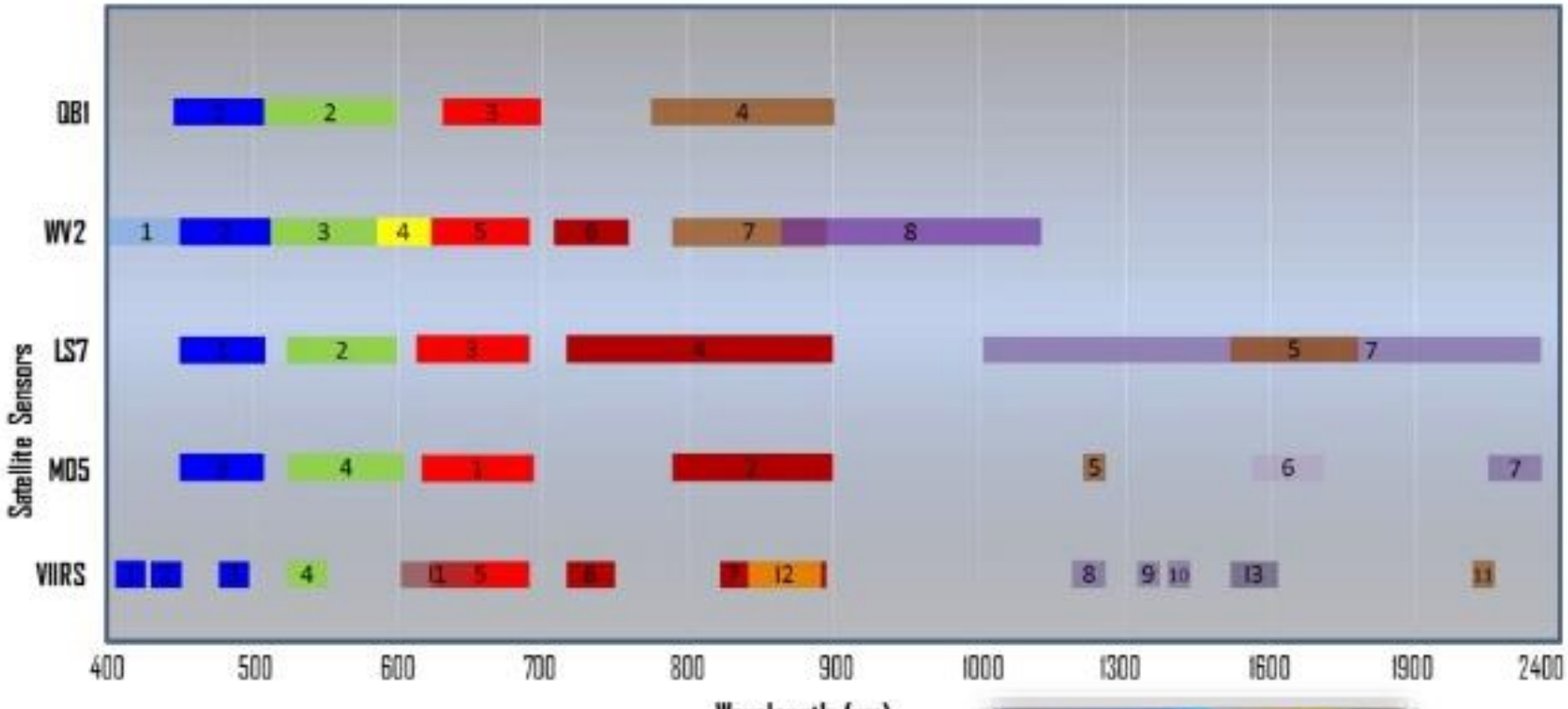
https://landsat.usgs.gov/ldcm_vs_previous.php



http://landsat.gsfc.nasa.gov/wp-content/uploads/2015/06/Landsat.v.Sentinel-2.png

Satellite Sensors Interoperability

Options for Up/Down Scaling



QB1- QuickBird (4 optical bands 2.62m)
WV2-WorldView2 (8 optical bands, 2.4m)
LS7-Landsat ETM+ (6 optical bands, 30m)
MO5-MODIS MOD09A1 (7 optical bands, 500m)
VIIRS-NPOESS VIIRS (11 optical bands, 375-750m)

Credits: Dr. C. Biradar, http://www.slideshare.net/ICARDA/hsad-geoinformatics

Channels on the VIIRS, OLS, and MODIS Imagers					
(1) VIIRS **	OLS **	MODIS **	(2) VIIRS **	OLS **	MODIS **
0.412 (M1)	—	0.412 (8)	1.378 (M9)	—	1.38 (26)
0.445 M2)	—	0.442 (9)	1.61 (I3, M10)	—	1.69 (6)
—	—	0.465 (3)	2.25 (M11)	—	2.11 (7)
0.488 (M3)	—	0.486 (10)	3.70 (M12)	—	—
—	—	0.529 (11)	3.74 (I4)	—	3.79 (20)
—	—	0.547 (12)	—	—	3.99 (21)
0.555 (M4)	—	0.553 (4)	—	—	3.97 (22)
0.640 (I1)	—	0.646 (1)	4.05 (M13)	—	4.06 (23)
—	—	0.665 (13)	—	—	6.76 (27)
0.672 (M5)	—	0.677 (14)	—	—	7.33 (28)
0.7 day/night	0.7 night visible	—	8.55 (M14)	—	8.52 (29)
0.746 (M6)	0.75 day visible	0.746 (15)	—	—	9.72 (30)
		0.856 (2)	10.763 (M15)	—	11.0 (31)
0.865 (I2, M7)	—	0.866 (16)	11.450 (I5)	11.6	12.0 (32)
—	—	0.904 (17)	12.013 (M16)	—	13.4 (33)
—	—	0.935 (18)	—	—	13.7 (34)
—	—	0.936 (19)	—	—	13.9 (35)
1.24 (M8)	—	1.24 (5)	—	—	14.2 (36)

M = Moderate resolution band (0.74 km) "smooth"
I = Imaging band (0.37 km) "fine"
** Wavelength (μm)

Comparison of 22-band NPOESS VIIRS with MODIS bands

NPOESS VIIRS		MODIS	
Band number	**Central wavelength (μm)**	**Band number**	**Central wavelength (μm)**
M1	0.412	**8**	0.412
M2	0.445	**9**	0.443
M3 (blue)	0.488	**3 (blue)**	0.469
M4 (green)	0.555	**4 (green)**	0.555
M5 (red)	0.672	**1 (red)**	0.645
M6	0.746	**15**	0.748
M7	0.865	**2**	0.858
M8	1.240	**5**	1.240
M9	1.378	**26**	1.375
M10	1.61	**6**	1.640
M11	2.25	**7**	2.13
M12	3.7	**22**	3.959
M13	4.05	**23**	4.05
M14	8.55	**29**	8.55
M15	10.763	**31**	11.03
M16	12.013	**32**	12.02
DNB	0.7	**No equivalent width**	No equivalent width
I1	0.64	**1 (red)**	0.645
I2	0.865	**2**	0.858
I3	1.61	**6**	1.64
I4	3.74	**22**	3.959
I5	11.45	**31**	11.03

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250
Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NE[delta]T(K)[4]
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in µm
[2] Spectral Radiance values are (W/m^2 -µm-sr)
[3] SNR = Signal-to-noise ratio
[4] NE(delta)T = Noise-equivalent temperature difference

Note: Performance goal is 30-40% better than required

Spectral Resolution

- Questions:
  - Is a finer spectral resolution better than a coarser resolution image?
  - S/N?
  - Redundancy?
  - Processing time and disk space required?
  - Scaling?

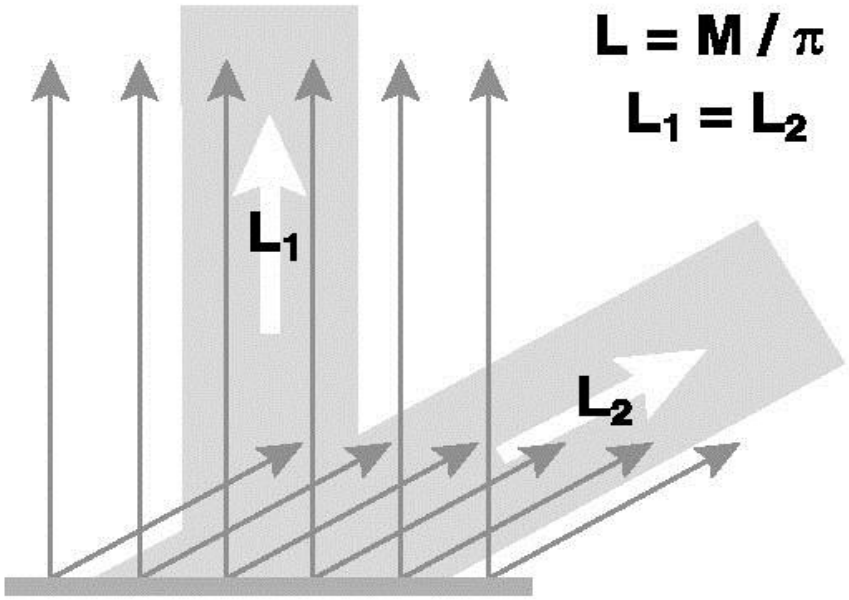
Exercises 02: Write a paragraph about your research questions and then discuss the ideal resolutions (spatial, radiometric and temporal). Be sure to include your justification.

Summary

- These terms are used frequently
- There are confusions, even among the "experts"
  - e.g. High resolution? What is your definition of high spatial resolution, sub meters, 10s meters, kms, or 10s kms? Check out AVHRR, MODIS and Landsat sensors and study their resolutions
- Temporal resolution is the same thing!

Radiometry

- Lambertian Surface
  - A Lambertian surface provides uniform diffusion of the incident radiation such that its radiance is the same in all directions from which it can be measured.



A surface radiating equally at 0° and at 60°.

Since, by the cosine law, a radiance detector sees twice as much surface area in the same solid angle for the 60° case, the average radiance must be half the magnitude of the radiance in the 0° case.

System Radiometric Correction

Landsat Example

Digital Numbers → Radiance

- DNs
  - Typical range: 0-255, depending the radiometric resolution of a sensor
  - Unitless
  - Often arbitrarily scaled
  - May vary from image to image
- Radiance
  - Range varies greatly
  - Unit ($w/m^2/sr$ or $mw/m^2/sr$)
  - Consistent from day to day or space to space or image to image
  - Not normalized for illumination, i.e. vary with illumination conditions, BRDF, and substrate conditions.

Digital Numbers → Radiance

$$L_\lambda = \alpha_\lambda \times DN_\lambda + \beta_\lambda$$

λ – wavelength

α – gain

β – offset

$$L_\lambda = (L\max - L\min)/255 \times DN_\lambda + L\min$$

Digital Numbers → Radiance

Table 1. ETM+ Spectral Radiance Range watts/(meter squared * ster * μm)				
Band Number	**Low Gain**		**High Gain**	
	LMIN	LMAX	LMIN	LMAX
1	-6.2	293.7	-6.2	191.6
2	-6.4	300.9	-6.4	196.5
3	-5.0	234.4	-5.0	152.9
4	-5.1	241.1	-5.1	157.4
5	-1.0	47.57	-1.0	31.06
6	0.0	17.04	3.2	12.65
7	-0.35	16.54	-0.35	10.80
8	-4.7	243.1	-4.7	158.3

Radiance → TOA Reflectance

- Assuming there is no atmospheric effect
  (equivalent to say that we consider reflectance at the top of the atmosphere)
- Reflectance ρ*

$$\rho^* = \frac{\pi \times Radiance}{Irradiance}$$

- Irradiance is Esun and π is to take into account the solid angle (steradian, sr).
- Then we have a TOA reflectance

$$\rho_\lambda^* = \frac{\pi \times L_\lambda \times d^2}{E_{sun}^\lambda \cos\theta_{sun}}$$

where d is sun-earth distance

Solar irradiance, Esun

ETM+ Solar Spectral Irradiances	
Band	watts/(meter squared * µm)
1	1970.000
2	1843.000
3	1555.000
4	1047.000
5	227.100
7	80.530
8	1368.000

Sun-Earth distance, d

- http://www.fourmilab.ch/cgi-bin/uncgi/Solar/action?sys=-Si

Earth-Sun Distance in Astronomical Units									
DOY	Distance	DOY	Distance	DOY	Distance	DOY	Distance	DOY	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

Data sources

- Register and create username/psswrd @ https://urs.earthdata.nasa.gov/
- NASA REVERB ECHO:
  http://reverb.echo.nasa.gov

Most MODIS data products and other EOS
https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table

Landsat and terrestrial data

- USGS Earth explorer:

  http://earthexplorer.usgs.gov/

- USGS GLOVIS:

  http://glovis.usgs.gov/