Observing the Earth: Resolutions Part 2

What you should be working on

- Assignment 3 due March 2nd
- Blog Post 4 due March 9th
- Assignment 4 due March 16th

Assignment 3 Office Hours

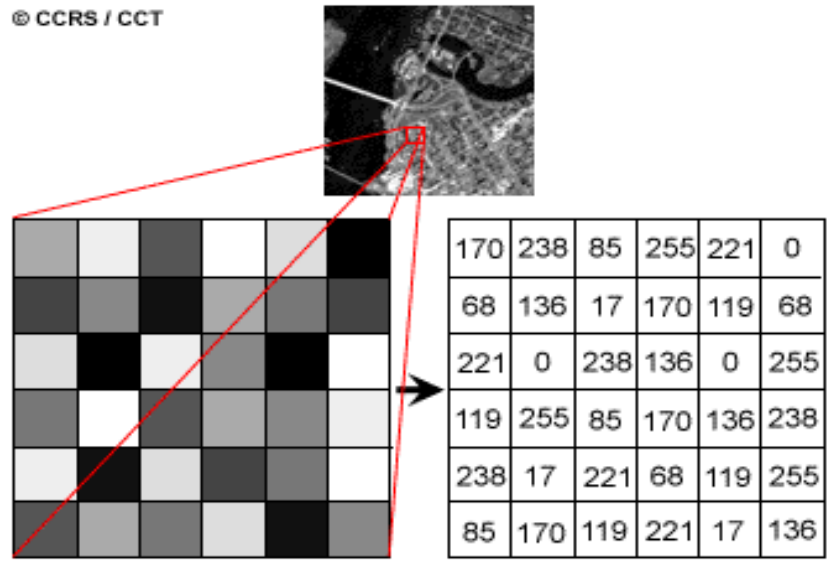
- Wednesday, March 1st - 10:00am-11:00am
- Wednesday, March 1st - 4:00pm-5:00pm
- Thursday, March 2nd - 10:00am-11:00am

Quick Review - The Resolutions:

- Spatial Resolution
- Spectral Resolution
- Temporal Resolution

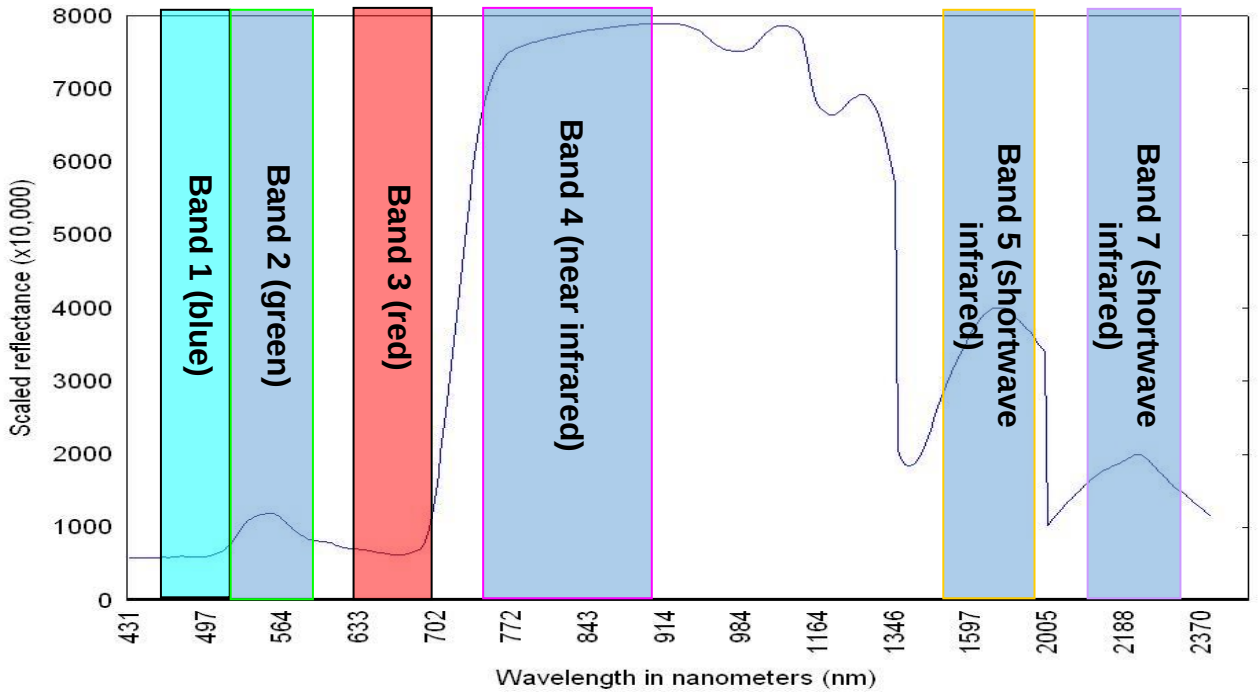
Spatial Resolution

- Smallest possible feature/objected that can be detected
- Typically defined by the pixel size
- Impacts level of detail/information
- Coarser resolution = less detail/information
- Other considerations:
  - Spatial arrangement of targets
  - Data quality
- Low, moderate, high and very high spatial res



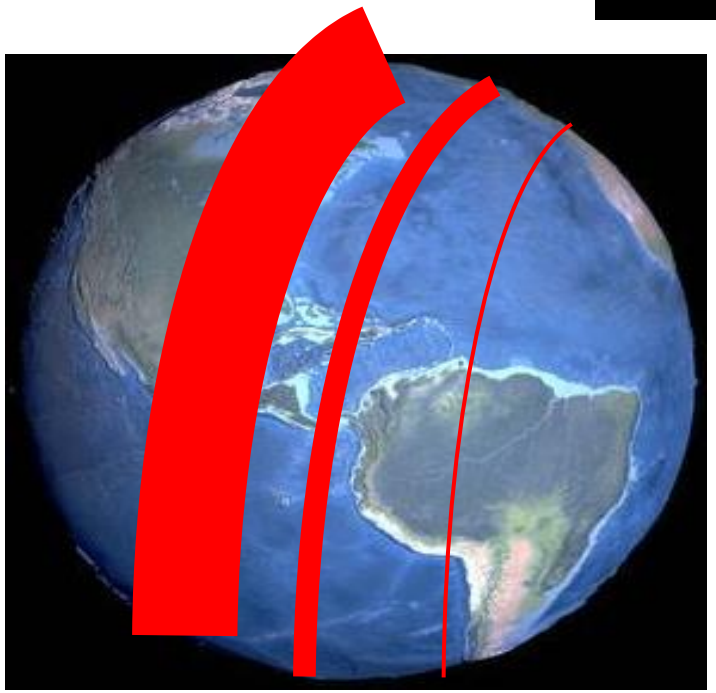
Spectral Resolution

- The number and dimension of wavelengths in the EMS that the sensor measures:
  - Number of spectral bands
  - Their location on the EMS
  - The bandwidth of each band



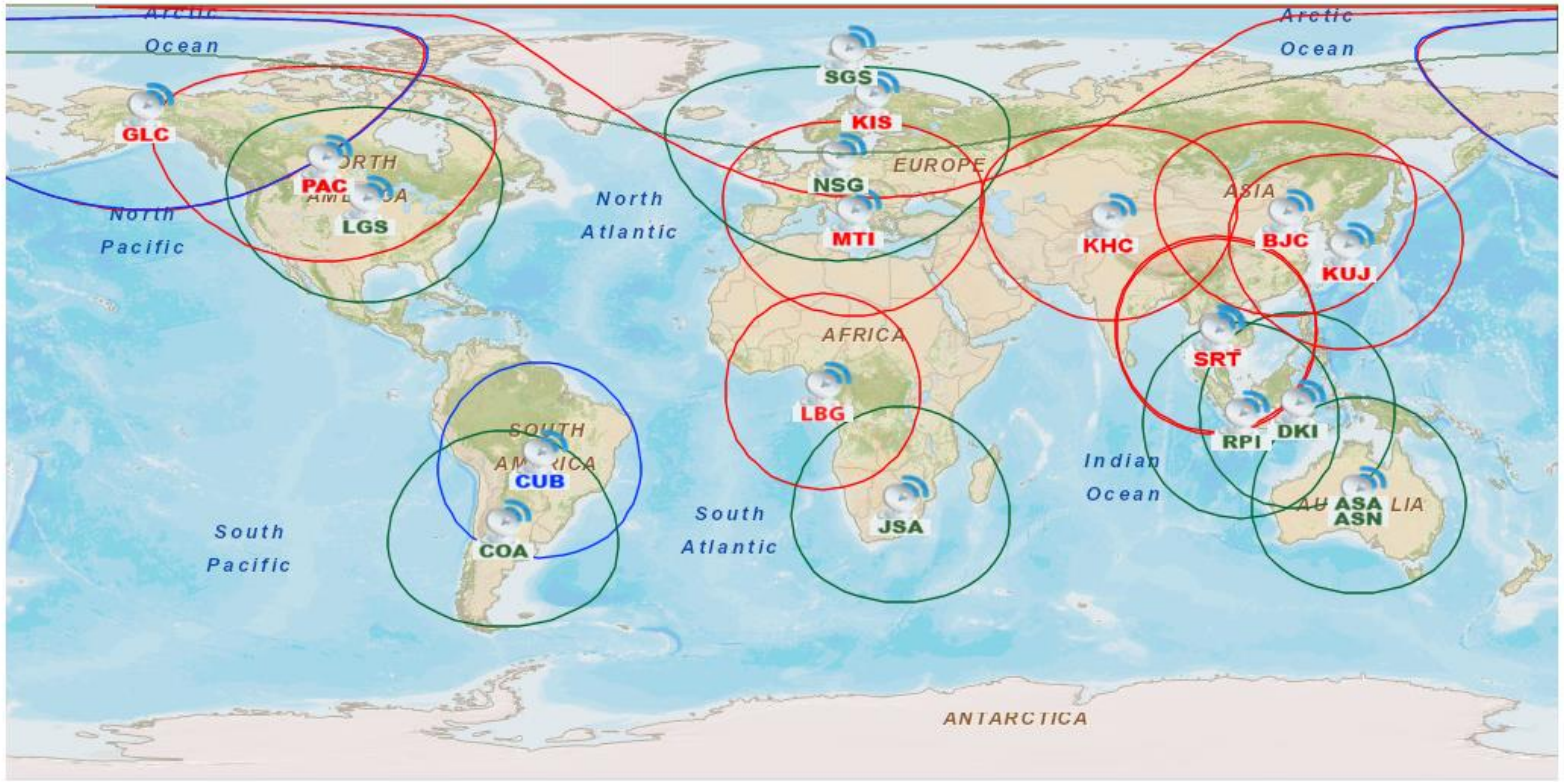
Temporal Resolution

- Amount of time it takes to revisit same place on Earth
- Impacts the level of temporal analysis possible
  - Ex: daily vs. seasonal vs. annual
- Depends on:
  - Orbit
  - Swath width
    - Larger swath width = finer temporal resolution
    - Smaller swath width = coarser temporal resolution

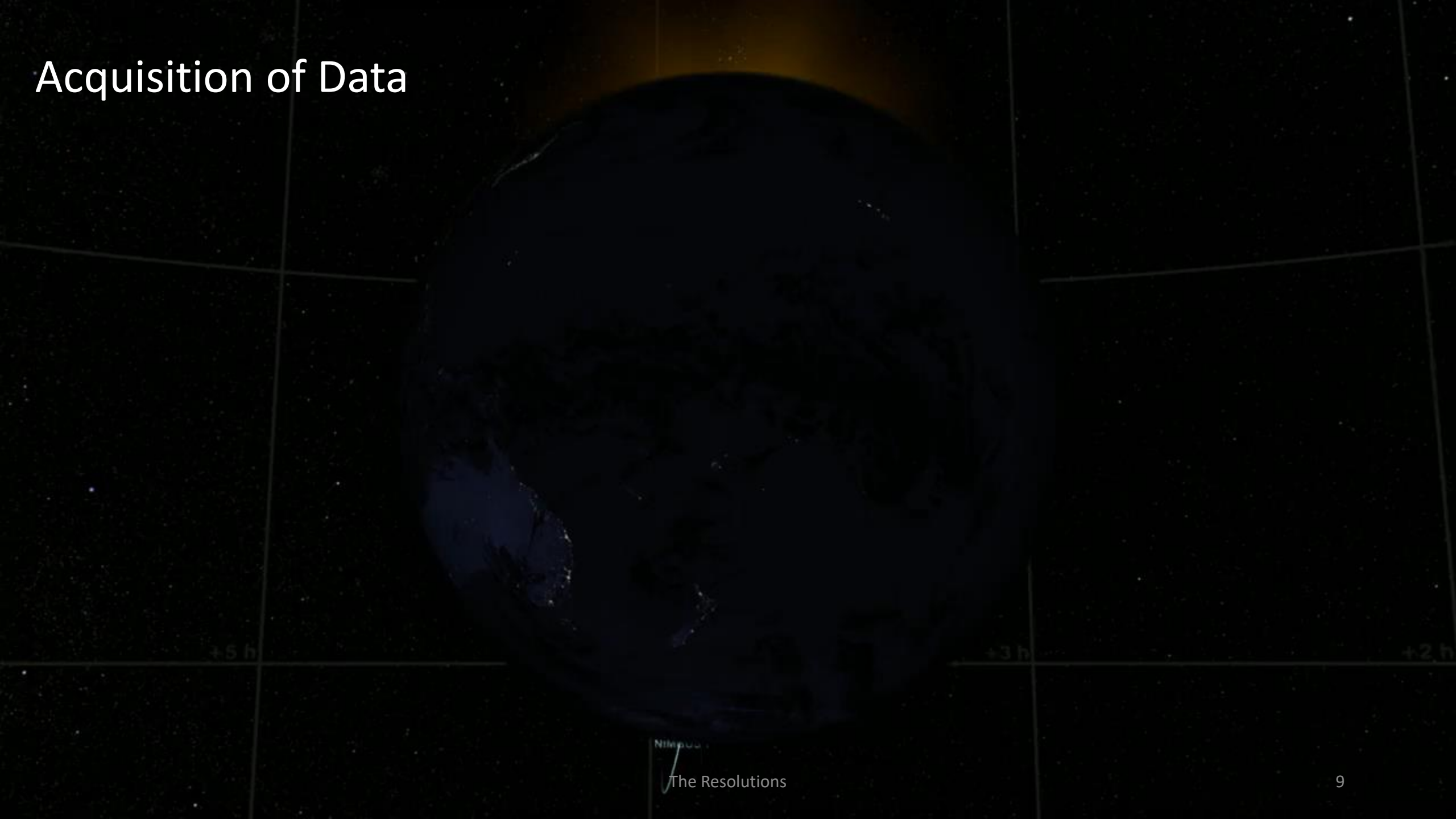


Acquisition of Data

- Most satellites do not have (a lot of) on-board recorders
- They need to directly downlink their acquired images to the antennas of suitably equipped Ground Stations or to other satellites



Acquisition of Data



Acquisition of Data

- In Canada, the government operates 3 **ground receiving stations** –
  - one at Gatineau, Québec
  - one at Prince Albert, Saskatchewan
  - and one at Inuvik, NWT
- Enables near real time data collection for most of Canada and parts of the USA
  - As well as transmission of recorded data

Three Earth Observation Programs we cover in CONS 127

- TERRA and AQUA – MODIS
- Landsat – Thematic Mapper and OLI
- WorldView 1 - 4

TERRA and AQUA – MODIS

Launch date: December 1999, May 2002

Equator crossing: 10:30 AM TERRA
1.30PM AQUA

Instruments:

- **Moderate Resolution Imaging Spectroradiometer (MODIS)**
- Advanced Spaceborne Thermal Emission Radiometer (ASTER)
- Multi-angle Imaging Spectroradiometer (MISR)
- Measurement of Pollution in the Troposphere (MOPITT)
- Clouds and the Earth Radiant Energy System (CERES)

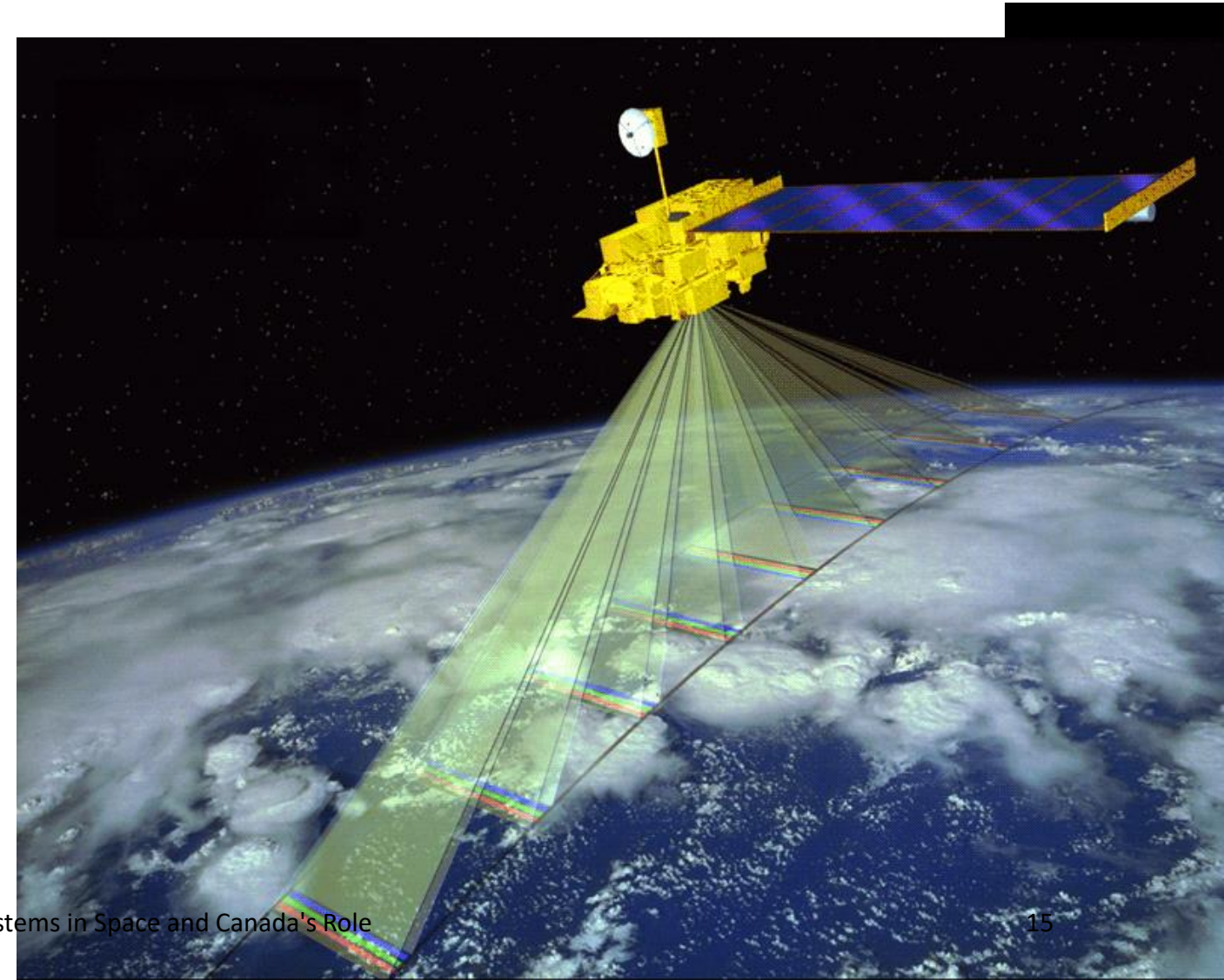
MODERATE RESOLUTION IMAGING SPECTRORADIOMETER (MODIS)

- Measurement of global biological and geophysical processes including:
  - temperature (land and sea)
  - ocean color
  - global vegetation
  - clouds and aerosols
  - snow cover
- 2330 km swath for global coverage in 1 – 2 days
- 20 spectral bands in visible and near-infrared
- 16 spectral bands in middle IR and thermal IR

Earth observation systems: Terra and Aqua

Moderate Resolution Imaging Spectroradiometer (MODIS)

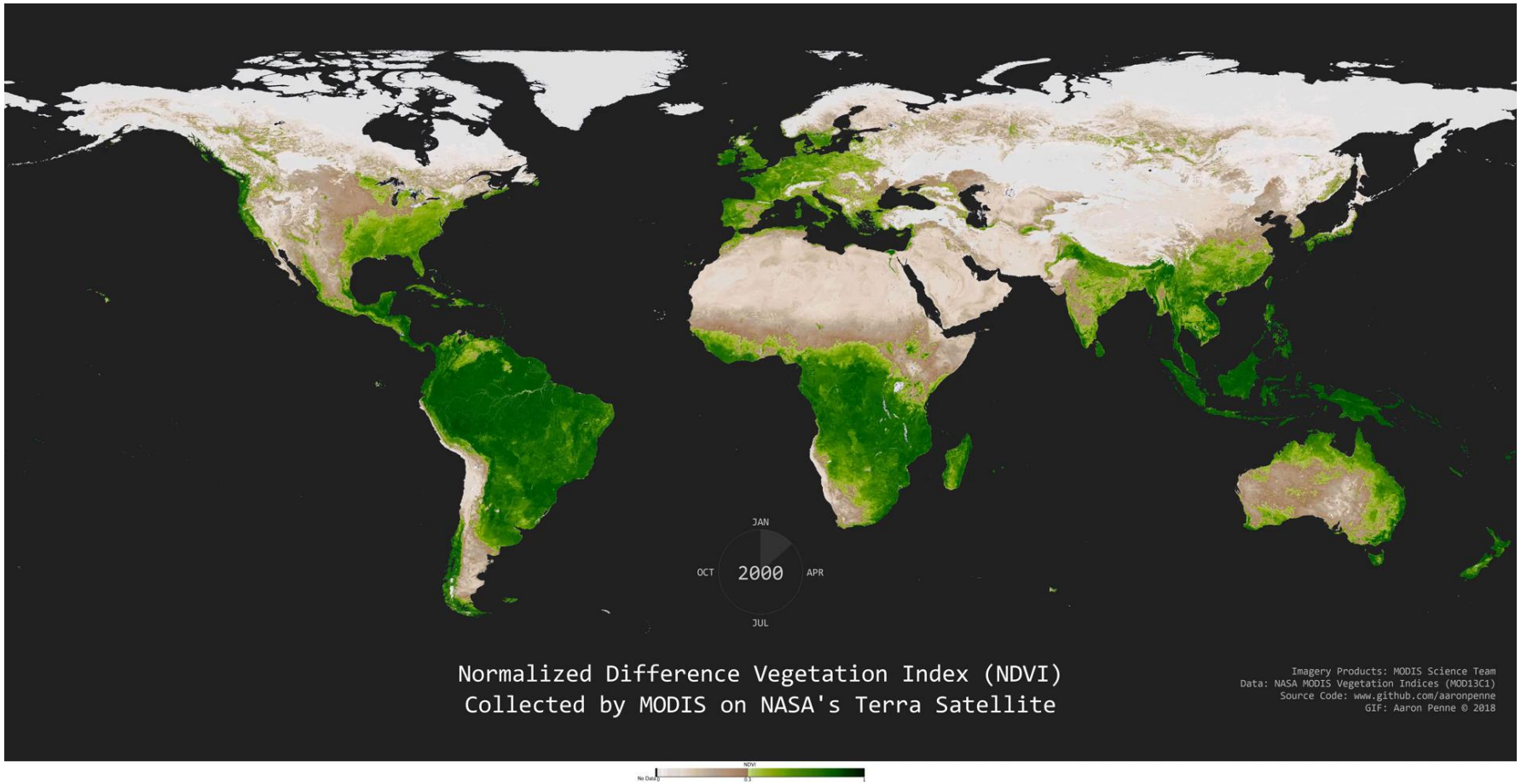
- 250-500m pixel for land research
- 1000m pixel for ocean and atmosphere research
- 1 – 2 day return period



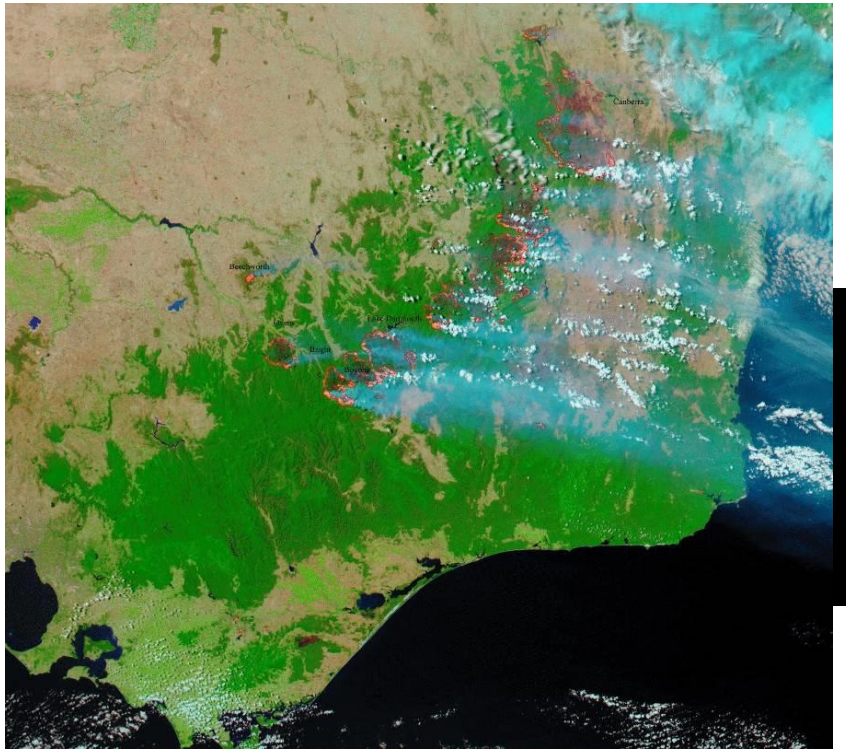
MODIS (Terra and Aqua)

Band nr.	Bandwidth (nm)	Spectral domain	Spatial res. (m)	
1	620 – 670	Shortwave / VIS	250	vegetation indices; land/cloud/aerosol boundaries
2	841 – 876	Shortwave / NIR	250	
3	459 – 479	Shortwave / VIS	500	land: vegetation indices; land-cover/land-use change; snow-cover mapping, etc. cloud and aerosol properties
4	545 – 565	Shortwave / VIS	500	
5	1230 - 1250	Shortwave / NIR	500	
6	1628 - 1652	Shortwave infrared/ SWIR	500	
7	2105 - 2155	Shortwave infrared/ SWIR	1000	
8	405 - 420	Shortwave / VIS	1000	ocean color; phytoplankton; biogeochemistry
9	438 - 448	Shortwave / VIS	1000	
10	483 - 493	Shortwave / VIS	1000	
11	526 - 536	Shortwave / VIS	1000	
12	546 - 556	Shortwave / VIS	1000	
13	662 - 672	Shortwave / VIS	1000	
14	673 - 683	Shortwave / VIS	1000	
15	743 - 753	Shortwave / VIS	1000	
16	862 - 877	Shortwave / NIR	1000	
17	890 - 920	Shortwave / NIR	1000	atmospheric water vapor
18	931 - 941	Shortwave / NIR	1000	
19	915 - 965	Shortwave / NIR	1000	
20	3660 – 3840	Longwave thermal infrared/ TIR	1000	surface/cloud temperature
21	3929 – 3989	Longwave thermal infrared/ TIR	1000	
22	3929 - 3989	Longwave thermal infrared/ TIR	1000	
23	4020 – 4080	Longwave thermal infrared/ TIR	1000	
24	4433 – 4498	Longwave thermal infrared/ TIR	1000	atmospheric temperature
25	4482 – 4549	Longwave thermal infrared/ TIR	1000	
26	1360 – 1390	Shortwave / NIR	1000	cirrus clouds; water vapor
27	6535 - 6895	Longwave thermal infrared/ TIR	1000	
28	7175 - 7475	Longwave thermal infrared/ TIR	1000	
29	8400 - 8700	Longwave thermal infrared/ TIR	1000	cloud properties
30	9580 - 9880	Longwave thermal infrared/ TIR	1000	ozone
31	10780 - 11280	Longwave thermal infrared/ TIR	1000	surface/cloud temperature
32	11770 - 12270	Longwave thermal infrared/ TIR	1000	
33	13185 - 13485	Longwave thermal infrared/ TIR	1000	cloud top attitude
34	13485 - 13785	Longwave thermal infrared/ TIR	1000	
35	13785 - 14085	Longwave thermal infrared/ TIR	1000	
36	14085 - 14385	Longwave thermal infrared/ TIR	1000	

Tables: http://marswiki.jrc.ec.europa.eu/; NASA

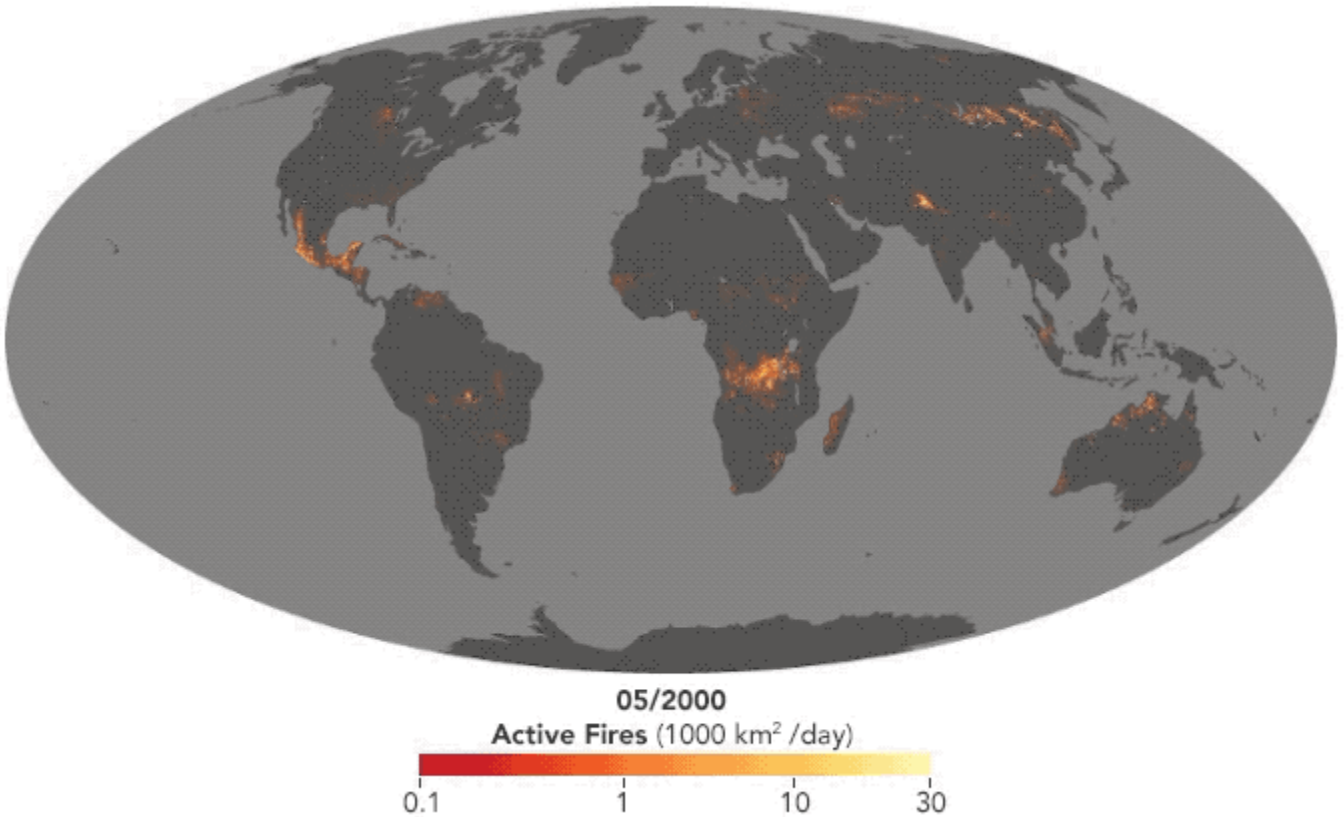

JAN
OCT
2000
APR
JUL
Normalized Difference Vegetation Index (NDVI)
Collected by MODIS on NASA's Terra Satellite
Imagery Products: MODIS Science Team
Data: NASA MODIS Vegetation Indices (MOD13C1)
Source Code: www.github.com/aaronpenne
GIF: Aaron Penne © 2018
NDVI

California (26th October 03)



Australia (02/01/02)

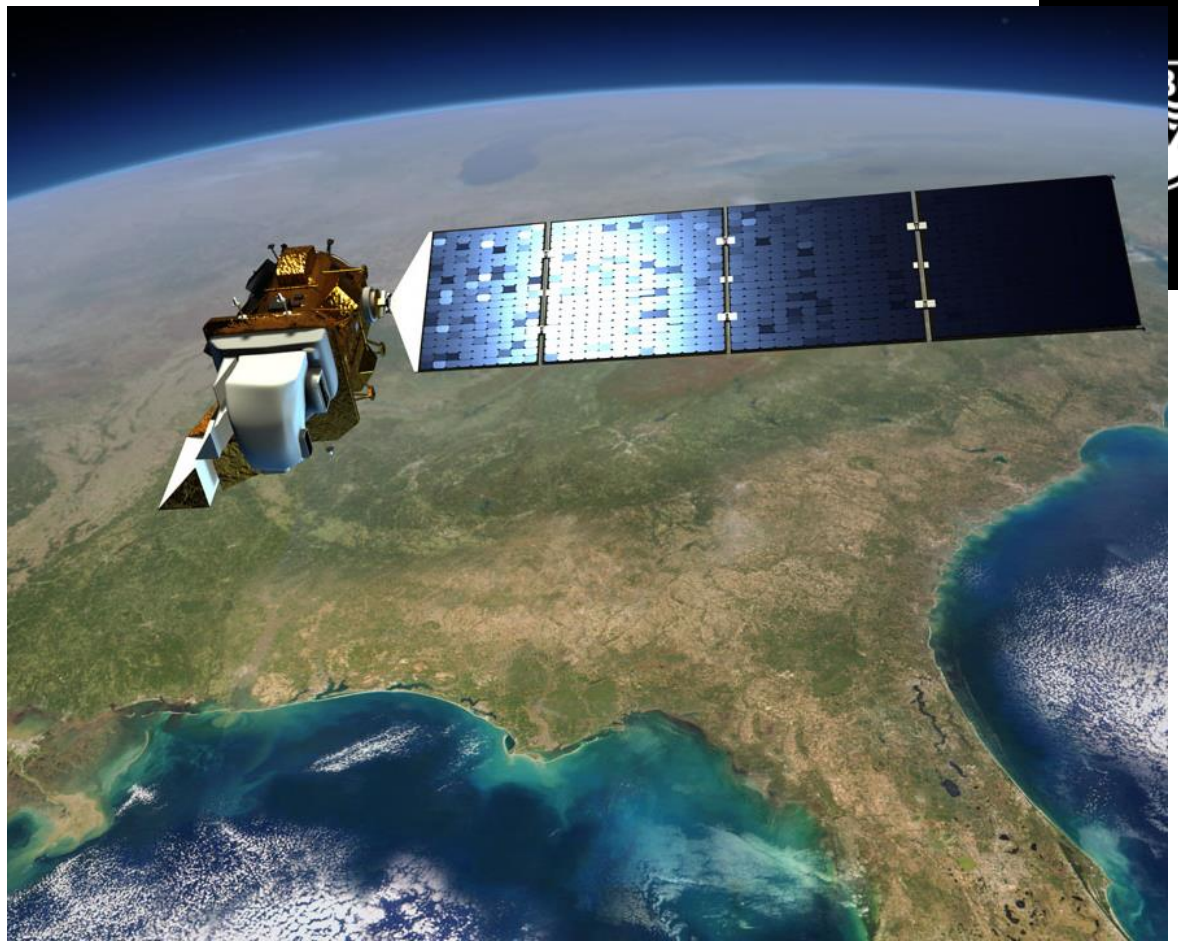
California (26th October 07)

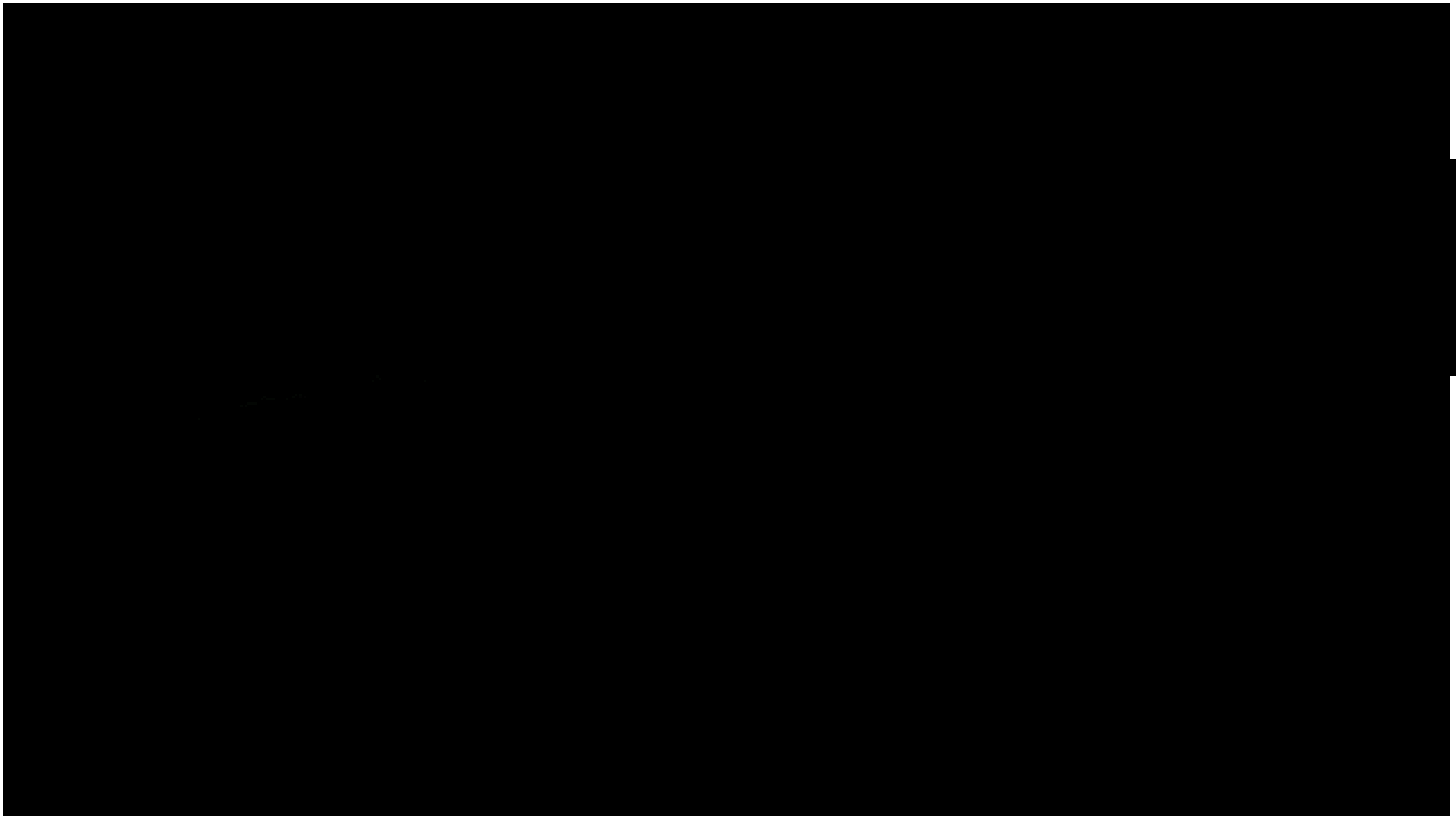

05/2000
Active Fires (1000 km² /day)
0.1
1
10
30

Earth observation systems: Landsat

Landsat

- 30m pixel
- 16-day return period
- Series of 8 satellites comprised of 4 different sensors
- 185km Swath width





Landsat Missions: Imaging the Earth Since 1972

Landsat History

- Landsat program known as the Earth Resources Observation Satellites Program when it was initiated in 1966
  - but the name was changed to Landsat in 1975
- Over the history of the program the satellites have passed from public, to private back to public ownership
- The value of the Landsat program was recognized by Congress in October, 1992 when it passed the Land Remote Sensing Policy Act (Public Law 102-555)
  - Authorizing the procurement of Landsat 7
  - And assuring the continued availability of Landsat digital data and images, at the lowest possible cost, to traditional and new users of the data.

Landsat Sensors

Landsat 4-5 Thematic Mapper (TM)

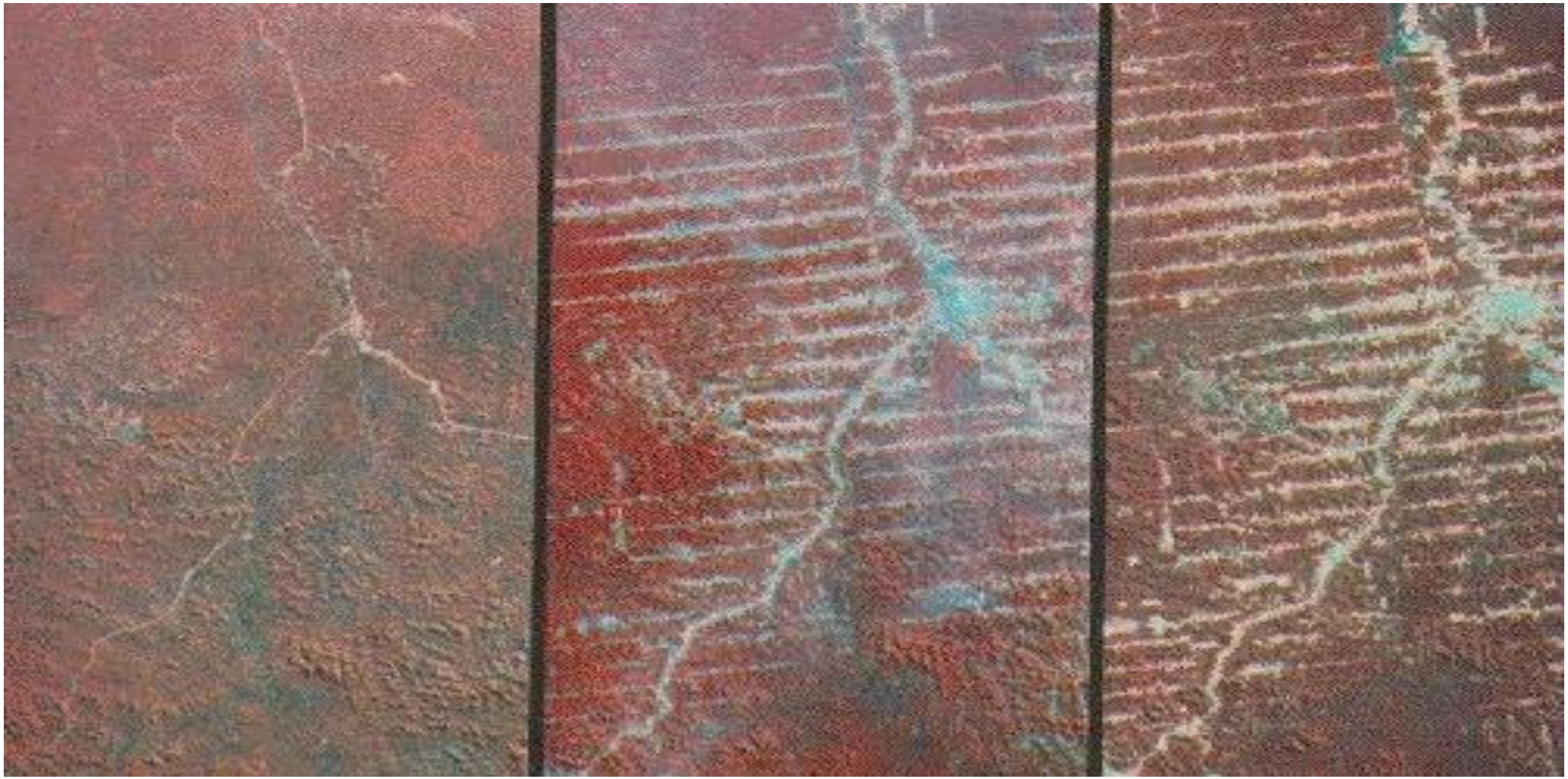
Landsat 4-5	Wavelenth (micrometers)	Resolution (meters)
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.76-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	120 (30)
Band 7	2.08-2.35	30

Landsat 7 Enhanced Thematic Mapper Plus (ETM+)

Landsat 7	Wavelength (micrometers)	Resolution (meters)
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.77-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	60 (30)
Band 7	2.09-2.35	30
Band 8	.52-.90	15

Landsat 8-9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

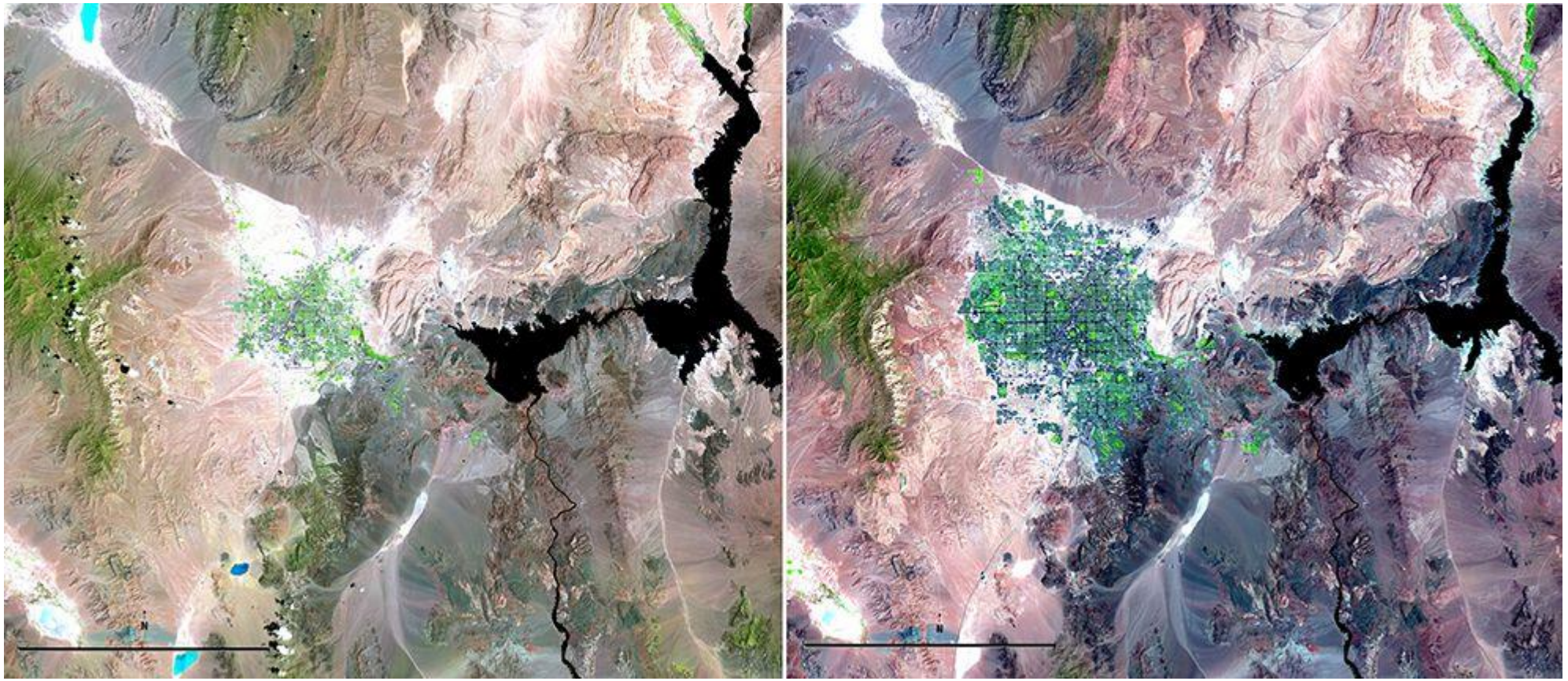
Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 - Red	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.11-2.29	30
Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19	100
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51	100



1975 1986 1991

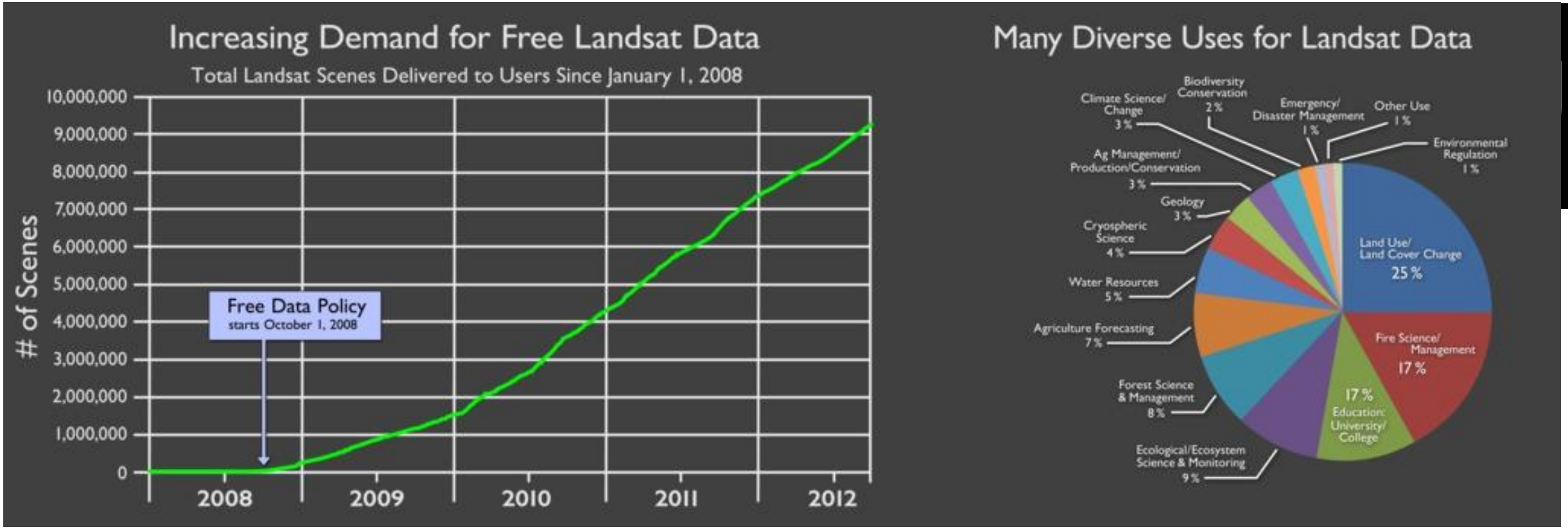
Time sequence of Brazlian Rainforest, Landsat MSS

Landsat Change Detection



Images from 1984 (left) and 2007 (right) show urban sprawl in Las Vegas, Nevada and shrinkage of Lake Mead

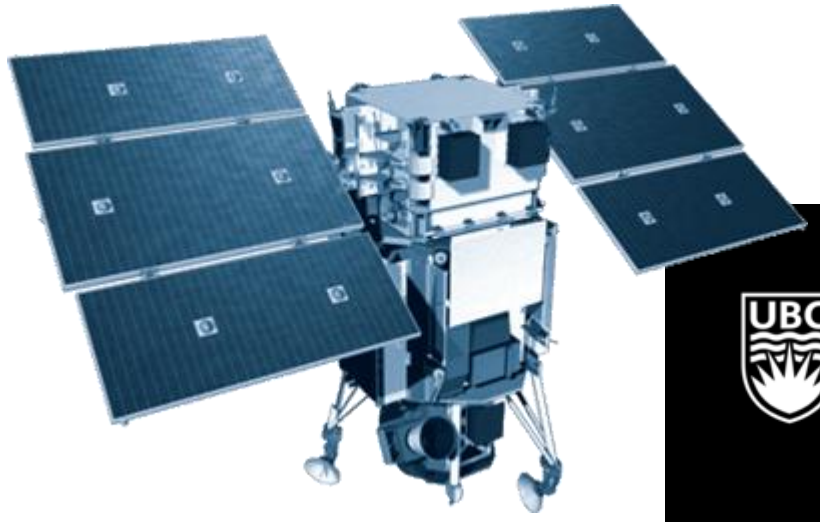

N
3 km
1979


Increasing Demand for Free Landsat Data
Total Landsat Scenes Delivered to Users Since January 1, 2008
# of Scenes
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
Free Data Policy
starts October 1, 2008
2008
2009
2010
2011
2012
Many Diverse Uses for Landsat Data
Land Use/ Land Cover Change 25 %
Fire Science/ Management 17 %
17 % Education: University/ College
Ecological/Ecosystem Science & Monitoring 9 %
Forest Science & Management 8 %
Agriculture Forecasting 7 %
Water Resources 5 %
Cryospheric Science 4 %
Geology 3 %
Ag Management/ Production/Conservation 3 %
Climate Science/ Change 3 %
Biodiversity Conservation 2 %
Emergency/ Disaster Management 1 %
Other Use 1 %
Environmental Regulation 1 %

Commercial Satellite Companies: World View 1 - 4

- DigitalGlobe is one of the largest and most successful private satellite companies which has launched 6 high spatial resolution satellites since 1999
- Most recently they launched the World View series of satellites of which there are now 4
- They are the highest spatial resolution available from a space platform, in some cases as low as 30cm

WorldView-1-4

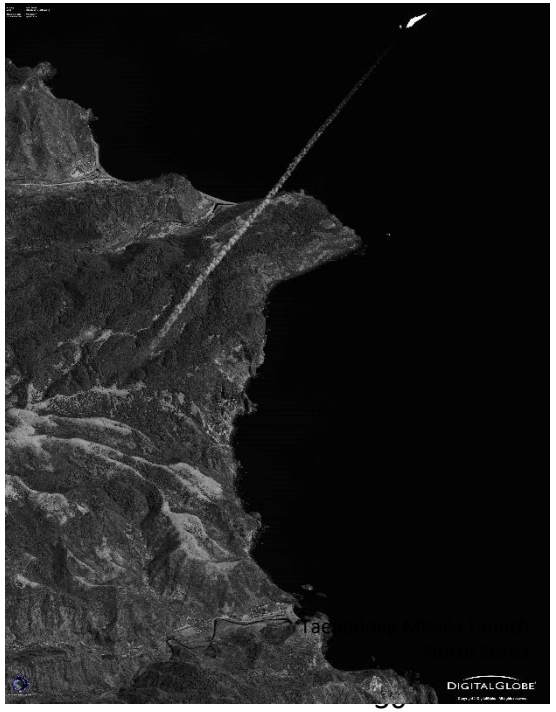


Launch date: 2007, 2009, 2014, 2016

- WorldView-1 was the first satellite in the “next generation” of satellites to be added to the DigitalGlobe constellation of satellites
- WorldView satellites are capable of collecting up to 750,000 km^2 per day of half-meter imagery

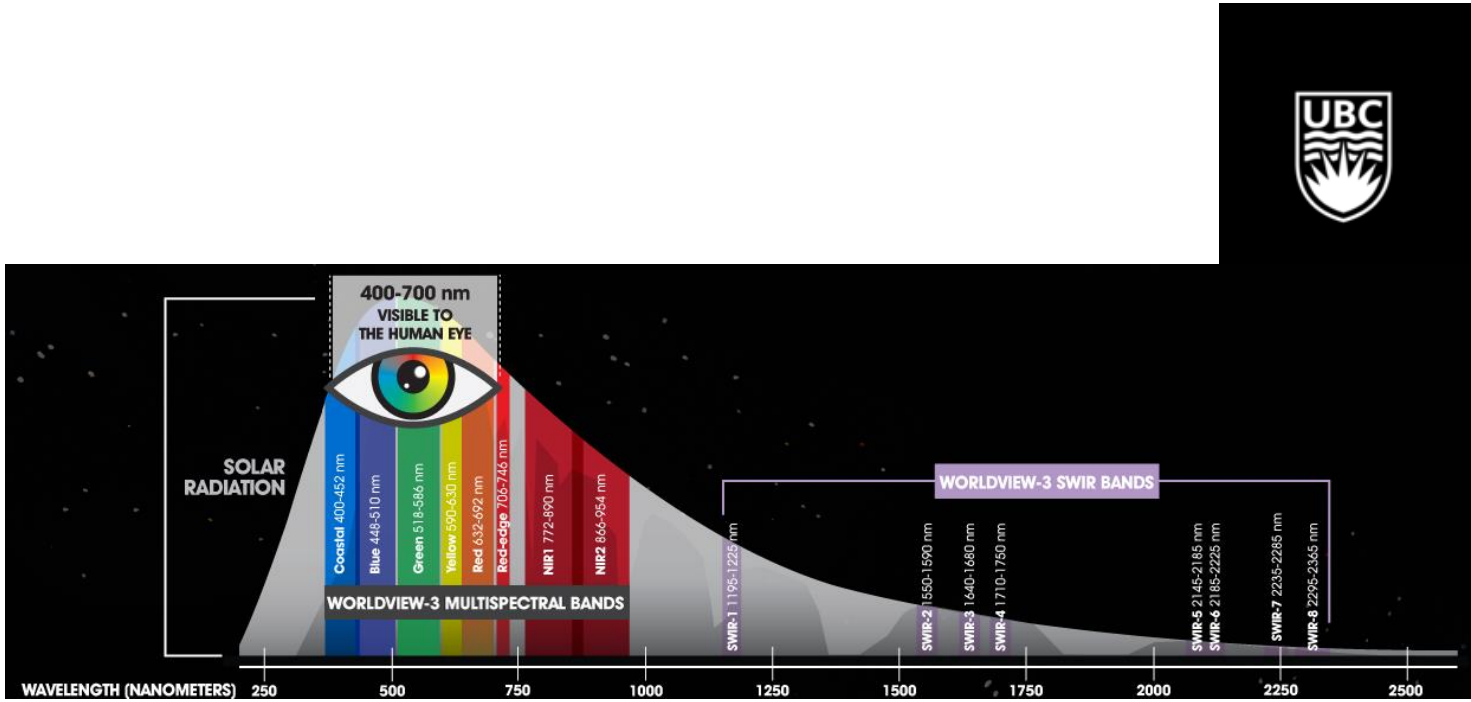
World View 4 - 8 Multispectral bands:

Coastal: 400 - 450 nm	Red: 630 - 690 nm
Blue: 450 - 510 nm	Red Edge: 705 - 745 nm
Green: 510 - 580 nm	Near-IR1: 770 - 895 nm
Yellow: 585 - 625 nm	Near-IR2: 860 - 1040 nm



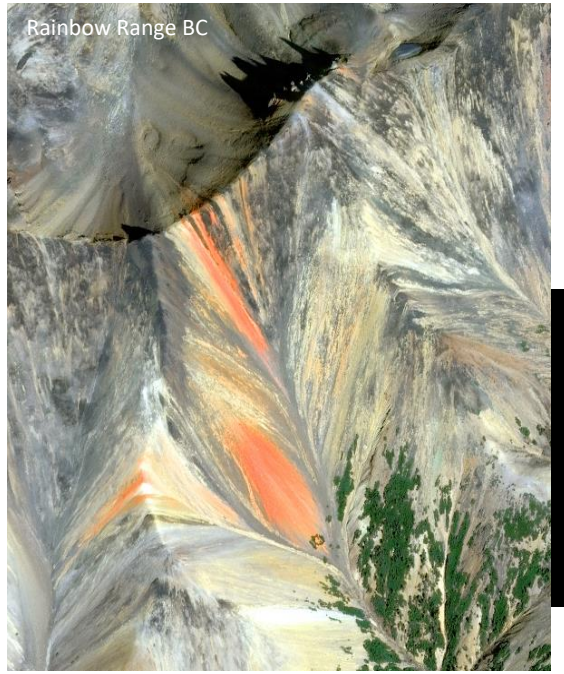
WorldView-3 | WorldView Series | Mission

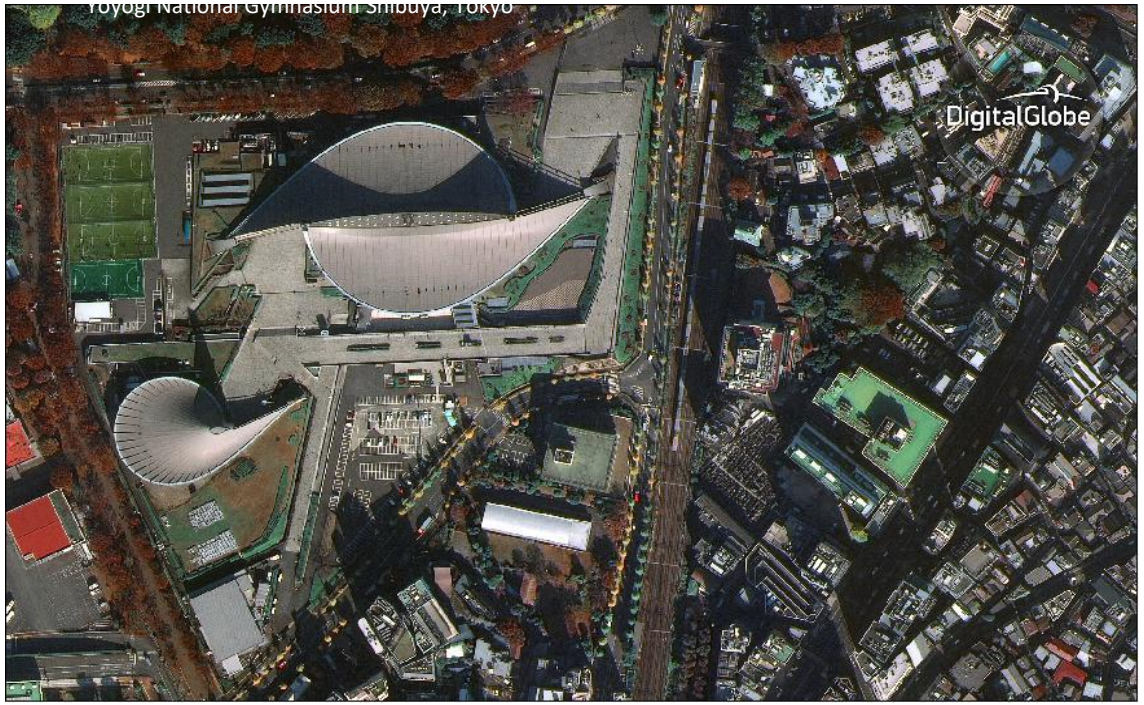
Spectral range	Band name	Spectral band	GSD (Ground Sample Distance)
Panchromatic band (1)	450 - 800 nm		Nadir: 0.31 m, 20º off-nadir: 0.34 m
MS (Multispectral) bands (8) in VNIR (Visible Near Infrared)	Coastal Blue	400 - 450 nm	Nadir: 1.24 m 20º off-nadir: 1.38 m
	Blue	450 - 510 nm	
	Green	510 - 580 nm	
	Yellow	585 - 625 nm	
	Red	630 - 690 nm	
	Red edge	705 - 745 nm	
	Near-IR1	770 - 895 nm	
	Near-IR2	860 - 1040 nm	
Multiband (8 bands) in SWIR (Shortwave Infrared) spectral range	SWIR-1	1195 - 1225 nm	Nadir: 3.70 m 20º off-nadir: 4.10 m
	SWIR-2	1550 - 1590 nm	
	SWIR-3	1640 - 1680 nm	
	SWIR-4	1710 - 1750 nm	
	SWIR-5	2145 - 2185 nm	
	SWIR-6	2185 - 2225 nm	
	SWIR-7	2235 - 2285 nm	
	SWIR-8	2295 - 2365 nm	



Runway detail visible, such as expansion joints in runway materials, numbering and directional lines

Aircraft detail visible, such as seams in the aircraft's wings, logos and identification numbers





WorldView 3 Imagery

High Resolution New Tasking Pricing

High Resolution New Tasking Pricing (50cm)	WorldView-1	WorldView-2 WorldView-3	QuickBird	GeoEye-1	IKONOS (80cm)	Pléiades 1A/1B
Panchromatic	$24	$24	$24	$24	n/a	$23
3-Band Pan-Sharpened	n/a	$27.50	$27.50	$27.50	n/a	$23
4-Band Pan-Sharpened	n/a	$27.50	$27.50	$27.50	n/a	$23
Panchromatic + 4-band Multispectral Bundle	n/a	$27.50	$27.50	$27.50	n/a	$23
8-Band Multispectral	n/a	$31.50	n/a	n/a	n/a	n/a
8-Band Panchromatic + Multispectral Bundle	n/a	$31.50	n/a	n/a	n/a	n/a

Price per square km in USD. Minimum order is 100km2

Important Topics (Part 2)

- What is the spatial resolution of Landsat?
- What is the temporal resolution of MODIS?
- When was Landsat 1 launched?
- Which satellite might I use for urban mapping?
- Which satellite might I use for daily vegetation indices?
- If I were to ask you to design a satellite for monitoring regional forest cover change – what attributes and resolutions would be appropriate?