Carleton UNIVERSITY

GEOM 3002 – Lecture 8

Remote Sensors

Readings

- The following provide details relevant to what was presented in class. There is a lot of material on sensors in the textbooks. You are not responsible for aspects not presented.

Lillesand et al.

5.1-5.9 (5.10-5.11; 5.14 not all the details)

6.1-6.16; 6.19 to the extent of details covered in class

8.1-8.3; 8.9; 8.18; 8.23

Jensen: Remote Sensing of the Environment

Ch. 7: pp. 181-201; 205-206; 211-220; 222-233

Ch. 8: pp. 246-252; 258-260; 266-270

Ch. 9: pp. 288-289, 323 (radar); 326-329 (lidar)

Jensen: Introductory Digital Image Processing

Ch. 2: pp. 44-62; 66 (AVHRR); 73-97 (much of this is same as in other Jensen book)

Digital Remote Sensing

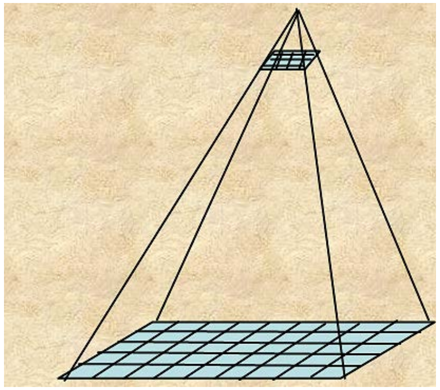
- Terrain Scanning Mechanisms
  - Frame sensors
  - Mechanical (Across Track) Scanners
  - Pushbroom (Along Track) Scanners
  - Active sensors

- Platforms
  - Satellite
  - Airborne

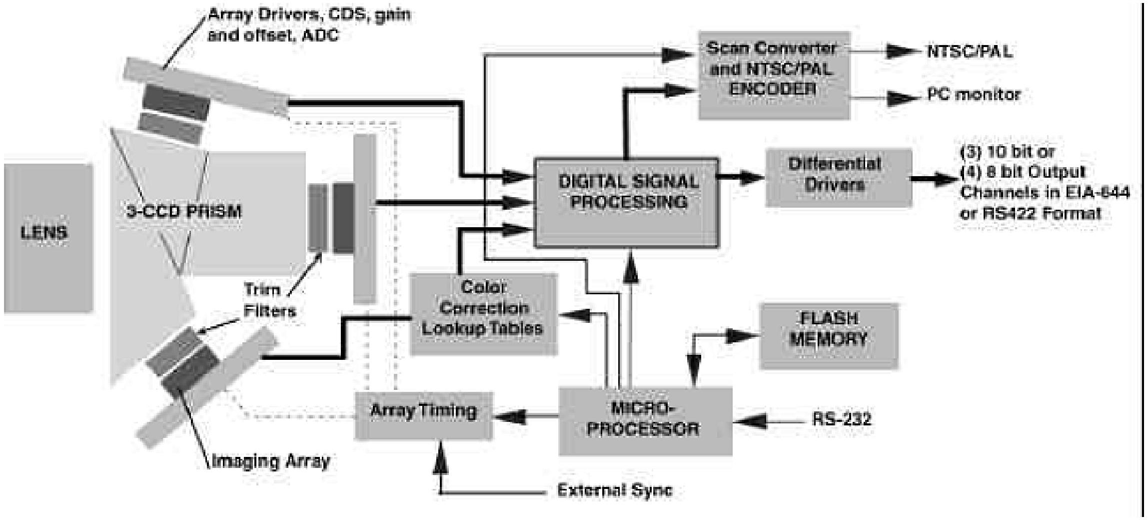
Mechanisms for Optical Digital Imaging

Frame sensor

- E.g., digital camera with imaging chip



GLEL airborne CIR camera



Digital Cameras

Leica RCD30 Series
Multispectral. Metric. Modular.

The new Leica RCD30 Series – Imaging revolution from the leader

The new Leica RCD30 Series of medium format cameras represents a true revolution in airborne imaging. Just like the RC30 has once set standards in film based airborne imaging, the new Leica RCD30 is setting new standards in what you and your customers can expect from a medium format digital camera.

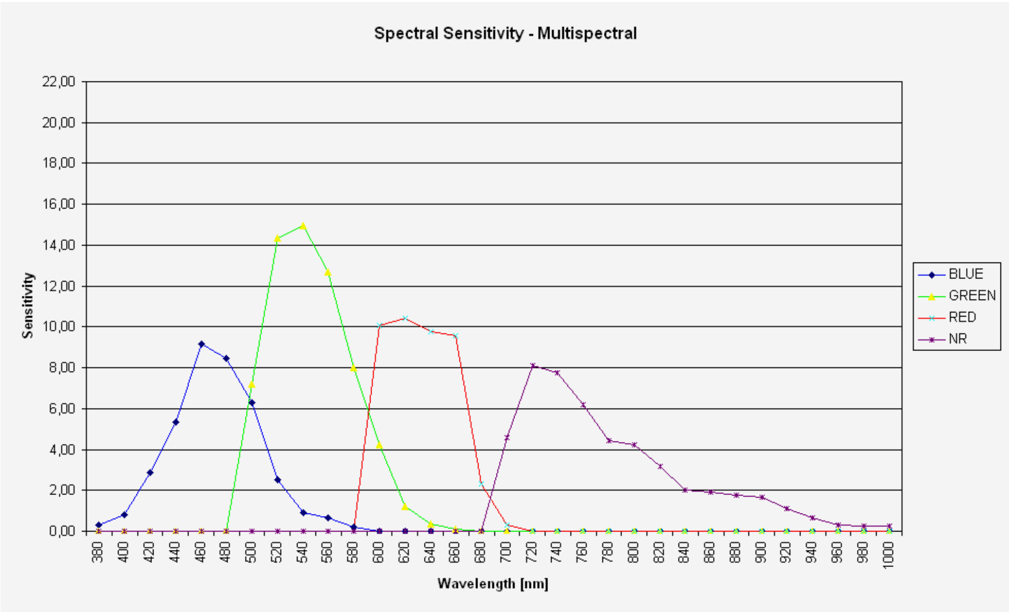
A true Masterpiece

The Leica RCD30 Series is not only true imaging innovation, it's a masterpiece. The Leica RCD30's offers performance that is otherwise only known from large-format airborne sensors at a lower cost and thus makes digital multispectral photogrammetry available to everyone.

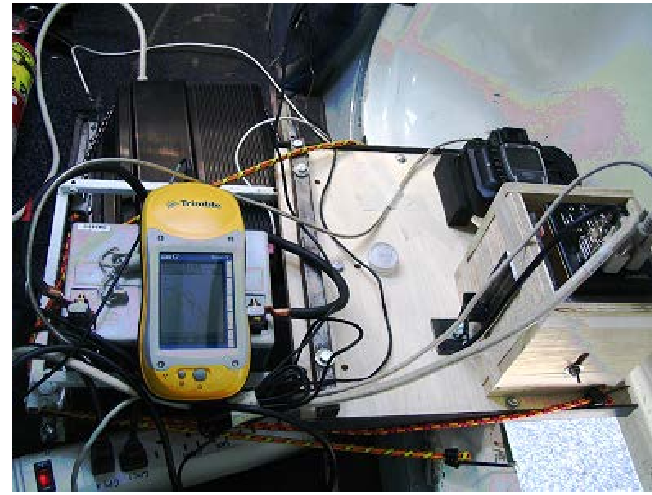
The Leica RCD30 boasts quite a number of innovative and unique „world's first" features and is the only suitable medium format camera for photogrammetric and remote sensing applications:

- 60MP single camera head delivers co-registered, multi-spectral RGBN imagery
- Mechanical Forward Motion Compensation (FMC) along two axis
- Ruggedized and thermal stabilized lens system with innovative bajonet mount and user replaceable central shutter with automatically controlled high precision aperture
- Modular concept for single standalone and multihead-configurations
- Full integration with Leica ALS LIDAR and other third party sensors

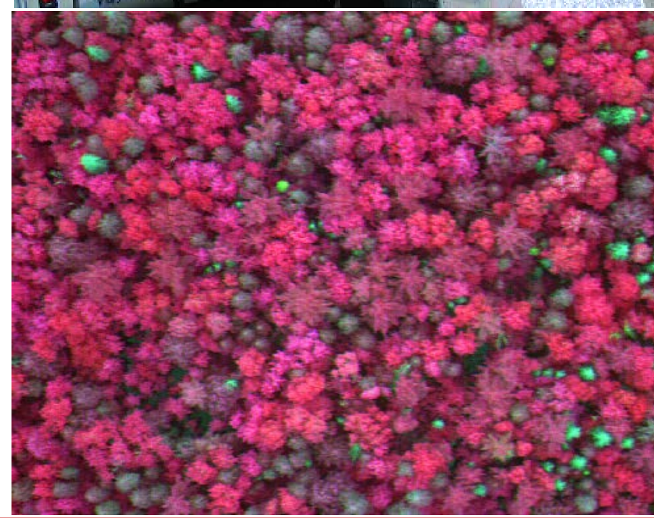
Example spectral sensitivity for multi-sensor camera



Digital Camera on Fixed Wing Aircraft



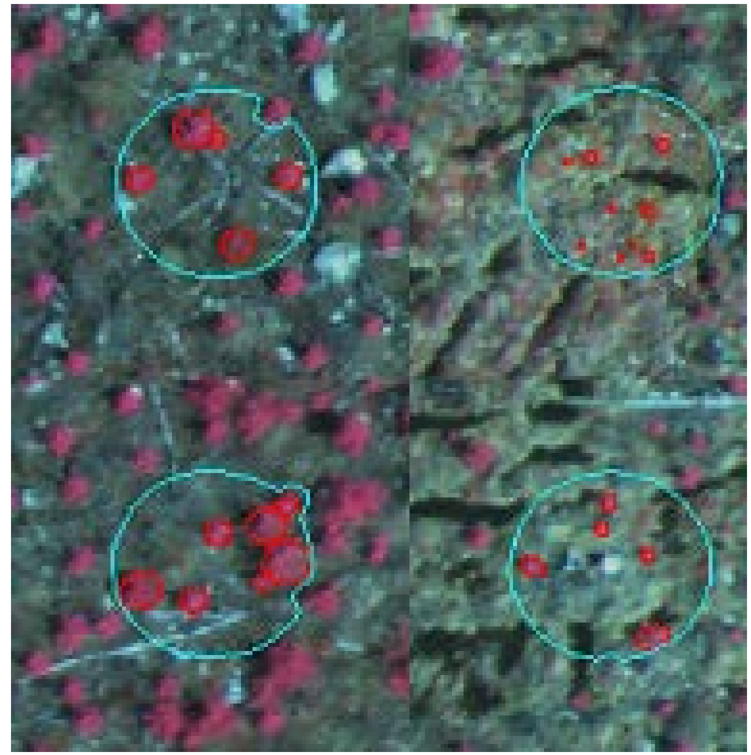
Pasher and King



Digital Camera on Helicopter

- Camera mounted at end of boom

Pouliot and King



Duncantech MS3100 images of field plots with conifers delineated

Digital Cameras on UAV

UAV with 6 multispectral cameras

Richardson, King, Mueller

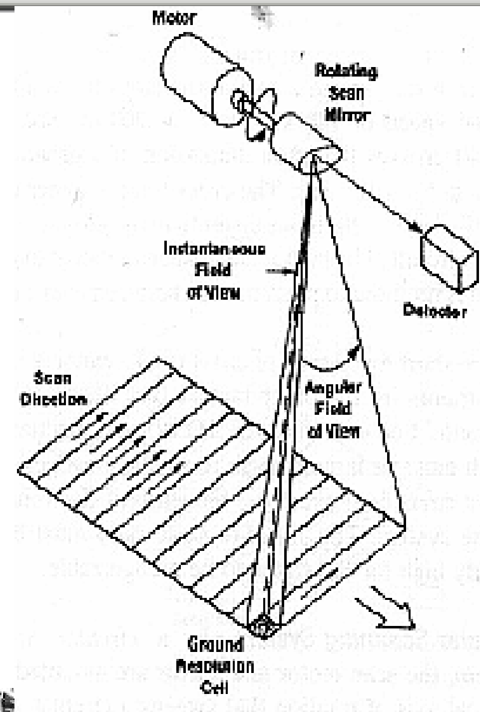
Red

NIR

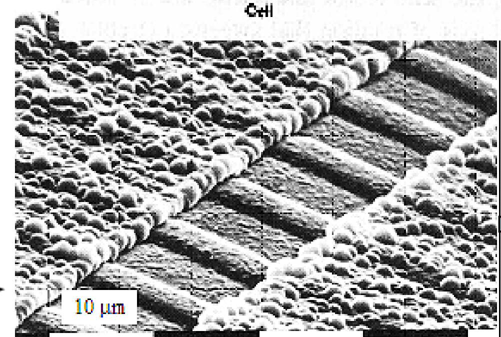
Mechanisms for Optical Digital Imaging

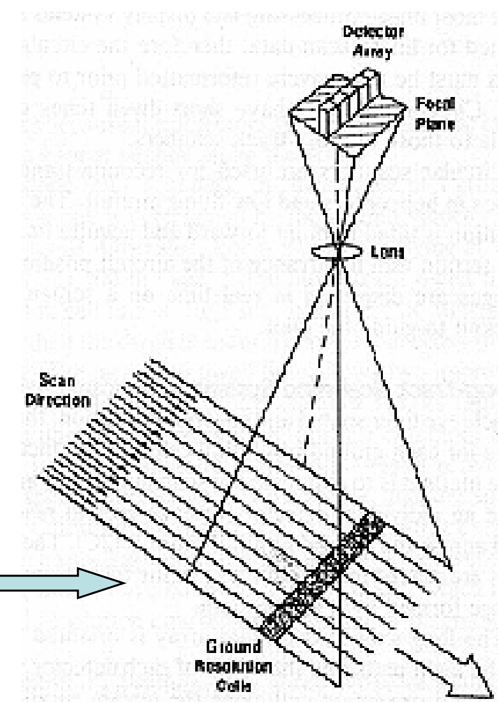
Line sensor

1. Scanner that turns on a mechanical axis
   - Mechanical or ‘Across Track’ scanner



2. Single line of detectors that advances over the terrain as platform advances
   - Pushbroom or ‘Along track’ scanner





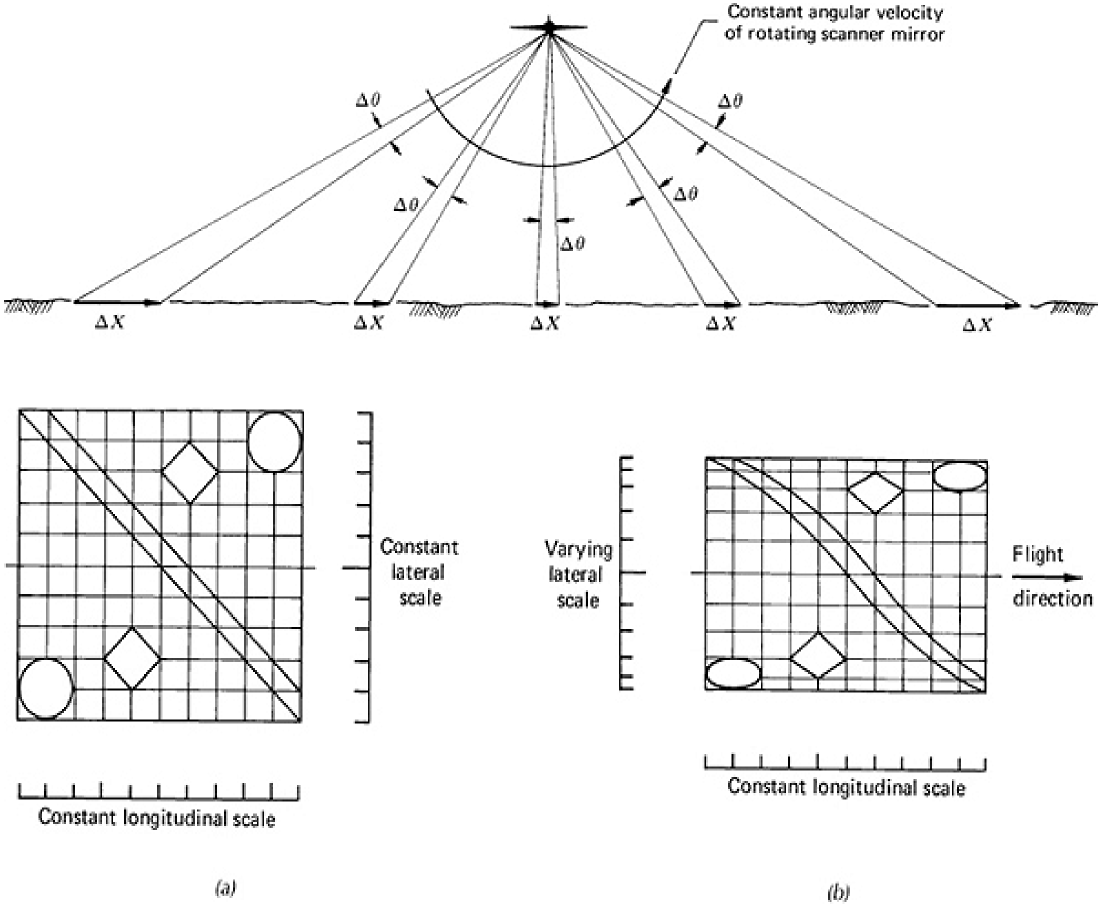
Jensen 2007

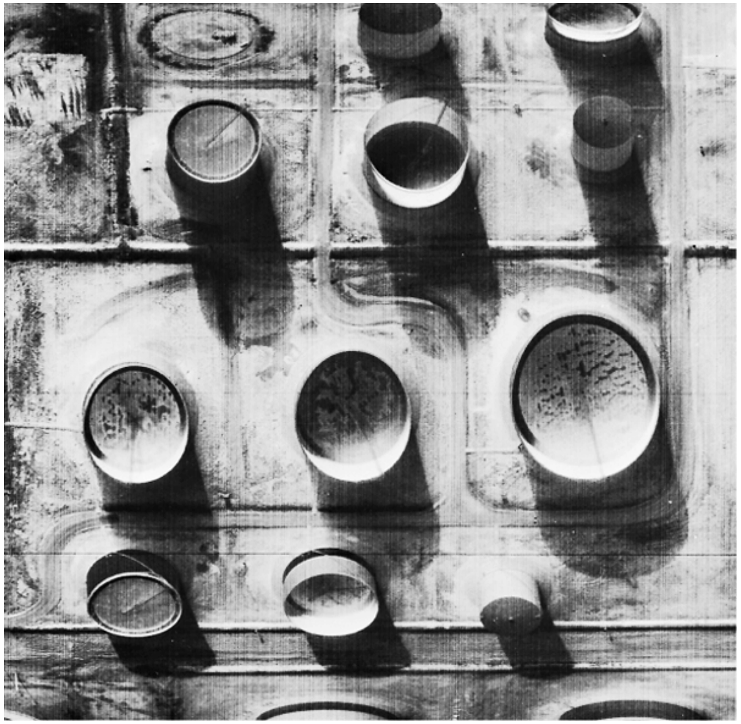
Mechanical vs Pushbroom Scanners

- Advantages of pushbroom scanner:
  1. Greater geometric integrity.
  2. Errors introduced into sensing process by rotating mirrors are not present in pushbroom scanners.
  3. Lighter and more reliable.
  4. Longer dwell time over each cell, giving a higher Signal-to-Noise ratio.

- Disadvantages:
  1. Each spectral band requires its own array.
  2. Have to cross-calibrate thousands of detectors to achieve uniform sensitivity across the sensor.

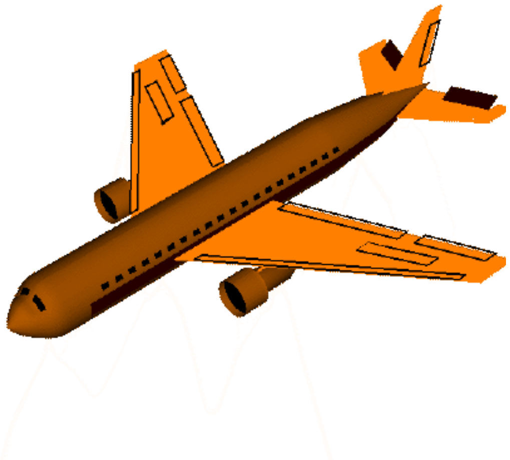
Tangential Geometric Distortion in Mechanical Scanners



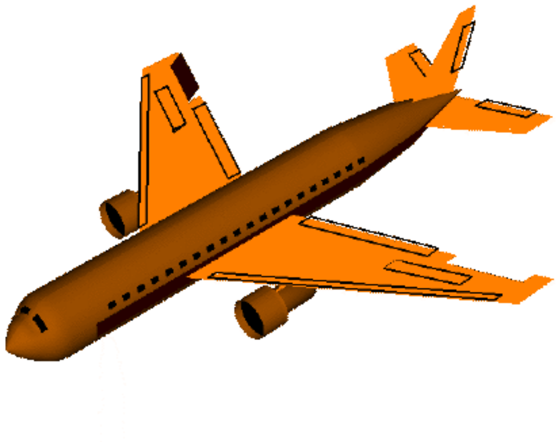


Lillesand et al., 2008

Platform Rotation



Pitch



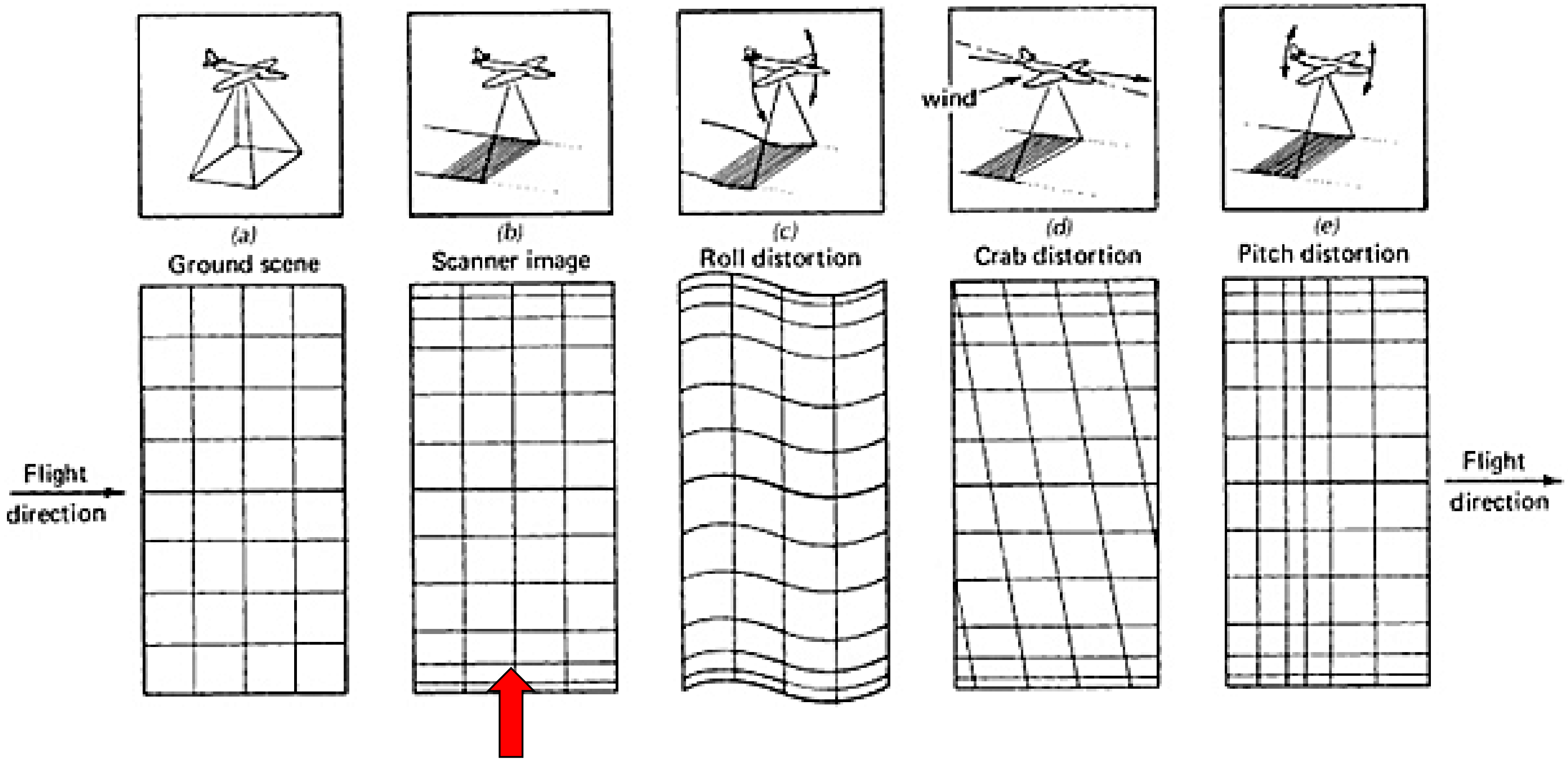
Roll

Yaw (crab)

University of California, San Diego Dept. of Mathematics

http://www.math.ucsd.edu/~math20d/Fall/Lab4/Lab4.shtml

Geometric Distortion in Mechanical Scanner and Pushbroom Scanner Images due to Aircraft Rotation

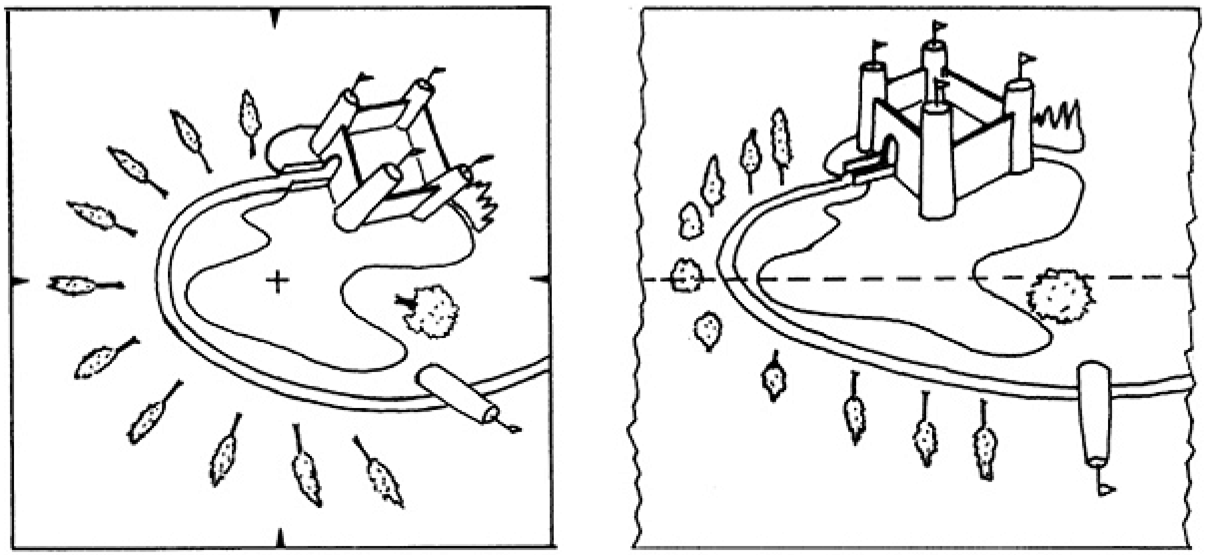


These distortions only exist
in mechanical scanner,
not line scanner imagery

Lillesand et al., 2008

Relief Displacement in Mechanical Scanner and Pushbroom Scanner Imagery

- In air photos and digital cameras, relief displacement causes 3-d objects (buildings, trees, hills, etc.) to be displaced radially towards the corners.
- In line scan imagery the displacement is perpendicular to the flight line towards the swath edges.



(a) Photo   (b) Line scanner

Lillesand et al., 2008

Examples of Each Mechanism

- Frame sensor
  - Airborne or satellite (e.g. Airborne and Int. Space Station digital cameras)
- Mechanical scanner (Across track)
  - Landsat; AVHRR; MODIS; GOES; SeaWiFs; AVIRIS
- Pushbroom (Along track)
  - SPOT; IRS; GeoEye; Worldview; ASTER

Types of Orbits

- Before we go into specific sensors:

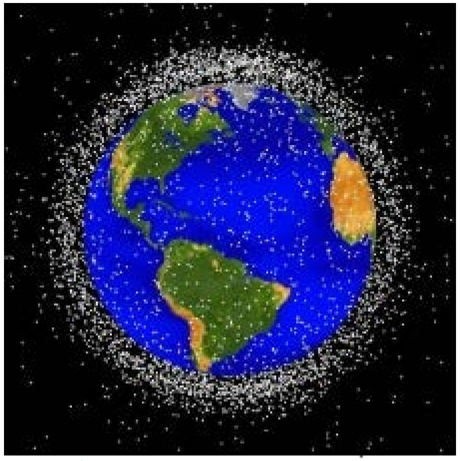
Orbit details

  – Altitude
  – Period
  – Inclination
  – Equatorial Crossing Time

- Sun-synchronous orbit
- Geostationary orbit

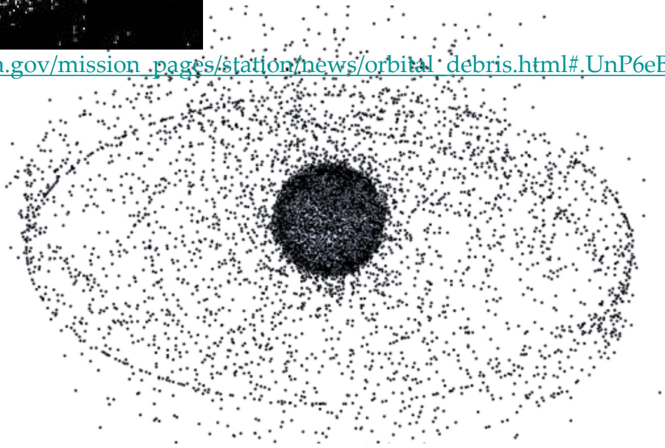
Space Objects

- > 500,000 objects > 1cm; about 21,000 > 10cm
- Several thousand satellites
- Orbits described by
  - Altitude
  - Period
  - Inclination
  - Equatorial Crossing Time
- Sun-synchronous orbit
- Geostationary orbit



Low Earth Orbit

http://www.nasa.gov/mission_pages/station/news/orbital_debris.html#.UnP6eBCPbX5

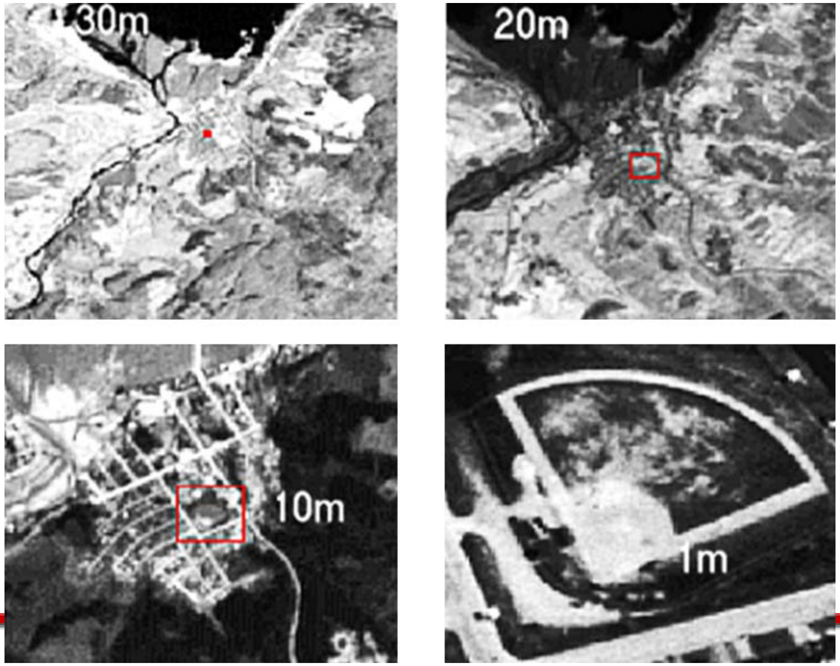


High and Low Earth Orbit

http://earthobservatory.nasa.gov/IOTD/view.php?id=40173&src=eoa-iotd

The Common Optical Satellite Remote Sensors

- Often categorized by their image scale
  - i.e. Coverage and pixel size (resolution)
  - Smaller ground pixel sizes are generally associated with smaller ground coverage per scene.



Moderate Resolution Satellite Sensors

- Pixel sizes in 10m-100m range (approx.)
- Regional coverage per scene:
  - about 50km – 200km swath
- The longest temporal series of Earth Observation sensors: **Landsat**

Landsat MSS
On Landsats 1-5 1972-1999

- Spectral Bands:
  - 0.5-0.6μm (G); 0.6-0.7μm (R); 0.7-0.8μm (NIR); 0.8-1.1μm (NIR)
- Ground pixel size: 79 x 79m
- FOV: 185 x 185km
- Scale of prints: 1:1,000,000
- Image format: 3240(H) x 2340(V)
- Quantization: 6-bit (64 grey levels - DN)
- Return Period: 18 days

http://landsat.usgs.gov/about_landsat1.php

Landsat Thematic Mapper (TM) Landsats 4,5,(6)

- Spectral Bands:
  - 0.45-0.52μm (B/G); 0.52-0.60μm (G); 0.63-0.69μm (R); 0.76-0.90μm (NIR), 1.55-1.75μm (MIR), 2.08-2.35μm (MIR), 10.4-12.5μm (Thermal IR)
- Ground pixel size: 30 x 30m, except thermal: 120 x 120m
- FOV: 185 x 185km
- Image format: 6167 x 6167
- Quantization: 8-bit (256 grey levels), except thermal: 6-bit
- Return Period: 16 days
- Landsat 4: 1982 - 1993
- Landsat 5: 1984 – 2011; longest single satellite sensor record
- Landsat 6 failed on launch, 1993

Landsats 7, 8

- Landsat 7, 1999+
  - ETM+ like TM but with better calibration; 60m TIR band; and 15m panchromatic band added.
  - Developed a striping problem, 2003
    - Towards scene edges data are duplicated or missing. (See Lillesand et al., 2008, Fig. 6.12 for an example).
- Landsat 8, 2013+ http://ldcm.nasa.gov/
  - Operational Land Imager (OLI) like ETM+, but improved
  - 7000 pixel pushbroom sensor
  - 12-bit data
  - Separate VIS/NIR/MIR sensores and 2 TIR sensors
  - Deep blue band for coastal waters; Special NIR band for high cirrus clouds.

- **Overall, Landsat provides the longest temporal sequence of remotely sensed data**

Landsat Legacy Special Issue
Volume 122, Pages 1-202 (July 2012)
http://www.sciencedirect.com/science/journal/00344257/122

http://earthobservatory.nasa.gov/IOTD/view.php?id=80408&src=eoa-iotd

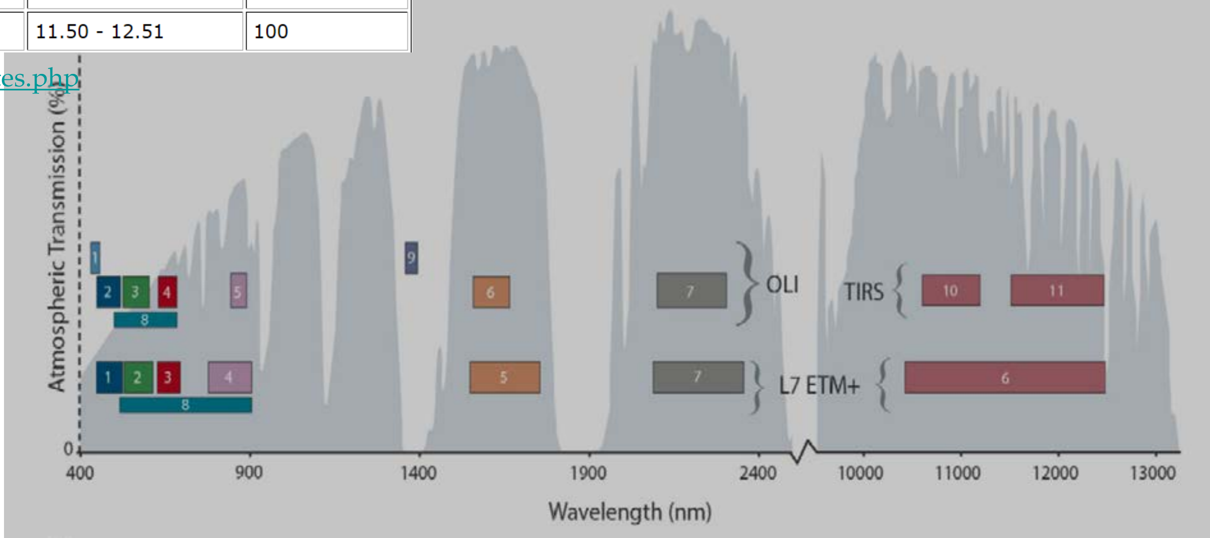
Landsat 8 bands vs Landsat 7

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Launched February 11, 2013	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	10.60 - 11.19	100
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100

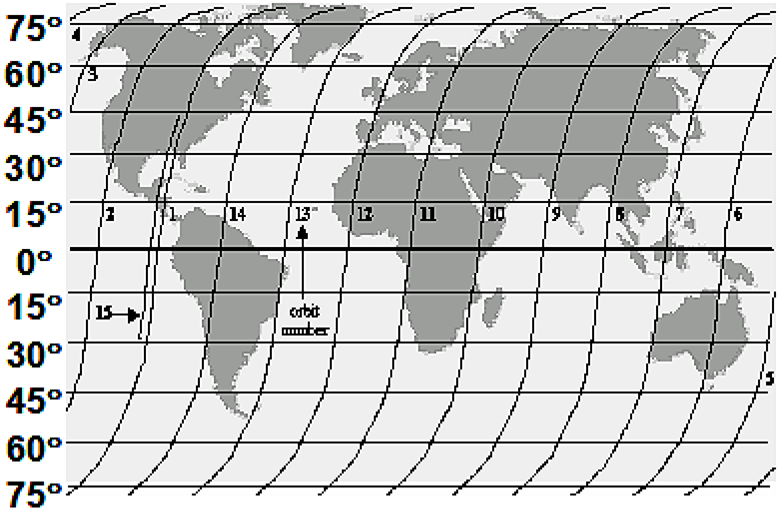
http://landsat.usgs.gov/band_designations_landsat_satellites.php

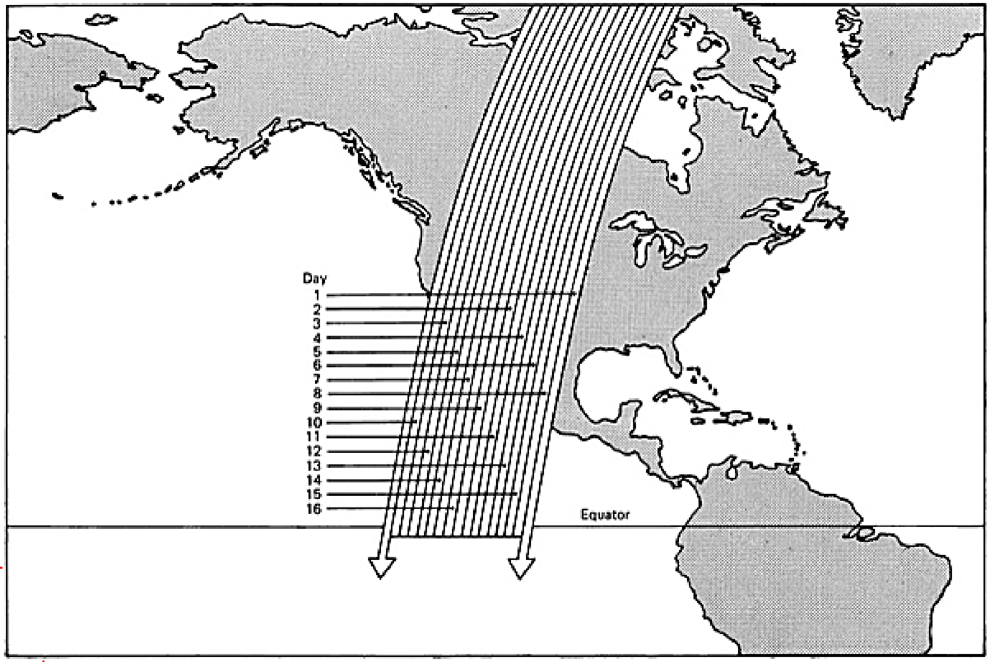
- Bands similar to TM and ETM + except most more spectrally narrow and:
- Band 1 is coastal aerosol band;
- Band 8 is Panchromatic band (15m);
- Band 9 is high cirrus cloud band.

http://landsat.usgs.gov/about_project_descriptions.php



Landsat Orbital Path





Lillesand et al., 2008

E.g. Landsat TM

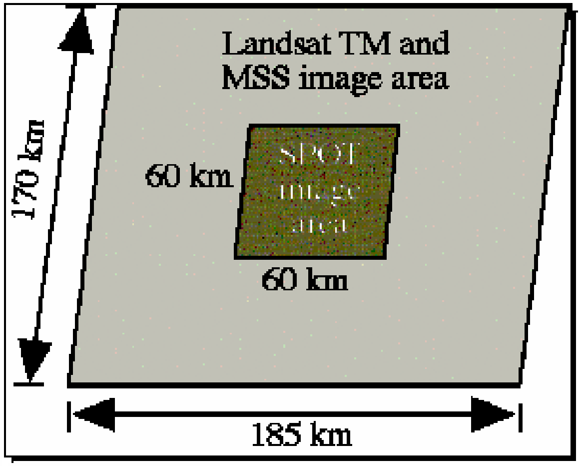
- Sun-synchronous orbit
  - Each orbit takes about 99min.
  - 14.5 orbits/day
- Earth rotates 2752km between orbits
  - Sidelap = 7% (Equator) to 84% (80° latitude)

Real-time Satellite Tracker:

http://www.n2yo.com/satellite/?s=39084

SPOT 1-3: 1986 - 1996

- Commercially developed
- 4 bands, each with 20m pixels
  - B, G, R, NIR
- Panchromatic (B&W) image with 10m pixels
- 60km swath
- Pointable mirror allows imaging from two directions
  - i.e. stereo for DEM development



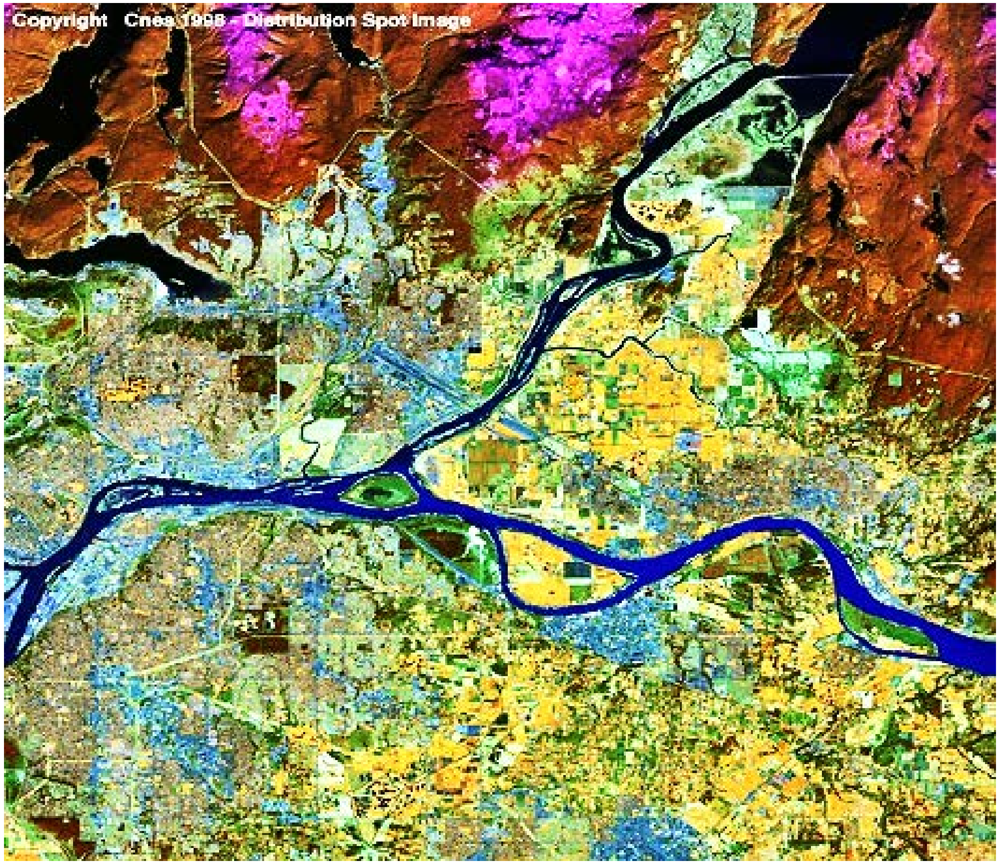
http://www.astrium-geo.com/na/1028-spot-satellite-imagery/

Jensen, 2007

SPOT 4-7: 1998+

- 6000-7000 pixel pushbroom scanners
- G, R, NIR pixel sizes decreased with each new sensor from 20m to 8m
- SPOT 4,5 had a MIR band
- Panchromatic band pixel sizes decreased with each new sensor from 10 m to 1.5m
- SPOT 6 launched 09/2012, SPOT 7 to launch in 2014

R = b, MIR = g, NIR = r



Examples of Other Moderate Resolution Sensors

- Indian IRS satellite series
  - Pixel sizes between Landsat and SPOT
  - Similar spectral bands

- Hyperion (2000+): Hyperspectral sensor on NASA EO-1 satellite
  - 220 bands between 0.4 - 2.5 µm; Bandwidth = 10 nm
  - Ground coverage (Swath) = 7.6 km
  - 30 m pixels
  - Revisit Frequency = 16 days

http://www.ga.gov.au/acres/prod_ser/eo1price.jsp

http://eo1.usgs.gov/sensors

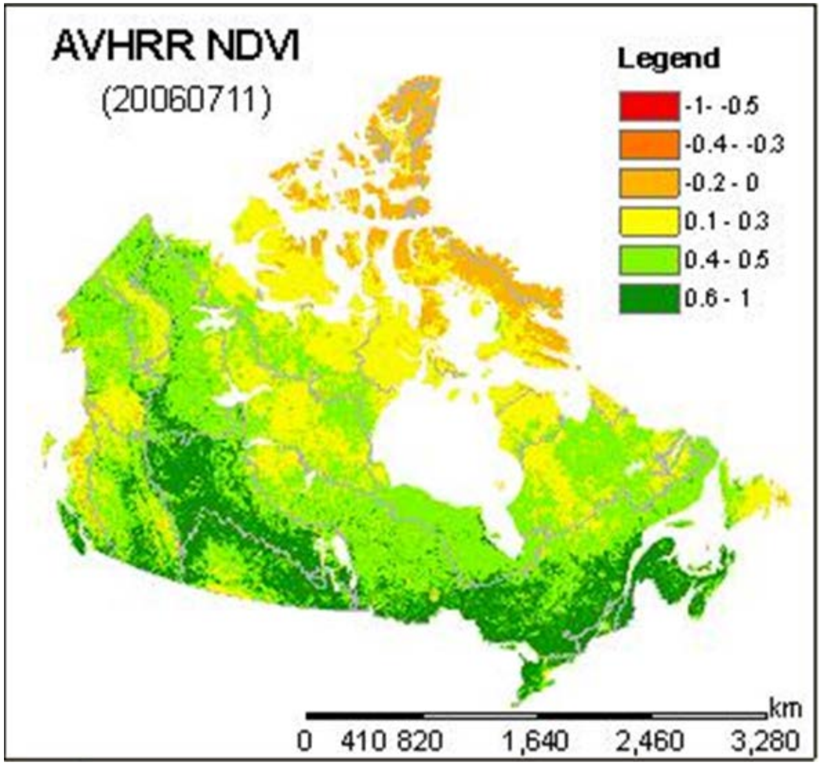
Large Area, Low Spatial Resolution Satellite Sensors

- Pixel sizes > approx. 100m (some in global studies would say 100m is ‘moderate’ resolution)
- Regional coverage per scene:
  - > about 200km across

AVHRR: Advanced Very High Resolution Radiometer: 1978 +

- Part of NOAA POES (Polar Orbiting Environment Satellite) program
  - weather program with many satellites
- Was used for large area mapping for many years due to lack of other sensors
- R, NIR, MIR, TIR bands
- 1.1km pixels; 2400km swath
- New version is Visible/Infrared Imager Radiometer Suite (VIIRS)
  - has multiple bands from VIS to TIR, and a day/night low light level Pan band

NDVI = (NIR – R) / (NIR + R)

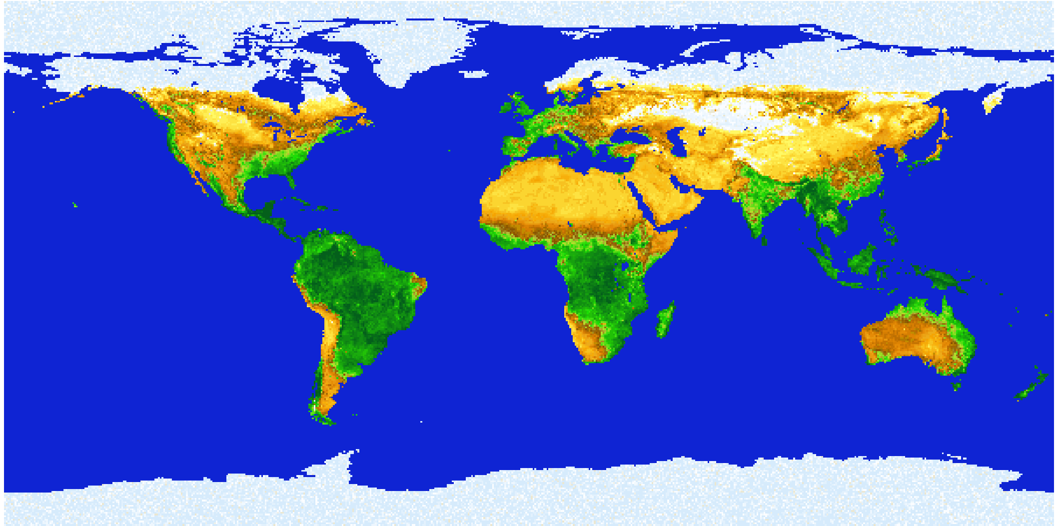


Yuhong He, Geography U of T

SPOT VGT (1998-2013) and PROBA-V (2013+)

- SPOT Vegetation Sensor (VGT1 and 2)
  - France, Belgium, Sweden
  - B/G, R, NIR, MIR
  - 1km pixels
  - 2250km swath
  - 90% daily global coverage
- PROBA-V
  - European Space Agency (ESA) sensor replaced SPOT VGT in 2013
  - Same spectral bands and pixels http://proba-v.vgt.vito.be/content/welcome-proba-v-website

Global Vegetation Mapping



http://www.spot-vegetation.com/

NASA Terra and Aqua Satellite Sensors

- Set of satellites and sensors that measure how the earth is changing – part of EOS – Earth Observatory Satellites
  - Launched in 2000
  - Various global maps produced by these sensors are given at:

    http://earthobservatory.nasa.gov/GlobalMaps/

MODIS
on NASA's Terra and Aqua Satellites

Primary Use	Band	Bandwidth[1]
Land/Cloud/Aerosols Boundaries	1	620 - 670
	2	841 - 876
Land/Cloud/Aerosols Properties	3	459 - 479
	4	545 - 565
	5	1230 - 1250
	6	1628 - 1652
	7	2105 - 2155
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420
	9	438 - 448
	10	483 - 493
	11	526 - 536
	12	546 - 556
	13	662 - 672
	14	673 - 683
	15	743 - 753
	16	862 - 877
Atmospheric Water Vapor	17	890 - 920
	18	931 - 941
	19	915 - 965

Primary Use	Band	Bandwidth[1]
Surface/Cloud Temperature	20	3.660 - 3.840
	21	3.929 - 3.989
	22	3.929 - 3.989
	23	4.020 - 4.080
Atmospheric Temperature	24	4.433 - 4.498
	25	4.482 - 4.549
Cirrus Clouds Water Vapor	26	1.360 - 1.390
	27	6.535 - 6.895
	28	7.175 - 7.475
Cloud Properties	29	8.400 - 8.700
Ozone	30	9.580 - 9.880
Surface/Cloud Temperature	31	10.780 - 11.280
	32	11.770 - 12.270
Cloud Top Altitude	33	13.185 - 13.485
	34	13.485 - 13.785
	35	13.785 - 14.085
	36	14.085 - 14.385

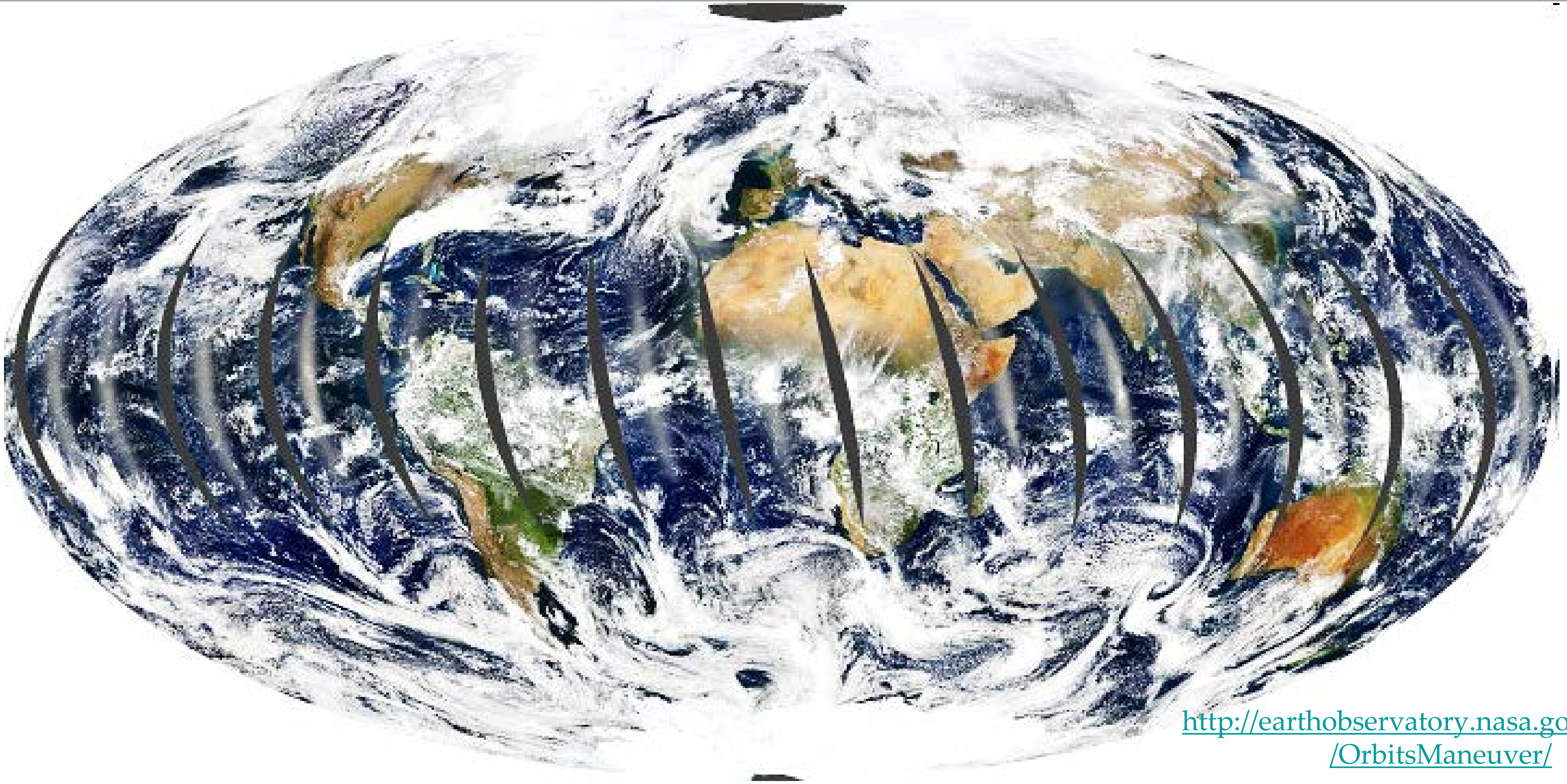
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)

[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in µm

Carleton UNIVERSITY

Note – MODIS stands for Moderate Resolution Imaging Spectrometer, hence a difference in what is considered moderate, low, and high resolution.

MODIS Daily Coverage



http://earthobservatory.nasa.gov/Features/OrbitsManeuver/

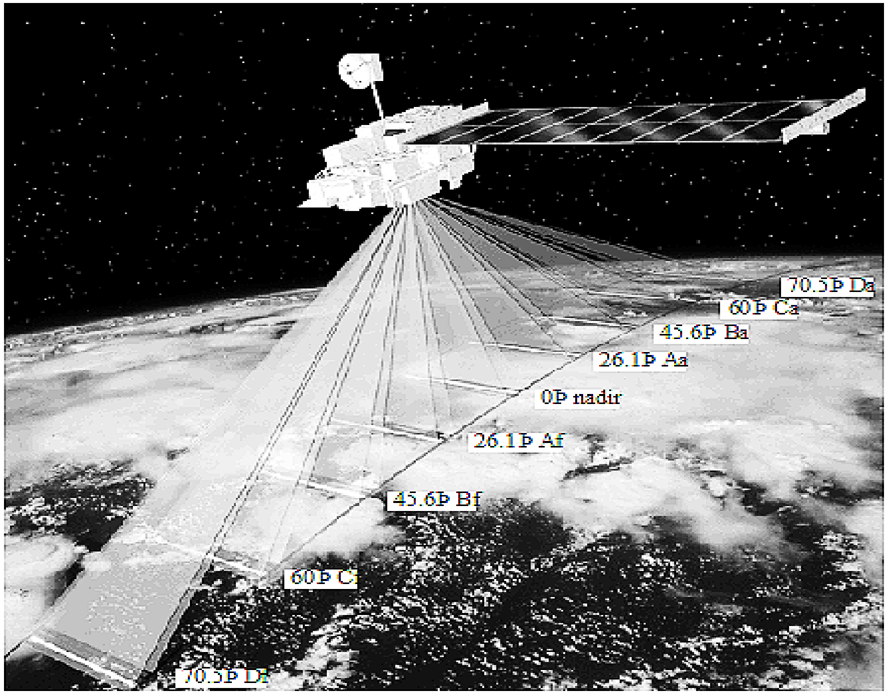
MODIS website with image gallery:

http://modis.gsfc.nasa.gov/gallery/showall.php

Petermann Glacier Calving

http://www.youtube.com/watch?v=G08xPmxR28U&src=eoa-ann

Multi-angle Imaging Spectroradiometer (MISR)



Sensors	Df	Cf	Bf	Af	An	Aa	Ba	Ca	Da
View angle	70.5Þ	60Þ	45.6Þ	26.1Þ	0Þ	26.1Þ	45.6Þ	60Þ	70.5Þ
425 – 467 nm									
543 – 571 nm									
660 – 682 nm									
846 – 886 nm									

275 x 275 m | 1.1 x 1.1 km | 275 m x 1.1 km

Jensen, 2007

- On same Terra satellite as MODIS.
- See Lillesand et al. (2008) Table 6.23 for other sensors on Terra and Aqua.

Small Area, High Resolution Satellite Sensors

- Pixel sizes < about 10m (some in more regional studies would call this 'very high resolution')
- Regional coverage per scene < about 50km
- Quantization of 11 or 12 bits (2^{12} = 4096 DN per pixel)

IKONOS (1999+), GeoEye

IKONOS

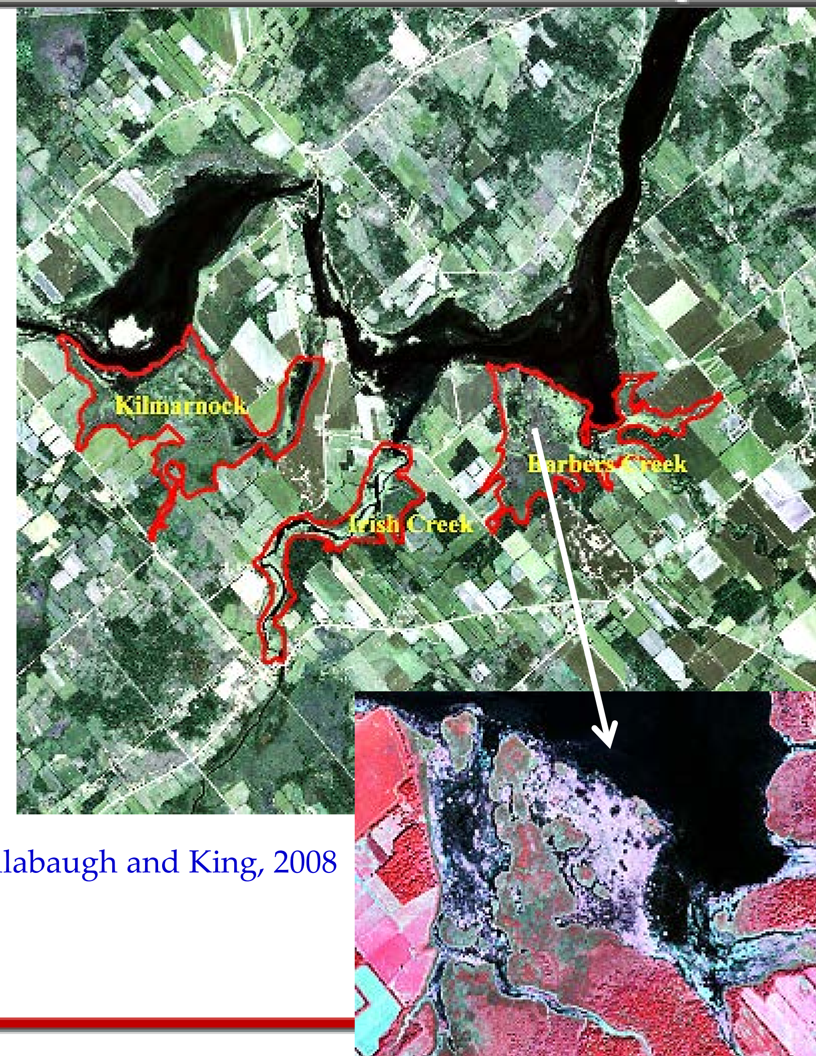
- Commercially developed high resolution sensor
- B, G, R, NIR bands
- Pointable mirror allows off-nadir imaging up to 26°
  - Can cover an area from an adjacent path
  - Revisit time = 3 days
- At Nadir:
  - 0.82 m panchromatic;3.2 m multispectral
  - 11km swath

GeoEye-1 (2008)

- Successor to IKONOS
  - 0.41 m panchromatic;1.65 m multispectral
  - Revisit time less than three days

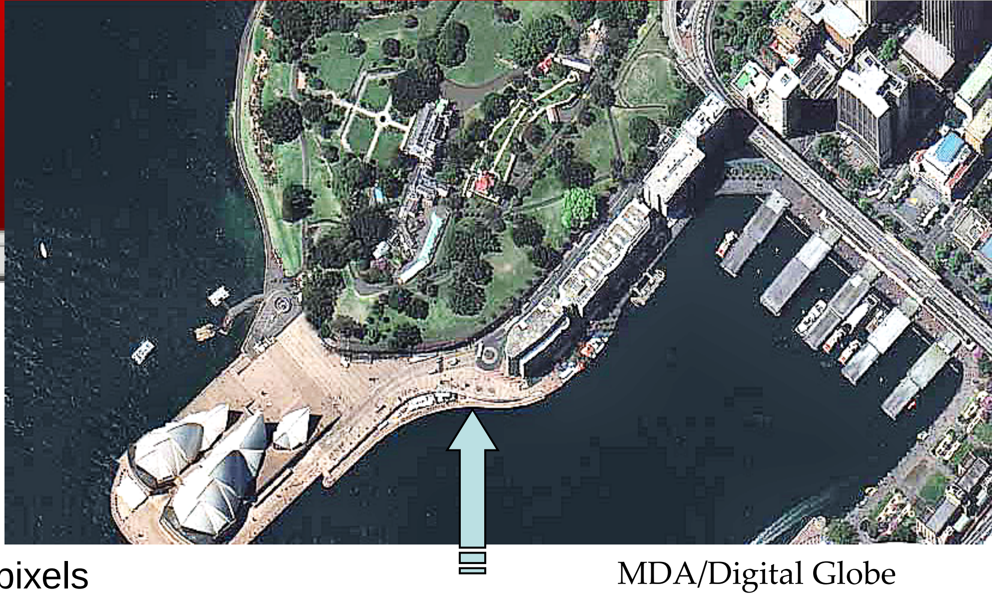
GeoEye-2 (2013)

- 0.38 m panchromatic



Dillabaugh and King, 2008

Quickbird, Worldview and Others



MDA/Digital Globe

- **Quickbird (2001+)** - similar to Ikonos
- **Worldview** succeeded Quickbird
  - Worldview-1 (2007+): panchromatic 0.5m pixels
  - Worldview-2 (2009): 0.5m panchromatic + 8 multispectral bands with 1.8m resolution (sold as 2m pixels); swath approx. 16km
  - Worldview-3 (2014): 0.31 m pan + 1.24m VIS-NIR bands + 3.7m MIR bands.

Other Examples

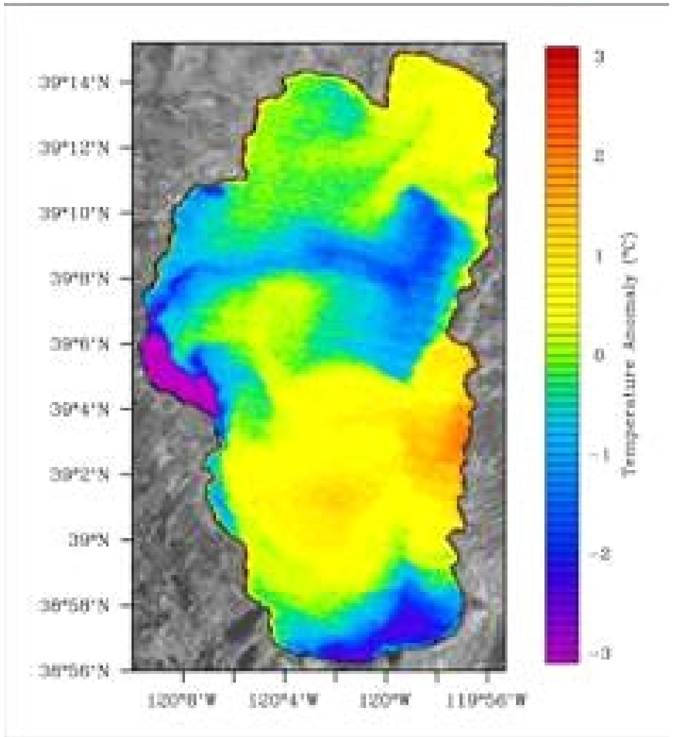
- **Pleiades (2011+)**
  - 2m multispectral; 70 cm PAN; 20km swath
- **RapidEye (2008+)**
  - Constellation of 5 satellites; 5 bands in VIS-NIR, 6.5m pixels, 25x25km or 27x77 km.
- **Formosat-2 (2004+)**
  - Taiwanese-US (commercial) collaboration; Images sold by SPOT-Image
  - Slightly poorer resolution than others but greater coverage
- Many current satellite sensors now have frequent (sometimes daily) coverage anywhere on globe by viewing up to 45° off-nadir for single satellite or by have multiple satellites with small off nadir angles
- See Lillesand et al. (2008) Table 6.20 for many others.

THERMAL IMAGING

- Important Aspects:
  - Wavelength range
  - Emission not reflection
  - Diurnal Temperature Variation
- Applications:
  - Building heat loss / urban heat island mapping
  - Thermal plumes from rivers, springs, industrial effluent
  - Ocean/lake temperature
  - Geology
  - Vegetation health

Thermal Imaging

- Temperature can be internal (kinetic) as measured by a thermometer or external (radiant) as measured by its emitted radiation.
- Radiant temperature can be derived using thermal sensors and converted to kinetic temperature

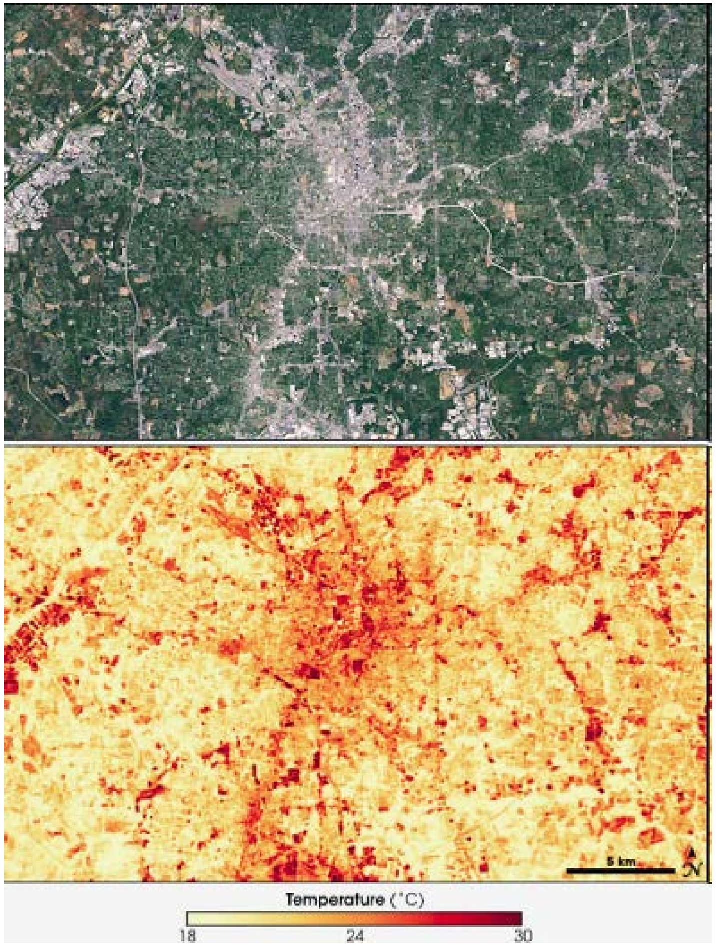


Thermal upwelling, Lake Tahoe
Landsat and MODIS data

http://terc.ucdavis.edu/research/remotesensing.html

Global temperature change graph and video
http://www.nasa.gov/topics/earth/features/2011-temps.html

Thermal Heat Island



Atlanta core at centre of image (cooler temperature yellow; hotter temperatures red)

http://www2.ucar.edu/staffnotes/research/2563/capturing-heat-islands-climate-models

Thermal Imaging

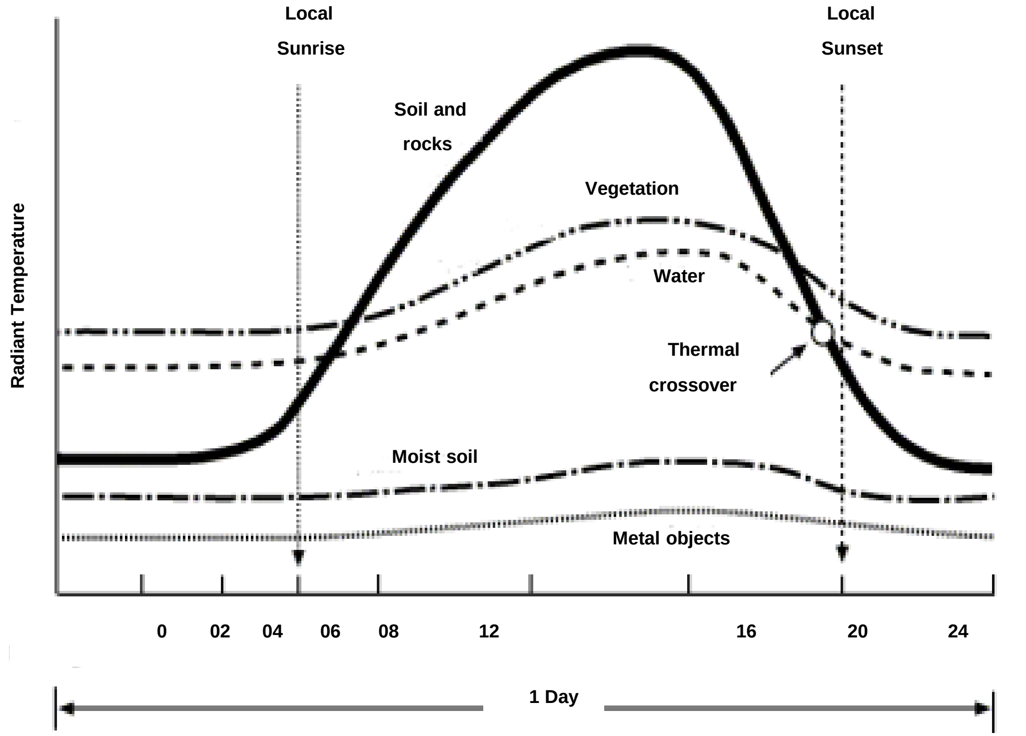
- Peak emission of most Earth surface objects is between 8-14μm
  - 8-14 μm also has good atmospheric transmission.
  - Most thermal sensing conducted using sensors in this spectral region.
- However, hot objects emit more at shorter λ.
  - The 3-5 μm range is sometimes useful.
  - EMR between 5 and 8 μm cannot be used due to almost complete atmospheric absorption
- Note: water vapour and other atmospheric components absorb, scatter and emit thermal EMR
  - They have to be corrected for in order to conduct precise temperature measurement.
    - Atmospheric scattering and absorption <u>reduce</u> the apparent ground temperature
    - Atmospheric emission (path radiance) <u>increases</u> the apparent ground temperature.

Timing of Thermal Imaging

- Diurnal (24 hr) heating and cooling curves depend on the thermal properties of the material
  - Thermal inertia: the resistance to heating (temperature rise) and cooling (temperature decrease)

    E.g.

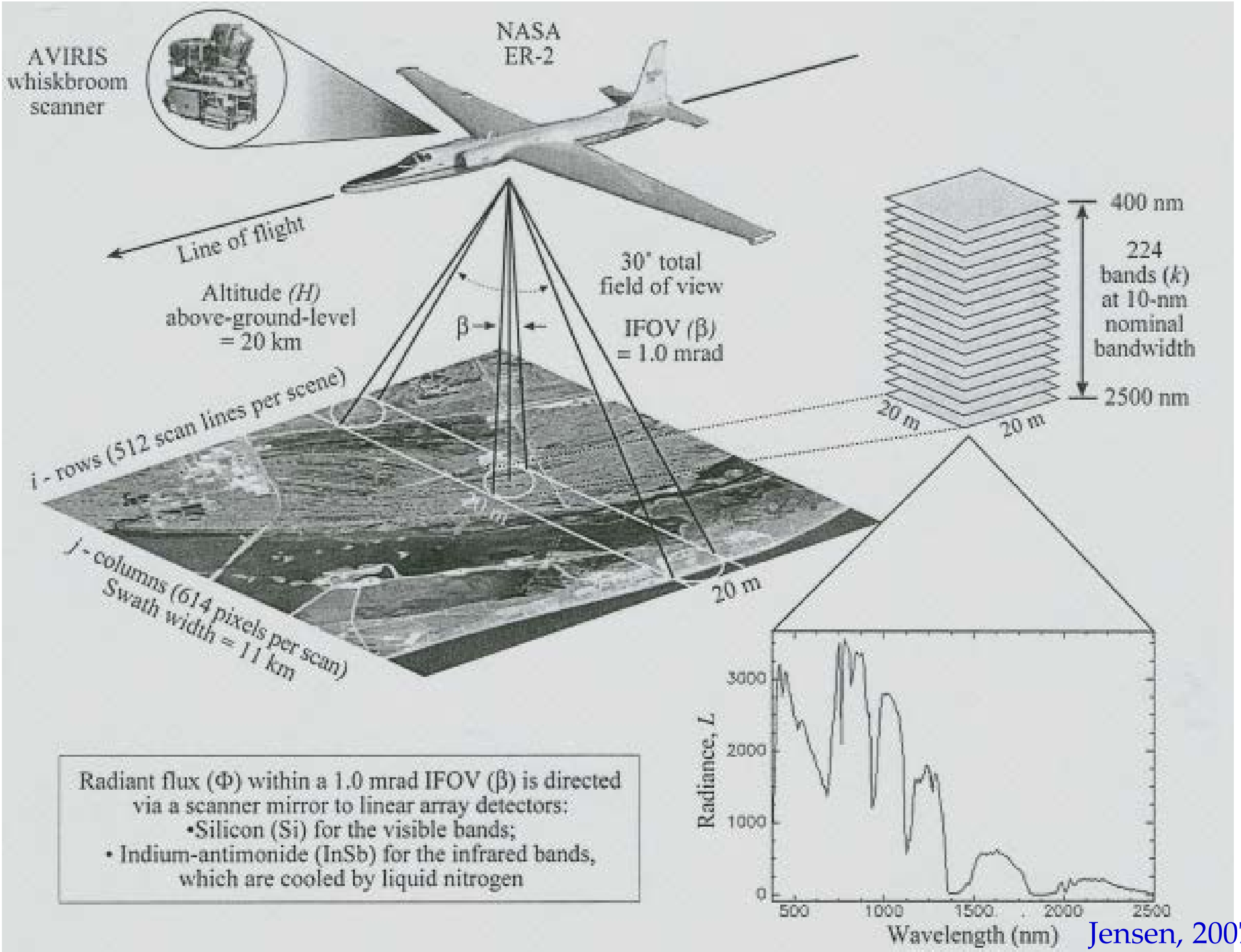
    - Water: high thermal inertia
    - Dry soil and rock: low thermal inertia
- Imaging near dawn gives minimum temperatures
- Imaging in mid afternoon gives maximum temperatures
- Sometimes do both to measure temperature change (max-min) and determine the surface material or characteristics



Jensen, 2007

Hyperspectral Remote Sensing

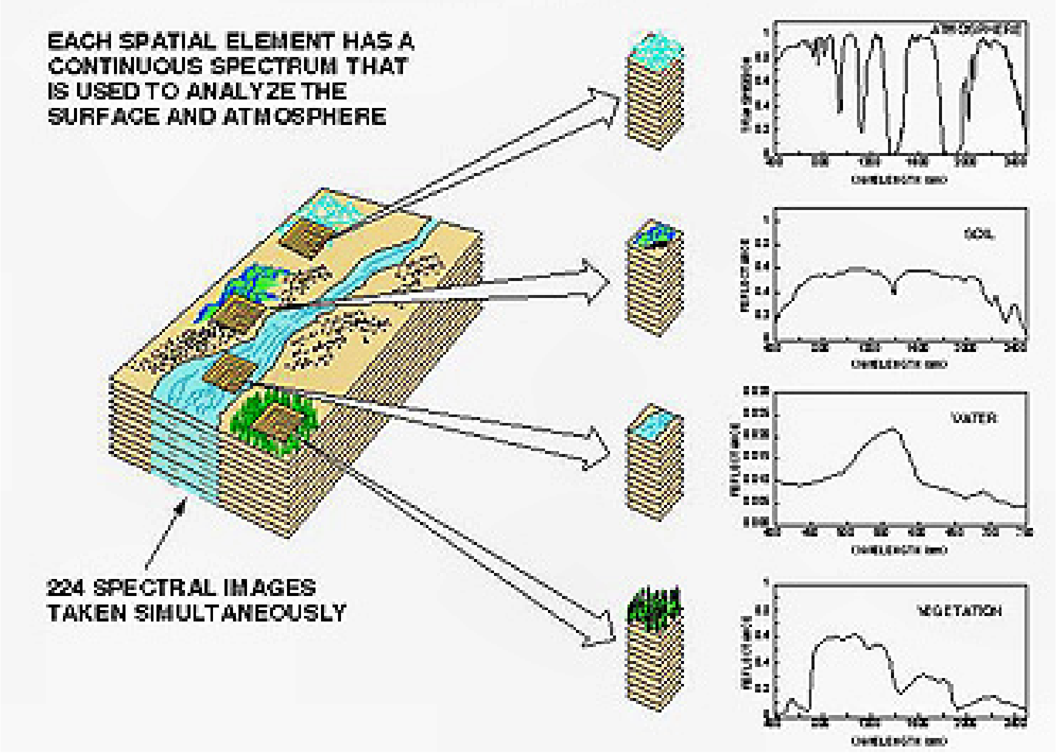
- Reflectance curves derived from airborne and spaceborne sensors



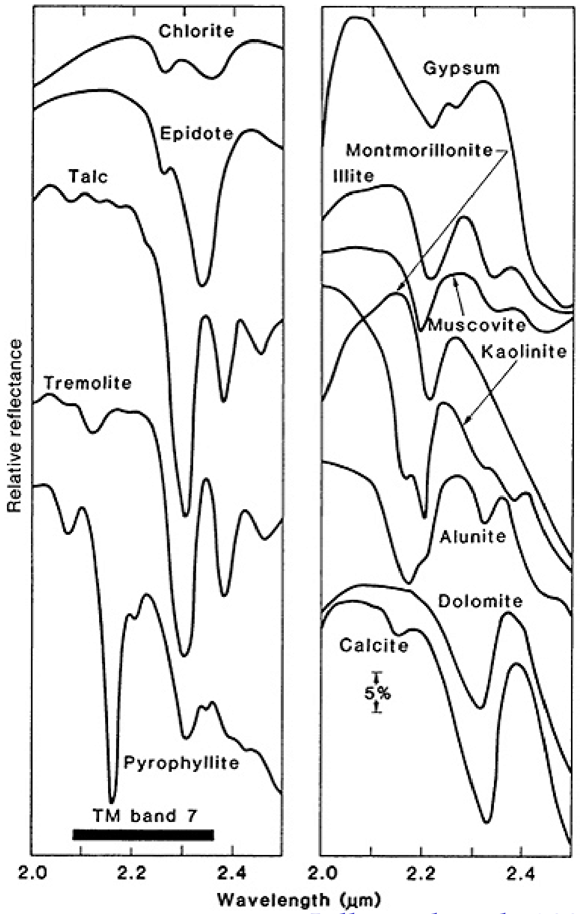
Jensen, 2007

Hyperspectral Remote Sensing

- Some surface materials have diagnostic absorption or reflectance features 10-20 nm wide.

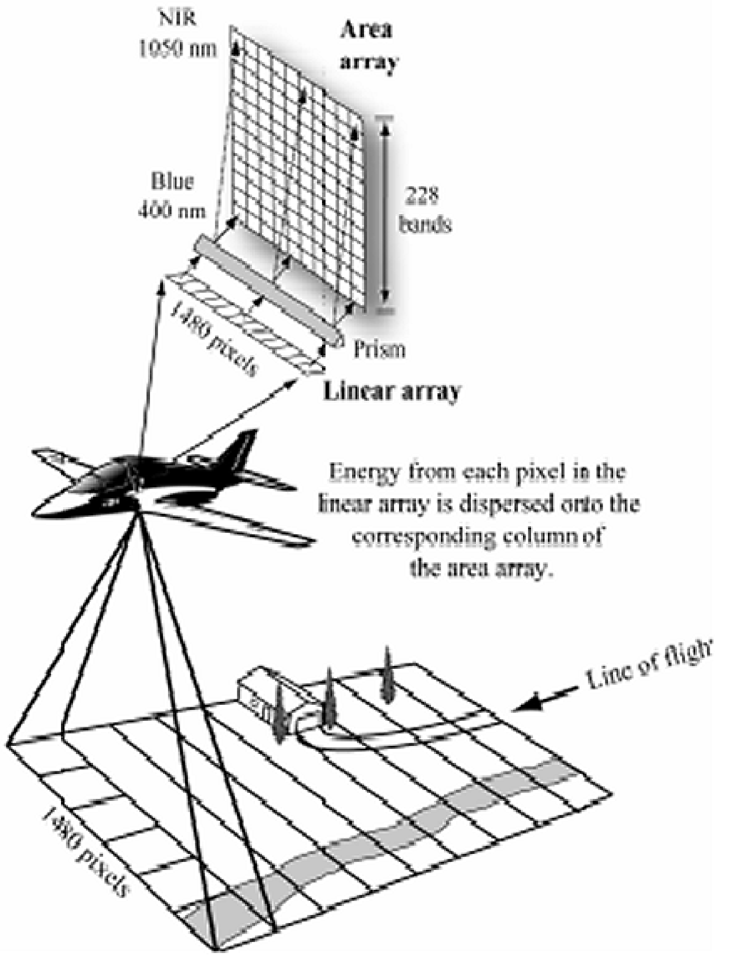


http://www.fas.org/irp/imint/docs/rst/Intro/originals/FIG_48.JPG



Lillesand et al., 2008.

Hyperspectral Remote Sensing

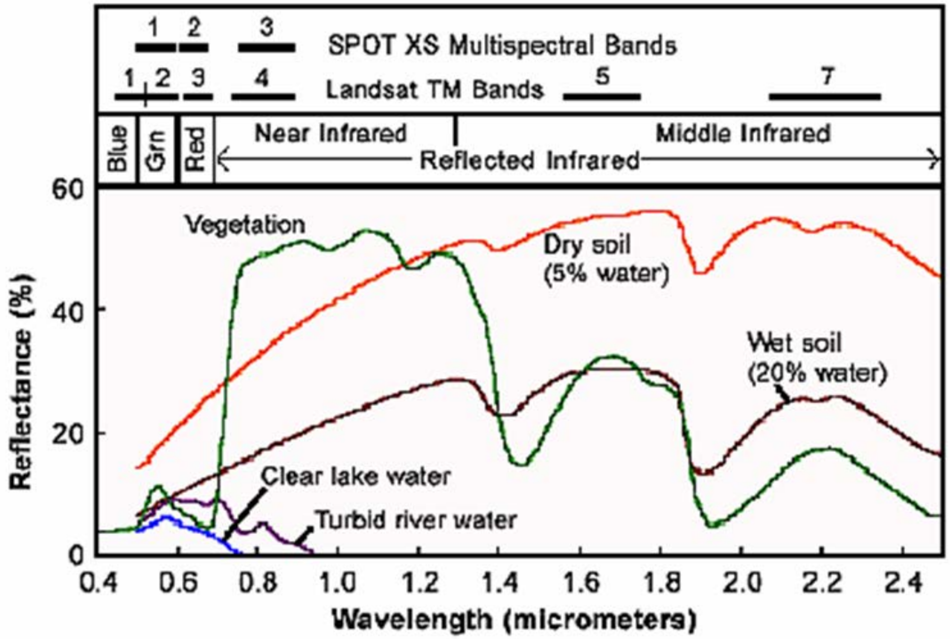


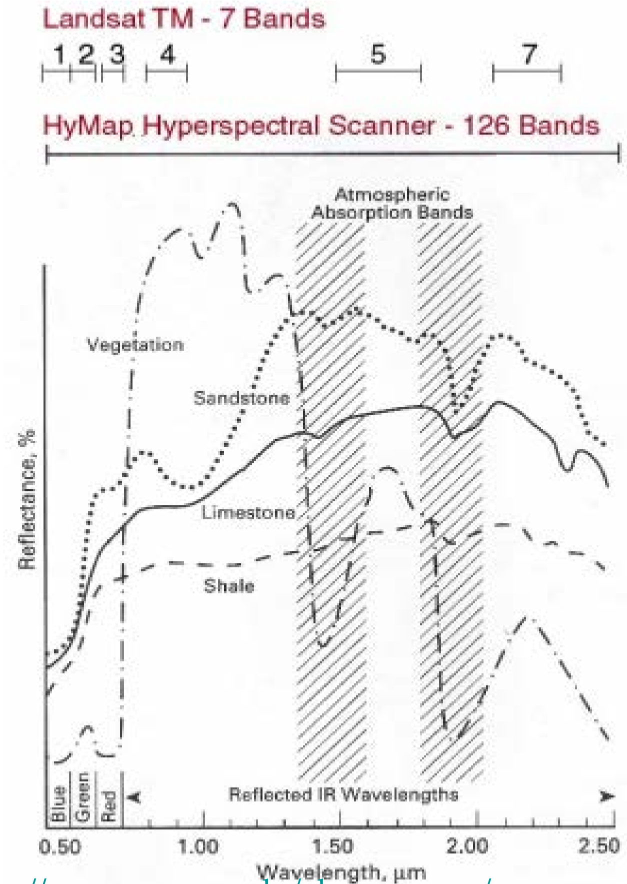
Jensen, 2007

- Sensors can be mechanical scanners (e.g. AVIRIS)
- Can be 2-d sensor array (chip) as in a digital camera
  - Dispersion optics (e.g. prism) spread the radiance spectrum across the chip
  - Analogous to many pushbroom scanners side by side, each for a different spectral band

Multispectral vs. Hyperspectral

- Multispectral scanners acquire data in about 2 to 10 coarse or narrow spectral bands (from 0.3 (UV) to 14.0 µm (thermal-IR).
- Hyperspectral scanners acquire data in tens to hundreds of narrow bands.





http://www.es.ucsc.edu/~hyperwww/compspec.jpg

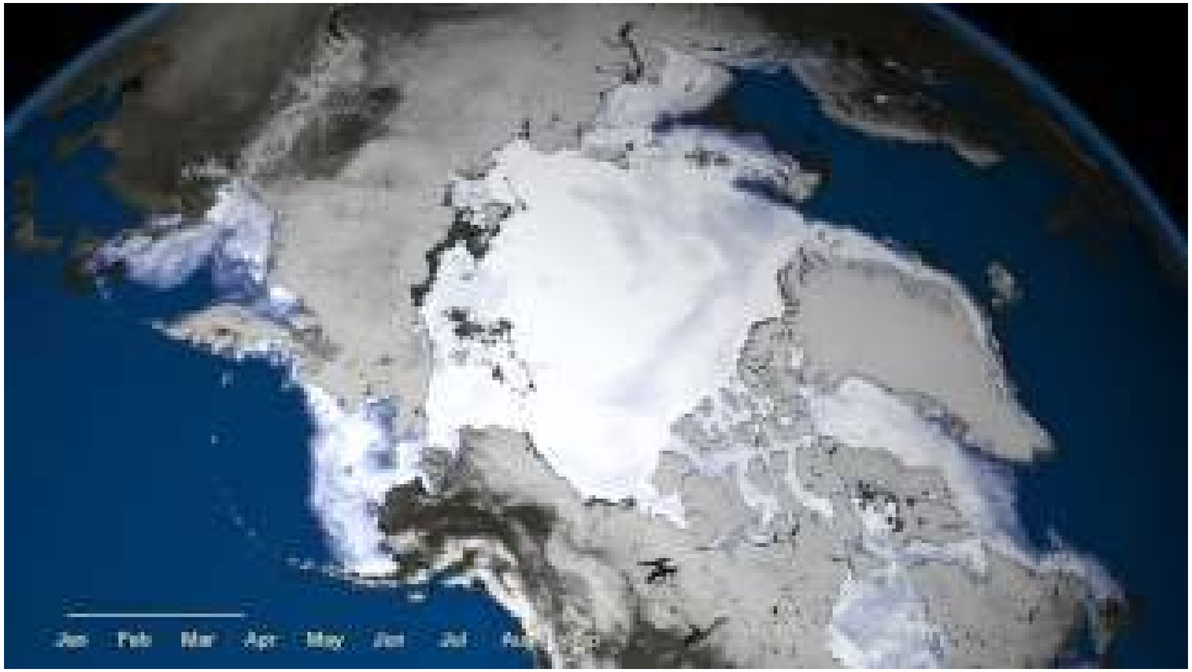
Radar

- Some radar sensors passively detect Earth emitted microwaves
  - Often to convert to a radiant temperature
  - Animation:

  http://earthobservatory.nasa.gov/IOTD/view.php?id=41576&src=eoa-iotd

- Most actively send a microwave signal from an antenna to Earth
  - Detect strength of return (reflected or 'backscattered') signal

Passive Radar

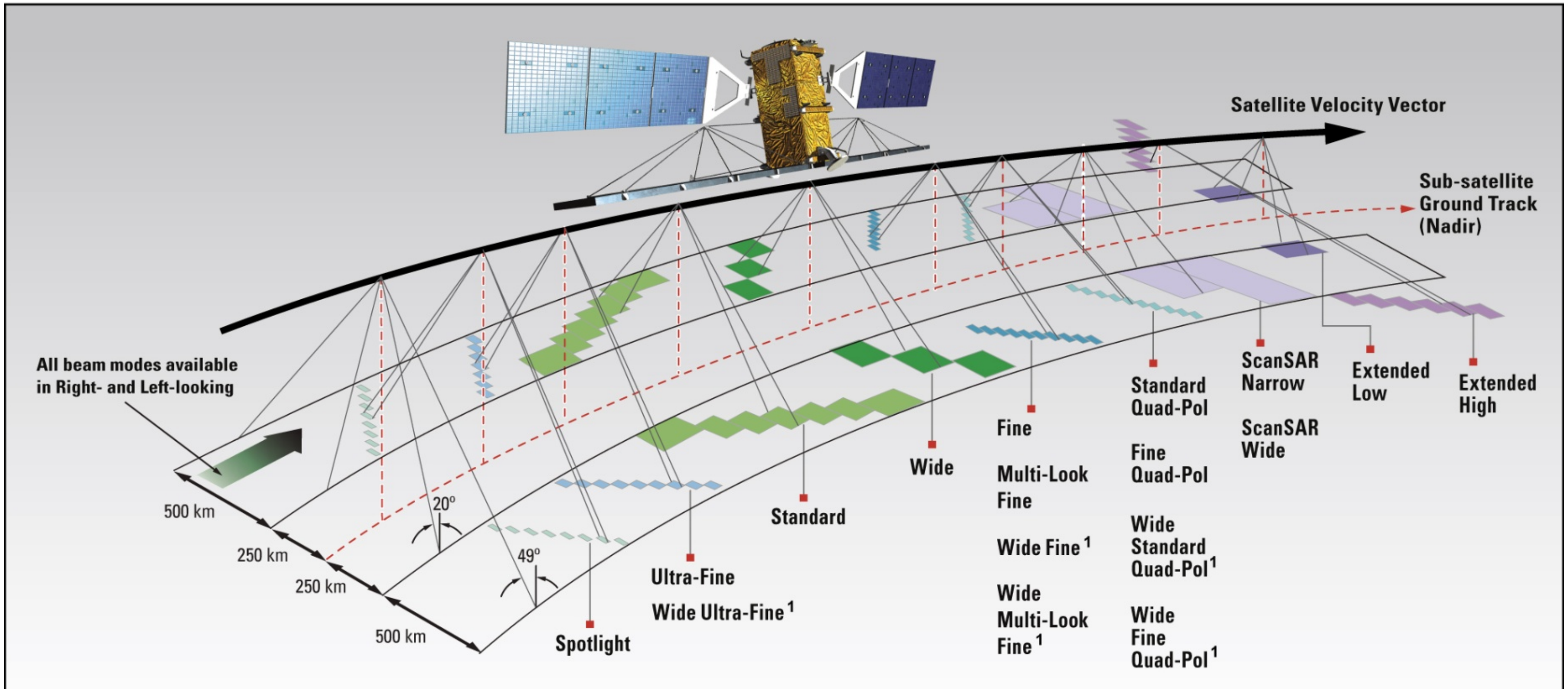


- NOAA 2012 sea ice extent video (compared to 1979-2000 median)
- Special Sensor Microwave Imager SSM/I

http://www.youtube.com/watch?v=UaKqhRTqSlg&list=UU-87aDLv5WFJ83fxt21gsEQ&index=2&feature=plcp

Active Radar

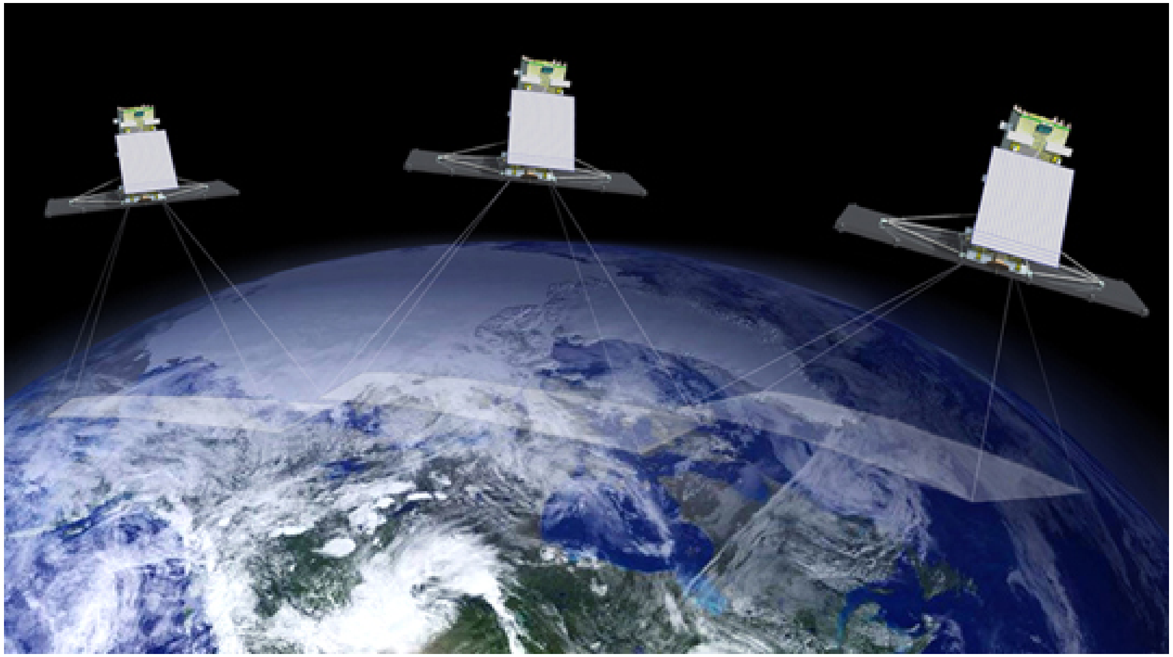
- Oblique side viewing geometry



RadarSat 2 configurations

http://gs.mdacorporation.com/SatelliteData/Radarsat2/Products.aspx

Radarsat



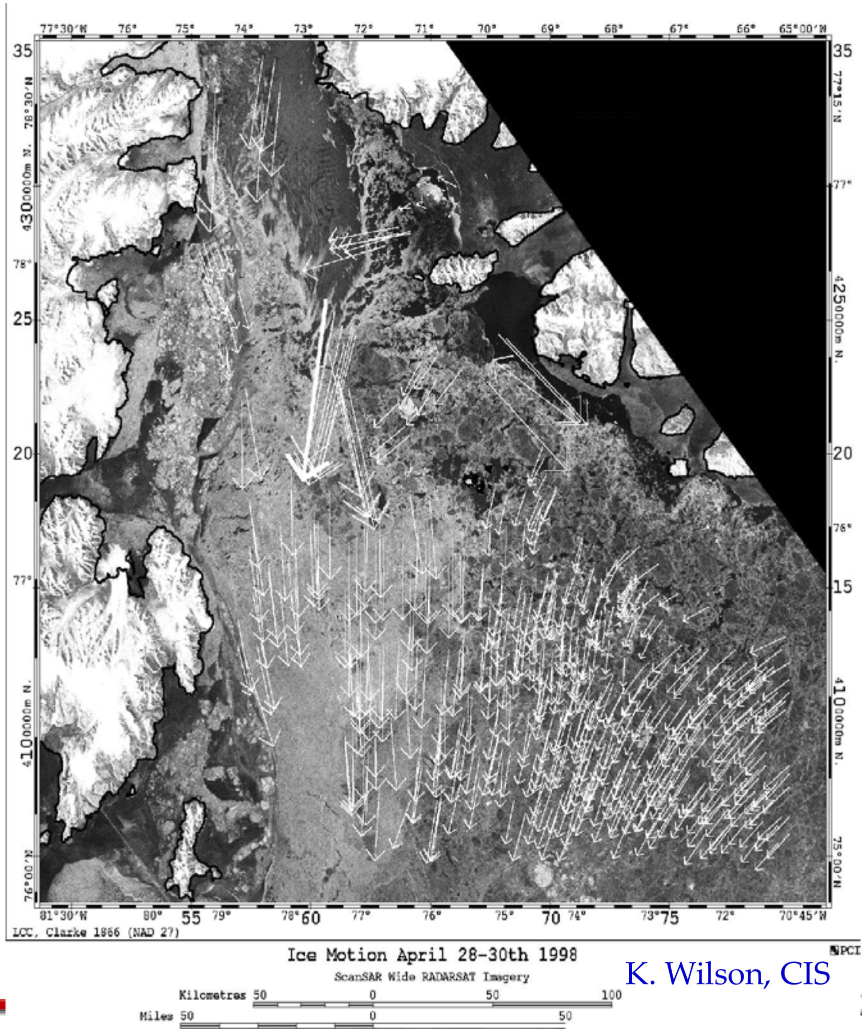
http://www.asc-csa.gc.ca/eng/satellites/radarsat/

- RadarSat 1, 1995-2013
- RadarSat 2 2008-
- Radarsat Constellation planned for 2018
  - Daily coverage of Canada's landmass and oceans/lakes.

Major Applications of Radar

- Ice mapping and ice motion monitoring
- Structural geology
- Soil moisture and type (where no surface cover)
- Water bodies
- Land cover, forest and hydrologic mapping in tropics where cloud cover prevails

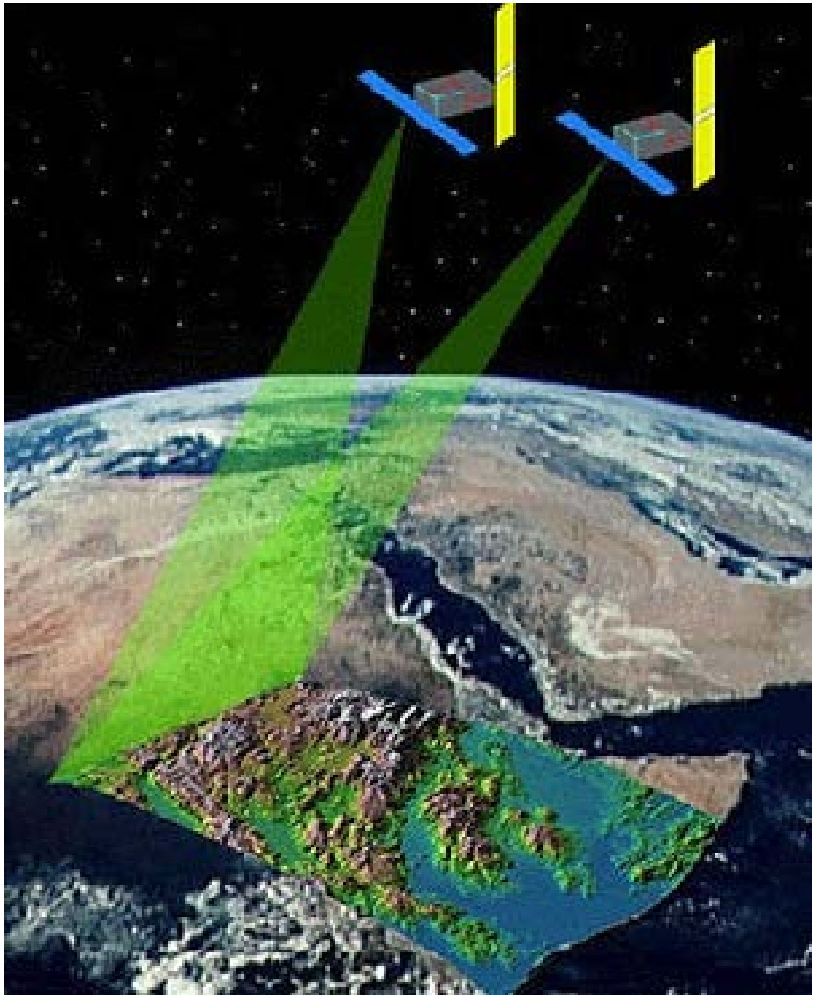
- >> detail in GEOM 4003



K. Wilson, CIS

Radar Interferometry

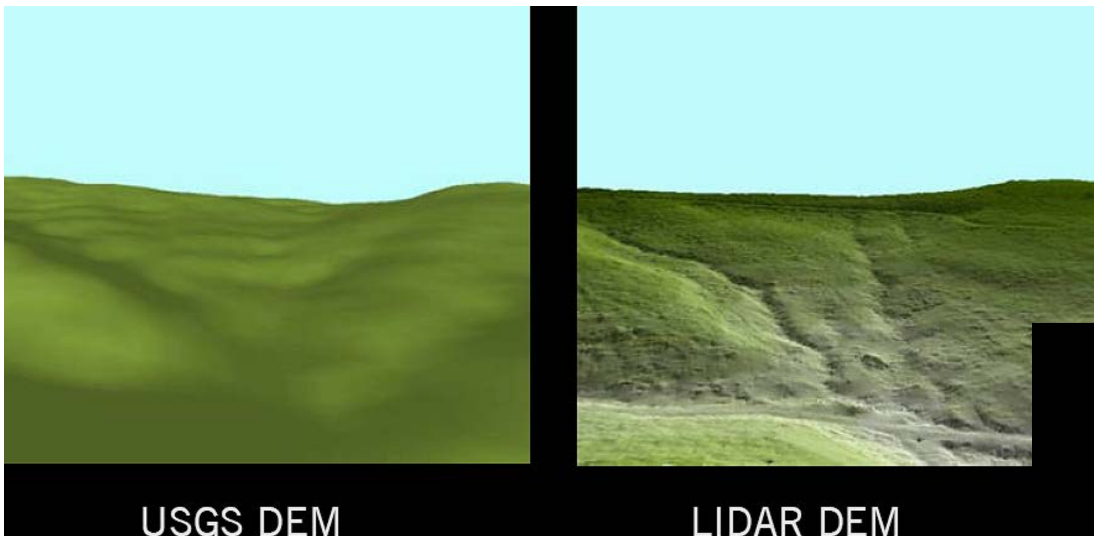
- Signals from two radar sensors at different angles produces phase differences that are related to elevation and changes in position.
  - E.g. Terra SAR and TanDEM SAR X-band satellites (Germany) fly approx. 200m apart.
- Can be used to produce DEMs or map land subsidence and deformation with accuracy of a few centimetres.



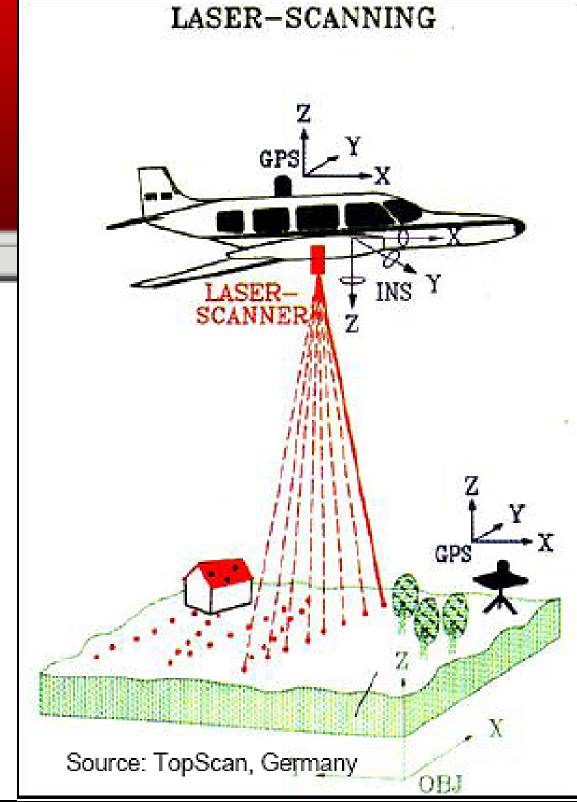
http://ee.stanford.edu/~zebker/images/ersgeometry_small.gif

Lidar

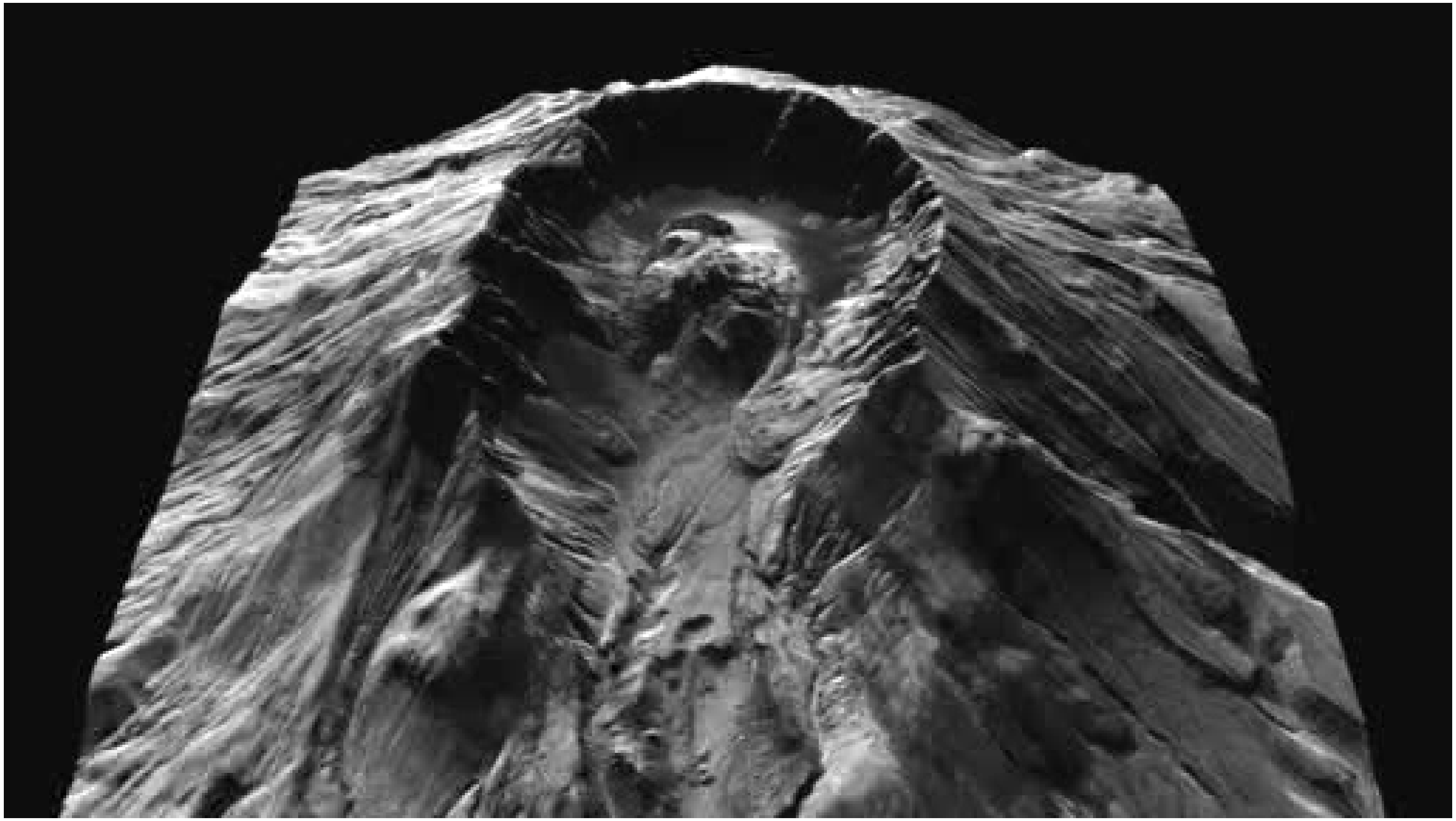
- Scanning laser for large scale DEMs



Chen, Q. Naval Postgraduate School Lidar Workshop, Monterey, CA



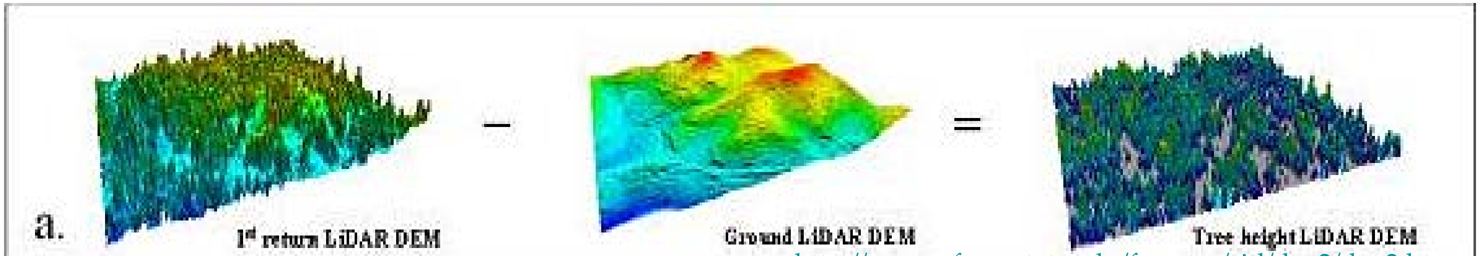
Ikonos Pan band over Lidar: Flythrough of Mt. St Helens



http://www.nasa.gov/vision/earth/lookingatearth/mshelenslidar.html

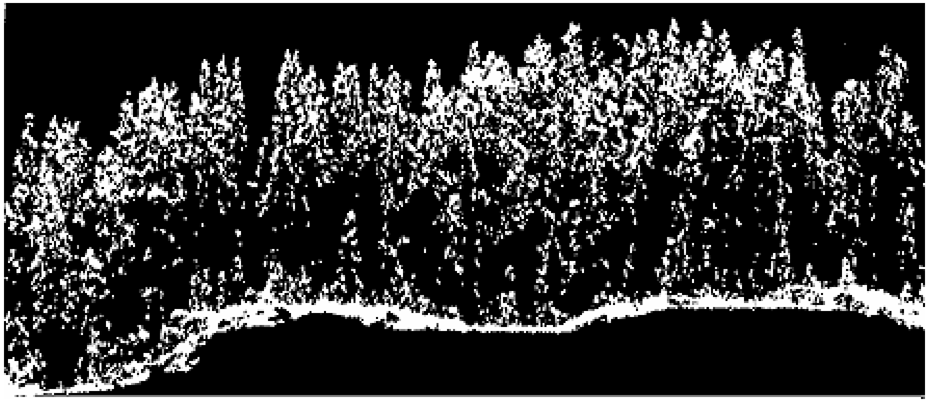
Lidar

- Forest applications
  - 1st return and Ground DEM for Tree height

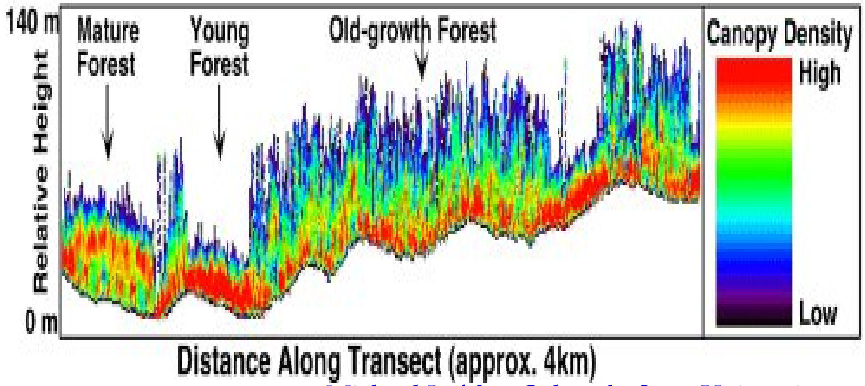


http://www.cfr.msstate.edu/forestry/sitl/dan2/dan2.htm

  - Multiple return lidar for vertical forest structure



Naesset et al., Norwegian University of Life Sciences
http://www.umb.no/statisk/umnumb/presentations/2006/developing_and_testing_nsset.pdf



Michael Lefsky, Colorado State University

Lidar

- Forest Heights of the U.S. from GLAS (laser height) and MODIS (to classify forest vs. other land cover types).

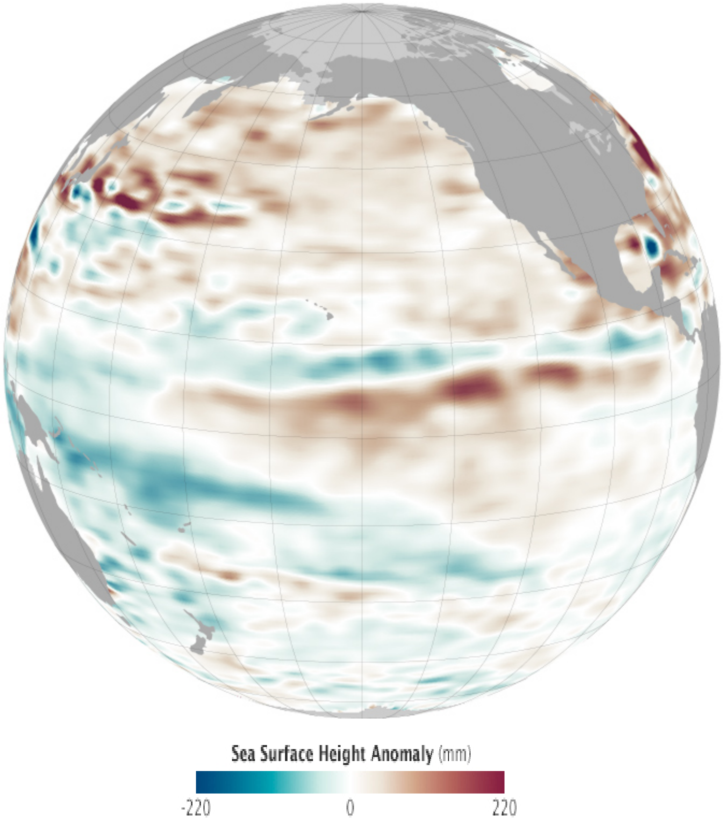
http://earthobservatory.nasa.gov/IOTD/view.php?id=44717&src=eoa-iotd

Radiohead Lidar Video

- http://www.youtube.com/watch?v=8nTFjVm9sTQ

Radar Altimetry

- E.g., JASON-2 satellite
- Has various sensors:
  - Poseidon-3 radar altimeter measures ocean surface height
  - Advanced Microwave Radiometer (AMR) used to measure atmospheric water vapour and derive corrections to improve altimeter accuracy to cm level.
  - Radar, laser, GPS positioning of satellite position to cm level.
- Higher sea surface = warmer water.
  - Can track El Nino (warm water on west coast of S. America), La Nina (warm water on east coast of Asia) and periods in between with less predictable weather (La Nada – as shown here.)



http://earthobservatory.nasa.gov/IOTD/view.php?id=82041&src=eoa-iotd

NOVEMBER 20
GUEST SPEAKER + GIS DAY

- Blair Kennedy: Modelling and Mapping Arctic Vegetation Biochemistry using Multi-angle Hyperspectral Satellite Imagery

- GIS DAY visit.

- Please attend – some aspects will be on the exam.