Platforms and sensors

Dr Kawawa Banda

Introduction

- Energy reflected or emitted from Earth's surface is measured by sensors
- Sensors are attached to platforms (typically airborne or spaceborne)
- The sensor-platform combination determines the characteristics of the resulting data
- Example: when platform altitude is increased, the total area imaged is increased, while the the level of detail is reduced

Overview

- Sensors
  - Passive vs. active sensors
- Platforms
- Satellite orbits
- Multispectral scanners
  - Whiskbroom
  - Pushbroom
- Examples of multispectral scanners

Historical Landmarks

- Theory of light and the electromagnetic spectrum
- Platforms
  - the vehicles that carry the sensors
- Sensor systems
  - instruments that take the photos or images

Milestones in the History of Remote Sensing (Source: Aggrawal, 2003)

1800 Discovery of Infrared by Sir W. Herschel
1839 Beginning of Practice of Photography
1847 Infrared Spectrum Shown by J.B.L. Foucault
1859 Photography from Balloons
1873 Theory of Electromagnetic Spectrum by J.C. Maxwell
1909 Photography from Airplanes
1916 World War I: Aerial Reconnaissance
1935 Development of Radar in Germany
1940 WW II: Applications of Non-Visible Part of EMS
1950 Military Research and Development
1959 First Space Photograph of the Earth (Explorer-6)
1960 First TIROS Meteorological Satellite Launched
1970 Skylab Remote Sensing Observations from Space
1972 Launch Landsat-1 (ERTS-1) : MSS Sensor
1972 Rapid Advances in Digital Image Processing
1982 Launch of Landsat -4 : New Generation of Landsat Sensors: TM
1986 French Commercial Earth Observation Satellite SPOT
1986 Development Hyperspectral Sensors
1990 Development High Resolution Space borne Systems
First Commercial Developments in Remote Sensing
1998 Towards Cheap One-Goal Satellite Missions
1999 Launch EOS : NASA Earth Observing Mission
1999 Launch of IKONOS, very high spatial resolution sensor system

Main image sources

Aerial	Satellite
small area coverage	Large area coverage
narrow spectral range (visible)	broader spectral range
mostly analog, now digital also	digital formats
Relatively inexpensive	- Inexpensive for large areas
Have tilt and relief displacement errors though Can be corrected	geometrically accurate (little distortion or RD
common	Increasing ………
easy to interpret (Can visually interpret and digitise	✓Require special software to classify/interpret and digitise)
easy/ flexible to acquire	Limited flexibility in acquisition (but changing)

Platform Development

- Balloons (1850-1860)
  - “Nadar”, King and Black, and others
- Kites (1880)
- Pigeons (1880s)
- Aircraft (1909)
- Satellites (1960s)

Value of Remote Sensing (2)

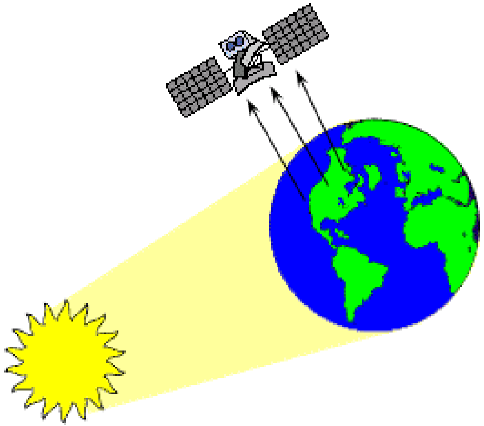
- Data consistency over time - replicable results
- Spatially continuous data (vs. point samples)
- Computer compatible - digital
- Frequency of data collection - regular revisit
- Near-simultaneous data collection over large areas (no time lag)
- Can be calibrated with ground (in-situ) observations
- Relatively low cost per unit area
- Multispectral data
- A caveat: not a panacea for all geographic problems

Sensors

A sensor is a device that measures and records electromagnetic energy

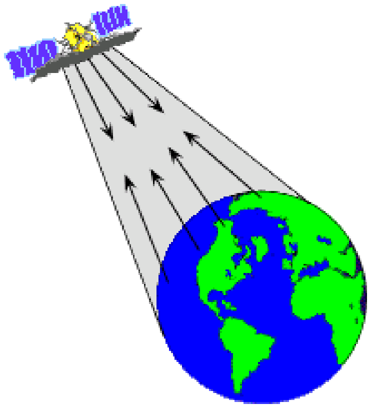
Passive vs. active sensors

- **Passive systems depend on other energy sources (illumination by the sun, emission of thermal radiation from the Earth)**



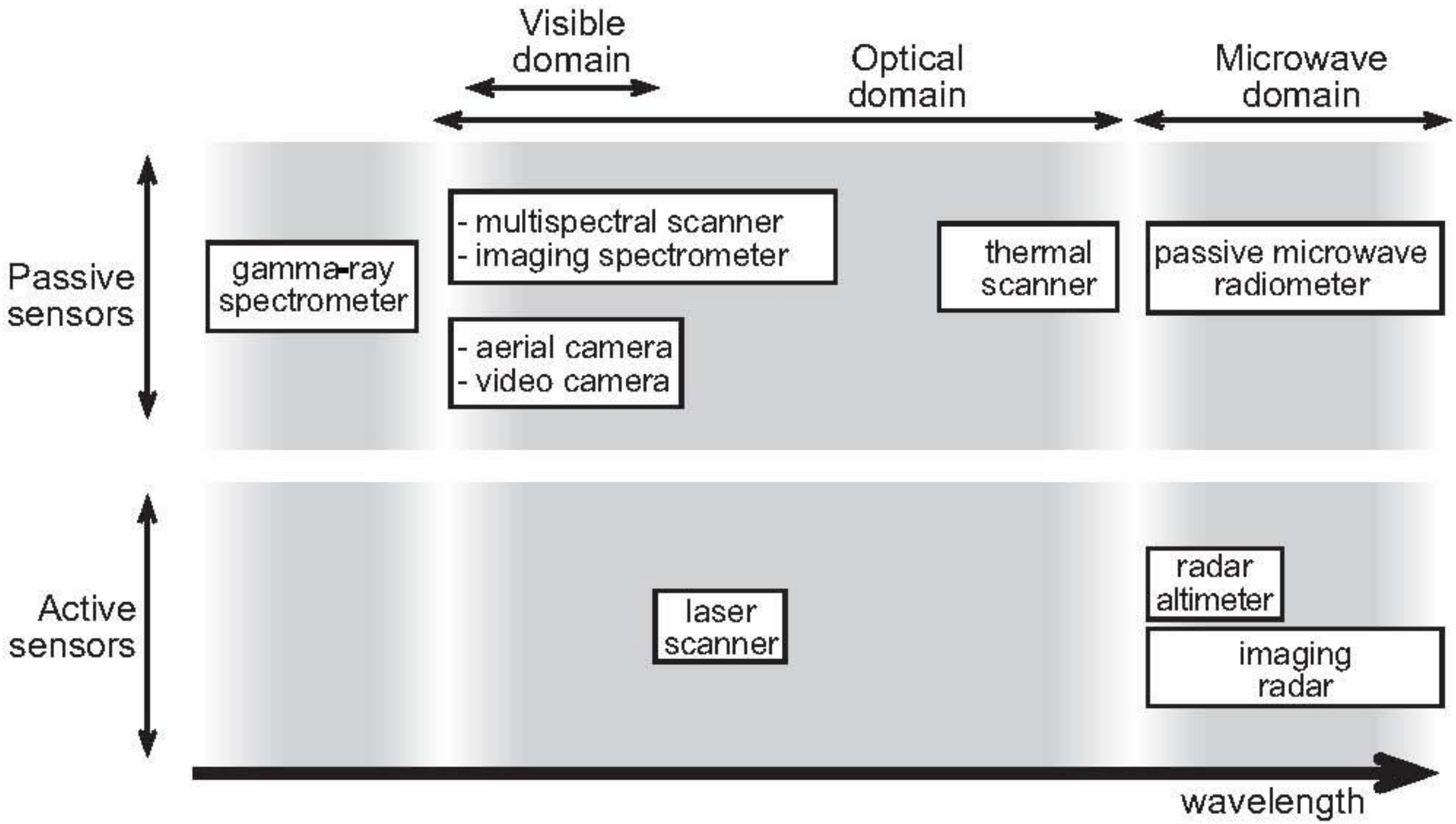
- aerial cameras
- multispectral scanners
- thermal scanners

- **Active systems generate their own illumination**

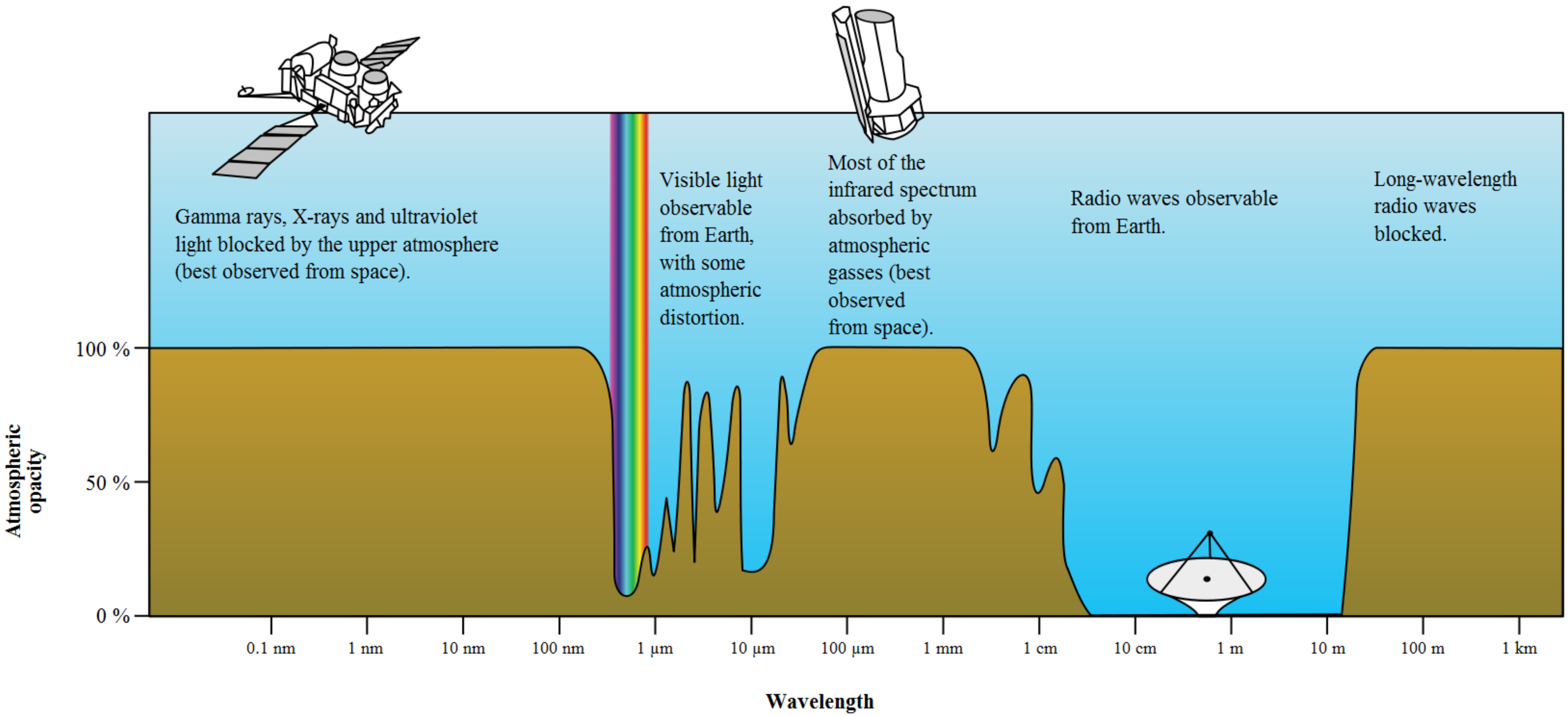


  - radar (micro waves)
  - laser scanners, lidar (1.0-1.5 μm usually)

Sensor overview (passive & active)



Atmospheric windows

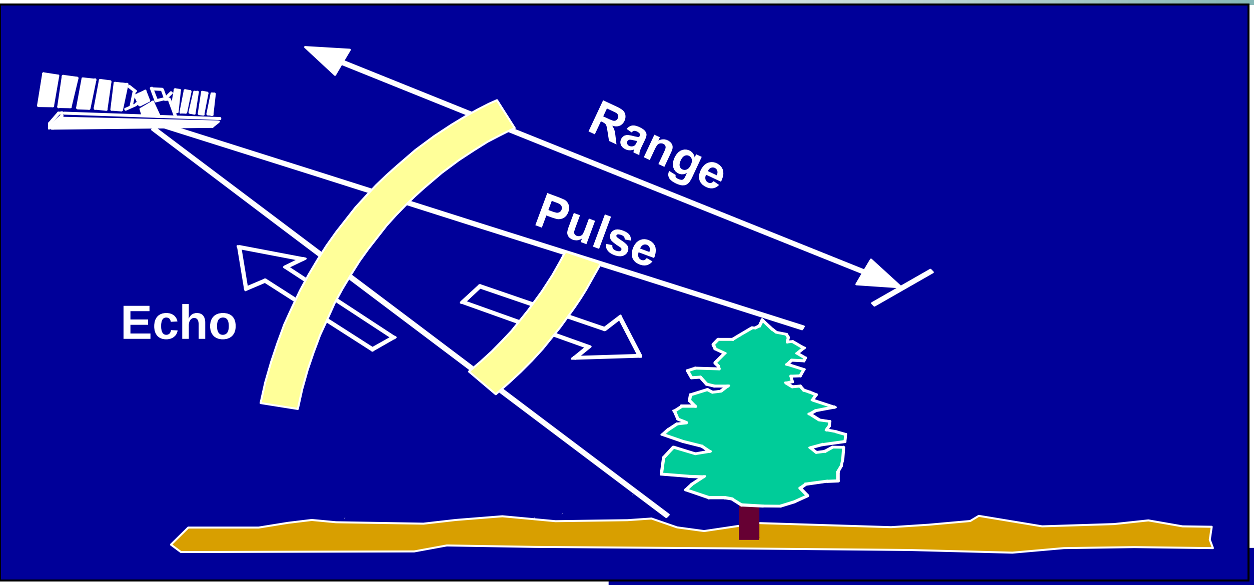


Active sensors: Laser scanner (Lidar)

(Light detection and ranging)

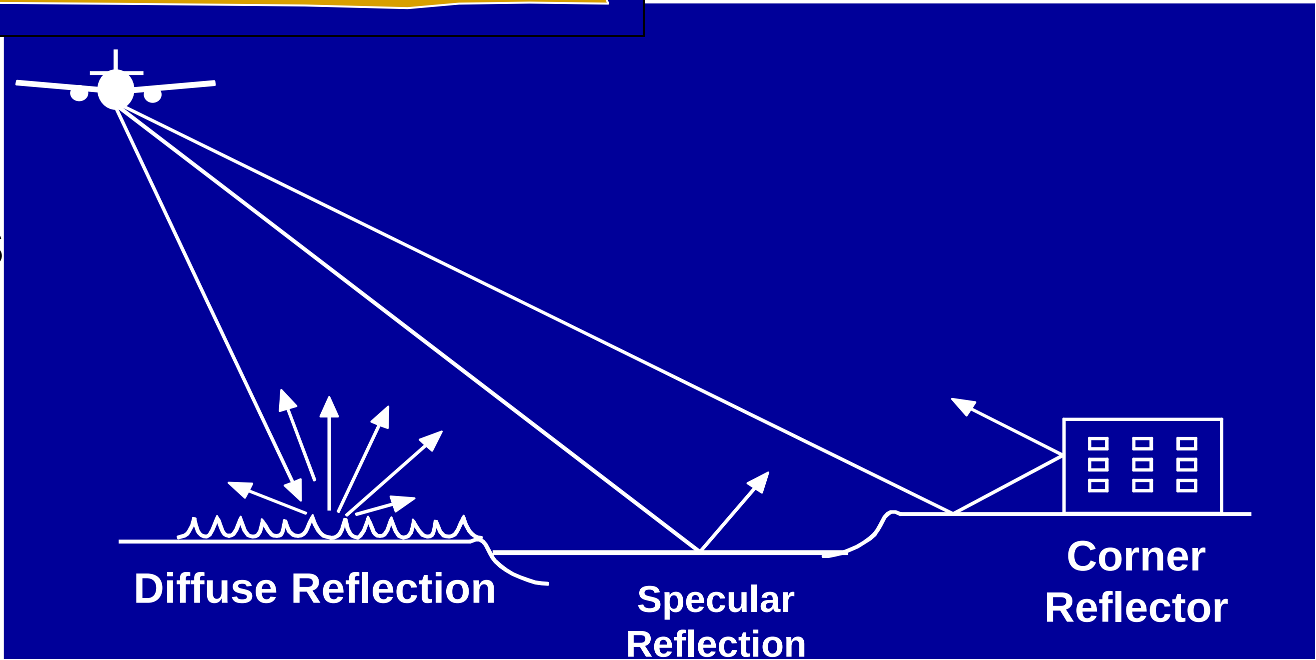
- Laser beam measures distance from point to aircraft (used to calculate terrain elevation)

RADAR - Radio Detection And Ranging

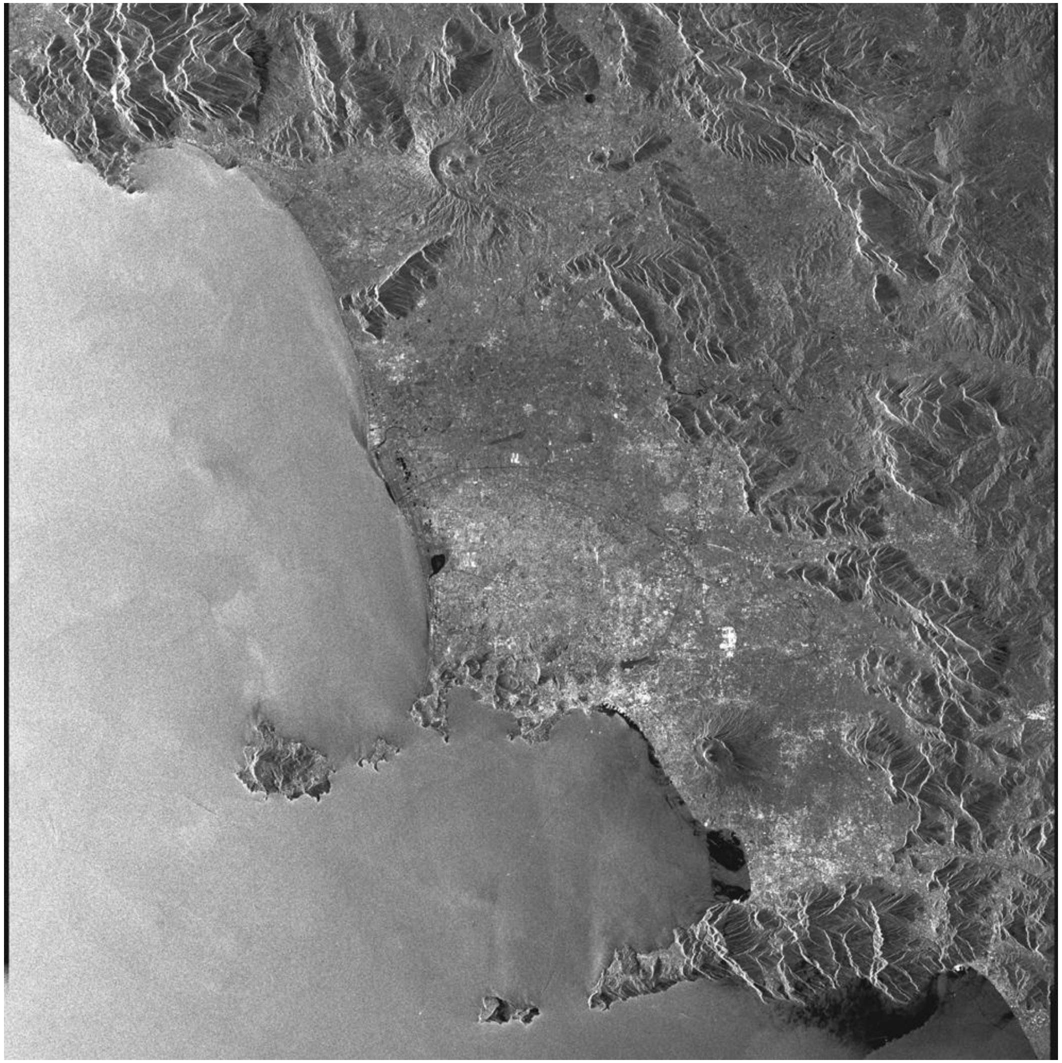


- 1-100 cm
- All weather
- Day & night

Backscatter:
- Surface roughness
- Moisture content
- underground



Active sensors: Imaging radar



ENVISAT ASAR 13-Nov-2002

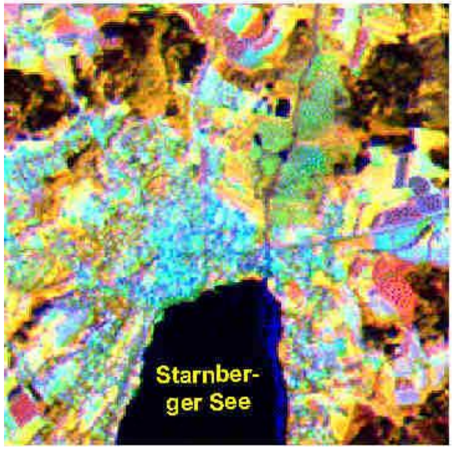
Passive sensors

- Aerial camera
  - Airplanes, kites, balloons
- Video camera
- Gamma ray spectrometer
- Multispectral scanner
- Thermal scanner
- Imaging spectrometer

Multispectral scanners vs Thermal scanners

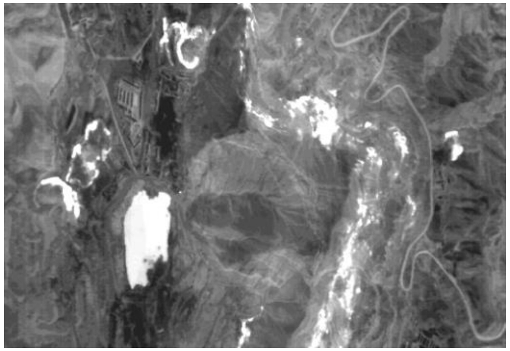
MSS

- Scans reflected sunlight in the optical domain (0.4-2.5 µm)
- Multiple bands (30-100 nm wide)
- Works in atmospheric windows
- Land cover, biomass, soil properties



Thermal scanners

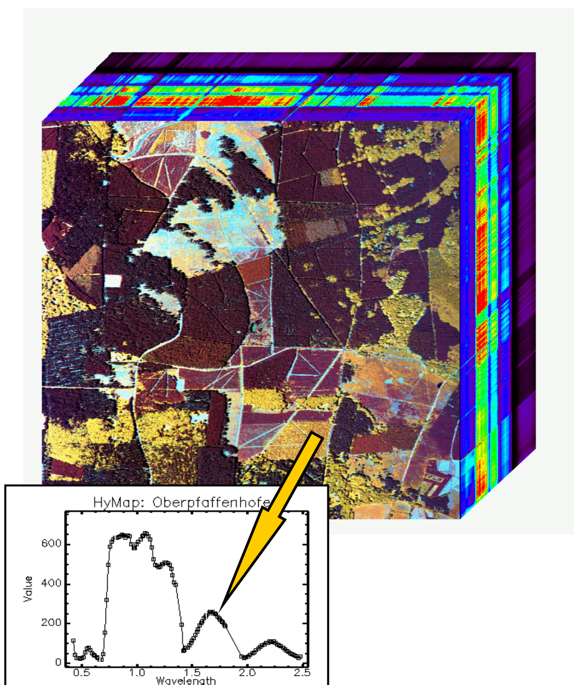
- Measures thermal emission (8-14 µm)
- Evapotranspiration, forest fires, coal fires



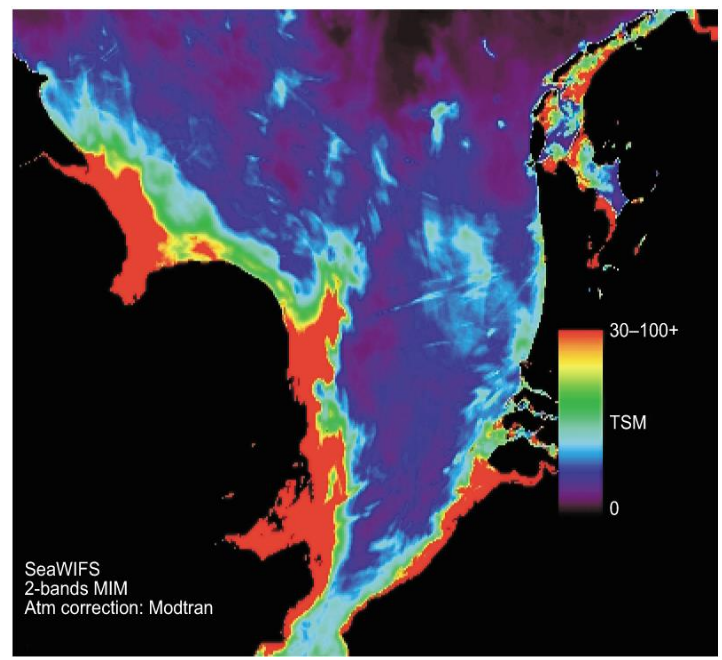
Nighttime thermal image of coal mining area affected by underground coal fires

Imaging spectrometer (hyperspectral imager)

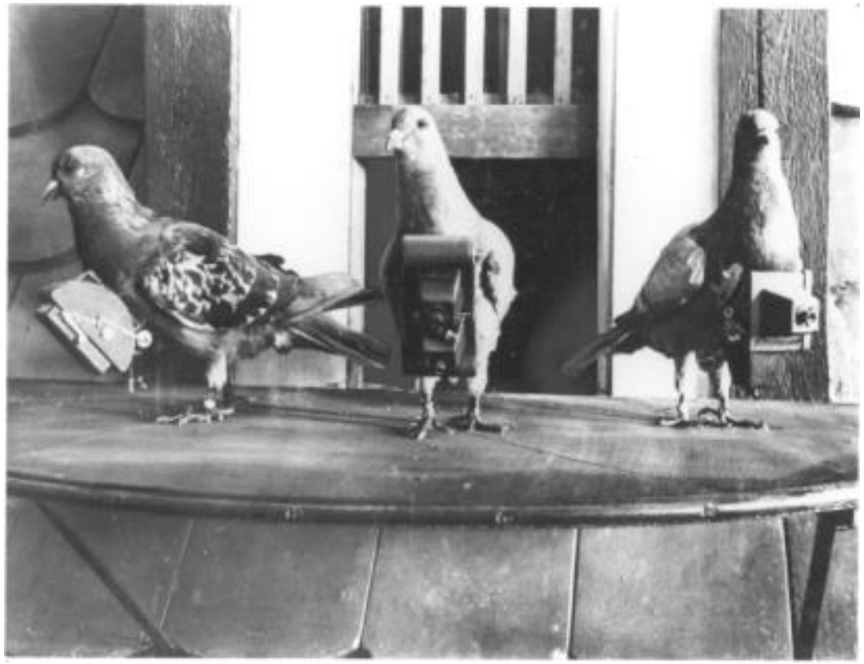
- Similar to multispectral scanner - measures many (very narrow) spectral bands (5-10 nm wide)
- Continuous reflection curves
- Application: vegetation studies (LAI, chlorophyll content), geology (mineral composition), etc.



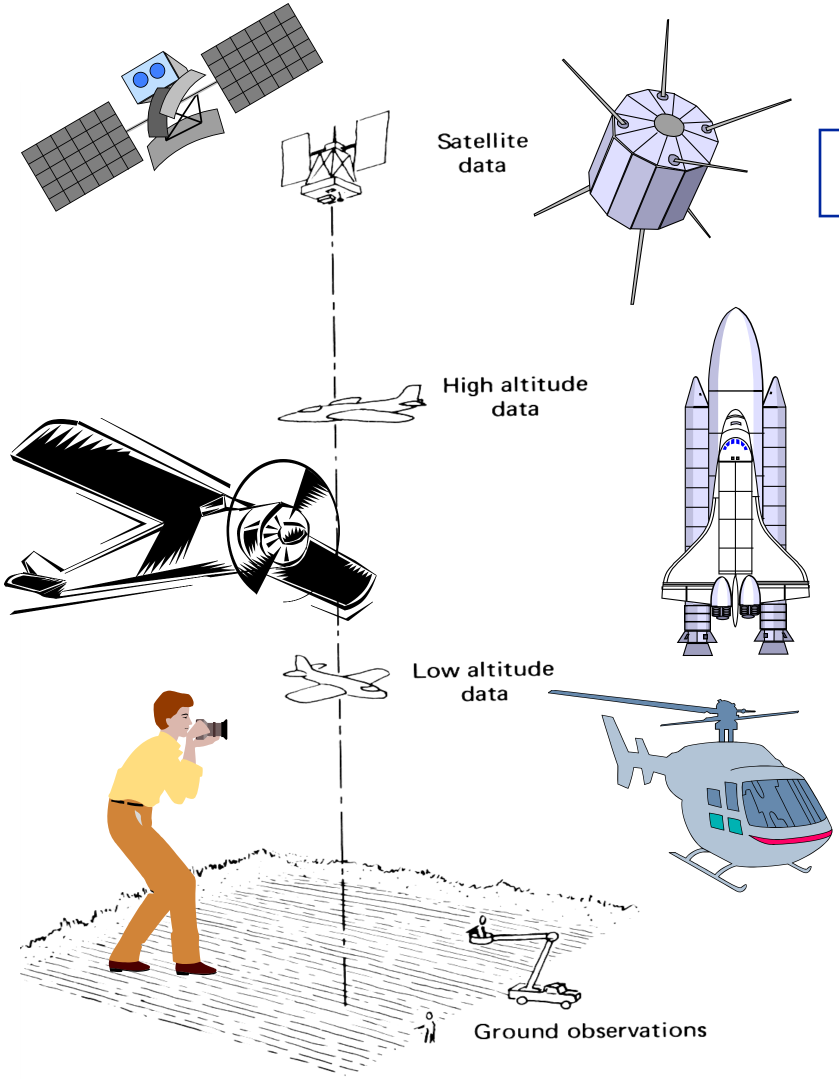
Total Suspended Matter Concentration



Platforms



Platforms



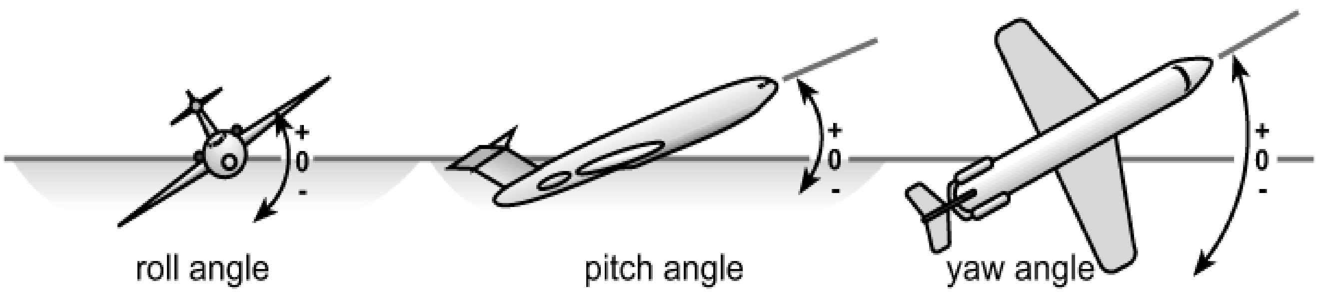
Sensing from 1m to 36,000 km height

Platforms may be:

- Ground based
- Airborne
- Spaceborne

Platforms

- Ground-based (hand-held and mast/tower)
- Airborne
  - 100 meter up to 30-40 km
  - aircraft rotations cause image distortions
  - corrected through GPS and Navigation System

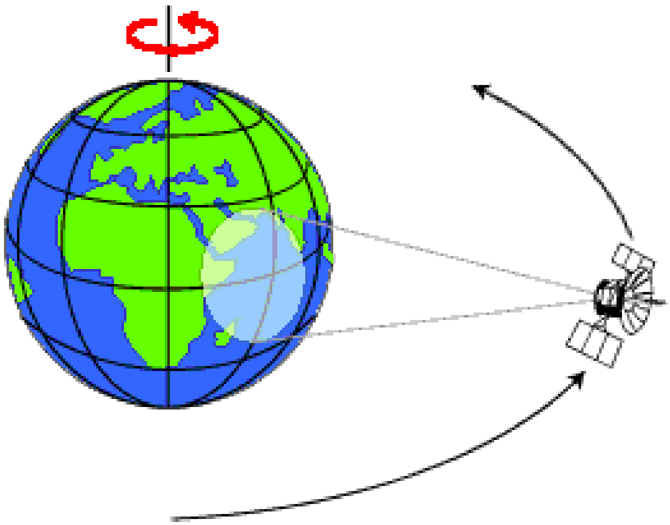


- Spaceborne
  - 150-36000 km altitude

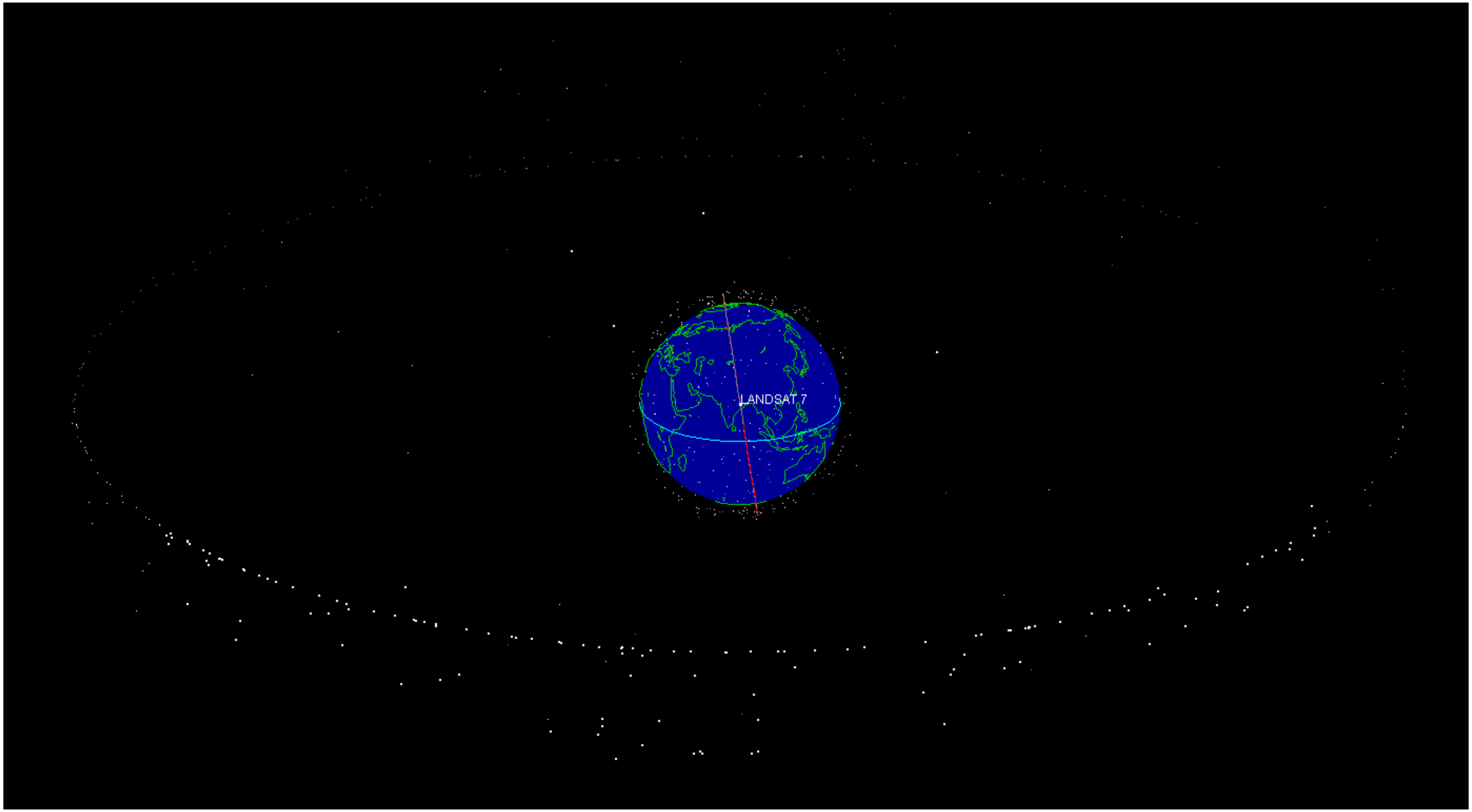
Satellite orbits

Satellite remote sensing

- Sensor are mounted on satellites or space stations
- What the sensor can see is largely determined by the satellite orbit
- Orbit: circular path described by the satellite when moving around the Earth



Satellites in space



http://science.nasa.gov/Realtime/jtrack/3d/JTrack3D.html → tracking > 900 satellites

Orbit characteristics

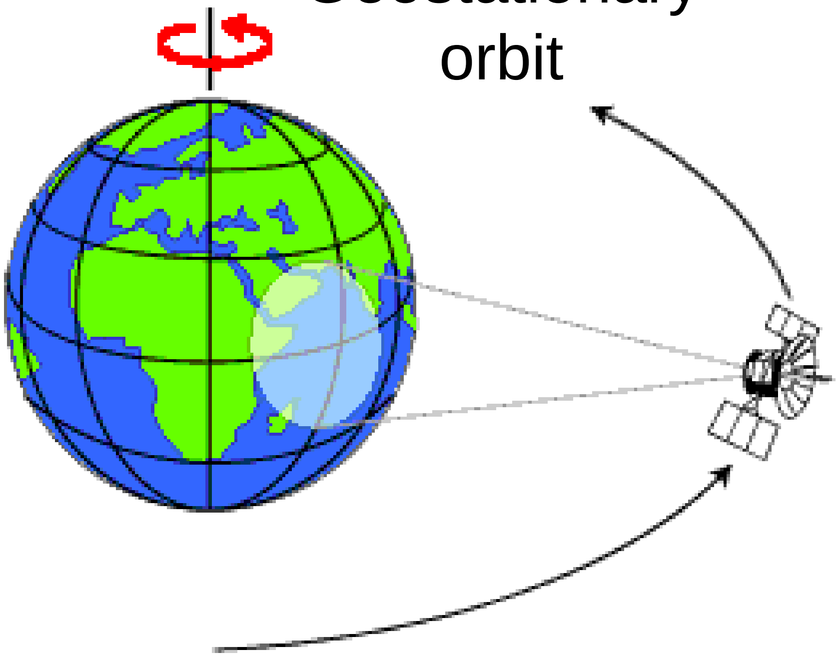
- Orbital altitude
  - Distance (in km) from the satellite to the Earth's surface
  - Determines coverage and observed details
- Orbital inclination angle
  - Angle between orbital plane and equatorial plane
  - Determines the latitudes up to which the Earth can be observed
- Orbital period
  - Time (in minutes) required to complete one full orbit
  - 806 km altitude → period: 101 min, speed: 24000 km/h
- Repeat cycle
  - Time (in days) between two successive identical orbits
  - Determines the revisit time (together with the pointing capability)

Orbital altitude

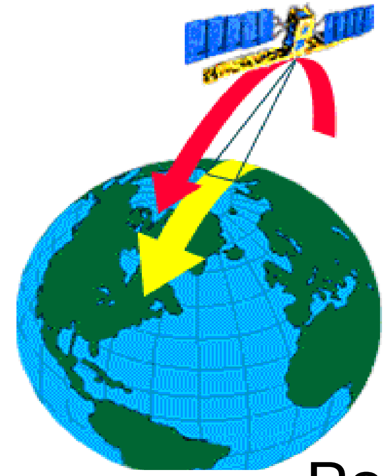
- Low earth orbits (LEO)
  - 150-300 km: spy satellites, space shuttle
- Near earth orbit (NEO)
  - 300-6000 km above atmosphere for earth observation
- Geo stationary (GEO)
  - 36000 km above the equator
  - view 45% of the earth
  - over one fixed point

Orbit types

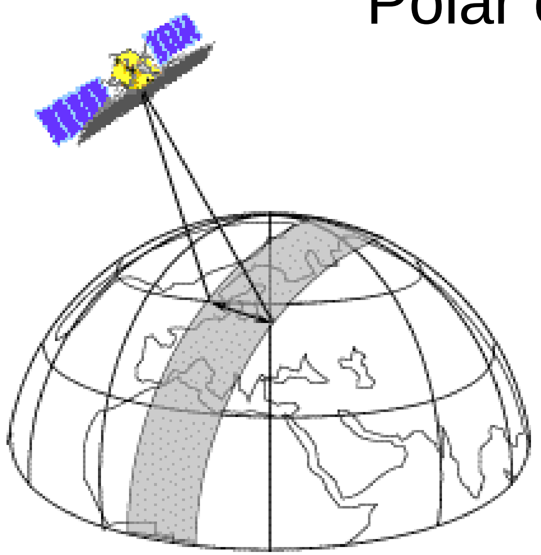
Geostationary orbit



Orbital period satellite = rotational period of Earth



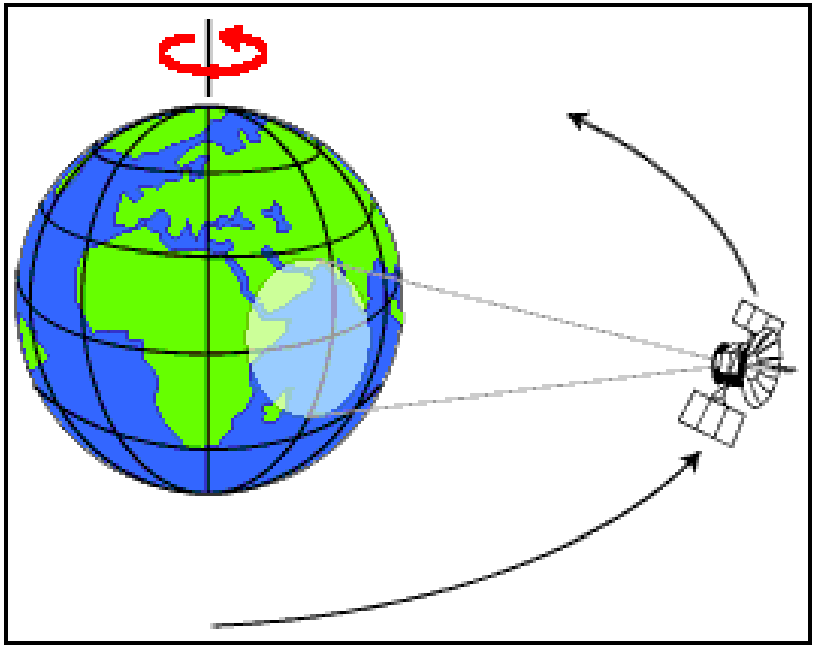
Polar orbit



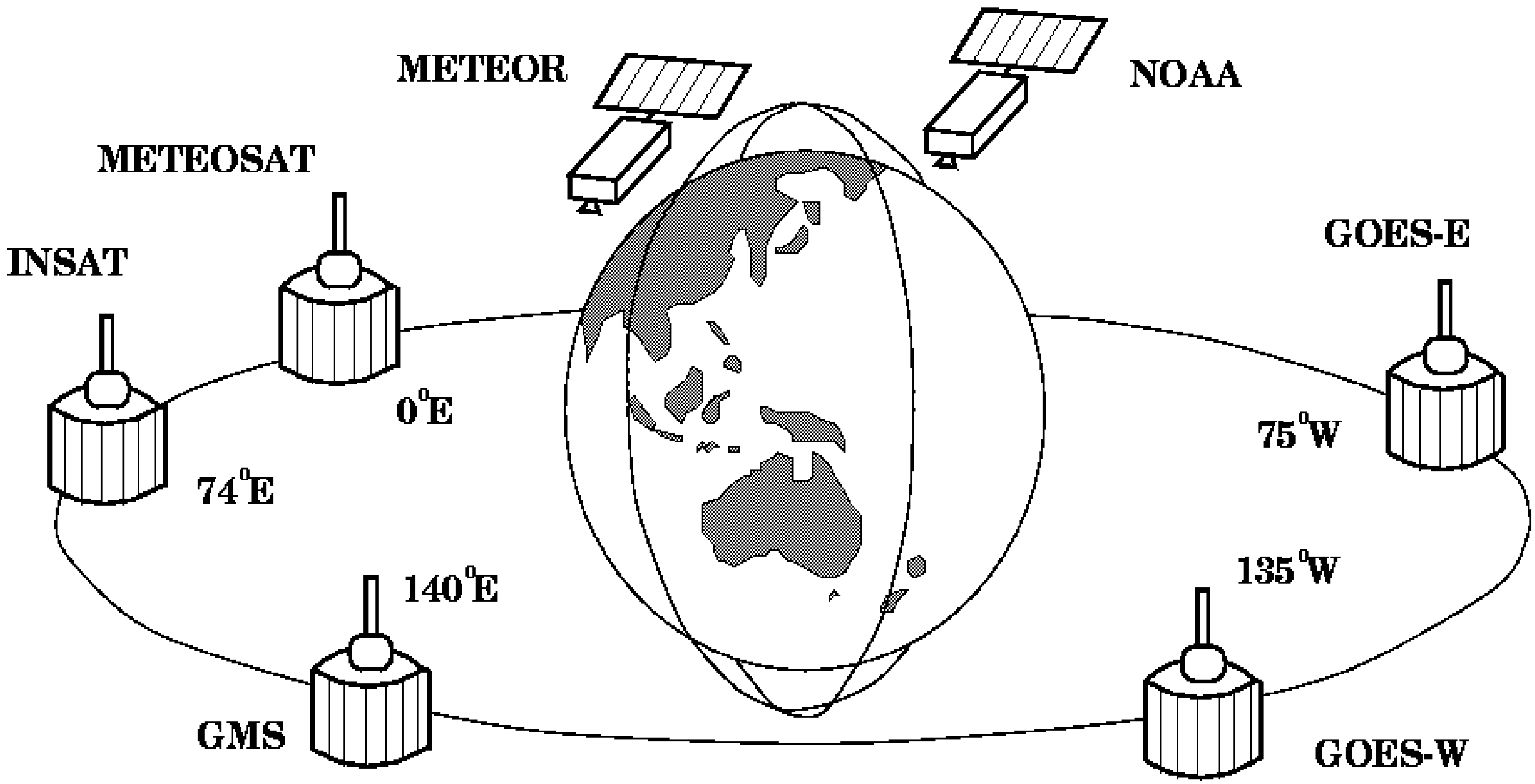
Sun-synchronous orbit

Geo stationary orbits

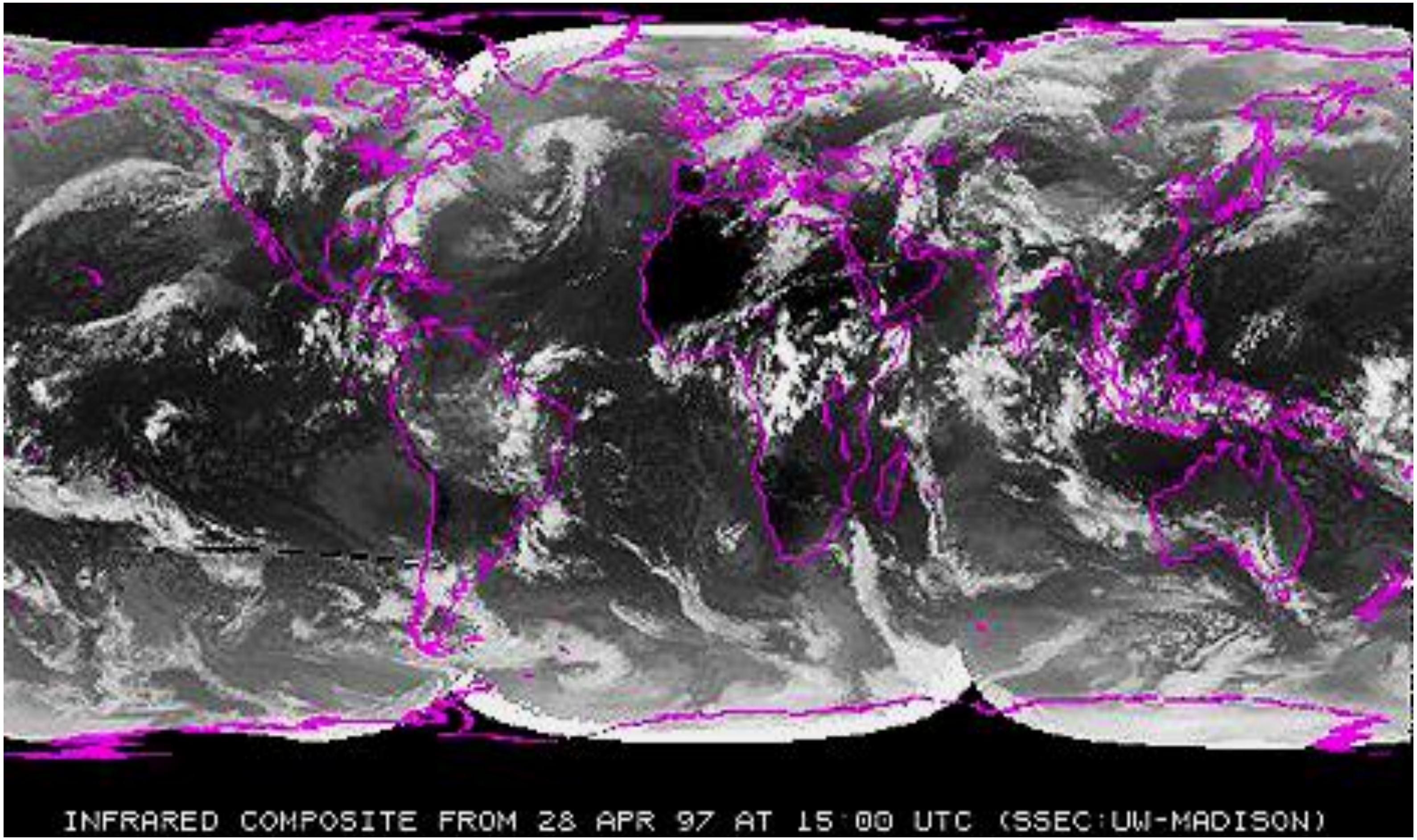
- Meterology, Telecommunication
- Always above the same location (fixed position relative to Earth)
- Requires: Orbital period = rotational period = 1 day
- Requires: Altitude of 36000 km
- Consequences:
  - 45 percent of Earth is seen
  - Limited spatial resolution (~ 5km)
  - Distorted view of polar regions



Orbits: GEO and LEO

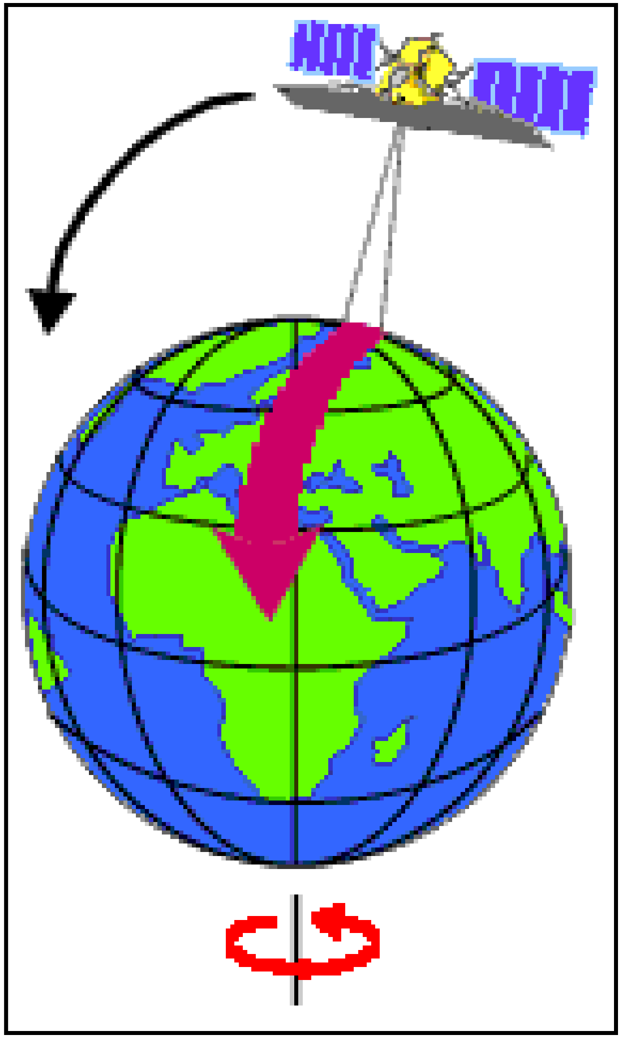


Geostationary satellites - combination

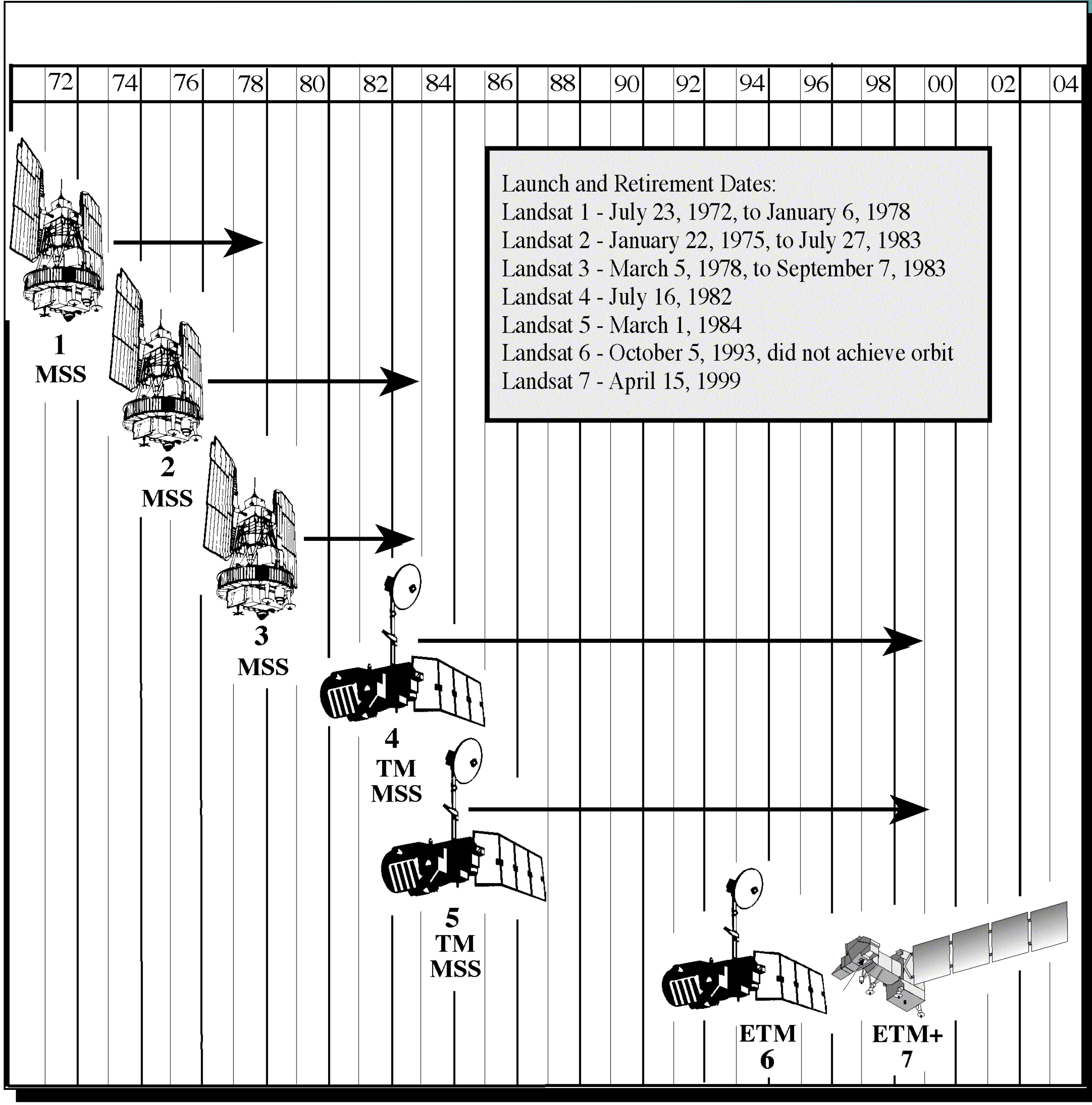


(Near polar) sun synchronous orbit

- Most important orbit for land surface studies
- Inclination angle 98°-99° (near polar)
- Maps all areas of Earth except polar regions
- passes at same local solar time, e.g. equator mid-morning at 10:30 (sun synchronous)
- 14 orbits per day
- ascending (night) and descending (day) passes

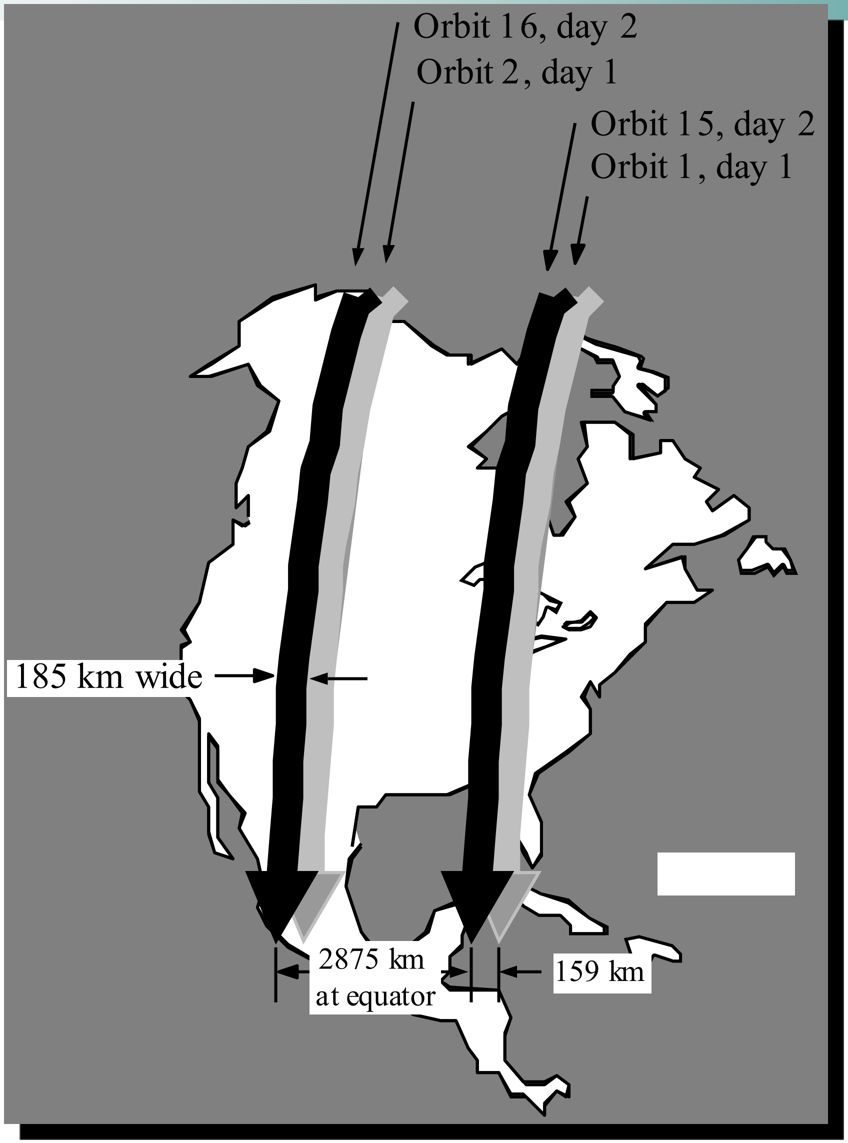


Chronological Launch and Retirement History of the Landsat Satellite Series



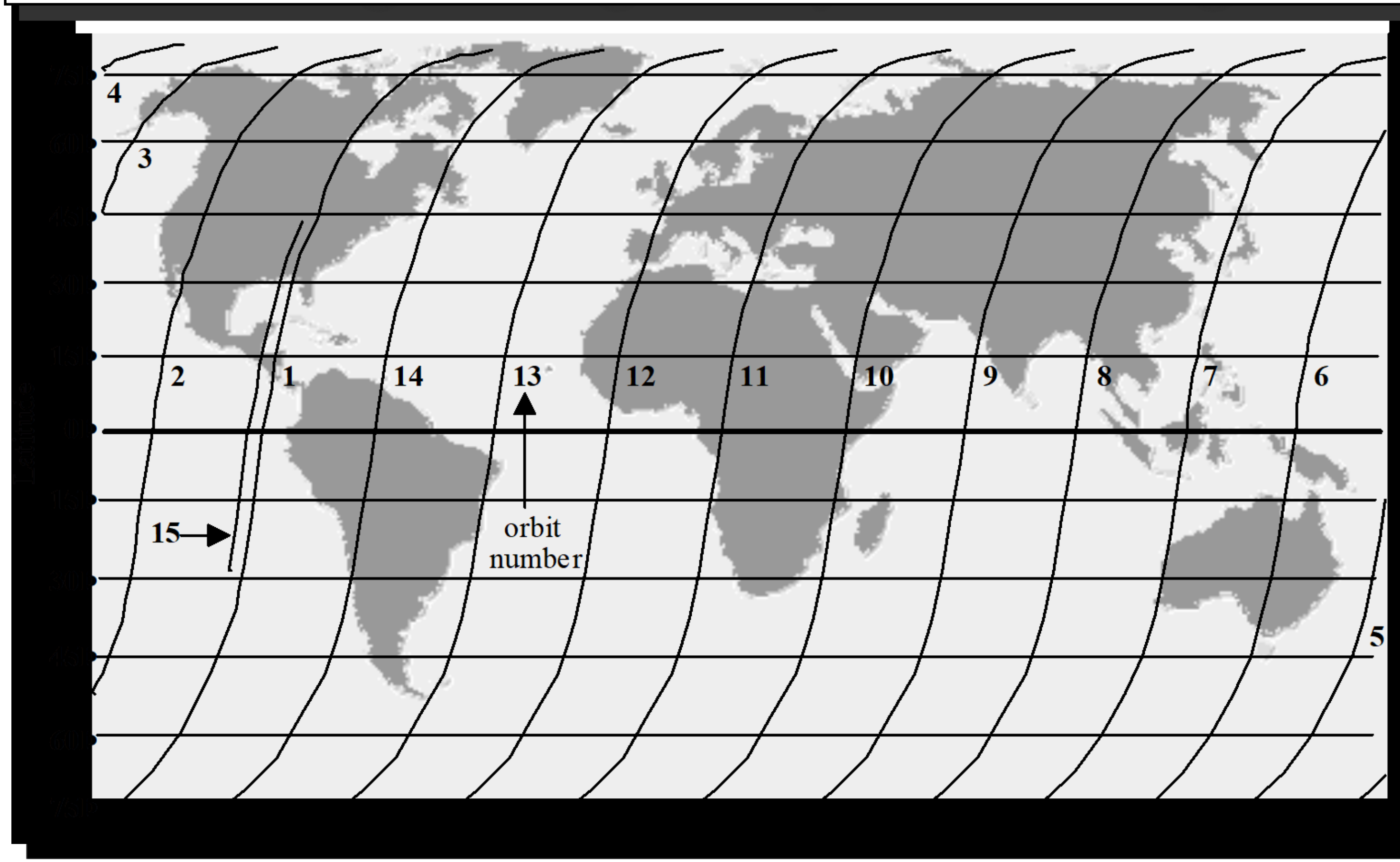
Jensen, 2000

Landsat Multispectral Scanning System (MSS) Orbit



Jensen, 2000

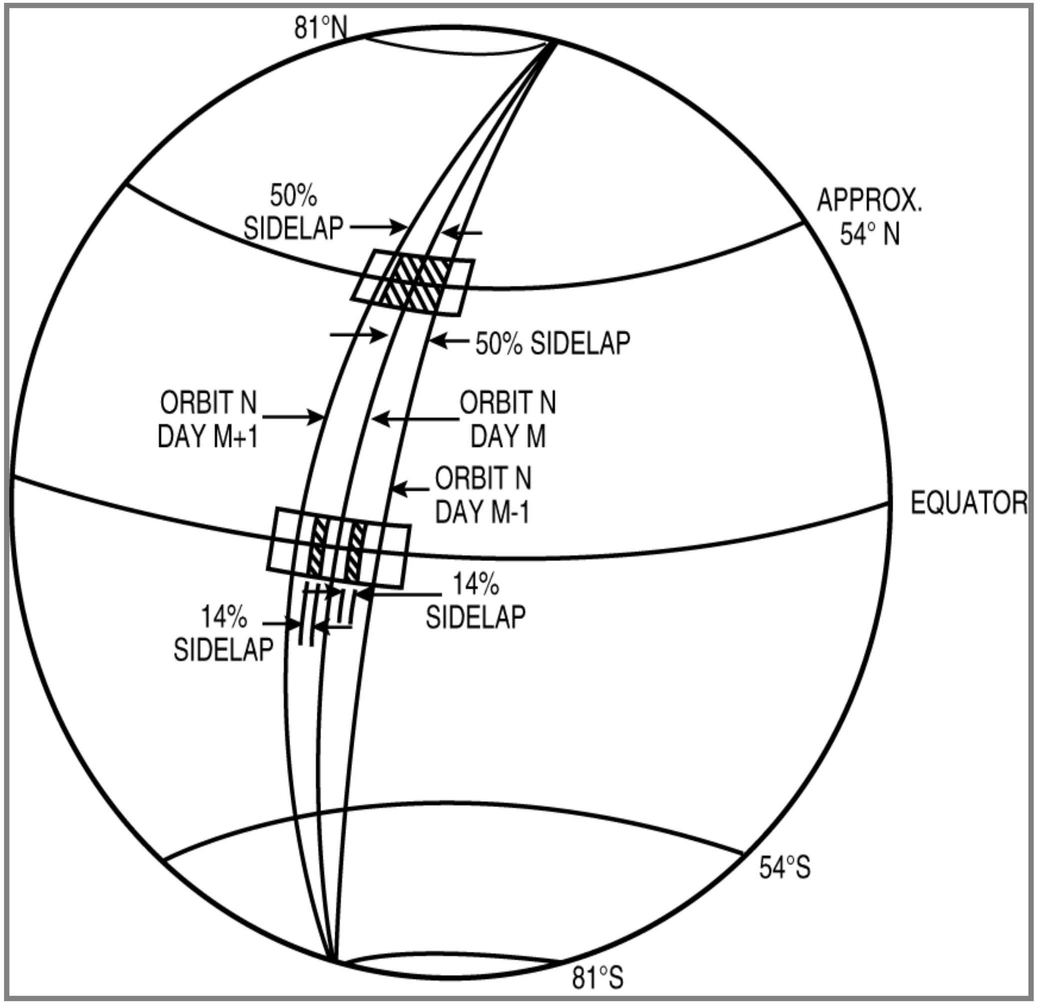
Orbit Tracks of Landsat 1, 2, or 3 During A Single Day of Coverage



Day 1: orbit 1-14, Day 2: orbit 15-28

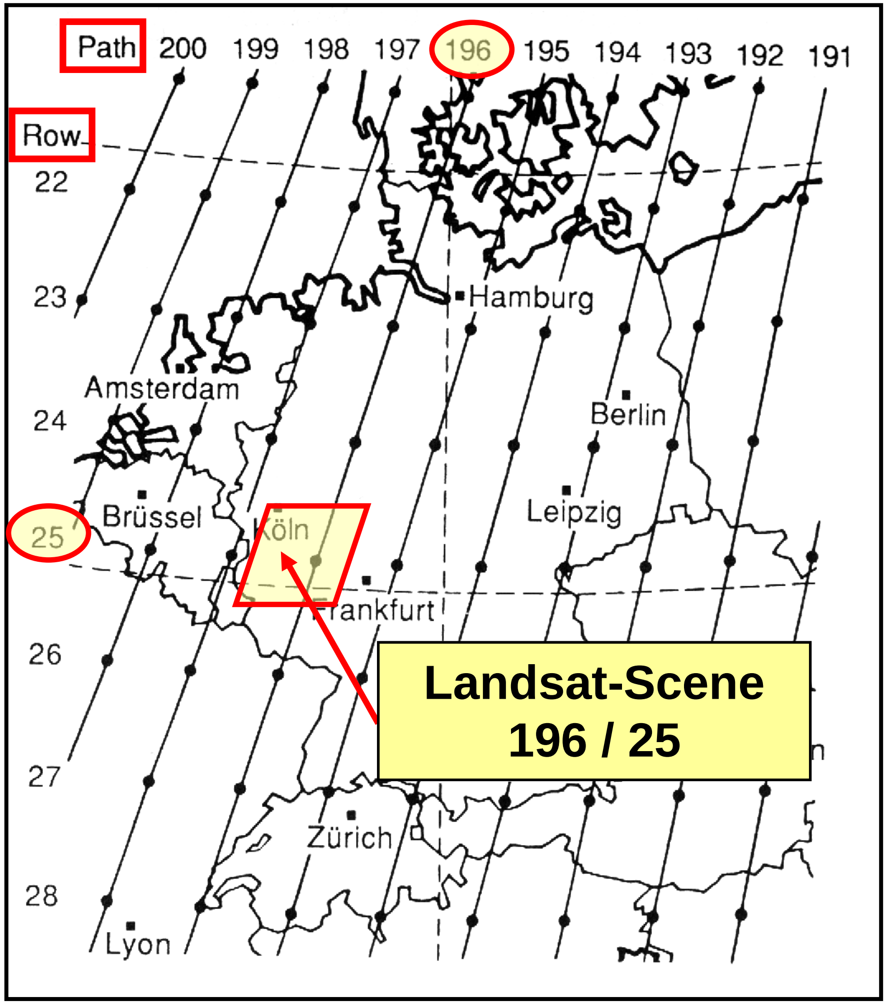
Landsat 5 / 7 passes over the same area as day 1 on day <u>16</u>

Side-overlap



Side-overlap of neighbouring orbits depends on latitude

Worldwide Reference System (WRS) Landsat 4 / 5 / 7



- Each Landsat image scene can be identified through an index
- Each path corresponds to an orbit
- In direction of the orbit the data stream is continous but is cut every 185 km into rows
- The resulting Landsat images are data matrices of 185 x 185 km²

Multispectral scanners

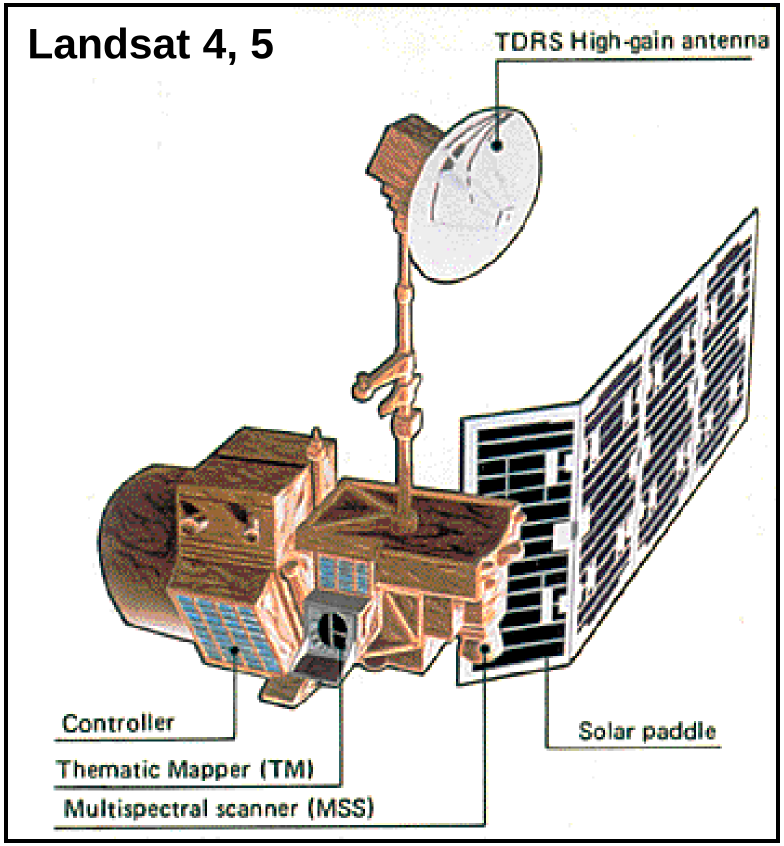
Multi-spectral scanner (MSS)

- Measure EM energy by scanning the Earth’ surface
- Most commonly used sensor type after the aerial camera
- Two types of MSS
  - Whiskbroom scanner
  - Pushbroom scanner

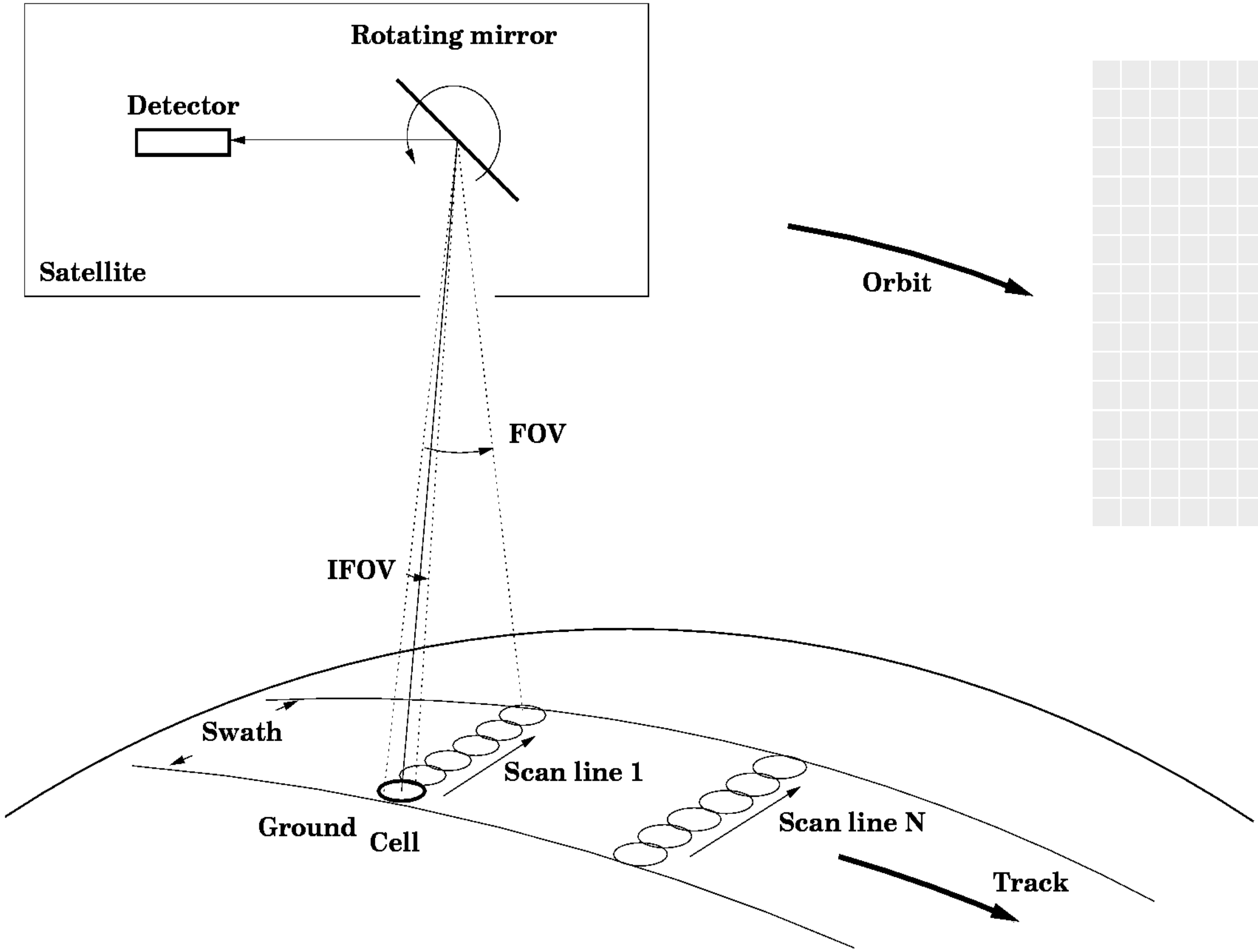
Whiskbroom Scanner

Examples

- NOAA/AVHRR
- Landsat5/TM



Principle of Whiskbroom Scanner



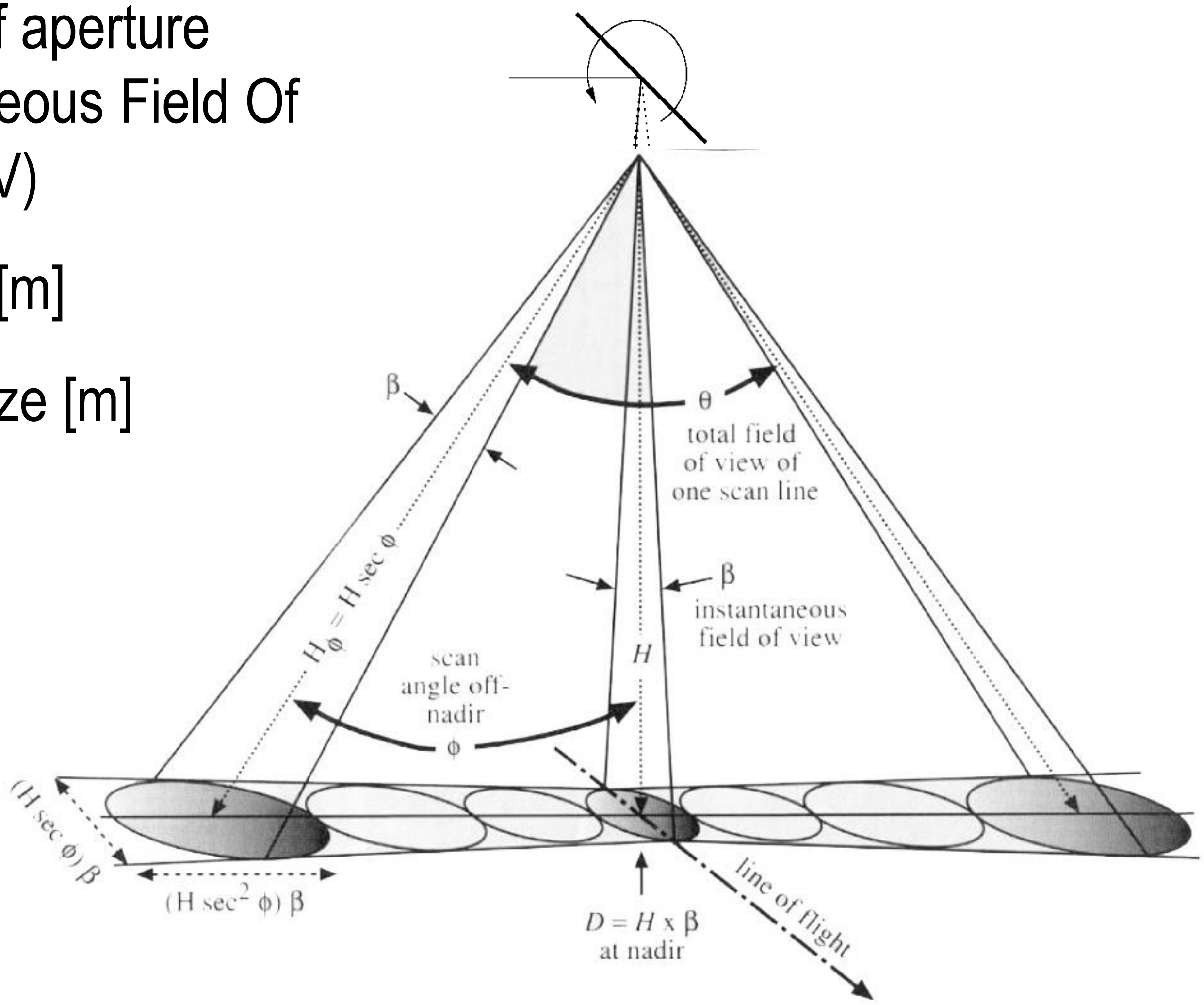
Geometric characteristics

β: angle of aperture (Instantaneous Field Of View, IFOV)

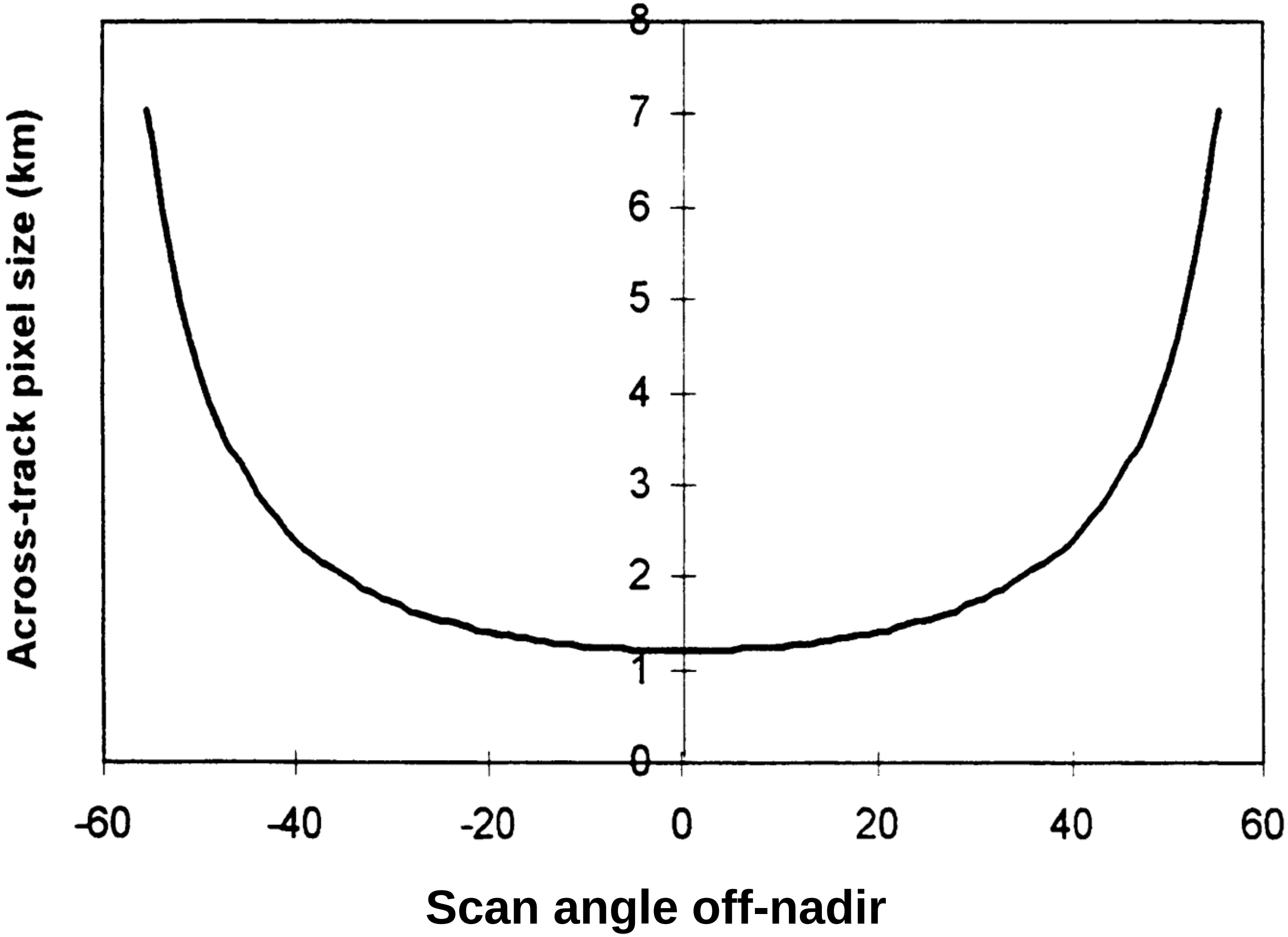
H: Height [m]

D: Pixel size [m]

D = β * H

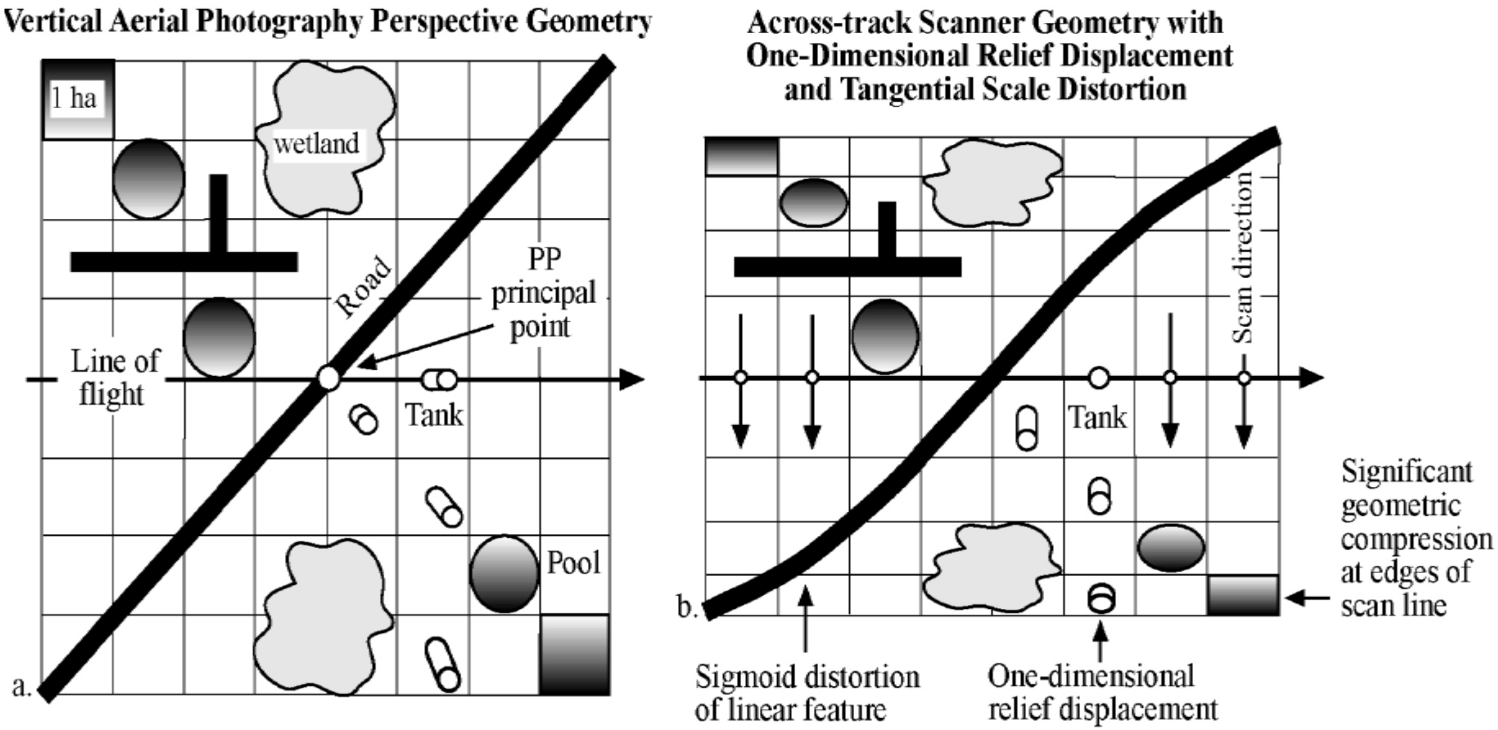


Whiskbroom: across-track pixel size



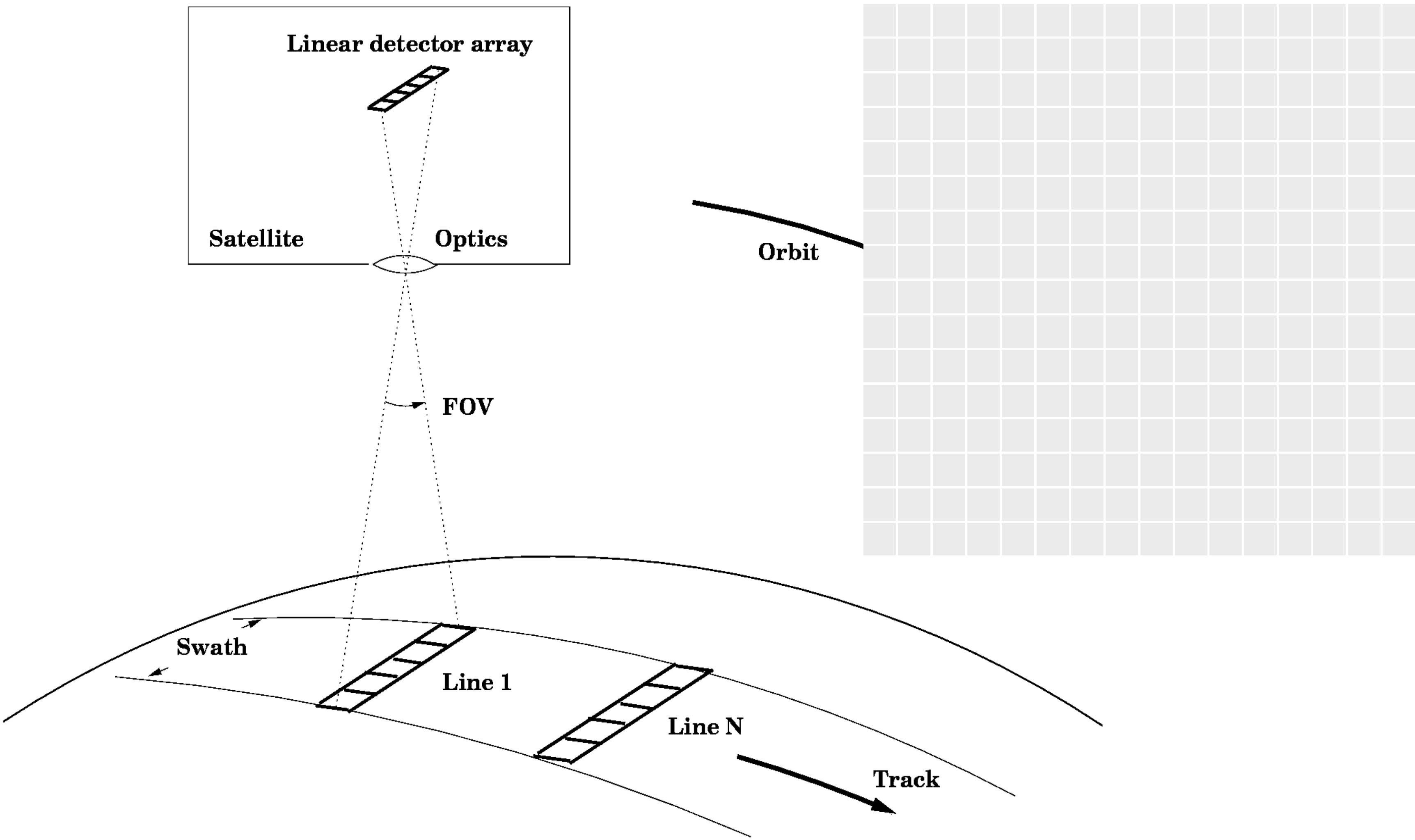
Degradation of resolution across one scan-line of the AVHRR sensor of the NOAA satellite.

Tangential scale distortion



- straight lines occur curved
- away from nadir larger areas imaged in the same time
- can be corrected for

Pushbroom scanners



Pushbroom scanners

- Along track scanners
- Linear array of detectors
- Numerous charge coupled devices (ccd)
- Each detector for one ground cell
- Each spectral band has one array

Pushbroom scanners

Advantages

- Longer residence time per ground cell resulting in a stronger signal
- Better spatial and radiometric resolution
- Higher geometric integrity
- Light equipment / no moving parts

Pushbroom scanners

Disadvantages

- Calibration of many detectors (3000 +)
- Limited sensitivity beyond near-infrared

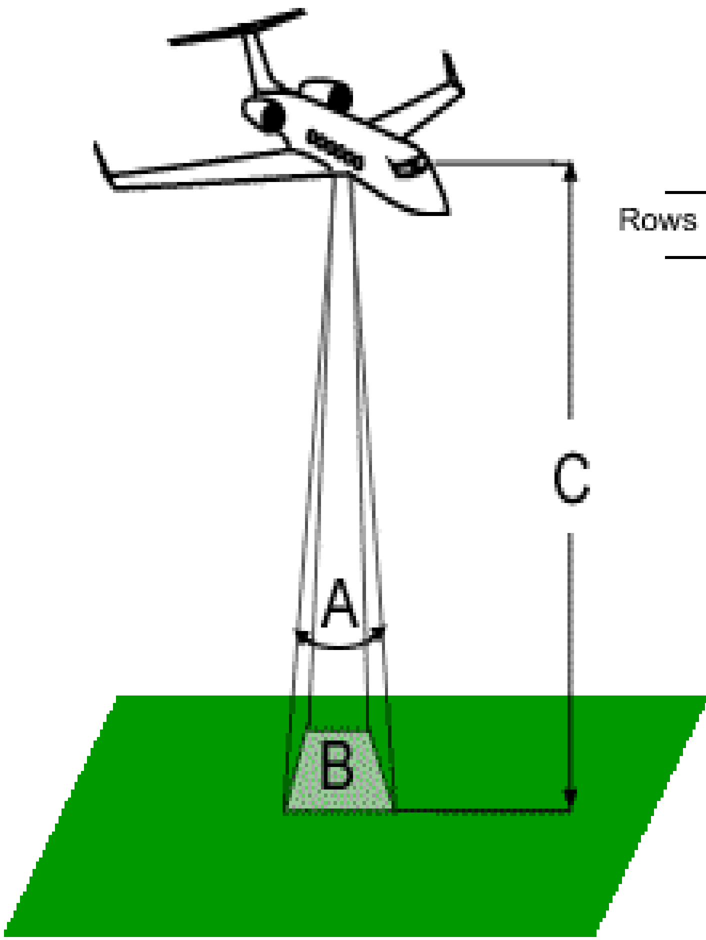
Terms and concepts

- Image characteristics:
  - Spectral bands
  - Radiometric resolution
  - Spatial resolution
  - Temporal resolution
- Off nadir viewing, pointing capability
- Swath width
- Revisit time
- General characteristics of low, medium and high resolution satellites

Image characteristics
Types of resolution

- Spectral
  - Band width
- Radiometric
  - Smallest observable difference in energy
- Spatial
  - Size of picture element
- Spatio-temporal
  - revisit time over the same area

Image characteristics:
Spatial resolution



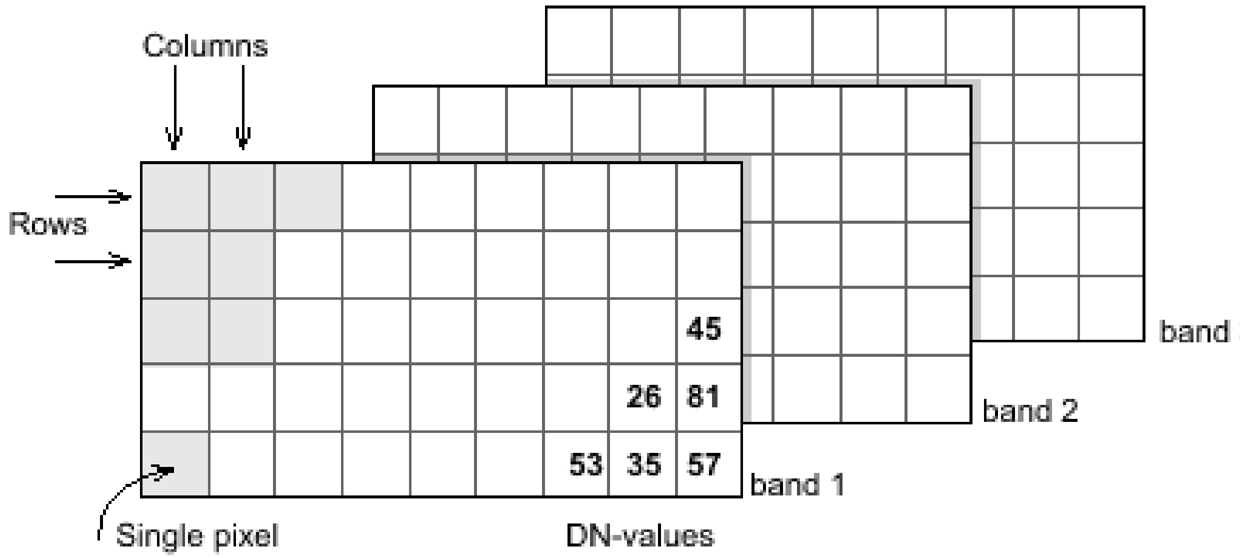
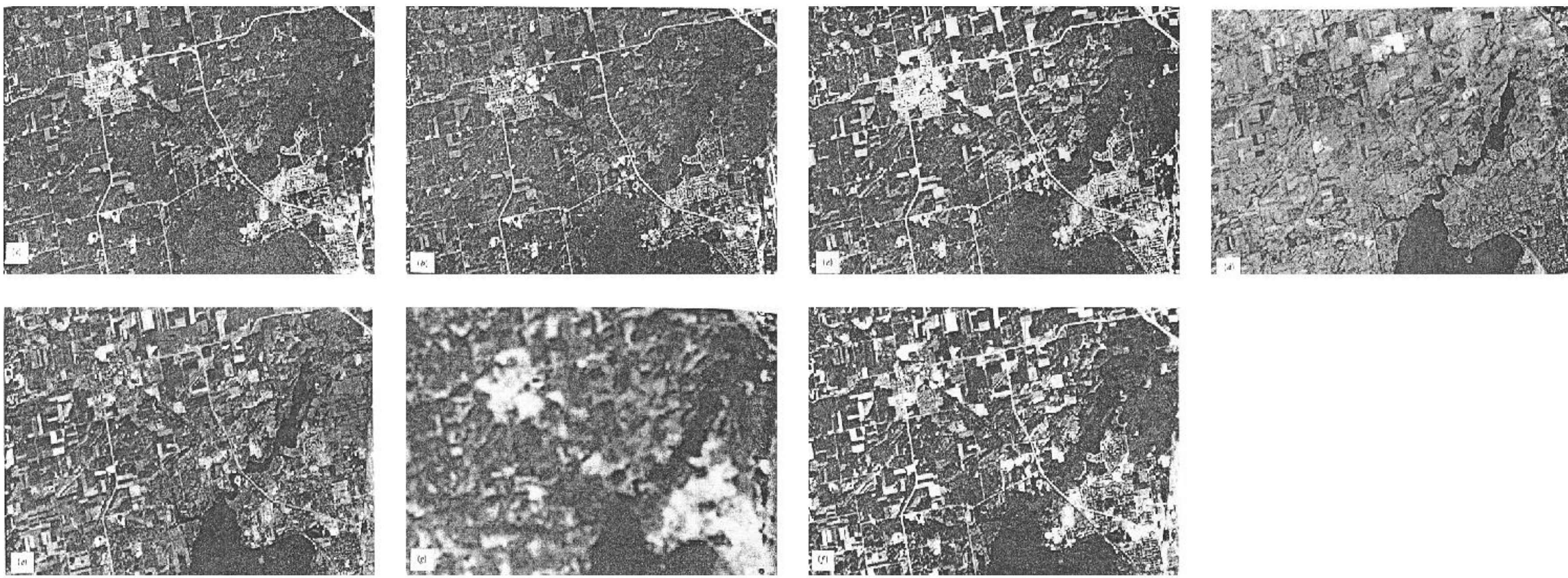


Image characteristics:
Spectral resolution

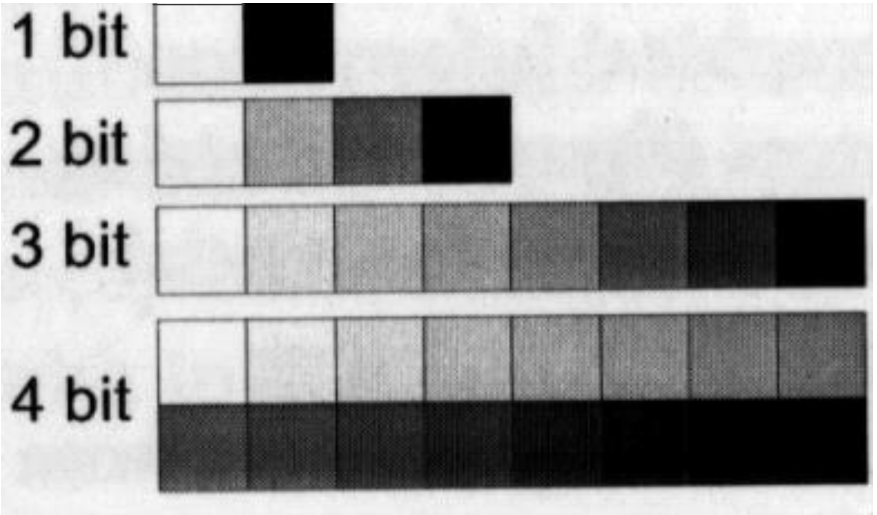
Example: Landsat TM



Number of bands, band width and wavelengths

Image characteristics:
Radiometric resolution

Number of bits = number of grey levels



bits	GL's	range (b-w)
1	2	0-1
2	4	0-3
3	8	0-7
4	16	0-15
5	32	0-31
6	64	0-63
7	128	0-127
8	256	0-255
9	512	0-511
10	1024	0-1203

Image characteristics
Temporal resolution (repetition orbit!)

- period
  - time required to complete one orbit
  - 800 km is about 90 minutes
- repeat cycle
  - time between two subsequent images of the same area

Spaceborne Multispectral Systems
Spatial resolution

- Low resolution satellites: > 100 m
- Medium-resolution satellites: 10-100 m
- high-resolution satellites: <10m

Examples of multi-spectral scanners

Examples of low resolution satellites

Meteosat, NOAA, Resurs-01, Seastar

- Spatial resolution > 100m
- 3 to 8 spectral bands
- Swath width > 500km
- Daily revisit capability

NOAA-AVHHR (National Oceanic and Atmospheric Administration - Advanced Very High Resolution Radiometer)

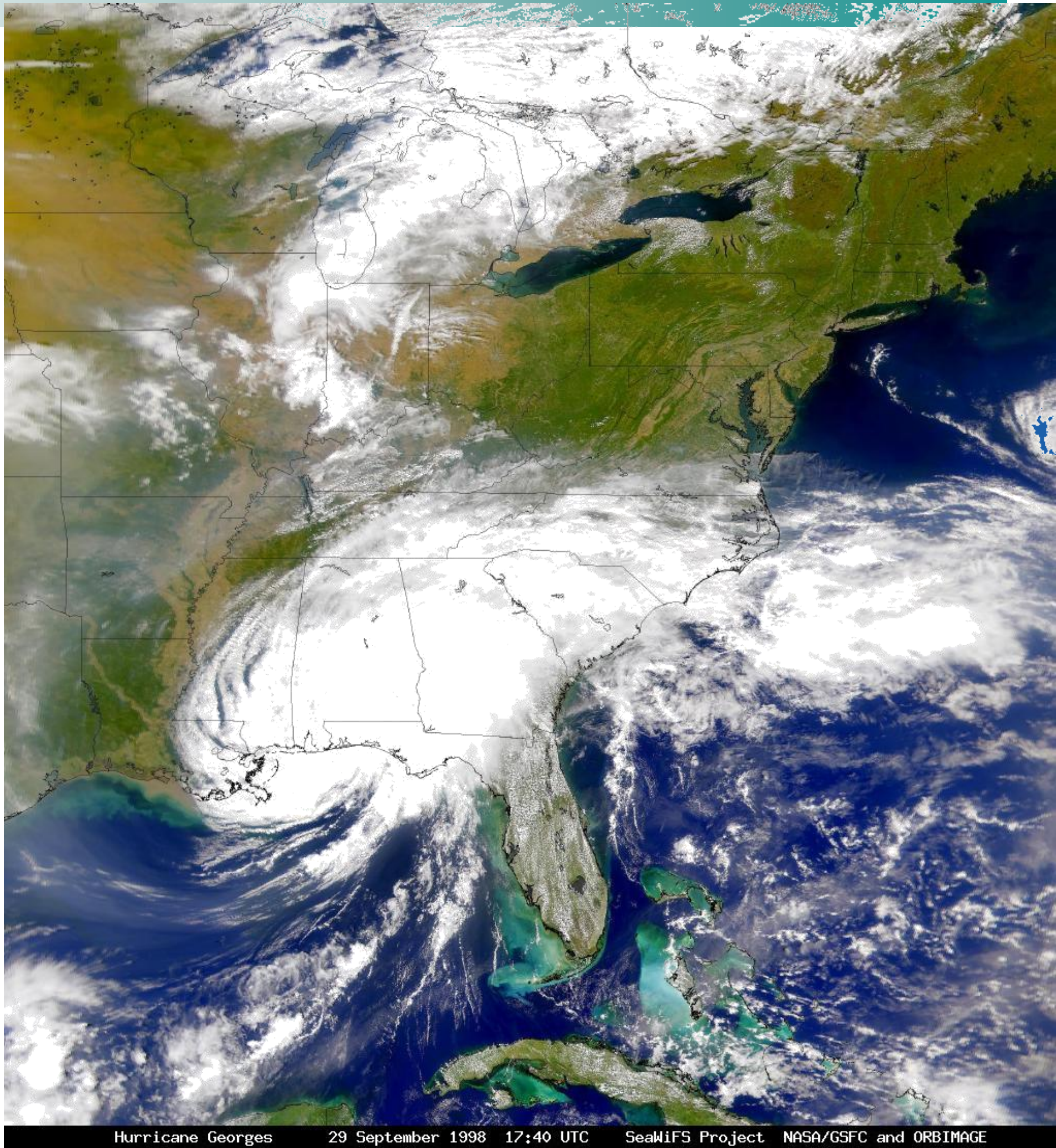
- Weather satellite / whisk broom / Polar orbit
- Band / Wavelengths (μm) / Main Uses

Band	Wavelengths (μm)	Main Uses
1	0.58-0.68	Day clouds; snow; ice
2	0.725-1.10	Surface water; snow; ice
3	3.55-3.93	Fires; clouds at night
4	10.30-11.30	Day/night cloud & surface temperatures and mapping
5	11.50-12.50	Same as 4; water vapour

- Resolution 1100m at nadir / 2400*6900m at max scan angle 55.4°

NOAA - AVHRR images

http://weather.gov/



Examples of medium resolution satellites

- Spatial resolution 10 - 100m
- 3 to 7 spectral bands
- Swath width 50km and 200 km
- 3 days or more revisit capability
- Sun-synchronous orbit
- LANDSAT, SPOT, IRS, ASTER

Landsat 1-3 Multi Spectral Scanner

- whiskbroom system
- swath angle 12 degrees
- swath width 185 kilometer
- 79*79 meter ground resolution
- 6 lines are scanned in one sweep
- 4 arrays (bands) with each 6 detectors
- radiometric resolution in 6 bits (0-64)

http://www.landsat.org

Landsat 4-5 TM sensor

- whiskbroom system
- swath angle 15.4 degrees
- swath width 170 kilometer
- 30* 30 meter resolution
- 16 detectors for non thermal band
- 4 detectors for thermal band
- 8 bits

Landsat TM
Spectral characteristics

Band	Wavelength	Colour	Resolution
1	0.45 - 0.52	Blue-Green	30
2	0.52 - 0.60	Green	30
3	0.63 - 0.69	Red	30
4	0.76 - 0.90	Near IR	30
5	1.55 - 1.75	Mid-IR	30
6	10.40 - 12.50	Thermal IR	120
7	2.08 - 2.35	Mid-IR	30

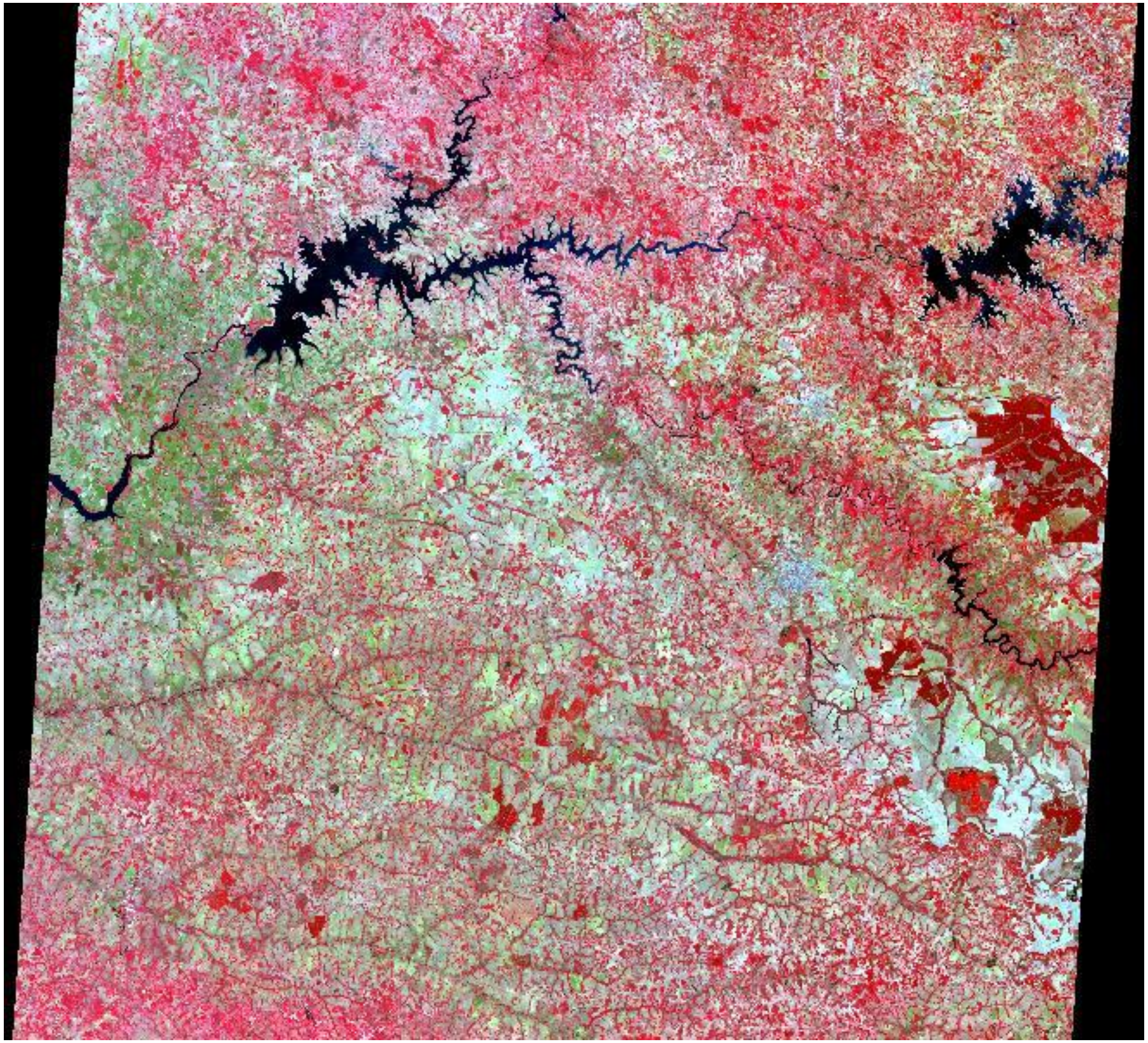
Landsat overview '72 - '99

	Launch	Decommission	Altitude	Revisit	Sensors
1	23 Jul 1972	6 Jan 1978	917 km	18 days	MSS, RBV
2	22 Jan 1975	25 Feb 1982	917 km	18 days	MSS, RBV
3	5 Mar 1978	31 Mar 1983	917 km	18 days	MSS, RBV
4	16 Jul 1982	*	705 km	16 days	MSS, TM
5	1 Mar 1984		705 km	16 days	MSS, TM
6	5 Oct 1993	failed	705 km	16 days	ETM
7	15 Apr 1999		705 km	16 days	ETM+

ETM: Enhanced Thematic Mapper:

Panchromatic Mapper (15m) and TIR (60m)

Landsat TM
False colour Central Brazil (11 Oct 2002)



SPOT

- Launches in 1986, 1990, 1993, 1998 and 2002
- Altitude 822
- Revisit 26 days
- 256 bits radiometric resolution

http://www.spotimage.fr/html/_167_.php

Spot sensor characteristics

- 2 identical high resolution visible (hrv) imaging instruments
- Width 117 km (2*60km)
- Panchromatic mode
  - 10m resolution (6000 pixels per line)
  - 0.51 - 0.73 um
- Xs mode multi-spectral
  - green, red and infrared
  - 20m resolution
- Stereo capability

HRV SPOT


SPOT 4 - 20m - Rotterdam - Netherlands - September 1999
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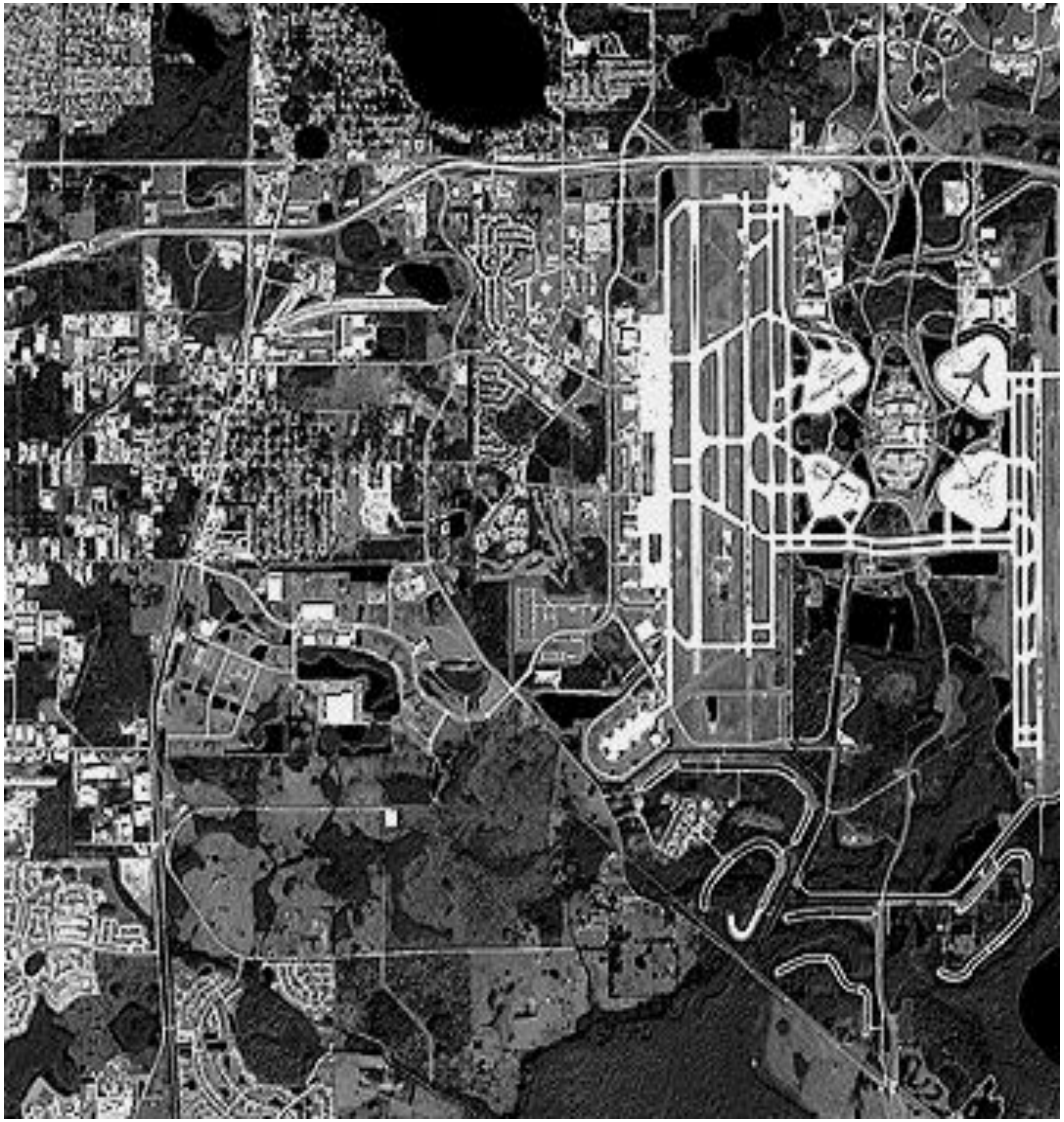
SPOT IMAGE

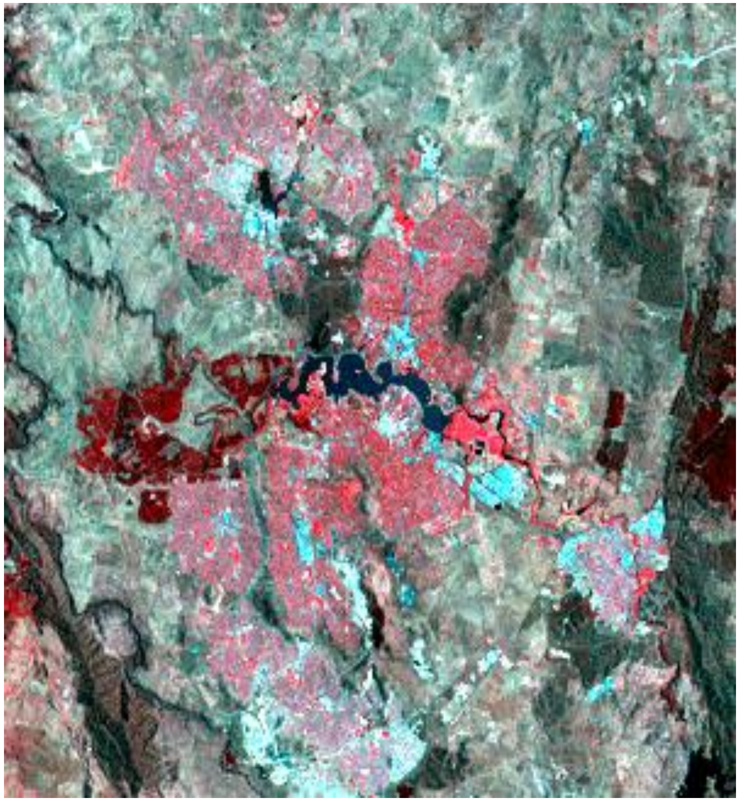
SPOT panchromatic (10m)



SPOT 4

- Addition of mid infra-red band
- Band 2 is also used for panchromatic images
- Vegetation instrument 1 km resolution bands 2,3,4 +b0 (blue)

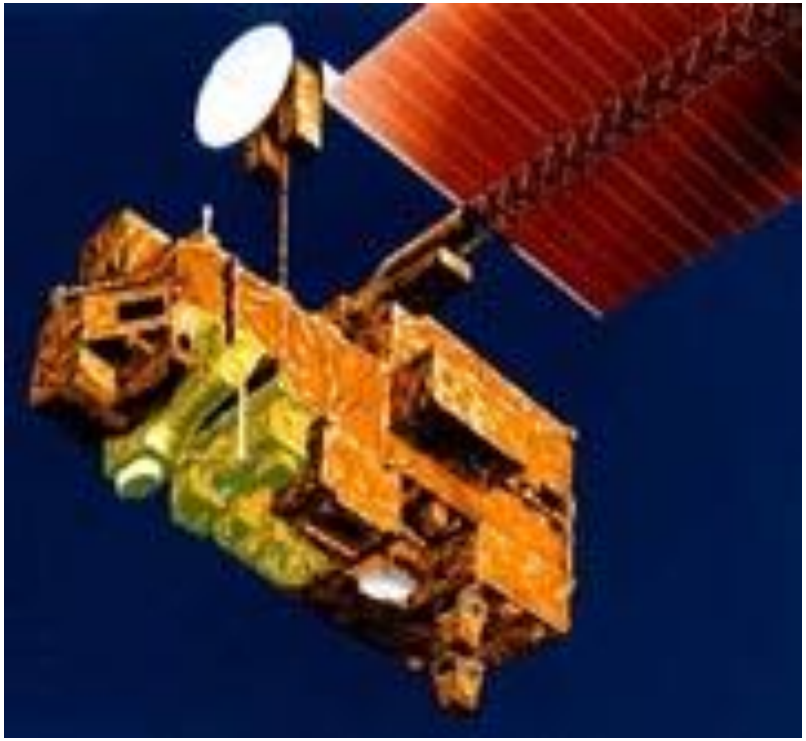
Medium resolution from space:
SPOT & Landsat

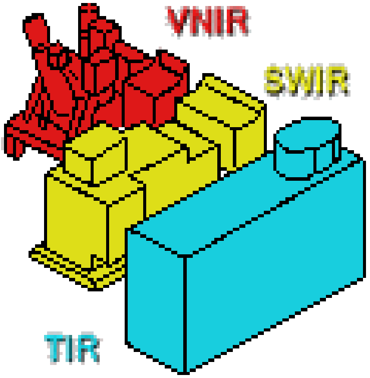


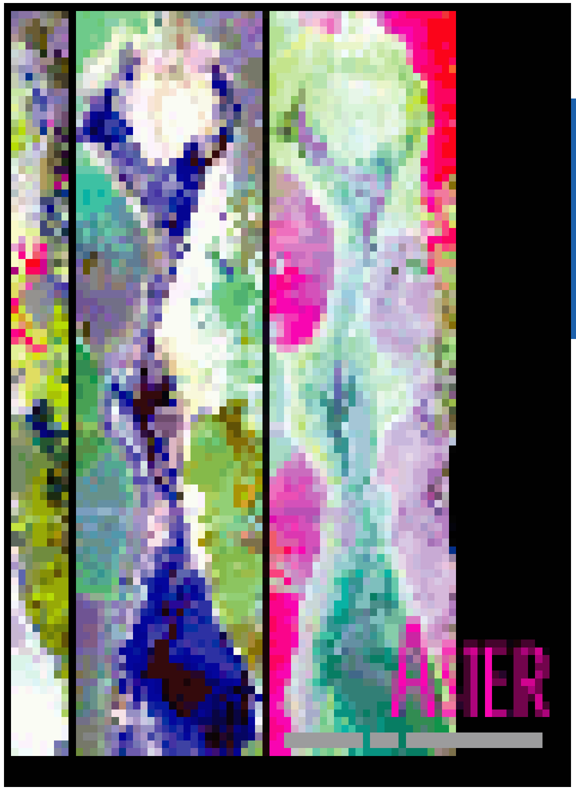
Landsat MSS 80m
Landsat TM 30m
Landast ETM+ 15m

Spot MSS 20m

Aster (Advanced Spaceborne Thermal Emission and Reflection Radiometer)







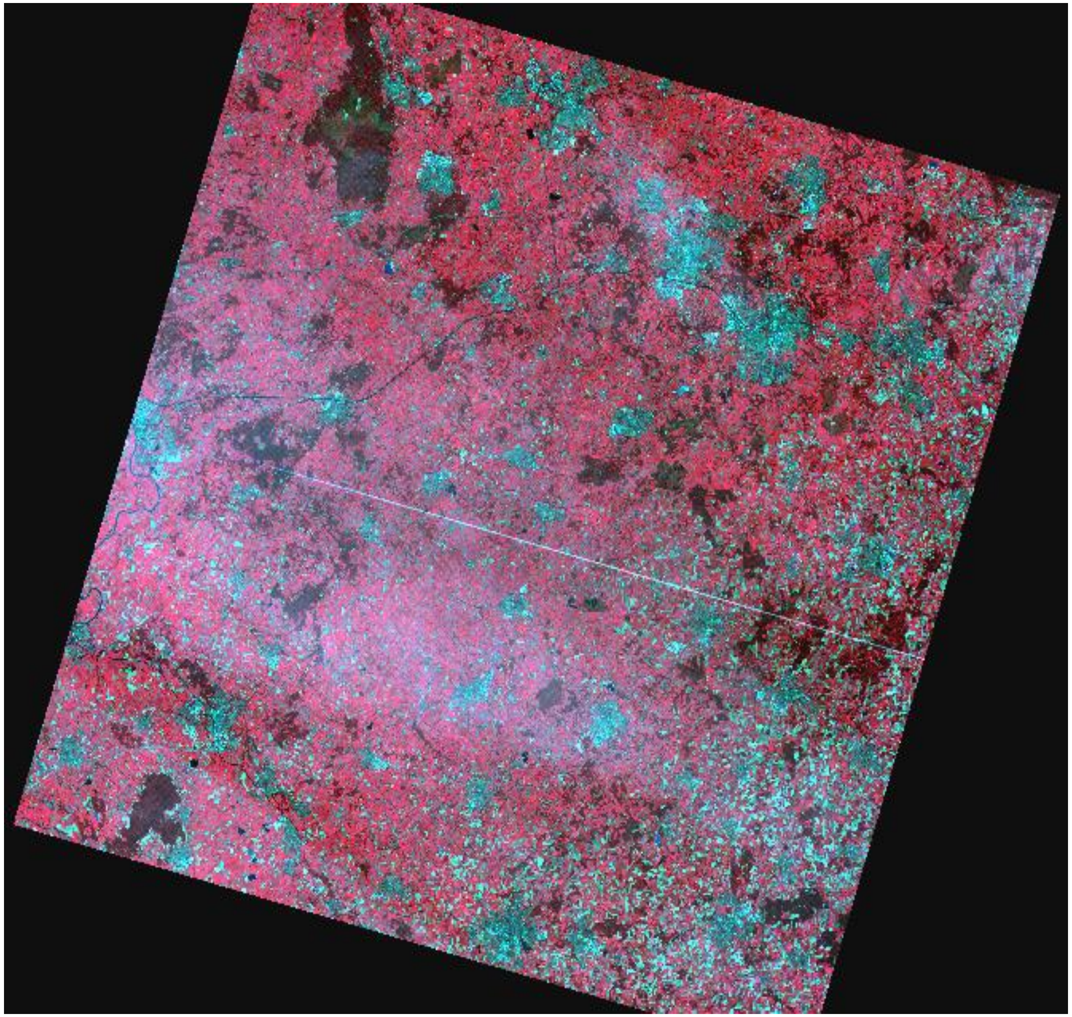
http://asterweb.jpl.nasa.gov/

Aster characteristics

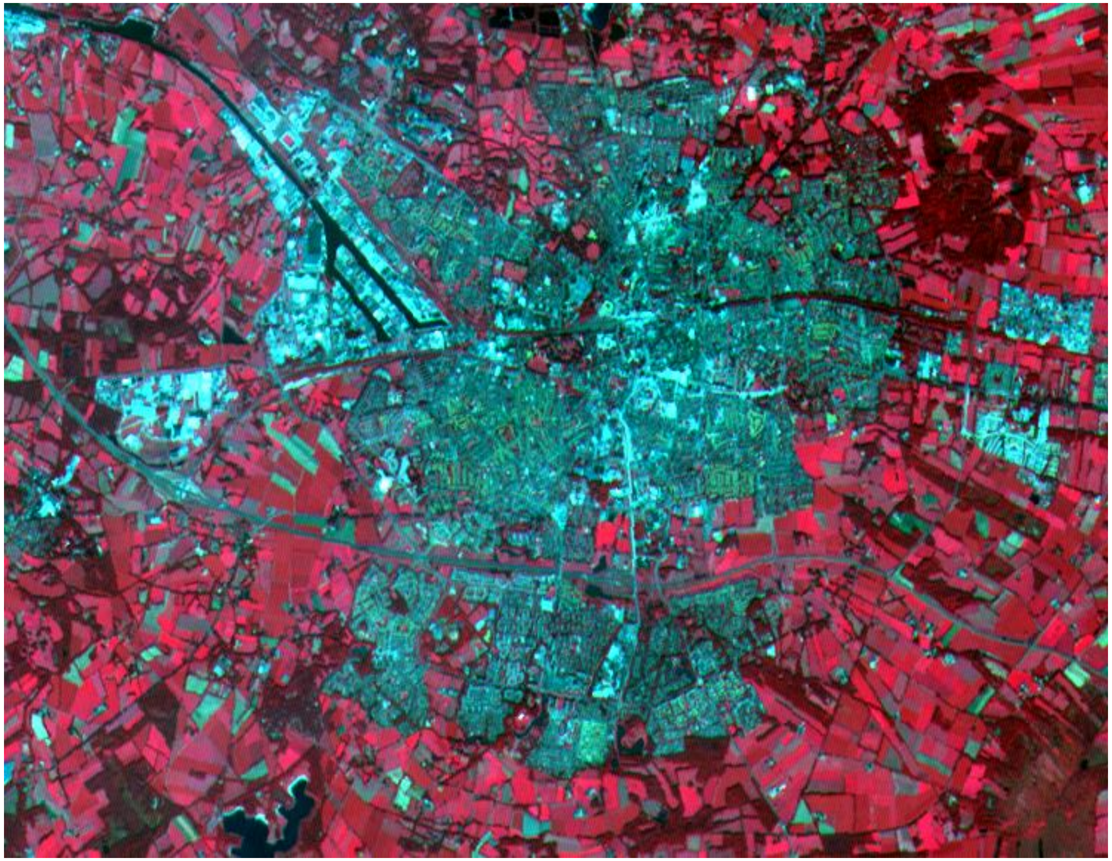
Swath width 60 km

Band	Label	Wavelength	Resolution
B1	VNIR_Band1	0.52 - 0.60	15m
B2	VNIR_Band2	0.63 - 0.69	15m
B3	VNIR_Band3N	0.76 - 0.86	15m - Nadir view
B4	VNIR_Band3B	0.76 - 0.86	15m - Backward scan
B5	SWIR_Band4	1.60 - 1.70	30m
B6	SWIR_Band5	2.145 - 2.185	30m
B7	SWIR_Band6	2.185 - 2.225	30m
B8	SWIR_Band7	2.235 - 2.285	30m
B9	SWIR_Band8	2.295 - 2.365	30m
B10	SWIR_Band9	2.36 - 2.43	30m
B11	TIR_Band10	8.125 - 8.475	90m
B12	TIR_Band11	8.475 - 8.825	90m
B13	TIR_Band12	8.925 - 9.275	90m
B14	TIR_Band13	10.25 - 10.95	90m
B15	TIR_Band14	10.95 - 11.65	90m

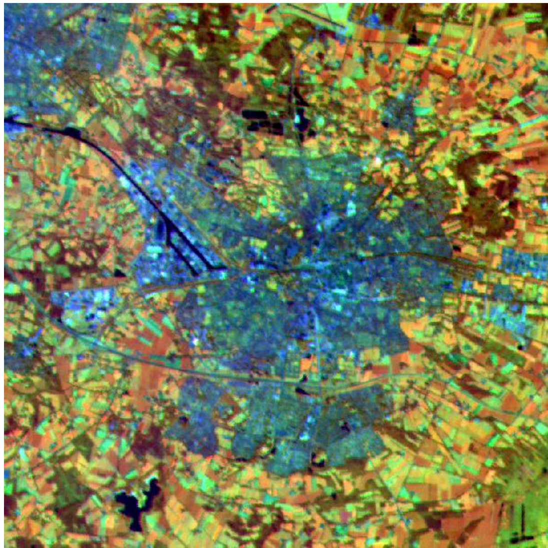
Aster image East Netherlands
15 m (Band combination 3, 2, 1)



ASTER image Enschede
15 m (Band combination 3, 2, 1)



3, 4, 2



Characteristics of high-resolution sat.

- Spatial resolution < 10 m
- 1 to 4 spectral bands
- Swath width < 100km
- Extreme pointing capabilities
- Revisit time 3 days and better
- IRS 1C&D,IKONOS,QUICKBIRD
- Precision farming, urban application

Some high-resolution satellites

Platform	Sensor	Res.	#Bands	Swath	Angle	Revisit
IRS 1C & 1D	PAN	5.8 m	1	70 km	±26°	5 days
Ikonos	OSA	1 m	4	11 km	±45°	1-3 days
QuickBird	BGIS	61 cm	4	16.5 km	±25°	1-3 days
GeoEye-1		41 cm	4	15 km	any	~
WorldView		50 cm	4	18 km	any	~

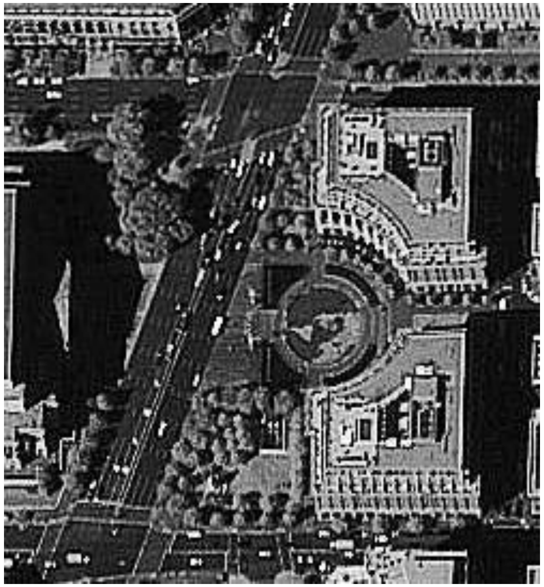
and many more to come....

~20 $/km^2

Ikonos image Enschede
Multi Spectral 4 m

High resolution from space

IKONOS
Panchromatic
1m resolution
London (right),
Washington DC ↓

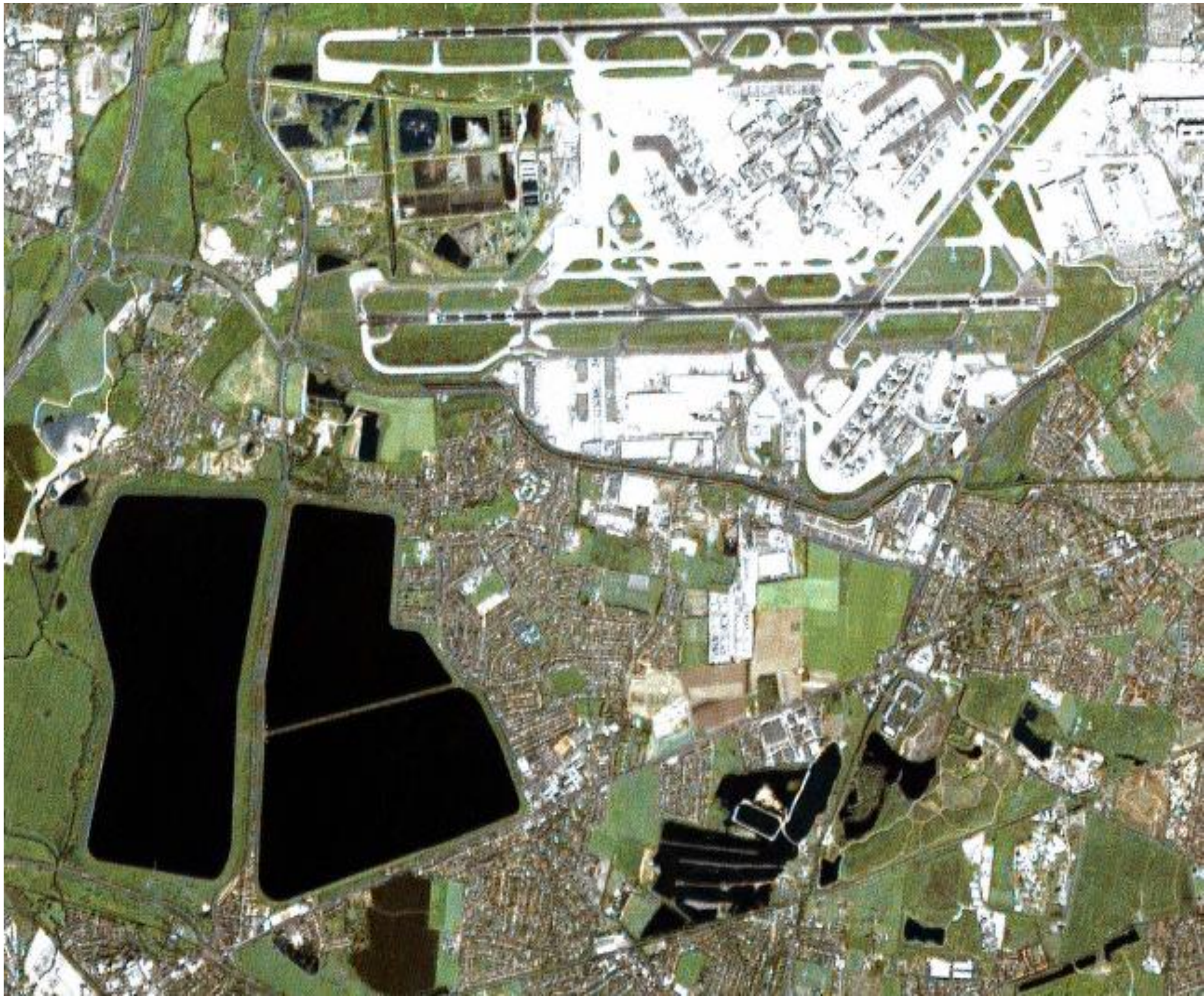


High resolution from space

IRS

(coloured) 1m resolution

Heathrow airport, London



Quickbird