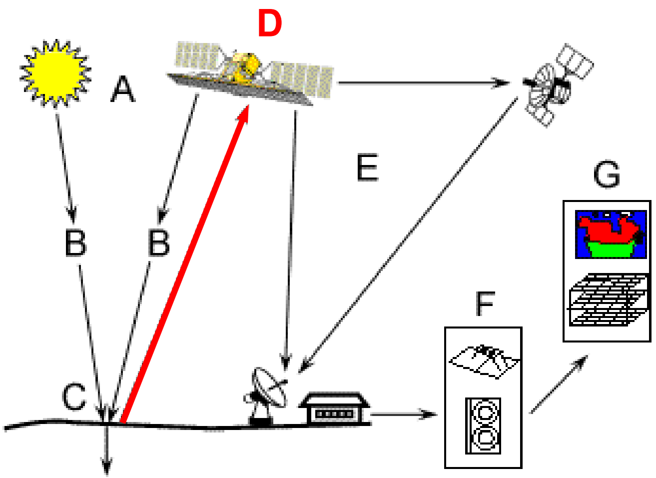
EARTH RESOURCES SATELLITES

Definition of satellite imaging systems:

An orbiting platform containing imaging equipment gathers data from a specified section of the earth and transmits the data to an earth-bound receiving station.



A - Energy source/illumination
B - Radiation and atmosphere
C - Interaction with target
D - Recording energy
E - Transmission, reception and processing
F - Interpretation and analysis
G - Application

Magaly Koch – mkoch@bu.edu

SENSOR PLATFORMS

Ground-based sensors

Aircraft

Space Shuttle

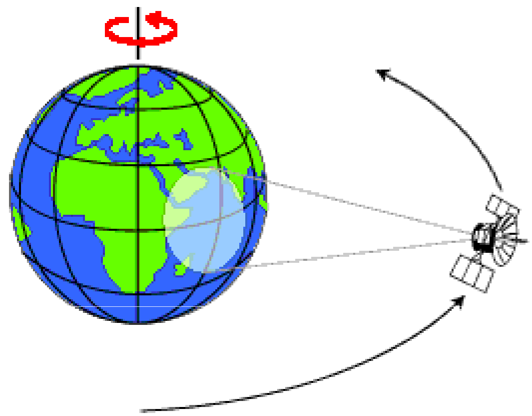
Satellite

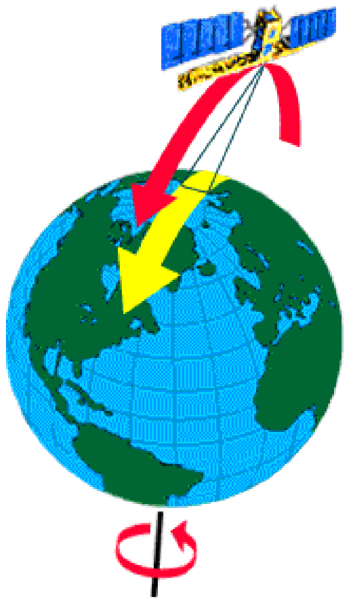
ORBIT PATTERNS

The path followed by a satellite is referred to as its **orbit**. Orbit selection can vary in terms of altitude and their orientation and rotation relative to the earth.

Geostationary orbits: satellites, at very high altitudes (36,000 km), revolve at speeds which match the rotation of the earth -> they seem stationary relative to the earth.

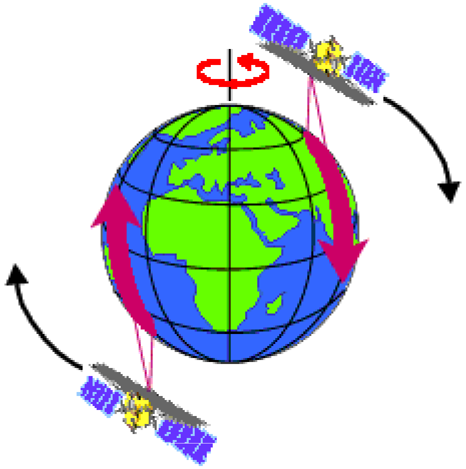
Weather and communication satellites have these types of orbits.



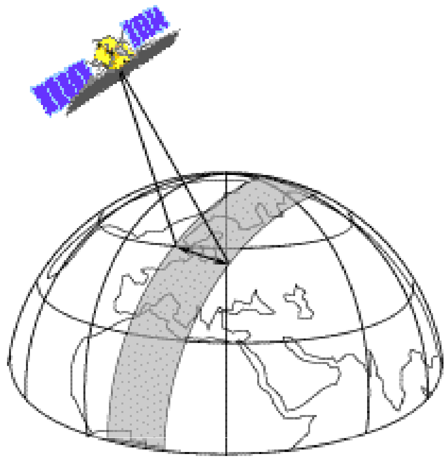


Near-polar orbits: have an inclination almost parallel to a line running between the North and South poles. Many of these orbits are also *sun-synchronous*, i.e. they cover each area at a constant local time of the day (*local sun time*).

ORBIT PATTERNS

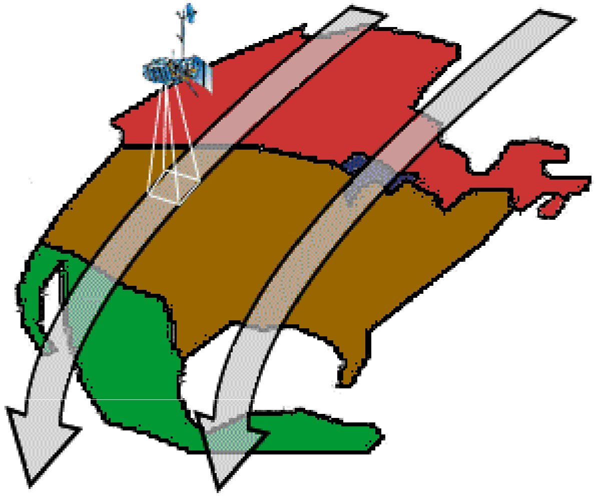


Ascending and descending passes:
The satellite (placed in near-polar orbits) travels northwards on one side of the earth and southwards on the second half of its orbit.

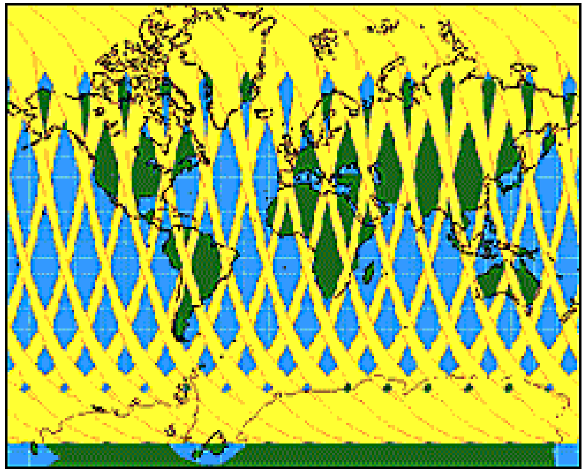


Swath: is the area imaged on the surface. Because the earth is rotating the satellite swath covers a new area with each consecutive pass. The satellite's orbit and the earth rotation work together to allow complete coverage of the earth.

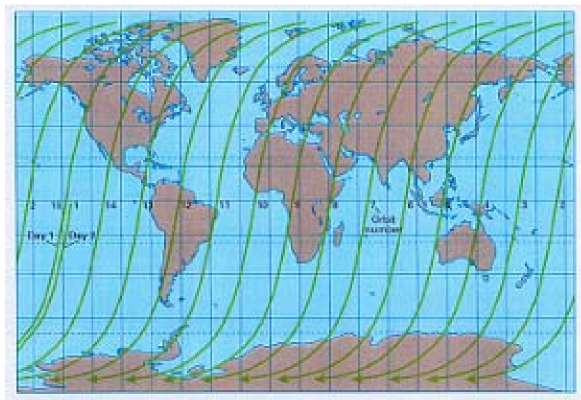
ORBIT PATTERNS



Apparent movement of satellite swath.
An orbit cycle will be completed when the satellite retraces its path.
<u>Note:</u> the interval of time required for the satellite to complete its orbit cycle is not necessarily the same as the *revisit period*.



Overlap in adjacent swaths. Areas at high latitude will be imaged more frequently than the equatorial zone.



Orbit cycles.

SENSOR CHARACTERISTICS

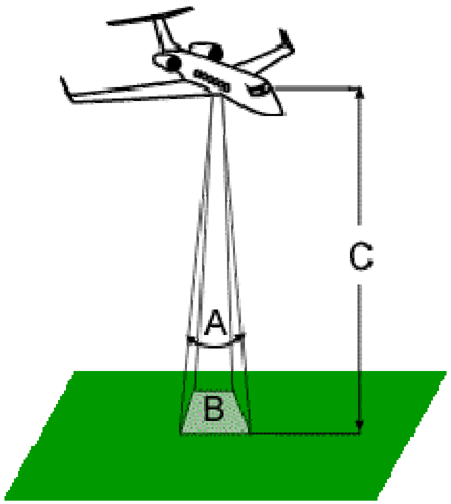
There are four types of sensor resolutions:

- **Spatial resolution**: relates to the pixel size, extent to the overall image coverage.
- **Spectral resolution**: range of wavelengths recorded by a sensor (bands: number, position and width).
- **Radiometric resolution**: range of integers that can be recorded by a sensor; measured in binary computer codes.
- **Temporal resolution**: the time that elapses between successive dates of imagery acquisition.

Temporal resolution is a function of orbit parameters (orbital altitude, shape, inclination). The greater the altitude, the longer the orbital period (acceleration due to gravity).

SPATIAL RESOLUTION

Spatial resolution refers to the size of the smallest feature that can be detected. It depends primarily on the Instantaneous Field Of View (IFOV). The IFOV is the angular cone of visibility of the sensor and determines the area which is “seen” on the ground from a given altitude at a given instant of time.

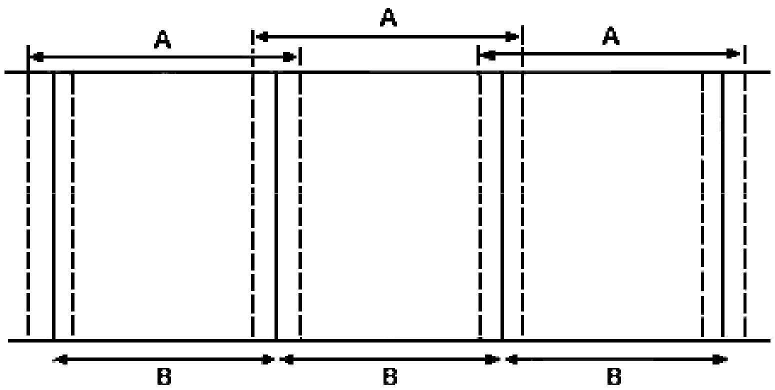


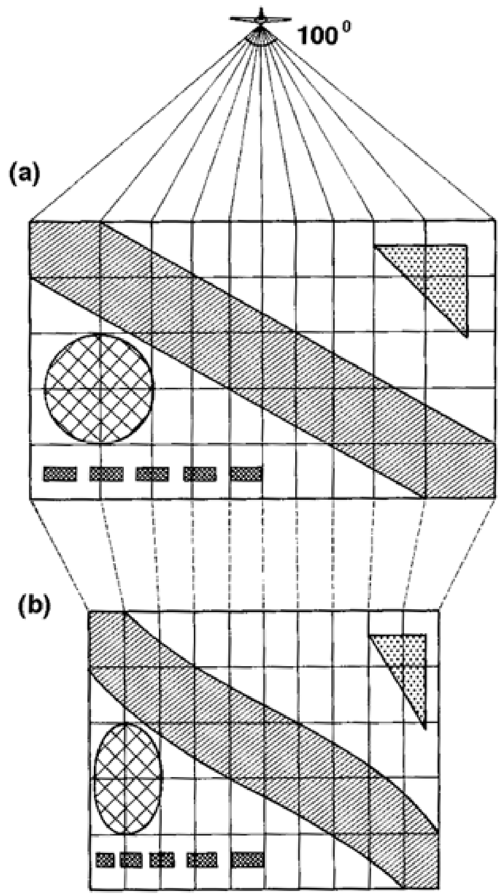
Coarse or low resolution.

Fine or high resolution.

PIXEL GEOMETRY

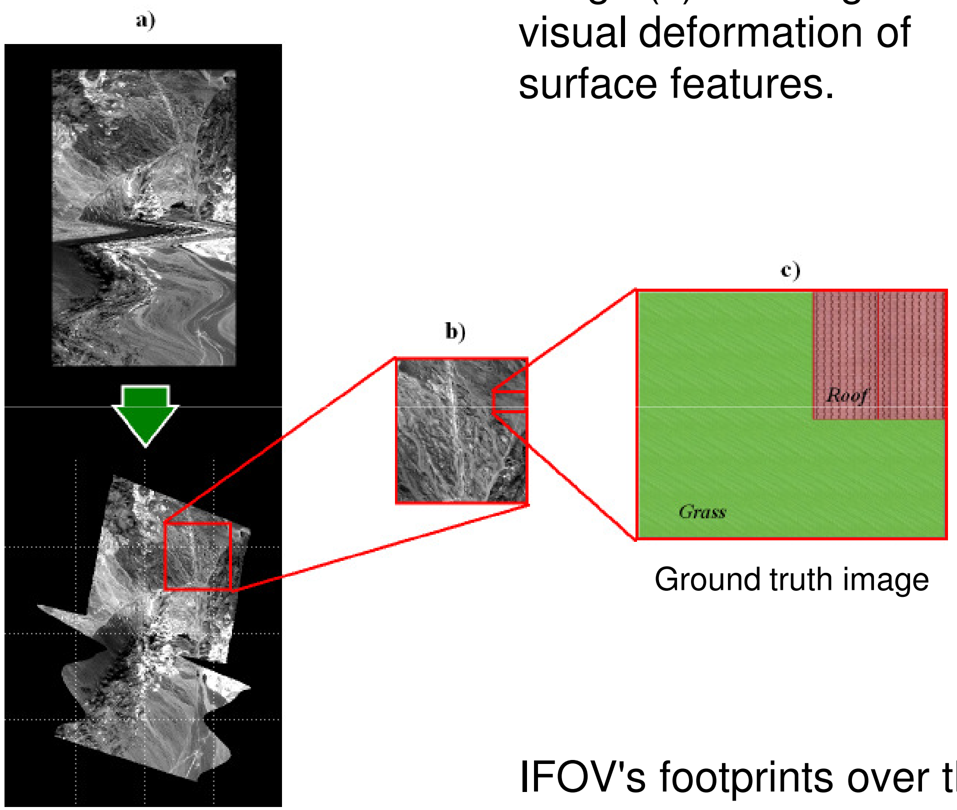
Optical versus *geometric pixel size*. The optical pixel width (the area imaged by the sensor) is A but these ground areas overlap. Overlapping pixels are scaled to match geometric pixel size B.





Effect of scan angle in aircraft imagery: (a) *Panoramic distortion*: pixel width increases away from a vertical view. (b) Resulting *image distortion*: image features have lateral distortion when displayed with a constant pixel width.

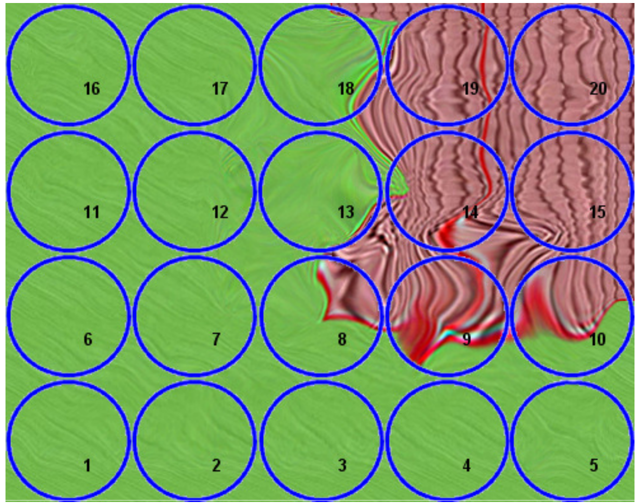
IMAGE DISTORTION



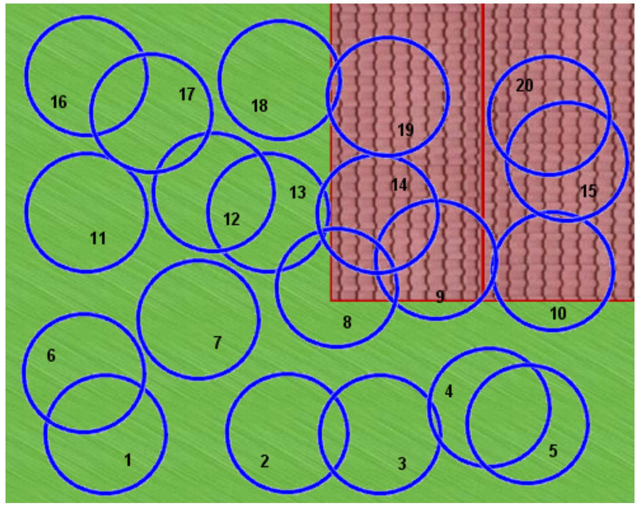
Airborne image:
a) raw; b) rectified

Ground truth image

Simulated airborne image (c) showing the visual deformation of surface features.

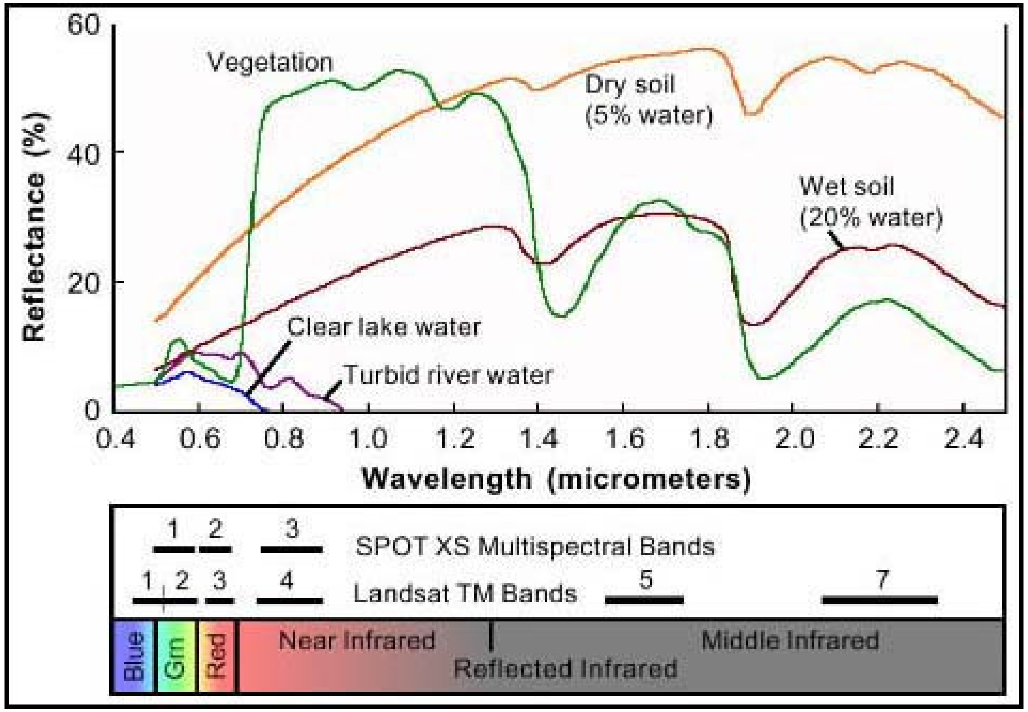


IFOV's footprints over the simulated ground image showing the real distribution of the measurements.

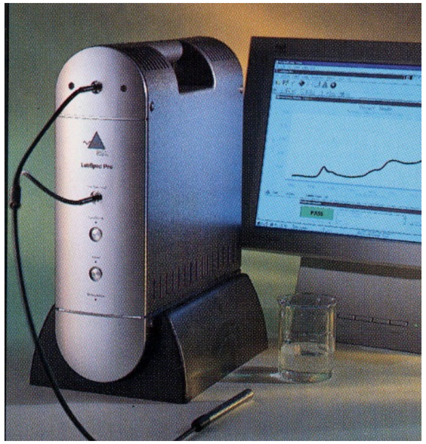


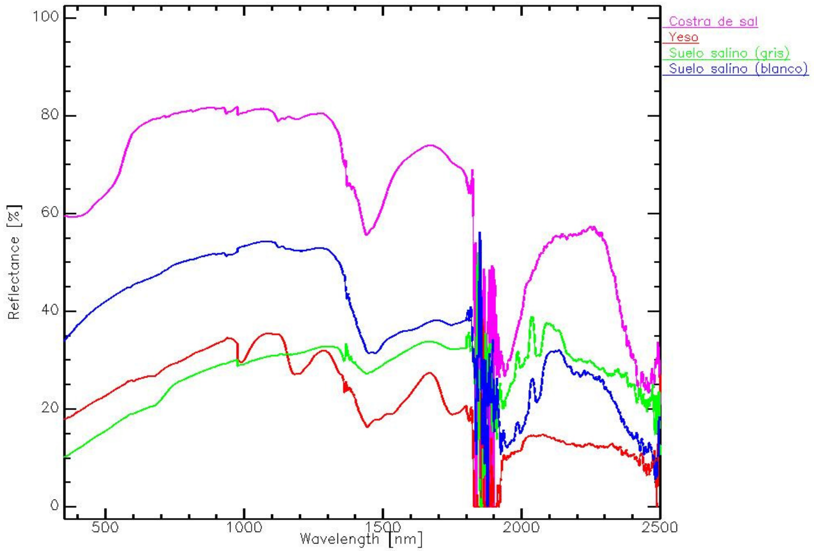
SPECTRAL RESOLUTION

Spectral resolution describes the ability of a sensor to define wavelength intervals. Many remote sensing systems record energy over several separate wavelength ranges at various spectral resolutions (*multi-spectral* versus *hyperspectral sensors, field spectrometers*).



FIELD SPECTROMETERS





RADIOMETRIC RESOLUTION

Radiometric resolution relates to the energy difference which determines different radiation (brightness) levels in an image, extent to the number of levels detected. Levels are stored as binary numbers in a computer.

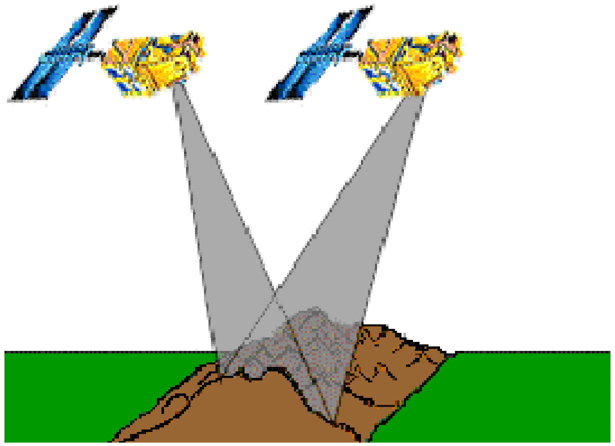
1 bit data = 2 levels

2 bit data = 4 levels

6 bit data = 64 levels

TEMPORAL RESOLUTION

The **temporal resolution** refers to the length of time it takes for a satellite to complete one entire orbit cycle. The *absolute temporal resolution* of a RS system to image the exact same area at the same viewing angle a second time is equal to the *orbit cycle time*. However, because of some overlap in the image swaths and off-nadir pointing capability of some satellite sensors, some areas of the earth can be re-image more frequently -> *revisit time = actual temporal resolution*.

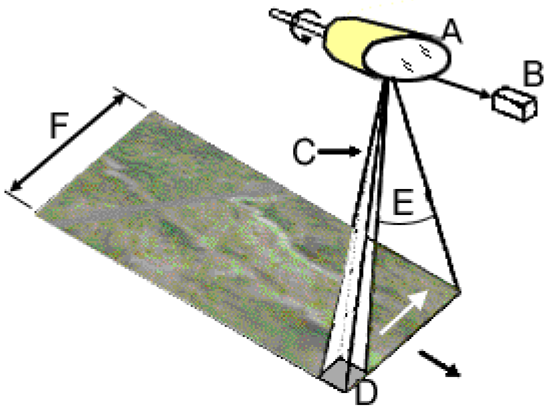


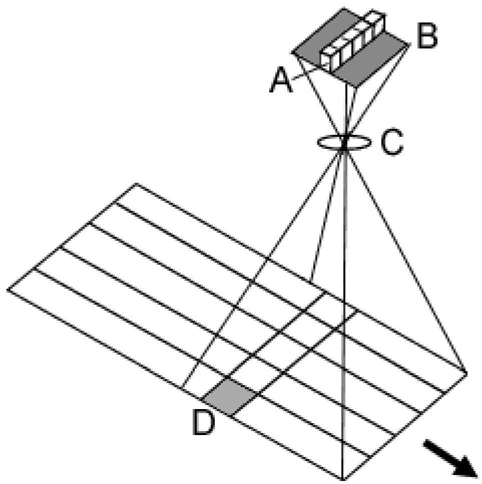
SCANNING SYSTEM

There are two main modes or methods of scanning employed to acquire multispectral image data: **across-track** scanning, and **along-track** scanning.

Across-track scan the surface in a series of lines. The lines are scanned from one side to the other, using a *rotating mirror*. Along-track scanners use a linear array of detectors which are pushed along in the flight track direction. These systems are referred to as *pushbroom scanners*.

The **IFOV** (instantaneous field of view) is influenced by: 1) changes in orbit altitude (pixel size), 2) the point spread function PSF (the way a sensor sees a reflective point source; recorded intensity distribution of the signal).





SATELLITES AND SENSORS

Optical and Infrared Satellites

- SPOT
- LANDSAT
- MODIS
- ADEOS
- IRS
- IKONOS
- WorldView 2

Microwave Satellites

- ERS
- ALOS PALSAR
- RADARSAT

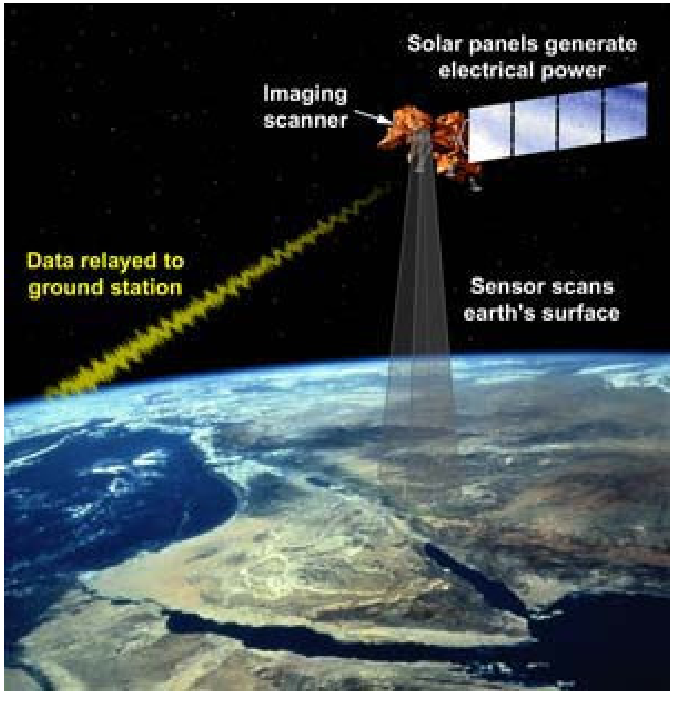
Hyperspectral Satellites /Aircrafts

- Hyperion
- DAIS 7915

Meteorological Satellites

- NOAA-GOES
- NOAA-POES
- METEOSAT
- GMS

LANDSAT TM AND ETM+

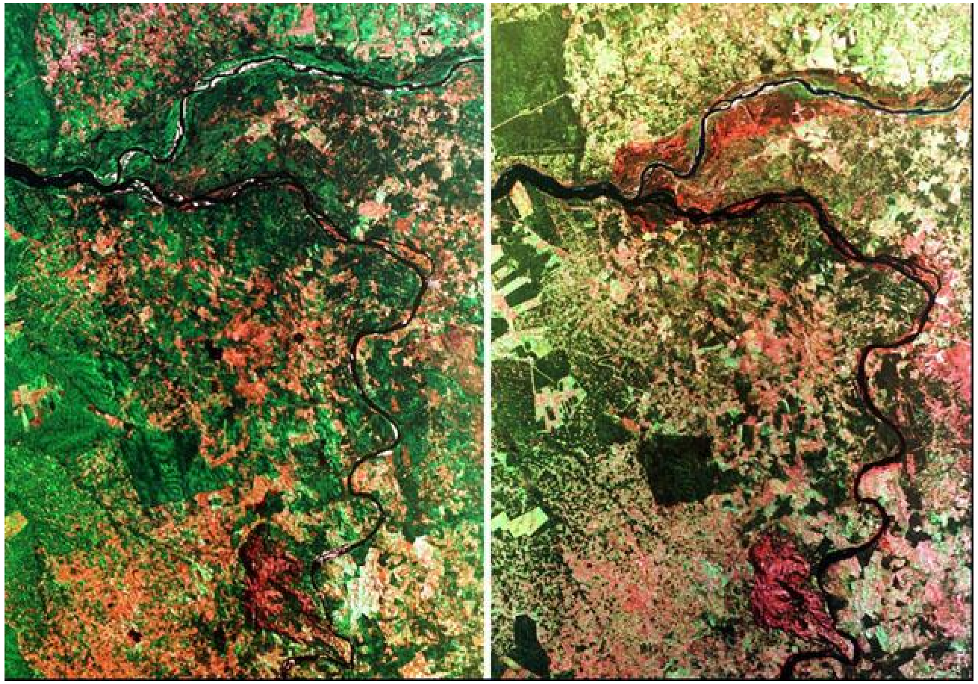


Characteristics of LANDSAT 4 / 5 and 7

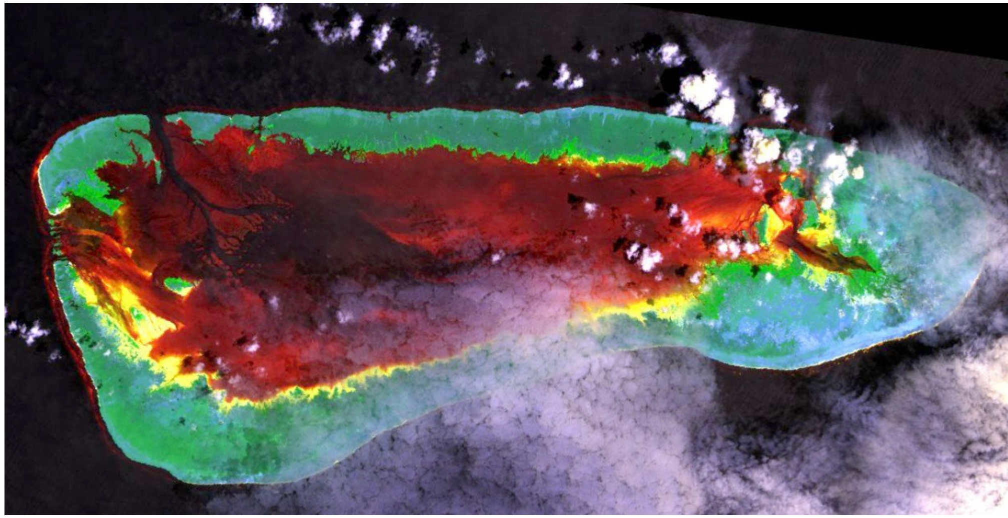
Type:	Sun-synchronous
Altitude:	705 km
Inclination:	98,2 deg
Orbital period:	99 min
Temporal resolution:	16 days (233 orbits)
Swath width:	185 km
Sensors :	Thematic Mapper
	Enhanced Thematic Mapper

		LANDSAT 4 & 5 TM		LANDSAT 7 ETM+	
	Band	**Wavelength (µm)**	**Resolution (m)**	**Wavelength (µm)**	**Resolution (m)**
Blue	1	0,45 – 0,52	30	0,45 – 0,515	30
Green	2	0,52 – 0,60	30	0,525 – 0,605	30
Red	3	0,63 – 0,69	30	0,63 – 0,69	30
Near IR	4	0,76 – 0,90	30	0,75 – 0,90	30
SWIR	5	1,55 – 1,75	30	1,55 – 1,75	30
Thermal IR	6	10,40 – 12,50	120	10,40 – 12,50	60
SWIR	7	2,08 – 2,35	30	2,09 – 2,35	30
Pan				0.52 – 0.90	15

LANDSAT IMAGES



Amazon, Brazil:
monitoring forest clear-cutting



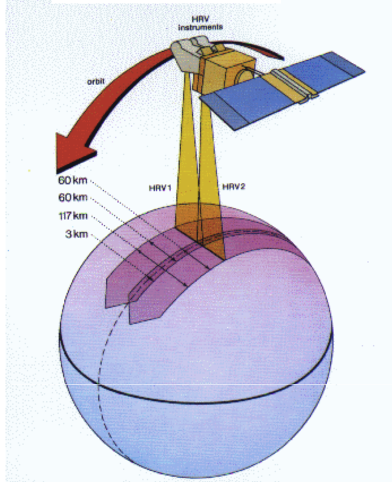
Seychelles Islands (Bands 5, 4, 3):
coral reefs

SPOT (SYSTEME POUR L'OBSERVATION DE LA TERRE)

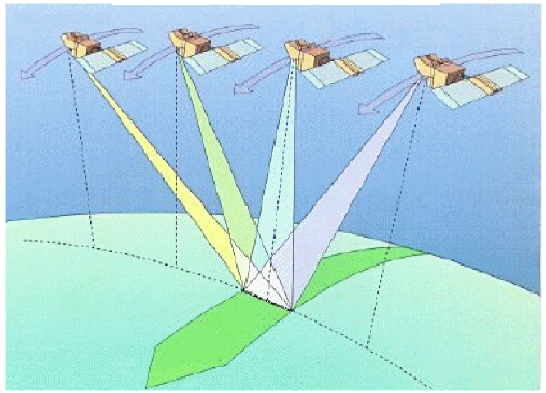
Characteristics of SPOT

Type:	Sun-synchronous
Altitude:	832 km
Inclination:	98.7 deg
Orbital period:	101 min
Temp. resolution:	26 days
Off-Nadir:	1 to 3 days
Swath width:	185 km
Sensors:	High Resolution Visible

Nadir View



Off- Nadir View



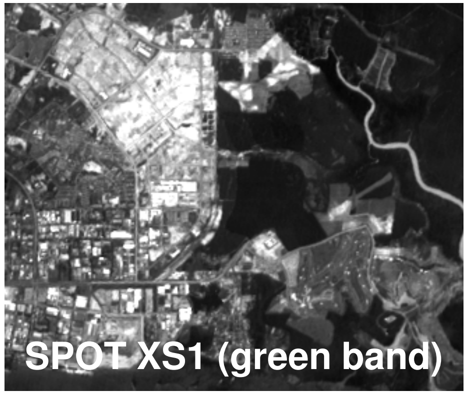
SPOT HRV

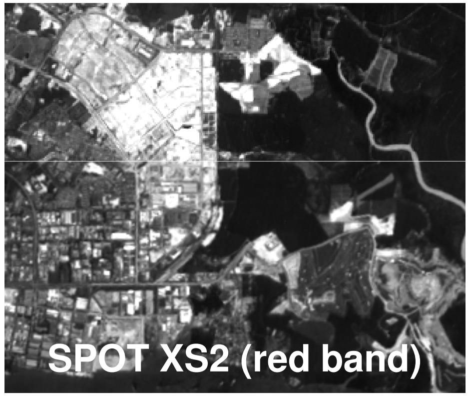
Mode	Band	Wavelength (µm)	Resolution (m)
Multispectral	XS1	0.50 – 0.59 (Green)	20
Multispectral	XS2	0.61 – 0.68 (Red)	20
Multispectral	XS3	0.79 – 0.89 (NIR)	20
Panchromatic	P	0.51 – 0.73 (Visible)	10

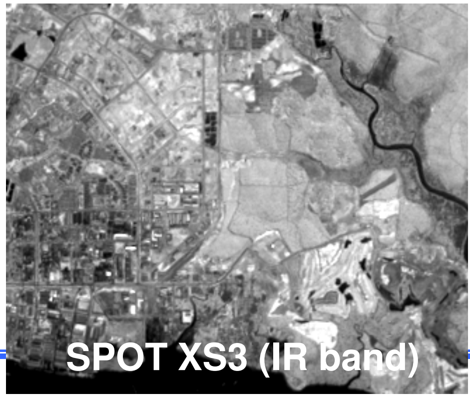
SPOT PANCHROMATIC MODE

SPOT panchromatic image with
10 m resolution

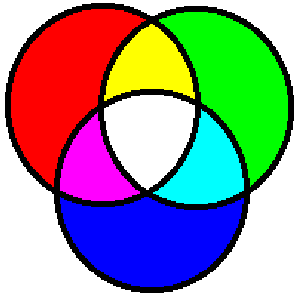
SPOT MULTISPECTRAL MODE



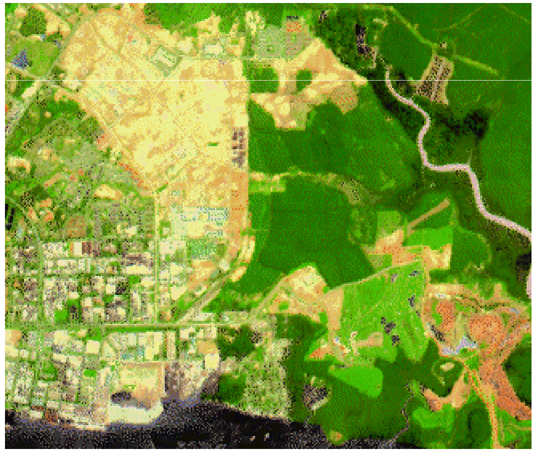




Primary Colors
Red, Green, Blue

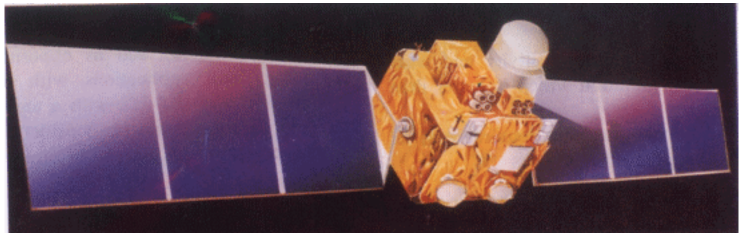


False color composite
Red: XS3
Green: XS2
Blue: XS1



Natural color composite
Red: XS2
Green: (0.75)XS1 + (0.25)XS3
Blue: (0.75)XS2 - (0.25)XS1

IRS (INDIAN REMOTE SENSING)



Characteristics of IRS

Type:	Sun-synchronous
Altitude:	817 km
Inclination:	98.69 deg
Orbital period:	101 min
Temp. resolution:	24 days
Sensors:	LISS -Linear Imaging Self Scanning Sensor PAN - Single channel panchromatic WIFS - Wide Field Sensor

IRS-1C PAN, LISS y WIFS

Sensor	Band	Wavelength (μm)	Resolution (m)	Swath Width (km)
PAN	1	0.5 – 0.9	<10	70,5
LISS	2	0.52 – 0.59 (green)	23,5	142
LISS	3	0.62 – 0.68 (red)	23,5	142
LISS	4	0.77 – 0.86 (NIR)	23,5	142
LISS	5	1.55 – 1.75 (SWIR)	23,5	142
WIFS	3	0.62 – 0.68 (Red)	188	810
WIFS	4	0.77 – 0.86 (NIR)	188	810

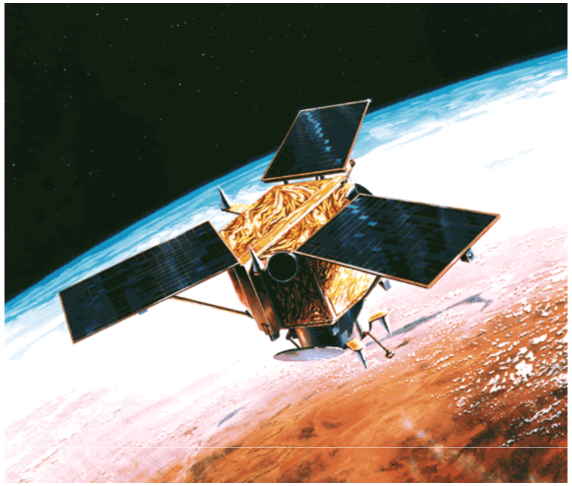
IMAGES OF IRS

IRS fusion PAN + LISS
Landes

IRS LISS
Airport in Frankfurt

IRS WIFS
Greece and Turkey

IKONOS



Characteristics

Type:	Sun-synchronous
Altitude:	682 km
Inclination:	98.69 deg
Temp. resolution:	11 days
Swath width:	11 km
Scanning:	Across & along track

IKONOS

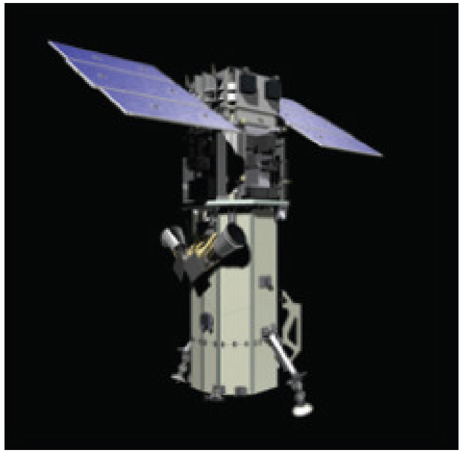
Mode	Band	Wavelength (μm)	Resolution (m)
Multispectral	1	0.45 – 0.52 (blue)	4
Multispectral	2	0.51 – 0.60 (green)	4
Multispectral	3	0.63 – 0.70 (red)	4
Multispectral	4	0.76 – 0.85 (NIR)	4
Panchromatic	P	0.45 – 0.90 (visible)	1

IKONOS IMAGES

Buenos Aires
Multispectral image with 4 m resolution

Sydney
Panchromatic image with 1 m resolution

WorldView - 2



Characteristics

Type:	Sun-synchronous
Altitude:	770 km
Inclination:	98.69 deg
Orbital period:	100 min
Temp. resolution:	3.7 days
Off-nadir temp. res.:	1.1 days
Swath width:	16.4 km
Scanning:	Across & along track

WV-2

Mode	Band	Wavelength (µm)	Resolution (m)
Multispectral	1	0.40 – 0.45 (coastal blue)	2
Multispectral	2	0.45 – 0.51 (blue)	2
Multispectral	3	0.51 – 0.58 (green)	2
Multispectral	4	0.585 – 0.625 (yellow)	2
Multispectral	5	0.63 – 0.69 (red)	2
Multispectral	6	0.707 – 0.745 (red-edge)	2
Multispectral	7	0.77 – 0.895 (NIR1)	2
Multispectral	8	0.86 – 1.04 (NIR2)	2
Panchromatic	P	0.45 – 0.80 (Visible)	0.5

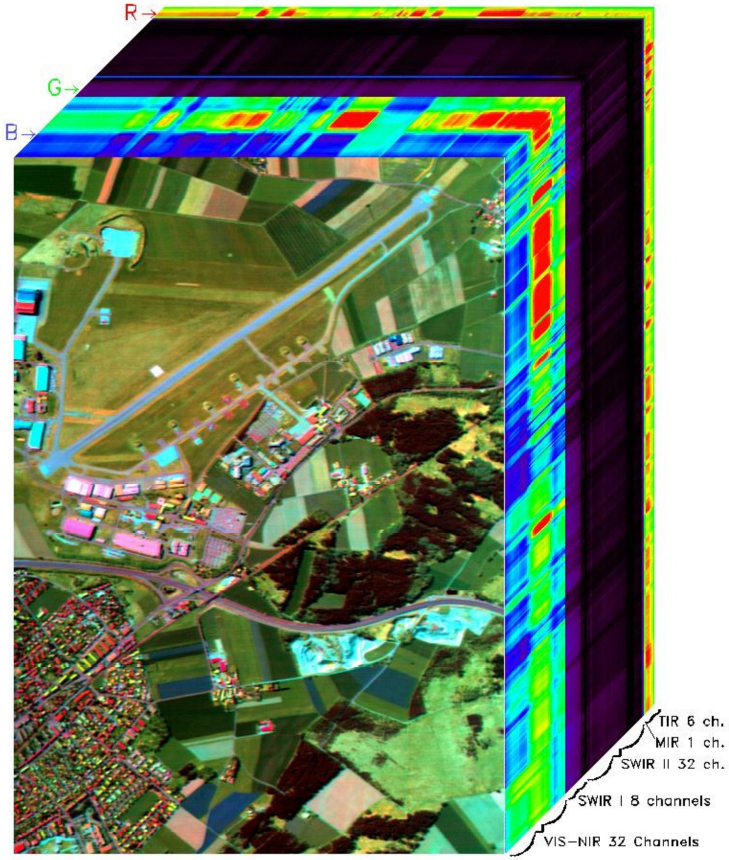
DAIS 7915 HYPERSPECTRAL SENSOR

Characteristics

- Airborne sensor
- Hyperspectral - 79 bands
- “Whiskbroom” - scanner
- 4 spectrometers
- 5 m resolution (3300 m)
- Swath width 3 km

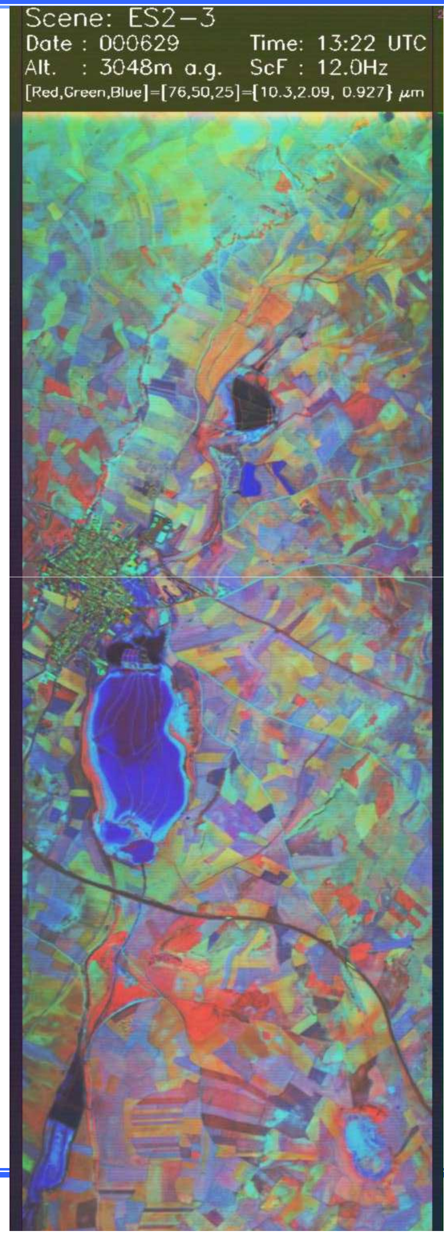
Spectrometer		**Bands**	**Wavelength** (μm)
1	VIS/NIR	32	0.5 - 1.05
2	SWIR I	8	1.5 - 1.8
3	SWIR II	32	1.9 - 2.5
	MIR	1	3.0 - 5.0
4	TIR	4	8.7 - 12.5

DAIS 7915 IMAGES



DLR's Research Center at Oberpfaffenhofen
Sensor: Digital Airborne Imaging Spectrometer DAIS
Flight Altitude: 3000 m, Date: 4 May 1995
Color Composite: R/G/B = 9600/1600/860 nm

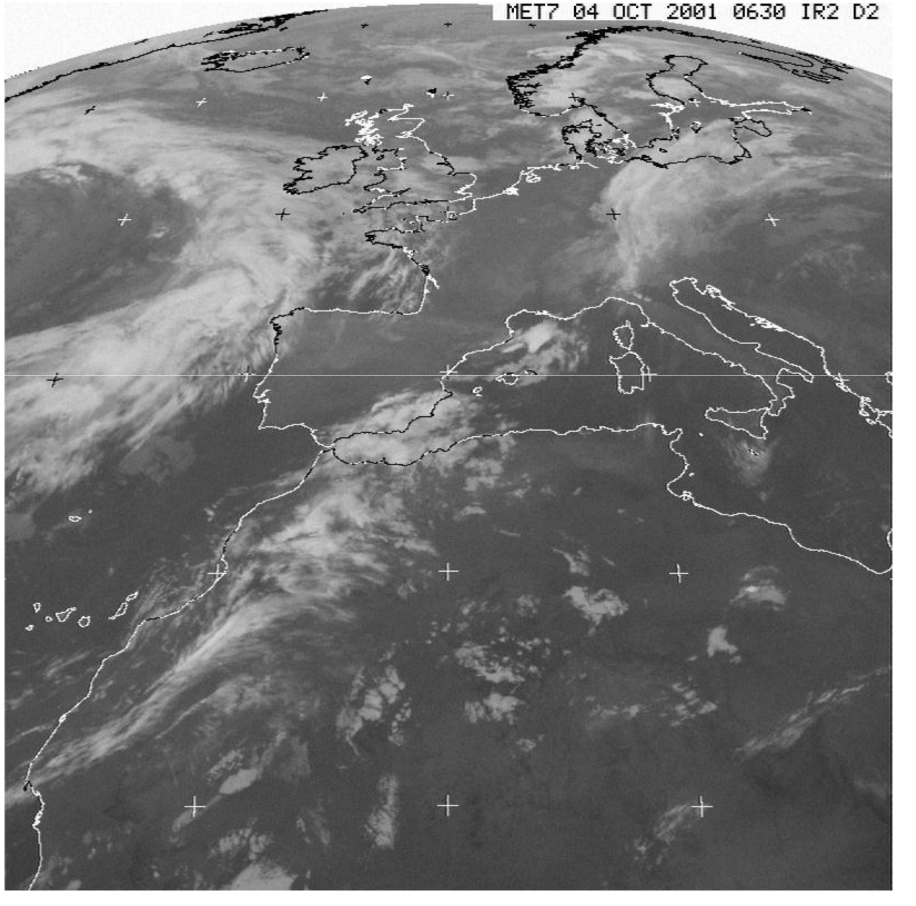
DAIS 7915



WEATHER SATELLITES

GOES (Geostationary Operational Environmental Satellite)

Meteosat



NOAA AVHRR
(ADVANCED VERY HIGH RESOLUTION RADIOMETER)

Ocean surface temperature

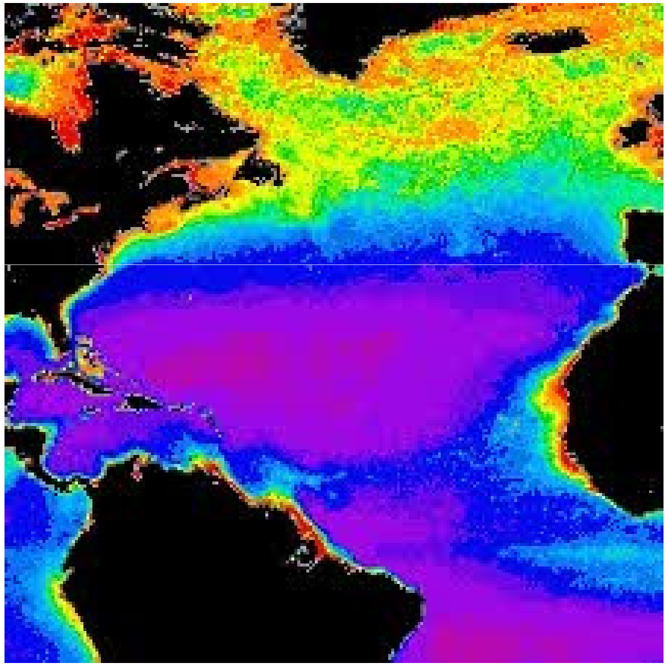
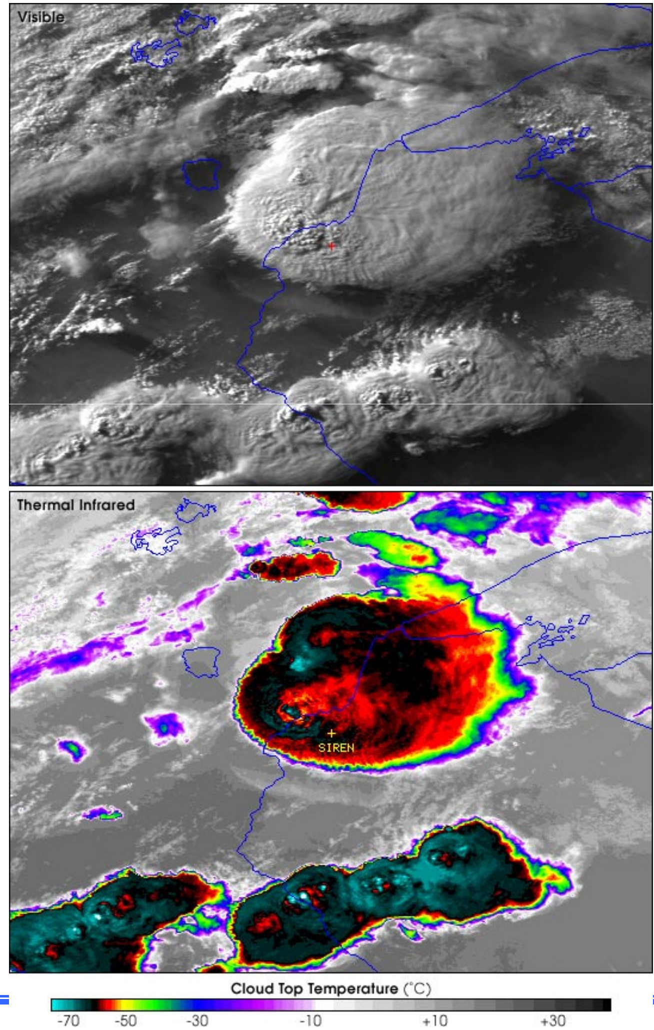
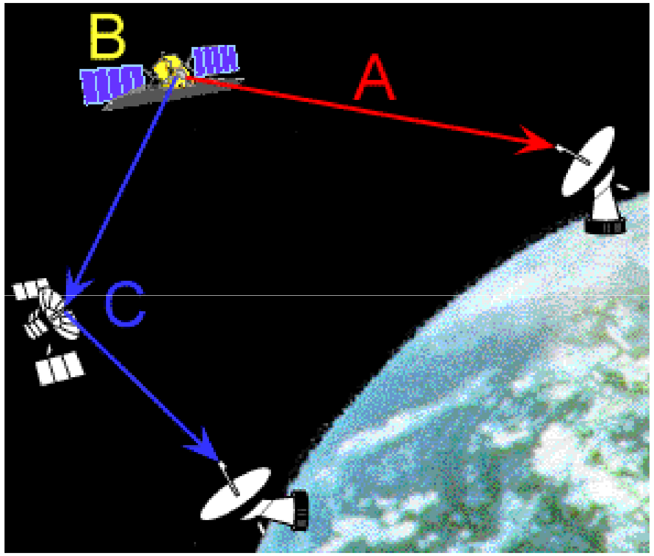


Image of a tornado
(6:59 June 18, 2001)

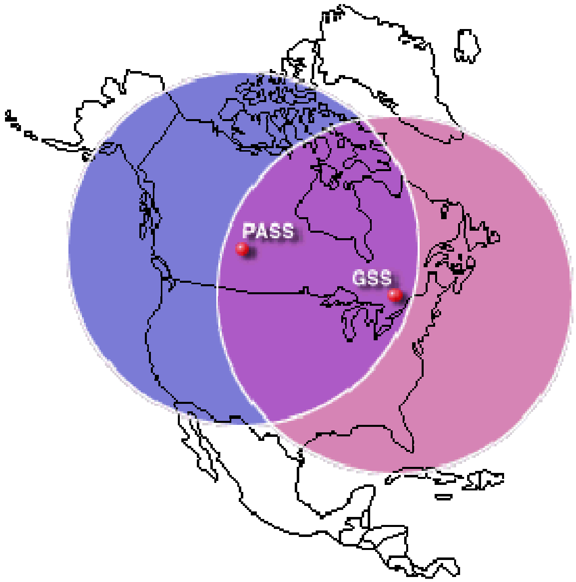


DATA RECEPTION & TRANSMISSION



Three options for data transmission:

(1) Data can be directly transmitted to Ground Receiving Station (GRS);
(2) Data can be recorded on board the satellite (tape recorder);
(3) Data can be relayed to the GRS through the Tracking and Data Relay Satellite System (TDRSS).



OTHER SATELLITE SENSORS

A new generation of satellite sensors enables precise and repeated mapping of the earth surface and its resources.

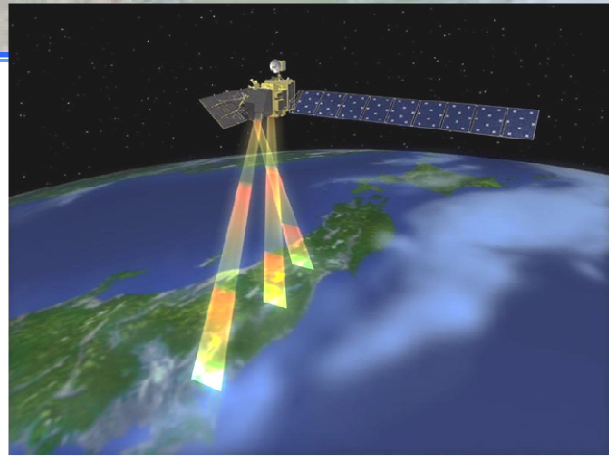
Two examples are given here:

- ALOS (Advanced Land Observation Satellite)
- GRACE (Gravity Recovery And Climate Experiment)

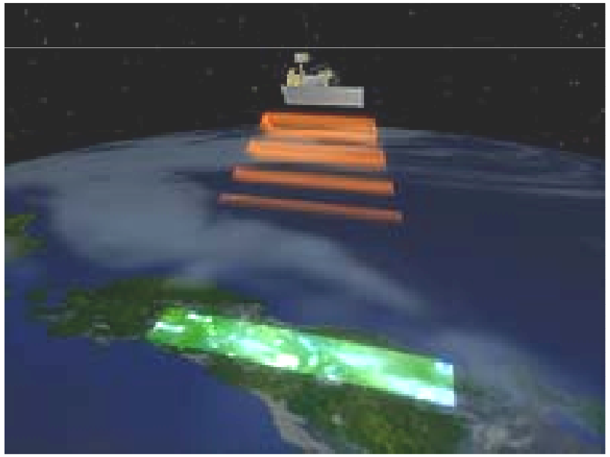
Advanced Land Observing Satellite (ALOS)

Main Characteristics of ALOS	
Orbit	Sun Synchronous Sub-Recurrent Orbit
	Recurrent Period: 46 days, Sub cycle: 2 days
	Altitude: Approx. 692km (above the equator)
	Inclination: Approx. 98.2 deg
Launched in January 2006 Lost in April 2011	

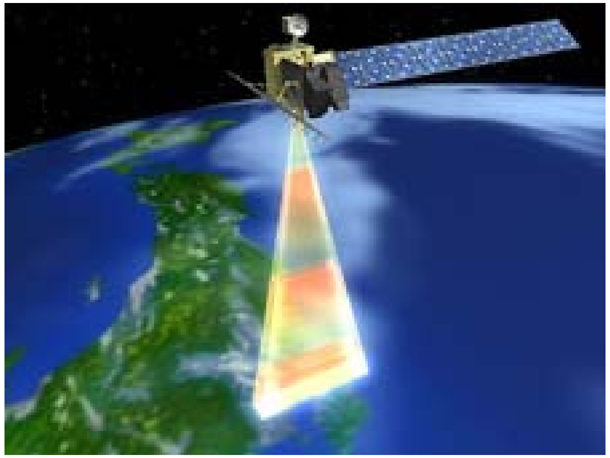
ALOS is one of the world largest earth observation satellites in size and has contributed to disaster monitoring and resource surveying in addition to mapping and precise land coverage observation.



PRISM is a panchromatic radiometer with 2.5-meter spatial resolution



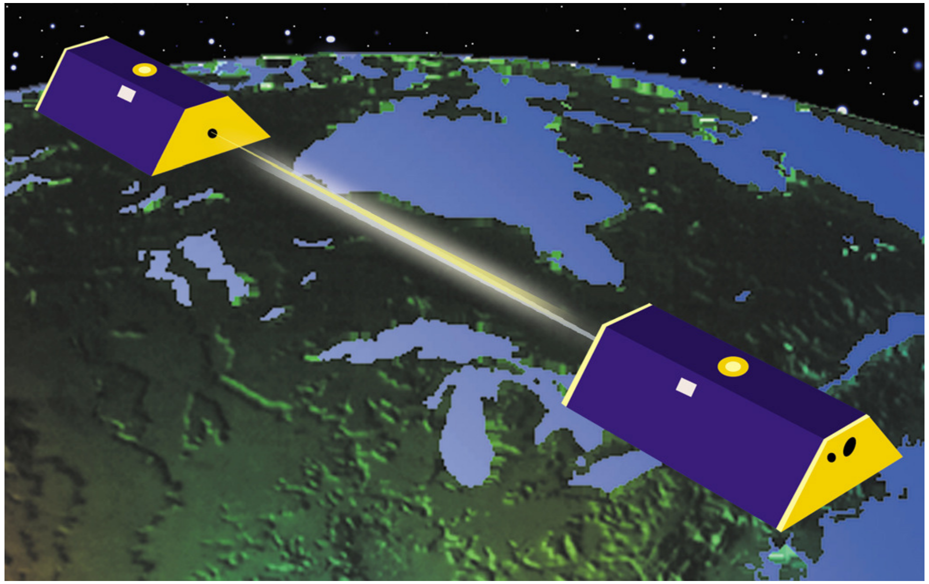
PALSAR is an active microwave sensor for cloud-free and day-and night land observation

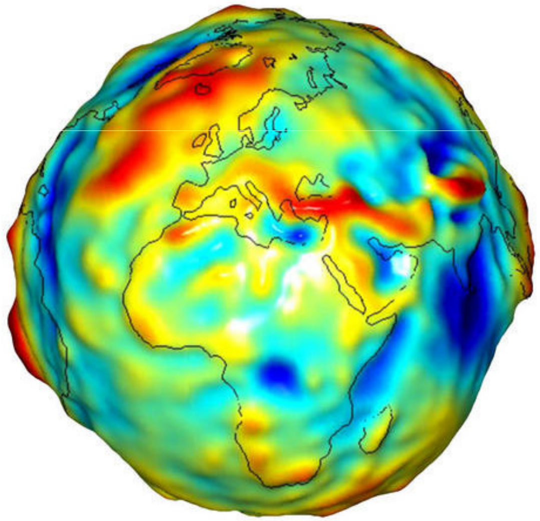


AVNIR-2 is a visible and near-infrared radiometer

GRACE: The Gravity Recovery And Climate Experiment

A microwave link “connects” the two satellites and makes extremely precise measurements of the changes in distance between the two satellites. These fluctuations are caused by changes in the orbital motion of the twin spacecraft as they respond to changes in the density of the surface they are passing over. Density changes correspond directly to changes in the gravitational field.





Due to an uneven distribution of mass inside the earth, the earth's gravity field is not uniform - that is, it has "lumps". This model greatly exaggerates the scale so that many smaller features can be seen.