ES6: Environmental Science and Technology

Tools for Monitoring the Environmental Processes of Earth: Satellites

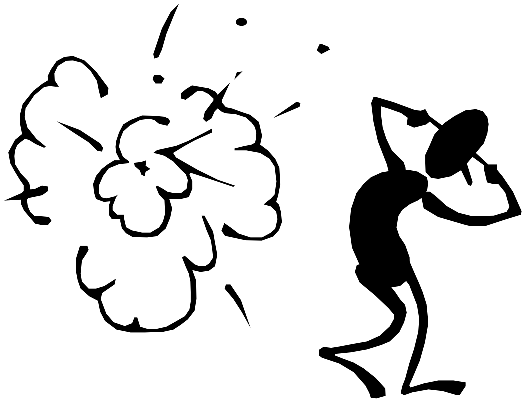
Akiyuki KAWASAKI

Visiting Scholar at Harvard University's
School of Engineering and Applied Sciences as well as
the Center for Geographic Analysis.

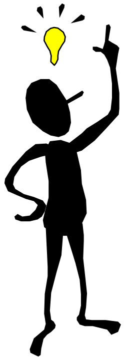
e-mail: kawasaki@seas.harvard.edu

Question

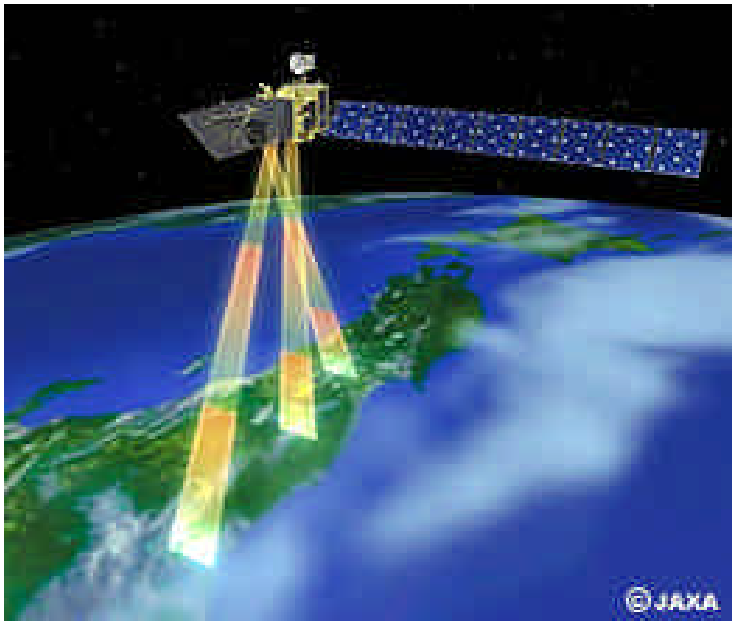
- ✓ What do you think remote sensing is all about?
- ✓ Try to make up a simple definition. Then, list practical applications of remote sensing as you defined it.

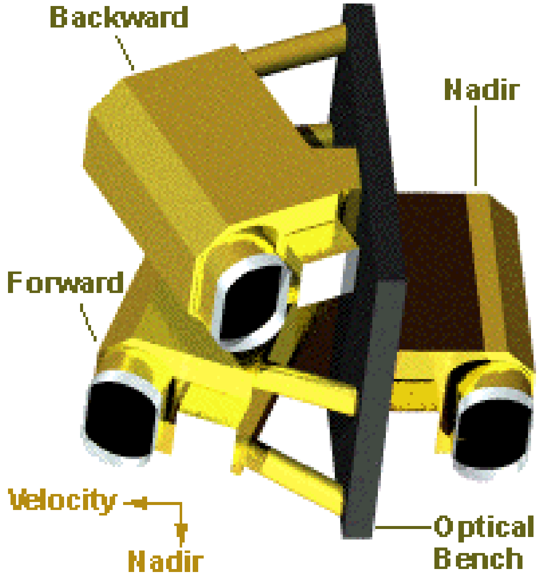


Definition



Remote sensing involves the use of instruments or sensors to "capture" the spectral and spatial relations of objects and materials observable at a distance - typically from above them.

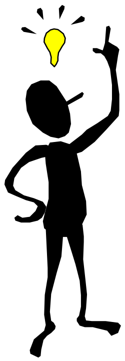




Sensor

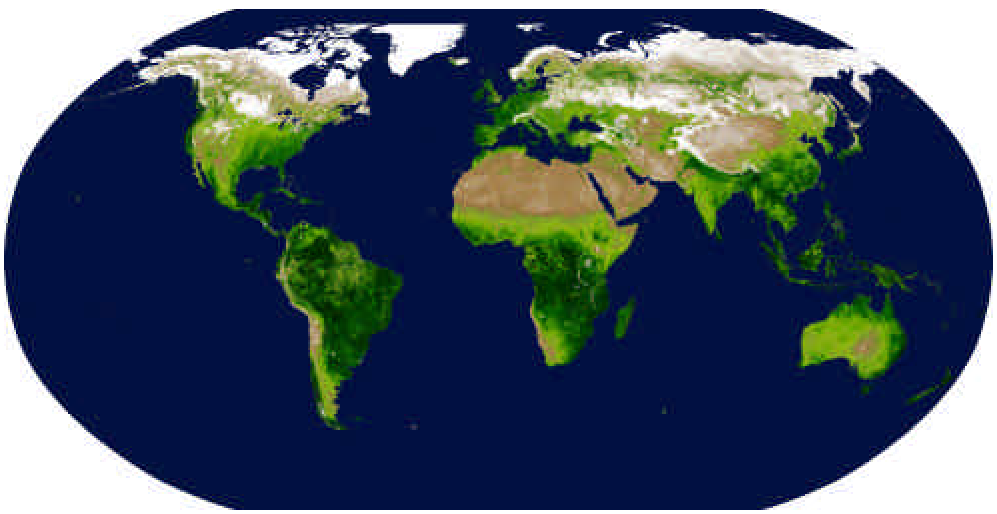
NASA Remote Sensing Tutorial (2007): RECTEC (2006)

Application

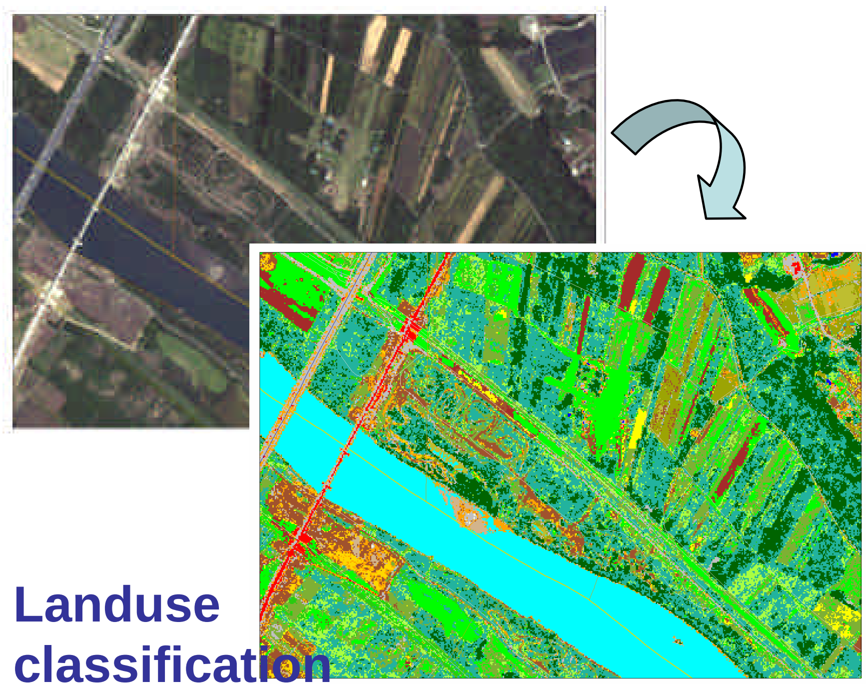


There are probably hundreds of applications

- these are typical: 1) determining the status of a growing crop; 2) defining urban patterns; 3) delineating the extent of flooding; 4) recognizing rock types; 5) pinpointing areas of deforestation.



Vegetation Index Global mosaics (NDVI)



Landuse classification

Agenda

I. Brief History of Remote Sensing

II. Theoretical Background

III. Sensor Technologies

IV. Characteristics of Satellite Remote Sensing

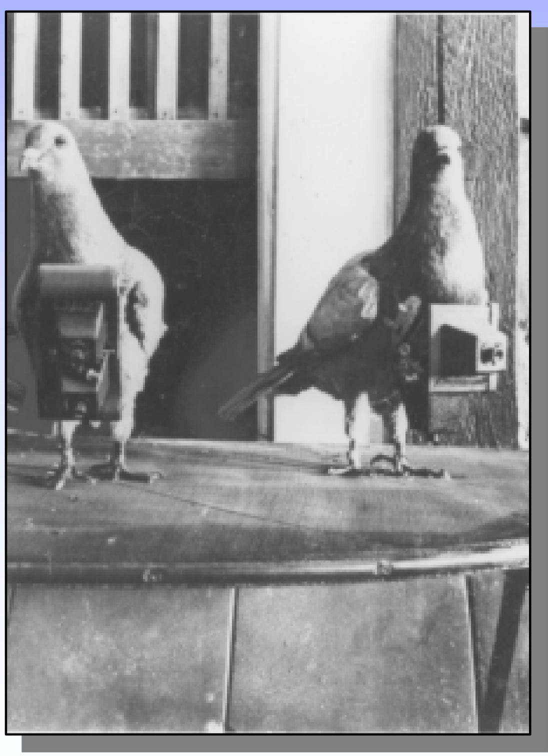
V. Cutting Edge Technology: ALOS

VI. Summary

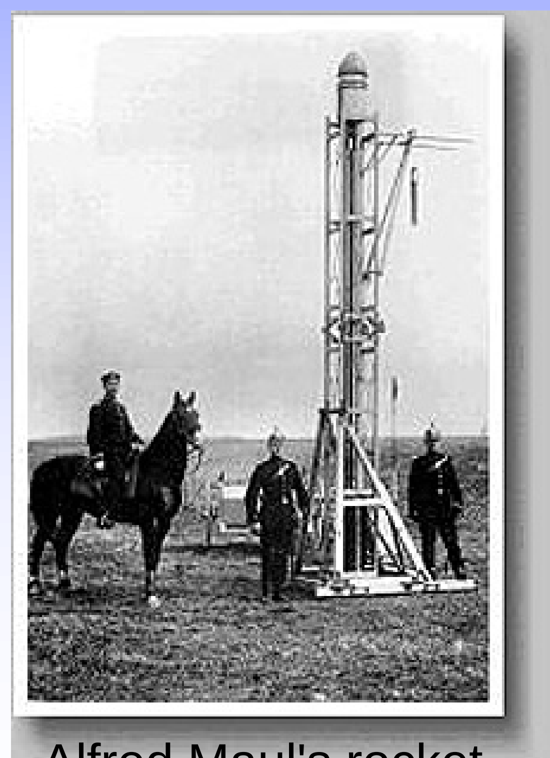
$\Rightarrow$ *This class puts emphasis on theoretical background and sensing / satellite technologies rather than applications.*

I. Brief history of Remote Sensing

Remote sensing involves the use of instruments or sensors to "capture" the spectral and spatial relations of objects and materials observable at a distance - typically from above them (= Platform).



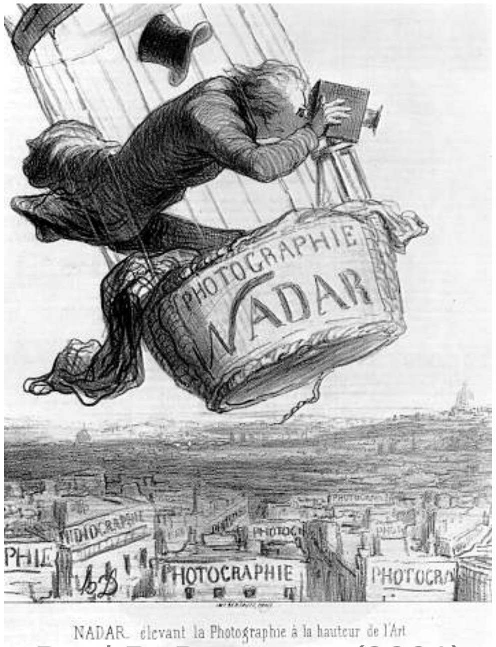
Bavarian pigeon fleet (1903)



Alfred Maul's rocket during a 1904 launch

NASA Remote Sensing Tutorial (2007)

Aerial photo using balloon : The 19th century



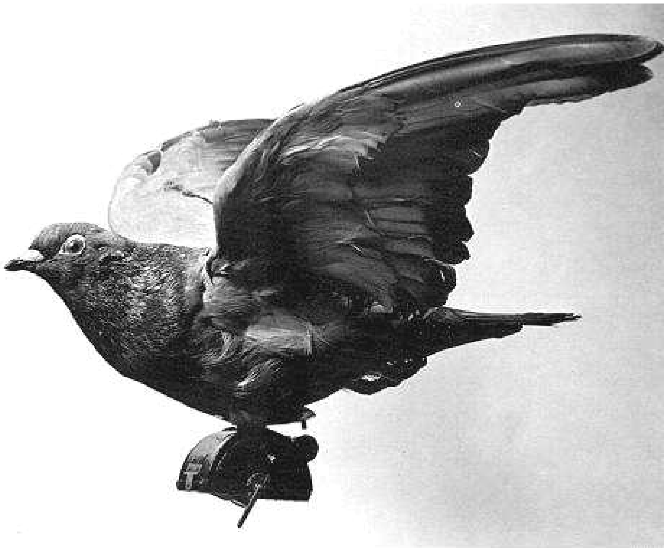
Paul R. Baumann (2001)

- The practice of remote sensing can be said to have begun with the invention of photography.
- Close-up photography began in 1839.
- Remote Sensing from above ground began with the earliest balloon photo made above a Paris, France in 1850s.

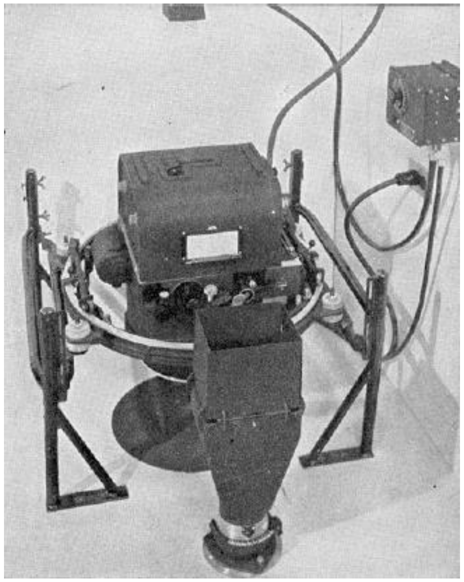
- In 1860s during the Civil War balloonists took pictures of the Earth's surface using the newly invented photo-camera for reconnaissance.
- The photo (right) was made from a balloon anchored above a Boston in 1860 and is the first surviving aerial photo in the world.

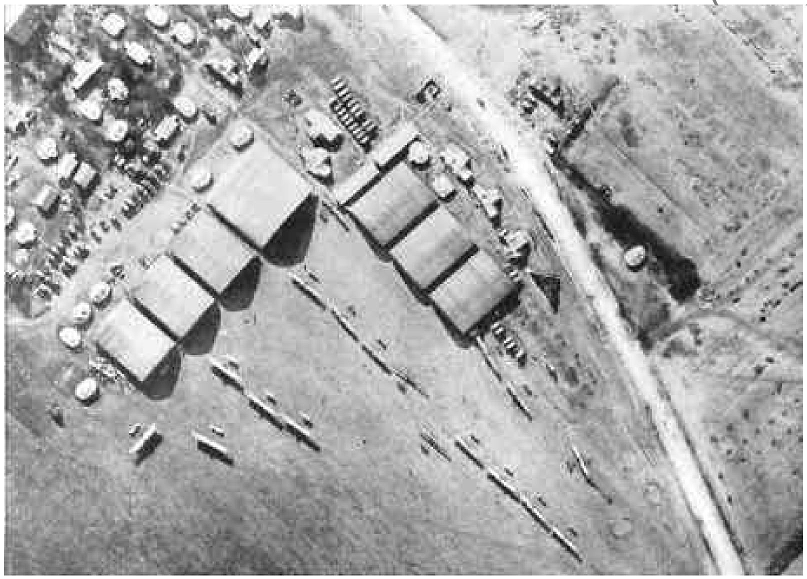
NASA Remote Sensing Tutorial (2007)

Pigeon, Airplane, and Rocket: The former part of The 20th century



Paul R. Baumann (2001)





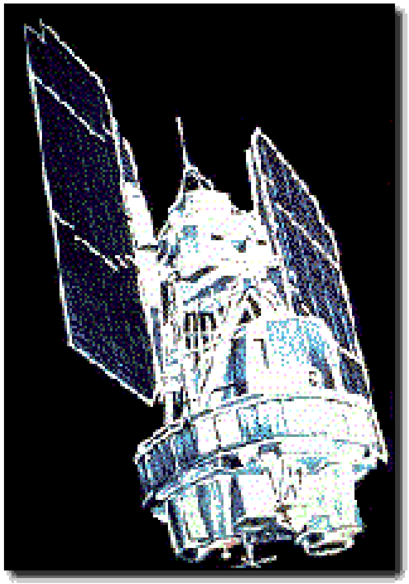
Paul R. Baumann (2001)

Aerial photography became a valuable reconnaissance tool during the First World War and further developed during the Second World War.

NASA Remote Sensing Tutorial (2007)

Civilian satellite remote sensing: The latter part of The 20th century

- As an operational system for collecting information about Earth on a repetitive schedule, satellite remote sensing matured in the 1970s



ERTS-1

- The first Earth Resources Technology Satellite (ERTS-1, and later called **LANDSAT**) launched by NASA in 1972, flowing on Skylab (and later, **the Space Shuttle**), which to mapping natural and cultural resources on land and ocean surfaces.

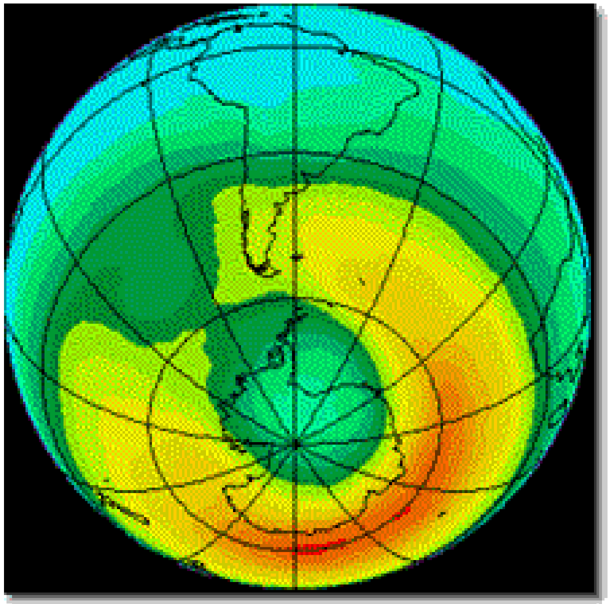
The Space Shuttle

NASA Remote Sensing Tutorial (2007)

The Ozone Hole: 1985

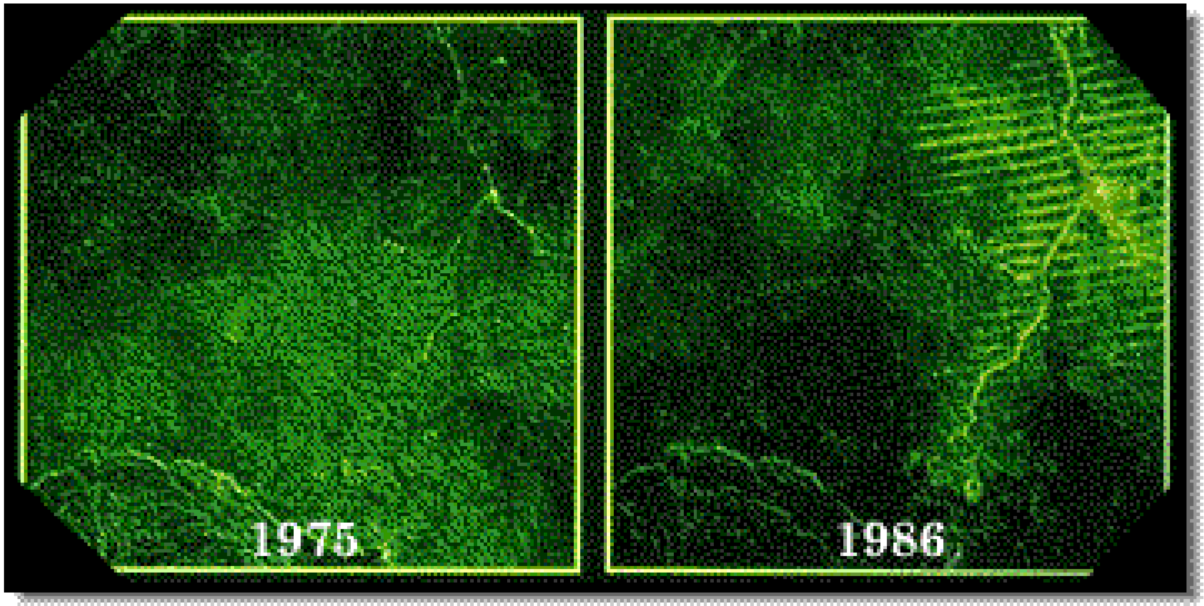
Ozone depletion over Antarctica, first noted by British scientists, was confirmed by measurements from the Total Ozone Mapping Spectrometer (TOMS), launched in 1978.

Since then, TOMS has made daily polar ozone maps of an ozone hole as large as the US.



Satellite data were invaluable in supporting the first Montreal Protocol, wherein forty nations agreed to a fifty percent reduction in the use of chlorofluorocarbons by 1999.

Deforestation: 1986



Detecting changes through time is one of the most powerful uses of remote sensing.

These Landsat images, taken in 1975 and 1986, disclose how many acres of forest lands were converted to agricultural use in the Brazil.

The fishbone pattern of roads radiating from the major highway indicates the changes. NASA researchers have estimated that 9,000 square miles have been converted from forest to agriculture in this area of Brazil.

II. Theoretical back ground of Remote Sensing

Remote sensing involves the use of instruments or sensors to "capture" **the spectral and spatial relations of objects and materials observable at a distance** - typically from above them.

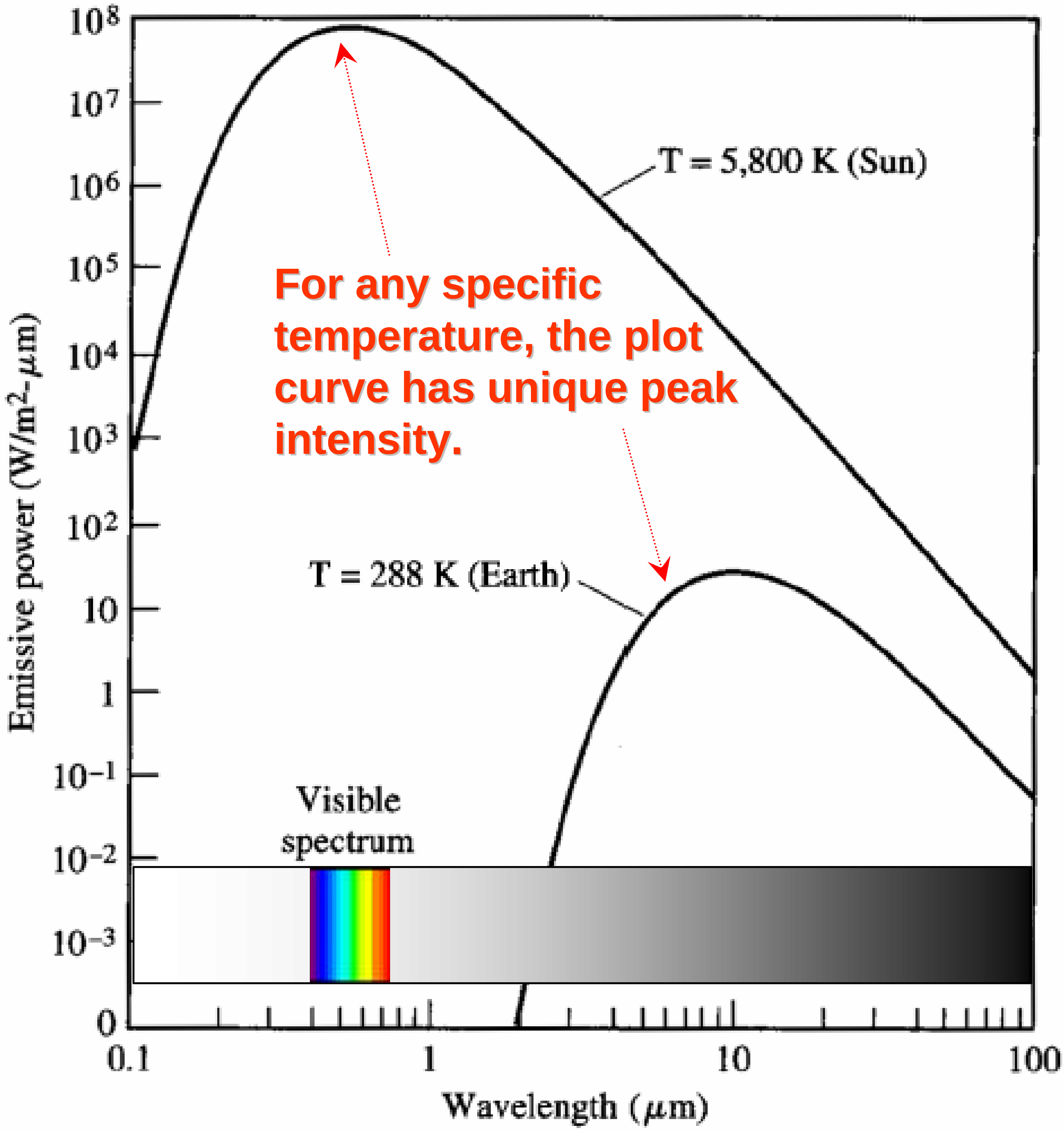
⇒ *How is remote sensing actually done from above such as airplanes or satellites?*

Black Body Radiation (BBR): Solar Energy

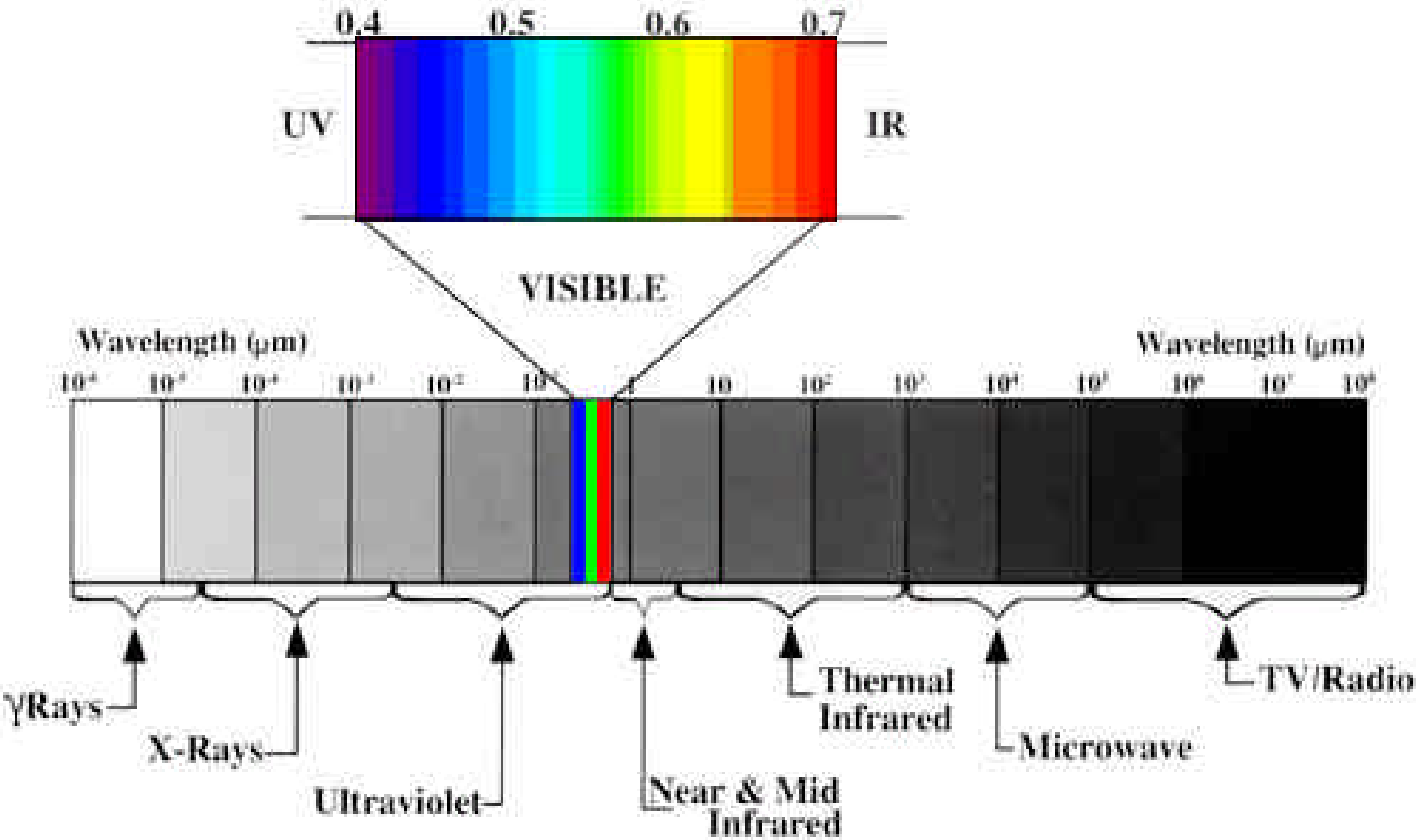
- All bodies whose temperature is above absolute zero emit BBR.

- The thermal state of the object determines BBR spectral plot, characterized by a total spectral interval.

- EM Spectrum chart shows the characteristics of <u>photons, emitted by thermal bodies</u>.

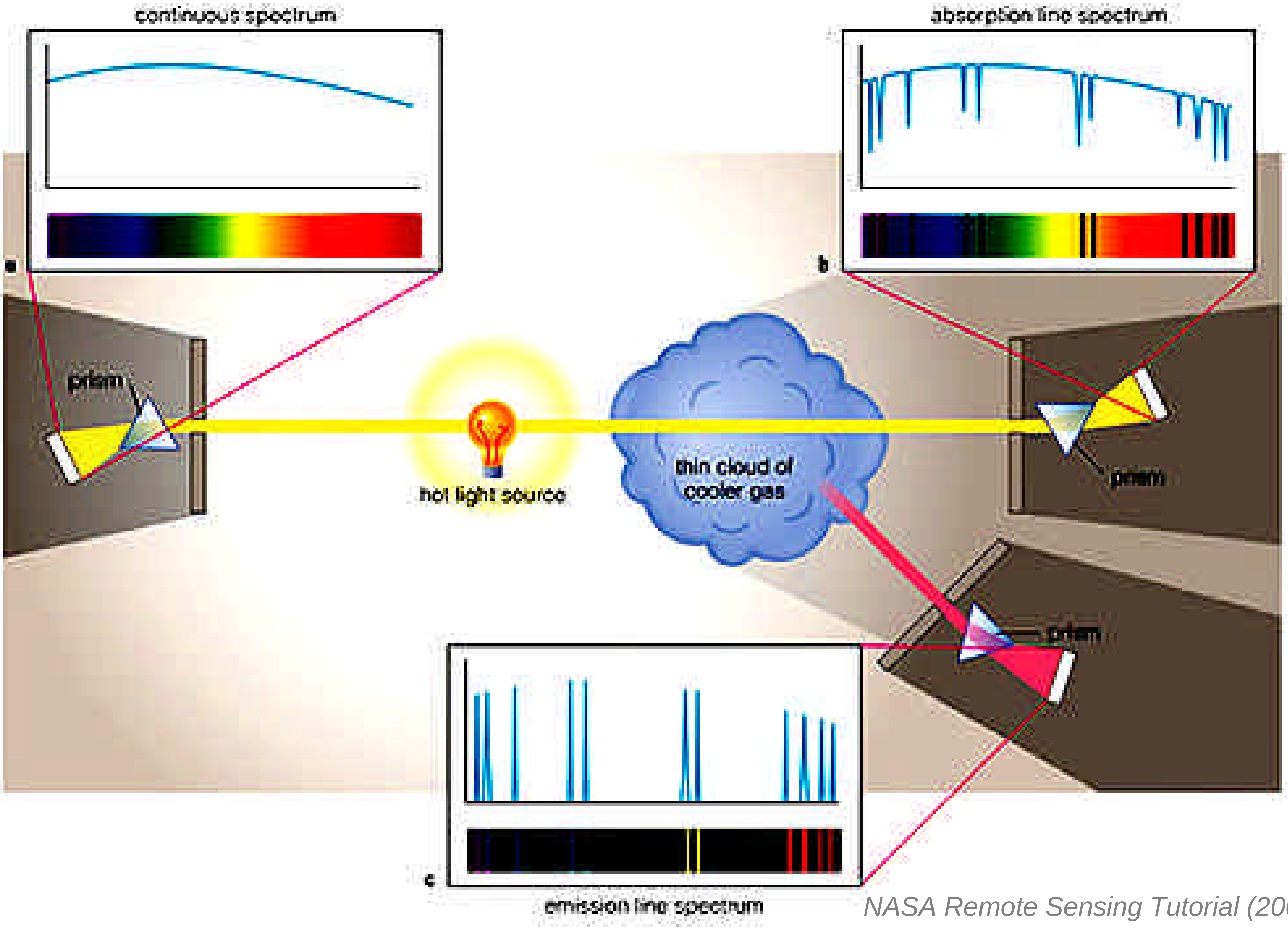


Electromagnetic Spectrum: Distribution of Radiant Energies



University of New Hampshire, Coastal Observing Center

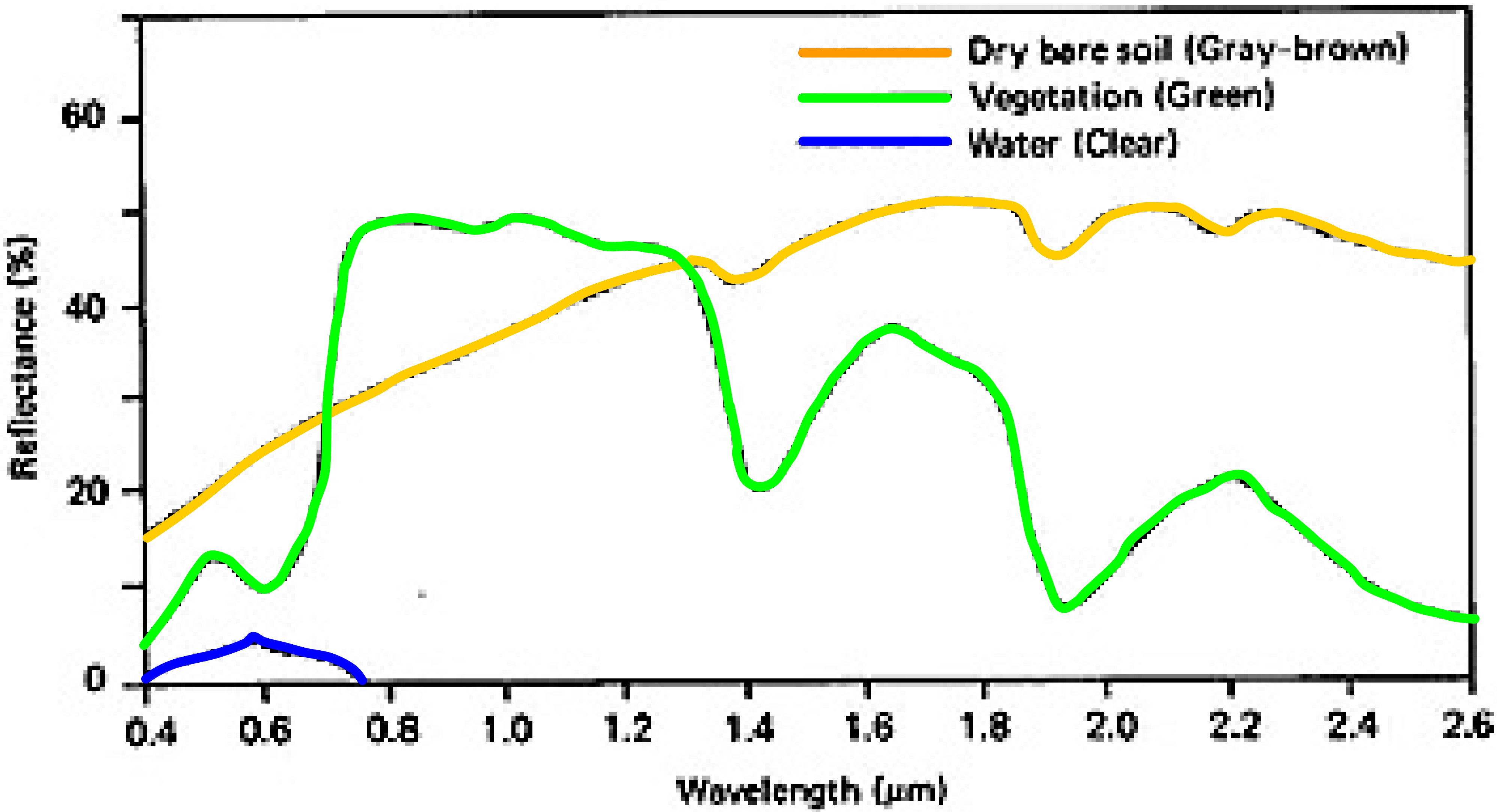
EM Spectrum: Transmittance, Absorptance, and Reflectance



NASA Remote Sensing Tutorial (2007)

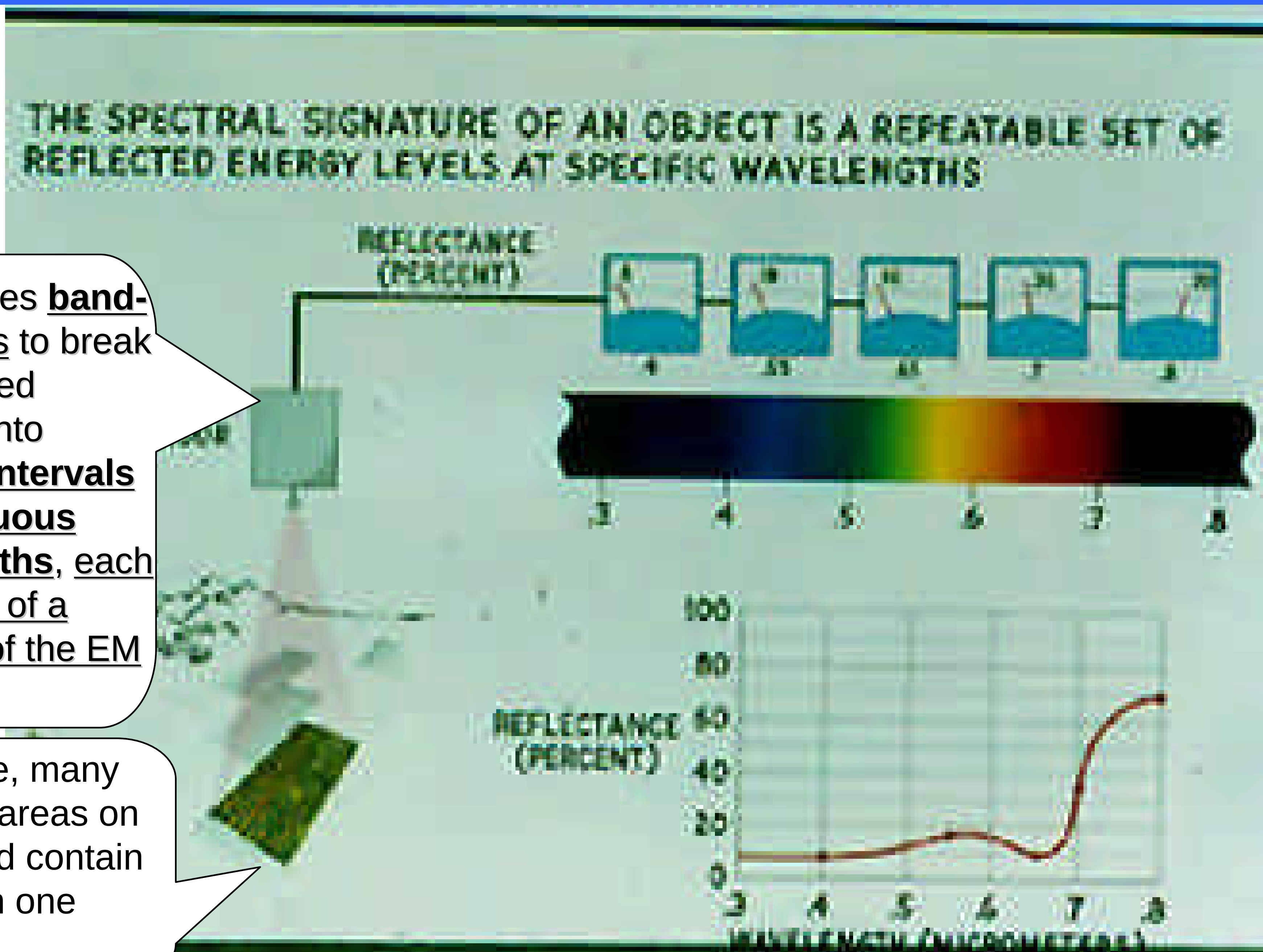
Spectral Signatures

Different features have differing and distinctive spectral signatures



NASA Remote Sensing Tutorial (2007)

Spectral Signatures: **bands** (channel)



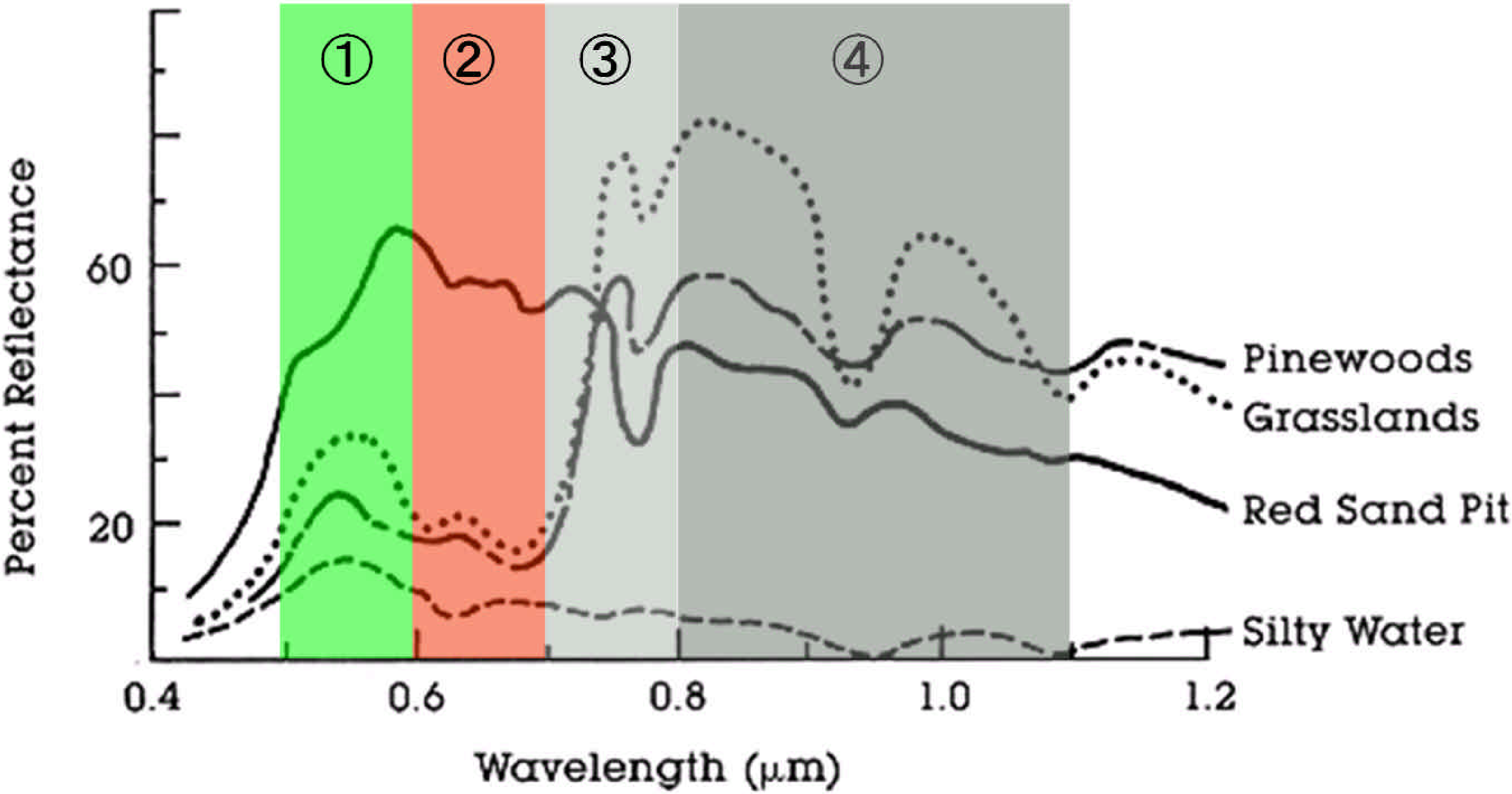
Sensor uses **band-pass filters** to break the reflected radiation into **discrete intervals of continuous wavelengths**, each consisting of a segment of the EM spectrum

In practice, many sampling areas on the ground contain more than one features.

NASA Remote Sensing Tutorial (2007)

Spectral Signatures: bands (channel)

MSS sensor (Landsat 1,2) with four bands



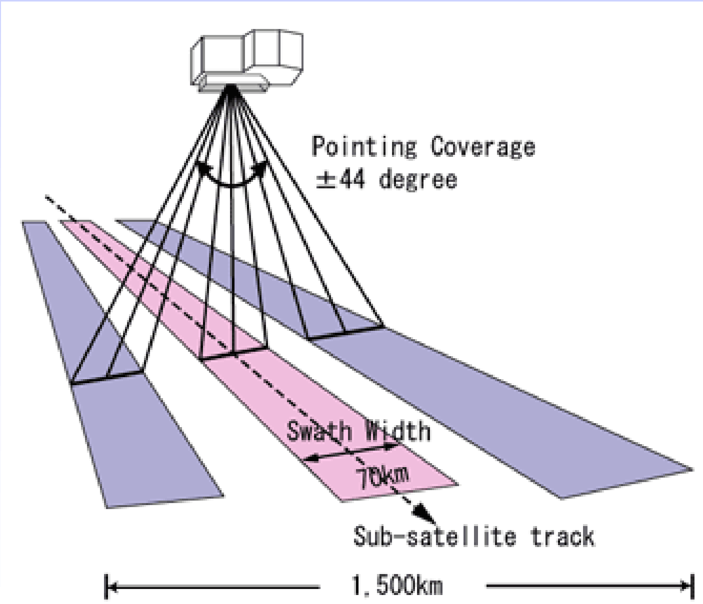
★ **Electromagnetic radiation is the information carrier about materials, objects and features**

NASA Remote Sensing Tutorial (2007)

III. Sensor Technologies

Remote sensing involves the use of **instruments or sensors to "capture"** the spectral and spatial relations of objects and materials observable at a distance - typically from above them.

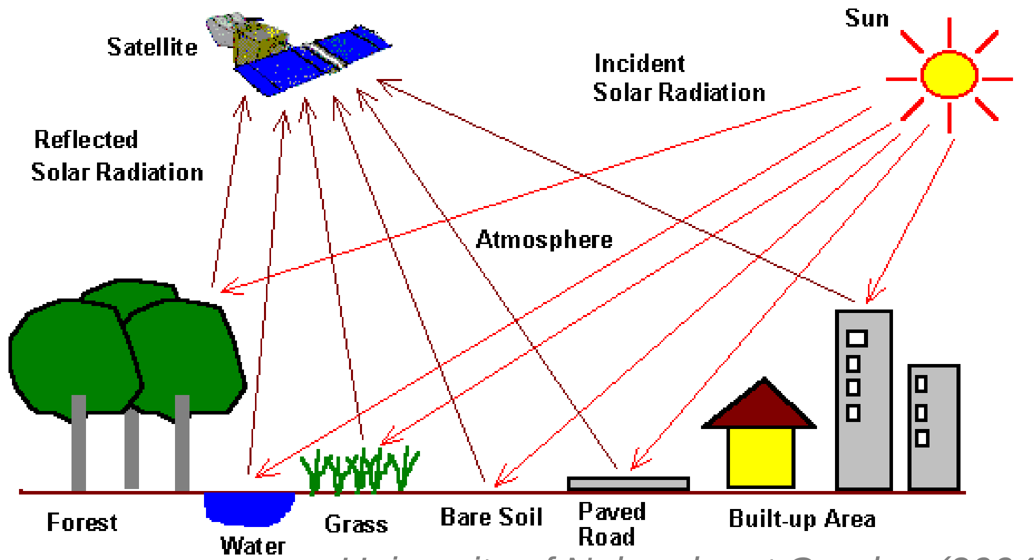
JERS-1



JAXA EORC (2007)

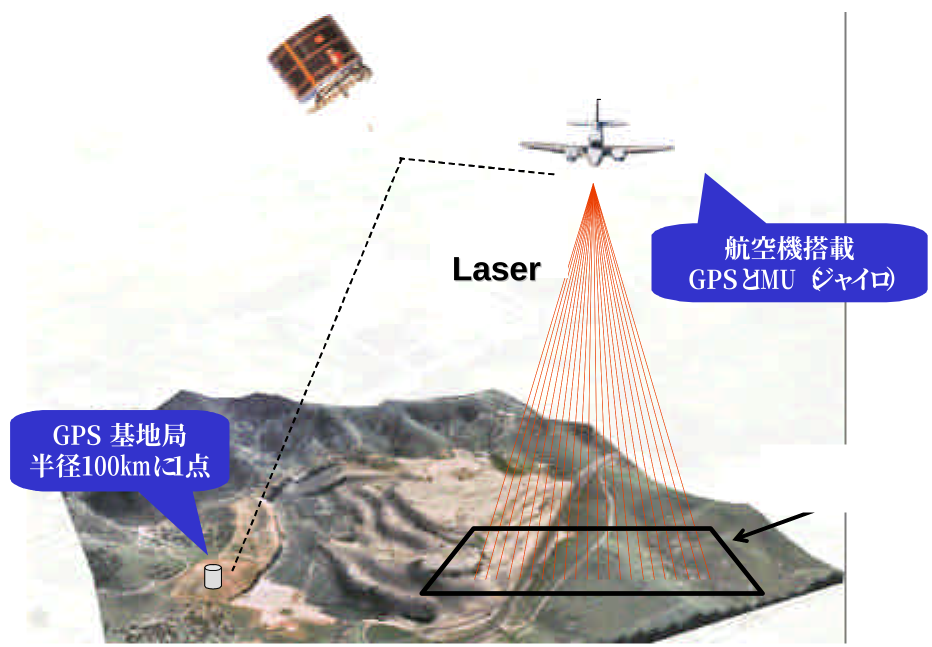
Two Classes of Sensors

Passive sensors detect natural radiation that is emitted or reflected by the object being observed. Sunlight is the most common source of radiation.



University of Nebraska at Omaha (2004)

Active sensors emit energy in order to scan objects and areas. The time delay between emission and return is measured, establishing the location, height, speed and direction of an object.



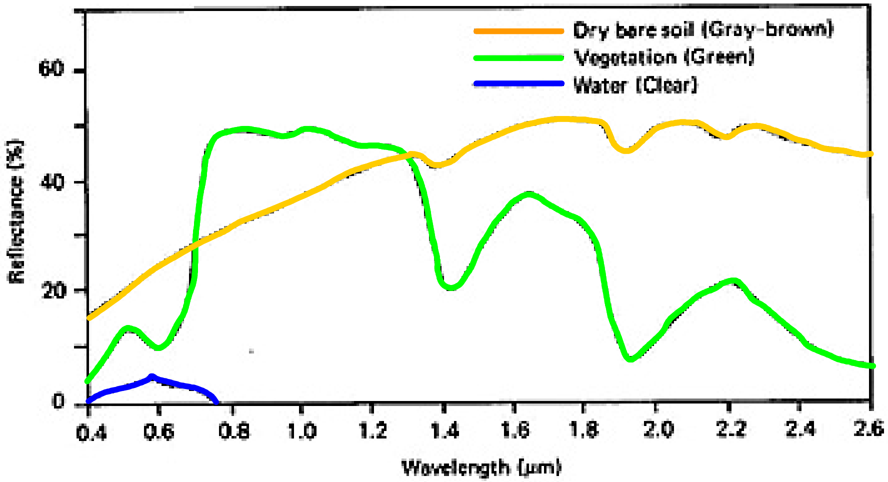
Resolution: The ability of remote sensors to identify

Sensors have four types of resolution

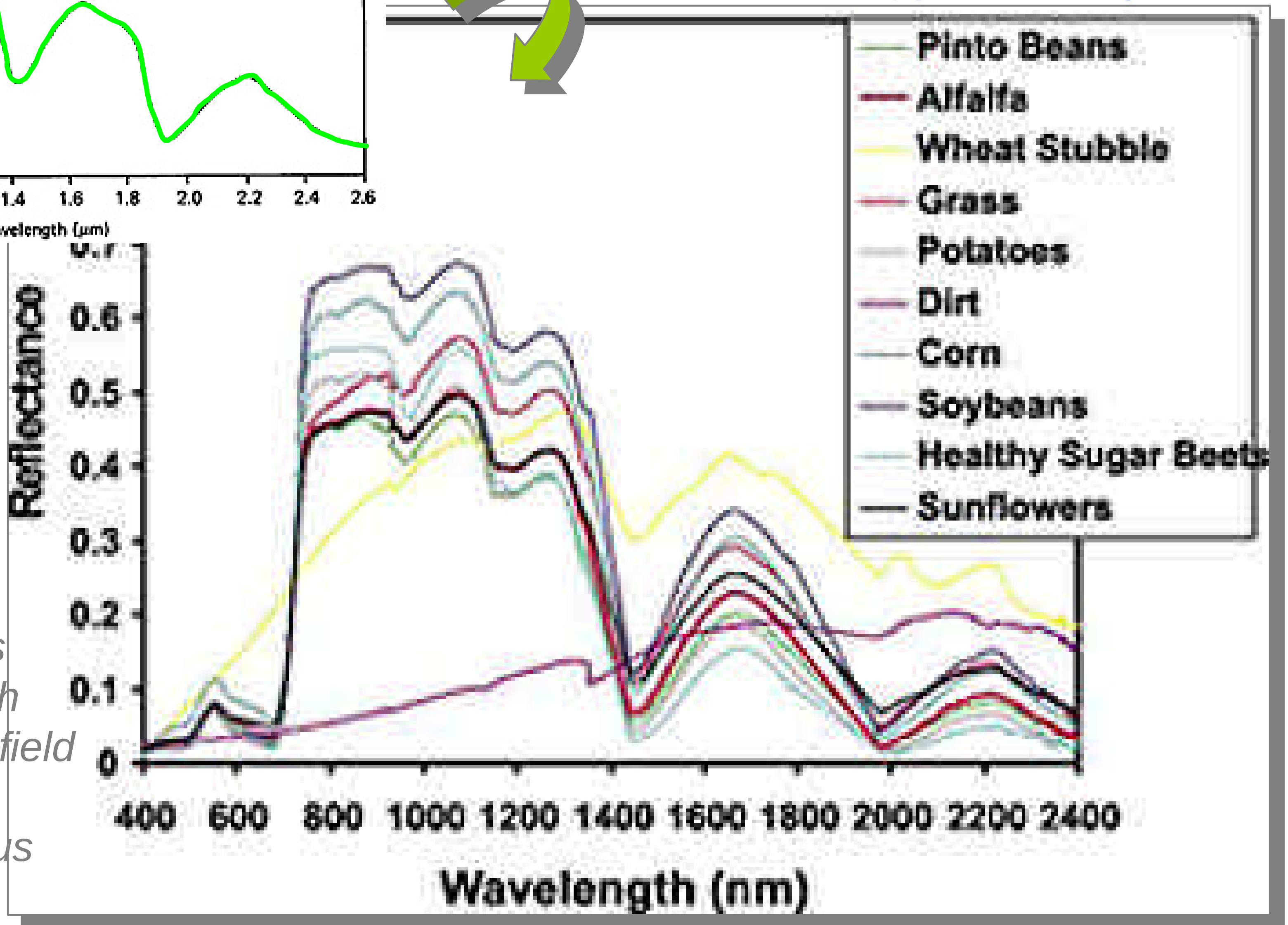
- ***Spectral resolution***
- ***Spatial resolution***
- ***Radiometric resolution***
- ***Temporal resolution****

** In a precise sense, temporal resolutions are not categorized in sensor technologies but <u>the satellite orbits</u>*

Spectral Resolution (1)



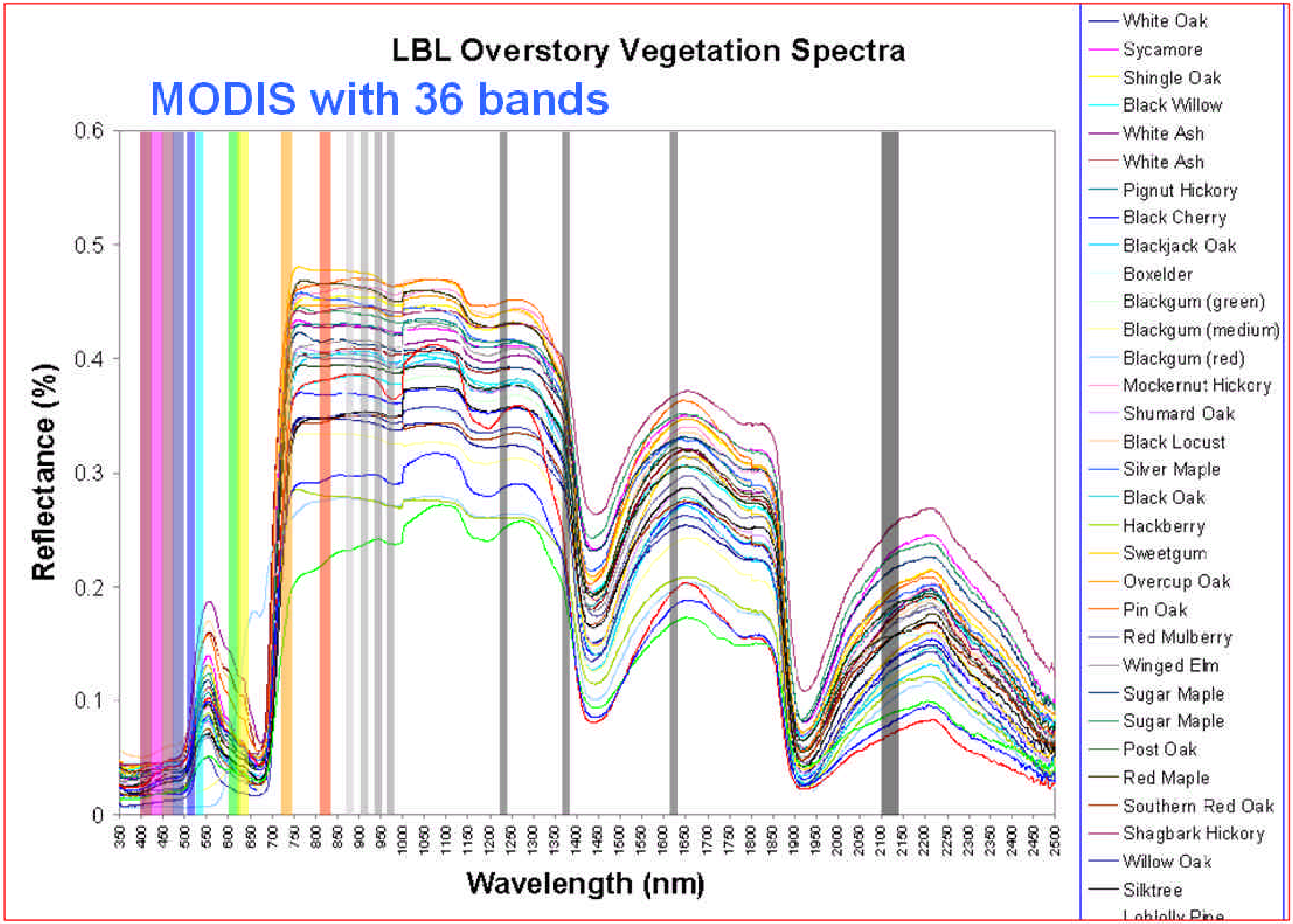
This is possible if good approximations of spectral signatures for each specific material type can be gained.



Spectral signatures obtained with a high spectral resolution field spectrometer that looked at the various species involved

NASA Remote Sensing Tutorial (2007)

Spectral Resolution (2)



NASA Remote Sensing Tutorial (2007)

Radiometric Resolution (1)

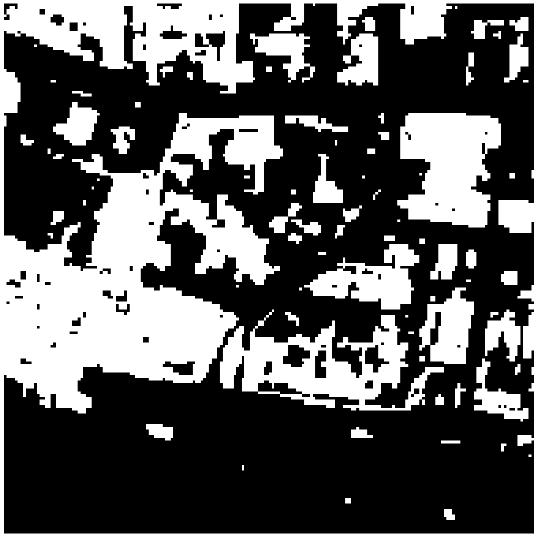
✓ **Radiometric resolution** is a rather deep concept that relates to the levels of quantization that can be established to improve scene quality

✓ For example, consider a range of radiation intensities like brightness levels.

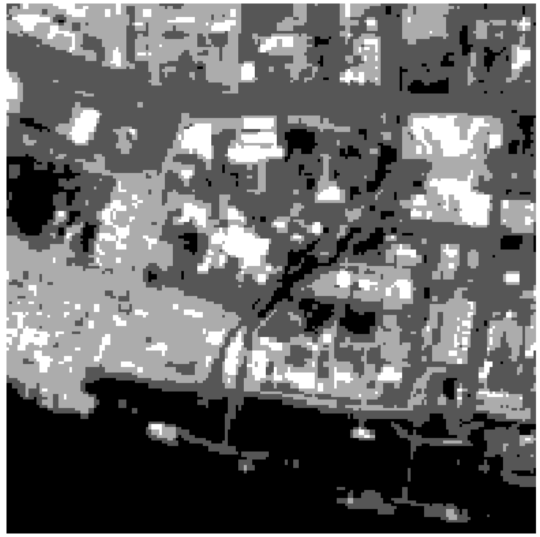
⇒ *This continuous range can be subdivided into a set of values of steadily increasing intensity.*

⇒ *Each subdivision is a "level" that in a black and white version of a scene represented by some degree of grayness.*

Radiometric Resolution (2)



2 *(2^1)*



4 *(2^2)*

8 *(2^3)*

16 *(2^4)*

- ✓ Most sensors convert intercepted radiation into a digital form, which consists of a number that falls within some range of values. **Radiometric resolution** defines this range of values.

- ✓ A 6-bit sensor (e.g. Landsat MSS) has a range of 64.
- ✓ A sensor with 8-bit resolution (e.g. Landsat TM) has a range of 256 levels.

Spatial Resolution

Spatial resolution **2.4m**
(QuickBird: True color)

Spatial resolution **0.6m**
(QuickBird: Pan sharpen)

The "ability to recognize and separate features of specific sizes"

Temporal Resolution

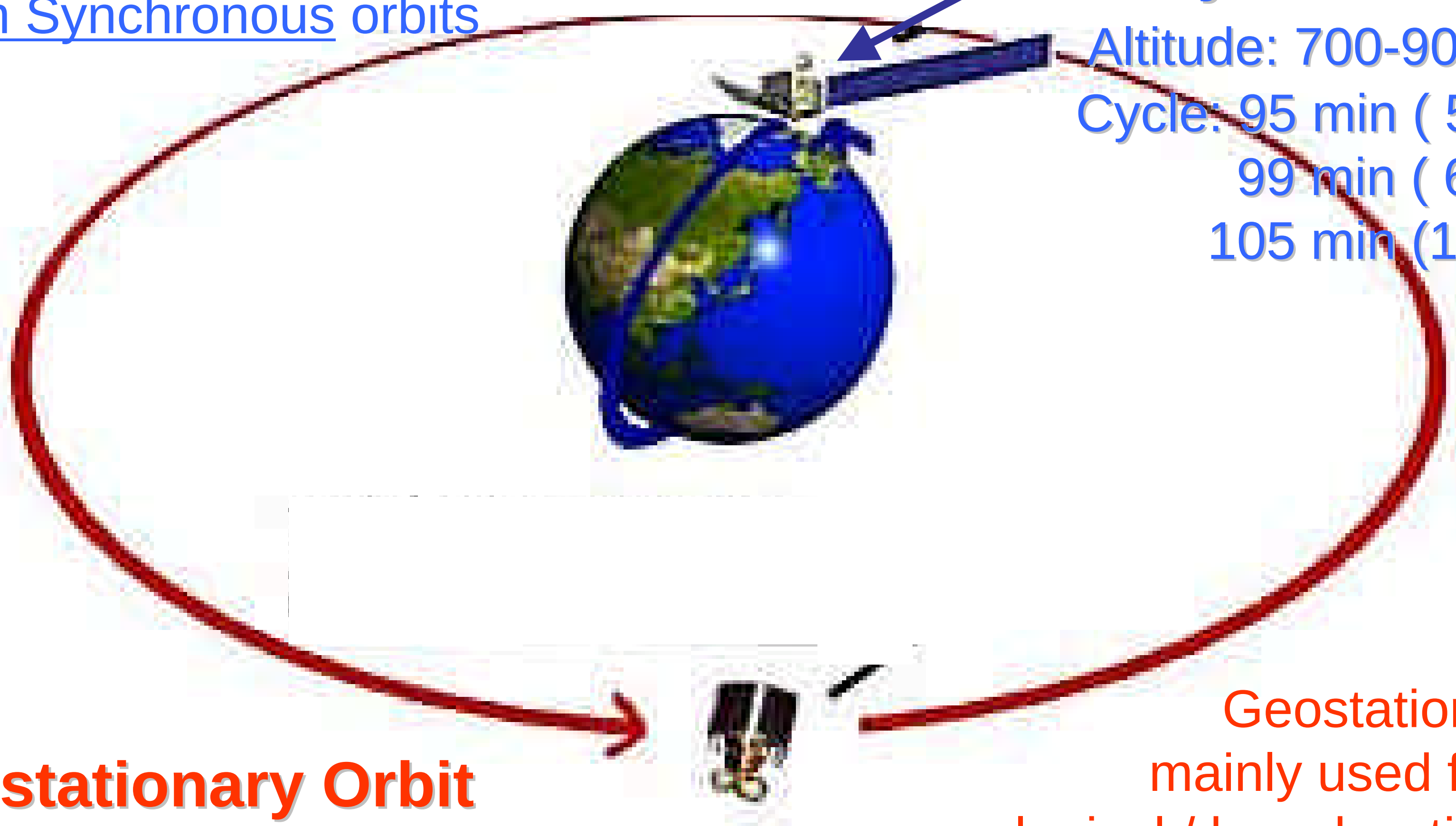
JAXA (2005)

The time taken for a satellite to make one complete orbit highly depends on the height above ground. The higher the satellite is, the longer it takes to make a complete orbit.

Many remote sensing satellites are in Sun Synchronous orbits

Sun Synchronous Orbit

Altitude: 700-900km
Cycle: 95 min (500km)
99 min (692km)
105 min (1,000km)



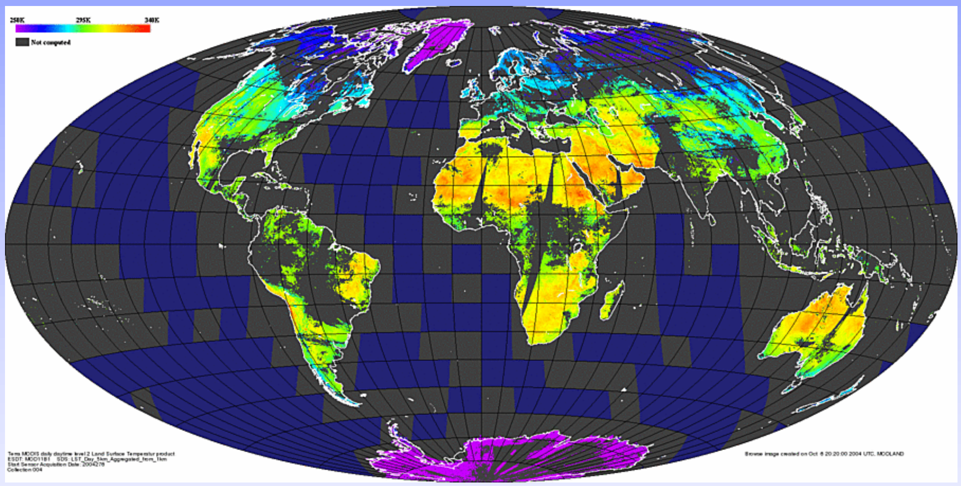
Geostationary Orbit

Altitude: 36,000km, Cycle: 24 hrs

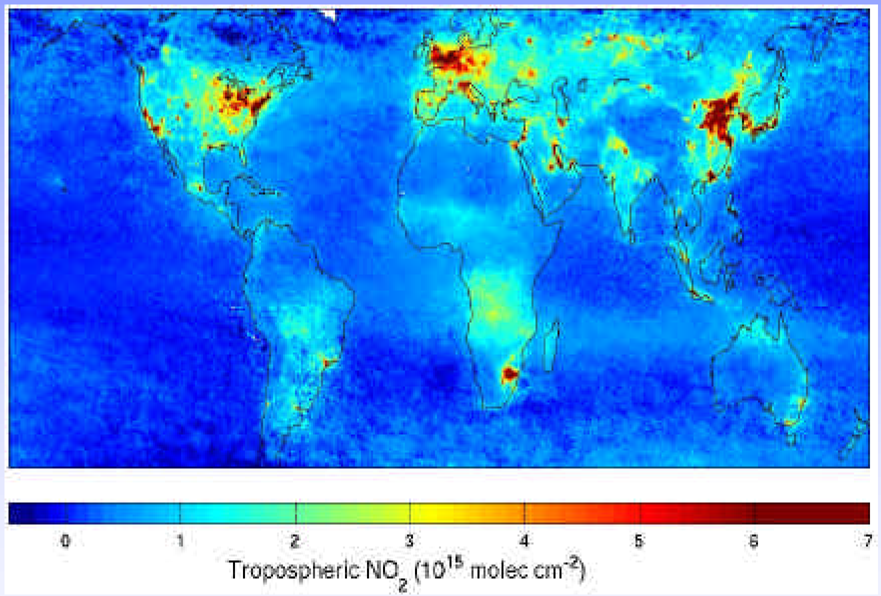
Geostationary Orbit is mainly used for meteorological / broadcasting satellites

JAXA ALOS (2008)

IV. Characteristics of Satellite Remote Sensing



Surface Temperature 2004/10/2
by MODIS *(SED, 2004)*



Tropospheric NO2 during May-Oct 2004
by SCIAMACHY *(R.V. Martin, Dalhousie U.)*

Advantage of Satellite Remote Sensing

- Global coverage with multiple scales

  Various spatial scale and wide spectral range

- Data homogeneity

  Repetitive coverage with same resolutions with a regular cruising

- Relatively economical

  Non-intrusive and wide coverage

  Computer-based data processing

- Results is visual

  Intuitive understand

⇒ ***Essential Tools for Monitoring the Environmental Processes of Earth***

Forefront of Satellite Remote Sensing

- ✓ Hyper spatial
  10 m ⇒ 10 cm
- ✓ Hyper spectral
  100 nm ⇒ 10 nm [nano: one billionth]
- ✓ Wide range use
  Visible/near-infrared ⇒ Microwave
- ✓ Three dimensional measuring
  Area ⇒ Three dimension

Current Major Satellite Remote Sensing (1)

	Satellite	Sensor	Spectrum	Num of band	Spa. Resol.	Swath Width	Rep.Cycle
1984	LANDSAT5	TM	0.45 - 12.5 μm	**7 bands**	30 m	180km	**17days**
1986	SPOT	HRV	0.50 - 0.89 μm	4 bands	**10-20 m**	60km	26days
1991	ERS-1	**SAR**	**5.3 GHz**		30 m	100km	35days
1992	JERS-1	OPS	0.52 - 0.86 μm	4 bands	18 m	75km	44days
	“	**SAR**	**1.275 GHz**		18 m	75km	“
1996	ADEOS	AVNIR	0.40 - 0.92 μm	4 bands	8 - 16 m	80km	41days
	“	OCTS	0.40 - 12.5 μm	**12 bands**	700 m	**1400 km**	“
1981	NOAA7	AVHRR	0.58 - 12.5 μm	5 bands	1 km	2700 km	**0.5 day**

(Yasuoka, 2007) + α

Current Major Satellite Remote Sensing (2)

	Satellite	Sensor	Spectrum	Num of band	Spa. Resol.	Swath Width	Rep.Cycle
1999	TERRA	ASTER	0.52 - 11.3 µm	**14bands**	**15, 30, 90 m**	60km	
		MODIS	0.4 - 14.4 µm	**36 bands**	250,500m, 1km	2330km	
2002	ADEOS-2	GLI	0.375 - 12.5 µm	**36 bands**	250m, 1km	1600km	
1999	IKONOS	Pan/MSS	V/NIR	1band / 3bands	**1 / 4m**	21km	20days
2001	QuickBird	Pan/MSS	V/NIR	1band / 3bands	**1 / 8m**	8km	16days

⇒ ***Have to select a suitable sensor, by considering purpose, budget, and characteristics of sensors***

(Yasuoka, 2007) + α

Information Extraction **(Land)**

	MODIS	GLI	AMSR	SeaWiFS	NOAA/ AVHRR	TRMM/ PR、TMI、VIRS	LANDSAT /TM	ASTER	QuickBird
Land cover	◎ (1km)	○ (250m)	×	△ (1.1Km~)	○ (1.1Km~)	×	○ (30m）	○ (15m）	○ (0.6m）
Soil moisture	○ (1km)	○ (250m)	◎ (10km）	△ (1.1Km~)	×	○	○ (30m）	○ (15m）	○ (0.6m）
Vegetation	◎ (250m～)	◎ (250m)	×	◎ (1.1Km~)	◎ (1.1Km~)	×	○ (30m）	○ (15m）	○ (0.6m）
Surface te-mperature	◎ (1km～)	○ (250m)	×	×	◎ (1.1Km~)	×	○ (120m）	◎ (90m）	×
Terrain (DEM）	×	×	×	×	×	×	×	◎ (30m）	○
Land cov-er change	◎ (1km)	△ (250m)	×	×	○ (1.1Km~	×	○ (30m）	○ (15m）	△ (0.6m）

◎ :Product ○ :Extractable by process △ :Unfavorable × :Non-extractable

(SED, 2004)

Information extraction **(Ocean / Water body)**

	MODIS	GLI	AMSR	SeaWiFS	NOAA/ AVHRR	TRMM/ PR、TMI、VIRS	LANDSAT /TM	ASTER	QuickBird
Ocean color	◎ (1km)	○ (1km)	×	◎ (1.1Km~)	◎ (1.1Km~)	×	○ (30m）	△ (15m）	○ (0.6m）
Turbidity	○ (1km)	◎ (1km)	×	◎	○ (1.1Km~)	×	○ (30m）	△ (15m）	○ (0.6m）
Tempratu-re (SST)	◎ (1km)	◎ (1km)	◎ (10km）	◎ (1.1Km~)	◎ (1.1Km~)	◎ (0.25度）	○ (120m）	◎ (90m）	×
Chlorophyll	◎ (1km)	◎ (1km)	×	◎ (1.1Km~)	◎ (1.1Km~)	×	○ (30m）	△ (15m）	△ (0.6m）
Ocean wind	×	×	◎ (10km）	×	×	◎ (0.25度）	×	×	×
Precipitation	×	×	◎ (10km）	×	×	◎ (0.25度）	×	×	×

◎ :Product ○ :Extractable by process △ :Unfavorable × :Non-extractable

(SED, 2004)

PRESENT AND FUTURE SATELLITE OBSERVATIONS OF TROPOSPHERIC CHEMISTRY

Platform	multiple		ERS-2	Terra		ENVISAT		Space station	Aura			TBD	TBD
Sensor	TOMS	AVHRR/ SeaWIFS	GOME	MOPITT	MODIS/ MISR	SCIAMACHY	MIPAS	SAGE-3	TES	OMI	MLS	CALIPSO	OCO
Launch	1979		1995	1999	1999	2002	2002	2004	2004	2004	2004	2004	2005
O_3	N					N/L	L	L	N/L	N	L		
CO				N		N/L	L		N/L				
CO_2						N/L							N
NO									L				
NO_2			N			N/L				N			
HNO_3							L		L				
CH_4						N/L			N				
HCHO			N			N/L				N			
SO_2			N			N/L				N			
BrO			N			N/L				N			
HCN											L		
aerosol	N	N			N	N		L		N		N	

N: Nadir mode, L: Limb mode
N/L: Nadir/Limb matching

Increasing spatial resolution

Randall V. Martin (2003)

Limits and errors of Satellite Remote Sensing

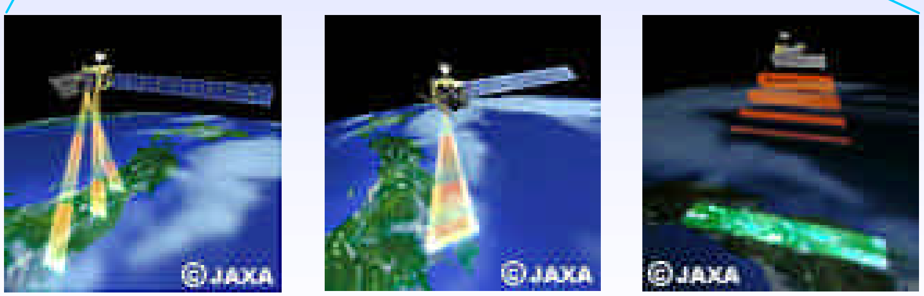
- Each sensor has strength and weakness, and own limitation
  - *No perfect single sensor exists*
  - *Combination of resolutions generates additional limitation*

- Accidental errors exist
  - *Errors by the sensors' omitted energy itself*
  - *Detector (semiconductor device) errors and bios*
  - *Sensor calibration error*
  - *Platform sensors' control errors of the altitude and position determination accuracy (,which will affect geometric correction precision of images)*

- Validation is necessary for improving the credibility of sensor observation.

(Takeuchi, 2008)

V. Cutting Edge Technology:
ALOS (Advanced Land Observing Satellite)



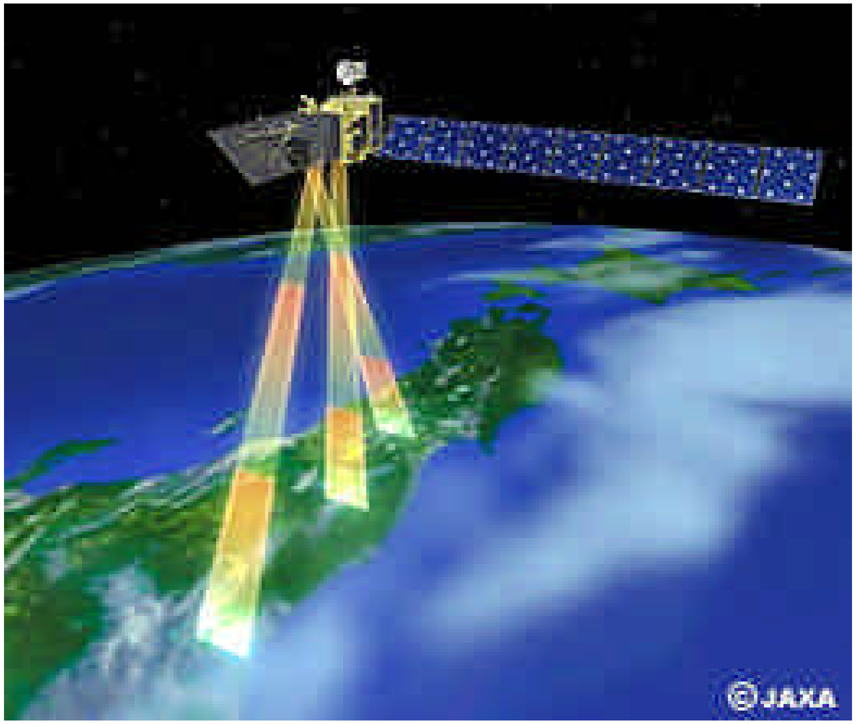
Three sensors

Launched by Japan Aerospace Exploration Agency in 2006.
The size of ALOS is 3.5m wide x 4.5m long x 6.5m high, with its Solar Battery Paddle is 22m x 3m wide, gross weight is approximately 4 tons, which is one of the largest among Land Observing Satellites.

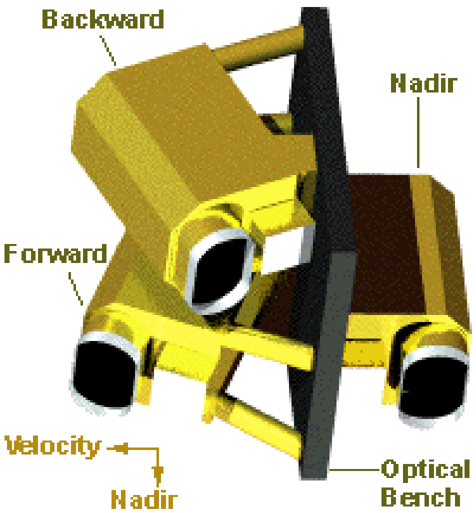
Major Mission of ALOS includes cartography, regional observation, disaster monitoring and resource surveying.

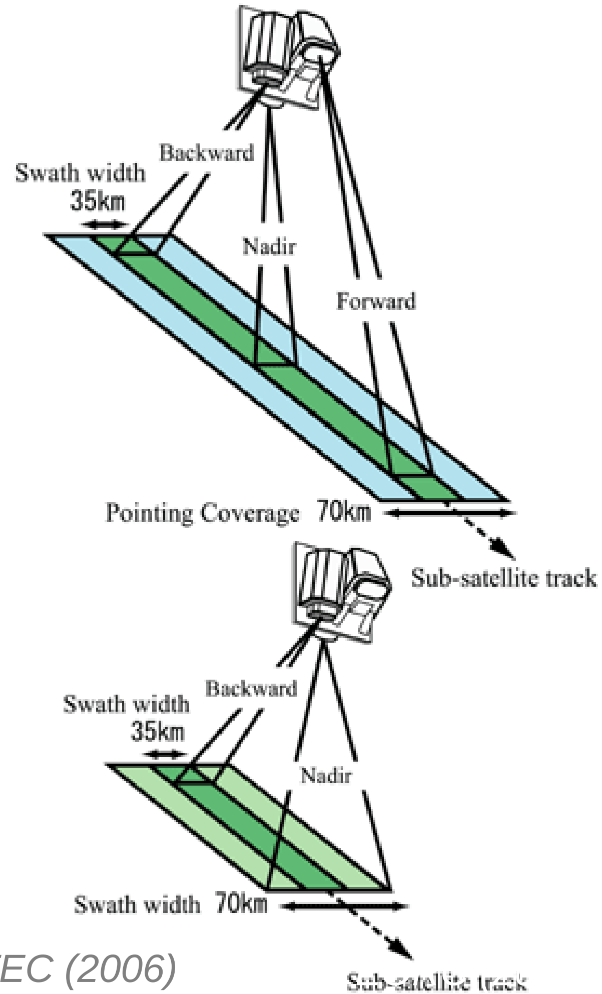
RECTEC (2006)

PRISM: Panchromatic Remote-sensing Instrument for Stereo Mapping



"PRISM" has three independent optical systems for viewing nadir, forward and backward producing a stereoscopic image along the satellite's track.





RECTEC (2006)

- ✓ PRISM observes earth surface with <u>2.5m spatial resolution</u>, so that it is used for mapping, urban planning, monitoring designated area etc.
- ✓ PRISM can also support so called as "3D image".

PRISM: Panchromatic Remote-sensing Instrument for Stereo Mapping

RECTEC (2006)

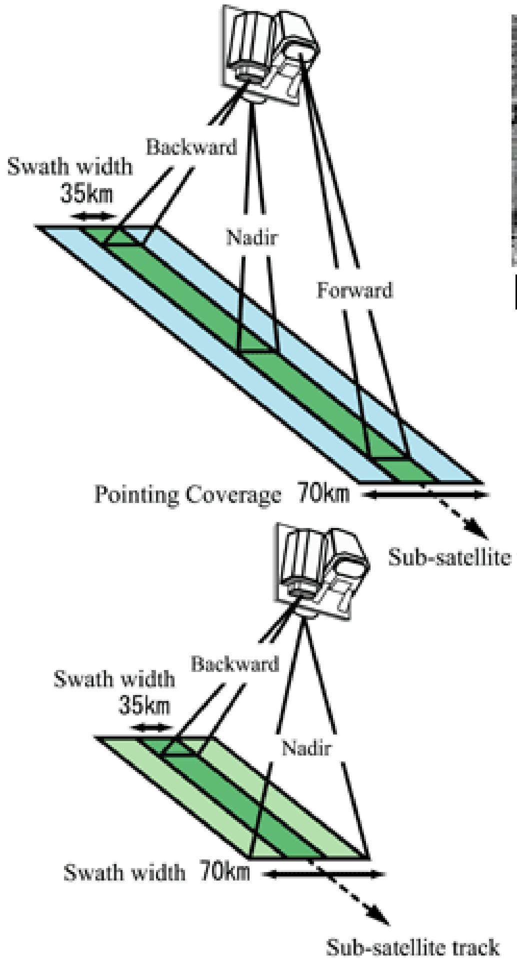


Image backward

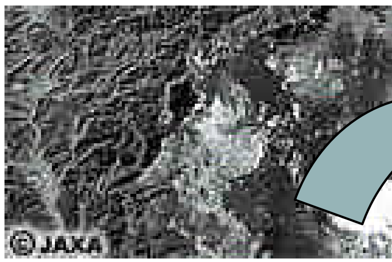


Image at Nadir

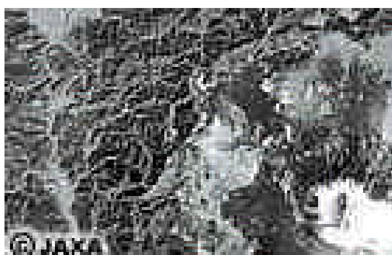
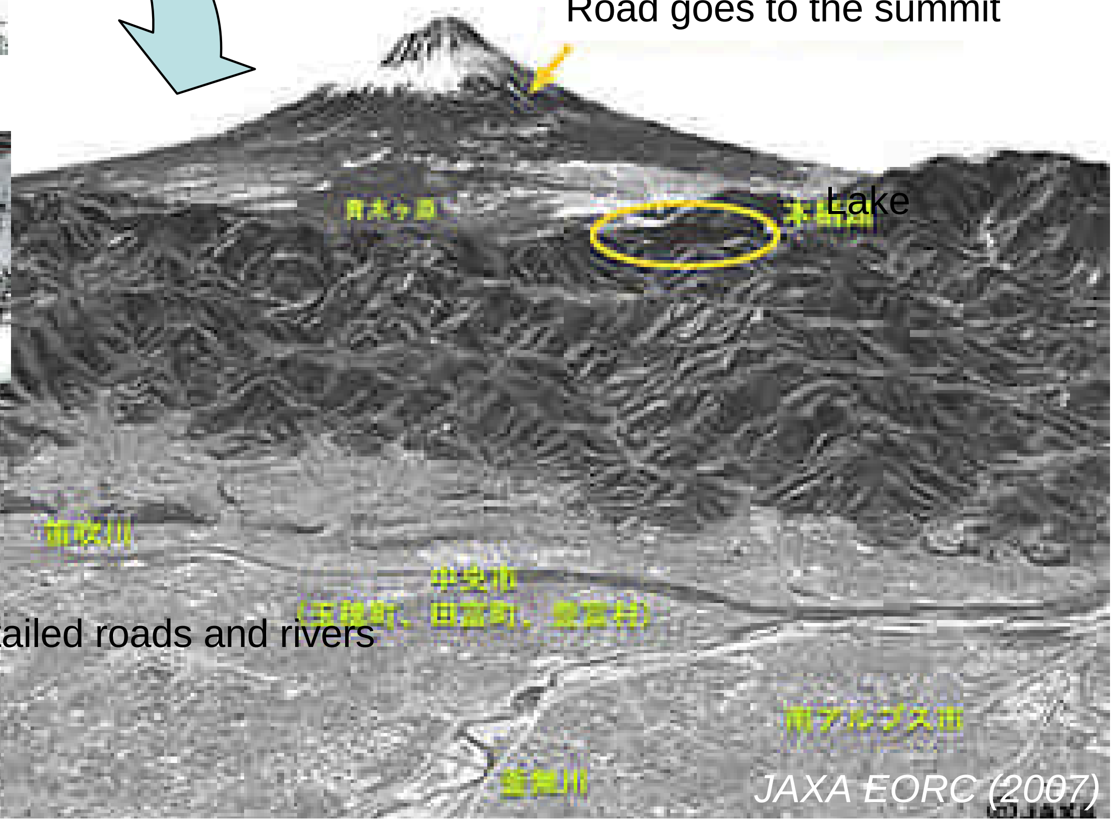


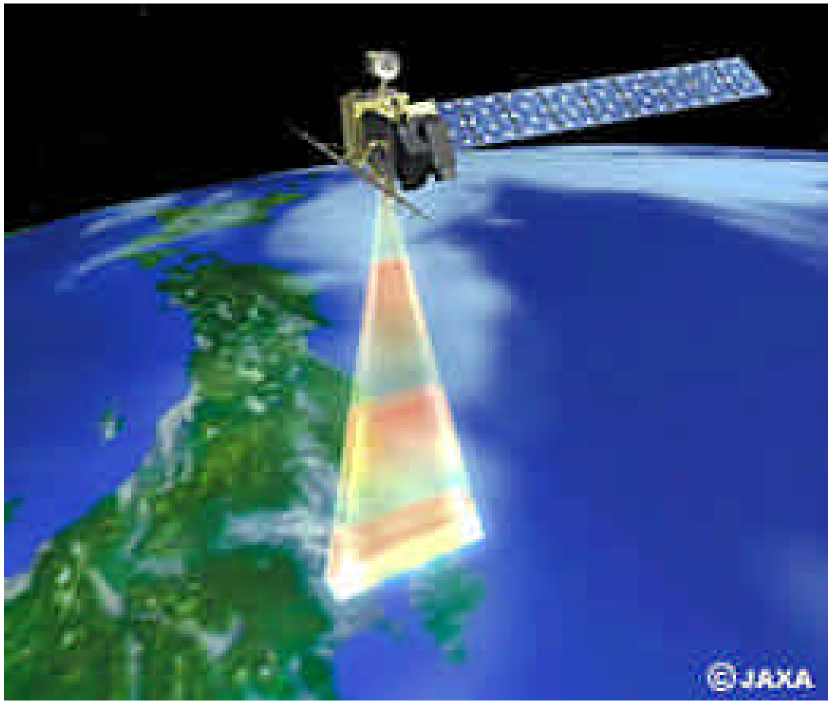
Image Forward

Altitude information is calculated through those images on the left, then pile PRISM image at Nadir to make an bird's eye view.

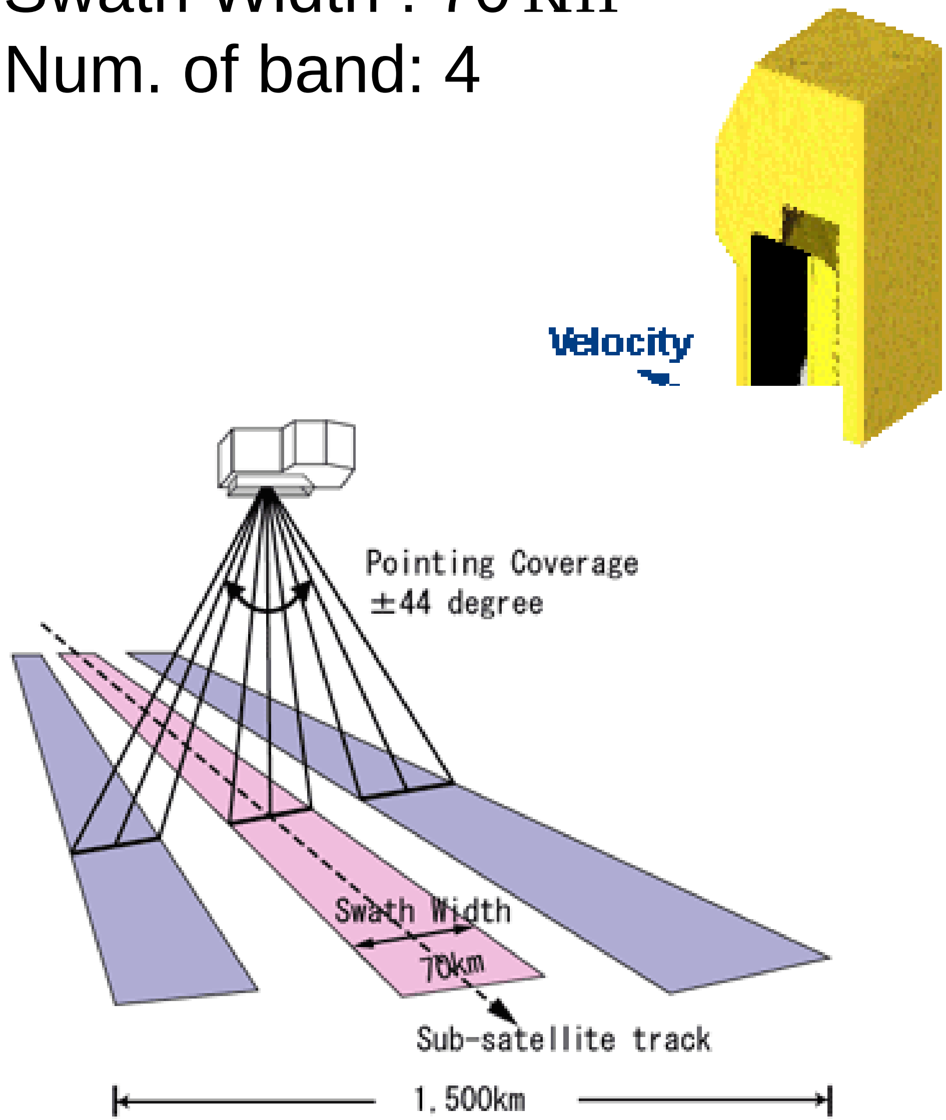


PRISM extracted image of Mt. Fuji

AVNIR-2: Advance Visible and Near Infrared Radiometer type 2



Spatial Resolution : 10m
Swath Width : 70 ㎞
Num. of band: 4

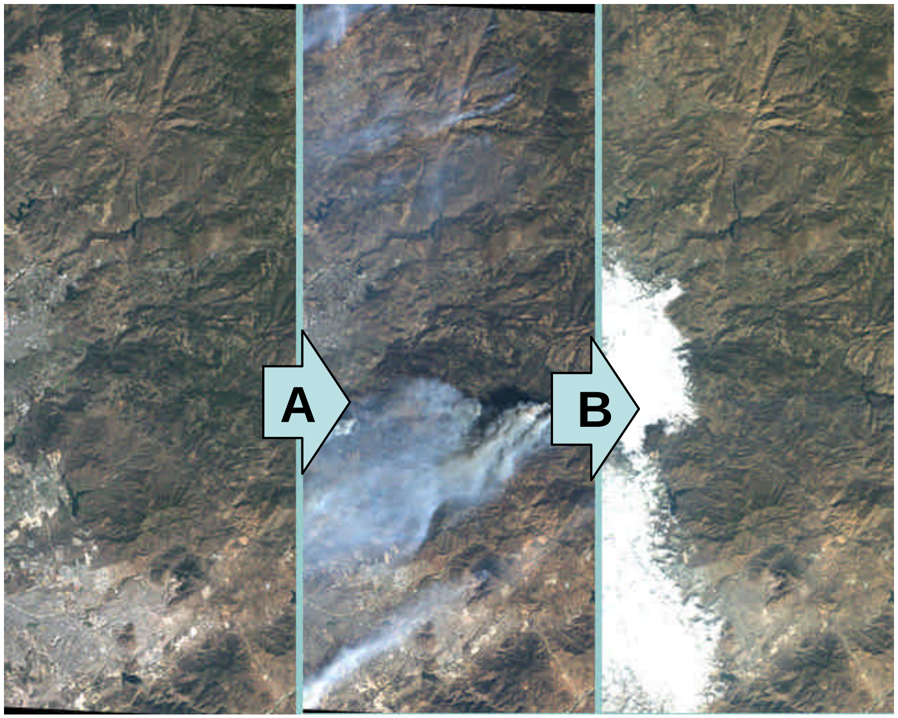


AVNIR-2 is sensor for a visible and near infrared radiometer for observing land and coastal zones.

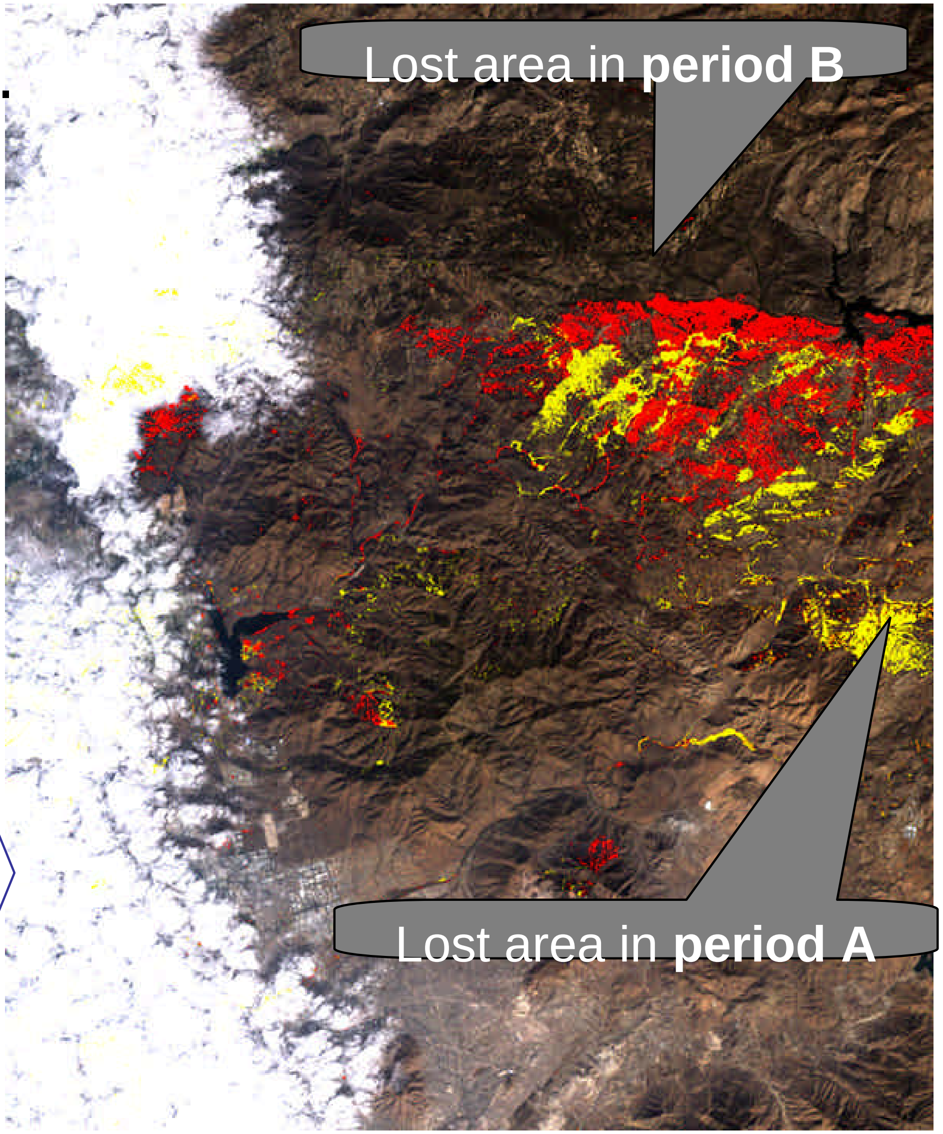
RECTEC (2006)

AVNIR-2: Advance Visible and Near Infrared Radiometer type 2

Vegetation loss area **by the forest fire in** Southern California. This estimation map of vegetation loss was created by analyzing three AVNIR images taken by ALOS.



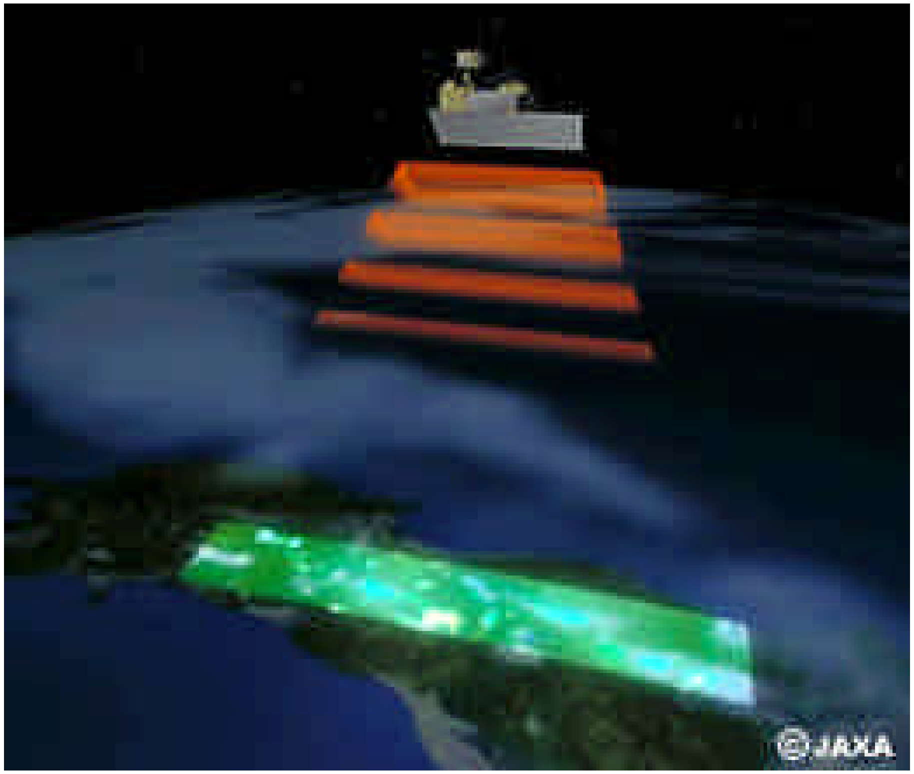
2006/10/20, 2007/10/23, 2007/11/06



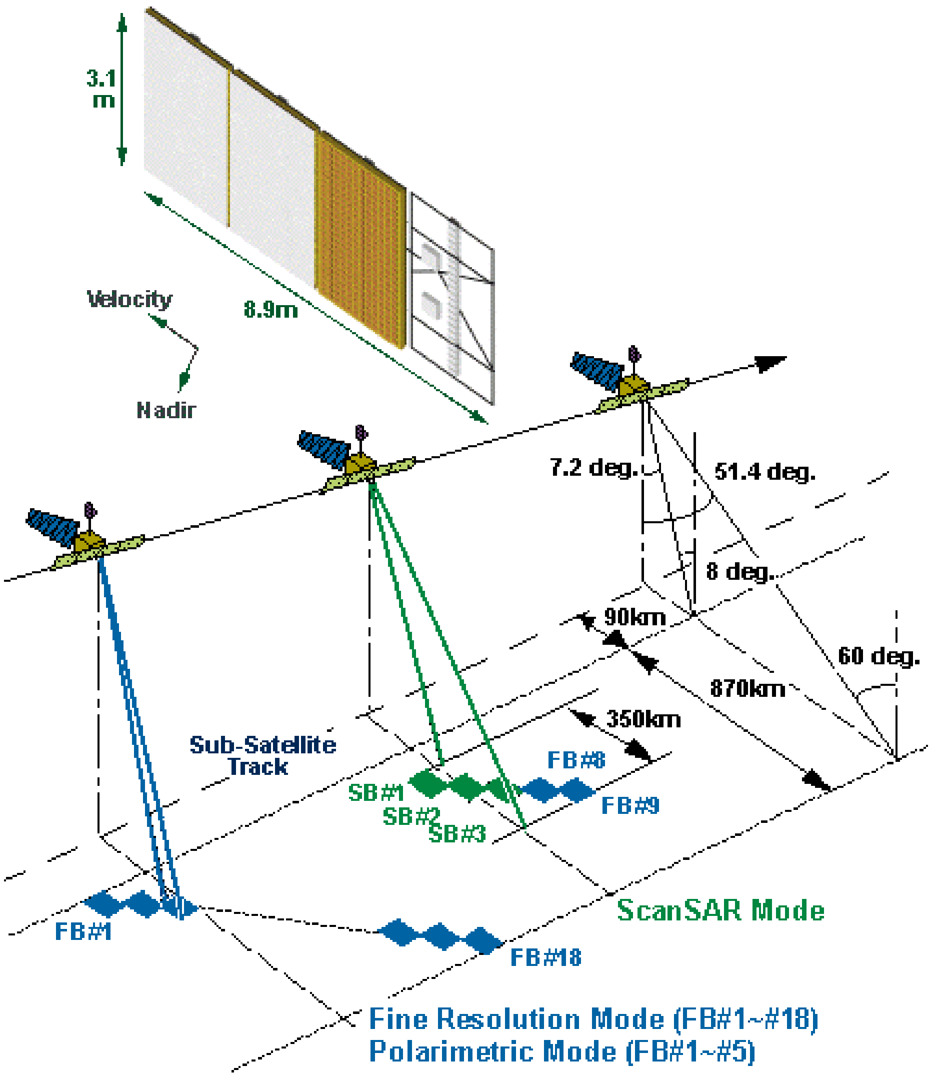
JAXA EORC (2007)

PALSAR: The Phased Array type L-band **Synthetic Aperture Radar**

RECTEC (2006)



PALSAR is an active microwave sensor using L-band frequency, called Synthetic Aperture Radar.

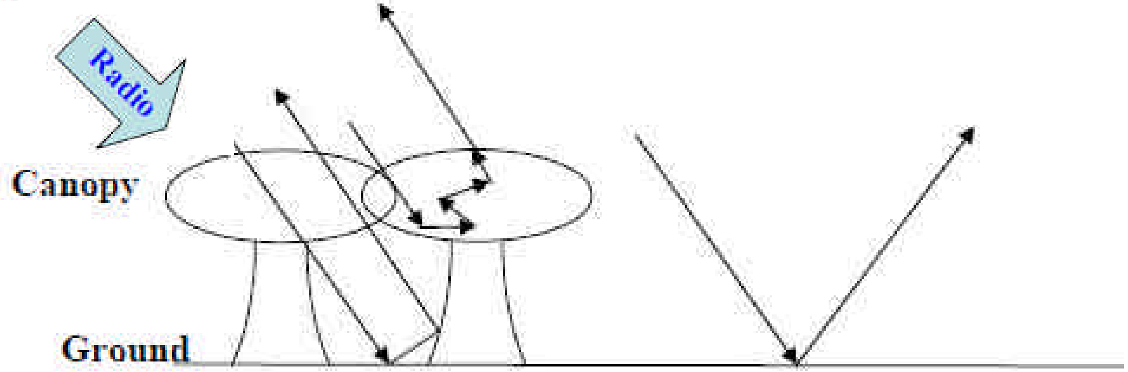


- ✓ It enables to conduct **<u>cloud-free</u>** and **<u>day-and-night</u>** land observation.
- ✓ It is utilized to <u>make DEM</u> and to <u>monitor designated area</u>.

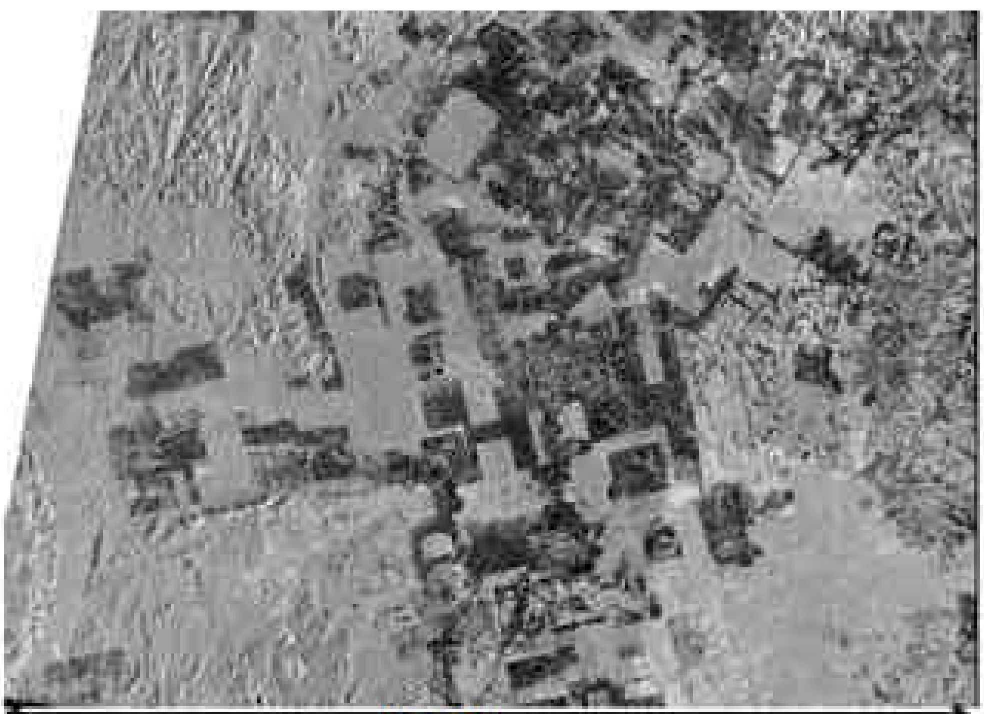
PALSAR: The Phased Array type L-band **Synthetic Aperture Radar**

JAXA EORC (2007)

Spatial Resolution : 10m/100m

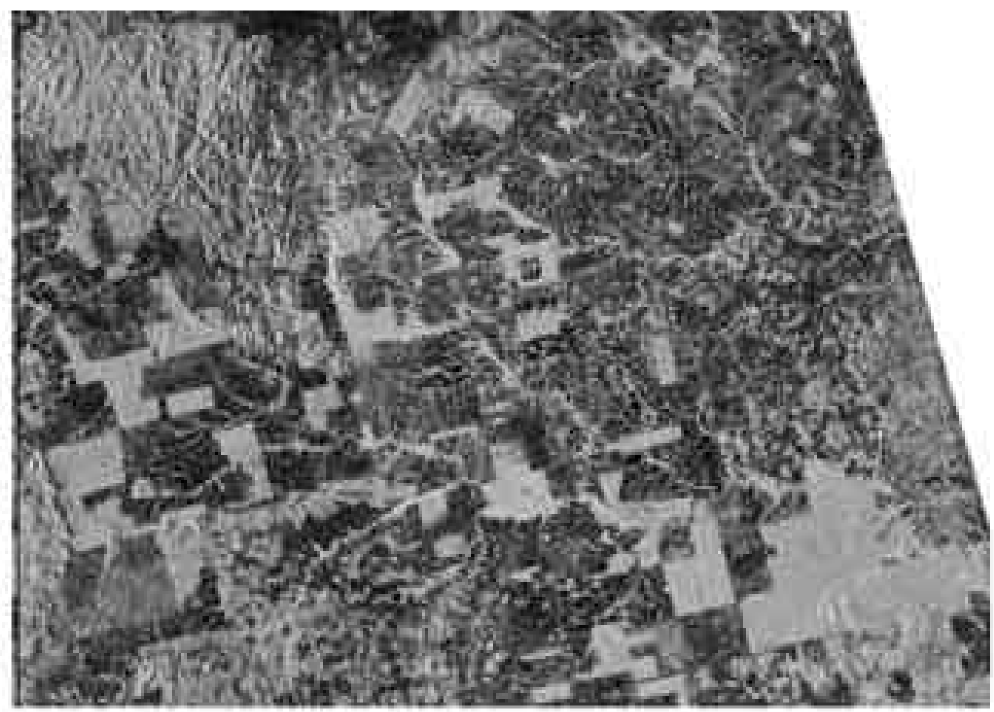


Amazon deforestation in 10 years as determined using L-band SAR data.



100km

October 1996 (JERS-1)



June 2006 (PALSAR)

ALOS Major Specifications

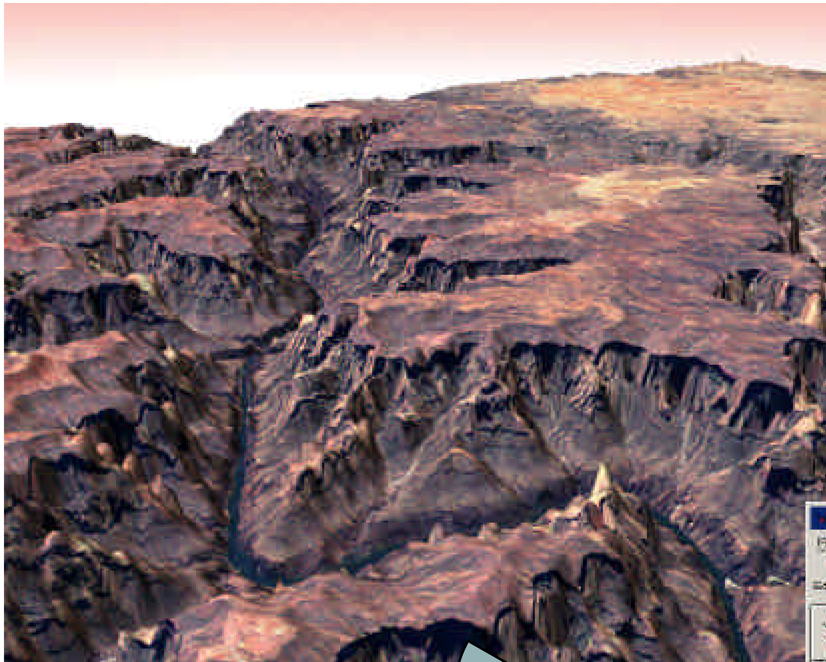
Launch Site	Tanegashima Space Center, Japan (2006)
Spacecraft Mass	Approx. 4 tons
Generated Power (Solar paddle)	Approx. 7kw (at End Of Life)
Designed EOL	3-5 years
Orbit	Sun Synchronous, Sub recurrent Repeat Cycle: 46 days Altitude : 691.65km (Above the equator)
Attitude Determination Accuracy	2.0 x 10-4 deg. (off-line, with GCP)
Position Determination Accuracy	1m (off-line)
Data Transfer Rate	240Mbps (Via Data Relay Test Satellite) 120Mbps (Direct Transmission)
On-board Data Recorder	Solid-state Data Recorder (90Gbytes)

671 circles for covering all Earth surface

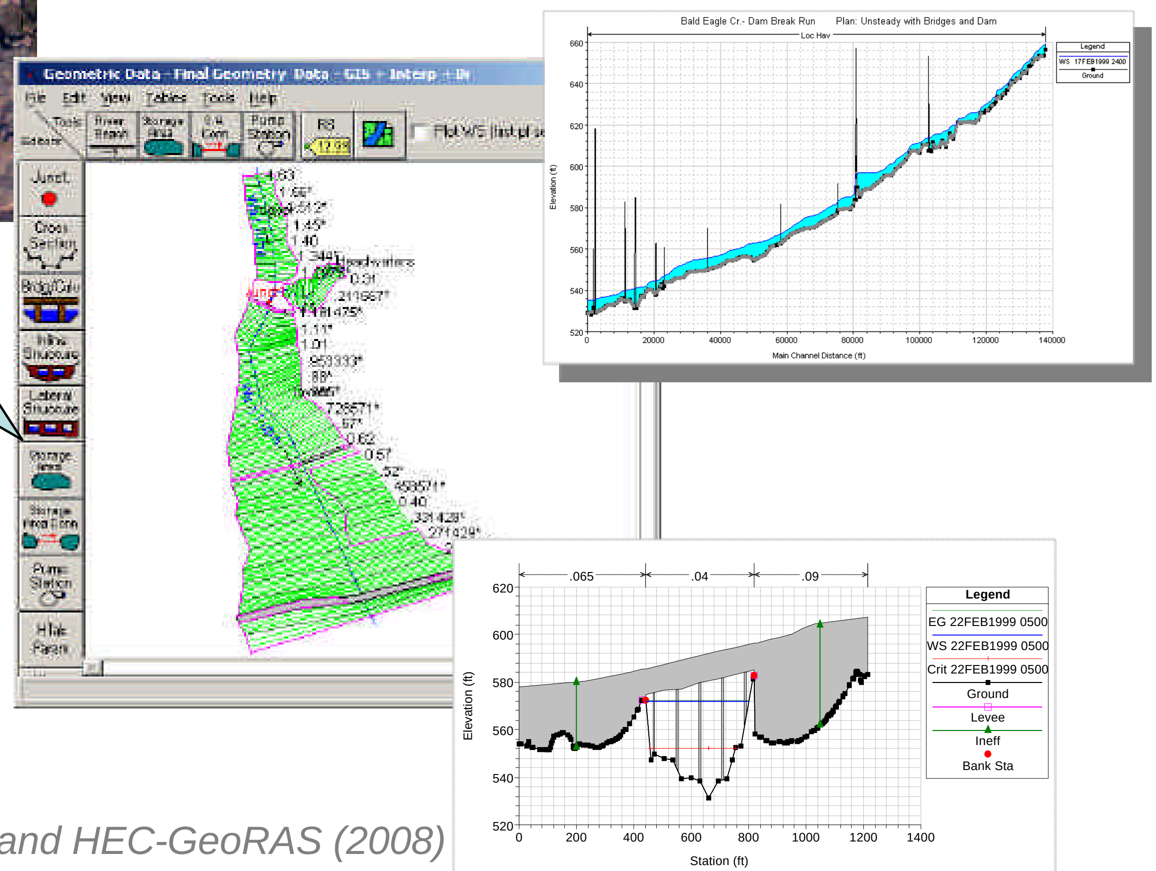
Data equal to about 16 CD-ROMs (PRISM 11, AVNIR 2, PALSAR 3) are collected every minute in ALOS!

RECTEC (2006)

How to contribute to environmental management?



E.g., understand the flow mechanism under the various conditions in climate and landuse in local scale, because it allows analyzing and simulating water flow even in **the area where complete flow analysis was difficult in past days, because of the lack of appropriate spatial resolution data.**



 Analysis images using JAXA EORC (2006) and HEC-GeoRAS (2008)

VI. Conclusions

Summary

- The emergence of a satellite platform improved spatial extend and frequency of an observation dramatically.
- Understanding the nature and characteristics of the electromagnetic radiation in terms of sources and behavior is important, because the EM radiation is the information carrier about materials, objects and features
- Developing various sensors such as micro wave, thermal infrared, and multi-spectral sensors increased information quality
- Each sensor has it’s own characteristics in spectral, radiational, spatial and temporal resolutions.
- Understanding the limits and errors of Satellite Remote Sensing is also important

Future earth observation programs *(selected)*

- **OCO (Orbiting Carbon Observatory)** , USA, scheduled for fall 2008
- **SAOCOM (Satellites for Observation and Communications),** Argentina, scheduled for 2008
- **GOSAT (Greenhouse gases Observing Satellite)**, Japan, scheduled for August 2008
- **CBERS Satellite Series-3**, China (and Brazil), planned in 2008 (CBERS-4: planned in 2011)
- **Pleiades-HR (High-Resolution Optical Imaging Constellation),** France, planned for late 2009

Reference of this lecture note 1

- **NASA Remote Sensing Tutorial**
  http://rst.gsfc.nasa.gov/
- **SED: Space Engineering Development Co., Ltd.**
  http://www.sed.co.jp/en/index.html
- **RESTEC: Remote Sensing Technology Center of JAPAN,** http://www.restec.or.jp/top_e.html
- **JAXA EORC: Japan Aerospace Exploration Agency Earth Observation research Center**
  http://www.eorc.jaxa.jp/en/index.html
- **JAXA ALOS Website**
  http://alos.jaxa.jp/index-e.html
- **Dr. Wataru TAKEUCHI's Website (IIS, UT)**
  http://yasulab.iis.u-tokyo.ac.jp/~wataru/index_j.php

Reference of this lecture note 2

- **University of New Hampshire, Coastal Observing Center**
  http://www.cooa.unh.edu/primer/data.jsp
- **Cartography & GIS Lab, University of Nebraska at Omaha**
  http://maps.unomaha.edu/Peterson/gis/notes/RS2.htm
- **Professor Paul R. Baumann's Website**
  http://employees.oneonta.edu/baumanpr/geosat2/RSHistory/HistoryRSPart1.htm
- **Harvard Atmospheric Chemistry Modeling Group home page**
  http://www-as.harvard.edu/chemistry/trop/presentations/