UNIT II

PLATFORMS AND SENSORS

Types of platforms – orbit types, Sun-synchronous and Geosynchronous – Passive and Active sensors – resolution concept – Pay load description of important Earth Resources and Meteorological satellites – Airborne and spaceborne TIR and microwave sensors.

1. Types of platforms used for remote sensing:

Ground-based platforms: ground, vehicles and/or towers => up to 50 m
Airborne platforms: airplanes, helicopters, high-altitude aircrafts, balloons => up to 50 km
Spaceborne: rockets, satellites, shuttle => from about 100 km to 36000 km
Space shuttle: 250-300 km
Space station: 300-400 km
Low-level satellites: 700-1500 km
High-level satellites: about 36000 kmppp

3. Satellite platforms: orbits, resolutions, sensor types.

_ Satellites orbits:

Low-level (700-1500 km) Earth observation satellites (called LEO) fall into three broad groups:

i). Equatorial orbiting satellites
ii). Polar orbiting satellite
iii). Oblique orbiting (or near-polar) satellites

LEO satellites are often on**sunsynchronous** orbits. **Sunsynchronous** means that the satellite remains fixed with respect to the sun with the earth rotating under the satellite.

Type of Orbits

1) Zero Inclination Orbit $i = 0$ $\theta = 0$ and the orbit precession frequency is zero.

Using formulas for the sin and cosine of sums of angles (e.g., sin (a-b) = sin a cos b - cos a sin b) one can simplify the longitude function to the obvious result

$$\phi(t) = tan^{-1}\left[\frac{sin\,(\omega_s - \omega_e)t}{cos\,(\omega_s - \omega_e)t}\right] = (\omega_s - \omega_e)t$$

2) Geostationary Orbit $i = 0,\ e = 0,\ a_e = 6378135\text{m}$

Again the the satellite orbit frequency matches the Earth rotation rate $\omega_s = \omega_e$. From the equation above we have an expression for the orbit frequency for a flattened Earth.

$$\omega_s = \left(\frac{GM}{a^3}\right)^{1/2}\left[1 - \frac{9J_2}{2}\left(\frac{a_e}{a}\right)^2\right]^{-1} \qquad \omega_e = 2\pi/86146$$

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The radius of the requires orbit is a = 42170 km or about 6.6 times the Earth radius. Usually this type of orbit is used for communications or for monitoring the weather patterns from a global

perspective. Coverage of this type of orbit is a small circle of radius 55° centered on the subsatellite point. About 6 satellites are needed to provide a complete equatorial view of the Earth and these orbits are not used for high-latitude coverage.

3) Geosynchronous Orbit $i \neq 0, e = 0, \omega_S = \omega_e$

With a non-zero inclination, this orbit can cover higher latitudes but is spends only 1/2 of its time in the correct hemisphere. Inserting these parameters into the above ground track equations and neglecting the precession frequency of the orbit plane one obtains

$$\theta(t) = sin^{-1}\left[sin\ \omega_e t\ \ sin\ i\right]$$

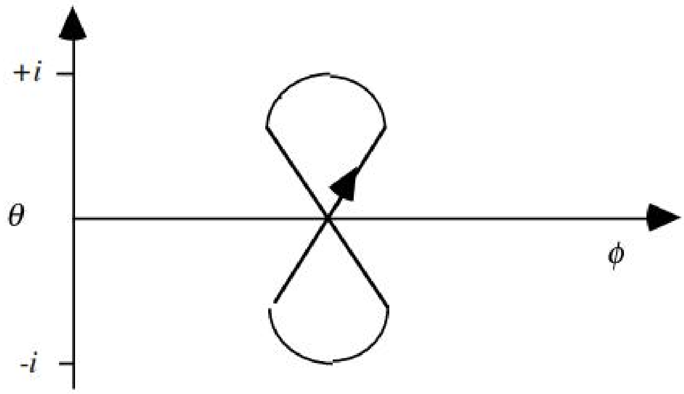
$$\phi(t) = tan^{-1}\left[\frac{cos\ \omega_e t\ \ sin\ \omega_e t\ \left(cos\ i\ -\ 1\right)}{cos^2\omega_e t\ + cos\ i\ sin^2\omega_e t}\right]$$

Now consider the case of small inclination so cos $i \cong 1 - i^2/2$. The denominator is about 1 and the numerator can be simplified so the approximate results for longitude and latitude versus time are

$$\phi(t) = tan^{-1}\left[\frac{i^2}{2}\frac{1}{2}\ sin\ 2\omega_e t\right] \cong \frac{i^2}{4}\ sin\ 2\omega_e t$$

$$\theta(t) = sin^{-1}\left[sin\ \omega_e t\ \ sin\ i\right] \cong i\ sin\ \omega_e t$$

The latitude varies as a sine wave with a frequency of ω_e while the longitude varies like a sine wave with a frequency of $2\omega_e$. At $t = 0$ both the latitude and longitude are zero. The ground track of the orbit follows a figure 8.



This orbit spends less than 1/2 of its time at a high latitude in the correct hemisphere. To optimize the time spent in the northern hemisphere, the Soviets developed a special type of orbit called a Molniya orbit. It is highly elliptical with $\omega_S = 2\,\omega_e$. Apogee placed spent over the former Soviet Union where the satellite spends 92% of its time.

4) Sun-synchronous Orbit

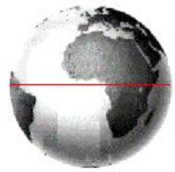
For many remote sensing applications it is important to have the ascending node pass over the equator at the same local time. To create a sun-synchronous orbit, the plane of the orbit must precess in a prograde direction with a period of exactly 1 year.

$$\omega_n = 2\pi/(365.25 \times 86400) = 1.991 \times 10^{-7}\ s^{-1}$$

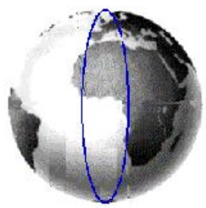
Remember $\frac{\omega_n}{\omega_s} = -\frac{3J_2}{2}\left(\frac{a_e}{a}\right)^2 \frac{\cos i}{(1-e^2)^2}$ so prograde precession requires $i > 90^\circ$. Thus the orbital inclination is dictated by the orbital altitude. For example, a sun-synchronous orbit with an orbital radius of $a = 7878$ km (altitude 1500 km) must have an inclination of 102°.

High-level (about 36000 km) satellites: **geosynchronous** satellites precess around the Earth at rates related to the rotation of the Earth on its polar axes

Polar orbiting satellites:



Equatorial orbiting satellites, whose orbits are within the plane of the Equator,



Polar orbiting satellites, whose orbits are in the plane of the Earth's polar axis,

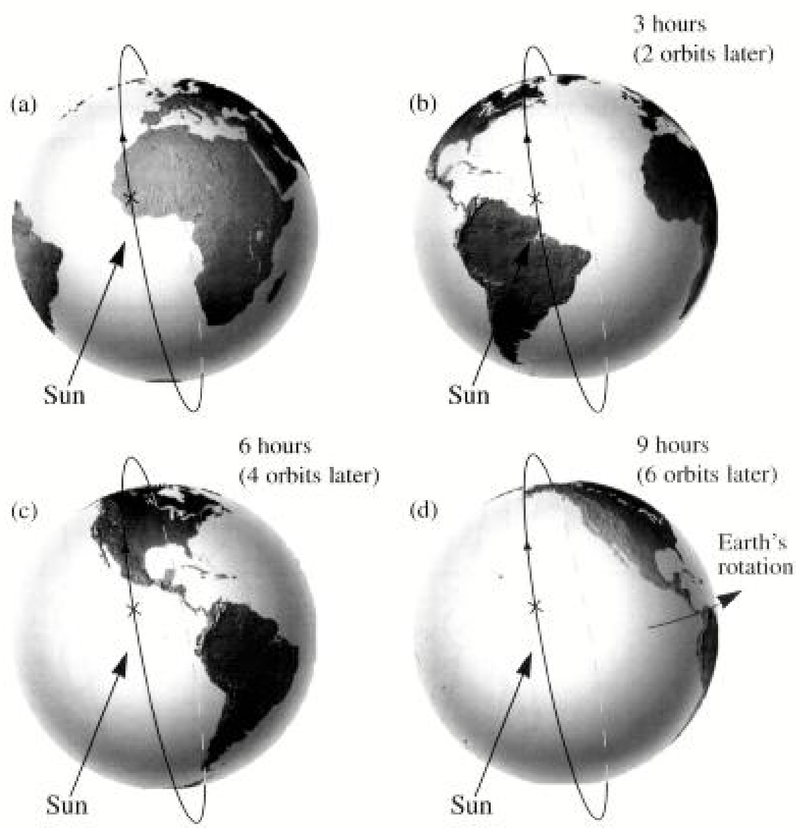


Figure 3.1 Oblique orbiting (near-polar orbiting) satellites: Sun-synchronous orbits (each 3hours)

- Ascending pass is when the satellite travels from south to north, and descending when the satellite travels from north to south.
- Oblique orbiting satellites can be launched eastwards into direct (called prograde) orbit (so called because the movement of such satellites is in the same direction as the rotation of the Earth), or westwards into retrograde orbit.
- The inclination of a orbit is specified in terms of the angle between its ascending track and the Equator.
- Prograde orbits regress while retrograde orbits precess with respect to the planes of their initial orbits because the Earth is not a perfect sphere and it causes a gyroscopic influence on satellites in oblique orbits.

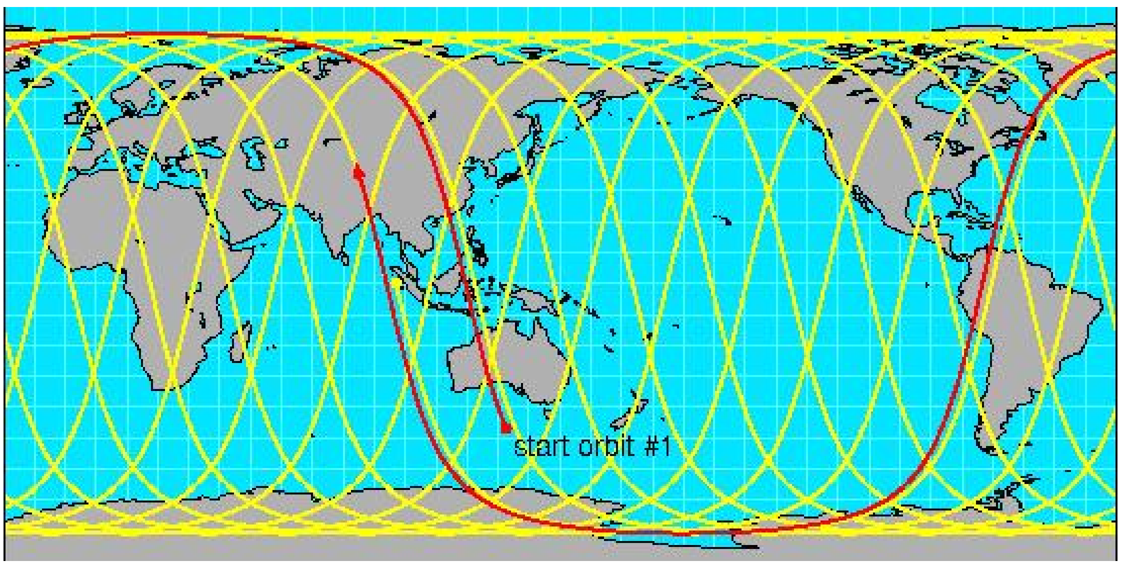


Figure 3.2 Example of the ground track of a polar orbiting satellite.

Swath is the area imaged on the surface by the sensor. Imaging swaths for Space borne sensors generally vary between tens and hundreds of kilometers wide.

Examples of near-polar orbiting satellites:

EOS TERRA: inclination=98.2^0

TOPEX/Poseidon (Topography Experiment for Ocean Circulation): inclination=66^0

Geosynchronous satellites:

Geostationary satellites (often called weather satellites) are "fixed" above a given point on the Earth surface because their circular orbits above the equator have rotation period equals to the earth's rotation period.

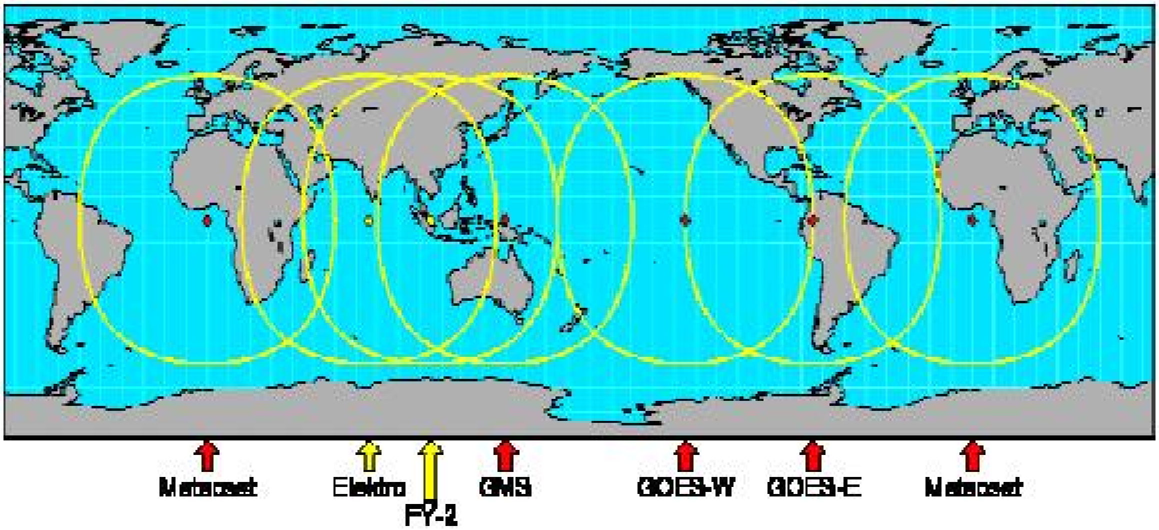


Figure 3.3 Example of geostationary satellite coverage.

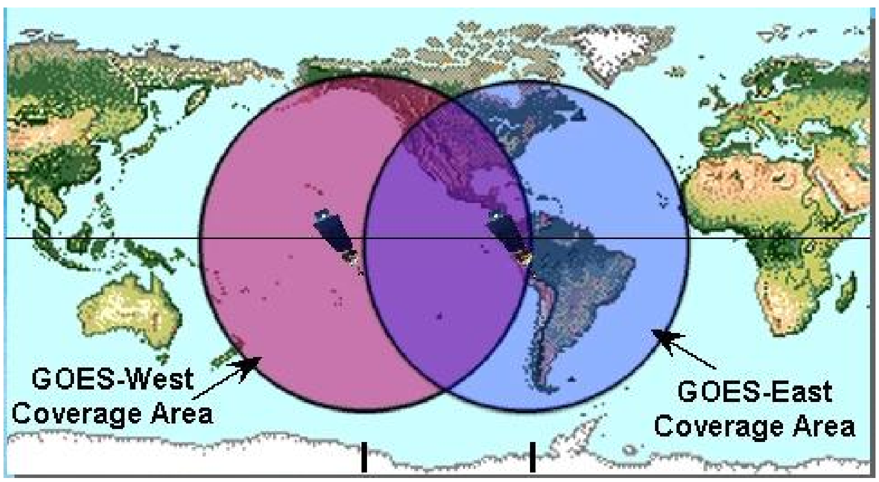


Figure 3.4 US geostationary satellites: GOES

Passive and active remote sensing:

Passive sensors measure natural radiation emitted by the target material or/and radiation energy from other sources reflected from the target.

Examples :

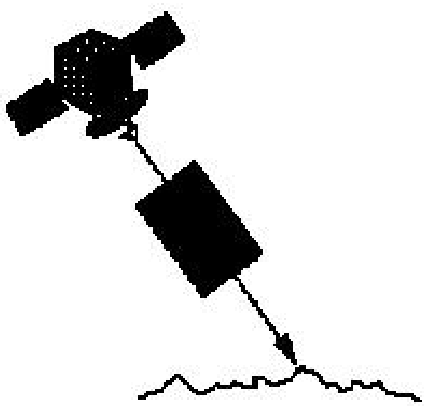
Passive microwave radiometer that detects naturally emitted microwave energy.

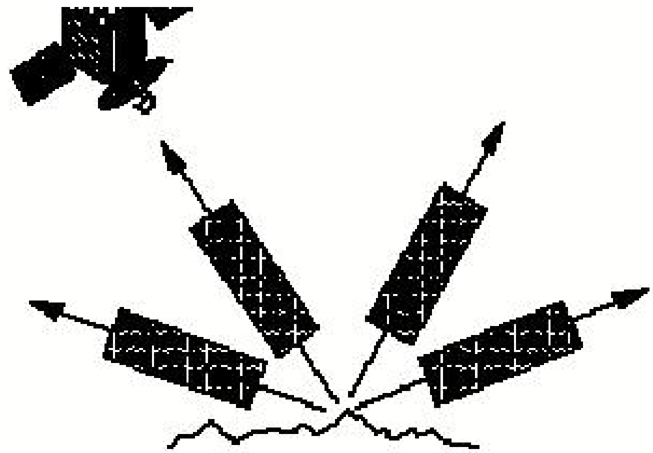
Radiometers that measure reflected (or backscattered) sun light from the atmosphere and ocean.

Active sensors transmit their own signal and measure the energy that is reflected (or scattered back) from the target material.

Examples:

Lidar (LIght Detection And Ranging)
Radar (RAdio Detection And Ranging)





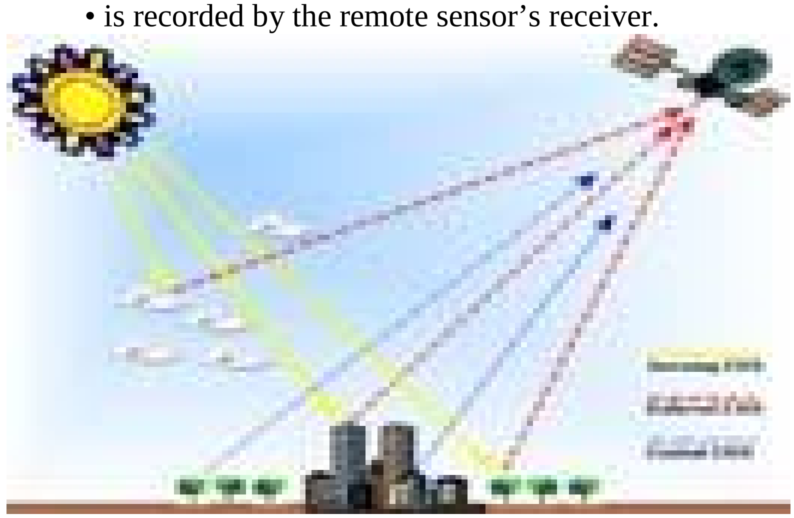
Radar transmits a pulse and measures reflected echo (backscatter)

Active and Passive Remote Sensing

Passive remote sensing systems record EMR that is *reflected* (e.g., blue, green, red, and near-infrared light) or *emitted* (e.g., thermal infrared energy) from the surface of the Earth.

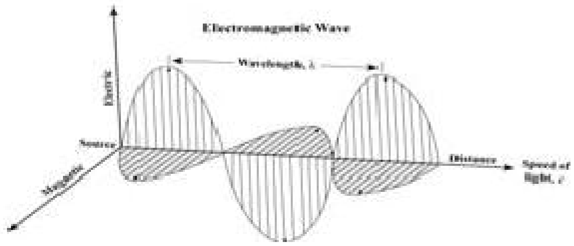
Active remote sensing systems are not dependent on the Sun's EMR or the thermal properties of the Earth. Active remote sensors create their own electromagnetic energy that

- is transmitted from the sensor toward the terrain
- interacts with the terrain producing a backscatter of energy
- is recorded by the remote sensor's receiver.



The most widely used active remote sensing systems include:

Active microwave (RADAR= **RA**dio **D**etection **a**nd **R**anging), which is based on the transmission of long-wavelength microwave (e.g., 3-25 cm) through the atmosphere and then recording the amount of energy backscattered from the terrain.
The beginning of the RADAR technology was using radio waves. Although radar systems now use microwave wavelength energy almost exclusively instead of radio wave, the acronym was never changed.



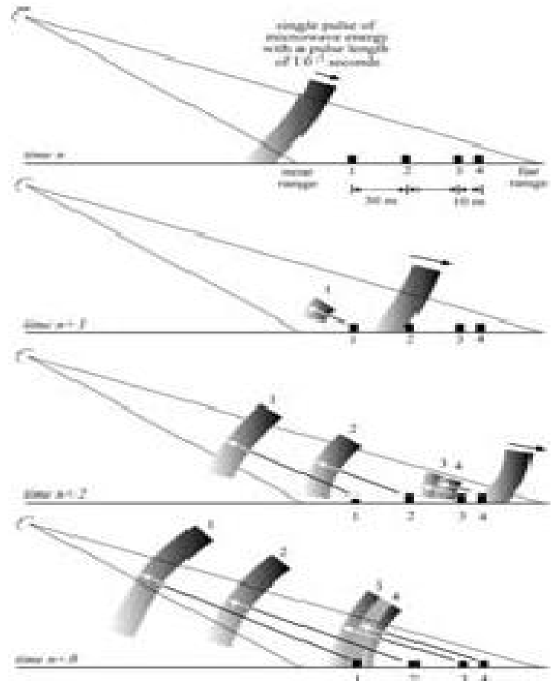
LIDAR (LIght Detection And Ranging),
which is based on the transmission of relatively short-wavelength laser light (e.g., 0.90 μm) and then recording the amount of light backscattered from the terrain;

SONAR (SOund NAvigation Ranging),
which is based on the transmission of sound waves through a water column and then recording the amount of energy backscattered from the bottom or from objects within the water column.

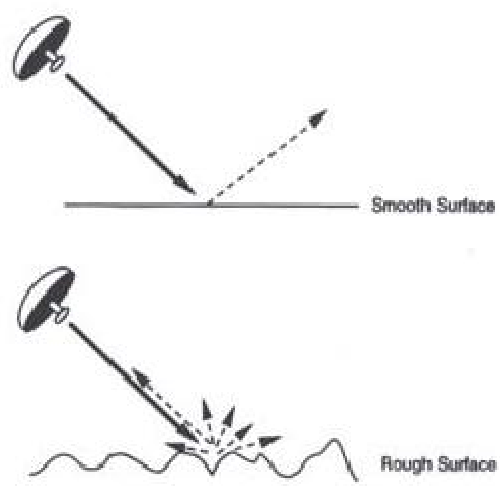
RADAR

The "ranging capability is achieved by measuring the time delay from the time a signal is transmitted to the terrain until its echo is received.

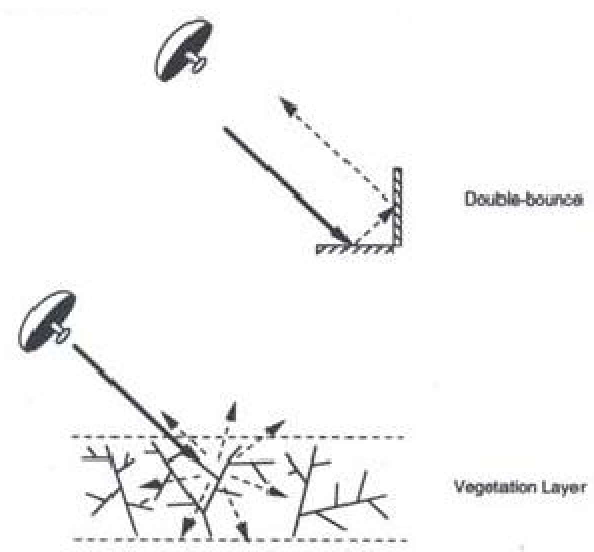
Because the sensor transmitted a signal of known wavelength, it is possible to compare the received signal with the transmitted signal. From such comparisons imaging radar detects changes in frequency that form the basis of capabilities not possible with other sensors.



Radar Measurements



Radar Measurements



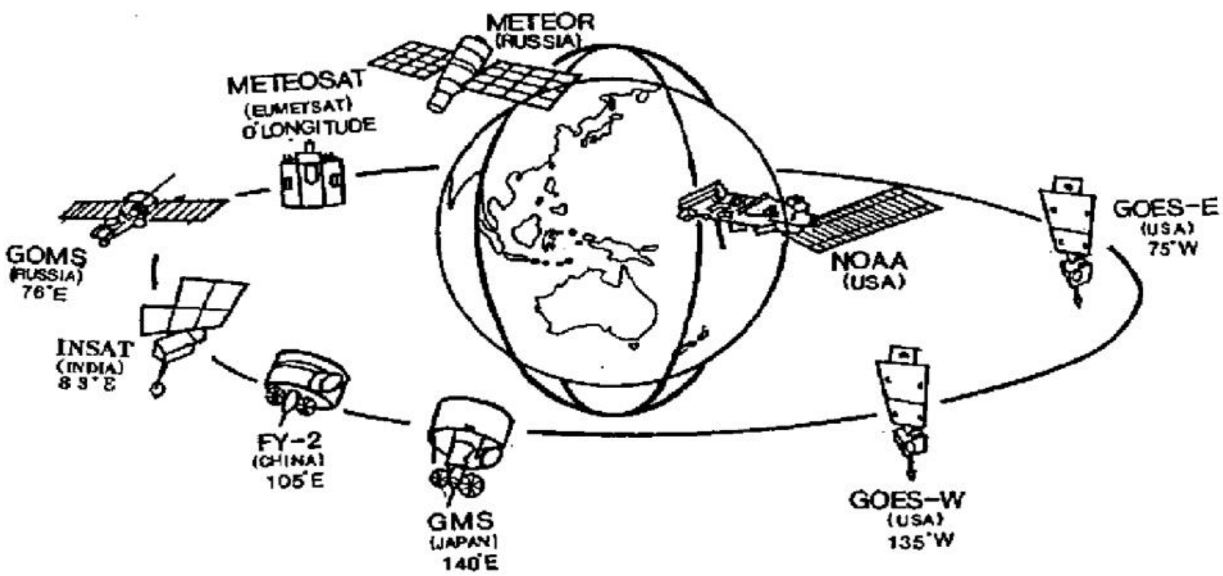
History of meteorological satellites

- Sputnik was the first satellite in the world. After 3 years flight, the first meteorological satellite TIROS-1 was launched by the United States of America in April 1960. For 6 years after that, 10 satellites of the TIROS series were launched and used for conducting various observations and experiments.
- The TIROS series were low elevation orbit satellites. In 1966, the first geostationary meteorological satellite ATS-1 was launched by the United States and it was confirmed that the satellite observation was effective for meteorological monitoring.
- The success of meteorological satellite observation intensified the trend toward using this new technology to develop meteorology and improve weather forecasting.
- In 1963, the World Meteorological Organization (WMO) drafted the WWW (World Weather Watch) Programmed and started a meteorological satellite observation network plan covering the globe.
- In response to this plan, various countries launched their meteorological satellites and these established an observation network covering the globe with 5 geostationary satellites and 2 polar orbiting satellites (NOAA and METEOR series) at the beginning of the 1980s (Table 1-1-1).
- After that, Russia and China launched geostationary satellites. As of 1999, the meteorological satellite observation network is as shown in Figure 1-1-1.
- Japan launched Himawari (GMS hereafter) I in 1977. Five satellites of the GMS series were launched up to date and GMS-5 is in operation. As a successor to the GMS series satellites,

Multi-functional Transport Satellite (MTSAT hereafter) is to be launched.

Table 1-1-1. History of meteorological satellites

Year	Item	Country
1960	First meteorological satellite TIROS I launched	USA
1966	First geostationary meteorological satellite launched	USA
1970	NOAA series launched	USA
1975	GOES launched	USA
1977	GMS and METEOSAT launched	Japan, Europe
1982	INSAT launched	India
1994	GOMS launched	Russia
1997	FY-II launched	China



1.2 Observation by meteorological satellites

The advantages of the meteorological observation using meteorological satellites (simply referred to as satellites) include its capability of observing the whole earth uniformly with a fine spatial density.

Therefore, it is effective for monitoring short-time atmospheric phenomena including the cloud motion and drift of typhoons and lows.

It is also used for monitoring of climate changes based on the accumulation of the global data over a long period.

1.2.1 Satellite orbits

- For the satellites, geostationary orbits and sun synchronous polar orbits have been used so far.
- A geostationary satellite circles around the earth above the equator with the same speed as the period of rotation of the earth so that it is seen at a stationary position from earth (the GMS is located at 140 degrees of east longitude and 36,000 km above the equator). The GMS observes the perspective areas on the earth from

north to south for 25 minutes and is displaying its power in monitoring and tracking meteorological disturbances.

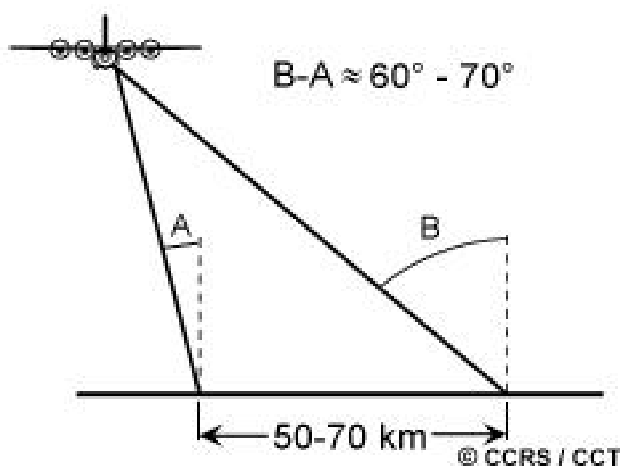
- The polar orbiting satellite circles the earth over the north and south poles at low altitude (for the NOAA, around 850 km) and in a short period (for the NOAA, about 100 minutes) and observes a swath width of about 2,000 km centering the nadir.
- The polar orbiting satellite passes over the same point on the earth only twice a day but it can observe the Polar Regions, which the geostationary satellite cannot.

1.2.3 Resolution

The characteristics of a sensor on board the GMS-5 are shown in Table 1-2-1 accompanied with those of MTSAT for reference. The horizontal spatial resolution of the GMS-5 is 1.25 km in the VIS image and 5 km in the IR images at the sub-satellite point (SSP). The more distant from SSP, the more the earth's surface is viewed obliquely and the resolution deteriorates. In the vicinity of Japan, the resolution is 1.8 km in the VIS image and 7 km in the IR images. The gray scale of GMS-5 images is 6 bits (64 levels) in the VIS image. In the IR images, it is 8 bits (256 levels) and one level corresponds to a temperature resolution of 0.5 to 1.0°C.

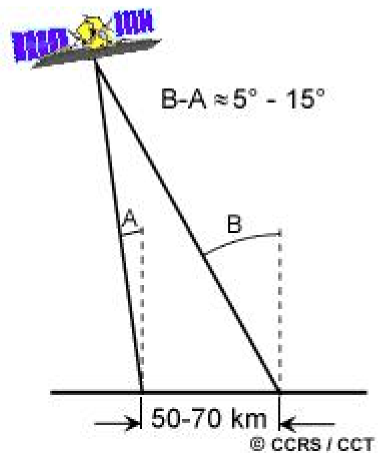
Airborne versus Space borne Radars

Like other remote sensing systems, an imaging radar sensor may be carried on either an airborne or space borne platform. Depending on the use of the prospective imagery, there are trade-offs between the two types of platforms. Regardless of the platform used, a significant advantage of using a Synthetic Aperture Radar (SAR) is that the spatial resolution is independent of platform altitude. Thus, fine resolution can be achieved from both airborne and space borne platforms.



Although spatial resolution is independent of altitude, viewing geometry and swath coverage can be greatly affected by altitude variations. At aircraft operating altitudes, an airborne radar must image over a wide range of incidence angles, perhaps as much as 60 or 70 degrees, in order to achieve relatively wide swaths (let's say 50 to 70 km). As we have learned in the preceding sections, incidence angle (or look angle) has a significant effect on the backscatter from surface features and on their appearance on an image. Image characteristics such as foreshortening, layover, and shadowing will be subject to wide variations, across a large incidence angle range. Space borne radars are able to avoid some of these imaging geometry problems since they operate at altitudes up to one hundred times higher than airborne radars.

At altitudes of several hundred kilometers, space borne radars can image comparable swath widths, but over a much narrower range of incidence angles, typically ranging from five to 15 degrees. This provides for more uniform illumination and reduces undesirable imaging variations across the swath due to viewing geometry.



- Although airborne radar systems may be more susceptible to imaging geometry problems, they are flexible in their capability to collect data from different look angles and look directions.
- By optimizing the geometry for the particular terrain being imaged, or by acquiring imagery from more than one look direction, some of these effects may be reduced. Additionally, airborne radar is able to collect data anywhere and at any time (as long as weather and flying conditions are acceptable!).
- A space borne radar does not have this degree of flexibility, as its viewing geometry and data acquisition schedule is controlled by the pattern of its orbit.
- However, satellite radars do have the advantage of being able to collect imagery more quickly over a larger area than an airborne radar, and provide consistent viewing geometry.
- The frequency of coverage may not be as often as that possible with an airborne platform, but depending on the orbit parameters, the viewing geometry flexibility, and the geographic area of interest, a spaceborne radar may have a revisit period as short as one day.
- As with any aircraft, airborne radar will be susceptible to variations in velocity and other motions of the aircraft as well as to environmental (weather) conditions. In order to avoid image artifacts or geometric positioning errors due to random variations in the motion of the aircraft, the radar system must use sophisticated navigation/positioning equipment and advanced image processing to compensate for these variations. Generally, this will be

able to correct for all but the most severe variations in motion, such as significant air turbulence.

- Space borne radars are not affected by motion of this type. Indeed, the geometry of their orbits is usually very stable and their positions can be accurately calculated. However, geometric correction of imagery from spaceborne platforms must take into account other factors, such as the rotation and curvature of the Earth, to achieve proper geometric positioning of features on the surface.

3.10 Airborne and Spaceborne Radar Systems

In order to more clearly illustrate the differences between airborne and spaceborne radars, we will briefly outline a few of the representative systems of each type, starting with airborne systems.

The **Convair-580 C/X SAR** system developed and operated by the Canada Centre for Remote Sensing was a workhorse for experimental research into advanced SAR applications in Canada and around the world, particularly in preparation for satellite-borne SARs. The system was transferred to Environment Canada in 1996 for use in oil spill research and other environmental applications. This system operates at two radar bands, C- (5.66 cm) and X- (3.24 cm). Cross-polarization data can be recorded simultaneously for both the C- and X-band channels, and the C-band system can be operated as a fully polarimetric radar. Imagery can be acquired at three different imaging geometries (nadir, narrow and wide swath modes) over a wide range of incidence angles (five degrees to almost 90 degrees). In addition to being a fully calibratable system for quantitative measurements, the system has a second antenna mounted on the aircraft fuselage to allow the C-band system to be operated as an interferometric radar.

The **Sea Ice and Terrain Assessment (STAR)** systems operated by Intera Technologies Limited of Calgary, Alberta, Canada, (later Intermap Technologies) were among the first SAR systems used commercially around the world. Both STAR-1 and STAR-2 operate at X-band (3.2 cm) with HH polarization in two different resolution modes. The swath coverage varies from 19 to 50 km, and the resolution from 5 to 18 m. They were primarily designed for monitoring sea ice (one of the key applications for radar, in Canada) and for terrain analysis. Radar's all-weather, day or night imaging capabilities are well-suited to monitoring ice in Canada's northern and coastal waters. STAR-1 was also the first SAR system to use on-board data processing and to offer real-time down linking of data to surface stations. The United States National Aeronautics and Space Administration (NASA) has been at the forefront of multi-frequency, multi-polarization synthetic aperture radar research for many years. The Jet Propulsion Laboratory (JPL) in California has operated various advanced systems on contract for NASA. The

AirSAR system is a C-, L-, and P-band advanced polarimetric SAR which can collect data for each of these bands at all possible combinations of horizontal and vertical transmit and receive polarizations (i.e. HH, HV, VH, and VV). Data from the AirSAR system can be fully calibrated to allow extraction of quantitative measurements of radar backscatter. Spatial resolution of the AirSAR system is on the order of 12 metres in both range and azimuth. Incidence angle ranges from zero degrees at nadir to about 70 degrees at the far range. This capability to collect multi-frequency, multi-polarization data over such a diverse range of incidence angles allows a wide variety of specialized research experiments to be carried out. With the advances and success of airborne imaging radar, satellite radars were the next logical step to complement the optical satellite sensors in operation.

SEASAT, launched in 1978, was the first civilian remote sensing satellite to carry a space borne SAR sensor. The SAR operated at L-band (23.5 cm) with HH polarization. The viewing geometry was fixed between nine and 15 degrees with a swath width of 100 km and a spatial resolution of 25 meters. This steep viewing geometry was designed primarily for observations of ocean and sea ice, but a great deal of imagery was also collected over land areas. However, the small incidence angles amplified foreshortening and layover effects over terrain with high relief, limiting its utility in these areas. Although the satellite was only operational for three months, it demonstrated the wealth of information (and the large volumes of data!) possible from a space borne radar. With the success of the short-lived SEASAT mission, and impetus provided from positive results with several airborne SARs, the European Space Agency (ESA) launched ERS-1 in July of 1991.

ERS-1 carried on-board a radar altimeter, an infrared radiometer and microwave sounder, and a C-band (5.66 cm), active microwave instrument. This is a flexible instrument which can be operated as a scatter meter to measure reflectivity of the ocean surface, as well as ocean surface wind speed and direction. It can also operate as synthetic aperture radar, collecting imagery over a 100 km swath over an incidence angle range of 20 to 26 degrees, at a resolution of approximately 30 meters. Polarization is Canada Centre for Remote Sensing Page 127Section 3.10 Airborne and Space borne Radar Systems vertical transmit and vertical receive (VV) which, combined with the fairly steep viewing angles, make ERS-1 particularly sensitive to surface roughness.

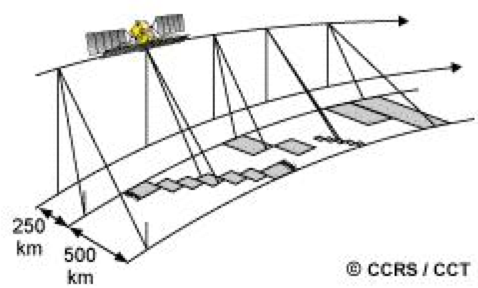
The revisit period (or repeat cycle) of ERS-1 can be varied by adjusting the orbit, and has ranged from three to 168 days, depending on the mode of operation. Generally, the repeat cycle is about 35 days. A second satellite, ERS-2, was launched in April of 1995 and carries the same active microwave sensor as ERS-1. Designed primarily for ocean monitoring applications and research, ERS-1 provided the worldwide remote sensing community with the first wide-spread access to space borne SAR data. Imagery from both satellites has been used in a wide range of applications, over both ocean and land environments. Like SEASAT, the steep viewing angles limit their utility for some land applications due to geometry effects.

The National Space Development Agency of Japan

(NASDA), launched the **JERS-1** satellite in February of

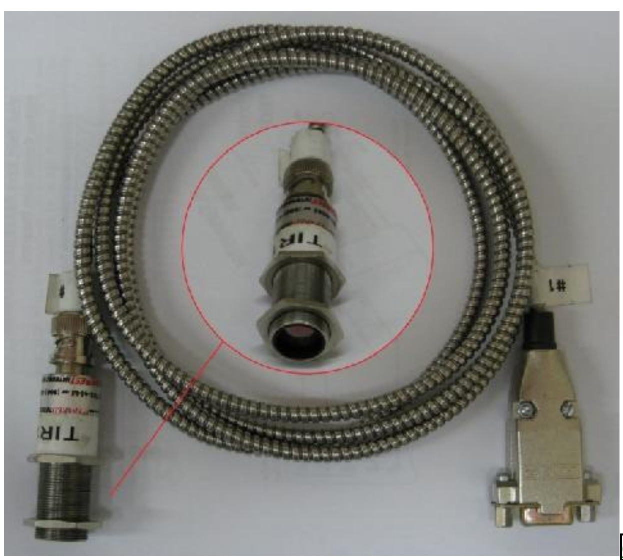
1992. In addition to carrying two optical sensors, JERS1 has an L-band (23.5 cm) SAR operating at HH polarization.
The swath width is approximately 75 km and spatial resolution is approximately 18 metres in both range and azimuth.
The imaging geometry of JERS-1 is slightly shallower than either SEASAT or the ERS satellites, with the incidence angle at the middle of the swath being 35 degrees.
Thus, JERS-1 images are slightly less susceptible to geometry and terrain effects.
The longer L-band wavelength of JERS-1 allows some penetration of the radar energy through vegetation and other surface types.
Space borne SAR remote sensing took a giant leap forward with the launch of Canada's **RADARSAT** satellite on Nov. 4, 1995.

The RADARSAT project, led by the Canadian Space Agency (CSA), was built on the development of remote sensing technologies and applications work carried out by the Canada Centre for Remote Sensing (CCRS) since the 1970s. RADARSAT carries an advanced C-band (5.6 cm), HH-polarized SAR with a steerable radar beam allowing,
Various imaging options over a 500 km range. Imaging swaths can be varied from 35 to 500 km in width, with resolutions from 10 to 100 meters.
Viewing geometry is also flexible, with incidence angles ranging from less than 20 degrees to more than 50 degrees. Although the satellite's orbit repeat cycle is 24 days, the flexibility of the steerable radar beam gives RADARSAT the ability to image regions much more frequently and to address specific geographic requests for data acquisition. RADARSAT's orbit is optimized for frequent coverage of mid-latitude to polar regions, and is able to provide daily images of the entire Arctic region as well as view any part of Canada within three days.
Even at equatorial latitudes, complete coverage can be obtained within six days using the widest swath of 500 km.



The thermal infrared radiometers (TIR)

During the airborne data acquisition there were 6 thermal infrared radiometers (top picture: bottom row sensors) with additional 12 multi-spectral sensors operational (top picture: first 2 rows of sensors). The thermal infrared radiometers used are the 8.0 to 14.0µm **Everest Interscience 3800ZL** with 15°FOV and 0-5 V output (-40°C to 100°C). The six TIR sensors are installed at the same incidence angles as PLMR (±7°, ±21.5° and ±38.5°), so as to give coincident footprints with the PLMR observations. The nominal relationship between voltage and temperature is given by the manufacturer as V = 1.42857 + (0.03571428×T).



Thermal Infrared sensor