Chapter 5 Platforms

5.1 Types of Platform

The vehicle or carrier for remote sensors are borne is called the **platform**. Typical platforms are **satellite** and **aircraft**, but they can also include radio controlled airplanes, balloons, kites for low altitude remote sensing, as well as ladder trucks or "**cherry pickers**" for ground investigations.

Table 5.1.1 shows various platforms, altitudes and objects being sensed. Platforms with the highest altitude are geosynchronous satellites such as the Geosynchronous Meteorological Satellite (GMS), which has an altitude of 36,000 km at the Equator. Most of the earth observation satellites, such as Landsat, SPOT, MOS etc. are at about 900 km altitude with a sun synchronous orbit.

From lower orbit, there are space shuttle (240-280 km), radio sonde (- 100 km), high altitude jet-plane (10,000 m), low or middle altitude plane (500-8,000 m), radio controlled plane (- 500 m) and so on.

The key factor for the selection of a platform is the altitude which determines the ground resolution if IFOV (instantaneous field of view) of the sensor is constant, where

$$\gamma = H\beta$$

The selection of platform also depends on the purpose which is sometime requested for example a constant altitude is required for aerial surveys, while various altitudes are needed to survey vertical atmospheric distribution, for example.

For aerial photogrammetry, the flight path is strictly controlled to meet the requirement of geometric accuracy. However, helicopter or radio controlled planes are used for a free path approach, for example in disaster monitoring.

Table 5.1.1 Platform types and observation objects

platform	altitude	observation	remarks
geostationary satellite	36,000m	fixed point observation	GMS
circular orbit satellite (earth observation)	500km - 1,000km	regular observation	Landsat,SPOT, MOS-1,etc
space shuttle	240km - 350km	irregular observation space experiment	
radio-sonde	100m - 100km	various investigations (meteorological, etc)	
high altitude jet-plane	10km - 12km	reconnaissance wide area investigations	
low or middle altitude plane	500m - 8,000m	various investigation aero surveys	
aerostat	500m - 3,000m	reconnaissance various investigations	
helicopter	100m - 2,000m	various investigations aero surveys	
radio-controlled plane	below 500m	various investigations aero surveys	aeroplane helicopter
hang-plane	50 - 500m	various investigations aero surveys	hang-glider para-glider
hang-balloon	800m -	various investigations	
cable	10 - 40m	archeologic investigations	
crane car	5 - 50m	close range surveys	
ground measurement car	0 - 30m	ground truth	cherrypicker

5.2 Atmospheric Condition and Altitude

Atmospheric condition is different depending on the altitude. This factor must be considered in the selection of platforms or sensors. In this section, air pressure, air density and temperature are considered.

Dependence of air pressure on altitude is based on the hydro-static equilibrium of balance between the vertical pressure of the atmosphere and gravity.

The atmospheric constituents without water vapor are assumed constant in volume ratio with 78.08 % nitrogen, 20.95 % oxygen, and argon 0.93 % up to about 100 km regardless of time and place. It gives an average molecular weight at 28.97 for the atmosphere and the average molecular mass of 4.810×10^{-26} kg.

When temperature is constant with respect to altitude, the air pressure decreases as an exponential function, which gives about an 8 km altitude for a decrease of air pressure to 1/e, as shown in Figure 5.2.1.

However, since the actual atmosphere varies in temperature with altitude as shown in Figure 5.2.2, the air pressure can be calculated from the hydro-static equilibrium with a given temperature.

For general purposes, the standard **model atmosphere** has been specified with respect to the average temperature distribution and the vertical air pressure. Also the average model with respect to latitude and season has been specified, although the actual temperature sometimes has a difference of 10 - 20 °K. Therefore the measurement of temperature using radio-sonde is necessary for high accuracy. The vertical structure of the atmosphere is composed of the following layers.

Troposphere : from the ground surface to 10 - 17 km
Stratosphere : from 10 - 17 km to about 50 km
Mesosphere : from about 50 km to about 90 km
Thermosphere : from about 90 km to 500 km

The classification of the above layers depends on the distribution of thermal energy and thermal transportation. The vertical decrease of temperature in the troposphere is 9.8 °K km^{-1} for dry atmosphere, but 6.5 °K km^{-1} for the actual atmosphere because of water vapor. The boarder between the troposphere and the stratosphere is called **tropopause**. The tropics tropopause is rather constant at 17 km in altitude while the middle latitude tropopause depends on seasonal change and jet stream with 10 - 17 km in altitude as shown in Figure 5.2.3.

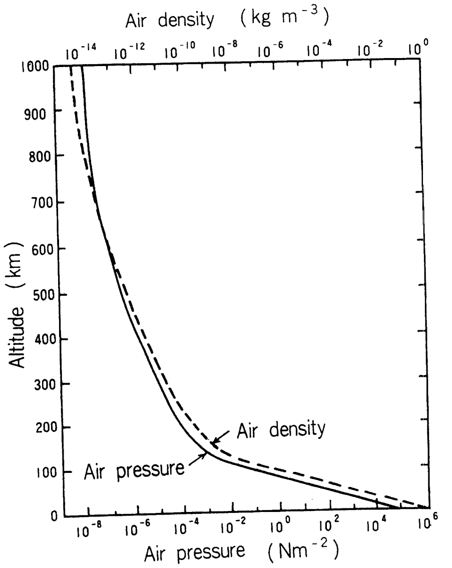


Figure 5.2.1 Altitude distribution of air pressure and air density (measured)

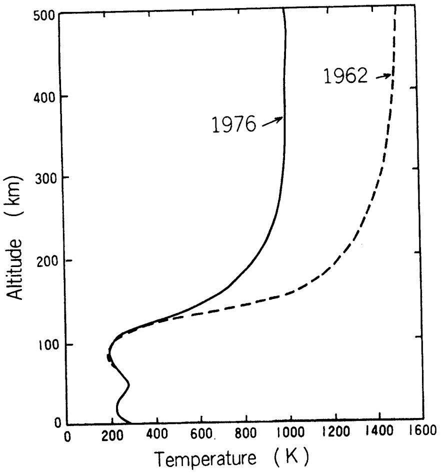


Figure 5.2.2 Altitude distribution of temperature

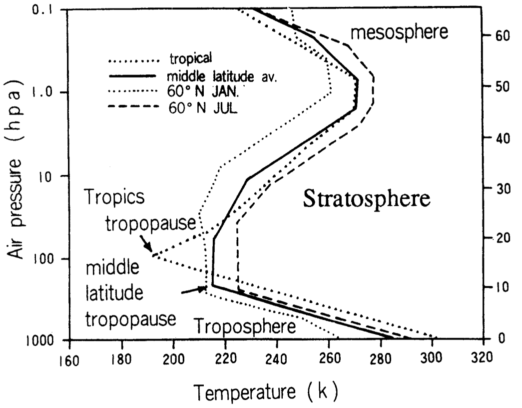


Figure 5.2.3 Seasonal and latitude change,altitude distribution of temperature(1hPa = $10^2 Nm^{-2}$ = 1mb)

5.3 Attitude of Platform

The geometric distortion depends on not only the geometry of the sensor but also the attitude of the platform. Therefore it is very important to measure the attitude of the platform for the consequent geometric correction.

The attitude of the platform is classified by the following two components.

a. Rotation angles around the three axes ; **roll, pitch** and **yaw**
b. **Jitter** ; random and unsystematic vibration which cannot be measured.

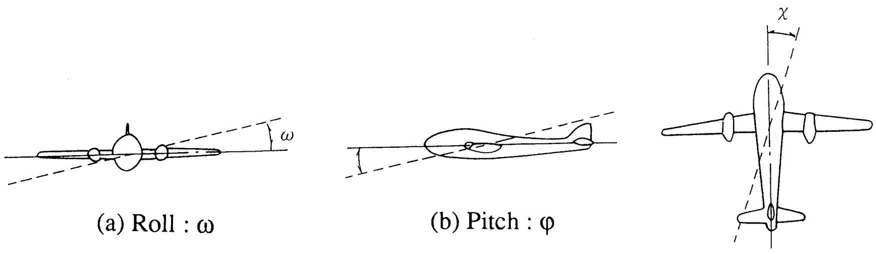
The rotation angles ; roll (ω), pitch (φ) and yaw (κ) are defined as the rotation angles around the flight direction, the main wing and the vertical line respectively, as shown in Figure 5.3.1. Figure 5.3.2 show the satellite attitude parameters.

For a frame camera, the rotation angles are single values common to a full scene of aerial photograph, while for a line scanner the attitude changes as a function of line number or time. In the case of satellites, the variation of the position and the attitude will be continuous, though in case of aircraft, the variation will not always be smooth, which makes the geometric correction more difficult.

The typical attitude sensors for aircraft are as follows.

- Speedometer
- altimeter
- gyro compass (for attitude measurement)
- Doppler radar (for measurement of altitude)
- GPS (for positioning)
- gyro horizon
- TV camera
- flight recorder

The attitude sensors for satellites are introduced in section 5.4.



(a) Roll : ω

(b) Pitch : φ

(c) Yaw : χ

Figure 5.3.1 Aeroplane attitude change

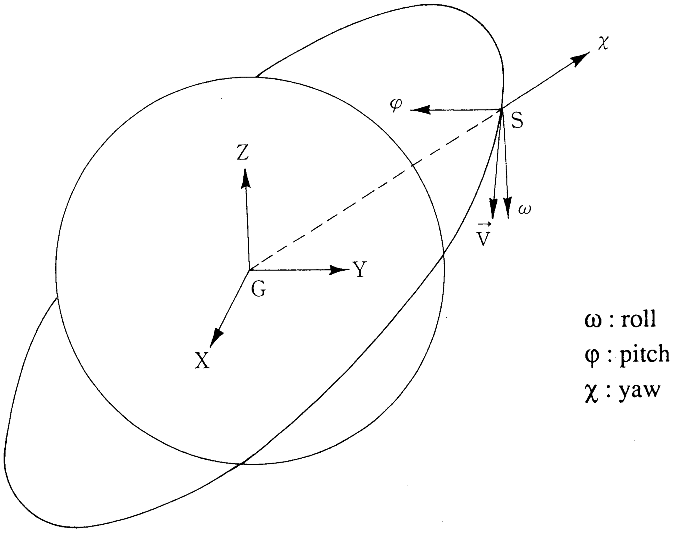


Figure 5.3.2 Satellite attitude parameters

5.4 Attitude Sensors

Attitude control of a satellite is classified by two methods ; **spin control** and **three axis control**. The former method is usually adopted for **geosynchronous meteorological satellites** which itself rotates itself together with rotating scanner. The latter method is mainly adopted for earth observation satellites such as Landsat which needs accurate look angle in the direction of the earth.

The spin control is rather simple but has a low S/N ratio, while the three axis control is more complex, but has a high S/N.

Figure 5.4.1 shows the typical types of attitude measurement sensors, which are used for different purposes.

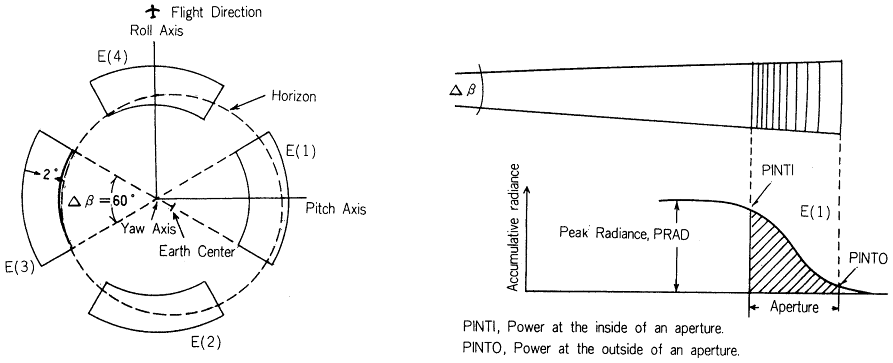
A **gyro-compass** is used for measurement of attitude variation over a short interval. **Earth sensor** detects the radiation of CO2 with in the wavelength range of 14 - 16 mm emitted from the rim of the earth, from which two axis attitude of roll and pitch can be measured with an accuracy of 0.3 - 1 degree, as shown in Figure 5.4.2. If the earth sensor is combined with a sun sensor and gyro-compass, the three axis attitude can be measured with higher accuracy of 0.1 - 0.3 degree. Magnetic sensors can measure the three axis attitude but with a slightly low an accuracy. The responsivity of the above sensors is 2 Hz at maximum. If the high frequency attitude such as jitter is to be measured, the **angular displacement sensor (ADS)** is necessary.

The angular displacement sensor of Landsat 4 and 5 has a responsivity of 2 - 18 Hz. The highest accuracy of attitude can be achieved by the **star sensor**. For example, the **standard star tracker (SST)** on board Landsat 4 and 5 will measure an accurate attitude from the image of stars acquired by an **image dissector** with a reference of about 300 star catalogue up to the sixth grade stars stored in an **on board computer**. The accuracy of SST is about ± 0.03 degree (3σ).(3 standard deviations).

In case of the space shuttle, the star sensor has a lower accuracy with only about a 50 star catalog compared to the SST, because the space shuttle does not need the higher attitude control when it returns to the troposphere.

- attitude measurement sensor
  - angular sensor ... earth sensor, sun sensor, fixed star sensor
  - magnetic sensor ... magnetic sensor
  - angular moment sensor ... gyro-compass, rate integral gyro-compass, laser-gyro-compass
  - angular displacement sensor ... ADS

Figure 5.4.1 Typical attitude measurement



(a) Focal surface of Attitude Measurement Sensor ; AMS.

(b) Example of accumulative radiance from CO_2 through an aperture.

Figure 5.4.2 aperture of static type of earth sensor and CO_2 radiation from limb

5.5 Orbital Elements of Satellite

A set of numerical values to define an orbit of a satellite or planet are called **orbital elements**. The independent orbital elements of the earth observation satellite are six elements of the **Keplerian orbit.**

A satellite can be considered to rotate around the earth in a plane, called the orbital plane, because the influence of gravity of the moon and the sun can be neglected as compared with the gravity of the earth.

A point in space can be expressed in the **equatorial coordinate system** as follows. The origin of equatorial coordinate system is the center of the earth.

The reference great circle : the equatorial plane
The origin of astronomical longitude (right ascension) : the vernal equinox
The astronomical longitude (right ascension) : 0 - 24 hours to the east from the vernal equinox
The astronomical latitude (declination) : angle from the equatorial plane (+90 degree in the north pole ; -90 degree in the south pole)
The six elements of Keplerian orbit are ;

(1) The **semi-major axis** (A):
(2) **Eccentricity** of orbit (e) :
(3) **Inclination angle** (i) :
(4) **Right ascension** of **ascending node** (h)
(5) **Argument of perigee** (g)
(6) **Time of passage of the perigee** (τ)

(instead of this element, mean anomaly (M) or true anomaly(v) is sometimes used.)

Figure 5.5.1 shows the above elements. The shape and size of an orbit can be defined by A and e, while the orbit plane can be defined by i and h. The longer axis of the orbit ellipse can be determined by g. The position of a satellite can be located by T.

Sometime the orbital elements are replaced by three dimensional geocentric coordinates and velocity for numerical analysis instead of the elements of the the Keplerian orbit.

Table 5.5.1 shows the relationship between the elements of the Keplerian orbit and the geocentric coordinates and velocity.

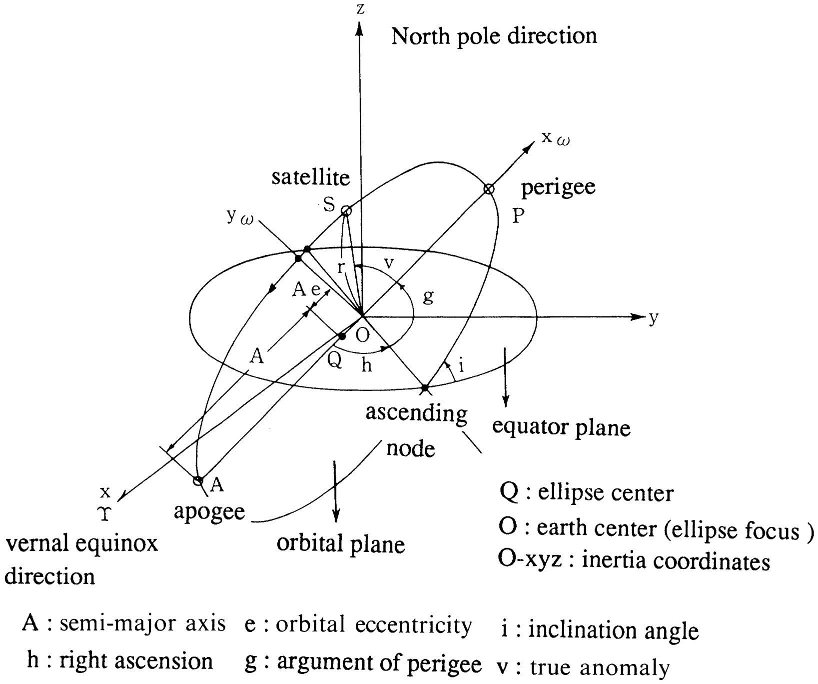


Figure 5.5.1 Orbital elements of Kepler

Table 5.5.1 Conversion formula of orbital elements

The position coordinates on the orbital plane is computed with the following formula.

$$\mu = GM = 3.986008 \times 10^{14} m^3 \cdot s^{-2}$$

(G : universal gravitation constant, M : mass of Earth)

$$n = \sqrt{\mu / A^3}$$

(n : mean motion, A : semi-major axis)

T_1, time, M, mean anomaly

$$M = n (T_1 - T)$$

(T : time of passage of perigee)

Keplerian formula

$$E - e \sin E = M$$

(E : Eccentric anomaly , e : orbital eccentricity)

If M,e are known, we can solve approximately the formula for E, e.g., using the Newton' s formula. Using the E , we can solve r, the distanace between the origin(O) of earth and the satellite (S) and coordinates x,y on the orbital plane.

$$r = A (1 - e \cos E)$$
$$x = A (\cos E - e)$$
$$y = A \sqrt{1 - e^2} \sin E$$

5.6 Orbit of Satellite

The orbit of a satellite is referred to by several names with respect to orbit figure, inclination, period and recurrence as shown in Figure 5.6.1.

The **circular orbit** is the most basic orbit and is explained as follows.
The orbit can be expressed as the polar coordinates (r,θ).

$$r = r_e + h_s \qquad \theta = \theta_0 t$$

where r_e : radius of the earth 6,378,160 m
h_s : altitude of satellite
t : time
θ_0 : angular velocity

The angular velocity and the period are expressed as follows.

$$\theta_0=\sqrt{\mu/\gamma^3}$$

$$T=2\pi/\theta_0=2\pi\sqrt{(r_e+h_s)^3/\mu}$$

where μ : gravity constant ; $3.986005 \times 10^{14}\ m^3 / S^2$

a. **Geosynchronous orbit**
The orbit with the same earth rotation rate (h_{24} = the sidereal day ; 86164.1 sec) is called an earth synchronous orbit or geosynchronous orbit. The geosynchronous orbit with an inclination of $i = 0$ is called a geostationary orbit because the satellite looks stationary over the equator from a ground surface view. As such, a geostationary satellite is useful for covering wide areas. Many meteorological satellites and communication satellites are geosynchronous types.

b. **Sun synchronous orbit**
Most earth observation satellites, such as Landsat, with lower altitudes have sun synchronous and semi-recurrent orbits. The sun synchronous orbit can be defined as the orbit in which the orbital plane rotates in a year in unison with the one revolution / year apparent motion of the sun. The model precession rate Ω, is a function of inclination i, orbit altitude h_s and orbital period T as shown in Figure 5.6.2. As seen in the figure, the sun synchronous orbit has $\Omega=1$ (revolution / year). For example, in case of i = 100 degree, the altitude of the sun synchronous orbit is about 1,200 km with about 108 minutes of orbit period.
The advantage of the sun synchronous orbit is that the observation conditions can be kept with a constant solar incident angle.

c. **Semi-recurrent orbit**
While the recurrent orbit can be defined as the orbit which returns to the same nadir point in a day, the semi-recurrent orbit returns to the same nadir point in N days repetition (N>1), which is much better for covering all of the earth than the recurrent orbit.

orbit figure	circular orbit	$e = 0$
	elliptical orbit	$0 < e < 1$
	parabolic orbit	$e = 1$
	hyperbolic orbit	$1 < e$
inclination	equator orbit	$i \fallingdotseq 0$
	slant orbit	$0 < i < 90$
	polar orbit	$i \fallingdotseq 90$
period	earth synchronous	
	sun synchronous	
recurrency	recurrent orbit	
	semi-recurrent orbit	

Figure 5.6.1 Name of satellite orbit

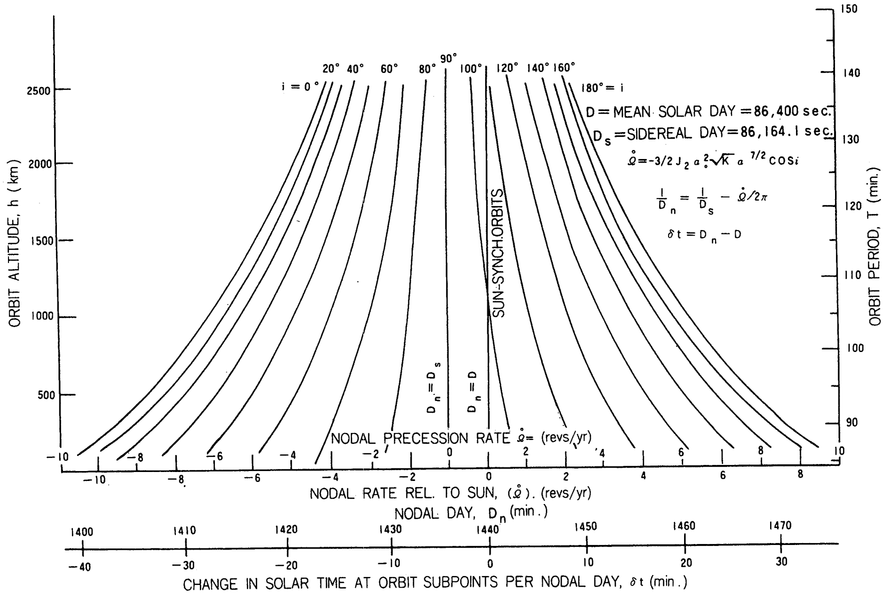


Figure 5.6.2 Satellite orbit precession and related viewing parameters, nodal precession rate $\dot{\Omega}$, orbit period T and orbit altitude h

5.7 Satellite Positioning Systems

There are two methods for positioning a satellite: distance measurement from the ground station, and **GPS** as shown in figure 5.7.1. As GPS is explained in 6.8, the former method will be explained here. The measurement of distance for satellite positioning is called the **range and range rate system**, by which the time of a radio wave transmitted between the ground station and a transponder onboard the satellite is measured with the Doppler frequency. It enables the distance or range and the range rate to be measured. The accuracy of the range and range rate is a few meters/second, respectively. The accuracy depends on the parameters of frequency, signal, the location of the ground station, coordinate system, time measurement system, reflection in the troposphere and the ionosphere etc.

The position of a satellite by the range and range rate method is limited only near the ground station and is also discrete. In order to determine the satellite orbit in a time sequential function, it is necessary to construct a model.

A primitive model is a parabolic curve based on the **third theory of Kepler** that defines the motion of two bodies in space, termed the **two body problem,** under the law of universal gravitation. The parabolic curve can be expressed with the six elements of the Keplerian orbit.

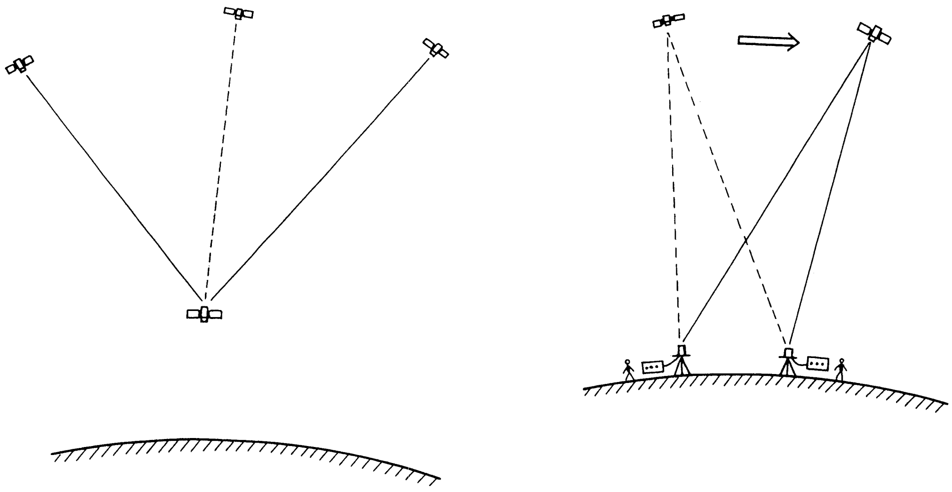
However in reality there are influences from other planets, which results in departure from the parabolic curve. This is called the **perturbation**.

There are two methods to determine the precision for an body problem (n>2); the numerical integral calculation, which has high accuracy but is time consuming and the analytical method with a lower accuracy but faster calculation, as shown in Table 5.7.1.

The satellite position in an orbit will be determined at certain time intervals, from which the orbit at an arbitrary time can be interpolated by the least square method for high order polynomials or by Lagrange's interpolation method.

Table 5.7.1 The methods for satellite orbit calculation

	method	remarks	examples
numerical integral calculation	the following solution of the Newtonian equation of motion is directly obtained through a numerical integral calculation $f = - GMm\gamma/\gamma^3 + f_1 + f_2 + \cdots$	high precision since the method takes gravities of other planets, sun, air drag etc. into account time consuming	NASA NASDA etc.
analytic method	the influences of the long term purturbation in the Newtonian equation of motion, beyond the J2 term, are analytically determined with a mathematical model for the earth's potential	accuracy is lower than the above method	Kozai Model (National Observatory in Japan) NASDA Smithsonian Observatory
	based on the Vinti Potential Model	fast calculation	Brouwer Mean Model NASA
			Vinti Model NASA NASDA etc.



a) Positioning by GPS

b) R&RR measurement from ground station

Figure 5.7.1 Measurement methods for satellite position

5.8 Remote Sensing Satellites

A satellite with remote sensors to observe the earth is called a remote sensing satellite or earth observation satellite. Meteorological satellites are sometimes discriminated from the other remote sensing satellites.

Remote sensing satellites are characterized by their altitude, orbit and sensors. The main purpose of the geosynchronous meteorological satellite (GMS) with an altitude of 36,000 km is meteorological observations, while Landsat with an altitude of about 700 km, in a polar orbit, is mainly for land area observation.

NOAA AVHRR with an altitude of 850 km in a polar orbit is mainly designed for meteorological observation but is also successfully used for vegetation monitoring.

In future some remote sensing satellites will have large payloads with many kinds of multi-purpose sensors, such as the polar orbit platform (POP) project under the international cooperation of US, EEC, Japan and Canada. As well, there will be more specialized missions using small satellites.

Appendix-1 shows the Plan of Earth Observation Satellites up to the year 2,000. The details of major satellites are shown in appendix-2.

Figure 5.8.1 shows the JERS-1(Japanese Earth Resource Satellite-1) spacecraft with SAR, Visible and Near Infrared Radiometer (VNIR) and Short Wavelength Infrared Radiometer (SWIR).

The important functions of a remote sensing satellite system include the following three major systems.

a. Tracking and control system: determination of satellite orbit, orbital control, processing of housekeeping data etc.

b. Operation control system: planning of mission operation, evaluation of observed data, data base of processed data etc.

c. Data acquisition system: receiving, recording, processing, archiving and distribution of observed data.

Figure 5.8.2 shows the total system of the JERS-1.

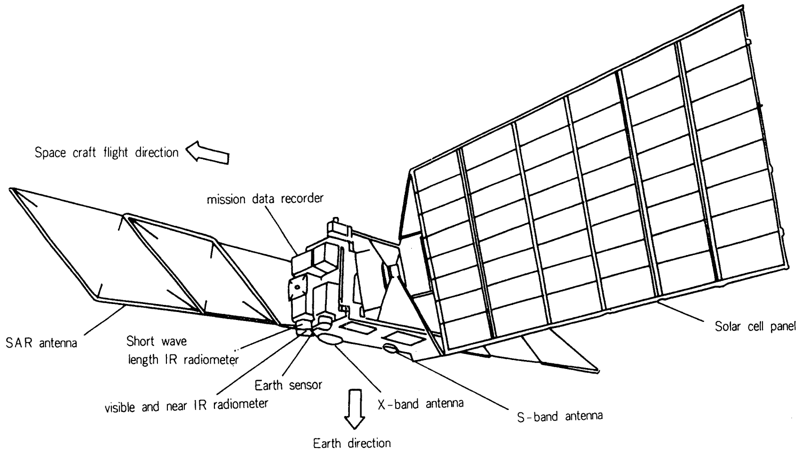


Figure 5.8.1 JERS-1 spacecraft

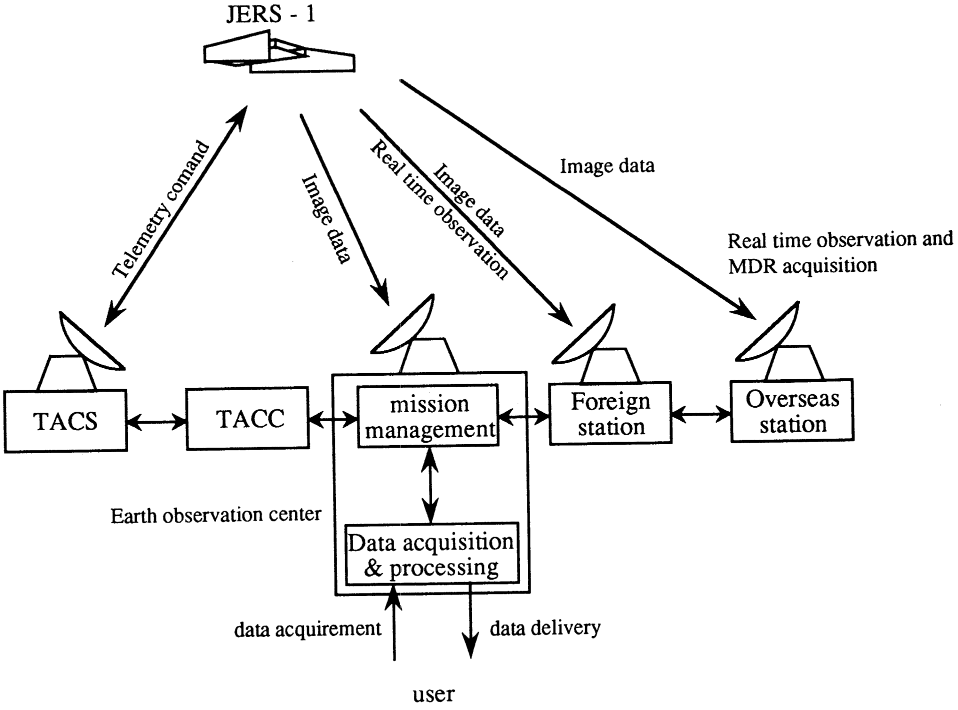


Figure 5.8.2 Major elements of the JERS - 1 system

5.9 Landsat

Landsat-1 was launched by the USA in 1972, and was the first earth observation satellite in the world, which initiated the remarkable advance of remote sensing. To date, five Landsat's (Landsat 1-5) have been launched, with only Landsat 5 still in operation.

Figure 5.9.1 shows the general configuration of Landsat 4 and 5.

a. Orbit of Landsat 4,5 and 6
Altitude; 705 km, Inclination; 98°,
Sun synchronous and semi-recurrent orbit,
Time of passage of the equator; 9:39a.m.,
Recurrent: 17 days
Swath: 185 km

b. Sensors
(1) **MSS** (multispectral scanner)
(2) **TM** (thematic mapper)

Both the sensors are optical-mechanical scanners.

Table 5.9.1 shows the bands, wavelength and resolution of MSS and TM. Landsat 6 will have only ETM (enhanced thematic mapper) with an additional panchromatic mode with 15 meter resolution.

c. Data
MSS and TM data are composed in a unit of scene with a size of 185 x 170 km. Each scene is coded with path number and row number, based on what is called **WRS** (world reference system). For example, Japan is covered with about 63 scenes of path number 104 - 114 and row numbers 28 - 42. Image data are recorded with respect to each pixel with a numerical value (V) of 8 bits (0 - 255). The absolute radiance R ($mW / cm^2.sr$) can be computed by the following formula.

$$R = V[(R_{max} - R_{min}) / D_{max}] + R_{min}$$

where R_{max} : maximum recorded radiance
R_{min} : minimum recorded radiance
D_{max}: 255 for TM
127 for MSS

Table 5.9.2 and Table 5.9.3 show Rmin and Rmax of TM and MSS respectively. One should note that the radiances Rmax and Rmin are measured onboard but not on the ground. Therefore they include atmospheric influences.

d. Data Utilization
There are 15 Landsat receiving stations in the world from which Landsat data are distributed to users for resources management and environmental monitoring.

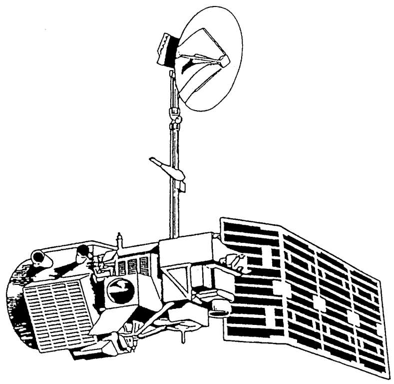


Figure 5.9.1 General configuration of Landsat4 and 5

Table 5.9.1 Landsat MSS and TM observation function

Sensor	Band	Spectral range (micro m)		IFOV
MSS	4	0.50 ~ 0.60	green	80m
	5	0.60 ~ 0.70	red	80m
	6	0.70 ~ 0.80	near - IR	80m
	7	0.80 ~ 1.10	near - IR	80m
TM	1	0.45 ~ 0.52	blue	30m
	2	0.52 ~ 0.60	green	30m
	3	0.63 ~ 0.69	red	30m
	4	0.76 ~ 0.90	near - IR	30m
	5	1.55 ~ 1.75	interm - IR	30m
	6	10.40 ~ 12.50	thermal - IR	120m
	7	2.08 ~ 2.35	mid. - IR	30m

Table 5.9.2 LandsatTM sensitivity Rmin. and Rmax. radiance (unit : mW/cm^2*sr)

band	Rmin/Rmax	band width
1	-0.0099/1.004	0.066μm
2	-0.0227/2.404	0.081μm
3	-0.0083/1.410	0.069μm
4	-0.0194/2.660	0.129μm
5	-0.00799/0.5873	0.216μm
6	-0.00375/0.3595	0.250μm
7	0.1534/1.896	1.239μm

Table 5.9.3 Landsat MSS sensitivity Rmin. and Rmax. of radiance (unit : mW/cm^2*sr)

band	Landsat-2	Landsat-3	Landsat-4	Landsat-5	width
4	0.08/2.63	0.04/2.50	0.04/2.38	0.04/2.38	0.1μm
5	0.06/1.76	0.03/2.00	0.04/1.64	0.04/1.64	0.1μm
6	0.06/1.52	0.03/1.65	0.05/1.42	0.05/1.42	0.1μm
7	0.11/3.91	0.03/4.50	0.12/3.49	0.12/3.49	0.3μm

5.10 SPOT

SPOT was first launched in February, 1986 by the French Government. SPOT-2 was launched in February, 1990 and is now in operation. SPOT-3 will be launched in 1993. SPOT has two **HRV** (High Resolution Visible imaging system) sensors with stereoscopic and oblique pointing functions. Figure 5.10.1 shows the general configuration of SPOT.

a. Orbit

Altitude; 830 Km, Inclination; 98.7°,
Sun synchronous and semi-recurrent orbit,
Time of passage of the equator; 10:30a.m.,
Recurrent : 26 days nominally but 4 - 5 days
if observed with oblique pointing.

b. Sensors

HRV is not an optical-mechanical sensor but a linear **CCD** (charge coupled device) camera with an electronic scanning system. Table 5.10.1 shows the HRV characteristics for the three multi-spectral bands with 20 m IFOV, and a panchromatic mode with 10 m IFOV.

HRV can change the look angle by changing the pointing mirror angle by up to ±27 degrees, as shown in Figure 5.10.2. The enables it to look at the same position from two different orbits as shown in Figure 5.10.3. Such a sidelooking function produces stereoscopic images, with a baseline to height ratio (B/H ratio) of up to 1, for measurement of topographic elevation.

c. Data

A scene of HRV has a nadir coverage of 60 x 60 km, but an oblique coverage of 81 km square, at maximum look angle of 27°. Each scene is coded with column number (K) and row number (J), termed the **GRS** (SPOT Grid Reference System).

Each node is basically given for a nadir observation with odd numbers of K for the coverage of the first HRV sensor. For the oblique scene, the nearest node to the center of the scene is assigned to that scene.

d. Data Utilization

SPOT data are received at 14 ground receiving stations. The main purpose of data utilization is for land area observation as well as for topographic mapping at scales 1/50,000 and smaller.

Sometimes SPOT HRV Panchromatic band (10 m IFOV) and Landsat TM (30 m IFOV) are combined into a color composite for better image interpretation. SPOT panchromatic and multispectral modes are also often overlaid to aid in interpretation.

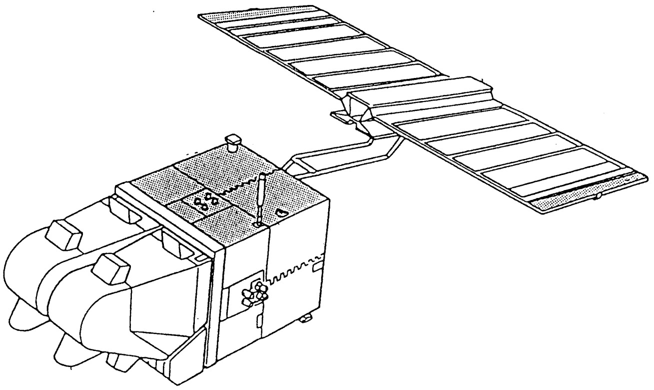


Figure 5.10.1 General configuration of SPOT

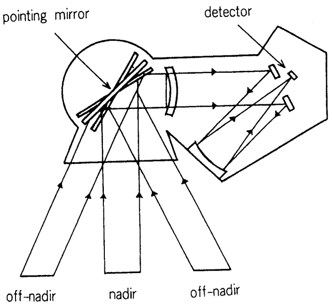


Figure 5.10.2 Principle of oblique investigation

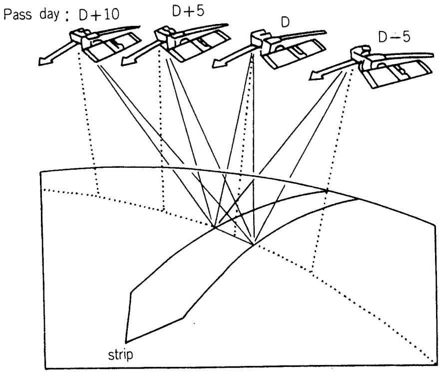


Figure 5.10.3 Repeated observation by SPOT

Table 5.10.1 SPOT HRV characteristics

Band	Spectral range (micro m)		IFOV
XS1	0.50 ~ 0.59	green	20m
XS2	0.61 ~ 0.68	red	20m
XS3	0.79 ~ 0.89	near - IR	20m
PA	0.51 ~ 0.73		10m

XS: indicates multi-spectral mode

PA: panchromatic

5.11 NOAA

The NOAA satellite series are the third generation of meteorological satellites operated by the National Oceanic and Atmospheric Administration (NOAA), USA (see Figure 5.11.1).

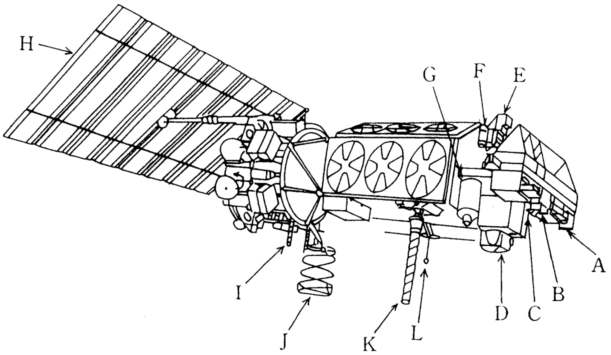
The first generation was the TIROS series (1960 - 1965), while the second generation was ITOS series (1970 - 1976). The NOAA series, the third generation, are listed in Appendix 2.

NOAA has a circular and sun synchronous orbit. The altitude is 870 km (NOAA-11) and 833 km (NOAA-12) with inclination of 98.7 degree (NOAA-11) and 98.9 degree (NOAA-12)to the equator. The orbital period is 101.4 minutes.

As the NOAA series are operational for meteorological observation, two NOAA satellites (currently NOAA-11 and NOAA-n) are in operation. A NOAA satellite can observe the same are area twice a day (day and night), so that the two satellite can cover the same area four times a day. Figure 5.11.2 shows the flyover times of NOAA-11 and NOAA-12 over Japan.

The major sensors of NOAA are **AVHRR/2** (Advanced Very High Resolution Radiometer; model 2) with a 1.1 km IFOV for a swath of 2,800 km, and **TOVS** (TIROS Operational Vertical Sounder) including **HIRS/2** (High Resolution Infrared Sounder; model 2) with 20 km IFOV, for a 2,200 km swath, **SSU** (Stratospheric Sounding Unit) with 147 km IFOV, for a 736 km swath and **MSU** (Microwave Sounding Unit) with 110 km IFOV, for a 2,347 km swath.

Table 5.11.1 shows the characteristics of AVHRR/2, while Table 5.11.2 shows those of the TOVS Channels.



A : AVHRR sensor, B : the stratospheric sounding unit, C : high resolution infrared radiation sounder, D : microwave sounding unit (B - D : TOVS), E : observation unit for proton and electron, F : α–particle measure unit, G : earth sensor, H : solar battery array, I : S band antenna, J : VHF antenna, K : data collection system antenna, L : X band antenna

Figure 5.11.1 Appearance of NOAA satellite

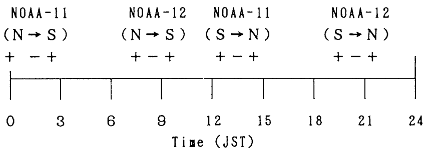


Figure 5.11.2 Flyover Time of NOAA Satellite for Japan

Table 5.11.1 Characteristics of AVHRR/2 Channels

Ch	Wavelength (μm)	Purpose of the Radiance Observation
1	0.58～ 0.68(Visible)	Cloud,Ice,Snow Area
2	0.725～1.10(Near Infrared)	Water Area on Land
3	1.60～1.80 (Near Infrared)	Water Area on Land
4	3.55～ 3.93(Intermediate IR)	Surface Temperature,Cloud Area
5	10.3～ 11.3(Far Infrared)	Surface Temperature,Cloud Area
6	11.5～ 12.5(Far Infrared)	Surface Temperature,Cloud Area

Table 5.11.2 Characteristics of TOVS channels

	Ch. No.	Central Wavenumber (μm)	Principal Absorbing Constituents	Level of Peak Energy Contribution	Purpose of the Radiance Observation
HIRS/2	1	15.00		30	
	2	14.70		60	
	3	14.50	CO_2	100	
	4	14.20		400	Temperature sounding
	5	14.00		600	
	6	13.70	CO_2/H_2O	800	
	7	13.40		900	
	8	11.10	H_2O	surface	Surface temperature & cloud detection
	9	9.70	O_2/H_2O	25	Total ozone concentration
	10	8.30		900	Water apor sounding
	11	7.30	H_2O	700	
	12	6.70		500	
	13	4.57	N_2O	1000	Temperature sounding
	14	4.52		950	
	15	4.46	CO_2/N_2O	700	
	16	4.40		400	
	17	4.24	CO_2	5	
	18	4.00	$N_2/CO_2/N_2O$	surface	Surface temperature
	19	3.70	N_2O/H_2O	surface	
	20	0.70	H_2O	surface	Cloud detection
SSU	1	15.00		15.0	Temperature sounding
	2	15.00	CO_2	14.0	
	3	15.00		1.5	
MSU	1	50.31(GHz)	O_2/H_2O	surface	Surface emissivity
	2	53.73(GHz)		700	Temperature sounding
	3	54.96(GHz)	O_2	300	
	4	57.95(GHz)		90	

5.12 Geostationary Meteorological Satellites

Geostationary meteorological satellites are launched under the WWW (World Weather Watch) project organized by the WMO (World Meteorological Organization), which will cover all the earth with five satellites as shown in Figure 5.12.1.

The five geostationary meteorological satellites are **METEOSAT** (ESA), **INSAT** (India), **GMS** (Japan), **GOES-E** (USA) and **GOES-W** (USA). The schedules for these satellites are shown in Appendix 1.

As of 1991, METEOSAT-5, INSAT-1D, GMS-4 and GOES-7 are in operation.

GMS-4 has a sensor called VISSR (Visible and Infrared Spin Scan Radiometer) with two bands of visible and thermal infrared. The VISSR scans four lines for the visible band and a line for the thermal band simultaneously from the north to the south, which takes 25 minutes to cover the semi-sphere as shown in Figure 5.12.2.

The total scan lines are 10,000 lines for the visible band and 2,500 lines for the thermal band.

GMS has a data collection platform (DCP) system to collect various information, not only from the ground station, but also from the stations on the sea as shown in Figure 5.12.3.

The image data are transmitted to the ground station in a high resolution mode of S-VISSR signals, and also in a low resolution mode of WEFAX, which can be received by cheaper and simpler receiving facilities. Some statistical data such as histograms, cloud volumes, sea surface temperatures, wind distribution and so on, are recorded in the archives including the ISCCP (International Satellite Cloud Climatology Project) data set.

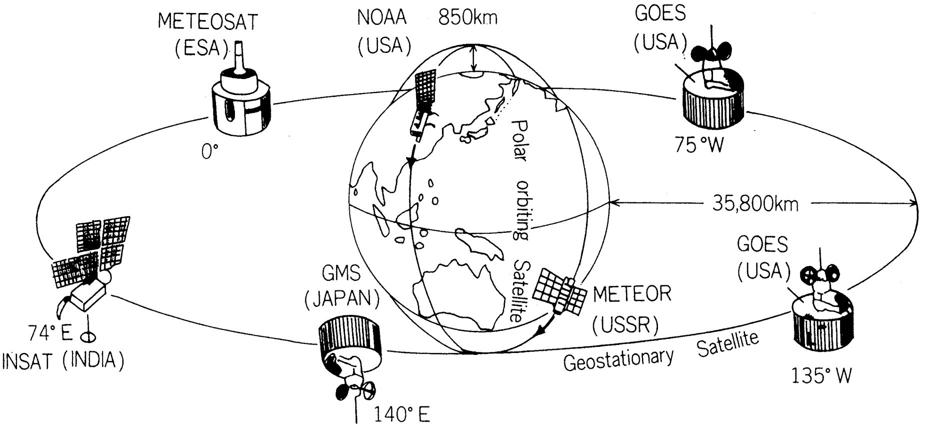


Figure 5.12.1 Location of geostationary satellite

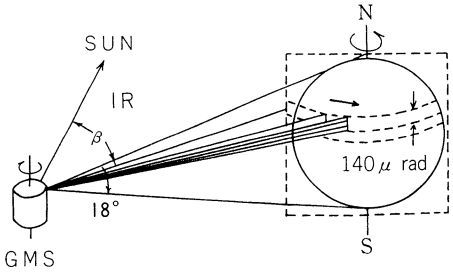


Figure 5.12.2 GMS observation characteristics

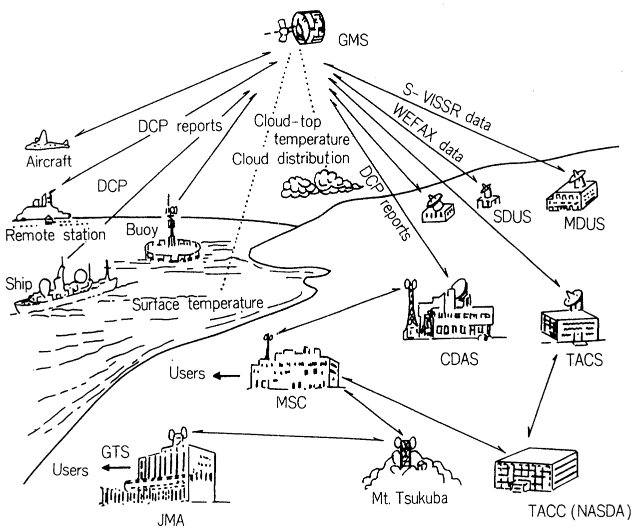


Figure 5.12.3 GMS, major elements of observatory system

5.13 Polar Orbit Platform

The **Polar orbit platform (POP)** is a newly designed system for the 21st century, intended to establish a longer life space infrastructure with multiple sensors as well as multiple uses, when compared with the existing satellites which are used for a limited period and purpose.

POP is composed of a main space station, a space shuttle and an inter-orbital vehicle as shown in Figure 5.13.1, by which exchange of mission equipments and repair of the form will be possible.

POP is made of a module structure with ORU (Orbital Replacement Unit) for replacement of mission parts and battery. Such functions of POP will make the system large in size and payload, but long in life.

Japanese ADEOS (Advanced Earth Observation Satellite) as shown in 5.13.1 is not POP a but is designed for a future type platform of earth observation satellite with the function of data relay. ADEOS is characterized by the multiple sensors of OCTS (Ocean Color and Temperature Scanner by NASDA), AVNIR (Advanced Visible and Near Infrared Radiometer by NASDA), and AO (Applications of Opportunity) sensors such as NSCAT, TOMS, IMG, POLDER, and ILAS as seen in Appendix 2.

At present the space station project is delayed and cut back to a smaller system without orbital services. For example, NASA EOS-a and b, ESA POEM-1 and 2 will be launched at the end of the 20th century for earth environmental monitoring.

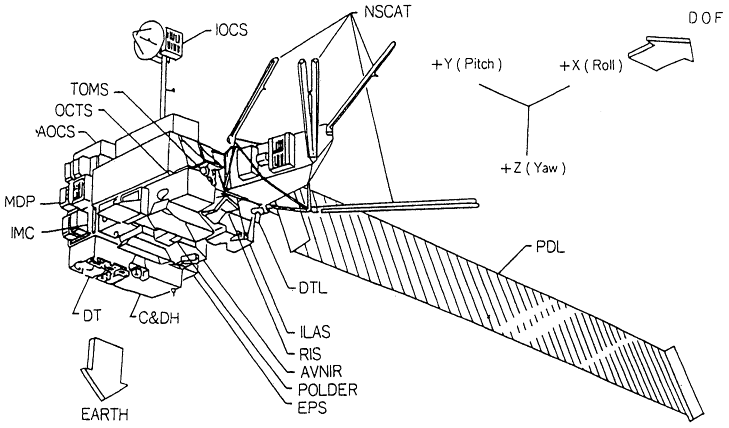


Figure 5.13.1 Artist's view of ADEOS

Table 5.13.1Main characteristics of ADEOS

Shape	Module type with deployable solar paddle (one wing)	
	Body approx. 4 x 4 x 5 (m) (mission, bus, prop. module)	
	Solar paddle approx. 3 x 13 (m)	
Weight	Approx. 3.6ton (at lift-off)	
Attitude control	Three-axis stabilized (zero-momentum)	
Launch vehcle	H-II (5m fairing)	
Orbit	Type	Sun synchronous subrecurrent
	Altitude	Approx. 800km
	Inclination	Approx. 98.6 deg.
	Period	Approx. 101 min.
	Recurrent Period	41 days
	Local time at descending node	10:15 - 45 AM
Transmission	Direct transmission and inter-orbit communication	