Platforms

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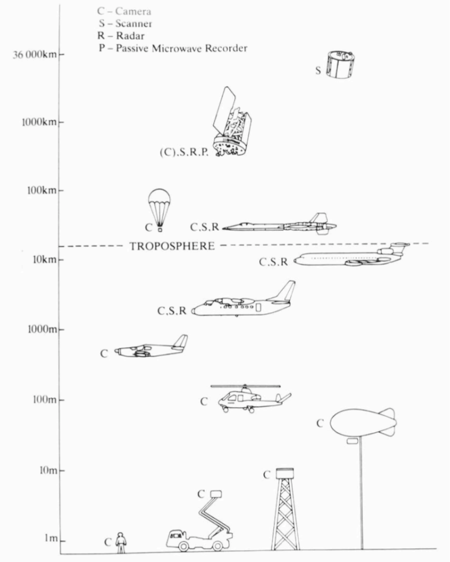
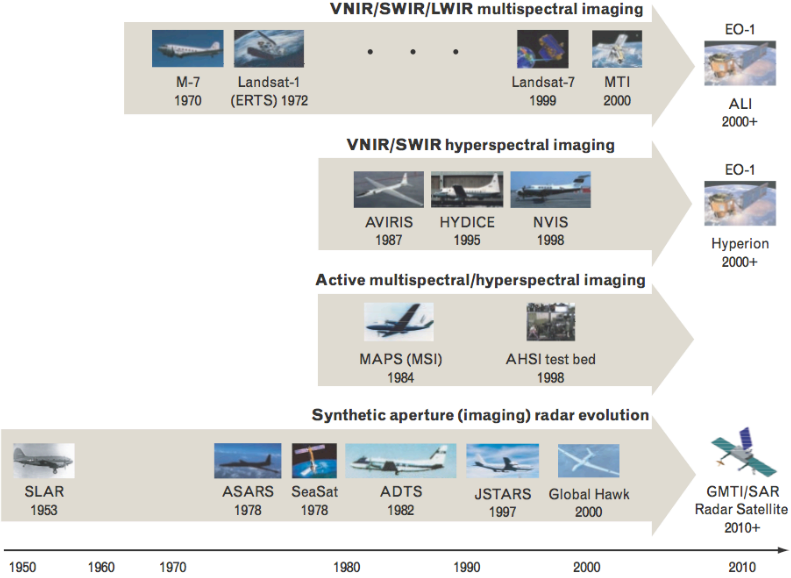
Platforms



C – Camera
S – Scanner
R – Radar
P – Passive Microwave Recorder
36 000km
1000km
100km
10km
1000m
100m
10m
1m
S
(C).S.R.P.
C
C.S.R
TROPOSPHERE
C.S.R
C.S.R
C
C
C
C
C
C

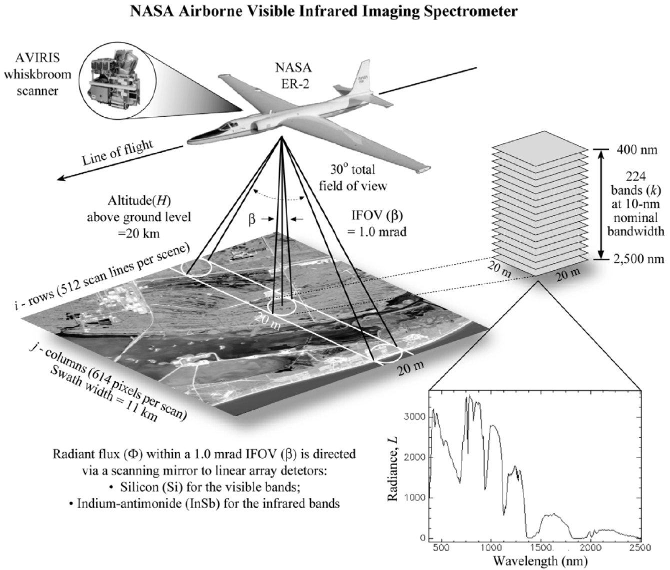
Airborne and Satellite platforms



Airplanes

- Usually fly at elevation from few hundreds to 3-10 thousands meters
- Pros:
  - Flexible choice of altitude and resolution
  - Very useful for local high resolution acquisitions
  - Relatively low cost for specific small areas
- Cons:
  - Difficult to use over large areas
  - Difficult to use for long term monitoring (e.g., 10 years)

Airplanes

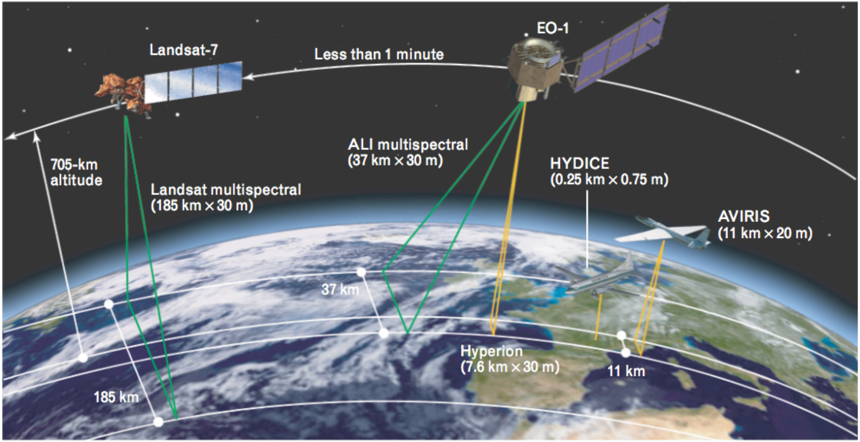


NASA Airborne Visible Infrared Imaging Spectrometer
AVIRIS whiskbroom scanner
NASA ER-2
Line of flight
30° total field of view
Altitude(H) above ground level =20 km
β
IFOV (β) = 1.0 mrad
400 nm
224 bands (k) at 10-nm nominal bandwidth
2,500 nm
20 m
20 m
i - rows (512 scan lines per scene)
20 m
20 m
j - columns (614 pixels per scan)
Swath width = 11 km
Radiant flux (Φ) within a 1.0 mrad IFOV (β) is directed via a scanning mirror to linear array detetors:
• Silicon (Si) for the visible bands;
• Indium-antimonide (InSb) for the infrared bands
Radiance, L
3000
2000
1000
0
500
1000
1500
2000
2500
Wavelength (nm)

Satellites

- From few hundreds to tens of thousands kilometers in altitude
- Pros:
  - They allow constant very large scale acquisitions, both in time and in area
  - In the long term, the system becomes cheap since it can acquire more and more data with virtually no costs
- Cons:
  - Too expensive for short term missions
  - Limited by the physical constraints imposed by orbits
  - Not appropriate for small areas remote sensing

Satellites

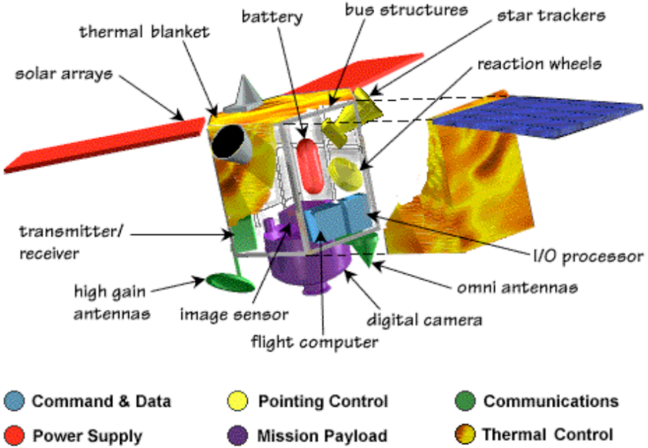


Landsat-7
Less than 1 minute
EO-1
705-km
altitude
Landsat multispectral
(185 km × 30 m)
ALI multispectral
(37 km × 30 m)
HYDICE
(0.25 km × 0.75 m)
AVIRIS
(11 km × 20 m)
37 km
185 km
Hyperion
(7.6 km × 30 m)
11 km

Satellite systems

- Space segment
  - Data acquisition
  - Storage and compression
  - Transmission to Earth

- Earth segment
  - Data reception
  - Processing and Interpretation
  - Archiving
  - Control


battery
bus structures
star trackers
thermal blanket
reaction wheels
solar arrays
transmitter/
receiver
I/O processor
high gain
antennas
omni antennas
image sensor
digital camera
flight computer
Command & Data
Pointing Control
Communications
Power Supply
Mission Payload
Thermal Control

Components

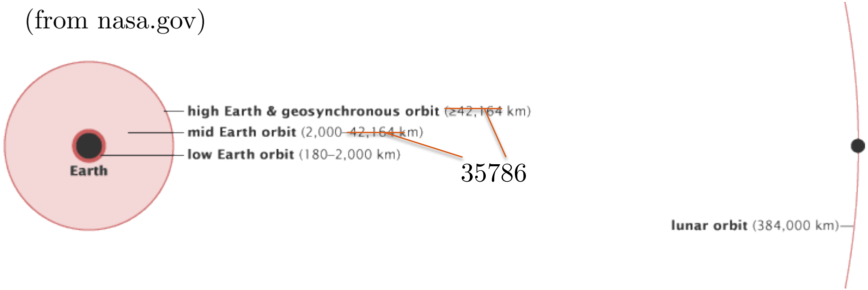
- Communication sub-system
  - Composed of transceivers and antennas
  - It sends images and information to Earth
  - It receives control commands from Earth
- Mission Payload
  - The set of sensors and acquisition components
  - Cameras, radars etc depending on the type of remote sensing activity planned
  - Different partners often share the payload of the same satellite
- Command and Data Handling
  - It is in charge of handling the sensors
  - It also handles the storage/processing of collected data

Components

- Attitude and orbit control subsystem
  - It monitors the position and orientation of the satellite and performs the required actions to maintain or change position and/or pointing direction etc.
  - It contains reaction wheels, gyroscopes etc.
- Power supply
  - Solar panels to derive energy from sunlight
  - Batteries for storing energy
- Thermal control
  - It monitors and control the temperature of critical components
  - This is critical for example for sensing in the thermal infrared

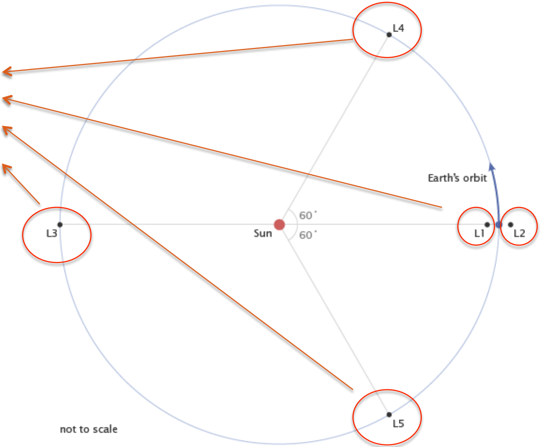
Orbits around the Earth

(from nasa.gov)



Orbits around the Sun (example)

Lagrangian points: Two satellites can be placed in these points and they will orbit the Sun maintaining fixed angles with the Earth. Useful for stereo vision of the Sun



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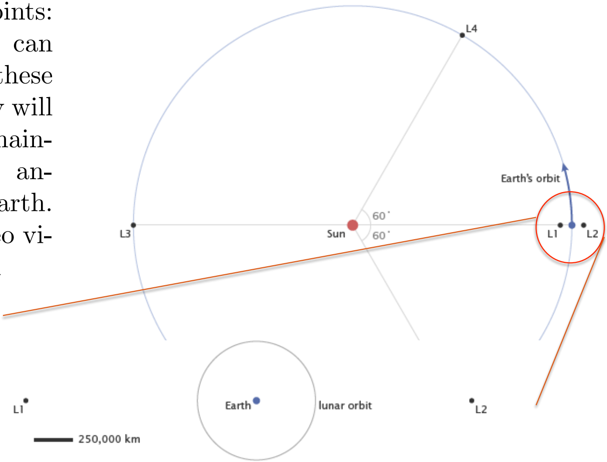
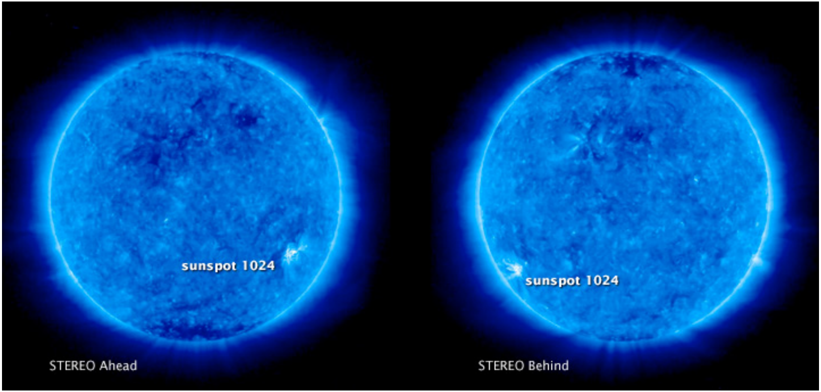
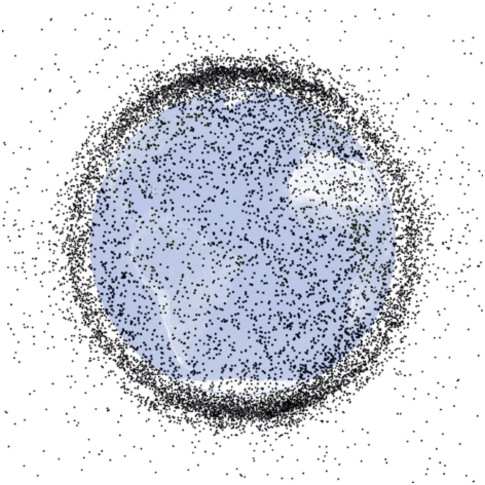


Stereo Vision of the Sun



What is orbiting the Earth?



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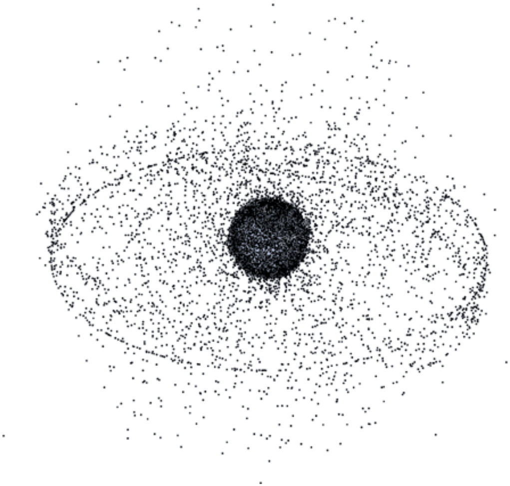
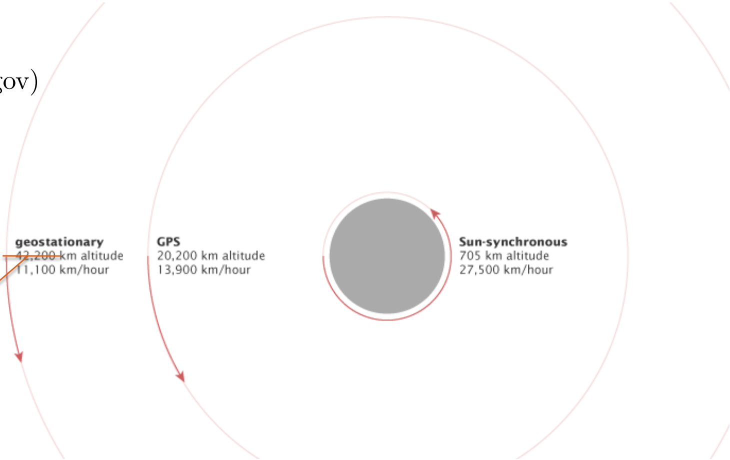


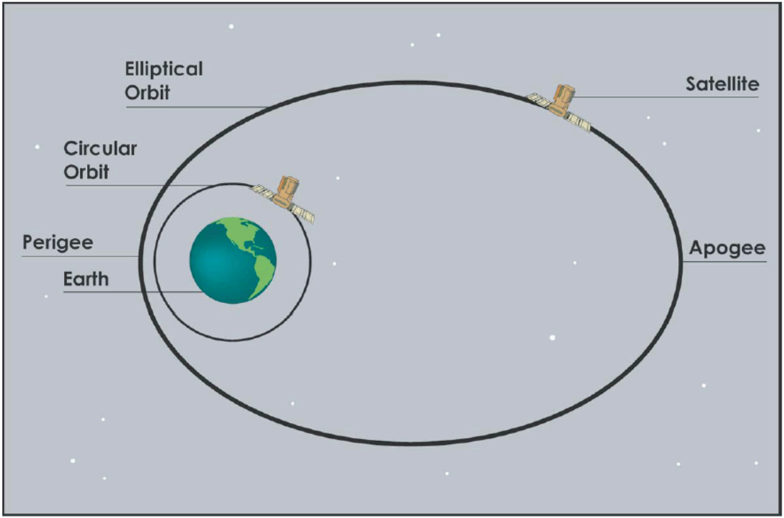
Example of orbits around the Earth

(from nasa.gov)



35786

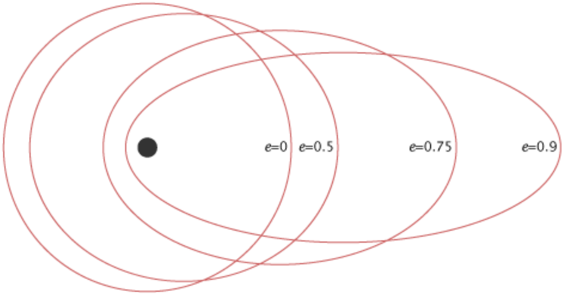
Orbits around the Earth



Orbit characteristics

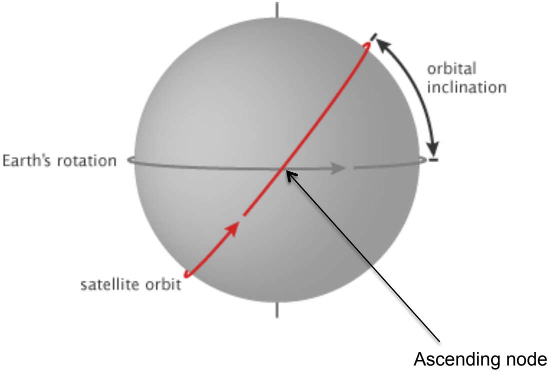
- Orbital Eccentricity
- Inclination: the angle between the orbital plane and the equatorial plane
- Altitude (for circular orbits): the distance of the orbit from the Earth surface. It varies from around around 400 Km and 36000 Km. It impacts on the field of view, achievable definition, orbit period and more
- Period: the time required for one revolution around the Earth (from about 80 minutes to about 24 hours)
- Revisit time: time required for the satellite to observe again the same point on the Earth. In the order of days.

- Orbital eccentricity e



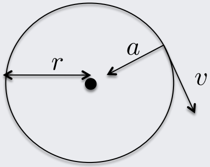
Satellite Orbits

- Orbital inclination i
  - $i < 90°$: prograde orbit
  - $i > 90°$: retrograde orbit



Circular orbit: basic principle

Consider an object orbiting the Earth in circular orbit



- Gravitational acceleration at distance r from the center of the Earth

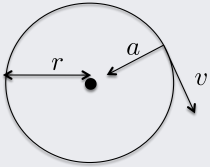
$$a_g = \frac{GM}{r^2}$$

- Centripetal acceleration for circular motion

$$a_c = \frac{v^2}{r}$$

Circular orbit: basic principle

Consider an object orbiting the Earth in circular orbit



- Equating these two values

$$v = \sqrt{\frac{GM}{r}}$$

- Orbital period

$$T = 2\pi\sqrt{\frac{r^3}{GM}} = \sqrt{\frac{4\pi^2 r^3}{gR_E^2}}$$

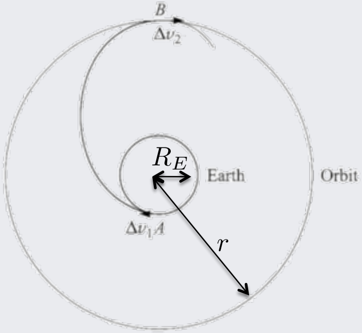
Satellite launch

- The satellite is carried into outer space by a rocket
- Initial boost: it brings the satellite on an elliptical orbit

$$\Delta v_1 = \sqrt{\frac{2rGM}{R_E(r + R_E)}}$$

- Correction: the speed is increased to put the satellite on a circular orbit

$$\Delta v_2 = \sqrt{\frac{GM}{r}} - \sqrt{\frac{2rGM}{R_E(r + R_E)}}$$



Elliptical orbits

- Eccentricity $e \in [0, 1)$

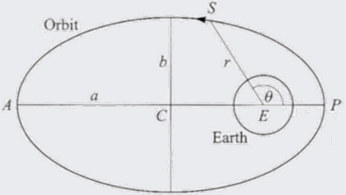
  $e = \overline{CE}/\overline{CA}$ or $b^2 = a^2(1-e^2)$

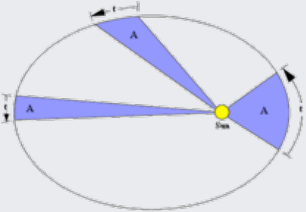
- Period

$$T = 2\pi\sqrt{\frac{a^3}{GM}}$$

- Conservation of the angular momentum

$$r^2\frac{\partial\theta}{\partial t} = \text{Constant}$$





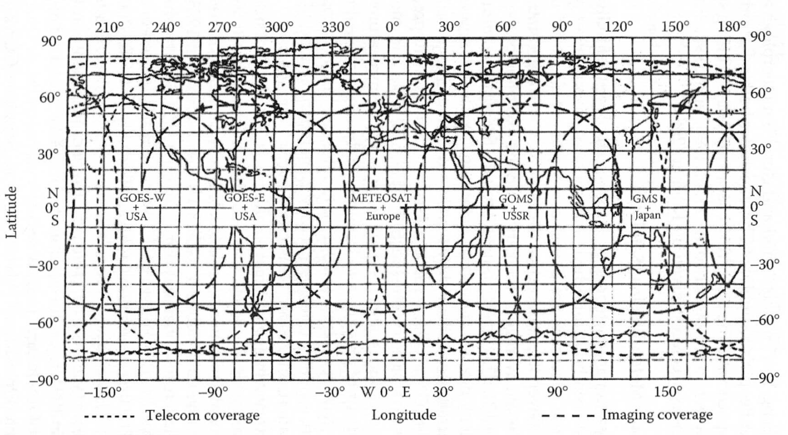
Circular orbits

- Low Earth Orbits (LEO):
  - Altitude in the range from about 180 Km to 2000 Km
  - They allow very high resolutions
  - Small periods and high speed
  - Example, for a 400 Km altitude, T=90 min., v= 7,67 Km/sec.
- Medium Earth orbits (MEO)
  - Altitude in the range 2000-35768 Km
  - The most used altitude is around 20000 Km
  - Period from 2 to 24 hours (usually near 12 hours)
- Geostationary orbit: 35768 Km
- High Earth orbits (HEO)
  - Above 35768 Km
  - Example: Vela, altitude $h > 100000$ Km

Geostationary orbit

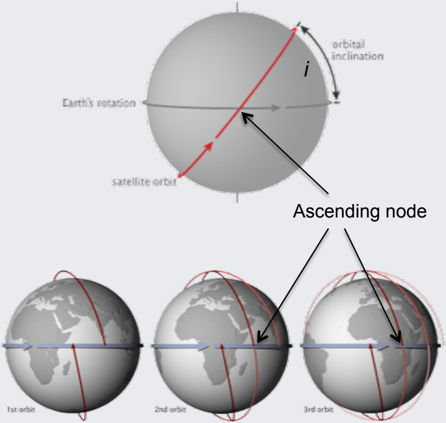
- The satellite orbits the Earth with the same period of the Earths rotation
- The satellite thus stays in a fixed point in the Earths reference frame
- Equatorial orbit (inclination is zero)
- Elevation of about 36000 Kilometers
- Much used for weather satellites (Meteosat, etc.)
- Much used for telecommunication satellites (TV, etc.)

- Regions covered by some geostationary satellites



Near-polar orbits

- Inclination i is near 90°
  - $i < 90°$ prograde orbit
  - $i > 90°$ retrograde orbit
- Usually from 12 to 16 revolutions per day
- Due to the Earth's rotation, the ascending node moves round the equator
- Examples
  - $h = 566$ Km, $T = 95$ min., $v = 7,58$ Km/s.
  - $h = 1680$ Km, $T = 120$ min., $v = 7$ Km/s.



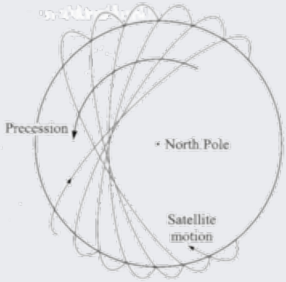
Precession

- The Earth is not a perfect sphere
  - Equatorial radius: $R_e = 6378$ Km approximately
  - Polar radius: $R_p = 6356$ Km approximately
  - This causes two types of precession
- Nodal precession
  - The orbital plane changes its direction with a rotation around the Earth's axis
  - Important for sun-synchronous orbits
- Apsidal precession (for elliptic orbits)
  - The rotation of the axes of the ellipse in orbital plane
  - Important for certain particular satellites with highly elliptical orbits, for example for the Molnyia

Precession

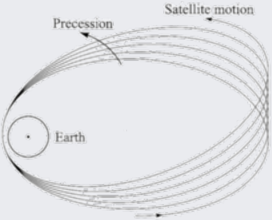
- Nodal precession The ascending node rotates with a constant speed

$$\Omega_p = -\frac{3J_2\sqrt{GM}R_E^2\,a^{-7/2}\cos i}{2(1-e^2)^2}$$



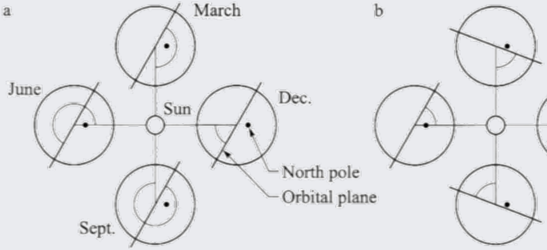
- Apsidal precession The ellipse axes rotate with a constant speed

$$\omega_p = -\frac{3J_2\sqrt{GM}R_E^2\,a^{-7/2}(1-5\cos^2 i)}{2(1-e^2)^2}$$



Sun-synchronous orbits

It is useful to exploit nodal precession to make the orbital plane rotate with the same period with which the Earth orbits the Sun. These orbits ensure a constant illumination during the whole year.



Variable illumination   Constant illumination

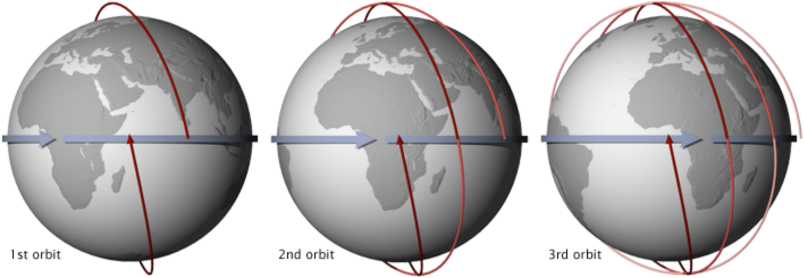
Sun-synchronous orbits

- For a sun-synchronous orbit, a prograde precession is needed. The ascending node rotates with speed

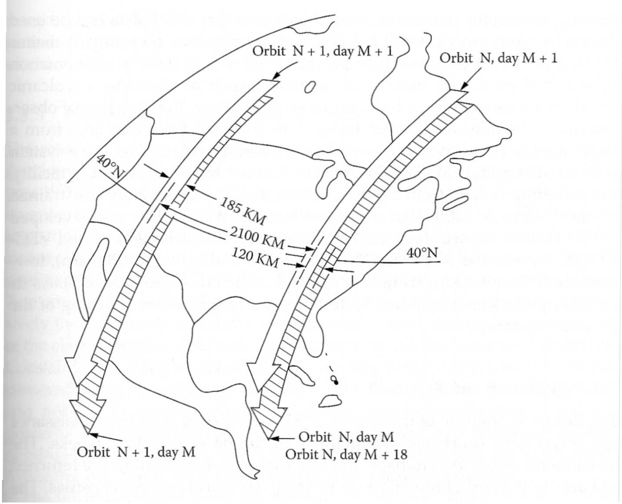
$$\Omega_p = -\frac{3J_2\sqrt{GM}R_E^2 a^{-7/2}\cos i}{2(1-e^2)^2},$$

  and we want $\Omega_p > 0$. Thus, the inclination i must be larger than $90°$. Thus the orbit itself is retrograde.
- The satellite visits each point of the Earth surface always at the same time (for example at 10:30, which is a good choice for illumination conditions)

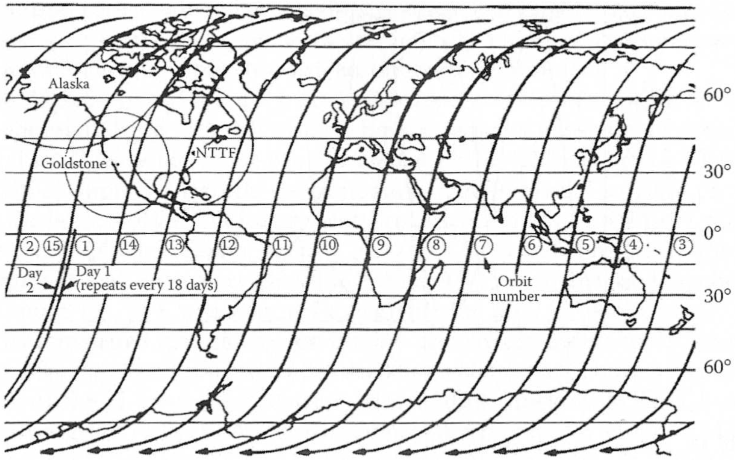
Sun-synchronous orbits



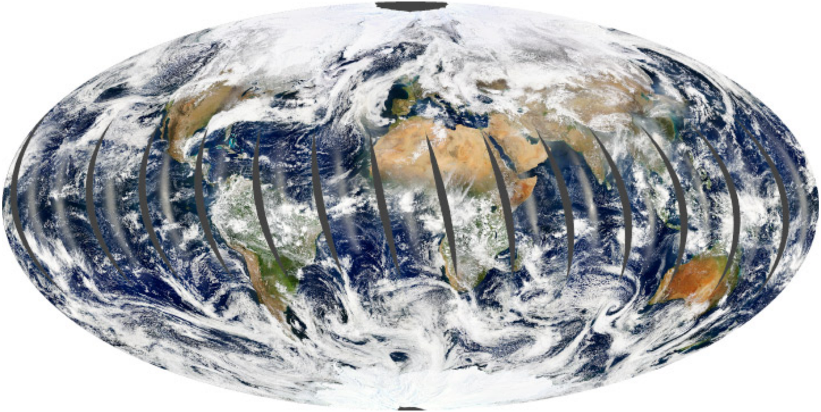
Sun-synchronous orbits: revisit time



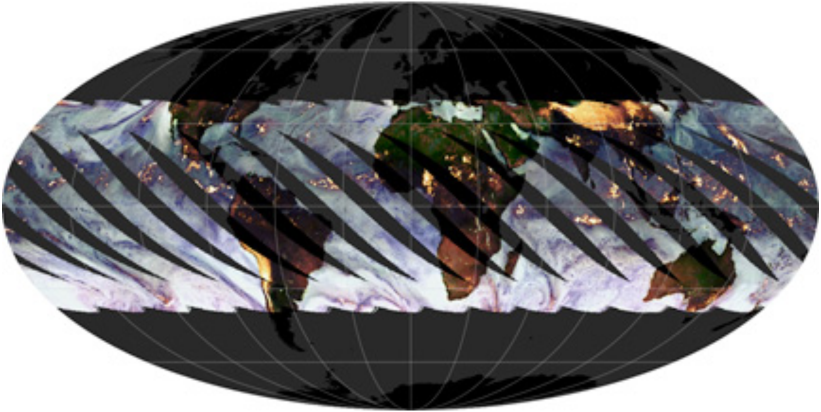
- Sun-synchronous orbits



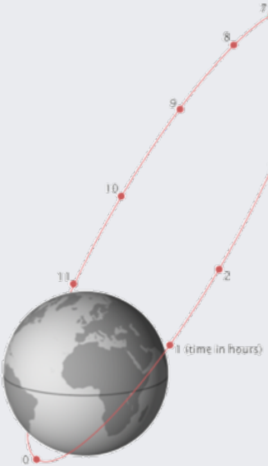
- Result (NASA Aqua)



- Near-equatorial orbit (NASA Tropical Rainfall Measuring Mission)

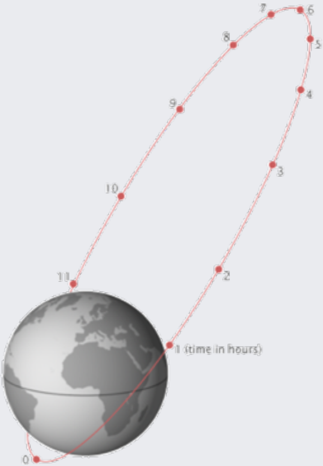


Molniya



- Very high eccentricity orbit
- Devised by the russians in the 60s
- Allows for a prolonged observation of the north hemisphere

Molniya



- By Kepler's law, the motion is slower at the apogee
- The major axis must not rotate in the orbital plane, that is, there must be no apsidal precession. Hence, we must have

$$(1 - 5\cos^2 i) = 0$$

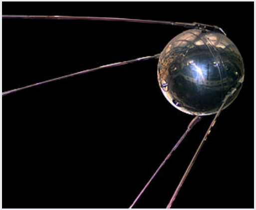
which implies $i \approx 63.4°$ or $i \approx 116.6°$.

Death of a satellite

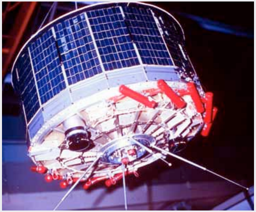
- When it is no more possible to correct the orbit due to fuel exhaustion, the satellite is destined to be lost or, often, fall back to Earth due to friction with higher layers of the atmosphere
- At each revolution, a satellite like for example Landsat 5, looses initially half a meter in altitude, which means 5 meters per day.
- As he falls, the atmosphere becomes denser and the satellites usually burns completely without reaching the Earth surface
- If the orbit has altitude of around 800 Km, it takes approximately a hundred years to for the satellite to fall
- With a very low orbit of 180 Km (only for military) it only takes a few days

Examples: history

- Sputnik: first (successful) satellite
  - Russian satellite launched in 1957
  - Elliptic orbit ($e = 0.05$)
  - Altitude from 200Km and 1000 Km
  - Fallen in 1958 (burned in the atmosphere)



- TIROS-1
  - Launched by NASA in 1960
  - First successful weather satellite
  - Operated for 78 days
  - Followed by TIROS 2,3,..10



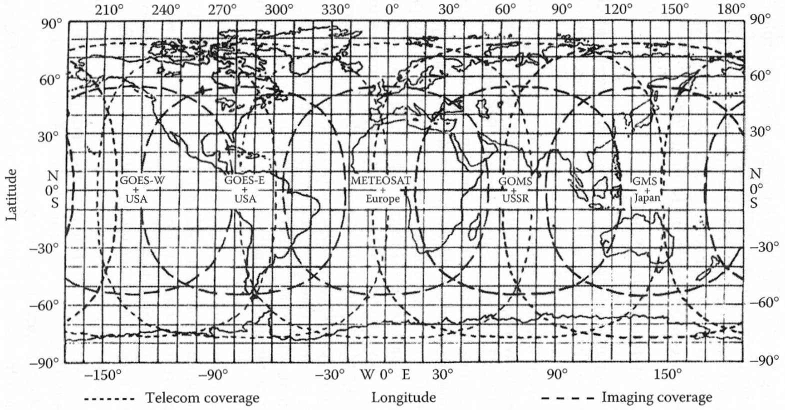
Examples: meteorological satellites

- METEOSAT: satellites of the EUMETSAT organization
  - Geostationary orbit
  - First generation
    - Meteosat 1 (1977)
    - Meteosat 2 (1981)
    - ...
    - Meteosat 7 (1997)
  - Second generation (MSG):
    - 20 times more information at twice the speed
    - Meteosat 8 (2002)
    - Meteosat 9 (2005)
  - Third generation (MTG)
    - ... 2015?

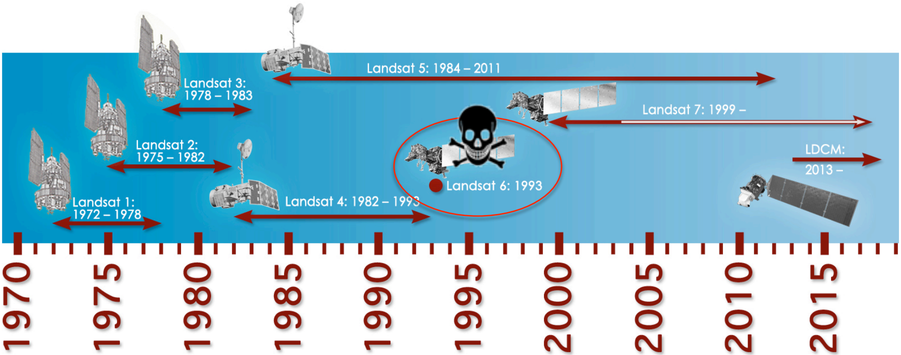
Examples: meteorological satellites

- NOAA (National Oceanic and Atmospheric Admin.) satellites
  - GOES: short range weather forecast
    - Geostationary orbit
    - GOES-12 South America
    - GOES-13 Operational East
    - GOES 14 On-Orbit Storage
    - GOES 15 Operational West
  - NPOES: long range forecast and monitoring
    - Near polar orbit, sun-synchronous
    - 14 revolutions per day
    - It is actually used for all kind of environmental applications

- Regions covered by some geostationary satellites



Examples: NASA Landsat



Examples: NASA Landsat

- The oldest Earth observation program
- Satellites are on near-polar sun-synchronous orbits, inclinations $i = 98,2°$ and $i = 99,2°$
- Altitude 700-900 Km
- Landsat 5 retiring early 2013
- Landsat 6 failed to reach orbit
- Landsat 7 active
    - Main source of data used in the recent period also for academic studies
    - Since 2009, data are freely available
    - `http://landsat.gsfc.nasa.gov/about/landsat7.html`
- Landsat 8: Landsat Data Continuity Mission (LDCM)
    - Launched February 11, 2013!
    - `http://ldcm.nasa.gov/`

http://www.nasa.gov/missions/index.html