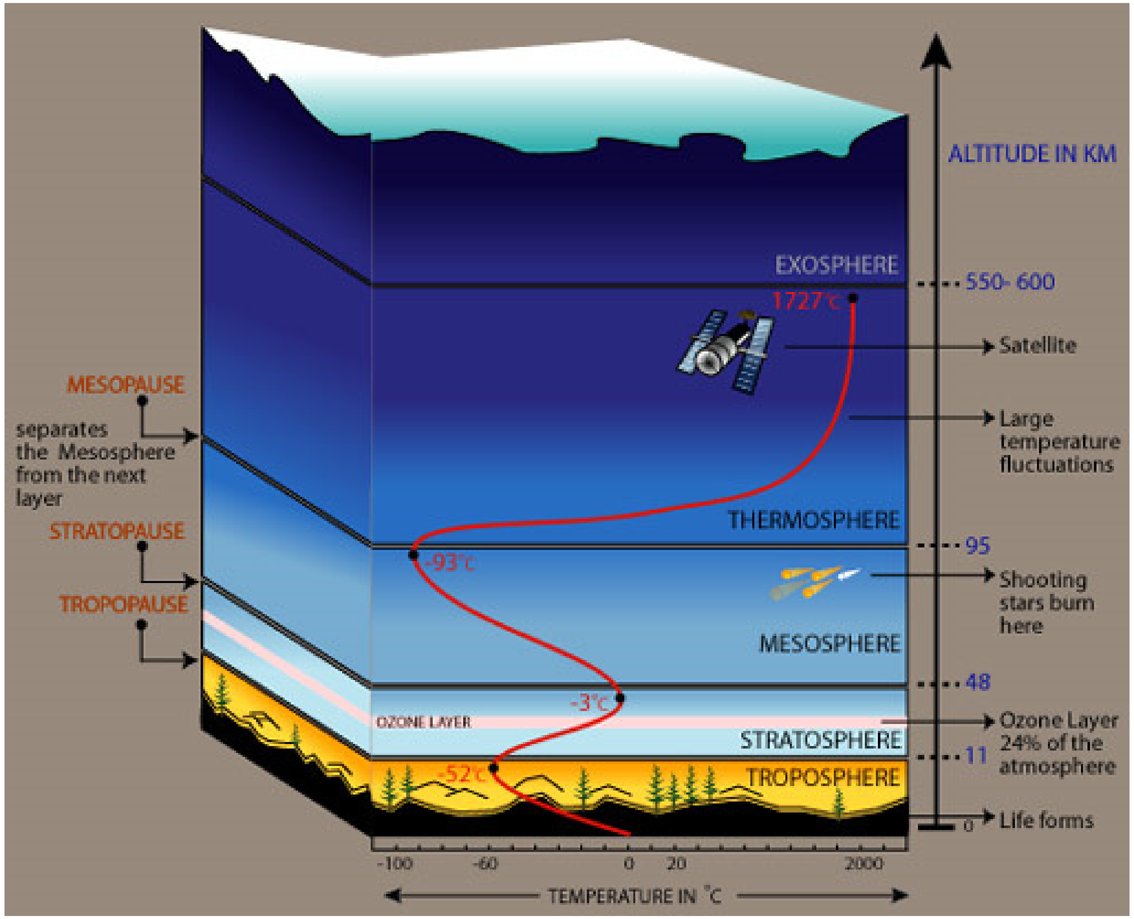
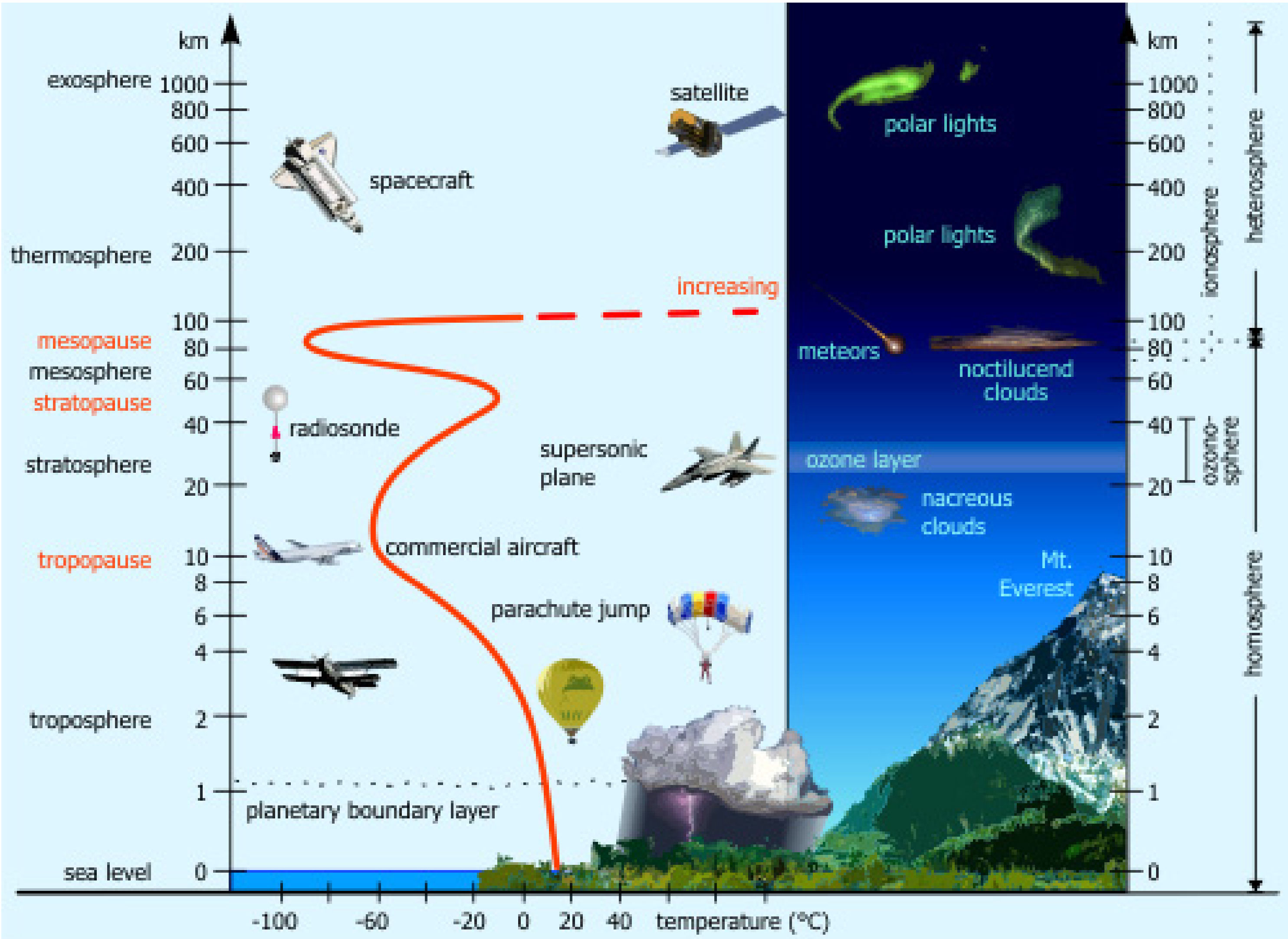
SATELLITES

Artificial satellites are used as platforms for remote sensing. The choice of the satellite altitude and orbit will determine the spatial coverage and the spatial resolution of the images. It is also important to select carefully the relative speed of the satellite with respect to the ground. A satellite offers a spatial data coverage which is substantially better than the one that can be achieved by means of an aircraft. Moreover, the satellite continues to function for several years.



Atmosphere layers

<u>Troposphere</u>: 0-12 km
<u>Stratosphere</u>: 12-50 km
Mesosphere: 50-80 km
<u>Thermosphere</u>: 80-700 km
Exosphere: 700-10000 km



http://ds9.ssl.berkeley.edu/LWS_GEMS/3/layers.htm

http://www.theozonehole.com/atmosphere.htm

Kepler's laws

These laws arise from observations by Kepler of the movement of the planets around the Sun:

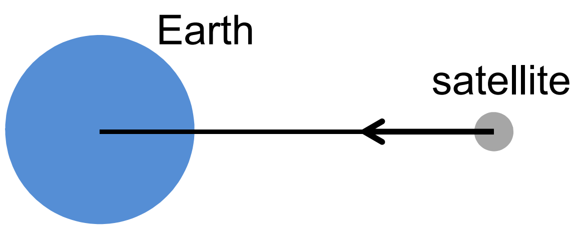
(a) The planets move in a plane; the orbits described are ellipses with the Sun at one focus.

(b) The vector from the Sun to the planet sweeps equal areas in equal times (the law of areas).

(c) The ratio of the square of the period T of revolution of a planet around the Sun to the cube of the semi-major axis of the ellipse is the same for all planets.

Law of gravitation

$$\boxed{\mathbf{F} = -G\frac{Mm}{r^2}\hat{\mathbf{r}}}$$



satellite mass m distance between satellite and Earth r

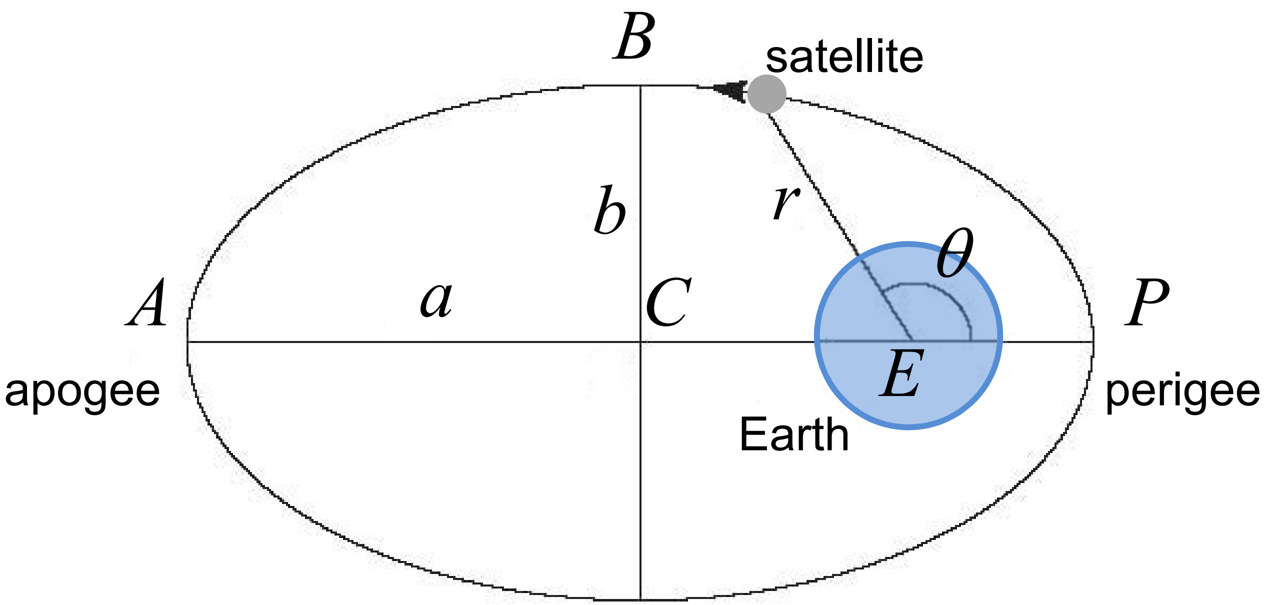
universal gravitational constant $G = 6.672\times10^{-11}\ \mathrm{m}^3\cdot\mathrm{kg}^{-1}\cdot\mathrm{s}^{-2}$

Earth's mass $M = 5.974\times10^{24}\ \mathrm{kg}$

Earth's radius $R = 6371\ \mathrm{km}$

geocentric gravitational constant $\mu = GM = 3.986\times10^{14}\ \mathrm{m}^3/\mathrm{s}^2$

From the law of gravitation it can be proved that a satellite follows an elliptical orbit and the center of the Earth is located in one of the two focal points of the ellipse (the mass of the satellite is much smaller than the Earth's mass).
The eccentricity of the orbit is the ratio of the distance of the focus from the ellipse center to the ellipse semi-major axis.
The perigee is the nearest point of the orbit from the Earth's center.
The apogee is the furthest point of the orbit from the Earth's center.



Distance of the satellite as a function of its angle with respect to the major axis (and from the perigee)

$$r = \frac{a\left(1-e^2\right)}{1+e\cos\theta}$$

semi-major axis

$$a = \overline{AC}$$

semi-minor axis

$$b = \overline{BC}$$

eccentricity $e = \dfrac{\overline{CE}}{\overline{CA}} = \sqrt{1-\dfrac{b^2}{a^2}}$

satellite velocity

$$v = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)}$$

period of the satellite motion

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

as predicted by Kepler's third law

Under the hypothesis that the orbit is circular, period T and altitude h can be readily obtained by observing that the inward gravitational force must be equal to the outward centrifugal force.

gravitational force

$$F = \frac{GMm}{(R+h)^2} = \frac{GM}{R^2} m \left(\frac{R}{R+h}\right)^2 \cong gm$$

$$g = 9.81\,\mathrm{m/s^2}$$

centrifugal force

$$F = \frac{mv^2}{R+h} = m\omega^2(R+h) \qquad T = \frac{2\pi(R+h)}{v}$$

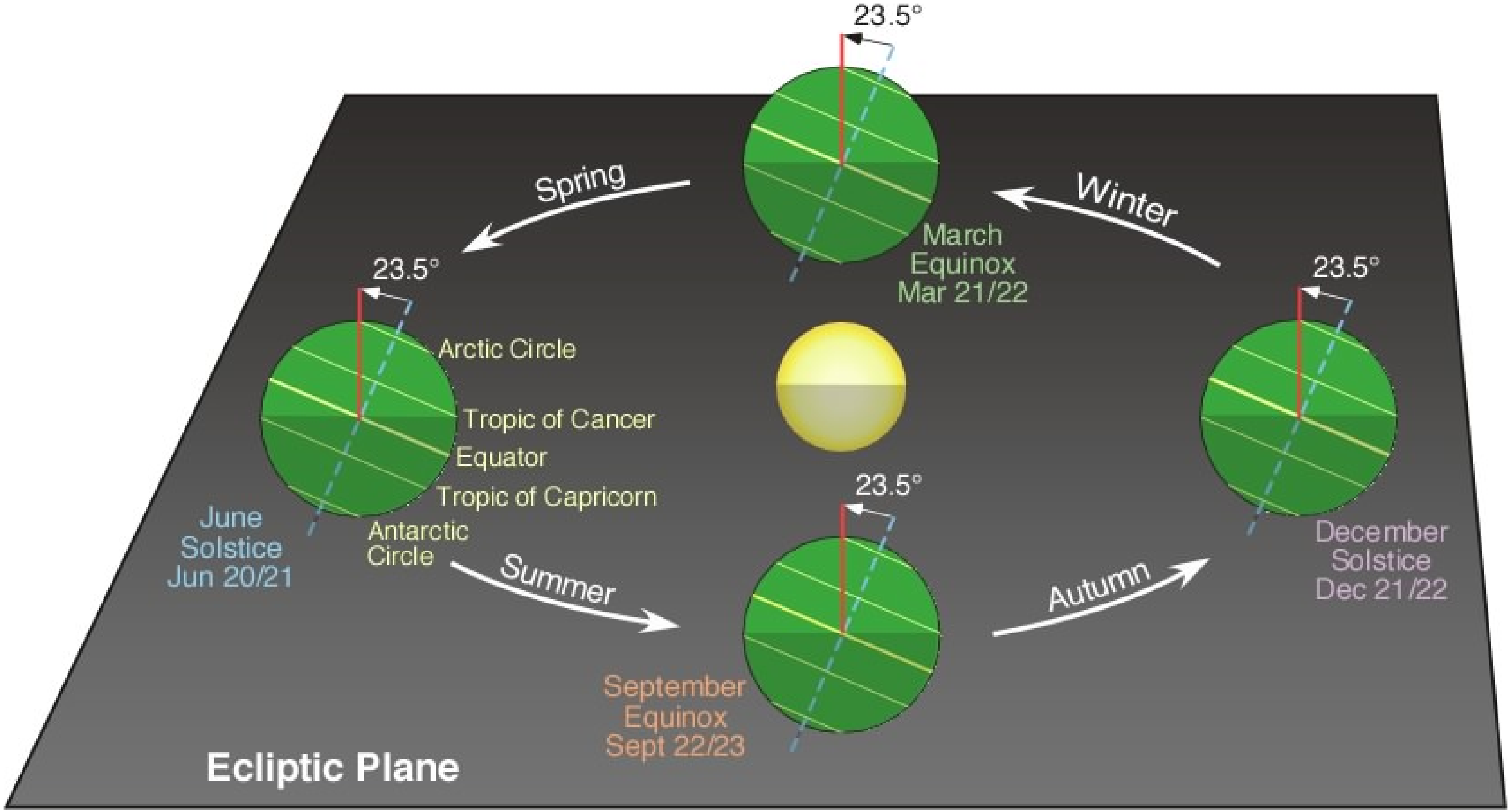
satellite velocity

$$\boxed{v = \sqrt{\frac{gR^2}{R+h}} \cong \sqrt{gR}}$$

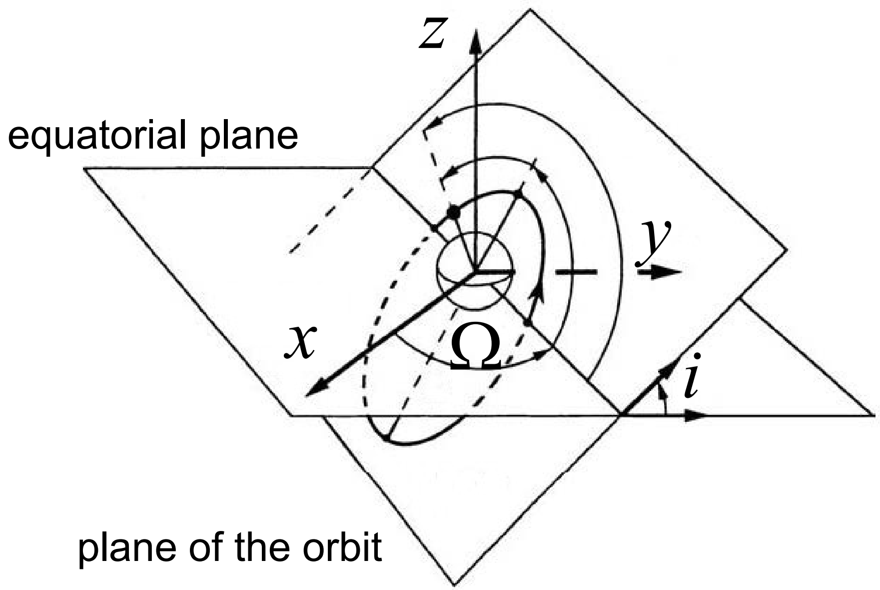
period of the satellite motion

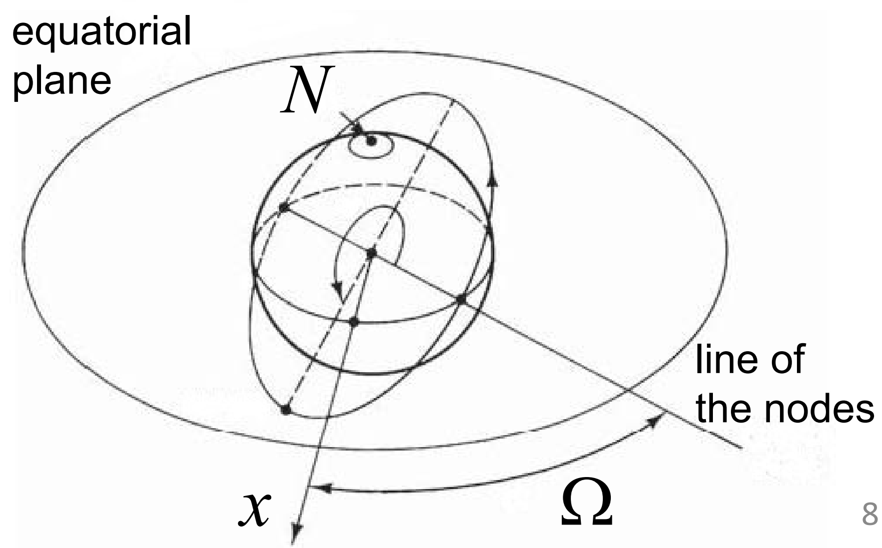
$$\boxed{T = 2\pi\sqrt{\frac{(R+h)^3}{gR^2}} \cong 2\pi\sqrt{\frac{R+h}{g}}}$$

$$h = \left(\frac{T^2}{4\pi^2}gR^2\right)^{\frac{1}{3}} - R$$

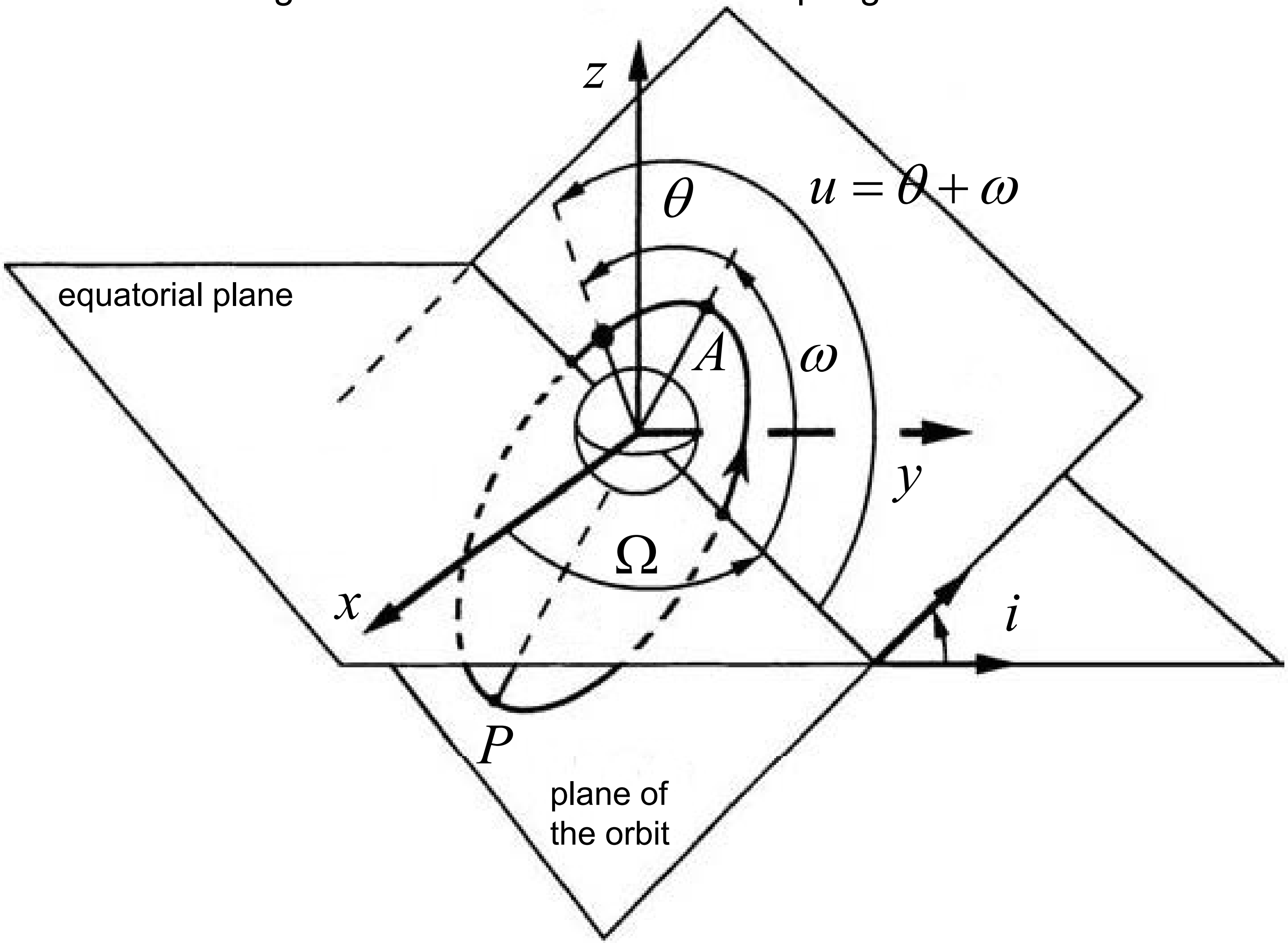

23.5°
Spring
Winter
March
Equinox
Mar 21/22
23.5°
23.5°
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic
Circle
June
Solstice
Jun 20/21
23.5°
December
Solstice
Dec 21/22
Summer
Autumn
September
Equinox
Sept 22/23
Ecliptic Plane

The position of the orbital plane in space is specified by means of two parameters:
Inclination of the plane of the orbit i. This is the angle between the normal (directed towards the east) to the line of nodes in the equatorial plane and the normal (in the direction of the velocity) to the line of nodes in the orbital plane. For an inclination less than 90°, the satellite rotates eastward in the same direction as the Earth (this is called a prograde orbit). For an inclination greater than 90°, the satellite rotates westward in the opposite direction to the Earth (this is called a retrograde orbit).
Right ascension of the ascending node Ω. This is the angle taken positively from 0° to 360° in the forward direction, between the reference direction and that of the ascending node of the orbit (the intersection of the orbit with the plane of the equator, the satellite crossing this plane from south to north).
The reference direction (axis X) is given by the line of intersection of the equatorial plane and the plane of the ecliptic, oriented positively towards the Sun; this line (which is contained in the equatorial plane) maintains a fixed orientation in space with time and passes through the Sun at the spring (March) equinox.



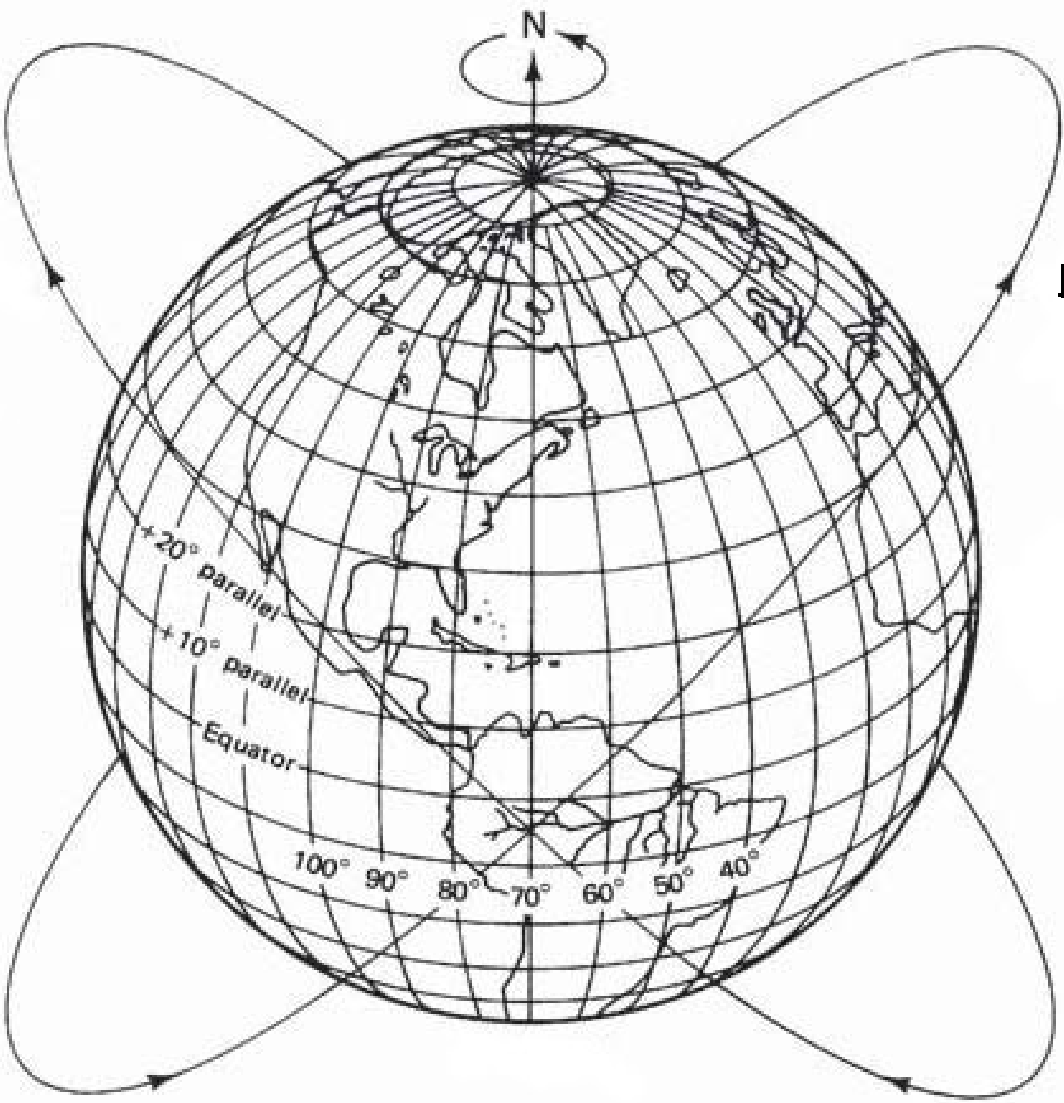


The orientation of the orbit in its plane is defined by the argument of the perigee: the angle ω, taken positively from 0° to 360° in the direction of motion of the satellite, between the direction of the ascending node and the direction of the perigee.



The five parameters (a, e, i, Ω and ω) completely define the trajectory of the satellite in space. The motion of the satellite in this trajectory can be described by θ (or u).

retrograde orbit



prograde orbit

USEFUL ORBITS

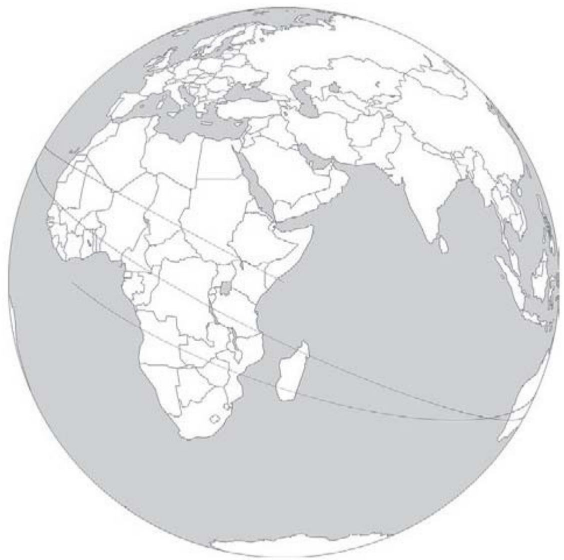
The orbital parameters are determined by the initial conditions as the satellite is injected into orbit. In principle, shape and orientation of the orbit in space remain constant with time, but under the effect of various perturbations, the orbital parameters can change: if it is required to maintain the satellite in a particular orbit, orbit control operations are necessary.
Systems based on polar or non-polar circular orbits have been proposed to provide worldwide communications and remote sensing services using low Earth orbits or medium Earth orbits. These systems entail constellations of several satellites, increasing in number with decreasing altitude of the orbit. Moreover, satellites are viewed from the user with high elevation angle, whatever the user's location: this makes such constellations attractive for personal mobile communications.
Inclined elliptical orbits are most useful for providing regional services to regions below the apogee of the orbit and these satellites are viewed with a near-zenith elevation angle. This is of interest for mobile communications, but the high altitude of the apogee introduces a large path loss and delay, but only a few satellites are required.
Geostationary satellite systems (prograde circular orbit in the equatorial plane at an altitude of 35800 km) provide large coverage of the Earth with a single satellite, or nearly worldwide coverage (polar regions excepted) with as few as three satellites.

It is also always necessary to know the sub-satellite position of a satellite (i.e. the point on the Earth's surface which is directly below the satellite) as a function of time and to know the corresponding ground-track.

Even if we assume that the satellite orbit is fixed in space, the sub-satellite track does not describe a circumference because when the satellite has completed one orbit, the Earth would have turned to the East and so the orbit will appear to drift to the west.
It can be proved that a prograde orbit of inclination *i* reaches a maximum north and south latitude of *i*, and a retrograde orbit of inclination *i* reaches a maximum latitude of 180° -*i*

sub-satellite tracks for
i=60° (two orbits)

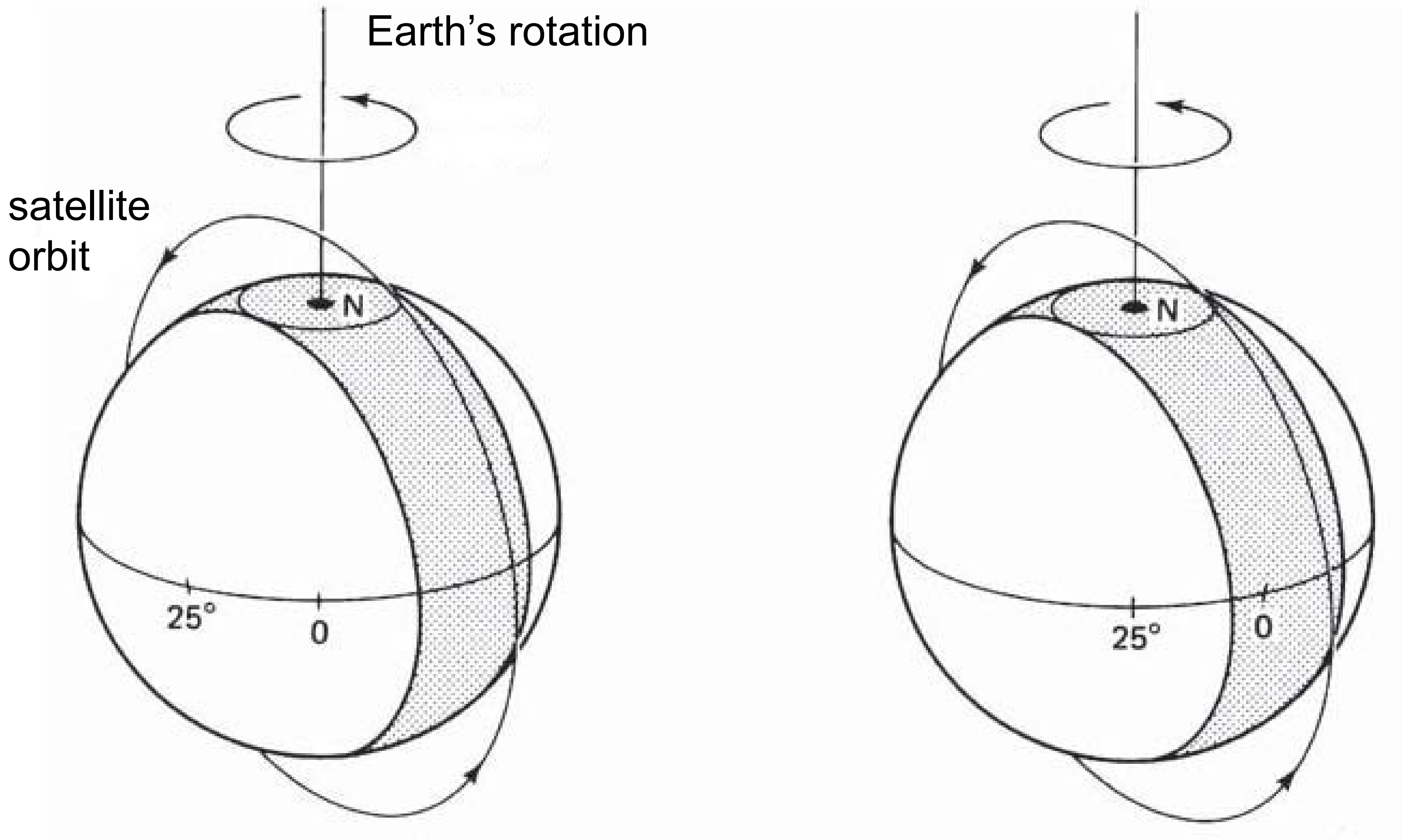
sub-satellite tracks for
i=89° (two orbits)



sub-satellite tracks for
i=150° (two orbits)

Example: POLAR ORBIT

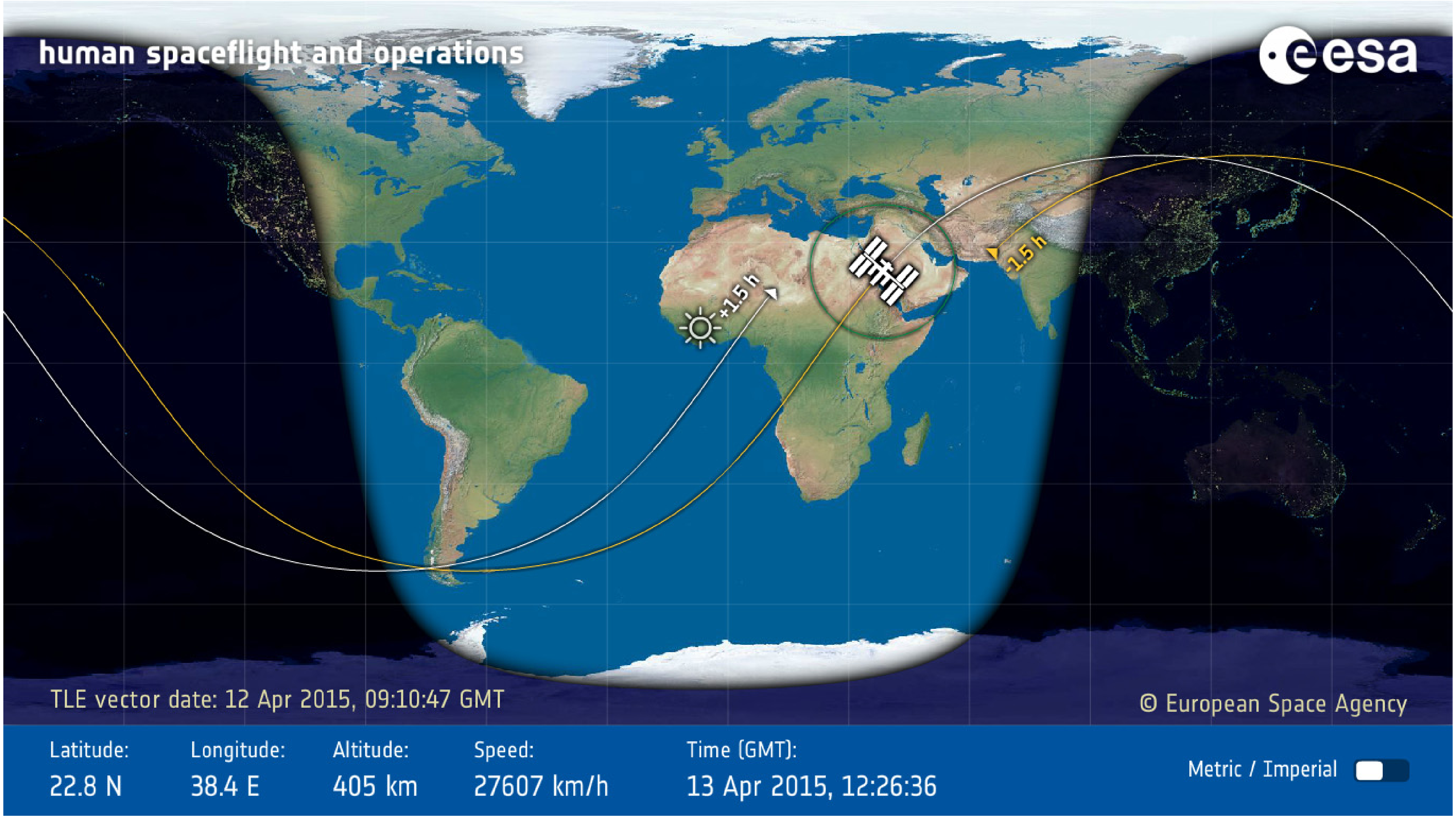
Polar orbiting satellites orbit the Earth in such a way as to cover the north and south polar regions. These low orbits are almost circular and their altitudes range between 800 and 900 km.



First pass …

… second pass, Earth having rotated 25°, the satellite period is 102 min.

Example: GROUND-TRACK OF THE INTERNATIONAL SPACE STATION



http://www.esa.int/Our_Activities/Human_Spaceflight/International_Space_Station/

http://iss.astroviewer.net/

GEOSTATIONARY SATELLITE

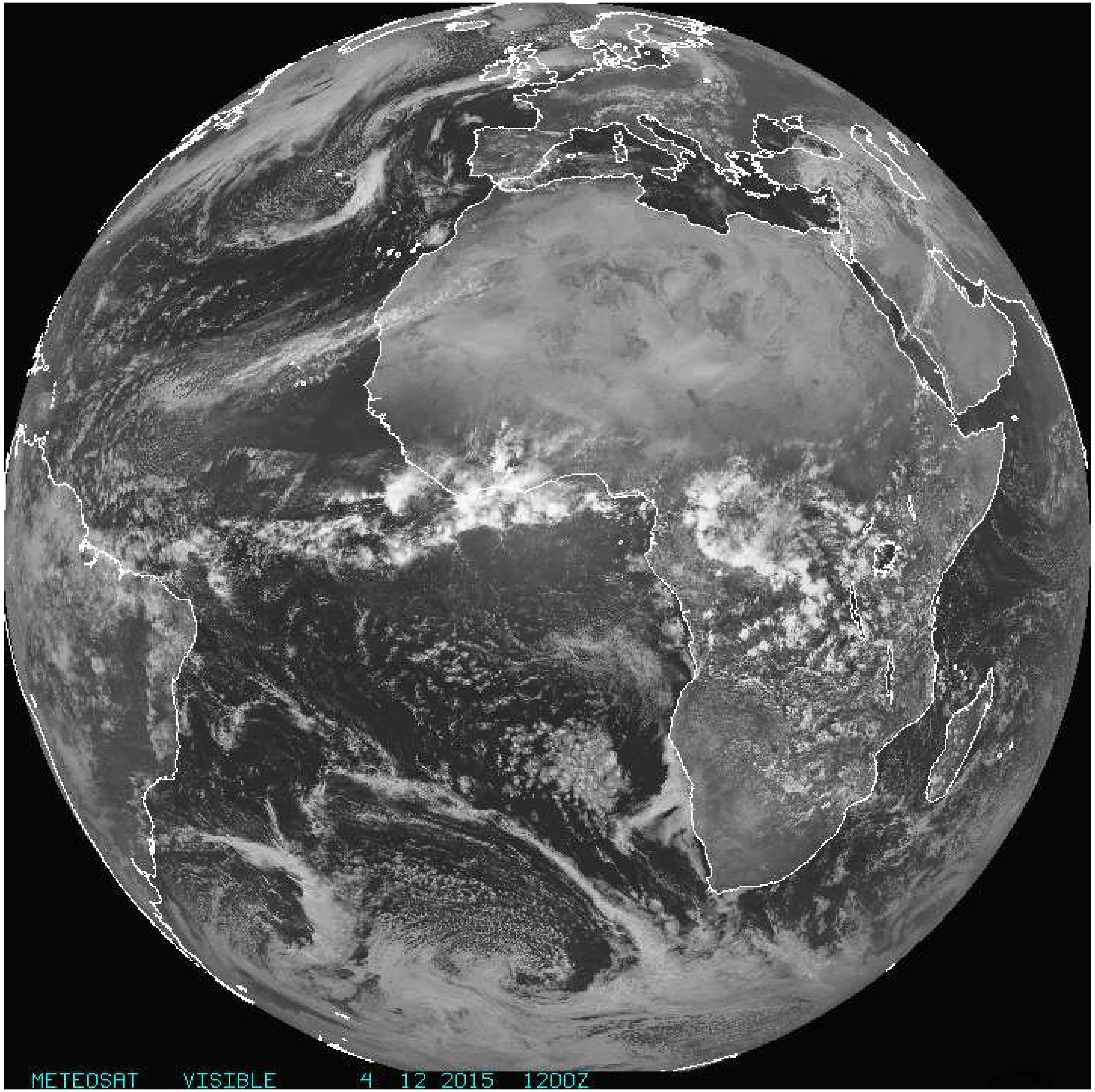
A satellite in a geostationary orbit is at rest with respect to the rotating Earth. This is achieved by putting the satellite into a circular orbit above the equator, with a period equal to the Earth's rotational period. This period is not equal to 24 hours because in a period of 24 hours the Earth does indeed rotate once with respect to the Sun but, since it is also orbiting the Sun in the same direction as it rotates on its axis, it has in fact rotated by slightly more than one complete turn with respect to a fixed reference system.

The Earth takes approximately 365.24 days to orbit the Sun, so in 24 hours it makes 1+1/365.24 complete turns: the correct period is about 23.9345 hours or 86164 seconds and it is called a sidereal day (it is the time the Earth takes to rotate once with respect to the stars).

The requirements for a geostationary orbit are therefore that its inclination and eccentricity should be zero, and its orbital period should be 86164 seconds. The corresponding value of the orbit radius is about 42170 km (about 6.6 times the Earth's radius), so geostationary satellites are located approximately 35800 km above the equator. Such orbits are used for geostationary meteorological satellites such as GOES and METEOSAT, as well as for telephone and television relay satellites.

The ground-track of a geostationary satellite is just a fixed point on the Earth surface.

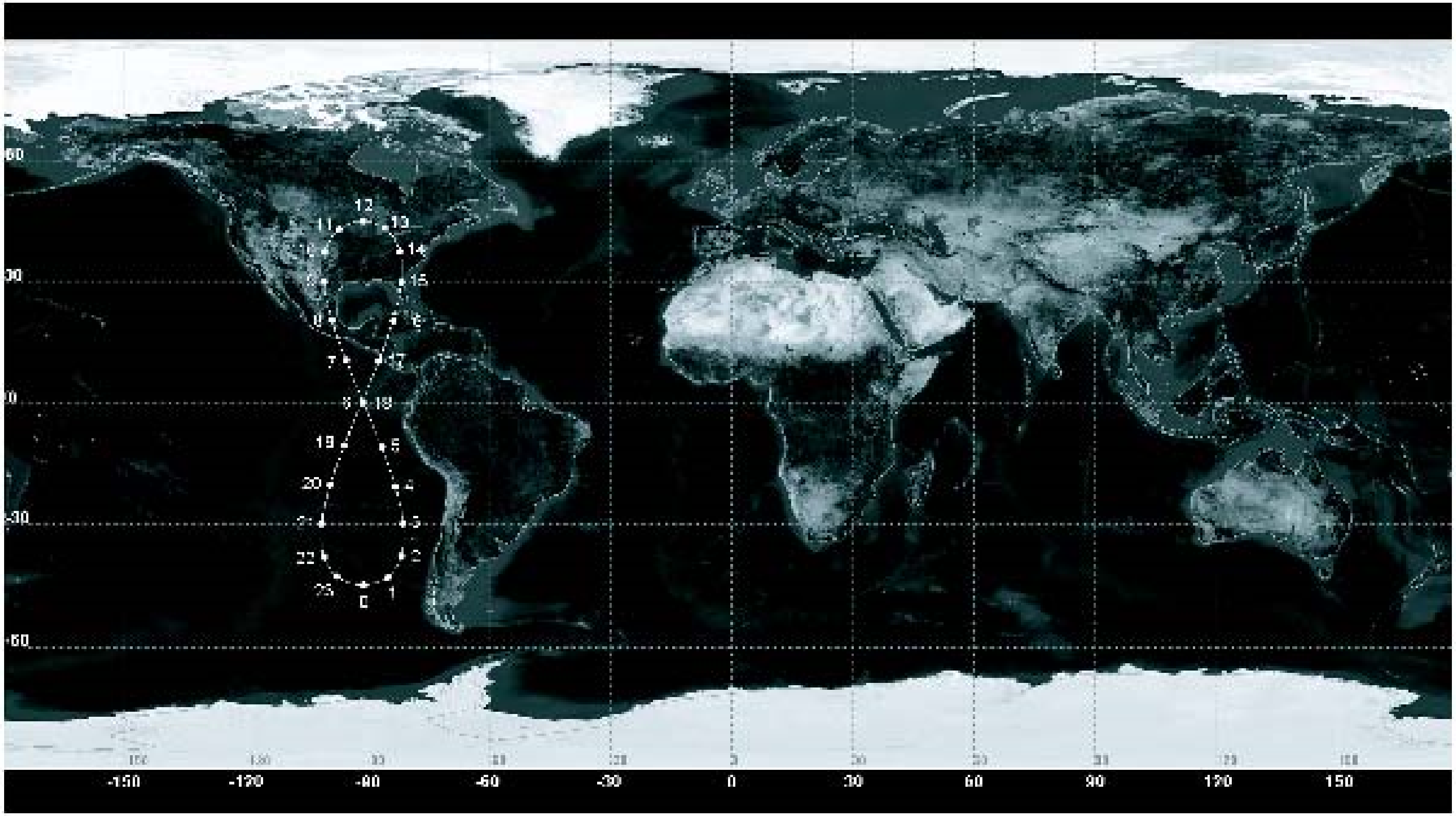
Example: image (in the visible range) from METEOSAT



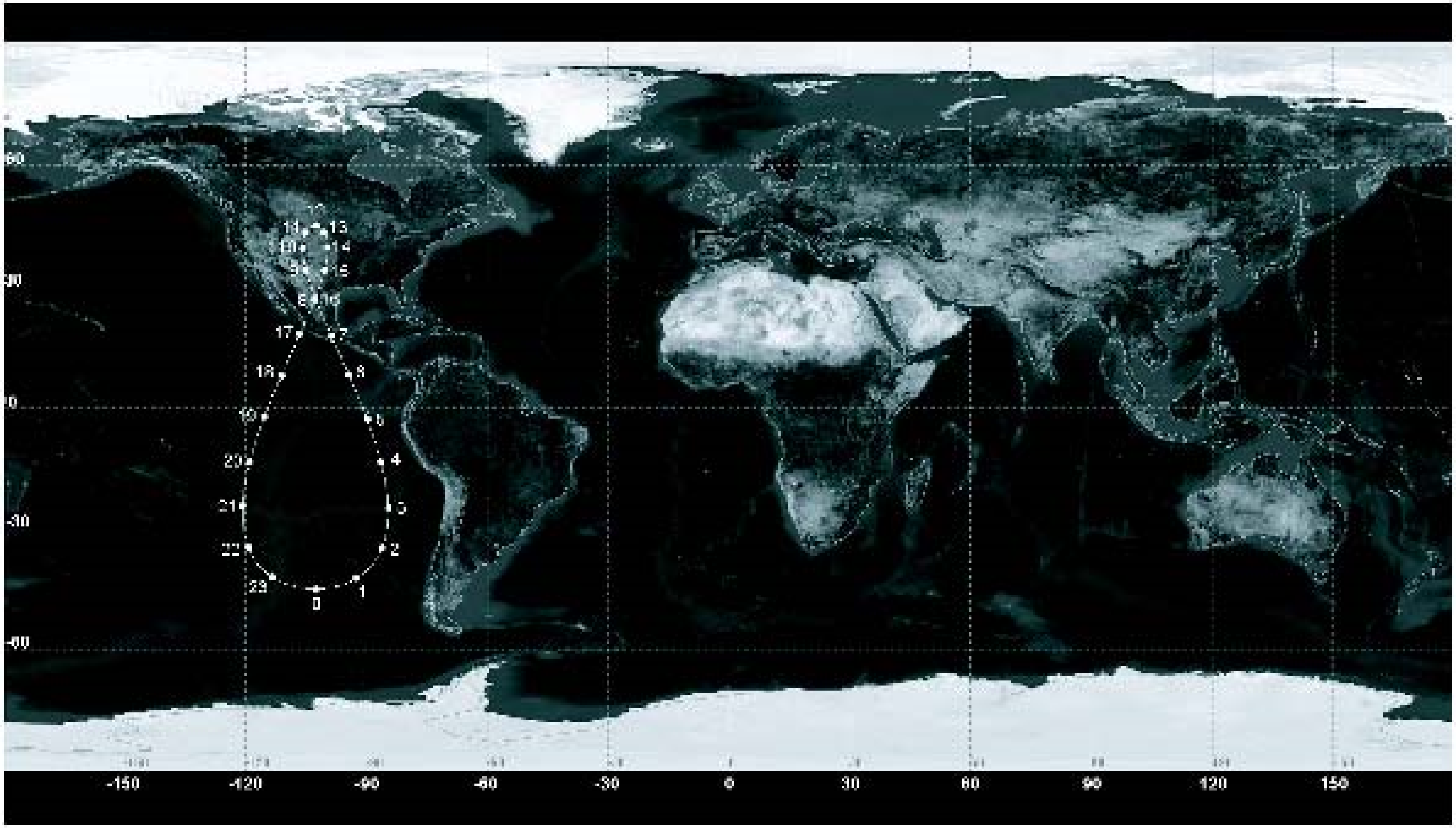
http://www.goes.noaa.gov/f_meteo.html

GEOSYNCHRONOUS SATELLITE

It is impossible to place a satellite in a geostationary orbit above a point that is not located on the equator. If a satellite is placed in a circular orbit and has a nodal period of one sidereal day and a non-zero inclination *i*, the sub-satellite path traces a lemniscate, or figure-of-eight pattern, crossing at a fixed point on the equator and reaching maximum north and south latitudes of *i*. This can be called a geosynchronous orbit.

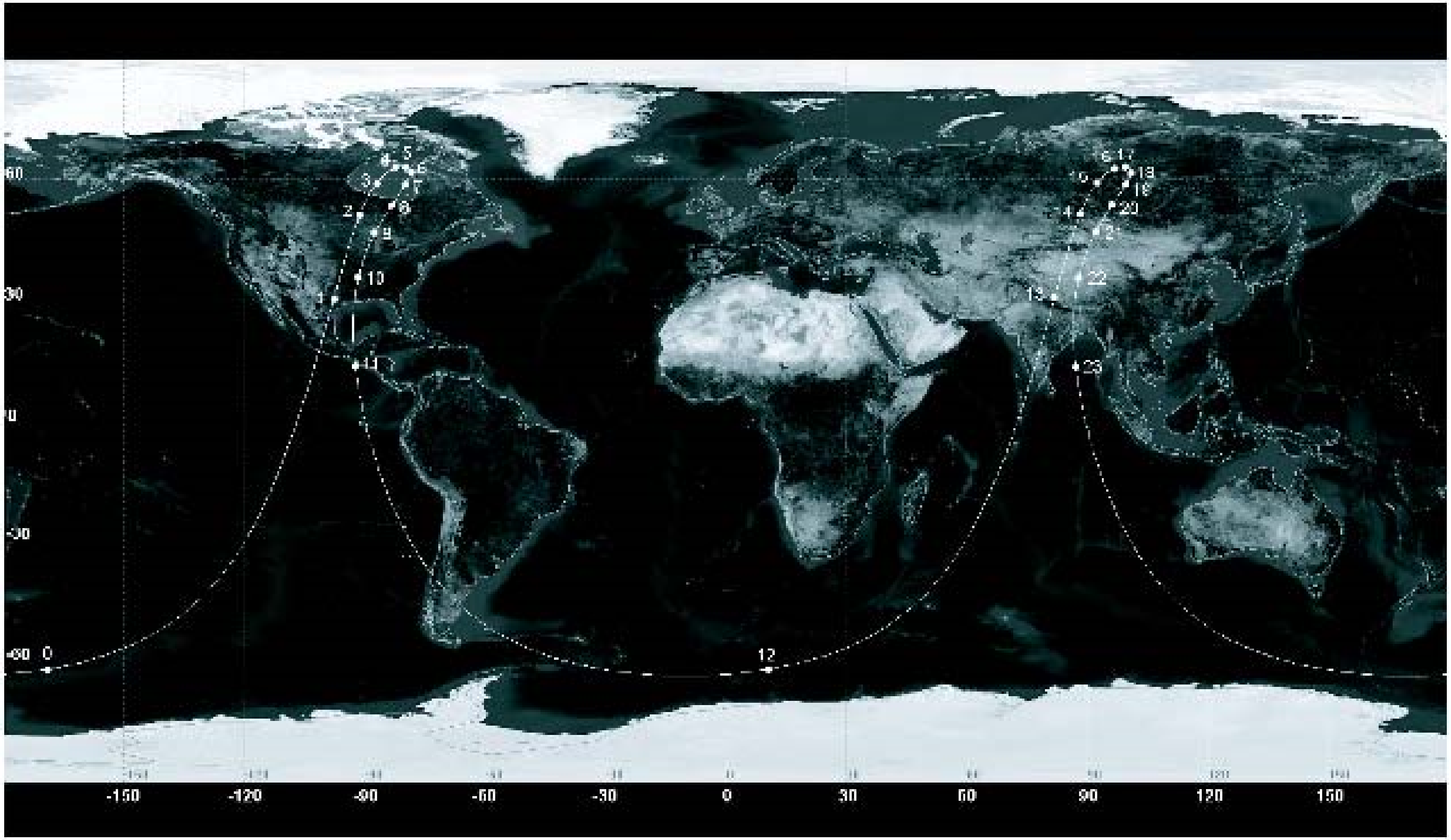


Surface trace of a circular geosynchronous orbit with an inclination of 45°



Surface trace of an elliptical geosynchronous orbit with an inclination of 45° and an ellipticity of 0.1.

The Molniya (Russian for ‘lightning’) orbit provides a partial solution to the problem of placing a satellite above a fixed point on the Earth’s surface that is not on the equator. The orbit is highly eccentric, with the apogee (furthest distance) positioned above the desired point. Since a satellite’s angular velocity is much smaller when it is far from the Earth than when it is near to it, with a suitable choice of orbital parameters, the satellite can spend much longer ‘on station’ than in the wrong hemisphere.
The period is chosen to be half a sidereal day and the semi-major axis is about 26560 km. The eccentricity is chosen to give a minimum altitude above the Earth’s surface of the order of 500 km. For example, if we set e=0.740, the satellite will have a perigee distance of about 6900 km, giving a minimum altitude of about 500 km, and an apogee distance of about 46200 km.



Ground trace for a 12 hour elliptical orbit with an ellipticity of 0.7 and an inclination of 63.4° (Molniya orbit).