Topic: Sun-synchronous Satellites

Course: Remote Sensing and GIS (CC-11)

M.A. Geography (Sem.-3)

By

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Lecture-3

Concept: Orbits and their Types:

Any object that moves around the Earth has an orbit. An ***orbit*** *is the path that a satellite follows as it revolves round the Earth. The plane in which a satellite always moves is called the* ***orbital plane*** *and the time taken for completing one orbit is called* ***orbital period****. Orbit is defined by the following three factors:*

1. Shape of the orbit, which can be either circular or elliptical depending upon the eccentricity that gives the shape of the orbit,

2. Altitude of the orbit which remains constant for a circular orbit but changes continuously for an elliptical orbit, and

3. Angle that an orbital plane makes with the equator.

Depending upon the angle between the orbital plane and equator, orbits can be categorised into three types - equatorial, inclined and polar orbits. *Different orbits serve different purposes. Each has its own advantages and disadvantages. There are several types of orbits:*

1. Polar 2. Sunsynchronous and 3. Geosynchronous

Field of View *(FOV) is the total view angle of the camera, which defines the swath. When a satellite revolves around the Earth, the sensor observes a certain portion of the Earth's surface. Swath or swath width is the area (strip of land of Earth surface) which a sensor observes during its orbital motion. Swaths vary from one sensor to another but are generally higher for space borne sensors (ranging between tens and hundreds of kilometers wide) in comparison to airborne sensors. The polar orbiting satellites are able to acquire images of almost the entire Earth despite the fact that as the satellite orbits the Earth from pole to pole; its east-west position does not change. This becomes possible because of the fact that Earth is rotating from west to east beneath the satellites. The rotation of the Earth causes a steady westward shift of the swath which allows the satellite swath to cover a new area with each consecutive pass. Thus, the swath is generated by the combined action of satellite orbital motion and the Earth's rotation relative to the orbital plane and it allows complete coverage of the Earth's surface.*

You should also be familiar with the following two terms of ***- Instantaneous Field of View (IFOV) and Spatial resolution.*** *The term Instantaneous Field of View (IFOV) characterises the sensor. It refers to projection of the detector element (i.e. one Charged-coupled Device (CCD element)) on the ground. It is also known as the 'footprint' of the detector element on the ground. IFOV is also referred to as resolution element. The term spatial resolution is used to denote the projection of the detector element (CCD) on to the ground through imaging optics from the satellite/aerial orbit. You should note that elevation of the satellite orbit* *is designed in such a way that the same location will be retraced (imaged) in a period of few weeks. The time taken for a sensor to complete tracing (imaging) of almost the entire Earth before it starts tracing of the same area for a second time is known as orbital cycle. The exact length of time of the orbital cycle varies with each satellite. It is also important to note that an orbit that brings the satellite over the poles close to the equator has a small angle. As a consequence, the distance away from the Earth will affect the speed of the object in orbit. So, the orbit selection can vary in terms of:*

1. Altitude above the surface of the Earth, and
2. The orientation and rotation of orbits relative to the Earth.

Choice of an orbit depends upon the purpose as different orbits serve different purposes and each has its own advantages. Kepler has formulated the mathematical laws describing satellite orbits in 18th century. Based on his planets and moons motion observations, Kepler has demonstrated that satellites may be flown on elliptical orbit instead of circular orbit.

(Johannes Kepler (December 27, 1571 – November 15, 1630) was a German mathematician, astronomer and astrologer. He is best known for his laws of planetary motion).

Broadly, orbits are classified into two types -Closed and Open orbits:

Closed orbits: *They can be either circular or elliptical in shape. A body on a closed orbit constantly travels around another body, such as a planet orbiting the Sun or the Moon orbiting the Earth. All planets and moons in our solar system follow this type of orbit.*

Open orbits: *They follow mathematical shapes which are either known as a parabola or a hyperbola. Unlike circles, parabolas and hyperbolas form curves whose ends never join up.*

There are different types of closed orbits used for operating various satellites. Most commonly used satellite orbits are;

1. Geosynchronous Orbit
2. Sunsynchronous Orbit

If the angle (known as orbital inclination) is 0° or 180° then the orbital plane lies in the equatorial plane and the orbit is called an equatorial orbit. When the angle is 90°, the satellite moves over the north and south poles and the orbit is called a polar orbit. However, an orbit with inclination close to 90° is called a near polar orbit. There could be different orbits having inclination between 0° or 90° which are known as inclined orbits.

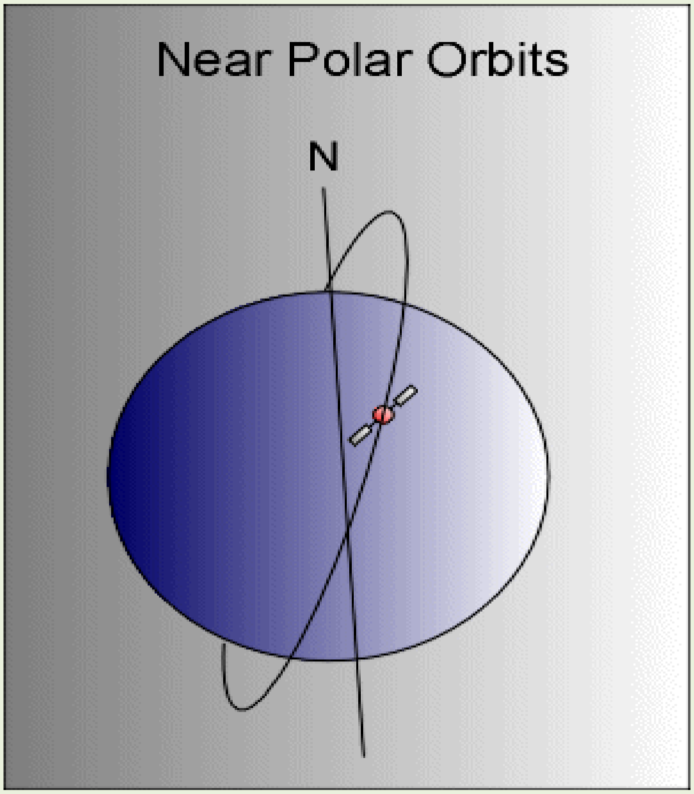
When the satellite is moving from south to north it is called ascending pass or ascending node of the orbit. Similarly, when the satellite is moving from north to south it is called descending pass or descending node of the orbit. Most of the polar orbiting satellites acquire images during they pass from north to south (i.e. descending passes) over the sunlit hemisphere and return from south to north (ascending passes) over the night-time hemisphere.

Polar Orbits:

The more correct term would be near polar orbits. These orbits have an inclination near 90 degrees. This allows the satellite to see virtually every part of the Earth as the Earth rotates underneath it. It takes approximately 90 minutes for the satellite to complete one orbit. These satellites have many uses such as measuring ozone concentrations in the stratosphere or measuring temperatures in the atmosphere. Polar orbits have an inclination of 90° with respect to the equatorial plane of the Earth.

A polar orbit is a satellite orbit that passes close to the both poles of the Earth. As the name suggests, polar orbits pass over the Earth's Polar Regions from north to south. During a 12-hour day, a satellite in such an orbit can observe all points on the Earth. The satellite moving in a polar orbit is called a polar satellite. The satellites always follow the same orbits. The Earth rotates underneath and allows satellite to see virtually every part of the Earth. It takes approximately 90 minutes for the satellite to complete one orbit. These satellites pass over the equator at the same solar time every single day, which allows it to collect data consistently. The orbits are low altitude orbits between 200 and 1000 km above the earth. The satellite offers the best views of the planet, particularly of areas that are often difficult to cover.

Polar orbit satellites are used for reconnaissance and Earth observation. They are also used for measuring ozone concentrations in the stratosphere or measuring temperatures in the atmosphere. Polar orbits are also sometimes used for weather satellites.



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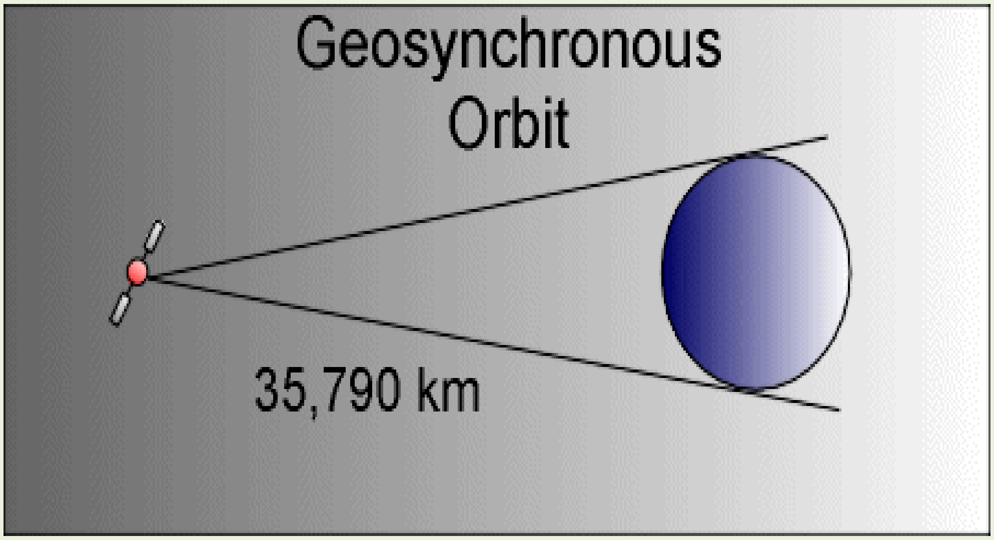
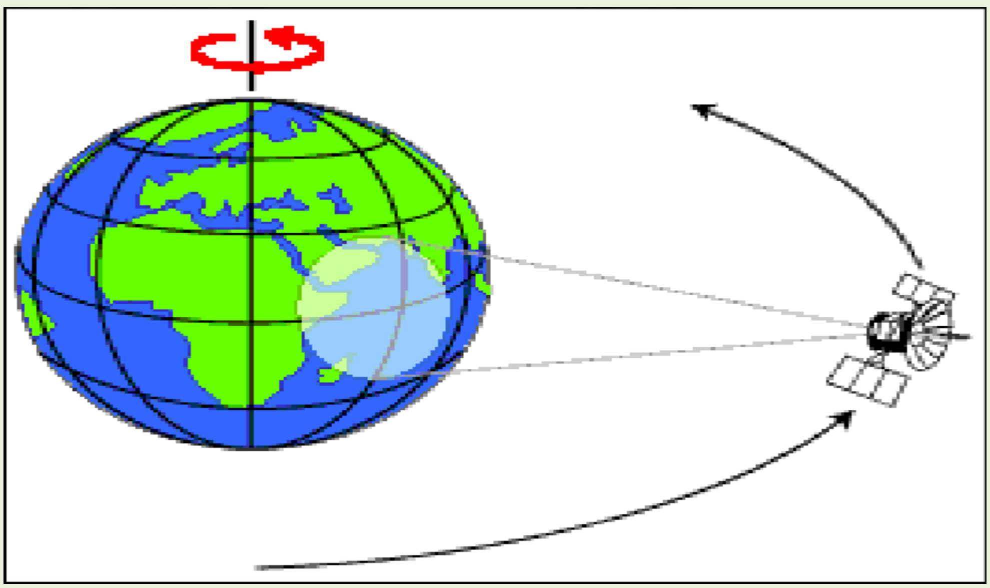
Geosynchronous Orbits:

Also known as geostationary orbits, satellites in these orbits circle the Earth at the same rate as the Earth spins. The Earth actually takes 23 hours, 56 minutes, and 4.09 seconds to make one full revolution. So based on Kepler's Laws of Planetary Motion, this would put the satellite at approximately 35,790 km above the Earth. The satellites are located near the equator since at this latitude; there is a constant force of gravity from all directions. At other latitudes, the bulge at the center of the Earth would pull on the satellite. Geosynchronous orbits allow the satellite to observe almost a full hemisphere of the Earth. These satellites are used to study large scale phenomenon such as hurricanes, or cyclones. These orbits are also used for communication satellites. The disadvantage of this type of orbit is that since these satellites are very far away, they have poor resolution. The other disadvantage is that these satellites have trouble monitoring activities near the poles.





Geostationary Orbit

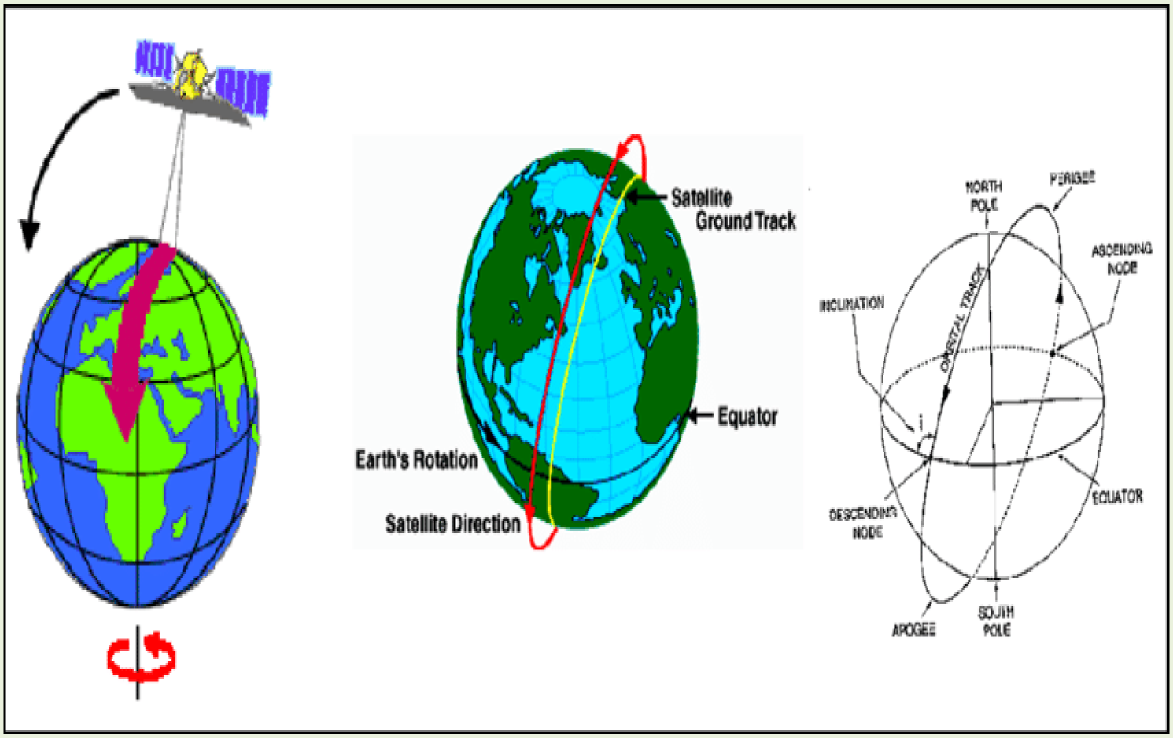
Sunsynchronous Orbits:

These orbits allow a satellite to pass over a section of the Earth at the same time of day. Since there are 365 days in a year and 360 degrees in a circle, it means that the satellite has to shift its orbit by approximately one degree per day. These satellites orbit at an altitude between700 to 800 km. These satellites use the fact since the Earth is not perfectly round (the Earth bulges in the center, the bulge *near the equator will cause additional gravitational forces to act on the satellite. This causes the satellite's orbit to either proceed or recede. These orbits are used for satellites that need a constant amount of sunlight. Satellites that take pictures of the Earth would work best with bright sunlight, while satellites that measure long wave radiation would work best in complete darkness.*

A ***Sun-synchronous orbit*** *(****SSO****, also called a* ***helio-synchronous orbit****) is a nearly polar orbit around a planet, in which the satellite passes over any given point of the planet's surface at the same local mean solar time. More technically, it is an orbit arranged so that it precesses through one complete revolution each year, so it always maintains the same relationship with the Sun.*

A Sun-synchronous orbit is useful for imaging, spy, and weather satellites, because every time that the satellite is overhead, the surface illumination angle on the planet underneath it will be nearly the same. This consistent lighting is a useful characteristic for satellites that image the Earth's surface in visible or infrared wavelengths, such as weather and spy satellites; and for other remote-sensing satellites, such as those carrying ocean and atmospheric remote-sensing instruments that require sunlight. For example, a satellite in Sun-synchronous orbit might ascend across the equator twelve times a day each time at approximately 15:00 mean local time.

Special cases of the Sun-synchronous orbit are the ***noon/midnight orbit****, where the local mean solar time of passage for equatorial latitudes is around noon or midnight, and the* ***dawn/dusk orbit****, where the local mean solar time of passage for equatorial latitudes is around sunrise or sunset, so that the satellite rides the terminator between day and night. Riding the terminator is useful for active radar satellites, as the satellites' solar panels can always see the Sun, without being shadowed by the Earth. It is also useful for some satellites with passive instruments that need to limit the Sun's influence on the measurements, as it is possible to always point the instruments towards the night side of the Earth. The dawn/dusk orbit has been used for solar-observing scientific satellites such as Yohkoh, TRACE, Hinode and PROBA2, affording them a nearly continuous view of the Sun.*



Sunsynchronous Orbit

Orbital precession:

A Sun-synchronous orbit is achieved by having the osculating orbital plane precess (rotate) approximately one degree eastward each day with respect to the celestial sphere to keep pace with the Earth's movement around the Sun. This precession is achieved by tuning the inclination to the altitude of the orbit such that Earth's equatorial bulge, which perturbs inclined orbits, causes the orbital plane of the spacecraft to precess with the desired rate. The plane of the orbit is not fixed in space relative to the distant stars, but rotates slowly about the Earth's axis.

Typical Sun-synchronous orbits around Earth are about 600–800 km in altitude, with periods in the 96–100-minute range, and inclinations of around 98°. This is slightly retrograde compared to the direction of Earth's rotation: 0° represents an equatorial orbit, and 90° represents a polar orbit.

Sun-synchronous orbits can happen around other oblate planets, such as Mars. A satellite around the almost spherical Venus, for example, will need an outside push to maintain a Sun-synchronous orbit.

When one says that a Sun-synchronous orbit goes over a spot on the Earth at the same local time each time, this refers to mean solar time, not to apparent solar time. The Sun will not be in exactly the same position in the sky during the course of the year (see Equation of time and Analemma).

Sun-synchronous orbits are mostly selected for Earth observation satellites, with an altitude typically between 600 and 1000 km over the Earth surface. Even if an orbit remains Sun-synchronous, however, other orbital parameters such as argument of periapsis and the orbital eccentricity will evolve, due to higher order perturbations in the Earth's gravitational field, the pressure of sunlight, and other causes. Earth observation satellites, in particular, prefers orbits with constant altitude when passing over the same spot. Careful selection of eccentricity and location of perigee reveals specific combinations where the perturbations largely cancel and hence the orbit is relatively stable – a frozen orbit. The ERS-1, ERS-2 and Envisat of European Space Agency, as well as the MetOp spacecraft of EUMETSATand RADARSAT-2 of the Canadian Space Agency, are all operated in such Sun-synchronous frozen orbits.

Ideally, all satellite images should be acquired under uniform illumination condition, so that features present in images of same area taken on different dates show the changes in ground conditions rather than changes in conditions of observation. However, in reality, satellite images of different dates vary because of differences in latitude, time of day and season resulting into different illumination conditions. When the orbits are designed in such as way that the satellite's orientation is fixed relative to the Sun throughout the year such orbits are called sunsynchronous orbits. These orbits are designed to remove one source of variation in illumination which is caused by differences in time of day. Satellite in sunsynchronous orbit passes over a given part of the Earth at roughly the same local time of day (though not necessarily every day). In other words, whenever the satellite observes a given ground scene, the Sun is always in the same location in the sky. Since there are 365 days in a year and 360° in a circle, it means that the satellite in this orbit has to shift its orbit by approximately 1° per day. The satellite orbiting in this orbit is called a sunsynchronous satellite. Sunsynchronous satellite flies at an altitude between 700 and 800 km with an *orbital period between 90 and 110 minutes. Satellites in sunsynchronous orbits pass from north to south poles on the sunlit side (the descending node) and from south to north on the shadowed side (the ascending node). Sensors that depend upon the solar radiation acquire images only during their descending pass but other sensors can acquire data independently during both the passes. Sunsynchronous orbits are particularly useful for missions that acquire images of the Earth because shadows from objects at a given location on the Earth's surface are always cast from the same angle. This simplifies the comparison of images taken on different days to detect changes. Satellites in this orbit are often placed at low altitudes (700 to 800 km) so that they provide complete coverage of the Earth's surface at least once per day.*

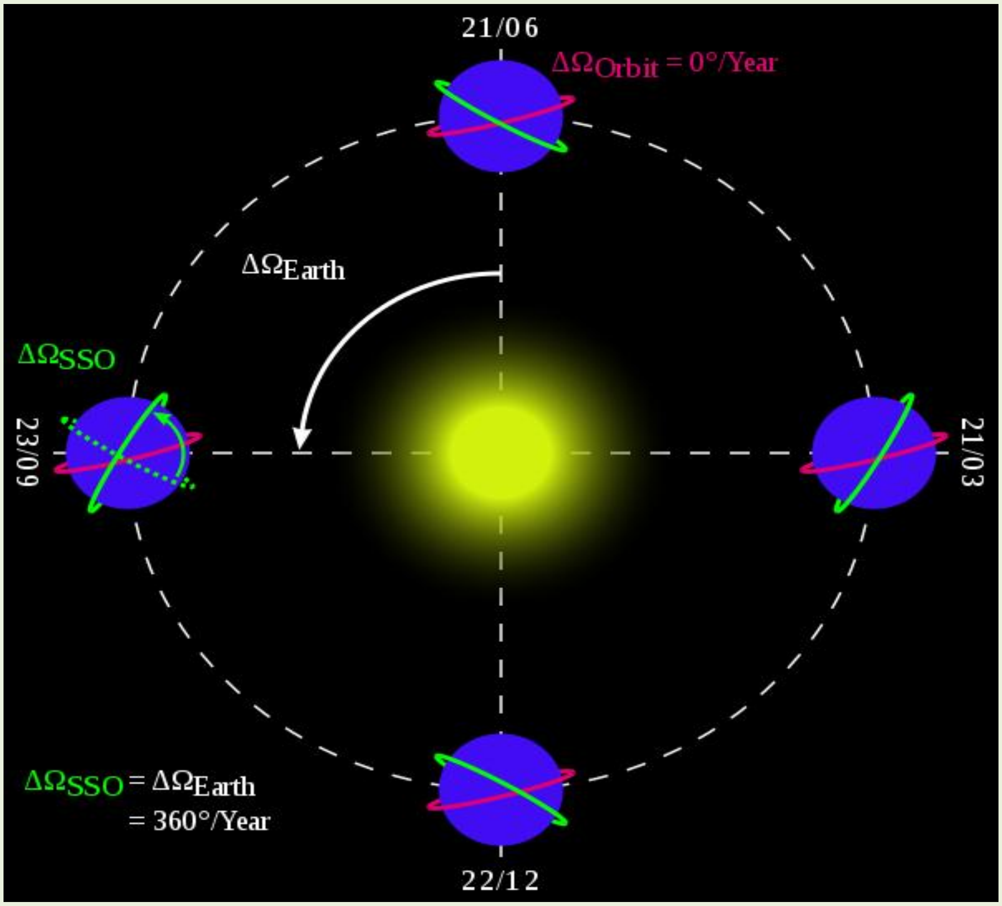


Diagram showing the orientation of Sun-synchronous orbit (green) at four points in a year. A non-Sun-synchronous orbit (magenta) is also shown for reference. Dates are shown in white: day/month.

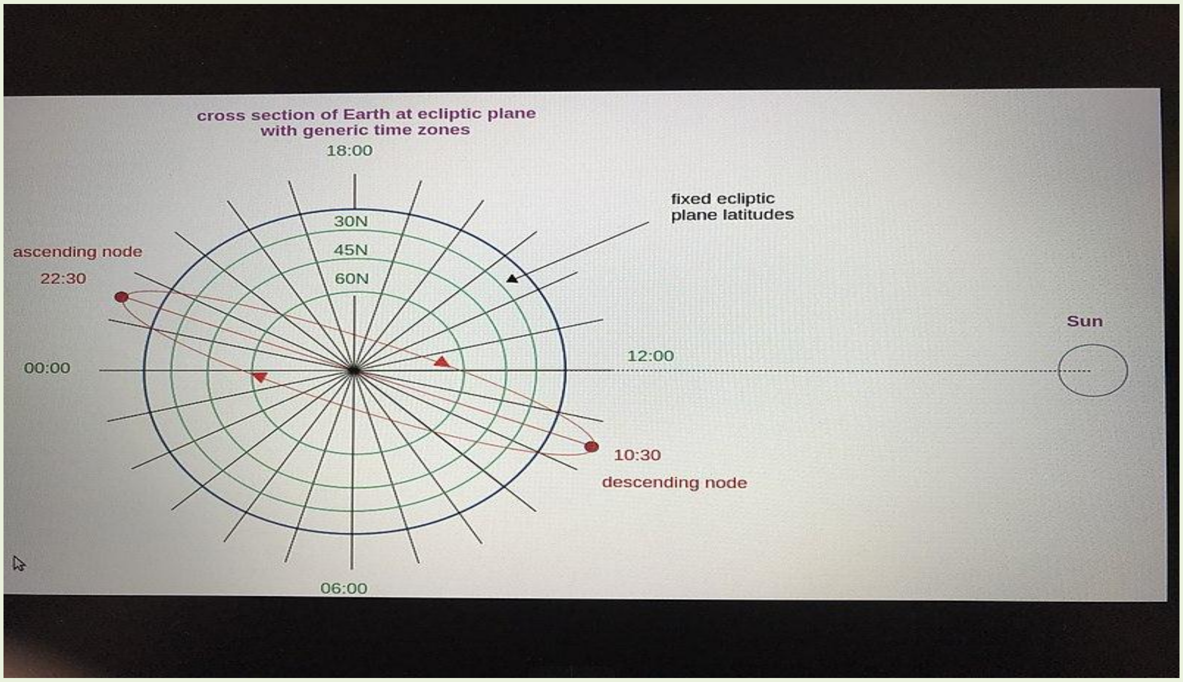
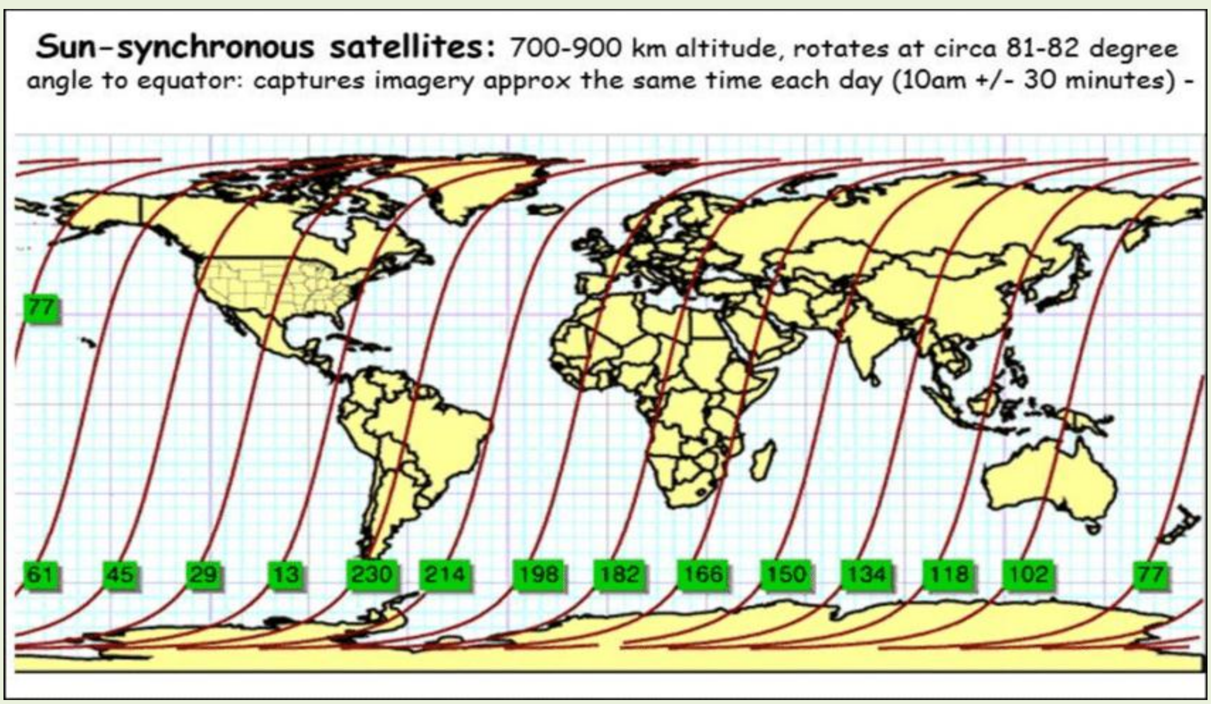


Diagram showing a Sun-synchronous orbit from a top view of the ecliptic plane with Local Solar Time (LST) zones for reference and a descending node of 10:30 am. The LST zones show how the local time beneath the satellite varies at different latitudes and different points on its orbits.



Remote sensing and meteorological satellites are placed in the sun-synchronous orbit. Orbview, Quickbird, IKONOS, SPOT, Landsat, ERS, RADARSAT, etc. are examples of the satellites orbiting in sunsynchronous orbit. ***Dawn-to-dusk orbit*** *is a special case of sunsynchronous orbit, in which the orbital plane of the satellite coincides with the plane that divides the half of the Earth that is illuminated by the Sun from the half that is dark. If the plane were aligned slightly differently, the satellite would spend half of its time in full sunlight and half in shadow but a dawn-to-dusk orbit allows the satellite 17 to always have its solar panels illuminated by the Sun. For example, the* ***Sensors and Platforms*** *Canadian Radarsat Earth observation satellites use such a dawn-to-dusk orbit to keep their solar panels facing the Sun constantly, so they can rely primarily on solar power rather than batteries.*

As you know that the Earth is not a perfect sphere. The bulging near the equator causes additional gravitational forces to act on the satellite. This causes satellite orbit to either proceed or recede. These orbits are used for satellites that need a constant amount of sunlight. Satellites that take pictures of the Earth would work best with bright sunlight, while those which measure long wave radiation would work best in complete darkness. Generally, these orbits are used for Earth observation, solar study, weather forecasting and reconnaissance.