Satellite Coverages and Orbits

If you've looked at these pages before, you might want to jump directly to the section you are interested in:

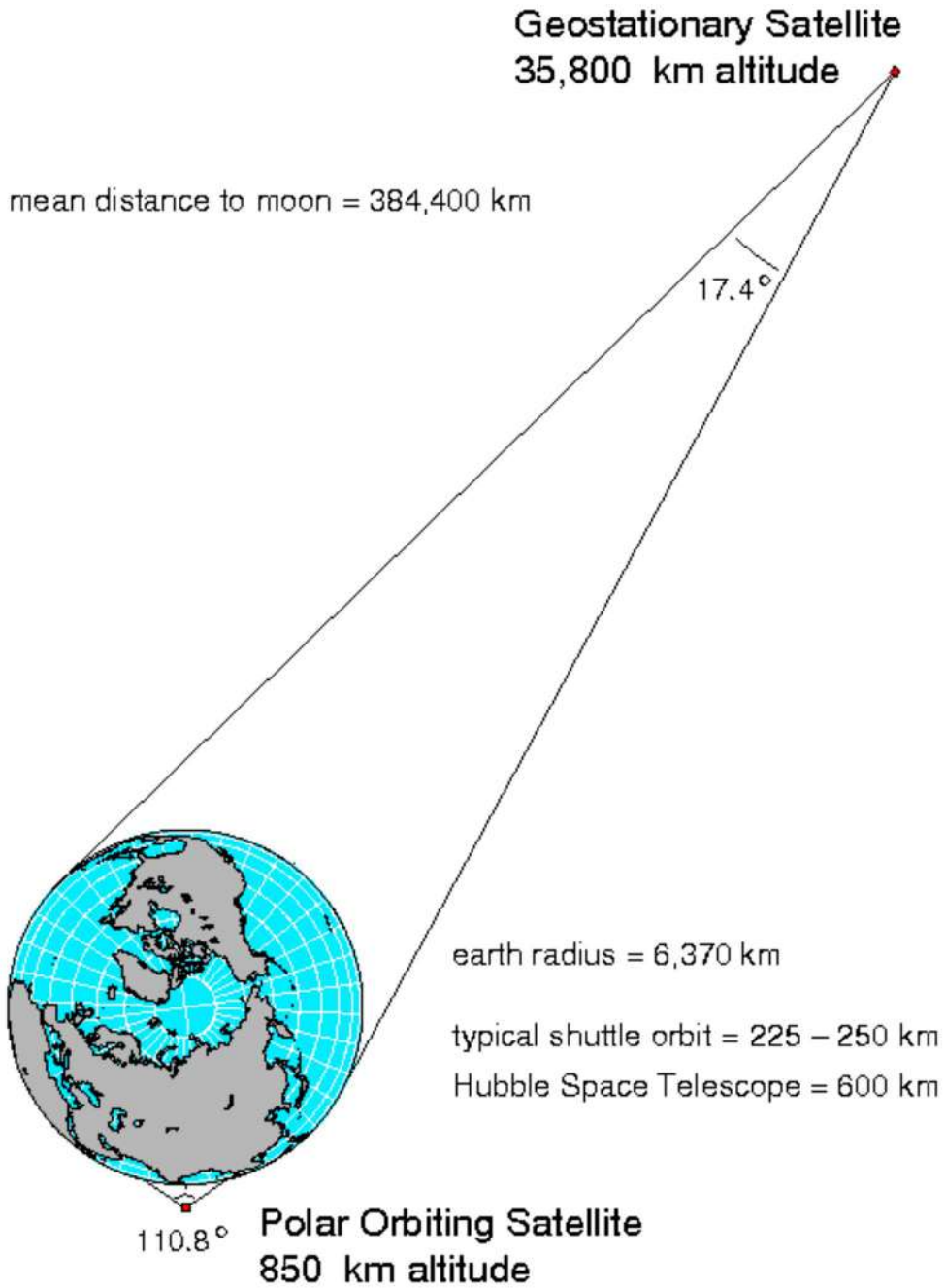
- Geostationary Satellites
- Polar orbiting Satellites
- Introductory Figure (follows brief introductory text)

There are literally an infinate number of possible orbits for an Earth satellite. While there are special orbits that are designed for specific purposes, two general classes of orbits have come into wide spread use for meteorological observations of the Earth: **geostationary orbits** and sun-synchronous near-polar orbits. In spite of the qualifiers, the sun-synchronous orbits are normally just refered to as **polar orbits**.

Geostationary orbits are circular orbits that are orientated in the plane of the Earth's equator. By placing the satellite at an altitude where it's orbital period exactly matches the rotation of the earth (35,800 km), the satellite appears to "hover" over one spot on the Earth's equator. While geostationary satellite are ideal for making repeated observations of a fixed geographical area centered on the equator, they are far enough away from the Earth to make it difficult to obtain high quality, quantitative observations. The current generation of geostationary meteorological satellite are truely technological marvels. These satellites, however, do not see the poles at all, and to get global coverage of just the equatorial regions, you need a network of 5-6 satellites.

A satellite in lower Earth orbits is better positioned to obtain high quality remote-sensing data. If placed in a polar orbit, the Earth will rotate beneath the orbiting satellite allow global coverage from a single satellite. The critical design goal then is to place the satellite in an orbit that is low enough to permit a relatively short orbital period while at the same time the orbit is high enough to permit observation of a wide enough swath so that during a single orbit the Earth will rotate by less than the scan swath of the satellite's instrumentation. By placing a satellite at an altitude of about 850 km, you get an orbital period of roughly 100 minutes. At this altitude, you can get true global coverage if the scan swath of the satellite's instrumenation is about 3000 km.

The orbit, however, can be improved if the orbital plane is inclined slightly away from a true N-S orbit. In this case, the asymmetric gravitational pull of the Earth introduces a slow precession in the orbital plane. With a inclination of about 98.7 degrees, the orbit will precess at almost exactly the same rate that the Earth rotates around the sun. That means that the satellite's orbital plane will appear to be fixed with respect to the sun, or sun-synchronous. Due to the inclination away from N-S, these satellites do not go directly over the poles, but do get close enough to provide true global coverages from a single satellite. Since the orbit is aligned with respect to the sun, in fact, you get twice daily coverage of every portion of the globe.



CAPTION: This illustration shows the true relative distances from the Earth of geostationary and polar orbiting satellites. From geostationary altitude, the entire Earth disk only subtends an angle of 17.4 degrees. A typical polar orbiting meteorological satellite, at an altitude of about 850 km, sees a relatively small portion of the globe at any one time. For example, the Advanced Very High Resolution Radiometer or AVHRR scans a swath that is 110.8 degrees in width, corresponding to a surface distance of roughly 3000 km. As seen at this scale, the Earth's atmosophere, most of which is limited to altitudes below 30 km, is only slightly thicker than the width of the lines used to draw the illustration.

Geostationary Satellites

Geostationary satellites orbit in the earth's equatorial plane at a height of 38,500 km. At this height, the satellite's orbital period matches the rotation of the Earth, so the satellite seems to stay stationary over the same point on the equator. Since the field of view of a satellite in geostationary orbit is fixed, it always views the same geographical area, day or night. This is ideal for making regular sequential observations of

cloud patterns over a region with visible and infrared radiometers. High temporal resolution and constant viewing angles are the defining features of geostationary imagery.

At present, the US operates two geostationary satellites (GOES-EAST and (GOES-WEST). The GOES acronym stands for Geostationary Operational Environmental Satellite. The European Space Agency operates the Meteosat satellite. The Japan Meteorological Agency operates the GMS satellite. In this case, the acronym GMS stands for Geostationary Meteorological Satellite. The Indian Space Research Organization operates the Indian National Satellite System, or INSAT, but meteorological images from this satellite have bee primarily archived as photographic prints, with digital data being notoriously difficult to obtain.

Russia has launched a geostatoinary satellite with meteorological capabilities, but has had difficulty producing useful imagery on a regular basis. In the next year or two, China plans to launch their own geostationary meteorological satellite, named Fengyun-2.

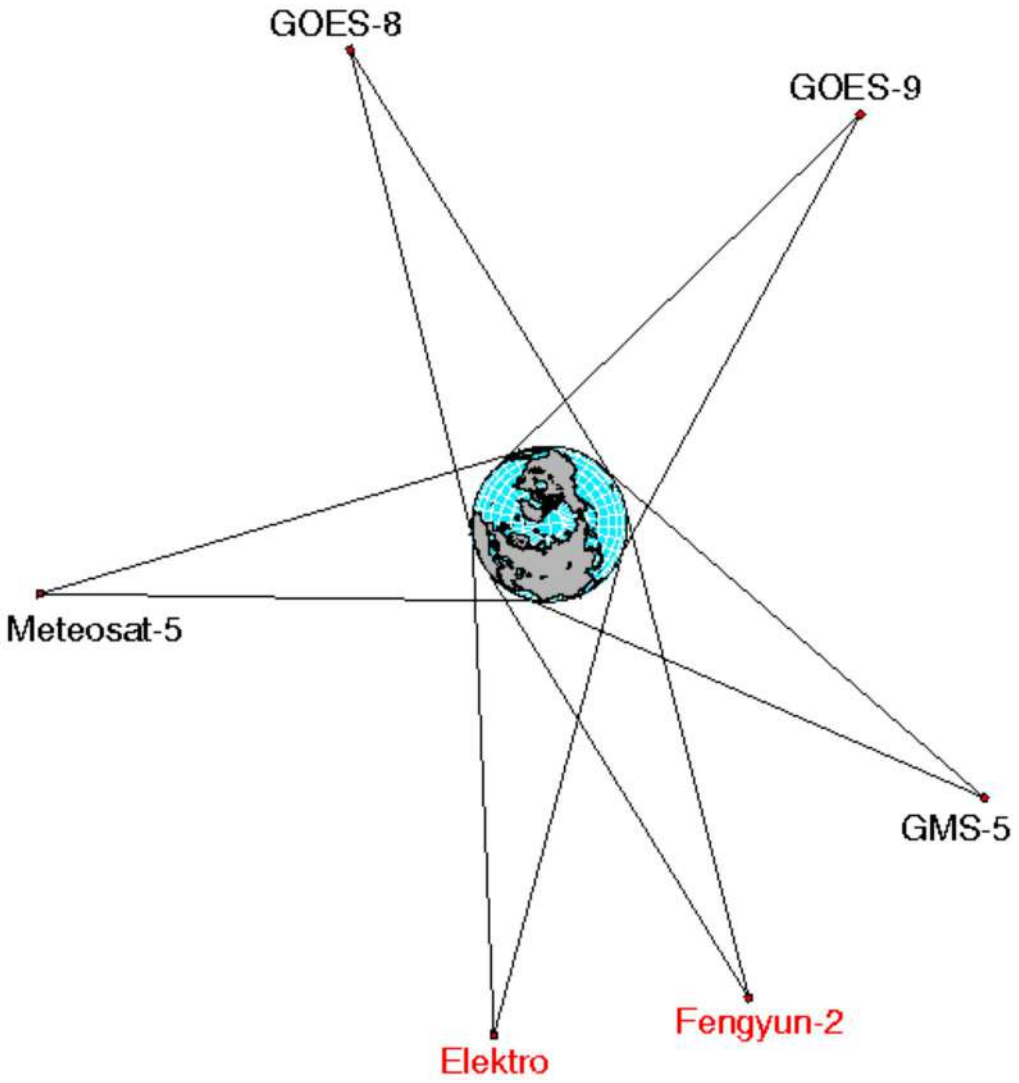
Individual Geographical Coverages

This is an illustration of the geographical coverare of the GOES-EAST satellite. Similar illustrations of the coverage areas for each of the other current or proposed geostationary satellites are linked below.

- Meteosat (Europe and Africa)
- GOES-EAST (North and South America)
- GOES-WEST (Eastern Pacific)
- GMS (Japan and Australia, Western Pacific)
- Fengyun-2 (China and the Indian Ocean)
- Elektro (Central Asia and the Indian Ocean)

(55 k, total for all 6 illustrations)

Global Geostationary Satellite Coverage



CAPTION: This view of the locations of the six geostationary meteorological satellites shows their relative positions and fields of view, as seen from far above the Earth's north pole. In general, coverage of the globe is quite excellent, with the exception of a slight gap in coverage over the Indian Ocean. Two satellite, Fengyun-2 and Elektro, promise to fill this gap in the near future.

- An alternate view (19 k) of the global geostationary satellite coverage, based on a cylindrical equidistant map is also available.

Parallax Induced Cloud Displacements: One of the critical issues in the interpretation of satellite imagery is the naviations of the image pixels to Earth-based latitude and longitudes. For an idealized Earth which can be modeled on the basis of a relatively simple geometrical shape, this is straightforward. The problem is more difficult when you try to include realistic deviations from ideal simple geometries, such as mountains or other terrain features. For meteorological satellites, such deviations from ideal geometry are usually just ignored without any significant difficulty. Clouds, on on the other hand, represent a significant problem, both because of their variability and because of their potential height compared with surface terrain features.

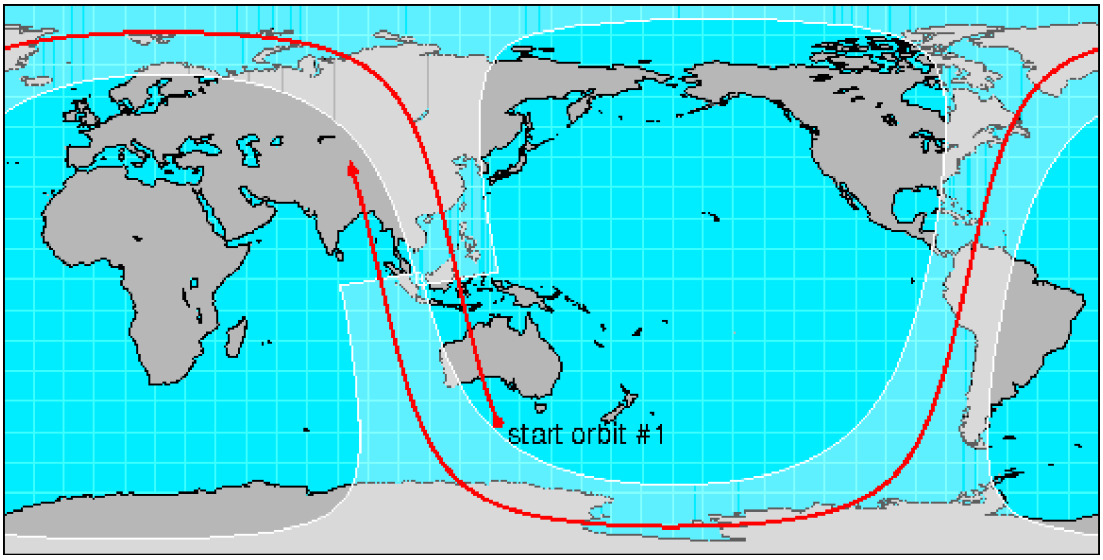
With the exception of the subsatellite point, the oblique angle from which the clouds are being observed can typically result in a significant displacement in their apparent earth location. This parallax induced cloud displacement is a function of the viewing angle relative to the local plane of the Earth's surface and the height of the clouds above the ground. For geostationary satellites, the earth curvature term is the critical factor.

Parallax induced cloud displacements for geostationary satellites (link to figure, 9 k)

Polar Orbiting Satellites

Polar orbiting satellites are an important class of meteorological and geophysical satellite. Typically, these satellites are placed in circular sun-synchronous orbits. Their altitudes usually range from 700 to 800 km, with orbital periods of 98 to 102 minutes. Satellites in this category include the NOAA Polar-orbiting Operational Environmental Satellites (POES), satellites of the Defense Meteorological Satellite Program (DMSP), Landsat, and SPOT. The DMSP and NOAA/POES satellites are operational meteorological satellites. Imagery from successive orbits overlay with each other, giving global daily coverage from each satellite. Landsat and SPOT, on the other hand, are intended for geophysical remote sensing, with an emphasis on high-resolution and multispectral imagery, at the cost of daily global coverage.

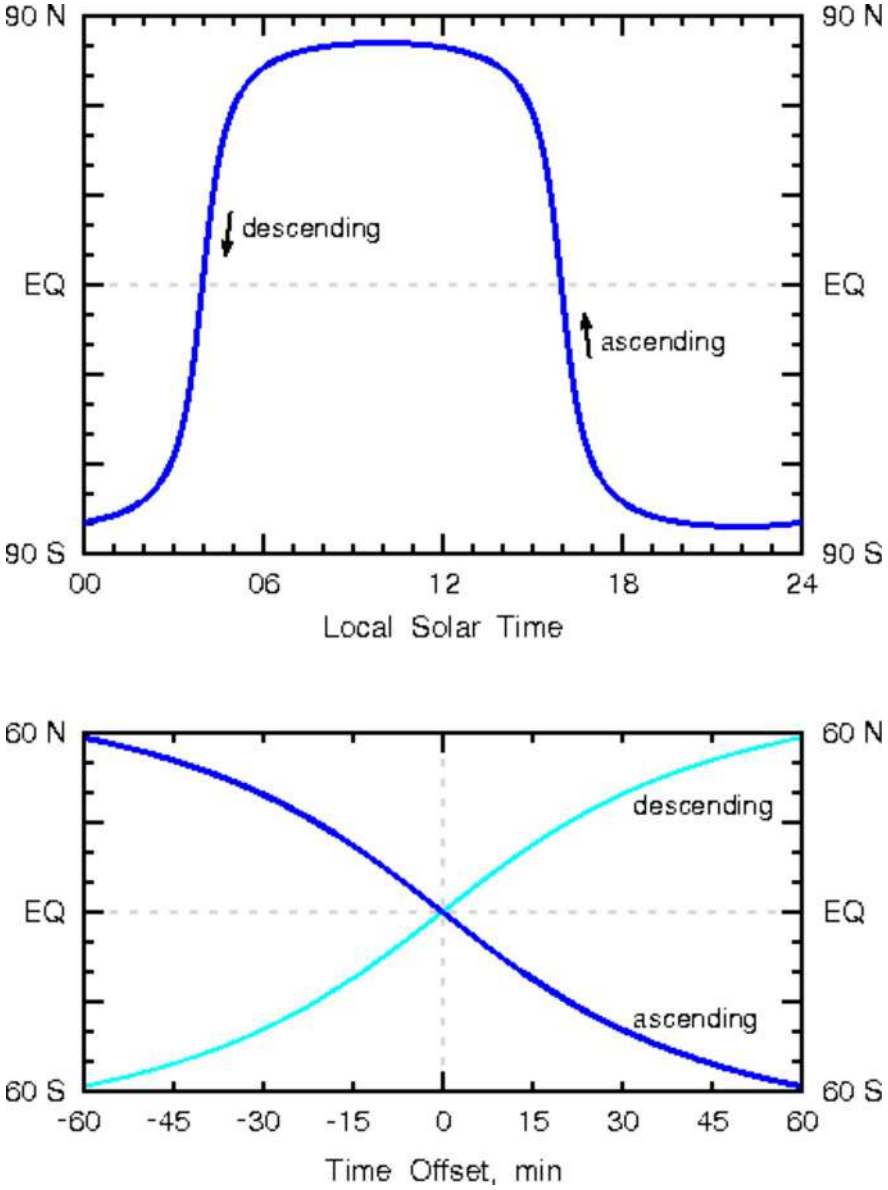
POES Orbits



This figure illustrates the orbital track for a sun-synchronous satellite in near-polar orbit. The orbital track relative to the Earth's surface is due to a combination of the orbital plane of the satellite coupled with the rotation of the Earth beneath the satellite. To achieve a syn-synchronous orbit, the orbital plane is inclined slightly away from a true north-south track to introduce a slow precession in the orbital plane, roughly one degree per day. This precession ensures that the equatorial crossing times of the satellites, in terms of the local solar time, remain nearly constant throughout the year. This means that a satellite can make repeated global observations from a single set of sensors with similar illumination from pass to pass.

Note that the orbit is slightly tilted towards the northwest and does not actually go over the poles. While the red path follows the earth track of the satellite, the transparent overlay indicates the coverage area for the AVHRR imaging instrument carried by NOAA/POES satellites. This instrument scans a roughly 3000 km wide swath. The map projection used in this illustration, a cylindrical equidistant projection, becomes increasingly distorted near the poles, as can be seen by the seeming explosion of the viewing area as the satellite nears its northern and southern most orbital limits. For a more realistic view of the satellite orbit in the polar regions, it is better to use a differend map projection, such as the polar stereographic (see examples, 73 k).

POES / NOAA-11



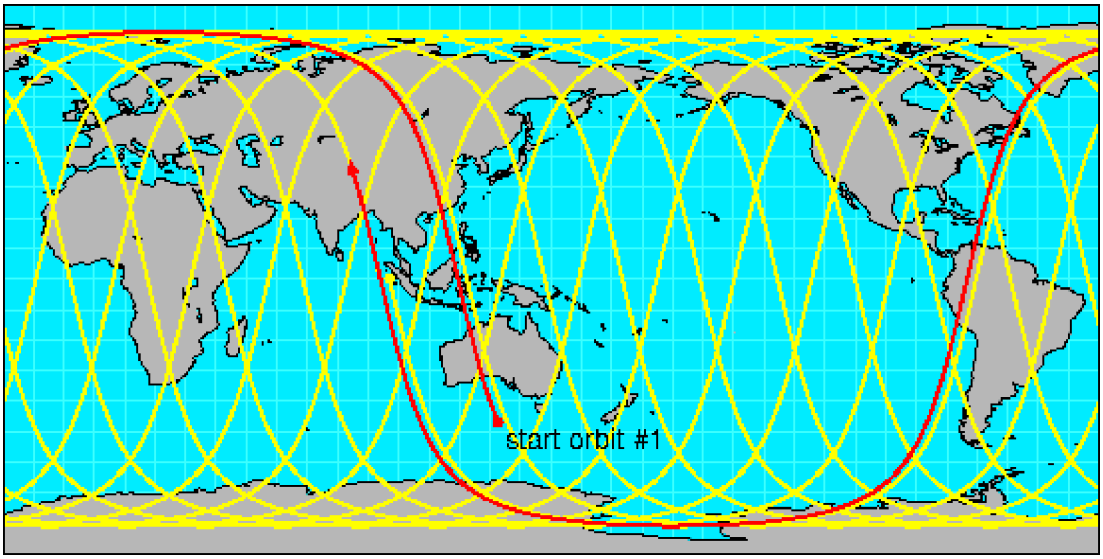
Reprinted from Johnson et al., 1994 (Bulletin of the American Meteorological Society, Volume 75, pp. 5-33).

Sun-synchonous orbits are typically described by their equatorial crossing times. Having a sun-synchronous orbit, however, does not mean that the solar illumination angles are constant throughout the orbit. Most obviously, the sun will generally be lower in the sky as you move northward or southward towards the poles. In addition, the local solar time will also vary during the orbit. The upper panel in the above figure illustrates the local solar time at the subsatellite point throughout one entire orbit of a sun-synchronous satellite. The "ascending" portion of the orbit corresponds to that portion of the orbit when the satellite is moving from south to north, while the "descending" part of the orbit corresponds to north to south movement. This specific example is based on the NOAA-11 satellite, with orbital parameters from July 1993. The furthest poleward excursion of the satellite is at 81 degrees latitude. The equatorial crossing times are at 0400 and 1600 LST. While the equatorial crossing times are precisely 12 hours apart, passes at other latitudes are not evenly spacen in time. For this example, the satellite will cross 40 degree north latitude at 0431 and 1529 LST. The bottom panel of this figure shows the time offfset from the equatorial crossing time as a function of latitude. Unlike the top panel, which strictly speaking, is only applicable to a single satellite and date, the bottom panel is more general and can be used to make a good first approximation of the equatorial crossing times at any latitude up to 60 degrees for any of the NOAA/POES, DMSP, Landsat, or SPOT satellites.

With an orbital period of about 100 minutes, these satellites will complete slightly more than 14 orbits in a

single day.

POES Orbits



This figure duplicated the orbital track shown in an earlier figure, but with 14 additional orbits drawn in yellow. This figure gives a good indication of the daily coverage of a single satellite in sun-synchronous orbit. Note that the satellite does not make an integer number of orbits in a single day, so that there is a slight offset in the orbital tracks after 14 orbits. This means that although the equatorial crossing time in terms of the **local solar time** is constant, the **clock time** for the satellite overpass at a fixed location will vary from day to day, as will the distance and azimuth to the satellite.

Coverage in Polar Regions: The above maps give a good view of the equatorial regions, but distort the polar regions rather grossly. Since polar orbiting satellites are naturally of particular importance in polar regions (due to a combination of poor coverage by geostationary satellites and the frequent overflights of the satellites) it is useful to look at the orbits in a polar stereographic point of view.

- North Pole
- South Pole

(73 k, for both illustrations)

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With the exception of the subsatellite point, the oblique angle from which the clouds are being observed can result in a significant displacement in the apparent earth location of cloud features. This parallax induced cloud displacement is a function of the viewing angle relative to the local plane of the Earth's surface and the height of the cloud. For polar-orbiting satellites in low earth orbit, both the viewing angle and the curvature of the earth are important.

- Parallax induced cloud displacements for polar orbiting satellites in low earth orbit, such as NOAA's POES and DMSP (link to figure, 9 k).

Where did these illustrations come from and how were they made?

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