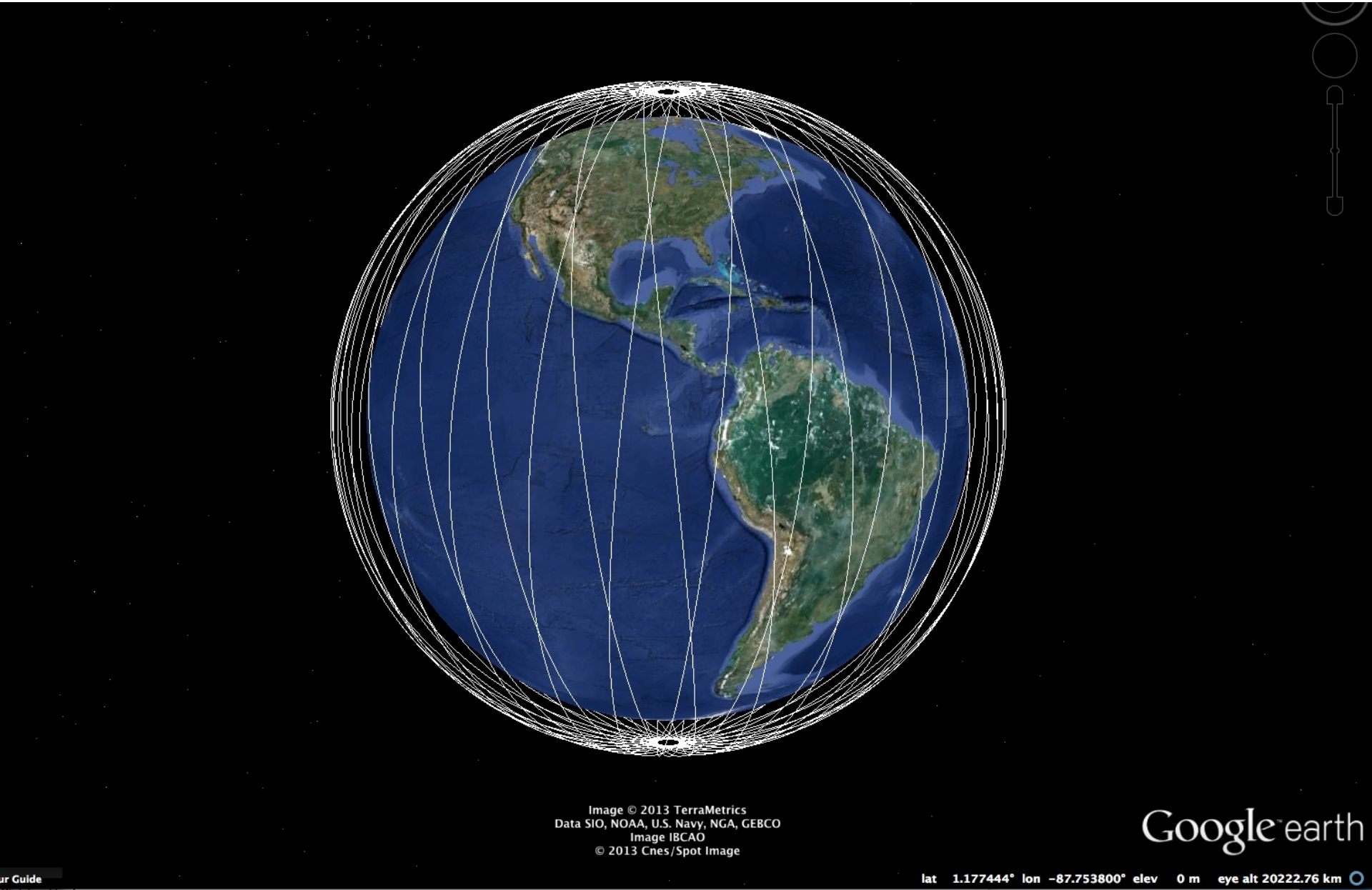
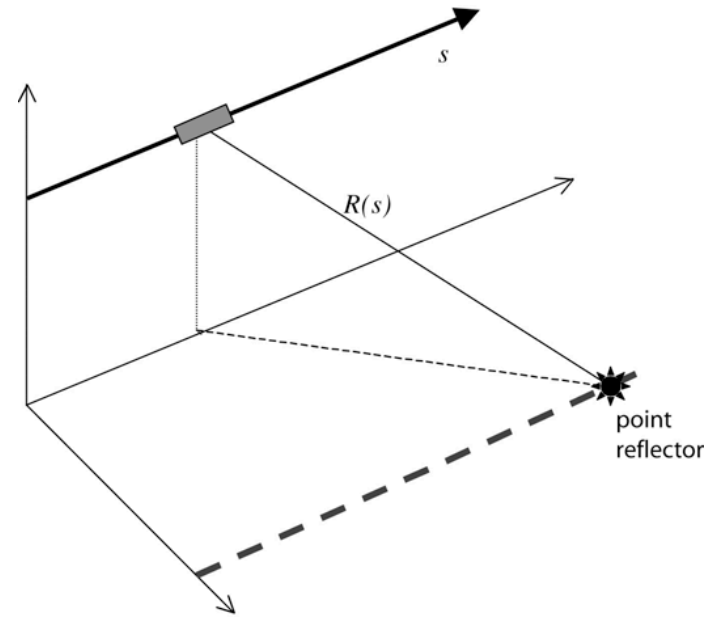
Satellite Orbits for InSAR

David Sandwell



Need for Precise Orbits

1. proper focus
2. transform from geographic radar coordinates
3. image alignment
4. flattening interferogram



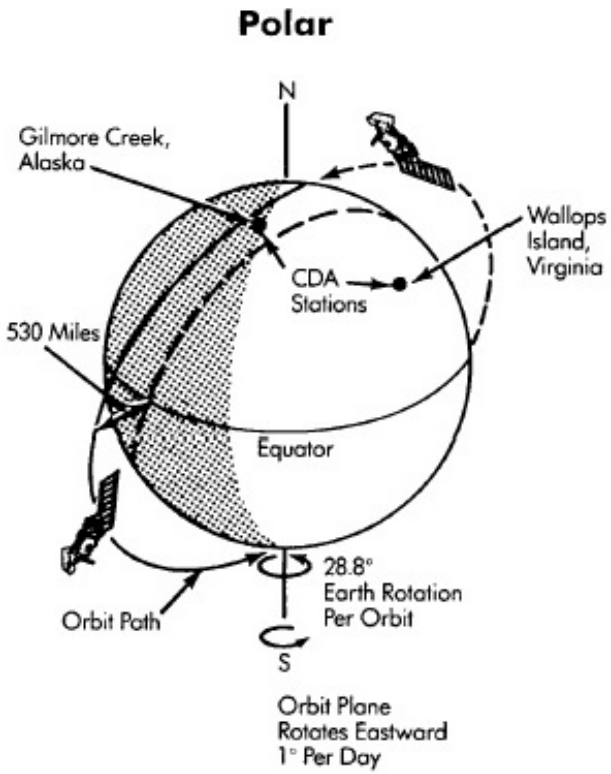
Brute force algorithm given precise orbit subroutine

pick target point

fly satellite along orbit and identify point of closest approach

(This is inefficient but computers are fast so don't waste time coding.)

low and high orbits



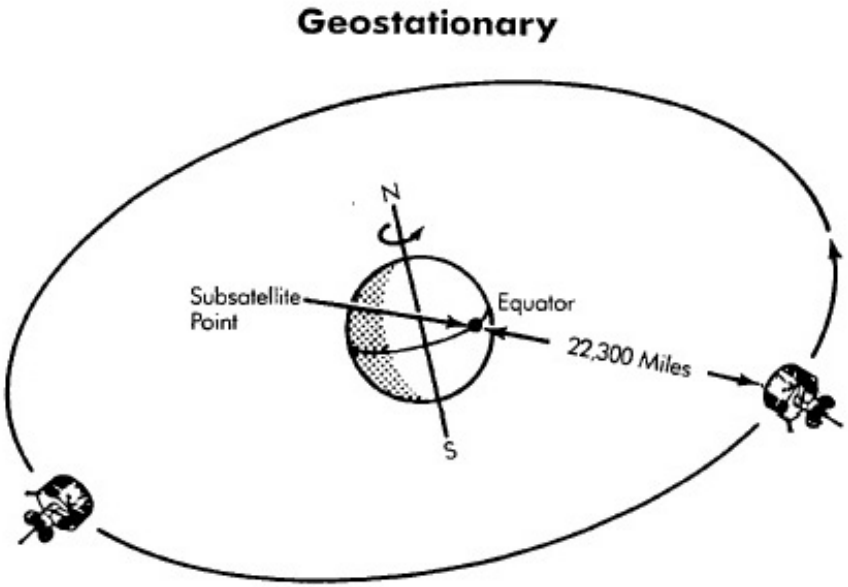
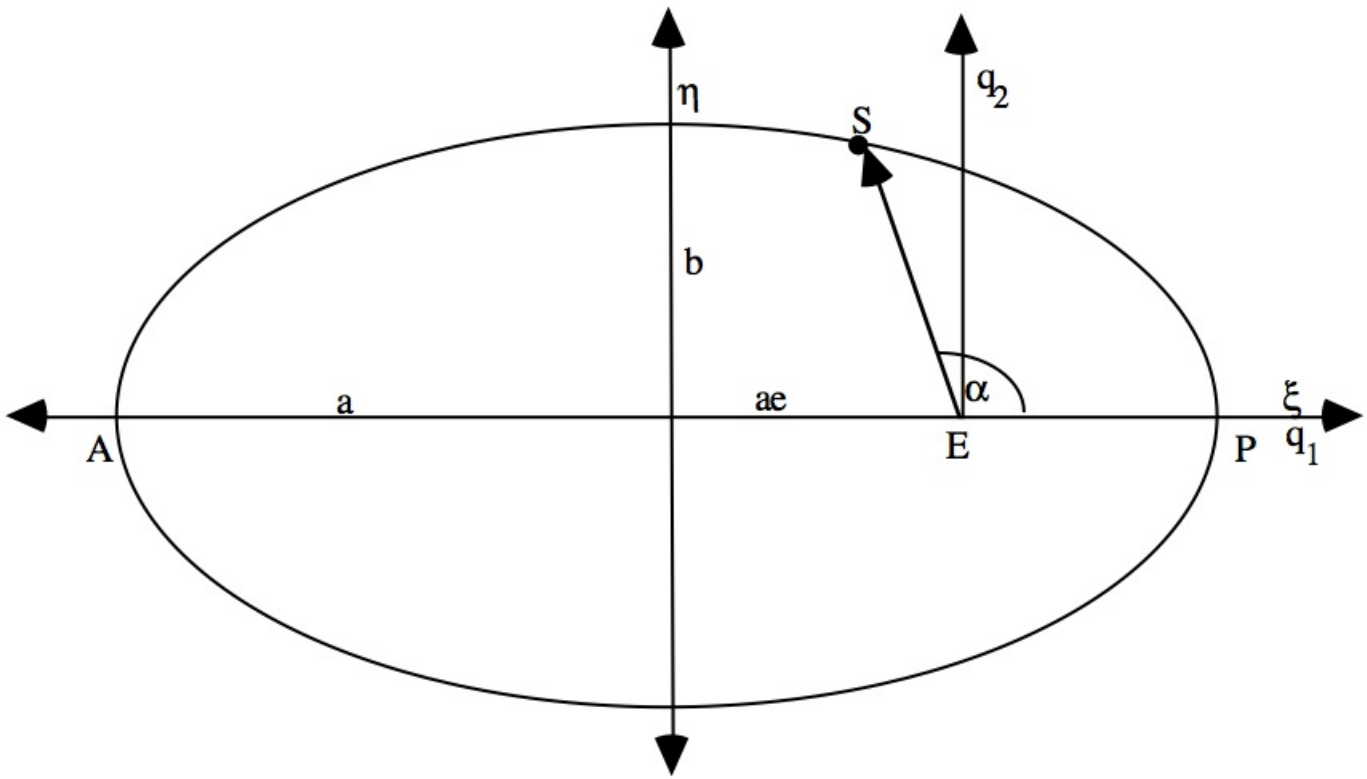


Figure 4. Opposite and above: polar and geostationary orbits for NOAA satellites. Note that the polar orbit rotates one degree per day; this is to make it synchronous with the sun. The geostationary satellite stays continuously above one spot on Earth.

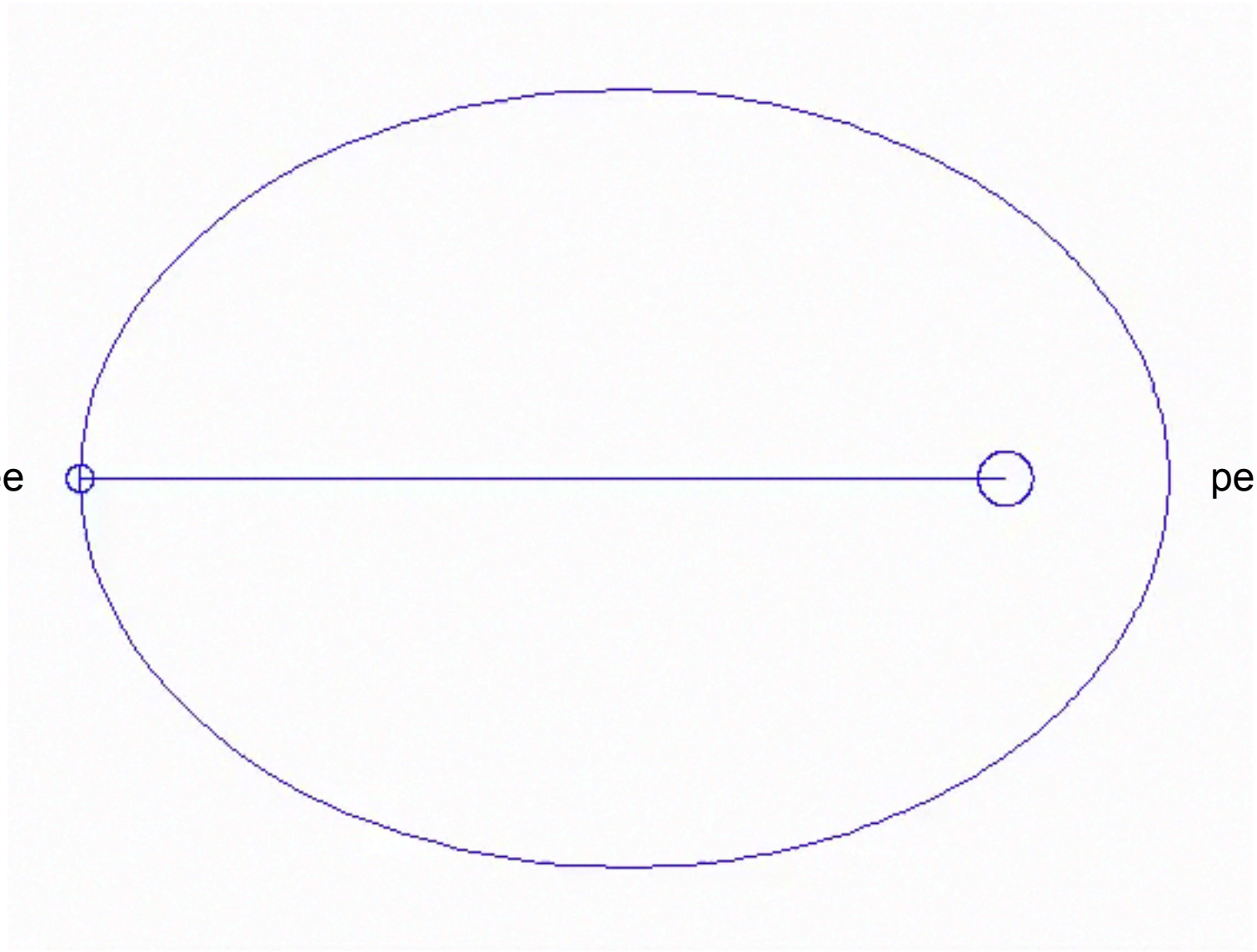
geometry of orbit plane



S	-	satellite
E	-	Earth
A	-	apogee
P	-	perigee
a	-	semimajor axis
b	-	semiminor axis
e	-	eccentricity

$$e^2 = \frac{a^2 - b^2}{a^2}$$

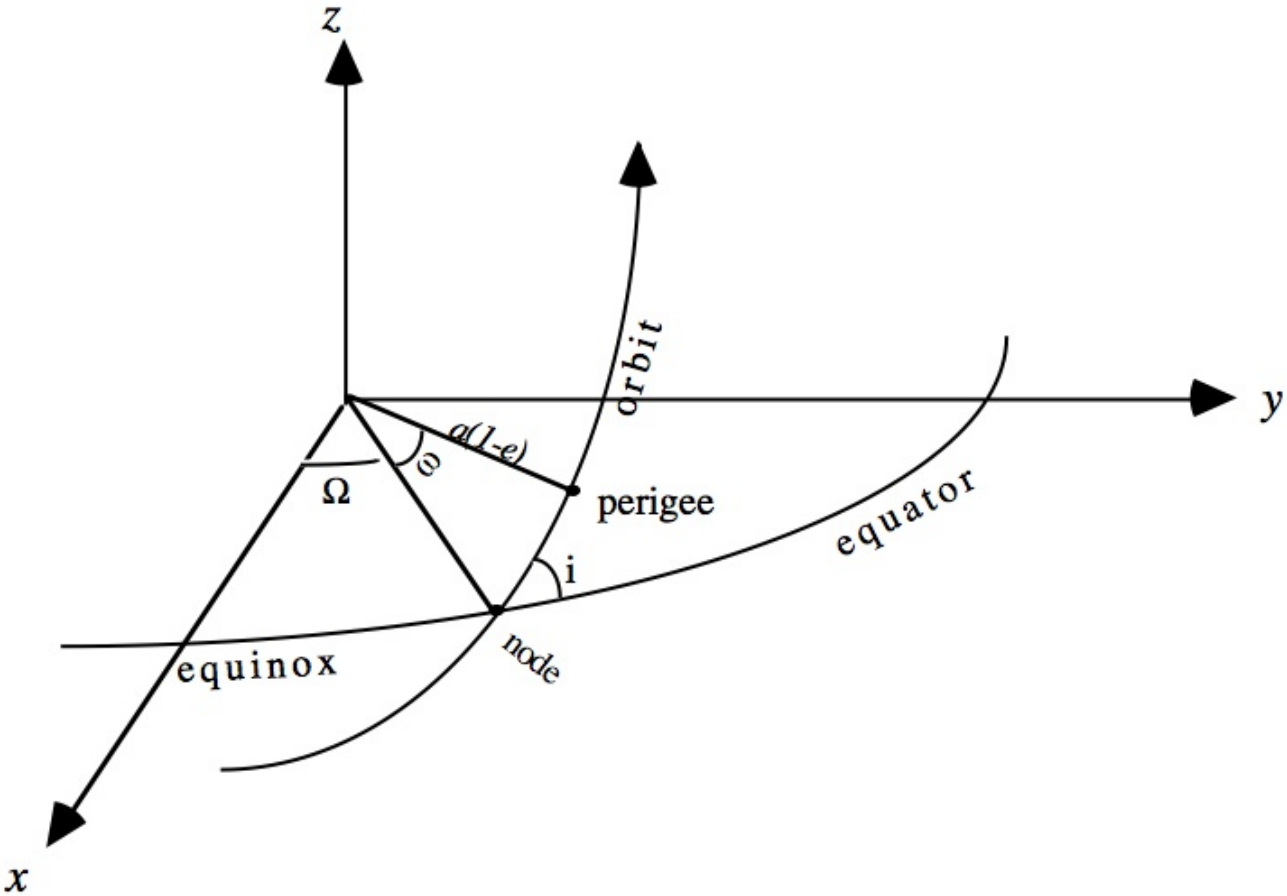
elliptical orbit motion



Orbital Geometry

The ideal elliptical orbit is described by 6 Keplerian elements:

α	-	true anomaly (instaneous angle from satellite to perigee)
ω	-	argument of perigee
Ω	-	longitude of node
a	-	semimajor axis
e	-	eccentricity
i	-	inclination



Two ways to describe an orbit with 6 numbers

Kepler elements
lower accuracy > 10 m

Used for making ground tracks for planning and data management

The ideal elliptical orbit is described by 6 Keplerian elements:

α	-	true anomaly (instaneous angle from satellite to perigee)
ω	-	argument of perigee
Ω	-	longitude of node
a	-	semimajor axis
e	-	eccentricity
i	-	inclination

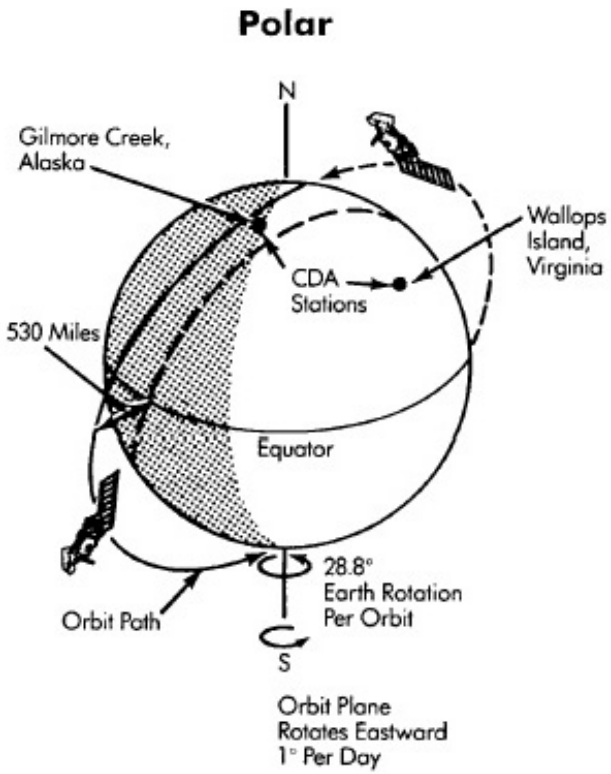
Cartesian state vector
Can be high accuracy
~3 cm for Sentinel-1

PRECISE STATE VECTORS FOR ENVISAT SPACED AT 60 SECOND INTERVALS

TIME	X	Y	Z	DX/DT	DY/DT	DZ/DT
21:55:28.00	+4925775.296	-0672489.270	+5149599.921	-5468.045305	-1230.624128	+5056.89226
21:56:28.00	+4588023.337	-0743509.493	+5442738.786	-5786.560443	-1135.486760	+4711.22472
21:57:28.00	+4231855.868	-0808605.919	+5714579.288	-6081.687559	-1033.262456	+4347.17957
21:58:28.00	+3858712.626	-0867371.390	+5964061.354	-6352.228261	-0924.559337	+3966.18750
21:59:28.00	+3470102.184	-0919436.302	+6190212.706	-6597.087114	-0810.020339	+3569.74320
22:00:28.00	+3067595.664	-0964470.578	+6392152.503	-6815.275024	-0690.319610	+3159.39884
22:01:28.00	+2652820.268	-1002185.442	+6569094.621	-7005.912367	-0566.159017	+2736.75872
22:02:28.00	+2227452.596	-1032334.971	+6720350.620	-7168.232800	-0438.264632	+2303.47344
22:03:28.00	+1793211.746	-1054717.441	+6845332.311	-7301.586442	-0307.382928	+1861.23307
22:04:28.00	+1351852.262	-1069176.424	+6943553.921	-7405.442085	-0174.276681	+1411.76019
22:05:28.00	+0905156.961	-1075601.647	+7014633.841	-7479.388480	-0039.720920	+0956.80327

Orbital elements are based on precise GPS tracking and orbit dynamic modeling.

low and high orbits



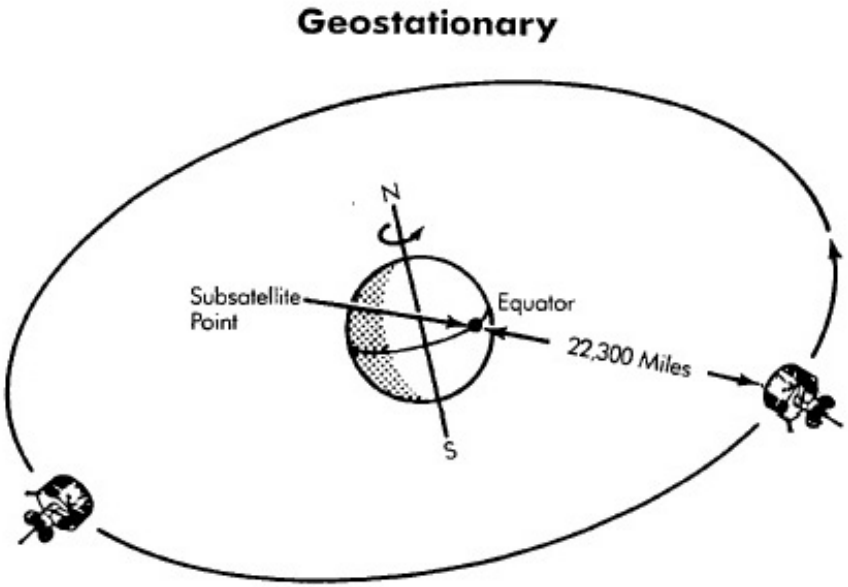
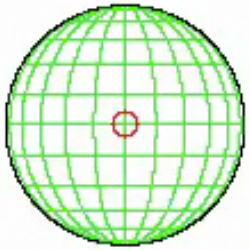


Figure 4. Opposite and above: polar and geostationary orbits for NOAA satellites. Note that the polar orbit rotates one degree per day; this is to make it synchronous with the sun. The geostationary satellite stays continuously above one spot on Earth.

geostationary orbit

orbit period = 1 day

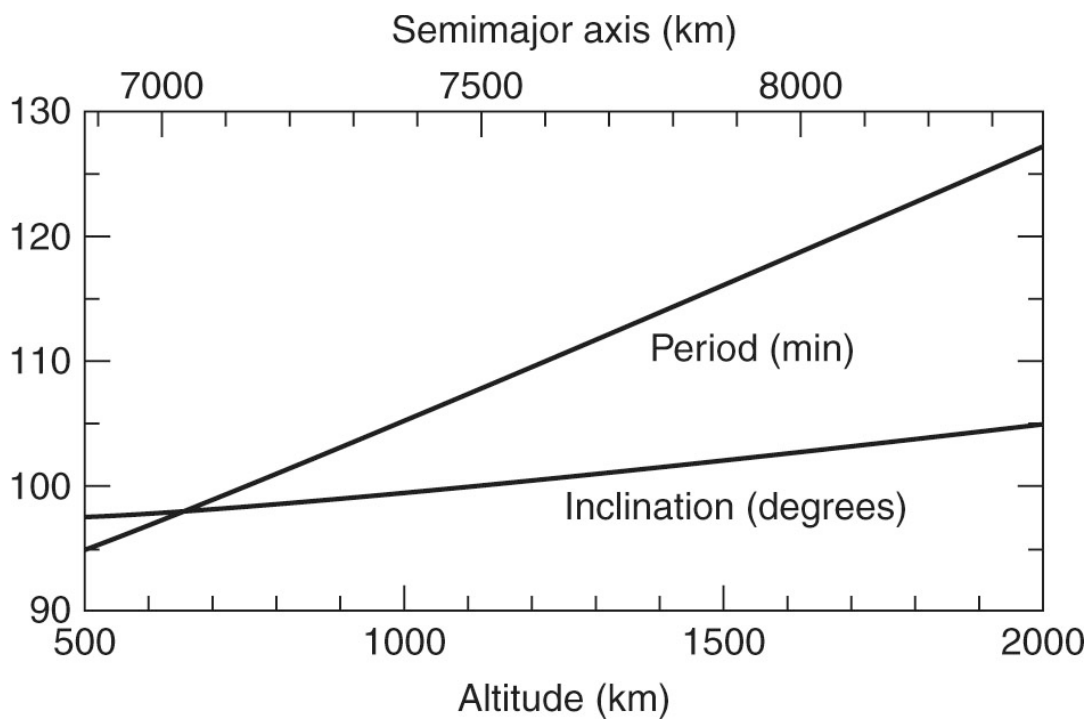


4) Sun-synchronous Orbit

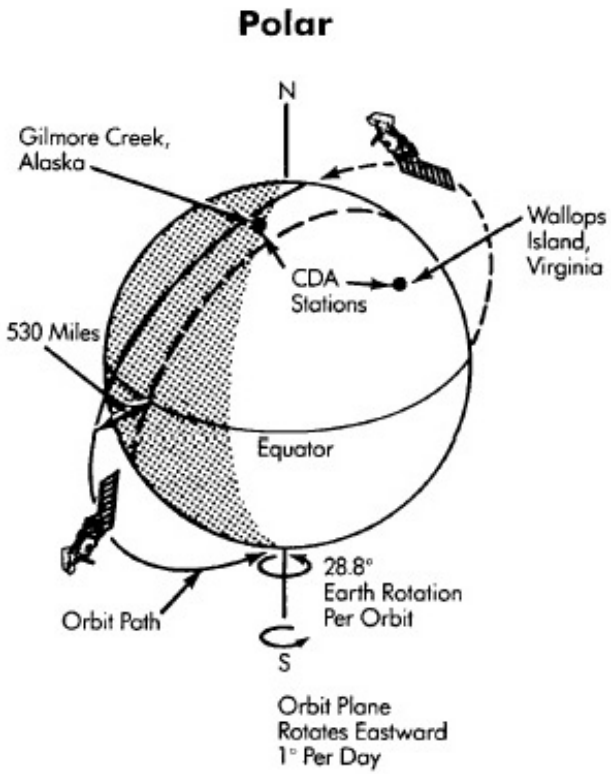
For many remote sensing applications it is important to have the ascending node pass over the equator at the same local time. To create a sun-synchronous orbit, the plane of the orbit must precess in a prograde direction with a period of exactly 1 year.

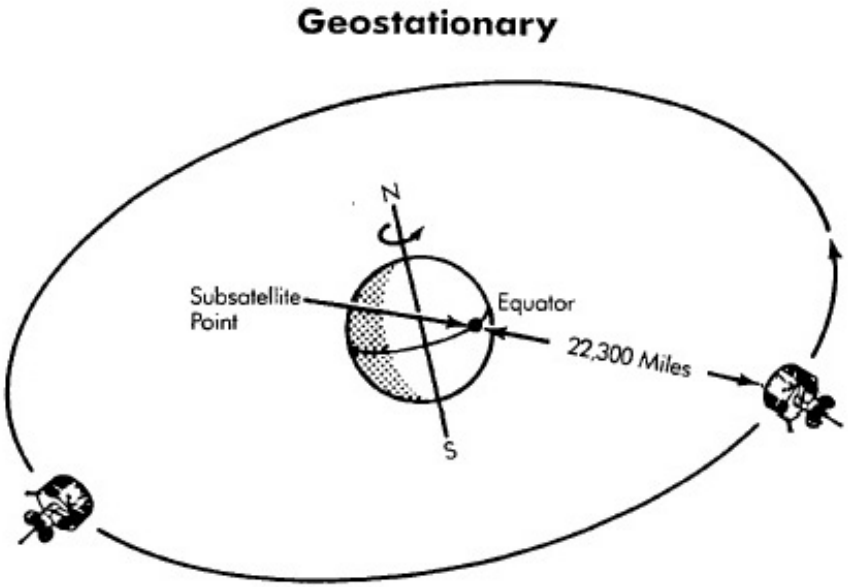
$\omega_n = 2\pi/(365.25 \times 86400) = 1.991 \times 10^{-7}\ s^{-1}$

Remember $\frac{\omega_n}{\omega_s} = -\frac{3J_2}{2}\left(\frac{a_e}{a}\right)^2 \frac{\cos i}{(1-e^2)^2}$ so prograde precession requires $i > 90°$. Thus the orbital inclination is dictated by the orbital altitude. For example, a sun-synchronous orbit with an orbital radius of $a = 7878$ km (altitude 1500 km) must have an inclination of 102°.



low and high orbits





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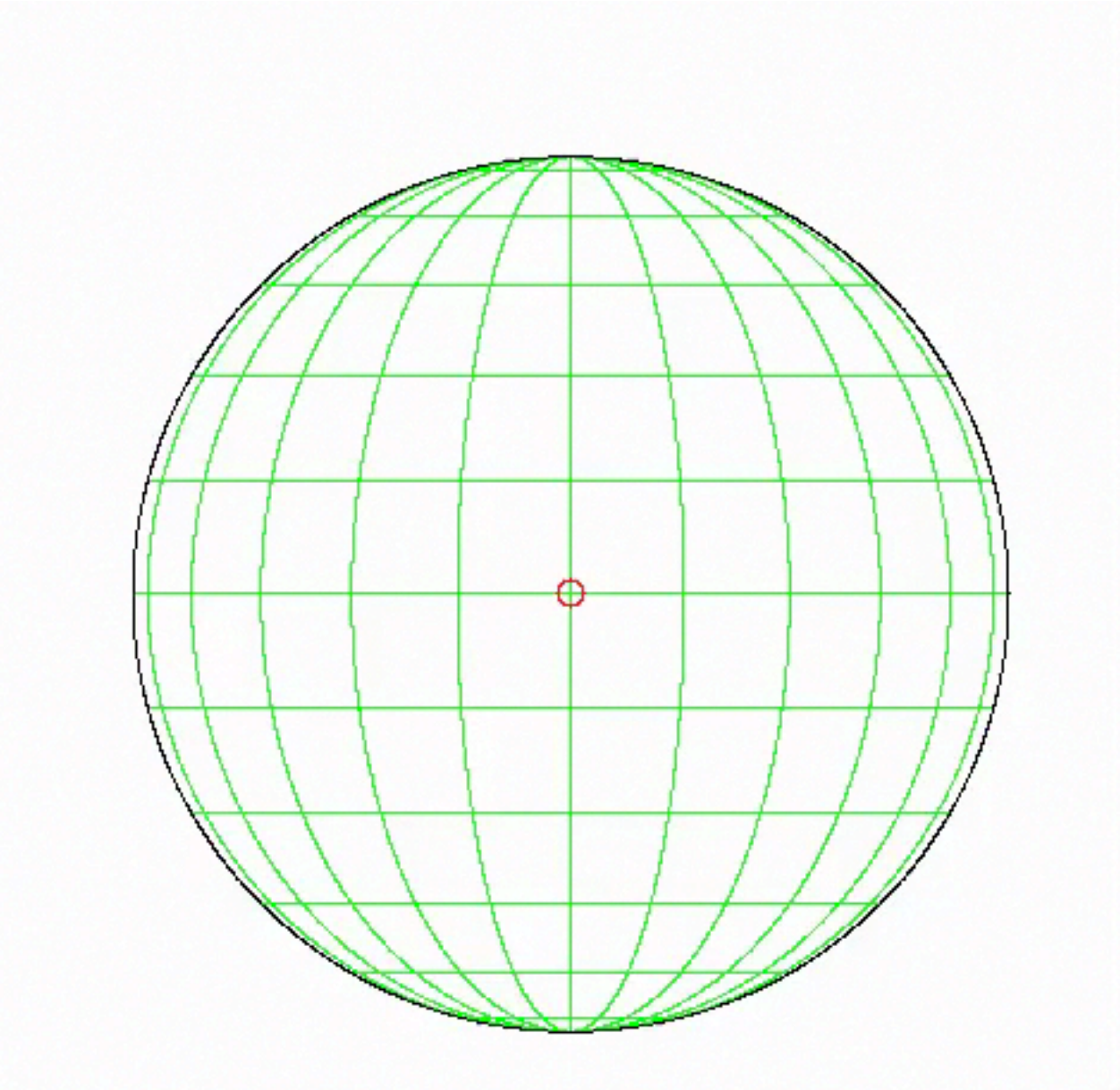
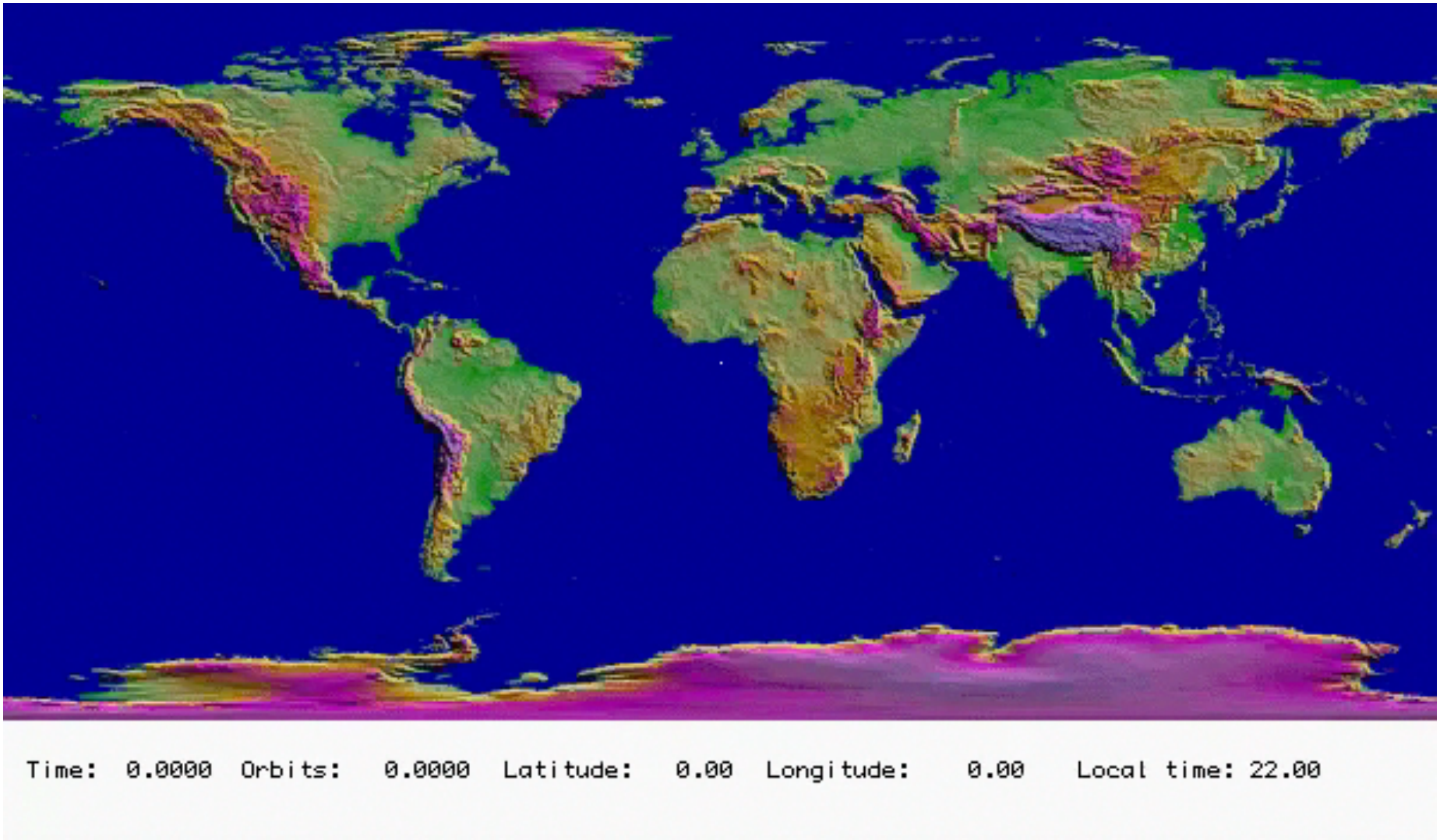
sun synchronous orbit



Landsat ground tracks



How to compute precise orbits from elements

Hermite polynomial interpolation

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Orbital elements are based on precise GPS tracking and orbit dynamic modeling.

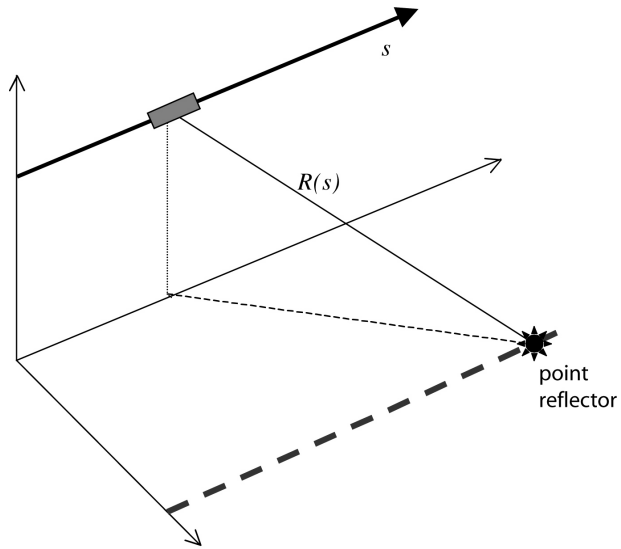
In GMTSAR this is called a **.LED* file

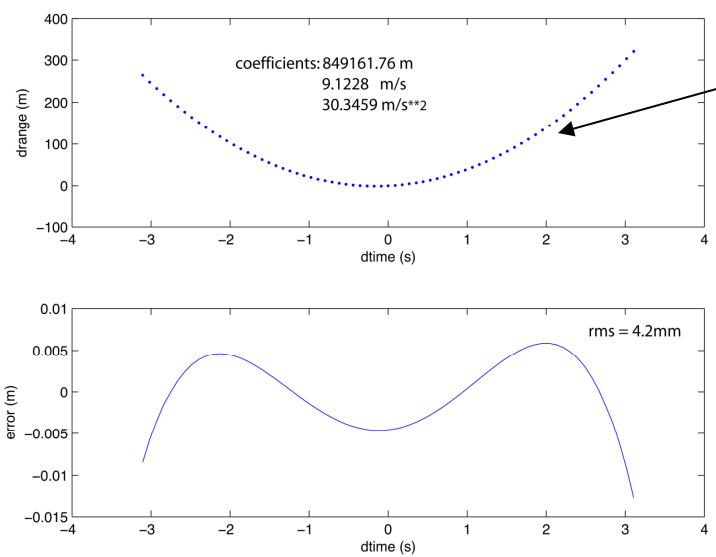
C-PROGRAM TO INTERPOALTE STATE VECTORS

```
/*-----------------------------------------------------------------*/
void interpolate_ALOS_orbit(struct ALOS_ORB *orb, double *pt, double *p,
                double *pv, double time, double *x, double *y, double *z, int *ir)
{
/* ir;                return code          */
/* time;              seconds since Jan 1    */
/* x, y, z;           position             */
int    k, nval, nd;

      nval = 6; /* number of points to use in interpolation */
      nd = orb->nd;

      if (debug) fprintf(stderr," time %lf nd %d\n",time,nd);

      /* interpolate for each coordinate direction    */

      /* hermite_c c version                          */
      for (k=0; k<nd; k++) {
            p[k] = orb->points[k].px;
            pv[k] = orb->points[k].vx;
            }

      hermite_c(pt, p, pv, nd, nval, time, x, ir);

      for (k=0; k<nd; k++) {
            p[k] = orb->points[k].py;
            pv[k] = orb->points[k].vy;
            }
      hermite_c(pt, p, pv, nd, nval, time, y, ir);

      for (k=0; k<nd; k++) {
            p[k] = orb->points[k].pz;
            pv[k] = orb->points[k].vz;
            }
      hermite_c(pt, p, pv, nd, nval, time, z, ir);

}
```


2.4 m corner reflectors
D1, D2 installed 1996
A1 installed Nov, 2005
A1

Back Projection



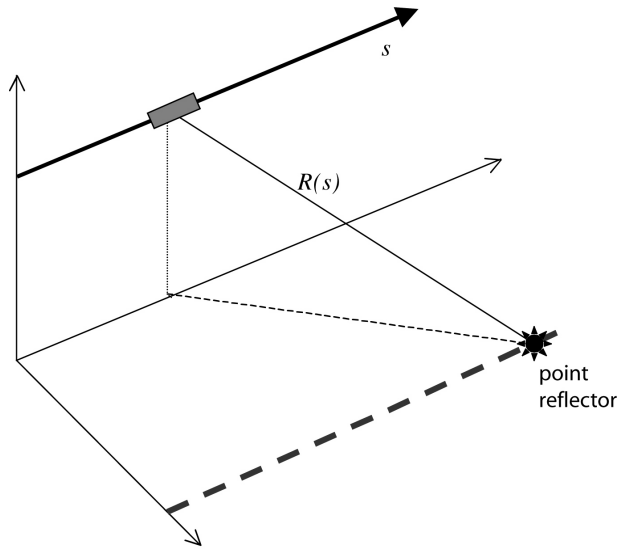


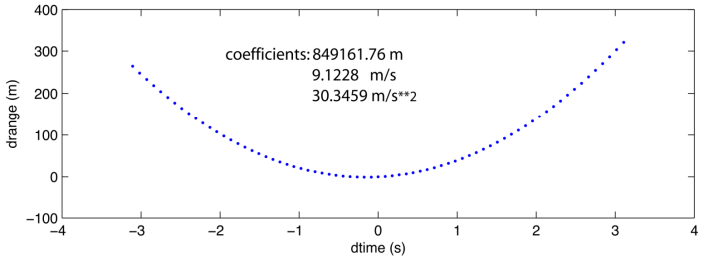
parabolic approximation to range history

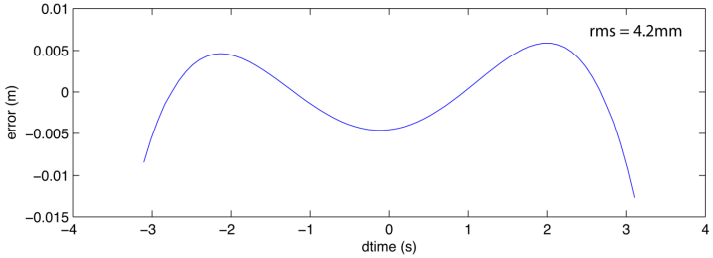
$$R(s) = R_o + \dot{R}_o(s - s_o) + \frac{\ddot{R}_o}{2}(s - s_o)^2 + \ldots$$

Least-squares fit of range history for each point in DEM provides both the accurate position in range azimuth $\left[R_o, s_o\right]$ space and the Dopper centroid and rate parameters needed to focus the image. This analysis only needs to be applied to the master image.

Back Projection







back projection algorithm

① select a point on the DEM (lon, lat, height above WGS84 ellipsoid)

② convert lon, lat, height to *x, y, z* .

③ use the state vector to “fly” the satellite over the point

④ calculate the minimum distance (range) and time of minimum distance (azimuth)

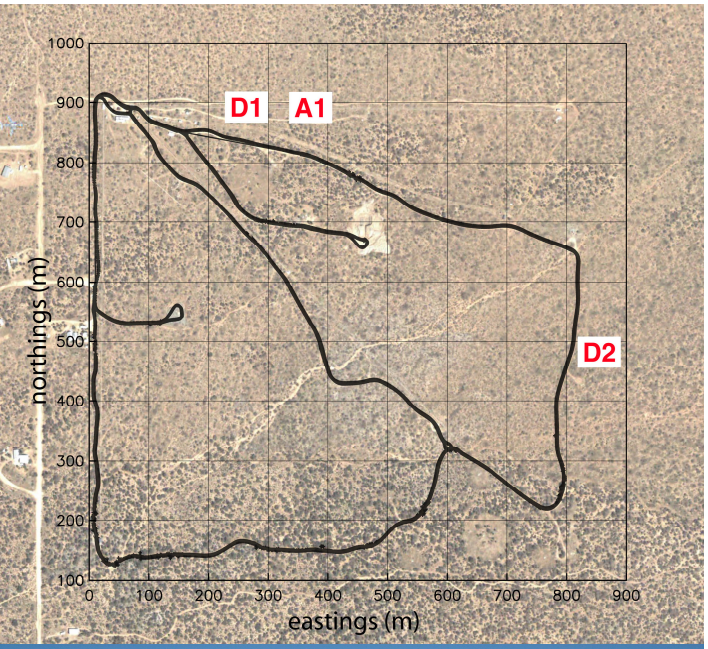
⑤ do that for every point in the DEM

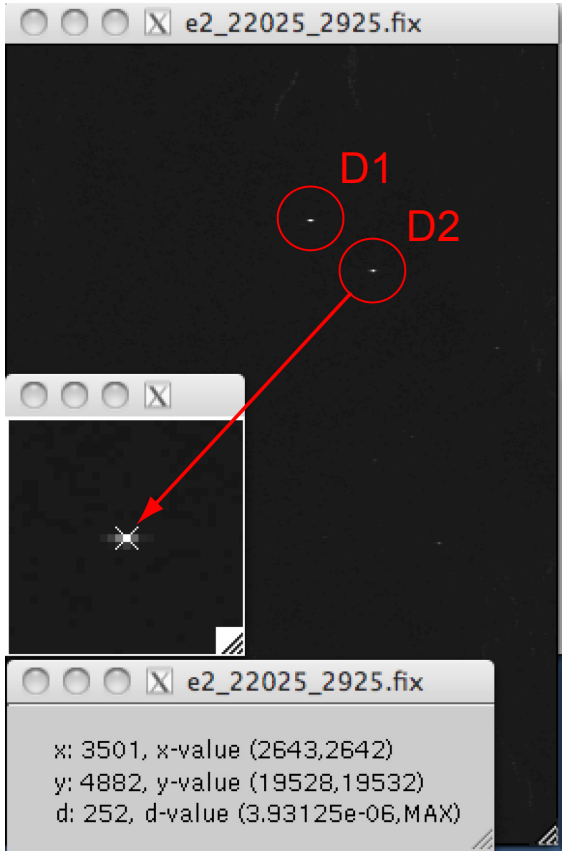
⑥ keep that transformation table

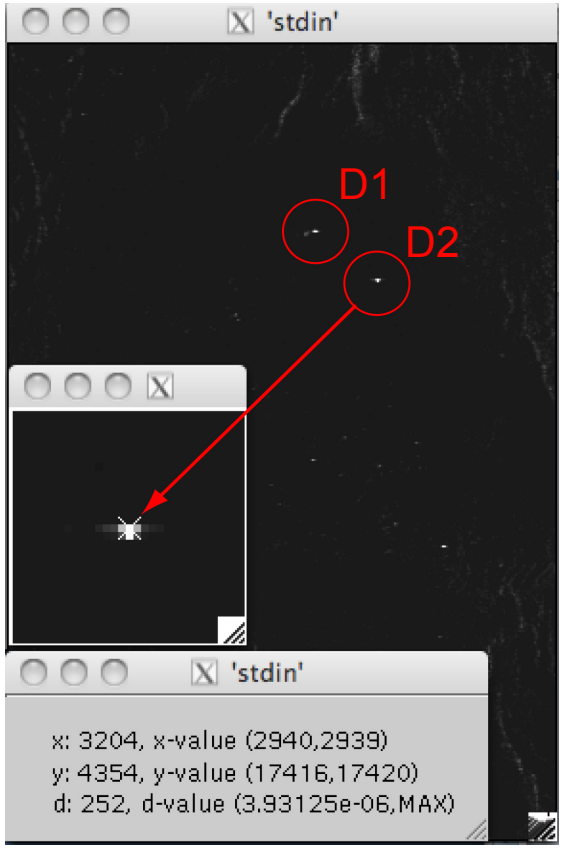
In GMTSAR the transformation file is called *trans.dat* in the /topo directory.

lon, lat, height, range azimuth

Precise orbit for image focussing and geolocation - ERS, Envisat







ERS 36 acquisitions

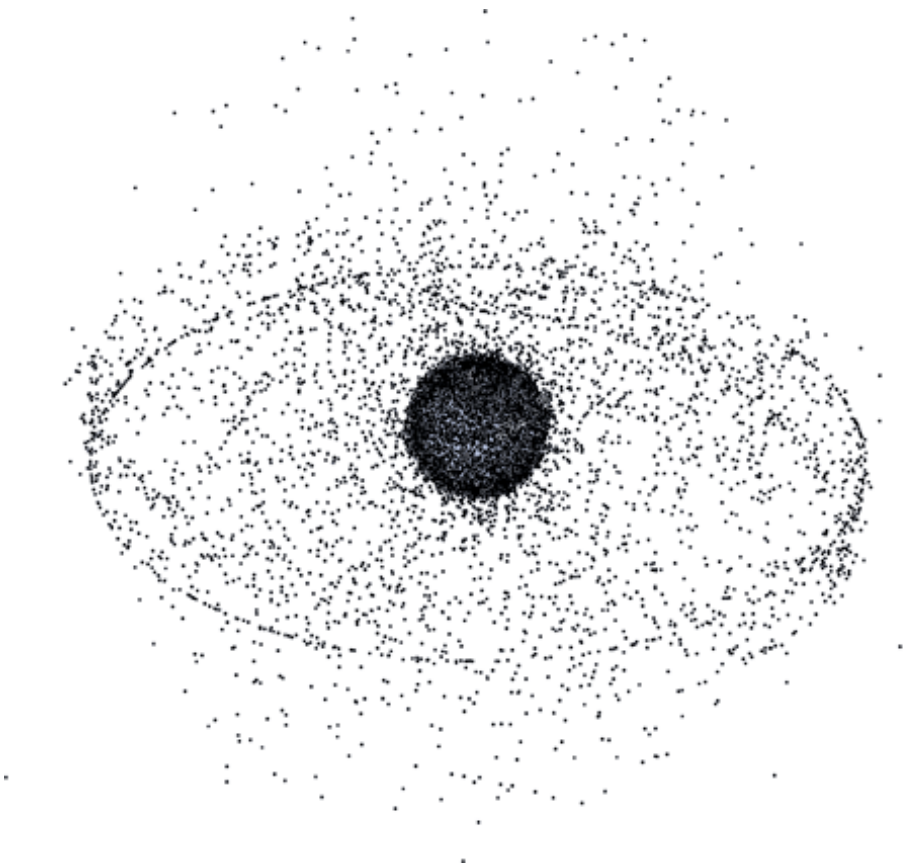
	mean	**rms**
range	-17.2 m	**2.8 m**
azimuth	14.8 m	**10.4 m**

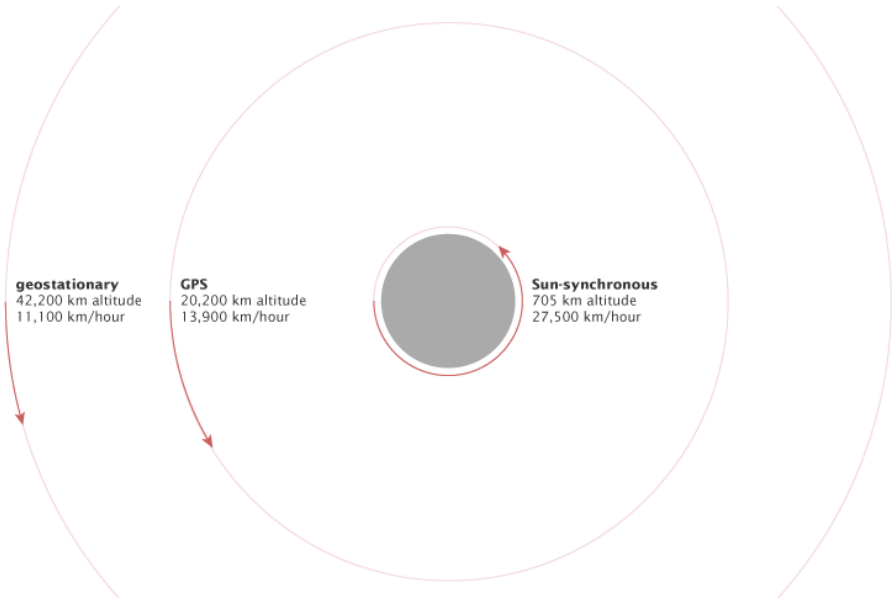
Envisat 10 acquisitions

	mean	**rms**
range	80.6 m	**1.9 m**
azimuth	3.6 m	**8.8 m**

Platforms for Remote Sensing – Rees, Ch. 1

~18,000 man-made objects orbiting the Earth





http://earthobservatory.nasa.gov/Features/OrbitsCatalog/page3.php

Conclusions

- All SAR satellites are in low Earth orbit at an altitude of 600-800 km.
- The ground track speed is ~7000 m/s and cannot be adjusted.
- The orbits repeat exactly (Envisat 35 days; ALOS-1 42 days; Sentinel-1 12 days
- Accurate orbits (< 1 m) greatly simplify InSAR processing. They are used for:

  proper focus

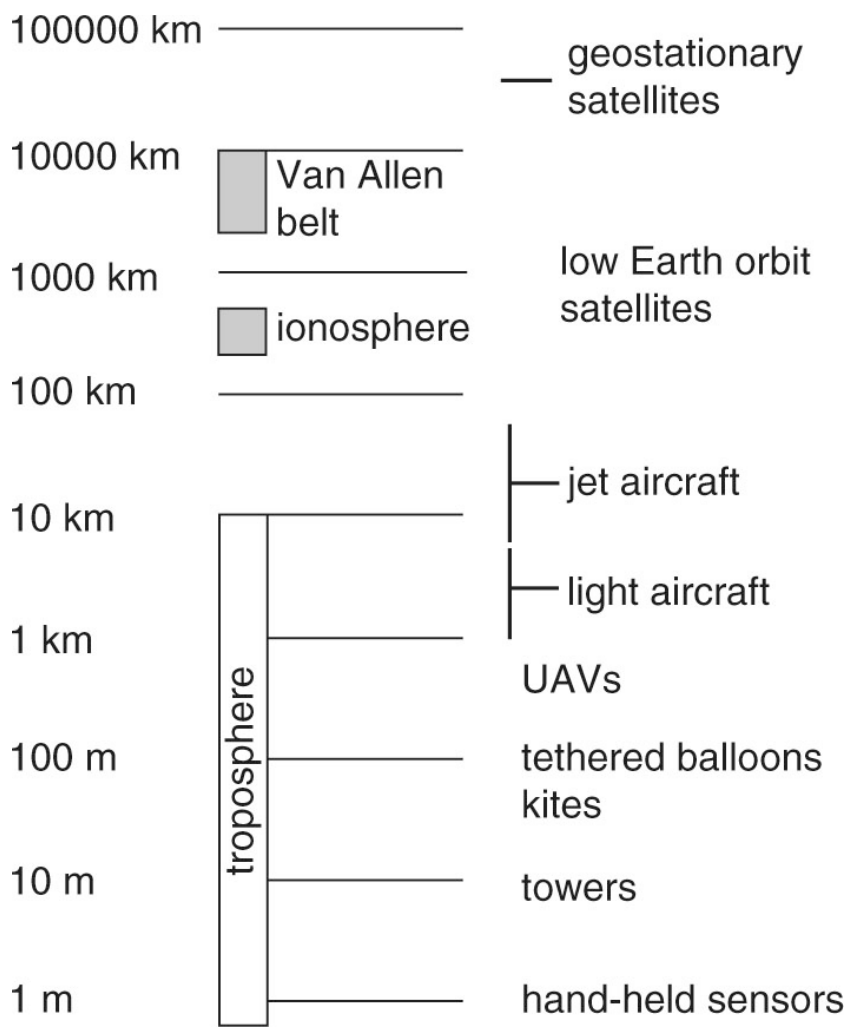
  transformation (lon, lat, height) to (range, azimuth) coordinates (back projection)

  image alignment to sub-pixel accuracy

  flattening the interferogram (i.e. removing the topographic phase)

In GMTSAR the orbits (state vectors) are stored in **.LED* files.
The transformation is stored in *trans.dat* file.

Altitudes of various remote sensing platforms



REES_Fig 10.01

NOTES ON BB

http://topex.ucsd.edu/rs/orbits.pdf