Review
Orbits

Balance of gravity and centripetal forces

\[ \frac{GMm}{r^2} = \frac{mv^2}{r} \]

\[ v = \sqrt{\frac{GM}{r}} \]

Kepler:

\[ T^2 \propto r^3 \]

\[ T = 2\pi \sqrt{\frac{r^3}{GM}} \]

\[ T = \frac{4\pi^2 r^3}{GM} \]

e.g. ISS:

\[ T = 91.6 \text{ minutes at a speed of } 7.69 \times 10^3 \text{ m s}^{-1} \]
or 17,200 mph

\[ T = 2\pi \sqrt{\frac{(6373 + 360)^3 \times 10^9}{3.986 \times 10^{14}}} \]

\[ = 5.498 \times 10^3 \text{ s} \]
Terra satellite, Modis instrument, day 01/28/2006

*Sun synchronous orbit* has equator crossings at the same local time each day
Sidereal day = time it takes for Earth to rotate 360° is slightly shorter than a solar day (24 hours) (because there 365.25 solar days in a year but 366.25 sidereal days) 

Sidereal day = \( \frac{365.25}{366.25} \times 24 = 29.93 \) hours

For a sun synchronous orbit, we need the orbital plane to precess slightly each day to keep the same local time on each orbit

Engineers exploit the radial asymmetry of Earth’s gravity to cause the orbit to precess at the right rate for sun synchronous
Sea surface temperature

Atmospheric windows in the infrared used for sea surface temperature observation

3.5-4.1 μm
10-12 μm
Figure 7.4. Comparison of characteristic temperature profiles for day and night conditions. Depth is on a log scale. (a) Day and night strong wind case, where $U > 6 \text{ms}^{-1}$. (b) Daytime weak wind and strong solar insolation case that yields a stratified upper ocean. On the figure, $T_S$ is the surface temperature, the bar marked $T_{11 \mu m}$ shows the depth range that contributes to the infrared 11-\text{\mu}m SST; the bar marked $T_{10 \text{GHz}}$ shows the depth range that contributes to the microwave surface temperature, $T_b$ is the buoy or bulk temperature and $\Delta T$ is the temperature difference between the buoy and surface temperatures (Adapted from Figure 1, Donlon et al., 2002).
SST processing algorithms must consider:

- Atmosphere absorption, scattering, clouds, aerosols, reflection
- Skin temperature effect
- Instrument calibration (internal checks and by ocean observations comparison)
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Altimeters

nadir-pointing radars measures the range from satellite to surface of the Earth

• radar pulse is reflected from the Earth’s surface

• measure the round-trip travel time

• range from satellite to surface is  \( R = \frac{1}{2} ct \) where \( c \) = speed of light

• Precision Orbit Determination (POD) systems measure the altitude of the satellite above a reference ellipsoid

• several corrections must be made for atmosphere and sea state effects on range calculation
How altimetry works:

Sea Surface Height

\[ SSH = altitude - range \]
\[ = Geoid + dyn. topography \]

To get dynamic topography the easiest way would be to subtract the geoid from SSH

\[ D = SSH - G \]

Need to know the satellite position very accurately to get centimeter precision in the range data

The geoid is not yet known accurately enough for all oceanographic applications, but this is changing due to the GRACE mission.
The slope of the sea surface relative to the geoid is directly related to the geostrophic current that balances the pressure gradient (due to the sea surface gradient) and the Coriolis force.

\[ v_g = \frac{g}{f} \frac{d\zeta}{dx} \]
The challenges to achieving 2 cm accuracy are:

- computing the satellite position accurately
- range corrections for the atmosphere
  - density of atmosphere, water vapor, ionosphere effects
- range corrections for sea state
- accounting for the aliasing of tides
- knowing the shape of a reference gravitational potential surface, or “geoid”, that defines a surface along which gravity is constant (and therefore dynamically “level”)
Precision Orbit Determination

1. Turbo-Rogue Space Receiver (TRSR)
   - tracks GPS satellites carrier signal
   - estimate position to better than 20 m and time to 100 nanoseconds

2. Laser Retroflector Array (LRA)
   - round-trip time of laser range measurement
   - accuracy is a few mm

3. DORIS
   - Doppler shift of signal from ground-station beacons gives satellite velocity

Dynamic orbit model integrates the velocity and position data, drag, solar forces on satellite, to continuously compute the satellite trajectory

Where is Jason now?
GRACE: Gravity Recovery and Climate Experiment

Dedicated mission for observing the mean gravity field (geoid) and gravity changes due to the hydrologic cycle.
Applications: ENSO observation
Applications

Sea-level rise

FIGURE 8  Same as Figure 4, but after correcting for instrument effects using the tide gauge calibration time series (lower panel, Figure 7) and removing annual and semi-annual variations.
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Scatterometers

Bragg scattering

*Figure 11.* Bragg scattering: A plan-parallel radar beam with wavelength $\lambda$ hits the rough ocean surface at incidence angle $\theta$, where capillary gravity waves with Bragg wavelength $\lambda_B$ will cause microwave resonance.
Figure 12.4 The scattering cross section per unit area of the sea as a function of angle relative to the mean wind for 13.9 GHz radio signals at 40° incidence angle (from Jones and Schroeder, 1978).
Figure 12.5  If a radar observes a particular cross section $\sigma_0(\theta)$ at an azimuthal angle $\theta$ relative to the wind, all points on the curve are possible wind vectors that yield the observed cross section. If the oceanic area is observed from two different directions, $\theta$ and $\theta + 90^\circ$ in this example, up to four possible wind vectors satisfy the observations. These are the intersections of the two curves. Thus wind direction is not uniquely determined. If three observations are made, the ambiguity is reduced, but the observations must be very precise because scatter is only weakly anisotropic (from Jones et al., 1982).
From Rick Knabb, Tropical Prediction Center