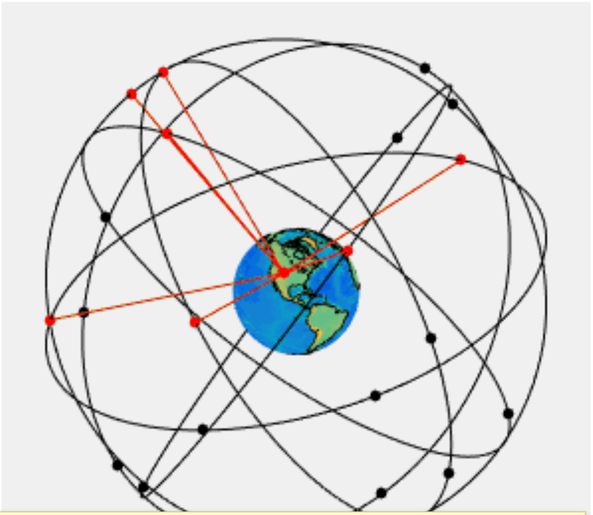
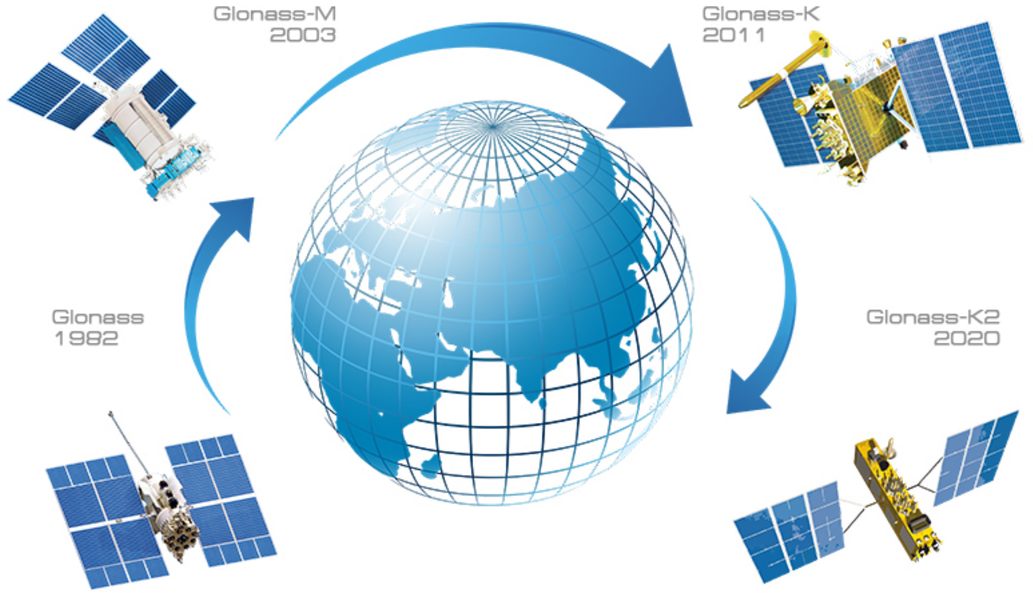
GNSS | Accurate Global Positioning

- **Global Navigation Satellite System (GNSS)** is a catch-all term for a satellite system(s) that can be used to pinpoint a receiver's position anywhere in the world.



Can we find a different graphic for GPS?

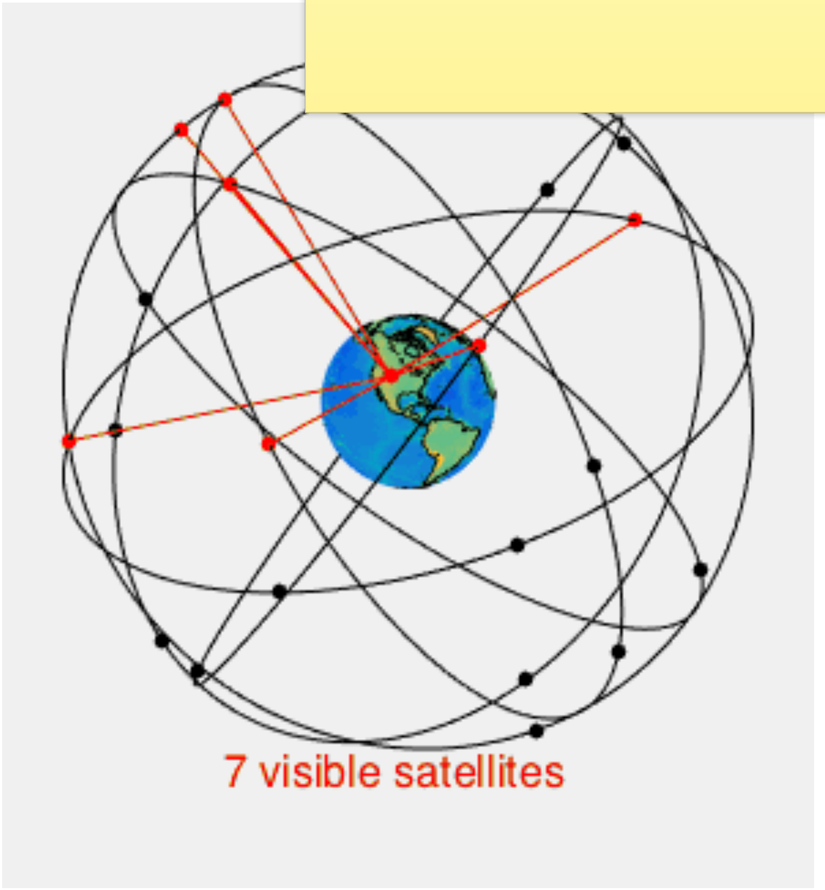


Globalnaya navigatsionnaya sputnikovaya sistema (GLONASS)

GPS | Global Positioning System

Need a better looking graphic here as well

- Composed of 24 to 32 satellites in 6 orbital planes.
  - *Altitude of ~20,200 km (12,550 miles)*
  - *Orbital period of ~12 hours*
- Each satellite broadcasts on two frequencies:
  - *L1 (1575.42 MHz, civilian + military)*
  - *L2 (1227.6 MHz, military)*



GPS | Computing Position

- Each GPS satellite transmits a signal that encodes

    1. its *position*
       (via accurate ephemeris information)

    2. time of signal transmission
       (via onboard atomic clock)

- To compute a GPS position fix in the Earth-centred frame, the receiver uses the **speed of light** to compute distances to each satellite based on time of signal arrival.

At least **four** satellites are required to solve for 3D position,
three if only 2D is required (e.g., if altitude is known)

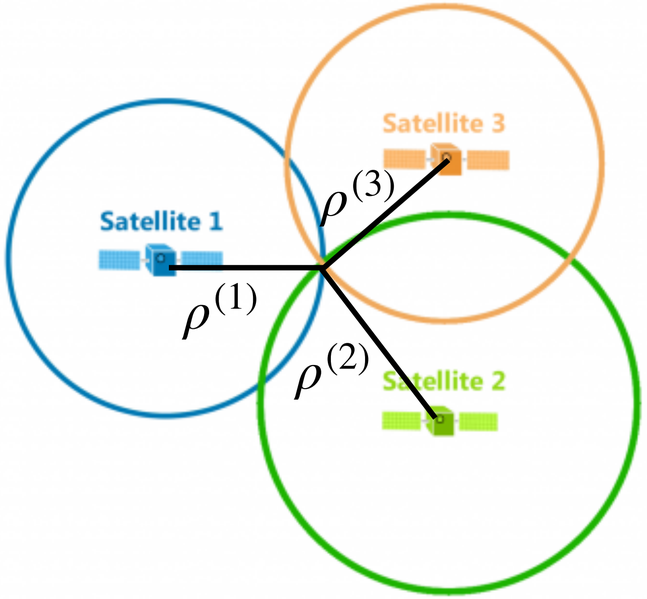
Trilateration

Wrong title - fixed now

- For each satellite, we measure the ***pseudorange*** as follows:

$$\rho^{(i)} = c\,(t_r - t_s) = \sqrt{\left(\mathbf{p}^{(i)} - \mathbf{r}\right)^T \left(\mathbf{p}^{(i)} - \mathbf{r}\right)} + c\Delta t_r + c\Delta t_a^{(i)} + \eta^{(i)}$$

$\mathbf{r}$	receiver (3D) position
$\mathbf{p}^{(i)}$	position of satellite i
Δt_r	receiver clock error
$\Delta t_a^{(i)}$	atmospheric propagation delay
η	measurement noise
c	speed of light
t_s, t_r	time sent, time received

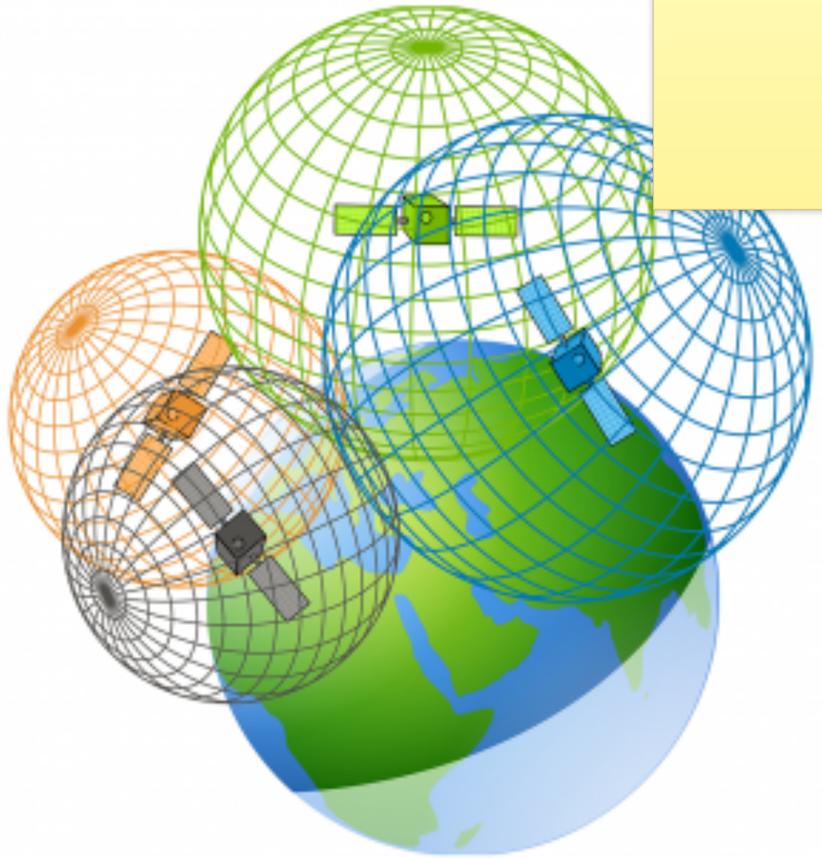


Trilateration in 2D

Trilateration

Wrong slide title - fixed it

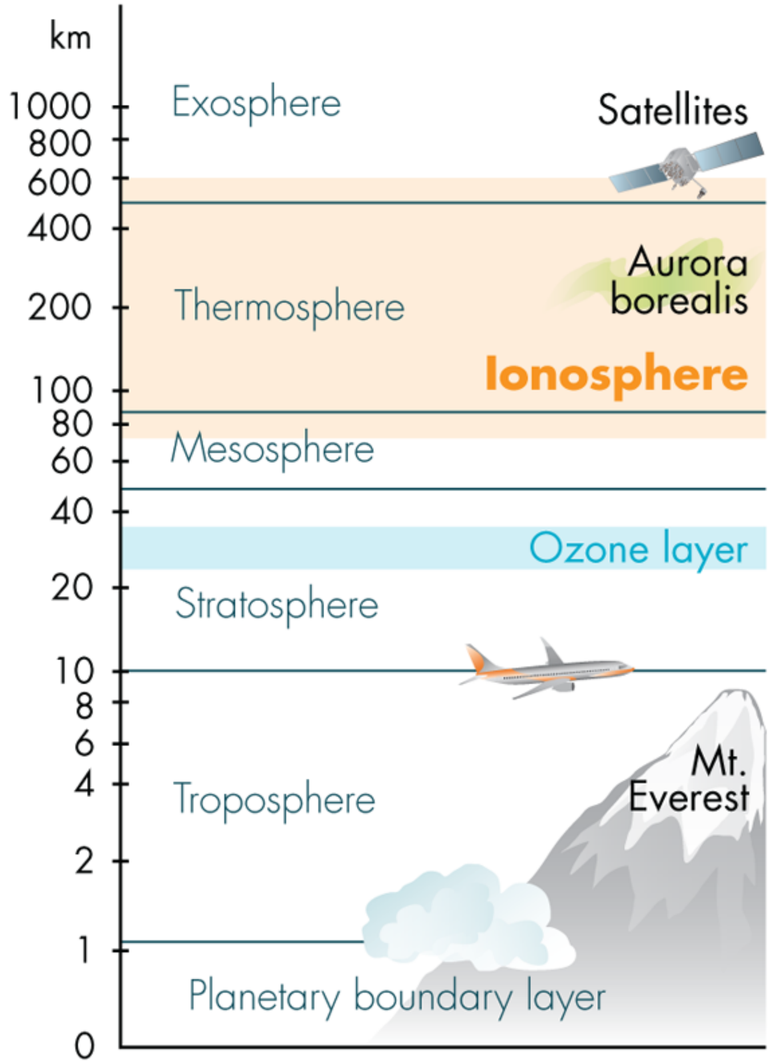
- By using at least 4 satellites, we can solve for:
  - $\mathbf{r}$ receiver (3D) position
  - Δt_r receiver clock error



Trilateration in 3D

GPS | Error Sources (I)

- **Ionospheric delay**
  - Charged ions in the atmosphere affect signal propagation.
- **Multipath effects**
  - Surrounding terrain, buildings can cause unwanted reflections.



GPS | Error Sources (II)

- **Ephemeris & clock errors**
  - A clock error of 1×10^{-6} s gives a 300 m position error!
- **Geometric Dilution of Precision (GDOP)**
  - The configuration of the visible satellites affects position precision.

Minor fixes.

Poor config - high GDOP

Good config - low GDOP

GPS | Improvements

Minor change to accuracy number (lower right of table)

Basic GPS	Differential GPS (DGPS)	Real-Time Kinemat (RTK) GPS
mobile receiver	mobile receiver + fixed base station(s)	mobile receiver + fixed base station
no error correction	estimate error caused by atmospheric effects	estimate relative position using phase of carrier signal
~10 m accuracy	~10 cm accuracy	~2 cm accuracy