Module 3 | Lesson 3

GLOBAL NAVIGATION SATELLITE SYSTEMS

Global Navigation Satellite Systems

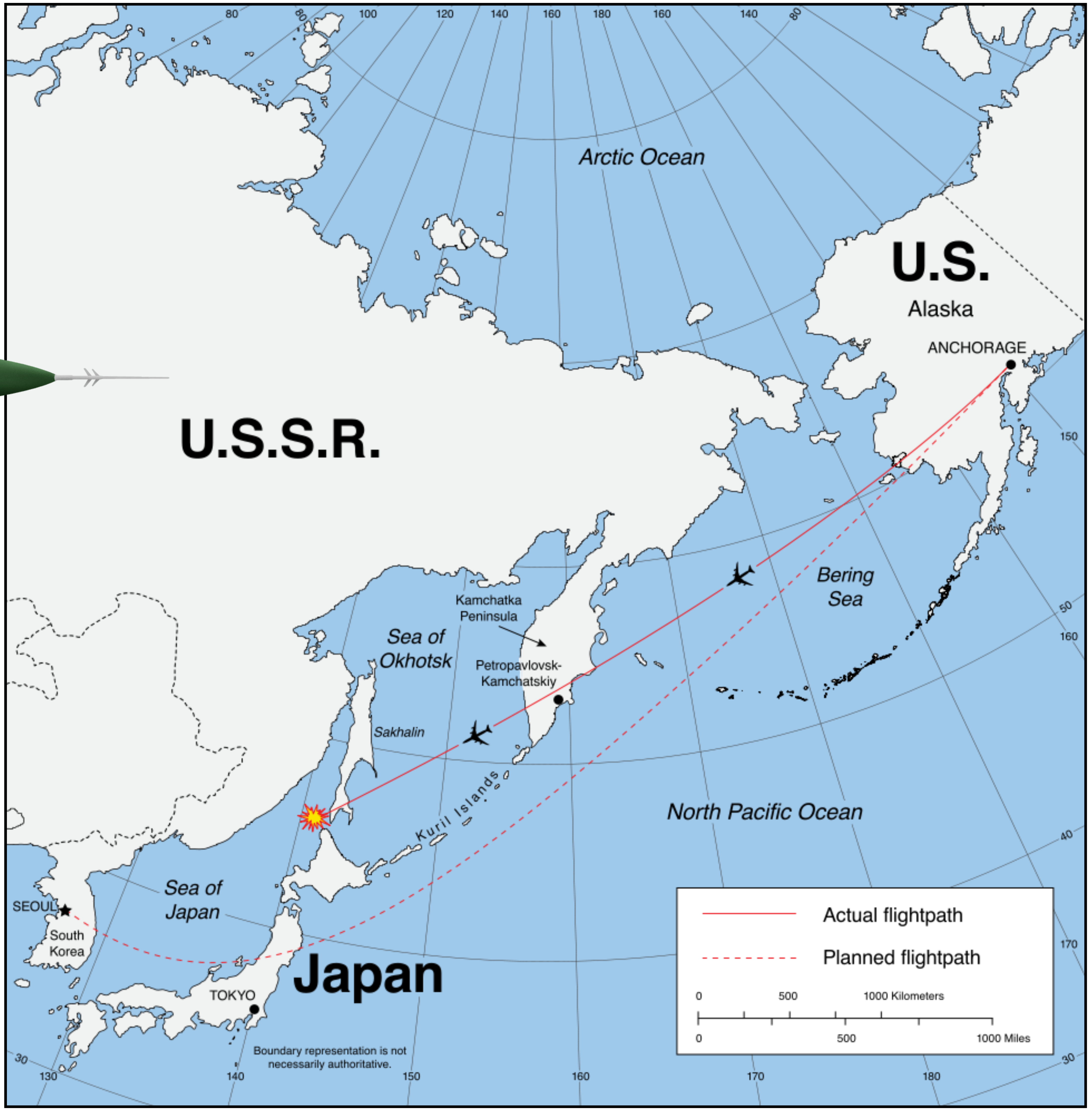
By the end of this video, you will be able to…

- Develop a model of GNSS positioning based on pseudoranging and trilateration.
- Become familiar with the sources of GNSS positioning error.
- Describe two ways to improve GNSS.

Korean Air Lines Flight 007

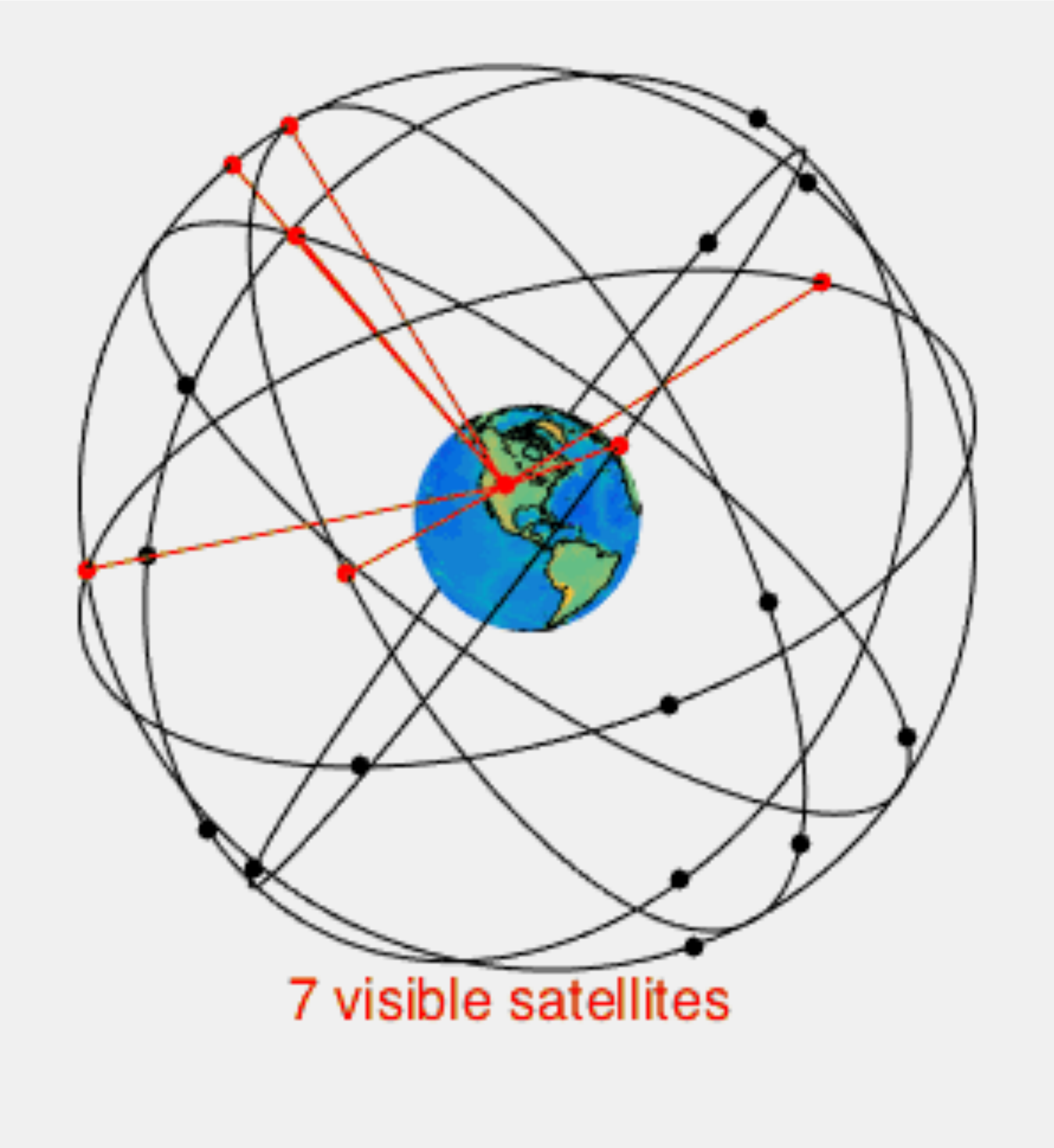
Korean Air Flight 007 was shot down in 1983 after deviating into Soviet airspace due to improper use of their Inertial Navigation System.

This prompted the U.S. to open GPS for worldwide use.

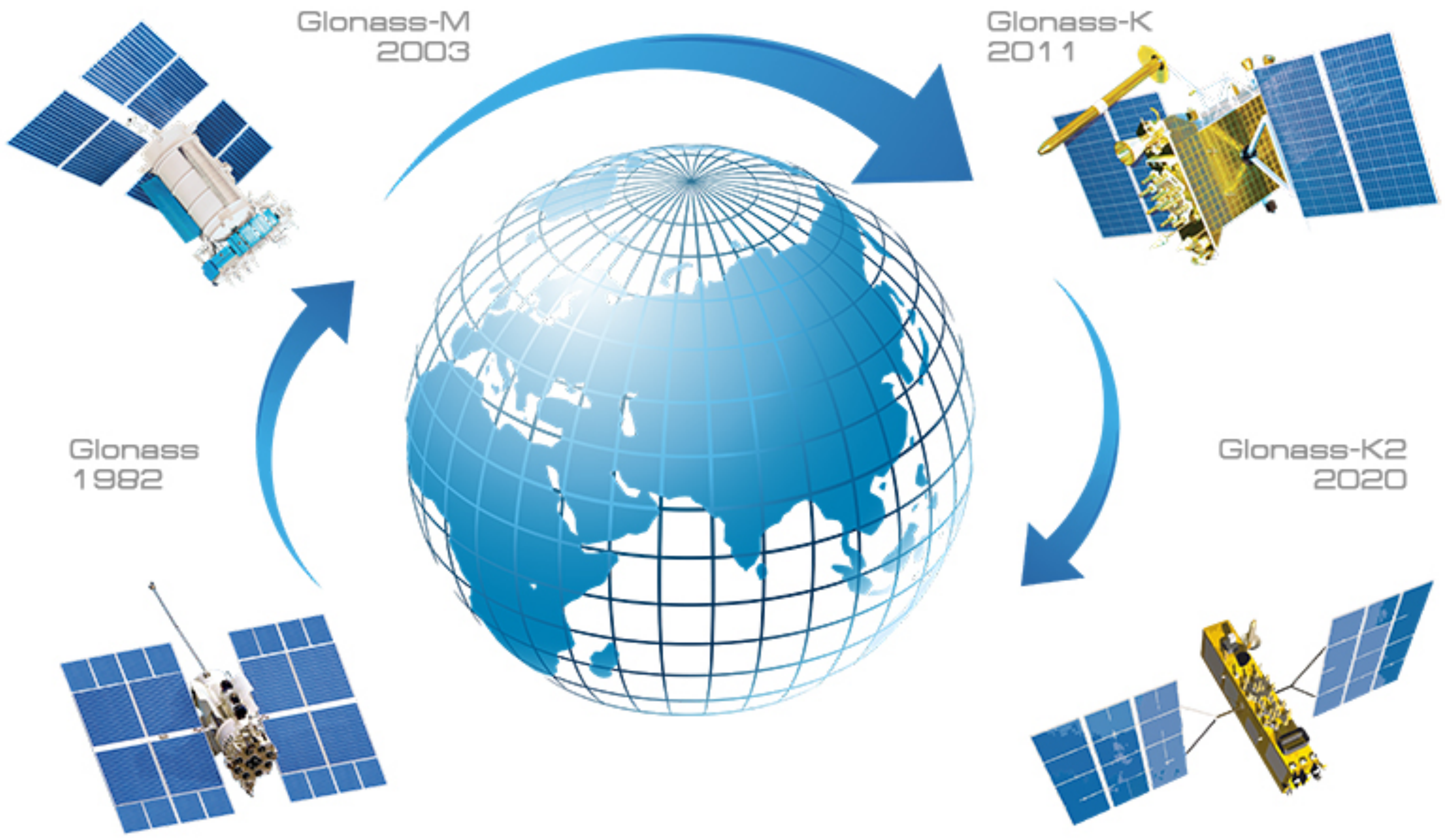


GNSS | Accurate Global Positioning

- **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



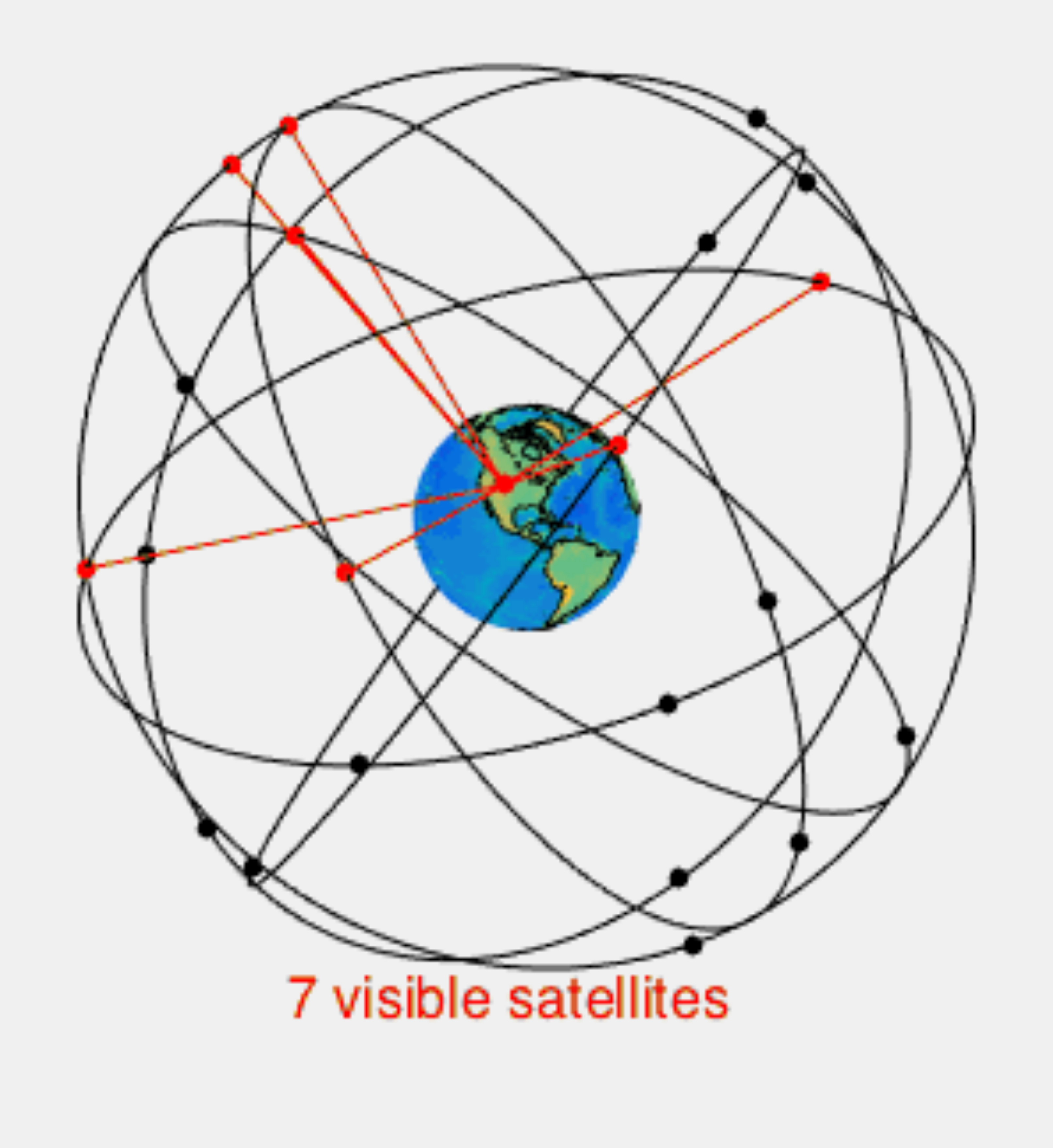
Global Positioning System (GPS)



Globalnaya navigatsionnaya sputnikovaya sistema (GLONASS)

GPS | Global Positioning System

- 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)*



4 satellites are visible at any surface point on earth at all time

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)

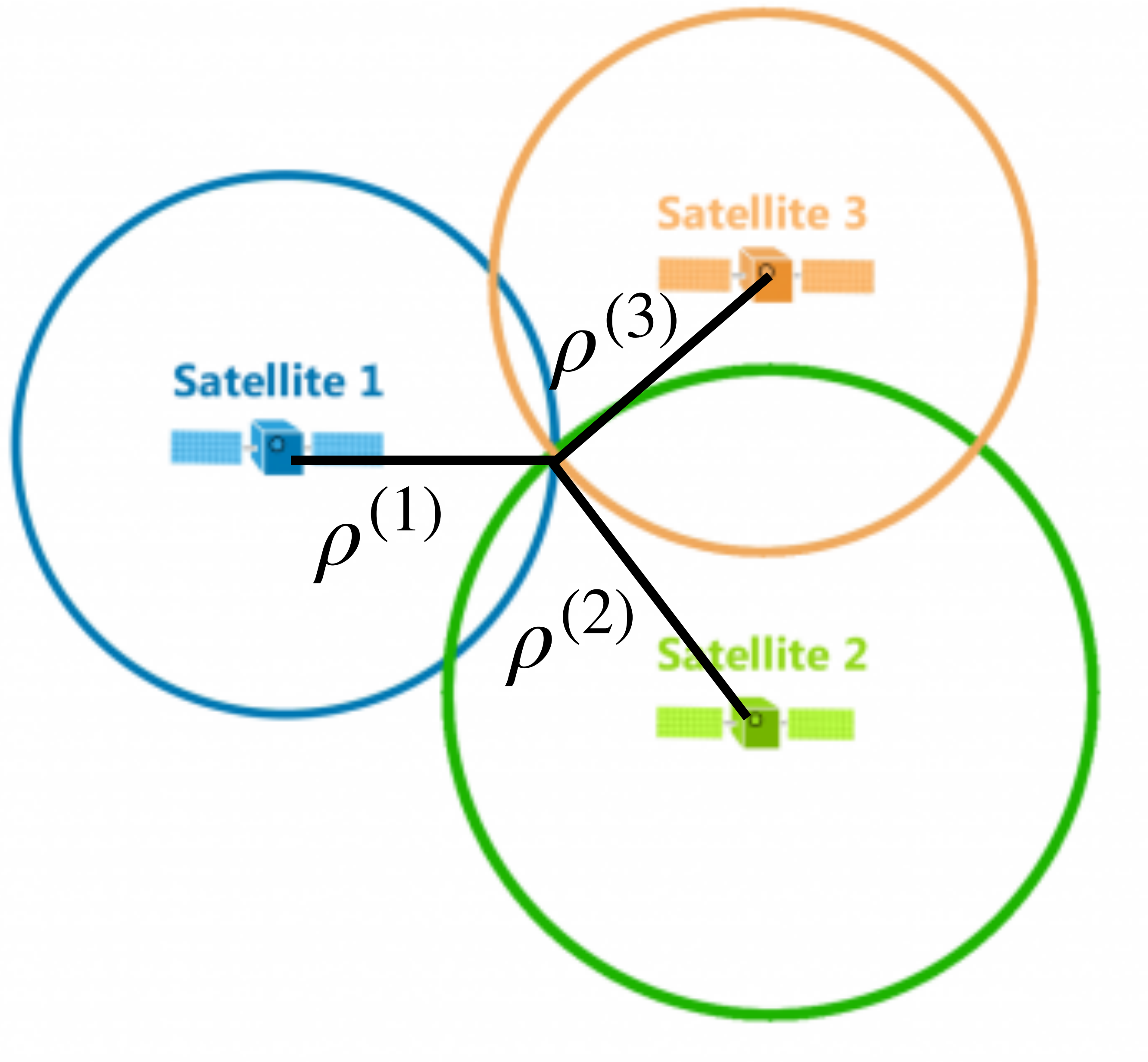
Trilateration

Corrupted by errors & noises

- 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

- By using at least 4 satellites, we can solve for:

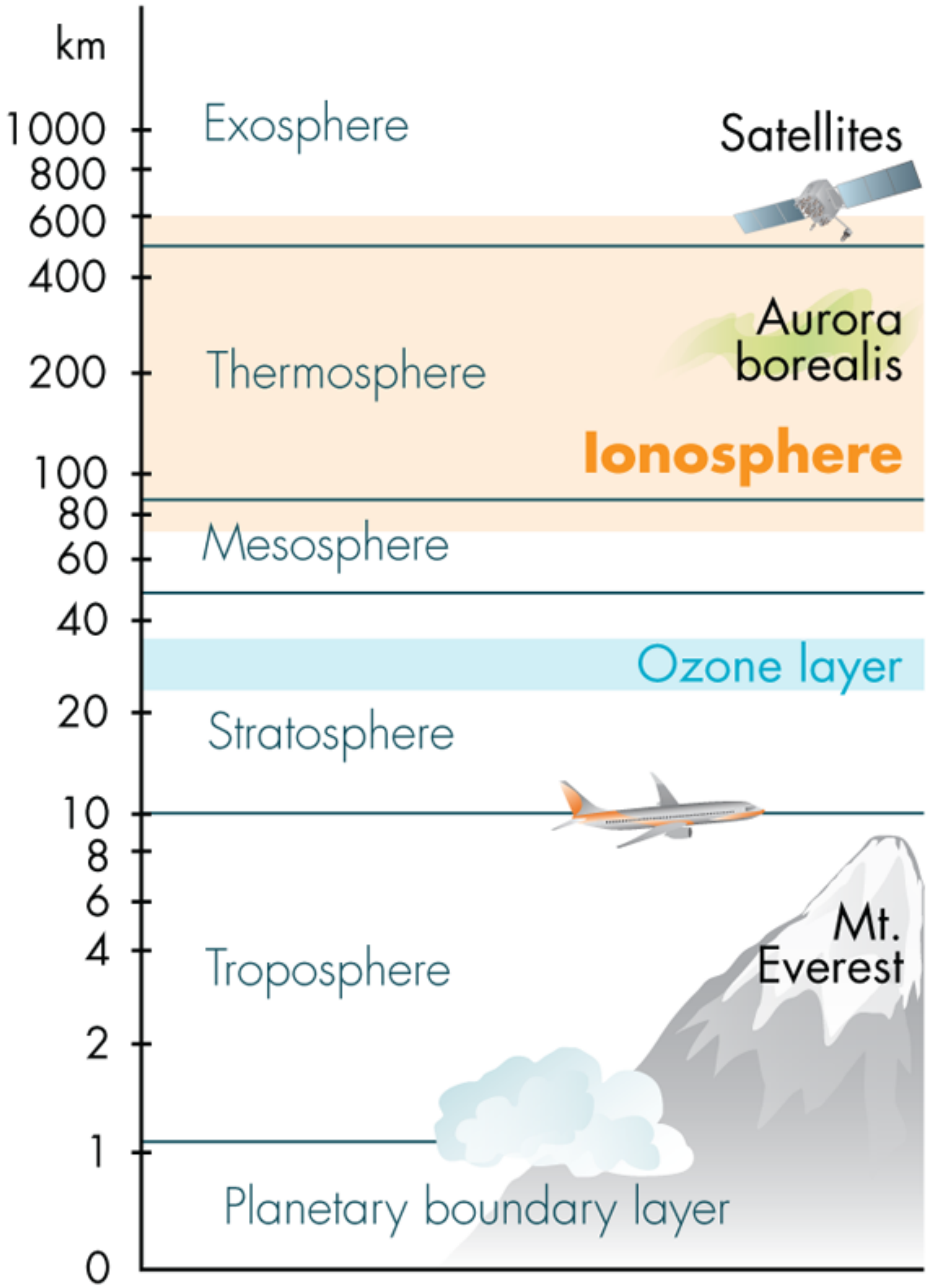
  $\mathbf{r}$ receiver (3D) position

  Δt_r receiver clock error

Multilateration 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.

Poor config - high GDOP

Good config - low GDOP

GPS | Improvements

Costly to implement

Basic GPS	Differential GPS (DGPS)	Real-Time Kinematic (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

Summary | The Global Navigation Satellite System

- A GNSS works through trilateration via pseudoranging from at least 4 satellites (for a 3D position fix).

- GNSS error can be caused by ionospheric delays, multipath effects, and precision is also affected by GDOP.

- For GPS, differential GPS and RTK GPS are potential methods to substantially improve performance.