ERRORS IN GNSS

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GNSS Training

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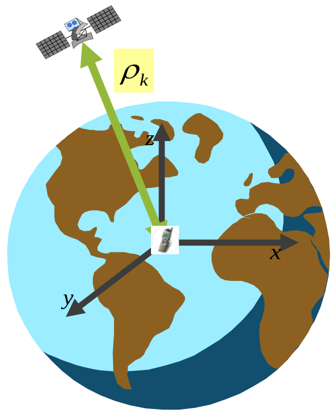
INTRODUCTION

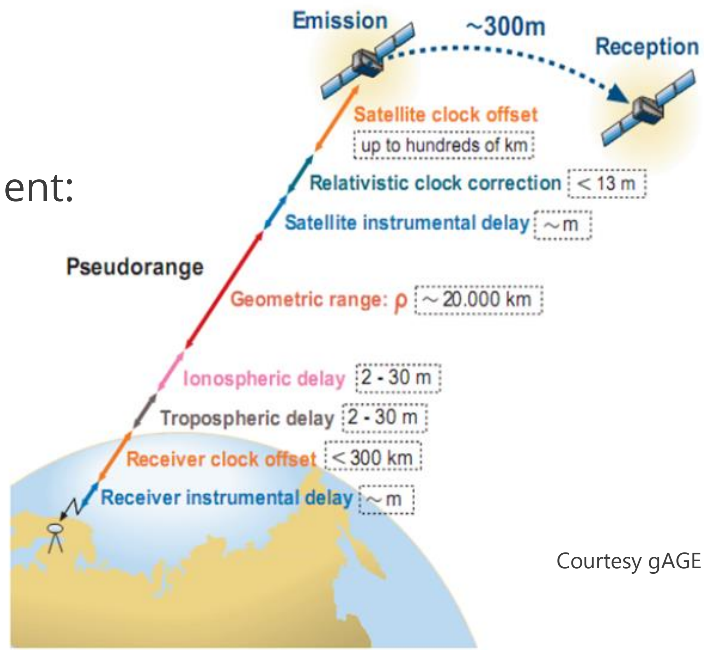


Ideal measured pseudorange

$$\rho_k = \sqrt{(x_{sk}-x_u)^2+(y_{sk}-y_u)^2+(z_{sk}-z_u)^2} - c\cdot\delta t_u$$
$$= r_k - \boxed{c\cdot\delta t_u}$$

Other errors impact on the measurement:

$$\rho_k = r_k + c\cdot(\delta t_k - \delta t_u) + I_{\rho_k} + T_{\rho_k} + \varepsilon_{\rho_k}$$



Courtesy gAGE

ERROR SOURCES

Errors affecting GNSS performance depend on several factors:

- **At system (space-control) level:**
  - Selective availability (off since May 1st, 2000)
  - Number of satellites that can be seen from the receiver and their geometry (DOP)
  - Error in the orbits, ephemerid, clock etc.
- **During the path from satellite to receiver:**
  - Ionosphere effects
  - Troposphere effects
- **At receiver level:**
  - Receiver noise
  - Multipaths, interfering signals, etc.

REMARKS ON ERRORS SOURCES

- Navigation solution and error budgets are valid under the hypothesis of errors:
  - **statistically independent** for different SVs
  - error modeled as **random Gaussian variables** with zero mean

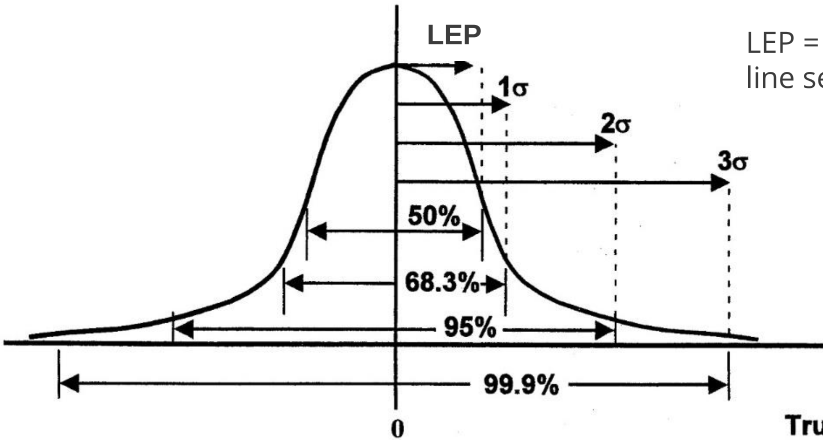
- Under these hypotheses the standard deviation of the total pseudorange error is:

$$\sigma_{UERE} = \sqrt{\sum_j \sigma_j^2} \quad [\mathrm{m}]$$

Segment	Error Source	PPS 1σ [m]	SPS 1σ [m]	SPS (no SA) 1σ [m]
Space	Sat. Clock			
	SV Orbit			
	S.A.			
	Other			
Control	Ephemeris			
	Other			
User	Ionospheric delay			
	Tropospheric delay			
	Receiver Noise			
	Multipath			
	Other			
UERE	**TOTAL (rss)**			

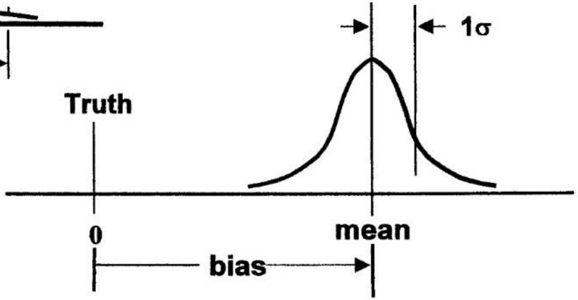
POSITIONING ERRORS

The Gaussian Distribution



Zero mean
Normal Distribution

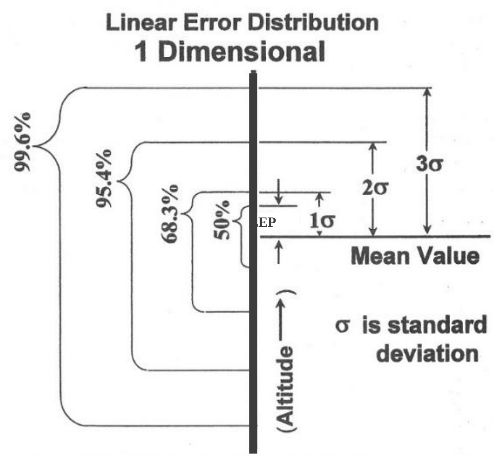
LEP = Linear Error Probable = length of line segment containing 50% of fixes (1D)

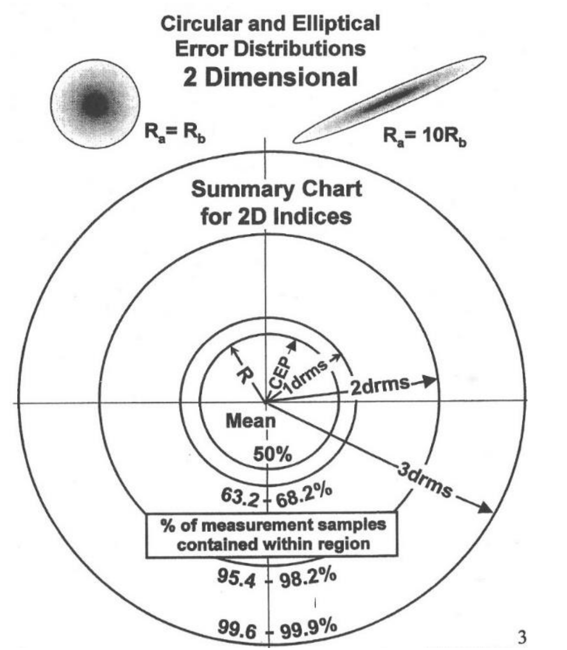


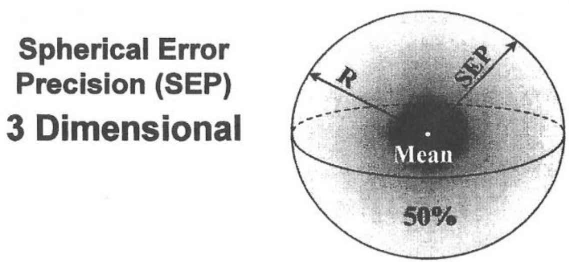
Biased Normal Distribution

POSITIONING ERRORS

Accuracy Indexes





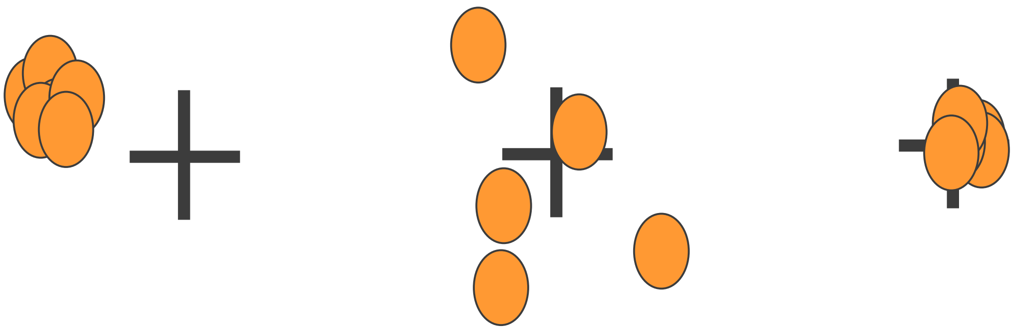


Circular Error Probable (CEP) = 0.75 drms

Distance root mean square error (drms) = $\sqrt{\sigma_x^2 + \sigma_y^2}$

ACCURACY AND PRECISION

- **Accuracy:** measure of how close a point is to its true position
- **Precision:** measure of how closely the estimated points are in relation to each other



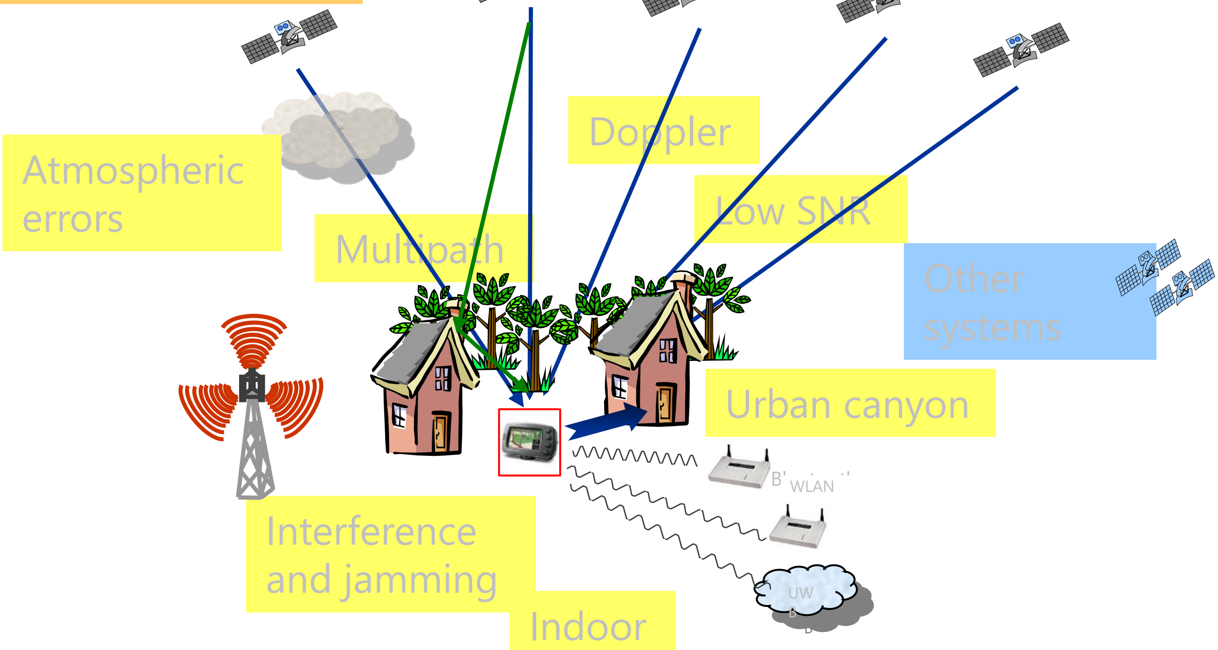
High Precision Low Accuracy

Low Precision Low Accuracy

High Precision High Accuracy

SYSTEM (SPACE-CONTROL SEGMENT) ERRORS

System errors (clocks, ephemerides, codes, ...)



ERROR SOURCES

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  - Ionosphere effects
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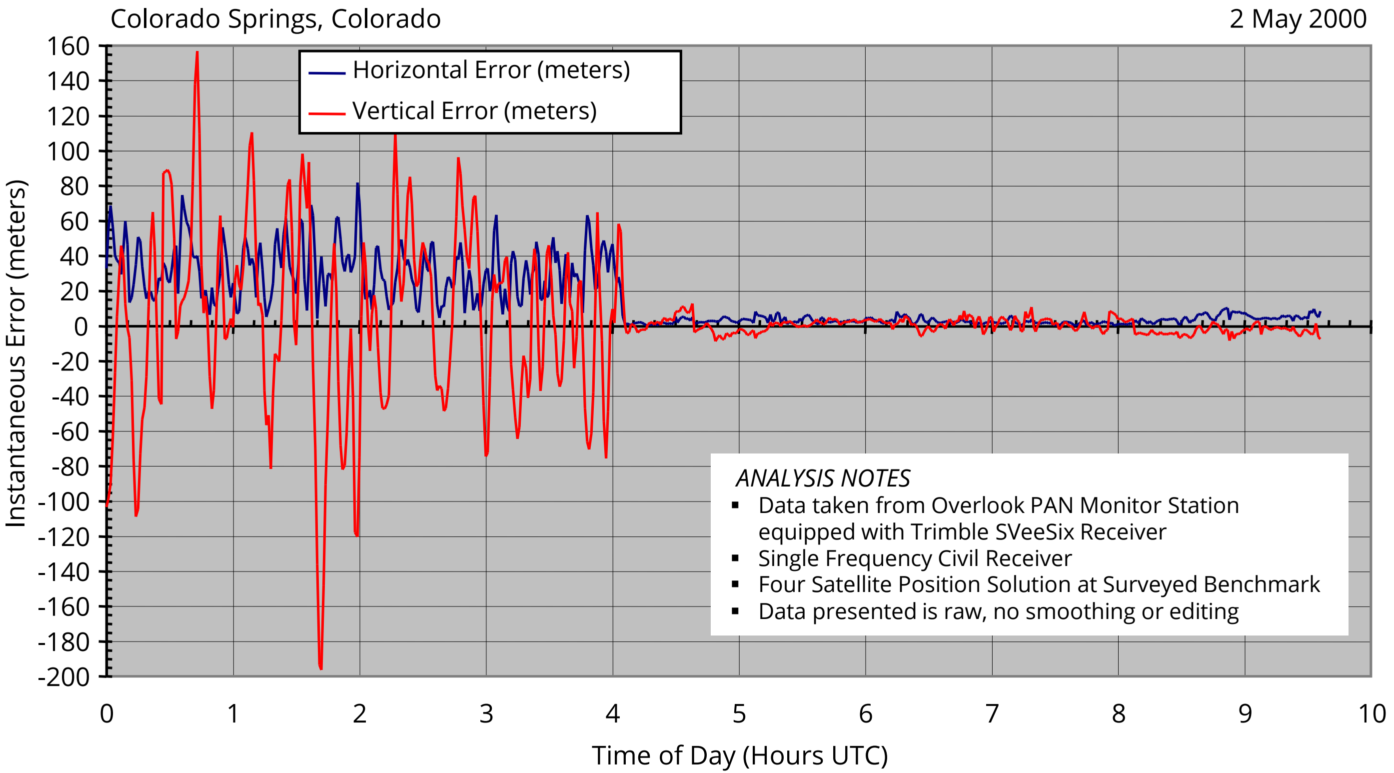
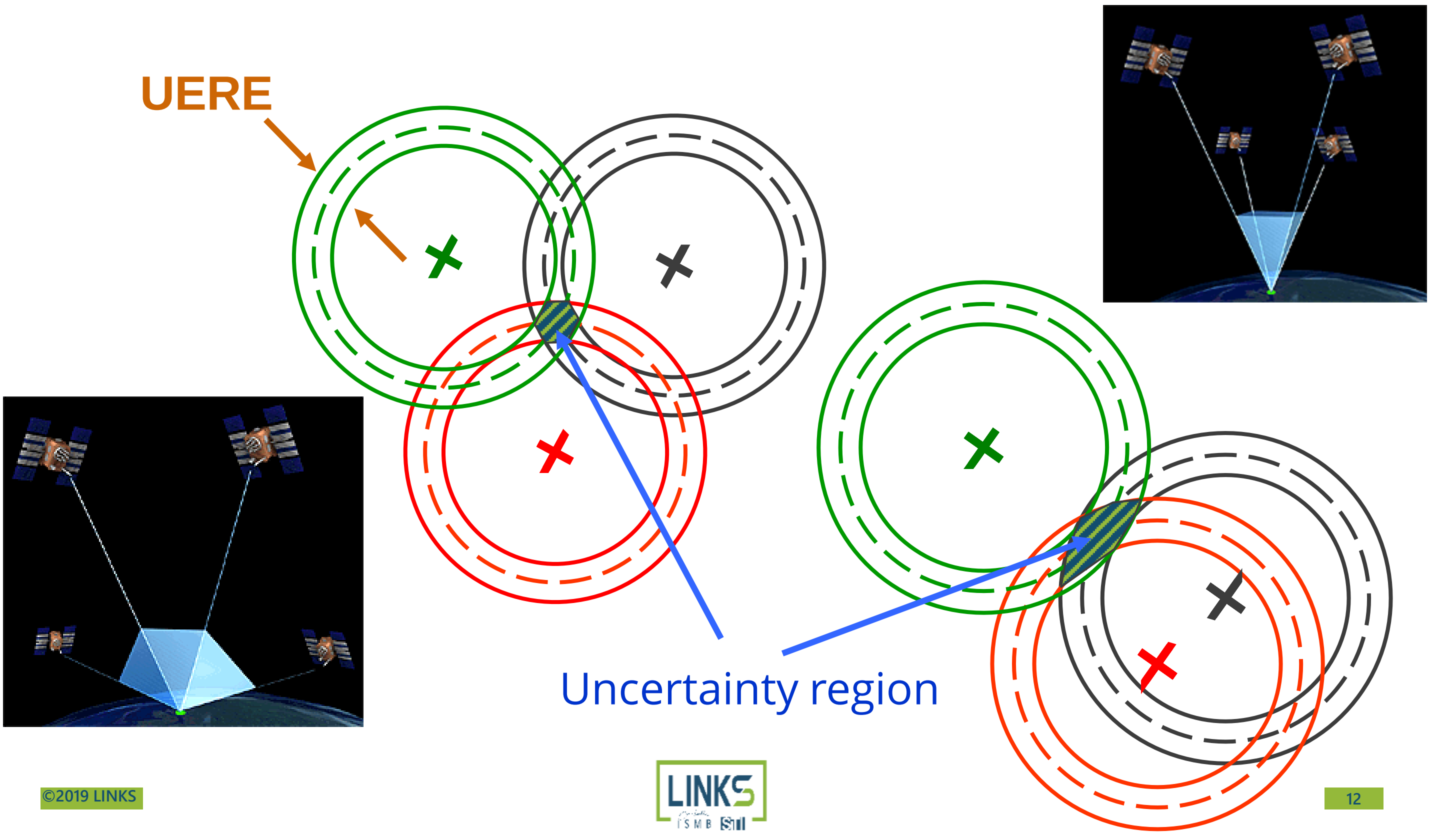
THE EFFECT OF SELECTIVE AVAILABILITY



DILUTION OF PRECISION

The impact of the pseudorange error on the final estimated position depends on the displacement of the satellites



DILUTION OF PRECISION

$$\mathrm{GDOP} = \sqrt{g_{11} + g_{22} + g_{33} + g_{44}}$$

(x, y, z, and time)

Partial factors can be defined

Position Dilution of Precision (x, y, z)

$$\mathrm{PDOP} = \sqrt{g_{11} + g_{22} + g_{33}}$$

Time Dilution of Precision (time only)

$$\mathrm{TDOP} = \sqrt{g_{44}}$$

Vertical Dilution of Precision (z only)

$$\mathrm{VDOP} = \sqrt{g_{33}}$$

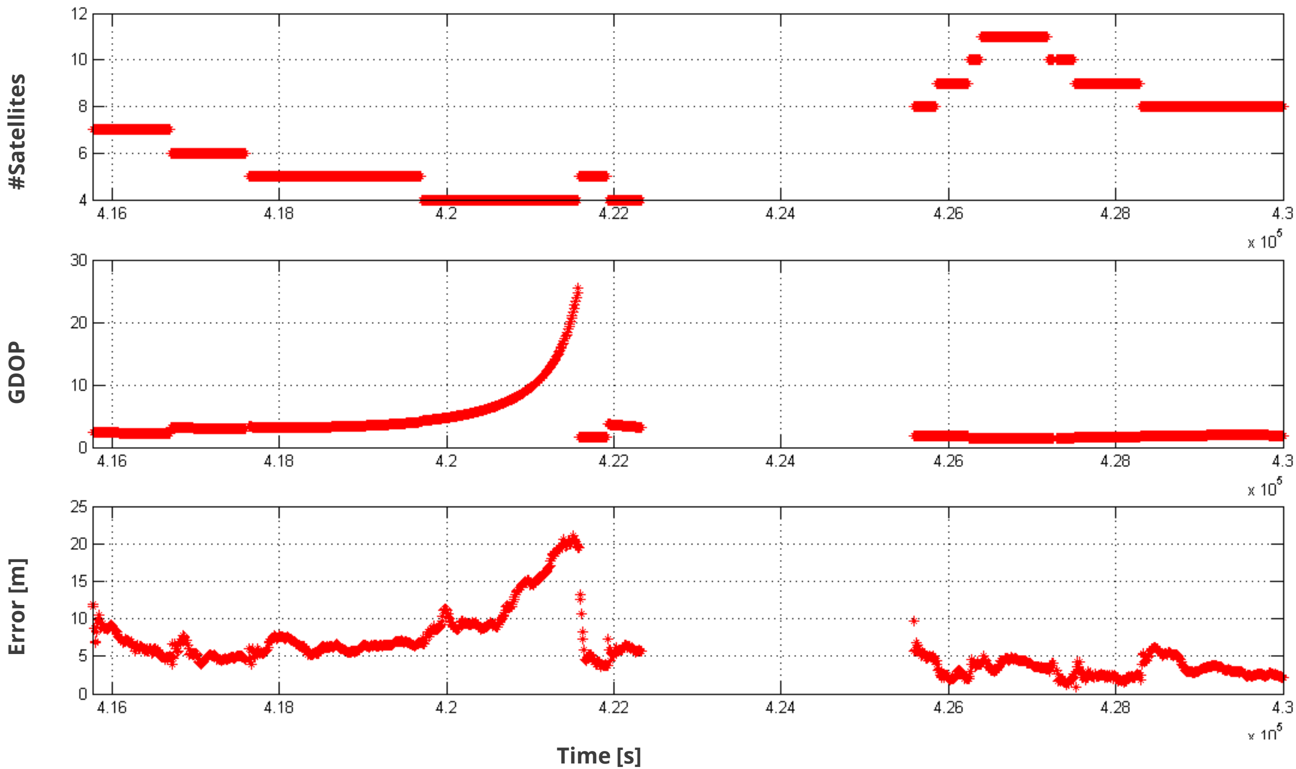
Horizontal Dilution of Precision (x and y)

$$\mathrm{HDOP} = \sqrt{g_{11} + g_{22}}$$

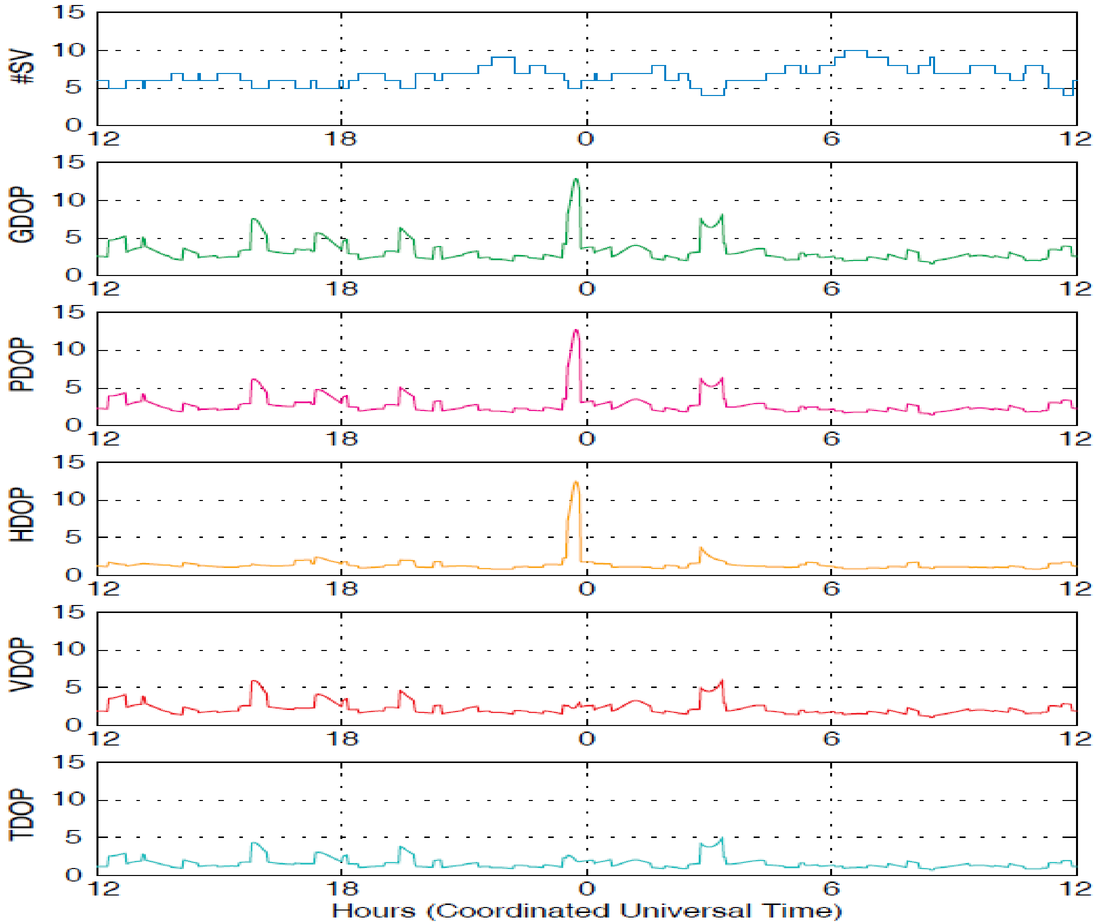
DOP TYPICAL VALUES

DOP Value	Rating	Description
<1	**Ideal**	This is the highest possible confidence level to be used for applications demanding the highest possible precision at all times.
1-2	**Excellent**	At this confidence level, positional measurements are considered accurate enough to meet all but the most sensitive applications.
2-5	**Good**	Represents a level that marks the minimum appropriate for making business decisions. Positional measurements could be used to make reliable in-route navigation suggestions to the user.
5-10	**Moderate**	Positional measurements could be used for calculations, but the fix quality could still be improved. A more open view of the sky is recommended.
10-20	**Fair**	Represents a low confidence level. Positional measurements should be discarded or used only to indicate a very rough estimate of the current location.
>20	**Poor**	At this level, measurements are inaccurate by as much as 300 meters with a 6 meter accurate device (50 DOP × 6 meters) and should be discarded.

REAL GDOP BEHAVIOUR



OTHER EXAMPLES



EPHEMERIS AND CLOCK ERRORS

- **Ephemeris data**
  Transmitted every 30 seconds, but the information may be up to two hours old

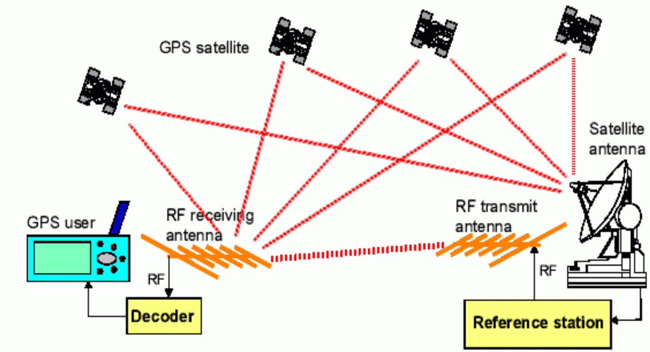
- **Atomic clocks**
  Noise and clock drift errors

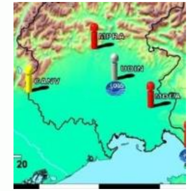
The navigation message contains corrections for ephemeris and clock errors and estimates of the accuracy of the atomic clock. They are based on observations and may not indicate the clock's current state.

These problems tend to be very small, but may add up to a few meters of inaccuracy

REMEDY FOR EPHEMERIS AND CLOCK ERRORS

For very precise positioning (e.g., in geodesy), these effects can be eliminated by Differential GPS.





Precise Point Positioning (PPP) is an enhanced single point positioning technique using precise orbits and clocks instead of broadcast data.
(Applications: precision farming, hydrography, deformation monitoring)

These data are freely provided by, e.g., the IGS (International GNSS Service). A detailed list of products provided by IGS can be found on http://igscb.jpl.nasa.gov/.

RELATIVISTIC EFFECTS

- The satellite clock drift is affected by the relativistic effect. In GPS the satellite clock frequency is adjusted so that the frequency observed by the user at sea level has the nominal value.

- The user has to take into account a relativistic periodic effect due to the eccentricity of the satellite orbit.
  - half of the error is due to the periodic change in the speed of the satellite relative to the ECI (Earth Centered Inertial) frame
  - the other half is caused by the satellite's periodic change in its **gravitational potential**

- Another relativistic effect is due to the rotation of the Earth during the signal transmission (Sagnac Effect). During the propagation time, a clock on the Earth's surface will experience a rotation with respect to the reference frame

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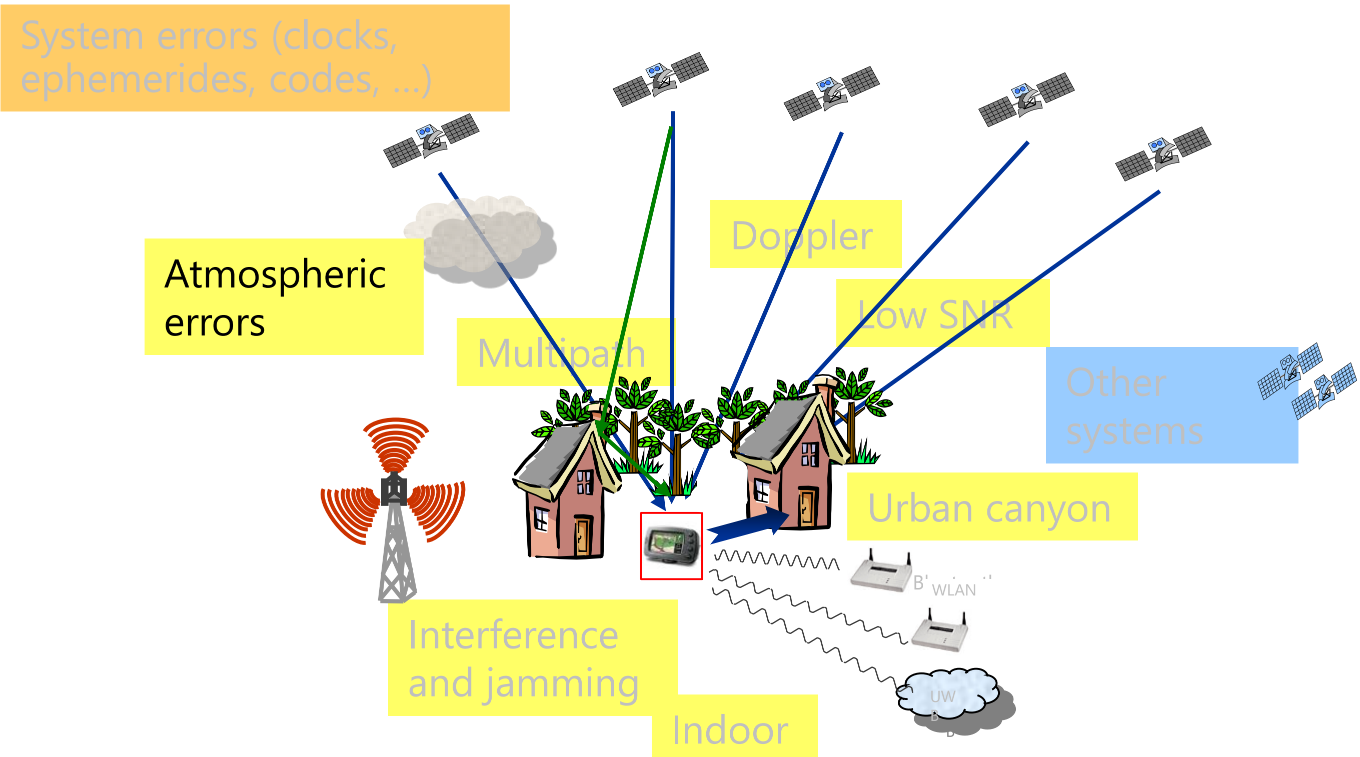
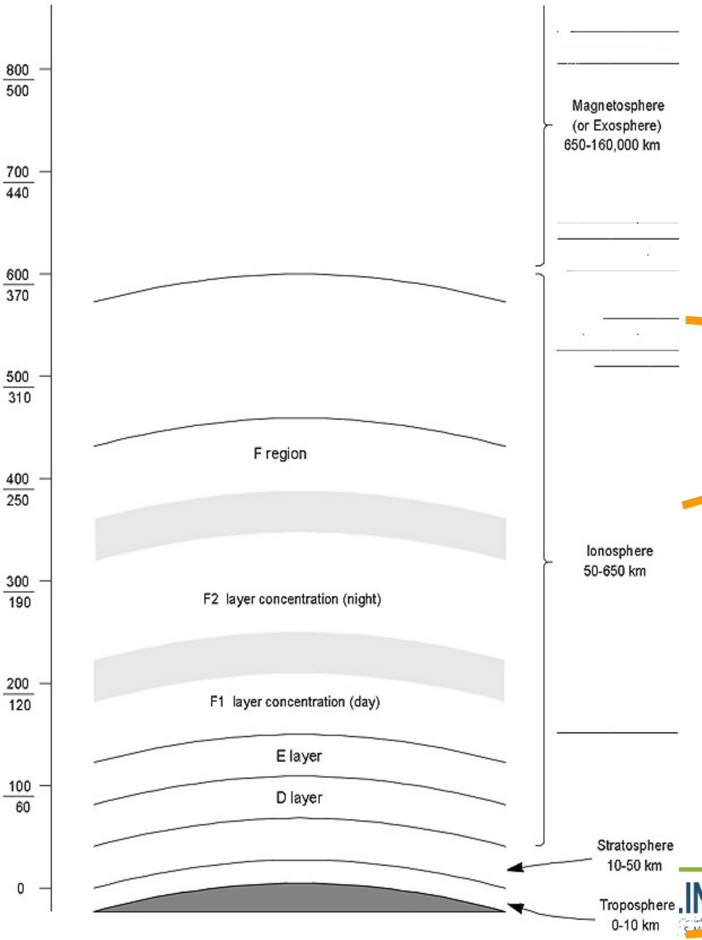
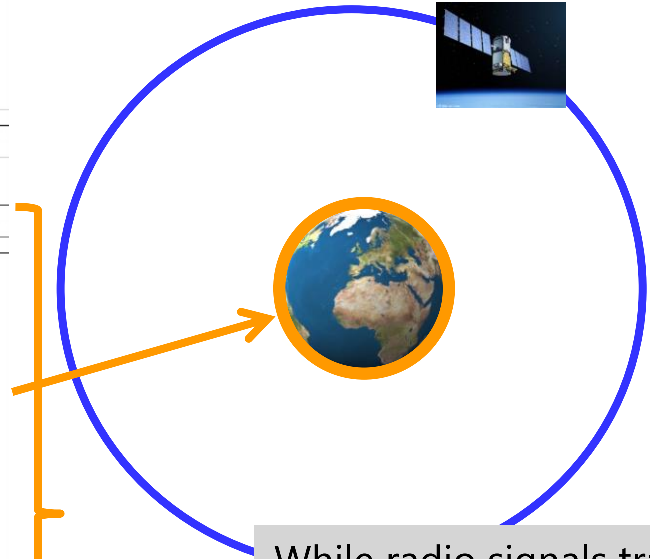
ATMOSPHERIC ERRORS



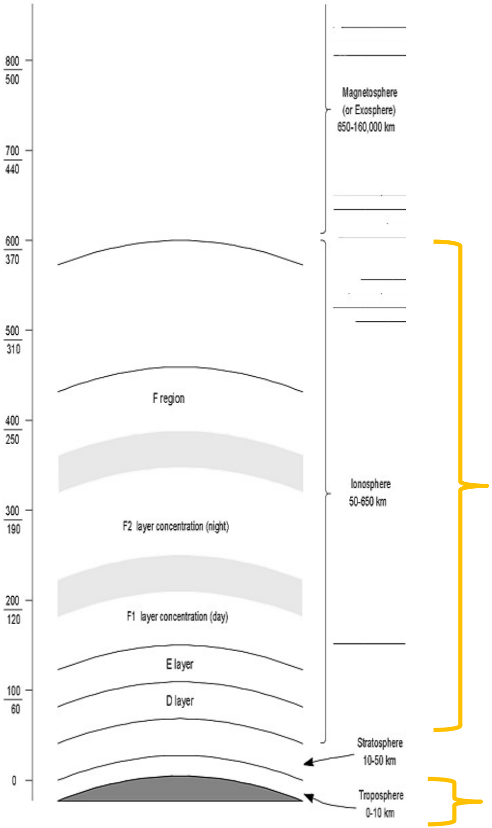
IONOSPHERE AND TROPOSPHERE





While radio signals travel with the velocity of light in the outer space, their propagation in the ionosphere and troposphere is **slower**.

IONO-TROPO ERROR COMPENSATION



- <u>Single frequency RX</u>:
  Ionospheric errors are corrected by calculations (information in the **navigation message**).
- <u>Dual frequency RX</u>:
  Different frequencies are influenced in different ways by the ionosphere.
  By using two frequencies (e.g, L1 and L2) it is possible to eliminate this inaccuracy by calculation.

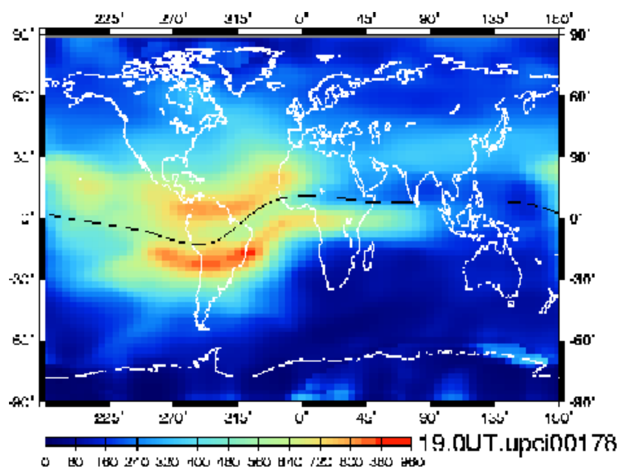
The error caused by the tropospheric effect is smaller than the ionospheric error, but cannot be eliminated by calculation. It can only be approximated by a general calculation model.

IONOSPHERE

- Ionosphere is a region of ionized gases (free electrons and ions)
- Ionization is caused by the sun's radiation (day/generation – night/recombination)
- The propagation speed of a radio signal depends on the number of free electrons in its path (electron density)
- Ionosphere is a **dispersive** medium (refractive index depends on the signal frequency)

Courtesy gAGE (UPC)

Total electron content (TEC) is defined as the *number of electrons in a tube of 1m² cross section from receiver to satellite*



Example of Vertical TEC Map

IONOSPHERIC ERROR

- Ionosphere induces a delay on pseudorange measurement

$$I_\rho = \frac{40.3 \cdot TEC}{f^2}$$

- The delay in phase measurement has same magnitude but opposite sign
- **In dual frequency** receivers, it can be estimated and compensated for:

$$\rho^* = \frac{f_1^2}{f_1^2 - f_2^2}\rho_1 - \frac{f_2^2}{f_1^2 - f_2^2}\rho_2$$

- In **single frequency** receivers, models are used to partially compensate the error induced by the ionosphere:
  - Klobuchar model in GPS
  - NeQuickG model in Galileo

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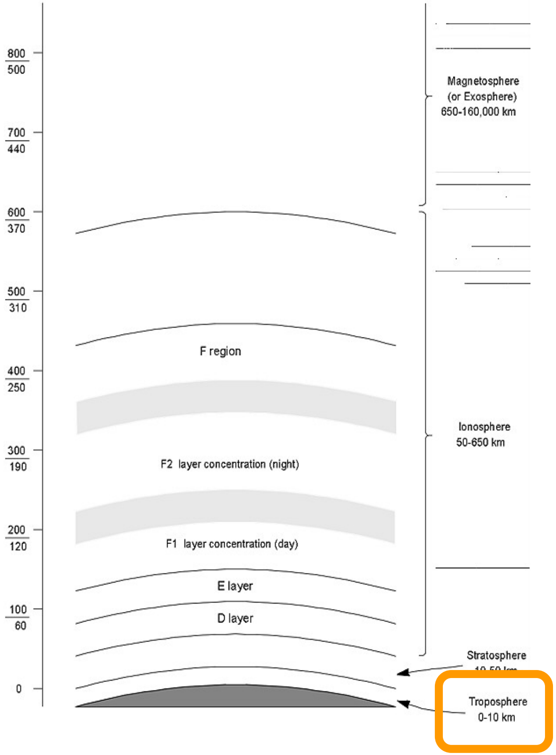
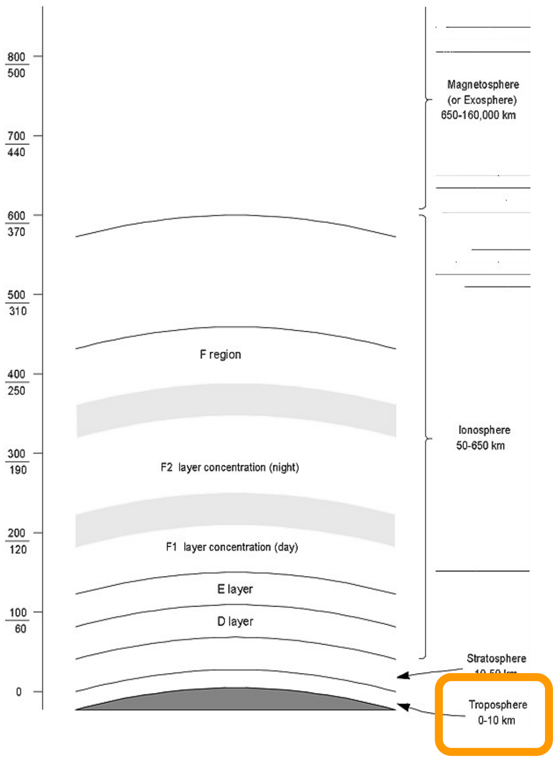
TROPOSPHERE



- It is extended up to 60 km from the Earth surface
- Troposphere is a **non dispersive** medium for frequencies up to 15 GHz
- Refractivity: $N=(n-1)\times10^{-6}$ where n is the refractive index – it is related to the delay of signals – n depends on temperature, pressure, humidity
- It can be split in **dry** and **wet** refractivity (dry gases and water vapour)

TROPOSPHERE



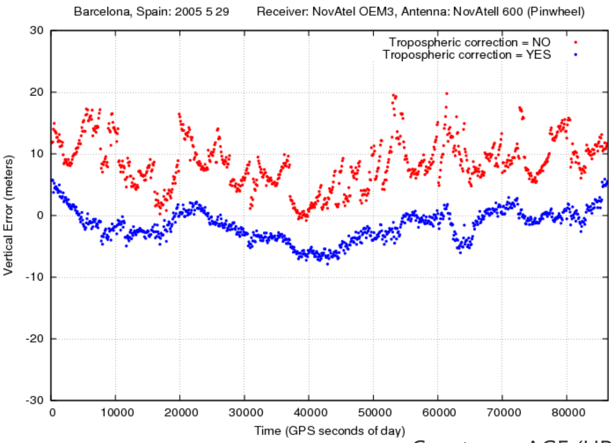
- **Dry (hydrostatic) delay**:
  - Varies with local temperature and pressure
  - Predictable and slow variation
  - Error of about <u>2.3 m</u> for satellites at zenit and <u>10 m</u> at lower elevation
  - Can be <u>modeled</u> from surface temperature and pressure
- **Wet delay**:
  - Depends on weather conditions (clouds, water vapour)
  - Varies faster and randomly (difficult to model)
  - Error of about <u>tens of cm</u>

TROPOSPHERE MODELS

- In general, troposphere delay depends on signal path and can be modeled as a function of satellite elevation

- Several models available in literature
  - <u>Geodetic-oriented models</u> more accurate, more complex, need surface data
  - <u>Navigation oriented models</u> less accurate but do not need meteorological data

- Sastamoinen model
- Hopfield model
- TropGrid model (ESA)



Courtesy gAGE (UPC)

REMARKS ON ERRORS SOURCES

Segment	Error Source	PPS 1s [m]	SPS 1s [m]	SPS (no SA) 1s [m]
Space	Sat. Clock	3.0	3.0	3.0
	SV Orbit	1.0	1.0	1.0
	S.A.	-	32.3	-
	Other	0.5	0.5	0.5
Control	Ephemeris prediction	4.2	4.2	4.2
	Other	0.9	0.9	0.9
User	Ionospheric delay	2.3	5.0	5.0
	Tropospheric delay	2.0	1.5	1.5
	Receiver Noise	1.5	1.5	1.5
	Multipath	1.2	2.5	2.5
	Other	0.5	0.5	0.5
UERE	**TOTAL (rss)**	**6.6**	**33.3**	**8.0**

CONTACT

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