Characterization of ionospheric effects on GNSS systems

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OUTLINE

- **The Ionosphere**
- The GNSS
- The ionospheric effects on GNSS signals
- Methods to reduce the ionospheric impact on GNSS
- Future goals

The Ionosphere

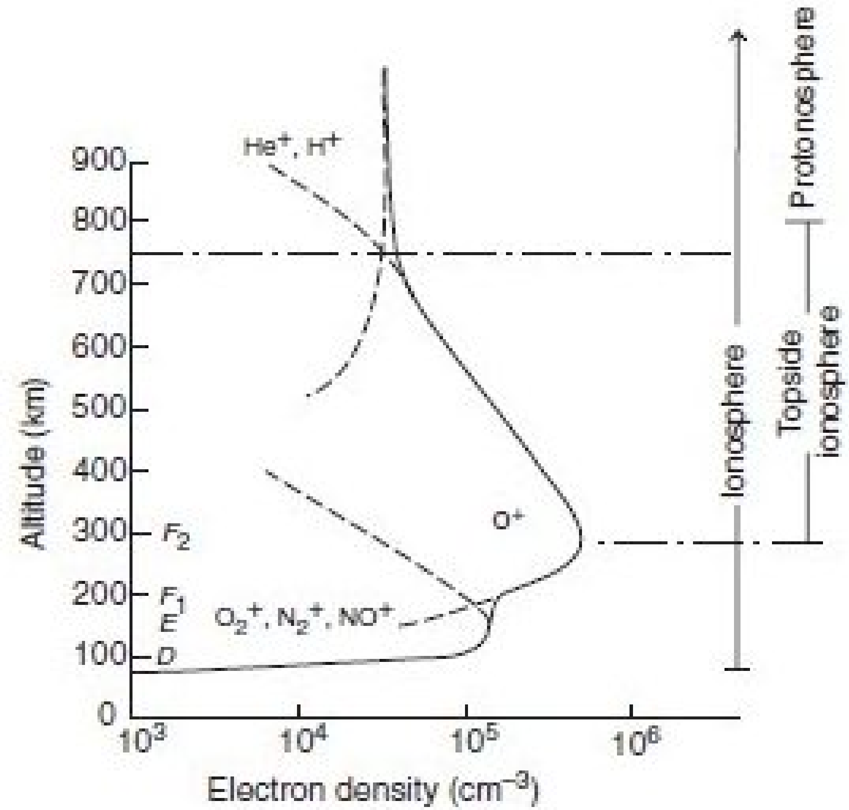
- Is the upper part of the Earth's atmosphere that is ionized by solar radiati
- Extends from about 60 to 1000 km and completely encircles the Earth.

The ionosphere has been divided into three main layers (regions): the D, E, and F regions:

- (the lowest) D-region: 50-90 km, relatively weak ionization due to its position at the bottom,

- E-region: 90-150 km, contains mostly O_2 + and NO + ions, with metallic long lived ions to a minor extent,

- F-region: 150-1000 km contains a range of ions from NO+ and O+ at the bottom to H+ and He+ ions at the top. Electron density reaches an absolute maximum in this region (F2 layer).

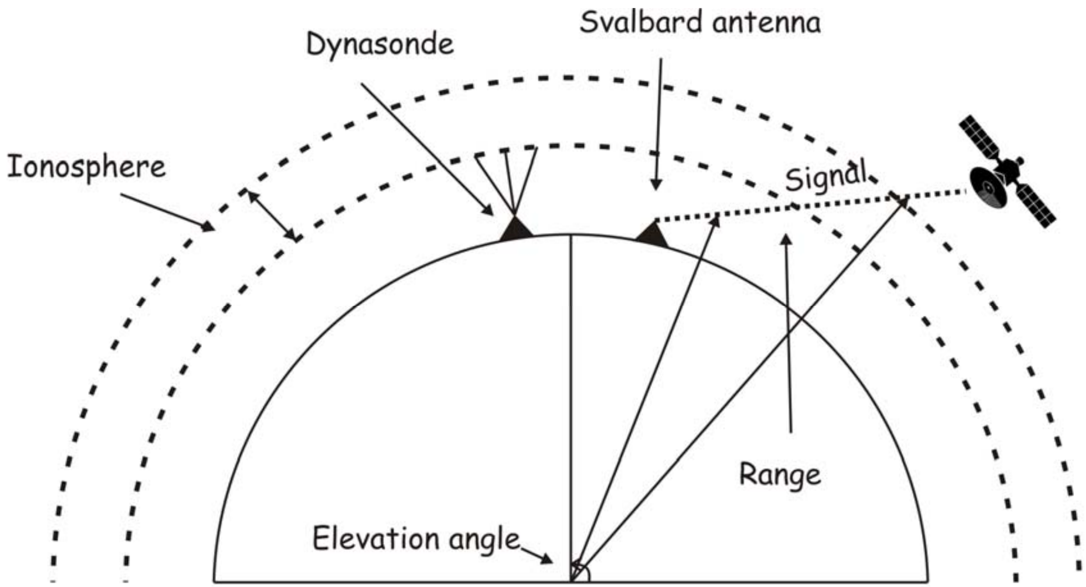


Banks, P. M., R. W. Schunk, and W. J. Raitt, The topside ionosphere: the region of dynamic transition, *Annl. Rev. Earth Planet. Sci.*, 4, 381, 1976.

The Ionosphere

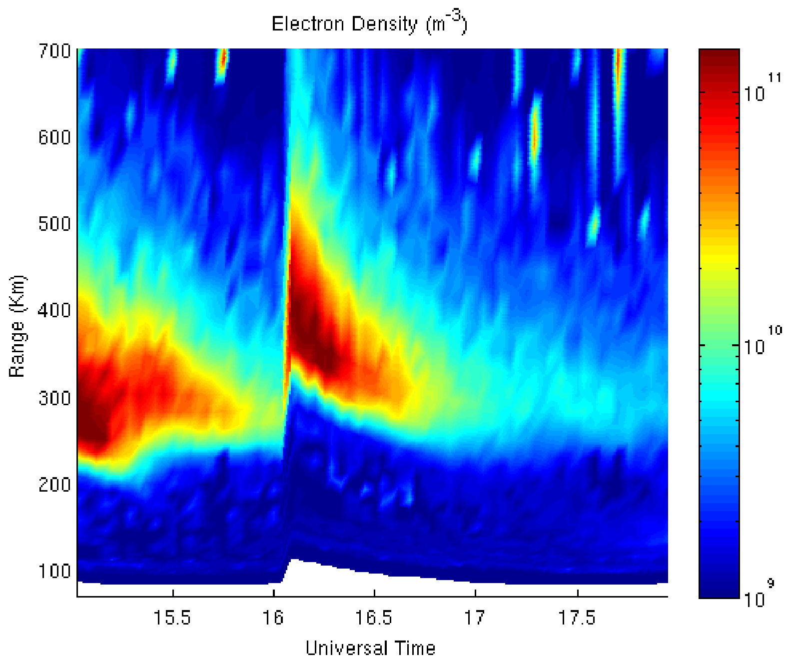
- The EISCAT measurements were done to observe parameters:
  - Ne
  - Ti
  - Te/Ti
  - Vi

Fixed 42 m and steerable 32 m UHF parabolic antennas, Svalbard



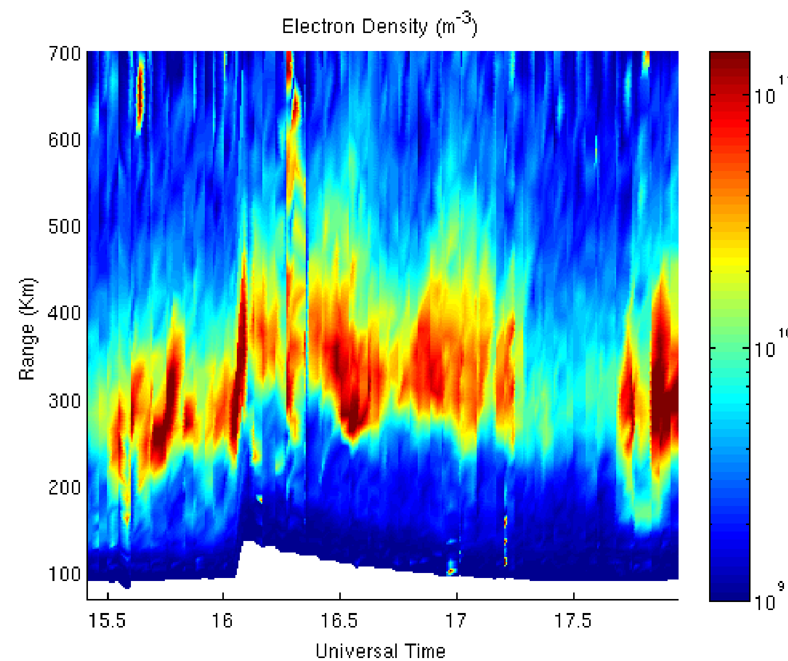
Experimental setup

The Ionosphere



Electron density, Tromsø, 13.12.11.

Electron density, Svalbard, 13.12.11



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- **The GNSS**
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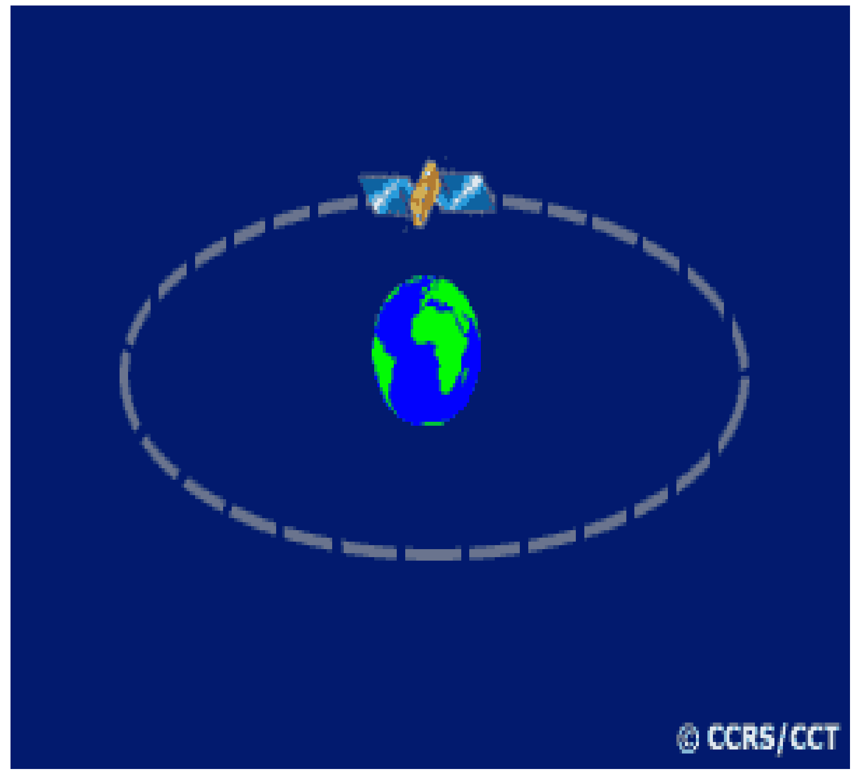
- Future goals

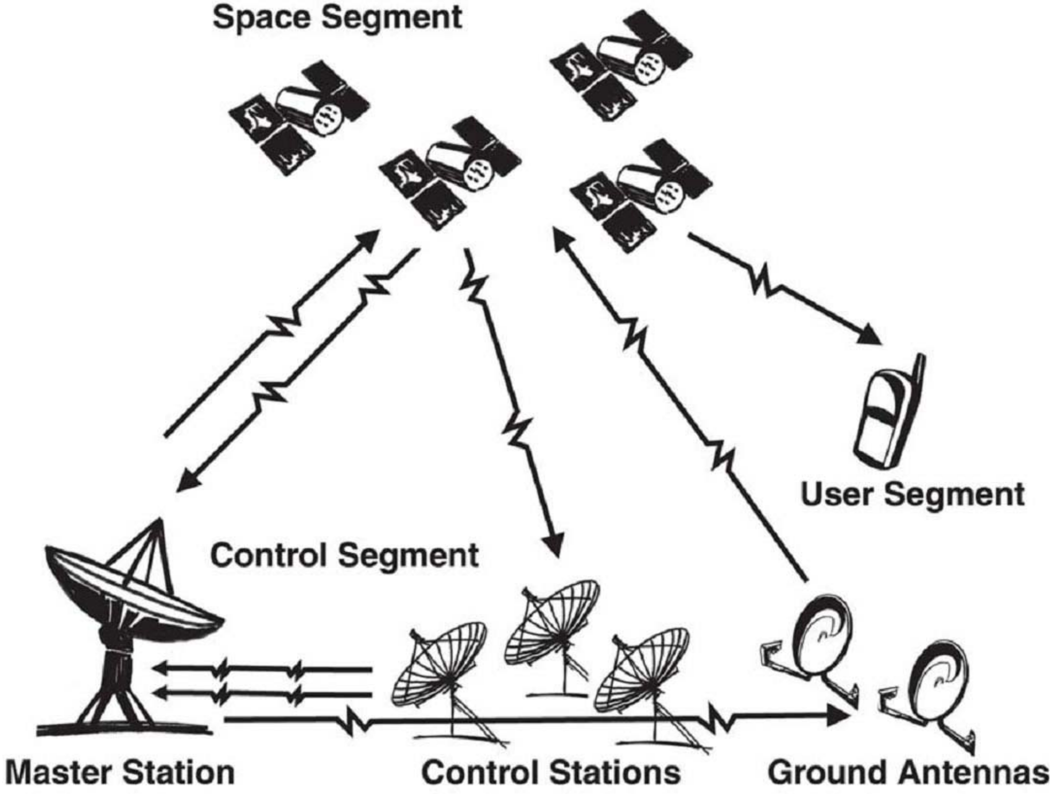
The GNSS

- GNSS - Global Navigation Satellite System:
  - → GPS
  - → GLONASS
  - → Galileo
  - → COMPASS



The GNSS

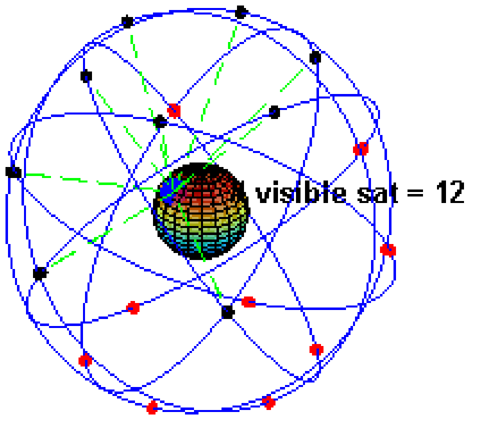
- GPS - Global Positioning System
- The GPS system consists of three segments:
    - Space segment
    - Control segment
    - User segment

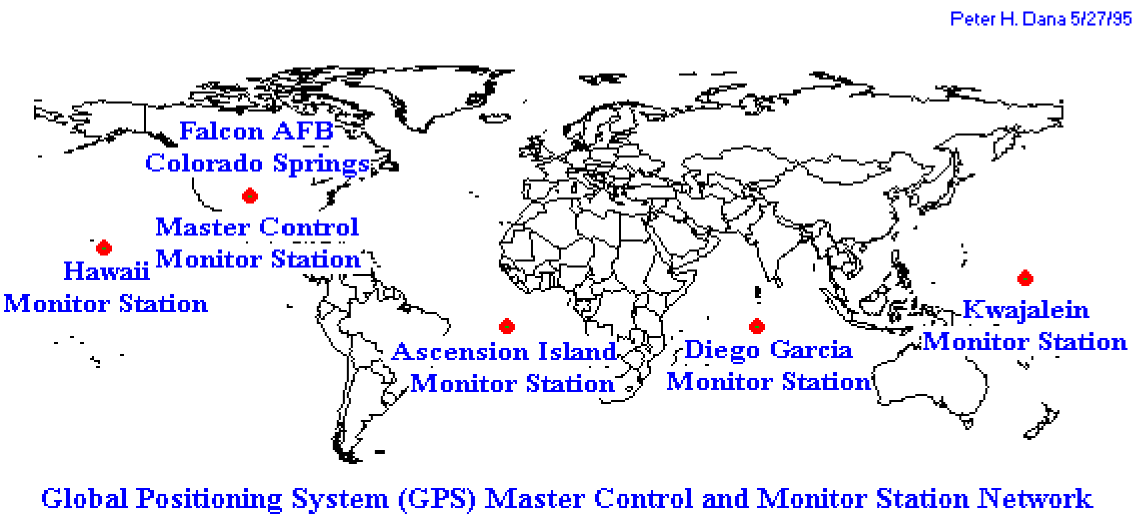


The GNSS

- About 30 satellites
- Altitude of about 20200 km
- Distributed among 6 orbital planes

- One master control station
- Five monitor stations
- Ground antennas



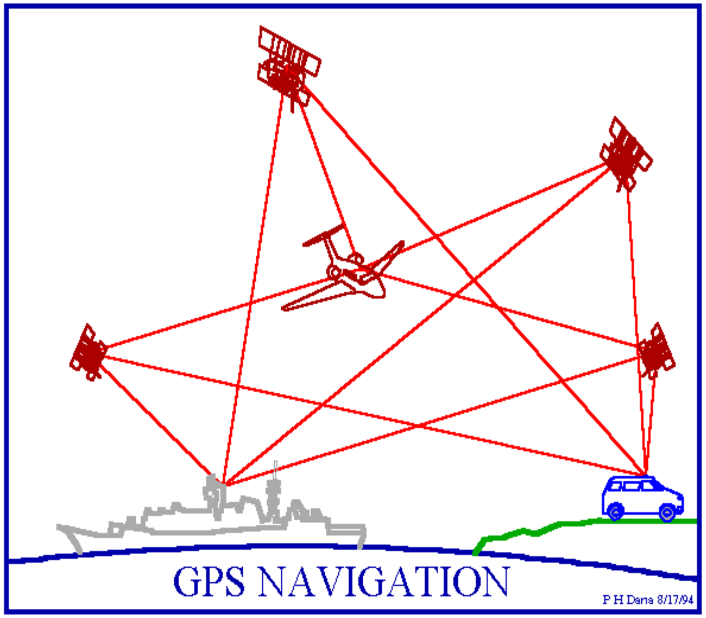


- Applications:
  - navigation
  - aviation
  - geodesy
  - survey

The GNSS

How does it work?

- Four satellites are required.
- GPS satellites transmit signals to GPS receivers on the ground.
- The exact location and current time is transmitted from each GPS satellite.
- GPS receivers convert satellite's signals into position, velocity, and time estimates.



The GNSS

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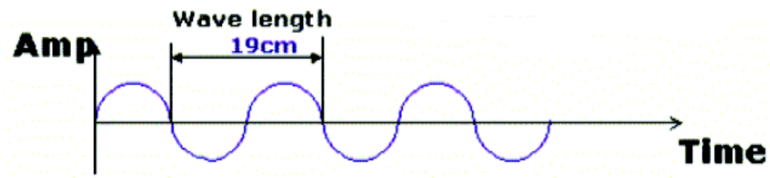
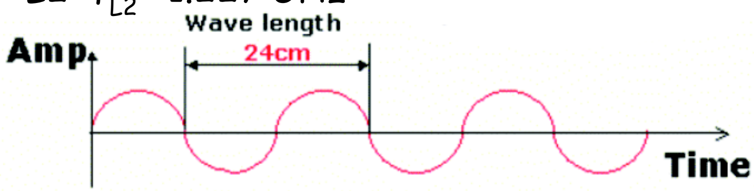
L1: f_{L1}= 1.575 GHz

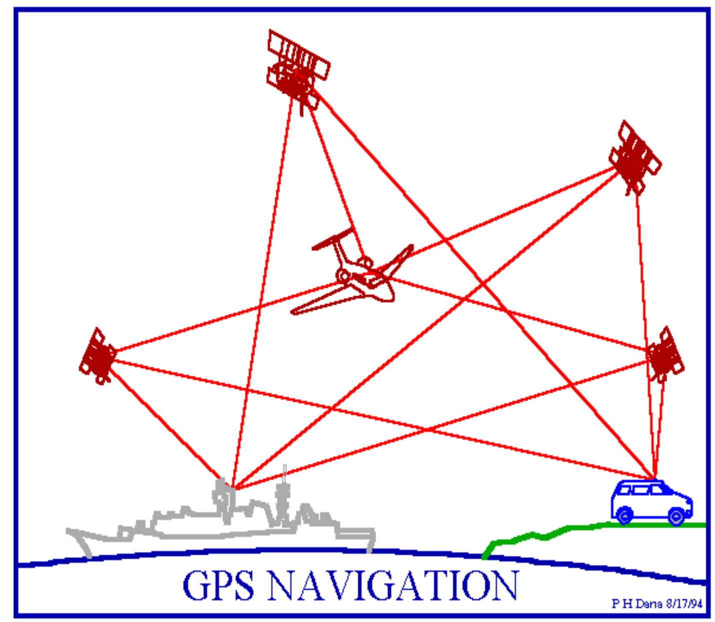


L2: f_{L2}= 1.227 GHz



Signal structure:

- Carrier
- Navigation data
- Ranging code (pseudorandom codes, PRN):
  - → C/A (Coarse Acquisition code)
  - → P (Precise code)



The GNSS

GALILEO

- 27 satellites (+3 spares)
- Emits 3 frequencies:
  - E5, E6, E1

GLONASS

- 21 satellites (+ 3 active spares)
- Altitude: 19,100 km
- 3 orbital planes
- Emits two frequencies:
  - L1
  - L2

The GNSS

New GNSS signals

- **GPS III:**
  - L2C (f_{L2}=1222,6 MHz)
  - L5 (f_{L5}=1176,5 MHz, two PRN codes)
  - L1C (f_{L1}=1575,4 MHz, interoperability with Galileo L1)

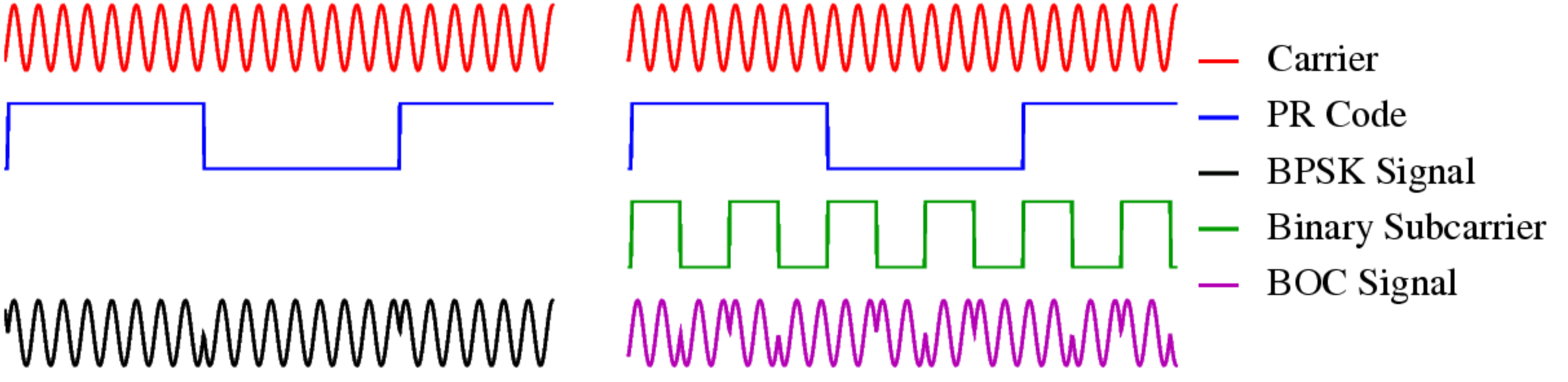
- **GALILEO:**
  - L1 (f_{L1}=1575,4 MHz)
  - E6 (f_{E6}=1278,75 MHz)
  - E5 (E5a (f_{E5a}=1176,45 MHz) and E5b (f_{E5b}=1207,14 MHz))

- **GLONASS:**
  - L1OC (f_{L1}=1602 MHz, between 1597 and 1617 MHz)
  - L2OC (f_{L2}=1246 MHz, between 1240 and 1260 MHz)

The GNSS

Modulation schemes

- **GPS:**
  - TMBOC(6,1,1/11)
  - BPSK-R(10)
- **GALILEO:**
  - AltBOC(15,10)
  - CBOC(6,1,1/11)
- **GLONASS:**
  - BPSK-R(1)

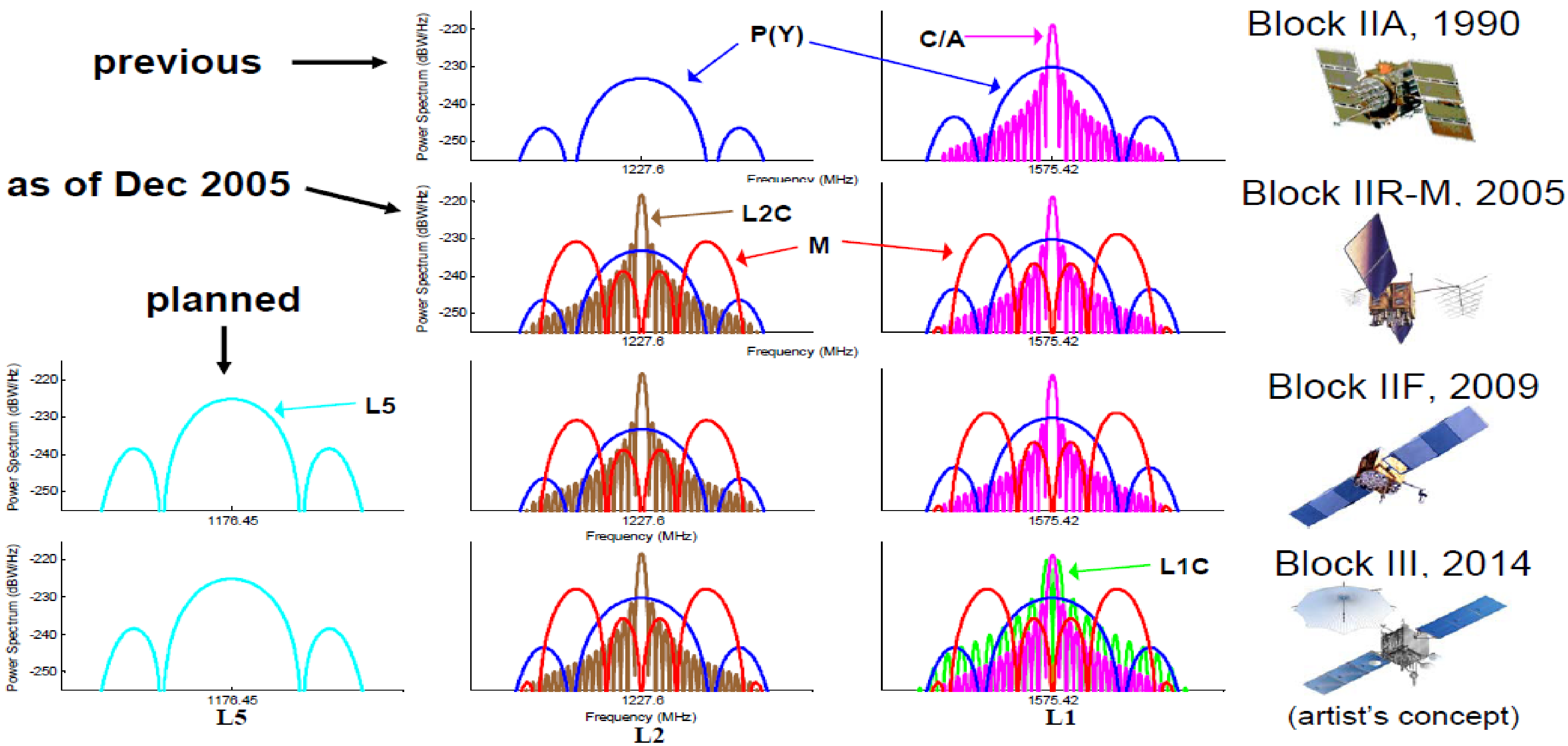


- Improvements:
  - More signal power.
  - Better multi-path mitigation capabilities.
  - More robust navigation.

The GNSS

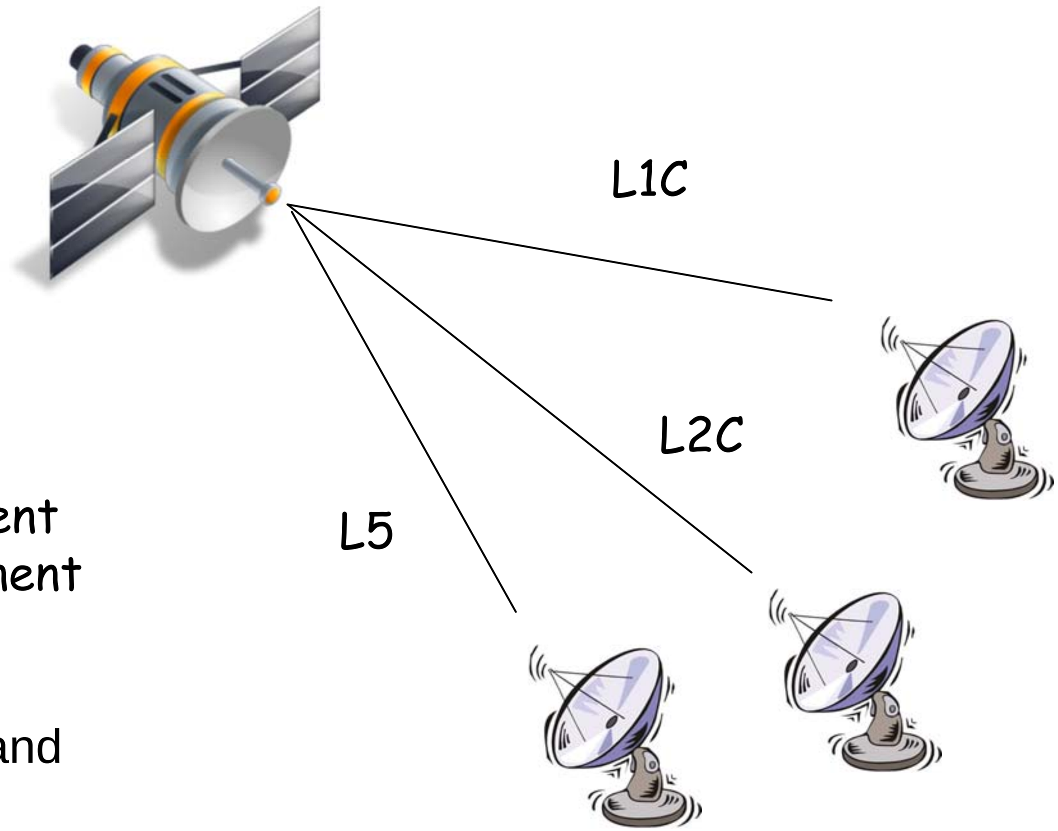
GPS III SIGNALS

GPS frequency spectrum



The GNSS

GPS III SIGNALS



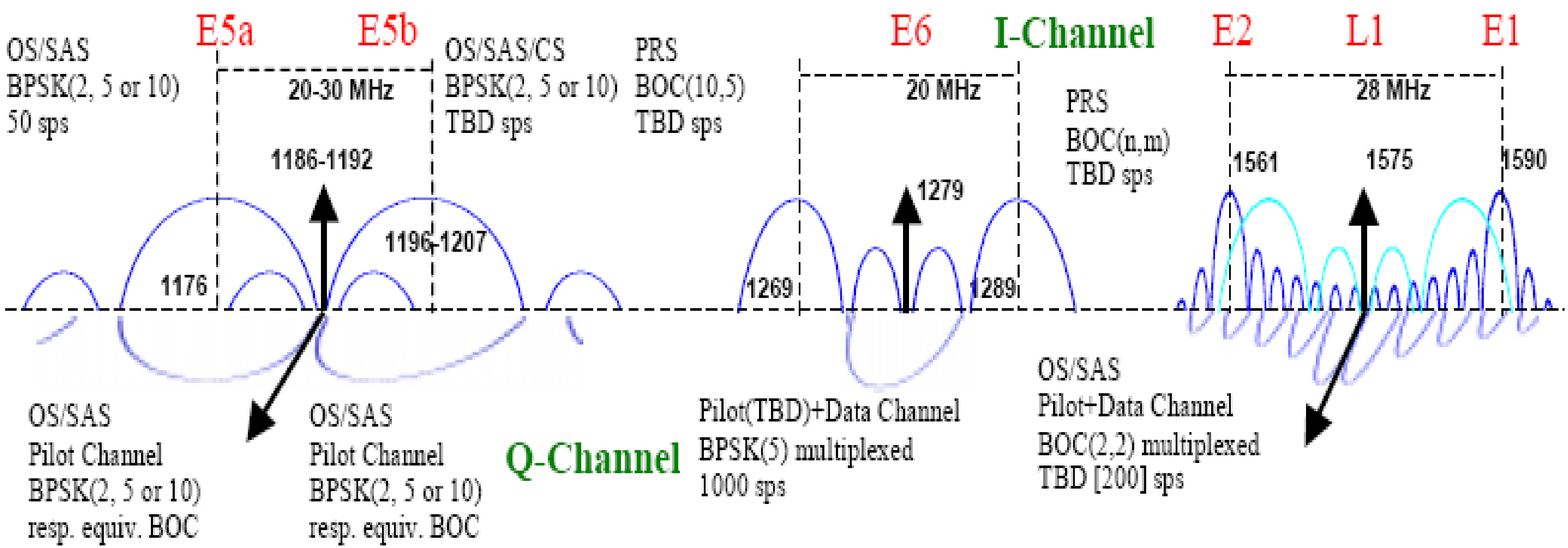
- Characteristics of new GPS signals:
  - Different PRN codes
  - Longer codes
  - Faster codes
  - Pilot (data free) component
  - Data (modulated) component
  - FEC
  - Bigger bandwidth
  - Will provide compatibility and interoperability with GNSS

Forward error correction (FEC) – it is used to correct bit decision errors suffered while demodulating the navigation message.

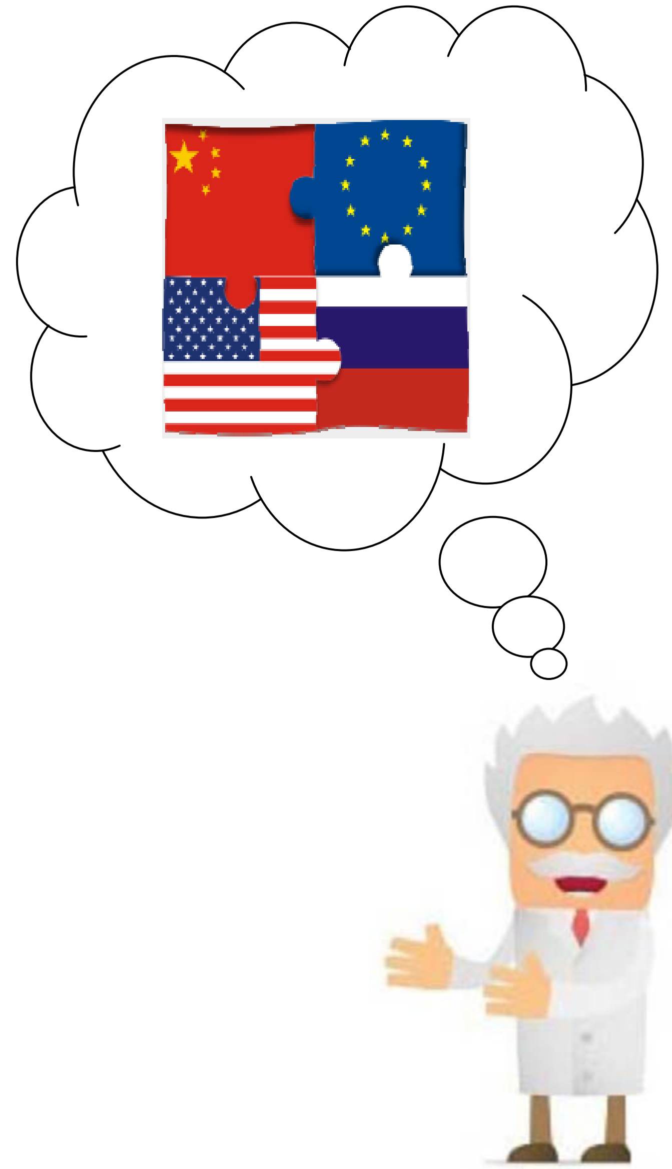
The GNSS

GALILEO SIGNALS

GALILEO frequency spectrum



The GNSS



GALILEO SIGNALS

- Characteristics of new GALILEO signals:
  - Different PRN codes
  - Longer codes
  - Faster codes (10x)
  - Pilot (data free) component
  - Data (modulated) component
  - Bigger bandwidth (20,46 MHz)
  - New modulation schemes
  - New services:
    - Open service
    - Commercial service
    - Safety of life service

The GNSS

GLONASS SIGNALS

	L1	L2	L3	L1, L2	Future	Status
"Glonass"	L1OF, L1SF	L2OF, L2SF	–	–		Done
"Glonass-M"	L1OF, L1SF	L2OF, L2SF	–	–		Done
"Glonass-K1"	L1OF, L1SF	L2OF, L2SF	L3OC test	–		Done
"Glonass-K2"	L1OF, L1SF	L2OF, L2SF	L3OC	L1OC, L1SC, L2SC		From №3 sat "Glonass-K"
"Glonass-KM"	L1OF, L1SF	L2OF, L2SF	L3OC	L1OC, L1SC, L2SC	L3SC, L1OCM, L2OC, L5OC	Under development after 2015

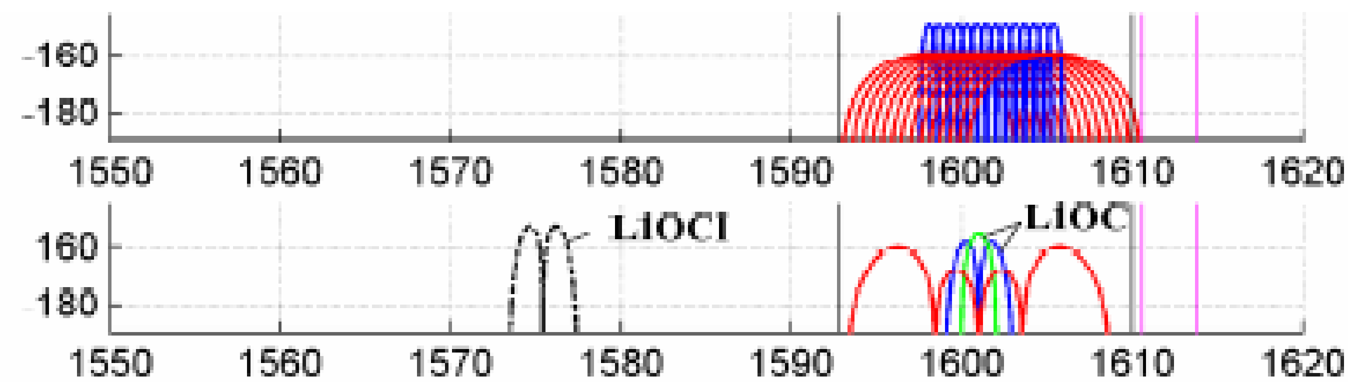
FDMA signals   CDMA signals

The GNSS

GLONASS SIGNALS

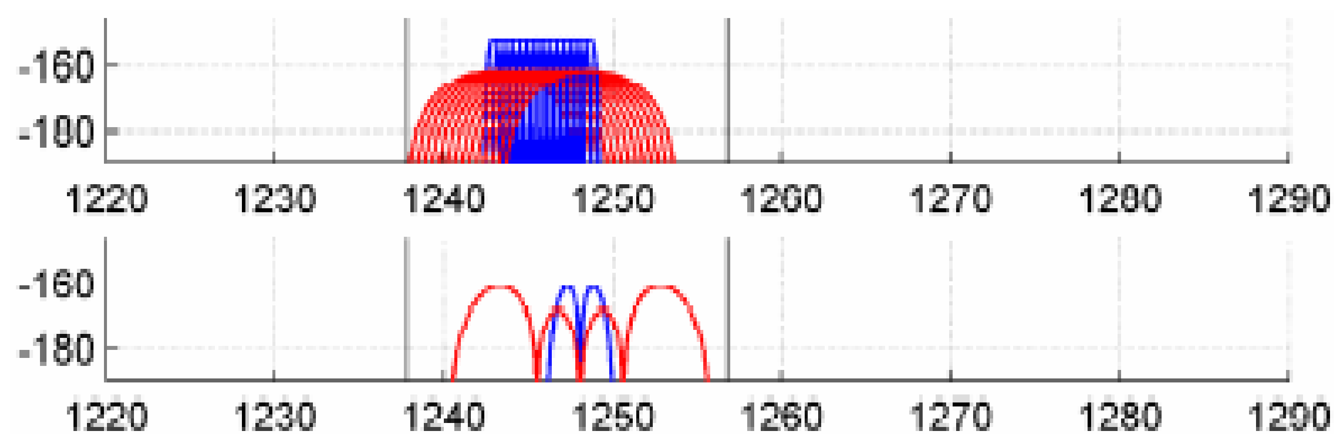
The old L1OF signal

The new L1OC signal



The old L2OF signal

The new L2OC signal



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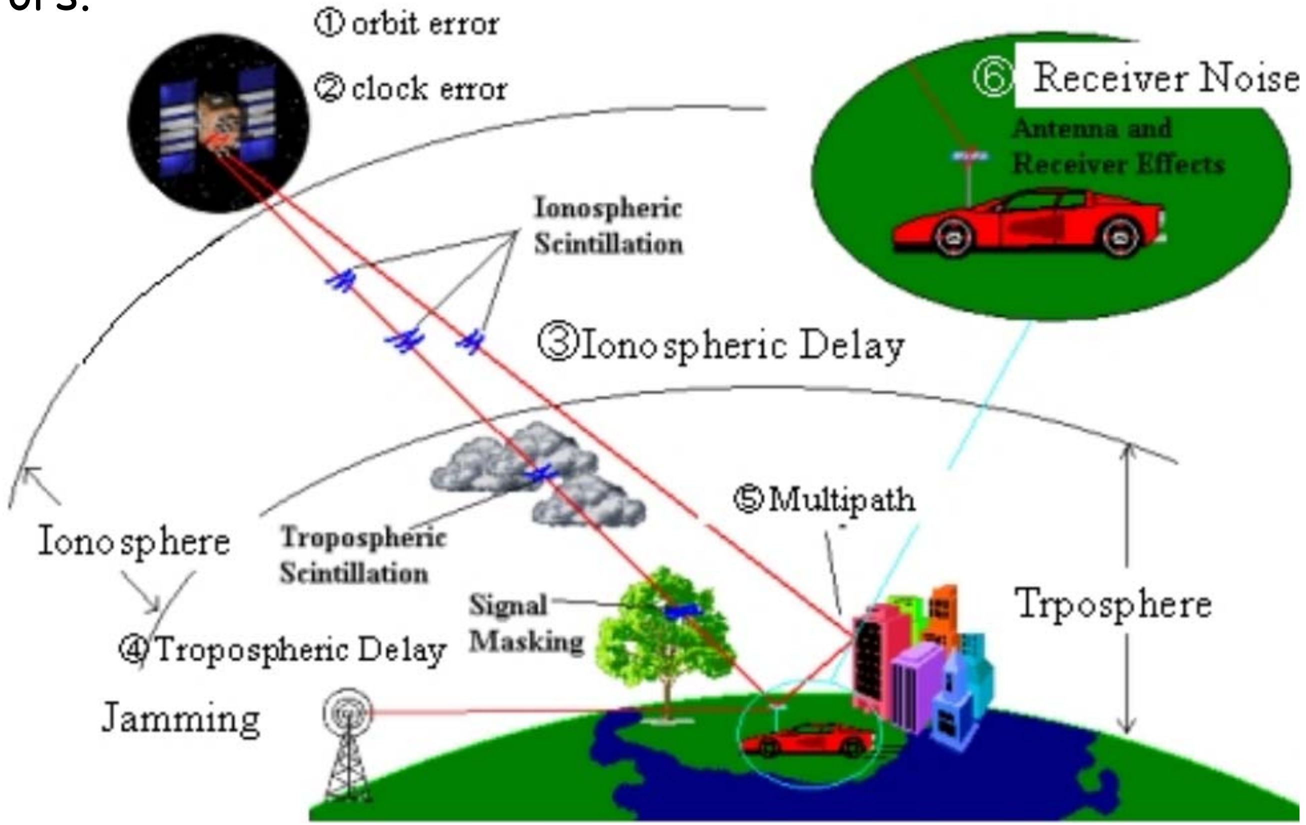
The ionospheric effects

GNSS Positioning Errors:

- Weaker geometry.
- Large positioning errors.

Error Sources



The ionospheric effects

Ionospheric delay

Effects proportional to TEC:

→ Group Delay
→ Phase Advance
→ Doppler Shift
→ Faraday Rotation
→ Ray-path bending

Ionospheric scintillations

→ Random fluctuations, in both amplitude and phase

TOTAL ELECTRON CONTENT (TEC) is the total number of electrons present along a path between two points, with units of electrons per square meter, where 10^{16} electrons/m^2 = 1 TEC unit (TECU).

$$TEC = \int_{ray\_path} N_e ds$$

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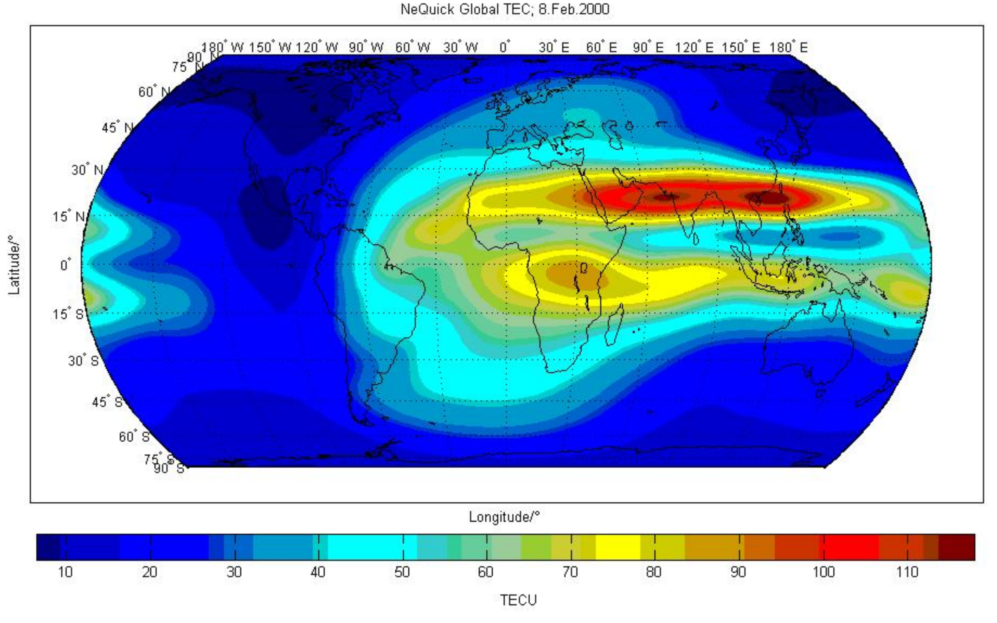
Methods to reduce the ionospheric impact on GNSS

- Using one frequency:
  - → Klobuchar model (GPS)
  - → NeQuick model (GALILEO)

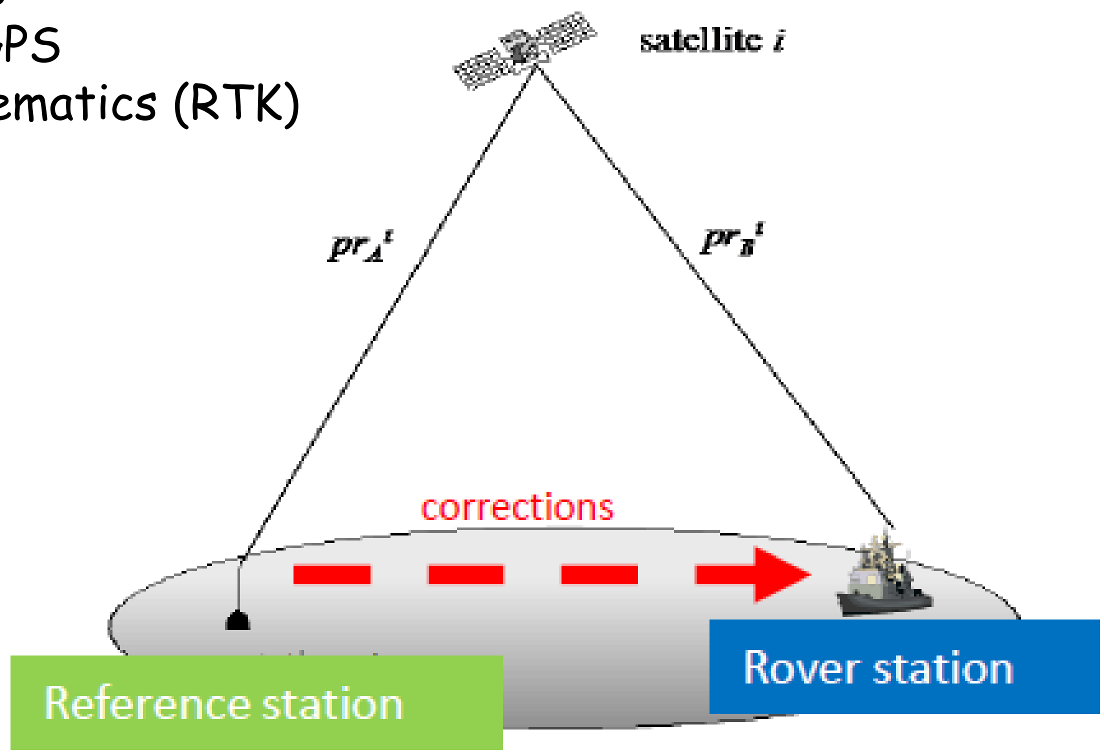
Correct for approximately 50% of the ionospheric range delay.

Allows calculation of the electron concentration at any given location in the ionosphere.



Methods to reduce the ionospheric impact on GNSS

- Using two frequencies
  - → Differential GPS
  - → Real Time Kinematics (RTK)



Methods to reduce the ionospheric impact on GNSS

- Pseudo range IONO FREE

$$P_{k,L1}^{p} = \rho_{k}^{p} - cdt_{k} + c\left(dt^{p} + T_{GD}\right) + I_{k,L1}^{p} + A_{k}^{p} + M_{k,L1}^{p} + HD_{k,L1} + HD^{p,L1} + \varepsilon_{p}$$

$$P_{k,L2}^{p} = \rho_{k}^{p} - cdt_{k} + c\left(dt^{p} + T_{GD}\frac{L_1^2}{L_2^2}\right) + I_{k,L2}^{p} + A_{k}^{p} + M_{k,L2}^{p} + HD_{k,L2} + HD^{p,L2} + \varepsilon_{p}$$

⇓

$$P_{k,IF}^{p} = \rho_{k}^{p} - c\left(dt_{k} - dt^{p}\right) + A_{k}^{p} + M_{k,IF}^{p} + HD_{k,IF} + HD^{p,IF} + \varepsilon_{p}$$

Methods to reduce the ionospheric impact on GNSS

- Carrier phase IONO FREE

$$\Phi^p_{k,L_1} = \left[\rho^p_k\right]\mathrm{mod}_\lambda + \lambda N^p_{k,L_1} - cdt_k + cdt^p - I^p_{k,L_1} + A^p_k + M^p_{k,L_1,\varphi} + HD_{k,L_1,\varphi} + HD^{p,L_1,\varphi} + \varepsilon_{L_1,\varphi}$$

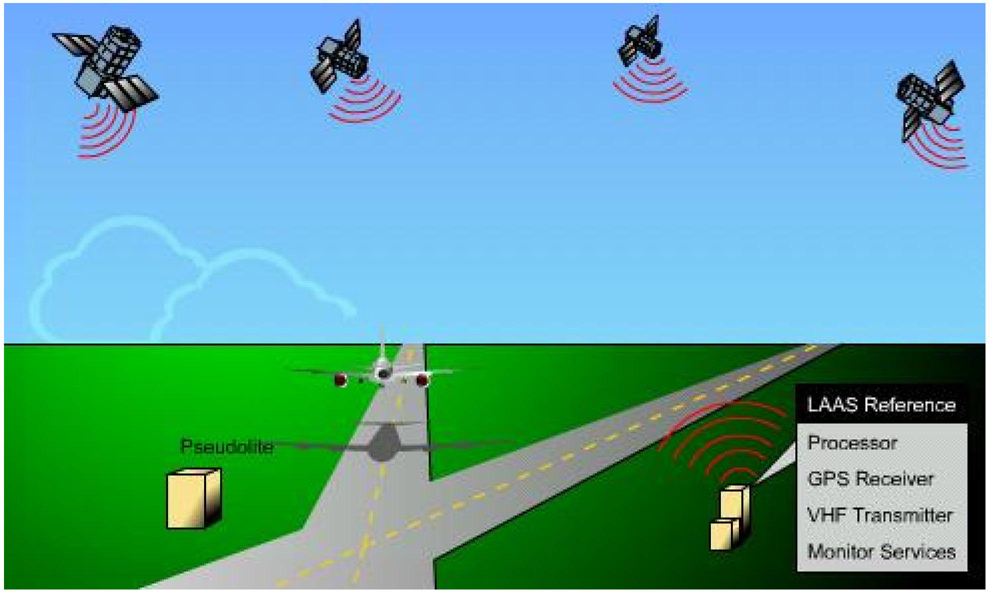
$$\Phi^p_{k,L_2} = \left[\rho^p_k\right]\mathrm{mod}_\lambda + \lambda N^p_{k,L_2} - cdt_k + cdt^p - I^p_{k,L_2} + A^p_k + M^p_{k,L_2,\varphi} + HD_{k,L_2,\varphi} + HD^{p,L_2,\varphi} + \varepsilon_{L_2,\varphi}$$

⬇

$$\Phi^p_{k,IF} = \left[\rho^p_k\right]\mathrm{mod}_\lambda + \lambda N^p_{k,IF} - c\left(dt_k - dt^p\right) + A^p_{k,\Phi} + M^p_{k,IF,\Phi} + HD_{k,IF,\Phi} + HD^{p,IF,\Phi} + \varepsilon_\Phi$$

Methods to reduce the ionospheric impact on GNSS

- Benefits from new GNSS signals:
  - New special applications:
    - Open service
    - Commercial service
    - Safety of life service
  - Better accuracy (up to 1 cm)
  - Operation at low signal to noise ratio
  - Better multi-path mitigation capabilities
  - More robust navigation



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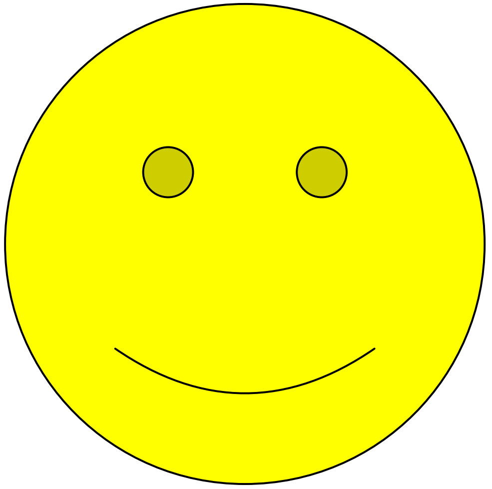
- **Future goals**

Future goals

- Will investigate the effects of small scale plasma density structures on new signals by taking into account their architecture and the consequent demodulation schemes.
- Will investigate the main threats to the reliable and safe operation of GNSS.
- Will work on new data processing, commercial and scientific applications algorithms.



Thanks for listening