Ionosphere Modelling for GALILEO Single Frequency Users

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GALILEO

- **European GNSS** (Global Navigation Satellite System) under development
- Several advantages e.g.
  - **interoperability** with existing systems mainly GPS (Global Positioning System) = combination of signals from various constellations possible in order to improve performances of measurements
  - **guaranteed precision** as it will broadcast related information contrary to the preceding systems

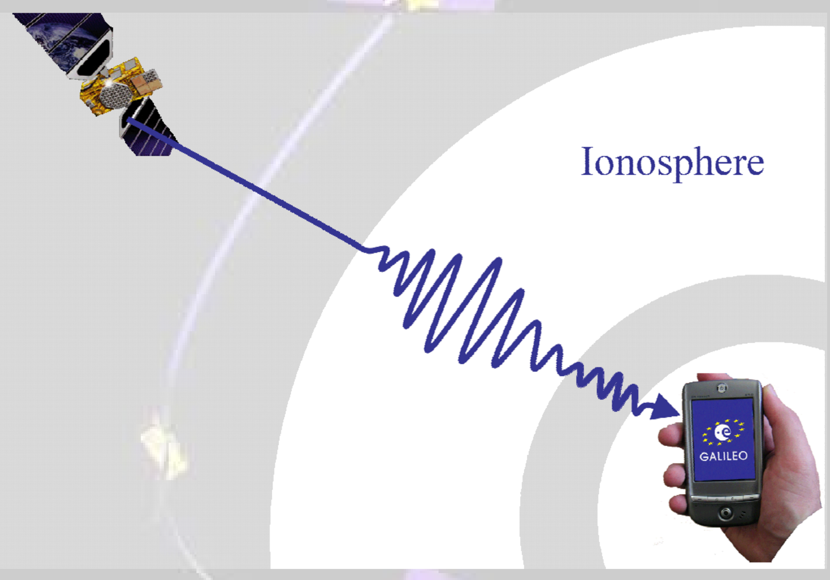
GALILEO constellation (credits: ESA)

Basic obedience	Civilian
Number of services	5
Number of carrier frequencies	3
Horizontal accuracy for civilian users [*m*]	15
Number of satellites (operational/in orbit)	27/3
Average altitude [*km*]	23222
Number of orbital planes	3
Inclination [°]	56
Period [hours]	14

- Development:
  - space segment of 30 satellites to be launched, beginning with experimental ones (the first, GIOVE-A, in December 2005 and the second, GIOVE-B, in December 2007)
  - ground segment including 40 sensor stations
  - completion foreseen for **2013**

Influence of the Ionosphere

- Different effects **affecting precision** one of which induced by the ionosphere, the electrically charged part of the atmosphere → positioning errors exceeding 100 m in extreme cases



Signals propagating through the ionosphere

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

I [m] = ionospheric range error
TEC [TECu] = total electron content
f [MHz] = signal frequency

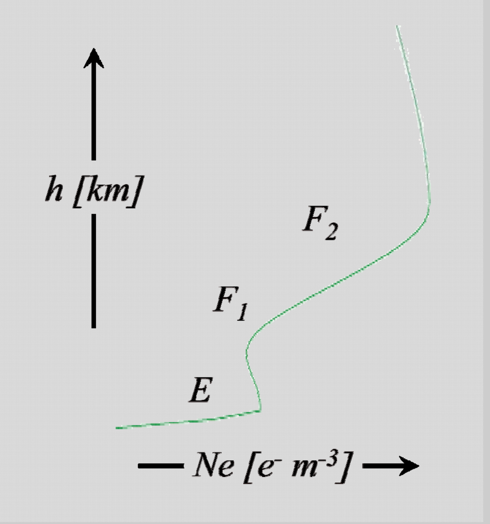
1 TECu on L_1 [1575.46 MHz] → I = 16 cm

- Ionospheric effect *I* depending at first approximation
  - on the frequency *f* of the incident signal (dispersive property)
  - on the total content in free electrons of the ionosphere ("**total electron content**", ***TEC***) = integral of the electron density *Ne* on the path between the satellite and the receiver
- TEC **modelling**
  - crucial in particular for **single frequency receivers**, the most common ones constituting the mass market
  - also for multiple frequency devices (fallback mode in single frequency for critical applications e.g. civil aviation)
  - by means of a 3D method using the NeQuick model for GALILEO

3D method scheme (credits: ICTP)

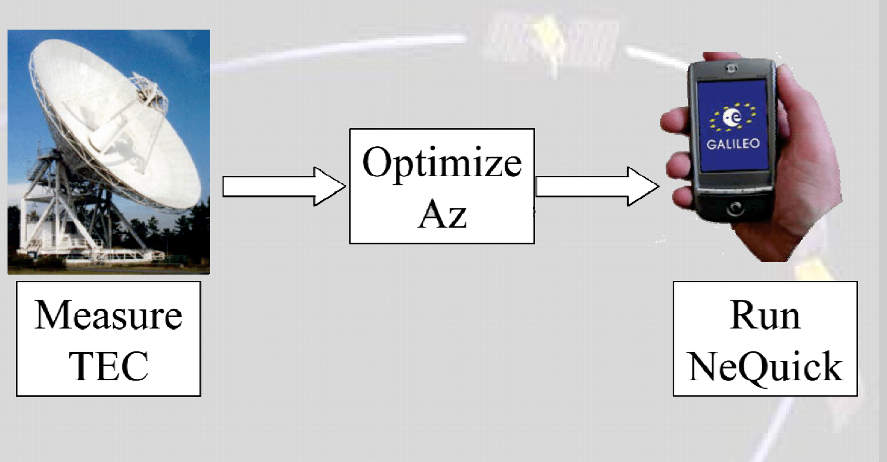
NeQuick

- Empirical model of the electron density *Ne*:
  - "**profiler**" = several mathematical functions fitted on anchor points corresponding to the maxima of the layers of the ionosphere
  - peaks and profile characteristics calculated on the basis of **monthly median measurements**
  - adaptation to given ionospheric conditions by means of input parameters e.g. the monthly solar radio flux at 10.7 cm



Electron density profile

- GALILEO single frequency ionospheric correction algorithm:
  - "**refreshment**" at a daily rate by replacing the input solar flux by a daily parameter called effective ionization level (Az)
  - based on TEC measurements performed by the tracking stations of the GALILEO network
  - Az determined on a daily basis and on a worldwide scale (optimization)
  - Az broadcast to the receiver through the navigation message
  - objective = **30%** RMS residual error or 20 TECu whichever is larger



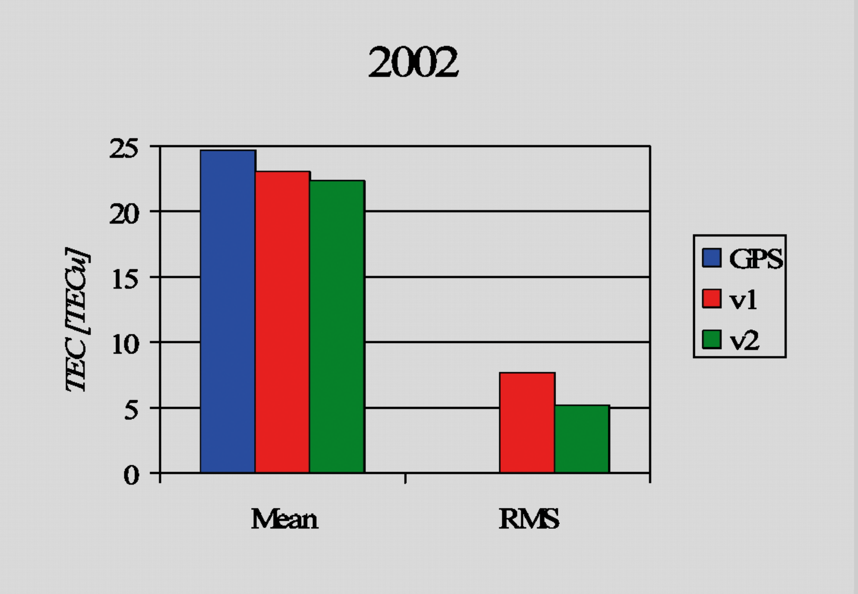
GALILEO single frequency algorithm

- Research issues
  - about the model itself e.g. not realistic too simple description of the **higher part of the ionosphere** ("topside")
  - about GALILEO algorithm e.g. **formulation of Az** chosen to compensate for the observed residual errors

GALILEO

PhD Thesis

- **Objectives**
  1. Analysis of NeQuick **weaknesses** and results: development of a software and gathering of reference measurements among which those of Belgian GPS stations and the ionosonde of the RMI
  2. **Intrinsic** improvement: analysis of more realistic TEC representation techniques and investigation of the topside formulation
  3. Study of NeQuick best use for satellite navigation: focus on techniques of data **ingestion** (adaptation of modelled values to measured ones by minimizing their difference by means of Az)
  4. Study of **implementation** e.g. evaluation of cost in data-processing resources
- First results:
  - test of NeQuick profile formulation at **mid-latitudes**
  - model constrained by means of ionosonde data and compared to GPS TEC data
  - evolution between official baseline version (v1) and latest release (v2) including an improved topside
  - comparison for Dourbes location (50.1N, 4.6E) and two solar activity levels (2002 for high and 2006 for low)
  - **improvement from v2**



TEC comparison for Dourbes in 2002