Modelling the Ionosphere over Europe: Investigation of NeQuick Formulation

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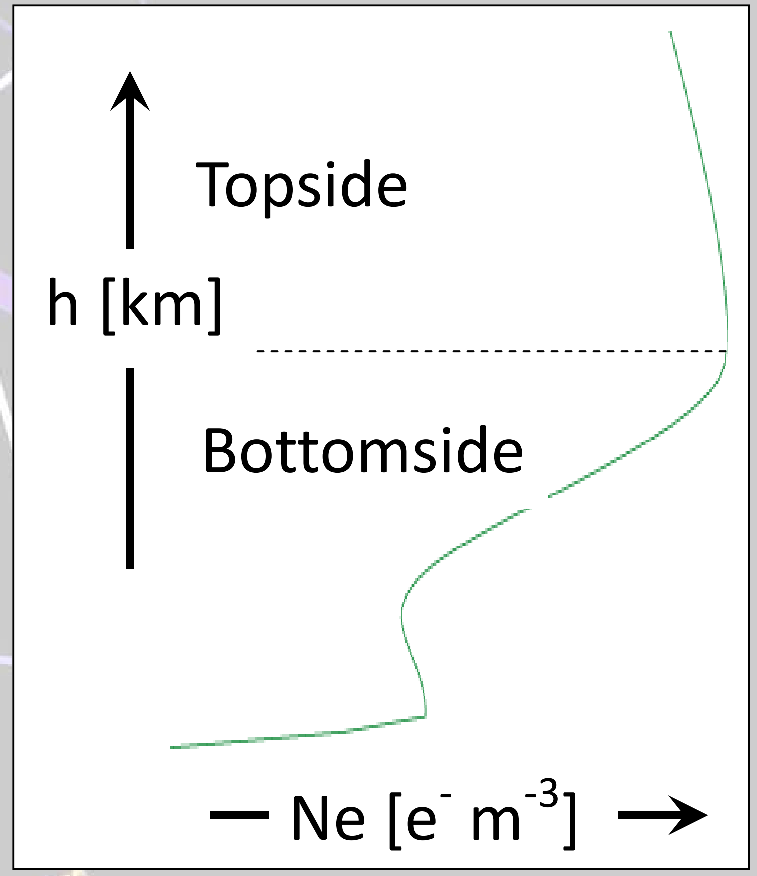
The NeQuick Ionosphere Model

- **Ionosphere affecting** radio propagation and hence **GNSS**
  - Positioning errors exceeding 100 m in extreme cases
  - **Total Electron Content** (TEC, integral of the electron density Ne) = main driver
- Importance of **TEC modelling**
  - Crucial especially for **single frequency receivers**, the most common ones constituting the mass market
  - By means of a 3D method using the **NeQuick** model **for GALILEO** (Orus et al., 2007a)
- 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 (Radicella et Leitinger, 2001)
  - Peaks and profile characteristics calculated on the basis of **monthly median measurements**
  - **New version** (NeQuick 2): main modification regarding the description of the **higher part of the ionosphere** ("topside") → two formulas for shape parameter k (each for six months of the year) replaced by a single one (Nava et al., 2008)

Electron density profile



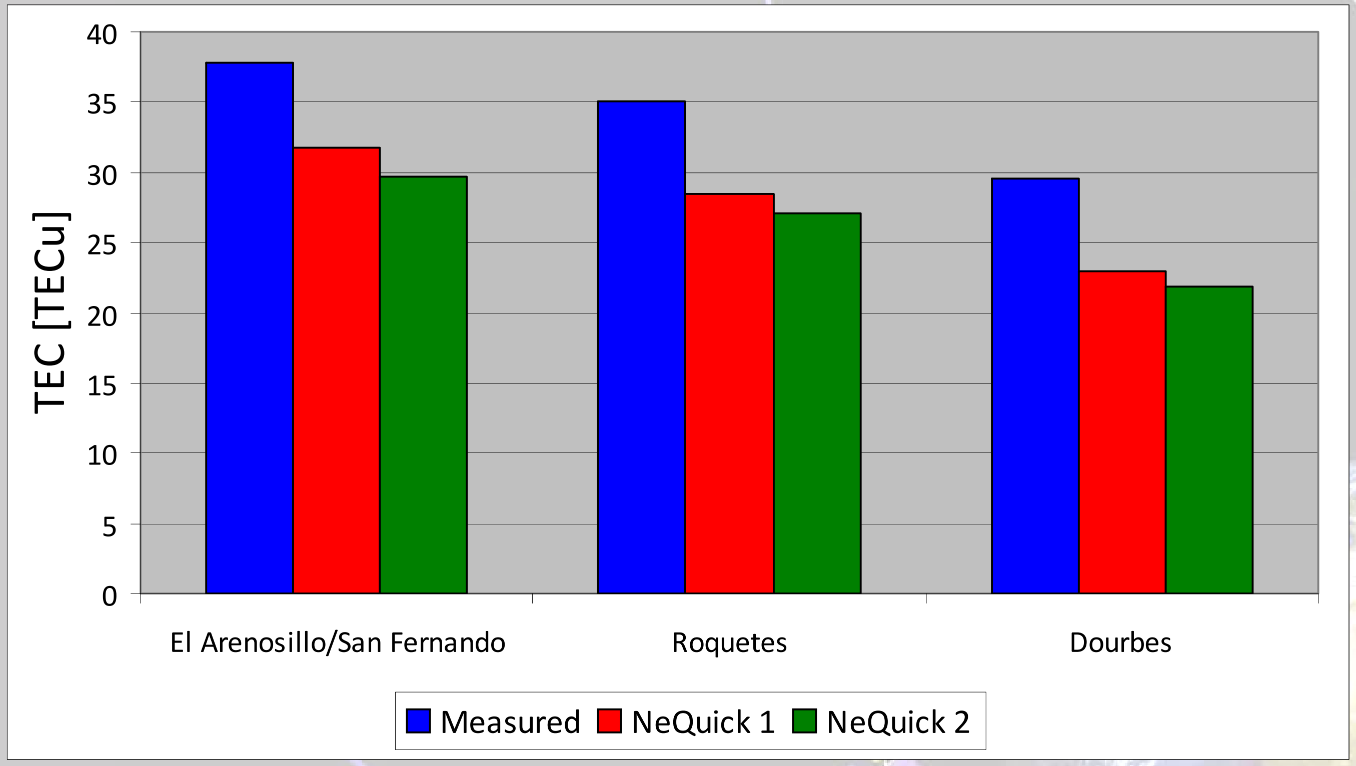
Tools and Method

- Investigation of NeQuick **profile formulation**
  - Monthly median measurements replaced by actual ones → **model constrained by means of ionosonde data** (Bidaine et Warnant, 2007)
  - Obtained vertical TEC compared to GPS TEC data → **collocated ionosonde and GPS receiver** needed
- Data types
  - **Manually validated digisonde** data
  - **Slant TEC data levelled using Global Ionospheric Maps** (Orus et al., 2007b) and mapped to vertical + elevation filter and average to obtain vertical TEC
- Tests for **mid-latitudes and high solar activity**
  - Year 2002
  - Three European locations with (nearly) collocated digisonde and IGS/EUREF station

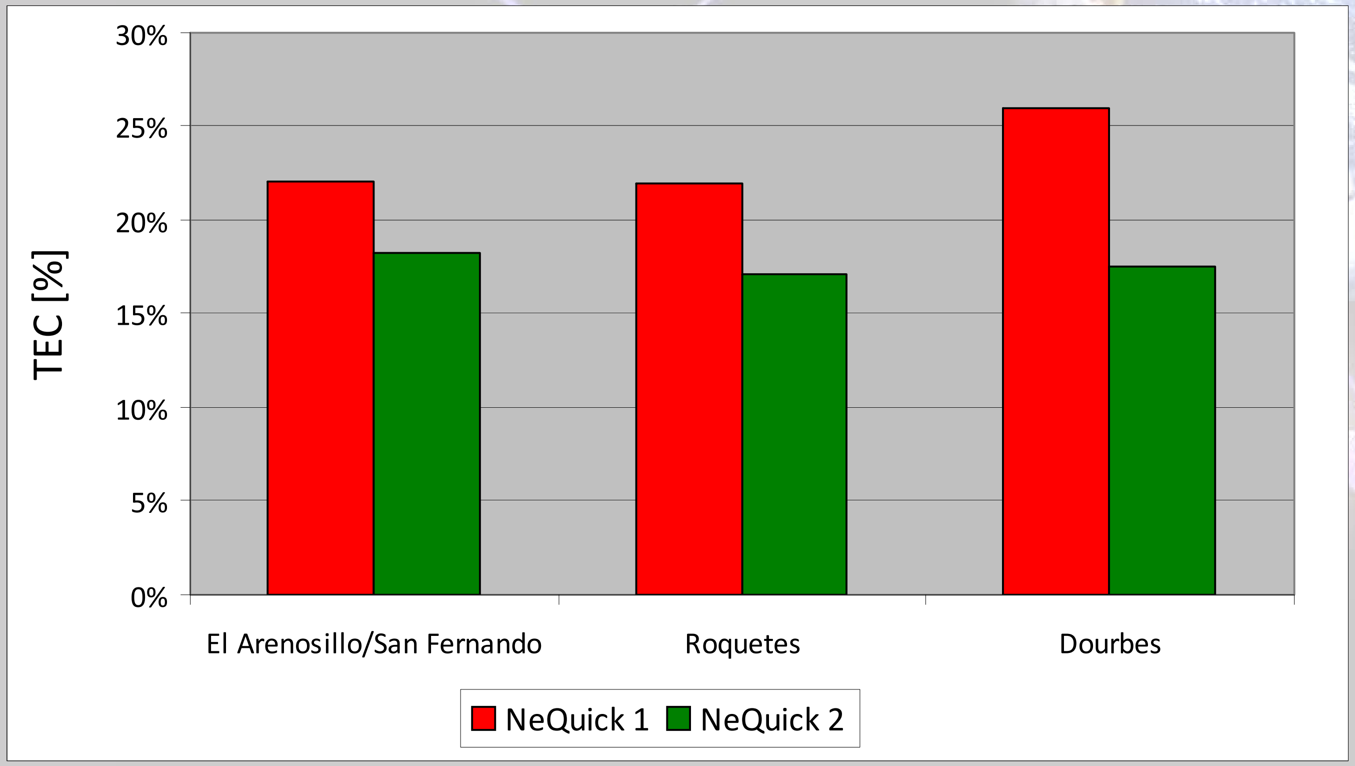
Digisondes and IGS/EUREF stations

Yearly Statistics

Yearly TEC mean



Yearly relative TEC standard deviation



- Influence of **latitude**: vertical TEC mean decreasing northwards (TEC in TECu = $10^{16}\ e^{-}\ m^{-2}$)
- TEC **underestimated** on average (potential bias in GPS TEC data to take into account)
- **Bigger** (around 20%) **underestimation** with NeQuick 2
- **Lower** (around 20%) **standard deviation** for NeQuick 2 → better behaviour

$$dTEC = TEC_{meas} - TEC_{mod} \qquad Bias = \langle dTEC \rangle$$

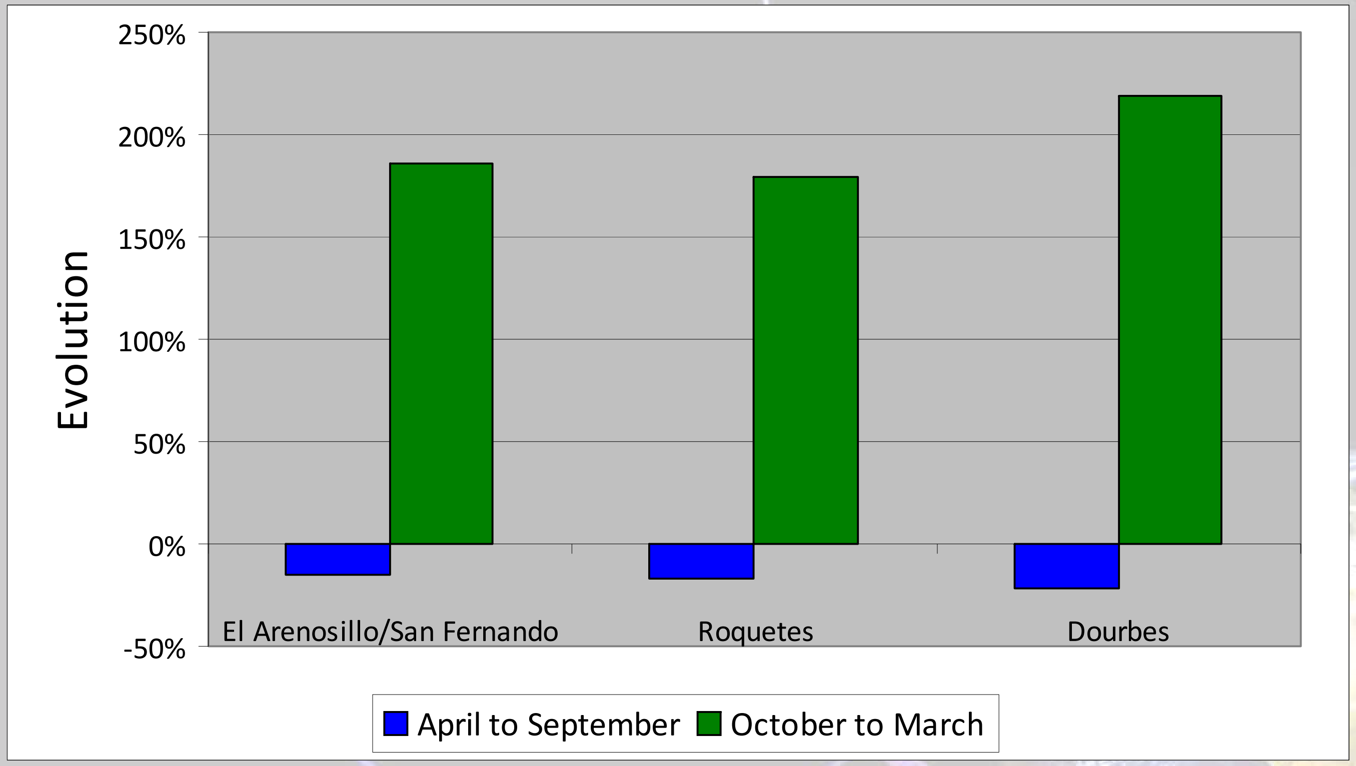
$$\text{Standard deviation} = \sqrt{\langle (dTEC - Bias)^2 \rangle}$$

$$\text{Relative parameter} = \frac{\text{Parameter}}{\langle TEC_{meas} \rangle}$$

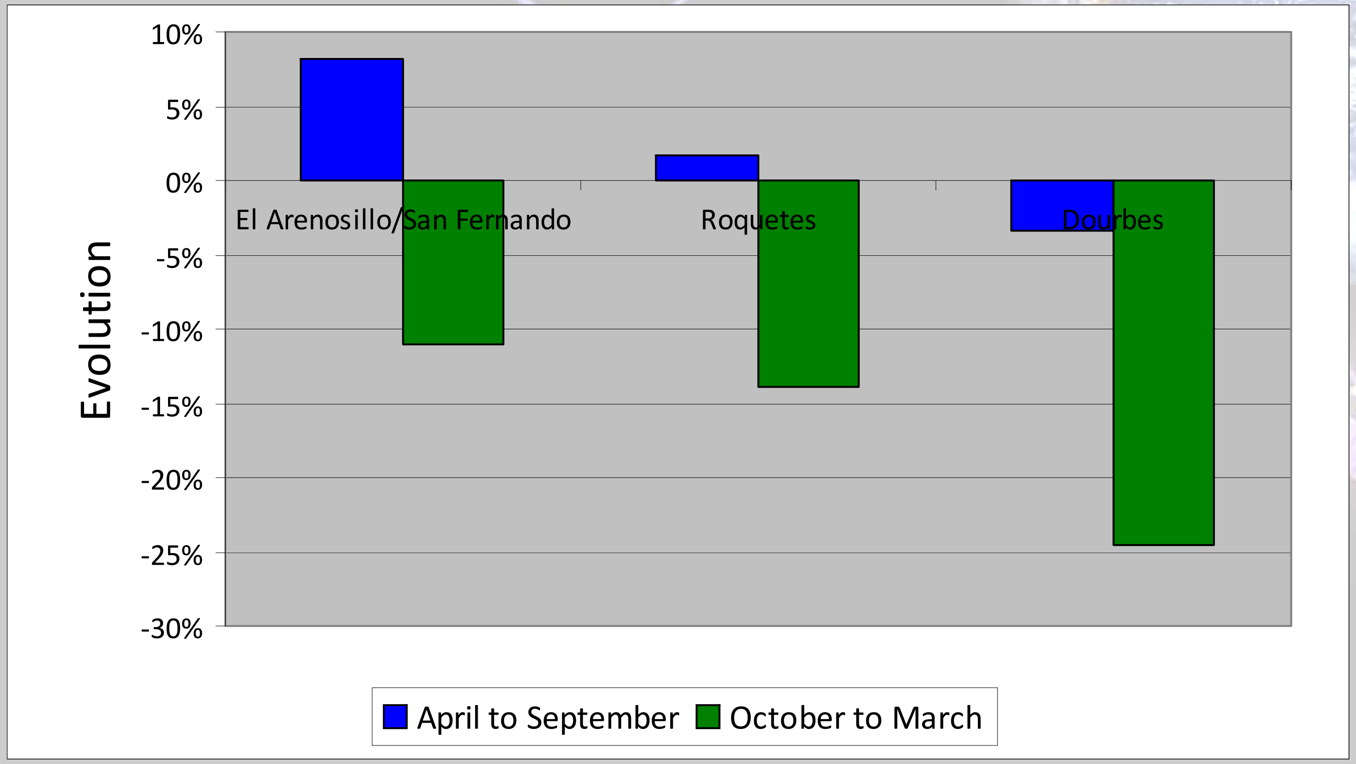
$$\text{Evolution} = \frac{\text{Parameter}_{NeQuick\,2} - \text{Parameter}_{NeQuick\,1}}{\text{Parameter}_{NeQuick\,1}}$$

Influence of k Unification

Evolution of TEC bias from NeQuick 1 to 2



Evolution of TEC standard deviation

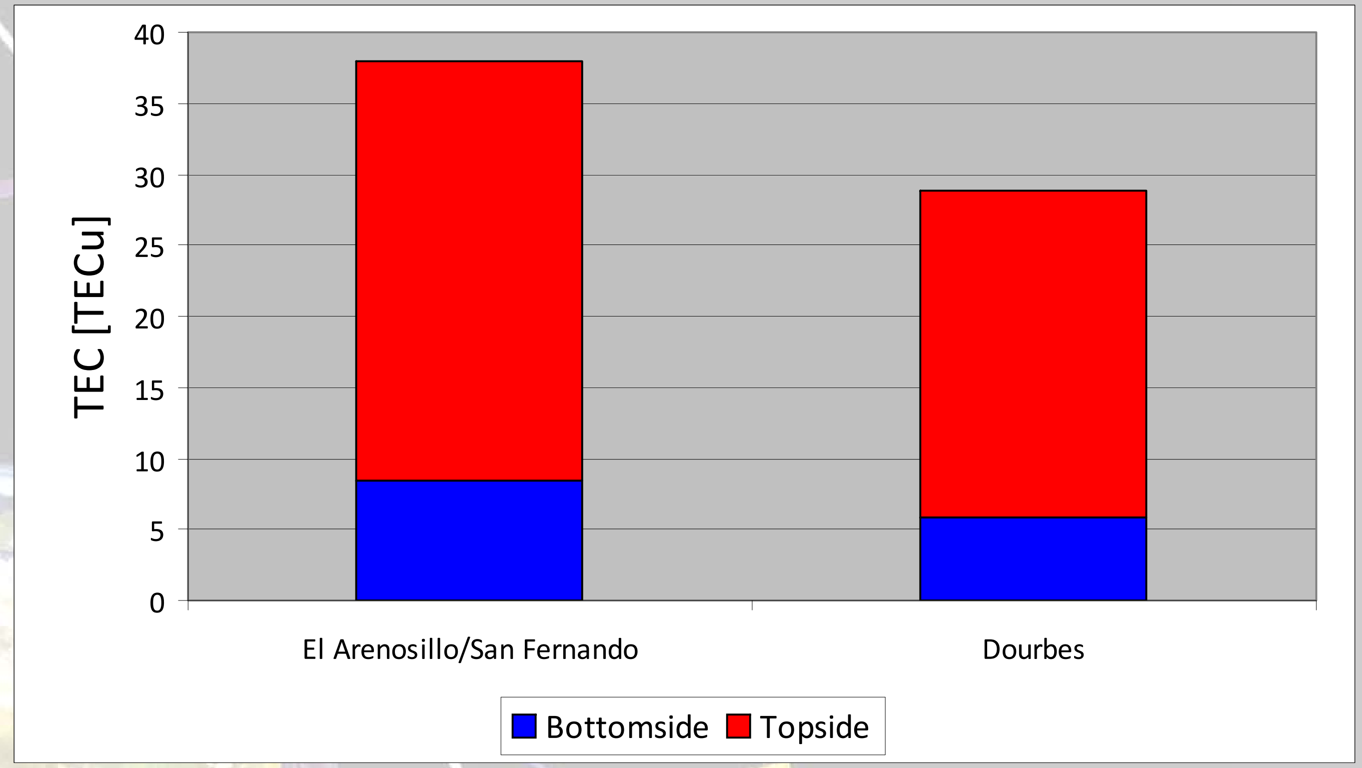


- **Major modification between model versions**: 2 formulas for k (April to September and October to March) in NeQuick 1 replaced by a single one in NeQuick 2
- Apparently **different behaviour for periods corresponding to both k formulas** in NeQuick 1
- April to September: lower (20%) bias and slightly higher standard deviation in NeQuick 2
- **October to March**:
  - In NeQuick 1, lower bias and higher standard deviation than first period
  - **In NeQuick 2**, much higher (200%) bias and lower (15%) standard deviation → **more homogenous with first period**

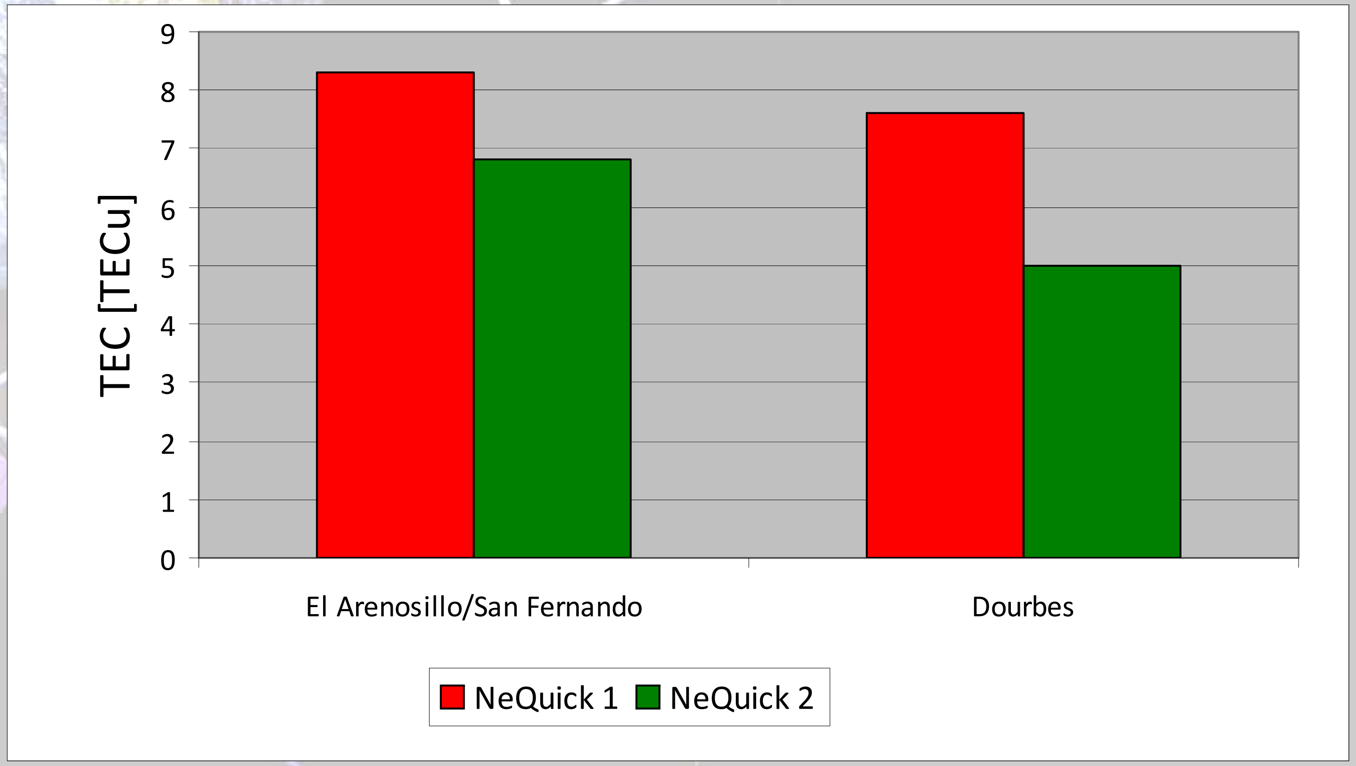
TEC Splitting

- **Integrate bottomside Ne profile** from digisonde to obtain bottomside TEC
- **Subtract** bottomside TEC **to GPS TEC** to obtain estimate of topside TEC (caution with interpretation about topside because resulting TEC value containing whole GPS TEC uncertainty)
- **Big proportion of TEC within topside** (3/4, 1/4)
- Bottomside: low bias (at least in absolute value) and relatively high standard deviation, no big evolution between NeQuick versions
- **Topside**: higher relative bias and standard deviation than bottomside, **bias/standard deviation evolution between NeQuick versions corresponding to global statistics**

Proportion of TEC in bottomside and topside



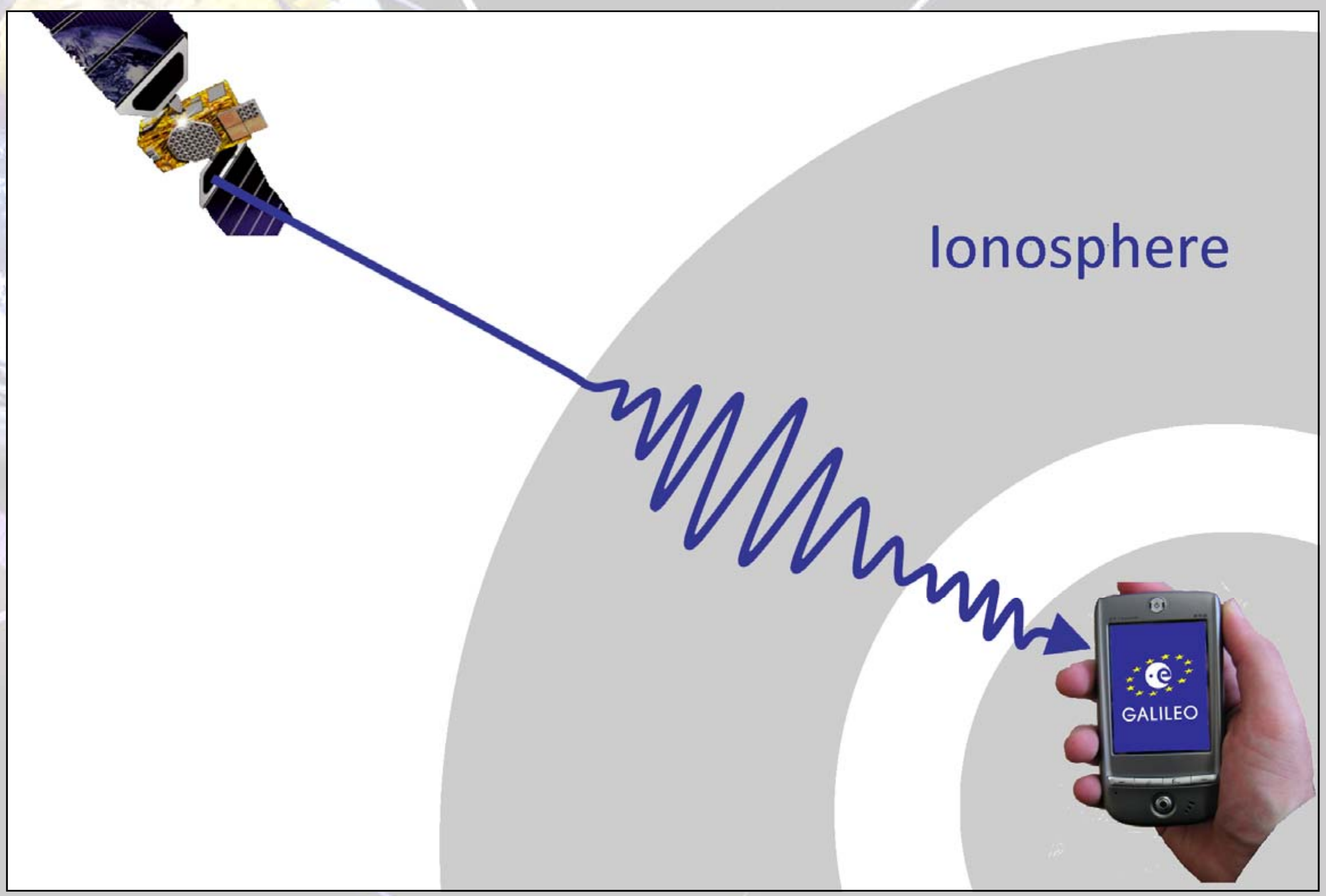
Yearly topside TEC standard deviation



Conclusion and Perspectives

- **Investigation of NeQuick profile formulation** for mid-latitudes and high solar activity
  - Constraining NeQuick with ionosonde measurements and comparing resulting vertical TEC with GPS TEC
  - **Standard deviation decreasing by 20% to reach less than 20% with NeQuick 2**, bias increasing by 20% up to 25% but caution with GPS TEC data
  - Homogenisation thanks to topside modification
  - **Major role of the topside**
- **Further** research
  - **Ingestion**: adapt NeQuick TEC to GPS TEC by means of effective parameters
  - Investigate **GALILEO** Single Frequency Ionospheric Correction Algorithm

Signals propagating through the ionosphere



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