Ionosphere Modelling
Based on the NeQuick Model
and GNSS Data Ingestion

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Introduction

- **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
  - For **GALILEO**, by means of a 3D method using the **NeQuick** model and data ingestion (Orus et al., 2007a)

NeQuick Model

- **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”) $\rightarrow$ two formulas for shape parameter $k$ (each for six months of the year) replaced by a single one (Nava et al., 2008)
Data Ingestion

- Solar activity indices = standard input of ionospheric models
- Use of “effective” indices to drive a model towards measured values
- Effective ionization level Az when applied to NeQuick with TEC data (Nava et al., 2006)
- Minimisation of mismodelling between model and subset of TEC values

Data sets

- Data types
  - Manually validated ionosonde data
  - Slant TEC (sTEC) data levelled using Global Ionospheric Maps (Orus et al., 2007b)
  - Vertical TEC (vTEC) obtained from sTEC mapped to vertical, elevation filter at 61.8° and mean over 15-minute periods
- Tests for mid and high latitudes and high solar activity
  - 12 locations with collocated ionosonde and GPS station grouped in 4 regions
  - Year 2002
**Analysis Method**

- **Uncoupling** NeQuick formulation from underlying data: monthly median measurements replaced by actual ones → model constrained by means of ionosonde data

- **Ingestion** scheme similar to Galileo Sensor Stations operation: daily Az values minimising Root-Mean-Square (RMS) of sTEC difference

\[
RMS = \sqrt{\langle \left( sTEC_{\text{mod}}(Az) - sTEC_{\text{meas}} \right)^2 \rangle}
\]

- **Statistics of vTEC difference** between NeQuick and GPS TEC: mean \(\overline{\Delta TEC}\) and relative standard deviation \(\sigma_{\Delta TEC, \text{Relative}}\)

\[
dTEC = TEC_{\text{mod}} - TEC_{\text{meas}} \\
\Delta TEC = \langle dTEC \rangle \\
\sigma_{\Delta TEC} = \sqrt{\langle (dTEC - \Delta TEC)^2 \rangle} \\
\sigma_{\Delta TEC, \text{Relative}} = \frac{\sigma_{\Delta TEC}}{\langle TEC_{\text{meas}} \rangle}
\]
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Ionosonde Parameters Constrain

- **Influence of latitude**: lower mean TEC values at high-latitudes (TEC in TECu = \(10^{16}\ e^{-}\ m^{-2}\))

- **Average TEC underestimation** of about 25% but potential bias in GPS TEC data to take into account (Bidaine et Warnant, 2009)

- **Bigger underestimation** with NeQuick 2 (inconsistency for high-latitude Europe and Australia because several months of data missing and improvement from topside modification during that period)

- **Lower standard deviation** (about 24% decreasing by about 17%) for NeQuick 2 → better behaviour

- **Best results in mid-latitude Europe** and worst in high-latitude Europe
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**Slant TEC Ingestion**

### Yearly vTEC mean

- **Bias absorbed thanks to ingestion**
  - Lower underestimation than for ionosonde parameters constrain
  - Even lower underestimation with NeQuick 2

- **Residual errors handled by ingestion**
  - Lower (around 16%) than for ionosonde parameters constrain
  - 15% decrease with NeQuick 2

- **Best and worst cases unchanged**

- **Effective ionization level Az**
  - Larger than solar flux
  - Lower values for NeQuick 2
  - Dependent on latitude (increasing towards high-latitudes)

### Yearly relative vTEC standard deviation
Conclusion and Perspectives

- Ingestion = optimisation procedure involving the NeQuick model and GNSS sTEC data
- **Intrinsic mismodelling characterised through ionosonde parameters constrain:** standard deviation decreasing by 17% to reach about 22% with NeQuick 2
- **Slant TEC ingestion absorbing residual errors:** standard deviation decreasing by 15% to reach about 15% with NeQuick 2
- **Best results in mid-latitude Europe** and worst in high-latitude Europe
- Statistics of other ionospheric parameters such as maximum electron concentrations
- Similar analysis with **Galileo** Single Frequency Ionospheric Correction Algorithm

*Find material about this poster on http://orbi.ulg.ac.be/handle/2268/19132*
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References