Ionosphere Modelling Based on the NeQuick Model and GNSS Data Ingestion

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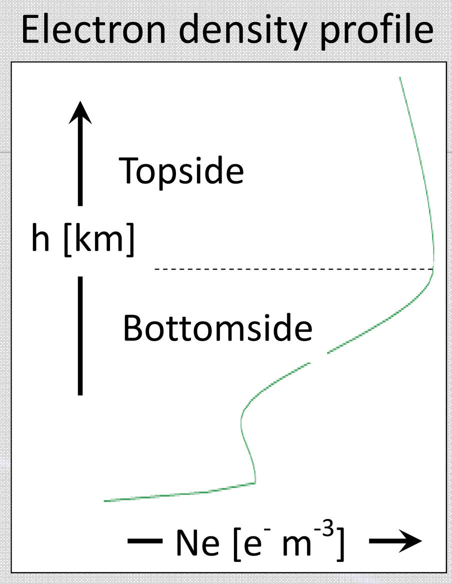
Introduction

- **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") → 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



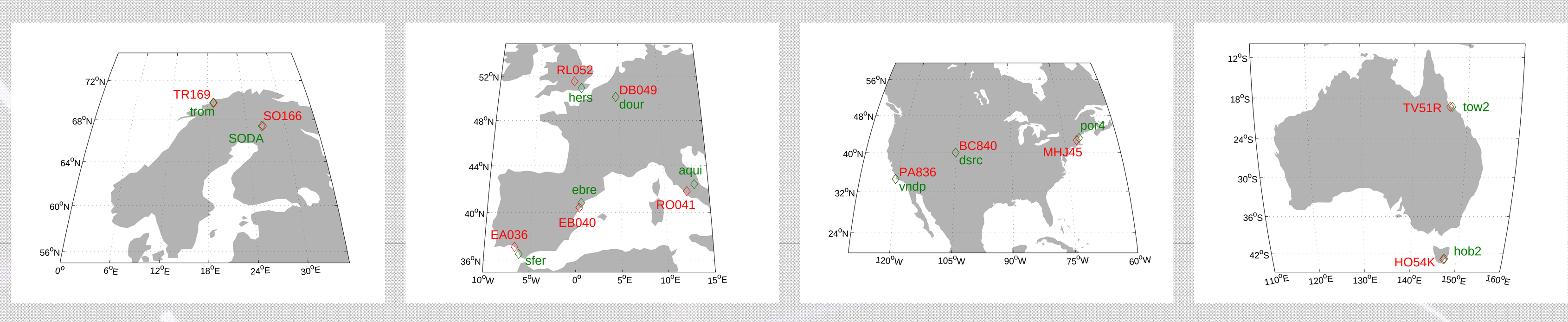
Data Ingestion

- **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

Collocated ionosondes and GPS stations



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

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

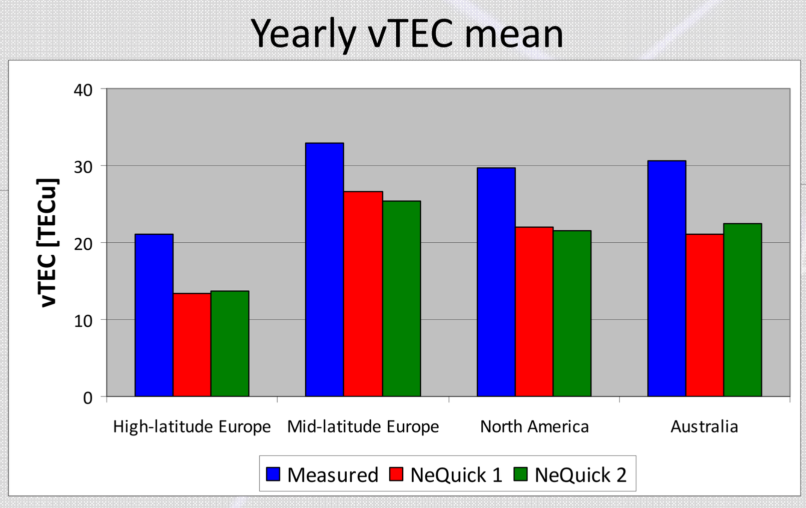
- **Statistics of vTEC difference** between NeQuick and GPS TEC: mean $\overline{\Delta TEC}$ and relative standard deviation $\sigma_{\Delta TEC,Relative}$

$$dTEC = TEC_{mod} - TEC_{meas} \qquad \overline{\Delta TEC} = \langle dTEC \rangle$$

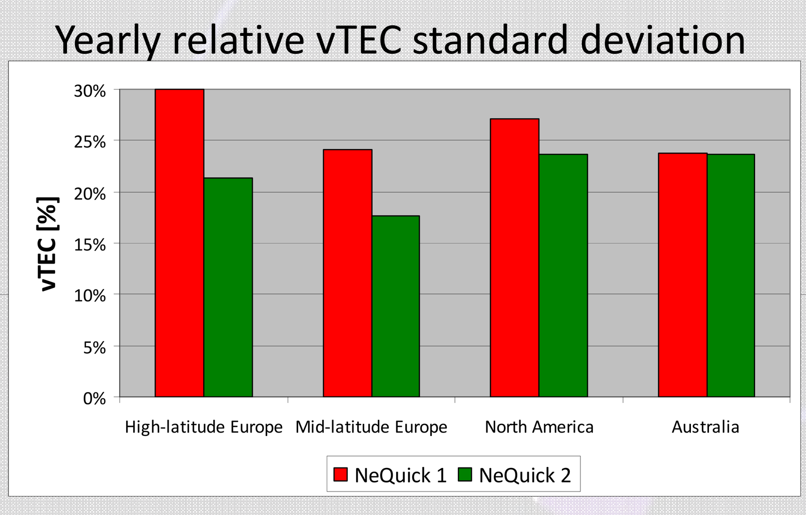
$$\sigma_{\Delta TEC} = \sqrt{\left\langle (dTEC - \overline{\Delta TEC})^2 \right\rangle} \qquad \sigma_{\Delta TEC,Relative} = \frac{\sigma_{\Delta TEC}}{\langle TEC_{meas} \rangle}$$

Ionosonde Parameters Constrain

Yearly vTEC mean



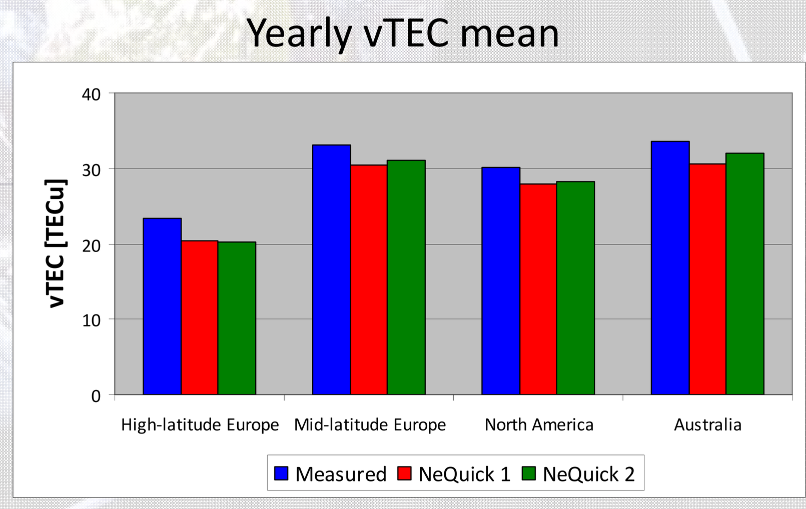
Yearly relative vTEC standard deviation



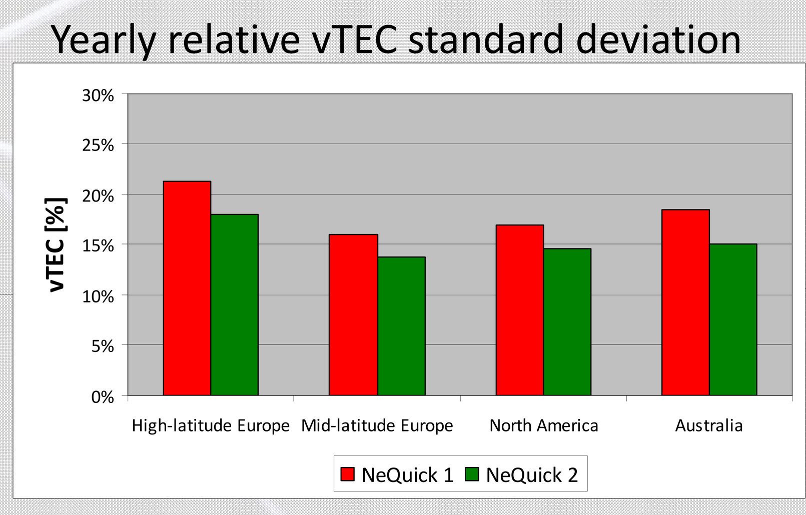
- Influence of **latitude**: lower mean TEC values at high-latitudes (TEC in TECu = 10^{16} e^{-} m^{-2})
- Average TEC **underestimation** of about 25% but potential bias in GPS TEC data to take into account (Bidaine et Warnant, 2009)
- **Bigger underestimation** with NeQuick 2 (inconsistency for high-latitude 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

Slant TEC Ingestion

Yearly vTEC mean



Yearly relative vTEC standard deviation



- **Bias absorbed thanks to ingestion**
  - Lower underestimation than for ionosonde parameters constrain
  - Even lower underestimation with NeQuick 2
- **Residual errors handled by ingestion**
  - Lower $\sigma_{\Delta TEC,Relative}$ (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)

Conclusion

- 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

Perspectives

- 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

- BIDAINE, B. and R. WARNANT (2009): Measuring Total Electron Content with GNSS:Investigation of Two Different Techniques, *Proc. 11th International Conference on Ionospheric Radio Systems and Techniques (IRST 2009).* http://orbi.ulg.ac.be/handle/2268/1553
- NAVA, B., S.M. RADICELLA, R. LEITINGER and P. COISSON (2006): A near-real-time model-assisted ionosphere electron density retrieval method, *Radio Sc.*, Vol. 41, RS6S16, doi:10.1029/2005RS003386
- NAVA, B., P. COISSON and S.M. RADICELLA (2008): A new version of the NeQuick ionosphere electron density model, *J. Atmos. and Sol.-Terr. Phys.*, in press, corrected proof. doi:10.1016/j.jastp.2008.01.015
- ORUS, R., B. ARBESSER-RASTBURG, R. PRIETO-CERDEIRA, M. HERNANDEZ-PAJARES, J. M. JUAN and J. SANZ (2007a): Performance of Different Ionospheric Models for Single Frequency Navigation Receivers, *Proc. Beacon Satellite Symposium 2007.*
- ORUS, R., Lj. R. CANDER and M. HERNANDEZ-PAJARES (2007b): Testing regional vTEC maps over Europe during the 17-21 January 2005 sudden space weather event, *Radio Sc.*, Vol. 42, RS3004. doi:10.1029/2006RS003515
- RADICELLA, S. M., and R. LEITINGER (2001): The evolution of the DGR approach to model electron density profiles, *Adv. Space Res.*, Vol. 27, No. 1, p. 35-40. doi:10.1016/S0273-1177(00)00138-1