Assessment of the NeQuick model at mid-latitudes using GPS TEC and ionosonde data

Benoît Bidaine (ULg – Geomatics, Belgium)
René Warnant (RMI, Belgium)
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\[ I = 40.3 \cdot \frac{TEC}{f^2} \]
1. Tools

*Modelling and measuring the ionosphere*
1. Tools
   
   Modelling and measuring the ionosphere

2. vTEC analysis
   
   NeQuick vs GPS TEC data
1. Tools
   Modelling and measuring the ionosphere

2. vTEC analysis
   NeQuick vs GPS TEC data

3. Case days
   Using GPS TEC data to identify situations for profile analysis
1. Tools
   *Modelling and measuring the ionosphere*

2. vTEC analysis
   *NeQuick vs GPS TEC data*

3. Case days
   *Using GPS TEC data to identify situations for profile analysis*

4. Profile analysis
   *NeQuick vs ionosonde data*
1. Tools
2. vTEC analysis
3. Case days
4. Profile analysis
1. Tools

NeQuick is an empirical « profiler ».

- **Output** = Ne $\rightarrow$ TEC with integration
- **Layer peaks** = anchor points
  $\rightarrow$ *monthly* median CCIR maps
- **Input** = ionospheric variations such as solar flux
It will be used on a daily basis for GALILEO SF users.

- Monthly flux replaced by *daily* parameter (Az)

1. Tools

- Measure sTEC
- Optimize Az
- Run NeQuick
TEC can be determined with GPS.

- **Geometric free** observables (code and phase)

\[
P^i_{p,GF} = 40.3 \cdot TEC^i_p \left( \frac{1}{f_{L1}^2} - \frac{1}{f_{L2}^2} \right) + CG^i_{p,GF} \quad \varphi^i_{p,GF} = -40.3 \cdot TEC^i_p \frac{f_{L1}}{c} \left( \frac{1}{f_{L2}^2} - \frac{1}{f_{L1}^2} \right) + CP^i_{p,GF}
\]

- **Differential code biases** estimated and eliminated

- **Latitude filter** $\rightarrow$ vertical: $\Phi_{sta} - 1^\circ \leq \Phi_{iono} \leq \Phi_{sta} + 1^\circ$

- **Mean** over 15 minutes
1. Tools

Ne profiles can be obtained with an ionosonde.

- Vertical sounding $\rightarrow$ virtual heights 
  
  $h' = \frac{cT}{2}$

  and plasma frequencies $f = 8.98 \cdot \sqrt{Ne}$

- Scaling $\rightarrow$ true heights and Ne

- Digisonde from UMLCAR
  
  $\rightarrow$ shifted Chebyshev polynomials
Ne profiles have different analytical formulations.

1. Tools

- NeQuick
  - Semi-Epstein layer
  - Sum of Epstein layers

- Digisonde
  - $\alpha$-Chapman function
  - Each layer in terms of shifted Chebyshev polynomials
    + valley
1. Tools

We can learn a lot using collocated data.

- **Dourbes** (Belgium; 50.1N 4.6E)
- **GPS station**: vTEC every 15 minutes
- **Digisonde** DGS256: profiles every hour till 2005 and every 20 minutes afterwards

→ use of collocated data for the last solar cycle
1. Tools

2. vTEC analysis

3. Case days

4. Profile analysis
Let’s compare measured and modelled vTEC evolution with time.

- **Variations:**
  1. solar activity (year and solar flux)
  2. season (month)
  3. UT (expected monthly median)

- **Statistics:**
  1. mean (bias) [or median]
     - over/underestimation
  2. RMS ➔ error
Solar activity
Tools

- **Data:**  1998 for average solar activity, 2000 to 2002 for high, 2006 for low

- **Model:** ITU-R version

  index $R_{12}$ (SIDC) or $\Phi_{12}$ (NOAA)
Solar activity analysis

TEC

Flux!
Solar activity

Conclusion

• SA index
  – Better monthly smoothed flux
  – Conversion formula to investigate

• Focus
  – Low SA level: 2006 ➔ overestimation
  – High SA level: 2002 ➔ underestimation
2. vTEC analysis

Season
Low solar activity level

6-month fluctuations
2. vTEC analysis

High solar activity level

Solar flux influence
2. vTEC analysis

• Ambivalent behaviour

• Flux influence

• Focus
  – Low SA level: July 2006 \(\rightarrow\) good
  – Autumn: October 2006 \(\rightarrow\) bad
  – Summer: July 2002 \(\rightarrow\) good
  – High SA level: February 2002 \(\rightarrow\) bad
1. Tools

2. vTEC analysis

3. Case days

4. Profile analysis
3. Case days

Low solar activity level

July: best month

Lowest RMS: 27th
3. Case days

Low solar activity level

July: best month

Lowest range comparable with GPS TEC uncertainty
Low solar activity level

3. Case days

Lowest RMS: 27th
Lowest range comparable with GPS TEC uncertainty

Maximum: 19h

July: best month

Lowest RMS: 27th
Lowest range comparable with GPS TEC uncertainty

Maximum: 19h
3. Case days

Low solar activity level

October: worst month

Highest RMS: 30th
3. Case days

Low solar activity level

October: worst month

False maximum: 17h30
3. Case days

Low solar activity level

October: worst month

Highest RMS: 30th

False maximum: 17h30
3. Case days

High solar activity level

July: best month

Lowest RMS: 10th
High solar activity level

3. Case days

July: best month

Small bias: 9h45
3. Case days

High solar activity level

July: best month

Lowest RMS: 10th

Small bias: 9h45
3. Case days

High solar activity level

February: worst month

Highest RMS: 26th
3. Case days

High solar activity level

February: worst month

Maximum underestimation: 10h30
3. Case days

High solar activity level

February: worst month

Highest RMS: 26th

Maximum underestimation: 10h30
3. Case days

Conclusion

• **Afternoon** maximum in summer:
  
  July 27th, 2006 – 19h

• **False** afternoon maximum in autumn:
  
  October 30th, 2006 – 17h40

• **Morning** maximum in summer:
  
  July 10th, 2002 – 10h

• **Underestimation at high solar activity**:
  
  February 26th, 2002 – 10h
1. Tools

2. vTEC analysis

3. Case days

4. Profile analysis
4. Profile analysis

July 27th, 2006
19h

Denser topside

Slightly less dense

F2 peak
Denser topside
Slower decrease
Slightly denser F2 peak
Denser bottomside
4. Profile analysis

July 10th, 2002
10h

Less Dense topside

Denser F2 peak
February 26th, 2002

10h

Huge difference for F2 peak
4. Profile analysis

Conclusion

- **Topside** to be investigated
- **CCIR maps** to be investigated
  - SA dependence
  - Month dependence
  - UT dependence
General conclusion

- Benefit from collocated data
- NeQuick behaviour: *varying* even at mid-latitudes
- Elements to investigate:
  - solar activity parameter
  - topside formulation
  - CCIR maps
Perspectives

- Ionosonde scaled characteristics
- Evolutions of NeQuick
- Other solar activity parameters
- Generalization:
  - other latitudes, sTEC, GALILEO
Framework

- **PhD** at University of Liège (Geomatics)
- Collaborations
  - **RMI** (Brussels)
  - **ESA/ESTEC** (TEC-EEP)
  - Others to come…
Ionosphere

Troposphere