GNSS ground based data as part of the ESPAS

M Mainul Hoque, Jens Berdermann, Martin Kriegel
Overview

- What are GNSS data?
- Impact of ionosphere on GNSS signals
  - Signal propagation delay
  - Signal strength fluctuations (scintillation)
- Ionospheric parameters derived from GNSS data
  - Total Electron Content
  - Electron density profile
  - scintillation indices
  - Slab Thickness
- ESPAS datasets from ground-based GNSS experiments and related applications
- ESPAS Value Added Services- TEC Time Series Plotter
What are GNSS data?

Ionospheric effects are relevant for technical systems of several kinds using radio frequencies below 10 GHz.

Trans-ionospheric signals propagating through the ionosphere!

Ionosphere vertical structure

$$TEC_V = \int n_e(h) \, dh$$

Electron density $$n_e$$

Day

Night

Refraction

Ray path

LoS

$$f_1 > f_2$$

$$f_2$$

$$f_1$$
The plasma of the ionosphere causes a delay of the radio signals resulting in an enlarged distance between the satellite and the measurement site. Plasma instabilities cause:

- Signal strength fluctuations
- Defocussing of the signals

Loss of the signal possible.
Ionospheric effects on GNSS signals

\[ \Phi = \rho + c(dt - dT) + d_I + d_A + d_{MP\Phi} + dq + dQ + \epsilon_{\Phi} \]

\[ \Psi = \rho + c(dt - dT) + d_{igr} + d_A + d_{MP\Psi} + dq + dQ + \epsilon_{\Psi} \]

Ionospheric delay

\[ d_I = \frac{40.3}{f^2} \int n_e ds = \frac{40.3}{f^2} TEC_{slnt} \]
TEC derived from GNSS measurements

\[
TEC_{\psi}^{s\text{ln}t} = \frac{f_1^2 f_2^2}{40.3 (f_1^2 - f_2^2)} [\Psi_2 - \Psi_1] + b_{RX\psi} - b_{TX\psi} + \epsilon_{N\psi}
\]

\[
TEC_{\phi}^{s\text{ln}t} = \frac{f_1^2 f_2^2}{40.3 (f_1^2 - f_2^2)} [\Phi_1 - \Phi_2] + B_{\text{ambiguity}} + b_{RX\phi} - b_{TX\phi} + \epsilon_{N\phi}
\]

\[
TEC_i^{s\text{ln}t} = TEC_{\text{NTCM}}^{s\text{ln}t} + b_{RX\psi} - b_{TX\psi} + \epsilon_{N\phi}
\]
Development of empirical TEC models in DLR

For modelling ionospheric TEC, a physical approach is used which takes into account the natural behaviour of the ionosphere as e.g. diurnal and semiannual variation, dependence from solar activity.

\[
\text{TEC} = \sum_{i=1}^{5} \sum_{j=1}^{3} \sum_{k=1}^{2} \sum_{l=1}^{2} H_i(h) \cdot Y_j(d) \cdot L_k(\varphi, \lambda, h, d) \cdot S_l(F10.7)
\]

H: Diurnal variation, Y: Seasonal variation, L: Geographic/geomagnetic dependence
S: Solar activity control

A family of TEC models has been developed at the DLR for monitoring different areas:

European region: NTCM-EU
Global TEC model: NTCM-GL


NTCM: Neustrelitz TEC Model
TEC map generation in SWACI/IMPC

**TEC**

\[
TEC_V = \int n_e(h)dh
\]

Measurement, Conversion, Assimilation of measurements, TEC-Map
Calibration to vertical into the TEC model

[Diagram showing GPS data, model data, weighting, and TEC map.]

[NTCM-EU, NTCM-GL]
Applying a model assisted technique, it is possible to extrapolate measurement information to regions outside the observation area.

1 s sampled GPS data
Model-assisted TEC reconstruction:
- Used model: NTCM-EU
- Least squares estimation of coefficients and biases
Amplitude and phase scintillation indices

To quantify the severity of scintillation events two scintillation indices are widely used (S₄ and σφ) as statistical measures.

The S₄-Index describes the amplitude or intensity fluctuation of a radio signal.

\[ S_4 = \sqrt{\frac{\langle A^4 \rangle - \langle A^2 \rangle^2}{\langle A^2 \rangle^2}} = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}} \]

with \( A \) = signal amplitude and \( I \) = signal intensity \( (I = A^2/2) \), mean value \( <> \) is computed over one minute.

The index \( \sigma_\phi \) describes the effect on the phase of the radio signal.

\[ \sigma_\phi = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (\phi_i - \langle \phi \rangle)^2} \]

The index \( \sigma_\phi \) is the standard deviation of the phase noise over one minute.
Spatial and temporal dependence of scintillation

- Geomagnetic latitude
  - Equatorial: greatest extremes
- Diurnal
  - Equatorial: maximum – evening/nighttime
- Seasonal
- Solar cycle
- Magnetic activity

Amplitude scintillation, Basu et al., 2002
Occurrence and classification of scintillation

- Duration of several minutes up to several hours
- Classification for different intensities:

<table>
<thead>
<tr>
<th>Value of $S_4$</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.2 &lt; S_4 \leq 0.4$</td>
<td>Weak</td>
</tr>
<tr>
<td>$0.4 &lt; S_4 \leq 0.6$</td>
<td>Moderate</td>
</tr>
<tr>
<td>$0.6 &lt; S_4 \leq 1.0$</td>
<td>Strong</td>
</tr>
</tbody>
</table>

[Gwal et al., 2004]
Equivalent slab thickness – physical meaning

- Equivalent slab thickness $\tau$
  
  \[ TEC = \tau \cdot NmF2 \]

- Slab thickness changes indicate deformation of the electron density profile

- Important information for estimating the driving forces of ionospheric perturbations

- Peak density $NmF2$

- Peak height $hmF2$

- Slab thickness
Equivalent Slab Thickness provided by SWACI

SWACI - TEC

http://swaciweb.dlr.de

IAP $f_{\text{o}F2}$

Slab thickness computation in NRT using SWACI-TEC over Juliusruh/IAP and corresponding ionosonde data of the IAP Kuehlungborn (54.4°N;13.4°E) with an update rate of 15 min.
NOA GNSS

Observed Properties
[receiver location: Athens, Greece]
- Raw data (RINEX files): Athens GNSS (NOA)
- TEC
  - Local estimates: Athens GNSS (NOA)
## Observed Properties

[receiver location: Chania (Greece – 35.51°N, 24.02°E)]

- Raw data (RINEX files) [time resolution: 60 min (since June 2007)]
  - CHA1 GPS RINEX data (INGV)
- Scintillation indices [time resolution: 15 min (since June 2007)]
  - CHA1 GPS Scintillation and TEC Parameters (INGV)
- TEC
  - Local estimates [time resolution: 60 min (since 2007)]
    - CHA1 GPS Scintillation and TEC raw data (INGV)
    - CHA1 GPS Scintillation and TEC Parameters (INGV)
<table>
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<tr>
<th>DLR GNSS</th>
<th>Observed Properties</th>
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<tr>
<td></td>
<td>TEC Maps/Grids</td>
</tr>
<tr>
<td></td>
<td>- European &amp; Global [2 x 2, 2.5 x 5 degrees, 15 min]</td>
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<tr>
<td></td>
<td>TEC derivatives</td>
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<tr>
<td></td>
<td>- Latitudinal gradients</td>
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<tr>
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<td>- European &amp; Global maps [2 x 2, 2.5 x 5 degrees, 15 min]</td>
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<tr>
<td></td>
<td>- Rate of change</td>
</tr>
<tr>
<td></td>
<td>- European &amp; Global maps [2 x 2, 2.5 x 5 degrees, 15 min]</td>
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</tbody>
</table>
### ESPAS datasets from ground-based GNSS experiments and related applications

<table>
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<tr>
<th>DLR GNSS</th>
<th>Observed Properties</th>
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<tbody>
<tr>
<td></td>
<td>TEC Median (27 day median)</td>
</tr>
<tr>
<td></td>
<td>- European maps [spatial/time resolution: 2 x 2 degrees, 15 min]</td>
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<tr>
<td></td>
<td>- Global maps [spatial/time resolution: 2.5 x 5 degrees, 15 min]</td>
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<tr>
<td></td>
<td>Scintillation indices [time resolution: &lt; 1 hour]</td>
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<tr>
<td></td>
<td>Slab Thickness [location/time resolution: Over Juliusruh and Tromso, &lt; 1 hour]</td>
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</tbody>
</table>
### Overview of ESPAS ground based GNSS data

<table>
<thead>
<tr>
<th>Raw data</th>
<th>(Athens, Chania)</th>
<th>(RINEX files)</th>
</tr>
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<tr>
<td>TEC local estimate</td>
<td>(Athens, Chania)</td>
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<tr>
<td>TEC maps</td>
<td>(European, Global)</td>
<td>DLR format</td>
</tr>
<tr>
<td>TEC derivatives (LAT, LONG, TIME)</td>
<td>(European, Global)</td>
<td>DLR format</td>
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<td>TEC median (27 day)</td>
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<td>Scintillation indices (S4, sigma phi)</td>
<td>Local estimates</td>
<td></td>
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<tr>
<td>Slabthickness</td>
<td>(Juliusruh and Tromso)</td>
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</table>
### Time period of SWACI products available at ESPAS

<table>
<thead>
<tr>
<th>Collection name</th>
<th>Asset (Instrument and/or Model)</th>
<th>Data file format</th>
<th>Time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maps TEC Assimiliated (EU)</td>
<td>gnssReceiver</td>
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<td>Scintillation Plots Neustrelitz</td>
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<td>Slab Thickness Plots Juliusruh</td>
<td>gnssReceiver</td>
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</table>
European TEC maps

Actual state

**Total Electron Content (TEC)**

2015-10-08 12:45:00 UT

27 day median

**TEC Median – 27 days**

2015-10-08 12:45:00 UT

Ionospheric Range Error (L1) / m

- 0.00
- 1.62
- 3.24
- 4.86
- 6.48
- 8.10
- 9.72
- 11.34
- 2.96
- 4.58
- 6.20

DLR
Global TEC maps

Actual state

27 day median
Monitoring of the ionospheric state

Example from the 27th February 2014 at 8 pm and 10 pm shows ionospheric disturbances above North America caused by a medium size geomagnetic storm. Such disturbances can have effects on the performance of Space Based Augmentation Systems (SBAS) such as the American WAAS or the European EGNOS system.
Ionospheric response in TEC during solar eclipse 20 March 2015

Actual state

Relative deviation from 27 day median
TEC Gradient maps

Longitude Gradient

Latitude Gradient

Time Gradient
DLR generated a scintillation network consisting of high rate GNSS stations (20/50/100 Hz) distributed along North-South and East-West direction to monitor ionospheric scintillation in real time.
Amplitude and phase scintillation indices

Toulouse (43.57° N, 1.47° E)

Amplitude scintillation

Phase scintillation

ESPAS available stations

✓ Neustrelitz, Germany
✓ Toulouse, France
✓ Teneriffa, Spain
Format Description- SWACI TEC Maps (TEC derivatives)

ASCII files
First line is header line specifying: product type, unit, product date, minimal and maximal latitude, minimal and maximal longitude, grid size, pixel size

Second line starts writing data for the specified grid (orientation of first cell: north west)
ASCII files
First line is header line specifying: GPS_Week, GPS_TOW, PRN, S4(CA), Sigma(L1,60Sec)/radian, -999.99 = invalid value
Second line starts writing data for the specified column
How to download GNSS ground based data via ESPAS?

Log in ESPAS Portal

https://www.espas-fp7.eu/portal/search.html#search
How to download SWACI/IMPC products via ESPAS?

Click **Assets**

Select **GNSS Receiver**
How to download SWACI/IMPC products via ESPAS?

Click **Observed Properties**

Select **Total Electron Content (I)**
How to download SWACI/IMPC products via ESPAS?

Click Time Period

Current Selections
Assets: GNSS Receiver
Observed Properties: Total Vertical Electron Content

Search by time period
Select a period of the observations [Option: specify the time of day to narrow down your results]

Time period [start to end in UTC]
From date 2013/01/01 00:00
To date 2013/07/01 00:00

Subset of day [Fancy]
Subset start 00:00
Subset end 23:59
Demonstration together with ESPAS Training School Students!!
Note for ESPAS Training School Students:

Please log in to the site https://www.espas-fp7.eu/portal/index.html. Go to the following page and download „TEC Time Series Plotter“ and „Demo Data“ in your PC. Take care about your operating system!