Characterisation of effects on current GNSS observing system

Marija Čokrlić
Technische Universitat Berlin
Department for Geodesy and Geoinformation Sciences

Overview

1. Observations
2. Ionosphere
3. Total electron content
4. High order ionosphere effect
5. Measurements
   1. Ground based
   2. Space based
6. Ionospheric models
7. Global and regional models, Small Scale Network
8. Scintillation
9. Scintillation monitoring at TU Berlin
10. Software under development at TU Berlin
11. Outlook
Observation equations for code and carrier phase - range

- Dual frequency code phase ($r$) and carrier phase ($\Phi$) observables

\[
\begin{align*}
  r &= \rho + c(dt - dT) + d_{lgr} + d_A + (d_{MP})_r + dq + dQ + \varepsilon_r \\
  \Phi &= \rho + c(dt - dT) - d_I + d_A + (d_{MP})_{\Phi} + dq + dQ + N\lambda + \varepsilon_{\Phi}
\end{align*}
\]

(1)

(2)

- To point out the ionosphere (3) and (4) are written

\[
\begin{align*}
  r &= \rho + d_{lgr} \\
  \Phi &= \rho + d_I
\end{align*}
\]

(3)

(4)
Ionosphere

<table>
<thead>
<tr>
<th>Layer</th>
<th>Height $^1$ [km]</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2</td>
<td>210-1000</td>
<td>Reduced during the night</td>
</tr>
<tr>
<td>F1</td>
<td>130-210</td>
<td>Completely disappears during the night</td>
</tr>
<tr>
<td>E</td>
<td>90-130</td>
<td>Present during the night and day</td>
</tr>
<tr>
<td>D</td>
<td>50-90</td>
<td>Present only during the day</td>
</tr>
</tbody>
</table>

1) Hoque, M.M. Higher order ionospheric propagation effects and their corrections in precise GNSS positioning
Total Electron Content

**slant TEC**
- Value given by integrating the number of free electrons along the signal path

\[ STEC = \int_{S}^{R} N_e(s) ds \]  \hspace{1cm} (5)

**vertical TEC**
- Total electron content in the zenith direction
- Relationship between VTEC and VTEC is described by mapping function:

\[ m_I(z) = \frac{STEC}{VTEC} = \frac{1}{\cos(z')} \]  \hspace{1cm} (6)

\[ \sin(z') = \frac{R_E}{R_E + H} \sin(z) \]  \hspace{1cm} (7)
Characterisation of effects on current GNSS observing system

Marija Čokrilic

Total Electron Content
High Order Ionospheric Effects

code phase: \[ r_i = \rho + \frac{p_i}{f_i^2} + \frac{q}{f_i^3} + \frac{t}{f_i^4} + d_i^{b(length)} \] (8)

carrier phase \[ \Phi_i = \rho - \frac{p_i}{f_i^2} - \frac{q}{2f_i^3} - \frac{t}{3f_i^4} + d_i^{b(length)} \] (9)

where \( p, q \) and \( t \) are coefficients of the first, second and third order ionospheric effects

\[ p_i = 40.3 \times sTEC \] (10)
\[ q = 2.2566 \times 10^{12} \int n_e B \cos \Theta \, ds \] (11)
\[ t = 2437 \int n_e^2 ds + 4.74 \times 10^{22} \int n_e B^2 (1 - \cos^2 \Theta) ds \] (12)
Ground based measurements

Global Ionospheric Map

- more than 100 GPS receivers connected in network
- current snapshot of TEC
- GIMs represent a new tool for monitoring global patterns of ionospheric weather
- GIMs are being used for global ionospheric delay calibrations, for scientific investigations of the upper atmosphere, and will be an important data source for the National Space Weather Program.

Source: http://iono.jpl.nasa.gov/gim.html
Ground based measurements

Ionosonde

- specific radar for examination of the ionosphere
- typical frequency interval is [1-40] MHz
- these pulses are reflected from various layers of ionosphere with data from ionosphere
- from received information ionosphere can be profiled (VTEC)
Space based measurements form satellite altimetry

**TOPEX/POSEIDON**

- Satellite radar altimetry provides height measurements of the instantaneous surface (sea, ice, or open water on land) with respect to a fixed reference
- Dual-frequency radar are needed
- VTEC is derived from satellite altimetry
- One of the system used was TOPEX/POSEIDON (primary purpose was to measure precise height of sea surface)
- Orbit on the height of 1,336km above the Earth in a 66° of inclination
Space based measurements form radio occultation

CHAMP

- VTEC is derived from radio occultation
- LEO orbit (<450)
- algorithm uses an adaptive (Champman layer superposed by a simple plasmasphere contribution) for estimating the topside ionosphere and plasmasphere above the CHAMP orbit²

---

Ionospheric models

• For positioning and navigation purposes using radio-systems the ionospheric models must allow to calculate delay along slant line between satellite and receiver antennas.
• the models make available “vertical delay”.
• mapping functions allow to convert vertical delays to delay along line-of-sight (slant range)
### Ionospheric models

<table>
<thead>
<tr>
<th>Physical models</th>
<th>Mathematical models</th>
</tr>
</thead>
<tbody>
<tr>
<td>theoretical</td>
<td>deterministic</td>
</tr>
<tr>
<td>empirical</td>
<td>stochastic</td>
</tr>
</tbody>
</table>

- **Physical models**
  - based on the physical laws which describe space- and time-dependent behavior of the ionosphere.
  - created using observations of ionosphere (scatter radars, ionosondes, GNSS observations)

- **Mathematical models**
  - deterministic
  - stochastic
  - based on physical properties of ionosphere but described using relatively simple mathematical expressions
  - from a large number of observations: stochastical models describing space- and time-dependent properties of ionosphere are derived
Global and Regional Models

1. Global
   - Bent, IRI, Klobuchar, NTCM-GL (DLR maps), CODE maps
2. Regional
   - high –latitude
   - mid –latitude
   - equatorial –region
3. Small Scale models
   - compute the positioning error only due to the ionosphere for a given baseline
   - Methodology:
     1. from geometric-free combination of double-difference phase measurements: neglecting multipath and noise
     2. compute ambiguity considering the whole double-difference period
     3. isolate the ionospheric residual term on each carrier
     4. compute the positioning error only due to the ionosphere through a least-square adjustment
**Selected ionospheric models**

<table>
<thead>
<tr>
<th>Model</th>
<th>Ionosphere Region</th>
<th>Database</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bent</td>
<td>Full profile</td>
<td>Ionosonde, Satellites</td>
<td>Parabolic and exponential segments</td>
</tr>
<tr>
<td>IRI</td>
<td>Full profile</td>
<td>Ionosonde, Inc. Scatter Radar, Satellites (TS, in-situ), Absorp. Rockets,</td>
<td>Recommended by URSI and COSPAR for international use</td>
</tr>
<tr>
<td>NeQuick</td>
<td>Full profile and plasmasphere</td>
<td>Ionosonde and VTEC</td>
<td>Epstein functions and plasmaspheric models COST European, ESA, and ITU-R models</td>
</tr>
</tbody>
</table>

Source: Bilitza D. Ionospheric Models for Radio Propagation Studies
Scintillation

• Signals interact with free electrons (expressed as TEC) along its transmission path
• Causes rapid fluctuations of the amplitude and the phase of signals
• Scintillations are due to the diffraction caused by irregularities in motion relative to the ray path.

AMPLITUDE SCINTILLATION:

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

• S4 is a dimensionless number with a theoretical upper limit of 1.0, commonly estimated over an interval of 60 seconds.

PHASE SCINTILLATION

• index which is defined as the standard deviation of the signal phase over a given time interval.
Scintillation: other parameters

**SCINTILLATION INTENSITY INDEX**

- Derived from recorded scintillation data
- Scintillation Intensity index (SI) is defined as:

\[
SI = \frac{P_{\text{max}} - P_{\text{min}}}{P_{\text{max}} + P_{\text{min}}}
\]

- \(P_{\text{max}}\) is the power of the 3rd peak down from the maximum excursion shown during a scintillation occurrence
- \(P_{\text{min}}\) is the power of the 3rd peak up from the minimum excursion
Scintillation monitoring at TU Berlin

1. step: Setup station

- receiver were run and in the moment continuously track state of ionosphere above TU Berlin
- Setup parameters:
  - Measurements epoch: 1Hz rate
  - I/Q correlation: 50Hz rate
  - Receiver and channel status: 0.1 Hz
  - navigation message: “on-change”
- form logged file, we will use information about
  - Amplitude scintillation index $S_4$ - is the standard deviation of the 50-Hz raw signal power
  - Phase scintillation index $\sigma_\phi$ - standard deviation of carrier phase
  - TEC - reported every 15 seconds
Scintillation monitoring at TU Berlin

2. step: what to do with data?

- develop software for processing scintillation and for validation of software
- implement models and high –order models
- tracking scintillation and use it for forecasting
- issue of warning messages: warn user “do not use data – high disturbances
- forecasting and distribution second and third order ionospheric corrections

Development of new algorithms for generation and prediction of ionospheric corrections for high precise GNSS

in cooperation with Ms. Kinga Wezka and prof. Galas
Software under development at TU Berlin

- UDP data stream contains GPS observations and broadcast ephemeris
- GPS raw data is sent epoch by epoch in proprietary receiver formats

To overcome the restrictions of most firewall additional UDP/TCP relay was developed and must be updated
Outlook

• develop TUB software – for scintillation
• set up permanent monitoring station at TU Berlin
• Upgrade and reimplement DLR scintillation tools
• post-process data from DLR
Thank you!