Ionospheric perturbations analysis in the South East Asia (SEA) region

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Short Outline

• Introduction
• MS Travelling Ionospheric Disturbances
• Ionospheric Activity Indices:
  • Single Receiver TID Indicator (SRTI)
  • Along Arc vertical TEC Rate (AATR)
• Results for the South East Asia (SEA) region
• Conclusions
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Introduction

- Nominal Ionosphere from ionospheric models is useful to predict the ionospheric delays affecting GNSS signals.

- Estimated values may be degraded due to large gradients of Electron Content (EC) in case of ionospheric perturbations.

- At low latitudes, like in the SEA region, the degradation could be specially critical.

- The capabilities to detect and mitigate those perturbations are of great interest since they can produce a significant impact on GNSS precise navigation performance.
Nominal Ionosphere based on IGS GIMs

VTEC absolute level
- SEA: 90 TECUs
- EU: 45 TECUs

VTEC gradients
- SEA: 0.3 cm/Km
- EU: 0.17 cm/Km

Diff. scales!
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MS Travelling Ionospheric Disturbances

• But… there can also be ionospheric perturbations affecting the performance of Ionospheric models.

• We have studied **Medium Scale Travelling Ionospheric Disturbances (MSTIDs)** since these perturbations have a huge impact in global GNSS precise positioning.

• In the past, we characterized MSTIDs for mid-latitudes*. Now, the ionospheric activity index is applied to the SEA region.

MSTIDs are ionospheric signatures of waves with periods from minutes to less than one hour, amplitudes of few TECU (tens of cm in L1) and velocities of 50-300 m/s.

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Ionospheric Activity indices

Single Receiver TID Indicator (SRTI)

- SRTI is based on analysing the curvature of the second time difference of the GPS ionospheric combination of observables \((d^2L_i)\) for each GPS receiver-satellite pair.

- SRTI ionospheric activity index is linked to the performance of precise navigation techniques such as Real Time Kinematics (RTK), Network RTK (like Virtual Reference Station, VRS), or Wide Area RTK (WARTK).

Along Arc Vertical TEC Rate (AATR)

- AATR is a measurement of the ionospheric perturbations in general.

- AATR is related with generalized fast STEC variations, affecting most of the satellites and during a large period, as we should expect under ionospheric activity.

- AATR is linked to the capability of Augmentation Systems, such as WAAS or EGNOS, to provide ionospheric corrections for single receiver users with a certain quality.

\[
AATR_i = \frac{\Delta STEC}{(M(\varepsilon))^2 \Delta t}
\]

\[
AATR = \sqrt{\frac{1}{N} \sum AATR_i^2}
\]
Along Arc vertical TEC Rate (AATR)

APV-I Daily availability vs. RMS AASG.

- A significant drop in availability is correlated with an increase of RMS AASG (and thus, of RMS AATR).
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Results

• By using the SRTI index, the ionospheric perturbations will be analysed and characterised in both temporal and spatial domains for GPS data gathered in the South East Asian (SEA) Region.

• The obtained results at such low latitudes will also be compared to those obtained in the past for mid-latitudes at Europe.

• In order to study the ionospheric perturbations in the SEA Region, more than one solar cycle has been studied covering years from 2000 to 2013.

• In this work, the occurrence of TIDs and other ionospheric perturbations in the SEA region will be assessed by studying their impact on several IGS receivers. Also, one additional receiver will be considered that will be located in Europe for comparison purposes.

• Finally, a comparison with AATR results will be given.
Selected receivers at the SEA region
Occurrence of ionospheric perturbations activity in terms of time and local time.

Different occurrence pattern between SEA and EU regions.
Most significant SRTI values

SRTI most significant detections for the percentil 99.9th (highest 0.01% of the SRTI values).
Most significant SRTI values

SRTI most significant detections for the percentil 99.9\textsuperscript{th} (highest 0.01\% of the SRTI values).

Solar cycle / Seasonal dependences

Most significant peaks after Solar Terminator

KUNM  time

LT

NTUS

PIMO
Most significant SRTI values

SRTI most significant detections for the **percentil 99.99th.**
Most significant SRTI values ($L_1$)

**PIMO**

*Figure 28* $L_1$ at 30 seconds sampling rate in function of time. Data obtained for the GPS ray between the IGS receiver PIMO and PRN25 during day of year 97, 2002. A TEC depletion occurs at around second 59430/60060.

**KUNM**

*Figure 30* $L_1$ at 30 seconds sampling rate in function of time. Data obtained for the GPS ray between the IGS receiver KUNM and PRN8 during day of year 250, 2001. A potential MSTID of more than 1 m of amplitude occurs at around second 54300.

**KUNM**

*Figure 29* $L_1$ at 30 seconds sampling rate in function of time. Data obtained for the GPS ray between the IGS receiver KUNM and PRN27 during day of year 271, 2000. A potential MSTID of more than 1 m of amplitude occurs at around second 54510.

**NTUS**

*Figure 31* $L_1$ at 30 seconds sampling rate in function of time. Data obtained for the GPS ray between the IGS receiver NTUS and PRN13 during day of year 267, 2001. A significant TEC depletion occurs at around second 48270.
Seasonal dependences

SRTI ionospheric perturbations activity in terms of the day of year for maximum and minimum of solar cycle.

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Daily dependences

Zoom of the SRTI ionospheric perturbations in terms of the local time for Equinoxes and Solstices.

- The ionospheric perturbations at the SEA region will mainly occur near the equinoxes and at night, after the Solar Terminator, during solar maximum.
AATR compared to SRTI

<table>
<thead>
<tr>
<th>IGS Receiver ID</th>
<th>Region</th>
<th>Latitude[^°]</th>
<th>Longitude[^°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAS1</td>
<td>Africa</td>
<td>27.61</td>
<td>344.37</td>
</tr>
<tr>
<td>KUNM</td>
<td>SEA</td>
<td>24.88</td>
<td>102.80</td>
</tr>
<tr>
<td>NKLG</td>
<td>Africa</td>
<td>0.35</td>
<td>9.67</td>
</tr>
<tr>
<td>NTUS</td>
<td>SEA</td>
<td>1.34</td>
<td>103.68</td>
</tr>
</tbody>
</table>
Most significant AATR values

Relationship between the AATR peak events and the ST.
AATR seasonal dependence

- Seasonal dependence for AATR RMS values is compatible with SRTI values.
AATR daily dependence

- Daily dependence for AATR RMS values is compatible with SRTI values.

- The highest values of AATR typically occur during the equinoxes and close to the Solar Maximum.
- The occurrence of high values of AATR also depends on the latitude: the lower the latitude the larger the occurrence.
- Large values of AATR only appear during certain hours after the ST.
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Conclusions

• The VTEC absolute level and the VTEC gradients obtained from the IGS GIMs are much higher in the SEA region than in Europe.

• The ionospheric perturbations activity is also greater for the SEA region.

• The detected ionospheric perturbations (MSTIDs and other phenomena) mainly occur near the equinoxes and at night, after the Solar Terminator.

• AATR and SRTI have led to similar conclusions regarding the solar cycle/seasonal/daily occurrence of perturbations.
Thank you very much!

• This study has been carried out in the frame of the projects:
  ❖ Growing NAVIS (FP7)
  ❖ ICASES (ESA)

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Back-up slides
Lc cycle-slip detector

- To detect ionospheric perturbations **you cannot use the geometry-free combination, since false cycle slips could be reported.**
- A new detector based on ionosphere-free combination Lc has been developed to match the real scenario better.
Single Receiver TID Index (SRTI)

• First of all, in order to cancel out the low frequency variations, a simple algorithm is applied to the GPS ionospheric combination $L_1$:

\[ L_I = L_1 - L_2 \]

\[ d^2L_I(t) = L_I(t) - \frac{1}{2}(L_I(t + \tau) + L_I(t - \tau)) \]

• Note that $L_I$ is proportional to the Slant Total Electron Content (STEC).

• We are working at 30s time resolution and $\tau$ is set to 300 s in order to enable the detection of MSTIDs (highest sensitivity for perturbations with periods of 600s). We are assuming a thin single layer model of the ionosphere at 450 Km and a masking angle in elevation of 30 degrees.

• In order to detect the perturbations in $d^2L_I$ automatically, the SRTI is applied considering a moving window that covers two times the adopted $\tau$, as follows:

\[ SRTI(t) = \frac{1}{N} \sum_{n=0}^{N-1} (d^2L_I(t + 30 * n))^2 \]

• SRTI ionospheric activity index is linked to the performance of precise navigation techniques such as Real Time Kinematics (RTK), Network RTK (like Virtual Reference Station, VRS), or Wide Area RTK (WARTK).
Along Arc vertical TEC Rate (AATR)

- AATR is linked to the capability of Augmentation Systems, such as WAAS or EGNOS, to provide ionospheric corrections for single receiver users with a certain quality. It is a measurement of the ionospheric perturbations, in general, which difficult the generation of an ionospheric model to be transmitted to the user.

- AATR is related with generalized fast STEC variations, affecting most of the satellites and during a large period, as we should expect under ionospheric activity. In order to avoid spurious values of Vertical TEC Rate (VTR), one can compute, for any receiver, the RMS of all the VTRs (all the satellites involved) during 1 hour.

- Deprojection in order to estimate the VTEC value associated to the receiver.

- Low elevation VTEC values are mitigated by using an elevation dependent weighting factor

\[
AATR_i = \frac{\Delta STEC}{(M(\varepsilon))^2 \Delta t}
\]

\[
AATR = \sqrt{\frac{1}{N} \sum AATR_i^2}
\]
Definition of an indicator of ionospheric activity

\[ \text{AATR} = \frac{VTR}{M(\varepsilon)} = \frac{\Delta \text{STEC}}{(M(\varepsilon))^2 \Delta t} \]

**AATR**: Along-Track TEC Rate  
**AASG**: Along-Track STEC Rate

**Spurious high values of the AATR:**

In TN1.2 it was shown that some large AATR values were associated to local effects or receiver mis-functioning. In order to avoid such spurious values of AATR, one can compute, for any receiver, the RMS of all the AATRs (all the satellites) during 1 hour.

Other ionospheric activity indicators and relationships:

\[ \text{AASG} = \frac{\Delta \text{STEC}}{\Delta s} = \frac{\Delta \text{STEC}}{v_{ipp} \Delta t} \]

\[ \text{AATR} = \frac{1}{(M(\varepsilon))^2} \quad \text{AASR} = \frac{\Delta \text{STEC}}{(M(\varepsilon))^2 \Delta t} \]

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## Most significant SRTI values

<table>
<thead>
<tr>
<th>Id</th>
<th>Station</th>
<th>year</th>
<th>doy</th>
<th>second</th>
<th>PRN</th>
<th>Tentative type of perturbation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PIMO</td>
<td>2002</td>
<td>097</td>
<td>59430/60060</td>
<td>25</td>
<td>TEC depletion</td>
</tr>
<tr>
<td>2</td>
<td>KUNM</td>
<td>2000</td>
<td>271</td>
<td>54510</td>
<td>27</td>
<td>MSTID</td>
</tr>
<tr>
<td>3</td>
<td>KUNM</td>
<td>2001</td>
<td>250</td>
<td>54300</td>
<td>8</td>
<td>MSTID</td>
</tr>
<tr>
<td>4</td>
<td>NTUS</td>
<td>2001</td>
<td>267</td>
<td>48270</td>
<td>13</td>
<td>TEC depletion</td>
</tr>
<tr>
<td>5</td>
<td>NTUS</td>
<td>2001</td>
<td>290</td>
<td>51570</td>
<td>4</td>
<td>TEC depletion</td>
</tr>
<tr>
<td>6</td>
<td>NTUS</td>
<td>2001</td>
<td>314</td>
<td>55290</td>
<td>10</td>
<td>TEC depletion</td>
</tr>
<tr>
<td>7</td>
<td>EBRE</td>
<td>2001</td>
<td>294</td>
<td>85320</td>
<td>22</td>
<td>MSTID</td>
</tr>
<tr>
<td>8</td>
<td>EBRE</td>
<td>2002</td>
<td>250</td>
<td>81330/81960</td>
<td>15</td>
<td>MSTID</td>
</tr>
<tr>
<td>9</td>
<td>EBRE</td>
<td>2003</td>
<td>301</td>
<td>39450-40170</td>
<td>9/26/29</td>
<td>Solar Flare</td>
</tr>
<tr>
<td>10</td>
<td>EBRE</td>
<td>2005</td>
<td>164</td>
<td>960/1590</td>
<td>21</td>
<td>MSTID</td>
</tr>
</tbody>
</table>

Most significant SRTI peaks and their potential cause
Lc cycle-slip detector (TBD)