Analysis of Ionospheric delay gradients over Thailand during geomagnetic storm on 8 September 2017

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Outline

1. Background and motivation.
2. Objective.
3. Ionospheric threat model parameters.
4. Experimental setup.
5. Experimental results.
6. Conclusion.
**Ground based augmentation system, GBAS**

- GBAS is developed to support the aircraft landing based on **GNSS signal**.
- The **plasma bubble** is the phenomena that originate from magnetic **equatorial region**.

**Thailand** is located near the magnetic equator, then free electron over the area are **variation!!!**

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John Retterer, www.nasa.com
Ionospheric anomaly impact on GBAS

Background and motivation

 Ionosphere

<table>
<thead>
<tr>
<th>Front speed ((v))</th>
<th>Upper bound of Ionospheric delay gradient ((\nabla I))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(v &lt; 750) m/s</td>
<td>500 mm/km</td>
</tr>
<tr>
<td>(750 \leq v \leq 1500) m/s</td>
<td>100 mm/km</td>
</tr>
</tbody>
</table>

- The International Civil Aviation Organization (ICAO) has recommended every country member to analyze her own ionospheric background characteristic.

- The ionospheric threat model consist of
  1.) front slope
  2.) front speed
  3.) front width

Literature reviews

Storm-enhanced density (SED) over CONUS (mid-latitude)

- Red: delay 20 m
- Blue: delay 0 m

Large ionospheric spatial gradient (360mm/km) in low-elevation satellites.

[J. Lee et al., 2011]
In previous work, S. Pullen et al. describe the impact that extreme ionospheric spatial gradients occurring during severe ionosphere storms have on GNSS Ground Based Augmentation Systems (GBAS) over CONUS.

[S. Pullen et al., 2009]

Discovered spatial gradients in slant ionosphere delay of as large as 425 mm/km over baselines of 50-100 km. This large gradients could cause the hazardous vertical position errors for GBAS users.
The results show that the ionospheric delay gradients varying from 28 to 178 mm/km during plasma bubble occurrences.

[Z. Wang et al., 2017]

[S. Rungraengwajiake et al., 2015]

[M. Kim et al., 2015]
Objective

This work aims to study the ionospheric irregularity and its travelling time period during storm date, 8 September 2017.

1. Absolute TEC values.
2. Ionospheric delay gradients.
Ionospheric threat model parameters

The Ionospheric threat model is the model for estimate the risk affected GBAS, the ICAO has recommended every country member to analyze her own ionospheric background characteristics.

**Ionospheric delay (m)**

- **Front speed**: \( V = \frac{D_{k1,k2}}{\Delta t} \text{ m/s} \), \( \Delta t = \text{lagtime} \left[ R_{xy} \right] \text{ sec} \)

  \[ R_{xy}(\tau) = E\{x_{i+\tau}y^*_i\} = E\{x_iy^*_{i-\tau}\} \]

- \( D \) = distance between two reference stations
- \( \Delta t \) = travelling time of plasma bubble
- \( R_{xy} \) = Cross-correlation of STEC from two stations

**Front slope**: \( \nabla I = \frac{I_{k1}^s - I_{k2}^s}{D_{k1,k2}} \text{ mm/km} \), \( \text{Ionospheric delay}: \ I = \frac{40.3 \text{STEC}}{f^2} \text{ m} \)

- \( f \) = frequency
- \( s \) = Satellite
- \( k_1, k_2, k_3 \) = reference stations

*\( f_1 = 1575.42 \text{ MHz}, \ f_2 = 1227.60 \text{ MHz} \)
Experimental setup

- The data from KMITL and STFD stations are used to analyze the front speed and front slope parameters.
- The data are obtained at every second.

![Diagram showing the experimental setup]

- STFD station
  - Antenna
  - Coaxial cable
  - GPS receiver
  - ProPak®-V3
- KMITL station
  - Antenna
  - Coaxial cable
  - GPS receiver
  - DL-V3™
  - Serial

STAMFORD-GPS

Internet

Data Server

RINEX files format
Experimental setup (cont.)

Absolute TEC diagram

1. Rinex files (o-file and n-file) → Pre-processing (remove some cycle slip) → STEC computation → VTEC computation → The absolute TEC
   - Remove The satellite biases
   - The receiver biases calculation


Experimental results

The solar flare occurred on 6 September 2017.
The STEC over Thailand is fluctuated on 8 sept. 2017

\[ D_{st} \] and VTEC at KMITL and STFD stations.

[Graph showing \( D_{st} \) and VTEC over time with a peak around September 8, 2017]
Experimental results

STEC on 8 September 2017/DOY251

Front speed

<table>
<thead>
<tr>
<th>PRN</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>167</td>
</tr>
<tr>
<td>14</td>
<td>162</td>
</tr>
<tr>
<td>16</td>
<td>104</td>
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<td>18</td>
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<tr>
<td>31</td>
<td>182</td>
</tr>
<tr>
<td>32</td>
<td>109</td>
</tr>
</tbody>
</table>

The average of front speed is 153 m/s.
Experimental results

KMIT station

STFD station

Ionospheric delay gradients

The maximum ionospheric gradient is obtained from PRN10 which is 96.4 mm/km
Experimental results

The example results form **PRN26**

STEC with 30 degrees elevation mask

The separation distance between observed EPBs over KMITL station is ~132 km.
Additional results

The GBAS availability is degraded on this day.

DOY251 (8 September 2018)
Conclusions

1. The ionospheric threat model parameters are analyzed on 8 September 2017 during storm occurred with the Dst index decreasing from -20 to -140 nT.

2. To study the ionospheric irregularity and its travelling time period, slant total electron content (STEC) is analyzed.

3. The result shows that the maximum ionospheric delay gradient which is obtained from PRN10 is approximately 96 mm/km and the average of anomaly front speed is 153 m/s. The estimated separation distance between EPB is 132 km.

4. The ionospheric threat model parameters are important for the aviation, so, the long-term study of ionospheric disturbance is also an essential issue.
Thank you

Q&A