Consistency of DORIS and GPS Assessments for the Real-time Global Ionospheric Maps

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• Motivation and background

• RT-GIM generation with GNSS Technique

• RT-GIM validation with DORIS & GNSS Techniques

• Conclusions and future work
Motivation

- Validation of ionospheric electron content models
- Data-driven IONO models within Geodetic community
  Using ground-based GNSS data to estimate the distribution of ionospheric total electron contents (TECs) in a thin-shell approximation
- Performance validation of IONO models with GNSS technique
  - Comparison w.r.t GNSS absolute TECs
    **Slant/vertical absolute TECs**, using code leveled carrier phase, but affected *code biases, leveling errors, obs. noises, multipath effects and mapping errors* etc.
  - Comparison w.r.t GNSS relative TECs
    **Relative TECs (rate of TECs)**, using dual-frequency carrier phase, concept of *dsTEC*
- Performance validation of IONO models with altimeter satellites
  **Vertical absolute TECs** to altimeter orbit height, affected by bias calibration errors
Comparison of diff. TEC sources for IONO model performance validation

<table>
<thead>
<tr>
<th></th>
<th>GNSS TEC</th>
<th>GNSS dsTEC</th>
<th>Altimeter vTEC</th>
<th>DORIS dsTEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs.</td>
<td>GF comb.+ CLC</td>
<td>GF Comb.+ Phase</td>
<td>GF Comb.</td>
<td>GF Comb.+ Phase</td>
</tr>
<tr>
<td>TEC types</td>
<td>Absolute (V/S)</td>
<td>Relative</td>
<td>Absolute (V)</td>
<td>Relative</td>
</tr>
<tr>
<td>Data coverage</td>
<td>Mainly over continents</td>
<td>Only over oceans</td>
<td></td>
<td>Globally uniform distribution</td>
</tr>
<tr>
<td>Assessment types</td>
<td>Self- or external consistency</td>
<td>External consistency</td>
<td></td>
<td>External consistency</td>
</tr>
</tbody>
</table>

**Purposes of the research**

- Extend the current methods for the independent validation of IONO electron content models (GNSSs, Altimeters -> DORIS)
- Routine retrieval of **IONO info. from DORIS dual-freq. phase obs.**
- Extension of DORIS applications in GNSS community, and as the first step by **routine generation of DORIS relative TEC info.** for ionosphere sensing
• **CAS Ionosphere Analysis Center of the IGS**
  
  - Routine generation of rapid (carg) and final (casg) GIMs since 2014
  - New Ionosphere AC (1/7) of the IGS since 02/2016
  - Deliver to CDDIS on routine basis since 01/2017 (data: 1998-now)
  - Routine RT-GIM generation since 3rd quarter of 2017

- Tracking networks – IGS + MGEX (> 300 sites)
- Observations – GPS(L1+L2), GLONASS(L1+L2), BeiDou(B1+B3 since 2016)
- Global grids – ΔLon X ΔLat (5.0 X 2.5)  Temporal resolution – 1 hour (30 mins since mid-2016)
RT-GIM Generation

- Real-time GNSS data processing at CAS
  - IGS+MGEX (mainly) RT data streams
  - ~120 stations
  - supporting GPS+GLO+GAL+BDS
  - SW — IGGNtrip (modified BNC, Win+Linux)
• RT-IONO SW developed at CAS

Mount point (Account required): products.gipp.org.cn/CAS01
RT-GIM validation

• DORIS and GNSS dsTEC assessment
  • Input data: dual-frequency phase obs.
  • Retravel of IONO info: geometry-free combination
  • $L_i(t_k)$ denotes phase derived TEC at epoch $t_k$
  • $L_i(t_{ref})$ denotes phase derived TEC with highest satellite elevation of the arc
  • dsTEC is calculated from

  \[
  \text{dsTEC}(t_k) = L_i(t_k) - L_i(t_{ref})
  \]

  • Accuracy of dsTEC is much higher than that of the TECs derived from code leveled carrier phase technique
Details in calculating GNSS (GPS) and DORIS (Jason-3) dsTEC

<table>
<thead>
<tr>
<th>Terms</th>
<th>GPS dsTEC</th>
<th>Jason-3 DORIS dsTEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs. Comb.</td>
<td>L4 (geometry-free comb. of dual-freq. phases)</td>
<td></td>
</tr>
<tr>
<td>Obs. interval</td>
<td>30 s</td>
<td>10 s</td>
</tr>
<tr>
<td>Cycle slip detection</td>
<td>IONO residual algorithm + MW comb.</td>
<td>IONO residual algorithm + $3\sigma$ criterion</td>
</tr>
<tr>
<td>Cycle slip repair</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>Obs. noise</td>
<td>ignored</td>
<td></td>
</tr>
<tr>
<td>Satellite elevation cut-off</td>
<td>10°</td>
<td></td>
</tr>
<tr>
<td>Max satellite elevation</td>
<td>No detection</td>
<td>20°</td>
</tr>
<tr>
<td>within each arc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks for Jason-3</td>
<td>* Geometry corrections in satellite and receiver parts are applied</td>
<td></td>
</tr>
<tr>
<td>DORIS data processing</td>
<td>** Jason-3 TECs NOT converted to GPS orbit height</td>
<td></td>
</tr>
</tbody>
</table>
RT-GIM validation

- Experimental setup
  - Time span: 001/2018-060/2018
  - Selected sites: 14, globally distributed
  - GIMs: CRTG (real-time, 5 mins), CASG (final, 30 mins) & IGSG (final, 2 hours)
  - TEC references: GPS & Jason-3 DORIS dsTEC, GPS vTEC (bias-free)
Comparison of GIMs w.r.t GPS (left) and DORIS (right) dsTEC

- TEC sources: GPS dsTEC
- Time: UT 0:00-04:40, 001/2018
- Data interval: 30 s
- GPS satellite: G23

- TEC sources: DORIS dsTEC
- Time: UT 17:00-17:25, 001/2018
- Data interval: 10 s
- Altimeter satellite: Jason-3
RT-GIM validation

- Comparison w.r.t GPS dsTEC
RT-GIM validation

- Comparison w.r.t Jason-3 DORIS dsTEC
RT-GIM validation

- Relationship between GPS and Jason-3 DORIS dsTEC errors
Comparison of RT and final GIMs w.r.t diff TEC sources (001-060, 2018)

<table>
<thead>
<tr>
<th></th>
<th>CRTG*</th>
<th>CASG*</th>
<th>IGSG*</th>
</tr>
</thead>
<tbody>
<tr>
<td>w.r.t GPS vTEC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bias</td>
<td>-0.11</td>
<td>-0.09</td>
<td>0.64</td>
</tr>
<tr>
<td>Std</td>
<td>1.68</td>
<td>0.83</td>
<td>1.03</td>
</tr>
<tr>
<td>Rms</td>
<td>2.17</td>
<td>1.22</td>
<td>1.51</td>
</tr>
<tr>
<td>w.r.t GPS dsTEC</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Bias</td>
<td>0.31</td>
<td>0.26</td>
<td>0.45</td>
</tr>
<tr>
<td>Std</td>
<td>2.36</td>
<td>1.77</td>
<td>1.86</td>
</tr>
<tr>
<td>Rms</td>
<td>2.45</td>
<td>1.86</td>
<td>1.97</td>
</tr>
<tr>
<td>w.r.t DORIS dsTEC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bias</td>
<td>0.37</td>
<td>0.34</td>
<td>0.63</td>
</tr>
<tr>
<td>(Jason-3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std</td>
<td>2.64</td>
<td>2.20</td>
<td>2.22</td>
</tr>
<tr>
<td>Rms</td>
<td>2.69</td>
<td>2.26</td>
<td>2.34</td>
</tr>
</tbody>
</table>

(*Unit: TECu)
Conclusions

• Extension of current method to validate the performance of IONO electron content models using DORIS data (in addition to GNSS techniques)

• Easy handling of DORIS carrier phase measurements compared to that of GNSS

• Quality of DORIS-derived dsTEC info comparable to that of GPS

• Validation of CAS’s real-time (URTG) and final (CASG) GIMs w.r.t dsTEC sources derived from GPS and Jason-3 DORIS phase observations

• RMS of URTG compared to GPS and DORIS dsTEC are 2.45 and 2.69 TECu, respectively

• Advantages of DORIS technique (site distribution, frequencies, independent assessment)
Future work

• **Routine generation** of relative IONO TECs using dual-frequency phase observations of DORIS-series missions

• Definition of **DIRIS TEC file format (internal)**, and make them available to users who are interested via CAS FTP archive

• **Application** of DORIS data in ionosphere sensing
  
  • Ionospheric irregularity monitoring (RT or NRT)
  • Global ionospheric map generation (TEC modeling)
Thanks for your attention

If any questions, please feel free to contact:
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