International GNSS Service Workshop 2018

CAS Ionosphere Associate Analysis Center: Status Report
—— Recent Activities within IGS

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CAS: Chinese Academy of Sciences
Overview

1. Introduction of the CAS IAAC
2. Validation of the final GIM product from 2015
3. Definition and estimation of OSB(DCB) with MGEX
4. New product for real-time global ionospheric map
5. Development of global and regional ROTI maps
6. Conclusions
1. Introduction of the CAS IAAC

1.1 The research history of CAS IAAC

- 1995, start to study the variation of ionosphere using GPS.
- 2001, a new approach for generating the ionospheric TEC map over China region was developed, naming DADS (Different Areas Different Stations).
- 2007, a simplified and well-performance global ionospheric model was developed for BDS’s broadcast ionospheric model.
- 2012, the two-step method, named IGGDCB, for the determination of satellite and receiver DCB using only a few global station was proposed.
- 2013, the SHPTS method is proposed for calculating the GIM.
- 2015, GIMs from 1998 to 2015 were re-processed using SHPTS approach, and participated in the GIM validation organized by IGS ionospheric WG.
- 2017, begin to broadcast the real-time global ionospheric maps and OSB products.
1. Introduction of the CAS IAAC in China

1.2 CAS IAAC was nominated as the 5th IGS IAAC

- The CAS was nominated as a new IGS ionosphere Associate Analysis Center during the IGS Workshop held at Sydney, Australia in 2016.
- The CAS IAAC is administered by the Academy of Opto-Electronics (AOE, located at Beijing, China) and the Institute of Geodesy of Geophysics (IGG, located at Wuhan, China).
- The coordinator of CAS center is Prof. Yunbin Yuan, and the main researchers are Dr. Zishen Li and Dr. Ningbo Wang with more than 3 PhD candidates.
2. Validation of the final GIM product from 2015

- **GIM** is the traditional and essential product for the IGS ionospheric workgroup.
- Tracking networks – IGS + MGEX (about 300 sites)
- Observations – **GPS, GLONASS, BDS** (since 2016)
- Global grids – ΔLon X ΔLat (5.0 X 2.5)
- Temporal resolution – 1 hour (30 mins since mid-2016), 15 mins
- Method: **SH** (global TEC modeling) + **modified GTS** (local TEC modeling)
2. Validation of the final GIM product from 2015

- The GIM from 2015 to now has been further validated using the dSTEC only from GNSS phase observation and the vertical TEC from altimeter satellites JASON-3.

**Validation by JASON-3**

<table>
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<th>Bias</th>
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<th>RMS</th>
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<tr>
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<td>UPCG</td>
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</tr>
<tr>
<td>IGSG</td>
<td>2.13</td>
<td>3.50</td>
<td>4.22</td>
</tr>
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</table>
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<th>Bias</th>
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<th>RMS</th>
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<tr>
<td>CASG</td>
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<td>1.97</td>
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<tr>
<td>CODG</td>
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<tr>
<td>IGSG</td>
<td>0.29</td>
<td>1.79</td>
<td>1.87</td>
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</table>
2. Validation of the final GIM product from 2015

- The correlation coefficients of GIM from each IAAC and the IGS final product is analyzed.

![Graph showing correlation coefficients and weights]

- The correlation coefficient for CODG and JPL is the largest.
- The accuracy of JPLG over the ocean is not very good enough.
- The weights of each individual GIM is suggested to be different for different areas, such as the land and ocean.
3. Definition and estimation of OSB(DCB) with MGEX

- Differential code biases (sat. and rec. parts)
  - defined as the biases between code obs. at the same/diff. frequencies
  - needed for code-based positioning, bias-free TEC extraction, etc.
  - multi-GNSS DCBs required for new emerging constellations & new signals

- CAS’s MGEX DCB products
  - Routine estimation of daily GPS, GLO, BDS and Galileo DCBs since 10/2015
  - An alignment procedure added for the automatic generation of weekly and monthly DCB solutions since early 2017
  - Galileo E6 and QZSS signals were added since 05/2018
  - Supporting all trackable multi-GNSS signals within MGEX network
    GPS(9) + GLONASS(5) + BeiDou(2) + Galileo(7) + QZSS(6)
  - Daily DCB solutions available at CAS, IGN and CDDIS archives, weekly and monthly solutions available at CAS archive.
3. Definition and estimation of OSB(DCB) with MGEX

- How to easily handle multi-GNSS biases during current multi-freq & multi-constellation situation?

**DCB (Differential Code Biases) -> OSB (Observation-Specific Biases)**

\[
P_{L_{i,x}} = \rho_{los} + c \cdot \delta t_r - c \cdot \delta t^s + \tau_{L_{i,x}}^S + \tau_{r,L_{i,x}} + \alpha_i \cdot I + T + \varepsilon \left( P_{L_{i,x}} \right) \\
P_{L_{j,z}} = \rho_{los} + c \cdot \delta t_r - c \cdot \delta t^s + \tau_{L_{j,z}}^S + \tau_{r,L_{j,z}} + \alpha_j \cdot I + T + \varepsilon \left( P_{L_{j,z}} \right)
\]

(where, \( i/j \) denotes the signal frequency, and \( x/z \) denotes the signal type)

**Satellite DCB:**

\[
DCB^s \left( L_{i,x}, L_{j,z} \right) = \tau_{L_{i,x}}^S - \tau_{L_{j,z}}^S
\]

**Receiver DCB:**

\[
DCB_r \left( L_{i,x}, L_{j,z} \right) = \tau_{r,L_{i,x}} - \tau_{r,L_{j,z}}
\]

**CDMA OSB:**

\[
\tau_{L_{i,x}}^S, \tau_{L_{j,z}}^S, \tau_{r,L_{i,x}}, \tau_{r,L_{j,z}}
\]

**FDMA OSB:**

\[
\left( \tau_{L_{i,x}}^S + \tau_{r,L_{i,x}} \right), \left( \tau_{L_{j,z}}^S + \tau_{r,L_{j,z}} \right)
\]
3. Definition and estimation of OSB(DCB) with MGEX

- **Highlights for multi-GNSS OSB estimation**
  - One code bias set for *each individual observable*
  - Code observation selection: *predefined list* (RINEX 3 format)
  - Bias reference: sat. clock convention (IF combination)
  - Bias reference selection: *priority list*
  - Reference definition: zero-mean condition/constraint
  - **Different OSB** parameterization applied for CDMA and FDMA (GLO, affected by *inter-channel bias*) signals:
    - **CDMA signals**: \( SAT_{osb}, REC_{osb} \)
    - **FDMA signals**: \( SPR_{osb} \)
  - Global and regional modeling is introduced in the OSB estimation at CAS.
3. Definition and estimation of OSB(DCB) with MGEX

- Estimation of BDS and Galileo OSB for the new signals

Beidou satellite C2I OSB solutions of BDS-2 and BDS3-IOV (C31-C34)

Galileo satellite C1C, C5Q and C6C OSB solutions (doy 152-273, 2018)
3. Definition and estimation of OSB(DCB) with MGEX

Weekly STD of Galileo OSB solutions

Weekly STD of Galileo satellite (E201) C1C and C6C OSB solutions

STD of Galileo satellite C1C, C5Q and C6C OSB solutions (doy 152-273, 2018)

More validation result can be found on the poster PS06-06

“Multi-GNSS code biases handing: an observation specific perspective”
4. New product for real-time global ionospheric map

- The **spherical harmonic function** has been considered as one of the sophisticated approaches for modeling the variations of TEC in global scale.
- The **distribution** of global GNSS stations is **uneven** (less over the ocean) and particularly the **number** of stations for real-time data stream is very **limited**.

![Distribution of global GNSS stations that can be used for final product generation](image)

![Currently distribution of real-time GNSS stations](image)
4. New product for real-time global ionospheric map

- The approach of real-time GIM Generation is developed by **combining the real and predicted ionospheric TEC** to avoid the limitation of global real-time data stream.

- The predicted TEC is calculated from a 2-day forecast SH-based ionospheric model.

  - **Real TEC**: phase-leveling code
  - **DCB**: correction using the solution one-day before.
  - **TEC Prediction**: using the coefficients of SH function, and the predicted TEC is considered as the pseudo-observation and the weight is adjusted following the distances between the corresponding grid-point and nearby stations.
4. New product for real-time global ionospheric map

- The real-time GIM is routinely validated individually by UPC (Prof. Manuel) and CAS (Dr. Zishen Li and Ningbo Wang).
- The vTEC, dSTEC from GNSS stations and vTEC from altimeter satellite are introduced as the reference for validation.

The real-time GIM based on about 120 stations can achieve the accuracy of about 1.0-2.0 TECu, and it is likely better than the rapid product from IGS.
4. New product for real-time global ionospheric map

- The real-time GIM is also broadcast to the smartphone with the real-time orbit and clock and it can **improve the accuracy of smartphone positioning**, particularly in the vertical component (about 50%).

More validation result can be found on the poster PS11-03

**“Modeling Real-time Global Ionospheric Map based on the Spare and Uneven Distributed GNSS Stations”**

<table>
<thead>
<tr>
<th></th>
<th>Android</th>
<th>4.16</th>
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<td>With Ion.</td>
<td>2.14</td>
<td>2.39</td>
<td>3.14</td>
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<tr>
<td>Improve</td>
<td>48.56%</td>
<td>42.96%</td>
<td>59.33%</td>
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</table>
5. Development of global and regional ROTI maps

• IGS IONO WG plans to provide ROTI maps (motivation) from 2017.
• Developing a new ionosphere activity index – RROT
• ~ 2000 GPS receivers processed pre day (post-processing mode)
• Routine products for ionospheric irregularity monitoring, such as ROTI, RROT, AART...
• Product files provided in IONEX-like format
• Routine validation w.r.t IS obs. from Canadian network (high-lat. of Canada)
• RT products are coming soon

More validation result can be found on the poster PS11-04

“RROT: a new ionospheric activity index for ionospheric irregularity monitoring”
5. Development of global and regional ROTI maps

- Tracking networks – IGS+EPN+USCORS+ARGN (~2000 sites)
- Observations – GPS(L1+L2)
- Global grids – ΔLon X ΔLat (5.0 X 2.5)
- Temporal resolution – 1 hrs (& 15 mins)
5. Development of global and regional ROTI maps

- IGS+USCORS (~1200 sites)
- GPS + GLONASS (L1+L2)
- Grid resolution:
  - $\Delta$Lon X $\Delta$Lat (5.0 X 2.5)
- Temporal resolution:
  - 15 mins
5. Development of global and regional ROTI maps

- EPN network (~120 sites)
- GPS + GLONASS (L1+L2)
- Grid resolution:
  - $\Delta$Lon X $\Delta$Lat (2.0 X 2.0)
- Temporal resolution:
  - 15 mins
6. Conclusions

This presentation will be closed with a brief introduction of our ftp archive.
ftp.gipp.org.cn

/products/ionex/
- final GIM
- rapid GIM
- real-time GIM

/products/dcb/
- daily DCB and OSB
- weekly DCB and OSB
- monthly DCB and OSB
- TGD solutions

/products/iondist/
- Globe
- Europe
- USA
- Australia

/products/brdion/
- refined Klobuchar for GPS
- refined Nequick for GAL
- BDGIM model for BDS
Many thanks to Prof. Andrzej Krankowski, Prof. Manuel Hernández-Pajares and Dr. Oliver Montenbruck for their helpful discussions and comments as well as the coordination in the delivery of CAS’s products to the IGS.