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

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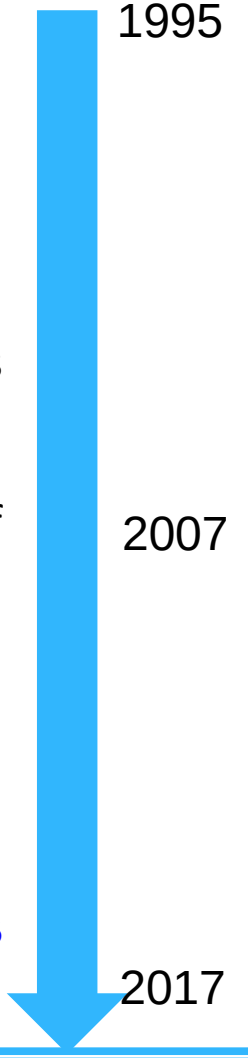
Overview

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

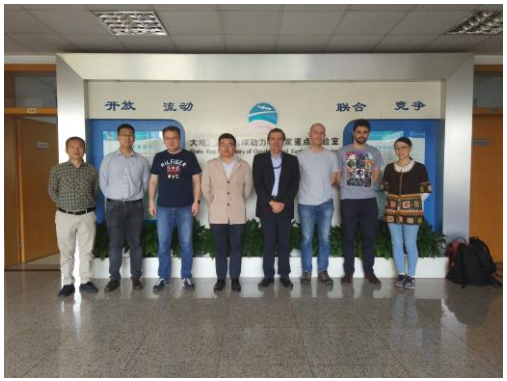
- 1995, start to study the variation of ionosphere using GPS.
- 2001, a new approach for generating the ionospheric TEC map over China region was developed, naming **DADS** (Different Areas Different Stations).
- 2007, a simplified and well-performance global ionospheric model was developed for **BDS's 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**.



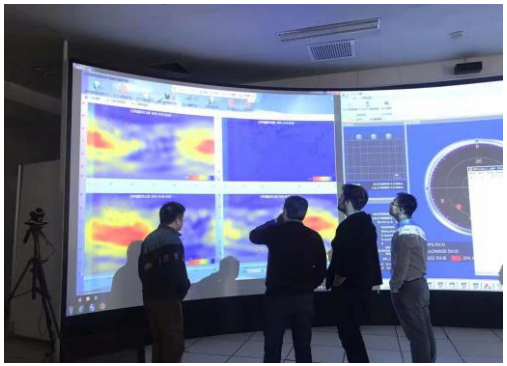
1. Introduction of the CAS IAAC in China

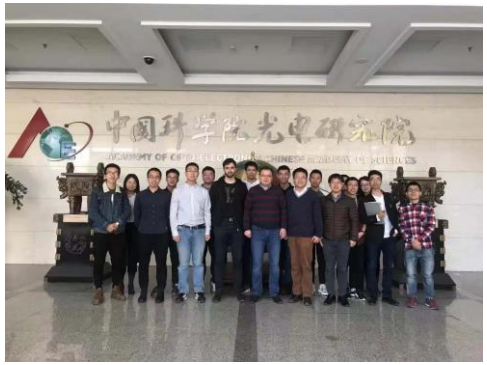
1.2 CAS IAAC was nominated as the 5th IGS IAAC

- 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.



Institute of Geodesy of Geophysics
Wuhan, China





Academy of Opto-Electronics
Beijing, China

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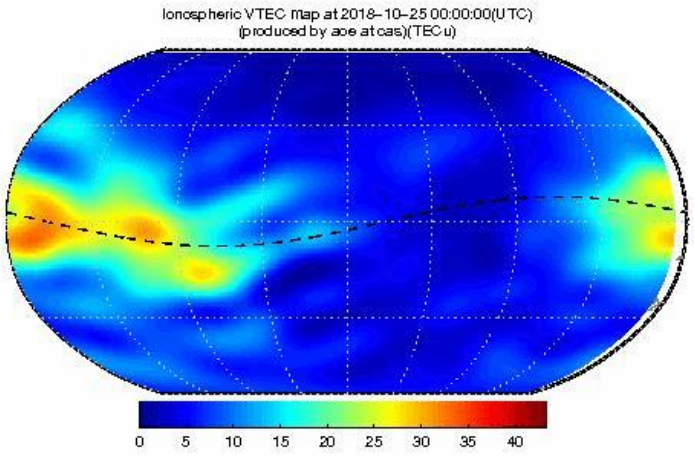
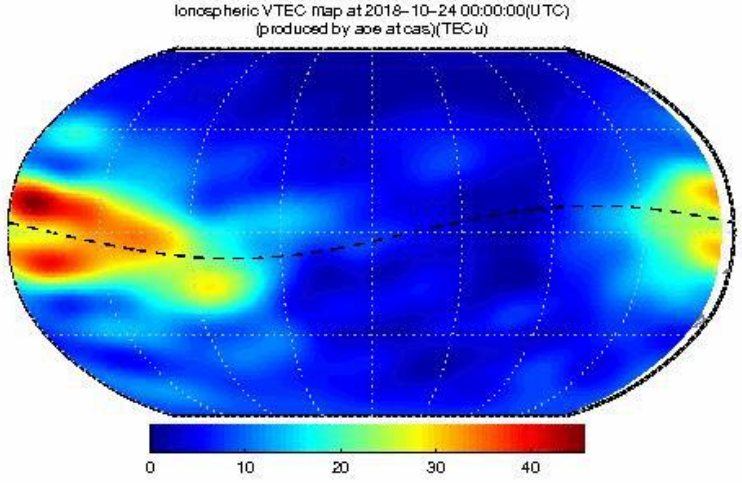
2. Validation of the final GIM product from 2015

- **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)

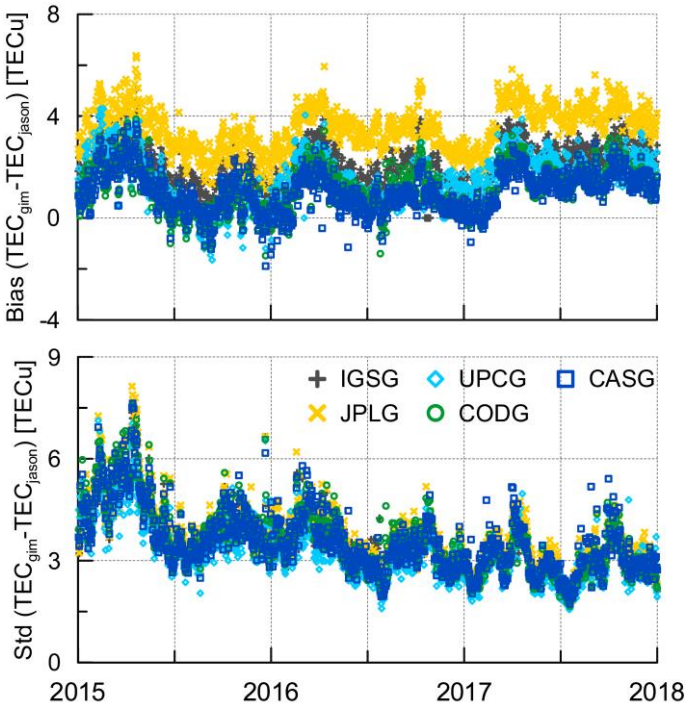




2. Validation of the final GIM product from 2015

- 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



	Bias	STD	RMS
CASG	**1.03**	**3.60**	**3.90**
CODG	1.16	3.60	3.94
ESAG	0.85	4.18	4.43
JPLG	3.55	3.71	5.52
WHUG	0.81	4.21	4.48
UPCG	1.52	3.29	3.80
IGSG	2.13	3.50	4.22

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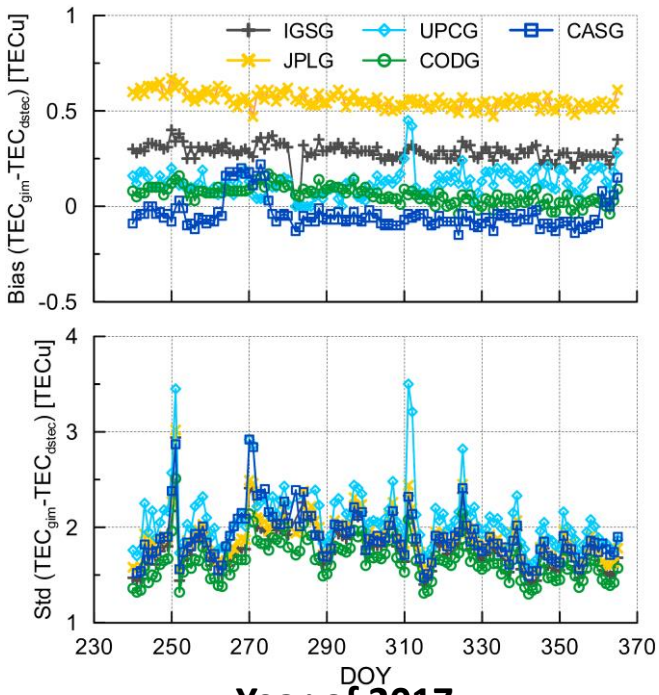
2. Validation of the final GIM product from 2015

- 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 dSTEC



Year of 2017

	Bias	STD	RMS
CASG	**-0.04**	**1.91**	**1.97**
CODG	**0.06**	**1.64**	**1.72**
ESAG	0.17	2.13	2.22
JPLG	0.56	1.89	2.01
WHUG	0.19	4.13	4.21
UPCG	0.13	2.08	2.13
IGSG	0.29	1.79	1.87

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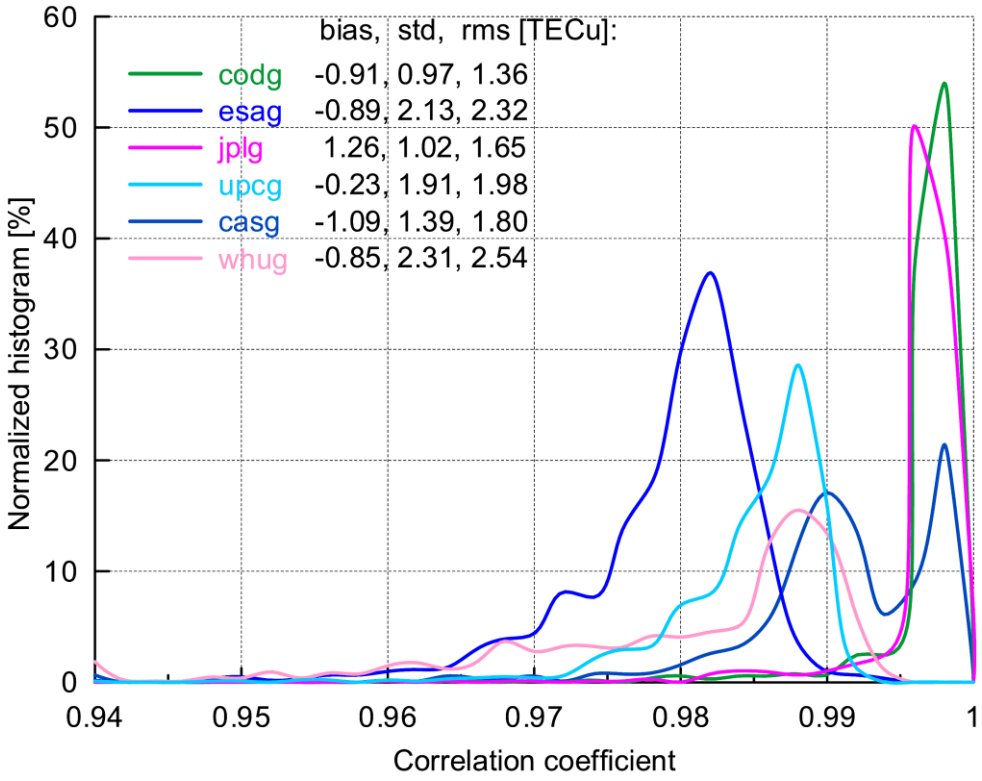
2. Validation of the final GIM product from 2015

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



- ✓ 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.**

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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.

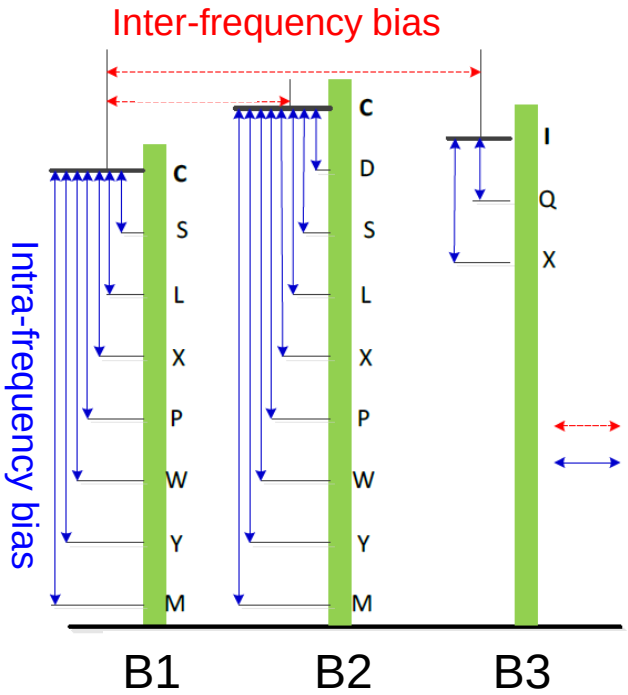
3. Definition and estimation of OSB(DCB) with MGEX

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

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

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

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



Satellite DCB:

$$DCB^s\left(L_{i,x}, L_{j,z}\right) = \tau^S_{L_{i,x}} - \tau^S_{L_{j,z}}$$

Receiver DCB:

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

CDMA OSB:

$$\tau^S_{L_{i,x}},\ \tau^S_{L_{j,z}},\ \tau_{r,L_{i,x}},\ \tau_{r,L_{j,z}}$$

FDMA OSB:

$$\left(\tau^S_{L_{i,x}} + \tau_{r,L_{i,x}}\right),\ \left(\tau^S_{L_{j,z}} + \tau_{r,L_{j,z}}\right)$$

3. Definition and estimation of OSB(DCB) with MGEX

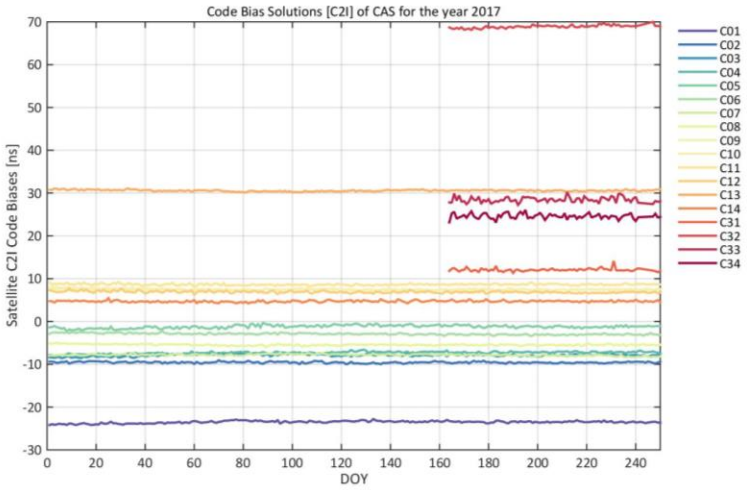
- **Highlights for multi-GNSS OSB estimation**
  - One code bias set for each individual observable
  - Code observation selection: predefined list (RINEX 3 format)
  - Bias reference: sat. clock convention (IF combination)
  - Bias reference selection: priority list
  - Reference definition: zero-mean 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}**

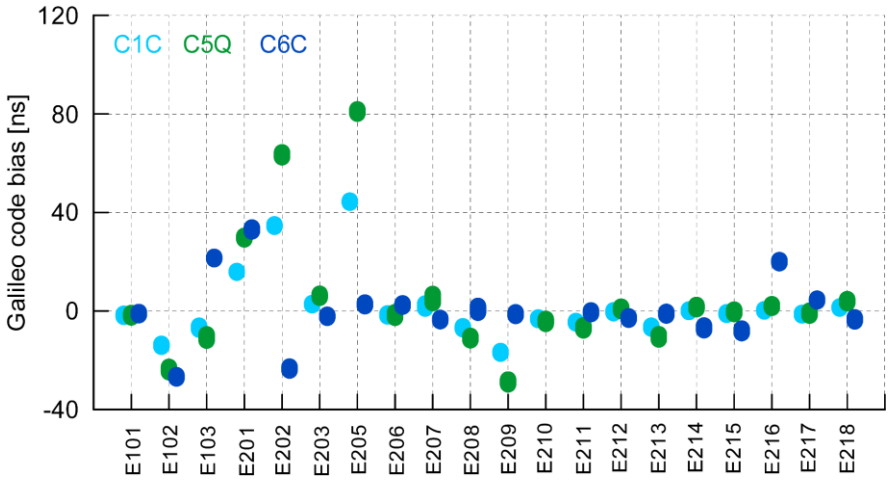
  - Global and regional modeling is introduced in the OSB estimation at CAS.

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)

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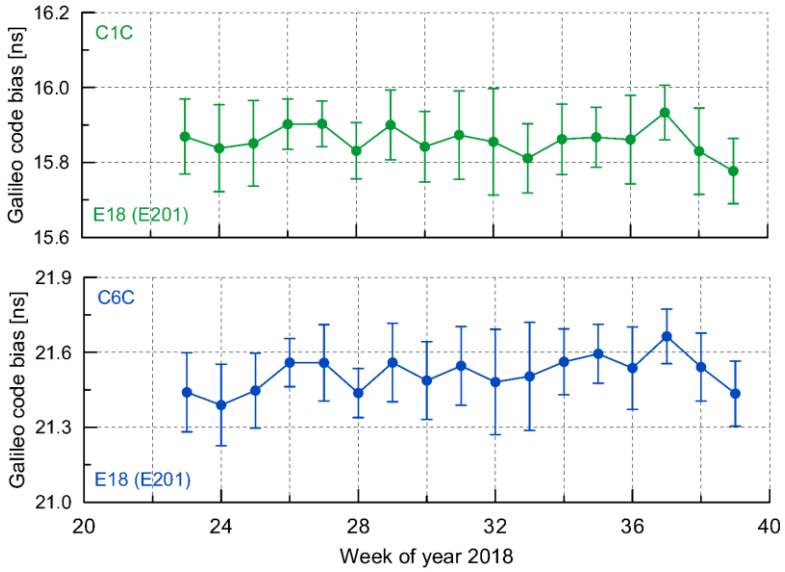
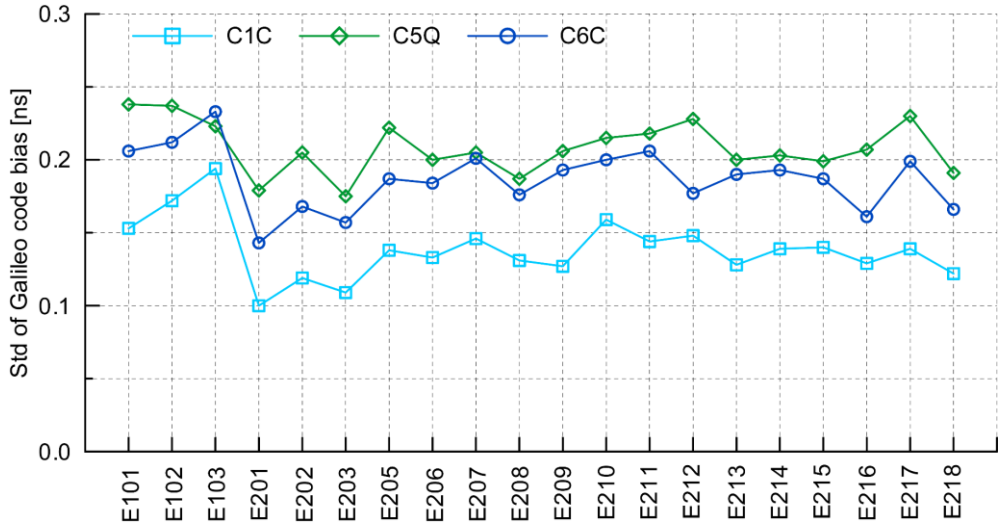
3. Definition and estimation of OSB(DCB) with MGEX

- **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*"

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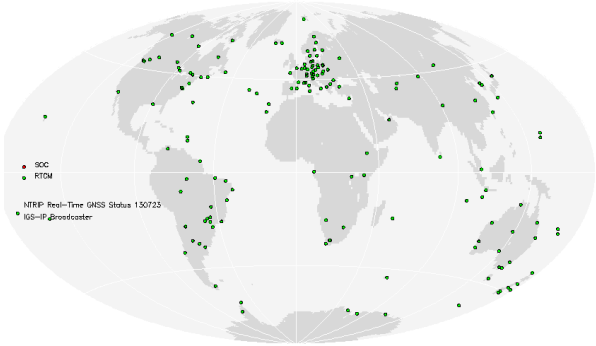
4. New product for real-time global ionospheric map

- 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**.

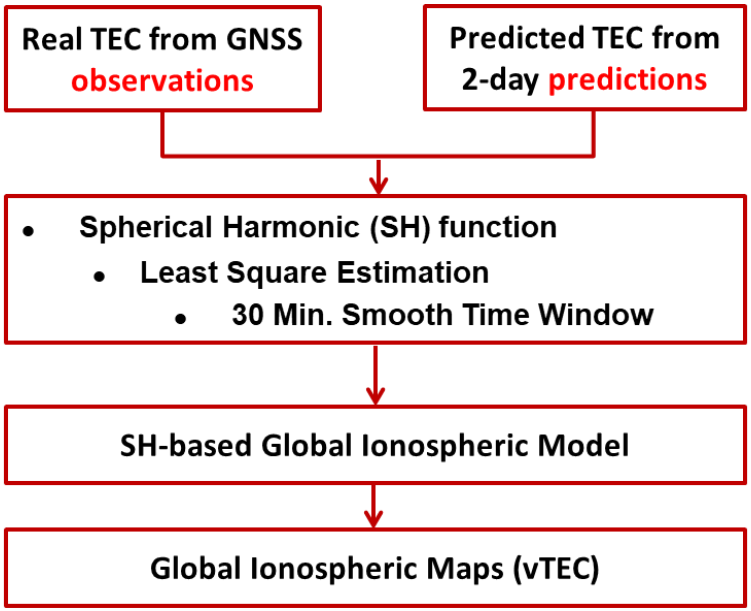
Distribution of global GNSS stations that can be used for final product generation



Currently distribution of real-time GNSS stations

4. New product for real-time global ionospheric map

- The approach of real-time GIM Generation is developed by **combing 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.

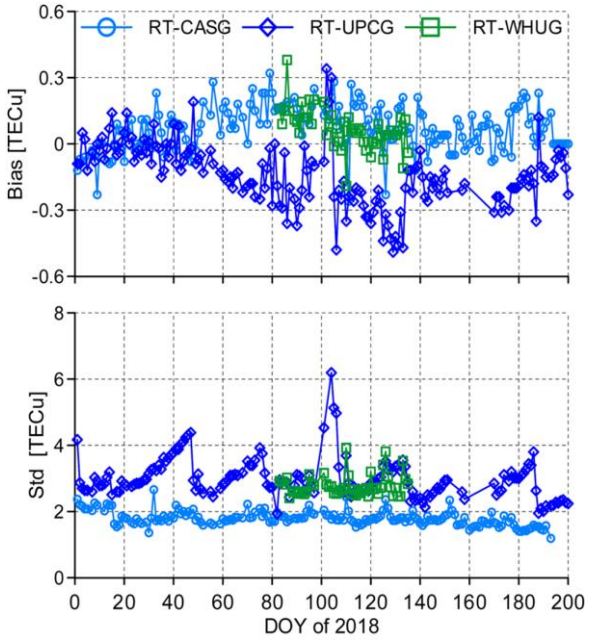


- **Real TEC：** phase-leveling code
- **DCB :** correction using the solution one-day before.
- **TEC Prediction:** using the coefficients of SH function, and the predicted TEC is considered as the pseudo-observation and the weight is adjusted following the distances between the corresponding grid-point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

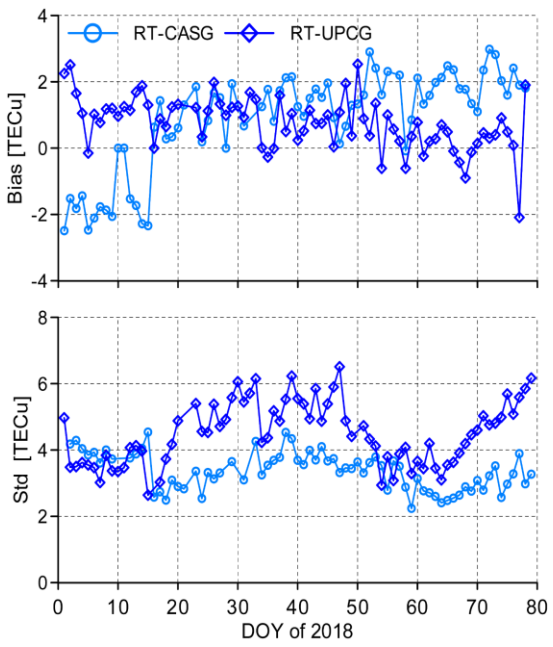
4. New product for real-time global ionospheric map

- 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.

dSTEC



JASON-3



The real-time GIM based on about 120 stations can achieves the accuracy of **about 1.0-2.0 TECu**, and it is likely **better than the rapid product** from IGS.

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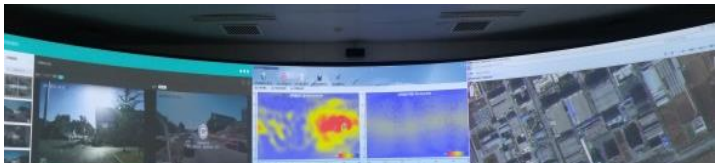
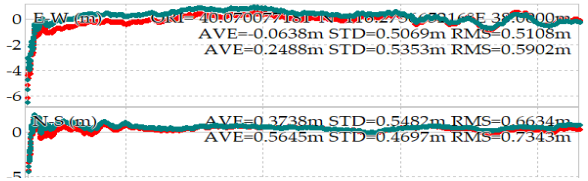
4. New product for real-time global ionospheric map

- The real-time GIM is also broadcast to the smartphone with the real-time orbit and clock and it can **improve the accuracy of smart phone 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*"

Android	4.16	4.19	7.72
With Ion.	2.14	2.39	3.14
Improve	48.56%	42.96%	59.33%

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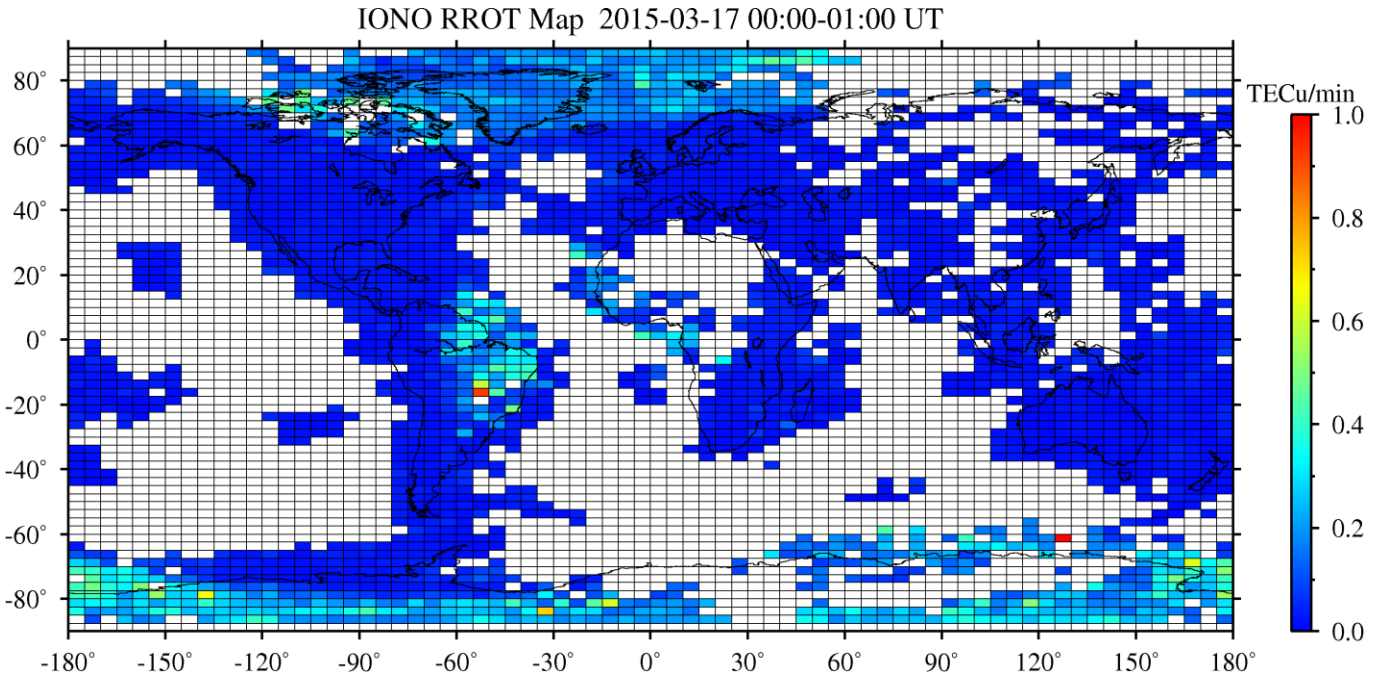
5. Development of global and regional ROTI maps

- 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)
- Data archive: ftp://ftp.gipp.org.cn/product/iondist/

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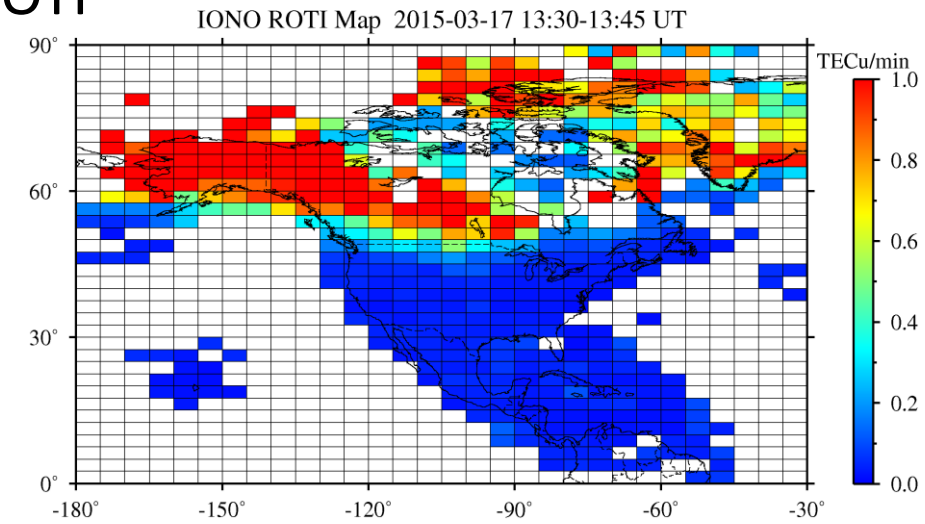
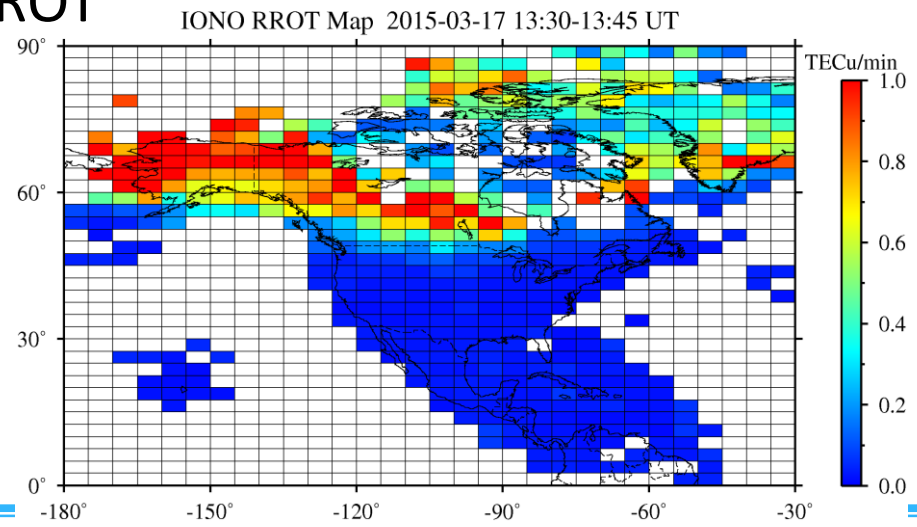
5. Development of global and regional ROTI maps

ROTI



RROT



- IGS+USCORS (~1200 sites)
- GPS + GLONASS (L1+L2)
- Grid resolution:
  - ΔLon X ΔLat (5.0 X 2.5)
- Temporal resolution:
  - 15 mins

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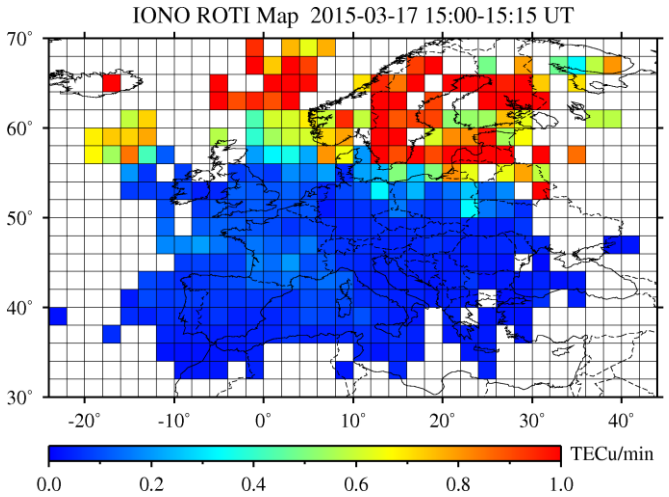
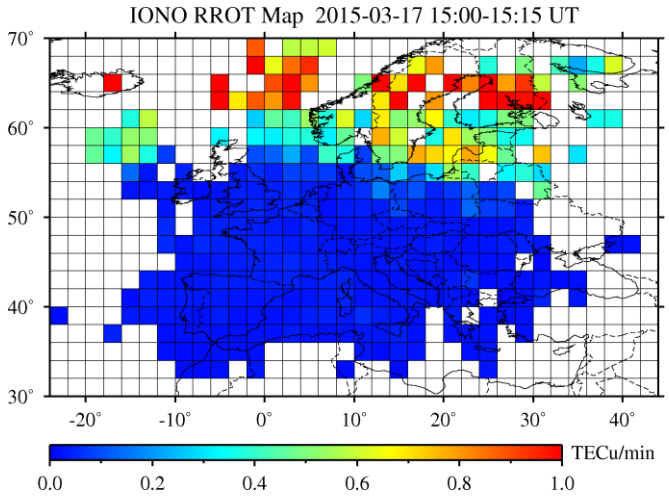
5. Development of global and regional ROTI maps

ROTI



RROT



- EPN network (~120 sites)
- GPS + GLONASS (L1+L2)
- Grid resolution:
  - ΔLon X ΔLat (2.0 X 2.0)
- Temporal resolution:
  - 15 mins

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6. Conclusions

This presentation will be closed with a brief introduction of our **ftp archive.**

ftp.gipp.org.cn

/product/ionex/

- final GIM
- rapid GIM
- real-time GIM

/product/dcb/

- daily DCB and OSB
- weekly DCB and OSB
- monthly DCB and OSB
- TGD solutions

/product/iondist/

- Globe
- Europe
- USA
- Australia

/product/brdion/

- refined Klobuchar for GPS
- refined Nequick for GAL
- BDGIM model for BDS

Tanks for your attention!

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.

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