ACADEMY OF OPTO-ELECTRONICS,CHINESE ACADEMY OF SCIENCES

Validation of the Global Ionospheric Map (GIM) from the new IGS Ionospheric Associate Analysis Center CAS (*Chinese Academy of Sciences*)

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1. Introduction

Since the mid-to-late 1990s, first Global Positioning System (GPS), and later Global Navigation Satellite Systems (GNSS) have become one of the most important ways to continuously observe the global ionosphere with high spatial and temporal resolution. To set up a global public service for monitoring ionospheric Total Electron Content (TEC) based on ground GNSS receivers, the International GNSS Service (IGS) working group on ionosphere was established in 1998.

Due to the outstanding achievement on the GNSS-based ionospheric modeling research, **the Chinese Academy of Sciences (CAS) has been nominated as a new IGS Ionospheric Associate Analysis Center (IAAC) in the IGS workshop 2016 held in Sydney, Australia.** Thus, there are currently five IGS IAACs which submitted the Global Ionospheric Map (GIM) product to IGS, including CODE, JPL, ESA, UPC and CAS. The mission of GIM generation in CAS is undertaken by the Academy of Opto-Electronics in Beijing and the Institute of Geodesy and Geophysics in Wuhan. CAS started to routinely submit the GIM product to IGS from the beginning of 2017, and the product can be downloaded from CDDIS (cddis.gsfc.nasa.gov) and GIPP (ftp.gipp.org.cn).

This paper describes briefly the approach used by the CAS for GIM generation and illustrates the GIM performance validation results during the period of 1998-2016. The validation is carried out by comparing the CAS-GIM with the ionospheric TEC directly extracted from the raw GNSS observations, the IGS-combined GIM and the ionospheric TEC from TOPEX satellites, as well as that the GIMs from other IAAC are introduced for comparison.

2. Methodology

The approach used for the GIM generation in CAS is named as SHPTS proposed by *Zishen Li (2015),* where SHPTS means Spherical Harmonic function Plus generalized Trigonometric Series functions. This approach is to improve the accuracy of GIM computation based on the increase in global GNSS stations. In the proposed approach, the variation in global ionospheric TEC is modeled by the SH function with the order and degree of 15, and the variation in local ionospheric TEC is modeled by the GTS function over each individual station. Ionospheric VTEC at the grid points that are near contributing stations is estimated using the corresponding local models, while ionospheric VTEC at the grid points that are far from contributing stations is calculated using the global model. Compared with the existing approaches, the SHPTS could improve ionospheric TEC estimates significantly over the area covered by real GNSS data and ensure a reasonable accuracy over the area where no real data are available. In addition, a software package has been developed for daily GIM processing in an automatic mode. More about SHPTS can be found from *Zishen Li (2015).*

Zishen Li et al., SHPTS: towards a new method for generating precise global ionospheric TEC map based on spherical harmonic and generalized trigonometric series functions. Journal of Geodesy, 2015. 89(4).

3. Validation result of CAS-GIM calculated using SHPTS

The GIM from January 1st 1998 to December 31st, 2015 (about 1.5 solar cycle) has been generated using the global GPS and GLONASS data for this validation, and the number of stations contributing to the daily GIM computation is shown by Fig. 1, where the number of stations used by other IAACs is also given for comparison. It can be observed that the number of global stations increases from approximately 70 at the beginning of 1998 to approximately 300 at the end of 2015. The number of stations used in CAS is a little larger than that used by CODE. Moreover, the number of contributing stations in the southern hemisphere is much lower than that in the northern hemisphere because most of the current GPS stations are only installed on land.

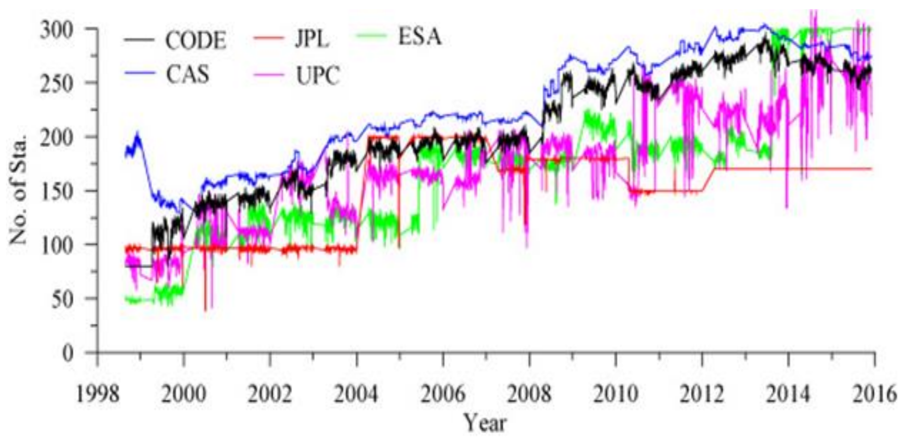

Fig.1 Number of global stations contributed to the GIM generation at each IAAC.

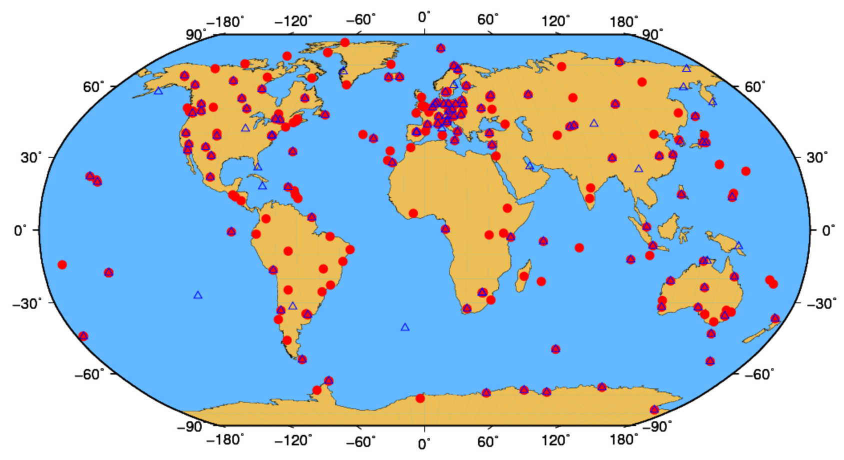

Fig.2 Distribution of contributed stations in 1999 (Δ) and 2015(●).

3.1 Validation with the GPS-based ionospheric TEC

The LOS ionospheric TEC can be directly extracted from the raw dual-frequency measurements by removing the DCB in satellite and receiver. Considering the different levels of ionospheric activities at different latitudes, the global area is divided into 9 latitudinal bands with an interval of 15◦ and the precision of the GIM in each band is individually calculated using only the ionospheric TEC from those stations located in the corresponding band. The validation result is shown in Fig. 3. It can be observed that the CAS-GIM is more precise (better than 2.0TECu in all latitudes) than the GIM from other IAAC. Table 1 shows the average precision of GIM at different levels of ionospheric activities. It can be found that the ionospheric TEC from CAS-GIM is more consistent with that of the dual-frequency measurements of GPS data. The global average precision of the CAS-GIM is more precise (approximately 0.5–1.8TECu) than that of the current IAAC. This is because the ionospheric TEC over each station is individually modeled by the GTS function, and the local ionospheric model can capture the variation of the ionospheric TEC more accurately than the global ionospheric model.

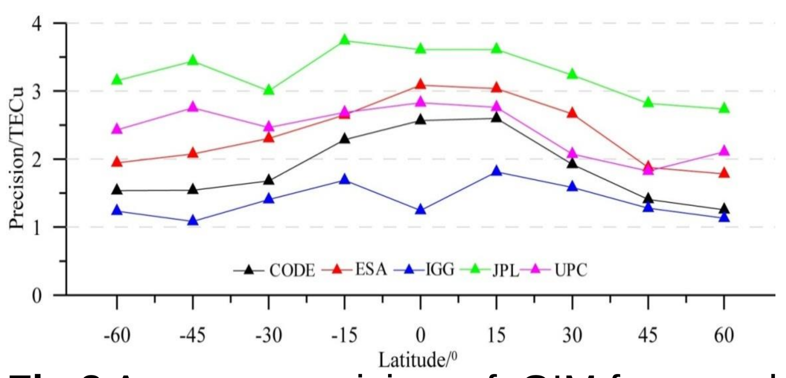

Fig.3 Average precision of GIM from each IAAC with respect to the ionospheric TEC from real GPS data in different latitudes.

IAACs	2001-2003		2004-2006		2007-2009		2010-2011	
	S	N	S	N	S	N	S	N
CODE	2.32	1.88	1.56	1.22	1.17	1.04	3.03	2.53
ESA	3.30	3.32	2.26	1.91	1.62	1.33	3.05	2.26
CAS	1.51	1.50	1.18	1.08	0.96	0.95	2.31	2.02
JPL	3.95	3.63	3.04	2.57	2.66	2.31	4.08	3.70
UPC	3.49	2.94	2.25	1.64	1.99	1.46	3.38	2.43

Tab.1 Precision of GIMs from each IAAC at different levels of solar activity (TECu).
(S: southern hemisphere, N: Northern hemisphere)

3.2 Validation with the IGS-combined GIM

The differences of GIM between the GIM from each IAAC and the IGS combined GIM can reflect the consistency of the GIM in terms of the modeling method. The RMS of the differences of ionospheric TEC at the same grid between the IAAC-GIM and IGS-GIM are show in Fig. 5. It can be seen that the differences of CODE- and CAS-GIM with respect to the IGS-GIM is much smaller than that of GIIMs from other IAAC. The yearly average RMS of the GIM from each IAAC is shown in Tab. 2. The mean RMS during the period of 1998-2016 are about 2.43TECU, 2.31TECu, 3.05TECu, 3.44 TECu and 4.35TECu for the GIM from CODE, CAS, JPL, UPC and ESA, respectively. This finding indicates that (1) the differences in the GIM obtained by different methods become smaller when ionospheric activity is at a relatively low level, (2) the differences become less significant with the increase in the number of global contributing stations for the GIM computation, and (3) the techniques have evolved, leading to more consistent results.

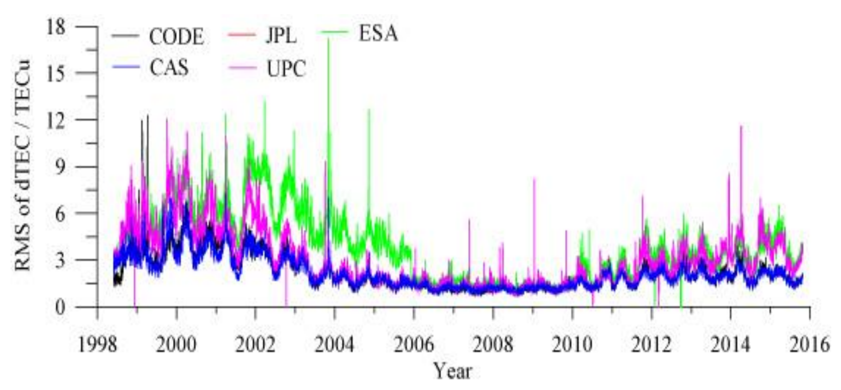

Fig.4 The accuracies of GIM from different IGS IAACs with regard to the IGS final GIM product during 1998-2015.

Year \ IAAC	CODE	CAS	JPL	UPC	ESA	Year \ IAAC	CODE	CAS	JPL	UPC	ESA
1998	3.01	3.02	4.27	4.62	4.49	2007	1.08	1.18	1.92	1.32	1.52
1999	3.64	3.54	4.64	5.64	5.79	2008	1.10	1.15	1.79	1.28	1.43
2000	4.41	3.91	4.91	6.45	6.94	2009	1.23	1.22	1.82	1.40	1.45
2001	3.87	3.47	4.34	5.21	6.81	2010	1.66	1.60	1.94	1.79	2.19
2002	3.26	3.07	3.78	4.27	7.50	2011	1.88	1.76	2.45	2.44	2.92
2003	2.23	2.21	2.71	2.56	5.57	2012	2.18	2.05	2.89	2.85	3.44
2004	1.68	1.78	2.45	2.01	4.42	2013	2.09	2.00	2.73	3.20	3.38
2005	1.49	1.59	2.17	1.68	3.57	2014	2.19	2.04	2.80	3.77	3.63
2006	1.20	1.25	2.00	1.47	1.67	2015	1.89	1.86	2.10	3.24	3.71

Tab.2 The yearly accuracy of GIM from different IGS IAACs with respect to the IGS final GIM product(TECu).

3.3 Validation with the TOPEX-based ionospheric TEC

Signals at two carrier frequencies (5.3 and 13.6 GHz) transmitted from the TOPEX satellite and reflected by the sea surface to measure the altitude of sea level can also be used to extract the ionospheric TEC along the signal propagation path. The IPP of the TOPEX satellite are distributed between the latitudes from approximately 65◦ N and 65◦S and only over the ocean. Fig.5 shows the mean and RMS of the differences in ionospheric TEC between the GIM and the ionospheric TEC from the TOPEX satellite, where (a) and (b) are for the northern hemisphere and (c) and (d) are for the southern hemisphere.

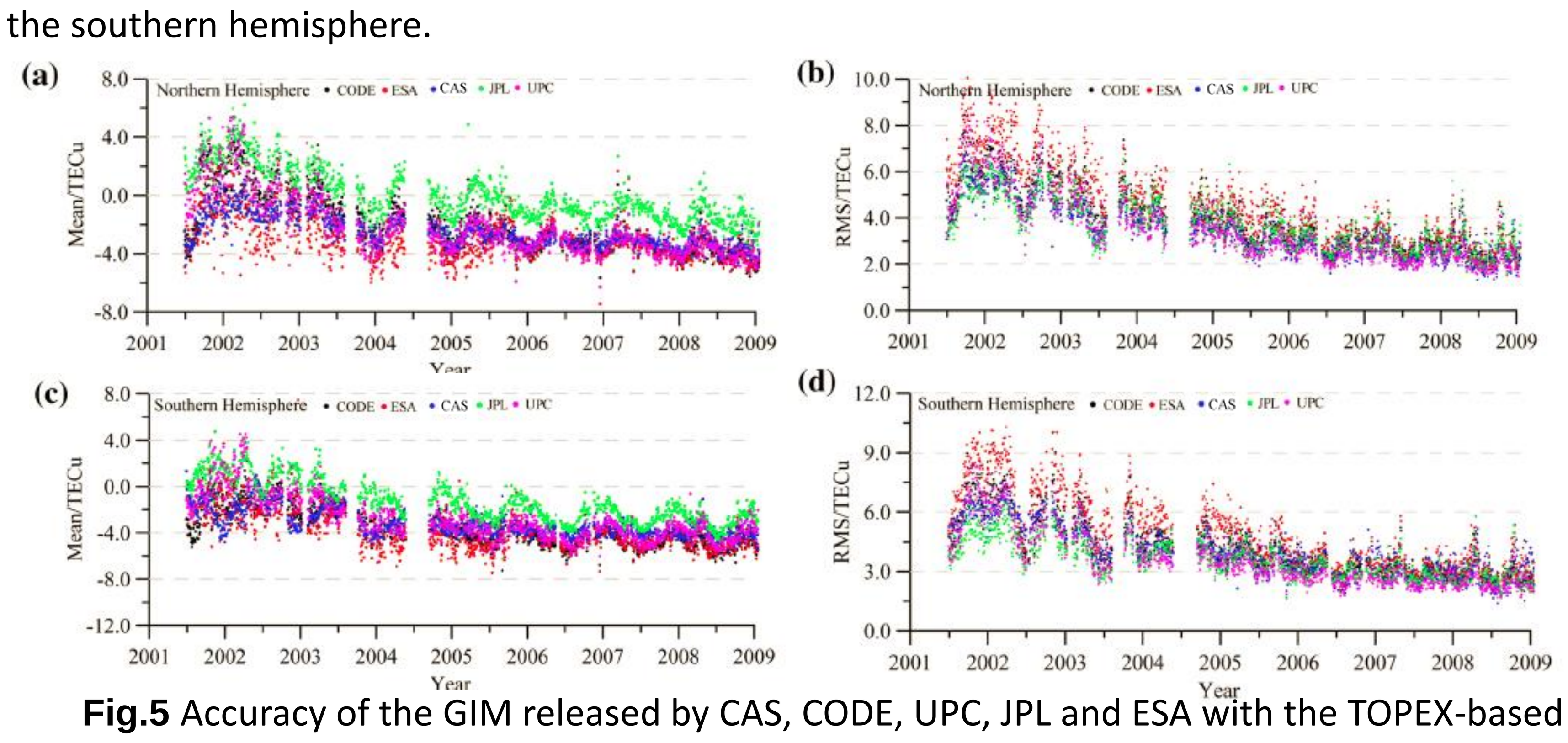

Fig.5 Accuracy of the GIM released by CAS, CODE, UPC, JPL and ESA with the TOPEX-based ionospheric TEC.

The differences in ionospheric TEC between the GIM and the TOPEX satellite are larger in the period of high solar activities (2001–2004) than in the periods of middle and low solar activities (2005–2008). The mean and standard deviation of the differences of the ionospheric VTEC between the GIM and the TOPEX satellite present obvious periodic variations, such as annual variations, semi-annual variations and seasonal variations. In terms of RMS based on the TOPEX-based ionospheric TEC, the accuracies of the GIM from CODE, CAS and UPC are similar to each other, whereas the accuracy of the GIM from JPL is a little better only during the period from 2001–2003 (high solar activities). This result indicates that (1) the discrete spherical-triangles adopted by JPL could be advantageous to present subtle variations in the local ionosphere during high levels of solar activities and (2) the global ionospheric TEC model based on SH function becomes more accurate with higher orders of the SH function and with more contributing stations.

4. Conclusions

CAS has been granted as the fifth IGS IAAC in Feb., 2016 and the daily GIM is calculated using SHPTS method. Based on SHPTS, the ionospheric TEC at the grid point covered by real GNSS data is estimated by corresponding local model and that at the grid point not covered by real data is estimated by global model.

The GIMs from 1998 to 2015 have been reprocessed and validated at CAS using SHPTS. The accuracy of CAS-GIM is equivalent to that of GIM released by CODE and JPL(about 3-6 TECu) and it is a little better than that of ESA and UPC. The accuracy of CAS-GIM over northern hemisphere (3-5TECu) is a little better than that over southern hemisphere (4-6TECu).

The future aim is to further improve the accuracy of GIM by introducing more ionospheric data gathered by other technical strategies, e.g. satellite altimetry, DORIS and ionosonde.

Welcome to download our GIM and DCB product from ftp.gipp.org.cn.

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