Comparing TEC obtained from space geodetic techniques

Jinsong Ping[1], Hongping Zhang[2], Guangli Wang[3], Matsumoto Koji[4], C.K. Shum[5]

(1) Shanghai Astronomical Observatory, CAS, Nandan Raod No.80, Shanghai 200030 China and email: pjs@shao.ac.cn
(2) as (1) above, but email: hpzhang@shao.ac.cn
(3) as (1) above, but email: wgl@shao.ac.cn
(4) Mizusawa Observatory, NAOJ, Hoshigaoka-chyo 2-12, Mizusawa, Iwate, 023-0861, Japan and email Matumoto@miz.nao.ac.jp
(5) Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University, USA and email: ckshum@osu.edu

ABSTRACT

Radio band dual frequency space techniques have been widely used in modern geodetic research fields. Ionospheric TEC along the track from detector to target radio source can be obtained accurately from the simultaneous observable at two different frequencies for these quickly developing space geodetic techniques, i.e., GPS, Satellite altimetry, integrated Doppler, VLBI. After estimating and removing the instrumental effects successfully for them, the TEC distribution and time variation can be measured precisely. During the past 2 decades, many workers from various related research backgrounds have contributed to this study. We developed effective method to remove the instrumental effects; retrieved and modeled the ionospheric TEC based on some of the radio geodetic techniques by means of global and regional observation. Then we compared the obtained results and other released TEC models with each other. Systematic biases between them have been noticed, for example, the seasonal and annual periodical difference in temporal variation; the zonal like difference in spatial distribution; and the unreasonable step-like changes in some models. Some of the biases are due to the under or overestimate of the TEC, some of the biases are due to unknown errors. This comparison is helpful on modeling global ionosphere. Before modeling 3D global ionosphere, 2D TEC model is suggested based on the GIM from IGS GPS and the TEC obtained from satellite altimetry..

1. Validating GIM using T/P nadir observable.

Based on the observation of the worldwide GPS network, a commonly accepted method is adapted to model the global scale ionospheric TEC distribution and variation by the expansions of spherical harmonic functions called GIM (Schaer *et al*. 1995). GIM is released in both of the format of spherical harmonic coefficients (http://www.aiub.unibe.ch/ionosphere) and IONEX format. Now, it is expanded through full 15 degrees and orders for every 2 hours, by assuming the ionosphere as a thin shell 2D model above 370-450KM of the earth surface.

At the same time, many satellite altimetry (Chelton et al. 2001) missions are operated with radar altimeters to measure the global sea surface height (SSH) with an accuracy batter than 3 cm (Shum et al., 2003). At radio band, these space missions are suffering the effects introduced by the earth ionosphere. During the past decades, some well-developed empirical or semi-empirical ionosphere modes, i.e. the International Referencing Ionosphere series (IRI) (http:// nssdc.gsfc.nasa.gov/space/ model/ionos/iri.html), have been adopted to correct this kind of effect for the missions operated at single frequency. However, the empirical ionosphere models can only describe the large scale stable components with slow variation of the global ionosphere, hence the precision of single frequency altimetry is seriously limited by the model errors, even a high frequency Ku-band system is applied. The launching of the newly developed duel frequency altimetry mission, T/P, has changed the history of satellite altimetry totally from 1992 (Fu et al., 1994). Along T/P track, the total electron content of ionosphere (TEC, $1TECu=1x10^{16}/m^2$) can be detected directly from the nadir altimetry sampling data at two widely separated frequencies of C-band and Ku-band. For this reason, the SSH research has been dramatically improved. Beyond this, the nadir TEC can also be applied to check and improve the empirical and/or semi-empirical models.

During the period of T/P mission, the rapid development of GPS gives a unique chance to monitor the global ionosphere variation with high time wise and spatial resolution, as well as with high precision (Afraimovich *et al.*, 2000). The major spatial and temporal features of ionosphere from GIM agree well with that of T/P ground-truth data. GIM is recommended to correct the single-frequency altimeter path delay, augmented by the IRI2001 (Chao et al, 2004). Long-term T/P GDR data from Cycle85 to Cycle403 are adopted in the data analysis to comparing with GPS ionospheric TEC models. An 8mm instrumental step of TEC correction for T/P before MJD52161 is noticed. Using the J1 SSHA data, the difference between T/P and Jason-1 is also compared (Ping et al 2004).

A simple comparison between T/P TEC and GIM TEC is carried out: point by point along T/P track difference; a sampling data number distribution by fitting a Gaussian normal function; re-grid the along track difference to spherical coverage, and then fitting it by a full 360x360 orders and degrees spherical function; correlation analysis between T/P TEC and GIM TEC by fitting a straight line. See Figure 3, all of them show a systematic bias between GIM and T/P by 1.5 to 1.9 TECu, about 3-4

mm in height at Ku-band. At low latitude area, the GIM is larger than T/P TEC in either daytime and at night; however, following the increase of latitude, GIM drops quickly, and becomes smaller than T/P TEC. It is difficult to simply say that an average bias between T/P and GIM can explain everything, especially the difference at high latitude area the T/P TEC is larger than GIM TEC by sever to dozen TEC even at night. On this case, we can reasonably guess the GIM underestimated the global TEC at high latitude area, especially at the southern hemisphere, where the GPS receiver number is less than the northern hemisphere.

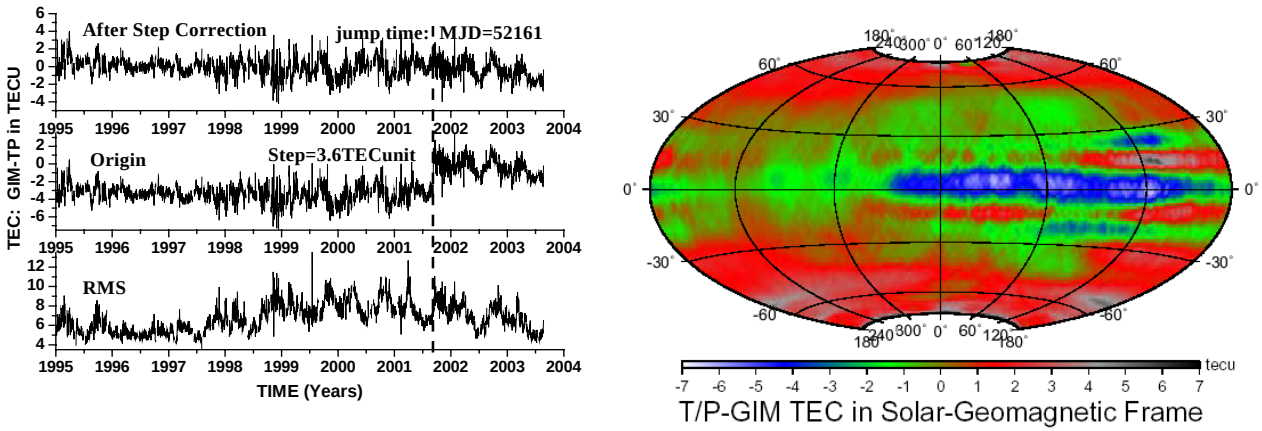

Figure 1, T/P-GIM TEC: left, long period daily variation; right: global distribuation.

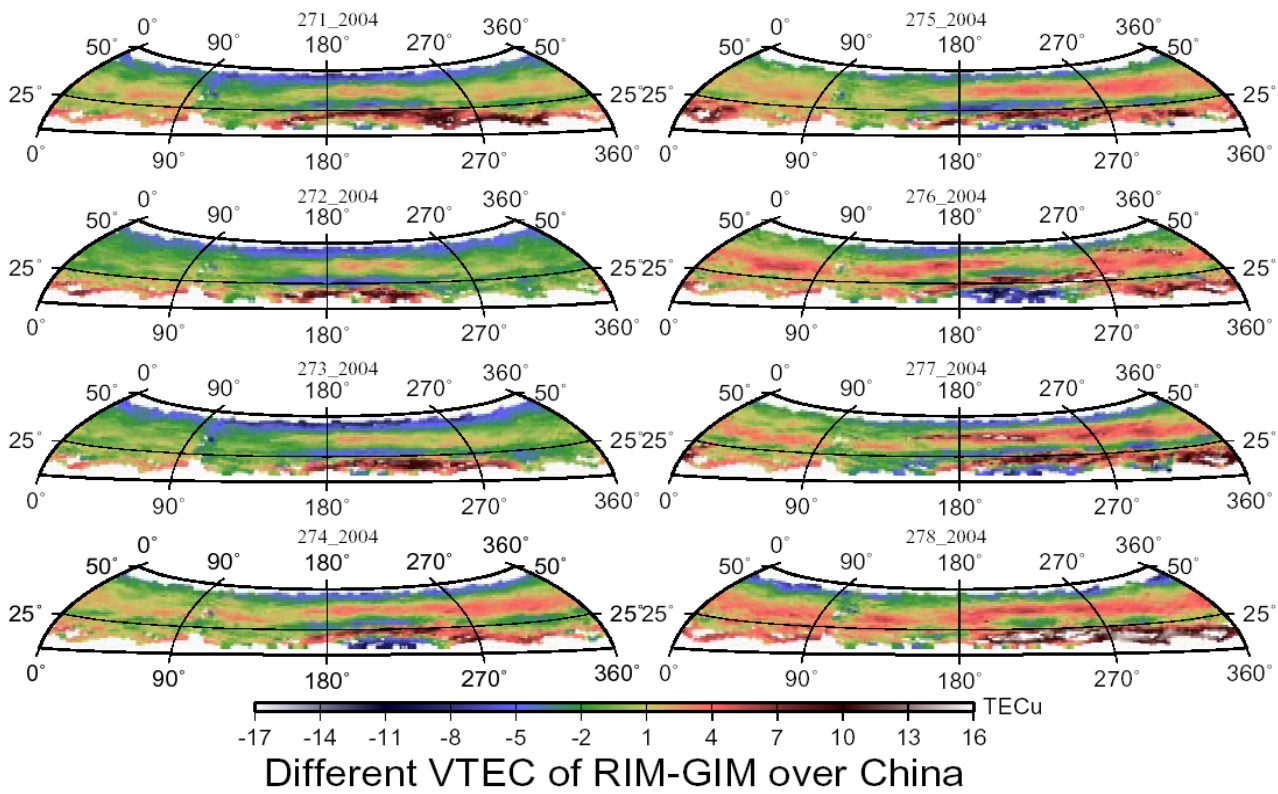

Figure 2a, RIM-GIM TEC over China: spatial distribution, gridded as 1° by 1°.

2. Validating GIM using RIM over China

In China, a regional GPS network of 27 GPS sites has been operated for many years. It is a powerful mission system to monitor the regional plate movement. From 2002, a local GPS network of 19 GPS sites has been operated at Yangzi Delta area for regional meteorological and space meteorological research. Using this system, we develop a technique at to mapping the regional TEC with a spatial resolution of 1°x1° from the differenced GPS dual frequency phase and code observable. The

standard deviation of the TEC estimated from this technique is less than 2 TECU over China.

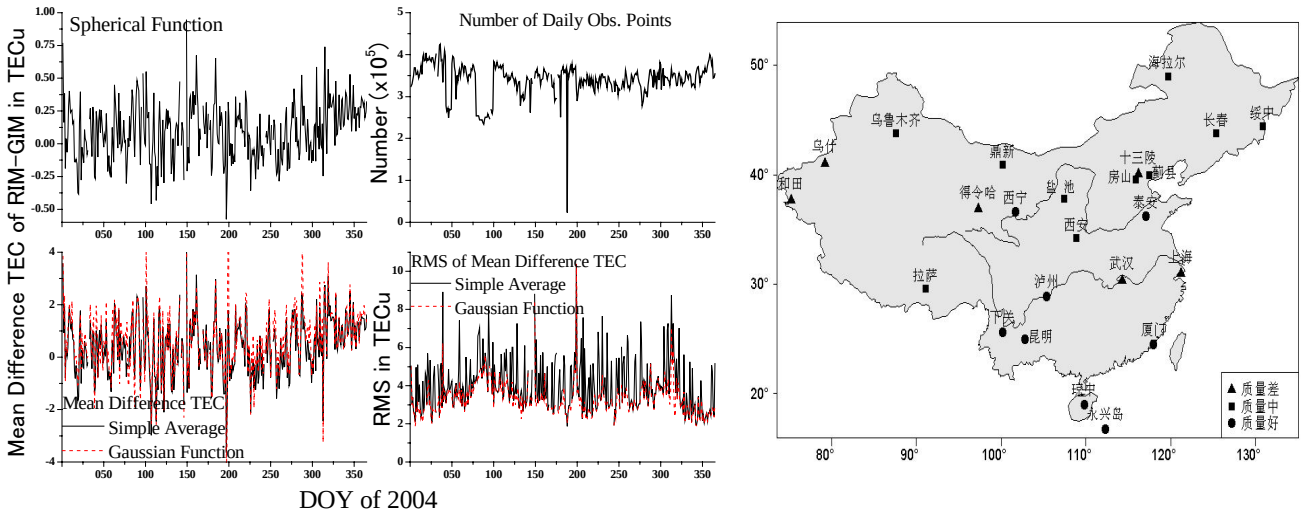

Figure 2b, RIM-GIM TEC over China: left, daily mean difference in 2004; right, regional GPS network of China.

The RIM TEC over China and GIM is compared point by point along the GPS satellite-GPS receiver track. The daily spatial distribution of the difference shows the similar zone like systematic biases between RIM and GIM. See Figure 2a. This can be explained by the different modeling methods for them. In the case of GIM, data from only 3-5 GPS receivers are used in China. GIM model smoothes the regional TEC remarkably. On the other hand, 40-50 GPS receivers are used to model RIM over China. The fine structure of TEC in this middle latitude area can be resolved perfectly.

However, when estimate the daily mean difference between GIM and RIM, they show small systematic biases. Three methods have been used to calculate the daily mean difference, the simple difference, the Gaussian distribution of the simple difference, and the 0 order and degree of the spherical function of the simple difference. The mean difference is less than 2 TECu. The long period (1year) difference is less than 0.5 TECu. The RMS of the difference is a little large, about 2-6 TECu. See Figure 2b. This comparison indicates that the result of RIM is reasonable and reliable. Also, the regional RIM is useful to validate the GIM obtained by IGS data analyzing center.

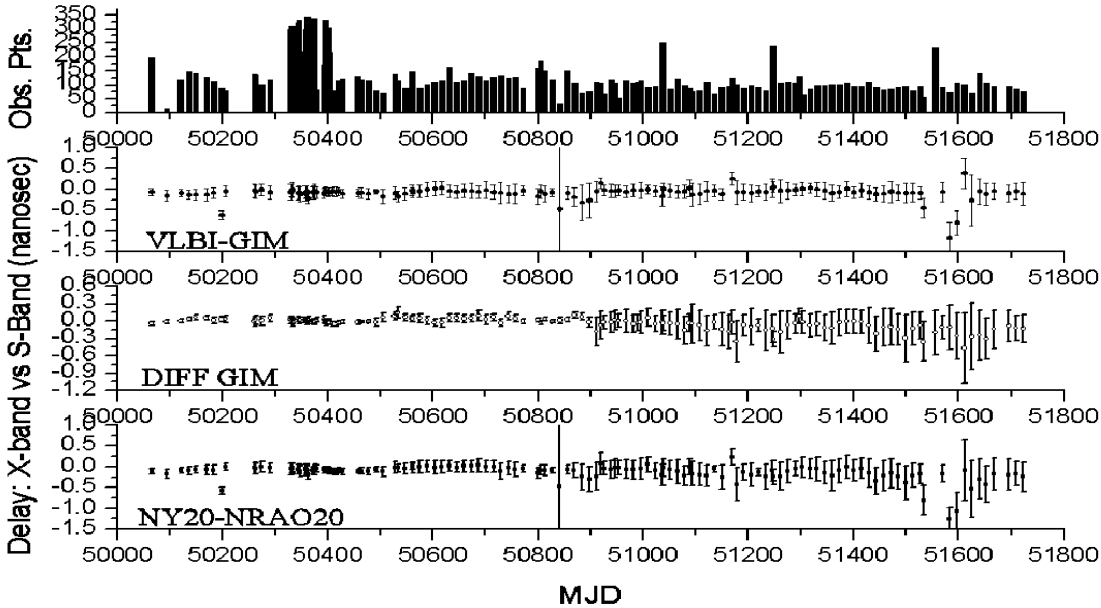

Figure 3. Daily mean TEC difference between VLBI and GPS for baseline NY20-NRAO20

3. Comparing TEC between VLBI and GPS

The IVS dual-frequency (S/X band) geodetic VLBI observation has also give a chance to study the ionospehric effects. Over 30-year VLBI database is used to retrieve the differential TEC from the delay and delay rate observable, scan by scan for each baseline. The obtained differential TEC is compared with the GIM from 1994, where the GIM TEC pairs are mapped to the same line-of-sight direction of VLBI observable. Usually, constant bias between VLBI TEC and RIM can be noticed. It shows the instrumental delay of VLBI. For the baseline of long history observation, like NY20-NRAO20 (Figure 3), it covers almost a solar period. The SDV of VLBI TEC from this kind of baseline show typical periodical variation by following the solar active. After remove the GIM part from VLBI TEC, this phenomenon related to solar active can be removed totally. Which means, there are two parts in VLBI TEC observable, the instrumental delay and ionospheric delay. This method can be used to check or to monitor the instrumental delay variation of VLBI system.

4. Summary: to confirm the possibility of retrieving ionospheric TEC from S/C VLBI observation

It can be seen that the comparison of TEC between different space geodetic techniques can benefit the research mainly in two ways, 1) to improve the spatial resolution and temporal resolution of TEC, and to improve the precision of TEC; 2) to monitor the systematic biases or the instrumental delays of the geodetic instruments. One of the basic objectives of this research is to calibrate the space or deep space radio matrix data so as to do precise orbit determination for the spacecraft.

To develop an VLBI system for the dual frequency S/C tracking in SELENE (Hanada, 2005) and Chang'E lunar missions, on Nov.15th and 16th in 2004, the Japanese space weather satellite GEOTAL was tracked by using Mizusawa 10 meter and Seshan 25 meter antennas. Both of X-band and S-band C/W have been observed, the frequencies of C/W are read as 8.474GHz and 2.260GHz respectively. However, due to a wrong setting of local frequency for BBC, the folding back signal of X-Band main C/W was recorded at both sites. RICO has not the option to process this kind of folding back signal currently. So, only 30 minutes very weak sub-carrier signal at X-band is correlated. The residual correlation phase in both orders of Mizusawa x Shanghai and Shanghai x Mizusawa have been obtained for this observation period. From the cross correlating phase, relative difference slant TEC have been obtained with a precision of 0.1 TECu. Please see following figures. This is a very high precision of ionospheric TEC observation obtained by VLBI method. Because the bolding back signal is stronger than the sub-carrier signal. We will try to solve the TEC by using it in the future data analysis.

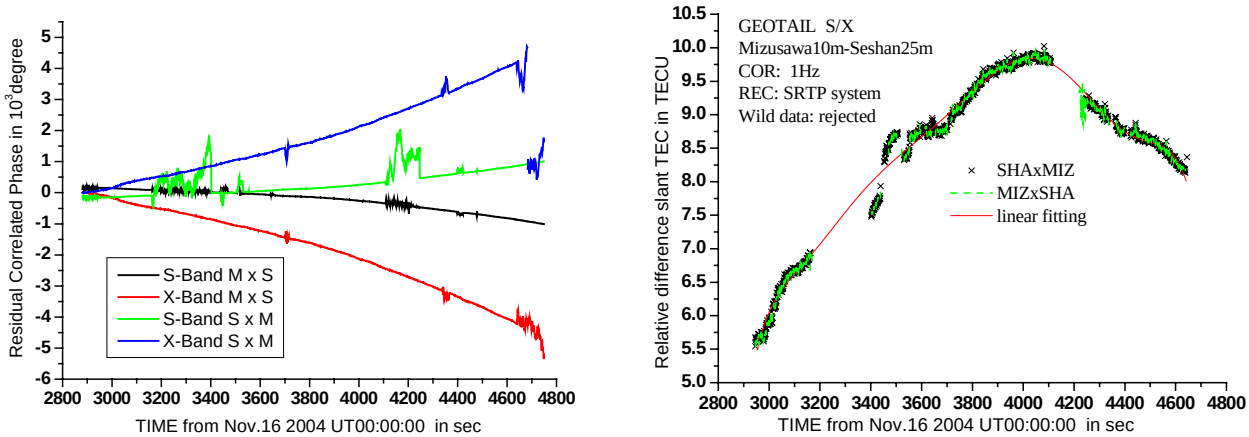

Figure 4, GEOTAIL S/C dual frequency VLBI experiment: cross-correlation and differential TEC.

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