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Research Paper

Accuracy assessment of the global ionospheric model over the Southern Ocean based on dynamic observation

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ABSTRACT

The global ionospheric model based on the reference stations of the Global Navigation Satellite System (GNSS) of the International GNSS Services is presently the most commonly used products of the global ionosphere. It is very important to comprehensively analyze and evaluate the accuracy and reliability of the model for the reasonable use of this kind of ionospheric product. In terms of receiver station deployment, this work is different from the traditional performance evaluation of the global ionosphere model based on observation data of ground-based static reference stations. The preliminary evaluation and analysis of the the global ionospheric model was conducted with the dynamic observation data across different latitudes over the southern oceans. The validation results showed that the accuracy of the global ionospheric model over the southern oceans is about 5 TECu, which deviates from the measured ionospheric TEC by about −0.6 TECu.

1. Introduction

With the global construction and rapid development of the satellite navigation systems, the Global Navigation Satellite System (GNSS) has become the main technical means of ionospheric remote sensing due to its characteristics such as continuous, all-weather, low-cost, and high accuracy (Dyrud et al., 2008; Davies and Kenneth, 1990; Feltens, 2007; Lanyi et al., 1988; Mannucci et al., 1998; Schaer, 1999). The International GNSS Services (IGS) Organization uses the global GNSS reference stations to routinely make an estimated model of the global ionosphere, which has become one of the most important products for the research and applications of the ionosphere (Hernández-Pajares et al., 2009). It is therefore a rational decision for us to effectively analyze and evaluate the accuracy and reliability of such global ionospheric products. However, most of the global satellite navigation receiver systems have been distributed only on land" (Mannucci et al., 1999; Hernández-Pajares, 2003, 2004). Such a distribution limits the accuracy of the global ionosphere product released by the IGS, especially for places far away from any land. The number of reference stations in the southern hemisphere is relatively small. So the accuracy of the land-based ionosphere products in the southern hemisphere is lower than that in the northern hemisphere (Jee et al., 2010; Li et al., 2015). Most of the existing research on the analysis and evaluation is also concentrated in the land area. Only a small number of researchers used the ionospheric data from satellite altimetry to analyze and study the accuracy of the ionospheric grid over the oceans (Dettmering et al., 2014; Brunini et al., 2005; Orús et al., 2003). However, usually there are some systematic deviations between ionospheric observation data from the satellite altimetry and that from the satellite navigation due to the differences in the method of observation and background geophysical conditions during the ionospheric observation. These factors lead to the difficulty of using the assessment result to fully and effectively reflect the true accuracy of the ionospheric grid products.

The route of the annual scientific task of the Chinese Antarctic scientific expedition has been covering the majority of the southern hemisphere, and all are over the oceans. The GNSS receiver on the scientific expedition ship has been providing very valuable data for the analysis and evaluation of the accuracy of the global ionosphere products over the oceans in the southern hemisphere area. In this

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contribution, the accuracy of the global ionospheric model is quantitatively evaluated in the exploration region by using the observation data provided by the GNSS receiver on the China's scientific expedition of oceans in the period January 1–15, 2015. The second part of this paper focuses on the description of existing modeling method of the global ionosphere. In the third part, the observation data, the evaluation method and the evaluation results are described and analyzed. In the last part, the main research conclusions and contributions of this paper will be briefly summarized, where the direction of future research is also pointed out.

2. Introduction to the global ionospheric model

Since the working group on the global ionosphere established by the IGS started to realize the research on the Total Electron Content (TEC) of the global ionosphere by using the GNSS/Global Positioning System (GPS) in 1998, the TEC of the global ionosphere mesh (GIM) has been published in the IONosphere map Exchange (IONEX) format (Hernández-Pajares et al., 2011, 2009; Li et al., 2012). It has been an important part of the international GNSS products and provides a wealth of basic data for research on the global ionosphere. It further demonstrates the advantages of the GNSS technology for exploring the ionosphere, for which there is no substitute.

There are presently four ionosphere analysis centers under the IGS working group, which basically represents the highest processing level of the TEC of the global ionosphere. The four centers are the Center for Orbit Determination in Europe (CODE), the Jet Propulsion Laboratory (JPL), the European Space Agency (ESA), and the Technical University of Catalonia (UPC, Barcelona, Spain)(Hernández-Pajares et al., 2009).

Among the four IGS analysis centers, both CODE and ESA adopted the spherical harmonic function (SHF) for modeling the global ionospheric TEC (Feltens and Dow, 2006; Schaer and Dach, 2010). The SFH method can effectively realize reasonable extrapolations of the ionospheric TEC, and provide ionospheric TEC values with reasonable accuracy over the oceanic areas without any measured data. However, the extrapolated values only represent the overall TEC distribution and would not be capable of capturing fine features in the local ionospheric TEC.. Both JPL and UPC established the TEC on the GIM by using a global triangular grid and two thin-layer tomography on each individual station, respectively (Mannucci et al., 1993; Juan et al., 1997). They can effectively guarantee an accurate representation of ionospheric TEC variation in the observation area. But this method cannot produce reasonable extrapolation of the ionospheric TEC values outside the observation area. In this case, the extrapolation can only rely on empirical ionospheric models (for example, the IRI model) or a purely mathematical interpolation (for example, linear interpolation, Kriging interpolation), and its accuracy cannot be effectively guaranteed. At the present stage, there is no very mature and reliable method for the ionospheric interpolation / extrapolation at a distance about a hundred kilometers. Relatively speaking, the SHF method can be used to realize the interpolation and extrapolation of the ionospheric TEC in the global scope, and it also effectively maintains the continuity and reliability of the ionospheric TEC. Therefore, an ionospheric model based on the SHF method was chosen as the focus in this work and it was evaluated by using the measured ionospheric data over the oceans.

A SHF series expansion describing the physical quantity of the global change is shown in Eq. (1)(Schaer, 1999).

$$VTEC(\phi,\lambda) = \sum_{n=0}^{n_{d\,\max}} \sum_{m=0}^{n} \widetilde{P}_{nm}(\sin\varphi)\cdot(\widetilde{A}_{nm}\cos(m\lambda) + \widetilde{B}_{nm}\sin(m\lambda)) \tag{1}$$

where $VTEC(\phi,\lambda)$ stands for the ionospheric VTEC at the ionospheric pierce point (IPP) (ϕ,λ); ϕ and λ are the IPP's latitude and longitude; $n_{d\,\max}$ is the maximum degree of the SHF expansion; $\widetilde{P}_{nm}(\sin\phi) = MC(n,m)\cdot P_{nm}(\sin\phi)$ is the n-th degree, m-order normalized Legendre function; $MC(n,m)$ stands for the normalization function, as shown in Eq. (2); $\widetilde{A}_{nm}$ and $\widetilde{B}_{nm}$ are the model parameters to be estimated.

$$MC(n,m) = \sqrt{(n-m)!(2n+1)(2-\delta_{0m})/(n+m)!} \tag{2}$$

3. Test and result analysis

3.1. Introduction to the dynamic observation from the Chinese Antarctic expedition ship

A monitoring-type GNSS receiver was carried on the ship for the annual Antarctic scientific expedition of China in 2015. The receiver can track the satellite signals from the GPS of the USA, the GLObal NAvigation Satellite System (GLONASS) of Russia, and the Beidou Global Navigation Satellite System (BDS) of China. The ionospheric TEC information along the propagation path of the satellite signal can be obtained from the dual-frequency observation data of the receiver. Table 1 shows the different observation data types, the receiver type, and antenna type for the calculation of the ionosphere when using the receiver to track different satellite navigation systems.

Since crossing the equator and entering the southern hemisphere at the end of 2014, the Chinese marine research vessel headed to the Antarctic after a rest. The specific trajectory of the ship is shown in Fig. 1 (the ship was at Antarctica on 1 Jan 2015 and later at New Zealand on 15 Jan 2015). It can be seen that the voyage crossed the low-, mid-, and high-latitude areas of the southern hemisphere. The

Table 1
The observation data types of the satellite navigation receiver on Chinese Antarctic expedition ship.

Tracking system			
Item	**GPS**	**GLONASS**	**BDS**
Pseudorange type	C1C, C2W	C1P, C2P	C2I, C6I
Carrier phase type	L1C, L2W	L1P, L2P	L2I, L6I
Receiver type	Trimble NetR9		
Antenna type	TRM57971.00		

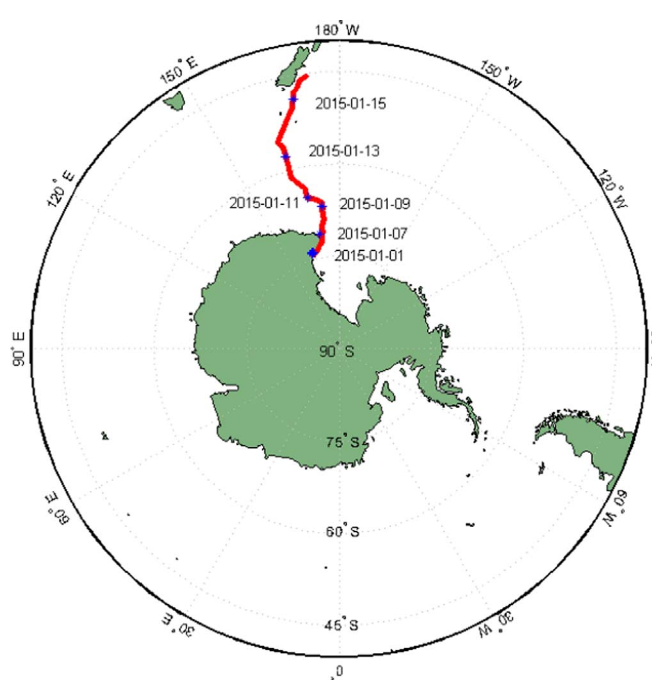

Fig. 1. The trajectory of Chinese Antarctic expedition ship on the southern ocean.