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 new global 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 (odds.gsfc.nasa.gov) and GIPP (ftp.gipp.org.cn).

This 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 Zhenhui Li (2015), where SHPTS means Spherical Harmonic function Plus generalized Trigonometric Series functions. 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 GIM function over each individual station. Ionospheric VTEC at the grid points that are near contributing stations is estimated using the corresponding local model, 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 Zhenhui Li (2015).

3. Validation of the GIM generation by SHPTS

3.1 Validation with the GPS-based ionospheric TEC
The IGS Ionospheric Map can be directly extracted from the raw dual-frequency measurements by removing the DCB in satellite 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 from 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 (approximate at 3.5TECu in all latitudes) than the ionospheric TEC from the daily GIM, which 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.

3.2 Validation with the TOPEX-based ionospheric TEC
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 shown 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 GIMs 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.

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 of 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.

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 UP. The accuracy of GIM over northern hemisphere (3-6TEcu) 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.