Study the effect of strong magnetic storm on the ionosphere of August 2003 in the China region

∗ Wen Debao[1,2], Yuan Yunbin[1], Ou Jikun[1], Huo Xingliang[1,2]

1. Key Laboratory of Dynamic Geodesy, Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan 430077, China
2. Graduate School of Chinese Academy of Sciences, Beijing 100039,China

(E-mail: iontomgraphy@hotmail.com,yybgps@asch.whigg.ac.cn, ojk1009@public.wh.hb.cn, xingliang.huo@gmail.com)

Abstract The ionospheric strom evolution process was monitored during the 18 August 2003 magnetic strom over China, through inversion of the ionospheric electron density from GPS observations. The temporal and spatial variations of the ionosphere were analysed as a time series of ionospheric electron density profiles. Results show that the main ionospheric effects of the storm over China under consideration are: the positive storm phase effect usually happens in the low latitudinal ionospheric; the negative storm phase effect occurs in the middle latitude, and the equatorial anomaly structure can be found as well.

Keywords: Global Positioning System (GPS); ionospheric electron density; computerized ionospheric tomography; magnetic storm.

1. Introduction

The knowledge of the free electron density distribution in the earth's ionosphere is important for various aspects, such as: estimation and correction of propagation delays in Global Positioning System (GPS); improving the accuracy of satellite navigation; predicting ionospheric variations due to magnetic storms; and predicting space weather effects on telecommunications [1]. Because of the dispersive nature of the ionosphere, the ionosphere may cause substantial signal delays when the satellite radio signals through the ionosphere; the ionospheric delay is proportional to the line integral of ionospheric electron density along the ray path from satellite to receiver. In addition, variations of ionospheric irregular structure produce the scintillation of the phase and amplitude that may impact on radio signals propagation and degrade performance of satellite navigation system [2]. During the magnetic storms, ionospheric irregularities are enhanced in amplitude and may cause further signal degradation. Therefore, it is necessary to monitor and study the variation of ionospheric irregular structure and explore its effect on the living environment of human being during magnetic storm. In the past, many researchers [3-6] studied the effects of magnetic storms on the ionosphere. Conventional ionospheric investigations mainly adopted the limited ground observation, such as ionosondes and incoherent scatter radar data from a few locations, to investigate the disturb characteristics of the ionosphere under magnetic storm condition. With these means, only the ionospheric variations over a fixed location can be obtained, and it is difficult to obtain large-scale ionospheric electron density variation during magnetic storms. However, since magnetic storms have a global effect, large-scale ionospheric disturbance information needed to be understood in most cases. The GPS-based tomographic imaging technique provides the possibility of studying the ionosphere on a large scale.

At present, imaging ionosphere with GPS data and CIT technique is a research focus in the ionosphere field. Some authors have presented their tomographic results that reflect the ionospheric response to severe magnetic storms [1, 7-8]. However, monitoring of ionospheric response to strong magnetic storms by the tomography technique has not been reported up to now. Also, during magnetic storms, the temporal and spatial variations of ionospheric electron density over China have not been studied yet. In view of this, this work focuses on studying the evolution of the ionospheric response to a strong magnetic storm of August 18, 2003, in China. The goal is to track the ionospheric response from middle to low latitudes to obtain a complete picture of the sequence and relationship of storm-time ionospheric changes. We perform tomographic reconstruction of ionospheric electron density to examine the altitude/ latitude dependent dynamics during the magnetic storm.

2. Method

In this study, tomography method is used to reconstruct the image of earth's ionosphere. The computerized ionospheric tomography applies total electron content (TEC) to invert ionospheric electron density. However, ionospheric slant TEC (STEC) is the line integral of ionospheric electron density along the ray path between satellite and receiver. To obtain accurate distribution information of ionospheric electron density, precise STEC should be first derived from dual-frequency GPS measurements. Differential phase measurements are therefore adopted to create a matrix of relative STEC observations. Provided that there is a continuous record of observations, the relative STEC can be derived from differential phase for a particular satellite-receiver pair. In general, the relative STEC can be considered as an input data of the ionospheric tomography system. Only using the differential phase measurements, the absolute values of STEC cannot be directly determined because of ambiguities of phase measurements. Just the relative variation of ionospheric TEC can be obtained during pass of GPS satellites. Since the multipath effects less affect carrier phase measurements, the precision of STEC, which is derived from carrier phase, is higher than that of STEC derived from the combination of P code (P4). If not taking into account the absolute value of TEC, the relative TEC may be used to investigate various types of disturbance such as traveling ionospheric disturbances (TID), solar flares and magnetic storms.

3. Inversion algorithm

In this work, the algebraic reconstruction technique (ART) [9] is applied to invert the two-dimensional image of ionospheric electron density. The ART algorithm, which can converge quickly in an iterative fashion compared to other reconstruction algorithms, is the preferable algorithm to use for ionospheric reconstruction in a region with a limited number of widely distributed receivers, such as the GPS receiver network in the China region. Basically, the ART algorithm, which requires an initial guess to start with, improves the reconstruction on the initial value with the experimental TEC data in an iterative fashion. The initial value may be gotten from IRI2001 [10] ionospheric model.

4. Result

A strong magnetic storm occurred on 18 August 2003. The Storm Sudden Commencement (SSC) occurred at 14:21UT on 17 August 2003. During this storm, the planetary geomagnetic activity indices reached the extreme values: $\sum k_p = 52$ +, and the Kp indices amount to 7+ at 18:00UT, and the maximum absolute value of the field intensity variation was recorded as 168nT at 16:00UT.

To study the characteristics of the ionospheric disturbance over China during the storm, the whole ionosphere is divided into a number of small cells. Ionospheric electron density profiles can be derived through the tomographic reconstruction techniques, based on the observation data of 23 GPS observation stations from the Crustal Movement Observation Network of China (CMONOC).

Inverted results show that ionospheric electron density in F region enhanced between $10°N$ and $35°N$ and reached 27% during the magnetic storm on 18 August 2003, which appeared the positive storm phase effect. Outside the above latitude range, the negative storm phase effect of the ionosphere appeared between 200km and 600km in height. However, the positive storm phase effect also appeared outside the above height ranges. But maximum enhancement of the ionospheric electron density occurred between $15°N$ and $25°N$ and reached 260%. This indicates that the storm is different in different height and latitude ranges. A disturb structure of the ionosphere over China occurred on 18 August 2003. At the same time, one can see that the equatorial anomaly still existed, the equatorial anomaly crest moved to $27°N$, and then the crest of anomaly structure recovered the original locations on 19 August 2003.

From the series of GPS tomographic images at a longitude chain of $130°E$, the evolution of disturb structure of the ionospheric over China region can be seen. At about 1:00UT, a clear disturb structure occurred between $30°N$ and $40°N$. The average F-layer peak density height was about 340km.The same disturb structure can be also seen at the same geographic position at 5:00UT, but the intensity was intensified in contrast to the tomographic images at 1:00UT. However, a new disturb structure of the ionosphere occurred between $12°N$ and $27°N$ at 9:00UT, the original disturb structure of the ionosphere still existed, but its intensity was weakened. The disturb structure of the ionosphere occurring at 1:00UT and 5:00UT is completely disappeared at 13:00UT, but the disturb structure occurred at 9:00UT still appeared at 13:00UT. From the tomographic images above, one can see that the equator anomaly still existed. At 17:00UT and 21:00UT, it can also be found that the disturb structure occurred at 13:00UT moved to north and reached the geographic range between $20°N$ and $35°N$, the equator anomaly structure disappeared completely, and the average F-layer peak density height fell to 270km at 21:00UT. But a new disturb structure appeared between $40°N$ and $50°N$ at 21:00UT, and the ionospheric electron density reached the minimum.

5. Conclusion

The two-dimensional tomography methods originally applied to the reconstruction of polar-orbital satellites observations (e.g. Navy Navigation Satellite system) have been adopted to ground GPS observation. GPS data is generally continuous in temporal/spatial domain. This can enable the evolution of large-scale ionospheric features to be studied. The tomographic imaging method has been demonstrated for a disturb storm period during 18 August 2003. The reconstruction results show the intense disturbance of the ionosphere over China, and the difference of ionospheric storm phase exists in different height and latitude ranges. The positive storm phase effect is dominant between $10°$ and $35°$. Outside this latitudinal range, the negative storm phase occurred between 200km and 600km in height. The results are very significative to understand the characteristics and variation mechanism of the ionosphere during magnetic storms. It was found that the equator anomaly structure also existed during this magnetic storm, which is recommended to discuss in the future.

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