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Monitoring the ionospheric storm effect with multiple instruments in North China: July 15–16, 2012 magnetic storm event ☆

Min Wang [a,*], Wenyu Lou [a,1], Peng Li [a,2], Xuhui Shen [a,1], Qiang Li [b]

[a] Institute of Earthquake Science, China Earthquake Administration, Beijing, China
[b] National Earthquake Infrastructure Service, Beijing, China

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ABSTRACT

A major geomagnetic storm occurred on July 15–16, 2012, which is characterized by a long-lasting southward turning of interplanetary geomagnetic field (IMF) for ~30 h below −10 nT. Prominent large-scale ionospheric disturbances were observed in North China during this extreme space weather event. This study reveals the possibility of using the newly built China seismo-ionospheric ground-based monitoring network (CSGMN) to investigate the ionospheric storm effect during different phase of the storm. As a main part of the CSGMN, the oblique and vertical sounding systems and global position system (GPS) network all observed a moderate and a strong positive storm effects around the noon and the sunset sector on 15 July. The maximum enhancement of parameter peak electron density ($NmF2$) increased 100% and TEC 60%. The positive phase then is followed by an intense negative storm effect during the entire day on July 16 with $NmF2$ and TEC fell below 40% of the previous quiet day values. Also, the electron density profiles retrieved from the COSMIC radio occultation measurements were examined and validated with the ground measurements in order to estimate the possibility of its use as an additional data source to study altitude distribution of ionospheric storms. Good agreement has been reached between the ground and satellite occultation measurements even if they are not close. The result here shows that CSGMN can be a very powerful network not only for the seismo-ionospheric study but also in monitoring space weather.

1. Introduction

Ionospheric storm represents a kind of extreme space weather event in the geospace which can have a strong influence on the trans-ionospheric radio wave propagation relating the space-based navigation and communication systems. After decades of study, it is still not yet possible to accurately forecast the response of the ionosphere to the magnetic storm, due to complexity and unique characteristic of each particular case. A number of excellent reviews have been published to summarize the progress of the ionospheric storm study from both the observations and theoretical models (e.g., Prölss, 1995; Buonsanto, 1999; Danilov and Lastovička, 2001; Mendillo, 2006). From the middle of the last century, for every decade, the understanding in the ionospheric behavior during the magnetic storm is advanced associated with the observational measurements upgrading and diversification. The instruments involve from very beginning the ionosonde to the various types of radar, optical instrument, in-situ satellite and remote sensing technique.

Since 1990s, the Global Positioning System (GPS) TEC, an integration along a given ray path between the GPS satellite in space and the receiver on the ground, is widely used to monitor the temporal and spatial behavior of the ionosphere. Thousands of GPS stations are distributed in US, Japan and Europe providing dense measurements of ionospheric TEC at middle latitude (Saito et al., 1998; Rideout and Coster, 2006; Valladares and Chau, 2012), which is a strong tool to investigate the ionospheric structures in detail. For example, the two-dimensional TEC observations revealed unprecedented high resolution spatial structures and temporal evolutions of large scale traveling ionospheric disturbances (LSTIDs) during the magnetic storm (e.g., Saito et al., 1998;

* Correspondence to: Laboratory of Earthquake Observation from Space, Institute of Earthquake Science, China Earthquake Administration, 63 Fuxing Avenue, P.O. Box 166, Beijing 100036, China

E-mail addresses: wangmin@seis.ac.cn (M. Wang), lwy@seis.ac.cn (W. Lou), lipeng@gps.gov.cn (P. Li), shenxh@seis.ac.cn (X. Shen).

[1] Laboratory of Earthquake Observation from Space, Institute of Earthquake Science, China Earthquake Administration, 63 Fuxing Avenue, P.O. Box 166, Beijing 100036, China.

[2] Data Center of Crustal Movement Observation Network of China, Institute of Earthquake Science, China Earthquake Administration, 63 Fuxing Avenue, P.O. Box 166, Beijing 100036, China.

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Shiokawa et al., 2002; Tsugawa et al., 2003; Ding et al., 2007; Wang et al., 2007). Also a storm enhanced density (SED) plume in the total electron content (TEC) was observed in the middle latitudes using a network of GPS receivers in North America (Foster and Rideout, 2005; Pokhotelov et al., 2009). Such a structure is identified as a signature of the plasmaspheric tails associated with the magnetospheric convection. Moreover, equatorial ionospheric irregularities including ionospheric plasma bubbles and dynamic behavior of the ionospheric F-region in the South American sector were observed, and a hemispheric asymmetries in the ionospheric response observed in the American sector during an intense geomagnetic storm by using 12 GPS receiver stations and ionospheric sounding located from 32.4°N to 53.8°S (de Abreu et al., 2010; de Jesus et al., 2010). Although the above or similar refined structures in the ionosphere were revealed, we are still unclear about the whole picture of their general feature. Are these phenomena a global behavior or have longitude dependence? In order to develop a global specification and forecast system for the ionosphere during a magnetic storm, we need more observational data at different place. China seismo-ionospheric ground-based monitoring network (CSGMN) is a composite observational system aims at exploring and developing the seismo-electromagnetic observation technology that is applied for the earthquake forecasting. The system was operated routinely for 2 years including a vertical and oblique sounding network, a GPS network. At the present time, there are huge amount of data which can be used not only for the seismo-ionospheric research but also for the ionospheric space weather monitoring and investigation.

The solar cycle 24 began from January 2008 as a reversed-polarity sunspot appeared according to NASA's report (http://science.nasa.gov/science-news). After a minimum activity through early stage of 2009, the sun became increasingly active when sunspot 1041 produced the first solar flare above the M-class in January 2010. Since then, a series of magnetic storms from the moderate to intense level occurred according to ring current index (*Dst*). The largest two events with $Dst < -120$ nT appeared on the 25th October 2011 and 15th July 2012, which provide a chance to study the ionospheric effect. Here we select the latter storm since the interplanetary magnetic field (IMF) of this storm has a very prolonged large southward component (32 h) which produces much more severe ionospheric disturbance in the Far East Asian region.

This paper reports some of the most recent findings in connection with the critical frequency of the F2 layer foF2, and the vertical TEC over North China during this extreme space weather conditions on the most disturbed days of July 2012. We examine the solar-terrestrial conditions surrounding the 13–17 July 2012 storm to illustrate F-region spatial and temporal variations. Firstly, Sections 2 and 3 give details concerning the use of ionospheric data available in the North China and the interplanetary environment of the storm period. Sections 4.1 and 4.2 presents geomagnetic and F-region storm morphology seen by temporal and spatial variations, foF2 and TEC from the CSGMN network of observational sites. Section 4.3 presents the electron density profiles (EDPs) during the storm time derived from radio occultation (RO) technique of a Constellation Observing System for Meteorology, Ionosphere, and Climate mission (COSMIC) and a comparison with the ground data is carried out for validation of the COSMIC data during the storm time. Finally we discuss how identified patterns in these variations can be used for real-time specification and forecasting of ionospheric F-region storms.

2. Data

Ionosonde data was from the ground-based high-resolution ionospheric observational network which was setup in June 2009 as a subsystem of CSGMN, shown in Fig. 1. This network consists of 5 vertical sounding stations Changchun (43.84°N, 125.27°W), Beijing (40.11°N, 116.27°W), Qingdao (36.24°N, 120.41°W), Xinxiang (35.26°N, 113.95°W) and Suzhou (31.32°N, 120.63°W), (CC, BJ, QD, XX and SZ) and 20 oblique receivers, forming 99 channels of radio wave transmission through the ionosphere and 99 maximum observable frequencies (*MOFs*, *fO*) at different paths can be obtained, with which we can achieve the information of the reflected points of the ionosphere with the relationship $fO = foF2\,k\sec\varphi$, where k is the Earth sphericity coefficient and φ is the incidence angle. 45 radio paths are chosen, whose ground distances $D \le 600$ km, which makes up 10% of the path length and does not significantly affect the accuracy of foF2 calculations (Kotovich et al., 2006). The values of 45 points were grouped in a 2° latitude bin and slide every 0.5°, for each bin, a mean value was obtained thus making a 2D map of parameter foF2. The temporal resolution of the oblique sounding data is half an hour while the vertical sounding data is an hour.

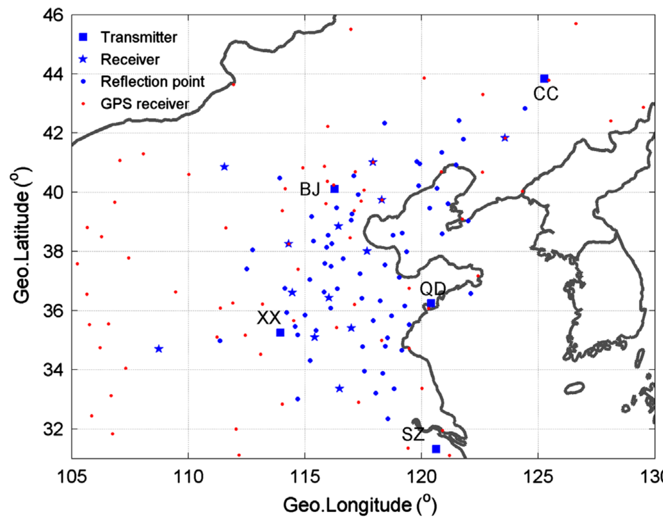

Fig. 1. Information of China seismo-ionopheric ground-based monitoring network (CSGMN), including a vertical sounding system (Transmitter) and an oblique sounding system and GPS receiver network.

GPS TEC data were obtained from 55 GPS stations (Fig. 1) located throughout the North China from the Crustal Movement Observation Network of China (CMONC) and the International GNSS service (IGS). CMONC is a comprehensive observational network in the earth sciences on the basis of GNSS supplemented by a variety of space-based techniques, which aims to perform real-time dynamic monitoring of changes in continental tectonic setting and explore its effect on the resources, environment and disasters. It now consists of 200 reference stations and thousands of moving stations all around China. An automated technique for processing GPS data from multiple receivers was developed by Mao et al. (2008) and Xiong (2006) and applied for “Halloween storm” study (Zhao et al., 2005). By incorporating a network of GPS vertical TEC at ionospheric piece points, a UT/latitude map can be reconstructed by applying nearest interpolation to the longitude 115°E with a 20° window. The latitude resolution is 2.5° and temporal resolution is half an hour.

The COSMIC constellation, 6 microsatellites, provides approximately 24 h of local time coverage and globally ~2000 vertical EDPs (100–800 km) per day. The raw observations are processed by the COSMIC Data Analysis and Archive Center (CDAAC) and the processed data are now available for the period from day of year (DOY) 111 in 2006 to DOY 280 in 2012, which provides about 2.7 millions of EDPs. The amount of EDPs decreases to ~1000 during recent years as some of the microsatellites have power