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ScienceDirect

Advances in Space Research xxx (2017) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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Response of the equatorial and low-latitude ionosphere over the West Pacific Ocean Sector to an X1.2 solar flare on 15 May 2013

Tian Mao [a], Lingfeng Sun [b,*], Yungang Wang [a], Chengli She [b], Bo Xiong [c], Lianhuan Hu [b]

[a] Key Laboratory of Space Weather, National Center for Space Weather, China Meteorological Administration, Beijing 100081, China
[b] Key Laboratory of Earth and Planetary Physics, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[c] School of Mathematics and Physics, North China Electric Power University, Baoding 071000, China

Received 8 November 2016; received in revised form 18 May 2017; accepted 22 May 2017

Abstract

On the basis of multiple observations of ionosondes, meteor radars, magnetometers and GNSS receivers, we present the response of the equatorial and low latitude ionosphere over the West Pacific Ocean Sector to an X1.2 solar flare that peaked at 1:48 UT on 15 May 2013. The geomagnetic H component observations indicate the equatorial electrojet strength over the East Asia region is obviously enhancement during the flare. After the end time of solar flare, the ionosonde observations at Guam, an ionosonde station near the geomagnetic equatorial region, show the decrease of the peak height of ionospheric F2 layer which is related to the decrease of the eastward electric field. Simultaneous strong southern wind is observed by meteor radar over Sanya, a geomagnetic low latitude station, which probably product the westward dynamo electric field and further result in the decrease of vertical drift velocity over the geomagnetic equatorial region. In addition, GNSS total electron content (TEC) observations from six stations in the researching region show the TEC enhancement only appears nearby the geomagnetic equator region.
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Keywords: Solar flare; EEJ; Meridional wind; TEC

1. Introduction

Solar flare is one of the most complicated space weather phenomena. During solar flares, the sudden enhancements in the solar extreme ultraviolet (EUV) and X-ray photons induce an extra ionization of the upper neutral atmosphere and cause many kinds of sudden ionospheric disturbances phenomena in the sunlit hemisphere (Garriott et al., 1967; Thome and Wagner, 1971; Donnelly, 1976; Afraimovich, 2000; Zhang and Xiao, 2002; Wan et al., 2005; Liu et al., 2006; Kumar et al., 2015; Abdu et al., 2017). The X-ray and EUV flux cause the ionization in the ionospheric E and F region while X-ray enhances the ionization in the D region. Many researchers have studied the response of ionosphere or thermosphere to intensity solar flare (Mendillo and Evans, 1974; Le et al., 2007; Xiong et al., 2011; Qian et al., 2012).

By using X-ray, EUV and TEC data, Mahajan et al. (2010) found that peak enhancement in TEC is highly correlated with peak enhancement in EUV flux and the correlation between TEC enhancement and X-ray flux improves greatly when the central meridian distance (CMD) of flare location is considered. Le et al. (2011) statistically analyzed the relationship between enhancement in X-ray flux and that in EUV flux during solar flares breaking out from 1996 to 2006 using the 0.1–0.8 nm X-ray flux data and 26–34 nm EUV flux data observed by Goes and SOHO satellite. They pointed out that EUV enhancement, unlike X-ray enhancement, is greatly affected by CMD during a

* Corresponding author.
E-mail address: sunlingfeng@mail.iggcas.ac.cn (L. Sun).

http://dx.doi.org/10.1016/j.asr.2017.05.036
0273-1177/© 2017 Published by Elsevier Ltd on behalf of COSPAR.

Please cite this article in press as: Mao, T., et al. Response of the equatorial and low-latitude ionosphere over the West Pacific Ocean Sector to an X1.2 solar flare on 15 May 2013. Adv. Space Res. (2017), http://dx.doi.org/10.1016/j.asr.2017.05.036

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flare. The larger value of CMD results in the smaller EUV enhancement. On the basis of the density data derived from accelerometers on the Challenging Minisatellite Payload (CHAMP) and Gravity Recovery and Climate Experiment (GRACE) satellites, Le et al. (2012) analyzed the response of thermospheric neutral density to all X-class solar flares during 2001–2006. They found that X5 and stronger solar flares could induce an average enhancement of 10–13% in thermospheric density in latitude 50°S–50°N within ~4 h after the flare onset and the thermospheric density enhancement is great correlated with integrated EUV flux than with peak EUV flux.

Using GNSS track network, Wan et al. (2005) have studied the sudden increase of TEC due to intense solar flare on 14 July 2000. They found that both the flare-induced TEC increment and variation rate are closely related with the solar zenith angles. Using the GNSS data from as many as 114 GNSS stations of the International GPS Service for Geodynamics (IGS), Zhang and Xiao (2005) studied the morphological features of the ionospheric total electron content (TEC) variations on sunlit hemisphere during the 4B solar flare, Classified based on an area (0–4) and brightness (faint "F," normal "N," and bright "B") of the Ha line (6563 Å) at maximum brightness, on 28 October 2003. They found that the strongest sudden increase of TEC (SITEC) happened during the flare, and the magnitudes of SITEC vary at regions with different local solar zenith angle (SZA). Based on the observed data of the GNSS, ionosondes and magnetometers, Manju et al. (2009) also investigated the response of the low-mid latitude ionosphere to the very large solar flare (X17.2/4B) of 28 October 2003. The obvious enhancements of Ne and TEC were observed during the solar flare and the flare related flux enhancements in different longitude sectors produced positive and negative variations in electrojet strength. Sripathi et al. (2013) studied the response of equatorial and low-latitude ionosphere to an intense solar flare of class X7/2B on 9 August 2011 in the solar cycle 24. They found that the EEJ strength suddenly depresses and the counter electrojet (CEJ) strength starts to increase over Indian region at the appearance of solar flare. Using the data of the incoherent scatter radar (ISR), ionosonde, magnetometers, and GNSS receivers in the American sector, Xiong et al. (2014) investigated the electrodynamic effects on the equatorial and low-latitude ionosphere during the intense solar flare (X1.5/2B) on 13 September 2005. They pointed out that the increase of Cowling conductivity induced by intensity flare changes the ionospheric dynamo electric field and further results in the weakening of eastward electric field and the decrease of the upward vertical $E \times B$ drift velocity.

The numerical models of ionosphere have also been used to study the response of ionosphere to the strength solar flare since 1990s. Le et al. (2007) investigated the solar flare effects of the ionosphere at middle latitude with a one-dimensional ionosphere theoretical model. The model calculations showed that the ionospheric responses to solar flares are largely related to the SZA and most of the electron density enhancements responding to a flare occur in the E and low F regions (below 300 km). Using the Flare Irradiance Spectral Model (FISM) and the NCAR TIME-GCM model, Qian et al. (2011) investigated how the rise rate and decay rate of solar flares affect the thermosphere and ionosphere responses to them. Model simulations and data analysis were conducted for two flares of similar magnitude (X6.2 and X5.4) that had the same location on the solar limb, but the X6.2 flare had longer rise and decay times. Simulated total electron content (TEC) enhancements from the X6.2 and X5.4 flares were about 6 TECU and 2 TECU, and the simulated neutral density enhancements were about 15–20% and 5%, respectively. In addition, model simulations showed that increased $E \times B$ plasma transport due to conductivity increases during the flares caused a significant equatorial anomaly feature in the electron density enhancement in the F region but a relatively weaker equatorial anomaly feature in TEC enhancement, owing to dominant contributions by photochemical production and loss processes. Qian et al. (2012) also used model simulations to investigate possible additional contributions from electrodynamics, finding that the vertical $E \times B$ drifts weaken in the magnetic equatorial region, causing a weakened equatorial fountain effect, which in turn causes lowering of the peak height of the F2 region and depletion of the peak electron density of the F2 region. Nogueira et al. (2015) investigated the ionospheric response close to the subsolar point in South America due to the strong solar flare (X2.8) that occurred on 13 May 2013. Using a theoretical ionospheric model, they simulated the solar flare effect in the E and F regions of the equatorial ionosphere, with reasonable success to explain many important features of the TEC variations in the observational data.

Although many researchers studied the ionosphere response to intensity solar flare, there are still many questions about the topic. For example, why does the eastward electric field and the vertical drift velocity decrease in the magnetic equator during flare? What is the relationship between EEJ strength and solar flare strength? The present work analyzes the responses of the equatorial and low-latitude ionosphere over the West Pacific Ocean Sector to the X1.2 solar flare event occurred on 15 May 2013. The rests of this paper are arranged as follows. Section 2 describes the data sources. Section 3 shows the ionosphere response to the solar flare. The last part gives the summary of the paper.

2. Data

The observation data include X-ray flux, solar EUV flux, geomagnetic horizontal component, neutral wind, ionospheric parameters and GNSS TEC data. Table 1 describes the information of the instruments used in the present study. The 1 min averaged X-ray data observed by GOES in the wavelength bands of 0.1–0.8 nm and

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