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Multi-instrument observations of plasma features in the Arctic ionosphere during the main phase of a geomagnetic storm in December 2006

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ABSTRACT

Arctic ionospheric variations during the main phase of a magnetic storm on 14–15 December, 2006 were investigated to characterize the high energy particle precipitation caused effects, based on multi-instrument observations. These include electron density observations provided by the Global Positioning System (GPS) total electron content (TEC) measurements, European Incoherent Scatter (EISCAT) radar, the radio occultation (RO) from both the CHAMP satellite and the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) satellite, as well as the ionospheric absorption of cosmic radio noise measured by the Imaging Riometer for Ionospheric Studies (IRIS) at Kilpisjärvi in the northern Finland (69.05°N, 20.79°E). Significant increases in the electron density for these different observations were found in the Arctic ionosphere during the main phase of the magnetic storm. These increase occurred in Scandinavian, Northwest part of Russia and Svalbard (SNRS) region, primarily at an altitude of about 110 km. These results are first reported for the SNRS region, and our study contributes to a more complete description of this space weather event during 14–15 December, 2006. Our observations also provide direct evidence that the stormtime E-layer electron density enhancement (e.g., the sporadic E) can form a nearly dominant portion in the observed TEC increase. These increases were accompanied by the ionospheric absorption enhancement at the altitude of about 90 km. The Y-component of magnetic field to the south of SNRS decreased, indicating strong upward field aligned electric current in the Arctic ionosphere. These features are interpreted as the effect of the high energy electron precipitation during the magnetic storm, which is caused by the sub-storm reflected on AL index and the measurements of IMAGE (International Monitor for Auroral Geomagnetic Effects) chain. The average energy of the precipitation electrons reached to about 10 keV and the boundary of the high energy electron precipitation was also found to move poleward with a speed of about 800 m/s.

1. Introduction

A geomagnetic storm is the result of strong enhancement of ring current, which is caused by disturbances in the solar wind and interplanetary magnetic field (IMF) and their interaction with the magnetosphere (Mansilla and Zossi, 2011). During geomagnetic storms the magnetospheric energy input into the polar upper atmosphere can significantly modify the chemical and electrodynamic processes in the ionosphere–thermosphere (I–T) system. Consequently, large disturbances in ionospheric electron densities including total electron content (TEC) were observed during geomagnetic storms (e.g. Mansilla, 2008; Zhao et al., 2009). The geomagnetic storms have strong relationship with ionospheric disturbances. To comprehend well the response of the ionosphere to the magnetic storm, it is very helpful to understand not only the coupling of magnetosphere and ionosphere, but also the dynamics of the ionosphere at high, middle and low latitudes. It is also understood that severe ionospheric disturbances caused by geomagnetic storms can place a visible impact on our space-and ground-based technology systems (e.g. Buonsanto, 1999; Trivedi et al., 2011). Therefore, researching ionospheric disturbances (ionospheric storm) during the magnetic storm remains to be a very challenging but active topic. More comprehensive reviews on

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our current understanding can be found in Prölss (1995), Buonsanto (1999), Burns et al. (2007), Maltsev (2003) and Mendillo (2006).

More recently, the ionospheric response to geomagnetic storms at high, middle and low latitudes have been perused by many authors (e.g. Kumar and Singh, 2011; Sharma et al., 2011a; Sharma et al., 2011b). By using the Coupled Magnetosphere Ionosphere Thermosphere (CMIT) 2.0 model, Lei et al. (2008a, 2008b) have successfully reproduced the significant positive storm effects in the Atlantic sector and the main characteristics of the ionospheric oscillations in Japan after the onset of the December, 2006 magnetic storm. By introducing ion continuity equations, the authors also demonstrated that changes in the electric fields and the disturbed neutral winds played a dominant role in generating the observed ionospheric positive storm effect and the ionospheric oscillations, respectively. Mansilla (2008) has reported on the enhancement of electron density during the initial stages of the storm on 26 September, 1982 at middle latitudes, followed by reduction of electron density at high and mid-high latitudes during the main phase of the storm. Also delayed increases of the electron density have been observed at mid-latitudes during the recovery phase, which are likely associated with an increase in atomic oxygen density. Foster et al. (2005a), Foster and Rideout (2005b) analyzed a magnetic storm of 20 November, 2003 and found that the tongue of ionization (TOI) spanned polar latitudes from a source in the dayside mid-latitude ionosphere, through the dayside cusp, and acrossed the polar cap to auroral latitudes in the midnight sector. The polar TOI is the plume of storm enhanced density (SED) transported toward noon from sub-auroral latitudes by the Sub-Auroral Polarization Streams (SAPS) disturbance electric field. This work shows that during the main phase of a major magnetic storm, the low latitude, auroral and polar latitude regions were coupled by processes which redistribute thermal plasma throughout the system. The expansion of high-latitude convection to mid-latitude and the buildup of the source plasma in the mid-latitudes were considered to be two necessary conditions for the TOI to develop as pointed out by Hosokawa et al. (2010).

In this paper, we analyze the ionospheric plasma features during a magnetic storm on 14–15 December, 2006. For this storm, ionospheric effects at low and middle latitudes have been discussed by Lei et al. (2008a, 2008b) as mentioned above. The long-duration positive storm effect in low and middle latitude are reported by Pedatella et al. (2009) where the topside ionospheric electron density enhancement are ascribed to the soft particles precipitation. Some strong oscillations, an unusual uplifting of the F-region and ionospheric plasma bubbles are observed in the South American sector, too (Jesusa et al., 2010). It is also indicated that the GPS-TEC showed both positive and negative storm phase on the night of 14 and 15 December, 2006. In the high latitude, there were many intense irregularities appeared in the ionosphere, which extended to high altitudes (van de Kamp, 2013). The TOI structure are found during the magnetic storm by an all-sky imager in the northern part of Canada at Resolute Bay (Hosokawa et al., 2009). Hosokawa et al. (2010) had discussed the temporal evolution and spatial structure of the TOI during this storm in the dusk-side. Here, we will exam the same event but mainly focus on the Arctic ionospheric plasma features in the post mid-night sector during the main phase of this magnetic storm based on multi-instruments observations, including GPS/TEC, radio occultation (RO), EISCAT, IRIS and magnetometer, and discuss the possible mechanism of these plasma features.

2. Solar wind and geomagnetic conditions

A coronal mass ejection occurred on 13 December, 2006 and produced an intense geomagnetic storm. Solar geophysical parameters during this geomagnetic storm, including SYM-H and AL indices, IMF in the GSM coordinates, the solar wind speed (V_x), the solar wind dynamic pressure (P_{dyn}) and proton number density (Np), are shown in Fig. 1. The solar wind and IMF measurements are from ACE satellite and are offset to account for the propagation time from the satellite location to the magnetopause. From the variations of the SYM-H index, we can find that there was a typical

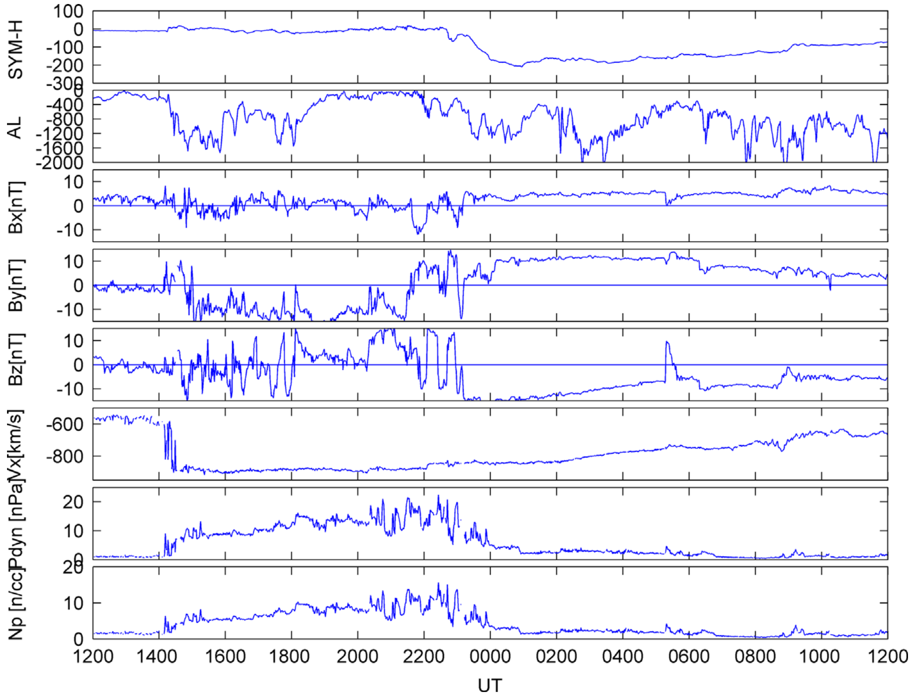

Fig. 1. Geomagnetic indices (SYM-H and AL), interplanetary magnetic field and solar wind velocity, density and pressure for the period from 12:00 on 14th December to 12:00 on 15th December in 2006.