Combined ESR and EISCAT observations of the dayside polar cap and auroral oval during the May 15, 1997 storm

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Abstract. The high-latitude ionospheric response to a major magnetic storm on May 15, 1997 is studied and different responses in the polar cap and the auroral oval are highlighted. Depletion of the F₂ region electron density occurred in both the polar cap and the auroral zone, but due to different physical processes. The increased recombination rate of O⁺ ions caused by a strong electric field played a crucial role in the auroral zone. The transport effect, however, especially the strong upward ion flow was also of great importance in the dayside polar cap. During the main phase and the beginning of the recovery phase soft particle precipitation in the polar cap showed a clear relation to the dynamic pressure of the solar wind, with a maximum cross-correlation coefficient of 0.63 at a time lag of 5 min.

Key words: Ionosphere (auroral ionosphere; polar ionosphere) – Magnetospheric physics (storms and substorms)

1 Introduction

The ionospheric storm is a chain of events in general caused by the energy transferred from the solar wind to the magnetosphere during periods of southward interplanetary magnetic field (IMF). According to variations of the maximum electron density in the F₂ region (NₘF₂), the ionosphere may show a positive or a negative storm phase, with enhancement or depletion of NₘF₂. The negative storm phase is usually caused by changes in the thermospheric composition and the positive one by elevated F region heights driven by disturbed thermospheric winds (Szaszczewicz et al., 1998). Other mechanisms, e.g. effects of heating and vibrationally excited constituents on reaction rates, or the escape of plasma upward along the magnetic field line were also discussed (Richards and Torr, 1986; Pavlov, 1998). The ionospheric response varies strongly with latitude. In the auroral zone the F₂ region usually exhibits a negative storm phase, but the E region a positive one due to strong particle precipitation. In contrast to extensive studies of storm effects in the auroral region, ionospheric responses in the polar cap have been studied far less intensively, especially at low altitudes (<600 km) due to various difficulties in observation. Combined observations of the auroral and the polar cap ionosphere will provide a better understanding of the storm-time high-latitude ionosphere and physical processes of geomagnetic storms.

The EISCAT Svalbard (ESR) and the mainland Tromso radar are located at 78°N geographic (74° geomagnetic) and 69.7°N geographic (66° geomagnetic) latitudes, respectively. Under disturbed conditions the auroral oval expands equatorward and the polar cap boundary moves to lower latitude as well (Holzworth and Meng, 1984). The ESR was in the dayside polar cap (on open field lines) during the main phase and the beginning of the recovery phase of the May 15, 1997 storm according to results calculated by using the T96 magnetic field model. The EISCAT Tromso radar was in the dayside auroral oval (on closed field lines) during the same period, which was proven by the UV images taken from the ultraviolet imager (UVI) on board the POLAR satellite (Torr et al., 1995). This situation provides us with a valuable opportunity to observe storm effects in both the polar cap and the auroral oval simultaneously.

2 Observations

2.1 Solar-geophysical conditions

Figure 1 shows 1-min integrated solar wind and IMF data (in GSM coordinates) from the WIND spacecraft, together with the related geomagnetic indices for May 15, 1997. WIND observed the passage of an
The solar wind dynamic pressure, the IMF $B_y$ and $B_z$ component, the $D$$_{st}$ and $Kp$ index on May 15, 1997

interplanetary shock at 0116 UT, followed by several hours of high solar wind dynamic pressure. The arrival of the magnetic cloud at the WIND location was marked by a sharp southward turning of the IMF $B_z$ at 0446 UT (Cane et al., 1998). The IMF $B_z$ showed two minima, the first minimum of $-24.3$ nT at 0556 UT and the second one of $-24.7$ nT at 1023 UT followed by a long period of gradual recovery to a northward direction. WIND was located at $X_{SW} = 1.21 \times 10^6$ km at 1200 UT and the $X$ component of the solar wind velocity $V_x$ was $-440$ km s$^{-1}$, giving a travelling time of $\sim 43$ min from the position of the WIND spacecraft to the subsolar magnetopause.

The $D$$_{st}$ index rose slightly at 0159 UT, indicating the storm sudden commencement (SSC) caused by the interplanetary shock at 0116 UT (Cane et al., 1998). After being nearly constant for four hours, it decreased rapidly and reached a minimum of $-120$ nT at 1200 UT. Afterwards it recovered gradually to the normal level. The maximum $Kp$ value was 7$^+$.

2.2 Storm effects in the auroral zone

Figure 2 shows the key ionospheric parameters measured by the EISCAT mainland radar in the auroral zone. The electron density $N_e$ and the field-parallel ion temperature $T_i$ are averaged over a height range 250–350 km. The electric field was derived from the tri-static ion drift measurement at a height of 278.5 km. The Joule heating rate is height-integrated over the range 90–240 km. Dashed curves represent values on June 26, 1997, a magnetically quiet day with $Kp_{max} = 2$, shown here as a reference.

The F$_2$ region exhibited a negative storm effect through the whole day, with average $N_e$ depleted from the quiet reference level of $2.3 \times 10^{11}$ to $0.7 \times 10^{11}$ m$^{-3}$ in the storm main phase. This large depletion was caused by strong electric fields (see Fig. 2c), which peaked to $120$ mV m$^{-1}$ during the storm main phase, nearly ten times the quiet-time value. As a result, this large electric field caused strong Joule heating in the ionosphere (Fig. 2d), thereby heating the ions from about 900 to nearly 2000 K. Simultaneously, the heating in the E region resulted in an increase of the neutral temperature and an upwelling of the neutral gas, providing enriched concentrations of molecules (e.g., N$_2$ and O$_3$) in the F region. Both processes contribute to the F$_2$-region depletion mainly by increasing the recombination rate of O$^+$ ions. The detailed physical mechanism of strong negative storm effects in the F$_2$ region has been studied by Mikhailov and Schlegel (1998) and references therein. Enhancements of $N_e$ around 0800 UT and between 0900–1100 UT are caused by particle precipitation.

It should be noted that the peak ion temperature may be underestimated in our data because of a possible ion temperature anisotropy and a more molecular ion composition than accounted for by the standard EISCAT data analysis during periods of large electric field