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Regional response of the mesosphere–lower thermosphere dynamics over Scandinavia to solar proton events and geomagnetic storms in late October 2003

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Abstract

The short-term regional responses of the mesosphere–lower thermosphere (MLT) dynamics over Scandinavia to the exceptionally strong solar storms with their accompanying solar proton fluxes on the Earth in late October 2003 have been investigated using radar measurements at Andenes (69°N, 16°E) and Esrange (68°N, 21°E). Several solar activity storms resulted in solar proton events (SPEs) at this time, but a particularly active period of high proton fluxes occurred between 28 and 31 October 2003. The significant temperature drop (~25 K), detected by the meteor radar at Andenes at altitude ~90 km, was in line with the enhancement of the proton fluxes and was caused by the dramatic reduction of the ozone in the high-latitude middle atmosphere monitored by satellite measurements. This exceptionally strong phenomenon in late October 2003 was composed of three geomagnetic storms, with the first one occurring in the daytime of 29 October and the other two storms in the nighttime of 29 and 30 October, respectively. The responses of the prevailing wind and the main tides (24- and 12-h tides) were studied in detail. It was found that the response of the MLT dynamics to the first geomagnetic storm occurring in the daytime and accompanied by solar proton fluxes is very different from those to the second and third geomagnetic storms with onsets during the nighttime. Some physical mechanisms have been suggested in order to explain the observed short-term variability of the MLT dynamics. This case study revealed the impact of the SPEs observed in late October 2003 and the timing of the geomagnetic storms on the MLT neutral wind responses observed over Scandinavia.

Keywords: Mesospheric dynamics; Winds and tides; Solar proton event; Geomagnetic storm

1. Introduction

The atmospheric dynamics of the high-latitude mesosphere/lower thermosphere (MLT) region is strongly controlled by vertically upward-propagating waves of large amplitudes. They provide/transfer energy and momentum from lower to upper

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atmospheric layers. This region, however, can also be disturbed by transient external energy sources in the auroral zone related mainly to enhanced solar and geomagnetic activity. The energy involved in these forcings is derived from the Joule dissipation of electric currents (Joule heating), the kinetic heating due to precipitating charged particles originating from the radiation belts (particle heating), and the collisional coupling of the movement of neutral particles with ions in the lower thermosphere driven into motion by electric fields (ion drag). The effects of these energy sources are relatively well studied in the thermosphere and ionosphere F-region heights, where the response to them is very strong. The response of the MLT region is still not well understood. In general, it is weaker than that of the thermosphere–ionosphere system and, frequently it is overwhelmed by the internal coupling processes that are usually dominant at these heights.

The observational reports on the MLT region wind response to the geomagnetic storms provide quite contradictory results. Hook (1970), using meteor wind radar at College, Alaska, found evidence of enhanced southward wind at altitudes of 75–110 km, while Ma et al. (2001) reported enhanced eastward wind several days after the storm onset at midlatitude stations situated in Japan, with the magnitude of the enhancement depending on the season. Recently, Balan et al. (2004), using MU and MF radars located in Japan, found that the meridional MLT wind becomes more equatorward, while the zonal wind becomes more eastward. Price et al. (1991) have observed the neutral winds in the altitude region between 70 and 110 km at a high-latitude station (70°S) and found a tendency for equatorially directed wind in the early morning hours. Singer et al. (1994), using superposed-epoch analysis, demonstrated that there was enhanced westward zonal wind at middle latitudes and an eastward wind at higher latitudes and no reaction in the meridional wind. However, Fahrutdinova et al. (2001) reported a reduction in the mean zonal wind and appearance of the northward meridional wind. Nozawa and Brekke (1995), using the EISCAT measurements, found that the differences in the neutral wind patterns between disturbed and quiet days below 109 km are rather small and within the error bars of the experiments, which supported the earlier observations made by Kunitake and Schlegel (1991). Therefore, observations accumulated to date show that the neutral MLT winds could be enhanced, reduced or not affected during the geomagnetic storms and that the changes could be in different directions.

The observational reports on the tidal response to the geomagnetic forcing are also quite conflicting. Wand (1983), using incoherent scatter observations at Millstone Hill (42.6°N), found that the semidiurnal tidal amplitudes at 105 and 115 km heights were depressed by 20–50%. Singer et al. (1994), using MF and meteor radars, as well as LF wind profilers, also observed a weak reduction of the semidiurnal tide due to geomagnetic storms. In contrast, Pancheva and Mukhtarov (1998) and Fahrutdinova et al. (2001) reported an increase in the amplitude of the diurnal and semidiurnal tides. Balan et al. (2004) observed different behaviour of the tides in the zonal and meridional wind components. While the amplitude of the diurnal tide in the meridional component indicated some enhancement, that in the zonal component almost disappeared. In contrast, the semidiurnal tide in the meridional components decreased significantly during the disturbed conditions, while the zonal component strengthened at the mesopause level.

The model simulations describing the geomagnetic effects on the tides (Fesen et al., 1993; Fesen, 1997) unfortunately cannot predict the tidal behaviour at the mesosphere heights because usually the lower boundary of these models is around 95 km high. The NCAR thermosphere–ionosphere general circulation model used by Fesen (1997) showed obvious storm effects on tides only above 110–120 km altitude.

The inconsistent observational evidence about the response of the MLT dynamics to the geomagnetic disturbances indicates that the response is dependent on the season, geomagnetic latitude and probably longitude, and on the timing of the disturbances. Zhang et al. (2003) found different responses of the dayside and the nightside MLT winds to the April 2002 geomagnetic storm. While the neutral winds at sites situated in the sunlit hemisphere showed a pattern similar to the ion convection pattern, the winds at sites in the nightside hemisphere showed no obvious storm effect. The location of the observations and the timing of the geomagnetic disturbances are particularly important for case studies.

Most of the strong geomagnetic storms, particularly those near the solar maximum, are accompanied by huge fluxes of high-energy solar protons at the Earth. A period of time when the solar proton