Variations in Ionospheric E-region Dynamics at Mid-latitudes during Intense Geomagnetic Storms

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ABSTRACT

High-resolution observations of the dynamics of the ionospheric E-region (100-150 km) at mid-latitudes have been made with the incoherent scatter radar at Millstone Hill (42.6N, 71.5W) during several intense geomagnetic storms (Kp ~ 8-9). These included the storms of 25 September 1998, 15 July 2000, and 31 March 2001. The observations reveal electric fields up to 100 mV/m during some of these events, and indicate E-region westward plasma drifts of 300-500 m/s with smaller southward drifts. The tidal pattern of neutral winds in the lower thermosphere is heavily disrupted and dominated by the ion-driven convection during these intense storms.

INTRODUCTION

This paper[1] reports the observations of the ionospheric E-region by the Millstone Hill incoherent radar during three intense geomagnetic storms: 25 September 1998, 15 July 2000, and 31 March 2001, where geomagnetic indices Kp reached levels of 8-9, and Dst variations reached 200-400 nT. In general, the effects of geomagnetic storms are not detected at mid-latitudes in the E-region unless the disturbances are intense and the Kp index exceeds values of about 6 [1,2]. The variations of the geomagnetic indices during the three storms are given in Figure 1. The intensities of these storms are therefore expected to introduce major perturbations to the ionospheric E-region at midlatitudes.

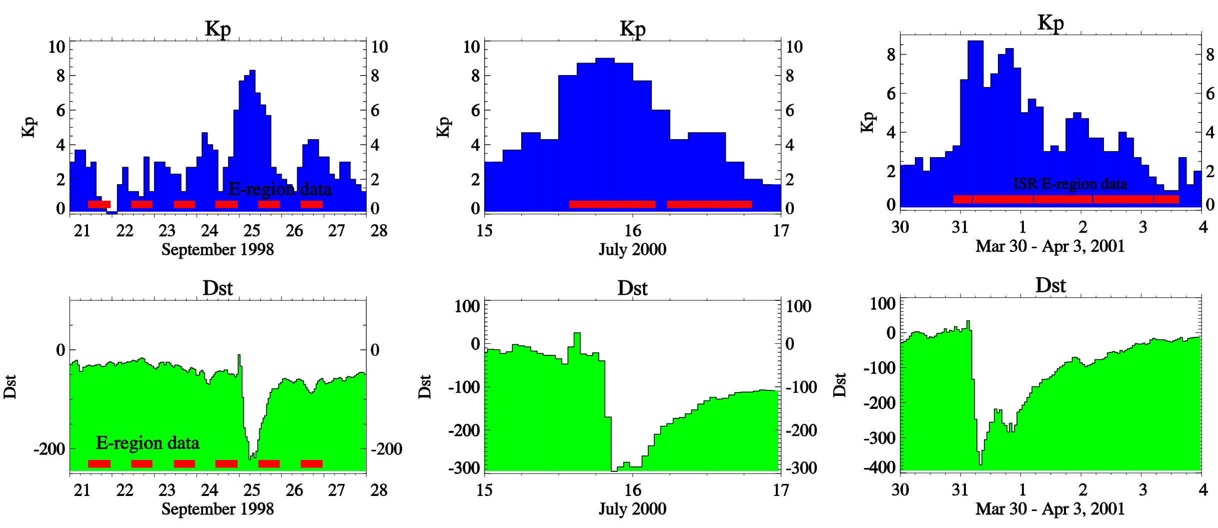

Figure 1. Variations of the geomagnetic indices Kp and Dst for the three storms.

The observational mode for the radar included a measurement of the full ion velocity vector, as well as electron density and plasma temperatures with an altitude resolution of 3 km. Although we report measurements of plasma drifts in the F-region that are used to derive the electric fields in the ionosphere, we emphasize here the study of the variations of the plasma drifts in the E-region at altitudes from 100 to 150 km. We will also address the coupling between the ion and neutral components. The objective of the study is to assess the penetration extent of the storm effects in latitude and altitude. Due to the heavy particle precipitation at mid-latitudes during the storms, observations at Millstone Hill in the

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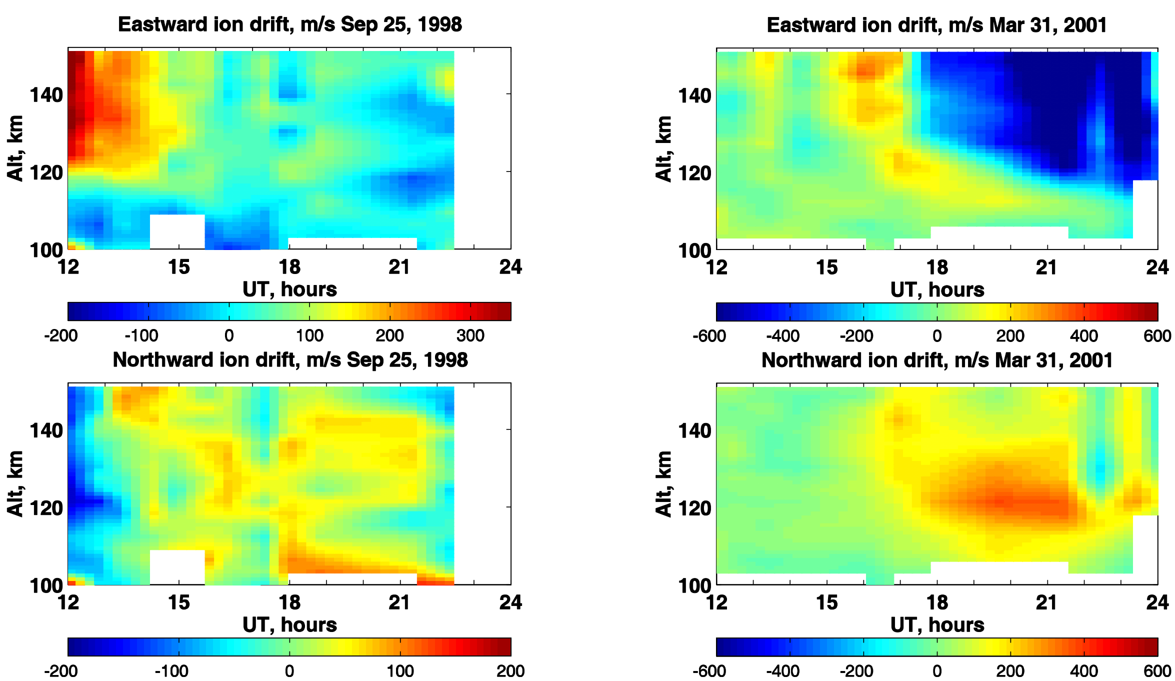
E-region during the nighttime were possible and allowed a near-continuous description of the time variations of the ionospheric E-region during the storm. This is in contrast to measurements made in this region during geomagnetically quiet times, which are limited only to daytime periods when the signal-to-noise ratio from the backscattered signal is sufficiently strong. The range of E-region coverage by the radar for each of the events is indicated in Figure 1 with the red bars at the bottom parts of the panels.

PLASMA DRIFTS OBSERVATIONS

The following summarizes the main features of the plasma drift observations in the E-region over Millstone Hill during the three storms. Figure 2 shows the horizontal plasma drifts for the September 25, 1998 and the March 31, 2001 storm. In both storms, the E-region plasma drifts show large zonal speeds, reversing from eastward to westward directions. This reversal in direction from eastward flow in the morning hours to westward flow in the evening hours follows the two-cell auroral convection pattern and indicates the penetration of the convection pattern to the midlatitude E-region. The observed are of order 200-300 m/s, with large westward components as large as 500 m/s in the March storm. The peak ion velocity on September 25 at 130-140 km is seen at around 12 UT when the measurements were started, roughly 6 hours after the maximum Kp or Dst deviation. The large westward drifts are observed during the March storm starting at 18 UT, coincident with the second maximum of the Kp index. Radar data from the time of the first Kp maximum during this storm contains gaps and is not presented here. The meridional drifts show change from southward directions in the morning hours to northward directions in the evening hours during both storms. During the September storm, a strong southward drift is observed around 12 UT, coincident with the intense eastward component. During the March storm, a strong cell is observed at about 120 km with northward drifts reaching 200-300 m/s.



(a) (b)

Figure 2. Plasma drift velocity in both eastward and northward directions for (a) September 25, 1998 storm, and (b) March 31, 2001 storm.

The observations from the July 2000 storm also show a similar pattern. Figure 3 displays the plasma drifts velocities showing very large speeds, exceeding 1000 m/s in the E-region with a clear reversal from eastward to westward directions at around 20 UT. The results also show that the large westward cell extends throughout the E-region into the F-region. A strong cell of northward drifts with peaks of 300-400 m/s is seen at about 120 km after 20 UT. The reversal from the strong northward velocities to southward velocities above about 135 km indicates the completion of the magnetospheric circuit by Pedersen currents.

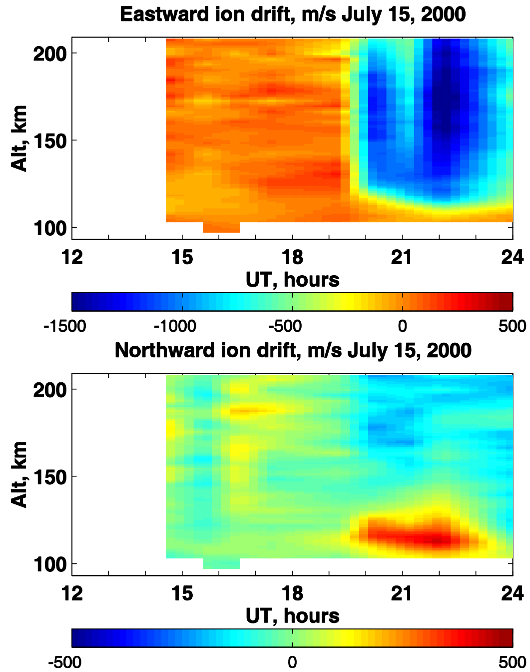


Figure 3. Plasma drift velocity in the eastward and northward directions for the July 15, 2000 storm,

It is noteworthy that the electric fields recorded during the July 2000 storm were the largest recorded by the Millstone Hill radar, reaching 120 mV/m northward component at the peak of the storm. The electric field measurements obtained from F-region plasma drifts are shown in Figure 4. It is these large electric fields that drive the strong plasma drifts in the E-region, indicating the influence of the auroral convection patterns on mid-latitude ionospheric dynamics when the storm effects penetrate to middle latitudes.

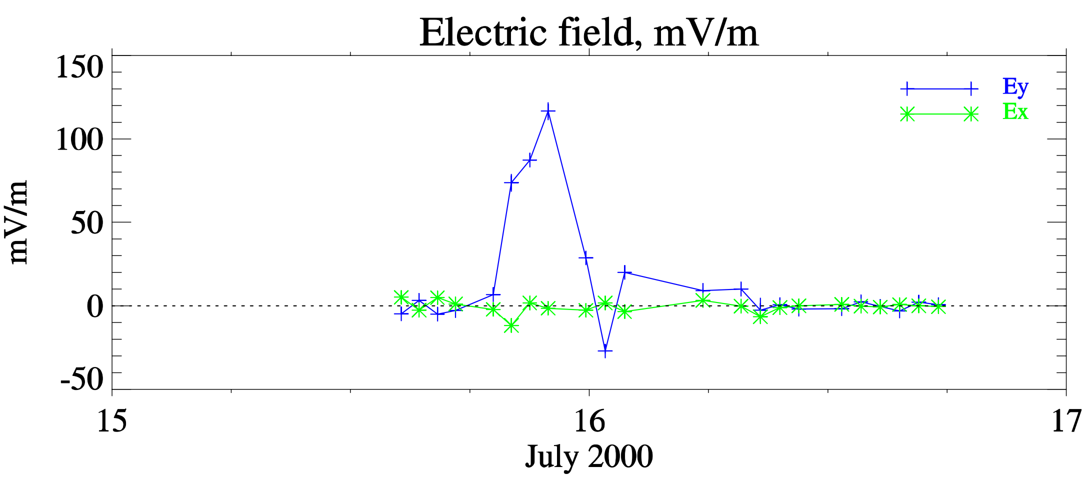


Figure 4. Variation of the electric field vector determined from F-region plasma drifts during the July 2000 storm event.

NEUTRAL WINDS

The large plasma drifts introduce uncertainties in the simplified method used for deriving neutral dynamics from radar observations and limit the ability to reliably determine the neutral winds during such events. Nonetheless, a derivation of the neutral winds was attempted and the results are shown in Figure 5. A large cell of westward neutral wind dominates the lower thermosphere above 110 km after the onset of the storm. Winds speeds of 300-500 m/s are observed. The meridional component is seen to reverse towards large northward velocities, exceeding 500 m/s. The large wind cells, and their similarity to the ion drifts which drive them, indicates that the normal pattern of relatively small amplitudes in the lower thermosphere induced by tidal propagation from the lower atmosphere are disrupted and become dominated by the ion-driven convection during intense storms. Comparison with winds obtained from atmospheric general circulation models [3] support the expected large enhancements of neutral dynamics driven by the ion plasma flows observed with the radar. Westward motions reflecting the expansion of the polar convection cell is predicted, together with a circulation pattern with a return northward flow in the lower thermosphere that completes the southward circulation cell generated in the F-region or upper thermosphere.

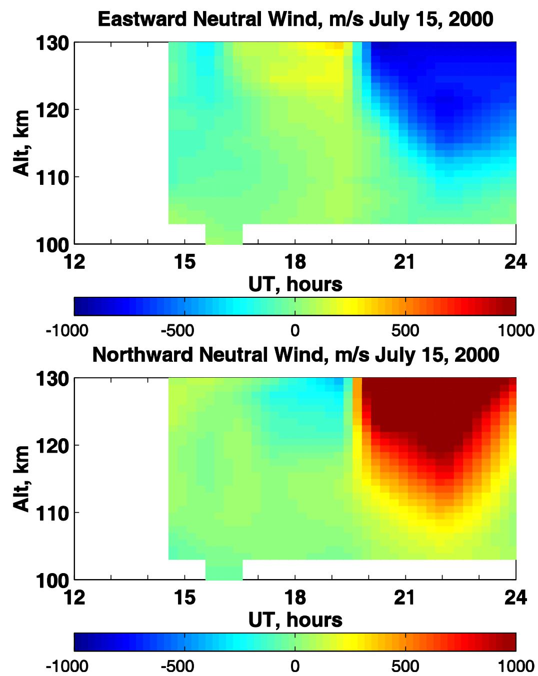


Figure 5. Derived neutral wind velocity in the eastward and northward directions for the July 15 storm.

DISCUSSION AND SUMMARY

The radar observations of drifts in the F-region reveal electric fields as high as 100 mV/m during the storm events and are found to drive E-region plasma drifts primarily in the westward direction, with magnitudes of 300-500 m/s. During the most intense storm in July 2000, westward ion drifts as large as 1000 m/s were observed. Smaller drift velocities in the meridional direction are measured, and a common feature amongst the three storms is the development of a northward cell of plasma drift in the 120 km altitude range. Derivation of neutral winds in the lower thermosphere during the storms is difficult, but our calculations suggest a large north-westward component, indicating a strong coupling to the auroral convection pattern that expands towards middle latitudes. These results illustrate the important coupling that takes place between the polar and middle latitudes during intense storms and reveals the influence of the storm effects to altitudes as low as 100 km.

References:

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