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NIGHTTIME THERMOSPHERIC WINDS OVER SONDRE STROMFJORD, GREENLAND

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Abstract. Observations of nighttime thermospheric neutral winds made at Sondre Stromfjord, Greenland, with optical and radar instrumentation, showed an occasional abatement in the equatorward meridional wind at a magnetic local time corresponding to the nighttime division between the evening and morning convection cells. This abatement appeared primarily in the poleward observations. In contrast, however, the characteristic midnight "surge" was usually seen in the equatorward set of observations. The apparent acceleration of about 250 m/s or greater within 4.6° latitude we attribute, in part, to a merging of neutral jet streams generated by polar cap ion drag adjacent to the auroral zone boundary, and, in part, to the higher electron densities and plasma convection speeds adjacent to the auroral zone. Comparison of these results with those from NCAR/TGCM computations that assumed an analytical plasma convection model showed reasonable agreement, except for the abatement feature.

Introduction

An important discovery in the thermospheric dynamics of the auroral zone was the "midnight surge". This refers to a phenomenon found in observations of the meridional nighttime thermospheric wind, namely an increase to speeds of 300 m/s or greater in the equatorward direction for times shortly after local magnetic midnight [see references in the review by Meriwether, 1983]. There are two major driving forces for this surge. One is the day-to-night solar forcing generated by the daytime pressure bulge created by the heating of the thermosphere through solar insolation. The other is momentum transfer to the neutral atmosphere from convecting ions driven by the magnetospheric electric field imposed upon the ionosphere; this particular force is referred to as ion drag. Theoretical studies [Rees et al., 1980; Roble et al., 1982] have been successful in modelling thermospheric winds with a time-dependent three dimensional thermospheric general circulation model (TGCM) combined with a symmetric ion convection distribution in the polar cap as proposed by Sojka et al. [1979]. This work has found ion drag to be more effective in generating thermospheric winds for high latitudes than solar heating.

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The new radar site of Sondre Stromfjord, Greenland, combined with the installation of a Fabry-Perot interferometer at this location was an opportunity to study the nighttime thermospheric dynamics for a station located poleward of the auroral zone boundary. Our results on the thermospheric winds differ from previous findings in two respects. First, rather than the midnight surge, we find on occasion a large decrease in the meridional component during the midnight sector in the direction poleward of the station, especially during periods of quiet magnetic activity. Second, the winds observed south of the station were larger in magnitude than those observed poleward. This implies an enhancement in the meridional wind, typically about 250 m/s across a span of 4.6° latitude, in contrast to the deceleration observed at lower latitudes by previous workers [Hernandez and Roble, 1976; Hays et al., 1979; Sipler and Biondi, 1979].

Observational Details

The line of sight motion of the atmosphere is measured directly by the Fabry-Perot optical instrument from high resolution observations of the Doppler shift of the 630.0 nm emission line of atomic oxygen. The normal observing cycle for this instrument was a sequence of 8 equally-spaced azimuthal directions designed to map the thermospheric wind field over a latitude span of 4.6° with a zenith angle of 45°. A neon source provided a relative wavelength calibration at the close of each mapping cycle. Two zenith measurements were included in each cycle, and the zero velocity reference was determined from the total average of all 630.0 nm zenith offsets from the neon reference. The etalon instrumental function was calibrated periodically with a frequency stablized laser. Details on the electronics, data acquisition equipment, and computer software for the automated optical facility are given by Meriwether et al. [1983]; further information on the Greenland Fabry-Perot interferometer will be provided elsewhere.

The Sondrestrom radar [Kelly, 1983] determines the meridional wind in the magnetic zenith from measurements of the field-aligned ion motion with corrections for ambipolar diffusion [Wickwar et al., 1984]. We show results for the range gates of 210, 260 and 310 km as these had the best signal-to-noise ratios. The antenna was directed towards magnetic zenith with a total integration of 7 minutes. This was followed by 1 minute integration in each of two successive positions, magnetic zonal and magnetic meridional; these observations measured the plasma drift components generated by the magnetospheric electric field.

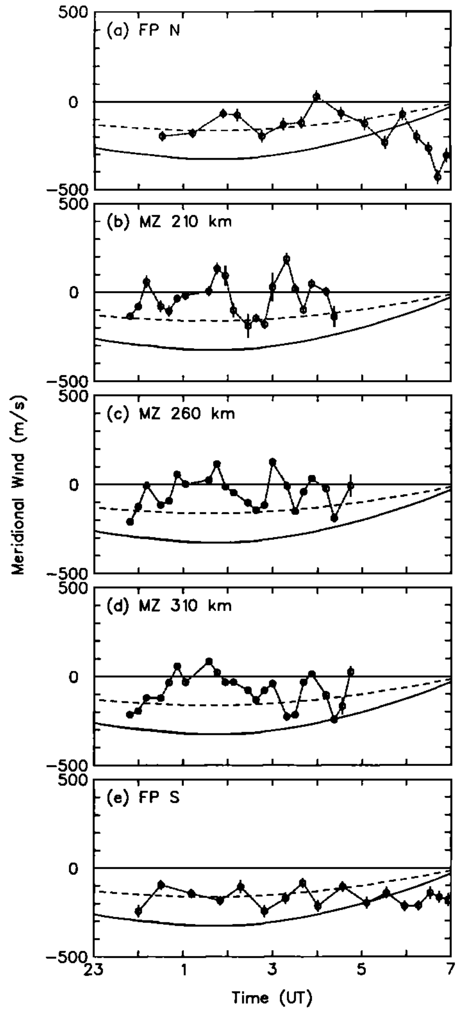

Fig. 1 Comparison of simultaneous radar and optical observations of the meridional thermospheric wind with the NCAR/TGCM meridional wind for 6 September, 1983, for cross tail potentials of 40 and 70 kV. Magnetic and local midnights occur at 0200 UT and 0300 UT, respectively.

Results

Figure 1 presents the simultaneous Fabry-Perot and radar observations of the meridional wind obtained 6 September, 1983(UT). The top and bottom panels of this figure show the optical measurements of the meridional wind (with respect to the geomagnetic meridian) obtained north and south of the station, and the other three panels show the radar results for the range gates of 210, 260, and 310 km in the magnetic zenith. Also included in each panel are the model curves extracted from the TGCM calculations with the aid of the diagnostic package [Killeen and Roble, 1984] for 40 and 70 kV cross tail potentials [Roble et al., 1984]. The abatement is seen plainly in both the poleward optical and the magnetic zenith radar observations but is not evident in the equatorwards optical observations or in the TGCM model calculations. The distance between the radar observations in magnetic zenith and the southward Fabry-Perot observations for 45° zenith angle is about 200 km; within this span the meridional wind increases by about 200 m/s. This example is representative of nearly all cases of the midnight abatement observed. Occasionally, for active magnetic disturbances, a significant decrease in the geomagnetic meridional component has been observed in the equatorwards observations as well. In Figure 2 we show averaged northward and southward optical meridional wind observations for 9 nights of observations in September, 1983; also included is the 70-kV TGCM curve presented in Figure 1. The abatement feature occurred frequently enough in this month to be seen in the northward set of averaged optical observations.

The set of 8 azimuthal observations obtained routinely makes possible the composition of vectors for the north and south geomagnetic directions from pairs of observations obtained in the geomagnetic northeast and northwest, and the geomagnetic southeast and southwest directions, respectively [Tepley et al., 1984]. By comparing the meridional component of each composed vector with the north or south set of observations, we may demonstrate the validity of this composition. In general, the agreement was found to be good. The plot of these vectors in a geomagnetic polar diagram for 6 December, 1983, in Figure 3a shows an asymmetric twin vortex pattern in which the evening cell appears more dominant. The abatement is seen at 02 MLT at the separatrix between these two cells for both sets of vectors.

An example of the more normal situation in which the abatement is seen only in the poleward direction is presented in Figure 3b showing results obtained on 22/23 February 1983. Here at 0030 MLT there is an increase of about 300 m/s in the observed meridional wind across the distance of 3.2° latitude between the two sets of vectors. There is also apparent a general indication of acceleration between the northern and southern sets of vectors throughout the night.

Figure 3c portrays the thermospheric neutral wind field at a cross tail potential of 70 kV determined for the Sondrestrom grid point by the NCAR/TGCM computations [Roble et al., 1982] that included simulation of effects related to particle precipitation. These calculations do not reproduce the observed abatement, but otherwise the comparison of direction and magnitude of the observed vectors with the TGCM vectors shows reasonable agreement. Further work on the simulation of this abatement through modifications of the plasma convection model used in the computations is in progress.

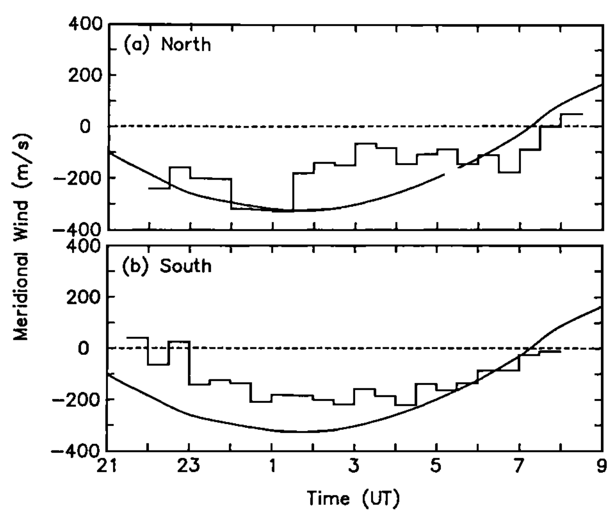

Fig. 2 Comparison of averaged poleward (north) and equatorward (south) geomagnetic meridional winds with TGCM model calculations for 70 kV cross tail potential.

Discussion

The differences between our observations of Sondrestrom thermospheric neutral winds and the results of the TGCM simulations signify the sensitivity of polar cap thermospheric winds to structural features of the plasma convection distribution for a polar cap station located near the auroral zone boundary. Hence, we believe the abatement phenomenon of the observed winds is related to the attenuation of the anti-sunward flow of plasma convection between the center of the polar cap and the auroral zone boundary. This condition is generally satisfied when IMF $B_z \geq 0$ [Heppner, 1972; Heppner, 1977]. In this case, significant polar cap thermospheric winds generated by ion drag would exist only for the region adjacent to the boundary. This would explain the maximum seen in the north set of meridional wind observations at a time before magnetic midnight and again after the period of the abatement; these peaks represent the neutral streams generated by polar cap ion drag near the auroral zone boundary.

We have considered other mechanisms such as back pressure from a region of high joule heating or particle precipitation located equatorward of the station. Such ideas are not well supported by TGCM calculations as these do not show large horizontal flows generated by the divergence of the upwelling motion in the heated area [Roble and Kasting, 1984]. An alternative view is that the acceleration arises from momentum transfer taking place north of the Sondrestrom station. However, Sondrestrom radar observations of the convection pattern do not show large meridional plasma drifts in the midnight sector. Chatanika results show zonal flows with large magnitudes near the dusk/dawn meridian during substorm activity [de la Beaujardiere et al., 1983].

The reduced momentum transfer in the thermosphere for the region poleward of Sondrestrom may occur as a consequence of a history of either smaller plasma convection speeds or lower electron densities further into the polar cap during the period between the afternoon and midnight sectors. Its occurrence is likely to be related to the formation of the "polar hole", a region of significant ionization depletion in the polar cap observed during periods of low magnetic activity within the midnight sector [Brinton et al., 1978; Sojka et al., 1979].

The latitudinal extent of the merging region near the midnight sector would typically be confined to the region south of Sondrestrom, but magnetic activity affecting the size of the auroral zone would be a factor in defining the location and breadth of this merging zone. This would explain in part the absence of the midnight surge to the north of Sondrestrom while present south of the station. It would also explain why the abatement feature was not detected in previous work as these stations were located sufficiently equatorwards of the merging region that the union of the two streams destroyed the abatement before it could be seen.

Further work is needed to explore this geometry of the neutral wind field in greater detail and to investigate possible relations connecting the abatement phenomenon to magnetic activity conditions and the polar cap distribution of both plasma convection and electron densities. Future Sondrestrom Fabry-Perot observations will be supplemented by simultaneous observations from a Fabry-Perot observatory to be installed near the center of the polar cap at Thule, Greenland (invariant latitude of 86°); observations from other stations in the polar cap and auroral zone would be highly desirable.

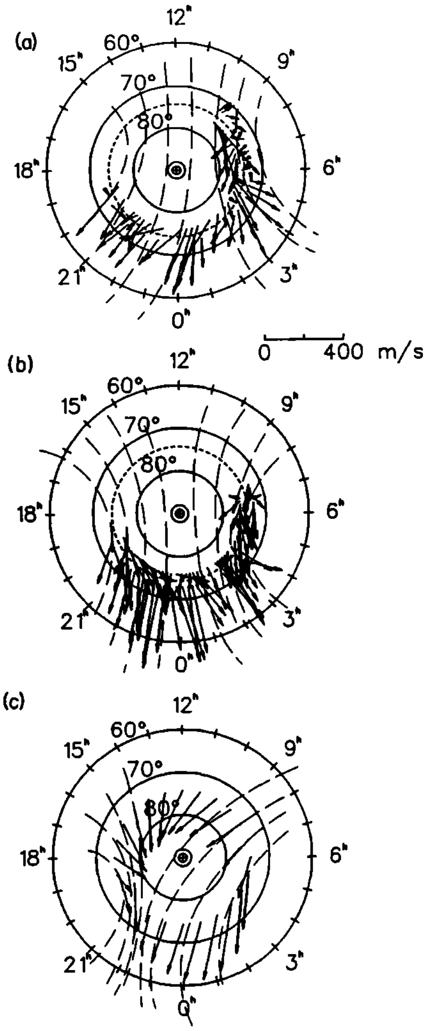

Fig. 3 Comparison of neutral wind fields with the results of the NCAR/TGCM model for 70 kV cross tail potential: a), 6 December, 1983; b) 23 February 1983; c), NCAR/TGCM computed winds for Sondrestrom at 70 kV cross tail potential in December. The streamlines shown were sketched in by eye.

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