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THERMOSPHERIC NEUTRAL WIND AT -39° AZIMUTH DURING THE DAYTIME SECTOR AT SONDRESTROM

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Abstract. Measurements with the Sondrestrom radar have been used to examine the daytime thermospheric neutral wind and to relate that wind to other geophysical parameters. Ion drag is found to be particularly important for determining the wind pattern. However, evidence is presented that the wind pattern is significantly influenced by soft particle precipitation and, possibly, by Joule heating.

Introduction

The thermospheric neutral wind at high latitude [Meriwether, 1983] is a basic parameter for the study of the upper atmosphere, ionosphere, and magnetosphere. On the one hand, it is important for the transport of energy and atmospheric constituents to lower latitudes, which leads to temperature increases and changes in optical emissions. On the other hand, it is a tracer of the effects of energy input from the sun, as well as energy input and momentum transfer from the magnetosphere to the ionosphere and neutral atmosphere.

The neutral wind's role as a tracer at high and very high latitudes of coupling among the neutral atmosphere, ionosphere, and magnetosphere, has been examined in several recent research efforts [Fuller-Rowell et al., 1981; Heppner and Miller, 1982; Roble et al., 1982; Hays et al., 1984; Meriwether et al., 1984], which have shown the importance of momentum transfer from the magnetosphere to the neutrals. Because of magnetospheric convection, ions at F-region altitudes in the auroral and polar cap regions usually move in two cells. Simply put, plasma trajectories traverse the polar cap from roughly magnetic noon to midnight (antisunward flow), then split and return to noon along the aurora oval (sunward flow). [The relative sizes of the cells, their shapes, and the locations of the boundaries between sunward and antisunward flow are among high latitude questions under intense study (e.g., Jorgensen et al., 1984; Clauer et al., 1984; and references therein).] The ions move with a typical velocity of 500 m/s, but a velocity of 2 km/s is not unusual. When an ion collides with a neutral, it transfers considerable momentum to it. If the plasma density is great enough and the ions and neutrals are in contact long enough, then the ions tend to drag the neutrals along with them.

While ion drag appears to be particularly important for affecting neutral motions, energy from the magnetosphere is also deposited by particle precipitation and Joule heating into the ionosphere and neutral atmosphere. Energy deposition by soft particle precipitation shows up clearly in electron temperature increases. Approximately an equal amount of energy goes into neutral heating between 220 and 400 km [Rees, 1975]. Joule heating, which on a microscopic scale is the frictional heating caused by ions passing through neutrals and vice versa, shows up clearly in ion temperature increases. Again, approximately an equal amount of energy goes into neutral heating. An important question is whether the energy deposited in the neutrals creates enough of a pressure increase to affect the neutral winds. Indications that energy deposition might suffice have come from differences between daytime winds determined from radar measurements in the magnetic meridian at Chatanika and from model calculations [Wickwar et al., 1984a]. Whereas the Chatanika radar was at 64° Λ, the Sondrestrom radar at 74° Λ is much closer to the regions of momentum transfer and energy input in the daytime sector. The Sondrestrom radar, therefore, is well situated to examine the daytime winds and the factors affecting them.

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Radar Determination of Thermospheric Neutral Wind

The data examined were acquired during thirteen 24-hr or longer experiments between April and September 1983 with the radar operating in a general survey mode [Wickwar et al., 1984b]. This mode provides an extensive set of parameters with 27-min time resolution [Wickwar et al., 1984b, and references therein] with which to derive a component of the thermospheric neutral wind as well as the background ionospheric conditions.

The neutral wind is derived from the ion velocity parallel to the magnetic field after appropriate corrects. Consider a plane passing through the local zenith and the magnetic field line that goes through the radar. [At Sondrestrom, the geographic azimuth of this plane in the north is -39°; in the south it is 141°. Thus, this plane has an azimuth angle 12° less than that of the magnetic meridian plane (Wickwar et al., 1984b).] When a neutral particle moving horizontally toward the south in this plane collides with an ion, the ion moves up the field line. Similarly, northward neutral motion gives rise to downward ion motion. Neutral motion perpendicular to this plane does not effect ion motion along the magnetic field line. Assuming that the magnetic field lines are equipotentials and that vertical neutral winds are zero, the only other contributions to the ion motion parallel to the magnetic field arise from ion-neutral diffusion caused by gravity and gradients in both ion density and plasma temperature.

The ion velocities are measured directly at several altitudes in the F region. The ion-neutral diffusion term is calculated using other radar measurements and an appropriately adjusted model atmosphere. The details are described by Wickwar et al. [1984a] and the exospheric temperature determination by Kofman and Wickwar [1984].

In the qualitative discussion above, as in the detailed derivation, it is assumed that the neutral wind is horizontal.

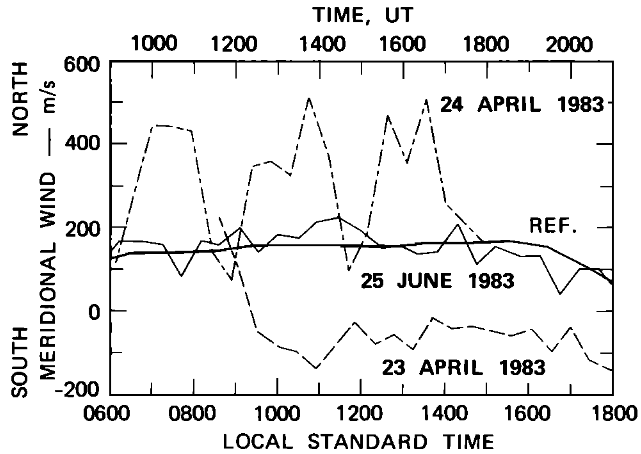

Fig 1 Thermospheric neutral wind at -39° azimuth: the reference curve, 25 June 1983, 24 April 1983, and 23 April 1983

However, a vertical neutral wind would have a large effect on the ion velocity parallel to **B** because of the 80° dip angle. A vertical velocity would be interpreted as a horizontal velocity nearly six times as large. If a vertical velocity could be sustained for a long period of time, it would be hard to detect Detection would be easier if the velocity were transitory [e.g., Meriwether, 1983].

Confidence in the radar technique for determining a component of the thermospheric neutral wind has been acquired by the good agreement obtained between winds at Chatanika determined from radar and Fabry Perot measurements [Wickwar et al., 1984a] and between winds at Sondrestrom determined from radar and Fabry Perot measurements [Meriwether et al., 1984]. The Fabry Perot technique is totally independent of the radar technique. At Chatanika, the good agreement was obtained for average winds and for simultaneous comparisons. At Sondrestrom, the good agreement was obtained for simultaneous comparisons

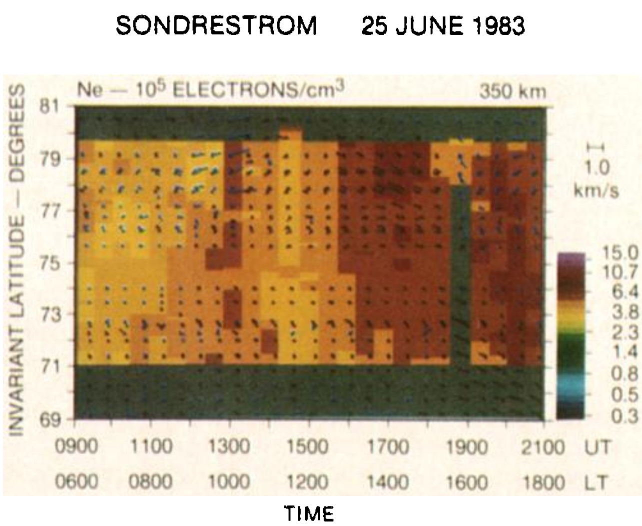

Fig 2 Electron density at 350 km and vector ion velocity on 25 June 1983. Vectors with an eastward component are in blue; those with a westward component are in red

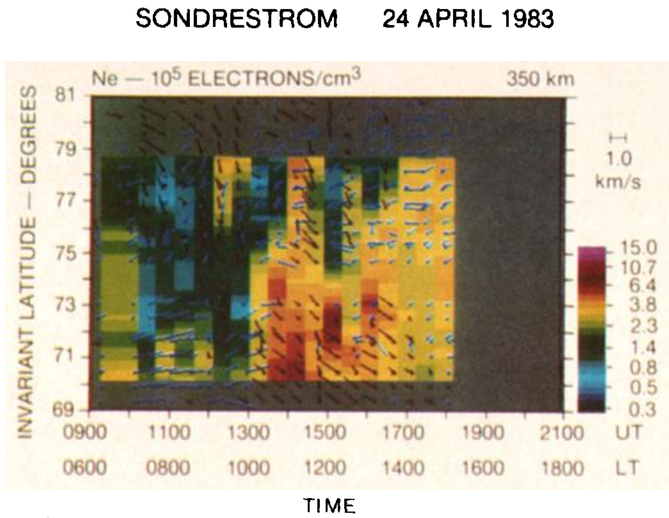

Fig. 3. Electron density at 350 km and vector ion velocity on 24 April 1983. Vectors with an eastward component are in blue; those with a westward component are in red.

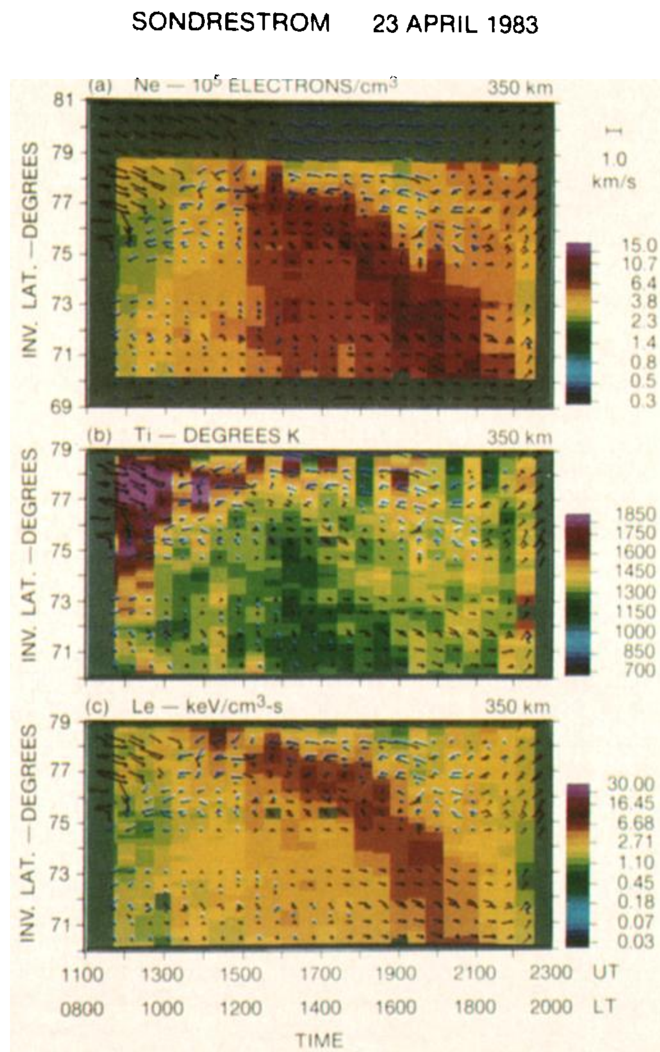

Fig. 4. At 350 km on 23 April 1983 (a) electron density, (b) ion temperature, and (c) electron loss rate. Also included in each part is the vector ion velocity Vectors with an eastward component are in blue, those with a westward component are in red

For this study the meridional wind was derived at four altitudes: 175, 230, 285, and 340 km. The lowest three correspond to the region from which a Fabry Perot usually determines the wind at night. The correction for ion-neutral diffusion is also relatively small, being typically less than 15 m/s at 175 km. However, that correction increases with altitude, typically becoming 100 m/s at 340 km. At higher altitudes, it is possible that the assumptions used to derive the diffusion term would lead to an unacceptably large uncertainty. The values have been further restricted to those for which the uncertainty of individual line-of-sight measurements, converted to the horizontal, is less than 100 m/s. Because of the relatively large uncertainties that would mask altitude gradients in the wind, the good values have been averaged together.

Observations and Discussion

To facilitate comparison of winds from the 13 days of data examined, a mean or reference curve was constructed from 1-hr averages of the winds from the four altitudes and a 3-hr running average performed on those 24 values. Data from periods on three days that differed drastically from the others were excluded. The dayside portion of the resultant curve appears in Figure 1.

The wind component at -39° azimuth for 25 June 1983 is also shown in Figure 1. In Figure 2, the vector ion velocity **V** is superimposed on the electron density Ne for 350 km. The **V** are all very small. Indeed, this is the quietest day in the data set, where "quietest" is defined either as having the smallest convection velocities within the radar field of view or the smallest Kp values (0+, 0, 0+, 1, 1, 1, 3, 2). Therefore, despite the large Ne, ion drag does not contribute significantly on this day. In the day sector 0900 to 2100 UT (subtract 3 hr for local standard time and approximately 2 hr for magnetic local time), the wind agrees closely with the mean curve. Similar behavior occurs for extended periods on three other days.

On 24 April 1983 the situation is very different; it is a very active day (Kp values of 5-, 5+, 5-, 5, 6-, 6-, 6+, 6). The wind component for this day is also shown in Figure 1, and **V** superimposed on Ne is shown in Figure 3. Between 1030 UT and 1300 UT, the radar is in the morning convection cell and is located where the **V** are pointing poleward as they rotate from eastward (sunward) to westward (antisunward). Between 1330 and 1800 UT, the radar is in the evening convection cell; most of the time it is located close to where the **V** have a large poleward component as they rotate from westward (sunward) to eastward (antisunward). These ion velocities, coupled with moderate to large Ne, give rise to considerable poleward ion drag, i.e., a very strong northward wind is found. Near 1400 UT, the large **V** also give rise to considerable Joule heating, which is indicated by large ion temperature increases. Ion drag, however, has a much more important effect on the meridional wind than Joule heating. This is seen at 1510 UT when the ion velocities have an equatorward component for a short period, while the Joule heating persists equatorward of the radar. The neutral wind abates considerably. The importance of ion drag is also seen, but not as clearly, in the effect of the ion motion alone on the neutrals near 1100 UT.

The important role of ion drag also stands out on three other days.

On 23 April 1983, yet a third situation exists. This is a moderately active day (Kp values of 4-, 4-, 3, 2, 2, 2+, 2, 5). And again, the wind component is shown in Figure 1. Between 1200 and 2000 UT, it is about 200 m/s equatorward of the reference curve. The **V** and superimposed Ne at 350 km are shown in Figure 4(a). The morning and evening convection cells are very clear in the figure and the convection reversal is located just poleward of the radar throughout this period. At the radar, **V** is either small or in the direction nearly perpendicular to the neutral wind component. Therefore ion drag cannot be invoked to account for the greatly diminished wind.

An indication of F-region Joule heating is given by Ti at 350 km [Figure 4(b)]. An indication of energy deposited in the F-region electrons by all sources, including photoelectrons, soft particle precipitation, and heat conduction is given by Le [Kofman and Wickwar, 1984] at 350 km [Figure 4(c)]. It is readily apparent that there is considerable Joule heating in the morning cell where **V** turns antisunward. Similarly there is considerable soft particle energy input in the evening cell at the convection reversal. Furthermore, these energy inputs occur poleward of the radar.

This is the only example, so far, of the possible importance of Joule heating. However, two other examples exist concerning the importance of particle heating. As on 23 April 1983, when the neutral wind was far less than the reference curve, the radar was equatorward of the energy input at the convection reversal in the afternoon cell and **V** was directed mostly toward the west with a small poleward component. The correlation of the reduction in the northward wind with the location of the radar relative to the afternoon convection reversal gives considerable support to the idea that soft particle precipitation can deposit enough energy in the F region to affect the neutral wind.

Conclusions

In the daytime sector major variations have been detected in the component of the neutral wind at -39° azimuth (approximately along the magnetic meridian). Under quiet conditions, such that the radar is considerably equatorward of the convection cells, the neutral wind is approximately that given by the reference curve. Possibly this is the magnitude that would be produced by solar heating. Under more active conditions, the radar is in the region of sunward convection, which is roughly perpendicular to the plane of the neutral wind determination. Just poleward of the radar, there is considerable Joule heating in the morning cell and considerable heating by soft particle precipitation at the convection reversal in the evening cell. The wind component becomes about 200 m/s more equatorward than the reference curve. This situation strongly suggests that particle and possibly Joule heating can significantly affect the neutral wind. Under still more active conditions, the radar is in the convection reversal region, where **V** has a strong poleward component. The neutral wind component becomes 200 to 300 m/s more poleward than the reference curve. In addition, short-term fluctuations in the ion velocities are reflected in changes in the neutral wind magnitude. Thus, as seen before at high latitudes, ion drag is very important.

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