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Mapping the Wind in the Polar Thermosphere: A Case Study within the CEDAR Program

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A Case Study Within the CEDAR Program

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Introduction

The thermosphere is that region of neutral atmosphere in which atmospheric constituents are gravitationally bound to the Earth but are barometrically distributed according to their molecular or atomic weights. Unlike the lower atmosphere, mixing processes are weak, which allows each constituent gas to behave independently. The thermosphere begins at about 100-km-altitude and extends up to 500 km or beyond. The temperature increases with height throughout the layer, which is a stabilizing influence. Solar ultraviolet radiation partially ionizes the ambient gas to produce an ionosphere.

The lower thermosphere is host to the F region of the ionosphere in which the ions move with the neutral atmosphere since their collision frequency with neutral atoms far exceeds the gyrofrequency. The upper thermosphere, where the motion is partly driven by the drag from collisional heating density or the conductivity of the ionosphere, is a stabilizing influence. Solar ultraviolet radiation partially ionizes the ambient gas to produce an ionosphere.

The thermosphere couples back into the ionosphere by the diurnal cycle of heating and cooling of the ionosphere induced by solar heating and the rotation of the Earth. Also, the meridional component of the neutral wind induces field-aligned diffusion of ionospheric plasma, changing the F layer height and density on a global scale. Additionally, the same meridional wind affects the global F region energy budget through the movement of mass, energy, and reactive minor constituents via a giant pole-to-pole Hadley cell.

Thermospheric wind investigations at all latitudes are crucial in context of this coupling. Although the dynamic processes in the thermosphere and many previous programs which have been organized to gain a global perspective, such as the Global Thermospheric Mapping Study, and satellite programs such as the NASA Atmospheric Explorer series and Dynamics Explorer series, and many previous programs which have been organized to gain a global perspective, such as the Global Thermospheric Mapping Study, and satellite programs such as the NASA Atmospheric Explorer series and Dynamics Explorer series. The purpose of this paper is to present a global perspective of the CEDAR approach to global studies.

In principle, the investigation of the coupling of the ionosphere and thermosphere can be achieved by the combination of measurements from optical interferometers, incoherent scatter radars, and rocket sounders (ionosondes). The incoherent scatter radars are relatively few in number (six at the time of the experiment reported here) but are the most valuable component of the CEDAR campaign. This coupling is of great importance to the lower thermosphere region where the neutral atmosphere has a stabilizing influence. Solar ultraviolet radiation partially ionizes the ambient gas to produce an ionosphere.

The fact that the ionosphere and thermosphere are interpenetrating fluids causes interesting coupling phenomena in which, at low altitudes, the thermospheric wind drives the ionosphere across magnetic field lines in the E region of a giant dynamic atmosphere. At high altitudes above 180 km and particularly at high latitudes, upper thermospheric motion is partly driven by the drag from collisions with ions. The coupling is achieved by the combination of incoherent scatter radars and rocket sounders (ionosondes). The incoherent scatter radars are relatively few in number (six at the time of the experiment reported here) but are the most valuable component of the CEDAR campaign.

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Kiruna, Thule, and Fairbanks, and these were able to contribute major amounts of vector wind data representative of heights close to 250 km. These stations, being in contiguous regions and close to the three northern hemisphere high-latitude radars, have been selected for a study of the wind field during one day of the period when the activity was particularly low (Figures 1 and 2). On this day there was data from all stations, but Kiruna was in daytime at the time of interest and thus unable to observe. The coordinates of the stations used in the study are given in Table 1.

### Table 1. Coordinates of Stations

<table>
<thead>
<tr>
<th>Geographic - Magnetic</th>
<th>Geographic</th>
<th>Magnetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sondrestrom</td>
<td>67.0</td>
<td>-50.0</td>
</tr>
<tr>
<td>Fairbanks</td>
<td>65.1</td>
<td>-147.5</td>
</tr>
<tr>
<td>Svalbard</td>
<td>78.2</td>
<td>15.6</td>
</tr>
<tr>
<td>Thule</td>
<td>76.5</td>
<td>-68.7</td>
</tr>
</tbody>
</table>

This paper concentrates on the dynamics of the high-latitude region using the optical wind data and the radar ion drifts to study the situation. These observations will be considered against the backdrop of a representative general circulation model. This is the first study of its type to include such a good grouping of stations making it worthwhile to represent the data obtained on a scale of the entire high-latitude region.

### Description of Data

The plot of the magnetic auroral index AU/AL for the day in Figure 1 shows continuous low activity. It is presumed for the discussion of the data that the rather quiet $Q = 2$ auroral oval [Feldstein, 1985] is appropriate for orientation. A sequence of four station maps is shown in Figure 2 with the auroral oval included for guidance on the topographic relation to magnetospheric coupling at 0900, 1200, 1400, and 1600 UT. Since these are estimates only, no great reliance should be placed on borderline positions of stations in relation to the auroral oval.

The polar cap, in the context of this work, is the region inside the inner circle of the auroral oval. Previous work [McCormac and Smith, 1984; McCormac et al., 1985; Rees et al., 1986] has indicated that the direction of the magnetic vector in the solar wind just upstream of the Earth is an important factor in determining the ionospheric drift pattern in the F-region and the thermospheric wind. The component of the wind field in the axial direction of the Earth's dipole ($B_z$) was initially southward but turned northward near 1000 UT and remained so until 1700 UT. The peak northward value was 6 nT. After 1700 UT, $B_z$ was southward by a few nanotesla. For the whole period from 1000 UT to 2300 UT the transverse component ($B_y$) was toward dawn (negative).

The Sondrestromfjord radar measured ion drift and the record reflects the observation that the first appearance of northward turning was near 1200 UT as shown in Figure 4. An hour under these circumstances of (asumed) weak coupling. Hence it is consistent with the observation that the first appearance of sunward winds due to the sunward polar cap convection expected for northward $B_z$ conditions [Heppner, 1977; Heppner and Mennard, 1987; Heppner, 1984] appeared near 1000 UT.

The Thule station spent about 4 hours in the sunward wind disturbance and was determined by factors which are almost stationary in an Earth-Sun coordinate frame. Other possibilities such as a large-scale gravity wave are not entirely eliminated, but also not thought likely because of the low activity and expected lack of sources. This disturbance, first seen at around 1100 UT poleward of Thule in the morningside of the polar cap, was not observed 6 hours earlier when Svalbard passed at the same local time. It is reasonable to suppose that it appeared in the period 0600-1200 UT. As mentioned above, the northward turning of $B_z$ occurred at about 1000 UT. Any response to the accompanying changes in the convection pattern would be expected to take at least one hour under these circumstances of (assumed) weak coupling. Hence it is consistent with the observation that the first appearance of sunward winds due to the sunward polar cap convection expected for northward $B_z$ conditions [Heppner, 1977; Heppner and Mennard, 1987; Heppner, 1984] appeared near 1200 UT.
appear at about local noon. The Svalbard station first saw the sunward wind disturbance at 1300 UT and observed it for several hours on the poleward side, then disappearing equatorward at about 1600 UT. The period of $B_x$ northward ended near 1700 UT, which indicates that if the ionospheric convection pattern remained approximately constant during the 7-hour period, the Svalbard station merely passed under the nightside edge of part of the sunward wind disturbance.

Most modeled wind structures in the polar thermosphere show a broad swath of antisolar flow across the cap with minor changes of direction due to changing solar wind and the offset of the magnetic pole from the rotation axis. Recent coupled thermosphere-ionosphere modeling by the University College London group [Fuller-Rowell et al., 1987] shows that it is reasonable to expect localized eddies of sunward wind in a generally ant.sunward flow for conditions such as occurred near noon UT on January 17, 1986. Figure 5 shows a plot of winds simulated by the UCL group over the northern polar cap at a height of about 300 km when $B_y$ was negative and $B_x$ was northward. This computation uses the convection model of Heppner and Maynard [1987], which has a region of sunward convection in the polar cap. The implication of the wind pattern shown is that near 1200 UT under winter solar minimum conditions ion-neutral collisions transfer sufficient

![Maps showing the relative positions of stations (Thule (T), Svalbard (L), Sondrestromfjord (S), Kiruna (K), and Fairbanks (F)) involved in this study and the $Q = 2$ Auroral Zone. The shaded part indicates regions of darkness beyond 12° solar depression. The terminator and loci of 6° and 12° solar depression are also shown. The curve marked M is the boundary of moonlit atmosphere, the dark side being indicated by MD. Panels (a)–(d) show the changing relationship of the stations to the oval as a function of Universal Time.](image)
momentum to reverse the normal antisunward flow in restricted regions, one in the morning and one in the afternoon. The collisions also generate heat and raise the temperature of the gas as is seen from the dark-shaded tongue extending into the morning-side of the polar cap from noon. This is where the strong sunward ion drift is located which causes the thermosphere also to flow sunward. It will also be noticed that there is another region of sunward flow at relatively high latitudes up to 80° geographic on the evening side. At 1200 UT the local time at Thule is about 0700, which places it near the morning eddy. The 1200 plot shows that the poleward vector has turned sunward. According to observation, the eddy lies poleward of the station as it does in the simulation. Svalbard local time is 1300, which places it near the poleward wind on their poleward sides which is sunward. At 1300 UT both stations show sunward flow at relatively high latitudes which is consistent with the hypothesis that it occurred due to ion-neutral coupling associated with sunward ion drift accompanying the northward turning of $B_x$. This is a much more detailed and convincing application of thermospheric wind modeling to multistation data than has been obtained good multistation campaigns such as this, but the data can also agree with the simulation even in a relatively complex case such as this.

**Conclusion**

The multistation data documenting this sunward wind disturbance is consistent with the hypothesis that it occurred due to ion-neutral coupling associated with sunward ion drift accompanying the northward turning of $B_x$. This is a much more detailed and convincing application of thermospheric wind modeling to multistation data than has been possible in the past. It has been difficult to obtain good simultaneous optical coverage in contiguous regions during an event as interesting as this one discussed here to provide a testing situation.

It would have been argued in the past that the coupling efficiency between ions and neutrals in the dark winter solar minimum polar cap would be too small to allow such a departure from the strong antisolar flow which is so commonly seen. The situation of strong ion-neutral coupling is now accepted to prevail at solar minimum despite weakened coupling which is known to exist. This case is a triumph for the CEDAR approach and shows that not only can we observe such things in unprecedented detail if we organize enough

**Acknowledgments**

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**References**


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Fig. 4. Polar plots of the neutral wind measured from the four stations, Thule (T), Svalbard (L), and Fairbanks (F). Panels (a)–(d) cover Universal Times 0900, 1200, 1400, and 1600. Vectors are drawn with tails fixed to short arcs which represent the locus of the station as a function of time. For comparison, a simulation is shown as a backdrop with arrows.

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Fig. 5. Simulation by the coupled thermosphere-ionosphere model developed at University College London and Sheffield University for conditions of solar minimum winter solstice when IMF $B_z$ is northward and $B_y$ is negative. Winds are shown by the vectors at a constant pressure level near 300 km altitude along with underlying shading indicating the temperature at the same height. This figure originally appeared in full color. See the back of the second volume of 1989 (Volume 70, Numbers 27-52) for the color plate.