GEOPHYSICAL RESEARCH LETTERS, VOL. 1, NO. 9, PAGES 911-914, SEPTEMBER 1984

INITIAL MILLSTONE HILL, SONDRESTROM, AND HILAT OBSERVATIONS OF THERMOSPHERIC TEMPERATURES AND FRICTIONAL HEATING

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Abstract. Elevation scan observations made by the Millstone Hill and Sondrestrom incoherent scatter radars are combined to provide extended latitudinal coverage of thermospheric measurements. Maps of the latitudinal and temporal structure of the exospheric temperature are presented for two 24-hour periods over the latitude range 45 to 72 degrees north. On the magnetically quiet June day the Millstone and Sondrestrom data formed a consistent picture of thermospheric structure. On the disturbed July day the two radars observed very different behavior, with Millstone Hill observing strong, long-lived ion frictional heating events but Sondrestrom observing more quiescent behavior. Comparison with HILAT satellite data recorded on the July day suggest that the two radars were observing different ionospheric regions separated by a bright auroral arc with a very turbulent ionosphere to the south of the arc but smooth flow to the north.

Introduction

Recent global semi-empirical models of the upper atmosphere have been based on a combination of in-situ satellite and remote incoherent scatter radar data. The global structure of these models has been defined largely by the satellite measurements. The orbits for many of these satellites, particularly those capable of reaching mid and high latitudes through the use of high inclinations, however, are such that local time coverage is achieved only statistically over a period of time. Here the incoherent scatter radars have provided valuable complementary information from direct measurements of the detailed temporal variations of the thermosphere. This radar information has been available from only a few isolated global positions, however, and the detailed latitudinal structure of the temporal variation has not been directly observed and verified.

Recently, Oliver (1984) has used meridional elevation scans of the Millstone Hill steerable antenna to map the latitudinal and temporal variation of the exospheric temperature over the latitude span 25 to 60 degrees north. This new capability provides for simultaneous detailed monitoring of the temporal and spatial behavior of the thermosphere.

In 1983 the U.S. National Science Foundation upgraded the four incoherent scatter radars in the American longitude sector and realigned them into a chain in recognition of the global nature of the ionosphere/thermosphere system. In particular, the SRI radar previously located at Chatanika, Alaska was moved to Sondrestrom, Greenland, completing radar chain coverage from the polar cap to the magnetic equator. This large latitude span, together with the detailed latitude coverage afforded by the fully steerable antennas of the chain, provides a new scope of opportunities for thermospheric research.

The present paper presents the initial combined thermospheric temperature maps from the Millstone Hill and Sondrestrom radars. Chosen for this presentation are two successful joint campaigns conducted on 25 June and 23 July 1983. Measurements of auroral properties measured by the HILAT satellite are presented to aid in the interpretation of the July measurements.

Data Collection and Analysis

Joint campaigns were conducted by the Millstone Hill and Sondrestrom incoherent scatter radars on 25 June and 23 July 1983. Both radars included north-south elevation scans in their measurement schemes. Millstone Hill (43 degrees north latitude) was observing only to its north during these experiments, covering the latitude range 45 to 60 degrees. Sondrestrom (67 degrees north latitude) was conducting full north-south elevation scans, but its antenna was restricted during this period to elevation angles above 30 degrees (whereas the Millstone antenna was lowered to 4 degrees) and hence acquired data only from 62 to 72 degrees latitude.

Oliver (1984) has described the method used for calculating the latitudinal profile of exospheric temperature from a radar elevation scan. This involves rearrangement of the scan data into altitude profiles at 1-degree

Paper number 4L6179.
0094-8276/84/004L-6179$03.00

latitudinal increments and then an ionosphere-thermosphere thermodynamic heat transfer calculation to obtain the neutral temperature from the measured ionospheric quantities. The method used to determine neutral temperature is widely accepted to yield accurate results under the thermodynamic conditions normally prevailing at mid and low latitudes, where the warmer electron gas is the main source of ion heating and the cooler neutral gas is the main heat sink. This assumption fails at high latitudes in those frequent cases in which strong electric fields drive the ionospheric plasma through the neutral gas at such a rate that frictional heating between these two gases becomes an important ion heat source (Watkins and Banks, 1974). In such cases the normal "mid latitude" type of exospheric temperature analysis, as used in the present analysis, causes the elevated ion temperatures to be misinterpreted as elevated neutral temepratures, possibly producing errors of many hundreds of degrees. Alcaydé et al. (1983) have recently discussed the frictional heating problem in more detail.

Results and Discussion

Exospheric temperatures from the two radars are displayed versus universal time (UT) in hours and north latitude in degrees in Figure 1. Millstone Hill and Sondrestrom are 21 degrees apart in longitude and 4.8 and 3.4 hours, respectively, behind UT. The starting times for the observation periods were about 02 UT on 25 June and 00 UT on 23 July, as marked on Figure 1. Missing data panels are caused either by true gaps in data taking or by poor data quality due to weak signal strength (low electron density) or external interference. Figure 1 also shows the magnetic activity index Kp for the two days.

The June day was very quiet with some small increase in activity toward the end of the period. The two data sets form an overall consistent pattern of the spatial and temporal morphology of the exospheric temperature from 45 to 72 degrees latitude. The observations began in the evening (of the previous local time day) with both radars showing an increase in temperature toward a latitude near the gap in latitude coverage. As night progressed the long-range coverage of the Millstone measurements became more limited as the electron densities decreased. Toward morning the Millstone Hill temperatures increased moderately without any apparent correspondence in the Sondrestrom measurements. Into the afternoon and evening the level of magnetic activity increased, and again both radars showed an increase in temperature near the gap in latitude coverage.

The July day, on the other hand, experienced persistent magnetic activity throughout the measurement period. The Millstone Hill and Sondrestrom measurements displayed in Figure 1 do not appear capable of being reconciled into a consistent pattern over the intervening latitude gap. There are two several-hour periods, approximately 06-12 and 18-24 UT, when the Millstone Hill temperatures are enormously higher than the neighboring Sondrestrom temperatures. We believe that these are not true neutral temperature increases but rather that they are largely ion temperature enhancements due to frictional heating. Although we have no measurements of the vector velocity difference between the ions and neutrals during this period with which to evaluate the importance of frictional heating, we have verified from the line-of-sight velocity data (not shown) that the ions were generally in rapid motion during these periods of temperature enhancement. Across the latitude gap, however, no such strong heating occurs, except perhaps very locally at the southern end of Sondrestrom's field of view near 10 UT. A possible explanation for this apparent disagreement is provided by measurements available from the HILAT satellite during the July experiment, also shown in Figure 1.

The HILAT satellite (The HILAT Science Team, 1983) was launched on 27 June 1983 into an 82 degree inclination orbit. Its principal axes are aligned with the local vertical coordinate system, but interaction of non-spherical terms of the earth's gravity field with the gravity boom stabilizing system causes the satellite to have some small oscillation about its nominal orientation. Displayed in Figure 1 are the measurements made by the HILAT UV Auroral Imager/Mapper (AIM), ion driftmeter, and magnetometer as the satellite passed south to north off the east coast of Greenland. The imager data were measured remotely, transversely across the orbit path, which was positioned along the center of the image map in Figure 1. The driftmeter and magnetometer data were measured in situ along the satellite orbit. A coastal outline is shown on the imager map for spatial orientation. The satellite stabilization perturbations mentioned above yield some uncertainty in the exact east-west placement of the ground map with respect to the UV image.

The HILAT imager UV arc shown in Figure 1 was obtained near 1917 UT, a time at which Millstone Hill was measuring very elevated temperatures. The arc, as shown, passed just south of Sondrestrom and intensified westward and southward toward the North American coast. The map terminates somewhat eastward of the area covered by the Millstone Hill elevation scans. The HILAT magnetic field data show large and variable fluctuations southward of the arc but a more regular behavior to the north. The driftmeter data similarly show rapid and very structured ionospheric convection south of the arc but a more regular (though still very rapid) flow north of the arc.

We believe that these HILAT data provide a possible explanation of the radically different Millstone Hill and Sondrestrom observations on 23 July. We suggest that the UV arc represents a boundary separating regions of the ionosphere under different controlling mechanisms. South of this arc energetic and variable auroral processes were active and produced large ionospheric velocities with large temporal and spatial structure. This turbulent ionospheric flow caused the ions to be continually forced through the neutrals in varying directions. Baron and Wand (1983) have derived estimates of the time constant for the ion collisions to drag the neutrals into motion with them. For ion number densities of about 2×10^{11} per cubic meter, as measured in the F region near 1900 UT from

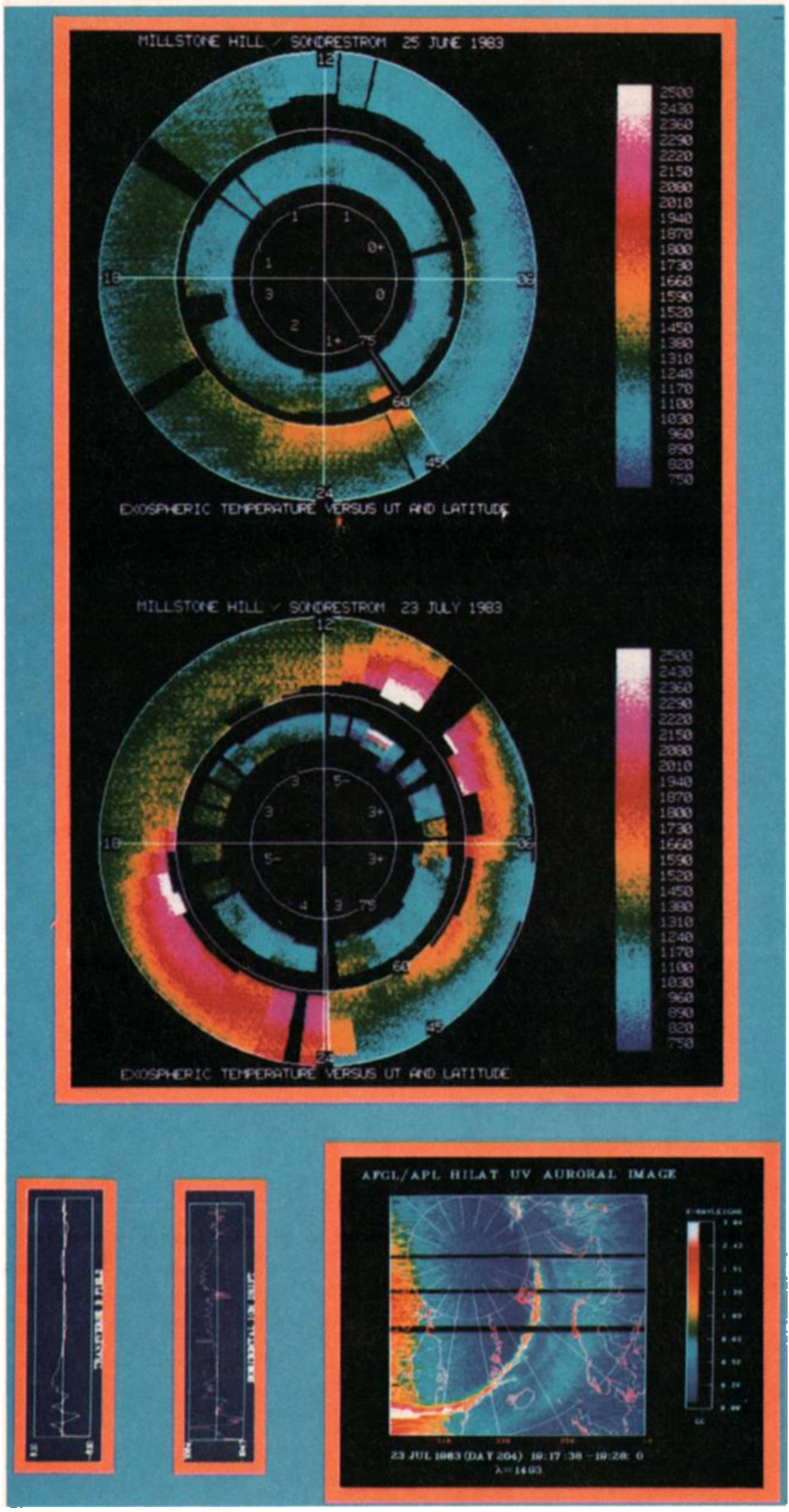

Fig. 1. The combined exospheric temperature results from the Millstone Hill and Sondrestrom radars for 25 June and 23 July 1983. HILAT auroral imager, driftmeter, and magnetic field data are included for the July period.

Millstone Hill, about three hours would be required. Because of the spatially and temporally turbulent structure of the ion flow, as evidenced by the driftmeter data south of the auroral arc, we suggest that the neutrals never had sufficient time during these two extended intervals to gain a velocity similar to that of the ions. While the HILAT driftmeter velocities north of the UV arc were also sizable, the flow was not so turbulent and the neutrals presumably had sufficient time to achieve the ion velocity before it changed greatly.

It is interesting to note that the Sondrestrom temperatures did increase substantially near 05 UT on July 23, near the time that the Millstone Hill temperatures began their first six-hour period of enhancement. This may mean that large electric fields were impressed simultaneously in both radar fields of view, with both sets of ion temperatures increasing simultaneously with the onset of frictional heating. The Sondrestrom enhancements abated after an hour, however, perhaps as the neutral flow achieved uniformity with the constant ion flow, while the Millstone Hill enhancements continued due to the persistent changes in the ion convection. There is also a suggestion of a similar increase in Sondrestrom temperatures at the start of the second long period of Millstone Hill enhancements near 17 UT.

Summary and Conclusions

Millstone Hill and Sondrestrom incoherent scatter data have been combined to display the observed thermal structure over the latitude range 45 to 72 degrees north for joint observation periods in June and July 1983. The additional use of southward observations from Millstone Hill and the planned lowering of the Sondrestrom elevation limit promise to provide an extended latitude coverage from 25 to 78 degrees and to eliminate the gap now existing between their latitudinal coverages. Together with observations from the Arecibo and Jicamarca radars, the radar chain will have the capability of coverage from the polar cap to the equator.

The June observations from the two radar sets showed a consistent combined picture of thermospheric structure versus latitude. This was a magnetically quiet period, but nevertheless both radars show extensive time periods during which the temperature increased with latitude toward the gap between the radar coverages near 60 degrees. The July day was persistently disturbed, and the radar data sets showed prolonged periods of very different behavior, with Millstone Hill observing highly elevated temperatures but Sondrestrom observing more normal values. Interpretation of these results was aided by HILAT satellite observations of auroral phenomena. While the HILAT coverage did not extend quite as far west as the area scanned by the Millstone Hill radar, these data suggest that an auroral arc extended between the Millstone Hill and Sondrestrom fields of view, with a very turbulent ionosphere to the south of the arc but more stable flow to the north. This turbulent flow is believed to have caused strong frictional heating of the ions in the Millstone Hill measurements while the smoother flow within Sondrestrom's field of view did not provide a major source of ion heating, beyond, perhaps, a short initial onset period.

Acknowledgements. This material is based upon work supported by the National Science Foundation under Grant ATM 81-19812 to MIT and Cooperative Agreement ATM 81-21671 with SRI. HILAT is a program of the Defense Nuclear Agency.

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(Received May 10, 1984;
accepted June 5, 1984.)