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THE BEHAVIOR OF THE HIGH-LATITUDE F-REGION NEUTRAL THERMOSPHERE IN RELATION TO IMF PARAMETERS

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ABSTRACT

Ground based incoherent scatter radar (ISR) and Fabry Perot interferometer (FPI) studies in the northern high latitudes during the period 1983 to 1989 have shown that the F-region neutral wind field pattern depends upon the sign of the IMF parameters. For example, the cell structure of the northern hemisphere high latitude neutral wind field during periods of low geomagnetic activity depends to a large degree upon the sign of the IMF B_y parameter.

Long term monitoring of the F-region thermosphere by FPI in Thule, Greenland, and by both FPI and ISR in Søndre Strømfjord, Greenland, have made it possible to produce maps of average meridional and zonal wind fields for various IMF configurations for northern high latitudes. Comparison of observations with theoretical wind field modelling, such as the Vector Spherical Harmonic model, indicates that most observed features are consistent with the models.

INTRODUCTION

Neutral winds in the polar cap F-region are controlled by a combination of pressure gradient forces and ion drag forces, the latter being the primary driving force at high latitudes. Coupling between the ion and the neutral constituents in the F-region thermosphere, which is dependant upon the ion neutral collision frequency, forces the neutral component to follow the ion drift convection pattern with an appropriate time constant. As a result, the F-region neutral wind circulation pattern for high latitudes usually exhibits a similarity to the ion convection cell pattern.

The configuration of the Interplanetary Magnetic Field (IMF) has a marked effect upon the size and geometry of the ion convection cell pattern, and consequently, the neutral circulation pattern. In particular, the sign of the B_y component of the IMF controls the relative size of the dawn and dusk ionospheric circulation cells. However, the time constant for momentum transfer from ions to neutrals is of the order of several hours, implying that rapid changes in the IMF are not immediately apparent in the neutral wind pattern. Several studies have been published which document the influence of the B_y component on the high latitude thermosphere: ground-based optical /1-5/, ground-based radar /6/, satellite /7/, and theoretical studies /8/.

In this study, data acquired by optical techniques at Søndre Strømfjord and Thule, Greenland are used to construct averaged horizontal winds for both signs of the IMF B_y component. These results are compared with predicted thermospheric circulation patterns from a Vector Spherical Harmonic (VSH) model. The comparison indicates that this model provides a reasonable representation of the optically observed horizontal wind components in the thermosphere for the two signs of the IMF B_y component. Finally, the averaged neutral winds derived from the incoherent scatter radar at Søndre Strømfjord for the same geomagnetic conditions are compared with the optical measurements and the modelled winds.

RESULTS

Similar Fabry Perot interferometers are located in both Søndre Strømfjord and Thule, Greenland, the former collocated with an incoherent scatter radar system. The optical instrument is described in *Meriwether et al.* /4/. The interferometers were in routine, automated operation during the solar minimum period acquiring F-region neutral wind measurements during dark sky periods through the entire optical observing season - September to April. Cloud cover data for both stations was obtained from the Danish Meteorological Institute and the United States Air Force for Søndre Strømfjord and Thule, respectively. This information permitted the removal of data acquired during non-ideal observing periods. Geomagnetic indices and IMF values (in Geocentric Solar Magnetospheric coordinates) were obtained from the NSSDC data base. In total, four years of Søndre Strømfjord data and three years of Thule data during solar minimum were used to generate the final averages. The horizontal wind components may be considered as representative of the neutral wind pattern for the northern polar cap for conditions of average geomagnetic activity during the solar minimum period.

The conditions chosen for the binning process are similar to those used by *Thayer et al.* /7/. The IMF parameters used in the current sorting scheme were one hour averages for both B_y and B_z, which is the same resolution as the cloud cover data. Each horizontal wind measurement was assigned B_y, B_z, K_p, and cloud index values. The winds were then sorted into one hour wide bins based upon the following criteria: a) low geomagnetic activity ($K_p \leq 3$); b) southward B_z component ($B_z < 1$ nT); c) the sign of B_y constant for at least two hours preceding the wind measurement; d) no inclusion of wind data within the bins if there are no IMF data available for the measurement period; e) cloud cover must be low. This strict filtering criteria reduced the neutral wind data set to slightly over 2% of its original size.

Figures 1a) and 1b) display the results of the sorting analysis. The figures are shown using a geomagnetic latitude/magnetic local time coordinate system in a polar dial display. The length of the vector is proportional to the magnitude of the horizontal wind as indicated by the vector in the bottom right-hand corner. The tail of a vector is located at the geomagnetic latitude of the station and the magnetic hour of the bin. The outer ring of vectors corresponds to F-region neutral winds over Søndre Strømfjord, while the inner ring shows the same for Thule. Even though Søndre Strømfjord is at the arctic circle, there are still periods at winter solstice during which the sky illumination is too high to perform data acquisition. As a result, this ring of data does not cover an entire day. Figure 1a) refers to B_y negative conditions, while Figure 1b) shows B_y positive results.

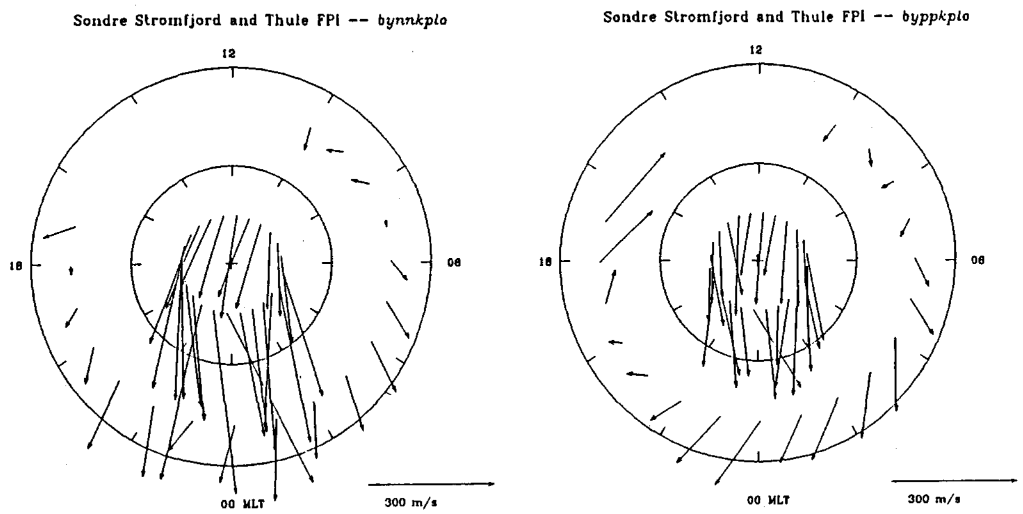

Fig. 1. *a)* Polar dial plot representing average horizontal neutral wind vectors in the F-region thermosphere. The coordinate system is geomagnetic latitude/corrected geomagnetic local time. The plot is centered on the north geomagnetic pole with circles shown for 80° and 70° latitude. The magnitude of the horizontal neutral wind is proportional to the length of the vector, as shown by the arrow in the lower right corner. The location of the tails of the vectors correspond to the geomagnetic latitudes of Thule (inner circle) and Søndre Strømfjord (outer circle). This panel is for B_y negative conditions, filtered as described in the text. *b)* Same as *a)* but for B_y positive conditions.

The neutral wind model chosen for the comparison was the VSH model /9/. This is a computer model which provides time dependent, horizontal neutral wind vectors. This model consists of a set of coefficients derived from geophysical field outputs generated by a selection of various NCAR thermospheric general circulation model runs. A vector spherical harmonic expansion of the coefficients is used to represent the wind field, while a Fourier expansion represents the temporal dimension.

In this study, two diurnally reproducible NCAR TGCM "steady state" runs were chosen for comparison with the optically measured winds, one for the B_y positive case and the other for the B_y negative case. Both runs were made for conditions of average geomagnetic during the solstice periods. Average geomagnetic activity was defined as: a) $K_p = 3$; b) $A_p = 20$; c) cross-cap potential = 30 kV. In both runs, the absolute magnitude of B_y was 7 nT.

Neutral winds derived from incoherent scatter radar data for Søndre Strømfjord have previously been presented for similar conditions by *de la Beaujardière and Wickwar* /6/. In their study, neutral winds from a two year set were used. In the current study, neutral winds derived from the entire radar data base (April, 1983 to July, 1988) were used to construct averaged neutral winds in the geomagnetic meridional direction. Prior to sorting of the winds according to IMF conditions, the winds for range gates between 210 and 360 km were averaged to generate a single value representing the neutral thermospheric meridional wind in the F-region. Next, the winds were sorted into one hour wide bins using similar B_y and B_z criteria as for the optical data sorting, the only difference being that the hourly averaged wind measurements were associated with the average of the IMF parameters obtained 1 to 2 hours prior to the wind measurements.

A comparison of the observed neutral winds with the modelled neutral winds is shown in Figures 2a) and 2b), the former for B_y negative conditions and the latter for B_y positive conditions. Here, only the averaged geomagnetic meridional winds as a function of time for Søndre Strømfjord are shown. The statistical uncertainty in the mean is also indicated for both the radar (R) and optical (O) averages. There are no optical measurements between 13 and 18 hours Universal Time since this period brackets local noon in Søndre Strømfjord.

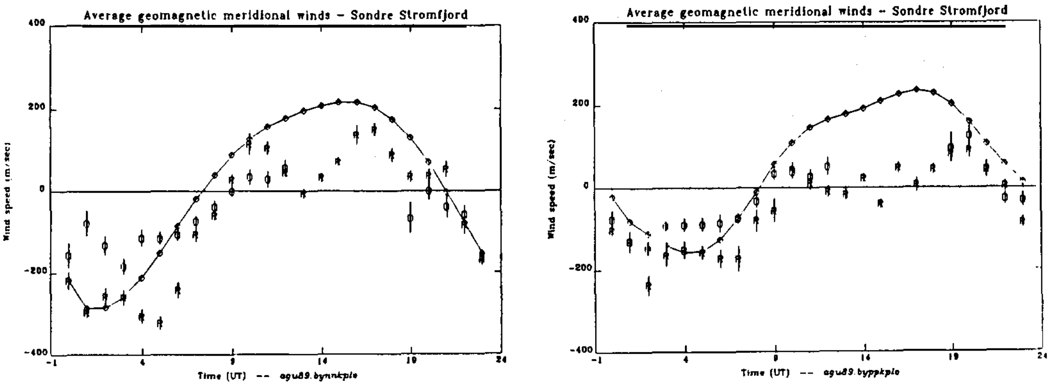

Fig. 2. *a)* Average neutral meridional winds for Søndre Strømfjord, Greenland in the geomagnetic meridian. The average neutral winds acquired experimentally are shown with their respective statistical uncertainties in their means: O refers to FPI data and R refers to ISR data. The curve displays the corresponding model winds from the VSH code. This panel refers to B_y negative conditions. *b)* Same as *a)* but for B_y positive conditions.

DISCUSSION

Several features are obvious from the polar dial plots of Figure 1 and the collated data in Figure 2. For B_y positive conditions, the magnitude of the horizontal neutral winds is smaller in Thule than for B_y negative periods. In addition, the magnitude of the meridional winds measured at Søndre Strømfjord is smaller for B_y positive. Although not shown here, the absolute magnitude of the experimental averaged zonal winds for Søndre Strømfjord is larger for the B_y positive case, unlike the meridional averages. Assuming a two cell structure in the neutral horizontal wind flow within the polar cap and fitting that with the observed horizontal wind vectors indicates that during the B_y negative case the cells appear to be similar in size. Likewise, for the B_y positive condition, an asymmetry is apparent between the two cells, the dusk cell being much larger in size than the dawn cell, encroaching into the dawn sector.

The behavior of the presumed cell structure of the neutral wind field as a function of the sign of IMF B_y within this study has some similarities with the comprehensive study performed by *Thayer et al.* /7/. Their work is based upon DE2 satellite measurements of the neutral wind field during solar maximum. The asymmetry in the cell pattern during B_y positive in the northern hemisphere observed by the satellite is also evident during the current study's solar minimum observations. They also observed a symmetric pattern during B_y negative conditions. However, the large surge that they observed in the magnitude of the winds at ~75° invariant latitude during B_y positive periods is not evident during the solar minimum study. Similarities between the averaged wind vectors in Figure 1a) and 1b) and the data presented by *Meriwether and Shih* /3/, for Søndre Strømfjord and *Meriwether et al.* /4/, for Thule are also evident. In the latter two studies, individual nights of data were shown to display a B_y dependence: an enlargement in the evening cell towards the morning cell for B_y positive conditions.

The observed geomagnetic meridional neutral winds shown in Figures 2a) and 2b) show reasonable agreement with the VSH model winds during dark conditions. In both the B_y negative and the B_y positive cases, the phase of the observed wind is similar to the modelled wind with zero crossings differing by no more than about one hour. The magnitude of the observed winds during dark hours is similar to the modelled winds, but both the optical and the radar winds show structure in the binned averages. The fact that the optical winds differ from the radar neutral winds is not surprising since there were very few, if any, coordinated measurements between the two sets of observations. The greatest discrepancy between the model and the observations occurs during daylight conditions. This also is not too surprising when consideration is made regarding the geometry of the auroral oval with respect to Søndre Strømfjord. The cusp/cleft region passes through the geomagnetic meridian over this station at approximately 1400 UT which corresponds to the period of greatest discrepancy. The modelled results provide wind vectors on a 5° by 5° grid which tends to average the fine structure expected in the cusp/cleft area. In addition, the observations correspond to a range of K_p indices, while the modelled results are calculated for $K_p = 3$. Søndre Strømfjord is at the location of the dayside boundary between the polar cap and the sub auroral region, and as a result, neutral wind measurements acquired during midday periods will be very sensitive to the latitude of the cusp/cleft. It is not clear from this data set the cause of the discrepancy between the midday winds and the model, but it seems likely that the differences are due to sampling winds in or about the cleft.

In summary, we have sorted several years of optical and radar data based upon the sign of the IMF B_y component. In all cases, the IMF B_z component was taken to be near zero, or definitely southward. The binned averages from the optical measurements in Thule and Søndre Strømfjord have been displayed in a polar dial form for both signs of B_y and indicate a definite asymmetry in the cell size of the neutral wind convection pattern for B_y positive conditions. The cells appear to be similar in size for the B_y negative case. These observations are consistent with the empirical plasma convection patterns described by *Heppner and Maynard* /10/. Neutral horizontal winds in the F-region obtained from the VSH model indicates a good correspondence with observations acquired at Søndre Strømfjord during periods in which this station is within the polar cap. The greatest discrepancy between modelled and measured winds occurs during the cusp transit over Søndre Strømfjord.

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