GEOPHYSICAL RESEARCH LETTERS, VOL. 12, NO. 4, PAGES 155-158, APRIL 1985

CONFIGURATION OF THE HIGH-LATITUDE THERMOSPHERE NEUTRAL CIRCULATION FOR IMF B_y NEGATIVE AND POSITIVE

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Abstract. Measurements of the neutral wind in the polar F-region from Dynamics Explorer-2 (DE-2) have been used to illustrate asymmetries in the Northern hemisphere neutral circulation that are dependent on the sign of the B_y (East-West) component of the interplanetary magnetic field (IMF). Individual DE-2 orbits and averaged data sets from different Universal times are presented. The data are categorized according to the sign of the hourly averaged IMF B_y component measured by ISEE-3 for the hour preceding the DE-2 measurement. The major features observed are: 1), an asymmetry in the polar cap neutral flow velocity with the region of most rapid anti-sunward flow shifting from the dawn-side to the dusk-side of the polar cap as B_y changes from positive to negative; 2), a shift in magnetic local time of the region of entry of neutral gas into the polar cap from a location on the dawn-side of the noon-midnight meridian for B_y positive to one more biased towards the dusk-side for B_y negative; 3), an enhancement in the velocities associated with the dawn, anti-clockwise neutral vortex for B_y negative relative to those observed for B_y positive. The B_y neutral wind asymmetries can be explained by similar asymmetries, previously observed, in the polar ion convection pattern. They imply a direct causal relationship between solar wind/magnetosphere coupling and neutral thermospheric dynamics.

Introduction

The neutral air in the Polar Thermosphere is primarily driven by momentum transfer from convecting ions (e.g. Killeen et al., 1982, 1984a,b; Roble et al., 1984; Rees et al., 1983; Hays et al., 1979, 1984). Observations made by the Dynamics Explorer (DE-2) spacecraft show the presence, under most circumstances, of a large clockwise vortex of neutral air in the winter polar region (Killeen et al., 1984b). This large vortex is approximately coincident with the position of the dusk cell of ion convection. The influence of the dawn cell of ion convection on the neutral circulation is usually less apparent and sunward neutral velocities in the morning auroral zone are generally smaller in magnitude than those in the evening sector. Since the geometry of the ion convection pattern is not fixed but varies with changes in the orientation of the Interplanetary Magnetic Field (IMF) (Heelis, 1984), we may expect the configuration of the neutral circulation to vary also with the IMF. However, since the response of the thermosphere is different for the dawn and dusk cells, changes in, for example, the size of these cells, will not necessarily result in a direct, indentifiable change in the size of the neutral vortices. Furthermore, since the time constant for momentum transfer between ions and neutrals is of the order of hours, rapid fluctuations in the ion convection driven by solar wind variability will be strongly damped for the neutral circulation.

Atmospheric effects resulting from changes in the orientation of the IMF may be categorized according to the sign of the various components of the IMF. It is known that, for a positive value of the IMF, East-West, Y-component (B_y), a large dusk convection cell predominates at high-latitude. When B_y is negative, the dawn cell becomes larger (Heelis, 1984). The largest electric fields and therefore ion convection velocities in the polar cap show an asymmetry associated with B_y. When B_y is positive (negative) the largest electric fields are found near the dawn (dusk) cell reversals, respectively, (Heppner, 1972).

Recent measurements obtained from Spitsbergen, Norway (Λ75) have shown a definite dependence of zonal ion and neutral motion in the vicinity of the polar cusp on the sign of B_y, (McCormac and Smith, 1984). Rees et al, (1985) have investigated details of the B_y dependence using experimental results together with theoretical simulations for a number of case-studies. Here, we use the extensive data-base obtained from measurements by the Fabry-Perot interferometer (FPI), (Hays et al., 1981), and the Wind and Temperature Spectrometer (WATS), (Spencer et al., 1981), on Dynamics Explorer-2 (DE-2), to investigate the dependence of the neutral wind at Northern (winter) high latitudes on the orientation of the IMF. In a companion paper (Killeen et al., 1985), DE-2 measurements are used to illustrate the neutral circulation for conditions of large northward IMF (B_z positive). The results presented here illustrate some characteristic asymmetries in the neutral polar thermospheric flow that are related to the sign of B_y.

Observations

The WATS instrument on DE-2 obtained the neutral wind component perpendicular to the satellite track. The FPI measured the neutral wind component in the orbit plane. By appropriate combination of these two components, neutral wind vectors, referred to an altitude of approximately 320-350km, can be determined along the track of the polar orbiting spacecraft. The details of this data merging process have been discussed by Killeen et al., (1982).

The data in the present study were obtained during December, 1981 when DE-2 was in an orbital configuration that enabled sampling of the Northern hemisphere polar regions from a dawn-dusk plane. They are categorized according to the sign of B_y and are presented in geomagnetic polar coordinates

Paper number 5L6464
0094-8276/85/005L-6464$03.00

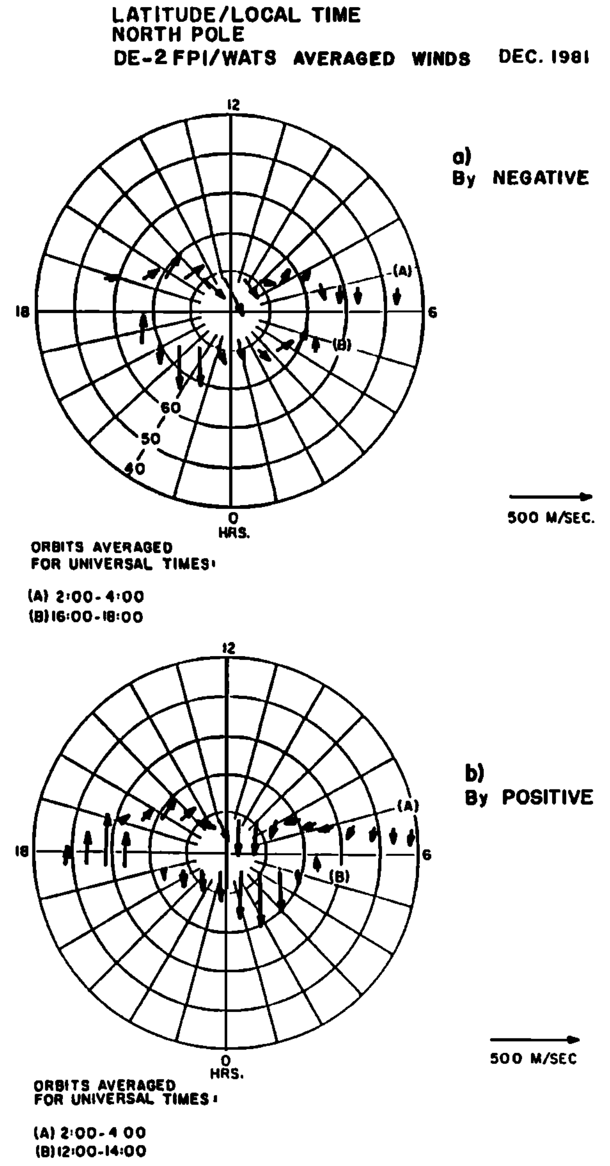

Fig. 1. Average neutral wind vectors for December 1981 plotted in geomagnetic polar coordinates (magnetic latitude and local time) obtained for the specified UT intervals with a) B_y negative and b) B_y positive.

(geomagnetic latitude and magnetic local time) in two forms: 1, mean winds obtained by averaging the data from many orbits into individual Universal Time (UT) "bins" of 2 hours width (Figure 1); 2, wind snapshots from individual orbits (Figure 2). The data averages have been previously used by Killeen et al., 1983 and Hays et al., 1984, to illustrate the basic geomagnetic dependence of polar thermospheric dynamics. Hourly averaged values of the Y-component of the IMF were used to categorize the data selected according to the sign of B_y. Since the neutral thermosphere has a variable response time to changes in ion velocity, which is rarely less than one hour, and since there is a delay between the effects of the recorded IMF values reaching the F-region, we used IMF values for the hour preceding the time at which DE-2 measurements were made. This "filtering" of the ion convection pattern by the neutral fluid implies that rapid fluctuations in the IMF orientation will not be discernable in the neutral circulation. Thus, for example, it would be invalid to include measurements that had a positive hourly averaged IMF value in the preceding hour, if the sign of the IMF value for the hour before were negative. We use only data for which B_y had a definite sign for a period of hours preceding the pass in question.

Figures 1a and b show the averaged neutral wind vectors for B_y negative and positive respectively. The UT's for which the data are presented were chosen to give vectors on either side of the magnetic dawn-dusk meridian with sufficient statistical accuracy in terms of the number of orbits included in each case. The data-set presented here, except for the ordering by B_y, is a subset of that used by Hays et al., (1984), and we refer the reader to our previous paper for a more full description of the data selection procedure.

Figure 2 shows wind vectors obtained for four examples of single passes of DE-2. The passes were selected to illustrate the B_y dependence of the neutral circulation in two different regions of the geomagnetic polar cap for quiet and steady geomagnetic conditions. Figures 2a and 2b show data for passes that crossed the geomagnetic polar cap on the dayside of the dawn-dusk meridian for B_y positive and negative, respectively, while Figures 2c and 2d show data from passes that crossed on the nightside of the dawn-dusk meridian. Due to a calibration procedure carried out for FPI at the beginning and end of all data collection sequences, there are commonly several minutes during which WATS data are available but FPI data are not. Where only the WATS (or zonal) wind measurements are available we use dotted bars in the figures to differentiate from the vector results (full arrows).

Discussion

The averaged neutral wind vectors, plotted in figures 1a and b, illustrate asymmetries in the neutral circulation associated with the sign of B_y. The most obvious asymmetry is the variation in polar cap wind velocity with the sign of B_y. The largest wind velocities are coincident with the expected maximum of electric field strengths i.e. at the dusk reversal boundary for B_y negative and at the dawn reversal boundary for B_y positive. This previously unobserved asymmetry should be seen from the ground by high-latitude observing stations with the appropriate UT/LT relationship. It is probably related to the "abatement" feature in the polar flow observed.by Meriwether et al., 1984.

The dominance of the clockwise dusk neutral vortex for conditions of B_y positive is also apparent, the dawn cell being barely discernable. This changes somewhat when B_y is negative. The morning neutral vortex is better defined with neutral winds travelling in a sunward direction in the morning auroral zone albeit with low velocities ~50-100 m/sec. The rotation region of the neutral flow from sunward to antisunward moves towards dusk by a few degrees of longitude. This may be an effect related to the diminution of the dusk convection cell and the enlargement of the dawn cell rather than to an entire translation of the circulation pattern or shifting of the convection reversal.

The characteristics of the neutral circulation associated with the sign of B_y that are seen in the averages are seen also in the quiet-time individual passes shown in figure 2. Orbit 1861 (figures 2a) shows neutral wind vectors for a period when B_y was ~ +3.2nT. It is indicative of a large dusk neutral vortex

DE-FPI/WATS NEUTRAL WIND VECTORS (GEOMAGNETIC COORDINATES)

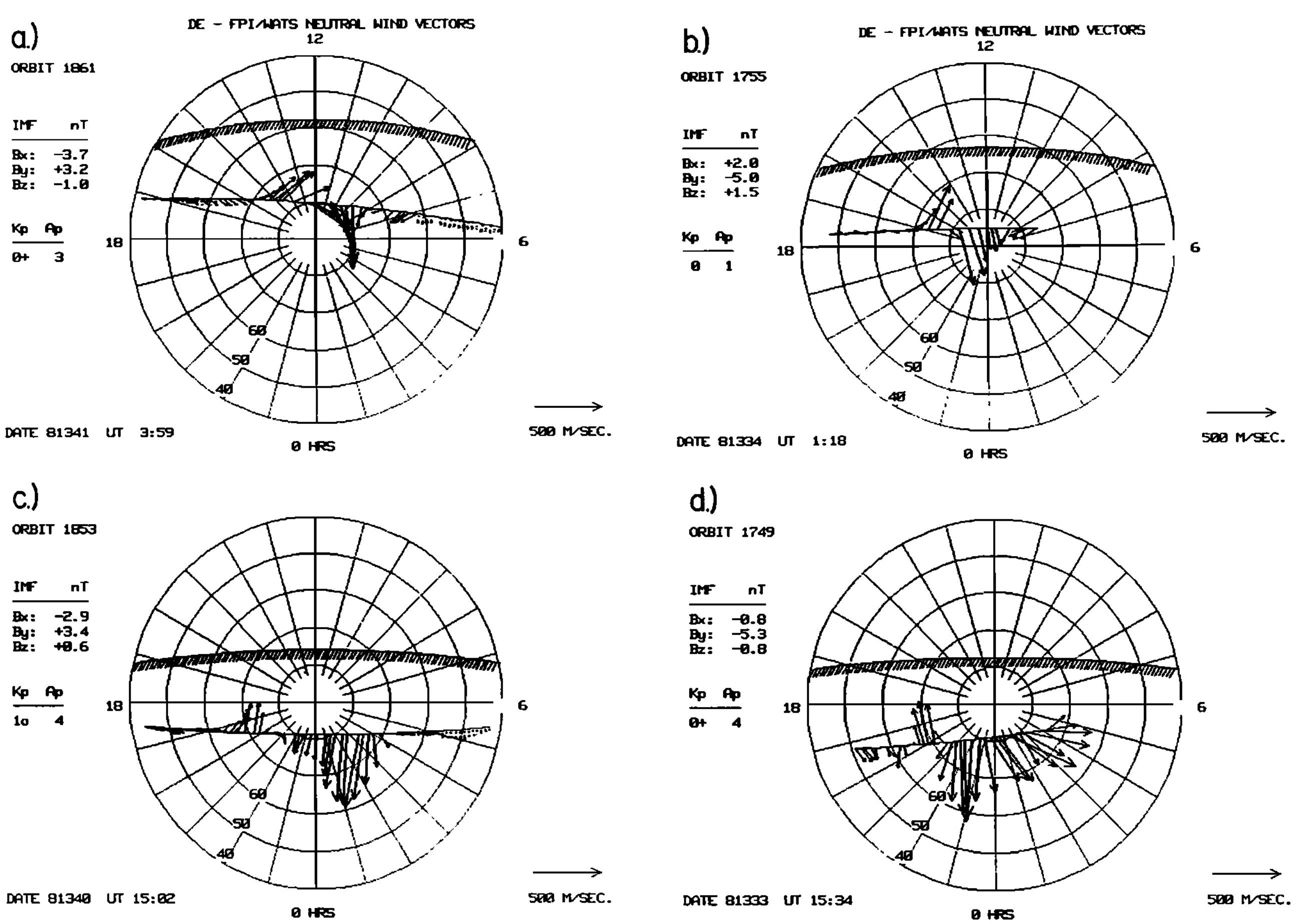

Fig. 2. Vector neutral wind measurements for individual orbits of DE-2; a) orbit 1861, b) orbit 1755, c) orbit 1853 and d) orbit 1749. The winds are plotted in geomagnetic polar coordinates. The solar terminator is indicated by the curved hatched line. Where no FPI data are available, the WATS measurements are indicated by the dotted bars plotted at right angles to the track of the satellite. The hourly averaged IMF values from ISEE-3 taken for the hour preceding the pass are shown at left with the Kp and Ap indices. The wind scale is given at bottom right.

with the neutral air entering the polar cap on the dawn side of the magnetic pole. There is little evidence of a sunward return flow in the dawn auroral zone. Neutral winds across the polar cap are ~500m/sec while dusk return flow velocities are ~400m/sec. Orbit 1755 (figure 2b) shows the neutral wind vectors for a period when B_y was ~ -5nT and indicates that the region of entry into the polar cap has been shifted substantially towards dusk relative to that for orbit 1861. Figure 2c shows wind vectors for orbit 1853 when B_y was $\sim +3.5$nT and figure 2d shows the vectors for orbit 1749, taken at a similar UT but for a value of B_y ~ -5.3nT. These two examples illustrate the B_y-dependent, asymmetric polar cap flow that is also evident in the averaged data. For orbit 1853, the region of largest wind speed is near the dawn polar cap/auroral zone boundary while for orbit 1749 the region of largest velocities is on the other side of the polar cap near the dusk auroral zone boundary.

It is considered that the asymmetric "jetstreaming" of the neutral polar cap flow, seen in both the averages and the individual orbits, is due to asymmetric ion drag forcing associated with the B_y dependent polar cap electric fields (Heppner, 1972; Heelis, 1984).

We note that, in our examination of many tens of DE-2 orbits over the winter (northern) hemisphere polar cap for which there exists a well-defined and steady B_y IMF component as determined by ISEE-3, the characteristic asymmetries discussed above are always present. A preliminary study of Southern hemisphere data has indicated that the B_y-dependent, polar cap "jetstreaming" effect is present but reversed (with respect to the noon-midnight meridian) from that indicated by the Northern hemisphere data shown. Clear B_y signatures are most evident for relatively steady IMF conditions where the various components remain roughly constant (or at least have the same sign) for a period of a few hours preceding the pass. They would appear to represent, therefore, basic structural characteristics of high-latitude thermospheric dynamics. We predict that similar signatures should be evident in high-latitude, ground-based Fabry-Perot and incoherent-scatter radar neutral wind data.

Conclusions

Measurements of the neutral wind in the polar F-region from Dynamics Explorer-2 (DE-2) have been used to illustrate asymmetries in the neutral circulation that are dependent on the sign of the B_y component of the interplanetary magnetic field (IMF). The main contrasting features are: 1), an asymmetry in the polar cap neutral flow velocity with the region of most rapid anti-sunward flow shifting from the dawn-side to the dusk-side of the polar cap as B_y changes from positive to negative; 2), a shift in magnetic local time of the region of entry of neutral gas into the polar cap from a location on the dawn-side of the noon-midnight meridian for B_y positive to one more biased towards the dusk-side for B_y negative; 3), an enhancement in the velocities associated with the dawn, anti-clockwise neutral vortex for B_y negative relative to those observed for B_y positive. The B_y neutral wind asymmetries can be explained by similar asymmetries, previously observed, in the polar ion convection pattern.

The correlations between the polar neutral flows and the IMF orientation discussed here (see also Killeen et al., 1985) testify to the rather direct causal relationship between solar wind/ magnetosphere coupling and dynamical phenomena in the neutral thermosphere. A future paper will discuss the mean, B_y-dependent neutral polar flows observed from DE-2 in greater detail, using a more extensive data-set than that presented here and incorporating theoretical predictions from the NCAR Thermospheric General Circulation model for appropriate ion convection inputs.

Acknowledgements. The work was supported by NASA grant number NAG5-465 to the University of Michigan. The IMF values were provided by the National Space Science Data Center (NSSDC) from measurements made on ISEE-3 (E.J. Smith, Principal Investigator). Useful discussions with Drs. R. G. Roble, J. W. Meriwether, D. Rees, R. A. Heelis and P. H. Reiff are acknowledged.

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(Received February 5, 1985;
accepted February 22, 1985.)