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NEUTRAL MOTIONS IN THE POLAR THERMOSPHERE FOR NORTHWARD INTERPLANETARY MAGNETIC FIELD

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Abstract. On 24th November, 1982, The North-South (B_z) component of the Interplanetary Magnetic Field (IMF) became positive for a period of about 11 hours reaching a relatively large and steady value of ~25 nT. During this rare occurrence, the Dynamics Explorer-2 (DE-2) spacecraft was in a configuration that enabled the dynamics of both ionic and neutral species of the high-latitude F-region to be measured simultaneously along the track of the polar-orbiting satellite. Results from two Northern (winter) polar passes of DE-2, extracted from a larger data set, are shown to illustrate the response of the neutral F-region to ion drag forcing arising from a configuration of ion convection characteristic of strongly northward IMF. The measured neutral winds differ appreciably from those more commonly observed for periods of southward IMF. The multicellular ion drift pattern associated with positive B_z is observed to drive a similar but less structured and weaker neutral wind configuration in the winter polar cap. Major features of the ion drift pattern are mimicked by the neutral circulation but smaller-scale and more irregular structures of ion flow are not. This is ascribed to the relatively long time constant (few hours) for momentum exchange between the ion and neutral gases. The results demonstrate that sunward flow of neutral gas can be established and maintained by ion drag in the central polar cap for positive B_z.

Introduction

In recent years much attention has been given to the problem of the geometrical dependence of the high-latitude ion convection pattern on the orientation of the Interplanetary Magnetic Field (IMF) (Heppner, 1972; Crooker, 1979; Heelis, 1984; Reiff and Burch, 1984). It has been shown that the sign of the IMF B_y (East-West) component is related to asymmetries in the twin-cell convection system observed for a negative B_z (North-South) component (Heppner, 1972; Heelis, 1984). For periods of positive B_z, the ion convection pattern becomes more complex as the auroral oval contracts and more highly structured ion flow is observed, particularly on the nightside of the solar terminator. General features associated with positive B_z include a multi-cellular convection pattern at high latitudes (Zanetti et al., 1984), pronounced sunward ion flow in the central polar cap (Burke et al., 1979) probably associated with the transpolar theta auroral arcs (Frank et al., 1982) and a system of large-scale field-aligned currents in the polar cap (Iijima et al., 1984; Potemra et al., 1984).

While the IMF-dependent morphology of convection patterns and current systems has received attention, very little study has been given to the response of the neutral thermospheric fluid to changes in the forcing terms associated with the orientation and magnitude of the IMF. Three recent studies have investigated the possibility of a B_y effect. McCormac and Smith (1984) demonstrated a definite dependency of F-region winds measured from the ground at Spitzbergen, Norway, on the sign of B_y, and Rees et al. (1985) studied several case-histories using satellite and ground-based data, together with model simulations, to elucidate details of this dependency. In a companion to this paper (McCormac et al., 1985, this issue), the effect of sign changes in B_y has been further studied using individual orbits and averaged data-sets from the DE-2 satellite.

No observational evidence has, however, been hitherto reported to relate the high-latitude neutral wind system to the sign or magnitude of B_z, the component of the IMF that plays the most fundamental role in controlling the coupling between the solar wind and the magnetospheric boundary regions. Here, we present data from DE-2 to illustrate the F-region neutral thermospheric wind system for conditions of strong and steady northward IMF (B_z positive). The results demonstrate a circulation that is quite different from the "classical", twin-cell, contra-rotating vortex system that is commonly observed for negative B_z conditions (e.g. Killeen et al., 1982, 1984a; Hays et al., 1984). In particular, the results show that a region of

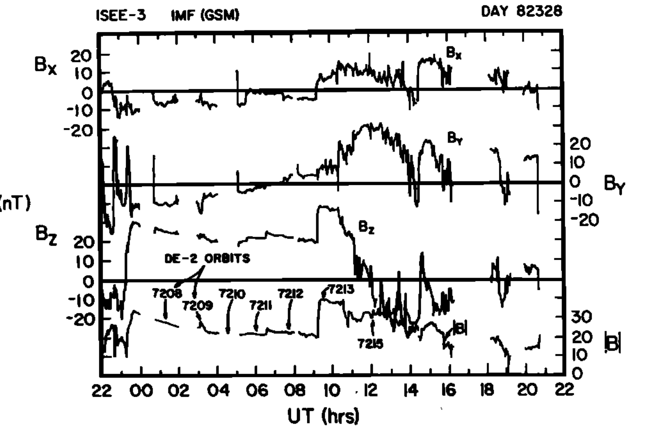

Fig. 1. Variation of the Interplanetary Magnetic Field as measured by ISEE-3 during 24th November, 1982. The times corresponding to the orbits studied are indicated.

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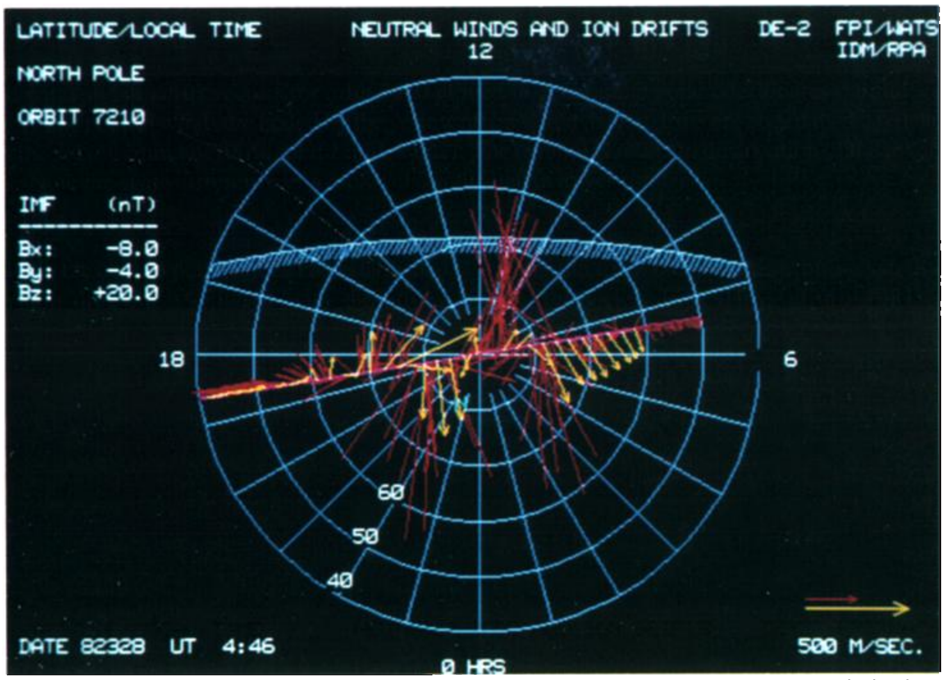

Fig. 2. Neutral wind and ion drift vectors for orbit 7210 plotted in geographic polar coordinates (latitude, pole to 40%N, local solar time). The neutral winds are coded by the yellow arrows, and the ion drifts are coded by the red bars. The curved line represents the solar terminator (90% solar zenith angle). The symbol N refers to the location of the invariant pole at the UT of the pass. Note the scale difference of a factor of 2 indicated at lower right.

sunward neutral flow in the central polar cap can be established and maintained by ion drag in association with the strong sunward convection characteristic of positive B_z.

Observations

Instrumentation on board the Dynamics Explorer-2 satellite enables both the neutral wind and the ion drift to be measured along the track of the polar-orbiting satellite. The Fabry-Perot Interferometer, FPI, (Hays et al., 1981) and the Wind and Temperature Spectrometer, WATS, (Spencer et al , 1981) measure the meridional and zonal components of the neutral wind vector, respectively, while the Retarding Potential Analyser, RPA, (Hanson et al., 1981) and the Ion Drift Meter, IDM, (Heelis et al., 1981) measure the corresponding ion drift components. Details of the synthesis of neutral wind vector

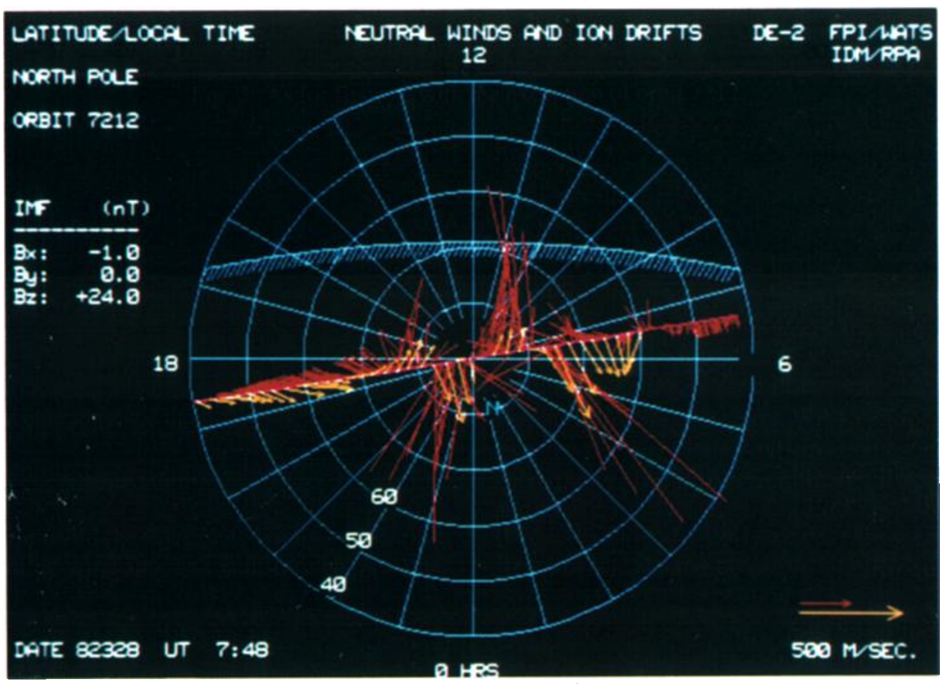

Fig 3 As for figure 2 with the exception of orbit 7212

measurements from the remote sensing (FPI) and in-situ (WATS) instruments have been described by Killeen et al., (1982), and data from all four instruments have been previously used by Killeen et al., (1984b), to enable a quantitative study of ion-neutral coupling in the summer polar region.

Six consecutive passes (orbits 7208-7213) of DE-2 over the Northern (winter) hemisphere polar cap during November 24th 1982 have provided vector measurements of ion drifts and neutral winds during a time period when the IMF was strongly northward. We show data from two of these orbits to illustrate the neutral wind pattern for conditions of steady and positive B_Z. A future paper will present the full sequence of passes for the entire period of positive B_Z and for the substorm that followed, triggered by a strong "southward turning" of the IMF at ~11:00 hrs UT.

The relevant ISEE-3 measurements of the IMF are shown in Figure 1 together with an indication of the appropriate times for the DE-2 passes. No IMF propagation effects have been accounted for in locating the times in Figure 1 but since the ISEE-3 spacecraft was located at 04:00 hrs local time these are not expected to be large. Figure 2 and 3 show the satellite measurements for orbits 7210 and 7212, respectively. The ion drifts (red bars) and neutral winds (yellow arrows) are plotted in polar coordinates (geographic latitude, and local solar time, LT) along the track of the satellite. The altitude of the measurements is ~320km. The solar terminator is indicated by the blue hatched curve and the location of the geomagnetic pole at the UT of the pass is given by the symbol "N". As discussed by Killeen et al., (1984b) there are fewer neutral wind vectors plotted than ion drift vectors due to the reduced latitudinal resolution of the remote sensing (FPI) instrument compared to the in-situ sensors.

It can be seen from Figure 1 that both orbits occurred several hours into the period of steady northward IMF with B_Z ~ +25nT. Since the time constant for the ion gas to set the entire neutral gas in motion in the winter polar F-region is on the order of 2-3 hours, we consider the measured neutral circulation for these two orbits to be characteristic of positive and steady B_Z conditions and not of a transition flow regime associated with major changes in either the IMF or the ion convection pattern.

The data for the two passes show similar signatures and this is taken to be an indication of a state of quasi (dynamic) equilibrium attained for both ion and neutral species during the second half of the period of strong northward IMF (i.e. ~04:00-09:00 hrs UT). In both examples the ion drift velocities display highly-structured convective flow with numerous small-scale fluctuations embedded within a basic multicellular pattern characteristic of positive B_Z. The neutral winds show less small-scale variability and are, in general, significantly smaller in magnitude than the ion drifts (note the difference of a factor of two in the scales used for ions and neutrals in Figures 2 and 3). It is clear that, to a certain extent, the neutral circulation "mimics" the ion convection pattern with reduced wind speeds. The strong correlation between ion and neutral flow patterns is evident, for both passes, in the co-location of flow reversals in the ion and neutral fluids. Both examples show a well-defined region of sunward flow for ions and neutrals in the central polar cap. We note that, although sunward polar cap ion convection has been previously reported for positive B_Z (e.g. Burke et al., 1979), sunward neutral flow has not, due to the relative paucity of neutral wind measurements in the central polar cap. The neutral wind speeds in this sunward flow region are ~50-150m/sec whereas the ion drift velocities are typically ~900 m/sec. We conclude that sunward ion convection in the polar cap, at times of positive B_Z, can provide a sufficiently strong momentum source for the neutral gas to overcome the effects of the anti-sunward directed pressure gradient force. The fact that the neutral winds only attain a small fraction (~10%) of the sunward ion drift velocity is due, in part, to the competing influence of anti-sunward pressure gradient forces and, in part, to the relatively short period of time during which any given parcel of neutral gas comes under the influence of the sunward ion drag.

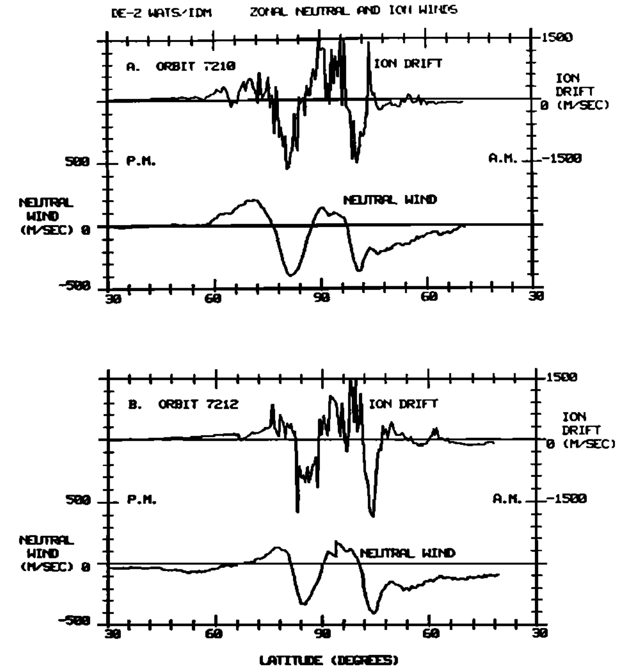

Fig. 4. Zonal neutral winds and ion drifts measured on DE-2 for a) orbit 7210 and b) orbit 7212 plotted as a function of latitude along the track of the satellite. Neutral zonal winds are plotted according to the scale shown on the right, ion zonal drifts according to the scale on the left.

The region of sunward polar cap flow seen in Figures 2 and 3 is bounded by regions of anti-sunward ion and neutral flow with, once again, the neutrals following the ions at reduced speed. To illustrate further the nature of the coupling between the ion and neutral gases we show, in Figure 4, the detailed zonal (i.e. sun-aligned for the particular LT plane of the orbits used) ion and neutral wind components from IDM and WATS respectively. These components are shown using comparable temporal (8 sec) and spatial (~60km) resolutions and a 3:1 scale difference has been introduced to highlight the similarities between the ion and neutral zonal motion. It can be seen that, throughout the polar region, the zonal neutral wind follows the "averaged" zonal ion drift with a significant reduction in speed. The extent to which the zonal wind curves resemble "low order" fits to the more structured zonal ion drift curves is remarkable, and is a testament to both the spatial and temporal scales over which the ion and neutral gases are coupled. This latter scale is determined by the time delays involved in the transfer of momentum from the relatively few convecting ions to the more numerous neutrals (e.g. Killeen et al., 1984b).

We note that the general signatures of both the ion and neutral zonal winds, shown in Figure 4, are highly reminiscent of the "W" patterns reported from measurements of magnetic field perturbations in the polar cap for northward IMF (Zanetti et al., 1984, Potemra et al., 1984) and with electric field measurements reported by Burke et al., 1979. We consider the present results, therefore, to be consistent with the growing body of information concerning the dynamics of the ionosphere during periods of northward IMF. The present results extend earlier work by incorporating neutral thermospheric effects.

Summary

We have used data from two northern (winter) hemisphere polar passes of DE-2 to illustrate the neutral wind configuration for conditions of strong and steady northward IMF. Simultaneous measurements of ion drifts enable the observed neutral winds to be directly related to ion drag forces arising from ion/neutral momentum transfer collisions. The measured neutral winds for positive B_z differ appreciably from those more commonly observed for periods of southward IMF. The multicellular ion drift pattern associated with positive B_z is observed to drive a similar but weaker neutral wind system in the winter polar cap. Major features of the ion drift pattern are mimicked by the neutral circulation but smaller-scale and more irregular structures of ion flow are not. Sunward flow of neutral gas can be established and maintained by ion drag in the central (winter) polar cap.

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