N90-28200

THE INFLUENCE OF IMF ON THE LOWER IONOSPHERE PLASMA IN HIGH AND MIDDLE LATITUDES

J. Bremer
Academy of Sciences of the GDR
Heinrich-Hertz-Institute of Atmospheric Research and Geomagnetism
Observatory of Atmospheric Research
DDR-2565 Kühlungsborn, GDR

Abstract: As shown by ground-based absorption measurements, the lower ionospheric plasma is markedly controlled by the structure of the IMF. Whereas in high auroral and subauroral latitudes this effect is very pronounced, in midlatitudes its influence is less important. A comparison of these results with satellite data of the IMF and the solar wind speed confirms the important role of these components, not only during special events but also for the normal state of the ionospheric D-region plasma.

1. Introduction

As known from DUNGEY (1961) the vertical component B_z of the IMF in the solar-magnetospheric coordinate system markedly controls the energy transfer from the solar wind into the magnetosphere. Whereas negative B_z components should favor this transfer, positive B_z values should inhibit such an input.

Assuming an IMF which is emitted together with the solar wind parallel to the solar equator, the B_z component shows systematic variations due to daily and seasonal changes of the position of the geomagnetic dipole axis of the Earth with respect to the solar rotation axis. In Figure 1 the seasonal (a) as well as diurnal (b) variations of B_z are presented for an IMF with A- (full curves) as well as T- (dashed curves) polarity. After Figure 1a an IMF with A-polarity induces positive B_z values during the spring half-year and negative B_z values during autumn, whereas an IMF with T-polarity causes reverse signs of B_z, respectively. Following a proposal by LAUTER et al. (1978) IMF sectors with negative B_z values are called "pro sectors" and sectors with positive B_z values "anti sectors". The diurnal B_z variation (Figure lb) having a markedly smaller amplitude than the seasonal component has minima near 11 UT for A- and near 23 UT for T-polarity.

In this paper the influence of the IMF on the plasma of the lower ionosphere shall be investigated mainly during IMF sector boundary crossings (SBC). The dates of these SBC are taken from a special list of WILCOX (1982).

2. Results

As the ionospheric plasma markedly depends on the highly variable solar EUV radiation as well as internal atmospheric processes, it is often difficult or even impossible to separate these phenomena from effects caused by the IMF sector structure. On the other hand, the individual SBC data are sometimes incorrect. Therefore, here mainly the results of statistical investigations are shown using the method of superposed-epoch analysis with the first day of the new IMF sector as the key day (zero).

In Figure 2 the results of such an analysis are shown using noon absorption data at 3 MHz measured at the GDR Antarctic Station "Georg Forster" (70.77°S; 11.83°E) during June 1976 and November 1978. Whereas in the upper part (Figure 2a) all SBC are used independently of the direction of the IMF, in the other parts the total number of SBC are divided into transitions with respect to IMF polarity (T $\rightarrow$ A transitions: Figure 2b; A $\rightarrow$ T transitions: Figure 2c) and transitions with respect to the B_z component of the IMF (anti $\rightarrow$ pro, pro $\rightarrow$ anti sector transitions:

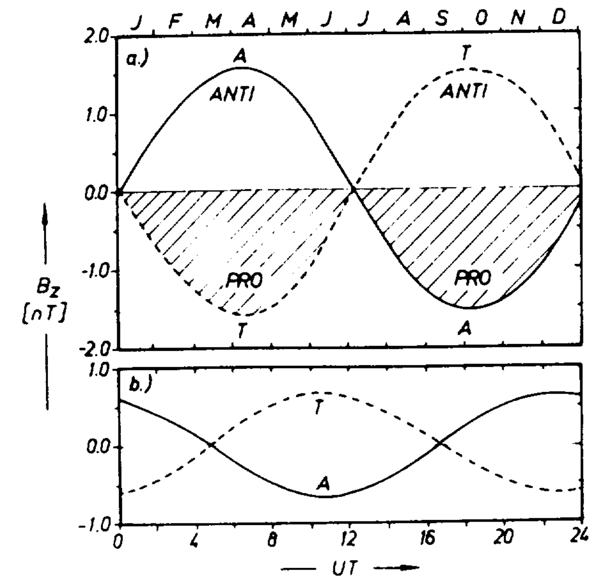

Figure 1. Mean seasonal (a) and diurnal (b) variation of the B_z component of the IMF in the solar-magnetospheric coordinate system for A- (full curves) and %-polarities (dashed curves) with an IMF amplitude B = 5 nT.

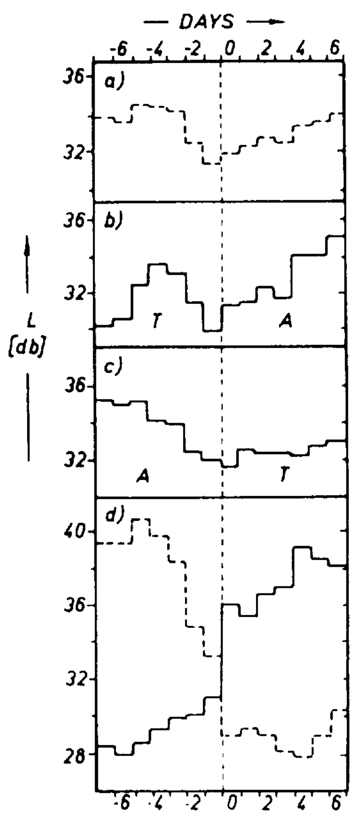

Figure 2. Mean variation of ionospheric noon absorption in Georg Forster station (70.77°S, 11.83°E) at 3 MHz during IMF sector boundary crossings independent of IM direction (a), for crossings from T→ A polarity (b), for crossings from A → T polarity (c) and for crossings from pro → anti (dashed curve) as well as anti → pro sectors (full curve) (d), respectively.

Figure 2d). In Figure 2a-c only small variations of ionospheric absorption are to be seen, only the minimum near day –1 seems to be typical. The slightly enhanced absorption at A polarity (Figure 2b and c) also observed by MANSUROV et al. (1976) seems to be connected with enhanced particle precipitation during noontime because due to the diurnal B_z variation (see Figure 1b) near noon IMF sectors with A-polarity induce lower B_z values than T-sectors. More pronounced variations of ionospheric absorption are observed, however, if IMF sectors are distinguished by their B_z component. In pro sectors the absorption is higher by about 10 - 12 dB than in anti sectors. The transition between both sectors is very steep with absorption changes of about 4 - 5 dB from day –1 to day 0. As can be seen from Figure 2d, but also from similar investigations with other ionospheric absorption data as well as different geomagnetic indices (BREMER and LAUTER, 1984; BREMER, 1986), the transition from anti → pro sectors is more pronounced than the transition from pro → anti sectors. As the B_z component of the IMF plays an essential role in the ionospheric plasma, in the following only pro → anti and anti → pro SBC will be used.

To investigate the IMF influence on the plasma of the lower ionosphere in dependence on latitude we used the results of the Finnish riometer chain. In the left part of Figure 3 daily mean values of the hourly maximum CNA data at 27.6 MHz are shown for the period between February 17 and March 2, 1981. After WILCOX (1982) a sector boundary crossing from A to T sector occurs between February 23 and 24, marked by the dashed line. Whereas before the SBC which is an anti sector the absorption is very small at all stations; during pro sector conditions after February 24 the absorption is markedly enhanced. The excessive absorption is highest in high geomagnetic latitudes (shown in brackets in Figure 3) and is smaller in lower latitudes but nevertheless remarkable also in 57.6°N geom. latitude. The geomagnetic Ap index shown at the top of the right part of Figure 3 is also enhanced after the sector boundary crossing. Beside these ground-based data also interplanetary data are shown (KING, 1986) like solar wind speed and the IMF B_z component as well as the energy coupling function ε introduced by PERREAULT and AKASOFU (1978). Whereas the solar wind speed is characterized by a minimum before the sector boundary crossing the B_z component changes its sign from plus to minus. To demonstrate this change more clearly, on February 24 half-day mean values have been calculated for B_z and ε instead of daily mean values estimated otherwise. In conclusion we can state that during pro sector conditions the energy input from solar wind into the magnetosphere markedly increases, followed by precipitation of high energetic particles into the middle atmosphere and enhanced CNA.

At the top of the left-hand part of Figure 3 also the IMF data derived from ground-based measurements (Solar Geophysical Data, 1981) are shown which in this case do not agree with the SBC data from WILCOX (1982) who took into consideration also satellite data. Such uncertainties in SBC data estimated from ground-based measurements are not so critical if statistical investigations like superposed-epoch analyses are made only, since about 85% of these SBC data should be correct (SVALGAARD, 1976).

In Figure 4 the results of superposed-epoch analyses are shown using again daily mean values calculated from hourly maximum CNA data at 27.6 MHz measured at 7 stations of the Finnish riometer chain. The SBC are characterized by dashed lines. For pro → anti sector transitions as well as anti → pro transitions we always observe higher absorption during pro sector conditions rather than during anti sectors. The differences between both conditions become smaller with decreasing latitude but can also be detected at Nurmijärvi in 57.6° geom. latitude. Generally the increases of absorption with anti → pro transitions are steeper than for pro → anti transitions, mainly to be seen above 60° geom. latitude, a fact already mentioned above.

In order to compare the superposed-epoch analyses of Figures 2 and 4 with interplanetary data in Figure 5, the results of similar analyses are shown using daily mean values of the solar wind speed, the B_z component and the ε function during the period from 1975 to 1979 where a lot

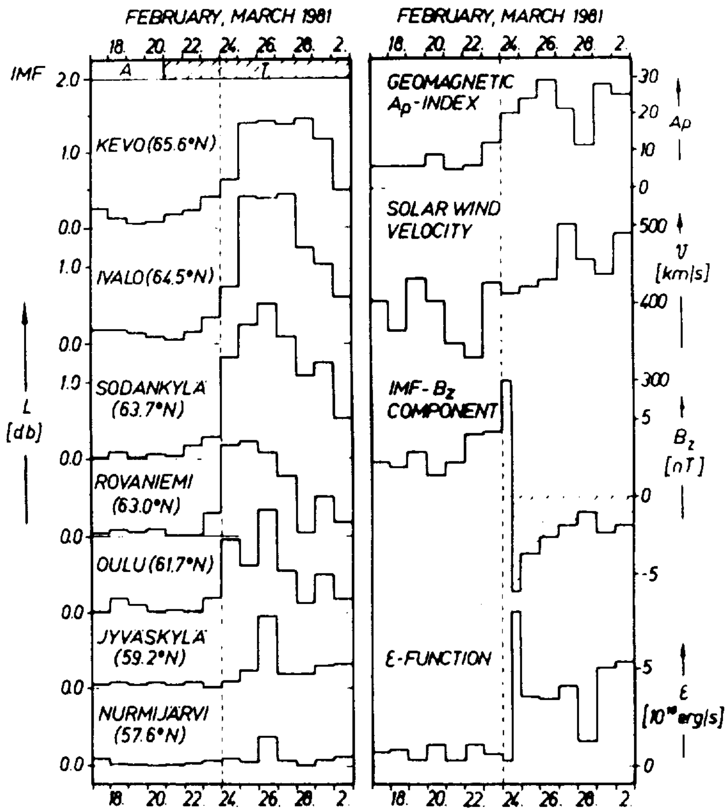

Figure 3. Variation of CNA at different geomagnetic latitudes, geomagnetic Ap index as well as satellite data of solar wind speed, B_z component of the IMF and energy transfer function ε during the period from February 17 until March 2, 1981. The IMF polarity data (A or T) are from Solar Geophys. Data and the SBC (dashed lines) from WILCOX (1982).

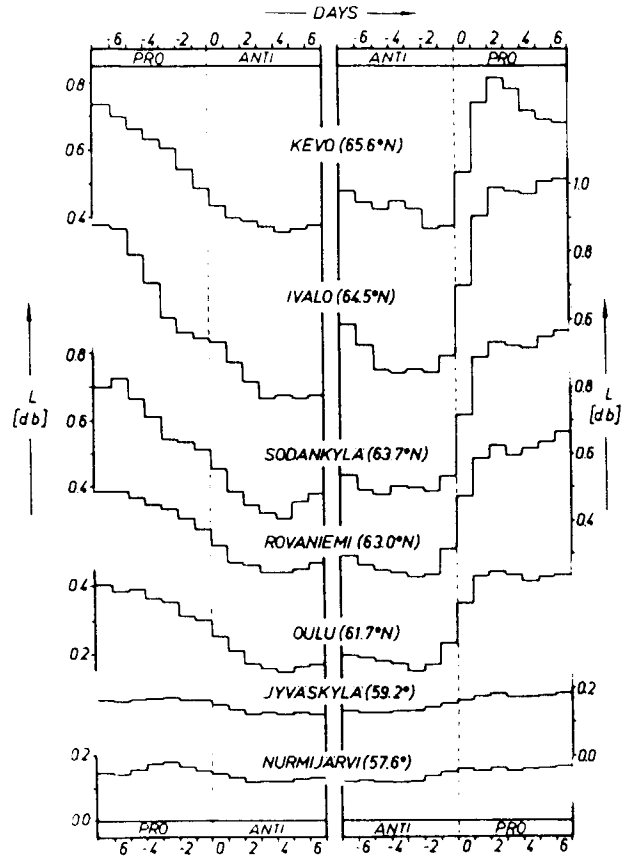

Figure 4. Mean variation of daily mean values derived from hourly maximum CNA data for 1979 until 1982, during IMF sector boundary crossing from pro → anti and anti → pro sector conditions in dependence on geom. latitude. The dashed lines mark the SBC after WILCOX (1982).

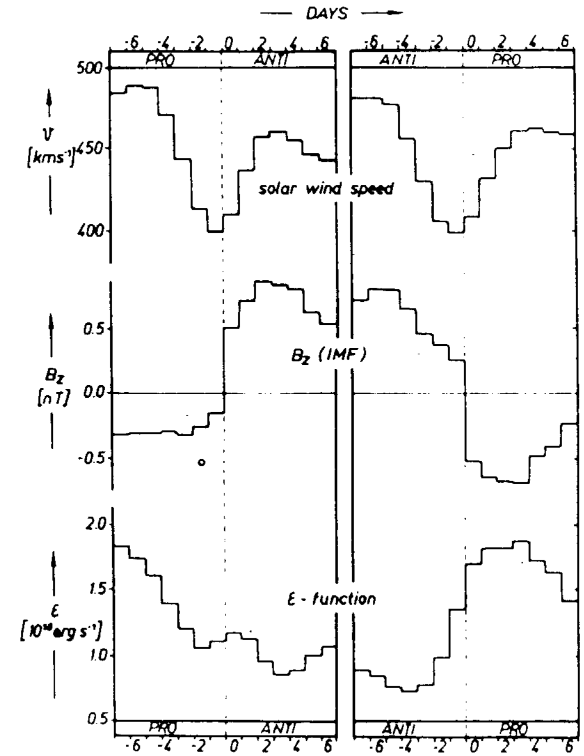

Figure 5. Mean variation of the solar wind speed v, the IMF B_z component and the energy transfer function ε calculated for transitions of IMF pro → anti and anti → pro sector conditions using satellite data 1975-1979.

of such satellite data is available (KING, 1979, 1986). The mean variation of the solar wind speed is very similar for pro → anti and anti → pro sector transitions with a pronounced minimum at day −1 just before the SBC. As to be expected, the B_z component is negative during pro sectors, but positive during anti sectors. The energy coupling function ε is higher during pro sectors than during anti sectors. Whereas ε shows a steep increase during the anti → pro sector transition, the decrease of ε during pro → anti transitions is not so steep and even shows a small secondary maximum just after the SBC on day 0.

3. Discussion and Conclusions

As demonstrated by Figure 5, the energy transfer from solar wind into the magnetosphere connected with a precipitation of high energetic particles into the middle atmosphere mainly depends on the B_z component of the IMF. Thus during times with negative B_z values enhanced fluxes of precipitating particles induce a higher ionization level in the ionospheric D region and therefore higher absorption of radio waves as observed in Figures 2 - 4. Therefore, the proposed classification of IMF sector in pro and anti sectors after their B_z component seems to be well justified.

Whereas the main differences between pro and anti sectors are caused by the B_z component also the solar wind speed v modulates the particle precipitation and, therefore, the ionospheric absorption since ε is proportional to v. Thus the relatively flat variation of absorption during pro → anti sector transitions (Figures 2 and 4), connected with the secondary maximum of the solar coupling function ε (Figure 5), is caused by the steep increase of the solar wind speed at the front of the anti sector. In geomagnetic indices even a secondary maximum can be observed during the transition from pro → anti sector (BREMER, 1986). Also the absorption minimum on day −1 just before the SBC in Figure 2a where all SBC were used irrespective of their polarization, is caused by the minimum of solar wind speed (see Figure 5) as in this case the influence of the B_z component is covered by the averaging process.

As the precipitation of high energetic particles becomes smaller with decreasing geom. latitude also the effect of IMF sector structure becomes less important in midlatitudes (Figures 3 and 4). This fact could be confirmed by investigations using LF absorption data at Central Europe not shown here. Only when using a large amount of data, small effects similar to those discussed here could be detected. At geom. latitudes above about 60°, however, the IMF influence may be essential if the concept of pro and anti sectors is used.

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