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SOLAR FLARE AND IMF SECTOR STRUCTURE EFFECTS IN THE LOWER IONOSPHERE

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ABSTRACT

About 1% of all SIDs observed at the Panska Ves Observatory (Czechoslovakia), has been found to be not of solar-XUV origin. Among them, the very rare SWF events (observed at L = 2.4) of corpuscular origin are the most interesting.

The IMF sector structure effects in the midlatitude lower ionosphere are minor in comparison with effects of solar flares, geomagnetic storms, etc. There are two basic types of effects. The first type is a *disturbance*, best developed in geomagnetic activity, and observed in the *night*-time ionosphere. It can be interpreted as a response to sector structure related changes of geomagnetic (= magnetospheric) activity. The other type is best developed in the tropospheric vorticity area index and is also observed in the *day*-time ionosphere in winter. This effect is *quietening* in the ionosphere as well as troposphere. While the occurrence of the former type is persistent in time, the latter is severely diminished in some periods (e.g. 1974-77). All the effects are stronger for so-called "proton" sector boundaries. As regards the stratosphere, the 10-mb level temperature and height above Berlin-Tempelhof do not display any observable IMF sector structure effect.

SOLAR FLARE EFFECTS

Are all sudden ionospheric disturbances (SID), recorded at high midlatitudes, of solar flare origin (or more precisely of solar-XUV origin)? About 1% of all SIDs, observed at the Panska Ves Observatory (Czechoslovakia) during the period 1960-1973, has been found to be not of solar XUV-origin. The SID monitoring system at Panska Ves consists of SWF, SFA, SEA and SDA. Almost all peculiar SIDs, however, have been recorded by one SID monitoring method only. Among them, the very rare SWF events of corpuscular origin, observed at L = 2.4, are most interesting. They are shown in Table 1. The first event was observed under quite calm solar conditions. The second event was associated with a very weak radio burst at the beginning of the event, and with a very weak radio burst and subflare near the end of the event. The third event was accompanied by an unconfirmed flare with its maximum before the beginning of the event. None of these three events was associated with X-ray bursts. On the other hand, these events were observed under considerably enhanced geomagnetic activity, which is favourable for precipitation of high-energy electrons (E > 20-40 keV).

A similar event was observed on 17 June 1970 near noon (1048-1055-110 UT) as a SWF of a medium importance and a very weak SFA accompanied by a weak flare with quite insufficient X-ray flux to explain the observed SWF. The event was observed near the maximum of a moderate geomagnetic storm. Fortunately, the COSMOS-348 satellite, which measured high-energy electrons (both trapped and penetrating fluxes, crossed L = 2.4 at 1052 UT (i.e. during the event). Figure 1 shows energetic spectra of trapped electrons observed at the same local time and place at L = 2.4 during the event and during a strong geomagnetic storm a few days later. These spectra demonstrate well the extremely strong and unexpected enhancement of high-energy electrons during the event. Fluxes of precipitating electrons were sufficiently large to explain the observed SWF

Table 1: Peculiar SWF events of corpuscular origin, recorded at 2775 kHz (reflection point 52°27 N, 12°27 E, L = 2.4) and 2614 kHz (reflection point 52°08 N, 11°00 E, L = 2.4). x - unconfirmed flare.

Date	start	max SWF	end	imp	X-rays (1.8Å)	Optical flare start end imp	Radio burst start end imp	K_p ΣK_p
1971 09/25	0602	0610	0627	1	no burst	no flare	no burst	5- 29+
1972 08/26	0637		0737	2	no burst	0718 0736 -N	0633 0638 weak 0706 0712 weak	5- 25-
1973 10/18	1249		1330	1	no burst	1236 1254 1F^x max 1238	no burst	5 28+

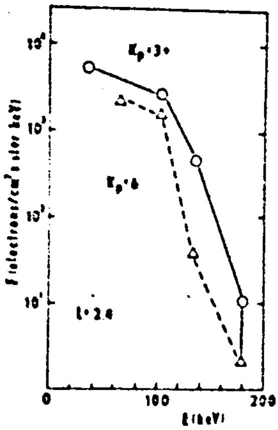

Figure 1. Energetic spectra of trapped electrons between 20-200 keV at L = 2.4 for the SID event in question (top curve) and for a severe geomagnetic storm (bottom curve) as measured onboard COSMOS-348 (after LASTOVICKA and FEDOROVA, 1976).

(LASTOVICKA and FEDOROVA, 1976). Unfortunately, this result is not full proof, because the satellite measurements were performed over the Southern Hemisphere, but it strongly supports the corpuscular origin of such peculiar SWFs.

IMF SECTOR STRUCTURE EFFECTS

There are several effects of the interplanetary magnetic field (IMF) - those of the north-south component B_z, those of changes of polarity of the azimuthal, B_y, and radial, B_x, components, and those of crossing of the IMF sector boundary. The effects of changes of polarity and magnitude of all three IMF components in the lower ionosphere are essentially a response to the IMF generated changes in geomagnetic (i.e., magnetospheric substorm) activity. This not the case, however, when the IMF sector boundary crossing effects are concerned.

The IMF sector boundary is a well developed physical structure, a warped current sheet (WILCOX, 1979) dividing the interplanetary space into two parts with opposite prevailing B_x polarity. A crossing of such a well-developed space structure, accompanied by an increase of the IMF magnitude B (LASTOVICKA, 1979) and of its geoactive southward component B_z (SCHREIBER, 1977), affects the Earth's magnetosphere, ionosphere and even troposphere.

There are two basic types of responses to the IMF sector boundary crossing (Fig. 2), both being observed, among others, in the ionosphere. The geomagnetic type is manifested best in geomagnetic activity. This effect is a <u>disturbance</u> and consists in a change across the sector boundary and in a significant difference between the level before and after boundary crossing. In equinoctial periods, the effect of IMF polarity changes (B_x) becomes comparable to that of the sector boundary crossing itself. The effect has been observed in B, southward B_z and cosmic rays (LASTOVICKA, 1979). The tropospheric type is manifested best in the tropospheric vorticity area index (VAI) and consists in a narrow deep depression centered at the day of boundary crossing. This effect is <u>quietening</u>, not a disturbance.

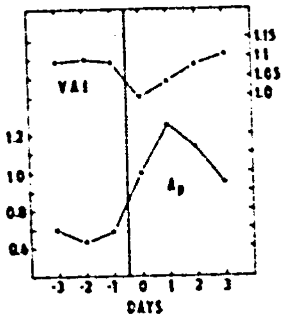

Figure 2. The IMF sector boundary crossing effect of the geomagnetic type in A_p (logarithmic mean) and of the tropospheric type in VAI (tropospheric vorticity area index at the 500 mb level). The data are expressed in ratio to the zero-day values. Vertical line - boundary crossing (reported to 00 UT).

Figure 3 shows the geomagnetic type effect in the nighttime radio wave absorption in the lower ionosphere over Central Europe in winter. The absorption is higher after the crossing than before at both frequencies. The effect in absorption is much weaker than that in A_p, minor in comparison with geomagnetic storm or solar activity effects in the lower ionosphere.

In order to estimate the statistical significance of data points in Figs. 3-5, the significance of the difference between extreme mean data points, P, and the probability of this difference being positive in individual crossings, B, are given in Table 2. <u>P</u> represents mainly the reliability of the effects, while <u>B</u> mainly their importance. The effect at 245 kHz is statistically significant and important but the effect at 272 kHz appears to be unimportant. This is caused by different L-shells of reflection points - 2.7 and 2.1. Fluxes of precipitating electrons controlled by geomagnetic activity are considerably weaker at L = 2.1.

The geomagnetic-type effect is observed in the lower ionosphere in winter only at night. In equinoctial periods, we can again observe the geomagnetic-type effect in absorption only at night. No significant effect is observed near noon. The boundary crossing effect itself is a little weaker than that in winter, but the effect of changes in IMF polarity is comparable to (or even stronger than) that of boundary crossing (LASTOVICKA, 1982).

Figure 4 shows the tropospheric type effect in the noon radio wave absorp-

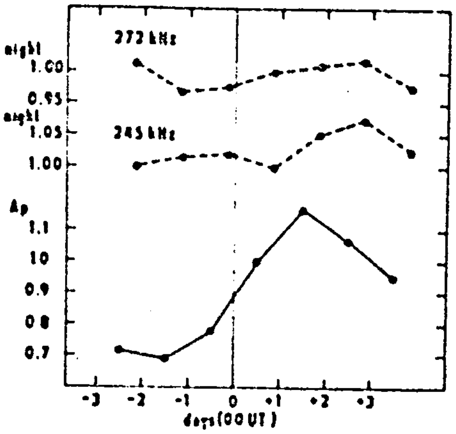

Figure 3. The geomagnetic-type effect in A_p and nighttime radio wave absorption in the lower ionosphere over Central Europe in winter (1966-73 - after LASTOVICKA, 1979). The data are expressed in ratio to the crossing-day values.

Table 2: Statistical significance of the difference between extreme mean data points, P, the probability of this difference being positive in individual crossings, B, and the number of boundary crossings used, n.

	night		day		
	272 kHz	245 kHz	2775 kHz	245 kHz	5kHz
P	86%	99.5%	98.5%	99.5%	99%
B	57%	64%	62%	64%	62%
n	41	69	56	70	61

tion in the lower ionosphere over Central Europe in winter. The behaviour of the absorption is similar to that of VAI - a narrow decrease of absorption (even if considerably smaller than that in VAI), i.e. quietening in the lower ionosphere, just after boundary crossing. Table 2 shows that the effect is statistically significant and important at both frequencies. The effect of such type is observed in the lower ionosphere in winter during day-time only.

Figure 5 shows the IMF sector boundary crossing effect at the 5 kHz and 27 kHz integrated level of atmospherics observed in Central Europe in winter. In view of differences in the patterns from different observatories, of the shape of curves and of the low statistical significance of the results, hardly any effect can be observed at 27 kHz. However, the 5 kHz atmospherics display

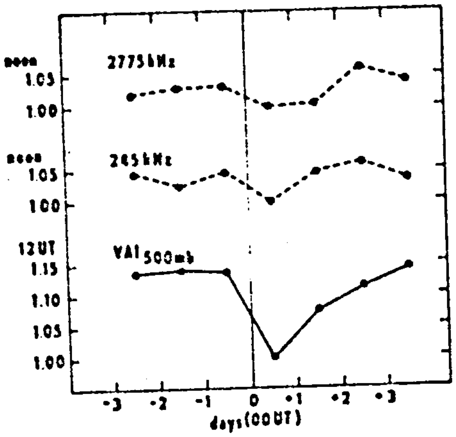

Figure 4. The tropospheric-type effect in $\mathrm{VAI}_{500\mathrm{mb}}$ and noon radio wave absorption in the lower ionosphere over Central Europe in winter (1966-73 - after LASTOVICKA, 1979).

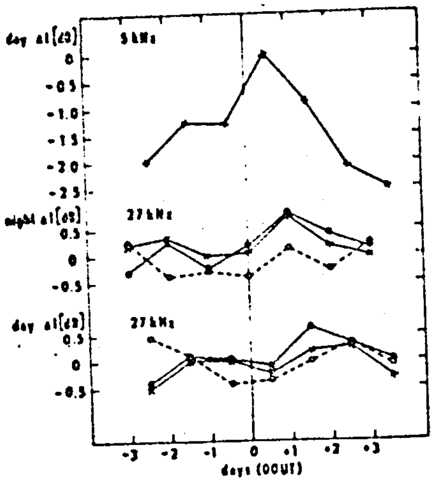

Figure 5. Sector boundary crossing effects in 5 kHz and 27 kHz atmospherics in winter (1966-73 - LASTOVICKA and SATORI, 1982). Full circles - Uppsala (59.8°N, 17.6°E); open circles - Kuhlungsborn (54.1°N, 11.8°E); crosses - Panska Ves (50.5°N, 14.6°E).

a sharp maximum just after crossing. The shape of the 5 kHz curve resembles an inverse form of the VAI curve from Fig. 4. Unfortunately, comparing the SID, geomagnetic storm and Forbush decrease effects in the 5 kHz atmospherics, it is difficult to say definitely, whether the observed effect is quietening or not.

As regards the stratosphere, the IMF sector structure effects were studied in the 10-mb level temperature and the 10-mb level height above Berlin-Tempelhof during day-time (LASTOVICKA, 1979). No significant effect was observed in either quantity in spite of the fact that statistically significant effects were observed in the lower ionosphere in the same geographic region.

General solar activity ($F_{10.7}$) increased quasimonotonicaly from the -3 to the +2 day by about 1.5%. Thus the solar XUV radiation did not affect the obtained results significantly.

The f_oF2 response to the IMF sector structure is quite similar to that of the lower ionosphere. We observe simultaneously the geomagnetic-type effect in the lower ionosphere and the F2 region, and the same is valid also for the tropospheric-type effect (LASTOVICKA, 1982, 1983; LASTOVICKA and SATORI, 1982; TRISKOVA, 1982). There is only very weak (if any) effect of the IMF sector structure in the E-region over Central Europe (LASTOVICKA, 1982; LASTOVICKA and SATORI, 1982). Thus the vertical pattern of the IMF sector structure effect in the F2 region, small effect (if any) in the E- region, a significant effect in the lower ionosphere, no effect rather than any in the stratosphere and significant effect in the troposphere (only of the tropospheric type).

The geomagnetic type effect is ionospheric response to the IMF sector structure related changes in geomagnetic activity. It consists of two components - IMF polarity changes and the boundary crossing itself. According to my opinion, the latter effect is caused by crossing-related changes of B or geoactive southward B_z.

The tropospheric type effect is quite a new phenomenon. It cannot be explained in terms of geomagnetic, cosmic ray or general solar activity. The effect seems to be caused by an action of the sector boundary (= warped current sheet) itself. The main problem with finding the mechanism is that the effect is quietening. The effect looks like switching off, not switching on, an energy source. However, this is not acceptable to solar, solar wind and magnetospheric physics.

There are two factors, which make studies of the IMF sector structure effects more difficult. The tropospheric (but not the geomagnetic) type effect practically disappears in some periods. LASTOVICKA (1981) showed that, in the period 1974-1977, the tropospheric-type effect practically disappeared not only in the troposphere (VAI), but simultaneously also in the lower ionosphere. However, the situation in the years 1974-77 (solar minimum) was quiet enough. Perhaps no other important quietening was possible.

The geoactivity of different sector boundaries varies. SVESTKA et al. (1976) found some sector boundaries (called proton boundaries) to be followed by streams of low-energy protons. WILCOX (1979) found the effect of such proton boundaries in VAI, as well as in geomagnetic activity, to be considerably stronger than that of non-proton boundaries. Figure 6 shows the effect of proton as well as non-proton boundaries on radio wave absorption in the lower ionosphere in winter. The effects of proton boundary crossing are considerably stronger and evidently more important than the effects of crossings of non-proton boundaries. However, as far as I know, information on proton boundaries is available only for the period 1963-1969.

In conclusion it can be said that the IMF sector structure effects in the

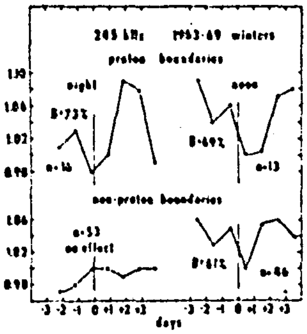

Figure 6. Sector boundary crossing effects in absorption at 245 kHz separated for night and noon, proton and non-proton sector boundaries. Winters 1963-1969. The data are expressed in ratio to the crossing-day values.

midlatitude ionosphere are minor in comparison with the effects of solar flares, geomagnetic storms etc., and are of two different types. The geomagnetic-type effect is a disturbance, representing an ionospheric response to changes in geomagnetic (= magnetospheric) activity, and its mechanism is at least qualitatively understood. The tropospheric-type effect is developed best in the tropospheric vorticity area index with possible relations to weather. It is a quietening, not a disturbance, in the troposphere as well as in the ionosphere. Its mechanism is not understood. The IMF sector structure effects are partly different for different seasons and they are considerably stronger for proton than for non-proton sector boundaries. I think the main task of this field of research is to discover the mechanism of the tropospheric-type effect and to determine the role of the IMF effects among various solar-terrestrial relations.

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