ANNALI DI GEOFISICA, VOL. XXXIX, N. 4, August 1996

The mean solar magnetic field as an indicator of the interplanetary magnetic field

Jürgen Bremer
Institute of Atmospheric Physics, Kühlungsborn, Germany

Abstract
The Mean Solar Magnetic Field (MSMF) measured daily by ground based observations at the Standford Observatory shows similar structures like the Interplanetary Magnetic Field (IMF) near the Earth about 5 to 7 days later. The ionospheric effect in the mid-latitude F_2-region due to such MSMF changes is most marked for strong MSMF changes from anti to pro sectors. The mean ionospheric response is very similar to the results obtained earlier with IMF sector structure data derived from Svalgaard (1976) and Wilcox (1982, private communication). Therefore, the MSMF data can successfully be used to predict the mean IMF sector structure and the mean ionospheric response 5 to 7 days in advance.

Key words *mean solar magnetic field – IMF – ionosphere*

1. Introduction

As known from earlier investigations (Bremer, 1992) the Interplanetary Magnetic Field (IMF) markedly modulates the ionospheric plasma of the *D*-, E_s-, and F_2-layers. Whereas during IMF pro sectors (sectors with negative B_z-components) the energy transfer from solar wind into the magnetosphere and ionosphere is enhanced, during anti sectors (positive B_z-components) this energy transfer is reduced. Especially during IMF sector boundary crossings a marked ionospheric effect can be detected, if the conception of pro and anti sectors is used.

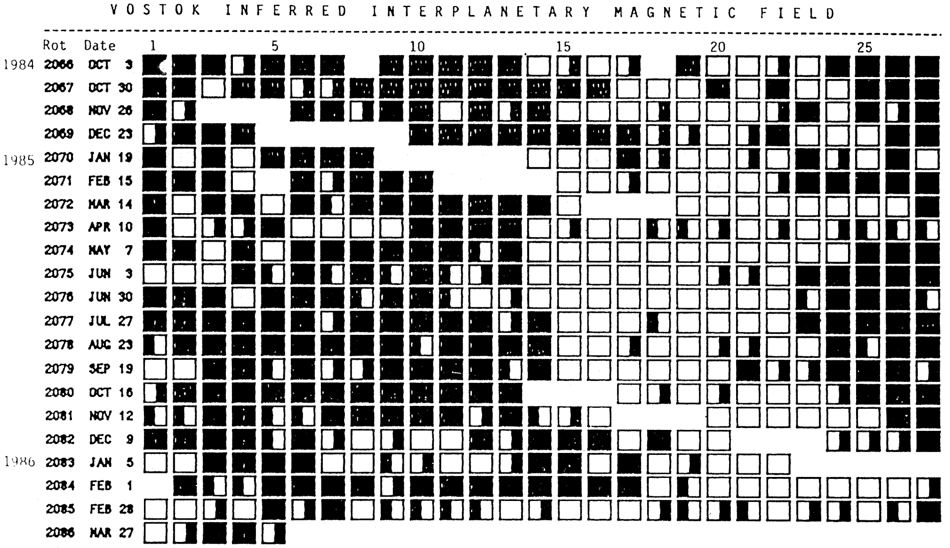
For a ionospheric short-term prediction it would be desirable to have information on the IMF with its sector crossing dates in advance. Therefore, in this paper tests will be made if the Mean Solar Magnetic Field (MSMF) which is the cause of the IMF can give some hints about the future IMF structure. At the Standford Observatory MSMF data are measured daily by a Babcock-type magnetograph attached to a 23 m vertical Littrow spectrograph and have been regularly published in the *Solar Geophysical Data* since May 16, 1975.

2. Results

Figure 1a,b presents Standford MSMF data as well as IMF data for some Bartels rotations in 1984-1986. Whereas the IMF data were derived from Earth's magnetic field measurements at the Russian Vostok Antarctic Station, the MSMF data are estimated at the Stanford Observatory. In both cases white areas mark magnetic fields directed away from the sun (positive values), whereas dark areas corre-

---

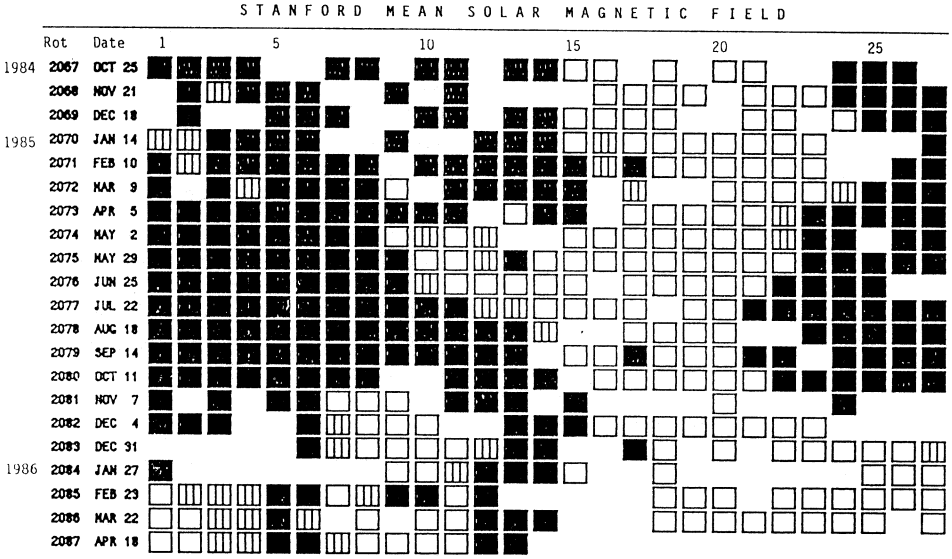
Mailing address: Dr. Jürgen Bremer, Institut für Atmosphärenphysik an der Universität Rostock, Schloßstraße 4-6, 18225 Ostseebad Kühlungsborn, Germany; e-mail: bremer@iap-kborn.d400.dc



Inferred Interplanetary Magnetic Field Polarity:

(a) No box = no data available ■ = definitely towards the Sun ☐ = definitely away from the Sun

The chart shows the daily inferences of the polarity of the interplanetary magnetic field based principally on the magnetograms produced by the magnetometer at the Vostok Antarctic Station of the USSR.



Mean Solar Magnetic Field Polarity: ☐ = field > 2 microT; ▥ = -2 microT ≤ field ≤ 2 microT

■ = field <-2 microT; No box = no data available

(b) Observations are taken at 2000 UT. Rotation numbers given are the Bartels series, but the dates are not; these dates mark times of occurrence of phenomena on the Sun that affect the Earth during the given Bartels Rotation.

Fig. 1a,b. IMF data (a) and MSMF data (b) for different Bartels rotations in 1984-1986 (reproduced from *Solar Geophysical Data*, promt reports, No. 501, part I, May 1986, 20-21).

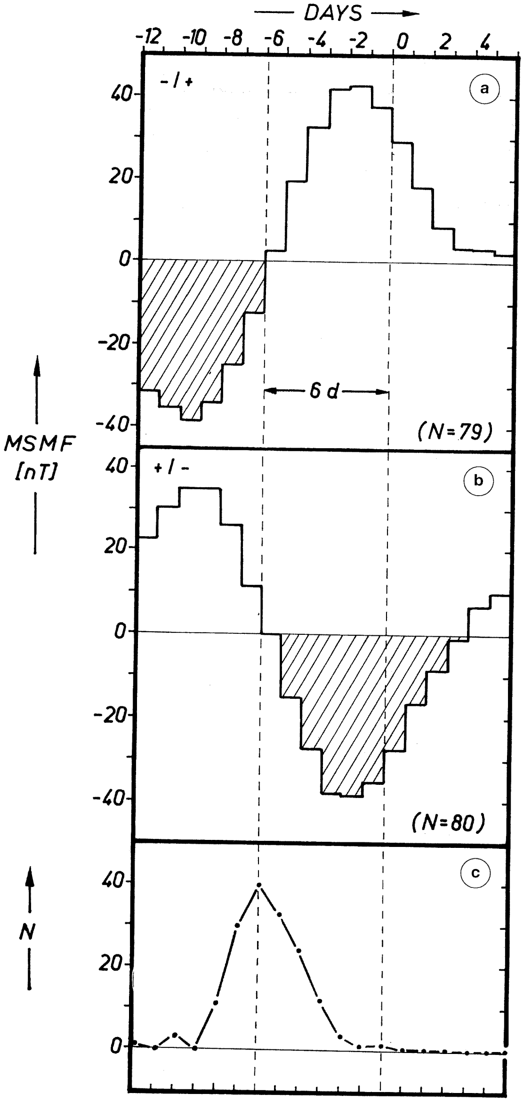


Fig. 2a-c. Mean MSMF-variations for –/+ (a) as well as +/– IMF sector boundary crossings (b) and occurrence probability distribution of MSMF sign changes between adjacent days (c) for 159 sector boundary crossings during the period May 1975 until December 1982.

spond to fields directed towards the sun (negative values). The dates for the MSMF data are 5 days earlier than the dates for the IMF values, taking into account that the phenomena on the sun start earlier. A first comparison of the main structure of IMF and MSMF show a quite similar behaviour suggesting that in general the IMF structure could be estimated some days in advance from MSMF data.

Beside graphic presentations as in fig. 1b the MSMF data are also available as numeric field strength values in nT. In fig. 2a-c these daily MSMF values have been used in a superimposed-epoch analysis. For the period between May 1975 and December 1982 the mean variation of MSMF is calculated for 159 IMF sector boundary crossings from the catalogues of Svalgaard (1976) and Wilcox (1982, private communication) separately for –/+ as well as +/– transitions (fig. 2a,b). The key day 0 is the first day of the new IMF sector. In fig. 2c the occurrence probability distribution of changes of the MSMF sign between adjacent days is presented showing in agreement with the upper two curves that this change of MSMF sign is about 6 days earlier than the IMF sector crossing. The curve in fig. 2c demonstrates moreover that for individual cases this difference may deviate from the most probable value by 6 days.

To demonstrate the connection between the ionospheric plasma of the F_2-region at mid-latitudes and the MSMF-data a correlation analysis is carried out with f_0F_2 values of Juliusruh (54.63°N, 13.38°E) and the MSMF data. Concerning f_0F_2, we used the mean daily deviations of f_0F_2 from 27-day-mean values according to:

$$\Delta f_0F_2 = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{f_0F_{2_i} - \overline{f_0F_{2_i}}}{\overline{f_0F_{2_i}}}\right)\cdot 100\% \qquad (2.1)$$

with hourly $f_0F_{2_i}$ values, the mean values $\overline{f_0F_{2_i}}$ centred around the actual day and N the number of observed hourly values ($N \leq 24$). Figure 3 presents the results of the correlations in dependence on time delay IV (days) between Δf_0F_2 and MSMF. The calculations were made for the spring and autumn half-year as well as high and low solar activity separately. In spring we got a positive correlation with maxima near day -7 ($R_{\min}$) or -5 ($R_{\max}$), whereas in autumn we got negative correlation maxima

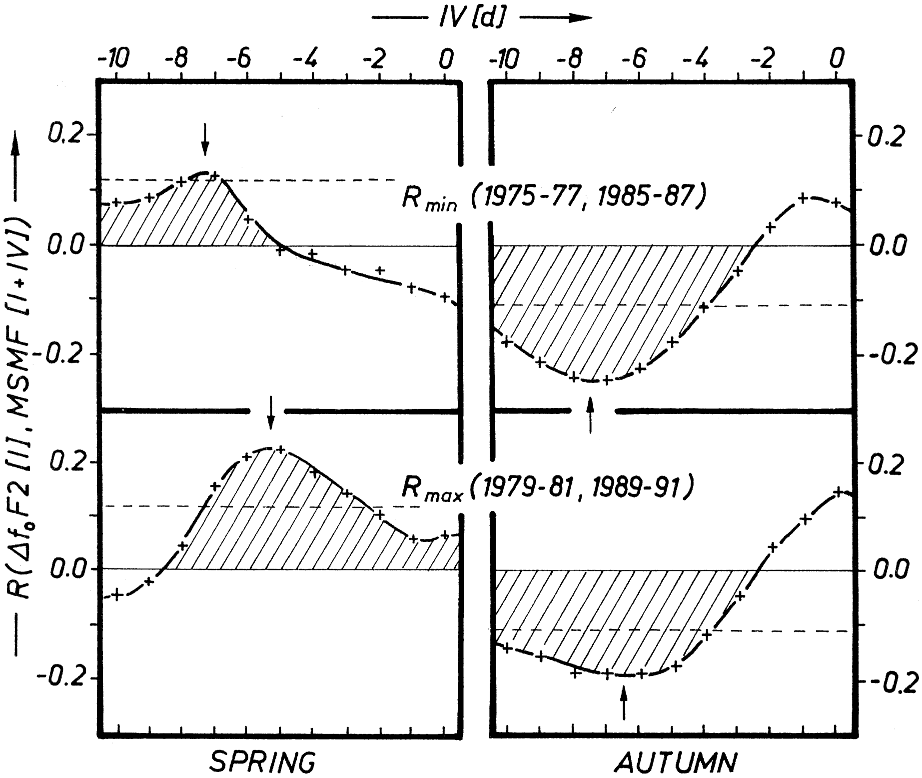


Fig. 3. Correlation coefficients R between Δf_0F_2 (Juliusruh) and MSMF in dependence on time delay IV (days) for high ($R_{\max}$) as well as low solar activity ($R_{\min}$) during spring and autumn half-year. The dashed lines mark a significance level of 99.9%.

near -7 ($R_{\min}$) or -6 ($R_{\max}$). The different signs of correlation near the maxima during spring and autumn are understandable if we remember that on the one hand pro sectors (negative B_z) have in spring negative MSMF-values, in autumn, however, positive values, and on the other hand pro sectors cause normally negative ionospheric effects in the mid-latitude F_2-region (Bremer, 1992). The correlation coefficients shown in fig. 3 are not very high, due to the large number of data used, however, the correlation maxima are significant with more than 99.9% as indicated by the dashed lines. As remarked above, the correlation maxima at low solar activity have larger time delays (-7d) than at high solar activity (-5d ... -6d).

A comparison of ionospheric effects due to sector boundary crossings using IMF data or MSMF data as key day is given in fig. 4a,b. In both investigations 136 sector crossings during the time period between June 1975 and December 1982 were divided into 63 transitions from anti to pro sectors and 73 transitions from pro to anti sectors. The key day zero is in both cases the first day of the new sector near Earth (IMF) or on the surface of the sun (MSMF). The general ionospheric variations are very similar in both investigations taking into account a time shift of about 7 days between IMF and MSMF. This time shift can best be derived for anti → pro sector transitions where the beginning of the negative ionospheric effect is well-defined. For pro → anti sector transitions the ionospheric variations are more gradual, perhaps the transition using IMF data is a little steeper.

The ionospheric effect caused by MSMF sector boundary crossings at different solar activity levels is shown in fig. 5a,b. Similar to the results of fig. 3 here again the ionospheric effect of the MSMF sector transition starts about 2 days earlier during high solar activity (day 5) than at lower activity (day 7). This effect can again more clearly be seen for the steep ionospheric variations during anti → pro sector transitions.

Figure 6a,b subdivides the MSMF transitions into three classes with different changes of the MSMF during the transition. ΔMSMF is here the maximum difference of daily MSMF values during the time interval between 5 days before until 5 days after the MSMF transition. As expected the ionospheric effect increases with increasing ΔMSMF. The effect is again more pronounced for anti → pro sector transitions. The effect in the opposite direction is in agreement with figs. 4a,b and 5a,b more gradual and only detectable for greater MSMF changes (ΔMSMF > 40 nT). The ionospheric effect starts earlier at high ΔMSMF-values most clearly to be seen for anti → pro transitions. This result, which agrees again with the findings of fig. 5a,b, could be expected because during solar maximum the ΔMSMF values are in general higher than during solar minimum.

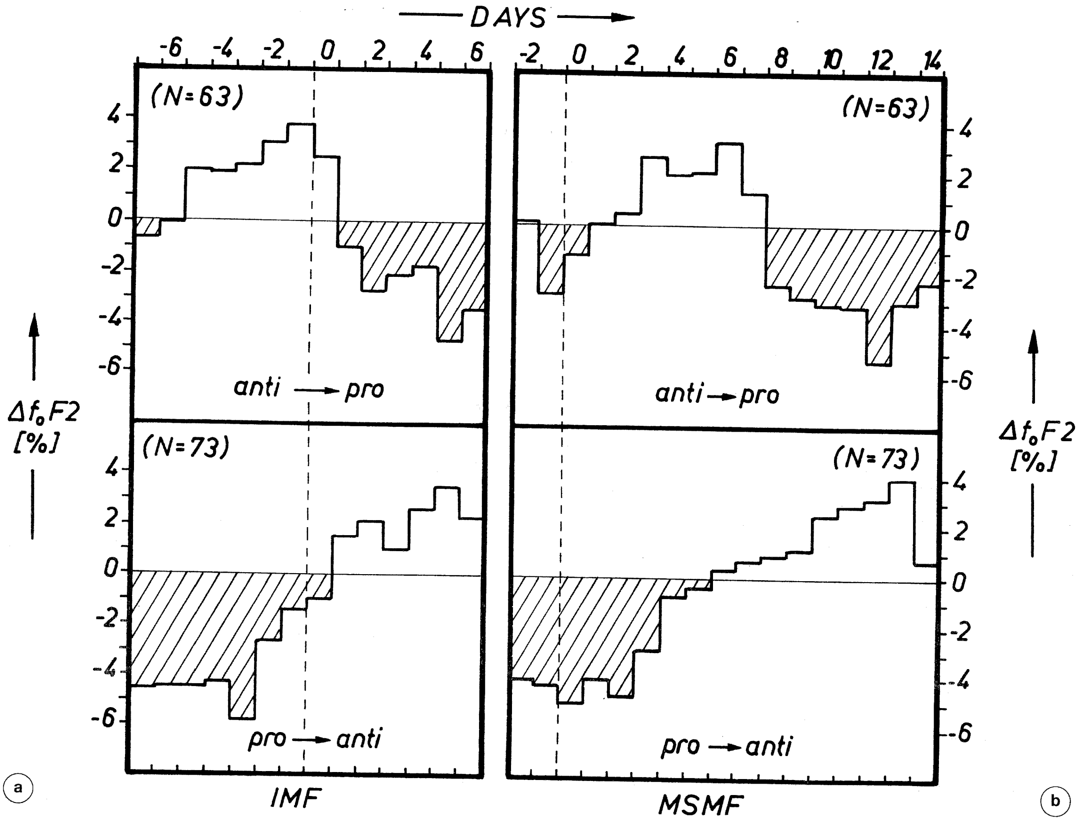


Fig. 4a,b. Mean variation of Δf_0F_2 (Juliusruh) during IMF (a) as well as MSMF sector boundary crossings (b) for anti → pro as well as pro → anti sector transitions.

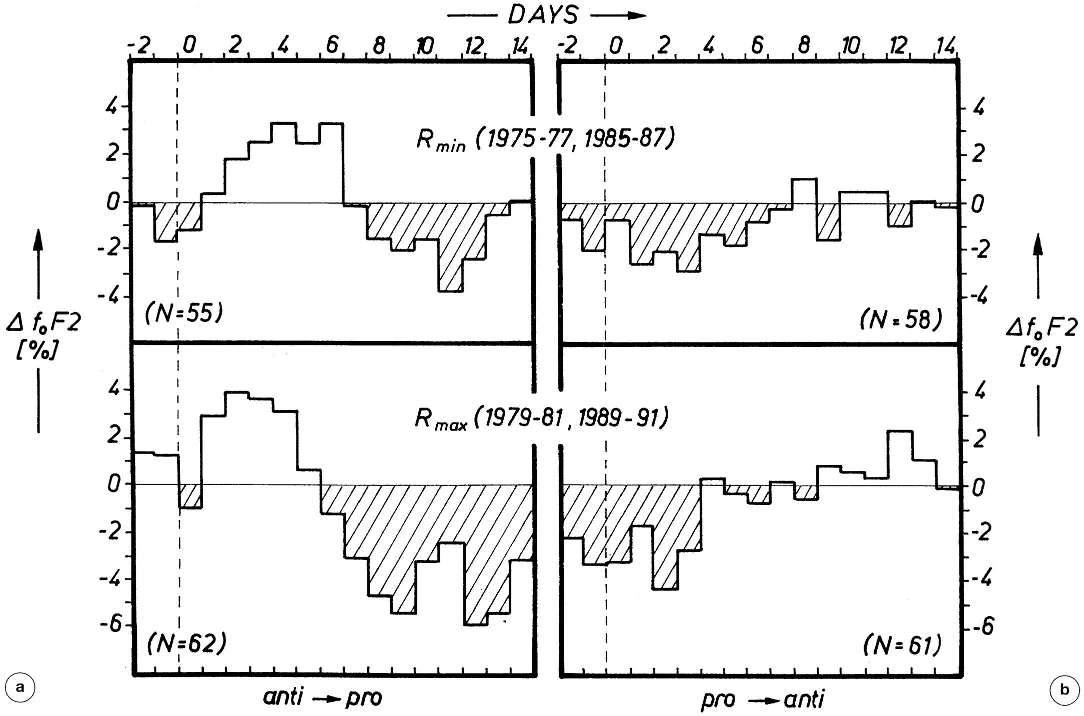


Fig. 5a,b. Mean variation of Δf_0F_2 (Juliusruh) during MSMF sector boundary crossings at low ($R_{\min}$) and high solar activity ($R_{\max}$) for anti → pro (a) as well as pro → anti sector transitions (b).

3. Discussion and conclusions

As shown in fig. 4a,b the mean ionospheric effect of MSMF sector boundary crossings is comparable with the effect corresponding to IMF sector crossings if we take into account that the MSMF variations at the surface of the sun start earlier by about 5-7 days. This time delay depends of course on the solar wind speed which is normally higher at years of high solar activity than near solar minimum. But also during times of nearly constant solar activity the solar wind velocity can change rapidly (*e.g.*, high speed solar plasma streams as defined by Lindblad and Lundstedt (1981)). Therefore, the time delay between MSMF and IMF structures may vary. The probability distribution of MSMF sector crossings dates (fig. 2c) is certainly caused by such velocity changes and could be the reason that the ionospheric effect due to MSMF sector transitions may be more gradual than using IMF data. The same effect is also observed in superposed-epoch analyses using geomagnetic A_p values instead of f_0F_2 values. Figure 7a,b shows the results for IMF as well as MSMF sector boundary crossings for anti to pro sector transitions. Whereas the geomagnetic activity increases very sharply with the beginning of the IMF pro sector at day 0, we observe a more gradual increase in A_p about 7 days after the change of the sign of the MSMF.

The general physical background of the IMF or MSMF influence on the ionospheric plasma as well as on the geomagnetic activity seems to be clear. During IMF pro sectors (sectors with negative B_z) energy from the solar wind is transferred into the magnetosphere and ionosphere and induces there a small geomagnetic disturbance (increase of A_p or other

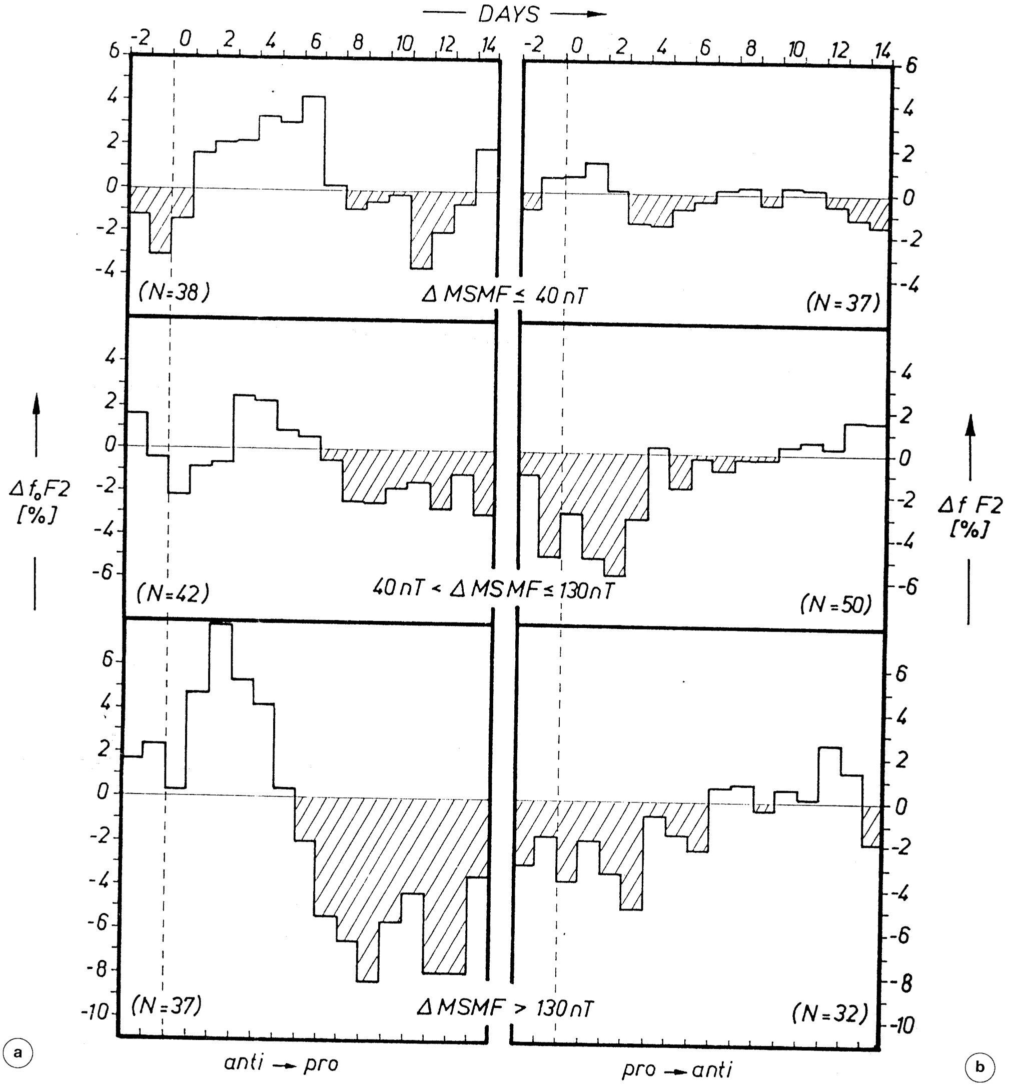


Fig. 6a,b. Mean variation of Δf_0F_2 (Juliusruh) during MSMF sector boundary crossings for 3 different levels of MSMF changes during sector crossing for anti → pro (a) as well as pro → anti sector transitions (b).

geomagnetic indices) as well as a small ionospheric storm (f_0F_2 decrease at high and middle latitudes, the effects on other ionospheric parameters are investigated in detail by Bremer, 1988, 1992).

After figs. 3, 5a,b and 6a,b the mean time delay between IMF and MSMF at solar maximum should be about 5 days and near solar minimum near 7 days.

The strength of the ionospheric effect is positively related to the strength of the MSMF change during sector crossing. The most marked mean ionospheric variations during strong MSMF effects are about 15% (fig. 6a

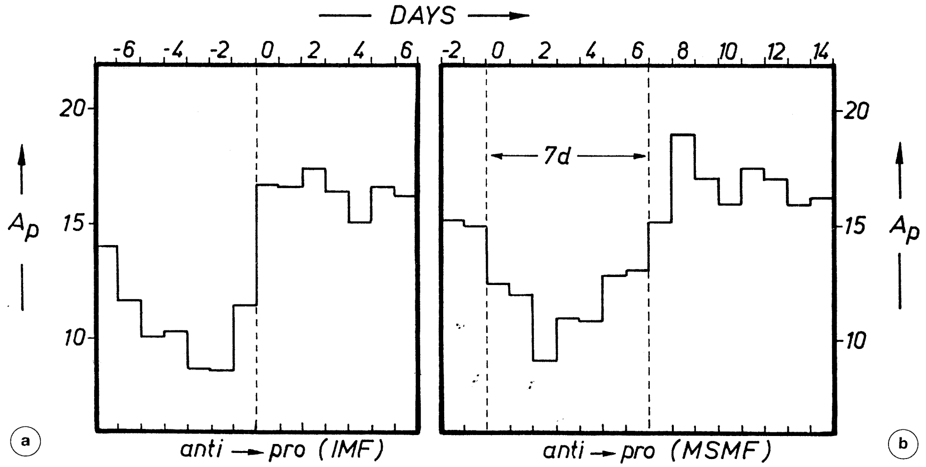


Fig. 7a,b. Mean variation of geomagnetic activity (A_p) during IMF (a) as well as MSMF sector boundary crossings (b) for anti → pro sector transitions.

bottom) for transition from anti to pro sector. In individual cases the effects may be even stronger.

In general, the transitions from anti to pro sectors are markedly more pronounced (figs. 4a,b, 5a,b and 6a,b) than in the opposite direction. This result is already known from investigations of IMF sector boundary crossings (Bremer, 1988, 1992).

As the results of the mean ionospheric response during MSMF sector crossings are comparable with similar results using data of the IMF polarity, the MSMF data can be used as raw indicators to predict the IMF influence on the ionospheric F_2-layer at mid-latitudes about 5 days in advance. But here only mean variations up to about 15% of the f_0F_2-values could be predicted. The prediction of big ionospheric storms cannot be done, however, using MSMF or IMF polarity data alone. Here *in situ* measured complex satellite data of the solar wind structure (B_z, v, T, n; collected *e.g.* by King (1977)) are necessary together with different prediction methods (*e.g.*, linear filtering prediction as introduced by Iyemore *et al.* (1979) or a neural network as used by Lundstedt and Wintoft (1994)). In spite of these very complex methods, the prediction time of storms is only very small (1 h for the model of Lundstedt and Wintoft, 1994) and limited to the initial and main phase of the geomagnetic part of the storm. A prediction of the ionospheric effects would require further calculations using complex ionospheric models.

REFERENCES

BREMER, J. (1988): The influence of the IMF sector structure on the ionospheric *F*-region, *J. Atmos. Terr. Phys.*, **50**, 831-838.

BREMER, J. (1992): Influence of the IMF on the ionospheric plasma of the *D*-, *E*- and *F*-layer, Publicationes del Observatorio del Ebro, Roquetes, Tarragona, *Memoria*, **16**, 403-409.

IYEMORE, T., H. MAEDA and T. KAMAI (1979): Impulse response of geomagnetic indices to interplanetary magnetic fields, *J. Geomagn. Geoelectr.*, **31**, 1-11.

KING, J. H. (1977): Interplanetary medium data book-Appendix, NSSDC/WDC-A-R & S 77-04a, Greenbelt, Maryland.

LINDBLAD, B.A. and H. LUNDSTEDT (1981): A catalogue of high speed plasma streams in the solar wind, *Solar Physics*, **74**, 187-207.

LUNDSTEDT, H. and P. WINTOFT (1994): Prediction of geomagnetic storms from solar wind data with the use of a neural network, *Ann. Geophysicae*, **12**, 19-24.

SOLAR GEOPHYSICAL DATA (1975-1991): NOAA, Boulder, Co. U.S.A.

SVALGAARD, L. (1976): Interplanetary sector structure 1947-1975, SUPR-Rep. 629, Stanford, Ca. U.S.A.