J Geophys (1983) 53: 68–71

Journal of Geophysics

foF2 Response to IMF Sector-Boundary Crossings

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Abstract. An analysis of night-time critical F2-layer frequencies in the equinoxial period of the 19th, 20th and 21st solar cycles has shown that the F2-layer response to sector-boundary crossings represents a response to the change of geomagnetic activity caused by the change of IMF polarity. For boundary crossings of the +/− type, the critical frequencies in both hemispheres in general decrease in March and April, and increase in September and October while the reverse holds for −/+ crossings.

Key words: Solar sector boundary – Interplanetary magnetic field – Ionosphere – Night foF2.

Introduction

Observations have shown that, in the Earth's orbital plane, the interplanetary magnetic field (IMF) is divided into sectors that co-rotate with the Sun. On the average, the nature of this structure is quasi-stationary and it consists alternately of regions with the magnetic field pointing away from (+) and towards the Sun (−), roughly along the Archimedean spiral. These sections, oriented almost opposite to one another, are separated by relatively sharp boundaries. According to results of satellite experiments, these boundaries can be thought of as intersections of the ecliptic plane with a warped global current sheet that surrounds the sun near its equatorial plane (Smith et al., 1978; Behannon et al., 1981).

In recent years, considerable attention has been paid to the effect of the sector-boundary crossing on various geophysical phenomena. The influence of the IMF polarity on geomagnetic activity has been proved in several papers, e.g. Berthelier (1976), the variation of Kp at sector boundaries has been dealt with by Schreiber (1977), the effect of the sector-boundary passage on geomagnetic activity has been studied in detail by Arora and Rangarajan (1981).

The influence of IMF polarity changes on the state of the lower ionosphere can be considered proved, e.g. by Schlegel et al. (1977), Laštovička (1979) Oksman and Ranta (1980), whereas the relation between the sector-boundary crossing and the condition of the F2-layer has not been fully clarified yet. F2-layer phenomena associated with the boundary passage were dealt with by D'Angelo (1980) and Lyon and Bhatanagar (1979), where a decrease of the nighttime foF2 after the boundary crossing is indicated for both types of passage. The influence of the IMF polarity on the nighttime critical F2-layer frequency in the equinoxial period has been demonstrated by Třísková (1982). From that paper it follows that the effect of the sectorial structure of the IMF appears in the F2-region as a response to changes in geomagnetic activity caused by the changes of the IMF polarity. Thus the foF2 response should differ with the type of boundary crossing.

In this paper, foF2 changes during sector-boundary passages are analyzed, taking the type of the boundary and the season of the year into account. The analysis has been made for the equinoxial period at solar cycle maximum when the IMF influence on geomagnetic activity (and hence also on foF2) should be most pronounced.

Experimental Data, Method of Analysis

The average of six hourly values of the critical F2-layer frequency between 00 and 05 h local time was chosen as the characteristic value f_r representing the state of the nighttime F-region on individual days. Vertical sounding data from middle latitudes in the Northern and Southern Hemispheres have been analyzed; the list of ionospheric stations and the time periods for which the data were used is given in Table 1.

Equinoxial periods for three years of the maxima of the 19th, 20th and 21st solar cycle have been examined; the data given by Svalgaard (1975) were taken as the days of boundary crossings for 1957–1959 and 1968–1970, whereas the days of boundary passages for 1979–1981 come from the Solar Geophysical Data (1979, 1981). For northern latitudes, where more data are available, a parallel analysis has been made for data from two stations; the aim was to verify whether the nature of the foF2-variation for boundary crossings of a given type remains the same and whether disturbances or local conditions can be excluded as the possible cause. For three days before and after the sector boundary crossing the average value $\bar{f}_r$ was calculated separately for both boundary types and both equinoxial periods, irrespective of the degree of geomagnetic activity.

Table 2 shows the numbers and types of analyzed crossings. The resultant numbers of events in the individual groups are low; the cause, on the one hand, is that usually not more than two crossings of a given type occurred in a month, and on the other, that not all observed crossings could be analyzed because of the lack of processed data. The f_r-value was not determined if less than four of the six foF2-values on a given day were available and, similarly,

Table 1

Station	Geographic		Invariant latitude	L	Data available
	Latitude	Longitude			
Juliusruh	54.62° N	13.38° E	51.67°	2.60	Sept. 1957–April 1981
Lindau	51.65° N	10.13° E	48.86°	2.31	April 1957–April 1979
Průhonice	49.99° N	14.55° E	46.75°	2.13	Sept. 1958–April 1981
Hobart	42.92° S	147.17° E	−53.60°	2.84	March 1957–March 1959 March 1969–Oct. 1980
Canberra	35.32° S	149.00° E	−44.86°	1.99	March 27, Oct. 11, 1970

Table 2

Station	Season	Boundary	Number of analyzed crossings			
			1957 to 59	1968 to 70	1979 to 81	in sum
Lindau, Průhonice	March,	+/−	7	7	4	18
	April	−/+	5	6	4	15
	Sept.,	+/−	5	7	6	18
	Oct.	−/+	5	7	5	17
Juliusruh	March,	+/−	5	7	4	16
	April	−/+	5	6	4	15
	Sept.,	+/−	7	6	6	19
	Oct.	−/+	5	7	5	17
Hobart	March,	+/−	5	7	3	15
	April	−/+	5	6	2	13
	Sept.,	+/−	5	7	6	19
	Oct.	−/+	4	7	5	16

a boundary crossing for which the data from less than four of seven subsequent days were available, was omitted. In the Lindau data set, data from the ionospheric station Průhonice were used, beginning with September 1979.

Results and Discussion

The main results are given in Figures 1 and 2 showing the average variation of the characteristic frequency f_r and, therefore, also the variation of the maximum electron density in the F-region in the course of sector-boundary crossings. Figure 1 gives the results obtained for the maxima of the individual solar cycles, whereas Figure 2 shows the average variation of f_r for the whole period under investigation. Average values of characteristic frequencies are normalized here by the value $\bar{f}_r$ (0) for the day of the sector-boundary crossing. It follows from the analysis that the characteristic frequencies decrease in March and April during boundary crossings of the +/− type as well as in September and October for the −/+ crossings, while they increase for crossings of opposite types. The same variation occurred both in northern and southern mid-latitudes; thus it can be concluded that the influence of the sector-boundary crossings on the F2-region is of a global nature.

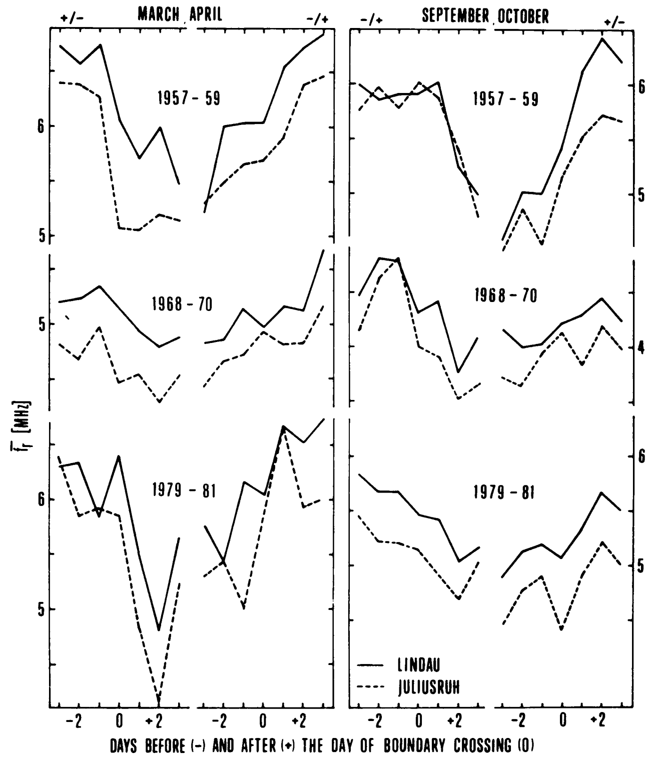

Fig. 1. Average variation of the characteristic frequency at solar cycle maxima in dependence on the season and on the type of the sector boundary crossing

One should take into account that f_r-variations are affected by several kinds of error. Firstly, they are distorted by a low number of events in individual groups as well as by the non-equal numbers of f_r-values for corresponding days before and after the boundary crossing; secondly, the uncertainty in determining the day of the boundary passage plays a role. The date given by Svalgaard (1975) refers to 00 h UT, assuming that the boundary was crossed very probably within ±12 h of this instant. Under the assumption that boundary crossings within this interval are distributed uniformly and that nighttime foF2-values can be influenced only by boundary passages occurring before 03 h local time, then for the Lindau, Průhonice and Juliusruh data the crossing day as given by Svalgaard (1975) can coincide with the day on which its influence is reflected in the nighttime foF2-values in more than half the events. As regards the Hobart data, on the contrary, the influence of the boundary crossing can be expected on the next day in most events. Therefore, normalized variations of $\bar{f}_r$ are

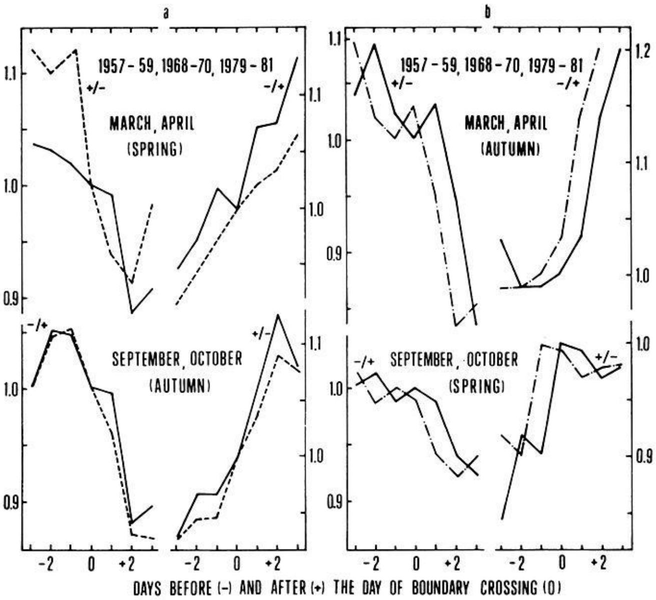

Fig. 2a and b. Average variation of the characteristic frequency in equinoxial periods in dependence on the type of the sector boundary crossing. Calculated for the maxima of the 19th, 20th and 21st solar cycle, normalized by the average characteristic frequency value on the day of the boundary crossing. (**a**) —— Lindau, ----- Juliusruh (**b**) —— Hobart, the crossing day is identical with the date of the zero day in (**a**); —·—·— Hobart, the influence of the boundary crossing delayed by one day with respect to the zero day in (**a**)

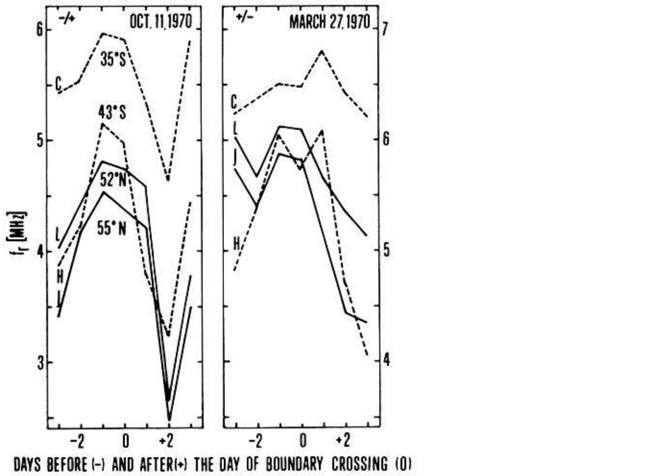

Fig. 3. Variations of the characteristic frequency for sector-boundary crossings at stations C = Canberra, H = Hobart, L = Lindau, J = Juliusruh

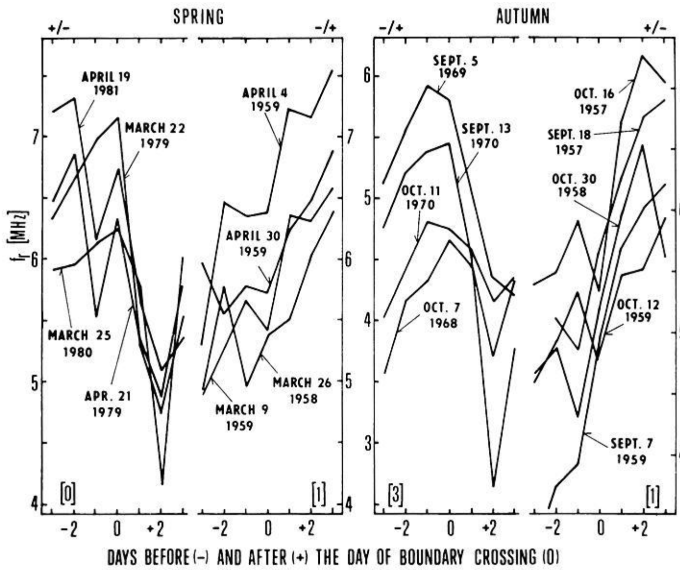

Fig. 4. Variation of characteristic frequencies for boundary crossings of individual types at ionosphere stations Lindau and Průhonice. The dates of boundary-crossing days mark the curves. The numbers in square brackets give the number of crossings in the given group where the f_r-variation showed a different behaviour (not included in the plot)

plotted in Figure 2b for both alternatives. Beside that, the original systematic foF2 variation connected with the boundary crossing can sometimes be added to by large fluctuations associated with sporadic but strong geomagnetic disturbances.

In view of the circumstances described, the credibility of the results given in Figure 1 and 2 has been investigated in two ways. The first was to observe the influence of the same boundary crossing at four stations, two of them in northern and two in southern latitudes. The second dealt with the nature of f_r-variations at one station, always for all events of a given data set.

The F2-layer response at the two pairs of stations was very similar in most cases as demonstrated by f_r-variations in Figure 3; the f_r-variation at one station also shows a very similar pattern in most crossings of the same type, as shown in Figure 4. Despite the occurrence of single variations not behaving according to the laws shown, it can be suggested that conclusions made on the basis of the results contained in Figures 1 and 2 may be considered as valid.

Considering that the critical F2-layer frequencies decrease with increasing magnetic activity, the f_r-variation should correspond to an opposite variation of the A_p-indices. Comparison can be made with results given by Arora and Rangarajan (1981) where an analysis of A_p-variation during sector-boundary crossings is made. As can be seen in Figure 2 of that paper, the A_p-variation at solar activity maximum really shows an increasing tendency for vernal +/− and autumnal −/+ crossings (with respect to the Northern Hemisphere) while a decreasing tendency appears for the remaining two types of crossings. Thus the A_p-variation after Arora and Rangarajan and the f_r-variation shown herein confirm that changes of geomagnetic activity caused by the polarity of the departing and incoming sector are decisive for the behaviour of the F2-region during sector-boundary crossings.

The enhancement of geomagnetic activity in the (−) sector in Northern Hemisphere spring and in the (+) sector in autumn can be explained by a stronger interaction between the magnetosphere and the solar wind, when a southward pointing component of the IMF exists. The IMF is supposed to be ordered in the GSEQ (geocentric solar equatorial) coordinate system with the B_z component symmetrically distributed around a zero mean value, while its interaction with the magnetosphere is thought to be ordered in the GSM (geocentric solar magnetospheric) coordinate system. In GSM coordinates, southward fields of the IMF are more probable when the Earth is in a negative sector in spring and in a positive sector in autumn (e.g. Russel and McPherron, 1973; Berthelier, 1976; Paulikas and Blake, 1976).

The foF2 depression, representing a marked decrease of the F2-layer maximum electron density, on days of enhanced geomagnetic activity is thought to be a consequence of the negative phase of magnetic storms. This negative phase, which occurs at mid-latitudes in summer and at equinoxes, can be caused by composition changes due to the storm circulation (introduction of air with an enhanced molecular gas concentration into the F-region). A detailed study of F-region storm effects and mechanisms has been given e.g. by Rishbeth (1975).

As can be found from Figures 2, 3 and 4, the crossings with a decrease of characteristic frequencies show a pronounced f_r-decrease (and thus foF2 decrease) on the second day after the boundary passage. Attention to the foF2-decrease on two days after the boundary crossing is drawn, for example, by D'Angelo (1980) as to a phenomenon valid for both types of passages in the time interval April to December 1974. This conclusion can be affected by the fact that, in this period, the foF2-decrease for vernal $+/-$ and autumnal $-/+$ crossings was stronger than the frequency increase for other events, so that the former prevailed on the average. This is also indicated by Arora and Rangarajan (1981). For the data set centred around 1974, a different change of magnetic activity appears in the equinoxial period dependending on the season and on the crossing type, but for the annual average these differences are overlapped by a stronger change in the case of an increase in magnetic activity which corresponds to the prevailing change for the foF2-decrease.

Conclusion

From the analysis presented here, it follows that the F-layer response to sector-boundary crossings represents a response to the change of geomagnetic activity caused by these crossings. The response is practically the same in both hemispheres; after boundary crossings of the $+/-$ type, the critical frequencies decrease in March and April, and increase in September and October while the opposite variation appears for $-/+$ crossings. Thus, considering the various physical mechanisms and couplings referring to sector-boundary passages, not only the type of the passage but also the season of occurrence have to be taken into account.

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Received May 14, 1982. Revised version December 15, 1982.
Accepted December 15, 1982