ESTIMATION OF CORONAL MAGNETIC FIELDS USING TYPE-I EMISSION

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ОЦЕНКИ КОРОНАЛЬНЫХ МАГНИТНЫХ ПОЛЕЙ С ПОМОЩЬЮ ВСПЛЕСКОВ I. ТИПА

Радиальная зависимость магнитного поля в короне над солнечными активными областями вычислена с помощью цепочек всплесков I-го типа на основании данных опубликованных в литературе. Предполагается, что цепочки всплесков I-го типа вызваны ударной волной в короне. Скорость ударной волны определена по смещению частоты цепочек I-го типа а изменение плотности по ширине полосы I-го типа. Используя скорость ударной волны и изменение плотности в соотношении Rankine-Hugoniot получена альвеновская скорость и следовательно магнитное поле в короне. Результаты сравниваются с существующими вычислениями.

The radial dependence of the coronal magnetic field above active regions is calculated using Type-I chain data existing in the literature. Assuming that Type-I emission is due to shock waves, the upstream shock velocity and the density jump across the shock are obtained respectively from the drift rate and the bandwidth of the Type-I chains. Making use of the shock velocity and the density jump in the Rankine-Hugoniot relation, the Alfven velocity and hence the magnetic field in the corona is calculated. The results are compared with existing estimates.

Key words: Sun: magnetic fields — bursts: type I.

1. Introduction

The coronal magnetic fields can be estimated only indirectly from the various types of radio emissions emanating from different heights in the solar atmosphere. Because of solar activity it is difficult to define an average magnetic field in the solar corona. Like density and temperature, magnetic field also is enhanced in the active regions. These parameters, moreover, vary from one active region to another. The magnetic field also depends on the evolution of the active region in time. The estimation of magnetic field using a particular radiation applies only to that situation which gives rise to the radiation in question. For example, if one estimates magnetic field using noise storm measurements, then the field corresponds to a slowly varying active sun. If the magnetic field is derived using other radio bursts, like Type-II etc., then it corresponds to a fast changing active sun because of their close association with flares.

Using the properties of various radio emissions, Newkirk (1967, 1971) estimated the magnetic field strength, Dulk and McLean (1978) re-evaluated the sources of data and improved the estimates by eliminating those data which involved an interpretation in terms of out moded, incorrect or inapplicable plasma concepts. The radio emission based estimates included in the analysis of Dulk and McLean (1978) correspond only to fast changing active regions because all these radio bursts are flare associated. The Type-I bursts, which correspond to a slowly changing active region, are not used for magnetic field estimates mainly because the theories of these bursts were uncertain at that time.

Apart from slowly varying component, (Kakinuma and Swarup, 1962), the Type-I storms are probably the only phenomena that could be used to estimate the magnetic field in the active regions in the absence of flares. The understanding of the Type-I phenomenon has improved very much after the emerging flux theory of Spicer et al., (1981). A working model based on this theory has been proposed by Wentzel (1982). It is therefore worthwhile attempting the magnetic field estimation using Type-I storms. This provides an opportunity to compare the estimates with those of Dulk and McLean (1978) who excluded estimates from Type-I phenomena. Wild and Tlamicha (1964) made use of the spectral characteristics of Type-I chains to estimate the coronal magnetic field. This was included in the compilation of Newkirk (1967, 1971). It was mentioned by Wild and Tlamicha that shock waves could generate the Type-I bursts. They

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assumed that the velocity of the exciting disturbance to be the same as Alfven velocity and estimated the radial field. Actually the shock wave has super-Alfvenic velocity and therefore their estimate may correspond to the upper limit of the magnetic fields. Takakura (1966) attempted to use the polarization properties of the Type-I bursts to calculate the radial field which sets a lower limit. The result was nearly 10×10^{-4} Tesla at 50 MHz which is a very high value. This is basically because the theory used by him has severe draw backs (Melrose, 1980). In this paper, we derive the coronal magnetic fields at various heights based on the Type-I chain observations assuming that the emission is at local plasma frequency. The velocity of the shock, calculated from the drift rate of the chains, and the density jump across the shock, obtained from the observed bandwidth, are used as the input in the Rankine-Hugoniot relations and the magnetic field is calculated.

2. Method of Calculating the Magnetic Fields

Zaitsev and Fomichev (1973) suggested that the Type-I bursts could be caused by perpendicular shocks, without identifying the driving agency. They also assumed shocks of strengths similar to Type-II shocks which are flare associated. But Type-I bursts are not flare associated and hence the shocks may not be so strong. The shocks causing Type-I bursts, therefore correspond to evolving active regions in a quasi-stationary corona where the magnetic field and density are not conductive for flares. Zaitsev and Fomichev (1973) assumed that the plasma frequency (ω_{pe}) is much smaller than the gyrofrequency (ω_{He}) which is not a realistic approximation. The gyrofrequency can exceed the plasma frequency probably only at frequencies much higher than 300 MHz which is in the cut off range for Type-I bursts (Melrose, 1982). Wentzel (1981) proposed that the interaction of upper hybrid (UH) waves generated by the loss cone distribution of electrons trapped in the closed magnetic fields with the lower hybrid (LH) waves generated by a shock wave gives rise to Type-I emission, Spicer et al., (1981) identified the newly emerging flux as the agency which drives the shocks perpendicular to the magnetic field. They also estimate the turbulence level of the (LH) waves excited by the shocks. The LH turbulence stochastically accelerates the electrons, which in turn generate UH waves, once they develop a loss cone. The interaction between UH and LH waves gives rise to the radiation.

One of the interesting features of the Type-I bursts is their narrow bandwidth, which implies that the density jump across the shock must be only of the order of a few percent of the ambient density (Spicer et al., 1981). Since $\omega_{\mathrm{He}} \ll \omega_{\mathrm{pe}}$ the emission is assumed to be at the local plasma frequency, the bandwidth and relative density jump could be related as follows:

$$\omega_{\mathrm{pe}} = 4\pi n_e^2/m \tag{1}$$

$$|\Delta\omega_{\mathrm{pe}}/\omega_{\mathrm{pe}}| = \tfrac{1}{2}\,\Delta \mathrm{n}/\mathrm{n} \tag{2}$$

where n_e and m are the ambient density, charge and mass of electrons and Δn is the density jump. As the bandwidth of the Type-I chains is very small, the shock travels only a small distance in the corona compared to the coronal scale height. Suppose the emission starts at a frequency f_1, corresponding to a plasma layer of density n_1, and the emission stops at the frequency f_2 corresponding to a layer with density n_2. Because of the closeness of the layers, the difference $(n_1 - n_2)$ will be very small compared to the average density. When the shock reaches the n_2 layer, the n_1, layer will be within the shock wake as the shocked region takes a long time to relax to the equilibrium situation (Lampe and Papadopoulos, 1977; Lacombe and Møller-Pedersen, 1971) compared to the time taken for the shock to travel from the n_1 layer to the n_2 layer. Hence one can assume that the density remains almost same from immediately behind the shock to the starting layer. Therefore one can equate the density jump Δn across the shock to the difference $(n_1 - n_2)$ and hence relate it to the bandwidth $\Delta f = f_1 - f_2$. (Wentzel, 1981; Spicer et al., 1981; Wentzel, 1982).

The chains of Type-I bursts (Wild & Tlamicha, 1964, Hanasz, 1966, De Groot et al., 1975) have very small drift rates. Assuming a particular density model above the active regions, the observed drift rate can be converted into radial velocity v_1 of the agency (the shock) causing the bursts as follows:

$$v_1 = f/|\nabla f_{\mathrm{pe}}| \tag{3}$$

where $f_{\mathrm{pe}} = \omega_{\mathrm{pe}}/2\pi, f$ is the frequency drift and ∇f_{pe} is the gradient of the plasma frequency of the corona. Since $f_{\mathrm{pe}}^2 = n(r)\, e^2/\pi_m$ the radial velocity depends upon the assumed density model. If we assume strictly perpendicular shock, then v_1 corresponds to the upstream velocity. The density jump and the upstream shock velocity are related to the Alfven velocity and ion-sound velocity through the Rankine-Hugoniot (RH) relation (Tidman and Krall, 1971) as follows:

$$\begin{aligned} \Delta n/n = 1 - \tfrac{1}{8}\{5c_5^2/v_1^2 + 1 + \tfrac{5}{2}v_a^2/v_1^2 + \\ + [(5c_5^2/v_1^2 + 1 + \tfrac{5}{2}v_a^2/v_1^2)^2 + 8v_a^2/v_1^2]^{1/2}\} \end{aligned} \tag{4}$$

where $v_a = B/\sqrt{(4\pi n m_i)}$ is the Alfven velocity, m_i

is the ion mass, c_5 is the ion sound velocity and B is the ambient magnetic field. If the coronal temperature is assumed to be constant ($T_e \sim 10^6$K) then c_s is a constant. Knowing $\Delta n/n$ and v_1 from observations, v_a and hence the magnetic field can be estimated.

We used Type-I chain data, covering the range from 250 to 46 MHz (collected from various references) which approximately lies between one and two solar radii. This is the region in which the noise storm activity is maximum. The shock velocity and the density jump are used in the RH relation (4) to get:

$$(5)\quad v_a^2/v_1^2 = \frac{8(1 - \Delta n/n)^2 - 2(1 - \Delta n/n)(1 + 5c_s^2/v_1^2)}{1 + 5(1 - \Delta n/n)}$$

Those data which give negative values for the right hand side of the relation (5) have been excluded. In other words c_s, v_1 and $\Delta n/n$ must satisfy the folowing inequality:

$$(6)\qquad 5c_s^2/v_1^2 < 3 - 4\,\Delta n/n$$

The Type-I bursts occur at the top of the closed magnetic fields according to the emerging flux theory as well as other observations (Krüger, 1977). Therefore the plasma beta must be less than unity or, in other words, the Alfven velocity has to exceed the ion-sound velocity. Therefore, (6) becomes,

$$(7)\qquad \left[\frac{5}{(3 - 4\Delta n/n)}\right] c_s^2 < v_a^2 < v_1^2$$

where we have also included the requirement that the shock velocity v_1 must exceed the Alfven velocity for the shock to exist (Tidman and Krall, 1971). We have used the density model,

$$(8)\qquad n(\varrho) = 4{\cdot}2x \times 10^{4+4{,}32/\varrho}$$

where $\varrho = R/R_{\odot}$ is the radial distance in units of solar radius $R_{\odot}$, $x = 2$ for Newkirk streamer model and $x = 4$ for 2 times Newkirk's streamer model. The quantities ϱ and n are related by

$$(9)\qquad \varrho = \frac{4{\cdot}975}{\ln(f_6/2{\cdot}583)}, \quad x = 2$$

and

$$(10)\qquad \varrho = \frac{4{\cdot}975}{\ln(f_6/3{\cdot}65)}, \quad x = 4$$

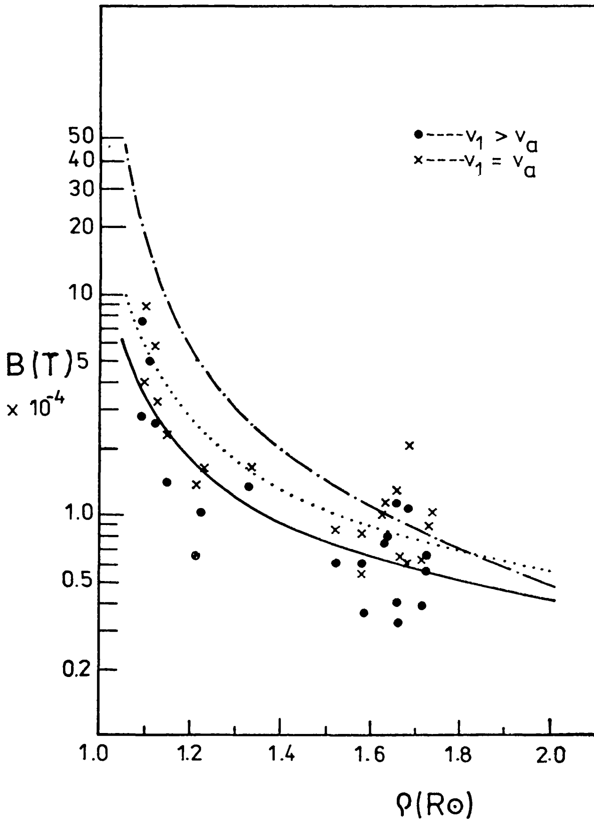

Fig. 1a. (for $x = 2$): The magnetic field B, versus radial distance, ϱ (in units of solar radius $R_{\odot}$). The least square fits for the $v_1 > v_a$ and $v_1 = v_a$ cases, are represented by ——— and ...... respectively. The empirical fit of Dulk and McLean (1978) is represented by .—.—.—.

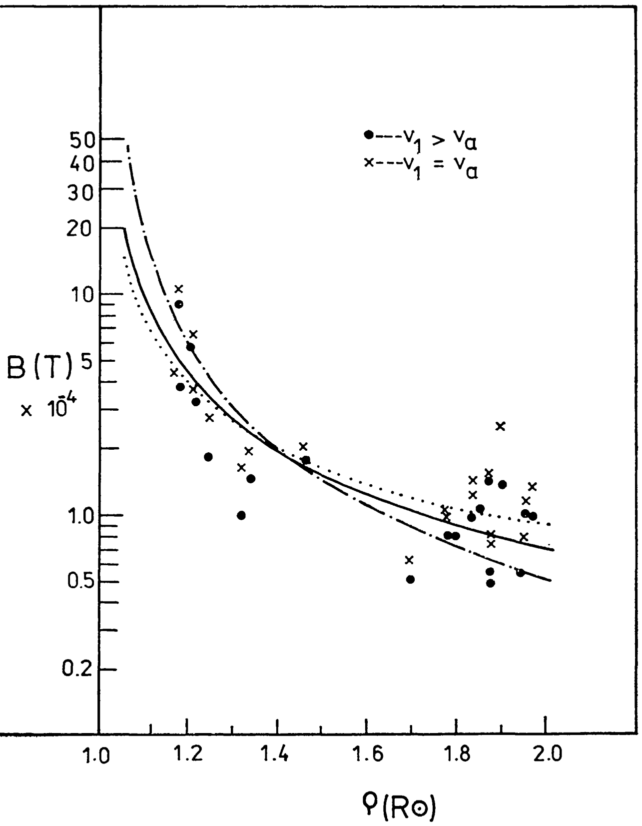

Fig. 1b. (for $x = 4$): The magnetic field B, versus radial distance, ϱ (in units of solar radius $R_{\odot}$). The least square fits for the $v_1 > v_a$ and $v_1 = v_a$ cases, are represented by ——— and ...... respectively. The empirical fit of Dulk and McLean (1978) is represented by .—.—.—.

where $f_6 = f_p/10^6$ is the frequency in MHz. The corresponding shock velocities are,

$$v_1 = -\frac{3{\cdot}463 \times 10^6}{[\ln(f_6/2{\cdot}583)]^2}\frac{1}{f_6}\frac{\partial f_6}{\partial t}, \quad \text{km s}^{-1}, \quad x = 2 \tag{11}$$

and

$$v_1 = -\frac{3{\cdot}463 \times 10^6}{[\ln(f_6/3{\cdot}65)]^2}\frac{1}{f_6}\frac{\partial f_6}{\partial t}, \quad \text{km s}^{-1}, \quad x = 4 \tag{12}$$

Actually, the factor x can vary from 2 to 5 or even more for specific active regions. We have taken these two models to show that the magnetic field estimate is model dependent.

3. Results

The derived values of coronal magnetic field strengths are plotted in Figs (1) and (2) for $x = 2$ and $x = 4$ respectively. Also plotted are the values obtained by assuming that the shock velocity is the same as the Alfven velocity. For the sake of comparison, we have shown the curve obtained by Dulk and McLean (1978), viz.

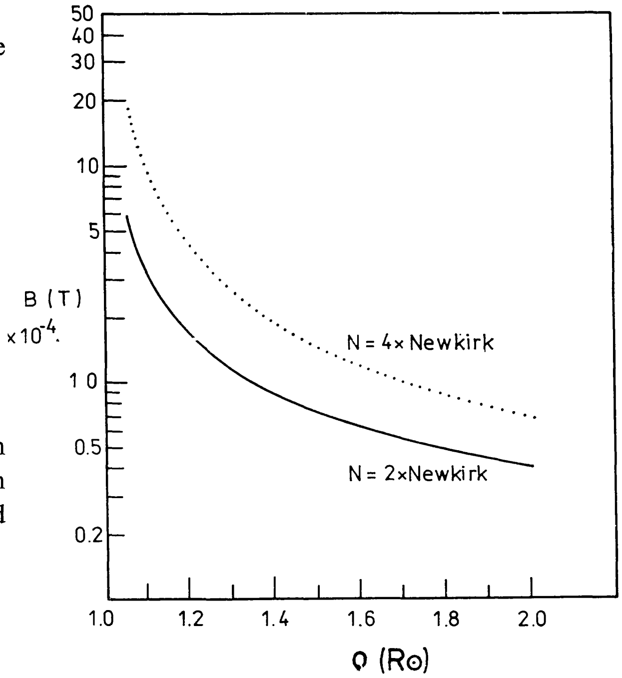

Fig. 2. The magnetic field versus radial distance, ϱ (in units of $R_\odot$) for the case $v_1 > v_a$. (Newkirk = $4{\cdot}2 \times 10^4 + 4{\cdot}32/\varrho$).

$$B = 0{\cdot}5(\varrho - 1)^{-1{\cdot}5} \tag{13}$$

This curve is obtained using the results of many techniques for coronal field estimation. The magnetic field values obtained from the Type-I chain data are given in Tab. 1. The values can be fitted by straight

Table I

The estimated magnetic fields for various cases

S. No.	Frequency (MHz)	$\varrho(R_\odot)$	$x = 2$ $B(T) \times 10^{-4}$ $v_1 > v_a$	$B(T) \times 10^{-4}$ $v_1 = v_a$	$\varrho(R_\odot)$	$x = 4$ $B(T) \times 10^{-4}$ $v_1 < v_a$	$B(T) \times 10^{-4}$ $v_1 = v_a$	References
1	250	1·09	7·510	8·444	1·177	8·960	10·02	De Groot (1966)
2	244·5	1·093	2·810	3·836	1·183	3·750	4·493	Karlický and Jiřička (1982)
3	230	1·108	5·001	5·581	1·201	6·020	6·645	De Groot (1976)
4	219	1·121	2·630	3·157	1·215	3·250	3·766	— do —
5	197·5	1·147	1·410	2·298	1·247	1·820	2·710	Wild and Tlamicha (1964)
6	158·5	1·208	0·663	1·347	1·319	0·992	1·605	Karlický and Jiřička (1982)
7	150	1·225	1·060	1·594	1·339	1·490	1·932	Elgaroy and Ugland (1970)
8	109	1·329	1·350	1·607	1·465	1·730	1·980	Tlamicha (1982)
9	68	1·520	0·613	0·843	1·700	0·525	0·620	Aurass et al., (1982)
10	60·5	1·578	0·618	0·820	1·772	0·830	1·036	Wild and Tlamicha (1964)
11	60	1·582	0·369	0·538	1·780	0·824	0·950	Aubier et al., (1978)
12	55	1·627	0·752	0·993	1·834	·990	1·263	Wild and Tlamicha (1964)
13	54·5	1·632	0·813	1·106	1·840	1·070	1·409	Wild and Tlamicha (1964)
14	52·25	1·654	1·125	1·222	1·869	1·460	1·558	Wild and Tlamicha (1964)
15	52·0	1·657	0·403	0·621	1·873	0·570	0·793	— do —
16	51·75	1·660	0·340	0·602	1·876	0·497	0·763	— do —
17	50·0	1·679	1·090	2·090	1·901	1·402	2·577	— do —
18	47	1·715	0·402	0·616	1·947	0·564	0·793	— do —
19	46·5	1·721	0·575	0·880	1·955	1·020	1·134	— do —
20	46	1·728	0·750	1·013	1·963	0·990	1·308	— do —

lines to get the following single parameter formulae:

$$(14)\quad \left.\begin{aligned} B &= 0.41(\varrho - 1)^{-0.89} & v_1 &> v_a \\ B &= 0.57(\varrho - 1)^{-0.94} & v_1 &= v_a \end{aligned}\right\} x = 2$$

and

$$(15)\quad \left.\begin{aligned} B &= 0.70(\varrho - 1)^{-1.10} & v_1 &> v_a \\ B &= 0.89(\varrho - 1)^{-0.92} & v_1 &= v_a \end{aligned}\right\} x = 4$$

The above curves are depicted in Figs 1a,b and 2. It is clear from Figs 1a and 1b and also from Tab. I that the magnetic fields obtained by the method ($v_1 = v_a$) of Wild and Tlamicha (1964) are slightly more than the values obtained by our method ($v_1 > v_a$). The field strengths obtained by Dulk and McLean (1978) are larger compared to both $v_1 = v_a$ and $v_1 > v_a$ cases for the density model, $x = 2$ while all the values come closer for $x = 4$ model. The qualitative behaviour of the magnetic field as a function of the radial distance is almost same in all the cases. It is clear from Fig. 2 that an enhancement in electron density leads to higher values of the magnetic field

4. Discussion and Conclusions

The coronal magnetic fields are deduced mainly from the data of various radio emissions from the sun. The Type-I emission is of particular importance because it is the only nonthermal emission which is not associated with flares. There were a couple of attempts to estimate the magnetic fields using Type-I bursts (Wild and Tlamicha, 1964; Takakura, 1966). The fields obtained by Takakura (1966) are overestimates because of the inadequate theory, used. The approach of Wild and Tlamicha (1964) is correct in that they assumed the velocity of the agency causing Type-I chains to be equal to the Alfven velocity. Now it is known that the Type-I emission is caused by super-Alfvenic shocks and hence the magnetic fields deduced will be less than the above. Since the Type-I bursts correspond to mild variations in the active regions, the shocks have to be weak. Therefore the shock velocity will be slightly more than the Alfven velocity. Comparison of our values with those of Wild and Tlamicha (1964) supports this fact because our values are only slightly less.

The field strengths obtained by Dulk and McLean are larger than both our values and those of Wild and Tlamicha (1964) for $x = 2$ density model. This is because the values obtained by Dulk and McLean (1978) correspond to active regions conductive for flares where one expects enhanced density and magnetic fields. In the $x = 4$ density model, the curves due to our method and of Wild and Tlamicha (1964) come closer to that of Dulk and McLean (1978) because we assume a higher density in this model which may not be realistic approximation. This therefore provides an indirect evidence for the fact that the flare associated bursts correspond to a corona with enhanced density and magnetic fields.

The collected data of the Type-I chains correspond to various times and locations in the corona and from instruments of various characteristics. Therefore, the calculated field may not correspond to a particular active region.

In conclusion, we point out that our estimates agree well with those of Wild and Tlamicha (1964) based on shock waves. It is also evident that the density and magnetic fields in the active regions from where Type-I emissions originate must be less than those in the active regions associated with flares. In summary, the formula $B = 0.41(\varrho - 1)^{-0.89}$ gives the coronal magnetic field B above mild active regions as a function of the radial distance ϱ.

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THE HIGHEST GEOACTIVITY IN 1981 AND ITS SOURCE ON THE SUN

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ВЫСШАЯ ГЕОАКТИВНОСТЬ В 1981 г. И ЕЕ ИСТОЧНИК НА СОЛНЦЕ

По наблюдениям геомагнетизма и нижней и верхней ионосферы предлагаются свойства исключительно высокой геоактивности в течение последней декады июля 1981 г. Описаны некоторые интересные отклонения ионосферы от типичного ее поведения во время очень сильныхгеомагнитных бурь, особенно необычно слабый отклик среднеширотной нижней ионосферы. Изучаемая геоактивность возникла в явно невозмущенном промежутке времени, когда на Солнце не наблюдались ни большие вспышки, ни исчезающие волокна. На основе обработки монохроматических снимков солнечной короны во время полного солнечного затмения 31-ого июля 1981 г. авторы считают, что исключительную геоактивность вызвала низкоширотная, вероятно спорадическая, корональная дыра.

The last decade of July 1981 was characterized by exceedingly high geoactivity, which we present in terms the activity in the geomagnetic field and in the lower and upper ionosphere. Some interesting deviations from the common behaviour of the ionosphere during the highest geomagnetic stroms are described, especially unusually weak response of the midlatitude lower ionosphere. The studied geoactivity originated during an evidently inactive period on the sun — no "classical" source of this geoactivity, i.e. no large flare or eruption of filament were observed. Based on the monochromatic corona observations carried out during the total solar eclipse of July 31, 1981 the authors conclude that a sporadic, low-latitude coronal hole could have been the source of this exceptionally high geoactivity.

Key words: solar-terrestrial relations — solar eclipses: coronal holes — ionospheric and geomagnetic activity.

1. Introduction

For some years it has been more or less clear that, from the point of view of solar-terrestrial relations, solar activity is not much more important than solar "inactivity". Both realize themselves in the interplanetary space and in travel from the Sun to the Earth's atmosphere by the proper mechanism. In the literature covering the field of solar-terrestrial relations, a large number of cases is known when: (a) huge active regions on the Sun containing even 100 individual sunspots were very quiet and caused no geoactivity (such active regions were described by Sýkora (1979) and Ishkov et al. (1980), among others), and on the contrary, (b) during evidently inactive periods on the Sun, disturbances in the Earth's magnetosphere and ionosphere were unexpectedly large.

As an example of the above assertion, we illustrate one case of productivity of the active region which we have analysed and found abnormal to the classical imagination. We have in mind Hale region No 17 751 ($l = 337{\cdot}5°$, $\varphi = -8{\cdot}5°$) and its surroundings (Fig. 1 – see Plate 3). Although this AR kept its typical δ-configuration of the magnetic field for several days – whirl chromospheric structures, changes in magnetic flux, large horizontal gradients of the magnetic field, and also remarkable vertical motions of chromospheric matter took place (Ioshpa et al., 1982, 1984), nevertheless, no large manifestations of eruptive activity were observed. No flare of importance

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