STRUCTURE OF THE JULY 1982 EVENT IN RELATION TO THE MAGNETOSPHERE'S RESPONSE

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Abstract. A large Forbush-type decrease with an amplitude of 16–22% was observed by the world-wide network of cosmic-ray detectors during the period 13–14 July, 1982. Combined neutron–monitor measurements with interplanetary plasma and magnetic field data, auroral data, and Earth's magnetospheric data are used for the study of this event. It is suggested that this interesting event is probably a consequence of the dynamic interactions of the solar wind with the Earth's magnetosphere as it is obvious from the large magnetic storm which was recorded in the auroral electrojet indices.

1. Introduction

During the time period between 13 July, 1982, 16 : 00 UT and 14 July, 03 : 00 UT a large cosmic-ray intensity depression with an amplitude of ≈ 16–22% was observed by the world-wide network of cosmic-ray detectors. This depression was identified as a typical Forbush decrease large amplitude which presented a great interest.

Okano and Wada (1983) have reported that this Forbush decrease was detected by a NaI spherical scintillator on board of a commercial jetline between Tokyo and Sapporo. The decrease was more than 10% which can be compared to the same amount obtained by sea level neutron monitor. Dulding (1987) discovered in the observations of this Forbush decrease a significant new modulation in the form of intensity waves of the isotropic cosmic-ray flux. Debrunner *et al.* (1983) have indicated unusual distinct periodicities in the cosmic-ray intensity during this Forbush decrease of 13–14 July, 1982 with time periods of the order of 2 hours and amplitudes of ≈ 3%. According to these authors the recorded these oscillations are must probably a consequence of dynamic interactions between the solar wind and the Earth's magnetosphere.

In this work we attempt to intercorrelate the cosmic-ray data recorded by eight ground-based stations with the geomagnetic and interplanetary data in order to find the conditions which are responsible for this special interesting effect. Continuously, using magnetospheric and solar wind data we study the energy input from the solar wind to the Earth's magnetosphere obtaining useful results for the dynamic of the magnetosphere during this large cosmic-ray intensity depression.

2. Possible Geomagnetic Origin of the Cosmic-Ray Decrease

In order to examine the possible geomagnetic origin of the observed effect of July 1982, we have used hourly values of cosmic-ray data covering a rigidity spectrum from 0.00 to 7.30 GV for eight neutron–monitor stations. These values were normalized to the

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relatively undisturbed period of three days (7, 8, 9 July) before the beginning of the event. The main characteristics of these stations and the main features of the examining here cosmic-ray intensity depression are given in Table I. Intensity time-plots of these stations during the large Forbush decrease are presented in Figure 1. It is observed that the decrease began on 11 July, with a small depression in intensity reaching $\approx 5\%$ of the pre-decrease level on 10 July and reached its minimum on 14 July between 02 : 00 and 03 : 00 UT. We can report that this large cosmic-ray depression was strong on the low-latitudes while was much less pronounced at middle latitudes (e.g., Hermanus and Potchefstroom). Debrunner *et al.* (1983) had also remarked that the oscillations which were recorded in the cosmic-ray intensity during the Forbush decrease at 13–14 July, 1982 were much less pronounced at high latitudes and was almost missing at locations with large cut-off rigidities and at American longitudes.

TABLE I

The main characteristics of the examined Forbush decrease of the here used neutron monitoring stations

Station	Cut-off rigidity (GV)	Correction coefficient (%/100γ)	Onset time (UT) 13 July	Tme of maximum (UT) 14 July	Maximum depression (%) 14 July
Alert	0.00	0.00	14:00	02:00	22.45
Inuvik	0.18	0.00	14:00	02:00	21.45
Goose-Bay	0.52	0.00	16:00	02:00	21.07
Deep River	1.02	0.10	16:00	02:00	20.94
Sanae	1.06	0.10	16:00	02:00	21.85
Jungfraujoch	4.48	0.90	16:00	03:00	20.42
Hermanus	4.90	1.00	16:00	03:00	17.98
Potchefstroom	7.30	0.90	16:00	02:00	16.08

For a more accurate estimation of the minimum cosmic-ray depression we took into account the depression due to the K_p variation (Figure 1). A strong sudden commencement magnetic storm (SSC) is appeared on 13 July, 16 : 00 UT and continued until 15 July. It is interesting to note that the SSC's maximum happened simultaneously with the cosmic-ray intensity minimum. Smaller magnetic storms and disturbances continued until the end of the event when the field gradually recovered to its initial 'stable' conditions. Moreover, we took into account the depression of the equatorial D_{st} variation using hourly values of this index (*Solar-Geophysical Data*, 1982). The maximum value of the D_{st} variation, as it is shown in Figure 2 occurred simultaneously with the cosmic-ray minimum and reached the extremely large value of $\approx 340\gamma$. From this it is resulted that the large amplitude of the observed decrease was caused by the large depression of the equatorial wave. Applying the method proposed by Dorman (1974) we can correct the cosmic-ray depression for D_{st} values. This correction is based on the theoretical prediction of Dorman (1974) according to which the increase of the cosmic-ray flux is calculated as a function of D_{st} decrement for different rigidities components,

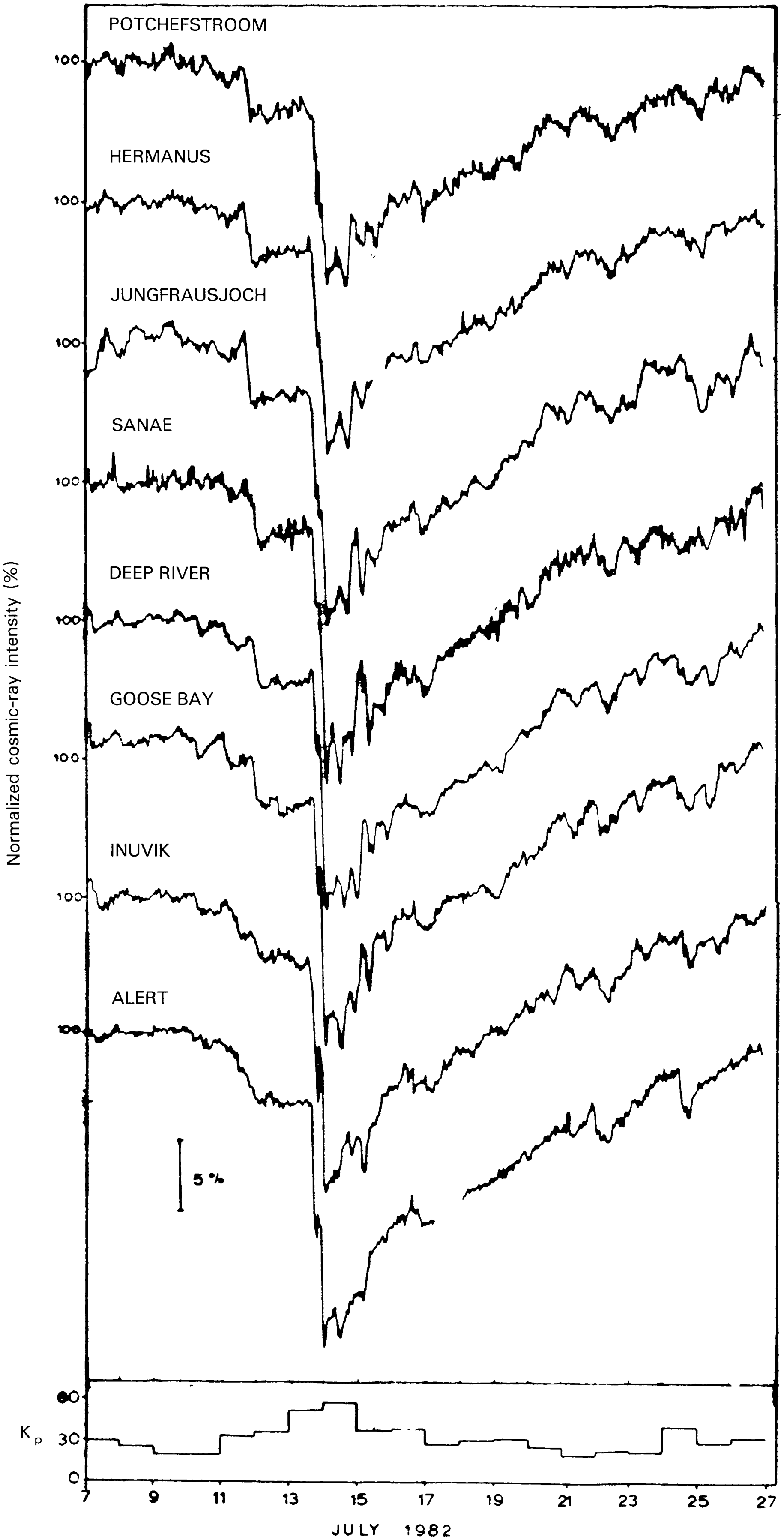

Fig. 1. The large cosmic-ray depression of the large amplitude Forbush decrease of July 1982 for several neutron-monitoring stations with increasing cut-off rigidity. The K_p-index is also indicated.

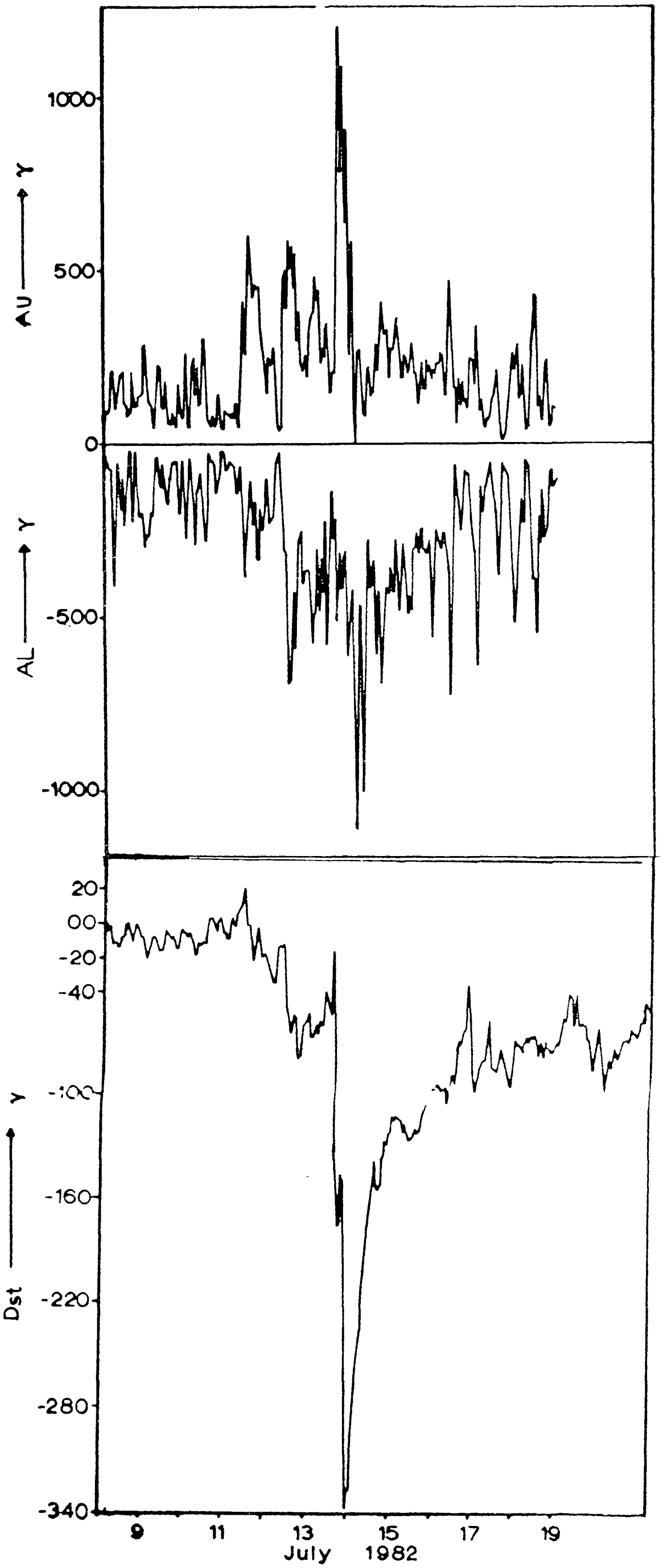

Fig. 2. Auroral electrojet indices and D_{st} variations.

heights of station and for the maximum of solar activity. The correction coefficient for each station is given in Table I. For low-latitude stations such correction does not apply, since their cut-off rigidity is below the atmospheric cut-off (≈ 1 GV) and consequently, any lowering of their cut-off value due to the D_{st} decrement should not affect the cosmic-ray intensity. For the other stations, there is a more or less linear dependence of the intensity on D_{st} variation. We have found that $\approx 1\%/100\gamma$ of the depression was due to the D_{st} variation. Consequently the cosmic-ray depression of 14 July due to the interplanetary origin should be $\approx 15\%$ instead of $\approx 18\%$ for the Hermanus Neutron Monitoring station (Geranios and Mavromichalaki, 1982).

3. Selectivity of Solar Flares

As it is well-known solar activity seems to be responsible for both the Forbush decreases and geomagnetic disturbances. Some research has been made in order to determine the most probable candidates, cause of all considered effects, among those Hα solar flares, which occurred in July 1982.

Assuming 11 July as the onset day of the first cosmic-ray depression, we scanned back three days for identification the possible flares responsible for this decrease. As candidate flares we accept flares of optical importance $\geq 1B$ and accompanied by a type II burst or a type IV radio emission.

Indeed on 9 July at 07:31 UT two solar flares of optical importance $2B$ and $3B$, respectively, and heliographic coordinates N 17, F 73 were recorded. These were accompanied by a $2B$ solar flare at N 17, F 78 heliographic coordinates (onset time 07:32 UT). It is quite possible that this group of solar flares may have produced the Forbush decrease recorded on 11–12 July.

On 12 July at 09:08 UT a flare of optical importance $3B$ occurred at N 12, E 40 heliographic coordinates. It was followed at 09:10 UT by another one of the same optical importance with coordinates N 12, E 39. Almost an hour later two more flares of optical importance $3B$ appeared: the first one at 10:18 UT with heliographic coordinates N 12, E 36 and the second one at 10:32 UT with heliographic coordinates N 12, E 37. It is most likely that these flares were candidates for the cosmic-ray large depression on 14 July. Many other important flares recorded during the following days may no longer be associated to the main phase of the 13–14 July Forbush decrease. They must though have contributed to the gradual recovery of cosmic-ray intensity to the pre-decrease level.

It is characteristic to note that most of the solar flares which are responsible for the described events are appeared in the east-central regions of the Sun and in low heliographic latitudes. So the produced Forbush decreases may have the characteristics of the decreases caused by east-situated flares as, for example, the short falling phase of the main decreases (only one day), the relative long recovery phase of this decrease, etc. (Iucci *et al.*, 1975; Geranios, 1980).

Except of these decreases a small Forbush decrease on 15–16 July is appeared falling in the main large decrease of 13–14 July. A series of also east-situated flares importance

2*B* is appeared on 14 and 15 July (Table II) with two sudden storm commencements on 16 July happening in 08 : 40 and 15 : 19 UT.

4. Interplanetary Space Conditions

For the explanation of the large cosmic-ray depression of 14 July, we have also searched in interplanetary and magnetic field data for possible shocks or shock pairs. These data have been taken by the spacecrafts IMP-8 and ISEE-3 (Couzens and King, 1986). Time-plots of the disturbances observed in the magnitude of interplanetary magnetic field (IMF) B as well as in its components B_x, B_y, B_z in the period 7–18 July are given in Figure 3(a). The plasma parameters (velocity density and temperature) are shown in Figure 3(b). It is obvious that enhanced and fast moving solar plasma has been ejected from the Sun and reached the Earth's magnetosphere on 11, 13, and 16 July. These data are the same with the data of the observed cosmic-ray decreases in the ground-based stations. The temperature recorded has also been increased during the days above. We must report here that the time of sudden storm commencement (which occurred on

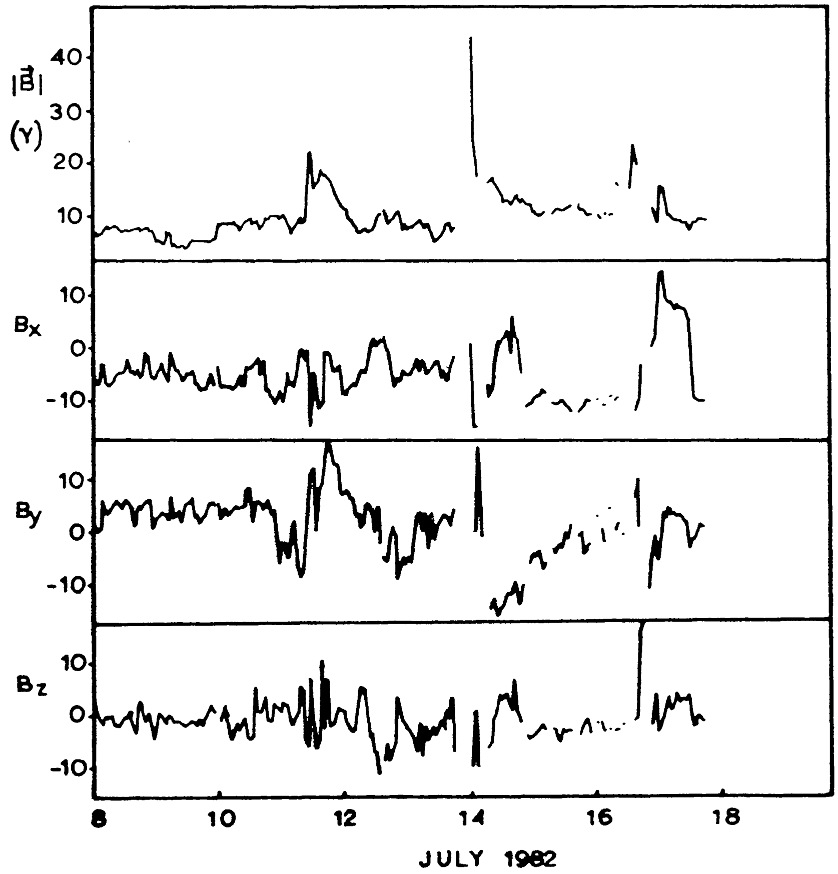

Fig. 3a. The interplanetary magnetic field and its components for the period 8–18 July, 1982.

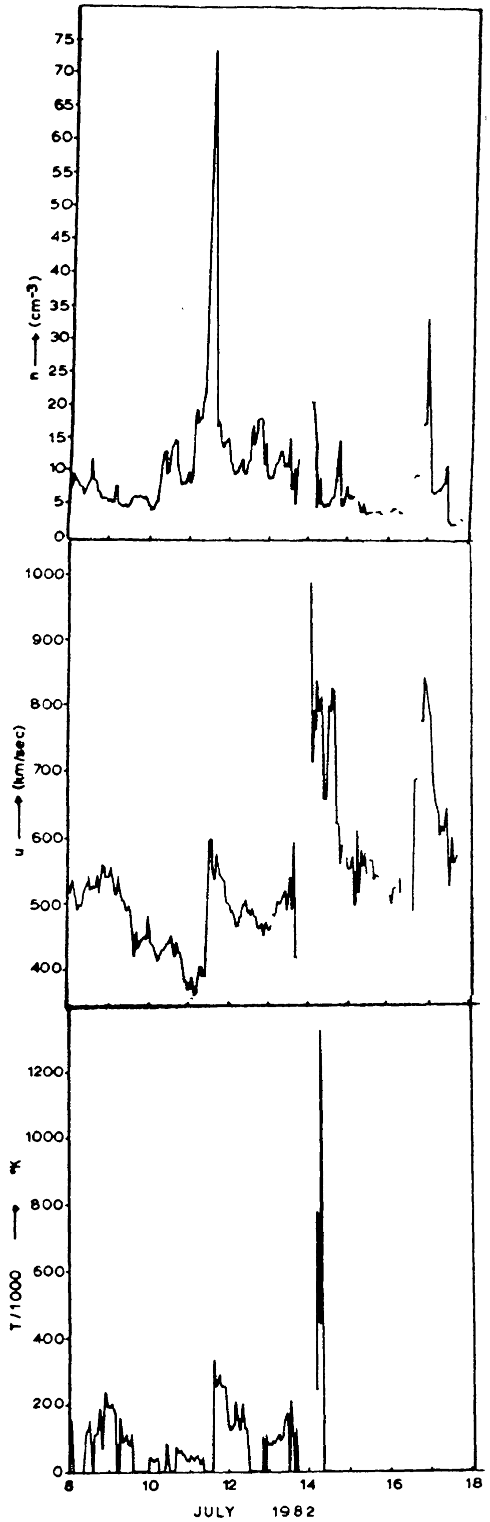

Fig. 3b. The interplanetary plasma parameters for the period 8–18 July, 1982.

11 July, 09 : 53 UT; 13 July, 16 : 17 UT; and 16 July, 08 : 40 UT and 15 : 19 UT) assuming it as the signature of the passage of an interplanetary shock wave was a few hours or simultaneously with the shock front as it was recorded by the spacecrafts located at a distance of 30–50 R_e far from the Earth. Unfortunately we have not more detailed data from the spacecrafts in order to estimate more accurately the time of the shock passage at the spacecrafts.

Another interesting point is the following: as already mentioned three sequential shock waves changed the interplanetary magnetic field on 11, 13, and 16 July. The first two were responsible for the Forbush decreases observed on Earth during the same data as well as for the occurred geomagnetic storms. The third effect, however, was hardly detectable on Earth although Figure 3 indicates the passage of a rather significant shock wave through the region between the Earth and the Sun. The variations of the interplanetary magnetic field components in Figure 3(a) show that this event of 16 July was predominant in the B_x and B_z components, while it was of less importance in the B_y direction. In opposite the IMF's variations of the two other events of 11 and 13 July were neglected while large variations were recorded in the B_y component.

A suggested possible explanation for this structure is that the two first shock waves (11 and 13 July) were expanding in the B_y-direction where the Earth was located, while the third one (16 July) was moving in the $B_x - B_z$ plane in a direction away from the Sun. Considering the fact that the third shock wave was detected on the satellites but was almost negligible on the Earth, a possible model of the modulation could be the following: intense solar activity provokes the creation and expansion of three interplanetary shock waves on 11, 13, and 16 July. The ejected solar plasma moves away from the Sun following the spiral orbits. According to theoretical models, plasma ejected from central-eastern regions of the Sun surface reaches easily the Earth, while solar plasma ejected from western regions moves away from the Earth. From 14 July on, data of solar activity show an increase of activity in western regions of the solar disk. So it was created a shock wave which passed through the satellite orbit but continued away from the Earth moving in the $B_x - B_z$ plane.

5. Response of the Magnetosophere

As it is known, the shock waves which are formated in the interplanetary space depress the magnetopause produced various magnetospheric disturbances in relation to the interplanetary space conditions (Fairfield and Gahill, 1966). When the z-component of the interplanetary magnetic field is directed southward ($B_z < 0$) we observe large magnetic storms in the magnetosphere which are detected by the variations of the D_{st}-index and of the auroral electrojet indices. Time-plots of these indices for the here examined time period 8–19 July taken from the WDC – C_2 are presented in Figure 2. We can observe in this figure that there is an intense activity in the eastward auroral electrojet as well as in the westward one. As it is expected the westward electrojet appears a slightly greater value than the one in the eastward. We also observe in the lower panel of this figure (AL-index) that there is a consequence of onset of magnetospheric substorms. An extremely large value of these indices is appeared during the 13–14 July days, where we have superposition of magnetic substorms. We can also report that the magnetosphere was not in its ground state in the data before the event of 11 July because the indices AU and AL appear some disturbances.

In order to be studied the state of the magnetosphere beyond the auroral oval, we have examined the variations of the D_{st}-index which describes the activity of the equatorial ring current. We can remark from this index (Figure 2) that although there are three sudden storm commencements (SSC) in the 11, 13, and 16 July, respectively, there are not appeared magnetic disturbances except of the second one reported on 13 July. Moreover, in order to justify this behaviour of the magnetosphere we have calculated Akasofu's energy ε which is the energy coupling between solar wind and magnetosphere. Perreault and Akasofu (1978) assumed that the solar wind energy flux ε, responsible for magnetospheric substorms and storms, would have the form

$$\varepsilon = VB^2F(\theta)l_0^2 \quad (\text{erg s}^{-1}), \tag{1}$$

where $F(\theta) = \sin^4(\theta/2)$ which is a function of the polar angle of the IMF vector projected on the $Y - Z$ plane: namely,

$$\theta = \tan^{-1}(|B_y|/|B_z|) \quad \text{for } B_z > 0,$$

$$\theta = 180^\circ - \tan^{-1}(|B_y|/|B_z|) \quad \text{for} \quad B_z < 0,$$

V is the solar wind velocity measured in the interplanetary space; B, total interplanetary magnetic field; l_0 is a constant equal to 7 R_e.

In this work we have calculated this energy coupling for the period 7–18 July, 1982 using hourly values of the interplanetary and solar plasma parameters from the spacecrafts IMP-8 and ISEE-3 (Couzens and King, 1986) and is presented in Figure 4. We can observe in this figure that we have an extremely large value of this energy during the days 13–14 July, 1982 which are the days where the large Forbush decreases occurred in the cosmic-ray data. Some small increases of the energy are also indicated during the other two events, on 11 and 16 July.

As it is shown in Equation (1) the energy coupling between solar wind and the magnetosphere is expressed by a particular combination of three quantities V, B, and θ. Among these quantities the solar wind speed is the least variable while the variations of the magnetic field B has the major contribution to the variation of ε. For a better understanding of this mechanism of B we have calculated the magnetic energy $B^2/8\pi$ as it is shown in Figure 4. In this energy $B^2/8\pi$ we can note three large peaks during 11, 13, 14, and 16 July, respectively, which are associated with the mentioned above shock waves generated by solar flares. We note that the first and the third peaks of the magnetic energy are corresponded to small values of the energy coupling between solar wind and magnetosphere while in the second case we have large values of the energies. It means that in the first and third cases the IMF was not recorded with the geomagnetic field lines while in the second one we have reconnection of these lines at the dayside of the magnetosphere.

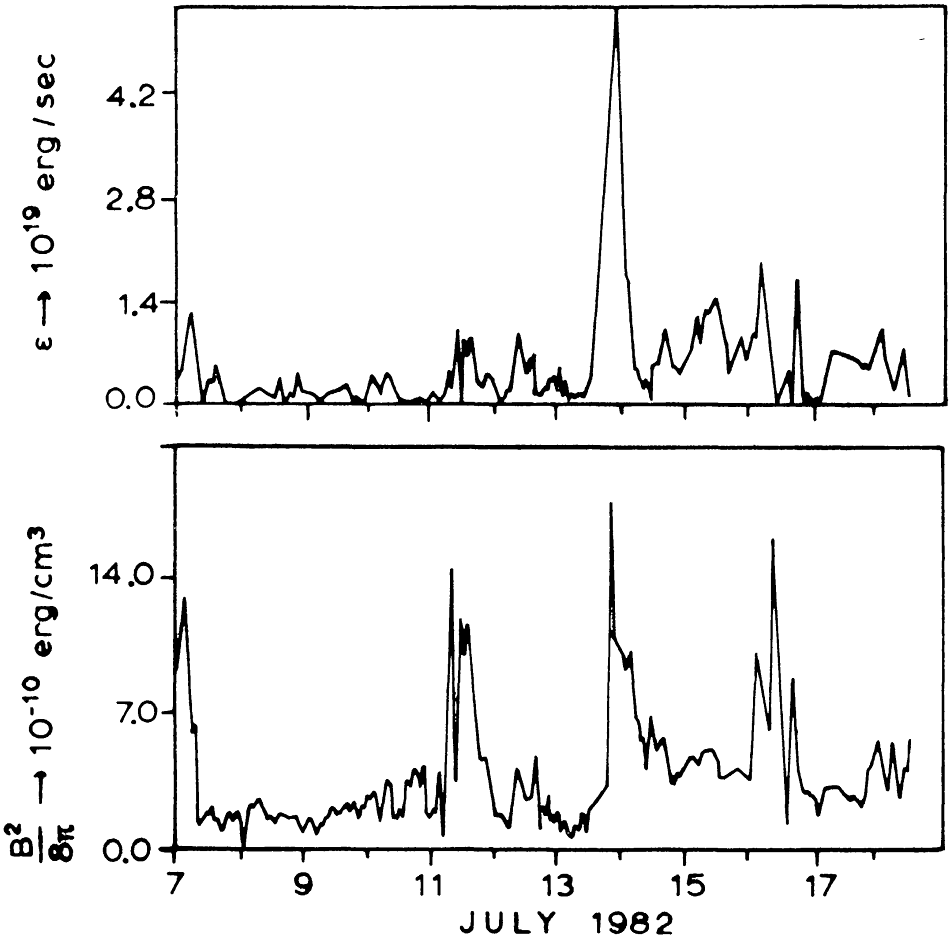

Fig. 4. Akasofu energy ε and magnetic energy $B^2/8\pi$ for the period examined here.

From these remarks we can confirm the importance of the IMF B_x-component on the magnetosphere activity. In the first and third cases of the examined events is expected that the B_z-component is directed northward ($B_z > 0$) while in the second one the B_z-component is directed southward ($B_z < 0$). Indeed, our data of the B_z-component as it is appeared in Figure 3(a) show that we have positive values of this component during 11 and 16 July, while on 13–14 July the B_z-component was remained negative for many hours.

Another interesting remark concerns the fact that during 11 and 16 July as it is shown from the AL-index data, a consequence of substorms are presented and the IMF B_z-component is positive. The result is that during these events the magnetosphere was not acted like a half-wave rectifier as it was believed by Burton *et al.* (1975), but during all this period of twelve days there was a remarkable activity of the magnetosphere.

6. Conclusions

In this work we have described the enhanced density of the solar-interplanetary and cosmic-ray phenomena concentrated in the period 9–18 July, 1982.

During the large Forbush-decrease happening on 13–14 July, 1982, we had an intense activity in the interplanetary and geomagnetic space. Three shock waves generated by solar flares were occurred in the interplanetary space produced three cosmic-ray decreases on 11, 13–14, and 16 July. They also produced many substorms in the geomagnetic data while the superposition of them gave the large storm of 13–14 July. It is characteristic that these simultaneously decreases or increases of the interplanetary and geomagnetic parameters were most probably a consequence of dynamic interactions between the solar wind and the Earth's magnetosphere.

So, examining magnetospheric and solar wind data available for this period, we attempted to construct a consistent picture of the physical processes producing the observed effect. For this purpose we calculated the energy coupling of the solar wind-magnetosphere according to the Akasofu method. From this analysis we concluded that the first and the third variation of the magnetospheric data which appear a positive value of the z-component of the IMF are accompanied by small amplitude Forbush decreases and small variations in D_{st} and AE indices and also in the computing Akasofu energy. In opposite, the second and greatest variation of the cosmic-ray intensity occurred in the same time where the B_z-component of the IMF was negative. The computing energy coupling between solar wind and magnetosphere reached the large value of 5.6×10^{19} erg s^{-1}. It is an evidence that in this case there is a reconnection of the interplanetary and geomagnetic field lines.

In the future, in a more detailed analysis of this special interesting event using data of the Earth's magnetotail, we can investigate the mechanism with which the input energy of the solar to the magnetosphere was dissipated.

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