COSMIC-RAY VARIATIONS RELATED TO SOLAR, GEOMAGNETIC AND INTERPLANETARY DISTURBANCES (23 MARCH–7 APRIL, 1976)

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Abstract. During the second interval of the Study of Travelling Interplanetary Phenomena (STIP, 20 March–5 May, 1976) a series of solar, interplanetary, geomagnetic and cosmic-ray events have occurred. These are surprising events, since this period falls into the minimum of the solar activity of the past solar cycle. The present analysis is concentrated on Forbush decreases, cosmic-ray increases, geomagnetic variations and the related solar wind disturbances recorded by the heliocentric satellites Helios-1, 2 and the geocentric IMP-8, in the period 23 March–7 April, 1976. The cosmic-ray enhancements on 26 March and 1 April were of geomagnetic origin and particularly expressed in middle latitude stations during the large *D*st magnetic field depressions. The detected multiple Forbush decreases are related with the type IV solar flares, all produced by the same active region (McMath Plage 14143). The relative positions among the satellites Helios-1, 2, the Sun, and the Earth were very favorable in this period for studying these events, since Helios-1 approached the Sun to its perihelion and Helios-2 was lined-up with the Earth. Helios-2 detected two shock fronts on 30 March and 1 April, respectively, and Helios-1 detected a tangential discontinuity on 26 March. An attempt is made to relate these shock fronts with the erupted solar flares and Storm Sudden Commencements (SSC) recorded on the Earth and to estimate a lower limit of the deceleration distance of the involved shock waves.

1. Origin of the Cosmic-Ray Increase

The direct influence of geomagnetic field changes on cosmic rays was first demonstrated by Yoshida and Wada (1959) using neutron monitoring data from the world-wide network of cosmic-ray stations. They showed that world-wide cosmic-ray intensity increases were related to geomagnetic storms and not to solar flares. These storm-type enhancements in cosmic-ray intensity during the IGY (International Geophysical Year) period were interpreted by Kondo *et al.* (1960) as geomagnetic effects on the cut-off rigidity of the stations. These predominantly affected the intensity of middle geomagnetic latitude-positioned stations during periods of large *D*st geomagnetic field depressions (Wada, 1977). During the STIP interval II two such geomagnetic storms have occurred, on 26 March and 1 April, respectively, during which the *D*st value has changed by more than 200 γ's (SGD, 1976). During the first geomagnetic storm, the cosmic-ray intensity recorded by the Athens neutron monitor (cut-off rigidity 8.72 GV; Shea *et al.*, 1968) displayed a clear increase of about 4% (Figure 1). For a series of neutron monitoring stations (Table I) with different cut-off rigidities, the

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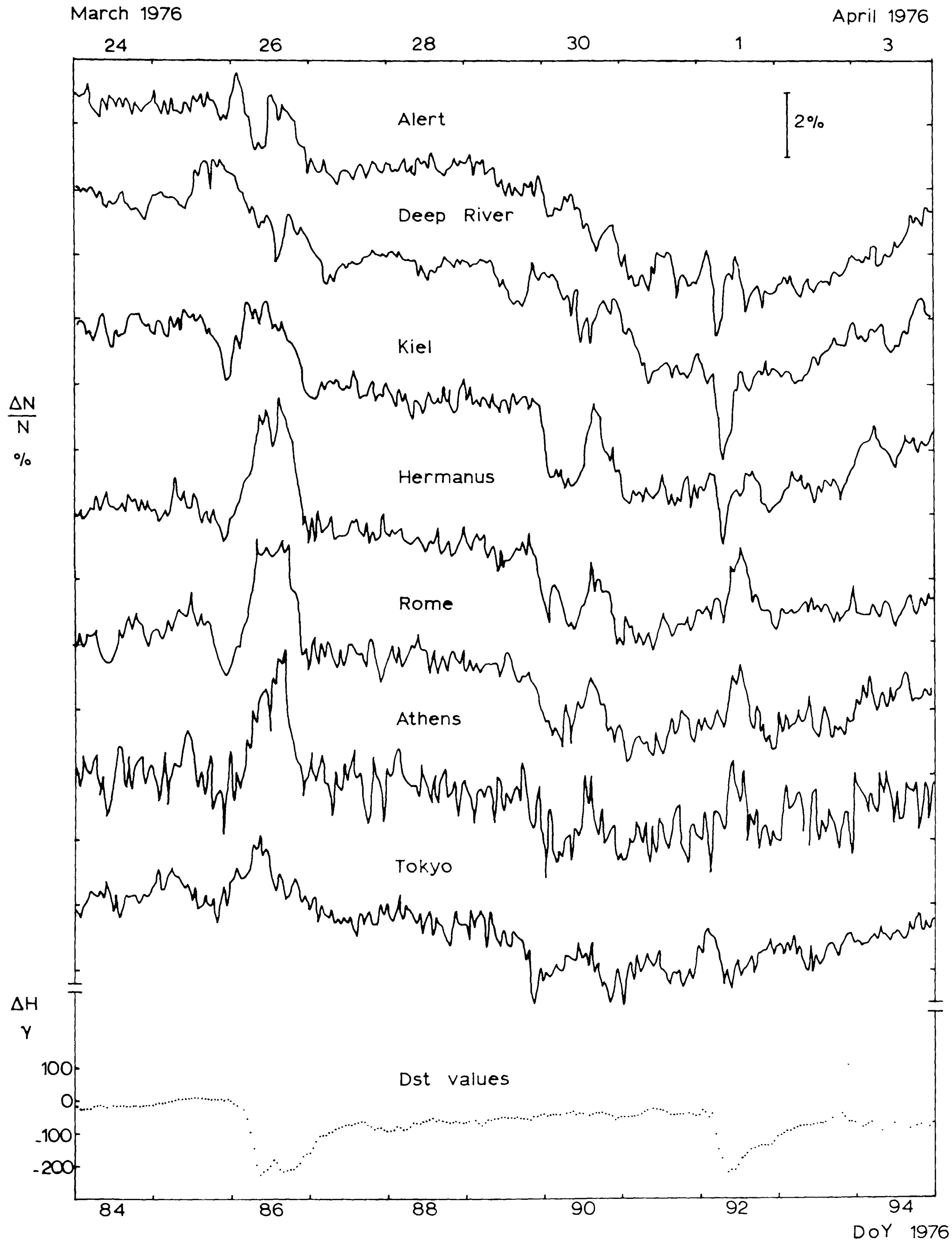

Fig. 1. The decrease-phase of the long-lasting Forbush decrease for several neutron monitoring stations with increasing cut-off rigidity. Normalization 100% for the mean daily value on 23 March, 1976. The simultaneous *D*st variation is also shown.

TABLE I

The characteristics of the used for the present analysis neutron monitoring stations

NM stations	Geographic lat. (deg)	Coord. long (deg)	Cut-off rigidity (GV)	Height (m)	Correction coefficient (%/100γ)	Geom. cut-off correction (GV)
Alert	82.52N	62.33W	0.00	57	0.00	—
Deep River	46.10N	77.50W	1.02	145	0.00	—
Kiel	54.30N	10.10E	2.29	54	0.43	—
Hermanus	34.42S	19.22E	4.90	26	1.55	0.65
Rome	41.91N	12.50E	6.32	60	1.40	0.57
Athens	37.97N	23.72E	8.72	110	1.00	0.43
Tokyo	35.75N	139.72E	11.61	20	0.70	0.22

cosmic-ray data covering the period 24 March–3 April, are shown in the same figure. As one can realize, the enhancement is pronounced at middle geomagnetic latitude-situated stations, like Hermanus, Rome and Athens, while for low and high latitudes, the same increase is relatively small, like Alert, D. River, Kiel and Tokyo stations. The cosmic-ray increase, shown in Figure 1, could generally be attributed to a solar or geomagnetic origin. As the flux of the solar protons, which could have caused the increase is energy-dependent, a solar-source candidate of this increase should have rigidity-dependent characteristics, i.e., should be larger near the poles than near the equator. But it is not matched in our case, where only at middle latitude stations is the increase clearly seen, while at polar or equatorial stations this feature is hardly distinguishable.

The correction for *D*st values cosmic-ray intensities for the Athens neutron monitoring station and the other stations given in Table I, are shown in Figure 2. 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, heights of stations and for the minimum of solar activity. This relation between cosmic-ray increase and *D*st decrease is shown Figure 3 for each station used in this work. For Alert and D. River stations such correction does not apply, since their cut-off rigidity (Table I) is below the atmospheric cut-off (~ 1 GV) and, consequently, any lowering of their cut-off value due to *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. The correction coefficient for each station is given in Table I.

The consecutive Forbush decrease which characterizes the concerned period in this way, could be masked-off from the influence of the geomagnetic field variation. The lowering of the cut-off rigidity in neutron monitoring stations is calculated by several authors (Aldagarova *et al.*, 1975; Flückiger *et al.*, 1975; Flückiger *et al.*, 1979) and has been ascribed to the decrease of the threshold rigidity of the neutron monitoring stations by the geomagnetic field of the ring

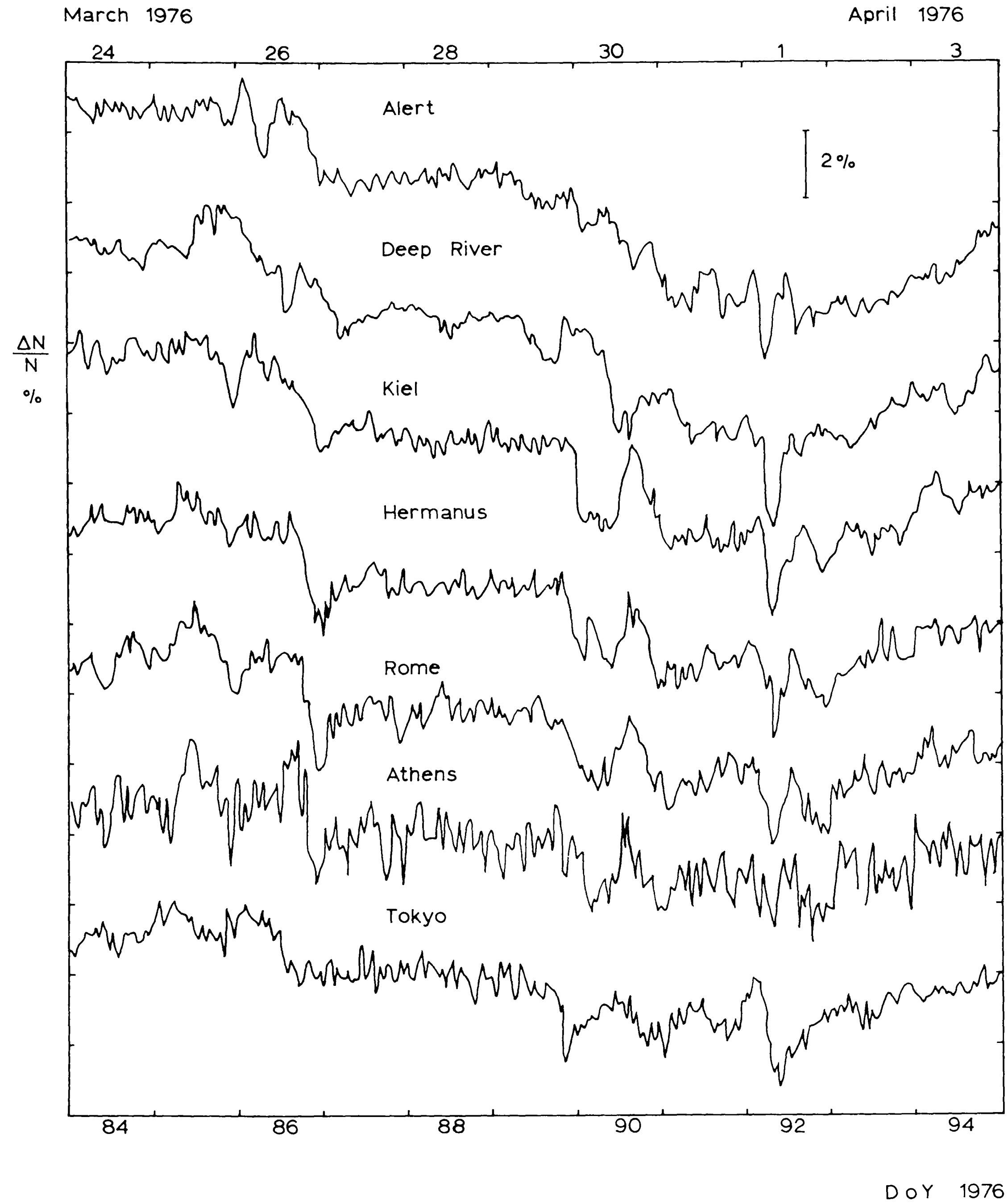

Fig. 2. The correction for Dst variation cosmic-ray intensities recorded by the same neutron monitoring stations of Figure 1.

current. The variation of the geomagnetic threshold rigidity ΔRc, due to the present Dst decreases for stations of different cut-off rigidities used here, is derived according to the method of Krestyannikov *et al.* (1977) and is shown in Figure 4. The digital values are given in Table I.

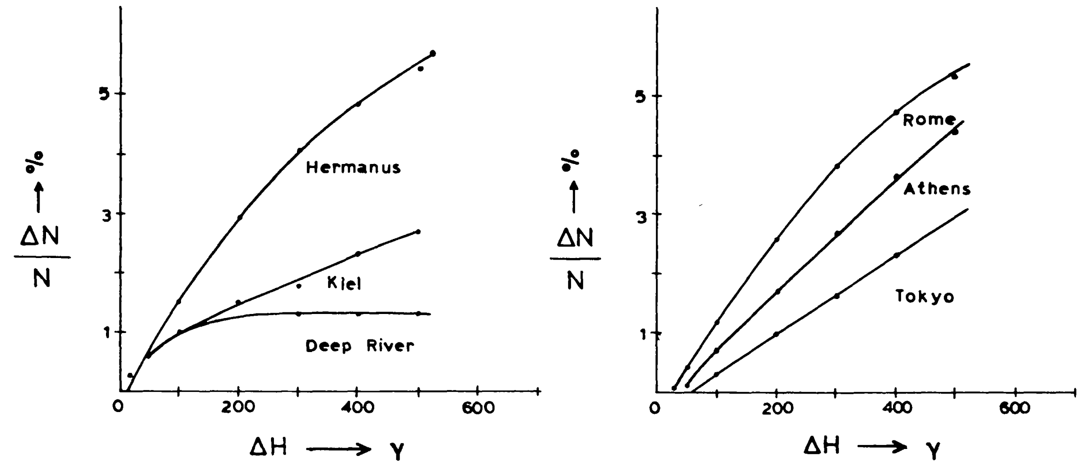

Fig. 3. The relative cosmic-ray intensity variation of the NM stations as a function of *D*st expressed in γ's. These variations are derived from the theoretical calculations of Dorman (1974) for the solar minimum period and applied for the correction of the cosmic ray intensities.

2. Selectivity of Solar Flares

Our selection criteria for solar-activity centers causing the described events, are concentrated in the McMath Plage 14143. This activity center was initiated early in March and lasted until late in June 1976. Assuming 26 March as the onset-day of the large Forbush decrease (perhaps the second one after the August 1972 decrease), we scan back seven-days for identification of the possible flare responsible for this decrease. A candidate-flare is the flare which is accompanied by a type II burst or a type IV radio emission. According to Dodson and

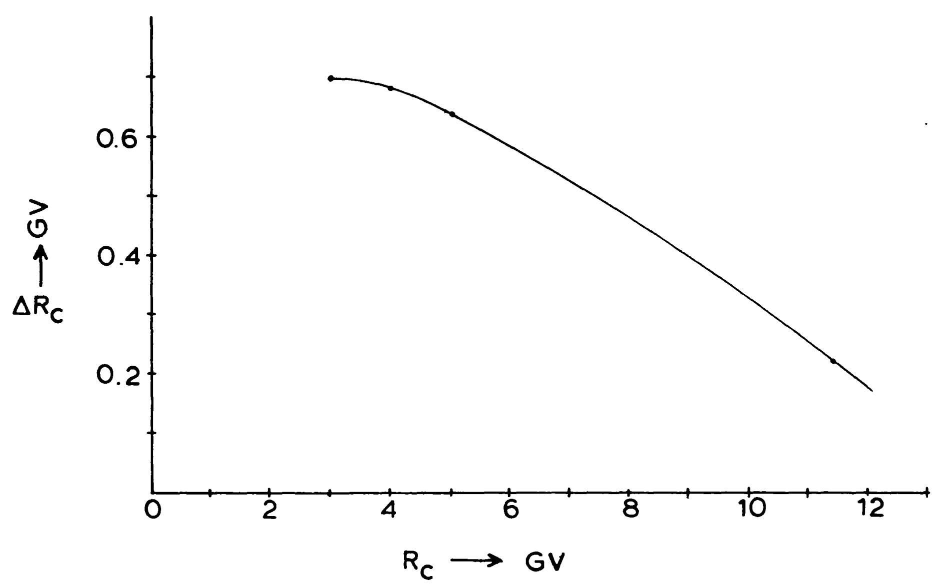

Fig. 4. The variation of the geomagnetic threshold rigidity due to the decrease of *D*st values on 26 March 1976, as a function of the rigidity (Krestyannikov *et al.*, 1977), used for geomagnetic cutoff correction.

Hedeman (1977), the two type-II radio-bursts on 20 March are not accompanied by a solar flare report of the Culgoora radio-heliograph.

On 21 March, at 07:50 UT, a solar flare of optical importance 1B and heliographic coordinates N04°, W29° in McMath Plage 14127 is reported. This Plage is renumbered (14143) during the next solar rotation No. 1369. The site of this flare was very favorable, having produced the Forbush decrease on 26 March. On 23 March, a solar flare of optical importance SB, onset time 08:37 UT and heliographic coordinates S05°, E90° in McMath Plage 14143, is reported (Dodson and Hedeman, 1977). In addition, two other flare-candidates, on 25 March in the same Plage at onset times 11:54 and 13:05 UT, coordinates S06°, E75° and S05°, E69° and optical importance SN and 1N, respectively, are reported (Dodson and Hedeman, 1977).

The heliographic longitude of the flare on 21 March was rather well connected with the Earth along the spiral interplanetary magnetic field lines and was close to Helios-1 and -2 by about 7° and 35°, respectively (Figure 5). But, due to the rather long time required from the onset of the flare to the onset of the Forbush decrease (about six days), this flare-candidate should be excluded as the cause of this large decrease (Figure 2).

Although the heliographic longitude of the flare on 23 March was 90° in the eastern limb, it very probably produced this cosmic-ray decrease and the associated storm sudden commencement, since the time-lag between the flare-onset and the decrease is quite reasonable (three days) (Dodson and Hedeman, 1977) and, in addition, the produced Forbush decrease has a very long falling-phase (~6 days), which characterizes decreases caused by east-situated flares (Iucci *et al.*, 1975).

The two last flares (on 25 March) under consideration, should probably be excluded for the large decrease candidacy, since the following onset of the Forbush decrease took place surprisingly fast (on 26 March). In addition, even if we assume that these flares could produce this cosmic-ray depression, the decrease-phase should be very sharp and the causing flare should be in the western limb. In our case, both flares are in the eastern limb, quite far from the central meridian. At least two other Forbush decreases falling into the main large decrease are produced by solar flares, probably on 28 and 31 March, 1976 (Shea, 1977). Both are of type IV and are discussed later in connection with the related interplanetary shock waves, which have been registered by the Helios spacecraft.

The main characteristics of the discussed flares, cosmic-ray decreases and SSCs are shown in Table II.

3. Measurements in the Interplanetary Space

During the first half of STIP interval II the topology in the interplanetary space, as concerns the heliocentric satellites Helios-1 and 2, was quite favorable for

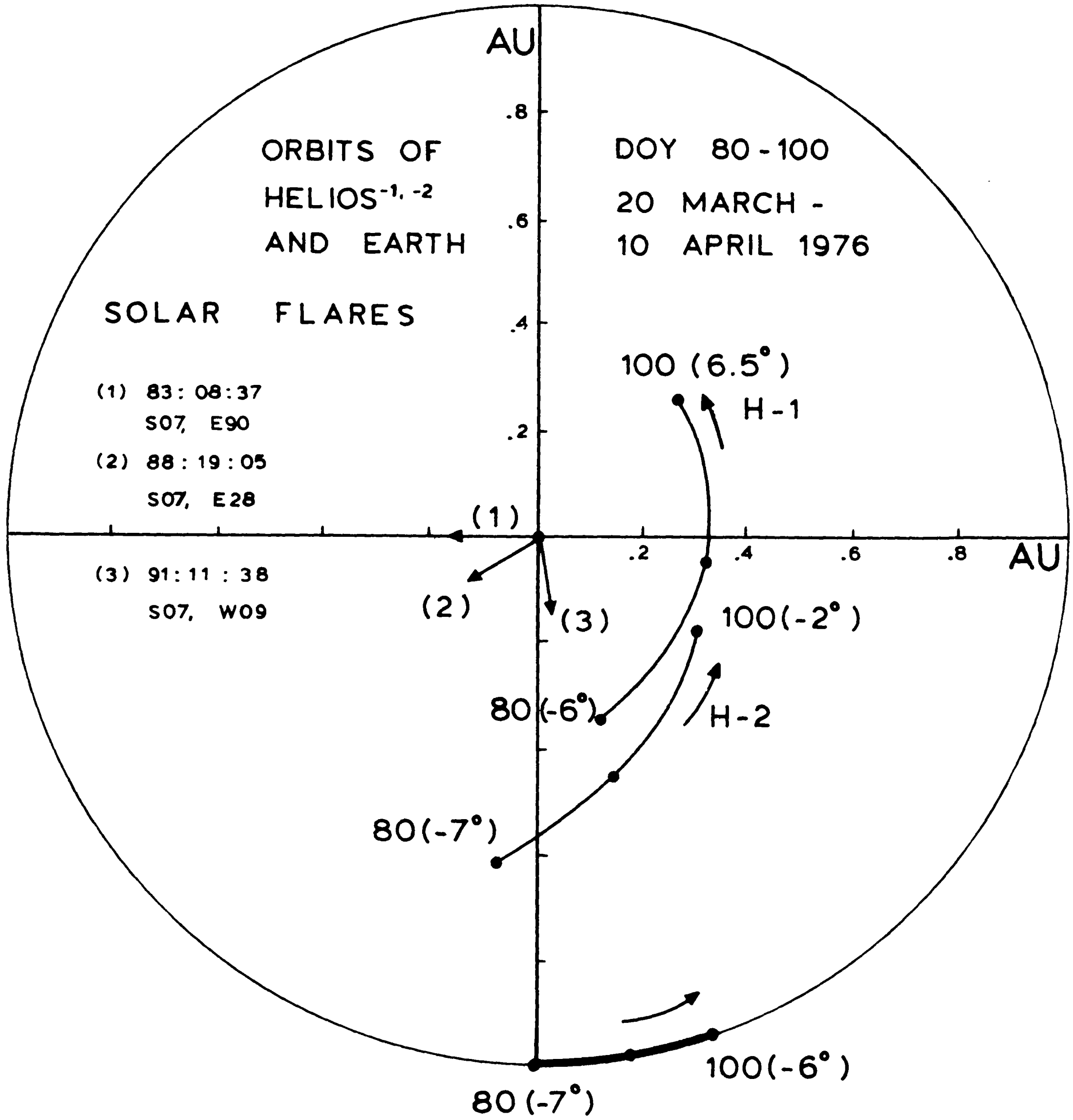

Fig. 5. The projection of the trajectories of Helios-1 and Helios-2 and IMP-8 satellites into the ecliptic plane, during the period 20 March (DoY 80)–10 April (DoY 100) 1976. The corresponding heliographic latitudes at the beginning and the end of the period are also indicated. The numbered arrows indicate the listed flares.

studying, in a macroscopic view, the events of the discussed period (Figure 5). Both these spacecraft observed a high speed stream structure associated with the north polar coronal hole (Schwenn *et al.*, 1977).

On 23 March (DoY 83), the day of the eruption of the flare (Figure 5), both H-1 and H-2, being at the same heliographic latitude (~7°) and at a radial distance of about 0.5 and 0.7 AU, respectively, observed the decay of a Fast Solar Wind Stream (FSWS), the front of which was detected at H-1 on 13 March at 22 UT. The energy channels of H-1 and H-2 showed, on the same day of the eruption, an increase in proton and a-particle intensity. In addition, a Forbush

TABLE II

The characteristics of the intercorrelated solar flares, Forbush decreases, SSC's and interplanetary shocks

Solar flares	Region (McMath)	Onset (UT)	Forb. decr.		SSC		Interplanetary shocks				Spacecr. name
Date Coord. (1976)			Date 1976	Ampl. (%)	Date (1976)	Onset (UT)	Date (1976)	Onset (UT)	M. speed (km s^{-1})	Speed (km s^{-1})	
23.3 S7-E90	14143	08:37	26.3	~2.5	26.3	02:33	—	—	—	—	H1?
							—	—	—	—	IMP?
28.3 S7-E28	14143	19:05	30.3	~3.0	1.4	02:55	30.3	17:43	420	627*	H2
							1.4	02:55	522	—	IMP
							—	—	665	—	H2-IMP
31.3 S7-W9	14143	11:38	?	—	—	—	1.4	13:26	710	616	H2

* Gurnett *et al.* (1979).

decrease is also observed by H-2 as a decrease of the proton intensity with energies $E > 51$ MeV/n (Kunow *et al.*, 1977).

According to the reported SSC on 26 March at 02:33 (Shea, 1977), a shock wave should have crossed the Earth's magnetosphere (Pintér, 1977). Unfortunately, the geocentric satellites IMP-7 and -8, due to a data gap in interplanetary space between 26 and 30 March, could not confirm the passage of such a shock front (Dryer *et al.*, 1978). During the considered period, H-2 and IMP-8 were at the same heliographic latitude and, as is shown in Figure 6, they should have seen the same FSWS with an approximate time-delay of $2\frac{1}{2}$ days (feature A). H-1, being about 50° west from the Sun–H-2 line, could have seen the same structure after approximately five days (corotational delay) but, perhaps due to its different heliographic latitude, it did not 'see' this structure (Figure 6, top panel).

4. The Discontinuity on 86:02:33 UT

On 26 March (DoY 86), an SSC at 02:33 is reported (Shea, 1977). This information, together with the report of the solar flare on 23 March, is used by Pintér (1977) in order to calculate the mean propagation speed of the related shock. Although it is generally believed that a SSC characterizes the passage of a shock front, observations of IMP-8 satellite at that time do not show any clear characteristical feature for such structure (Figure 6). Apparently, at the time of the reported SSC (02:33 UT), the variation of the solar wind parameters, proton-speed, -density and -temperature show a tangential discontinuity-like feature, since the speed is increasing while the density and temperature are decreasing. The type of this discontinuity, according to Burlaga (1968), is classified into type T-3. Taylor (1969) examined 36 SSCs during 1965–67, which occurred when the IMP-3 interplanetary magnetic field data became available. Among these events, 26 were probably caused by shock waves. According to a statistical analysis of a number of SSCs, Chao and Lepping (1974) have attributed 15% of the SSCs to tangential discontinuities and the rest to interplanetary shock waves. Unfortunately, there was a gap in the IMP data on March 26 (DoY 86), so that it was not possible to identify any other shock wave after the reported SSC, caused by the flare on 23 March (Figure 6). The satellites H-1 and H-2 were approaching the Sun in the western part of their orbits and, at the time of the reported SSC, they were very far from each other (Figure 5).

As it can be drawn out from Figure 6, the discussed SSC falls into the onset of a FSWS which, according to the IMP data, reaches a speed of about 600 km s^{-1} within one day. Due to the similar heliographic latitude of the IMP-8 and H-2 spacecraft ($\sim -7°$), we were able to recognize the same feature in a distance of about 0.5 AU (A) after $2\frac{1}{2}$ days. Rather close to the Sun ($\sim$0.3 AU), H-1 measured the same parameters but in a different heliographic latitude ($\sim -3°$), so that identification of the under consideration feature was rather difficult. On 26

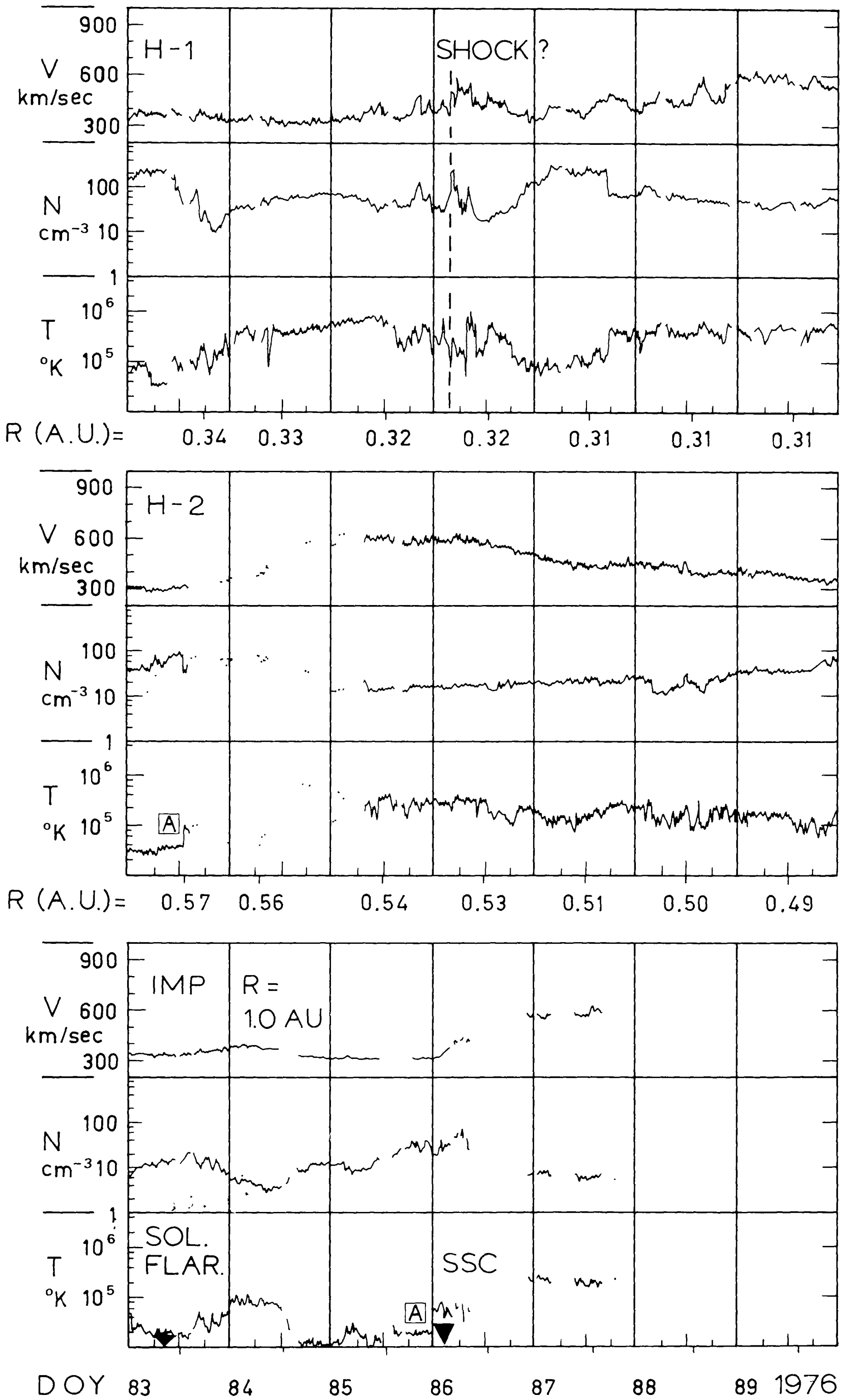

Fig. 6. The solar wind speed, the proton density and the temperature measured by Helios-1 and Helios-2 and IMP-8 spacecrafts during 23–30 March, 1976 (DoY 83–89). A possible shock front observed by H-1 is also indicated. Feature A corresponds to the commencement of a fast solar wind stream observed by H-2 and later by IMP-8. The H-1 and IMP-8 data are based on 15 min averages and the H-2 data on 12 min averages.

March H-1 recorded many fluctuations of the plasma parameters, among which a discontinuity-like configuration around 04 UT is also included (Figure 6).

Due to the very short time delay between the discontinuity at H-1 and the SSC on Earth, and due to the fact that both spacecraft were almost magnetically lined-up, it is reasonable to assume a corotational feature of the related FSWS, which H-1 first detected (Figure 6). The corotational delay of the FSWS between H-2 and H-1 is calculated according to Lin *et al.* (1968) and is about the same as the time lag between the detection of the stream by H-2 and the recorded SSC on Earth (cf. feature A, Figure 6)

$$\Delta t = (\Delta R/V) - (\Delta\Phi/\Omega) \cot \varphi,$$

where

ΔR = the radial separation between H-1 and H-2;
V = the solar wind speed between H-1 and H-2 assumed as constant;
$\Delta\Phi$ = the heliographic longitude difference between H-1 and H-2;
Ω = the angular velocity of the Sun; and
φ = the angle between the interplanetary magnetic field line and the radial direction Sun-satellite.

This time-similarity could mean that the discontinuity or shock (?) at H-1 and the SSC were the signature of the passage of this stream. According to these remarks, and because the considered-as-candidate flare was too far in heliographic longitude, it is hard to believe that the SSC on 26 March, 1976 was due to the solar flare-related shock wave.

5. The Flare on 31 March at 11:38 UT

On 31 March (DoY 91), a solar flare of optical importance 1N occurred at S07°, W09° in McMath Plage 14143. This flare was also accompanied by a type IV radio burst (Shea, 1977). Helios-2 was, at the time, about 24° west from the flare at a radial distance of 0.44 AU, while Helios-1 was in a more distant longitude west from this Plage (~74°). Helios-1 was almost at the perihelion (Figure 5). A strong interplanetary shock wave reached H-2 on 1 April (DoY 92) at 13:25 UT (Schwenn *et al.*, 1977).

From Figure 7 one could realize that this shock was only detected by H-2 a few hours after the recorded SSC on Earth, i.e., two days later from the preceding shock. The recorded SSC also indicates the onset of a sudden cosmic-ray decrease, which was clearly registered by Alert and D. River neutron monitors. For middle latitude stations, because of the large Dst decrease, this cosmic-ray depression can hardly be seen (Figure 1). But, after correction for Dst variations, the same decrease is clearly seen (Figure 2).

The fact that the reported SSC was only about 15 hr after the eruption of the flare, with which it was presumably related, according to Iucci *et al.* (1977),

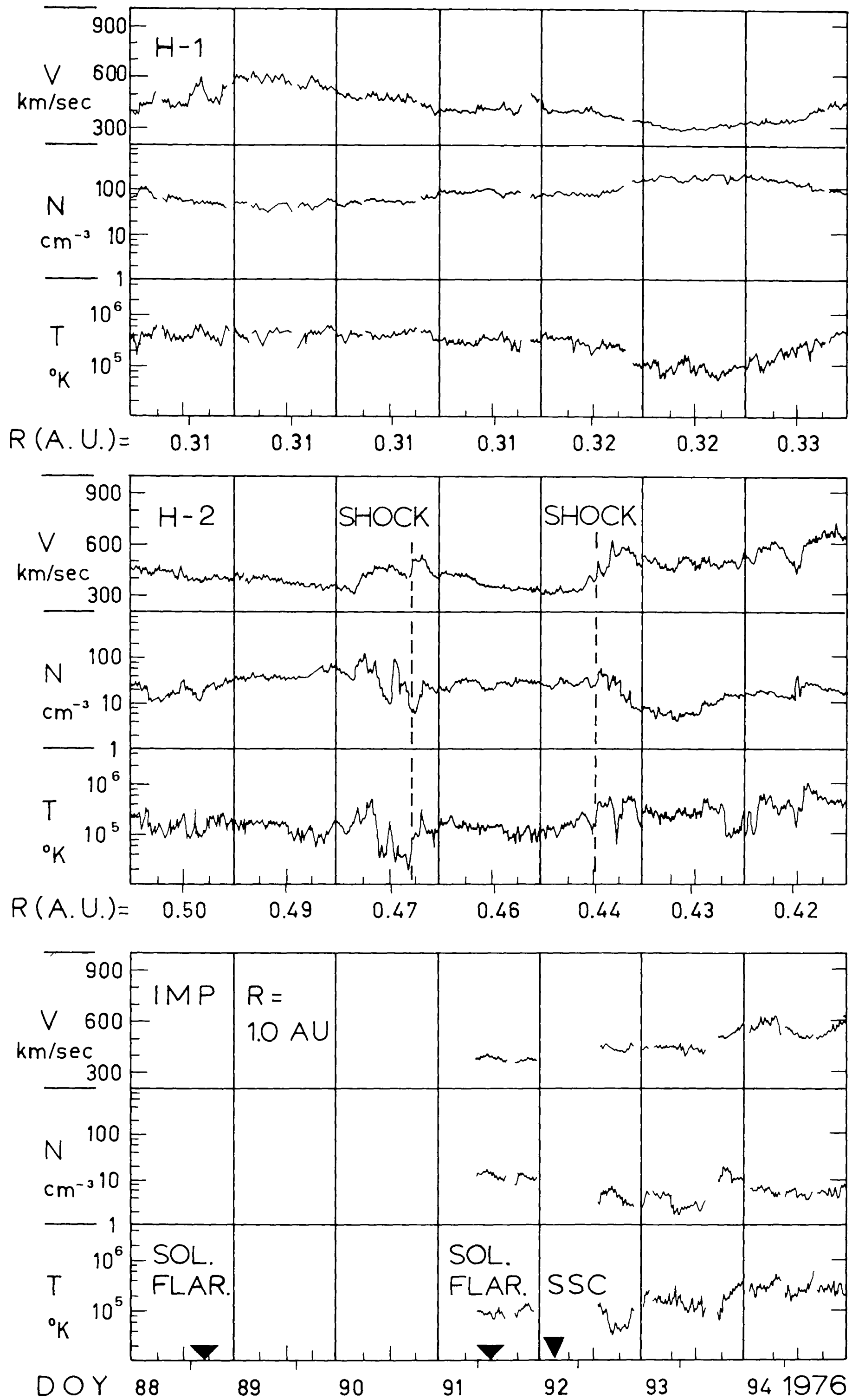

Fig. 7. The solar wind speed, the proton density and the temperature measured by Helios-1, Helios-2 and IMP-8 spacecraft during 28 March–4 April, 1976 (DoY 88–94). Two shock fronts were observed by Helios-2, the related flares are indicated in the bottom panel. The SSC recorded on the Earth is probably related to the solar flare on 28 March, 1976. The H-1 and IMP-8 data are based on 15 min averages and the H-2 data on 12 min averages.

Takahashi and Chiba (1977), means that the interplanetary perturbation was extremely fast. The related shock front, on its way from the Sun to the Earth, should have had a mean speed of the order of 3000 km s^{-1}. A rather unusual speed. The most exciting fact is that H-2 observed the shock 9 hr after the recorded geomagnetic SSC! If this shock is the same as that indicated by the SSC, it means that its speed was very anisotropic, and although H-2 was near to the Sun (0.44 AU), it observed this shock much later than was recorded on

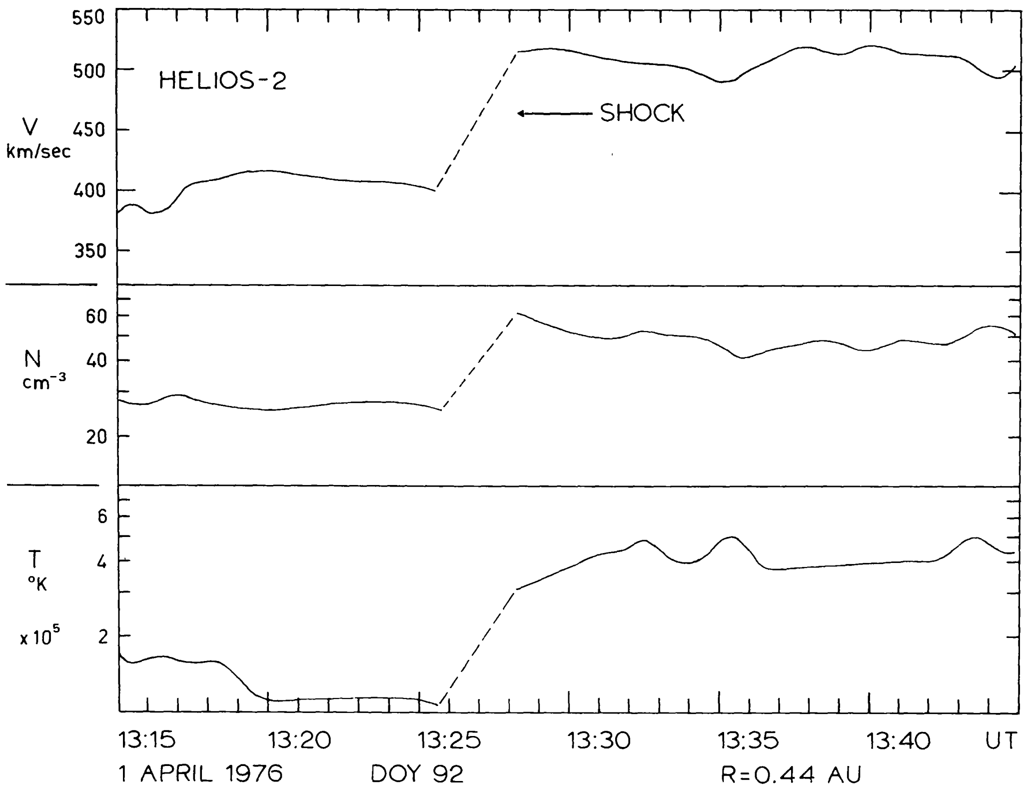

Fig. 8. The solar wind speed, the proton density and the temperature measured by Helios-2 spacecraft for the recorded shock front. The data are based on 40.5-s measurements.

Earth. Such a high longitudinal speed anisotropy is quite unexpected (the fastest shock during the August 1972 events had an anisotropy of the order of 30 km s^{-1} deg^{-1} (Zastenker *et al.*, 1978)). Helios-2 was separated in longitude from the flare only by 24°, while the Earth was separated by almost 0°. In a more detailed scale, the time-variation of the solar wind speed, density and radial proton temperature of this shock measured by H-2 is shown in Figure 8. These profiles show a jump of between 13:25:36 and 13:28:18 UT during which the detection of the front should have taken place.

For a preliminary calculation of the shock speed, we averaged the data in a 6 min interval before (1) and, after (2), this jump and assuming a radially, spherically symmetric shock, we obtained using the conservation of mass,

$$V_s = (n_2 V_2 - n_1 V_1)/(n_2 - n_1)$$

with $V_1 = 410$ km s^{-1}, $V_2 = 512$ km s^{-1}, $n_1 = 26.7$ cm^3, and $n_2 = 53$ cm^3, a shock speed $V_s = 616$ km s^{-1}.

This value is less than the mean speed of the shock estimated from the time-delay between the flare-onset and the observation of the shock by H-2 ($\bar{V} = 710$ km s^{-1}). If we assume that, in the direction ~26° in heliographic longitude west from the flare, the shock speed was constant after being detected by H-2 (~616 km s^{-1}), and if we take into account the shock mean speed estimated from the time-delay between the flare onset and the SSC (~3000 km s^{-1}), we get a shock-speed longitudinal anisotropy of the order of 100 km s^{-1} deg^{-1}! These conclusions, of course, are consistent only if the discussed SSC is related with the flare on 31 March, according to the previously cited authors (No. 3 in Figure 5) and not with the flare on 28 March (No. 2 in the same Figure), which seems to be more probable (Pintér, 1977). For the flare No. 3, an associated SSC is not reported (Shea, 1977), so we could not estimate a mean shock-speed from the Sun to the Earth. However, according to the speed values measured by H-2, it is suggested that the deceleration region should have an upper limit of 0.44 AU.

6. Conclusions

The enhanced density of the solar-interplanetary and cosmic-ray phenomena concentrated in the period 23 March–7 April, 1976 (almost at solar minimum) has been described.

An attempt has been made to correlate the causes (solar flares) with the effects (geomagnetic, cosmic-ray, and solar wind) in the interplanetary space. For this reason, we analysed these phenomena macroscopically in this space, adding (except the Sun's activity, and cosmic-ray information) information also from interplanetary sources between the Sun and the Earth.

Since the enhanced cosmic-ray intensities, especially for middle latitude neutron monitoring stations, on 26 March and 1 April 1976, fell into the Dst decreases recorded in those days, and since these enhancements were not rigidity-dependent, they should have been due to the lowering of the geomagnetic cut-off at the recording stations and the formed ring current magnetosphere.

Due to the very slow decreasing-phase of the main Forbush depression (Figure 2), the causing flare, among others, should have been errupted in the eastern solar limb (Table II). Usually, but not as a rule the SSCs are due to the interaction of interplanetary shock waves with the magnetosphere. But for the recorded SSC on 26 March at 02:33 UT, it is more likely to assume that it was produced from the interaction of a fast solar wind stream with the magnetosphere (Figure 6). Concerning the second described SSC, we conclude that it arose from the shock front interaction with the magnetosphere on 30 and not on 1 April. This shock was detected by H-2 at about 0.5 AU distance from the

Sun and, as a causing flare, should be considered the flare on 28 and 31 March (Figure 7).

In conclusion, according to the shock front observations by H-2 on 30 March and 1 April, 1976 (Figure 1), it seems that for these two shocks the estimated deceleration region is consistent with the upper limit deceleration distance (0.4 AU) derived from type II bursts observations.

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References

Aldagarova, Kh., Bogdanova, O., Kolomeets, E., and Pivneva, V.: 1975, in *14th Int. Cosmic-Ray Conf.* (*München*) **4**, 1327.
Burlaga, L.: 1968, *Solar Phys.* **4**, 67.
Chao, J. and Lepping, R.: 1974, *J. Geophys. Res.* **79**, 1799.
Dodson, H. and Hedeman, E.: 1977, World Data Center A, Report UAG-61, p. 10.
Dorman, L.: 1974, *Cosmic-Ray Variations*, North-Holland Publ. Co., p. 460.
Dryer, M., Shea, M., Smart, D., Collard, H., Michalov, J., Wolfe, J., and Warwick, J.: 1978, *J. Geophys. Res.* **83**, 1165.
Flückiger, E., Debrunner, H., Arens, M., and Binder, O.: 1975, in *14th Int. Cosmic-Ray Conf.* (*München*) **4**, 1331.
Flückiger, E., Debrunner, H., Smart, D., and Shea, M.: 1979, in *16th Int. Cosmic-Ray Conf.* (*Kyoto*) **4**, 273.
Gurnett, D., Neubauer, F., and Schwenn, R.: 1979, *J. Geophys. Res.* **84**, 541.
Iucci, N., Parisi, M., Storini, M., Villoresi, G., and Zangrilli, N. L.: 1975, in *14th Int. Cosmic-Ray Conf.* (*München*) **3**, 1064.
Iucci, N., Parisi, M., Storini, M., Villoresi, G., Zangrilli, L., and Felici, A.: 1977, World Data Center A, Report UAG-61, p. 224.
Kondo, I., Nagashima, K., Yoshida, S., and Wada, M.: 1960, in *Int. Cosmic-Ray Conf.* (*Moscow*) **4**, 208.
Krestyannikov, Yu., Sergeev, A., Tergoev, V., and Shapovalova, L.: 1977, World Data Center A, Report UAG-61, p. 221.
Kunow, H., Müller-Mellin, R., Iwers, B., Witte, M., Hempe, H., Wibberenz, G., Green, G., and Fukner, J.: 1977, World Data Center A, Report UAG-61, p. 134.
Lin, R., Kahler, S., and Roelof, E.: 1968, *Solar Phys.* **4**, 338.
Pintér, S.: 1977, World Data Center A, Report UAG-61, p. 127.
Schwenn, R., Rosenbauer, H., and Mühlhäuser, K.: 1977, *Proc. of COSPAR Symposium* (*Tel Aviv*), p. 351.
Shea, M., Smart, D., and Mc Cracken, K.: 1968, 'Instruction Manual 10', Air Force Cambridge Res. Lab., Bedford, Mass.
Shea, M.: 1977, World Data Center A, Report UAG-61, p. 1.
Solar-Geophysical-Data (SGD): 1976, U.S. Department of Colorado, USA 80302, Part I, p. 381.

Taylor, H.: 1969, *Solar Phys.* **6**, 320.
Takahashi, H. and Chiba, T.: 1977, World Data Center A, UAG-61 Report, p. 213.
Wada, M.: 1977, World Data Center A, Report UAG-61, p. 216.
Yoshida, S. and Wada, M.: 1959, *Nature* **183**, 381.
Zastenker, G., Temny, V., d'Uston, C., and Bosqued, J.: 1978, *J. Geophys. Res.* **83**, 1035.