LONGITUDINAL DEPENDENCE OF THE INTERPLANETARY PERTURBATION PRODUCED BY ENERGETIC TYPE IV SOLAR FLARES AND OF THE ASSOCIATED COSMIC RAY MODULATION

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1. Introduction. One of the most significant features of the flare-associated Forbush decreases (Fds) in the galactic cosmic ray (c.r.) intensity is the so-called East-West asymmetry /1-5/ : the solar flares (Sfs) observed in the Eastern or central region of the solar disk exhibit a higher probability to cause large Fds than the Sfs occurring in the Western portion of the disk. In particular IUCCI et al./5,6/ showed that the interplanetary perturbations generated by Type IV Sfs depress the c.r. intensity in a vast spiral cone-like region (modulated region) which extends along the interplanetary magnetic field from the neighbourhood of the active region to the advancing perturbation, and that, immediately after the flare-generated perturbation, the maximum c.r. modulation is observed between 0° and 40° W (see Figures 4 and 13 in IUCCI et al./5/) of the meridian plane crossing the flare site at time of flare (flare's meridian plane). This asymmetric c.r. modulation could be due to a longitudinal asymmetry in the interplanetary perturbation producing Fds, as suggested by AKASOFU and YOSHIDA /2/ . This expected asymmetry seems to be, at a first glance, in contradiction with the results obtained by PINTER /7/ on the base of multiple spacecraft plasma and magnetic field observations, which indicate that the flare-generated shock waves expand on a broad front which is not spherical but nearly symmetrical with respect to the flare's meridian plane . In fact, if a flare-generated shock wave, displayed symmetrically with respect to the flare's meridian plane, is the only agent responsible for Fds we could hardly explain the observed East-West asymmeytry of the modulated region.

IUCCI et al. /8,6/ showed that the front edge perturbation "strength" made up by the shock and magnetic blob effects, is well correlated (correlation coeff. 0.96) with the observed Fd-amplitude. Therefore if the shock is almost symmetrical about the flare longitude, the asymmetry of the Fd-modulated region is likely to be due to the magnetic perturbation following the shock which should be displayed asymmetrically in longitude, as suggested by HAURWITZ et al/9/.

BARNDEN/10/ found that the descending phase of some Fds exhibits a clear two-step structure which is located inside the associated interplanetary disturbance.The magnetic field intensity and solar wind plasma parameters indicate that the first step begins with the shock passage at the Earth/10,6/; the second step occurs generally near a discontinuity located inside the magnetic blob and followed by the flare ejecta or driver gas, this second decrease can be often connected to the entry of the Earth into a region with loop-like magnetic field configuration (e.g./11/ and ref. therein).

The main purpose of the present paper is to verify experimentally that an asymmetric perturbation (magnetic blob and discontinuities) following the shock is indeed responsible for the longitudinal asymmetry of the c.r. modulation; this will be done by studying statistically the separate contributions of the shock front and the following magnetic perturbation on the amplitude of the first and second step of Fds as a function of the associated Sf longitude.

2.The influence of shock and magnetic perturbation following the shock on the Fd-amplitude at 1 AU. An example of a two-step Fd time behaviour and associated parameters of the interplanetary medium is given in Figure 1.

First of all we analyzed,over the period 1964-1982, the total Fd-amplitudes as a function of the heliolongitude of the associated Sfs. Figure 2 shows that the total Fd-amplitude depends on the longitudinal position of the parent flare on the Sun; this result shows in particular that the maximum Fd-amplitude is observed when the flare is located ~20° East of the central meridian of the solar disk, in other words when the Earth enters the Fd-modulated region at ~20° West of the flare's meridian plane.

We next analyzed the relation between the amplitude of the first step of Fds and the longitudinal position of the parent Sfs. Figure 3 shows that, as an average, the highest amplitudes are observed near the flare's meridian plane, in agreement with the results obtained by PINTER /7/.

By means of the envelope curves of Figures 2 and 3 we can determine the large-scale characteristics of the two-step Fds; the polar diagram given in Figure 4 represents the heliolongitude dependence, relative to the flare longitude, of the total amplitude together with the amplitudes of the first and second steps of Fds. The asymmetric second step of Fds may be due to the longitudinal asymmetry of the magnetic perturbation following the shock /9,2/ ; the magnetic field compression produced by a nearly symmetric shock, sustained by the driver gas and expanding into the Archimedean interplanetary magnetic field, will be more pronounced somewhere in the West of the flare's meridian plane, but not too far from this plane on which the shock exhibits the highest velocities. This asymmetry is shown in Figure 5 where the parameter < B >.Δt of the magnetic blob following the shock is plotted against the heliolongitude of the parent Type IV Sf, where Δt is the time duration and < B > the average field magnitude during the blob .

3. Relation between the Fd-amplitude and the associated interplanetary perturbation. IUCCI et al./8,6/ found that when the observed interplanetary perturbation is produced by a Type IV Sf the Fd-amplitude is well correlated with an empiric perturbation parameter which is the sum of two parameters: the shock "strength" P_s and the magnetic blob "strength" P_b. If we assume that the magnetic blob "strength" is representative of the magnetic perturbation following the shock, the two parameters will correspond to the two effects reported above and therefore they can be separately correlated with each of the two steps of Fds. On the other hand a shock plus a magnetic blob were recently proved /12/ to form a suitable semipermeable obstacle to particle motion in order to produce the observed Fds. We investigated first the correlation between the total Fd-amplitude and the total perturbation parameter P_0 defined as:

$$P_0 = P_s + A.P_b = V_L + (V_1 - V_0) + 40[(N_1 - N_0)/N_0 + (B_1 - B_0)/B_0] + A(<B>\Delta t),$$

where V_L is the local shock velocity (not considered in IUCCI et al. /8,6/) in km/s computed by using the flux conservation equation: $V_L = (V_1 N_1 - V_0 N_0) \; / \; (N_1 - N_0)$; indexes 0 and 1 refer to the pre- and post-shock values respectively. The coefficient $A = 1/3600 \text{ km.s}^{-2}.\text{nT}^{-1}$ was estimated by making $<P_s> \; = \; A.<P_b>$ as indicated by the similar average amplitudes of the two steps of Fds (see Figure 3). For 21 two-step Fds an accurate estimate of P_s and P_b was possible; in Figure 6 the correlation plot between P_0 and the total Fd-amplitude confirms the results obtained by IUCCI et al./8,6/ (correlation coefficient 0.96); moreover the first step of the decrease is rather well correlated with the shock parameter P_s (correlation coeff. 0.88) as shown in Figure 7, this lower correlation may be attributed to the lower accuracy in the estimate of the first-step amplitudes.

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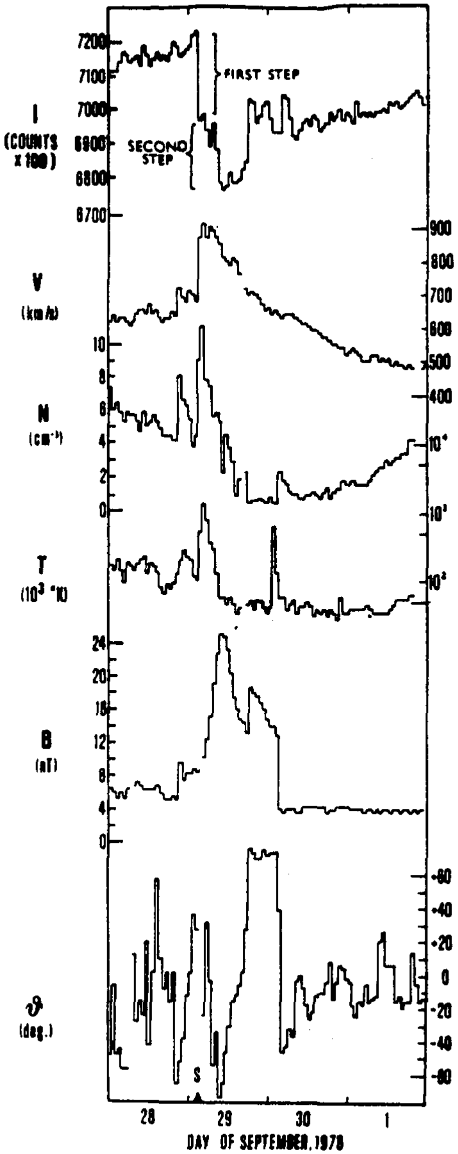

Figure 1

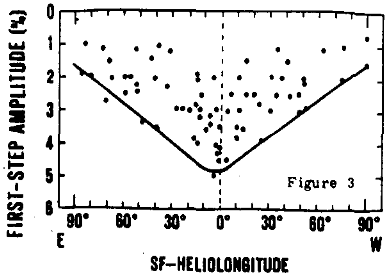

Figure 3

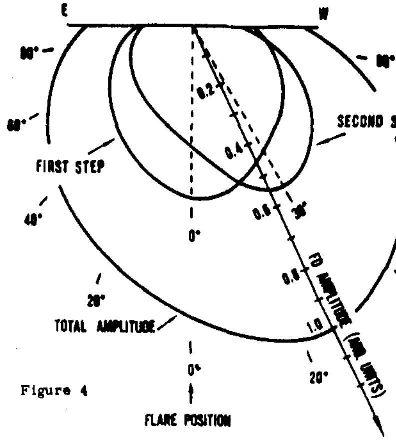

Figure 4

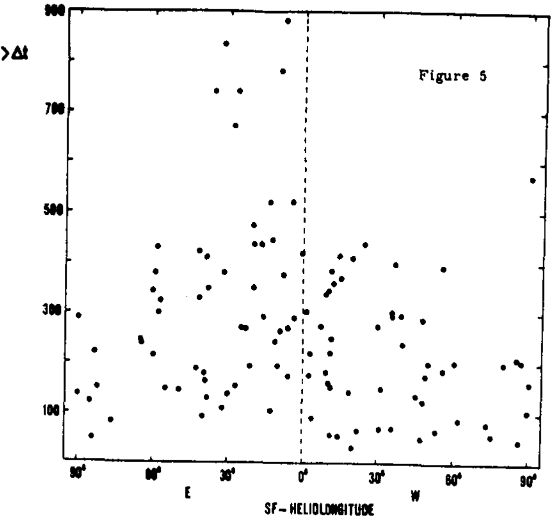

Figure 5

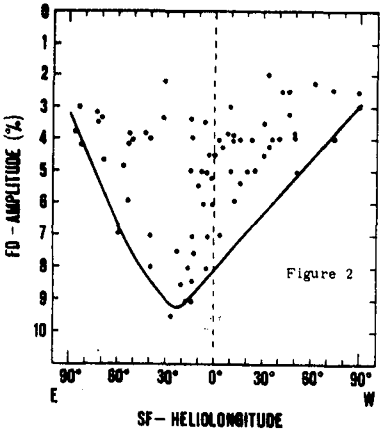

Figure 2

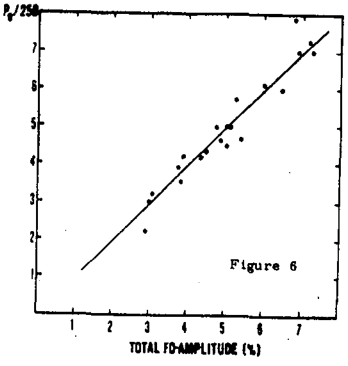

Figure 6

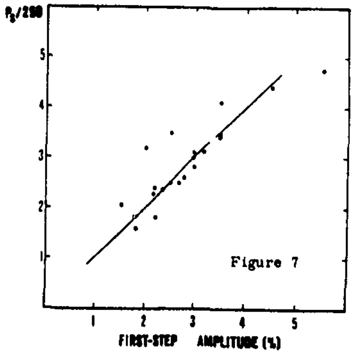

Figure 7