A database for solar energetic particles studies

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***Abstract*. Proton fluxes recorded in the energy range ∼ 4-40 MeV by Helios 1, Helios 2, and IMP 8 spacecraft (SC) during 1974-1982 were used to create a dataset of solar energetic particle (SEP) events for which at least two SC have their nominal magnetic footpoint within 20° in heliocentric longitude from each other. Solar and interplanetary conditions are also investigated for each SEP event. Eight SEP events are used to show that IMP 8 data can present some saturation period (e.g. SEP event of 27 December 1977).**

***Keywords*: solar energetic particles, flare/spacecraft parameters, data calibration**

I. INTRODUCTION

The dependence of SEP fluxes on the heliocentric radial and longitudinal distances between different observational points is a fundamental issue to understand the mechanisms involved in particle acceleration and to evaluate the conditions for SEP propagation in the interplanetary space. Moreover, knowledge of the radial dependence of solar particle intensities is necessary to estimate the SEP impact on interplanetary missions traveling into the inner solar system.

Recently, Lario et al. [1] found that the radial dependence of SEP flux is less steep than the one deduced from the diffusion transport model, when SEP fluxes are extrapolated from radial distance R = 1 AU to R < 1 AU. They noted that the SEP events, observed by at least two SC, show ensemble-averaged variations of the order of $R^{-2.7}$ for 4-13 MeV and $R^{-1.9}$ for 27-37 MeV proton peak flux. In addition, studies of multiple SC data to estimate the SEP radial gradient for individual events are complicated by the different longitudes of the space vehicles. This means that the longitudinal separation existing between the solar active region, (at the origin of the SEP event) and the footpoint of the interplanetary magnetic field (IMF) line, connecting each SC with the Sun, produces an additional gradient (longitudinal gradient).

In this paper we perform a detailed study of SEP observations by Helios 1, Helios 2 and IMP 8 SC during the period 1974-1982, taking into account both the radial distance of the SC and the magnetic connection between them and their position with respect to the solar source of the SEP event.

II. SELECTED EVENTS

SEP events with proton (electron) enhancements in the ∼ 4−40 (0.3−0.8) MeV range and recorded by at least two SC among Helios 1, Helios 2, and IMP 8 SC were reported by Gardini et al. [2]. To notice that for those events, at least two SC have their nominal magnetic footpoint within 20° in heliocentric longitude from each other. Among all SEP events reported in [2], we selected those for which at least two SC are at about the same R from the Sun, (i.e. the radial difference among SC was $\Delta R_{SC} \leq$ 0.05 AU).

Table I lists the selected events. For each SEP event, column 1 reports the assigned number, column 2 the date (year, month, day) and column 3 the longitude of associated flare (Φ_{Flare}). In column 4 are shown the names of the SC that observed the event: H1 for Helios 1, H2 for Helios 2 and I8 for IMP 8. Finally, for each SC, we report R in column 5, the heliocentric longitude (Φ_{SC}) in column 6, the heliocentric longitude (Φ_{Foot}) of the footpoint of the IMF line connecting the SC with the Sun in column 7, and the distance in longitude between the Φ_{Foot} and Φ_{Flare} in column 8. The value of Φ_{Foot} was computed by assuming the Parker spiral for the IMF configuration, with a constant solar wind speed of 450 km/s. To check that a constant solar wind velocity is a good approximation, we compared the Φ_{Foot} with the one computed by taking into account the measured solar wind speeds at the different SC. Large errors can result from the deviation of the IMF configuration from the Archimedean spiral, particularly when transient perturbations are traveling in the interplanetary medium. We checked the interplanetary space conditions at all the SC locations.

H1 and H2 particle data were obtained by the identical cosmic-ray instruments of the University of Kiel[1,2][3]. The I8 data were recorded by the Charged Particle Measurement Experiment (CPME)[3][4]. We use 1-h averaged data (see Table II for energy channels) for both the two Helios SC (whose R ranges from ∼ 0.3 to 1.0 AU) and the Earth-orbiting SC I8 (R ∼ 1 AU).

In this paper we concentrate our attention on the lowest proton energy channel. The 1-h averaged solar wind data, were provided by the plasma analyzer experiment for the two Helios SC[4,5] and by the solar plasma electrostatic analyzer for the I8 satellite[6].

To identify the coordinates of the different SC respect to the flare position at the SEP event time, we use 1-h

[1] http://nssdcftp.gsfc.nasa.gov/spacecraft_data/helios/helios1/particle/
[2] http://nssdcftp.gsfc.nasa.gov/spacecraft_data/helios/helios2/particle/
[3] http://sd-www.jhuapl.edu/IMP/data/imp8/cpme/cpme_1h/
[4] ftp://nssdcftp.gsfc.nasa.gov/spacecraft_data/helios/helios1/merged/
[5] ftp://nssdcftp.gsfc.nasa.gov/spacecraft_data/helios/helios2/merged/
[6] ftp://nssdcftp.gsfc.nasa.gov/spacecraft_data/imp/imp8/plasma_lanl/

TABLE I: List of selected SEP events; columns fifth to eighth report for each SC: - the heliocentric radial distance R, - the heliocentric longitude (Φ_{SC}), - the heliocentric longitude (Φ_{Foot}) of the footpoint of the IMF line connecting the SC with the Sun, - the distance in longitude between the Φ_{Foot} and Φ_{Flare}.

Event number	Date yy-mm-dd (DOY)	Φ_{Flare}	SC	R [AU]	$\Phi_{SC}[°]$	$\Phi_{Foot}[°]$	$\Phi_{Foot} - \Phi_{Flare}[°]$
1	1974-12-22 (356)	E14	H1	0.97	356	46	60
			I8	0.98	0	50	64
2	1974-12-25 (359)	W26	H1	0.97	355	45	19
			I8	0.98	0	50	24
3	1977-12-27 (361)	W79	I8	0.98	0	50	-29
			H2	0.90	356	42	-37
			H1	0.92	322	9	-70
4	1978-01-01 (1)	E06	H1	0.95	321	10	16
			H2	0.93	355	43	49
			I8	0.98	0	50	56
5	1978-02-13 (44)	W20	H2	0.96	342	31	11
			H1	0.95	308	-3	-23
			I8	0.99	0	51	31
6	1978-04-28 (118)	E38	I8	1.01	0	52	90
			H1	0.31	44	60	98
			H2	0.29	67	82	120
7	1979-01-05 (5)	E54	H1	0.89	309	-5	49
			H2	0.92	349	36	90
			I8	0.98	0	50	104
8	1979-01-21 (21)	W85	I8	0.98	0	50	-35
			H2	0.97	345	35	-50
			H1	0.96	307	-7	-92

averaged trajectories data for the two Helios SC[7,8]; when those data were not available and for the I8 ones, we used the 1-day averages one[9]. The time for the passage of interplanetary shocks at H1 and H2 were taken from [5]. Finally, the SEP association with specific solar flares was based on either previous works (e.g. [6], [7]) or on the temporal coincidence with intense solar flares listed in the Solar Geophysical Data.

TABLE II: Energy channels of SC experiments

SC	PROTONS CHANNELS [MeV]			ELECTRONS CHANNEL [MeV]
H1	4-13	13-27	27-37	0.3-0.8
H2	4-13	13-27	27-37	0.3-0.8
I8	4-15	15-25	25-48	0.2-2.5

III. Data analysis

Figure 1 illustrates the eight analyzed proton events (see Table I) for the lowest energy channel of each SC.

Events N° 1 and 2 are recorded by H1 and I8 at about the same R, Φ_{Foot} and $|\Phi_{Foot} - \Phi_{Flare}|$. Hence, we expect peak flux values of the event similar in both SC. A comparisons shows that this is not the case. We argue that the use of the data requires a calibration, given that the interplanetary conditions for both events do not suggest any physical reason for such behavior.

For event N° 4, the three SC are at the same R; H2 and I8 are well connected ($\Delta\Phi_{Foot} \leq 7°$) between each other, with an angular distance from the parent flare around 50°. As for the above events a calibration between H2 and I8 SC is necessary. H1 is not connected with the other SC but the distance of Φ_{Foot} from the Φ_{Flare} is less than 20°. Hence, it records the steepest increase of the event and the highest peak flux value.

For event N° 7, H2 and I8 are well connected ($\Delta\Phi_{Foot} \leq 14°$), although they are not at the same R. The shape of the proton flux profiles are similar, suggesting that the I8 decrease is due either to the greater R and to a calibration problem. On the contrary, H1 and H2 are at the same R but not connected with each other. The corresponding proton flux variation among H1 and H2 is almost one order of magnitude and it can be attributed mostly to the longitudinal gradient between the SC, given that they are no more than 0.03 AU apart between each other in radial distance.

[7] http://nssdcftp.gsfc.nasa.gov/spacecraft_data/helios/helios1/traj/
[8] http://nssdcftp.gsfc.nasa.gov/spacecraft_data/helios/helios2/traj/
[9] http://cohoweb.gsfc.nasa.gov/

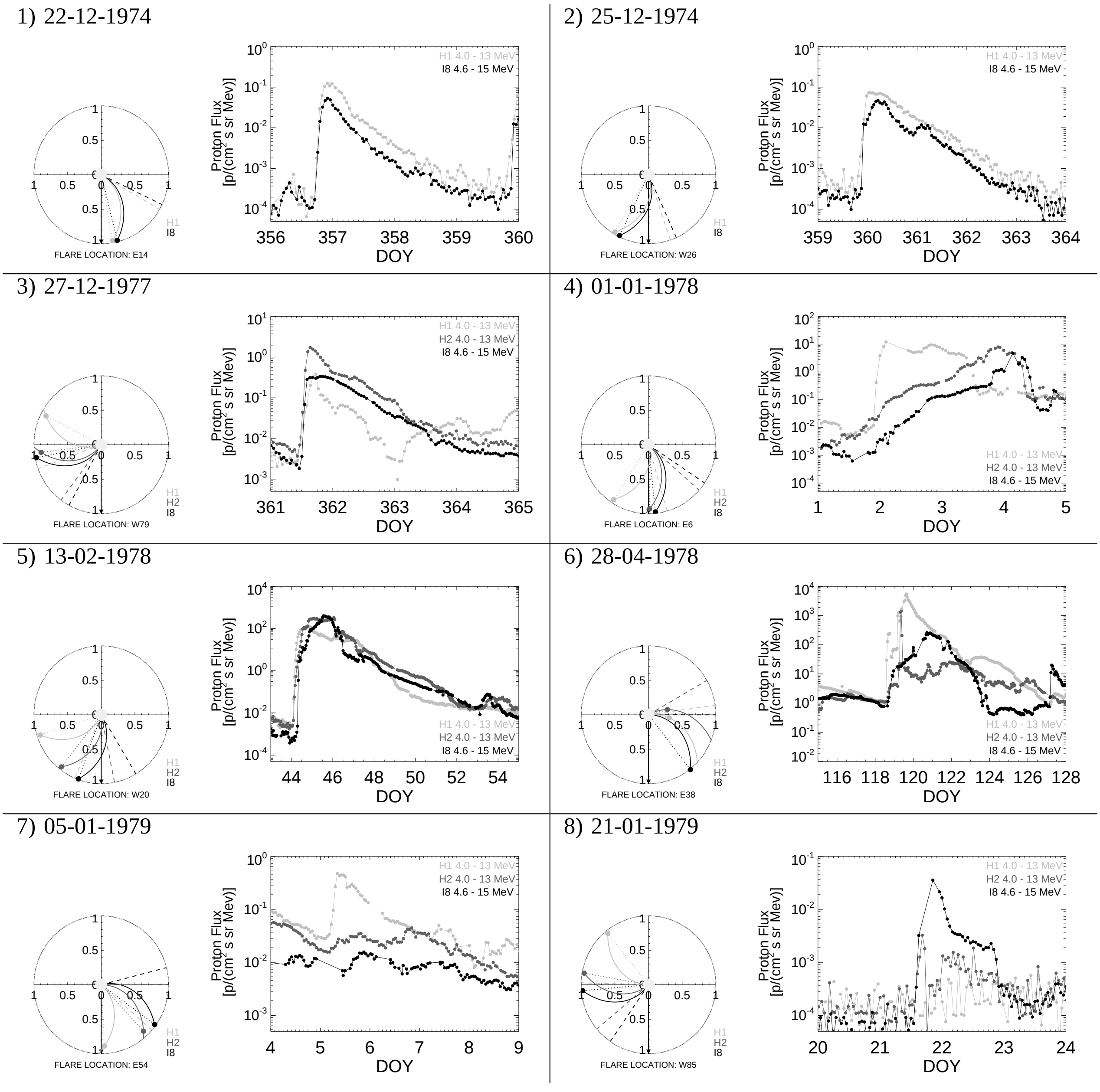

Fig. 1: The eight SEP events as listed in Table I. For each event, left panel :Φ_{Flare} (black arrow), Φ_{SC} (dotted line), Φ_{Foot} (dashed line), and the nominal magnetic connection line with the Sun (solid line), for H1 (light grey), H2 (dark grey) and I8 (black), computed by assuming a constant solar wind speed. Rigth panel: proton fluxes recorded by the three SC.

Moreover, the magnetic angular distance from the flare is $\geq 49°$ for H1, $\geq 90°$ for H2, up to at least $108°$ for I8, that gives the minimum extension of the associated shock, if we assume that the events associated with flares far from the observing SC magnetic footpoints, result from particle injection by broad coronal shocks (e.g. [8]).

For event N° 8, the three SC are at the same R; I8 and H2 are connected ($\Delta\Phi_{Foot} \leq 15°$) with each other. In particular, for this event, even if the nominal connection among the two SC is close, H2 hardly observes a significant intensity increase. This cannot result from flux dissipation from one spacecraft to the other (implying a steep radial dependence of peak intensities), given that both the SC are at the same heliocentric distance. We could suppose that SC are not really connected between themselves, as suggested by the nominal Archimedean spiral, and that the IMF structures formed between H2 and I8 might have impeded the particle transport from one spacecraft to the other. Examination of the solar wind conditions for the event does not show the presence of great perturbations at the considered SC orbits, although a more detailed analysis is needed. Another possible explanation is that, although connected, both the SC are inside the longitude range $30°-50°$, where a greater flux decrease might happen with respect to other longitude ranges as proposed by [2]. Indeed, [9], [10], [11], [12], and [13] estimated a *cone of emission* of $\pm 30°$ for impulsive flares, indicating that the particles are released in a localized region and not at a coronal shock. Nevertheless, [7] showed that impulsive flares (as in the last case) have a greater *cone of emission*, of the order of $\pm 50°$ while the gradual flares ones is $\pm 120°$, and interpreted them as a reflection of the different size of the CMEs in these events.

For event N° 5, the three SC are at the same R and with the distances of their Φ_{Foot} from the (gradual) Φ_{Flare} less than $\sim$ 31°, i.e. all inside the *cone of emission*. To notice that the magnitude of event profiles recorded by SC decreases with the increasing distances of their Φ_{Foot} from the parent flare. In addition, although I8 and H2 are connected, their flux profiles have different shape, suggesting that this difference is not only due to the calibration. Indeed, since $\Delta\Phi_{Foot}$ among H2 and I8 is about 20°, it is possible that the two SC are not really connected between themselves, as suggested by the nominal Archimedean spiral.

During event N° 6, the SC at the same R (i.e. H1 and H2) are not connected each other, therefore we can only verify that the peak flux recorded by the three SC decrease with increasing $|\Phi_{Foot} - \Phi_{Flare}|$, as expected. Moreover, the magnetic footpoints distances of the three SC from the parent (gradual) flare are all greater than 90°; the I8 one is about 120°, exactly the half width of *cone of emission*. In this case we are no able to separate the different contributions (due to $\Delta R \geq 0.7$ AU among H1 and I8 and the distance of their Φ_{Foot} respect to the parent flare) responsible for a proton flux decrease.

Finally, we show, for event 3, that saturation might compromise the proton flux evaluation. During this event, H2 and I8 are connected ($\Delta\Phi_{Foot} \leq 8°$) with each other, but at slightly different distances. In addition, I8 has the smallest distance of Φ_{Foot} from the flare, H1 the farthest, and their ΔR is $\sim$ 0.06 AU. From these considerations, we should expect that the I8-flux would be higher than H1-flux and comparable to the H2-flux. Nevertheless, experimental results demonstrate that the flux is higher in H1 than in I8, suggesting saturation for the $\sim$ 4-15 MeV channel of the IMP 8 SC.

IV. Conclusion

In previous papers we analyzed several SEP events recorded by three space vehicles (I8, H1, H2) aiming to investigate SEP radial dependence [14], [2]. Nevertheless we identified some inconsistences in the recorded SEP fluxes from the different SC that cannot be attributed to any physical condition in the interplanetary space. It was suspected that a data calibration of the I8 data is necessary before any investigation. Here eight SEP events are reported in detail and it is demonstrated that I8 data seem to present also some saturation periods.

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