Solar-Heliospheric-Magnetospheric Observations on March 23-April 26, 2001: Similarities to Observations in April 1979.

D. B. Berdichevsky[1,2], C. J. Farrugia[3], R. P. Lepping[2], I. G. Richardson[4,2], A. B. Galvin[3], R. Schwenn[5], D. V. Reames[2], K. W. Ogilvie[2], and M. L. Kaiser[2]

[1]*L-3 Communications Analytics Corporation, Largo, Maryland 20774, USA*

[2]*NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, Mail Code 600, USA*

[3]*Space Science Center, University of New Hampshire, Durham, NH 03824, USA*

[4]*Department of Astronomy, University of Maryland, College Park, MD 20742, USA*

[5]*Max-Plank-Institut für Aeronomie, D 37191 Katlenburg-Lindau, Germany*

Abstract. We discuss the similarities and differences of two intervals of extreme interplanetary solar wind conditions, separated almost precisely by two solar cycles, in April 1979 and March-April 2001. The similarities extend to various data-sets: Energetic particles, solar wind plasma and interplanetary magnetic field. In April 1979 observations were made by three spacecraft covering a wide longitudinal range (~ 70°) in the heliosphere. Data are presented from Helios 2, located 28° East of the Sun-Earth line at ~ 2/3 AU, and from near the Earth. Observations of the 2001 interval are from Wind. We examine the geomagnetic activity during each interval.

1. INTRODUCTION

Interplanetary coronal mass ejections (ICME) also named ejecta cause the largest geomagnetic disturbances at Earth (e.g., Richardson et al., 2001). Their effect may be altered (enhanced or reduced) if instead of single ejecta, we have a sequence interacting with each other. We focus on the interplanetary causes of two geomagneticaly active intervals, one during the maximum of the current solar cycle (March-April 2001), the other at the maximum of cycle 21 (April 1979).

The 2001 interval was dominated by activity associated with the largest sun spot group in 10 years, consisting of three or more active regions (ARs) centered near AR 9393. For this period of unusually intense solar activity we discuss here energetic particle, radio, solar wind plasma and magnetic field parameters observed by the Wind spacecraft. An unusual sequence of fast ejecta accompanied by a comprehensive set of related signatures (long-lasting, intense radio emissions, gradual solar energetic particle (SEP) enhancements, unusually strong magnetic fields and extreme plasma conditions) were detected. In this paper we list the sequence of disturbances during the extended interval of March-April 2001. We also compare part of this interval with April 1 to 7, 1979. The geomagnetic response of the Dst index will be contrasted.

2. INTERPLANETARY OBSERVATIONS

Figure 1 shows the observations at Wind from March 26-April 26, 2001.

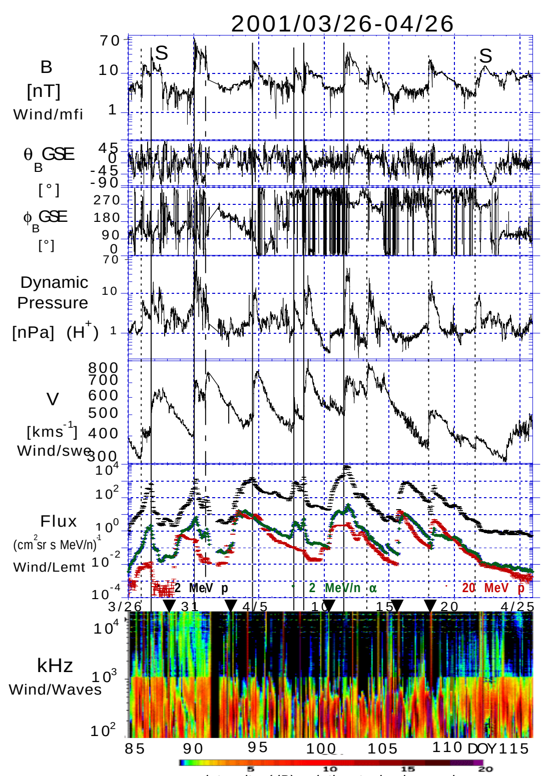

Figure 1. Presented IMF and plasma observations are 5-min averages. SEP: 2 MeV protons (black), 8 MeV α (green), and 20 MeV protons (red) are 1-hour averages. The radio frequency spectrogram shows 1-min average with color scale 0.1-20 decibels. For details see text.

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From top to bottom are plotted the total magnetic field and its components in GSE coordinates, the proton dynamic pressure ($m_pN_pV_{SW}$), bulk speed, SEP intensities at Wind in the MeV range, and radio signals in the range 10^2–$1.2 10^4$ kHz. These observations were made while Wind was executing a distant prograde orbit at (X1, Y1, Z1~) 0, −240, 0 R_E (GSE coordinates). Vertical lines in Figure 1 mark the passage by Wind of 11 shock candidates. Solid vertical lines indicate solar wind discontinuities at shocks with MeV energetic particle enhancement, other shock passages are marked with dashed-lines. Another less distinct shocks may be present. An example is indicated by the long-dashed vertical line late on March 31. The onsets of the SEP events –two to three days prior to the passage of the shock – align with type III radio bursts (vertical radio intensification lines which are in the bottom panel). Those associated with the lift-off of five of the CMEs that generated moderately strong SEP events are indicated with solid inverted triangles between the two bottom panels. During the interval in Figure 1, 11 halo CMEs were observed with LASCO/SOHO, 7 candidate ejecta intervals (suggested by the slow rotation of the IMF) may be identified, and there were at least 3 extended regions of very low, almost disappearing solar wind plasma (dynamic pressure was ≤ 1 nPa).

We will now focus on the period March 28-April 1, 2001. During this interval, SOHO LASCO and EIT observed signatures of two full halo CMEs directed toward Earth. One lifted off at ~ 1100-1200UT, from ~0° longitude on March 28, the other at ~1030UT from ~ N20W19 on March 29. The speed of the March 28 CME in the plane of the sky was estimated at 500 km/s over the south pole and there was negligible deceleration. This CME is possibly associated with a flare in AR 9397 [see e.g.,

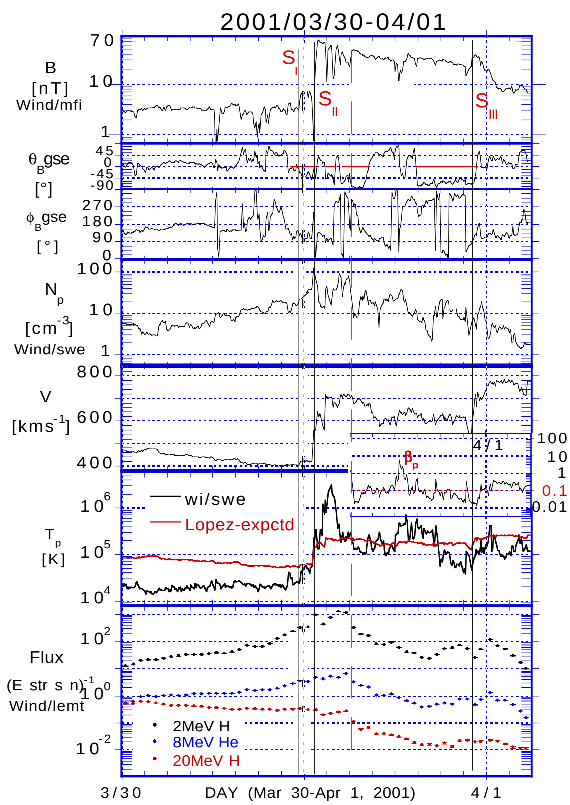

Figure 2a: Observations for the period 00UT March 30 to 06UT April 1, lines are 5-min average. Starting from the top: IMF strength B, latitudinal, longitudinal orientation of **B** in GSE coordinates, proton density N_p, solar wind speed V, and proton temperature T_p. The bottom panels contain the intensity of 2 MeV proton (black), 8 MeV α (blue) and 20 MeV proton (red).

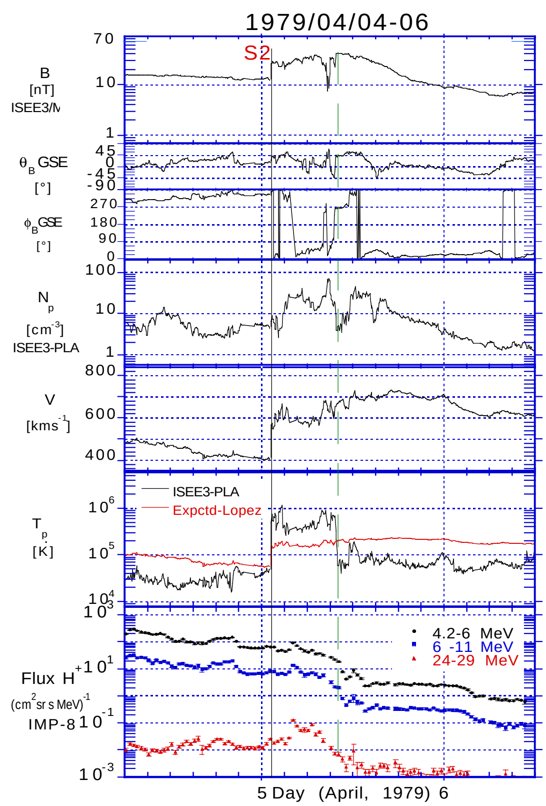

Figure 2b: ISEE-3 observed for the period 06UT April 4–12UT April 6, 1979, same as in Fig. 2a except that bottom panel shows IMP-8 energetic proton chanels: 4.2-6 MeV (black, higher flux), 6-10 MeV (blue, medium), and 24-29 MeV (red, lower).

Sun et al., 2002]. The March 29 halo CME had the much higher plane of the sky speed of ~1000 km/s with apparently significant deceleration. It was associated with an X1.7 flare in AR 9393. Figure 2a shows at Wind the total interplanetary magnetic field, and components in GSE coordinates, the proton density, bulk speed, temperature, and finally energetic particles in the MeV range. Figure 2a reveals two, almost coincident, shocks, S_I at 2330 UT on March 30 and S_{II} at 0111UT on March 31. These are more clearly identified from the twofold impulsive rise in T_p panel. A third shock S_{III} was seen by Wind 21 hours later. What is the relationship between these three shocks and the two halo CMEs? Both the arrival time and high speed of S_{III} at Wind exclude any association with the halo CMEs. The two first shocks are more likely related to the halo CMEs. Their proximity in time is consistent with the observation that the second halo CME twice as fast as the first one. Approximately six hours after the shocks S_I and S_{II} are two distinct regions of very strong magnetic fields (approximately ~18 hours of ≥30 nT) of low variance, each with low proton beta plasma ($\beta_p \leq 0.1$,

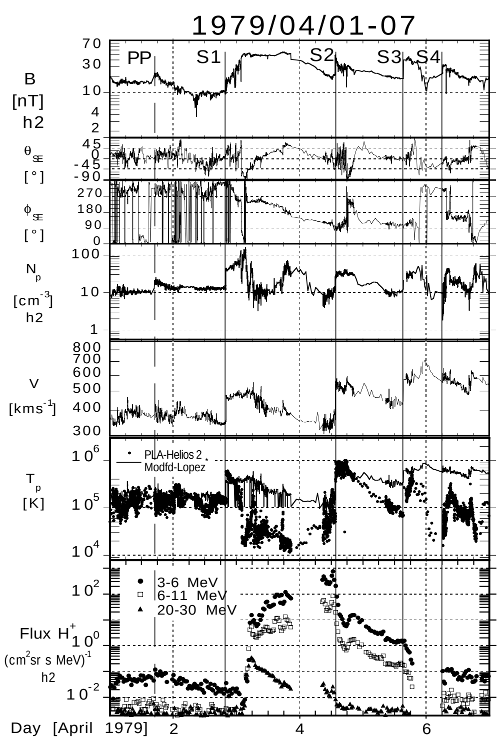

Figure 3: Helio 2 data for the time period 12UT April 1-12UT April 7, 1979, in the same format as in Figures 2a and 2b. The bottom panel shows Helios 2 energetic proton chanels: 3-6 MeV (full circles, higher flux), 6-11 MeV (open squares, medium), and 20-30 MeV (full triangles, lower).

illustrated in inset in Figure 2a). They are separated by a narrower region where the field is weaker (10 nT at ~12-13UT) and proton beta is high. These may be the ejecta corresponding to the two halo CMEs. The weakness of the first shock relative to the second is in our view an indication that the ejecta are in the process of coalescing, and the first shock in the process of disappearing. The complex nature of the interval is seen from the SEP profile with spike at the strong shock S_{II} and later at the start of the first extended low β_p region. A decrease in the proton temperature (T_p) and a substantial drop in the flux of MeV particles help to identify the start of the ejecta interval in Figure 2a, indicated with a vertical long-dashed line.

Next we focus on a similar interval on April 1-7 1979 in which CMEs were observed in the process of overtaking each other (Burlaga et al., 1987), in observations from Helios 2 (see Figure 3, same parameters as in Figure 2a). The location of Helios 2 and 1 are shown in Figure 4.

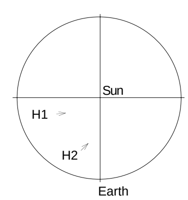

Figure 4. Shown are locations at approximately 68° of Helios 1, 28° of Helios 2 on the interval April 1-9, 1979. Length of line indicates the approximate displacement of the Helios spacecraft for the interval and arrow the direction of displacement.

Helios 1 observes different solar wind streams, placing in that way a limit to the longitudinal extent of the ejecta observed at Earth and Helios 2. There are at least four shocks at Helios 2, each preceding an ejecta. As during the March 27-April 1, 2001 period, a single SEP event (associated to a sun disk lift-off location W43° (W15°) from Helios 2 (Earth) at ~ 1100 UT on April 3, 1979) was present (Richardson and Cane, 1996). This was related to the ejecta driving shock S2. Did these ejecta observed in the inner heliosphere eventually coalesce? In fact those associated with S2 and S3 had done so by the time they arrived at Earth. Figure 2b shows data from ISEE-3 (situated near L1 point). Only one shock corresponding to S2 at Helios was still present at Earth. The disturbances in the B and V profiles are now much attenuated. The shock S3 and a possible shock S4 at Helios have dissipated. It is suggested that the ejecta passing Helios 2, and driving shocks S2, S3 and possibly S4 coalesced within about 0.3 AU downstream and 27° West of Helios 2, to form a "complex-ejecta", to use the terminology of Burlaga et al. 2002.

Both the March 30-April 1, 2001 ISTP era events and the April 4-6, 1979 Helios 2 events are related to solar CMEs that followed in quick succession (Sun et al., 2002; Burlaga et al., 1987). Similarities in Figures 2a and 2b are: i) the shocks S_{II} and S2 moving into low proton beta regions, ii) extraordinary heating and extreme densities in the shocked regions, iii) sharp decrease of the MeV SEP fluxes (~ 50%) at the beginning of the ejecta intervals, indicated by vertical long-dashed line in Figures 2a and 2b. There are also differences such as the latitudinal orientation of the IMF, the attenuated variations in IMF, V, T_p and SEP on April 5, 1979 at Earth, in Figure 2b when compared with those on March 31, 2001, in Figure 2a.

3. CONCLUSIONS

We have examined two intervals separated by 22 years, where solar wind conditions show some stricking similarities, in particular the merging of multiple ejecta.

How do the two events compare in their geoeffectiveness? In 2001, a great storm (minimum Dst < -380 nT, the largest of the current solar cycle) started on March 31 with a recovery phase lasting up to April 5. The Kp index exceeded 6 for the whole day and reached saturation at 9 UT. A second major storm was observed on April 11 (minimum Dst <-240 nT), with a recovery lasting to April 18. Two further, moderate storms (minimum Dst ~ -100 nT) followed.

By contrast during the 1979 period only one moderate-major storm was recorded (minimum Dst <-180 nT), on April 4, 1979, due to the passage of a magnetic cloud with a substantial southward excursion of the IMF (Burlaga et al., 1987). The following, putative coalesced ejecta discussed here barely affected the recovery phase of the earlier magnetospheric disturbances. Thus, there is a sharp contrast between the magnetic disturbances elicited by the respective magnetic configurations. This weaker activity in 1979 is due to the absence of a strong southward orientation of the IMF. This may be the result of a combination of factors: (1) the coalescence of the ICMEs, and/or (2) the longitudinal separation between Helios 2 and the Sun-Earth line. This is the subject of further study.

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