INTERPLANETARY SHOCKS AND SOLAR WIND STRUCTURE APPROACHING SOLAR MAXIMUM: *HELIOS, IMP-8* AND *VOYAGER OBSERVATIONS*

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Abstract. We studied solar wind observations of five different spacecraft: *Helios 1*, *Helios 2*, *IMP-8*, *Voyager 1* and *Voyager 2*, from November 1977 to February 1978. In this period the large-scale dynamics of the solar wind near of the ecliptic plane was characterized by transient forward shocks (TFSs), ejecta, unstable corotating interaction regions (CIRs), and complex and variable magnetic sector structures. We identified 12 forward shock events of different origin. We did not find any clear tendency of the shock parameters with heliocentric distance nor longitudinal angle, but comparing the observations of each shock event we found local variations in the shock strength and the mean propagation velocities from one spacecraft to another. These unsystematic variations indicate that there were local deformations of the shock fronts, which we attribute to the inhomogenuos solar wind structure that affects the shock propagation.

1. Introduction

During the ascending phase of the solar sunspot cycle the Sun has a very complex magnetic field topology, the latitudinal extent of the current sheet increases, solar activity rises, and polar coronal holes shrink, with smaller holes appearing at low latitudes. This produces a complex pattern of solar wind streams and ejecta in the interplanetary medium. In late 1977 and early 1978 (ascending phase of solar cycle 21), a unique 'conjunction' of five interplanetary missions: *Helios 1* (H1), *Helios 2* (H2), *IMP-8*, *Voyager 1* (V1) and *Voyager 2* (V2), occurred within a relatively small heliographic range. We combined the simultaneous solar wind observations of these spacecraft from November 1977 to March 1978, to perform a multi-point study of forward heliospheric shock waves. We obtained trajectory files and one-hourly averages of solar wind plasma and interplanetary magnetic field (IMF) data of the spacecraft using NSSDC's COHOWeb.

Figure 1 shows the spacecraft trajectories in a frame of reference where the line Sun–Earth is fixed. During this interval the spacecraft angular separations were always less than 60 deg. H1 and H2 covered a heliocentric rage from 0.3 to 1 AU, *IMP-8* was always located at 1 AU, and V1 and V2 were on route to Jupiter, covering a heliocentric range from 1.2 to 2.4 AU.

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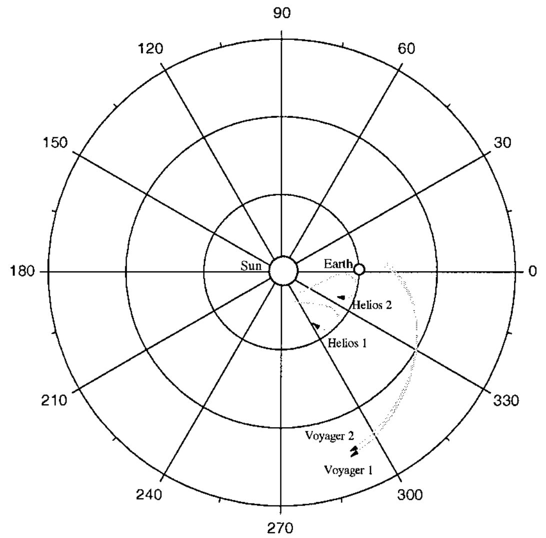

Figure 1. Spacecraft trajectories from November 1977 to March 1977. Sun-Earth line reference system.

2. Solar Wind Streams and Shock Analysis

Using data from the five spacecraft, we produced 27-day plots of solar wind velocity, density, temperature and IMF magnitude. We visually inspected the plots looking for the characteristics profiles of corotating interaction regions (CIRs), transient forward shocks (TFSs) and ejecta to produce a shock list. We corroborated the shock identifications by plotting each event in detail and checking against the H1 and H2 shock list by (Volkmer and Neubauer, 1985), the IMP shock list by (Borrini *et al.*, 1982); and the V1 and V2 studies by (Burlaga *et al.*, 1984; González-Esparza and Smith, 1996). We identified 12 different shock events: 7 TFSs and 5 CIR-associated shocks, which some of them are not listed in the references above.

Figure 2 shows the solar wind bulk speed observations of the five spacecraft. All the plots have the same scale and the numbers are the shock events: shadowed cases are CIRs and vertical lines TFSs. As expected, the five CIR-events were observed by the all spacecraft, but this was not the case for the TFSs. For instance, shocks no. 2 and 7 were observed by only four spacecraft; shocks no. 4 and 12 by only three spacecraft; and shock no. 9 by H2 and IMP only. The patterns of solar wind bulk speeds are similar in the five plots, indicating that the streams were corotating with the Sun in a stable way within the angular range covered by the five spacecraft. Note the process of speed attenuation with heliocentric distance, the speed differences between slow and fast winds are higher in H1 and H2 observations than in V1 and V2 observations.

When we compare proton density, temperature, and IMF magnitude observations of the five spacecraft, as in Figure 2, we find many local variations in plasma

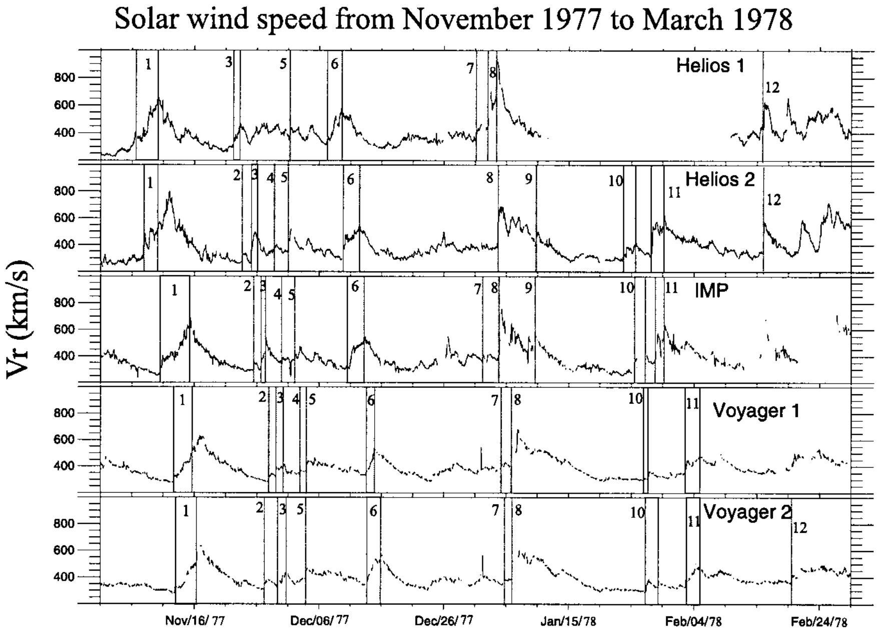

Figure 2. Solar wind bulk speeds observed by the five spacecraft.

and IMF parameters, i.e., variations detected by only one spacecraft, in any of these parameters. These local inhomogeneities are not compressive events since the variations in density, temperature and IMF magnitude are uncorrelated. These small-scale plasma and IMF inhomogeneities reflect the structured nature of the solar wind streams.

We scanned the plasma and IMF data series of the five spacecraft to take the first set of one-hourly averaged solar wind values just before (upstream) and just after (downstream) every shock. Then we estimated the local jumps in density, temperature and IMF magnitude related to each shock. With this information we compared the approximate shock strength of the same event at different locations. We analyzed the 12 shocks to see if we could find any tendency of the shock jumps with heliocentric distance or longitudinal angle. We did not find any clear tendency either for forward CIR-related shocks or for TFSs. These unsystematic variations of the shock strength at different locations imply that the fronts of TFSs have irregular shapes with different strengths at different shock front positions.

We found some differences in the characteristics of CIR-associated shocks and TFSs. Within the region of study, transient shocks tended to be stronger than CIR-shocks, and they appeared to propagate through faster ambient wind than the CIR-shocks.

3. Conclusions

The study of the 12 shock events reveals variations in the shock parameters that do not show a clear tendency with heliocentric distance or heliolongitude, but suggests that the shock fronts have irregular shapes. We attribute these shock front deformations to the evolution of the interplanetary disturbances through structured ambient solar wind.

Acknowledgements

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