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IPS OBSERVATIONS OF FLARE-ASSOCIATED INTERPLANETARY DISTURBANCES IN FEBRUARY 1979

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Abstract

Directional properties of the propagation of three flare-associated interplanetary disturbances in February 1979 are studied on the basis of the solar wind data obtained by the scintillation (IPS) technique. These disturbances were associated with intense solar flares which occurred within the McMath plage region No. 15380 at the heliolongitudes of E59, E13, and W15 on Feb. 16, 18, and 20, 1979 respectively. It is found that the directional velocity distributions of these flare-associated disturbances near 1 AU were distorted by the ambient solar wind stream structure.

1. Introduction

The active region of McMath No. 15830 produced a series of solar flares in February 1979. Among them, at least three solar flares were accompanied by type II radio bursts, and several sudden commencements (SC's) of high geomagnetic activity were observed in Feb. 18-22. Since the solar flares which produced the interplanetary disturbances occurred at various heliolongitudes (E59, E13 and W15), it is appropriate to see how the propagation properties depend on the longitudes of the solar flares. Furthermore, there were two corotating high-speed streams during the interval in question. It is particularly interesting to see the relationship between the configurations of the shock disturbances and the solar wind stream structure because several authors predicted anisotropic propagation of flare-associated disturbances within an inhomogeneous solar wind (e.g., Heinemann and Siscoe, 1974; Hirshberg et al., 1974; Chao and Lepping, 1974; Akasofu et al., 1983). We construct three-dimensional directional diagrams of the propagation velocities of the flare-associated disturbances in February 1979 using the solar wind data obtained by the three-station IPS observations, and compare them with velocity distribution of the ambient solar wind.

2. Flare-shock associations and dynamical characterists of the interplanetary disturbances

The data of H_{α} solar-flare monitors, solar radio bursts and geomagnetic activity are taken from the Solar Geophysical Data. The sudden commencements (SC's) of high geomagnetic activity were observed on Feb. 18, 21 and 22, 1979. Since the active region No. 15830 produced numerous solar flares during the relevant interval, it is difficult to determine a definite association between a given solar flare and a given enhancement of geomagnetic activity. Among the solar flares, at least three solar flares were accompanied by Type II radio bursts, which indicated the occurrence of coronal shock waves. We propose the associations given in Table 1. In the case of the shock 3, the Type II radio burst was reported at 0934 UT on Feb. 20. Unfortunately, there was a data gap of the H_{α} monitor when the radio burst took place. Although we cannot pinpoint the active region which produced the Type II burst, the active region No. 15380 seems to be the most plausible candidate because this active region showed very high flare activity during the interval. The average velocity of each disturbance, V(AVE), between the sun and the Earth is given in Table 1. Approximate hydrodynamical shock speeds (Vs's) of the shocks 1 and 3 are estimated on the basis of the solar wind data obtained by IMP-8 and ISEE-3 (King, 1983), and given in Table 1. For the shock 2, Ogilvie et al. (1982) estimated the local shock speed at ISEE-3, and their result is shown in this table. It is seen that the average speeds of the shocks 1 and 3 are considerably faster than the corresponding local shock speeds near the Earth. This means that these disturbances were decelerated on their way to the Earth. If velocity evolution of an interplanetary disturbance is expressed by a form of $V_s \propto R^{-\alpha}$, where R is the heliocentric distance (e.g., Dryer, 1974), the power low deceleration coefficient α is determined using the observed shock speed at the Earth and the time interval between the onset of the solar flare and the arrival of the disturbance at the Earth (Gosling et al., 1975). Obtained deceleration coefficient of each disturbance is also given in Table 1.

Tabel 1: Flare-shock associations in February 1979.

	SOLAR FLARE			SC	V(AVE)	Vs	
SHOCK	M/D/UT	POSITION	CLASS	M/D/UT	km/s	km/s	α
SHOCK 1	2/16/0144	N16E59	3B	2/18/0304	844	520	0.8
SHOCK 2	2/18/0637	N16E13	1B	2/21/0302	610	618	0
SHOCK 3	2/20/0934*	N16W15	?	2/22/12-13	820	620	0.6

* Type II burst.

3. IPS observations

The geometry of the lines of sight of five radio sources on Feb. 21, 1979 is shown in Fig. 1. The position of the peak of the weighting function of each line of sight is indicated by a tick (Readhead, 1971). Daily solar wind flow speeds were obtained using the three-station IPS technique by two independent groups at Toyokawa (TYKW) and at University of California, San Diego (UCSD). Detailed description of the observational procedures were given by Kojima (1979), and Coles and Kaufman (1978) respectively. The observational frequency at TYKW was 69 MHz, and 74 MHz at UCSD. The solar wind data (flow speeds) taken at UCSD were published in the Solar Geophysical Data, and plotted also in Fig. 2. Typical uncertainty in the flow-speed estimation by means of the three-station IPS technique is less than 10 % of a measured value. IPS activity of each radio source was estimated at TYKW from the rms of intensity fluctuations normalized by the galactic background noise level. When high IPS activity was observed, the dates are indicated by shadings in Fig. 2. Flare-associated interplanetary disturbances are identified by the simultaneous increase in the IPS activity and the flow speed (Watanabe et al., 1973; Kakinuma and Watanabe, 1976). Since the level of IPS activity is a measure of level of turbulent state in the solar wind plasma, it is considered that highly turbulent post-shock plasma (or driver gas) is detected by the IPS observations.

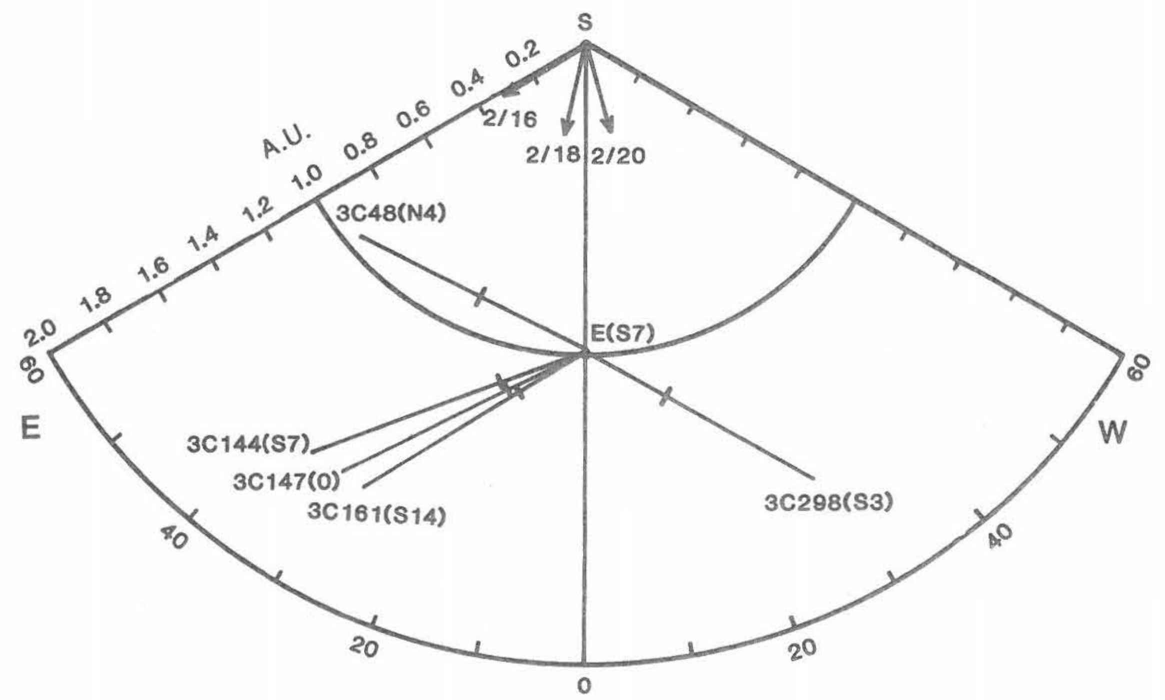

Fig. 1: Geometry of the lines of sight of five radio sources on Feb. 21, 1979. The peak of the weighting function of each line of sight is indicated by a tick. The longitudes of the solar flares given in Table 1 are indicated by arrows.

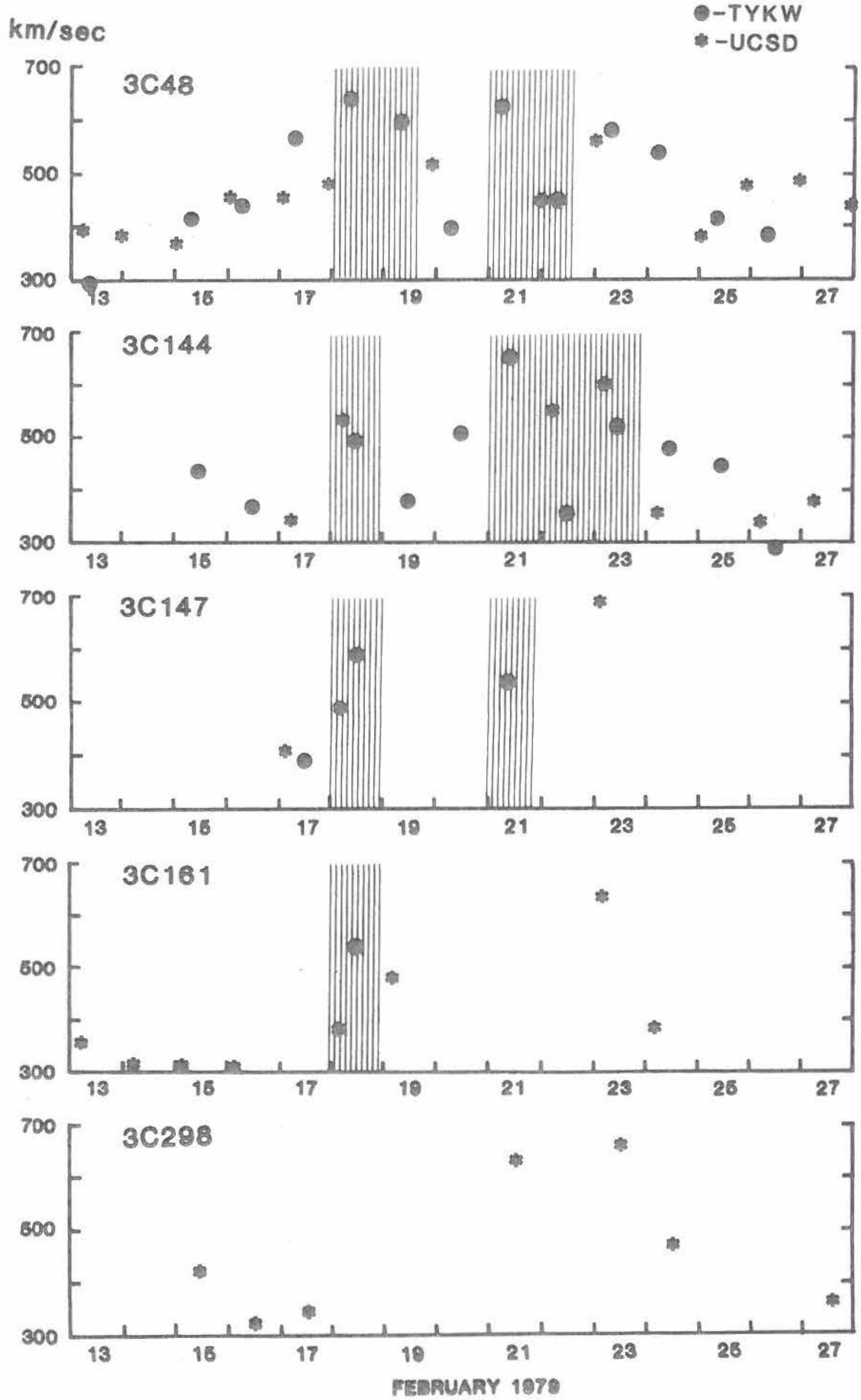

Fig. 2: Daily flow speeds observed by the three-station IPS technique at Toyokawa (TYKW) and at University of California, San Diego (UCSD). Shadings indicate high IPS activity.

4. Directional properties of the propagation of interplanetary disturbances in February 1979

Three dimensional distributions of propagation velocities of the flare-associated disturbances in February 1979 are determined in this section on the basis of the IPS observations. In the case of the IPS observations, hydrodynamical shock speeds of the disturbances are not obtained through the usage of the Rankine-Hougoniot equation because solar wind density cannot be determined by the observations (the degree of electron-density fluctuations is estimated by the IPS observations). Average shock speeds between the Sun and the lines of sight of several radio sources were employed to find directional characteristics of several disturbances (e.g., Rickett, 1975; Pintér, 1977). The directional diagrams of the propagation speeds determined by this method have, however, considerable ambiguity because the time of the first detection of a disturbance has uncertainty of up to 24 hours. The ambiguity in the arrival time will destroy the details of obtained directional diagrams. This limitation of the IPS technique is improved when the IPS observations made at different geographycal longitudes are available.

Since the average shock speeds are not determined unambiguously at present, we employ an empirical method to estimate the hydrodynamical shock speed on the basis of the IPS observations. It is known that the shock speed of a spherical shock wave disturbance within an ideal gas ($\gamma=5/3$) is $4/3$ ($\simeq 1.3$) times as high as the post-shock flow speed (Simon and Axford, 1966). Provisional statistics of published examples of flare-associated disturbances show that the ratio of the shock speeds to the post-shock flow speeds are about $1.1 \sim 1.2$. In the following discussion, the local shock speed of a disturbance is estimated in such a way that the observed flow speed of the post-shock region is multiplied by 1.2. We call the shock speed obtained by this method the inferred shock speed. We normalize the inferred shock speeds (Vi's) to those at 1 AU (Vl's) using the formula, $Vl=Vi\ Rp^{\alpha}$, where Rp (in AU) is the heliocentric distance of the peak of the weighting function of each line of sight.

4-1. Shock 1

As shown in Table 1, the solar flare accompanied by the Type II radio burst took place at N16E59 on Feb. 16, and associated SC was reported on Feb. 18. Enhancements of IPS-activity levels and flow speeds were observed on Feb. 18 by the IPS observations of 3C48, 3C144, 3C147 and 3C161 (see Fig. 2). The directional diagrams of the normalized, inferred shock speeds of the disturbance in the longitudinal and the latitudinal directions are shown in Fig. 3. The local shock speed near the Earth (ISEE-3) is also shown. For comparison, approximate longitudinal distribution of the ambient solar wind speeds at 1 AU on Feb. 18 is also shown in Fig. 3. This velocity distribution is drawn on the basis of the solar wind data obtained by IMP-8 and ISEE-3 (King, 1983) assuming that the pattern of velocity distribution did not change during +5 days around Feb. 18. We removed the data which are considered to have been affected by the disturbances, and replaced with the flow speeds observed in the next rotation assuming that the stream structure was stable for one solar rotation. It is seen in Fig. 3 that the shock 1 made considerably anisotropic expansion particularly in the longitudinal direction and that high propagation velocities are found in the radial direction of the high-speed stream, situated in the region to the east of the Sun-Earth line. It is difficult to distinguish between a corotating shock and a flare-associated shock on the basis of shock normal angle alone when a corotating high-speed stream exist immediately to the east of the Earth as in the case of this disturbance.

4-2. Shock 2

The solar flare occurred at N16E13 on Feb. 18, and associated SC took place on Feb. 21 as shown in Table 1. In the case of this disturbance, the average shock speed was approximately equal to the local shock speed at 1 AU (Table 1). This means that the shock 2 was of a driven-type, and propagated with nearly constant speed out to the Earth. Zwickle et al (1983) found several characteristic properties of the driver gas of this disturbance in the solar wind data obtained by ISEE-3 such as the He/H increase. The IPS observations of 3C48,

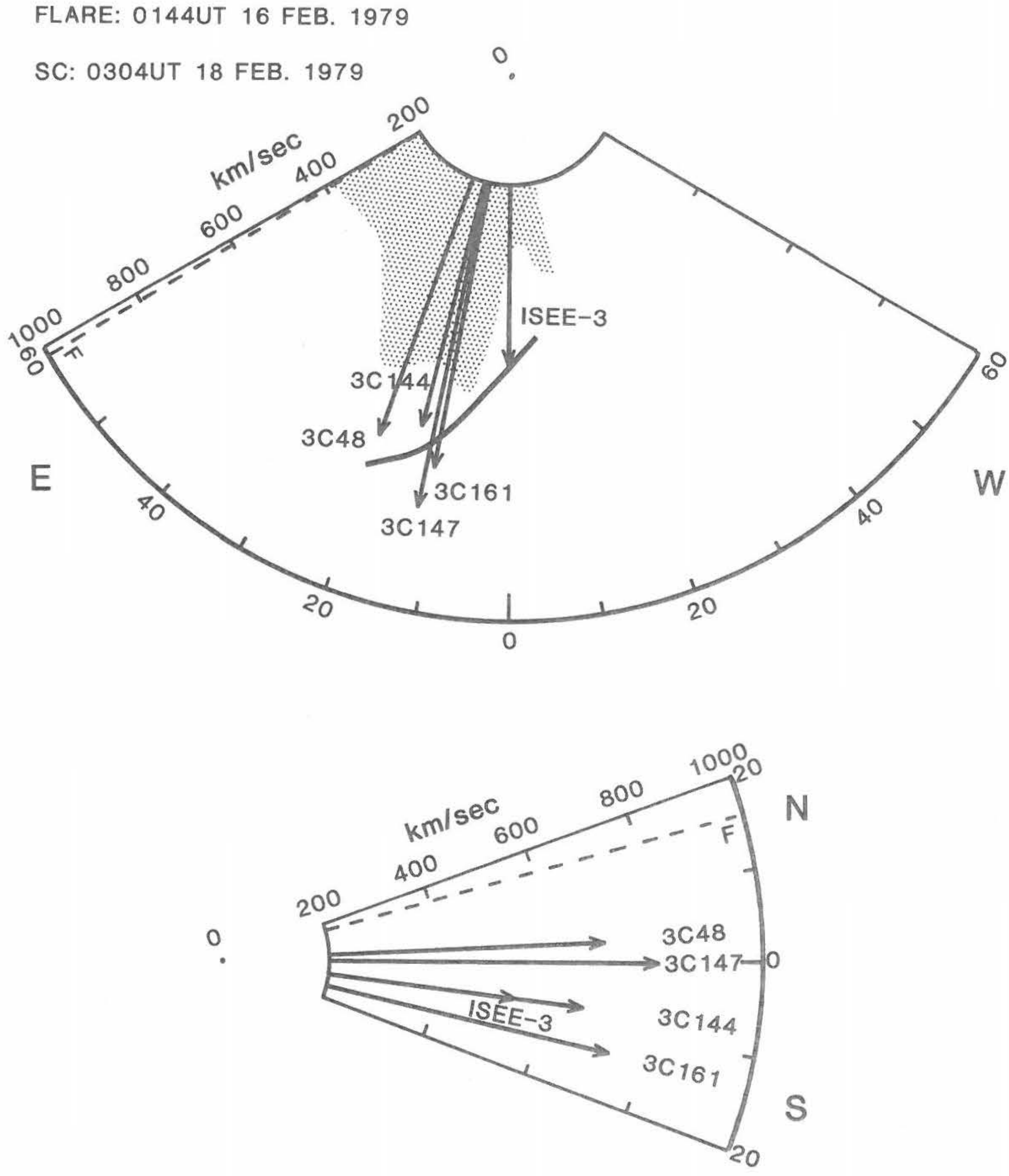

Fig. 3: Directional diagrams of the propagation speeds of the shock 1 at 1 AU in the longitudinal direction (upper panel) and in the latitudinal direction (lower panel).

Broken line in each panel indicates the flare normal (F). Shading in the upper panel is approximate velocity distribution of the ambient solar wind near 1 AU (see text).

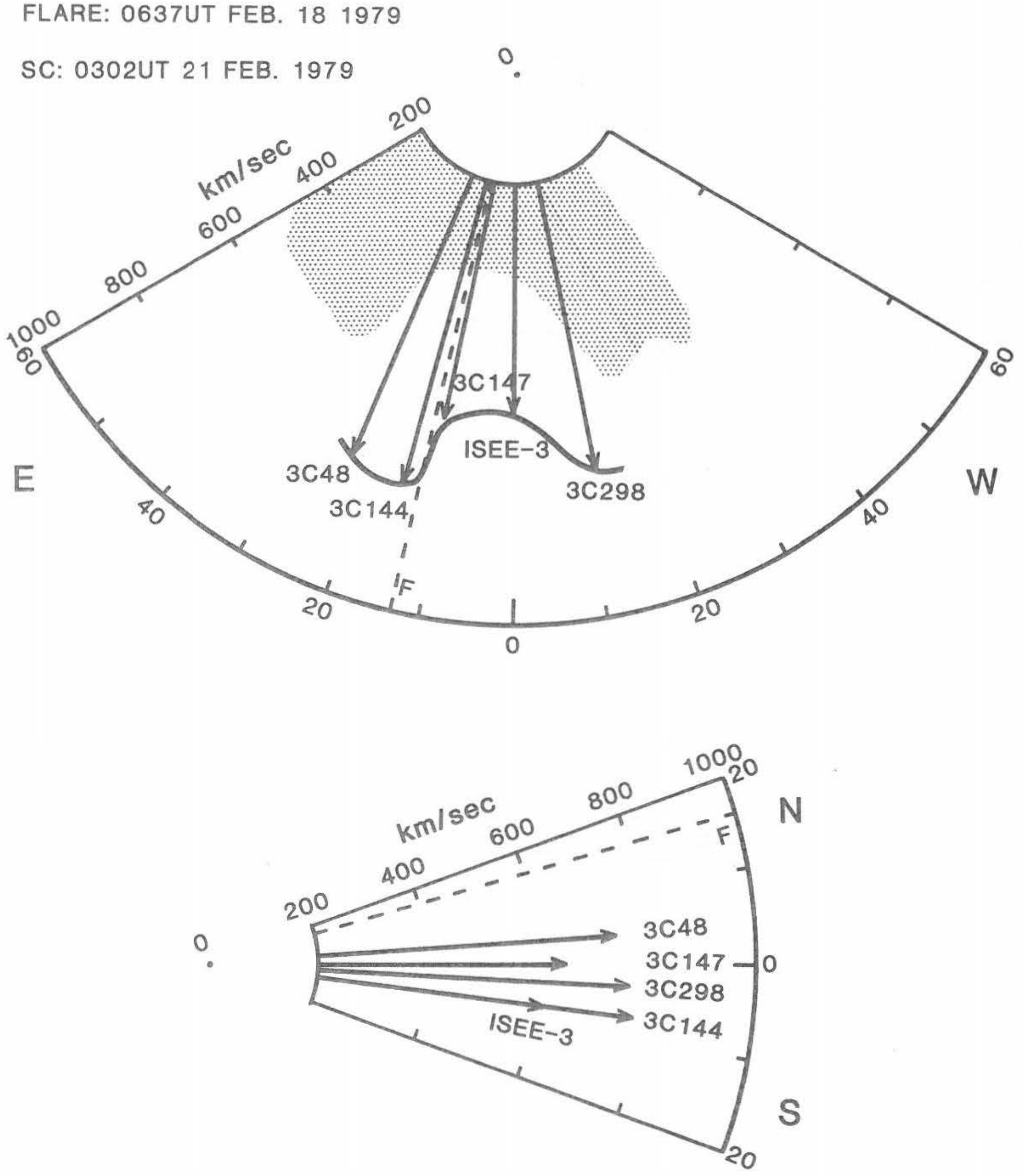

Fig. 4: Same as Fig. 3 but for the shock 2.

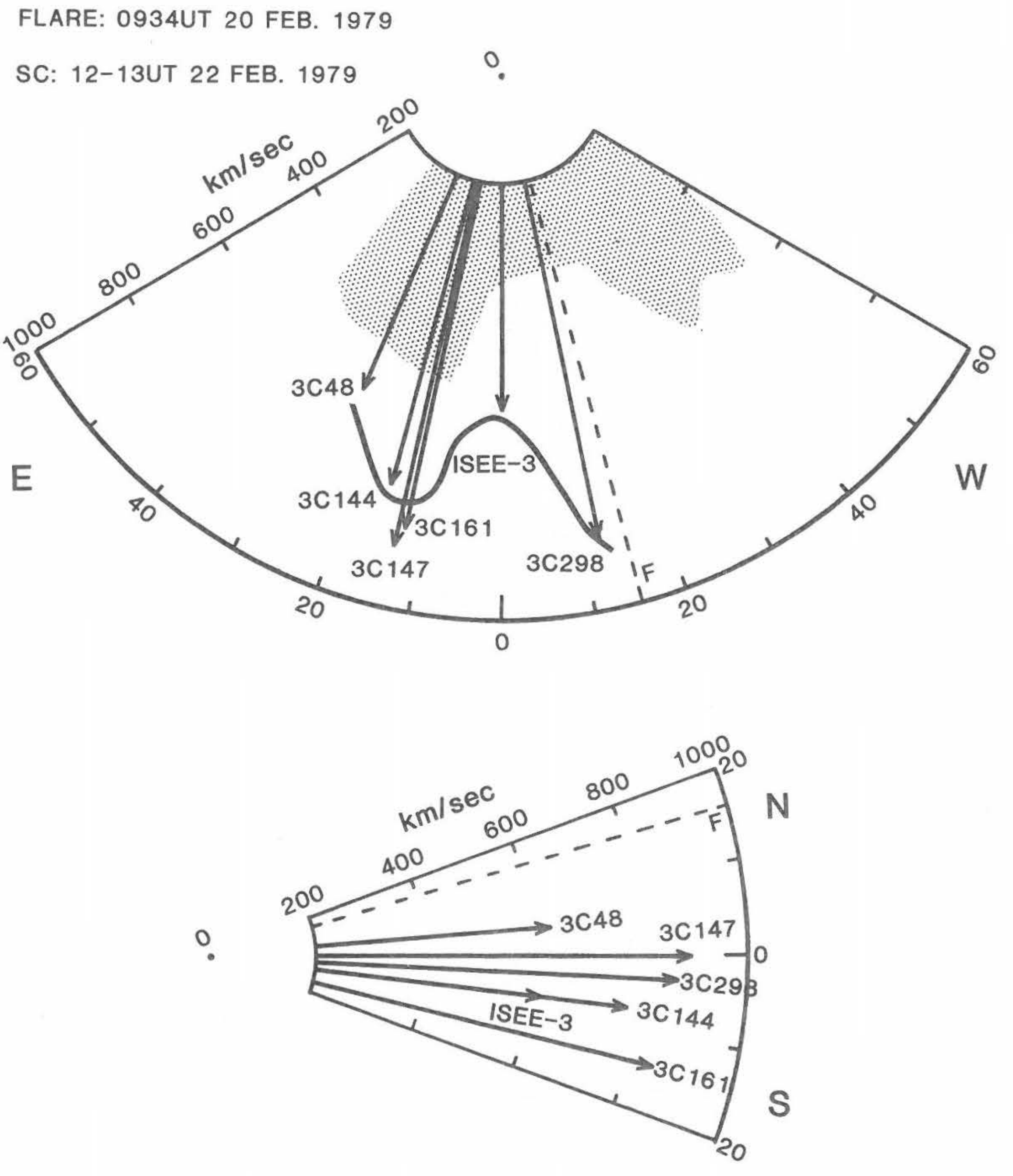

Fig. 5: Same as Fig. 3 but for the shock 3.

3C144, 3C147 and 3C298 detected the interplanetary disturbance associated with the flare on Feb. 21. The longitudinal and the latitudinal distributions of the normalized, inferred shock speeds of the disturbance are shown in Fig. 4. The longitudinal velocity distribution of the ambient solar wind at 1 AU is also shown in Fig. 4a. This disturbance showed weak anisotropic nature both in the longitudinal and the latitudinal directions. The longitudinal shock-speed distribution shown in Fig. 4a reflects the velocity distribution of the ambient solar wind near 1 AU. Two high-speed streams are found in Fig. 4a in the eastern and the western hemispheres of the interplanetary space respectively. The portion within each corotating high-speed stream propagated faster than the portion within the low-speed stream.

4-3. Shock 3

As described in section 2, the identification of the solar flare relating to the Type II radio burst of Feb. 20 is somewhat ambiguous, but the Type II burst seems to have occurred at N16W15 on Feb. 20. The SC of high geomagnetic activity took place on Feb. 22 between 12 UT and 13 UT. This disturbance was detected by the IPS observations of 3C48, 3C144, 3C147, 3C161 and 3C298 during Feb. 22-23 as seen in Fig. 2. The directional diagrams of normalized, inferred shock speeds in the longitudinal and the latitudinal directions are shown in Fig. 5. Since the ratio of the shock speed to the post-shock flow speed of this disturbance at ISEE-3 was about 1.1, the anisotropic nature of the disturbance is somewhat strengthened in Fig. 5. The velocity distribution of the ambient solar wind is also shown in Fig. 5. The longitudinal velocity distribution of the shock 3 still reflected the solar wind stream structure as seen in Fig. 5, although the solar wind state is considered to have been highly disturbed by the preceding disturbance (shock 2).

5. Concluding remarks

We have seen that the propagation properties of the flare-associated disturbances observed near 1 AU in February 1979 were largely governed by the ambient solar wind stream structure. It is suggested that the propagation of a shock wave disturbance through interplanetary space is largely the result of the general outward flow of the solar wind plasma. The IPS observations of many interplanetary disturbances will be useful to study the propagation of the disturbances through inhomogeneous solar wind.

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