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INTERPLANETARY DOPPLER SCINTILLATION OBSERVATIONS OF SAKIGAKE IN FEBRUARY 1986

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Abstract

A series of flare-associated interplanetary disturbances produced high level Doppler scintillations of Sakigake on 5–7 February 1986. The levels of electron density fluctuations within the disturbances were about 10 times higher than the ambient level.

1. Observations

Interplanetary Doppler scintillation (IPDS) responds to solar wind speed in addition to electron density fluctuations, is roughly the product of solar wind speed and electron density fluctuations (Woo et al., 1985). It is expected that the IPDS observation will be useful to detect interplanetary disturbances because both the solar wind speed and the degree of density fluctuations are enhanced in the postshock region, as observed by the intensity-scintillation (IPS) technique (Watanabe and Kakinuma, 1984). We discuss propagation properties of solar flare-associated interplanetary disturbances observed in early February 1986 on the basis of IPDS observations of a Japanese deep-space spacecraft Sakigake (MS–T5). The heliocentric distance of the spacecraft was about 0.84 AU, and its longitude was about W57° on 10 February 1986. The radio signal generated by an Earth-based cesium clock at the frequency of 2.11161 GHz was sent back from the spacecraft to the Earth at 2.29315 GHz. A 36–bit frequency counter at the 64–m ISAS deep space station in Usuda, Japan was employed to measure the Doppler frequency. The measurements were performed on almost every day at 20^h UT. The standard deviation of frequency fluctuations are calculated as the daily IPDS level at a sampling frequency of 1 per minute for time spans of 20 minutes. The contamination due to instability of the cesium clock (about 3×10^{-3}Hz) is removed.

2. Empirical Modeling

High level IPDS was observed for 3–4 days from immediately before the onset of high geomagnetic activity on 6 Feb. We try to explain the enhancement of the IPDS level by subsequent passage of flare-associated interplanetary disturbances. We determine the empirical models of the interplanetary disturbances in association with several intense solar flares assuming that the IPDS level is proportional to the product of the plasma speed and the degree of electron density fluctuations. We also assume that the degree of density fluctuations is proportional to R^{-2} where R is the heliocentric distance. The plasma speed of an interplanetary disturbance is expressed as follows (Watanabe et al., 1986);

$$V = V_{MAX} \ (R/R_0)^{-DE} \cos \ M(L - SL) \ \cos \ N(B - SB) + V_0 \qquad (1)$$

where VMAX is the initial plasma seed at the apex, R_0 is the heliocentric distance from which the disturbance begins to decelerate, DE is the exponent, (L, B) are the longitude and the latitude measured from the Sun–Earth line, (SL, SB) are those of the apex, M and N are multiplication factors, and V_0 is the ambient flow speed. In the region between the Sun and R_0, we assume that the plasma speed is $(V_{MAX}+V_0)$. It is necessary to assume also the radial thickness of the shell of the enhanced plasma speed (DR). The degree of electron density fluctuations within the disturbance is assumed to be NDE times higher than the ambient level. The level of IPDS which is expected to be observed is calculated through the integration of the product of the transverse component of the flow vector and the degree of electron density fluctuations along the line-of-sight of Sakigake, then the result is compared with the observed IPDS level. We also check consistency among the predicted flow speeds at the Earth and the observed plasma speeds at IMP-8 (Solar-Geophysical Data).

Dryer and Smith (1986) performed an MHD simulation of the solar/interplanetary events in early February 1986 for six flares which are listed in Table 1. Proposed flare-ssc associations are added (Solar-Geophysical Data).

Table 1. Major Solar Flares and SSC's During 3–9 February 1986

Flare	Date (X-ray max.)	Location (Active Region)	Classification (Optical/X-ray)	Radio Burst (Metric Sweep)	SSC
1	3 Feb. (2049 UT)	S09 E26 (AR4711)	1B / M2.3	Type II/IV	
2	4 Feb. (0741 UT)	S03 E21 (AR4711)	3B / X3.0	Type II	6 Feb. (1312 UT)
3	4 Feb. (1029 UT)	S02 F68 (AR4713)	1B / M6.4		
4	5 Feb. (1255 UT)	S07 E06 (AR4711)	2B / M3.0		
5	6 Feb. (0625 UT)	S04 W06 (AR4711)	3B / X1.7	Type II	7 Feb. (1512 UT)
6	7 Feb. (1034 UT)	S10 W20 (AR4711)	2B / M5.2	Type IV	9 Feb. (1748 UT)

From the result of the simulation, the interplanetary shock wave associated with Flare 1 would have been overtaken by the second shock wave en route to 1 AU. The effect of Flare 3 is seen to be of no importance. The fourth shock waves would have been overtaken by the fifth one. Thus, for simplicity, we discuss propagation properties of interplanetary disturbance for Flares 2, 5, and 6 in this provisional work. Since we have no information on the solar wind conditions in the region to the east of the Sun-Earth line at present, we only discuss the propagation properties of these disturbances in the region to the west of the Sun-Earth line. The predicted time variation of the IPDS level is shown in Figure 1 with daily IPDS data of Sakigake. The parameters assumed in the modeling are also given in Figure 1. We cannot check the model for Flare 6 because of a data gap of IPDS observations.

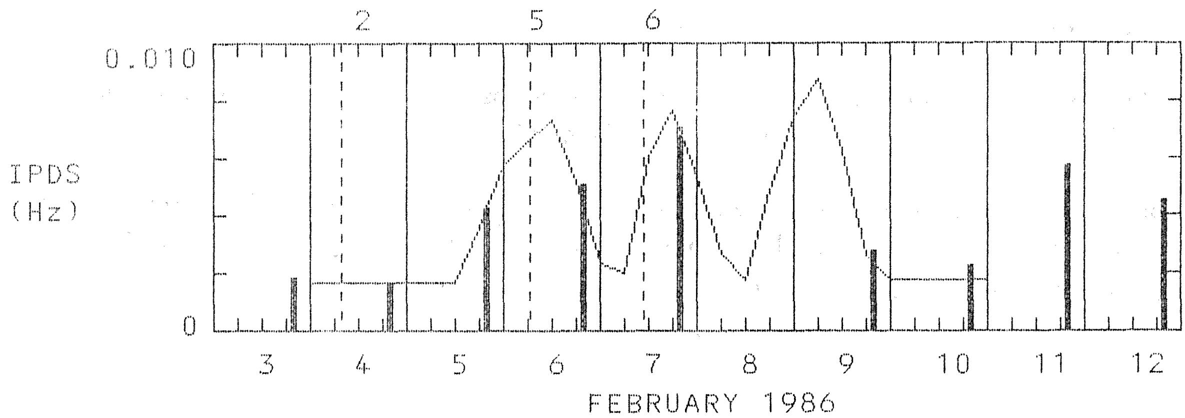

Fig. 1. The standard deviation of Doppler scintillations (IPDS) of Sakigake in Hz (bars) and the predicted time variation of the IPDS level (a solid curve) in early February 1986. The prediction is made using eq. (1) and parameters are given in this figure. The occurrence time of each solar flare is indicated by a vertical broken line.

3. Discussion

It is seen in Figure 1 that the enhancement of the IPDS level during 5–7 February can be attributed to the interplanetary disturbances in association with a series of energetic solar flares. The interplanetary disturbance associated with Flare 2 had somewhat peculiar propagation properties. As seen in Figure 1, the enhancement in the IPDS level was observed at about 2000 UT on Feb. 5, about 17 hours before the relevant ssc at 1312 UT on 6 Feb. To explain this, it is necessary to assume that the apex of the interplanetary disturbance was located in the region to the "west" of the Sun-Earth line (W25), although the Flare 2 took place in the eastern hemisphere of the Sun (E21). We tentatively assumed that the apex was located near the normal of each flare for the case of Flares 5 and 6. Because of poor time coverage of IPDS observations, it is not possible to check the models in detail for these two events. This work also showed that the degree of electron density fluctuations within the disturbances was about 10 times the ambient level.

References

Dryer, M., and Z.K. Smith, Multi-Spacecraft testing of time-dependent interplanetary MHD models for operational forecasting of geomagnetic storms, Presented at the Workshop on the Multi-Comet Mission, NASA-Goddard Space Flight Centre, Greenbelt, MD, Preprint 1986.

Watanabe, T., and T. Kakinuma, Radio scintillation observations of interplanetary disturbances, *Adv. Space Res.*, 4, No.7, 331, 1984.

Watanabe, T., T. Kakinuma, and M. Kojima, IPS observations of the solar wind in late March 1979 (CDAW–6), *Geophys. Res. Lett.*, 13, 913, 1986.

Woo, R., J.E. Armstrong, N.R. Sheeley, Jr., R.A. Howard, M.J. Koomen, D.J. Michels, and R. Schwenn, Doppler scintillation observations of interplanetary shocks within 0.3 AU, *J. Geophys. Res.*, 90, 154, 1985.