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Evidence For Solar Wind Control of Saturn Radio Emission

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EVIDENCE FOR SOLAR WIND CONTROL OF SATURN RADIO EMISSION

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Abstract. Using data collected by the Voyager 1 and 2 spacecraft in 1980 and 1981, strong evidence is presented for a direct correlation between variations in the solar wind at Saturn and the level of activity of Saturn's nonthermal radio emission. Correlation coefficients of 57-58% are reached at lag times of 0-1 days between the arrival at Saturn of high pressure solar wind streams and the onset of increased radio emission. During both 160-day analysis intervals studied, the radio emission exhibits a long-term periodicity of 25 days, identical to the periodicity seen in the solar wind at this time and consistent with the solar rotation period. The energy coupling efficiency between the solar wind the Saturn radio emission is estimated and compared with that for the earth.

Introduction

Saturn emits intense, polarized nonthermal radio waves (SKR) in the kilometerwavelength band with a spectral peak near 200 kHz (Kaiser et al., 1980). The emission intensity is modulated at the planet's 10h 40m magnetic rotation period (Desch and Kaiser, 1981a) and, occasionally, by the satellite Dione at a period near 66h (Kurth et al., 1981; Desch and Kaiser, 1981b). Warwick et al. (1982) noted pronounced decreases in emission level lasting several days; however, no long-term periodic modulations of SKR, that is on the order of several days or more, have been reported.

Two spatially separated sources of radio emission have been identified (Warwick et al., 1981); they are distinguished by their opposite polarization sense and differing spectral bandwidth. Kaiser and Desch (1982) and Lecacheux and Genova (1982) localized these two sources to high latitudes near the noon meridian in the planet's northern and southern hemispheres. Because of the likelihood of an association of these sources with the dayside polar cusps of the planet (Kaiser et al., 1981), at least some control of the SKR by the solar wind seems plausible. Indeed, evidence exists for solar control of both the terrestrial (auroral) kilometer wavelength emission, or AKR (Gallagher and D'Angelo, 1981) and the jovian decameter-wavelength emission, or DAM (Terasawa et al., 1978; Barrow, 1979), although the case for the former is on much firmer grounds.

In the present paper the evidence for external control of the SKR is investigated through cross correlation of the solar wind bulk speed and ram pressure with the planetary radio emission and by examining long-term periodicities inherent in both the plasma and radio data. All data were collected by experiments on the Voyager 1 and 2 spacecraft; the plasma data, in the form of solar wind bulk speed and density, were recorded by the plasma science (PLS) experiment (Bridge et al., 1977), and the radio emission data by the planetary radio astronomy (PRA) experiment (Warwick et al., 1977).

Observations

Although no periodic long-term modulation of the SKR has yet been reported, it is clear from Figure 1 that the radio emission level can fluctuate dramatically on a time scale of days. Three 24-hr frequency-time spectrograms from the PRA experiment on Voyager 2 are shown. On 5 June 1981 (middle panel), with Voyager 2 still 81 days from Saturn encounter, an unusually high level of activity was recorded near the 200 kHz spectral peak, where emission is detected for nearly 22 hr out of a possible 24 hr. The emission bandwidth extends at times to over 1 MHz, from below 20 kHz to about 1100 kHz. Three days earlier and 4 days later (top and bottom panels of Figure 1), the emission levels are substantially lower, but more representative of the mean emission levels during this time. On 2 June, only 5 hr of activity extending over about 500 kHz bandwidth were detected, and on 9 June, only about 1 hr extending over 500 kHz. The variation in emission level seen in this figure is even more apparent when expressed in absolute energy units, that is, emission flux density integrated over time and bandwidth. Approximately 6×10^{10} joules/sr were emitted on 1 June compared with 5×10^{12} joules/sr on 5 June, an increase by almost two orders of magnitude.

Since this modulation takes place on time scales that are decidedly longer than either the 10 hr 40 min rotation modulation or the 66 hr modulation attributed to Dione, one must look elsewhere to explain it. The outer Saturnian satellites, such as Rhea, with a period of about 4.5 days and Titan (15.9 days) are within Saturn's magnetosphere and could interact magnetically with the radio source. However, Desch and Kaiser (1981a) previously failed to find any evidence of modulation at these or any other satellite periods in a power spectral study of 267 days of radio data taken in early 1980.

That a solar wind interaction must be considered a serious candidate is illustrated in Figure 2. Here we show quantitatively the variation in SKR emission level along with the change in the solar wind bulk speed and ram pressure at Saturn for the interval surrounding the data illustrated in Figure 1. The time resolution of each plot is 24 hr; that is, each data point is a

24-hr average of the appropriate quantity (see Figure 2 caption). The solar wind at Saturn was estimated by dividing the spacecraft-Saturn distance by the observed bulk speed. Since the heliocentric angle between Voyger 2 and Saturn is only 0.64 degrees at this time, corresponding to about 1 hr of solar rotation, this part of the estimation is negligible and so was not included. For the data in Figure 2, the radial propagation time varied between 1.2 and 2.2 days.

There is clearly a striking correspondence between the variation in the solar wind parameters used here and the radio emission level. The solar wind bulk speed peaks about 1.8 days before the SKR peak occurs, and the ram pressure about 0.5 days later than the SKR peak. The steep rising edges of both solar wind parameters either coincide with or slightly precede the major increase in radio emission. As we shall see, this particular episode represents one of the most significant enhancements in all three parameters recorded in this study.

In order to draw conclusions based on firmer statistical grounds than those of Figure 2, a more extensive investigation into the influence of the solar wind on SKR was undertaken. The fundamental results are shown in Figures 3a and b, where the SKR emission level and solar wind ram pressure at Saturn are plotted for 161-day and 164-day intervals from Voyagers 1 and 2, respectively. Note that both quantities are expressed in sigma, that is, the departure of a given value from a 30-day running mean in terms of the standard deviation (sigma) of the values in that 30-day interval. Thirty days is the approximate time between major changes in both quantities. This procedure permits easier comparison of quantities with inherently different value ranges, and eliminates the inverse-distance-squared variation to which the radio emission data are subject. As in Figure 2, the data are initially constructed of 24-hr averages. The solar wind is radially propagated to Saturn; the rotation time, which was never more than about 3.5 hr, was insignificant throughout the analysis interval. Radial propagation times varied between 7.4 and 0.4 days. Gaps in the solar wind data or SKR records have been linearly interpolated across to permit cross correlation of the two time series. Overall, data coverage was about 93% for V1 and 85% for V2, so that the data gaps have little or no effect on the outcome.

Visual inspection of Figures 3a and b shows a remarkably good correspondence between ram pressure changes and the level of Saturn radio emission. Just as Figure 2 showed, when the ram pressure is large, the radio source tends to be active, and when the ram pressure is below zero (in sigma units) the SKR is also very weak (for clarity, the ram pressure curve has been displaced upward by 1 sigma in both figures). There are notable exceptions, however. For example, in Figure 3a there is a major SKR increase on days 186-187 that is unaccompanied by any change in the pressure. A very similar occurrence can be seen in Figure 3b on days 92-93. The converse situation also arises in which ram pressure increases are not associated with any significant change in SKR level. Note day 210 in Figure 3 and day 69 in Figure 3b, for example. Exceptions of this sort occur far less frequently, however, than do the correlated variations.

For lack of space we do not show similar plots of the SKR variation with the solar wind bulk speed. Generally the bulk speed does not appear as well correlated with SKR as does the ram pressure; however, there is a clear association present. Quantitative statistical estimates of the significance of the pressure and speed correlations are made in the next section. Correlations of SKR with interplanetary magnetic field properties, while important, require special attention and are beyond the scope of the present paper.

If the SKR level is in fact well correlated with solar wind pressure, then the SKR should manifest the same fundamental periodicity that the pressure does, that is, the 25-day solar rotation period. Figure 4 shows the result of autocorrelating the Voyager 2 SKR and pressure curves of Figure 3b. It is apparent that the two autocorrelation functions track each other extremely well. Both have minima in the neighborhood of 10 days and, as we supposed should be the case, maxima at 25 1 days, indicative of the solar rotation period. However, the main peaks, which by definition are centered at 0 days lag, exhibit significantly different widths, with first zero points at 2.5 and 4.5 days for SKR and pressure, respectively. These values reflect a characteristic 'persistence' time of the phenomena, indicating that on the average the pressure can remain high longer than the radio emission can. This conclusion is consistent with the variations apparent in Figure 3b.

The results of a similar autocorrelation analysis of the Voyager 1 data of Figure 3a are identical to those of Voyager 2, with the exception that the maxima of the two curves is at 26 ± 1 days. In view of the noise level inherent in the autocorrelation curves and the fact that only about 6 cycles of a 25-day period are present in the two original time series, this is not a significantly different periodicity.

Analysis

In order to assess the statistical significance of the apparent correlations shown in Figures 3a and b, the data were cross correlated to yield the results shown in Figure 5 (solid curves). The results of cross correlating the SKR level with the solar wind speed variations as measured by both Voyagers 1 and 2 are also shown (dashed curves). The linear correlation coefficients at 0 days lag for each of these quantities are summarized in Table 1.

Table 1. Linear Correlation Coefficients at 0 Days Lag

Spacecraft	Pressure	Speed
Voyager 1	.57	.24
Voyager 2	.58	.45

The peak correlations with ram pressure occur at 0 days lag for both V1 and V2 and have magnitudes of .57 and .58 respectively. For the number of sample pairs used here ($\sim$ 160), this is a highly significant correlation; the probability of this large a coefficient being exceeded by chance is less than 10^{-7}. Further, virtually the same result has been obtained with two

completely independent sets of data: the Voyager 1 set in 1980 and Voyager 2 in 1981. The correlation coefficients with solar wind speed are substantially less than for those with pressure, although both figures are statistically significant. The Voyager 1 wind speed correlation is very much noisier than the other three and has peaks at about ± 12.5 days that are probably due to the presence of two-sector solar structure in the speed data.

Discussion

It is manifestly evident that variations in the solar wind are effective in controlling the level of Saturn radio emission, and that the ram pressure or some property associated with it is more important than the solar wind speed in exercising this control. This direct evidence of the importance of solar wind interactions with Saturn's magnetosphere is consistent with conclusions suggested by several previous studies. For example, Kaiser and Desch (1982) localized Saturn's radio sources within the planet's dayside polar cusps, and hypothesized that the sources should be responsive to solar wind variations. Bridge et al. (1982), in comparing inner magnetosphere plasma conditions measured by Voyagers 1 and 2, tentatively invoked a plasma loss mechanism stimulated by a factor of two increase in solar wind pressure during the Voyager 1 flyby. Behannon et al. (1981) attributed temporal variations observed in Saturn's magnetic tail to solar wind variations, and Ness et al. (1982) invoked similar variations to explain observed changes in the size of the magnetosphere during the Voyager 2 encounter. Finally, Warwick et al. (1982) and Scarf et al. (1982) hypothesized that the marked, 2-3 day disappearance of SKR observed during the Voyager 2 encounter might be due to the absence of solar wind flux owing to the presence of Saturn in Jupiter's magnetic tail or tail filament. While the results shown here only bear directly on the hypothesis of Kaiser and Desch (1982), the present study does emphasize the importance of solar wind convection driven dynamics in Saturn's magnetosphere, in contrast to Jupiter's, where rotational dynamics seems to dominate. That is, at least in the context of auroral radio emissions, Saturn appears to be more earth-like in the extent to which it is driven by external forces. Both earth and Saturn have radio sources whose energetics are strongly influenced by fluctuations in solar wind flow, and that are not strongly rotation modulated (Desch and Kaiser, 1981a). However, Jupiter's radio sources are very strongly rotation modulated and solar wind correlation studies have met with only moderate success (Carr et al., 1983).

Since energy coupling between the solar wind and Saturn's magnetosphere is clearly indicated, it is of interest to consider the solar wind-SKR energy budget and compare the inferred efficiency with that for AKR, the earth's auroral kilometer-wave source. An estimate by Kennel (1973) of the solar wind energy dissipation rate at Saturn yields (with an updated magnetic moment for Saturn) 10^{12} watts. Since the median isotropic power radiated from Saturn in the form of kilometric radiation is about 10^{8} watts (Kaiser et al., 1981), the efficiency is 0.01 percent. The figure for AKR is almost identical. The median isotropic power level for AKR is also 10^{8} watts (Kaiser and Alexander, 1977) with a solar wind energy dissipation rate of 5×10^{11} watts, yielding an efficiency of 0.02 percent. This is hardly a significant difference considering the uncertainties in the individual figures.

In this paper the importance of the solar wind in influencing the SKR has been established. While the results indicate that an excellent correlation exists with solar wind pressure, it is fully appreciated that this has not been an exhaustive study, and that other solar wind properties such as the magnetic field magnitude and direction are likely to be of importance also. In the future, more detailed studies using higher time resolution observations very near Saturn should make it possible to specify the interplanetary magnetic field magnitude and direction at the planet. This will allow definitive identification of the actual solar wind property most closely associated with the SKR.

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References

Barrow, C.H., Association of corotating magnetic sector structure with Jupiter's decameter-wave radio emission, J. Geophys. Res., 84, 5366-5372, 1979.

Behannon, K. W., J. E. P. Connerney, and N. F. Ness, Saturn's magnetic tail: Structure and dynamics, Nature, 292, 753-755, 1981.

Bridge, H. S. et al., The plasma experiment on the 1977 Voyager mission, Space Sci. Rev., 21, 259, 1977.

Bridge, H. S. et al., Plasma observations near Saturn: Initial results from Voyager 2, Science, 215, 563-570, 1982.

Carr, T. D., M. D. Desch, and J. K. Alexander, Phenomenology of magnetospheric radio emission, in Physics of the Jovian Magnetosphere (A. J. Dessler, ed.), in press, 1982.

Desch, M. D., and M. L. Kaiser, Voyager measurement of the rotation period of Saturn's magnetic field, Geophys. Res. Lett., 8, 253-256, 1981a.

Desch, M. D., and M. L. Kaiser, Saturn's kilometric radiation: satellite modulation, Nature, 292, 739-741, 1981b.

Gallagher, D. L. and N. D'Angelo, Correlations between solar wind parameters and auroral kilometric radiation intensity, Geophys. Res. Lett., 8, 1087-1089, 1981.

Kaiser, M. L. and J. K. Alexander, Terrestrial kilometric radiation 3. Average spectral properties, J. Geophys. Res., 82, 3273-3280, 1977.

Kaiser, M. L., M. D. Desch, J. W. Warwick and J. B. Pearce, Voyager detection of nonthermal radio emission from Saturn, Science, 209, 1238-1240, 1980.

Kaiser, M. L., M. D. Desch and A. Lecacheux, Saturnian kilometric radiation: statistical properties and beam geometry, Nature, 292, 731-733, 1981.

Kaiser, M. L, and M. D. Desch, Saturnian kilometric radiation: Source locations, submitted to Geophys. Res. Lett., 1982.

Kennel, C. F., Magnetospheres of the planets, Space Sci. Rev., 14, 511-533, 1973.

Kurth, W. S., D. A. Gurnett, and F. L. Scarf, Control of Saturn's kilometric radiation by Dione, Nature, 292, 742-745, 1981.

Lecacheux, A. and F. Genova, Localization of the sources of Saturn radio emission, submitted to Geophys. Res. Lett., 1982.

Ness, N. F. et al., Magnetic field studies by Voyager 2: Preliminary results at Saturn, Science, 215, 558-563, 1982.

Scarf, F. L., D. A. Gurnett, W. S. Kurth, and R. L. Poynter, Voyager 2 plasma wave observations at Saturn, Science, 215, 587-594, 1982.

Terasawa, T., K. Maezawa and S. Machida, Solar wind effect on Jupiter's non-Io-related radio emission, Nature, 273, 131-132, 1978.

Warwick, J. W., J. B. Pearce, R. G. Peltzer and A. C. Riddle, Planetary radio astronomy experiment for Voyager missions, Space Sci. Rev., 21, 309-319, 1977.

Warwick, J. W. et al., Planetary radio astronomy observations from Voyager 1 near Saturn, Science, 212, 239-243, 1981.

Warwick, J. W. et al., Planetary radio astronomy observations from Voyager 2 near Saturn, Science, 215, 582-587, 1982.

FIGURE CAPTIONS

Figure 1. Three 24-hr frequency-time dynamic spectrograms showing the variation in the level of Saturn kilometric radiation (SKR) during early June 1981. All of the emission seen here is Saturnian in origin except for the solar type III bursts, which appear as short-duration vertical stripes with negative frequency drifts below about 500 kHz. Increasing darkness is proportional to increasing radio intensity.

Figure 2. A plot of the radio emission level, solar wind bulk speed and ram pressure from day 140 (20 May 1981) through day 164 (13 June 1981) and covering the interval shown in Figure 1. The solar wind profiles are shown as they would appear at Saturn, following propagation along a radial from Voyager 2 to the planet. The data are 24-hr averages of the solar wind bulk speed, ram pressure (proton mass density in the solar wind times bulk speed squared (nmv^2) expressed in mks units) and radio emission level in hr of activity/day.

Figure 3a. Plot shows the variation in the Saturn radio emission level (solid) and solar wind ram pressure (dotted) for a 160-day interval in 1980 as measured by Voyager 1. Both curves consist of 24-hr averages and are expressed in units of the standard deviation (sigma) above and below a 30-day running mean. Approximate conversion from relative to absolute units is possible with the following means and standard deviations: for the SKR, 1.3 ± 1.4 hr of activity for events exceeding a 1 AU normalized flux density of 10^{-20} W/m^2Hz; for the pressure, 25 ± 30 nt/m^2. The pressure curve is displaced upward 1 sigma for clarity.

Figure 3b. Same as Figure 3a but for a 164-day interval in 1981 as measured by Voyager 2. The approximate relative-to-absolute conversion figures are: 2.6 ± 3.0 hr at 5 x 10^{-21} W/m^2Hz for SKR and 29 ± 45 nt/m^2 for pressure.

Figure 4. Autocorrelation curves of the SKR and pressure plots of Figure 3b. Maxima at 25 ± 1 days lag shows the effect of the sun's roation in controlling the periodic nature of both phenomena.

Figure 5. Results of cross correlating solar wind pressure (solid) and speed (dashed) with the level of SKR for both Voyager 1 and 2 data sets. The cross correlated curves are those of Figures 3a and b. Statistically significant linear correlation coefficients of .57 and .58 for pressure establishes the importance of solar wind control over the SKR.

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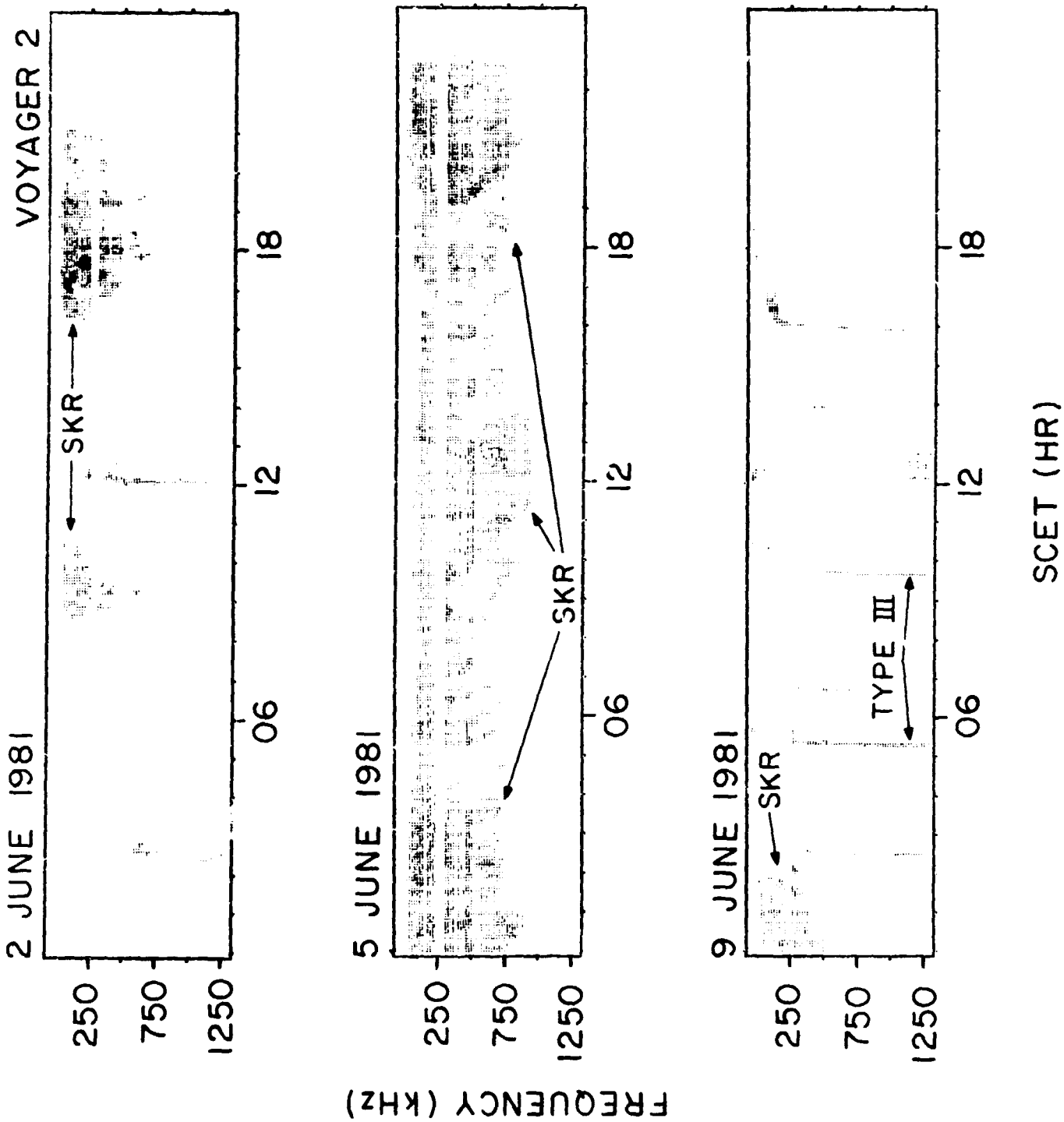
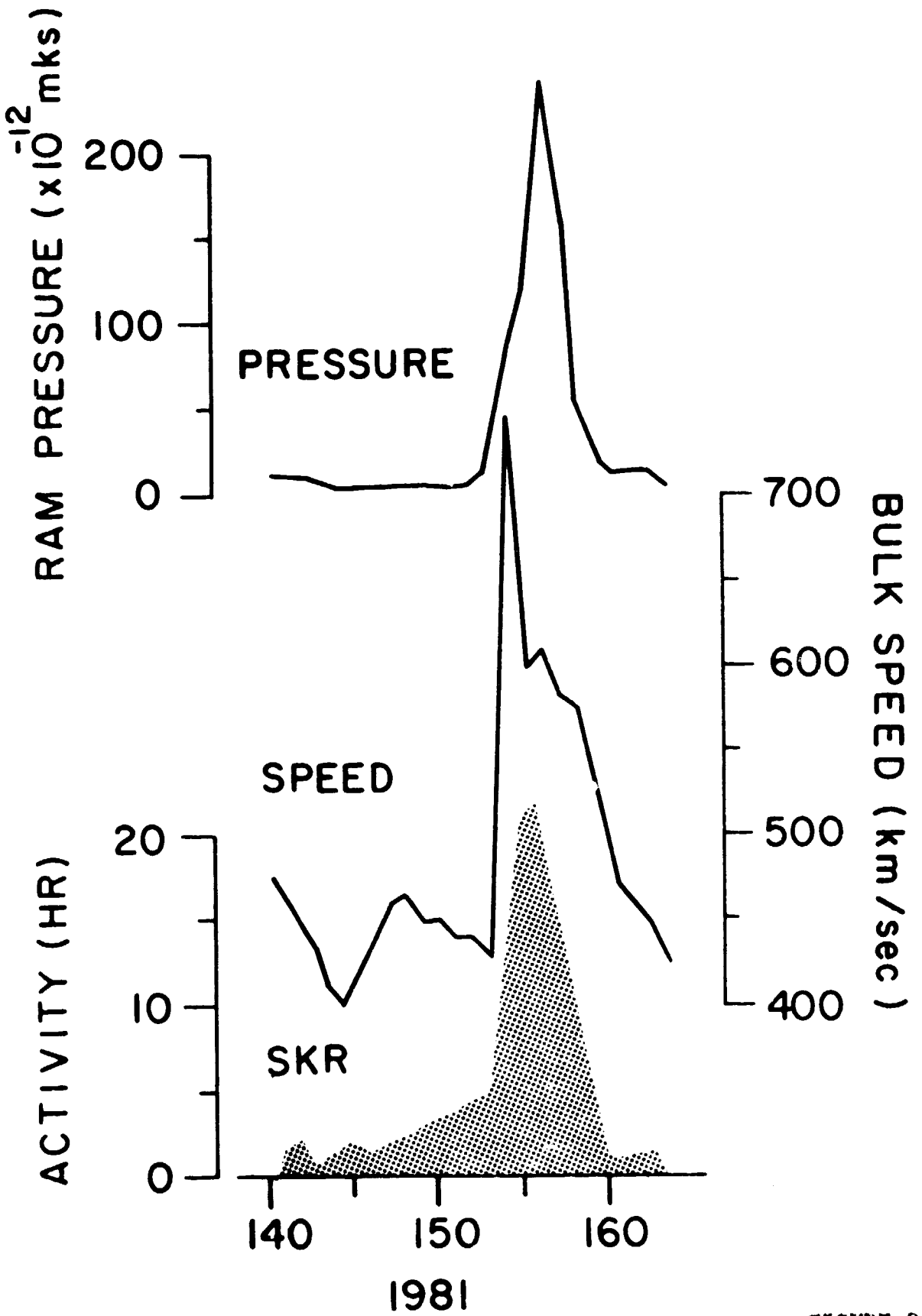


FIGURE 1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PRESSURE
SPEED
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BULK SPEED (km/sec)
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FIGURE 2

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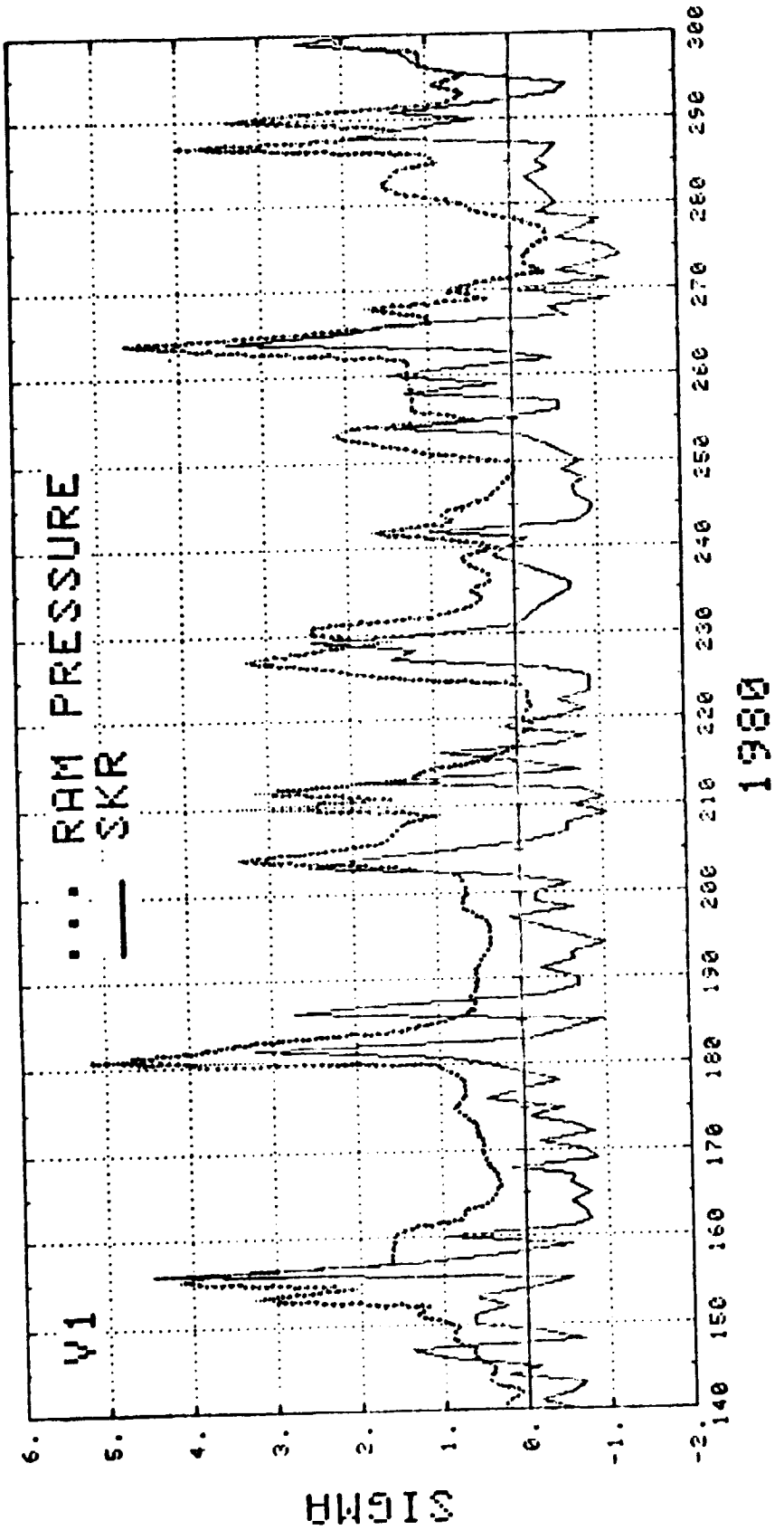

FIGURE 3a

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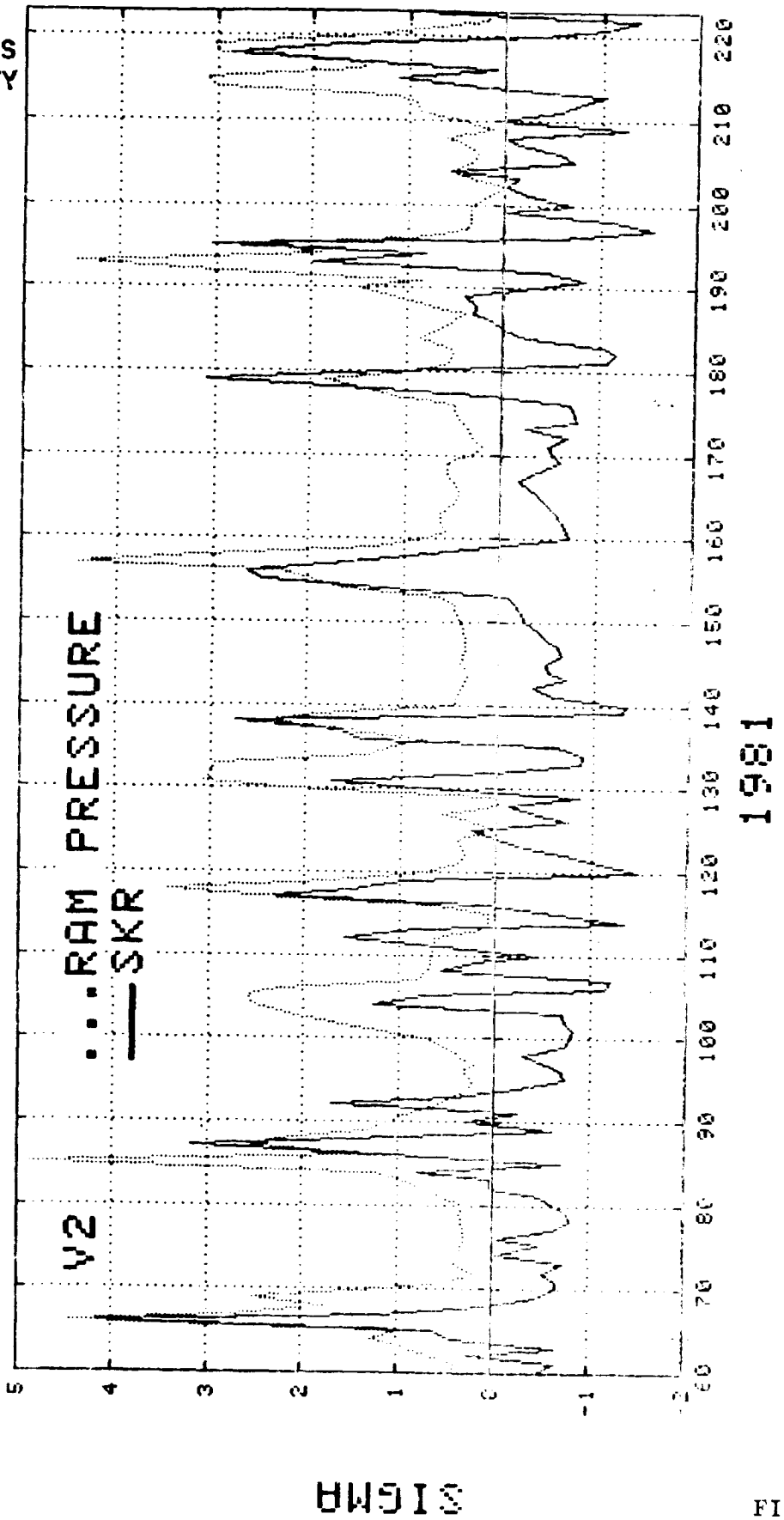

FIGURE 3b

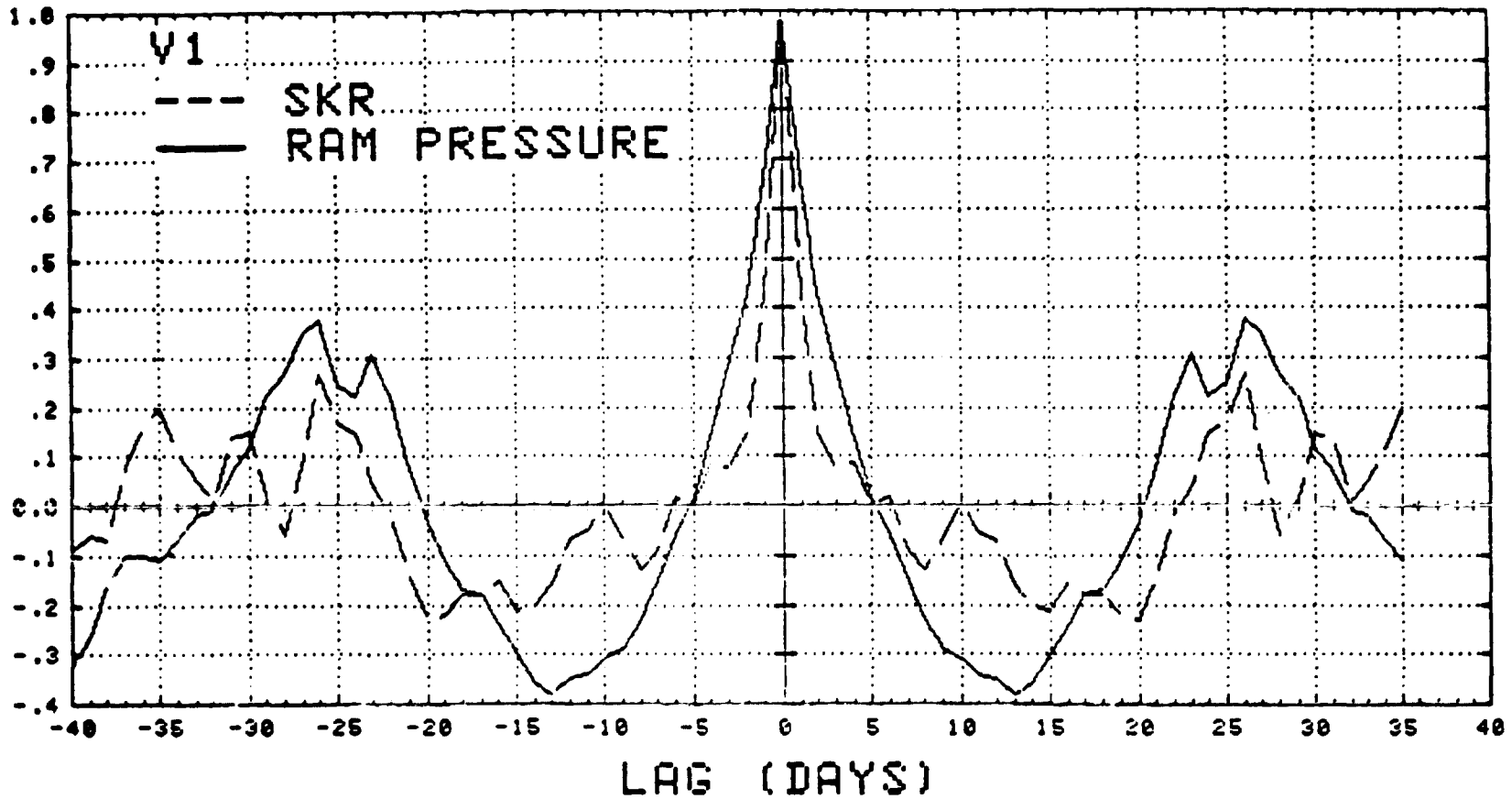
V1
SKR
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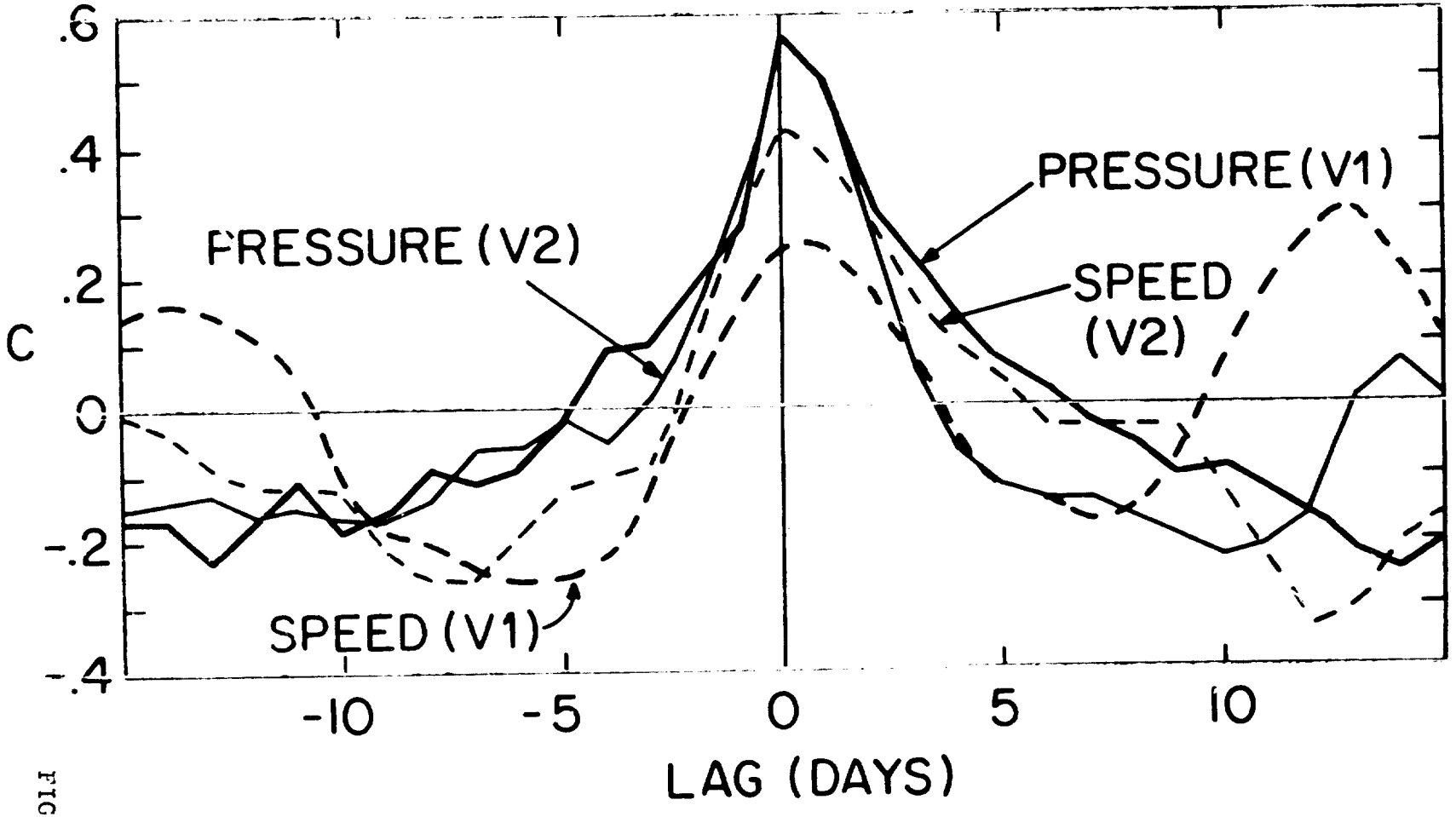
FIGURE 4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-5
0
5
10
LAG (DAYS)

FIGURE 5