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DROPOUTS

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Plasma Signatures of Radial Field Power Dropouts

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Abstract. A class of small scale structures, with a near-radial magnetic field and a drop in magnetic field fluctuation power, have recently been identified in the polar solar wind. An earlier study of 24 events, each lasting for 6 hours or more, identified no clear plasma signature. In an extension of that work, radial intervals lasting for 4 hours or more (89 in total), have been used to search for a statistically significant plasma signature. It was found that, despite considerable variations between intervals, there was a small but significant drop, on average, in plasma temperature, density and β during these events.

INTRODUCTION

Ulysses spent over two years in high speed solar wind ($V_R \sim 750 \text{ km/s}$) flowing from the Sun's polar coronal holes. Although these polar flows are relatively steady and homogeneous, bulk plasma parameters and magnetic field data show structure over a range of scales from seconds to days. It is known that the polar solar wind is populated by Alfvénic fluctuations (1), pressure balanced structures and microstreams (2), (3). A recent study of data recorded by the magnetometer experiment (4) during the Northern and Southern polar passes led to the identification of a new class of structures, characterised by a drop in magnetic field fluctuation power together with near radially directed magnetic field, lasting for several hours (5). In the earlier study, no clear plasma signature of these events was identified. In this paper a search for a statistically significant relationship between radial field power dropouts and a range of bulk plasma parameters is presented, with the aim of better characterising these events.

POWER DROPOUTS AND RADIAL FIELDS

It was shown in (5) that well defined decreases in magnetic field fluctuation power, lasting for several hours, can be identified in polar solar wind data. Such decreases often occur during intervals of near radial field. Identification of these events using power levels is difficult as a result of the large scatter in

power estimates, and so a search was made for near-radial field intervals and the power signature associated with these radial field events then analysed statistically. The same method has been used here but with the minimum interval length decreased from 6 to 4 hours to increase the number of events. In 770 days of polar data 89 events were found when the hourly averaged magnetic field direction remained within 30° of the radial direction for four hours or more. Visual examination of a number of these radial field events showed that while many showed no clear power signature, some were associated with significant power decreases as expected. As in the earlier study, however, no consistent plasma signature could be identified by eye.

Figures 1 and 2 show two examples of radial field power dropouts in the polar solar wind. Both figures have the same format. The top panel shows the log of the average power per unit mass (that is, magnetic field power divided by the mean density) in $nT^2 \text{ Hz}^{-1} \text{ kg}^{-1}$, summed across the three magnetic field components in the wavenumber range $6.5 \times 10^{-5} - 1.3 \times 10^{-4} \text{ km}^{-1}$, which corresponds to spacecraft scales of a few minutes. Each power estimate is calculated using a 15 minute interval of data as described in detail in (5). Although data are only shown at a single scale, variations in power levels tend to be broad band in nature. Panels 2, 3 and 4 show the field latitude and longitude angles (θ and ϕ), both in RTN co-ordinates and the magnetic field magnitude $|B|$. Panels 5, 6, 7 and 8 show the proton temperature (T_p), proton number density (N_p), proton and alpha gas pressure (heavy line, P_{Gas}), magnetic field pressure (faint line, P_B) and radial solar

FIGURE 1. A radial field event at 43°N and 3.5 AU showing a clear power decrease but little plasma signature apart from a velocity decrease. Such velocity variations are common in polar flows. Figure 3 shows power spectra calculated from data within two regions marked in the top panel by thick horizontal bars.

wind velocity (V_R). In each figure the vertical lines indicate the approximate extent of the radial field interval. The plasma parameters were measured by the SWOOPS instrument (6).

Although the power estimates show a large natural variation (which is much larger than the statistical uncertainty in each value) Figure 1 shows that there is a decrease in underlying power levels by around an order of magnitude during the radial field interval, and that the start and end times of the power decrease correspond to the start and end of the radial interval. In contrast the plasma parameters do not appear to have a clear correlated signature.

Figure 3 shows power spectra calculated from data within the two regions marked by thick horizontal bars in the top panel of Figure 1. Each spectrum shows the total component power calculated using 2 hours of 10 second averaged data. The faint line is calculated from data outside the power dropout and the heavy line is calculated using data from within the event. It is clear that there is a broadband drop in power within the event and that the slopes of both spectra are $\sim -5/3$. This broad band power decrease is characteristic of these structures.

FIGURE 2. A radial field event at 45°N and 3.4 AU. Power levels decrease by around an order of magnitude, although the field direction is still rather variable. There is no clear plasma signature.

A second power dropout is shown in Figure 2. Here the start time of the power dropout is not well correlated with the start of the radial field event, but the end times are nearly coincident. In Figures 1 and 2 the radial field intervals occur during a period of declining solar wind velocity and end as the velocity increases, but this is not the case with all events.

For each radial field event the ratio was found between the mean fluctuation power in two six hour intervals either side of the event, each separated from it by six hours, and the mean power within it. The log of these values are plotted on Figure 4 as a function of time. Shaded areas indicate regions of non-polar flow, and no attempt has yet been made to identify events in these regions. The mean log ratio was more than 4 standard deviations from zero, showing that there is a statistically significant decrease in power during radial field intervals as shown in (5). A large fraction of events have power ratios within one standard error of zero, and so the mean offset of 0.08 is small, but this is not unexpected. Many of the radial field events are likely to arise from random motions of the magnetic field (e.g. caused by Alfvén waves) and would therefore not exhibit a power decrease. Radial field events with significant power decreases,

FIGURE 3. Power spectra from the radial field event on day 76, 1996.

such as those shown in Figures 1 and 2, appear to be discrete structures however.

PLASMA SIGNATURES OF RADIAL FIELD EVENTS

Several radial field events were presented in (5) and it was argued that there was no clear associated plasma signature. The analysis described in the previous section has been extended to bulk plasma parameters in an attempt to find a statistical association between radial fields and variations in V_R , N_p and N_α , T_p , proton to alpha ratio (N_p/N_α), β and total pressure (P_T). For each parameter ratios were calculated between the mean value during six hours near the radial field event, separated from it by six hours, and the mean value within the radial field event. Upstream and downstream conditions were considered separately in order to be able to distinguish trends in the plasma data as well as the mean level.

Table 1 summarises the results: for each plasma parameter, listed in column 1, columns 2 and 3 give the average ratio for upstream and downstream conditions respectively. The offset from 1 of each ratio is given in terms of the number of standard errors (shown in brackets). As with the power ratios, the deviations from 1 are small because of the presence of null events where the field is radial only by chance, and so no plasma signature would be expected. Table 1 shows that there are significant (more than 3 standard errors) decreases in N_p and N_α , and plasma β . No significant signature is seen in $|B|$, or in N_p/N_α . The latter is of particular interest since it is often an indicator of changes in solar wind source conditions.

FIGURE 4. Ratio between power levels near radial field events and those within them.

Although Table 1 indicates that there are significant decreases in T_p and V_R , looking at the events in the Northern and Southern passes separately gave conflicting results, suggesting that variations in these parameters are not associated with as many events. It was also noticed that, in general, the events from the Northern pass show clearer plasma signatures. For comparison, ratios were also calculated between upstream and downstream parameters. In this case, none of the parameters showed a significant offset from unity: offsets were always less than 2 standard errors and usually within one standard error, indicating that there were no consistent trends (e.g. a velocity decline) across the events.

Figure 5 shows the histogram of the ratio of average proton number density six hours upstream of the radial field events to that inside them. The histogram is clearly skewed and the mean value is 4 standard errors above 1. If a number of radial field intervals are re-examined by eye, it is noticeable that in cases where there is some change in plasma parameters, decreases in number density and β often occur in the vicinity of the events. The changes in plasma parameters, however, are typically not well bounded by the start and end times of the radial field event. Although velocity changes are often observed in high speed wind, V_R varies on a similar timescale to the radial field events, and the current method may not be best suited for observing a velocity signature. If radial field events are selected which show a log power ratio 1 standard error or more above zero, and the analysis of the above parameters repeated, significant offsets are found for the same parameters. Although the size of the offsets are not greatly increased, there is a tendency for events showing plasma ratios above 1 to be selected.

Table 1. Mean ratios between quantities outside radial field events and those within them.

	Upstream ratio	Downstream ratio
V_R	1.00 ± 0.01 (0.1)	1.008 ± 0.003 (2.7)
N_p	1.07 ± 0.02 (4.1)	1.10 ± 0.02 (5.0)
N_α	1.08 ± 0.02 (3.6)	1.13 ± 0.02 (5.2)
T_p	1.04 ± 0.02 (2.4)	1.04 ± 0.02 (2.7)
$ B $	0.99 ± 0.02 (-0.7)	0.98 ± 0.02 (-0.9)
N_p/N_α	1.01 ± 0.02 (0.7)	0.99 ± 0.02 (-0.5)
β	1.25 ± 0.06 (4.5)	1.29 ± 0.06 (5.1)
P_T	1.06 ± 0.02 (2.8)	1.08 ± 0.02 (4.0)

CONCLUSIONS

In an earlier study of radial field power dropouts (5) no obvious plasma signature was identified. In this study a search was made for a statistically significant relationship between event occurrence and various plasma parameters. It has been demonstrated that radial field power dropouts are associated with lower N_p , N_α and β than would be expected by chance, although the calculated offsets are small because of the presence of many null events. It appears therefore, that radial field events are associated with lower density regions (and hence lower β) as well as reduced power levels. They may also tend to be colder, although this association is less clear. Any suggestion of a potential source for these events would have to account for these characteristics, as well as the reduced power and near radial field.

It has been pointed out that radial field power dropouts share some common features with electron propagation channels identified in the ecliptic plane (7). Unfortunately, in the polar heliosphere energetic particle densities are very low, and no data are available during the polar passes. An alternative approach would be to study radial field power dropouts during the Ulysses in-ecliptic cruise, and to compare any events identified in this region with the electron propagation channels.

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FIGURE 5. Histogram of the ratio between proton number density upstream of radial field events and that inside them. The histogram is clearly skewed.

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