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The heliospheric magnetic field at solar minimum: Ulysses observations from pole to pole

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Abstract. The fast transit of the Ulysses spacecraft from the south polar regions of the heliosphere to the north polar regions has allowed us to obtain a unique perspective on the configuration and properties of the heliospheric magnetic field at a time of solar minimum activity. We compare the magnetic field in the northern and southern hemispheres and find no evidence of asymmetry in the radial component of the field or in the variances of the field. We find that the magnetic field polarity corresponds to that observed at the Sun. The only difference between the hemispheres is that, while magnetic field lines in the southern hemisphere have a most probable azimuth angle approximately 24° more tightly wound than predicted by the Parker model, those in the northern hemisphere are in good agreement with the model.

Key words: Sun: magnetic fields – solar wind – interplanetary medium

1. Introduction

At the minimum of the 11-year solar activity cycle, the heliosphere is dominated by the influence of high speed solar wind originating from two well developed polar coronal holes at the Sun, with a relatively narrow streamer belt of low speed solar wind close to the equatorial regions (see, for example, the review of Schwenn 1990), this scenario being confirmed by Ulysses (Phillips et al. 1994). Most heliospheric magnetic field lines have their origin in the coronal holes and are swept out into the heliosphere by the solar wind (e.g. Balogh et al. 1995). Embedded in the streamer belt is the heliospheric current sheet which separates the two regions of opposite polarity of the magnetic field.

This paper presents a summary of the heliospheric magnetic field measurements obtained by the Ulysses magnetometer experiment (Balogh et al. 1992) during 1994 and 1995 while the spacecraft made its fast transit from the southern (80°S) up to the northern polar regions (80°N) of the heliosphere, crossing the equatorial regions on the way (Smith & Marsden 1995). This portion of the Ulysses trajectory is often referred to as the 'fast latitude scan'. Ulysses magnetic fields results from the southern polar regions have already been presented by Balogh et al. (1995) and a first analysis of the data from the fast crossing of the streamer belt regions has been carried out by Smith et al. (1995a). This purpose of this paper is to present the first results based on the complete pole to pole dataset and to make a comparison between data obtained in the solar wind flows originating in the southern and northern polar coronal holes. In addition to this north-south comparison being scientifically important in its own right, it is also relevant to the understanding of the results obtained by other Ulysses experiments during the fast latitude scan. In particular, Simpson et al. (1996) have noted that the plane of symmetry of the fluxes of galactic cosmic rays measured by Ulysses is displaced southwards from the heliographic equator by about 10°.

North-south asymmetries in the heliospheric magnetic field have previously been inferred from analyses of data from near-ecliptic spacecraft. For example, Luhmann et al. (1988) found evidence of a north-south asymmetry in the radial component of the magnetic field using data from two spacecraft separated in latitude. A number of authors have reported an asymmetry between the mean spiral angle of the magnetic field north and south of the heliospheric current sheet (e.g. Svalgaard & Wilcox 1974; Smith & Bieber 1993). Forsyth et al. (1996a) found mean spiral angles in the Ulysses near-ecliptic cruise data consistent with these reports but found that, as Ulysses travelled to higher latitudes, the effect did not extend beyond the maximum latitude extent of the heliospheric current sheet. It is possible that many of these effects observed near the ecliptic plane may be limited to the relatively complex magnetic fields of the streamer belt region. North-south asymmetries have also been noted in various solar observations, for example, in the rotation rates of the photosphere and corona (e.g. Howard 1984; Hoeksema & Scherrer

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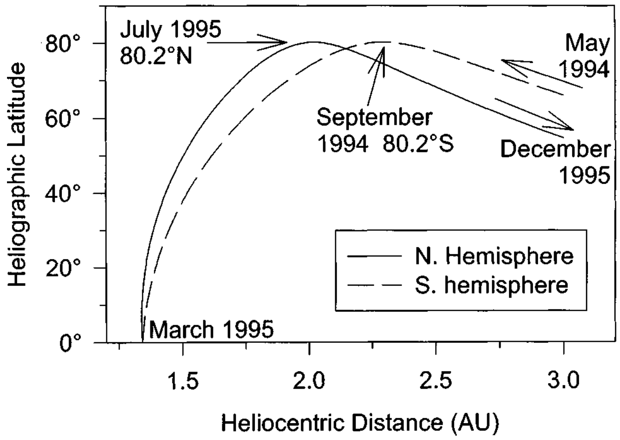

Fig. 1. The trajectory of Ulysses from May 1994 to December 1995. The absolute value of latitude is plotted against radial distance, thus emphasising the difference in the trajectory between the northern and southern hemispheres.

1987), or in solar activity (e.g. Swinson et al. 1991), all of which have the potential to influence the heliospheric magnetic field.

In contrast to the long slow two and a half year journey from 6°S to 80°S after the Jupiter flyby, the fast latitude scan of Ulysses from 80°S to 80°N took only 10 months. Whereas in the earlier part of the mission a greater allowance had to be made for the time and solar activity evolution of the heliospheric magnetic field and related features on the Sun, the pole to pole passage effectively provided a snapshot of the three dimensional structure of the heliosphere at the time of solar minimum activity.

The trajectory of Ulysses for the portion of its orbit within 3 AU of the Sun is shown in Fig. 1. In this figure the absolute value of the spacecraft's heliographic latitude is plotted against its radial distance from the Sun. The purpose of this representation is to show that, due to the major axis of the orbital ellipse being slightly inclined in latitude to the heliographic equator, a particular latitude was not sampled by Ulysses at the same radial distance in the northern hemisphere as it was in the southern hemisphere. Thus, for example, plotting a particular field parameter against latitude from 80°S to 80°N might lead to the mistaken conclusion that an asymmetry was present between the northern and southern hemispheres which, in reality, is more likely due to a radial dependence of the parameter.

2. Overview of magnetic field observations

Fig. 2 shows an overview of the magnetic field observations (6 hour averages) obtained as Ulysses travelled northwards from 80°S to 80°N. The top two panels show the magnetic field meridional (north-south) angle, δ_B, and azimuthal angle, ϕ_B, defining the magnetic field direction in the RTN coordinate system, and the third panel shows the magnetic field magnitude. The RTN coordinate system is defined by an R axis pointing radially antisunward, such that the RT plane is inclined to the equator at an angle equal to the heliographic latitude of

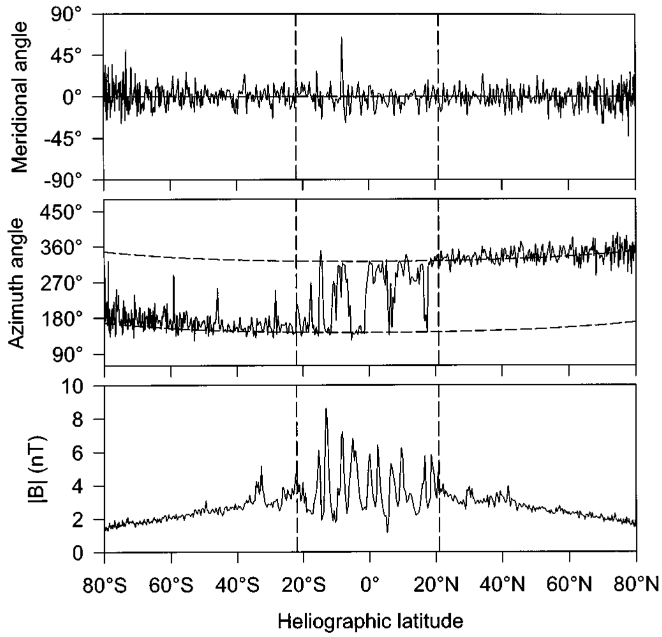

Fig. 2. Overview of the Ulysses magnetic field observations obtained during the fast pole to pole transit of the spacecraft. The top panel shows the meridional and azimuthal angles defining the field direction and the third panel shows the field magnitude. The curved dashed lines in the azimuth angle panel represent the expected Parker spiral field directions, assuming a solar wind velocity of 750km/s. The vertical dashed lines indicate the low latitude boundaries of the high speed solar wind.

the spacecraft, with T in the direction of solar rotation and N perpendicular to the RT plane, positive northwards. The field azimuth angle, ϕ_B, is measured in a right handed sense within the RT plane and the meridional angle, δ_B, with respect to the RT plane.

We discuss Fig. 2 with reference to the results of Phillips et al. (1995) who reported on the pole to pole observations from the Ulysses solar wind plasma instrument. They found that the medium to low speed (~400 km/s) solar wind typically found in near-ecliptic observations was confined to a band of latitude from 22°S to 21°N. Vertical lines have been drawn on Fig. 2 at these latitudes to aid interpretation. At all latitudes poleward of this range, high speed solar wind (700-800 km/s) originating from the southern and northern polar coronal holes, was observed. The latitudes of the boundaries between the high and low speed solar wind regimes were found by Gosling et al. (1995a) to correspond well with the boundaries between the coronal holes and the streamer belt deduced from solar observations, taking into account the non-radial expansion of the solar wind from the polar coronal hole.

Beginning with the lower panel of Fig. 2, this shows that in the latitude range dominated by the low speed solar wind, the strength of the magnetic field is dominated by a series of large increases above the background strength. These increases have been identified as the compressed magnetic field signatures of corotating interaction regions (CIRs) driven by the interaction

Table 1. Shock waves identified from magnetometer data during the Ulysses fast latitude scan.

Date	Day No.	Time UT	Type	Notes
14 Jan 1995	014	0834	Reverse	
19 Jan 1995	019	2147	Reverse	1
29 Jan 1995	029	2030	Reverse	
2 Feb 1995	033	1405	Reverse	
3 Feb 1995	034	0312	Forward	1,2
10 Feb 1995	041	2305	Forward	
16 Feb 1995	047	0350	Forward	1
17 Feb 1995	048	0102	Reverse	1,3
31 Mar 1995	090	0528	Reverse	
12 Apr 1995	102	1902	Reverse	

Notes

1 Supported by well defined signature in solar wind data (Gosling et al. 1995b).

2 Driven by CME (Gosling et al. 1995a), all others are associated with interaction regions.

3 Very weak signature in magnetometer data.

of high and low speed solar wind streams, typical of what has been observed near the ecliptic over previous solar minima by many spacecraft (e.g. Smith & Wolfe 1976; Burlaga et al. 1984). The coronal hole sources (that is whether from the north or south polar coronal hole) for the high speed solar wind streams driving these CIRs observed by Ulysses have already been determined (Smith et al. 1995a; Gosling et al. 1995a). Gosling et al. (1995a) report that the only compressional feature not identified as a CIR is a coronal mass ejection encountered as Ulysses entered the region of low speed solar wind at 22°S.

At latitudes within about 10-20° poleward of the low solar wind speed region, weaker compressional features are still apparent in the magnetic field strength. That centred on the latitude of 35°S corresponds to a brief drop in solar wind velocity below 700km/s (Phillips et al. 1995). These features are likely to be associated with the spacecraft briefly encountering the poleward edges of the streamer belt region.

A number of interplanetary shock waves have been identified in the Ulysses data from the fast latitude scan, associated with the compressed magnetic field features discussed in the previous two paragraphs. Table 1 provides a list of these shock waves identified in the magnetometer data. All, apart from one which is weak, have a clear signature in the highest time resolution (1 or 2 second) magnetometer data. Those reported by Gosling et al. (1995b) to have well defined signatures in the solar wind plasma data are indicated in the table, the remainder have weaker plasma data signatures not inconsistent with being shocks (J. L. Phillips, private communication). Apart from one driven by the coronal mass ejection previously mentioned, these shock waves are all associated with CIRs or the related weaker compressional features just poleward of the region of low speed solar wind. Those on the poleward edges of this region are all reverse shocks consistent with the interpretation of Gosling et al. (1993).

Once Ulysses is at latitudes poleward of 40°, and is sampling solar wind purely originating from the polar coronal holes, there is no large scale modulation of the magnetic field strength in either hemisphere, consistent with the results from the southern polar regions previously reported by Balogh et al. (1995). The apparent gradients in magnetic field strength with latitude are almost entirely due to the changing radial distance of the spacecraft. If the lower panel of Fig. 2 were to be reflected about the equator, an asymmetry in the field strength at a particular latitude would be observed. Most of this apparent asymmetry is accounted for by the difference in radial distance of the spacecraft with latitude highlighted in Fig. 1. Nonetheless, there is an inherent latitude dependence expected in the strength of the magnetic field at the radial distance of Ulysses related to the latitude dependence of the spiral geometry of the heliospheric field. In the next section we will use the radial component of the magnetic field as a measure of the field strength near the Sun to compare the two hemispheres.

The top panel of Fig. 2 shows that the meridional angle of the magnetic field fluctuates about an angle of 0° as required by Parker's model of the heliospheric magnetic field (Parker 1958). The centre panel confirms that the azimuth angle of the field is oriented sunward in the southern hemisphere and antisunward in the northern hemisphere, with a number of switches from one polarity to the other in the equatorial regions due to multiple crossings of the warped heliospheric current sheet. These polarities of the heliospheric magnetic field correspond to the dominant field polarities observed on the Sun at the current minimum phase of the solar cycle. A unique visualisation of the polarity of the heliospheric magnetic field made possible by the fast latitude scan of Ulysses will be presented later in the paper. The slight trends with latitude apparent in the azimuth angle in the regions poleward of 20° in both hemispheres are related to the variation of the magnetic field spiral angle with position in in the heliosphere. The curved dashed lines in this panel represent the expected Parker spiral directions assuming a solar wind velocity of 750 km/s. The fact that the mean azimuth angle plotted consistently lies above the dashed lines, particularly in the southern hemisphere is due to the mean azimuth angle being consistently underwound compared to the Parker prediction as reported by Forsyth et al. (1996a). A more detailed comparison of the azimuth angle with the Parker prediction in the polar regions will also be presented in a further section. Finally, the high level of fluctuations apparent in both meridional and azimuthal angle of the magnetic field, particularly in the polar regions will form the subject matter of the last part of the paper where the fluctuations will be discussed in terms of the magnetic field variances.

3. Radial component of the magnetic field

To use the Ulysses data in making deductions about the magnetic field strength near the Sun in the solar wind source regions, it is the radial component of the magnetic field, B_r, which must be studied. This is based on the assumption in Parker's model that the magnetic field is radial in the solar wind source region.

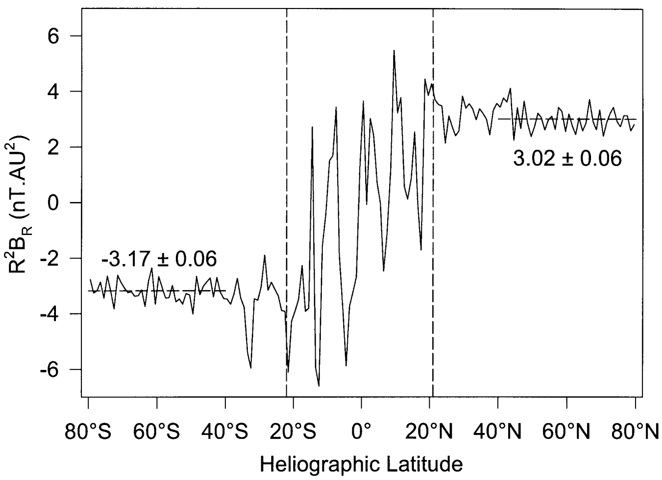

Fig. 3. The radial component of the heliospheric magnetic field normalised to 1 AU, plotted from 80°S to 80°N. The straight lines fitted in the high latitude regions are described in the text. The vertical dashed lines represent the same region as in Fig. 2.

The azimuthal component of the magnetic field out in the heliosphere is therefore not directly caused by the source field but is induced by the twisting of the field lines into a spiral by the sun's rotation. Magnetic flux conservation requires that the quantity r^2B_r should be invariant with radial distance, thus using this quantity allows a radial distance independent measure of changes of the source field strength with latitude to be made.

Smith & Balogh (1995) have carried out such an analysis using the Ulysses data from the first slow latitude scan southwards to 80°S. They found good agreement between r^2B_r measured at the high latitudes of Ulysses and that measured by the IMP-8 spacecraft near the Earth, thus concluding that the magnetic field strength near the Sun becomes independent of latitude within a few solar radii.

In Fig. 3 we have plotted averages of r^2B_r against latitude in 1° bins for the pole to pole passage. This figure shows that in the solar wind flows from the polar coronal holes, polewards of 40° both north and south of the equator, the value of r^2B_r is effectively constant, thus confirming that the result of Smith & Balogh (1995) is valid in both solar hemispheres. The change in sign between the southern and northern regions is simply due to crossing of the heliospheric current sheet into the opposite polarity region. While we have not attempted the same detailed comparison with near-equator observations in this paper, the constancy of r^2B_r in the polar regions suggests that the time variability of the magnetic field in the coronal holes during this period close to solar minimum was low. Making the assumption of low time variability also allows us to compare the magnitude of r^2B_r between the south and north polar regions. We find, using the data in Fig. 3, that the mean magnitude of r^2B_r between 40° and 80° in the southern hemisphere is 3.17 (nT.AU^2) and the same in the northern hemisphere is 3.02, both with a standard error of 0.06. We thus have little, if any, evidence during this time period for any north-south asymmetry in the magnetic field strength in the regions where we are sampling magnetic fields purely in the high speed solar wind.

4. Magnetic field polarity

Smith et al. (1995a) have mapped the crossings of the heliospheric current sheet during the fast latitude scan in heliographic latitude and Carrington longitude and by fitting a cubic spline were able to deduce an approximate shape for the current sheet at the distance of Ulysses. By analysing the full pole to pole dataset we have been able to produce a three dimensional representation of the polarity of the heliospheric magnetic field which is shown in Fig. 4. To produce this figure we first calculated the spiral angle of the magnetic field predicted by Parker's model along the trajectory of the spacecraft, assuming antisunward directed field lines, based on the solar wind velocity measured by Ulysses. We then obtained the cosine of the angle, α, between the measured azimuth angle of the magnetic field and the calculated spiral angle which ideally will take the value +1 in the northern hemisphere (that is north of the heliospheric current sheet) where the field polarity is presently antisunward and the value -1 in the southern hemisphere where the field polarity is sunward. We have used a sliding colour scale with dark red representing +1 and black/dark blue representing -1 as shown on the colour bar in the figure. Using this colour code we have plotted the value of cos α versus the Carrington longitude and latitude of the spacecraft projected back to Sun, assuming that the solar wind velocity measured at Ulysses is constant between the Sun and the spacecraft. A spiralling track is thus obtained due to the rotation of the Sun beneath the spacecraft. The two panels that have been plotted represent the same spherical projection viewed from opposite sides.

Assuming that there was little time variation in the configuration of the current sheet during the passage of Ulysses from south pole to north pole, visually interpolating between the colour bands in Fig. 4 allows us to obtain a three dimensional picture (effectively a snapshot) of the current sheet boundary between the regions dominated by the opposite polarities of the heliospheric magnetic field. This can be compared to the sketch drawn by Smith et al. (1978) in their paper first confirming that the current sheet formed a warped surface lying close to the equator at solar minimum, from the data obtained when Pioneer 11 first passed above the maximum latitude of the current sheet at 16°N.

The green lines which have been superimposed in Fig. 4 represent the location of the neutral line at the magnetic field source surface in the solar corona for the four Carrington rotations (1891−1894) when Ulysses was close to the current sheet, obtained from the computed coronal magnetic fields published in the *Solar Geophysical Data* series based on photospheric field observations made at the Wilcox Solar Observatory. The time order of the neutral lines for successive Carrington rotations can be identified in the left hand panel of Fig. 4 where they evolve in position from left to right with time across the centre of the figure. Comparing the neutral lines with the Ulysses observations shows a first approximation agreement. It also confirms a result

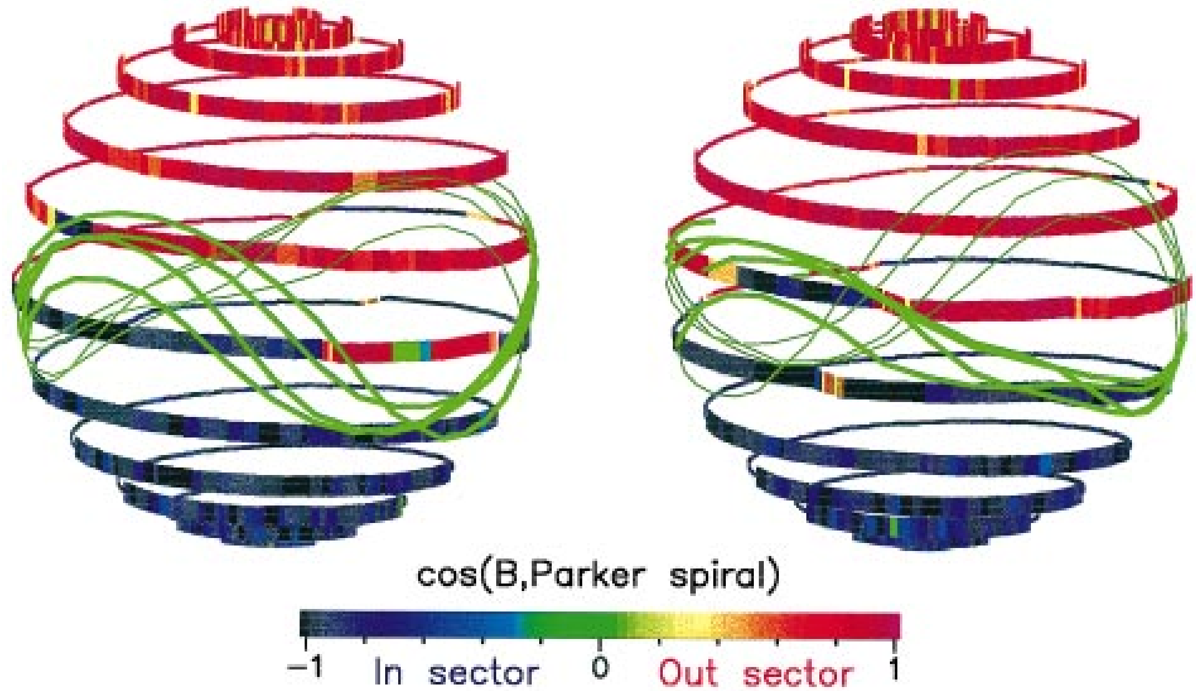

Fig. 4. A three dimensional representation of the polarity of the heliospheric magnetic field as observed by Ulysses, plotted using a colour scale based on the angle between the measured and expected field directions. Red represents antisunward polarities and blue sunward. The green lines show the location of the neutral line inferred from solar observations. The central meridian longitudes of the left and right panels are 240° and 60° respectively.

previously found that the maximum latitude of the heliospheric current sheet is lower than the maximum latitude of the neutral line indicating that the latitudinal extent of the warps in the current sheet decreases with distance from the Sun (e.g. Smith et al. 1993).

5. The underlying field direction

Both Fig. 2 (centre panel) and Fig. 4 show that, although the underlying direction of the magnetic field agrees to a first approximation with that predicted by the Parker (1958) model, superimposed on this long term trend there are large amplitude fluctuations, particularly in the regions where pure high speed solar wind from the polar coronal holes was being sampled. These have been shown to be due mainly to the presence of large amplitude, long period (of order of several hours) Alfvén waves in the high latitude solar wind (Smith et al. 1995b). Thus to make a detailed study of the underlying field direction, a careful statistical analysis is needed. With this aim, we have constructed histograms of $\phi_B - \phi_P$, the azimuth angular deviation of the measured field direction, ϕ_B, from the (antisunward) field direction predicted by the Parker model, ϕ_P. Full details of this analysis procedure have been given by Forsyth et al. (1996a). If the measured magnetic field agrees perfectly with Parker's model then in the southern hemisphere, where the magnetic field is presently directed sunward, $\phi_B - \phi_P$ will take the value 180° and in the antisunward directed fields of the northern hemisphere $\phi_B - \phi_P$ will be 0°. In both cases, values of $\phi_B - \phi_P$ less than 0° or 180° correspond to field lines that are more tightly wound than expected while values greater than 0° or 180° correspond to field lines that are less tightly wound than expected.

Fig. 5 shows two histograms constructed using estimates of $\phi_B - \phi_P$ obtained from hourly averages of the magnetic field components, binned in 10° intervals, the top panel accumulated using all the data obtained while the spacecraft was poleward of 60°S, and the second panel poleward of 60°N. The southern hemisphere data is that first presented by Forsyth et al. (1995) and is reproduced here for comparison with the north. At these high southerly latitudes it was found that the most probable value of $\phi_B - \phi_P$ was located at 156° rather than the expected 180°, corresponding to field lines 24° more tightly wound than expected. At latitudes equatorward of 60°S the most probable value was found to be in good agreement with the expected 180°. However at all latitudes at which Ulysses was sampling purely southern hemisphere magnetic fields an asymmetry was found in the azimuth angle distributions such that there were a greater number of observations of field lines less tightly wound than expected compared to field lines more tightly wound, that is in the opposite sense to the shift in the most probable angle. This is shown in Fig. 5 by indicating the percentage of observations less than and greater than the expected values of 180° or 0°. Forsyth et al. (1996a) attributed this asymmetry to the influence of the large amplitude Alfvén waves in the distributions which led to the mean values of the distributions being in a less tightly wound direction in all cases. They point out that in these circumstances

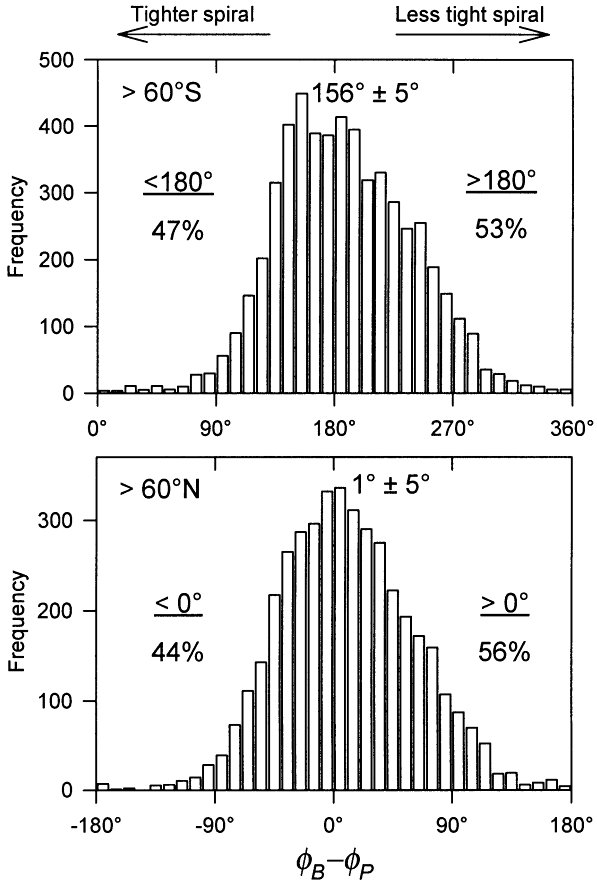

Fig. 5. Histograms of the deviations, $\phi_B - \phi_P$, of the azimuthal angle of the magnetic field from that predicted by the Parker model. The upper histogram is accumulated from data obtained at latitudes above 60° in the southern hemisphere and the lower histogram is the same for the northern hemisphere.

it is more appropriate to compare the most probable value of the distribution with the Parker model rather than the mean value.

The lower panel of Fig. 5 presents for the first time the equivalent histogram accumulated at latitudes poleward of 60°N. The most probable value of this distribution is +1°±5°, unlike the southern hemisphere, in good agreement with the value of 0° expected from Parker's model. The difference in the shape of the two histograms can be clearly seen in the figure indicating that the high probability of finding overwound field lines at high southerly latitudes is not reproduced at high northerly latitudes. In the lower panel, 56% of the total observations are found to be greater than the expected value of 0°, leading to the mean of the northern distribution being +10.1° with a standard error of 0.8°, compared with +7.4° relative to the expected 180° in the southern distribution with a standard error of 0.7°. Thus the asymmetry in the distributions leading to the mean azimuth angle consistently being less tightly wound than expected is also present in the northern regions and remains biased in the appropriate sense to be consistent with the Alfvén wave deflections as suggested by Forsyth et al. (1996a).

When discussing the cause of the most probable magnetic field azimuth angle being more tightly wound than expected in the southern hemisphere, Forsyth et al. (1995) did not reach firm conclusions, but could not eliminate the possibility that the Alfvén waves might be influencing the most probable value as well as the mean.

However, as we will discuss in the next section, the directional properties of the magnetic field variances have been found to be identical within errors in the northern hemisphere to those in the southern hemisphere, which provides evidence against the Alfvén waves being the cause of the overwinding. Possibilities for further investigation include looking for asymmetries in observations of the solar photosphere and corona, for example in the configuration of the polar coronal holes.

6. Variances of the magnetic field

Balogh et al. (1995) and Forsyth et al. (1996b) have analysed the fluctuations in the heliospheric magnetic field data measured by Ulysses in terms of the variances of the field components and magnitude. In the high speed solar wind from the polar coronal holes, hourly variances calculated from the highest time resolution (1 or 2 seconds) data showed a much higher degree of variability in the magnetic field transverse and normal components relative to the magnitude than was found at low latitudes.

Fig. 6 shows two intervals of magnetic field data selected to illustrate the clear difference in the variability of the field components in high speed solar wind from the polar coronal hole and low speed streams near the ecliptic. The left hand panel shows the abrupt change in variability that took place early on day 34 (3rd February 1995) at about 22.7°S as Ulysses descended towards the equator. The time that the change takes place is in close agreement with the time of entry of Ulysses into a coronal mass ejection (CME) event deduced from Fig. 2 of Gosling et al. (1995a). The magnetic field compression associated with the CME can be seen in the field magnitude panel of Fig. 6. Note that the change in variability does not take place immediately at the forward shock (indicated by the first sharp increase in field magnitude on day 34) leading the event, rather the change takes place at the start of a magnetic cloud feature seen in the field components which is associated with the CME. However, on the basis of Fig. 6 alone we cannot say that the nature of the fluctuations in the compression region ahead of the CME is necessarily the same as in the uncompressed high speed solar wind ahead of it.

In the right hand panel of Fig. 6 it can be seen that the return, also abrupt, to the higher degree of variability took place on day 87 (28th March 1995) at about 18.8°N. This is in good agreement with the latitude reported by Phillips et al. (1995) for the last slow speed solar wind seen as Ulysses travelled northwards away from the equatorial regions. The structure seen in the magnetic field magnitude at the time of the transition is due to the compression of the magnetic field by the higher speed solar wind interacting with the slower wind leading it.

As confirmation of the abrupt change in the nature of magnetic field fluctuations as Ulysses crossed the near ecliptic re-

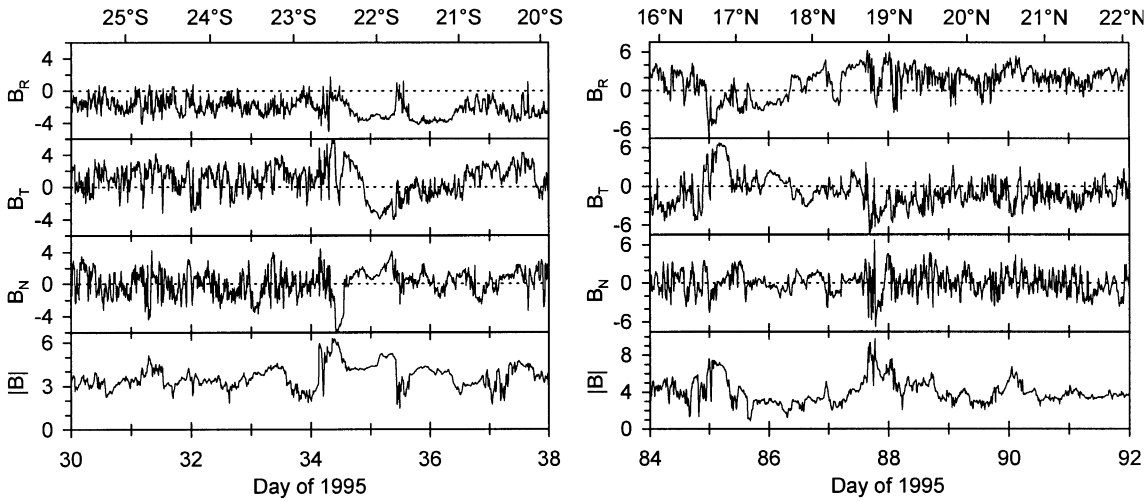

Fig. 6. Two 8 day intervals of magnetic field data showing the change in variability of the field observed as Ulysses moved from polar to equatorial flows (left) and back again (right).

gions, Fig. 7 shows variances σ_R^2, σ_T^2, σ_N^2 and σ_B^2 of the R, T and N components and the field magnitude respectively which have been normalised by dividing by $|\mathrm{B}|^2$. These are hourly estimates of the variances, calculated from the highest (1 or 2 second) time resolution magnetic field data, which have been further averaged over 2° latitude intervals. Full details of the analysis have been given by Forsyth et al. (1996b). In the equatorial regions the variances in all three components are similar, while at higher latitudes in the high speed solar wind, the two transverse component variances are very much enhanced over the radial component variances which remain close to their equatorial levels, indicative of the presence of the Alfvén waves analysed by Smith et al. (1995b). The radial scaling of the variances in the southern hemisphere on this time scale has also been analysed by Forsyth et al. (1996b). When un-normalised variances were examined in solar wind which was clearly unaffected by large scale compressions due to solar wind stream structure and CMEs (between 3 and 1.5 AU as Ulysses travelled inward through the southern polar regions) a power law dependence on radial distance was found. Fitting an r^{-n} law to the data produced exponents n of the order of 3.4 for the component variances and 2.5 for the magnitude variance. Here we extend the analysis of the polar variances to the same distance range in the northern polar heliosphere to check for possible north-south asymmetries.

Fig. 8 shows a log-log plot of the un-normalised variances in both hemispheres averaged over 0.1 AU intervals and plotted against radial distance. The straight line behaviour corresponding to the power law referred to above can be easily seen. Southern hemisphere data is represented by filled circles and northern hemisphere data by unfilled circles. Only the variances of the radial and the normal components and of the field magnitude have been plotted. The tangential component variance has been omitted for clarity as it closely overlies that of the normal component, but the behaviour is as for the other components. In most cases the error estimates are smaller than the size of the symbols plotted. Clearly, the southern and northern hemisphere variances closely overlie each other, indicating no systematic difference in the variances on these timescales between the two hemispheres. Table 2 shows the gradients and associated one standard error ranges of straight line fits to the variances in Fig. 8 using the linear least squares method. Again, no significant difference can be seen between the northern and southern hemisphere radial scaling given the error estimates quoted. Given the importance of the radial scaling of the variances for cosmic ray propagation (Jokipii et al. 1995) this result needs to be taken into account when interpreting the asymmetries in cosmic rays reported by Simpson et al. (1996). The time scales we have analysed in the present paper are shorter than those considered by Jokipii et al. (1995). However, we have completed the same analysis over a large number of time scales, extending to an upper limit of 16 day variances (calculated from 8 hour averaged field data), as part of a detailed study of the time scale dependence of magnetic field variances in the polar heliosphere (Balogh et al., manuscript in preparation). No asymmetry between the northern and southern hemisphere has been found on any of the time scales analysed. This lack of north-south asymmetry in the properties of the magnetic field fluctuations is corroborated by the analysis of the evolution of the shape of the power spectrum with distance presented by Horbury et al. (1996) in this issue.

Table 2. Variance scaling with radial distance.

Hemisphere	Southern Gradient	Error	Northern Gradient	Error
σ_R^2	−3.39	±0.07	−3.42	±0.06
σ_T^2	−3.45	±0.09	−3.43	±0.06
σ_N^2	−3.37	±0.09	−3.40	±0.09
σ_B^2	−2.48	±0.14	−2.67	±0.16

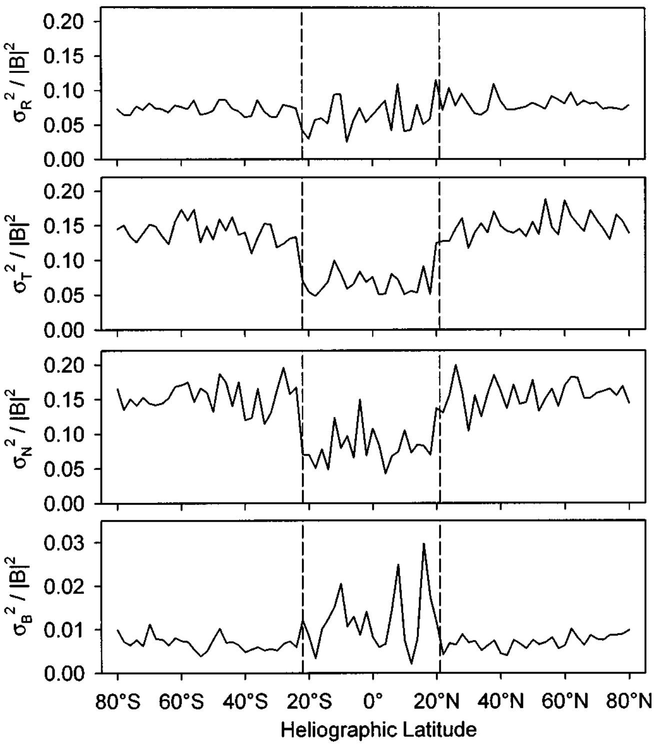

Fig. 7. Normalised variances of the R, T and N components of the magnetic field and of the field magnitude, averaged over 2° latitude intervals, plotted against heliographic latitude for the fast latitude scan from 80°S to 80°N. Typical one standard error estimates for the component variances are ±0.01 and for the magnitude variances ±0.003. The vertical dashed lines represent the same region as in Fig. 2.

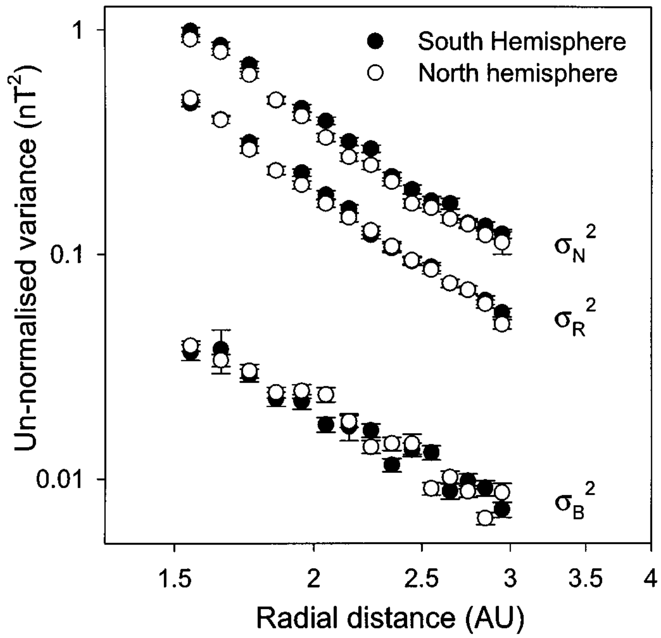

Fig. 8. A comparison of magnetic field variances between the southern and northern hemispheres in polar solar wind flows between distances of 1.5 and 3 AU.

7. Summary and conclusions

Analysis of the magnetic field data from the fast latitude scan of Ulysses at a time of minimum solar activity has shown that:
1) The polarities observed in the heliospheric magnetic field correspond to the dominant polarities on the Sun.
2) The latitude independence of the radial component of the magnetic field is confirmed in both the north and south hemispheres with no significant difference in the magnitude of r^2B_r between the hemispheres.
3) The most probable value of the magnetic field azimuth angle in the northern hemisphere at latitudes poleward of 60° is in good agreement with that predicted by the Parker model of the heliospheric magnetic field, unlike that in the same region of the southern hemisphere which corresponded to field lines more tightly wound than expected.
4) Magnetic field variances compared between the northern and southern hemispheres of the heliosphere show no difference in amplitude or in radial gradient.

Thus, apart from the difference in the field winding angle reported in 3) above, the heliospheric magnetic field has proved to be remarkably free of north-south asymmetries when comparisons are made between fields originating from the northern and southern polar coronal holes. These observations provide constraints in the interpretation of asymmetries observed in data from other Ulysses experiments, for example, the cosmic ray asymmetry reported by Simpson et al. (1996). The results we have presented are very much representative of the solar minimum configuration of the heliosphere. During the next fast latitude scan of Ulysses at a time of maximum solar activity it is likely that the picture will be much more complex.

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