(NASA-TM-86209) AN INTERPLANETARY MAGNETIC FIELD ENSEMBLE AT 1 AU (NASA) 48 p N85-27784
HC A03/MF A01 CSCL 03B
Unclas
G3/90 21360

NASA

Technical Memorandum 86209

AN INTERPLANETARY MAGNETIC FIELD ENSEMBLE AT 1 AU

W.H. Matthaeus
M.L. Goldstein
J.H. King

APRIL, 1985

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

AN INTERPLANETARY MAGNETIC FIELD ENSEMBLE AT 1 AU

W.H. Matthaeus
Bartol Research Foundation
University of Delaware
Newark, DE 19716

M.L. Goldstein
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, MD 20771

and

J.H. King
National Space Science Data Center
Goddard Space Flight Center
Greenbelt, MD 20771

National Aeronautics and
Space Administration

Goddard Space Flight Center

Abstract.

A method for calculating ensemble averages from magnetic field data is described. A data set comprising approximately sixteen months of nearly continuous ISEE-3 magnetic field data is used in this study. Individual subintervals of this data, ranging from 15 hours to 15.6 days comprise the ensemble. The sole condition for including each subinterval in the averages is the degree to which it represents a weakly time-stationary process. Averages obtained by this method are appropriate for a turbulence description of the interplanetary medium. The ensemble average correlation length obtained from all subintervals is found to be 4.9×10^{11} cm. The average value of the variances of the magnetic field components are in the approximate ratio 8:9:10, where the third component is the local mean field direction. The correlation lengths and variances are found to have a systematic variation with subinterval duration, reflecting the important role of low-frequency fluctuations in the interplanetary medium.

Introduction.

Studies of solar wind fluctuations have been carried out by a number of investigators [Coleman, 1966; Jokipii and Coleman, 1968; Sari and Ness, 1969; Belcher and Davis, 1971; Barnes, 1979; Burlaga, 1985; among others]. Most previous studies have sought to characterize specific types of solar wind flows or to give examples of specific phenomenological features of interplanetary fluctuations. Usually the number of intervals analyzed in a given study has not been large. Comparison of studies is hampered because the criteria for selecting data intervals have varied according to the objectives of the investigation, as have the data analysis procedures. Only a small fraction of the available interplanetary data has been studied statistically. A considerably sharper perspective of the state of interplanetary magnetic fluctuations would be available if a systematic procedure for extracting convergent statistical estimates were applied to large numbers of field samples. In essence, one would like to have an appropriate algorithm for constructing statistically valid ensembles of solar wind data sets. The properties of such ensembles could then be used to investigate physical problems ranging from magnetohydrodynamic (MHD) turbulence to cosmic ray propagation and modulation.

We describe here a method for accomplishing this task and apply it to solar wind magnetic field data acquired at 1 AU. Accurate determination of quantities relevant to the development of a turbulence description of the solar wind is a primary motivation in the present study; however, the bulk of the results do not rely on specific dynamical models of the interplanetary medium. The methods used are an extension of those employed previously by Matthaeus and Goldstein [1982a,b] to investigate the MHD turbulence properties of the solar wind.

The essence of our approach is that reproducible turbulence properties of the magnetic field are average properties of a statistical ensemble, and that a large collection of appropriately chosen analyses of solar wind data intervals constitute, in effect, rather precise knowledge of that ensemble.

In the following sections, some background is presented and the method is presented in detail. Subsequently, the data base used is described, and the results presented. Finally, implications of the results are discussed and directions for future work presented.

Background.

Statistical methods are useful in describing physical systems that exhibit irreproducible behavior. Such methods have been an essential ingredient in turbulence theory [Taylor, 1938; Batchelor, 1970; Orszag, 1977] and experiments [Grant, Stewart and Moilliet, 1962; Hinze, 1975] for most of this century. In the statistical perspective, individual samples of the dynamical variables, which may be, for example, experimentally determined values of fluid velocity in a turbulent fluid, are taken to be particular values of random variables, or "realizations". A probability distribution function, specifying the relative likelihood of occurrence of the various realizations, is assumed to exist when it is not calculable from first principles. The use of probability methods for a deterministic system is most easily made plausible by appealing to the notion of an "ensemble", which may be thought of [Van Kampen, 1981] as the collection of all possible samples of a system, or equivalently a collection of a very large number of similarly prepared systems. Expectation values calculated from the probability distribution are identical to averages over the ensemble. In effect, the probability distribution is just the tabulation of the frequency of occurrence of specific values of the random variables in the ensemble.

If the solar wind is viewed as a turbulent medium, it is natural to apply this type of method to its study. Unfortunately, the current level of knowledge (see, e. g., Whang [1977]) about the probability distribution is not sufficient to base these investigations on the probability function itself. Consequently, most work has concentrated on statements about empirically determined statistical quantities, such as correlation times and lengths, spectra and correlation functions [Jokippi, 1973]. If accurately determined, these quantities are mathematically related to the probability distribution, but their validity as estimates of ensemble averages is rarely considered in specific cases. In all cases, the scope of applicability of a statistical measurement in the solar wind must be judged in accordance with the defensibility of the data selection criteria, the rationale for the method of analysis, and the stability of the results when data intervals and analysis parameters are varied. At the same time, physically useful statistical results must preserve information that may be both model-dependent and sensitive to analysis procedures.

The nature of the interplanetary medium renders the task of living up to these ideals difficult, particularly when real-world limitations on the number, duration, sampling rates and instrumental accuracy of spacecraft experiments are taken into account. The solar wind contains structure ranging over a wide dynamic range of both spatial and temporal scales. At the largest scales and lowest frequencies, the solar wind exhibits organization, including systematic variations of many physical properties with heliocentric distance as well as the global Parker spiral magnetic structure. In addition, large scale features such as high-speed streams and sector structure

[Holzer, 1979], interaction regions, corotating and transient flow patterns [Dryer et al., 1978; Burlaga, 1983] influence and organize significant volumes of the interplanetary plasma. There are also levels of organization at intermediate scales that might be thought of as "coherent structures", such as shocks and MHD waves and discontinuities. Finally, present in all plasma variables, are broad-band stochastic fluctuations extending roughly from the reciprocal of the correlation time to beyond the ion-cyclotron frequency. These structural characteristics are important ingredients in the physics we study, but they also make the signals that must be selected and interpreted much more difficult to deal with than unstructured random processes, for example, the random telegraph signal [Rice, 1954].

Researchers have responded to these complications with a variety of selection and analysis methods. Most often, selection of data has proceeded with the goal of studying a particular class of solar wind behavior. In many cases, the scientific conclusions depend to some degree on the method used.

For example "Alfvénic" periods are probably the most widely studied [Coleman, 1968; Jokippi and Coleman, 1968; Belcher and Davis, 1971] because of their frequency of occurrence and the likelihood that they represent MHD behavior, as well as because of their potential influence on solar and galactic cosmic rays. However, the conclusion that Alfvénic periods consist entirely of "outward travelling waves" [Belcher and Davis, 1971; Dobrowolny, Mangeney and Veltri, 1980] has been questioned. Matthaeus and Goldstein [1982a] found intervals which displayed outward travelling Alfvénic correlations between velocity and magnetic field vectors at frequencies corresponding to the inertial range of MHD turbulence, but correlations corresponding to "inward-travelling" waves were found at lower frequencies. To see this reversal of the sign of the cross helicity, the data interval must be sufficiently long. In addition, in one interval obtained near 5 AU, Alfvénic fluctuations with periods within the inertial range were observed to propagate randomly both inward and outward. The characteristic mixed sign of the velocity-magnetic field correlation was also seen in two-dimensional MHD turbulence simulations [Matthaeus, Goldstein and Montgomery, 1983], which led to the suggestion that Alfvénic periods may be produced by in situ MHD turbulence rather than representing a remnant of coronal processes.

The processing of data can also influence statistical conclusions. The standard time-series analysis technique of time domain windowing [Otnes and Enochsen, 1972] is justified by citing the requirement of strict periodicity when fast Fourier transform spectral analysis is used. However, windowing systematically reduces the complement of low frequency power, causing a reduction in estimates of correlation lengths and times [Matthaeus and Goldstein, 1982a]. Another type of data preprocessing which gives results that must be interpreted with care is exemplified by the analysis of Pioneer 6 data by Fisk and Sari [1973] (also see Sari and Valley [1976]). They removed tangential discontinuities from selected data intervals before analysis with the goal of extracting properties of the "underlying" random signal. This method is of questionable applicability to a turbulence description of the solar wind since MHD turbulence seems to have a propensity for producing nearly discontinuous vorticity and current structures [Matthaeus and Montgomery, 1980; Matthaeus, 1982].

Data selection and processing can also influence the sensitive issue of defining the mean magnetic field. Typically it is desirable to decompose the magnetic field $\underline{B}$ as

$$\underline{B} = \langle \underline{B} \rangle + \delta \underline{B} \quad (1)$$

where ⟨...⟩ denotes an averaging operation and $\delta\underline{B}$ is the fluctuating field. This decomposition is of essential importance in MHD because the mean field cannot be eliminated by transformation to a moving frame [Elsasser, 1956] and it produces dynamical couplings that produce anisotropies in both wave-like [Cowling, 1976]) and turbulent [Shebalin, Matthaeus and Montgomery, 1983; Montgomery, 1983] magnetohydrodynamics. In the interplanetary medium, the mean field is not a DC field - there are time variations in the field at essentially all scales. On the other hand, MHD is local and allows small scale fluctuations to respond to the slowly varying long wavelength component of the magnetic field as though the magnetic field were strictly uniform and constant. In some cases, interplanetary intervals have unambiguous mean field values (e. g., Alfvénic periods of sufficient duration). In general, however, the decomposition into mean and fluctuating fields may be modified in several ways. First, the calculated value of the mean may not be stable. For example, the mean might undergo unacceptably large changes if the endpoints of the interval are shifted across a sector boundary. In addition, if time domain windowing or detrending is performed, the calculated mean would be changed. Irrespective of the implications of the dynamical interpretation, the variances and correlation times will be ill-defined whenever the decomposition represented by equation (1) is ambiguous.

The basis for alleviating some of the ambiguities in data selection can be found in the theory of stationary random processes [Pugachiev, 1962; Panchev, 1971]. A method has been developed to quantitatively test the hypothesis that interplanetary magnetic field data intervals that are either of sufficient duration or otherwise properly chosen behave as if they are weakly stationary random functions of time [Matthaeus and Goldstein, 1982b]. By definition, a weakly stationary magnetic field signal is one for which the ensemble values of the mean and the correlation functions are independent of the selection of the origin of time. Under rather mild conditions, an ergodic theorem guarantees that time averages converge to ensemble averages as the duration of the data sample is increased without bound. It can be shown that this implies not only that the value of ⟨B⟩ calculated from the data converges to its ensemble value, but also that the form of the convergence is specified.

In cases where convergence to weakly stationary behavior can be demonstrated, the mean field, variances, correlation functions and spectra can be reliably obtained. Matthaeus and Goldstein [1982b] showed that the theoretical predictions for the rate of convergence of means and variances of magnetic field components agree remarkably well with the appropriate quantities obtained from solar wind data comprising many solar rotations. There are, however, several difficulties with simply using such very long data intervals to obtain highly convergent statistical estimates of ensemble properties of the solar wind. Long and continuous data sets are not always available. More fundamentally, the mean field which can be accurately obtained by averaging over many solar rotations is not the local mean field to which MHD fluctuations and plasma particles respond. In fact, averaging over many months causes a cancellation of the sector structure through many reversals of sign, and ⟨B⟩ tends to lie in the direction normal to the ecliptic plane. Statistical quantities so obtained have lost information about the dynamically important local mean field and are biased by inappropriately classifying very low frequency changes of the solar field as fluctuations. Furthermore, long data intervals disallow [Mattheaus and Goldstein, 1982a; Goldstein, Burlaga and Matthaeus, 1984] the conversion from frequency to wavelength in the super-Alfvénic solar wind flows. This is undesirable since turbulence theory usually emphasizes the role or spatial correlations and wavenumber spectra.

What is needed are methods to calculate convergent statistics using intervals that are not so long as to wash out information about the local mean field. Fortunately, an adequate degree of convergence to the predictions of ergodic theory has also been obtained for intervals which are not many solar rotations in duration, but are still long compared with the correlation time [Matthaeus and Goldstein, 1982b]. In some cases, it is possible to select data intervals that do not contain individual anomalies such as sector crossings or shocks and subsequently verify that the theoretically expected convergence properties are well satisfied. Conversely, a "stationarity test" procedure can be constructed in which an arbitrary data set is compared to the predictions of the ergodic theory and the data is then judged as "stationary" or "nonstationary" in accordance with a quantitative figure of merit of agreement with the theory.

In the following section we describe in detail a method for obtaining convergent estimates of ensemble properties of the interplanetary magnetic field. The basic assumption is that the collection of a large number of statistically stable estimates of the field properties constitutes an adequate representation of the ensemble. The principal data selection criterion will be the stationarity test method applied to data intervals for which a local mean field is physically meaningful and which do not violate the assumption of local spatial homogeneity. In this way we seek to characterize the interplanetary magnetic field in a manner that is relevant to statistical theories of MHD turbulence.

Method.

We assume that one or more sets of magnetic field data are available, which we designate as S^{α} where

$$S^{\alpha} \equiv \{B_j(t_{\alpha} + n\Delta t) \mid n = 0,1\ldots N_{\alpha};\ j = 1,2,3\} \qquad (2)$$

indicating that three orthogonal components ($j = 1,2,3$) are known for the magnetic field, $\underline{B}$, at time values of $t_{\alpha} + n\Delta t$. Data set S^{α} contains N_{α} values of $\underline{B}$. These are taken for convenience to have a constant time spacing Δt. The division of available data into sets labelled by different values of α is somewhat arbitrary and has significance mainly as a computational convenience. For example, a large data set with a data gap of significant duration in the middle should probably be broken into two sets. On the other hand, small data gaps can be included in a single set by the usual method of flagging "bad points" or data gaps. It is intended that each set S^{α} be large enough that it would show highly convergent results in a stationarity test. However, if an interplanetary data set is as long or longer than a solar rotation, then the test used on the entire set must use the form of the ergodic theory that includes solar rotation effects (see equation 12 in Matthaeus and Goldstein [1982b].

We do not perform stationarity tests on the entirety of each interval S^{α} in view of the very long computational time required. However, a simple criterion for the acceptability of a set S^{α} is that it should span a very large number of correlation times, say, several hundred. Six months to a year of data is a convenient interval. It would be possible to proceed with sets that are not of such large duration, but then a larger number of sets would be required. In the analyses described below, data gaps have been filled by linear interpolation and a low band-pass digital filter was used to suppress aliasing.

The main part of the technique consists of operations on each of the sets S^{α}. An automated procedure is established, in the form of a modularized FORTRAN code to search the data in each set for subintervals of a predetermined length, and to store statistical information from those subintervals judged adequately stationary for later use. In advance of a single "run", parameters must be specified governing the selection of subintervals and determining the stationarity test criteria. The steps taken in each run, which are also depicted in Figure 1, are:

I. Select a subinterval from S^{α}. For a given run, the number of points (time values) is fixed at NLEN, which should be large enough to correspond to at least several correlation times. The next subinterval begins at a fixed number of points (NSLIDE) from the last interval's starting time index. The position within the set S^{α} is analyzed to check if further processing is requested.

II. Preliminary statistics are calculated from the subinterval data. First, the subinterval is rejected if the number of bad points flagged exceeds a predetermined percentage. Plasma velocity data is also used to calculate mean radial flow speeds in the subinterval for the purpose of converting frequency data to wavenumber data. If the speed data has too many gaps, the mean solar wind speed defaults to a previously specified value (usually 400 km/s), otherwise the mean speed is calculated. Next, the mean values and variances of the magnetic field components are calculated.

III. The data are transformed to a mean field coordinate system. The elements of the rotation matrix are retained, as are the calculated means and variances of the components in the new coordinates. The data we used are initially in heliocentric coordinates. In this coordinate system $\hat{R}$ is along the sun-spacecraft line, positive away from the sun, $\hat{T}$ is perpendicular to $\hat{R}$, and $\hat{N} = \hat{R} \times \hat{T}$. The rotated coordinates are in the directions $\underline{\bar{B}} \times \hat{N}$, $\underline{\bar{B}} \times (\underline{\bar{B}} \times \hat{N})$ and $\underline{\bar{B}}$, where $\underline{\bar{B}}$ is the mean field vector calculated from the subinterval.

IV. A Blackman-Tukey mean-lagged-product correlation analysis is performed on the subinterval data using the method described by Matthaeus and Goldstein [1982a]. Estimates of the three diagonal and three antisymmetric off-diagonal elements of the correlation matrix [Matthaeus and Smith, 1981] are calculated and retained, as are the statistical weights of each estimate and the values of the corresponding spatial lag. The latter is formed by multiplication of the time lags by the mean solar wind speed in the subinterval. The correlation time and length are also calculated. If the subinterval contains less than NC correlation times, the subinterval is rejected (usually we take NC = 10). Note that even though the mean field direction varies according to the particular subinterval, the spatial lags always correspond to radial separations. Information about the statistical weight of each correlation estimate can be easily used later to calculate composite correlation functions.

V. A stationarity test is performed on the three components of the magnetic field in the subinterval. The procedure consists of averaging the field data over time intervals of duration τ, where τ varies from the sampling time up to one-fifth of the subinterval duration, NLEN Δt. We require that the variance of these averages calculated from all such samples within the subinterval be sufficiently close to the value expected for a stationary random process converging to its ensemble mean. If an average over time τ of field component B_j is denoted by $[B_j]_\tau$ and the variance of such an average within the subinterval is denoted by $\Delta^2[\underline{B}_j]_\tau$, then the relevant convergence behavior is given by [Matthaeus and Goldstein, 1982b, equation 11]

$$\Delta^2[B_j]_\tau = 2(\tau_c)_j \, \sigma_j^{\,2}/\tau \tag{3}$$

where $(\tau_c)_j$ and $\sigma_j^{\,2}$ are the correlation time and variance of the jth component calculated for the entire subinterval in step IV. The weighted vector version of (3),

$$\Delta^2[\underline{B}]_\tau/\sigma^2 \equiv \sum_j \Delta^2[B_j]_\tau \;/\; \sum_j \sigma_j^2 \tag{4}$$

is used in the stationarity test [cf. Matthaeus and Goldstein, 1982b].

The correlation analysis is done first so that these parameters are available for the stationarity test. The left hand side of (4) is calculated from the subinterval data and compared with the right hand side for specified values of τ_c/τ. We have usually chosen τ_c/τ values of one and two.

The subinterval is judged as adequately stationary if the fractional difference of the empirical value of the left hand side of (3) and the right hand side is less than one at $\tau_c/\tau = 1$ and if it is also less than one-half at $\tau_c/\tau = 2$. These parameters control the sensitivity of the test and are specified at the beginning of the run. If the subinterval is judged "nonstationary", it is rejected.

VI. The statistics and characterizing parameters of stationary intervals are stored. This includes means, variances, correlation lengths and correlation functions, as well as the position of the subinterval within S^{α}, the mean solar wind speed, the rotation matrix, the correlation lags and the statistical weights of the correlation estimates. Processing then continues with step 1.

Steps I through VI are applied to all selected sets S^{α}. Several such runs through all the data can be done with differing values of NLEN, and with various values of stationarity test sensitivity. The entire procedure (see Fig. 1) results in a collection of statistical analyses that may be quite large in number, all of which have been calculated from a method involving minimal subjectivity. The data base obtained may then be treated as a representation of the magnetic field ensemble corresponding to the conditions prevalent in the data intervals S^{α}.

<u>ISEE data: A Magnetic Ensemble at 1 AU</u>.

The method has been used to analyze ISEE-3 magnetic field data made available to us under the auspices of the ISEE Guest Investigator program. We are indebted to E. J. Smith and B. Tsurutani for providing us with the data that made this study possible. At various stages we have made use of ISEE plasma velocity data (P. I.: S. J. Bame, LANL) from the National Space Science Data Center (NSSDC) Omnitape and ISEE-3 helium speed data (provided by K. W. Ogilvie) to estimate mean solar wind speeds.

We have used two time intervals of magnetic field data. The five minute data samples were linearly interpolated over gaps, filtered with a 128 point Remez finite impulse response filter

[McClellan, Parks and Rabiner, 1979], and decimated to every third point. This preprocessing produced fifteen minute averages relatively free of aliasing errors. The first data set, S^1, consists of 27,736 fifteen minute averages, spanning the interval from day 152 (1978) to day 228 (1979). The second set, S^2, begins on day 180 (1979) and ends on day 365 (1979), for a total of 17,814 samples of each component. The total percentage of gaps and bad points was 11.5% in S^1 and 11.9% in S^2.

Runs were performed on S^1 and S^2 according to the procedure given in the last section. Twelve runs were made using six subinterval lengths on each set. We selected subinterval lengths (NLEN in step I above) of 60, 125, 250, 500, 1000 and 1500 fifteen minute points. The criteria for acceptability of a subinterval were, for all cases: (i) at least ten correlation times are present in the subinterval and (ii) the stationarity test was satisfied in that the data was consistent with eq. (3) evaluated at the points and with the precision described in step V above. Criterion (i) must be satisfied to perform the stationarity test. The parameter for incrementing the starting point when selecting a new subinterval (NSLIDE in step I) was either 50 or 100 in all twelve runs.

Table 1 summarizes the run parameters, and indicates the number of acceptably stationary intervals found in each case. The total number of data intervals considered was approximately 355 for each of the six set S^2 runs, and was approximately 550 for the set S^1 runs with NSLIDE = 50, and half that number for the set S^1, NSLIDE = 100, runs. Using this information, a percentage of intervals found to be stationary is included in Table 1. The percentages found for both S^1 and S^2 when NLEN = 250 and 500 are quite similar. These subinterval lengths correspond to durations of 2.6 and 5.2 days. The frequency of finding stationary data subintervals falls off by about 10% when NLEN is increased to 1000, corresponding to subintervals of 10.4 days duration. The NLEN = 1500 runs (15.6 days) are found to be stationary even more rarely.

The relative probability that data sets of a few days duration are stationary is consistent with the viewpoint [Matthaeus and Goldstein, 1982a] that spectral analysis of stationary data requires samples of at least several correlation times. At first sight, the decrease in likelihood that longer data sets are stationary might appear puzzling because one expects that longer samples should behave more like the ensemble, and therefore should be more consistent with eq. (3). However, it must be borne in mind that the ensemble we are constructing is one that is consistent with the notion of stationarity about a local, well defined mean magnetic field direction. We are separating the behavior with respect to the local mean field from the behavior due to the systematic variations in the field produced by phenomena linked to the solar rotation period (see discussion in the paragraph following equation (1)). The use of eq. (3) above rather than eq. (12) in Matthaeus and Goldstein [1982b] (which includes solar rotation effects) precludes finer agreement in the longer data subintervals as effects of solar rotation become significant. The NLEN = 1500 runs are more than half a solar rotation period, and the decrease in percentage of stationary intervals for those cases simply reflects the dependence of the mean field calculated over that interval on the systematic behavior of low frequency structures in the solar wind.

We now turn to a discussion of the some of the statistical information that can be gleaned from the output of these runs.

Average Properties of the Ensemble.

Averages may be calculated from the data produced by the runs listed in Table 1 in several meaningful ways. A statistical quantity calculated in each of the stationary subintervals may be averaged over all of the 1,959 data sets produced without regard for subinterval length. Averages may also be accumulated separately from each of the twelve runs listed in Table 1. Possible dependence of the averages on the subinterval length can be investigated by forming averages using all subintervals having a specific length in both S^1 and S^2. Finally, just the data in S^1 or in S^2 may be used, again ignoring subinterval length. We will associate the symbol "S_{tot}" with averages accumulated from all the stationary subintervals in the union of S^1 and S^2. When an average is calculated from all of the 60, 125, 250, 500, 1000 or 1500 point stationary subintervals in the union of S^1 and S^2, it will be associated with the symbol "S_{60}", "S_{125}", "S_{250}", "S_{500}", "S_{1000}", or "S_{1500}" respectively. To avoid confusion, an overbar will indicate averaging within a subinterval, while angle brackets will indicate averaging over a collection of subintervals.

The first class of averages we discuss pertains to mean field values in the subintervals. Table 2 shows averages of the means of the R, T and N components of the magnetic field, the average vector magnitude, the average of the angle θ between the radial direction and the mean field, and the average deviation of θ from 90°. These quantities are given for the entire collection of stationary subintervals, S_{tot}, for the 60 point subintervals, S_{60}, and for the 1500 point subintervals, S_{1500}. The first thing to notice is that the average magnitude is larger for the R and T components than for the N component, in qualitative agreement with the Parker model of the mean interplanetary field. The average of the mean vector magnitude is 5.3 nT when calculated from S_{60}. This is comparable to quoted values of typical low speed "structureless" solar wind [Hundhausen, 1972, page 44]. However, values of the average magnitude of the local mean calculated from both S_{tot} and S_{1500} are somewhat smaller, which probably arises because low frequency fluctuations are included. We have not included the contribution to the average field magnitude due to the fluctuations in the subintervals, i. e. we have calculated the magnitude of the average field, not the average of the magnitude of the field.

The average of θ is 97° indicating nearly complete cancellation of inward and outward directed fields due to the sector structure. The average deviation of θ from 90° is about 38° for S_{tot}, and systematically decreases from 40° in S_{60} down to 30° for S_{1500} averages. This suggests that the average mean fields subtend an angle of about 52° with respect to the radial direction. Note that this angle includes contributions from the small but non-negligible normal component of the mean field. The mean solar wind speed is 405 km/s for the entire ensemble and ranges from 411 km/s in S_{60} down to 394 km/s in the S_{1500} averages. This indicates a slight systematic correlation of higher solar wind speed with stationary periods of shorter duration. High speed flows generally tend to be shorter than 15.6 days (the duration of a 1500 point subinterval). Similarly, these results suggest that low speed flows are more likely to be stationary over longer time periods than high speed flows.

The mean solar wind speed in set S^1 was 377 km/s compared with 429 km/s for set S^2. This effect is larger than the variation of speed with subinterval length and may be a consequence of the fact that set S^2 covers a time interval closer to solar maximum than set S^1. However, this conclusion is uncertain in view of the relatively high percentage of data gaps in the solar wind speed data used.

Statistics involving the variances of the magnetic field are presented in Table 3. Ensemble averages of the variances of the field components in heliocentric and in mean field coordinates are given, as are the ensemble average values of total field variance, $\overline{\delta B}^2$, the fluctuation magnitude, $\overline{\delta B} \equiv \sqrt{(\overline{\delta \underline{B} \cdot \delta \underline{B}})}$, and the value of $\langle \overline{\delta B}/|\overline{\underline{B}}| \rangle$. These data are shown for S_{tot}, S_{60}, S_{250}, S_{500} and S_{1500}. Recall that the ensemble averaging procedure does not commute with nonlinear algebraic operations on field quantities in each subinterval. Thus, for example, $\langle \overline{\delta B}/|\overline{\underline{B}}| \rangle$ is not necessarily equal to $\langle \overline{\delta B} \rangle / \langle |\underline{B}| \rangle$.

One interesting feature of this data is that the field variance is quite large for the component of the fluctuations parallel to the mean field. The ratio is about 8:9:10 for the entire ensemble and is about 11:16:10 for the S_{60} subintervals. The dominance of the fluctuations parallel to the mean field increases up to a ratio of about 6:7:10 for the long S_{1500} samples.

The total field variance systematically increases as the subinterval size is increased from about 25 nT^2 for S_{60} samples to 55 nT^2 for S_{1500} samples. The quantity $\langle \overline{\delta B}/|\overline{\underline{B}}| \rangle$ is about 2.3 for the entire ensemble, but also shows systematic dependence on the sample size, varying from 0.95 for the shortest subintervals up to 5.0 for the longest. This behavior of both the variances and the values of $\langle \overline{\delta B}/|\overline{\underline{B}}| \rangle$ supports the view that long-wavelength fluctuations play an important role in determining the structure of the interplanetary field [Burlaga, 1983; Goldstein, Burlaga and Matthaeus, 1984] and may also have implications for theoretical treatment of particle motions in the heliosphere. This issue will be taken up in the discussion section.

Averages of the correlation lengths and correlation times of the components and the total field are shown in Table 4 for S_{tot}, S_{60}, S_{250}, S_{500} and S_{1500} samples. The value of the correlation time is calculated from the correlation function [Matthaeus and Goldstein, 1982a] for each subinterval. Frozen-in-flow [Taylor, 1938] is used to convert correlation times to correlation lengths using the mean solar wind speed in the subinterval. Again there is a systematic increase in the correlation lengths and times as the subinterval size increases. The total ensemble value of the correlation length L_c is 4.9×10^{11} cm; the S_{60} value is 1.2×10^{11} cm and the S_{1500} value is 1.5×10^{12} cm. There is also an anisotropy in the correlation lengths in all but the S_{60} run with the largest values appearing for the components parallel to the mean field. The correlation length in the S_{60} run is almost perfectly isotropic. The same pattern of anisotropy and dependence on interval size is seen in the correlation time averages, which indicates that there is not a strong positive correlation between increasing solar wind speed and correlation time. The correlation time is about 3.4 hours for S_{tot}, and ranges from 0.81 hours for S_{60} up to 10.4 hours for S_{1500}. In all cases the average correlation time is considerably less than the duration of the subintervals (see Table 1) which is a posteriori a requirement for accurate determination of T_c. (The expression we use for T_c guarantees that T_c becomes comparable to NLEN Δt if all the power in the signal is at the lowest sampled frequency [see Matthaeus and Goldstein, 1982a].)

Other systematic variations in the statistics can be investigated by calculating separately averages from the S^1 and S^2 subintervals. Since S^1 and S^2 are data sets of comparable length, comparisons of the average statistics from these separate analyses provide a certain measure of confidence that the ensemble average results represent a fairly stable statistical representation of the solar wind, at least during this portion of the solar cycle.

In Table 5 the correlation lengths and times and variances of the components and the total field, and the magnitude of the local mean field components are compared for the major intervals S^1 and S^2. The entries in Table 5 should be compared with the corresponding entries in Tables 2, 3, and 4. The values of the correlation length calculated from set S^1 differ by just a few percent from those calculated from set S^2. For example, the total correlation length from set S^1, 5.12×10^{12} cm, differs from the set S^2 value, 4.73×10^{12} cm, by 8%. The correlation times are actually more variable than the correlation lengths, with differences in S^1 and S^2 estimates of the total correlation time differing by 20%. The variances of the field calculated from S^1 and S^2 also compare well. The total variance from set S^1 is 40.0 nT^2 and from set S^2 is 41.0 nT^2 which differ by only 2.5%. In contrast, the average magnitude of the local mean field varied by 14% in the two cases (3.77 nT in S^1 and 4.39 nT in S^2). Evidently the statistical averages are reproducible with good precision, particularly the correlation lengths and field variances which are closely tied to the structure of the turbulence. Nevertheless, the standard deviations of these same statistical estimates, shown in Tables 2, 3, and 4, indicate that there is a considerable spread in the estimates in the subintervals. For example, the standard deviation of the estimates of the total field variance from the entire set S_{tot} was 34.2 nT^2 (Table 3), a significant fraction of the average variance, 40.6 nT^2, even though the average variance was almost identical in S^1 and S^2.

Distribution of Values in the Ensemble.

Each of the statistical quantities in Tables 2-5 may be viewed as properties of a random variable with well-defined mean value. The distribution of these variables in the ensemble can be studied by calculating the frequency of occurrence of values, which is equivalent to a coarse-grained zero-lag probability distribution function. Extensive correlation analysis would contain information characterizing more complete probability descriptions of these random variables. A complete presentation of these properties will not be undertaken here. Rather, we shall focus on a small subset of diagnostics that describe distributions which may be of broad interest.

Figure 2 shows a histogram of solar wind speed values for the entire ensemble. In this and all subsequent figures, 1,958 data sets are used; i. e., one data set with an anomalously high variance (in excess of 525 nT^2) was dropped from the ensemble. The distribution is peaked just below the mean speed of 405 km/s, and has a high-speed tail extending beyond 600 km/s. The shape of the distribution and its mean value are quite comparable to the results obtained from Vela 3 during 1965 to 1967 [Hundhausen, 1972, page 44; Hundhausen et al., 1970].

A histogram of values of the S_{tot} magnetic field variance, $\overline{\delta B}^2$, is given in Figure 3. The distribution again displays a tail at large values of the variance, so that the mean value lies a little above the main peak of the distribution. There is also a rapid fall-off just above 60 nT^2.

Figure 4 is a histogram of the correlation length calculated from the S_{tot} data. The main maximum of the distribution is again at a value somewhat lower than the mean of 4.9×10^{11} cm. The maximum is displaced from the mean by a relatively greater amount than in Figure 3 because the high correlation length tail is more populated than the high variance tail. In fact, there is a small but noticeable secondary peak in the population near 2.3×10^{12} cm which is predominantly due to the S_{1000} and S_{1500} data intervals.

Scatter plots are convenient for displaying qualitative information about the elements of the ensemble. For each stationary subinterval a point is plotted in a plane whose axes are each a characterizing statistical parameter. Figure 5 is a scatter plot with the variance plotted on the ordinate and the solar wind speed plotted on the abscissa. A total of 1,958 points are plotted. While there are a few points that have large variance in conjunction with high speed, the overall impression is that there is little correlation between the variance and mean solar wind speed in the collection of intervals S_{tot}. The small number of samples at speeds greater than 575 km/s prohibits drawing firm conclusions about possible correlation between very high speed and very high variance.

A scatter plot of the total correlation length vs. solar wind speed is shown in Figure 6. The great majority of points lie below 10^{12} cm, and most of these are for intervals in which the speed is less than 400 to 450 km/s, which also follows by inspection of Figures 3 and 4. There is a subpopulation of intervals with L_c on the order of 10^{12} cm and solar wind speed less than 400 km/s. There is an even more sparse subpopulation at L_c ranging from 1.5×10^{12} cm up to 3×10^{12} cm. These seem to be less concentrated at speeds under 400 km/s. The latter subpopulation is associated predominantly with the longer data intervals S_{1000} and S_{1500}. The shorter intervals, such as S_{60}, have lower L_c and slightly higher than average speed.

Finally, Figure 7 is a scatter plot of the correlation length vs. the field variance. Here we see a concentration of intervals with variance below 50 nT^2 and L_c near a few times 10^{11} cm. This region is preferentially populated by the shorter intervals and also appears to have a broad but discernible positive correlation between variance and correlation length. In the area around $\overline{\delta B}^2$ = 50 nT^2 the points span a wide range of values of L_c, but are still mostly below 10^{12} cm. Higher variance intervals are also mostly found with $L_c < 10^{12}$cm, but several patches of points are found at higher L_c.

Discussion.

The method we have used to characterize the statistical properties of the interplanetary magnetic field involves averaging over many subintervals of available data without regard to classification into specific types of intervals such as "transient flows" or "corotating flows" [cf. Goldstein, Burlaga, and Matthaeus, 1984]. The features of the data we have emphasized are the local "stationarity property", stability of calculated local mean magnetic field, and effects of subinterval length.

One point of contrast between previous results and those presented here concerns the issue of "Alfvénic" periods. Since the work of Coleman [1968], Belcher and Davis [1971] and others, a considerable amount of effort has been directed towards investigating interplanetary data intervals that show a high degree of correlation between fluctuating magnetic and plasma velocity fields. Belcher and Davis found that these periods are characterized by fluctuations whose variance is least in component parallel to the local mean magnetic field, $\overline{\mathbf{B}}$. In the wave picture of MHD, this corresponds to a spectrum of fluctuations with wavevectors predominantly parallel to $\overline{\mathbf{B}}$, i. e.

"slab" geometry, and has led to use of "slab" models for the scattering of cosmic rays in the interplanetary medium [Fisk, 1979]. A comprehensive survey of the frequency of appearance of Alfvénic periods would be necessary to judge the extent to which characterizing interplanetary fluctuations as being Alfvénic is appropriate.

While the present study has not attempted to isolate Alfvénic periods, our results do bear on this issue. The value of the ratio of variances in Alfvénic periods is found by Belcher and Davis [1971] is 5:4:1. In contrast, we find that the ratio is 8:9:10 for the total ensemble, 6:7:10 for the 1500 point data intervals, and 11:16:10 for the 60 point data intervals. In all subinterval sets longer than and including the 500 point set, the maximum variance was found to be in the component parallel to $\underline{B}$. In the S_{250}, S_{125} and S_{60} sets, the maximum variance was in a component other than the parallel component, but only in the S_{60} set was the minimum variance found in the parallel component. Even in the S_{60} run, the variance ratio was quite different from that found by Belcher and Davis [1971] to be typical of Alfvénic periods. This strongly suggests that it is inappropriate to associate the properties of Alfvénic periods with interplanetary turbulence in general. For all interval sizes used, the results obtained here give component variances which are much closer to isotropic than slab-like.

The calculated average correlation lengths of the components (see Table 4) are in the approximate ratio 8:6:10 for the entire ensemble, but they also show a systematic dependence on interval length. In particular, the degree of anisotropy of component correlation lengths decreases with decreasing data interval size. The correlation lengths of the three components are essentially identical for the S_{60} data intervals (Table 4).

This does not imply that the wavevectors are isotropically distributed, but it does indicate that certain anisotropic features are more pronounced in the very long wavelength part of the fluctuation spectrum.

One of the most significant features of these results is that the variances, correlation lengths and values of $\overline{\delta B}/|\underline{B}|$ systematically depend on the data interval length (see Tables 3 and 4). As the interval length is increased, lower frequency signals are sampled, presumably including signals associated with stream and sector structure and other large scale coherent features of the heliosphere. There is also the possibility that the random component of the turbulence contains "excess" energy at very low wavenumber, due to self organization effects such as the inverse cascade of magnetic helicity [Frisch et al., 1975] or selective decay processes [Montgomery, Turner and Vahala, 1978; Matthaeus and Montgomery, 1980]. Some indication of this low wavenumber behavior has been seen in analysis of Voyager data [Goldstein, Burlaga and Matthaeus, 1984; Burlaga and Goldstein, 1984].

The present results support the view that the very large scale structures in the interplanetary medium affect statistical estimates in the following way: The variance of the magnetic field, which is proportional to the local mean magnetic energy density of the fluctuations, increases monotonically as the data interval size is increased from 0.625 days to more than 15 days. Accordingly, estimates of the strength of the mean magnetic field decrease so that the calculated values of $\overline{\delta B}/|\underline{B}|$ decrease as the interval size increases. Similarly, the correlation lengths and correlation times of the components and the total field also monotonically increase as the interval size is increased over the range we have examined.

Estimates of the correlation time calculated from intervals much longer than those used here [Matthaeus and Goldstein, 1982b; Goldstein, Burlaga and Matthaeus, 1984] are only slightly greater than the value we find for the longest intervals. For example 15 hours is a typical correlation time calculated from intervals ranging from two to 22 solar rotations while the S_{1500} estimate above corresponding to about a half solar rotation is about 10 hours. This indicates that the changes seen above as the interval size is increased may saturate at times comparable to the solar rotation period. However, the method used here becomes increasingly ineffective for interval lengths longer than 15 days because the frequency of finding stationary intervals decreases rapidly for longer intervals (see Table 1). We attempted a 3000 point run on set S^1 and found no stationary intervals.

Summary and Future Directions.

In this paper we have presented a technique for extracting high statistical weight statistical estimates from a collection of data intervals. We have applied the method to the study of interplanetary magnetic fluctuations at 1 AU using ISEE-3 data. The focus of this method is the characterization of interplanetary fluctuations in the context of a locally homogeneous, time-stationary, MHD turbulence description. The local mean magnetic field plays a central role in such a theoretical model. Therefore the method has been constructed to choose intervals that are judged to be weakly stationary with respect to a local mean field in accordance with ergodic theory. No further data selection criteria were used. The output of the computational algorithm consists of a large number of data sets each of which contains statistical information from a single stationary subinterval. Further analysis was presented giving the ensemble average values of mean and fluctuating field statistics and correlation lengths and times.

The main results found from this preliminary study indicate that the correlation times and lengths and the field variances and estimates of mean field strength have reproducible values that nonetheless have a systematic dependence on the length of the data subinterval. We also found that the variances of the components of the magnetic field calculated from the ensemble do not have the characteristics of Alfvénic periods.

The method presented may find future application in the study of data from other spacecraft when long intervals of nearly continuous data coverage are available. Similar techniques can be applied to plasma velocities, densities, and other experimental data in turbulent plasmas. Additional physical problems of the interplanetary magnetic field at 1 AU can also be studied with this method. For example, the one-dimensional magnetic correlation functions can be calculated from the ensemble. Furthermore, because the ensemble has retained information about the direction of the mean magnetic field in each subinterval, it is possible to calculate a three-dimensional correlation function and spectrum from the ensemble under the assumption that the turbulence is axisymmetric with respect to the local mean field direction. It is likely that the ensemble methods can be generalized to calculate the one-point probability distribution function of the magnetic field fluctuations, extending the work of Whang [1977]. Finally, in a separate publication, we will report on a study of the dependence of the variance and correlation times on the data interval length which may further elucidate the role of large scale structures in the solar wind.

Acknowledgments. We have benefited from a number of useful discussions with David Montgomery. This work was supported in part by an ISEE Guest Investigator Program grant to the Interplanetary Physics Branch, Goddard Space Flight Center, by National Science Foundation Grant ATM-8408449 to the Bartol Research Foundation, and by National Aeronautics and Space Administration grant NSG7416 to the College of William and Mary. We are indebted to E. Smith and B. Tsurutani for supplying us with the ISEE-3 magnetic field data used in this analysis.

References.

Barnes, A., Hydromagnetic waves and turbulence in the solar wind in Solar System Plasma Physics, Vol. 1, p. 249, C. F. Kennel, L. J. Lanzerotti, and E. N. Parker, editors, North-Holland, 1979.

Batchelor, G. K., Theory of Homogeneous Turbulence, Cambridge Univ. Press 1970.

Belcher, J. W., and L. Davis, Large amplitude Alfvén waves in the interplanetary medium, 2, J. Geophys. Res., 76, 3534, 1971.

Burlaga, L. F., Heliospheric magnetic fields and plasma, Rev. Geophys. Space Phys., 21, 363, 1983.

Burlaga, L. F., MHD Processes in the outer heliosphere, Space Sci. Rev., in press, 1985 (Available as NASA Tech. Memo. TM-86137, August 1984).

Burlaga, L. F., and M. L. Goldstein, Radial variations of large-scale magnetohydrodynamic fluctuations in the solar wind, J. Geophys. Res., 89, 6813, 1984.

Coleman, P. J., Hydromagnetic waves in the interplanetary medium, Phys. Rev. Lett., 17, 207, 1966.

Coleman, P. J., Turbulence, viscosity and dissipation in the solar wind plasma, Astrophys. J., 153, 371, 1968.

Cowling, T. G., Magnetohydrodynamics, Adam Hilger, Ltd., Bristol, England, 1976.

Dobrowolny, M., A. Mangeney, and P. Veltri, Properties of magnetohydrodynamic turbulence in the solar wind, Astron. Astrophys., 83, 26, 1980.

Dryer, M., Z. K. Smith, E. J. Smith, J. D. Mihalov, J. H. Wolfe, R. S. Steinolfson, and S. T. Wu, Dynamic MHD modelling of solar wind corotating stream interaction regions observed by Pioneer 10 and 11, J. Geophys. Res., 83, 4347, 1978.

Elsasser, W. M., Hydromagnetic dynamo theory, Rev. Mod. Phys., 18, 135, 1956.

Fisk, L. A., The interactions of energetic particles with the solar wind, in Solar System Plasma Physics, edited by C. F. Kennel, L. J. Lanzerotti, and E. N. Parker, vol. 1, North-Holland, Amsterdam 1979.

Fisk, L., and J. Sari, Correlation length for interplanetary magnetic field fluctuations, J. Geophys. Res., 78, 6729, 1973.

Frisch, U., A. Pouquet, J. Léorat, and A. Mazure, Possibility of an inverse cascade of magnetic helicity in magnetohydrodynamic turbulence, J. Fluid Mech., 68, 769, 1975.

Goldstein, M. L., L. F. Burlaga, and W. H. Matthaeus, Power spectral signatures of interplanetary corotating and transient flows, J. Geophys. Res., 89, 3747, 1984.

Grant, H. R., R. W. Stewart, and A. Moilliet, Turbulence spectra from a tidal channel, J. Fluid Mech., 12, 241, 1962.

Hinze, J. O., Turbulence, second edition, McGraw Hill, Inc., New York, 1975.

Holzer, T. E., The solar wind and related astrophysical phenomena, in Solar System Plasma Physics, ed. C. F. Kennel, L. J. Lanzerotti and E. N. Parker, vol. 1, North-Holland, 1979.

Hundhausen, A. J., Coronal Expansion and Solar Wind, p. 44, Springer-Verlag, 1972.

Hundhausen, A. J., S. J. Bame, J. R. Asbridge, and S. J. Sydoriak, Solar wind proton properties: Vela 3 observations from July 1965 to June 1967, J. Geophys. Res., 75, 4643, 1970.

Jokipii, J. R., Turbulence and scintillations in the interplanetary plasma, Ann. Rev. of Astron. and Astrophys., 11, 1, 1973.

Jokipii, J. R., and P. J. Coleman, Cosmic ray diffusion tensor and its variation observed with Mariner 4, J. Geophys. Res., 73, 5495, 1968.

Kraichnan, R. H., Inertial range spectrum in hydromagnetic turbulence, Phys. Fluids, 8, 1385, 1965.

Matthaeus, W. H., Magnetic reconnection in two dimensions, Geophys. Res. Lett., 9, 660, 1982.

Matthaeus, W. H., and M. L. Goldstein, Measurements of the rugged invariants of magnetohydrodynamic turbulence in the solar wind, J. Geophys. Res., 87, 6011, 1982a.

Matthaeus, W. H., and M. L. Goldstein, Stationarity of magnetohydrodynamic fluctuations in the solar wind, J. Geophys. Res., 87, 10347, 1982b.

Matthaeus, W. H., M. L. Goldstein, and D. C. Montgomery, The turbulent generation of outward traveling Alfvénic fluctuations in the solar wind, Phys. Rev. Lett., 51, 1484, 1983.

Matthaeus, W. H., and D. C. Montgomery, Selective decay hypothesis at high mechanical and magnetic Reynolds numbers, Ann. N. Y. Acad. Sci., 357, 203, 1980.

Matthaeus, W. H., and C. W. Smith, The structure of correlation tensors in homogeneous anisotropic turbulence, Phys. Rev. A, 24, 2135, 1981.

McClellan, J. H., T. W. Parks, and L. R. Rabiner, FIR linear phase filter design program, in Programs for Digital Signal Processing, IEEE Press, 1979.

Montgomery, D. C., Theory of hydromagnetic turbulence, in Solar Wind Five, M. Neugebauer, editor, NASA Conference Publication 2280, 1983.

Montgomery, D. C., L. Turner, G. Vahala, Three dimensional magnetohydrodynamic turbulence in cylindrical geometry, Phys. Fluids, 21, 757, 1978.

Orszag, S. A., Lectures on the statistical theory of turbulence, in Fluid Dynamics, 1973 Les Houches Summer School of Theoretical Physics, ed. by R. Balian and J.-L. Peube, p. 235, Gordon and Breach, N. Y., 1977.

Otnes, R. K., and L. Enochsen, Digital Time Series Analysis, John Wiley & Sons, Inc., 1972.

Panchev, S., Random Functions and Turbulence, Pergammon Press, 1971.

Pugachiev, V. S., Theory of Random Functions and its Application to Problems of Automatic Control, Physics Mathematics Press, Moscow, 1962.

Rice, S. O., Mathematical Analysis of Random Noise, in Noise and Stochastic Processes, N. Wax, editor, Dover Publications, Inc., 1954.

Sari, J. W., and N. F. Ness, Power spectra of the interplanetary magnetic field, Solar Phys., 8, 155, 1969.

Sari, J. W., and G. C. Valley, Interplanetary magnetic field power spectra: mean field radial or perpendicular to radial, J. Geophys. Res., 81, 5489, 1976.

Shebalin, J., W. H. Matthaeus, and D. Montgomery, Anisotropy in MHD turbulence due to a mean magnetic field, J. Plasma Phys., 29, 525, 1983.

Taylor, G. I., The spectrum of turbulence, Proc. Roy. Soc. A, 164, 476, 1938.

Van Kampen, N. G., Stochastic Processes in Physics and Chemistry, North-Holland, Amsterdam, 1981.

Whang, Y. C., Probability distribution functions of microscale magnetic fluctuations during quiet conditions, Solar Phys., 53, 507, 1977.

TABLE 1. Stationary Subintervals in Sets S^1 and S^2

NLEN	NSLIDE (15m samples)	DURATION (days)	NUMBER STATIONARY	PERCENT STATIONARY
(set S^1)				
60	50	0.625	231	42%
125	50	1.3	251	46%
250	50	2.6	250	45%
500	100	5.2	119	43%
1000	100	10.4	94	34%
1500	50	15.6	98	18%
(set S^2)				
60	50	0.625	166	46%
125	50	1.3	170	48%
250	50	2.6	172	48%
500	50	5.2	177	50%
1000	50	10.4	132	37%
1500	50	15.6	99	28%

TABLE 2. Ensemble Averages of the Mean Field (and Standard Deviations)

		S_{tot}		S_{60}		S_{1500}	
$\lvert\overline{B_R}\rvert$	(nT)	2.44	(1.6)	3.21	(1.8)	1.06	(0.8)
$\lvert\overline{B_T}\rvert$	(nT)	2.80	(1.7)	3.49	(2.0)	1.68	(1.0)
$\lvert\overline{B_N}\rvert$	(nT)	0.90	(0.9)	1.31	(1.3)	0.42	(0.3)
$\lvert\overline{\underline{B}}\rvert$	(nT)	4.11	(2.1)	5.30	(2.2)	2.16	(1.1)
$\overline{\theta}$	(°)	96.6	(41.)	96.7	(43.)	99.8	(34.)
$\lvert\overline{\theta}-90°\rvert$	(°)	35.9		38.9		30.4	
V_{sw}	(km/s)	401.	(69.)	411.	(79.)	394.	(47.)

TABLE 3. **Ensemble Average Variances of the Magnetic Field (and Standard Deviations)**

	S_{TOT}	S_{60}	S_{250}	S_{500}	S_{1500}
$\overline{\delta B_R^2}$	11.4 (12)	5.7 (8)	10.9 (10)	13.0 (8)	15.2 (7)
$\overline{\delta B_T^2}$	16.5 (16)	9.0 (18)	16.2 (16)	21.3 (12)	25.2 (9)
$\overline{\delta B_N^2}$	13.7 (12)	10.3 (15)	14.5 (13)	16.3 (10)	15.1 (7)
$\overline{\delta B_1^2}$	11.4 (12)	7.5 (13)	12.3 (14)	14.0 (11)	14.3 (9)
$\overline{\delta B_2^2}$	14.1 (13)	10.7 (17)	14.9 (12)	16.7 (9)	16.5 (8)
$\overline{\delta B_3^2}$	15.0 (15)	6.9 (14)	14.4 (15)	19.9 (13)	24.7 (10)
$\overline{\delta B^2}$	40.6 (34)	25.0 (39)	41.6 (35)	50.6 (27)	55.5 (18)
$\overline{\delta B}$	5.9 (2)	4.4 (2)	6.03(2)	6.89(2)	7.36 (1)
$\overline{\delta B}/\lvert\underline{B}\rvert$	2.26 (3)	0.95(.7)	1.69(1.4)	2.84(2.6)	5.02 (4)

TABLE 4. Ensemble Average Correlation Times and Lengths

(and Standard Deviations)

(T_c in hours, L_c in 10^{11} cm)

	S_{tot}	S_{60}	S_{250}	S_{500}	S_{1500}
T_{c1}	3.2 (4.0)	0.80 (.15)	2.2 (1.0)	3.9 (1.9)	9.6 (7.4)
T_{c2}	2.2 (2.3)	0.75 (.22)	1.8 (.84)	3.0 (1.7)	5.0 (4.4)
T_{c3}	3.8 (4.7)	0.76 (.24)	2.4 (1.0)	4.6 (2.0)	11.8 (8.2)
T_c	3.4 (3.7)	0.81 (.15)	2.2 (.68)	4.1 (1.3)	10.4 (5.7)
L_{c1}	4.6 (5.6)	1.2 (.39)	3.3 (1.7)	5.7 (3.0)	13.5 (10.)
L_{c2}	3.2 (3.6)	1.1 (.39)	2.7 (1.3)	4.3 (2.5)	7.2 (7.3)
L_{c3}	5.4 (6.9)	1.2 (.31)	3.5 (1.7)	6.6 (2.9)	16.8 (12.1)
L_c	4.9 (5.4)	1.2 (.31)	3.3 (1.2)	5.9 (2.0)	14.8 (8.5)

TABLE 5. Comparison of S^1 and S^2

		S^1	S^2
$\lvert\overline{B_R}\rvert$	(nT)	2.69	2.69
$\lvert\overline{B_T}\rvert$	(nT)	2.64	2.95
$\lvert\overline{B_N}\rvert$	(nT)	0.87	0.92
$\overline{\delta B_R^2}$	(nT^2)	9.5	11.1
$\overline{\delta B_T^2}$	(nT^2)	17.2	15.9
$\overline{\delta B_N^2}$	(nT^2)	13.3	14.0
$\overline{\delta B^2}$	(nT^2)	40.0	41.0
T_{c1}	(hours)	3.6	2.9
T_{c2}	(hours)	2.5	2.0
T_{c3}	(hours)	4.3	3.3
T_c	(hours)	3.84	3.06
L_{c1}	(10^{11}cm)	4.8	4.6
L_{c2}	(10^{11}cm)	3.4	3.1
L_{c3}	(10^{11}cm)	5.7	5.2
L_c	(10^{11}cm)	5.12	4.73

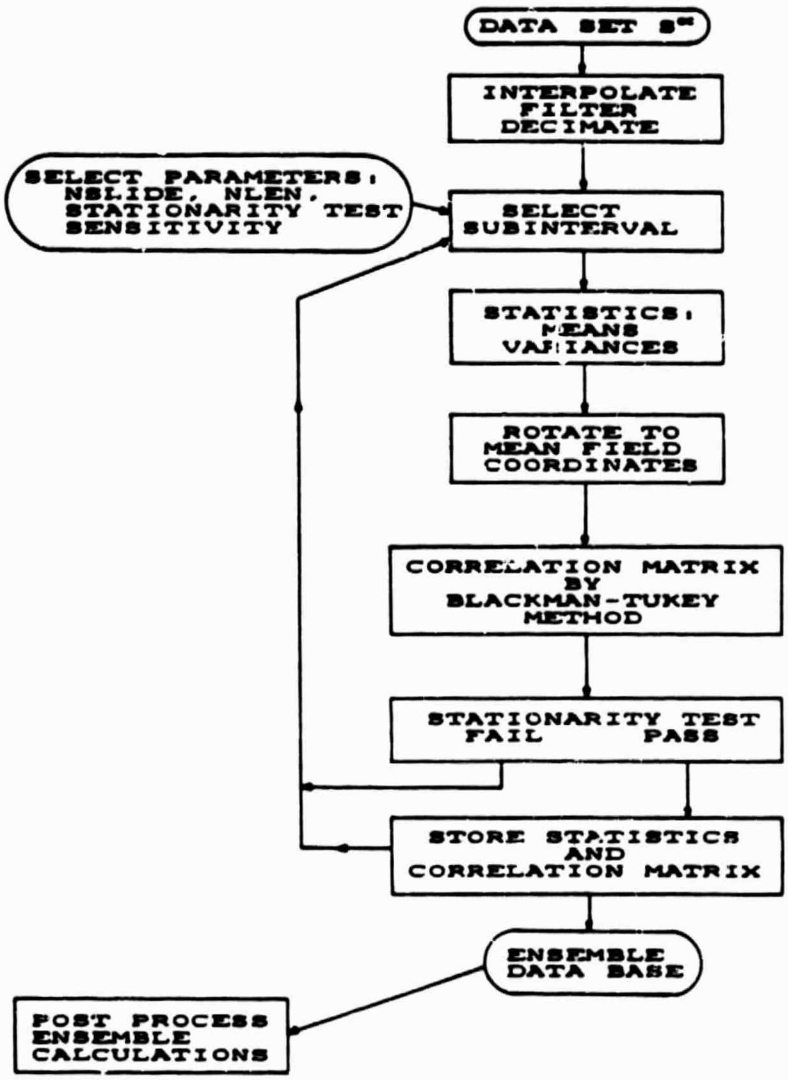

Figure 1. Overview of the general algorithm used in constructing the magnetic field ensemble.

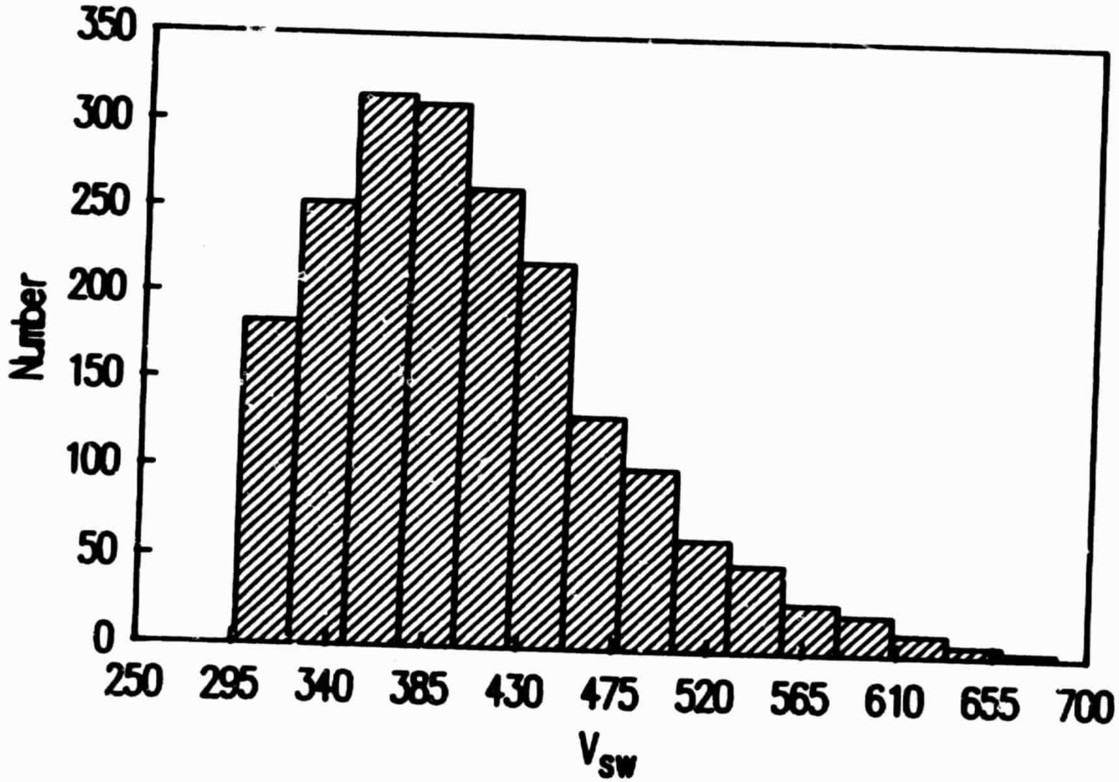

Figure 2. A histogram of solar wind speed values for the entire ensemble. Speed is plotted in km/s.

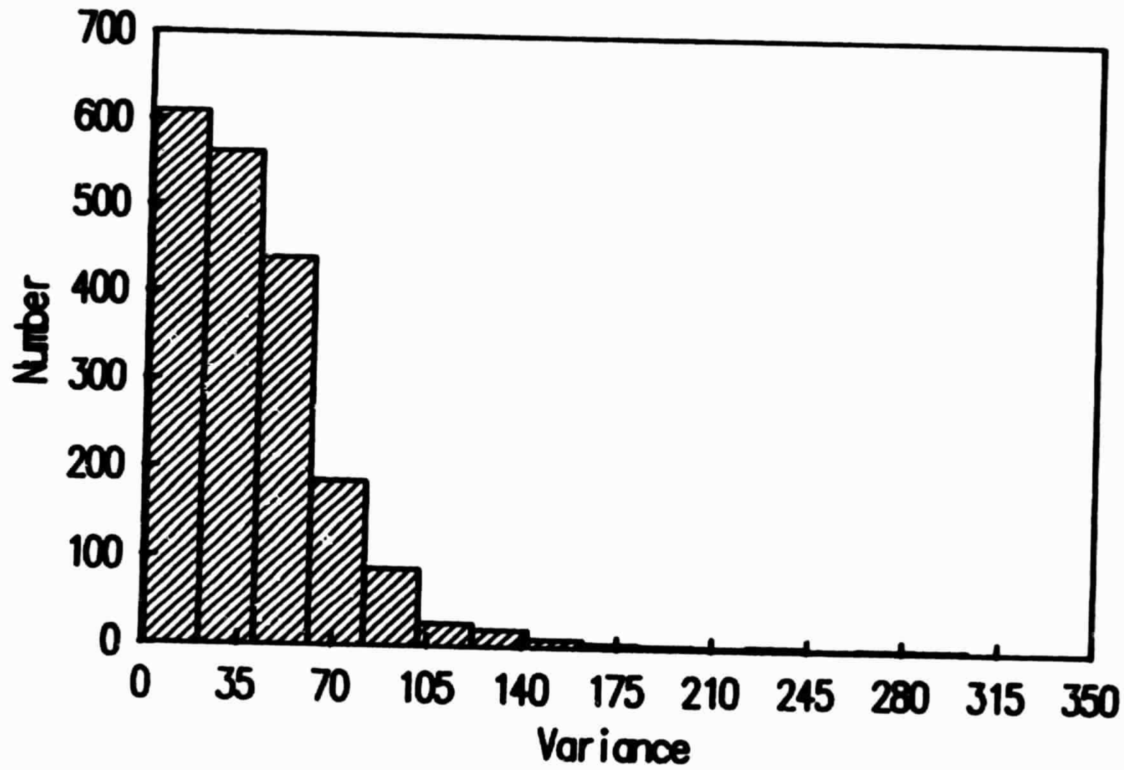

Figure 3. A histogram of values of the S_{tot} magnetic field variance, $\overline{\delta B^2}$ (in nT^2).

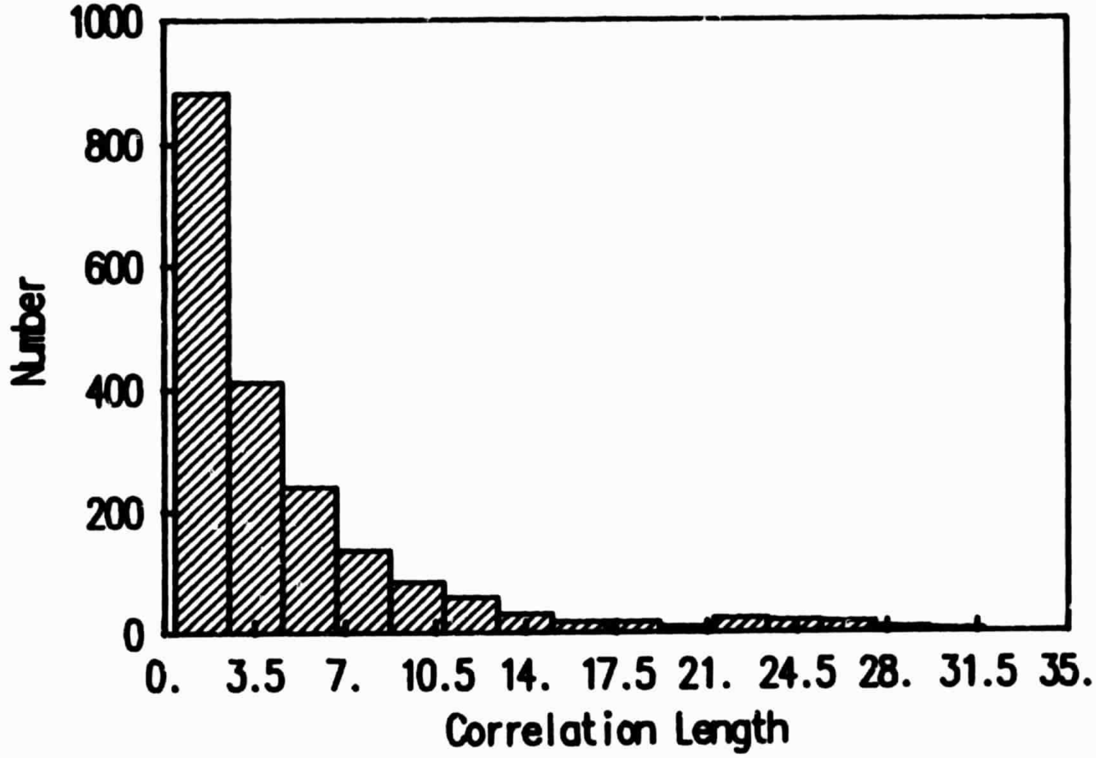

Figure 4. A histogram of the correlation length (in units of 10^{11} cm) calculated from the S_{tot} data. The main maximum of the distribution appears at a value somewhat lower than the mean of 4.9×10^{11} cm.

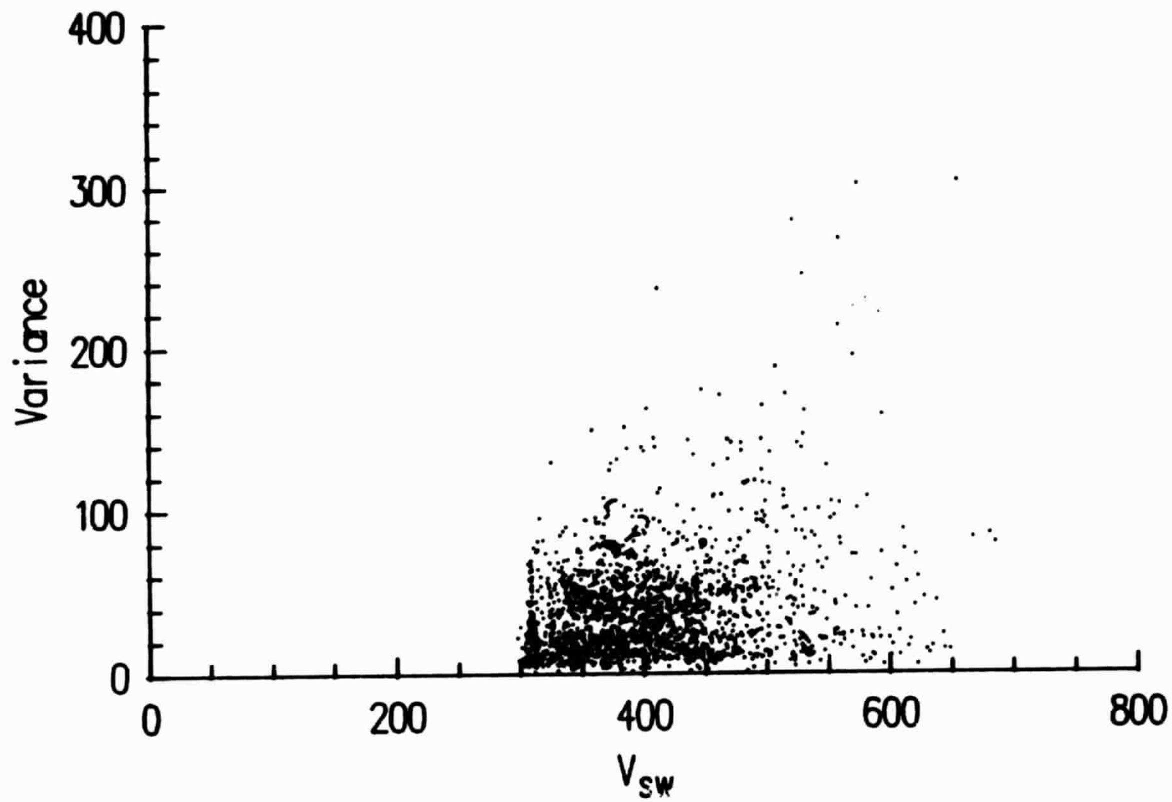

Figure 5. A scatter plot with the variance (in nT^2) plotted on the ordinate and the solar wind speed (in km/s) plotted on the abscissa. A total of 1,958 points from S_{tot} are plotted.

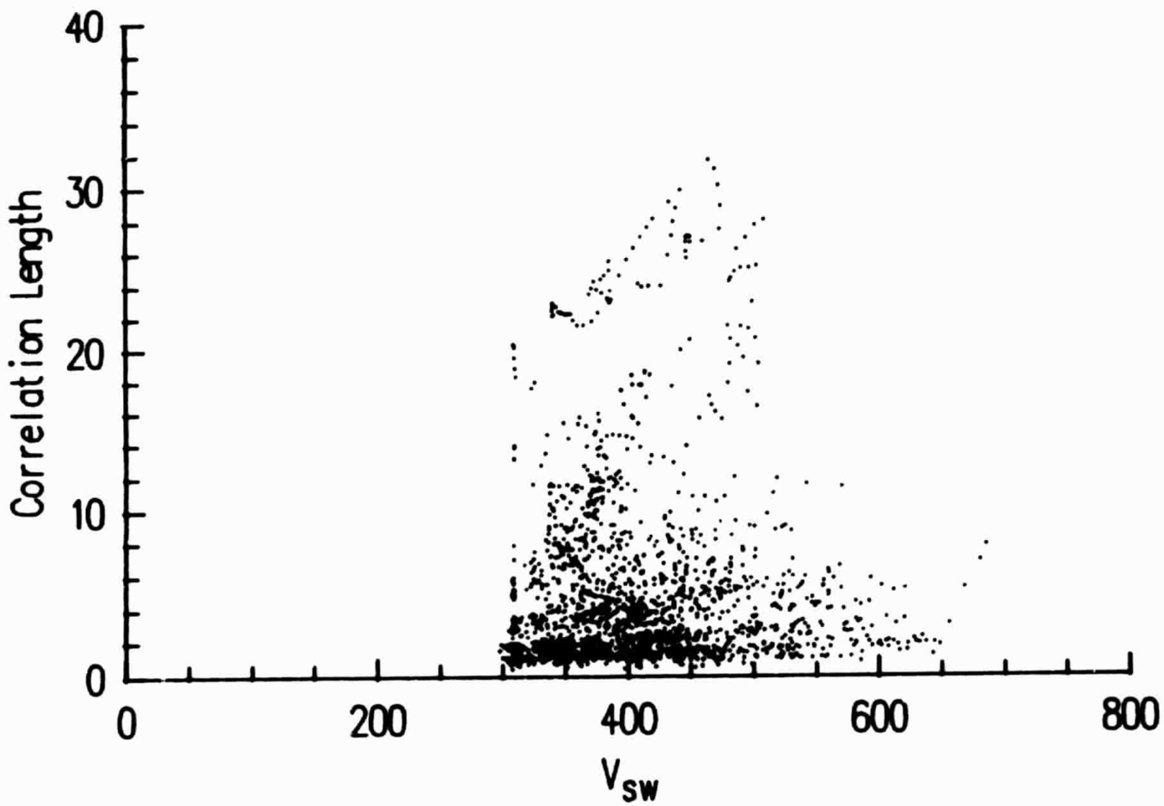

Figure 6. A scatter plot of the total correlation length (divided by 10^{11} cm) vs. solar wind speed (in km/s). The great majority of points lie below 10^{12} cm, and most of these are for intervals in which the speed is less than 400 to 450 km/s.

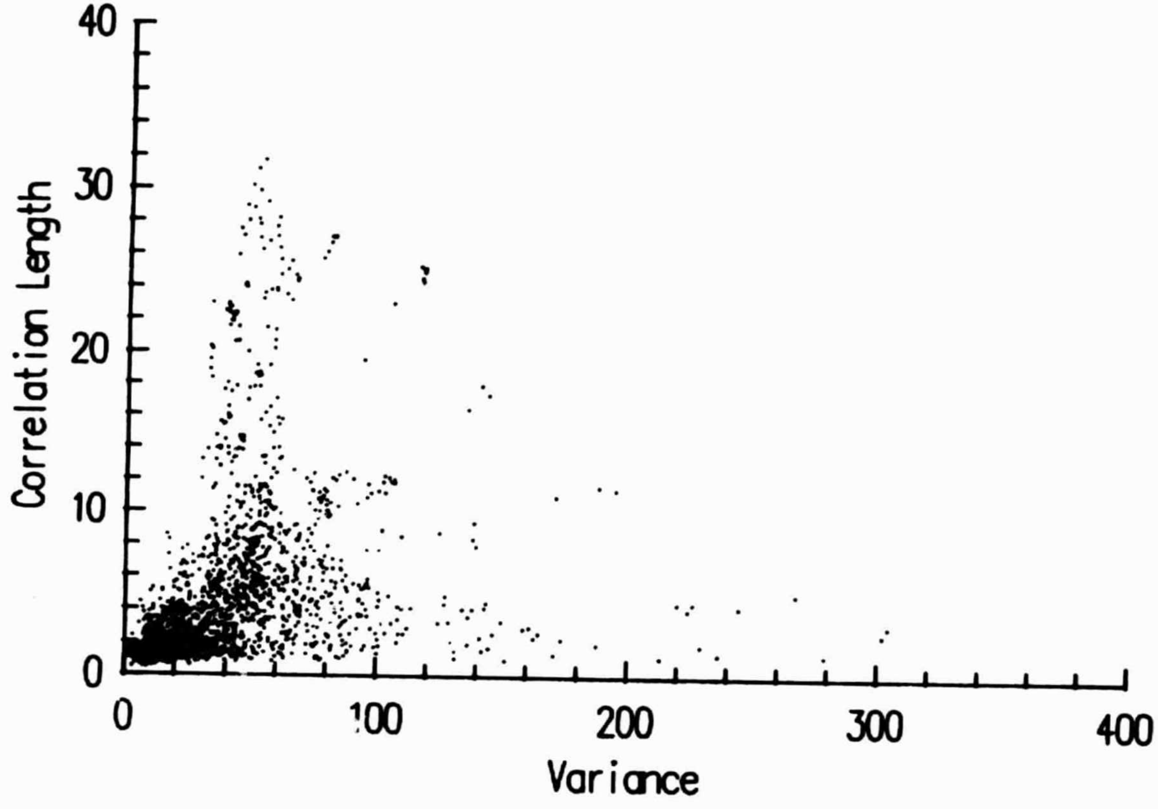

Figure 7. A scatter plot of the correlation length (divided by 10^{11} cm) vs. the field variance (in nT^2).

BIBLIOGRAPHIC DATA SHEET

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TM 86209		

4. Title and Subtitle
An Interplanetary Magnetic Field Ensemble at 1 AU

5. Report Date
April 1985

6. Performing Organization Code

7. Author(s)
W. H. Matthaeus, M. L. Goldstein and J. H. King

8. Performing Organization Report No.

9. Performing Organization Name and Address
NASA/GSFC
Laboratory for Extraterrestrial Physics
Interplanetary Physics Branch, Code 692
Greenbelt, MD 20771

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A method for calculating ensemble averages from magnetic field data is described. A data set comprising approximately sixteen months of nearly continuous ISEE-3 magnetic field data is used in this study. Individual subintervals of this data, ranging from 15 hours to 15.6 days comprise the ensemble. The sole condition for including each subinterval in the averages is the degree to which it represents a weakly time-stationary process. Averages obtained by this method are appropriate for a turbulence description of the interplanetary medium. The ensemble average correlation length obtained from all subintervals is found to be 4.9×10^{11} cm. The average value of the variances of the magnetic field components are in the approximate ratio 8:9:10, where the third component is the local mean field direction. The correlation lengths and variances are found to have a systematic variation with subinterval duration, reflecting the important role of low-frequency fluctuations in the interplanetary medium.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Solar wind, magnetic field, MHD turbulence	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
U	U	46	

*For sale by the National Technical Information Service, Springfield, Virginia 22161