Program of Solar Wind Data Analysis Utilizing Data from Pioneer 6, Mariner 5, and Explorer 35

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Abstract

A combined data analysis and theoretical program aimed at interpreting and utilizing solar wind data obtained from Pioneer 6, Mariner 5, and Explorer 35 has been completed. A theoretical model of the radial dependence of large scale solar wind inhomogeneities was developed and used to map solar wind variations measured by Explorer 35 to various heliocentric distances namely 20 solar radii (R_s) and the orbits of Mercury, Venus, and Mars. It was found that velocity variations changed little with distance, becoming somewhat larger closer to the sun; but the density spike associated with the leading edge of a high speed stream disappears as one gets closer to the sun. The model was also used to determine power spectra of velocity, density and temperature variations at 20 R_s from spectra obtained from the Mariner 5 data at an average heliocentric distance of 180 R_s. In addition to power spectra, the Mariner 5 data were used to obtain cross spectra between all plasma and magnetic field variables. The study showed a sharp division in the frequency scale at a period of approximately one day between large scale features (quasi-stationary) and small scale waves and distontinuities. The division separates frequency regimes where different physical processes dominate. Five stream-stream interaction events in the Pioneer 6 data were analyzed which confirmed the picture of a spiral compression ridge interfacing the two streams and the associated east-west deflections of the solar wind flow. Magnetopause crossings observed in the Explorer 35 plasma data were used to develop statistics on boundary motions at the lunar distance. It was found that the dawn side boundary is more active than the dusk side. The boundary motion is well represented by a two component picture, one with a characteristic period near one hour has the largest amplitude, the smaller amplitude component has a characteristic period near 10 minutes. Boundary speeds fall typically in the range 10 to 20 km/sec. A study of the geomagnetic disturbance field asymmetry was performed and a model of disturbance field from a partial ring current was developed. The model allows use of ring current particle data and examples are given from published data.

Introduction

A broad based program of study of space probe plasma data has been completed which dealt with aspects of solar wind structure and its evolution from the sun, the motions of the magnetopause at the lunar distance, and the geomagnetic disturbance field asymmetry. The results are detailed in the following reports and papers. Summary abstracts are given here.

Solar Wind Structure Determined by Corotating Coronal Inhomogeneities.

The problem of the solar-wind structure resulting from long-lived inhomogeneities in the solar corona has been extended within the framework of a linearized hydrodynamic approach to allow for arbitrary perturbations in the plasma parameters, namely, velocity, density, and temperature. By using a Parker model for the zero-order flow speed, solutions are given for perturbations imposed at the zero-order critical point. Using the restriction that the solutions must be regular at the critical point, it is possible to express all situations as a linear sum of the solutions for pure velocity, density, and temperature perturbations at the critical point. The results of the integrations for the three inner-boundary conditions can be used as the elements of matrices that map arbitrary perturbations at one heliocentric distance to any other distance. One interesting feature of the solutions is that the amplitudes at earth for the pure initial temperature situation are larger than for the other two

situations. Thus, if the perturbation amplitudes at the critical point are all of the same order of magnitude, the temperature perturbation will dominate the structure at earth. In fact, the phases between the perturbations at earth given by the pure initial temperature situation are similar to the observations.

Structure and Orientation of Solar-Wind Interaction Fronts: Pioneer 6

An analysis is given of five stream-stream interaction events observed in the Pioneer 6 plasma and field data. That the time profiles of all the parameters are consistent among the events and with previous descriptions given in the literature substantiates the notion of a common interaction type. The velocity variations in four of the events tend to lie in planes approximately parallel to the corotation spiral; thus it is implied that the events are reasonably stationary in time in the corotating frame. The data are interpreted in terms of a corotating interaction front, which is a ridge of high pressure parallel to a corotating spiral. The increased pressure is due to radial compression of the streams. The east-west (zonal) flow directions also occur in the front and are shown to be produced by the zonal pressure gradient of the pressure ridge.

Significance Criteria for Variance Matrix Applications

The variance matrix technique for determining preference or avoidance directions in space of a group of vectors is used frequently in the analysis of satellite data, especially in the analysis of magnetic-field and solar-wind

velocity data. The method gives automatically a parameter that indicates the strength of the preference or avoidance. However, no sifnificance criterion has yet been given that compares the strength parameter against the parameter expected from a random group of vectors. This note gives such a criterion.

A Study of Solar Wind Structure Between 20 Solar Radii and the Orbit of Mars

The model developed in the previous sections is applied to satellite data for both the case where input parameters are radial velocity, density and temperature and the case where aximuthal velocity is included. In addition, the model is modified to include two fluid effects for both cases. Solar wind power spectra is also mapped to 20 R_s for both single and two fluid treatments.

The velocity profile remains essentially unchanged over the range. The positive correlation between velocity and temperature and the negative correlation between velocity and density persists from 20 R_s to Mars. Density maxima precede velocity maxima and grow as the plasma flows outward which implies that the faster moving gas piles up the slower moving gas.

Results at 20 R_s show agreement between the occurrence of high velocity peaks and 1.77 meter wavelength enhanced coronal radio emissions. It is suggested that the lack of correlation between solar wind parameters and solar surface features and the high correlation found when solar wind velocity

is compared with coronal meter wavelength radiation might be due to effects of the magnetic field close to the surface of the sun.

Spectra and Cross-Spectra of Solar Wind Parameters from Mariner 5 in the Period Range 10 min. to 10 days.

The spectra of the radial (V_R) and non-radial (V_T, V_N) velocity components of the solar wind, the proton density (ρ) and the proton thermal speed (W) show increasing power with increasing period up to a period of about 1 day. The powers tend to level off above 1 day except for that of V_R which continues to increase up to a period of 10 days. At all periods the power in V_R is greater than that in V_T, V_N and W and the difference becomes very large at the longest periods because of the increasing power in V_R. The powers in V_T, V_N and W are similar at all periods.

The cross-spectra reveal a sharp change in behavior at periods above and below approximately 1 days, suggesting two distinct types of physical processes must dominate above and below this dividing period. In general the coherences at the long periods are larger than at the short periods suggesting that the physical situation in the long period regime may be simpler than in the short period regime where multiple processes appear to be required to account for the low coherences. At periods less than 1 day, the cross-spectra are consistent with the presence of intermediate hydromagnetic waves propagating outwards in the frame of reference of the wind and with non-propagating

constant pressure fluctuations. However, one or more other processes are required to account for all of the observed correlations. At periods greater than 1 day the models of corotating structure and the spherically symmetric two fluid model jointly appear capable of accounting for most of the correlations.

Magnetopause Motions at Lunar Distance Determined from the Explorer 35 Plasma Experiment

From solar wind plasma observations on the lunar orbiting Explorer 35 satellite multiple boundary crossings have been analyzed to give statistical information on the tail boundary motions at lunar distance. In eleven months of observations, more than twice as many crossings occurred on the dawn side than on the dusk side, indicating a dwn-dusk asymmetry. The amplitude of boundary motion, given by the standard deviation of the observed positions around its average value is 4.9 Re on the dawn side and 2.8 Re on the dusk side. Histograms of the time intervals between boundary crossings indicate two time scales are simultaneously present (16.7 minutes and 63.3 minutes--dawn side values). A fit of the number of crossings and the histogram data to models of the motion indicate that the amplitude of the long-period motion is 2 to 3 times larger than the short period motion. The inferred speeds for both motions lie in the range 10 to 20 km/sec. The models also give an estimate of the thickness of a boundary layer in the plasma data of 2 Re.

The Low-Latitude Asymmetric Disturbance in the Geomagnetic Field

Harmonic analysis of the low-latitude disturbance field is performed on hourly and 2.5-minute magnetic data. The interrelationships between the resulting parameters and other storm indices are studied using histograms, scatter plots, and correlations. The histograms reveal local time, longitude, and universal time preferences of 18 h, 45°, and 15 h, respectively, for the asymmetric disturbance field. The amplitude G of the first harmonic is typically 50γ for large storms. The correlation coefficient between G and D_{st} reaches a maximum of -0.64 when D_{st} lags G by $2\frac{1}{2}$ hours. The correlation coefficient between G and AE reaches a maximum of 0.71 when G lags AE by 12 minutes. The local-time position of maximum depression moves in the evening hours toward earlier local time and then back again in response to peaks in AE and G.

The results of the data analysis are interpreted in terms of suggested current system models. Emphasis is given to a two-current-system model: a partial ring current centered near 18 h local time and a second system connected to the westward electrojet in the midnight sector.

A numerical model of a partial ring current distributed along and across L-shells is developed in which measurements or models of the ring current particles can be used to determine the disturbance field and magnetization currents can be taken into account. These are advantages over previous line-current models. The magnetization currents are shown to contribute as much as 26% to the disturbance field in the case of a symmetric ring current. A comparison

between the predicted and observed disturbance fields suggests that either the typical radial distribution of partial-ring-current particles peaks closer to the earth than the single satellite observation indicates or as an upper limit only half of the partial ring current closes as the eastward electrojet, the remainder possibly closing along distributed ionospheric paths or outside of the ionosphere.

On the Distinction Between the Auroral Electrojet and Partial Ring Current Systems

An asymmetric distribution of ring current particles has been inferred from spacecraft magnetic field measurements (Cahill, 1966) and more directly from particle measurements at the beginning of a magnetic storm by Frank (1970). Following Parker's (1966) argument, a partial ring current similar to that modeled by Cummings (1966) then exists. Several authors (Fejer, 1961; Swift, 1967, 1968; Akasofu and Meng, 1969) have suggested models for substorms in which a partial ring current is directly connected to both of the auroral electrojets. However, Kamide and Fukushima (1971) suggest that the eastward electrojet is the ionospheric closure of a partial ring current and that the westward electrojet is part of a separate current system. New analysis of geomagnetic data is presented here which supports the suggestion of such separate current systems. This analysis also allows for interpretation of some systematic behavior of disturbance parameters presented by Crooker (1972). Furthermore, it is shown that observations of auroral positive and low-latitude negative bays are consistent with two separate current systems.

Publications Supported in Total or in Part by this Contract

Siscoe, G.L. and L. T. Finley, Solar-wind structure determined by corotating coronal inhomogeneities: 2. Arbitrary perturbations, J. Geophys. Res., 77, 35-45, 1972.

Siscoe, G. L., Structure and orientation of solar-wind interaction fronts: Pioneer 6, J. Geophys. Res., 77, 27-34, 1972.

Siscoe, G. L. and R. W. Suey, Significance criteria for variance matrix applications, J. Geophys. Res., 77, 1321-1322, 1972.

Goldstein, B.and G. L. Siscoe, Spectra and cross-spectra of solar wind parameters from Mariner 5 in the period range 10 min. to 10 days, Proceeding of the Solar Wind Conference, Asilomar Pacific Grove, California, March 1971, C. P. Sonett, J. M. Wilcox, P. J. Coleman, Jr., editors, NASA Special Publication, in press, 1972.

Howe, H. C. and G. L. Siscoe, Magnetopause motions a lunar distance determined from the Explorer 35 plasma experiment, J. Geophys. Res., in press, 1972.

Lewis, R. R., A study of the solar wind structure between 20 solar radii and the orbit of Mars, Ph.D. Thesis, Department of Meteorology, UCLA, 1972. Material in preparation for journal publication.

Crooker, N. U., The low-latitude asymmetric disturbance in the geomagnetic field, Ph.D. Thesis, Department of Meteorology, UCLA, 1972. Material in preparation for journal publication.

Crooker, N. U. and R. L. McPherron. On the distinction between the auroral electrojet and partial ring current systems, J. Geophys. Res., in press, 1972.

Invited Presentations

Siscoe, G. L., Solar-terrestrial relations, Weather Officers Orientation Program, UCLA, May 1971.

Siscoe, G. L., Theoretical models of corotating structure in the solar wind, National Meeting of the A.G.U., April 1972.

Siscoe, G. L., Properties of solar wind fluctuations, Solar Terrestrial Relations Conference, Calgary, Canada, August 1972.

Contributed Presentations

Siscoe, G. L. and B. Goldstein, Spectra and cross-spectra of solar wind parameters from Mariner 5 in the period range 10 min. to 10 days, Asilomar Conference on the Solar Wind, March 1971.

Goldstein, B. and G. L. Siscoe, Power spectra and cross-spectra of solar wind parameters, National Meeting of the A.G.U., April 1971.

Howe, H. and G. L. Siscoe, A study of magnetopause fluctuations at 60 earth radii, National Meeting of the A.G.U., April 1971.

Crooker, N. U. and R. L. McPherron, On the distinction between the auroral electrojet and partial ring current systems, Substorms Workshop, UCSD, March 1972.

Students Supported in Part by this Contract

Chin Kung Chen - Magnetospheric dynamics
Nancy Uss Crooker - Disturbance field asymmetry
Moshe Harel - Solar wind - Venus interaction
Roy R. Lewis - Solar wind structure

Degrees Conferred During Term of this Contract

Nancy Uss Crooker, Ph.D. Thesis title: The low latitude asymmetric disturbance in the geomagnetic field, Spring 1972.

Roy R. Lewis, Ph.D. Thesis title: A study of the solar wind structure between 20 solar radii and the orbit of mars, Spring 1972.