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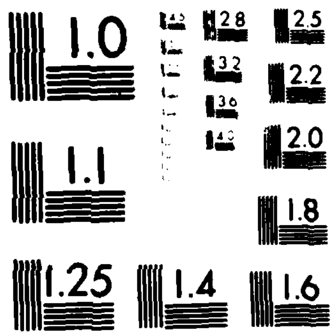
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A STUDY OF THE RELATIONSHIP BETWEEN SOLAR ACTIVITY AND INTERPLANETARY FIELD VARIATIONS

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"This technical report has been reviewed and is approved for publication"

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The origin of large values of the interplanetary magnetic field B_z component, the nature of the so-called 'driver gas,' the origin of the high speed solar wind streams are the three major issues in solar-terrestrial physics. We have made several initial attempts to study them and found new steps toward a better understanding.

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1. Introduction

Solar-terrestrial physics has been considerably advanced during the last two decades. In particular, the progress has been prominant in almost every discipline, namely studies of solar flares, interplanetary disturbances and magnetospheric disturbances. In flare studies, a large deviation of the magnetic field configuration from a potential field and emergence of new sunspot pairs have been identified as necessary conditions for the occurrence of solar flares. Various radio emissions, x- and γ-ray observations have added greatly to our knowledge on the flare morphology. A new transient phenomenon called coronal transients or coronal mass ejection (CME) has been discovered. The source region of high speed solar wind streams, namely the coronal holes, have been identified. The so-called 'disappearance of filaments (DF)' has been added as a new possible source of interplanetary disturbances.

A study of interplanetary disturbances has been greatly advanced by the availability of in situ observations of the solar wind and the interplanetary magnetic field (IMF) by deep space probes and earth-bound satellites. The interaction between the 'quiet time' solar wind and a high speed solar wind stream, namely the stream-stream interaction, has been studied extensively, both observationally and theoretically. The basic IMF discontinuities, such as shock waves, rotational discontinuities, tangential discontinuities, have been identified and investigated. In magnetospheric physics, a number of plasma processes which lead to magnetospheric substorms and storms have been investigated, and some of them have been identified. The potential structure responsible for the acceleration of auroral electron has been found.

In addition to great progress in each discipline of solar-terrestrial physics, there have been considerable efforts in relating specific solar activity to specific interplanetary disturbances. An extensive study of the large-scale magnetic field in the photospheric level and in interplanetary space has been made. The relationship between solar activities (such as flares, CME and DF) and shock waves in interplanetary space has been investigated. In solar wind-magnetosphere interaction studies, some of the key physical quantities in the energy transfer processes have been identified. Among them, the north-south component of the IMF is found to play a crucial role in the energy transfer. A series of plasma processes leading to magnetospheric substorms after the so-called 'southward turning' of the IMF vector has become increasingly clear.

In spite of such progress in each discipline and in some inter-disciplinary areas, our understanding of some of the most crucial aspects of solar-terrestrial physics has not improved greatly. Origins of large values (positive and negative) of the IMF B_z component are an example. We have paid little attention to this problem, in spite of the fact that it is a sort of 'missing link' in understanding the solar activity-geomagnetic disturbances relationship. Another example is the so-called 'driver gas' which is supposed to be ejected during a solar flare and to cause an interplanetary shock wave. However, there has been no agreed signature to identify the driver gas. In this final report, we report some of the progress we have made during the last year under contract.

2. Results

2.1 Origins of the IMF B_z Component

The configuration of the magnetic field in the disturbed solar wind has long been an important topic for solar, cosmic ray, and magnetospheric physicists (Gold, 1962). This topic has become particularly important in magnetospheric physics, since it has been found that the direction of the interplanetary magnetic field (IMF) is an important factor in causing geomagnetic disturbances. Although both the solar wind speed V and the magnitude B of the IMF are also important in this regard and are expected to be large in the disturbed solar wind, the north-south component of the IMF B_z (accurately speaking, in the solar-magnetospheric coordinate system) plays a crucial role in determining the amount of solar wind energy to be transferred to the magnetosphere (Arnoldy, 1971; Tsurutani and Meng, 1972; Russell and McPherron, 1973; Akasofu, 1981; Akasofu et al., 1985 and references therein).

Most investigators assume, implicitly or explicitly, that the B_z component is associated with the so-called 'magnetic tongue' (Gold, 1962), or 'magnetic cloud' (Klein and Burlaga, 1982) or the wavy solar current sheet (Smith, 1981; Akasofu, 1979; Tsurutani et al., 1984).

The magnetic tongue model has been partially supported by Pudovkin et al. (1976, 1977, 1979) who claimed that the degree of magnetic disturbances can be predicted by the north-south component of the photospheric magnetic field at the site of a solar flare, implying that the polarity of the IMF can be predicted from the flare field. In addition, a bi-directional streaming of solar cosmic rays has also been considered as supporting evidence of the magnetic tongue model (Palmer et al., 1978).

Since the possible relationship between the photospheric magnetic field orientation and the polarity of the IMF B_z component is an important issue, we have been examining this problem using full-disk and high resolution solar data obtained at the Big Bear Solar Observatory, the Kitt Peak and Stanford Observatories and the corresponding ISEE-3 IMF data.

Here we show an example of our study of the relationship between photospheric magnetic fields and the IMF B_z component. In Figure 1, the NOAA region 4022 in the northern hemisphere can easily be identified, since it is a N/S oriented region; it passed the central meridian on December 13, 1982. It is the N/S region about 25° to the west of the central meridian in the northern hemisphere shown in the Kitt Peak magnetogram in Figure 1 (see the arrow). On December 14 a class 1 flare was observed in this region.

The corresponding IMF B_z record in Figure 1 shows a large positive change for about 24 hours on December 15-16. But this positive change is exactly opposite to polarity orientations of the photospheric field of region 4022. It is also not correlated to the E/W flare field of region 4022 on December 14. Geomagnetic disturbances decreased markedly during the positive peak period of the IMF B_z, being 0_+ during 21 - 24 UT on December 15.

So far, we find that regardless of the orientation of the flare field, the associated IMF B_z responds with rapid fluctuations in both magnitude and direction for about 50% of the cases. When the IMF B_z variations are of the stable kind either in the N or S direction, the probability of them being in agreement with the flare field is not more than the combined probabilities of them being opposite or having no relation to the flare field (Tang et al., 1985).

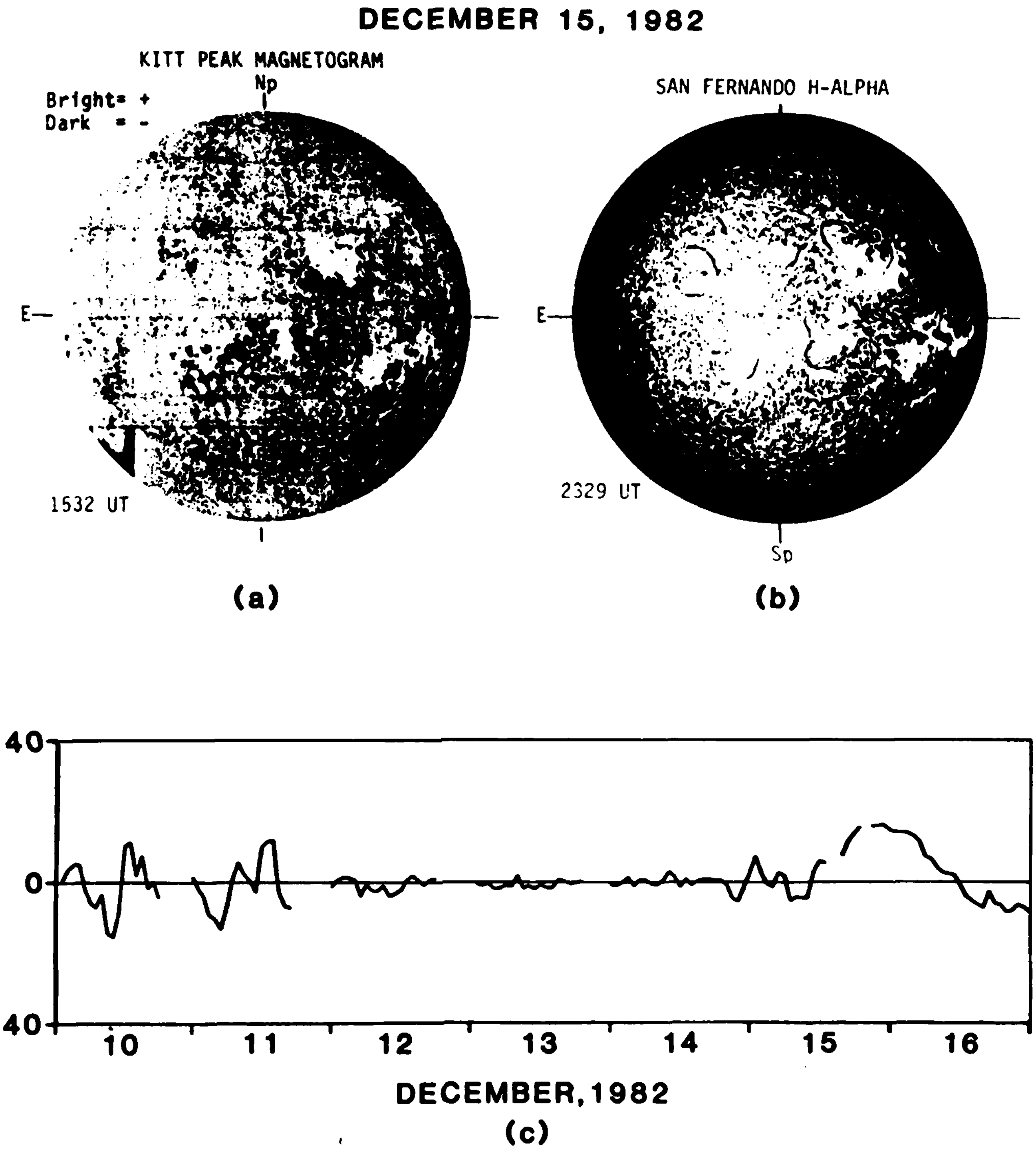

Figure 1. (a) The Kitt Peak magnetogram, (b) the San Fernando Hα gram on December 15, 1982 and (c) the corresponding IMF B_z component (December 10-16, 1982) from ISEE-3. One can see a large earthward-directed (white) and anti-earthward-directed (black) field pair in the northern hemisphere. We would expect a large negative IMF B_z, if this pair field would be extended by flare activity. However, the observed field was positive.

2.2 'Driver Gas'

It has long been suggested that intense solar activites, such as a solar flare, disappearing filaments, and/or a coronal mass ejection (CME), are often associated with an ejection of a piece of the solar atmosphere, and that the ejecta generates an interplanetary shock wave as it advances into the slow solar wind. For this reason, such an ejecta is often referred to as the 'driver gas'.

However, the 'driver gas' has been rather elusive in that there have been no agreed physical quantities for the identification. Some workers consider that a high ratio of He/H after the passage of the shock waves is an important signature of the 'driver gas' (Hirshberg et al, 1972a,b; Borrini et al., 1982a,b); some others consider a prominent decrease of the proton temperature as the most important signature (Zwickl et al., 1983), and still others consider that the driver gas is associated with a very steady, large magnitude of the interplanetary magnetic field (Smith, 1983).

A systematic approach to the problem of identification of the driver gas may thus be needed. For such a systematic study, the continuous ISEE-3 data (compared with that of other earth-bound satellites) are ideal. As a new approach to this problem, we begin our study by examining the shock waves whose source activity can be identified with a high degree of confidence and has been documented. The source activities are grouped into:

(i) Solar flares

(ii) Coronal mass ejections

(iii) Disappearing filaments

(iv) Solar electrons

In the following, we show one example of our preliminary results. Here, in

Figure 2, we show the shock wave observed by ISEE-3 at 0028 UT, November 12, 1978 due to a flare on November 10, 1978 (N17, E02, 0057 UT). This identification is fairly certain, and this is one of the three examples which agree with the identification by Cane et al (1982). Furthermore, the flare occurred near the central meridian, but it was not in the list of Zwickl et al. (1983, see their Table 1). In Figure 2, the key solar wind quantities, the IMF B_y and B_z components, the IMF magnitude, the solar wind-magnetosphere coupling parameter ε and the two geomagnetic indices AE and Dst are shown. In the past, neither solar physicists nor magnetospheric physicists have assembled the relevant data in this way. The ISEE-3 data in 1978 and 1979 have now been assembled in this way. A careful selection of the events thus assembled is underway.

Our preliminary results suggest that the large temperature decrease at about ~13 UT, identified as the arrival of the driver gas by Zwickl et al. (1983), was simply a reduction of the temperature of the solar wind and has no relation to the driver gas because the decreased temperature lasted (though not shown) for more than 3 days; it is much more natural to assume that the disturbed solar wind ended at ~13 UT, rather than to assume that the driver gas lasted for more than 3 days. It is interesting to speculate that a sudden increase of the momentum ~6 UT may be an indication of the driver gas, since the increase indicates that the higher momentum gas must be driving the flow.

2.3 Three-Dimensional Structure of the Coronal Magnetic Field and the Solar Wind Speed Distribution Projected on the Photosphere in 1974

The generation mechanism of the solar wind is one of the most important problems in space physics. It is still controversial as to how the coronal

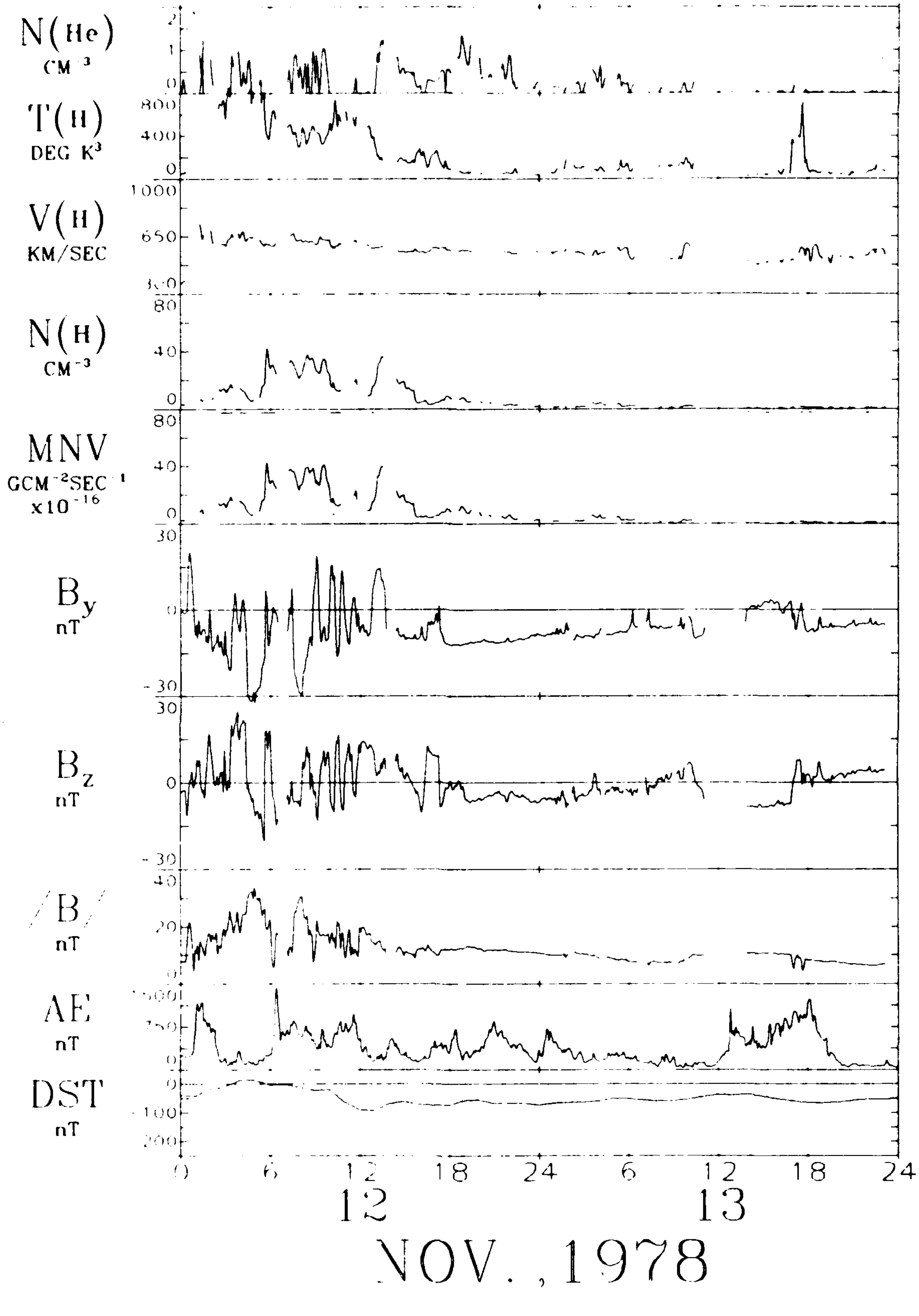

Figure 2. Compiled solar wind, IMF parameters and the two geomagnetic indices (AE and Dst) for the storm of November 12, 1978. From the top, the helium density, H temperature, H velocity, H density, the IMF B_y, B_z and magnitude B, the solar-wind-magnetosphere energy coupling parameter and the AE and Dst indices.

plasma is accelerated to become the solar wind plasma. For this reason, it is important to examine why high speed streams emanate from coronal holes which are cooler than surrounding regions (for this subject see Zirker, 1977). Therefore, it is worthwhile to find out coronal or photospheric properties that are closely related to the generation mechanism of the solar wind and solar wind properties observed at ~1 AU. For this particular study, it is necessary to map the solar wind speed observed at ~1 AU back to the photosphere and also to examine the three-dimensional structure of the solar wind flow in the corona.

The solar wind speed distribution on the source surface of 2.5 solar radii (R_S) have been estimated by the group of UCSD (Coles and Rickett, 1976; Sime and Rickett, 1978; Coles et al., 1980) on the basis of interplanetary scintillation (IPS) observations. The three-dimensional structure of the coronal magnetic fields has been constructed by many workers by using the line-of-sight component of the photospheric magnetic fields ($B_\parallel$) on the basis of the potential model (Shatten et al., 1969; Altshuler and Newkirk, 1969; Levine et al., 1977; Wilcox et al., 1980; Hoeksema et al., 1982).

By using both methods, we attempt to map back the distribution of the solar wind speed on the source surface determined by the IPS study onto the photosphere along the magnetic field lines in the corona. Table 1 shows the relevant observations and the projection procedures used in this paper. This study allows us to infer the source regions of the solar wind in the photosphere and the three-dimensional structure of the solar wind streams in the corona.

First of all, the average map of $B_\parallel$ is constructed by superposing the synoptic maps for the period between the Carrington rotation 1609 and 1620 in 1974. During this period, most of the solar features were relatively steady.

The magnetic field line configuration is then computed by the method developed by the authors cited earlier.

All closed magnetic field lines (CFLs) starting at 10° x 10° mesh points on the photosphere are traced and shown in Figure 3. Solid and dashed curves show parts of CFLs which have positive and negative signs of B_r (radial component), respectively. Very high and well-regulated arcade structures appear in ~180° meridian in the southern middle latitudes, where the strongest bipolar magnetic region is present. The three-dimensional structure of the open magnetic field lines (OFLs) are also shown in Figure 4 with the same format as Figure 3. Field lines are traced from 10° x 10° mesh points on the source surface down to the photosphere. Figure 5 shows the projection of CFLs onto the photosphere showing a clear sinusoidal belt of CFL region which crosses the equator at ~30° and ~190° in longitude.

Figure 6 shows the solar wind speed distribution projected onto the photosphere. In spite of great uncertainty in the procedures taken here, this is encouraging. The horizontal speed gradient of the OFL region becomes steeper in the photosphere than in the source surface. In addition, the speed gradient is steeper at the eastern edge than at the western edge of the high-speed regions in each hemisphere. Coronal hole boundaries in 1974 have been inferred by J. W. Harvey (private communication, 1985) from the HeI (10830 A) absorption line. A typical example of the maps for Carrington rotation No. 1615 is shown in Figure 7. Although other maps in 1974 are not shown in this paper, the coronal holes were relatively steady in this particular period. Especially, the southern polar hole extending from ~70° in longitude to the northwest direction persisted in the almost same location. The northern coronal holes appearing at ~230° longitude shifted between ~210° and ~290° longitude. Although there were northern polar holes, those polar holes were

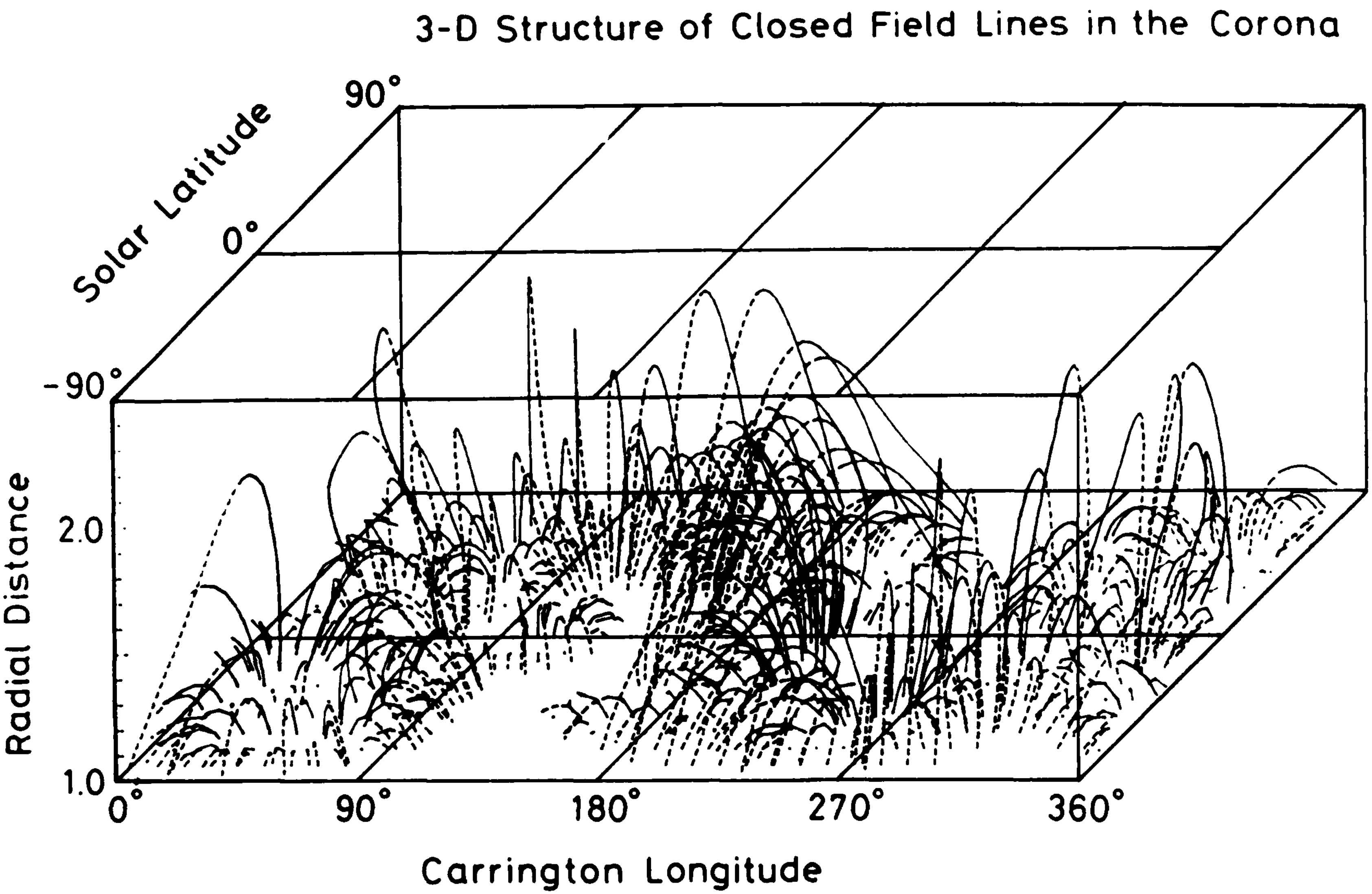

Figure 3. Three-dimensional representation of closed field lines (CFLs) of the coronal magnetic field (CMF) starting at 10° and 10° mesh point in the photosphere, estimated on the basis of the average synoptic map between the Carrington rotation 1609 and 1620. A part of CFL whose radial component (B_r) is positive is drawn by a solid line, and negative by a dashed line. CFLs form arcade structures of various heights. High and well-regulated arcade structures appear near - 180° in longitude in the southern middle latitudes where the strongest large scale bipolar magnetic region is also present in the photosphere.

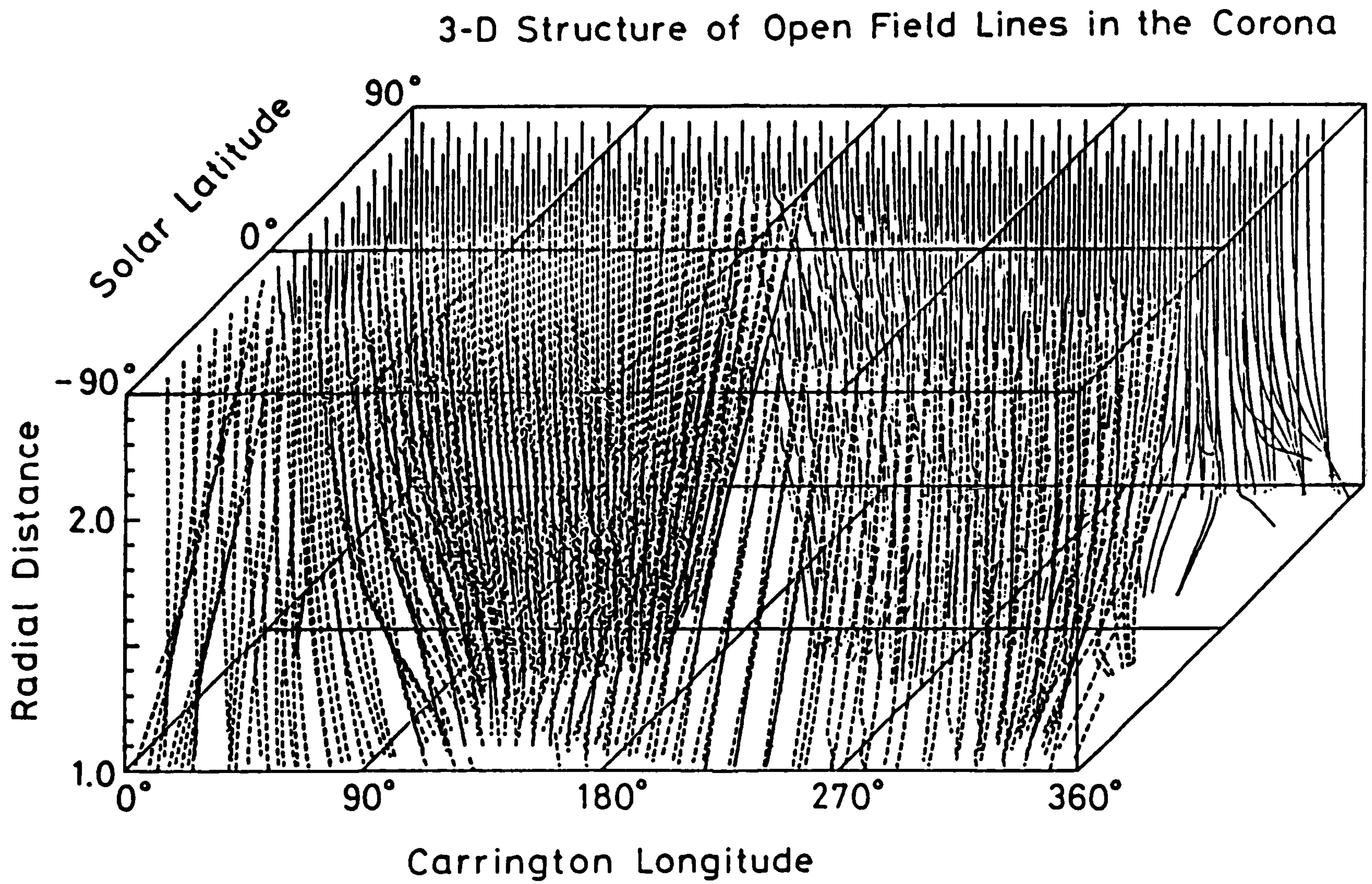

Figure 4. Three-dimensional structure of open magnetic field lines in the corona. All field lines are traced from 10° x 10° mesh points on the source surface of 2.5 solar radii down to the photosphere, with the same format as Figure 3.

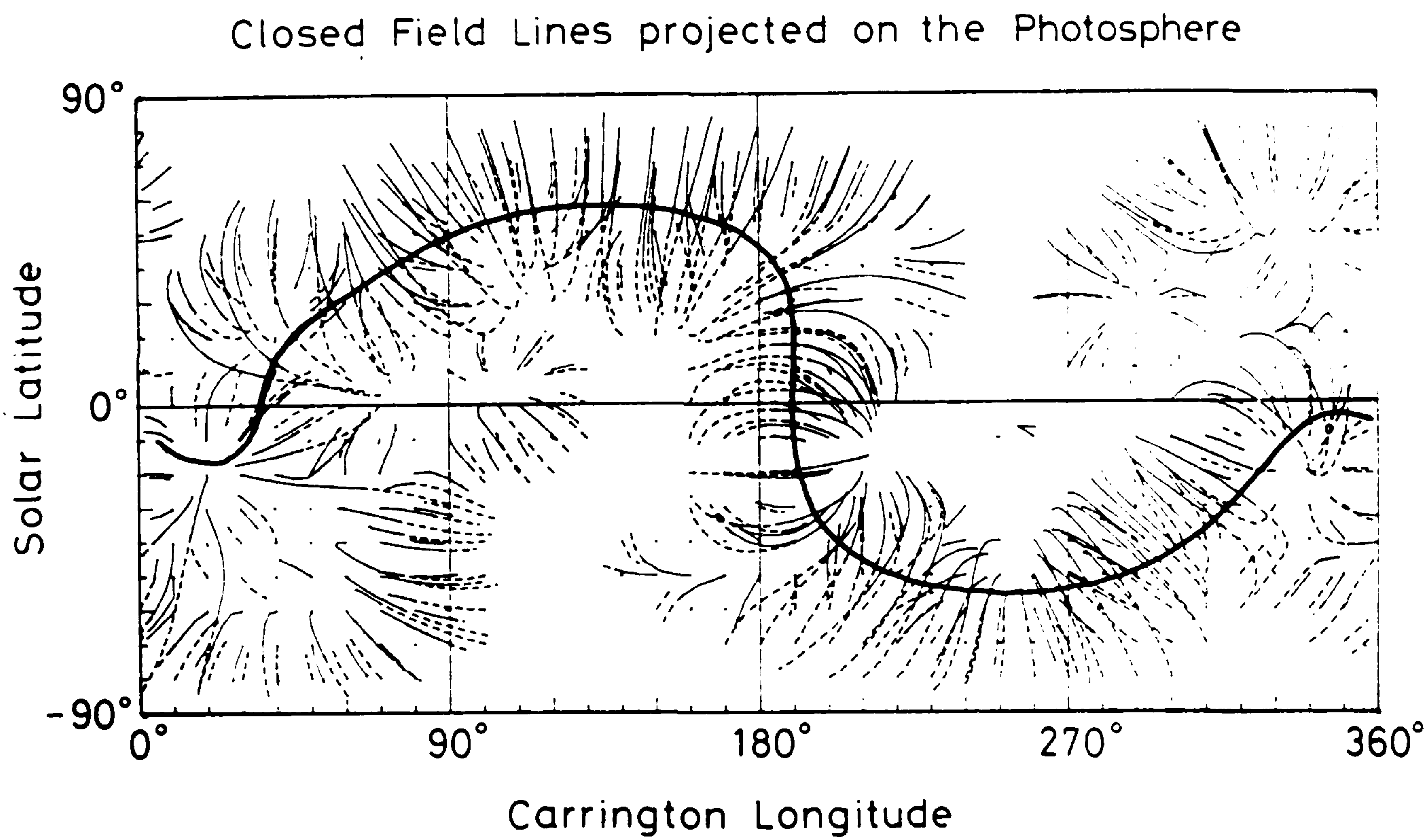

Figure 5. Closed field lines (CFLs) projected onto the photosphere are drawn in heliographic latitude-longitude coordinates. It is clearly seen that almost all CFLs are confined in a sinusoidal belt in the photosphere.

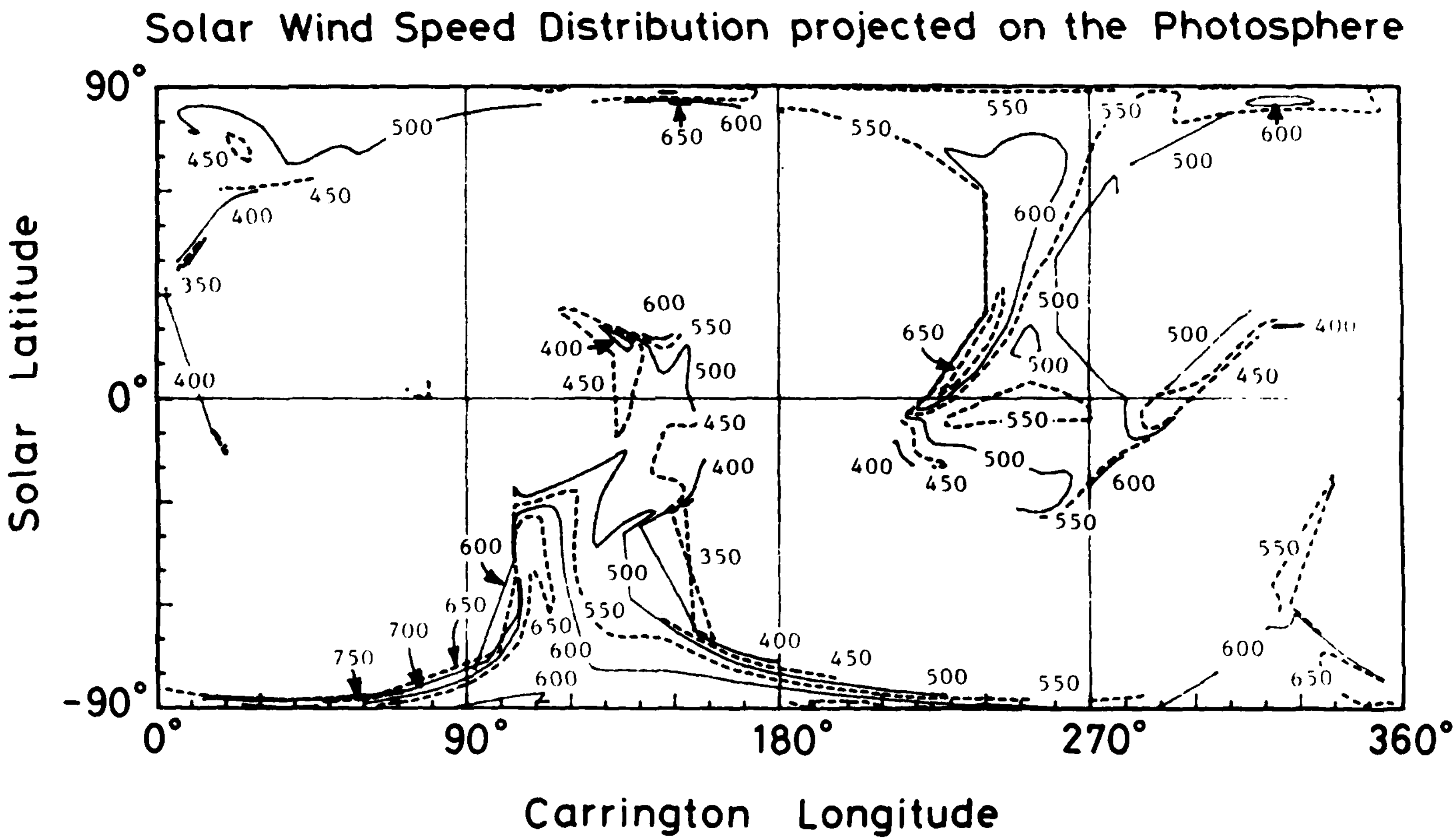

Figure 6. The solar wind speed distribution projected from the source surface onto the photosphere along the open field lines in the corona. All contour lines are converged into relatively narrow regions in the photosphere. Consequently the speed gradient in these regions becomes steeper than that on the source surface. The speed gradient is steeper at the eastern edge of these regions than at the western edge.

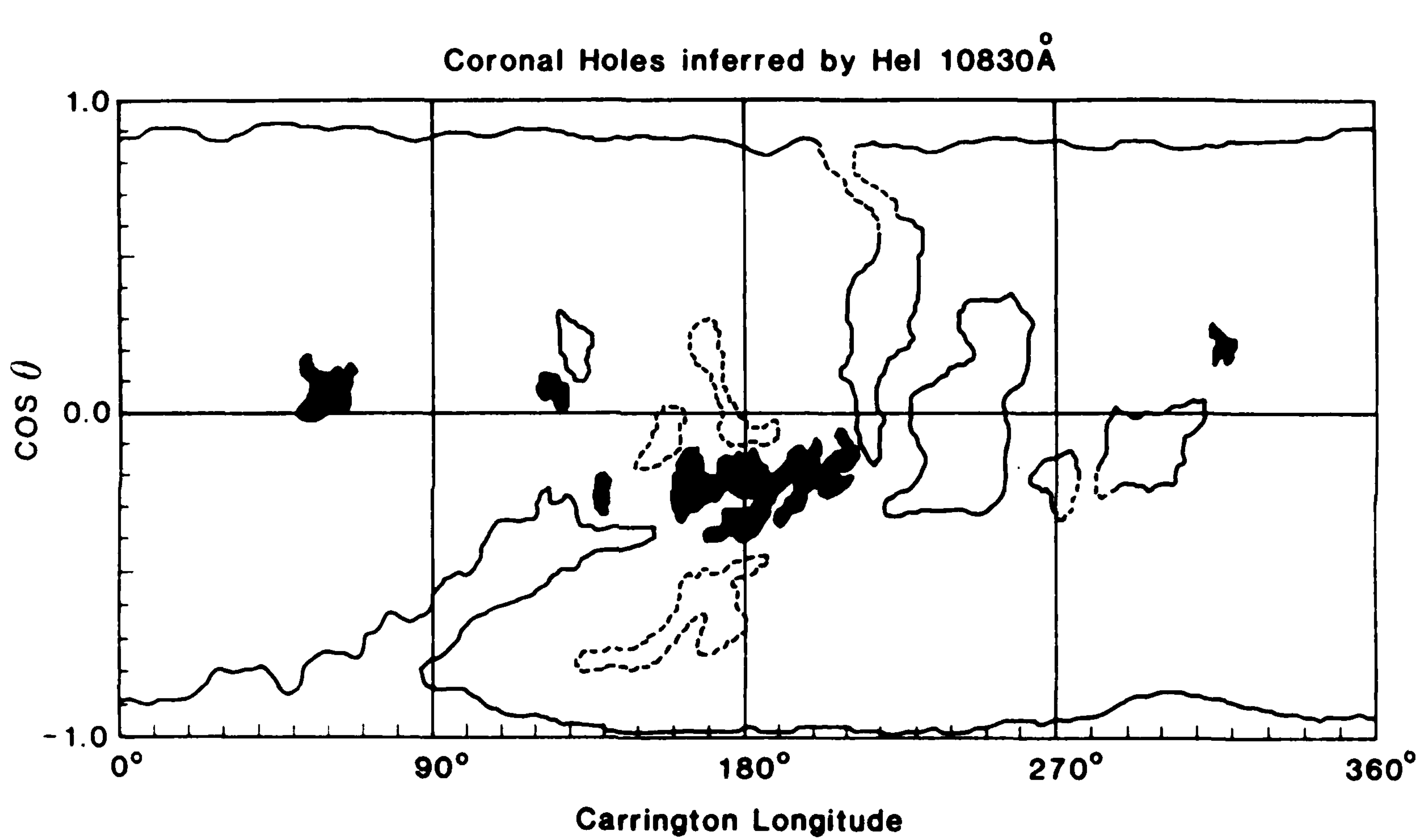

Figure 7. Coronal hole boundaries inferred by HeI (10830 A) during Carrington rotation No. 1615. A solid line indicates a stable and well-defined boundary. A dashed line means a questionable boundary. Filled areas represent active regions and their remnants. The southern polar hole extending from ~ 70° in longitude to the northwest persisted in almost the same location during 1974.

separated from the middle latitude holes.

The HeI (10830 A) absorption line can be directly observed at the central meridian, while the white-light coronal intensity integrated along the line-of-sight can be observed only at the solar limb. Thus, small coronal holes and narrow coronal holes like those in the southern hemisphere, which can be observed by the HeI (10830 A) line, might be obstructed by the surrounding bright regions in the white light corona. This might be one of the reasons that there is no small structure in the K-corona. The constructing procedure for a coronal hole boundary map of the HeI (10830 A) line is similar to the one for $B_{|}$ of the photospheric magnetic fields.

Since the solar wind and coronal holes were relatively steady in 1974, the average distribution of the solar wind speed and of the line-of-sight component of the photospheric magnetic fields ($B_{|}$) on the source surface can be constructed, with fair accuracy, by the superposed epoch analysis. The three-dimensional structure of the coronal magnetic fields is then computed from this average map of $B_{|}$ based on the potential model. The average distribution of the solar wind speed on the source surface, obtained from interplanetary scintillation observations, is then projected onto the photosphere along the open field lines in the corona. The high speed regions thus projected are compared with the HeI (108030 A) coronal holes and are found to have a similar geometry. The results are also suggestive that the solar wind does not blow out uniformly from the vicinity of a coronal hole and the speed is higher at the east side in that region than at the west side. The slower speed regions on the source surface have a sinusoidal structure in heliographic latitude-longitude coordinates and are similar to the brightness distribution of the K-corona and the structure of closed field line regions projected onto the photosphere. It is hoped that the above method will be extended in future, so that the source region of the high speed streams can be mapped for each Carrington rotation.

References

Akasofu, S.-I., Radial deformation of the solar current sheet as a cause of geomagnetic storms, Planet. Space Sci., 21, 1055, 1979.

Akasofu, S.-I., C. Olmsted, E. J. Smith, B. Tsurutani and R. Okida, Solar wind and geomagnetic storms: A study of individual storms based on high time resolution ISEE 3 data, J. Geophys. Res., 90, 235, 1985.

Altshuler, M. D. and G. Newkirk, Jr., Magnetic fields and the structure of the solar corona, I: Method of calculating coronal fields, Solar Physics, 9, 131, 1969.

Arnoldy, R. L., Signature in the interplanetary medium for substorms, J. Geophys. Res., 76, 5189, 1971.

Borrini, G., J. T. Gosling, S. J. Bame and W. C. Feldman, Helium abundance enhancements in the solar wind, J. Geophys. Res., 87, 7370, 1982a.

Borrini, G., J. T. Gosling, S. J. Bame and W. C. Feldman, An analysis of shock wave disturbances observed at 1 a.u. from 1971 through 1978, J. Geophys. Res., 87, 4365, 1982b.

Cane, H. V., R. G. Stone, J. Fainberg, J. L. Steinberg and S. Hoang, Type II solar radio events observed in the interplanetary medium, Solar Phys., 78, 187, 1982.

Coles, W. A. and B. J. Rickett, IPS observations of the solar wind speed out of ecliptic, J. Geophys. Res., 81, 4797, 1976.

Coles, W. A., B. J. Rickett, V. H. Rumsey, J. J. Kaufman, D. G. Turley, S. Ananthakrishnan, J. W. Armstrong, J. K. Harmons, S. L. Scott and D. G. Sime, Solar cycle changes in the polar solar wind, Nature, 286,239, 1980.

Gold, T., Magnetic storms, Space Sci. Rev., 1, 100, 1962.

Hoeksema, J. T., J. M. Wilcox and P. H. Sherrer, Structure of the heliospheric current sheet in the early portion of sunspot cycle 21, J. Geophys. Res., 87, 10331, 1982.

Hirshberg, J., S. J. Bame and D. E. Robbins, Solar flares and solar wind helium enrichments: July 1967, Solar Phys., 23, 467, 1972a.

Hirshberg, J., J. R. Asbridge and D. E. Robbins, Velocity and flux dependence of solar wind helium abundance, J. Geophys. Res., 77, 3583, 1972b.

Klein and Burlaga, Interplanetary magnetic flouds at 1 a.u., J. Geophys. Res., 87, 613, 1982.

Levine, R. H., M. D. Altschuler and J. W. Harvey, Solar source of the interplanetary magnetic field solar wind, J. Geophys. Res., 82, 1061, 1977.

Palmer, I. D., F. R. Allum and S. Singer, Bidirectional anisotropies in solar cosmic ray events: Evidence for magnetic bottles, J. Geophys. Res., 83, 75, 1978.

Pudovkin, M. I. and A. D. Chertkov, Magnetic field of the solar wind, Solar Phys., 50, 213, 1976.

Pudvokin, M. I., S. A. Zaitseva, I. P. Oleferenko and A. D. Chertkov, The structure of the solar flare stream magnetic field, Solar Phys., 54, 155, 1977.

Pudovkin, M. I., S. A. Zaitseva and E. E. Benevslenska, The structure and parameters of flare streams, J. Geophys. Res., 84, 6649, 1979.

Russell, C. T. and R. L. McPherron, The magnetotail and substorms, Space Sci. Rev., 28, 121, 1973.

Shatten, K. H., J. M. Wilcox and N. F. Ness, A model of corona and interplanetary magnetic fields, Solar Phys., 9, 442, 1969.

Sime, D. G. and B. J. Rickett, The latitude and longitude structure of the solar wind speed from IPS observations, J. Geophys. Res., 83, 5757, 1978.

Smith, E. J., Solar wind magnetic field observations, Solar Wind, 4, p. 96, ed. by H. Rosenbauer, Max-Planck-Institut fur extraterrestrische Physik, Garching, W. Germany, 1981.

Smith, E. J., Observations of interplanetary shocks: Recent progress, Space Sci. Rev., 34, 101, 1983.

Tang, F., S.-I. Akasofu, E. Smith and B. Tsurutani, Magnetic fields on the sun and the north-south component of transient variation of the interplanetary magnetotail at IAU, J. Geophys. Res., 90, 2703, 1985.

Tsurutani, B. T., C. T. Russell, J. H. King, R. D. Zwickl and R. P. Lin, A kinky heliospheric current sheet: Cause of CDAW-6 substorms, Geophys. Res. Lett., 11, 339, 1984.

Wilcox, J. M., J. T. Hoeksema and P. H. Scherrer, Origin of the warped heliospheric current sheet, Science, 209, 603, 1980.

Zirker, J. B., Coronal holes and high-speed wind streams, Rev. Geophys. Space Phys., 15, 257, 1977.

Zwickl, R. D., J. R. Asbridge, S. J. Bame, W. C. Feldman, J. T. Gosling and E. J. Smith, Plasma properties of driver gas following interplanetary shocks observed by ISEE-3, Solar Wind, #5, 711, 1983.

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