GEOMAGNETIC DISTURBANCES

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LONG-TERM GOAL

The Sun's changing magnetic field interacts with the Earth's magnetosphere causing geomagnetic activity. The fundamental questions we seek to understand are the origin of solar activity seen at the Sun's surface, how the photospheric magnetic field is expressed in the corona and interplanetary medium, and how, ultimately, the variations of the solar field affect the terrestrial environment. Our goal is to develop tools for reliably forecasting, from photospheric observations, the solar events and solar wind conditions that result in the geomagnetic disturbances that impact human activities on and near Earth.

SCIENTIFIC OBJECTIVES

To achieve these goals we are working on four specific scientific objectives:

1. Measurement of the large-scale photospheric magnetic and velocity fields that characterize the emergence, development, and distribution of magnetic fields during the solar cycle;
2. Evaluation of models of the solar corona and the solar wind throughout the heliosphere using a variety of techniques to identify the photospheric sources of changes in the stable component of the corona and solar wind;
3. Determination of the causes of coronal mass ejections (CME) and other solar wind disturbances and of how photospheric observations can be used to predict the parameters that determine the geomagnetic activity response; and
4. Clarification of the interrelationship between the photospheric field patterns, the emergence and redistribution of magnetic flux, solar activity, and the solar cycle.

APPROACH

These objectives require that we extend the collection and analysis of the time series of uniform, high-quality solar magnetic field measurements made at WSO since 1976 and distribute both preliminary and archival data sets rapidly and conveniently to other researchers. To facilitate predictions made by others, we are continuing to develop a system by which a variety of daily data products are made conveniently and quickly available via WSO's world wide web site at http://quake.stanford.edu/~wso.

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These two tasks are the prime responsibility of J.T. Hoeksema with assistance from P.H. Scherrer. They and Drs. Zhao and Bai at Stanford analyze WSO and other solar data and work to develop methods for predicting parameters that determine geomagnetic activity. The approach is to improve our models of the coronal field and compare results with solar wind observations to validate the results.

WORK COMPLETED

WWW pages now provide immediate access to daily magnetograms, daily and monthly updates of synoptic charts of the photospheric and coronal field, harmonic coefficients of the solar field, and a variety of other materials. Immediate FTP access is also provided for automatic retrieval of preliminary data. The data are typically reduced and released the day following observations. We are working to decrease this delay further. During the first 10 months of 1997 there were over 6000 remote accesses to the WSO web pages. We continue to provide solar mean field values daily to the SEL forecast center, publish magnetograms and synoptic charts each month in Solar Geophysical Data, directly distribute data to about 10 groups each month, provide e-mail access to synoptic data (~400 requests/year), and fulfill requests for special data products (~40 per/year).

We analyzed the solar sources of CMEs, Bz events, and other geoeffective features in the solar wind and made progress toward predicting their characteristics. We refined our models of the coronal field and investigated how changes in the solar field lead to reconfiguration of the corona and heliosphere. Model results have been compared with various solar and interplanetary observations to improve accuracy. We found further evidence for periodicities in the rate of solar flare occurrence and believe that these may be useful for making mid-range solar activity forecasts.

An upgrade to the WSO computer control system is virtually completed. The new system operated without major problems during September and October 1997. The upgrade replaces an aging PDP 11/24 running a unique operating system with a Pentium running QNX, a commercial UNIX-like real time operating system.

RESULTS

The following provides a list of accomplishments:

1. *Solar Causes of Bz events:*

   Observational evidence has shown that CME cause all large geomagnetic storms and their attendant effects. We are currently working with J. Luhmann at Berkeley to develop a predictive scheme for CMEs (Luhmann et al., 1997). When photospheric field lines open up, the likelihood of a CME is much higher. We are setting up an automated procedure to identify likely source regions of CME initiation, and therefore of geomagnetic storms.

   Bz events are intervals of several hours with a large out-of-ecliptic interplanetary magnetic field (IMF) component. This component is a key factor regulating the energy transfer from the solar wind to the Earth's magnetosphere. Nearly all such events are associated with CME proxies, especially magnetic clouds and bidirectional electron events. However, not all CME proxies are accompanied by -Bz events. Those magnetic clouds associated with disappearing filaments at the Sun display a similar magnetic flux rope structure, i.e., a cylindrical configuration with a strong axial field in the center and weaker and more azimuthal fields away from the center. We find high correlations between the axial field directions of magnetic clouds and DBs and between the axial field direction in the DBs and the duration and intensity of -Bz events. This suggests that the axial field direction in DBs remains virtually unchanged while propagating through interplanetary space, and that it is the axial field direction that determines whether a CME will be geoeffective (Zhao and Hoeksema, 1997a, b).

Figure 1 shows our most recent preliminary results (see pages 5-6). Using a new analysis of several magnetic clouds provided by Marubashi (private communication), we are able to determine the correlation between the duration of the interval of southward IMF associated with each cloud and the axial direction of the field in the cloud. We can make a similar association between the maximum southward field strength and the direction of the axial field in the cloud. The correlations are quite good. The results shown at the top ignore the obvious effects of the impact parameter (how far the center of the cloud is from Earth) and the overall size and orientation of the cloud in space. The middle and lower panels show how the correlation improves when first the impact parameter and then the cloud geometry are taken into account. In principle these should eventually be determinable from a complete coronal and solar wind model.

2. *Coronal and Heliospheric Field Modeling:*
   With significant improvements to the coronal field models, we can now compute both the field structure and magnitude in the solar wind. To reproduce the time evolution of the monthly averaged radial IMF component observed near the Earth's orbit we developed the current sheet-source surface model (Zhao and Hoeksema, 1995, 1996). This model also reproduces the uniform IMF field strength seen at high latitude by Ulysses.

   Determining the magnetic field harmonic coefficients in the global solution requires knowledge of the photospheric field over the whole solar surface. The composite photospheric field synoptic charts typically used in global field models are certainly not valid for modeling events evolving on time scales of a day or less. To overcome this limitation, we can replace the central part of the standard chart with the data from a single magnetogram observed just before or after an event (Zhao & Hoeksema, 1997a, b). We have recently ported the computation to a more capable SGI workstation procured with funds from this grant.

3. *Solar Sources of Heliospheric Structures at Mid-latitudes:*
   As Ulysses began moving toward the Sun's southern pole in 1992-1993, the spacecraft observed 26-day quasi-periodic modulations of solar wind speed, energetic particle fluxes, and interplanetary magnetic fields.

   Bai, Hoeksema, Webber, and Acton (1997) analyzed observed photospheric field strengths, computed coronal fields, and the soft X-ray emissions observed by the Yohkoh spacecraft. We found that the mid-latitude photospheric magnetic field pattern in the southern hemisphere was dominated by two broad unipolar regions, each of which extended about 180 degrees in longitude. The pattern remained stable from late 1991 until 1995. Its synodic rotation period was about 28.4 days, corresponding to a sidereal period of 26.3 days. The Yohkoh observations show that the southern polar coronal hole protruded to about 40 S when

Ulysses observed the 26-day periodicity. The protrusion was stable and its rotation period during 1992 was also about 28.4 days.

IMPACT/APPLICATION

The importance of space weather is becoming increasingly apparent. Reliable techniques for predicting inputs to the terrestrial environment from solar observations are essential. It seems that predicting certain background solar wind conditions from solar observations with some level of confidence is nearly within our reach, though steps need to be taken to characterize the uncertainties and make the routine application of the techniques practical. There are intriguing developments in predicting CME and in knowing ahead of time which will be more geoeffective. Much work needs to be done to verify and advance this from a statistical and preliminary result to something reliable and practical. On longer time scales, the solar cycle itself remains an enigma. While intermediate predictions of flare occurrence can be made, mechanisms for physical understanding of these periodicities are a long way off. More complete knowledge of the internal motions in the solar convection zone provided by helioseismology should help greatly in the next few years.

TRANSITIONS

WSO data are used regularly to make predictions of the solar wind velocity, magnetic field direction, and magnitude several days in advance. N. Sheeley at NRL uses these data each month to make predictions of the solar field a month in advance and from that generates space weather predictions. V. Pizzo and N. Arge (ONR funded at SEL, see http://solar.sec.noaa.gov/~narge/) are currently developing a system to make predictions available to forecasters in a much more timely fashion. We are working with J. Luhmann at UC Berkeley to develop an automated prediction scheme for CME.

RELATED PROJECTS

Collaborations with other observers and modelers increase our understanding of the whole solar-terrestrial system. Our group is also responsible for the MDI instrument on SOHO and we benefit greatly from interactions with that project. One element of that program is the Stanford SOLAR Center, http://solar-center.stanford.edu, a web-based program for educational outreach.

REFERENCES

Bai, T, J.T. Hoeksema, M. Weber & L.W. Acton, 1997. *J. Geophys. Res.*, 102, 9793.

J.G. Luhmann, J.T. Gosling, J.T. Hoeksema & X.P. Zhao, 1997. *J. Geophys. R.*, in press.

Zhao, X.P., & J.T. Hoeksema, 1997a. *Geophys. Res. Lett.*, in press.

Zhao, X.P., & J.T. Hoeksema, 1997b. *J Geophys Res.*, in press.

Zhao, X.P., & J.T. Hoeksema, 1996. *Solar Wind*, 8, 92.

Zhao, X.P., & J.T. Hoeksema, 1995. *J. Geophys. Res.*, 100, 19.

Zhao, X.P., & J.T. Hoeksema, 1994. *Solar Phys.*, 151, 91.

Zhao, X.P., J.T. Hoeksema, J.T. Gosling, & J.T. Phillips, 1993. *Proc. Solar-Terr. Predictions-IV*, V.2, 712.

WEB ADDRESS

http://quake.stanford.edu/~wso

http://solar.sec.noaa.gov/~narge/

http://solar-center.stanford.edu/

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Figure 1. A Southward IMF Event.

Bs, is characterized by its duration (D_Bs) and intensity (I_Bs). The panels on the left show how the duration of the Bs event (normalized to the maximum duration determined from the model of the magnetic cloud) depends on the ecliptic latitude of the axial field of the magnetic cloud. The panels on the right show the relationship between the intensity of the Bs event (normalized to the maximum intensity in the model of the cloud) and the ecliptic latitude of the cloud’s axial field.

In each panel the correlation coefficient is given by (c) and the multiple regression expression is given at the top of each panel. The solid dots are the results of the expression and the open circles are the observed values.The top panels show the single parameter linear least squares fit based on the latitude of the cloud’s axial field. The middle panels show a fit based on both axial field latitude and impact parameter. The impact parameter is the the closest approach of a space craft to the cloud central axis. The bottom panels show the multiple regression fit account for magnetic axial field latitude and longitude as well as the impact parameter. Approximately 90% of the variance is explained using these parameters, which should be, at least in theory, predictable from solar parameters.