Geomagnetic Disturbances

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LONG-TERM GOALS

Interactions of the changing magnetic field of the Sun with the Earth's magnetosphere cause geomagnetic activity. We seek to understand the physical processes that affect the inputs to the terrestrial system and generate geomagnetospheric disturbances. The goal is to understand how solar activity originates, how it is expressed in the corona and interplanetary medium, and how it ultimately affects the terrestrial environment. We are working to develop tools that can, from photospheric observations, reliably forecast the solar events and solar wind conditions that cause the geomagnetic disturbances that impact human activities on and near the Earth.

OBJECTIVES

Our research concentrates on four specific scientific objectives:

1. Measurement of the large-scale photospheric magnetic and velocity fields that characterize the development of the solar cycle.

2. Investigation of the interrelationship between the emergence and redistribution of magnetic flux in active regions and in the 'quiet Sun,' the development of large-scale photospheric field patterns, and the characteristics of each solar cycle.

3. Development of improved models of the solar corona and the solar wind throughout the heliosphere using a variety of techniques to identify the photospheric sources of change in the large-scale structure of the corona and solar wind.

4. Determination of the causes of coronal mass ejections (CMEs) and other solar wind disturbances, with an emphasis on how photospheric observations can be used to predict the parameters that determine the geomagnetic response.

APPROACH

We extend the 23+ year time series of uniform high-quality solar magnetic field measurements by operating the Wilcox Solar Observatory (WSO) here at Stanford. We distribute both preliminary and

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archival WSO data sets rapidly and conveniently to other researchers, often by the end of the observing day. To facilitate predictions, a variety of data products are made conveniently available via WSO's world wide web site at http://quake.stanford.edu/~wso and by e-mail and anonymous ftp.

We continually monitor the data quality by evaluating long-term trends and by following the evolution of the solar cycle. We constantly compare results of modeling with observations. We collaborate with other researchers, including ONR sponsored investigators Pizzo & Arge at SEL in Boulder and Sheeley & Wang at NRL, to get the most out of the data and analysis. We analyze times of activity with special care and work to determine the causes of solar, interplanetary, and geomagnetic events.

These tasks are the prime responsibility of J.T. Hoeksema together with P.H. Scherrer. Routine observations are carried out by a Stanford graduate student. They with Drs. X.P. Zhao and T. Bai at Stanford analyze WSO and other solar data and work to develop methods for predicting parameters that determine geomagnetic activity. We strive to improve our modeling of the coronal field and compare results with solar wind observations to validate the results.

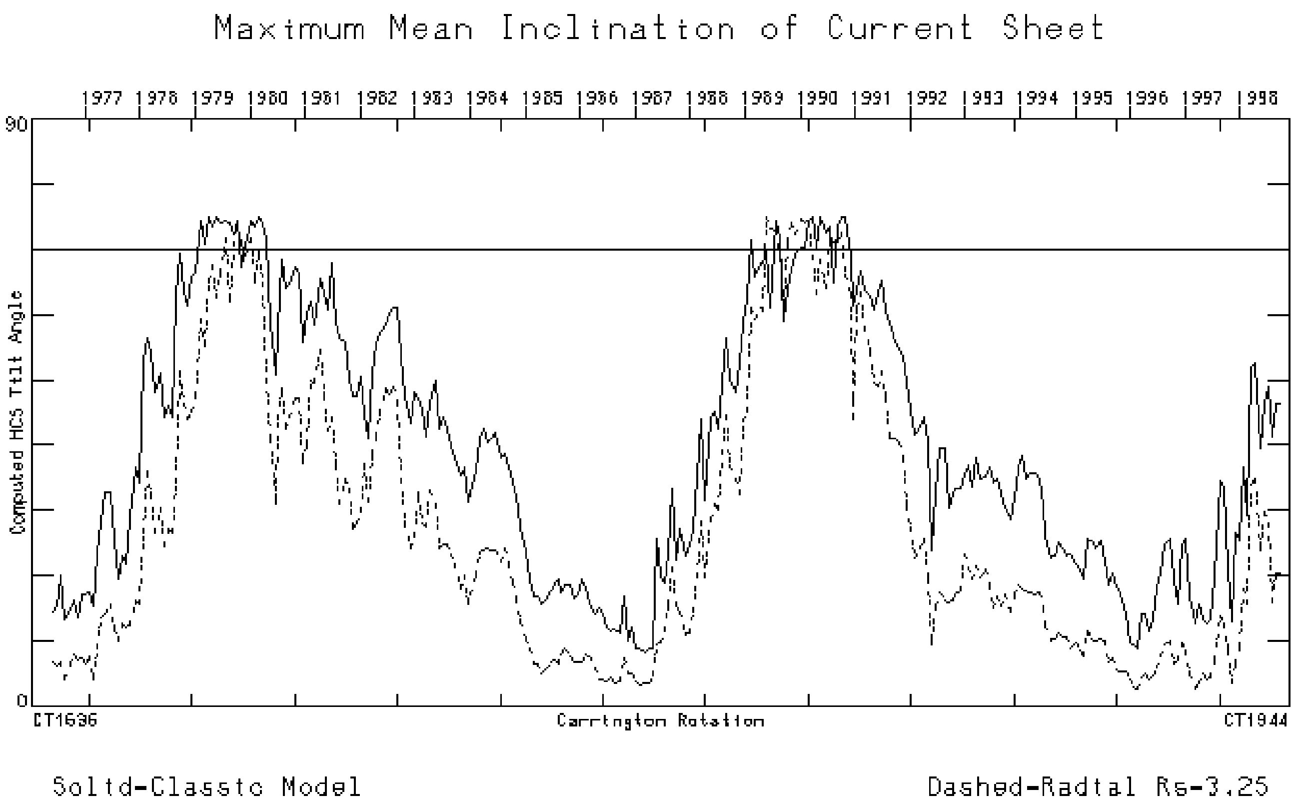

Figure 1: Calculations of the maximum inclination of the heliospheric current sheet (HCS) from spring 1976 through fall 1998 show the effects of the phase of the solar cycle. Part of the difference between the two models in 1998 is due to a difference in sensitivity to the unusual imbalance between the northern and southern polar fields of the Sun. The inclination of the HCS is important for determining the distance of the Earth from the HCS and for the propagation of cosmic rays.

WORK COMPLETED

We measured the solar magnetic field during the start of the rising phase of solar cycle 23 (see Figure 1 for an example of one measure of changes related to the solar cycle). Data analysis has been largely automated and results are generally posted within hours on our observatory web site. The data products available have been tailored to meet the requirements of our users (e.g. we now provide individual magnetograms in Carrington coordinates and harmonic coefficients of the coronal field are now generated). We increased the frequency of magnetogram observations and now provide updates of the changing photospheric and coronal magnetic field twice daily during good weather.

We completed and verified the operation of an upgrade to the observatory hardware control computer and clock. We finished the initial implementation of a new software and a replacement hardware system for higher level control of WSO observations.

RESULTS

We published an analysis showing a clear relationship between the axial field direction observed in disappearing filaments on the Sun and the geoeffective characteristics (size, orientation, intensity) of magnetic clouds or flux ropes at Earth (Zhao & Hoeksema, 1997, 1998). Clouds are among the strongest sources of southward-directed interplanetary field, and thus generate some of the most intense geomagnetic disturbances. The field in disappearing filaments can be observed, so the discovery that the flux rope field characteristics do not change much between Sun and Earth gives some hope that their geoeffectiveness is predictable. Disappearing filaments are associated with many CMEs, but only a fraction of the CMEs result in clouds at Earth.

Our initial results suggest that changes in the configuration of the open flux in the solar corona are related to the launch of Coronal Mass Ejections (CMEs) (Luhmann et al., 1998). The computed configuration of the field changes in response to the changing photospheric field distribution. By updating the photospheric boundary conditions after each magnetogram (Zhao et al., 1997), changes in the distribution of open field lines can be determined. When the number of field lines open to the interplanetary medium increases, there appears to be an increased likelihood of a coronal mass ejection.

In comparisons of modeled interplanetary magnetic field structure, our models match in situ observations of the stable background polarity pattern very well, both in the ecliptic (Sanderson et al., 1998; Neugebauer et al., 1998) and at higher latitudes (Brandt et al., 1998). This gives us some confidence that changes leading to the disturbances discussed above can be understood in relation to the ambient structure of the heliosphere.

IMPACT/APPLICATIONS

We find evidence that solar observations can be used to forecast geomagnetic disturbances. The background, recurrent structure of the solar wind responds to slow evolution of the large-scale photospheric field and can already be fairly well modeled. Coronal mass ejections and associated clouds that cause the most intense storms have their source at the Sun. These too can be detected in photospheric field observations. Our results suggest that the important characteristics of disturbances that affect Earth are related to photospheric conditions. If we can find ways to more effectively determine which events will reach the Earth, storm predictions should be improved.

Solar observations are now available much more quickly. Long baselines for comparison mean we can now compare several solar cycles to understand how each unfolds. The imbalance of activity between the northern and southern hemispheres during the rising phase of Cycle 23 has led to a significant difference in the polar field strength in the north and south. This may have long term impact on the characteristics of high-speed streams originating in the two hemispheres.

TRANSITIONS

Observations are used to make monthly predictions of solar wind speed (available from N. Sheeley at NRL) using WSO and other solar data sources. Daily data are provided to N. Arge and V. Pizzo for use at the Rapid Prototyping Center at SEC in Boulder. They provide predictions of solar wind velocity, interplanetary magnetic field polarity, and the locations of coronal holes at their website at http://solar.sec.noaa.gov/~narge/ using WSO data and adaptations of models developed here and elsewhere. Daily solar magnetic mean field values are also provided to the Solar Forecast Center in Boulder. We are working with J. Luhmann at Berkeley to make daily computations of changing open field regions available in a timely fashion.

RELATED PROJECTS

Our group is responsible for the SOI/MDI instrument on SOHO and progress on our scientific objectives will benefit from analysis of MDI and other SOHO data; such direct comparisons are being supported by NASA funds.

Operation of the Wilcox Solar Observatory is supported in roughly equal measures by NASA, NSF and ONR.

Collaborations with other observers and modelers increase our understanding of the whole solar-terrestrial system. Specific collaborations with other ONR sponsored researchers (Pizzo & Arge; Sheeley & Wang) have been mentioned above. Other involvements include Whole Sun Month (a SOHO program organized by D. Biesecker & S. Gibson at GSFC); investigation of changing coronal field configurations (J. Luhmann at UC Berkeley); and contributing to the development of MHD models of the coronal field (Mikic & Linker of SAIC in San Diego); Other projects are indicated by co-authorship in the publications list.

Our group is responsible for a public outreach program called the Stanford Solar Center (http://solar-center.stanford.edu) that seeks to make solar science accessible and interesting to students and the general public.

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