Solar Origins of Space Weather: Confronting Models with Observations

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LONG-TERM GOALS

The major goal for this two-year project is to acquire and use improved observational data to test predictive models of space weather events.

OBJECTIVES

We have three primary scientific objectives for this project: (1) To develop methods to use new observations to enhance understanding and forecasting prospects of solar eruptions that produce significant space weather events. (2) To test models that intend to predict solar activity occurrence by confronting the model predictions with actual observations. (3) To explore observational diagnostics that offer promise for predicting and modeling space weather events.

APPROACH

For the first objective, we concentrate on development of reduction, calibration, display, storage and community access methods to be used with data forthcoming from the new Synoptic Optical Long-term Investigations of the Sun (SOLIS) suite of synoptic observing equipment. We are also developing methods to calibrate unique magnetic field data from the world-wide GONG instruments.

Achieving the second objective involves construction of models that have potential to predict the occurrence of solar activity. These models are used with real data and then the predictions are compared with actual space weather events.

The approach for the third objective is to try new types of data and new ways of looking at old data to find promising predictors for the occurrence of space weather events.

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The individuals participating in this work are Dr. John Harvey, PI, who directs and organizes the work of the project and concentrates on calibration and display methods for SOLIS and GONG data, Dr. Frank Hill, Co-PI, who concentrates on the development of new SOLIS codes, data storage and access for both SOLIS and GONG data, and educational outreach. Dr. Carl Henney, Assistant Astronomer, who has developed SOLIS data reduction codes and does the formulation and verification of predictive models, and works on community data access and educational outreach, and Dr. Roberta Toussaint, Assistant Scientist, who is an expert on the calibration of GONG data and is now developing calibration codes for SOLIS instruments.

WORK COMPLETED

Henney and Harvey (2002) published an analysis of NSO synoptic data that confirms the existence of a 27.03 day persistent periodicity in solar activity, but for only the last 25 years. The 27.03 day periodicity had been pointed out earlier by Neugebauer et al. (2000), and Ruzmaikin et al.(2001). Our results on this subject were described in some detail in last year's Annual Report for a predecessor grant and will not be repeated here.

Reduction code for vector magnetic field observations has been prepared and tested (Henney et al. 2002) and awaits first observational data from the SOLIS vector spectromagnetograph. Five methods of doing quick-look reductions were tested and two high-accuracy techniques were examined before selecting one of each type for use.

A Virtual Reality Modeling Language (VRML) display of solar magnetic flux and extrapolated magnetic field lines has been prepared and is updated on a daily basis. This allows an Internet user to view the solar magnetic field from any vantage point around the sun and to zoom in on interesting regions using a browser plug in. It gives a 3D perspective to a 3D object that has been sorely missing until now.

RESULTS

As described in last year's Annual Report for the preceding grant, we have been producing daily solar maps that estimate the potential for flare activity based on an analysis of our magnetic field measurements. Dr. Henney compared these estimates with actual activity for a period of about a year. The comparison was disappointing at even a basic level by not giving a good correlation between the magnitude of flare activity that happened within 24 hours (or 72 hours - also tested) subsequent to a prediction and the magnitude of the predictor. This result is not entirely surprising because the magnetic field information currently available is limited to just one component of the vector field. We anticipate that SOLIS full vector data will greatly improve the predictive success of the model. On the other hand, the model was quite successful in indicating *where* on the solar disk flare activity was likely to take place.

Better success was obtained in an effort to detect signatures of coronal mass ejections (CMEs) in the chromosphere and estimating the sign of the z-component of the interplanetary magnetic field that accompanies CMEs (Harvey, Harvey and Henney, 2002). A southward-directed z-component at Earth is associated with strong geomagnetic storms. The chromospheric signature of some CMEs becomes visible by calculating the difference between two helium 1083 nm full disk images, taken before and after the start of the CME. Two examples are shown in Figure 1. The signature, a weakening of chromospheric absorption, is essentially an indicator of loss of mass from the chromosphere and shows up as a light feature in the difference image. Our basic assumption is that CMEs involve mass that is visible in the chromosphere prior to the CME. Using these images, unlike direct coronagraph limb observations, we can see where the CME mass came from. We then use magnetic field measurements in a potential field extrapolation to calculate the net z-component of the magnetic field of the mass in the CME. To date, this full analysis has been done only in two cases, but with success in both cases. A major limitation to more extensive testing is uncertainty in linking a specific shock near Earth with a specific event at the sun. Difference images are computed every day and have shown many interesting and unexpected phenomena that were too faint to have been previously noticed. About 25% of CMEs originate away from active regions and this technique works best for this subset. The other 75% appear to come from active regions and our present observational cadence is too slow to spot CME-related changes amongst the normal 24-hour evolution of active regions. SOLIS will provide much higher cadence observations that should reveal the launch details of CMEs from active regions.

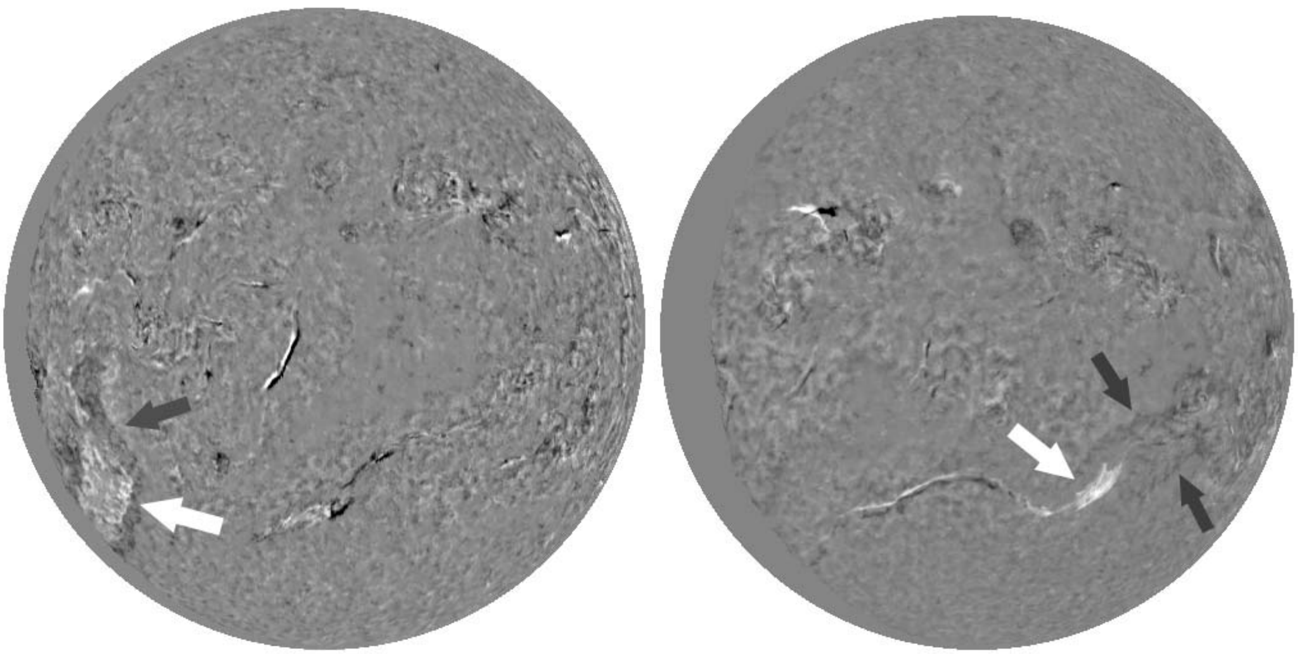

Figure 1. Chromospheric signatures of coronal mass ejections. These two images are time differences of the strength of the He I 1083 nm absorption across the solar disk. A white arrow in the left image indicates a light area where material left the sun as a CME. A dark arrow indicates enhanced dark absorption caused by coronal heating straddling the CME launch site. A white arrow in the right image indicates where part of a filament (light shade) left the sun in a CME event. Dark arrows indicate faint, dark lanes of enhanced heating straddling the CME launch site.

A spectacular improvement to a widely-used algorithm for correcting image sensor gain variations was developed by Dr. R. Toussaint. The original algorithm (Kuhn, Lin and Loranz 1991) assumes that an input image of some object is stable in time, uses several images placed at different locations on the detector and then iteratively solves for the original image and the gain variations across the detector. The implementation now in general use is very slow for large format detectors and has limited precision. By using successive over relaxation in the iterative solution of the basic problem and by allowing for fractional pixel shifts, both speed and accuracy are enhanced nearly two orders of magnitude. This work is being prepared for publication and promises to greatly improve the general quality of digital solar imagery. One consequence of this work will be an improvement in our ability to detect subtle solar changes related to space weather events.

An educational outreach activity was developed by Drs. Henney and Hill in collaboration with Dr. H. Jones to engage high-school students and teachers in useful solar activity research using our magnetogram data base. The activity is called "Researching Active Solar Longitudes" with interactive Web pages located at http://eo.nso.edu/rasl. The RASL project was a highlight at a workshop sponsored by the National Science Foundation and NASA: Teacher Leaders in Research-Based Science Education, July 2002.

IMPACT/APPLICATIONS

The improved maps that we produce allow far superior predictions of certain types of space weather events to be made compared with the older maps we have provided to the research and operational communities since 1973. The data archive has been widely used to good effect by many researchers according to a survey of published literature. The data are being used in several prototype systems to predict space weather. Algorithms have been developed that will be used to reduce forthcoming superior observations from instruments such as SOLIS. A major improvement to a widely-used calibration method has been devised. A technique has been developed that indicates where some types of CMEs originate on the solar disk and what their magnetic field z-component sign at Earth is likely to be.

TRANSITIONS

The improved maps that we produce are being used by several research and operational groups. The maps are provided to the Space Environment Laboratory in near real time to support an operational solar wind speed forecast (http://solar.sec.noaa.gov/ws/index.html). Luhmann and Li are using the maps as input to a model that attempts to detect the occurrence of coronal mass ejections before they have an influence on Earth (http://sprg.ssl.berkeley.edu/mf_evol). Linker and Mikic use our maps as boundary conditions for a sophisticated MHD model prediction of the structure of the solar corona (http://haven.saic.com/corona/model_desc.html). G. V. Rudenko at the Institute of Solar-Terrestrial Physics in Irkutsk, Russia uses our real time data and maps to construct solar corona structure estimates (http://bdm.iszf.irk.ru). In addition to these specific users, the data are openly available on the Internet and are widely used. To cite just two recent examples, a study by Zhang et al. (2002) used NSO coronal hole measurements to show a significant asymmetry between the north and south polar regions of the near-sun heliosphere at the time of the last solar minimum. Another study that used the same data base (Harvey and Recely, 2002) showed that the asymmetry persisted through the recent maximum of solar activity.

RELATED PROJECTS

We work closely with most of the groups mentioned in the previous section. In particular, with Y.-M. Wang and N. Sheeley at NRL, C. Arge, E. Hildner and V. Pizzo at the Space Environment Center of NOAA, and Y. Li at the Space Sciences Lab at Berkeley. An instrumental project at NSO is nearing installation. This NSF-funded project, Synoptic Optical Long-term Investigations of the Sun (SOLIS), will replace all of the existing synoptic observing instruments on Kitt Peak and will provide greatly improved observations for use with the products of this grant.

REFERENCES

Harvey, K. L. and Recely, F. 2002, Polar Coronal Holes During Cycles 22 and 23, Solar Phys., in press.

Kuhn, J. R., Lin, H. and Loranz, D. 1991, Gain calibrating nonuniform image-array data using only the image data, Pub. Astron. Soc. Pacific 103, 1097.

Neugebauer, M., Smith, E. J., Ruzmaikin, A., Feynman, J., and Vaughan, A. H.. 2000, The solar magnetic field and the solar wind: Existence of preferred longitudes, J. Geophys. Res. 105, 2315.

Ruzmaikin, A., Feynman, J., Neugebauer, M. and Smith, E. J. 2001, Preferred Solar Longitudes with Signatures in the Solar Wind, J. Geophys. Res. 106, 28325.

Zhang, J., Woch, J., Solanki, S. and von Steiger, R. 2002, The Sun at Solar Minimum: North-South Asymmetry of the Polar Coronal Holes, Geophys. Res. Lett. 29 (8), 10.1029/2001GL014471.

PUBLICATIONS

Donaldson Hanna, K. L. and Harvey, J. W. 2002, GONG+ Synoptic Magnetic Field Maps, Bull. Amer. Astron. Soc. 34, 643.

Harvey, J. W., Harvey, K. L. and Henney, C. J. 2002, Signatures of CMEs in HeI 1083 nm Images and Estimation of ICME Bz Direction, Bull. Amer. Astron. Soc. 34, 695.

Henney, C. J. and Harvey, J. W. 2002, Phase Coherence Analysis of Solar Magnetic Activity, Solar Phys. 207, 199-218.

Henney, C. J., Keller, C. U., Jones, H. P. and the SOLIS Team 2002, Stokes Inversion Techniques for the SOLIS-VSM, Bull. Amer. Astron. Soc. 34, 734.