

Improvement of Solar Magnetic Field Data for Space Weather Applications

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LONG-TERM GOALS

The major goal for this two-year grant is to improve the accuracy and timeliness of solar magnetic field data that are used to predict space weather disturbances that affect Earth.

OBJECTIVES

We have three primary scientific objectives for this project: (1) to continue to improve the accuracy and utility of archival and current solar magnetic field data that are used to help understand and predict space weather; (2) to develop ways of utilizing the significantly improved data to be provided by the SOLIS instruments starting in 2002; and (3) To investigate the predictive potential of chromospheric magnetic field measurements for explosive events such as flares and coronal mass ejections that are the causes of major space weather storms.

APPROACH

For the first objective, we continued to locate and correct instrumental effects and to develop and test new computer codes to process daily observations of the solar magnetic field taken at the National Solar Observatory on Kitt Peak, AZ. We used the reduced data to investigate two specific, current problems associated with long-term variations of the solar magnetic field. This serves to validate the reduction codes and also to learn more about the sources of space weather.

The second objective involves a new suite of instruments under construction by the National Solar Observatory with funding provided by the National Science Foundation. The new instrument suite, called SOLIS, will provide greatly improved quality and quantity data of the type that we have acquired for the last quarter century. It will also offer new types of data that will enhance our ability to understand and predict space weather. Our approach to take advantage of the new SOLIS data is: (1) prepare real-time reduction codes based on existing algorithms that will produce data similar to what

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we are currently getting; and (2) develop codes to take advantage of the new types of data to be provided by SOLIS.

Our third objective is classical scientific research involving newly discovered phenomena. We formulate a hypothesis to explain new findings and test it using the magnetic field data.

The individuals participating in this work are Dr. John Harvey, PI, who directs and organizes the work of the grant and concentrates on the processing of existing data, Dr. Frank Hill, Co-PI, who concentrates on the development of new SOLIS codes and manages the National Solar Observatory Digital Archive, and Dr. Carl Henney, Assistant Astronomer, who does the bulk of the work and concentrates on testing the improved and new codes as well as using the archive to study science questions.

WORK COMPLETED

Dr. Carl Henney completed work begun in his previous position. This produced two publications that appeared during this report period as listed in the bibliography. These dealt with helioseismology research.

During the second year of this two-year project, we developed and implemented code that corrected poor calibration of historic magnetic field measurements in our archive. In cooperation with Drs. E. Hildner and C. Arge of NOAA, we used these improved data to demonstrate that the claim (Lockwood et al. 1999a,b,c; Stamper et al. 1999) of a secular increase of the solar polar magnetic field strength is not supported by direct measurements (Hildner et al. 2000, 2001).

Thanks to recalibration efforts by a summer student, Ms. Jessica Erickson, we corrected our existing 25-year archive of measurements of solar chromospheric variability as manifested by the strength of the 1083 nm helium spectrum line. These improved data have been used by Drs. J. Pap and O. R. White, among others, to study the anomalously large increase of solar total irradiance during the present solar cycle.

We studied the behavior of polar magnetic fields and the most likely correction of the observations to best estimates of the polar magnetic flux. As a result, new code was implemented as a standard part of our regular data processing to produce best estimates of the distribution of magnetic flux over the entire solar surface. These corrected data are regularly used by several research groups to extrapolate the coronal magnetic field and resulting solar wind streams in near real time.

We completed a pilot Web page that contains maps of the sun processed daily according to various models that are thought to indicate where solar activity is likely to occur. At present, the models tested consist of magnetic complexity, magnetic flux change and surface origins of high speed solar wind streams. This *solar activity model test bench* will be greatly expanded when new data from the SOLIS project become available.

A week of observing time was devoted to careful study of the chromospheric magnetic field in collaboration with Drs. K. S. Balasubramaniam, H. Jones and H. Uitenbroeck. Tiny, opposite polarity magnetic field features, thought to be indicators of future flare activity, turned out to be primarily related to strong Doppler shifts. The relation with flare activity is now considered dubious. As a result of this observing run, we realized that it would be possible to make strictly simultaneous measurements

of the photospheric and chromospheric magnetic fields. This has been incorporated into the observing plans for SOLIS.

RESULTS

Archived magnetic field and chromospheric line strength measurements were recalibrated. For magnetic field data this consisted mainly of correcting a zero-point bias that was a function of radius from the center of the solar disk for data taken with an instrument that was retired in 1992. Improved extrapolation of the polar magnetic fields was also applied. These improved data were used to study a suggested secular increase of the solar polar magnetic field over the last century. If true, this would have been an important (and mysterious) component of long-term space weather. We found that the polar field over the last quarter century does not show any anomalous long-term trend.

Recalibrated measurements of the strength of the chromospheric 1083 nm He I spectrum line were used to study a reported (Neugebauer et al. 2000, Ruzmaikin et al. 2001) 27.03 day recurrence period in heliospheric space weather activity. The same signal was clearly detected in our archived data. A method for measuring phase stability of a coherent signal over long time periods in the presence of noise was developed. We found that the phase and amplitude of the signal vary somewhat over the course of three solar cycles. Furthermore, we found that the signal originated from active regions in the northern hemisphere of the Sun. Using the sunspot number, we also found that the phase is not stable prior to the 1960s, nor is the 27.03 day period particularly evident in early data. This raises the distinct possibility that the phase-stable behavior in the latter part of the 20th century may just be a random event. This suggestion cannot be proven and the whole issue of clustering tendencies of solar activity in space and time needs more work as a potential aid in forecasting space weather.

In anticipation of SOLIS data, high cadence, albeit low-spatial resolution measurements of the line-of-sight component of the magnetic field of flaring active regions became available in limited amounts from the GONG project in mid 2000. These data have clearly shown sustained field changes of the order of tens of Gauss associated with large flares. Importantly, similar measurements from two other instruments observing the same events show the same changes. These consistent observations are a breakthrough in the study of solar activity. Unfortunately, with only one component of the field vector available, the physical interpretation of the observed changes is ambiguous. Vector observations from SOLIS and other instruments should greatly reduce this ambiguity. Much to our surprise, it was possible to see the magnetic field change of at least one flare in the average magnetic field of the entire solar disk. Most coronal mass ejections are associated with flares, but about 20% are not. One example of such a CME was studied but revealed no detectable field change.

Following recent trends in other areas of space physics, we developed a Web page that uses near real-time data and numerical models to determine the likelihood of geoeffective space weather events. Our effort uses magnetic field and chromospheric activity observations together with simple models based on traditional predictive lore in solar physics. The result is maps that show the location and probability of solar activity on a daily basis. It is intended to expand this activity when new and more frequent data become available from the SOLIS instruments in 2002. Such modeling is becoming a powerful technique for studying complex phenomena having either limited observational or theoretical foundations – certainly the case for solar activity. A recent example from our pilot Web page is shown in Figure 1.

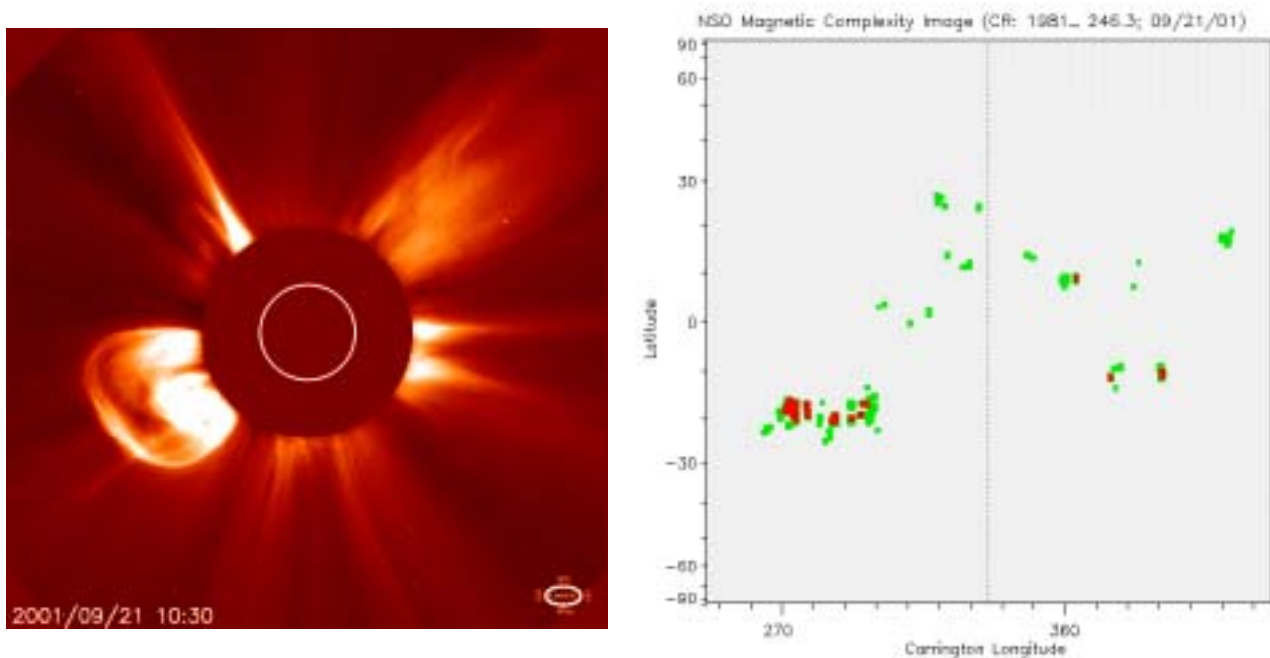


Figure 1. The left image shows the corona and a large coronal mass ejection in the lower left quadrant as observed by the LASCO instrument on board SOHO. The right image is a map of magnetic complexity derived for the same day using our data in a Lambert cylindrical projection. Green indicates moderate complexity and red a high degree of complexity. The active region in the lower left is indicated as having a high probability of major eruptions. This indeed proved to be the case, as seen in the left image and in other subsequent major activity.

In further preparation for SOLIS data, we have explored basic algorithms for reducing vector magnetic field measurements. Three types of quick-look reductions and two precise reduction methods have been examined. A decision about which ones to use will be made in the next few months.

Our real-time synoptic magnetic flux maps were used by a group at SAIC to predict the form of the corona at the time of the 21 June 2001 solar eclipse. The results were satisfactory, especially given the rapid changes of the solar magnetic field at the present maximum phase of solar activity. The synoptic data are also used regularly by groups at NOAA, NRL and at Irkutsk to predict solar wind speeds, interplanetary magnetic field at Earth, as well as the form of the corona close to the Sun.

A summer undergraduate student, Mr. T. Donaghy, studied whether changes associated with erupting prominences and CMEs could be detected in our daily chromospheric magnetograms. The results were marginal and ambiguous. It is clear that higher sensitivity and cadence observations from SOLIS are required to obtain credible results.

A long-term visitor to NSO, Dr. T. Sakurai, developed a method for use with SOLIS chromospheric magnetograms to help resolve a 180° ambiguity in the direction of the observed photospheric vector magnetic field.

IMPACT/APPLICATIONS

The improved maps that we produce allow far superior predictions of space weather events to be made compared with the older maps we have provided to the research and operational communities since 1973. The archive has been used to test new results in the literature with good effect. 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.

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/~narge/predictions.html>). Luhman 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. In addition to these specific users, the data are openly available on the Internet and are widely used.

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 now in the construction phase is underway at NSO. 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

Lockwood, M. and Stamper, R. 1999a, "Long-term drift of the coronal source magnetic flux and the total solar irradiance," *Geophys. Res. Let.*, 26, 2461.

Lockwood, M., Stamper, R., and Wild, M. N. 1999b, "A doubling of the Sun's coronal magnetic field during the past 100 years," *Nature*, 399, 437.

Lockwood, M., Stamper, R., Wild, M. N., Balogh, A., and Jones, G. 1999c, "Our changing Sun," *Astron. & Geophys.*, 40, 4.10.

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.

Stamper, R. Lockwood, M., Wild, M. N., and Clark, T. D. G. 1999, "Solar causes of the long term increase in geomagnetic activity," *J. Geophys. Res.*, 104, 28325.

PUBLICATIONS

Garcia, R. A., Regulo, C. A., Turck-Chieze, S., Bertello, L., Kosovichev, A. G., Brun, A. S., Couvidat, S., Henney, C. J., Ulrich, R. K., and Varadi, F. 2001, "Low-degree low-order solar p modes as seen by GOLF on board SOHO," *Solar Phys.*, 200, 361.

Donaghy, T. Q. and Harvey, J. W. 2000, "Filament channel magnetic field changes and prominence eruptions," *Bull. Amer. Astro. Soc.*, 31, 1531.

Harvey, J. W. 2001, "Search for photospheric magnetic field changes with flares and CMEs," *EOS*, 82(20), S302.

Henney, C. J. and Harvey, J. W. 2001, "New NSO solar surface activity maps," *EOS*, 82(20), S397.

Henney, C. J. and Harvey, J. W. 2001, "Analysis of the 27.03 day period found in synoptic data from NSO-Kitt Peak," *EOS*, 82(20), S397.

Hildner, E., Arge, N., Pizzo, V. J., and Harvey, J. W. 2000, "Data imply the solar magnetic field is not increasing," *EOS*, 81(48), F999.

Hildner, E., Arge, N., Pizzo, V. J., and Harvey, J. W. 2001, "Three solar cycles of non-increasing magnetic field," *EOS*, 82(20), S327.

Stagg, T., Gearen, M., Jacoby, S. H., Jones, H. P., Henney, C. J., and Hill, F. 2000, "Real research in the classroom – solar active longitudes," *Bull. Amer. Astro. Soc.*, 32, 1556.

Ulrich, R. K., Boumier, P., Robillot, J.-M., Garcia, R. A., Roca Cortes, T., and Henney, C. J. 2000, "Simulation of resonance scattering helioseismometer signals from spatially resolved images: Application to the GOLF instrument on SOHO," *Astron. and Astrophys.*, 364, 816.

Worden, J. R. and Harvey, J. 2000, "An evolving synoptic magnetic flux map: implications for the distribution of photospheric magnetic flux," *Solar Phys.*, 196, 247.