I. ABSTRACT

Improved Solar Optical Observing Network (ISOON) is an extremely important Air Force task in which a series of optical telescopes is to be positioned around the world to monitor solar magnetic eruptions directed toward the Earth, and even to predict them in advance. Magnetic eruptions can have deleterious effects on satellites, upper atmosphere communications and the North American power grid. Thus, it is critical to have the most reliable early warning system possible. ISOON is still some time from fruition.

At Big Bear Solar Observatory (BBSO), we have been studying space weather for several years. Here we propose to utilize two sets of unique real-time data from four observatories around the world to develop a much improved, expanded and more quantitative program of space weather prediction.

(1) We will use the data from our new, three-station Hα network (located at BBSO, Kanzelhöhe Solar Observatory in Austria, and Yunnan Observatory in China) to continuously monitor the whole sun with 1 arcsec pixel resolution and 1 minute cadence. This unique data set will enable us to provide real-time reports of all flux emergences, filament disappearances and flares - all with high resolution and cadence. Based on the detailed structure of the active regions and filaments, we will predict the probability of flaring in each particular region, and the probability of the eruption of filaments. Our software for data analysis will be available to the ISOON project, and our data will supplement and complement those which will come from ISOON.

(2) We will use combined high resolution vector magnetograph data from BBSO and Huairou Solar Observatory in China to monitor the magnetic structure of solar active regions almost continuously. Depending on the time of year, the night gap is between 4 and 8 hours for the combined data. Based on real time monitoring of the magnetic evolution and structures, we will make forecasts of solar flares. The quantitative parameters that we will develop, which will aid forecasts, include integrated magnetic shear, total and net vertical electrical currents in the target active regions. Both current and shear represent free energy stored in magnetic fields.

(3) We will carry out a statistical study of filament eruptions and flares, their underlying magnetic structure, the onset of Coronal Mass Ejections, interplanetary magnetic clouds and geomagnetic storms. The results from this statistical study will provide better tools for predicting solar activity and geomagnetic storms. Filament eruptions and flares will be compared with magnetic field data observed by ACE and Wind, and with geomagnetic indices.

(4) We will upgrade the daily forecasts we now place on our web page to include the above mentioned forecasting and monitoring information: curves of electric currents and shears of the most important active regions; a list of all filaments and filament disappearances; a list of new flux emergences, activity reports and warnings from each of the three stations of our network. We will also provide data and forecasts to ISOON.

(5) Finally, we will compare our observational results with some theoretical models to advance our understanding of the physics of CMEs.

All the fruits of our labors will be available to the ISOON project.

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II. STATEMENT OF OBJECTIVES

The main objective of this project is to utilize two unique sets of real-time data from four observatories around the world to develop a much improved, expanded and more quantitative program of space weather prediction.

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III. BACKGROUND

1. Overview

Big Bear Solar Observatory (BBSO) is located in a mountain lake with 300+ sunny days a year, and superb seeing conditions. BBSO is the largest university-based observatory in the United States, possibly the world. It carries out as extensive a program of solar observations as any observatory.

New Jersey Institute of Technology (NJIT) took over the operation of BBSO on July 1, 1997. Over the last three years, we have significantly improved the observatory by largely solving the dome seeing problems, and building many new intruments which allow us to take advantage of the improved seeing.

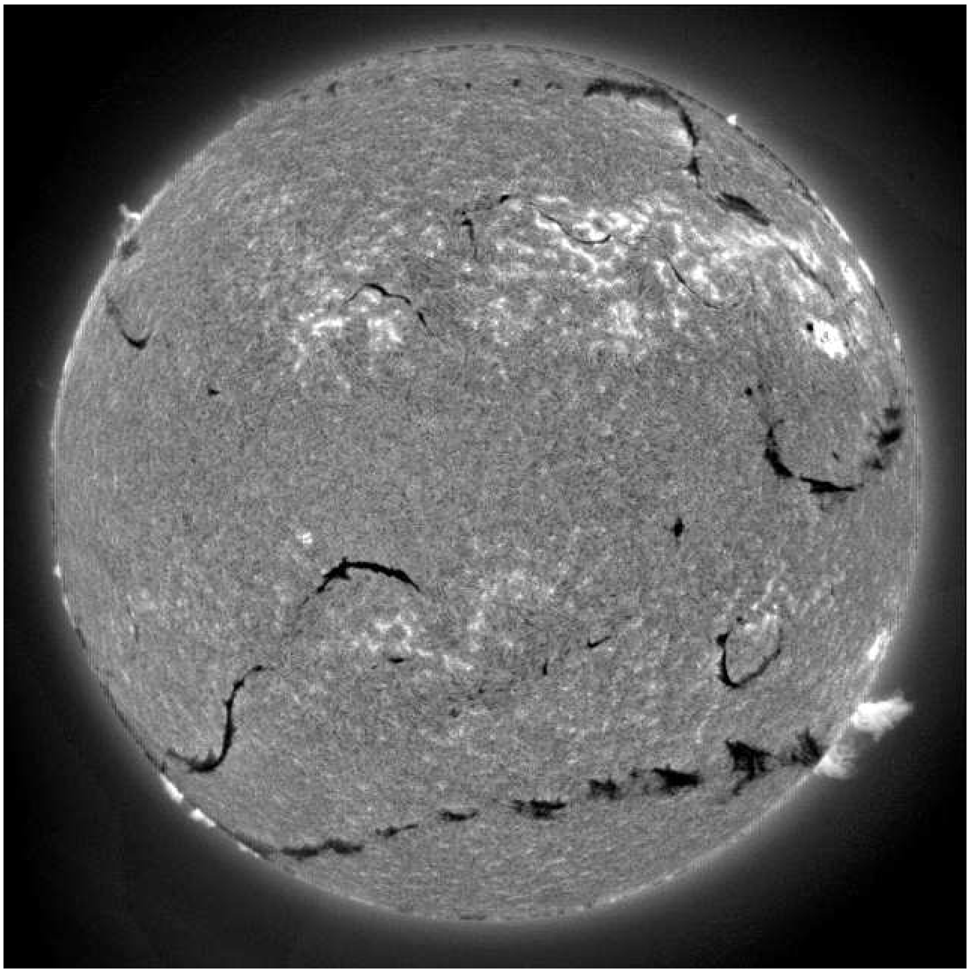


Fig. 1. Hα full disk image from January 30, 1999, with a pixel resolution of $1''$. It is flat field corrected and has limb darkening removed. Such images are obtained every minute from sunrise to sunset every day at BBSO.

We have written and implemented software which significantly improves our synoptic data (Denker et al., 1999). These data are critical in efforts to detect the onset of solar magnetic storms, and to understand their nature. In Figure 1, we show a typical processed Hα image. Such images clearly show filaments which are critical in studying flares and CMEs. However, we only have partial coverage from BBSO. With that in mind, we have set up a three-station Hα network, to continuously monitor space weather. Our three stations are located at BBSO, Kanzelhöhe Solar Observatory in Austria, and Yunnan Observatory in China. Each station has a 2K$\times$2K camera. We will continuously monitor the whole sun with 1 arcsec pixel resolution and 1 minute cadence. This unique data set will enable us to provide real-time reports of all flux emergences, filament disappearances and flares - all with high resolution and cadence. Based on the detailed structure of the active regions and filaments, we will predict the probability of flaring in each particular region and the probability of the eruption of filaments. The first raw images from the three stations in the same 24 hour period are shown in Figure 2.

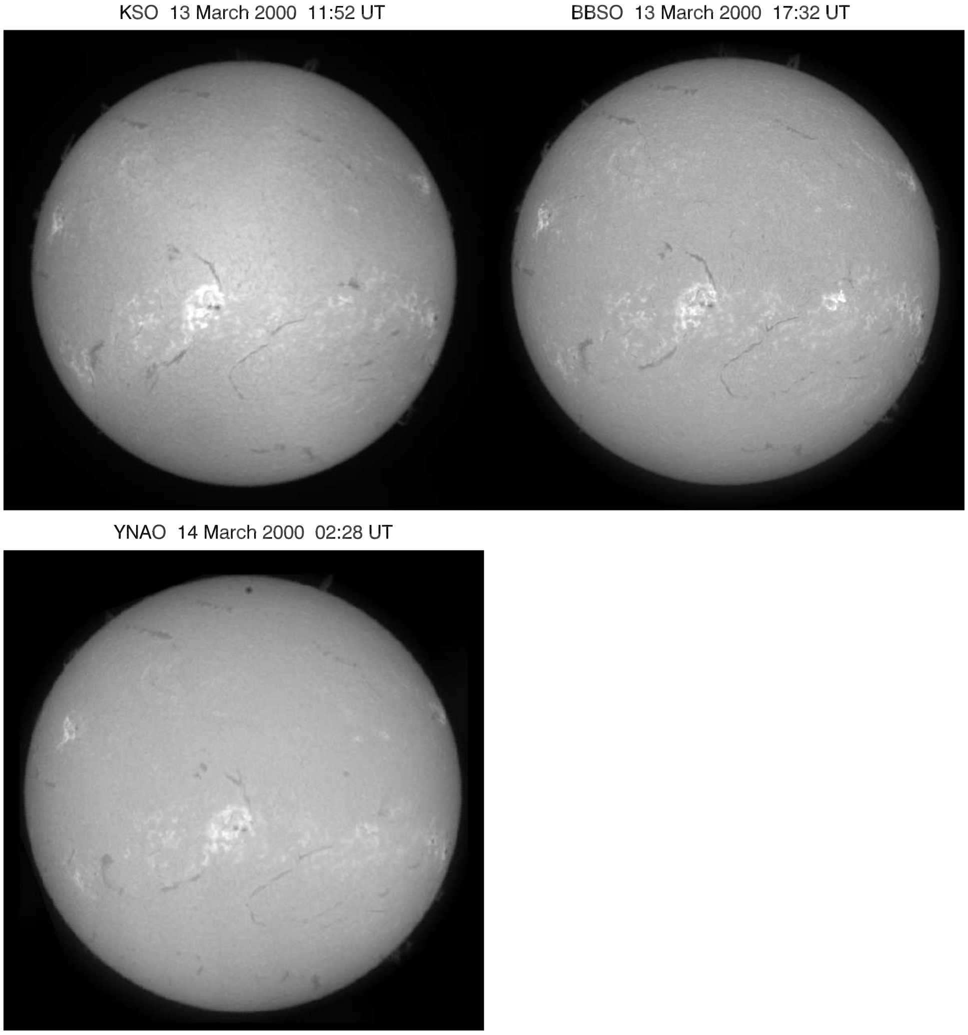


Fig. 2. Raw Hα full disk images from March 14-15, 2000. From left to right, KSO on 13 March 2000 at 11:52 UT , BBSO on 13 March 2000 at 17:32 UT and YNO on 14 March 2000 at 02:28 UT. Each has a pixel resolution of $1''$. The Yunnan image is not flat-fielded because a re-imaging lens must be replaced before we can apply the flat-field correction. After that, we expect images of the same quality as Figure 1 from all three sites.

In addition, we have written and implemented pattern recognition software that is especially useful in space weather studies. In particular, space weather storms are associated with filament eruptions, and detection of them is of special use in space weather forecasting. We have developed a software package to automatically detect solar filament disappearances. This software is now in operation, and a result of it is illustrated in Figure 3. In addition, we have upgraded BBSO synoptic Hα observations, and have carried out statistical studies of filament disappearances. We have also improved our forecasting of solar activity.

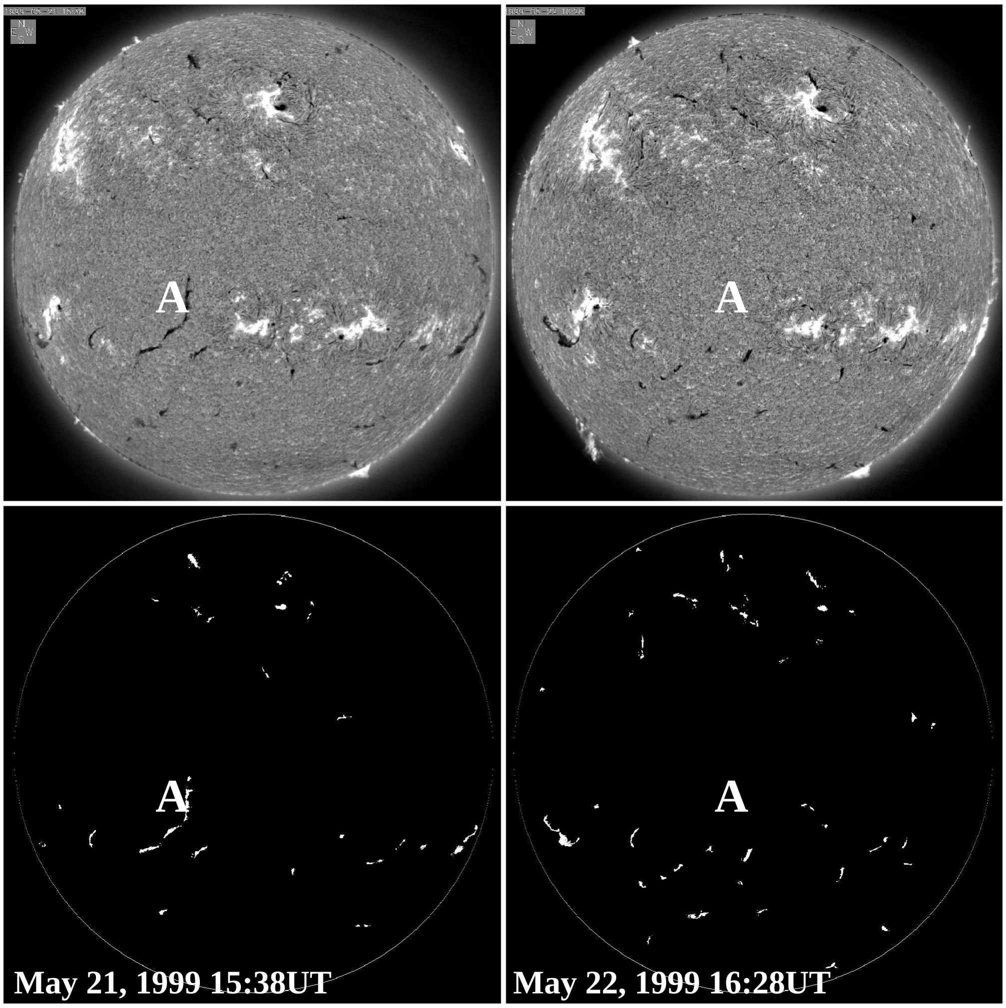


Fig. 3. Images that demonstrate our detection of a filament disappearance: The top row shows two Hα images obtained on May 21 and 22, 1999, respectively; the bottom row shows filaments detected by our program. A big filament marked by "A" clearly disappeared, and was just as clearly detected by our program.

In addition, space weather prediction requires continuous monitoring of the solar surface with high resolution and high cadence. Especially, the vector magnetic structure of important active regions needs to be continuously monitored. We have a unique capability to do this, as described below. We will use the almost continuous vector magnetograms from BBSO and

Huairou Solar Observatory (HSO) in China, and continuous high resolution Hα full-disk data from our three-station Hα network.

2.Results from Earlier AFOSR Support

For several years, the New Jersey Institute of Technology (NJIT) operated an observing program at the National Solar Observatory (NSO) in Sunspot, New Mexico. This program largely ended in 1997, when NJIT acquired BBSO. Coincidentally, our AFOSR support ended at about that time. Here, we are seeking new AFOSR funding for a different kind of work than we did earlier under AFOSR support. Still, it is worth briefly reviewing some of the outcomes of that earlier work.

AFOSR supported three postdocs at NJIT. The Air Force has directly benefited from the work of our postdoctoral associates, even after they left the NJIT group. Dr. Louis Strous was our last postdoctoral associate supported by AFOSR. After he left our group, he took a position working with Dr. George Simon (AFGL/PHS) in Sunspot, New Mexico. Dr. Strous now works in Dr. Alan Title's lab at Lockheed. Dr. Thomas Rimmele preceded Dr. Strous. Dr. Rimmele is now a tenured Associate Astronomer at the National Solar Observatory. Dr. Rimmele still works closely with the Air Force group in Sunspot. Dr. Rimmele was preceded by Dr. Sergio Restaino. Dr. Restaino is now an Air Force Senior Research Associate at Kirtland Air Force Base in New Mexico.

We developed an IR camera system in cooperation with other faculty members at NJIT. The system is used to observe at BBSO. This work was partially supported by an AASRT grant (AFOSR-95-0368) to support the studies of Tom Spirock (NJIT Ph.D. student). The first step in this IR work was to use the PtSi/Si camera that was invented and developed by the late Prof. Walter Kosonocky of the ECE department of NJIT. The project has been expanded by using the new InGaAs camera, which NJIT also played an important role in developing. The InGaAs camera has a much higher quantum efficiency and uniformity. *Recently, we obtained a DURIP award in the amount of \$181K from AFOSR, to develop a next generation IR imaging system– combining a Fabry-Perot filter with a Lyot prefilter to obtain a clean and narrow bandpass. The project is well underway and will be finished in time to greatly aid the field measurements proposed here.*

Under AFOSR support, we determined the source of solar oscillations. Earthquakes shake the earth allowing one to seismically sound our planet's interior. In an analogous way, sunquakes enable a sounding of the solar interior. The two kinds of quakes are also alike in that both are near-surface phenomena. However, sunquakes are occurring somewhere on the sun all the time, so that energy is being continuously fed to the sun's resonant modes, implying that in principle, one could continuously sound the sun. From the global solar seismic data we have learned a great deal about the sun's interior. However, the precise origin of individual sunquakes had been shrouded in mystery, unlike the origin of earthquakes.

It is generally agreed that the sun's global modes of vibration are excited near the sun's surface as a part of the process in which convection stops being an efficient mechanism of energy transport. Until recently, it was widely believed that this deceleration of the upgoing granules induced a steady drumming that fed the resonant acoustic modes. However, in Rimmele, et al. (1995), we observed that there are seismic events which we associated with the excitation of solar oscillations. These events originate in the dark intergranular lanes. Furthermore, we observed that the seismic events were preceded by a further darkening of an already dark lane, and on the temporal leading edge of the seismic event there is a still further, and more abrupt darkening. From this, we suggested that the excitation of the resonant modes was caused by the occasional, catastrophic cooling and collapse of the lanes. In Goode and Strous (1996), we observed that the presence of even a weak magnetic field tends to suppress the seismic events. For weak fields, the suppression is presumably due to the nearly vertical fibril fields disrupting horizontal flows. However, in all of these works we were unable to show a causal link between the seismic events and the resonant modes of vibrations of the sun. The causal link was shown by Goode, et al. (1998). In Goode, et al. (1998), we observed sunquake energy being pumped into the resonant modes of vibration of the sun. We reported the physical properties of the events, and related them to theories of the excitation of solar oscillations. In the paper, we also discussed the local seismic potential of these events.

The resonant or normal modes of vibration of the sun are compressional waves. These so-called p-modes have been long known to have a period of about five minutes, and in the solar photosphere they are evanescent vertically, and traveling horizontally. Using the seismic sounding of the Sun's interior by these waves (detected in the photosphere) is called helioseismology. Our current understanding of the internal structure of the sun was reviewed in a paper supported by AFOSR, Goode (1995).

IV. TECHNICAL PROPOSAL

1. Background

The sun is rapidly approaching activity maximum. Solar activity related geomagnetic storms can have adverse effects on our lives, ranging from power grid failures, to the loss of telecommunications, to damaging satellites. The accurate prediction of solar activity and geomagnetic storms is a significant scientific problem, and is critically important to prevent possible damage caused by these effects. In this context, we know that the most important phenomenon associated with space weather is the Coronal Mass Ejection (CME).

A CME is due to a large scale rearrangement of the solar magnetic structure which can provide a geo-effective solar wind structure. Each CME may carry away a mass of up to 10^{13} kg and release up to 10^{25} J of energy from coronal magnetic fields (Harrison, 1993 and 1995). Following their discovery, CMEs were soon found to be correlated with the occurrence of geomagnetic storms. CMEs are easily observed at the solar limb, where they are seen against a dark background. However, the earth-directed, disk CMEs are much harder to detect – although they are the ones that have the important geomagnetic effects. Therefore, detecting CMEs' manifestation on the solar surface will provide important clues to understanding earth-directed CMEs themselves. Establishing the correlation among the occurrence of CMEs and some other solar surface phenomena, such as filament eruptions and flares, is a long-standing problem in solar physics. If firm relationships are established, the correlated solar surface phenomena can be used as a proxy for the occurrence of earth-directed CMEs.

CMEs have been studied using a number of coronagraphs since the 1970s, e.g. Skylab and Solar Maximum Mission (SMM). The launch of a new generation coronagraph – the Large Angle Spectroscopic Coronagraph (LASCO) on board SOHO– has provided the most advanced tool studying the dynamics of coronal structure (Brueckner et al., 1995). With its improved sensitivity and a field of view covering a sun-centered region of 2 to 32 solar radii, LASCO has yielded observations of solar eruptions affecting the corona on a global scale. One of our ultimate goals is to establish the correlation between solar disk events (such as filament eruptions and flares) and geomagnetic disturbances. To do this, we will directly compare solar disk events and disturbances (in the form of magnetic clouds) observed by ACE and Wind.

Predicting solar activity and geomagnetic storms is a very important, but difficult task. To our knowledge, there are three institutes in the US that provide solar activity predictions regularly: Space Environment Lab (SEC) of NOAA, BBSO and Helio-Synoptic, Inc. We believe that the next level of accuracy in prediction should incorporate physical parameters into the effort. This is the central task of the research proposed here.

In addition, space weather prediction requires continuous monitoring of the solar surface with high resolution and high cadence. Especially, the vector magnetic structure of important active regions needs to be continuously monitored. We have a unique capability to do this, as described below. We will use the almost continuous vector magnetograms from BBSO and Huairou Solar Observatory (HSO) in China, and continuous high resolution Hα full-disk data from our three-station Hα network.

2. Description of Magnetograph Observations

BBSO and Huairou Solar Observing Station (HSO) of Beijing Observatory in China pioneered coordinated round-the-clock magnetograph observations. Under our NSF-INT supported US-China collaborative research program, we have had very productive years on several projects, centered on studies of vector magnetic fields.

The vector magnetograph data discussed here are obtained with the BBSO Digital Magnetograph (DMG) system, and the videomagnetograph (VMG) at HSO. Recently, we completed the critical steps for the new BBSO DMG – replacing the optical train with one having no moving parts, and replacing the video camera with a 1K$\times$1K 12-bit SMD digital camera. We anticipate that this Lyot filter based DMG will be complemented by a Fabry-Pérot based DMG by Fall 2000.

In the first paper reporting BBSO vector magnetograph observations, Cacciani, Varsik and Zirin (1989) described the BBSO system for measuring the vector field using a magneto-optical filter (MOF) and a video camera. A Lyot filter soon replaced the MOF. The system uses a narrow photospheric spectral line, Ca I 6103 Å line ($g_L = 2.0$). The center of the bandpass is set at $\Delta\lambda = 70$ mÅ on the blue side of the spectral line. The temporal and spatial resolution of BBSO vector magnetograms depends on the number of individual frames that are combined to produce them. They have a time resolution of about 1 minute, and a spatial resolution of 1-2$''$. The calibration of the system was described by Varsik (1995).

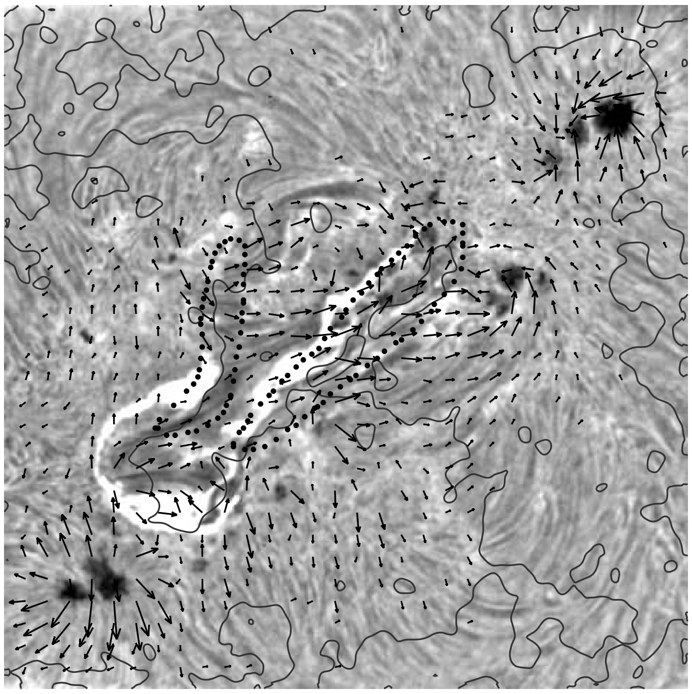
An earlier version of our new generation digital magnetograph system at BBSO was described by Wang et al. (1998). The long existing system was upgraded to a 12-bit 256 by 256

Dalsa digital camera, where images were put in computer memory quickly, and image alignment and frame selection could be performed before constructing the magnetograms. Therefore, the spatial resolution and sensitivity have been markedly improved to $1''$ and 0.5 G, respectively. We further upgraded the system to a 1K$\times$1K SMD camera, and introduced a pair of nematic liquid crystals instead of a filter wheel. A second, further improved version of the DMG will use a Fabry-Pérot filter so that 3 to 20 line positions can be scanned. For each spatial position, a spectral profile can be constructed and fit to derive much more accurate magnetograms. We will be extremely careful and cautious in phasing in the Fabry-Pérot system. For this reason, BBSO will have two DMG systems (Lyot and Fabry-Pérot) for a long period of time. Two distinct systems will allow careful inter-calibration between the Lyot and Fabry-Pérot systems, and will provide significant flexibility in the observing setup. In fact, the flexibility may lead us to keep both systems operational. As an example, when the Fabry-Pérot system is used to obtain high cadence Hα flare observations, the Lyot system still can produce magnetograms. We can achieve most of our scientific objectives with the existing Lyot DMG. The planned Fabry-Pérot system adds capability. Figure 4 shows a sample digital vector magnetogram. The background is an Hα image during a M2.6 flare of October 20, 1999. The cross-talk and instrument polarization have been minimized in the data with our new system.

As we mentioned earlier, we have just obtained a DURIP award to develop a filter based IR magnetograph by combining a Fabry-Pérot and Lyot filter. For us, DURIP support opens a new and powerful avenue of studying space weather. This system will be the first in the world using a narrow band (2.8 Å) Lyot prefilter. In this context, narrow means narrower than the free spectral range of the Fabry-Pérot. This system will have the same optical set-up as the visible light system. Before this IR system, the lack of a narrowband IR prefilter has forced others to more complicated and difficult systems (like ones with multiple Fabry-Pérots). IR polarimetry, once the technology is in place, has several advantages over visible light field measurements. First, we see deeper into the sun because of the opacity minimum near 1.6 μ. Second, the Zeeman splitting increases as the square of the wavelength, enabling a more precise measurement of the field than with visible light. Third, the effect of terrestrial atmospheric turbulence or "seeing" decreases with increasing wavelength ($\propto \lambda^{\frac{6}{5}}$), so that we have better images. In sum, we will measure magnetic fields more accurately, which is critical in testing any flare related models.

The VMG system at HSO was developed by Ai (1987). It is very similar to the old BBSO VMG system, except that it uses the Fe I 5324 Å line ($g_L = 1.5$), and sets the filter at $\Delta\lambda = 75$ mÅ from line center. The bandpass of the birefringent filter is 1/8 Å. Like the BBSO magnetograms, the temporal and spatial resolution of its magnetograms depend on the number of frames that are added. We include HSO magnetograms to take advantage of the time difference between China and the US, so that we can follow active regions nearly continuously (with 4 to 8 hour night gaps, depending on the season). This system has been used many times for coordinated, round-the-clock observations with BBSO (Wang et al., 1989). We understand that when the BBSO system is improved by a Fabry-Pérot, the data quality between BBSO and HSO will not be the same, and we will take this into account when interpreting the combined data.

M 2.3 Flare on October 26, 1999



FOV 174"x174"

Fig. 4. A vector magnetogram from October 26, 1999. The background is the Hα image during the M2.6 flare. Arrows mark the transverse fields, and the lines are neutral lines of line-of-sight magnetic fields. Strong magnetic shear is clearly visible in the areas near flare ribbons, as circled by dotted lines.

For the Lyot DMG at BBSO and the VMG system at HSO, each data set consists of narrow-band images (filtergrams) in each of the four Stokes parameters: I, the direct intensity image; V, the difference between left and right circularly-polarized images; U, the difference between two orthogonal linearly-polarized images in a certain azimuthal direction; and Q, the same as U, but with a 45° change in the azimuthal angle. V provides the signal for the longitudinal field, Q and U for the transverse field. The amplitude of the transverse field is determined by:

$$B_T = C \times (Q^2 + U^2)^{\frac{1}{4}}, \tag{1}$$

where C is a calibration constant, and the field's azimuthal angle is determined by:

$$\theta = \frac{1}{2}\arctan\left(\frac{U}{Q}\right). \tag{2}$$

When the Fabry-Pérot DMG system at BBSO is completed, for each spatial point we will have up to 20 spectral points. So Stokes Q, U, V and I profiles will be obtained and inverted to produce more accurate measurements of vector fields. We can avoid Zeeman saturation in areas of strong field, and obtain the filling factor in addition to the magnetic flux density. A set of Stokes images, covering the wavelength range of interest, will take less than 5 minutes to scan.

3. Description of Global High Resolution Hα Network

Based on our successful experience in making high resolution full disk Hα observations at BBSO, and the urgent need to monitor the evolution of the solar chromosphere continuously during the solar maximum, we have deployed a network for Hα full disk observations utilizing existing facilities at BBSO in California, Kanzelhöhe Solar Observatory (KSO) in Austria, and Yunnan Observatory (YO) in China. All these observatories have over 300 sunny days a year, good seeing conditions, adequate observing staffs and well-established Hα telescope systems. 2K$\times$2K digital camera will replace the film systems in KSO and YO. The upgrade in BBSO is a new 2K$\times$2K digital camera with 14 bits instead of 8. We will also provide KSO and YO the data reduction software and analysis techniques already developed at BBSO, which will significantly improve the data quality, while providing a consistent and linked data set. KSO and YO will provide the manpower required to collect and reduce their data. With this network, we can monitor solar chromospheric activity with $1''$ pixel resolution and one minute cadence round-the-clock for most of the year, with the data quality shown in Figure 1. Three systems have been built at BBSO, and are deployed. The three observatories are in ready e-mail contact for prompt forecasting and reporting. Detailed exchange of full data sets will be done on a weekly basis.

4. Projects

4.1 Quantitative Flare Prediction Parameters

To accurately predict solar flares, some quantitative parameters need to be established in order to understand flares better, and to make more objective predictions.

We will provide quantitative parameters to elucidate the non-potential properties of active regions. Based on analyses of vector magnetograms, one may establish several parameters to describe the degree of deviation from a pure potential field which is the minimum energy configuration. Initially, we plan to use two parameters, integrated magnetic shear and integrated vertical electric currents, as the indices for flare prediction. Some other parameters may be used when we have a better understanding of magnetic structures and their parameters. Although a relationship between magnetic shear and the onset of flares has been somehow established (Hagyard et al. 1984, 1990; Falconer, 1999), a quantitative description of such a relationship and the forecasting parameters needs to be established $--$ based on a much larger number of events which will be observed by BBSO and HSO.

(a) Integrated Shear

The term 'magnetic shear' was first introduced by the NASA/MSFC group, when they found that the shear angle (the angle between the observed field vector and the potential field calculated from the longitudinal field), the transverse field strength and the length of the sheared neutral lines are closely associated with the probability of flares.

At BBSO, we defined the new term 'shear' as the product of the shear angle and the measured transverse field strength (Wang, 1992). This term was introduced to describe the magnetic shear in active regions. We introduced this new definition of shear, instead of the pure shear angle defined by Hagyard et al. (1984, 1990), because (1) the strong transverse field regions contribute more significantly to the free magnetic energy of shear, and (2) the measurement errors in the azimuthal angles for strong field regions are significantly reduced. Since every point has a well-defined magnetic shear, two dimensional shear maps can be constructed. A time sequence of shear maps will be compiled to visualize the development of magnetic shears. Such data sets have been made and studied for several flares (Wang, 1992). The shear integrated over some particular active region will be called "integrated shear". We will monitor this shear parameter for each active region and set a threshold for triggering a warning of possible, impending major flares.

(b) Integrated Vertical Currents

The vertical current density is calculated by

$$J_z = \frac{dB_y}{dx} - \frac{dB_x}{dy}, \tag{3}$$

which is another important way to quantitatively describe the degree of non-potentiality in an active region. Since only one layer of the magnetic field can be obtained, only the vertical component of the electric current can be derived directly. The analyses of vector magnetograph data from Mees Solar Observatory (MSO) yielded important results about the relationship between the vertical currents and electron precipitation of flares (Canfield et al., 1993; Leka et al., 1993). They found that the precipitation of electrons is concentrated at the borders of strong, vertical current regions – the two sites are not co-spatial. At BBSO, Li et al. (1999) found an important link between the occurrence of major flares and the appearance of new currents brought up by flux emergence. More recently, Falconer (1999) found a close connection between the occurrence of major flares and net currents, and the length of the sheared neutral line in active regions. We will do a real-time monitoring of the integrated net and total current in active regions, and establish a threshold that would trigger the warnings of solar flares.

There are two major obstacles to producing vector magnetograms, and the resulting shear and vertical current maps: (1) the 180° ambiguity in determining the direction of the transverse fields and (2) the transformation of the magnetic fields in the observed plane to the true heliographic coordinate system. For (1), many methods have been developed, and we have obtained software to implement two of them (Metcalf, 1994; Wang, H. N. and Lin, 1993). For (2), our strategy is to first select data sets containing flares that occur near disk center, where projection effects are not important. It is clear that disk events play a more important role in space weather effects, anyway. For the remaining events, we will apply the method developed by Gary and Hagyard (1990) at MSFC to do the full-scale transformation.

Our shear and current curves will be updated hourly when BBSO or HSO is observing, and will be posted on the BBSO web site. When we are following particularly interesting regions, these curves will be updated every few minutes. We only need to transmit calculated parameters to BBSO from HSO. Even though the internet connection speed in HSO is slow, the parameters can be updated in near real-time. At this time, we do not have an exact projection about the threshold values for triggering a warning. As this project progresses, many events will be observed and studied, and reasonable thresholds will be set based on the statistical results.

The magnetograms obtained from our IR system will help the calibration of our visible system, and will produce more accurate measurement with lower cadence. The more accurate magnetograms will be critical in constructing current and shear maps.

4.2 Monitoring of Emergence Flux Regions (EFR), Flares and Filament Eruptions

EFRs have two known effects in triggering solar activity. Tang and Wang (1993) found that major flares tend to be associated with new flux emergence. Feynman and Martin (1995) found that filament eruptions are likely to be triggered by EFRs. The underlying physics for these two observations is straightforward – an unstable magnetic configuration can be sharply perturbed by new flux emergence. So, monitoring of new flux emergence is very important in tracking solar activity. EFRs can be monitored by full disk magnetograms; however, our full disk Hα network observations will be able to provide good detection, based on the appearance of arch-filament systems. Based on our experience, arch-filaments and the brightenings associated with them, appear even before new flux is noticed in the magnetograms. EFRs will be reported on our web site in real-time. SOHO/MDI and GONG full disk magnetograph data will be used to confirm the new flux emergences.

Flares and filament disappearances can occur anywhere, and at any time, on the solar disk. High resolution, high cadence solar images with 24 hour coverage will certainly be essential to catch all flares on the visible disk of the Sun. High spatial resolution and cadence will also allow a detailed description of the evolution of flares, as well as their associated active region(s). This is the core scientific objective of our Hα network.

Until now, Hα full disk images depicting solar flares were normally saturated because the exposure time was set to a constant value, and optimized to yield high contrast images of the quiet sun. The bright flaring regions were therefore over-exposed. Since the Hα intensity gives a minimum temperature for the flaring region, it is important to obtain proper photometric data, especially when the full disk brightness is suddenly rising during a flare. While two of the cameras in our network have a 14 bit dynamic range, one has only an 8 bit range. But an automatic software control has been implemented in the camera control software, changing cadence and exposure time, which permits an accurate evaluation of flare brightness even for this camera. This significantly improves the photometric measurements. As an example, the temporal evolution of an M7 flare is shown in Figure 5 during its maximum phase from 16:31 to 16:51 UT on 29 April 1998 to demonstrate the capability of flare monitoring.

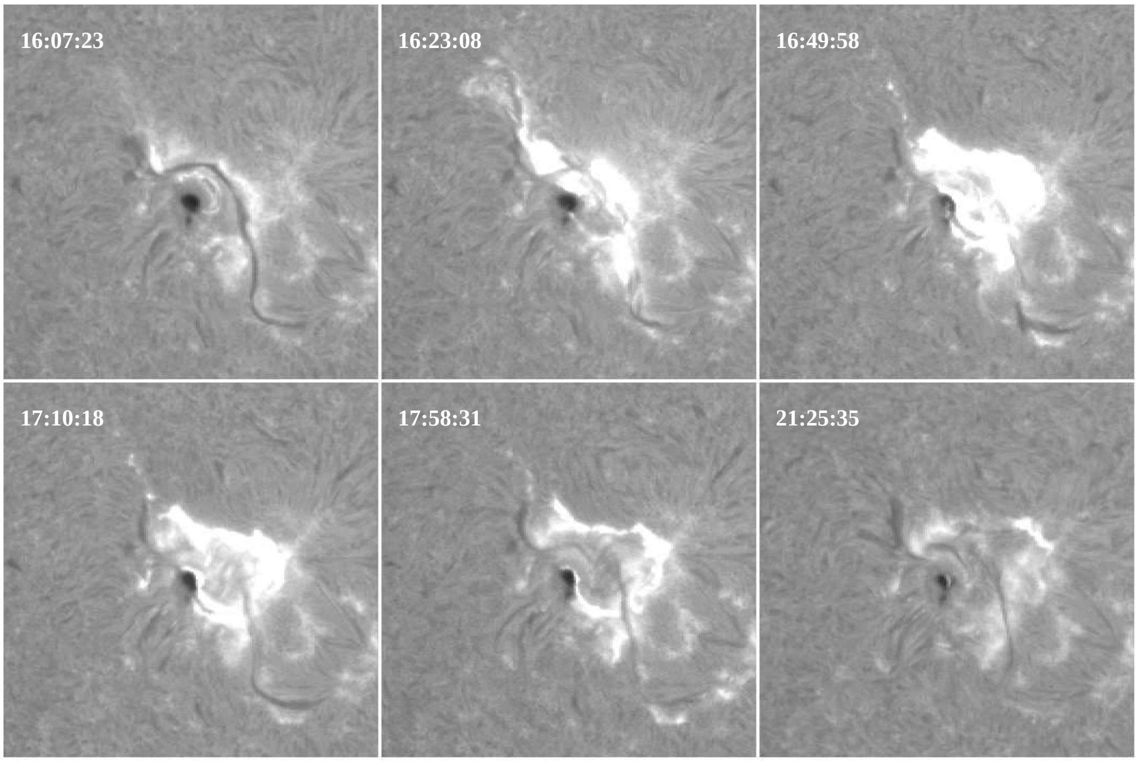


Fig. 5. Temporal evolution of an M7 flare and eruption of a filament in the active region NOAA 8210 observed on 29 April 1998. The field of view of the individual frames amounts to $400'' \times 400''$. The images are from BBSO full disk data.

We anticipate that our duty cycle of our Hα network will be over 80%. So most flares and filament disappearances on the disk will be detected by our automatic program. Their time of occurrence, location and size will be posted on the web page in real-time.

4.3 BBSO Activity Reports and Warnings

Based on our observations and real-time monitoring of solar magnetic fields and activity, we propose to develop an improved activity report and warning system.

Certain parameters are necessary to carry out the predictions. The primary input is very good records of the sun – high-resolution images which show the configuration of the magnetic field, and the existence of stressed fields which appear to be closely connected to the occurrence of flares. Once one observes the stressed fields, it is a fairly easy matter to predict flares and to issue warnings. However, the warnings have only a one- or two-day horizon, since we cannot predict the time at which a flare will occur. We believe the best, and most important, direction for investigation is to study the emerging flux regions and develop criteria for whether or not they will grow to great size, or to the level of complexity which will produce flares. This will lead to longer term and more accurate forecasts.

The improved program will have quantitative parameters to guide us, while we will also rely on our experience. In addition, we will have staff members on duty 24 hours. For this, we have a commitment from Yunnan Observatory. They will use the Hα data obtained on-site and the vector magnetograms from HSO to guide forecasting. Similarly, the staff at KSO will be on duty in their time zone, and their predictions will be mainly based on their Hα observations.

Each of the three stations will issue an activity report once a day. If we believe that a major event is imminent, any station will issue a warning by e-mail during its local day time.

4.4 Statistical Studies of Eruptive Filaments, Flares, CMEs, and Geomagnetic Disturbances

We understand that the ultimate goal of space weather prediction is to predict geomagnetic disturbances at or near 1 AU. This is the most difficult part. We do not intend to make predictions of geomagnetic storms directly. We propose to carry out statistical studies to understand physical connections between solar surface activity and geomagnetic disturbances, to enhance our knowledge about the prediction of geomagnetic disturbances.

Large geomagnetic storms are usually caused by a structure in the solar wind having specific features–a long duration of strong southward interplanetary magnetic fields (IMF) impinging on the Earth's magnetosphere. There are two possible stages at which to monitor geomagnetic storms: (1) to observe magnetic field fluctuations by a satellite, such as ACE or Wind. This may give a few hours of advance warning as the disturbance travels from the satellite to earth. However, the prediction is still not very certain. (2) to measure the Dst index (degree of equatorial magnetic field deviation, by ground stations). This gives a "nowcast", but no advance warning can be given.

Our objective is to obtain statistical results on filament eruptions and geomagnetic disturbances based on hundreds of events. A correlation between filament eruptions and magnetic clouds has been suggested (e.g. Bothmer and Schwenn, 1994; Burlaga et al., 1997; Wilson and Hildner, 1986; Marubashi, 1997). In particular, Marubashi (1997) found a good correlation between the structure of erupted solar filaments and the structure of interplanetary magnetic clouds. With a much improved data base, we will search for possible relationships between filament eruptions and geomagnetic disturbances reported by ACE and Wind in the form of in-situ magnetic field fluctuations. We will also directly study filament eruptions and the Dst index. We plan to plot the Dst index, the Bx, By and Bz (in-situ magnetic field components measured by Wind and ACE) as a function of time, then mark the filament eruption events in the curves. We are especially interested in the time delay between solar surface phenomenon and geomagnetic disturbances. This delay will be tabulated for statistical study. Quantitative correlation coefficients will be established to aid future forecasts.

4.5 Comparison with Models

There are several models that have been put forward to describe the process of filament eruption to eventual geomagnetic storms. As an example, we will initially examine the model developed by Chen (1996, 1997) which assumes that the events are triggered by emerging flux ropes, and the model developed by Gibson and Low (1998), which describes CMEs as 3-D MHD expulsion.

For Chen's model, as a working hypothesis, we will use the length of the neutral line underlying a filament as a proxy for the footpoint separation, and the flux rope itself lies above the neutral line. This is consistent with certain theoretical considerations (Chen and Garren 1993; Low and Hundhausen 1995; Chen 1996).

Chen's model proposes that new flux emergences trigger CMEs. We have found supporting evidence in our observations. Feynman and Martin (1995) have previously reported this connection, as well. Wang and Sheeley (1999) demonstrated that prominences and filaments erupt preferentially in the vicinity of emerging magnetic flux. We propose to work on this subject, but with many more events. Although the emerging azimuthal flux may be difficult to determine, the azimuthal magnetic field component in the photosphere near the footpoints can be computed as a function of time during eruption (Chen 1996). For impulsive eruptions, the azimuthal field may increase by 30-50% for a few tens of minutes. The theory predicts that the more impulsive an eruption is, the greater the percentage variation is. The measured azimuthal magnetic field can be related to the emerging azimuthal flux, providing the second input parameter of the model. Note that the emerging azimuthal flux of the flux rope as a trigger is a new feature, and our high-cadence vector magnetograph observations can test this aspect of the model for selected active region filament eruptions.

In Chen's CME model (1996, 1997), the helicity of the erupting filaments determines their speed of eruption. Helicity in a filament is defined as number of turns per unit length, and its shear is defined as the ratio of the width to the length of its S-shape (the "sigmoid" configuration, Canfield et al. 1999). Chirality describes the handedness of filaments (Martin, 1998). Our Hα network's 2K$\times$2K full-disk movies cover all the filaments, with $1''$ pixel resolution, which can resolve the structure of the larger filaments. Higher resolution Hα observations with BBSO's 65 cm telescope on selected targets can regularly achieve $0.5''$ resolution. We will carefully select the regions for high resolution study. We will test Chen's predictions for magnetic structure at 1 AU based on the chirality and helicity of erupted filaments as initial conditions.

The model output for CMEs near the sun consists of the height-time curves for the leading and trailing edges and the aspect ratio, which is the ratio of the height of a CME to its transverse width. The above quantities are directly comparable to coronagraph data, if the eruption is from the disk center. The test of such a model requires an accurate determination of the onset of eruption. Continuous Hα monitoring at our three stations will provide an ideal setup to obtain the onset time and location of an eruption which causes a CME. We will identify the times of surface eruptions and corresponding magnetic disturbances at 1AU to test the CME speed predicted in Chen's model.

For the Gibson and Low model, one requires large scale flows to twist magnetic ropes. However, when a CME erupts, there will be no sudden change in the photospheric magnetic configuration. The large scale flows are persistent flows, lasting for days. Such a shear flow, if it exists, will be detected by our 24-hour, high resolution observations from the Hα network, using local correlation tracking.

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BIOGRAPHICAL SKETCHES

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VI. BUDGET

The proposed annual budgets include two months summer salary for Goode. NJIT will also match with 1/4 of Goode's AY time to free him to do the needed scientific work during the academic year. The annual budget also includes one month of summer salary for Wang.

Each annual budget also is for one-half a year of work by Randy Fear to gather and organize the data. It also includes support for a postdoc to write software to reduce the data. The software wil be provided to the ISOON project at no charge. Goode, Wang and the postdoc will do the proposed scientific work. We will keep the ISOON team posted on our progress.

The travel budget includes travel money for a trip for one person to a national meeting each year.

Goode is a professor at the New Jersey Institute of Technology (NJIT). He is the PI on grants from NASA and NSF-ATM which are primarily to support BBSO.