

Figure 1: Sample of the thumbnail page. Each image is linked to a larger but still reduced size version of the image.

1 Results from Prior NSF Support

1.1 Results from NSF Support on Grant ATM-0236682 – Digitization of Ca K image in the Mt. Wilson Archive

Total Amount	Start Date	End Date
\$1,977,282	March 15, 2003	Feb. 29, 2008

This project will provide a digital database of 70 years of Ca K images within the next 18 months. At that time we will begin the digitization of the direct images, the “white light” series. The present status is given in the web page at:

http://www.astro.ucla.edu/~ulrich/MW_SPADP/

There are currently 11,751 images spanning the interval 1915 to 1940 available for study. These are not yet corrected for vignetting and photographic response but they do have their centers and radii determined and are in a standard fits format. As an aid to image selection, we also provide a complete set of thumbnail images linked to intermediate size jpg versions of the images. An example of the thumbnail pages is shown in figure 1

We anticipate that the digitization project and the synoptic program of magnetic and velocity observa-

tions for which this proposal requests funding will allow a continuous record of rotation rate as a function of latitude over a period of 90 years. There is also some analogue magnetogram data in the form of photographs of oscilloscope traces taken by Babcock (Babcock and Babcock, 1955; Babcock, 1963). Original photographic films from this program are available to us and can be scanned using facilities of the photographic archive project.

1.2 Results from NSF Support on Grant ATM-0101350

Total Amount	Start Date	End Date
\$360,238	June 15, 2001	May 31, 2004

This project has supported the continuation of regular full-disk observations of the solar surface line-of-sight magnetic field and velocity components along with the intensity in the spectral lines used for the measurements. The status of the instrument system and a description of the reduction/analysis methods was given by Ulrich et al. (2002). An important part of our approach is the method using solar rotation to resolve the transverse and meridional structure of vector fields for slowly varying components. The details of this method have been described in the above publication. For the velocity and the magnetic field the method in the meridional plane and the east-west direction perpendicular to this plane. When Ulrich began managing this program in late 1985 a program of multiple observations per day was begun. This approach samples the time-variable parameters more continuously than did the previous program and reduces the aliasing of high temporal frequency variations into the rotationally induced changes allowing for an accurate decomposition of the above two components.

The synoptic observations yield four independent parameters: meridional velocity, the East-West or zonal velocity, meridional magnetic field and East-West or zonal magnetic field. The time dependence of the first and last of these have not been previously available. The most persistent features of these patterns can be isolated by averaging them over a complete Carrington rotation. The resulting time dependence is shown in the four panels of figure 1.2.3. The top figure gives the torsional oscillations, the second is new and gives the time dependence of the

meridional circulation velocity, the third is also new and gives the surface toroidal magnetic field and the fourth is the familiar magnetic synoptic chart. The meridional velocity and toroidal magnetic field results are discussed further below. We will see that the record of nearly two solar cycles permits a new description of the of the solar cycle processes.

1.2.1 *Toroidal Magnetic Field*

The set of figures in figure 1.2.3 includes a new result which is the east-west projection of the magnetic field (considered to be positive if the arrow of the field points toward the direction of solar rotation). The average of this field over the full circumference of the small circle at constant latitude must represent a net toroidal field. Thus the plot of east-west magnetic field gives the time and latitude dependence of the sun's surface toroidal field - clearly a parameter of great interest for the study of the solar dynamo. The presence of a systematic and persistent non-zero result for this toroidal field is significant.

1.2.2 *Solar Cycle Considerations*

We can combine the results from our synoptic program as illustrated in figure 1.2.3 to advance our understanding of how the solar cycle operates. This figure encompasses nearly a full 22-year cycle so that we are able to identify a sequence of events indicating the mechanism of the magnetic field decline and growth. We start with the time of dipole field reversal when the number of sunspots is near the maximum and describe four steps in the cycle. Following the dipole reversal, the dipole field strength reaches a plateau that persists for about half the 11-year cycle. To make the description definite, consider the north-polar region starting in 1990. This is near the maximum of cycle 22. The northern part of the dipole field is positive after that year. The magnetic field lines in the bulk of the convective envelope must have a directional sense which points from south to north to maintain continuity of field lines. The faster rotation toward the equator then twists the field lines so that they point against rotation and are negative according to our sign convention. During this time the toroidal field plot shows the development of a weak but pervasive negative component in agreement with the model. This toroidal field is correctly oriented to produce sunspot pairs for the

subsequent solar cycle 23 even though cycle 22 is still several years away from its end in 1996. This result is the first time that a critical part of the $\alpha - \Omega$ dynamo - the toroidal field - has been confirmed observationally. It is, however, very weak and in the wrong latitude region to produce the spots and magnetic field of cycle 23.

The second step in the process can now be identified from another of our data products: the meridional circulation. The meridional circulation result for the years 1986 to 1992 was originally presented by Ulrich (1993) in a somewhat different format. We see from this panel of figure 1.2.3 that during the years 1986 to 1991 and from 1994 to 1999 there is a zone of convergence near latitude of 60° where the flow from lower latitudes is toward the pole and the flow from higher latitudes is away from the pole. This means that there must be a zone of subsidence in the high latitudes. Dense-pack ring diagram analysis from helioseismic data may have seen an inward extension of this subsidence at latitudes near 50° N from 1999 to 2001 (Haber et al., 2002). As long as the toroidal field pervades the bulk of the convective zone, the total magnetic flux can be much greater than that part which is observed in the solar atmosphere. The bulk inward sweep of the meridional return flow can carry this toroidal field to the inner boundary of the convection zone where it is concentrated into strong flux tubes by the convective motions at this level. Near the maximum of cycle 23, the strength of the toroidal field in the band of solar activity is comparable to that of the meridional plane field that makes up the dipole and active region field. This comparability makes it plausible that both the dipole and toroidal fields are connected as parts of the same process that concentrates and disperses the fields.

After the toroidal field is concentrated at the tachocline, the further development of the dynamo process can follow along the lines discussed by a number of authors (Choudhuri, 2003; Gilman, 2000; Ossendrijver, 2003; Tobias, 2002; Rempel et al., 2000; Spruit, 2003) { the toroidal field is collected into flux tubes where the magnetic buoyancy becomes high enough to permit the magnetized fluid to form a loop that rises through the convective zone to the solar surface to become a sunspot pair. While the loop is moving outward through the rotating so-

lar interior, it experiences a Coriolis force which twists it in the direction to cause the trailing spot to be closer to the pole than the leading spot (Fisher et al., 2000). This trailing spot polarity opposes the existing dipole field and is swept toward the poles by the meridional circulation. Due to the higher average latitude of the trailing spot polarity, eventually this field component comes to dominate both polar regions and reverses the solar dipole. The cycle can then repeat.

Our detection of the toroidal magnetic field provides a new tool for the study of long-term trends in the sun's field strength.

1.2.3 Torsional Oscillations

During this reporting period, we published a report showing that the pattern known as the Torsional Oscillations is composed of a wave-like structure having characteristics of inertial waves like the Rosby waves. The geometry reported by Ulrich (2001) finds that the motions are coherent in the direction parallel to solar latitudes but have little if any coherence in the direction parallel to the solar longitudes. The relationship between these motions and solar activity remains elusive. However, for those motions having a global scale, these patterns have the largest amplitude motion after solar differential rotation so that they must be included in any model of the solar cycle.

The relationship of the torsional oscillations to the overall magnetic cycle can be seen in figure 1.2.3. The exact role of this E-W velocity pattern in the sun's dynamo process is not yet established. Nonetheless, the appearance of the pattern prior the onset of both cycles 22 and 23 along with the greater strength of the southern hemisphere component during 1996 anticipating the greater magnetic activity in that hemisphere implies that the torsional oscillations do play a significant role in the regeneration of the magnetic field pattern.

1.2.4 Comparison to Magnetic Field Measurements from the MDI instrument on SOHO

The scientific community has available 5 sets of full-disk magnetograms in a digital format. The Mt. Wilson digital magnetogram record extends back to 1967 but is from a single ground-based observatory so that it contains substantial night-time gaps. The

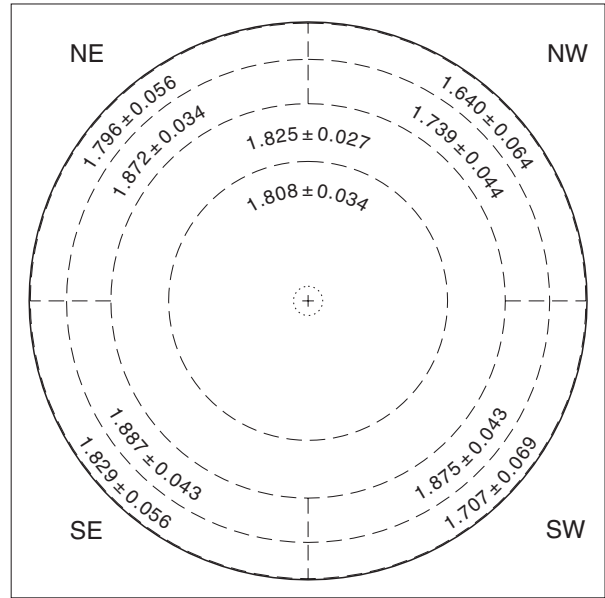
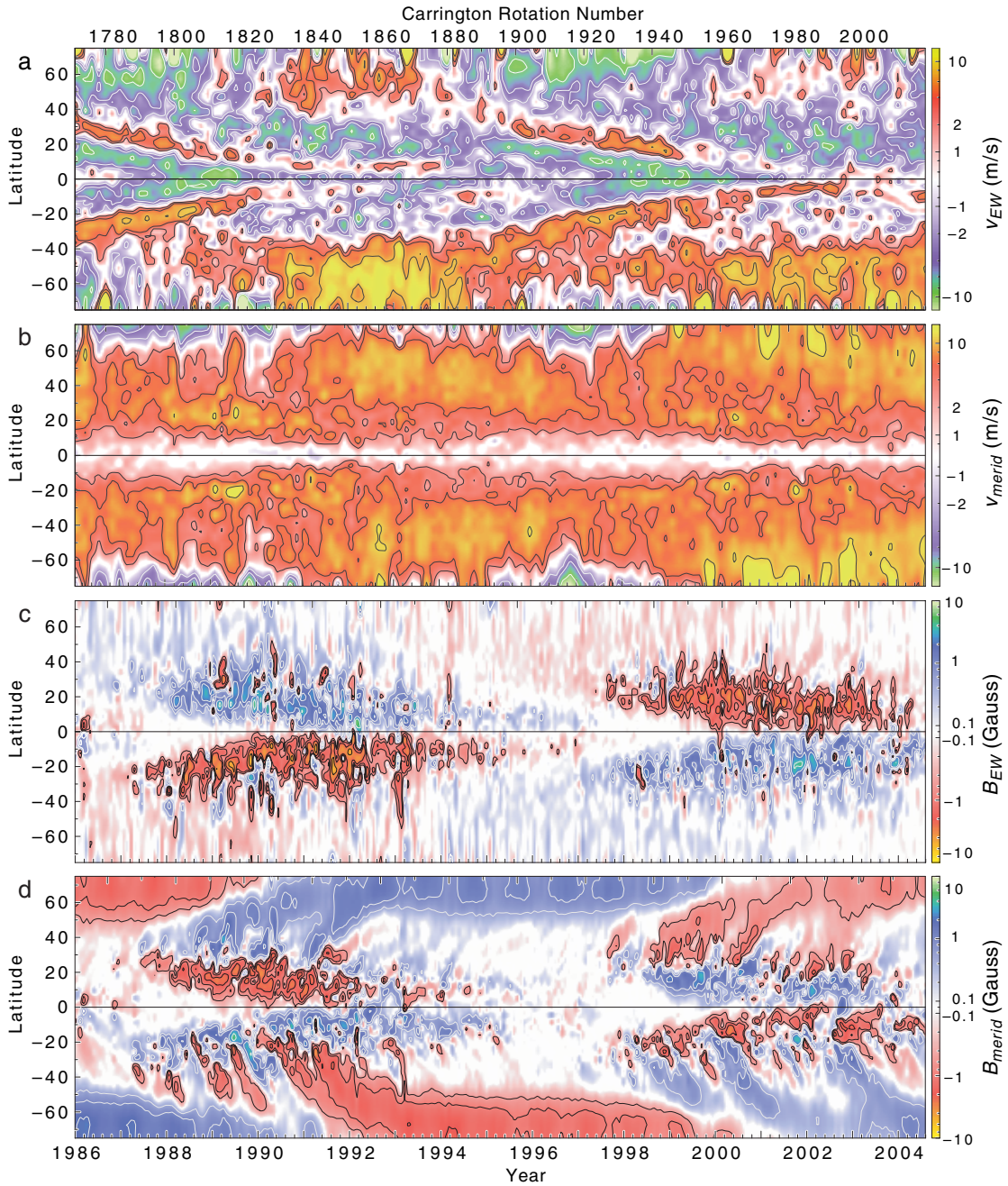


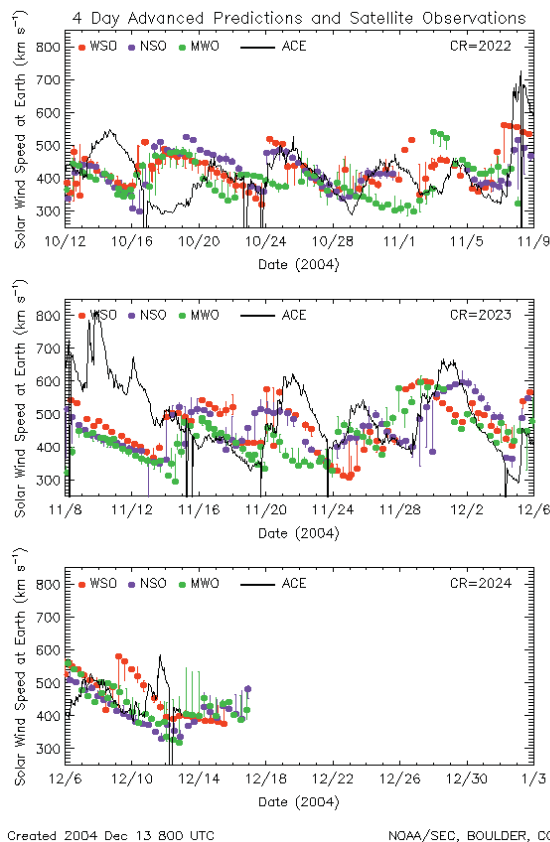
Figure 2: This figure shows the regions on the apparent solar image that have been selected and studied for the purpose of determining a scale factor by which the MDI magnetic fields need to be multiplied in order to recover the magnetic field as measured by $\lambda 5250.0$. The final $\lambda 5250.0$ fields are stated on the scale compatible with measurements $\lambda 5233$ and have been saturation corrected.

magnetograms from the MDI instrument on SOHO and the GONG2 instruments sponsored by the US National Solar Observatory do not have significant gaps beyond those imposed by the sampling interval. While the space-based and global network-based observations have better continuity than does the Mt. Wilson database, the shorter duration of observation makes use of the high-continuity data difficult because it has not been calibrated in terms of the implication of the measured line-of-sight fields for conditions in the solar wind.

In order to increase the utility of the MDI field measurements, we have carried out an extensive cross-comparison of the MDI magnetograms to the Mt. Wilson magnetograms. This comparison yields a position-dependent scale factor co-efficient that can convert the MDI magnetograms to the scale of the Mt. Wilson observations. A paper reporting on this analysis is in press at the Astrophysical Journal Supplement series. The principal results from the



Summary averages of magnetic and velocity measurements from the Mt. Wilson synoptic program carried out at the 150-solar tower telescope. The vector fields have been resolved into east-west and meridional components by carrying out sine and cosine weighted averages for each point over the period time it is on the Earth-facing side of the sun each rotation. These panels give a secondary average over all longitudes of the sine and cosine weighted averages for one (the magnetic panels) or two (the velocity panels) Carrington rotations. The resolved components are given in the sequence east-west velocity, meridional-plane velocity, east-west magnetic and meridional-plane magnetic. The contour levels are at ± 8 , ± 4 and ± 2 m/s for the torsional oscillation panel, ± 12 , ± 6 and ± 3 m/s for the meridional circulation panel and at ± 4 , ± 2 , ± 1 and ± 0.5 gauss for both magnetic field panels.



Created 2004 Dec 13 800 UTC NOAA/SEC, BOULDER, CO, USA

Figure 3: The predicted solar wind speed compared to observations from ACE on the day 13-Dec-2004. The solar surface magnetic fields are obtained from three observatories: Mt. Wilson, Wilcox Observatory and the National Solar Observatory. Cloudy weather and equipment factors often cause one or more of these to be unavailable.

comparison are given in figure 2. Most important, our time dependent analysis shows that the periodic retuning of the MDI filter system does not influence the measured magnetic field. Without an independent reference like that provided by the Mt. Wilson system, there would be no way to verify the stability of the MDI magnetic field determination.

2 Proposed Investigations in Support of the National Space Weather Program

2.1 Purpose and Scope of This Proposal

Ultimately the sun is the source of space weather as it provides the variable energetic and magnetic field input to the conditions in the heliosphere. The sun's magnetic field interacts with the rotating and convecting, ionized plasma of the solar envelope in a complex and only partially understood process most prominently marked by the 11-year sunspot cycle. From a condition of few magnetized regions and a weak overall field strength at sunspot minimum, bipolar magnetized regions appear and influence an increasing portion of the solar surface up to the time sunspot maximum. The magnetic field configuration becomes more irregular and occurs more often near the solar equator until the fields die out at the time of the next sunspot minimum. The emergence bipolar magnetized regions, along with their diffusion and advection produces a continuously varying pattern over the solar surface that governs the structure of the heliosphere as a whole and forms a required set of input conditions for models of the solar wind. This proposal is for funding to continue and enhance the synoptic acquisition and distribution of measurements of the solar surface magnetic field strength carried out at the 150-foot tower telescope on Mt. Wilson. These measurements are an essential link in the chain of data necessary for understanding Space Weather.

As indicated in the sections giving prior results from this program, the 150-foot tower telescope synoptic solar measurements provide a stable sequence of very long duration that can be used to establish long-term behavior of solar magnetism. This record was used by Arge et al. (2002) to check on a suggestion by Lockwood et al. (1999) that the total open solar magnetic flux increased by 41% from 1964 to 1995. In addition, the regular observations and their prompt distribution permits a prediction of solar wind speed (Arge and Pizzo, 2000) as is shown in figure 3 which is a typical prediction plot available from the website: http://solar.sec.noaa.gov/ws/predvel_4d.html.

This proposal and a companion proposal to be submitted to the NASA Living With a Star/ Support-

ing Research and Technology opportunity in Feb. 2005 will provide the primary funding for the continuation of the synoptic observations at the 150-foot tower telescope. Without funding from these proposals, these observations will be discontinued. With funding from these proposals, the existing magnetic field observations will be continued and enhanced through the development and distribution to the community of quantitative measures of the degree of deviation of the magnetic field from potential field models based on the multiple altitude data as well as the deduced east-west field component. We will retrospectively validate any correlations between nonpotential field characteristics and the occurrence of Coronal Mass Ejections. We will also increase the availability of our data products by placing a larger volume of the archival data in a web-based retrieval system. The tasks to be completed with support from this proposal are listed in Table 1.

2.2 Synoptic Program Summary

- The Synoptic Program

- The program was begun by G. E. Hale in 1906 and, with only a few brief interruptions, has continuously monitored the state of solar activity up to the present time.
- Early observations included full disk spectroheliograms in Ca K and H_{α} , white light images and prominence spectroheliograms in H_{α} .
- In 1954 Horace Babcock began photographically recording oscilloscope traces showing magnetic field strengths.
- In 1967 Robert Howard began digitally recording magnetograms. These are part of the currently maintained digital database we regularly analyze. This database also includes spectral line intensity and Doppler velocity.
- In 1986 Roger Ulrich began a program of multiple observations per day in order to reduce the effects of short term temporal variations.
- In 1996 Roger Ulrich began a program of observing with the light from four spectral lines simultaneously. Two lines, the Na D line and the line used by GONG and MDI at $\lambda 676.8$ nm

Table 1: Project Tasks

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| <ol style="list-style-type: none"> 1. We will continue the synoptic program of magnetic field observations at the 150-foot solar tower telescope on Mt. Wilson. This task includes maintenance and repair of the observing systems as well as assistance with maintenance of the observatory systems. 2. We will make available on-line magnetic field synoptic maps and snapshot full surface maps (this is a new product). 3. We will make available on-line magnetic maps based on the near-core spectral samples of the Na D₁ line that measures the magnetic field strength in the low chromosphere (this is a new product). 4. We will study the relationship between the non-potential properties of the solar photospheric magnetic field and the frequency of occurrence of Coronal Mass Ejections. We will use both the multiple altitude data from the Mt. Wilson system as well as the deduced east-west component of the magnetic field to provide measures of the nonpotential characteristics of the field beyond what is directly obtained from the line-of-sight measurements. |
|--|

are each observed in ten spectral samples while the two lines previously observed: Fe I at $\lambda 525.0$ nm and Cr II at $\lambda 523.7$ nm continue to be observed in two spectral samples each.

- Current Science Objectives

- Provide near-real-time photospheric magnetic field measurements for forecasting solar wind speed.
- Extend the observations of surface velocity measurements to improve our understanding of the nature of the solar cycle.
- Intercompare magnetic field measurements between different observing systems in order to develop a long-term stable record.

- Operational Personnel

These employees carry out the daily observations, maintain and upgrade the 150-foot tower telescope systems, carry out the routine reductions and posting of standard quantities on the web, and maintain and develop the reduction software.

- Telescope Technicians: Larry Webster, Pamela Gilman and Steve Padilla.
- Programmer Analysts: John Boyden and Larry Webster.
- Cost of Operations
 - This project is treated as off-campus and charged a 26% overhead rate.
 - As an off-campus project some utility and site charges must be charged directly to the project.
 - Personnel Costs with benefits and overhead: \$330K/yr.
 - MWO Site fees and utilities: \$70K/yr.
- Sources of Support
 - Current: \$150K/yr from NSF for analysis of Ca K spectroheliograms.
 - Needed: \$250K/yr from NSF and/or NASA. This proposal is for half of the needed funds and will support Webster and Boyden, each part time.

2.3 Data Reduction and Map Preparation

The analysis of conditions throughout the heliosphere starts with the magnetic field on the surface of the sun. Following the ideas set out by Wang and Sheeley (1990) and Wang and Sheeley (1992), it has become increasingly important to trace solar wind conditions back to an originating surface known as the source surface where the magnetic field is assumed to be purely radial. The field is taken to be a solution of the potential field equations between the photosphere and the source surface. The pattern of field deduced to be present at the source surface then determines the directional of the magnetic field in the solar wind while the geometry between the photosphere and the source surface determines the solar wind speed. Consequently, conditions deduced for the solar wind speed depend on the solar observations and our ability to calculate the magnetic field

over the whole solar surface from the observations that are of necessity confined to the viewing direction from Earth.

There are an number of areas of difficulty in the treatment of photospheric fields that need further study:

- The solar surface field is normally taken from synoptic charts distributed from the National Solar Observatory, the Mt. Wilson Observatory, the Wilcox Solar Observatory and the Michelson-Doppler Imager. These synoptic charts use the “Carrington Longitude” and Carrington Latitude as the horizontal and vertical axes of the synoptic chart. Due to differential rotation, the Carrington longitude is generally not a heliographic latitude giving the position of a quantity on a solar surface map.
- The zero point of the magnetic field is difficult to establish but can influence the heliospheric magnetic structure since a small shift of this set point can influence the polarity of large regions over the solar surface.
- While portions of the solar surface are on the unseen back side of the sun, we not able to measure the changing in their magnetic field strength yet these fields are part of the solar surface boundary conditions needed to calculate the potential field solution.

Differential rotation was not included in the tracking of magnetic features until the work by Ulrich et al. (2002) where for the first time multiple observations were averaged together after shifting their positions to account for the distance of each point from the central meridian. We introduced the concept of a supersynoptic chart formed by reversing the horizontal axis direction and placing successive charts end to end. It is furthermore necessary to recognize that the horizontal coordinate is not a longitude as it is commonly called but rather a quantity we call the Carrington time t_C that is the time that a particular point on the solar surface crosses the central meridian. Traditional synoptic charts are formed by accepting only observations near the time of central meridian crossing and melding together successive observations until a full circumference is built up. When a point is not near the central meridian,

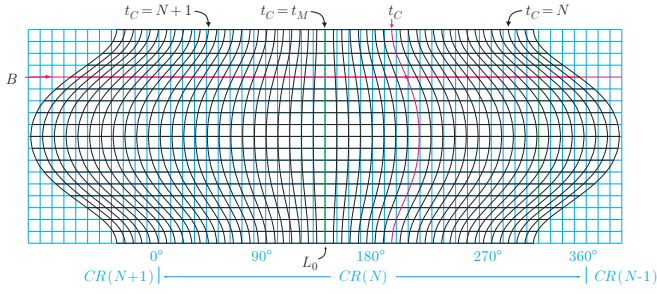


Figure 4: This figure shows the relationship between synoptic map coordinates t_C and B and heliographic coordinates $L - L_0$ and B in a snapshot full-surface map. The black lines represent synoptic chart coordinates while blue lines represent heliographic coordinates. An example point is indicated by a red circle and the coordinate lines through the point are red as well. The central meridian line for the selected time as well as the points at $\pm 180^\circ$ of heliographic longitude are shown as green. We define the Carrington time for the central meridian line with Carrington longitude L_0 as the mapping time t_M .

its central meridian crossing time can be calculated from its angular distance from the central meridian and its local rotation rate. At any time t_M , the mapping time, heliographic coordinates can be converted to a Carrington time by using a differential rotation law which we take to be the surface magnetic rotation rate according to:

$$L = L_0 + (180^\circ/\pi)(t_M - t_C) \times (\Omega(B)/\Omega(\text{Carr}))$$

All observations of a point defined by constant t_C and B can then be collected together and analyzed for vector components in the meridional and e-w direction. Unless a synoptic chart is treated as being a function of t_C instead of Carrington longitude, it is not possible to include observations beyond a few days of central meridian crossing. Furthermore, without mapping to heliographic coordinates, it is inappropriate to carry out a spherical harmonic expansion since the synoptic chart mixes time and space.

It is common to treat the magnetic field observations on a synoptic chart as if they represent values over the solar surface using the ‘‘Carrington longitude’’ as a heliographic longitude. Although at the time of each observation, the Carrington longitude is well defined and easy to determine from the spatio-temporal coordinates associated with each solar fea-

ture, for all other times, differential rotation causes the Carrington longitude to change. Thus it is incorrect to use a fixed value for the Carrington longitude since the higher latitudes rotate more slowly and are at distances from the central meridian smaller than the difference between the ‘‘Carrington longitude’’ of the point and that of the central meridian. In order to be precise in our construction of full disk maps of solar magnetic fields, we introduce the concept of a snapshot magnetic map that best describes the solar surface at a particular mapping time t_M . Figure 4 illustrates the steps between a traditional synoptic chart and a proper snapshot magnetic map.

The data obtained by the Mt. Wilson synoptic solar program has been reduced, recorded into the project database and made available to the community for the period 1986 to present. Some data have been reduced in a similar way for the period 1972 to 1986. One of the tasks in the re-reduction is the establishment of a magnetic zero point using a histogram procedure that assumes the very weak magnetic fields come from local dynamo action on the solar surface and, as long as active regions can be identified and removed from the algorithm, the peak of the weak field distribution function should serve as a zero point for the magnetic scale. This method works well with the Mt. Wilson data where it is possible to demonstrate that the observed weak fields are in fact being measured and are not an instrumental uncertainty of measurement or bias. Figure 6 of Ulrich et al. (2002) compared a distribution function for the sun to an instrumentally created distribution function measured by removing the circular polarization analyzer from the system. so that What this figure shows is that the bulk of the observed magnetic field distribution function is of solar origin and not instrumental. Consequently, we are able to use the distribution function to establish a good zero point to the magnetic field observations of our program. The coincidence of the zero field crossing line and the location of the polar crown filaments shown in figures 9 to 11 of Ulrich et al. (2002) gives us confidence that our procedure is effective in establishing the magnetic zero point.

The recent work by Tran et al. (2005) compares the MWO magnetic field measurements to those from MDI and shows that there are small zero point offsets from one observation to the next for the MDI

magnetograms. Although these offsets are small, they are large compared to the variations of the weak field and will cause a general shift in the boundaries between regions of different net polarity and could have an impact on potential field solutions based on MDI data. Liu et al. (2004) have recently applied a distribution function method to the MDI data and also find small shifts for the magnetogram as a whole. However, the results of Tran et al. (2005) show that different portions of the MDI images are characterized by separate shift amounts so a single shift parameter is not enough to apply to the MDI data. We will investigate this question further during the proposed funding period. We will also apply the distribution function zero point correction to the earlier MWO data.

The zero point of fields measured by the Wilcox Solar Observatory are well calibrated. A recent study by Poduval and Zhao (2004) found that the derived solar wind speed based on the Wang and Sheeley flux tube expansion model depended on the number of terms included in the spherical harmonic expansion up to a total of 22 terms. Beyond that number their result became erratic and additional terms did not have a systematic effect. However, beyond a total of 22 terms, their ability to reproduce the solar surface field configuration was not improved further due to the inherent spatial resolution provided by the WSO system. The combination of zero point calibration and higher spatial resolution provided by the MWO system raises the possibility that a similar study using MWO data might be improved by inclusion of additional terms.

2.4 Potential Field Models and the Role of the Transverse Field

The heliosphere is filled with the solar wind that leaves the sun as a magnetized plasma. The sun's magnetic field controls the flow of energy (Falconer et al., 2003) to the corona and guides the flow of gas as it is accelerated (Schatten et al., 1969). Instabilities leading to Coronal Mass Ejections (CME's) are related to the coronal magnetic structures (Luhmann et al., 2003; Falconer et al., 2002; Wang et al., 2002). The variability of the geomagnetic field is related to the sunspot cycle and probably to the sun's open magnetic field flux (Lockwood et al., 1999). The

size and distribution of coronal holes, polar versus active region, depends on the phase of the solar cycle and influences geomagnetic activity indices (Luhmann et al., 2002). Interplanetary scintillations are related to solar wind variations and dependent on the magnetic structure of the solar wind (Hakamada and Kojima, 1999; Hakamada et al., 2002). The solar wind speed at near-earth points is predicted in near-real-time based on models of the region between the solar photosphere and the base of the solar wind (Arge and Pizzo, 2000; Arge et al., 2003).

In many of these applications, the data set used has been from either the Wilcox Solar Observatory (WSO) or the National Solar Observatory (NSO). We will make it easier to use the MWO data by establishing a web-based distribution system that will provide the most useful quantities without the need for a special request. We believe the data from the Mt. Wilson Observatory program is an alternative with some significant advantages that should be more frequently used. The spatial resolution of 12 arcsec is not as good as that from NSO but is significantly better than what is available from WSO. Probably the most troublesome aspect of magnetogram data is the need to eliminate a bias offset of the zero point. The WSO procedure establishes this through a regular calibration. The MWO procedure is based on the fact that the system is sufficiently sensitive that the weak fields can be measured over the whole solar image and that the analyzer does not have any dependence on position on that image. The systems in use at NSO and the MDI analyzer have not demonstrated that the same zero point calibration system can be used. A recent study by Liu et al. (2004) has used the distribution function approach to determine the offset for the MDI instrument. However, two aspects of the MDI system make the results less reliable than is the case for MWO: the noise per pixel for MDI is 20 gauss and this is larger than is often the case for the weak solar fields and the optical system is a filtergram approach that can introduce a position dependent offset to the zero point. Thus we see that MWO combines the advantages of a spatial resolution higher than WSO and a well defined zero point similar to that provided by WSO.

All these applications share in common the need to represent the magnetic field between the layer

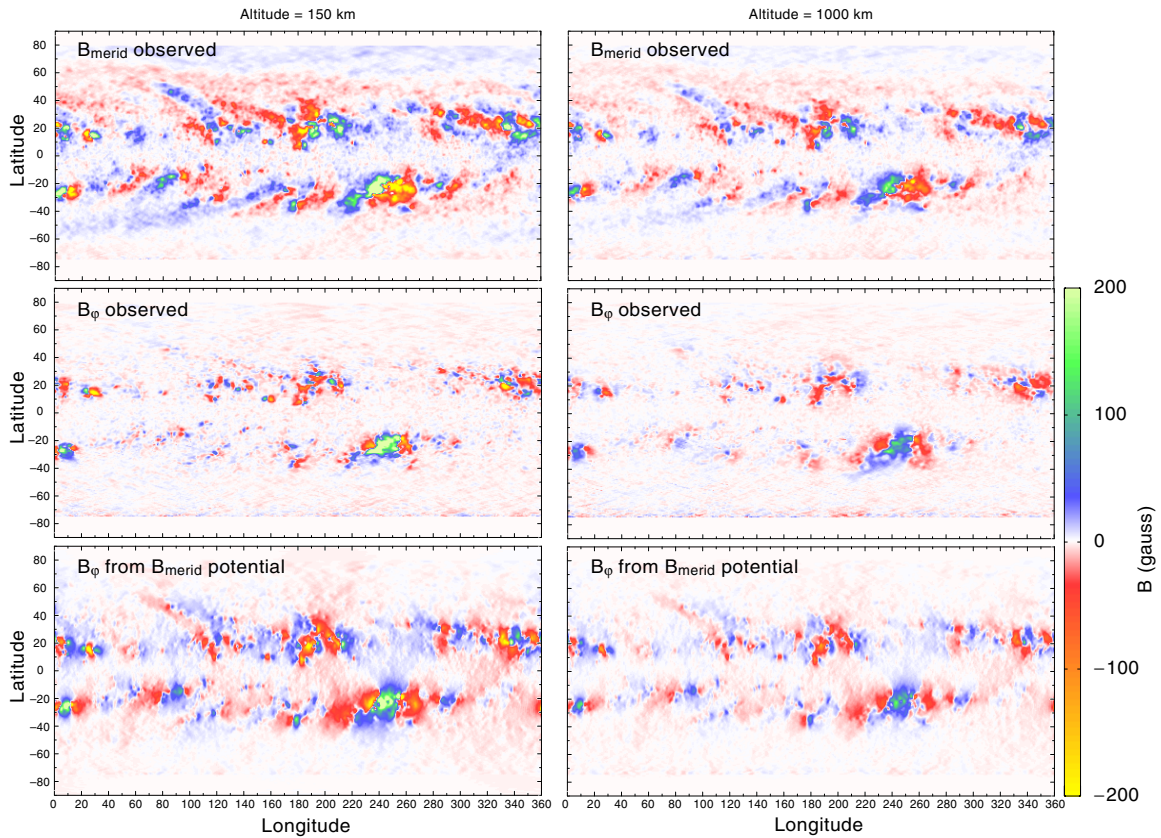


Figure 5: This figure is derived from observations of the Na D₁ line. The transverse and meridional magnetic field components have been deduced using rotation as described by Ulrich et al. (2002). The middle two images give the transverse magnetic fields and while the lower two images give the same component deduced from a potential field fitted to the meridional magnetic fields. The top two synoptic maps are included for reference and give the meridional component of the magnetic field. Two separate spectral sampling pairs are used: the left column of images use spectral samples on the wings of the line which are formed near the altitude characterized by the $\lambda 525.0$ nm spectral sampling that has been observed by the Mt. Wilson synoptic program since 1967 while the right column uses a pair near the core of the Na D₁ line that is formed at the base of the chromosphere.

where it is observed and where it becomes part of the expanding solar wind. The latter layer is called the source surface. It is generally assumed that the magnetic field is free of currents in this intermediate layer even though there is good evidence that currents are present. With the current free approximation the governing equations reduce to Laplace's equation with appropriate boundary conditions. Following the arguments by Wang and Sheeley (1992), the boundary conditions have been chosen to be matching of the radial component of the magnetic field at the photosphere and vanishing of the trans-

verse components at the source surface. These authors recognized that the use of the radial boundary condition at the photosphere is incorrect due to the associated prediction of a strong transverse component which is not observed. They argued that motions in the photosphere have enough force that they distort the field lines into a more nearly vertical shape than is consistent with solutions to Laplace's equation. If the transverse field components are matched at the photosphere as well as the radial component, the solutions are less successful in matching observed corona/solar wind properties

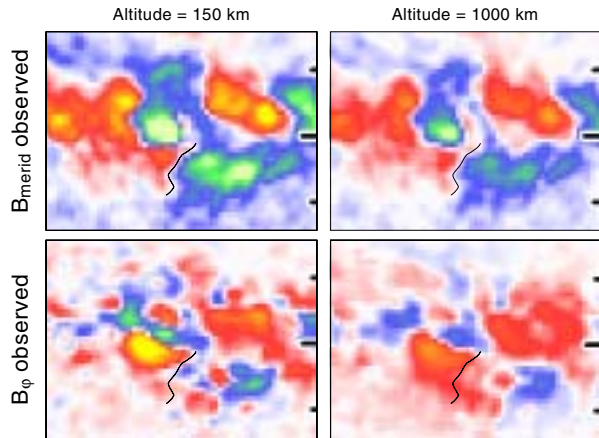


Figure 6: This figure shows extracted sections from figure 5. The sections are near 360° and in the northern hemisphere. The solid line indicates the location of the neutral line on the meridional projection plots. Note the associated change in B_ϕ which shows that there is a vertical gradient in this component - hence an associated current along the neutral line.

than is the case with the photospheric radial field condition alone.

If one applies the two boundary conditions: photospheric transverse field and vanishing source surface transverse field, the problem becomes overdetermined. The synoptic program at the 150-foot tower telescope on Mt. Wilson now systematically evaluates the transverse magnetic field using the Shrauner and Scherrer (1994); Ulrich et al. (2002) method. Consistent with the earlier data summarized by Wang and Sheeley (1992) the transverse field is systematically less than required by the potential field theory. This result indicates that the magnetic field at the altitude of formation of the $\lambda 525.0$ nm line is influenced by currents and is non-potential. However, as described in Ulrich et al. (2002), our program now measures magnetic fields using a range of spectroscopic samples. Of particular interest is the data obtained for the Na D₁ line. These pairs are formed at altitudes which range from 125 km to 1000 km on the scale established by the Vernazza et al. (1981) model atmosphere. All pairs of spectroscopic samples have been obtained simultaneously since 1996 when the new exit slit/digitization system was put into operation. We show in figure 5

a set of synoptic charts showing a standard meridional magnetic synoptic chart on top, the observed east-west transverse field synoptic chart in the middle and the east-west transverse field deduced from a potential field solution fit to the meridional field configuration. Two pairs for the Na D₁ line are shown: on the left is the pair formed at nearly the same altitude as is the case for $\lambda 525.0$ nm and a second pair near the line core that is formed at the base of the chromosphere at 1000 km. It is clear that the degree of non-potentiality is diminished for the spectral sampling pair near the chromosphere. We will collaborate with C. N. Arge to evaluate the solar wind speed predictions based on the core Na D₁ spectral sampling pair.

A detail from figure 5 illustrates another application of the combined transverse magnetic field information and the altitude dependence available from our multiple spectral sampling system. This detail is shown in figure 6 which is extracted from the right edge of the observed synoptic charts. The solid, curved line indicates the location of the neutral line on the meridional maps. Just to the right of the line it is clear that there is a significant difference in character between the transverse field map at 125 km versus that for 1000 km. In particular the direction changes from being in opposition to the typical direction at the lower altitude to being in alignment at the higher altitude. Since the y component of $\nabla \times \mathbf{B}$ is the altitude derivative of B_x , this change indicates the presence of a current in the y direction near the neutral line. The studies by Falconer (2001) and Falconer et al. (2002) show that the shear along neutral lines as well as the current are indicators of magnetic instability which can lead to a magnetic field reconfiguration and a CME. We will investigate CMEs catalogued by Yashiro et al. (2004) during the period 1996 to present in order to determine the frequency with which a current in the y direction is present prior to the CME.

3 Management Plan

The proposed tasks are given in Table 1. The continuation of the project is the most important task and funding from this proposal will allow the resumption of full time activity by the observatory personnel. Two (Ms. Pam Gilman and Mr. Steve

Padilla) are currently on 50% status and some activities have been curtailed. In addition, Senior programmer analyst Mr. John Boyden is supported from other sources that are inadequate to continue his full time activity without approval of this proposal. With the full-time services of these personnel, we will be able to carry out the tasks of Table 1

A minimum staff level of three full-time employees is required to carry out this project on the full-time basis that is essential to avoid data gaps created by vacations or illness. It is also important to have at least one member of the team on the observatory grounds in addition to the observer in order to provide a backup in the event of the observer getting into difficulty on the tower telescope. The on duty observer does not require a full time effort to carry out the observations due to a variety of system improvements over the years. The extra time is utilized to assist with the digitization project and that portion of the observers time is covered by that grant.

In addition to the basic staffing question, we plan to improve the distribution and availability of our data products. In particular we will carry out a full re-reduction of the data and place the resulting products into a web-based access system similar to that we have developed for the Mt. Wilson Solar Photographic Archive Digitization Project (MW_SPADP). In order to adequately provide this data we are including an upgrade for the web serving computer system as a request for \$10,000 of computer equipment purchase. This will consist of an upgraded Linux/pc box and associated mass storage.

The proposal also includes funding for Dr. C.N. Arge to visit us at UCLA/Mt. Wilson once per year. Our collaboration thus far has been primarily by telephone and e-mail and has allowed us to help Dr. Arge utilize our most advanced and well calibrated products. Other investigators using Mt. Wilson data have not had the advantage of the correction to the magnetic zero point.

The facilities of the Mt. Wilson Observatory are available to us under agreement between the Carnegie Institution of Washington and the Mount Wilson Institute under the directorship of Dr. Hal McAlister of the University of Georgia. Observatory maintenance is carried out by cooperative work between MWI and UCLA employees and through a site fee shared by all users of the Mt. Wilson Ob-

servatory. Part of this fee is included in the funding request of this proposal. The UCLA project is responsible for maintenance of the 150-foot tower system and receives no funding from Carnegie or UCLA to assist with these expenses.

4 References

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