Annual Report: Understanding Magnetic Eruptions on the Sun and their Interplanetary Consequences: 
August 1 2001 – June 30 2002

PI: George H. Fisher
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Overview

Notable accomplishments of our MURI award over the past year include these major developments:

• The addition of new personnel working on the Solar Origins of Space Weather: Brian Welsch at UC Berkeley; Andrew Phillips at Drexel University; Jimin Gao at Drexel University; Stephane Regnier at Montana State University; Yong Jae Moon at BBSO/NJIT
• Significant improvements in numerical capability by members of our core group of computational physicists - Bill Abbett & Steve Ledvina (UCB), Peter MacNeice (Drexel), and Dusan Odstrcil (University of Colorado / CIRES)
• The selection of 2 candidate active regions for detailed observational and theoretical modeling of eruptive events
• The continued development of new observational capabilities at BBSO/NJIT and at Haleakala (University of Hawaii)
• The hosting of several small, highly focused workshops to sharpen the focus of the research funded by the MURI projects
• Significant progress in solving some of the outstanding problems identified at these workshops
• Forefront research on many observational and theoretical topics related to understanding magnetic eruptions and their propagation through the Heliosphere.

This annual report is organized as follows: We first provide a brief exposition of several of the major accomplishments identified above, followed by 4 detailed, chronological quarterly reports that were provided by all 9 University Teams over the course of the year. Finally, at the end of the report, we provide a list of publications funded in part or in full by the Solar MURI project.

New Personnel

Efforts like the MURIIs are important in that they provide a rare opportunity to get new talent into targeted fields, such as the solar origins of Space Weather. The Solar MURI grant has resulted in these new hires:

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1 Note that the first annual report covered May 1 2001 – July 31 2001. After this year’s report, subsequent annual reports will report on work performed from July 1 – June 30 of each year.
Brian Welsch, a recent PhD graduate of the Physics Department at Montana State University, was hired as a new postdoc at UC Berkeley to work on scientific topics related to Solar MURI. He is also collaborating closely with Spiro Antiochos, Rick Devore, and Mark Linton at the Naval Research Laboratory in Washington DC, and spends significant time each year at NRL. Brian is pursuing a project aimed at understanding whether shearing and reconnection of a simple bipolar active region can lead to an erupting flux-ropo configuration. This project is an outgrowth of the “Numerical Experiments” MURI workshop that was held at UNH earlier this year (and described further below).

Andrew Phillips is a new postdoc at Drexel University working for Peter MacNeice. He began work in mid February, after finishing a PhD degree in the UK. He has been developing a Sedov test of the hydrodynamics of a High Order Godunov code using the Paramesh adaptive mesh refinement algorithm.

Jimin Gao is a graduate student interested in computational physics that is working with MacNeice on the Solar MURI project.

Stephane Regnier is a new postdoc at Montana State University, working with Dick Canfield and Dana Longcope. He received his PhD recently in France, and is now working with Canfield & Longcope on the reduction of vector magnetograms, the development of coronal force-free-field models based on the magnetogram data, and comparison of the theoretical models with solar coronal observations. He is playing a key role in the use of observed data in NOAA region 8210 to drive MHD simulations of magnetic eruptions.

Yong-Jae Moon is a new postdoc at BBSO/NJIT. He has expertise in the analysis of data from solar flares and CMEs, and the use of vector magnetograph data. He has been an especially prolific contributor to MURI funded publications over the past year.

**Improved Numerical Capabilities**

Adaptive mesh refinement (AMR) is essential if one wishes to simultaneously resolve small scale structures on the Sun and large scale structures in the outer corona and the heliosphere. Therefore one of the goals we set for ourselves at the beginning of the Solar MURI project was to use the expertise of Peter MacNeice, one of the originators of the Paramesh AMR and domain decomposition software, to help integrate Paramesh into our already existent numerical MHD codes, Zeus-3D (corona) and ENLIL (heliosphere). This process was begun during a 1 week mini-workshop at GSFC during July of 2001, attended by Odstrcil, Abbett, Ledvina, & MacNeice, and was successfully completed this year. In addition to the inclusion of Paramesh, Abbett & Ledvina incorporated other improvements into Zeus-3D, such as the elimination of operator splitting in the transport step (an improvement originally implemented by Yuhong Fan of HAO), which improved the code’s efficiency and accuracy. Abbett & Ledvina have dubbed their new version of ZEUS “ZeusAMR”.

Abbett also worked to include a much more physically consistent coupling between our interior MHD code, ANMHD, which is used for simulations of the solar interior, and Zeus-3D and ZeusAMR. An example of the computed evolution of the emergence of an active region, performed with ANMHD and Zeus-3D is shown in Figures 1. The left hand side of Figure 1 shows how the 2 codes are coupled together in space, while the right hand side shows a comparison between the MHD solution and a potential field solution with increasing time for an emerging, twisted active region flux with different levels of twist within each tube.

Figure 1 – Bottom red box on left shows the volume encompassed by the ANMHD simulation of an emerging, twisted active region flux tube rising though the solar interior toward the solar surface. The grey plane and the field lines above it show the Zeus-3D simulation of the response of the solar corona to the emerging flux. The 6 images on the right hand side show comparisons between the MHD simulations of coronal evolution and a potential field extrapolation. The left hand column shows the MHD results, and the right hand column the potential field extrapolation. Each row shows a different amount of twist in the emerging active region flux tube, with the top row corresponding to no initial twist, and the bottom row to substantial twist. These results are presented in a paper by Abbett & Fisher to be published in ApJ on January 1 2003.

Improvements to the ANMHD code were made as a collaboration between team member Abbett and Yuhong Fan of HAO, while they were both participants in the “Origins of Solar Magnetism” program at the Institute for Theoretical Physics at UCSB. The ANMHD source code is publicly available on our Solar MURI website as the file Anmhd.tar.gz in the directory http://solarmuri.ssl.berkeley.edu/~abbett/public/software/.
An illustration of a similar calculation performed with ZeusAMR, exhibiting the use of a block adaptive mesh, is shown in Figure 2.

Figure 2 – Emerging flux simulation showing field lines (white) and vertical velocity contours in a single vertical plane (blue). Mesh size is shown as the checkerboard patterns. The adaptive mesh allows for a large dynamic range in size scales.

Simulations such as these can also be incorporated in a fairly straightforward way into simple source surface models of the large-scale corona. Figure 3 shows how one of Abbett’s emerging active regions affects an initially dipolar magnetic field on the Sun.
and how the active region changes the location of the coronal hole boundaries.

Figure 3 – Illustration of how an emerging active region simulation can be used to study its effects on an initially simple dipolar solar magnetic field. Note the distortion of the northward coronal hole toward the active region. A similar configuration resulted in the famous “elephant trunk” coronal hole in 1996 when a large active region formed at low latitudes near solar minimum.

During a 1 week visit by Dusan Odstrcil to Berkeley in August of 2002, Ledvina & Odstrcil settled on a code-coupling framework for connecting ZeusAMR simulations of the outer corona with ENLIL simulations of the heliosphere. To facilitate this coupling, a spherical version of ZeusAMR is being developed and tested.

The MURI Workshops

It was clear early on that many of the problems that must be solved to achieve a solar and heliospheric numerical modeling system are too complex to be tackled by individual researchers working alone. We therefore decided to organize a series of focused workshops to tackle what we regarded as the most pressing problems in modeling the solar origins of space weather. At this point, we have held 4 of these workshops, and plan to hold 2 more: UH team members are hosting a workshop in Honolulu Nov. 18-20 on the use of the new coronal IR / magnetic field measurements to be made on Haleakala, and how to make best use of this new data in our theoretical and numerical modeling efforts. Jozsef Kota, Janet Luhmann, and Marty Lee are organizing one on SEP acceleration to be held at the University of Arizona March 17-18 of 2003.
The first of the workshops held this past year was on the Paramesh adaptive mesh and domain decomposition tool, which has now been successfully incorporated in both ZeusAMR and ENLIL. It was the success of that workshop that led us to organize 3 more – one on the construction of synoptic magnetic maps, one on the use of vector magnetograms to drive numerical models of the corona, and a workshop on numerical experiments for CME initiation.

**Summary of Synoptic Magnetic Map Workshop (April 15, 2002)**

This one-day workshop was held in Boulder, CO just before Space Weather Week. The workshop was organized by team member Bernie Jackson, and was attended by scientists from both MURI teams, as well as participants from SEC/NOAA.

Synoptic maps of the photospheric field distribution remain the sole quantitative observational input for coronal and solar wind models and thus are key to the success of Sun-Earth modeling efforts.

Although digital synoptic maps of the photospheric field distribution are now routinely available from a number of solar observatories (e.g., Mount Wilson, Wilcox, and National (on Kitt Peak), the methods and processing used to construct them differ considerably, as do their archive file formats, spatial resolutions, and physical data units. This general lack of uniformity makes it very tedious and cumbersome for users to switch back and forth between synoptic maps generated by different facilities (data gaps being a prime example as to why such a switch might be necessary).

As more groups coordinate their research efforts by studying specific events and as more models are run in a (near) real-time mode, the ability to use uniformly assembled synoptic maps from multiple observatories is becoming increasingly critical. The solar and heliospheric communities would benefit from a reliable, centrally located public site providing synoptic maps (from multiple observatories) which have a uniform file format and which have been constructed using an established and documented assembly technique.

Over the last few years, through support from ONR, NSF, and NASA, a generalized synoptic map assembly code has been developed by Nick Arge at NOAA/SEC. This code can merge line-of-sight magnetograms from virtually any solar observatory into daily updated and full Carrington synoptic maps, as well as other types. It is versatile in that it provides greater control over how the maps are constructed and as to what corrections (unique to each observatory) need to be applied to the magnetic field data. It is thus ideally suited to provide the solar community with a standardized set of synoptic maps. In addition, the model is housed at a facility (NOAA/SEC) that is both reliable and readily accessible to the public. The ready availability of regularly updated, uniformly constructed synoptic maps from several observational sources will significantly facilitate the development of Sun-Earth propagation modeling capabilities.

**Vector Magnetogram Workshop (April 29-May 1 2002)**
The workshop was held at SSL/UC Berkeley, and was organized by Dick Canfield and George Fisher. It was attended by MURI team members, and by other experts on vector magnetogram data (Tom Metcalf [LMSAL] and KD Leka [CoRA], as well as Zoran Mikic [SAIC]). Here is the resulting “plan of action”:

Plan of Action:

Phase I

1. Analyze available data for 1998 May 1 event
   - Generate a sequence of IVM magnetograms for the 1998 May 1 23:40 UT halo CME event (AR 8210), time cadence ~15 min before, during, and after eruption. (Regnier)
   - Determine line of sight and transverse velocities. (Welsch, Metcalf)
   - Analyze the global solar (Li, Liu) and IP (Li, Luhmann) context (spatial, temporal) of this event, time scale ~ several days, including previous and following events.
   - Estimate the magnetic field uncertainties. (Metcalf, Leka)
   - Make an instrument vs time array on WWW (Li)

2. Construct coronal magnetic equilibria
   - Build force-free magnetic field models for each magnetogram, combined with a potential extrapolation of MDI data. (Regnier)
   - Build magnetohydrostatic models from the same magnetograms (Heinemann).
   - Compare force-free magnetic field models to available coronal imaging data (Canfield, Metcalf)
   - Compare connectivity of force-free models to that of point charge models (Regnier, Longcope, Leka)

3. Develop velocity inversion methods
   - Use vertical component of induction equation to derive velocity fields (Longcope, Fisher, Welsch)
   - Constrain the solutions by minimizing total kinetic energy (ditto)

4. Test velocity inversion methods
   - Generate fake magnetogram sequences from the MHD simulations (Abbet, Fisher)
   - Use velocity inversion techniques to infer velocities from these sequences (ditto + Welsch)
   - Compare photospheric boundary velocities from the simulation to those inferred from the inversion (same as above)
   - Explore implications of magnetogram uncertainties through Monte Carlo methods (same as above).
5. Study a second (simpler) event – May 12, 1997
   - Identify a simpler solar and IP event for analysis (1997 May 12 halo CME in AR8038?).
   - Produce a vector magnetogram (Solar Flare Telescope / Mitaka?) sequence for this event.
   - Carry out an analysis parallel to that of the 1998 May 1 event (no velocity observations available – or use LCT methods for $v_t$, MDI for $v_I$) (Liu + Welsch)

Figure 4 – vertical magnetic field map of AR 8210 with all magnetic flux concentrations labeled (courtesy Dana Longcope).

Phase II. Carry out MHD simulations

1. Do Zeus AMR simulations using real magnetic field data near time of CME using synoptic magnetic field solutions as boundary condition. (Berkeley team members)
2. Couple coronal and interplanetary codes (Abbett, Ledvina, Odstrcil)

Phase III. Validation of modelling using available solar and IP data (team)
**Numerical experiments to understand CME initiation:**
*(Workshop held May 14-16 at UNH in Durham)*

This workshop was organized by Terry Forbes, and was attended by many members of both the Michigan and Berkeley MURI teams, as well as scientists from AFRL and NRL. The objective of the workshop was to define the most urgent numerical MHD simulations needed to understand the physics of magnetic field eruption on the Sun (ie CME initiation). What emerged were 3 different classes of investigation that the participants felt were necessary. These are outlined below in a very skeletal form.

**I. The emerged bipole**

- 3-d Emerged Bipole: Form a flux-rope in a simulated corona by converging footpoints of coronal fields (analogous to “flux cancellation” seen near neutral lines in filament channels)
- the computational domain is 3-d non-periodic box with high $\beta = 10^?\) on bottom boundary, with stratification such that $\beta << 1$ within lower part of simulation volume.
- initial condition (IC) has volume-filling dipole field.
- impose incompressible converging flows on bottom boundary (if initial configuration is slightly twisted) or converging flows with shear (if initial configuration is untwisted).

**II. The emerging, twisted bipole**

- Flux rope in coronal volume is formed via the emergence of a pre-existing twisted flux tube from a region of high $\beta$ to low $\beta$
- Initial conditions: buoyantly unstable horizontal twisted flux tube immersed in high-$\beta$ plasma at base of gravitationally stratified 3-d box.
- Follow rise of twisted flux tube from deep in convection zone through photosphere into corona. Critical issue: initial position of tube cannot be too near surface, as flux tube curvature matters.
- Unspecified parameter: degree of twist in emerging tube. Twist too high perhaps prevents mass drainage, hampering emergence; twist too low does not give true flux rope in corona.
- Unspecified parameter: Magnetic field configuration in corona prior to flux rope emergence. Initial runs w/field-free corona envisioned.
- As above, primary goal is to get flux rope in corona; subsequent efforts to attain eruption envisioned after attainment of primary.
- As above, some modification of existing codes necessary.

**III. Emergence Within a Multi-Polar Configuration**
- Emerge one flux tube into into a background magnetic field; the sheared arcade/flux rope formation is by reconnection between emerging flux and pre-existing flux. Initial conditions: buoyantly unstable flux tube immersed in high-β plasma at base of gravitationally stratified 3-d box with background magnetic field configuration composed of a pre-emerged flux tube and large scale “restricting field”, and form sheared arcade/flux rope by reconnection between the two flux tubes. The critical issue: without restraining field, reconnected flux expected to rise to top of computational volume in non-explosive manner.
- Primary goal is attainment of sheared arcade/flux rope in corona; subsequent effort to attain eruption envisioned.
- In one effort to attain eruption, additional polarity will be added to restraining field to make it quadrupolar.
- Unspecified parameter: twist in either pre-emerged or newly-emerging flux ropes. Presence of twist might either enhance or diminish storage of energy in the field, and hence likelihood of eruption.
- The full specification of all the necessary magnetic elements for this class of simulations is illustrated with the simple diagram below:

![Diagram](image)

Figure 5 – an illustration of the full multi-polar configuration for the 3rd class of numerical experiments. Initially, only the interaction between the two central bipoles (one pre-existing, the other emerging) will be considered. The magnetic neutral line between them is shown as the dashed curve. An additional overlying, constraining bipole field will then be considered; finally, a very large-scale bipole with the opposite polarity will be added. The last bipole can be considered as a schematic representation of the overall solar dipole field. This last level of complexity is necessary to create magnetic null points in the corona and hence achieve a “breakout” topology.

**Deriving Self-Consistent Velocities from Sequential Vector Magnetograms**
One of the major technical obstacles identified at the vector magnetogram workshop was determining the physically self-consistent vector velocity field at the surface where vector magnetic fields are measured. Dana Longcope (MSU) has achieved a major breakthrough on this problem, and has created a mathematical framework to describe the problem and has proposed a solution, and written an “alpha” version of an IDL procedure to implement the solution. The details of Dana’s formalism can be found on the Solar MURI website at http://solarmuri.ssl.berkeley.edu/~dana/public/presentations/ as SHINE02.ps. Current versions of the IDL software can be found in the “team” part of the website as http://solarmuri.ssl.berkeley.edu/~dana/team/software/. Shown below is a comparison of the velocity field from a real MHD simulation of flux emergence, and that derived using Dana’s inversion technique.

![Comparison of velocity fields](image)

Figure 6 – Comparison between velocity field from an MHD simulation (left) and the reconstructed velocity field using Longcope’s inversion technique (right)

The Quarterly Reports:

Work Performed from August 1 2001 – September 30, 2001

OVERVIEW OF ACCOMPLISHMENTS FOR PAST 2 MONTHS

Major progress was made in numerical modeling capabilities over the past 2 months, with both the solar coronal (ZeusAMR) and heliospheric MHD codes (ENLIL) being upgraded to include adaptive mesh refinement. These efforts are not complete, but the codes are running and are currently being debugged and tested.

Observational efforts continued at BBSO, UH, MSU, and UCB, with Yan Li and Dick Canfield continuing their efforts to construct a database of well-observed CMEs for in depth studies, and BBSO conducting a coordinated flare campaign.
Instrument construction, repair, and upgrades continue at BBSO and UH.

New papers were reported by Jing et al. (UH), Wang et al. (BBSO).

The Solar MURI website and data sharing server was set up and is now operational; the URL is http://solarmuri.ssl.berkeley.edu. All Solar MURI team members should have received email about how to use the data sharing aspects of the website, as well as how to log in and what the passwords are. If a login account for new MURI team members is necessary, please contact George Fisher (fisher@ssl.berkeley.edu) or Bill Abbett (abbett@ssl.berkeley.edu).

Detailed descriptions of work accomplished at each institution now follow. In the plain text, emailed version of this report, the Figures will be included as attachments (.jpg or .gif images), while the web-page version, which should appear within the next few days, will have the figures incorporated into the report itself. You should find 3 Figures attached to this email message, in addition to the text itself.

**UC Berkeley Report compiled by George H. Fisher**

Steve Ledvina and Bill Abbett have worked on combining the PARAMESH adaptive mesh algorithm with the ZEUS 3D MHD code after attending our "Paramesh" mini-workshop with MacNeice and Odstrcil at GSFC in July. They have succeeded in getting the combined new code (dubbed "ZeusAMR") to run, and are performing a series of test simulations. This effort involved a significant re-write of the underlying ZEUS code. The ZeusAMR code will eventually be used for both large and small scale coronal simulations. Abbott, Ledvina, Fisher, and MacNeice have submitted an AGU abstract describing this work for the Fall 2001.

Yan Li worked with Dick Canfield at Montana State University on the continuing construction of the MURI case studies data access website. She has also started to make the MDI magnetogram data sets to be linked to this table. These data are also available as movies made to show the time evolution of the active regions in the full-disk field context, see http://sprg.ssl.berkeley.edu/~yanli/mdicrmov.html. An abstract has been submitted to the Fall AGU meeting on the work described in the previous monthly report, involving the response of global potential field models to Bill Abbett’s modeled emergence of active region fields.

Janet Luhmann is examining the helmet streamer belt configuration at times of CMEs and the location of the involved active region with respect to the helmet streamer belt. This work relates to understanding both global coronal context of CMEs and CME initiation in future global MHD models. An abstract on this has also been submitted for the Fall AGU meeting.

George Fisher and Neil Griffiths have mostly completed the Solar MURI web site, http://solarmuri.ssl.berkeley.edu, and have set up a new server to host the web page, as
well as to serve as a centralized exchange for data and other information pertinent to the Solar MURI project.

**BBSO/NJIT Contributions - Report received from Peter T. Gallagher**

(1) Coordinated Flare Observations: During August, we coordinated a week-long campaign to search for impulsive chromospheric Doppler shifts associated with large solar flares. Two simultaneously clocked 50 Hz CCD cameras were set up on two orthogonal benches of the 65-cm telescope at BBSO. Light from the telescope was directed to each bench by a 50:50 beamsplitter, and then to two H-alpha Lyot filters tuned to H-alpha line center +/- 0.3 A. In conjunction with these data, high-sensitivity vector magnetograms were simultaneously obtained using the Digital Vector Magnetograph (DVMG). We are currently in the process of reducing and analysing the data.

(2) Max Millennium Flare Catalogue: Software was completed to format the observing logs from the Owen's Valley Solar Array (OVSA) and the BBSO lead Global H-alpha Network for the Max Millennium Flare Catalog.

(3) Visible-Light Fabry-Perot: Control software is now being developed to synchronize the Queensgate ET-50 Fabry-Perot with an SMD 1M60 camera. The system will be moved to the dome for testing in October or November.


**Drexel University - Report received from Peter MacNeice.**

We continued development work on our existing CME `breakout' model code, continued development work on a High Order Godonov version, and interviewed candidates for a post-doctoral position in support of this project.

Previously we implemented a number of fixes to handle a numerical cavitation problem which had appeared in high resolution runs of the ARC_FCT2.5D_AMR code. These fixes seem to be a source of instability, which we have been attempting to characterize. Mr. Jimin Gao has been working to generate a more general initial field configuration for the numerical model. Specifically, we have generated a multipole field which will enable us to test the breakout model in 2.5D by applying shear away from the equator.

Mr. Jimin Gao has designed a test problem for the high order Godonov code under development, using the Sedov-Taylor analytic solution for a large point explosion in 3D.
We conducted phone interviews with four candidates for a post-doctoral position that will support this project.

**Montana State University - Report received from Dana W. Longcope.**

To choose appropriate case studies for the observational part of our project, it is necessary to gather information -- which regions are well observed from the point of view of modeling? For this purpose, Canfield worked with Yan Li (UCB) to add Robert Leamon's extensive list of eruptions from sigmoids to her Solar MURI event list. Although the two lists have not yet been integrated, Yan Li has now put Leamon's list on the web: [http://sprg.ssl.berkeley.edu/~yanli/muri/sigmoid.table.html](http://sprg.ssl.berkeley.edu/~yanli/muri/sigmoid.table.html).

Canfield and MSU undergraduate Zachary Holder started a web page that documents the availability of Hawaii vector magnetograms for events in Yan Li's event list: [http://solar.physics.montana.edu/muri/vec/](http://solar.physics.montana.edu/muri/vec/). Our next job is to identify vector magnetograms that are relevant to events in Leamon's list and add them to this web page.

Piet Martens submitted an abstract and prepared a paper for the Yohkoh 10 meeting, but its delivery has been postponed to January. He has been reading up on recent Big Bear papers on onset and triggers of filament eruptions.

Dana Longcope began work with Stephan Regnier, who will begin Post Doctoral research under MURI funding in November. The two set about comparing topologies found using full MHD extrapolation to those found using Magnetic Charge Topology models. Active region 8151 was selected since Regnier had previously performed extrapolations of this region. The comparisons will later be perfomed on regions selected from MURI event list.

The following paper, which was reported as "in press" at the last bi-monthly report, has now been published:


**Stanford Contributions - Report received from Yang Liu.**

In the past two months from August 1 to September 30, we have tested our method to generate the Carrington synoptic maps using vector photospheric magnetic field in place of the light-of-sight photospheric magnetic field, and developed our extrapolation code so that this code can be used to calculate non-linear force free field in heliospheric coordinate system.

To generate vector magnetic field synoptic charts, we firstly calculate potential field from synoptic charts. So, we obtain potential field in the photosphere.
Secondly, we remap the photospheric vector magnetograms taken by the magnetographs. Generally such observations are available in active regions. Finally, we replace those remapped vector magnetograms to the potential field synoptic chart. We use Gaussian function to smooth the vector magnetic field synoptic chart in order to reduce the 'seam' effect (see attached figures).

Figure 7 - left panels -- the potential field synoptic chart; right panels -- the vector magnetic field synoptic chart.

The extrapolation code based on Boundary Element Method has been developed to be able to calculate non-linear force free field in the heliospheric coordinate system. Thus the global non-linear force free field can be reproduced from the vector magnetic field synoptic chart. We have calculated the potential field using this code, and will compare it with other methods.
Figure 8 - top panel-- the vector magnetic field synoptic chart; low panel-- the potential field synoptic chart

UCSD Contributions - Report received from Bernard V. Jackson

During these months of the MURI project Tamsen Dunn's work has allowed an accurate incorporation of magnetic field into our time-dependent tomographic model. With the help of the UCSD MURI Co-Is and Todd Hoeksema and Xuepu Zhao, Tamsen has successfully incorporated the Zhao and Hoeksema (1995) magnetic field model into our solar wind analysis for eventual use in real-time magnetic field forecasting. Tamsen has also included the conversion of coordinates at Earth from our model into GSM coordinates for comparison with ACE and other data sets. These data comparisons are now underway, and will be presented at the fall AGU (Dunn et al., 2001). With the help of other students we have made these magnetic field data available for viewing in three-dimensions and will also present these visualizations at the AGU (Hick et al., 2001).
Further MURI work was also continued on the incorporation of a 3D MHD model into our computer code with the help of the group at NOAA's Space Environment Center. A version of Tom Detman's 3D MHD code to compiles and runs here on our UCSD computers. We have explored some aspects of the way to place this program into our time-dependent tomography.

References:


**Colorado/CIRES Report received from Dusan Odstrcil**

We continued incorporation of the Paramesh package into the 3-D interplanetary solar wind code ENLIL. The hydrodynamic part of the code was successfully tested on various test problems. An example (interaction of shocks, origin of new contact discontinuity, and formation of a jet due to Rayleigh-Taylor instability) can be seen as an animated gif at this URL: [http://solarmuri.ssl.berkeley.edu/~odstrcil/public/images/r468.gif](http://solarmuri.ssl.berkeley.edu/~odstrcil/public/images/r468.gif). We spent some time investigating various criteria and conditions for refinement and derefinement of the numerical grid. The magnetic part of the code has been modified as well and its verification is in progress; together with development of IDL procedures for visualization of the magnetic field on block-structured data.

Odstrcil was invited to present a talk on "Numerical Simulations of Interplanetary Disturbances" at the SOLSPA (Solar Cycle and Space Weather) conference in Vico Equense, Italy, September 24-29, 2001.

**University of Hawaii - received from Jeff Kuhn.**

We continue to support the on-line vector magnetic field measurements obtained from the IVM. An intermittent electronic steering-mirror servo gain problem was identified and tentatively solved. A replacement servo control module for the IVM mechanisms was identified and has been procured. The filter wheel required for rapid line selection (between photospheric and chromospheric lines) has been fabricated.

The SOLARC instrument declination drive and clutch assembly were fabricated and installed in the telescope in order to improve its pointing stability.
The paper "Persistent Coronal Streamers and Identification of Sunspot Clusters" by Jing et al. has been accepted for publication in ApJ. This paper shows how large scale coronal streamers can be sustained by the global field contribution from long-lived sunspot clusters.

**University of New Hampshire - received from Terry Forbes.**

Terry Forbes has been working with Dave Webb on a comparison of CME observations from SMM and SOHO with predictions of a previously published model by Lin and Forbes (2000) for the growth of the current sheet which forms in the aftermath of a CME. One of the key factors which affects how the position of the lower and upper tips of the current sheet evolve with time is the variation of the coronal density with height. This variation affects the rate of reconnection in the sheet, and thus, the rate at which the current sheet is eroded by reconnection.

After comparison of the SMM observations with the published model it has become apparent that the exponential density model previously used is not adequate. However, by replacing the exponential density model with a much more realistic one published by Sittler and Guhathakurta (1999), we have now been able to obtain as reasonable agreement as can be expected for the Lin and Forbes model which is not really valid at large distances (> 3 Rsolar) away from the Sun.

Two aspects of this work which may be of interest to other team members are: (1) the Sittler and Guhathakurta model provides a fairly realistic density model of the inner corona while at the same time being relatively easy to implement in a theoretical analysis. (2) Although the Lin and Forbes model provides the essential ingredients to account for the onset and initial propagation of CMEs it is severely limited by being a planar, two-dimensional model. In its present form in can only provide qualitative results, but it has the potential to serve as a guide to the behavior expected to occur in more realistic, three-dimensional models.
Figure 9 - This diagram shows the emergence from the Sun of a CME/flux-rope (blue shaded region) which drives a shock (thick red arc) into the ambient solar wind. Ions (dots) are accelerated by the process of diffusive shock acceleration and excite hydromagnetic waves in front of the shock (denoted by wiggles in the spiral magnetic field). The excited waves, which greatly enhance the rate of ion acceleration, are transmitted through the shock and trap accelerated ions downstream where they are cooled in the expanding solar wind. At the outer extent of the excited-wave sheath some precursor ions escape the shock by magnetic focusing and propagate nearly scatter-free to Earth orbit (denoted by a schematic Earth with bow shock).

References:


Work Performed From October 1 2001 – December 31 2001

Progress toward our MURI goals is described in detail in the sections as organized by sub-award institution. During the next 10 weeks, George Fisher and Dana Longcope (member of the Solar MURI team) will be at the Institute for Theoretical Physics in Santa Barbara, participating as "program coordinators" for a special program on Solar Magnetic Fields. Many other members of our team will also be participating in this program, and our next quarterly report will describe research done at the ITP that is supportive of our project.

UC Berkeley Report (assembled by George Fisher)

Fisher organized the December 9 2001 MURI team meeting which was held at the Space Sciences Lab. The focus of that meeting was the organization of several "mini-workshops" over the coming year. The minutes of the meeting will be posted on the "solarmuri" website separately. Briefly, the mini-workshops will address these topics: (1) Well defined numerical experiments exploring CME eruption mechanisms (hosted by Terry Forbes at UNH from May 14-16), (2) How to use vector magnetogram observing sequences to drive MHD codes (hosted by George Fisher at UCB around the 1st week of May), and (3) a workshop on constructing global magnetic maps of the Sun, to be held in Boulder on April 15. Bernie Jackson is organizing this workshop.

Abbett and Ledvina demonstrated the new code ZeusAMR, a merge between PARAMESH and Zeus3D, at the Fall AGU by performing simulations of magnetic flux emergence into the low corona. The 3D MHD code ANMHD was used to drive the photospheric boundary with the top of a rising, moderately twisted Omega loop, and ZeusAMR was able to refine the mesh where the bipole emerged through the photosphere and corona, allowing the simulation box to span a large portion of the low corona while simultaneously resolving the region of interest.

Ledvina has continued work with the non-AMR version of ZEUS-3D in spherical coordinates. The current challenges in that area are the proper description of the inner boundary conditions, and the need for implementation of the Boris correction scheme in order to reduce the time step size.

This spring, Ledvina will take the lead role in developing a spherical version of ZEUS-AMR that will be applied to the global corona.

Yan Li has made major progress working with Dick Canfield on the MURI case studies data collection and website. The event list is becoming quite large since different groups are studying different types of phenomena (e.g., the Montana focus on sigmoids, her own focus on CMEs). The progress on this can be seen at the website http://sprg.ssl.berkeley.edu/~yanli/muri/events.html. Yan Li also presented a poster at the Fall AGU meeting showing the response of global potential field models, based on a large-scale photospheric dipole field, to Bill Abbett's model of emerging active region
fields. The poster included a first attempt to model the same event in a time-dependent global MHD simulation, carried out by Jon Linker at SAIC, who collaborates with us through a related NSF Space Weather project. The work shows the evolution of coronal hole extensions in response to the active region emergence, similar to the "Whole Sun Month" study period scenario. The helmet streamer above the active region has the appearance of splitting when it is on the limb, as is sometimes observed in coronagraph images. No major transient loop eruption was produced in this preliminary study using the MHD model, but the emergence was slow enough to allow almost quasistatic adjustment of the corona, and there was no twist in the emerging active region fields or shear in the initial helmet streamer belt. Future work along these lines is planned to consider the impact of all of these factors.

Janet Luhmann presented a Fall AGU poster focused on examining the relative locations of helmet streamer belt and the involved active regions at times of CMEs. In the low solar activity cases examined, the involved active regions were often located in closed field regions outside of the main helmet streamer belt determined from potential field source surface models. Occasionally, the active regions lay beneath the helmet streamer belt. The interplanetary consequences for these scenarios seem to differ, with the former producing ICMEs in low speed wind at ACE and the latter producing ICMEs on the leading edge of high speed streams. However, tooo few cases have been examine thus far to conclude that this occurs as a rule. It also appears that the active region fields become engaged in the helmet streamer belt following eruptions in the cases where they are initially isolated. However, this interpretation is greatly limited by the use of potential field models to describe the active region fields. Work along these lines will continue in an effort to help define realistic CME simulation scenarios.

We have made an offer of a postdoctoral appointment to Brian Welsch, who is completing his PhD in Physics at Montana State University under Prof. Dana Longcope. Welsch plans to join our group in February or March, and will work on projects in collaboration with MURI team members and with our solar colleagues at the Naval Research Laboratory.

**BBSO Report (sent by Yong-Jae Moon)**

(1) Visible-Light Fabry-Perot for Imaging Vector Magnetograph: After successful testing a Queensgate ET-50 Fabry-Perot in our laboratory, we are preparing for testing it on our 65 cm telescope. We expect camera control software to be ready soon.

(2) Global H-alpha Network: Now we are providing recent solar flare movies and daily full disk movies from global H-alpha network (http://www.bbso.njit.edu/Research/Halpha/). Their observing logs and charts are also available.

(3) Field orientation in the interplanetary flux ropes and filaments: Using ACE measurements of the interplanetary magnetic fields, we define the orientation of magnetic flux ropes in magnetic clouds and compare them to the orientation of the solar magnetic fields and disappearing filaments. We have found that the direction of the axial field in
the flux ropes and their helicity are consistent with the direction of the axial field and helicity of the erupted filaments. Thus, the geoeffectiveness of a CME is defined by the orientation and structure of the erupted filament, and by its magnetic helicity, as well. We now use this technique to forecast geoeffectiveness of CMEs using full disk H-alpha images from the Global H-alpha Network, full disk SOHO/MDI and high resolution BBSO DMG magnetograms (Yurchyshyn al., ApJ, in press).

(4) Magnetic field changes associated with a X20 flare: Big Bear Solar Observatory observed the X20 flare that occurred at approximately 21:50 UT on 2001 April 2 with its standard complement of instruments. We have studied the evolution of high resolution and high cadence longitudinal magnetograph observations in the region of the flare. The data reveal that there was a significant increase in the magnetic field on the limbward side of the neutral line of the active region at the location of the flare, while the magnetic field on the side of the neutral line closer to the disk center remained constant (Spirock et al. submitted to AJ).

(5) Relationship between magnetic helicity and flaring flux: Using a set of 6.5 hour 1 minute cadence MDI magnetograms of NOAA 8100, we have obtained the magnetic helicity transport rate via photospheric footpoint shuffling motions. As a result, we have found a very close correlation between the integrated X-ray fluxes of homologous flares and the corresponding magnetic helicity accumulated during the flaring time interval. We also note an abrupt increase of photospheric shuffling motion around the flaring time of M4.1 flare. (Moon et al. in preparation)

(6) Statistical evidence of sympathetic flares We collected 48 sets of sympathetic flare candidates, a pair of consecutive flares in which the second flare starts before the first one ends. To separate highly probable sympathetic flares from them, we estimated the ratio of actual flaring overlap time divided by random- coincidence time. We have found a noticeable overabundance at short time intervals in the waiting time distribution of highly probable data, implying that sympathetic flares really exist. It is also noted that transequatorial loops are more intimately associated with them than longitudinal loops are. (Moon et al. in preparation)

(7) Publications:

Yurchyshyn al.'s paper entitled with "Orientation of magnetic field in the interplanetary flux ropes and solar filaments" is accepted for the publication in the ApJ.

Moon et al's paper entitled with "Force-freeness of solar magnetic fields in the photosphere" is accepted for the publication in the ApJ.

Moon et al's paper entitled with "Flaring time interval distribution and spatial correlation of major X-ray solar flares" is published in the A12, 2001 issue of JGR-space physics.

Drexel University Report received from Peter MacNeice
In summary, we continued development work on our existing CME `breakout' model code, continued development work on a High Order Godonov version, and we filled a post-doctoral position.

We have implemented a revision of the Boris correction, in combination with a Lorentz factor, in an attempt to control spurious velocities associated with the cavitation phenomenon. We are currently testing this design.

We have begun building support for non-cartesian coordinates into the development version of Paramesh, in preparation for its use with the high order Godonov code under development.

We made an offer of a post-doctoral research position to Mr. Andrew Phillips from the University of Manchester, UK, contingent upon his successful completion of his PhD, which he has accepted. His expected start date is early February 2002.

**Montana - report received from Dana Longcope**

To choose appropriate observational case studies for our project, it is necessary to determine which regions are well observed, in the sense that they provide useful constraints for numerical modeling (case studies). One of the necessary conditions is that the region be well observed in the form of Hawaii vector magnetograms. For this purpose Canfield and MSU undergraduate Zachary Holder completed a web page [http://solar.physics.montana.edu/muri/vec/](http://solar.physics.montana.edu/muri/vec/) that documents the available Hawaii vector magnetograms for all solar events that appear in either Yan Li's list of interplanetary events and Bob Leamon's list of interplanetary events associated with eruptions in sigmoid.

On November 26th, Dr. Stephane Regnier, from the Institut d'Astrophysique Spatiale in Orsay, France, took up a postdoctoral fellowship in the MSU solar group immediately after successfully defending his thesis on modeling of the 3D structure of coronal magnetic fields. He promptly set to work to identify those regions on the lists of Li and Leamon which are best observed from the point of view of the Hawaii magnetograms, using the information gathered by Canfield and Holder.

In November, Dr. Stephane Regnier joined the group as a Post Doctoral Research Associate. He has begun installing the code with which he will extrapolate vector magnetogram data.

Piet Matens participated in Sara Martin's PROM workshop in Sac Peak in the week of October 12, and presented my paper on "Origin and Evolution of Filament-Prominence Systems", as a well as a summary of the work I did with REU student Paul Wood (St. Andrews) in the summer of 2000.

On November first Matens gave the Astronomy research seminar at MSU, entitled

Piet martens worked on a model of filament formation in delta-spots, that is consistent with my "head-to-tail" linkage idea, yet works for newly emerged flux in this delta spot as well.


**Stanford (report received from Yang Liu)**

Our website began to provide magnetic maps of the whole Sun. We continued development work on vector magnetic field synoptic charts and reconstruction of global non-linear force free field, and continued the 'synoptic chart' improvement.

The magnetic maps of the whole Sun are now available at [http://soi.stanford.edu/data/farside/index.html](http://soi.stanford.edu/data/farside/index.html). The farside images are computed from MDI surface velocity data using the seismic holography method developed by Lindsey and Braun (2000). Those farside images can show the locations of an accumulation of magnetic field on the far surface. A new whole-Sun map is computed for each 12 hours.

We have generated the synoptic magnetogram map and vector magnetic field synoptic map of CR1968 in combination with the full disk magnetograms taken by SOHO/MDI and vector magnetograms taken by ground-based magnetographs. We have therefore computed the global potential field and non-linear force free field from these maps. Comparison shows that force free field is evidently sheared while potential field has additional magnetic connectivities between active regions that don't show up in force free field. Observation suggests force free field is more realistic.

Improvement of the "synoptic chart", the monthly synoptic magnetogram maps, is going on. We are correcting the effect of east-west inclination of large-scale photospheric magnetic fields in order to get the "real" radial component by using the method suggested by Shrauner and Scherrer(1994) and further developed by Ulrich et al.(2001).

UCSD (Report received from Bernie Jackson)

During the last 3 months of the MURI project Tamsen Dunn's work allowed an accurate incorporation of Zhao and Hoeksema (1995) magnetic field model into our solar wind time-dependent tomographic model. Data comparisons were presented at the fall AGU (Dunn et al., 2001). We have made these magnetic field data available for viewing in three-dimensions and presented these visualizations at the AGU (Hick et al., 2001; Jackson and Hick, 2001). Tamsen has incorporated this magnetic field analysis into both our time-dependent and corotating IPS tomographic model. The corotating model is more stable and with higher spatial resolution than the time-dependent model, and thus
we intend the first use of our real-time Space Weather analysis to include the corotational technique.

Further MURI work was also continued on how to incorporate changing magnetic fields into our computer code with Nick Arge and the help of others in the group at NOAA's Space Environment Center. This has involved attempts to get different observatory data sets to accurately show daily changes in order that we may possibly observe CMEs in global solar surface magnetic fields as changes on short time scales as the CMEs occur. To this end we have begun a MURI mini-workshop to be convened on April 15, 2002 at NOAA at the beginning of Space Weather Week (April 16-19, 2002) for those interested in helping with this forecasting project. If you are interested in attending, please contact Bernie Jackson.

In a more recent development, we have begun a collaborative effort with Len Burlaga at Goddard to use the time-dependent tomography to map heliospheric structures that have been observed previously by multi-spacecraft in situ observations. In one of the well-studied time periods, the Helios photometer data appear to show the presence of a density enhancement behind a shock front in the inner heliosphere. Although these shock fronts have been observed in white-light before (Jackson, 1986), images of them from the tomography are a first.

References:

Dunn, T, B.V. Jackson, P.P. Hick and A. Buffington, 2001, "Introduction of the CSSS magnetic field model into the UCSD tomographic solar wind model", to the fall 2001 AGU.

Hick, P.P., B.V. Jackson, A. Buffington and M.J. Bailey, 2001, "Visualization of remotely-sensed heliospheric plasmas", to the fall 2001 AGU.


Jackson, B.V and P.P. Hick, 2001, "A study of interacting plasma phenomena using the tomographic 3-dimensional reconstruction techniques developed for the Solar Mass Ejection Imager", to the fall 2001 AGU.


Colorado/CIRE (Report received from Dusan Odstrcil)

Three different computational studies were realized by the numerical code ENLIL and results were presented at the Fall AGU 2001 Meeting.
In the first study, 3-D heliospheric computations were driven by the empirical model of the ambient solar wind for 12 Carrington rotations in 1995. This study was realized with Nick Arge from NOAA/SEC, and its aim is to develop more realistic model of the ambient background solar wind. Many large-scale structures match observations quite well, however, improvements are necessary for fast flows from coronal holes at high latitudes as well as detail structures of the slow streamer belt.

In the second study, the near-Earth solar wind was driven by WIND observations for May 14-18, 1996 events when IMP-8 and INTERBALL spacecrafts were upstream the magnetosphere. This study was realized with Chuck Goodrich from University of Maryland, and its aim is to determine how many spacecrafts at L1-halo orbit are adequate for reliable and accurate forecasting of solar wind parameters hitting the magnetosphere. Though, during studied time period, the WIND was closer to Earth than to the L1-point and solar wind did not involved large variations in speed; simulations showed difficulties in using single-spacecraft observations. Work is in progress to use other, probably more suitable, events.

In the third study, a hypothetic 2-D scenario of interacting magnetic flux ropes was considered. This study was realized with Marek Vandas from Astronomical Institute Ondrejov and Peter MacNeice from Drexel University, and its aim is to provide first insight into interacting CMEs, reported recently as cannibalistic CMEs. Numerical simulations have shown (a) distortion of a shock passing through flux rope, (b) amplification of the shock strength, (c) gradual coalescence of flux ropes, and (d) origin of plasmoids due to tearing instability. These effects strongly depend on specific plasma conditions, and work is in progress to investigate dynamic phenomena under various "typical" conditions. Using the Paramesh is particularly effective for this problem, because of fine resolution of shock interaction, reducing numerical diffusion at magnetic reconnection, and reducing computational demands.

Presentations


University of Hawaii report, sent by Jeff Kuhn

Mees synoptic data continues to be obtained in conjunction with the Hessi targets defined by the Max Millennium Chief Observer. IVM magnetograms have been obtained for all active regions and rapid cadence magnetograms of Max Millennium selected regions are
being archived. MCCD-H-alpha imaging spectroscopy of Max Millennium targets have also been obtained. Mees data will soon be archived to DVD media.

Hardware modifications to the IVM have been completed. A filter wheel for Na and Fe-line magnetograms is installed and awaits software integration into the observing system. The clutch assembly for the SOLARC declination drive was tested and removed -- we anticipate installing a tangent arm assembly to stiffen the declination pointing. The prime focus heat dump and occulting assembly has been designed and optical baffling assemblies are currently being fabricated in the mechanical shops.

The IR camera and fiber spectrograph has been operated in the Waiakoa laboratory but currently is waiting for a repaired vacuum pump.

Jing Li is extending her study of persistent coronal streamers (ApJ, 2002, Feb. 1) to see if photospheric magnetograms can be used to predict and understand the large scale coronal structure. Li will also combine this study with CME data to look for statistical clues to the triggering mechanisms for CMEs.

**New Hampshire - report received from Terry Forbes**

M.A. Lee gave a presentation at the Dec. 9th 2001 Team Meeting prepared by T.G. Forbes. The presentation included a proposed configuration for the onset of CMEs which could be tested using a global 3D MHD model. The proposed configuration is a generalization of a configuration published in 1999 by S. Titov and P. Demoulin (1999), and it is shown in the attached figure. The configuration is based on previous work by many authors (e.g. van Ballegooijen and Martens 1989 and Lin et al. 1998) and is closely related to configurations proposed by Low (1994), Amari et al. (2000), and Sturrock et al. (2001), among others.
Figure 10 - Field sources for an idealized configuration which has been proposed by Titov and Demoulin to explain the onset of CMEs. The field is comprised of three different sources: (1) a flux rope, (2) an imaginary circular line current at depth, d, below the surface, and (3) positive and negative imaginary magnetic charges (monopoles) also at depth d below the surface. It has been conjectured that the field will lose equilibrium or stability when the larger radius, R, of the flux rope exceeds the square root of two times the distance, L, between the two charges.

The MURI contingent at the University of New Hampshire will host a three-day workshop devoted to the topic of CME initiation will at the Durham campus of the University of New Hampshire from May 14 to 16, 2002. Participation will be by invitation only but will include Navy, Air Force, and other non-university participants. The principal goal of the workshop is to come up with a series of magnetic field configurations which can be used to test various proposals for the onset of CMEs based on either ideal-MHD, or resistive-MHD mechanisms.

Cited References:


Low, B. C., Magnetohydrodynamic processes in the solar corona: Flares,


ITP program on solar magnetism

Solar MURI team members Fisher and Longcope were the coordinators of a program at the Institute for Theoretical Physics at UCSB entitled "Solar Magnetism and Related Astrophysics", which took place between January 14 and March 29 of 2002. The program was attended by solar physicists and other astrophysicists from many parts of the world, and included several other Solar MURI team members (e.g. Abbet, Forbes, Goode, Ledvina, Luhmann, Lundquist & Wang) and a number of our Associate team members (e.g. Fan, Gibson, & Metcalf). To kick off our program, we organized a conference entitled “Observational Challenges for the next Decade of Solar Magnetohydrodynamics” which took place January 16-18. The schedule of talks, and the slides and actual audio/video of the talks at this conference can be viewed or downloaded from http://online.itp.ucsb.edu/online/solar02/si-conf-schedule.html. A significant part of the conference was devoted to observations of eruptive flares and CMEs.

The scientific topics addressed by program members ranged from the origin of magnetic fields in the solar interior to the structure of the outer corona. During most of the 11 weeks of the program, we had roughly 3 talks per week. The slides of these talks, as well as the audio/video of these talks, can be viewed or downloaded from http://online.itp.ucsb.edu/online/solar02/. The talks are a representative sample of the work that was done during the program.

We are grateful that the ITP decided to fund a program in Solar Physics at this time, and honored to play a major role in coordinating the program. The Solar MURI project benefited greatly because of collaborative research that occurred on several problems of interest to the project.

New MURI scientists

Two new postdocs were hired with MURI funding, including Andrew Phillips (Drexel University) and Brian Welsch (UC Berkeley).

DURIP Funding for New Equipment

Congratulations to MURI team members from UH and BBSO for their successful DURIP proposal to AFOSR! This DURIP proposal will greatly improve observing facilities on Haleakala and at BBSO that support our Solar MURI observational research.

MURI Mini-Workshops
Planning for at least 3 MURI mini-workshops has taken place over the past 3 months. Bernie Jackson is sponsoring a workshop on synoptic-scale magnetogram data on April 15 in Boulder; Fisher and Canfield are sponsoring a workshop April 29-May 1 at Berkeley on the use of vector magnetogram data in numerical simulation, and Forbes is hosting a workshop May 14-16 in Durham NH on magnetic configurations that lead to eruptive phenomena. If you are interested in attending one of these workshops contact Bernie Jackson, George Fisher, or Terry Forbes, respectively.

The next Solar MURI team meeting will take place at the SPD/AAS meeting in Albuquerque, most likely Sunday June 2. The date will be finalized in the near future.

Following are the reports from the individual institutions:

**Berkeley (Assembled by G. Fisher)**

Brian Welsch, a recent Physics graduate of Montana State University, was hired as our “Solar MURI postdoc”. Brian will collaborate with various members of our team and with our Associate team members at NRL in Washington. Brian started work as of March 1, 2002.

Fisher spent most of his effort in the past 3 months as a program coordinator for the ITP program on Solar Magnetism, along with Dana Longcope. He and Canfield hashed together the agenda for the MURI mini-workshop on using vector magnetograms in MHD modeling of the solar atmosphere.

Abbett and Associate team member Yuhong Fan from HAO have successfully merged Fan’s version of ZEUS-3D into the ZeusAMR code. One of the many improvements of this updated version is that the Zeus-3D transport step is no longer directionally split; thus, far fewer inter-block communications are necessary in a given time step, making the AMR code more efficient. Abbett has begun work on using MacNeice’s PARAMESH framework as a "code-coupling" tool to merge subsurface simulations of active region flux emergence to the ZeusAMR model corona.

Ledvina has continued work on the develop a steady-state global MHD coronal model using the Zeus-3D code. He has added the Boris correction/Alfven limiter to Zeus-3D. Standard MHD does not restrict the propagation speed of Alfven waves. Plasma conditions near the base of the corona can result in unphysically high Alfven speeds. Boris (1970) included the displacement current in his re-derivation of the MHD equation. This resulted restricting the propagation speed of the Alfven waves to the speed of light. Boris then suggested that the speed of light could artificially be lowered allowing an explicit calculation to take larger time steps. This has resulted in a factor of five increase in the speed of our simulation runs. Ledvina has also experimented with different ways of treating the subsonic subAlfvenic lower coronal boundary. Together with Abbett he has begun work on using MacNeice’s PARAMESH as a frame work for coupling different simulations. He has carried out a few proof of
concept experiments and examined some of the dangers of miss-matched physics at code interfaces.

Janet Luhmann participated in the solar magnetism Institute for Theoretical Physics Workshop convened by Longcope & Fisher at UCSB, where she presented a seminar on "The large scale coronal context of CMEs". Other aspects of this work were also described in a poster presented at the First STEREO Science Workshop in Paris.

A collaboration between Yan Li, Luhmann, and Stanford MURI Cols, is slowly converging on a picture that rules out large-scale photospheric field changes as an underlying cause of CMEs. Rather, it is pointing to the interaction of nonpotential active regions with the helmet streamers as the underlying process. They are examining several periods where the relative locations of the helmet streamer belt and active regions can initially be analyzed with a potential field source surface model. Yang Liu at Stanford is applying vector magnetograms and nonlinear force free global modeling to one of these periods. The aim is to reconstruct scenarios for the interactions of active region and helmet streamer fields that can be tested with the MHD models under development by Steve Ledvina and Bill Abbett. Luhmann and Ledvina will also be giving invited presentations at the upcoming CCMC workshop in Maryland. Yan Li will be attending the MURI Magnetogram Synoptic Map workshop organized by Bernie Jackson at Space Weather Week.

**BBSO (received from Y.J. Moon)**

**Global H-alpha Network:**

Major progress is as follows.
1. Every observing day a full disk (512x512 pixels) H_alpha movie is generated.
2. BBSO also provides a real time full disk H-alpha image of the Sun.
3. An observing log in form of a graphical chart is available, which makes it easy to find out if there were observations during certain period of time.
4. Some statistics on the network performance is also available.
5. Since the beginning of the network operation, two new stations joined the network: Huairou Solar Observing Station (HSOS, China) and Catania Astrophysical Observatory of Italian National Institute for Astrophysics (CAO INAF).

**Active Region Monitor (ARM):**

We have updated the ARM with the following changes:
1. Solar event movies in EIT FeXII (19.5 nm) added.
2. Updated flare probabilities to use Poisson statistics.
3. Replaced Yohkoh/SXT images with EIT FeXV (28.4 nm).
4. Added dynamic GOES X-rays plots (updates automatically every 5-mins). This work was done primarily by Peter Gallagher, now at NASA/GSFC.
5. Gallagher et al's paper about "ARM", entitled with "Active Region Monitoring and Flare Forecasting", was submitted to Solar Physics.

Rapid Changes of Magnetic Fields Associated with Six X-class Flares:

We found significant changes in the photospheric magnetic fields associated with six X-class flares. Based on the analyses of the line-of-sight magnetograms, all six events had an increase of the magnetic flux of the leading polarity on the order of a few times $10^{20}$ Mx while each event had some degree of decrease in the magnetic flux of the following polarity. The flux changes are considered impulsive, as the “change-over" time, which we defined as the time to change from pre-flare to post-flare state, ranged from 10 to 100 minutes. The observed changes are permanent. Therefore, the changes are not due to changes in the line profile caused by flare emissions. For the three most recent events, when vector magnetograms were available, two showed an impulsive increase of the transverse field strength and magnetic shear after the flares, as well as new sunspot area in the form of penumbral structure. One of the events in this study was from the previous solar cycle. This event showed a similar increase in all components of the magnetic field, magnetic shear and sunspot area. We present three possible explanations to explain the observed changes: (1) the emergence of very inclined flux loops, (2) the changing of the magnetic field direction and (3) the expansion of the sunspot which moved some flux out of Zeeman saturation. However, we have no explanation for the polarity preference, i.e. the flux of leading polarity tends to increase while the flux of following polarity tends to decrease slightly. (Wang et al., submitted to ApJ)

A Revised Shock Time of Arrival Model for IP Propagation (STOA-2):

We have examined a possibility for improvement of the STOA Shock Time Of Arrival) model for interplanetary shock propagation. Noting observational and numerical findings that the radial dependence of shock wave velocity depends on initial shock wave velocity, we suggest a simple modified STOA model (STOA-2) which has a linear relationship between initial coronal shock wave velocity and its deceleration exponent. Our results show that the STOA-2 model not only removes a systematic dependence of the transit time difference predicted by the previous STOA model on initial shock velocity, but also reduces the number of events with large transit time differences.(Moon et al., Geophys. Res. Let., in press)

A statistical study of two classes of CMEs:

We made a comprehensive statistical study to address the question whether two classes of coronal mass ejections (CMEs) exist. We have analyzed 3217 CME events observed by SOHO/LASCO in 1996 to 2000, which are compiled in the CME catalogue by Yashiro \& Michalek. We have examined the distributions of CMEs according respectively to speed and to acceleration and investigate the correlation between speed and acceleration of CMEs. The same statistical analysis is conducted not only for the whole CME data
set, but also for two subsets containing those CMEs that show a temporal and spatial association either with GOES X-ray solar flares or with eruptive filaments. The eruptive filaments data were collected from NGDC and BBSO. The fraction of flare-associated CMEs increases with the CME speed, whereas the fraction of eruptive-filament-associated CMEs decreases with the CME speed. This result supports the concept of two CME classes. We also found evidence for two components in the CME speed distribution in the CME data associated with flares larger than M1 class and in the CME data related with limb flares. Our results suggest that the apparent single-peak distribution of CME speed can be attributed to the projection effect and possibly to abundance of small flares too.

We also note that there is a likely correlation between the speed of CMEs and associated limb flare's X-ray flux integrated over the flaring time. (Moon et al., in preparation)

Publications:

Wang et al's paper entitled with "Core and large-scale structure of 2000 November 24 X-class Flare and CME" is accepted for the publication in the ApJ.

Moon et al's paper entitled with "Statistical evidence for sympathetic flares" is accepted for the publication in the ApJ.

Moon et al's paper entitled with "Flare activity and magnetic helicity injection by photospheric horizontal motions" is accepted for the publication in the ApJ.

Moon et al's paper entitled with "A revised shock time of arrival (STOA) model for interplanetary shock propagation" is accepted for the publication in the Geophys. Res. Letter.

Shakhovskaya et al.’s paper entitled with "Limb Prominence Eruption on 11 August 2000, as Seen from Ground- and Space-Based Observations" is accepted for the publication in the Solar Physics.

Spirock et al's paper entitled with "Rapid changes in the longitudinal magnetic field related with the 2001 April 2 X20 flare" is accepted for the publication in the ApJL.

Drexel (received from Peter MacNeice)

We continued development work on our existing CME `breakout' model code, continued development work on a High Order Godunov version, and completed development work on version 3.0 of the Paramesh AMR package.

We tested a revision of the Boris correction, in combination with a Lorentz factor, in an attempt to control spurious velocities associated with the cavitation phenomenon, which appear in higher resolution runs. This fix and all of the other fixes we have attempted to date have introduced other failure modes. We are exploring the role which the FCT and
AMR play in the evolution of all these failure modes. Mr. Gao continued development of a high latitude, low resolution version of the same ‘breakout’ calculation.

We completed the coding of support for non-cartesian coordinates in the development version of Paramesh, in preparation for its use with the high order Godonov code under development. Testing is now in progress. This functionality will also be used by the Berkeley and NCAR codes.

Dr. Andrew Phillips, a new postdoc, began work on the project in mid February. He has been developing a Sedov test of the hydrodynamics of the High Order Godunov code that is under development.

Montana State University (received from D. Longcope)

During this period a key milestone was achieved -- the selection of NOAA 8210 for the first of what may be several case studies of an eruption from the Sun observed from the photosphere to interplanetary space. The reader is referred to the MSU MURI nugget written on this subject: 

While Longcope was in Santa Barbara, leading the workshop at the Institute for Theoretical Physics (UCSB), Canfield acted as MSU PI. The main work was preparation for Hawaii Imaging Vector Magnetograph (IVM) data reduction and 3D numerical modeling. We purchased and installed an Exabyte Mammoth tape drive to read IVM data tapes sent by Labonte from JHU/APL. We determined empirically that the MSU-UH Internet-2 connection is adequate for transfer of future IVM data from Hawaii. We took advantage of a two-for-one matching offer from Sun Microsystems and ordered two Sun Fire V880 workstations for the price of one. One will be used for MURI IVM data reduction and one for MURI modeling. We expect that we will be able to reduce about four IVM magnetograms per day, which will allow us to fully take advantage of the over-100 magnetograms we have for NOAA 8210 before, during, and after its May 1, 1998 ~2240 UT eruption.

Canfield gave a public talk "Sunspots, Galileo, and You" to over 400 students representing 82 schools in southeastern Montana in a regional science fair -- Science Expo 2002 -- on March 22 in Billings, MT: 

Finally, Canfield collaborated with Regnier and LaBonte to achieve a capability to reduce IVM magnetograms at MSU.

Stephane Regnier worked with R. Canfield, Y. Li and Y. Liu on the selection of a good active region as MURI case study. The active region NOAA 8210 has been the selected flaring region associated with interplanetary events. The large number of magnetic data
related to these events will allow us to study the evolution of the coronal magnetic field and the interplanetary field.

Stephane Regnier worked with the advices of B. Labonte on the reduction of IVM (MSO) data of the chosen active region.

Yang Liu and Stephane Regnier performed a successful comparison of 3D coronal magnetic fields reconstructed using two different methods.

Piet Martens presented a paper entitled "The Origin of Prominences and Their Hemispheric Preferences for Chirality and the Skew of Overlying Loops" at then Yohkoh 10th Anniversary Meeting "Multi- Wavelength Observations of Coronal Structure and Dynamics", in January in Hawaii. A paper with the same title has been submitted for the proceedings. The paper demonstrates that the SXT observed skew of soft X-ray arcades connected to prominences is consistent with the Martens-Zwaan model for the origin of prominences.

His proposal to the M.J. Murdock Foundation entitled "Correlation Between Solar Prominences and Sigmoids" was accepted. It will allow a local High School teacher to work with him and Alex Pevtsov to develop a visual on-line sigmoid-prominence catalog for the duration of the Yohkoh mission, an activity clearly relevant to our MURI effort.

Piet also contributed significantly w.r.t. filaments, their eruptions, and flares.

Piet worked further on his model for prominence formation in emerging delta-spots, the results of which will be submitted to ApJ later this year.

While at the Institute for Theoretical Physics in Santa Barbara, Longcope collaborated with Terry Forbes and Leon Golub to analyze observations of a flare on March 17, 2001 in NOAA 8906. This was a two-ribbon flare whose ribbons seems to extend into single contiguous ring. TRACE images revealed post-flare loops suggestive of a magnetic separatrix extending from what appeared to be a coronal null point. Longcope further refined his magnetic topology tools, and used them to identify the magnetic separatrix. MDI magnetograms were used to identify magnetic sources with active region NOAA 8906. From these it is possible to identify separatrices in linear force-free fields.

No value of alpha leads to a coronal null point. There was, however, a separatrix surface roughly outlining the chromospheric ribbons. A summary of this analysis is located at http://solarmuri.ssl.berkeley.edu/~dana/public/data/ar8906 flare.html.

**Stanford University (received from Y. Liu)**

In the first three months of this year, we employed a 2-D MHD code to study CME properties, and we also compared various methods of reconstruction of 3-D magnetic field based on observation.
Liu W. is using a 2-D MHD code to study the effects of topology on CME kinematic properties motivated by a new qualitative theory proposed by Low and Zhang (2002). In that theory, fast or slow CMEs result from initial states with magnetic configurations characterized by the normal or inverse quiescent prominences, respectively. The preliminary numerical results show that the distinct topologies indeed lead to fast and slow initial speeds of CMEs, which supports the theory.

We continue our work on comparison of 3-D magnetic field structure computed from observational data based on various models and techniques. It has been shown that the calculation from vector magnetic field at the surface is the best match to the observation. We expect further models, especially MHD simulation, to examine methods and to understand coronal structure. This work can be found at http://soi.Stanford.EDU/~yliu/fieldcomp/fieldcomp.html.

UCSD (received from B. Jackson)

Work these months on the MURI project has allowed further of Tamsen Dunn’s analyses to be presented at the STEREO workshop in Paris (March 18-20, 2002) (Jackson et al., 2002). To do this our magnetic modeling has been incorporated into the time-dependent tomographic model using Helios photometer data brightness measurements and archival Wilcox Solar Observatory magnetic maps. This is a first step in using magnetic data with the Thomson-scattering analyses that will eventually become available from SMEI. In addition, the Zhao and Hoeksema (1995) magnetic field model is currently used to map magnetic fields into our solar wind analysis for use in real-time magnetic field forecasting associated with the IPS data analysis. More of our work with the group at NOAA (Nick Arge) using several ground-based and space-based observatories will be presented at a MURI mini-workshop at NOAA’s Space Weather Week April 15-19, 2002.

The presentation at the fall AGU (Dunn et al., 2001) was successful, and a presentation at the AGU by Jackson and Hick (2001) is currently being readied for publication with Len Burlaga of Goddard. Len made the results of a portion of these analyses into a Christmas Card and a Goddard “Nugget” (February, 2002)

References:


University of Colorado (Received from Dusan Odstrcil)

We have learned the TECPLOT software package for visualization of 2-D and 3-D data sets (including numerical results on adaptive meshes). This enables us to investigate 3-D topology of magnetic field during propagation of interplanetary CMEs. Further, we have developed IDL procedures for producing line-of-sight images of white light scattering from the simulated density structures. Finally, in view of recent papers on accurate solution of magnetic field on adaptive meshes, we have initiated modification of the ENLIL code for using of staggered grid, and performed the first verification tests.

Presentations:


University of Hawaii (received from Jeff Kuhn)

Mees synoptic IVM data are now being archived to DVD (starting Oct. 23, 2001). Data distribution is significantly more efficient. Jing Li now has responsibility for overseeing the data distribution and for the IVM analysis. The overall data archive is accessible at http://www.solar.ifa.hawaii.edu/Reference/IVM/survey_tape_logs/ (tapes) and the new DVD logs can be found at http://www.solar.ifa.hawaii.edu/Reference/IVM/dvdlogs/. In order to accelerate the analysis of vector field data we have planned for and ordered a faster computer that will be dedicated to daily IVM analysis and distribution. External data users will have the ability to access and analyze vector magnetic field data using this system.

The SOLARC spectrograph optical bench is now in place on the summit and the grating and optics are ordered. The upper shroud for the SOLARC secondary optics has been installed. A new declination drive and an X-Y stage for the M2 mirror assembly have been fabricated. Data on the light scattering properties of the off-axis design were collected and analyzed along with planetary imagery demonstrating the optical performance of the telescope. These results were presented in a report --The Circumstellar Imaging Telescope: Concepts for a High Dynamic Range Imaging Telescope.
Jing Li and collaborators continue investigations of coronal streamers.
Between SXT and LASCO heights there are significant differences in the streamers that
can be attributed to changes from closed to open field lines. She is developing a plausible
streamer model to simulate the measurements. Related work is published in Li et al.
"Large-scale, Long-lived Coronal Structures Detected in Limb Synoptic Maps" in the
Yohkoh 10 Proceedings.

Planning for the IR camera and spectrograph began with the unofficial announcement
that hardware DURIP funds would likely be available for this activity. An active
collaboration with BBSO to develop the IR instrumentation has been initiated involving
Lin and Kuhn (IfA) and Goode and Denker (BBSO).

A Powerpoint summary of these and other results was generated for Col. Bellaire and is
available from the IfA web site.

University of New Hampshire (received from Terry Forbes)

Progress on Solar Energetic Particle Predictions:

Work has continued on perfecting a new theory for solar energetic particles
(SEPs) which treats the acceleration of particles near the shock and their transport
through space self-consistently. Unlike previous theories, the new one does not have an
arbitrary free-escape boundary where the standard Parker acceleration equations and the
free-streaming transport equations are patched together. Consequently, it is now possible
to make reasonable predictions at one AU (i.e. Earth) about the details of the energy
spectrum and abundances of the energy particles. For example the reason for the
existence of a free-streaming plateau prior to the arrival of the shock, an effect which was
pointed out by Reames (1990), can now be understood in quantitative terms.

The new theory provides a relatively easy method for obtaining SEP predictions for
various ion species from large scale MHD simulations. These predictions are made by
imputing the compression ratio and the orientation of the magnetic field at each point on
the CME shock and then applying the algebraic formulas of the new theory along the
field lines mapping to these points. No additional level of numerical simulation is
required to make these predictions, but it would be useful to test the assumptions of the
theory by carrying out numerical particle simulations.

During the next quarter Marty Lee should complete his extensive manuscript in which the
new theory is laid out and submit it to the Astrophysical Journal. The manuscript is
complete, except for a section which discusses the errors introduced by the various
approximations that the theory uses and a section on the effect of wave-wave mode
coupling (i.e. turbulence) in the shock acceleration region has on the sharp roll-off of the
particle fluxes at high energy.
Preparations continue for the Mini-Workshop on CME Initiation to be held May 14-16, 2002 at Morse Hall on the UNH campus in Durham, New Hampshire. The confirmed participants are:

Terry Forbes (UNH)
Marty Lee (UNH)
George Fisher (Berkeley)
Bill Abbett (Berkeley)
Brian Welsch (Berkeley)
Tamas Gombosi (Michigan)
Chip Manchester (Michigan)
Ilya Roussev (Michigan)
Dana Longcope (Montana)
Piet Martens (Montana)
Sarah Gibson (HAO)
Spiro Antiochos (NRL)
Rick DeVore (NRL)
Dave Webb (AFGL)
Ed Cliver (AFGL)

The goal of this workshop is to provide initial conditions that can be used to test proposed mechanisms for the onset of Coronal Mass Ejections.

Reference:

Work Performed from April 1 2002 – June 30, 2002

During the April-June period, there were a number of developments that greatly sharpened the focus of our team, as a result of 3 workshops that were hosted by several of our team members.

First, Bernie Jackson (UCSD) organized a one-day workshop on the topic of standardizing the generation of magnetic field maps made from synoptic magnetogram data, in such a way that the format of the map would be independent of the magnetogram data source. These maps are the essential input to a number of coronal source-surface models, and will eventually form the basis by which background MHD models of the solar wind are generated. The conclusion of that workshop was to endorse a plan by Nick Arge of CIERES to carry out the magnetic map standardization. This workshop was attended by members of our MURI team, the Michigan MURI team, and several other interested members of the community. A summary of the recommendations can be viewed on the Solar MURI website in the directory http://solarmuri.ssl.berkeley.edu/~fisher/public/presentations/synoptic/.

Fisher and Canfield then organized a 2 1/2 day workshop held at SSL with the objective of understanding how to use time dependent vector magnetogram data, measured at the photosphere, to drive time dependent MHD simulations of the corona. One of the main stumbling blocks is deriving a velocity field at the photosphere that is physically consistent with the evolving magnetic field there, and one which correctly incorporates flux emergence as well as horizontal flows. During the workshop we decided to focus on 2 well-observed eruptive events: The May 1 1998 eruptions from AR-8210, and the May 12 1997 event from a very simple decaying active region. This workshop was attended by members of our team, plus outside experts on the use of vector magnetograms in theoretical models such as Zoran Mikic of SAIC, and vector magnetograph experts Tom Metcalf of Lockheed and KD Leka of CORA. Mike Heinemann of AFRL also attended the workshop. An agenda of the meeting can be downloaded from the Solar MURI website in the directory http://solarmuri.ssl.berkeley.edu/~fisher/public/presentations/vmgram-workshop-2002/.

The “Plan of Action” that resulted is also available from that same directory. Immediately after the workshop, Dana Longcope made substantial headway into solving the velocity problem described above. More details are described in the Montana State University Contribution below in this report.

Terry Forbes hosted and organized a workshop to define numerical experiments on CME initiation mechanisms. The result of that workshop was a description of 3 classes of eruption models, including the evolution (shear and/or reconnection) of a single emerged dipole; the emergence of new, highly twisted magnetic flux ropes from below the photosphere; and the evolution of multi-polar configurations in which reconnection between different flux systems provides the catalyst for eruption. A summary of the 3 classes of proposed numerical experiment can be obtained from the solar MURI website...
A Solar MURI Team Meeting was held June 2 in Albuquerque at the AAS/SPD meeting to inform the team members and other interested members of the community of the results of these workshops.

Below are now the individual reports from each of our constituent team institutions.

**Report from UC Berkeley: (assembled by George Fisher)**

Fisher presented an invited talk describing work that has been done on the MURI project during the first year of funding at Space Weather week in Boulder, April 16-19.

Fisher and Canfield (MSU) organized the MURI mini-workshop on the use of vector magnetogram data that was held in Berkeley April 29-May 1 to outline strategies for using time dependent sequences of vector magnetograms to drive MHD simulations of the corona, geared towards understanding the dynamics leading to CME initiation.

Fisher, Abbett, Luhmann & Welsch attended the MURI mini-workshop at UNH on “Numerical Experiments” that are designed to organized by Terry Forbes. The outcome of that workshop was a definition of 3 classes of numerical experiment that are the most urgent for understanding the basic physics of CME initiation.

Fisher organized the summer Solar MURI team meeting held the day before the SPD/AAS meeting in Albuquerque, Sunday June 2nd. The primary purpose of the team meeting was to inform all the team members the results of the workshops, and to facilitate collaboration between team members.

To ease the storage problem for data resulting from large scale simulations for the Solar MURI project, as well as other related projects, Fisher purchased and set up a dual RAID system running on a Linux box. The RAID system uses all IDE disks, making the system far cheaper than SCSI RAID systems. The cost for 2 TB of on-line disk storage was $10K. This storage is available to all the other computers in the UCB Solar MURI group via NFS and Samba network access.

Abbett and Ledvina are currently working on the implementation of spherical coordinates into ZeusAMR, and will be working with Dusan Odstrcil for two weeks (at Berkeley) at the end of July to develop the framework necessary to couple ZeusAMR to ENLIL. Abbett and Fisher have submitted a paper to the ApJ entitled: "A Coupled Model for the Emergence of Active Region Magnetic Flux into the Solar Corona". This paper summarizes the effort to drive a simple Zeus3D model corona with a subsurface calculation performed by ANMHD. A pre-print is available to team members in Abbett's "manuscripts" directory on the solarmuri website.
At the end of June, a small miniworkshop was held at Berkeley, where Abbett, Bercik, Ledvina, Li, and Fisher worked with Yuhong Fan, and Sarah Gibson (associate members of the MURI team from HAO) on resolving specific issues of self-consistently driving models of the corona (with a prescribed initial field configuration) with simulated data from sub-surface flux emergence calculations. These types of simulations are critical for investigating the CME initiation process, and the types of boundary issues discussed at this miniworkshop are directly relevant to the numerical experiments that were proposed at the New Hamshire workshop hosted by Forbes and Lee.


After returning from the Institute for Theoretical Physics, Dr. Welsch spent the month of April running Monte Carlo simulations to test the stability of coronal holes predicted by Dr. Luhmann's potential field source surface (PFSS) code to perturbations in the surface magnetic field. In May, he attended the MURI numerical experiment definition meeting at UNH - Manchester. He then travelled to Washington, DC, for two weeks to establish the bureaucratic framework necessary to begin collaboration with Naval Research Lab (NRL) researchers Drs. Antiochos, Linton, and DeVore. While Dr. Welsch was there, these researchers agreed to undertake a simplified version of a numerical experiment proposed at the MURI meeting in New Hampshire: the forced collision of two initially distinct flux systems in a coronal MHD code, with the ultimate goal of creating a prominence-like configuration with realistic driving on the lower boundary (see figure 1). It is thought that fields possessing the correct sign of magnetic helicity should lead to a prominence-like topology, while fields with the incorrect sign will not. Efforts are now underway to begin the simulations; preliminary results should be ready for presentation to the community at the AGU meeting in December.

Graduate Student Loraine Lundquist has tentatively settled on a dissertation topic related to re-constructing a 3D temperature and density map of the solar corona, using potential field models, simple solutions for coronal loop energy equations, and a series of postulated coronal heating mechanisms. The resulting coronal configurations can then be compared with the large existing database of coronal observations of active regions to test the viability of various proposed coronal heating mechanisms.
Figure 11. In the proposed collaboration with NRL, the initial state a) consists of two bipoles which do not share flux. After applying the differential-rotation-like shear profile illustrated by the dotted velocity vectors in panel a), the boundary condition will appear as that in panels b), c), and d). In the absence of reconnection, the topology would be that of the solid arrows in panel b). As the numerical code is dissipative, reconnection will occur, yielding either the prominence-like topology in panel c), or the alternate topology in panel d). It is thought that fields containing the correct sign of magnetic helicity will lead to the topology in panel c).

Janet Luhmann and Yan Li continue to work on defining the coronal settings for CME case studies, with the goal of providing realistic boundary conditions for simulations. Janet Luhmann spent a day at the New Hampshire CME initiation workshop in May to represent some observational viewpoints. Luhmann (invited by Paul Belleria) also presented a talk on benefits of community access to models at the CCMC special session at the Spring AGU meeting in Washington DC in May. She also attended the annual Solar Physics Division Meeting in Albuquerque to give an invited paper in Bernie Jackson’s special session on magnetic field signatures of CMEs (paper title: "Using Potential Field Models to Learn About CME Coronal Context and Consequences"), and the Solar Wind X Conference in Pisa to present a contribution on development of tools for solar wind source tracking (paper title: "A Solar Wind Source Tracking Concept for Inner Heliosphere Constellations of Spacecraft"). Both the Solar Wind X Conference paper and the SPD paper are in the process of being written up for publication. Plans for the summer include a visit by Dusan Odstrcil, during which he will demonstrate how to access the output from his CME interplanetary propagation simulation. The plan is to use these MHD results to design complementary models for
solar energetic particle acceleration and transport. Lastly, with the pending start of the highly complementary Boston University-led NSF Science and Technology Center: "Center for Integrated Space Weather Modeling", plans are being discussed with George Fisher on how to take advantage of the highly complementary nature of the MURI activity and the co-located solar and heliospheric STC effort at UCB.

Yan Li attended the 2002 Space weather week at NOAA/SEC in Boulder, CO, and presented a poster paper entitled "Long term variations of the magnetic signature of ICMEs and their geoeffectiveness. Another project that Yan Li has been working on is to study the interactions of the CMEs and the coronal helmet streamer belt, and whether the different interactions are controlled by the location of the CME source regions relative to the helmet streamer belt. This work was presented as a poster at the 2002 AAS/SPD meeting in Albuquerque, NM. Both projects are on going.

Yan Li also attended the Synoptic Magnetic Map workshop held in Boulder just before Space Weather Week, and organized by MURI team member Bernie Jackson.

Steve Ledvina continues to develop his three dimensional MHD model of the solar corona using ZEUS. He is currently in the process of adding Spitzer conductivity to the model. Once it is successfully implemented it will be incorporated into Bill Abbet's emerging flux simulations and ZeusAMR. Steve has successfully incorporated Alfven wave acceleration into his simulations using a WKB approximation. He presented a paper at both the SPD and Solar Wind X meetings that compared solar wind speeds predicted by the empirical Wang-Sheeley relationship to wind speed obtained by the MHD model. The results are currently being written up for publication.

Report from BBSO/NJIT: Sent by Yong-Jae Moon

Digital Vector Magnetogram Archive Program:

Recently, the archive programs for the digital vector magnetograph (DMG) have been completed and incorporated into the BBSO archive package. Major changes are as follows.

1. Raw and corrected (for dark and flat) data files are saved in DLT tapes.
2. Corrected JPEG images are saved in CD media.
3. A set of Stokes images for an active region is used to inspect dark and flat images.

2. WWW page of DMG Data:

A web page is being made at the end of every day which is a summary of the DMG data for that day. It shows a IVQU set of every unique region observed that day. This should make searching for old DMG data in the future easier. The www page can be found in the daily archive directory as YYMMDD_dmg.html.
Impulsive Magnetic Helicity Injection:

We investigated the impulsive injection of magnetic helicity associated with major solar flares (three X-class flares and one M-Class flare) accompanying halo CMEs. By analyzing four sets of 1 minute cadence full-disk magnetograms taken by SOHO/MDI, we have determined the rates of magnetic helicity transport due to horizontal photospheric motions. We have found that magnetic helicity of the order of \(10^{41} \text{ Mx}^2\) was impulsively injected into the corona around the flaring peak time of all the flares. The impulsive helicity variations are attributed to horizontal velocity kernels localized near the polarity inversion lines. In all the events except one, the helicity injection increased the absolute value of the magnetic helicity in the corona. Another mode of magnetic helicity transport due to flux emergence and submergence is estimated to be negligible because no significant change of magnetic flux was observed during the flares. We found that there is a positive correlation between the impulsively injected magnetic helicity and the X-ray peak flux of the associated flare. Finally, we report that there is a close spatial proximity between the horizontal velocity kernels and H\(\alpha\) bright points (Moon et al. submitted to ApJ).

4. Publications:

Gallagher et al.'s paper entitled with "Active Region Monitoring and Flare Forecasting" is accepted for the publication in the Solar Physics.

Wang et al.'s paper entitled with "Rapid Changes of Magnetic Fields associated with Six X-class Flares" is accepted for the publication in the ApJ.

Moon et al.'s paper entitled with "Impulsive Injection of Magnetic Helicity Associated With Major Flares" is submitted to ApJ.

Moon et al.'s paper entitled with "A Statistical Study of Two Classes of Coronal Mass Ejections" is submitted to ApJ.

**Report from Colorado/CIRES: sent by Dusan Odstrcil**

We have realized two different computational studies by the numerical codes ENLIL and the results were presented at the Space Weather Week and Solar Wind 10 conferences. Both studies represent continuation in our effort to obtain more realistic background solar wind and more accurate resolution of fine structures.

In the first study, 3-D MHD heliospheric computations were driven by the empirical model of the ambient solar wind for 12 Carrington rotations in 1995. This study was realized with Nick Arge from NOAA/SEC, and its aim is to develop more realistic model of the ambient background solar wind. The new results (with respect to our presentation at Fall 2001 AGU Meeting) are based on empirical modifications of the solar wind velocities provided by Wang-Sheeley model. Figure 12 shows the results driven by the original model (used at the NOAA/SEC as a real-time assistance to space weather
forecasters). Figure 13 shows results driven by empirically increased flow velocities in higher latitudes. It can be seen improved match with observations. This has encouraged work on further sophistication of the source surface model.

In the second study,

**Figure 12**

a hypothetic 2-D scenario of interacting magnetic flux ropes was considered. This study was realized with Marek Vandas from Astronomical Institute Ondrejov and Peter MacNeice from Drexel University, and its aim is to provide first insight into interacting CMEs, reported recently as cannibalistic CMEs. The new results (with respect to our presentation at Fall 2001 AGU meeting) stems from considering different parameters within the interacting magnetic clouds. We found different distortions of the shock that can propagate faster (slower) in the cloud with larger (smaller) characteristic speeds. Correspondingly, the density behind the shock front becomes smaller (larger). We think that an enhancement of type II radio burst, its slope change, and irregular patterns can be associated with a localized shock strengthening and distortion.
Figure 13

Presentations

Arge C. N., Odstrcil D., Pizzo V. J., and Mayer L.,
Towards an operational Sun-to-Earth propagation model,
Space Weather Week, Boulder, CO, April 16-19, 2002,
(poster)

Arge C. N., Odstrcil,D., Pizzo V. J., and Mayer L.,
A simple modular Sun-to-Earth propagation model: Verification
of model predictions,
Solar Wind 10, Pisa, Italy, June 17-21, 2002.
(poster)

Odstrcil D., Vandas M., Pizzo V. J., and MacNeice P. J.,
Numerical simulation of interacting magnetic flux ropes,
Solar Wind 10, Pisa, Italy, June 17-21, 2002.
(oral)

Publications

Odstrcil D., and Pizzo V. J.,
Numerical simulation of interplanetary disturbances,
Report from Drexel University: Sent by Peter MacNeice

Drexel University Personnel: Dr. Peter MacNeice, Dr. Andrew Phillips, Mr. Jimin Gao

In summary, we continued development work on our existing CME `breakout' model code, continued development work on a High Order Godunov version, and fixed some minor bugs in version 3.0 of the Paramesh AMR package.

The new High Order Godunov code successfully modeled a spherical Sedov test explosion. We have now implemented the initial conditions appropriate for the idealized `breakout' model calculation. We have introduced and successfully tested a modification to the basic algorithm to enable the initial force-free state to remain stationary, unless perturbed.

We developed a post-processing tool that extracts `pseudo-spacecraft' measurements of the plasma state from the CME model results generated using the FCT code. These are timelines of gas properties and field strengths that a spacecraft with a specified trajectory through the inner Heliosphere might measure. We are collaborating with a student from the University of Michigan on analysis of these timelines and comparison with observation.

We have successfully tested Paramesh V3.0 on a clustered system with both Ethernet and Myrinet interconnect, and are now working to optimize the performance of the MPI messaging.

Report from Hawaii: Sent by Jeff Kuhn

Mees synoptic vector magnetic field data were obtained using the Haleakala Stokes Polarimeter and the Imaging Vector Magnetograph during this period. H-alpha chromospheric spectroheliograms were obtained using the MCCD. Hardware and software changes have been implemented that place our current H-alpha Coronagraph data on the Mees solar web site.

The SOLARC telescope has a new roller drive declination assembly that fixes our previous drive problems. Permanent baffling assemblies have been installed around M2. A Kodak CCD camera has been obtained for visible photospheric and coronal imaging use. Sky brightness (coronal) observations have been obtained and are being prepared for publication (SPIE, August). Preliminary design of an Ebert-Fastie long wavelength IR spectrograph has been completed. Components are being ordered. Don Mickey has
returned to the IfA and has begun the hardware and software integration required for the multi-spectral line upgrade for the IVM.

Li continues to work on a sunspot cluster study covering the period 1991 to 2001. This extends previous work on "active nest" models for persistent solar activity. A detailed analysis of EIT, SXT and LASCO data for two CMEs has been completed. The analysis focuses on deriving the temperature and EM of the front, cavity and core of the developing CME. A publication of this work with the UVCS team is under preparation.

**Montana State University Report: Sent by Dana Longcope**

One objective of the Solar MURI collaboration is to develop techniques to drive three-dimensional numerical simulations of the dynamical evolution of observed solar active regions. One of the observational inputs for such a simulation will be a regular sequence of vector magnetograms of the entire active region covering an extended period. To solve the MHD equations in the corona above the active region it is necessary to specify an evolving velocity field at the lower boundary, the photosphere. This velocity field should drive the magnetic field, according to the induction equation, along an evolution closely matching the observed magnetogram sequence.

A MURI min-workshop was held in Berkeley to make progress toward achieving this objective. At this workshop Longcope presented a method using a variational technique to better define this ill-posed problem. With inputs from many of the workshop participants this algorithm was improved. In its present form the algorithm will supply the velocity field connecting any pair of vector magnetograms. Following the workshop Longcope wrote an IDL code implementing the algorithm. During this process he worked with Isaac Klappe (MSU) to understand the nature of singularities in the governing equations. The existing code has been tested using analytically-derived "magnetograms" without perpendicular field. He has submitted a poster to the SHINE workshop describing the algorithm.

Stephane Regnier attended to the MURI mini-workshop on the use of vector magnetograms to determine the coronal structures of active regions and to model eruptive events. The numerical scheme and the results concerning a highly non-potential active region have been presented (Regnier, Amari & Kersale, A&A, 2002, accepted).

Dr. Regnier worked on the IVM data reduction with the advice of K.D. Leka. Two 15-min averaged vector magnetograms have been produced in order to determine the 3D magnetic configurations of the active region 8210 before and after a series of C-class flares. The results have been presented during the "Magnetic Coupling of the Solar Atmosphere" (EC and IAU colloquium) in Santorini/Greece (15 minutes talk and the related proceeding).

Piet Martens participated in the three day MURI mini-workshop at UNH, to decide on the best setup for numerical experiments on filament and CME formation and eruption. This
was a very good meeting: after three days of open sessions we had still interesting things to say to each other!

The final experiment we agreed on is a combination of Piet's own `head-to-tail' linkage model for filament formation and Spiro's `break-out' model for filament eruption -- a complex magnetic structure that actually looks like what one sees with MDI and EIT.

His contribution to the Yohkoh 10 Proceedings is now on-line; it discusses relevant observational material (the skew of X-ray arcades overlying filaments) for numerical simulations, and models them \url{http://solar.physics.montana.edu/martens/papers/y10.ps.gz}.

During this period Canfield helped organize and lead the MURI mini-workshop on the use of vector magnetograms to model coronal magnetic fields. This workshop served to educate its participants on the capabilities of fellow team members and to build bridges to important external collaborators whose expertise on vector magnetograms (Metcalf, Leka) and modeling (Mikic) will be very useful to our team.

The first of our two recently purchased Sun Microsystems Sun Fire V880 workstations is now up and running for MURI IVM data reduction, using the IVM scattered light correction procedure we learned from Leka. Thanks to its superior speed, we are able to use the full "triplet" code for this data reduction. Regnier has already finished reducing more than 60 of the over-100 magnetograms we have for NOAA 8210 before, during, and after its May 1, 1998 ~2240 UT eruption. As well, it is being used by MSU undergrads Trish Jibben and Kendall Harwood (a participant in the American Indian Research Opportunities program) for the reduction of H-alpha spectroheliograms for the same day's data from the Hawaii MCCD Imaging Spectrograph. Movies are being produced of the motion of chromospheric material during the early stages of the eruption. We plan to compare the dynamics of the MHD simulations to these movies of the May 1, 1998 ~2240 UT eruption.

**OUR QUARTERLY NUGGET**

The quarter's nugget describes the method of topological field modeling presently being applied to AR8210 (but using a different flare). This nugget is found at \url{http://solar.physics.montana.edu/muri/nuggets/jun2002/flare.html}. A compilation of all MSU nuggets is located at \url{http://solar.physics.montana.edu/muri/nuggets/}.

**Report from Stanford: Sent by Yang Liu**

In the period from April 2002 to June 2002, we collected data and materials on the 1997 May 12 event that is in Yan Li's event list, and finished two papers on origination of frontside full halo coronal mass ejections in the first half solar cycle 23 and the super active regions in 22nd and 23rd cycles. We also continued to collect and analyze solar magnetic field data. We produced and distributed daily synoptic charts using both WSO
and MDI data. We produced a variety of synoptic frames used in others’ analyses and produced daily updates of synoptic charts using MDI data from longitudes other than central meridian.

Xuepu Zhao and D. Webb studied all frontside full halo coronal mass ejections during the first half of solar cycle 23 to search for possibility for prediction of geomagnetic storms. They examine the locations of the frontside full halo CMEs from 1996 to 2000 with respect to two kinds of coronal closed field region: closed field regions between opposite-polarity open field regions and closed regions between like-polarity open field regions. They found that even during solar maximum when the occurrence frequency of the two kinds of regions is nearly the same, the central positions of the frontside full halo CMEs are mostly located under the coronal streamer belt. This in turn suggests that most full halo CMEs originate in the coronal helmet streamers that are sandwiched between coronal holes having opposite magnetic polarity. This finding and the solar cycle evolution of the inclination of the heliospheric current sheet may be used, at least partially, to understand the cause of the solar cycle effect on the storm-effectiveness of frontside full halo CMEs.

1997 May 12 event is a complete halo CME associated with a C1.3 flare in the active region NOAA8038 that is the only active region in solar disk. Observation also recorded eruption of filament and EIT wave (see Webb, et al, 2000, JGR, 105, 27251). The kinematic property of this event was determined by Zhao et al (2002) using the 'cone model' which show that this halo CME was radially accelerated from 200 km/s at about 9.5 solar radii to 650 km/s at about 24 solar radii, and the front acceleration is about 18.5 m/s^2. The speed in the plane of the sky thereby ranges from 237 km/s to 307 km/s for the asymptotic radial speed of 650 km/s that consists with Sheeley's. (see Summary of the paper for details). Unlike the 1998 May 01 event, a major event that MURI groups are coordinate analyzing, the magnetic configuration in this event is much simpler and may provide certain clues on understanding of relationship of small-scale and large-scale fields, and thus is of high interest. We put collected materials, data and our preliminary analysis at http://soi.Stanford.EDU/~yliu/may121997/event_May_12.html.

In a statistical study, we surveyed 29 super active regions that produced major flares and solar storms in the 22nd and 23rd cycles, and explored the properties of those regions. We found most of them have significant net magnetic flux, and present abnormal magnetic configurations such as violating the Hale-Nicholson Law, large tilt angle, and strong magnetic twist and writhe. These active regions tended to occur preferentially in the certain longitudes.

We are continuing our effort on development and improvement of the magnetic synoptic charts and test and evaluate the effectiveness and necessity of corrections we suggest to be made.

**Report from UCSD: Received from Bernie Jackson**

The Zhao and Hoeksema (1995) CSSS magnetic field model is currently used to map magnetic fields into our solar wind analysis for use in real-time magnetic field
forecasting associated with the IPS data analysis. To this end our group will employ Nick Arge of SEC NOAA to provide magnetic field maps from different observatories that are updated at regularly defined intervals (generally daily from ground-based observatories). These maps are presented in a standard format so that they can be easily compared and convected out to Earth using UCSD tomographic techniques. These maps will also be made available to the community via anonymous FTP at NOAA’s website. The ideas used in these analyses, their presentation and some of the worries and benefits of these updated data sets were presented at a MURI mini-workshop on April 15 at NOAA’s Space Weather Week April 15-19, 2002. These magnetic field maps are currently being obtained automatically at UCSD in real time as soon as they are available for use in the UCSD space weather forecast.

As an additional project, an interface has been built for different versions of the UCSD tomography program so that they can incorporate other’s 3D-MHD programs (or kinematic models) as a kernel instead of the currently used UCSD kinematic model. This is expected to provide a far better physical model for the UCSD tomography, necessary when SMEI begins to operate and will allow testing of each model incorporated. Because the UCSD tomographic technique allows a three-dimensional model to be obtained, we expect to use this technique to forward model solar wind features such as CMEs and corotating structures also observed in coronagraphs near the solar surface. The two programs first to be incorporated this way are the Tom Detman 3D-MHD code that is currently operating on UCSD computers and the HAF model currently operated by Ghee Fry and others at SEC NOAA.

In addition to graduate students Tamsen Dunn and Susan Rappoport, two additional students were hired and are currently employed using non-MURI funds at UCSD, but are working on associated projects. One of these students, graduate student Cindy Wang, is expected to help student Tamsen Dunn in the real-time access and analysis of magnetic field data. An undergraduate student is jointly hired by UCSD and SAIC’s Mickic, Linker and Riley to work on projects of mutual interest and eventually, the interface between the UCSD tomography program and the SAIC 3D-MHD programs.

A presentation (Jackson et al., 2002a) at the spring American Astronomical Society 200th meeting (joint with the Solar Physics Division) was successful. A presentation at Solar Wind 10 and the subsequent paper (Jackson et al., 2002b) is currently being readied for publication for these proceedings with UCSD’s Japanese colleagues.

References:

Jackson, B.V., P.P. Hick and A. Buffington, 3-D Tomography of Interplanetary Disturbances, BAAS, 34, No. 2, 723, 2002a.

Jackson, B.V., P.P. Hick and A. Buffington, M. Kojima, M. Tokumaru, K. Fujiki, T. Ohmi and M. Yamashita, Time-dependent tomography of heliospheric features using interplanetary scintillation (IPS) remote-sensing observations, oral presentation to be
submitted for publication in the proceedings of Solar Wind 10, Pisa, Italy, June 17-21, 2002b.


**UNH Report: Sent by Terry Forbes**

A Mini-Workshop on CME Initiation was held May 14-16, 2002 at the UNH campus in Durham, New Hampshire. At this workshop was to provide initial conditions that can be used to test proposed mechanisms for the onset of CMEs. The workshop was attended by participants from the University of New Hampshire, the University of California at Berkeley, the University of Michigan, Montana State university, The Naval Research Laboratory, and the Air Force Research Laboratory. Three different modules initial and boundary conditions modules were agreed upon which will be used to investigate what kind of coronal current structures form during flux emergence and whether some of the proposed eruptive mechanisms work as expected.

T.G. Forbes, in collaboration with Dave Webb and Joan Burkepile, has adapted a previous model for current sheet evolution in CMEs developed by Lin *et al.* (2000) to match observations of current-sheet-like structures, called "rays", which are observed below CMEs. As shown in Figure 5, the model provides predictions for the trajectory and expansion of the flux rope and the current sheet during the acceleration phase of the eruption. The model also provides an explanation for the prominence activation phase which precedes the appearance of the flare ribbons and loops. (The occurrence of the latter signals the appearance of the x-line.) The main difference in the new model from the old is that the new one uses a more realistic model for coronal density as a function of height. The old model assumed that the density decreases exponentially with height which is only valid within a solar radius of the surface. The new model incorporates the more realistic density model of Sittler and Guhathakurta (1999).
Figure 14 Model prediction by Lin et al. (2000) for the evolution of a coronal mass ejection triggered by an ideal-MHD instability. The letters SMM stand for the Solar Maximum Mission satellite launched by NASA in 1980.

As a result of this improvement in the description of the ambient coronal density, the evolution of the CME current sheet predicted by the theoretical model is in much better agreement with the observed evolution of the rays. Since this model includes an early evolution phase which is suggestive of the pre-eruptive, activation phase in filaments, verification of the model during its post-eruptive period strengthens the case that the model provides a reasonable explanation of the physics underlying the activation phase.

T.G. Forbes has also published a review (Forbes, T.G., Reconnection in different environments, in Physics of Magnetic Reconnection in High-Temperature Plasmas, edited by, M. Ugai, Research Signpost, Kerala, India, in press, 2002) that discusses the role of reconnection in coronal mass ejections among other topics.
Publications Supported in Part or in Full by the Solar MURI Grant

We do not include abstracts at AGU or AAS meetings in this list; only publications which have been submitted to a refereed journal or a topical conference proceedings are provided here. More details about talks and abstracts can be found in the quarterly reports in the preceeding pages. These are publications that involved some effort by MURI team members during the period reviewed in this report.


Chae, J., Moon, Y.-J., Wang, H., Yun, H. S. 2002 "Flux cancellation rates and converging speeds of canceling magnetic features” Solar Physics, 200, 73


J.G. Luhmann, Yan Li (Space Sciences Laboratory, University of California Berkeley) C.N. Arge (CRES, University of Colorado and NOAA-SEC) Todd Hoeksema and Xuepu Zhao (Stanford University) “A Solar Wind Source Tracking Concept for Inner Heliosphere Constellations of Spacecraft”, submitted to SWX proceedings


Regnier, S., Amari, T., Canfield, R. C. "Non-constant-alpha force-free field of active region NOAA 8210", to appear in "Magnetic Coupling of the solar atmosphere", IAU Colloquium 188


