Solar Imaging Needs for the Space Environment Monitor on the Geostationary Operational Environmental Satellites (GOES R+)

A Report of the GOES R Solar Imager Workshop

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NOAA Space Environment Center (SEC), 325 Broadway, Boulder, CO 80305

Prepared by: Francis G. Eparvier, Laboratory for Atmospheric & Space Physics, University of Colorado, Boulder

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1. Executive Summary

On 23–25 October 2001 the “GOES R Solar Imager Workshop” was held at the NOAA Space Environment Center (SEC) in Boulder, Colorado. This workshop was the initial step in the planning process for the solar imaging instrumentation to be included in the GOES Space Environment Monitor (SEM) package starting with the GOES R+ series. The workshop was attended by and included presentations by representatives from NOAA, the United States Air Force, NASA, the scientific research community, the space instrumentation industry, and a range of industries affected by space weather.

The workshop participants were asked the basic question: What solar imaging sensors should be flown on the next generation of GOES? They were asked to keep in mind during the presentations and discussion the benefits to space weather forecasting, the needs of space weather customers, the cost, the constraints of the GOES platform, the readiness of the measurement to be operationalized, and ultimately the value to the nation. The two and a half day workshop consisted of eight consecutive sessions as listed below:

1. Geoeffective Events and Space Weather Customer Needs
2. Solar Sources of Geoeffective Events
3. Predicting Events at the Sun
4. Review of Observables and Instrument Types
5. Spaceborne versus Ground-based Solar Observations
6. Instrument Case Studies (Old and New)
7. Technological Frontiers
8. Roundtable Discussion: What NOAA and the USAF Should Fly and Why

The strong recommendation of the workshop is that the GOES R series of satellites should include both a solar XUV (in the 0.1–31 nm portion of the spectrum) imager and a solar coronagraph. Additional studies are recommended to determine the detailed requirements for each instrument (including, but not limited to, wavelengths and bandpasses for the XUV imager, and field of view and time cadence for the coronagraph), and to analyze the costs versus benefits of various deployment schemes.

2. Introduction

This report is not intended as a detailed transcript of the presentations and discussion of the workshop, but rather as a distillation of the key points raised and a summary of the recommendations arrived at during the workshop. Section 3 of the report gives background information about national space weather needs and connections to the Sun. Measurement options for meeting space weather needs through solar imaging are detailed in Section 4. The workshop consensus recommendations for solar imagers and further studies are presented in Section 5. Selected references are given in Section 6. Section 7 has a list of all of the participants in the workshop, and Section 8 gives brief summaries of the workshop presentations.

3. Space Weather Needs

3.1. Space Weather Nowcasting and Forecasting

The basic needs of space weather customers can be divided into two categories based on time. The first category is the specification of the current state of the geospace environment, otherwise known as a "nowcast". A nowcast tells the customer what is happening at the moment, or within minutes to a few hours that will affect the customer's interests or activities. One example (among many) of a useful nowcast would be the specification of the total electron content (TEC) of the atmosphere at the current time with global coverage and fairly high spatial resolution. The global positioning system (GPS) is affected by TEC, and the ability to locate position using GPS can vary by tens to hundreds of meters during disturbances. To some customers, such as the military, such errors could have significant realtime consequences. An accurate nowcast of TEC would allow the customer to correct for those realtime errors in location due to ionospheric disturbances.

The second temporal category is the prediction of the state of the geospace environment several hours or even days ahead of time, otherwise known as a "forecast". One example of a useful forecast would be the accurate prediction of the timing and magnitude of geomagnetic substorms. Power companies are interested in the geographic location, time, and quantitative level of ground-induced currents (GICs) caused by geomagnetic substorms because, under certain circumstances GICs can lead to transformer damage or power grid failures. A large, sudden, and unexpected GIC on an already stressed grid, such as on a hot summer afternoon when air conditioning presents peak load, could have a disastrous result. However, the same GIC on an unstressed grid experiencing low demand, such as in the middle of a clement night, would have little effect. Accurate forecasts of geomagnetic substorms would allow power companies to decide how to prepare for potential effects on their power grids.

Many more examples of space weather effects could be given, but the primary point is that both nowcasts and forecasts are important to different customers based on their differing needs and risks.

3.2. Space Weather Domains and Solar Imaging

Several agencies, both domestic and foreign, have published thorough studies of space weather parameters and the flowdown from source on the Sun to the geospace consequences that are of concern to space weather customers. Examples of such studies are, from the United States: the National Space Weather Program Strategic Plan [1995] and the National Space Weather Program Implementation Plan [1997]; and from the European Space Agency: Horne [2001], Koskinen et al. [2001], and Murphy and Rodgers [2001]. Also, "Space Weather" [2000], an AGU Geophysical Monograph, gives an excellent overview of the topic. The NOAA Space Environment Center has annual workshops called "Space Weather Week" where forecasters, researchers, and space weather customers interface with each other. The United States Air Force has also made an extensive study of their space weather needs, which, while presented at the workshop, is not available to the public for security reasons.

It is not necessary for this report to present the details of the above studies, but a brief overview will be helpful as background for the consideration of prospective solar imagers for GOES.

Table 1 lists the fourteen space weather "domains" as delineated in the National Space Weather Program Implementation Plan [1997]. These domains reflect the areas of the space environment in which space weather customers have needs or concerns, and in which they desire accurate nowcast and/or forecasts of space weather parameters, which quantify and describe the domains.

Table 1. Space Weather Domains
Coronal Mass Ejections
Solar Activity/Flares
Solar and Galactic Energetic Particles
Solar UV/EUV/Soft X-Rays
Solar Radio Noise
Solar Wind
Magnetospheric Particles and Fields
Geomagnetic Disturbances
Radiation Belts
Aurora
Ionospheric Properties
Ionospheric Disturbances
Ionospheric Scintillations
Neutral Atmosphere (Thermosphere and Mesosphere)

Ultimately the space weather in all of the domains listed in Table 1 is controlled by the Sun, but not all of the domains can be directly parameterized through solar imaging measurements. The first two: CMEs and Solar Activity/Flares, are by their nature directly accessible through imaging techniques. Therefore, much of the discussion of solar imaging options in the next section tends to be dominated by these two domains. All of the space weather domains are interlinked, however, so while solar imaging may not give a measure of the current state of the other domains, it can give information vital to predictions of the conditions in those other domains. For example, an Earth-directed CME is a precursor for geomagnetic disturbances, enhanced aurora, energetic particle events, and ionospheric and neutral atmospheric disturbances. To accurately predict the geospace consequences of a solar event such as a CME, it is therefore necessary to accurately observe that originating solar event. Benefit to space weather for a solar imaging measurement is judged not only by its ability to parameterize a specific domain, but also to aid in the nowcasting and forecasting of other domains.

4. Solar Imaging Options

The following list of potential solar imaging measurements was distilled from the presentations and discussion of Sessions 1 through 7 of the workshop. The list was the basis for the broad discussion of Session 8 on the final day of the workshop. The imaging measurements were assessed for their: benefit to space weather forecasting and nowcasting, improvement over current operations, and readiness to be brought into the operational arena. In addition, the need for the suggested measurements to be made from space, specifically from the GOES platform, was discussed. Note that the imaging measurement options were grouped as to High, Medium, and Lower priority, but it was deemed beyond the scope of the workshop to distinguish priority between the measurements within each group. The two high priority measurements were found to be equally, and jointly essential. Following the list is a short description and justification for each type of measurement.

High Priority Measurements:
- XUV Images
- Solar Coronagraph Imager

Medium Priority Measurements:
- Line-of-Sight Magnetograms
- Hard X-ray Spectrometer Data

Lower Priority Measurements:
- Hα Images
- White Light Images
- Vector Magnetograms

4.1. XUV IMAGER

Currently the GOES 12 SEM package carries the first Solar X-ray Imager (SXI). At least several GOES N-Q SEM packages will include an SXI. Based on ten years of results from the Yohkoh Soft X-ray Telescope (SXT) research instrument (e.g., Watanabe et al., 1998) and from the short checkout phase for the first SXI on GOES 12 (Aug.–Dec., 2001), the usefulness of broadband soft X-ray images has been demonstrated to NOAA SEC forecasters [Balch et al., 2002]. The operational usefulness of longer wavelength, spectral line-resolution images has also become evident from the research results of the Extreme Ultraviolet Imaging Telescope (EIT) on the Solar and Heliospheric Observatory (SOHO) (Delaboudinière et al., 1995).

Images at XUV wavelengths (0.1–31nm) can give predictive information about geoeffective phenomena by identifying and quantifying features on the disk of the Sun such as flares, eruptive prominences, coronal holes, and so on. Along with a coronagraph, XUV images can also indicate whether a halo CME is earth-directed or not, by identifying whether activity associated with the CME is seen on the disk of the Sun. Note that all XUV radiation from the Sun is absorbed by the atmosphere and none penetrates to the surface of Earth, so images at these wavelengths must be made from space. For these reasons, an XUV imager is deemed essential and is given high priority for inclusion on GOES.

4.2. Solar Coronagraph

Just as XUV images produced by research satellites have become an essential part of space weather forecasting, so have the coronagraph images from the Large Angle and Spectrometric Coronagraph (LASCO) instrument on SOHO (Bruekner et al., 1995; Howard et al., 1997). Coronagraph observations are the only way to directly observe CMEs. In addition, they are able to indicate halo CMEs, which, when Earth-directed, are the best and earliest predictor of non-recurrent geomagnetic disturbances. In essence, a coronagraph can indicate what's coming at Earth up to several days in advance. Coronagraphic observations with proper resolution and cadence allow prediction of the arrival time at Earth of a halo CME. No other measurement can give earlier reliable warning than a coronagraph's. In addition to halo CMEs, coronagraphic observations constrain the uncertainty in direction and speed of non-Earth directed CMEs and gives some information about backside coronal events. Coronagraph images may also be combined to produce synoptic maps of the corona, which have the potential to improve solar wind models. For all of these reasons, a solar coronagraph is also deemed essential and is given high priority for inclusion on GOES.

Note that a coronagraph alone will not distinguish between halo CMEs heading directly towards and away from the Earth. To make that distinction it is necessary to see the feature on the Earth-facing disk of the Sun (for instance, using an XUV image) which is associated with an Earth-directed CME. Having both an XUV imager and a coronagraph is important, which is why both measurements were given highest priority. The benefits of having both is greater than twice the benefit of having just one, since combined they provide space weather information that cannot be obtained from just one instrument.

4.3. Line-of-Sight Magnetograph

A full-disk, line-of-sight (LOS) magnetograph gives very important information about the Sun: magnetic field strength and polarity (in the line-of-sight), the complexity of active regions, the emergence of new flux, and the location where the magnetic polarity switches sign, the so-called neutral-line. Synoptic maps of the solar magnetic field, produced from magnetograms, are used to construct the inputs for background solar wind models, which calculate solar wind velocities and magnetic polarity from the Sun out to Earth. Currently LOS magnetograms are made with ground-based instruments. Because of the rotation of Earth and weather effects, the measurements are not always continuous or regularly timed. In addition, instruments in the ground-based network are not always inter-calibrated well enough to combine measurements without introducing a large uncertainty. This inter-calibration uncertainty especially affects the determination of neutral lines. LOS magnetic measurements would benefit in continuity and calibration from being space-based, but the measurements do not necessarily need to be made from space. The benefits were judged to be incrementally small, and for that reason putting an LOS magnetograph on GOES was given medium priority, with the assumption that the measurements must continue to be made by a ground network.

4.4. Hard X-ray Spectrometer

Much discussion was expended by, and great interest was shown in, the results of a study by Kiplinger [1995]. This study indicated that analysis of the time evolution of the hard X-ray spectrum of a solar flare can be used to predict whether that flare will produce a solar radiation storm with geoeffective consequences (high-energy proton events at Earth). Because predicting proton events is a high priority for some space weather customers, the results of the Kiplinger study were given great attention, even though they do not require an imaging instrument, but rather a full-disk integrating spectrometer in the hard X-ray wavelength range. This method of predicting solar radiation storms, or proton events at Earth was found to be quite promising, but not developed nor demonstrated fully enough to be made operational. Further study was urged, along with the desire for a demonstration or research flight of an instrument capable of making the required measurements. A hard X-ray spectrometer was thus given a medium priority for inclusion on GOES.

4.5. Hα IMAGER

Full disk images of the Sun at the Hα wavelength have been made from the ground since 1926 and have become an integral part of the space weather forecasting effort. Hα images give information about flares and chromospheric features. Along with a coronagraph and XUV imager, Hα images can give information about the direction of a halo CME. Currently, the ground-based network(s) give at least 70% temporal coverage and will continue at that level into the foreseeable future. Hα images do not need to be made from space, but the biggest advantage for making the measurements space-based is to achieve near 100% temporal coverage from a single, well-characterized instrument. As plans are already in the works to continue Hα imaging from the ground, a thorough cost-benefit analysis should be done for taking it to space. It was agreed that Hα images are required for space weather, but because of the ground network, Hα observations were given only a low priority for inclusion on GOES.

4.6. WHITE LIGHT IMAGER

Full-disk white light images are also currently obtained by ground-based network(s) and are another integral part of the space weather forecasting effort. White light images give information about sunspots and other photospheric features. A study similar to that for Hα images should be done to determine the costs and benefits of taking white light imaging to a space platform. White light images were given a low priority for inclusion on GOES.

4.7. VECTOR MAGNETOGRAPH

A vector magnetograph gives all of the information that a LOS magnetograph gives (magnetic field strength, complexity of active regions, neutral lines, flux emergence, and the inputs to solar wind models), but it also gives full three-axis magnetic field direction information. Having the full magnetic field vector improves the quality of all of the information derived from the magnetograms and holds the eventual promise to allow more accurate and longer lead-time predictions for flares. In particular, vector magnetograms are necessary to calculate magnetic shear and stored magnetic field energy in active regions, both thought to be related to flare occurrence and strength. Both photospheric and chromospheric vector magnetograph measurements are possible by changing the wavelengths used. White light images can also be constructed as a by product of the magnetic measurements. Although they are not currently part of an established ground network, vector magnetograph measurements can and are planned to be done from the ground in the future. The same reasoning as for Hα and white light images can be applied to the need for a cost-benefit analysis of putting the instrument in space . A topic for further research study would be the impact of having full vector magnetic field (compared to LOS) information on solar wind modeling. A vector magnetograph was given low priority for inclusion on GOES primarily because it is a measurement that can be made from the ground and the use of vector magnetograms for space weather is not yet demonstrated.

5. Conclusions

5.1. GOES Solar Imager Recommendations

It was the conclusion of the workshop that **both an XUV imager and a coronagraph are essential** to NOAA's space weather effort, and it is strongly recommended that both be included in the GOES R+ SEM packages. While having one or the other instrument will provide great benefits, the advantage of having both is considered to be much greater than twice the benefits of having just one. The following studies are also recommended.

5.2. Further Studies

5.2.1. XUV Imager Definition Study

A thorough trade study and cost-benefit analysis needs to be done to determine which wavelengths should be included in an XUV imager for GOES. The current broadband wavelength coverage of the SXI is useful for identifying coronal features and flares both on the disk and, to some degree, around the limb. The SXI has multiple bandpass options in the 0.6–6 nm range, thereby imaging the Sun's corona in the 1–10 million K temperature range. Narrow-band, or line images of the Sun at different XUV wavelengths also give specific information about solar features. For instance, the EIT instrument on SOHO makes images at 17.1, 19.5, 28.4, and 30.4 nm, which correspond to temperatures of 1 MK, 1.5 MK, 2 MK, and 80 kK, respectively. The shorter EIT wavelengths image the cooler end of the range of coronal temperatures that SXI images, but can also give information abut coronal features and flares. The significantly lower temperature HeII 30.4 nm images from EIT can show filaments and chromospheric phenomena, in addition to aiding in flare observation and flare prediction. Narrow-band measurements can also give information about absorption features in the solar atmosphere, which broadband measurements cannot.

While all the aforementioned XUV wavelength broad and narrow bandpasses are well known, because they are included on the SXI and EIT instruments, they must not be taken as an exclusive list. Any analysis must include discussion of other wavelengths not currently included on these two instruments but with proven advantages for space weather. The feasibility of a single instrument that measures both broad and narrow bandpasses should be considered, along with the option of flying two separate instruments to cover both types of images. Decisions about wavelengths and bandpasses must be based on incremental space weather benefit over current SXI design, and technical feasibility.

In addition to wavelength issues, the time-cadence and spatial resolution requirements for XUV images must be studied and refined. Finally, it must be noted that XUV images from GOES do not negate the need for continued disk-integrated measurements of 0.05–0.4 nm and 0.1–0.8 nm from the X-ray Spectrometer (XRS) on the GOES SEM. Additionally some of the workshop attendees expressed the belief that XUV images will not soon supercede the need for continued Hα and white light images of the Sun, primarily because of the long heritage of those observations, although this was not necessarily a consensus opinion.

5.2.2. Coronagraph Definition Study

A detailed study should be made to define the requirements for a space weather operational coronagraph. In broad terms, a GOES coronagraph must be able to detect halo CMEs. It must also be able to indicate the speed and direction of a halo CME to predict sufficiently the arrival time at Earth. To do this, the coronagraph must have a large enough field of view (FOV), sufficient rejection of solar disk irradiance, adequate sampling cadence, and adequate spatial resolution. Preliminary analysis from the workshop indicates that an FOV covering 4–17 solar radii, a cadence of an image every fifteen minutes, and a resolution of 50 arc seconds would be the minimum requirements to capture three images of the fastest observed CMEs, allowing for determination of speed and direction. In addition, some consideration should be made to determine whether GOES is necessarily the best space platform for an operational coronagraph.

5.2.3. Solar Imager Deployment Study

Beyond the already mentioned necessary studies to define the requirements and details of a solar XUV imager and a coronagraph for inclusion on GOES, an additional study concerning deployment schemes must be undertaken. The current SXI deployment has the instrument on every other satellite, and the SXI does not (nor does any other part of the SEM package) have “call up” status on the satellite. Not having the solar imager on every satellite means that if it fails there is no redundant instrument to take over. It also means that there is some data continuity loss during the periods when the satellite goes into eclipse, which is a hindrance to the flare patrol aspect of an XUV imager. In addition, not having “call up” status means that if the solar imaging instrumentation fails, a satellite in on-orbit storage that has another solar imager on it will not be brought out of storage to continue solar imaging measurements. Under current NOAA policy, if a solar imager fails, but the meteorological instruments do not, there could be interruptions of solar imaging lasting for several years, causing a significant disruption to the nation’s space weather program.

For these reasons it is recommended that a thorough cost-benefit analysis be done on the various options for deploying the solar imaging instrumentation on GOES. The primary options include: 1) maintain the current deployment scheme with solar imaging on alternating satellites; 2) maintain the current deployment scheme, but make the solar imagers more robust by building complete redundancy into the instruments; 3) include the solar imaging instrumentation on all GOES; or 4) execute a hybrid deployment scheme with a solar XUV imager and a solar coronagraph on alternating satellites from each other. Most beneficial (and most costly) for the space weather effort is to have both an XUV imager and a coronagraph on all satellites. The operational benefits are: redundancy in case of failure, complete continuity of data even during eclipse periods, doubling of data (except during eclipses), and the opportunity to use the two operational instrument packages in a complementary fashion. The major drawback of this scheme is cost. It should be the purpose of this study to determine which scheme is in the best interests of the nation.

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7. Workshop Attendance

Alan Kiplinger	alan.kiplinger@noaa.gov	303 492-2011	Univ. of Colo.
Barry LaBonte	labonbj1@labontes-pc.jhuapl.edu		JHU/APL
Bill Gail			Ball Corp.
Brian Dougherty	BLD@caltech.edu		Caltech
Capt. Bradford Green	bradford.green@afwa.af.mil	402-232-8087	AFWA
Bryan Richter	Bryan.Richter@colorado.edu		CU/LASP
Chris St. Cyr	cstcyr@cpi.com	(301) 286-2575	Catholic University
Christian Wohlwend	christian.wohlwend@peterson.af.mil	719 554-9683	AFSPC
Christopher Balch	Christopher.Balch@noaa.gov	(303) 497-5693	NOAA/SEC
Cliff Minter	cliff.minter@noaa.gov		NOAA/SEC
Craig Langford	craig.langford@lmco.com		LMCO
David Hathaway	david.hathaway@msfc.nasa.gov		MSFC
David Huber	huber@researchsupport.com		RSI
Dennis Gallager			Ball Corp.
Dennis Socker	dsocker@ssd5.nrl.navy.mil		NRL
Dick Reynolds	rrrr@erols.com	410-268-5630	NOAA/NESDIS
Donald Heath			RSI
Don Neidig	neidig@nso.edu		AFRL
Eric Chipman	eric.chipman@noaa.gov	301-817-4167	NOAA/NESDIS
Ernest Hildner	Ernest.Hildner@noaa.gov	(303) 497-3311	NOAA/SEC
Frank Eparvier	eparvier@colorado.edu	303-492-4546	CU/LASP
Frank Guy	frank.guy@schriever.af.mil		USAF 55SWXS
George Lawrence	George.Lawrence@lasp.colorado.edu	303-492-5389	CU/LASP
Gerry Dittberner	Gerald.Dittberner@noaa.gov	(301) 457-5225 ext. 113	NOAA/NESDIS
Greg Berthiume	gdb@ll.mit.edu	(781) 981-7962	Lincoln Lab
Greg Ginet	ginet@phl.af.mil		USAF/AFRL
Harry Farthing	hfarthing@swales.com		Swales
James Manley	james.manley@afwa.af.mil		AFWA
Jane Luu			Lincoln Labs
Jaya Bajpayee	jbajpaye@pop800.gsfc.gov		GSFC
Jeff Cadieus			CU/LASP
Joan Burkepile	iguana@ucar.edu		HAO
John Kappenman	john@metatechcorp.com		Metatech
Joe Kunches	Joseph.Kunches@noaa.gov	(303) 497-5275	NOAA/SEC
K.D. Leka	leka@colorado-research.com	(303)415-9701	NW Research
Keith Strong	keith.strong@lmco.com	650 354 5136	Lockheed
Kelly Hand	kelly.hand@Peterson.af.mil		USAF/AFSPC
Kristen Clouser			Lincoln Labs
Larry Combs	larry.combs@noaa.gov		SEC
LtCol Jeffrey Carson	jeffrey.carson@schriever.af.mil		USAF 55th
Michael Crison	Michael.Crison@noaa.gov		NOAA/NESDIS
Michael Gottschall	michael.gottschall@afwa.af.mil	402-294-5161	AFWA
Nariaki Nitta	nitta@sag.lmsal.com		LMSAL
Nick Arge	nick.arge@noaa.gov		NOAA/SEC
Nick Ganiaris	nick.j.ganiaris@lmco.com		LMSAL
Pamela Taylor	Pamela.Taylor@noaa.gov		NOAA/NESDIS
Pat Bornmann	pbornman@ball.com		Ball Corp.
Patricia Mulligan	pmulligan@nesdis.noaa.gov	(301) 457-5125 x109	NESDIS
Peter Engelmann	Peter.Engelmann@Peterson.af.mil	719-554-4313	AFSPC
Peter Fox	pfox@hao.ucar.edu	301-497-1511	HAO
Phil Judge	judge@ucar.edu	303-497-1502	HAO

Rainer Illing			Ball Corp.
Rod Viereck	Rodney.Viereck@noaa.gov	(303) 497-7348	NOAA/SEC
Ron Hooker	Ronald.Hooker@gsfc.nasa.gov	(301) 286-3216	NOAA/NESDIS
Russ Howard	russell.howard@nrl.navy.mil	202-767-3137	NRL
Ryan Keenan			CU/LASP
Sarah Gibson	sgibson@ucar.edu	301-286-4586	HAO
Sara Martin	saraf03@dellepro.com	818-957507	Helio Research
Simon Plunkett	plunkett@sunrise.nrl.navy.mil		NRL
Steve Kahler	kahler@plh.af.mil		USAF
Stephen Quigley	Stephen.Quigley@cisf.af.mil		USAF
Steve Hill	Steven.Hill@noaa.gov	(303) 497-3283	NOAA/SEC
Steve Tomczyk	tomczyk@ucar.edu	303-497-1579	HAO
Tom Ayres	ayres@casa.Colorado.EDU		CU
Tom Woods	tom.woods@lasp.colorado.edu	303-492-4224	CU
Vic Pizzo	vic.pizzo@noaa.gov	303-497-6608	NOAA/SEC
Werner Neupert	werner.neupert@noaa.gov		NOAA/SEC
William Murtagh	William.Murtagh@noaa.gov		USAF
Yan Li	yanli@ssl.berkeley.edu		UCB

8. Workshop Presentation Summaries

October 23: Customer Needs and Solar Forecasting

MORNING

9:00-9:30 AM WELCOME AND INTRODUCTION

1. Presenter: **Ernie Hildner (NOAA/SEC)**
   Topic: NOAA Welcome
   Summary:
   Dr. Hildner welcomed the participants to the Workshop. He asked that they keep in mind throughout the workshop the following questions as they pertain to solar imaging for GOES:
   What are the best sensors to monitor space weather from space?
   What sensors should be flown by NOAA?
   What sensors should NOAA ask Congress to fund?
   What makes the chosen sensors better than other sensors?
   What makes the chosen sensors better done in space than on the ground?
   An additional consideration in the proceedings is the recognition that doing science research from GOES is a bonus, not the main priority. The selection of an instrument for GOES must be a balance between the considerations of space weather benefits, cost, spacecraft constraints, and the ultimate value to the nation.

2. Presenter: **Maj. Peter Engelmann (UASF/AFSPC)**
   Topic: USAF Welcome
   Summary:
   Major Engelmann presented an overview of the considerations of the USAF for the selection of the GOES R Solar Imager. Constant evaluation must be made between "new and improved" research products and methods versus "old standards" that have heritage. The keyword for GOES is "operationalizing" which has an underlying meaning of cost and involves consideration of lifetime, backups, replacements, and logistics. The decision of what sensor to fly requires facing hard decisions. The nation can't afford to fly everything desirable, or anything just on a whim or dream of potential benefits. The decision must be done carefully.

3. Presenter: **Pat Mulligan (NOAA/NESDIS)**
   Topic: NOAA Requirements Process
   Summary:
   Pat Mulligan stood in for Pam Taylor who wasn't able to attend the workshop. She gave a broad overview of the new requirements process for selection of GOES instruments. GOES is using the NPOESS experience as a guide. The first step of the process is to develop objectives and requirements. The second step is to do a cost-benefit analysis. This workshop is just the beginning of the first step.

9:30 AM -12:10 PM SESSION 1: GEOEFFECTIVE EVENTS AND SPACE WEATHER CUSTOMER NEEDS

Co-Chairs:* *Gerry Dittberner (NOAA/NESDIS) and Christopher Balch (NOAA/SEC)

1. Presenter: **Chris Balch (NOAA/SEC)**
   Title: Overview of Space Weather Problems
   Summary:

   This presentation was a brief introduction to the session. The goal of this session is to give a broad overview of space weather user needs. Examples of space weather concerns are: radio blackouts, solar radiation storms, geomagnetic storms, ionospheric disturbances, and high-energy electrons. Examples of space weather users are: spacecraft operators, radio communications, human health, navigation,

2. Presenter: **Maj. Peter Engelmann (USAF/AFSPC)**
   Title: Space Weather Initiatives in the New AFSPC Mission Area Plan (MAP)
   Summary:

   A Mission Area Plan (MAP) is a baseline-planning document to drive the Planning Phase of the military Planning, Programming, and Budgeting System (PPBS). A MAP is the long-range vision for MAJCOM out to the year 2028. It defines mission linkage to national goals and security objectives. It is updated every two years and can be thought of as a roadmap for the future. Prior versions of the Air Force Space Command (AFSPC) Force Enhancement MAP did not list all AFSPC space environmental sensing requirements, resulting in failed efforts to procure military funding for new sensing initiatives. This year's MAP fully documents AFSPC space environmental sensing requirements and proposes five new initiatives to meet those sensing requirements.

   The USAF MAP includes a Mission Needs Analysis (MNA), which defines the space weather needs of the military in terms of parameters that need to be measured. The parameters in the current MNA are grouped into the categories of: solar events, solar electromagnetic emission spectra, solar wind, magnetosphere, ionosphere, and neutral atmosphere. Following the MNA is a Mission Solutions Analysis (MSA), which takes many possible solutions for meeting the needs outlined in the MNA, and performs a constrained optimization. From the results of the MNA, a true planning roadmap for meeting the space weather requirements of the military is formulated.

3. Presenter: **Christian Wohlwend (USAF/AFSPC)**
   Title: Space Environmental Impacts on Spacecraft Operations
   Summary:

   The impacts of space weather on spacecraft operations can be broken down into three categories. The first is Electromagnetic (EM) Radiation, including X-rays, the EUV, and radio bursts. EM radiation variability can cause satellite communications interference, radio communications interference, short-wave fades, and ionospheric scintillation and refraction effects on GPS navigation. The second category is High Energy Particles, in particular proton events. These can cause satellite disorientation, false sensor readings on satellite instruments, spacecraft damage, launch payload failure, short-wave fades, and potential radiation exposure for high altitude aircraft and crews. The final category is

Low to Medium Energy Particles, primarily in the form of precipitating electrons during geomagnetic storms. Enhancements in these can cause spacecraft charging, single-event-upsets in spacecraft electronics, and ground-induced-currents that can cause fluctuations in power grids.

4. Presenter: **Craig Lanfgord (Lockheed-Martin)**
   Title: Effects on Atlas Launch Vehicles
   Summary:
   This talk concentrated on the effects of space weather on the Atlas launch vehicle system. A failure of an Atlas during the launch of a satellite can cost anywhere from $250 million up to even a few billion dollars. Single Event Upsets (SEUs) in the guidance control electronics of the Atlas are the primary concern. Error-correcting can cope with a single SEU, but double SEUs in the same word can't be fixed and can cause catastrophic problems during launch. Double, or even multiple upsets at a single time can be caused by heavy ions such as iron with energies in the tens of MeV to a few GeV range. The Atlas has no uplink and deployments of payloads can last up to six hours from the time of launch so the need is for accurate predictions of particle events six to seven hours ahead of time. Currently the Atlas program has T—3 hour and T—20 minute space weather briefings and they will delay a launch if there is a large X-ray flare (M—X class), based on the assumption that a large proton flux will follow such a flare, but they have no contingency if a flare occurs after launch but before deployment is complete. The Atlas program greatly desires accurate forecasts, but is also wary of using forecasts until proven accurate since the consequences of false predicts (delaying a launch, potentially in the last few minutes) can be quite expensive.

5. Presenter: **Joe Kunches (NOAA/SEC)**
   Title: Space Weather Impacts on Electronic Navigation Systems
   Summary:
   Space weather affects the intended functions of the Global Positioning System (GPS) and Loran navigation systems, although the impacts are not necessarily the same for each system. For Loran, which is a ground-based pulsed radio system, the affected area of interest is the D-layer of the ionosphere (<100 km altitude). Variations in this part of the ionosphere can cause signal blinking and ground/sky wave interference. For GPS, which is a space-based continuous radio system, the affected area of interest includes the E- and F-layers of the ionosphere (>100 km altitude). Space weather effects include the inability to acquire or lock-on to a signal and erroneous location determination. A simple experiment with a personal GPS showed horizontal errors of 30-40 meters during a geomagnetic storm. The FAA and military currently use TEC knowledge in a model to augment and correct GPS. Better global specification (nowcasting) of TEC would vastly improve GPS corrections.

6. Presenter: **John Kappenman (Metatech)**
   Title: Space Weather and Geomagnetic Storms and Impacts on Electric Power Systems
   Summary:
   Even small, but simultaneous widespread changes in load on a power grid can cause serious problems. Space weather can cause up to 3300-megawatt power shifts in a grid

with no precise warning, the end result of which could be large system outages, interruptions in critical services, and huge cost impacts (hundreds of millions of dollars). Geomagnetic storms can cause fluctuating ground induced currents (GICs) in power lines. GICs can cause potentially catastrophic transformer damage. The ever-expanding nature of power grids, and new technology transformers have made the system even more susceptible to space weather-induced effects. Relay and protective systems can respond in about 70 milliseconds, and backup systems can come on in half a second, but without prior warning, even that is not always fast enough. Current nowcasts and 3-hour Kp values are not enough. The forecast needs of the power companies are as follows: an accurate predictive and real-time electrojet model, a model of EM coupling to ground-based systems, a detailed ground conductivity and network model, and a translation from monitored space weather parameters to power grid effects. All of this must be continuously updated on a timescale of less than or equal to one minute. The models should be driven by the solar wind and be geographic-location specific. Power plants can take corrective measures based on predictions and confidence levels. They do a very complex cost-benefits analysis. Currently they look at X-ray flares, active regions, coronal holes, recurrence and other parameters to make their predictions.

AFTERNOON

1:30-3:40 PM SESSION 2: SOLAR SOURCES OF GEOEFFECTIVE EVENTS

Chair: Vic Pizzo (NOAA/SEC)

1. Presenter: **Vic Pizzo (NOAA/SEC)**
   Title: Introduction
   Summary:
   This session traces geoeffective events back to their sources on the Sun, including propagation through the interplanetary medium. The goal is to describe observable solar events and models of such events leading to space weather events at Earth. Note that our understanding of the solar sources of geoeffective events continually evolves.

2. Presenter: **Nick Arge (NOAA/SEC)**
   Title: Coronal Structure and Global Solar Wind
   Summary:
   There are varieties of coronal and solar wind models: magnetohydrodynamic (MHD) models based on first principles, force-free models, magneto-static models, and kinematic or semi-empirical models such as that of Wang and Sheeley. We use models because the coronal magnetospheric field is not measurable, but the photospheric magnetic field is, so that is used as a boundary condition to calculate the coronal field. Networks make ground-based photospheric magnetic measurements regularly, but are subject to weather outages, and intercalibration between stations is difficult. Space-based measurements are currently made with the MDI instrument on SOHO. All of the routine ground-based measurements being made produce full-disk, line-of-sight (LOS) magnetograms; however all of the models require full spherical Sun specification. To make up for this deficiency modelers use various techniques to make synoptic maps from the full-disk

magnetograms. The Wang and Sheeley model is semi-empirical and uses photospheric magnetic maps with various corrections and predicts solar wind speed and magnetic polarity at Earth. The model is good for predicting background solar wind, but poor at capturing eruptive events. Knowing the background, however, is critical for predicting how a CME will propagate through the solar wind. To improve solar wind models it is desirable to have long-term, intercalibrated, high time cadence (better than daily) photospheric magnetic field measurements.

3 Presenter: **Yan Li (UC/Berkeley)**
Title: Study of Coronal Field Changes Using Photospheric Magnetographs
Summary:

Changes in the solar photospheric magnetic field lead to changes in the corona. This talk presented a new method of combining the standard LOS magnetograms into synoptic maps for use in corona/solar wind models. The new method is to use synoptic "frames" to replace old data with the latest data as they update daily, rather than the standard method of preparing a new synoptic map once every rotation (28 days). Two ways of updating the synoptic maps were presented: the "center frame" method in which the oldest data are 15 days old, and the "left frame" method in which the oldest data are 30 days old. In principle, coronal models would be greatly improved if vector magnetograph data were used instead of LOS.

4. Presenter: **Stephen Kahler (USAF/AFRL)**
Title: Solar Sources of Space Weather
Summary:

This talk considered two aspects of space weather: geomagnetic storms and solar energetic particle events (SEPs). Both are strongly associated with, and are now known to be caused by, CMEs. CMEs have several signatures observable in solar measurements. In white light coronagraph images halo CMEs are visible. In Hα and HeII one can see root activity associated with CMEs such as double ribbon flares and filament eruptions. In X-rays and the EUV one sees long duration arcade events, dimming regions, active region sigmoids, and "EIT waves", all associated with CMEs. In a study of geomagnetic storms at Earth there was a high probability that a CME occurred prior to the storm, there was also a high probability that a flare occurred. In the reverse direction, about half of the halo CMEs in the study were geoeffective. It was found that the solar wind's magnetic field direction is an important factor. Two upcoming instruments, the Solar Mass Ejection Imager (SMEI) and the All Sky Heliospheric Imager (ASHI) were described, along with their capabilities to observe CMEs. For SEPs, it is important to understand CME size and propagation as SEPs come from the bow shock of CMEs. There is a general correlation between SEP peak intensity and the speed of a CME, but other factors beyond speed are involved.

What should GOES measure? The answer, according to the speaker is as follows: A coronagraph with the capability to determine leading edge speed, angular extent, and location of a CME; an SXT/SXI type soft X-ray imager capable of flare location, discriminating sigmoids, dimmings, and arcades; an EIT type EUV imager able to see dimmings and waves; and possibly an all-sky white light imager like SMEI, which has promising capabilities but has yet to be proven ready for operationalization.

5. Presenter: **Joan Burkepile (NCAR/HAO)**
   Title: Solar Disk Signatures of Coronal Mass Ejections
   Summary:
   The major questions for predicting CMEs and their geoeffective effects are: Where are the CMEs located and how are they getting to Earth, where does the CME start on the Sun and what is its structure there, and what is Bz and how is the CME trajectory evolving with time. There are many signatures of CMEs observable on the solar disk. So-called "dimmings" are seen in soft X-ray and EUV images of the Sun as mass is lifted away from the corona. FeXII images from EIT show that CMEs generate global waves displacing coronal material. Hα and helium images show that prominences/erupting filaments always accompany CMEs. Helium images also show waves. Long duration and high intensity X-ray flares are also often associated with CMEs. In addition to disk signatures, the primary observations of CMEs come from coronagraphs. Coronagraphic images give the best handle on location and propagation of CMEs, can indicate halo CMEs, and can give CME density information, but cannot give temperature information. Flare images and magnetograms do not give enough information to determine the full geoeffectiveness of a CME. Trajectory information is vital. Additional desired measurements for predicting CMEs include: in situ measurements closer to the Sun than Earth, routine coronal magnetic field measurements, and full disk vector magnetic field measurements. Funding of modeling efforts is also needed in addition to measurements.

4:00-6:10 PM SESSION 3: PREDICTING EVENTS AT THE SUN

Co-Chairs: ***Larry Combs (NOAA/SEC) and MSgt. Bill Murtagh (USAF/55th SWXS)***

1. Presenter: **Larry Combs & MSgt. Bill Murtagh (NOAA/SEC)**
   Title: Introduction
   Summary:
   The purpose of this session is to review current and potential processes used in forecasting. None of the primary pre-flare, pre-eruptive event signatures used in operations today are perfect indicators for making geoeffective predictions. The currently used signatures include: stressed magnetic structure, sigmoids, trans-equatorial arches, enhanced X-ray emissions, active filaments, increased radio activity, coronal holes, and helioseismology. Operationally, these signatures are detected in Hα and white light images, magnetograms, X-ray spectra, radio spectra, and soft x-ray images. Still in the research phase are Yohkoh SXT images and SOHO LASCO and EIT images since the data from these instruments are not updated sufficiently for forecasting purposes. Of the research instruments, MSgt Murtagh believes that a coronagraph is the most essential for improved operations.

2. Presenter: **Sara Martin (Helio Research)**
   Title: Tests of Three Techniques for Forecasting Solar Events
   Summary:

The development and initial testing of three techniques of forecasting solar events were reviewed: (1) the eruption of targeted filaments (prominences observed against the solar disk) based on proximity and scale of newly emerging active regions, (2) the eruption of quiescent prominences (above the limb only) based on their rate of change in height in EIT He II 304A images, and (3) magnetic clouds and magnetic flux ropes in interplanetary space based on the chirality and orientation of recently erupted quiescent filaments. Each technique employed at least one specific measurable structure in solar images. The first technique allows the successful anticipation of a relatively small fraction of quiescent filaments with over 50% success rate; it is useful in limited circumstances for anticipating and recording the eruption of selected erupting filaments. The second technique allows the anticipation of a relatively high percentage (50% or more) of quiescent erupting prominences at the limb with few false alarms. This technique is marginal for application to earth directed solar events with current data sets but offers high potential for the anticipation of some major earth-directed events using images from a future spacecraft such as STEREO. The third technique was not successful as tested on quiescent filaments; distinct signatures of flux ropes, known to date, were not identifiable with most quiescent erupting filaments in a 5-month trial forecasting interval. From this latter experiment and other recent studies it has become evident that solar associations of distinct magnetic clouds or interplanetary magnetic flux ropes are primarily with flares and erupting filaments from active regions rather than with quiescent erupting filaments. Refinement and improvement of the first two techniques is possible and recommended. The third technique should be tested again for specific applicability to fast solar events with CMEs from active regions.

The recommendations of the speaker were that GOES needs, in priority order: LASCO C1 and C2 type coronagraphs, HeII 304 Å EIT-like images (at high resolution and high time cadence), and X-rays in the high corona.

3. Presenter: **Sarah Gibson (NCAR/HAO)**
   Title: Evolution and Eruptions of Twisted Coronal Structures
   Summary:

   Observations of coronal mass ejections (CMEs) show distinctly twisted structures, providing a clue to the nature of the magnetic field underlying them. Recent studies have shown that regions observed to possess a large degree of twist (such as S-shaped, or "sigmoid" active regions) are statistically more likely to erupt (two to one) than non-sigmoid regions. Sigmoids have a very robust structure. They persist, with the region even returning to its s-shape after an eruption. SOHO and TRACE performed a joint observation program to determine why sigmoids are so robust. A sigmoid appears to have three stages: An active stage associated with flares, CMEs, and filament formation; a quiescent filament stage where the shape is clear; and an eruptive filament stage where there is loss of shape. The interpretation is that sigmoids are indicative of an emerging flux rope, with the sigmoid as the interface between the flux rope and the external environment. Energy is stored in the “twist” and cannot be flared away. Sigmoid activity is associated with equilibration and reformation, not with removal of the flux rope. Magnetic helicity has to be bodily ejected to be removed. Sigmoids are most readily observed in X-ray wavelengths. They are seen at other wavelengths, but only briefly and during certain times. The conclusions of the SOHO/TRACE study are that sigmoids move back and forth between active and quiescent stages, that sigmoids cannot be considered independently of the surrounding environment, and that with current understanding, sigmoids have limited use for prediction of geoeffective events.

4. Presenter: **Nariaki Nitta (LMSAL)**
Title: Observations of CMEs with the Yohkoh Soft X-ray Telescope
Summary:

The Soft X-ray Telescope (SXT) on Yohkoh has both unique capabilities and limitations for observing CMEs. The limitations come primarily from the day/night cycle and the memory of the on-board data recorder. The unique capabilities are due largely to the broad sensitivity to high temperatures. Despite the prevailing feeling of the community as a result of the 'Flare Myth' debate, many global and fast (and hence geoeffective) CMEs are in fact associated with major flares in active regions. SXT has successfully traced high-temperature ejecta, which are well correlated with CMEs, in flare sequence data that have high temporal resolution. Global search is presently under way to detect CME-associated waves in SXT images. They are considered to be a counterpart to the chromospheric Moreton waves or coronal EIT waves. SXT has also revealed two pre-CME signatures (S-shaped and large-scale trans-equatorial loops), which may be useful for predicting CMEs. They are not usually observed at low temperatures (< 2 MK). A geoeffective CME can arise also from a quiescent region, in which case acceleration takes place over a large distance and a long time, to produce shocks in the interplanetary space. SXT can provide useful information on coronal restructuring in this type of event. Dimming (a pre-event signature readily seen in the EUV) can also be seen in SXT images, but the images must be manipulated beyond the standard data product. Low corona measurements are important for space weather since that is the region in which CMEs start. Soft X-ray and EUV instruments like SXT image this region of the corona and so can be vital to the space weather effort.

5. Presenter: **K. D. Leka (Northwest Research)**
Title: Uses, Possibilities, & Limitations for Forecasting using Vector Magnetograph Data
Summary:

Are vector magnetograms suitable for use by forecasters as a real-time, quantitative measure of solar active region complexity and activity level? Photospheric magnetograms have both plusses and minuses. On the plus side, they give a "map" of the magnetic flux vector at the photosphere. They are a familiar data product. They can quantify active region complexity, and they are well understood in terms of both the measurement and the physics. On the minus side, photospheric vector magnetograms are not available in real time. They are not a consistent data product. There is not currently a worldwide network of observation sites. What sites do exist are not well inter-calibrated. The measurement is very sensitive to terrestrial atmospheric conditions. Finally, it is still unclear whether even temporally well-sampled photospheric vector magnetograms can actually help predict geoeffective solar energetic events as the photosphere is still forced by plasma motion. Ideally, one would want chromospheric magnetic information instead of photospheric, since the chromosphere is a force-free region.

Chromospheric vector magnetograms also have both plusses and minuses. On the positive side, the data will look similar to the familiar photospheric measurements. They also provide a quantitative measure of active region complexity. Most significantly, there is a physical basis to expect to observe a pre-event signature since the chromosphere is force free and energy can be tapped by the corona for eruptive events, so they should be useful for geoeffective predictions. On the negative side are all of the same limitations on realtime data availability and lack of worldwide observation sites. In addition, chromospheric vector magnetic measurements are still on the cutting edge of research, and so are not ready for operational use. Chromospheric vector magnetograms are possible with the same instrumentation as for photospheric vector magnetograms with the modification to allow different filters. The wings of the sodium D-line are good for chromospheric observations. Further research into chromospheric vector magnetograms is contingent upon funding and will probably not be a proven technique in time for GOES-R; however, they are promising and should be kept in mind for the future.

October 24: Instruments and Technology

MORNING

8:00-10:10 AM SESSION 4: REVIEW OF OBSERVABLES AND INSTRUMENT TYPES

Co-Chairs: ***Chris St. Cyr (Catholic U.) and Vic Pizzo (NOAA/SEC)***

1. Presenter: **Vic Pizzo (NOAA/SEC)**
   Title: Overview
   Summary:
   While previous sessions detailed solar phenomena, today's sessions cover how those phenomena are observed. The expected constraints for instruments on GOES R will be described, in addition to specific observation and instrumentation types used for solar monitoring.

2. Presenter: **Chris St. Cyr (Catholic U.)**
   Title: GOES Needs a Patrol Coronagraph
   Summary:
   The strong recommendation of the speaker is that GOES needs a coronagraph. This assertion is based on the assumptions that CMEs cause most severe geomagnetic storms and that a properly designed white-light coronagraph is able to detect all significant, Earth-directed, halo CMEs. Currently, forecasters cannot detect halo CMEs in any other way. Attempted proxies for CMEs (such as flares in Hα, X-ray and EUV activity, and dimming in EIT image) are unreliable as signatures of CMEs. The locations of such proxy events are misleading when transfer is attempted to CME location and trajectory. Future research coronagraphs may not be suitable to detect halo CMEs as LASCO on SOHO currently does. GOES R and beyond should have white light coronagraphs as part of the baseline payload to insure that reliable geomagnetic storm prediction continues beyond the lifetime of SOHO.

3. Presenter: **Simon Plunkett (NRL)**
   Title: Halo CME Observations with LASCO and EIT
   Summary:

   The LASCO and EIT experiments on SOHO have been observing the solar corona almost continuously since early 1996. Coronal mass ejections directed along the Sun-Earth line can be identified by their "halo" appearance in the LASCO images. A halo CME is distinguished in the coronagraph images as a CME which spans more than 120 degrees around the Sun and has some portion of it appearing in projection over one or both of the solar poles. EIT images can be used to identify activity on the solar disk associated with halo CMEs, and thus to distinguish between halo events that are directed towards the Earth, and those that are directed away from the Earth. Such EIT disk activity includes depletions, dimmings, waves, arcades, and flares. A study of LASCO/EIT images from the period of October 1998 to December 2000 found that 63% of observed full frontside halo CMEs were followed by geomagnetic disturbances with Kp>6. The LASCO and EIT operations staff has developed a system for alerting interested parties when an Earth-directed halo CME is observed, usually in near-real time. (MSgt Murtagh later reported on a similar study which showed that out of 52 halo CMEs: 88% had a signature seen in ACE and/or impulse seen in magnetic field data, 79% were followed by Ap>=20, 60% were followed by Ap>=30, and 30% were followed by Ap>=50.)

4. Presenter: **Vic Pizzo (NOAA/SEC)**
   Title: Soft X-ray and EUV Imagers for GOES-R
   Summary:

   X-ray and EUV instruments have been part of many missions including: Skylab, Yohkoh (SXT), SOHO (EIT), TRACE, and GOES M (SXI), and are planned for GOES N-Q (SXI), Solar B, SDO, and STEREO. Soft X-ray instruments generally have used grazing incidence optics and film, CCDs, or MCPs as detectors. EUV instruments have used normal incidence optics and either CCD or MCP detectors. Observational considerations for potential soft X-ray and EUV imagers for GOES include: wavelength response and control, absolute sensitivities and contrast ratios, spatial resolution, dynamic range, field of view, observing cadence, and continuity of measurements. It should be noted that space weather purposes are not the same as scientific research purposes, so the requirements for a GOES operational instrument will not necessarily be the same as for existing and previous research instruments.

5. Presenter: **David Hathaway (NASA/MSFC)**
   Title: "Photospheric" Observations for Monitoring and Predicting Solar Events
   Summary:

   Several ground-based observations have proved to be useful in monitoring and predicting solar eruptive events. H-α filtergrams can be used to monitor the occurrence of flares and filament eruptions - both of which can lead to CMEs. Helium 10830 Å filtergrams can be used to monitor coronal structures including coronal holes that can be the source of high-speed streams that induce geomagnetic activity. Longitudinal line-of-sight magnetograms can be used to determine the magnetic complexity of active regions - an important factor for predicting flares. Vector magnetograms can be used to quantitatively determine the degree of non-potentiality (or available magnetic energy) in an active region and the likelihood of flares and CMEs. Studies of erupting and non-erupting active regions show the importance of obtaining vector magnetic field information for flare and CME predictions. All of these observations can be obtained from ground-based instruments; however, vector magnetograms would benefit enormously from a space-based vantage point. A small (2 kg, 3 W) vector magnetograph could be produced for future GOES satellites.

10:30-12:00 PM SESSION 5: SPACE-BORNE VERSUS GROUND-BASED SOLAR OBSERVATIONS

Co-Chairs: Maj. Peter Engelmann (USAF/AFSPC) and Bill Murtagh (USAF/55th SWXS)

1. Presenter: **MSgt. Bill Murtagh (NOAA/SEC)**
   Title: Introduction
   Summary:
   This session will look at the trade-offs regarding observations that can be made from space only or from the ground and space. One issue is functional equivalence of observations: Where can different observations provide the same types of information for forecasting? Another issue is exact equivalence: When is a given instrument better hosted in space than on the ground?

2. Presenter: **Maj. Peter Engelmann (USAF/AFSPC)**
   Title: Ground-Based vs. Space-Based Solar Observations
   Summary:
   Air Force Command requirements for solar monitoring basically fall into two categories: continuous and synoptic measurements. Continuous monitoring detects all impulsive events and allows for forecasting of their effects. The Air Force desires forecasting of the onset and intensity of proton events, the detection of all radio bursts, and the forecasting of the onset and intensity of geomagnetic disturbances. Synoptic monitoring allows for the forecasting of the onset of impulsive events and of recurring events. Thought must be given to what observations are needed for each type of monitoring and whether the measurements are best done from the ground or from space. The bottom line for space-based observations is that they can be done both reliably and cost effectively.

Presenter: **Brian Dougherty (Caltech)**
Title: Solar Radio Burst Locator
Summary:
This was an unscheduled talk, added during the workshop. The Caltech Solar Radio Burst Locator (SRBL) is a ground-based, circularly polarized spectrometer using a six-foot radio telescope and a single receiver. It operates in the microwave region with spectral resolution between 1200—18000 MHz. It is a single instrument that replaces eight spectrally specific radiometers in RSTN. The SRBL is not an imager, but it has a spiral feed which gives location information via spectral inversion. It is capable of locating a burst to within approximately 2.6 arcminutes on the sky. The goal is to reach 2.0 arcminute locating ability. A network of six SRBLs around the globe would be an ideal distribution. The SRBL has the advantage over optical techniques in that it can see

through clouds. Almost all halo CMEs can be associated with radio bursts. In addition, all X-ray producing flares can be observed as radio bursts. Unfortunately, radio bursts are not associated with all proton-producing events.

4. Presenter: **Alan Kiplinger (CU)**
Title: Progressive Spectral Hardening for use in Proton Event Prediction using Microwave and Hard X-ray observations
Summary:
Typical solar flares (95% or more) have X-ray spectra that are soft at the beginning, become hard at the peak, and are soft at the end. Some flares, however, show progressive spectral hardening in the X-rays, being soft at the beginning, hard at the peak, and hard at the end. These types of flares are very highly correlated with proton events. A study of 750 hard X-ray flare events with the SMM spectrometer was done. The spectral hardening technique predicted 30 proton events during the study period. In actuality 22 proton events occurred. The technique also predicted that for 701 of the flares no proton event would occur. In actuality, only one of these non-event predictions actually produced a proton event. The technique seems exceptionally reliable for predicting proton events. A similar spectral hardening technique is also possible using microwave spectra of flares, but does not appear as reliable as the X-ray method. It is anticipated that X-ray images from HESSI will provide more physical insight into why the technique works.

AFTERNOON

1:00-3:00 PM SESSION 6: INSTRUMENT CASE STUDIES (OLD AND NEW)

Chair: Steven Hill (NOAA/SEC)

1. Presenter: **Jaya Bajpayee (NASA GSFC, for NOAA/NESDIS)**
Title: GOES R Spacecraft Constraints and Solar Imager Accommodations
Summary:
This talk provided an overview of the GOES spacecraft, its operations, and the constraints that apply to solar-pointing instruments. The GOES constellation consists of two operational satellites at 75º W and 135º W longitude and one spare satellite in storage between the two. The primary mission of GOES is fulfilled with the Earth Imager and Atmospheric Sounder instruments. Additional instrumentation includes equipment for telecommunications, the Space Environment Monitor (SEM) with the Solar X-Ray Imager (SXI), and space for an Instrument of Opportunity (IOO). Solar imaging on GOES is done with the SXI (or will be when GOES M becomes operational). SXI will provide one image per minute continuously. As currently planned, SXI will only be on every other satellite, so there will be a loss of data during eclipses that will occur for 1.5 hours per day for a period of 80 days per year. The SXI resides on the yoke of the GOES solar panel and has its own pointing platform and a high accuracy sun sensor. The SXI operates on 40 Watts and has a mass of 34 kg.

Each "block" change for GOES (usually every four satellites) is typically accompanied by a major upgrade of instrumentation and satellite. GOES R represents such a block change. The improvements planned include: ten times greater data volume, 85 Mbps data link, better pointing knowledge, and generic instrument interfaces. Accommodation for instrumentation is planned as: Mass: SXI=34 kg, SEM=48 kg, IOO=50kg; Power: SXI=60—80 W, SEM=80 W, IOO=150—250W; Size: SXI=30.4x24.1x79.2 cm, SEM=various, IOO=113.5x67.2x53.3 cm. Any changes in the solar imaging instrumentation should consider power, mass, size, data-rate, and the impacts to the design of the solar array yoke or sun-pointing platform and to the meteorological payload. Timely requirements definitions should be developed and passed through a NOAA and Air Force cost-benefits analysis. Consideration should be given to whether the solar imager should be required for every satellite rather than every other one.

2. Presenter: **Steve Hill (NOAA/SEC) talk given by Vic Pizzo**
   Title: GOES-12 Solar X-ray Imager
   Summary:

   The Solar X-ray Imager (SXI) for GOES started with a requirements document in 1983. The first SXI was launched on GOES-12 on 23 July 2001. It serves as the prototype of future GOES SXIs and represents NOAA's first operational solar X-ray observations for space weather forecasting. The first SXI uses an MCP—CCD stack for the detector with a variety of filters to provide different wavelength bandpasses. It allows for gain adjustments for dynamic range changes. The SXI will get a 98% on duty cycle (the 2% missing is from eclipse outages). It has been run with a seven-image cycle with one image per minute. Initial checkout phases for SXI showed a few problems, which are considered "correctable". Ground tests showed an "image fog" or halo in the images, but the effect was at the 0.01% level and deemed acceptable. The reference pixel row of the CCD is not downlinked with the rest of the image data. The consequence of this oversight is that the images have streaks if a pixel in the reference row gets a particle hit. Future SXIs use an alternative design. The effect of the motion of the solar pointing platform is an approximately one-pixel jitter in the images. The filters produce a diffraction pattern in the images. These latter effects can be removed and the images sharpened in data processing. GOES-12 completed its on-orbit checkout and was put into storage orbit in December 2001. It will not be called up to duty until GOES-8 or 10 requires replacement. Note that the SXI does not have "call up" status for a new GOES.

3. Presenter: **Chris St. Cyr (NRL)**
   Title: Experience with Spaceborne Coronagraphs
   Summary:

   Spaceborne white light coronagraphs have been flown for 30 years on such missions as Skylab, Solwind, SMM, Spartan, and SOHO. The technique is very mature and accommodation issues are well defined. The primary issue for a coronagraph design is the elimination of stray light. Mechanical considerations include: pointing stability, exposure times, unobstructed FOV, thermal stability, and contamination. Telemetry considerations are primarily based on image size and resolution, and image cadence. Coronagraphs do not require high voltage, have no hazardous materials, and have no special EMI/EMC special requirements. Off-Sun pointing is required during the spacecraft checkout phase. A GOES coronagraph must be able to detect all Earth-directed CMEs capable of causing geomagnetic disturbances and it must be capable of measuring the apparent speed and acceleration of such CMEs.

4. Presenter: **Werner Neupert (NOAA/SEC)**
   Title: EIT on SOHO
   Summary:
   The EIT on SOHO is a Ritchy-Chretien telescope with four spectral-line resolution channels. The four channels, in order of source region temperature from cool to hot are: HeII (304 Å); FeIX, X (171, 174 Å); FeXII (195 Å); and FeXV (284 Å). The field of view (FOV) is selectable electronically and has image cadence impacts (smaller FOV is possible with a higher cadence). One full disk image is possible every twelve minutes. EIT can show disk signatures of CME initiation. Some lessons were learned from SOHO pertaining to using EIT-type images for space weather. First, the 12-minute cadence is too slow. A cadence of one minute or faster would be better. The gap in FOV between EIT and the LASCO C2 coronagraph is too large. The operations of the EIT need to be simplified and regularized (pick a measurement to make and stick with it), and not enough telemetry was allocated for the EIT. Wavelength switching by a filter wheel in the EIT has posed a limitation on the instrument's use due to wear and sticking of the mechanism. Aging or degradation of the detector has also been noticed, with a negative imprint of the Sun now seen on the EIT dark images (this effect is correctable in data processing). Recommendations for improvements for a GOES EUV imager compared to the SOHO EIT include: a faster image cadence, an expanded FOV, better S/N, more telemetry bandwidth, and parallel imagers for backup and lessening of mechanical wear.

3:20-5:50 PM SESSION 7: TECHNOLOGICAL FRONTIERS

Chair: Steven Hill (NOAA/SEC)

1. Presenter: **Greg Berthiume (MIT Lincoln Lab)**
   Title: CCDs: Evolution and Impacts for Solar Imaging
   Summary:
   CCDs are a highly developed technology with continuing improvements being motivated primarily by military and public consumer needs. Five major areas of improvement can be foreseen in the next eight years. (1) Amplifier technology will improve, allowing imaging spectroscopy or photon counting with CCDs (already being done on astronomy satellites today). (2) Back-surface processing will improve, providing better EUV sensitivity. (3) Integrated CCD/CMOS technology is being developed which will give higher speed readouts with lower power. (4) Curved CCDs are being developed which will better match the CCD with the focal surface of instruments. (5) Orthogonal transfer CCDs are also being developed, which will allow for on-chip jitter suppression.

2. Presenter: **George Lawrence (CU/LASP)**
   Title: MCPs (Micro Channel Plates) In Solar Imaging
   Summary:

MCPs are photo-emissive, secondary emission amplifiers of images. Why would one choose to use MCPs for solar imaging? Primarily, they block visible light, which CCDs cannot do without filters. In other words, MCP wavelength sensitivity can be such that they are responsive in the UV or EUV with very little or no sensitivity in longer wavelengths. MCPs also have very low dark currents and have very large quantum efficiencies (~10^6 at 253.7 nm). MCPs are available in a variety of sizes with pore sizes as small as 6 microns. The gain of an MCP detector depends on the high voltage across it and the number of plates in the stack. A single MCP has a gain of < 10^4, whereas a triple (or Z-) stack can provide gain up to 10^8. Scrubbing of the plates improves the pulse height distribution of the photon detection, but lowers the gain. MCPs can be coated with photocathodes to provide better QEs in different wavelength ranges. The current limitations include: degradation with use (based on total charge extracted per unit area), curved channels in the plates causing image shear, and Moiré patterns in readout. One of the new frontiers in MCP technology includes square pores in square bundles, which is better for photon event location and for imaging.

3. Presenter: **Tom Woods (CU/LASP)**
   Title: Calibration Issues for Array Detectors: Experiences at LASP/CU
   Summary:

   There are several calibration issues for array detectors. For microchannel plate (MCP) based detectors, it is important to characterize the gain changes as a function of high voltage (HV) and temperature, both measured pre-flight and tracked throughout flight. For CCD detectors, it is important to characterize the noise levels and degradation as a function of temperature and vacuum condition and to provide a means of baking out a CCD in-flight if the CCD is cooled. For all types of array detectors, it is important to characterize the pixel-to-pixel uniformity as a function of temperature and gain levels, to provide an absolute pre-flight calibration, and to track instrument / detector degradation during flight.

   Several techniques can be used for in-flight calibrations. Two common on-board calibration solutions for X-ray detectors is to provide redundant channels, one used more frequently than the other, to estimate instrument degradation and to provide a lamp to at least track the pixel-to-pixel (flatfield) variations but also can provide absolute calibration. Validation of the in-flight measurements with other satellite or rocket instruments is valuable to ascertain the absolute calibration of an instrument; thus, these comparisons can provide information about the instrument degradation function. Finally, the solar images themselves can provide in-flight calibration results, such as flatfield images if the Sun is rastered over the detector and degradation functions if the "quiet Sun" pixels can be assumed to be constant with time.

4. Presenter: **Phil Judge (HAO)**
   Title: An initiative to measure coronal magnetic fields
   Summary:

   Magnetic free energy in the solar corona leads to coronal heating, coronal dynamics, and subsequent space weather phenomena. Magnetic field measurements are used to study the relationship between the coronal field and the sunspot cycle, the magnetic field before, during, and after CMEs and flares, prominence cavity models, and the relationships between solar plasma and magnetic fields. Solar magnetic fields are measured in a variety of methods: magnetic dipole transitions, the Hanle effect, direct magnetometry, and radio emissions on the disk and on the limb. The High Altitude Observatory at NCAR wants to measure the coronal magnetic field from the ground using polarimetry on forbidden coronal lines. This has been done before by KELP (K-corona Emission-Line Polarimeter) in the 1970s. The limitations are that we can only measure the direction of the magnetic field on the plane of the sky using linearly polarization, and the line-of-sight density using circularly polarized light. Limb measurements will be possible from about 1.09 to 3 solar radii. The results are highly calculation intensive, and the observations are difficult to do, as they require excellent seeing conditions. Using forbidden lines in the one-micron wavelength range is ideal.

5. Presenter: **Cliff Minter (NOAA/SEC)**
   Title: Data Assimilation
   Summary:

   Data assimilation is often referred to as "black magic", obtaining good data from bad. Data assimilation is the process of minimizing errors in data after the fact by making an optimized combination of data, a model, and statistics. It is used to analyze data for trends and correlations, to remove errors, to optimize forecasts and models, and to provide error estimates for forecasts and models. The losses if data assimilation is not used on a data set include: not obtaining the full benefit of the measurements, missing an important feature, mistaking false trends for real, making weak or false correlations appear significant, not fully optimizing forecast accuracy, and not being able to quantify results as easily. Popular data assimilation techniques include: nudging, averaging, traditional least squares, adjoint or inverse methods, batch methods, and Kalman filters. An example of data assimilation was shown using SSUSI data and the CTIM model.