Improvement of Two Operational Models for Advance Warning of Geoeffective Disturbances of Solar Origin

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LONG-TERM GOALS

To improve the prediction of traveling solar disturbances that impact the geospace environment. Such disturbances, which are associated with both coronal holes and coronal mass ejections (CMEs) launched from the Sun, can cause substantial geomagnetic effects, including the crippling of satellites, disruption of radio communications, and damage to electric power grids.

OBJECTIVES

To improve and extend the predictive capabilities of two space weather models currently in operational use at the National Oceanic and Atmospheric Administration's Space Environment Center (NOAA/SEC). The first, the Wang & Sheeley model (WS), predicts the background solar wind speed and interplanetary magnetic field (IMF) at Earth. The WS model is being improved though the incorporation of additional and more realistic, physics-based models into the prediction routine. The second is the Chen model that predicts the occurrence, strength, and duration of large non-recurrent storms due to transient events on the Sun such as CMEs. This model's prediction routine is being modified in an effort to improve its predictive capability and reliability.

APPROACH

The Wang & Sheeley model [Wang and Sheeley, 1992] is a physics-based representation of the quasi-steady global solar wind flow (see year 2000 report for details). The NOAA/SEC implementation of the model serves two purposes with respect to space weather forecasting: (1) it provides advance warning of high-speed solar wind streams, which are associated with recurrent geomagnetic disturbances and increased high-energy electron fluences near Earth; and (2) it provides our best estimate of flow conditions and structures lying in the path of transient disturbances (such as CMEs and magnetic clouds) headed toward Earth. That is, dynamic interactions with intervening structures can have a significant impact upon the propagation speed of CMEs and can significantly influence their physical properties, such as magnetic field intensities and orientations.

Two major modifications are being made to the WS model which are anticipated to further improve its predictive capability and reliability. The first is the inclusion of an improved upper coronal model that

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14. ABSTRACT
To improve the prediction of traveling solar disturbances that impact the geospace environment. Such disturbances, which are associated with both coronal holes and coronal mass ejections (CMEs) launched from the Sun, can cause substantial geomagnetic effects, including the crippling of satellites, disruption of radio communications, and damage to electric power grids.

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spans the region from 2.5 $R_\odot < R <$ 20-30 $R_\odot$. The second is the incorporation of a quick running interplanetary 3-D magnetohydrodynamic (MHD) propagation code of the solar wind (i.e., from 20-30 $R_\odot < R <$ 1 AU). These two modifications replace the extremely crude assumption made in the original version of the model of radial propagation beyond 2.5 $R_\odot$. We are also attempting to modularize the code so as to make future improvements/modifications simpler.

The NOAA/SEC implementation of the Chen model [Chen, 1996 and 1997] provides real-time forecasts of the occurrence, duration, and strength of large geomagnetic storms using real-time solar wind data. The method estimates the IMF and the geoeffectiveness of the solar wind upstream of an L1 monitor such as Advanced Composition Explorer (ACE) (refer to year 2000 report for model details). As discussed below, the model can more than double (on average) the ~1-hour advanced warning time presently available using L1 data alone. We are working to extend the predictive capabilities of the Chen model by incorporating additional improvements (see year 2000 proposal). A recently completed verification study on the basic version of the model will serve as baseline to objectively measure the degree of improvement in future model upgrades.

WORK COMPLETED

Under the advisement of the PI, primary implementation responsibilities for this project have been assumed by Dr. C. N. Arge.

The NOAA/SEC implementation of the original Chen model makes hourly forecasts of the likelihood of the imminent approach of a large geomagnetic storm producing solar wind using a near-real-time data link from the ACE satellite in an L1 orbit. The real-time predictions are made available and current to the SEC forecasters and the broader research community via the Chen model web page listed above.

Last year we reported the results of a verification study conducted on the Chen model using 2-years of ACE real-time data. While promising, an expanded verification study using the significantly more reliable Level 2 ACE data was deemed necessary due to the problematic nature of the real-time ACE data, especially the real-time data available in 1998. The goal was to establish a reliable benchmark of the model's performance using the best data possible (i.e., ACE Level 2 data). With the assistance of a newly hired part-time programmer, Susan Wahl, a new verification study using Level 2 ACE data and now spanning 3 years (1998-2000) has recently been completed. The results obtained are very promising both for the performance of the basic model and for the likelihood of enhanced model performance via future improvements. In the new study, the model successfully predicted 33 out of 41 (i.e., ~80%) actual events with only 11 false alarms, 9 warnings, and 8 misses. It provided an average warning time of 2.1±2.5 hours (i.e., two-thirds of the correctly predicted events had warning times between 4.6 and 0 hours) with a maximum of ~10 hours. Switching to half-hour updating instead of hourly, as presently done, may extend warning times even further. Our results also reveal the seasonal effect first noted by Cliver et al. [2000] and brought to our attention by David Webb [private communication] at the 2001 Space Weather Week conference. Cliver found that there are substantially fewer storm days (i.e., where *Dst* falls below –100 nT) during the 4 months near the solstices (i.e., December, January, June, and July) compared to the rest of the year. In apparent confirmation of this result, we found that ~50% of the false alarms and warnings made by the Chen model occur during these same four months, while one would expect only ~33% to occur due to chance. Only 10% of the correctly predicted events occur during the above four months. The results of the verification study were presented at two recent conferences: Space Weather Week held in Boulder, Colorado (May 2001) and the COSPAR meeting in Beijing, China (September 2001). A paper reporting these results is in preparation and will be submitted to a refereed journal soon.

We are also in the process of greatly improving the Chen prediction model web page and plan to have it ready by the end of the first year funding (i.e., January 2002) as promised in our proposal. The new page will have an improved graphical display that includes real-time *Dst* predictions (provided by Janet Luhmann at Berkeley) to compare with the Chen model predictions. It will also have a model explanation and example pages along with suitable links to other web sites.

Much of the effort spent on the WS model over the last year has been concerned with incorporating both an improved upper coronal model and interplanetary 3-D MHD propagation code into the WS prediction scheme. This has been accomplished and initial test runs have been successfully conducted. We are now working to improve and generalize the interfaces between the various models used in WS.

Arge obtained Y.-M. Wang's (NRL) version of the Schatten model and tested and modified it so that it can be used in the WS prediction routine to model the upper corona. The Schatten current sheet model [Schatten, 1971] provides a more realistic representation of the magnetic field topology of the upper corona. The output (i.e., magnetic field and solar wind speed) from the current sheet model is used as input to a 3-D MHD code, which is then used to propagate the solar wind to 1 AU. Two 3-D MHD codes have now been successfully tested using this approach. The first, accomplished by collaborator Detman at NOAA/SEC, is the 3-D MHD Han-Detman code [Detman et al., 1991] and the second, achieved by collaborator Odstrcil (University of Colorado/CIRES), is the Odstrcil 3-D MHD [Odstrcil and Pizzo, 1999a,b] code.

As a preliminary test, Detman generated solar wind speed predictions (and other parameters such as magnetic field phi angle, pressure, etc.) using the 3-D Han-Detman code for all of 1995 (see Figure 1). The inputs, provided by Arge, were current sheet model results derived from Carrington maps of the photospheric field data from Mount Wilson Solar Observatory. While the model still requires substantial refinement, tuning, and testing, these very preliminary results are nonetheless encouraging. For instance, as can be seen in the plot below, the agreement between the solar wind speed predictions and observations is quite good after mid-1995, with, however, the high speed streams being frequently under predicted before this time.

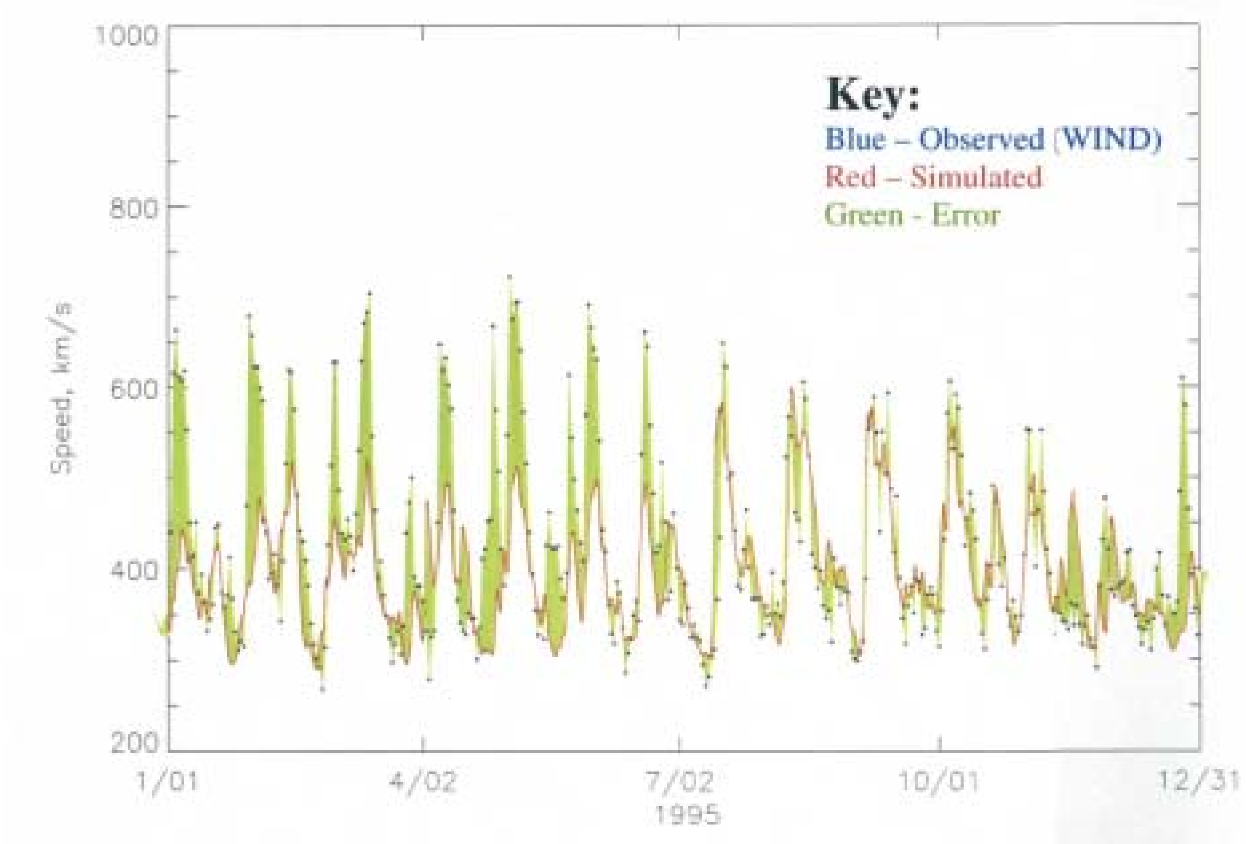

Figure 1: Comparison of Solar Wind Speed Predications and Observations at Earth [Predictions (blue dots) generated by the Han-Detman 3-D MHD Code and Observations (red line) from the WIND satellite. The green shaded areas highlight the discrepancies between the predictions and observations. (Figure courtesy of Tom Detman, NOAA/SEC)]

Finally, Arge has improved and extensively tested the synoptic map assembly code using data from Wilcox (WSO), SOHO/MDI, and GONG Solar Observatories. The code now includes a routine that fills data gaps that frequently occur at the Sun's poles. It is important to fill data gaps at the poles whenever possible, since the solutions generated by potential field source surface model are rather sensitive to the polar fields (e.g., [Arge et al., 2000]). We are now in the process of generalizing the entire routine so that it can assemble synoptic maps using magnetograms from any observatory with only a small interface routine required. The code now includes Zhao's [Zhao et al., 1997] synoptic frame method for assembling the maps. This method directly splices (rather than merges) the most recent magnetogram into the eastern edge of the currently updated synoptic map. The frame method has real potential for improving the predictions made by our simple Sun-to-Earth model, since it makes the most of the latest full disk magnetograms.

RESULTS

The incorporation of more sophisticated physical models within the WS model framework is likely to measurably improve forecasts of the background solar wind. Modularization of the WS prediction routine will permit easy replacement of individual models by improved models as they (and any required data streams) become available. In addition to direct operational use at NOAA/SEC and other forecast centers, the WS model has been enjoying increasing interest and application in the areas of space weather and solar-interplanetary research as well as educational outreach. For instance, Dr. Arge was invited to teach a lab at Boston University's Space Weather (CISM) Summer School this year (July 30-August 10 2001). He used the WS model to demonstrate general properties of the solar wind as well as provide the students with practical "hands-on" experience using a simple solar wind model. The individuals attending the school consisted primarily of first and second year graduate students from the US and abroad.

The Chen model continues to show real promise as an operational forecasting tool. The results of the new verification study will serve as reliable statistical baseline to measure the degree of improvement of planned upgrades (scheduled for year 2 of the project) to the model. It will also provide SEC forecasters and other interested users with an objective guide to the model's predictive capabilities and limitations.

IMPACT/APPLICATIONS

Eventually, a highly verified and robust modular version of the WS will replace the operational WS model presently used at NOAA/SEC. The improved models, predictions, and graphics that emerge from the development of this model will augment or replace those presently found on the NOAA/SEC WS web site listed above.

The results of the recent validation study of the Chen model are very encouraging. We expect measurable improvement in the model's predictive capability and reliability once improvements are incorporated.

TRANSITIONS

As mentioned above, SEC forecasters are using these tools, as does the space weather research community.

RELATED PROJECTS

Dr. Arge continues to collaborate with Dr. J. Luhmann et al. in a project aimed at detecting the launch of CMEs based on discerning changes in the global coronal magnetic topology taking place on a time scale of hours (see last year's report for details). He has also been working closely with Drs. Hildner and Pizzo at NOAA/SEC to examine recent claims (i.e., Lockwood et al. [1999]) that the Sun's global magnetic field is increasing over time. A comprehensive study of the long-term behavior of the Sun's magnetic field using magnetic field data from three solar observatories and spanning more than two solar cycles was conducted to test Lockwood et al.'s claim. The results of the study do not support the findings of Lockwood et al. A paper on this research has recently been submitted to JGR.

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