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Provision of a Bz Determination

Bernard Jackson
UNIVERSITY OF CALIFORNIA SAN DIEGO

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14. ABSTRACT

One of the most sought-after parameters is the heliospheric vector magnetic field, because this field interacts with other objects imbedded in the interplanetary medium. These interactions are of primary interest at Earth because a southward interplanetary magnetic field in Geocentric Solar Magnetospheric (GSM) coordinates (Bz negative) can couple with the Earth's magnetic field at the boundary of the magnetosphere, causing geomagnetic storms.

UCSD's present measurements from the Current–Sheet Source Surface CSSS modeling (Zhao & Hoeksema, 1995) arguably give the very best radial and tangential component fields to date at Earth and globally throughout the heliosphere in Sun-centered Heliographic coordinates (HEEQ). We submitted articles Jackson *et al*., (2015; 2016a) showing how all three vector field components in HEEQ can be provided from the CSSS modeling. We also discovered that our regularly-provided CSSS-modeled fields converted to GSM coordinates Bx, By, and Bz on a daily basis provide a prediction of low-level geomagnetic activity. We ready an article (Jackson *et al*., 2018c) detailing this work that compares our GSM Bz magnetic fields with those from *in-situ* spacecraft fields for the years 2006 through 2017, and present how this predicts geomagnetic activity and allows excellent few-day ahead forecasts.

15. SUBJECT TERMS

Sun-Earth Connection Predictions - Coronal mass ejections - heliospheric plasma – 3-D tomography – Ground-based radio and Spaceborne optical instrumentation

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1. Objectives:

One of the most sought-after heliospheric parameters is the vector (three-component) magnetic field, because this field interacts with other objects imbedded in the interplanetary medium. These interactions are of primary interest at Earth where a southward interplanetary magnetic field component in Geocentric Solar Magnetospheric (GSM) coordinates (Bz negative) can couple with the Earth's magnetic field at the boundary of the magnetosphere, causing geomagnetic storms.

UCSD's present measurements from the Current–Sheet Source Surface CSSS modeling (Zhao & Hoeksema, 1995) (Figure 1) arguably gives the very best radial and tangential component fields to date at Earth and globally throughout the heliosphere in Sun-centered Heliographic coordinates (HEEQ). We submitted two journal articles (Jackson *et al*., 2015, 2016a) detailing our automatic technique that allows determination of the Bn (north-south) magnetic field from "closed" surface fields first over a period from 2006 through 2008, and then extended from 2006 to 2016. The process we have developed allows an insertion of all three short-term vector field components from the solar surface not currently available from the CSSS modeling. Often, the process we have developed gives an indication of the fields associated with CMEs, especially at their onset. Here we have continued this study and augment it with more numerous analyses that are aimed at refining the technique so that it can be used to predict all three field components at Earth and globally around the heliosphere.

Real-time analyses of solar wind conditions at Earth provide a daily confirmation of how well these programming techniques work, and insight into the physical principles governing solar wind flow and magnetospheric interactions. As these real-time analyses become available, we intend for their use by the AFOSR, at the CCMC, at other world locations, and on our UCSD Website.

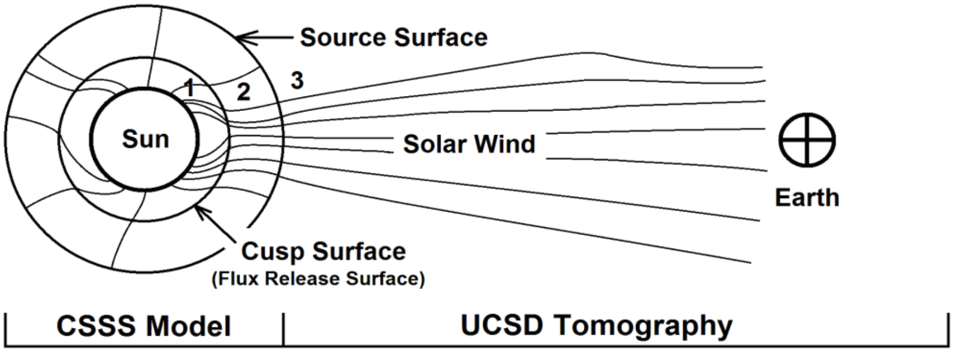


Figure 1. In the inner region (1), the CSSS model calculates the magnetic field using solar photospheric magnetograms. In the middle region (2), the CSSS model opens the field lines by imposing a horizontal current at the cusp surface. In the outer region (3), the UCSD 3D tomography extrapolates the magnetic field along velocity flow lines (from *Dunn et al.,* 2005). This is the usual way the CSSS model provides **open fields** to provide a radial field at the tomographic source surface (usually set at 15 Rs for the kinematic model) that is then convected outward to become radial and tangential fields in RTN coordinates at Earth. However, there is another way to provide these fields, namely by translating **closed fields** outward from near the surface of the Sun directly (from below the CSSS model Cusp Surface). Here all three components exist, radial, tangential, and normal, and by translating these directly to the source surface and then outward by the IPS they too can populate the inner heliosphere.

2. Progress during this contract:

There were at least four aspects of this work, and we made progress on all four of these research efforts during the contract. These four work aspects were:

1) Augmentation and expansion of our analysis of the short-term closed component fields for ten years of GONG and SOLIS magnetogram data. This analysis is discussed in Jackson *et al*., (2016a).

2) An analysis of the differences between projected and *in-situ* and CSSS-field magnitudes for Bn, and an expansion of the analysis to the Br and Bt HEEQ components and their comparison at Earth. The latter portion of this analysis is also discussed at length in Jackson *et al*., (2016a). The work to provide a valid Bn HEEQ component at 1 AU that correlates well with short-term transient variations has turned out to be more difficult than anticipated and is still an open question. The study has provided only limited results so far, and a few reports. This study has the potential to become far more valid at a future date, and is worth pursuing in further work. However, the work to compare the Br and Bt field components to three-component GSM fields led to surprise discovery; this work provided a method to predict GSM Bz field, and allowed a limited forecast of enhanced geomagnetic activity several days in advance. In the last year of this contract we concentrated some of our effort from the grant on this analysis.

3) An addition of the long-term RTN Br and Bt components that are derived by the CSSS model to the closed field Br, Bt, and Bn components. We did not implement this during the current grant period because we found the Bn component did not give a consistently better value throughout our ten-year study in Jackson *et al*. (2016a) even though positive results with specific CMEs have been described by Japanese colleagues (Nishimura *et al*., 2016; Nozaki *et al*., 2016). We concentrated our efforts on this issue by studies of the non-radial transport of fields, first close to the solar surface by tracing along field lines down to nearer the closed field regions on the solar surface, and second by exploring non-radial transport in the inner heliosphere using 3-D MHD analyses. These studies continue as presented below, but as yet have not given a result better than presently available.

4) The analysis of Bz has been made available on our UCSD website and has been distributed to others for their evaluation. The work has been reported at many meetings and in various journal articles as detailed below.

2.1 Open and Closed Field CSSS Model Component Analysis

Over the contract period we were able to provide a shell scripting effort that repeated analyses of the fields propagated to Earth and globally over the heliosphere using the IPS tomography; a version of the IPS tomographic analysis was used to forward model fields from the solar surface for eleven years from 2006 up through the 2017. In 2006, data from NSO GONG ground-based instrumentation became regularly available, and this allowed its comparison with the NSO SOLIS ground-based data we have used to compare with *in-situ* data since the year 2005. This also allowed provision of open fields using the CSSS model as we always have in order to provide a basis for comparison of the near-surface ("closed field") analyses from different modelling efforts and their comparison at Earth. Because of the way open-fields are provided using the CSSS modelling, they have little way of reflecting the fast transient changes that can occur in the solar wind (see Dunn *et al*., 2005). As others have suggested (*e.g*., Hoeksema and Zhao, 1992; Tokumaru *et al*., 2007), the surface closed fields indicate the transient fields from Coronal Mass Ejections (CMEs), and we explored how these fields can be predicted in a regular way. The metric we have used to indicate a good comparison with *in-situ* measurements is the Pearson's "R" correlation between modelled and observed component fields over the period of a single Carrington Rotation as in the example for CSSS open field analyses of

Figure 2. Figure 2 shows a fairly typical Carrington rotation time series comparison between the outward-propagated CSSS-modelled fields from GONG data and ACE magnetometer results for radial and tangential RTN fields. This type analysis was duplicated for over 100 Carrington rotations from 2006 until 2016. Similar closed field analyses using the CSSS model are given for all three RTN coordinates in Figure 3. This type analysis was also duplicated for all available Carrington rotations since 2006 and included the Bn field component.

The results from this effort have been presented in an article (Jackson *et al*., 2016a). Figures 1-3 have been copied from this article. This was a comprehensive analysis. It showed slightly higher correlations for the ten-year open-field study for comparisons with GONG and ACE than with SOLIS and ACE, but this difference may have been due to the editing of the on-line data set and our use of it. Surprisingly, the closed-field comparisons over the ten-year period of study showed that the **radial** closed fields from 1.3Rs had nearly the same average good correlation comparisons as did the open-field comparisons. Average closed-field **tangential** and **normal** fields had much poorer correlations in general, and this was surprising given the results of the **radial** closed-field comparisons. We also found that even though results were different for a given Carrington rotation depending on whether Wind or ACE magnetometer data were compared, that there was little difference in either data set's overall average Pearsons' R correlation scores from the more than 100 Carrington rotations studied.

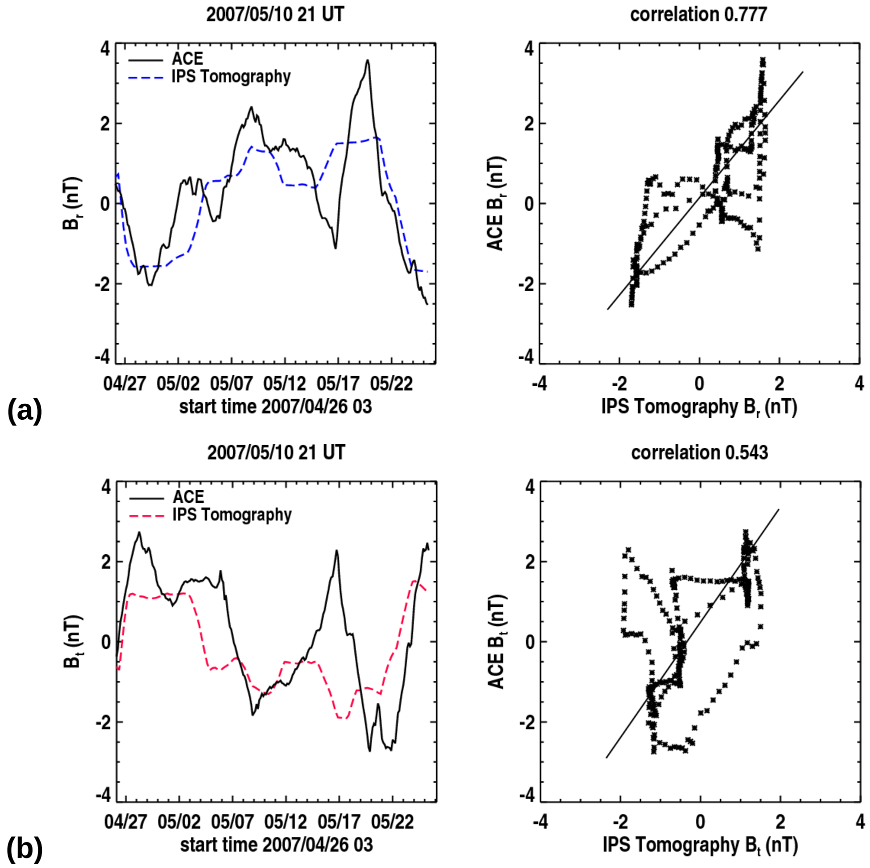


Figure 2. Time series (left), and Pearson's "R" correlations (right) from the CSSS **open-field modeling** and IPS 3D reconstruction extrapolations of GONG data compared with ACE magnetometer measurements over the Carrington rotation 2056 time period. The *in-situ* measurements have been smoothed by a three-day "boxcar" filter to provide a signal commensurate with the smoothed measurements from the CSSS modeling. **(a)** radial fields **(b)** tangential fields.

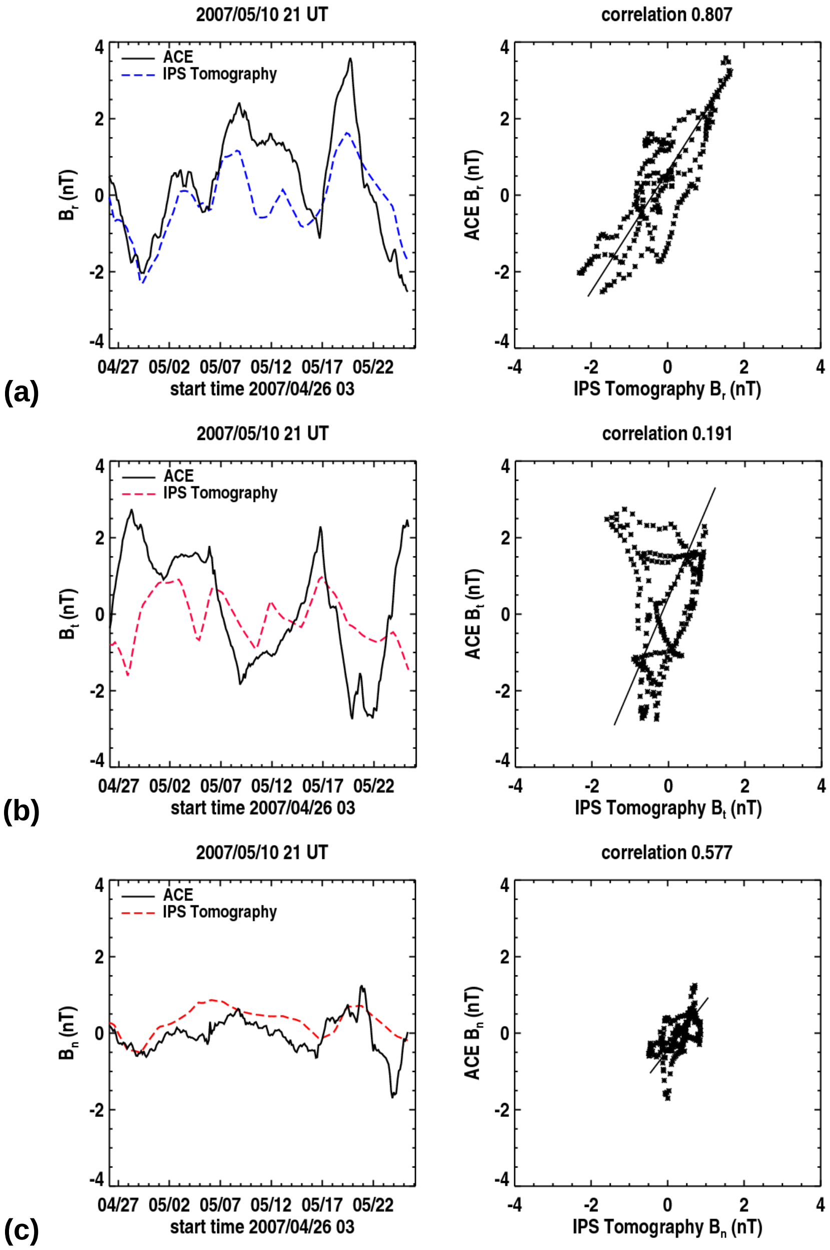


Figure 3. Time series (left), and correlations (right) from the CSSS **closed-field modeling** at 1.3 Rs and IPS 3D reconstruction extrapolations of GONG data compared with ACE magnetometer measurements over the Carrington rotation 2056 time period. The *in-situ* measurements have been smoothed by a three-day "boxcar" filter to provide a signal commensurate with the smoothed measurements from the CSSS modeling. **(a)** radial fields **(b)** tangential fields **(c)** normal fields.

To provide a truly good prediction of component fields at Earth and elsewhere in the interplanetary medium, we wished to understand more about this process, and how the oftentimes good results can be repeated consistently. Because closed radial fields in the Jackson *et al*. (2016a) study are present at Earth from radial propagation all the way from near the solar surface, we initially anticipated that the two other components would be present at Earth with high positive correlations. However, radial fields appear either positive or negative over large areas on the solar surface, whereas tangential and normal fields are generally found in smaller patchy areas. Thus, we suspected that a good portion of the poorer results for tangential and normal fields in comparison with these fields at ACE or Wind have to do in part with the non-radial transport of fields near the solar surface and beyond. This began a study of 1) non-radial transport in the region between where the closed fields are obtained and the source surface where the UCSD tomographic analysis takes over at 15 Rs (see Figure 1), and 2) non–radial transport of structures in the heliosphere caused by magnetic fields that expand structures such as flux ropes to larger that their original shape. Examples of flux rope expansion have been observed in the Solar Mass Ejection Imager (SMEI) analyses (e.g., Sharma *et al*., 2013). Thus, the use of magnetic fields that have unprecedented accuracy from the current UCSD IPS analysis provide a complementary study that can be enhanced by the use of 3-D MHD physics. This placed added emphasis on attempts to provide an iterative use of the 3-D MHD models as a kernel in the UCSD tomography, since this new tomography analysis allows non-radial transport caused by magnetic fields as well as hydrodynamic interactions. Sections 2.2 and 2.3 discuss our efforts in this work.

2.2. Non-Radial Transport From Below the CSSS Model Source Surface

The closed modeling transport of heliospheric field in the above studies (Jackson *et al*., 2016a) used the assumption that closed fields presented below the cusp surface propagated outward radially from where they originated. Clearly this is not generally thought to be a good physical interpretation of how solar wind flow proceeds from a region below the cusp surface that is shown in Figure 1. Usually flow in this region is assumed to proceed to some extent along magnetic field lines until the field strength becomes too weak to confine the flow.

In the early portion of this contract we therefore built a tracing system that could follow field lines from the source surface to the cusp surface in the CSSS model and then downward to the location of the flux component origin. The CSSS modeled values from that location were then smoothed and presented at 15 Rs on the tomographic source surface for further extrapolation using the UCSD tomography in order to check the validity of this analysis as in Jackson et al. (2016a). The programming to do this took considerable effort over more than a year’s time interval from 2015-2016, and was never very efficient of computer time. Thus, we were only able to check a few Carrington rotations in this way, and those we checked gave inconsistent results for tangential and normal fields. While a good idea to attempt with the CSSS (or for that matter PFSS) field modeling, we were unable to complete this study within the time limits of the current proposed effort.

2.3. Current Status of the Iterative 3-D MHD Analysis

For many reasons it is important to provide a 3-D MHD modeling effort that can be iteratively modified by the IPS analyses. Firstly, current modeling using 3-D MHD programming is not that accurate primarily because these analyses are essentially forward models from the lower corona with no guidance from existing intermediate heliospheric measurements. Additionally, the heliospheric models generally depend on a series of ad hoc assumptions about solar wind speed and density near the solar surface. Driving 3-D MHD models from a boundary provided by IPS measurements is a way to provide source surface speeds and densities and to use intermediate constraints that give a fairly accurate representation of these values *in situ* where measurements can be made. As mentioned, adding the better physics of an MHD heliospheric model into the IPS tomographic analysis can potentially include expansion and non-radial motions caused by magnetic fields. Thus, for further refinements to UCSD tomographic techniques, MHD physics is certainly a step forward as long as these analyses match observations as well or better than the current UCSD kinematic modeling.

In early 2015 a new volume traceback analysis that incorporated the 3-component velocities from the imported volume using the same coordinate system and resolution as the tomography program was shown to work. If this volume is presented to the tomography program, in the tomography program resolutions and RTN coordinates it can then provide a traceback that the iterative 3-D reconstruction program needs to complete one iteration. This traceback provides a new inner boundary for the 3-D MHD program. All quantities in a 3-D MHD program can now be now traced, three-component velocities, and magnetic fields, and one-component densities, and temperature.

In one scheme, the volumes of the MHD programs are provided at the 3-D MHD programmer's institution by running these with the UCSD-provided inner boundary (as is done now). A conversion of these volumes to the UCSD coordinate system is produced at that institution by interpolation from the native much higher and more numerous volumes of the 3-D MHD program. Once accomplished, this smaller volume subset is transferred via ftp over the web to UCSD where it is input to the UCSD tomography program for a single iteration. Then as now the new boundaries from the iterative run are transported back to MHD programmer's institution for operation on their main computers. In this way, for instance, we operated the MS-FLUKSS 3-D MHD program which is the responsibility of the MHD programmer while the latest data-handling portion of the UCSD tomography program can be used to match the 3-D MHD modeling volumetric analysis for further iterations. Eventually, when a standard 3-D reconstruction program is produced that is not being modified and tested with different specific 3-D MHD program outputs, it can be shipped to the MHD programmer's institution for use at that location. Web transportation of volumes in initial tests insures a way that the latest version of each institution's 3-D MHD program is the responsibility of the MHD program host institution and allows updates as frequently as each institute's new 3-D MHD program becomes available.

Three current 3-D MHD programs have been operated with UCSD-provided boundaries (Yu *et al*., 2015), and the iterative scheme could potentially be implemented for each one. In early 2017, a time-dependent volumetric output in the form of daily-cadence asci files from both the MS-FLUKSS and ENLIL programs in their native IHG formats was available, and these were able to be interpreted at UCSD and translated for use into the corotating heliographic coordinate system used by the UCSD tomography program. Shell scripting was updated and prepared to provide the whole sequence of analyses of the multiple programs used in the iterative sequence as shown in the flow diagram of Figure 4. In early 2017, a current version of ENLIL that provides the asci output for the tomographic analysis was installed by colleague Dusan Odstrcil on the UCSD processor, and was shown to work successfully. In this way the IPS boundary 3-D reconstruction FORTRAN program, and the IPS boundary-driven 3-D MHD program were iterated without the transferal of boundaries and volumes across the Web and the whole sequence was combined by shell scripting on the same computer. A single iteration using this scheme completes in about two hours on 8 nodes of the current UCSD 16-node computer system. As shown with the analyses so far, when begun with a fully converged kinematic input model, the whole system takes only 2 to 3 iterations to converge within tolerable specifications using an ENLIL 3-D MHD kernel.

Figure 5 shows samples of the analysis for the fits of both the kinematic and ENLIL models in velocity and density compared with Wind spacecraft *in-situ* measurements for Carrington rotation 2114.5 during the year 2011 for a period that has been well studied (Yu *et al*., 2015). Figure 6 shows a time interval within this period in the form of ecliptic cuts when a fast CME was observed to nearly reach Earth, first for the kinematic model and then for the ENLIL model after 2 iterations. Figure 7 shows this same CME in ecliptic cuts of velocity and density using the ENLIL visualization scheme. With this type analysis and solar surface locations and timings, IPS data fits, and *in-situ* fits, we are able to certify some of the unknown parameters that need to be used in 3-D MHD models.

All components of the above scheme have worked successfully; the ENLIL 3-D MHD model and MS-FLUKSS have been tested including using the production of input magnetic fields for the 3-D

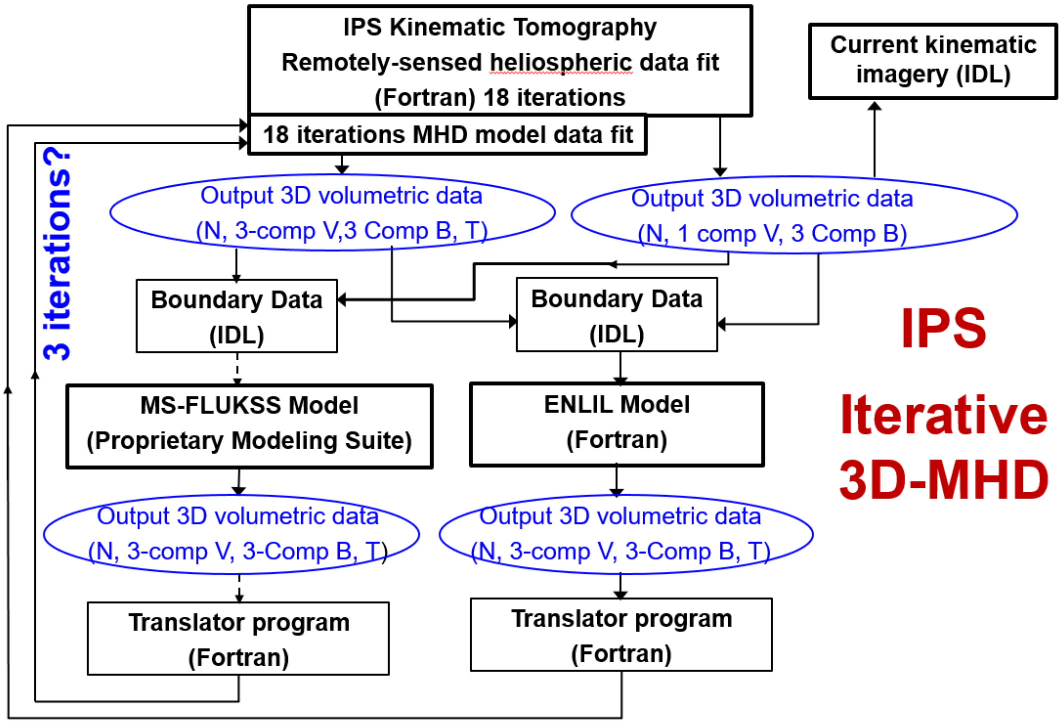


Figure 4. Flow Diagram showing the sequence of programming steps required to provide an iterative MHD analysis. The dashed lines between the Boundary and the MS-FLUKSS Model, and between its output and the Translator program indicate shipment of the analysis over the Web from UCSD to the University of Alabama and back again.

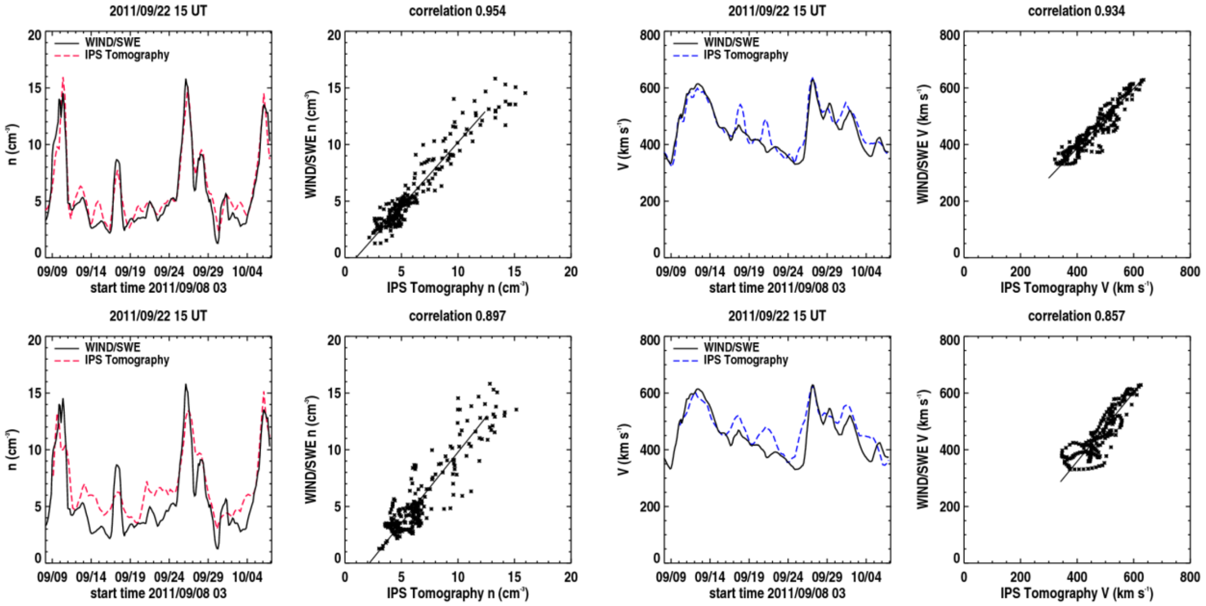


Figure 5. Density and velocity time series for Carrington rotation 2114.5 compared with the Wind measurements (left to right). Kinematic and ENLIL 3-D MHD model (upper to lower). A CME is observed at 2011/09/26 in the time series. Densities and velocities at Earth at the second iteration stage are nearly as good for the ENLIL model as for the UCSD kinematic model (from Jackson *et al*., 2018b).

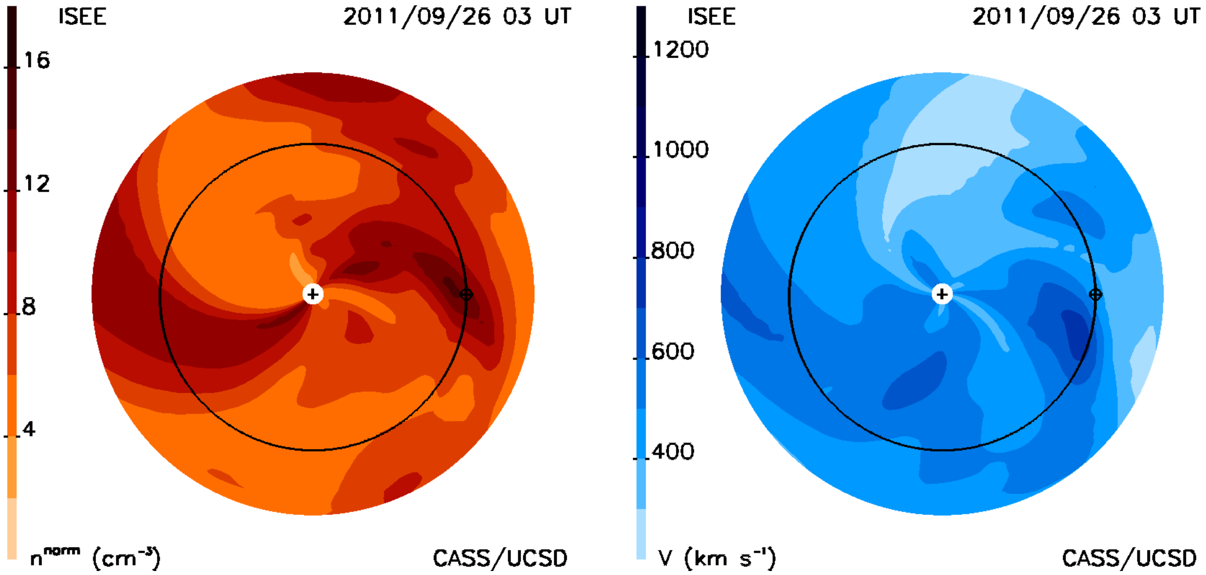


Figure 6. Ecliptic cuts from the UCSD kinematic model of density (left) and velocity (right). The Sun is centered in the image. The Earth is positioned to the right on its orbit. The CME mentioned in Figure 5 has just reached the Earth (from Jackson *et al*., 2018b)

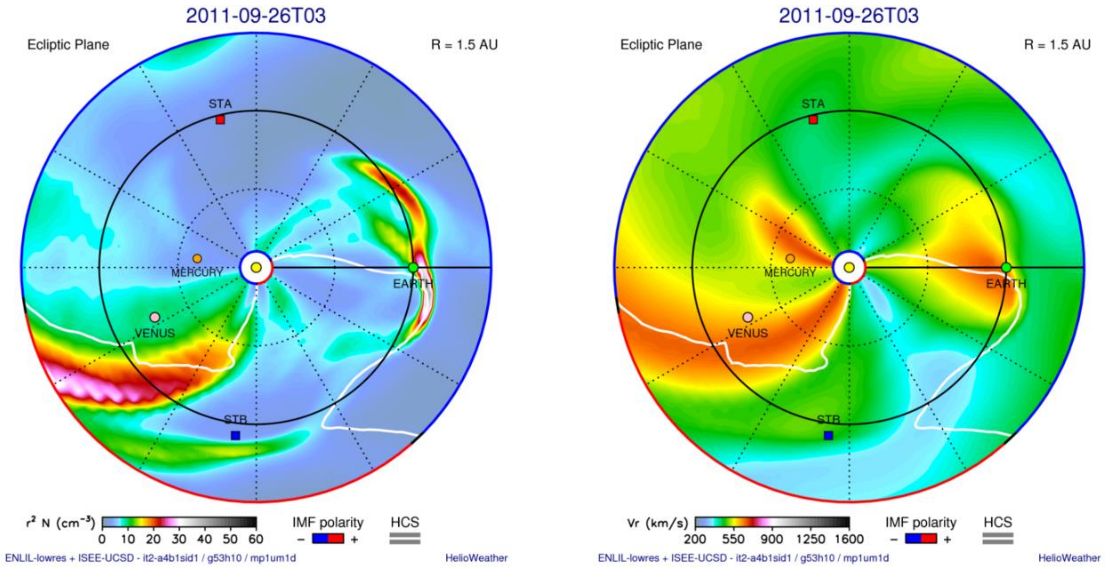


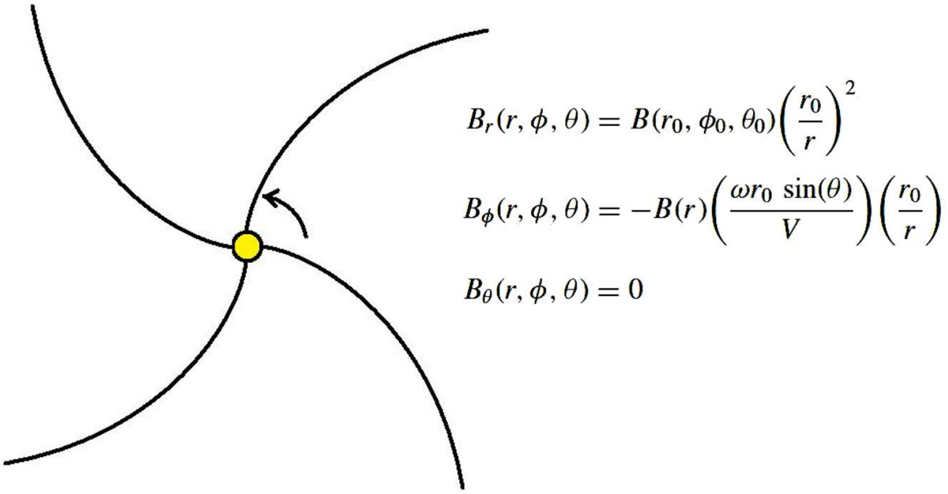
Figure 7. ENLIL model showing density (left) and radial velocity (right) of the CME as shown in Figure 6. These images are from a UCSD second iteration run of ENLIL. Two shocks observed that front the high speed wind and are far more pronounced in these 3-D reconstructions (from Jackson *et al*., 2018b).

MHD models. A difficulty arises from the conversion of the corotating field measurements at the solar surface to the inertial coordinates of most 3-D MHD models. Heliospheric 3-D MHD models usually begin at a location beyond the Alfven surface where there is no longer communication of heliospheric information back to the Sun. UCSD normally begins its interface assuming the field stops corotating at a fixed location 15 Rs above the Sun's surface. In the UCSD tomography any solar wind acceleration above this location is assumed due to the kinematic solution that assumes mass and mass flux conservation. 3-D MHD models do not operate in this way. To be expedient these models begin generally above the Alfven surface assumed to be at 21.5 Rs (0.1 AU) or greater, and provide outward expansion from this solar distance. To convert from the inertial frame systems of most 3-D MHD models to that of UCSD's, the lowest height speeds given by the 3-D MHD input volumes need to be extrapolated downward from above the Alfven surface from the UCSD inner boundary. If this is not done, a time lag between the inner boundary fields provided by UCSD and those needed by the MHD modeling can become excessive. The programming to provide an extrapolation of three-component fields from the from the lower UCSD magnetic field surface utilizing the higher-up three-component velocities of the MHD model to provide this extrapolation was shown to operate successfully in 2016. If 3-D MHD heliospheric models alone are used to provide the magnetic field analyses then some ad hoc accommodation must be made to provide the timing of these fields that accelerate from zero speed at the solar surface to the fields provided at inner 3-D MHD boundary. Additionally, currently there is no facility in most 3-D MHD models to include three component fields at their lower boundary, and usually only a field magnitude is carried outward.

2.4. Use RTN Br and Bt Open Fields from the CSSS Model to Predict GSM Bz

By far the most significant achievement to date promoted by this AFOSR funding has been the system used at UCSD to regularly-provide a low-resolution prediction and several day ahead forecast of Bz in GSM coordinates. Over the last year of operation this has been refined to both enable a better determination of Bz, as well as a visualization of the impending GSM Bz field approach. This has allowed a good determination of the length and duration of geomagnetic activity related to minor and moderate storms, especially those not associated with transient effects such as CMEs.

In the first instance this technique simply utilizes UCSD's existing CSSS model determination of open fields available in RTN coordinates (see Section 2.1) that UCSD has propagated outward for over a decade. Figure 8 gives the Parker (1958) description of the spiral field at Earth in RTN coordinates. In this formulization the normal (Bn, or north-south) component of the field is zero. Jaehun Kim of the Korean Space Weather Center wished to see if the UCSD technique somehow worked in real time so that the KSWC could use this to forecast GSM Bz. The small effect from the background field (Figure 9) has generally precluded anyone actually trying to determine this effect



$$B_r(r,\phi,\theta) = B(r_0,\phi_0,\theta_0)\left(\frac{r_0}{r}\right)^2$$

$$B_\phi(r,\phi,\theta) = -B(r)\left(\frac{\omega r_0\,\sin(\theta)}{V}\right)\left(\frac{r_0}{r}\right)$$

$$B_\theta(r,\phi,\theta) = 0$$

Figure 8. In the heliosphere beyond the CSSS model source surface, the rotating Sun provides a spiral field that approximately follows the equations given above in RTN coordinates as structures flow approximately radially outward from the source surface near the Sun. The spiral field that gives rise to both a radial and tangential field component in RTN coordinates provides no field normal to the solar equatorial plane.

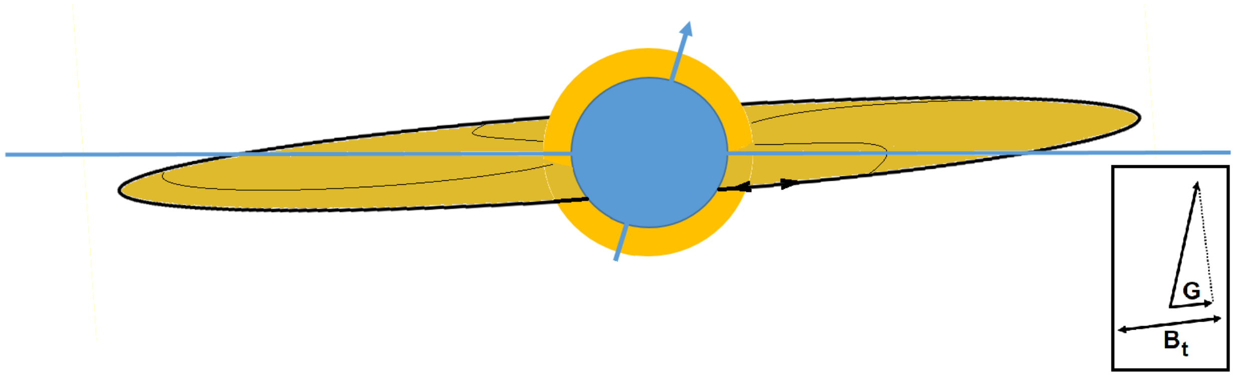


Figure 9. GSM coordinate vector map at the autumnal equinox. The Earth in blue is depicted in front of the Sun. The inset to the right gives the direction of the tangential field relative to the average daily geomagnetic field component.

regularly on a daily basis even though its annual variation and correlation with geomagnetic activity was explored long ago by Russell and McPherron (1973). Using extant software available at UCSD (also uploaded to SolarSoft weekly) to convert RTN Br, Bt, and Bn=0.0 to GSM, we were able to display GSM coordinates Bx, By, and Bz. To our surprise in the fall of 2016, Bz projected in this way provided our first several-day advance forecast of a geomagnetic storm. Since that time there have been many additional examples presented on: **http://ips.ucsd.edu/high_resolutions_predictions/**.

To show this in a graphical way, Figure 9 depicts the Earth's position at the autumnal equinox. The ecliptic is shown as the straight horizontal line; the heliographic equator as an elongated ellipse. The Earth covers the Sun and is shown with an arrow depicting the direction of the north geographic pole. The average daily geomagnetic field with a slight daily wobble is aligned approximately with the geographic polar axis that has a 23° tilt relative to the ecliptic plane. This tilt is even slightly greater than 23° relative to the heliospheric tangential component of field at this time. The GSM coordinate system is defined by a plane that is perpendicular to the radial from the Sun, and is here the plane of the paper or screen viewing this depiction. UCSD extrapolates the radial and tangential magnetic fields in RTN coordinates. In RTN coordinates Br is antiparallel to Bx in GSM coordinates, but the difference between the Earth's polar direction and the heliographic equator provides a small component of field that is either in the direction of the Earth's pole or away from that direction. This field component variation becomes a maximum at either the vernal or autumnal equinox, and is essentially the Russell-McPherron effect. The inset to the lower left gives the ± direction (Bt) of the RTN tangential field component at Earth at this time; the average daily geomagnetic field component (G) is also shown. Plotted as a daily average, or more frequently, this can provide a slight component of the field relative to the Earth's polar field. Figure 10 shows a time series sequence ending at a value when Bz decreased to a minimum at about 2017 March 27 at 09 UT, and correlations of our extrapolated RTN fields converted to GSM Bz field compared with the ACE GSM Bz field. The Pearson's R correlation here is worth mentioning. With the exception of the last zero days ahead (lower right hand) presentation, this comparison is the one-day ahead comparison of the field as presented for the tangential field relative to the ACE tangential field that the UCSD website (**http://ips.ucsd.edu**) provides. The comparison correlation, that is continually updated, is made from the value that is forecast relative to that present when the *in-situ* value is measured several days later.

Figure 11 shows the NOAA planetary K index slightly following the UCSD measurement of Bz on 2017 March 27. In this instance enhanced moderate storm activity began about 03 UT just as the UCSD forecast Bz value and ACE Bz value reached minimum. Enhanced geomagnetic activity

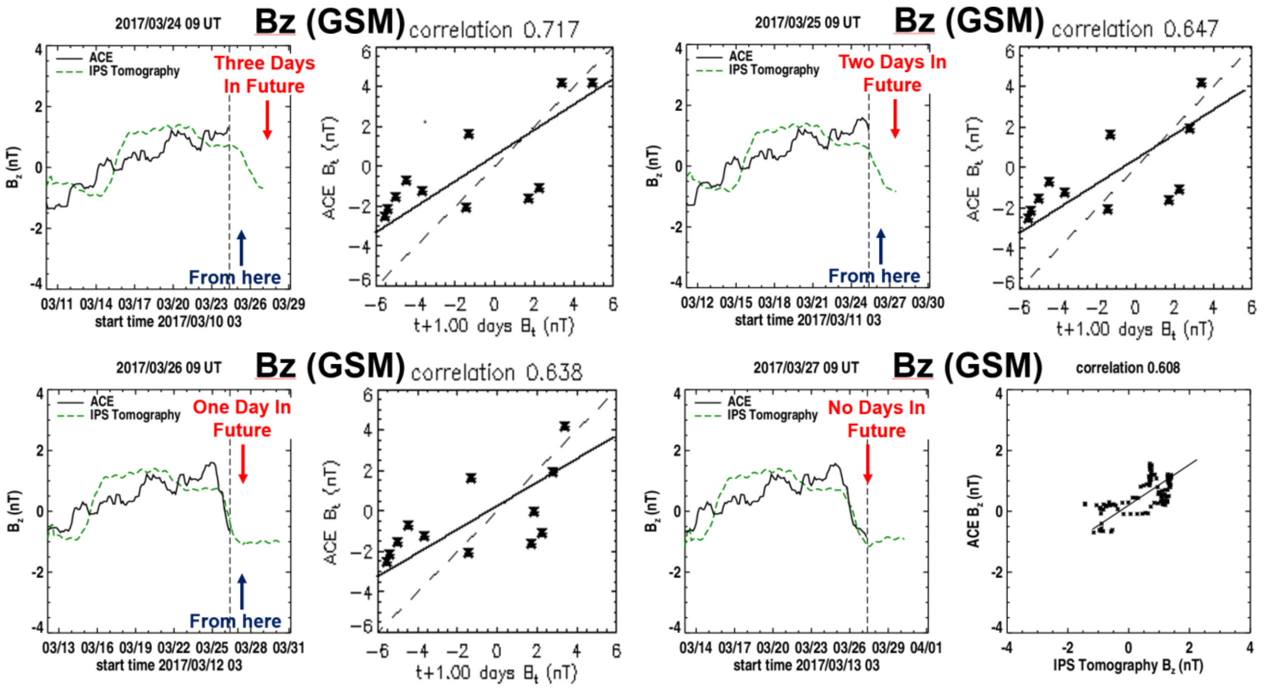


Figure 10. A March 2017 sequence of timeseries of the GSM Bz component field relative to the value predicted showing that the Bz field did turn negative at the time forecast three days into the future.

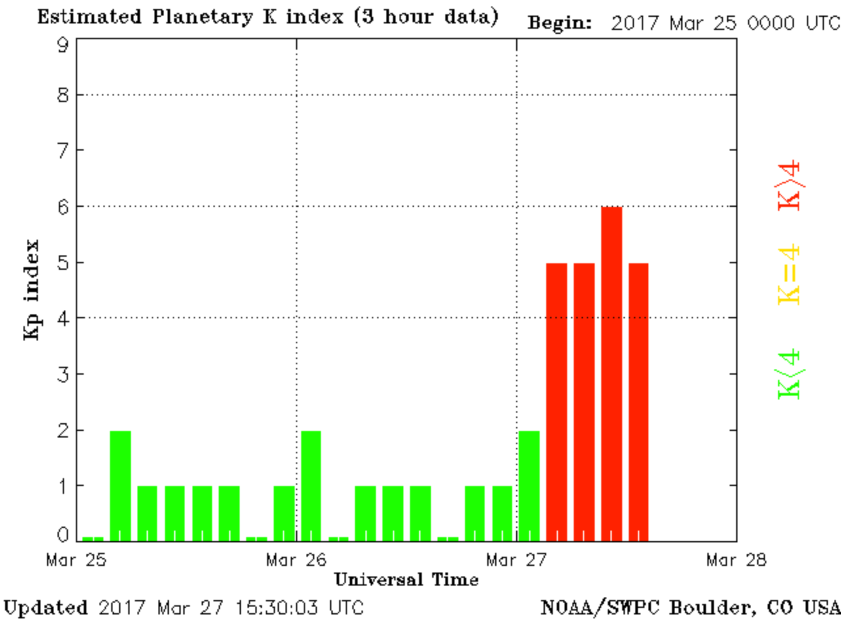


Figure 11. The NOAA planetary K index plotted from 2017 March 25 through to March 27 at 15:30 UT. Substorm activity is shown indicated by an enhanced K index beginning at about 03 UT March 27.

continued for several days following this, and until Bz turned positive. This is not an isolated incident. There is a significant correlation by Carrington rotation between predicted and measured Bz in the past eleven years, and we have shown that this has generally been correlated with both an enhanced planetary K index, and a decrease in Dst in many examples (Jackson, 2016, 2017, Jackson *et al*., 2016b, c, 2017a-f, 2018a; Yu, *et al*., 2017a, b, 2018), and now as presented in Jackson *et al*. (2018c).

The current work is only a low resolution analysis. In the future, what is needed is to take into account: 1) non-radial transport of magnetic fields near the Sun and in the heliosphere as explained previously, 2) closed as well as open field analyses to refine the Bn and hence Bz contribution, and 3) possibly the inclusion of CME fields from work of our collaborator Dusan Odstrcil, who has made significant strides in depicting three-component magnetic fields associated with typical CMEs and their onset locations input at the 21.4 Rs ENLIL source surface that can be added to cone model inputs in the form of flux ropes or spheromaks.

2.5. UCSD Website Analysis and Distribution

The results of some of the new visualizations can be viewed on a recently-provided UCSD IPS real-time website at: **http://ips.ucsd.edu** (see **High_Resolution_Predictions**). The new UCSD analysis provides a far higher resolution depiction of the time-dependent tomographic results than those found at: **http://ips.ucsd.edu**. It also runs our most recent time-dependent tomography program (version 18) that can input IPS data from more than one IPS radio array, thus allowing sites other than ISEE the ability to input values and to substitute data when IPS from this single site is unavailable or sparse, or at Earth longitudes where fast-moving CME structures might escape detection during the night-time outage at a single array location. So far IPS data from the MEXART array, from LOFAR in Western Europe, and from Pushchino, Russia, have been used in addition to radio source observations from ISEE to prove this programming works successfully. However, these analyses have only been tried so far for short one-month periods, owing to the difficulty in providing these analyses in a regular way from each radio site similar to those provided in ISEE, Japan. However, these results have so far provided the major impetus to combine these data sets for the newly-formed Worldwide Interplanetary Scintillation Stations (WIPSS) Network organization, as well as provide the basis of at least one doctoral thesis for Oyuki Chang, a Morelia, Mexico UNAM now a post-doctoral fellow at the Rutherford Appleton Laboratory in the UK who continues this work at that institution.

2.6. Personnel and Publications

The IPS data available for use in this analysis and in comparison with IPS and AFOSR magnetic field data is particularly important in the mentoring of young researchers in the field, and over the duration of this contract has included seven UCSD undergraduate students, three graduate students, one of whom (Oyuki Chang) has since gotten her PhD. The three other graduate students include Nobuhiko Nishimura, and Nishiki Nozaki of the Institute for Space-Earth Environmental Research (ISEE) Japan. Additionally, other young researchers include one postdoctoral fellow (Tae Kim of the University of Alabama, Huntsville), and now a UCSD post-doctoral fellow turned Assistant Research Scientist, Dr. Hsiu-Shan Yu. Dr. Hsiu-Shan Yu joined the UCSD group from North Central University (NCU), Taiwan in December 2011. Partially supported by this AFOSR contract and mentored by the P.I., she has provided a wealth of data analysis expertise at UCSD since her arrival and particularly over the last three years. She now has her H1 Visa and “Green card”.

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Buffington, A., Bisi, M.M., Clover, J.M., Hick, P.P., Jackson, B.V., Kuchar, T.A., and Price, S., 2015, ‘Measurements and an Empirical Model of the Zodiacal Brightness as Observed by the Solar Mass Ejection Imager (SMEI)’, AGU Session SH53B-2501 presentation, 14-18 December, San Francisco.

Buffington, A., Jackson, B., Hick, P.P., Yu, H.S., and Bisi, M.M., 2016, ‘ASHI, an All Sky Heliospheric Imager for Future NASA Missions’, AGU Session SH11C-2276 poster presentation, San Francisco, 12-16 December.

Buffington, A., Jackson, B., Hick, P.P., Yu, H.S., and Bisi, M.M., 2017, ‘ASHI, an All Sky Heliospheric Imager for Viewing Thomson-Sacttered Light’, poster presentation SH23D-2689 at the AGU Fall Meeting, New Orleans, LA, 11-15 December.

Chang, O., Jackson, B.V., González-Esparza, A., Yu., H.-S., and Mejia-Ambriz, J., 2016, ‘Incorporation of MEXART Interplanetary Scintillation (IPS) Data into the UCSD 3-D Tomography as Part of the Worldwide IPS Stations (WIPSS) Initiative: Enhancing Space Weather Science and Forecasting’, poster presentation, SHINE workshop, 11-15 July, Santa Fe, NM.

Edara, J., 2018, ‘A New Primary Mirror Optic Design for the All Sky Heliospheric Imager’, presentation at the Faculty Mentor Program, UCSD San Diego, California, 30 May.

Howard, R, Vourlidas, A., Harrison, R., Bisi, M., Plunkett, S., Socker, D., Eyles, C., Webb, D., DeForest, C., Davies, J., Howard, T., de Koning, C., Gopalswamy, N., Davila, J., Tappin, J., and Jackson, B., 2015, ‘Requirements for an Operational Coronagraph’, AGU Session SH14A-02 oral presentation, San Francisco, 14-18 December.

Jackson, B.V., 2016, ‘From the Ground to Space and Back’, Remote Sensing of Heliospheric Structures’, invited oral plenary talk presentation at the Reunion Annual 2016 Union Geofisica, Puerto Vallarta, Mexico, 30 October - 4 November.

Jackson, B.V., 2017, ‘Different Techniques For (and Some Success In) Measurement of Bs’, invited oral scene-setting presentation at the ISEST Conference, Jeju, South Korea, 18-22 September.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Gonzalez-Esparza, A., Hong, S., Kim, J, Lee, B., Yi, J., Yun, J., Bisi, M.M., and Odstrcil, D., 2015, ‘Space Weather Forecasting Using Remotely-sensed Heliospheric IPS Data Sets from Around the World’, oral presentation at the Third Remote Sensing Workshop, Morelia, Mexico, 20-24 October.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Bisi, M.M., Tokumaru, M., Fujiki, K., Hayashi, K., Nozaki, N., Nishimura, N., Kim, J., Hong, S., Lee, B., Yi, J., and Yun, J., 2015, ‘Magnetic-Field Components from Inner-Coronal Closed-Loop Outward Propagation’, invited oral presentation at the 2nd SEREN Workshop, 30 November - 02 December, DeVere Milton Hill House, Steventon, Oxfordshire, OX13 6AF, UK.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Kim, J., Hong, S., Lee, B., Yi, J., and Yun, J., 2015, ‘Determination of the North-South Heliospheric Magnetic Field from Inner-

Corona Closed-Loop Propagation', AGU Session SH43C-03 oral presentation, San Francisco, 14-18 December.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Odstrcil, D., Hong, S., Kim, J, Lee, B., Yi, J., Yun, J., Bisi, M.M., and Gonzalez-Esparza, A., 2016, 'Using World Interplanetary Scintillation Systems for Space Weather Predictions', invited oral presentation at the PSTEP symposium conference, Nagoya, Japan, 13-15 January.

Jackson, B.V., Hick, P.P., Buffington, A., Yu, H.-S., Tokumaru, M., Kojima, M., and Odstrcil, D., 2016, 'An Iterated Time-dependent IPS 3D-MHD Model', oral seminar presentation at ISEE, Nagoya University, Japan, 18 January.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Odstrcil, D., Hong, S., Kim, J, Lee, B., Yi, J., Yun, J., Bisi, M.M., and Gonzalez-Esparza, A., 2016, 'Using World Interplanetary Scintillation Systems for Space Weather Predictions', oral presentation at the CCMC Workshop, 11-15 April, Annapolis, MD.

Jackson, B.V., Yu, H.-S., Chang, O., Hick, P.P., Buffington, A., Tokumaru, M., Gonzalez-Esparza, A., Mejia-Ambriz, J., Bisi, M.M., Kim, J, Hong, S., Lee, B., Yi, J., and Yun, Y., 2016, 'Space Weather Forecasting Using Remotely-sensed Heliospheric IPS Data Sets From Around the World – an Inclusion of MEXART and BSA Pushchino Data into the UCSD STELab IPS Tomography', presentation at the Space Weather Workshop, 26-29 April, Broomfield, CO.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Gonzalez-Esparza, A., Mejia-Ambriz, J., Chang, O., Odstrcil, D., Hong, S., Kim, J, Lee, B., Yi, J., Yun, J., and Bisi, M.M., 2016, 'Using World Interplanetary Scintillation Systems for Space Weather Predictions', oral presentation at the NASA Goddard Community Coordinated Modeling Center, 26 May, Greenbelt, MD.

Jackson, B.V., Yu, H.-S., Buffington, A., Hick, P.P., Nishimura, N., Nozaki, N. Tokumaru, M., Fujiki, K., and Hayashi., K., 2016, 'Exploration of SOLIS and GONG data sets Using the UCSD ISEE IPS time-dependent tomography and the CSSS magnetic field model', poster presentation, SHINE workshop, 11-15 July, Santa Fe, NM.

Jackson, B.V., Yu, H.-S., Hick, P.P., and Buffington, A., 2016, 'What does jetting tell us about the solar wind?', oral presentation, SHINE workshop, 11-15 July, Santa Fe, NM.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Gonzalez-Esparza, A., Mejia-Ambriz, J., Chang, O., Odstrcil, D., Hong, S., Kim, J, Lee, B., Yi, J., Yun, J., and Bisi, M.M., 2016, 3-D Tomography for Remote Sensing and Space Weather', oral presentation, SHINE workshop, 11-15 July, Santa Fe, NM.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Nishimura, N., Nozaki, N., Fujiki, K., and Hayashi., K., Gonzalez-Esparza, A., Mejia-Ambriz, J., Chang, O., Odstrcil, D., Hong, S., Kim, J, Lee, B., Yi, J., Yun, J., and Bisi, M.M., 2016, 'Provision of a Bz Determination', oral presentation, AFOSR Workshop, 18-19 July, Albuquerque, NM.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Nishimura, N., Nozaki, N., Fujiki, K., and Hayashi, K., Gonzalez-Esparza, A., Bisi, M.M., Kim, J., and Hong, S., 2016, 'Determination of Magnetic-Field Components from Inner-Corona Closed-Loop Propagation and IPS Analysis', invited oral presentation abstract for the 41st COSPAR, 30 July – 7 August, Istanbul, Turkey (cancelled).

Jackson, B.V., Gonzalez-Esparza, A., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Nishimura, N., Nozaki, N., Fujiki, K., and Hayashi, K., Bisi, M.M., Kim, J., and Hong, S., 2016, 'Exploration of Closed-component Magnetic Field Propagation Using the CSSS Model and UCSD Time-dependent Tomography', poster presentation, AOGS, 31 July – 5 August, Beijing, China.

Jackson, B.V., Yu, H.-S., Hick, P.P, Buffington, A., Tokumaru, M., Gonzalez-Esparza, A., Mejia-Ambriz, J., Odstrcil, D., Hong, S., Kim, J., Lee, B., Yi, J., Yun, J., and Bisi, M.M., 2016, 'Using Interplanetary Scintillation (IPS) Observations for Space Weather Predictions', paper presented at UCSD Lecture for course 191, Center for Astrophysics and Space Sciences, CA, USA, 5 October.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Chang, O., Gonzalez-Esparza, A., Rodriguez, E., Mejia-Ambriz, J., Odstrcil, D., Kim, J, Yun, J., and Bisi, M.M,, 2016, 'Worldwide Interplanetary Scintillation Stations (WIPSS) Use of the UCSD IPS Tomography Program for Space Weather Forecasting', invited oral presentation and poster at the 4th Asia Oceania Space Weather Alliance, Jeju Island, South Korea, 24-27 October.

Jackson, B.V., Yu, H.-S., Hick, P.P., and Buffington, A., 2016, 'Potential Future Projects - KSWC / Korea / USA', invited oral presentation at the 4th Asia Oceania Space Weather Alliance, Jeju Island, South Korea, 24-27 October.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Gonzalez-Esparza, A., Rodriguez, E., Mejia-Ambriz, J., De La Luz, V.H., Chang, O., Tokumaru, M., Kojima, M., Nishimura, N., Nozaki, N., Fujiki, K., Hayashi, K., Bisi, M.M., Odstrcil, D., Kim, J, and Yun, J., 2016, 'Use of the UCSD IPS Tomography Program for Predicting Heliospheric Plasma Parameters from World Interplanetary Scintillation Stations (WIPSS)', invited oral presentation at the Reunion Annual 2016 Union Geofisica, Puerto Vallarta, Mexico, 30 October - 4 November.

Jackson, B.V., Yu, H.-S., Hick, P.P., and Buffington, A., 2016, 'Observations of the Variable Coronal Solar Wind, and its Implications for Solar Probe Plus and Solar Orbiter', AGU Session SH43B-2565 poster presentation, San Francisco, 12-16 December.

Jackson, B.V., Yu, H.-S., Hick, P.P., and Buffington, A., 2016, 'Scientific tomography use overview', paper presented at IPS Workshop, San Diego, CA, USA, 18-20 December.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M. Gonzalez-Esparza, A., Mejia-Ambriz, J., Chang, O., Odstrcil, D., Hong, S., Kim, J., Lee, B., Yi, J., Yun, J., and Bisi, M.M., 2016, 'UCSD IPS Time-Dependent Tomography', paper presented at IPS Workshop, San Diego, CA, USA, 18-20 December.

Jackson, B.V., and Webb, D.F., 2017, 'Session 16 -The time histories and topologies of heliospheric structures measured in-situ - Introduction', oral introduction to SHINE Workshop session 16, Saint-Sauveur, Canada, 23-28 July.

Jackson, B.V., Yu, H.-S., Buffington, A., Hick, P.P., Tokumaru, M., and Odstrcil, D., 2017, 'The UCSD IPS time-dependent tomography for use as an overview of heliospheric structure', paper presented at ISEE Combined Workshop on "Inner Heliospheric Plasma" and "Space Weather and Cosmic Ray Modulation", Nagoya, Japan, 1-3 March.

Jackson, B., Buffington, A., Hick, P.P., Yu, H.-S., and Bisi, M.M., 2017, 'ASHI, an All Sky Heliospheric Imager for L1', oral presentation presented at the L5 in Tandem with L1: Future Space-Weather Missions Workshop, London, UK, 6-9 March.

Jackson, B., Yu, H.-S., Hick, P., Buffington, A., Tokumaru, M., Fujiki, K., Chang, O., Gonzalez-Esparza, A., Mejia-Ambriz, J., Rodriguez, E., Odstrcil, D., Kim, J., and Yun, J., 2017, 'A world interplanetary scintillation stations (WIPSS) tomography program for space weather forecasting', invited oral presentation at the 2nd PSTEP International Symposium, Kyoto, Japan, 23-24 March.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Fujiki, K., Odstrcil, D., Kim, J., and Yun, J., 2017, 'A Low Resolution Bz CCMC Heliospheric Model Forecast', paper presented at International CCMC-LWS Working Meeting, Cape Canaveral, Florida, USA, 3-7 April.

Jackson, B., Yu, H.-S., Hick, P.P., Buffington, A., Tokumaru, M., Kim, J., and Yun, J., 2017, 'Low Resolution Bz Determinations and Forecasts From Field Coupling Between the Solar Wind and Geomagnetic Fields', poster presentation at Space Weather Workshop, Broomfield, CO, USA, 1-5 May.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Bisi, M.M., Odstrcil, D., Kim, T., Pogorelov, N., Tokumaru, M., Kim, J., and Yun, J., 2017, '3-D MHD Modeling Fit to Interplanetary Scintillation (IPS) Observations', oral and poster presentation SHINE sessions 12 and 16, Saint-Sauveur, Canada, 23-28 July.

Jackson, B.V., Webb, D.F., Manchester, W., and Jian, L.K., 2017, 'Session 16 -The time histories and topologies of heliospheric structures measured in-situ - Recap', oral recap of SHINE session 16, Saint-Sauveur, Canada, 23-28 July.

Jackson, B., Tokumaru, M., Fujiki, K., Odstrcil, D., Bisi, M.M., Kim, J., and Yun, J., 2017, 'A Bz Determination Technique, New Forecast Display, and Potential Scientific Upgrades', AFOSR oral conference presentation, Washington D.C, 1-2 August.

Jackson, B.V., Buffington, A., Yu, H.-S., Hick, P.P., and Bisi, M.M., 2017, 'ASHI: An All Sky Heliospheric Imager for Viewing Thomson-Scattered Light', oral and poster presentation, AOGS, 06-11 August, Singapore.

Jackson, B.V., Buffington, A., Yu, H.-S., Hick, P.P., and Bisi, M.M., 2017, 'ASHI: An All Sky Heliospheric Imager for Viewing Thomson-Scattered Light', session ST20 oral and poster presentation, AOGS, 06-11 August, Singapore.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, Tokumaru, M., Odstrcil, D., Kim, T., Pogorelov, N., Bisi, M.M., Kim, J., and Yun, J., 2017, 'A 3D-MHD Model Interface Using Interplanetary Scintillation (IPS) Observations', session ST20 poster presentation, AOGS, 06-11 August, Singapore.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, Odstrcil, D., Tokumaru, M., Kim, J., and Yun, J., 2017, 'Iterative 3-D MHD ENLIL Modeling Using Interplanetary Scintillation (IPS) Observations', oral presentation at the ISEST Conference, Jeju, South Korea, 18-22 September.

Jackson, B.V., Buffington, A., Yu, H.-S., Hick, P.P., and Bisi, M.M., 2017, 'ASHI: an All-Sky Heliospheric Imager for Inclusion on a Near-Earth Small Satellite', 3rd COSPAR Small Satellite Symposium, Jeju, South Korea, 18-22 September.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., and Bisi, M.M., Odstrcil, D., Kim, T., Pogorelov, N., Tokumaru, M., Kim, J., Yun, J., 2017, '3D-MHD Modeling Using Interplanetary Scintillation (IPS) Observations', oral presentation at session 9 at the European Space Weather Week 14, Oostende, Belgium, 27 November – 01 December.

Jackson, B., Buffington, A., Hick, P.P., Yu, H.-S., and Bisi, M.M., 2017, 'Bz Determinations and Forecasts Using the UCSD IPS Analysis', oral presentation at the UK remote sensing workshop, Cardiff, Wales, 03 - 07 December.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Odstrcil, D., Kim, T., Pogorelov, N., Tokumaru, M., Bisi, M.M., Kim, J., and Yun, J., 2017, 'An Iterative Interplanetary Scintillation (IPS) Analysis Using Time-dependent 3-D MHD Models as Kernels', presentation SH21A-2650, AGU Fall Meeting, New Orleans, LA, 11-15 December.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Odstrcil, D., Pogorelov, N., 2018, 'Iterative interplanetary scintillation (IPS) analyses using time-dependent 3-D MHD models as kernels', oral presentation at the Air Force Research Laboratory, Albuquerque, N.M., 13 April.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Odstrcil, D., Pogorelov, N., 2018, 'Iterative heliospheric tomogaphy analyses using time-dependent 3-D MHD models as kernels', presentation at the NOAA Space Weather Week, Westminster, CO, 16-20 April.

Jackson, B.V., Yu, H.-S., Hick, P.P., Buffington, A., Odstrcil, D., Pogorelov, N., and Kim, T., 2018, 'Heliospheric Tomography – Results Using 3-D MHD Kernels', oral presentation at the CCMC Workshop, College Park, MD, 23-27 April.

Jackson, B.V., Buffington, A., Yu, H.-S., Hick, P.P., Edara, J., and Bisi, M.M., 2018, 'ASHI: An All-Sky Heliospheric Imager for Viewing Thomson-Scattered Light', oral presentation at the AOGS Meeting, Waikiki, Oahu, Hawaii, 3-8 June.

Jackson, B.V., Yu, H.-S., Hick, P. P., Buffington, A., Odstrcil, D., Kim, T., and Pogorelov, N., 2018, '3-D MHD time-dependent model kernels that use UCSD's iterative scintillation (IPS) analysis', presentation at the AOGS Meeting, Waikiki, Oahu, Hawaii, 3-8 June.

Jackson, B.V., Buffington, A., Yu, H.-S., Hick, P.P., Edara, J., Bisi, M.M., and Kahler, S., 2018, 'ASHI: An All-Sky Heliospheric Imager for Viewing Thomson-Scattered Light', poster FS-256 presentation at the COSPAR General Assembly, Pasadena, California, July 14-22.

Jackson, B.V., Yu, H.-S., Hick, P. P., and Buffington, A., 2018, 'Bz Determinations and Forecasts Using UCSD IPS Analysis Techniques', invited presentation D23-0022 at the COSPAR General Assembly, Pasadena, California, July 14-22.

Jackson, B.V., Yu, H.-S., Hick, P. P., Buffington, A., Odstrcil, D., Kim, T., and Pogorelov, N., Tokumaru, M., and Bisi, M.M., 018, '3-D MHD time-dependent model kernels that use UCSD's iterative scintillation (IPS) analysis', poster presentation at the SHINE Workshop, Cocoa Beach Florida, 30 July - 03 August.

Jackson, B.V., Buffington, A., Kahler, S.W., Bisi, M.M. et al., 2018, 'ASHI: An All Sky Heliospheric Imager', Invited one-slide oral presentation at the NASA town hall meeting, SHINE Workshop, Cocoa Beach Florida, 30 July - 03 August.

Jackson, B.V., Yu, H.-S., Hick, P. P., Buffington, A., Bisi, M.M., Odstrcil, D., Tokumaru, M., Manoharan, P.K., Gonzalez-Esparza, P., and Kim, J., 2018, 'LWS16 Proposal 80NSSC17K0684: A NASA Focused Science Topic to Combine World IPS data and Standardize its Analysis', Invited presentation at the First NASA 2016 LWS Workshop, Boulder, Colorado, 16-17 August.

Jensen, E.A., Bisi, M.M., Sobey, C., Fallows, R.A., Jackson, B.V., Barnes, D., Giunta, A.S., Hick, P.P., Eftekhari, T., Yu, H.-S., Odstrcil, D., Tokumaru, M., and Wood, B., 2016, 'Observations of Heliospheric Faraday Rotation of a CME Using LOFAR and Space-Based Imaging', AGU Session SH11C-2251 poster presentation, San Francisco, 12-16 December.

Jian, L.K., MacNeice, P.J., Taktakishvili, A., Odstrcil, D., Jackson, B., Yu, H.-S., Riley, P., and Sokolov, I.V., 2015, 'How Reliable Is the Solar Wind Prediction from the Models Installed at the CCMC?', oral presentation SH14A-08 at the AGU Session fall meeting, San Francisco, 14-18 December.

Jian, L.K., with collaborators MacNeice, P.J., Mays, M.L, Odstrcil, D., Jackson, B, P. Riley, Sokolov, I.V., Stevens, M., 2017, 'Solar Wind Model Validation and Solar Wind Data Accuracy', oral presentation at SHINE session 16, Saint-Sauveur, Canada, 23-28 July.

Khabarova, O., Malandraki, O., Zank, G., Jackson, B., Bisi, M., Desai, M., Li, G., le Roux, J., and Yu, H.-S., 2017, 'Atypical energetic particle events observed prior energetic particle

enhancements associated with corotating interaction regions', presention at Geophysical Res. Abstracts, EGU General Assembly, Vienna, Austria, 23-28 April.

Kim, T.K., Pogorelov, N.V., Arge, C., Jackson, B.V., Kryukov, I., Manoharan, P.K., Manoharan, P., Tropf, D., Yu, H.-S., Zank, G., 2015, 'Using In Situ and Remote Sensing Data to Model the Plasma Flow throughout the Heliosphere', SH31C-2441 presentation, AGU fall meeting, San Francisco, 14-18 December.

Kim, T.K., Pogorelov, N.V., Arge, C.N., Elliot, H.A., Jackson, B.V., Kryukov, I., Manoharan, P.K., McComas, D.J., Yu, H.-S., and Zank, G., 2016, 'Modeling the Solar Wind throughout Interplanetary Space Using Ground-based and Spacecraft Observational Data', AGU Session SM32A-03 oral presentation, San Francisco, 12-16 December.

McKenna-Lawlor, S., Jackson, B., and Odstrcil, D., 2017, 'Space Weather at Planet Venus during the forthcoming BepiColombo flybys', session ST20 oral presentation, AOGS, 06-11 August, Singapore.

McKenna-Lawlor, S., Jackson, B., and Odstrcil, D., 2018, 'Tools for providing forecasts of Space Weather at the BepiColombo spacecraft pair during their, forthcoming flybys of Venus and Mercury', presentation at the European Geophysical Union Meeting, Vienna, Austria, April 9-13.

Morgan, J.S., Macquart, J.-P., Ekers, R., Bisi, M.M., Jackson, B.V., Tokumaru, M., Manoharan, P.K., Chhetri, R., 2016, 'Interplanetary Scintillation Observations with a New Generation of Radio Telescopes: First results from the MWA', AGU Session SH22B-05 oral presentation, San Francisco, 12-16 December.

Nishimura, N., Nozaki, N., Jackson, B.V., Yu, H.-S., Tokumaru, M., Fujiki, K., and Hakamada, K., 2016, 'Comparison of calculated and observed IMF near magnetic cloud start times', abstract to the Japan Geophysical Union Meeting, 22-23 May, Makuhari, Japan.

Nozaki, N., Nishimura, N., Jackson, B.V., Yu, H.-S., Tokumaru, M., Fujiki, K., Hayashi, K., and Hakamada, K., 2016, 'A Statistical Study of the Radial and North-South Component Values of Heliospheric Magnetic Field', abstract to the Japan Geophysical Union Meeting, 22-23 May, Makuhari, Japan.

Pogorelov, N., Hathaway, D., Kim, T., Liu, Y., Singh, T., and Yalim, M.S., 2017, 'A Data-driven Model of the Solar Atmosphere and Heliosphere', poster and oral presentation in SHINE session 16, Saint-Sauveur, Canada, 23-28 July.

Webb, D.F., Gopalswamy, N., Jackson, B., Marubashi, M., Moestl, C., Nitta, N., Mulligan, T., Temmer, M., Wang, Y., Wu, C.-C., and Zhang, J., 2015, 'Update on Studies from VarSITI ISEST/MiniMax24: WG 4 on Campaign Events', SHINE conference oral presentation, 6-10 July, Stowe, Vermont.

Wu, C.-C., Liou, K., Socker, D., Howard, R.A., Jackson, B.V., Yu, H.-S., Hutting, L., and Plunkett, S., 2015, 'The first super geomagnetic storm of solar cycle 24: "The St. Patrick day (17 March 2015)" event', AGU Session SH51A-2433 presentation, San Francisco, 14-18 December.

Yu, H.-S., Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Odstrcil, D., Tokumaru, M., Kim, J., Hong, S., Lee, B., Yi, J., and Yun, J., 2015, ‘A Global Solar Wind Boundary from Remotely-Sensed IPS Data for Driving ENLIL’, oral presentation at the Third Remote Sensing Workshop, Morelia, Mexico, 20-24 October.

Yu, H.-S., Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Odstrcil, D., Hong, S., Kim, J., Yi, J., Tokumaru, M., and Gonzalez-Esparza, A., 2015, ‘3D Analysis of Remote-Sensed Heliospheric Data for Space Weather Forecasting’, AGU Session SH21B-2396 presentation, San Francisco, 14-18 December.

Yu, H.-S., Jackson, B.V., Hick, P.P., and Buffington, A., 2016, ‘Preliminary Results of the Bn Study’, oral seminar presentation at ISEE, Nagoya University, Japan, 18 January.

Yu, H.-S., Jackson, B.V., Buffington, A., Hick, P.P., Chang, O., Tokumaru, M., 2016, ‘The 2014 August 19 CME VarSITI ISEST Event Observed in ISEE IPS Observations with the UCSD Time-dependent Tomography’, poster and oral presentation, SHINE workshop, 11-15 July, Santa Fe, NM.

Yu, H.-S., Jackson, B.V., Buffington, A., Hick, P.P., Tokumaru, M., Odstrcil, Kim, J., and Yun, J., 2016, ‘The UCSD Time-dependent Tomography and IPS use for Exploring Space Weather Events, AGU Session SH22B-06 oral presentation, San Francisco, 12-16 December.

Yu, H.-S., Jackson, B.V., Buffington, A., Hick, P.P., Tokumaru, M., Odstrcil, D., and Wu C.-C., 2016, ‘Driving 3D-MHD codes Using the UCSD Tomography’, oral presentation at the IPS Workshop, San Diego, CA, USA, 18-20 December.

Yu, H.-S., Jackson, B.V., Hick, P.P., and Buffington, A., 2016, ‘Tracing the Polar Jet Manifestations into the Inner Heliosphere by Using Spaceborn and Ground-based Observations’, oral presentation at the IPS Workshop, San Diego, CA, USA, 18-20 December.

Yu, H.-S., Jackson, B.V., Hick, P.P., and Buffington A., 2017, ‘Observations of the variable solar wind, and its implications for Solar Probe Plus and Solar Orbiter’, invited oral presentation at the ISEE Combined Workshop on "Inner Heliospheric Plasma" and "Space Weather and Cosmic Ray Modulation", Nagoya, Japan, 1-3 March.

Yu, H.-S., Jackson, B., Hick, P., Buffington, A., Tokumaru, M., Nishimura, N. Nozaki, N., Fujiki, K., and Hayashi, K., 2017, ‘Exploration of Solar Magnetic Fields from Propagating GONG Magnetograms Using the CSSS Model and UCSD Time-Dependent Tomography’, poster presentation at the 2nd PSTEP International Symposium, Kyoto, Japan, 23-24 March.

Yu, H.-S., Jackson, B., Hick, P., Buffington, A., Tokumaru, M., Nishimura, N. Nozaki, N., Fujiki, K., and Hayashi, K., 2017, ‘Real-time Prediction of GSM Bz Fields at Earth Using the CSSS Model and UCSD IPS Tomography’, session ST20 oral presentation, AOGS, 06-11 August, Singapore.

Yu, H.-S., Jackson, B., Buffington, A., and Hick, P., 2017, ‘The variable nature of the solar wind’, presentation SH23D-2684, AGU Fall Meeting, New Orleans, LA, 11-15 December.

Yu, H.-S., Jackson, B., Hick, P., and Buffington, A., 2018, ‘Speed measurements of the fine-scale features within CMEs’, oral presentation at the AOGS Meeting, Waikiki, Oahu, Hawaii, 3-8 June.

Yu, H.-S., Jackson, B., Hick, P., Buffington, A., Zhao, G. Tokumaru, M., and Fujiki, K., 2018, ‘ Real-time Prediction and Forecast of GSM Bz Fields at Earth Using the CSSS Model and UCSD IPS Tomography’, presentation at the AOGS Meeting, Waikiki, Oahu, Hawaii, 3-8 June.

Supported Personnel:

The following personnel benefited from or were partially funded by this AFOSR project and include:

Dr. Bernard V. Jackson	UCSD Research Scientist
Dr. Andrew Buffington	UCSD Research Scientist (Emeritus)
Dr. Hsiu-Shan Yu	UCSD Post-doctoral fellow/Assistant Research Scientist (Fm. 2016/8)
Mr. Gary Zhao	UCSD Undergraduate Student
Mr. Pushpak Gautham	UCSD Undergraduate Student
Ms. Tamalika De	UCSD Undergraduate Student
Ms. Jyothirmayi Edara	UCSD Undergraduate Student
Mr. Vicente Pena	UCSD Undergraduate Student
Mr. Matthew Bracamontes	UCSD Undergraduate Student
Mr. Sepehr Foroughi-Shafiei	UCSD Undergraduate Student
Dr. Tae Kim	UAH Post-doctoral Fellow
Mr. Nobuhiko Nishimura	ISEE Graduate student
Mr. Nishiki Nozaki	ISEE Graduate student
Ms. Oyuki Chang	UNAM Graduate student, now a postdoctoral fellow at RAL-Space

AFOSR Deliverables Submission Survey

Response ID:10322 Data

1.

Report Type

Final Report

Primary Contact Email
Contact email if there is a problem with the report.

bvjackson@ucsd.edu

Primary Contact Phone Number
Contact phone number if there is a problem with the report

8585343358

Organization / Institution name

CASS/UCSD

Grant/Contract Title
The full title of the funded effort.

Provision of a Bz Determination

Grant/Contract Number
AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-15-1-0477

Principal Investigator Name
The full name of the principal investigator on the grant or contract.

Bernard V. Jackson

Program Officer
The AFOSR Program Officer currently assigned to the award

Dr. Julie Moses

Reporting Period Start Date

09/30/2016

Reporting Period End Date

09/29/2018

Abstract

One of the most sought-after parameters is the heliospheric vector magnetic field, because this field interacts with other objects embedded in the interplanetary medium. These interactions are of primary interest at Earth because a southward interplanetary magnetic field in Geocentric Solar Magnetospheric (GSM) coordinates (Bz negative) can couple with the Earth's magnetic field at the boundary of the magnetosphere, causing geomagnetic storms.

UCSD's present measurements from the Current–Sheet Source Surface CSSS modeling (Zhao & Hoeksema, 1995) arguably give the very best radial and tangential component fields to date at Earth and globally throughout the heliosphere in Sun-centered Heliographic coordinates (HEEQ). We submitted articles Jackson et al. (2015, Astrophys. J. Letts., 803:L1 1-5; 2016, Space Weather 14 (12), 1107-1124) showing how all three vector field components in HEEQ can be provided from the CSSS modeling. We also discovered that our regularly-provided CSSS-modeled fields converted to GSM coordinates Bx, By, and Bz on a daily basis provide a prediction of low-level geomagnetic activity. We ready an article (Jackson et al., 2018, Space Weather) detailing this work that compares our GSM Bz magnetic fields with those from in-situ spacecraft fields for the years 2006 through 2017, and present how this predicts geomagnetic activity and

allows excellent few-day ahead forecasts of minor to moderate geomagnetic storms.

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afosr2015_pro_final_2018.pdf

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Archival Publications (published) during reporting period:

Please see the attached Report Document for a more complete reporting of the associated publications and presentations. There have been 14 refereed journal articles published, in press, or ready to submit that have been associated with this work, and 52 abstracts published for 51 presentations that are associated with this work so far.

New discoveries, inventions, or patent disclosures:
Do you have any discoveries, inventions, or patent disclosures to report for this period?

Yes

Please describe and include any notable dates

In mid-2016 we discovered we were able to provide a GSM Bz analysis that gave a reasonable few-day advance warning of impending minor to moderate geomagnetic storms. Since then we and several other knowledgeable Space Weather institutions have used this technique to help in their daily forecasts.

Do you plan to pursue a claim for personal or organizational intellectual property?

No

Changes in research objectives (if any):

None that were significant. In the course of the work for the contract we found that we could not consistently provide a north-south field from our RTN closed field analysis in an easy way as we had originally hoped. Effort following that knowledge began a more complete study of why this happened, and was not completely resolved by the end of the contract. Effort in this area of the program was concentrated more on the GSM Bz analysis we could predict for use in forecasts.

Change in AFOSR Program Officer, if any:

At the beginning of the first year of the contract, the original Program Manager, DR. Kent Miller moved to the UK. His position was taken over at AFOSR by Dr. Julie Moses.

Extensions granted or milestones slipped, if any:

none

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

E-mail user

Sep 10, 2018 19:01:26 Success: Email Sent to: bvjackson@ucsd.edu