Toward Improved Space Weather Prediction Through the Observation and Modeling of Coronal Magnetism

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Year 1 Report

**Sarah Gibson (HAO) – Project PI; Ed DeLuca (CfA PI),
Kevin Dalmasse (HAO), Giuliana de Toma (HAO), Yuhong Fan (HAO), Duncan Mackay (U. St Andrews), Patricia Jibben (CfA), Karen Meyer (U. Abertay), Jenna Samra (CfA), Antonia Savcheva (CfA), Steven Tomczyk (HAO)**

Abstract. The goal of our project is to develop a new methodology for assimilating coronal magnetic diagnostic data into magnetohydrodynamic (MHD) models in order to establish not only the magnetic structure of the source region of coronal mass ejections, but also the global field into which it erupts. We have a new name for this effort: **Data-Optimized Coronal Field Model**, or **DOC-FM**. Our objectives for Year 1 were to begin data gathering/forward modeling, goodness-of-fit (GOF) characterization, flux-rope insertion, hydrostatic modeling, and the exploration of advanced statistical methods for forward fitting. We have concluded the first of specific objectives, by implementing an automatic method for extracting online coronal magnetic field data and creating comparable synthetic observables from potential field and MHD models. We are currently optimizing our GOF measure using synthetic data generated from an idealized flux-rope model, in order to examine sensitivities of parameters to observable properties. We have begun to apply the flux-rope insertion method to these synthetic data. We are also leveraging our effort through 1) a collaboration with AFRL and NMSU to explore hydrostatic extensions to potential field models, 2) a collaboration with PSI (one of the other AFOSR Bz teams) to explore hydrodynamic modeling, 3) a collaboration between HAO and NCAR's computing lab, in order to apply statistical methods to increase efficiency of our forward fitting, and 4) a collaboration with Observatory of Turin (Italy) to increase multiwavelength coronal polarimetric capability.

We now provide more detail and summarize our achievements to date.

Data gathering/forward modeling

DOC-FM employs observations taken with the unique Coronal Multichannel Polarimeter (CoMP) instrument to develop and constrain models of coronal magnetism. We also make use of a suite of forward-modeling SolarSoft IDL codes (FORWARD) to convert analytic models or simulation data cubes into coronal observables, including Stokes polarization parameters (I, Q, U, V) directly comparable to CoMP observations. Our primary goal was to develop automated implementation for forward modeling the synthetic equivalents of CoMP data from an initial potential field source surface (PFSS) global field and spherically-symmetric density distribution, using only date as input.

Progress: Automated method completed – with added capability; data gathering underway.

Not only did we complete the goal as set, but we also added the capability of automatically synthesizing CoMP data based on the Predictive Science Inc. (PSI) MAS MHD simulation cubes available online. Please see **publication** Gibson, 2015 - attached). This work was also presented at the Fall 2014 AGU meeting in poster form (Gibson et al.).

In addition, we have begun to identify CoMP data regions of interest. Because of their symmetry along the line of sight, coronal cavities and pseudostreamers are particularly useful regions to test our methods. We are currently working on a paper on a good CoMP pseudostreamer case (April 18, 2015), and have multiple examples of CoMP cavities with both polarimetric and Doppler velocity observations, as well as other multiwavelength data (paper in preparation to be submitted next month to the Coronal Magnetometry Topical Issue in Frontiers Space Sciences, Jibben et al.).

<u>GOF characterization</u>

The difference between synthetic data and CoMP observations represent a measure of non-potentiality for the PFSS model, and a means of validating/quantifying accuracy of the MAS model. Our goal was to develop a GOF measure that effectively captures information represented in the CoMP data, and consider how complementary data sets might be incorporated to further enhance GOF.

Progress: Underway.

This objective is a main focus for HAO postdoctoral associate Kevin Dalmasse. Starting with an idealized flux-rope model of co-I Fan, Dalmasse has produced “ground truth” synthetic data and then examined the effect of varying a set of parameters including rope position, rope height, and rope orientation. For each parameter set he has created new synthetic data to compare to the ground truth, and from this extracted GOF measures. He has experimented with different GOF measures, including sum-of-square-differences, and sum-of-absolute-differences. He has also examined the effect of combining multiple observables within the GOF measure, and demonstrated that degeneracy in parameter space can be eliminated. He is currently writing up his results as part of a paper to be submitted within the next month to the Frontiers Coronal Magnetometry Topical Issue (Dalmasse et al.) . This will also be presented in poster form at the Fall 2015 AGU.

In addition, the creation of multiwavelength synthetic data as testbeds for these efforts has begun, and has been reported on by a talk by Gibson at the August 2015 IAU meeting and will be further discussed in a talk by Gibson at the Fall 2015 AGU meeting. These testbeds include the prominence cavity model of Fan and a global model of Mackay. The capability for creating these testbeds using the FORWARD codes will be comprehensively discussed in a paper to be submitted with the next month to the Frontiers issue (Gibson et al.).

Our multiwavelength analysis effort is being further leveraged through a collaboration with Observatory of Turin (Italy) scientist Silvano Fineschi. Fineschi has coronal polarimetric observations in FeXIV (green line) that are complementary to the FeXIII (infrared) CoMP observations. He is also working with Gibson to add capability in ultraviolet coronal polarimetry to FORWARD. AF *Window on Science* funds supported a visit by Fineschi to HAO to join in a Bz-teams meeting in April 2015, and Fineschi helped to support two visits by Gibson to Turin in March 2015 and June 2015.

<u>Flux-rope insertion</u>

Our plan for assimilating data into models is to designate a limited number of "hot spots" where GOF comparison to CoMP data indicates that a global model (either PFSS, or MHD) is inaccurate, and to use flux-rope-insertion models to add or remove currents to these spots in a parameterized fashion.

Progress: Underway.

This objective is the focus of the CfA members of our team. In particular, CfA postdoctoral associate Antonia Savcheva is applying the flux-rope insertion model to reproduce the ground-truth synthetic data of the Fan model, using the magnetic boundary of that model as an additional constraint. This will be the subject of another poster at the Fall 2015 AGU (Savcheva et al.) In addition, Dalmasse has studied the build up of net currents in coronal active regions (presentation at May 2015 TESS meeting; **publication** Dalmasse et al. 2015, attached).

<u>Hydrostatic modeling</u>

The flux-rope insertion model is a force-free magnetic model, and so does not provide any information about coronal density and temperature. Our goal is to establish density/temperature model dependence using e.g. hydrostatic models based on magnetic field strength and topology (open vs. closed field).

Progress: Underway, with augmentation.

We are exploring synergies between our goals for hydrostatic models based on topology with those of graduate student Gordon Macdonald (working with AFRL scientist Nick Arge). To that end, Macdonald connected with Dalmasse at the May 2015 TESS meeting, and subsequently visited HAO in June and August 2015.In addition to developing a simple hydrostatic model based on magnetic field topology, we are considering evolving hydrodynamic models along field lines. Dalmasse visited our PSI colleagues in April of 2015 and was given a hydrodynamic code to use for that purpose.

<u>Statistical methods for forward fitting</u>

Our ultimate goal is to draw all of the above strands together as part of a forward-fitting technique. In particular, we will iterate model parameters to obtain best-fit solutions to the CoMP data (with possible incorporation of additional multiwavelength data). To maximize efficiency, we are exploring advanced statistical methods.

Progress: Underway.

We are leveraging our AFOSR project with a collaboration with NCAR's computing laboratory (CISL), with the participation in particular of CISL scientists Doug Nychka and Natasha Flyer. Postdoctoral associate Dalmasse is jointly funded by CISL to work on statistical methods for optimization. To that end, he has applied sparse sampling of parameter space (Latin Hypercube) and created interpolated surfaces of GOF measures that minimize iterations. This work will be part of the paper to be submitted to Frontiers and Fall 2015 AGU poster described above (Dalmasse et al.).

<u>Team interactions</u>

In addition to telecons and email exchanges, our team (and participants in its extended collaborations) has met in person on multiple occasions. In particular, Gibson, Dalmasse, Nychka, Deluca, Savcheva, and Samra met at the Fall 2014 AGU meeting. Savcheva visited HAO in February 2015. Gibson travelled to CfA to give a colloquium in March 2015. Gibson, Dalmasse, de Toma, Fan, Tomczyk, Fineschi, and Deluca attended the AFOSR Bz team meeting in April 2015. Gibson, Dalmasse, de Toma, Fan, Tomczyk, Nychka, Flyer, Deluca, Savcheva, and U.K. collaborator Meyer attended a team meeting at HAO in August 2015. Interactions with PSI scientists, Fineschi and MacDonald occurred as described above.