Project Details

ROSES ID: NNH18ZDA001N
Selection Year: 2018
Program Element: Focused Science Topic

Topic: Understanding Global-scale Solar Processes and their Implications for the Solar Interior

Project Title:
Simulating active longitudes by coupling magnetograms with a nonlinear MHD tachocline model: a data assimilation approach

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Summary:
This project addresses the Focused Science Topic (FST) #4: Understanding Global-scale Solar Processes and their Implications for the Solar Interior, which addresses LWS program objective 1: Understand how the Sun varies and what drives solar variability.

Scientific goals and objectives: The goal of this project is to simulate the timing, strength and latitude-longitude location of activity bursts, called active longitudes, and their subsequent evolution, which play a crucial role in creating the major space weather events that impact the Earth. The objective is to simulate active longitudes up to several months and even 1-2 years in advance. Therefore this project includes prediction as an applied component. As required by NASA for LWS-FSTs, this project will address the uncertainties in the data, model and simulation. Our measure of success will be prediction of the strength, timing and locations of active latitudes and longitudes for the next solar cycle, cycle 25, in addition to hindcasting cycles 23 and 24.

Methodology: The method builds on our recently developed global, nonlinear, MHD 'shallow water' model of the solar tachocline. This model has already demonstrated the existence of Tachocline Nonlinear Oscillations (TNOs) that produce the seasonal (6-18 months) solar variability and potentially can be the source of amplitude, latitude and longitude variations of the bursts of activity. Our model will dynamically evolve the dynamo-generated toroidal fields that are already present in the tachocline, along with the differential rotation, MHD Rossby waves and bulges of the tachocline upward into the convection zone. The bulges that contain dynamo-generated sunspot-producing toroidal fields will be the sources for imprints of emerging magnetic flux that are then compared with magnetic patterns observed at the surface. We will use a physical model to relate the bulging toroidal fields to emerged flux at the surface. We will couple a data assimilation capability to the MHD tachocline model, into which we will assimilate surface magnetic data from SDO/HMI, to advance the model-outputs, to simulate and predict the amplitude, surface location and eruption timing of emerged magnetic patterns, i.e. active longitudes. This predictive tool will be validated through hindcasts of active longitudes during solar cycles 23 and 24. We will also apply information theory to observational and simulation data, for example, to examine the information flow and response timing between the bulging toroidal field and emerging magnetic flux at the surface. We will use the same technique to explore the links of the activity bursts with other ingredients, including Rossby waves and differential rotation.

Contributions to the Focused Science Team effort: This study mines global MHD simulations of the solar tachocline and its connection to surface magnetic observations, in order to assist interpretations of other global studies of the solar interior, including variations in differential rotation and meridional circulation and helioseismic inversions. Our model includes tachocline MHD for all latitudes, so it is ideal for complementary understanding of new observations and inversions of high latitude phenomena. Our model will also be complementary to solar dynamo models, which are simulating solar cycles and spot-producing magnetic fields, but have not yet simulated active longitudes. Our model, coupled with data assimilation technology, will dynamically evolve the dynamo-generated fields to simulate and predict active longitudes. The coupled model-system will create predictive tools, including the potential for real-time updating, which is particularly encouraged by NASA for this FST. Furthermore, our information theory-based technique can easily be applied to data produced by other team members under this FST.

Publication References:

no references