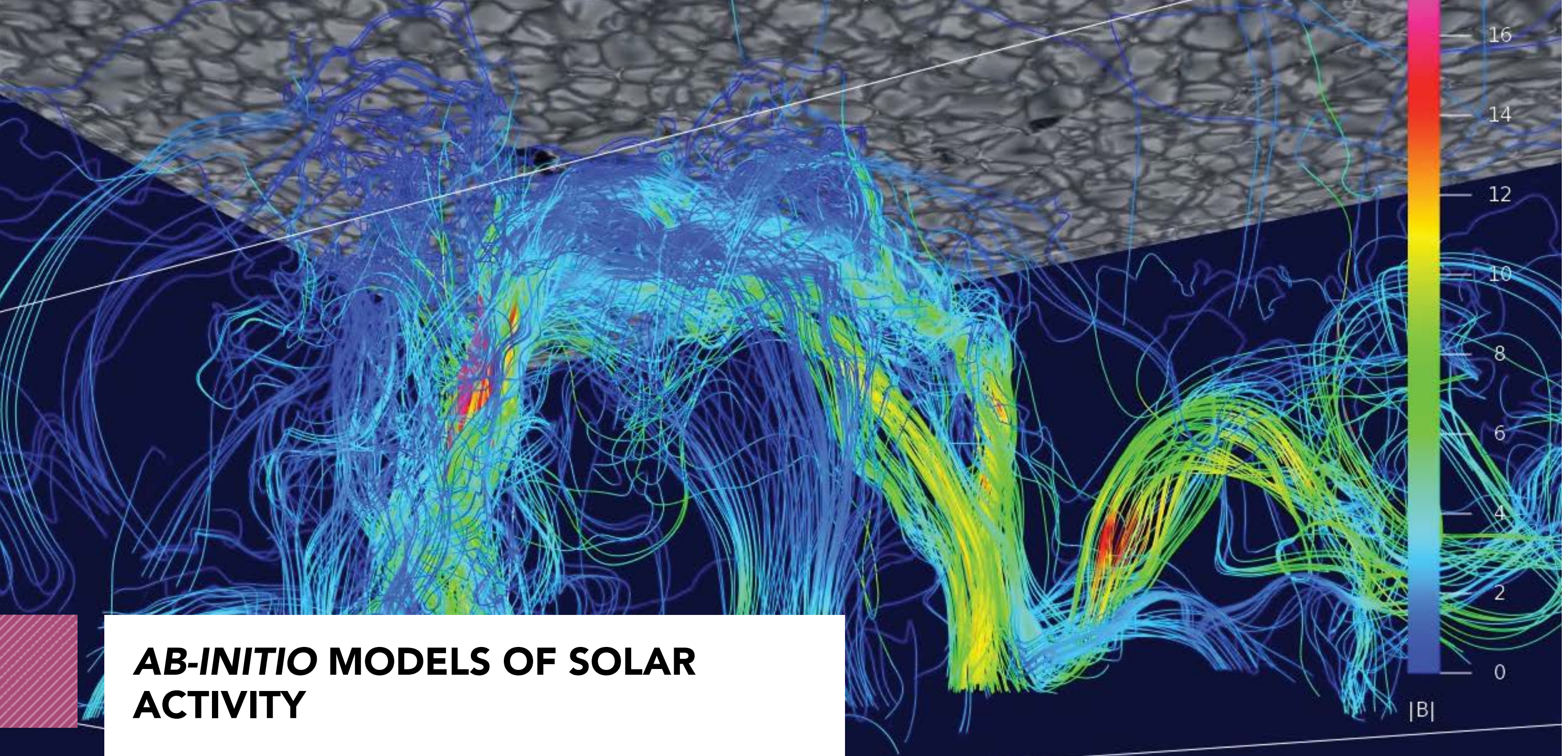

AB-INITIO MODELS OF SOLAR ACTIVITY

Allocation: NSF PRAC/6.5 Mnh
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EXECUTIVE SUMMARY:

The objective of this project is to understand how solar magneto-convection powers the Sun's activity, heats the chromosphere and corona, and accelerates charged particles. To achieve this we have begun modeling the emergence of dynamo-generated magnetic fields through the solar surface. The first task was to thermally and dynamically relax a model of solar magneto-convection from the top of the photosphere to a depth of 30 megameters (Mm)—one million meters—in order to use results from the deep convection zone dynamo and flux emergence calculations as boundary conditions for the surface magneto-convection simulations. A second task was to improve the code performance by implementing MPI decomposition in all three dimensions rather than just two.

INTRODUCTION

Our project attempts to model the following chain of processes that connects the inner workings of the Sun to the Earth and space weather:

- The Sun controls Earth's weather and space weather via radiation, coronal mass ejections into the solar wind, and energetic particles originating from solar active regions.
- In turn, the interaction of magnetic fields, convection, and radiation influence the Sun.
- How magnetic fields emerge through the photosphere of the Sun and are shuffled around by convective motions governs chromospheric and coronal heating and determines the generation of flares and coronal mass ejections.
- The solar convective dynamo influences the behavior of magnetic fields at the solar surface. New magnetic flux emerging in active regions interacts with existing fields to release huge amounts of energy when the fields reconnect. This heats the local coronal environment to many millions Kelvin and can produce flares and coronal mass ejections.

METHODS & RESULTS

An anelastic, global dynamo code is used to provide bottom boundary conditions for the 3D compressible, local thermodynamic equilibrium radiation, magneto-hydrodynamic code STAGGER, which models the upper (15% geometrically and 75% of the scale height) solar convection zone. These results in turn provide lower boundary conditions for the non-equilibrium 3D radiation, magneto-hydrodynamic code BIFROST to model the chromosphere and corona.

A major effort by co-PI Nordlund this past year was to enable MPI decomposition in the vertical and horizontal directions for radiation transfer and dynamics in STAGGER in order to allow larger blocks of data and reduce communication. The STAGGER code is used in many applications (star formation, turbulence, as well as stellar and solar convection) so this work can benefit many other research teams.

An ongoing effort is to obtain a thermally and dynamically statistically relaxed initial magneto-convection model from the solar surface down to 30 Mm depth. This is necessary to use the results of a global dynamo simulation as a bottom boundary condition for the spatial and temporal evolution of the magnetic field and possibly also for vertical velocity. The global simulation of the upper boundary is near 20 Mm depth and it is necessary to use values away from any boundary effects. The thermal relaxation time is several days at these depths, so an initial state close to thermal equilibrium is essential. An earlier extended model was found to be too far from thermal equilibrium to relax in a reasonable computation time. A new extended model was constructed extending a relaxed 20 Mm depth model in hydrostatic equilibrium. The density and internal energy were then adjusted to make entropy constant both on horizontal planes and with depth in the extended layers. Because the temperature and density fluctuations are very small fractions of their mean values at large depths a new table was constructed with finer resolution in density and energy per unit mass at large depths than near the surface.

WHY BLUE WATERS?

To model the emergence of magnetic flux through the solar surface requires simulating the time evolution of magneto-convection for many hours of solar time. To obtain results in a feasable time requires as many processors as possible. Currently, only Blue Waters provides a substantial number of useable processors. The relaxation of magneto-convection down to a depth of 30 Mm is running on 32,000 and 64,000 cores on Blue Waters.

PUBLICATIONS

Stein, R., and A. Nordlund, Simulations of Magnetic Flux Emergence. *40th COSPAR Scientific Assembly*, Moscow, Russia, August 2–10, 2014.

Granules, Flux Emergence and Subsurface Structure of Sunspots. *Max Planck Institute for Solar System Research colloquium*, Göttingen, Germany, January 14, 2015.

Flux Emergence and Active Region Formation. *NORDITA invited talk*, Stockholm, Sweden, March 10, 2015.

FIGURE 1 (BACKGROUND): Magnetic field lines formed into a loop by the up and down motions of convecting plasma. The loop apex in ascending plasma moves toward and then through the visible solar surface, leaving behind legs in downflowing plasma that produce dark pores and Sunspots because convective transport of energy to the surface is inhibited.