TN

MP

PREDICTION OF GEOMAGNETIC SECULAR VARIATION WITH LARGE-ENSEMBLE GEOMAGNETIC DATA ASSIMILATION

Allocation: Innovation and Exploration/80 Knh
PI: Nikolaos Pavlis[1]
Co-PI: Weijia Kuang[2]

[1]National Geospatial–Intelligence Agency
[2]NASA Goddard Space Flight Center

EXECUTIVE SUMMARY

The geomagnetic field varies in time, mostly owing to the fluid motion in the Earth's outer core. Geomagnetic data assimilation can provide accurate estimates of the core state for fundamental research into such questions as the Earth's interior structure and its evolution. Geomagnetic data can also provide accurate secular variation (SV) forecasts for global geomagnetic models that are used for industrial and navigational applications.

Accurate prediction of SV can be achieved via large-ensemble assimilation of geomagnetic observations and theoretical geodynamo models that investigate the self-sustaining process responsible for maintaining the Earth's magnetic field. However, this requires at least one thousand times more computing resources (in both CPU time and data storage) than those for pure geodynamo simulation, which alone is already computationally challenging. Blue Waters enables this research by reducing the research time from years to weeks and by increasing resolutions for geodynamo simulations with Earthlike parameters.

RESEARCH CHALLENGE

The time-varying geomagnetic field is of fundamental importance for basic and applied scientific research: it provides key information about the Earth's evolution over geological time scales; it plays a critical role in interactions between the Earth's core and other components of the Earth, which give rise to other geodynamic variations, *e.g.*, long-term variations in the Earth's rotation; it protects the Earth's surface and atmosphere from high-energy particles from coronal mass ejections and extreme ultraviolet fluxes from the Sun that are detrimental to life on Earth; and it has long been used by mankind for navigation, exploration, and other applications. Geomagnetic studies are very challenging because the dynamics vary over a broad spectrum in time (from subannual timescales to billions of years) and in space (from centimeters to 10,000 kilometers). Modeling and predicting such processes involve physical parameters (and thus model parameters) varying over 10^{20} in magnitude, thus demanding extremely high spatial and temporal resolution, which lead to approximately 10^{21} floating point operations for a typical simulation. Therefore, petascale supercomputing systems such as Blue Waters are instrumental for geomagnetic field research.

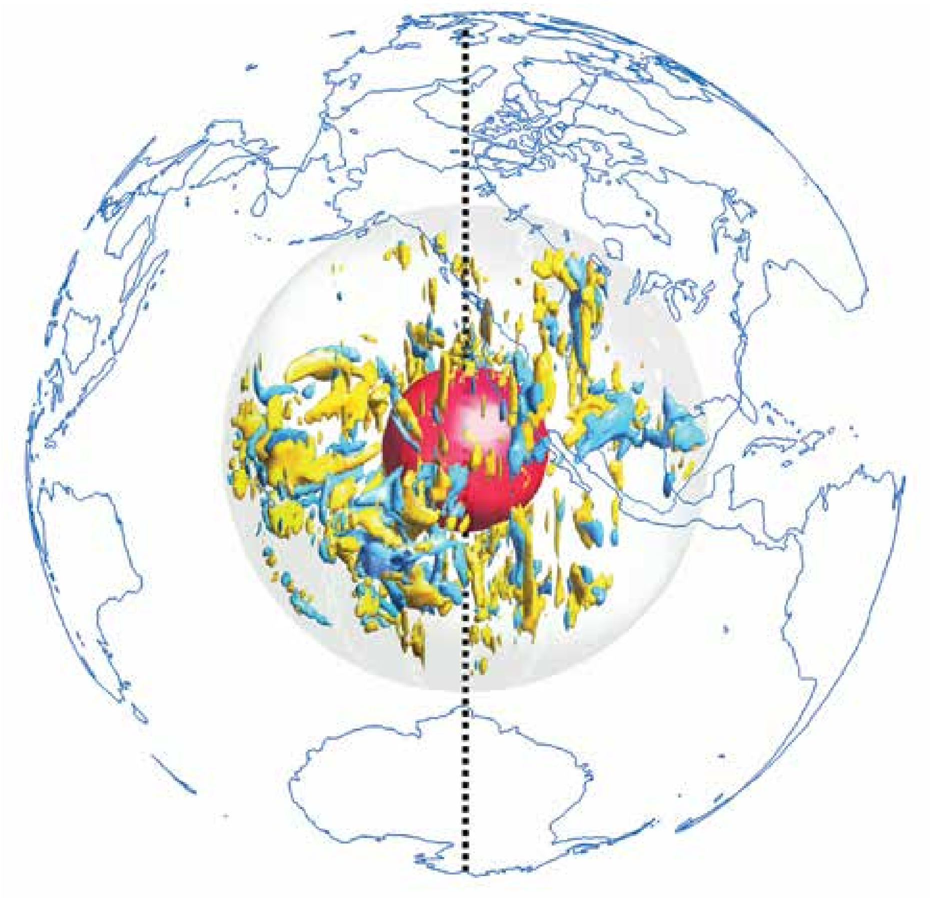

Figure 1: A snapshot of dynamo action in the Earth's outer core, defined between the (red) inner core and the (transparent) core–mantle boundary. The net gain and loss of magnetic energy is described by the yellow and blue blocks, respectively. The dashed line is the mean rotation axis of the Earth.

METHODS & CODES

The research team's system, called the Geomagnetic Ensemble Modeling System (GEMS), was developed exclusively in NASA's Goddard Space Flight Center [4,9,10,12]. It comprises three major subsystems: a geodynamo model (called MoSST) to provide forecast results, an ensemble Kalman filter model (called EnKF) to provide analysis (initial state) for making forecasts, and a geomagnetic data assimilation driver (called GDAS) to manage the entire analysis–forecast cycle. MoSST [2,5,6], was written in Fortran 2003, is based on a hybrid spectral-finite difference algorithm to solve the magnetohydrodynamic state in the Earth's core, and is computationally most demanding (> 90%). EnKF [9] utilizes an ensemble Kalman filter methodology to optimally integrate geodynamo model outputs and global geomagnetic field models derived from surface geomagnetic, paleo/archaeomagnetic data [1,3,7,8] to provide analysis for forecasts. GDAS is a shell-script-based system that manages the interactions between MoSST and EnKF, and controls the forecast cycles.

RESULTS & IMPACT

The main objective of this project is to investigate the convergence of assimilation with different ensemble sizes and simulation resolutions for given physical parameters. In two months of work, the research team found that the ensemble size of approximately 256 is optimal for assimilation, based on the computational needs and the forecast accuracies. This result is very important as it establishes a quantitative correlation among the forecast accuracy requirements, computational resource needs, and time periods for progress. For example, with the spatial resolution of approximately 256 x 256 x 256, a single geodynamo simulation (*i.e.*, an ensemble member of GEMS) could require a one-month (wall-clock) computation time with 256 processors/cores. Optimal ensemble sizes can greatly reduce the computational expense and research time without compromising research objectives. In addition, simultaneous 256-ensemble runs can make accurate forecasts of five-year geomagnetic SVs in one month that would otherwise require 20 years if the ensemble runs were limited to sequential executions (one member at a time).

WHY BLUE WATERS

Blue Waters provides the computing resources needed for the research team's geomagnetic data assimilation research project. Further, the technical staff provide much-needed knowledge to improve and optimize GEMS.