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INDUCTIVE E FIELDS IN EARTH'S MAGNETOSPHERE

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EXECUTIVE SUMMARY

The terrestrial magnetosphere has the capability to rapidly accelerate charged particles up to high energies over relatively short times and distances, leading to an increase in near-Earth currents. Since the energy of charged particles can be increased only by means of electric fields, knowledge of the relative importance of the potential versus inductive electric fields at intensifying the hot ion population is required to fully understand the dynamics of the inner magnetosphere. However, the contribution of potential and inductive electric field-driven convection resulting in the development of the storm-time ring current has remained an unresolved question in geospace research. Understanding the implications of the induced electric fields requires a continuous global representation of the electromagnetic fields. This involves a combination of fluid and kinetic approaches that includes all relevant species (ions and electrons), and self-consistent three-dimensional magnetic, convective, and induced electric fields, as well as the relevant loss mechanisms.

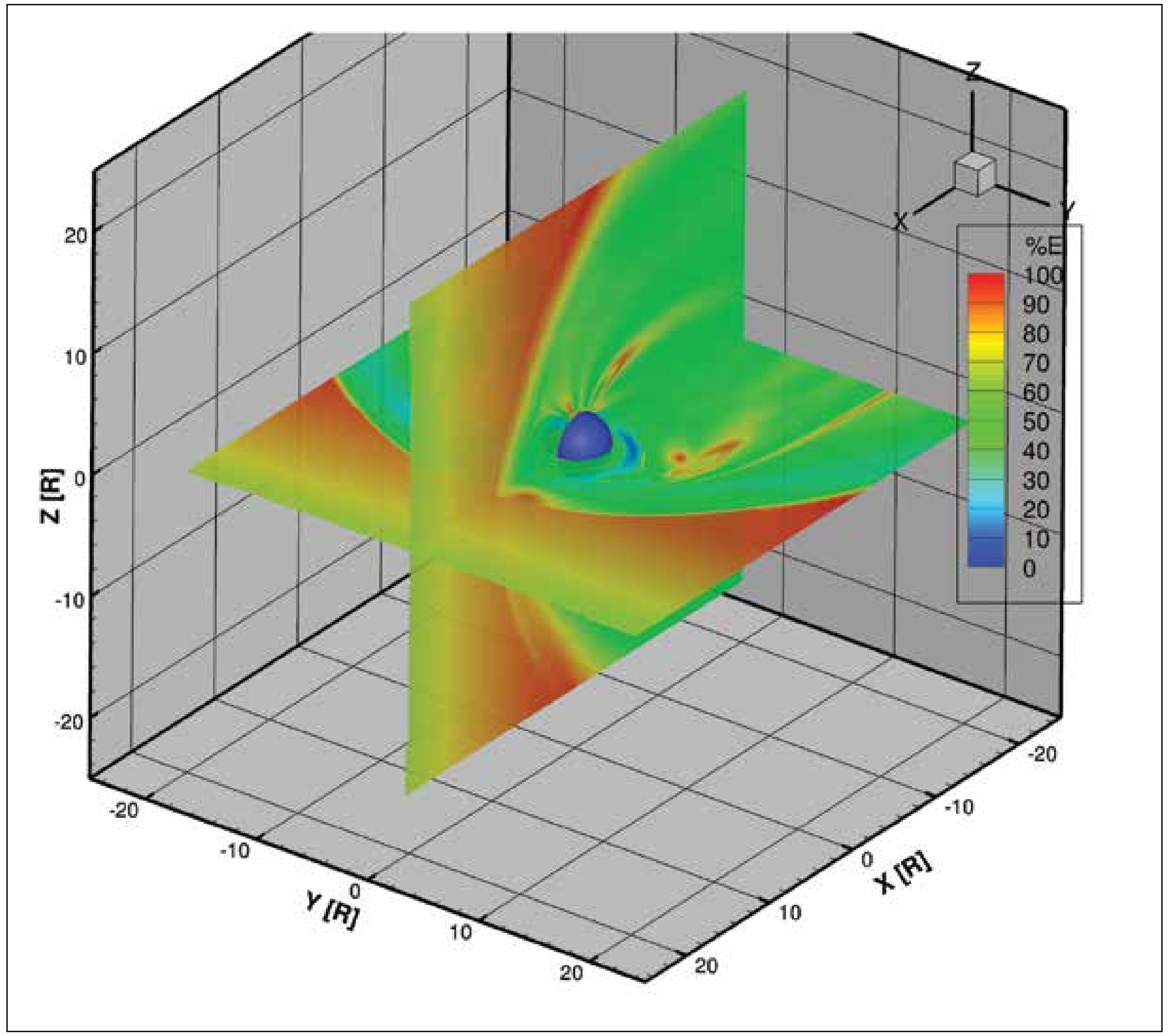

Figure 1: The figure shows the percent of the inductive field (color) from the total electric field at a specific time during a geomagnetic storm. The blue sphere represents the inner boundary of the simulation, which is set at 2.5 Earth radii.

RESEARCH CHALLENGE

The overarching goal of this research is to determine what role the electric field induced by the time-varying magnetic field plays in the overall particle energization and to achieve cross-scale knowledge of the particle transport across the magnetosphere system. Thus, we will gain insight into the relationship that controls the global and local dynamical changes in the inner magnetosphere particle population. This new knowledge will allow us to work toward improvements of physics-based space weather prediction models.

METHODS & CODES

Due to the large variability in both temporal and spatial scales of various processes that control different domains inside the terrestrial magnetosphere, physics-based space weather modeling becomes a challenging problem. Therefore, software frameworks are suitable to model multiphysics systems since they offer the possibility of treating each region of the space with an appropriate numerical model. For this project, we use the Space Weather Modeling Framework (SWMF), which is capable of simulating physical processes and coupled domains from the solar surface to the upper atmosphere of the Earth. The SWMF is a robust, high-performance numerical tool for heliophysical simulations. It resolves the disparate spatial and temporal scales with independent spatial and temporal discretizations in the various integrated numerical models. Each domain/component may be represented with one of several alternative physics models, and the coupling of these modules makes the SWMF a unique and powerful tool in simulating the dynamic evolution and interactive physical dependencies within and between coupled systems of the space environment.

RESULTS & IMPACT

Assessing the relative contribution of potential versus inductive electric fields at the energization of the hot ion population in the terrestrial magnetosphere is only possible by thorough examination of the time-varying magnetic field and current systems using global modeling of the entire system. Numerical experiments using our method of separation of the electric field into inductive and potential components, based on Helmholtz vector decomposition of the motional electric field, reveal that the inductive component of the electric field is comparable, and even higher at times than the potential component. This suggests that the electric field induced by the time-varying magnetic field plays a crucial role in the overall particle energization in the inner magnetosphere.

In addition, due to the localized nature of the inductive electric field, knowledge of the relative contribution of potential versus inductive electric fields at intensifying the hot ion population provided new insight into the connection between the macroscale dynamics and microscale processes that govern this region. Further, it solidified our comprehension of the physical processes controlling the magnetosphere dynamics. The results highlight the importance of accounting for inductive electric fields in space weather prediction models, a component long ignored in the description of near-Earth plasma dynamics. The implications of these findings are immediate as space weather prediction is critical to a forewarning of solar events that could generate severe space weather at Earth.

WHY BLUE WATERS

In order to obtain a physically consistent, realistic, and accurate understanding of plasma transport we use an array of numerical approaches for several disturbed condition intervals, comparing the results against each other and against satellite and ground-based observations. This involves modeling very disparate spatial and temporal scales and, therefore, requires a multiscale modeling approach combined with large computational resources. Blue Waters provided the much-needed platform to run the simulations. The vector decomposition and the calculation of the electric field components by source requires high-accuracy, high-resolution simulations across a very large domain, which is not possible on smaller clusters.