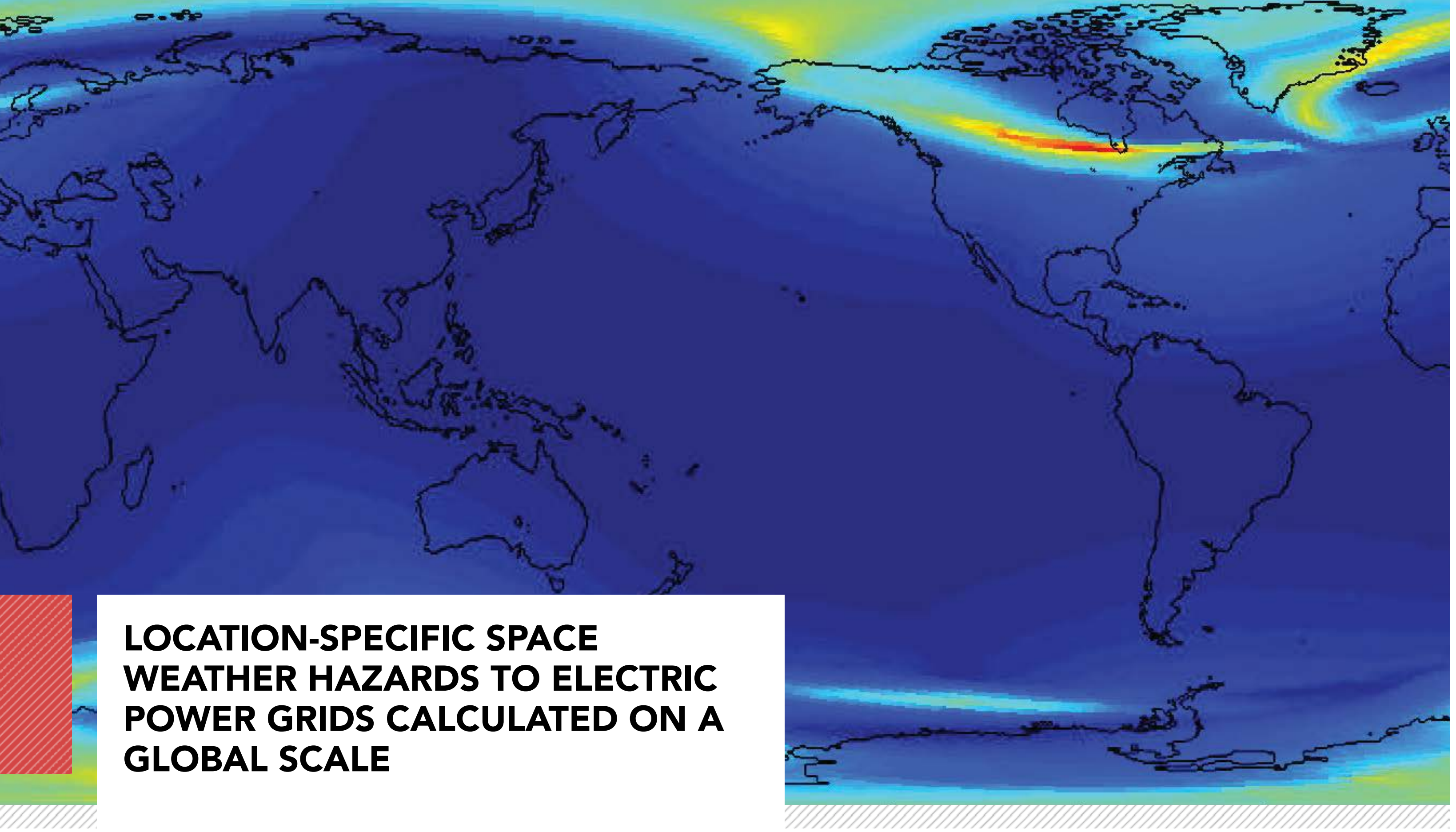

LOCATION-SPECIFIC SPACE WEATHER HAZARDS TO ELECTRIC POWER GRIDS CALCULATED ON A GLOBAL SCALE

Allocation: PRAC/2.3 Mnh
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EXECUTIVE SUMMARY:

The historical record suggests that extreme space weather is likely to impact the Earth again in the future. However, modern electrotechnologies will be affected by space weather to a much larger degree than in the past. We are using a global Maxwell's equations model of the Earth-ionosphere waveguide to calculate location-specific space weather hazards to electric power grids. Specifically, we are calculating and analyzing electromagnetic field behavior during a recent geomagnetic storm in March 2015. Blue Waters permits us to account for the Earth's topography, oceans, variable composition of the lithosphere, as well as the variable ionospheric composition and source conditions according to time, altitude, and position around the globe. Blue Waters also allows us to calculate and analyze ground-level electromagnetic fields values over time-spans of hours at microsecond time resolution (as required by our algorithm). Previous analytical and computational approaches were localized in nature, assumed highly simplified geometries, and could not model arbitrary (realistic) source waveforms in time or space.

FIGURE 2 (BACKGROUND): Electric field source amplitude for March 17, 2015, at 13:34 UT as calculated by BATS-R-US available through the Community Coordinated Modeling Center (CCMC) hosted by NASA Goddard Space Flight Center.

INTRODUCTION

The historical record indicates the possibility of extremely intense space weather events directed toward the Earth. The largest documented geomagnetic storm in 1859 [1] caused telegraph operators communicating over 100 km wire lines to experience electric shocks, some nearly fatal [2]. Business transactions requiring telegraphic exchanges were completely shut down in the world's major capitals [2].

A 2008 National Academies report [3] indicates that extreme space weather events, "though rare, are likely to occur again some time in the future." However, a reoccurrence of an 1859-magnitude (coronal mass ejection-driven geomagnetic) storm could disrupt today's society to a much greater degree due to the proliferation of vital but vulnerable electrotechnologies. Interruptions to radio communications, commercial airline flight plans, satellite operations, transportation, banking, financial systems, home and industrial computer electronics, and power grids are just some examples. The National Academies report estimates the overall economic cost of one such extreme event as ranging from millions to trillions of dollars, with a recovery time of four to 10 years [3].

METHODS & RESULTS

The goal of the proposed work is to greatly improve our ability to understand and predict space weather hazards in the near-Earth environment, especially on the operation of electric power grids. To achieve this goal, we are advancing and applying detailed, high-resolution Maxwell's equations models of the Earth-ionosphere waveguide developed by the principal investigator over the past 12 years (e.g. [4, 5]). These models are based on the finite-difference time-domain (FDTD) method. FDTD is a time-domain and grid-based approach that permits us to account for such details as the Earth's complete topography, oceans, variable composition of the lithosphere, as well as the variable ionospheric composition and disturbances according to time, altitude, and position around the globe.

Using the global FDTD models, we are generating location-specific ground-level electromagnetic field data to help predict the induced voltages on electric power grids during space weather events. Figure 1 illustrates a planar cut of the 3D FDTD grid as seen from constant radial coordinate. Figure 2 illustrates an example snapshot of the disturbed ionospheric electric fields during the March 2015 geomagnetic storm. These disturbed ionospheric fields are used as sources to the FDTD grid at ~100 km altitude, and then the ground-level electromagnetic fields are calculated. Individual power grid operators may use the FDTD-computed results to design and implement effective mitigation strategies to protect the grid from voltages induced by geomagnetic storms.

WHY BLUE WATERS

FDTD can account for highly detailed geometries and material compositions. However, it is computationally expensive, especially when modeling the entire world. Blue Waters has helped us improve the parallelization of our global model, so that we can now model at resolutions of 2.4 km and higher (previously, our highest grid resolution was 40 km). Achieving these high resolutions has been challenging because, referring to Fig. 1, dividing the grid into equal sections for each processing core is challenging due to the merging of grid cells in the polar regions.

Furthermore, Blue Waters is allowing us to model more realistic ionospheric sources and their variation in both time and space than previously possible (at resolutions down to 1 km globally in space). Hazards to electric power grids critically depend on the complex distribution of storm-driven ionospheric sources overhead, the grid's vicinity to ocean-continent boundaries, and the underlying rock structure. As such, the FDTD-calculated results may be instrumental for protecting individual power grids substations.

Blue Waters project staff have been instrumental to our success. They improved the efficiency of our model by 4% by helping us incorporate non-blocking message-passing interface (MPI) send and receive commands into a section of our code. Also, the staff significantly aided our productivity by rapidly addressing issues and questions.

So far at higher spatial resolutions, our model assumes a relatively simple exponential ionospheric profile. The next Track-1 system would allow us to model a more realistic magnetized ionospheric plasma that accounts for the geomagnetic field and variable electron and/or ion content of the ionosphere.

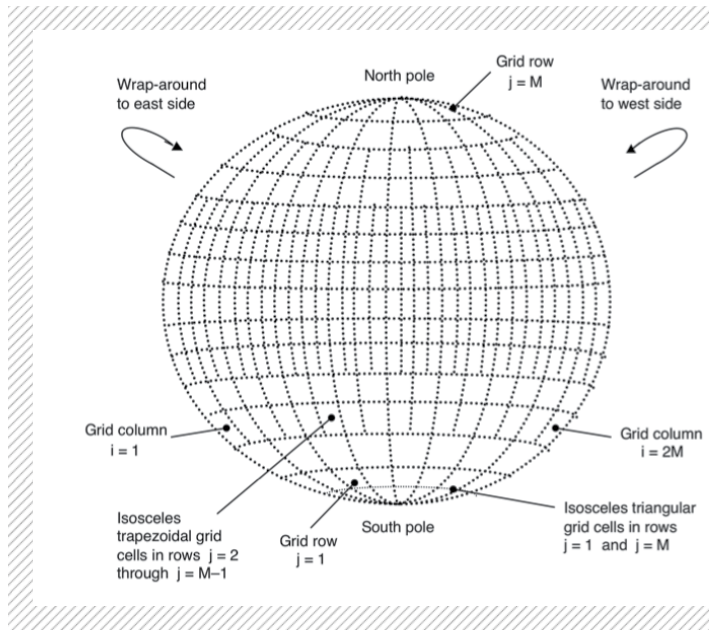

FIGURE 1: Layout of the 3D FDTD grid as seen from a constant radial coordinate.