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Operational Space Weather Entering a New Era

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U.S. operational space weather is maturing because of two competing factors. On one hand, directed agency funding at about $1 billion for model development over the past decade has brought modeling maturity to five broad Sun-to-Earth domains, i.e., Sun, heliosphere, magnetosphere, ionosphere, and thermosphere. On the other hand, agency funding for transitioning these models into operations has been a small fraction of the level provided for model development. This situation has left implementation of operational space weather largely unfunded and woefully undirected, with the exception of a few U.S. Air Force Weather Agency projects. A new vision is needed so that operational space weather can help solve 21st-century challenges.

The current paradigm for operational space weather began in the 1990s, when the idea was to build complete systems at single facilities. These rapid prototyping centers were envisioned as a means for implementing new operational systems, but this path was unsuccessful. Although increased funding for operational space weather would have benefited the community, this did not happen, and in the lopsided funding profile, operational space weather was forced to develop an unusual but robust architecture. This architecture consists of distributed networks—automated systems of models, data streams, and algorithms at multiple, geographically dispersed facilities linked by operational servers. A central server manages the network and uses a database enabling remote nodes to deposit output data and access input data at their geophysical or measurement cadences and latencies.

The emergence of distributed networks represents a paradigm shift from 1995, when the National Space Weather Program (NSWP) strategic plan was first published. At that time, very few models existed that could be even considered for use in operations. Model development increased due to the funding surge, and by 2000 seventy-three models characterizing 15 space environment domains were listed in the NSWP implementation plan (2nd edition).

During the past decade some of these models were implemented operationally and became important components of distributed networks. Early examples were the Magnetospheric Specfication Model (MSM; 2000), SOLAR2000 (S2K; 2001), and High Accuracy Satellite Drag Model (HASDM; 2004). More recently, systems of coupled models and data streams have been created, including Global Assimilation of Ionospheric Measurements (GAIM; 2006), Hakamada-Akasofu-Fry (HAF; 2007), and Communication Alert and Prediction System (CAPS; 2008). Coupled model/data systems that are currently being implemented include the Jacchia-Bowman 2008 (JB2008), the Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS), U.S. Geological Survey Dst, ENLIL with Cone, and Ionosphere Operational System (IONS; i.e., the commercial version of GAIM at the Utah Science Technology and Research (USTAR) Center for Space Weather). Of added note is that the Space Weather Modeling Framework (SWMF) and the Center for Integrated Space Weather Modeling (CISM) have developed multidomain systems to represent the entire Sun-to-Earth environment, in which some of the models have been running for years.

The need to test coupled systems existed even without funding, and the lack of funds drove small businesses, universities, and the multiagency Community Coordinated Modeling Center to create innovative, cost-effective solutions. Basically, these organizations had to find cheaper ways to accomplish testing and operational implementation. The result was the development of distributed networks to close the Technology Readiness Level (TRL) 7–9 gap. TRL is the concept used by agencies and companies to assess the maturity of evolving technologies. TRL 7 models and data can operate in stand-alone mode within the context of an operational environment. TRL 8 signifies the completion of a fully functional system prototype, and TRL 9 describes a fully delivered, operational system. The distributed network systems at TRL 7–9 are linked in a way that allows developers to maintain versioning and proprietary control over their models, permits data streams to be integrated at their own measurement cadence, results in testing flexibility, enables rapid

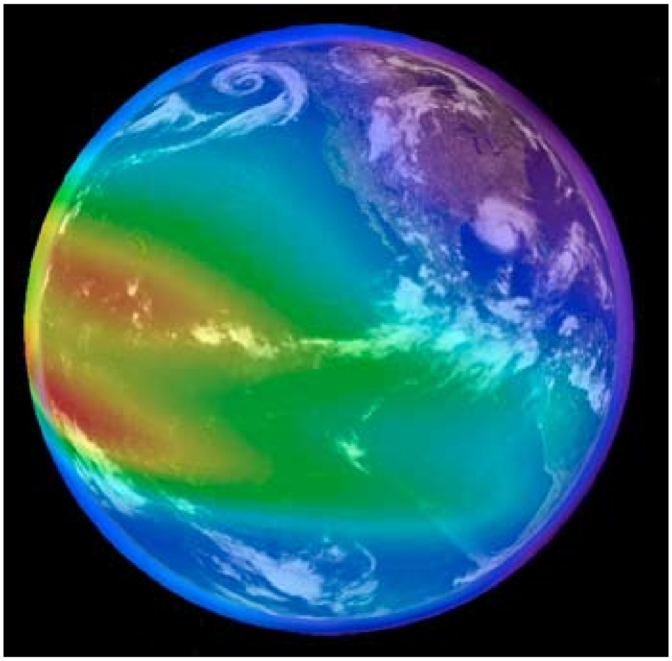

Figure 1. A screenshot of the real-time Communication Alert and Prediction System Earth-Space 4-D (ES4D) system using Google Earth™. This image, created using data and models from Space Environment Technologies in California and Space Environment Corporation in Utah, shows the real-time ionospheric total electron content when Hurricane Gustav hit Louisiana on 1 September 2008. The ionosphere was relatively quiet at this time (red indicates higher electron density; blue indicates lower electron density), and the "all-clear" visualization indicated to emergency responders that high-frequency communications would not be disrupted by space weather, contrary to the Hurricane Katrina rescue communications on 7 September 2005. Google Earth™ imagery ©Google Inc., 2008 TerraMetrics, and 2008 DigitalGlobe. Used with permission.

updates, and ultimately provides reduced costs for all users and developers.

A well-known example of a small business–developed, automated, distributed network with commercial applications is CAPS, created by Space Environment Technologies (SET) and Space Environment Corporation (SEC). CAPS provides real-time ionospheric information, including total electron content (TEC; see Figure 1). The information is based on 1-minute SOLAR2000 and SOLARFLARE modeled irradiances that are ingested by the physics-based Ionosphere Forecast Model, which is at the core of GAIM. Aviation users, emergency responders, and amateur radio operators rely on the derived high-frequency (HF) information from this system to determine their radio communication availability.

As we look to the future using networked systems, operational space weather looks like a supply chain, i.e., a system of organizations, people, technology, activities, information, and resources that move space weather products or services from raw material suppliers to customers. The raw materials are space environment measurements such as solar irradiances observed by satellite or TEC from Global Positioning System ground stations. These data are processed by models into current epoch and forecast ionosphere electron densities that have spatial and temporal information. The information is refined into specialized products such as optimal high frequencies for a specific propagation path at a moment in time. The final HF availability product is delivered to end customers such as aviation HF users via third-party content providers.

Supply chain space weather will find even greater value when it is integrated as an information layer within broader systems. For example, the Federal Aviation Administration's NextGen air transportation system four-dimensional data cube can include all the aforementioned HF availability as one "layer" of global information, even though there is an entire networked system behind the production of that information.

So what is needed now? Our society increasingly relies on technology that is affected by space weather, and the number of space weather stakeholders is growing. No single organization can fully identify, much less organize, the universe of operational space weather activity. The space weather community has a wake-up call to forge a new vision that can provide effective, timely mitigation and management of space weather risks for our technological systems. Our new vision must be framed in the context of protecting space and ground assets so they, in turn, can be used to help solve 21st-century challenges such as climate change, energy abundance, and freshwater availability. Distributed networks, born from funding adversity, are part of that vision because they are enabling operational space weather to move forward as mature, integrated components within broader systems of systems.

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