Technology Transfer Award

For research that resulted in a technological solution with widespread and/or significantly measurable societal utilization, with related impact on a global challenge or issue.

Breakthrough Space Weather Model Serves Many Economic Sectors with Better Impact Forecasts

NOMINATION ABSTRACT:

Incoming space weather from the Sun can briefly blot out radio communications here on Earth, shift satellite trajectories, create ground currents that degrade power operations, and force the hands of airline and human space flight managers. It can be costly and sudden: Enhanced atmospheric drag from a minor geomagnetic storm, for example, an event that started on the Sun, led to the loss of 38 of 49 SpaceX Starlink satellites during a 2022 launch.

In 2021, NOAA's National Weather Service (NWS) transitioned a collaboratively-developed space weather computer forecast model into operations, helping the agency better understand and anticipate space weather events and their impacts on people, especially our technological systems. The breakthrough new model, dubbed WAM-IPE, had taken shape at CIRES, CU Boulder, NOAA's Space Weather Prediction Center, and NOAA's Environmental Modeling Center during the previous 15 years. Its transition to operations was an enormous achievement that the agency has called a "research-to-operations success story," (https://www.weather.gov/news/072121-swpc-new-model). The first-of-a-kind model is helping forecasters provide better information to the public about potential impacts from a solar storm and helping various economic sectors—including communications, satellite and airline operations, human space flight, and navigation and surveying—mitigate damages.

THE BACKGROUND CONTEXT SHAPING THE NEED AND INTEREST IN THIS RESEARCH.

Events on the surface of the Sun and conditions in the 93 million miles of space between the Sun and Earth can cause damage here, blocking radio communications, damaging power grids, and diminishing navigation system accuracy. Those conditions—broadly called "space weather"—include: solar flares, which can produce x-rays that block HF radio waves, creating "radio blackout storms" on Earth with impacts for air traffic, especially over Earth's polar regions; storms of solar energetic particles or "energetic protons" that can strike satellite electronics, causing failures, or dose unprotected astronauts with radiation; and coronal mass ejections, which can induce geomagnetic storming on and around Earth. Such geomagnetic storms can modify GPS and other navigation system signals, harming accuracy and they can also induce ground currents and degrade power grid operations.

NAME OF PRINCIPAL INVESTIGATOR(S) OR TEAM:

Tzu-Wei Fang, Space Scientist, NOAA Space Weather Prediction Center
Timothy Fuller-Rowell, CIRES Senior Research Scientist
Zhuxiao Li, CIRES Research Scientist
George Millward, CIRES Research Scientist
Raffaele Montuoro, Lead Project Manager, NOAA Environmental Modeling Center
Adam Kubaryk, CIRES Research Associate

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THE BACKGROUND CONTEXT SHAPING THE NEED AND INTEREST IN THIS RESEARCH. (CONTINUED)

In many cases, operators can take action to protect systems. Astronauts on space walks can go back inside protected environments; directional oil or gas drillers requiring precision navigation guidance can pause while GPS satellites recover from fluctuations; and aircraft flying over the North Pole to save miles can re-route to lower latitudes.

Such actions require accurate and timely warning of incoming space weather conditions, and although forecasters have had some very good observations and modeling tools at their disposal, some key connections were missing. Research by the early 2000s had made it increasingly clear that any skillful space weather predictive model would need to consider the many interconnected events that begin in the Sun and end at Earth. And model would also need to consider the ways in which terrestrial weather systems could change the space weather environment (i.e., accounting for "the whole atmosphere.")

One lead developer of the model, Dr. Timothy Fuller-Rowell, put it this way: "WAM-IPE closes the final link, taking us from the Sun to mud, considering everything that comes up from the troposphere and down."

THE COMPELLING FACETS OF THE, OR THIS TEAM/PERSON'S, RESEARCH AND WHAT WAS THE ULTIMATE KNOWLEDGE AND INSIGHT DISCOVERED.

We nominate the team of researchers who developed the Whole Atmosphere Model and Ionosphere Plasmasphere Electrodynamics model (WAM-IPE), a coupled whole atmosphere - ionosphere - plasmasphere modeling system, and transitioned it into real-time operations at the National Weather Service. The implementation of this model represents the culmination of more than a decade of work and serves as an exemplary Research to Operation (R2O) success story. The model enhances the Space Weather Prediction Center's space weather forecasting capabilities by assisting forecasters in providing better information to the public regarding potential impacts from solar storms and enables mitigation across varied economic sectors.

Development of WAM-IPE began in 2004 as a multi-agency funded research project. Starting at the applied research stage, a CU Boulder-based team led by Fuller-Rowell initiated the development of the Whole Atmosphere Model (WAM). To achieve this, the NOAA National Weather Service Global Forecast System (GFS), used for global terrestrial weather forecasts, was extended from its original upper limit of 60 km to 600 km (the thermosphere), with all the necessary new physics and parameterizations diligently incorporated into the terrestrial forecast model. To create a 3D model capable of providing seamless perpendicular plasma transport pole-to-pole, this team developed a second model, the Ionosphere, Plasmasphere, Electrodynamics (IPE) model. The researchers then coupled those models, incorporating the complex information exchange to fully capture the critical processes within the ionosphere-thermosphere system.

The team also had to create a real-time workflow process that captured the lower atmosphere data-assimilation system (bringing in observations). The development and coupling of these models and the accompanying real-time workflow process were the essential combination of science and operations that resulted in the WAM-IPE model, the first operational model to provide atmospheric parameters from the ground to space (~600 km).

The nominees listed here are the foremost contributors and the driving force behind this extraordinary and expansive modeling endeavor. Dr. Fuller-Rowell has been leading model development since 2004 and coordinated the establishment of all the diverse model components. Dr. Fang contributed substantially to both the model development and validation; she adeptly focused the team's efforts on meeting the goal for the operational implementation of the model by July 2021. Dr. Li's neutral atmosphere expertise was an essential factor in developing and validating WAM. Dr. Millward contributed to developing the Concept of Operations (CONOPS) for the real-time workflow system. Dr. Montuoro's expertise was critical for coupling the WAM and IPE models. He established a unique Input-Output (IO) interface specifically designed for running the model in real-time operations. Mr. Kubaryk incorporated the whole atmosphere data assimilation system based on the operational weather data-assimilation system (GDAS) and developed the innovative workflow required to run in a real-time operational configuration.

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THE COMPELLING FACETS OF THE, OR THIS TEAM/PERSON'S, RESEARCH AND WHAT WAS THE ULTIMATE KNOWLEDGE AND INSIGHT DISCOVERED. (CONTINUED)

The development of the WAM-IPE model over the past decade involved numerous cross-disciplinary collaborations between multiple institutes, and the WAM-IPE team orchestrated leading scientists from different disciplines, including atmosphere dynamicists, numerical weather prediction experts, upper atmospheric physicists, coupling experts, and software engineers. In addition to this diverse science team, collaboration with end-users was required to produce actionable space weather forecast products. The team continues today with this end-user engagement work. For example, the WAM-IPE team recently participated in the inaugural Space Weather Prediction Testbed Experiment, a 3-day event that brought together representatives from all the major airline companies, including Flight Operations, Flight Safety, Dispatch, Meteorology, Pilots Union, Air Traffic Management and Communications Groups; Space Weather Operations and Scientists from the USA, Canada, and the UK; and Commercial Service Providers. The main objectives of the Testbed Experiment were to better prepare the aviation community for the upcoming solar maximum; to better understand the airlines' operational procedures responding to space weather alerts and warnings; to communicate the requirements and limitations based on the current space weather tools, and to explore future capabilities in support of the needs of the aviation community as related to radiation at aviation altitudes and communication and GNSS issues resulting from ionospheric disturbances.

The successful progression of the WAM-IPE model from a research model into operations opens a new era of space weather forecasting. The model provides space weather forecasters with a global ionosphere and thermosphere forecast 2-day in advance, allowing them to issue alerts and warnings relevant to aviation, communication, and navigation users. The neutral density forecast provided by WAM-IPE has already proven valuable for satellite orbit prediction. After the recent SpaceX Starlink satellite loss, the WAM-IPE team analyzed the relevant atmospheric disturbances and offered critical decision-making support for future satellite launches. Such partnerships are just the beginning of the significant contributions that the WAM-IPE model will provide toward safeguarding society. Other critical products will stem from WAM-IPE outputs, with the team building future capabilities that will include Space Traffic Coordination and Space Situational Awareness.

As our field continues to address more complex, system-wide questions, the WAM-IPE model's comprehensive skill set will only become more valuable. This highly collaborative team's ability to meld both scientific and societal interests in creating a world-class, operational model that will enable the protection of life and property embodies the ideals of this High-Impact Research Technology Transfer Award. This groundbreaking model has already demonstrated its societal benefit to the NOAA Space Weather Forecast Office and our satellite community. This is a big step forward for space weather modeling and the beginning of a new era of products and services that SWPC will be able to offer to our space weather customers.

The Cooperative Institute for Research in Environmental Science (CIRES) was recognized in two of the Awards, prompting this enthusiastic comment: "I am delighted to see CIRES researchers and our federal and university colleagues honored with two awards. Our scientists are extraordinarily collaborative and we work on research problems that can really make a difference in people's lives," said Waleed Abdalati, Director of CIRES at CU Boulder. "So it is especially meaningful to me that we've earned these honors for both 'pathfinding partnerships' and 'technology transfer.' Congratulations to our teams!"

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GOVERNOR'S AWARDS FOR HIGH-IMPACT RESEARCH 2022

HOW THIS RESEARCH BEEN APPLIED, UTILIZED, COMMERCIALIZED OR OTHERWISE ADOPTED OUTSIDE YOUR LAB?

WAM-IPE has been operational since July of 2021, and has served many sectors, through the NOAA Space Weather Prediction Center (SWPC) forecast operations. NASA's human space flight program, the international aviation community, launch companies, satellite operators and more rely on SWPC's expert guidance for making critical, sometimes life-saving decisions. One example of how the commercial sector has utilized this research-to-operations effort is the post-event analysis of the space weather conditions in February 2022 that resulted in the loss of 38 of 49 SpaceX Starlink satellites, representing an economic loss estimated between $12-24 million.

On Thursday, February 3rd at 1:13 p.m. EST, a SpaceX Falcon 9 rocket launched 49 Starlink satellites to Low Earth Orbit (LEO) from the Kennedy Space Center in Florida. SpaceX later reported the loss of up to 38 of the satellites after encountering increased atmospheric drag due to a geomagnetic storm while performing orbit-raising maneuvers. A series of Earth-directed and partially Earth-directed Coronal Mass Ejections (CMEs) were detected by SWPC between January 29-31, 2022. They were expected to arrive at Earth on February 2nd, generating a minor geomagnetic storm on February 3rd-4th. Even though this was considered only a minor geomagnetic storm, it led to thermospheric expansion that significantly enhanced the neutral density in the LEO environment impacting the Starlink satellites.

SWPC had several watch, warning, and alert products in effect for this event beginning on January 31st and continuing through February 5th. Commercial satellite operators receive general forecasts, watches, warnings, and alerts through NOAA's data and web services, but none of these products are currently specifically targeted to satellite drag at LEO. SWPC's newest operational space weather model, the Whole Atmosphere Model - Ionosphere Plasmasphere Electrodynamics Model (WAM-IPE), was able to capture the global neutral density enhancement that increases satellite drag. The WAM-IPE model showed increases in neutral density by more than 100% at most altitudes following the February 3rd storm. These increases persisted through February 5th.

The WAM-IPE team has been working closely with the guidance, navigation and control (GNC) team at Starlink to analyze the upper atmosphere environment for the event. The Starlink team has started using the WAM-IPE neutral density values for their drag estimation calculations. Motivated by this engagement with the Starlink team, SWPC is actively exploring new products tailored for satellite drag. The two groups have been working in collaboration on a scientific journal article that is currently in review.

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