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Examining Vulnerabilities of America's Power Supply

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Extreme Space Weather and the Electric Power Grid

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Extreme space weather events pose a threat to all forms of modern high technology, and particularly the backbone provided by the electric power grid. Such storms begin with an explosion--a "solar flare"—in the magnetic canopy of a localized magnetic active region on the Sun. X-rays and extreme ultraviolet radiation from the flare reach Earth at light speed, ionizing the upper layers of our atmosphere. Side effects of this solar electromagnetic pulse could include radio blackouts and global positioning satellite (GPS) navigation errors. Minutes to hours later, the solar energetic particles typically arrive. Moving only slightly slower than light itself, electrons and protons accelerated by the solar storm could charge satellites and damage their electronics. Then would arrive the coronal mass ejections (CMEs), which are billion-ton clouds of magnetized plasma that may take less than a day to blast across the Sun-Earth divide, and stand to cause the most damage to our terrestrial and space-based infrastructure, including the electric power grid.

The occurrence of severe space weather impacting our nation's infrastructure is not a question of "if" but "when." I, and my team, have studied a powerful solar event that occurred almost precisely 3 years ago on 23 July 2012. This solar eruption produced a CME that moved from the Sun's surface to the distance of Earth's orbit in only about 15 hours. This is among the very fastest moving solar blasts ever witnessed in the modern space age. It was a ferocious disturbance that—fortunately—was directed somewhat away from Earth. Space scientists realize that a direct hit by an extreme CME such as the one that narrowly missed Earth in July 2012 could cause widespread power blackouts, disabling everything that uses electricity. Most people would not even have water because urban water supplies largely rely on electric pumps as do gasoline pumps, communication systems, and myriad other modern human technologies. Damage from such an extreme event would run into the trillions of dollars.

Before July 2012, when researchers talked about extreme solar storms their touchstone was the iconic Carrington Event of Sept. 1859, named after English astronomer Richard Carrington who actually saw the instigating solar flare with his own eyes. In the days that followed his observation, a series of powerful CMEs hit Earth head-on with a potency not felt before or since. Intense geomagnetic storms ignited auroral displays as far south as Cuba and caused global telegraph lines to spark, setting fire to some telegraph offices and thus disabling the 'Victorian Internet." A similar storm today would have catastrophic effects. According to a study from the U. S. National Academies (chaired by myself and published in 2009), the total economic impact could exceed $2 trillion or 20 times greater than the costs of a Hurricane Katrina. Multi-ton power grid transformers disabled by such a storm could take years to repair or replace.

The severe space weather associated with extreme solar storms would affect humans on vast spatial scales. Notably, such storms have the real possibility of knocking out dozens to perhaps scores of spacecraft on which society depends. Loss of communication satellites, weather observing spacecraft, and the GPS network of navigation and timing platforms could have severe and rapidly propagating effects throughout society. Impacts on the power grid would quickly spread to be of continental scale size. Under the worst of scenarios, policy makers, emergency preparedness workers, and health practitioners could be left powerless and cut off from much of the modern societal infrastructure for extended periods of time. The risk of widespread space weather-related outages, which could result in society being without food, water, fuel, and information for days, weeks, or months, renders this a hazard of paramount concern.

The current capability of our technological society to predict space weather is primitive. Through research and operations programs supported by the National Science Foundation (NSF), NASA, and the National Oceanic and Atmospheric Administration (NOAA), we observe the Sun, and we can see the general properties of the expansion of the solar atmosphere, the solar wind, and powerful bursts from solar storms heading in our general direction. But the initial direct measurement we currently have of the solar wind or CMEs is at the first Lagrangian point (L1) where spacecraft can hover between Earth and the Sun. Measurements at L1 provide only about 45 minutes of warning (at best) as to what will impact Earth. This is insufficient time for implementing most mitigation strategies.

Compounding the space weather challenges to our society are the complex responses of the magnetosphere and ionosphere, the regions of Earth's atmosphere most vulnerable to solar inputs and disturbances. These responses are extremely difficult to predict in detail. With regard to major and potentially disastrous space weather events, our situation today is similar to the forecasting of terrestrial hurricanes prior to the era of satellite observations. In those earlier days one might know there was a hurricane at sea, but where and in what strength it would make landfall was determined only when the hurricane struck. One need only reflect back on the devastating hurricane in Galveston, Texas, in 1900 to realize the societal consequences of such blindness to natural hazards.

In July, I spent two sobering days at the 6th Electric Infrastructure Security (EIS) Summit here on Capitol Hill. Representatives from over 20 nations around the world attended the EIS Summit. CEOs from key electric power utilities and leaders from the U.S military and several federal agencies spent two days grappling with the immense challenges that would result if nuclear weapon-induced electromagnetic pulse (EMP) or geomagnetic disturbance (GMD) were to take down the North American power grid. In the EIS world, such events are termed "Black Sky" days. The hundred-plus EIS delegates all acknowledged that the collapse of the power system would be devastating and that industry, government, and academia must all work together to the greatest degree possible to minimize the impact when such a Black Sky Day occurs.

Thus, there is great economic value in improving our capability to predict space weather. More efficient management of our bulk electrical power grids is necessary so that these grids can more effectively respond to variations in the Earth's magnetic field resulting from space weather. This in turn would result in more effective utilization of our communication networks and GPS tracking systems, as these systems are strongly influenced by variations in the ionosphere. Under the most extreme conditions, protection would be possible from disastrous bursts from the Sun that can disable our orbiting satellites or completely paralyze the electric power system. In space weather, as in many things, forewarned is forearmed. Many studies have shown that improved predictions of space weather would have important economic impacts on our society in the same way that improved terrestrial weather forecasts have greatly improved our economic wellbeing and the quality of our daily lives.

Is our problem of improving space weather forecasting hopeless? Absolutely not! But it will require a substantially increased and dedicated government research program. The prediction of space weather, as with the prediction of terrestrial weather, must be based upon comprehensive numerical models that assimilate real-time observations. Then, based upon observations, these models can predict the space weather that will affect the Earth. However, unlike terrestrial weather models, observations of the space environment are by their very nature extremely sparse.

Quite importantly, there also are basic physical processes at work in space that are unknown or only poorly known to us. Knowledge of this underlying physics is essential for translating sparse observations into actionable predictions. The technology needed to advance the research is available, as is a dedicated community of researchers at our nation's research universities and federal laboratories. There is absolutely no reason why, with a focused effort, that prediction of space weather cannot be brought to a level that delivers economic value and protects our technological civilization.

It is crucial that government funded research programs be chosen to advance our civilization, our way of life, and our strategic importance in the world. Such research should protect our citizens and our economy. In fact, research that would result in a sufficient space weather prediction capability should be among our highest national priorities.

Unfortunately, today's federal investment and policies are not aligned with this set of space weather needs. In 2012, the National Research Council of the National Academies published a Decadal Survey in Solar and Space Physics, as it has similarly done for other space science disciplines. I was privileged to chair that activity for the U.S. National Academies. The Decadal Survey established the priorities for research relevant for space weather, among other activities, for NASA and the NSF in the years 2013-2022. The Steering Committee for the Decadal Survey was told to plan for at most a modestly increasing budget during this period, and that is what the committee did. However, to date, NASA has not requested, nor has Congress funded, any of the significant initiatives recommended by the Decadal Survey.

The Heliophysics Division of NASA, which has the main responsibility for the research required to improve space weather predictions, is NASA's smallest science division. The NSF also provides essential support for the research community conducting space weather research and NSF conducts important ground-based observations as well. This prominently includes our colleagues from the National Solar Observatory (NSO) who are now moving in full force to their new facilities on the University of Colorado campus in Boulder. Yet, these NSF activities are only a small part of the Geosciences division with high priorities for other areas of research. NOAA has the responsibility for making the actual space weather forecasts through the Boulder, Colorado based Space Weather Prediction Center, but these forecasts can only be based upon the models and observations provided by the much larger research efforts supported by NSF and NASA.

Even if the basic Decadal Survey initiatives were funded they would not be sufficient to perform fully the research required to advance our capabilities to predict space weather on a schedule that serves the needs of the nation. A much more substantial program was envisioned in the Decadal plan that would build a true operational 24/7 national space weather program. This would be costly, but is essential for our Nation's future. A key activity now is underway by federal agencies to address "The Federal Space Weather Framework". This work is identified as the Space Weather Operations, Research, and Mitigation Task Force—known by the acronym SWORM. The Decadal Survey initiatives recommended strongly such a framework in which the required research and actions can be conducted. With funding appropriately above the requested minimum level, the Decadal plan and the SWORM implementation plan could yield the required predictions in sufficient time.

It is worthwhile to recall earlier challenges that the nation has given to its space program. The landing of humans on the moon, for example, was recognized as being of national importance, difficult and expensive to achieve, and from President Kennedy's speech in 1961, "every scientist, every engineer, every technician and civil servant must give his personal pledge that this nation will move forward" in this exciting adventure. The existential threat to our society represented by severe space weather events—especially to the national power grid—demand a similar national commitment even in these times of fiscal constraint.

Our economy and our way of life are influenced by, and in many ways are vulnerable to, space weather. The nation should issue a challenge to the space research community to provide the predictive capability for space weather sufficient to make our economy more resilient and to reduce to an acceptable level our societal vulnerabilities. The nation should recognize that this is a pressing challenge, and that substantial resources will be required. In return the space research community must give its common pledge that it will deliver what the nation requires. I would respectfully suggest that the time for budgetary and policy action is now.

To summarize key points:

- A solar "superstorm" is a real and present danger to our society;
- The occurrence of such a storm is not a question of "if" but "when";
- We know how to better safeguard the electric grid from severe space weather damage;
- We should take the policy steps and the physical steps to protect the electric grid;
- We should fund immediately the program plans laid out in the NRC Decadal Survey to begin to assure that adequate alerts and warnings are provided for severe space weather events.