WHITE PAPER

SOLAR STORMS AND SATELLITES: IS OUR NATIONAL SECURITY READY FOR SPACE WEATHER?

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INTRODUCTION

Space has been a contested domain since the Soviet Union launched the first Sputnik, and the critical need for space domain awareness (SDA) has only continued to increase since. Today, spacecraft under the direction of commercial and government organizations deliver crucial services worldwide—and they collect and communicate intelligence that impacts national security for the U.S., our allies and our adversaries alike.

The recent and exponential increase in spacecraft and related orbital activity makes SDA vital to the nation's strategic interests. The effects of space weather, human-caused activity or issues, and geopolitical intent all come into play. For example: "I just lost communication with my billion-dollar satellite; how do I determine who or what is causing the problem, and how can I fix it?"

The process of answering that question is called "attribution," which is essential for achieving SDA and focuses on the three E's: equipment, environment and enemy.

Imagine interference with military early-detection systems, ongoing and intermittent cell phone network interruptions, or power system overloads causing widespread blackouts. These are all real outcomes of solar activity and geomagnetic storms, but they may also result from equipment failures or human-directed initiatives.

Quick, accurate attribution is essential for making rapid decisions about the appropriate response. The equipment and enemy aspects of attribution are often given the most weight, but space weather's effects are just as critical to readiness and resilience.

THE GROWING RISKS OF SPACE WEATHER TO NATIONAL SECURITY

We are currently in the midst of a highly active, 11-year cycle of increased solar activity. The solar cycle has progressed from several solar flares and coronal mass ejections (CMEs) per week at solar minimum to several per day as we approach solar maximum. For the next several years, we will see more sunspots, more solar flares, more CMEs, and, as a result, even more of an impact on Earth's atmosphere and magnetic field.

These impacts can dramatically affect key elements of the nation's readiness and response, including:

Loss or degradation of communications (LF to L-band radio), GPS and other positioning capabilities

Impacts on air transportation due to loss of HF communications, loss of GPS navigation and radiation hazards

Difficulty tracking space objects using outward-facing space observations due to increased atmospheric drag

Radiation risks to satellite electronics, computers, the International Space Station, astronauts and space tourists

Interruption of intelligence, surveillance, and reconnaissance systems

Loss or degradation of electric grid due to voltage irregularities, and, as a result, loss of other essential utilities

Increased and unpredicted drag on low Earth orbit (LEO) satellites, which can disturb their orbits and orientation, increasing the risk of collisions and reducing mission lifetimes

Loss of control systems for autonomous systems due to radiation or GPS impacts

On a broader scale, the effects of space weather can be felt around the world, affecting supply chains, communications and—most importantly—the safety of civilians, emergency responders and military personnel alike. Because space weather is a global phenomenon, it not only affects U.S. forces worldwide but can impede joint operations with our allies.

The unpredictable nature of solar activity and the randomness of space weather events multiply the risks to national security. Lead time to impact is often only measured in hours or even minutes. Solar flares can affect the ionosphere immediately, while CMEs can reach Earth in as little as 15 hours. Earlier, more precise alerts can empower faster, more effective responses, whether that means shifting a satellite's orbit, temporarily shutting down sensitive systems, or enabling backup protocols to minimize any disruptions.

Space weather that reaches lower layers of the atmosphere can disrupt activities people tend to take for granted. For example, a National Oceanic and Atmospheric Administration (NOAA) alert giving a day's notice of an impending solar event leads commercial airlines to reroute transatlantic flights to avoid the Arctic Circle, due to radiation effects and because HF communications may not be available. Concerns about the impact of radiation on passengers and crews along with the potential loss of navigation and radio communication make it too risky to fly the typical fuel- and time-saving routes. At the same time, dropping to a lower altitude provides more protection from radiation. However, the costs of these seemingly minor changes can be exorbitant — potentially over **$100,000 per flight.**

While military aircraft usually have greater protection against these effects, they are still a consideration, especially when it comes to radiation exposure. Communication and navigation issues affect more than just air traffic; land- and sea-based transportation can also be impacted.

Think of the domino effect if commercial supply chains are interrupted, slowed, or made more costly due to space weather: production and delivery of electronic components, repair parts, new equipment, weapons systems, and even food and clothing can be delayed, degrading readiness, situational awareness and response times.

While some government action is already underway, much more needs to be done to address the risks presented by space weather.

MODELING THE IMPACT. ACCELERATING THE RESPONSE.

Fortunately, greatly improved modeling and faster analysis could provide earlier warnings before a solar event impacts Earth and its surroundings. Multiple sources, including commercial space technology companies and NOAA, have created models of every layer of the atmosphere to help predict what, if any, effect a solar event may have on critical technologies and services.

Naturally, the quality and detail of these models vary by source, but they all have the potential to help defense and intelligence decision-makers and operators protect critical mission assets, minimize mission disruptions, and, above all, safeguard lives.

Lack of awareness of space weather events and their impacts can lead to dangerously slow or less-informed responses to national security threats, including aggressive moves by adversaries. For example, the Joint Commercial Office (JCO) for Space Domain Awareness detected a change in how much sunlight reflected off an adversary's military communications satellite. Was this change the result of a direct command maneuver, or caused by space weather?

Over a day later, using publicly available information, the JCO announced that space weather was not the cause—the satellite was purposely instructed to maneuver. With a better understanding of space weather and by utilizing tools designed to conduct these assessments faster, agencies can achieve rapid, informed decision-making.

Modeling space weather effects is essential for predicting the effects of a CME or other space weather event on operational systems and is crucial to reacting quickly to protect mission capabilities.

However, there are two key limitations to the use of models:

- Models rely on some kind of data input, whether that data is publicly available or from proprietary or commercial information sources. The quality and quantity of that data greatly affects the accuracy of the results, and those sources may not always be available.

- Regardless of the source, interpreting both the input data and the modeling results requires space weather expertise. The analysis isn't always straightforward, and experience can make the difference between protecting a vital asset and delaying a response to a potential threat.

What's needed are models that support space weather simulations with greater accuracy as well as analysis techniques that enable faster, more informed decisions. To achieve this, greater investment is needed, along with expertise that likely comes from outside of government.

IS ENOUGH BEING DONE?

Space weather's impact on national security is a high priority. Multiple agencies and organizations across the government are focused on understanding and preparing for the potential effects of space weather on national interests. The efforts of federal civilian agencies such as the National Aeronautics and Space Administration and NOAA are being augmented by several Department of Defense (DOD) resources. The 2nd Space Weather Squadron within the Space Force is charged with monitoring the impact of space weather events.

Beyond that, the DOD funds and sustains observational capabilities including ground-based telescopes to monitor solar activity and sensors to measure changes to the ionosphere.

> AI may soon play a larger role in analyzing both the data itself and the model's output to aid decision-making. Considering the thousands of ground and space-based sensors, the amount of data captured is enormous and growing daily. AI-powered systems can process and analyze massive amounts of data much faster than conventional systems, augmenting the expertise of human specialists.
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> This means that AI has the potential to spot space weather events and their possible impacts significantly sooner, giving decision-makers on the ground much more time to take necessary action, such as moving a satellite to a different location or alerting the International Space Station's crew of an impending spike in radiation and electromagnetic activity.

The White House Office of Science and Technology Policy (OSTP) released an implementation for national space weather policy in late 2023. This plan was the culmination of efforts that had been evolving since 2015.

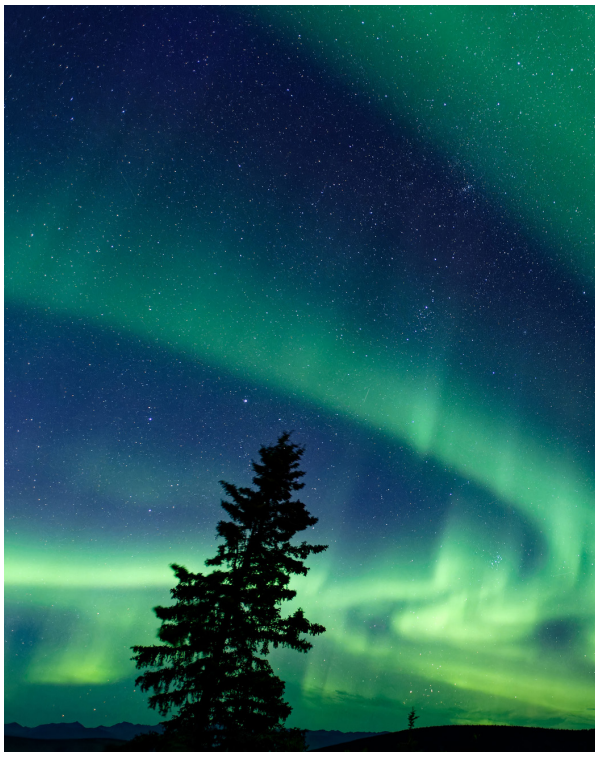
Other key players include the following:

- **Space Weather Operations, Research and Mitigation (SWORM):** a sub committee of OSTP that was formed in 2019 to coordinate inter-agency efforts to achieve the plan's goals
- **Space Weather Advisory Group (SWAG):** first met in December 2021 with the goal of improving forecasting and advising SWORM on space weather issues
- **National Academies of Sciences Space Weather Roundtable:** formed in 2022, this group brings together government, industry and academia to discuss ways to improve our understanding of space weather events. It also interacts with SWAG and SWORM to explore how we might improve forecasting, preparedness and mitigation

"National security priorities" covers a broad spectrum of challenges, and despite the government activity noted above, space weather may not be getting the resources and attention it needs. There is, however, a viable solution to this issue available today.

Dr. Ezinne Uzo-Okoro, the former assistant director of space policy at OSTP, said, "The government alone cannot manage all risks associated with space weather; we need a whole-of-community approach to effectively build a space-weather-resilient nation." In this era of reduced budgets, government agencies cannot continue doing everything themselves. There is an urgent need to transition to a hybrid government-industry model where the government takes advantage of commercial capabilities that have already been developed or can be developed more quickly and for lower cost than government-only solutions. This cooperation is currently helping the government design, build and launch satellites. It's time to apply these lessons to providing space weather services.

Greater government coordination with industry, as well as use of commercial space weather modeling and data collection capabilities and commercial operational warnings and analysis, can help the DOD and Intelligence Community leapfrog past barriers to innovation and ensure space operations success.



RECOMMENDATION: TAKE ADVANTAGE OF THE SHARED NEED FOR DOMAIN AWARENESS

The relationship between industry and government is becoming more interconnected at every turn. Commercial space companies continue to grow their involvement in government missions while pursuing their business goals. The outgrowth of this is a burst of innovation that can transfer from industry to government more quickly and cost-effectively than when government tries to innovate on its own.

The country's national security mission is vulnerable to the random fluctuations and real dangers of space weather. The risks can be mitigated, however, and deeper cooperation between the government and industry partners can pay off with new technologies and faster, more comprehensive responses. From a national security perspective, this translates to greater readiness, quicker response times and a competitive edge over adversaries.