Title: "The next era of weather forecasts: The aerospace industry and space weather"

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The star we orbit is not only what makes life on Earth possible, but is also a great source of scientific mystery, inquiry and development today.

The solar system is in a weather system driven by the Sun. Along with the heat and light that we rely on to survive, the Sun drives solar winds and bombards our planet with radiation and particles that can be harmful to life and technology.

While space weather has always impacted life on Earth, evidenced by phenomena like auroras and the Carrington Event, which famously crippled telegraph systems in 1859, technological advancement has made humanity more vulnerable.

The ability to forecast space weather and access to advanced warning when major storms are incoming will help humanity protect our critical systems and infrastructure, like power grids. Additionally, as we humans aim to adventure more past the protection of Earth, the ability to forecast space weather could keep our explorers safer.

At Ball Aerospace, we are using our decades of experience in space missions as well as satellite building and system expertise to develop, alongside our governmental partners, the next generation of space weather observatories.

Space weather 101

To understand the basics of extreme space weather, it's important to know about three types of solar activity. According to the National Oceanic and Atmospheric Administration (NOAA) this includes solar flares, coronal holes and coronal mass ejections (CME).

According to NOAA these events can "damage satellites in space, shut down power grids on Earth, cause GPS outages, and have serious health concerns to humans flying at high altitudes on Earth, as well as astronauts in space."

There are three types of space weather, caused by these solar events, that NOAA and other agencies around the world are most concerned about:

- Geomagnetic storms: These events can be caused by either CMEs or coronal holes. These storms are responsible for auroras, but can also cause disruptions to electrical systems, satellites, GPS and radio systems.
- Solar radiation storms: This type of storm can be caused by CMEs and solar flares and can be dangerous for astronauts and those flying at high altitudes. They can also impact satellites and radio systems.
- Radio blackouts: This solar flare driven event causes communication and GPS outages.

Image courtesy of the National Oceanic and Atmospheric Administration

Caption: Image courtesy of the National Oceanic and Atmospheric Administration showing some space weather impacts.

Ball Aerospace's own Dr. Nicole Duncan is both a member of NOAA's Space Weather Advisory Group and the recently announced chair of NASA's Space Weather Council. She understands, firsthand, that the implications of space weather can have broad implications across the globe.

"Our technological society is impacted by space weather and the Space Weather Advisory Group (SWAG) is chartered to understand what all of those potential impacts are, and then understand from impacted communities how the government can help prepare," Duncan said.

She added that it's essential for aerospace companies, like Ball Aerospace, to leverage our expertise in managing, designing and operating space missions to improve our resiliency to space weather as a planet and create stronger datasets for space exploration missions.

The history and future of space weather

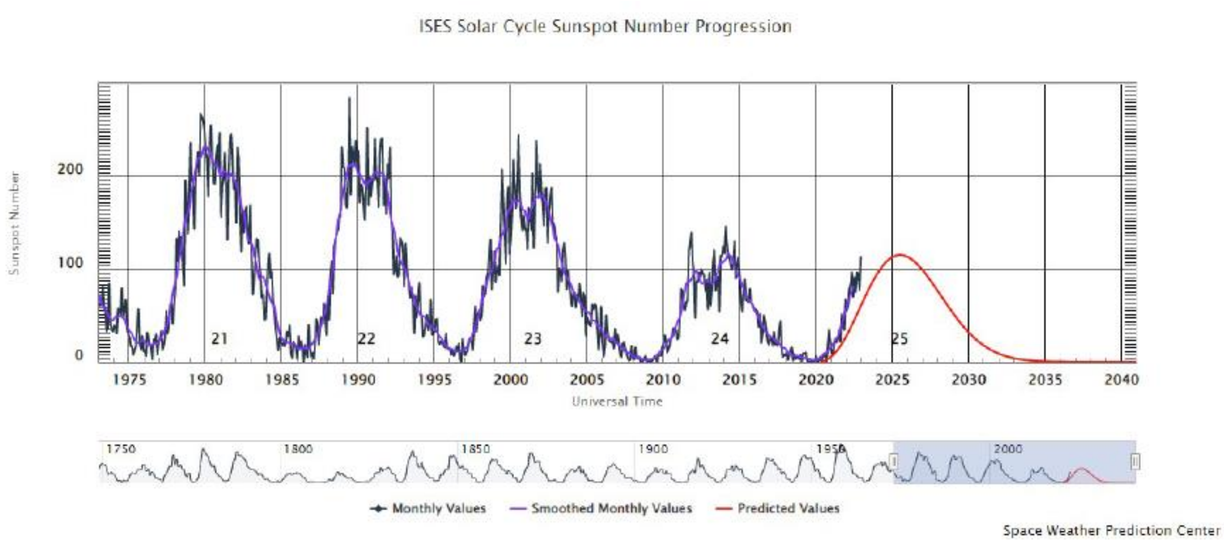
The impact of space weather is not theoretical. The Carrington Event is still the largest geomagnetic storm on record, driven by a massive solar flare and subsequent CME, according to NASA.

The event caused auroras across the planet that could be seen at very low latitudes and sent the time's critical communication system, telegraphs, into chaos. Telegraph machines reported failures and sparks, shocking operators and setting fires.

We have since seen less powerful but still impactful events on Earth, including:

- In 1972 when a solar flare caused long-distance calling to fail in Illinois

- In 1989 when a geomagnetic storm left 6 million Canadians without power by disrupting power transmission and melting transformers
- In 2006 when a storm disrupted satellite-to-ground communications and GPS for about 10 minutes
- In 2022 when a geomagnetic storm contributed to 38 low-earth orbit satellites deorbiting



This graph, courtesy of NOAA, shows the number of sunspots observed every month between February 1973 and December 2022. Higher levels of sunspots mean the Sun is in a period of increased activity, which results in more space weather.

Caption: This graph, courtesy of NOAA, shows the number of sunspots observed every month between February 1973 and December 2022. Higher levels of sunspots mean the Sun is in a period of increased activity, which results in more space weather. The lower plot shows historical sunspot numbers since the early 1700s. Understanding what drives solar activity is a key science question that could improve space weather forecasts.

One discovery, although not yet scientifically validated, suggests Earth has experienced much stronger space weather during recorded history.

Dr. Benjamin Pope, University of Queensland Department of Physics, recently published research suggesting space weather events may be a significant source of Carbon-14 fluctuations in tree rings. His research is still controversial because the source of the particle cannot yet be attributed to any source with certainty.

However, if the Carbon-14 fluctuations are in fact caused by space weather, Pope and his team may have discovered that in 774 AD, Earth was bombarded with space weather about 80 times as powerful as the Carrington Event. Pope said in the *Universe Today* Podcast there were few historical records around this event, aside from a report of a “red crucifix in the sky” by Anglo-Saxon monks.

Not only is protecting critical infrastructures essential for our safety on Earth, but it is incredibly important as human space exploration pushes to the Moon and beyond. While we on Earth are largely protected from the dangerous radiation emitted by our sun thanks to our molten iron core-generated magnetic field and atmosphere, our astronauts are left vulnerable.

Once humans pass beyond low Earth orbit (LEO), solar radiation can cause significantly increased risk of cancer, central nervous system effects and degenerative diseases through direct damage to DNA and an increase of free radicals. According to NASA, astronauts can be exposed to an equivalent amount of radiation as getting between 150 and 6,000 chest x-rays.

In fact, between the Apollo 16 and 17 missions a solar storm took place that, had astronauts been on the Moon at the time, would have had devastating impacts. According to Physics Today, if the astronauts, only protected by their spacesuits, had been on the surface of the Moon during the August 1972 event, the high levels or radiation would have caused:

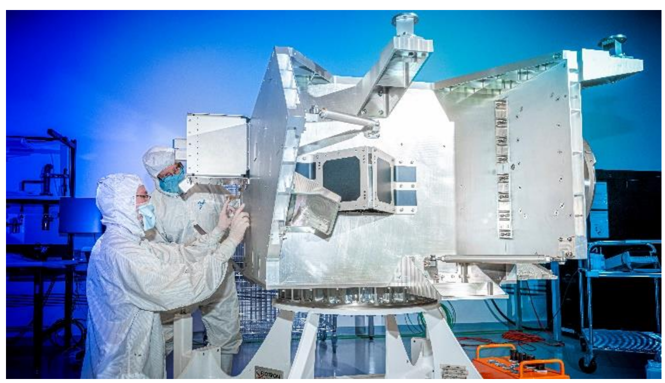
- Severe skin blistering
- Ulceration
- Tissue necrosis or the death of body tissue
- Radiation poisoning symptoms like nausea, vomiting and diarrhea
- Potential damage to bone marrow and destruction of stem cells

What are we doing about it?

After demonstrating our capabilities on weather satellites, including NOAA-20 and Suomi NPP, Ball Aerospace is turning our eyes to the future of space weather satellites. We are humbled and proud to play a role in the future of space weather forecasting.

Ball Aerospace was selected by NASA to design, build and integrate NOAA's latest space weather mission, the Space Weather Follow On-Lagrange 1 (SWFO-L1). When it launches, the mission will carry four instruments designed to give us the most clear and accurate space weather data yet.

The instruments, created by our mission partners and integrated by Ball, will monitor solar winds, high energy particles, in-situ magnetic fields and the Sun's corona, to help better understand space weather. In doing so, we as a nation will have access to better predictions and protections. In fact, some of the instruments will allow SWFO-L1 to send back data during solar events which would have temporarily blinded previous missions.



An image of the SWFO-L1 satellite's BUS at Ball Aerosapce.

Duncan said the mission will allow for several forecasting opportunities. First, the coronagraph will be able to spot a CME and give us 18 hours to several days of notice for a potential space weather event at Earth. Then, "like a Tsunami buoy," when the CME passes by SWFO-L1, we on Earth will get a 15-60-minute heads-up for the storm's arrival. At that time, we could also get advanced notice of a geomagnetic storm if the CME's magnetic field is properly aligned.

Along with this civil mission, we are also building a space weather sensor which will fly on the Weather System Follow-on – Microwave (WSF-M) for the U.S. Space Force Space and Missile Systems Center.

In addition, we're the spacecraft and observatory integration partner on the Carruthers Geocorona Observatory, which will collect data on how space weather, particularly solar winds, interacts with the outermost layer of our atmosphere.

The information will improve our understand of how the Sun's weather system effects our planet and help us theorize what's happening to the atmospheres of planets orbiting other stars.

What's the next step?

The world around us is advancing. Communication systems are crisscrossing the globe, devices from watches to medical equipment can access the internet and we are boldly going where no one has gone before.

Along with our partners, we at Ball Aerospace are using our expertise to safeguard infrastructure and people around the world and beyond. For us, working on these missions is not just about business, but about providing a service to humanity to aid our response to space weather today and allow scientists to better understand how to live harmoniously with our sun.

"The goal for the future is to build a comprehensive architecture that allows us to protect life and property," Duncan said. "We want to have a complete picture of all the ways that our technological society is dependent upon space weather in order to mitigate it's effects."

She also said creating these systems will help Ball and our partners protect those exploring the final frontier by giving them advanced warning of dangerous space weather events, just like any extreme weather alert here on Earth.

Ball Aerospace will work to explore and innovate tomorrow's space weather missions.