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THE SPACE REPORT

SPACE FOUNDATION

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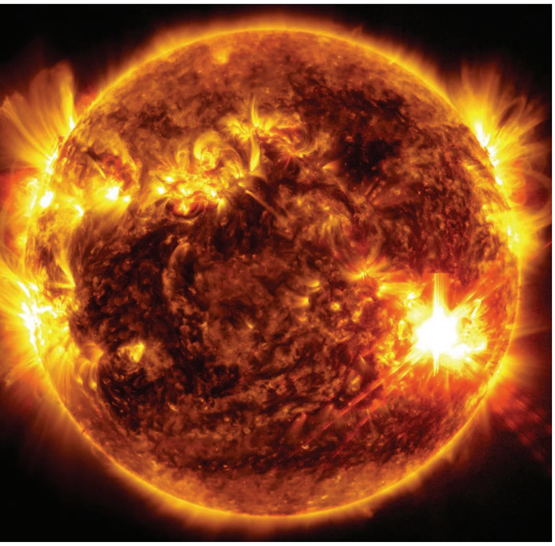


Introduction | *The peak of the current 11-year solar cycle is expected to occur within the next year, but Earth is already witnessing the Sun's increased power. The strongest solar storm in two decades struck the planet in May, disrupting satellites and spreading a brilliant array of northern lights across the skies. These solar flares and coronal mass ejections pose threats to spacecraft and the terrestrial power grid alike, but also underscore the important role satellites play in daily life.*

Solar flares peaking during the May 10 solar storm.
Credit: NASA

New missions, better warnings aim to mitigate solar storms

In 1859, the most intense solar storm ever recorded scorched telegraph wires across an unprepared planet. Known as the Carrington Event, it has become the benchmark heliophysicists use to model and prepare for future solar disruptions. This year, during solar cycle 25, there is much greater technology to estimate these storms, but much more to lose.

Solar storms can launch X-rays, ultraviolet light, protons, and electrons toward the Earth, causing radio blackouts, GPS interference, and entire power grid failures.[1] By observing sunspots, which often increase during peaks solar cycles, scientists can estimate when a solar storm may occur. The same satellites that help scientists prepare for these impacts sometimes are also first in the firing line. By building up satellites' defenses and capabilities against these powerful ejections, operators in turn create a stronger line of defense for Earth.

Solar storms can launch X-rays, ultraviolet light, protons, and electrons toward the Earth, causing radio blackouts, GPS interference, and entire power grid failures.[1]

Solar storms that whipped over the Earth earlier this year are a prime example. In mid-May, the strongest solar event in more than two decades struck Earth, disrupting some positioning, navigation and timing satellites. Just two days before the ejections hit Earth, scientists observed a cluster of sunspots launching several flares and coronal mass ejections (CMEs). This allowed for a brief window of preparation.

"That storm in May was the most successfully mitigated extreme space weather storm in history. We couldn't say that in 2003 the last time we experienced that level," said Shawn Dahl, forecaster at the National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center.[2] "In particular, solar storms affect our lives through the technology that we operate, and there can be profound implications."

As powerful as that May event was, worse may be coming. Solar cycle 25's peak is expected to occur sometime through the middle of 2025, with increased solar storm risk through 2026. The expected rise in solar activity comes as several initiatives are under way to improve monitoring, increase warning times, and learn more about coronal phenomena.

In June, NASA and NOAA launched the GOES-U satellite, now designated GOES-19, outfitted with the Naval Research Laboratory's Compact Coronagraph-1 (CCOR-1).[3] The instrument will block the direct light from the center of the Sun and transmit images of that scientists can evaluate to determine the size, velocity and density of CMEs. CCOR-1 will allow researchers to create better long-term forecasts of incoming solar events.

"The research satellite that we're using right now for coronal imagery, the [Solar and Heliospheric Observatory] satellite, can have gaps up to eight hours before we get the data down," said Elsayed Talaat, director of NOAA's Office of Space Weather Observations. "With the CCOR-1, we are basically going to get images to the forecaster within 30 minutes."[4]

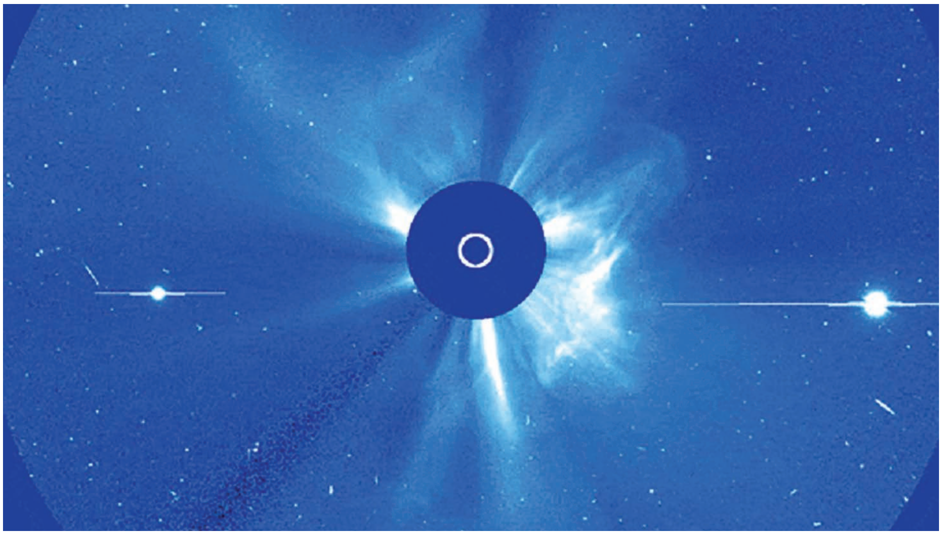
A rendering of the GOES-U satellite, launched in June 2024, which carries the Compact Coronagraph (CCOR) instrument to better monitor solar activity.
Credit: National Oceanic and Atmospheric Administration

A second coronagraph will launch on the Space Weather Follow on Lagrange 1 (SWFO-L1) mission, scheduled for the second half of 2025. This mission will record "upstream measurements" of solar activity before it reaches the Earth, providing the earliest possible notice of impending geomagnetic activity. CCOR-2 on this mission uses a larger field of view to provide more images of CMEs.[5]

Another planned mission, Vigil, led by the European Space Agency (ESA), will provide a complementary view of the Sun for near real-time data on potentially dangerous solar activity. Vigil is planned to orbit at Lagrange point five, much farther from the Earth than SWFO-L1, for a different point of view than other solar observation missions. In addition to a coronagraph, Vigil will also use a Heliospheric Imager to take side-angle images of the region of space between the Earth and Sun for better tracking of solar ejections. The ESA Vigil mission is expected to launch in 2031.[6]

Additionally, a new study[7] has found that solar storms have a greater impact on the Earth's ionosphere than previously thought. The researchers studied how solar flares can emit additional X-rays and ultraviolet radiation during a second smaller peak following a main flash. These smaller peaks can cause further failures in communication and navigation systems due to increased charged particles.

"These storms can cause the most problems for satellites, simply because on Earth we have additional atmospheric layers to protect us," said lead researcher Susanna Bekker, a research fellow at the Astrophysics Research Centre at Queen's University Belfast.[8] "But on orbit, satellites and people on the International Space Station can receive increased amounts of radiation."



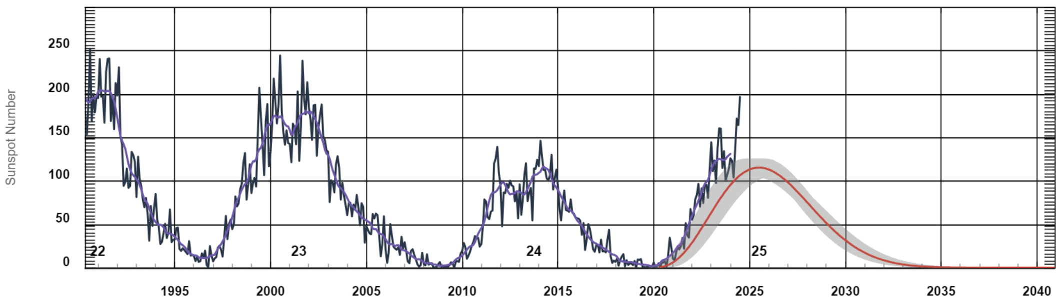
A coronagraph taken during the May solar storm showing coronal mass ejections.
Credit: NASA / ESA SOHO

Let there be light

The sunspot area at the core of the May storm, AR3664, was 15 times wider than the Earth.[9] These sunspots foretell two main types of solar storms: solar flares and CMEs. Solar flares are eruptions of radiation that travel at the speed of light, hitting Earth about eight minutes after ejecting from the Sun. Flares can interfere with satellite radio signals, and because of their speed, are only detected upon striking the Earth. CMEs are slower-moving clouds of charged particles that hit Earth one to two days after leaving the Sun. CMEs are more severe than flares and can cause massive damage to power grids and satellites.[10]

"For many operators managing satellites during the storm, such a sudden drop in orbital altitude is untenable," the study states. "Unplanned orbital decay can disrupt constellations by causing uneven satellite altitudes, which results in undesirable orbit phasing in the short term and relative plane drift over the long term."

The May storm disrupted but did not destroy any satellites. That's not always the case. A smaller solar storm in February caused 40 of SpaceX's satellites — out of a new batch of 49 — to fall out of orbit and burn up in the atmosphere. This was mostly due to the newly launched satellites not yet being in a stable orbit. SpaceX later announced that the satellite's onboard GPS indicated that the storm increased atmospheric drag up to 50% higher than normal, causing the satellites to slow and sink to Earth. [13]



The number of sunspots detected across multiple solar cycles. The black and blue lines indicate the monthly number of sunspots identified. The red line indicates the predicted number of sunspots. The current solar cycle is more active than predicted.
Credit: NOAA Space Weather Prediction Center

"The worst-case scenario for these storms is that it would be so impactful that the power grid could not mitigate properly the issues, and then we'd have some kind of major fault transmission, meaning a power blackout that could affect hundreds of thousands, or even millions of people," Dahl said. "This is why our government cares so much."

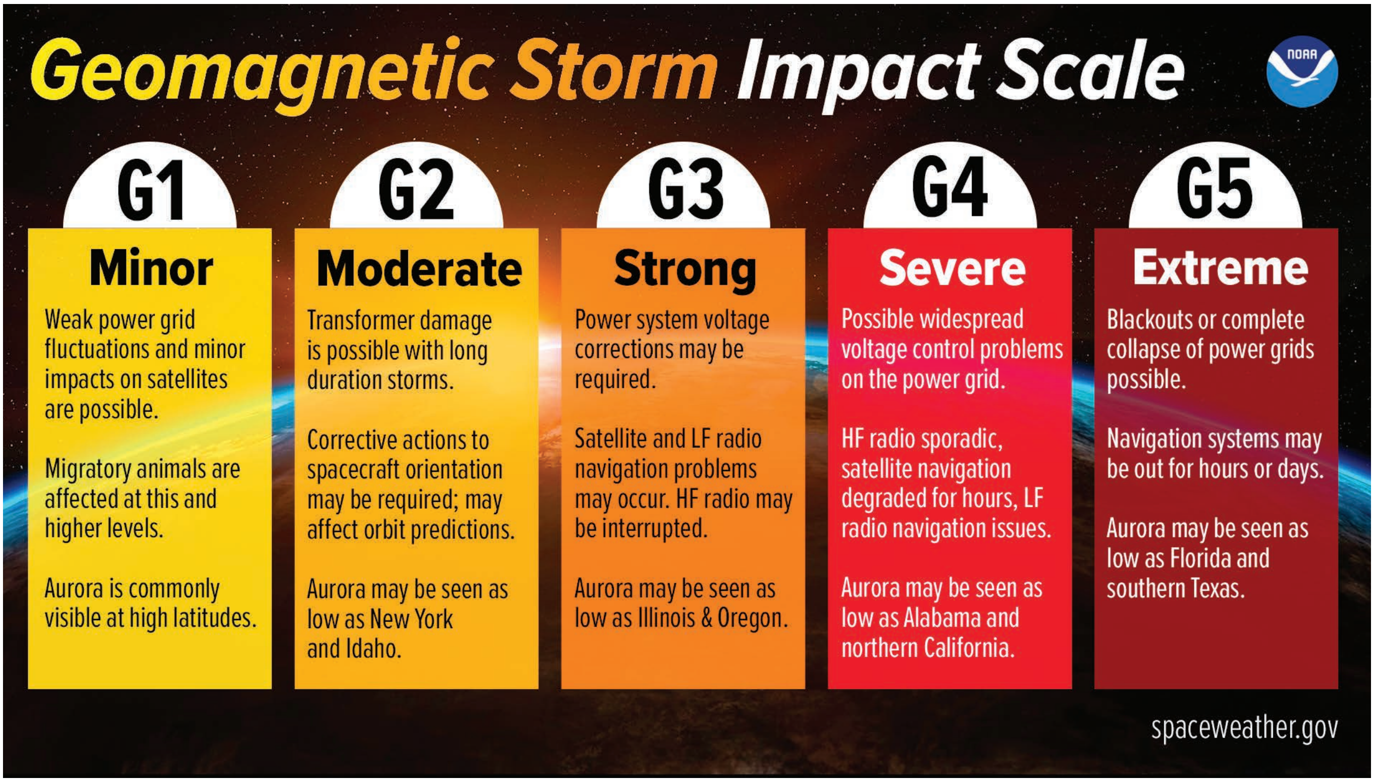
"People might wonder why there weren't any major impacts from the May storm, but there were," Dahl said. "GPS [disruption] was a major issue for farmers in the Midwest. We couldn't mitigate that. But those industries that can mitigate, like satellites trying to maintain their orbital levels, they were having a hard time maintaining their capabilities."

In addition to GPS problems, the storm caused the U.S. Federal Aviation Administration to issue a warning rerouting commercial trans-polar flights between Europe, Asia, and North America to avoid increased radiation.[11]

The blast of solar power also affected energy density in Earth's upper atmosphere, causing drag and orbital decay on thousands of satellites in low Earth orbit (LEO). The storm increased some satellites' rate of orbital decay by more than four times, according to a study by the Massachusetts Institute of Technology.[12]

Preparing for the peak

Solar flares during the May storm hit Earth in a matter of minutes, but scientists had roughly a day to warn and prepare before the geomagnetic storm struck. Power grid technicians can prepare much in the same way a single home resists a power surge. Large collections of capacitors absorb and throttle the waves of energy. Dampeners are also used to reduce excess energy stressing the power grid. America's power grid will be further strengthened by a federal initiative announced in May. The Federal-State Modern Grid Deployment Initiative will bolster the power system in 21 states by



adding high-performance conductors, new power flow controllers, and real-time sensors.[14]

But according to the Electric Infrastructure Security Council, the only certain way to prevent damage during a powerful enough CME would be to shut off areas of the grid that are at risk. [15]

On orbit, similar processes protect satellites. Operators can switch satellites into safe mode, designed to protect the spacecraft and its onboard instruments by stopping data collection and monitoring the health of the satellite. During the May storm, NASA's ICESat-2, which monitors the health of polar ice sheets, entered into safe mode.[16]

"When we have these highly energetic particles coming to Earth, they can end up hitting a computer chip aboard a spacecraft and cause a bit to flip, which can then cause either the computer software or the hardware to have an anomaly," said Russell DeHart, mission operation assurance lead engineer at NASA Goddard. [17]

Further research on how solar storms impact the upper atmosphere can be critical to health of spacecraft and the astronauts onboard. But there are few direct measurements from this part of the atmosphere. Two NASA missions aim to fix that. The Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) mission is designed to make measurements within Earth's upper atmosphere with multiple spacecraft to better understand how Earth's atmosphere and space weather affect each other.[18] The Geospace Dynamics Constellation (GDC) is designed as a group of six satellites that will take the first comprehensive measurements of the neutral and ion variability in the upper atmosphere.[19] Due to NASA's current budget uncertainties, neither of these missions has a definite launch date.

"Space companies and launches rely on our long-range predictions that go out years in advance trying to predict how strong a solar cycle might be," Dahl said. "When they're working on satellites and orbital locations, they need to know that as accurately as possible, because the lifetime of their satellites becomes at risk." ■

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