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PRESS RELEASE (2025/08/22)

As the atmosphere changes, so will its response to geomagnetic storms

Satellite operators can expect more dramatic changes in satellite drag during space weather events

Rising concentrations of carbon dioxide in the upper atmosphere will change the way geomagnetic storms impact Earth, with potential implications for thousands of orbiting satellites, according to new research led by scientists at the US National Science Foundation National Center for Atmospheric Research (NSF NCAR) in collaboration with Kyushu University.

Geomagnetic storms, caused by massive eruptions of charged particles from the surface of the Sun that buffet Earth's atmosphere, are a growing challenge for our technologically dependent society. The storms temporarily increase the density of the upper atmosphere and therefore the drag on satellites, which impacts their speed, altitude, and how long they remain operational. The new study used an advanced computer model to determine that the upper atmosphere's density will be lower during a future geomagnetic storm compared with a present-day storm of the same intensity. That's because the baseline density will be lower, and future storms won't increase it to levels as high as what occurs with storms currently.

"What does this mean for satellite operators? It means they will need to maneuver their satellites more frequently to cope with faster changes in atmospheric drag—even under the same level of geomagnetic storms. This, in turn, would expose satellites to more collisions. Simply put, space weather impacts may become more severe in the future," explains Professor Huixin Liu of Kyushu University's Faculty of Science one of the collaborators of the study.

However, the relative magnitude of the density increase—the rise from baseline to peak during a multiday storm—will be greater with future storms.

"The way that energy from the Sun affects the atmosphere will change in the future because the background density of the atmosphere is different and that creates a different response," said NSF NCAR scientist Nicholas Pedatella, the lead author. "For the satellite industry, this is an especially important question because of the need to design satellites for specific atmospheric conditions."

The study was published in *Geophysical Research Letters* and is a follow up from a 2021 study which revealed that increasing CO_2 level can lead to larger space weather impacts.

The full release can be found here:
https://news.ucar.edu/133035/atmosphere-changes-so-will-its-response-geomagnetic-storms

Colder and thinner air

Earth's upper atmosphere has become increasingly important in recent decades because of society's dependence on advanced navigation systems, online data transmission, national security applications, and other technologies that rely on satellite operations.

Unlike the lower atmosphere, which warms with emissions of carbon dioxide, the upper atmosphere becomes colder. This has to do with the varying impacts of carbon dioxide: instead of absorbing and reemitting heat to nearby molecules in the relatively dense air near Earth's surface, carbon dioxide reemits the heat out into space at high altitudes where the air is much thinner.

Previous studies have estimated the extent to which increasing levels of carbon dioxide and other greenhouse gases will lead to a decrease in the upper atmosphere's neutral density, or its concentration of non-ionized particles such as oxygen and nitrogen. But Pedatella and his colleagues posed a somewhat different question: how will future atmospheric density change during powerful geomagnetic storms?

The researchers homed in on the geomagnetic superstorm of May 10-11, 2024, when a series of powerful solar disturbances known as coronal mass ejections buffeted Earth's atmosphere. They analyzed how the atmosphere would have responded to the same storm in 2016 and in three future years that will each occur around the minimum of the 11-year solar cycle (2040, 2061, and 2084).

To perform the analysis, they turned to an NSF NCAR-based modeling system, the Community Earth System Model Whole Atmosphere Community Climate Model with thermosphere-ionosphere eXtension, that simulates the entire atmosphere from Earth's surface to the upper thermosphere, 500-700 kilometers (about 310-435 miles) above the surface. This enables scientists to determine how changes in the lower atmosphere, such as higher concentrations of greenhouse gases, can affect remote regions of the atmosphere far aloft.

They ran the simulations on the Derecho supercomputer at the NSF NCAR-Wyoming Supercomputing Center.

The researchers found that, later this century, various regions of the upper atmosphere will be 20-50% less dense at the peak of a storm comparable to the one that occurred last year, assuming significantly higher carbon dioxide levels. However, compared with the atmosphere's density just before and after the storm, the relative change in density will be greater. Whereas such a storm now more than doubles the density at its peak, it may nearly triple it in the future. This is because the same storm will have a proportionately larger impact on a less dense atmosphere.

Pedatella said more research is needed to better understand how space weather will change, including studying different types of geomagnetic storms and whether their impacts will vary at various times in the 11-year solar cycle, when the atmosphere's density changes.

"We now have the capability with our models to explore the very complex interconnections between the lower and upper atmosphere," he said. "It's critical to know how these changes will occur because they have profound ramifications for our atmosphere."

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For more information about this research, see "Impact of Increasing Greenhouse Gases on the Ionosphere and Thermosphere Response to a May 2024-Like Geomagnetic Superstorm" Nicholas M. Pedatella, Huixin Liu, Han-Li Liu, Adam Herrington, Joseph McInerney, *Geophysical Research Letters*, https://doi.org/10.1029/2025GL116445

About Kyushu University
Founded in 1911, Kyushu University is one of Japan's leading research-oriented institutes of higher education, consistently ranking as one of the top ten Japanese universities in the Times Higher Education World University Rankings and the QS World Rankings. The university is one of the seven national universities in Japan, located in Fukuoka, on the island of Kyushu—the most southwestern of Japan's four main islands with a population and land size slightly larger than Belgium. Kyushu U's multiple campuses—home to around 19,000 students and 8000 faculty and staff—are located around Fukuoka City, a coastal metropolis that is frequently ranked among the world's most livable cities and historically known as Japan's gateway to Asia. Through its VISION 2030, Kyushu U will "drive social change with integrative knowledge." By fusing the spectrum of knowledge, from the humanities and arts to engineering and medical sciences, Kyushu U will strengthen its research in the key areas of decarbonization, medicine and health, and environment and food, to tackle society's most pressing issues.

Fig. 1. An artist's conception of the Landsat Data Continuity Mission (LDCM), the eighth satellite in the long-running Landsat program, flying over the US Gulf Coast. (NASA/Goddard Space Flight Center Conceptual Image Lab)

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