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Data Mining Reveals the Dynamics of Auroral Substorms

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Aurorae shimmer over Lofoten, Norway, during a substorm, a disturbance in Earth's magnetic field that can cause aurorae to wash over the globe. Credit: Johannes Groll on Unsplash

Space physicists have long known that coronal mass ejections hurl into space vast amounts of charged particles, which can cause magnetic storms on Earth. These days-long periods of enhanced activity in the planet's magnetic field can create spectacular aurorae and take down power grids on continental scales.

But the dynamics of how the Sun interacts with Earth's magnetic field during such storms remains mysterious, especially the brief periods of peak intensity, which last just a few hours.

In the mid-1900s, scientists realized that there are distinct phases to these events, now called auroral substorms. First, the solar wind buffets and stretches out Earth's magnetic field, which stores energy like a rubber band. Next, the field's tail rebounds, jetting charged particles back toward the planet's nightside and causing a surge of aurora that sweeps west across the planet. Finally, the magnetic field recovers to a quieter state.

This picture emerged in the 1970s, but it's hard to piece together a comprehensive picture of Earth's magnetic field during any given substorm because of the limited number of satellites making observations.

Stephens et al. have taken a new approach: creating a unified data set spanning 5 decades by mining and merging the archives of 15 satellites from NASA, the National Oceanic and Atmospheric Administration, the European Space Agency, and the Japan Aerospace Exploration Agency. The resulting models behave as if 11,000–50,000 virtual satellites were observing a single representative substorm, making the simulation the most comprehensive view yet of substorms and their distinct phases.

As every substorm is unique and unfolds at its own pace, the researchers needed to synchronize all of them. To do this, they turned to magnetic field readings from ground monitoring stations and satellite observations of the solar wind. These observations track the phases of the storm in the form of calculated indices, which act as a sort of time code that allows the spacecraft data to be matched to the correct phase of the substorm.

This unified data set is powerful and flexible. It can be used to construct a model of a representative, "average" substorm. But it can also be used to reconstruct any individual substorm in greater detail by starting with data for that event and filling in the rest of Earth's magnetic field with closely matched data from the general data set.

This process allowed the team to track the system of currents that pulse around the planet as a substorm grows, expands, and recovers, including the wedge of current in the magnetic field's nightside tail, the ring current above the planet's equator (which is enhanced during a substorm), and the jets of particles that arc toward the poles to generate the aurora.

This global picture could help scientists better understand substorms on Earth, including their risk to infrastructure. It could also help scientists understand similar processes that have been observed in the magnetic fields of other planets and stars. (*Journal of Geophysical Research: Space Physics,* https://doi.org/10.1029/2018JA025843, 2019) **—Mark Zastrow, Freelance Writer**