

## Awash in solar winds, Earth experiences a variety of ill effects

by Scott\_LaFee

Appearances aside, outer space is not an empty vacuum but a blustery void roiled by superheated gases and unseen particles produced and propelled by the sun's sometimes manic energy.

**DARK AND STORMY SPACE** - Solar winds of ionized gases can damage satellites, affect electrical power grids and skew navigational data. Other effects can be harming unprotected astronauts and plane passengers on polar routes. CNS Graphic by Aaron Steckelberg. Speeding outward at millions of miles per hour, these solar winds blow unimpeded across space until they run smack into something like, well, the Earth.

When that occurs, amazing things happen. At the poles, where the Earth's protective magnetic field is thinnest, piercing solar winds create undulating atmospheric light shows called auroras.

But other effects aren't so lovely. Unexpected bursts of solar energy can knock out satellites and electrical power grids, accelerate corrosion in oil pipelines, skew measurements in the Global Positioning System, and expose unprotected astronauts and high-flying airline passengers to deadly radiation.

Fifty years ago, before Sputnik launched the Space Age, the perturbations and perils of space weather were mostly the province of astronomers and space scientists, who knew something was happening out there, if not exactly what.

They have learned a lot since, but now, with humans permanently employed in space, with more and more of Earthbound life dependent on space-based technologies, scientists need to know not just how space weather works, but also which way the solar winds will blow.

"We're where meteorology was back in the 1950s," said Tom Bogdan, director of the Space Weather

Prediction Center in Boulder, Colo., part of the National Oceanic and Atmospheric Administration. "We've created some tremendous numerical models of space weather. Now we're bringing them forward, seeing how they work, fine-tuning them as we make more observations."

The goal, he added, "is to be able to accurately predict any space weather events before they pose a danger to technologies or people. It's not unlike what hurricane watchers do now."

## SOLAR EXPLOSIONS

As with much else about the solar system, any understanding of space weather begins with the sun, a 4.5-million-year-old, middle-aged star whose internal thermonuclear furnace burns at 27 million degrees Fahrenheit, churning gases or plasma in its outer third in much the same way that a stove flame heats water to an agitated boil.

All that plasma in motion (the sun's volume equals 1.3 million Earths) generates a global magnetic field and smaller fields within the larger one. As these smaller fields rise to the surface of the sun, they form visible sunspots containing enormous amounts of concentrated energy, like mines bobbing in a molten sea. A medium-sized sunspot is about as large as the Earth.

Sometimes the sunspots release this energy gradually; at other times, they expel it explosively in flares and events called coronal mass ejections (CME).

Flares are intense outbursts of electromagnetic radiation and energetic particles created by the tearing and re-connecting of magnetic fields. They are the largest explosive events in the solar system, spewing out protons, electrons and ions at near light speed.

## CORONA

The corona is the sun's outer atmosphere, made up of different magnetic fields. When the fields are closed over sunspots, pressure within the confined solar atmosphere can rapidly increase, building up until bubbles of coronal plasma are suddenly belched out into space. These are coronal mass ejections. They are slower than flares, moving at just 1 million or 2 million miles per hour, but they may contain upward of 10 billion tons of matter.

Solar flares and coronal mass ejections can occur at any time, but their frequency seems to rise and fall on an 11-year cycle. There's a consensus among scientists that the current cycle - the 23rd on record - will end sometime early next year, marking a low point in solar activity.

"From then on," said Bogdan, "solar activity should increase, with more and more sunspots emerging, reaching maximum numbers around 2012."

Solar flares and mass ejections can explode out from the sun in any direction. It's the ones aimed toward Earth that attract researchers' interest and concern.

"Solar flares are like tornadoes. They move fast, their photons reaching us in just eight minutes or so," said Bogdan. "By the time we see them, they're already ionizing the atmosphere."

"CMEs are more like the hurricanes of space weather: big, lumbering storms. They take longer to get here, from several hours to a couple of days."

Both pose real threats.

In 1959, for example, telegraph operators in the United States reported that following a major solar flare, intense atmospheric currents flowed through their systems, causing telegraph keys to stick and melt.

In 1989, a coronal mass ejection triggered a power failure in Quebec three days later, resulting in a general blackout that lasted nine hours and affected 6 million people.

So far, no astronauts have been harmed by solar activity. "The International Space Station and the shuttle remain mostly hidden within the magnetosphere," said Bernard Jackson, a space scientist at University of California San Diego.

During the Apollo program, manned missions to the moon were scheduled to avoid periods of increased solar activity.

Unmanned spacecraft haven't been so lucky. In 1997, a coronal mass ejection was blamed for destroying a \$200 million communications satellite. In 2002, energized particles from a solar flare struck a Japanese probe en route to Mars, causing so much electronics damage that the probe was eventually abandoned.

Not all space-weather-related threats are so immediate and obvious. Shock waves caused by flares and mass ejections can temporarily compress parts of the Earth's magnetic field, making the upper atmosphere more dense and causing satellite orbits to decay and shorten from increased friction.

Geomagnetic storms caused by space weather can scramble radio frequencies. In one reported case, police officers in San Francisco calling their dispatchers suddenly got operators in Minneapolis.

More seriously, magnetic field disruptions corrupt signals between Global Positioning System satellites and receivers, creating measurement inaccuracies. According to NOAA scientists, a solar flare last December caused large numbers of receivers to stop tracking the GPS signal altogether.

"A small measurement mistake probably isn't crucial to somebody with GPS in their car," said Bogdan. "They will still know generally where they are. They're not going to drive into a ditch."

But such disruptions "can be crucial for industries and activities that require precise positioning, something within a few meters or less," he added. That includes "everybody from farmers to offshore oil drillers to soldiers on the battlefield."

## MAGNETIC ANOMALIES

The cost of these disruptions can be huge. Using polar routes for flights from North America to Asia significantly reduces hours and costs compared with other routes, but they are subject to the whims of space weather, which not only disrupt airborne communications but also expose passengers and crew to dangerously high levels of solar radiation.

To minimize the problems and threats, airlines do not send planes above 82 degrees latitude and prudently reroute flights when solar activity seems imminent.

Industries like offshore oil drilling require extremely precise GPS data to make sure they're hitting the right spot on the ocean floor and to avoid moving rigs unnecessarily, which generally costs about \$200,000 per day.

That's where Bogdan and colleagues at the Space Weather Prediction Center come in. It's their job to watch out for and predict solar storms so that others can take precautionary action, from temporarily shutting down vulnerable satellites and systems to warning future astronauts on the moon or en route to Mars to retreat into protective shelters.

Twenty-four hours a day at a "war room" in Boulder, NOAA and U.S. Air Force personnel monitor activity on the sun and the space between it and the Earth, using data collected from ground-based observatories and satellites like the nine-year-old Advanced Composition Explorer (ACE) satellite, which hovers like a sentinel at the gravitational midpoint between the sun and the Earth.

"ACE is our most important source of data because it monitors solar material flowing past it, giving us 30 minutes to four hours of lead time if a storm is detected," Bogdan said. "That can be a huge amount of time to prepare."

The system, of course, isn't perfect. In late-October 2003, for example, a massive sun-powered event - nicknamed the "Halloween storms" by space scientists - unexpectedly struck the Earth. Spawned by the largest solar X-ray flare on record, it hit the Earth's magnetosphere at 6 million miles per hour. Twenty-eight satellites were damaged, two fatally. Plane routes and schedules were temporarily thrown into chaos. There were major power outages in Sweden.

Bogdan said experiences like the Halloween storms are helping scientists improve their forecasting abilities. Every event and solar cycle adds to the knowledge base.

"Basically, space weather forecasting is like predicting weather on Earth," he said. "We now understand the basic physics and equations that govern space weather dynamics, but here, too, the 'butterfly effect' applies. Little things can have big, nonlinear ramifications.

"What makes things even harder is that space is far, far bigger than Earth weather. Events happen on a scale many more orders of magnitude."

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