BY WAYNE ROSENKRANS

Everyone's Business

Polar route operators routinely adapt to space weather, but scientists envision global communication interference and electrical blackouts.

A widely spreading coronal mass ejection (toward top of page) and multiple solar flares were digitally combined by the SOHO project from 2002 satellite images of the sun.

European Space Agency and U.S. National Aeronautics and Space Administration — Solar and Heliospheric Observatory (SOHO)

Maximum activity in the sun's current 11-year cycle[1] likely will occur in May 2013. By then, aircraft operators conducting flights on polar routes might not be the only aviation industry segment affected by scenarios that only recently seemed like science fiction (*ASW*, 6/07, p. 22). Space weather scientists and natural disaster specialists lately point to these flights to convince the rest of society that other solar concerns on the horizon are just as real as the threat of disrupted high-frequency (HF) radio communication.

During the third week of February 2011, airlines rerouted polar flights away from the poles to avoid the possibility of unusable HF radios, said Jane Lubchenco, undersecretary of commerce for oceans and atmosphere and administrator of the U.S. National Oceanic and Atmospheric Administration (NOAA). "That, in turn, resulted in individuals being bumped from flights and increased fuel costs because of the longer trajectories," she said. "Communication problems [also had been reported by flight crews in 2010] on flights from Hawaii to Southern California, and [a solar] flare also disrupted communications in parts of the Western Pacific Region, as well as in Asia. So this [so-called Valentine's Day 2011 geomagnetic] storm simply reinforced the fact that space weather is a serious concern and that we must continue to support the space weather observations and modeling tools to predict what might be coming our way."

The airlines flying from the United States to Asia in February had been forced to detour to the south over Alaska, added Thomas Bogdan, director of the NOAA Space Weather Prediction Center. "This unusual [rerouting] was in response to space weather," he said.

Lubchenco and Bogdan spoke during the Annual Meeting of the American Association for the Advancement of Science in Washington at a public symposium[2] titled "Space Weather: The Next Big Solar Storm Could Be a Global Katrina."

When the peak number of solar flares occurred in April 2000, tagged as the solar maximum of the last solar cycle, human reliance on technologies such as ultra-long-range airline travel and wireless smartphones was relatively new. "Many fewer aircraft were flying polar flights [then] just because of the long distances involved," Lubchenco said. "Space weather is certainly becoming more front-and-center as the threats to our critical infrastructure are realized. As we approach the solar maximum, it seems pretty clear that we are going to be looking at the possibility of not only more solar events, but … some very strong events. … So I suggest that space weather should be everyone's business."

Out of This World

Space weather "refers to the conditions on the sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and the reliability of space-borne and ground-based technological systems and endanger human life or health," said Juha-Pekka Luntama, program coordinator for space situational awareness, European Space Agency. Bogdan offered a briefer definition: "Energetic particles and radiation masses of magnetized plasma that come from the sun and impact us here on Earth."

Periodically, at some locations on the sun, its magnetic field "gets entangled and keeps twisting and twisting, further and further, until something breaks … and then we have [an extremely high] release of energy," Luntama said. Each of the resultant solar flares appears as a flash of light in videos and pictures taken by cameras aboard solar-imaging satellites <www.swpc.noaa.gov>. At these moments, the sun often releases ultraviolet (UV) radiation, extreme UV radiation and X-rays toward Earth, and they interact with Earth's ionosphere, causing various effects.

"Sometimes, solar flares are associated with a release of the matter of the sun itself into space — as a vast cloud of plasma [called a coronal mass ejection (CME)]," Luntama said. "When this plasma interacts with the magnetic field protecting Earth … very complex physical events [such as the aurora typically seen in polar regions] take place … and also rare events that can be very harmful. … When a CME takes place [and] if the conditions are just right, this plasma can enter inside the magnetosphere of Earth. The CME creates … geomagnetically induced currents [GICs in electric] power grids that can cause damage to transformers and cause blackouts."

The Valentine's Day geomagnetic storm unfolded in a typical way. One bright spot on the sun began Feb. 12 to produce M-class solar flares, those in the middle of the strength scale. "[Space weather prediction centers] sent messages that [this class of] solar flare had taken place … nothing extraordinary … nothing to seriously worry about — just be aware," Luntama said. On Feb. 13, worldwide subscribers to space weather alerts — widely available to the public, including as free and paid smartphone applications — learned that the solar flare involved a CME and were encouraged to monitor all further messages about this solar activity.

If any CME is visible from Earth, it very likely will strike the Earth's magnetosphere, he said. On Feb. 14, an X-class solar flare — a classification for very strong types — occurred, something scientists had not observed since December 2006. By Feb. 17, possible outcomes on Earth "began to get a bit more interesting," he recalled.

"X-ray peaks in observations from [U.S. Geostationary Operational Environmental Satellites were] the message that really woke us up," Luntama said. "They meant that a very powerful solar flare actually had ejected coronal mass towards us. We could not tell at this point what was going to happen because … we did not know [the determining factor —] the orientation of the magnetic field of the sun in [relation] to the magnetic field of Earth. … If the magnetic fields are parallel, then we are well protected, our 'shields are up' [— that is,] the particles would have a very hard time penetrating inside the magnetic field of Earth. If magnetic fields are pointing in the opposite direction … then we have a potential danger. … It turned out that we were quite well protected this time. … Effects were very minor."

Radiation from solar flares moves from the sun to Earth at the speed of light — a distance of 93 million miles [150 million km] — in about eight minutes and also signals the departure of coronal plasma if a CME is involved, NOAA's Bogdan said. Plasma from

CMEs, however, takes longer to reach Earth — typically several days. In the fastest known time, for an 1859 geomagnetic storm called the Carrington Event, plasma arrived at Earth in 17 to 18 hours. By comparison, the Valentine's Day event plasma reached Earth about three days after the associated solar flares were detected.

Swedish Lessons

Helena Lindberg, director general of the Swedish Civil Contingencies Agency (MSP), said that potential hardships of coping with a worst-case geomagnetic storm should be easy to imagine for anyone on Earth. "The harsh winter [of 2010–2011 that the United States and Europe] experienced has been a forceful reminder of how difficult it would be to have a massive electrical failure in prolonged cold weather," Lindberg said. "In the whole range of serious second-order and third-order consequences [after the first few hours] — with basic infrastructure being wiped out for an extended period of time — [we would not be] talking about days or weeks but several months without electric power, blackouts across large regions of Europe and the United States, the flows of essential goods and information disrupted. … Many of my European Union colleagues … still need to be convinced that space weather is just as important as normal weather."

The latitude of a country and its history can be highly influential in focusing public attention and encouraging government and private sector preparations for space weather mitigation, she added. "In 2003, during [a geomagnetic storm called the] Halloween Event, Sweden suffered from rather serious problems with power outages affecting a large area of the southern part of Sweden," Lindberg recalled. "Thanks to timely alerts and warnings from the Swedish Space Weather Prediction Center [and to the planned resilience of our power grid], the damage could be controlled. … To cope with the vulnerability of long transmission flows [for many north-south power lines], we had created a national grid protected by a high number of capacitors."

The latest Swedish goal for the power grid is design, configuration and manufacture of new transformers that will withstand GICs. Another of the country's highest space weather–related priorities, based on risk and vulnerability analyses so far, is fully understanding the interdependencies among its infrastructure components, she said.

The aviation industry, like the public at large, needs to understand the difference between brief disruptions of an operational service, perhaps lasting one or two days, that are already familiar to them and a worst-case geomagnetic storm that could damage physical infrastructure of telecommunications networks and power grids, some speakers said.

"If transformers burn and blow because of GICs, or if satellites are damaged because they are not shielded well enough, [these are things we] can't easily replace," said Stephan Lechner, director of the European Commission's Joint Research Centre Institute for the Protection and Security of the Citizen (JRC). "If many transformers in the Northern Hemisphere blew simultaneously, there would not be enough spare [backup transformer] capacity just to deliver spares everywhere — [replacement] could take literally years. That worst-case scenario would involve prolonged power outages while waiting for transformer replacement."

Lindberg added that studies have estimated that some countries could take four years to fully restore power grids, and five years to replace satellites for which spares do not exist. "So consider being without power for four years; in certain areas, that might constitute a severe problem," she said. "That is the worst-case scenario."

Restoring Network Operations

Worst-case space weather like the Carrington Event could cause significant damage and disruption if network and power grid weaknesses have not been mitigated, said Lechner. "The basic idea of shielding … would not work very nicely with large infrastructures … in our modern world," he said. Rather, by focusing on control centers that protect intelligent networks and power grids, "we [could plan] for a reconfiguration of the infrastructures," he said. "If we have to react to space weather in a hurry … we might even consider [preemptively] a partial infrastructure reconfiguration or shutdown."

A geomagnetic storm–induced disruption of global positioning system (GPS) timing signal receivers in telecommunication networks can be mitigated by a backup system such as local atomic clocks. However, network operators would not get email warnings if the synchronized time already had been lost. "If there is a bad space weather event — we have an outage for say, half a day, one day, two days — [operators would expect to exchange] quite a lot of emails," he said, noting that a network resynchronization typically requires at least 24 hours.

Another difficulty is reaching consensus about how nations should respond, implement common practices, establish requirements and assign responsibilities to the private sector. "In Europe alone, with more than 200 telecommunication network operators,

'Valentine's Day' Geomagnetic Storm of 2011

Wednesday, Feb. 9 — Four, that's right, four new active regions popped up on the sun yesterday. … Region 11153 … remains poised with the potential to produce some large solar flares.

Friday, Feb. 11 — Old Region 11149 is just beginning to reappear, having transited the far side of the sun. During that transit, multiple coronal mass ejections [CMEs] were observed that were directed away from Earth.

Monday, Feb. 14, Valentine's Day — The largest X-ray flare in over one year occurred yesterday at 1737 [Coordinated Universal Time (UTC)]. Region 1158 produced the impulsive R2 [class] (moderate) X-ray burst, part of the full eruption that also included a faint, Earth-directed CME plus radio bursts across the spectrum.

Tuesday, Feb. 15 — The hits just keep on coming! Region 1158 produced the largest X-ray flare in more than four years, an X2.2 [class], earlier today at 0156 UTC, reaching the R3 (strong) [U.S. National Oceanic and Atmospheric Administration (NOAA) Space Weather Scales] level.

Wednesday, Feb. 16 — The calm before the storm. Three CMEs are en route, all a part of the [high frequency] radio blackout events on Feb. 13, 14 and 15 (UTC).

Thursday, Feb. 17 — The first interplanetary shock, driven by the CME from Sunday, is expected [at Earth] any time. Soon thereafter, the shock from Monday evening's R3/CME is due. Look for G1–G2 [class geomagnetic storms] (and maybe periods of G3 [geomagnetic storms] if the following shock compresses and enhances the CME magnetic field).

Friday, Feb. 18 — A G1 [class] (minor) geomagnetic storm continues. … A long-awaited interplanetary shock, perhaps one of an ensemble of shocks, passed the ACE spacecraft [Advanced Composition Explorer satellite monitoring the solar wind at] about 0045 UTC.

Saturday, Feb. 19 — The geomagnetic storm has ended. The observations of the CMEs and the models of this solar eruption were unprecedented.

This narrative was excerpted from day-by-day Web site reports by the NOAA Space Weather Prediction Center in Boulder, Colorado, U.S. <www.swpc.noaa.gov>.

the standards only tell them what accuracy of timing [is required] but not how to do it," Lechner said. "So they could [synchronize] timing only based on GPS or without GPS. Nothing is standardized."

These network operators in Europe received a January 2011 JRC survey of existing equipment and space weather contingency planning. As of the symposium, a small number had responded to the survey, and some of their engineers said they were entirely dependent on GPS time references. They estimated that disruptions to accurate time signal sources caused by geomagnetic storm–induced effects would require two to four weeks to fully resume normal operations, he said.

Today's Readiness

Sir John Beddington, chief scientist and adviser to the prime minister of the United Kingdom, voiced concern about any scientific, engineering or governmental work on space weather mitigation that assumes specific levels of infrastructure vulnerability with "absolutely no empirical testing."

"Space weather is so serious that we don't want to learn by our experience of it," he said. "It is slightly scary and properly so — we have got to be slightly scared by these events; otherwise, we will not take them seriously, and then they will surprise us."

National industry sectors such as commercial air transport require the most accurate predictions possible of space weather timing and effects, and consensus about which worst-case scenario should be the basis of affordable emergency planning. "Our civil contingency group is characterizing what we would term a 'reasonable worst-case,'" Beddington said. "Everybody knows about the Carrington Event, [but] was that the reasonable worst-case that we need to [use in] our contingency planning?" Carrington involved "a conjunction of relatively low-probability factors and was far off the scale … so we haven't decided," he said.

When the next solar maximum occurs around 2025, societies on Earth likely will be even more "electronically vulnerable" than in 2011 unless they have prepared adequately, the JRC's Lechner said, adding, "We have lead time for that."

Notes

1. Solar cycles have a variable length. The shortest recorded in recent centuries have lasted about nine years and the longest have lasted 14 years.

2. The February 2011 symposium was organized by NOAA and the JRC. Presenters and panelists represented the European Space Agency, JRC, NOAA, MSP and the U.K. Government Office of Science.