Forecasting a STAR

BY WAYNE ROSENKRANS

Scientists urge aviation professionals to obtain space weather training before intense solar radiation and geomagnetic storms expected around 2012.

Aviation concern for space weather is not new. Dispatchers and flight crews at airlines carrying the growing volume of passenger and cargo traffic on four north transpolar routes between North America and Asia routinely conduct comprehensive checks on solar activity. But some specialists now recommend that a far wider range of aviation professionals receive training on space weather regardless of where on Earth they work. Their specific proposal says, "The U.S. Federal Aviation Administration (FAA) should define a minimum set of requirements for incorporating space weather into operational training for aircrew (pilots and cabin crew), dispatchers, air traffic controllers, meteorologists and engineers."

The report advocating this training — issued in March 2007 by the American Meteorological Society (AMS) Policy Program and SolarMetrics, a U.K. consultancy, with funding from the National Science Foundation and U.S. National Space Weather Program — cites the following internationally accepted definition of space weather by the U.S. Office of the Federal Coordinator for Meteorological Services and Supporting Research: "Space weather refers to the conditions on the sun and in the solar wind,[1] magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health." The report summarizes interviews with 50 subject specialists and products of a two-day workshop in November 2006, involving 60 space weather, government/military and civil aviation specialists.[2]

According to a June 2006 assessment of the National Space Weather Program, "When the [program] began in 1995, space weather needs of civil aviation were rarely noted, although such needs were widely recognized for U.S. Department of Defense missions, especially high-altitude

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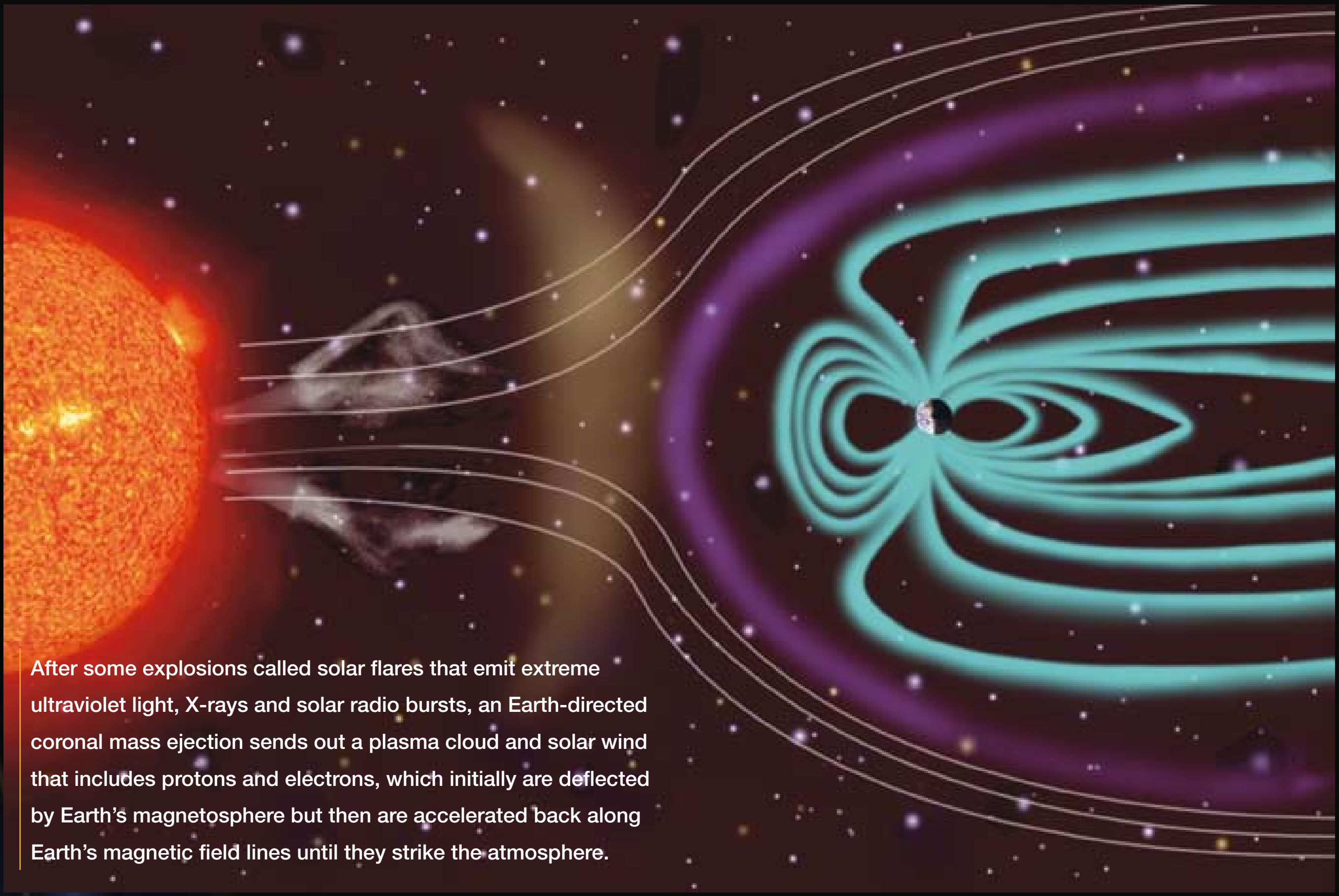
U.S. National Aeronautics and Space Administration



After some explosions called solar flares that emit extreme ultraviolet light, X-rays and solar radio bursts, an Earth-directed coronal mass ejection sends out a plasma cloud and solar wind that includes protons and electrons, which initially are deflected by Earth's magnetosphere but then are accelerated back along Earth's magnetic field lines until they strike the atmosphere.

reconnaissance missions or those in polar regions." One finding by participants in the workshop was, "Neither the aviation industry nor the space weather community has a clear understanding of the aviation industry's requirements for space weather information (e.g., content, timing, interpretation, level of risk)." The report also said, "The challenge for the scientific community is that in order to increase investment in space weather research, the aviation community needs to demonstrate a need, which requires further risk assessment of the impacts. However, the aviation community is still trying to understand why they should care about space weather."

Until this decade, airlines mainly have been concerned about space weather–related risks during high-latitude operations (above 50 degrees north) and polar operations (above 78 degrees north). "Effects include disruption in high-frequency (HF) communications, satellite navigation system errors, and radiation hazards to humans and avionics," the AMS report said. "These concerns … become even more important at all latitudes when considered within the framework for the Next Generation Air Transportation System (NextGen) … an interagency initiative to transform the U.S. air transportation system by 2025."

Pro-Training Rationale

Several events have demonstrated the relevance of space weather to aviation. In April 2007, for example, the U.S. National Aeronautics and Space Administration (NASA) said that researchers at Cornell University had confirmed that "a solar flare created an intense solar radio burst causing large numbers of receivers to stop tracking the global positioning system (GPS) signal[s]." The researchers who studied effects of two solar flares on Dec. 5–6, 2006, found that although these effects occurred during a period of minimum sunspot activity — called solar minimum — the burst produced 10 times more radio-frequency noise on Earth than they had ever recorded. "The burst produced 20,000 times more radio emission than the entire rest of the sun," said Dale Gary, Ph.D., a physicist at the New Jersey Institute of Technology. "This was enough to swamp GPS receivers over the entire sunlit side of the Earth."

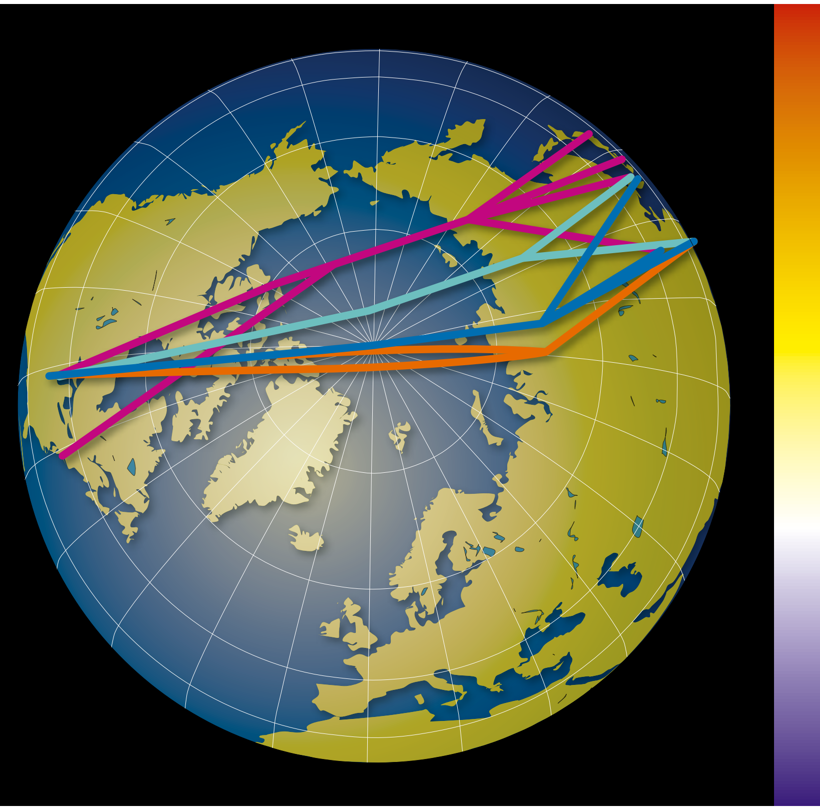
Also in April 2007, the 12 voting members of the international Solar Cycle 24 Panel issued a consensus prediction that solar cycle 24 — the 24th cycle of quiet to stormy to quiet status since astronomers recorded the 1755–1766 cycle — would begin in March 2008, plus or minus six months. Opinion was divided as to the characteristics of the solar maximum in the new cycle: some predicted that the sunspot number would peak at 140, plus or minus 20, in October 2011; others predicted that the sunspot number would peak at 90, plus or minus 10, in August 2012.[3]

In March 2006, scientists at the U.S. Center for Atmospheric Research — using computer simulations and satellite-based observations of the sun's interior — predicted "an increase in solar activity in late 2007 or early 2008, and there will be 30 to 50 percent more sunspots, [solar] flares and coronal mass ejections in [solar] cycle 24." Based on their relatively new methods of helioseismology,[4] which trace acoustic waves reverberating inside the sun, this solar cycle will begin about one year later than had been predicted using older methods, according to NASA.

On Oct. 28, 2003, the FAA issued its first solar radiation alert, advising airlines, "Satellite measurements indicate high levels of ionizing radiation coming from the sun. This may lead to excessive radiation doses to air travelers at corrected geomagnetic latitudes above 35 degrees north, or south. Avoiding excessive radiation exposure during pregnancy is particularly important. Reducing flight altitude may significantly reduce flight doses. Available data indicate that lowering flight altitude from 40,000 ft to 36,000 ft should result in about a 30 percent reduction in dose rate. A lowering of latitude may also reduce flight doses, but the degree is uncertain. Any changes in flight plan should be preceded by appropriate [air traffic control (ATC)] clearance."

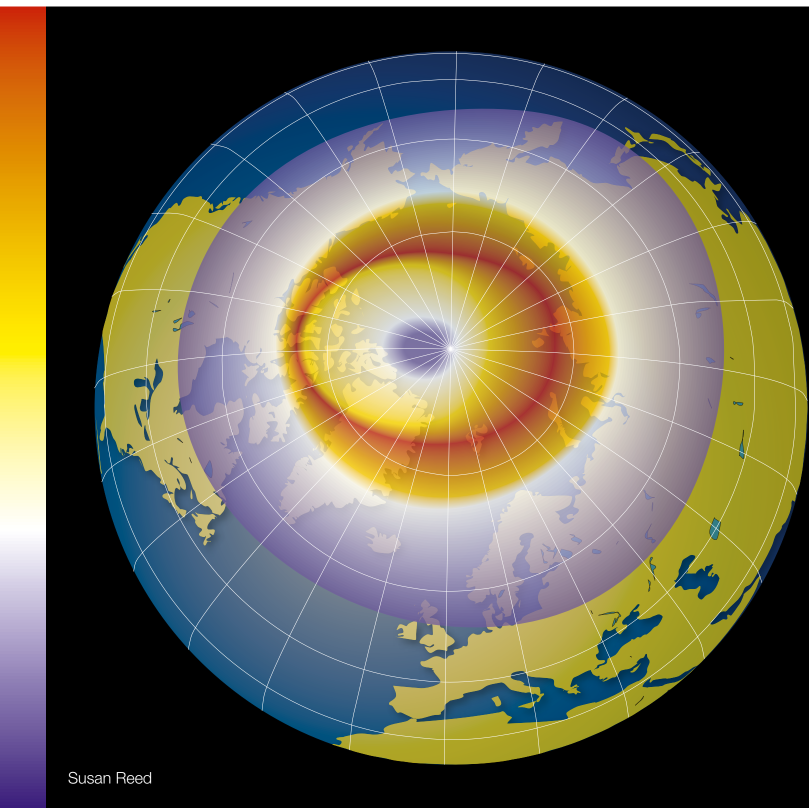
On several days in October and November 2003, flights from the United States to Europe were conducted at lower-than-normal altitudes. According to the U.S. National Oceanic and Atmospheric Administration (NOAA), "Airlines took unprecedented actions in their high-latitude routes to avoid the high radiation levels and communication blackout areas caused by three of the largest sunspot clusters in more than 10 years. … Airlines and air traffic controllers experienced problems almost daily, including severe degradation of high-latitude communications."[5]

The FAA's wide area augmentation system (WAAS) for GPS also was affected by the fall 2003 space weather storms. "For a 15-hour period on Oct. 29 and an 11-hour interval on Oct. 30, the ionosphere was so disturbed that the vertical error limit, as defined by the FAA's lateral navigation–vertical navigation (LNAV/VNAV) specification to be no more than 50 meters [164 ft], was exceeded," NOAA said.



Four transpolar routes between Asia and North America enable fuel-efficient, time-saving flights, but space weather–related time penalties can be 80 minutes for rerouting or 210 minutes if an en route stop is required.

Teleconferences of dispatchers and space weather forecasters, sometimes held daily as requested by airlines, also have enabled airlines to conduct flights on transpolar routes when data from the sun seemed to preclude the flights. "Perhaps the best example of the value of [a space weather storm] intensity prediction was on Nov. 3, 2003, when [a solar] flare erupted," NOAA said. "Airline companies immediately assumed [that] a flare this large would surely produce a significant radiation storm. NOAA Space Environment Center (SEC) forecasters told these dispatchers that because of the source location [of the flare] on the sun, an S3 storm [the 'strong' level on the NOAA Space Weather Scales that airlines have established as their 'go/no go' threshold for transpolar flights] was not likely. No route alterations were made, and the prediction materialized when a moderate-size S2 radiation storm unfolded."



Susan Reed

Monitoring the power flux carried by solar protons and electrons just above Earth's atmosphere at the North Pole, a U.S. polar-orbiting satellite's instruments transmit data to generate color-coded statistical maps of the aurora that help airline dispatchers visualize areas where these high-speed particles produce the aurora as they collide with the atmosphere.

Priority Policy Issues

The workshop participants agreed that priority space weather–aviation policy issues are communication that enables observations and forecasts to be integrated effectively into global flight operations; standardization of information and regulations; education and training; and cost benefit and risk analyses. To improve current practices, they proposed that the Cross Polar Trans-East Air Traffic Management Providers' Working Group — augmented by representatives of NOAA SEC and International Space Environment Services — help aviation stakeholders define future requirements; International Space Environment Services standardize the information formats; and the National Space Weather Program interact more frequently with the aviation community to ensure that future requirements factor into space weather research plans. Similarly, NextGen should be coordinated with NOAA SEC and relevant global initiatives on space weather, the report said.

Aircraft on the transpolar routes typically are equipped with GPS receivers and inertial reference units. For dispatchers and flight operations managers responsible for these flights, best practices for operating them have been refined by experience. By applying company policies for comparing data on the NOAA SEC Web page to predetermined ranges of values, and speaking with NOAA space weather duty forecasters to resolve any uncertainty, dispatchers know when they must consider rerouting flights to avoid specific transpolar routes. "Dispatchers receive space weather information from in-house meteorologists, private-sector companies and NOAA SEC alerts and forecasts, or go directly to the NOAA SEC Web site," the report said. "Typically, dispatchers … review [this Web site] and will modify polar flight plans if there is a threat of HF communication loss. … Some polar route operators will use [HF data link and] more expensive satellite communications as a backup communications medium; however, only the Iridium/Intelsat systems are available above 82 degrees north [latitude] and their installation [on] commercial aircraft is not widespread due to the costs."

Guidance Versus Regulation

Workshop participants favored additional official guidance for airlines to prepare them for the effects of space weather storms, and they said that regulators should respect the competitive requirement of a level playing field and not impose unwarranted costs. A related recommendation called for the FAA to mandate the use of space weather information by operators.

Workshop participants suggested that the FAA lead the aviation industry in collecting data about airline decisions, results and costs from using space weather forecasts; conduct related risk-benefit analysis and coordinate research studies. "Very little information

is available on how much space weather is responsible for delays or reroutes on polar routes [and related delays and costs]," the report said. "The International Civil Aviation Organization (ICAO), World Meteorological Organization, International Organization for Standardization and International Space Environment Services should harmonize their separate standards for aviation space weather information, products and services based upon a set of requirements [and] the FAA should provide [aircraft operators] with a minimum set of requirements for making decisions based on space weather information."

Beyond Transpolar Flights

Predeparture route changes and en route diversions caused by space weather storms and the resulting HF communication degradation or blackouts can affect flight operations in many world regions other than the polar regions. "[Flight crews operating in] the North Atlantic and Pacific Ocean [flight information] regions use HF for aircraft position reporting to maintain separation while outside of ATC radar coverage," the report said. "Even relatively minor space weather disturbances can seriously disrupt the HF signal, causing significant impact on these oceanic region procedures. While the newest aircraft can make use of the latest automated satellite reporting system, reducing their reliance upon HF in such regions, ATC can only communicate with older aircraft via HF. … Over vast areas of the South American and African continents, and the Indian Ocean, HF is the only means of communication. Furthermore, in some parts of central Africa, HF is the only way of communication between neighboring ATC units."

Very high frequency (VHF) radio communication also can be susceptible to effects of space weather storms. "Although less prone to interference, VHF signals can be lost in the noise produced by solar flares, a point not generally considered when investigating temporary losses of communication between aircraft and ATC," the report said.

GPS also is susceptible to space weather storm effects, according to the report. When they occur, however, the GPS receivers alert the flight crew if signals are unusable so that alternate navigation means can be used to complete the flight. "During a geomagnetic storm, the altitude of the lower boundary of the ionosphere changes rapidly and can introduce [GPS] horizontal and vertical errors of several tens of meters," the report said. "Dual-frequency satellite receivers actually measure [and correct for] the effect of the ionosphere on the satellite signals and can better adjust to, but not eradicate, these difficult circumstances."

Radiation Dose Issues

Even people who never fly are exposed to a normal background level of ionizing radiation from the particle shower produced by galactic cosmic rays. During high-altitude flight, the dose rates are greater compared with the dose rates on the ground, however, and international authorities provide analytical tools and guidance to estimate the level of health risk. "The 'particle shower' and corresponding level of radiation dose reach a maximum intensity at around 66,000 ft … and then slowly decrease with decreasing altitude down to sea level," the report said. "The dose rates also increase with increasing latitude until reaching about 50 degrees, whereupon they become almost constant. … The solar cycle can give plus or minus 20 percent variations in dose from solar minimum to [solar] maximum."

The reason for the FAA's October 2003 solar radiation alert was that energetic particles — highly accelerated protons and electrons — from solar flares increase dose rates at typical cruise altitudes all over the Earth. The critical issue for occupants of aircraft operating in polar and high-latitude regions is that the dose rate also increases more rapidly because of geomagnetic storms than because of increasing altitude and/or latitude. "Most solar flares emit protons with energies … [that] can produce [ionizing radiation] increases at aircraft altitudes and, on average, there have been approximately three events per solar cycle with sufficient intensity and energies to produce significant radiation in the atmosphere," the report said. The Earth's magnetic poles are especially vulnerable because of the shape and properties of the planet's magnetic field; geomagnetic storms weaken everywhere on Earth the protection provided by the magnetic field. "The Earth's magnetic field does offer some protection, but [ionizing radiation] particles can spiral down the [magnetic] field lines, entering the upper atmosphere in the polar regions where they produce additional ionization in the ionosphere and increase the radiation at aircraft altitudes," the report said.

Avionics Vulnerability

Despite protective design engineering and flight procedures, satellites have experienced temporary errors or permanent failures during space weather storms. Although these are more rare in large commercial jets or business jets — because avionics have been designed to continue functioning during the most severe space weather storms known, and because of the protection of Earth's ionosphere and magnetic field — avionics engineers remain vigilant. "The [space weather storm] hazard can … increase the risk of errors or failures in micro-electronic components installed in aircraft systems (e.g., flight and engine management computers)," the report said. "New technologies will increasingly use smaller and smaller micro-electronics, thereby further increasing the risks. … The electronic components of aircraft avionics systems are susceptible to damage from the highly ionizing interactions of cosmic rays, solar particles and the secondary particles generated in the atmosphere. This can corrupt systems leading to erroneous commands … [or] high current drain, leading to burnout and hardware failure."

Closing Policy Gaps

Discussion of ICAO's relevant standards and recommended practices led workshop participants to conclude that few currently apply to space weather reports and forecasts. "Annex 15, *Aeronautical Information Services,* does allow for issuance of a notice to airmen for solar radiation, but provides very little guidance for message content," the report said. "The ICAO International Airways Volcano Watch Operations Group … is assessing needs for information about solar radiation storms."

During NOAA SEC's Space Weather Workshop in April 2007, the authors of the AMS–SolarMetrics report discussed the next steps in their sponsoring organizations' initiative to promote space weather training to aviation professionals. The steps include briefing/meeting with committees of the U.S. Congress in July 2007; another aviation-oriented workshop Nov. 29–30, 2007; and further development of the policy framework and implementation of report recommendations until August 2008.[6]

Public interest in space weather — especially how it will affect society's reliance on communication and navigation technologies in civil aviation and other critical industries — prompted many scientists to revisit the geomagnetic "superstorm" of August and September 1859, the top-ranked event in the modern history of space weather storms.[7] One team's historical detective work at NASA Goddard Space Flight Center documented how telegraph services all over the world had been disrupted, ship captains at sea had observed vivid auroras at extremely low geomagnetic latitudes, and in many parts of the United States, red and white light from clouds in the night sky had been bright enough for people to read outdoors. Moreover, an English astronomer's 1859 observations of sunspots with an advanced telescope around the time of the superstorm — and his groundbreaking deductions about the causal relationship between the dates and times on his sunspot drawings and the strange phenomena observed in Earth skies — helped to launch the quest for the knowledge on which current transpolar flights now depend.[8] ●

For an enhanced version of this article and links to space weather information, go to <www.flightsafety.org/asw/june07/spaceweather.html>.

Notes

1. The term "solar wind" describes the continual outward flow of protons, electrons and magnetic field from the sun in all directions.
2. Fisher, Genene; Jones, Bryn. "Integrating Space Weather Observations and Forecasts Into Aviation Operations." American Meteorological Society (AMS) and SolarMetrics, March 2007. Fisher is a senior policy fellow of the AMS; Jones, CEO of SolarMetrics, is an airline captain and space weather research scientist.
3. Biesecker, Douglas; Solar Cycle 24 Panel. "The Solar Cycle 24 Consensus Prediction." A presentation to the U.S. National Oceanic and Atmospheric Administration (NOAA) Space Environment Center (SEC) Space Weather Workshop. April 2007.
4. Helioseismology is the study of the solar interior structure and dynamics by analysis of the propagation of acoustic waves through the sun's interior.
5. National Weather Service, NOAA, U.S. Department of Commerce. "Service Assessment: Intense Space Weather Storms October 19–November 7, 2003." April 2005.
6. Fisher; Jones. "Results From the Aviation and Space Weather Policy Workshop." A presentation to the Space Weather Workshop, April 24, 2007.
7. Odenwald, Sten; Green, Jim; Boardsen, Scott; Cliver, Edward. "The 1859 Geomagnetic Superstorm." A presentation to the NOAA SEC Space Weather Week conference, April 2006.
8. Clark, Stuart. *The Sun Kings: The Unexpected Tragedy of Richard Carrington and the Tale of How Modern Astronomy Began.* Princeton University Press, 2007.