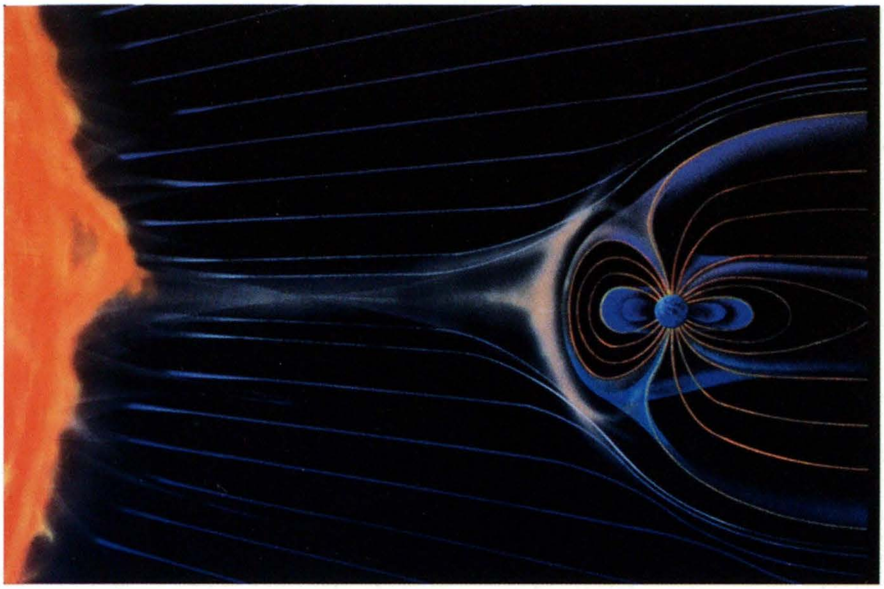
On the Watch for Geomagnetic Storms

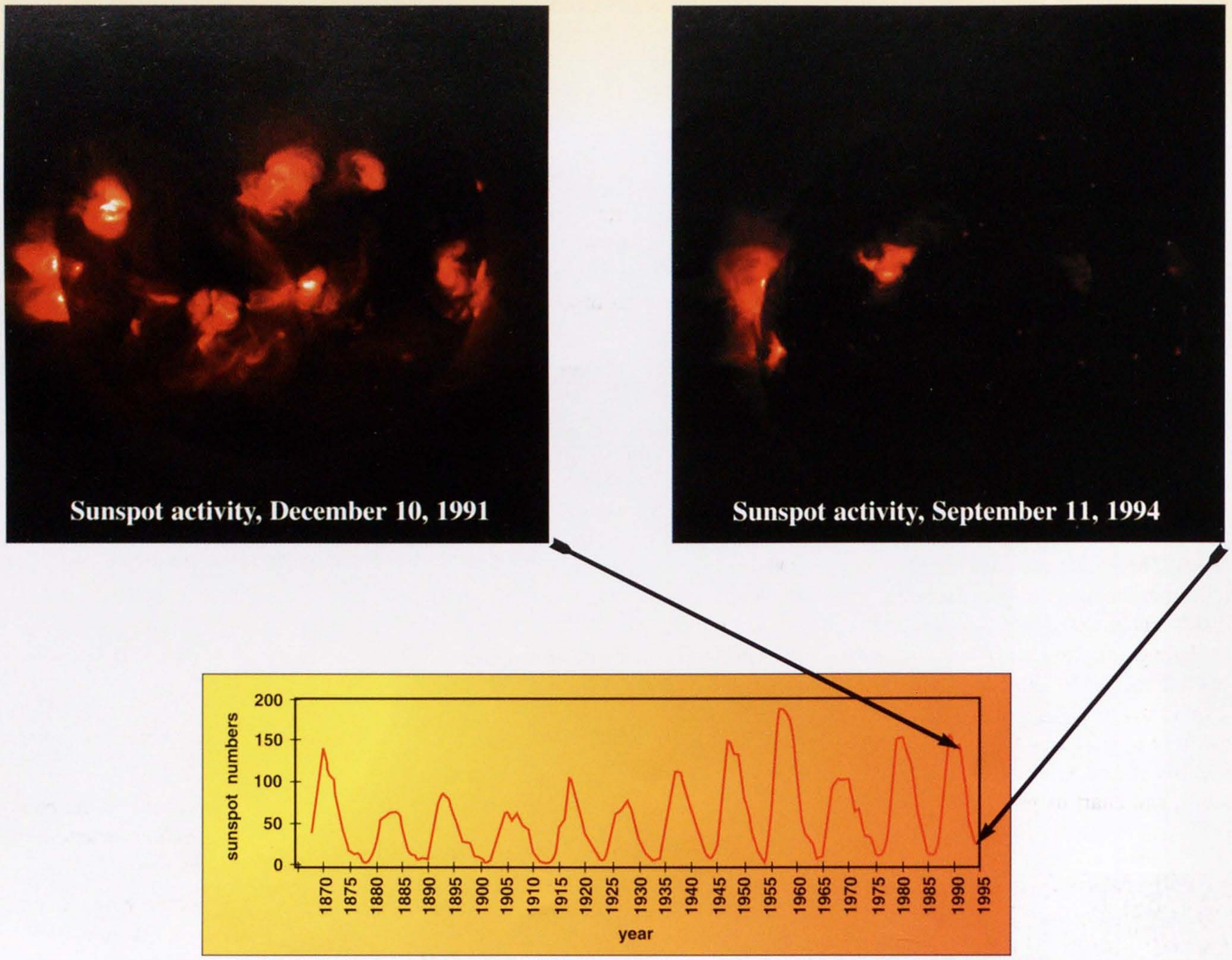
Geomagnetic storms, induced by solar activity, pose significant hazards to satellites, electrical power distribution systems, radio communications, navigation, and geophysical surveys. Strong storms can expose astronauts and crews of high-flying aircraft to dangerous levels of radiation. Economic losses from recent geomagnetic storms have run into hundreds of millions of dollars. With the U.S. Geological Survey (USGS) as the lead agency, an international network of geomagnetic observatories monitors the onset of solar-induced storms and gives warnings that help diminish losses to military and commercial operations and facilities.



Solar wind, as depicted in this artist's illustration, travels from the Sun and envelops the Earth's magnetic field. High-energy pulses of solar wind from sunspot activity ("solar bursts" or "plasma bubbles") travel from the Sun to the Earth at speeds exceeding 500 miles per second. The pulses distort the Earth's magnetic field and produce geomagnetic storms that disrupt the Earth's environment. **Illustration by K. Endo, Nikkei Science, Inc., Japan.**

In January 1997, a geomagnetic storm severely damaged the U.S. Telstar 401 communication satellite, which was valued at $200 million, and left it inoperable. A geomagnetic storm in 1994 damaged two Canadian communication satellites, which were replaced at a cost of about $400 million. A geomagnetic storm in 1989 "blacked out" the power distribution system for Quebec, Canada, and left 6 million people without electricity for 9 hours at a cost of $300 million. Although these events and their specific impacts were not predicted, current technology promises to provide real-time warnings and measures to contend with solar-induced storms.

Our society is depending more and more upon advanced technological systems that can be adversely affected by solar storms. Space vehicles and high-altitude aircraft rely on such systems for life safety and navigation. Global communications depend upon systems using high-frequency (HF), very high frequency (VHF), and ultra high frequency (UHF) radio signals. Electrical power distribution worldwide relies upon vast, interconnected systems of lines, transformers, computers, and other devices. Land surveying, and navigation via land, water, and air use the Global Positioning System (GPS) to determine routes and locations based on radio waves from satellites. Solar



The activity of the Sun's surface, indicated by many sunspots on December 10, 1991, contrasts dramatically with the level of activity on September 11, 1994. Individual sunspots and groups of sunspots can be accurately counted from X-ray images of the Sun like these. The counts produce a "sunspot number" used to gauge the dynamic behavior of the Sun's surface. The graph of annual averages of sunspot number reveals a clear pattern of cycles that are approximately 11 years in length. The next peak in the cycle should occur in the year 2000 and suggests a heightened concern for protecting technological systems at that time. The X-ray images were obtained by the Yohkoh satellite as part of a joint Japan-USA space mission. The images were provided by Lockheed Martin Missiles & Space, Sunnyvale, Calif. These and other images of the Sun may be viewed on the World Wide Web at the following URL: ***http://umbra.nascon.nasa.gov/***

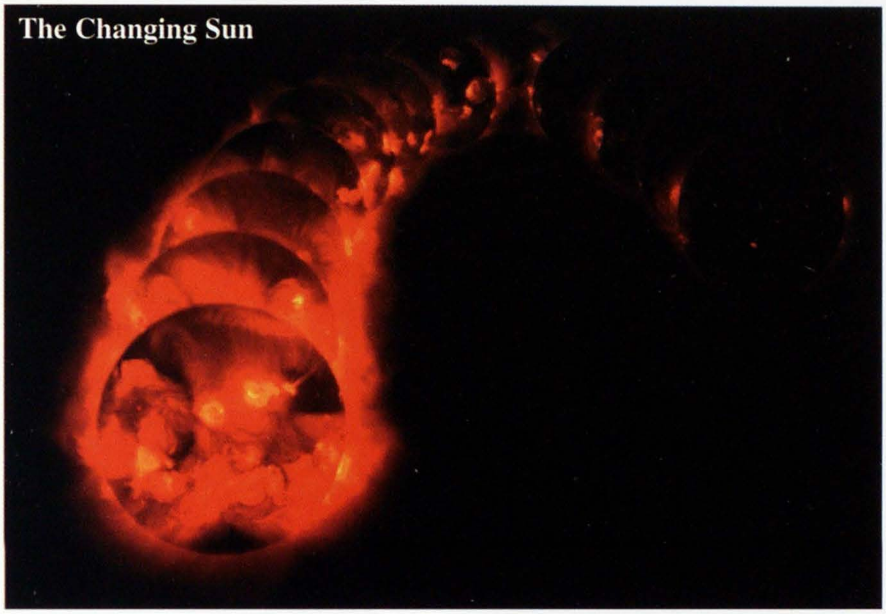
storms are capable of exposing space travelers to dangerous radiation, ruining miniature electronic components on satellites and high-altitude aircraft, inducing damaging electrical currents in power grids, and producing inaccuracies in GPS by altering the media through which GPS radio waves travel. Annually, magnetic storms cause hundreds of millions of dollars in economic losses.

Magnetic storms occur when a mass of plasma containing trapped magnetic fields is ejected from the Sun and strikes the Earth and its atmosphere. This mass, sometimes called a plasma "bubble," travels away from the Sun at about 2 million miles per hour. The "bubble" does not follow a straight course but rides the rotating three-dimensional spiral pattern of the Sun's magnetic field. If a "bubble" leaves the right place on the Sun to reach Earth, it travels the 93-million-mile distance in about 40 hours. Viewed from the Sun, our Earth is a very small target. Therefore, the vast majority of plasma "bubbles" miss Earth, and many that do reach the Earth are too weak to produce a significant storm. For these reasons, most plasma ejections and "solar flares" observed from Earth and by spacecraft do not produce magnetic storms and are poor predictors of storms.

Our records show that the solar activity that produces geomagnetic storms is greatest during cycles that repeat about every 11 years. The approaching peak of the 11-year solar (sunspot) cycle, which will occur in the year 2000, increases the possibility of damaging magnetic storms.

The U.S. Geological Survey's Geomagnetism Group in Golden, Colorado, operates a worldwide network of 13 magnetic observatories. Data from these observatories and some of the 65 worldwide observatories in the INTERMAGNET network are transmitted to Golden by satellite and e-mail links (much of it in real-time). These data are continuously monitored to warn of geomagnetic disturbances that could interfere with or damage military and commercial operations and facilities. Networks of ground magnetic observatories, such as those operated by the USGS, can identify the onset of a major magnetic storm and chart its progress during its lifetime of about 3 days. Even a few minutes advanced warning that a storm has begun can save millions of dollars in losses by permitting satellite and power system operators to take mitigating actions.

Whereas forecasting the effects of solar storms is in its infancy, the Nation possesses the technical skills and means to improve understanding, forecasts, and services related to these events. Moreover, the Internet makes it possible to collect and distribute nearly instantaneously any data or modeling result of interest to a user. Cooperating with other agencies and the international scientific community, the USGS is working toward real-time warnings to reduce the hazards and losses from solar storms.



These 12 X-ray images of the Sun's atmosphere, obtained between 1991 and 1995 at 90-day increments, provide a dramatic view of how solar activity changes during the waning part of the solar cycle. The X-ray images reveal a bright glow for the corona and a black disk for the surface of the sun. Solar "sunspot" activity throughout the cycle is readily apparent.

The solar X-ray images are from the joint Japan-USA Yohkoh satellite mission of the Institute of Space and Astronomical Science, Japan. The images were provided by Lockheed Martin Missiles & Space, Sunnyvale, Calif.

*See "**The Changing Sun,**" by G.L. Slater and G.A. Linford at the following URL:* ***http://www.space.lockheed.com/SXT/***

Coping with Solar Storms

Given accurate warnings about solar storms, system operators could use some of these alternatives to avoid or mitigate losses:

For satellites:

- put a satellite "to sleep," or turn off sensitive spacecraft subsystems
- increase satellite monitoring for anomalies
- calculate the best time to adjust a low Earth orbit for drag

For electrical power:

- disconnect links between power grids
- desensitize some automatic control systems, such as second harmonic detectors
- delay power station maintenance and equipment replacement

For communications:

- look for alternative frequencies
- plan means and timing to minimize communications outages

For aerial navigation:

- adjust flight altitude on polar routes to minimize health hazard
- use alternatives to GPS-based takeoff and landing procedures

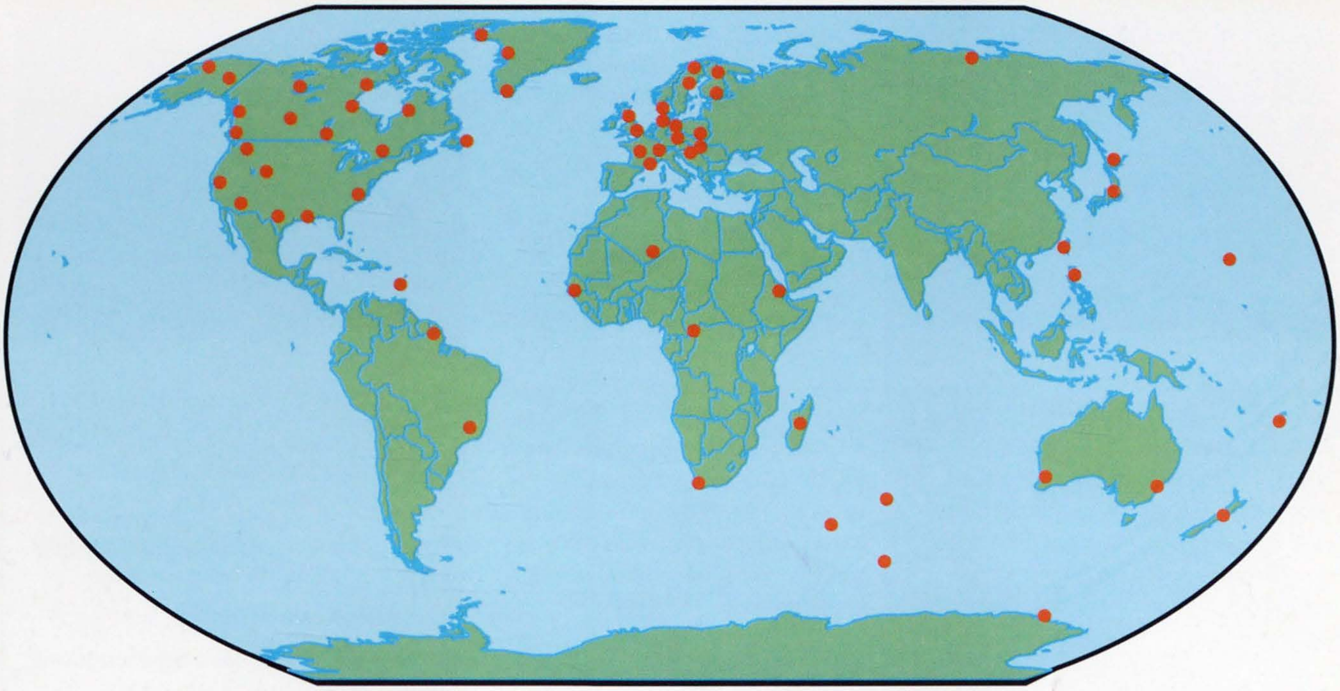
For surveying:

- delay high-resolution land surveying, exploration, or other research using GPS
- delay high-resolution magnetic surveying that would be degraded by geomagnetic disturbances

For space flight:

- delay activities such as space walks that risk exposing astronauts to radiation

The INTERMAGNET Network of Geomagnetic Observatories



INTERMAGNET *is an acronym for* ***international real-time magnetic observatory network****. It was formed in 1989 at the initiative of scientists from USGS and the British Geological Survey and was quickly joined by the geomagnetism programs in France and Canada. Under this program, data from a worldwide network of geomagnetic observatories are transmitted in near real-time via geostationary satellites or computer links to collection and distribution centers known as* ***Geomagnetic Information Nodes (GIN's). GIN's*** *are now operating in Golden, Colorado, U.S.A.; Edinburgh, Scotland, U.K.; Paris, France; Ottawa, Canada; and, most recently, Kyoto, Japan. About 60 observatories in about 20 nations in North America, South America, Asia, Europe, Africa, the Pacific, and Antarctica are now participating in* ***INTERMAGNET.*** *By the end of 1996, this number exceeded 75. The map shows observatories currently participating in* ***INTERMAGNET.***

INTERMAGNET is a growing network of geomagnetic sensors in observatories worldwide, many of which contribute data in real-time to the U.S. Air Force forecast center in Colorado Springs, Colorado. Information about the geomagnetic network is available on the World Wide Web at the following URL:

http://geomag.usgs.gov

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