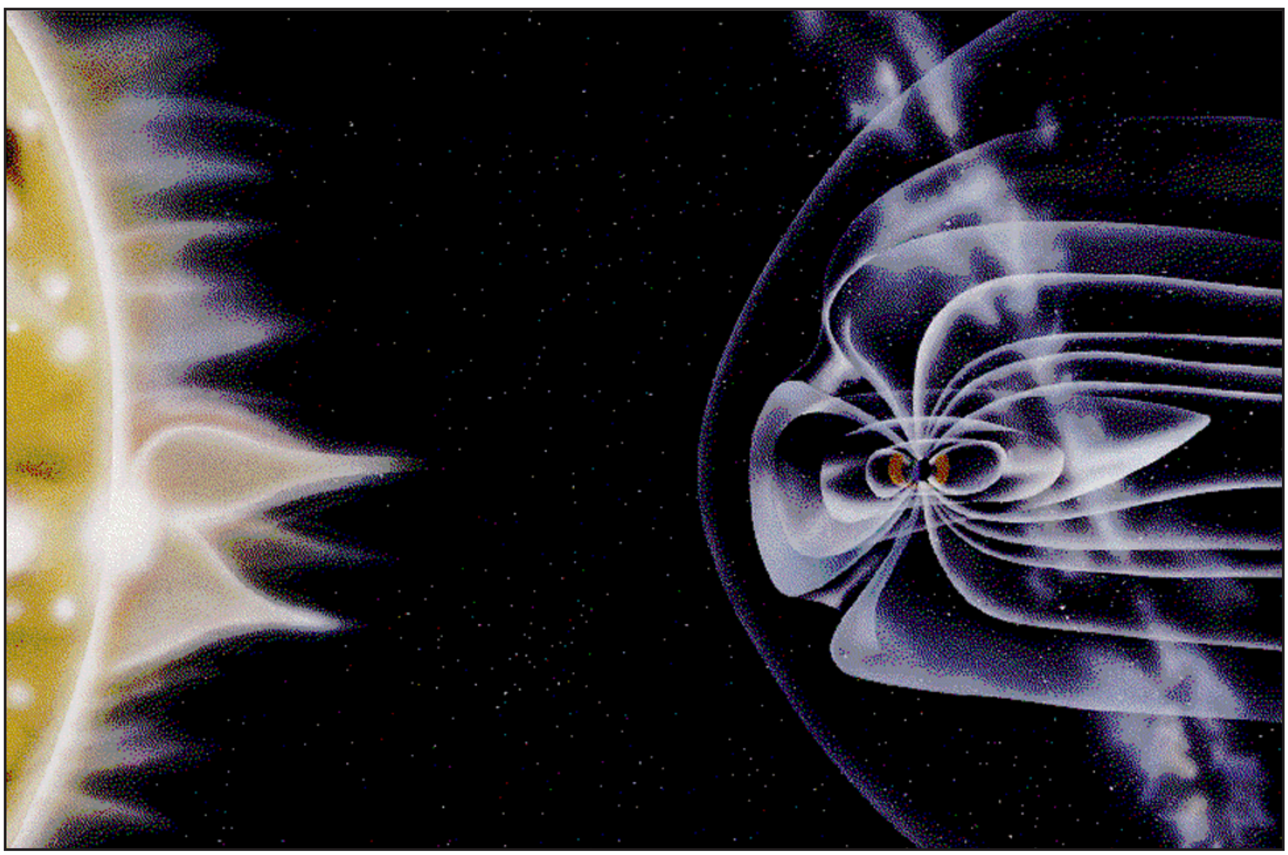
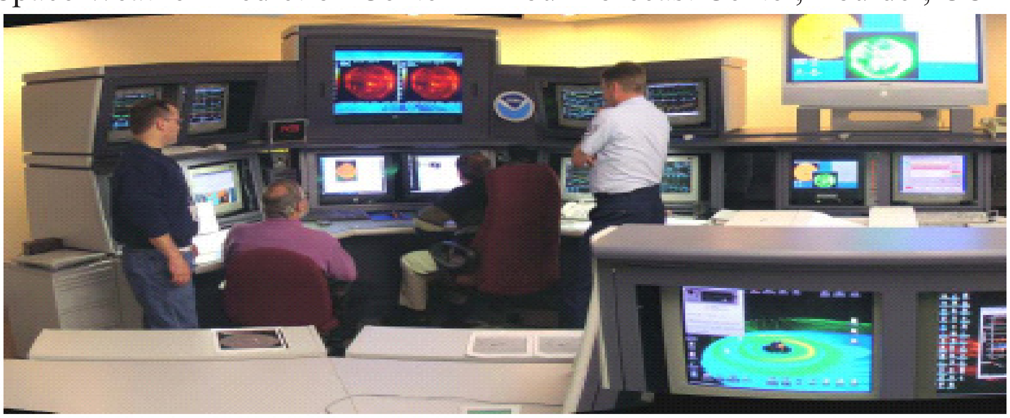
NOAA Space Weather Prediction Center

A Profile of Space Weather



Space Weather Prediction Center 24-hour Forecast Center, Boulder, CO



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A Profile of Space Weather

Space Weather describes the conditions in space that affect Earth and its technological systems. Space Weather is a consequence of the behavior of the Sun, the nature of Earth's magnetic field and atmosphere, and our location in the solar system. The active elements of space weather are particles, electromagnetic energy, and magnetic field, rather than the more commonly known weather contributors of water, temperature, and air.

Hurricanes and tsunamis are dangerous, and forecasting their arrival is a vital part of dealing with severe weather. Similarly, the Space Weather Prediction Center (SWPC) forecasts space weather to assist users in avoiding or mitigating severe space weather. These are storms that originate from the Sun and occur in space near Earth or in the Earth's atmosphere. Most of the disruptions caused by space weather storms affect technology, and susceptible technology is quickly growing in use. Satellites, for example, once rare and only government-owned, are now numerous and carry weather information, military surveillance, TV and other communications signals, credit card and pager transmissions, navigation data, and cell phone conversations. With the rising sophistication of our technologies, and the number of people that use technology, vulnerability to space weather events has increased dramatically.

The NOAA Space Weather Scales

For years, solar activity was reported and used to predict disruptions on Earth. Recently, the NOAA Space Weather Scales were designed to report three categories of disruptions. The types of storms are listed below with the kinds of problems they can cause. (A complete listing of the Scales is shown on the last page of the book.)

Geomagnetic Storms

Induced Currents in the atmosphere and on the ground

- Electric Power Grid systems suffer from wide-spread voltage control problems and possible transformer damage, with the biggest storms resulting in complete power grid collapse or black-outs.
- Pipelines carrying oil, for instance, can be damaged by the high currents.

Electric Charges in Space

- Satellites may acquire extensive surface and bulk charging (from energetic particles, primarily electrons), resulting in problems with the components and electronic systems on board the spacecraft.

Geomagnetic disruption in the upper atmosphere

- HF (high frequency) radio propagation may be impossible in many areas for a few hours to a couple of days. Aircraft relying on HF communications are often unable to communicate with their control centers.
- Satellite navigation (like GPS receivers) may be degraded for days, again putting many users at risk, including airlines, shipping, and recreational users.
- Satellites can experience satellite drag, causing them to slow and even change orbit. They will on occasion need to be boosted back to higher orbits.
- The Aurora, or northern/southern lights, can be seen in high latitudes (e.g. Alaska and across the northern states). In very large storms the aurora has been seen in middle and low latitudes such as Florida and further south. This is one of the delights of space weather, but it also signals trouble to groups impacted by geomagnetic storms.

Solar Radiation Storms

Radiation Hazard to Humans

- High radiation hazards to astronauts can be limited by staying inside a shielded spaceship. This is a problem for astronauts outside the International Space Station as well as on the Moon or any planet.
- The same kind of exposure, although less threatening, troubles passengers and crew in high-flying aircraft at high latitudes. Airplanes now fly higher and at higher latitudes, even over the poles, to make flights faster and more economical, but they run a greater risk of exposure to solar radiation.

Radiation Damage to Satellites in Space

- High-energy particles (mostly protons) can render satellites useless (either for a short time or permanently) by damaging any of the following parts: computer memory failure causing loss of control; star-trackers failing; or solar panels permanently damaged.

Radiation Impact on Communications

- HF communications and Low Frequency Navigation Signals are susceptible to radiation storms as well.HF communication at high latitudes.is often impossible for several days during radiation storms.

Radio Blackouts

Sunlit-Side impact on Communication

- HF Radio can suffer a complete blackout lasting for hours on the entire sunlit side of the Earth. This results in no HF radio contact with mariners and en route aviators in this sector.
- A large spectrum of radio noise may interfere directly with VHF signals.

Sunlit-Side impact on Navigation

- Low-frequency navigation signals (LORAN) used by maritime and general aviation systems have outages on the sunlit side of the Earth for many hours, causing a loss in positioning.
- Increased satellite navigation (GPS) errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.

The examples listed above illustrate some of the impacts of space weather storms. To learn more about these impacts, we need to learn about the source of the storms.

The Source of Space Weather

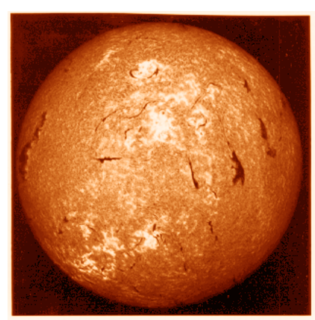
We have to start at the Sun, for although there are a few other contributions from outer space, the Sun is really the overwhelming source of space weather on Earth. The Sun is an average star, similar to millions of others in the Universe. It is a prodigious energy machine. The basic energy source for the Sun is nuclear fusion, which uses the high temperatures and densities within its center to fuse hydrogen, producing energy and creating helium. The Sun has been producing its radiant and thermal energies for the past four or five billion years, and will continue to produce energy as it begins its evolution to a white dwarf, in several billion years.

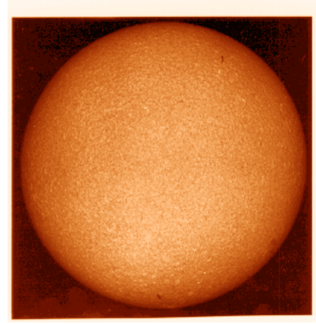
The features on the Sun reveal the active and turbulent nature of this highly magnetic, hot gaseous star. Sunspots were the first features to be identified on the Sun by man, as they can be seen by the naked eye. Galileo made observations in the early 1600's recording the spots as they moved from day-to-day; this also showed how the Sun rotated.

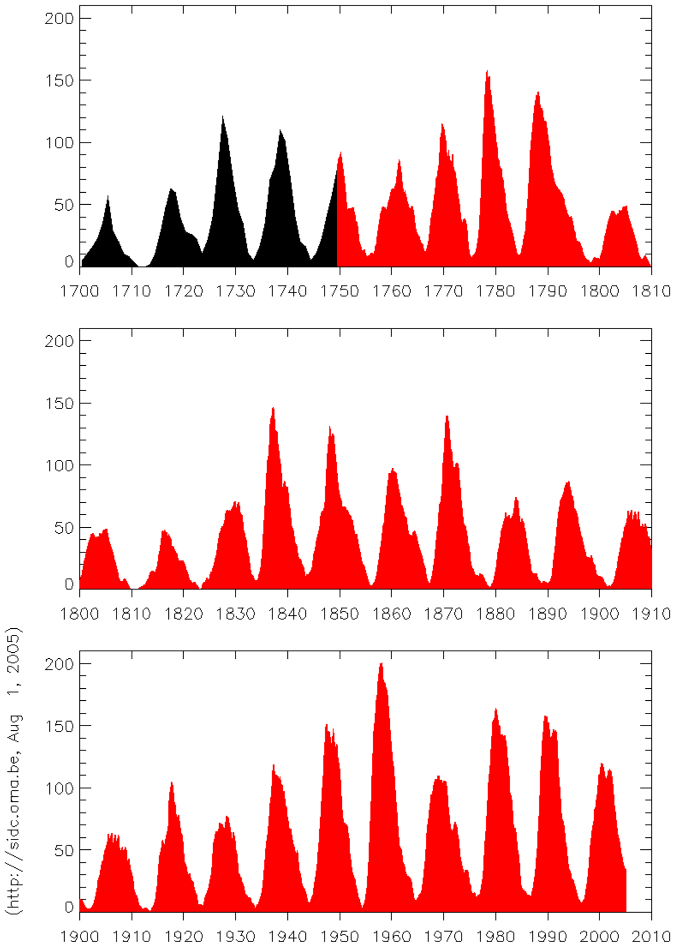
Sunspots

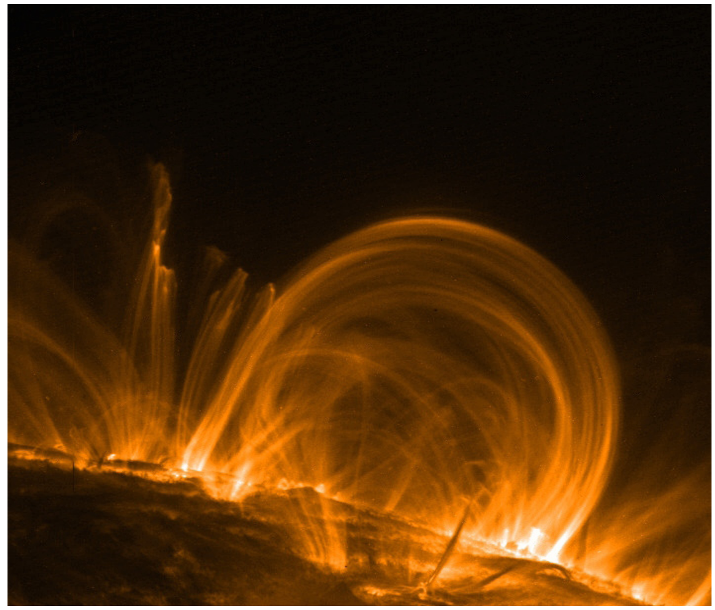
Sunspots, dark areas on the solar surface, contain strong magnetic fields that are constantly shifting. A moderate-sized sunspot is about as large as the Earth. Sunspots form and dissipate over periods of days or weeks. They occur when strong magnetic fields emerge through the solar surface and allow the area to cool slightly, from a background value of 6000 ° C down to about 4200 ° C; this area appears as a dark spot in contrast with the Sun. The rotation of these sunspots can be seen on the solar surface; they take about 27 days to make a complete rotation as seen from Earth. Sunspots remain more or less in place on the Sun. Near the solar equator the surface rotates at a faster rate than near the solar poles.

Groups of sunspots, especially those with complex magnetic field configurations, are often the sites of flares. Over the last 300 years, the average number of sunspots has regularly waxed and waned in an 11-year sunspot cycle. The Sun, like Earth, has its seasons but its "year" equals 11 of ours. This sunspot cycle is a useful way to mark the changes in the Sun. Solar Minimum refers to the several Earth years when the number of sunspots is lowest; Solar Maximum occurs in the years when sunspots are most numerous. During Solar Maximum, activity on the Sun and its effects on our terrestrial environment are high.









Magnetic field loops on the Sun.

Flares
Solar flares are intense, short-lived releases of energy. They are seen as bright areas on the Sun in optical wavelengths and as bursts of noise in radio wavelengths; they can last from minutes to hours. Flares are our solar system's largest explosive events. The primary energy source for flares appears to be the tearing and reconnection of strong magnetic fields. They radiate throughout the electromagnetic spectrum, from gamma rays to x-rays, through visible light out to kilometer-long radio waves.

Prominences
Solar prominences (seen as dark filaments on the disk) are usually slowly growing clouds of solar material held above the solar surface by magnetic fields. Occasionally prominences erupt at some point in their lifetime, breaking away from the solar surface and releasing large amounts of solar material into space.

Coronal Holes
Coronal holes are variable solar features that can last for weeks to months. They are large, dark areas when the Sun is viewed in x-ray wavelengths, sometimes as large as a quarter of the Sun's surface. These holes are rooted in large cells of unipolar magnetic fields on the Sun's surface; their field lines extend far out into the solar system. These open field lines allow a continuous outflow of high-speed solar wind. Coronal holes have a long-term cycle, but the cycle doesn't correspond exactly to the sunspot cycle; the holes tend to be most numerous in the years following sunspot maximum. At some stages of the solar cycle, these holes are continuously visible at the solar north and south poles.

Coronal Mass Ejection *(CME)*
The outer solar atmosphere, the corona, is structured by strong magnetic fields. Where these fields are closed, often above sunspot groups, the confined solar atmosphere can suddenly and violently release bubbles or tongues of gas and magnetic fields called coronal mass ejections. A large CME can contain 10^{16} grams (a billion tons) of matter that can be accelerated to several million miles per hour in a spectacular explosion. Solar material streaks out through the interplanetary medium, impacting any planet or spacecraft in its path. CMEs are sometimes associated with flares but usually occur independently.

Between Sun and Earth
The region between the Sun and the planets has been termed the interplanetary medium. Although

once considered a perfect vacuum, this is actually a turbulent region dominated by the solar wind, which flows at velocities of approximately 250-1000 km/s (about 600,000 to 2,000,000 miles per hour). Other characteristics of the solar wind (density, composition, and magnetic field strength, among others) vary with changing conditions on the Sun.

The solar wind flows around obstacles such as planets, but those planets with their own magnetic fields respond in specific ways. Earth's iron core produces a magnetic field that would look much like the field around a bar magnet. But under the influence of the solar wind, these magnetic field lines are compressed in the Sunward direction and stretched out in the downwind direction. This creates the magnetosphere, a complex, teardrop-shaped cavity around Earth. The Van Allen radiation belts are within this cavity, as is the ionosphere, a layer of Earth's upper atmosphere where photo ionization by solar x-rays and extreme ultraviolet rays creates free electrons. The Earth's magnetic field senses the solar wind, its speed, density, and magnetic field. Because the solar wind varies over time scales as short as seconds, the interface that separates interplanetary space from the magnetosphere is very dynamic. Normally this interface, called the magnetopause, lies at a distance equivalent to about 10 Earth radii in the direction of the Sun. However, during episodes of elevated solar wind density or velocity, the magnetopause can be pushed inward to within 6.6 Earth radii (the altitude of geosynchronous satellites). As the magnetosphere extracts energy from the solar wind, internal processes produce geomagnetic storms.

Effects of Space Weather Storms

Aurora

The aurora is a dynamic and visually delicate manifestation of solar-induced geomagnetic storms. The solar wind energizes electrons and ions in the magnetosphere. These particles usually enter the Earth's upper atmosphere near the polar regions. When the particles strike the molecules and atoms of the thin, high atmosphere, some of them start to glow in different colors. Aurora begin between 60 and 80 degrees latitude. As a storm intensifies, the aurora spread toward the equator. During an unusually large storm in 1909, an aurora was visible at Singapore, on the geomagnetic equator. The aurora provide pretty displays, but they are just a visible sign of atmospheric changes that may wreak havoc on technological systems.

Communications

Many communication systems utilize the ionosphere to reflect radio signals over long distances. Ionospheric storms can affect High Frequency (HF) radio communication at all latitudes. Some radio frequencies are absorbed and others are reflected, leading to rapidly fluctuating signals and unexpected propagation paths. TV and commercial radio stations are little affected by solar activity, but ground-to-air, ship-to-shore, Voice of America, Radio Free Europe, and amateur radio are frequently disrupted. Radio operators using high frequencies rely upon solar and geomagnetic alerts to keep their communication circuits up and running.

Some military detection or early-warning systems are also affected by solar activity. The Over-the-Horizon Radar bounces signals off the ionosphere in order to monitor the launch of aircraft and missiles from long distances. During geomagnetic storms, this system can be severely hampered by radio clutter. Some submarine detection systems use the magnetic signatures of submarines as one input to their locating schemes. Geomagnetic storms can mask and distort these signals.

The Federal Aviation Administration routinely receives alerts of solar radio bursts so that they can recognize communication problems and forego unnecessary maintenance. When an aircraft and a ground station are aligned with the Sun, jamming of air-control radio frequencies can occur. This can also happen when an Earth station, a satellite, and the Sun are in alignment.

Radiation storms, also known as solar particle events or proton events can affect the lower regions of the polar ionosphere. This region can become ionized and severe HF and VHF signal absorption may occur. This is called a polar cap absorption (PCA) event. PCA events may last for days or weeks and polar HF radio propagation often becomes impossible during these events.

Navigation Systems

Systems such as LORAN and OMEGA are adversely affected when solar activity disrupts their signal propagation. The OMEGA system consists of eight transmitters located through out the world. Airplanes and ships use the very low frequency signals from these transmitters to determine their positions. During solar events and geomagnetic storms, the system can give navigators information that is inaccurate by as much as several miles. If navigators are alerted that a radiation storm or geomagnetic storm is in progress, they can switch to a backup system. GPS signals are affected when solar activity causes sudden variations in the density of the ionosphere. Global Positioning Systems are being used for ever more precise applications, including mapping of coastlines, surveying for highway construction, landing airplanes, and oil drilling.

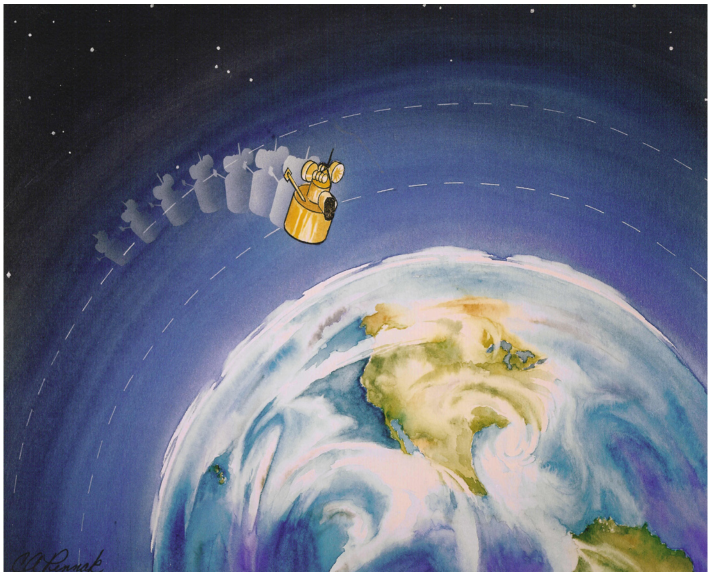
Satellites

Geomagnetic storms and increased solar ultraviolet emission heat the Earth's upper atmosphere, causing it to expand. The heated air rises, and the density at the orbit of satellites up to about 1000 km increases significantly. This results in increased drag on satellites in space, causing them to slow and change orbit slightly. Unless low-Earth-orbit satellites are routinely boosted to higher orbits, they slowly fall, and eventually burn up in the Earth's atmosphere. Skylab is an example of a spacecraft re-entering the Earth's atmosphere prematurely as a result of higher-than-expected solar activity. During the great geomagnetic storm of March 1989, four Navy navigational satellites had to be taken out of service for up to a week.

As technology has allowed spacecraft components to become smaller, their miniaturized systems have become increasingly vulnerable to the more energetic solar particles. These particles can cause single event upsets which often cause physical damage to microchips and change software commands in satellite-borne computers.

Another problem for satellite operators is differential charging. During geomagnetic storms, the number and energy of electrons and ions increase. When a satellite travels through this energized environment, the charged particles striking the spacecraft cause different portions of the spacecraft to be differentially charged. Eventually, electrical discharges can arc across spacecraft components, harming and possibly disabling them.

Bulk Charging. Bulk charging (also called deep charging) occurs when energetic particles, primarily electrons, penetrate the outer covering of a satellite and deposit their charge in its internal parts. If sufficient charge accumulates in any one component, it may attempt to neutralize by discharging to other components. This discharge is potentially hazardous to the electronic systems of the satellite.



Radiation Hazards to Humans

Intense solar eruptions release very-high-energy particles *(protons)* that can be as injurious to humans as the low-energy radiation from nuclear blasts. The Earth's atmosphere and magnetosphere of the Earth allow adequate protection for us on the ground, but astronauts in space are subject to potentially lethal dosages of radiation. The penetration of high-energy particles into living cells, measured as radiation dose, leads to chromosome damage and, potentially, cancer. Large doses can be fatal immediately. Solar protons with energies greater than 30 MeV are particularly hazardous. In October 1989, the Sun produced enough energetic particles that an astronaut on the Moon, wearing only a space suit and caught out in the brunt of the storm, would probably have died. (Astronauts who had time to gain safety in a shelter beneath moon soil would have absorbed only slight amounts of radiation.)

Solar proton events can also produce elevated radiation aboard aircraft flying at high altitudes and high latitudes. Although these risks are small, more airlines are taking advantage of polar flights. The threat of radiation to humans, electronics, navigation and communications have made airlines acutely aware of space weather conditions. Radiation risk is particularly worrisome to pregnant women, but the risk is still not well documented.

Geologic Exploration

The Earth's magnetic field is used by geologists to determine subterranean rock structures. For the most part, these geodetic surveyors are searching for oil, gas, or mineral deposits. They can accomplish this only when Earth's magnetic field is quiet, so that true magnetic signatures can be detected. Other surveyors prefer to work during geomagnetic storms, when the variations to normal subsurface electric currents help them to see subsurface oil or mineral structures. For these reasons, many surveyors use geomagnetic alerts and predictions to schedule their mapping activities.

Electric Power

When magnetic fields move about in the vicinity of a conductor such as a wire, an electric current is induced into the conductor. This happens on a grand scale during geomagnetic storms. Power companies transmit alternating current to their customers via long transmission lines. The nearly direct currents induced in these lines from geomagnetic storms are harmful to electrical transmission equipment. On March 13, 1989, in Montreal, Quebec, 6 million people were without commercial electric power for 9 hours as a result of a huge geomagnetic storm. Some areas in the northeastern U.S. and in Sweden also lost power. By receiving geomagnetic storm alerts and warnings, power companies can minimize damage and power outages.

Pipelines

Rapidly fluctuating geomagnetic fields can induce currents into pipelines. During these times, several problems can arise for pipeline engineers. Flow meters in the pipeline can transmit erroneous flow information, and the corrosion rate of the pipeline is dramatically increased. If engineers unwittingly attempt to balance the current during a geomagnetic storm, corrosion rates may increase even more. Pipeline managers routinely receive alerts and warnings to help them provide an efficient and long-lived system.

Climate

The Sun is the heat engine that drives the circulation of our atmosphere. Although it has long been assumed to be a constant source of energy, recent measurements of this solar constant have shown that the base output of the Sun can have temporary decreases of up to one-half percent. Atmospheric scientists say that this variation is significant and that it can modify climate over time. Plant growth has been shown to vary over the 11-year sunspot and 22-year magnetic cycles of the Sun, as evidenced in tree-ring records.

While the solar cycle has been nearly regular during the last 300 years, there was a period of 70 years during the 17th and 18th centuries when very few sunspots were seen. This drop in sunspot number coincided with the timing of the Little Ice Age in Europe, implying a Sun-climate connection. Recently, a more direct link between climate and solar variability has been speculated. Stratospheric winds near the equator blow in different directions, depending on the time in the solar cycle. Studies are under way to determine how this wind reversal affects global circulation patterns and weather. During proton events, many more energetic particles reach the Earth's middle atmosphere. There they cause molecular ionization, creating chemicals that destroy atmospheric ozone and allow increased amounts of harmful solar ultraviolet radiation to reach the surface of the Earth. A solar proton event in 1982 resulted in a temporary 70% decrease in ozone densities.

Geomagnetic Influence on People and Animals

There is a growing body of evidence indicating that changes in the geomagnetic field affect biological systems. Studies indicate that physically stressed human biological systems may respond to fluctuations in the geomagnetic field. Interest and concern in this subject have led the Union of Radio Science International to create a new commission entitled Electromagnetics in Biology and Medicine.

Possibly the most closely studied of the variable biological effects of the Sun has been the degradation of homing pigeons' navigational abilities during geomagnetic storms. Pigeons and other migratory animals, such as dolphins and whales, have internal biological compasses composed of the mineral magnetite wrapped in bundles of nerve cells. While this probably is not their primarily method of navigation, there have been many pigeon race smashes during a geomagnetic storm. A smash is a term used when only a small percentage of birds return home

from a release site. Because these losses have occurred during geomagnetic storms,
pigeon handlers have learned to ask for geomagnetic alerts and warnings as an aid to scheduling races.

Our Future

The list of consequences grows in proportion to our dependence on burgeoning technological systems. The subtleties of the interactions between the Sun and the Earth, and between solar particles and delicate instruments, have become factors that affect our well being. Thus there will be continued and intensified need for space environment services to address health, safety, and commercial needs. The Space Weather Prediction Center (SWPC) Forecast Center is jointly operated by NOAA and the U.S. Air Force and is the national and world warning center for disturbances that can affect people and equipment working in the space environment. SWPC works with many national and international partners who contribute data and observations; we also share our data and products with them. We are pleased to support efforts worldwide to inform users of space weather.

Better understanding and better forecasts are keys to providing better services. SWPC conducts research in solar-terrestrial physics, develops techniques for forecasting solar and geophysical disturbances, and provides real-time monitoring and forecasting of solar and geophysical events.

The SWPC is one of the nine National Centers for Environmental Prediction, part of the NOAA National Weather Service.
http://www.swpc.noaa.gov

NOAA Space Weather Scales

Category		Effect	Physical measure	Average
Scale	Descriptor	Duration of event will influence severity of effects		(1 cycle = 11 years)
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm days
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp=9	4 per cycle (4 days/cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**	Kp=8, including a 9-	100 per cycle (60 days/ cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**	Kp=7	200 per cycle (130 days/ cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**	Kp=6	600 per cycle (360 days/ cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**	Kp=5	1700 per cycle (900 days/ cycle)
Solar Radiation Storms			Flux level of ≥ 10 MeV particles	Number of
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1/cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3/cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10/cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25/cycle
Radio Blackouts			GOES X-ray brightness by class	Number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1/cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days/cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days/ cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days/ cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days/ cycle)