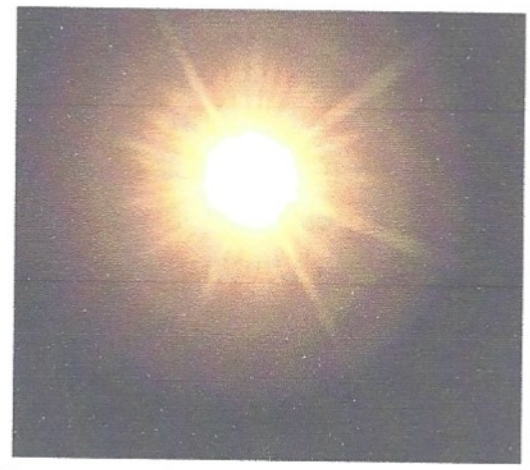
http://www.swpc.noaa.gov/primer/primer.html

NOAA / Space Weather Prediction Center

A Primer on Space Weather

Our Star, the Sun



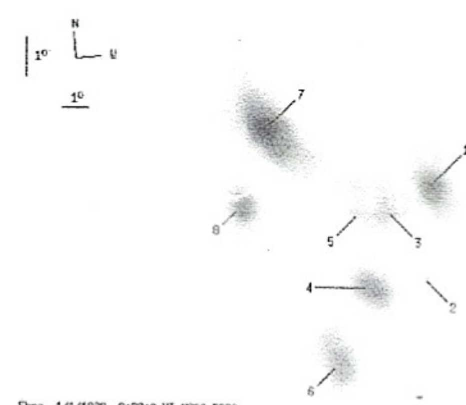
We all know that the Sun is overwhelmingly important to life on Earth, but few of us have been given a good description of our star and its variations.

The Sun is an average star, similar to millions of others in the Universe. It is a prodigious energy machine, manufacturing about 3.8 x 1023 kiloWatts (or kiloJoules/sec). In other words, if the total output of the Sun was gathered for one second it would provide the U.S. with enough energy, at its current usage rate, for the next 9,000,000 years. The basic energy source for the Sun is nuclear fusion, which uses the high temperatures and densities within the core to fuse hydrogen, producing energy and creating helium as a byproduct. The core is so dense and the size of the Sun so great that energy released at the center of the Sun takes about 50,000,000 years to make its way to the surface, undergoing countless absorptions and re-emissions in the process. If the Sun were to stop producing energy today, it would take 50,000,000 years for significant effects to be felt at Earth!

The Sun has been producing its radiant and thermal energies for the past four or five billion years. It has enough hydrogen to continue producing for another hundred billion years. However, in about ten to twenty billion years the surface of the Sun will begin to expand, enveloping the inner planets (including Earth). At that time, our Sun will be known as a red giant star. If the Sun were more massive, it would collapse and re-ignite as a helium-burning star. Due to its average size, however, the Sun is expected to merely contract into a relatively small, cool star known as a white dwarf.

It has long been known that the Sun is neither featureless nor steady. (Theophrastus first identified sunspots in the year 325 B.C.) Some of the more important solar features are explained in the following sections.

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.

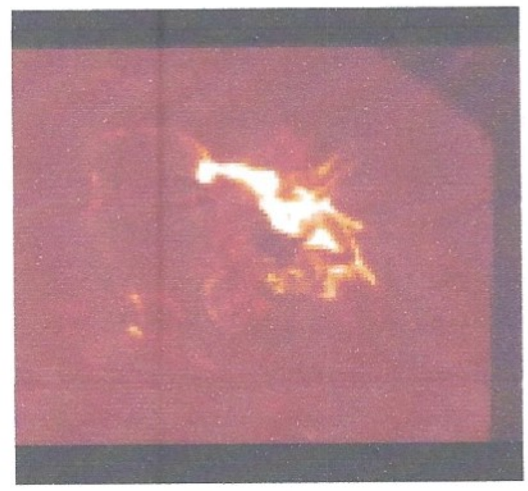
Sunspots remain more or less in place on the Sun. Near the solar equator the surface rotates at a faster rate than near the solar poles.

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.

Coronal Mass Ejection (CME)

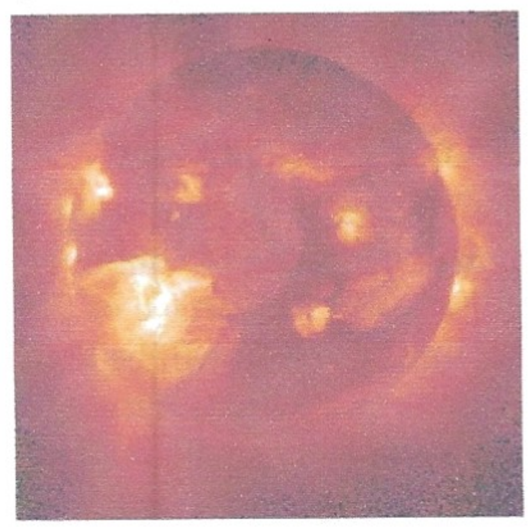
The outer solar atmosphere, the corona, is structured by strong magnetic fields. Where these fields are closed, often above sunspot groups, the confined solar atmosphere can suddenly and violently release bubbles or tongues of gas and magnetic fields called coronal mass ejections. A large CME can contain 10^{16} grams (ten 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.

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

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.

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.

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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 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.

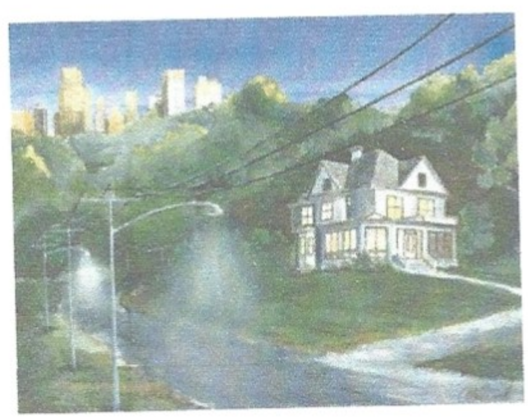
Another problem for satellite operators is differential charging. During geomagnetic storms, the number and energy of electrons and ions increase. When a satellite travels through this energized environment, the charged particles striking the spacecraft cause different portions of the spacecraft to be 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.

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

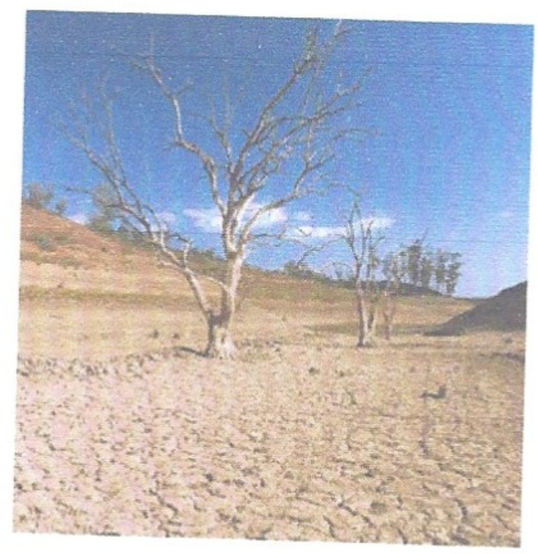


When magnetic fields move about in the vicinity of a conductor such as a wire, an electric current is induced into the conductor. This happens on a grand scale during geomagnetic storms. Power companies transmit alternating current to their customers via long transmission lines. The nearly direct currents 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.

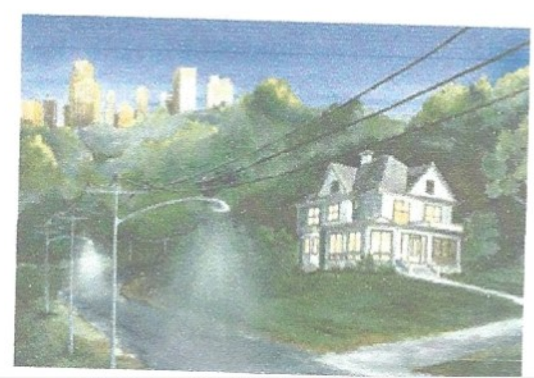
While the solar cycle has been nearly regular during the last 300 years, there was a period of 70 years during the 17th and 18th centuries when very few sunspots were seen. This drop in sunspot number coincided with the timing of the Little Ice Age in Europe, implying a Sun-climate connection. Recently, 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 Predictions 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.