Space weather

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For thousands of years, people in the north have marvelled at the space weather seen in the Northern Lights. But auroras never hurt a sailor or a farmer. Only with our modern electrical, electronic and space technologies have the Sun's effects become damaging, and even personally hazardous for astronauts. The more we do in space, the more serious and potentially costly the problems will become. The response of the space environment around the Earth to the constantly changing Sun is known as 'space weather'. Most of the time, space weather is of little concern in our everyday lives. However, when the space environment is disturbed by the variable outputs of the Sun, technologies that we depend on can be affected. This has been demonstrated by the large number of problems associated with the severe magnetic storms between 1989 and 1991, and more recently in 2000-2001 during the maximum of solar cycle 23.

Space weather disturbances are generally caused by transient events in the solar atmosphere. There are two different types of events, which trigger disturbances in the Earth's environment. One type is called a solar flare because the brightening of a small area on the Sun heralds its occurrence. However, not all solar flares result in geomagnetic storms, and, even more significantly, not all geomagnetic storms can be associated with solar flares. Some of the most dramatic space weather effects occur in association with eruptions of material from the solar atmosphere into interplanetary space. These eruptions are known as coronal mass ejections, or CMEs. Such eruptions are sometimes associated with flares and sometimes not, and they now appear to be a primary cause of geomagnetic activity.

The emission from the two types of disturbances can be divided into two classes: electromagnetic radiation and particles, which will have different effects on the Earth's environment, as discussed below.

Particle radiation

A continuous flow of charged particles (protons and electrons) is streaming out from the Sun and is called the solar wind. Several types of solar events can cause particles with high velocities to be superimposed on this background solar wind. CMEs are believed to be caused by sudden disruptions in the Sun's magnetic field. These magnetic fields stretch and twist like titanic rubber bands until they snap. A large CME can contain 1000 million tons of matter that can reach speeds at the Earth of up to 2000 kilometres per second, considerably greater than the normal solar wind speeds of about 400 kilometres per second. The cloud of charged particles (which also bring with them parts of the solar magnetic field) will interact with the Earth's magnetic field when the magnetic clouds reach the Earth's orbit. This results in a disturbance of the Earth's magnetic field, and the auroral particle precipitation into the atmosphere increases. The aurora is a dynamic and delicate visual manifestation of solar-induced geomagnetic storms.

One of the most dramatic effects on ground systems during geomagnetic storms is the disruption of power systems. During a geomagnetic storm the ionospheric currents, or electrojets, reach tens of thousands of amperes and produce fluctuations in the Earth's magnetic field. Such disturbances can induce near DC currents (Geomagnetically Induced Currents, GIC) in long power lines. For instance, during the March 13, 1989, storm, GIC's caused a complete shutdown of the Hydro-Quebec power grid resulting in a nine-hour power outage. The power pools that served the entire northeastern United States came uncomfortably close to a cascading system collapse.

The enhanced particle density within the Earth's magnetic fields during a geomagnetic storm can also cause damage to satellites. Less energetic particles contribute to a variety of spacecraft surface charging problems, especially during periods of high geomagnetic activity.

Under some conditions, solar eruptions can also accelerate charged particles to very high energies (protons and heavier particles, such as helium). These highly energetic particles can penetrate into electronic components, causing bit-flips in a chain of electronic signals that may result in spurious commands (phantom commands), appearing to spacecraft systems as being sent from the ground control. In addition one can experience erroneous data from the onboard instruments. These spurious commands have caused major failures to satellite systems, even causing the craft to point away from the earth direction. Energetic solar protons are also a radiation health hazard for astronauts on manned space flights, in particular for long space missions outside the Earth's protective magnetosphere.

Electromagnetic Radiation

The energetic radiation bursts from flares travel at the speed of light, and so arrive at Earth just eight minutes after leaving the flare site, well ahead of any particles or coronal material also associated with the flare. Moreover, unlike the electrons and ions of the solar wind plasma and the solar energetic particle populations, the passage of electromagnetic waves is not affected by the presence of Earth's magnetic field. The direct response of the upper atmosphere to a burst of solar flare ultraviolet and x-ray emissions is a temporary increase in ionisation (as well as temperature) in the sunlit hemisphere, lasting from minutes to hours and called a sudden ionospheric disturbance (SID). This can cause disruption of short-wave radio communication at HF frequencies (3-30 megahertz), which is still extensively used by the military and for overseas broadcasting.

In general, geomagnetic storms and increased solar ultraviolet emission heat the Earth's upper atmosphere, causing it to expand. The atmospheric density at the orbit of satellites up to about 1000 km from the Earth can increase significantly. This results in increased drag on satellites, and may shift their orbit enough to make them temporarily "lost" to communications links. At times,

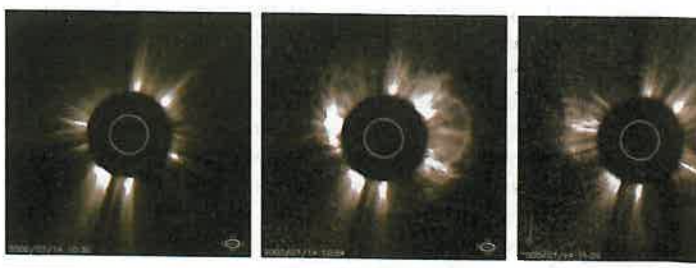

Fig. 1: A full halo coronal mass ejection (CME) was recorded on July 14, 200 by SOHO's LASCO/C2 coronagraph. The many speckles in the last two imag are energetic particles bombarding SOHO's electronic detectors. The resulti geomagnetic activity between July 14 and July 19 produced the largest geomagnetic storm observed since 1989, and one of the most intense sola proton events ever recorded. Several satellites experienced problems, and some permanent damages were reported.

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these effects may be sufficiently severe as to cause premature re-entry of orbiting objects, such as Skylab in 1979 and Solar Maximum Mission in 1989.

Space Weather Forecast

Today our society is much more sensitive to space weather activity than was the case during the last solar maximum in 1991. An example is the possible disruption of satellites. Our society depends on satellites for weather information, communications, navigation, exploration, search and rescue, research, and defence systems. Thus, the impact of satellite system failures is more far-reaching than ever before, and the trend will almost certainly continue at an increasing rate. Furthermore, safe operation of the International Space Station depends on timely warnings of eruptions on the Sun.

Navigation systems such as LORAN and OMEGA are adversely affected when solar activity disrupts their radio wavelengths. It also introduces position errors and decreases the accuracy and reliability of the Global Positioning System (GPS). Space weather-induced currents can also create galvanic effects in oil and gas pipelines, leading to rapid corrosion at the pipeline joints if they are not properly grounded. Such corrosion requires expensive repairs or can lead to permanent damage. Furthermore signals used during geomagnetic surveys (e.g. search for natural resources such as oil and gas) are significantly affected by the varying magnetic fields during geomagnetic storms.

It is therefore important to forecast and warn for major solar storms. The presence of two satellites located in the L1 Lagrangian point, SOHO and ACE, has definitely improved the accuracy of space weather forecasts. Two instruments on board SOHO have proved to be especially valuable for continuous real-time monitoring of solar storms that affect space weather. One is the Large Angle Spectrometric Coronagraph (LASCO) that takes images of the solar corona by blocking the light coming directly from the Sun itself with an occulter disk, creating an artificial eclipse within the instrument. It is the perfect tool for detecting CMEs heading towards (or away from!) the Earth. The other is the Extreme ultraviolet Imaging Telescope (EIT), providing images of the solar atmosphere at four wavelengths. It reveals flares and other stormy events in the atmosphere, and can usually determine whether CMEs seen by LASCO originated on the near or far side of the Sun, based on the presence or absence of corresponding events on the near side.

Before SOHO was operational, only 27% of major magnetic storms (Kp index of 6 or greater) were correctly forecast, and most forecasts were false alarms. The improvement offered by SOHO is apparent in a study of 25 front-side halo CMEs seen by LASCO and EIT during 1996 and 1997. Over 85% caused major magnetic storms and only 15% of such storms were not predicted.

The Sun has produced a series of large eruptions and flares during 2000-2001 and SOHO's role in the early-warning system for space weather has been demonstrated. On 14 July 2000, SOHO detected the bright flash of a solar flare near the centre of the Sun's disk and just half an hour later SOHO's LASCO instrument detected a mass of gas racing out from the Sun. Next, a burst of energetic particles from the solar explosion hit SOHO. In the imaging instruments it looked like a snowstorm that continued for some hours.