

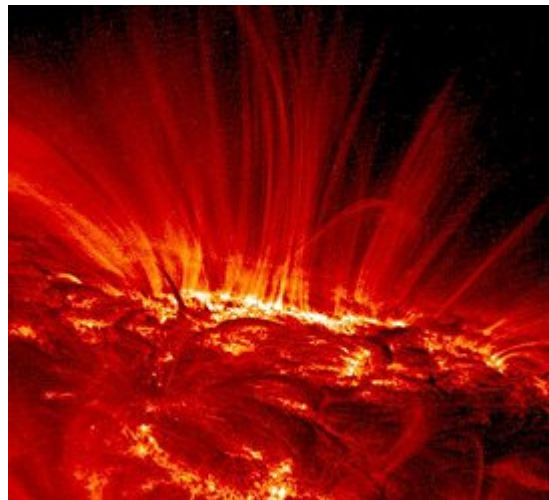
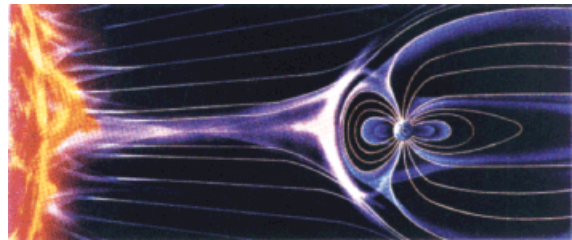
Introduction to Space Weather

We may have been taught that there is a friendly, peaceful nonhostile relationship between the Sun and the Earth and that the Sun provides a constant stream of energy and warmth to our planet. In fact, ancient people worshipped the Sun as a god and bringer of life. To the unaided eye, the space between the Sun and Earth appears to be a vast, dark void, and the Sun is a static, unblemished fireball. And...Not So Fast!

Space weather begins inside the Sun and ends in the circuits of man-made technologies. Simply defined, space weather is a range of disturbances that are born on the Sun, rush across interplanetary space into Earth's neighborhood, and disturb the environment around our planet and various technologies—cell phones, satellites, electric power grids, radios—operating in that environment. From Storms from the Sun, Carlowicz and Lopez

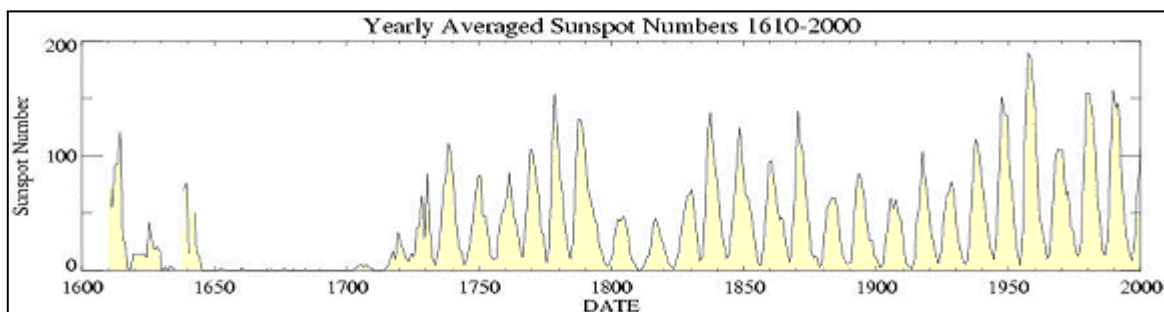
The Sun

The space between the Sun and Earth is **NOT** a static void. The Sun, like all stars, is a gigantic nuclear reactor, converting 700 million tons of hydrogen per second into 695 tons of helium and energy. The high temperatures cause atoms to collide, stripping off electrons and forming a plasma. We on Earth are not very familiar with plasmas but they are the most common form of matter that we see in the Universe. Plasma is the form of matter in stars. A solar wind, consisting of a stream of high-energy particles, strong electric and magnetic fields, and plasma, is showered throughout the solar system. Sometimes this intense energy which is confined by the Sun's complex magnetic fields (described as knots) becomes uncoiled like a spring and erupts spewing massive streams of particles with speeds of over 1 million km/hr, causing massive disruptions on Earth. The Sun blows this plasma continuously and some of it can come close to the Earth. The solar atmosphere has changeable weather and a dynamic climate with the cosmic equivalent of winds, clouds, waves, hurricanes, and blizzards.



The Sun's interior and exterior layers rotate at different speeds, and this creates rivers of hot plasma flowing beneath the surface. Since plasma consists of charged particles and moving charges (electric fields), it creates magnetic fields. Since plasma consists of charged particles, it creates magnetic fields and these fields interact with each other to create complex magnetic fields. Since moving magnetic fields create electric currents and plasmas conduct electric currents, the Sun has complex intertwined magnetic fields responsible for diverse behaviors from sunspots, solar flares, and coronal mass ejections, CMEs. This complex electric and magnetic behavior is responsible for various solar cycles in which sunspots are but one. Other phenomena, solar flares, CMEs and geomagnetic storms, have their own cycles. An excellent site for more details is:

<http://www.haystack.mit.edu/atm/resources/index.html>

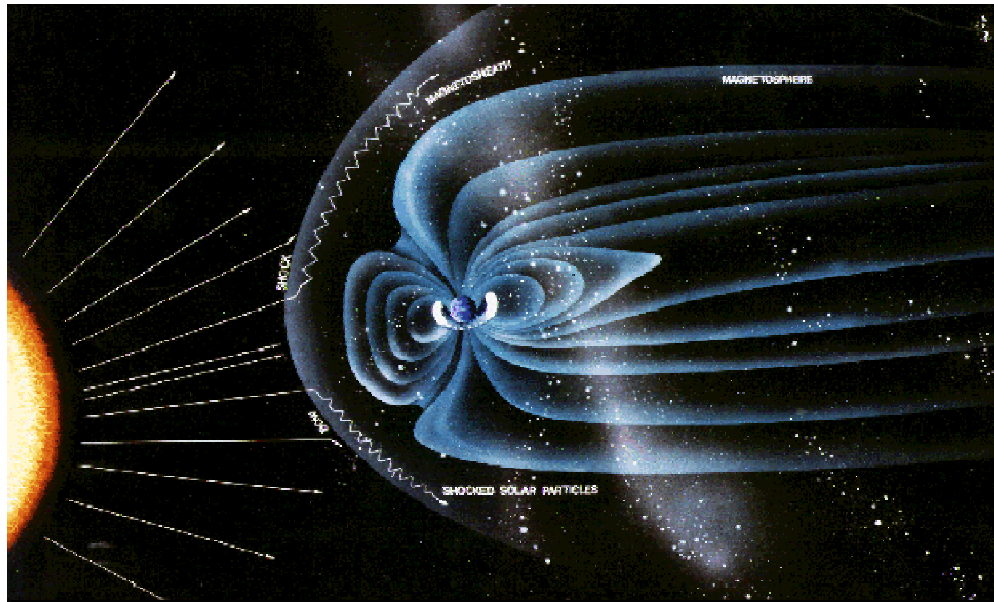


Space weather begins in the Sun's corona, starting just above the Sun's surface to millions of miles away from the Sun. The corona has magnetic loops with flowing plasma and holes that stretch out into space as high speed solar wind moving over one million mph carries one million tons of matter per second into space. When the material moves toward the Earth, it hits the Earth's magnetic field, the magnetosphere, and 99% of it is deflected. The one percent and its magnetic field interact with the magnetosphere creating global magnetic storms and auroras.

Solar flares occur when the built up magnetic energy on the chromosphere is suddenly released with an accompanied burst of electromagnetic radiation of radio waves, X-rays, and gamma rays, and high-energy material. This causes the Earth's upper atmosphere to heat up, swell, and expand which causes satellites more frictional drag. This frictional drag can cause the satellite to pummel to the Earth.

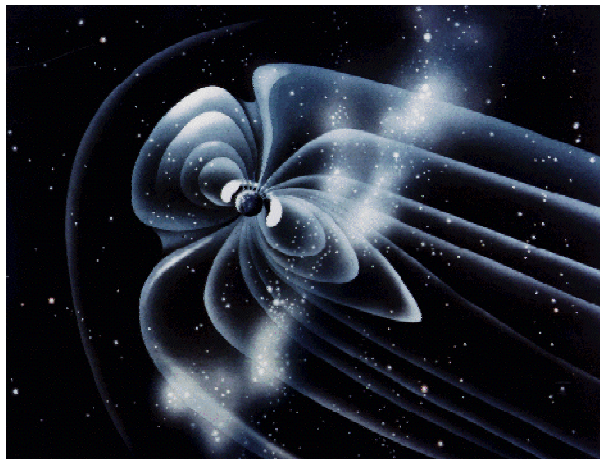
CMEs occur when a large plasma bubble bursts, rupturing the corona sending out 100 billion tons of material and energy traveling 1 to 5 million mph into space. CMEs create a bow shock and particles build up as it ploughs through the solar wind. When it hits the magnetosphere, it flattens it and charged electrons and ions

spiral around it creating disrupting magnetic and electric fields. The magnetosphere couples with the Sun's magnetic and electric fields, heating and expanding the ionosphere. Charge particles move around the magnetosphere and are swept back toward the Earth's night side magnetic field.



<http://science.nasa.gov/ssl/pad/sppb/edu/magnetosphere/mag3.html>

The Earth Magnetosphere



<http://science.nasa.gov/ssl/pad/sppb/edu/magnetosphere/>

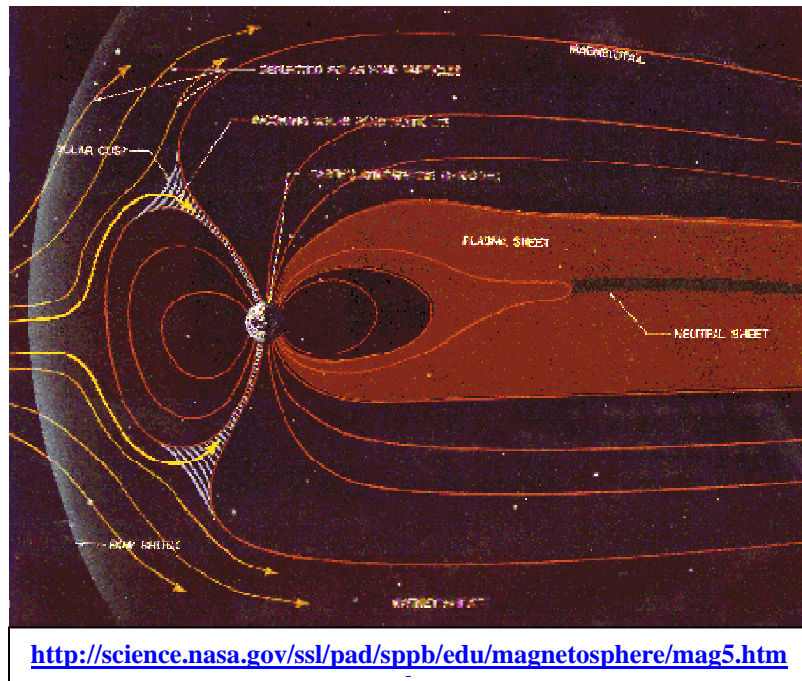
The magnetosphere is described in Storms from the Sun as the Earth's "goalkeeper." High energy particles and solar winds are blocked and deflected from the goal, the Earth. Without the Earth's magnetic field, we would be subject to intense searing radiation and damaging magnetic and electric fields like Mars. The magnetosphere is formed when the solar wind rams into the Earth's magnetic field and compresses the sunward side of the magnetosphere to a distance of 6-15 times the radius of the

Earth while leaving tails on the night side. A supersonic shock wave is created sunward of Earth somewhat like a sonic boom creating a bow shock. Most of the solar wind particles are heated and slowed at the bow shock and detoured around the Earth. Charged particles that reach the Earth do so at the poles. The magnetic

field of the magnetosphere is the result of the combination of the intrinsic magnetic field of the Earth plus those fields due to the flowing electrical currents in the magnetosphere and its boundaries. As the hot plasma sheet flows toward the Earth into an increasing magnetic field, the different motion of the ions and electrons produces a ring current in a radial distance of 3-5 Earth radii. The term "trapped radiation belts" is used to describe the trapped particles in the ring current region.

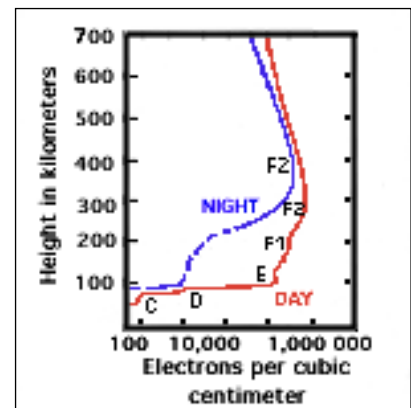
See <http://www.haystack.mit.edu/atm/science/magneto/index.html> for more details.

A map of the magnetosphere is shown. See the site listed in the drawing for more information.

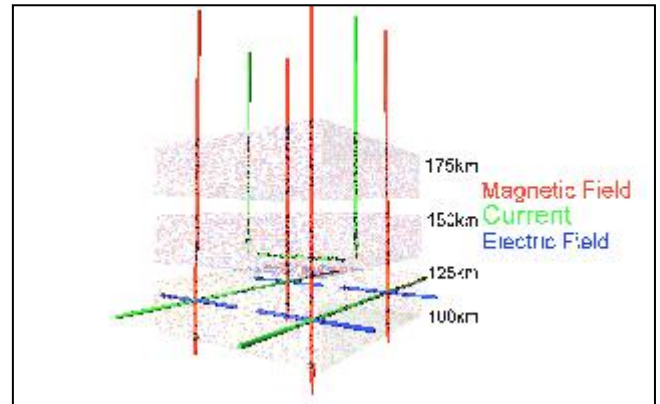
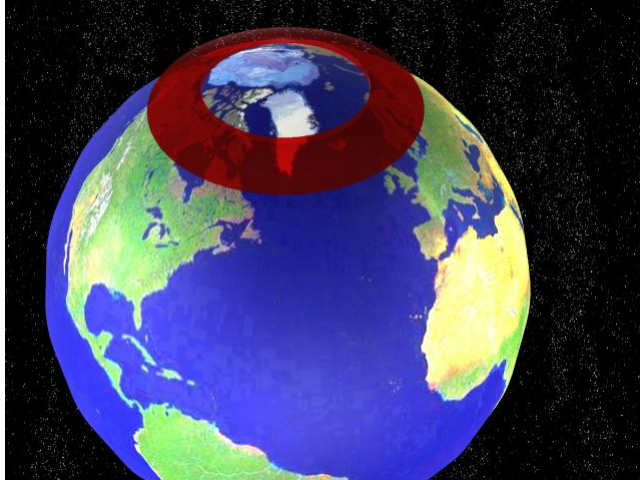


The Ionosphere

The ionosphere is the region surrounding the Earth of ionized charged particles caused by the Sun's ultraviolet radiation. The ionosphere begins at an altitude of about 90 km to over 1000 km into space. There are variations in the composition, density, and physical processes of the ionosphere with altitude and these regions, as they were discovered, are assigned letter names F, E, and D.



Other regions are called auroral zones are caused by ionization of charged particles from the Sun that slip by the magnetosphere. These rings surround both polar caps at latitudes of about 65 degrees and are responsible for the auroras.



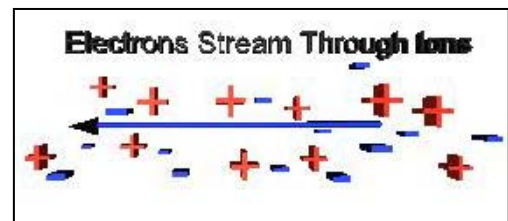
The Auroral Electrojet

Currents of the magnetosphere complete their circuit in the auroral zones, flowing down the Earth's magnetic field lines, through the ionosphere, and then up the field lines out into space. These highly conductive field lines carry electric fields from the magnetosphere into the ionosphere.

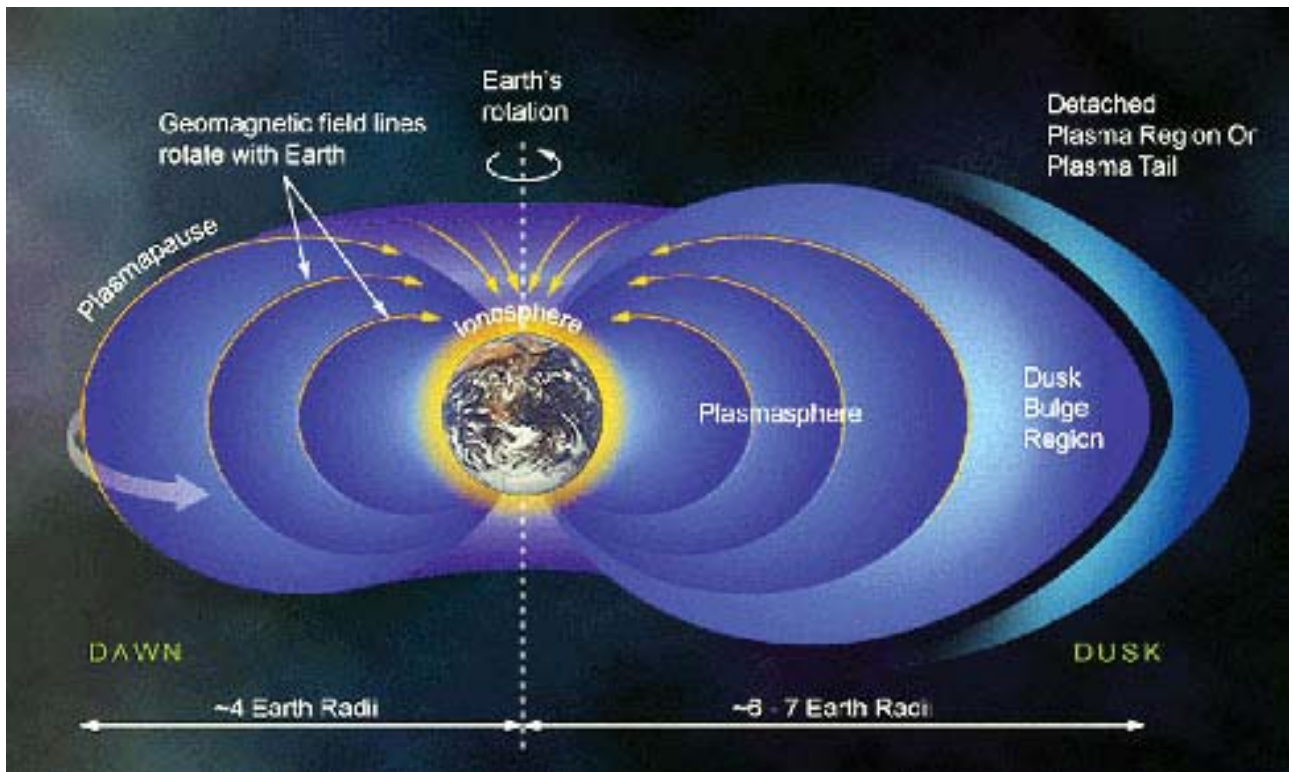
In combination with the Earth's magnetic field these electric fields produce several different types of currents in the ionosphere. One type, known as a Hall current, flows perpendicular both to the electric field and the magnetic field. The strong Hall current in the auroral regions is known as the Auroral Electrojet and it can be extremely intense, especially when bright auroras are being observed.

Ion Acoustic Waves

In the Auroral Electrojet the electrons rapidly move past the ions creating a current. When the electrons are driven to move faster than the sound speed, an unstable situation arises. At this point the rapidly moving electrons can easily cause density perturbations in the surrounding plasma to grow in size. The Ion Acoustic waves that result have frequencies in the range of human hearing. They propagate away from the disturbance at the speed of sound, and perpendicular to the Earth's magnetic field.



These Ion Acoustic waves strongly scatter radio waves of certain wavelengths, and because of this they can be easily observed by ground based radar systems. Incoherent scatter radars can measure the locations, velocities, and characteristic shapes of these waves and these observations can be related back to the processes that created them. (From: Physics of the Ionosphere: <http://rrsl.ee.washington.edu/ionosphere.htm>)



However, in spite of the awesome power of solar activities described above, life on Earth is fairly safe but the space around the Earth and the upper atmosphere is **not**. As a result, radio and TV communications, satellites, and electric power transmission are all affected.

The Effects of Space Weather

Some of the major effects of space weather will be summarized below.

- A. Satellites: Satellites can be slowed down and dragged down into the Earth's atmosphere and burn up. Because radio communications are interrupted, signals to booster rockets may not work. Damage to the components due to intense radiation on the electronics can occur. The satellite may be completely or partially inoperable due to radiation damage.

- B. Moving plasma, which consists of moving charged particles, causes large magnetic field fluctuations which power lines pick up. Power surges cause damage to power lines, transformers, and power grids. In some cases causing massive blackouts or brownouts. Manufacturing processes reliant upon electricity can be damaged.
- C. Radio Communications: Radio communications rely upon bouncing signals off the ionosphere. During solar storms radio blackouts are due to the disruption of the ionosphere which becomes rippled, compressed and elongated. Radio communications can be lost or misdirected. Communication from satellites can be lost and systems like the GPS can become completely unreliable.
- D. Life threatening radiation can disable or kill astronauts, for example, in space stations, shuttles, or in rocket ships.

In summary, a few years ago almost no one knew about space weather. It is, however, an important area of science to investigate because of its drastic influence upon our modern lives. A good article on The Solar Wind—Magnetosphere—Ionosphere System can be found at:

<http://www.sciencemag.org/cgi/reprint/288/5473/1987.pdf>

