For the Teacher
Introductory PowerPoint

Slide 1

Though the source of space weather is the sun, it is important to note that the solar energy responsible for space weather is a very small fraction of the total energy released by the sun. Of far more importance is the energy transfer through radiation responsible for heating the earth. However, this educational unit emphasizes that this small fraction of energy can, at times, have profound effects on our way of life.

Slide 2

The sun transfers energy to the earth through radiation. The sun emits electromagnetic radiation across the entire EM spectrum. This energy travels to the earth at the speed of light (an approximate 8 minute trip). Our atmosphere reflects or absorbs most of this radiation. The remainder reaches the earth's surface and is mostly within the visible, radio, and ultraviolet frequencies. The earth surface is heated by absorbing this energy.

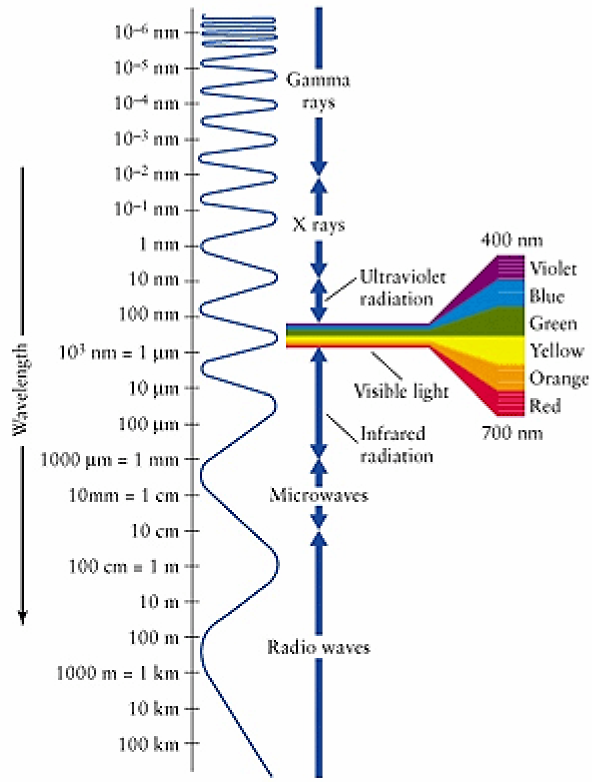

Image courtesy of NASA

An excellent additional web-based reference for students on the Electromagnetic Spectrum is http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html. This site includes a image of a detailed breakdown of the spectrum including everyday applications.

Slide 3 – The Solar Wind

The sun emits highly charged particles (protons and electrons) into space which form the solar wind. This wind creates a bubble around our solar system that extends well beyond the planets. The heliopause is the area of space where the solar wind is less dominant than the particles in interstellar space. This defines the physical end of the solar system.

The solar wind is thought to originate at the edges of convection cells on the sun's surface. Large fluxes of particles are released through coronal holes, which are dark cool areas within the sun's corona. When coronal holes face the earth, we can expect solar wind densities to increase 2-3 days later.

The density of the solar wind is very low. Its density is much less than the best vacuums achieved on earth. Its density fluctuates as the sun goes through its constant dynamic changes. The velocity of the solar wind is also variable depending upon the "push" from solar activity.

The solar wind carries with it the interplanetary magnetic field (IMF). The IMF is really an extension of the sun's magnetic field into interplanetary space. The strength and direction of the IMF within the solar wind is directly related to the magnetic properties of the solar wind source. The earth's magnetic field, called the magnetosphere, points northward. If the direction of the IMF carried by the solar wind is northward, then the charged particles are deflected by the magnetosphere (like two north pointing magnets). If the IMF points southward, then the magnetic field lines join together. Solar wind particles enter the magnetosphere, and through the process of magnetic reconnection, are energized, and enter the earth's atmosphere.

Tails of comets point away from the sun due to the existence of the solar wind.

Slide 4 – Sun Structure

The sun is an average sized star. It consists of approximately 94% hydrogen, 6% helium, and less than two tenths of a percent of other elements. It is over 100 times wider than the earth and over 300,000 times more massive. Over 1.3 million earths could fit inside the sun. Because of its mass and the force of gravity, nuclear fusion occurs within its core.

Slide 5 – The Core

The core occupies the first 25% of the distance from the center. The temperature ranges from 15,000,000 K in the center to 7,000,000 at the outer edge of the core. Its density changes from 8 times that of gold at the center to the density of gold at the outer edge. It is the combination of its temperature and density that creates the environment for nuclear fusion.

The core is a plasma. At core temperatures, electrons are stripped from atoms, and highly energized protons collide with one another to begin the fusion process

Slide 6 – Fusion

Six hundred million tons of hydrogen are fused each second, and 4 million tons of matter is converted to energy each second.

The fusion process can continue on the sun for another 7 billion years.

During the fusion process, 4 hydrogen (H) nuclei eventually become a helium-4 (^4He) nucleus. The mass lost in this process is converted to energy according to Einstein's equation $E = mc^2$.

An excellent reading on the fusion process can be found at
http://138.238.143.191/astronomy/Chaisson/AT416/HTML/AT41605.htm

For an animation of the fusion process, see proton-proton cycle section of
http://www.kingsu.ab.ca/%7Ebrian/astro/course/lectures/fall/a200l11a.htm

Slide 7 – Radiative Zone

Plasma of ionized hydrogen and helium atoms

Temperature decreases from 7 million to 2 million K within this zone. Energy from the core is absorbed and re-emitted from atom to atom.

Slide 8 – It's a LONG Road

As the energy travels toward the surface of the sun, it is constantly absorbed and re-emitted at lower and lower temperatures. The direction of the energy as it is released is random (has no specific outward direction). Therefore the time for energy generated at the sun's center to reach the surface is estimated to be thousands to millions of years.

If we could magically shut off fusion at the core, the sun would continue to shine for this same travel time.

Once at the surface, the energy takes only 8 minutes to reach the earth.

Slide 9 – Convective Zone

At this point, the nuclei are able to hold on to electrons, and atoms and ions are formed. Photon energy has decreased such that the gaseous atoms and ions hold on to the energy instead of re-emitting it. Their energy increases resulting in convection currents carrying the energy to the surface.

All the energy emitted at the surface of the sun is carried there by the convective zone. The energy transport from the radiative zone to the surface takes approximately 3 months.

Slide 10 – Photosphere

The photosphere is approximately 100-300 km thick (very thin compared to the radius of the sun). Within it, features such as sunspots and granules can be observed.

Slide 11 – Solar Granules

Of particular interest are solar granules, which prove the existence of the convective zone. The dark edges of the granules are cooler regions where gases are moving back into the sun's interior.

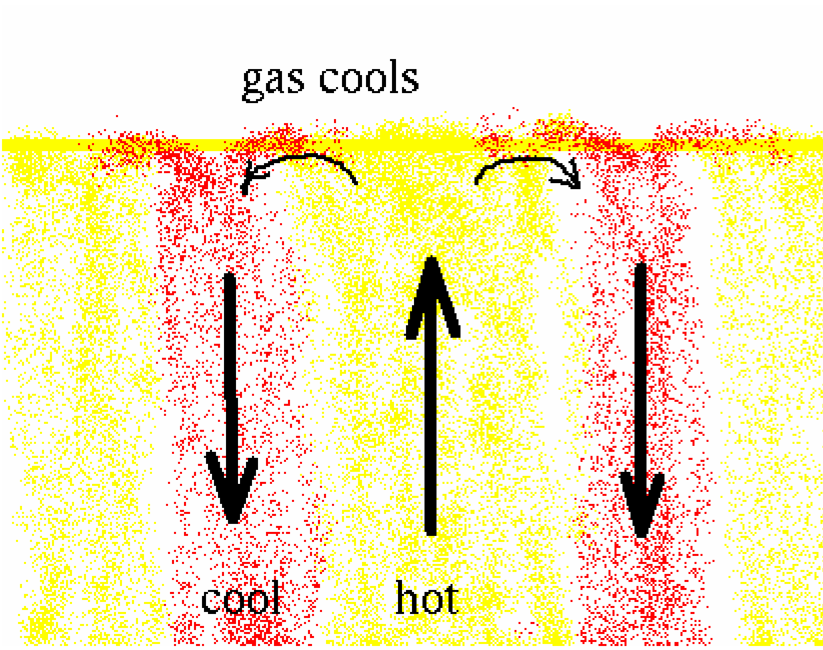

Image courtesy of David Soper, University of Oregon

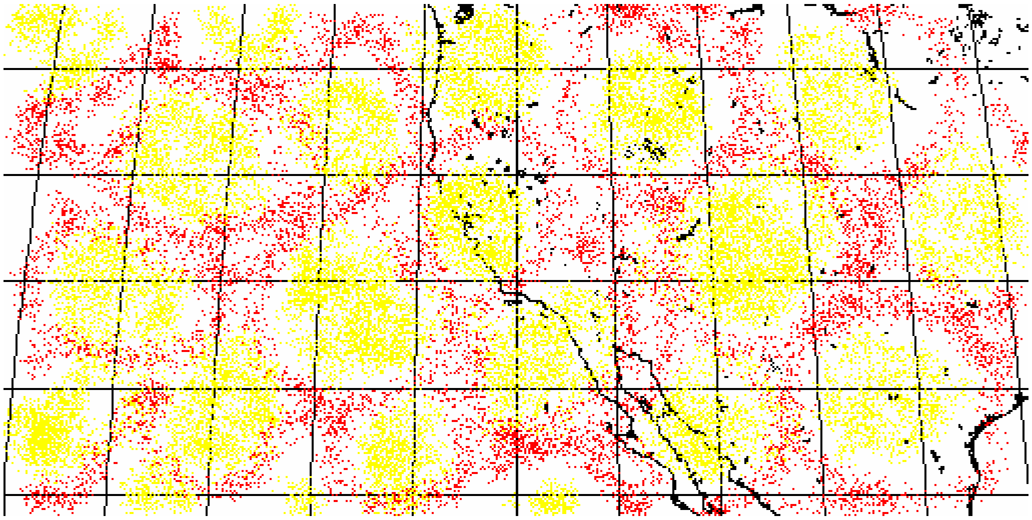

Image courtesy of David Soper, University of Oregon

Slide 12 – Corona

The corona is a plasma atmosphere of the sun, extending millions of kilometers into space. It can only be seen during a solar eclipse, or through the use of a coronagraph telescope, such as the LASCO telescope on the SOHO satellite.

The temperature of the corona has been estimated to be from 1 to as much as 3 million degrees K, much hotter than the adjacent photosphere. The reason for this increase in temperature is not fully understood.

The complexity of the magnetic fields reaching into the corona is evidenced by coronal loops and prominences, which often have their beginnings around sunspots. It is within the corona that solar flares and CME's occur.

Coronal holes are darker areas of the corona with open magnetic field lines, allowing considerably more solar material (protons and electrons) to be deposited into the solar wind.

Slide 13 – Solar Events

These three main solar events will be studied for their considerable effects on space weather.

Slide 14 – Sun Spots

Sunspots are cooler regions of the photosphere that appear darker than the surrounding photosphere. It is thought that strong magnetic fields inhibit the convective flow of material in these areas.

The number of sunspots follows an 11 year average cycle. Solar activity, and therefore the severity of space weather, is directly correlated to the sunspot solar cycle.

Slide 15 – Solar Flares

Flares are powered by a sudden release of magnetic energy within the corona. This energy release is in the form of radiation across the entire electromagnetic spectrum. They typically occur around sunspots where there are areas of intense magnetic fields.

Frequency of flares can be several per day at solar maximum, to one per week during solar minimum.

Solar flares are classified as A, B, C, M or X according to their intensity, X being the most violent.

The x-ray and ultraviolet radiation released by a flare can cause an increase in the ionization of the atmosphere. This increase in the ionosphere can disrupt radio communications, as well as create an increase in the drag of low orbit satellites.

Solar flares release a cloud of particles called a proton storm. These particles can travel to the earth in a matter of hours, and pose a biological risk to astronauts.

Slide 16 Coronal Mass Ejections

With respect to space weather, CME's pose the greatest threat to the earth. They are more frequent around solar maximum and are typically associated with solar flares.

CME's send a shock wave of very energetic particles through the solar wind ahead of the actual CME material. This shock wave can pose a radiation risk to astronauts.

The actual CME material typically arrives 1-3 days after the CME is observed. The polarity of the magnetic field embedded in the CME greatly determines its influence on the magnetosphere of the earth.

Slide 17 – The Structure of the Earth

Slide 18 – The Ionosphere

The ionosphere is considered to extend 1000 km above the surface of the earth. It is broken down into the D, E, and F regions. The D region is a weakly ionized region which disappears (becomes neutral) at night. This phenomenon explains the increase in AM radio range after sunset.

Its properties (thickness, density, temperature, movement) are dynamic and are often closely related to space weather and therefore solar activity. It is these changes that can, for example, cause disruption of satellite communications, increased drag on satellites, and disruption of radio communication.

Slide 19 – The Magnetosphere

The Earth's magnetosphere is a region in space whose shape is determined by the extent of Earth's internal magnetic field, the solar wind plasma, and the interplanetary magnetic field (IMF).

The sun side of the magnetosphere can range from 6 – 10 earth radii, while the night side is possibly 1000 earth radii in length. The compression of the sun side is due to the solar wind. During significant solar events (CME's, solar flares) the compression can be more pronounced, leaving satellites that are normally protected by the magnetosphere exposed to the solar plasma.

Of particular concern is the orientation of the IMF carried by the solar wind. A predominately southward orientation of the IMF allows the magnetic field lines of the earth and the IMF to combine, injecting more solar plasma into the ionosphere.

It is important to note that the Earth's magnetosphere is responsible for maintaining our atmosphere. The solar wind would tear the atmosphere from the planet were it not for the protection of the magnetosphere. An example of this would be the planet Mars, which has very little atmosphere due to no significant magnetic field.

Slide 20 – Space Weather

Space weather is the condition of interplanetary space that is influenced by the sun. It is important to note that space weather affects other planets as well (Mars example above). Auroras are observed on other planets, such as Jupiter and Saturn.

Space weather is greatly influenced by the condition of the solar wind as well as significant solar events such as CME's and solar flares.

Spaceweather.com is an excellent source of data and information on current space weather conditions.

Slide 21 – Aurora

Auroras are caused by electrons streaming down the open magnetic field lines at the poles. These electrons give up energy when they collide with atmospheric gases. The gases release this energy as light.

Like other space weather phenomena, the frequency and intensity of aurora is closely related to the solar cycle and current solar activity. For example, when high solar wind plasma density is associated with a southward IMF, particles are added to the magnetosphere tail. Through the process of magnetic reconnection, electrons and ions are pushed into the Earth's atmosphere which increases auroral activity.

Auroras occur at approximately a 100 km altitude.

Slide 22 – Satellite, communications and power disturbances

This slide highlights some of the disruptions which are associated with solar storms. Radiation from solar flares can pose biological risks to astronauts and airplane passengers. Changes in the ionosphere due to increased radiation and increased solar wind flux effect satellite communication, therefore affect the reliability of such technologies as cell phones, GPS, and television. Also these changes can result in a swelling of the ionosphere which can increase drag on low orbiting satellites.

Geomagnetic storms can induce current surges within electrical grids, causing electrical transformer malfunctions, which lead to black-outs.