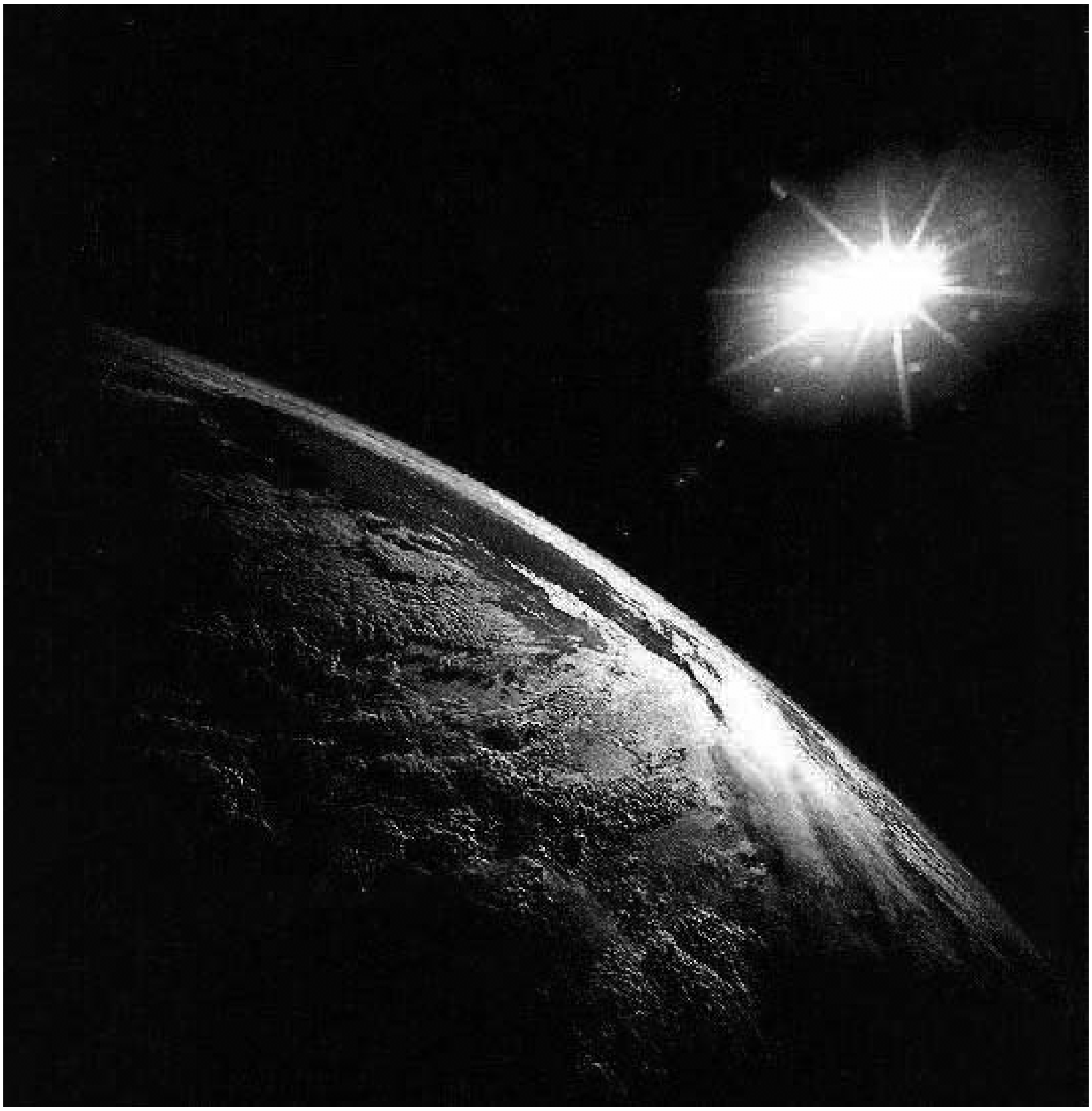
Making Sun-Earth Connections:



Background Information

[For use with versions 6-8 and 9-12]

Making Sun-Earth Connections

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Note: The following supplementary information can be found on the ***Making Sun-Earth Connections CD*** and on the ***Solar Day Website***:

- **Background Information**
  (correlates with versions 6-8 and 9-12)
- **Internet Resources**
- **Glossary**

Slide 1
Introduction

To the naked eye the Sun never changes. Today, many new and exciting discoveries are being made as we use satellites to look at different frequencies of the spectrum and computers to analyze the data. Now we know that the Sun does change, and that the changes are dramatic. For instance, storms on the Sun are thousands of times larger than the Earth itself, and they are more powerful than billions of atomic bombs. NASA is committed to the study of the Sun and has many missions underway to extend this study.

Slide 2
Main Areas of Research

Space Science/Technology

The Ulysses spacecraft was launched from the Space Shuttle *Discovery* on October 6, 1990 on its mission to study the solar wind. This mission required speeds that had never before been attained. Soon, other spacecraft will be designed to study the heliopause and will travel ten times further than any vehicle has traveled. One such mission, the Solar Probe, will be launched in 2007 and will travel 2 million kilometers from the Sun. As a result of such studies of our Sun, we have a better understanding of other stars in our universe.

Human Exploration and Development of Space

HEDS is dependent upon three factors; the ability to reach a given destination, the ability to perform the required tasks, and the ability to return. A full understanding of the Sun s processes will reduce human risk and enhance mission success.

Earth Science

Virtually all energy sources on Earth are the result of the Sun-Earth interaction. This interaction also affects weather systems including the nitrogen cycle, the water cycle, and the carbon cycle.

Slide 3
Importance of Space Technology

Science drives the development of the technology used to study the Sun-Earth system. Various satellite instruments are designed to study the interior of the Sun, its surface and corona, the solar wind, and the Earth s magnetosphere.

- Spectrometers are deployed on satellites with wavelengths ranging from the visible to the extreme ultraviolet.
- Space physicists depend on telescopes to detect visible light, ultraviolet light, gamma rays, and X-rays.
- Particle detectors are used to count solar wind particles, magnetometers to record changes in magnetic fields and cameras to observe auroral patterns.
- The Michelson Doppler Imager (MDI) provides magnetic field maps to show the complete record of eruption and distribution of photospheric magnetic fields.
- Radio receivers and transmitters are needed to detect shock waves created by coronal mass ejections and the solar wind.

Slide 4
Sun s Internal Structure

The structure of the Sun is a very complex system. The Sun s processes are not fully understood by today s scientists. However, the following list contains facts about the Sun that are universally agreed upon based on current measurements and data.

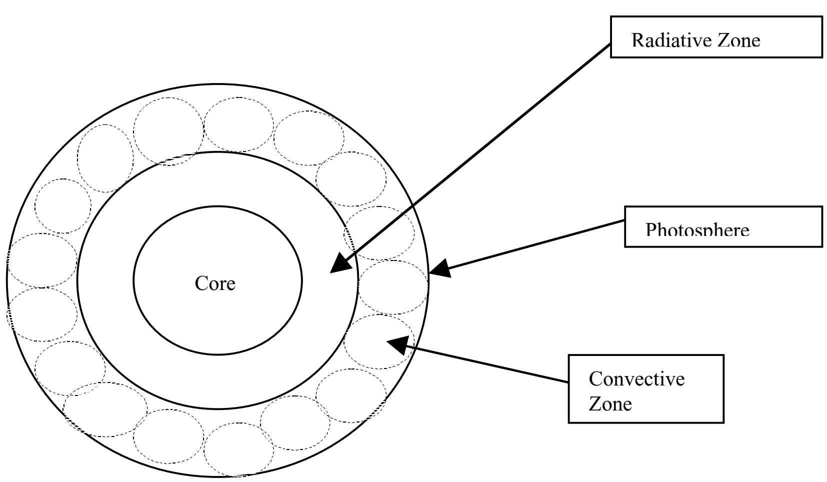
- The composition of the Sun is approximately 73 % hydrogen and 25 % helium. Many other elements make up the Sun, but their percentage composition is less than 2 %.
- The mass of the Sun is 332,831 times that of the Earth.
- The Sun releases large amounts of energy. Its luminosity is 383 billion billion megawatts.
- The power source for the Sun is the fusion of hydrogen atoms into helium.
- The Sun releases energy in all wavelengths of the electromagnetic spectrum, from radio waves to x-rays.
- There are different regions of the Sun.

The center of the Sun, the core, has an approximate temperature of 14,000,000 Celsius degrees. This energy is the result of fusion, a process that powers the Sun. In a fusion reaction the nuclei of hydrogen atoms fuse in a series of reactions to form the nucleus of the helium atom. Energy is radiated from the core in the form of light energy in various wavelengths, mostly gamma rays. Photons released from the core tend to take a long time to reach the surface of the Sun. It is estimated that these photons take hundreds of thousands of years to reach the surface. There are few measurements that have been made about the core and much of our knowledge of the core is the result of inference and secondary information.

The radiative zone surrounds the core of the Sun. In this zone it is too cool for fusion to take place and too hot for convection to take place. Light radiation streams through this region carrying the energy of the Sun with it.

The region outside the radiative zone is known as the convective zone. Parts of this zone rotate much faster than other parts. There are very turbulent and unusual interactions in the plasma of this zone. There are streams and currents that move horizontally with respect to the general flow of energy outwards. Through the use of Michelson Doppler Imaging, MDI, scientists have been able to determine the rate and direction of plasma motion. MDI enables scientists to determine the temperature and rotation of the Sun at various places above and below its surface, by measuring how the surface layers vibrate over time.

- *In the slide the two small pictures at the bottom represent MDI data in reference to temperature and rotation.*
    - *The picture on the right shows temperature with blue being coolest and red hottest. It is also possible to see where convection cells have been pencilled in.*
    - *The picture on the left shows rotation where red is rotating fastest and green is rotating slowest. It is easy to see how complicated the Sun s systems are.*



As one would expect, temperatures decrease from the core toward the photosphere. The temperature difference between the photosphere and the corona, or atmosphere of the Sun, is quite extreme. The photosphere is about 5,500 degrees Celsius. However, the corona is about a million degrees hotter. The reason for this is not yet understood, but this fact alone implies that there is much more to learn about the Sun.

Slide 5
Surface and Atmosphere of the Sun

A list of surface features follows that includes more detailed information:

Photosphere - The visible surface of the Sun.

- This is the boundary where the Sun goes from being opaque (internal) to being transparent (external) to visible light. There is a large quantity of gas and plasma that is above the photosphere, but the photosphere is often used interchangeably with the surface of the Sun. The photosphere gives off light primarily in the visible range, also in other wavelengths like UV (skin cancer, ozone).

Chromosphere - A transitional layer that is between the photosphere and the corona.

- It is hotter than the photosphere but cooler than the corona.

Corona- A layer of the Suns atmosphere where individual neutral gas atoms and plasma particles can travel long distances without colliding.

- The molecules and particles can move around freely without bouncing into other particles and atoms. The temperature of the corona is approximately a million degrees Celsius. The corona gives off light strongly in the UV and X-ray portions of the spectrum.

Heliosphere- A huge space that encloses all areas where the density of the solar wind exceeds the density of the interstellar medium.

- It extends far out beyond Pluto; the voyager spacecraft is now beginning to see the outer edges. Some scientists consider this boundary to be the outer limit of the Sun, although most of this space is, for all intents and purposes, empty.

Sunspot- A cooler area on the photosphere of the Sun.

- These Sunspots are also associated with hotter areas in the chromosphere where magnetic fields heat the gas. Furthermore, the corona tends to be hotter directly over Sunspots.

Coronal Hole- An area of the corona that is cooler than the rest.

- They are usually found near the poles of the Sun and give off less light in the UV and X-ray frequencies. The magnetic field lines from coronal holes extend far out into the heliosphere, so hot gases can easily escape into space.

Prominence- A dense blob of plasma that separates from the photosphere and shoots up into the corona.

- Prominences are also called filaments depending on the perspective of an observer. If viewed on the edge of the solar disk they are called prominences, otherwise they are called filaments.

Slide 6
Sunspots

Sunspots are cool areas that appear dark on the solar photosphere. These Sunspots actually give off light, but they are cooler and thus appear as dark areas on the Sun s surface. When observed over a short time frame, the Sunspots might appear random; however, more than a century of Sunspot observations has shown that the activity is cyclical. Approximately every eleven years the Sun cycles between periods of solar maximum and solar minimum. During solar maximum there are more Sunspots than during solar minimum. Sunspots form near the equator at solar maximum and near the poles at solar minimum. Other features such as solar flares, coronal mass ejections (CME) and solar prominences show a noticeable increase in number.

Plague regions or hot spots are substantially larger than Sunspots in size and consist of energy flowing out from the lower layers of the Sun that is temporarily blocked by the presence of Sunspots. These hot spots are harder to see, visually, than the darker Sunspots. During times of solar maximum there are many Sunspots and the Sun actually gives off slightly more energy from these hot spots than during times of solar minimum.

It is believed that both Sunspots and other types of solar activity are the result of the Sun s magnetic field becoming tangled as it wraps around the Sun. The central region of the Sun rotates faster than the poles and this results in a stretching of the magnetic field, which becomes tangled. This tangling results in reconnections of magnetic field lines and during the maximum the Sun may have several magnetic north poles and an equal number of magnetic south poles.

- *The animation in the upper left hand corner demonstrates the solar magnetic field lines twisting and tangling as a result of the differential rotation speed of the Sun.*
- *The movie in the middle shows a Sunspot as it appears on the photosphere.*
- *The image in the upper right hand corner is a computer image of a Sunspot using Michelson Doppler Imaging (MDI). Notice that the influence of the Sunspots on surrounding solar materials goes 20,000 or more kilometers below the surface of the Sun.*
- *The graph on the bottom shows one hundred and fifty years of Sunspot activity outlining the cyclical pattern of appearance of solar maximum and solar minimum.*

Slide 7
Solar Flares

Unlike Sunspots, solar flares appear as bright spots on the photosphere. The active regions are areas that connect strong magnetic fields. It is believed that flares form when the magnetic energy build-up in the Sun s atmosphere is suddenly released. The build-up of magnetic energy is due to the twisting, reconnection and formation of magnetic field loops. Much like twisted rubber bands, these will eventually break releasing energy. The released plasma blasts particles towards Earth. The radiation encompasses the entire electromagnetic spectrum from radio waves to gamma rays. Additionally, the magnetic energy heats and accelerates the particles in the solar atmosphere including electrons, protons, and heavy nuclei.

The solar flare develops in three stages.

- **Precursor stage** - magnetic energy is triggered with the detection of soft X-ray emissions.
- **Impulsive stage** - protons are accelerated with the emission of radio waves, hard X-rays and gamma rays.
- **Decay stage** - soft X-rays emitted.

Flares extends out to the corona and can reach temperatures between ten to twenty million degrees Celsius. The energy released is analogous to ten million volcanic eruptions or millions times more energy than the largest earthquake. An average size flare releases enough energy in one hour to power the United States for ten thousand years. The eruptions last from a few minutes to hours and can trigger nuclear fission and fusion for short periods of time, outside the core of the Sun.

Slide 8
Coronal Mass Ejection

Solar flares have electromagnetic energy and little effect on the Sun s magnetic field, while CMEs, containing plasma particles, can have a measurable effect on the Earth. The coronal plasma organizes itself into what is called a streamer, or helmet streamer. This organization is due to forces exerted by the Sun s magnetic field. Since solar flares occur deep in the chromosphere they have relatively little effect on these streamers or the magnetic field that contains them. A significant amount of their energy actually rebounds into the Sun in the form of pressure waves. It is easiest to see the Sun s magnetic field at solar minimum or during other times of relative quiet.

Slide 9
Solar Cycles

The eleven-year solar cycle is related to the twenty two-year cycles for the reversal of the Sun s magnetic field. In addition to Sunspot activity, the approach to solar maximum includes an increase in solar flares, prominences and coronal mass ejections.

Helioseismology (Earthquakes and Sun Earthquakes) a rapidly growing field in which the Sun s interior is analyzed using the vibrations that are the result of massive explosions at the surface. These explosions are natural and are called solar flares. Analysis of these vibrations has shown areas where the plasma rotates at different rates. The rapid movement of plasma across this boundary is believed to generate the magnetic field. It is believed that the magnetic fields are formed in the boundary between the circulation of plasma by convection currents and the inner regions where convection does not occur. The plasma emerges into the corona and the erupted magnetic fields migrate towards the poles. During the eleven-year cycle this results in the neutralization and reversal of the global magnetic dipole of the Sun. This explanation is being revised as additional images and data are collected from satellite-borne telescopes using shorter wavelengths such as extreme ultraviolet and X-rays. In addition to Sunspot activity, the approach to solar maximum includes an increase in solar flares, prominences and coronal mass ejections and a tangling of the Sun s magnetic field.

- *The video clip on the left shows the Sun s activity increasing from 1996 to 2000.*

- *The image in the upper right is a series of coronal images showing the progression from solar maximum to minimum. This image also shows a noticeable increase in solar activity.*
- *The images on the lower right show a comparison of the corona at solar maximum to that at solar minimum. The solar maximum shows an increase in coronal activity in all directions while the solar minimum shows the activity predominately in the equatorial region of the Sun.*

Slide 10
Solar Wind

Charged particles called plasma are blown away from the Sun at high speeds in all directions. This is called the solar wind. By the time this wind reaches the Earth it is not concentrated. In comparison, the lowest pressures that are attainable in the best vacuum chambers in laboratories on Earth are millions of times more concentrated.

The sum total of the mass of the solar wind is enormous. One of the results of the solar wind is a structure called the current sheet. This is not a structure that can be seen because it is too diffuse; however it is the largest coherent structure in the heliopause. It is roughly centered on the Sun and extends outwards until it reaches a point where its density is the same as that of the inter-stellar medium. No measurement has been made of its final limit, but it extends far past the orbit of Pluto.

The solar wind carries a substantial amount of energy. The particles that make up the solar wind, individually, have a great deal of energy. The solar wind that is ejected from the poles has an average speed of 800 kilometers per second; while the solar wind that is ejected from the equator has an average speed of 400-500 kilometers per second. These particles travel in clouds and contain significant amounts electromagnetic energy. This can distort the Earth s magnetic cavity (magnetosphere), squeezing the dayside and extending the tail.

- *The movie clip in the lower right hand corner demonstrates the distortion of the magnetosphere.*

Slide 11
Solar Sail- Interstellar Exploration

Sunlight, which is made up of photons, will be used in the next ten years to propel an interstellar vehicle beyond our solar system. NASA scientists believe that such a spacecraft could be launched using the pressure of the Sun s light. It would travel ten times the speed of the space shuttle in orbit; traveling toward the stars at ninety kilometers per second.

One concern in designing a solar sail is finding a material that is strong, lightweight and that could be unfurled in space. A leading candidate is a carbon fiber material whose crisscross nature makes it strong and extremely low in density. The use of carbon will allow the sail to withstand the intense heat from the Sun. The material will be tested under harsh conditions to simulate the space environment. In addition to photon propulsion, scientists and engineers are considering the use of high-powered lasers or microwave transmitters to provide additional thrust. The lasers or microwave transmitters would be directed toward the sail for a few weeks in order to add to the photon propulsion. This method is predicted to accelerate the sail to one hundred G s; one-tenth the speed of light.

The Solar Sail Technology Program plans to launch a flight demo in 2005 followed by the Interstellar Probe in 2010. The Interstellar Probe is a sail propelled craft expected to travel through our solar system. The mission is the joint effort of the Marshall Space Flight Center and NASA s Jet Propulsion Laboratory. The development of the solar sail will allow space travel otherwise not possible via chemical propulsion.

Slide 12
Earth s Magnetosphere

- **Bow Shock** - flanks the magnetosphere, on the day side, and partially deflects the solar wind. It causes a sudden transition of the solar wind, causing it to become more turbulent through sudden changes in temperature and density.
- **Magnetotail** - elongated region of the Earth s magnetic field extending away from the Earth, on the night side- changes in the magetotail cause brilliant aurora at the poles.
- **Cusp** - separates the magnetic field lines- north to south. This is an area of weak magnetic field that allows solar wind particles into the region, some interact with the Earth s upper atmosphere.

- **Magnetopause** - boundary where the inside pressure of the magnetosphere and the outside pressure of the solar wind are equal.
- **Magnetosheath** - region of very turbulent plasma between the bow shock and the magnetopause extending about two Earth radii in thickness.
- **Van Allen Belts —** Doughnut-shaped regions encircling Earth and containing high energy electrons and ions trapped in the Earth s magnetic field.

Slide 13
Coronal Mass Ejection:
Crossing the Earth s Path

When active regions on the Sun erupt, due to strong unbalanced magnetic forces on its surface, they carry plasma from the corona into space (Coronal Mass Ejections). This ejected plasma usually carries with it a prominent helical magnetic field in a huge structure called a magnetic cloud. (Such a field structure is shown in the figure to the right.) The internal (red) helical lines are like stretched out bedsprings. The green region represents Earth s magnetic field lines imbedded in the magnetic cloud at this time.

CMEs launch on the order of 1×10^{13} kilograms of material away from the Sun. One can see from the slide the size of these events in comparison to the Earth. The particles that are released from the Sun move in a clump or wave and have their own magnetic field. This number of charged and energetic particles moving together can have effects all along their path.

Slide 14
Coronal Mass Ejections:
Impact on Earth

There is a strong interaction between CMEs and the magnetic field of Earth. After traveling for about three days from the Sun, this cloud of plasma collides with the magnetosphere and can compress it. This compression does not occur during every CME, only those that carry sufficient energy. Most of the charged particles are diverted by the magnetosphere and travel to regions behind the Earth.

Under certain conditions the energy carried by the solar wind can enter the magnetosphere. This energy is converted into electromagnetic energy through further distortion of the magnetic cavity, squeezing the dayside and extending the tail. This energized magnetosphere becomes unstable, and the stored energy in the long tail is released suddenly. Some of the energy released causes electrons to be accelerated down magnetic field lines toward the atmosphere where they ultimately produce the aurora.

Slide 15
Aurora:
Points of View

Whether or not the auroras can be seen depend on several factors: The best places to see the aurora are in central Alaska, central Canada, and the northern Scandinavia during late evening hours. On rare occasions it can be seen as far south as Florida or Japan. The aurora can only be seen when it occurs at night. When the aurora grown to its peak intensity, it is still not bright enough to be seen in the daytime sky. A sufficient number of electrons must bombard the upper atmosphere so that oxygen and nitrogen emit enough photons for the eye to detect them. Also weather must cooperate, if the sky is cloudy the aurora is not visible.

The northern lights typically seen from the ground are caused by collisions between fast moving electrons and the oxygen and nitrogen in the atmosphere. The electrons impart energy to the oxygen and nitrogen, making them excited. When they return to their normal state each gives off a photon, a small burst of energy in the form of light. Oxygen emits either a greenish-yellow light (the most familiar color of the aurora) or red light; nitrogen generally gives off a blue light.

Slide 16
Aurora:
Lights in Motion

The ringed shaped areas as viewed on the slide are called aurora ovals. These can only be seen from space. The shape of the Aurora depends on the source of the electrons and the magnetosphere and the processes that cause the electrons to precipitate into the atmosphere.

- The use of false color in ultraviolet light is used in this animation. The brighter the color, the more intense the aurora. This particular solar event occurred between July 14th and 16th, 2000.

Slide 17
Space Weather:
Effects On Orbiting Spacecraft

Orbiting spacecraft are easily harmed by manifestations of space weather. One of the most serious effects is atmospheric drag. The orbits of most satellites are in the upper reaches of the Earth s atmosphere. Storms from the Sun bombard the atmosphere with large numbers of energetic particles resulting in atmospheric expansion. The density of gases around orbiting satellites increases creating drag that can pull satellites out of orbit. Satellites experiencing disorientation are no longer able to perform important tasks and have had their missions shortened by this phenomenon.

Slide 18
Space Weather:
Effects on Satellite Sensors

Satellite sensors like the CCD chips in a home video camcorder, are delicate electrical devises. High-speed particles from the Sun can penetrate these devises and cause them to malfunction or corrupt the information they are providing to scientists. Sometimes these particles have sufficient energy to penetrate insulation and can cause serious problems if charge is allowed to build up. Many of the systems onboard satellites that control their solar panels, pointing and communications with the Earth, may no longer function properly.

- *The video clip shows particles from the solar wind hitting the satellite instrument s camera lens.*

Slide 19
Solar Storms:
Effects On Humans in Space

If space flight is to become routine, there must be some way to forecast space weather events. The energetic particles released by the Sun during solar storms can damage sensitive tissues in the body, causing injuries similar to burns. The retinas of the eyes are particularly sensitive.

An astronaut in space during a solar storm can receive radiation dosages that are thousands of times greater than normal background radiation. This exposure to radiation can have long term effects on health including chromosome damage, a weakening of the immune system and possibly even cancer.

Highly energetic positive particles emanating from the Sun can pose a serious threat because of their relatively high mass and energy. These particles can cause severe tissue damage.

Slide 20
Solar Storms:
Effects On Societal Systems

The particles released from the Sun are charged and large numbers of these particles moving in a group carry a substantial magnetic field with them. When these particles interact with the Earth s magnetosphere they can cause perturbations in the ionosphere. Due to the shape of the magnetosphere charged particles tend to be funneled towards the north and south poles. Those particles with sufficient energy disrupt the ionosphere and cause a storm in that level of the atmosphere. These events occur once or twice during a solar cycle.

Disturbances in the ionosphere can cause other problems such as:
- *short wave fadeouts* - blackouts of communication.
- *scintillations* - radio communications to and from satellites can become filled with noise making the signal indecipherable, or add delays to critical timing signals.
- *maximum usable frequency* (MUF) - high frequencies can be lost.

The oceans conduct electricity easily and can carry large electric currents over hundreds of miles. When these currents reach shore, particularly when the crust is nonconductive, voltages can jump into wires and pipelines with potentials measuring thousands of volts.

Other problems can also occur:
- Currents induced in pipelines tend to increase corrosion and shorten the life of the system.
- Organisms such as sharks, pigeons and types of bacteria use the magnetic fields to navigate
- Storms result in ozone depletion, albeit a natural cause and unavoidable.
- Satellites and radio communication can hamper the ability of planes and ships to ascertain their true positions.
- Transformers can overheat and explode. All transformers operating on a network can be exposed to this current resulting in a blackout.

Slide 21
Energy From the Sun:
Driver of Earth Weather

There is another scale of storms that dwarf weather events that occur on Earth; this is referred to as space weather. The Sun s eleven-year cycle of Sunspot activity and coronal ejection result in variations in energy output. It is believed that the sunspot activity modifies climate over time. The combinations of the solar winds and energy output by the Sun are major factors in climate changes and global warming.

- *Images on the slide show: Water level in the Chesapeake Bay, Sahara dust plume off the African coast, hurricane in the Atlantic ocean and an infrared image of Atlanta, Georgia.*

Slide 22
Sun-Earth Connection

To the naked eye, the Sun hardly changes. But a closer look reveals that we live with a dynamic, turbulent star. Using everything from high-tech spacecraft, Earth-based telescopes and computers, and old-fashioned hand drawn sketches of the Sun, scientists are unraveling the secrets of the Sun-Earth system. They scan the face of the Sun for signs of flares and CMEs. They monitor the solar wind to see if it is carrying foul weather. And they measure the energy flowing in Earth's upper atmosphere to see if a magnetic storm is brewing. What they discover will help us to someday predict the weather in space and to better understand the impact of our closest star on our lives.