Earth's Magnetic Field and the Sun-Earth Connection

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TeXas Earth and Space Science (TXESS) Revolution Professional Development Academy

Document Contents:

TOPIC: EARTH'S MAGNETIC FIELD AND THE SUN-EARTH CONNECTION

OVERVIEW

Earth has a magnetic field that shields it from harmful cosmic radiation. In some ways, Earth's magnetic field behaves in the same way that magnetic fields on ordinary magnets behave (see the field around an ordinary bar magnet below as illustrated by the pattern of iron filings).

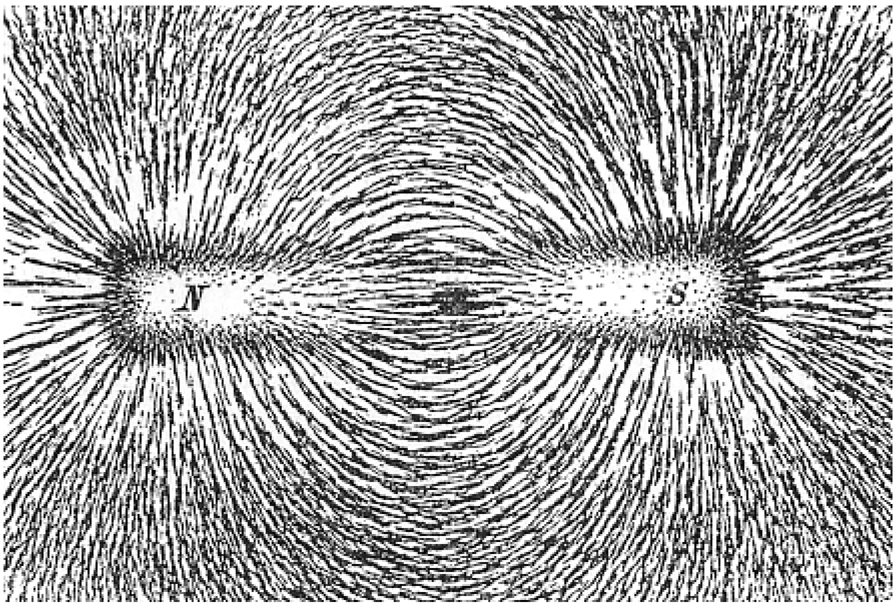


Image from http://en.wikipedia.org/wiki/File:Magnet0873.png; downloaded 10/13/2009

OBJECTIVES

The objectives of these activities are for students to:

- Be able to visualize a magnetic field
- Explore what creates Earth's magnetic field and that there are changes in the magnitude of Earth's magnetic field
- Demonstrate how magnetism can be induced in certain materials
- Build an instrument that can detect the direction of a magnetic field (magnetometer)
- Explore evidence that Earth's magnetic field not only changes magnitude, but also changes direction
- Identify positions of strong magnetic field on models of the Sun and describe those features

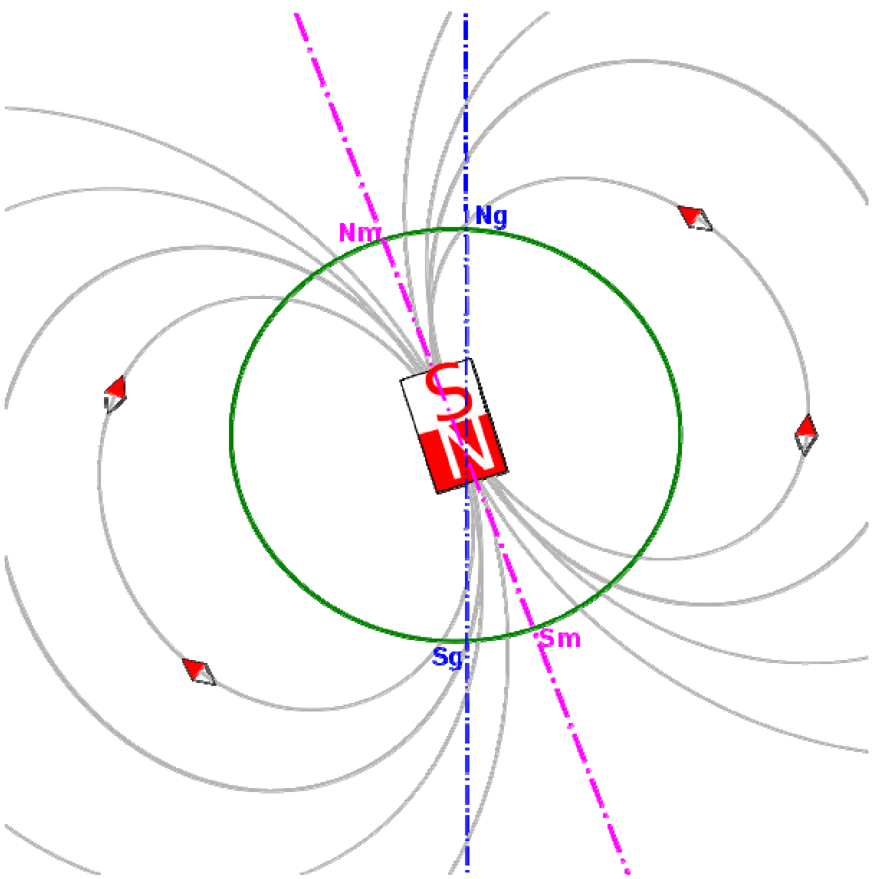
Correlation to Texas Essential Knowledge and Skills (TEKS). The high school science TEKS are available on the Texas Education Agency Website at http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112c.html#112.36. The correlation for each activity to the TEKS is listed in association with the activity instructions.

BACKGROUND INFORMATION FOR TEACHERS

DID YOU KNOW?

The Earth's magnetic field is both expansive and complicated. It is generated by electric currents that are deep within the Earth and high above the surface. All of these currents contribute to the total geomagnetic field. In some ways, one can consider the Earth's magnetic field, measured at a particular instance and at a particular location, to be the superposition of symptoms of a myriad of physical processes occurring everywhere else in the world. The challenge is to untangle the rich information content of the magnetic field so that we can better understand our planet and the surrounding space environment in which it resides. (http://geomag.usgs.gov/intro.php; downloaded 10/13/2009)

An interesting point is that what is considered Earth's magnetic North Pole is actually its magnetic South Pole. This is because magnetic field lines flow from the north to the south on a magnet. Earth's magnetic field lines flow outward from the Southern Hemisphere and inward to the Northern Hemisphere, technically making the magnetic North Pole Earth's southern magnetic pole. (http://www.pbs.org/wgbh/nova/teachers/activities/3016_magnetic.html; downloaded 10/13/2009) See the image below comparing the orientation of a bar magnet with the Earth's magnetic field. (image: http://en.wikipedia.org/wiki/File:Geomagnetisme.svg; downloaded 10/13/2009)

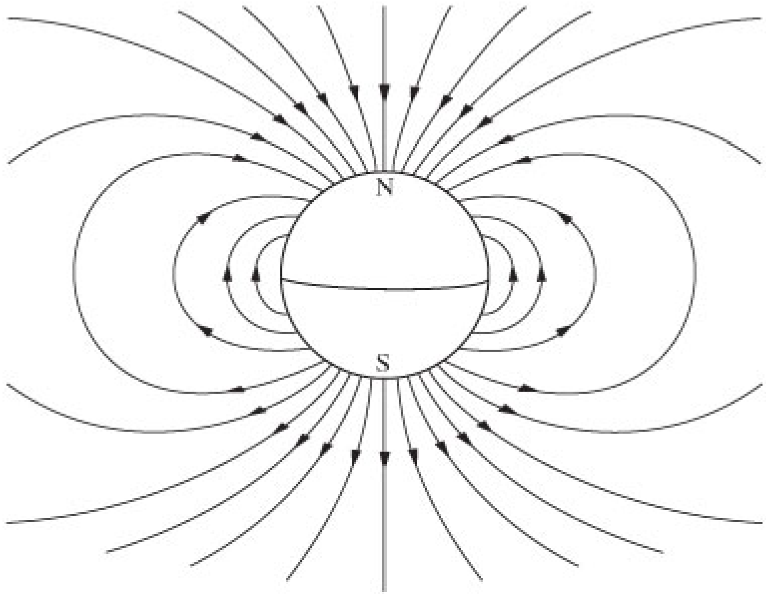


Magnetic-Field

Perhaps the most familiar demonstration of the reality of the Earth's magnetic field is the north-seeking tendency of the compass needle, a property that has been exploited by navigators for centuries. A compass is constructed, of course, such that its magnetic needle is free to rotate in the horizontal plane. But if we were to permit the compass needle to have full directional freedom, suspending the needle (say) from a thread so that it could freely obtain its orientation both horizontally and vertically, we would find that the alignment of the needle would vary continuously from one point in space to another. Furthermore, if we were to measure the force on the magnetic needle causing it to assume its preferred alignment, we would find that the strength of this force, proportional to the intensity of the magnetic field, also varies continuously with position in space. These properties can be used to map a continuous family of lines of force -- vectors having both direction and magnitude. At any one individual point on the surface of the Earth the orientation of the geomagnetic vector is conventionally described relative to a geographic coordinate system using two angles: declination, the angle between the horizontal component of the magnetic-field vector relative to true north, and inclination, the angle between the horizontal plane and the total field vector. The intensity of the magnetic field, which is independent of the orientation of the reference coordinate system, is represented by the length of the vector. (http://geomag.usgs.gov/intro.php; downloaded 10/13/2009)

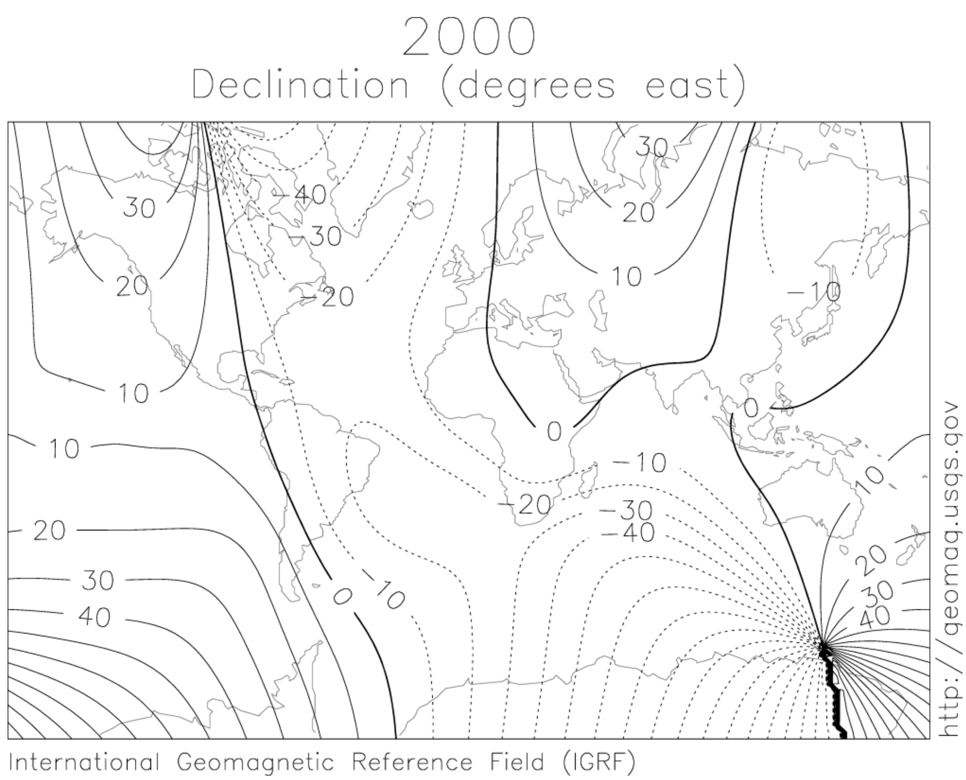
The Spatial Form of the Geomagnetic Field

The magnetic field of the Earth is often times described as being approximately dipolar, with field lines emanating from the south geomagnetic pole and converging at the north geomagnetic pole, as depicted in the figure below. Although this description is useful for many purposes, it is not particularly accurate. The dipolar part of the field is actually tilted by approximately 11° with respect to the rotational axis, and there are additional, non-dipolar ingredients in the geomagnetic field, all of which, when added together, are the total surficial field in all of its complex detail. As a result of this complexity, not only does the direction of the compass needle deviate from true north, but the amount of the deviation, the declination, varies as a function of geographic location; see the map below. This fact has been an historical nuisance for navigators, and, not surprisingly, it helped to motive some of the original global-scale surveys of the Earth's magnetic field. Another simple measure of the field's geometry is the position of the magnetic poles. At the north geomagnetic pole, our freely moving magnetic needle would point down, whilst at the south geomagnetic pole, the needle would point up. For these reasons, the geomagnetic poles are sometimes referred to as 'dip poles'. The north geomagnetic pole is located in the Canadian Arctic at about 82°N latitude and 248°E longitude. The south geomagnetic pole is located in the Antarctic Ocean south of Australia at about 65°S latitude and 138°E longitude. Note that the geomagnetic poles are not antipodal, an asymmetry that is just another measure of the field's geometric complexity. (http://geomag.usgs.gov/intro.php; downloaded 10/13/2009)



Dipole field.The axial-dipolar part of the Earth's magnetic field, with field lines emanating from near the south geographic pole and converging near the north geographic pole. Although the magnetic field at the Earth's surface is predominantly an axial dipole, the actual magnetic field is more complicated.

(http://geomag.usgs.gov/intro.php; downloaded 10/13/2009)



(http://en.wikipedia.org/wiki/File:IGRF_2000_magnetic_declination.gif; downloaded 10/13/2009)

The Geodynamo

The Earth is, of course, extremely complicated; it consists of many different interacting parts. But broadly speaking the Earth below our feet is stratified in radius, being composed of a solid-iron inner core, a liquid-iron outer core, and an electrically-insulating, rocky over-lying mantle; see the figure below. The main part of the Earth's magnetic field is generated by electric currents sustained by a dynamo situated in the core, and the study of the form and long-term behavior of the geomagnetic field can be used to discover how the geodynamo works. Paleomagnetic measurements of rocks indicate that the Earth has possessed a magnetic field for at least 3.5 billion years, and yet, without some sort of regenerative process to offset the inevitable ohmic dissipation of electric currents, the geomagnetic field would vanish in about 15,000 years. Therefore, the dynamo in the core must be regenerative, and it is generally thought that this regenerative process relies on the principles of magnetic induction. In effect, the core is a naturally occurring electric generator, where convection kinetic energy, driven by chemical differentiation and the heat of internal radioactivity, is converted into electrical-magnetic energy. More specifically, electrically-conducting fluid flowing across magnetic-field lines induces an electric current, and this generated current supports its own associated magnetic field. Depending on the geometrical relationship between the fluid flow and the magnetic field, the generated magnetic field can reinforce the pre-existing magnetic field, in which case the dynamo is said to be 'self-sustaining'. (http://geomag.usgs.gov/intro.php; downloaded 10/13/2009)

Field Variation Over Historical Timescales

Although the magnetic field is sustained by the dynamo within the Earth's core, part of the field threads its way through the mantle and up to the surface, where it has influence on compasses and where it can be measured by magnetometers. The same convective motion that drives the geodynamo also causes the field, measured at the surface, to be time-dependent over historical timescales, a phenomenon known as 'secular variation'. In fact, magnetic models and charts must be periodically updated to accommodate the continual secular variation of the field. Secular variation can also be clearly seen in long-timescale, magnetic records collected at ground-based observatories. (http://geomag.usgs.gov/intro.php; downloaded 10/13/2009)

The Earth's Magnetosphere

The magnetosphere is the outer part of the Earth's magnetic field, a region in the near-Earth space environment where the shape and behavior of the geomagnetic field is governed by the Sun. Of course, the Sun is a highly dynamic presence within the solar system. It has its own dynamo, generating a somewhat tangled magnetic field that extends out into interplanetary space. The Sun also emits a wind of electrically-charged particles, a plasma that flows outwards into space and which carries with it the heliomagnetic field. Because of the pressure exerted by the solar wind on the geomagnetic field, the magnetosphere is compressed on the day side and elongated on the night side of the Earth, such as depicted in the schematic figure below. In dimension along the equatorial plane, the day-side magnetosphere, the boundary of which is called the 'magnetopause', is about 10 Earth radii from the surface of the Earth, while the length of the 'magnetotail' varies greatly, being very approximately 100 Earth radii in length. Since the solar wind is supersonic, having a velocity relative to the Earth that is faster than the speed of sound within the plasma, there is a shockwave that precedes the Earth in its passage through the solar wind. (http://geomag.usgs.gov/intro.php; downloaded 10/13/2009)

Magnetic Storms

The pressure balance between the solar wind and the geomagnetic field is delicate, and perturbations in solar-wind velocity can cause the magnetosphere to oscillate. Even more dramatically, occasionally the Sun emits a sudden gust of solar wind, a so-called 'coronal mass ejection'. If this impacts upon the magnetosphere then a magnetic storm can follow. (http://geomag.usgs.gov/intro.php; downloaded 10/13/2009)

Sun Facts

The distance to the Earth from the sun at 149,000,000 km = 1 AU is 107 times the diameter of the Sun and 388 times the Earth-Moon distance.

The center temperature is modeled to be 15.5 million K. The Sun is fueled by the proton cycle of nuclear fusion.

Escape velocity = 618 km/s

Being a gaseous body, the Sun does not have a single period of rotation like a rigid body. The sunspots provide a convenient reference for the measurement of the rotation period at different latitudes. The period of rotation averages 25.4 days, varying from 34.4 days at the poles to 25.1 days at the equator (Chaisson). Its axis is tilted 7.25° relative to the ecliptic.

(http://hyperphysics.phy-astr.gsu.edu/HBASE/solar/sun.html#c1; downloaded 10/13/2009)

GLOSSARY

aurora	A colorful, rapidly varying glow in the sky caused by the collision of charged particles in the magnetosphere with atoms in the Earth's upper atmosphere. Auroras are most often observed at high latitudes and are enhanced during geomagnetic storms. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)
chromosphere	The chromosphere is an irregular layer above the photosphere where the temperature rises from 6000° C to about 20,000° C. At these higher temperatures hydrogen emits light that gives off a reddish color (H-alpha emission). This colorful emission can be seen in prominences that project above the limb of the sun during total solar eclipses. This is what gives the chromosphere its name (color-sphere). (http://solarscience.msfc.nasa.gov/chromos.shtml; downloaded 10/13/2009)
CMB	Core-Mantle Boundary
corona	The outermost layer of the solar atmosphere. The corona consists of a highly rarefied gas with a low density and a temperature greater than one million degrees Kelvin. It is visible to the naked eye during a solar eclipse. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)

coronagraph	A coronagraph is a telescopic attachment designed to block out the direct light from a star so that nearby objects – which otherwise would be hidden in the star's bright glare – can be resolved. Most coronagraphs are intended to view the corona of the Sun, but a new class of conceptually similar instruments (called stellar coronagraphs to distinguish them from solar coronagraphs) are being used to find extrasolar planets around nearby stars. (http://en.wikipedia.org/wiki/Coronagraph; downloaded 10/13/2009)
coronal mass ejection (CME)	Coronal mass ejections (or CMEs) are huge bubbles of gas threaded with magnetic field lines that are ejected from the Sun over the course of several hours. Although the Sun's corona has been observed during total eclipses of the Sun for thousands of years, the existence of coronal mass ejections was unrealized until the space age. The earliest evidence of these dynamical events came from observations made with a coronagraph on the 7th Orbiting Solar Observatory (OSO 7) from 1971 to 1973. A coronagraph produces an artificial eclipse of the Sun by placing an "occulting disk" over the image of the Sun. During a natural eclipse of the Sun the corona is only visible for a few minutes at most, too short a period of time to notice any changes in coronal features. With ground based coronagraphs only the innermost corona is visible above the brightness of the sky. From space the corona is visible out to large distances from the Sun and can be viewed continuously. Coronal Mass Ejections disrupt the flow of the solar wind and produce disturbances that strike the Earth with sometimes catastrophic results. The Large Angle and Spectrometric Coronagraph (LASCO) on the Solar and Heliospheric Observatory (SOHO) has observed a large number of CMEs. (http://solarscience.msfc.nasa.gov/CMEs.shtml; downloaded 10/13/2009)
ESA	European Space Agency
geomagnetic storm	A worldwide disturbance of the Earth's magnetic field, associated with solar activity. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)
ICB	Inner Core Boundary
magnetic field	Magnetic fields surround magnetic materials and electric currents and are detected by the force they exert on other magnetic materials and moving electric charges. The magnetic field at any given point is specified by both a direction and a magnitude (or strength); as such it is a vector field. (http://en.wikipedia.org/wiki/Magnetic_field; downloaded 10/13/2009)

magnetic field lines	Imaginary lines that indicate the strength and direction of a magnetic field. The orientation of the line and an arrow show the direction of the field. The lines are drawn closer together where the field is stronger. Charged particles move freely along magnetic field lines, but are inhibited by the magnetic force from moving across field lines. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)
magnetic pole	A pole can be described as the point where lines of magnetic force come together. (http://www.windows.ucar.edu/tour/link=/physical_science/magnetism/force_of_magnetism.html; downloaded 10/13/2009)
magnetosphere	If a planet has a magnetic field, it will interact with the solar wind to deflect the charged particles and form an elongated cavity in the solar wind. This cavity is called the magnetosphere of the planet. (http://hyperphysics.phy-astr.gsu.edu/HBASE/solar/solwin.html; downloaded 10/13/2009)
MHD	Magnetohydrodynamics (i.e., of the Earth's core)
NASA	National Aeronautics and Space Administration
penumbra	The penumbra is the lighter outer region of a sunspot. It has radiating lines called spines which indicate the magnetic field.
photosphere	The photosphere is the visible surface of the Sun that we are most familiar with. Since the Sun is a ball of gas, this is not a solid surface but is actually a layer about 100 km thick (very, very, thin compared to the 700,000 km radius of the Sun). (http://solarscience.msfc.nasa.gov/surface.shtml; downloaded 10/13/2009)
plasma	Plasma consists of a gas heated to sufficiently high temperatures that the atoms ionize. The properties of the gas are controlled by electromagnetic forces among constituent ions and electrons, which results in a different type of behavior. Plasma is often considered the fourth state of matter (besides solid, liquid, and gas). Most of the matter in the Universe is in the plasma state. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)

prominence	Prominences are dense clouds of material suspended above the surface of the Sun by loops of magnetic field. Prominences and filaments are actually the same things except that prominences are seen projecting out above the limb, or edge, of the Sun. Both filaments and prominences can remain in a quiet or quiescent state for days or weeks. However, as the magnetic loops that support them slowly change, filaments and prominences can erupt and rise off of the Sun over the course of a few minutes or hours. (http://solarscience.msfc.nasa.gov/feature2.shtml#Prominences; downloaded 10/13/2009)
SOHO	NASA's Solar and Heliospheric Observatory
solar flare	Rapid release of energy from a localized region on the Sun in the form of electromagnetic radiation, energetic particles, and mass motions. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)
solar limb	The apparent edge of the Sun as it is seen in the sky. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)
solar winds	A stream of charged particles flowing outward from the Sun's corona. The speed of the solar wind at the Earth is typically 450 kilometers per second, but varies from about 200 kilometers per second to 900 kilometers per second. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)
space weather	Space weather refers to conditions on the Sun and in the solar wind, Earth's magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based logical systems and can endanger human life of health. (http://solar-center.stanford.edu/sun-on-earth/sun-earth.html; downloaded 10/13/2009)
sunspot	A temporary disturbed area in the solar photosphere that appears dark because it is cooler than the surrounding areas. Sunspots consist of concentrations of strong magnetic flux. They usually occur in pairs or groups of opposite polarity that move in unison across the face of the Sun as it rotates. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)

The Space Environment Center	Many scientists today are working hard at forecasting space weather, which they aim at being able to predict at least as accurately as they forecast Earth weather. If scientists can warn a day or so in advance of an imminent geomagnetic storm, then satellite operators and power companies can try to protect equipment, averting millions of dollars in damage. The Space Environment Center (SEC) in Boulder, Colorado is one of those groups that works hard at forecasting solar and geophysical events. They conduct research in solar-terrestrial physics, they develop techniques for forecasting solar and geophysical disturbances, and they provide real-time monitoring and forecasting of solar and geophysical events. This site is an important one because of the breadth of their offerings. Their offerings include solar-terrestrial data and images, a daily report of space weather, a report and forecast of Solar Geophysical Data in an online Web document: "The Weekly", a primer on the Space Environment with descriptions of the sun and various solar phenomena, and they have a "Glossary of Solar-Terrestrial Terms", as well. (http://solar-center.stanford.edu/sun-on-earth/sun-earth.html; downloaded 10/13/2009)
umbra	The umbra is the dark central portion of a sunspot. Small sunspots may not have a well-defined umbra.
UT = Universal Time	Abbreviated UT. The same as Greenwich Mean Time (GMT) in England. Eastern Standard Time (EST) is five hours earlier than Universal Time. (http://hesperia.gsfc.nasa.gov/sftheory/glossary.htm; downloaded 10/13/2009)
Van Allen belts	Inside a boundary called the magnetopause, the earth's magnetic field is dominant over the effects of the solar wind. The small fraction of the charged particles which do leak through the magnetopause are trapped in two large doughnut-shaped rings called the Van Allen radiation belts. The earth satellite Explorer 1 carried a Geiger counter which detected bands of radiating particles surrounding the earth. James Van Allen headed the team of scientists who investigated these bands, and they were named the Van Allen belts. One motivation for naming the belts after Van Allen was that he was the one who insisted that the satellite carry a Geiger counter for particle detection. The two huge doughnut-shaped rings contain charged particles collected from the solar wind. The inner Van Allen belt extends over altitudes from about 2000 to 5000 kilometers and contains mainly protons. The outer Van Allen belt is about 6000 kilometers thick centered at about 16000 km from the earth. It contains mostly electrons. The outer belt was discovered by the Pioneer spacecraft. (http://hyperphysics.phy-astr.gsu.edu/HBASE/solar/solwin.html; downloaded 10/13/2009)

<u>Learning Experience 1</u>: Visualizing Magnetic Fields

This activity was developed by NOVA as a Student Activity to accompany the NOVA movie *Magnetic Storm.* Information on this excellent movie can be found at: http://www.pbs.org/wgbh/nova/magnetic/. The original broadcast was November 18, 2003. A teacher's classroom guide, including student handouts, can be found online at: http://www.pbs.org/wgbh/nova/teachers/activities/3016_magnetic.html. As an introduction to exploring Earth's magnetic field, we will do a short activity on Visualizing Magnetic Fields using the NOVA worksheets. We will pass out the NOVA Teacher's Guide and the Magnetic Storm Student Handout to you for this activity. **Follow the guidelines in the Student Handout to complete the activity today.**

Time Frame: 1 hr. (including lab activity and Magnetic Storm movie segments)

Objective
To study the magnetic fields around different shapes of magnets **(only bar magnets in this version of the activity)**.

Materials

- copy of the "Visualizing Magnetic Fields" student handout from the NOVA website (see above)
- 1 tablespoon of iron filings in paper cup
- 8 1/2-inch x 11-inch paper
- tape
- magnets of different shapes, including round, bar, and horseshoe magnets **(for today, we will use only bar magnets because we will explore another shape in a later activity)**
- compass
- ruler
- NOVA movie – Magnetic Storm

1. Earth has a magnetic field that shields it from harmful cosmic radiation. In some ways, Earth's magnetic field behaves in the same way that magnetic fields on ordinary magnets behave. Tell students they will be exploring some of the properties of magnetic fields in this activity.
2. Organize students into groups and distribute the "Visualizing Magnetic Fields" student handout, iron filings, paper, compasses, rulers, and different-shaped magnets to each group **(only bar magnet in this version of the activity).**
3. Have students select a magnet and place a sheet of paper on top. Instruct them to lightly sprinkle iron filings over the paper. Ask them to sketch the magnetic field on another piece of paper.
4. Have students use their compasses to determine the direction of the field and indicate this with arrows on their diagrams.

5. Ask students to move a compass farther and farther out to where the magnetic field weakens. (At this distance the compass will switch from indicating the magnet's magnetic field to indicating Earth's magnetic field.) Students should record this distance on their diagrams. **(Teachers, today we will record these distances on the board at the front of the room.)**
6. **(Omit this for this version of the activity.)** Have students repeat the experiment with magnets of different shapes.
7. Have each group answer the questions in the student handout. Discuss students' findings. What caused the compass to change direction when moved away from the magnet? What direction did the compass exhibit when moved away from each of the magnets? Why might this be? **(We will only consider the bar magnet in this version.)**
8. As an extension, have students create a timeline of Earth's magnetic field reversals. Find more information at www.pbs.org/nova/magnetic/. **(We will omit this activity because we will look at magnetic field reversals in a different activity.)**

Questions: There is a series of eight questions for this activity and they can be found on the Student Handout. Discuss questions #4-8 with your lab partner(s) for today's activity.

Video Activity: We will now view ~15 minutes of the Magnetic Storm movie produced by NOVA. These segments of the program:

- explain how scientists think Earth's magnetic field is generated and describes the role of the magnetic field in shielding our planet from radiation.
- explore the possibility that Mars once had a magnetic field that protected an atmosphere. (profile:
- show how scientists use ancient pottery and volcanic rock to study changes in the direction and strength of Earth's magnetic field over time.

Various scientists are profiled during the movie, along with their contributions to our understanding of the Earth's magnetic field, as well as the Sun-Earth connection.

Correlation to Texas Essential Knowledge and Skills (TEKS). The high school science TEKS are available on the Texas Education Agency Website at http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112c.html#112.36. The correlation for each activity to the TEKS is listed in association with the activity instructions. Below is a list of TEKS for this activity compiled by Marsha Willis of the Texas Regional Collaboratives for Excellence in Science and Mathematics Instruction.

Visualizing Magnetic Fields												
TEKS	1	2	3	4	5	6	7	8	9	10	11	12
ESS	A, B	G	A						C, D			

TEKS 1. Scientific processes. The student conducts laboratory and field investigations, for at least 40% of instructional time, using safe, environmentally appropriate, and ethical practices. The student is expected to:

(A) demonstrate safe practices during laboratory and field investigations;
(B) demonstrate and understanding of the use and conservation of resources and the proper disposal or recycling of materials

TEKS 2. Scientific processes. The student uses scientific methods during laboratory and field investigations. The student is expected to:

(G) organize, analyze, evaluate, make inferences, and predict trends from data

TEKS 3. Scientific processes. The student uses critical thinking, scientific resoning, and problem solving to make informed decisions within and outside the classroom. The student is expected to:

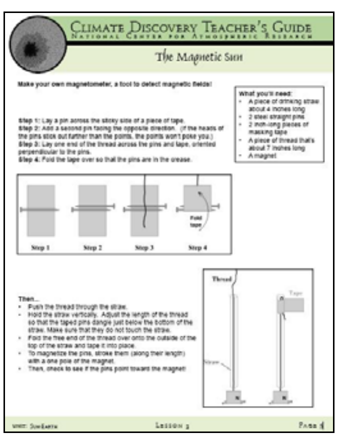
(A) analyze, review, and critique scientific explanations, by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student.

TEKS 9. Science concepts. Solid Earth: The student knows Earth's interior is differentiated chemically, physically, and thermally. The student is expected to:

(C) explain how scientists use geophysical methods such as seismic wave analysis, gravity and magnetism to interpret Earth's structure;
(D) describe the formation and structure of Earth's magnetic field, including its interaction with charged solar particles to form the Van Allen belts and auroras.

<u>Learning Experience 2a</u>: Build a Magnetometer

We will construct a magnetometer, a tool to detect magnetic fields. We will use the procedure described in the National Center for Atmospheric Research Climate Discovery Teacher's Guide on Magnetic Sun. This page will be distributed to you to start the activity.


Climate Discovery Teacher's Guide
National Center for Atmospheric Research
The Magnetic Sun

Make your own magnetometer, a tool to detect magnetic fields!

What you'll need:
- A piece of drinking straw about 4 inches long
- 2 steel straight pins
- 2 inch-long pieces of masking tape
- A piece of thread that's about 7 inches long
- A magnet

Step 1: Lay a pin across the sticky side of a piece of tape.
Step 2: Add a second pin facing the opposite direction. (If the heads of the pins stick out further than the points, the points won't poke you.)
Step 3: Lay one end of the thread across the pins and tape, oriented perpendicular to the pins.
Step 4: Fold the tape over so that the pins are in the crease.

Then...
- Push the thread through the straw.
- Hold the straw vertically. Adjust the length of the thread so that the taped pins dangle just below the bottom of the straw. Make sure that they do not touch the straw.
- Fold the free end of the thread over onto the outside of the top of the straw and tape it into place.
- To magnetize the pins, stroke them (along their length) with a one pole of the magnet.
- Then, check to see if the pins point toward the magnet!

Unit: SunEarth Lesson 3 Page 4

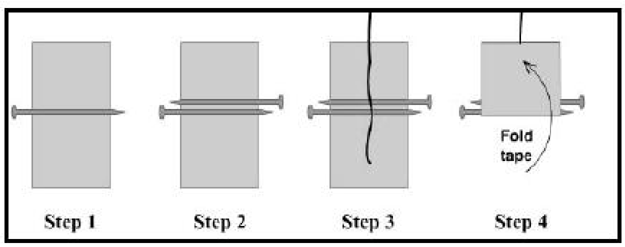
Time Frame – 30 minutes

Materials

- A piece of drinking straw about 4 inches long
- 2 steel straight pins
- 2 inch-long pieces of masking tape
- A piece of thread that's about 7 inches long
- A magnet

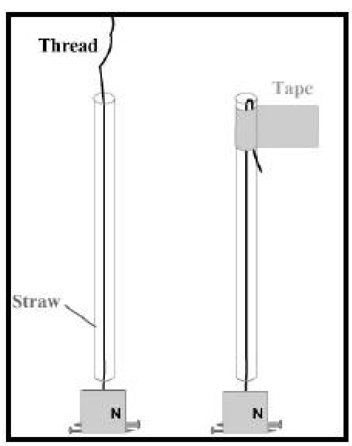
Procedure for Guided Inquiry Activity

1. Lay a pin across the sticky side of a piece of tape.
2. Add a second pin facing the opposite direction. (If the heads of the pins stick out further than the points, the points won't poke you.)
3. Lay one end of the thread across the pins and tape, oriented perpendicular to the pins.
4. Fold the tape over so that the pins are in the crease. (see figure below)



Then...

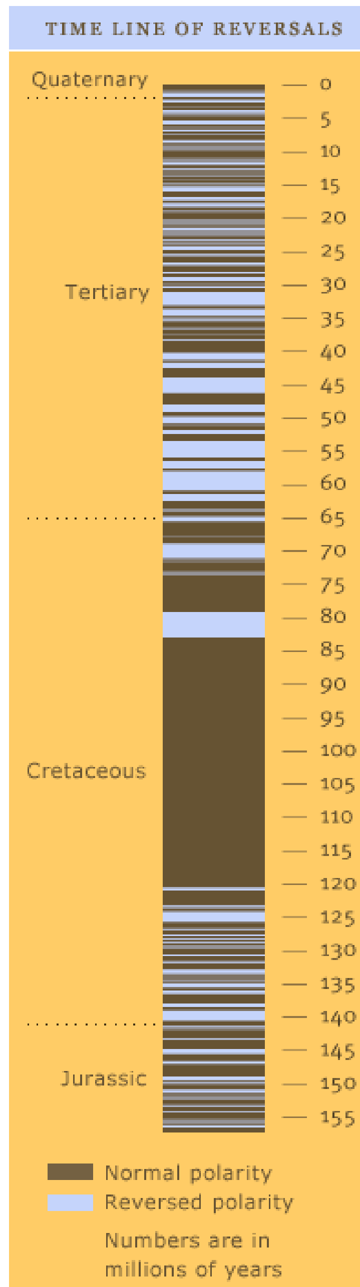
5. Push the thread through the straw.
6. Hold the straw vertically. Adjust the length of the thread so that the taped pins dangle just below the bottom of the straw. Make sure that they do not touch the straw.
7. Fold the free end of the thread over onto the outside of the top of the straw and tape it into place.
8. To magnetize the pins, stroke them (along their length) with a one pole of the magnet.
9. Then, check to see if the pins point toward the magnet!



Congratulations! You have built a magnetometer. We will use this instrument in the next activity.

Magnetic fields are invisible; we can only see the effects of the magnetic force. Magnetometers are devices used to detect and measure the strength of magnetic fields. Compasses are basically magnetometers with directions marked on them. A magnetometer will dip or point toward a source of magnetism. (You could also have students use their magnetometer to find things in your room or at home that are magnetic, e.g., some pliers).

<u>Learning Experience 2b</u>: Changes in the Direction of the Earth's Magnetic Field



If all the compasses in the world started pointing south rather than north, many people might think something very strange, very unusual, and possibly very dangerous was going on. Doomsayers would have a field day proclaiming the end is nigh, while more rational persons might head straight to scientists for an explanation.

Fortunately, those scientists in the know—paleomagnetists, to be exact—would have a ready answer. Such reversals in the Earth's magnetic field, they'd tell you, are, roughly speaking, as common as ice ages. That is, they're terrifically infrequent by human standards, but in geologic terms they happen all the time. As the time line at right shows, hundreds of times in our planet's history the polarity of the magnetic shield ensheathing the globe has gone from "normal," our current orientation to the north, to "reversed," and back again.

The Earth is not alone in this fickleness: The sun's magnetic shield appears to reverse its polarity approximately every 11 years. Even our Milky Way galaxy is magnetized, and experts say it probably reverses its polarity as well. Moreover, while a severe weakening or disappearance of the magnetic field would lay us open to harmful radiation from the sun, there's little evidence to date that "flips" per se inflict any lasting damage.

It might sound as if scientists have all the answers regarding magnetic reversals. But actually they know very little about them. Basic questions haunt researchers: What physical processes within the Earth trigger reversals? Why do the durations and frequencies of both normal and reversed states seem random? Why is there such a disproportionately long normal period between about 121 and 83 million years ago? Why does the reversal rate, at least during the past 160 million years, appear to peak around 12 million years ago?

All these questions remain unanswered, though experts like Dennis Kent, the Rutgers University geologist who supplied NOVA with updated figures for the time line, are hard at work trying to answer them. In the meantime, not to worry. Reversals happen on average only about once every 250,000 years, and they take hundreds if not thousands of years to complete.

Even the weakening currently under way may be a false alarm. The field often gets very weak, then bounces back, never having flipped. As Ron Merrill, a magnetic-field specialist at the University of Washington remarked when asked whether we're in for a reversal: "Ask me in 10,000 years, I'll give you a better answer." So hang on to your compass. For the foreseeable future, it should work as advertised.—Peter Tyson (http://www.pbs.org/wgbh/nova/magnetic/timeline.html; downloaded 10/13/2009)

Time Frame – 45 minutes

Objective

To understand that the Earth's magnetic field not only changes magnitude, but also direction over time.

Materials

- NOVA movie – Magnetic Storm
- poster of Earth's Magnetic Anomalies on the Earth

Video Activity: We will now view ~15 minutes of the Magnetic Storm movie produced by NOVA. These segments of the program:

- relate when magnetic field reversals have occurred in the past and speculates when the next reversal might take place.
- feature a computer model showing the flipping of the poles.
- discusse how cooling of Earth's core may be the cause of the weakening magnetic field.
- explore how a changing magnetic field might affect life on Earth.

Map Activity:

A map of the Earth's Magnetic Anomalies is posted on the wall. In groups, look at the map and discuss the following:

1. How are magnetic data collected?
2. What do you think these magnetic anomalies represent, in other words, they are anomalous compared to what?
3. What types of rocks are indicated by magnetic highs?
4. What patterns do you see on the map and can you give any explanation for them?

Correlation to Texas Essential Knowledge and Skills (TEKS). The high school science TEKS are available on the Texas Education Agency Website at http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112c.html#112.36. The correlation for each activity to the TEKS is listed in association with the activity instructions. Below is a list of TEKS for this activity compiled by Marsha Willis of the Texas Regional Collaboratives for Excellence in Science and Mathematics Instruction.

Building a Magnetometer and Changes in the Direction of the Earth's Magnetic Field												
TEKS	1	2	3	4	5	6	7	8	9	10	11	12
ESS	A,B	F,G,I	A									

TEKS 1. Scientific processes. The student conducts laboratory and field investigations, for at least 40% of instructional time, using safe, environmentally appropriate, and ethical practices. The student is expected to:

(A) demonstrate safe practices during laboratory and field investigations;
(B) demonstrate and understanding of the use and conservation of resources and the proper disposal or recycling of materials

TEKS 2. Scientific processes. The student uses scientific methods during laboratory and field investigations. The student is expected to:

(F) use a wide variety of additional course apparatuses, equipment, techniques, and procedures as appropriate such as satellite imagery and other remote sensing data, Geographic Information Systems (GIS), Global Positional System (GPS), scientific probes, microscopes, telescopes, modern video and image libraries, weather stations, fossil and rock kits, bar magnets, coiled springs, wave simulators, tectonic plate models, and planetary globes
(G) organize, analyze, evaluate, make inferences, and predict trends from data
(I) communicate valid conclusions supported by data using several formats such as technical reports, lab reports, labeled drawings, graphic organizers, journals, presentations, and technical posters.

TEKS 3. Scientific processes. The student uses critical thinking, scientific reasoning, and problem solving to make informed decisions within and outside the classroom. The student is expected to:

(A) analyze, review, and critique scientific explanations, by using empirical evidence, logical reasoning, and experimental and observational testing, including examining all sides of scientific evidence of those scientific explanations, so as to encourage critical thinking by the student.

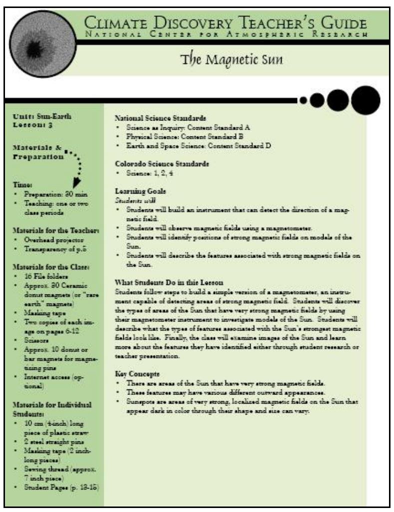
<u>Learning Experience 3</u>: The Magnetic Sun

During this activity, students will use a hand-made magnetometer to identify and describe positions of strong magnetic field on models of the Sun.

Time Frame – 1hr 15 minutes

Materials

- Student pages of the Magnetic Sun Handout (online at http://eo.ucar.edu/educators/ClimateDiscovery/SEC_lesson3_10.17.05.pdf)
- Sun images, laminated
- Donut magnets (attached as required to the back of the sun images
- Magnetometer – made in activity 2a
- Iron Filings
- Paper



Climate Discovery Teacher's Guide
National Center for Atmospheric Research

The Magnetic Sun

Unit: Sun-Earth
Lesson: 3

Materials & Preparation

Time:
- Preparation: 30 min
- Teaching: one or two class periods

Materials for the Teacher:
- Overhead projector
- Transparency of p.5

Materials for the Class:
- 16 File folders
- Approx. 30 Ceramic donut magnets (or "rare earth" magnets)
- Masking tape
- Two copies of each image on pages 6-12
- Scissors
- Approx. 10 donut or bar magnets for magnetizing pins
- Internet access (optional)

Materials for Individual Students:
- 10 cm (4-inch) long piece of plastic straw
- 2 steel straight pins
- Masking tape (2 inch-long pieces)
- Sewing thread (approx. 7 inch piece)
- Student Pages (p. 13-15)

National Science Standards
- Science as Inquiry: Content Standard A
- Physical Science: Content Standard B
- Earth and Space Science: Content Standard D

Colorado Science Standards
- Science: 1, 2, 4

Learning Goals
Students will
- Students will build an instrument that can detect the direction of a magnetic field.
- Students will observe magnetic fields using a magnetometer.
- Students will identify positions of strong magnetic fields on models of the Sun.
- Students will describe the features associated with strong magnetic fields on the Sun.

What Students Do in this Lesson
Students follow steps to build a simple version of a magnetometer, an instrument capable of detecting areas of strong magnetic field. Students will discover the types of areas of the Sun that have very strong magnetic fields by using their magnetometer instrument to investigate models of the Sun. Students will describe what the types of features associated with the Sun's strongest magnetic fields look like. Finally, the class will examine images of the Sun and learn more about the features they have identified either through student research or teacher presentation.

Key Concepts
- There are areas of the Sun that have very strong magnetic fields.
- These features may have various different outward appearances.
- Sunspots are areas of very strong, localized magnetic fields on the Sun that appear dark in color through their shape and size can vary.

Procedure for Guided Inquiry Activity

Using your magnetometer, investigate the eight images for areas of strong magnetic field. Below, and on the reverse side of the Student Page, there is space for data that you collect about each image. Find the space with the appropriate number, note the number of strong magnetic fields you found on each and describe with words and pictures what each area of strong magnetic field looks like. Note that there are several exhibits adjacent to the images you will find at different stations.

Questions

On the student handout, there is a series of five questions related to the images and magnetic fields. Please discuss these questions in your lab group.

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Extension

Intense Space Weather Storms of October/November, 2003

What are the hazardous effects of magnetic storms?
The infrastructure and activities of our modern technologically-based society can be adversely affected by rapid magnetic-field variations generated by electric currents in the near-Earth space environment, particularly in the ionosphere and magnetosphere. This is especially true during so-called 'magnetic storms'. Because the ionosphere is heated and distorted during storms, long-range radio communication, which relies on sub-ionospheric reflection, can be difficult or impossible and global-positioning systems (GPS), which relies on radio transmission through the ionosphere, can be degraded. Ionospheric expansion can enhance satellite drag and thereby make their orbits difficult to control. During magnetic storms, satellite electronics can be damaged through the build up and subsequent discharge of static-electric charges, and astronaut and high-altitude pilots can be subjected to increased levels of radiation. There can even be deleterious effects on the ground: pipe-line corrosion can be enhanced, and electric-power grids can experience voltage surges that cause blackouts. The reason why space-based effects can have consequences down here on the Earth's surface is related, at least in part, to our answer to the first question, 'What is a magnetic field?'. Electric currents in one place can induce electric currents in another place, this action at a distance is accomplished via a magnetic field. So, even though rapid magnetic-field variations are generated by currents in space, very real effects, such as unwanted electric currents induced in electric-power grids, can result down here on the Earth's surface. More generally, the hazardous effects associated with geomagnetic activity are one reason why the USGS Geomagnetism Program is part of the Central Region Geohazards Team.(http://geomag.usgs.gov/faqs.php; downloaded 10/13/2009)

Some great resources can be used to have students investigate the Intense Space Weather Storms of October 19-November 7, 2003. These include:

NOAA magazine article: OCTOBER-NOVEMBER 2003 SOLAR STORM
http://www.magazine.noaa.gov/stories/mag131b.htm

NOAA magazine article: SOLAR STORMS CAUSE SIGNIFICANT ECONOMIC AND OTHER IMPACTS ON EARTH
http://www.magazine.noaa.gov/stories/mag131.htm

Intense Space Weather Storms, October 19 – November 07, 2003
U.S. Department of Commerce, National Oceanic and Atmospheric Administration
National Weather Service
http://www.swpc.noaa.gov/Services/SWstorms_assessment.pdf
This is an incredible resource for a project for students to really understand the impact of Space Weather Storms.

Powerpoint .pdf report by United Airlines on the economic impact of solar weather to the airline industry and safety measures that are important during periods of intense solar weather.
http://www.ametsoc.org/atmospolicy/ESSS/cameron%20final%20DCA-SpaceWeather7-18-072.pdf

Other Websites of interest (10/13/2009)

http://www.es.ucsc.edu/~glatz/geodynamo.html
GeoDynamo reference: Dr. Gary Glatzmaier

http://www.sec.noaa.gov/
Space Environment Center, Boulder, CO

http://sunearthplan.net
SUN EARTH PLAN celebrates Britain's pivotal role in space science.

http://sunearth.gsfc.nasa.gov/
Goddard Space Flight Center, NASA

http://sunearth.gsfc.nasa.gov/spaceweather/FlexApp/bin-debug/index.html#app=d1c&7f6c-selectedIndex=3
videos on the sun, solar wind and other interesting concepts

http://svs.gsfc.nasa.gov/vis/a010000/a010400/a010421/index.html
Goddard Space Flight Center, NASA
SOHO/TRACE video page

http://sohowww.nascom.nasa.gov/
SOHO website