National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 5-8

EG-2000-03-002-GSFC

Solar Storms and You!

Exploring Sunspots and Solar Activity Cycles

An Educator Guide with Activities in Space Science

Solar Storms and You! is available in electronic format through NASA Spacelink - one of the Agency's electronic resources specifically developed for use by the educational community.

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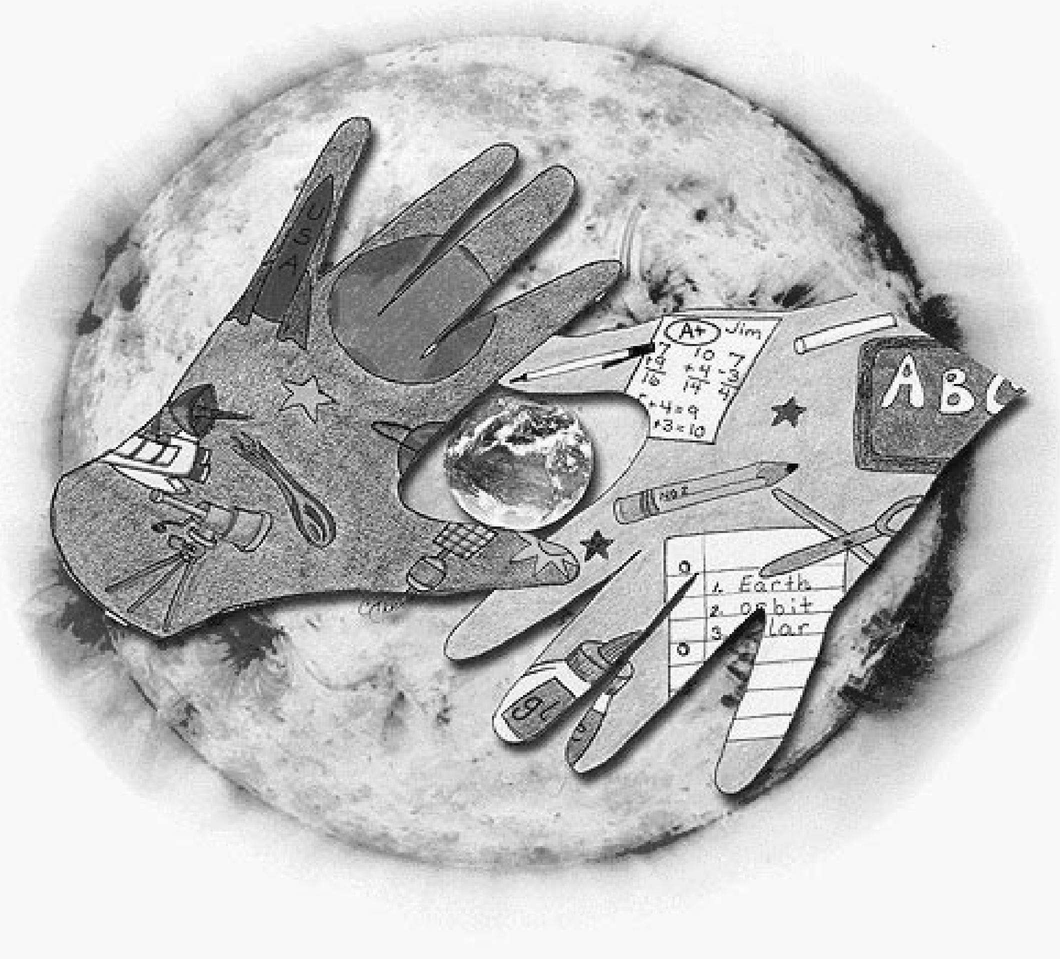

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http://pluto.space.swri.edu/IMAGE

Resources for teachers and students are available at:

http://image.gsfc.nasa.gov/poetry

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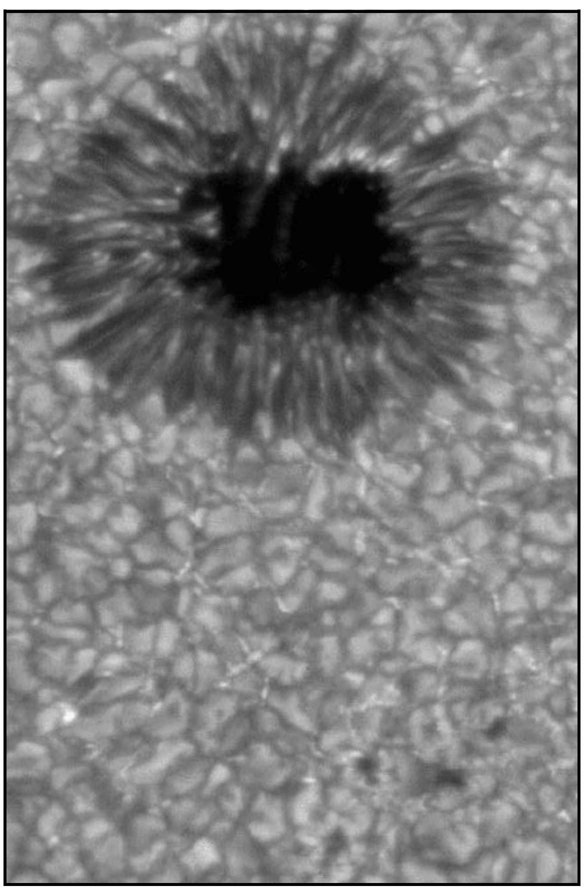
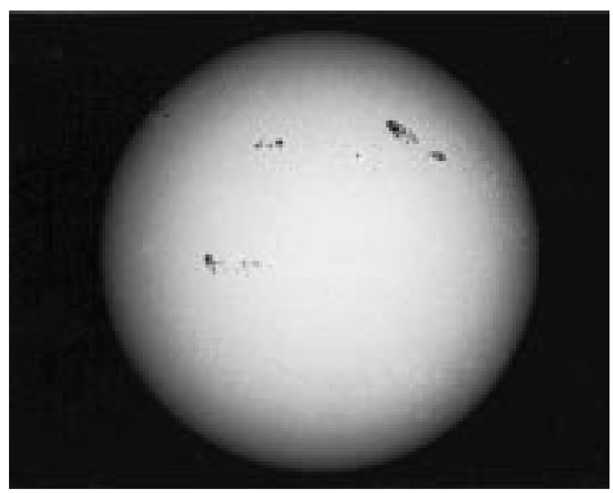




The Sun, our nearest star, is a powerful, seathing furnace that produces light and heat. For thousands of years, naked-eye ovservers have seen dark spots slowly cross the disk of the Sun. Today, with more powerful instruments, astronomers can zoom-in to see astonishing details in these 'sunspots'. The image on the left is a closeup view of a sunspot that is about twice the diameter of Planet Earth!

INTRODUCTION

A gas pipeline in Russia explodes
killing hundreds of people.

A satellite mysteriously falls silent
interrupting TV and cellular phone traffic.

A power blackout
throws millions of people into darkness.

These are only a few of the many things that solar storms can do when they arrive at the earth unexpected. In an age where we have increasingly come to rely upon the smooth operation of our technology, we have also made ourselves vulnerable to the ebb and flow of the solar storm cycle. Most people are not even aware of these cycles, but long ago we used to be!

Ancient Chinese sun observers knew that, from time to time, dark spots would glide slowly across the face of the setting sun. Once seen only as portends of political upheaval, we now see them as natural phenomena that can forewarn us of impending storms that can have dire consequences for us if we ignore them.

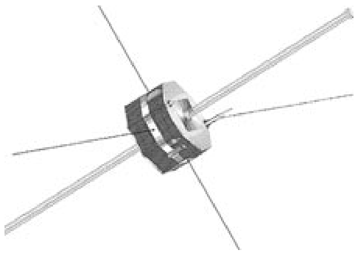
In this activity book, your students will study five key stages in the lifecycle of a solar storm, from its emergence on the solar surface to its impact upon some aspect of our lives. The book may be used in its entirety to study solar activity and how it directly affects us, or you may use individual activities of your choice as stand-alone mini lessons as an enrichment for math and physical science courses.

The student activities emphasize basic cognitive skills and higher-order processes such as plotting data, searching for patterns and correlations, and interpreting the results. By the end of the activity series, students will understand why we need to pay more attention to solar storms.

Visit the updated version of this workbook at:

http://image.gsfc.nasa.gov/poetry/workbook/workbook.html

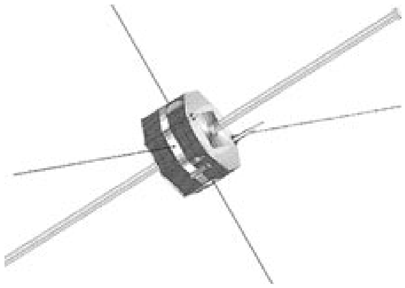
Science Process Skills
for *Solar Storms and You!*



This chart is designed to assist teachers in integrating the activities contained in the guide with existing curricula.

	Lesson 1 *"The Sunspot Cycle"*	**Lesson 2** *"The Sunspot Activity and Ocean Temperature"*	**Lesson 3** *"Sunspot Activity on Other Stars"*
Observing	○	○	○
Classifying			
Communicating	○	○	○
Measuring	○	○	○
Inferring	○	○	○
Predicting	○	○	
Experimental Design			
Gathering Data			
Organizing Data	○	○	
Controlling Variables	○		
Developing a Hypothesis	○	○	
Extending Senses			
Researching			
Team Work	○	○	
Mathematics	○	○	○
Interdisciplinary			
Introductory Activity	○	○	○
Advanced Activity			

Science and Mathematics Standards
for *Solar Storms and You!*

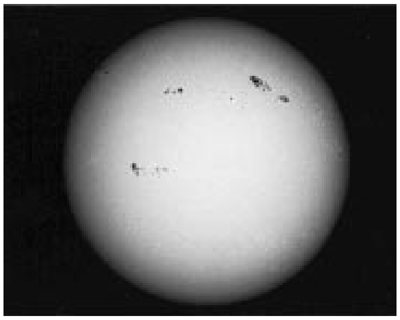


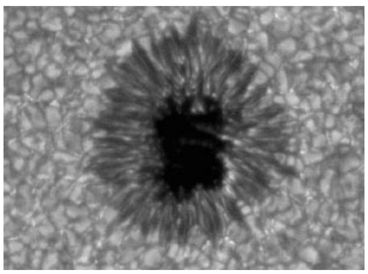
This chart is designed to assist teachers in integrating the activities contained in the guide with existing curicula.

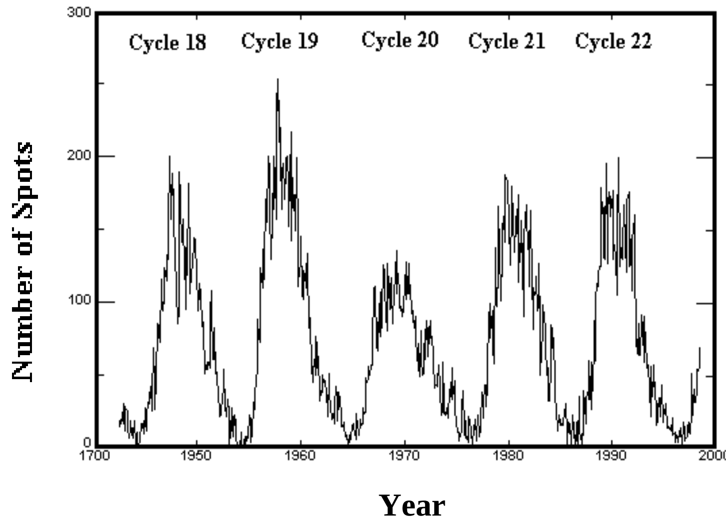
	Lesson 1 *"The Sunspot Cycle"*	**Lesson 2** *"The Sunspot Activity and Ocean Temperature"*	**Lesson 3** *"Sunspot Activity on Other Stars"*
Science as Inquiry	○	○	○
Structure and Energy of the Earth System			
Origin and History of the Earth			
Earth in the Solar System	○	○	○
Geochemical Cycles			
Physical Science	○	○	○
Populations and Ecosystems			
Understanding about Science and Technology	○	○	○
Science in Personal and Social Perspectives			
History and Nature of Science			
Problem Solving			
Measurement			
Computation and Estimation	○	○	○
Communication			
Geometry and Advanced Mathematics	○	○	○
Statistics and Probability			
Number and Number Relationships			

Patterns and Functions

Solar Activity Cycles







The Sun, our nearest star, provides us with warmth and light. But as long ago as 2000 BC, Chinese observers noted that black spots occasionally appeared, and that over the course of a week, they drifted across the disk of the setting sun. **Sunspots** are the most well known hints that the Sun's surface is constantly changing. Larger than the Earth, and with 10,000 times more intensity than the Earth's magnetic field, these are the breeding grounds for some of the most violent storms in the solar system!

The number of sunspots comes in cycles lasting from 6 to 17 years; the **Sunspot Cycle** With modern technology and space satellites, this solar activity cycle can now be detected in the ebb and flow of other phenomena on the Sun and on the Earth. Everything from ocean temperature to coral reef growth has been found to correlate with this cycle. In most cases the exact reason for the correlation is poorly understood by scientists.

Solar activity is a complex process that seems to be driven by the fact that, just below the surface, the sun’s gases convectlike mush boiling in a pot. The upwelling gases tangle-up and amplify the pervasive magnetic field of the sun and force it up through the surface. These concentrated regions of magnetic field cause the gases within them to be thousands of degrees cooler than the rest of the solar surface, which makes them glow with far less light by comparison, so that they only look black by comparison. If you were to put a single sunspot in the night sky, it would glow orange and be brighter than the full moon!

During the last 20 years, astronomers have studied many other stars like our sun, and have discovered that some of these have activity cycles similar to our sun’s sunspot cycle. They can vary from cycles as short as 5 years to as long as 30. Many stars also have irregular cycles that seem to come and go. Even the sun went through a phase in the 1600s when there was no sunspot cycle at all for nearly 50 years!

Teacher's Guide

The Sunspot Cycle

Objective

The student will create a list and construct a graph of the number of sunspots using both technology and paper. The student will explore patterns in the data and locate the maximum and minimum.

Materials

— Graph paper
— Ruler
— Colored pencils
—Sunspot data table

Optional:
—Teacher notes on the graphing calculator.
—Graphing calculator. TI-83 used in the examples

Procedure

1) Divide the students into groups and assign a time period from the data table that each group will graph. Some possible lengths are the 1900s, 1800s; every 50 years; a column of the table (be aware that assigning less than 50 data points will prevent pattern recognition).

2) Use the graphing calculators, the students will input their data. They will use the trace key to explore the graph of their data while they look for a pattern or observation. Allow each group to report on their findings. They may or may not agree on a pattern within the groups as well as within the classroom as a whole.

3) Students will then construct the graph of the table on graph paper. Some possible options here are to have students each construct the graph, have each group use their assigned data and put the results of the class as a whole on the wall, or have the groups do a graph of the entire data. Be sure to agree upon a consistent scale for ease of construction and display.

4) Discuss the results of the entire sunspot table as a whole. Look for patterns such as maximum and minimum.

5) Students then predict when the next maximum will occur. Students will then construct what the graph would look like if this pattern continued on through the year 2099.

What is a sunspot?

A sunspot is a region on the sun that can be seen as a small dark spot through a telescope. Since their discovery by Galileo in 1609, astronomers have learned that they are regions, about the size of the Earth, where powerful magnetic fields are concentrated. Often the site of solar flares and other storm activity, these spots are dark because the temperature of the solar gases inside them is about 2000 C cooler than the rest of the sun (5500 C). They appear black because they emit less light than the sun. In fact, if they were suspended in the night sky, they would glow a bright red color and be brighter than the full moon. The sunspot cycle has been seen since about 1670 and has a period of about 11 years. Before 1670, no such cycles were seen and this time also corresponded to the 'Little Ice Age' in Europe. Scientists now think that solar activity influences the Earth's weather in some way.

Conclusion

Sunspot activity comes in cycles which come and go with periods of about 11 years. No two cycles, however, are exactly the same shape or size.

Teacher Notes for the Graphing Calculator

The commands for the calculator are given in bold print below the window you will see in the right-hand screen. Read the setup guide at the end of this section under 'How to insure success.'

When choosing the group data assignments, the best situation may be to assign the 1700's, 1800's and 1900's, or a minimum of 50 data points to permit pattern recognition.

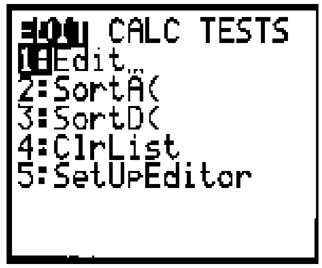
Entering data into the list will consist of the following key strokes :

This will put you at the window to input data for the year in list 1, and the data for the sunspot number in list 2. Screen images for the list beginning in 1900 are shown. The L1 data (year) was entered using only one or two digits for simplicity and to save time. This is acceptable since the scales on the axis are not displayed by the graphing calculator.

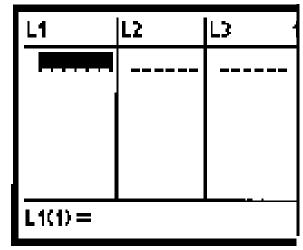
After the data has been entered into the lists, the stat plots will need to be turned on. To turn the plots on, use the right-hand key strokes. Note, turn on the second window to the right by using the arrow keys to place the cursor over each of the darkened items shown, and hitting **ENTER.**

Note: When selecting the type of graph, the student may want to pick the first plot. When they do so, the result is a plot of the individual data points. The second type shows the data as a set of connected points. The second type of graph is best for this example because it shows a continuous cycle. Students need to be aware that the data is continuous.

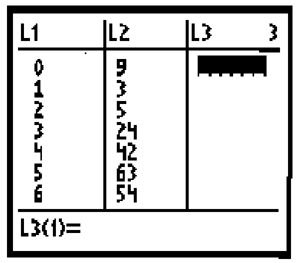
When the students hit the graph key, they may not see any data. They may see a graph of four quadrants with a small display of data.

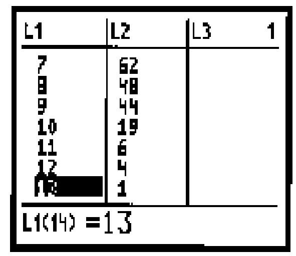


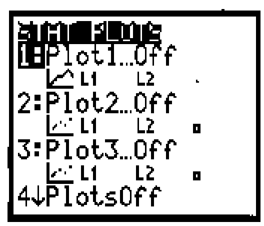
STAT



ENTER

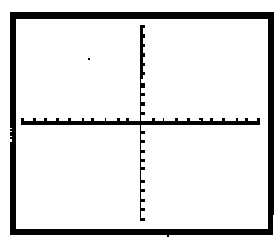






2ND Y=

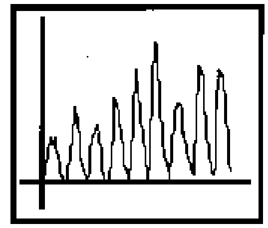
ENTER



GRAPH

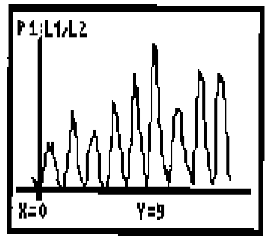
In order to get the correct window for the statistics plots, students will need to zoom the window:

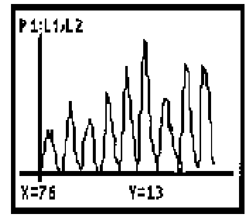
ZOOM



9

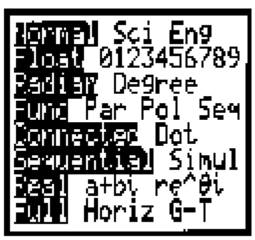
In order to check for pattern recognition and to trace the sunspot cycle maxima and minima, the students need to trace the cycle by using the left and right arrow keys to move along the graph. Some examples of the screen when using the **TRACE** command are shown to the right. When using the TRACE key, the students are able to see the year displayed from L1 and the number of sunspots from L2.



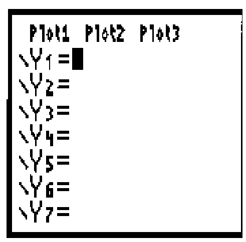


How to insure success for beginners

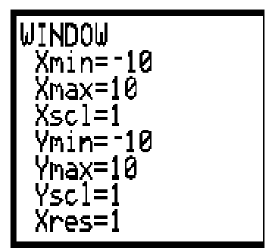
Before starting the activity with the students, have them insure that the following settings are in place on their calculators.



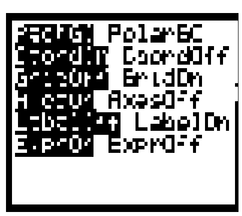
MODE



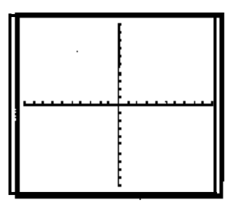
Y=



WINDOW



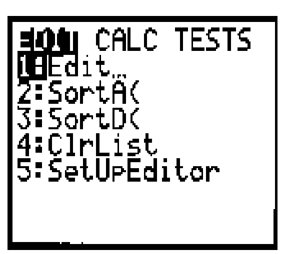
2ND ZOOM



GRAPH

To insure that the lists are cleared beforehand:

Then select ‘ClrList’ and use the keystrokes: 2**ND 1, 2ND 2, ENTER, CLEAR.** You can now begin the activity.



STAT

The Sunspot Cycle Data Table

The following numbers give the maximum sunspots counted during each year from telescopic observations on the ground. They are listed by year, and by the corresponding number seen 'N'. Example, for 1880 there were N = 32 sunspots counted.

Year....N	Year....N	Year...N	Year...N	Year.....N
1700... 5	**1760...63**	**1820...16**	**1880...32**	**1940...68**
1702...16	**1762...61**	**1822...4**	**1882...60**	**1942...31**
1704...36	**1764...36**	**1824...9**	**1884...64**	**1944...10**
1706...29	**1766...11**	**1826...36**	**1886...25**	**1946...93**
1708...10	**1768...70**	**1828...64**	**1888...7**	**1948...136**
1710... 3	**1770...101**	**1830...71**	**1890...7**	**1950...84**
1712... 0	**1772...67**	**1832...28**	**1892...73**	**1952...31**
1714...11	**1774... 31**	**1834...13**	**1894...78**	**1954...4**
1716...47	**1776...20**	**1836...121**	**1896...42**	**1956...142**
1718...60	**1778...154**	**1838...103**	**1898...27**	**1958...185**
1720...28	**1780...85**	**1840...65**	**1900...9**	**1960...112**
1722...22	**1782...38**	**1842...24**	**1902...5**	**1962...38**
1724...21	**1784...10**	**1844...15**	**1904...42**	**1964...10**
1726...78	**1786...83**	**1846...61**	**1906...54**	**1966...47**
1728...103	**1788...131**	**1848...125**	**1908...48**	**1968...106**
1730...47	**1790...90**	**1850...67**	**1910...19**	**1970...104**
1732...11	**1792...60**	**1852...54**	**1912...4**	**1972...69**
1734...16	**1794...41**	**1854...20**	**1914...10**	**1974...34**
1736...70	**1796...16**	**1856...4**	**1916...57**	**1976...13**
1738...111	**1798...4**	**1858...59**	**1918...81**	**1978...92**
1740...73	**1800...14**	**1860...96**	**1920...38**	**1980...154**
1742...20	**1802...45**	**1862...59**	**1922...14**	**1982...116**
1744... 5	**1804...48**	**1864...47**	**1924...17**	**1984...46**
1746...22	**1806...28**	**1866...16**	**1926...64**	**1986...14**
1748...60	**1808...8**	**1868...38**	**1928...78**	**1988...98**
1750...83	**1810...0**	**1870...139**	**1930...36**	**1990...146**
1752...48	**1812...5**	**1872...102**	**1932...11**	**1992...94**
1754...12	**1814...14**	**1874...45**	**1934...9**	**1994...30**
1756...10	**1816...46**	**1876...11**	**1936...80**	
1758...48	**1818...30**	**1878... 3**	**1938...110**	

Name ______________________

Date_________________

Teacher's Guide

Sunspot Activity and Ocean Temperature

Introduction

Scientists have found there is a possible correlation between the average ocean temperature and solar sunspot activity. By comparing the results from data that has been collected since the 1800's to the present, scientists have found a possible pattern. For example, there are many instances when the average ocean surface temperature and the sunspot activity were at a high or low at about the same time. The source of the controversy is that there are also times in which a correlation is not seen in the data.

Objective

Students will analyze and compare two graphs to determine if there is a correlation between solar activity and ocean temperature.

Procedure

1) Group students into either pairs or teams of four. Read the introduction to the students concerning the controversy.
2) Review with the students an example of how the graphs may be similar and different. Be sure to mention shape, distribution, highs, lows, scale, axis and time frame.
3) Provide students with sufficient time to compare the two graphs. A transparency used as an overlay may be useful for some students.
4) Have the groups present their findings to the class. Some of the groups will argue that the highs and lows of the ocean temperature correlate to the sunspot cycle. Other groups may not see a relationship, and still others may say that there is a relationship in some areas but not in others which leads to incomplete conclusions. This is precisely why the controversy exists.

Note: The start date for each graph is not the same year. Students will need to locate the appropriate year to begin the comparison. The temperature plots show the deviations in the number of degrees from an average global ocean temperature, so that -0.5 degrees means '0.5 C below the average' ocean temperature. You should also mention other factors that could alter the correlation such as El Nino events. **Be sure to mention this to the students.**

Materials

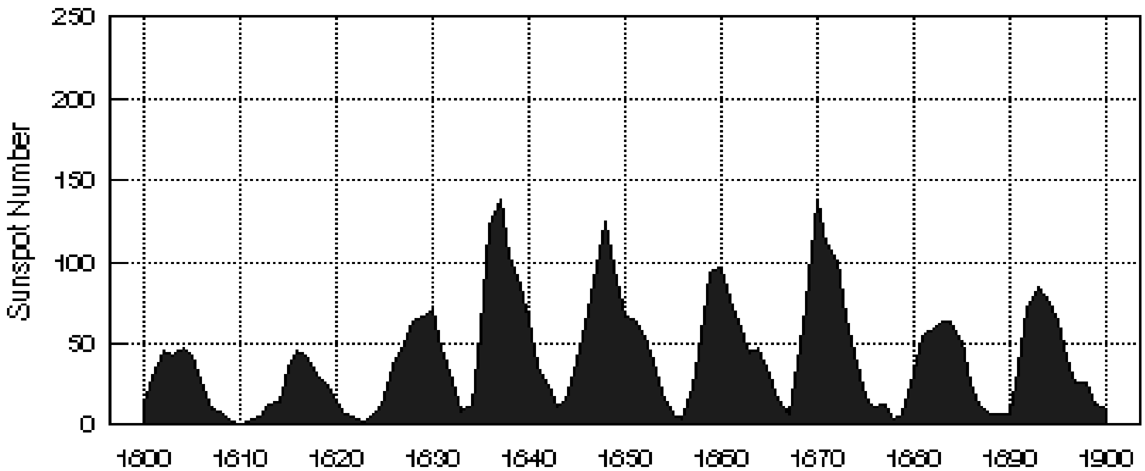
—Student Worksheet

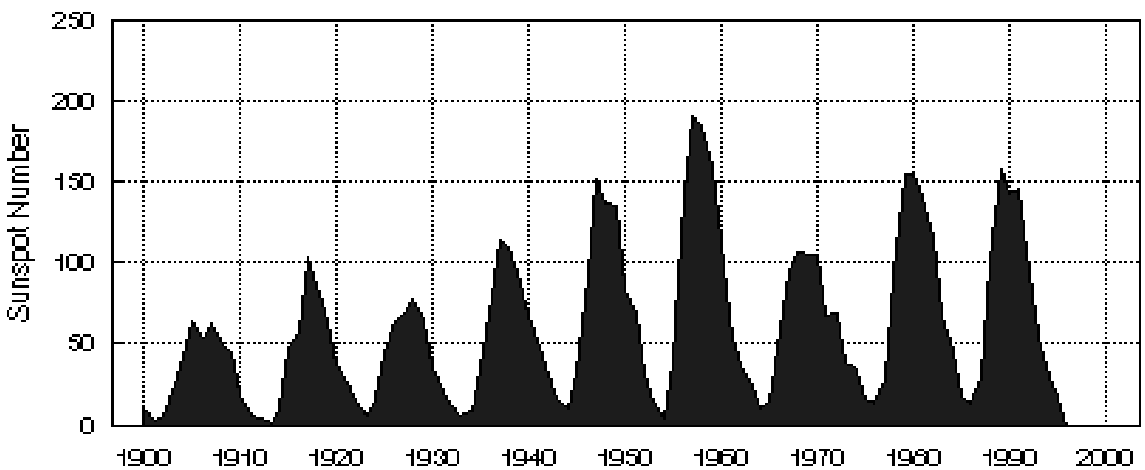
Note: The ocean temperature data are based on over 80 million measurements made by hundreds of ships that, every hour, dumped a bucket overboard to collect sea water.

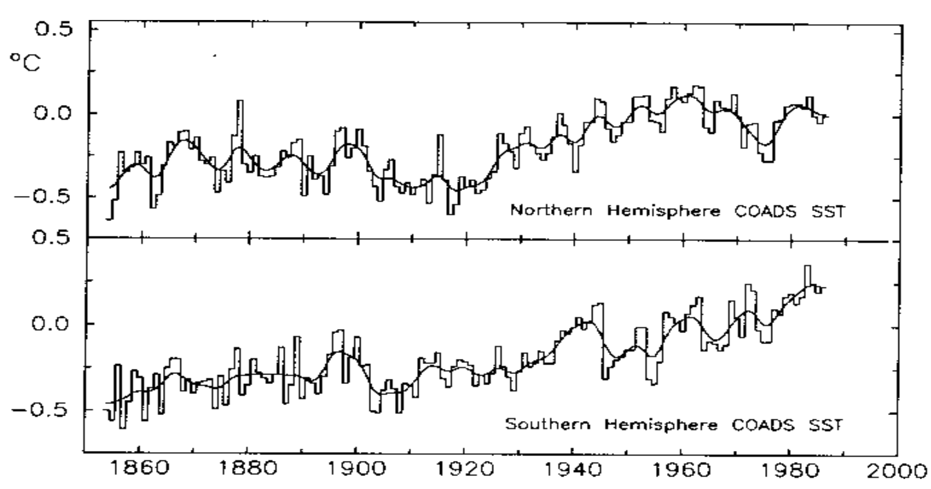
Conclusion

Explain that the relationship between the sunspot cycle and the ocean temperature has not been proven or disproven. However, there seems to be a grudging consensus that there is something going on between the two.

Student Worksheet







Teacher's Guide

Sunspot Activity on Other Stars

Introduction

Since the 1970's, astronomers have been studying dozens of other stars that resemble the Sun in size and temperature. By monitoring the month to month changes in the brightness of these stars using the light they emit at specific wavelengths, they can investigate how storms on these stars ebb and flow over time. These 'stellar activity cycles' may be caused by the same processes as our own Sun's sunspot cycle, but may have properties that make them unique.

Objective

Students will analyze and compare stellar activity graphs to determine how similar or different they are to the solar sunspot cycle.

Procedure

1) Group students into either pairs or teams of four. Read the introduction to the students concerning the current issues in astronomy having to do with solar activity.

2) Review with the students an example of how graphs may be similar and different. Be sure to mention shape, distribution, highs, lows, scale, axis and time frame.

3) Provide students with sufficient time to compare the stellar activity cycle graphs with the solar sunspot graphs.

4) Have the groups present their findings to the class.

Materials

—Student Worksheet

Answers:

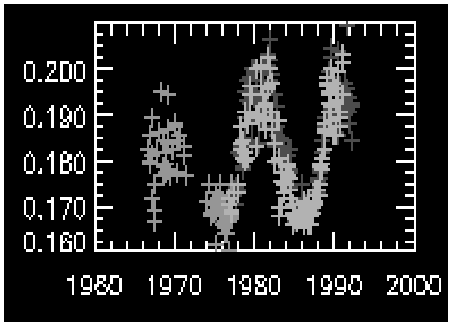
The Sun.............11 years
HD136202..........28 years
HD81809..............8 years
HD16160............12 years

Student answers may vary from these by a few years.

Conclusion

Explain that astronomers do not yet know why the sun has a sunspot cycle, or whether these cycles are permanent in the history of the sun, or come and go with time. By studying other stars we can learn just how typical our sun is, and study the possible factors that influence these cycles, such as the star's mass, temperature and age.

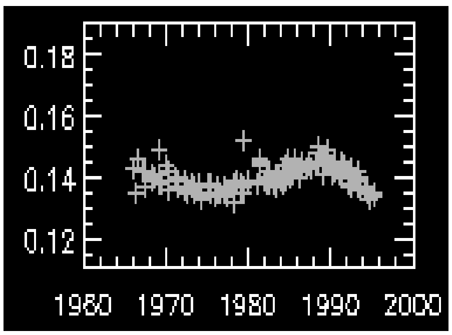
Name ______________________________ **Date**________________



The Sun

Average length of cycle:

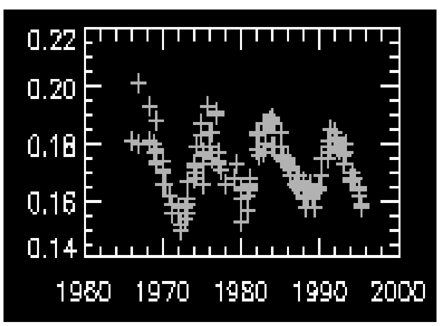
Temperature: **5770 K**



HD 136202

Average length of cycle:

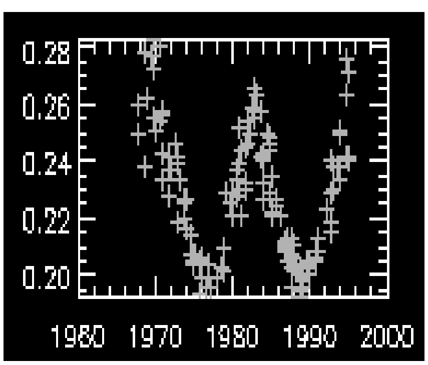
Temperature: **8400 K**



HD 81809

Average length of cycle:

Temperature: **4100 K**



HD 16160

Average length of cycle:

Temperature: **4800 K**

What is Solar Activity?

The Sun, our nearest star, provides us with warmth and light. For many civilizations, it was once thought to be a perfect orb, free of blemishes, eternal and changeless. **Sunspots** are the most well known hints that the Sun's surface is constantly changing. Larger than the Earth, and with magnetic fields that are 10,000 times stronger than the Earth's, sunspots are the breeding grounds for some of the most violent storms in the solar system!

The number of sunspots increases and decreases in cycles that last from 6 to 17 years; the **Sunspot Cycle.** With modern technology and space satellites, this solar activity cycle can now be detected in the ebb and flow of other phenomena on the Sun and on the Earth. Among the most enigmatic storms are the **solar flares** that erupt near sunspots. In a matter of 20 minutes, magnetic fields can heat gases to tens of thousands of degrees and release more energy than a thousand atomic bombs. Some of this gas can be hurled out from the Sun at millions of kilometers per hour in what are called **coronal mass ejections.** Both solar flares and coronal mass ejections can be very disruptive to human activity on earth and in space.

The outer atmosphere of the Sun, the **corona,** is familiar to many people who have watched total eclipses of the sun. The solar wind extends billions of kilometers further out into space than the corona**.** Like invisible roadways spanning the solar system, the magnetic field from the Sun flows out from the solar surface. Matter ejected from the Sun flows radially outwards from the solar surface. From the time a solar storm is seen on the Sun, it can take 2-3 days for the gas to travel to the orbit of the Earth, and if the Earth happens to be in the wrong place at the wrong time, it will be hit by a million-kilometer wide wall of high temperature gases and magnetic fields.

Anyone can tell you that a compass points 'north' because the Earth has a magnetic field, but until the advent of the Space Age, no one understood what this field really looked like or was capable of doing. Since Gilbert proposed in the 17th century that the Earth was a giant magnet, scientists have wondered just how this field is shaped, and how it has changed with time. The geomagnetic field which gives us our familiar compass bearings, also extends thousands of kilometers out into space in a region called the **magnetosphere**. On the Sun-side, it forms a protective boundary called the **bow shock.** Stretching millions of kilometers in the opposite direction behind the Earth is the **magnetotail.**

The solar wind blows upon the magnetosphere and gives it a wind-swept shape, but when solar storms and solar wind streams reach the Earth, the magnetosphere reacts violently. On the side nearest the impact, the magnetosphere compresses like squeezing a balloon, leaving communications satellites exposed. On the opposite side, it is stretched out, past the orbit of the Moon, or Mars and even Jupiter! The geomagnetic field is remarkably stiff, and so most of the solar wind is deflected or just slips by without notice. But some of the matter leaks in and takes up residence in donut-shaped clouds of trapped particles, or can penetrate to the atmosphere to produce the Aurora Borealis.

For thousands of years, humans have been treated to spectacles of glowing clouds above the northern horizon at night. Reports of these mysterious Northern Lights abound in the oral histories of the northern natives. On rare occasions, even ancient Greek and Chinese texts have mentioned them. It wasn't until 1896 that the Norwegian physicist Kristian Birkeland deduced that flows of electrons from the Sun were channeled into the polar regions by the geomagnetic field, and upon colliding with the outer atmosphere, would stimulate oxygen and nitrogen atoms to cast their ghostly and inspiring curtains of light.

The **Aurora Borealis** (near the north pole) and the **Aurora Australis** (near the south pole), as the ‘Northern Lights’ are more formally called, are seen most often in a band located at a latitude of 70 degrees, and about 10 degrees wide in latitude. From space, the auroral zone looks like a ghostly, glowing donut of light hovering over the north and south poles. This **auroral oval** can easily be seen in images from satellites designed to detect it. Its brightness and size change with the level of solar activity. Aurora come in many shapes and colors depending on what is happening to the geomagnetic field and the flows of charged particles and plasmas trapped in this field.

Magnetic sub-storms happen when the geomagnetic field is suddenly changed because of small changes in the magnetic polarity of the solar wind as it passes the Earth. Typically, magnetic storm aurora, also called **auroral storms,** last only a few hours. They begin in the evening as arcs of colored light which slowly change into rayed-arcs and the familiar folded ribbons or bands. Expanding over the whole sky, the folded bands are colorful, with green rays and red lower borders which change from minute to minute and move rapidly across the sky like some phantasmagoric serpent. After an hour, the auroral shapes become more diffuse and less distinct.

Geomagnetic storms are more severe than magnetic sub-storms and are caused by major changes in the direction and density of the solar wind as it reaches the Earth. These events are the most remembered historically as 'Great Aurora' or as the most disruptive to radio communications. The entire geomagnetic storm can last for several days as the particles and fields around the Earth continue to readjust themselves to the passing and ebbing solar wind.They begin with an ejection of mass by the Sun, and the impact of this plasma on the magnetosphere. Fast-moving coronal mass ejections produce shock waves in the solar wind, and this compression intensifies the density of particles impacting the magnetosphere. As the solar wind shock passes across the magnetosphere and magnetotail, magnetic fields re-orient and reconnect, releasing enormous amounts of energy and accelerating trapped particles to high speeds. These charged particles then travel down the geomagnetic field in huge currents, which cause bright and long lasting auroral displays.

Solar storms and the effects they produce in the Earth's environment, have been known for decades to be responsible for many harmful effects upon human technology on the ground and in space. Solar storms are known to do far more than just paint the sky with pretty colors! The multi-billion dollar 'Global Positioning System' consists of a constellation of two dozen navigation satellites orbiting within the Van Allen radiation belts. These satellites let humans find their position anywhere on Earth using a receiver no bigger than a watch.

During solar storms, these positions are quite a bit less accurate than under calm conditions, which in turn impacts the navigation of ships at sea and jets in the air. Solar storms have disabled multi-million dollar communication and navigation satellites such as Anik-A, Molynia, Marecs-A, and they have been implicated in many electrical problems that were experienced by other satellites.

Solar storms were responsible for causing the Skylab to burn up in the atmosphere sooner than expected, and for altering the orbits of hundreds of other satellites and even the Space Shuttle itself. A storm on March 13, 1989 knocked out the Quebec-Hydro power system, plunging 6 million people into darkness for 9 hours. Geomagnetic storms cause the magnetic field near the Earth's surface to change rapidly in just a matter of minutes or hours. These changes cause electrical currents to flow within long power transmission lines, telephone wires, and even in pipelines which makes the pipes corrode, sometimes with tragic consequences. On June 5, 1991 a natural gas pipeline in Russia was weakened by corrosion and began to leak its deadly, flammable cargo. A passenger train, loaded with 1,200 people, ignited the liquefied gas and caused an explosion equal to 10,000 tons of TNT. Over 500 people were killed, and 700 more were badly injured.

Would you believe...

Aurora can never get closer to the ground than about 60 kilometers.

A sunspot has a temperature of nearly 4000 C, and would be brighter than the full moon if placed in the night sky.

Sunspots are often several times larger than the entire earth.

The Sun rotates once every 25 days at the equator, but takes up to 36 days to rotate once around at the poles.

The corona of the Sun is over 5 million degrees hotter than the surface of the Sun.

The Earth's magnetic north pole is actually a magnetic south pole because the north end of a bar magnet is attracted to it.

The total power produced by an auroral event can exceed 1 million megawatts and produce voltages over 100,000 volts in the upper atmosphere.

Aurora are produced where the atmosphere has the same density as the vacuum inside a light bulb.

Some aurora occur at altitudes of over 1000 kilometers above the Earth's surface.

Lightning storms can eject particles into space at nearly the speed of light, and they are seen as 'sprites' on the top side of a thundercloud.

A single lightning storm can be detected on the other side of the earth because some of its radio energy travels along the local magnetic field lines that connect the pairs of points on the surface of the Earth that can be thousands of kilometers apart.

Glossary

Aurora : Also called the 'Northern Lights' in the Northern hemisphere, or the 'Southern Lights' in the Southern hemisphere. These wispy curtains of light in the sky are caused by energetic electrons which collide with atoms of oxygen and nitrogen in the air to cause these atoms to emit shades of green, red and blue light. They never descend nearer than 60 kilometers from the Earth's surface.

Corona : The very tenuous outer layers of the Sun which are seen during a total eclipse of the sun, but extending millions of miles into interplanetary space. It is heated to temperatures of over one million degrees by magnetic activity at the surface of the Sun. For decades, scientists puzzled over why the Corona could be so much hotter than the balmy 5770 degree Kelvin surface of the Sun.

Coronal Mass Ejection : The sudden expulsion of matter from the coronal regions of the sun, often involving billions of tons of plasma ejected at over one million miles per hour. During sunspot minimum conditions, about one 'CME' can be expelled every few days. During sunspot maximum conditions, as many as 3-5 can occur each day.

Magnetopause : A region that defines the outer edge of the magnetosphere where the pressure of the solar wind is balanced by the pressure of the earth's own magnetic field.

Magnetosphere : The region surrounding the Earth in space where its magnetic field is important in controlling the movements of charged particles. Also sometimes referred to as 'Geospace'.

Magnetotail : The solar wind pulls the magnetosphere into a comet-like shape. The long tail of this field, called the magnetotail' or also the 'geotail', extends millions of miles into space in a direction opposite to the Sun from the Earth.

Solar flare : A powerful release of energy on the surface of the sun usually lasting less than a few hours, but releasing as much energy as 1000 hydrogen bombs. These are often associated with active regions of the solar surface where magnetic fields have become badly tangled, and then snap, releasing energy and heating local gases to over 1 million degrees.

Solar storm : Although scientists prefer not to use this term because it is technically rather vague, it has come to mean any of a number of active conditions on the Sun's surface including flare activity or coronal mass ejections.

Sunspot : A dark spot on the Sun's surface that indicates a concentration of magnetic forces. They are actually about 2000 degrees cooler than the solar surface, and only look dark because they emit light faintly.

Sunspot Cycle : The change in the number of sunspots from one period of its maximum to the next, over the course of about 11 years.

Sunspot Maximum : The period during the sunspot cycle when you will see the largest number of sunspots. Also called the 'Solar Maximum'.

Sunspot Minimum: The period during the sunspot cycle when you will see the fewest number of sunspots. Also called the 'Solar Minimum'

Resources

IMAGE	http://image.gsfc.nasa.gov
POETRY	http://image.gsfc.nasa.gov/poetry
SOHO	http://sohowww.nascom.nasa.gov
NASA Sun-Earth Connection Resources	http://sunearth.gsfc.nasa.gov
The Earth's Magnetic Field	http://image.gsfc.nasa.gov/poetry/magneto.html
Satellite Glitches -Space Environment Info	http://envnet.gsfc.nasa.gov
Magnetic North Pole	http://www.nrcan.gc.ca/gsc/cpdnew/magnet.html
Solar Sounds	http://soi.stanford.edu/results/sounds.html
Sunspot Number Archives / Resources	http://image.gsfc.nasa.gov/poetry/sunspots.html
CME Archives at MLSO	http://www.hao.ucar.edu/public/research/mlso/movies.html
Stellar Activity Cycles at Mt. Wilson	http://www.mtwilson.edu/Science/HK_Project/
Satellite Data	http://cdaweb.gsfc.nasa.gov
Space Weather Resources	http://image.gsfc.nasa.gov/poetry/weather.html
Magnetic Observatories and Data	http://image.gsfc.nasa.gov/poetry/maglab/magobs.html
Space Environments and Effects	http://see.msfc.nasa.gov/sparkman/Section_Docs/sparkman.html
Sun-Earth Classroom Activities Archive	http://sunearth.gsfc.nasa.gov/educators/class.html
Storms from the Sun	http://www.istp.gsfc.nasa.gov/istp/outreach/learn.html
The Aurora Page	http://www.geo.mtu.edu/weather/aurora/
Space Weather Human Impacts	http://image.gsfc.nasa.gov/poetry/storm/storms.html
Ionosphere density and sunspot numbers	http://julius.ngdc.noaa.gov:8080/production/html/IONO/ionocontour_90.html
Space Weather Daily Reports	http://windows.engin.umich.edu/spaceweather/index.html
Solar wind density and speed	http://www.sel.noaa.gov/wind/rtwind.html
Mees Solar Observatory Archives	http://www.solar.ifa.hawaii.edu/MWLT/mwlt.html

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Educational Product	
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Solar Storms and You!

Exploring the Wind from the Sun

An Educator Guide with Activities in Space Science

Solar Storms and You! is available in electronic format through NASA Spacelink - one of the Agency's electronic resources specifically developed for use by the educational community.

The system may be accessed at the following address:
http://spacelink.nasa.gov

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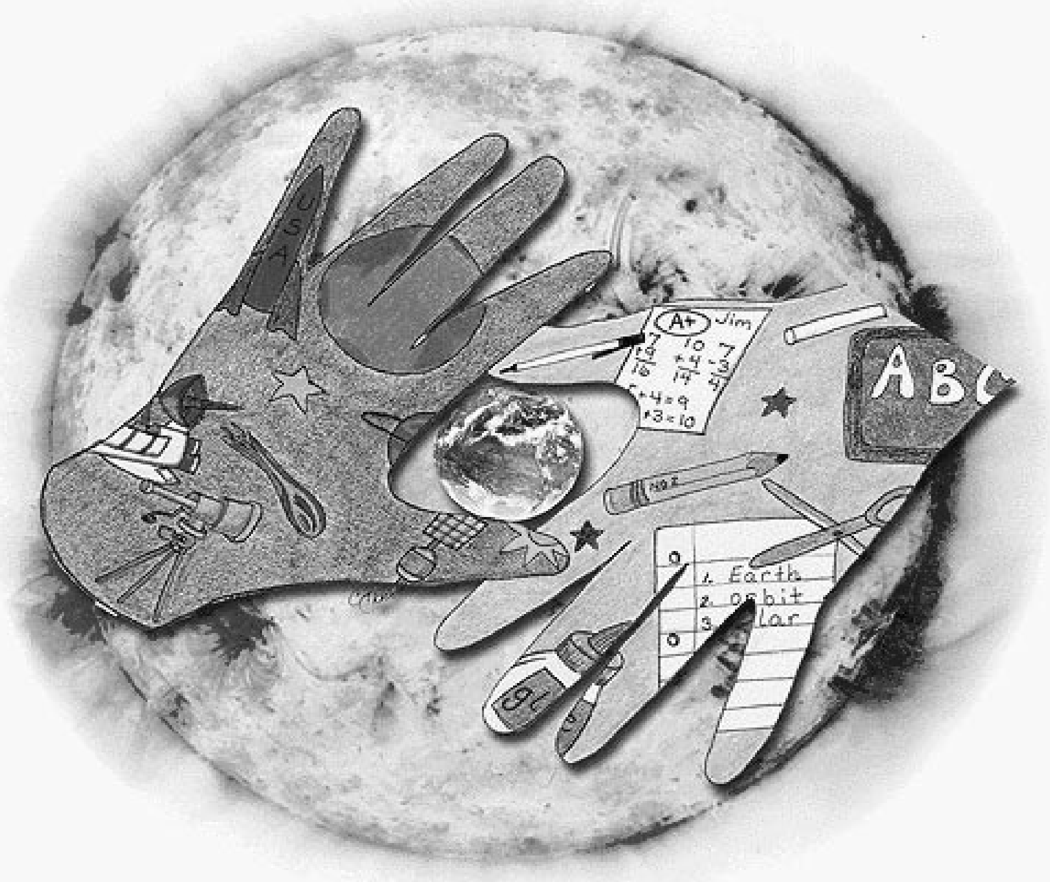

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This resource was developed by the NASA Imager for Magnetosphere-to-Auroral Global Exploration (IMAGE)

Information about the IMAGE mission is available at:

http://image.gsfc.nasa.gov
http://pluto.space.swri.edu/IMAGE

Resources for teachers and students are available at:

http://image.gsfc.nasa.gov/poetry

National Aeronautics and
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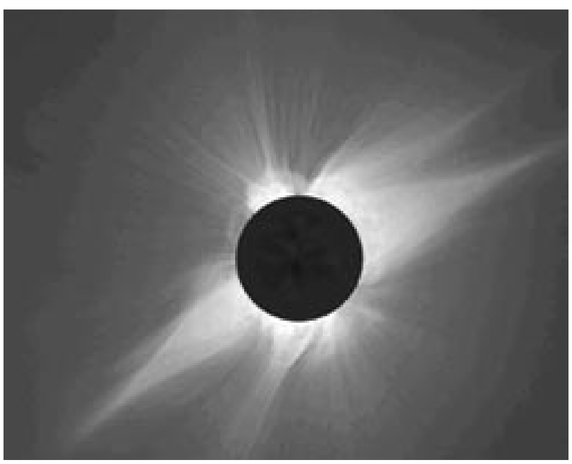
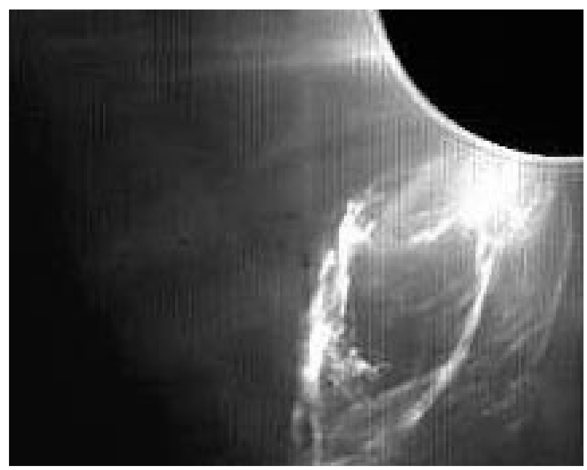
Goddard Space Flight Center

CONTENTS





The Sun is an active star. During times of sunspot maximum, it ejects over 100 clouds every month; many of these carry over a billion tons of matter. Along with these dramatic eruptions of matter and energy, the Sun steadily emits a wind from its surface which travels at speeds up to one million kilometers an hour. This wind is very dilute and contains fewer than ten atoms in each thimble-sized volume. Eventually after traveling throughout the solar system, it collides with the gases between the stars in interstellar space outside the orbit of Pluto.

INTRODUCTION

A gas pipeline in Russia explodes
killing hundreds of people.

A satellite mysteriously falls silent
interrupting TV and cellular phone traffic.

A power blackout
throws millions of people into darkness.

These are only a few of the many things that solar storms can do when they arrive at the earth unexpected. In an age where we have increasingly come to rely upon the smooth operation of our technology, we have also made ourselves vulnerable to the ebb and flow of the solar storm cycle. Most people are not even aware of this cycle, ut long ago we used to be!

Ancient Chinese sun observers knew that, from time to time, dark spots would glide slowly across the face of the setting sun. Once seen only as portends of political upheaval, we now see them as natural phenomena that can forewarn us of impending storms that can have dire consequences for us if we ignore them.

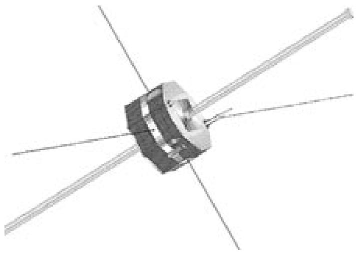
In this activity book, your students will study five key stages in the lifecycle of a solar storm, from its emergence on the solar surface to its impact upon some aspect of our lives. The book may be used in its entirety to study solar activity and how it directly affects us, or you may use individual activities of your choice as stand-alone mini lessons as an enrichment for math and physical science courses.

The student activities emphasize basic cognitive skills and higher-order processes such as plotting data, searching for patterns and correlations, and interpreting the results. By the end of the activity series, students will understand why we need to pay more attention to solar storms.

Visit the updated version of this workbook at:

http://image.gsfc.nasa.gov/poetry/workbook/workbook.html

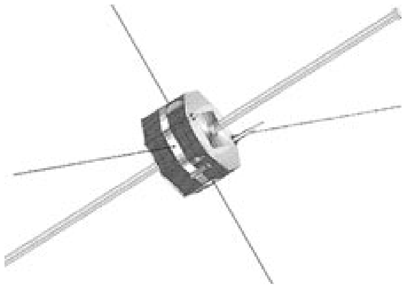
Science Process Skills
for *Solar Storms and You!*



This chart is designed to assist teachers in integrating the activities contained in the guide with existing curricula.

	Lesson 1 *"CME Plotting Activity"*	**Lesson 2** *"Solar Activity and CMEs"*	**Lesson 3** *"Anatomy of a CME"*
Observing	○	○	○
Classifying			
Communicating	○	○	○
Measuring	○	○	○
Inferring		○	○
Predicting	○		
Experimental Design			
Gathering Data			
Organizing Data			
Controlling Variables			
Developing a Hypothesis	○	○	○
Extending Senses			
Researching			
Team Work			
Mathematics	○	○	○
Interdisciplinary			
Introductory Activity	○	○	○
Advanced Activity			

Science and Mathematics Standards
for *Solar Storms and You!*



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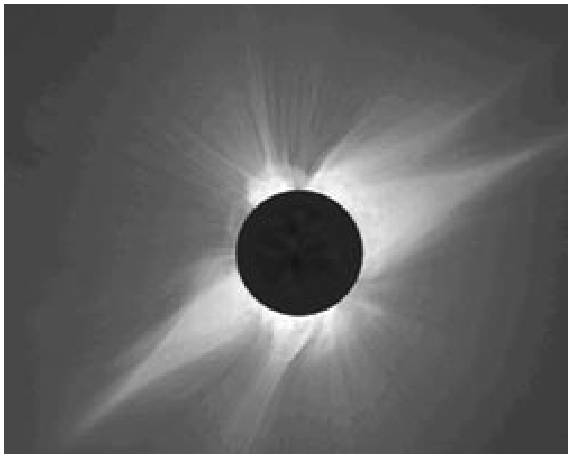
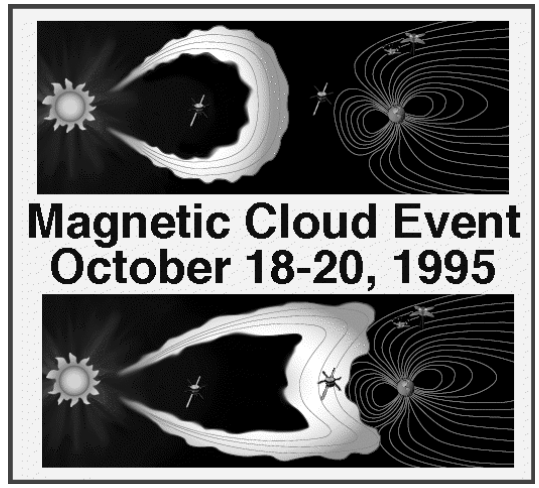
	Lesson 1 *"CME Plotting Activity"*	**Lesson 2** *"Solar Activity and CMEs"*	**Lesson 3** *"Anatomy of a CME"*
Science as Inquiry	○	○	○
Structure and Energy of the Earth System			
Origin and History of the Earth			
Earth in the Solar System	○	○	○
Geochemical Cycles			
Physical Science	○	○	○
Populations and Ecosystems			
Understanding Science and Technology	○	○	○
Science in Personal and Social Perspectives			
History and Nature of Science			
Problem Solving	○	○	○
Measurement	○	○	○
Computation and Estimation			
Communication			
Geometry and Advanced Mathematics	○		
Statistics and Probability		○	
Number and Number Relationships			
Patterns and Functions	○	○	○

The Solar Wind





The outer layers of the Sun, called the **Corona,** are not stable but are constantly escaping into space. Although the magnetic field of the Sun 'bottles up' some of the hot gases near the solar surface to make spectacular prominences, in other regions the magnetic field opens into interplanetary space and allows the million-degree gases to escape as a **Solar Wind.**

Within the equatorial region of the Sun, the solar wind travels outwards in a pinwheel-shaped spiral pattern due to the combination of the outward gas motion, at over 400 kilometers/sec (1 million miles/hour), and the rotational motion of the Sun.

Although its normal density is less than 10 atoms per cubic centimeter, because the wind is spread out over such a vast volume of space, it amounts to over 50 billion tons of mass lost per day mostly in the form of high-speed electrons and protons - the components of the most abundant element in the Sun: hydrogen.

On occasion, and for reasons not fully understood by scientists, the magnetically trapped gases in the Sun's corona can become unstable and get ejected into space as **Coronal Mass Ejections,** or **CME**s. These clouds are carried by the solar wind. They are often as big as the Sun itself, and they contain upwards of one billion tons of matter in a single event which may last only a few hours. Traveling at speeds from 450 to 1000 kilometers/sec, the trip from the Sun to the Earth's orbit takes only a few days.

Most of these clouds dissipate quickly and merge into the solar wind while others can remain cohesive, though substantially diluted by the time they reach the Earth. Most of these CMEs never collide with the Earth, but those that do can cause satellite damage and brilliant auroral displays, so their effects are not inconsequential.

Like Stealth Bombers, it is not the ones we can detect on the limb of the Sun that pose a hazard to us here on Earth, it is the ones that are lost in the glare of the solar surface that can potentially reach Earth. NASA has stationed satellites in space between the Earth and the Sun to provide advanced warning for stealthy CME events, but even so, only about 1-2 hours of warning is possible from such distant outposts.

Teacher's Guide — CME Plotting Activity

Introduction

Coronal Mass Ejections are major storms on the Sun which can hurl billions of tons of matter into space in a matter of a few hours. Traveling at millions of kilometers per hour, some of these clouds occasionally collide with the Earth and have produced power blackouts and satellite damage. CMEs can start out with a size of only a few 100,000 kilometers, but fan out to millions of kilometers by the time they reach Earth's orbit. Only the CMEs that emerge from near the Sun's eastern limb stand a chance of traveling all the way to Earth, so this is where astronomers look for early signs that one is on its way!

Objective

Students will construct a table of values and plot the points in order to make a prediction.

Procedure

1) Plot CME1 points from the appropriate tables and draw to scale the thickness of the CME indicated in the 'Width' column of the table.

2) Plot CME2 points from the appropriate tables and draw to scale the thickness of the CME indicated in the 'Width' column.

3) By hand, sketch the path of the CME that hits Earth and complete the shape of the CME using the width information from the table.

4) Identify the location on the Sun where the sketched CME in procedure #3 will emerge so that it hits the Earth. This point is about half way between the center of the Sun and the left (eastern) edge.

5) Show that most CMEs do not hit the Earth by choosing other CME locations on the Sun, and plotting the possible shape.

6) The points in the tables were calculated for an assumed CME speed of 450 kilometers/sec, however some CMEs can travel at a speed twice this fast. Challenge your students to re-calculate the table entries for a faster speed and repeat steps 1-4 in this procedure.

The students should see the shapes of the CME trajectories become flatter. The point where the Earth-hitting CME is ejected from the Sun will shift closer to the left (eastern) edge of the sun.

Materials

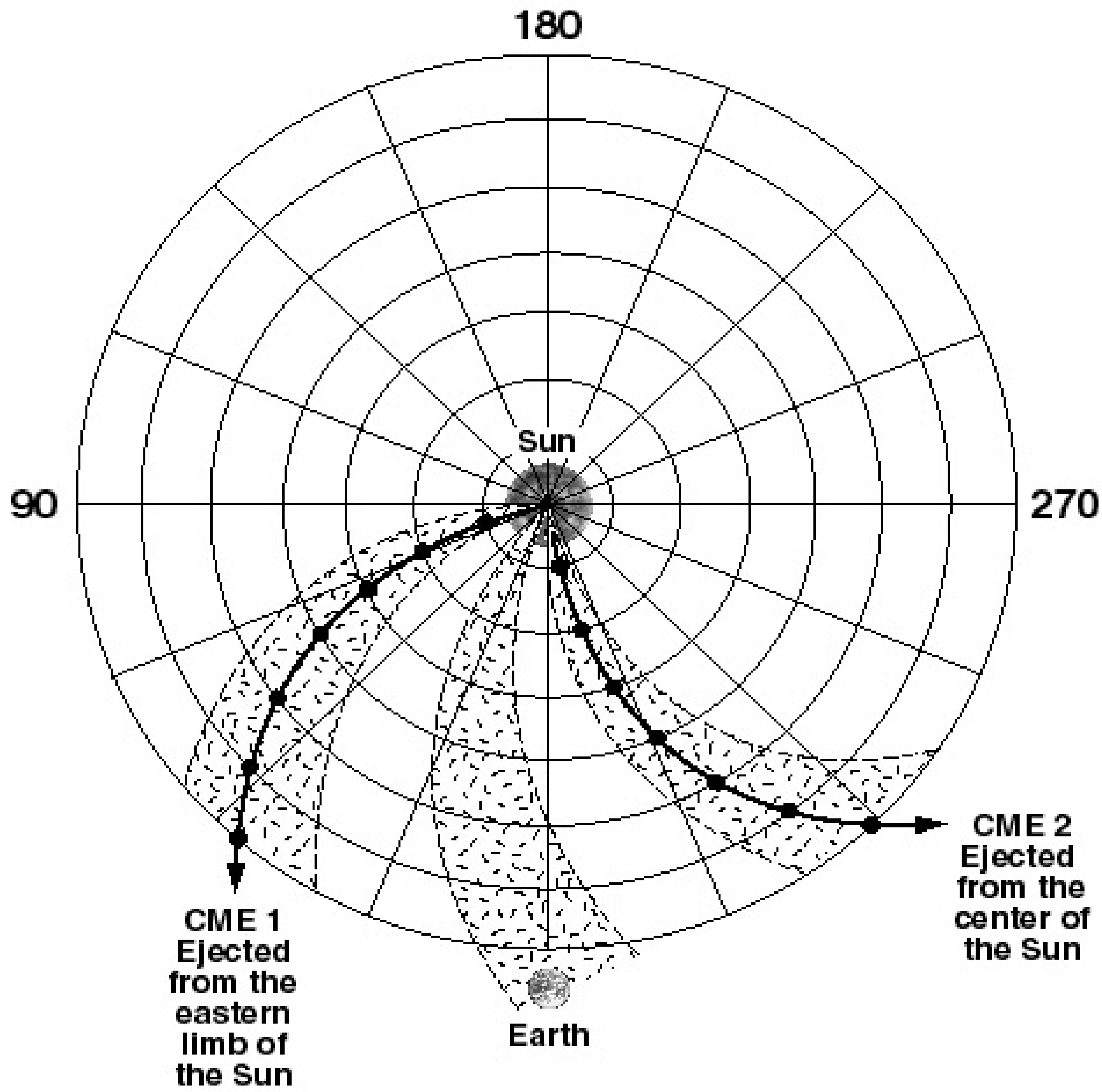
—Student work page
—Calculator
—Colored pencils

Teacher's Answer Key

	CME #1		CME #2		
Day	Distance	Angle	Distance	Angle	**Width**
0.0	0	90	0	360	0.5
0.5	20	83	20	353	7.0
1.0	40	76	40	346	13.5
1.5	60	69	60	339	20.0
2.0	80	62	80	332	26.5
2.5	100	55	100	325	33.0
3.0	120	48	120	318	39.5
3.5	140	41	140	311	46.0

From the table to the left, plot the path of two CMEs as they leave the Sun during its 3.5-day journey.

The distances and the widths of the CMEs are given in millions of kilometers.



Name ______________________

Date________________

Day	CME #1 Distance	CME #1 Angle	CME #2 Distance	CME #2 Angle	Width
0.0	0	90	0	360	0.5
0.5	20	83	20	353	7.0
1.0	40	76	40	346	13.5
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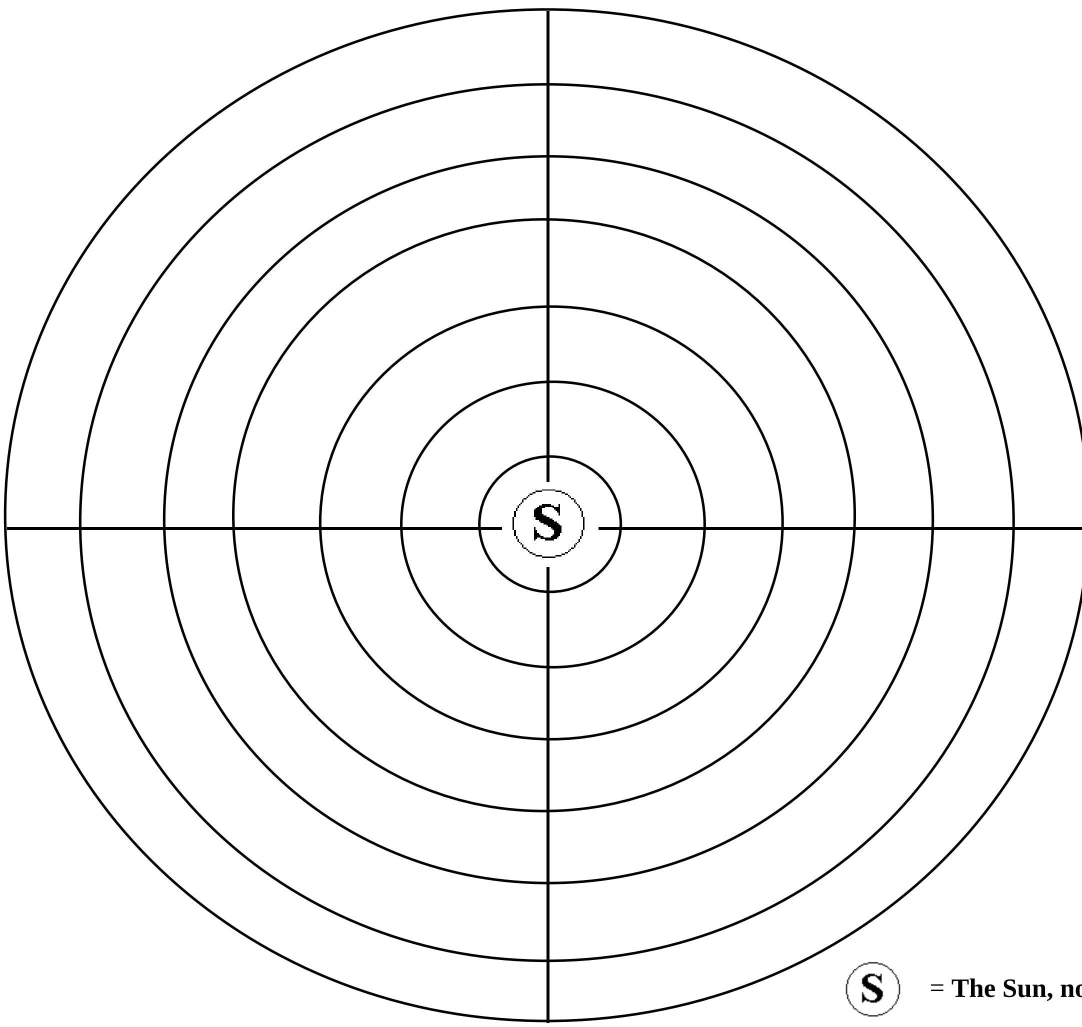


S = **The Sun, not to scale.**

Teacher's Guide

Solar Activity and Coronal Mass Ejections

Introduction

The Sun constantly emits matter into space in the form of a more or less steady solar wind. From time to time the Sun also ejects individual clouds of gas in an event called a Coronal Mass Ejection or CME. CMEs can cause storms in the environment of the earth that can have harmful impacts on humans working in space, on communication satellites, and many other aspects of our technology dependent society. For this reason, scientists look for many clues to tell when the next one may happen to provide us with an advanced warning.

Objective

Students will construct a graph to compare the sunspot cycle with Coronal Mass Ejections (CMEs).

Procedure

1) Students will use the graphing calculator to create the graphs for the sunspots and the CMEs. Students will graph the sunspots and CMEs on graph paper. **Note:** Using different colors to depict each graph will allow for ease when comparing the two graphs.

2) Students are to compare the two graphs. Location of the maximums, the minimums, and the time frames are the key components. Have students determine if there is a correlation.

3) Discuss the possible relationships that the students locate. Among other things to consider are:

—How well does the CME activity follow sunspot number?

—Do the maximums and the minimums happen at about the same time?

Some things you will find are:

—CME activity should follow rather closely to the sunspot cycle, but the correlation in exact counts may not be precise. This is probably because CMEs happen in layers of the sun that are much higher above the solar surface than the sunspots.

—The CME curve seems to have a longer, flatter minimum than the sunspot curve and its center is offset from the sunspot minimum by 2-3 years earlier. CME activity may decline to a minimum faster than sunspots after sunspot maximum.

Materials

—Graph paper
—Colored pencils
—Student worksheet

Optional:
—Teacher notes on the graphing calculator.
—Graphing Calculator
Note: TI-83 used in the examples

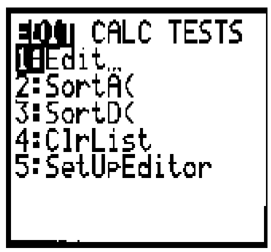
Teacher Notes for the Graphing Calculator

Reminder: Be sure to reset the calculator using the "Teacher Notes for the Graphing Calculator" included in the previous sunspot lesson .
The commands for the graphing calculator are given in bold print below the windows.

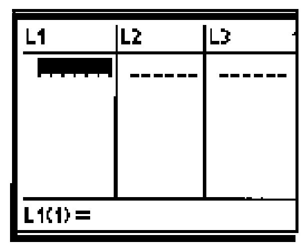
Students will enter the following data:

Year	CMEs	Sunspots	Year	CMEs	Sunspots
1980	12	154	1988	29	98
1981	26	140	1989	38	154
1982	7	116	1990	18	146
1983	8	67	1991	32	144
1984	6	46	1992	23	94
1985	2	18	1993	10	56
1986	4	14	1994	9	30
1987	5	32	1995	13	17

Entering the data into the list will consist of the following keystrokes:

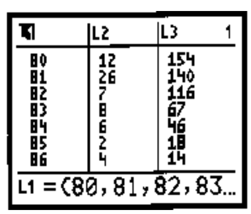


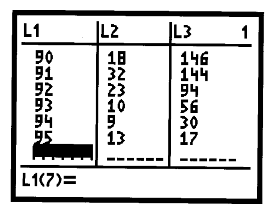
STAT



ENTER

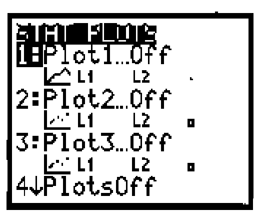
This will put you at the window to input the data for the year in List 1, CME number in List 2, and the sunspot number in List 3. Sample screen images are shown on the right:



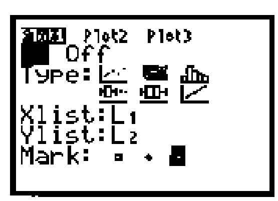


After the data has been entered into the lists, the stat plots need to be turned on. To turn the plots on, use the following keystrokes:

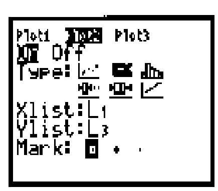
Plot 1 allows the year and CME data to be graphed. Plot 2 allows the year and sunspot number to be graphed. **Note:** To change the xlist and the ylist to L1, L2 and L3, use the **2nd 1, 2nd 2,** and **2nd 3,** commands.



2ND Y=



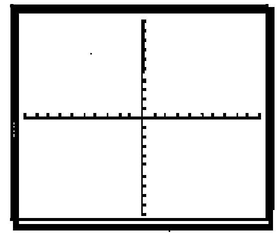
ENTER



2ND Y= 2

This would be a good time to discuss the appropriate graph for this situation. The explanation given in the sunspot lesson is consistent with this data. The data is continuous and should be displayed as such.

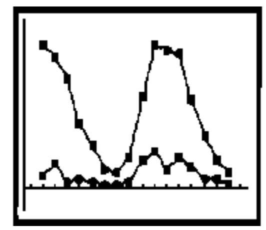
When the students push the graph key, they may not see any data. They may see a graph of four quadrants with a small display of data:



GRAPH

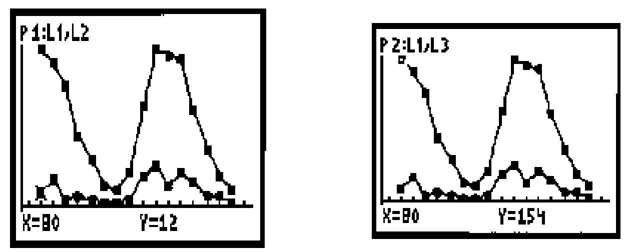
In order to get the correct window, the students need to zoom the screen:

ZOOM



9

In order to move along the values and make comparisons, use Trace. Note: The top graph is the number of sunspots and the bottom graph is the number of CMEs.



TRACE

When using the TRACE key, the students are able to see the year displayed in L1, the CMEs in L2, and the sunspot numbers in L3. By using the right and left arrow key, the students can move along a particular graph. To move to the other graph, the up and down arrow keys allow the students to move from one graph to the other.

Name ______________________________

Date________________

Teacher's Guide

Anatomy of a CME

Introduction

Coronal Mass Ejections (CMEs) are large clouds of gas ejected into space by the Sun which disable satellites, and can even cause power outages. Many of these CMEs cannot be easily detected on the solar surface so that adequate warning can be provided. NASA has begun to use satellites placed in orbit between the Earth and the Sun to provide early warning for detecting 'stealthy' CME events less than 1 hour from arrival at Earth. This exercise lets students analyze simplified data obtained from the SOHO and WIND satellites during the January 10, 1997 CME event which may have damaged Telstar 401; a $200 million AT&T satellite.

Objective

Students will compare and interpret four graphs involving the speed, temperature, magnetic field strength and density of a CME event.

Procedure

1) Because there are four different graphs for the students to analyze, this activity lends itself to a 'Four Corners'-style of execution. Divide the students into four groups in different parts of the room, and assign each group a specific graph to interpret. Have the students determine what happens to their respective graph as the CME Front passes.

2) Have individually prepared transparencies of the graphs (suggestion; make a copy and cut itapart for the groups). Have each group present their findings to the class.

3) Have prepared transparencies of all the graphs. Facilitate a discussion of the combined results using the transparency and the summary of the graph events. For a concluding event you may wish to discuss 'Combining the Clues'.

Materials

—Graph paper
—Prepared transparencies
—Graph Summaries
—Combining the Clues

Summary

The students should determine that the temperature dropped 50,000 C as the CME front passed the satellites, and then it rose sharply as the satellites were inside of the cloud. The density remained constant as the CME front passed, then it rose sharply inside the CME front, then dropped below the solar wind value before rising back to the normal solar wind level. The speed was constant at the solar wind-level until the CME passed, then the satellites were affected by the fast moving gas inside the CME cloud. The magnetic field in the CME front was three times higher than the average solar wind value which is near 5 nT. The CME front traveled at about 600 kilometers/sec (about two million miles/hour) so that for spacecraft at one million miles from Earth, the 'ETA' time is about 30 minutes.

Graph Summaries:

Temperature: This trace shows a 50,000 C dip in the temperature of the leading edge of the cloud between January 10 and January 11. This is followed by a sharp rise in the gas temperature inside the cloud , which then decreased the farther the leading edge of the CME cloud was from the satellite. The typical solar wind temperature is about 100,000 C.

Density: There was little change in the density of the gas near the satellite until January 11 . When the satellites encountered the interior of the CME, just behind the leading edge, it appears there was a ‘wall’ of high-density gas. Directly behind this wall is a low density cavity which contained nearly half the density of the gas typically detected in the solar wind.

Speed: The satellites detected the steady flow of the solar wind at about 450 kilometers/sec. Once the satellites were inside the main body of the CME cloud on January 11, they encountered the fast maving gas with speeds of 600 km/sec. This continued to be the case until the back of the cloud passed the satellites on January 12. Then, the contact with the slower-moving, normal solar wind flow was re-established.

Magnetic Field: Before January 10, the satellites were in contact with the solar wind’s magnetic field which had a strength of about 5 nT (The unit ‘nT’ means nanoTesla and is a measure of magnetic field strength. The Earth’s magnetic field is 50,000 nT at the surface). As the satellites encountered the leading edge of the CME between January 10 and January 11, the magnetic field tripled in strength. It then returned to the normal solar wind level after the back-side of the CME Front was encountered on January 11.

Combining the Clues:

Once the students have interpreted each trace, we can combine them into a simple model of the CME cloud, but not what the entire cloud looks like in three dimensions.

The solar wind, in this instance, has a temperature near 100,000 C, a density of about 10 particles per cubic centimeter, a speed near 400 kilometers/sec, and a magnetic field strength of 5 nT.

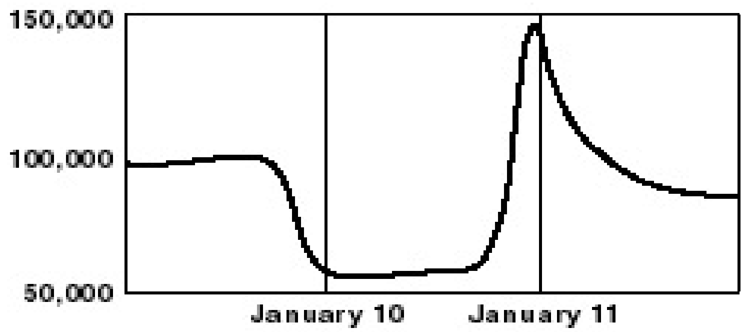
The leading edge of the CME contains a strong magnetic field. Although there is no change in the gas density and the solar wind speed , the entire magnetic field of the CME seems to be concentrated there. The magnetic field is responsible for the drop in solar wind temperature in this region. Scientists call this the CME ‘magnetic cloud’ region.

The back edge of this ‘magnetic cloud’ coincides with a sharp increase in gas density and temperature which defined the CME cloud boundary in what scientists call a ‘shock front’. Behind this shock front there is a fast-moving , but low density gas. In the interior of the CME cloud ‘bubble’ region, the gas density decreases with distance from the shock front, until it eventually returns to the temperature of the solar wind. Behind the fast-moving interior bubble is the back-side of the CME which is where the conditions have returned to those of the normal solar wind.

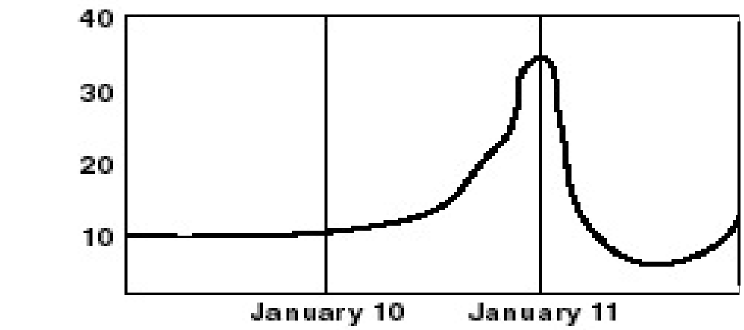
Traveling at a top speed of 500 kilometers/sec, the entire cloud took two days to pass the satellites. This means the thickness of the CME was about 86 million kilometers (500 km/sec x 2 days x 86,400 sec/day). This is about half the distance between the Sun and the Earth. Since the satellites were located about two million kilometers from the Earth, it took the cloud only about 30 minutes to reach the Earth on January 12.

Name ______________________________

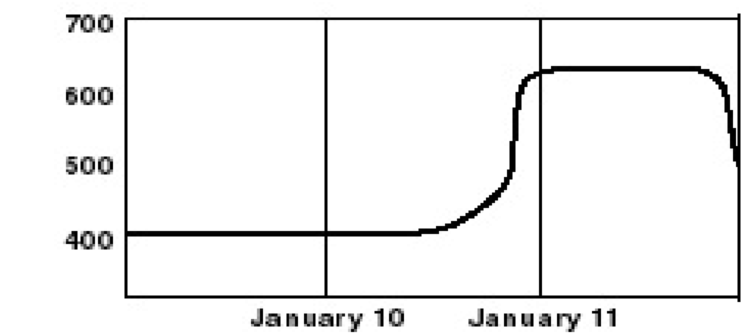
Date________________



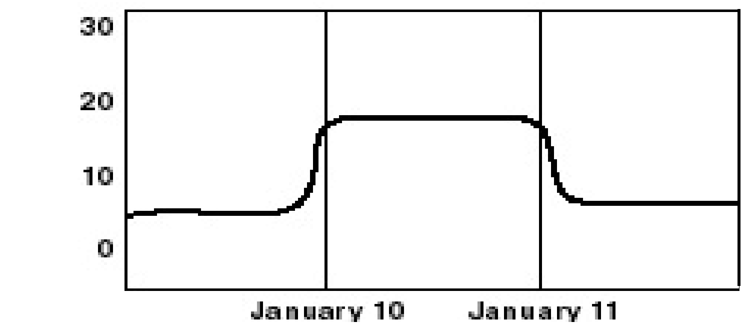
Temperature
(in degrees Celsius)



Density
(in particles per cubic centimeter)



Speed
(in kilometers/second)



Magnetic Field
(in nanoTeslas)

What is Solar Activity?

The Sun, our nearest star, provides us with warmth and light. For many civilizations, the sun was thought to be a perfect orb, free of blemishes, eternal and changeless. **Sunspots** are the most well known hints that the Sun's surface is constantly changing. Larger than the Earth, and with magnetic fields that are 10,000 times stronger than the Earth's, sunspots are the breeding grounds for some of the most violent storms in the solar system!

The number of sunspots increases and decreases in cycles that last from 6 to 17 years; the **Sunspot Cycle.** With modern technology and space satellites, this solar activity cycle can now be detected in the ebb and flow of other phenomena on the Sun and on the Earth. Among the most enigmatic storms are the **solar flares** that erupt near sunspots. In a matter of 20 minutes, magnetic fields can heat gases to tens of thousands of degrees and release more energy than a thousand atomic bombs. Some of this gas can be hurled out from the Sun at millions of kilometers per hour in what are called **coronal mass ejections.** Both solar flares and coronal mass ejections can be very disruptive to human activity on earth and in space.

The outer atmosphere of the Sun, the **corona,** is familiar to many people who have watched total eclipses of the sun. The solar wind extends billions of kilometers further out into space than the corona**.** Like invisible roadways spanning the solar system, the magnetic field from the Sun flows out from the solar surface. Matter ejected from the Sun flows radially outwards from the solar surface. From the time a solar storm is seen on the Sun, it can take 2-3 days for the gas to travel to the orbit of the Earth, and if the Earth happens to be in the wrong place at the wrong time, it will be hit by a million-kilometer wide wall of high temperature gases and magnetic fields.

Anyone can tell you that a compass points 'north' because the Earth has a magnetic field, but until the advent of the Space Age, no one understood what this field really looked like or was capable of doing. Since Gilbert proposed in the 17th century that the Earth was a giant magnet, scientists have wondered just how this field is shaped, and how it has changed with time. The geomagnetic field which gives us our familiar compass bearings, also extends thousands of kilometers out into space in a region called the **magnetosphere**. On the Sun-side, it forms a protective boundary called the **bow shock.** Stretching millions of kilometers in the opposite direction behind the Earth is the **magnetotail.**

The solar wind blows upon the magnetosphere and gives it a wind-swept shape, but when solar storms and solar wind streams reach the Earth, the magnetosphere reacts violently. On the side nearest the impact, the magnetosphere compresses like squeezing a balloon, leaving communications satellites exposed. On the opposite side, it is stretched out, past the orbit of the Moon, or Mars and even Jupiter! The geomagnetic field is remarkably stiff, and so most of the solar wind is deflected or just slips by without notice. But some of the matter leaks in and takes up residence in donut-shaped clouds of trapped particles, or can penetrate to the atmosphere to produce aurora.

For thousands of years, humans have been treated to spectacles of glowing clouds above the northern horizon at night. Reports of these mysterious Northern Lights abound in the oral histories of the northern natives. On rare occasions, even ancient Greek and Chinese texts have mentioned them. It wasn't until 1896 that the Norwegian physicist Kristian Birkeland deduced that flows of electrons from the Sun were channeled into the polar regions by the geomagnetic field, and upon colliding with the outer atmosphere, would stimulate oxygen and nitrogen atoms to cast their ghostly and inspiring curtains of light.

The **Aurora Borealis** (near the north pole) and the **Aurora Australis** (near the south pole), as the ‘Northern Lights’ are more formally called, are seen most often in a band located at a latitude of 70 degrees, and about 10 degrees wide in latitude. From space, the auroral zone looks like a ghostly, glowing donut of light hovering over the north and south poles. This **auroral oval** can easily be seen in images from satellites designed to detect it. Its brightness and size change with the level of solar activity. Aurora come in many shapes and colors depending on what is happening to the geomagnetic field and the flows of charged particles and plasmas trapped in this field.

Magnetic sub-storms happen when the geomagnetic field is suddenly changed because of small changes in the magnetic polarity of the solar wind as it passes the Earth. Typically, magnetic storm aurora, also called **auroral storms,** last only a few hours. They begin in the evening as arcs of colored light which slowly change into rayed-arcs and the familiar folded ribbons or bands. Expanding over the whole sky, the folded bands are colorful, with green rays and red lower borders which change from minute to minute and move rapidly across the sky like some phantasmagoric serpent. After an hour, the auroral shapes become more diffuse and less distinct.

Geomagnetic storms are more severe than magnetic sub-storms and are caused by major changes in the direction and density of the solar wind as it reaches the Earth. These events are the most remembered historically as 'Great Aurora' or as the most disruptive to radio communications. The entire geomagnetic storm can last for several days as the particles and fields around the Earth continue to readjust themselves to the passing and ebbing solar wind.They begin with an ejection of mass by the Sun, and the impact of this plasma on the magnetosphere. Fast-moving coronal mass ejections produce shock waves in the solar wind, and this compression intensifies the density of particles impacting the magnetosphere. As the solar wind shock passes across the magnetosphere and magnetotail, magnetic fields re-orient and reconnect, releasing enormous amounts of energy and accelerating trapped particles to high speeds. These charged particles then travel down the geomagnetic field in huge currents, which cause bright and long lasting auroral displays.

Solar storms and the effects they produce in the Earth's environment, have been known for decades to be responsible for many harmful effects upon human technology on the ground and in space. Solar storms are known to do far more than just paint the sky with pretty colors! The multi-billion dollar 'Global Positioning System' consists of a constellation of over a dozen navigation satellites orbiting within the Van Allen radiation belts. These satellites let humans find their position anywhere on Earth using a hand-held receiver no bigger than a pocket calculator.

During solar storms, these positions are quite a bit less accurate than under calm conditions, which in turn impacts the navigation of ships at sea and jets in the air. Solar storms have disabled multi-million dollar communication and navigation satellites such as Anik-A, Molynia, Marecs-A, and they have been implicated in many electrical problems that were experienced by other satellites.

Solar storms were responsible for causing the Skylab to burn up in the atmosphere sooner than expected, and for altering the orbits of hundreds of other satellites and even the Space Shuttle itself. A storm on March 13, 1989 knocked out the Quebec-Hydro power system, plunging 6 million people into darkness for 9 hours. Geomagnetic storms cause the magnetic field near the Earth's surface to change rapidly in just a matter of minutes or hours. These changes cause electrical currents to flow within long power transmission lines, telephone wires, and even in pipelines which makes the pipes corrode, sometimes with tragic consequences. On June 5, 1991 a natural gas pipeline in Russia was weakened by corrosion and began to leak its deadly, flammable cargo. A passenger train, loaded with 1,200 people, ignited the liquefied gas and caused an explosion equal to 10,000 tons of TNT. Over 500 people were killed, and 700 more were badly injured.

Would you believe...

Aurora can never get closer to the ground than about 60 kilometers.

A sunspot has a temperature of nearly 4000 C, and would be brighter than the full moon if placed in the night sky.

Sunspots are often several times larger than the entire earth.

The Sun rotates once every 25 days at the equator, but takes up to 36 days to rotate once around at the poles.

The corona of the Sun is over 5 million degrees hotter than the surface of the Sun.

The Earth's magnetic north pole is actually a magnetic south pole because the north end of a bar magnet is attracted to it.

The total power produced by an auroral event can exceed 1 million megawatts and produce voltages over 100,000 volts in the upper atmosphere.

Aurora are produced where the atmosphere has the same density as the vacuum inside a light bulb.

Some aurora occur at altitudes of over 1000 kilometers above the Earth's surface.

Lightning storms can eject particles into space at nearly the speed of light, and they are seen as 'sprites' on the top side of a thundercloud.

A single lightning storm can be detected on the other side of the earth because some of its radio energy travels along the local magnetic field lines that connect the pairs of points on the surface of the Earth that can be thousands of kilometers apart.

Glossary

Aurora : Also called the 'Northern Lights' in the Northern hemisphere, or the 'Southern Lights' in the Southern hemisphere. These wispy curtains of light in the sky are caused by energetic electrons which collide with atoms of oxygen and nitrogen in the air to cause these atoms to emit shades of green, red and blue light. They never descend nearer than 60 kilometers from the Earth's surface.

Corona : The very tenuous outer layers of the Sun which are seen during a total eclipse of the sun, but extending millions of miles into interplanetary space. It is heated to temperatures of over one million degrees by magnetic activity at the surface of the Sun. For decades, scientists puzzled over why the Corona could be so much hotter than the balmy 5770 degree Kelvin surface of the Sun.

Coronal Mass Ejection : The sudden expulsion of matter from the coronal regions of the sun, often involving billions of tons of plasma ejected at over one million kilometers per hour. During sunspot minimum conditions, about one 'CME' can be expelled every few days. During sunspot maximum conditions, as many as 3-5 can occur each day.

Magnetopause : A region that defines the outer edge of the magnetosphere where the pressure of the solar wind is balanced by the pressure of the earth's own magnetic field.

Magnetosphere : The region surrounding the Earth in space where its magnetic field is important in controlling the movements of charged particles. Also sometimes referred to as 'Geospace'.

Magnetotail : The solar wind pulls the magnetosphere into a comet-like shape. The long tail of this field, called the magnetotail' or also the 'geotail', extends millions of miles into space in a direction opposite to the Sun from the Earth.

Solar flare : A powerful release of energy on the surface of the sun usually lasting less than a few hours, but releasing as much energy as 1000 hydrogen bombs. These are often associated with active regions of the solar surface where magnetic fields have become badly tangled, and then snap, releasing energy and heating local gases to over 1 million degrees.

Solar storm : Although scientists prefer not to use this term because it is technically rather vague, it has come to mean any of a number of active conditions on the Sun's surface including flare activity or coronal mass ejections.

Sunspot : A dark spot on the Sun's surface that indicates a concentration of magnetic forces. They are actually about 2000 degrees cooler than the solar surface, and only look dark because they emit light faintly.

Sunspot Cycle : The change in the number of sunspots from one period of its maximum to the next, over the course of about 11 years.

Sunspot Maximum : The period during the sunspot cycle when you will see the largest number of sunspots. Also called the 'Solar Maximum'.

Sunspot Minimum: The period during the sunspot cycle when you will see the fewest number of sunspots. Also called the 'Solar Minimum'

Resources

IMAGE	http://image.gsfc.nasa.gov
POETRY	http://image.gsfc.nasa.gov/poetry
SOHO	http://sohowww.nascom.nasa.gov
NASA Sun-Earth Connection Resources	http://sunearth.gsfc.nasa.gov
The Earth's Magnetic Field	http://image.gsfc.nasa.gov/poetry/magneto.html
Satellite Glitches -Space Environment Info	http://envnet.gsfc.nasa.gov
Magnetic North Pole	http://www.nrcan.gc.ca/gsc/cpdnew/magnet.html
Solar Sounds	http://soi.stanford.edu/results/sounds.html
Sunspot Number Archives / Resources	http://image.gsfc.nasa.gov/poetry/sunspots.html
CME Archives at MLSO	http://www.hao.ucar.edu/public/research/mlso/movies.html
Stellar Activity Cycles at Mt. Wilson	http://www.mtwilson.edu/Science/HK_Project/
Satellite Data	http://cdaweb.gsfc.nasa.gov
Space Weather Resources	http://image.gsfc.nasa.gov/poetry/weather.html
Magnetic Observatories and Data	http://image.gsfc.nasa.gov/poetry/maglab/magobs.html
Space Environments and Effects	http://see.msfc.nasa.gov/sparkman/Section_Docs/sparkman.html
Sun-Earth Classroom Activities Archive	http://sunearth.gsfc.nasa.gov/educators/class.html
Storms from the Sun	http://www.istp.gsfc.nasa.gov/istp/outreach/learn.html
The Aurora Page	http://www.geo.mtu.edu/weather/aurora/
Space Weather Human Impacts	http://image.gsfc.nasa.gov/poetry/storm/storms.html
Ionosphere density and sunspot numbers	http://julius.ngdc.noaa.gov:8080/production/html/IONO/ionocontour_90.html
Space Weather Daily Reports	http://windows.engin.umich.edu/spaceweather/index.html
Solar wind density and speed	http://www.sel.noaa.gov/wind/rtwind.html
Mees Solar Observatory Archives	http://www.solar.ifa.hawaii.edu/MWLT/mwlt.html

Teacher Reply Card

National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 5-8

EG-2000-03-002-GSFC

Solar Storms and You!

Exploring Magnetic Storms

An Educator Guide with Activities in Space Science

Solar Storms and You! is available in electronic format through NASA Spacelink - one of the Agency's electronic resources specifically developed for use by the educational community.

The system may be accessed at the following address:
http://spacelink.nasa.gov

National Aeronautics and
Space Administration

EG-2000-03-002-GSFC

Solar Storms and You!

Exploring Magnetic Storms

An Educator Guide with Activities in Space Science

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This resource was developed by the NASA Imager for Magnetosphere-to-Auroral Global Exploration (IMAGE)

Information about the IMAGE mission is available at:

http://image.gsfc.nasa.gov
http://pluto.space.swri.edu/IMAGE

Resources for teachers and students are available at:

http://image.gsfc.nasa.gov/poetry

National Aeronautics and
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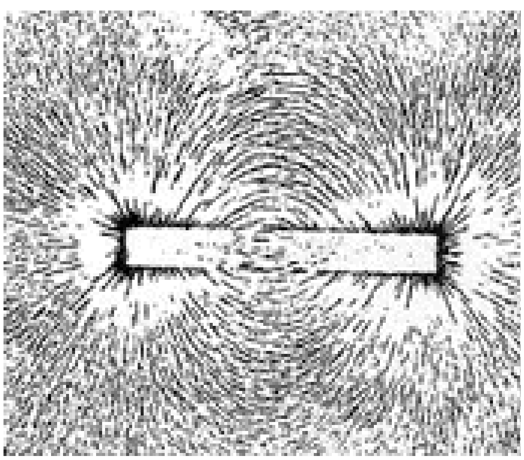
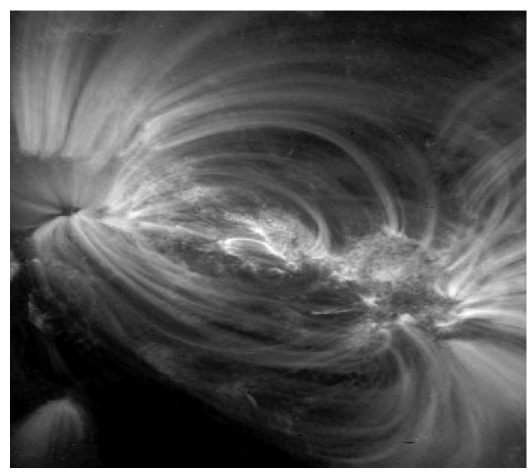
Goddard Space Flight Center

CONTENTS





Powerful magnetic forces are responsible for most of the activity on the Sun. Without these fields, there would be no sunspots, prominences, and the solar corona would be a much cooler gas, no where near the 2 million degrees it is today. Magnetic fields are the same everywhere in the universe so far as we can tell. Compare the two pictures above. The photo on the left is iron filings near a toy bar magnet. On the right are the magnetic field lines near an active region on the Sun. Even though the sunspot field is nearly one trillion times larger than the toy magnet field...they look identical!

INTRODUCTION

A gas pipeline in Russia explodes
killing hundreds of people.

A satellite mysteriously falls silent
interrupting TV and cellular phone traffic.

A power blackout
throws millions of people into darkness.

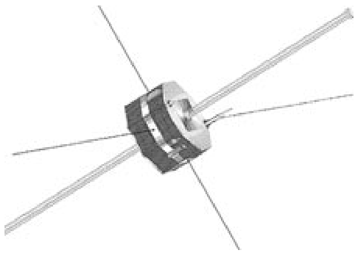
These are only a few of the many things that solar storms can do when they arrive at the earth unexpected. In an age where we have increasingly come to rely upon the smooth operation of our technology, we have also made ourselves vulnerable to the ebb and flow of the solar storm cycle. Most people are not even aware this cycle exists, but long ago we used to be!

Ancient Chinese sun observers knew that, from time to time, dark spots would glide slowly across the face of the setting sun. Once seen only as portends of political upheaval, we now see them as natural phenomena that can forewarn us of impending storms that can have dire consequences for us if we ignore them.

In this activity book, your students will study five key stages in the lifecycle of a solar storm, from its emergence on the solar surface to its impact upon some aspect of our lives. The book may be used in its entirety to study solar activity and how it directly affects us, or you may use individual activities of your choice as stand-alone mini lessons as an enrichment for math and physical science courses.

The student activities emphasize basic cognitive skills and higher-order processes such as plotting data, searching for patterns and correlations, and interpreting the results. By the end of the activity series, students will understand why we need to pay more attention to solar storms.

Science Process Skills
for *Solar Storms and You!*

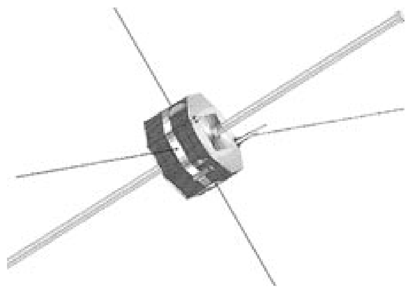


This chart is designed to assist teachers in integrating the activities contained in the guide with existing curricula.

	Lesson 1 *"Magnetic Storms from the Ground"*	**Lesson 2** *"Motion of the Magnetic Pole"*	**Lesson 3** *"A Soda Bottle Magnetometer"*
Observing	○	○	○
Classifying			
Communicating	○	○	○
Measuring	○	○	○
Inferring	○		
Predicting		○	
Experimental Design			○
Gathering Data			○
Organizing Data			○
Controlling Variables			○
Developing a Hypothesis	○		
Extending Senses			○
Researching		○	○
Team Work			○
Mathematics	○	○	○
Interdisciplinary			
Introductory Activity	○	○	○
Advanced Activity			

Science and Mathematics Standards

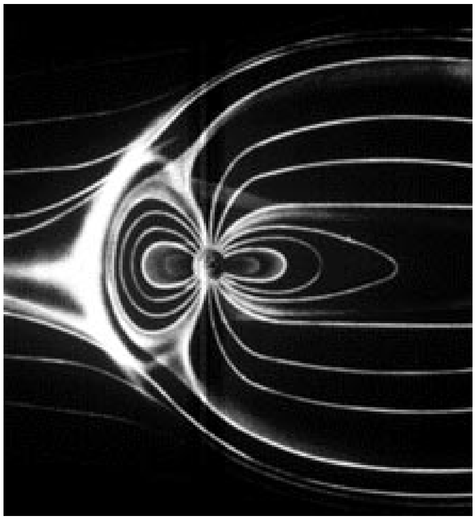
for *Solar Storms and You!*

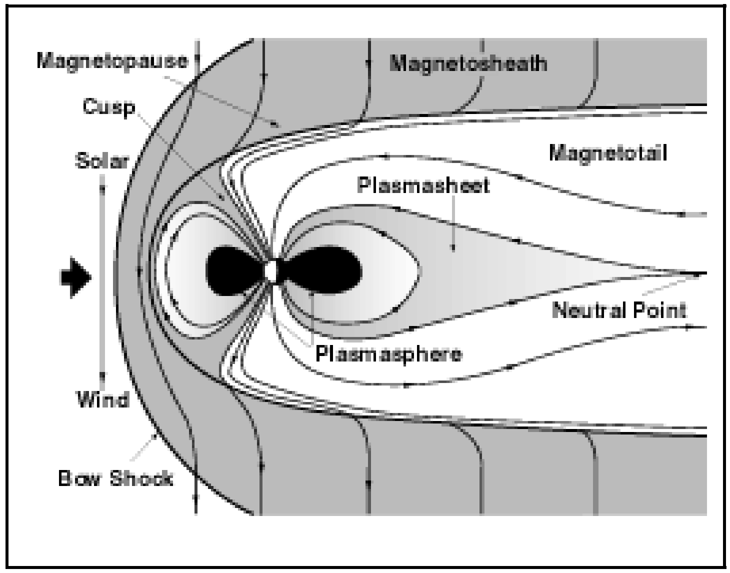


This chart is designed to assist teachers in integrating the activities contained in the guide with existing curicula.

	Lesson 1 *"Magnetic Storms from the Ground"*	**Lesson 2** *"Motion of the Magnetic Pole"*	**Lesson 3** *"A Soda Bottle Magneto-meter"*
Science as Inquiry	○	○	○
Structure and Energy of the Earth System	○	○	○
Origin and History of the Earth			
Earth in the Solar System	○	○	○
Geochemical Cycles			
Physical Science	○	○	○
Populations and Ecosystems			
Understanding Science and Technology	○	○	○
Science in Personal and Social Perspectives			
History and Nature of Science			
Problem Solving	○	○	○
Measurement	○	○	○
Computation and Estimation		○	○
Communication			○
Geometry and Advanced Mathematics		○	○
Statistics and Probability			○
Number and Number Relationships			
Patterns and Functions		○	○

Magnetic Storms





The Earth is the only one of the four inner planets (Mercury, Venus, Earth and Mars) that has a substantial magnetic field. Shaped very much like the field of a bar magnet, and powered by enormous currents of electricity in the molten core of the Earth, this field extends millions of kilometers into space to form the **magnetosphere**. Outside this region, charged particles from the Sun and deep space, may be deflected or may leak into the interior of this region to form the **Van Allen Belts,** or produce auroral activity.

This field changes in complex ways as CMEs find their way to the Earth and impact the magnetic field. Observatories on the ground have kept track of the strength and direction of the Earth's magnetic field for over a century. Their records show that rapidly changing field conditions are common, especially when the Sun is active.

The most dramatic of these episodes are called geomagnetic storms which can last several days. Less intense changes can last hours or minutes and are called geomagnetic sub-storms.

Navigation by compass is especially difficult during either of these magnetic storms because compass bearings can change by 10 degrees or more during the course of a few hours. As anyone familiar with using a map and compass can tell you, without knowing the 'magnetic deviation', it is impossible to use a compass to determine where geographic north is located. As a result, surface navigation can become dangerously imprecise.

Teacher's Guide

Magnetic Storms from the Ground

Introduction

Coronal Mass Ejections and other solar storms can buffet the magnetic field of the Earth with clouds of charged particles and magnetic fields. Not only do these interactions affect the large-scale properties of the geomagnetic field, but their affects can also be easily detected on the ground. During the last 100 years, many 'magnetic observatories' have been commissioned around the world to monitor the Earth's surface field conditions. These have been, historically, important for navigation by ships at sea. The data from these observatories can also be used to examine what happens when solar storms arrive at the Earth.

Objective

By analyzing graphical data, students will become familiar with the Earth's changing magnetic field through solar storm activity plots.

Procedure

1) Analyze the magnetic intensity plot for each station and identify the difference between stable activity, and the largest difference in change in activity (biggest peak) either positive or negative, on the plot. The units of magnetic intensity are in micro-Teslas, abbreviated as 'mT'.

2) Find the percentage change for each station. Round the answer to the nearest hundredth of a percent. Write the number below the location of the station on the map. See the Teacher's Answer Key.

3) Discuss and work the following questions and procedures:

—Where are the largest magnetic changes located for this event?

—Draw a circle around the three stations with the largest magnetic changes. Did the largest changes occur at the same time? Explain.

—On the Data Sheet, organize the plots in order from the largest to the smallest change. Do you see any patterns?

—Organize the magnetic intensity plots according to similar shapes. Are there any trends?

Materials

—5-station magnetic field Data Sheet.

—Calculator

—Map of Canada

Example: For Fort Churchill the normal 'stable' level was 59.3 mT and the largest deflection happened near 8:00 Universal Time (UT) at about 59.8 mT,

$$\% = 100 \times \frac{(\text{max - stable})}{\text{stable}}$$

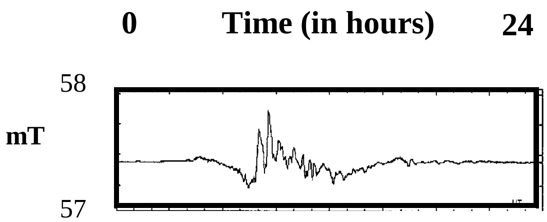
$$\% = 100\times \frac{(59.8-59.3)}{59.3}$$

or 0.85 percent.

Conclusion:

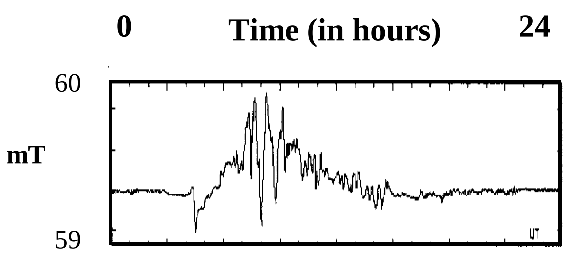
Students should have learned that the Earth's magnetic field does not remain constant in time, but can change its strength. By investigating and plotting data, students should have revealed the changes in intensity of the Earth's magnetic field due to solar storms. From this, students will locate those regions of the Earth that are most susceptible to solar storms.

Student Data Sheet



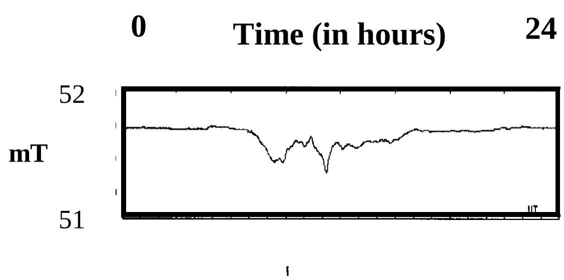
Station 1: **Meanook**
Latitude: **54.6 North** **Longitude:** **113.3 West**

Time: **Percent:**



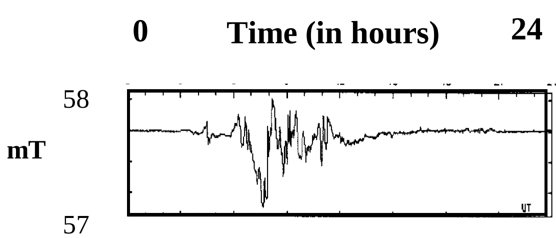
Station 2: **Fort Churchill**
Latitude: **58.8 North** **Longitude:** **94.1 West**

Time: **Percent:**



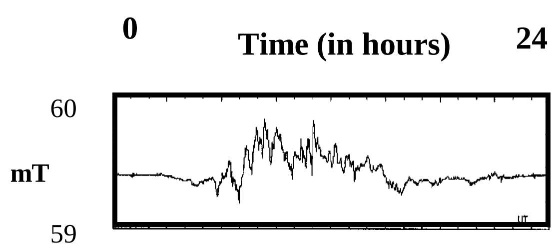
Station 3: **Victoria**
Latitude: **48.5 North** **Longitude:** **123.4 West**

Time: **Percent:**



Station 4: **Poste-de-la-Baleine**
Latitude: **55.3 North** **Longitude:** **77.8 West**

Time: **Percent:**



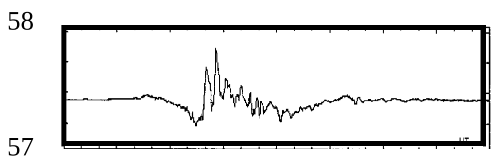
Station 5: **Yellowknife**
Latitude: **62.4 North** **Longitude:** **114.5 West**

Time: **Percent:**

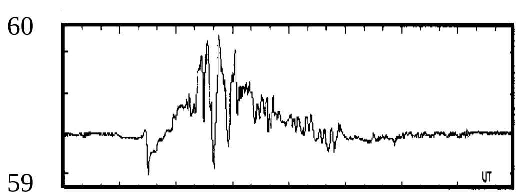
Teacher's Answer Key

Note: Times given to 1/2 hour accuracy are adequate for this exercise. Percentages may vary by 0.1 percent depending on how students measure. Students may average their results for each station to produce a better 'class average' percentage.

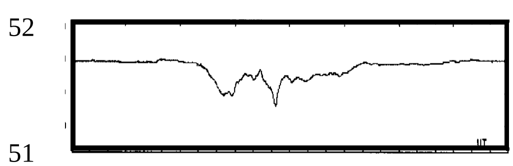
0 Time (in hours) 24



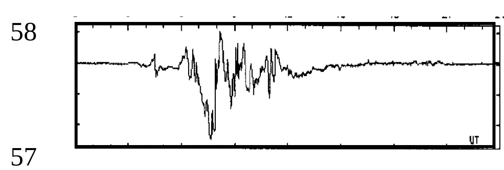
Station 1: **Meanook**
Latitude: **54.6 North** **Longitude:** **113.3 West**
Time: **8:00** **Percent:** **0.70**



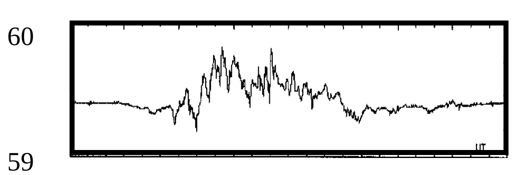
Station 2: **Fort Churchill**
Latitude: **58.8 North** **Longitude:** **94.1 West**
Time: **8:00** **Percent:** **0.85**



Station 3: **Victoria**
Latitude: **48.5 North** **Longitude:** **123.4 West**
Time: **11:00** **Percent:** **0.58**

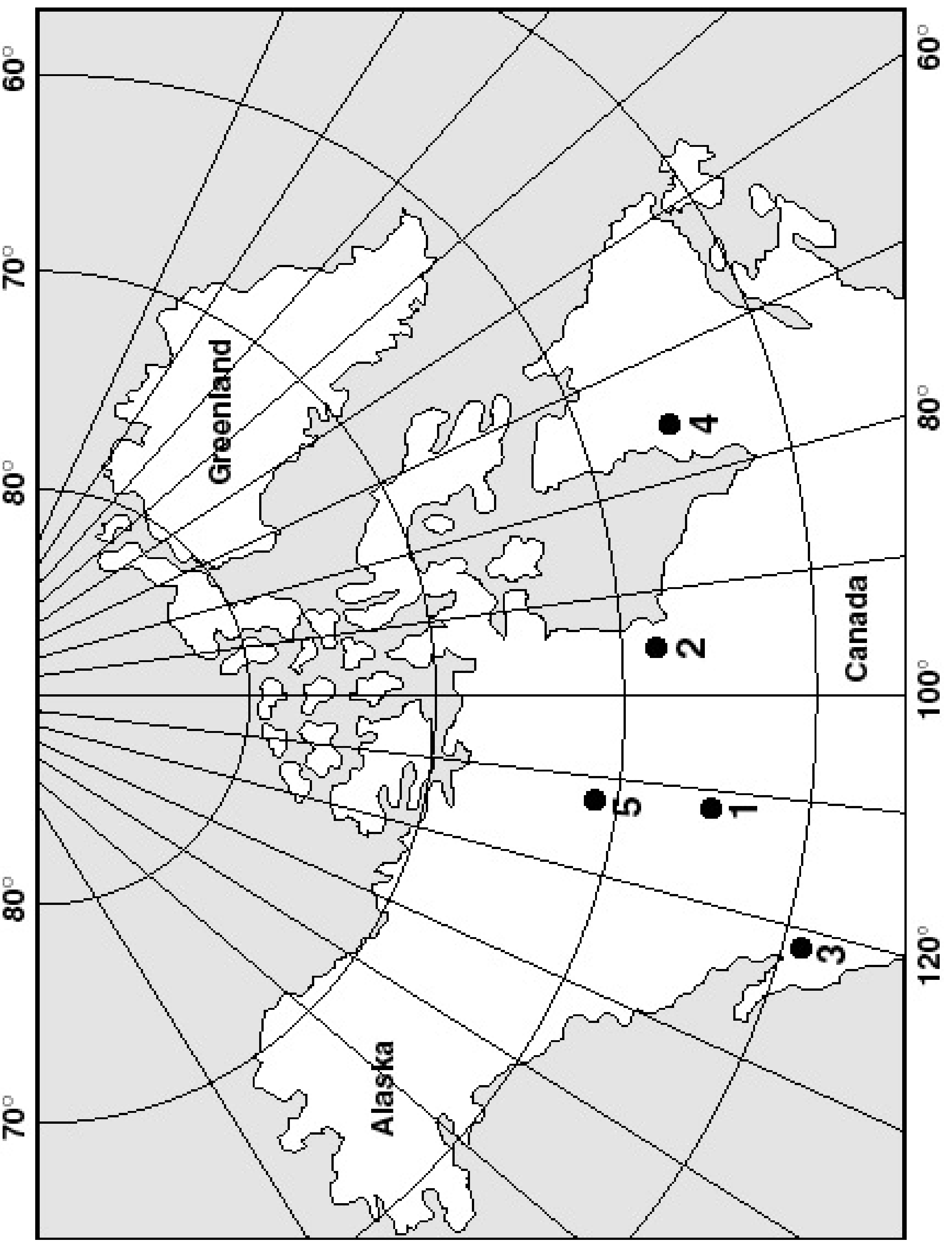


Station 4: **Poste-de-la-Baleine**
Latitude: **55.3 North** **Longitude:** **77.8 West**
Time: **7:30** **Percent:** **1.05**

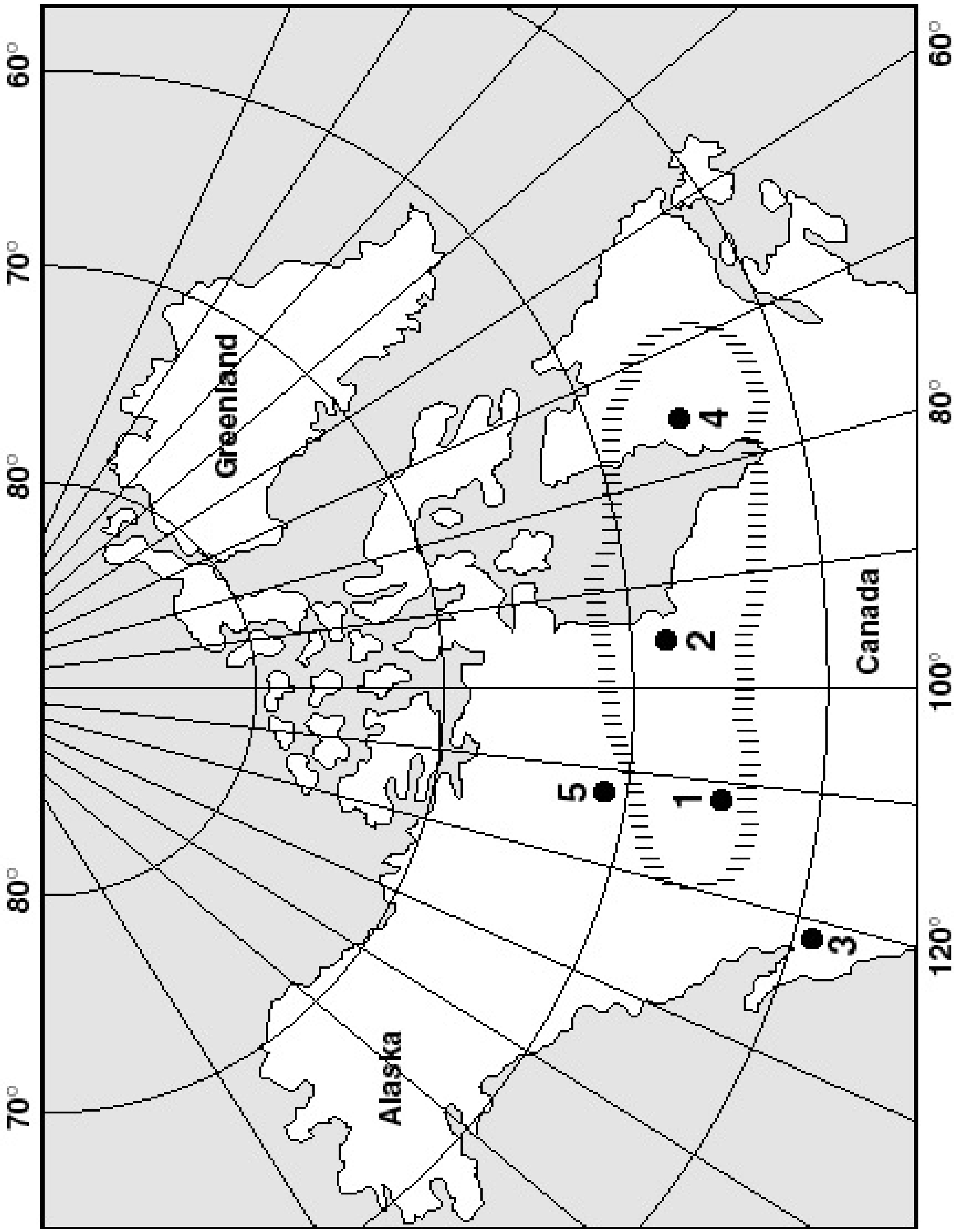


Station 5: **Yellowknife**
Latitude: **62.4 North** **Longitude:** **114.5 West**
Time: **8:00** **Percent:** **0.60**

Name ___________________________ Date_______________



Teacher's Answer Key



Teacher's Guide — Motion of the Magnetic Pole

Introduction

The Magnetic North Pole has been charted over the past several hundred years. The pole shifts between 1 and 20 kilometers/year. Navigation by compass is especially difficult during a magnetic storm. Compass bearings can shift by 10 degrees or more within the course of a few hours, therefore, it is important to know the pole's present location.

Objective

The student will plot the latitude and longitude involved in the movement of the Magnetic North Pole over a period of time, predict its location by the year 2000, and justify their reasoning.

Procedure

1) Students will plot the latitude and the longitude for the given years using the data in the table.

2) Students will connect the points in the given order to see the pattern of movement in the Magnetic North Pole.

3) Students will measure the distances between the points, and using the time between the years in the table, arrive at an average rate of movement. (See explanation).

4) Students will plot and justify their choice of location based on their results. Student's prediction and justification should be based on the speed and the distance that the Magnetic North Pole has shifted in prior years.

EXPLANATION:

To calculate the speed, use the following formula:

$$\text{speed} = \frac{\text{Tabulated Distance}}{\text{Difference in Years}}$$

Example:

For the first interval between 1831 and 1904, the North Magnetic Pole moved 50 kilometers. The difference in the years is 1904-1831 = 73 years, so the speed during this interval is

$$\text{speed} = \frac{50}{73}$$

$$= 0.7 \text{ kilometers/year}$$

Materials

—Student Page
—Teacher Graph
—Ruler with millimeter units
—Calculator

Conclusion:

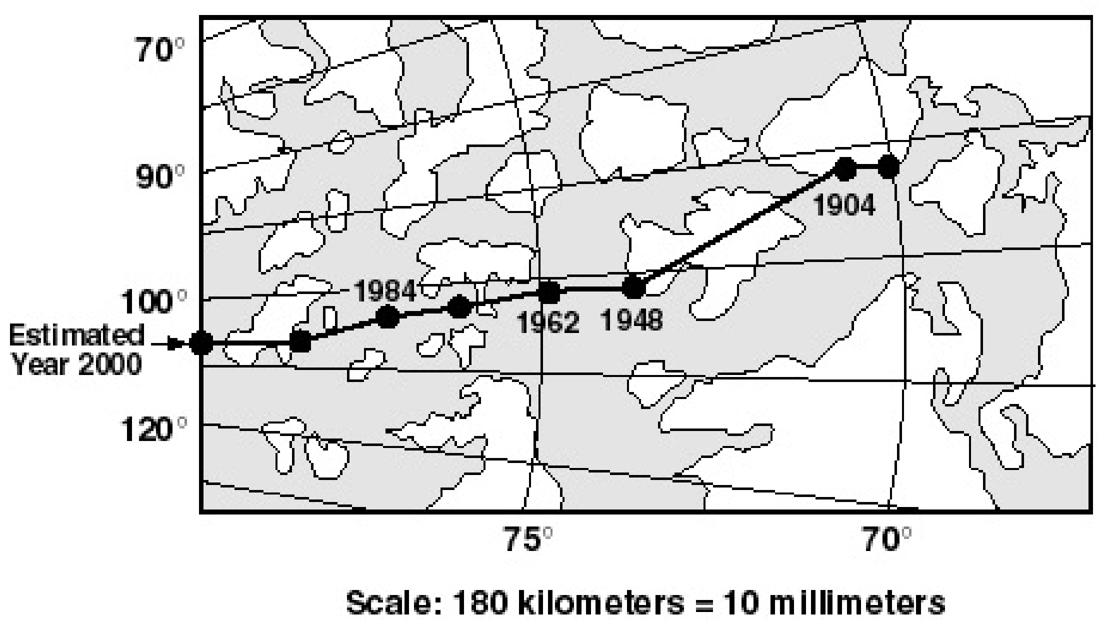
Students will understand that the Magnetic North Pole is not fixed at a specific geographic location, but moves from year to year by a significant amount.

Teacher's Answer Key

1. Plot the longitude and the latitude for the following years on the map below. NOTE: The distance that the Magnetic North Pole moved between the years has been calculated using the map scale.

YEAR	Longitude	Latitude	Distance	Speed (km/year)
1831	96.5	70.1		
1904	96.2	70.5	50 km	0.7 km/year
1948	101.1	73.8	420 km	9.5 km/year
1962	100.8	75.0	150 km	10.7 km/year
1973	101.3	76.1	120 km	10.9 km/year
1984	102.1	77.2	120 km	10.9 km/year
1994	104.0	78.5	180 km	18.0 km/year

2. Given the data in the table, plot a prediction for the location of the North Magnetic Pole for the year 2000.



3. In your own words, justify the location of the prediction you have chosen.

The student prediction and justification should be based on the speed and the distance that the Magnetic North Pole has shifted in prior years. Students may either use an average speed based on the motion between 1831 to 1994 (= 1040 km/163 years = 6.4 kilometers/year) or may use the speed during the last 10 years (18.0 kilometers/year) but should justify which way they computed the speed. Either method is technically correct.

Name ____________________________

Date________________

1. Plot the longitude and the latitude for the following years on the map below. NOTE: The distance that the Magnetic North Pole moved between the years has been calculated using the map scale.

YEAR	Longitude	Latitude	Distance	Speed (km/year)
1831	96.5	70.1		
1904	96.2	70.5	50 km	
1948	101.1	73.8	420 km	
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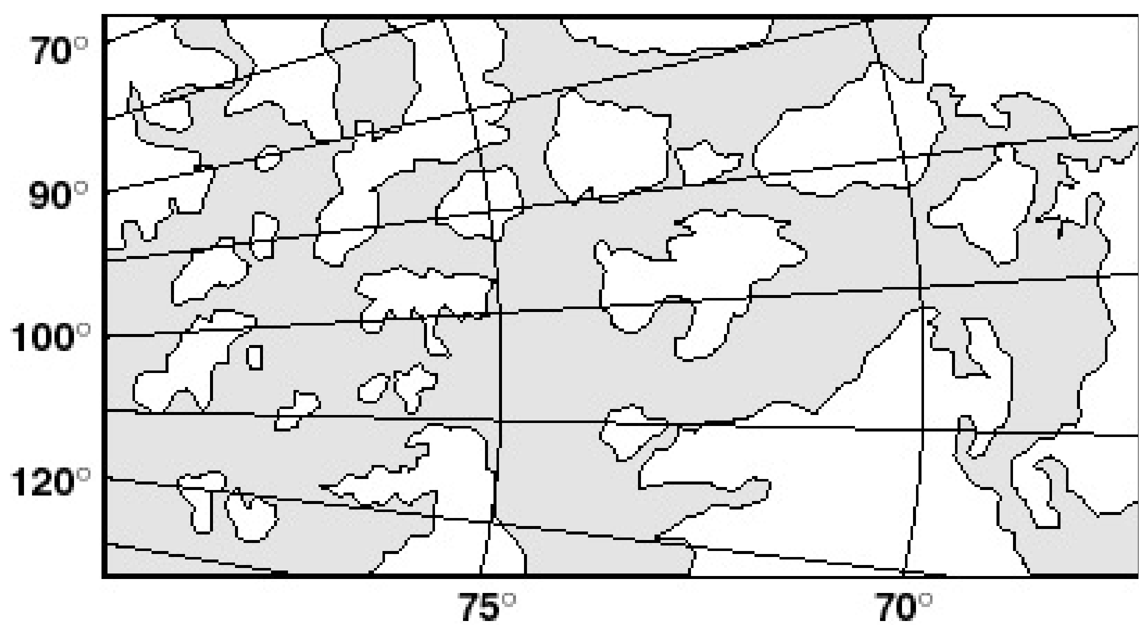
1973	101.3	76.1	120 km	
1984	102.1	77.2	120 km	
1994	104.0	78.5	180 km	



Scale: 180 kilometers = 10 millimeters

2. Given the data in the table, plot a prediction for the location of the North Magnetic Pole for the year 2000. Hint: Find the average rate of speed and complete the table. To calculate this for the given data, you will need to know that the speed is the distance the pole has moved divided by the difference between the two years in each interval . You may also decide to calculate the average speed for ALL of the time between 1831 and 1994. The units will be in kilometers/year.

3. In your own words, justify the location of the prediction you have chosen.

Teacher's Guide A Soda Bottle Magnetometer

Introduction

Solar storms can affect the Earth's magnetic field causing small changes in its direction at the surface which are called magnetic storms. A magnetometer operates like a sensitive compass and senses these slight changes. The soda bottle magnetometer is a simple device that can be built for under $5.00 which will let students monitor these changes in the magnetic field that occur inside the classroom. When magnetic storms occur, you will see the direction that the magnet points change by several degrees within a few hours, and then return to its normal orientation pointing towards the magnetic north pole.

Objective

The students will create a magnetometer to monitor changes in the Earth's magnetic field for signs of magnetic storms.

Procedure

1) Clean the soda bottle thoroughly and remove labeling.

2) Slice the bottle 1/3 way from the top.

3) Pierce a small hole in the center of the cap.

4) Fill one quarter of the bottom section with sand.

5) Cut the index card so that it fits inside the bottle. (See Figure 1)

6) Glue the magnet to the center of the top edge of the card.

7) Glue a 1-inch piece of soda straw to the top of the magnet.

8) Glue the mirror spot to the front of the magnet.

9) Thread the thread through the soda straw and tie it into a small triangle with 2-inch sides.

10) Tie a 6-inch thread to top of the triangle in #9 and thread it through the hole in the cap.

11) Put the bottle top and bottom together so that the 'Sensor Card' is free to swing with the mirror spot above the seam. (See Figure 2)

12) Tape the bottle together and glue the thread through the cap in place.

13) Place the bottle on a level surface and point the lamp so that a reflected spot shows on a nearby wall about 2-meters away. Measure the changes in this spot position to detect magnetic storm events. (See Figure 3 and 4)

Materials

—One clean 2-liter soda bottle
—2 pounds of sand
—2 feet of sewing thread
—A small bar magnet
—A 3x5 index card
—A 1-inch piece of soda straw
—A mirrored dress sequin
—Super Glue (be careful!)
—2-inch clear packing tape
—A meter stick
—An adjustable high intensity lamp

Conclusion:

Just as students may be asked to monitor their classroom barometer for signs of bad weather approaching, this magnetometer will let students monitor the Earth's environment in space for signs of bad space weather caused by solar activity.

Conclusions and Tips:

Here are some tips you will find helpful.

It is important that when you adjust the location of the Sensor Card inside the bottle that its edges to not touch the inside of the bottle, and that the mirror spot is above the bottle seam and the taping region of this seam so that it is unobstructed and free to spin around the suspension thread.

The magnetometer must be placed in an undisturbed location of the classroom where you can also set up the high intensity lamp so that a reflected light spot can be cast on a wall within two meters of the center of the bottle. This allows a one-centimeter change in the light spot position to equal 1/4 degree in angular shift of the north magnetic pole. At half this distance, one centimeter will equal 1/2 degree. Because magnetic storms produce shifts up to 5 or more degrees for some geographic locations, you will not need to measure angular shifts smaller than 1/4 degrees. Typically, these magnetic storms last a few hours or less.

To begin a measuring session which could last for several months, note the location of the spot on the wall by a small pencil mark. Measure the magnetic activity from day to day by measuring the distance between this reference spot and the current spot whose position you will mark, and note with the date and the time of day. Measure the distance from the reference mark and the new spot in centimeters. Convert this into degrees of deflection for a two-meter distance, by multiplying by 1/4 degrees for each centimeter of displacement.

You can check that this magnetometer is working by comparing the card’s pointing direction with an ordinary compass needle which should point parallel to the magnet in the soda bottle. You can also note this direction by marking the position of the light spot on the wall.

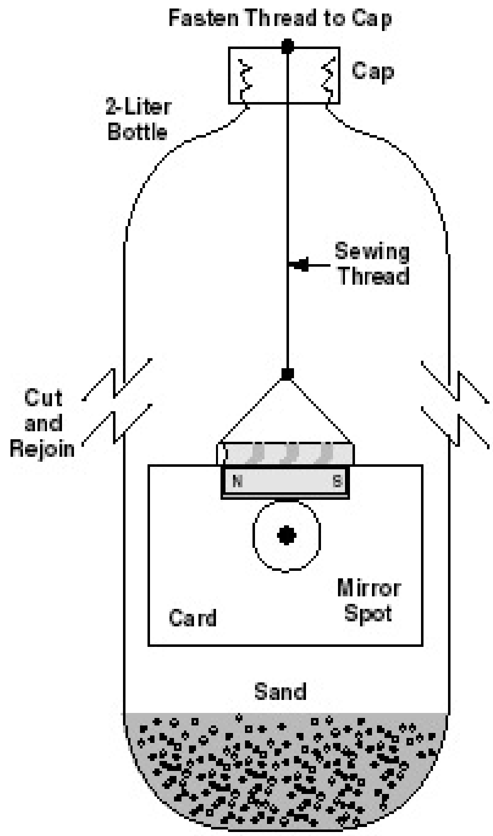
If you must move the soda bottle, you will have to note a new reference mark for the light spot and then resume measuring the new deflections from the new reference mark as before.

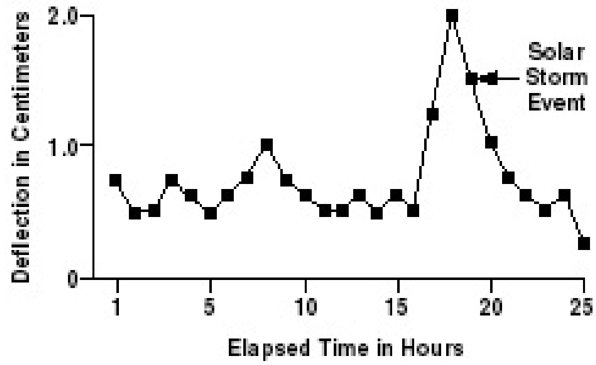
Most of the time there will be few detectable changes in the spot’s location so you will have to exercise some patience. However, as we approach sunspot maximum in the year 2000 there should be several good storms each month, and perhaps as often as one a week. Large magnetic storms are accompanied by major auroral displays, so you may want to use your magnetometer in the day time to predict if you will see a good auroral display after sunset. Note: Professional photographers use a similar device to get ready for photographing aurora in Alaska and Canada.

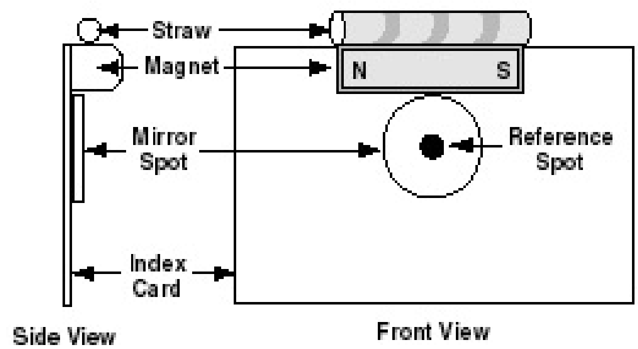
For more information about how to conduct this experiment, visit the NASA, IMAGE satellite web site’s ‘Join Magnet!’ page at

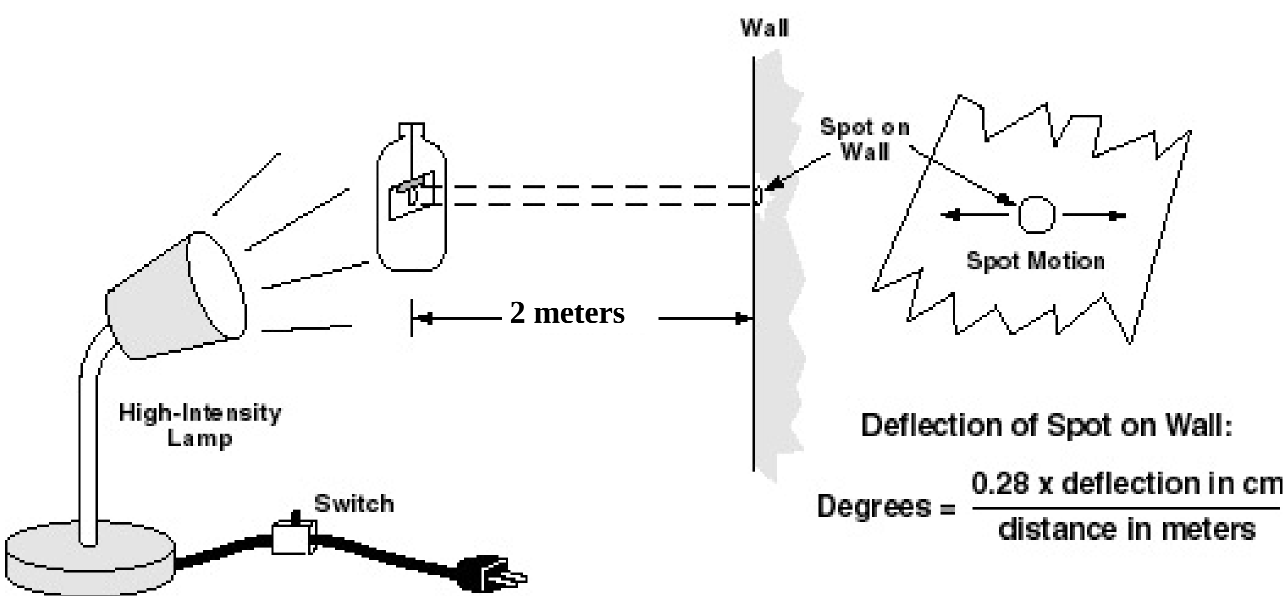
http://image.gsfc.nasa.gov/poetry

Plans for the Soda Bottle Magnetometer









What is Solar Activity?

The Sun, our nearest star, provides us with warmth and light. Many civilizations also thought the sun was it was a perfect orb, free of blemishes, eternal and changeless. **Sunspots** are the most well known hints that the Sun's surface is constantly changing. Larger than the Earth, and with magnetic fields that are 10,000 times stronger than the Earth's, sunspots are the breeding grounds for some of the most violent storms in the solar system!

The number of sunspots increases and decreases in cycles that last from 6 to 17 years; the **Sunspot Cycle.** With modern technology and space satellites, this solar activity cycle can now be detected in the ebb and flow of other phenomena on the Sun and on the Earth. Among the most enigmatic storms are the **solar flares** that erupt near sunspots. In a matter of 20 minutes, magnetic fields can heat gases to tens of thousands of degrees and release more energy than a thousand atomic bombs. Some of this gas can be hurled out from the Sun at millions of kilometers per hour in what are called **coronal mass ejections.** Both solar flares and coronal mass ejections can be very disruptive to human activity on earth and in space.

The outer atmosphere of the Sun, the **corona,** is familiar to many people who have watched total eclipses of the sun. The solar wind extends billions of kilometers further out into space than the corona**.** Like invisible roadways spanning the solar system, the magnetic field from the Sun flows out from the solar surface. Matter ejected from the Sun flows radially outwards from the solar surface. From the time a solar storm is seen on the Sun, it can take 2-3 days for the gas to travel to the orbit of the Earth, and if the Earth happens to be in the wrong place at the wrong time, it will be hit by a million-kilometer wide wall of high temperature gases and magnetic fields.

Anyone can tell you that a compass points 'north' because the Earth has a magnetic field, but until the advent of the Space Age, no one understood what this field really looked like or was capable of doing. Since Gilbert proposed in the 17th century that the Earth was a giant magnet, scientists have wondered just how this field is shaped, and how it has changed with time. The geomagnetic field which gives us our familiar compass bearings, also extends thousands of kilometers out into space in a region called the **magnetosphere**. On the Sun-side, it forms a protective boundary called the **bow shock.** Stretching millions of kilometers in the opposite direction behind the Earth is the **magnetotail.**

The solar wind blows upon the magnetosphere and gives it a wind-swept shape, but when solar storms and solar wind streams reach the Earth, the magnetosphere reacts violently. On the side nearest the impact, the magnetosphere compresses like squeezing a balloon, leaving communications satellites exposed. On the opposite side, it is stretched out, past the orbit of the Moon, or Mars and even Jupiter! The geomagnetic field is remarkably stiff, and so most of the solar wind is deflected or just slips by without notice. But some of the matter leaks in and takes up residence in donut-shaped clouds of trapped particles, or can penetrate to the atmosphere to produce aurora.

For thousands of years, humans have been treated to spectacles of glowing clouds above the northern horizon at night. Reports of these mysterious Northern Lights abound in the oral histories of the northern natives. On rare occasions, even ancient Greek and Chinese texts have mentioned them. It wasn't until 1896 that the Norwegian physicist Kristian Birkeland deduced that flows of electrons from the Sun were channeled into the polar regions by the geomagnetic field, and upon colliding with the outer atmosphere, would stimulate oxygen and nitrogen atoms to cast their ghostly and inspiring curtains of light.

The **Aurora Borealis** (near the north pole) and the **Aurora Australis** (near the south pole), as the ‘Northern Lights’ are more formally called, are seen most often in a band located at a latitude of 70 degrees, and about 10 degrees wide in latitude. From space, the auroral zone looks like a ghostly, glowing donut of light hovering over the north and south poles. This **auroral oval** can easily be seen in images from satellites designed to detect it. Its brightness and size change with the level of solar activity. Aurora come in many shapes and colors depending on what is happening to the geomagnetic field and the flows of charged particles and plasmas trapped in this field.

Magnetic sub-storms happen when the geomagnetic field is suddenly changed because of small changes in the magnetic polarity of the solar wind as it passes the Earth. Typically, magnetic storm aurora, also called **auroral storms,** last only a few hours. They begin in the evening as arcs of colored light which slowly change into rayed-arcs and the familiar folded ribbons or bands. Expanding over the whole sky, the folded bands are colorful, with green rays and red lower borders which change from minute to minute and move rapidly across the sky like some phantasmagoric serpent. After an hour, the auroral shapes become more diffuse and less distinct.

Geomagnetic storms are more severe than magnetic sub-storms and are caused by major changes in the direction and density of the solar wind as it reaches the Earth. These events are the most remembered historically as 'Great Aurora' or as the most disruptive to radio communications. The entire geomagnetic storm can last for several days as the particles and fields around the Earth continue to readjust themselves to the passing and ebbing solar wind.They begin with an ejection of mass by the Sun, and the impact of this plasma on the magnetosphere. Fast-moving coronal mass ejections produce shock waves in the solar wind, and this compression intensifies the density of particles impacting the magnetosphere. As the solar wind shock passes across the magnetosphere and magnetotail, magnetic fields re-orient and reconnect, releasing enormous amounts of energy and accelerating trapped particles to high speeds. These charged particles then travel down the geomagnetic field in huge currents, which cause bright and long lasting auroral displays.

Solar storms and the effects they produce in the Earth's environment, have been known for decades to be responsible for many harmful effects upon human technology on the ground and in space. Solar storms are known to do far more than just paint the sky with pretty colors! The multi-billion dollar 'Global Positioning System' consists of a constellation of over two dozen navigation satellites orbiting within the Van Allen radiation belts. These satellites let humans find their position anywhere on Earth using a hand-held receiver no bigger than a wrist watch.

During solar storms, these positions are quite a bit less accurate than under calm conditions, which in turn impacts the navigation of ships at sea and jets in the air. Solar storms have disabled multi-million dollar communication and navigation satellites such as Anik-A, Molynia, Marecs-A, and they have been implicated in many electrical problems that were experienced by other satellites.

Solar storms were responsible for causing the Skylab to burn up in the atmosphere sooner than expected, and for altering the orbits of hundreds of other satellites and even the Space Shuttle itself. A storm on March 13, 1989 knocked out the Quebec-Hydro power system, plunging 6 million people into darkness for 9 hours. Geomagnetic storms cause the magnetic field near the Earth's surface to change rapidly in just a matter of minutes or hours. These changes cause electrical currents to flow within long power transmission lines, telephone wires, and even in pipelines which makes the pipes corrode, sometimes with tragic consequences. On June 5, 1991 a natural gas pipeline in Russia was weakened by corrosion and began to leak its deadly, flammable cargo. A passenger train, loaded with 1,200 people, ignited the liquefied gas and caused an explosion equal to 10,000 tons of TNT. Over 500 people were killed, and 700 more were badly injured.

Would you believe...

Aurora can never get closer to the ground than about 60 kilometers.

A sunspot has a temperature of nearly 4000 C, and would be brighter than the full moon if placed in the night sky.

Sunspots are often several times larger than the entire earth.

The Sun rotates once every 25 days at the equator, but takes up to 36 days to rotate once around at the poles.

The corona of the Sun is over 5 million degrees hotter than the surface of the Sun.

The Earth's magnetic north pole is actually a magnetic south pole because the north end of a bar magnet is attracted to it.

The total power produced by an auroral event can exceed 1 million megawatts and produce voltages over 100,000 volts in the upper atmosphere.

Aurora are produced where the atmosphere has the same density as the vacuum inside a light bulb.

Some aurora occur at altitudes of over 1000 kilometers above the Earth's surface.

Lightning storms can eject particles into space at nearly the speed of light, and they are seen as 'sprites' on the top side of a thundercloud.

A single lightning storm can be detected on the other side of the earth because some of its radio energy travels along the local magnetic field lines that connect the pairs of points on the surface of the Earth that can be thousands of kilometers apart.

Glossary

Aurora : Also called the 'Northern Lights' in the Northern hemisphere, or the 'Southern Lights' in the Southern hemisphere. These wispy curtains of light in the sky are caused by energetic electrons which collide with atoms of oxygen and nitrogen in the air to cause these atoms to emit shades of green, red and blue light. They never descend nearer than 60 kilometers from the Earth's surface.

Corona : The very tenuous outer layers of the Sun which are seen during a total eclipse of the sun, but extending millions of miles into interplanetary space. It is heated to temperatures of over one million degrees by magnetic activity at the surface of the Sun. For decades, scientists puzzled over why the Corona could be so much hotter than the balmy 5770 degree Kelvin surface of the Sun.

Coronal Mass Ejection : The sudden expulsion of matter from the coronal regions of the sun, often involving billions of tons of plasma ejected at over one million kilometers per hour. During sunspot minimum conditions, about one 'CME' can be expelled every few days. During sunspot maximum conditions, as many as 3-5 can occur each day.

Magnetopause : A region that defines the outer edge of the magnetosphere where the pressure of the solar wind is balanced by the pressure of the earth's own magnetic field.

Magnetosphere : The region surrounding the Earth in space where its magnetic field is important in controlling the movements of charged particles. Also sometimes referred to as 'Geospace'.

Magnetotail : The solar wind pulls the magnetosphere into a comet-like shape. The long tail of this field, called the magnetotail' or also the 'geotail', extends millions of miles into space in a direction opposite to the Sun from the Earth.

Solar flare : A powerful release of energy on the surface of the sun usually lasting less than a few hours, but releasing as much energy as 1000 hydrogen bombs. These are often associated with active regions of the solar surface where magnetic fields have become badly tangled, and then snap, releasing energy and heating local gases to over 1 million degrees.

Solar storm : Although scientists prefer not to use this term because it is technically rather vague, it has come to mean any of a number of active conditions on the Sun's surface including flare activity or coronal mass ejections.

Sunspot : A dark spot on the Sun's surface that indicates a concentration of magnetic forces. They are actually about 2000 degrees cooler than the solar surface, and only look dark because they emit light faintly.

Sunspot Cycle : The change in the number of sunspots from one period of its maximum to the next, over the course of about 11 years.

Sunspot Maximum : The period during the sunspot cycle when you will see the largest number of sunspots. Also called the 'Solar Maximum'.

Sunspot Minimum: The period during the sunspot cycle when you will see the fewest number of sunspots. Also called the 'Solar Minimum'

Resources

IMAGE	http://image.gsfc.nasa.gov
POETRY	http://image.gsfc.nasa.gov/poetry
SOHO	http://sohowww.nascom.nasa.gov
NASA Sun-Earth Connection Resources	http://sunearth.gsfc.nasa.gov
The Earth's Magnetic Field	http://image.gsfc.nasa.gov/poetry/magneto.html
Satellite Glitches -Space Environment Info	http://envnet.gsfc.nasa.gov
Magnetic North Pole	http://www.nrcan.gc.ca/gsc/cpdnew/magnet.html
Solar Sounds	http://soi.stanford.edu/results/sounds.html
Sunspot Number Archives / Resources	http://image.gsfc.nasa.gov/poetry/sunspots.html
CME Archives at MLSO	http://www.hao.ucar.edu/public/research/mlso/movies.html
Stellar Activity Cycles at Mt. Wilson	http://www.mtwilson.edu/Science/HK_Project/
Satellite Data	http://cdaweb.gsfc.nasa.gov
Space Weather Resources	http://image.gsfc.nasa.gov/poetry/weather.html
Magnetic Observatories and Data	http://image.gsfc.nasa.gov/poetry/maglab/magobs.html
Space Environments and Effects	http://see.msfc.nasa.gov/sparkman/Section_Docs/sparkman.html
Sun-Earth Classroom Activities Archive	http://sunearth.gsfc.nasa.gov/educators/class.html
Storms from the Sun	http://www.istp.gsfc.nasa.gov/istp/outreach/learn.html
The Aurora Page	http://www.geo.mtu.edu/weather/aurora/
Space Weather Human Impacts	http://image.gsfc.nasa.gov/poetry/storm/storms.html
Ionosphere density and sunspot numbers	http://julius.ngdc.noaa.gov:8080/production/html/IONO/ionocontour_90.html
Space Weather Daily Reports	http://windows.engin.umich.edu/spaceweather/index.html
Solar wind density and speed	http://www.sel.noaa.gov/wind/rtwind.html
Mees Solar Observatory Archives	http://www.solar.ifa.hawaii.edu/MWLT/mwlt.html

Teacher Reply Card

National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 5-8

EG-2000-03-002-GSFC

Solar Storms and You!

Exploring the Aurora and the Ionosphere

An Educator Guide with Activities in Space Science

Solar Storms and You! is available in electronic format through NASA Spacelink - one of the Agency's electronic resources specifically developed for use by the educational community.

The system may be accessed at the following address:
http://spacelink.nasa.gov

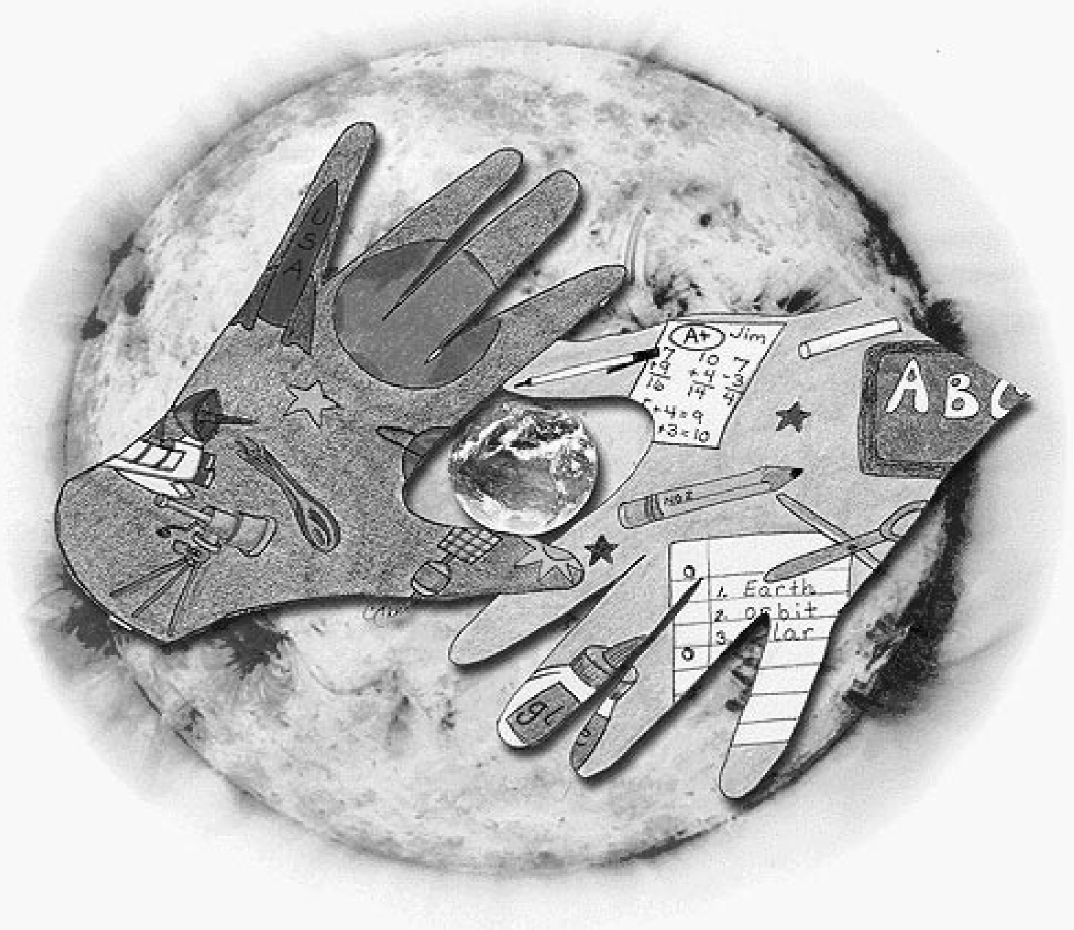
National Aeronautics and
Space Administration

EG-2000-03-002-GSFC

Solar Storms and You!

Exploring the Aurora and the Ionosphere

An Educator Guide with Activities in Space Science



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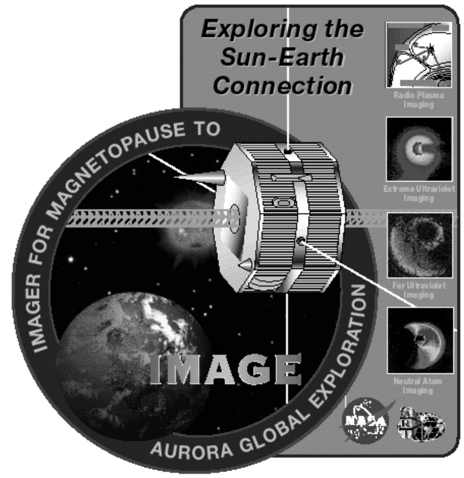

This resource was developed by the NASA Imager for Magnetosphere-to-Auroral Global Exploration (IMAGE)

Information about the IMAGE mission is available at:

http://image.gsfc.nasa.gov
http://pluto.space.swri.edu/IMAGE

Resources for teachers and students are available at:

http://image.gsfc.nasa.gov/poetry

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National Aeronautics and
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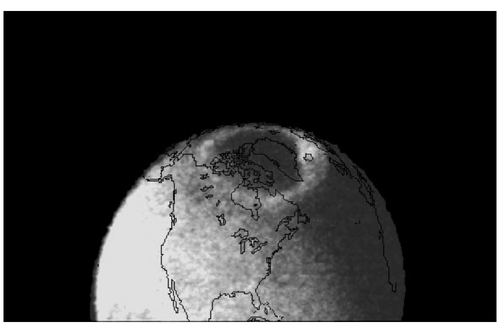
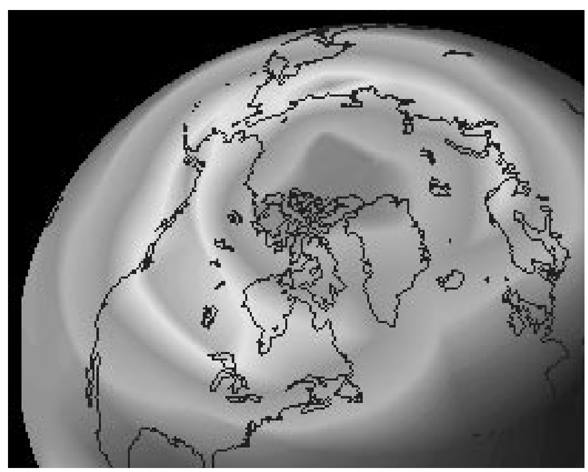
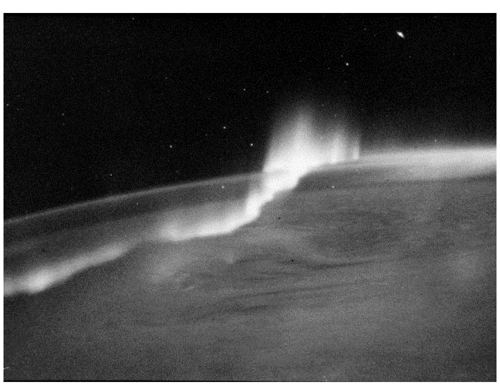
Goddard Space Flight Center

CONTENTS







Aurora seen from space look very different than from the ground. The space perspective lets you see the entire circle of auroral activity which encircles the north magnetic pole like a diamond ring. It also gives scientists a truely 3-D view of this phenomenon making it much easy to study.

INTRODUCTION

A gas pipeline in Russia explodes
killing hundreds of people.

A satellite mysteriously falls silent
interrupting TV and cellular phone traffic.

A power blackout
throws millions of people into darkness.

These are only a few of the many things that solar storms can do when they arrive at the earth unexpected. In an age where we have increasingly come to rely upon the smooth operation of our technology, we have also made ourselves vulnerable to the ebb and flow of the solar storm cycle. Most people are not even aware of this cycle, but long ago we used to be!

Ancient Chinese sun observers knew that, from time to time, dark spots would glide slowly across the face of the setting sun. Once seen only as portends of political upheaval, we now see them as natural phenomena that can forewarn us of impending storms that can have dire consequences for us if we ignore them.

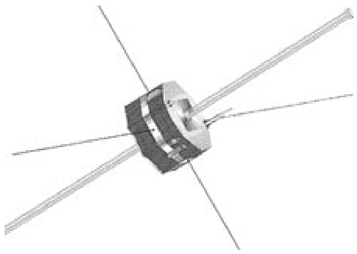
In this activity book, your students will study five key stages in the lifecycle of a solar storm, from its emergence on the solar surface to its impact upon some aspect of our lives. The book may be used in its entirety to study solar activity and how it directly affects us, or you may use individual activities of your choice as stand-alone mini lessons as an enrichment for math and physical science courses.

The student activities emphasize basic cognitive skills and higher-order processes such as plotting data, searching for patterns and correlations, and interpreting the results. By the end of the activity series, students will understand why we need to pay more attention to solar storms.

Visit the updated version of this workbook at:

http://image.gsfc.nasa.gov/poetry/workbook/workbook.html

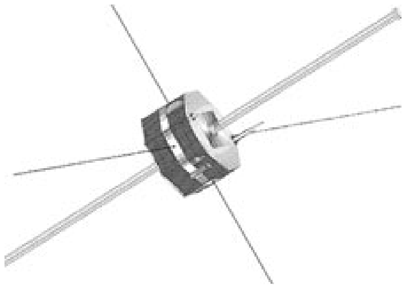
Science Process Skills
for *Solar Storms and You!*



This chart is designed to assist teachers in integrating the activities contained in the guide with existing curricula.

	Lesson 1 *"A Simple AM Radio Ionosphere Station"*	**Lesson 2** *"Radio Waves and the Ionosphere"*	**Lesson 3** *"The Aurora"*
Observing	○		○
Classifying			
Communicating	○		○
Measuring	○	○	
Inferring	○		
Predicting		○	
Experimental Design	○		
Gathering Data	○		
Organizing Data	○		
Controlling Variables	○	○	
Developing a Hypothesis			
Extending Senses	○		
Researching			
Team Work	○		
Mathematics	○	○	○
Interdisciplinary	○		○
Introductory Activity	○	○	○
Advanced Activity			

Science and Mathematics Standards
for *Solar Storms and You!*



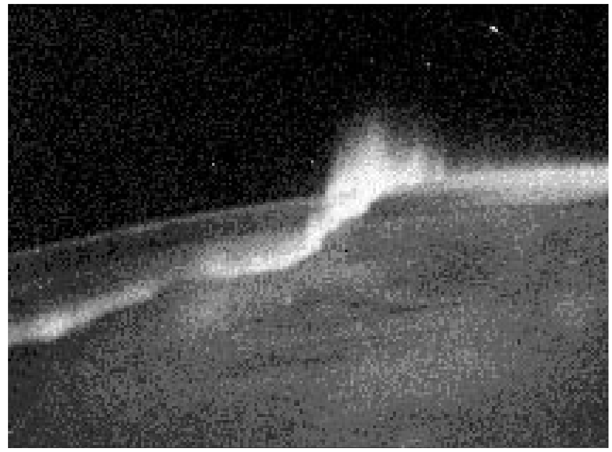
This chart is designed to assist teachers in integrating the activities contained in the guide with existing curicula.

	Lesson 1 *"A Simple AM Radio Ionosphere Station"*	**Lesson 2** *"Radio Waves and the Ionosphere"*	**Lesson 3** *"The Aurora"*
Science as Inquiry	O	O	O
Structure and Energy of the Earth System	O	O	O
Origin and History of the Earth			
Earth in the Solar System	O		O
Geochemical Cycles			
Physical Science	O	O	O
Populations and Ecosystems			
Understanding Science and Technology			
Science in Personal and Social Perspectives			
History and Nature of Science			
Problem Solving			
Measurement	O		
Computation and Estimation			
Communication		O	O
Geometry and Advanced Mathematics		O	
Statistics and Probability	O		
Number and Number Relationships			
Patterns and Functions		O	

Auroras and Ionosphere

Visible Auroral Emission Lines

Wavelength (Angstroms)	Altitude (kilometers)	Atom	Color
3914	1000	Nitrogen	Violet
4278	1000	Nitrogen	Violet
5577	90-150	Oxygen	Green
6300	150	Oxygen	Red
6364	150	Oxygen	Red
6563	120	Hydrogen	Red
6611	65-90	Nitrogen	Red
6696	65-90	Nitrogen	Red
6768	65-90	Nitrogen	Red
6861	65-90	Nitrogen	Red



Aurora have been observed for thousands of years and they are the most dramatic indications of solar activity. They are produced when flows of energetic charged particles collide with the upper atmosphere.

The brilliant colors from reds to purples indicate atoms of oxygen and nitrogen being stimulated by these collisions to give off specific wavelengths of light.

They are produced at altitudes from 65 kilometers to 1000 kilometers, under conditions where the atmosphere is a better vacuum than you would find inside a TV picture tube. Because of the specific way in which the light is produced, it is impossible for aurora to happen in the higher-density layers of the atmosphere below 50 kilometers. Despite the appearances to casual observers, the aurora never reaches the ground.

Auroral activity is most intense during times when solar activity is the highest and the Coronal Mass Ejections make their way to Earth to impact the magnetosphere. They can also be produced as various parts of the magnetosphere rearrange in the so-called **geotail** region, which extends millions of kilometers into space on the opposite 'night time' side of the earth from the sun.

The ionosphere is a narrow zone of charged particles in the earth's atmosphere. It was not discovered until radio communication was invented around the turn of the century. It has an average density of about 10 electrons per cubic centimeter, but can be 10 to 100 times as 'charged' during solar storms.

At low frequencies below 10 megaHertz, the ionosphere acts like a mirror and allows ground to ground signals to be 'bounced' long distances around the earth. At higher frequencies the ionosphere becomes transparent so that communication via ionosphere bounce becomes impossible. Instead, we must rely on satellite communication to relay signals from point to point on the earth.

The properties of the ionosphere change with the time of day, the season, and especially with the level of solar activity. In the latter case, solar flares can cause radio signal 'fade outs' which are well-known to amateur radio operators.

Teacher's Guide — AM Radio Ionosphere Station

Introduction

Above the earth's surface, a layer of charged particles has been used, since the turn of the century, to reflect radio waves for long distance communication. Radio waves, with frequencies less than about 10 megaHertz, are reflected by the ionosphere. They are used for military and civilian 'short wave' broadcasting. The properties of the ionosphere can change dramatically with daytime transmissions being noisier than night time ones. Solar flares also change the reflectivity of the ionosphere. This AM radio project will let students detect and study some of these changes.

Objective

Students will construct an Ionosphere Monitor by using an AM radio to track solar storms and other changes in ionosphere reflectivity.

Procedure

1) Break the class into equal groups and have one person in each group bring an AM radio to class.

2) Each group creates a graph of the AM band from 540 kiloHertz to 1700 kiloHertz marked every 50 kiloHertz or so over a 1-foot span.

3) Remove the volume control knob and place the paper disk over the shaft, then replace the knob. Tape the disk onto the radio and mark its edge with the numbers 0-10 counterclockwise.

4) Have the students slowly scan through the AM band and note the location of the station on the graph. Note its loudness by the number on the disk that makes the station hard to hear.

5) Identify the call letters and city of each station you find.

6) Have the groups compare their results to create a combined master plot of the AM band. Locate the most distant station you can hear and its distance in miles from your school.

7) Select a location in the band on the low end between stations. Note the kinds of 'noise' you hear in a journal log for that day. Lighting storms will sound like occasional pops and crackles. Electronic noise will sound like humming or buzzing.

8) Changes in the ionosphere near sunset or sunrise will be heard as a sudden change in the loudness of the background noise. New distant stations may suddenly become detectable. Note the time, the location on the plot, and the city or call letters. This will take some detective work.

Materials

—An AM radio with a tuner knob and a volume control knob.

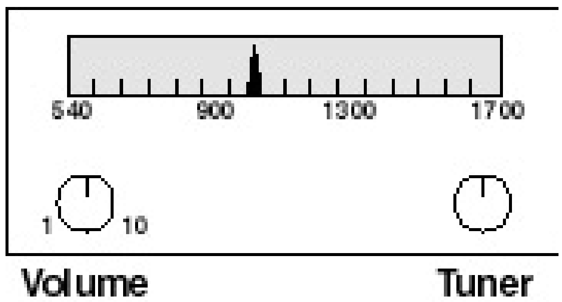
—A paper disk with a hole punched in its center to fit over the volume control.

For more things to do, advanced students may want to visit:

RadioJove at
http://radiojove.gsfc.nasa.gov
INSPIRE at:
http://image.gsfc.nasa.gov/poetry/in-spire

Conclusion

Students will learn that a simple everyday device can let them listen-in to invisible changes in their environment caused by solar activity.



Note:

On the volume control dial, you want to affix a circular scale so that when it is turned to '1', you are not very loud, and on '10' the radio is at maximum volume. When you are studying faint stations, you will typically have the volume control turned 'up' to hear them, so that the scale running from 1-10 will tell you about how loud the weak station is so that you are JUST able to hear it.

Online Internet resources you may fine helpful:

Today's Solar Activity:

http://umbra.nascom.nasa.gov/images/latest.html

Space Weather Forecasts:

http://www.sec.noaa.gov/today.html

http://www.sec.noaa.gov/index.html

This makes a good classroom project and homework assignment (watching the changes during and after sunset). It is also a good long-term science fair project, if you also correlate solar activity with the changes in the daytime radio noise loudness, and faint station reception. Solar flares will cause short-wave 'drop outs' and impared reception of distant radio stations during the daytime, lasting for several hours.

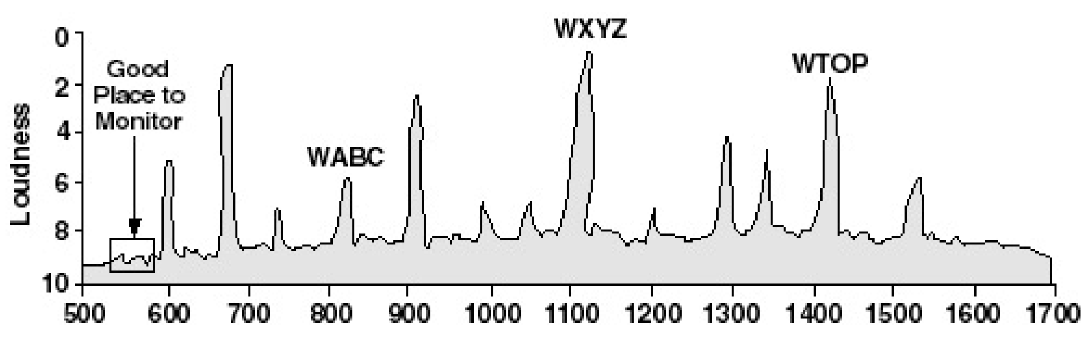
Sample Journal Entries:

April 5, 1997 10:45 EST Cambridge, Massachusetts

"We listened to a radio frequency setting of 610 kilo-Hertz. The noise seemed pretty steady at a loudness of 8.5, but every 10 seconds or so we heard a sharp crackle of noise. We think this was a distant thunder storm, and our TV weather report says that thunder storms were in progress in Kansas at the time."

February 6, 1997 6:00 PM EST, Dayton, Ohio:

"Sunset happened about 35 minutes ago, and I selected the same frequency we listened to at in school, to listen for the day/night changes. I can hear a faint station we did not hear in the daytime, and the background hiss is now less loud. Instead of 9.0, I have to put the volume control over to 9.5 to hear it at all. "



Frequency in kiloHertz (1000 cycles per second)

$$\text{Wavelength in meters} = \frac{300{,}000}{\textbf{Frequency in kiloHertz}}$$

Teacher's Guide

Radio Waves and the Ionosphere

Introduction

When AM radio waves travel from transmitter to a receiver far away, they have to bounce off the underside of the ionosphere to reach a distant receiver. The waves lose some of their energy each time they are reflected. Although this is normally a small amount, less than 5%, it can be several times larger than this during a solar storm. When solar flares erupt, the radiation arrives at the earth 8.5 minutes later and ionizes the D-layer located just below the ionosphere closest to Earth. Radio signals passing through this layer and bouncing off the ionosphere higher up, have some or all of their intensity absorbed. If you were listening to a distant radio station, you would hear its signal suddenly 'fade-out' for 5-10 minutes.

Objective

Students will calculate the ending percentage of radio wave strength at the receiving station.

Procedure

1) Introduce the concept of radio waves in the ionosphere. Be sure to include a discussion about the waves reflecting off of the ionosphere layer and the surface of the Earth, and the impact of a solar storm on these waves. A blank transparency of the Student Page may be helpful for student visualization.
2) Explain that the radio waves normally lose about 5% each time they cross the D-layer just below the ionosphere. During solar storms, the radio waves can lose as much as 30% with each crossing of the D-layer.
3) Provide students with the examples given, and check for understanding.
4) Allow sufficient time for the students to calculate the percentages, and to determine the remaining signal strength at the receiver's location.
5) Discuss the loss of wave strength and how that may affect communication. Some possible responses may include; mobile phone connections, AM radio station signals, and military communications.

This Lesson can conclude after the discussion, or the following additional procedure may be performed:

6) Group the students into pairs. Have them measure the given angles. Challenge each pair to vary the angle of the bounce to determine if there is an angle that will provide a stronger signal strength. For example, adjust the angle from the transmitter to a smaller degree, creating an isosceles triangle. This will change the number of bounces to a fewer number of triangles, instead of the 8 given in the first example. By decreasing the number of bounces, the signal strength is stronger at the receiver's location. Adjusting the angle to greater than the original will increase the number of bounces required, and in turn decrease the signal strength at the receiver.

Example for one bounce with two passes through the D-layer:

Normal 5% loss:

100% x 0.95 = 95%
95% x 0.95 = 90% (Final)

Solar Storm 30% loss:

100% x 0.70 = 70%
70% x 0.70 = 49% (Final)

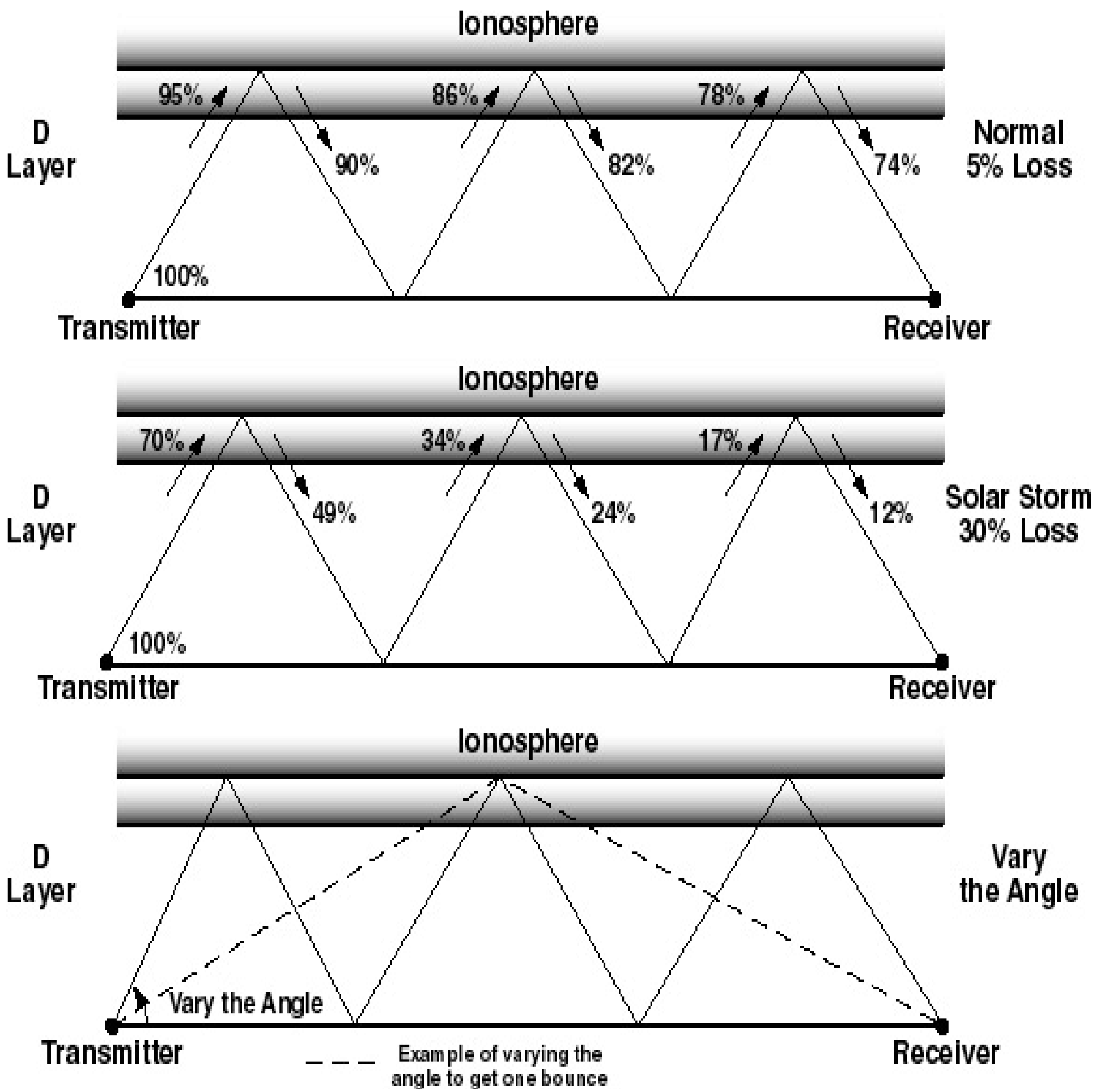
Materials

—Protractor
—Calculator (if available)

Conclusion

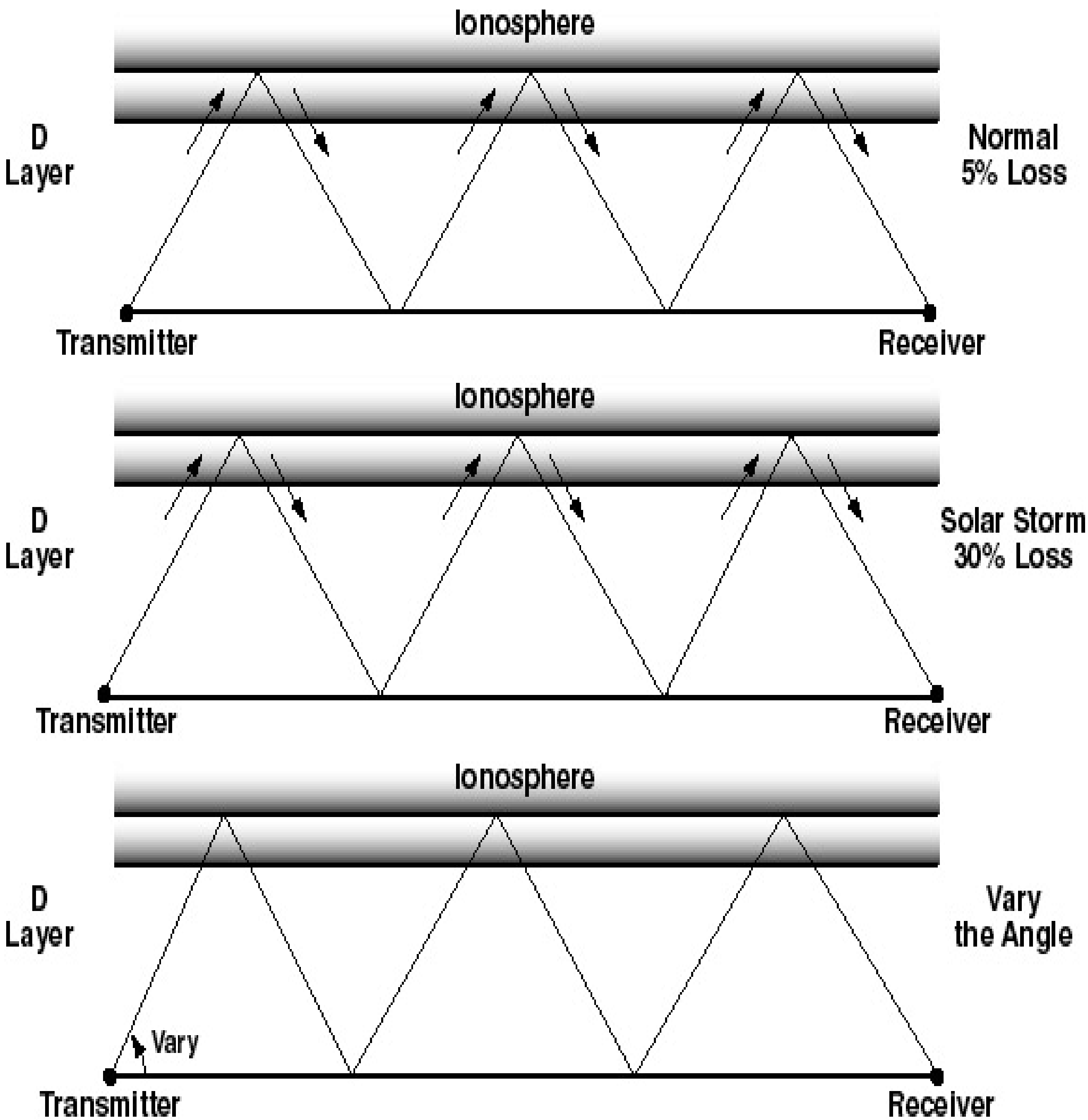
Students should learn about real everyday situations that occur with our radio systems. From their discussion, they should address that during a solar flare, the radio waves lose a great amount of strength. Students should realize that solar flares greatly affect daytime long distance communication.

Teacher Answer Key



Radio waves travel from the transmitter to the receiver. The signal bounces from the ground, through a layer called the D-Layer, and is then reflected from the ionosphere back through the D-Layer to the ground. The waves continue to be reflected in this way until they reach the receiver. When the waves pass through the D-Layer they normally lose 5% of their strength. The loss occurs for evey pass through the D-Layer, therefore, there is a 5% loss going up, and a 5% loss going down. When a solar storm occurs, the loss can be about 30%. The engineers have to adjust the angle that the signal is projected to create maximum reception by tilting their ‘satellite dish’. The angle of adjustment must permit the triangles to be isosceles triangles. The wave bounces should be adjusted so that the final bounce is a direct hit to the receiver’s location. If the signal is above or below the receiver’s location, or to either side, there will be no reception.

Name ______________________________ Date_________________



Calculate the remaining signal strength for each bounce from the transmitter to the receiver. Determine the amount remaining at the receiver's location. Round the answers to the nearest whole number.

Teacher's Guide

The Aurora

Introduction

Aurora are produced in the north and south magnetic polar regions when energetic particles from the Sun, or from other locations in the Earth's magnetic field, collide with atoms of oxygen, nitrogen or hydrogen in the atmosphere. A source of mystery for countless millennia, we now understand how they are produced, but can still admire them for their beauty. Scientists have studied them for over 100 years, and there are certain details about how aurora form and change with time that are the subject of new investigations from the ground, and from space.

Objective

Students will read an article to be informed about auroral activity, describe information given, and apply their understanding to create an auroral display.

Procedure

1) Discuss the student's prior knowledge about aurora.

2) Allow sufficient time for the students to read "The Aurora: New Light on an Old Subject".

3) Students complete questions number 1 through 6. Encourage the students to refer to the article as needed. Discuss the student responses.

4) Students can color the map according to their interpretation of the aurora.

For images of the aurora, and more information on the appearance of the aurora, arrange for the class to use the computer center. Visit the resource Internet pages on Aurora listed in the back of this workbook.

Materials

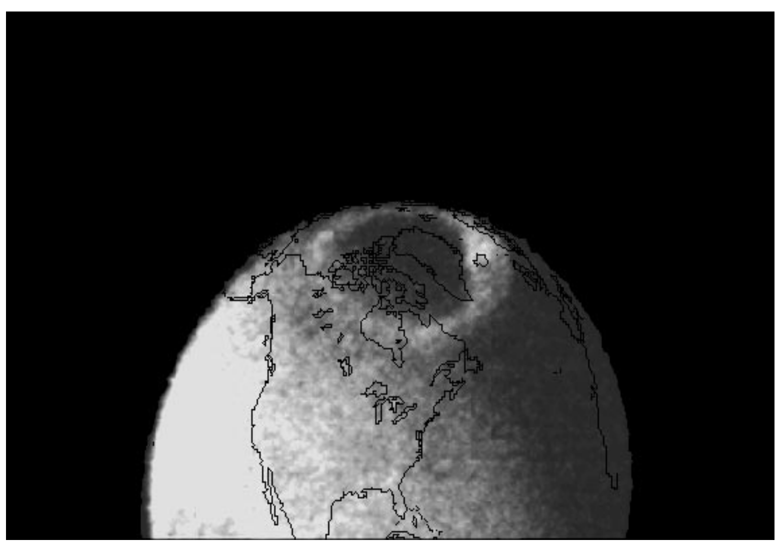
— "The Aurora: New Light on an Old Subject"

—Student Page

—Crayons, colored pencils or markers.

Conclusion

Students will learn about the aurora phenomenon and how scientists have studied it over the last few centuries. They will learn how older ideas have been replaced by newer theories.



The Aurora: New Light on an Old Subject

Dr. Sten Odenwald (Raytheon ITSS and NASA Goddard Space Flight Center)

For thousands of years, humans have admired the spectacle of the 'Northern Lights' also known as the Aurora Borealis. The multi-colored curtains of light that, from time to time, play across the skies like phantasmogoric serpents, have been seen by Scandanavian Vikings, Eskimos, and even on exceptional occasions, by inhabitants of the Mediterranean and Japan. Today, astronauts can see auroras from the vantage point of space where it appears as an oval-shaped glowing donut over 5000 kilometers in diameter, centered on the north magnetic pole. During the last few decades, scientific investigation of this natural phenomenon have uncovered many new insights to how auroral displays are produced, and that many other planets such as Jupiter and Saturn also share such a phenomenon. But first, some history!

In the mid-19th century, Anders Jonas Angstrom noted that there was a similarity between auroral displays and certain kinds of electrical discharges that could be studied under laboratory conditions. This was the first recognition that some kind of electrical discharge was responsible for producing auroras. This was in distinction to earlier popular ideas that auroras were reflections of light from ice crystals high up in the atmosphere, or that they were related to terrestrial lightning. It wasn't until around 1925 that spectroscopic investigations finally identified one of the atoms causing the distinctive greenish light: Oxygen. This particular light is only produced at a single wavelength near 5577 Angstroms, about mid-way through the familiar visible spectrum. It is a feature caused by oxygen atoms at very low gas densities being excited by specific amounts of energy.

Around the turn of the century, physicists and astronomers had identified certain prominent atomic emission lines in such objects as distant, interstellar gas clouds and even the solar surface. Such elements as 'nebulium', 'coronium' and 'geocoronium'. Following decades of spectral analysis, these emission lines were finally tracked down, all except for one. The element 'helium' was discovered in the solar spectrum before it was finally found on earth, however the remaining mysterious lines turned out not to be from exotic new elements, but from ordinary iron atoms. The coronium lines were found in the coronal regions of the sun high above the solar surface. Originally it was thought that they were produced by an even lighter element than hydrogen which makes up the bulk of the solar material. Instead, the emission lines attributed to coronium were found to come from iron atoms that had been stripped of 13 of their electrons!

Auroras are now known to be electrical phenomena triggered by high speed electrons that enter the upper atmosphere in powerful currents, following the magnetic field of the earth into the polar regions. These electrons collide with atoms of oxygen and nitrogen to stimulate them to emit specific wavelengths of light. The process works very much like a neon sign, in which a current of electrons passes through a low density neon gas inside the tube to stimulate the atoms to emit light.

Auroras can never touch the ground, contrary to the many reports handed down by folklore. The emission of the light requires very low density gas conditions so that the atoms do not become 'collisionally excited' into other states. Too many collisions in a high-density environment will eliminate the specific electronic transition needed to produce the specific auroral lines. The density of the atmosphere near the lower range of the auroral limit near 70 kilometers is nearly the same as what is found inside a neon bulb. At the upper range of the auroral display at 1000 kilometers, the atmosphere is even more rarified.

In April, 1741 Olof Hiorter discovered from studies of the earth's magnetism that,whenever a prominent auroral display occurred, the magnetic field of the earth in the vicinity of the aurora would be disturbed. By 1770, J.C. Wilcke discovered that prominent auroral rays tended to align with the direction of the earth's magnetic field. A prominent solar flare on September 1, 1859 was observed by Richard Carrington and at the same time, several miles away at a local magnetic observatory outside of London, a major disturbance in the earth's magnetic field was recorded. These separate clues revealed that aurora are not just pretty lights in the sky, but are indicators of a process which often begins on the sun as a solar storm. These storms emit particles which sometimes collide with the earth and produce currents that flow into the magnetic polar regions. Aurora result from these flows of particles, and these flows also modify the earth's magnetic field to produce magnetic 'storms'.

Because aurora are indicators of severe magnetic activity, they are often correlated with many problems that can arise with electrical equipment. Aurora produce their own forms of radio radiation that can interfere with long distance communication. The rapidly changing magnetic fields near the ground can induce electrical currents in power lines that result in power black-outs. On March 13, 1989 a major solar storm produced a dazzling auroral display that was observed as far south as Florida and Japan. It also caused a power blackout for 9 hours that affected 6 million people in Quebec. Even natural gas pipelines are affected. As auroral electrical currents flow along these pipelines, they produce enhanced corrosion which can have catastophic consequences. Although the Alaskan pipeline was specifically designed with proper insulation to reduce this corrosion, the Siberian natural gas pipeline was built much earlier without this safeguard. In 1990, a portion of the pipeline ruptured and flooded a small valley with the vapors of the liquid natural gas. When two passenger trains entered the valley, the conductors smelled the gas and seconds later the entire valley exploded sending over 500 people to their deaths.

One possible way of reducing the risk for such catastrophes is to devise a way to successfully forecast when such major auroral 'storms' will happen. NASA satellites such as SOHO, ACE, TRACE and others in planning are parked about 1.5 million kilometers towards the sun so that this front guard can sense an approaching storm and provide up to an hour's notice of a major storm approaching from the sun. Other satellites monitor the solar surface to watch for flares which transmit their influences at nearly the speed of light and arrive at the earth within 10 minutes. Scientists have begun to elevate 'Space Weather Forecasting' to a high-precision art form even though there is an inevitable aspect of random chance to the way that the sun produces these storms. In the future, we may have better ways of protecting ourselves from the disruptive aspects of auroral displays so that we can, once again, return to admiring their beauty with a restored piece of mind.

Name ______________________________ Date__________________

"The Aurora: New Light on an Old Subject"

1. **What is the main idea of the reading selection?**

2. **What conclusions can you draw from the article?**

3. **What new information did you learn?**

4. **What did the author have to know about the reading selection?**

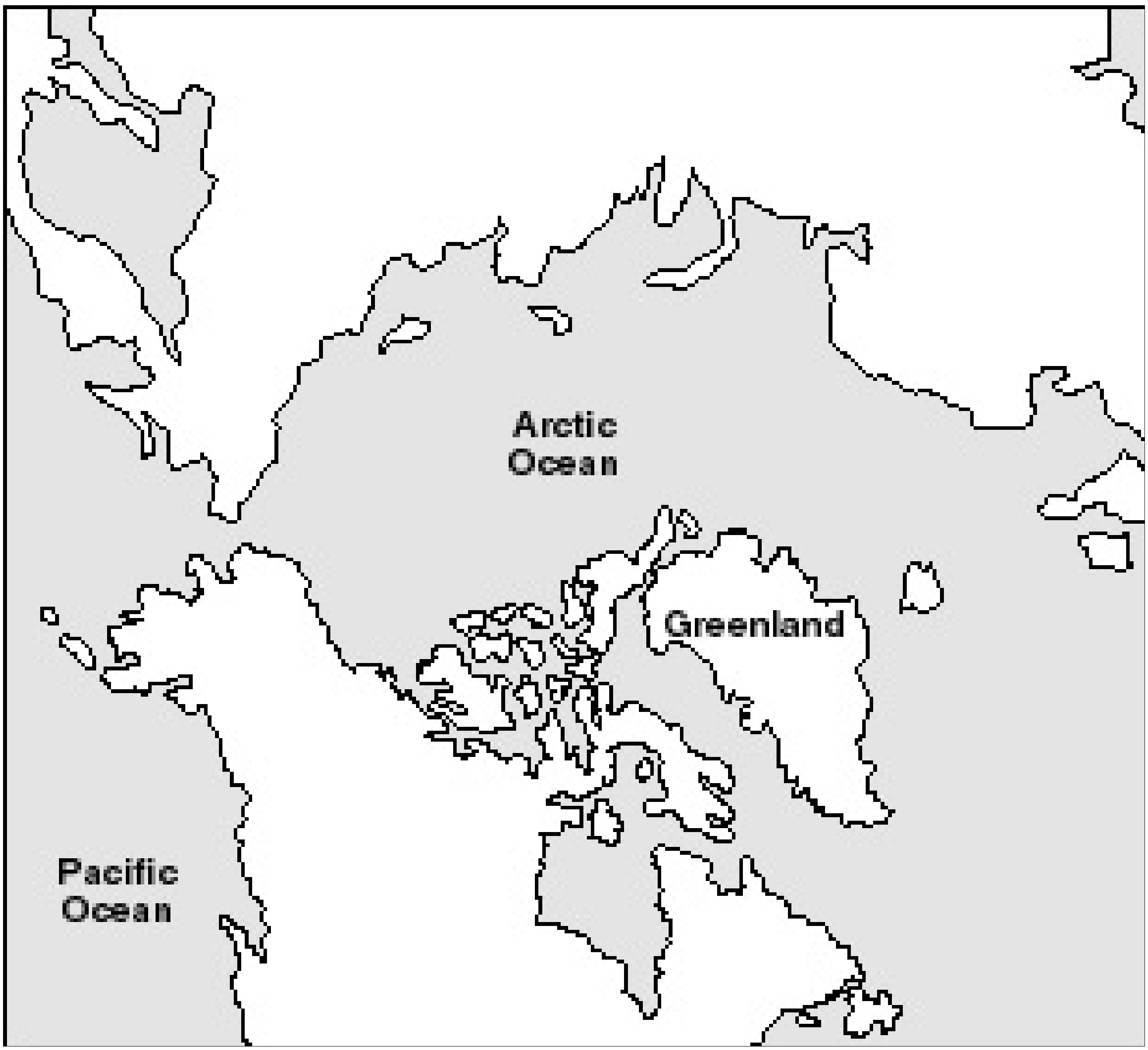
5. **In your own words, summarize the trouble to electrical installations that can be caused by aurora in the polar regions.**

6. **The science of studying the sun and the aurora is a complex process where some ideas may change while other ideas remain supported by new data. Identify ideas that have changed and why the change happened.**

7. **How might an astronaut describe viewing the aurora as seen from above the Earth's surface?**

8. **Color the map as you would expect it to appear using what you have learned from the article.**

Name ______________________________ Date__________________



Selected Responses

"The Aurora: New Light on an Old Subject"

1. What is the main idea of the reading selection?

" The main idea of the reading selection is to inform you what the Northern Lights are, where they are found, what they are made of, and the new technologies and discoveries being made about them."

"The main idea of the reading selection is the Aurora: New light on an old subject, what the auroras are, where they are located, and what causes them."

"The main idea is to inform people about the Aurora Borealis."

2. What conclusions can you draw from the article?

"The conclusions that I can draw from the article is that things are definitely going on in the lights and sun, and that scientists are trying to work it out."

"The conclusions that I can draw from the article are that the Aurora (Northern Lights) has been made from nitrogen and oxygen colliding in the sky. There are lots of ways to figure out science over the years with better equipment."

"I can say that the Aurora is very complex, and we have advanced in our knowledge of the auroras."

"Some conclusions that I drew from this article is that the auroras were caused by ice crystals high in the atmosphere. Finally, they found out that atoms caused the green lights, and also that they are caused by solar storms."

"The auroras are indicators of a process which often begins on the sun as a solar storm. Another conclusion is that we have advanced a lot in the study of space."

3. What new information did you learn?

"I have learned that auroras can never touch the ground, and that the auroras produce their own forms of radio radiation. This can interfere with long distance communication."

"I learned that the aurora was thought to be many different things and over the years and that it has kept changing."

"I learned about all of the scientists that helped to discover the Aurora. I also learned that one possible way of reducing the risks for catastrophes is to devise a way to successfully forecast when such major auroral storms will happen."

"I learned Auroras can never touch the ground and that Auroras indicate severe magnetic activity."

"I learned about all of the scientists that helped to discover the Aurora. I also learned that one possible way of reducing the risks for catastrophes is to devise a way to successfully forecast when such major auroral storms will happen."

Selected Responses

4. What did the author have to know about the reading selection?

The author had to know a lot about the aurora to be able to write the reading selection.

The author had to know his information and where to get the information to support his topic.

5. In your own words, summarize the trouble to electrical installations that can be caused by the aurora in the polar regions?

The trouble to electrical installations caused by the auroras in the polar regions is that they can cause currents to travel up and down the pipelines, into gas lines and they can cause blackouts and explosions.

The aurora produces their own forms of radiation that can interfere with long distance communication.The magnetic fields can cause currents in the power lines and cause blackouts.

6. The science of studying the sun and the aurora constantly changes. From the article, cite an example of where scientists have hypothesized or speculated an idea that was later proven correct or incorrect. How was this accomplished? Be sure to include examples from the text to support your answer.

One idea that has changed is that before we weren't able to find outways of disruptive aspects, but we might be able to in the future. Also,another idea that has changed is that the Alaskan pipeline was specifically designed with the proper insulation to reduce the effects of a solar storms, but it didn't work in Siberia.The pipeline exploded.

One idea that has changed was that they originally thought they were produced by an even lighter element than hydrogen, which makes up the bulk of solar material, but instead the emission lines attributed to coronium were found to come from iron atoms that had been stripped of 13 of their electrons. This idea was changed because of new information.

Before we weren't able to protect ourselves from the disruptive aspects, but now we might be able to in the future. Also another idea that has changed is that the Alaskan pipeline was specifically designed with proper insulation to reduce the effects of solar storms, the Siberian pipeline was not; and it broke.

7. How might an astronaut describe viewing the aurora as seen from above the Earth?

Astronauts would describe the Aurora as an oval-shaped glowing donut.

An astronaut may describe the aurora as an oval-shaped glowing donut over 5000 kilometers in diameter centered on the north magnetic pole.

8. Color the map as you would expect it to appear using what you have learned from the article.

Students may have trouble coloring the correct location for the Aurora. The map is presented from a different perspective than the students are accustomed.

What is Solar Activity?

The Sun, our nearest star, provides us with warmth and light. Many civilizations have thought the sun to be a perfect orb, free of blemishes, eternal and changeless. **Sunspots** are the most well known hints that the Sun's surface is constantly changing. Larger than the Earth, and with magnetic fields that are 10,000 times stronger than the Earth's, sunspots are the breeding grounds for some of the most violent storms in the solar system!

The number of sunspots increases and decreases in cycles that last from 6 to 17 years; the **Sunspot Cycle.** With modern technology and space satellites, this solar activity cycle can now be detected in the ebb and flow of other phenomena on the Sun and on the Earth. Among the most enigmatic storms are the **solar flares** that erupt near sunspots. In a matter of 20 minutes, magnetic fields can heat gases to tens of thousands of degrees and release more energy than a thousand atomic bombs. Some of this gas can be hurled out from the Sun at millions of kilometers per hour in what are called **coronal mass ejections.** Both solar flares and coronal mass ejections can be very disruptive to human activity on earth and in space.

The outer atmosphere of the Sun, the **corona,** is familiar to many people who have watched total eclipses of the sun. The solar wind extends billions of kilometers further out into space than the corona**.** Like invisible roadways spanning the solar system, the magnetic field from the Sun flows out from the solar surface. Matter ejected from the Sun flows radially outwards from the solar surface. From the time a solar storm is seen on the Sun, it can take 2-3 days for the gas to travel to the orbit of the Earth, and if the Earth happens to be in the wrong place at the wrong time, it will be hit by a million-kilometer wide wall of high temperature gases and magnetic fields.

Anyone can tell you that a compass points 'north' because the Earth has a magnetic field, but until the advent of the Space Age, no one understood what this field really looked like or was capable of doing. Since Gilbert proposed in the 17th century that the Earth was a giant magnet, scientists have wondered just how this field is shaped, and how it has changed with time. The geomagnetic field which gives us our familiar compass bearings, also extends thousands of kilometers out into space in a region called the **magnetosphere**. On the Sun-side, it forms a protective boundary called the **bow shock.** Stretching millions of kilometers in the opposite direction behind the Earth is the **magnetotail.**

The solar wind blows upon the magnetosphere and gives it a wind-swept shape, but when solar storms and solar wind streams reach the Earth, the magnetosphere reacts violently. On the side nearest the impact, the magnetosphere compresses like squeezing a balloon, leaving communications satellites exposed. On the opposite side, it is stretched out, past the orbit of the Moon, or Mars and even Jupiter! The geomagnetic field is remarkably stiff, and so most of the solar wind is deflected or just slips by without notice. But some of the matter leaks in and takes up residence in donut-shaped clouds of trapped particles, or can penetrate to the atmosphere to produce the Aurora Borealis.

For thousands of years, humans have been treated to spectacles of glowing clouds above the northern horizon at night. Reports of these mysterious Northern Lights abound in the oral histories of the northern natives. On rare occasions, even ancient Greek and Chinese texts have mentioned them. It wasn't until 1896 that the Norwegian physicist Kristian Birkeland deduced that flows of electrons from the Sun were channeled into the polar regions by the geomagnetic field, and upon colliding with the outer atmosphere, would stimulate oxygen and nitrogen atoms to cast their ghostly and inspiring curtains of light.

The **Aurora Borealis** (near the north pole) and the **Aurora Australis** (near the south pole), as the 'Northern Lights' are more formally called, are seen most often in a band located at a latitude of 70 degrees, and about 10 degrees wide in latitude. From space, the auroral zone looks like a ghostly, glowing donut of light hovering over the north and south poles. This **auroral oval** can easily be seen in images from satellites designed to detect it. Its brightness and size change with the level of solar activity. Aurora come in many shapes and colors depending on what is happening to the geomagnetic field and the flows of charged particles and plasmas trapped in this field.

Magnetic sub-storms happen when the geomagnetic field is suddenly changed because of small changes in the magnetic polarity of the solar wind as it passes the Earth. Typically, magnetic storm aurora, also called **auroral storms,** last only a few hours. They begin in the evening as arcs of colored light which slowly change into rayed-arcs and the familiar folded ribbons or bands. Expanding over the whole sky, the folded bands are colorful, with green rays and red lower borders which change from minute to minute and move rapidly across the sky like some phantasmagoric serpent. After an hour, the auroral shapes become more diffuse and less distinct.

Geomagnetic storms are more severe than magnetic sub-storms and are caused by major changes in the direction and density of the solar wind as it reaches the Earth. These events are the most remembered historically as 'Great Aurora' or as the most disruptive to radio communications. The entire geomagnetic storm can last for several days as the particles and fields around the Earth continue to readjust themselves to the passing and ebbing solar wind.They begin with an ejection of mass by the Sun, and the impact of this plasma on the magnetosphere. Fast-moving coronal mass ejections produce shock waves in the solar wind, and this compression intensifies the density of particles impacting the magnetosphere. As the solar wind shock passes across the magnetosphere and magnetotail, magnetic fields re-orient and reconnect, releasing enormous amounts of energy and accelerating trapped particles to high speeds. These charged particles then travel down the geomagnetic field in huge currents, which cause bright and long lasting auroral displays.

Solar storms and the effects they produce in the Earth's environment, have been known for decades to be responsible for many harmful effects upon human technology on the ground and in space. Solar storms are known to do far more than just paint the sky with pretty colors! The multi-billion dollar 'Global Positioning System' consists of a constellation of over two dozen navigation satellites orbiting within the Van Allen radiation belts. These satellites let humans find their position anywhere on Earth using a hand-held receiver no bigger than a wrist watch.

During solar storms, these positions are quite a bit less accurate than under calm conditions, which in turn impacts the navigation of ships at sea and jets in the air. Solar storms have disabled multi-million dollar communication and navigation satellites such as Anik-A, Molynia, Marecs-A, and they have been implicated in many electrical problems that were experienced by other satellites.

Solar storms were responsible for causing the Skylab to burn up in the atmosphere sooner than expected, and for altering the orbits of hundreds of other satellites and even the Space Shuttle itself. A storm on March 13, 1989 knocked out the Quebec-Hydro power system, plunging 6 million people into darkness for 9 hours. Geomagnetic storms cause the magnetic field near the Earth's surface to change rapidly in just a matter of minutes or hours. These changes cause electrical currents to flow within long power transmission lines, telephone wires, and even in pipelines which makes the pipes corrode, sometimes with tragic consequences. On June 5, 1991 a natural gas pipeline in Russia was weakened by corrosion and began to leak its deadly, flammable cargo. A passenger train, loaded with 1,200 people, ignited the liquefied gas and caused an explosion equal to 10,000 tons of TNT. Over 500 people were killed, and 700 more were badly injured.

Would you believe...

Aurora can never get closer to the ground than about 60 kilometers.

A sunspot has a temperature of nearly 4000 C, and would be brighter than the full moon if placed in the night sky.

Sunspots are often several times larger than the entire earth.

The Sun rotates once every 25 days at the equator, but takes up to 36 days to rotate once around at the poles.

The corona of the Sun is over 5 million degrees hotter than the surface of the Sun.

The Earth's magnetic north pole is actually a magnetic south pole because the north end of a bar magnet is attracted to it.

The total power produced by an auroral event can exceed 1 million megawatts and produce voltages over 100,000 volts in the upper atmosphere.

Aurora are produced where the atmosphere has the same density as the vacuum inside a light bulb.

Some aurora occur at altitudes of over 1000 kilometers above the Earth's surface.

Lightning storms can eject particles into space at nearly the speed of light, and they are seen as 'sprites' on the top side of a thundercloud.

A single lightning storm can be detected on the other side of the earth because some of its radio energy travels along the local magnetic field lines that connect the pairs of points on the surface of the Earth that can be thousands of kilometers apart.

Glossary

Aurora : Also called the ‘Northern Lights’ in the Northern hemisphere, or the ‘Southern Lights’ in the Southern hemisphere. These wispy curtains of light in the sky are caused by energetic electrons which collide with atoms of oxygen and nitrogen in the air to cause these atoms to emit shades of green, red and blue light. They never descend nearer than 60 kilometers from the Earth’s surface.

Corona : The very tenuous outer layers of the Sun which are seen during a total eclipse of the sun, but extending millions of miles into interplanetary space. It is heated to temperatures of over one million degrees by magnetic activity at the surface of the Sun. For decades, scientists puzzled over why the Corona could be so much hotter than the balmy 5770 degree Kelvin surface of the Sun.

Coronal Mass Ejection : The sudden expulsion of matter from the coronal regions of the sun, often involving billions of tons of plasma ejected at over one million miles per hour. During sunspot minimum conditions, about one ‘CME’ can be expelled every few days. During sunspot maximum conditions, as many as 3-5 can occur each day.

Magnetopause : A region that defines the outer edge of the magnetosphere where the pressure of the solar wind is balanced by the pressure of the earth’s own magnetic field.

Magnetosphere : The region surrounding the Earth in space where its magnetic field is important in controlling the movements of charged particles. Also sometimes referred to as ‘Geospace’.

Magnetotail : The solar wind pulls the magnetosphere into a comet-like shape. The long tail of this field, called the magnetotail’ or also the ‘geotail’, extends millions of miles into space in a direction opposite to the Sun from the Earth.

Solar flare : A powerful release of energy on the surface of the sun usually lasting less than a few hours, but releasing as much energy as 1000 hydrogen bombs. These are often associated with active regions of the solar surface where magnetic fields have become badly tangled, and then snap, releasing energy and heating local gases to over 1 million degrees.

Solar storm : Although scientists prefer not to use this term because it is technically rather vague, it has come to mean any of a number of active conditions on the Sun’s surface including flare activity or coronal mass ejections.

Sunspot : A dark spot on the Sun’s surface that indicates a concentration of magnetic forces. They are actually about 2000 degrees cooler than the solar surface, and only look dark because they emit light faintly.

Sunspot Cycle : The change in the number of sunspots from one period of its maximum to the next, over the course of about 11 years.

Sunspot Maximum : The period during the sunspot cycle when you will see the largest number of sunspots. Also called the ‘Solar Maximum’.

Sunspot Minimum: The period during the sunspot cycle when you will see the fewest number of sunspots. Also called the ‘Solar Minimum’

Resources

IMAGE	http://image.gsfc.nasa.gov
POETRY	http://image.gsfc.nasa.gov/poetry
SOHO	http://sohowww.nascom.nasa.gov
NASA Sun-Earth Connection Resources	http://sunearth.gsfc.nasa.gov
The Earth's Magnetic Field	http://image.gsfc.nasa.gov/poetry/magneto.html
Satellite Glitches -Space Environment Info	http://envnet.gsfc.nasa.gov
Magnetic North Pole	http://www.nrcan.gc.ca/gsc/cpdnew/magnet.html
Solar Sounds	http://soi.stanford.edu/results/sounds.html
Sunspot Number Archives / Resources	http://image.gsfc.nasa.gov/poetry/sunspots.html
CME Archives at MLSO	http://www.hao.ucar.edu/public/research/mlso/movies.html
Stellar Activity Cycles at Mt. Wilson	http://www.mtwilson.edu/Science/HK_Project/
Satellite Data	http://cdaweb.gsfc.nasa.gov
Space Weather Resources	http://image.gsfc.nasa.gov/poetry/weather.html
Magnetic Observatories and Data	http://image.gsfc.nasa.gov/poetry/maglab/magobs.html
Space Environments and Effects	http://see.msfc.nasa.gov/sparkman/Section_Docs/sparkman.html
Sun-Earth Classroom Activities Archive	http://sunearth.gsfc.nasa.gov/educators/class.html
Storms from the Sun	http://www.istp.gsfc.nasa.gov/istp/outreach/learn.html
The Aurora Page	http://www.geo.mtu.edu/weather/aurora/
Space Weather Human Impacts	http://image.gsfc.nasa.gov/poetry/storm/storms.html
Ionosphere density and sunspot numbers	http://julius.ngdc.noaa.gov:8080/production/html/IONO/ ionocontour_90.html
Space Weather Daily Reports	http://windows.engin.umich.edu/spaceweather/index.html
Solar wind density and speed	http://www.sel.noaa.gov/wind/rtwind.html

Teacher Reply Card

National Aeronautics and
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Educational Product	
Educators & Students	Grades 5-8

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Solar Storms and You!

Exploring Satellite Design

An Educator Guide with Activities in Space Science

Solar Storms and You! is available in electronic format through NASA Spacelink - one of the Agency's electronic resources specifically developed for use by the educational community.

The system may be accessed at the following address:
http://spacelink.nasa.gov

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Space Administration

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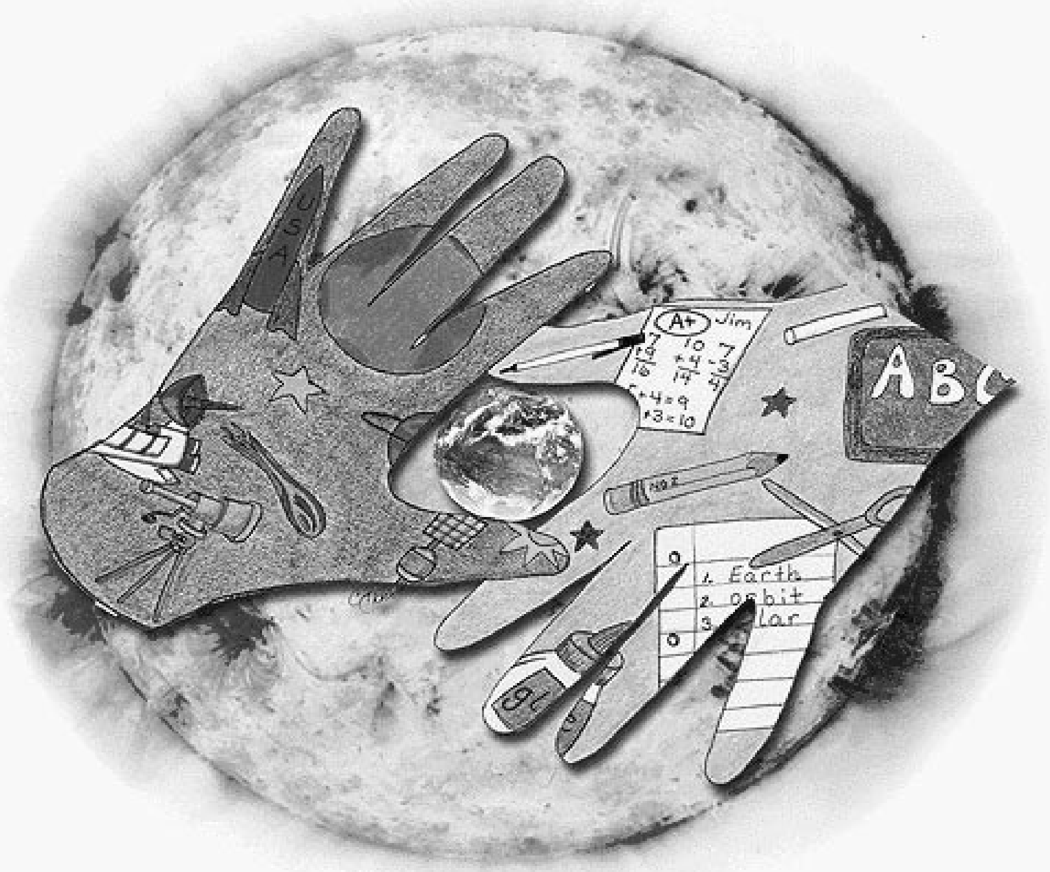

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Information about the IMAGE mission is available at:

http://image.gsfc.nasa.gov
http://pluto.space.swri.edu/IMAGE

Resources for teachers and students are available at:

http://image.gsfc.nasa.gov/poetry

National Aeronautics and
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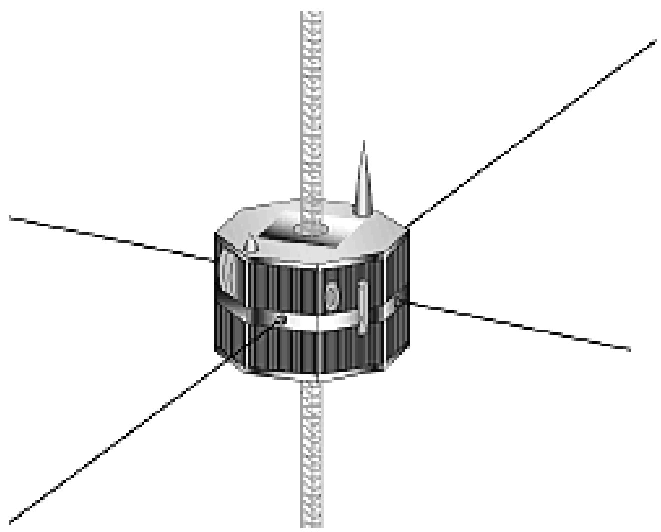


Research satellites are designed to be as light-weight as possible without skimping on the necessary strength or radiation shielding, and to provide detailed data on a variety of space conditions including magnetic fields, electromagnetic radiation, and energetic particles. The above drawing shows the NASA, IMAGE satellite which will be launched in February 2000, to explore the Earth's environment within the magnetosphere. It will be launched on a Delta 2 rocket like the one on the left.

INTRODUCTION

A gas pipeline in Russia explodes
killing hundreds of people.

A satellite mysteriously falls silent
interrupting TV and cellular phone traffic.

A power blackout
throws millions of people into darkness.

These are only a few of the many things that solar storms can do when they arrive at the earth unexpected. In an age where we have increasingly come to rely upon the smooth operation of our technology, we have also made ourselves vulnerable to the ebb and flow of the solar storm cycle. Most people are not even aware of these cycles, but long ago we used to be!

Ancient Chinese sun observers knew that, from time to time, dark spots would glide slowly across the face of the setting sun. Once seen only as portends of political upheaval, we now see them as natural phenomena that can forewarn us of impending storms that can have dire consequences for us if we ignore them.

In this activity book, your students will study five key stages in the lifecycle of a solar storm, from its emergence on the solar surface to its impact upon some aspect of our lives. The book may be used in its entirety to study solar activity and how it directly affects us, or you may use individual activities of your choice as stand-alone mini lessons as an enrichment for math and physical science courses.

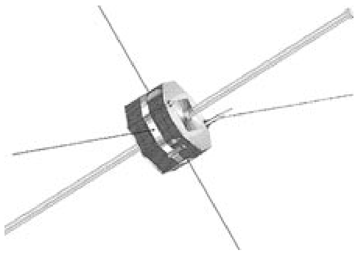
The student activities emphasize basic cognitive skills and higher-order processes such as plotting data, searching for patterns and correlations, and interpreting the results. By the end of the activity series, students will understand why we need to pay more attention to solar storms.

Visit the updated version of this workbook at:

http://image.gsfc.nasa.gov/poetry/workbook/workbook.html

Science Process Skills

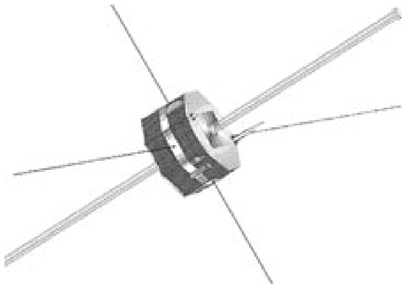
for *Solar Storms and You!*



This chart is designed to assist teachers in integrating the activities contained in the guide with existing curricula.

	Lesson 1 *"IMAGE Satellite Scaling"*	Lesson 2 *"IMAGE Satellite Scale Model"*	Lesson 3 *"IMAGE Satellite 1/4-scale Model"*	Lesson 4 *"Pie Charts in Science"*
Observing				
Classifying				
Communicating				
Measuring	O	O	O	O
Inferring				O
Predicting	O			O
Experimental Design				
Gathering Data				
Organizing Data				
Controlling Variables				
Developing a Hypothesis				
Extending Senses				
Researching				
Team Work	O	O	O	O
Mathematics	O	O	O	O
Interdisciplinary	O	O	O	O
Introductory Activity	O	O	O	O
Advanced Activity				

Science and Mathematics Standards
for *Solar Storms and You!*



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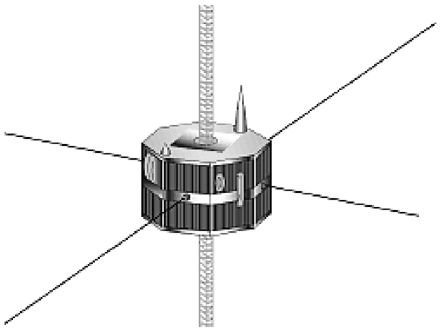
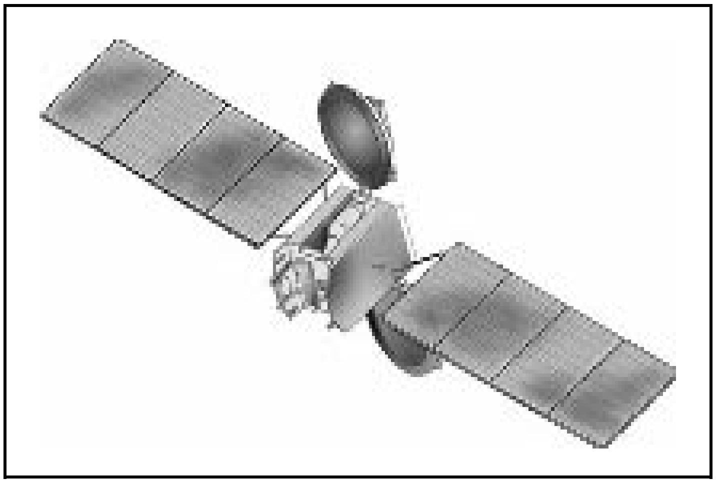
	Lesson 1 *"IMAGE Satellite Scaling"*	**Lesson 2** *"IMAGE Scale Model"*	**Lesson 3** *"IMAGE 1/4-scale Model"*	**Lesson 4** *"Pie Charts in Science"*
Science as Inquiry				
Structure and Energy of the Earth System				
Origin and History of the Earth				
Earth in the Solar System				
Geochemical Cycles				
Physical Science	○	○	○	○
Populations and Ecosystems				
Understanding about Science and Technol-				
ogy				
Science in Personal and Social Perspectives				
History and Nature of Science				
	○	○	○	○
Problem Solving	○	○	○	○
Measurement	○	○	○	○
Computation and Estimation				
Communication				
	○	○	○	○
Geometry and Advanced Mathematics				
Statistics and Probability				
Number and Number Relationships				

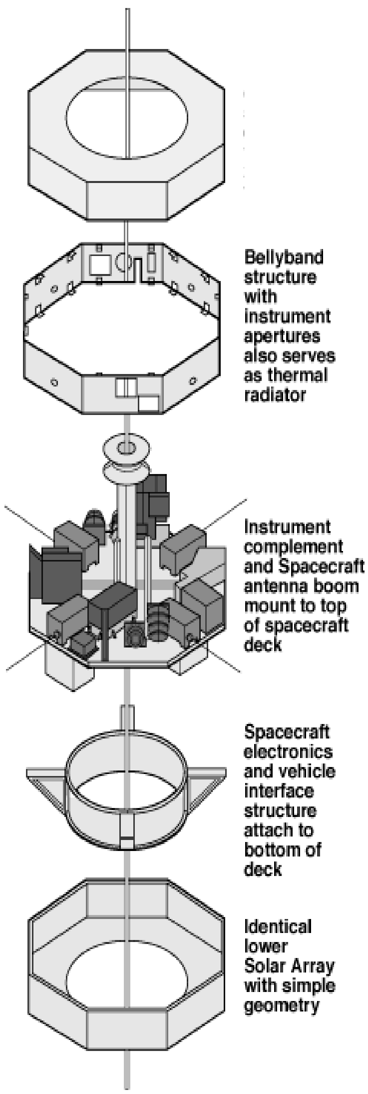
Patterns and Functions

Satellite Design



The IMAGE Satellite





Satellites are the work horses of modern society. Virtually all economic forecasts predict that the 21st century will witness an explosion of new satellites to relay cellular phone, television and computer data. They will provide services to society that we cannot even imagine today. Currently, the satellite industry in both the civilian and military sectors has amassed over $100 billion in space-based assets. Only a small fraction of this investment is in scientific research satellites, which are used to learn more about the space environment, and to safeguard all the other resources.

Satellites are vulnerable to many aspects of solar activity, particularly the streams of charged particles that flow in the magnetosphere. When you shuffle across a carpet, you pick up static electricity, which you then discharge in a painful ‘zap’ when you touch a grounded metal object. In space, satellites pick up charged particles constantly, but they cannot be so easily ‘grounded’ to discharge their load of static charge. As a result, satellites charge to thousands of volts. The smallest dust particle can cause a lightning bolt of discharge to ‘zap’ delicate electronic equipment. These discharges can cause false commands that can sometimes send the satellites into bizarre and unplanned ‘states’ which can cause the satellite to be lost.

Satellite designers work around this problem. They are making certain that as much as possible of the critical electronics in a satellite are ‘radiation hardened’. They are designing radiation-hardened versions of many common components.

Teacher's Guide

IMAGE Satellite Scaling

Introduction

Scientists need to consider size, mass and cost when designing a satellite. Although more data is returned by larger satellites, it isn't simply a matter of doubling or tripling the dimensions of a satellite that lead to a good design. When you double the size of a design, the volume increases by 8 times and so does the mass and cost of the satellite. The IMAGE satellite is designed to be built for under $30 million, and has a mass of 70 kilograms, but doubling its size would cause the mass to increase to 1/2 ton and its cost to rise to $240 million!

Objective

The student will calculate the volume of the satellite. Based on the results, the student will determine patterns and relationships to see how change affects the mass and the cost of the instruments.

Procedure

1) Read the students the introduction to the IMAGE Dimension Activity, or discuss the key points with the students.

2) Allow students to complete questions 1, 2 and 3. Discuss student responses to these questions and the implications of increasing the size of the instruments on the satellite .Refer to the Introduction as necessary.

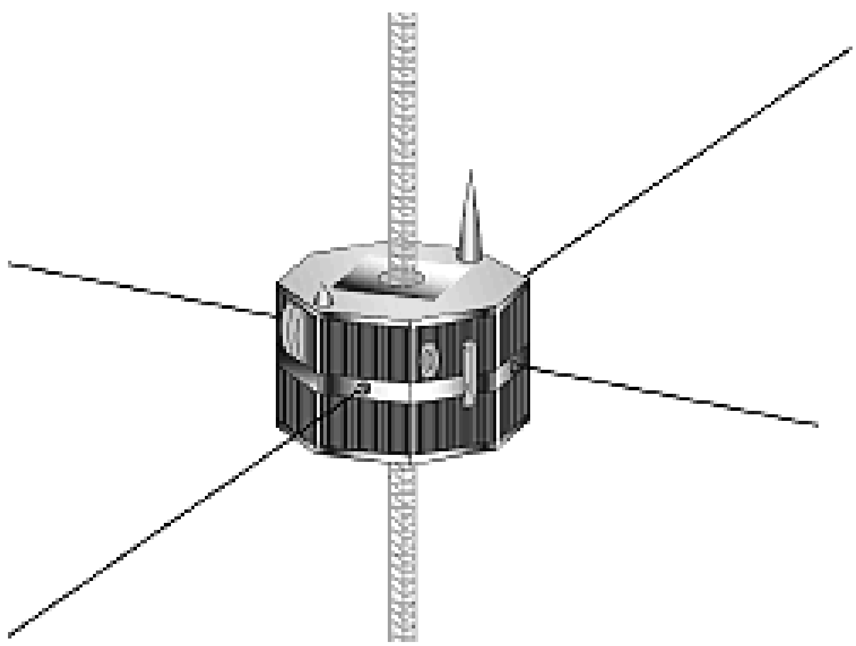
3) Discuss how the change in the dimensions affects the mass. Allow students time to complete activity 4. Discuss the results.

4) Discuss how the cost of the satellite is affected by increasing the dimensions and how it is proportional to the mass. Allow students to complete question 5. Discuss the results.

5) Have students complete question 6 and 7. Provide time for students to give possible responses. Discuss why a scientist may want a bigger satellite and the implications of scaling to the independent components.

Materials

—Introduction to the IMAGE Dimension Activity
—Teacher Answer Key
—Student Pages



Conclusion

When designing spacecraft, it is important to know how the cost and capabilities of the satellite will scale as you change its dimensions.

Introduction to the IMAGE Dimension Activity

The IMAGE satellite must meet certain requirements. It must meet a two year mission lifetime, and must be launched on a Delta II rocket with a payload mass limit of 1000 kilograms. It must also cost less than $50 million.

The scientists need to consider mass, cost, and volume when designing a satellite. There are numerous instruments that need to be scaled, and all of the factors mentioned above must be considered.

For instance, if a detector is chosen, the dimensions need to be investigated to determine the final instrument cost. As in the following activity, if a dimension is doubled, the mass increases by 2x2x2 or a factor of 8. In turn, the cost increases in proportion to the mass, which in this case is also a factor of 8.

In addition, any change in the dimensions impacts on the other instruments in the satellite, the labor needed to assemble it, salaries, and the launch vehicle required for the extra mass and size. The IMAGE satellite will require a rocket to launch it. If the satellite's size is quadrupled, it would require the Space Shuttle to launch it. The difference in the launch cost alone is $50 million for the rocket compared to $700 million for the Space Shuttle.

The major constraint on the IMAGE project is cost. The IMAGE satellite must be built, launched and operated for 2 years at a total cost less than or equal to $60 million. Nearly all of the cost of any mission is in the salaries of the scientists and engineers needed to manufacture the satellite and the rocket.

In response to the question of why a scientist would want a bigger satellite, it is purely based on the amount of information that is being sought. The IMAGE satellite is designed to provide 2-D images of various phenomena in space. An increase in the dimensions will cause an increase in the size due to the need to acquire more data. Doubling the sizes of an electronic camera, in turn, quadruples the amount of data it can capture and send down to the scientists on the ground.

However, the question of size is more involved than this. The instruments of the IMAGE satellite, which have been the major focus, are not the only things to consider in satellite design. In terms of scaling, when the size of the instruments double, it does not necessarily mean that the size of the satellite will double. Actually, the instruments are only a small part of the total spacecraft size compared to the other satellite systems and hardware. The components of the satellite can also be scaled independently. Doubling the size of one instrument may not necessarily double the size of the electrical power required to operate it, and so, double the size of the power supply needed to provide the electricity.

Teacher's Answer Page

The IMAGE satellite's construction involves a number of different instruments. These instruments are analyzed to determine the dimensions that will provide the most efficient satellite while minimizing the weight and cost. In order to help you understand the possible factors involved in the dimensions, mass and cost; complete the following activities.

1. Calculate the volume of the following instruments and spacecraft components. The dimensions are given in cubic centimeters in the following table:

Instrument	1x Volume	8x Volume	27x Volume	64x Volume
LENA	8100	64800	218700	518400
MENA	8100	64800	218700	518400
HENA	9000	72000	243000	576000
TAC/ADC	1620	12960	43740	103680
HV Electronics	2592	20736	69984	165888
Spectrometer	35712	285696	964224	2285568
WB Camera	5070	40560	136890	324480
Electronics	5400	38400	129600	307200
Sensors	2250	18000	60750	144000

2. When the dimensions of the satellite are doubled, by what factor is the volume increased? What factor is the increase when the dimensions are tripled and quadrupled?
8, 27, 64

3. Is there any noticeable connection between two or more of these factors of increase?
Doubling and quadrupling are multiples of each other, and the results of 8 and 64 are multiples as well.

4. The mass of the IMAGE satelllite increases proportional to the volume. If the dimensions are doubled, the mass increases by the cube of the factor or 2x2x2=8. The mass of the satellite is 261 kg. Determine the mass increase when the dimensions are doubled, tripled and quadrupled.

   Doubled = **2088 kg** Tripled= **7047 kg** Quadrupled= **16704 kg**

5. The cost of the satellite also increases proportional to the mass. The cost for the original dimensions is $28.4 million. What is the cost for each of the various increases?

   Doubled= **$227.2 million** Tripled= **$766.8 million** Quadrupled= **$1.818 billion**

6. In your own words, please write the process involved in determining the volume, mass and cost of the IMAGE satellite. Why would a scientist want a 'bigger' satellite?
Students response will vary. The bigger the satellite, the more information that is being sent to the scientists. Bigger does not necessarily mean better.

Name ____________________________ Date_________________

The IMAGE satellite's construction involves a number of different instruments. These instruments are analyzed to determine the dimensions that will provide the most efficient satellite while minimizing the weight and cost. In order to help you understand the possible factors involved in the dimensions, mass and cost; complete the following activities.

1. Calculate the volume of the following instruments and spacecraft components. The dimensions are given in centimeters in the following table:

Instrument	Dimension	Double	Triple	Quadruple
LENA	36x15x15	72x30x30	108x45x45	144x60x60
MENA	36x15x15	72x30x30	108x45x45	144x60x60
HENA	30x10x30	60x20x60	90x30x90	120x40x120
TAC/ADC	18x18x5	36x36x10	54x54x15	72x72x20
HV Electronics	18x18x8	36x36x16	54x54x24	72x72x32
Spectrometer	62x36x16	124x72x32	186x108x48	248x144x64
WB Camera	26x15x13	52x30x26	78x45x39	104x60x52
Electronics	15x20x18	30x40x32	45x60x48	60x80x64
Sensors	15x15x10	30x30x20	45x45x30	60x60x40

2. When the dimensions of the satellite are doubled, by what factor is the volume increased? What factor is the increase when the dimensions are tripled and quadrupled?

3. Is there any noticeable connection between two or more of these factors of increase?

4. The mass of the IMAGE satelllite increases proportional to the volume. If the dimensions are doubled, the mass increases by the cube of the factor or 2x2x2=8. The mass of the satellite is 261 kg. Determine the mass increase when the dimensions are doubled, tripled and quadrupled.

   Doubled = Tripled= Quadrupled=

5. The cost of the satellite also increases proportional to the mass. The cost for the original dimensions is $28.4 million. What is the cost for each of the various increases?

   Doubled= Tripled= Quadrupled=

6. In your own words, please write the process involved in determining the volume, mass and cost of the IMAGE satellite. Why would a scientist want a 'bigger' satellite?

Teacher's Guide

IMAGE Satellite Scale Model

Introduction

The construction of scale models of spacecraft has, historically, been an important engineering tool in designing spacecraft. Today, powerful 'CAD/CAM' software programs have become popular, but scale model building is still considered an important method of verifying satellite dimensions, tolerances and clearances.

Objective

The students will construct a scale model of the IMAGE satellite.

Procedure

1) Students will use the Spacecraft Dimensions Sheet to determine the scale model size. Note: When students are determining the diameter of the circle to construct the octagon, make sure that the measurement that is being used is from the opposite vertices.

2) Students will construct a pattern of the IMAGE satellite. They may opt to construct the pattern in a variety of ways; three methods are given below:

A—Students can inscribe an octagon using perpendicular and angle bisectors. Then they can cut the octagon out, and then use this to trace the second octagon. Students can create a rectangle using the corner of a sheet of paper, cut it out, and then trace the design seven more times. Students can then piece the design together using the tape.

B—The more advanced students may opt to determine how to construct the pattern in one piece. The students will need to determine the position on the paper to best fit the design. Students will then construct the design, cut it out, and then fold and tape it to complete the model.

C—Teachers may opt to use the included pattern. Cut out the satellite model, fold and tape it to complete the model.

3) Students can draw the IMAGE components on the model according to the Students Guide Sheet using the colored pencils.

Materials

—Compass

—Ruler

—8 1/2 x 11 paper

—Scissors

—Tape

—Spacecraft Dimensions

—Student Direction Guide

—Colored pencils

Conclusion

Scale model making is still an important tool for engineers and scientists to visualize how the various pieces of their spacecraft fit together.

Teacher Scaling Notes

The actual diameter for the NASA IMAGE satellite is 238 centimeters or 7.8 feet. The actual length of the rectangular side panels is 136 centimeters or 4.5 feet. The scale factor becomes 238 centimeters divided by 9 centimeters, which means that each centimeter on the diagram is equal to 26.4 centimeters on the actual IMAGE satellite.

The diameter of the Spacecraft Dimensions Sheet is 9 centimeters, which in turn makes the radius of the circle to be 4.5 centimeters. The width of the rectangle is 3.4 centimeters and the length is 5.1 centimeters. The length of the sides of the octagon will be 3.4 centimeters, the same as the width of the rectangular side panels.

NOTE!!!

Students may not be aware of the correct rectangle to measure. It would be hoped that they would realize that the width should be consistent with the length of the sides of the octagon. However, students may question why the top and the bottom rectangle 'look' different. Explain that this is due to the perspective of the drawing. When a side view of a three dimensional model is shown, the drawing tends to look distorted due to the perspective and the viewing angle.

Teacher, Pattern Construction Notes

1) With a compass, construct a circle with a 4.5 centimeter radius. Be sure to mark the center. Students should be aware that the sides of the octagon are 3.4 centimeters.

2) Use the ruler to draw a horizontal diameter.

3) Place the compass tip in the center of the circle. Open the compass a little and with the pencil end, mark an arc on both sides of the center of the circle.

4) Open the compass wider. (Note: If this step is forgotten, the marks will fail to cross.) From each of the arcs, swing the compass to make a large arc on both sides of the diameter. Where the two arcs cross is the point needed to draw the perpendicular diameter.

5) Draw the perpendicular diameter.

6) Place the compass point on the center mark. Construct a small concentric circle.

7) Using one of the angles created, open the compass wider, place the point on the spot where the new circle intersects the diameters. Swing the compass to create a semicircle. Place the point on the other diameter where the little circle meets, and construct another semicircle that intersects the previous one. Where the two semicircles meet will be two points. Connect the two points forming a new diameter. (Note: The new diameter will bisect the two angles.)

8) Repeat the process in Step 7 with the other two angles.

9) Connect the edges of the diameters drawn to construct the inscribed octagon.

10) Students will need to construct two octagons for the pattern.

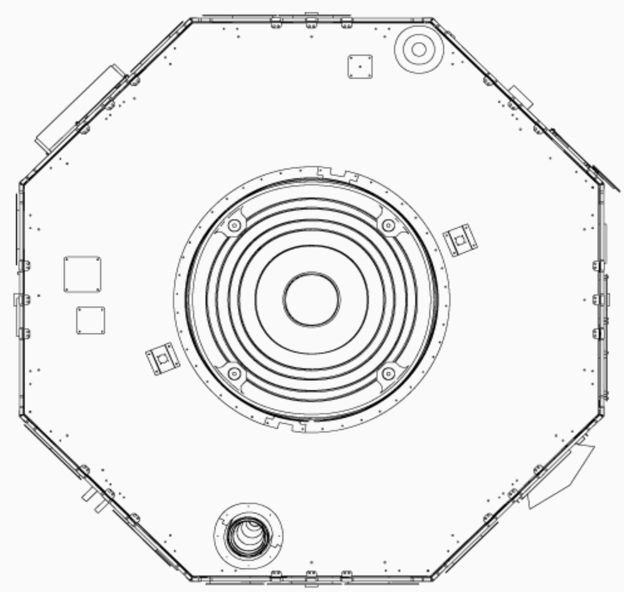
Constructing the Rectangles

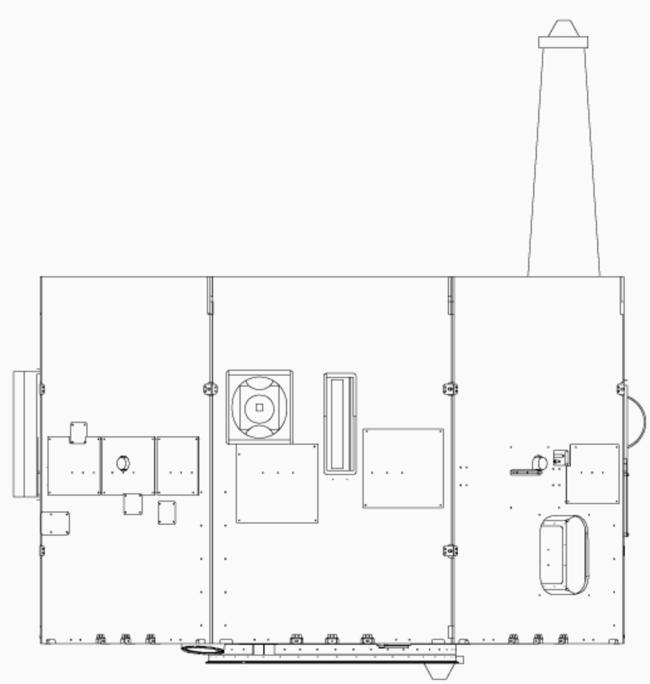
11) The eight rectangles need to be 3.4 centimeters by 5.1 centimeters .Some students may need to use the corner of a sheet of paper as the first two sides, and they can measure for the other two sides .The more advanced students can use perpendicular bisectors to construct parallel sides, and then they can do their measurements.

Note: If the pattern is being constructed entirely by hand, the given scale dimensions will fit on an 8 1/2 x 11 sheet of paper. The student will need to determine the lay-out of the the pattern.

IMAGE

Spacecraft Drawings





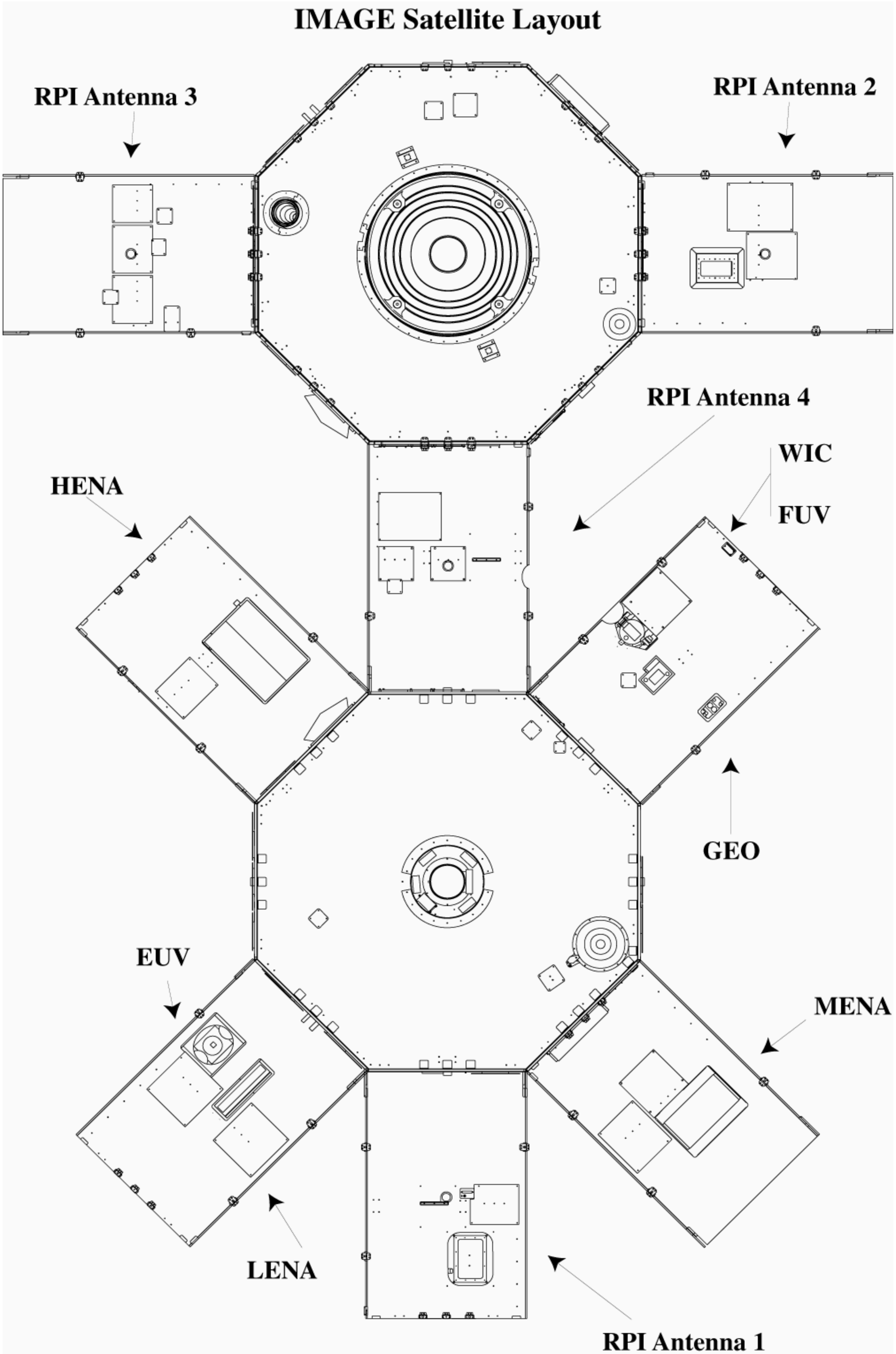


IMAGE Satellite Layout
RPI Antenna 3
RPI Antenna 2
RPI Antenna 4
WIC
FUV
HENA
GEO
EUV
MENA
LENA
RPI Antenna 1

Teacher's Guide

IMAGE Satellite Scale Model (One Fourth Actual Size)

Introduction

The construction of scale models of spacecraft has, historically, been an important engineering tool in designing spacecraft. Today, powerful 'CAD/CAM' software programs have become popular, but scale model building is still considered an important method of verifying satellite dimensions, tolerances and clearances.

Objective

The students will be able to construct a scale model of the IMAGE Satellite one-fourth of the original size.

Procedure

1) Students are given the scale drawing and the actual measurements.
2) Students are to determine the scale used in the schematic drawing.
3) Students are to determine the dimensions that are needed to construct a scale model one fourth of the original size.
4) Students determine the materials that will be necessary to construct the scale model.
5) Student may begin the construction with either the octagonal top and bottom, or the rectangular side panels:

i) Construct an octagonal panel and cut it out. Trace the second to save time.ii) Construct one rectangular side panel and cut it out.

iii) Trace the other seven and cut them out to save time.

For reasons of safety- again- only the teacher uses the utility knife. Students will need a lot of room to work. Remind the students that when they measure the diameter, the measurement must be from opposite vertices. Duct tape will help to hold the model together better than regular or masking tape.

6)Students construct the scale model.

7)Students will write a summary describing the process required to construct the scale model from the beginning, with the schematic drawing, and concluding with the steps necessary to finish the model.

Materials

—Compass, very big and/or a string and a nail to simulate a compass
—Ruler/ yardsticks
—Cardboard and /or wood
—Duct tape
—Spacecraft Dimension Worksheet
—Colored or regular aluminum foil
—Paper towel rolls or pipe cleaners
—Scissors or utility knives
Note: The teacher may want to be the only one to handle the utility knife for safety reasons.

Conclusions

Students apply concepts in mathematics to a real life event. Students enjoy the hands on activity and are very competitive in making sure that their satellite is the best and the most accurate. Students apply the concept of innovation in creating their scale model, and they are not willing to accept a model that is not constructed correctly. They persevere even when the task is difficult.

Teacher's Guide

Pie Charts in Science

Introduction

As part of the IMAGE satellite program, there has been a web site created for teachers and students called POETRY. One of the links is titled 'Ask the Space Scientist'. From this link students may ask a scientist questions about space and read the posted answers. Each topic contains specific questions and their appropriate answers at the site. This activity explores the frequency of specific topics to determine the categories that have the most frequently asked questions.

Objective

By completing the data table, students should be able to construct and interpret a graph which includes data from the table.

Procedure

1) Students should finish the table by filling in the blank central angle column.

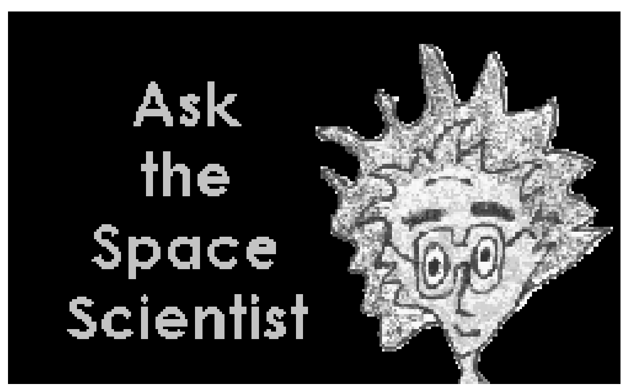
2) Students should create a circle graph to represent the topic request percentages.

3) Students should answer the accompanying questions based on the information in the pie chart.

NOTE: When students have completed the activity, they may want to visit the POETRY web site and have a look at some of the questions and answers they find at "Ask the Space Scientist."

Materials

—Calculator
—Protractor

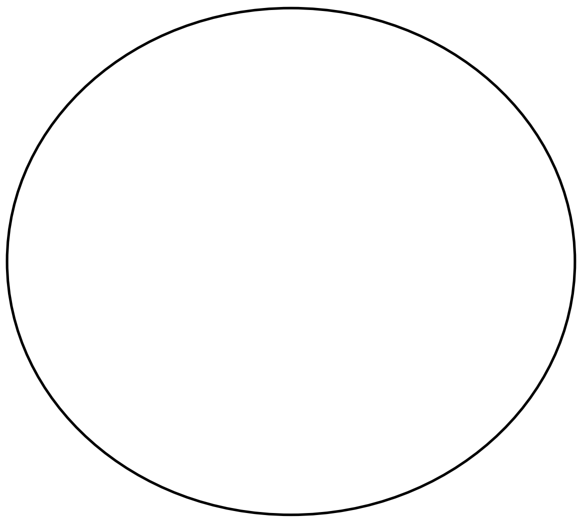


http://image.gsfc.nasa.gov/poetry

Name ______________________________

Date________________

Topic	Percent	Central Angle
The Earth	5	
The Planets	12	
Stars	18	
Black Holes	23	
The Big Bang	25	
Space Travel	9	
Careers	8	



Questions:

1) What topic areas have the most popular questions?

2) Which topic areas have the least popular questions?

3) Can you think of a question you might “Ask the Space Scientist” in each of the topic areas?

4) If this web site recorded 12,340 visitors during a week, how many would probably ask about Black Holes?

5) If the web site has limited resources, which topic areas would you consider dropping to operate more economically?

6) If the web site had only 20 visitors, which topic area would have the least chance of being visited?

What is Solar Activity?

The Sun, our nearest star, provides us with warmth and light. Until Galileo invented the telescope, it was once thought to be a perfect orb, free of blemishes, eternal and changeless. **Sunspots** are the most well known hints that the Sun's surface is constantly changing. Larger than the Earth, and with magnetic fields that are 10,000 times stronger than the Earth's, sunspots are the breeding grounds for some of the most violent storms in the solar system!

The number of sunspots increases and decreases in cycles that last from 6 to 17 years; the **Sunspot Cycle.** With modern technology and space satellites, this solar activity cycle can now be detected in the ebb and flow of other phenomena on the Sun and on the Earth. Among the most enigmatic storms are the **solar flares** that erupt near sunspots. In a matter of 20 minutes, magnetic fields can heat gases to tens of thousands of degrees and release more energy than a thousand atomic bombs. Some of this gas can be hurled out from the Sun at millions of kilometers per hour in what are called **coronal mass ejections.** Both solar flares and coronal mass ejections can be very disruptive to human activity on earth and in space.

The outer atmosphere of the Sun, the **corona,** is familiar to many people who have watched total eclipses of the sun. The solar wind extends billions of kilometers further out into space than the corona. Like invisible roadways spanning the solar system, the magnetic field from the Sun flows out from the solar surface. Matter ejected from the Sun flows radially outwards from the solar surface. From the time a solar storm is seen on the Sun, it can take 2-3 days for the gas to travel to the orbit of the Earth, and if the Earth happens to be in the wrong place at the wrong time, it will be hit by a million-kilometer wide wall of high temperature gases and magnetic fields.

Anyone can tell you that a compass points 'north' because the Earth has a magnetic field, but until the advent of the Space Age, no one understood what this field really looked like or was capable of doing. Since Gilbert proposed in the 17th century that the Earth was a giant magnet, scientists have wondered just how this field is shaped, and how it has changed with time. The geomagnetic field which gives us our familiar compass bearings, also extends thousands of kilometers out into space in a region called the **magnetosphere**. On the Sun-side, it forms a protective boundary called the **bow shock.** Stretching millions of kilometers in the opposite direction behind the Earth is the **magnetotail.**

The solar wind blows upon the magnetosphere and gives it a wind-swept shape, but when solar storms and solar wind streams reach the Earth, the magnetosphere reacts violently. On the side nearest the impact, the magnetosphere compresses like squeezing a balloon, leaving communications satellites exposed. On the opposite side, it is stretched out, past the orbit of the Moon, or Mars and even Jupiter! The geomagnetic field is remarkably stiff, and so most of the solar wind is deflected or just slips by without notice. But some of the matter leaks in and takes up residence in donut-shaped clouds of trapped particles, or can penetrate to the atmosphere to produce the Aurora Borealis.

For thousands of years, humans have been treated to spectacles of glowing clouds above the northern horizon at night. Reports of these mysterious Northern Lights abound in the oral histories of the northern natives. On rare occasions, even ancient Greek and Chinese texts have mentioned them. It wasn't until 1896 that the Norwegian physicist Kristian Birkeland deduced that flows of electrons from the Sun were channeled into the polar regions by the geomagnetic field, and upon colliding with the outer atmosphere, would stimulate oxygen and nitrogen atoms to cast their ghostly and inspiring curtains of light.

The **Aurora Borealis** (near the north pole) and the **Aurora Australis** (near the south pole), as the 'Northern Lights' are more formally called, are seen most often in a band located at a latitude of 65 degrees, and about 10 - 15 degrees wide in latitude. From space, the auroral zone looks like a ghostly, glowing donut of light hovering over the north and south poles. This **auroral oval** can easily be seen in images from satellites designed to detect it. Its brightness and size change with the level of solar activity. Aurora come in many shapes and colors depending on what is happening to the geomagnetic field and the flows of charged particles and plasmas trapped in this field.

Magnetic sub-storms happen when the geomagnetic field is suddenly changed because of small changes in the magnetic polarity of the solar wind as it passes the Earth. Typically, magnetic storm aurora, also called **auroral storms,** last only a few hours. They begin in the evening as arcs of colored light which slowly change into rayed-arcs and the familiar folded ribbons or bands. Expanding over the whole sky, the folded bands are colorful, with green rays and red lower borders which change from minute to minute and move rapidly across the sky like some phantasmagoric serpent. After an hour, the auroral shapes become more diffuse and less distinct.

Geomagnetic storms are more severe than magnetic sub-storms and are caused by major changes in the direction and density of the solar wind as it reaches the Earth. These events are the most remembered historically as 'Great Aurora' or as the most disruptive to radio communications. The entire geomagnetic storm can last for many days as the particles and fields around the Earth continue to readjust themselves to the passing and ebbing solar wind.They begin with an ejection of mass by the Sun, and the impact of this plasma on the magnetosphere. Fast-moving coronal mass ejections produce shock waves in the solar wind, and this compression intensifies the density of particles impacting the magnetosphere. As the solar wind shock passes across the magnetosphere and magnetotail, magnetic fields re-orient and reconnect, releasing enormous amounts of energy and accelerating trapped particles to high speeds. These charged particles then travel down the geomagnetic field in huge currents, which cause bright and long lasting auroral displays.

Solar storms and the effects they produce in the Earth's environment, have been known for decades to be responsible for many harmful effects upon human technology on the ground and in space. Solar storms are known to do far more than just paint the sky with pretty colors! The multi-billion dollar 'Global Positioning System' consists of a constellation of over a dozen navigation satellites orbiting within the Van Allen radiation belts. These satellites let humans find their position anywhere on Earth using a hand-held receiver no bigger than a pocket calculator.

During solar storms, these positions are quite a bit less accurate than under calm conditions, which in turn impacts the navigation of ships at sea and jets in the air. Solar storms have disabled multi-million dollar communication and navigation satellites such as Anik-A, Molynia, Marecs-A, and they have been implicated in many electrical problems that were experienced by other satellites.

Solar storms were responsible for causing the Skylab to burn up in the atmosphere sooner than expected, and for altering the orbits of hundreds of other satellites and even the Space Shuttle itself. A storm on March 13, 1989 knocked out the Quebec-Hydro power system, plunging 6 million people into darkness for 9 hours. Geomagnetic storms cause the magnetic field near the Earth's surface to change rapidly in just a matter of minutes or hours. These changes cause electrical currents to flow within long power transmission lines, telephone wires, and even in pipelines which makes the pipes corrode, sometimes with tragic consequences. On June 5, 1991 a natural gas pipeline in Russia was weakened by corrosion and began to leak its deadly, flammable cargo. A passenger train, loaded with 1,200 people, ignited the liquefied gas and caused an explosion equal to 10,000 tons of TNT. Over 500 people were killed, and 700 more were badly injured.

Would you believe...

Aurora can never get closer to the ground than about 60 kilometers.

A sunspot has a temperature of nearly 4000 C, and would be brighter than the full moon if placed in the night sky.

Sunspots are often several times larger than the entire earth.

The Sun rotates once every 25 days at the equator, but takes up to 36 days to rotate once around at the poles.

The corona of the Sun is over 5 million degrees hotter than the surface of the Sun.

The Earth's magnetic north pole is actually a magnetic south pole because the north end of a bar magnet is attracted to it.

The total power produced by an auroral event can exceed 1 million megawatts and produce voltages over 100,000 volts in the upper atmosphere.

Aurora are produced where the atmosphere has the same density as the vacuum inside a light bulb.

Some aurora occur at altitudes of over 1000 kilometers above the Earth's surface.

Lightning storms can eject particles into space at nearly the speed of light, and they are seen as 'sprites' on the top side of a thundercloud.

A single lightning storm can be detected on the other side of the earth because some of its energy travels along the local magnetic field lines that connect the pairs of points on the surface of the Earth that can be thousands of kilometers apart.

Glossary

Aurora : Also called the 'Northern Lights' in the Northern hemisphere, or the 'Southern Lights' in the Southern hemisphere. These whispy curtains of light in the sky are caused by energetic electrons which collide with atoms of oxygen and nitrogen in the air to cause these atoms to emit shades of green, red and blue light. They never descend nearer than 50 miles from the Earth's surface.

Corona : The very tenuous outer layers of the Sun which are seen during a total eclipse of the sun, but extending millions of miles into interplanetary space. It is heated to temperatures of over one million degrees by magnetic activity at the surface of the Sun. For decades, scientists puzzled over why the Corona could be so much hotter than the balmy 5770 degree Kelvin surface of the Sun.

Coronal Mass Ejection : The sudden expulsion of matter from the coronal regions of the sun, often involving billions of tons of plasma ejected at over one million miles per hour. During sunspot minimum conditions, about one 'CME' can be expelled every few days. During sunspot maximum conditions, as many as 3-5 can occur each day.

Magnetopause : A region that defines the outer edge of the magnetosphere where the pressure of the solar wind is balanced by the pressure of the earth's own magnetic field.

Magnetosphere : The region surrounding the Earth in space where its magnetic field is important in controlling the movements of charged particles. Also sometimes referred to as 'Geospace'.

Magnetotail : The solar wind pulls the magnetosphere into a comet-like shape. The long tail of this field, called the magnetotail' or also the 'geotail', extends millions of miles into space in a direction opposite to the Sun from the Earth.

Solar flare : A powerful release of energy on the surface of the sun usually lasting less than a few hours, but releasing as much energy as 1000 hydrogen bombs. These are often associated with active regions of the solar surface where magnetic fields have become badly tangled, and then snap, releasing energy and heating local gases to over 1 million degrees.

Solar storm : Although scientists prefer not to use this term because it is technically rather vague, it has come to mean any of a number of active conditions on the Sun's surface including flare activity or coronal mass ejections.

Sunspot : A dark spot on the Sun's surface that indicates a concentration of magnetic forces. They are actually about 2000 degrees cooler than the solar surface, and only look dark because they emit light faintly.

Sunspot Cycle : The change in the number of sunspots from one period of its maximum to the next, over the course of about 11 years.

Sunspot Maximum : The period during the sunspot cycle when you will see the largest number of sunspots. Also called the 'Solar Maximum'.

Sunspot Minimum: The period during the sunspot cycle when you will see the fewest number of sunspots. Also called the 'Solar Minimum'

Resources

IMAGE	http://image.gsfc.nasa.gov
POETRY	http://image.gsfc.nasa.gov/poetry
SOHO	http://sohowww.nascom.nasa.gov
NASA Sun-Earth Connection Resources	http://sunearth.gsfc.nasa.gov
The Earth's Magnetic Field	http://image.gsfc.nasa.gov/poetry/magneto.html
Satellite Glitches -Space Environment Info	http://envnet.gsfc.nasa.gov
Magnetic North Pole	http://www.nrcan.gc.ca/gsc/cpdnew/magnet.html
Solar Sounds	http://soi.stanford.edu/results/sounds.html
Sunspot Number Archives / Resources	http://image.gsfc.nasa.gov/poetry/sunspots.html
CME Archives at MLSO	http://www.hao.ucar.edu/public/research/mlso/movies.html
Stellar Activity Cycles at Mt. Wilson	http://www.mtwilson.edu/Science/HK_Project/
Satellite Data	http://cdaweb.gsfc.nasa.gov
Space Weather Resources	http://image.gsfc.nasa.gov/poetry/weather.html
Magnetic Observatories and Data	http://image.gsfc.nasa.gov/poetry/maglab/magobs.html
Space Environments and Effects	http://see.msfc.nasa.gov/sparkman/Section_Docs/sparkman.html
Sun-Earth Classroom Activities Archive	http://sunearth.gsfc.nasa.gov/educators/class.html
Storms from the Sun	http://www.istp.gsfc.nasa.gov/istp/outreach/learn.html
The Aurora Page	http://www.geo.mtu.edu/weather/aurora/
Space Weather Human Impacts	http://image.gsfc.nasa.gov/poetry/storm/storms.html
Ionosphere density and sunspot numbers	http://julius.ngdc.noaa.gov:8080/production/html/IONO/ionocontour_90.html
Space Weather Daily Reports	http://windows.engin.umich.edu/spaceweather/index.html
Solar wind density and speed	http://www.sel.noaa.gov/wind/rtwind.html

Teacher Reply Card

National Aeronautics and
Space Administration

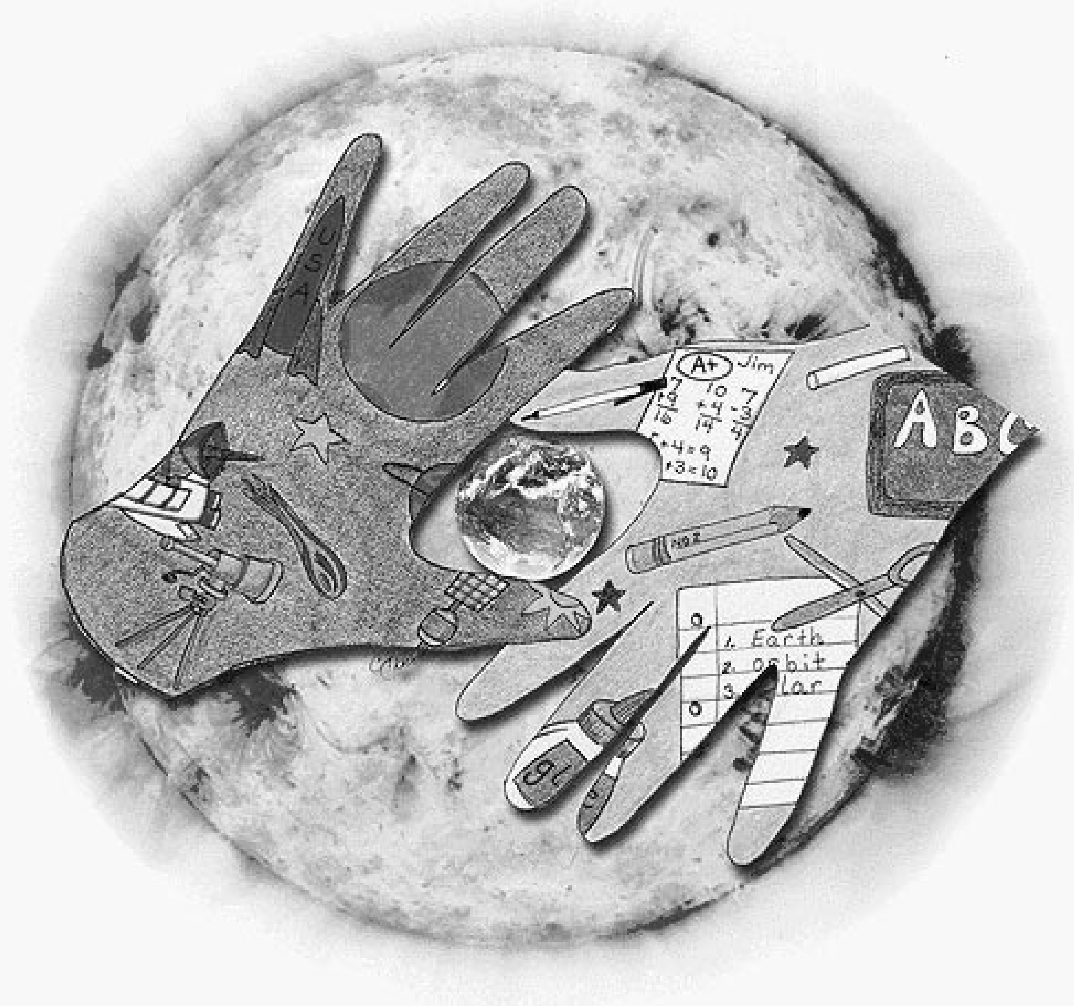
Educational Product	
Educators & Students	Grades 5-8

EG-2000-03-002-GSFC

Solar Storms and You!

Exploring the Human Impacts of Solar Activity

An Educator Guide with Activities in Space Science



Solar Storms and You! is available in electronic format through NASA Spacelink - one of the Agency's electronic resources specifically developed for use by the educational community.

The system may be accessed at the following address:
http://spacelink.nasa.gov

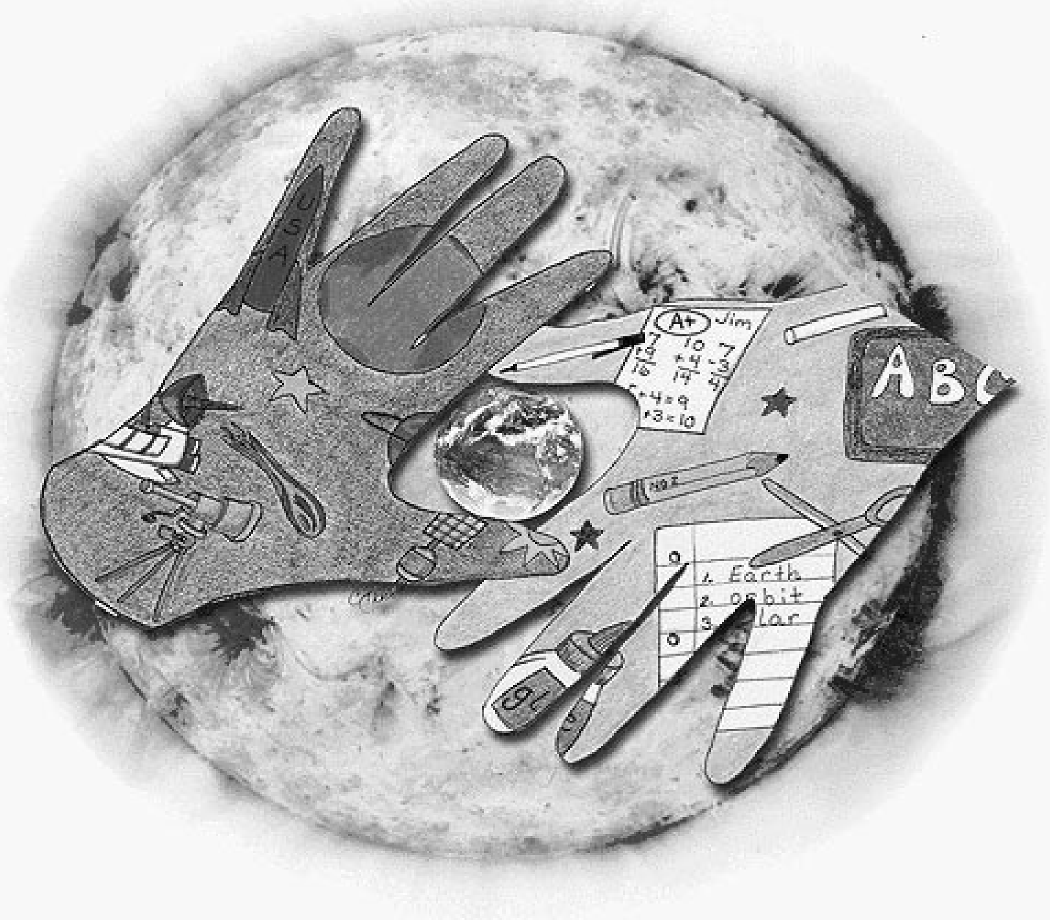
National Aeronautics and
Space Administration

EG-2000-03-002-GSFC

Solar Storms and You!

Exploring the Human Impacts of Solar Activity

An Educator Guide with Activities in Space Science



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Information about the IMAGE mission is available at:

http://image.gsfc.nasa.gov
http://pluto.space.swri.edu/IMAGE

Resources for teachers and students are available at:

http://image.gsfc.nasa.gov/poetry

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CONTENTS

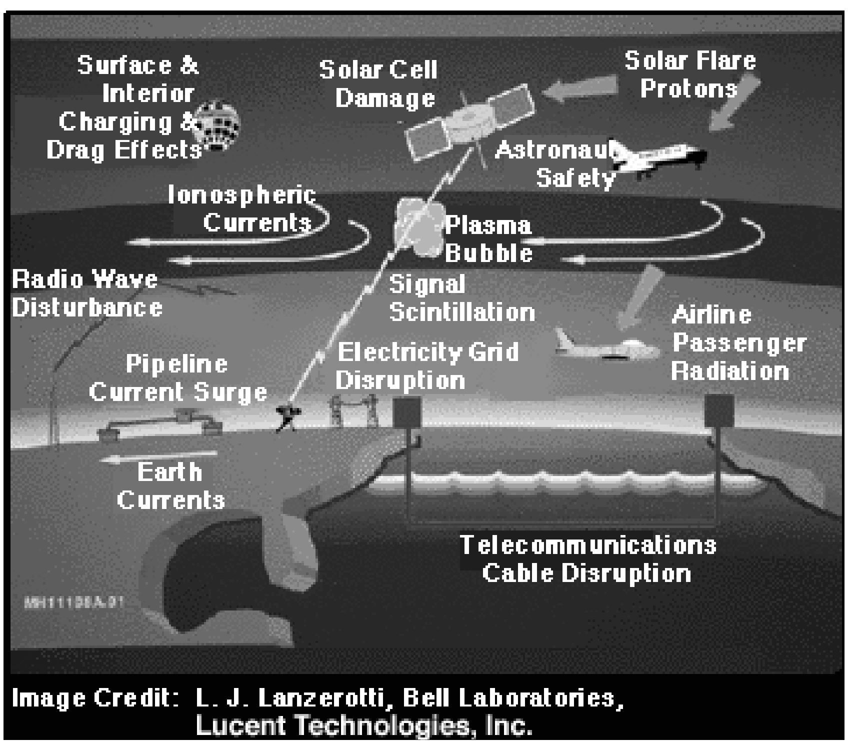


Image Credit: L. J. Lanzerotti, Bell Laboratories, Lucent Technologies, Inc.

Solar activity produces a variety of impacts upon our technology, both in space and on the ground.

INTRODUCTION

A gas pipeline in Russia explodes
killing hundreds of people.

A satellite mysteriously falls silent
interrupting TV and cellular phone traffic.

A power blackout
throws millions of people into darkness.

These are only a few of the many things that solar storms can do when they arrive at the earth unexpected. In an age where we have increasingly come to rely upon the smooth operation of our technology, we have also made ourselves vulnerable to the ebb and flow of the solar storm cycle. Most people are not even aware sunspots exist, but long ago we used to be!

Ancient Chinese sun observers knew that, from time to time, dark spots would glide slowly across the face of the setting sun. Once seen only as portends of political upheaval, we now see them as natural phenomena that can forewarn us of impending storms that can have dire consequences for us if we ignore them.

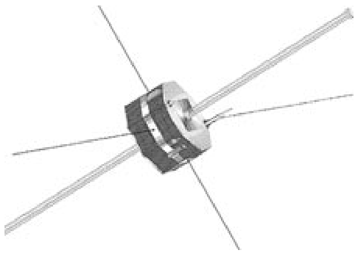
In this activity book, your students will study five key stages in the lifecycle of a solar storm, from its emergence on the solar surface to its impact upon some aspect of our lives. The book may be used in its entirety to study solar activity and how it directly affects us, or you may use individual activities of your choice as stand-alone mini lessons as an enrichment for math and physical science courses.

The student activities emphasize basic cognitive skills and higher-order processes such as plotting data, searching for patterns and correlations, and interpreting the results. By the end of the activity series, students will understand why we need to pay more attention to solar storms.

Visit the updated version of this workbook at:

http://image.gsfc.nasa.gov/poetry/workbook/workbook.html

Science Process Skills
for *Solar Storms and You!*



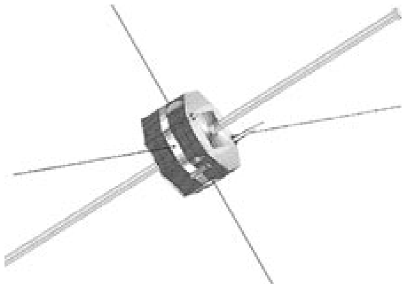
This chart is designed to assist teachers in integrating the activities contained in the guide with existing curricula.

Lesson

	1 *“Satellites*	2 *“Air Travel”*	3 *“Glitches”*	4 *“Sunspot Numbers”*	5 *“Trip to Mars”*
Observing					
Classifying					
Communicating	○	○	○	○	○
Measuring			○	○	○
Inferring	○	○			
Predicting			○	○	○
Experimental Design					
Gathering Data			○	○	○
Organizing Data			○	○	○
Controlling Variables					
Developing a Hypothesis					
Extending Senses					
Researching	○				○
Team Work	○	○		○	○
Mathematics			○	○	○
Interdisciplinary	○	○		○	○
Introductory Activity	○	○	○	○	○
Advanced Activity					

Science and Mathematics Standards

for *Solar Storms and You!*

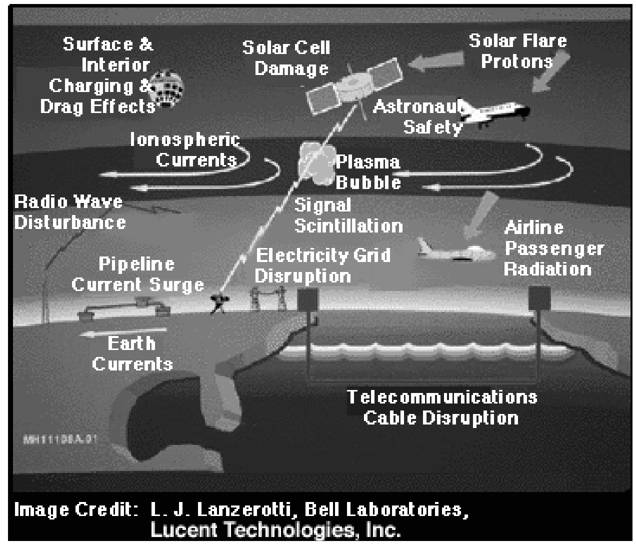


This chart is designed to assist teachers in integrating the activities contained in the guide with existing curicula.

Lessons

	1	2	3	4	5
Science as Inquiry	○	○	○	○	○
Structure and Energy of the Earth System					
Origin and History of the Earth					
Earth in the Solar System	○	○	○	○	○
Geochemical Cycles					
Physical Science	○	○	○	○	○
Populations and Ecosystems					
Understanding Science and Technology	○	○	○	○	○
Science in Personal and Social Perspectives					
History and Nature of Science					
Problem Solving	○	○	○	○	○
Measurement					
Computation and Estimation	○	○	○	○	○
Communication	○	○	○		
Geometry and Advanced Mathematics					
Statistics and Probability				○	○
Number and Number Relationships	○	○	○		
Patterns and Functions					

Human Impacts



As scientists have continued to study the sun and its many influences upon the earth, they have discovered many subtle interconnections. Apart from its obvious warmth and light, the sun produces many other dramatic impacts upon humans and their activity on the ground and in space.

Solar storms have interferred with the smooth operation of satellites in space. Sometimes satellites have been damaged because of electrical problems or false commands triggered by high energy charged particles.

The most dramatic effects involve power black outs caused by solar storms such as the one that occurred on March 10, 1989. A surge of electricity caused part of the power grid in eastern Quebec to shut down for hours.

During the early 1600s observers saw very few sunspots, and no cyclic changes in their numbers. This was also a time when Europe was affected by the so-called 'Little Ice Age'. Similar climate and solar activity correlations have also been found by studying ancient Chinese sunspot records going back thousands of years. Whenever solar activity seems to be dramatically low, or absent for a few decades, some part of the Earth seems to experience a major cooling episode.

Solar activity also affects the amount of light and heat we receive at the earth. Since the 1970s sensitive satellites have measured the power output of the sun. You would expect that when dark sunspots are present that the sun should be a little less bright. In fact the opposite is seen! This happens because sunspots are accompanied by brightenings of the surrounding solar surface far away from the darkened sunspot region, and this brightening more than compensates for the loss of light due to the sunspot itself.

Teacher's Guide

Solar Storms and Satellites

Introduction

Solar storms have long been known to affect delicate electronic circuitry in satellites orbiting the Earth. Given that the commercial, military and scientific satellite resources exceed $200 billion dollars, the issue of satellite vulnerability to solar storm damage is not only a serious consideration in satellite design, but also a highly controversial topic when specific instances are examined in detail.

Objective

Students will read to be informed.

Procedure

1) Students read "Forecasting Solar Storms" and answer the questions.

2) Discuss the answers and the article.

3) Students read "Solar Storm Eyed as Satellite Killer".

4) Construct a graphic organizer to compare and to contrast the two articles. Some of the items mentioned in both are $200 million Telstar 401 satellite, and the SOHO satellite. Both articles also mention the 1997 event, Stephen P. Maran's quote, " This is the first time a solar event has been captured from cradle to grave". It took the January 7 event, 3 3/4 days to reach the Earth, and other spacecraft that monitored the event.

5) Answer the remaining questions.

Materials

—A copy of "Forecasting Solar Storms" for each student.

—Student question sheet

—A copy of "Solar Storm Eyed as Satellite Killer"

—Student question sheet

Key Terminology:

Coronal Mass Ejection: A sudden expulsion of matter from the coronal regions of the Sun with typical speeds of millions of kilometers per hour.

Magnetic sub-storm: A rapid change in a portion of the magnetic field of the earth lasting hours to minutes.

Forecasting Solar Storms

Dr. Sten Odenwald (Raytheon ITSS and NASA Goddard Space Flight Center)

Solar storms are a problem. A big problem. Chances are you have never heard of them at all because, unlike the conventional storms that produce rain and thunder, solar storms are remote and distant. It really all depends on where you are and who you are. If you are an astronaut walking on the moon, a solar storm could give you a lethal dose of radiation in a matter of a few minutes. If you happened to be in Quebec on March 13, 1989, your entire province would have been blacked-out by a solar storm-induced power outage. If you were dialing '911' from a cellphone, the solar storm would have prevented your call from going through.

Scientists have spent a lot of time trying to predict solar storms so that, like hurricane warnings, we can have at least some forewarning of their approach. When solar storms buffet the earth's magnetic field they can, and often do, raise havoc with radio communication, power transmission, and even satellite functions. Nothing in our high-tech world seems to be entirely immune from the outfall from solar storms.

The sun and the wind from the sun are under around the clock surveillance by a network of ground-based, and satellite-based observatories such as SOHO, the Solar Heliospheric Observatory, and ACE, the Advanced Composition Experiment, to name a few. Other spacecraft orbiting the earth measure the changes in the earth's magnetic field and the populations of high-energy trapped particles which circulate within this vast magnetic bottle. Our sun has only recently begun to emerge from its lowest point in the famous 'sunspot cycle'. This ebb and flow of solar activity lasts an average of 11 years from peak to peak, with the current cycle, Number 23, destined to reach maximum in the summer of 2000.

Even though near its low point in the cycle, the sun has treated scientists to many spectacular storms which have reached earth and, in so doing, demonstrated that space weather forecasting is not an idle activity. On January 7, 1997, a region of intense activity on the sun's eastern sector launched a billion-ton gas cloud called a coronal mass ejection (CME) which, 3 3/4 days later, reached Earth. Its transit and arrival was monitored by 20 scientific research satellites as part of the International Solar-Terrestrial Physics program (ISTP). According to NASA astronomer Dr. Stephen Maran, "This is the first time a solar event has been captured from cradle to grave".

A small part of the million kilometer-wide cloud brushed by the earth, and shook the magnetic field of the earth for over 24 hours like a flame flickering in a breeze. This geomagnetic storm and the particles comprising it allegedly affected the operation of a $200 million Telstar 401 communications satellite which had to be taken out of commission on January 17 according to articles published in Sky and Telescope magazine (July, 1997 page 20) and Aviation Week and Space Technology (January 27, 1997 page 61-62).

With the upcoming 'solar maximum' approaching, and with our rapidly escalating dependence on satellite communication technology in the 21st century, additional space weather forecasting satellites will be launched so that as the older satellites reach the ends of their operating lifetimes, new generations of early-warning satellites will be on the scene to give scientists the data they need to make accurate forecasts in the next century.

Solar Storm Eyed as Satellite Killer

Dr. Sten Odenwald (Raytheon ITSS and NASA Goddard Space Flight Center)

On January 7, 1997 it seemed to be an ordinary day on the Sun. White light photographs taken at several ground-based solar observatories showed the surface to be quite ordinary. In fact, to the eye and other visible wavelength instruments, the images showed nothing at all. Not so much as a single sunspot.

But X-ray photographs taken by the YOHKOH satellite from earth orbit revealed some serious trouble brewing. High up above the solar surface in the tenuous atmosphere of the corona, invisible lines of magnetic force, like taught rubber bands, were coming undone. On January 6th, satellite images showed a coronal storm brewing from a small region of the corona, only a few hundred times the size of the Earth.

By Tuesday, January 7, solar astronomers recognized that a major Coronal Mass Ejection event was in progress, and in a sequence of daily X-ray images, the details of the event played themselves out in a deadly dance of magnetic fields, plasma and electromagnetic radiation.

The dance lasted several days, but by its end, a cloud of plasma was hurled away from the Sun at 1 million miles an hour. It crossed the orbit of Mercury in less than a day. By Wednesday it had passed Venus: An expanding cloud over 30 million miles deep, spanning the space between the orbits of Mercury and Venus. As NASA astronomer Stephen Maran noted about the 20 satellites that had monitored this event, "This is the first time a solar event has been captured from cradle to grave".

Despite the scientific excitement over this storm, it had other repercussions that were far less welcomed. The problem is that, even with detailed information about an incoming solar cloud, short of moving the earth out of the way, there was nothing we could do in the face of this looming calamity. All scientists could do was to sit back and cross their fingers that the Earth's magnetic field would repel most of the cloud like some gigantic security blanket. After all, it had done so for million of years in the past! But today, our daily sphere of activity extends off the surface of the Earth and far into space.

High up above the United States, AT&T's $200 million Telstar 401 satellite was busy relaying television programming between many destinations across the continent. Public Broadcasting Stations, ABC News and even the Home Shopping Channel were among its regular paid subscribers for the precious few channels that the satellite could re- broadcast back to our home television sets and to cable channel owners on the ground. Telstar 401 was launched from Cape Canaveral on December 13, 1993 and was the first of a fleet of modern communications satellites developed by Lockheed-Martin, and equipped with many new technologies. It was designed to last 12 years, but on Saturday, January 11 AT&T announced that it was having some communications difficulties with the satellite. Its day of reckoning had arrived, as the interplanetary coronal storm cloud, now over 30 million miles wide, slammed into the Earth's magnetosphere. Even the images from the YOHKOH satellite began to deteriorate as the plasma particles and magnetic fields invaded the delicate electronic circuitry, corrupting the images with noise.

In a report by Aviation Week and Space Technology (AWST) magazine (January 27, 1997, p. 61) the Telstar satellite "...suffered a massive power failure on Jan. 11 rendering it completely inoperative. Scientists and investigators believe the anomaly might have been triggered by an isolated but intense magnetic substorm, which in turn was caused by a coronal mass ejection...spewed from the Sun's atmosphere on Jan. 6". Some scientists were not so ready to implicate the solar storm in the damage to the satellite. Robert Hoffman, a NASA scientist, is quoted in AWST as saying that although the satellite was located in an affected area of the magnetosphere, "We have no idea what caused the failure".

Despite a number of attempts at diagnosing and repairing the problem with Telstar 401, on Saturday, January 17 AT&T had given up the effort and announced that they had lost the satellite. Paradoxically, no military satellites were apparently affected by this particular storm, and Hughes Space and Communications which manufactured over 40% of the commercial satellites now in orbit had also not received any reports of any anomalies related to the storm. According to AWST, Lockheed Martin which built the Telstar 401 satellite was investigating whether the failure could have been due to some problem in its design. Three earlier-model satellites were also disabled in 1994 by a solar storm which triggered electrical failures in these satellites: Intelsat K and two Canadian Anik television satellites. Two of them made partial recoveries but the third was lost completely. (AWST January 31, 1994 p. 28).

Satellite engineers and scientists are cautious to admit the sun was ultimately to blame when hundreds of millions of dollars are at stake and law suits could result from the wrong answers. For reasons of national security, there is also a good reason not to provide information about how vulnerable our military satellites may be to solar storm ‘attack’, perhaps emboldening an enemy to launch their own activities under the cloak of a solar storm event.

Many newspapers stories were ultimately filed about the January 1997 solar storm and its fallout, and on January 30, 1997 even George Will at the Washington Post, who normally covers political stories, wrote “Astronomy's Answer”, an anguished editorial about space calamities that can, and will, affect us.

Name ___________________________

Date_________________

Reading to be Informed

"Forecasting Solar Storms"

1. When a powerful solar wind buffets the Earth's magnetic field, what havoc can occur?

2. Name a satellite mentioned in the article and describe the events it photographed.

3. What was probably caused as a result of the power surge?

4. According to the article, what are the implications for future forecasting. and why do you think scientists consider forecasting to be so important?

5. Name some electronic gadgetry, according to the article, that is prone to disruption.

6. Summarize the article in your own words.

7. Why might a solar storm impact your life, and how might space weather forecasting be useful to you?

Name ______________________________

Date_________________

Reading to be Informed

"Solar Storm Eyed as Satellite Killer"

1. **In your own words, describe the solar storm and its results.**

2. **What is the meaning of the quote "This is the first time a solar event has been captured from cradle to grave" ?**

3. **What was the cost of the Telstar 401 satellite?**

4. **The satellite was insured for $145 million. For what percent of the original cost was the satellite insured?**

5. **The satellite was launched in _______ and was designed to operate for _______ years. What would that cost breakdown per year be, assuming that the value of the satellite decreased by 10% the first year, 9% the second year, and 8% the third year? (Remember, the satellite was launched in 1993, therefore for this case, year one will be 1994.)**

   1994
   1995
   1996

6. **Why would we not include 1997 in the cost breakdown?**

7. **The CME cloud was traveling at a speed of 1 million kilometers/hr, how far was the cloud after Day 1, Day 2, Day 3 and Day 4? Explain what you think will happen when it reaches the Earth.**

8. **What do you think about solar storms and their impact on you in the future?**

Sample Responses For Graphic Organizer

(Students may choose an organizer such as a Venn Diagram)

"Forecasting Solar Storms"

Trying to predict when a solar storm will happen.
Why we should forecast solar storms.
Solar storms affect the earth, like blackouts.
Solar storms raise havoc with radio transmissions and satellites.
Solar cycle
Improvements being made in science
Mainly about forecasting solar storms

Common Elements to the Stories:

Solar Storms
Telestar 401 satellite
$200 million dollar
Same author
NASA
TV and radio quotes
Studying about space
ACE and SOHO
Both had the quote by Stephen Moran, "This is the first time a solar event has been captured from cradle to grave".

"Solar Storm Eyed As Satellite Killer"

Coronal mass ejections
Magnetic field
Mostly one event
Communications disruptions
Telestar - what it does, where it was launched, and who made it
Maybe solar storms are satellite killers
YOHKOH
Talks about one major event
Mainly about solar storms destroying a satellite

Selected Responses

“Solar Storm Eyed as Satellite Killer”

1. In your own words, describe the solar storm and its results.

A solar storm is a discharge of particles from the Sun that can cause the Northern Lights, blackouts, and communication problems.

A solar storm is when particles shoot from the Sun and can cause Earth a lot of trouble. It can cause a power surge and the electricity can go out.

A solar storm is where a lot of particles fly out from the Sun. One thing that they can do is interfere with communications.

The solar storm described is radiation, magnetic forces, and particles from the Sun. It’s results are blackouts and non-communication. It also causes the Aurora Borealis, they are a bluish greenish color.

A solar storm is a storm on the Sun. Power surges can happen and also lots of radiation is in space.

A solar storm is when billions of particles meet the atmosphere and cause the aurora. Some results are cell phone not working and magnetic fields are disrupted.

The solar storm is when blasts of energy shoot out from the Sun. They sometimes mess with the Earth’s magnetic field. They can also disrupt cell phone connections.

A solar storm is like a huge nuclear bomb, only out in space. So by the time the storm reaches the Earth, it’s not so powerful. We only get our radio communications messed up and other things like power transmitters messed up.

Solar storms are ejections of particles from the Sun. They can do a lot of damage to satellites.

2. What is the meaning of the quote “This is the first time a solar event has been captured from cradle to grave” ?

It means that this is the first time a solar event has been seen from the time it starts until the time it ends.

It means that it’s the first time a solar event has been captured from beginning to end.

They saw the storm from satellites when it started until it ended.

Selected Responses

"Solar Storm Eyed as Satellite Killer"

3. What was the cost of the Telstar 401 satellite?

The cost of the Telstar 401 satellite was $200 million.

The satellite cost 200 million dollars.

The satellite cost 200,000,000 dollars.

4. The satellite was insured for $145 million. For what percent of the original cost was the satellite insured?

The satellite was insured for 72.5 %.

The percentage insured for the Telstar 401 satellite was 72.5% of the original $200 million.

5. The satellite was launched in _______ and was designed to operate for _______ years. What would that cost breakdown per year be, assuming that the value of the satellite decreased by 10% the first year, 9% the second year, and 8% the third year? (Remember, the satellite was launched in 1993, therefore for this case, year one will be 1994.)

1994 $180,000,000
1995 $163,800,000
1996 $150,696,000

6. Why would we not include 1997 in the cost breakdown?

We would not include 1997 in the breakdown because the satellite suffered a massive power failure and they lost it.

The storm that disabled it was on January 7th and this is close to the beginning of the year.

We would not include 1997 in the cost breakdown because that is when the cloud messed it up.

You would not include 1997 in the cost because the satellite was disabled by a solar storm then.

Selected Responses

"Solar Storm Eyed as Satellite Killer"

7. The CME cloud was traveling at a speed of 1 million kilometers/hr, how far was the cloud after Day 1, Day 2, Day 3 and Day 4? Explain what you think will happen when it reaches the Earth.

Day one - 24 mil. km; Day two - 48 mil km; Day three - 72 mil. km; Day four - 90 mil. km

I think that when it reaches the Earth it will cause a blackout.

The CME cloud will mess up satellites.

I think that the magnetic field will block most of it, but what comes down may affect a power outage.

8. What do you think about solar storms and their impact on you in the future?

I think in the future solar storms ,I feel, will not impact us as much because we'll have better forecasting and ways of protecting us a little. I think solar storms are a very interesting thing we should continue to study.

I think that solar storms are interesting to learn about but they cause many things to go wrong on Earth, like putting out cell phones and causing satellite disruptions that take a while to repair.

I think that solar storms will cause blackouts and suspenseful moments in my life, but not much else.

I think that the storms are neat and the impact on ones life is strange. Well in the future we may have space colonies and a solar storm could be disastrous.

I think that it is weird all this stuff that is going on out in space that I don't know about. The worst thing that can happen is a blackout, I think.

I think that solar storms will not have a huge effect on me because I like power outages and I don't have a television or a phone.

Selected Responses

"Forecasting Solar Storms"

1. When a powerful solar wind buffets the Earth's magnetic field, what havoc can occur?

When a powerful solar wind buffets the Earth's magnetic field, havoc with radio communication, power transmissions, and even satellite functions can occur.

Havoc can occur with radio communication, power transmissions, and satellite functions.

When solar storms buffet the Earth's magnetic field, they can raise havoc with radios, power transmissions, or even satellite functions.

Powerful solar winds can cause radio communication trouble, power transmission trouble, and also satellite trouble. Blackouts can occur and even powerful explosions.

2. Name a satellite mentioned in the article and describe the events it photographed.

One satellite mentioned was SOHO. This photographs the Sun and detects the wind from the Sun.

SOHO is a satellite mentioned in the article, that is the Solar Heliospheric Observatory. It photographs the Sun and the wind from the Sun.

The Ace, Advanced Composition Experiment, photographed the Sun and the wind from the Sun.

Two satellites mentioned are the SOHO and ACE. They measure the changes in the magnetic field, also high energy particles which circulate past.

The satellite SOHO took pictures of gas clouds which are called coronal mass ejections.

3. What was probably caused as a result of the power surge?

On March 13, 1989, the entire province would have been blacked out.

If you lived in Quebec on March 13, 1989 your entire province would have been blacked out because of a solar storm induced power outage.

The black out in Quebec on March 13, 1989 was probably caused as a result of the power surge.

In result of the power surge, a $200 million Telstar 401 satellite was knocked out.

Selected Responses

"Forecasting Solar Storms"

4. According to the article, what are the implications for future forecasting. and why do you think scientists consider forecasting to be so important?

According to the article, the implications for future forecasting are that as the older satellites kind of die out, new satellites will already be there. I think scientists should consider forecasting so important because they will need to prepare to know when havoc and catastrophe can be prevented.

The implications for future forecasting was to launch the new and improved satellites so that as the older satellites reach the ends of their operating lifetimes, new generations of early warning satellites will be on the scene to give scientists data. They need to make accurate forecasts. I think scientists consider forecasting so important because it helps other people to know what's going on and to be ready for what comes.

The implications for future forecasting are that more satellites will be giving the scientists more accurate forecasts in the next century. Forecasting is so important so that we know when communication may go down.

According to the article, some implications for future forecasting would be to be looking for more solar storms to know when to tell us to put away our satellites and to be able to forecast when a solar maximum is coming, which means major solar storm.

Some implications for future forecasting are that additional space weather forecasting satellites will be launched so that new generations of satellites will give scientists the data needed to make more accurate forecasts in the future, thus preventing damages.

5. Name some electronic gadgetry, according to the article, that is prone to disruption.

Some electronic gadgetry that is prone to disruption are the satellites and the cell phones.

Some things that are prone to disruptions are power transmissions, satellite functions, and radio communications.

6. Summarize the article in your own words.

Solar storms have been a problem over the years. Some places in the world have been affected by these storms. Scientists have been trying to study the storms so if it was to happen again we would have some kind of warning. The satellites have brought back a lot of information about the sun and the wind from the sun which helps the scientists to keep track of what is going on. Scientists now have a new generation of early warning satellites that will be launched to take the place of the old ones. Scientists now expect to get the data they need to make better updated forecasts about solar storms.

Selected Responses

“Forecasting Solar Storms”

Solar storms are a big problem and can blackout your entire province. Scientists have been trying to predict solar storms so that we can have at least some forewarning of their approach. With the upcoming ‘solar maximum’ approaching, additional space weather forecasting satellites will be launched so that the new generations of satellites will give scientists the data to make accurate forecasts in the next century.

Solar storms are a big problem. This article tells how solar storms are made. They are made from the sun, a wind from the sun makes the Earth’s magnetic field circulate with vast magnetic particles. Scientists are figuring out a way to get the forecast for the future that will help in the next century by replacing old satellites with new ones.

7. Why might a solar storm impact your life, and how might space weather forecasting be useful to you?

The solar storm may impact my life because we would have no way to communicate and no way to tell what would happen next because the phones and probably the television would be blacked out. Space weather forecasting is useful to me because I will have an idea of what will happen and I could be prepared.

A solar storm would impact my life because blackouts and the use of satellites and cell phones may be disrupted. Space weather forecasting would be useful so I would know when to put away supplies and so scientists know when to put away satellites.

A solar storm might impact your life because the Aurora colors are so beautiful. You would remember them forever, they might inspire you. Also if there was a blackout, you would also remember that event. You could be prepared.

A solar storm might impact me by causing a blackout. As a result, all electronics could go out and this would affect us greatly. Space weather forecasting would be useful because they could warn us when these storms would or will happen, and they can tell us what to do and how to deal with the blackouts before they happen.

Teacher's Guide

Cosmic Radiation Creates Unfriendly Skies

Introduction

On the Earth's surface, we are protected from the harmful effects of cosmic rays by the atmosphere. During a trip in a jet plane at altitudes of 30,000 feet, cosmic rays and other energetic particles pose a great problem and can lead to significant health risks, especially for airline pilots.

Objective

The student will read to be informed, and write a letter to persuade based on the article that was read.

Procedure

1) Students read the article "Cosmic radiation creates unfriendly skies".

2) Allow sufficient time for the students to complete questions #1 through #10.

3) Discuss the student responses to questions #1 through #10.

4) Allow students a sufficient amount of time to prewrite the letter.

5) Group students in pairs. Assign one member of the pair to be "A" and the other member to be "B". Student "A" reads the letter to student "B" and receives suggestions. Allow five minutes for the peer review. Then student "B" reads the letter to student "A" and receives suggestions. Allow five minutes for the peer review.

6) Separate the students for individual work.

7) Students complete the final copy of the letter.

Materials

—"Cosmic radiation creates unfriendly skies"

—Student question sheet

—Lined paper

Scoring rule: Writing to persuade.

2=Consistently addresses audience's needs by identifying a clear position and fully supporting or refuting that position with relevant information. Text is uniformly organized, and language choices often enhance the text.

1=Sometimes addresses the audience's needs by identifying a somewhat clear position and partially supporting or refuting that position with relevant information. Text is generally organized, and language choices sometimes enhance the text.

0=Rarely or never addresses audience's needs by failing to identify a clear position or failing to adequately support or refute a position that is identified. Text lacks organization and language choices seldom, if ever, enhance the text.

Cosmic Radiation Creates Unfriendly Skies

Dr. Sten Odenwald (Raytheon ITSS and NASA Goddard Space Flight Center)

A trip on a jet plane is often taken in a party-like atmosphere with passengers confident that, barring any unexpected accidents, they will return to earth safely and with no lasting physical affects. But depending on what the sun is doing, a solar storm can produce enough radiation to equal a significant fraction of a chest X-ray's dosage even at typical passenger altitudes of 35,000 feet. The situation is even worse for airline pilots and flight attendants who spend over 900 hours in the air every year. According to a report by the Department of Transportation (Science News magazine, vol. 137, p. 118), the highest dosages occur on international flights passing close to the poles where the earth's magnetic field concentrates the dosages. Estimates suggest that for such polar routes, flight crews can receive nearly 910 millirems of cosmic radiation dosage per year. The annual federally recommended limit for pregnant women is 500 millirems. Even at these levels, it has been estimated that there will be on the average four extra cases of mental retardation per 100,000 women due to this exposure between weeks 8 to 15 in the gestation cycle.

Although the dosage you receive on a single such flight per year is very small, frequent fliers who amass over 480 hours of flight per year would statistically expect to suffer from 500 extra cancer deaths per 100,000 travelers over a 20 year period. Airline crews who spend 960 hours in the air on such polar routes would have over 1000 additional cancer deaths per 100,000 crew members over a 20 year period of travel.

By comparison, the typical cancer rate is about 22,000 deaths per 100,000. This means that instead of a 22 in 100 chance of cancer, airline crews and frequent fliers would have as much as a 23 in 100 chance of cancer death. This doesn't sound like much, but for a population as large as the United States with nearly 300 million people, this means an additional 3 million people would die if they all traveled on such routes. Of course only a small number of people are this well-traveled, but nevertheless, without proper safeguards, hundreds of additional people would die from such radiation exposure.

Matthew H. Finucane, air safety and health director of the Association of Flight Attendants in Washington DC, as quoted in Science News (vol. 137, p. 118), advocates asking the FAA to monitor and regulate radiation exposure and, if possible, to warn crews of unusually intense bursts of cosmic radiation, or solar storm activity. Currently, the FAA guidelines are written in too technical a language to be readily useful to pilots and flight attendants so that they need to be re-written.

Name ___________________________

Date________________

Writing to Persuade

"Cosmic radiation creates unfriendly skies"

1. **What is the central idea of the reading selection?**

2. **How does the central idea relate to the title of the article?**

3. **In regards to a crew that spends 960 hours in the air each year for 20 years, how many total hours are spent per person in the air?**

4. **If this crew received the highest annual dose of cosmic radiation, 910 millirems, how many total millirems do they receive in a day assuming an equal amount per day.**

5. **Suppose that 910 millirems are spread equally over 32 routes from New York to Athens. How many millirems do they receive per trip?**

6. **If the crew had flown on September 29, 1989 and they received 110 millirems from the solar event, how might they have received the remaining dosage of the 910 millirems?**

7. **What is the expected cancer rate for a frequent flier over a 20 year period according to the article?**

8. **What is the percentage for the overall cancer rate in the general population, and how does it compare to the cancer rate for frequent fliers?**

9. **Determine the percentage for the typical cancer rate, and compare this to the cancer rate for the airline crews. Is this a significant threat to them? If so, explain your reasoning.**

10. **What could be the implications for solar weather forecasting?**

11. **Write a letter to the Federal Aviation Administration or the Department of Transportation why, or why not, it is important to educate, to predict, and to notify the public, about the effects of solar radiation. Be sure to include details from the text that support your reasoning.**

Teacher's Guide

Satellite Glitches and Cosmic Rays

Introduction

Electronic problems with orbiting satellites are more frequent when the environment has been bombarded with energetic particles called cosmic rays. These high energy, charged particles impact sensitive electronic circuits and causes 'glitches', which can alter the operation of a satellite in an unpredictable manner. This activity shows the correlation between cosmic ray hits and the electronic errors in the NASA TDRS-1 communication satellite which is used for keeping in touch with the Space Shuttle crew while in space.

Objective

Students will construct a graph from a data table. Students will look for correlations and patterns between the frequency of cosmic rays and glitches.

Procedure

1) Arrange the students into four groups.

2) Give each group a data table for an assigned year.

3) Students will create a double line graph with the months on the horizontal axis. Using two different colored pencils, plot the glitches and the cosmic ray counts.

4) Permit time for the students to analyze the graphs and look for a correlation.

5) Have the groups combine the graphs into a single graph in the proper time order from 1987 to 1990 to detect any long-term trends.

6) Provide each group with a transparency. Have each group prepare a presentation of their findings.They should note any correlation or discrepancy that they have found.

7) Have a prepared transparency of the four tables and graphs, and the combined four-year graph. Provide a concluding summary using the class results. Possible student conclusions include that when the cosmic ray hits are high, glitches are more common. There is a correlation between the two sets of data. Was there a year where there was a particularly high number of both, and did that relate to a solar storm event, sunspot number increase, or coronal mass ejection?

Materials

—Table of cosmic ray counts and TDRS-1 glitches.

—Graph paper

Extra Credit:

If you compare the cosmic ray hits against the sunspot cycle, you will note that when the solar cycle is near maximum, the number of cosmic ray hits is lowest. This is because cosmic rays come from interstellar space and not the sun. When the sunspot activity is highest, the sun's magnetic field is much stronger out near the Earth, and this helps to shield us from cosmic rays. When solar activity is lowest, the sun's magnetic field is weaker near the Earth and so the cosmic rays have an easier time reaching the Earth and affecting our satellites.

Conclusion:

Students should have correlated the data for the electronic glitches with the cosmic ray hits to the satellite. From the real data in the tables, the students have plotted, analyzed and have drawn a conclusion.

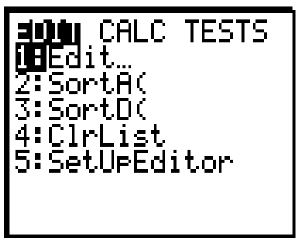
TEACHER NOTES FOR THE TI-83 GRAPHING CALCULATOR

Reminder: Be sure to reset the calculator using "Teacher Notes for the Graphing Calculator" included in the previous sunspot lesson.

The commands for the graphing calculator are given in bold print.

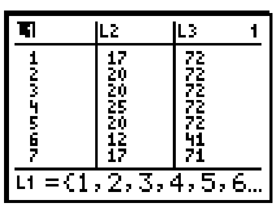
Students will enter the data for the years into list one, the data for the glitches in list two, and the cosmic ray hits (Cr hits) in list three. NOTE: Be sure to list the years as the numbers 1 through 48.

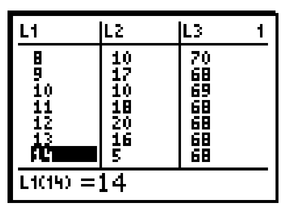
Entering the data into the list will consist of the following keystrokes:

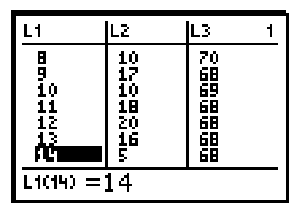


STAT **ENTER**

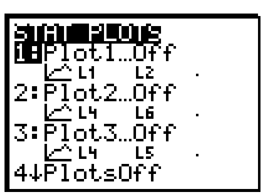
This will put you at the window to input the data for the year into your selected lists. Sample screen images are shown below.







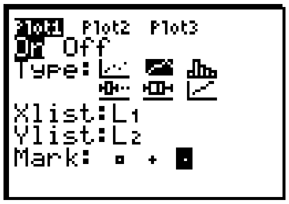
The next step is to turn on the appropriate graph and to use the correct lists. Since the data is in List 1, List 2, and List 3, those are the ones that we shall select. To turn the plots on, use the following keystrokes:

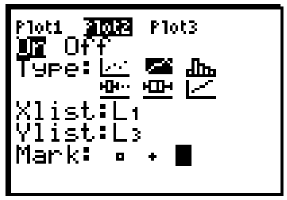


2ND **Y=** **ENTER**

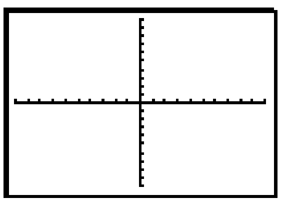
To turn the plot on, make sure that the cursor is blinking over the **ON** and push **ENTER**. Next arrow down and over to select the second graph. Once the cursor is flashing over it, push **ENTER**. Arrow down to the X list and push **2ND** **1**, arrow down to the Y list and push **2ND 2**. To turn on the second plot, **2ND** **Y=** **ENTER**. Arrow down and select 2. Again, make sure that the cursor is flashing over the **ON** and push **ENTER**. Then arrow down and over to the second graph, and **ENTER**. Arrow down to the X list and push **2ND** **1**, and arrow down to the Y list and push **2ND 3**.

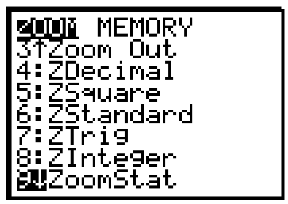
The correct windows are displayed below.



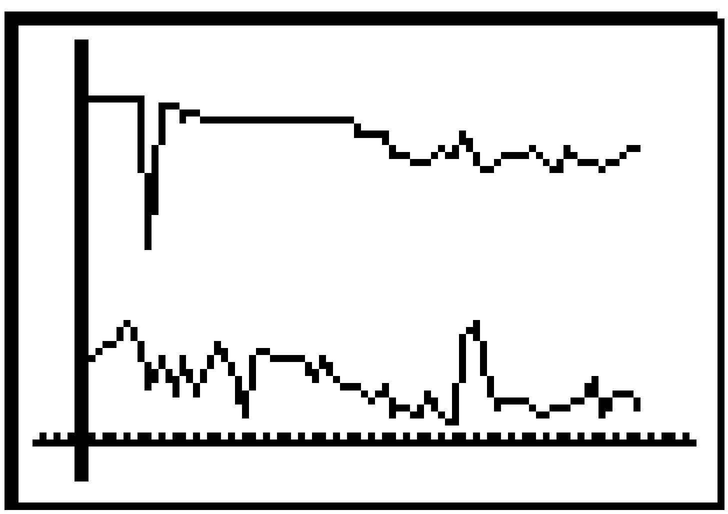


The next step is to graph the data. When the students push the graph key, they may or may not see a part of the graph. If the calculator was reset prior to the beginning of the lesson, the students would see the following blank display. It is necessary to adjust the viewing window using **ZOOM 9**. The window display for the zoom is shown below.





In order to move along the graphs and to display the values, push **TRACE**. The up and down arrow keys allow movement between the two graphs, and the right and left arrow keys allow movement along a particular graph.The appropriate graph display will appear as follows:



Students will probably say that there is no relationship evident between these two graphs, and they are right.There is a correlation between these two, it is just not evident with the small sampling of data that is presented. The overall slopes are similar in that there is a downward slant to both. Students need to be aware that in the scientific world, answers are not always readily apparent and that there may be a need to explore a relationship further. However, students can draw conclusions based on the given data.The discussion can also focus on the need to possibly scale one set of data to see if this allows for more concise results, or to collect more data to analyze.

Name ______________________________

Date________________

1987		
Month	Glitches	CR Hits
January	17	72
February	20	72
March	20	72
April	25	72
May	20	72
June	12	71
July	17	71
August	10	70
September	17	68
October	10	69
November	18	68
December	20	68

1988		
Month	Glitches	CR Hits
January	16	68
February	5	68
March	17	67
April	19	68
May	18	67
June	17	67
July	17	67
August	13	67
September	18	67
October	13	67
November	12	67
December	12	65

1989		
Month	Glitches	CR Hits
January	9	64
February	12	64
March	5	60
April	7	60
May	5	59
June	10	59
July	6	62
August	4	60
September	22	65
October	25	58
November	10	57
December	7	59

1990		
Month	Glitches	CR Hits
January	8	60
February	9	60
March	7	61
April	6	58
May	7	57
June	7	61
July	9	58
August	13	58
September	5	57
October	10	58
November	10	61
December	7	62

Name ______________________________

Date_________________

Name ______________________________

Date_________________

Teacher's Guide

Planning a Trip to Mars

Introduction

In the 21st century, NASA is planning a mission to Mars. You and a group of your peers are about to set off on this mission. The trip will take 240 days to get to Mars. Once there, you will explore the surface for fossils for 3 years. The return trip to Earth will take another 240 days. A concern exists for how the crew will be protected from radiation over-exposure during the 4-year expedition in space. You will assume during the trip that your shielding is the same as NASA uses on the Space Shuttle.

Objective

Students will calculate the cumulative radiation dosage for a trip to Mars, and participate in a probability-based exposure simulation.

Procedure

1) Read the introductory paragraph to the students.

2) Allow sufficient time for the students to complete questions #1 and 2 on the Student Worksheet. Discuss student results and answers.

3) Group the students into either pairs or groups of four.

4) Provide each group with a dice. Conduct the simulation and complete the remaining activities.

5) Discuss the outcome of the simulation, and review possible responses to the remaining exercises.

For a possible extension:

Have the students use the graph created in the first activity in this book **"The Sunspot Cycle"** to determine when would be the best opportunities in the next century to leave for the trip.

Materials

—A dice

—Student Worksheets

—Graph paper

—Calculator

Key Terminology:

SPE: Solar Proton Event. An unpredictable, major burst of high-energy particles from the sun which take less than 20 minutes to reach the orbit of the Earth.

Rad: The amount of radiation needed to deliver a specific amount of energy into a fixed mass of biological tissue. 100 rads equals one Joule of energy per kilogram of mass. One Joule is the amount of energy a 1 Watt bulb produces in a second.

Rem: A number that tells the actual damage done per rad of dosage which accounts for the fact that charged particles are 10 times more damaging than electromagnetic radiation.

Name ______________________

Date________________

1. NASA is concerned about the amount of radiation that your crew will be exposed to while on your trip. The table below shows the minimum and maximum dosages (in rems) that were received for different Space Shuttle flights, and at different altitudes given in Nautical Miles (NM). Find the combined average dosage.

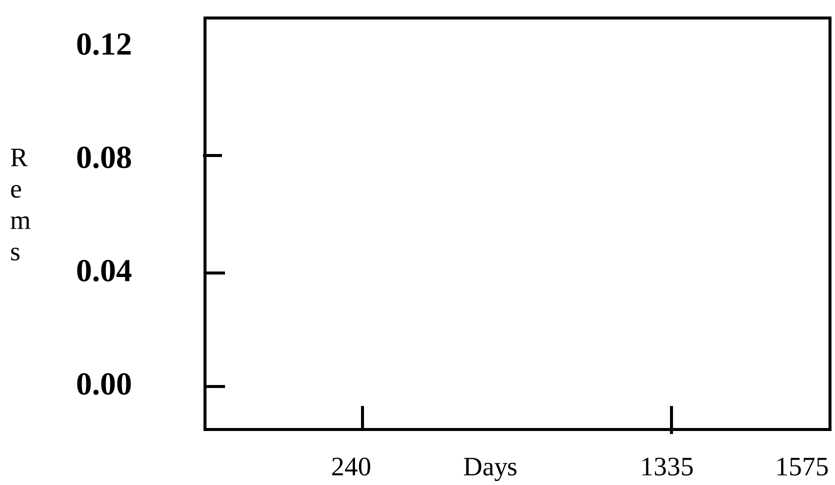
Mission	Altitude	Minimum	Maximum
STS-38	**125 NM**	**0.003**	**0.004**
STS-51G	**200 NM**	**0.015**	**0.020**
STS-37	**245 NM**	**0.040**	**0.070**
STS-31	**330 NM**	**0.140**	**0.220**

Average combined dosage in rems = ___________________

2. Suppose that NASA decides to send the expedition at a time near solar maximum. By the time you return, the conditions in space will be near those at solar minimum during the solar cycle which occurs about 5.5 years after solar maximum. During solar maximum, the sun is very active and effectively shields the inner solar system from most of the galactic cosmic rays (GCRs) which contain very high energy particles. During solar minimum, the Sun is relatively inactive and allows GCRs to reach the inner solar system in greater numbers. The integrated dose of GCRs is about 2.5 times higher at solar minimum than at solar maximum. Using the data in the table above during conditions of solar maximum, calculate the average dosage in rads/day during solar minimum.

Average dosage in rems during solar minimum = ____________

3. The next step in the process is to determine the number of rems for the crew. Also, you will need to calculate the total exposure over the entire 4.3 year trip. Total exposure is measured in units of rems. Your trip begins during solar maximum and ends during solar minimum. On the graph below, calculate the number of rems for each time period. Assume that while on Mars that you are adequately shielded with a natural background dose of 15 rem per year (or 0.04 rems/day). To calculate rems: Rems per day multiplied by the number of days of exposure = number of rems of total radiation dosage.



Number of rems on trip to Mars:

= ___________

Number of rems on Mars:

= ___________

Number of rems on trip to Earth:

= ___________

Name ____________________________ Date_________________

4. **There is an event that occurs in space known as a Solar Proton Event (SPE). SPEs are the most dangerous to astronauts because of our inability to predict them. They occur about once every month during solar maximum, and once every eight months during solar minimum. Typical radiation dosages are about 0.4 rems inside a spacecraft or similar shelter. The amount of rems varies due to the intensity of the SPE. During your trip, assume that you will encounter 3 SPEs on your way to Mars, 10 SPEs while on Mars, and 1 SPE on your trip home. To simulate the random amount of rems received from SPEs, toss a dice and using the chart below, the number on the dice equals the corresponding dosage. Example, a roll of 5 gives you a dosage of 2.0 rems. Repeat for each SPE and add the amount of the total SPE rems for each part of the trip.**

Dice	Dose
1	0.1
2	0.3
3	0.4
4	0.8
5	2.0
6	10.0

Trip to Mars:

SPE	Dose
1	
2	
3	

On Mars:

SPE	Dose
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Trip to Earth:

SPE	Dose
1	

Total Rems..... ______________ ______________ ______________

7. **Calculate the mission's total dose by filling in the numbers below:**

Amount of rems on trip to Mars + total SPE on trip to Mars = _____________

Amount of rems while on Mars + Total SPE while on Mars = ______________

Amount of rems on trip to Earth + Total SPE on trip to Earth = _____________

Total dosage for entire trip = __________

Name ______________________________ Date_________________

8. NASA's career equivalent doseages for astronauts is computed as follows:

200 + 7.5 (age - 30) rems (males up to 400 maximum rems)
200 + 7.5(age - 38) rems (females up to 400 maximum rems)

Using these formulas, answer the following questions:

How many trips to Mars could a 40 year old man take before reaching the maximum amount of 'career' radiation exposure recommended by NASA?

How many trips to Mars could a 40 year old woman take before reaching the maximum amount of 'career' radiation exposure recommended by NASA?

Name some ways that the amount of radiation you received on this trip could vary.

Which of the two sources of radiation, cosmic rays and SPEs, are the most hazerdous and how would you try to minimize its risk to the crew?

Based on what you have learned, what are some things you could do to minimize the amount of radiation that you would receive on a trip to Mars?

Teacher's Answer Key

1. NASA is concerned about the amount of radiation that your crew will be exposed to while on your trip. The table below shows the minimum and maximum dosages (in rems) that were received for different Space Shuttle flights, and at different altitudes given in Nautical Miles (NM). Find the combined average dosage.

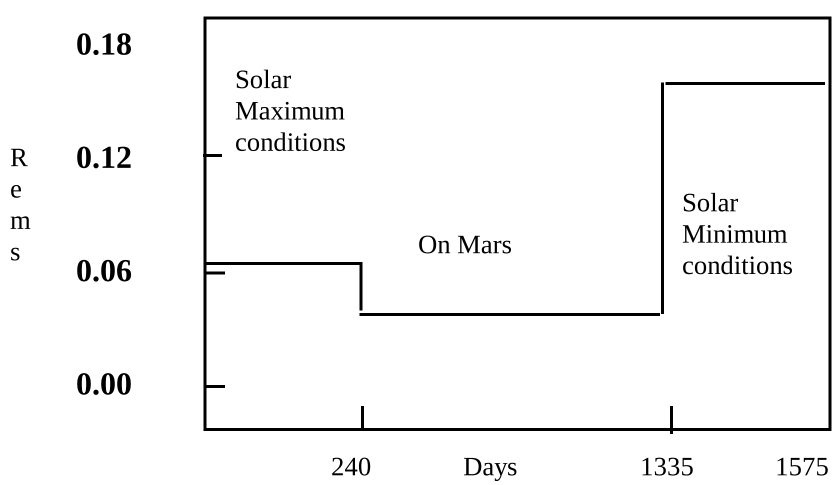
Mission	Altitude	Maximum	Minimum
STS-38	**125 NM**	**0.003**	**0.004**
STS-51G	**200 NM**	**0.015**	**0.020**
STS-37	**245 NM**	**0.040**	**0.070**
STS-31	**330 NM**	**0.140**	**0.220**

Average combined dosage in rems = **0.064**

2. Suppose that NASA decides to send the expedition at a time near solar maximum. By the time you return, the conditions in space will be near those at solar minimum during the solar cycle which occurs about 5.5 years after solar maximum. During solar maximum, the sun is very active and effectively shields the inner solar system from most of the galactic cosmic rays (GCRs) which contain very high energy particles. During solar minimum, the Sun is relatively inactive and allows GCRs to reach the inner solar system in greater numbers. The integrated dose of GCRs is about 2.5 times higher at solar minimum than at solar maximum. Using the data in the table above during conditions of solar maximum, calculate the average dosage in rems during solar minimum.

Dosage in rems during solar minimum = **0.064 x 2.5 = 0.16 rems**

3. The next step in the process is to determine the amount of rems for the crew. Also, you will need to calculate the total exposure over the entire 4.3 year trip. Total exposure is measured in units of rems. Your trip begins during solar maximum and ends during the solar minimum. On the graph below, calculate the number of rems/day for each time period. Assume that while on Mars that you are adequately shielded with a natural background dose of 15 rem per year (or 0.04 rems). To calculate rems: Rems per day multiplied by the number of days of exposure = number of rems of total radiation dosage.



Number of rems on trip to Mars:

= 0.064x240 = 15.4 rems

Number of rems on Mars:

= 0.04x(1335-240) = 43.8 rems

Number of rems on trip to Earth:

= 0.16x240 = 38.4 rems

Teacher's Answer Key

4. There is an event that occurs in space known as a Solar Proton Event (SPE). SPEs are the most dangerous to astronauts because of our inability to predict them. They occur about once every month during solar maximum, and once every eight months during solar minimum. Typical radiation dosages are about 0.4 rems inside a spacecraft or s similar shelter. The amount of rems varies due to the intensity of the SPE. During your trip, assume that you will encounter 3 SPEs on your way to Mars, 10 SPEs while on Mars, and 1 SPE on your trip home. To simulate the random amount of rems received from SPEs, toss a dice and using the chart below, the number on the dice equals the corresponding dosage. Example, a roll of 5 gives you a dosage of 2.0 rems. Repeat for each SPE and add the amount of the total SPE rems for each part of the trip. Here is a sample result of the dice tossing outcomes:

Dice	Dose
1	0.1
2	0.3
3	0.4
4	0.8
5	2.0
6	10.0

Trip to Mars:

SPE	Dose
1	0.4
2	2.0
3	0.1

On Mars:

SPE	Dose
1	0.3
2	2.0
3	0.4
4	0.3
5	10.0
6	0.4
7	0.1
8	2.0
9	0.3
10	0.3

Trip to Earth:

SPE	Dose
1	0.8

	Trip to Mars	On Mars	Trip to Earth
Total Rems.....	**2.5**	**16.1**	**0.8**

7. Calculate the mission's total dose by filling in the numbers below:

Amount of rems on trip to Mars + total SPE on trip to Mars = 15.4+2.5 = 17.9

Amount of rems while on Mars + Total SPE while on Mars = 43.8+16.1 = 59.9

Amount of rems on trip to Earth + Total SPE on trip to Earth = 38.4+0.8=39.2

Total dosage for entire trip = 117.0

NOTE: The values for the SPE contribution will vary depending on the dice tosses that come up for each group, but you may combine the results for all groups to get a 'class average' SPE dosage! These SPE doses assume the astronaut is shielded inside a spacecraft. If they are caught outside a shelter, the dosages from the SPEs are about 8-10 times higher!

Teacher's Answer Key

8. NASA's career equivalent doseages for astronauts is computed as follows:

200 + 7.5 (age - 30) rems (males up to 400 maximum rems)

200 + 7.5(age - 38) rems (females up to 400 maximum rems)

Using these formulas, answer the following questions:

How many trips to Mars could a 40 year old man take before reaching the maximum amount of 'career' radiation exposure recommended by NASA?

Total recommended dose = 200 + 7.5(40-30) = 275.0
Mars trip dose = 117.0 so number of trips is 2

How many trips to Mars could a 40 year old woman take before reaching the maximum amount of 'career' radiation exposure recommended by NASA?

Total recommended dose = 200 + 7.5(40-38) = 215.
Total trips = 215/117 = 1.8. This could either be stated as 1 or 2 trips.

Name some ways that the amount of radiation you received on this trip could vary.

Higher SPE exposure; more solar storms; defective shielding; less solar activity; better shielding. These are all possible answers.

Which of the two sources of radiation, cosmic rays and SPEs, are the most hazerdous and how would you try to minimize its risk to the crew?

SPEs are unpredictable and can deliver significant doses, especially if an astronaut is 'spacewalking' during which time little shielding is available. Some type of early warning system is required to anticipate when these storms may be starting on the solar surface. Either constant telescopic monitoring is needed, or some other method to sense the buildup of SPE conditions.

Based on what you have learned, what are some things you could do to minimize the amount of radiation that you would receive on a trip to Mars?

Stay in the spacecraft. Staying on Mars less than 2 years is not an option because you can only return when Mars and Earth are closest to each other every 2.1 years. It is not the stay on Mars that hurts you, it is the changing cosmic ray conditions during solar maximum and solar minimum. One possibility is to start and end your trip during the time that the sun is near its maximum in the solar cycle. This would reduce your non-SPE cumulative dose, which is the factor that dominates the total dosage. Start the trip 2 years before solar maximum, and end it 2 years after solar maximum would be a better strategy, provided you can reduce your risk for SPE events.

Teacher's Guide

Cosmic Rays And Sunspot Number

Introduction

Cosmic rays are very energetic particles, mostly protons and electrons, that enter the solar system from the depths of interstellar space. Although the Earth's magnetic field partially shields us from these particles, so too does the much more extended solar wind with its own magnetic field. When the sun is most active, the solar magnetic field is more intense, and so it provides additional sheilding from cosmic rays near the Earth. When the sun is less active, the wind is weaker and the shielding is less effective.

Objective

The student will analyze and compare two or more graphs to determine if there is a correlation between Sunspot Number and the variation of Cosmic Ray Flux.

Procedure

1. Divide the students into either pairs or groups of four. Read the introduction to the students.

2. Review with the students an example of how graphs may be similar and different. Be sure to include shape, distribution,highs, lows,scale, axis. and the time frame.

3. Provide students with a copy of the Student Activity # 1. Allow a sufficient amount of time for the students to complete the activities. Discuss their results and their conclusions.

4. Provide students with a copy of Student Activity #2 and provide them with appropriate time to complete the exercises.

Have the groups present their findings to the class. Some of the groups will argue that there is an almost perfect inverse relationship between the two graphs. Other groups may see the inverse pattern, but be unable to explain it in correct terminology. Finally, other students may take their explanations to a higher level by discussing the maxima and the minima and the actual fit of the data.

5. Provide students with a copy of Student Activity #3. Allow a sufficient amount of time to complete the activities. Discuss the results.

6. Provide students with the technology aspect using the TI - 83 graphing calculator and the magnification of the graphs.

Materials

Student Activity #1
Student Activity #2
Student Activity #3
Ruler
Transparencies (optional)
TI -83 Graphing Calculator (optional)

Have the groups present their findings to the class. Some of the groups will argue that there is an almost perfect inverse relationship between the two graphs. Other groups may see the inverse pattern, but be unable to explain it in correct terminology. Finally, other students may take their explanations to a higher level by discussing the maxima and the minima and the actual fit of the data.

Conclusions

Students will determine that the relationship between Sunspot Number and Cosmic Ray Flux is an inverse correlation. This may not be readily apparent to some students since the scales are so diverse. The activities introduce the students to the concept of magnifying a graph in order to better see the fit of the data. Students will also see that regardless of the location of the observatory, be it northern hemisphere or southern hemisphere, there is still an inverse correlation between the Sunspot Number and the Cosmic Ray Flux. Students will see that the data from the Huancayo, Peru observatory and the Climax, Colorado observatory are almost a perfect fit. Students can further investigate the relationship of Cosmic Ray Flux and Sunspot Number if they so choose. In order to do so, they may wish to check out more observatories and their data. For reference purposes:

Calgary, Canada	N51	W114	Altitude...1128m
Climax, Colorado	N39	W106	Altitude...3400m
Deep River, Canada	N46	W77	Altitude.....145m
Moscow, Russia	N55	E37	Altitude.....200m

Key Terminology:

Maxima: The locations on a curve where the y-axis values are largest.

Minima: The locations on a curve where the y-axis values are smallest.

Inverse Correlation: When one quantity increases, the other quantity decreases

Cosmic Ray Flux: The flow of particles through a region of space in a given amount of time.

Cosmic Rays: Particles, usually electrons or protons or even light atomic nuclei, which travel at high speed through interstellar space.

Flux: A term used to describe the flow of particles or radiation through space given in units of particles per second per square centimeter, or watts per square centimeter.

Name ____________________________ **Date**__________________

Student Activity # 1

The following table contains the data for the variation of Cosmic Ray Flux. From these averages, use the table to create an appropriate graph for Huancayo's observations of the measurement of Cosmic Ray Flux, and then answer the following questions. Please use a scale from 2 to -2 in increments of tenths.

Huancayo Observatory's Measurement Of Cosmic Ray Flux Over Time

Year	Cosmic Ray Flux	Year	Cosmic Ray Flux
1954	1.35	1976	1.10
1956	0.00	1978	.600
1958	-1.3	1980	-.20
1960	-1.2	1982	-.90
1962	.400	1984	-.40
1964	1.00	1986	1.25
1966	1.20	1988	.100
1968	.100	1990	-.70
1970	0.00	1992	-.10
1972	.600	1994	0.00
1974	.400		

1. Describe any patterns that may be evident. Be sure to include the years that span maxima or minima.

2. Why do you think that a scale using tenths was selected?

3. Would the shape and distribution of the graph change if we were to magnify the graph by a factor of ten?

Name ______________________________

Date________________

Name ____________________________

Date________________

Student Activity #2

Construct the appropriate graph based on the following table and determine if there is a correlation with the graph of the variation of Cosmic Ray Flux from Huancayo. Communicate your analysis in the space beside the graph. Be sure to include supporting evidence.

Recorded Sunspot Number

YEAR	Sunspot Number	YEAR	Sunspot Number
1950	84	1973	38
1951	69	1974	34
1952	31	1975	16
1953	14	1976	13
1954	4	1977	27
1955	38	1978	92
1956	142	1979	155
1957	190	1980	154
1958	185	1981	140
1959	159	1982	116
1960	112	1983	67
1961	54	1984	46
1962	38	1985	18
1963	28	1986	14
1964	10	1987	32
1965	15	1988	98
1966	47	1989	154
1967	94	1990	146
1968	106	1991	144
1969	106	1992	94
1970	104	1993	56
1971	67	1994	30
1972	69		

Name ______________________________

Date________________

Name ___________________________   Date________________

Student Activity #3

The observatory in Huancayo, Peru is in the southern hemisphere.After completing the prior activities, it should seem evident that certain events in our universe affect one another. In order to investigate this connection further, more data will need to be analyzed.

Suppose we were to make a hypothesis that is based on the results from Huancayo. It is assumed that an observatory in the north may also experience some sort of a correlation. Based on the previous data analysis, state a hypothesis about an observatory in the northern hemisphere that would be observing the same events.

It just so happens that there is an observatory located in Climax, Colorado. Please construct the appropriate graph to display the given data. Please use a scale from 2 to -2 with increments of tenths.

Climax Observatory's Measurement Of Cosmic Ray Flux Over Time

Year	**Cosmic Ray Flux**	**YEAR**	**Cosmic Ray Flux**
1954	1.30	1976	1.20
1956	0.70	1978	.800
1958	-1.7	1980	-.50
1960	-1.1	1982	-1.2
1962	.100	1984	-.40
1964	0.90	1986	1.20
1966	0.80	1988	.100
1968	-.40	1990	-1.8
1970	-.40	1992	-.70
1972	.900	1994	0.60
1974	.900		

Using the graphs for Huancayo and Climax, what conclusion can be drawn about the effects of the northern and southern hemisphere in regards to the variation of Cosmic Ray Flux. In addition, how does this conclusion relate with the Sunspot Number?

Suppose data from the observatories in Deep River and Calgary, Canada, as well as Moscow, Russia were given. What would be the expected correlation to both the variation of Cosmic Ray Flux as well as the Sunspot Number? Justify your reasoning.

Name ______________________________

Date________________

Teacher Notes For The Graphing Calculator

Reminder: Be sure to reset the calculator using “Teacher Notes for the Graphing Calculator” included in the previous sunspot lesson. The commands for the graphing calculator are given in bold print beside the windows.

Students will enter the following estimated table of values taken from the measurement of Cosmic Ray Flux for Huancayo. The year will be entered into list 4, the Cosmic Ray Flux intensity will be entered in list 5, and the Sunspot Number for the corresponding years will be entered in list 6.

Directions For Activity #1 and Activity #2

Cosmic Ray Flux For Huancayo Versus The Sunspot Number

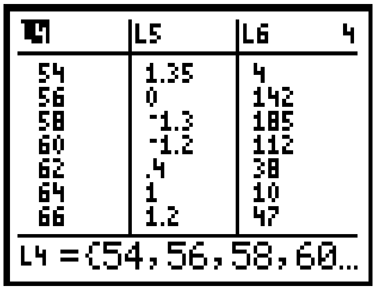
Year	Cosmic Ray Flux	Sunspot Number	YEAR	Cosmic Ray Flux	Sunspot Number
1954	1.35	4	1976	1.1	13
1956	0	142	1978	.6	92
1958	-1.3	185	1980	-.2	154
1960	-1.2	112	1982	-.9	116
1962	.4	38	1984	-.4	46
1964	1.0	10	1986	1.25	14
1966	1.2	47	1988	.1	98
1968	.1	106	1990	-.7	146
1970	0	104	1992	-.1	94
1972	.6	69	1994	0	30
1974	.4	34			

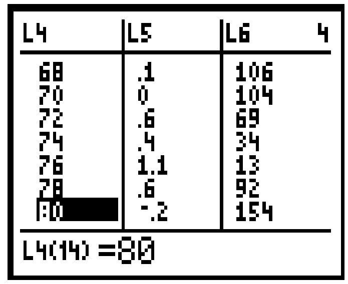
Entering the data into the list will consist of the following keystrokes:

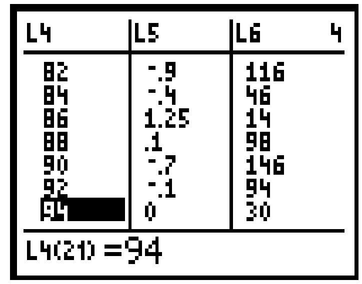
STAT **ENTER**

When entering data, enter the value and then **ENTER**, until the list is complete. Then arrow to the right, and enter the value for that list.

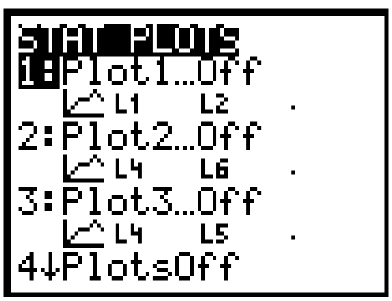
This will put you at the window to input the data for the year into your selected lists. **Note**: I selected to use lists 4, 5, and 6. When entering data, type the value and then push **ENTER**, until the list 4 is complete. Next arrow to the right, and enter the values for list 5 by typing the data value and pushing **ENTER**. Finally, arrow to the right, and enter the values for list 6 by typing the data value and pushing **ENTER**. Sample screen images shown below.





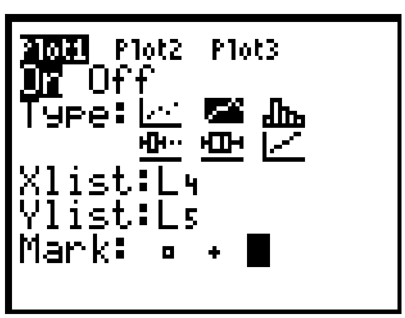


After the data has been entered into the lists, the stat plot needs to be turned on. To turn the plots on, use the following keystrokes:



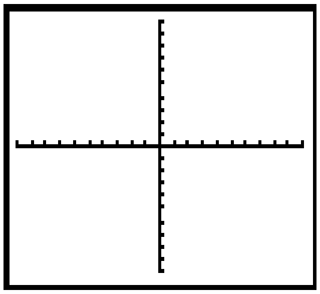
2ND Y = ENTER

The next step is to turn on the appropriate graph and to use the correct data lists.
Since the data is in List 4, List 5, and List 6, those are the ones we shall select. To turn the plot on, make sure that the cursor is blinking over the **ON** and push **ENTER**. Next arrow down and over to select the second graph. Once the cursor is flashing over it , push **ENTER**. Arrow down to the X list and push **2ND 4,** arrow down to the Y list and push **2ND 5.** These steps have allowed for the data in lists four and five to be graphed. The appropriate windows would appear as follows:

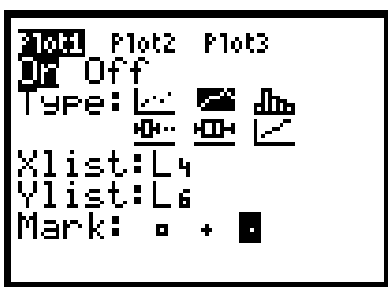


GRAPH

The next step is to graph the data. When the students push the graph key, they may or may not see a part of the graph. If the calculator was reset prior to beginning the lesson, the students would see the following blank display. It is necessary to adjust the viewing window using **ZOOM 9**. The window that the student should see is shown below.



To turn the second plot on, push **2ND Y =**. Next arrow down and select the second plot, **ENTER**. Make sure that the cursor is blinking over the **ON** and push **ENTER.** Next arrow down and over to select the second graph Once the cursor is flashing over it , push **ENTER**. Arrow down to the X list and push **2ND 4**, arrow down to the Y list and push **2ND 6**. These steps have allowed for the data in lists four and six to be graphed. Students may wish to see the graph at this point.

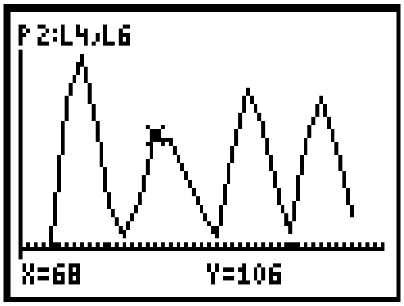


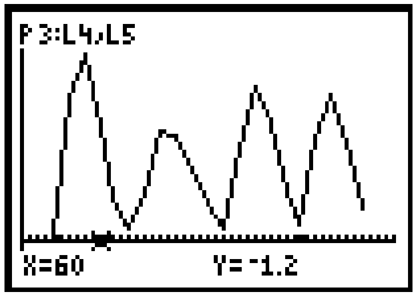
GRAPH

NOTE: The first time that the students did a zoom 9, they saw the data in list 4 and list 5, which is the Cosmic Ray Flux (ONE GRAPH!). When they push the graph button again they will see one graph, the Sunspot Number data in list 4 and list 6. It will not be until they use the **ZOOM 9** to fit the data that they will view both graphs. Even then, most students will believe that there is only one graph because the values in list 5 are so minimal. At this point, to help the students to understand that there are two graphs, it is necessary to move along the graphs and to look at the values displayed. In order to move along the values and to compare the two graphs, push **TRACE**.

The up and down arrow keys allow movement between the two graphs, and the right and left arrow keys allow movement along a graph.

This is a good time to discuss the appropriate graph for this data and why it should be a line graph. Students are aware that a line graph is appropriate for time. However, be sure to include the fact that the data is continuous and needs to be displayed as such.



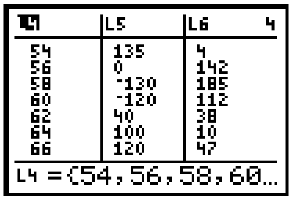


Students will have a very difficult time visualizing these two graphs, especially since the one for cosmic ray flux (L5) appears to not be there. If you look at the windows given above and note that the second window does display the values in the table, the students can start to understand that there really is a second graph. Explain to them that there are really two graphs displayed. This leads to a discussion about the scales and values needed to compare these two sets of data.

In the study of science, scientists need to sometimes magnify a certain set of data in order to visualize the correlation. In doing this exercise,and depending on your time available for exploration, a magnification of ten may be selected and applied to the values for Huancayo in list 5. The graph is still not readily apparent. This will lead the students to think that maybe they need to increase the magnification. Be aware that the magnification of 100 seems to be a nice visual representation. Have the students multiply the data for the Cosmic Ray Flux by 100, and then enter the data into list 5 . Follow the same procedures for entering and displaying the data.

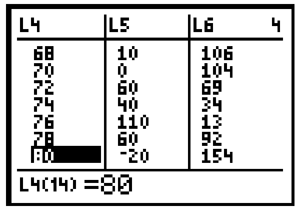
Directions For Magnification

Have the students begin with a magnification of ten, and then view the data. After discussing that further magnification is necessary, magnify the data to 100 times the original. Display the results and discuss the conclusions.The windows for magnification of 100 times are:



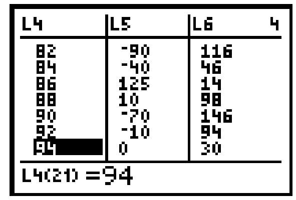
L4	L5	L6
54	135	4
56	0	142
58	-130	185
60	-120	112
62	40	38
64	100	10
66	120	47

L4 ={54,56,58,60…



L4	L5	L6
68	10	106
70	0	104
72	60	69
74	40	34
76	110	13
78	60	92
80	-20	154

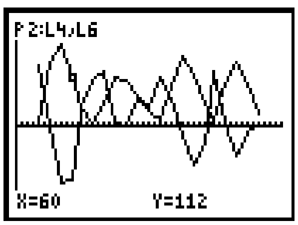
L4(14) =80



L4	L5	L6
82	-90	116
84	-40	46
86	125	14
88	10	98
90	-70	146
92	-10	94
94	0	30

L4(21) =94

The graph display then appears as the following:



TRACE

This allows the students to use the trace function, and to determine that there is an inverse relationship. That is, when the Sunspot Number is high, the Cosmic Ray Flux is low.

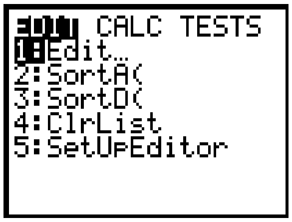
The same procedures can be followed for each of the remaining four stations. The results should be the same.

A variation may be to have the students decrease the scale on the Sunspot Number by a certain value.

Directions For Activity # 3

The data table for Huancayo and Climax will be needed. The year will be entered into list 1, Huancayo data in list 2, and Climax data in list 3.

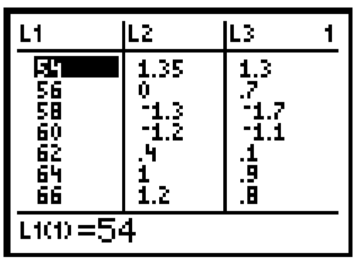
Entering the data into the list will consist of the following keystrokes:

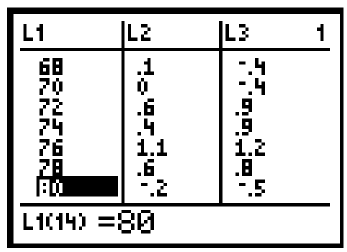


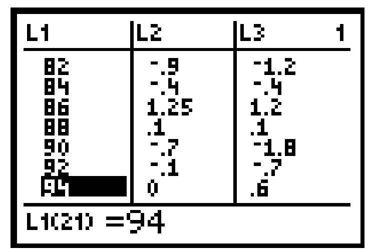
STAT ENTER

This will put you at the window to input the data for the year into your selected lists. When entering data, enter the value and then **ENTER,** until the list is complete. then arrow to the right, and enter the values for that list.

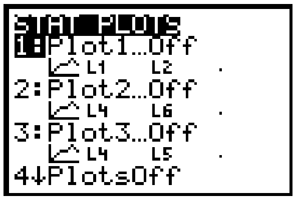
Sample screen images shown below.





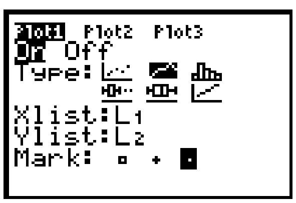


After the data has been entered into the lists, the stat plot needs to be turned on. To turn the plots on, use the following keystrokes:

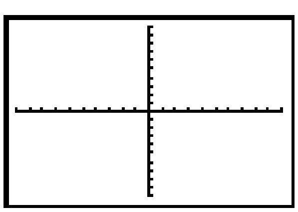


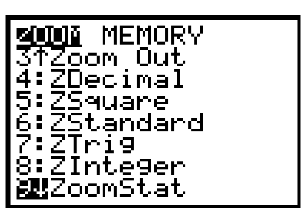
2ND Y = ENTER

The next step is to turn on the appropriate graph and to use the correct data lists.
Since the data is in List 1, List 2, and List 3, those are the ones we shall select. To turn the plot on, make sure that the cursor is blinking over the **ON** and push **ENTER**. Next arrow down and over to select the second graph. Once the cursor is flashing over it , push ENTER. Arrow down to the X list and push **2ND 1,** arrow down to the Y list and push **2ND 2.** These steps have allowed for the data in lists one and two to be graphed. Students may wish to see the graph at this point. The window is displayed below.

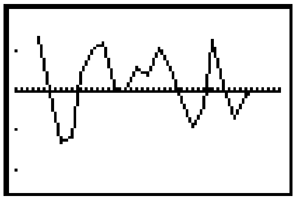


The next step is to graph the data. When the students push the graph key, they may or may not see a part of the graph. If the calculator was reset prior to beginning the lesson, the students would see the following blank display. It is necessary to adjust the viewing window using **ZOOM 9**. The window that the student should see is shown below.

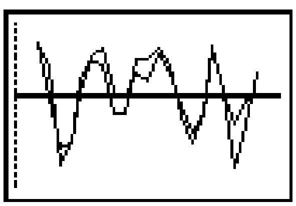




The students will be viewing the data for Huancayo only. The graph for Huancayo is as follows:



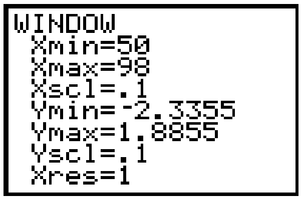
It is important that they realize that the second plot needs to be turned on to view Climax data.To turn the second plot on, push **2ND Y =.** Next arrow down and select the second plot, **ENTER**. Make sure that the cursor is blinking over the **ON** and push **ENTER.** Next arrow down and over to select the second graph Once the cursor is flashing over it , push **ENTER**. Arrow down to the X list and push **2ND 1**, arrow down to the Y list and push **2ND 3**. These steps have allowed for the data in lists one and three to be graphed. Students may wish to see the graph at this point. The graph is displayed below.



TRACE

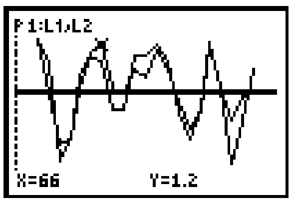
It is necessary to move along the graphs and to look at the values displayed.In order to move along the values and to compare the two graphs, push **TRACE**.The up and down arrow keys allow movement between the two graphs, and the right and left arrow keys allow movement along a graph.

Discuss with students the scale involved on the graphs. The calculator has used a scale, possibly of one. In order to more fully appreciate the graphs, the students will need to adjust their scale to tenths. Push the **WINDOW** key. Change the Xscl to .1 and the Yscl to.1. Return to the graph. A sample window is shown below.



GRAPH

Students can **TRACE** the graphs and see that they are almost exactly alike. The differences occur at the maxima and the minima, which are the inverse of the Sunspot Number's maxima and minima. The graph is displayed below.



This may be a good time to ask the students what they think will happen if the magnification is changed to .001, and then explore the effects on the graph by changing the window values. They should determine that it is the same graph with a different scale.

EXTENSION:

Have the students find or develop two sets of data that show a nice fit and correlation, a set of data that has an inverse correlation, and a set of data that appears to have no correlation. Next, have the students interpret that data and justify their results. Ask the students how they feel about manipulating data in this way to 'bring out detail'. Some students may not like to tamper with the data to be able to draw conclusions.

NOTE: This is a really nice activity and opportunity for students to explore and use real data on the internet.

Glossary

Aurora : Also called the ‘Northern Lights’ in the Northern hemisphere, or the ‘Southern Lights’ in the Southern hemisphere. These wispy curtains of light in the sky are caused by energetic electrons which collide with atoms of oxygen and nitrogen in the air to cause these atoms to emit shades of green, red and blue light. They never descend nearer than 60 kilometers from the Earth’s surface.

Corona : The very tenuous outer layers of the Sun which are seen during a total eclipse of the sun, but extending millions of miles into interplanetary space. It is heated to temperatures of over one million degrees by magnetic activity at the surface of the Sun. For decades, scientists puzzled over why the Corona could be so much hotter than the balmy 5770 degree Kelvin surface of the Sun.

Coronal Mass Ejection : The sudden expulsion of matter from the coronal regions of the sun, often involving billions of tons of plasma ejected at over one million kilometers per hour. During sunspot minimum conditions, about one ‘CME’ can be expelled every few days. During sunspot maximum conditions, as many as 3-5 can occur each day.

Magnetopause : A region that defines the outer edge of the magnetosphere where the pressure of the solar wind is balanced by the pressure of the earth’s own magnetic field.

Magnetosphere : The region surrounding the Earth in space where its magnetic field is important in controlling the movements of charged particles. Also sometimes referred to as ‘Geospace’.

Magnetotail : The solar wind pulls the magnetosphere into a comet-like shape. The long tail of this field, called the magnetotail’ or also the ‘geotail’, extends millions of kilometers into space in a direction opposite to the Sun from the Earth.

Solar flare : A powerful release of energy on the surface of the sun usually lasting less than a few hours, but releasing as much energy as 1000 hydrogen bombs. These are often associated with active regions of the solar surface where magnetic fields have become badly tangled, and then snap, releasing energy and heating local gases to over 1 million degrees.

Solar storm : Although scientists prefer not to use this term because it is technically rather vague, it has come to mean any of a number of active conditions on the Sun’s surface including flare activity or coronal mass ejections.

Sunspot : A dark spot on the Sun’s surface that indicates a concentration of magnetic forces. They are actually about 2000 degrees cooler than the solar surface, and only look dark because they emit light faintly.

Sunspot Cycle : The change in the number of sunspots from one period of its maximum to the next, over the course of about 11 years.

Sunspot Maximum : The period during the sunspot cycle when you will see the largest number of sunspots. Also called the ‘Solar Maximum’.

Sunspot Minimum: The period during the sunspot cycle when you will see the fewest number of sunspots. Also called the ‘Solar Minimum’

Resources

IMAGE	http://image.gsfc.nasa.gov
POETRY	http://image.gsfc.nasa.gov/poetry
SOHO	http://sohowww.nascom.nasa.gov
NASA Sun-Earth Connection Resources	http://sunearth.gsfc.nasa.gov
The Earth's Magnetic Field	http://image.gsfc.nasa.gov/poetry/magneto.html
Satellite Glitches -Space Environment Info	http://envnet.gsfc.nasa.gov
Magnetic North Pole	http://www.nrcan.gc.ca/gsc/cpdnew/magnet.html
Solar Sounds	http://soi.stanford.edu/results/sounds.html
Sunspot Number Archives / Resources	http://image.gsfc.nasa.gov/poetry/sunspots.html
CME Archives at MLSO	http://www.hao.ucar.edu/public/research/mlso/movies.html
Stellar Activity Cycles at Mt. Wilson	http://www.mtwilson.edu/Science/HK_Project/
Satellite Data	http://cdaweb.gsfc.nasa.gov
Space Weather Resources	http://image.gsfc.nasa.gov/poetry/weather.html
Magnetic Observatories and Data	http://image.gsfc.nasa.gov/poetry/maglab/magobs.html
Space Environments and Effects	http://see.msfc.nasa.gov/sparkman/Section_Docs/sparkman.html
Sun-Earth Classroom Activities Archive	http://sunearth.gsfc.nasa.gov/educators/class.html
Storms from the Sun	http://www.istp.gsfc.nasa.gov/istp/outreach/learn.html
The Aurora Page	http://www.geo.mtu.edu/weather/aurora/
Space Weather Human Impacts	http://image.gsfc.nasa.gov/poetry/storm/storms.html
Ionosphere density and sunspot numbers	http://julius.ngdc.noaa.gov:8080/production/html/IONO/ionocontour_90.html
Space Weather Daily Reports	http://windows.engin.umich.edu/spaceweather/index.html
Solar wind density and speed	http://www.sel.noaa.gov/wind/rtwind.html

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