National Aeronautics and
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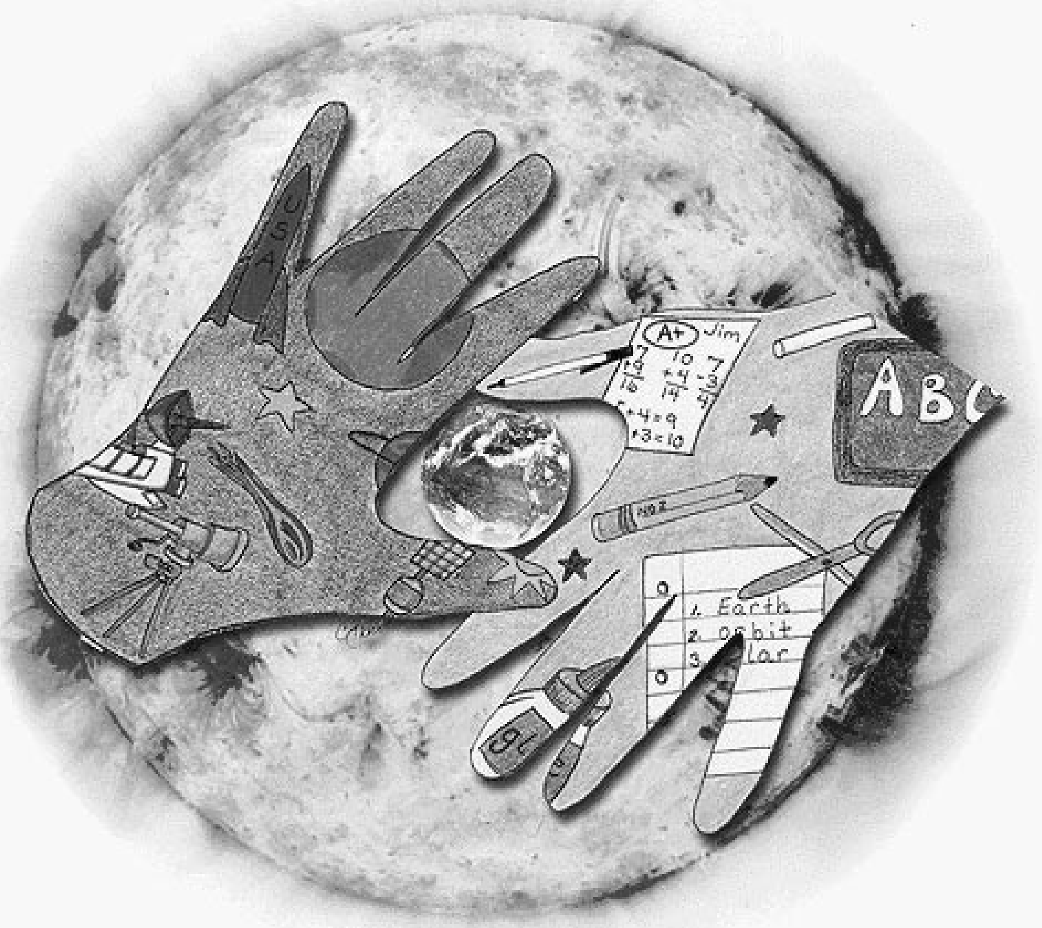
Educators & Students	Grades 5-8

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:
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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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Goddard Space Flight Center

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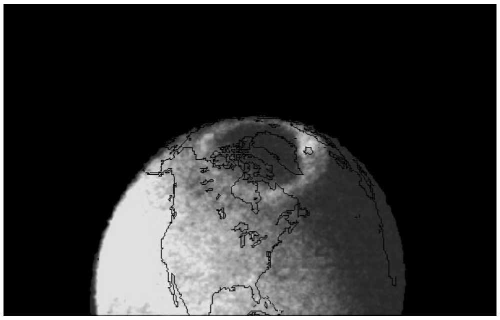
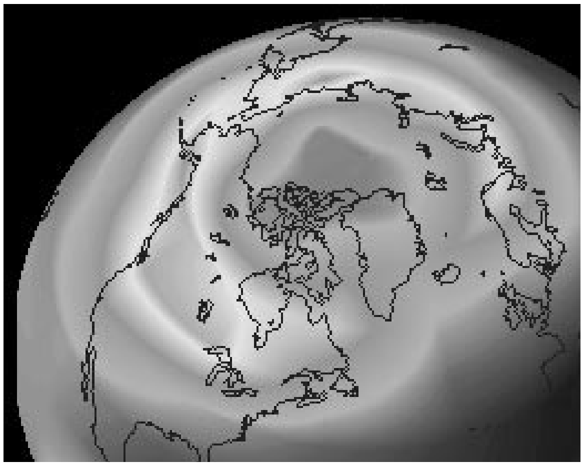




Aurora seen from space look very different than from the ground. The space perspective lets you see the entire circle of auroral activity which encircles the north magnetic pole like a diamond ring. It also gives scientists a truely 3-D view of this phenomenon making it much easy to study.

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.

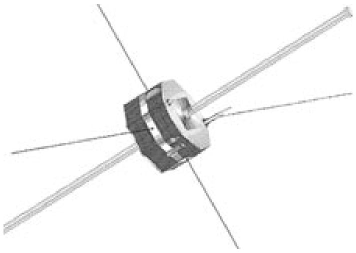
In this activity book, your students will study five key stages in the lifecycle of a solar storm, from its emergence on the solar surface to its impact upon some aspect of our lives. The book may be used in its entirety to study solar activity and how it directly affects us, or you may use individual 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!*

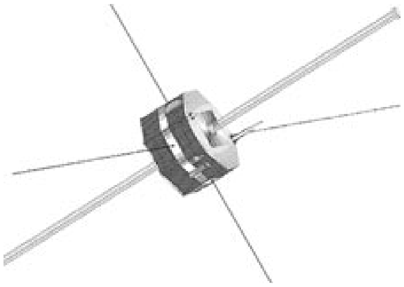


This chart is designed to assist teachers in integrating the activities contained in the guide with existing curricula.

	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!*



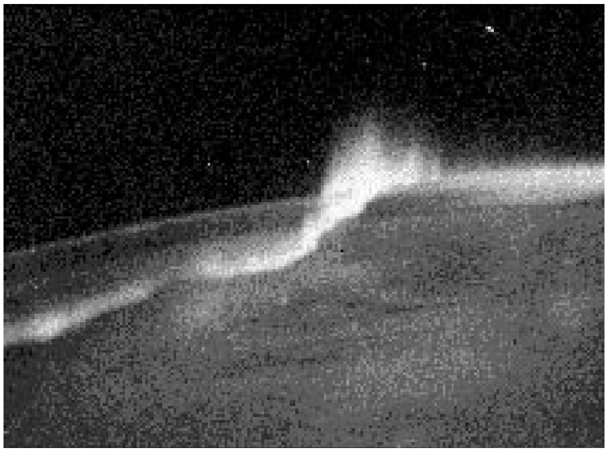
This chart is designed to assist teachers in integrating the activities contained in the guide with existing curicula.

	Lesson 1 *“A Simple AM Radio Ionosphere Station”*	**Lesson 2** *“Radio Waves and the Ionosphere”*	**Lesson 3** *“The Aurora”*
Science as Inquiry	○	○	○
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		○	

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.

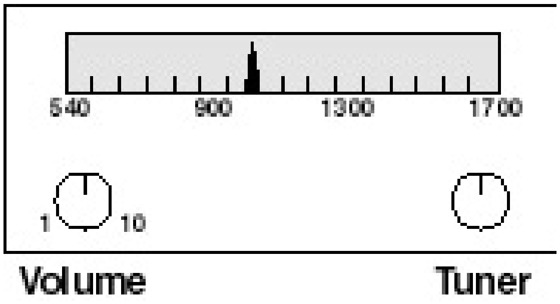
—A paper disk with a hole punched in its center to fit over the volume control.

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/inspire

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.

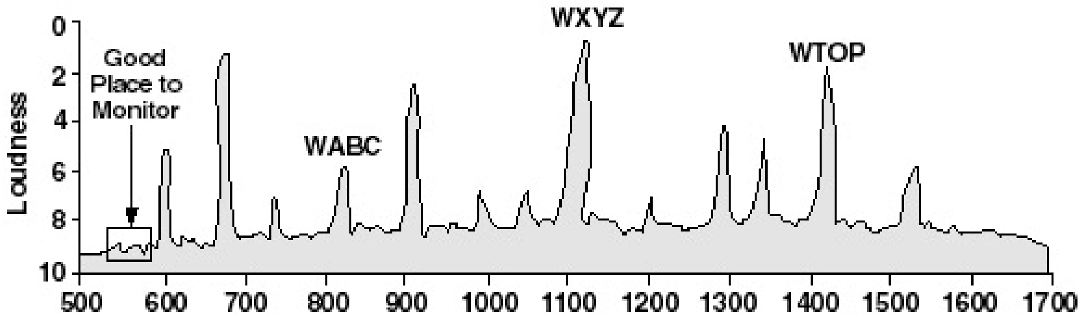
Sample Journal Entries:

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)

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

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.

Materials

—Protractor
—Calculator (if available)

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:

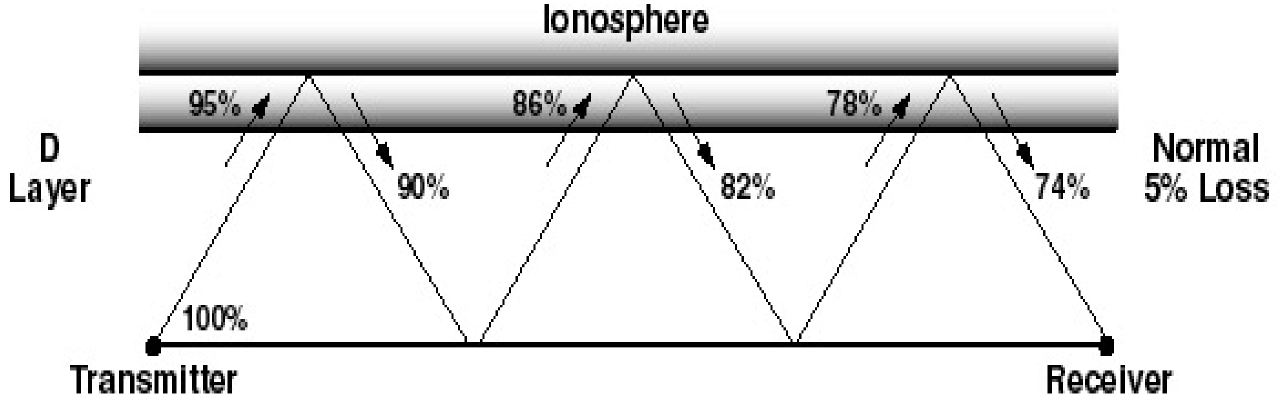
Normal 5% loss:
100% x 0.95 = 95%
95% x 0.95 = 90% (Final)

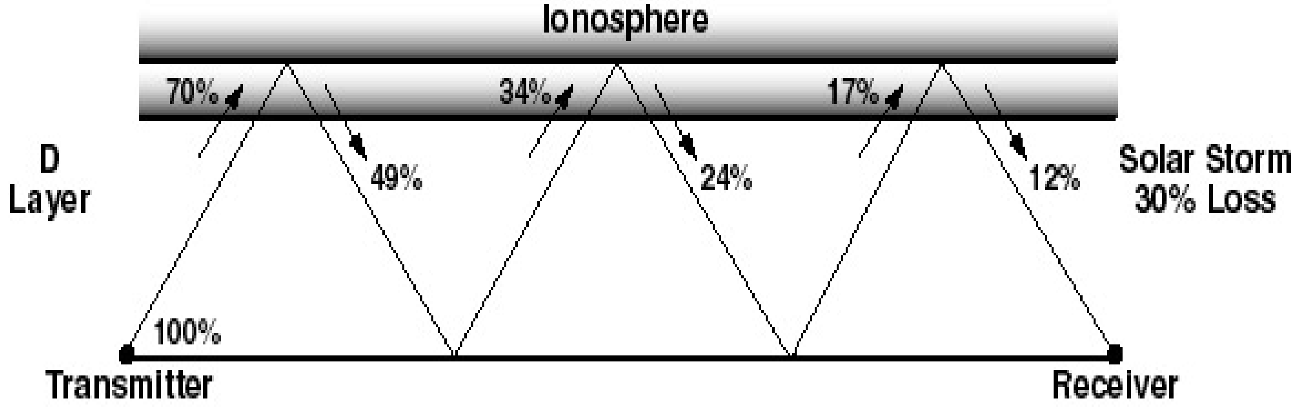
Solar Storm 30% loss:
100% x 0.70 = 70%
70% x 0.70 = 49% (Final)

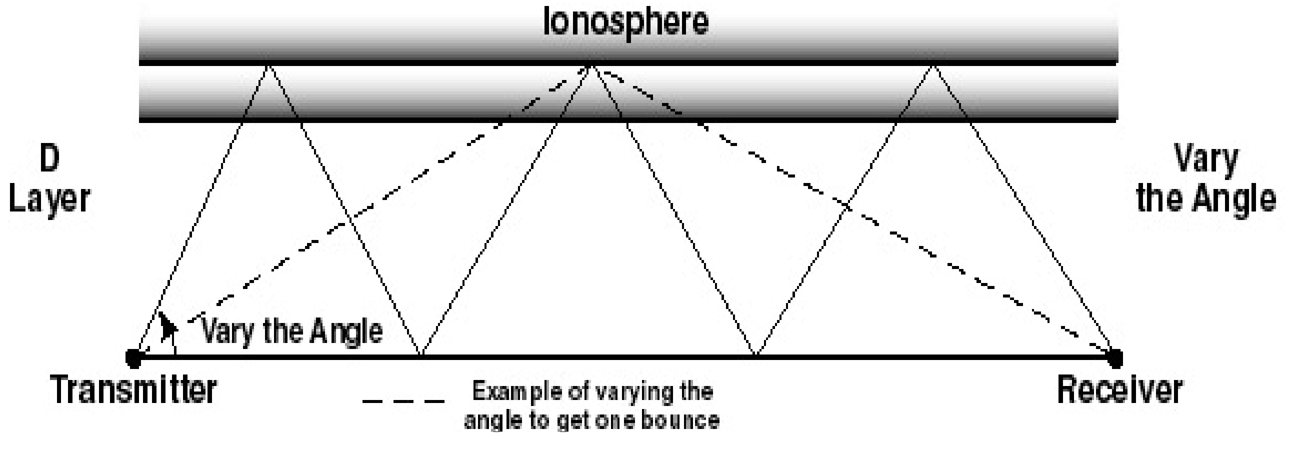
Conclusion

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



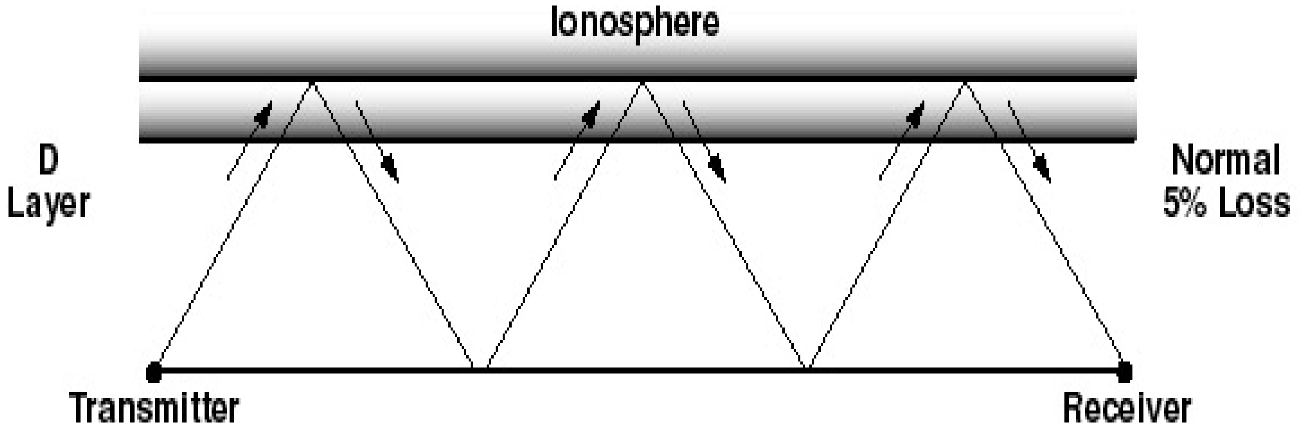


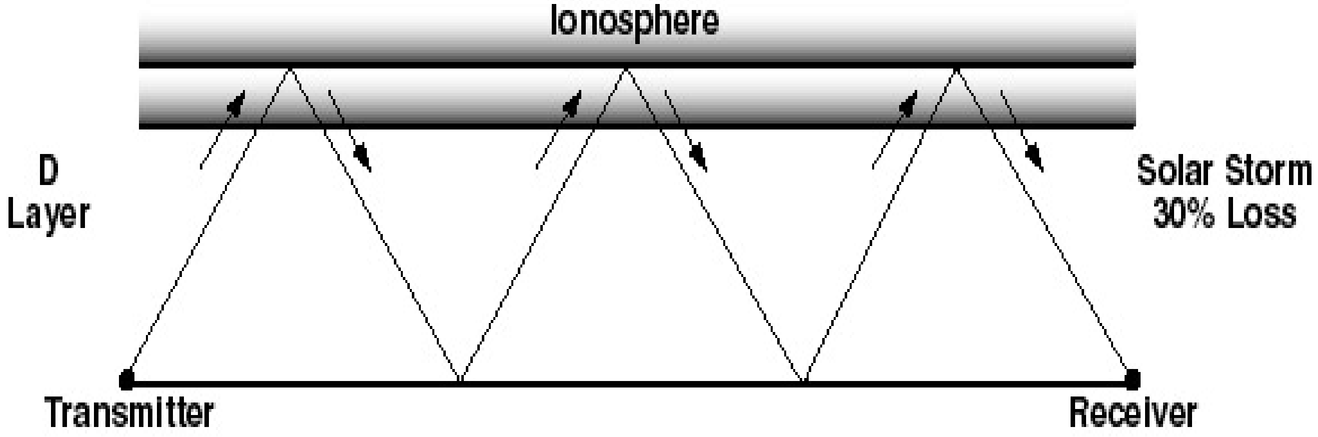


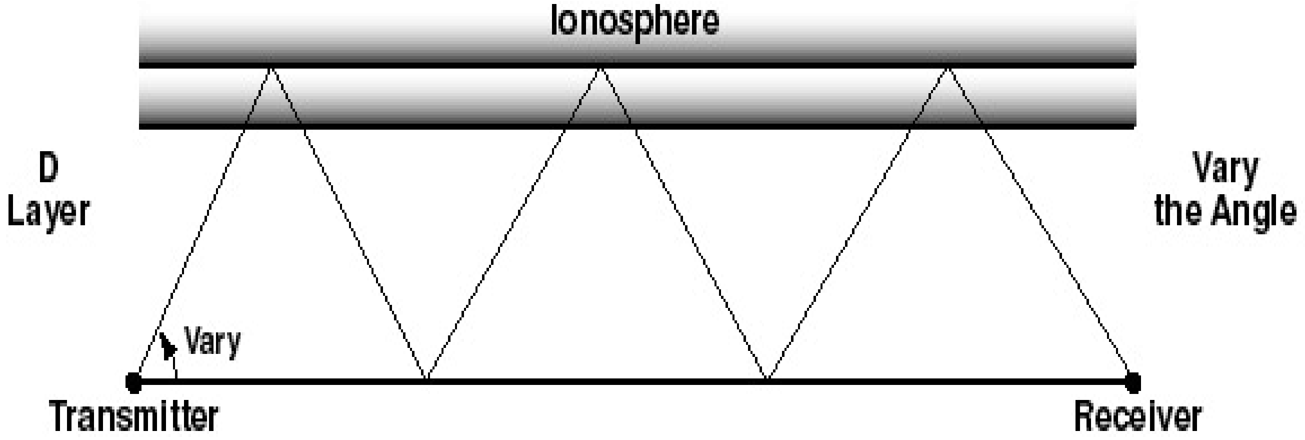
Radio waves travel from the transmitter to the receiver. The signal bounces from the ground, through a layer called the D-Layer, and is then reflected from the ionosphere back through the D-Layer to the ground. The waves continue to be reflected in this way until they reach the receiver. When the waves 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

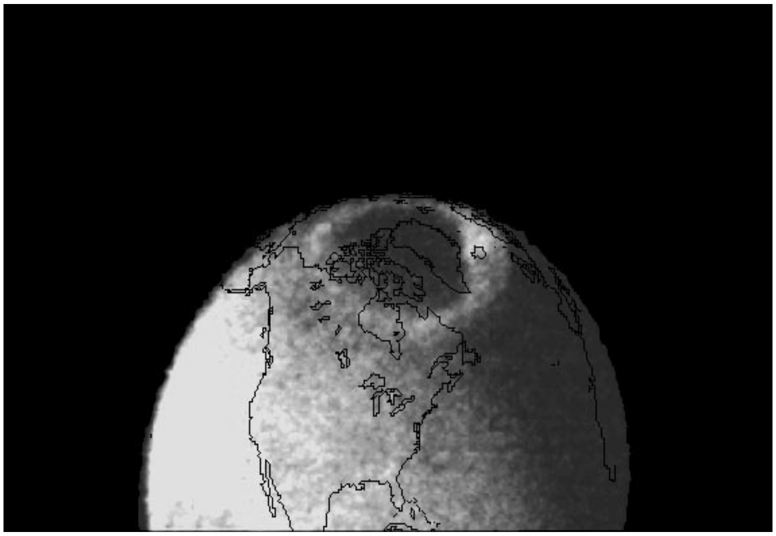
— "The Aurora: New Light on an Old Subject"

—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.**

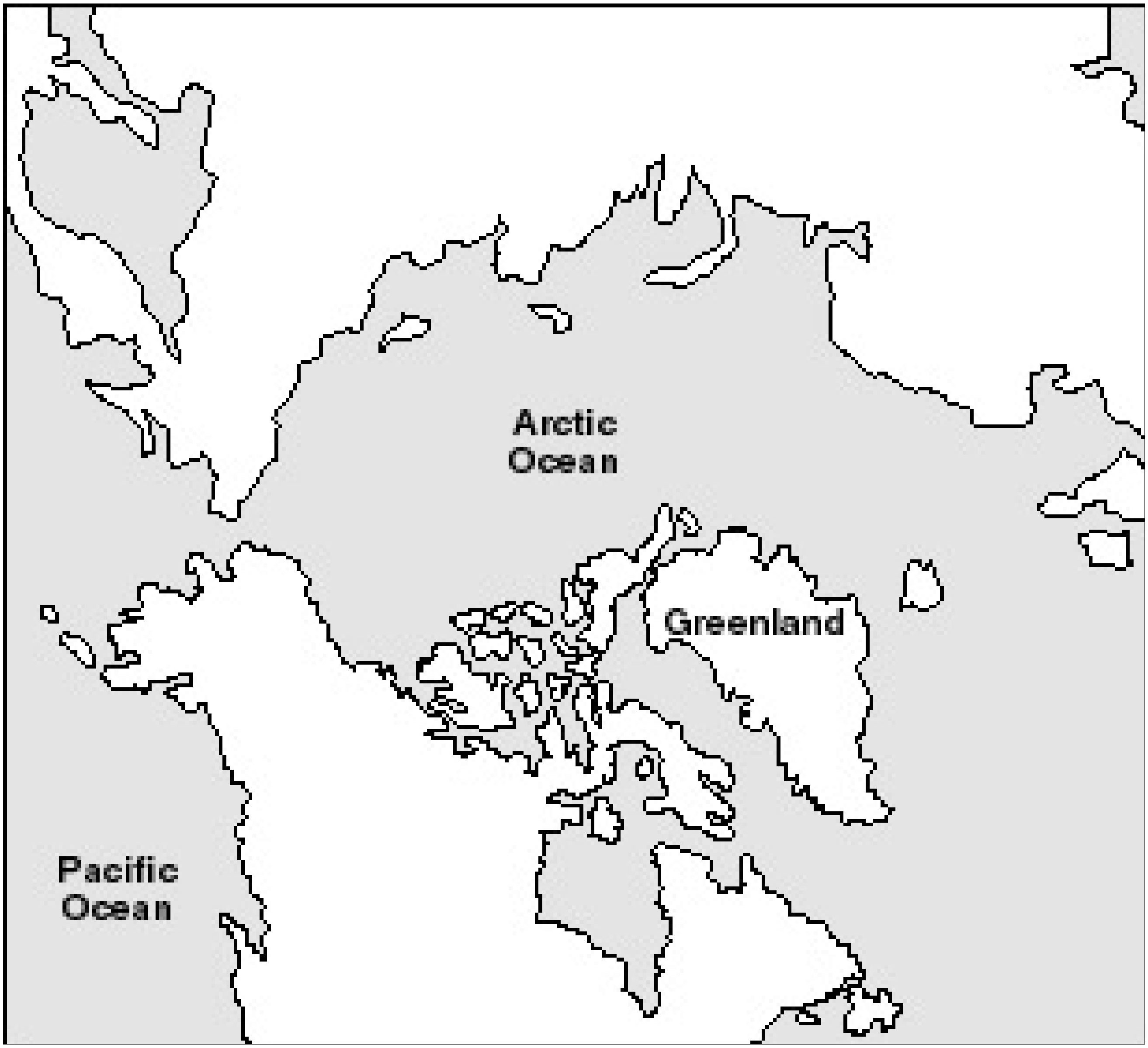
6. **The science of studying the sun and the aurora is a complex process where some ideas may change while other ideas remain supported by new data. Identify ideas that have changed and why the change happened.**

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

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