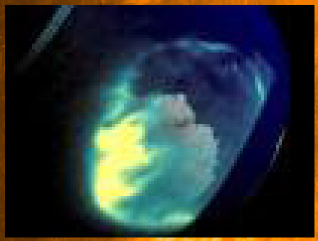
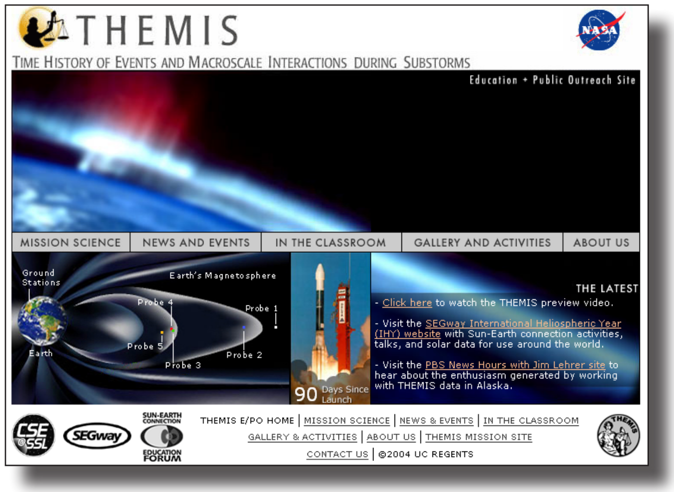
National Aeronautics and Space Administration

Magnetic Mysteries of the Aurora

grades 9-14





This teacher's guide is designed to support a multi-year investigation of Earth's magnetic field using the magnetometer network and resources of NASA's THEMIS (Time History of Events and Macroscale Interactions during Substorms) satellite mission education program. The education program's web site can be found at http://ds9.ssl.berkeley.edu/themis/. One particular THEMIS education program, the Geomagnetic Event Observation Network by Students (GEONS), aims to bring magnetometer data to high school classrooms. These guides support that effort.

The activities were designed in partnership with the IMAGE (Imager for Magnetopause-to-Aurora Global Exploration) satellite's education program (http://image.gsfc.nasa.gov/poetry) and the many activities developed for that mission in the exploration of the magnetosphere. The FAST (Fast Auroral Snapshot) education program also contributed to this effort (http://cse.ssl.berkeley.edu/fast_epo).

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Contents

National Science Education Standards

Standards Key

M - major emphasis

m - minor emphasis

i - indirect; i.e., not directly tied to standard, but important background information.

The letters A-G represent various areas in the National Science Education Standards, as follows:

A - Science as Inquiry

B - Physical Science: Motion and Forces

C - Life Science

D - Earth and Space Science

E - Science and Technology

F - Science in Personal and Social Perspectives

G - History and Nature of Science

Activity	A	B	D	E	F	G	Emphasis
9 - The Sun Earth Connection	m	M M M	m	M	M	m M	A: Identify questions and concepts that guide scientific investigations. B: (Structure of Atoms). Matter is made of minute particles called atoms, and atoms are composed of even smaller components.These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. B: (Forces and Motion). Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. B: (Interactions of Energy and Matter). Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. D: Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. E: (Understanding About Science and Technology). Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. F: (Natural and human-induced hazards). Natural and human-induced hazards present the need for humans to assess potential danger and risk. G: (Science as a Human Endeavor) Individuals and teams have contributed and will continue to contribute to the scientific enterprise. G: (Nature of Scientific Knowledge) Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available.
10 - The Magnetosphere		M M m	m	M		m M	B: (Structure of Atoms). Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. B: (Forces and Motion). Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. B: (Interactions of Energy and Matter). Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance. D: Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. E: (Understanding About Science and Technology). Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. G: (Science as a Human Endeavor) Individuals and teams have contributed and will continue to contribute to the scientific enterprise. G: (Nature of Scientific Knowledge) Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available.

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Activity	A	B	D	E	F	G	Emphasis
12 - Univ. Time			i			m	G: (Science as a Human Endeavor) Individuals and teams have contributed and will continue to contribute to the scientific enterprise.
13 - The Aurora	m	M M M	i	m		m	A: Identify questions and concepts that guide scientific investigations. B: (Structure of Atoms). Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. B: (Forces and Motion). Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. B: (Interactions of Energy and Matter). Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance. E: (Understanding About Science and Technology). Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. G: (Historical Perspectives) In history, diverse cultures have contributed scientific knowledge and technologic inventions.
14 - Magnetic Storms	M	m	i	M		m	A: Design and conduct scientific investigation; Use technology and mathematics to improve investigations and communications. B: (Forces and Motion). Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. E: (Understanding About Science and Technology). Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research. G: (Nature of Scientific Knowledge) Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available.

National Math Standards

NM-NUM.9-12.3: (Numbers and Operations). Compute fluently and make reasonable estimates.

NM-ALG.9-12.3: (Algebra). Use mathematical models to represent and understand quantitative relationships.

NM-GEO.9-12.2: (Geometry). Specify locations and describe spatial relationships using coordinate geometry and other representational systems.

NM-GEO.9-12.4: (Geometry). Use visualization, spatial reasoning, and geometric modeling to solve problems.

NM-MEA.9-12.1: (Measurement). Understand measurable attributes of objects and the units, systems, and processes of measurement.

NM-MEA.9-12.2: (Measurement). Apply appropriate techniques, tools, and formulas to determine measurements.

NM-DATA.9-12.1 (Data Analysis & Probability). Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer.

NM-DATA.9-12.2 (Data Analysis & Probability). Select and use appropriate statistical methods to analyze data.

NM-DATA.9-12.3: (Data Analysis & Probability). Develop and evaluate inferences and predictions that are based on data.

NM-DATA.9-12.4: (Data Analysis & Probability). Understand and apply basic concepts of probability

NM-PROB.CONN. PK-12.3: (Connections - Grades Pre-K - 12). Recognize and apply mathematics in contexts outside of mathematics.

Standards Key

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Activity	NM-NUM. 9-12.3	NM-ALG. 9-12.3	NM-GEO. 9-12.2	NM-GEO. 9-12.4	NM-MEA. 9-12.1	NM-MEA. 9-12.2	NM-DATA. 9-12.1	NM-DATA. 9-12.2	NM-DATA. 9-12.3	NM-DATA. 9-12.4	NM-PROB. CONN. PK-12.3
11 - Time Zone Math	m	m				M					m
12 - Universal Time	m	m				M					m
13 - The Aurora	m	m	M	M		M					m
14 - Magnetic Storms	m				M		M	m	M	M	m

Introduction to the THEMIS Magnetism Series

This is one of four magnetism activity guides—plus a background guide for teachers—that provide students with the opportunity to build on science concepts related to Earth's magnetism and its changes. If your students engage in the activities in these four guides, they will have the skills, language and conceptual understandings of magnetism— one-half of the four fundamental forces of nature (the whole force is known as electromagnetism).

All of these guides have been:

- Classroom tested
- Checked for science accuracy by NASA and THEMIS scientists
- Designed to utilize math and writing

The goal of these guides is to give students an appreciation of the major role magnetism plays on Earth and in space, and ultimately enable them to use NASA data as "scientists" researching our magnetic connection to the Sun. We achieve this goal through sequential activities in the four teachers' guides, from basic explorations with magnets, compasses and galvanometers to scientific discoveries using data from instruments called magnetometers. These magnetometers are located in schools across the U.S, as part of the THEMIS education project.

The four activity guides have been used in different types of classes, from physical science and physics classes, to geology and astronomy classes. The excitement of actually participating in the THEMIS project helps motivate the students to learn challenging physical science concepts.

1. **Magnetism and Electromagnetism** is a review of basic magnetism, similar to what is encountered in most grade-level physical science texts. Students map field lines around bar magnets to visualize the magnetic dipole field, and create their own electromagnet using copper wire, battery and a pencil to learn that electric currents create magnetic fields. Two activities introduce generators and Lenz's law, in one case using Earth's magnetic field and a large conducting wire. These materials can be used by teachers presenting Earth and Physical Science courses in grades 6-9, and would fit well into a lab at the end of a high school physics class. These activities are a classroom-ready prerequisite to understanding magnetism on Earth and in space.

2. **Exploring Magnetism on Earth** is intended to help students explore Earth's magnetic field through a variety of math-based activities. This guide contains problems focusing on Earth's changing magnetic field in time and space. Students use compasses to discover how these changes can impact navigation on Earth's surface. They use basic math skills to interpret graphical information showing polar wander and magnetic changes, and answer questions about quantitative aspects of these changes. These lessons can be used in geology and astronomy classes.

3. **Magnetic Mysteries of the Aurora** is a prerequisite to using magnetometer data as students will in the next guide, **Earth's Magnetic Personality**. **Magnetic Mysteries of the Aurora** introduces

students to Earth's magnetic field and Northern and Southern Lights (aurora) within the context of the Sun and space weather. Using worksheets, globes, and a single light source, students review time-keeping on Earth—time zones and Universal Time. Students then go through a series of activities to discover the causes of the aurora and their relation to Earth's magnetosphere and solar storms. Students classify images of aurora by shape and color, create a model of Earth's magnetosphere, forecast magnetic storms using geomagnetic indices, and engage in a presentation about space weather. These lessons have been used in physics and astronomy classes as well.

4. **Earth's Magnetic Personality** is the culmination of all the previous guides. It was developed with the goal that students can now work directly with the THEMIS magnetometer data. Students review vectors through calculations, learn to interpret x-y-z magnetometer plots, predict auroral activity using the x-y-z magnetometer data, calculate the total magnetic field strength and observe it over months, and discover that waves in Earth's magnetic field are excited by large magnetic storms by comparing spectrograms with magnetic indices.

5. The background guide for teachers, the **THEMIS GEONS Users Guide,** describes the important role that terrestrial magnetism plays in shaping a number of important Earth systems. It also explains the basic operating principles behind magnetometers—particularly the system you are now in the process of using to investigate magnetic storms at your school.

Activity 9 - A Review of Time Zone Mathematics

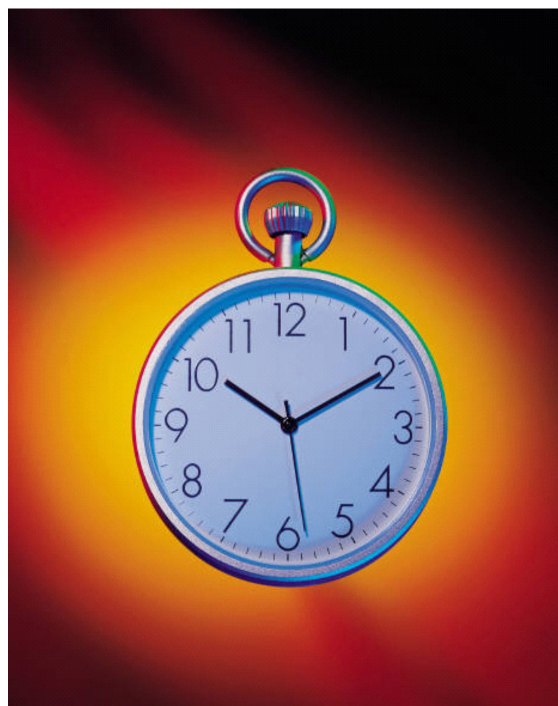
Teacher's Guide

The world is a big place! In fact it is so enormous that we, the citizens of the world, can't all use the same time on our clocks to measure the passage of day and night. Let's see how this works for the continental United States.

We have six "time zones" that divide the country from east to west. As you can see on the map on the next page, there are four time zones from the East Coast (yellow) to the Pacific Coast (red). We also have the Alaskan (purple) and Hawaiian (gold) time zones. Crossing into each time zone from east to west means that you have to move your clock back one hour. That means, for example, that on the East Coast it could be 3:00 PM (or 15:00) but in the Central Time Zone (green) it is one hour earlier, making it 2:00 PM (or 14:00). If you traveled to the Mountain Time Zone (blue) it would be 1:00 PM (or 13:00), and in the Pacific time zone (red) it would be 12:00 noon. In Alaska it would be 11:00 AM and in Hawaii it would be 10:00AM!

Goals

1) Students will know there are multiple time zones in the U.S.
2) Students will review how to calculate the difference between two clock times.
3) Students will review how to calculate the time in one time zone, given the time in a second time zone.



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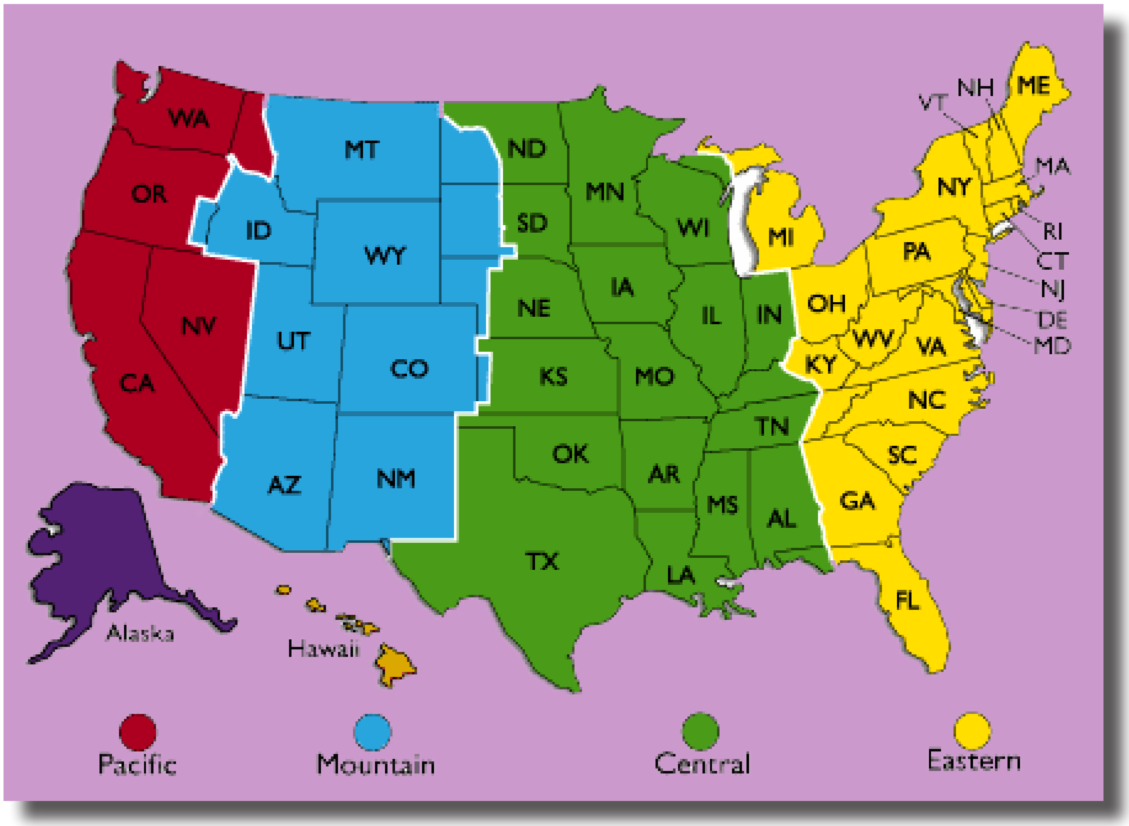


Without taking into account these time zone changes, suppose the sun set at 6:00 PM (or 18:00) on the East Coast. If you were living in Nevada, the sun would still be high up in the sky! It makes sense that sunset happens at the same clock time for each person around 6:00 PM. To do this, we all have to adopt the time zones idea and actually change our watches as we travel across the country. In all calculations, please use the "24-hour" clock to make calculations easier (i.e., 3:00 PM = 15:00, 9:45 AM = 09:45, etc.).

TEACHER ANSWER KEY

1) 7h 50m
2) 2h 50m
3) 09:00 Mountain Time Zone, Wednesday. And 07:00 Alaska Time Zone
4) 07:43 Wednesday
5) 03:14 Wednesday
6) 12:12 on Thursday 3 weeks later

Calculating time changes

Here are some solved problems with time arithmetic.

```
   23:25          23 hrs – 21hrs = 2 hours
-  21:15          25min – 15min = 10 minutes
_____________
```

2 hours 10 minutes - This is the difference in time between the two clock readings

```
   21:15          This problem asks you to add 4 hours to the clock time 21:15
+  4 hours
_____________
   01: 15 the next day
```

```
   02:00  Eastern Time     This problem asks you to calculate what clock time it is
-  3 hours                 in the Pacific Time Zone 3 hours earlier.
_____________
  23:00 Pacific Time the previous day.
```

```
   15:15                   Subtract 1 hour 55 minutes from 15:15   (or 3:15 PM)
-  1hour  55 minutes       because 15 is less than 55, borrow 1 hour from 15:00 and add
_____________              60 + 15 to get 75. Then the problem becomes:
    13:20                          14   75
                                  - 1    55
                                 --------------
                                   13:  20
```

Student Name ____________________________ ***Date*** ________

Time Zone Mathematics

1) 15:15 Wednesday

\- 7:25 Wednesday

____

Time difference

2) 09:15 Pacific Time Zone, Friday

\- 09:25 Eastern Time Zone, Friday

____

Time difference

3) 23:25 Mountain Time Zone, Tuesday

\+ 9h 35m Added time

____

(give answer both in Mountain and in Alaska Time Zones)

4) 04:25 Monday

\+ 51h 18m Added time

____

5) 18:35 Friday

\- 63h 21m Subtracted time

____

6) 03:25 Monday

\+ 584h 47m Added time

____

7) **Make up a scenario where you would have to use time zone math. Write down your story and its equation, and show how you solved it.** For example, you are vacationing in Hawaii in December. You want to call your friend Pat in New York at noon Hawaii time to report the whales you saw today. What time will it be for Pat? The equation would be:

12 noon Hawaii Standard Time

\+ five hours

= 5 pm Eastern Standard Time

We add **five** hours because December is during Standard Time in New York. *

**Not all parts of the US use Daylight Standard Time. If you were vacationing in Hawaii in August, say, we would add six hours because it would be during Daylight Savings Time in New York—but not in Hawaii, because Hawaii doesn't participate in Daylight Savings Time.*

Activity 10 - Universal Time

Teacher's Guide

Scientists use the Universal Time reference to talk about data that is taken around the globe. Universal Time is the time kept in the time zone centered on Greenwich, England (longitude zero). Universal Time does not participate in daylight savings time, so there is no springing forward or falling back one hour during the year. UT times are given in terms of a 24-hour clock. Thus, 14:42 is 2:42 p.m., and 21:17 is 9:17 p.m. As an example of how to compare times in different time zones to universal time, in the winter when it is 6:00 am in Oregon, it is 7:00 am in Montana, 9:00 am in Pennsylvania, and 14:00 Universal Time.

Goals

1. Students will translate their local time to times in other zones around the world.
2. Students will work with the concept of Universal Time.

Materials

Either

- Globe
- Ping-pong ball
- Class reading
- Two worksheet handouts

One of the most common tasks that astronomers have to perform involves calculating times in different *time zones*. When one astronomer observes a phenomenon from a particular place on Earth, it is often important to be able to communicate when exactly that phenomenon occurred to another astronomer located somewhere else on Earth. To make this as easy as possible, we adopt the time of the phenomenon as it would have been observed in Greenwich England – called Greenwich Mean Time (GMT) or Universal Time (UT). This requires converting the astronomer's local time to UT.

Note to Teachers: Time zone math is a challenge for most people, including seasoned travelers, because intuitively it makes no sense why times are earlier or later than what the clock on your wall indicate, depending on which direction east to west you travel.

Procedure

Review with your students that Earth rotates from west to east. Show them a globe, and then have a student hold a small ball (ping pong ball) a few meters from the globe. Explore the relationship between sun angle and local time by exploring the following questions:

1. Where on Earth is the sun-ball directly overhead?
2. What time it would be on Earth from where the sun-ball is directly overhead? (12 noon).
3. Without moving the ball, ask the students where in the sky the sun-ball would be when viewed from countries located to the east of the above "noon" longitude. **Answer**: The ball would be lower in the western sky. That means that the sun is setting and that local times are LATER than noon as you travel eastward. The reverse is true for a traveler moving westward from the 'noon' longitude of the sun-ball.

Make sure your students have done **Activity 11** before continuing with the following activity.

Working with the Concept of Universal Time

Next have your students imagine that a Coronal Mass Ejection (CME) has launched from the Sun today at 12:00pm Noon Local Time (LT). The CME is heading toward Earth and is predicted to hit Earth's magnetosphere 2 days and 3 hours after it left the Sun. Have the students work in teams to come up with developing a general way of communicating the time of this solar storm's departure from the Sun and its arrival at Earth's magnetosphere with other students around the world. Have them think about these questions as they approach this problem:

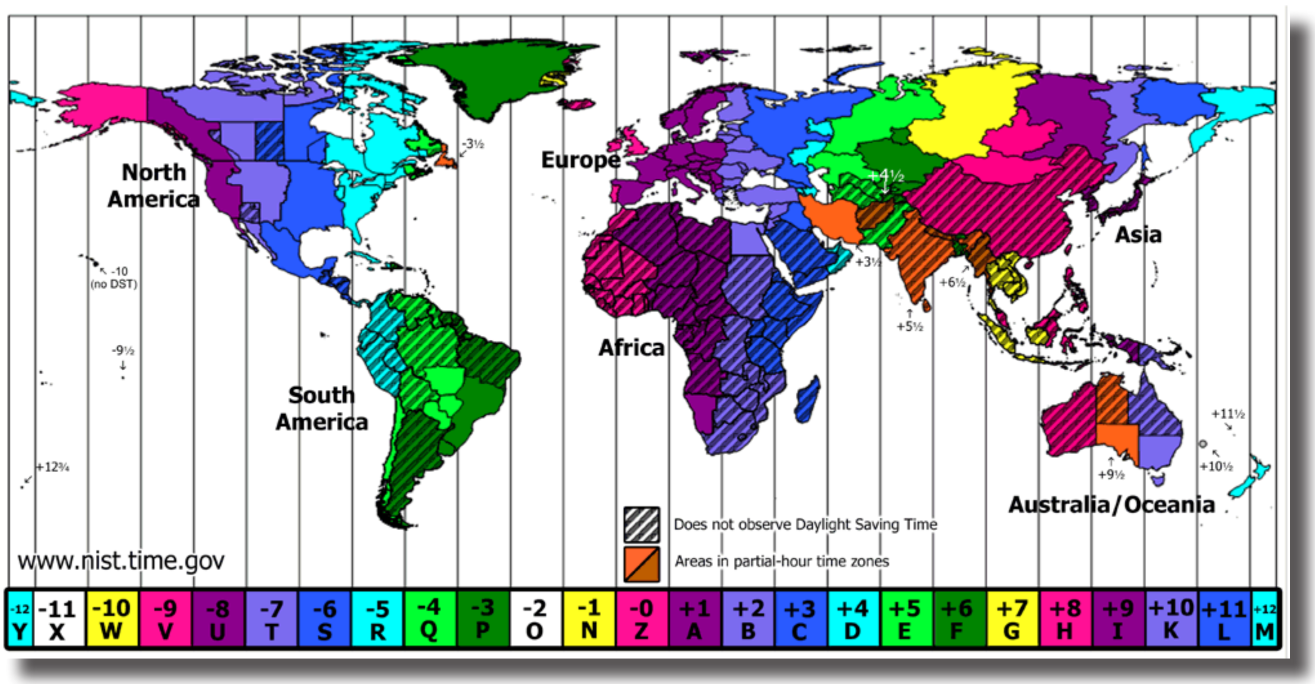
- What time would you use to tell someone in China about this event?
- Who would be awake when the CME arrived and does this matter in terms of what time to use?
- If many more CMEs were launched over the course of weeks, what general time would you use with other students around the world to communicate the timing of these CMEs?

Have the students share their ideas with each other in a class discussion. Then introduce the idea of Universal Time using the information at the beginning of this activity. Work a couple examples of converting local time to UT during daylight savings time and during standard time. Then have the students fill out the student worksheet to determine if they have understood how Universal Time works.

1. Students will read the material provided on their work sheet and note the local times for the solar flare, and the geographic locations of the observers.
2. They will identify in which time zone each observer is located.
3. They will read the diagram to determine the number of hours to add (+) or subtract (-) to determine the Universal Time (UT) of the solar flare.
4. They will answer questions about another event and whether it was observed by a scientist who was on a break from working.

Student Name ______________________________ ***Date*** ________

Universal Time



The above diagram shows the 24 time zones around the world. If you live in New York and want to call someone in San Francisco, you have to remember that the local time in San Francisco (Pacific Standard Time) is three hours BEHIND New York Time (Eastern Standard Time). By counting the time zones between the locations and keeping track of "ahead" or "behind" you, you can figure out the correct local times anywhere on the planet. Suppose an astronomer in Texas is viewing the Sun—with a special solar filter to protect her eyes—and notices a bright flash coming from a spot on the Sun (a solar flare) at 6:00 AM Central Standard Time near sunrise. Meanwhile, an astronomer in India spots the same solar flare at 17:00 India Time near sunset. Answer the following questions:

1) How can exactly the same event be seen at two different times on Earth?

2) What time would an astronomer with a solar telescope in West Africa (in the "z" time zone) have seen the same solar flare according to his local time?

continued on next page

3) What time in Universal Time (UT) did the solar flare occur?

4) Would an astronomer with a solar telescope in Central Australia have seen the flare? How about an astronomer in Alaska?

5) Suppose a solar flare happened at 10:31 UT. What time would the event have happened in California according to Pacific Standard Time?

6) A satellite registers a major solar explosion that lasts from 15:15 to 16:26 UT. A solar scientist monitoring the satellite data decided to go grab a cup of coffee between 7:00 AM and 7:45 AM Pacific Standard Time.

   a) How long did the explosion last?

   b) Did the scientist know about the flare before he left for coffee?

   c) How much of the flare event did the scientist get to see in the satellite data as it happened?

   d) Should the scientist have gone for coffee?

TEACHER ANSWER KEY

1) How can exactly the same event be seen at two different times on Earth?
Answer: Because the surface of Earth has different time zones.

2) What time would an astronomer with a solar telescope in West Africa have seen the same solar flare according to his local time?
Answer: From the diagram and the location of West Africa, the local time would be 11:00 AM.

3) What time in Universal time did the solar flare occur? **Answer:** Knowing that Universal Time is Greenwich Mean Time at the "Prime Meridian," the flare occurred at 12:00 UT.

4) Would an astronomer with a solar telescope in Central Australia have seen the flare? How about an astronomer in Alaska? **Answer:** Neither would have seen it because the sun had already set (Australia) or had not yet risen (Alaska).

5) Suppose a solar flare happened at 10:31 UT. What time would the event have happened in California according to Pacific Standard Time? **Answer:** By the diagram, PST is 8 hours behind UT so 10:31 UT – 8hrs = 2:31 AM PST. This is well before sunrise, so it wouldn't have been seen.

6) A satellite registers a major solar explosion that lasts from 15:15 to 16:26 UT. A solar scientist monitoring the satellite data decided to go for a coffee between 7:00 AM and 7:45 AM Pacific Standard Time.

a) How long did the explosion last? **Answer**: 16:26 – 15:15 UT = 1hour and 11 minutes.

b) Did the scientist know about the flare before he left for coffee? **Answer:** He left for coffee at 7:00 AM PST which is 7:00 + 8hrs = 15:00 UT so he didn't know about the solar explosion, which happened 15 minutes after he left.

c) How much of the flare event did the scientist get to see in the satellite data as it happened? **Answer:** When he returned to the satellite station, the time was 7:45 AM PST + 8hrs = 15:45 UT. The explosion ended at 16:26 UT, so the scientist got to see 16:26 PM – 15:45 PM = 41 minutes of the last part of the explosion.

d) Should the scientist have gone for coffee? **Answer:** Yes, of course! Because if he had been smart, he would have made sure that his data was being recorded for playback, just the way you program your VHS or DVD-recorder to record favorite programs you have to miss at regular broadcast time. Also, no scientist using satellite data ever relies on on-the-spot analysis. Scientists always record the satellite data so they can study it in detail later. Still, we can guess that after a long night at the satellite terminal, this scientist would have loved to have been there to see it happen in "real-time"!!

Activity 11 - The Aurora: A Critical Look at Phenomenology

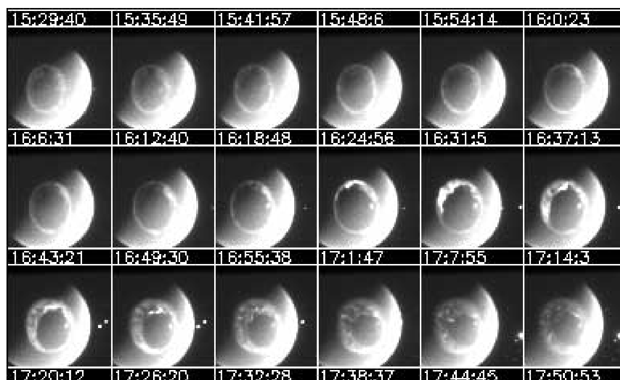
Teacher's Guide

Auroras have been sighted for thousands of years. Over time, many different terms have been used to describe them. For a glimpse at "aurora terminology," have a look at the newspaper archive at http://www.solarstorms.org/SRefStorms.html, which is a chronology of sightings and newspaper accounts since about 1850, each provided in PDF format.

Auroral "forms" do not always change in a random way, but often evolve over time as the display begins, reaches a climax, and fades away. Specific terms have been created to describe these forms. When placed along a timeline of observations, it becomes a much clearer way to identify reoccurring patterns.

Goals

1) Students will learn the names of the basic auroral forms.
2) Students will learn that auroral shapes evolve over time and sometimes follow a more-or-less well -organized pattern of changes known as an auroral substorm.
3) Students will apply their knowledge of auroral forms and substorms by sorting a collection of images online into a sequence of changes.



Auroras from space make the polar regions of Earth look like they are encircled by a ring of light. The Auroral Oval has been photographed by satellites such as IMAGE and Polar. This photograph, taken by the IMAGE satellite shows an auroral substorm. The substorm starts (onset) around 16:00:23, expands, and the recovery phase begins around 17:14:30.

About 90% of the time, the light from the aurora comes from an altitude of 100-250 km. Electrons from space follow Earth's magnetic field lines down to Earth's upper atmosphere near the magnetic poles. These electrons are sped up by electrical forces and move very fast. When the electrons collide with the gas in the upper atmosphere, mostly N_2, O_2, and O, they excite the gas. When the gas relaxes, it gives off light. This is the light of the aurora we can see. This light is found in an oval band around Earth's magnetic poles. Sometimes this oval moves and changes shape in a specific pattern, known as an *auroral substorm*.

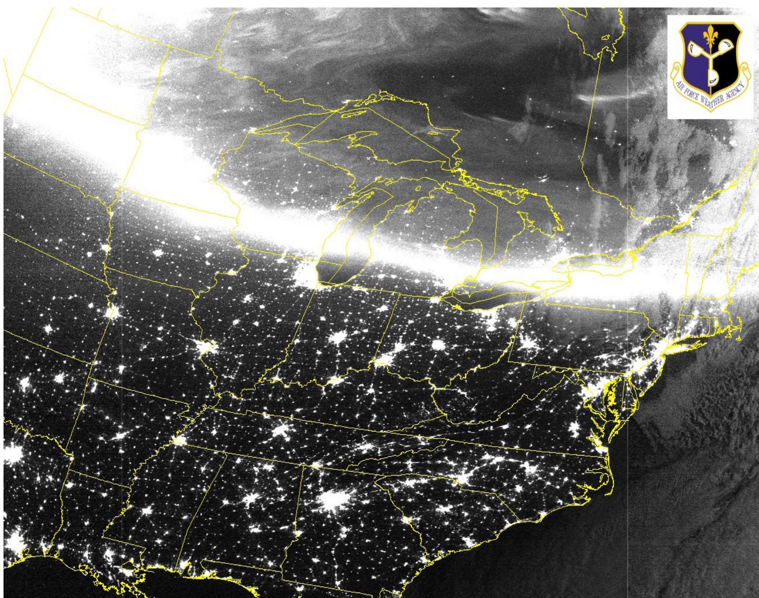
Procedure

Begin this activity by having students read the following article "A Brief Explanation of the Aurora." It can either be photocopied or students can read it from the on-line web site. Next, students will organize images, available on a website, of aurora from a magnetic storm in order to become familiar with the different types of aurora and where they are commonly located during a large storm. The students should follow the instructions on the worksheet and turn in a table with their categorization of the auroral images and answers to the worksheet questions. The answer sheet provides a way in which the students can go further with this activity to learn about magnetic latitudes and longitudes. Next the students will read through two descriptions of a single auroral substorm event on the second worksheet and compare the descriptions using UT to organize the timing of events. Students should turn in their responses to the questions on this worksheet.

Mysteries of the Aurora

Note: Because it's important to see these pictures in color, this article can also be found online at http://ds9.ssl.berkeley.edu/themis/mission_auroraexplain.html.

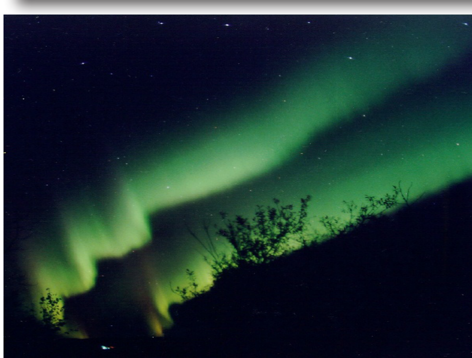
As you read the following description of the aurora, consider the general question of what causes an aurora. What might cause the shape to change? What might affect the timing of changes? Why might the aurora glow in different colors? Write down your ideas about the answers to these questions in your lab book. Don't worry about being wrong — science is about first coming up with hypotheses after gathering initial data. Scientists revise their ideas later, after they gather more information from experiments. You will gather more data later that you will incorporate into your hypothesis, which eventually becomes a scientific model of what causes the aurora.



Aurora and city lights were photographed by the US Air Force DMSP satellite on November 6, 2003, with a map drawn over the image in yellow. Auroras are found in an oval band around Earth's magnetic pole. Note the sharp southern edge in this image, defining the equatorward edge of the auroral oval as it passes over Montana, the Great Lakes, and New England. Observers as far south as Georgia saw a spectacular display looking north to the aurora, located at an elevation of 100 km.

The space shuttle crew photographed aurora from above Earth. The height of the aurora reaching above 100 km in altitude is plainly seen in this oblique view with the stars shining above Earth's surface. Also note the color changes from green at lower altitudes, to reddish at highest altitudes. Sometimes the auroral oval moves and changes shape in a specific pattern known as an *auroral substorm*.

Arches and *arcs* are long ribbons of light extending from horizon to horizon without structure, often from the east to west. Sometimes these arcs turn in forms called folds. Arcs are often green, sometimes with red above the green and sometimes with purple below the green. Arcs mostly remain motionless in the sky and are always present, usually at very high latitudes (such as far north). This is the type of aurora one can usually see during the quiet phase of the aurora. During the growth phase of an auroral substorm, this arc slowly drifts sideways in the direction of the equator. For an observer in the north, this would mean the arc drifts slowly towards the south. From an image, it is hard to tell if aurora is in a quiet phase of the aurora, or a growth phase of a substorm. If it is very bright, it is more likely to be in the growth phase.



Bands are arcs with structure. When seen on the horizon, bands often have rays and are called curtains or drapes. An auroral arc curling in its length-wise direction from horizon to horizon causes these curtains. These curls can be seen from below. Sometimes shooting rays will quickly flow down the curtain to lower altitudes, and "trains" of these rays may flow eastwards or westwards along the curtain. Other times, bands will rapidly move across the sky. Bands are often green, sometimes with red above the green and sometimes with purple below the green. These forms make their appearance during the *substorm expansion phase*, also known as the substorm break-up phase. The transition from a slowly moving arc in the growth phase to quickly moving aurora in the form of curtains and rays is known as *substorm onset***.**

Auroras appear as *coronas* during the *expansion phase* of a substorm whenever an active, rayed curtain passes over the observer's zenith. Geometric perspective effects make it look as though the auroral rays are coming from a "vanishing point" and flowing to the horizon in all directions. The top of an auroral curtain may be over 250 km above the ground, and the rays are only a few kilometers wide, giving a spectacular visual effect.

Diffuse glows are the most common at the end of an auroral display, during the substorm recovery phase. At high latitudes, the displays are usually greenish. At lower latitudes during intense storms, red diffuse aurora are common. Diffuse auroras are often hard to observe with one's eyes because they are very faint.

Above images courtesy Jan Curtis (http://climate.gi.alaska.edu/Curtis/aurora/aurora.html)

EVOLUTION

For Northern Hemisphere observers, an auroral substorm display begins with the appearance of an auroral arc above the northern horizon or in the zenith. Over the course of 30 minutes during *substorm growth phase*, this arc will grow in brightness exceeding that of the full moon, with a white or pale green color. It will also drift across the sky towards the zenith or towards the equator. The auroral arc often will resolve itself into folds of light extending from the eastern horizon to the western horizon in the northern sky. From the ground, the *substorm onset* begins suddenly within seconds.

This is followed by the *substorm expansion phase* (also known as the *break-up phase*). In the expansion phase, the auroral arcs or bands break into many moving bands, which dance wildly across the sky both to the north and south. Within minutes, rays of light will start streaming down the developing curtains, which often surge westwards. From space, the expansion or break-up phase is seen as a thickening of the auroral oval along its north-south extent. The auroral oval's substorm brightening region begins to expand westward, dissolving into numerous individual structures, which we see from the ground as individual curtains. As a curtain passes directly overhead, the rays flowing down the curtain create an auroral corona, which from a central point look like a meteor shower raining down the sky – an effect of perspective.

Within 30 minutes, the activity begins to slow and fade, and retreat northwards during the recovery phase. From space, the recovery phase is seen as a thick oval, often with two bright regions to the north and south. From the ground, pulsating aurora will be visible, which are large patches of diffuse aurora that brighten and fade with periods of seconds. The aurora slowly becomes a diffuse glow. An uninterrupted recovery phase lasts several hours. At any time during this sequence, the aurora may erupt into another auroral display if a new magnetic substorm event is triggered by disturbances in Earth's magnetotail region.

SOUNDS

Observers from many countries claim, rather steadfastly, that they sometimes hear sounds from aurora, such as crackling or swooshing. This subject is an interesting one for students to explore. Are people simply imagining the sound because auroras LOOK so much like fires in the sky? For decades, scientists have looked into this subject, but have not been able to capture any sound on tape.

One thing we do know is that direct observations show that auroras never occur closer than about 70 km above the ground, where the air is nearly a vacuum. There is no gas to carry pressure waves that could make our ears sense sound. This has caused some scientists to look into indirect "sympathetic" causes. Some of these are psychological. Others may involve powerful electrical currents flowing in the ground that cause electric "crackling" discharges on sharp objects near the observer (pine needles, etc). These currents are well-known to exist at the latitudes where sounds are reported.

Student Name _____________________________ ***Date*** ________

The Aurora: October 29-30th, 2003

In this exercise, you will examine a number of aurora photographs taken around the world by amateur photographers on October 29th and 30th, 2003. These observers were located at a number of different locations and latitudes. We will use photographs assembled from the photographs at the October, 2003 spaceweather.com aurora gallery and located at: http://ds9.ssl.berkeley.edu/themis/gallery_auroras.html

We will be studying the major "Great Aurora" that was viewed on October 29-30, 2003.

1. Create a table with 15 rows, and four columns.
2. Label the columns as follows: location, latitude, description, substorm phase.
3. Visit the above website and fill in the information in Columns 1 (location) and 3 (description) from the information provided in each picture's caption. For example, in Row 1, use the aurora photographed by Lionel Bernardi. In Column 1, enter "Tromsø, Norway." In Column 3 enter a description of the aurora, including color. Use the standard terms described in the photo gallery provided by your teacher. For example, this first row aurora could be described as "purple, white, and yellow corona."
4. From your descriptions in Column 3, assume the aurora was part of an auroral substorm and estimate the phase of the auroral substorm. Write this in Column 4 (substorm phase) using the descriptions provided by your teacher (quiet, growth, expansion, recovery phases). For example, Row 1 would be an expansion phase aurora.
5. When you are finished with the web gallery for pictures taken on October 29 and October 30, in Column 2 enter the latitudes of the locations given in Column 1 by using a map. Or, use a web page that gives the latitudes for a given location. Latitude degrees need only be integers, not decimals. For example, instead of writing "35.47 degrees" just round it to "35 degrees." For this first aurora in Row 1, you would write 69 degrees since Tromsø, Norway is located at 69 degrees.
6. When complete, answer the following questions:

Question 1 – Geographically, for which latitudes were the most diffuse aurora seen by observers?

Question 2 – What was the lowest latitude from which observers reported aurora?

Question 3 – What was the lowest latitude from which expansion-phase aurora were seen?

Question 4 – What were the most common expansion phase features that were seen?

Question 5 – Where would you have to live in the USA to see expansion phase features?

Teacher Answer Key

Question 1: Geographically, for which latitudes were the most diffuse aurora seen by observers?

Answer: Missouri, Ohio, West Virginia, Indiana, and Colorado all saw diffuse aurora. The latitudes vary from 39 to 41 degrees north.

Question 2: What was the lowest latitude from which observers reported aurora?

Answer: Elkins, West Virginia, at a latitude of 39 degrees north.

Question 3: What was the lowest latitude from which expansion phase aurora were seen?

Answer: For this storm, the lowest latitude where discrete auroral features were observed were from La Otto, Indiana at 41 degrees north. Expansion-phase auroras were seen from 41 degrees north to 69 degrees north.

Question 4: What were the most common expansion phase features that were seen?

Answer: Bands with rays.

Question 5: Where would you have to live in the USA to see expansion phase features?

Answer: From this activity, it seems it would be necessary to live above about 41 degrees north. However, since the magnetic pole is not located at the geographic pole, it would be more accurate to find the magnetic latitudes of all of these types of aurora and answer the questions.

Going Further

Have your students find the geographic longitude of all the locations, as well as the geographic latitudes. Then have them use a converter to obtain the magnetic latitudes for all of these locations using the geographic latitude, longitude to magnetic latitude, longitude converter on the webpage:

http://swdcwww.kugi.kyoto-u.ac.jp/igrf/gggm/

Have them then answer the same questions using magnetic latitude instead of geographic latitude and discuss any differences they find.

Student Name ____________________________ ***Date*** ________

Aurora of 1859

On August 28, 1859, people all over Earth saw spectacular aurora (Northern and Southern Lights.) It was reported in all the major newspapers, poems were written about it, and famous artists painted its shapes and forms. It also caused severe problems with telegraph networks at the time, which lasted for many hours worldwide. Although scientists gave detailed reports of the changing forms of this vivid display, many ordinary citizens offered their own impressions of this event too. Two of these descriptions, as seen from two different locations, are written below. Read these descriptions and respond to the following questions and instructions.

Galveston, Texas:

"August 28 as early as twilight closed, the northern sky was reddish, and at times lighter than other portions of the heavens. At 7:30 PM a few streamers showed themselves. Soon the whole sky from Ursa Major to the zodiac in the east was occupied by the streams or spiral columns that rose from the horizon. Spread over the same extent was an exquisite roseate tint which faded and returned. Stately columns of light reaching up about 45 degrees above the horizon moved westward. There were frequent flashes of lightning along the whole extent of the aurora. At 9:00 PM the whole of the streaking had faded leaving only a sort of twilight over the northern sky."

London, England.

"At 0:15 AM on August 28th the auroral light in the north assumed the form of a luminous arch, similar to daybreak, and in the southwest there was an intense glare of red covering a very large extent of the sky. At 00:20 AM streamers appeared; at 00:25 AM the streamers rose to the zenith and were tinged with crimson at their summits. At 00:45 AM frequent coruscations appeared in the aurora. At 01:20 AM the arch which had partially faded began to reform and the body of the light was very strong but not bright enough to read newspaper print. At 1:30 AM the light had begun to fade. By 2:00 AM the aurora was very indistinct."

When organizing observations from different places around the world, a common problem scientists face is that observers tend to note when things happened by their local time. Scientists simplify these accounts by converting them into Universal Time, which is the local time in Greenwich, England, also called Greenwich Mean Time (GMT). To make time calculations easier, UT is expressed in the 24-hour clock format —so that 11:00 AM is written as 11:00 UT— but times after noon such as 1:00 PM are written as 13:00 UT. 10:00 PM is written as 22:00 UT. Since London is very close to Greenwich, the times mentioned in the London account above are already in Universal Time and only need to be converted to the 24-hour format. For Galveston, Texas, the time is 5 hours behind UT so to get the equivalent UT for Galveston, first convert the Galveston times to the 24-hour format, then add 5 hours. See Activity 11 for more details.

Student Name ____________________________ ***Date*** ________

Aurora of 1859

QUESTIONS AND INSTRUCTIONS:

Write your responses to each of these questions and instructions in your lab book.

1) From the two descriptions, extract the time and description of specific events in each narrative. Write these down, including the given times converted to Universal Time. Note the stories' similarities.

2) From the sequences of events in each description, create a storyline for the aurora display that fits the most details. Draw pictures to help illustrate the storyline.

3) Rewrite the timeline using the auroral substorm phases. Would you call this an auroral substorm?

4) Describe your ideas for why the aurora was observed to reach closer to zenith (directly overhead) in London than in Galveston?

5) Telegraphs work in general by using long wires and electromagnetic devices at each end. At one end, the telegraph operator sends an electrical current through wires that causes a magnetic needle to move at the receiving end and then a device measuring the change in the magnetic field (magnetometer) indicates how much current was sent from the sender. Based on the fact that telegraph networks were disturbed during this time of spectacular auroras, describe how your hypothesis about what causes aurora is validated or needs to be changed.

6) If you have not done so already, also think and write about where the energy to make such unusually brilliant and far-reaching auroras might come from.

Teacher Answer Key

1) From these two descriptions, extract the specific points of each narrative. Change the times to Universal time while doing this. What are the stories' similarities? **Answer**: Here are the main points in each story with the similarities highlighted.

Story 1:

1. Display began at end of twilight with faint **reddish light in north**.
2. 7:30 PM (00:30 UT) **streamers began to appear**
3. Streamers of spiral columns filled eastern sky
4. Faint rose-colored light covered same eastern sky, fading and returning
5. Columns of light reached **45 degrees to zenith**, and moved westwards
6. Frequent flashes of light along the whole aurora
7. 9:00 PM (02:00 UT), the **aurora faded** and left a twilight glow in north.

Story 2:

1. 00:15 AM (00:15 UT) - Luminous arch **appeared in northern** sky
2. 00:16 AM (00:16 UT) - Intense glare of red in southwest
3. 00:20 AM (00:20 UT) - **Streamers appeared**
4. 00:25 AM (00:25 UT) - Streamers **reached zenith** and were crimson at highest points
5. 00:45 AM (00:45 UT) - Frequent **coruscations appeared in aurora**
6. 01:20 AM (01:20 UT) - Arch begins to fade and reform
7. 01:30 AM (01:30 UT) - Aurora **begins to fade**.
8. 02:00 AM (02:00 UT) - Aurora very indistinct.

Similarities: Auroral light appeared in northern sky. Streamers appeared soon afterwards. The streamers expanded in the sky until they were nearly overhead from Galveston, and overhead in London. The aurora shapes showed activity in the form of flashes and movement (coruscations). Soon after this active phase, the aurora faded. The auroral display started and ended at about the same Universal Time at each location.

2) From the sequences of events in each description, create a storyline for the aurora display that fits the most details. **Answer:** Each student might group the events differently because the eye-witness accounts are not detailed enough. Because this aurora is seen in the Northern Hemisphere, it is properly called the Aurora Borealis. Here is one way to organize the timeline:

   "The aurora borealis started with a faint wash of reddish light in the north. A brilliant arch of light formed. Five minutes later, streamers began to appear which were crimson at their highest points above the horizon. Then, coruscations (waves) began to appear in the brightening red glow of the aurora with the streamers filling the entire eastern sky. The columns of light and streamers began to move westwards, and frequent flashes of light were seen along the aurora as the luminous arch of began to fade and reform. After an hour and fifteen minutes, the aurora began to fade away, leaving behind a twilight glow that persisted for another half-hour."

3) Rewrite the timeline using the auroral substorm phases. Would you call this an auroral substorm? **Answer:** Yes, this could be called a substorm.
   The growth phase began with a brilliant arch of light. Substorm onset occurred at 00:20 UT with streamers and active aurora as the expansion phase started. Recovery phase started with the arch fading and reforming.

4) Why was the aurora observed to reach closer to zenith in London than in Galveston? **Answer**: because the aurora is a polar phenomenon and London is at a higher latitude than Galveston. That means that the aurora will be seen higher in the northern sky from London than from Galveston.

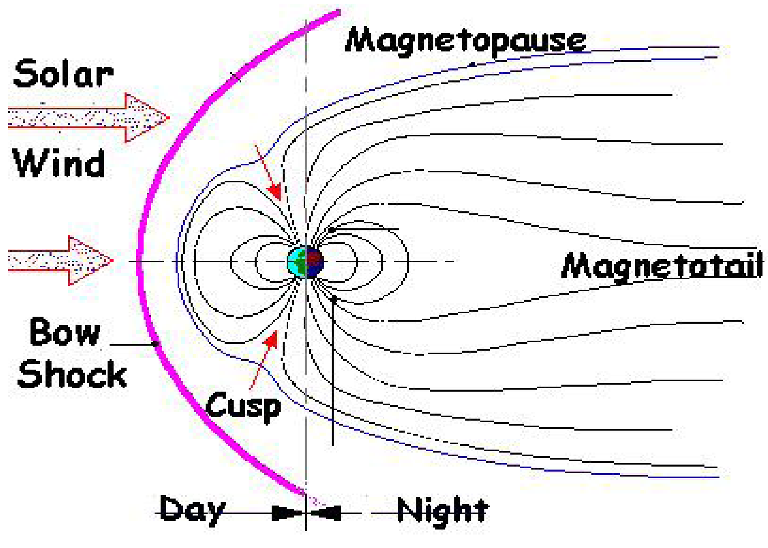
Activity 12 - The Magnetosphere

Teacher's Guide

In order to discuss Earth's magnetic field and its changes, we need a common vocabulary. Scientists recognize over two dozen distinct regions and processes occurring within the magnetosphere. Some are nearly permanent features, while others appear and disappear within minutes or hours. In this activity, students will visit a website and learn the main features of the magnetosphere and the functioning of the Sun-Earth system. Students should start a lab book in which to keep notes about Earth's magnetosphere, space weather, and magnetometer data.

Goals

1) Students will learn about the basic elements of the Sun-Earth system.
2) Students will appreciate that the magnetosphere has many different regions.



Procedure

- Students will identify the definitions for each term by reading the discovery pages from the IMAGE satellite education program.
- By reading each "discovery page," students will learn about recent advancements and see how the terms relate to each other. In all cases, the definitions are provided at the bottom of each page.

The collection of pages at: http://image.gsfc.nasa.gov/poetry/IMAGEdisc.html will provide summaries of each discovery, and definitions of the terms. Also, see the web resources at the end of this guide for additional sources. Students may also use Google™ or "WIKIPEDIA" to find relevant, brief definitions. This provides a great opportunity for students to compare definitions, and for the teacher to discuss the credibility of the various resources used in student web research.

The accompanying Teacher Answer Key indicates where on the NASA-IMAGE website the definitions can be found.

TEACHER ANSWER KEY

Magnetosphere - Answer at the link 2001- Discovery 14

Bow Shock - Answer at the link 2001 – Discovery 4

Magnetopause - Answer at the link 2003 – Discovery 3

Magnetotail - Answer at the link 2001 – Discovery 1

Polar Cusp – Answer at the link 2000 – Discovery 2

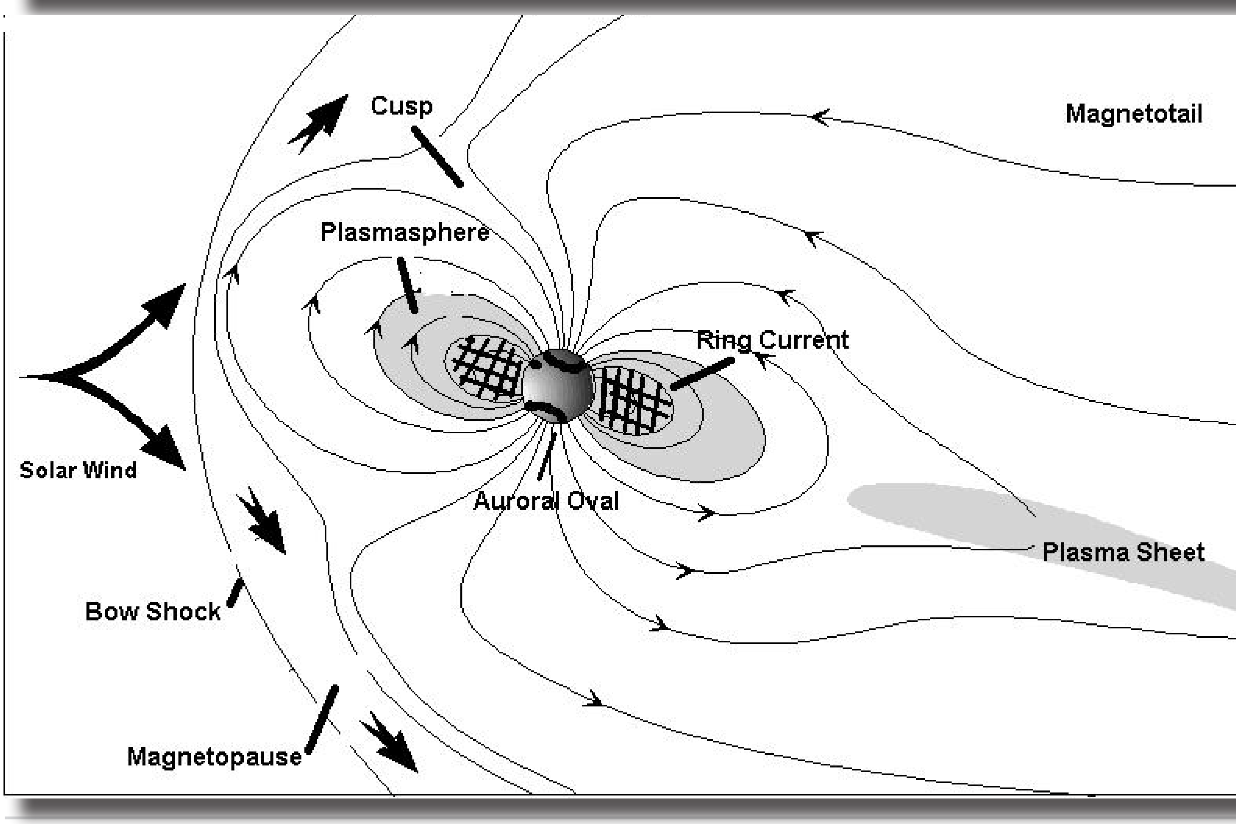
Plasma Sheet - Answer at the link 2001 – Discovery 8

Auroral Oval - Answer at the link 2001 – Discovery 7

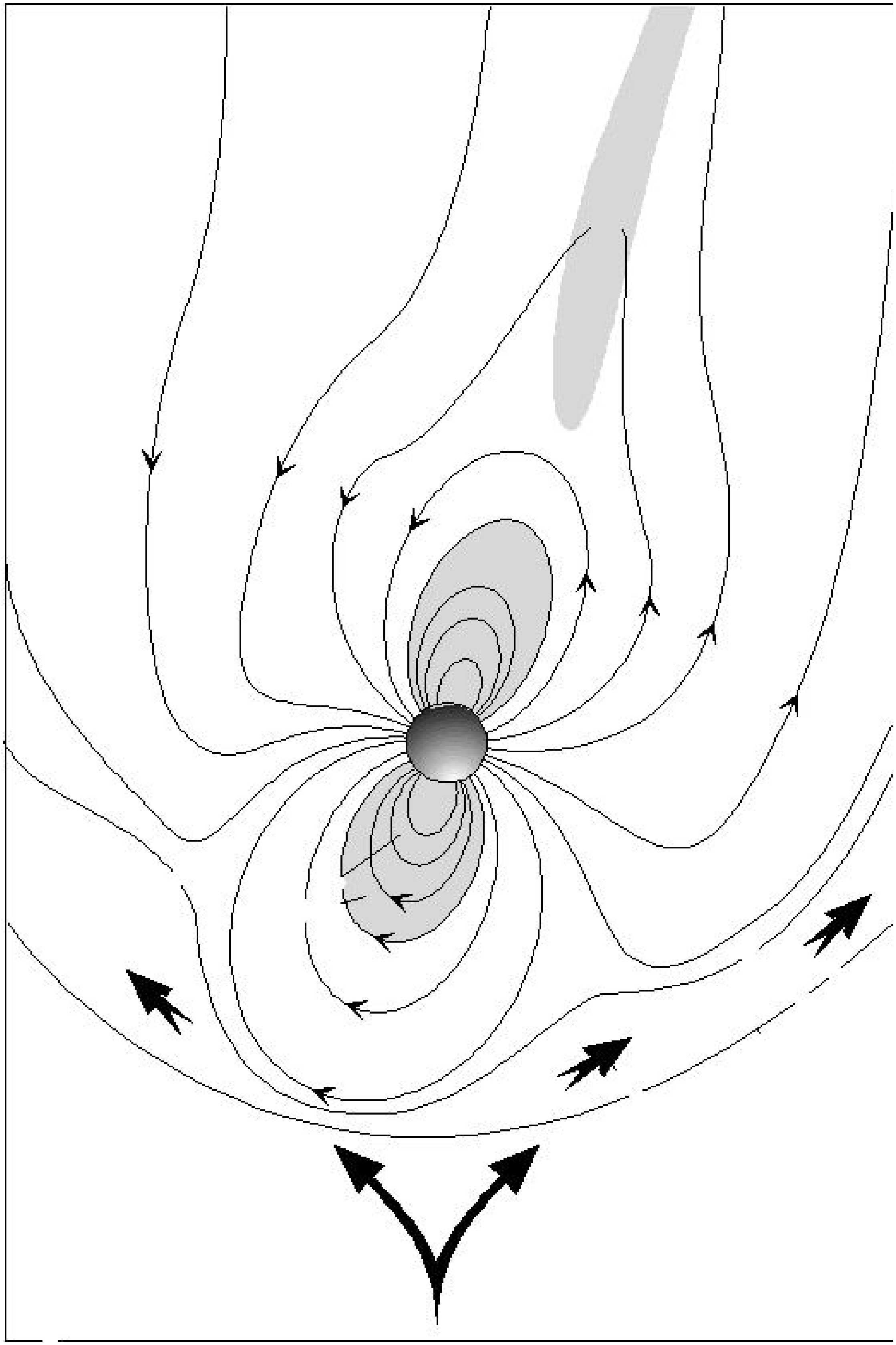
Ring Current – Answer at the link 2001 – Discovery 10

Solar Wind - Answer at link 2003 – Discovery 8

A Google™ image search (click on "images" under the Google™ page header) using the key word "magnetosphere" will call up many diagrams that look like the figure below. Note, the plasmasphere and ring current, as well as the inner Van Allen Belts, are situated in the same spatial locations, but differ significantly in the energy (in electron volts, or eV) of the particles involved. Plasmasphere (~1 eV), Ring Current (10,000 - 200,000 eV), Van Allen Belts (1 million to 50 million Volts). Note that 1 Joule = 1 kg m^2/s^2 = 10^7 ergs = 6.242 x 10^{18} eV, which is equivalent to to the energy of lifting a lemon 1 meter.



Earth's Magnetic Field in Space



Student Name ____________________________ ***Date*** ________

The Magnetosphere

The goal of this activity is for you to become familiar with the main terms that scientists use to discuss Earth's magnetic field. Review the information at the following website, which contains discoveries made by the IMAGE satellite, and the definitions for magnetospheric terms:

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

Start a lab book. In your lab book, provide definitions to the following terms, and locate them on the accompanying figure. You will be referring back to the entries in this book as your main source of basic information in the weeks to come.

Magnetosphere

Bow Shock

Magnetopause

Magnetotail

Polar Cusp

Plasma Sheet

Auroral Oval

Ring Current

Solar Wind

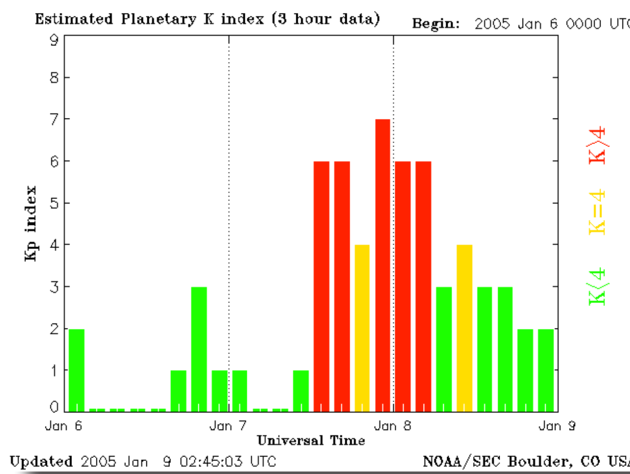
Inquiry Problem - Pick one of the terms and write a short essay in your own words about why scientists are trying to learn about it.

Activity 13 – Magnetic Storms

In this exercise, students will become familiar with a very common indicator of magnetic storminess: the Kp index. This index is assembled every three hours based on the level of the disturbances detected in dozens of magnetometer installations located at latitudes north of 50 degrees. It is a 9-point scale in which '9' is the most severe, largest disturbance, and '0' is the least severe, smallest to no disturbance. Typically, there are only one or two Kp=9 storms every year. Kp index plots, like the one below, can be obtained for this activity from the NOAA archive at:
http://www.sec.noaa.gov/ftpdir/warehouse
For this lesson, we have created a website using 2005 data from the NOAA archive, which can be found here: http://ds9.ssl.berkeley.edu/themis/classroom_kp2005.html

GOALS

1. Students will learn that strong magnetic storms are not as common as weaker ones.
2. Students will analyze plots of the Kp index and create a histogram of the number of days in the year that magnetic storms exceed a specific level on the Kp scale.



PROCEDURE

1. Students visit http://ds9.ssl.berkeley.edu/themis/classroom_kp2005.html
2. Students select one of the plot files and open it in the browser.
3. From the archive of Kp, students note the **maximum Kp reached each day**. This will give the number of days that magnetic storminess reached the following levels out of 90 days:

Calm storm conditions:	Kp = 4
Minor storm conditions:	Kp = 5
Moderate storm conditions:	Kp = 6
Strong storm conditions:	Kp = 7
Severe storm conditions:	Kp = 8
Extreme storm conditions:	Kp = 9

4. Students create a histogram of the tallies for at least one month's worth of Kp plots.

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5. At the conclusion of the assignment, consult the NOAA Space Weather site to compare. http://www.sec.noaa.gov/NOAAscales/#GeomagneticStorms

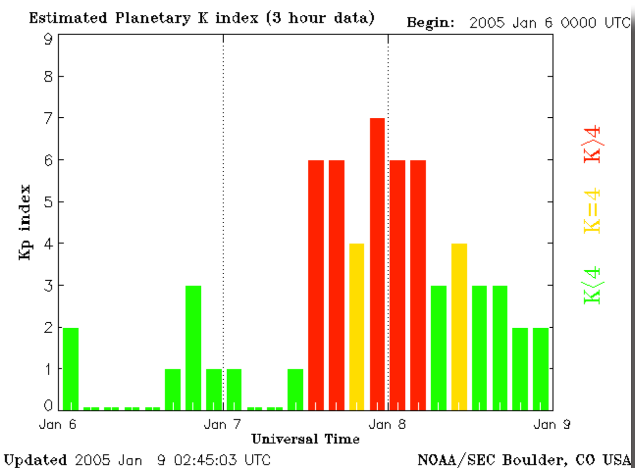
GOING FURTHER

- Have the students enter the data into a computer datasheet so they can perform additional calculations on the data and plot the data using the computer program.
- Every 3 days print out the most recent Kp index from NOAA's website http://www.sec.noaa.gov/rt_plots/kp_3d.html and post it on the wall in the classroom. Post other relevant space-weather data from NASA's Student Observation Network, http://son.nasa.gov/tass/ such as sunspot, radio wave data, or magnetometer data, underneath the Kp data. Have students compare datasets to notice the connection between the Sun and Earth's Magnetosphere.

Student Name ______________________________ **Date** ________

Magnetic Storms

Below is a plot of the Kp index for a storm obtained from the NOAA data archive and put on the following website: http://ds9.ssl.berkeley.edu/themis/classroom_kp2005.html Scientists use the Kp index to identify the strength of magnetic storms. The bar graph shows the Kp index from January 6, 7, and 8, 2005. On January 7th, there was a strong magnetic storm with Kp=7. In this activity, you will examine similar plots from an on-line data archive and determine how common it is to find storms at various levels of the Kp index, beginning January 1, 2005. **See the example below for an explanation for how to tally.**



From the Kp website above, tally **the maximum Kp reached each day.** This will give you the number of days that magnetic storminess reached the following levels during 90 days:

Calm Conditions:	Kp = 4
Minor storm conditions:	Kp = 5
Moderate storm conditions:	Kp = 6
Strong storm conditions:	Kp = 7
Severe storm conditions:	Kp = 8
Extreme storm conditions:	Kp = 9

Example: The plot shows one bar for every 3-hour interval starting at midnight on January 6. There are 8 bars for each day. The tally for the above plot would indicate for January 6, no counts. For January 7, one count for Kp=7, and for January 8, one count for Kp=6.

Kp Index	Number of days in January	Number of days in February	Number of days in March
9			
8			
7			
6			
5			
4			

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Student Name ___________________________ ***Date*** _______

Magnetic Storms

Question 1: From your 90-day sample, what percentage of days had either Severe or Extreme magnetic storm conditions?

Question 2: From your answer to Question 1, what is the chance (in percent) that your magnetometer will see at least a moderate magnetic storm tomorrow?

Question 3: What percentage of days are considered “stormy” during this period?

Inquiry Problem - 2005 was near sunspot minimum.

1. Find a year of sunspot maximum.
2. Repeat your tabulations of stormy days in a new chart, using the data from http://www.sec.noaa.gov/ftpdir/warehouse.
3. Compare your answers during sunspot maximum and sunspot minimum.

TEACHER ANSWER KEY

Kp Index	Number of days in January	Number of days in February	Number of days in March
9			
8				
7						
6								
5																	
4																											

Note: To simplify the calculations, only tally the maximum Kp reached in a given day. For example, in the Kp plot above, we count one day with Kp=7, which occurred on January 7, and one day with Kp=4 on January 8.

Question 1: From your 90-day sample, what percentage of days had either Severe or Extreme magnetic storm conditions?

Answer: There was only one day (in January) that reached at least Kp= 8 'Severe Storm', so the percentage is (1/90) x 100% = 1% of the time.

Question 2: From your answer to Question 1, what is the chance (in percent) that your magnetometer will see at least a moderate magnetic storm tomorrow?

Answer: There were 10 days where Kp was at 6 or higher, so the chance is (10/90) x 100% = 11%.

Question 3: What percentage of days are considered 'stormy' during this period?

Answer: Stormy days are days where Kp exceeds 4. There were 24 days in January, 10 in February, and 14 in March for a total of 48 days, so the percentage of days is (48/90) x 100% = 53%. During this period of time, about every other day had stormy conditions.

How is the Kp index actually determined?

Geomagnetic disturbances can be monitored by ground-based magnetic observatories called magnetometers. The global Kp index is obtained as the mean value of the disturbance levels in the two horizontal magnetic field components Bx and By, observed at 13 selected, subauroral stations. The name Kp originates from "planetarische Kennziffer" (planetary index). Kp was introduced as a magnetic index by physicist J. Bartels in 1949 and has been derived since then at the Institut für Geophysik of Göttingen University, Germany.

The following definition of K variations has been given by Siebert (1971):

> "K *variations are all irregular disturbances of the geomagnetic field caused by solar particle radiation within the 3-h interval concerned. All other regular and irregular disturbances are non K variations. Geomagnetic activity is the occurrence of K variations.*"

To calculate the Kp index from the K index, here's what you have to do:

1. Local disturbance levels which lead to a value for the K index are determined by measuring the range (difference between the highest and lowest values) during three-hourly time intervals for the most disturbed horizontal magnetic field component.
2. The quiet-day variation pattern has to be removed from the magnetometer data, a somewhat subjective procedure. The range is then converted into a local **K index** for the Niemegk Magnetic Observatory near Potsdam, taking the values 0 to 9 according to a quasi-logarithmic scale, which is station-specific; this is done in an attempt to normalize the frequency of occurrence of the different sizes of disturbances because smaller disturbances are so common compared with larger disturbances.
3. According to the geographic and geomagnetic coordinates of the observatories, each observatory still has an annual cycle of daily variations. Using statistical methods J. Bartles generated conversion tables to eliminate these effects. By applying the conversion tables, a standardized **Ks index** for each of the 13 selected observatories is determined. In contrast to the K values, the Ks index is expressed in a scale of thirds (28 values): 0-, 0, 0+, 1-, 1, 1+, 2-, 2, 2+, ... , 8, 8+, 9-, 9
4. The main purpose of the standardized index Ks is to provide a basis for the global geomagnetic **Kp index** which is the average of a number of the Ks index from the "Kp stations," originally 13. The Ks data for the two stations Brorfelde and Lovö are combined, as are the data from Eyrewell and Canberra. With these four stations combined into two stations, the total number of stations used for the Kp index is 11.

The official Kp indices are available since 1932 at:

http://swdcwww.kugi.kyoto-u.ac.jp/kp/

Activity 14 - The Sun-Earth Connection

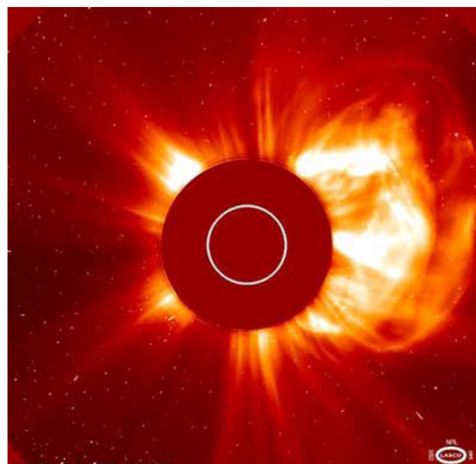
TEACHER'S GUIDE

This activity is a presentation for students about the Sun and its effects on Earth's magnetosphere and NASA's satellite mission to understand auroral substorms, THEMIS (Time History of Events and Macroscale Interactions during Substorms). This presentation and a script for the presentation is available as 1) a black and white Acrobat Reader PDF document in order to make overhead transparencies, 2) an Acrobat Reader PDF presentation, and 3) a Microsoft PowerPoint presentation. The script is available in the PowerPoint presentation in the notes section or you can download a PDF of the script. These are all found on the web at:

http://cse.ssl.berkeley.edu/exploringmagnetism/space_weather/presentation.html

GOALS

1. Students will know that the Sun is a dynamic and magnetic star.
2. Students will know that coronal mass ejections (CMEs) are large structures of magnetized plasma that are ejected at high speeds from the Sun's corona.
3. Students will know that the solar wind comes from the Sun and travels out past the planets in the solar system.
4. Students will know that Earth has a magnetic shield called the "magnetosphere."
5. Students will know that auroras are connected with Earth's magnetosphere.
6. Students will know that CMEs interact with Earth's magnetosphere and auroras are enhanced accordingly.
7. Students will know that the high-energy particles from CMEs can be dangerous to astronauts and can damage satellites.



CME photo. Courtesy SOHO satellite

MATERIALS

Either

- PDF or PowerPoint presentation from Website above
- PDF of script for the presentation
- Computer
- LCD projector

Or

- Overhead transparencies from the black and white PDF from website above
- PDF of script for the presentation
- Overhead projector

PROCEDURE

1. Give the presentation using the desired slide formats.
2. Follow the script if you would like.
3. Hand out the "IMPACT" story, and for homework have the students write about one aspect of the Sun-Earth Connection they learned from the talk and the story.

Notes: Click once on the movies to make them play in the PowerPoint presentation. Click twice on the movies to make them play in the PDF presentation.

The Sun-Earth Connection

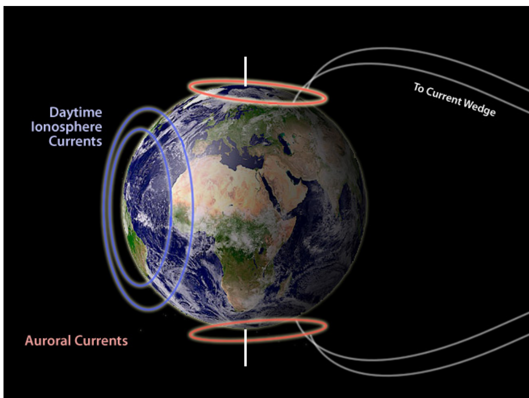
The Sun is a fiery ball of gas that reaches such extreme temperatures that gas flies out from it at very high speeds. In fact, many of the electrons in the Sun's atoms have enough energy to actually leave the atoms. The abandoned charged atoms are called *ions*. These ions and electrons (which are also charged) flow outward from the Sun, and together they are known as the *solar wind*. The ions spiral in one direction and the electrons spiral in the other—doing a kind of mirrored spiral dance around the "maypole" of the Sun's magnetic field. Scientists have discovered that the solar wind and its magnetic field flow together out past the orbits of Mercury, Earth, Pluto, and beyond. Because the magnetic field spreads throughout the solar system, we call it the *interplanetary magnetic field*—that is, the magnetic field found between (inter) the planets (planetary).

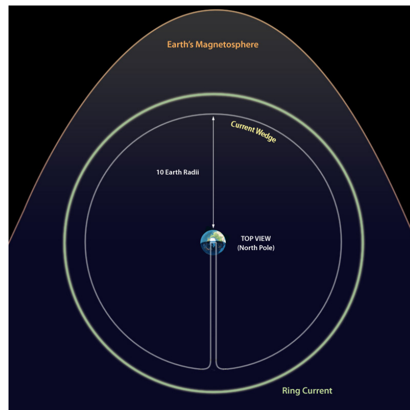
When the solar wind travels with the interplanetary magnetic field, or IMF for short, the charged particles and magnetic fields interact with Earth's magnetic field. Earth's magnetic field, as it stretches out in space, is known as its *magnetosphere*. The solar wind pushes on the side of the magnetosphere facing the Sun, and pulls it out on the side facing away from the Sun. The pulling forms a long tail moving away from the Sun, and thus the magnetosphere resembles a wind-sock blowing in the wind. Electrical currents flow in the magnetosphere, and generate the lights in the sky known as the Northern and Southern Lights. Together these lights are known as *aurora*.

Returning to our fiery Sun, scientists have noticed that the Sun goes through some markedly different cycles—rather like when people are calm and quiet some days, but on other days explode with energy and brilliance. But rather than biological rhythms driving the changes, physical principles—such as magnetic and electric forces—power the Sun's cycles. During the Sun's active cycle, parts of it will explode, sending out even more solar wind and magnetic fields than usual.

What happens to the solar wind and magnetic fields forced out into space by the explosions? Sometimes the explosive solar wind will rush by Earth, making us all potentially vulnerable. Luckily Earth has a magnetic field and a thick layer of atmosphere protecting all living creatures from the particles and radiation that can come from such solar explosions. But when astronauts are out in space, sometimes the magnetic field isn't strong enough to protect them. If they are outside their space vehicles, such as the space station, when conditions become possibly hazardous they need to hurriedly float back to the station's protection.

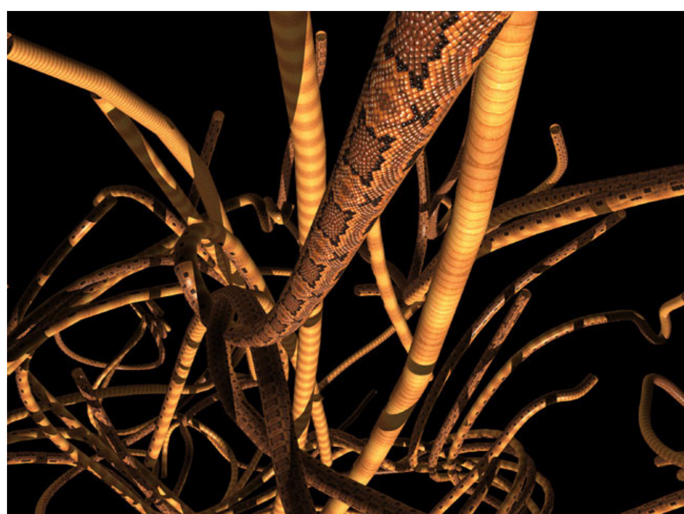
Scientists have named these solar explosions *coronal mass ejections*, or CMEs for short. When a CME interacts with Earth's magnetosphere, the electrical currents in the magnetosphere grow stronger and the aurora glows brighter. Because currents create magnetic fields, the changes in these electrical currents cause variations in magnetic data on Earth's surface. There are a number of important currents that cause magnetic changes observed on the ground as variations in Earth's magnetic field. Three specific currents are: 1) Electrical currents flow in the day-lit side of the ionosphere. The *ionosphere,* at 100 km (60 miles) above Earth's surface, is the closest signifcantly charged layer in the upper atmosphere (barring thunderstorms). In this region the Sun's light breaks apart a small portion of the gas into ions and electrons. These charged particles continually break apart and recombine throughout the day. The electrons and ions flow in different directions, creating a current above Earth's daytime surface. At night, without the Sun's influence, the electrons and ions "rest" in their recombined atomic state. Auroras also cause an enhanced ionosphere at night in an oval around Earth's magnetic poles. Enhanced currents are also found in these regions of aurora above Earth's surface during the night. 2) There is also electrical current flowing in a large belt-like region around Earth's equator, but far from Earth's surface—around 30,000 km above it. This current is called the ring current, because it makes a ring around Earth. 3) And there are also electrical currents at midnight above Earth's surface that hang out near the equator but even farther from Earth than the ring current at over 60,000 km altitude. These currents are called the *substorm current wedge*.





Two perspectives of a few of the electrical currents flowing around Earth. The figure on the left is a simplified diagram of the daytime currents, the auroral currents, and the field line currents coming from the magnetosphere. The figure on the right shows the ring current as viewed from above the North Pole.

The CMEs interacting with Earth's magnetosphere can influence all these currents. Because electrical currents create magnetic fields, the currents can be observed on the ground using devices that measure magnetic fields, called magnetometers. When a CME interacts with Earth's magnetic field, there are rapid changes in these current systems. Currents that change rapidly, within seconds, are usually carried by a wave known by the name of the man who discovered them through equations. These magnetic waves are called Alfvén waves. The picture below is a computer simulation of these waves—made to resemble snakes for fun.



A snapshot of Alfvén Waves on magnetic field lines rendered as 'snakes' at the Basic Plasma Science Facility at UCLA (http://128.97.43.7/bapsf/pages/gallery.html) which uses computer modeling to investigate laboratory plasmas in controlled fusion research. Who says scientists don't have a sense of humor?

Additional Web Resources

Space Weather terms

- Solar Terrestrial Dictionary - http://stp.gsfc.nasa.gov/stp_program/stp_dictionary.htm
- Space Physics Textbook - http://www.oulu.fi/~spaceweb/textbook/

Space Weather primers

- NASA-IMAGE - http://sunearth.gsfc.nasa.gov/sechtml/tut.html

Space Weather websites

- NOAA-Space Environment Center - http://www.noaa.sec.gov/SWN
- Spaceweather.com - http://www.spaceweather.com
- The Human Impacts of Space Weather - http://www.solarstorms.org

Space Weather books

- *The 23rd Cycle - Learning to Live with a Stormy Star* by Sten Odenwald, (Columbia University Press, 2001)
- *Sentinels of the Sun: Forecasting Space Weather* by Barbara Poppe and Kristen Jordan (Johnson Books, 2006)

Space Weather magazine and newspaper articles

- "Solar Storms" Sten Odenwald (*Washington Post* March 10, 1999) http://solar.physics.montana.edu/press/WashPost/Horizon/196l-031099-idx.html
- "Solar Storms: The Silent Menace" Sten Odenwald (*Sky and Telescope*, March 2000)
- "Storm Watch" C. Renee James (*Sky and Telescope*, July 2007)

National Aeronautics and Space Administration

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www.nasa.gov