- Measure, record and graph relationships to interpret data from the soda bottle magnetometer .
- Analyze data to determine disturbances in Earth's magnetic field from data.
- Recognize a high-intensity magnetic field of solar wind using real-time satellite data.
- Analyze satellite data to verify changes in magnetic field from magnetometer measurements by comparing terrestrial with space instrumentation.
- Discuss correlations within satellite data and magnetometer data.
- Predict sightings of aurora in Northern and Southern Hemispheres using geomagnetic coordinate map.

VOCABULARY:

Here are some terms that are used throughout this activity and in resource materials with which your students may not be familiar. You may want to spend some time developing their understandings of the relevant concepts.

- **Aurora**—a glow in a planet's ionosphere caused by the interaction between the planet's magnetic field and charged particles from the Sun.
- **Auroral oval**—the circular band in the Northern or Southern Hemisphere where aurora are most intense at any given time.
- **Coronagraph**—a special telescope that blocks light from the disk of the Sun in order to study the faint solar atmosphere.
- **Coronal mass ejection (CME)**—a disturbance of the Sun's corona involving eruptions from the lower part of the corona and ejection of large quantities of matter into the solar wind; sometimes have higher speed, density, and magnetic field strength than is typical for the solar wind.
- **Electron**—a lightweight particle that carries a negative charge, responsible for most electric phenomena and light emission in solid matter and in plasmas.
- **Solar flare**—is a sudden and intense variation of brightness off the Sun's surface interplanetary matter, the material in between the planets in the solar system, including that within the Earth's radius and out to and beyond the outer planets.
- **Magnetic poles**—the points on Earth towards which the compass needle points; a concentrated source of magnetic force, e.g., a bar magnet has two magnetic poles near its end.
- **Geomagnetic storm**—a large-scale disturbance of the magnetosphere, usually initiated by the arrival of an interplanetary shock, originating on the Sun.
- **Magnetosphere**—the region around Earth whose processes are dominated by the Earth's magnetic field.
- **Plasma**—the fourth state of matter or low-density gas made of charged particles.
- **Solar cycle**—the regular increase and decrease (maximum and minimum) in the level of solar activity lasting 11 years.
- **Solar wind**—a continuous flow of gas and energetic charged particles.
- **Sunspot**—a dark region on the solar surface where the magnetic field is so strong that the flow of energy from below is suppressed.]

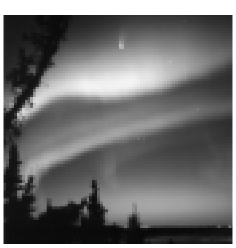
ACTIVITIES:

Preparing for the Activity

- The construction of one class soda bottle magnetometer (see instructions for construction in MAGNETISM section). Optional magnetometer is listed in Extensions.
- You can organize students in groups or pairs.

<u>Materials</u>
(for one magnetometer—4 students per group)

- 2-liter soda bottle or tennis ball canister
- 2 ft of sewing thread
- 1 small bar magnet
- 1-3 x 5 index card
- 1 mirrored dress sequin
- 1 adjustable high-intensity lamp



- Scissors
- 1 meter stick
- Super Glue
- 1-1 inch piece of soda straw

Mirror sequins may be obtained from any craft store.

Bar magnets may be obtained from this Web site – *http://www.wondermagnet.com/dev/magnets.html* Item #27, $2.01 each.

Students could bring in 2-liter soda bottles.

A desk lamp could be substituted for the high-intensity lamp.

For activity

- Instructions for magnetometer construction
- Photocopies of student worksheet
- Print out copies of Kp data and observatory data

Time

Overall, this activity will require two to three fourty-five minute periods, including:

- Construction of soda bottle magnetometer.
- Background discussion of space weather magnetic fields.
- Time to complete model; includes analysis of data and graphing activities.
- Acquiring observatory data and 3-day Kp plot from the Web.
- Time to analyze magnetometer data and predict where aurora will be seen.

Advance Preparation

- You may want to have the soda bottles already cut in half and prepared for the students.
- Drill holes in the caps of the soda bottles.
- Learn about magnetic fields and the magnetometer.
- Engagement and learning opportunities appear on the following url – *http://www-istp.gsfc.nasa.gov/istp/outreach/ed/*. Have students learn about magnetic fields while using the magnetometer to find the magnetic field lines around a bar magnet (see MAGNETISM). Also on this site are instructions for an additional magnetometer. Instructions include using a tennis ball canister to encase the sensor card instead of a soda bottle. If these are accessible to you (or from a nearby high school tennis team), then this may be easier for students to transport home.
- Photocopies of the worksheet, charts and graphs should be made for students to complete all tasks.

ACTIVITY 1

Introduce the Activity

Begin the activity by asking the students about today's weather and how it will affect any planned activities. Lead into the need for NASA scientists to know about space weather and how it may affect human activities. Also explain that NASA scientists use satellites not only to examine interplanetary matter but also to forecast space weather by measuring the effects of solar variability toward Earth. Point out that astronomers, satellite specialists and space physicists explore patterns in data gathered from solar wind. Utilizing mathematics is paramount in helping us and NASA scientists alike in examining and describing patterns and trends.

Completing the Model

1. Students will be examining a model approach to predicting aurora which will first include comparing data from solar and terrestrial instruments to describe magnetic fields. Solar data from the ACE magnetometer describes the magnitude of the magnetic field component, B_z. The more negative the values means the greater the potential of the field to interact and disrupt the Earth's magnetosphere. See Example 1 Answer Sheet.
2. Observatory data measures the Earth's magnetic field from the ground which will detect any changes in Earth's magnetic field. Students should be looking for large amounts of disruption and instability in the magnetic field demonstrated by the plots for data approximately within the same time period. See Example 2 Answer Sheet.
3. Once the correlation is confirmed and the time of disruption has been noted, then students may conclude that a geomagnetic storm had taken place.

4. To find the strength of the storm, students must then use the 3-day Kp plot for that time period to find the strength of the storm. Each Kp value comprises data in three-hour intervals for a total of eight values for each day. The higher the Kp value the greater the strength and effect of the geomagnetic event. Kp values are an indicator of how far south the aurora may be seen past the magnetic North Pole. [Note: It is important students understand that since geomagnetic storms cause changes in the Earth's magnetic field, using geographic coordinates is obsolete.] The enclosed chart of Kp index demonstrates the relationship between geomagnetic latitude and where the aurora may be seen.
5. Students are to use the chart with auroral boundaries and Kp indices to draw dark curved lines on the enclosed Mercator map according to the geomagnetic latitudes. Geographic coordinates are not included on the map. See Example 3 Answer Sheet. [Note: It is imperative that this map be used since the magnetic North Pole as a reference point for this kind of map moves as much as 1-20 kilometers per year.]
6. Using the city locations already plotted on the chart students should place in a chart where the aurora resulting from this particular geomagnetic event may be seen that day. Suggestion: Instead of saying the aurora may be seen at a particular time, ask students to supply whether it will be seen. Tell them possible restraints on seeing the aurora may be bright lights (Moon, Sun during daytime, and street lights in large cities).

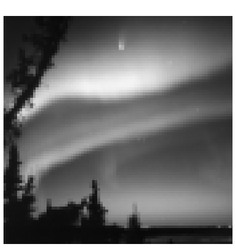
Using the Magnetometer

Show how the direction of the sensor card changes as a cow magnet is moved back and forth around the bottle. Explain that Earth's magnetic field is strong so the card will always return to its original position once the cow magnet is removed. Point out that the device you are working with when used properly is a good tool for predicting when and where a geomagnetic storm from solar wind may cause an aurora. The magnetic field from the solar wind interacts with Earth's magnetic field and causes movement of the sensor card of your magnetometer. The interactions of the two magnetic fields will result in the release of a pocket of energy displayed in the sky as the astronomical event over the poles called the aurora.

Make sure you tell the students that when data is collected the magnetometer must be placed near an undisturbed part of a room away from large appliances and windows near heavy traffic. There must also be efficient light to make accurate markings on the centimeter scale dark enough so that the reflected light spot can be seen on the scale.

Focus questions for opening discussion:

1. What is a magnetic field? Identify some things that may produce a magnetic field.
2. What causes the sensor card of the magnetometer to change direction?
3. Describe what happens when opposite poles of a magnet are put together. What about when two of the same poles are put together?
4. Why does the needle of a compass always point in one direction while you are still? What does this imply about the "North Pole"?



Collecting Data

1. Place the magnetometer in an undisturbed location of your home where the high-intensity lamp can also be placed. Do not place near another magnetometer, major appliance, or near a window on a busy street. Moving currents and electricity have their own magnetic fields.
2. Place the bottle on a level surface and point the lamp so that a reflected spot shows on a nearby wall about 2 meters away (See Figure 3). You should be able to see the reference spot in the middle of a light spot on the scale.
3. On white paper make a centimeter scale with zero (0) in the middle. Make tick marks up to 20 cm on each side. Keep your ruler level.
4. Tape the centimeter scale on the wall directly across from the magnetometer so the mirror spot reflects light onto the scale. (Make sure you can see the light spot during the day and have a light source to make measurements if the area is dark. Be sure the light source is not close to the magnetometer.)
5. Line up the magnetometer 2 meters away from the wall.
6. The first point is the reference point (most preferably zero). Note: If the bottle is moved, then a new reference point must be made.
7. Every 30 minutes for the duration measurements should be taken. Mark the position of your reference spot within the light spot.
8. You could test that the magnetometer is working by moving a cow magnet or handful of iron nails at various distances from the reference point.
9. The sensor card points at an angle to a horizontal surface—the direction of the magnetic North.
10. When taking measurements write down the time and movement of the sensor card in centimeters from the scale.
11. Mark the original position of the mirror spot on the scale as your reference point for measuring. Place the cow magnet about 0.5 meters away from the wall near the scale. Mark where the mirror spot has moved on the centimeter scale and note the time as the particular hour of the day.

Collecting Data–Teacher's Notes

12. Show students how to record the data and remind them of the frequency in which it should be done. Relay to them that all measurements are important and should be taken even if there is no change in the motion of the sensor card. In addition students should know if they move or change the direction of the magnetometer they must find another reference point.
13. Also tell them it is important to always keep the magnetometer 2 meters away from the wall. (Have a think quest or student competition as to the conversion of meters to feet or inches.) Ask them how they think the magnetometer's distance from the wall will change data values.
14. If students are taking measurements from the magnetometer at home make sure they start at the same day and hour.

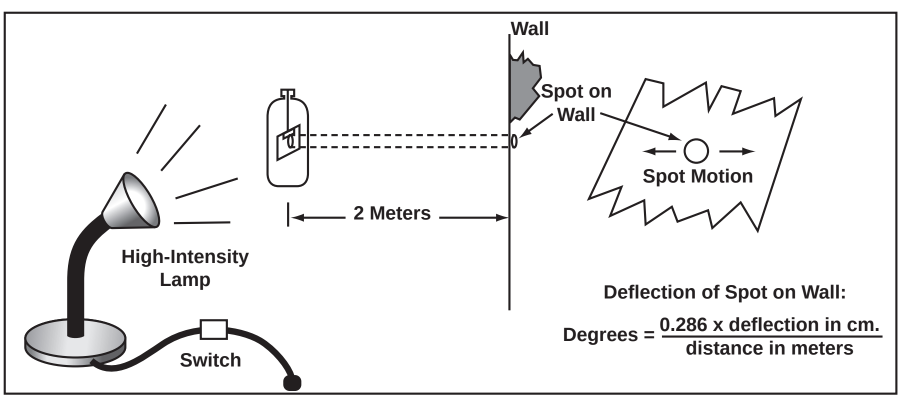


Figure 3. Set-up to collect data, IMAGE poetry

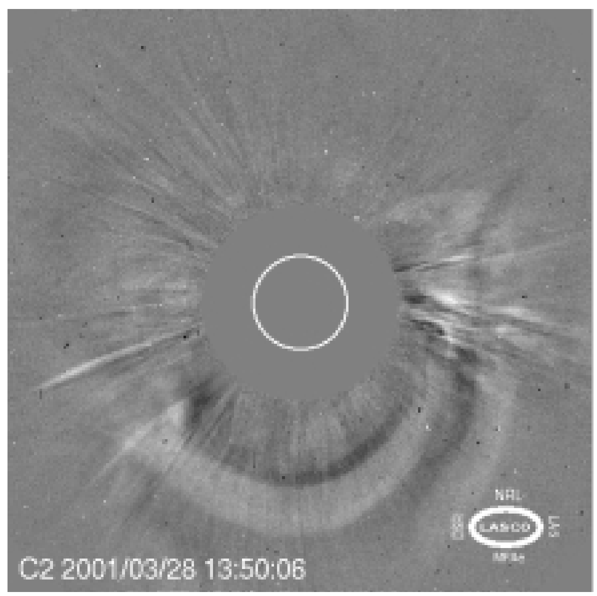
Analyzing Magnetometer Data

1. The magnetometer data should at least be taken over a 2-day period so variability in Earth's magnetic field can be detected.
2. Once students have made the plots with magnetometer data, it should be graphed at the same plane. See Example 4 Answer Sheet.
3. You should obtain observatory data for that day if the kids are to use the changes in Earth's magnetic field. This is for verification as you should not depend solely on one source to make conclusions. You can obtain observatory data for a specific day by going to the following url: *http://www.geolab.nrcan.gc.ca/geomag/e_digdat.html*

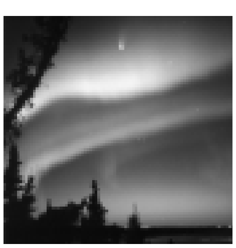
   Suggestion: This data is updated every minute. It is a good idea to obtain plots for the day before students began measuring. Each day must be submitted separately.
4. The Kp, planetary index, of the Earth's magnetic field is calculated from data collected by 13 geomagnetic observatories. A three-day plot of Kp indices for any date after 1996 can be obtained from NOAA's Web site at: *http://www.sec.noaa.gov/ftpmenu/plots/kp.html*. The name of the file for the sample Kp data plot (Example 5 of Teacher Answer Sheet) was 20010401_kp.gif which ranged from 3/30-4/2/2001. The Kp plot for the days under examination should be copied and distributed to student groups.
5. Students may then use the Kp values from the 3-day plot for that time period to predict where the aurora may be seen. They can refer back to the geomagnetic map to predict where the aurora is seen.
6. Magnetometer follow-up: Groups comprising students from different schools compare and analyze data taken from a constructed magnetometer during the school year. Data is put onto the MagNet (*http://sunearth.gsfc.nasa.gov/sunearthday/2003/network.htm*) and can be compared to the Kp values to monitor solar activity.

Extensions:

1. If it is possible to view the aurora in your area during geomagnetic storms, then you may want to use real-time data and compare that to the magnetometer. This would be done in the same manner as using observatory data; however, use observatory data as the verification when comparing to ACE solar data. Real-time data from ACE can be obtained at *http://www.sel.noaa.gov/ace/index.html*.
2. How long will it take a CME to reach Earth? SOHO images and ACE data could be used in conjunction to predict how long it will take a CME to reach Earth. This would require obtaining coronograph pictures from the LASCO instrument from the SOHO Web site. LASCO cameras in the image below captured the time (in UST) a full-halo CME entered space from the Sun. Images can be obtained from the following Web site—*http://lasco-www.nrl.navy.mil/cgi-bin/halocme_parse.* Real-time movies are available as well.



ACE data from the swepam instrument provides the speed of the solar wind (bulk speed component) in kilometers/second. You may use the same directions for acquiring ACE magnetometer data, however,



choose data for that day from "swepam" and not "mag." Since the distance from the Sun to Earth is approximately 150,000,000 km, to find the arrival time the "speed = distance/time" calculation is used.

Example data from swepam is provided below. If the measured solar wind speed is 750 kilometers/second from the data, the times it takes the CME to reach Earth and cause a disturbance in the Earth's magnetic field can be calculated. Students can then predict when an aurora will occur. Moreover, the correct CME from the SOHO image could be identified as the cause for the magnetic storm.

3. Exactly where was the aurora seen? Pictures from the Polar spacecraft would produce an image showing the auroral oval over the magnetic North Pole and its latitudinal boundaries.
   http://www-pi.physics.uiowa.edu/www/vis/
4. Images could be used to indicate the arrival of charged particles from CME to Earth's magnetosphere. Pictures show the auroral oval pervading the northern latitudes during day and night times by UV-ray analysis. The captured times on the images should correlate to the rise and fall of magnetic intensity of magnetic field, proton density, and wind speed from ACE data.
5. Students could use graphing calculator to learn the concept of maxima and minima, trends, and patterns in the data collected from ACE data.
6. The position for the magnetic North Pole serves as a reference point for auroral boundaries on the magnetic latitude. The magnetic North Pole shifts between 1 and 20 km/yr. Magnetic storms can shift a compass needle by 10 degrees or more, so it is important to know the pole's present location. Activity is found at the following url :
   http://image.gsfc.nasa.gov/poetry
7. A direct activity correlating solar activity to Kp index which involves graphing and data analysis can be found at the following url :
   http://image.gsfc.nasa.gov/poetry

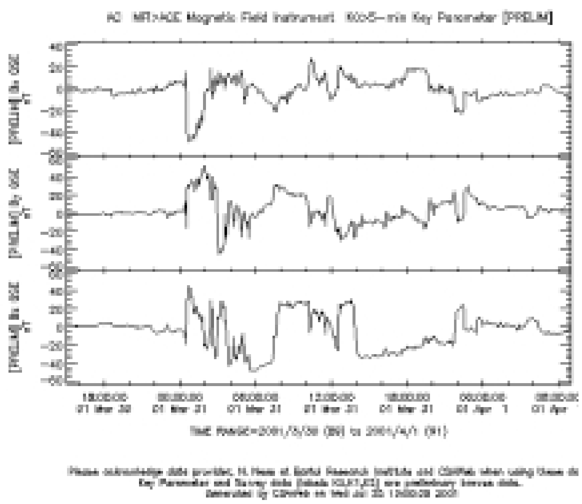
Teacher Answer Sheet

The following includes sample data retrieved from Web sites and also examples of what data should be used in each activity.

Analyzing Observatory Data

Bear Lake Observatory in Canada shows the Earth's magnetic field fluctuating mainly on March 31st. Prior to that date the magnetic field seems to be stable. This can be inferred from looking at how the maximum and minimum values for each component are not changing significantly. There also seems to be a large short-term disturbance on April 1st at 6 hours UST.

The plot could be analyzed in the same manner as above.



Example 1. Sample of Retrieved B_Z plot from CDAWeb

Analysis of Solar Data:

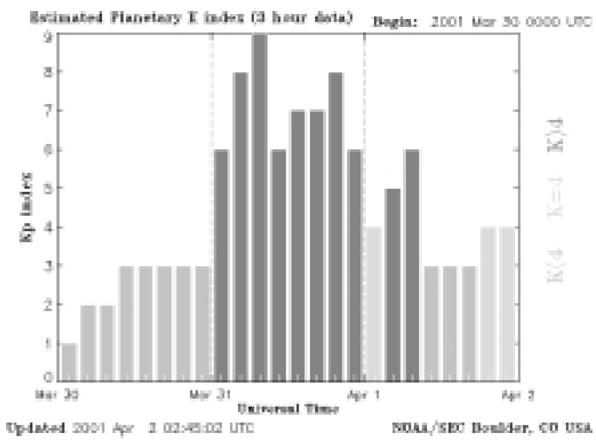
After drawing the zero line through the lines on each plot, students can see that values of each component can be negative or positive.

When examining the B_Z component, students can see the largest negative value at 06:00 UST, March 31. At this time the solar wind would have the greatest effect on Earth's magnetic field.

The observatory data shows a great disturbance in the Earth's magnetic field at the same time solar wind has been measured to have the greatest effect or interaction with Earth's magnetosphere. Other correlations can be made with specific times and magnetic field intensity values.

Predicting Aurora Location

After retrieving the 3-day Kp plot for the dates the magnetometer was utilized, it was possible to align the enormous disturbance in Bz magnetic field component and times of day on March 31, 2001, when Kp values were highest.



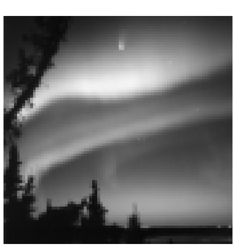
Example 2. Sample of Retrieved Data Plot for Kp indices from March 30 - April 2, 2001, Geomagnetic Event

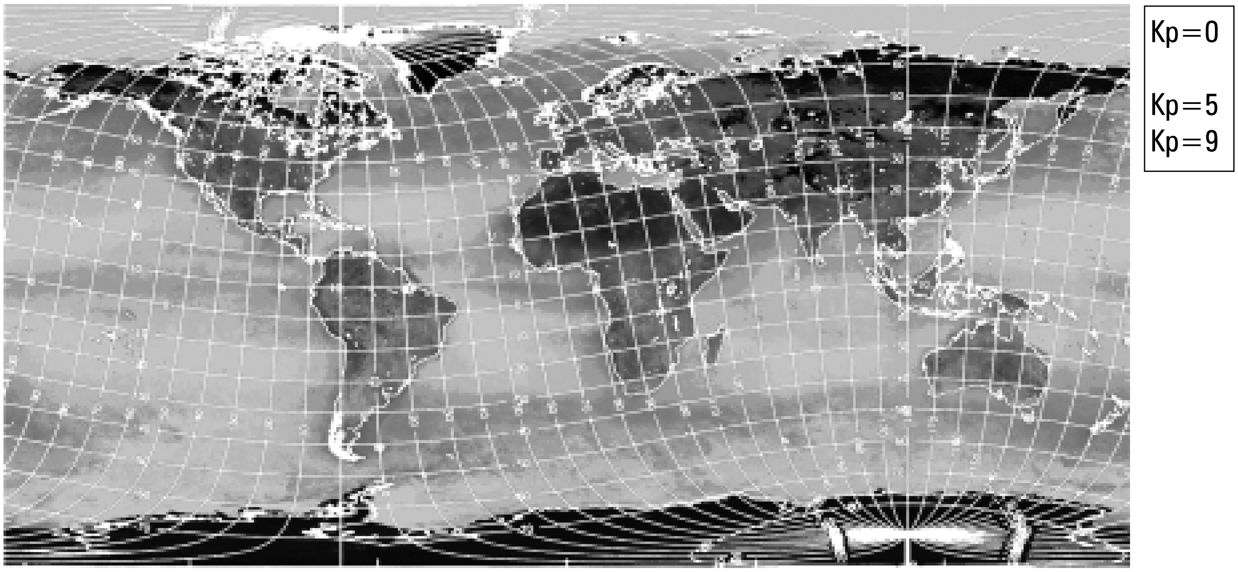
The Kp plot for March 30th through April 1st shows high Kp values for the whole day on March 31st. When Kp values are greater, then geomagnetic disturbance is considered large. This confirms that a magnetic storm had a large effect on Earth's magnetosphere.

Kp indices drawn on the map according to magnetic latitude indicate the southernmost sighting of an aurora. Students can then predict which cities have a high probability of viewing the aurora.

Using Magnetometer Data

Since the Kp values were as high as 8-9, the aurora boundaries may have reached as far south as Manhattan or even Washington, DC. Other places such as Tucson, Arizona, which are at lower magnetic latitudes, reported aurora sightings as well.

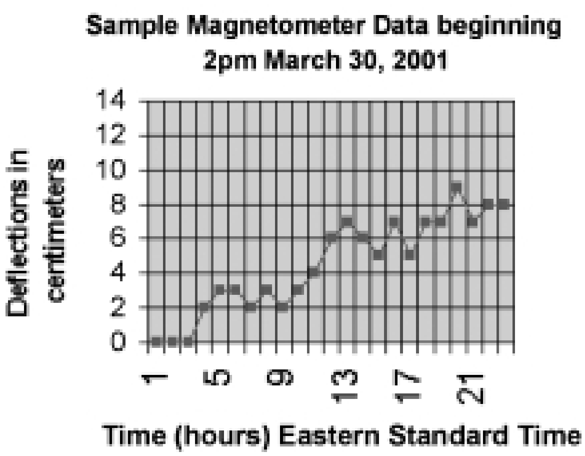




Example 3. Global Geomagnetic Coordinates

The probability of seeing an aurora at this latitude decreases as urbanization increases, due to city lights in the nighttime sky. Other factors include increased cloud cover and aurora appearing during daylight hours. In Alaska, it is difficult to see an aurora in the summer because there are mostly daylight hours.

The soda bottle magnetometer data should be graphed as above. Make sure the students have noted what time they started taking measurements.



Example 4. Soda Bottle Magnetometer Data

STUDENT WORKSHEET

Objective: To use model of analyzing geomagnetic storm in predicting aurora sighting

Complete model for Analyzing a Geomagnetic Storm

In the first part of the activity, you must look at the data as a NASA scientist does and decide if there are similarities or differences.

NASA scientists who study space weather obtain data about the Earth's magnetic field from a variety of sources. They often use solar (from space) and terrestrial (from the surface) instruments which gather data. Terrestrial data is acquired from an observatory whose main function is to monitor changes in the Earth's magnetic field. Solar data is retrieved from satellites that orbit around the Earth to measure the properties of solar wind.

Observatory Data Plot of Earth's Magnetic Field

To interpret changes there is need to look at a particular plot. Use data in Figure 1.

1. Pick any component (x, y, or z) and state the differences between the plots for the 3 days in question.

2. Do you think there are any changes? If so then what does that imply about the Earth's magnetic field? Justify your reasoning.

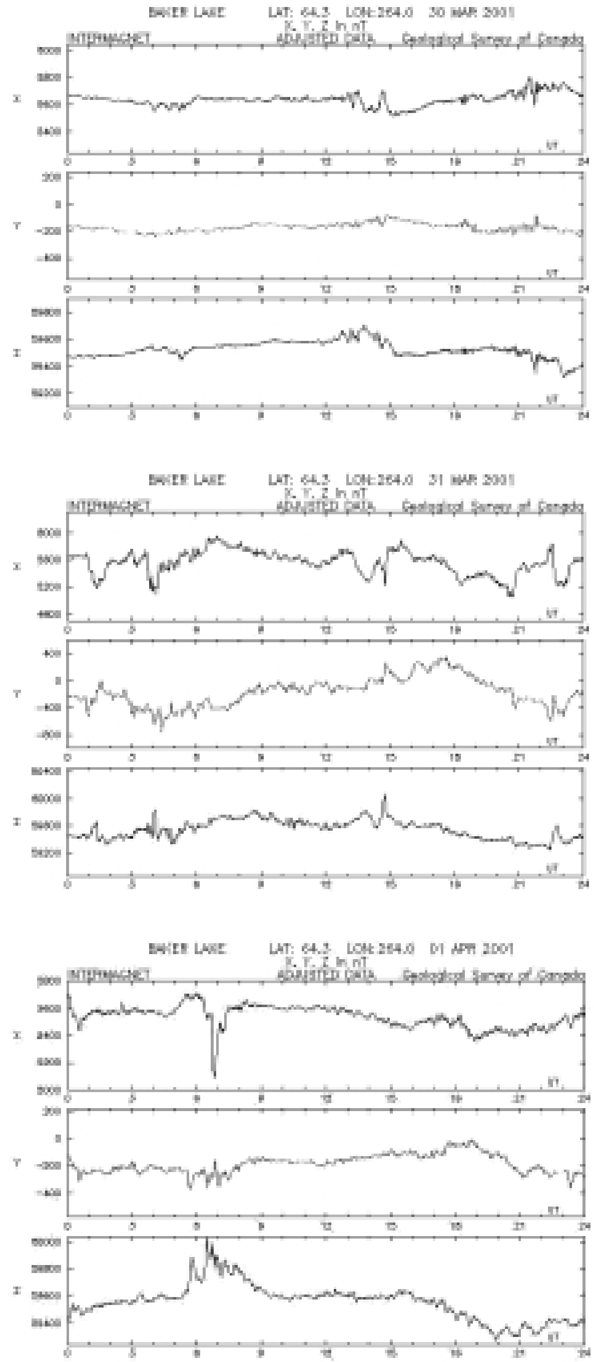
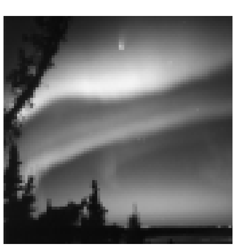


Figure 1. Bear Lake Observatory Data of Earth's Magnetic Field from March 30 - April 1, 2001

Note: Remember, we are only interested in observing changes/fluctuations in the data over a 3-day period.



Solar Data

ACE magnetometer shows the magnitude of the magnetic field component. Large negative values of the B_z component will determine the effect the solar wind will have on the Earth's magnetosphere. Examine the bottom plot, the B_z component.

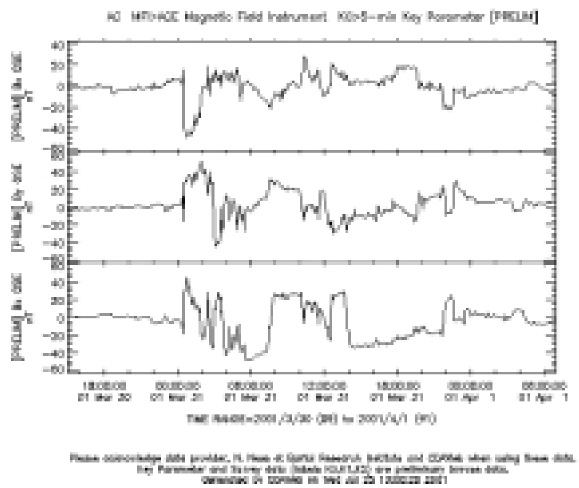


Figure 2. ACE Plot of Solar Wind Magnetic Field

Note : We are only interested in increasingly negative values for B_z plot.

3. Draw a horizontal line through point zero on the B_z axis. What does the plot tell you about the values of the magnetic field components?

4. The B_z component pertains to the direction of the magnetic field embedded in the solar wind. As B_z becomes increasingly negative, the solar wind's magnetic field will have the greatest effect on the Earth's magnetosphere. What time period does the data show the solar wind having the greatest effect?

5. Is there a noticeable pattern between the changing magnetic field of the solar wind and Earth's magnetic field from the Observatory Data? If so, then explain what the correlation(s) may be. Justify your conclusions with actual data from the table.

Predicting Aurora Location

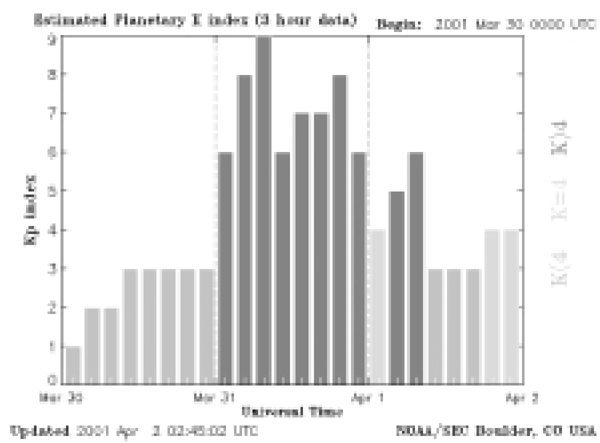


Figure 3. Sample of Retrieved Data Plot for Kp indices from March 30 - April 2, 2001, Geomagnetic Event

6. At what times are the Kp, planetary index seem to be the highest? What does this mean?

7. Kp indices drawn on the map according to magnetic latitude indicate the southern-most sighting of an aurora. Predict which cities have a high probability of viewing the aurora. Refer to the geomagnetic map.

Comparison of Auroral Boundaries from Kp at Local Midnight	
Magnetic Latitude	Kp Index
66.5	0
64.5	1
62.4	2
60.4	3
58.3	4
56.3	5
54.2	6
52.2	7
50.1	8
48.1	9

Probable Aurora Sightings according to Magnetic Latitude	
Place	Magnetic Latitude
Greenland	66.1
Yukon Territory	63.1
Anchorage, AK	60.8
Montreal, Quebec	56.4
Stockholm, Sweden	55.7
Chicago, IL	52.6
Moscow, Russia	51.4
New York City, NY	51.3
Washington, DC	49.8
Boulder, CO	48.9

Place measurements from magnetometer in table.

Magnetometer Measurements	
Time (hours)	Movement in centimeters

8. What times seem to have the greatest movement?

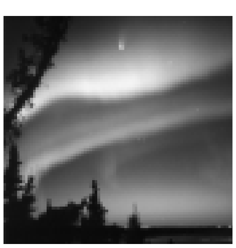
9. Convert the times of greatest movement to Universal Standard Time (UT)

   UT = Greenwich Mean Time—5 hours = Eastern Standard Time

   a. -6 hours = Central Standard Time
   b. -7 hours = Mountain Standard Time
   c. -8 hours = Pacific Standard Time
   d. -9 hours = Alaska Standard Time

Example: If the UT is 18:00 hours then Eastern Standard Time would be 13:00 hours or 1 p.m.

10. On the grid, plot the magnetometer data with movement in centimeters on the vertical axis against time (hours) on the horizontal axis.



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Verifying the magnetometer data from satellite data

Use data from Canadian Magnetic Observatories in order to verify the data you collected. Go to *http://www.geolab.nrcan.gc.ca/geomag/e_digdat.html* and choose an observatory from the list and specify the dates you wish to compare.

Time UT (hours)	Magnetic Intensity, B_z (nanoTeslas)

11. How closely does the observatory data correlate with your magnetometer data?

Correlating the strength of the storm to aurora sightings

Use the 3-day Kp plot bar (from *http://www.sec.noaa.gov/ftpmenu/plots/kp.html)* to identify the date and hours with the highest Kp indices. Kp values below 5 are not significant. Place in the table below.

Kp Chart	
Hours	Kp

Place in the table below names of cities from those most likely to see an aurora to those least likely to see the aurora. Check Auroral Friends Network as to where the predicted aurora may have been sighted.

Probable Auroral Sightings According to Magnetic Latitude	
City	Magnetic Latitude

List the factors that may affect aurora sightings in the cities you've chosen.

RESOURCES

Books and CDROMS

Campbell, Wallace H. (1997). Introduction to Geomagnetic Fields. New York: Cambridge University Press.

Web sites

Earth's Magnetic Field and the Aurora

http://www.gfz-potsdam.de/pb2/pb23/niemegk/kp_index/kp.html

http://space.rice.edu/hmns/dlt/Earthmag.html

http://www.sec.noaa.gov/info/kp-aurora.html

http://www.geo.mtu.edu/weather/aurora/

Space Weather/Solar Activity

http://sohowww.nascom.nasa.gov/explore/faq/flare.html

http://www.mtwilson.edu/Science/HK_Projects

http://www-istp.gsfc.nasa.gov/

Data Archives/ Geomagnetic Conversions

http://sunearth.gsfc.nasa.gov/

http://nssdc.gsfc.nasa.gov/space/cgm/cgm.html

http://www.sec.noaa.gov/SWN/

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

http://www.census.gov/

http://cdaweb.gsfc.nasa.gov

http://www.sel.noaa.gov/wind/rtwind.html

Education Materials

http://sd-www.jhuapl.edu/ACE/ACE_factsheet.html

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

http://soho.nascom.nasa.gov

http://helios.gsfc.nasa.gov/ace/ace_mission.html

http://www.exploratorium.edu/learning_studio/auroras/happen.html

http://www.istp.gsfc.nasa.gov/istp/nicky/cme-chase.html

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

Interactive Activities

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