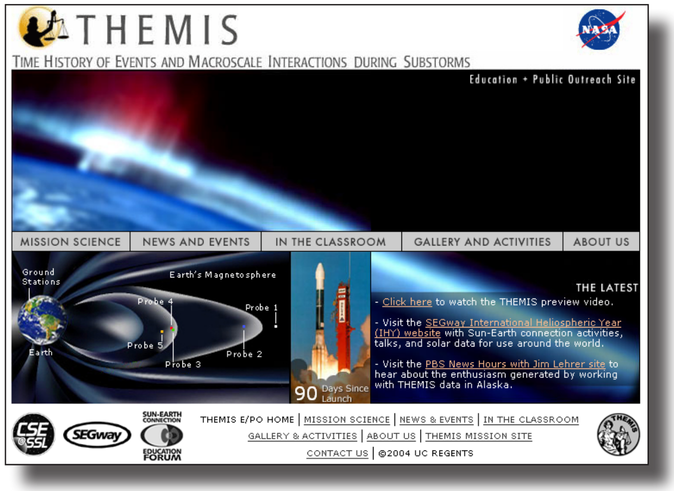
National Aeronautics and Space Administration

Earth's Magnetic Personality

Magnetic Data in the Classroom

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 website 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
16 - Mag. Line Plots		m					B: (Motion and Forces). Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces.
17 - Soda Bottle Mag.	M	M	i				A: Design and conduct scientific investigations; use technology and mathematics to improve investigations and communications. B: (Motion and Forces). Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces.
18 - Kp Index	M	M	i			m M	A: Design and conduct scientific investigations; use technology and mathematics to improve investigations and communications.B: (Motion and Forces). Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. 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) Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied.
19 - Mag. Mag. Changes	M	m	i			M	A: Design and conduct scientific investigations; use technology and mathematics to improve investigations and communications. B: (Motion and Forces). Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. G: (Nature of Scientific Knowledge) Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied.
20 - Spectro. Plots	M	m	i				A: Identify questions and concepts that guide scientific investigations, use technology and mathematics to improve investigations and communications. B: (Motion and Forces). Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. G: (Nature of Scientific Knowledge) Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied.

National Math Standards

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

NM-ALG.9-12.2: (Algebra). Represent and analyze mathematical situations and structures using algebraic symbols.

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-PROB.COMM. PK-12.2: (Communication - Grades Pre-K - 12). Communicate their mathematical thinking coherently and clearly to peers, teachers and others.

NM-PROB.COMM. PK-12.4: (Communication - Grades Pre-K - 12).Use the language of mathematics to express mathematical ideas precisely.

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

Standards Key
M - major emphasis
m - minor emphasis

continued on next page

Activity	NM-NUM. 9-12.3	NM-ALG. 9-12.2	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-PROB. COMM. PK-12.2	NM-PROB. COMM. PK-12.4	NM-PROB. CONN. PK-12.3
15- Vectors A-B	M	M		M	M		M				m		m
16 - Line Plots	m				M	M	M					m	m

continued from previous page

National Math Standards

Standards Key
M - major emphasis
m - minor emphasis

Activity	NM-NUM. 9-12.3	NM-ALG. 9-12.2	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-PROB. COMM. PK-12.2	NM-PROB. COMM. PK-12.4	NM-PROB. CONN. PK-12.3
17 - Soda Bottle Mag.					m	M	M	M	M	M			
18 - Kp Index			m			M	M	M	M	M			
19 - Mag. Mag. Ch.			m			M	M	M	M	M		m	M
20 - Plots & Spectrums						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 15: Vectors from A to B

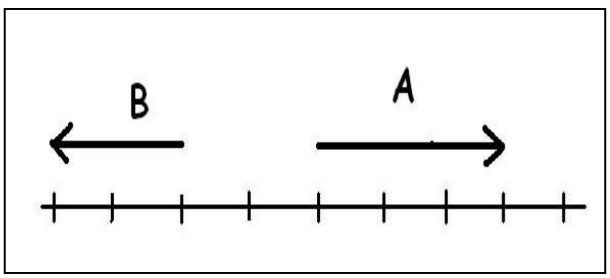
Teacher's Guide:

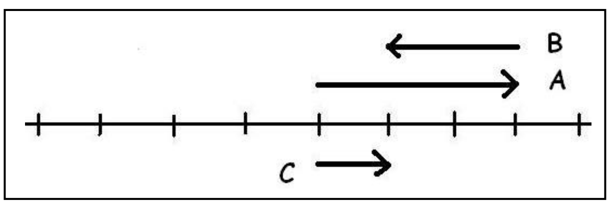
In order to understand the THEMIS Magnetometer line-plot data, students must first understand vectors. We introduce the concept of a vector, and point to additional web-based resources for teaching about vectors. Velocity is the most common and intuitively familiar form of a vector quantity, and we will start with this as an example.

Remind students that when they are in a car, there are two things that are the most important about the 'experience' : How fast are they going, and in what direction. We call this motion a vector because it consists of both a magnitude and a direction. One of these features, by itself, is not enough to completely describe how a car is moving at a particular moment.

Because a vector also requires a direction to specify it, it requires some kind of reference basis or 'coordinate system'. The simplest coordinate system for 1-dimensional vectors is the number line. Let's see how this works.

Vectors in 1-dimension.



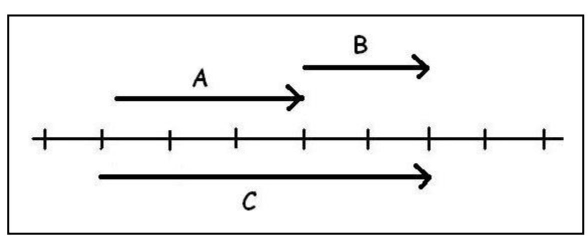


Above Figure: To add two vectors, A + B, place the tail of the arrow for B at the head of the arrow for A. The result is a third vector C which is called the Resultant. Note that the magnitude of C is 3 - 2 = 1 unit.

Right Figure: To subtract vectors, A - B, reverse the direction of B, and place it at the head of A. Note that the magnitude of C is 3 + 2 = 5 units.

Define two vectors called **A** and **B**. The **A** vector says 'Move three units to the right'. The **B** vector says 'Move 2 units to the left'. They look like the figure to the left. The length (magnitude) of Vector A is '3 Units' and its direction is 'Right'.

Suppose we added Vector **B** to Vector **A.** This could represent a person walking three blocks north on a street, then turning around and walking two blocks south on the same street. Although the total distance traveled is 3 + 2 = 5 blocks, this really doesn't tell us where the traveler ended up. To find this, we have to include in the addition the direction information at the same time.

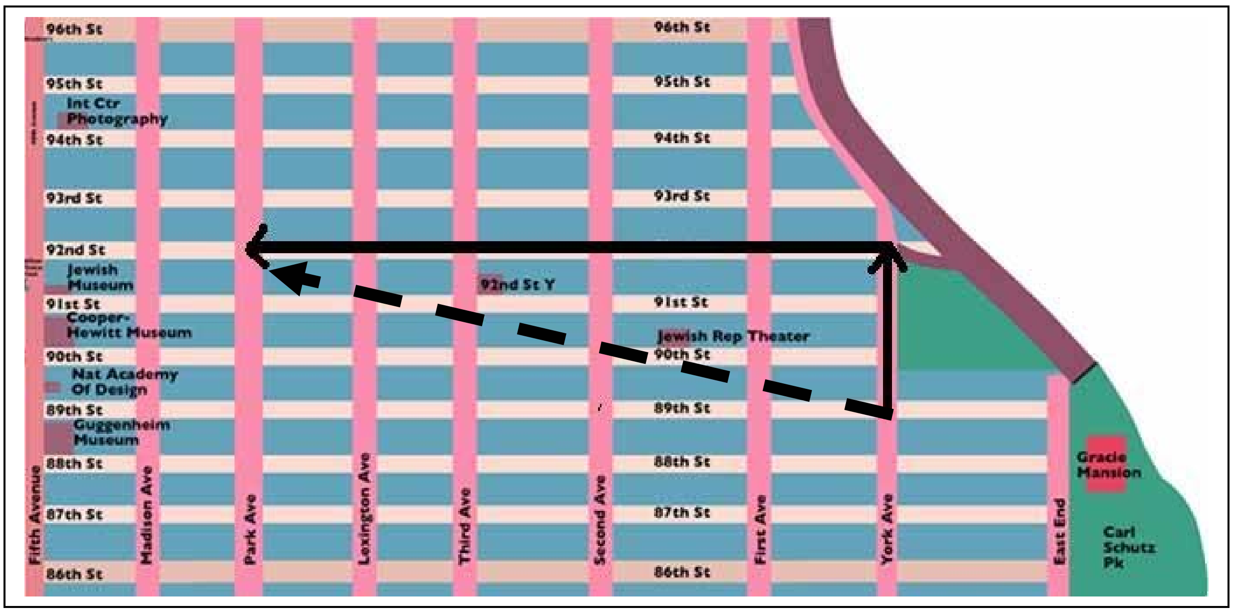


Vectors in 2-dimensions.

The previous example was simple, and can be used in systems that describe motion along a line, like water flowing down a hose, or relay sprinters on a 100-meter straight track. There are MANY of these kinds of problems. Can you and your students come up with other examples of 1-dimensional motion?

Motion in 2-dimensions is just a little more complicated. Think of the motion of balls on a pool table, or ATVs driving across the Bonneville Salt Flats. If you forget about vertical direction, traveling by car on the surface of Earth is also 2-dimensional motion. Because objects move, they can also be described by velocity vectors that are 2-dimensional. Again, you have to specify a coordinate system to serve as a direction reference. **With an Earth globe, show students that cars moving on Earth's surface travel north and south along directions of latitude, and east to west along directions of longitude.** This provides a simple 'geographic' coordinate system that we also use in city driving…especially now that many people have GPS systems. You can also use an ordinary compass to get the same coordinate 'bearings'.

In our previous example, lets assume that our New York City shopper traveled 3 blocks north on York Avenue along vector **A**, but then traveled 5 blocks west on 92nd Street on vector **B**. Let's see what the shopper's path looked like in the figure below.



Adding the two vectors, **A+B**, we see that, although the total distance walked is 3 + 5 = 8 blocks, the total distance from where the shopper started is a different length, and is represented by the dotted vector **C** in the above figure. Because the streets are perpendicular, the triangle formed by vectors **A**, **B** and **C** is a right-triangle, and **C** is the hypotenuse. This means that the total distance from the starting point is given by the sums of the squares of the magnitudes of the vectors **A** and **B** so that $C^2 = A^2 + B^2$ so that the magnitude of vector **C** is just the square-root of (25 + 9) which is 5.8 blocks. This would be called the 'as the crow flies' distance.

What does this have to do with velocity?

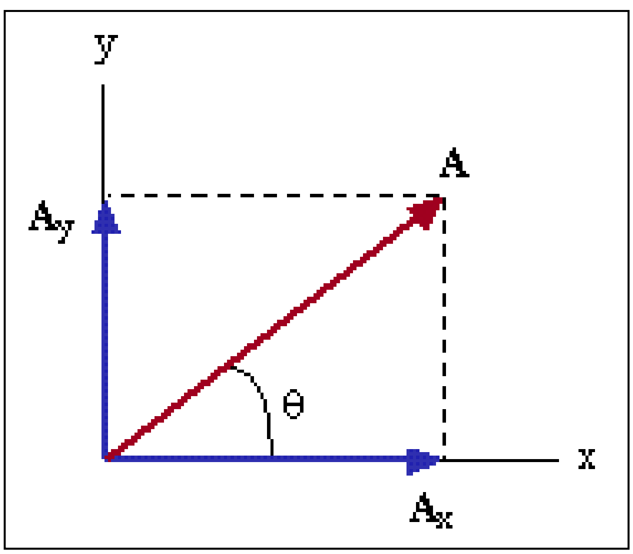
The above example described a vector quantity called 'position', but we can just as easily use this same set up to describe velocity. Imagine that a crow is actually flying along the position vector **C** that connects the shopper's starting position at the corner of 89th Street and York Avenue, with the shoppers destination at the corner of 92nd Street and Park Avenue. Let's call the crow's velocity vector **V**. Now the question is, how fast is the bird moving in a direction along York Avenue, and along 92nd Street?

You can see from the street map that, as the crow moves along the diagonal, its 'shadow' will travel at a certain speed along each of these two streets. This means that the vector **V** for the crow, can be thought of as two other vectors, call them **Vn** and **Vw,** added together. If we take the **Vn** vector that runs along York Avenue, and add to its head, the **Vw** vector that runs along 92nd Street, vector **V** is the Resultant vector. We can write this as the vector addition equation:

$$\mathbf{V} = \mathbf{Vw} + \mathbf{Vn}$$

Vector components:

A 2-dimensional vector is completely defined by the sum of the components of the vector along two coordinate axis. For example, let's look at the ordinary Cartesian plane with axis X and Y in the figure below.



The vector A is 'resolved' into two vectors Ax and Ay. Another way to look at these component vectors is that

$$\mathbf{Ax} = |Ax|\ \mathbf{x}$$
$$\mathbf{Ay} = |Ay|\ \mathbf{y}$$

Where |Ax| and |Ay| are the **magnitudes** of these vectors, and **x** and **y** are the direction vectors along the two axis for which |x| = |y| = 1.

Another important thing to see from this Cartesian coordinate system is that, with a little bit of trigonometry:

$$|Ax| = |A| \cos(\theta) \quad \text{and} \quad |Ay| = |A| \sin(\theta)$$

The nice thing about working with vector components is that you can now add and subtract vectors very easily. For example consider two vectors

$$\mathbf{A} = |Ax|\,\mathbf{x} + |Ay|\,\mathbf{y}$$
$$\mathbf{B} = |Bx|\,\mathbf{x} + |By|\,\mathbf{y}$$

Then to add them to get the vector **C** you have

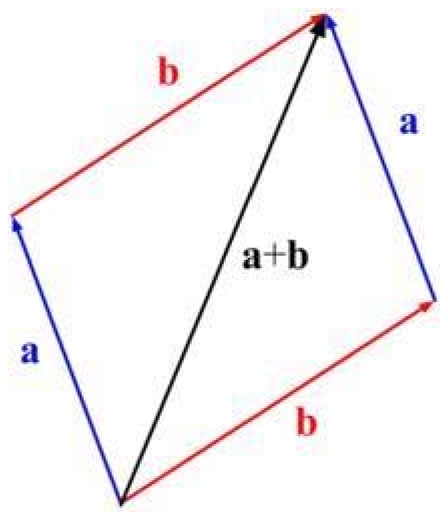
$$\mathbf{C} = (|Ax| + |Bx|)\,\mathbf{x} + (|Ay| + |By|)\,\mathbf{y}$$

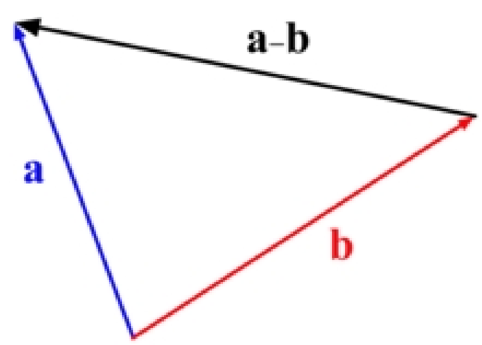
Similarly, to subtract them you have

$$\mathbf{C} = (|Ax| - |Bx|)\,\mathbf{x} + (|Ay| - |By|)\,\mathbf{y}$$

If you prefer adding vectors graphically, draw vector A on the Cartesian plane, and then draw vector B starting at the head of vector A to create the vector **A+B** as in the figure below to the left.

If you want to subtract these two vectors, draw vector A, then draw vector B starting at the base of vector A, draw a vector connecting the two tips of A and B to find **A-B** as in the figure below right.





Additional Resources

http://exploration.grc.nasa.gov/education/rocket/vectors.html

Procedure

Give the students a lecture about how to add and subtract vectors. Have the students who understand how it works solve a couple examples of vector addition and subtraction problems in front of the other students. Have the students answer the student worksheet to assess if they can add and subtract vectors in 2-dimensions. This is important before introducing the three dimensional magnetometer data.

Student's Name ___________________________ Date _______

Problem 1) A car travels along a path such that its speed is 30 miles per hour north and 25 miles per hour west. What is the total speed of the car along its actual path?

Problem 2) A jet plane takes off from O'Hare International Airport in Chicago. It is headed in a direction due West with a speed of 550 miles per hour. There is a wind blowing from the south to the north at a speed of 150 miles per hour.

A) Use vector addition to diagram the two vectors and calculate the resultant vector, which is the jets speed relative to the ground.

B) What is the direction of the jet's velocity vector relative to the ground?

Problem 3) On a piece of paper, iron filings are sprinkled to reveal the magnetic field of a bar magnet. At a particular point on the paper, the magnetic field vector is given by:

$$\mathbf{B1} = -15 \text{ gauss } \mathbf{X} + 10 \text{ gauss } \mathbf{Y}$$

On a second piece of paper, the iron filings from a second magnet are revealed using iron filings. At the same point on the paper as for the first magnet, a measurement is made of the magnetic field vector and it is given by

$$\mathbf{B2} = 26 \text{ gauss } \mathbf{X} - 5 \text{ gauss } \mathbf{Y}$$

A) If both magnets were placed under a third piece of paper at the same location, and iron filings were sprinkled on the paper, what would be net sum of the two magnetic fields at the point used in the first two papers?

B) What would be the difference in magnetic field strengths between the two magnets at the measurement point?

C) Which bar magnet has the strongest magnetic field?

Answer Sheet

Problem 1) A car travels along a path such that its speed is 30 miles per hour north and 25 miles per hour west. What is the total speed of the car along its actual path?

Answer: speed = square-root ($30^2 + 25^2$) = 39 miles per hour.

Problem 2) A jet plane takes off from O'Hare International Airport in Chicago. It is headed in a direction due West with a speed of 550 miles per hour. There is a wind blowing from the south to the north at a speed of 150 miles per hour.

A) Use vector addition to diagram the two vectors and calculate the resultant vector, which is the jets speed relative to the ground.

Answer: speed = square-root ($550^2 + 150^2$) = 570 miles per hour.

B) What is the direction of the jet's velocity vector relative to the ground?

Answer: Northwest. For 'experts' the angle is arcTan (150/550) = 15 degrees north of west.

Problem 3) On a piece of paper, iron filings are sprinkled to reveal the magnetic field of a bar magnet. At a particular point on the paper, the magnetic field vector is given by:

B1 = -15 gauss **X** + 10 gauss **Y**

On a second piece of paper, the iron filings from a second magnet are revealed using iron filings. At the same point on the paper as for the first magnet, a measurement is made of the magnetic field vector and it is given by

B2 = 26 gauss **X** - 5 gauss **Y**

A) If both magnets were placed under a third piece of paper at the same location, and iron filings were sprinkled on the paper, what would be net sum of the two magnetic fields at the point used in the first two papers?

Answer: **B1 + B2** = (-15 + 26) **X** + (10 -5) **Y** = 11 gauss **X** + 5 gauss **Y**

B) What would be the difference in magnetic field strengths between the two magnets at the measurement point?

Answer: B1 - B2 = (-15 -26) **X** +(10 +5) **Y** = -41 gauss **X** + 15 gauss **Y**

C) Which bar magnet has the strongest magnetic field?
Answer: Find the magnitude of B1 and B2 and compare.

|B1| = square-root ($(-15)^2 + (10)^2$) = 18.0 gauss.

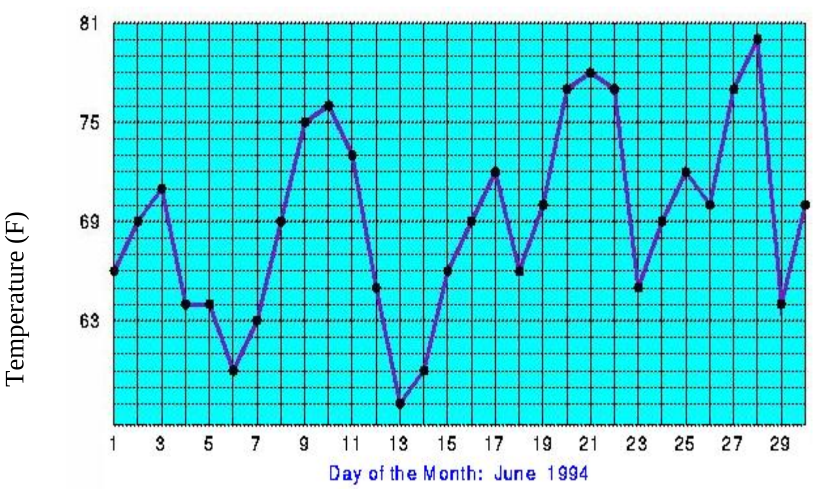
|B2| = square-root ($(26)^2 + (-5)^2$) = 26.5 gauss. **This is the strongest.**

Activity 16 – THEMIS Magnetometer Line-Plots

Teacher's Guide:

In this activity, students will learn about the magnetometer data and its 3D vector nature. In particular, the students will learn how to read the x, y, z plots and how to create a model of the 3D magnetic field in the location of the magnetometer closest to their town.

History: Since the early-1800's and the pioneering efforts by Baron Alexander von Humbolt, dozens of specially-designed observatories have been built around the world to make regular measurements of Earth's magnetic field. Modern 'Magnetic Observatories' use instruments called magnetometers to measure the three components to Earth's magnetic field at ground level. The three-component plots are easier to understand if we remember that many physical quantities are plotted according to the magnitude of a quantity and the time of the measurement. The most familiar is temperature, like the one of Seattle, Washington below.



Temperature is a physical quantity that is defined by a single number at each point in space. In the plot to the left, we used the Fahrenheit scale on the vertical axis to denote the units of temperature. There are other physical quantities that can also be described by a single number, for instance, density, mass, color and brightness. Notice that magnetism is not one of these!

Students who have taken a physical science course will have had to deal with the concepts of velocity and acceleration. Because these are physical quantities defined by BOTH a magnitude and a direction, they require a bit more work to describe fully, unlike temperature. Because the direction can be anywhere in 3-dimensional space, we have to define velocity and acceleration by its direction along each of the three Cartesian axis. Just as 'velocity' measures both the speed and direction of a bodies motion, the strength of a magnetic field is a similar 'vector' quantity that has to be defined both by its magnitude and its direction.

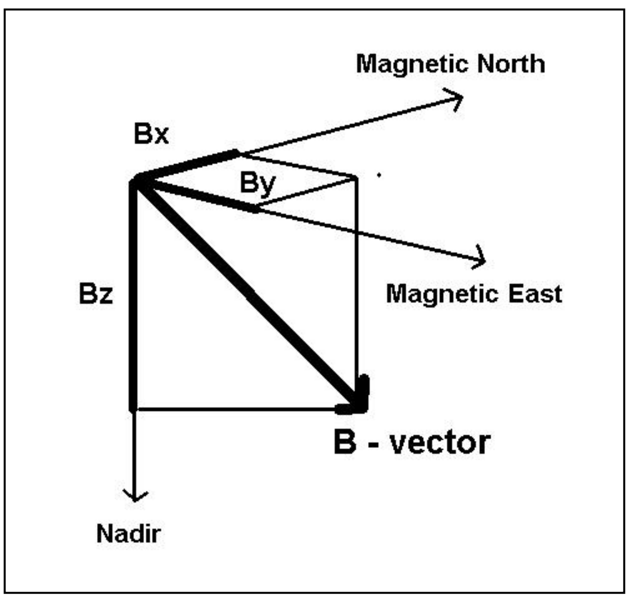
The units we use to measure magnetic strength is the *tesla*. A tesla is a unit of magnetic flux density. Earth's magnetic field is small compared to a tesla: 50 million times smaller (50 'micro-tesla' or 'µT').

The magnetic field changes on Earth's surface due to space weather is even smaller and are more conveniently defined by the 'nanoTesla' or nT, which is one billion times smaller than a Tesla. Earth's surface magnetic field is approximately 50,000 nT.

One way of demonstrating the idea of a billion times smaller, i.e. a billionth, to students is to use an hour glass type of table:

Orders of Magnitude Key			
Name	**Prefix**	**Number**	**Power**
Billion	giga (G)	1 000 000 000	10^{9}
Million	mega (M)	1 000 000	10^{6}
Thousand	kilo (k)	1 000	10^{3}
Hundred	hecto (h)	100	10^{2}
Ten	deca (da)	10	10^{1}
One		1	10^{0}
Tenth	deci (d)	0.1	10^{-1}
Hundredth	centri (c)	0.01	10^{-2}
Thousandth	milli (m)	0.001	10^{-3}
Millionth	micro (μ)	0.000 001	10^{-6}
Billionth	nano (n)	0.000 000 001	10^{-9}

The United States Geological Survey web site (http://geomag.usgs.gov/intro.html) introduces what magnetometers measure: *"The Earth's magnetic field is both expansive and complicated. It is generated by electric currents that are deep within the Earth and high above the surface. All of these currents contribute to the total geomagnetic field. In some ways, one can consider the Earth's magnetic field, measured at a particular instance and at a particular location, to be the superposition of symptoms of a myriad of physical processes occurring everywhere else in the world."*



The figure to the left shows the relationship between the direction that a magnetic field is pointing and its magnitude in a Cartesian coordinate system. The origin of the coordinate system is the physical point in space where the field is being measured. You can think of this as the place where your magnetometer is buried. The thick line connected to the Origin represents the magnetic field vector. Its length represents the magnitude of the magnetic field.

To describe its direction, the THEMIS, GEONS magnetometers are lined up so that they measure that the coordinate system is such that

- **X:** represents the magnetic field strength in roughly the direction of the north magnetic pole. A positive x-value means that part of the magnetic field is pointing north. A negative x-value means that part of the magnetic field is pointing south.
- **Y:** represents the magnetic field strength 90 degrees from the x-direction in the "magnetic east" direction. A positive y-value means that part of the magnetic field is pointing towards magnetic east. A negative y-value means that part of the magnetic field is pointing towards magnetic west.
- **Z:** represents the magnetic field strength in the local nadir direction (vertically down).

The THEMIS GEONS magnetometer data is also displayed in a compass-like coordinate system. This coordinate system is analogous to a special type of compass that could point down as well as horizontally with a needle that changed its length depending on the strength of the magnetic field. The letters associated with this coordinate system are:

- H: represents the strength of the magnetic field in the plane horizontal to Earth's surface (horizontal plane)
- D: represents the angle between magnetic north (x-direction) and the direction of the magnetic field in the horizontal plane
- Z: represents the magnetic field strength in the local nadir direction (vertically down).

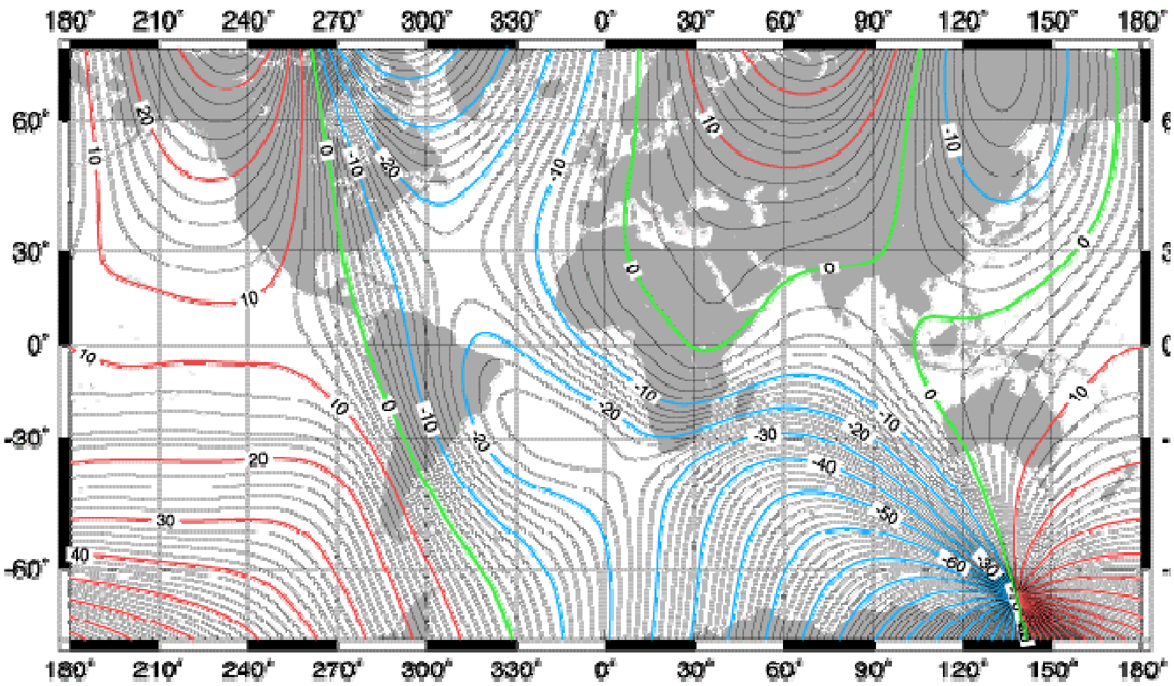
For a complete presentation on the magnetometer data and what it measures, please see the 'Magnetometer Signature Tutorial' found on the THEMIS Education and Public Outreach (E/PO) website. There are several different ways of viewing the tutorial (as an HTML page, a Acrobat Reader PDF document, and PowerPoint document). It can be found on the left side of this page of the THEMIS E/PO website:

`http://ds9.ssl.berkeley.edu/themis/classroom.html`

This tutorial presentation is aimed at teachers and is not intended for students, although teachers are encouraged to modify the presentation for students if they wish. As part of this Activity 16, however, students should watch at least one of the student podcast presentations created by students in Petersburg, AK about the magnetometer data (see "Procedure" below). These student presentations were created to teach fellow students about the magnetometer data. The presentations can be found on this page of the THEMIS E/PO website under "Podcasts":

`http://ds9.ssl.berkeley.edu/themis/schools/student_teacher_work.html`

The map below shows the value of D in degrees in the form of a contour map drawn over the normal latitude and longitude grid of Earth. Red lines means that True North is located to the East of Magnetic North by the number of degrees indicated on the contour. Blue means that True North is located to the West of Magnetic North by the indicated degrees. In the Southern Hemisphere, these directions are reversed for the magnetic pole in that hemisphere. Example: You are in San Francisco Bay. You want to head due-east at 270 degrees. From this map, D = +7 degrees east, so you have to set your magnetic compass at 270-7 = 263 degrees in order to be headed due-east, geographically.



Overall Procedure (detailed procedures are located in each section)

1) Students make several paper 3-dimensional (3-D) vector addition models to become familiar with 3-D vectors.
2) The teacher gives a lecture about 3-D vectors and the magnetometer plots using the information above and the “Magnetometer Signature Tutorial” found on the left side of this webpage:

http://ds9.ssl.berkeley.edu/themis/classroom.html

3) Students watch the AK student podcasts found at this webpage:

http://ds9.ssl.berkeley.edu/themis/schools/student_teacher_work.html

4) Students design and build a model to visualize the 3-D magnetometer vectors using vector addition of the three x, y, z, components of the magnetometer data from the THEMIS magnetometer closest to the school.   This procedure uses more stable materials than the paper 3D models in step 1).

3-Dimensional Vector Addition

Vectors are sometimes difficult to visualize, especially the fact that in 3-dimensions, they can be constructed from three independent components. This activity lets students explore how vectors are described, and constructed, in 3-D space. We will construct a distance vector composed of the following 3 components:

X - direction (Magnetic north; blue) = 3 inches
Y - direction (Magnetic east; red) = 5 inches
Z - direction (Down; black) = 4 inches

A possible example of what these vectors could represent would be the distance of a bird hoping from a bush to the ground.

Materials

Stiff construction paper or light-weight cardboard, 3 marker (red, blue, black), a ruler, and a pair of scissors

Procedure

1 – Model the procedure for the students outlined on the following student worksheet, but instead using x = 5 in, y = 4 in, z = 3 in
2 – Have students follow the procedure outlined on the following student worksheet
3 – Have the students answer the questions on the worksheet

Note: This could be done completely as an inquiry lesson by providing the students a strip of paper and asking them to develop a way of representing the 3-D vector of a bird hoping in the given x,y,z direction.

Answers

1. The first strip was folded so that there were 3 inches along the X-axis; 5-inches along the Y axis and 4 inches along the Z axis. These represent the projected distances along each cartesian axis that make up the final 'resultant' vector. The second strip with the arrow represents the total added vector.
2. The length of the resultant vector is 7.1 inches. It can be determined by measuring the final vector or by using the Pythagorean Theorem: total vector magnitude = square root of ($x^2 + y^2 + z^2$)
3. Because all of the units are distances, it represents the fixed location of a point from the origin of the coordinate system (at the start of the X-component). Note that we could just as easily have used this to represent an object moving with a speed of 7.1 miles per hour, with X-Y-Z component vectors of 3 mph, 5 mph and 4 mph. It would then be called a velocity vector.
4. 8.3 inches

A Student's Name ___________________________ Date _______

3-Dimensional Vector Addition

1. Take a strip of paper 1-inch wide and cut it to a length of 12 inches.
2. Using the ruler, mark 11 black lines one inch apart along the length of the strip. Flip the strip of paper over and copy these lines on this other side of the strip so that if the paper were transparent, the lines would overlap.
3. With the blue marker mark the first 3 lines with the letter 'X', color blue the edge of the paper with the marks, and put half of an arrow head pointing at the third line. This represents the **x** vector.
4. With the red marker, mark the next 5 lines with the letter 'Y', color red the edge of the paper with these marks, and put half of an arrow head pointing at the last of the 5 lines. This represents the **y** vector.
5. With the black marker, mark the final 4 lines with the letter 'Z', color black the edge of the paper with these marks, and put half of an arrow head pointing at the last line. This represents the **z** vector.
6. Repeat this on the back side of the strip making sure that the X's, Y's and Z' match up on both sides as if the paper were transparent.
7. At the first 3rd line where the blue arrow head points, fold the strip into a right-angle such that the red edge of the paper lines up with the 3rd line.
8. At the end of the next 5 lines, where the red arrow head points, fold the strip into a right-angle such that the paper is folded "down" at the red arrow head and the black arrow is pointing out of the plane of the other two vectors using the right-hand rule (x=pointer finger, y=middle finger, z=thumb).
9. With a second strip of paper 1-inch wide, connect the beginning of the folded strip and the end of the folded strip and trim the second strip so that it exactly meets each end. Draw a large arrow along the second strip between the beginning of the blue vector and the end of the black vector (arrow head).
10. Use the compass to orient the x, y, and z vectors so that x is pointing towards magnetic north, y towards magnetic east, and z down.

Answer the following questions:

1. Explain what this procedure represents in terms of vectors.

2. What is the final resultant vector's value in inches? List two ways of determining its value.

3. What does this vector represent?

4. Repeat this procedure for x=3.5 in, y=1 in, and z=7.5 in. What is the final vector's value?

A model of the THEMIS magnetometers XYZ vector coordinates

The next activity is an inquiry activity to help the students come up with their own manipulative model to demonstrate Earth's magnetic field vector, and the three coordinate directions, X, Y and Z that define it and that are displayed by the THEMIS magnetometer. Students will get a good sense of scale with this model since they will see how small the y-component is compared with the x-, and z-components. It is suggested that this model of the magnetometer vector be set up and left in the classroom if the classroom is near (within 160 kilometers, 100 miles) the same longitude as the magnetometer being used in this activity.

Materials per student group

- 7 Polystyrene balls 2-inch diameter (Molecular Model Enterprises: 608-884-9877)
- 7 bamboo skewers

Material Notes

Styrofoam balls were too soft and had only one use and then fell apart.

If you want to use a 3-D compass to get the 3D orientation in your town, you can buy a Magnaprobe (shown above) for $16. For more on how to use the Magnaprobe see the NASA - Tracking a Solar Storm lesson at

http://son.nasa.gov/tass/pdf/Mapping_Magnetic_Influence.pdf

Procedure

1. Hand-out the student worksheets to groups of students
2. Have students read off the magnetic field data from the magnetometer plots by having them do one of the following:
   a. Provide internet access to each group so they can go to the THEMIS school data page and pick the school closest to yours: http://ds9.ssl.berkeley.edu/themis/classroom_geons_data.html
   They will look at a x, y, z, 24-hour magnetometer data plot from that school's location, choosing either the real-time data or the archived data depending on the quality of the data. They will want to find data closest to a straight line as you can (there never be a completely straight line).
   b. Read off data from plots you have printed from the internet using the procedure in 2a.
3. Hand out materials to each group and have them come up with a way to model the resultant magnetic field vector in the correct orientation.
4. Have each group share their vector with the class to assess the groups understanding of the magnetometer vectors
5. Each student should then answer questions on the worksheet as an additional assessment of the student's understanding of vectors.

Answers

1. Explain how your model shows the resultant magnetic field vector from the data.
Here is one idea for how students might build their model and explain it

The center ball represents the magnetometer. The color coding of the skewer is as follows:

BLUE = X vector in nT
RED = Y vector in nT
BLACK = Z vector in nT

The length of the sticks are determined from the data by making the largest vector, Z, equal to the longest stick (30 cm). Then the other sticks are scaled according to the data. Blue X and Black Z are all glued into place to keep the coordinate system used by the magnetometer, where the Black Z will point down. Since the Red Y stick is so short compared with the balls it can be hard to incorporate, but should not be forgotten. The right hand rule should apply to X (pointer finger) and Y (middle finger) to give the correct direction of Z (thumb).

Start with the three Vectors (X, Y, Z) in the appropriate places on the magnetometer.

a. Move Y (Red) to the head of X (Blue).
b. The resultant of those two vectors is represented by a Blue/Red stick with the direction arrow towards the Y Red.
c. Using the Blue/Red stick as the vector sum of the X and Y, move it to the head of Z (Black) in a parallel direction.
d. Place the resultant Blue/Red/Black stick from the center ball (magnetometer) to the end of the Blue/Red ball.
e. By putting the Y (Red) back into the appropriate place you will get the magnitude and direction of the resultant of all three vectors, which is the actual magnetic force field line.

2. What does it mean if By is negative? That the magnetic field is pointing in the magnetic west direction

3 What is the main direction of the magnetic field at the school's location where the magnetometer is buried? Down.

4. Add the Bx and By vectors. The magnitude of this resultant vector is the value of the H-vector in the HDZ Compass Coordinate system on the HDZ plots for the school location you chose. Does your calculation or model give the same magnetic field magnitude for H for this days data? Yes. (It should – errors could occur in averaging the data).

Student's Name ___________________________ Date _______

A model of the THEMIS magnetometers XYZ vector coordinates

Goal: Make a visual representation of Earth's magnetic field.

1 – You should either use the x, y, z magnetometer plot your teacher handed out, or go to the THEMIS school data page and pick the school closest to yours:

http://ds9.ssl.berkeley.edu/themis/classroom_geons_data.html

Look at a x, y, z, 24-hour magnetometer data plot from that school's location. Choose either the real-time data or the archived data depending on the quality of the data. You want to find data closest to a straight line as you can (there never be a completely straight line).

2 – Guess the average magnetic field values (B) for the 24 hours in each of the x, y, z plots by reading off the middle-range values over the 24-hours of the magnetometer data for x, y, z (Bx, By, Bz). In the next activity you will do this more precisely. Write down your values here, remembering units.

Bx = ----------------- By = -------------------- Bz = ------------------------

3 – With the materials given to you by your teacher, work with a partner to come up with a way to make a 3-D model of the total magnetic field vector in the magnetometer school's location. Orient your model to the magnetic x, y, and z coordinate system. You will show the class your model and explain your model and the procedure you used to make it. Keep notes as you work through your ideas.

Answer the following questions:

1. Explain how your model shows the resultant magnetic field vector from the data.
2. What does it mean if By is negative?
3. What is the main direction of the magnetic field at the school's location where the magnetometer is buried?
4. Add the Bx and By vectors. The magnitude of this resultant vector is the value of the H-vector in the HDZ Compass Coordinate system on the HDZ plots for the school location you chose. Does your calculation or model give the same magnetic field magnitude for H for this days data?

Activity 17 – Soda Bottle Magnetometer and D-component

The NASA Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) developed a simple Soda Bottle Magnetometer to inexpensively study changes in Earth's ground-level magnetic field during magnetic storms. The operation of this simple $5.00 instrument can be directly related to the THEMIS display measurement of the magnetic 'D-component' which indicates the east-west magnetic variation angle.

Materials:

-- One clean 2 liter soda bottle
-- 2 pounds of sand
-- 2 feet of sewing thread
-- A small 1-cm magnet

-- A 3x5 index card
-- A 1 inch piece of soda straw
-- A mirrored dress sequin, or mirror.
-- Super glue (be careful!)
-- 2 inch clear packing tape
-- A meter stick
-- An adjustable goose neck high intensity lamp with a clear, not frosted, bulb.

Resources:

Magnet Source - They offer a Red Ceramic Bar Magnet with 'N' and 'S' marked.

Darice, Inc. 1/2-inch round mirror, item No. 1613-41, $0.99 for 10.

Extensive details for construction, calibration and operation can be found at the IMAGE education website:

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

Procedure

1 - Clean the soda bottle thoroughly and remove labeling.

2 - Slice the bottle 1/3 of the way from the top.

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

4 - Fill the bottom section with sand.

5 - Cut the index card so that it fits inside the bottle

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

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

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

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

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

11 - Put the bottle top and bottom together so that the 'sensor card' is free to swing with the mirror spot above the seam

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

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

Student's Name ____________________________ Date ________

How strong does a magnetic storm have to be before it is detectable with a simple soda bottle magnetometer?

Basic Idea:

During a magnetic storm of severity Kp = 8 or 9, the Themis data display will show large changes in the magnetic D-component. This means that, if you had a sensitive compass, you would see your magnetic bearing change by the number of degrees indicated by the THEMIS D-component display. The soda bottle magnetometer works like a compass and directly shows the change in the magnetic bearing as the reflected spot of light from the magnetic sensor card swings away from its normal quiet-time position. Depending on the severity of the magnetic storm, this deflection can amount to several centimeters or more if you are careful to set up the magnetometer correctly in an undisturbed environment.

1 - Wait for a strong magnetic deflection in the D-component on the THEMIS display, and simultaneously look for a large deviation in the light spot position on the soda bottle magnetometer.

2 - In a table, note the magnitude of the D-component deflection on the THEMIS display, and in a separate column, the number of centimeters of a soda bottle magnetometer deflection of the light spot. (Use the accompanying blank table) Provide table, and make additional copies as needed. Even better, enter the data into a Microsoft EXCEL spreadsheet!)

3 - Try to include the time of maximum D-component deviation, and include in your table the severity of this magnetic storm in terms of the Kp and Dst indices, which you can find at:

Kp today = http://www.sec.noaa.gov/rt_plots/kp_3d.html

Dst today = http://swdcdb.kugi.kyoto-u.ac.jp/dstdir/dst1/q/Dstqthism.html

4 - Correlate the Kp and Dst values for magnetic storms with the THEMIS D-component and soda bottle deflections to 'calibrate' your observations. How many degrees of soda bottle deflection equal one degree as measured by the D-component? (Hint: Draw a graph with the D-component on the vertical and soda bottle deflection on the horizontal axis and find the slope of the line through the data.)

Soda Bottle Magnetometer Data Table for

Month ________________ Year ______________

Sample	Day	Local Time	UT	Deflection (cm)	Degrees	THEMIS 'D' Component
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						

Activity 18 – Student Derived "Kp" index

Teacher's Guide:

Kp is a relative strength of a magnetic storm determined by the global averages of a large number of magnetometers that are scattered around the North American Continent and Europe. The **Kp-index** is determined by averaging all of the measured K index on a 3 hour or shorter interval. The **K- index** is determined by the average of the A index and then is converted by a table of comparison. The **A- index** is the difference between the maximum and minimum reading for the X component of the magnetometer.

This activity is not designed to replace the actual Kp index but to allow students to take reading from a magnetometer and make a Kp index estimate. Using this estimate you can make a prediction as to whether an aurora display will occur that night.

Student Objectives:

1. **Observing real time data**
2. **Measuring and collecting data**
3. **Analyzing the collected data and make predictions**
4. **Checking with observations to validate the data**

The effects of the aurora current may be seen as the Aurora Borealis. A magnetic storm will disturb all three of the components, but due to the right hand rule the change in the Aurora current will affect mostly the X- component directly. This is illustrated in the figure below where the black line in the aurora indicates the direction of the current and the red circles represent the magnetic field lines around this current. Directly below the aurora, the x-component will be the most affected. To the South and North of the auroral arc, the z-component will be affected.

The A index is determined by the maximum strength of the X component minus the minimum strength of the X component for a three hour time period. (X **max** - X **min**). For our Activity we will determine the Max-Min strength for a 24 hour time period. Thus, in a sense, your reading will be similar to an A index average. Using the following table we can convert the A- index component strength difference directly to a K index.

Table of Conversion for Boulder magnetometer

The K-index is related to the maximum fluctuations of horizontal components observed on a magnetometer relative to a quiet day

Procedure:

Finding the A-index

1 - Print off a days-worth of XYZ data from a THEMIS magnetometer site as close to your school as possible. To do this, visit the THEMIS education data website: http://ds9.ssl.berkeley.edu/themis/classroom_geons_data.html

From here you can either choose real-time data, that means data that is being taken and plotted right now. Or you can choose archived data - data from a previous day. To use the real-time data, find the "Site-Specific GEONS Real-Time Data" and click on the link under "24-hour Plots" for the station closest to your school. A map indicating the location of these magnetometer sites can be found at the bottom of this web page. Three plots will come up. You can click on them to make a larger version and then if you right click (PC), <CTRL>-click (Mac) you can save the images on your computer and print from your computer.

To use the archived data, go to "GEONS Archive Data" and click on "archive data page." Here, you will fill out a form. On the left side of the form, click on the "Day Plot" button. Click on the "Start Date/Time" button and then choose the date you want to look at. Note that the time for a "Day Plot" is not important since all day plots go from 12 midnight UT to 11:59pm UT. On the right side of the form, choose the School town you want and then click on the "XYZ" button. Then click on "Start Mag Search." If data is not available for the date you chose, try another date until you find some data. Once you have selected the XYZ data you want to work with, either print the plot from the web site or save the image to your computer and print from your computer.

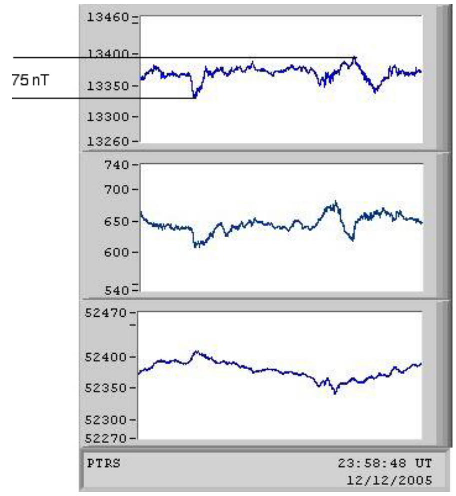
Continued on next page

2 - Using a clear metric ruler 15 mm length, place the ruler horizontally across the X-scale of the graph.

3 - Using a sharp pencil select the highest reading of the X component that does not look like a human made signal. To check if it is a human-made signal, compare with neighboring magnetometers to see if other magnetometers have the same signal. If they do, it is most likely NOT a human made signal and it can be used as the highest reading of the X-component scale. Place a horizontal line across the x-component plot that touches this highest reading.

4 - Repeat 3, but for the lowest x-component reading. At this point, your x-component plot will have two horizontal lines, one touching the maximum x-component reading and one touching the minimum x-component reading.

5 - Using the metric ruler, measure the distance between the two horizontal lines. Then use the ruler to determine the scale of mm to nT on your x-component plot (for example 1 mm = 5 nT). Using this scale determine the difference in nT from the maximum x-component reading to the minimum x-component reading in nT. We call this "nT diff." See the plot on this page as an example.



K-Conversion:

6 - Now that you have "nT diff." you can use the conversion table on this page to obtain an approximate K-index value. This is the strength of the magnetic storm on your magnetometer.

K index	nT diff.
0	0-5
1	5-10
2	10-20
3	20-40
4	40-70
5	70-120
6	120-200
7	200-330
8	330-500
9	>500

7 - Compare this information to the Kp index (http://www.sec.noaa.gov/rt_plots/kp_3d.html) Try to predict the possibility of the people in the town where the magnetometer is located of seeing an aurora display on the night of the data you choose.

Teacher Notes:

This activity can be used in Physical Science classes dealing with magnetism. This is also the place where you can introduce the magnetometer plots and look at them to get an idea of what is going on. The Kp strength and prediction activity can also be conducted with Geology students. First go over the background material in class and then do an activity recording the data when students artificially disturbed the magnetometer with various objects. Students can look at the plots and mentally predict what is happening to the magnetic field. See more teacher notes at the end of this activity.

1 - The actual disturbance may have been caused by a local event.

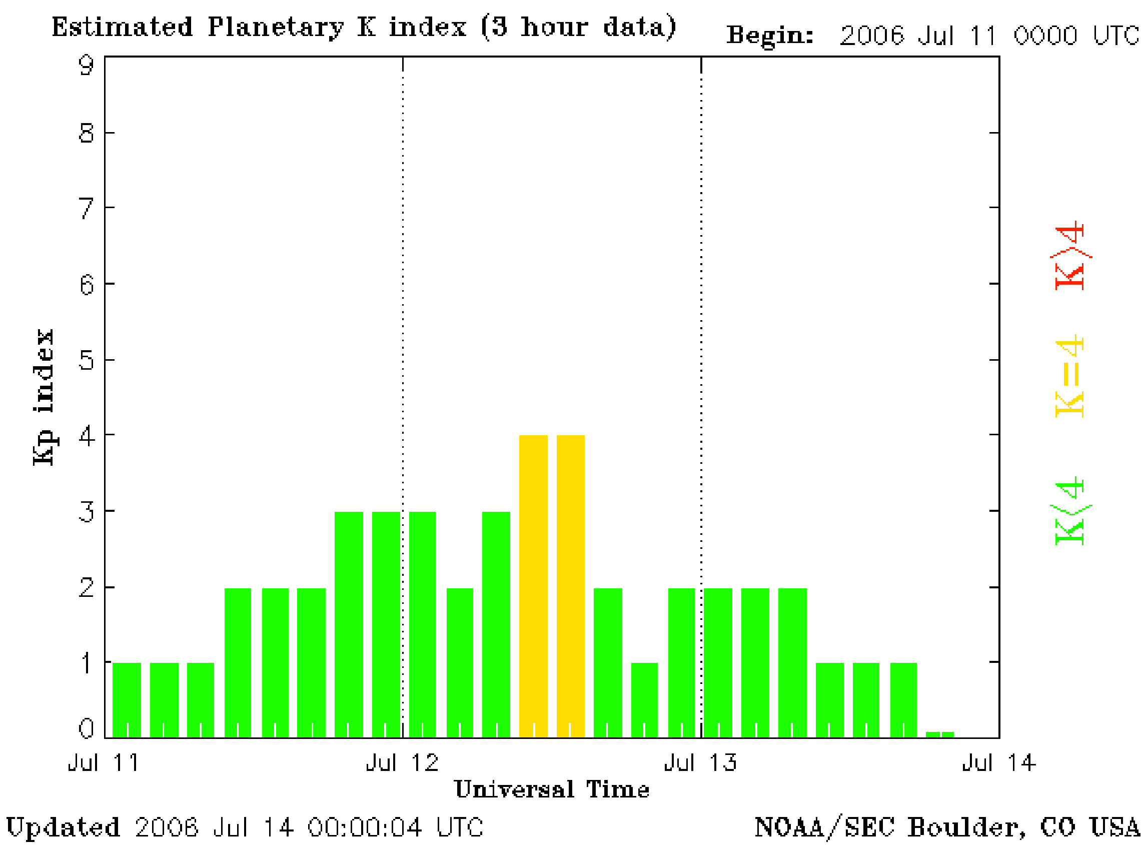
2 - If you are in the upper Northern Hemisphere a high Kp storm affects may be below your southern horizon.

3 - Not all storms produce Auroras.

4 - Daylight Auroras occur but are not visible.

5 - The global Kp index determined by three hour interval averages can always be used to authenticate the students data. The real-time plot below is available at

http://www.sec.noaa.gov/rt_plots/kp_3d.html



Activity A:

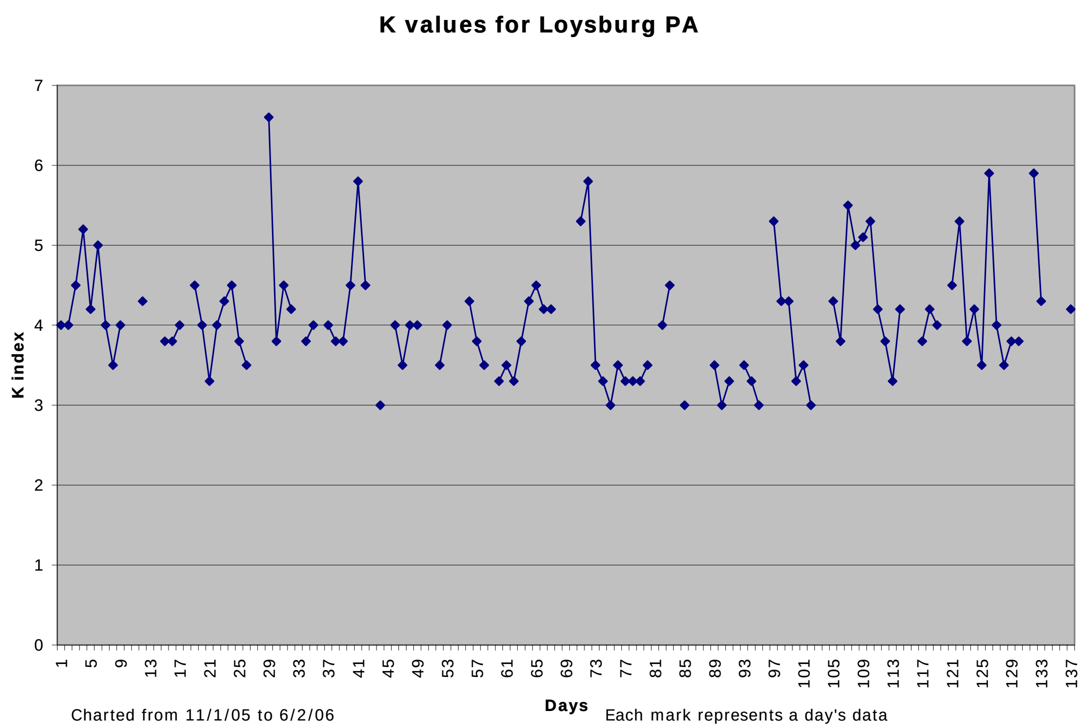
1 - Record the X component difference during the day.

2 - Using the table determine the K index.

3 - Find your locations Kp index for aurora display.

4 - Predict the possibility of staying up for an Aurora Show or going to bed and getting some sleep.

Example below is for Loysburg ,PA.



Activity B:

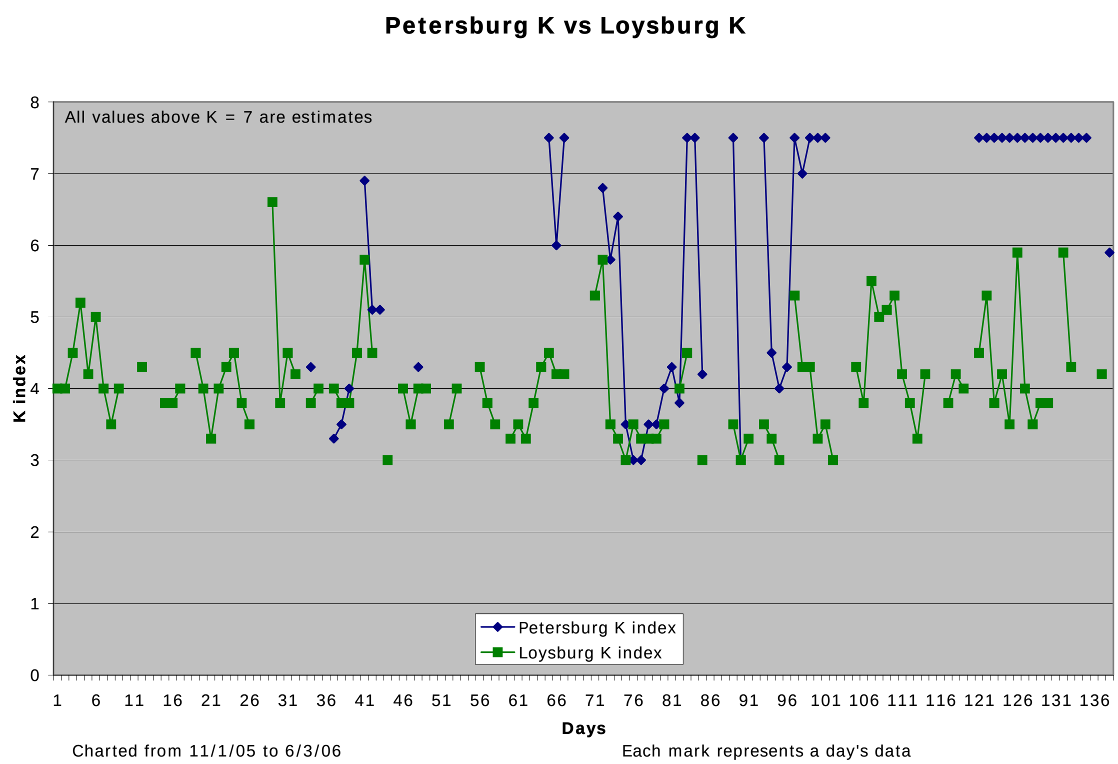
1 - Determine the K index for your school's magnetometer.

2 - Determine the K index for another school's magnetometer.

3 - Based on comparison you will be able to determine if the activity is the result of a magnetic storm or just a local event.

4 - Build a table on excel and using graphic comparison over a longer period will show relationships between your magnetometer and another school's magnetometer.

Example below compares Petersburg with Loysburg data.



Activity C:

Contact other schools in your region. The students would be able to share their data and get other students involved in using the Magnetometer data. Then through collaboration they could decide if it would warrant an Auroral Alert.

Notes to Teachers:

1 - The largest measurement you can make on the existing plots is about 200 nT but varies in the displays from school to school, and in time.

2 - You need a small (15 cm), clear, metric ruler. So that you can draw a line perpendicular to the left edge of the plot to get an precise measurement line.

3 - Print out and three hole punch the X,Y,Z, plots. This allows the students the ability to go back and double check questionable data

4 - When you do comparative graph have both the day number and actual date so you can graph the corresponding data together.

5 - Microsoft EXCEL treats all data as numbers, not dates, so you need to select the correct days and cut and paste to get a comparative graph.

Activity 19 – Magnetic Magnitude Changes

Teacher's Guide:

The THEMIS magnetometer we will be using is a professional-grade instrument capable of revealing many different types of disturbances in Earth's magnetic field. This activity explores vectors specifically using the THEMIS XYZ plots.

Recall that magnetism, like velocity, is a quantity defined by BOTH its direction in space and its magnitude along that direction. For more information, see Part K of this manual.

To find the speed of a body, you square the three components of its velocity and add them. Then you take the square-root.

$$S = \sqrt{V_x^2 + V_y^2 + V_z^2}$$

For magnetism, we have the same relationship. A magnetometer will record the three components to the local magnetic field and give you the quantities Bx, By and Bz. The total magnetic intensity, B, is then :

$$B = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

Student Objectives:

1. Observing real time data
2. Measuring and collecting data
3. Analyzing the collected data and make predictions
4. Checking with observations to validate the data

So, we can now think of Earth's magnetic field in the same way we do velocity; as a quantity that has both a magnitude and a direction. This also explains why we have to have three independent plots for the magnetometer data and not just one.

Notes to teachers:

1 - A quiet day is a matter of opinion, the only way to choose is to look at your data and find the X - plot with the least amount disturbances, yet you need data so you can not just throw out everything.

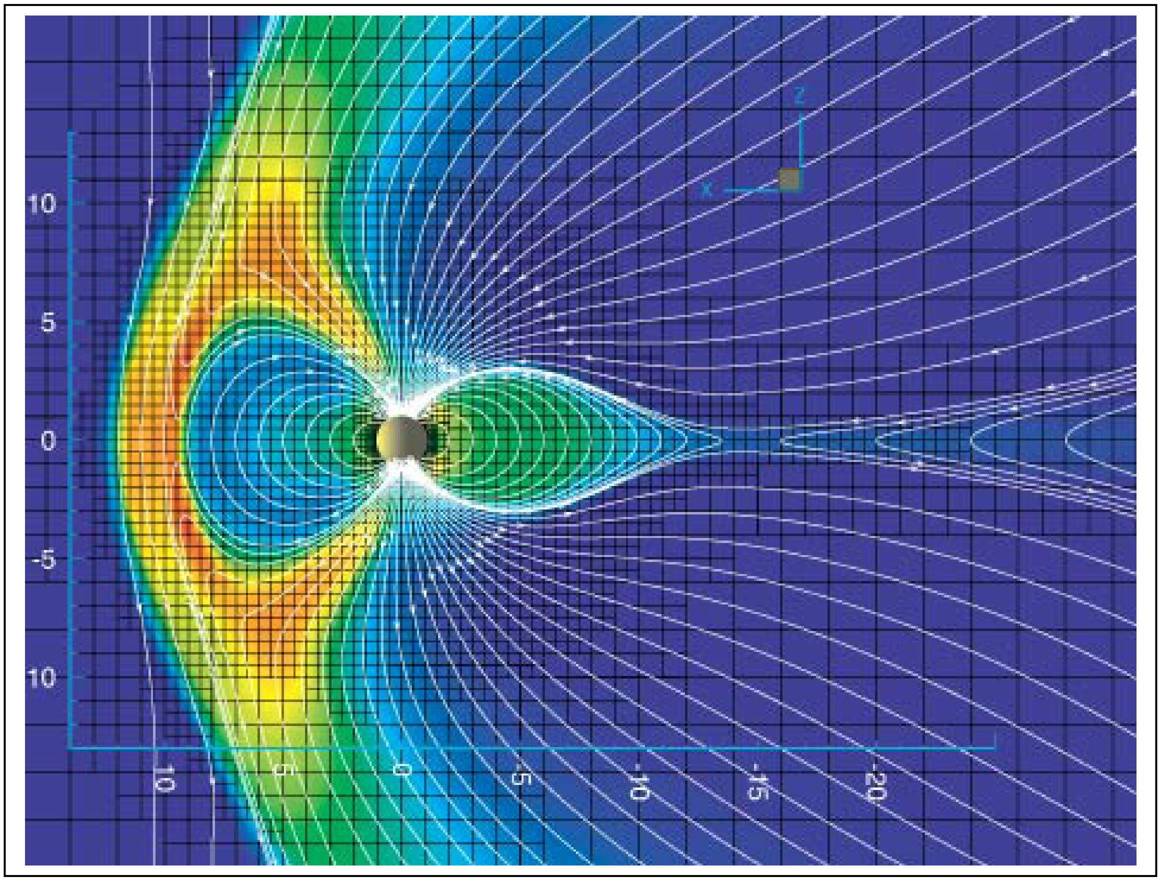
2 - You need a small (15 cm), clear, metric ruler. So that you can draw a line perpendicular to the left edge of the plot to get an precise measurement line.

3 - Print out and three hole punch the X,Y,Z, plots. This allows the students the ability to go back and double check questionable data

4 - If dividing the day into 1/2 does not simplify the estimate, the day may be too active.

5 - When you construct a comparative graph, have both the day number and actual date so you can graph the corresponding data together

Figure below of Earth's magnetic field courtesy University of Michigan, Space research laboratory. **http://www.tecplot.com/showcase/studies/2001/michigan.htm**

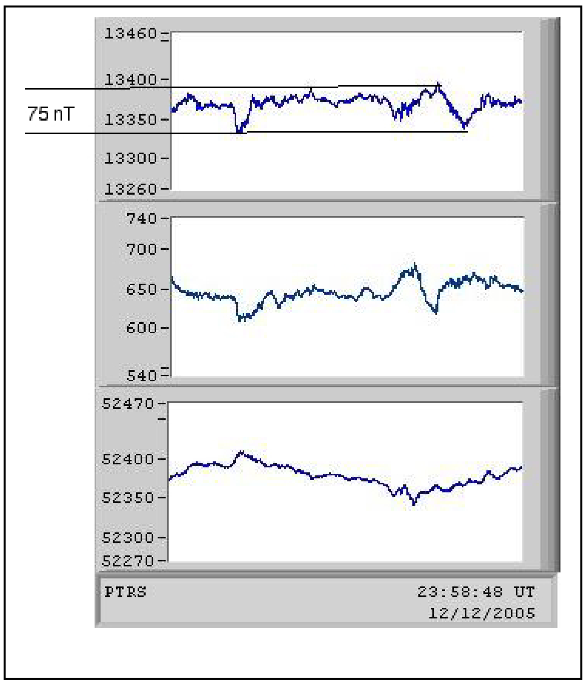


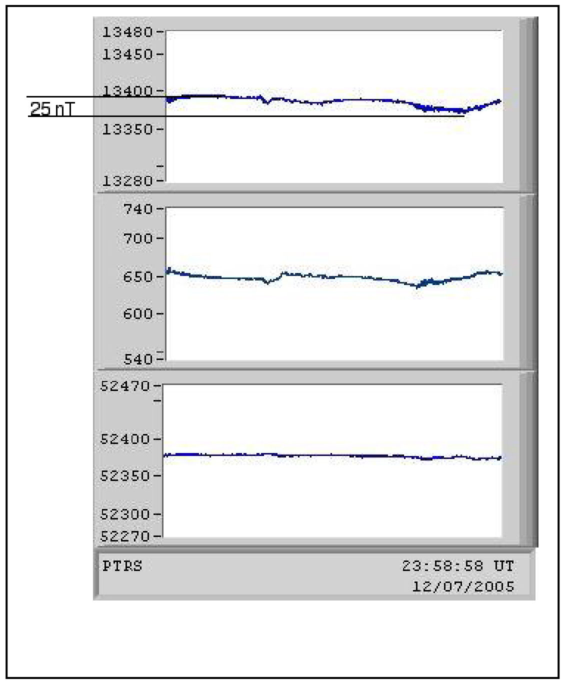
Data collection procedure:

1. Make paper copies of the XYZ plots archived by THEMIS at: http://sprg.ssl.berkeley.edu/themis/GEONS (use 24 hour plot options)

2. Determine a maximum, minimum nT difference for the X component from what you would consider a quiet day. It may help to do **Activity 18** first to determine a quiet day for your data. Remember you want to determine the undisturbed magnetic field strength for your area.

A quiet day for Petersburg AK was determined to be less than 50 nT difference.
A quiet day for Loysburg PA was determined to be less than 30 nT difference.





An active day **12/12/05 Petersburg AK** shows a greater than 50 nT difference between X max and X min

An quiet day **12/07/05 Petersburg AK** shows a less than 50 nT difference between X max and X min

Data Reduction Suggestions:

Divide each quiet day X, Y, Z, plot into half days.

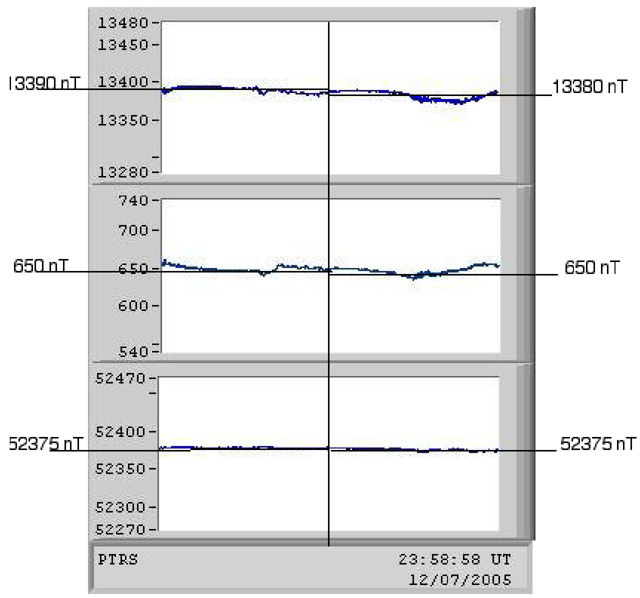
1. Using a clear metric ruler, visually determine the average nT for each half day for each X, Y, Z plot. The scale is 1mm = 5 nT, unless you resize the plots.

2. Determine the average of the two half days and then take the average for each day for X,Y,Z, plots.

X avg for the day =
13390nT + 13380 nT / 2 =
13385 nT

Y avg for the day =
650 nT + 650 nT / 2 =
650 nT

Z avg for the day =
52375 nT + 52375 nT / 2 =
52375 nT



3. Set up a spread sheet with a column for Date, X,Y,Z.

4. Using the spread sheet functions calculate B from the Pythagorean formula in the Teacher's Guide for this activity.

See the two tables that follow as examples.

	A	B	C	D	E	F	G
1		**Loysburg Pa**					
2	**Date**	**X**	**Y**	**Z**		**B value**	
3							
4	10/28/2001	22115	200	47543		52435	
5	10/31/2001	22095	200	47548		52431	
6	11/1/2001	22108	205	47540		52430	
7	11/2/2001	22095	205	47540		52424	
8	11/6/2001	22105	203	47540		52428	
9	11/7/2001	22118	203	47540		52434	
10	11/8/2001	22113	205	47540		52432	
11	11/11/2001	22105	195	47520		52410	
12	11/14/2001	22103	200	47520		52409	
13	11/15/2001	22105	200	47510		52401	
14	11/16/2001	22108	200	47515		52407	
15	11/20/2001	22095	200	47488		52377	
16	11/24/2001	22088	205	47490		52376	
17	11/25/2001	22095	203	47480		52370	
18	12/3/2001	22243	430	47385		52348	
19	12/7/2001	22240	430	47370		52333	
20	12/13/2001	22230	440	47373		52331	
21	12/16/2001	22230	425	47360		52319	
22					**2005 B Avg**		**52394**

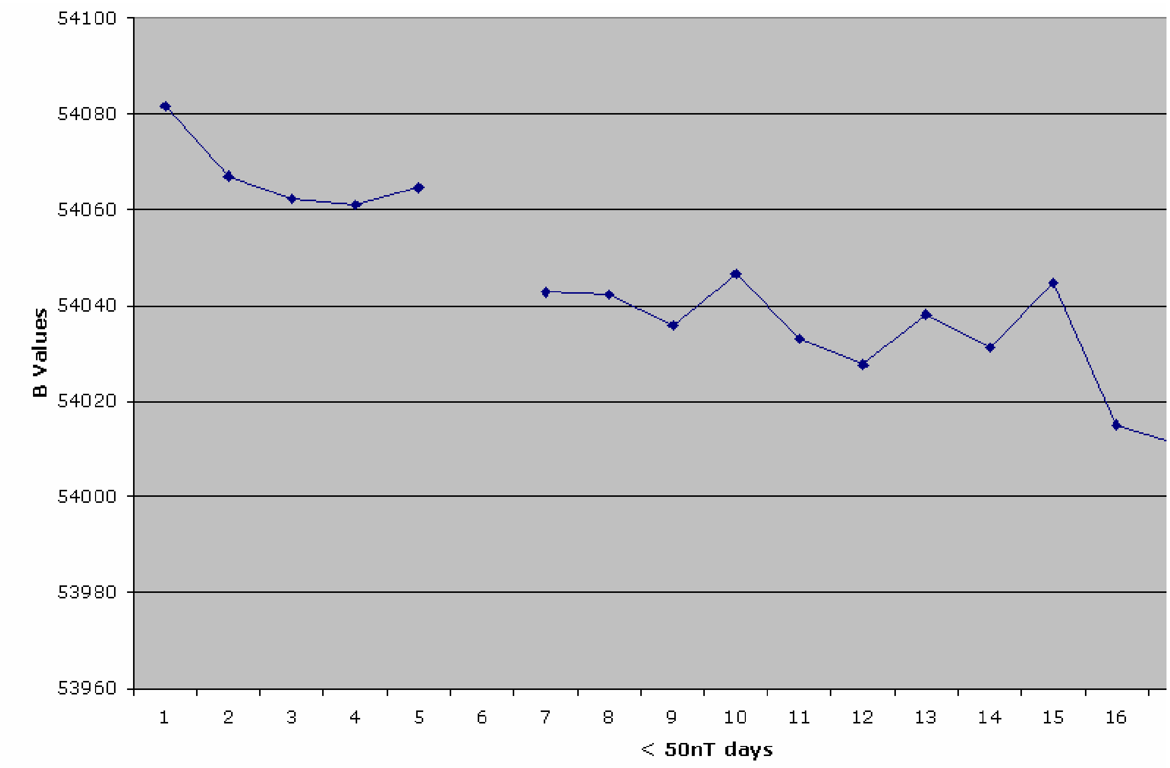
Note: Usable data for total quiet days from 10/29/05 to 4/13/06 is 45 days

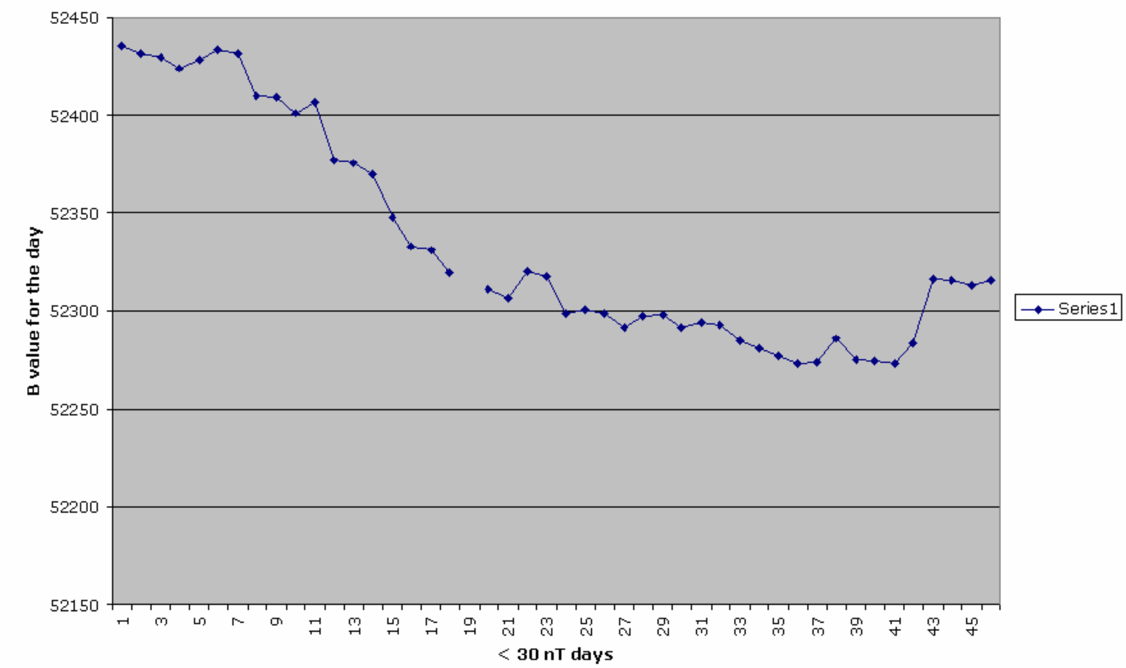
	A	B	C	D	E	F	G
23		**Loysburg Pa**					
24	**Date**	**X**	**Y**	**Z**		**B value**	
25	1/8/2002	22253	450	47340		52311	
26	1/10/2002	22263	445	47330		52306	
27	1/12/2002	22268	448	47343		52320	
28	1/13/2002	22268	443	47340		52318	
29	1/26/2002	22260	465	47323		52299	
30	1/27/2002	22260	463	47325		52301	
31	1/28/2002	22265	460	47320		52298	
32	1/29/2002	22260	460	47315		52292	
33	1/30/2002	22273	458	47315		52297	
34	2/1/2002	22265	458	47320		52298	
35	2/2/2002	22265	455	47313		52292	
36	2/4/2002	22280	463	47308		52294	
37	2/7/2002	22273	463	47310		52293	
38	2/11/2002	22275	473	47300		52285	
39	2/12/2002	22270	465	47298		52281	
40	2/13/2002	22273	460	47293		52277	
41	2/15/2002	22270	465	47290		52273	
42	2/16/2002	22260	455	47295		52274	
43	2/17/2002	22278	458	47300		52286	
44	2/22/2002	22263	473	47295		52275	
45	2/23/2002	22273	460	47290		52275	
46	2/24/2002	22270	465	47290		52273	
47	3/23/2002	22273	465	47300		52284	
48	4/7/2002	22327	548	47310		52317	
49	4/10/2002	22325	548	47310		52316	
50	4/11/2002	22320	548	47310		52314	
51	4/12/2002	22325	540	47310		52316	
52					**2006 B Avg**		**52295**

Activity A: **Graph the B data on a day by day basis, is there any long term change? Is the earth's magnetic field is slowly weakening?**

With enough data (very long term) this activity could be developed into an extension of Activity 8 "The Declining Magnetic Field"

The plot below shows the declining values for the Petersburg, Alaska (Top) and Loysburg, PA (Bottom) THEMIS stations.

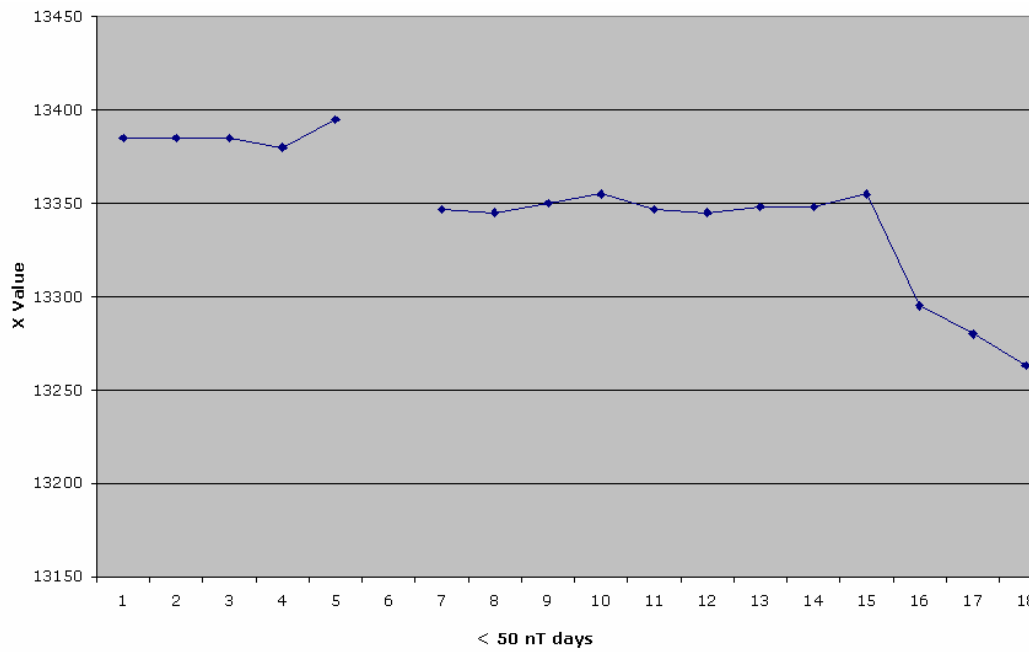


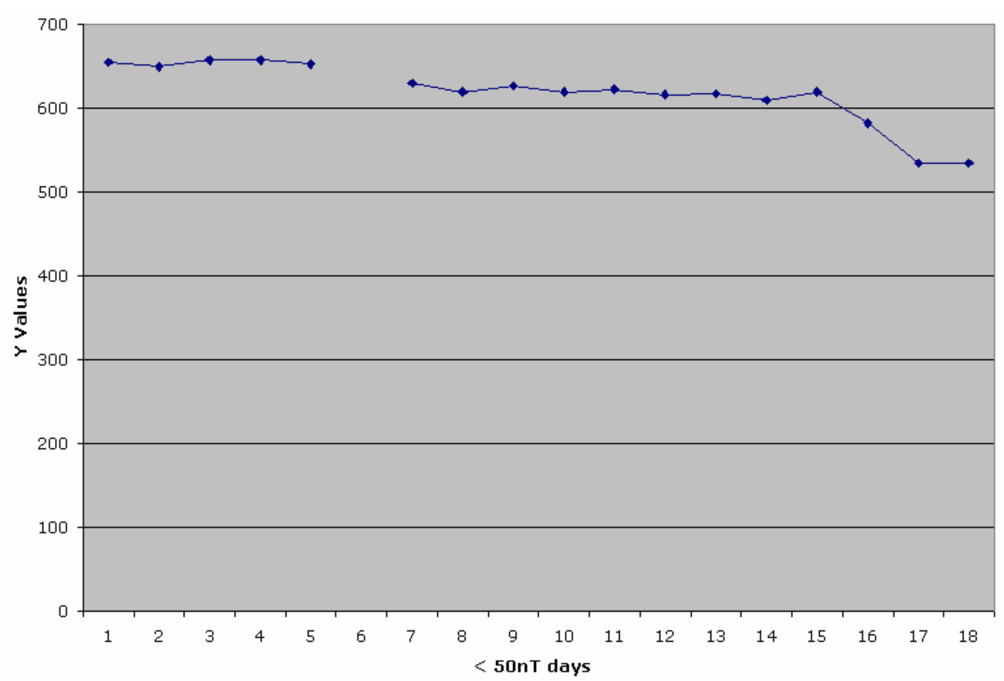


Activity B: **Graph each X,Y,Z, plot separately and look for changes or trends. Especially the Y east-west in relationship to the X north-south. Is Earth's North magnetic pole moving?**

With enough long term data this Activity could be used as an extension of Activity 6 Geomagnetism I: "Polar Wandering"

The Bx (Top) and By (Bottom) plots below show the declining values for the Petersburg, Alaska THEMIS Station.

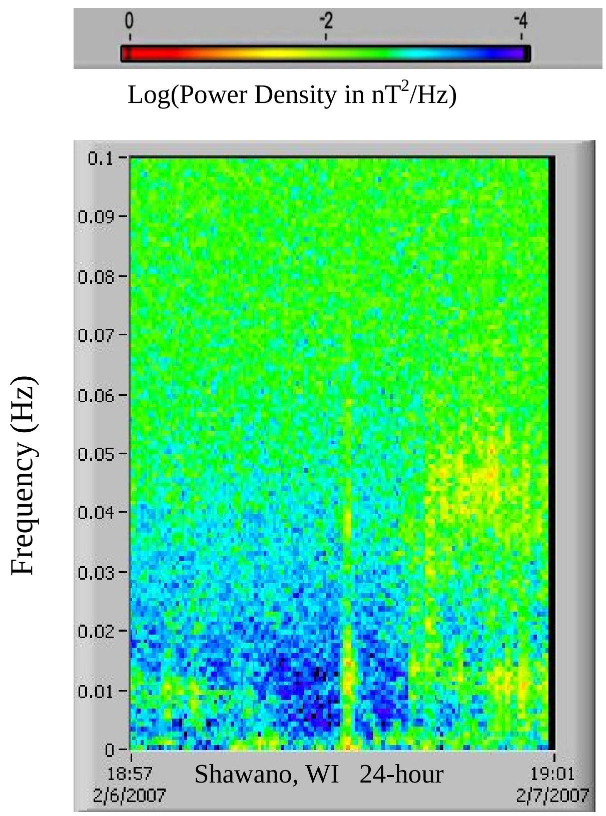




Activity 20 – Spectrogram Plots and Magnetic Storminess

Teacher's Guide:

The THEMIS magnetometer produces a second data product called the **Spectrogram**. Interpreting this data may be beyond the needs and or level of the students but it can be used to entice the students into wondering about the magnetometer data because of its colorful display. It can also be used to indicate magnetic activity. In this activity students learn how to read the spectrogram plots as an indicator of magnetic activity versus human activity for a 24 hour plot. For a more complete description of what the spectrogram represents, see the spectrogram background section at the end of this activity



Here is a brief description of the spectrograms: time is on the x-axis ***in Universal Time***, either 30 minutes or 24 hours depending on the spectrogram chosen. Waves in Earth's magnetic field have a frequency and that is given on the y-axis. The color represents the amount of power in the waves with red indicating a lot of power and blue very little power. A green-yellow solid background is noise in the magnetometer. Red or yellow often indicates interesting space weather. Red can also indicate cars passing by the school or other moving metal nearby the magnetometer. The wave power is obtained from the waves in the X panel of the line plot every 10 minutes for the 24-hour spectrograms and every 1 minute for the 30-hour spectrograms (see XYZ plot). Each spectrogram plot represents magnetic wave data observed at a particular school around the country, as indicated by their school name.

Materials

- Overhead transparencies or computer projection of the sample spectrograms
- Access to the internet
- Student worksheet

Procedure

1. Before this activity, have the students do the "Magnetic Storms" activity in the "Space Weather" THEMIS teacher's guide. (see http://ds9.ssl.berkeley.edu/themis/classroom.html) .
2. Show the students examples of quiet wave activity, medium active wave activity, very active wave activity, and human activity using the overhead transparency pages.
3. Describe the x and y axes of the spectrograms and the difference between the different levels of activity.
4. Have students follow the procedure on the student worksheet page.

Answer Key

6.

Day in Jan. 2007	Max. Kp for the day	Description of Spectrogram: Note that the background (no magnetic activity) is blue and green.	Human Made Signature?
1	3	Little orange, some yellow	No
2	5	Little red, some orange, half yellow	No
3	4	Little red, some orange, half yellow	No
4	4	Little red, little orange, some yellow	No
5	3	Little red, little orange, some yellow	No
6	2	Little red, little orange, little yellow	No
7	1	Little yellow	Maybe
8	2	Little orange, some yellow	Maybe
9	2	Little yellow	No
10	3	Little yellow	No
11	2	Little yellow (orange on human sig)	Yes
12	3	Tiny yellow	Maybe
13	0	(green line on human sig)	Yes
14	1	Little orange, little yellow	Maybe
15	6	Little red, some orange, some yellow	No
16	5	Little red, some orange, mostly yellow	No
17	5	Little red, little orange, some yellow	Maybe
18	4	Little red, mostly yellow, (orange on human sig)	Yes
19	4	Little red, little orange, half yellow	Maybe
20	3	Little orange, some yellow	Maybe
21	3	Little orange, some yellow	Maybe
22	1	Little orange, some yellow	No
23	1	Little orange, some yellow	No
24	1	Tiny orange, some yellow	No
25	1	(orange line on human sig)	Yes
26	1	Tiny orange, some yellow (red line on human sig)	Yes
27	2	Tiny yellow	Yes
28	2	Tiny yellow – maybe human sig	Maybe
29	7	One third red, some orange, half yellow	No
30	5	Some red, some orange, half yellow	No
31	3	Some red, some orange, some yellow	No

7.a) These days had strange vertical lines (to know for sure if they were human-made signatures we would need to check with other magnetometer sites): Jan 7th, 8th, 11th-14th, 17th-21st, 25th-28th,

b) Jan. 2nd-4th, 15th-19th, 29th, 30th had kp=4 or greater

c) All these days in b) had red areas on the spectrogram.

d) Jan. 5th: Kp=3; Jan 6th: Kp=2; Jan 31st: Kp=3 also had red on the spectrogram.

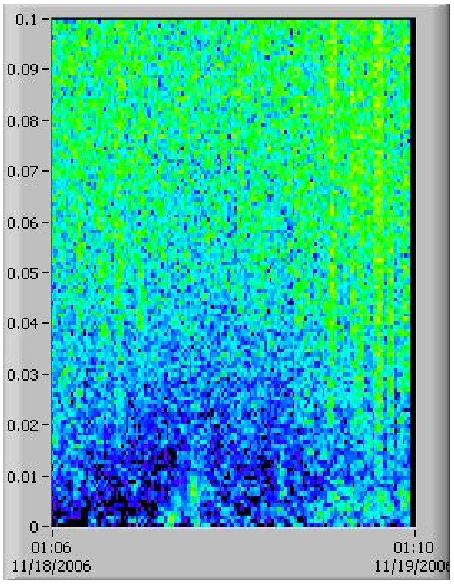
e) These days were days following days with magnetic stormy times, days of Kp of 4 or greater.

f) Jan. 29th: Kp = 7 had the most red.

g) Jan 13th: Kp=0; Jan. 25th: Kp=1 had only background color on the spectrogram.

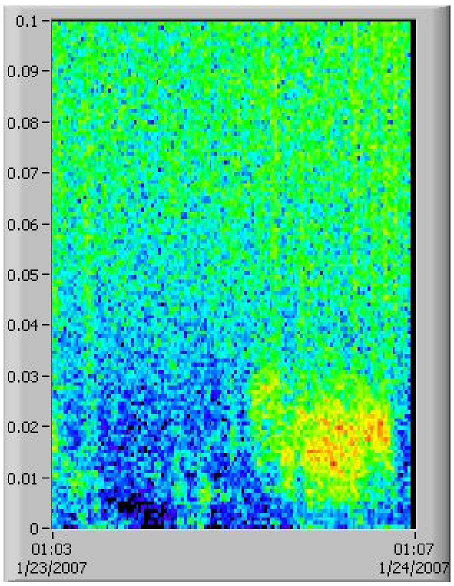
h) The magnetosphere continues to produce waves after the global magnetic storm has ended because the magnetic field is still vibrating or “ringing” like a violin string that has been plucked.

9. From this month of data, it appears that the spectrograms can indicate global magnetic storminess only at the beginning of a magnetic stormy time and can only be used to roughly guess the Kp index (Kp=0; Kp=1-3; Kp=4-6; Kp=7-9).



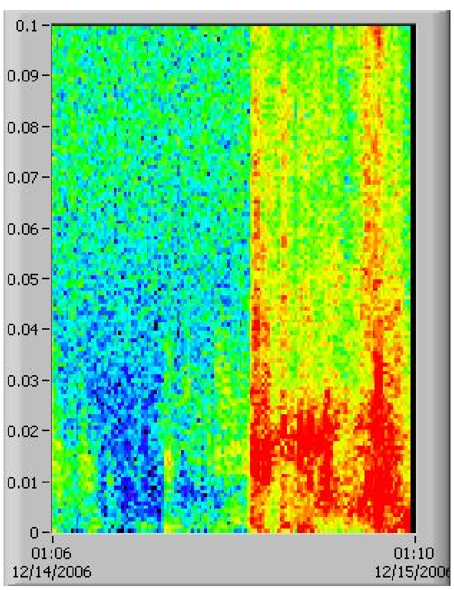
Quiet Magnetic Wave Activity in Ukiah, OR

The spectrogram mostly shows all green or blue with very little red. This indicates that there are not many waves and interesting currents occurring in space reaching Ukiah.



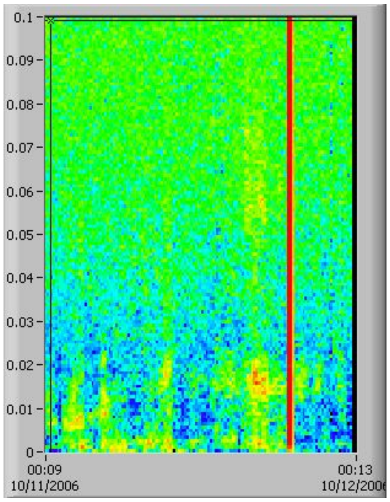
Medium Magnetic Wave Activity in Ukiah, OR

The spectrogram mostly shows all green or blue with some stripes of red. This means there is some magnetic wave activity from space reaching Ukiah.

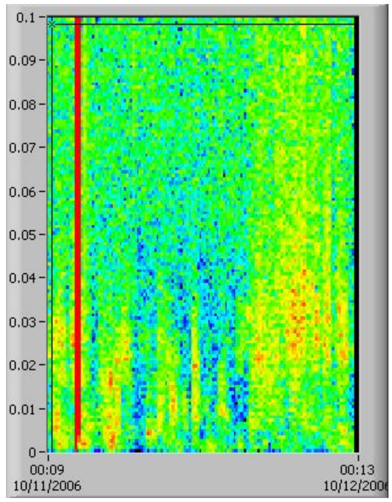


Active Magnetic Wave Activity in Ukiah, OR

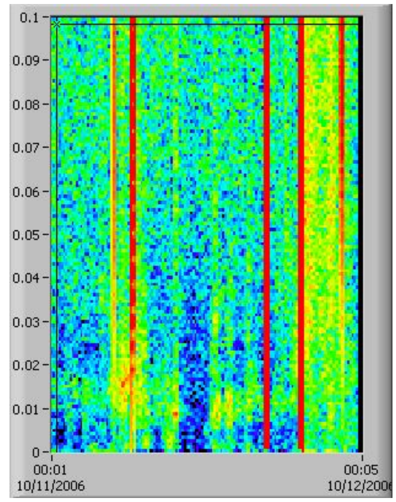
The spectrogram shows some interesting red horizontal and vertical lines on the right of the plot. This indicates there are some interesting magnetic waves occurring in space reaching this magnetometer in Ukiah in the second half of the day.



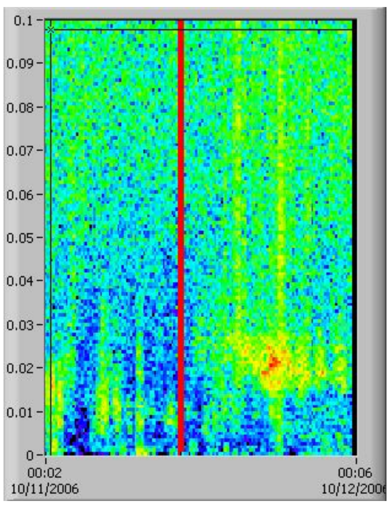
Petersburg, Alaska



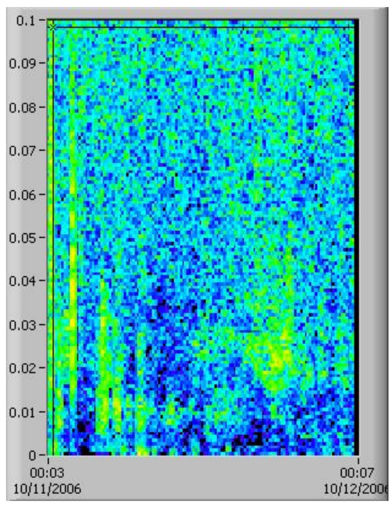
Shawano, Wisconsin



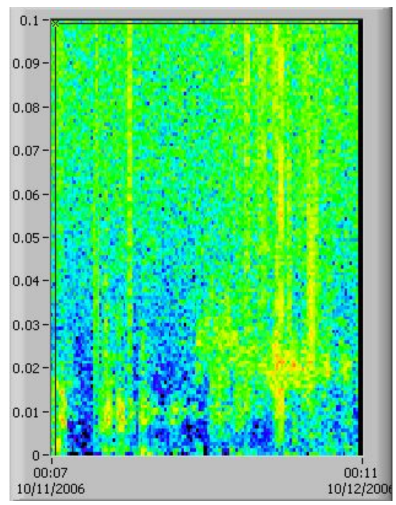
Remus, Michigan



Ukiah, Oregon



Carson City, Nevada



Pine Ridge, S. Dakota

Human-made signatures on a spectrogram most often show up as a vertical red or orange bar.

To determine if the signature on a spectrogram comes from some human event versus a space or atmospheric event, compare red lines with spectrograms from other magnetometers around the country

Above are six spectrograms from October 11, 2006 at six different locations around the country. Notice that when there are red vertical lines, they all happen at different times during the day, indicating they are due to human events locally at each school location.

Student's Name ___________________________ Date _______

By comparing Planetary Kp indices with the local magnetometer spectrogram plots, you will answer the question: "Can local spectrogram plots be used to determine the global magnetic storminess?"

1) Go to: **http://ds9.ssl.berkeley.edu/themis/classroom_geons_data.html**

2) Read about the spectrogram plots.

3) Find the link to the archive data page and click on it

4) Fill in the form to find the 24-hour spectrogram plot for Ukiah, OR for Jan. 1, 2007. Keep this window open on a computer.

5) Go to **http://ds9.ssl.berkeley.edu/themis/classroom_kp2007.html**

6) Look at each plot of Kp indices and compare each day of indices with the 24-hour spectrogram from Ukiah, OR in January 2007, starting with Jan. 1 (see step 4). Make a table with 3 columns for: 1) the date, 2) the maximum Kp index, 3) a description of the amount of yellow, orange and red on each spectrogram for each day (note that a gradation from green (top, higher frequencies) to blue (bottom, lower frequencies) are background colors and mean there is no magnetic signature), and 4) if there was a "human-activity" signature for that day. Highlight the rows of days with red on the spectrograms.

7) Using the table you created in step 6, answer the following questions:
a) What days may have signatures made from human-interactions around the magnetometer?
b) What days had one or more 3-hour period of Kp=4 or greater?
c) Of the days with Kp=4 or greater, how many had red areas on the spectrogram?
d) What days had at least one 3-hr interval of Kp<4 with a spectrogram which had red on it and what were the kp-indices for these days?
e) What was special about the days with red on the spectrogram and a Maximum Kp of 3 or less associated?
f) Which day had the most red and what was the maximum Kp index for that day?
g) What days had no color besides the background color of the spectrogram and maybe a human-made signature and what was the maximum Kp index?
h) Why might the spectrogram continue to show red after a magnetic storm has subsided?

8) Look at the real-time spectrogram (the one made today) and from your previous research, guess the range of values of the Kp index. Write that down here:

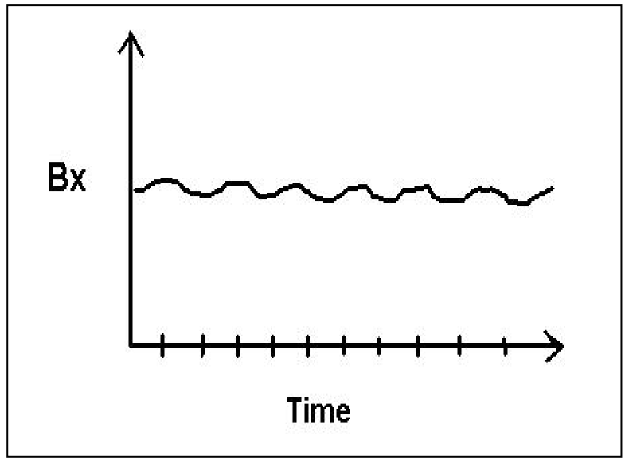
9) Go to: **http://www.sec.noaa.gov/rt_plots/kp_3d.html**. Look up the Kp indices for today to see if your guess was correct. Explain if it was or not and whether you think local spectrograms can be used as an indication for global magnetic storminess.

More Teacher Background on Spectrogram Plots

The THEMIS magnetometer produces a second data product called the **Spectrogram**. Interpreting this data is a bit more complicated than working with the XYZ plots, but once you understand the basic principles involved, it may turn out to be an exciting 'second window' onto what the magnetosphere is doing!

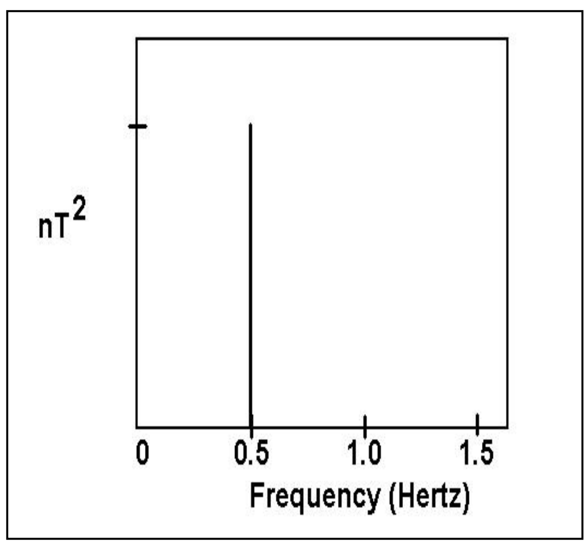
From time to time in the X plot you may see a periodic 'wiggle' of the magnetic intensity. Suppose it looks like this in the Bx trace:

Something is disturbing your local magnetic field in a periodic way. By looking at the time axis, suppose you measure the time interval to be 5 seconds between the peaks of the wave crests. This means that the disturbance has a **frequency** of 1 cycle per 5 seconds or **0.2 cycles per second**. Scientists usually use the unit 'Hertz' to denote cycles per second, so the signal frequency is 0.2 Hertz.



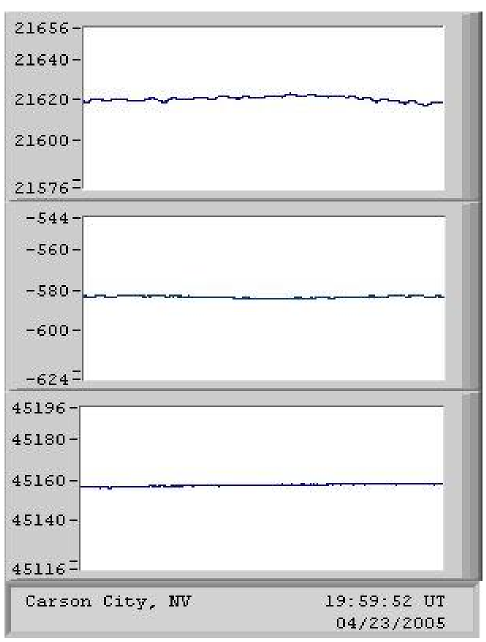
For very weak signals, it can be very hard to see them against all the other sources of noise in real data, so there is another way to make these kinds of periodic signals more prominent. We construct a spectrogram of the data that extends over a selected span of time. The figure below is what the spectrogram of the above signal would look like if this wiggle was all there was in the data:

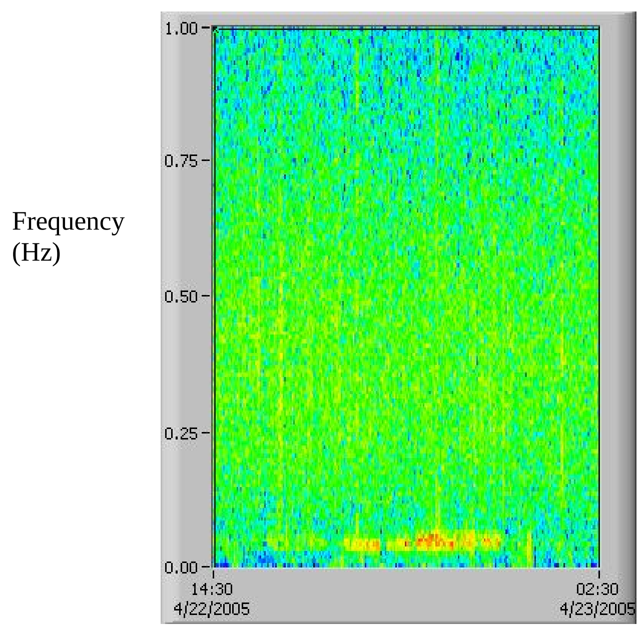
The entire wave train has been replaced in the spectrogram by a single '**spectral line'** that appears at exactly the frequency of the wave train in the Bx plot. The magnitude of this spectral line is proportional to the square of the magnetic intensity (in nT units) of the wiggle. It is the energy found in the wave at a particular frequency (nT^2/Hz). The stronger the wiggle (the bigger its Bx amplitude in nT) the taller will be the spectral line. In fact, the relationship between Bx and the spectral line height is like that between voltage and power (Ohm's Law: Power = V^2 x R). Scientists often call the plot a 'power spectrum' because of this similarity.



The nice thing about THEMIS spectrograms is that, with a mere glance, you can tell if there are any periodic events going on in the magnetosphere. You can make this assessment even more easily than you could by just looking at the raw data! The reason is that the spectrogram summarizes **all** of the periodic signals in the data spanning a broad frequency range. The slow, long waves that take 30 minutes from start to finish will appear at a frequency of 1 cycle per 30 minutes or 0.0006 Hertz, while faster waves that take a second from peak to peak will appear at frequencies of 1 Hertz. In a glance, the human eye can look at a spectrogram and pick out periodic phenomena spanning a wide range of times.

Since waves in Earth's magnetosphere come and go, we have to calculate the spectral lines from the line plots in a given time interval, such as every minute or every ten minutes. This is important so that we know what waves were present in the magnetometer data at a given time. For example, during the daytime, we detect magnetic field waves, which are caused by the solar wind's interaction with Earth's magnetosphere. They are strongest for a couple hours around noon and have periods of 10-45 sec (22-100 mHz). To see them, we can calculate the spectral lines of these waves every 10 minutes and plot the value of the spectral line in color according to its value so we can see the results on a 12-hour plot.





On the left is a 10 minute plot on the x-axis of the magnetic field measured with the magnetometer at Carson City, NV. The time is in UT, which translates to 12:59:52 pm at Carson City. The XH, YD, and Z components are shown from top to bottom in units of nanotesla (nT) on the y-axes. There are waves in the top plot that originate from the interaction of the solar wind with Earth's magnetosphere. These waves can be seen in redish-orange on the right in a 12-hour spectrogram showing data from 14:30 UT on 4/22/2005 to 2:30 UT on 4/23/2005 on the x-axis. This corresponds to 7:30am to 7:30pm Carson City (local) time. The green and blue colors are noise in the magnetic data and the yellow-red represent the spectral power in the waves in units of nT^2/Hz. The redder the color the more spectral power in the waves, which would be represented as larger amplitude in the line plots. The frequency of the waves are indicated by the y-axis. So these waves are primarily found around 0.042 Hz, or 42mHz, as shown above in the power spectrum.

Note: the range you can inspect is limited by the maximum duration of the data stream you are displaying.

If the data we use to calculate the spectral power has a time resolution of 0.5 seconds, then the shortest wave period we can study is 1 second. This corresponds to the highest possible frequency we can study of 1 Hz. The spectrogram frequency window has to be rescaled to the proper frequency range on the y-axis. In this example, the maximum frequency on the y-axis would be 1 Hz.

If we use a time range of 1 minute of the 0.5 second resolution line plot data to determine a power spectrum, then the longest wave period we can study is 30 sec. This corresponds to the lowest possible frequency we can study using the power spectrum of 0.033 Hz (or 33 mHz). If we use a longer time range of the line-plot data, we can study longer wave period waves (lower frequency waves.)

Where do common Magnetometer signatures come from?

So, why are there waves in the magnetic data? As it turns out there are many different reasons why there are waves in the magnetic field data. In this lesson, students will study the magnetic signature of two types of waves: waves in the electrical currents in 1) the aurora and 2) the bow shock. The bow shock is the region of the interaction between the solar wind and Earth's magnetosphere. The auroral waves are best observed at high latitudes, like in Alaska, whereas the bow shock waves are best observed at lower latitudes such as in Nevada. Aurora waves are complex because they can originate in the magnetosphere with the electrons that cause the aurora or in the ionosphere where the light from the aurora is observed. These currents are always very complex and can be extremely strong, producing lots of red on the spectrometer plots. Bow shock waves start at the bow shock and then travel into Earth's magnetosphere where they resonate with Earth's magnetic field lines and can be observed in magnetometer data on the ground during the day.

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