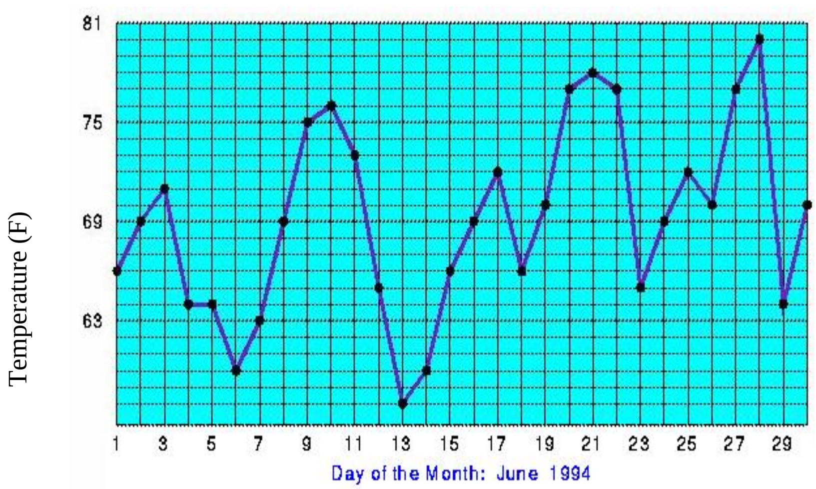
Activity 16 – THEMIS Magnetometer Line-Plots

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.

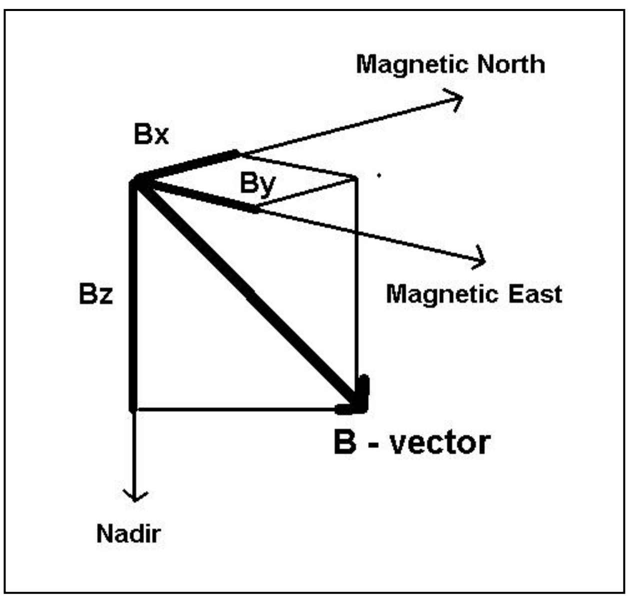
The units we use to measure magnetic strength is the *tesla*. A tesla is a unit of magnetic flux density. Earth's magnetic field is small compared to a tesla: 50 million times smaller (50 'micro-tesla' or 'µT').

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).

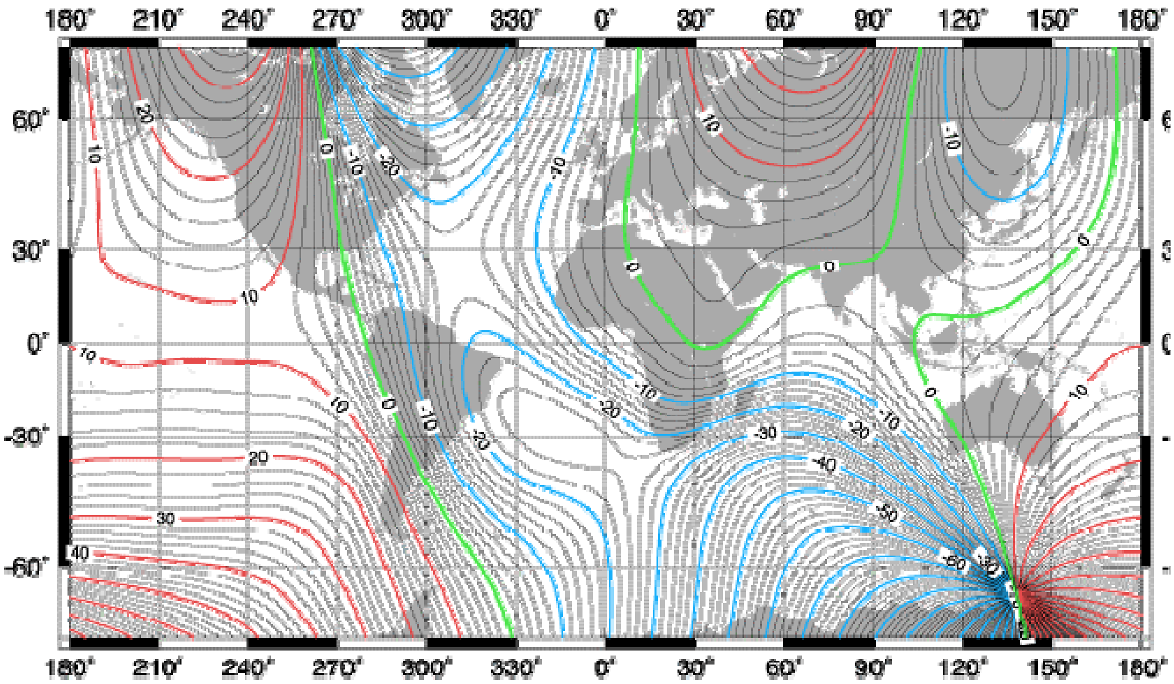
For a complete presentation on the magnetometer data and what it measures, please see the ‘Magnetometer Signature Tutorial’ found on the THEMIS Education and Public Outreach (E/PO) website. There are several different ways of viewing the tutorial (as an HTML page, a Acrobat Reader PDF document, and PowerPoint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