CHICAGO BOTANIC GARDEN

Activity 3.4: Plant Phenology Data Analysis

Grades 10 – 12

Description:
Part 1: Meet the Naturalists: students read about the five individuals who collected data in Concord, Massachusetts, and consider the challenges and benefits of having multiple individuals collect data over long time periods.

Part 2: Graphing Historical Data: Students will learn the story behind more than 150 years of plant phenology data collected in Concord, Mass., then graph plant phenology data and draw conclusions about how climate and climate change affect plant phenology.

Part 3: Explaining the Variation: In this section, students will determine if the variation in first flowering date in Concord, Mass., can be explained by temperature (maximum, minimum or mean) or precipitation (annual rainfall).

Part 4: BudBurst and NASA Green-up Data: and compare historical data, and their BudBurst data, to NASA Normalized Difference Vegetation Index (NDVI) visualization and graphs.

Students will discuss how BudBurst can contribute to our understanding of plants' responses to climate change.

Time: Three class periods

Materials:

Part 1: Meet the Naturalists
- Copies of the "meet the naturalists" handout
- Journals

Part 2: Graphing the Data
- Copies of blank plant phenology data analysis handouts
- Graph paper
- Optional: overhead projector and sheets, or computers with graphing software and projector for students to share graphs.

Part 3: Explaining the Variation
- Copies of blank plant phenology data analysis handouts
- Graph paper
- Optional: overhead projector and sheets, or computers with graphing software and projector for students to share graphs.

Part 4: Project BudBurst and NASA Green-up Data
- LCD or overhead projector
- Computers with internet access Printer
- Rulers

National Science Education Standards:
C3.A All organisms must be able to obtain and use resources, grow, reproduce, and maintain stable internal conditions while living in a constantly changing external environment.
5D/E4 Changes in an organism's habitat are sometimes beneficial to it and sometimes harmful.

AAAS Benchmarks:
5D/E4 Changes in an organism's habitat are sometimes beneficial to it and sometimes harmful.
5D/E1 For any particular environment, some kinds of plants and animals thrive, some do not live as well, and some do not survive at all.
5F/H6c When an environment, including other organisms that inhabit it changes, the survival value of inherited characteristics may change.

Guiding Questions:

- Who were the people who collected phenology data in Concord, Massachusetts, and why did they collect that information?
- How did plant bloom time change between the 1850s and today?
- What variables can explain the differences in bloom time?
- How does plant phenology in the Concord data sets compare to current plant phenology? What does that tell us about changing climates?
- How does NASA data and satellite imagery help us understand and interpret the phenology data that we collected through Project BudBurst?
- How are plants responding to changing climates?

Background:
Henry David Thoreau began collecting plant phenology data in Concord, MA in the 1850s. Recently, scientists at Boston University uncovered Thoreau's work and that of several other plant phenologists working in Concord, and began collecting modern data using the same methods as these phenologists. These scientists, Richard Primak and Abraham Miller-Rushing found a relationship between first flowering date and temperature in many native and nonnative plants. Their work provides a basis for predicting how future climate change will affect species in Concord, and throughout the world.

In this lesson, students will "meet" the phenologists involved in Primak and Miller-Rushing's study. Students will brainstorm and discuss the motivation behind collecting plant phenology data. Students will make predictions about how first flowering data may have changed since 1851. Next, students will graph and interpret first flowering data from 5 Concord, Massachusetts, plant species. Students will use their graphs to draw conclusions regarding how climate change (and other factors) effect plant phenology.

Part 1: Meet the Naturalists

Procedure

1. Explain to students that the data they are going to be looking at was collected from in Concord, Massachusetts. Hand out the student handout "Plant phenology data analysis part 1." Have students quickly read over the descriptions of the five naturalists that contributed to the Concord, Massachusetts, data set and think about the questions this raises about collecting long-term data sets.

2. Have students answer the three questions on the student handout themselves, and then discuss their answers as a class. Problems and opportunities associated with amassing data collected by different individuals over a long time span are important questions from an experimental-design standpoint. On one hand, this is the only way to collect data over a long time span. On the other hand – individuals may differ in their methods, they may have different names for the same plants, surroundings may change drastically, etc.

3. Discuss the students' participation in Project BudBurst – BudBurst data is collected all over the country by thousands of people. What challenges might this present in terms of designing a good experiment? What are the benefits of having so many people participate?

4. As an extension, students may research more information about the naturalists. Several sources of information can be found in the "For more information" section below.

5. Tell the students that they will now have a chance to analyze the data that's been collected since 1852!

For more information:

- Miller-Rushing and Primack's study: "Global Warming and Flowering Times in Thoreau's Concord: A Community Perspective," Abraham J. Miller-Rushing and Richard B. Primack *Ecology,* Vol. 89, No. 2 (Feb., 2008), pp. 332-341
- "Thoreau is rediscovered as a climatologist:" an article about Miller-Rushing and Primack's study of Concord, MA, plants, from *The New York Times*: http://www.nytimes.com/2008/10/28/science/earth/28wald.html?pagewanted=print
- "Teaming up with Thoreau:" an article about Miller-Rushing and Primack's study of Concord, MA, plants, *Smithsonian Magazine*. http://www.smithsonianmag.com/science-nature/walden.html
- Alfred Hosmer information from the Concord Library: http://www.concordlibrary.org/scollect/fin_aids/Hosmer_Botanical.htm)
- Pennie Logemann obituary: http://www.legacy.com/obituaries/wickedlocal-concord/obituary.aspx?n=pennie-logemann&pid=154088667&fhid=9284
- Richard Primack's website at Boston University: http://people.bu.edu/primack/
- Abraham Miller-Rushing's website: http://www.sercinstitute.org/news/abe-miller-rushing-phenologist

Part 2: Graphing the Data

Procedure:

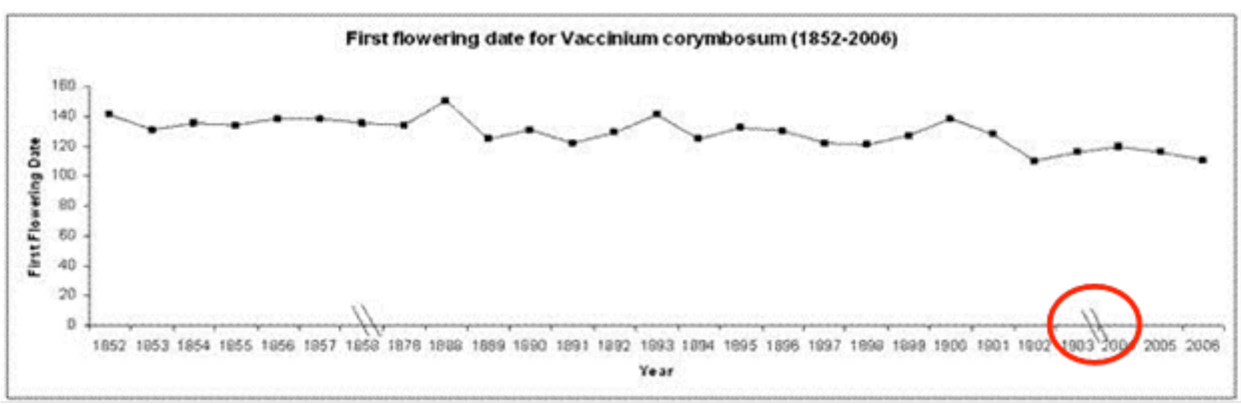
1. Hand out the second sheet, "Plant phenology data analysis part 2, graphing." Students are provided with first flower data for five species of plants. Common names and scientific names of the plants are listed, as are first flowering dates between the years of 1852 and 2006.

2. Prediction, part 1: Have students make predictions about what patterns they would expect to see if they were to graph the first flowering dates. You may have students share their predictions with a partner or with the class.

3. Prediction, part 2: Draw students' attention to the weather data in Figure 1. This data was collected from Blue Hill Meteorological Observatory, likely the closest weather station to Concord, MA. These graphs show a shift of about 2 degrees C in mean temperature between the years of 1852 and 2006. Have students modify their predictions from part 1 based on the temperature graph. Again, you may have students share their information with a partner or with the class. Students may suggest that since temperature is going up, first flowering date will be earlier in the year.

4. Prediction, part 3: First flowering date can be influenced by many things, including day length (the number of hours of light vs. dark) and temperature. Students should understand that if first flowering date is primarily influenced by day length, then first flowering date should not change over time, as the number of hours of light vs. dark in a day does not change from year to year. However, if the first flowering date is influenced by temperature, than it will change from year to year, and since figure 1 shows an increase in temperature in Concord, MA, than first flowering date should be earlier than it was in 1852.

5. Next, students will graph the data. The amount of instruction you provide in terms of the graphing will depend on how much experience they have graphing. You may want to have groups of students each work on one of the 5 species. Then, groups can draw their graph on an overhead slide, or create a graph in excel to share their graphs with the class. Or, you can have students graph all species on the same graph in different colors. Several things to note:
   - Time will be on the x axis and first flowering date on the y axis.
   - First flowering date is shown in days of the year, where January first is day 1. Several practice problems to determine the corresponding calendar date are provided. This is just for students' knowledge, as graphing will be easier with the data in the form shown. (day 111 = April 20th in a leap year, and April 21st in a non leap year)
   - There are some large gaps in the data. Students will visualize the patterns better if they do not graph the large spans of time for which there are no data (1859-1877 and 1904 – 2003). This can be shown with the symbol "\ \" on the x axis as shown on the sample graph below.



6. Once students have completed their graph (along with a title and axis labels) and worksheet, bring them back together for a class discussion. (Remember, if the graph is decreasing, this means that the first flowering date is earlier in the year).
   - Did students see the pattern they expected? How does the pattern relate to the temperature data from Concord, MA?
   - Do you think the trend in the Concord MA data would be the same for BudBurst species? Explain.
   - How you might figure out whether your species followed the same trend. What kind of experiment could you design? What kind of data would you need to collect? Over how long?

- How do you think the first flower data for Concord, MA, and for your own observations compare to overall bloom times for all species in each location?

Part 2: Extensions

- Students can research their plant species and find out some background information, including the plant's duration (annual, perennial), growth form (grass, forb, shrub, tree), distribution (where it grows), uses of the plant (medicinal, cultural, etc.), and photographs.
- Many interesting articles have been written about the Concord, MA, phenology data. Students can read these articles individually or as a class. See the "For more information" section below.
- Additional plant phenology data sets (including 1000+ species from the Concord study) can be found on the National Phenology Network's website: http://www.usanpn.org/results/dataset-list

Part 3: Explaining the Variation

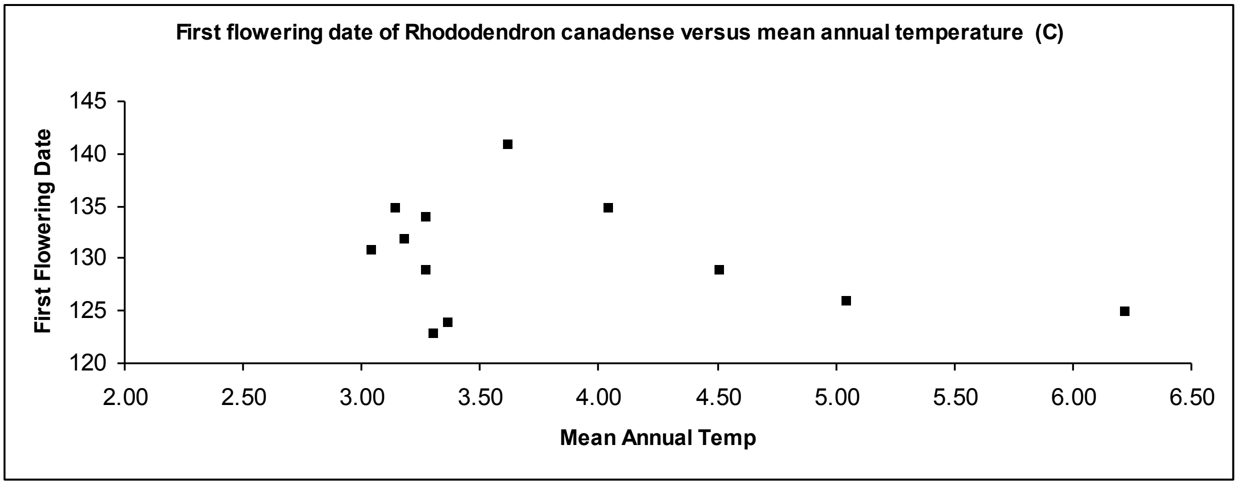
Procedure:

1. In this section, students will determine if the variation in first flowering date in Concord, MA, can be explained by temperature (maximum, minimum, or mean) or precipitation (annual rainfall).

2. Hand out the third sheet, "Plant phenology data analysis part 3, explaining the variation." Have students make a prediction about which factor might explain the variation in first flowering date of the Concord, MA, plant species. You may want to discuss as a group why any of the particular climate measurements would affect first flowering date.

3. Based on their prediction, students should choose a climate variable to test. They will graph the climate variable (x-axis) versus the first flowering date (y-axis) to determine whether a relationship exists. *Ask students how they will know if there is a strong relationship between the climate variable and first flowering date?*

4. Next, students will graph the data. As in part 2, the amount of instruction you provide in terms of the graphing will depend on how much experience they have graphing. You may either have each student choose one variable to graph (make sure that approximately equal numbers of students are working on each of the four variables, so there are opportunities for discussion) or break students into groups and have each group graph all four variables. Students can use the species they graphed in part 2, choose a new species, or if you'd like, the students could graph all the data. Students can also draw their graph on an overhead slide, or create a graph in excel and share their graphs with the class.



Sample Graph

Several things to note:

- The climate variable will be on the x-axis and the first flowering date on the y-axis.
- Students should only graph data points for which they have both a climate variable and a first flowering date. Climate data are only available for years after1895.
- Graphs may not show a perfect relationship, but students can still draw some conclusions. For instance, in the sample graph below, it appears that as mean annual temp increases, first flowering date decreases (gets earlier).

5. Once students have completed their graph(s) (along with a title and axis labels) you may have them complete the discussion questions. Remember, if the graph is decreasing, this means that the first flowering date is earlier in the year.

6. If students made graphs of different species, they can then share their graphs with the class.

7. Tell students that in Part 4, they will look at satellite imagery from NASA that will help them determine whether the recent Concord MA, data, and their own BudBurst observations, are consistent with the bloom times of all plants at these locations.

Extensions

- Students can research their plant species and find out some background information, including the plants duration (annual, perennial), growth form (grass, forb, shrub, tree), distribution (where it grows), uses of the plant (medicinal, cultural, etc.), and photographs.
- Many interesting articles have been written about the Concord, MA, phenology data. Students can read these articles individually or as a class. See the "For more information" section below.
- Additional plant phenology data sets (including 1000+ species from the Concord study) can be found on the National Phenology Network's website: http://www.usanpn.org/results/dataset-list

Part 4: Project BudBurst and NASA Satellite Imagery

Pre-Activity:

- Review how NASA uses visible and near infrared light reflected by plants to calculate the Normalized Difference Vegetation Index (NDVI). There is a good description at: http://earthobservatory.nasa.gov/Features/MeasuringVegetation/
- Practice using MyNasaData to generate NDVI maps and graphs (http://mynasadata.larc.nasa.gov/las2/UI.vm)
- Print out and make copies of graphs and maps if you plan to have students work from those rather than generate their own.

NOTES: There are two ways you can implement this activity depending on how much experience your students have working with data and computers, and how much time you have to devote to the activity. Students will be using the same NASA interface, MyNASAData, as they did in Activity 2.4 Climate Change Around the World to generate graphs of temperature, precipitation, and cloud cover, to generate images and graphs of the Normalized Difference Vegetation Index (NDVI).

NDVI is a measure of the visible and near infrared light reflected by the land surface back into space. By measuring these wavelengths, it is possible, using an algorithm called a Vegetation Index to quantify the concentrations of green leaf vegetation around the globe. By combining the daily Vegetation Indices into 8-, 16-, or 30-day composites, scientists can create detailed maps of the Earth's green vegetation density that identify where plants are thriving and where they are under stress (i.e., due to lack of water). Students will be generating these visualizations using the MyNASAData website.

After going over what the maps and graphs represent as a class, you can either have students generate their own maps and graphs (student instructions are included below) or **you** can generate the required Normalized Difference Vegetation Index (NDVI) images and graphs for students. You may then print them out and provide a set to each student group that they can use to answer the questions on the datasheet as a group or you can project them on the overhead and answer the questions as a class. You will need to generate a graph and image of NDVI data for the location where you collected your BudBurst data. Students will be working with 2009 data because that is the most recent fully year of data in the system at the writing of this curriculum. If newer data is available, students should use the most recent data. **A graph of the NDVI for Concord, MA, and an image of the NDVI index for the months of February, March, April, and May are included at the end of the activity.**

Procedure:

1. Project the class BudBurst site and project the data history for your species and data collection site(s) using the BudBurst Data Viewer, so the data is visible as your students enter the classroom.

2. Begin the class with a discussion of when the first bloom dates were for the BudBurst data the class has collected. Compare your data to the first bloom dates for the Concord, MA, data. Discussion questions might include:

- Are the dates close to each other?
- What factors might determine any similarity or difference in the dates? Answers might include different weather each year, different location (latitude/longitude) or elevation, different plant species.

3. Have students record the dates of first flower for their BudBurst species on their worksheet (or you can print out or download their data from the BudBurst Data Viewer), along with the dates of first flower for the Concord, MA, species they graphed in Part 2.

4. Tell students they will be comparing their Project Budburst data and the Concord data to satellite data collected by NASA that let us draw conclusions about how much vegetation is present in a location. Satellites can measure how much sunlight is being absorbed by plants on the surface of the Earth. So if lots of sunlight is being absorbed, it is a good indicator of how much vegetation is present in a location. If lots of sunlight is being absorbed, that probably means that there are many plants present. On the other hand, if little energy is absorbed, there are few or no plants present. You might want to note this on the board, so students remember what NDVI represents while they are looking at their maps. Write on the board: **NDVI = amount of sunlight absorbed by plants**

5. Project one of the sample NASA NDVI maps, and discuss what the color key represents (white is where there is little to no absorption, purple is low light absorption and red is the most with the maximum = 100% light absorption). Discuss what this means in terms of vegetation. Discussion questions might include:
   - Why do we see blue (low vegetation) in many parts of the U.S. in January? (It's winter, so there is little plant growth in the northern areas.)
   - What about the places in Africa near the equator that are blue/green? Why might there be low vegetation there? (Desert, drought etc.)
   - What about Australia? It's in the southern hemisphere, so it should be summer there?

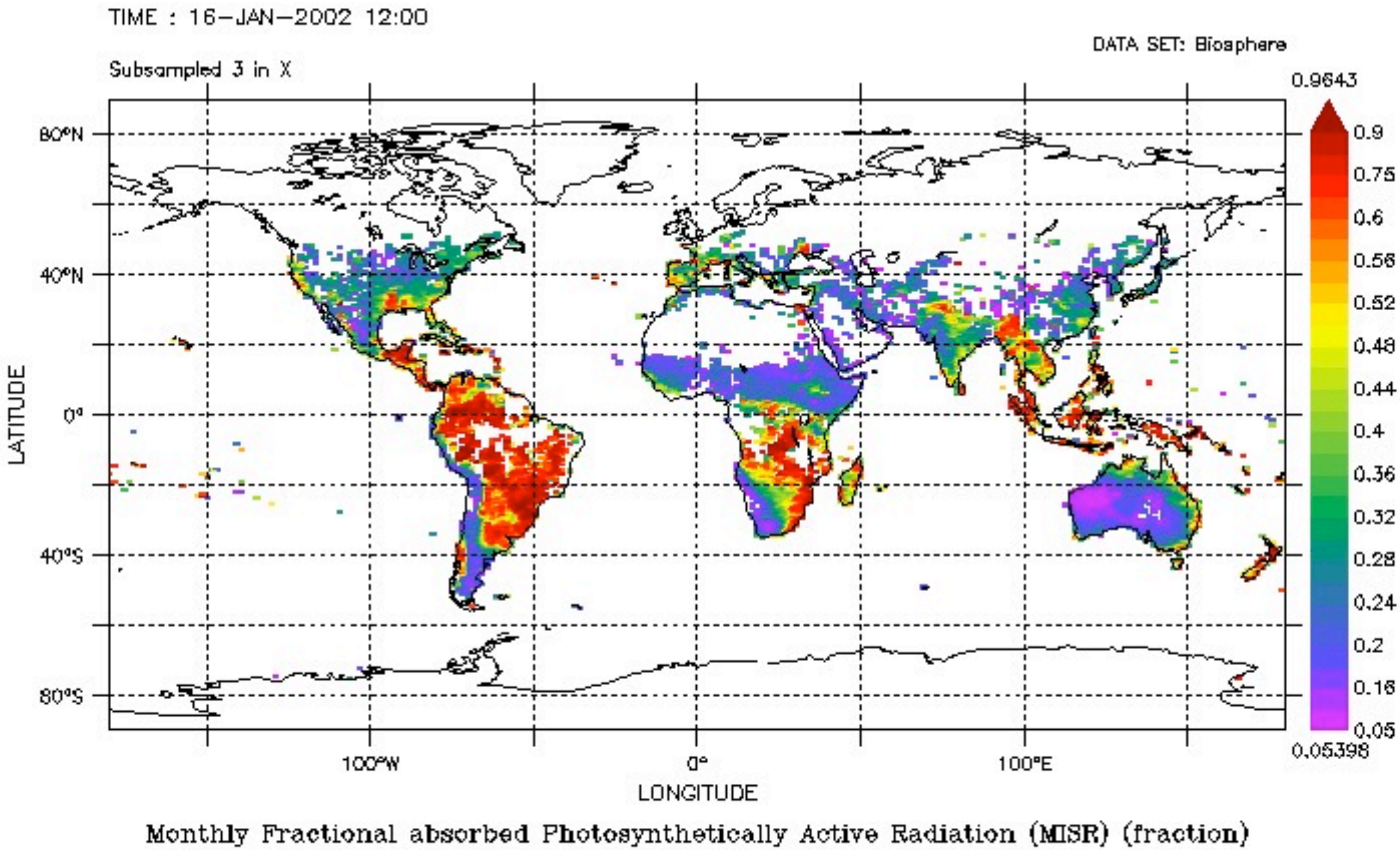
6. Students should understand that NDVI doesn't only vary by season, but also by climate and geography, (temperature, precipitation levels, and elevation). You can either go over both maps and make the comparison between winter and summer as a class, or let students figure out the differences as they answer the questions on their worksheets.

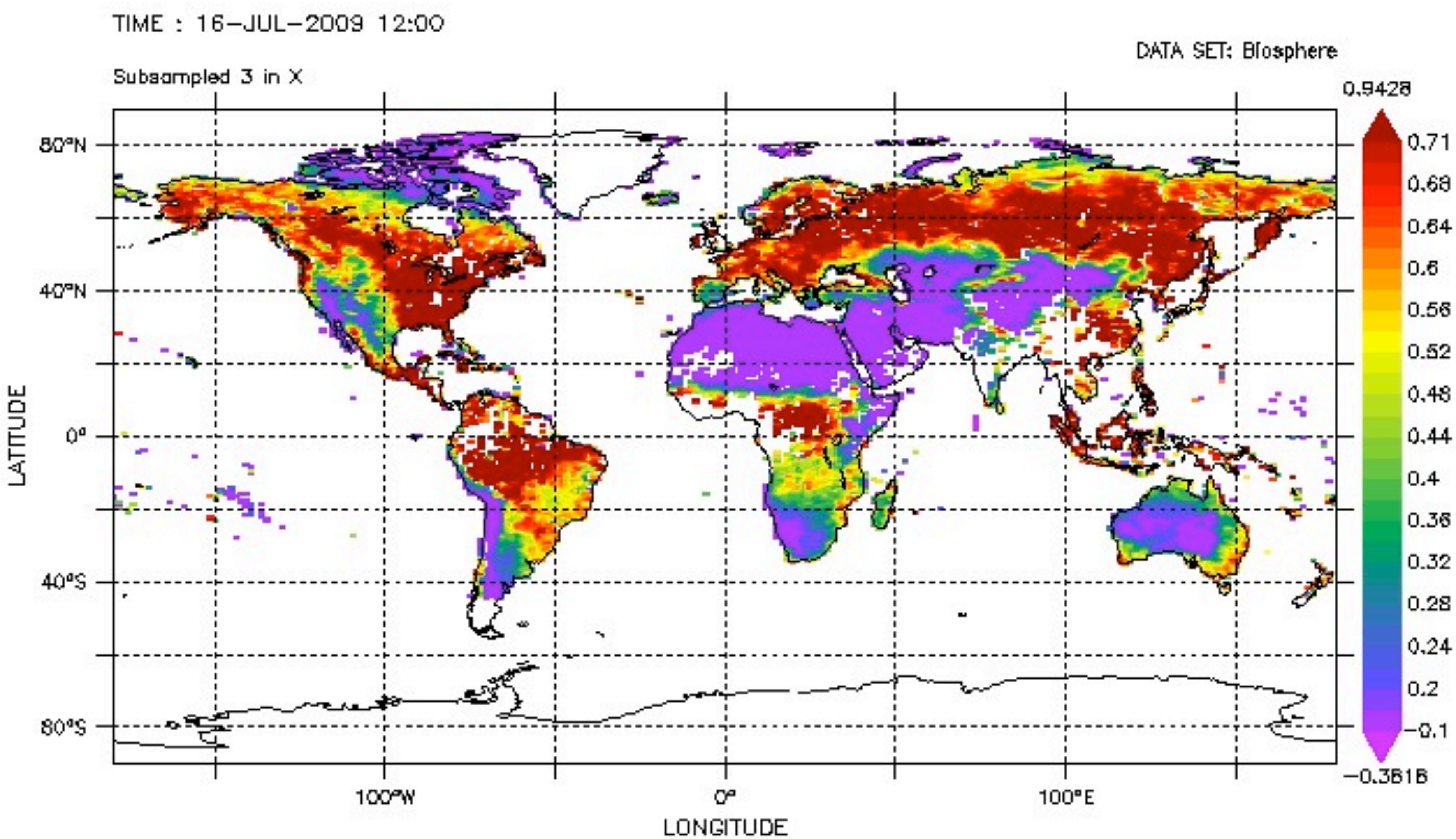
7. Demonstrate how the website works by walking through the first example, and projecting it using an LCD projector. Answer any questions students have. Break students into groups to complete the worksheet on their own after the first example.

8. Once students have completed the activity and the worksheets, bring them back together for a class discussion of the results focusing on Question 4.
   - What if any patterns do you see in the graphs? What are they? Are they similar?
   - How does the bloom time of your plant species compare to the overall monthly changes in vegetation shown on the Concord, MA, graph?

- Based on the pattern in your graphs, explain how the bloom time of your BudBurst plant compares to the overall monthly changes in vegetation.
- Based on what you know about climate change, what changes might you expect to see in both the maps and the graphs in the future?

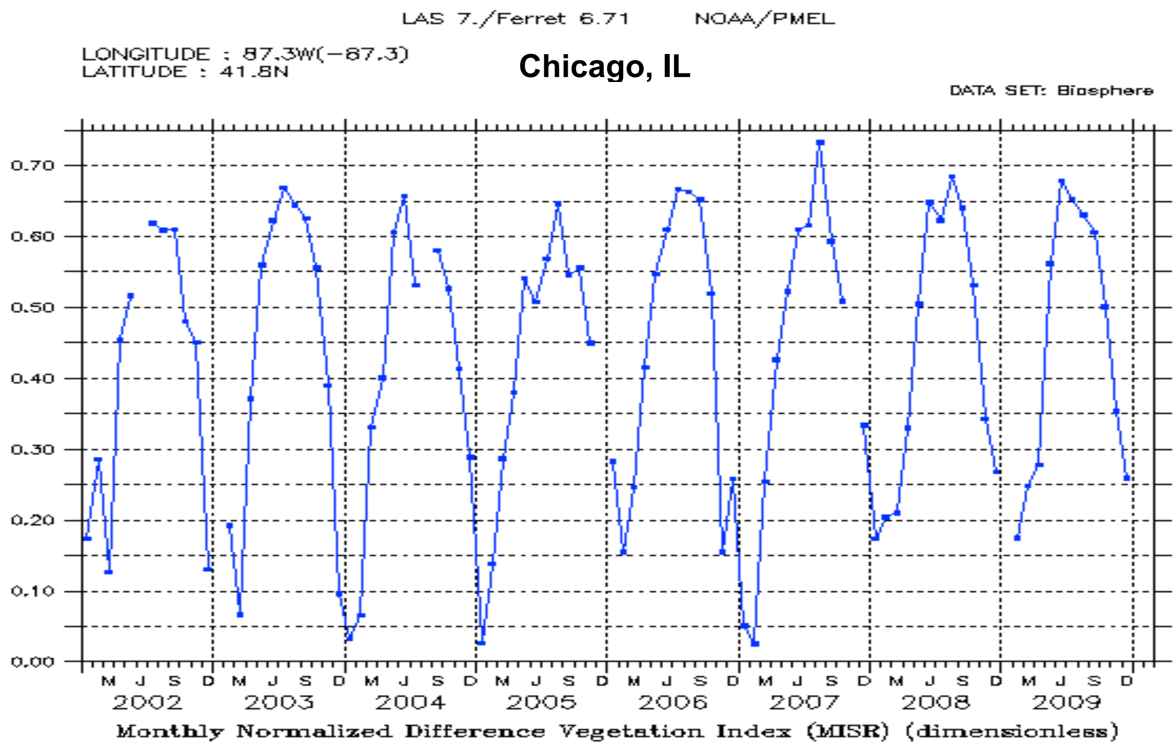
9. Close the discussion by bringing the class back to consider climate change and its impacts on ecosystems.
    - How does looking at bloom times help us understand the impacts of climate change?
    - What repercussions might these changes have for ecosystem functioning?

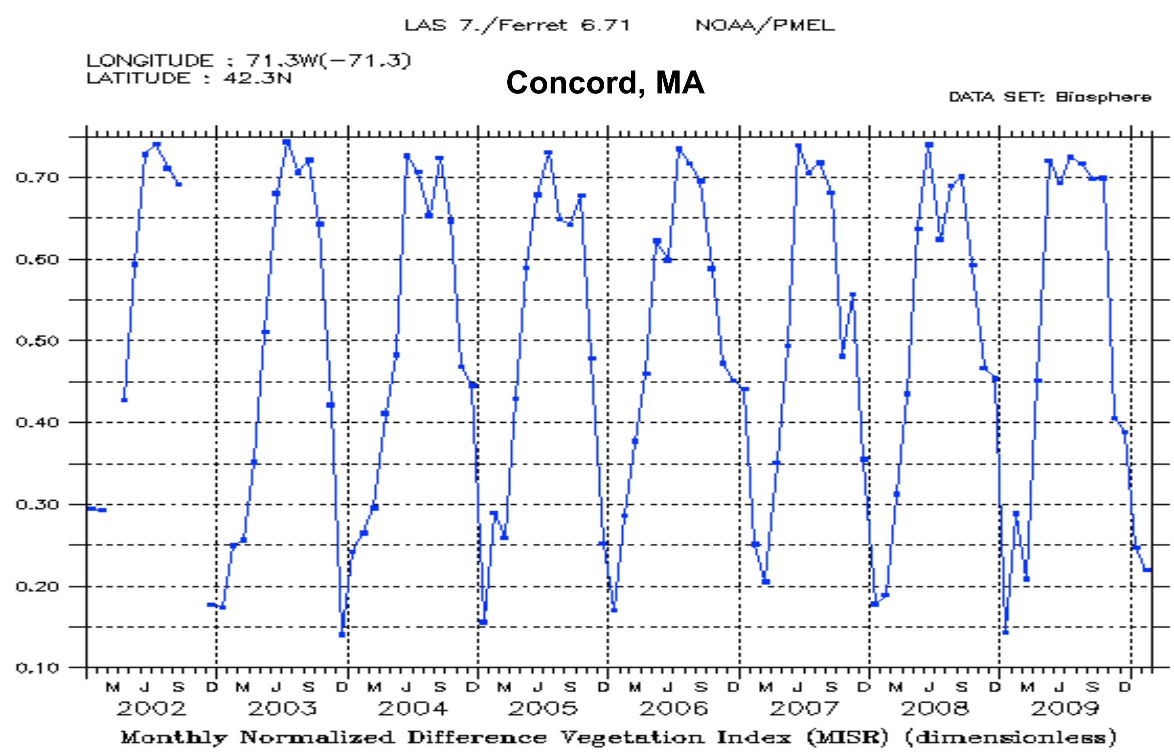

TIME : 16-JAN-2002 12:00
DATA SET: Biosphere
Subsampled 3 in X
0.9643
0.9
0.75
0.6
0.56
0.52
0.48
0.44
0.4
0.36
0.32
0.28
0.24
0.2
0.16
0.05
0.05398
80°N
40°N
0°
40°S
80°S
LATITUDE
100°W
0°
100°E
LONGITUDE
Monthly Fractional absorbed Photosynthetically Active Radiation (MISR) (fraction)



Monthly Normalized Difference Vegetation Index (MISR) (dimensionless)

Sample Graphs





Part 1: Meet the Naturalists

The data that you are about to analyze is old. The first observations came from 1851! The naturalists listed below would walk around a few times a week and observe flowers. They would write notes about the stages of the plant, for instance: emergence, first leaf, first flower, full flower, first fruit, etc. Read the information about these five naturalists and answer the questions below:

Who was watching the flowers?

Henry David Thoreau (1817–62) was an author, poet, naturalist, historian, and abolitionist, among other things. His most famous work is a book called *Walden,* which is about living in harmony with nature. Between 1852 and 1858 he noted the first flowering dates of more than 500 species of plants in Concord MA. However, he did not publish his data.

Alfred Hosmer (1851–1903) was a photographer and owner of a dry goods store. He was a follower of Thoreau and helped make him famous. Hosmer observed the first flowering date of more than 700 species of plants in the years 1878 and 1888–1902. He also published articles about the plants of Concord, MA.

Pennie Logemann (1918-2011) was head of a bacteriology lab. In 1966 she became a landscape designer. Logemann observed more than 250 species of plants near her home in Concord between the years of 1963 and 1993. Her work was used in a study by Miller-Rushing and Primack in 2008.

Richard B. Primack is a biology professor at Boston University. He teaches on plant biology and conservation biology. He also researches the effects of climate change on plant flowering in Concord, MA, and in Japan and South Korea. Primack has studied plant flowering in Concord, MA, since 2003.

Abraham Miller-Rushing is a phenologist and the head of science at Acadia National Park in Maine. He studied with Primack at Boston University. Primack and Miller-Rushing put together data from Thoreau, Hosmer, and Logemann with data they collected in 2003–08 to study how plant flowering in Concord, MA, has changed over time.

1. Describe some of the problems associated with compiling data collected by different individuals over a long time span.
2. Describe some of the opportunities associated with compiling data collected by different individuals over a long time span.
3. Think about Project BudBurst. How might the issues raised in questions #2 and #3 affect BudBurst data? What are the positives and negatives for BudBurst, a national project with thousands of participants?

Part 2: Graphing the Data

Table 1: First flowering dates of five plant species in the Concord, MA, area between 1852 and 2006. First flowering dates are shown in days of the year, where January first is day 1.

Plant common name →	Highbush blueberry	Canada Mayflower	Larger blue flag	Rhodora	Downy yellow violet
Plant scientific name →	*Vaccinium corymbosum*	*Maianthemum canadense*	*Iris versicolor*	*Rhododendron canadense*	*Viola pubescens*
1852	141		163	139	146
1853	131	137	150	135	136
1854	135	141	158	136	147
1855	134		161	138	
1856	138	160	165	138	
1857	138		157	138	
1858	135	139	161	137	136
1878	134	130	177	125	137
1888	150	153	162	144	145
1889	125	132	146	128	125
1890	131	138	151	131	124
1891	122	137	151	130	120
1892	129	143	155	143	131
1893	141	148	162	140	140
1894	125	133	147	125	119
1895	132	135	148	132	125
1896	130	135	146	131	131
1897	122	136	143	129	129
1898	121	140	157	135	128
1899	127	134	155	134	127
1900	138	143	158	141	138
1901	128	139	160	135	134
1902	110	135	150	124	124
1903	116			123	123
2004	120	135	155	129	127
2005	116	132	158	126	113
2006	111	129		125	111
Mean					
Minimum					
Maximum					

Name ____________________________________Teacher/Class ________________________

Part 2: Graphing the Data

A. Make a Prediction: If you were to graph the first flowering date of these five plant species, what pattern would you expect to see? Why?

B. Refine your Prediction: Describe the graph in figure 1, below. Use the information in this graph to refine the prediction you made in part A in the space below the graph.

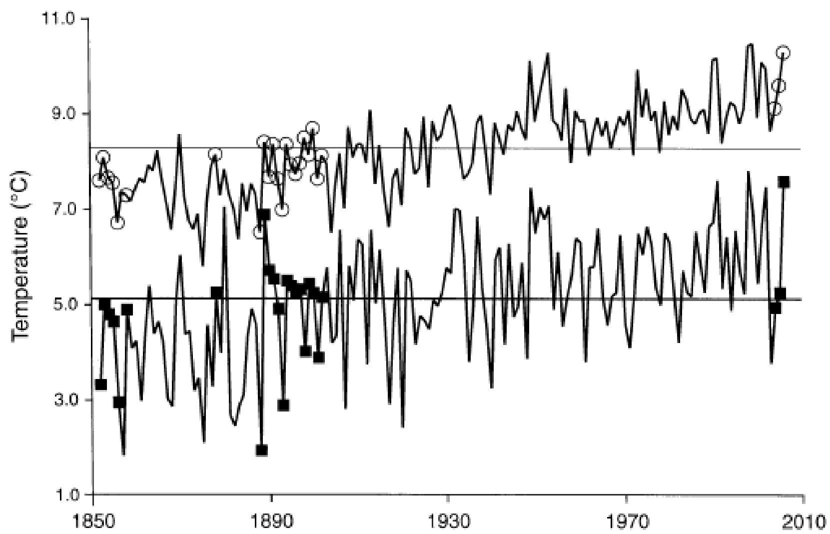


FIG. 1. Temperatures at Blue Hill Meteorological Observatory (33 km southeast of Concord, Massachusetts, USA) from 1852 to 2006. The upper line and open circles represent mean annual temperatures. The lower line and solid squares represent mean monthly temperatures in January, April, and May, temperatures that were highly correlated with flowering times for many species. Horizontal lines show long-term means for each (annual = 8.3°C; Jan, Apr, May = 5.1°C). Circles and squares show years with flowering data.

(From Miller-Rushing and Primak, 2008)

Name ___________________________________Teacher/Class ________________________

Part 2: Graphing the Data

C. Considering Variables

First flowering date can be influenced by many things, including day length (the number of hours of light vs. dark), precipitation, and temperature.

1. If the first flowering date for your species was primarily influenced by day length, how would you expect the date of first flowering to change between 1852 and 2006?

2. If the first flowering date for your species was primarily influenced by temperature, how would you expect the date of first flowering to change between 1852 and 2006?

D. Creating the Graph

Graph the date of first flower for the species you have chosen or been assigned by your teacher.

1. Write the scientific name and the common name of your species below.

   Scientific name:____

   Common name:____

2. Remember, the first flowering dates are shown as numbers, with Jan 1 being the number 1. Just for practice, determine the **calendar date** of day number 111 using a calendar.

   Write the date here:_____________________________

3. Label the X an Y axes to reflect the data you are graphing.

4. Next, for each species, determine the **mean** date of first flower, the **maximum** date of first flower, and the **minimum** date of first flower. Add your data to table 1.

Name ______________________________________ Teacher/Class _________________________

Name ___________________________________Teacher/Class _______________________

Part 2: Graphing the Data (cont.)
E. Analyzing the Data
After you have completed your graph, answer the following questions:

1. Describe the pattern you see in the data. Did first flowering dates for your species change between 1852 and 2006?

2. Did first flowering days for your species get earlier or later? Why do you think this is the case?

3. Do you think the first flowering date for your species was influenced primarily by day length, temperature, or some other factor? Explain your answer.

4. Primak and Miller-Rushing found that, on average, native plants flowered 2.9 days earlier with each 1 degree C. of warming. Using the average first flowering date of the last three years studied as a baseline, when would your species flower if Concord, MA, warmed 5 degrees Celsius. What would be the calendar date for this day? Show your work.

Name ____________________________________Teacher/Class ________________________

Part 2: Graphing the Data (cont.)
E. Analyzing the Data (cont.)

5. Primak and Miller-Rushing found that invasive plants flowered 3.4 days earlier with each 1 degree C. of warming. If an invasive plant had the same baseline first flowering date as your species, when would this species flower if Concord, MA, warmed 5 degrees C. What would be the calendar date for this day? Show your work.

6. Explain why this is might be dangerous for native plants.

7. Do you think the trend you see in your species will be the same with the BudBurst species you are observing? Explain how you might figure out whether your species followed the same trend.

8. What are benefits and risks to plants of flowering earlier in the season?

Part 3: Explaining the Variation

In this section, you will attempt to explain whether the changes in first flowering day for your species are explained by temperature (mean, maximum, or minimum annual temperature), precipitation, or some other factor.

A. **Prediction:** Of the following four factors: mean annual temperature, maximum annual temperature, minimum annual temperature, or mean annual precipitation, which do you think may explain the variation in first flowering date of the Concord, MA, plant species? Explain your answer.

B. **Graphing**: Based on your prediction, select a column from Table 2. The climate variable will represent the independent variable (x-axis) and the first flowering date will represent the dependent variable (y-axis). On the next page, plot the data for each year that you have data for *both* variables.

Table 2: Temperature and precipitation data from Blue Hill, MA.

Year	Maximum annual temperature (C.)	Mean annual temperature (C.)	Minimum annual temperature (C.)	Mean annual precipitation (cm.)
1895	13.22	8.21	3.18	117.32
1896	12.78	7.92	3.03	120.50
1897	13.04	8.17	3.27	115.32
1898	13.33	8.69	4.03	149.07
1899	13.45	8.37	3.27	103.30
1900	14.16	8.90	3.61	122.28
1901	12.44	7.80	3.13	137.11
1902	13.28	8.33	3.36	108.51
1903	13.07	8.21	3.30	118.77
2004	13.72	9.13	4.50	140.06
2005	14.14	9.61	5.04	168.20
2006	15.31	10.77	6.22	153.44

Note: Blue Hill, MA, is the closest weather station to Concord, MA, for which historical data are available. Source: MJ Menne CN Williams Jr. RS Vose NOAA National Climatic Data Center Asheville NC

After you have completed your graph, answer the questions in **Section C: Interpreting your graph**.

Name ___________________________________Teacher/Class _______________________

Part 3: Interpreting your Graph (cont.)

C. Interpreting your graph

1. Describe the pattern you see in the data. Explain the relationship between the variables (e.g.: does precipitation influence first flowering date? How do you know?).

2. Do you think the first flowering date for your species was influenced primarily by temperature, precipitation, or another factor such as day length? Explain your answer.

3. Comparing graphs with your classmates, which species seemed to show a strong relationship between temperature and first flowering date? What about between precipitation and first flowering date?

4. How could the information from the study be used?

Part 4: Project BudBurst and NASA Satellite Imagery

1. In the spaces below, record the first flower or first leaf date of your BudBurst species from the website and Concord, MA, species that you graphed in Part 2:

Concord, MA, species: ____

First flower/leaf date(s):____

Latitude: ______________________ Longitude: ________________________

BudBurst Species:_________________________ First flower/leaf date:_________

Your city and state: ____

Latitude: ______________________ Longitude: ________________________

2. Follow the instructions outlined on the sheet "**How to create maps and graphs using My NASA Data Live Access Server,**" **Part 1,** to generate four comparison maps of the monthly normalized difference vegetation index (NDVI) index for the most recent year available for the United States for the months Feb, March, April, and May. Then answer questions A-C below.
   A. Look at all four maps. Which month shows the lowest amount of vegetation? Which month shows the highest? Based on what you know about plants and climate, explain your answers.

   B. Where in the U.S. is there the most plant growth overall (over all four months)? Where is there the least? Based on what you know about plants and climate, explain your answers.

C. Compare the first bloom dates for your budburst species and your Concord, MA, species to the four maps. Do the bloom dates appear to fit into the general trends of plant growth over the four-month period? Explain your answer.

3. Follow the instructions outlined on the sheet **How to Create Maps and Graphs using My NASA Data Live Access Server," Part 2,** to generate graphs of monthly changes in NDVI for the city where your school is located and for Concord using the entire NASA data set from 2002 through the most recent month and year available. Then answer questions A-G below.
   A. Look at the labels on the x and y-axes. Explain what the labels mean. (Hint: look at the scale on the right-hand side of the maps you generated.)

   B. Look at the Concord graph and fill in the following information:
      i. Highest amount of light absorbed ______________________________________
      ii. Month/year of the highest amount of light absorbed ______________________
      iii. Lowest amount of light absorbed ______________________________________
      iv. Month/year of the lowest amount of light absorbed _______________________

   C. Do the same for the graph of your city:
      i. Highest amount of light absorbed ______________________________________
      ii. Month/year of the highest amount of light absorbed ______________________
      iii. Lowest amount of light absorbed ______________________________________
      iv. Month/year of the lowest amount of light absorbed _______________________

   D. Compare the two graphs and your answers to questions B and C. Do you see any patterns in the graphs? Are they similar? Describe any patterns you see.

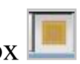
E. Look at your Concord, Massachusetts, species data on the phenology data table. What date did your plant bloom (remember you will need to convert the day of the year back to the month/date)? How does the bloom time of your plant species compare to the overall monthly changes in vegetation shown on the Concord graph?

F. Look at your city's graph. Although the graph does not continue through 2011–12, based on the pattern, explain how the bloom time of your BudBurst plant compares to the overall monthly changes in vegetation.

G. Based on what you know about climate change, what changes might you expect to see in both the maps and the graphs in the future

How to Create Maps using My NASA Data Live Access Server

Part 1: Generate four comparison maps of the **monthly normalized difference vegetation index** (NDVI) index for 2009 for the United States by following the instructions below:

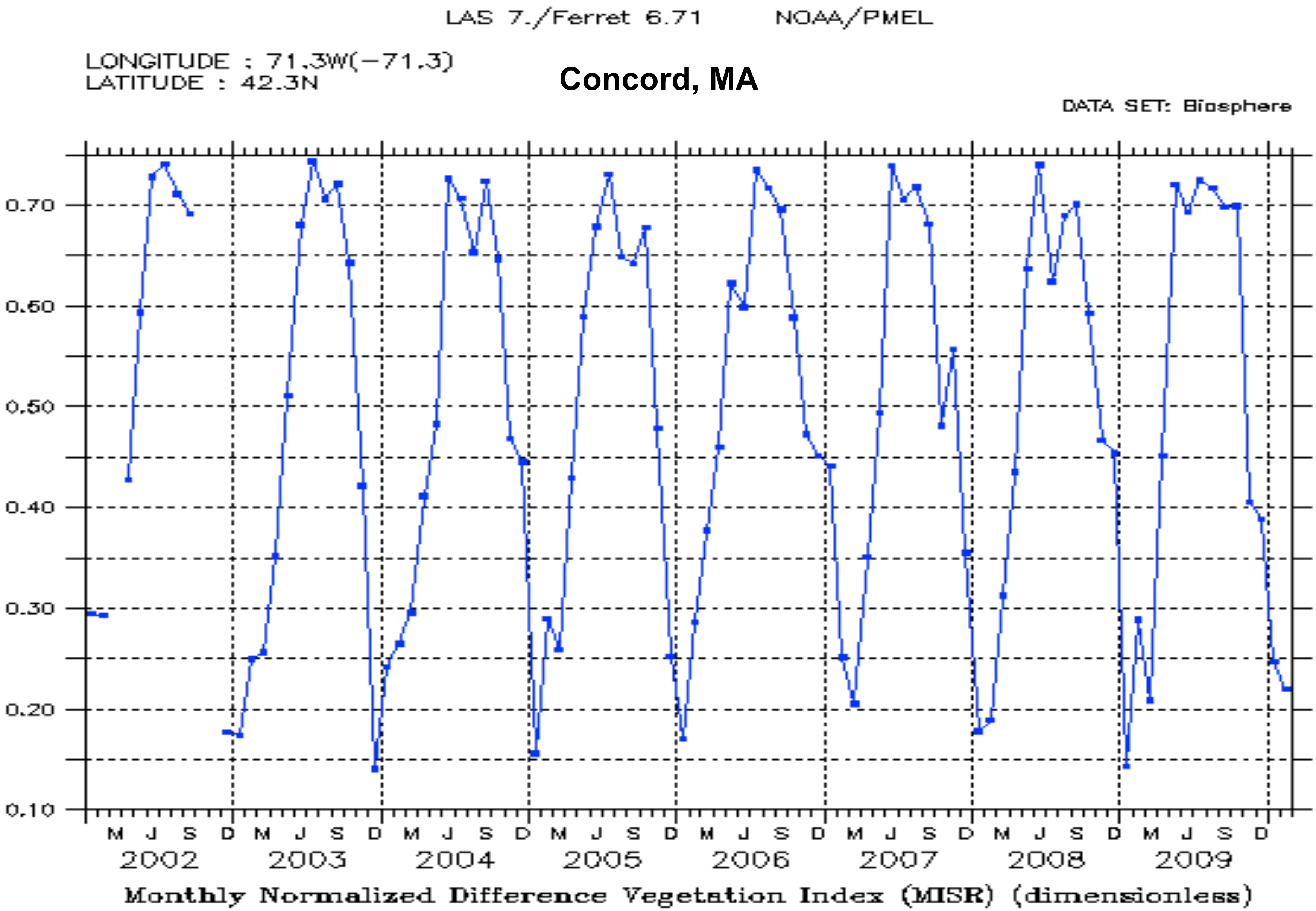
1. Open the My NASA Data Live Access Server (LAS) Advanced Edition http://mynasadata.larc.nasa.gov/las/UI.vm
2. Click in the checkbox on the **UPDATE PLOT** button. This will ensure that when you make a new selection, your map or graph will update automatically.
3. Click on the **CHOOSE DATASET** button
4. Click on **BIOSPHERE**
5. Choose **MONTHLY NORMALIZED DIFFERENCE VEGETATION INDEX (MISR)**.
6. Click on the +/- magnifying glass  and the globe to zoom in and out on the world map.
7. Click on the orange box  in the map menu bar then select a box encompassing the continental United States.
8. Using the drop down menu, select the time **FEB 2009**, the map will update automatically.
9. Click the **COMPARE** button in the middle of the top menu bar. You will now see four identical maps. Under each map you can select the month and year. Modify the months, so that you can see Feb, Mar, Apr, & May 2009.
10. Click the **UPDATE PLOTS** button on the top menu bar. This will update the maps to reflect your changes.
11. Compare the maps to the dates of your BudBurst/First Leaf data and to that of the Concord data, and answer the questions on your datasheet. Once you have answered the questions, move on to Part 4.2.

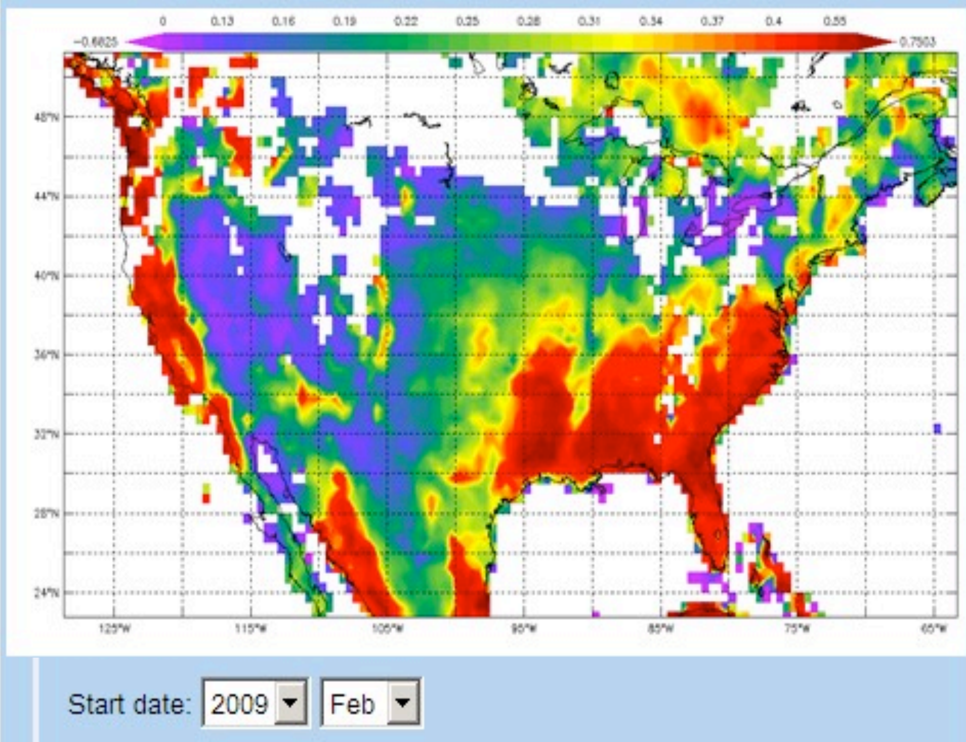
How to Create Graphs using My NASA Data Live Access Server *(cont.)*

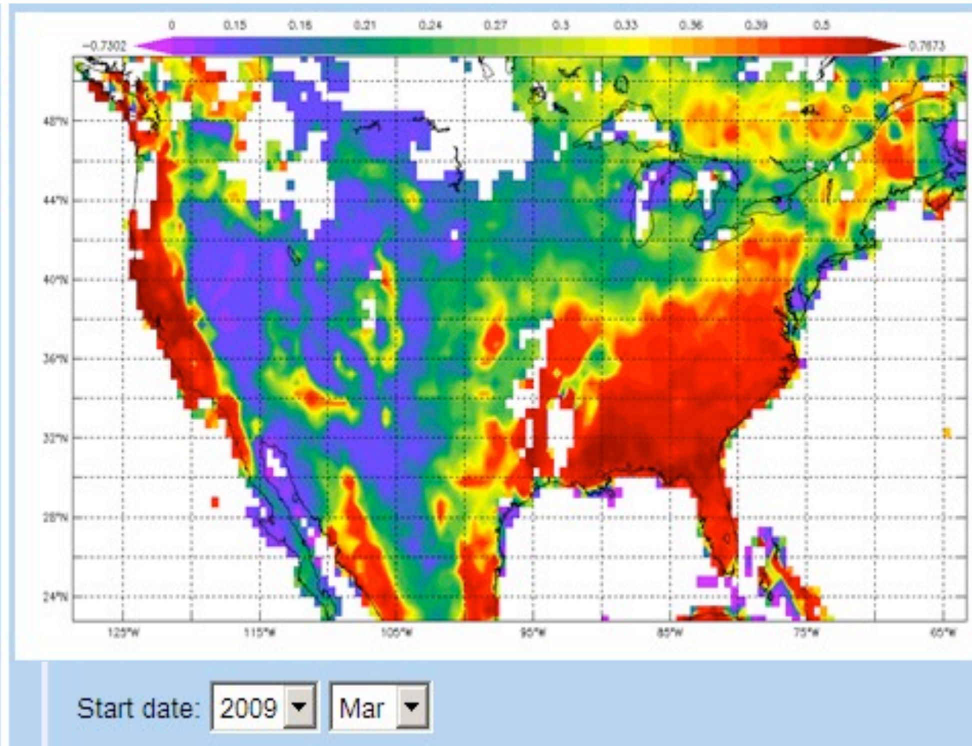
Part 2: Generate a graph of monthly changes in NDVI for your city and for Concord, Massachusetts, using the entire NASA data set from 2002 through the most recent month/year available.

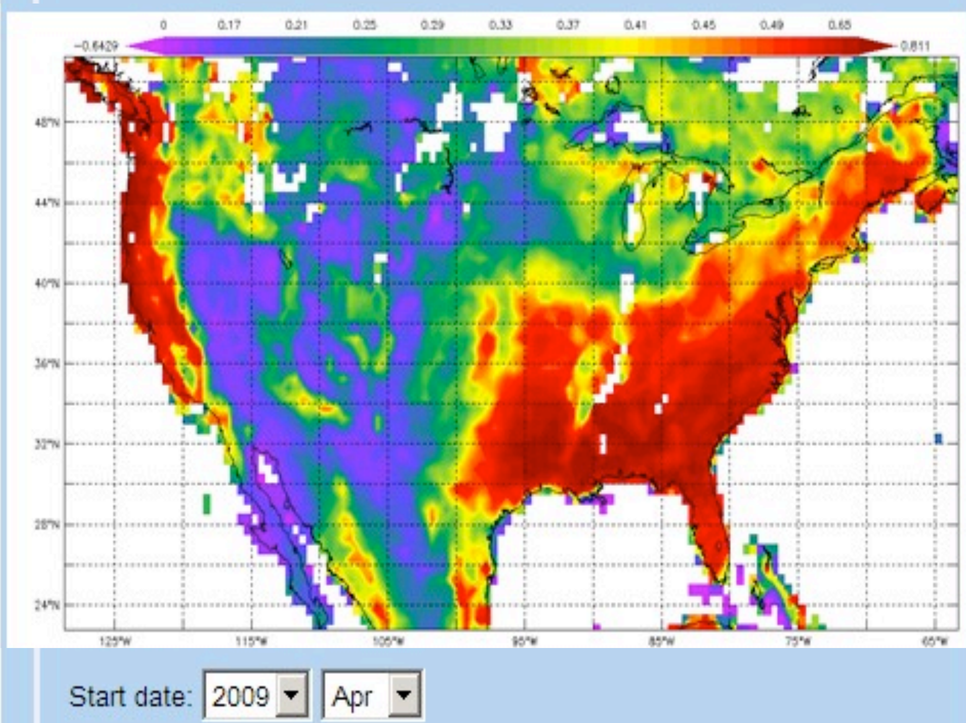
1. Click on the **CHOOSE DATASET** button.
2. Click on **BIOSPHERE.**
3. Choose **MONTHLY NORMALIZED DIFFERENCE VEGETATION INDEX (MISR)**.
4. Under **LINE PLOTS**, click the **TIME SERIES** option.
5. Enter your latitude and longitude into the top and left-hand text boxes under the world map (you can also drag and drop the orange circle on your city).
6. Make sure the **DATE RANGE** covers all the available data (choose the first month/year available for the first date, and the most recent month/year available for the second date).
7. A graph of the monthly NDVI for your location will be generated automatically in the right window (if it does not generate automatically, make sure that you have checked the **UPDATE PLOT** checkbox).
8. Right click on the graph to save the image. Name it "your city" NDVI.jpg
9. Follow steps #5-8 to generate and save the graph of the NDVI data for Concord, Massachusetts.

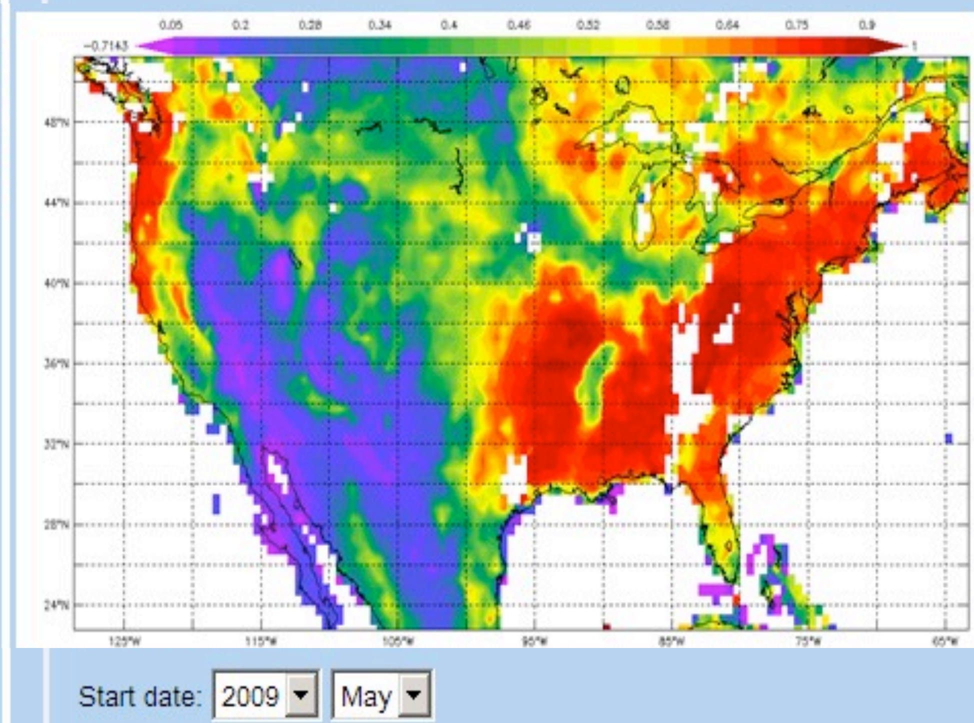
CHICAGO BOTANIC GARDEN




Start date: 2009 Feb


Start date: 2009 Mar


Start date: 2009 Apr


Start date: 2009 May

Teacher Answer Key

Part 1: Meet the Naturalists

1. Describe some of the problems associated with compiling data collected by different individuals over a long time span.

   Different people might pay attention to different aspects of the data, or use different data collection protocols. It would be difficult to determine whether data were comparable.

2. Describe some of the opportunities associated with compiling data collected by different individuals over a long time span.

   You are able to collect data over very long periods of time, beyond one person's individual life-span. This would give you a larger data set and allow you to identify gradual trends that might not be apparent over a shorter time.

3. Think about Project BudBurst, how might the issues raised in questions #2 and #3 affect BudBurst data? What are the positives and negatives for BudBurst, a national project with thousands of participants?

   If you have multiple people collecting data, they can collect more data over a larger region than one person could on their own. BudBurst has data collection protocols, to help guide everyone who is collecting data, but people still might interpret phenophases differently, and collect data that is not comparable.

Part 2: Graphing the Data

A. **Make a Prediction:** If you were to graph the first flowering date of these five plant species, what pattern would you expect to see? Why?

   Answers will vary, but may include:
   - *Bloom dates will be different every year*
   - *Bloom dates will be related to temperature*
   - *Bloom dates will be getting earlier each year, if temperatures are warming*

Teacher Answer Key

B. Refine your Prediction: Describe the graph in Figure 1, below. Use the information in this graph to refine the prediction you made in Part A in the space below the graph.

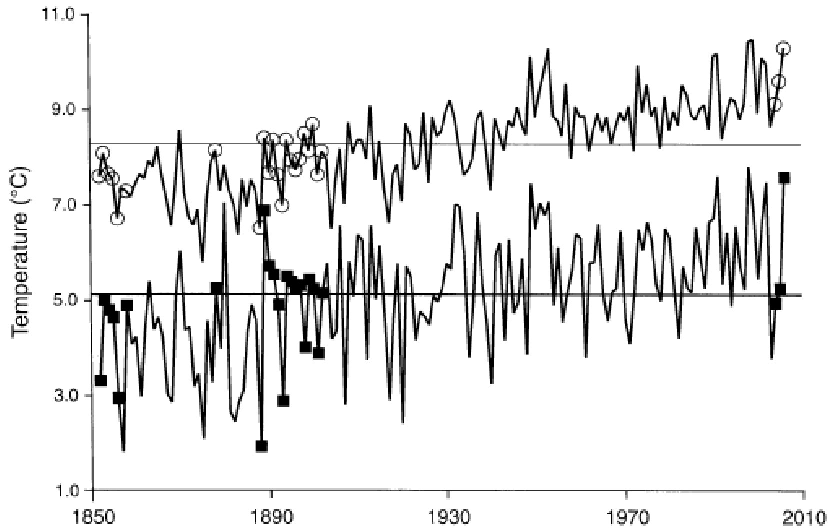


FIG. 1. Temperatures at Blue Hill Meteorological Observatory (33 km southeast of Concord, Massachusetts, USA) from 1852 to 2006. The upper line and open circles represent mean annual temperatures. The lower line and solid squares represent mean monthly temperatures in January, April, and May, temperatures that were highly correlated with flowering times for many species. Horizontal lines show long-term means for each (annual = 8.3°C; Jan, Apr, May = 5.1°C). Circles and squares show years with flowering data.

(From Miller-Rushing and Primak, 2008)

The graph tells us that temperatures have increased in Concord, MA, over the past 60 years, and based on that, I would expect that plants will be blooming earlier in the year

Part 2: Graphing the Data

C. Considering Variables

First flowering date can be influenced by many things, including day length (the number of hours of light vs. dark), precipitation, and temperature.

3. If the first flowering date for your species was primarily influenced by day length, how would you expect the date of first flowering to change between 1852 and 2006?

   You would not expect it to change at all, because day length for a particular time of year does not change from year to year.

4. If the first flowering date for your species was primarily influenced by temperature, how would you expect the date of first flowering to change between 1852 and 2006?

   You would expect it to bloom earlier, because temperatures are getting warmer

Teacher Answer Key

D. Creating the Graph
Graph the date of first flower for the species you have chosen or been assigned by your teacher.

1. Write the scientific name and the common name of your species below.

   Scientific name:_________*Answers will vary*__________

   Common name:_________*Answers will vary*__________

2. Remember, the first flowering dates are shown as numbers, with Jan 1 being the number 1. Just for practice, determine the **calendar date** of day number 111 using a calendar.

   Write the date here:______*April 20 (non-leap year)/April 21 (leap year)*____________

3. Label the X an Y axes to reflect the data you are graphing.
   X should be year (independent variable)
   Y should be flowering date (dependent variable)

4. Next, for each species, determine the **mean** date of first flower, the **maximum** date of first flower, and the **minimum** date of first flower. Add your data to table 1.

Species	Mean	Min.	Max.
Highbush blueberry *Vaccinium corymbosum*	128.9	110	150
Canada mayflower *Maianthemum canadense*	138.4	129	160
Larger blue flag *Iris versicolor*	155.8	143	177
Rhodora *Rhododendron canadense*	133.0	123	143
Downy yellow violet *Viola pubescens*	129.8	111	147

E. Analyzing the Data
After you have completed your graph, answer the following questions:

1. Describe the pattern you see in the data. Did first flowering dates for your species change between 1852 and 2006?

   Answers will vary, but all five data sets trend towards earlier bloom times. The Larger blue flag (Iris versicolor*) has the least obvious trend.*

Teacher Answer Key

2. Did first flowering days for your species get earlier or later? Why do you think this is the case?

   The first flowering date got earlier for all species. While there is variation up and down, overall the flowers bloom earlier over time.

3. Do you think the first flowering date for your species was influenced primarily by day length, temperature, or some other factor? Explain your answer.

   I think it is influenced primarily by temperature. If it were influenced by day length, the bloom dates would not change much from year to year.

4. Primak and Miller-Rushing found that, on average, native plants flowered 2.9 days earlier with each 1 degree Celsius of warming. Using the average first flowering date of the last three years studied as a baseline, when would your species flower if Concord, MA, warmed 5 degrees C. What would be the calendar date for this day? Show your work.

   Sample calculation for the Highbush blueberry:
   3 year average bloom date = (120+116+111)/3 = 115.6
   2.9 (days) x 5 degrees C = 14.5 days
   New bloom date based on a 5 degree C. increase = 115.6-14.5 = 101.1 (round down to 101)
   Calendar date would be April 11 on a non leap year, April 12 on a leap year.

5. Primak and Miller-Rushing found that invasive plants flowered 3.4 days earlier with each 1 degree C. of warming. If an invasive plant had the same baseline first flowering date as your species, when would this species flower if Concord, MA, warmed 5 degrees C. What would be the calendar date for this day? Show your work.

   3 year average bloom date = (120+116+111)/3 = 115.6
   3.4 (days) x 5 degrees C = 17 days
   New bloom date based on a 5 degree C. increase = 115.6-17 = 98.6 (rounded up to 99)
   Calendar date would be April 9 on a non leap year, April 10 on a leap year.

6. Explain why this is might be dangerous for native plants.

   This might be a problem for native plants because if the invasive plants start growing and bloom earlier, they may take resources away from native plants (water) or block the sun and prevent the native plants from growing well.

Teacher Answer Key

7. Do you think the trend you see in your species will be the same with the BudBurst species you are observing? Explain how you might figure out whether your species followed the same trend.

   I will probably see the same trend in my BudBurst species because temperatures overall have been warming. You could figure this out by making many observations over time, or comparing current bloom dates to historical dates, if they were available.

8. What are benefits and risks to plants of flowering earlier in the season?

   One benefit of early flowering might be that the plant will attract pollinators and thus increase the number of seeds produced. A risk might be that if it flowers too early, and there is a cold front, the blooms might be damaged, and produce no seed at all.

Part 3: Explaining the Variation

In this section, you will attempt to explain whether the changes in first flowering day for your species are explained by temperature (mean, maximum, or minimum annual temperature), precipitation, or some other factor.

A. **Prediction:** Of the following four factors: mean annual temperature, maximum annual temperature, minimum annual temperature, or mean annual precipitation, which do you think may explain the variation in first flowering date of the Concord, MA, plant species? Explain your answer.

   I predict that the mean annual temperature will be the best predictor for variation in flowering date because the minimum temperature will not cause plants to grow and the maximum temperature generally is later in the summer, and so wouldn't have an impact on plants that bloom earlier in the spring. I think it is mean temperature and not precipitation because the graphs we made of bloom time show that it is related to temperature and there is no evidence so far that precipitation influences bloom time.

B. **Graphing**: Based on your prediction, select a column from Table 2. The climate variable will represent the independent variable (x-axis) and the first flowering date will represent the dependent variable (y-axis). On the next page, plot the data for each year that you have data for *both* variables.

   Answers will vary depending on the column and species selected.

Teacher Answer Key

Part 3: Interpreting your Graph (cont.)

C. Interpreting your graph

1. Describe the pattern you see in the data. Explain the relationship between the variables (eg: does precipitation influence first flowering date? How do you know?).

   Answers will vary depending on the column and species selected.

2. Do you think the first flowering date for your species was influenced primarily by temperature, precipitation, or another factor such as day length? Explain your answer.

   Answers will vary depending on the column and species selected.

3. Comparing graphs with your classmates, which species seemed to show a strong relationship between temperature and first flowering date? What about between precipitation and first flowering date?

   Answers will vary depending on the column and species selected.

4. How could the information from the study be used?

   Information from the study could be used to predict future flowering dates and, if we had information about other plant and animal species in an ecosystem, how changes in phenology could impact ecosystem survival and function.

Part 4: Project BudBurst and NASA Satellite Imagery

1. In the spaces below, record the first flower or first leaf date of your BudBurst species from the website and Concord, MA, species that you graphed in Part 2:

   Concord, MA, species: ___*Answers will vary depending on the species chosen*_______________

   First flower/leaf date(s):____

   Latitude: ____________________________ Longitude: __________________________________

   BudBurst species:_*Answers will vary*_____ First flower/leaf date:____________

   Your city and state: ____

   Latitude: ____________________________ Longitude: __________________________________

Teacher Answer Key

2. Follow the instructions outlined on the sheet "**How to create maps and graphs using MY NASA DATA Live Access Server,**" **Part 1,** to generate four comparison maps of the monthly normalized difference vegetation index (NDVI) index for 2009 (or the most recent year available) for the United States for the months Jan, Feb, March, and April. Then answer questions A-C below.

   A. Look at all four maps. Which month shows the lowest amount of vegetation? Which month shows the highest? Based on what you know about plants and climate, explain your answers.

      February shows the least overall vegetation and May shows the most. This is because in most places in the U.S. it is still cold in February, but as winter ends and spring begins, the temperatures warm and many plants begin to grow in response to rising temperatures.

   B. Where in the U.S. is there the most plant growth overall (over all four months)? Where is there the least? Based on what you know about plants and climate, explain your answers.

      Over all four months there is the most plant growth in the Southeast. This is because the south is generally warmer (it is closer to the equator) and has more precipitation. There is less plant growth in the southwest because it is dryer, and some areas are desert, where fewer plants are able to grow.

   C. Compare the first bloom dates for your budburst species and your Concord, Massachusetts, species to the four maps. Do the bloom dates appear to fit into the general trends of plant growth over the four-month period? Explain your answer.

      The bloom dates to tend to fit into the larger context of the NDVI satellite images. The Concord MA, species bloom primarily in April and May, when the satellite images show more growth in the northeastern part of the United States.

Teacher Answer Key

3. Follow the instructions outlined on the sheet “**How to Create Maps and Graphs using MY NASA DATA Live Access Server,” Part 2,** to generate graphs of monthly changes in NDVI for the city where your school is located and for Concord using the entire NASA data set from 2002 through the most recent month and year available. Then answer questions A-G below.
   A. Look at the labels on the x and y-axes. Explain what the labels mean. (Hint: look at the scale on the right hand side of the maps you generated.)

      The X axis is the month and year.
      The Y axis is the percentage of sunlight absorbed by plants .

   B. Look at the Concord graph and fill in the following information:
      i. Highest amount of light absorbed ______*almost 74%*______
      ii. Month/year of the highest amount of light absorbed ___*June/July 2003*___
      iii. Lowest amount of light absorbed ______*about 14%*______
      iv. Month/year of the lowest amount of light absorbed ___*Nov/Dec 2003*___

   C. Do the same for the graph of your city:
      i. Highest amount of light absorbed ______*Answers will vary*______
      ii. Month/year of the highest amount of light absorbed ____________
      iii. Lowest amount of light absorbed ____________
      iv. Month/year of the lowest amount of light absorbed ____________

   D. Compare the two graphs and your answers to questions B and C. Do you see any patterns in the graphs? Are they similar? Describe any patterns you see.

      In both cases the most light is absorbed in the summer months, while the least light is absorbed during the winter months. This is because there is less plant growth in the winter than in the summer.

   E. Look at your Concord, Massachusetts, species data on the <u>phenology data table</u>. What date did your plant bloom (remember you will need to covert the day of the year back to the month/date)? How does the bloom time of your plant species compare to the overall monthly changes in vegetation shown on the Concord graph?

      Answers will vary, but a general response should be: my species blooms during the time when plants are beginning to grow, not at the peak of growth.

F. Look at your city's graph. Although the graph does not continue through 2011-2012, based on the pattern, explain how the bloom time of your BudBurst plant compares to the overall monthly changes in vegetation.

Answers will vary depending on the species observed and whether students are observing first leaf of first bloom. Plants that bloom early in the season will align with the Concord data, while those that bloom late in the seaso, may do so at peak green-up, or even as fall approaches.

G. Based on what you know about climate change, what changes might you expect to see in both the maps and the graphs in the future?

Based on what I know about climate change, I would expect that the maps will show increased plant growth earlier in the year, and that this would be reflected in the graphs. The highest NDVI might be earlier in the year, in May/June instead of June/July for example.

