CHICAGO BOTANIC GARDEN

Activity 3.5: Plant Phenology Data Analysis

Grades 7 – 9

Description:

Part 1: Meet the Naturalists: Students will learn the story behind more than 150 years of plant phenology data collected in Concord, Massachusetts. First, students will be introduced to five individuals who collected data in this location.

Part 2: Graphing Historical Data: Students will graph plant phenology data and draw conclusions about how climate and climate change affect plant phenology.

Part 3: BudBurst and NASA Green-up Data: Students will 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: Two sessions

Materials:

Part 1: Meet the Naturalists
- Copies of blank plant phenology data analysis handouts

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: Project BudBurst and NASA Green-up Data
- LCD or overhead projector
- Printouts of NASA NDVI visualization maps and graphs one set per student group.
- 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
- What are some of the challenges of collecting long-term data sets?
- 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?

Assessments

- Meet the Naturalist worksheet
- Predictions worksheets
- Graphs of historical phenology data
- NASA NDVI maps & question responses

Background

Henry David Thoreau began collecting plant phenology data in Concord, Massachusetts, 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 five Concord plant species. Students will use their graphs to draw conclusions regarding how climate change and other factors affect plant phenology.

Part 1: Meet the Naturalists

Procedure

1. Distribute the student handout "Meet the Naturalists." Explain to students that the data they are going to be looking at was collected from plants in Concord, Massachusetts. Have students read over the descriptions of the five naturalists who contributed to the Concord data set. Students can read this information to themselves, in groups, or as a class. (Note: Pennie Logemann's data does not appear in the data set that students receive. However, her data was used by Primak and Miller-Rushing to help draw conclusions about the effects of climate change on flowering dates.)

2. Have students answer the questions on the student work page themselves, and then discuss their answers with a partner, and then with the whole class. The questions focus on problems and opportunities associated with amassing data collected by different individuals over a long time span. These 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. In question 8, students will brainstorm what changes may have occurred in Concord since 1851.

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!

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.

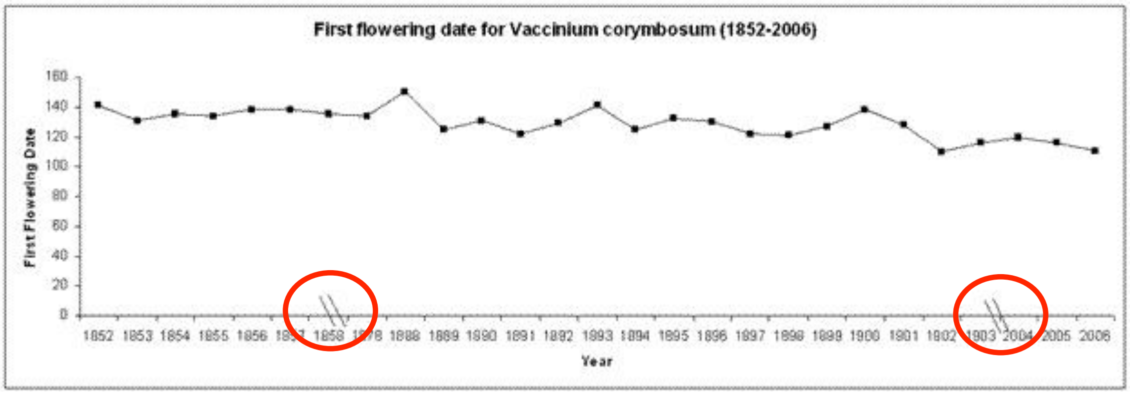
2. Prediction, part 1: Have students make predictions about what patterns they would expect to see if they were to graph the first flowering dates. You may have students share their predictions with a partner or with the class.

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. These graphs show a shift of about 2 degrees Celcius in mean temperature between 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 dates 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, then first flowering dates should be earlier than they were 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 five species. Then, groups can draw their graph on an overhead slide, or create a graph in Excel to share their graphs with the class. Alternatively, 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 20 in a leap year, and April 21 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 (1859–77 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 handout, bring them back together for a class discussion. (Remember, if the graph line 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?
   - Do you think the trend in the Concord data would be the same for BudBurst species? Explain.
   - How might you 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 and for your own observations compare to overall bloom times for all species in each location?

7. Tell students that in part 3, they will look at satellite imagery from NASA that will help them determine whether the recent Concord data, and their own BudBurst observations, are consistent with the bloom times of all plants at these locations.

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 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 more than 1000 species from the Concord study) can be found on the National Phenology Network's website: http://www.usanpn.org/results/dataset-list

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, Massachusetts plants, from the *New York Times:* http://www.nytimes.com/2008/10/28/science/earth/28wald.html?pagewanted=print&_r=0
- "Teaming up with Thoreau," an article about Miller-Rushing and Primack's study of Concord 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 BU: http://people.bu.edu/primack/
- Abraham Miller-Rushing's website: http://www.sercinstitute.org/news/abe-miller-rushing-phenologist

Part 3: Project BudBurst and NASA Satellite Imagery

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, MY NASA DATA, 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 MY NASA DATA 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 full 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, Massachusetts, and an image of the NDVI index for the months of February, March, April, and May are included at the end of the activity.**

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 MY NASA DATA to generate NDVI maps and graphs (http://mynasadata.larc.nasa.gov/las/)
- Print out and make copies of graphs and maps if you plan to have students work from those rather than generate their own.

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 data. Discussion questions might include:
   a. Are the dates close to each other?
   b. 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 data sheet (or you can print out or download their data from the BudBurst Data Viewer), along with the dates of first flower for the Concord species they graphed in Part 2.

4. Tell students they will be comparing their Project Budburst data and the Concord data to data collected by NASA satellites 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**

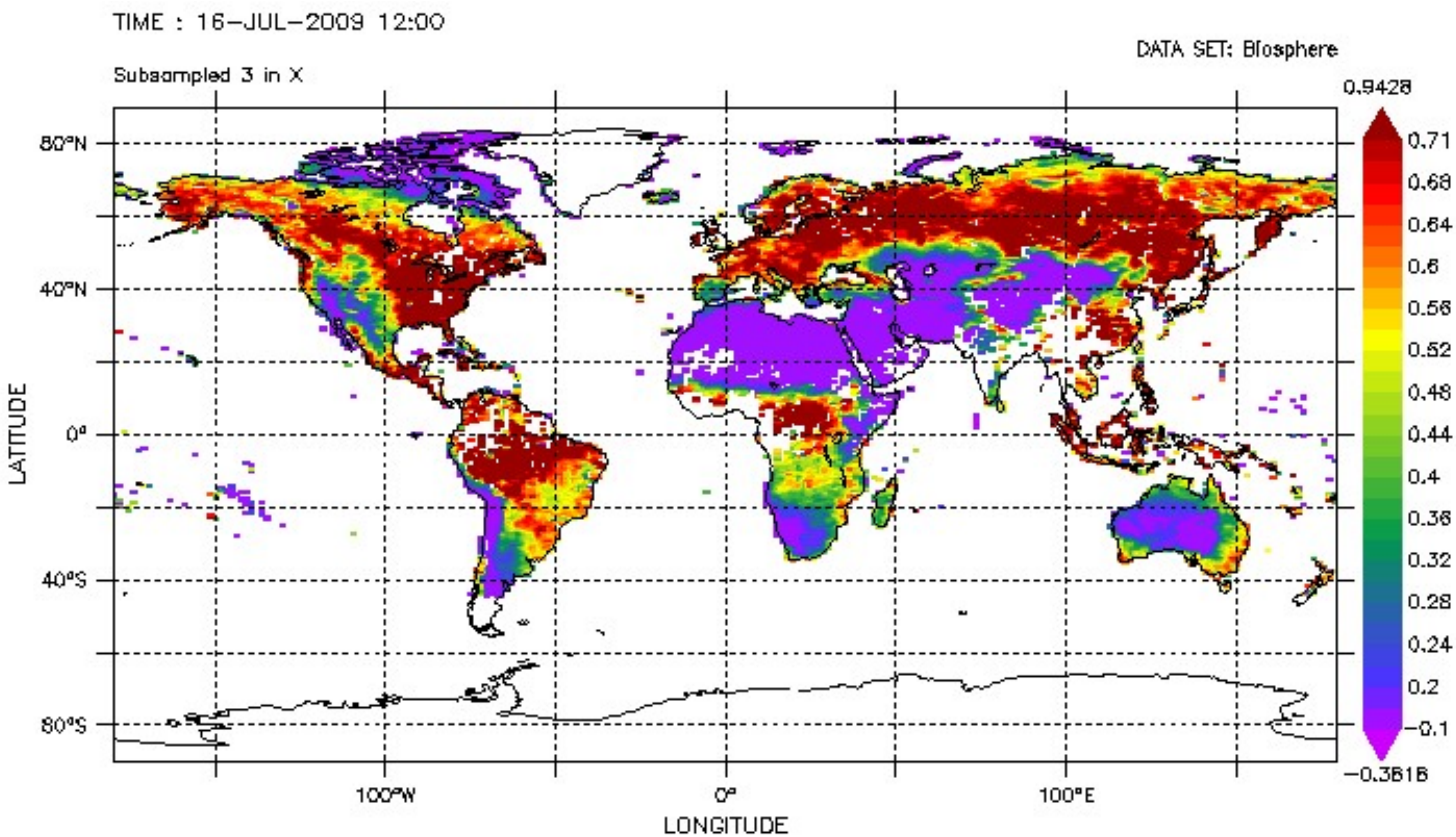
5. Project one of the sample NASA NDVI maps, and discuss what the color key represents (The color scale represents the amount of light absorbed by the plants in that region. **White** indicates there is no light absorption by plants. At one end of the scale, **purple** indicates very low light absorption and as you progress through the colors of the rainbow to red, it indicates

increasing light absorption. **Red** represents the maximum 100 percent light absorption.) Discuss what this means in terms of vegetation. Discussion questions might include:

   a. Why do we see purple and blue (low vegetation) in many parts of the United States in January? (It's winter, so there is little plant growth in the Northern areas.)
   b. What about the places in Africa near the equator that are purple/blue/green? Why might there be low vegetation there? (Desert, drought, etc.)
   c. What about Australia? It's in the southern hemisphere, so it should be summer there.

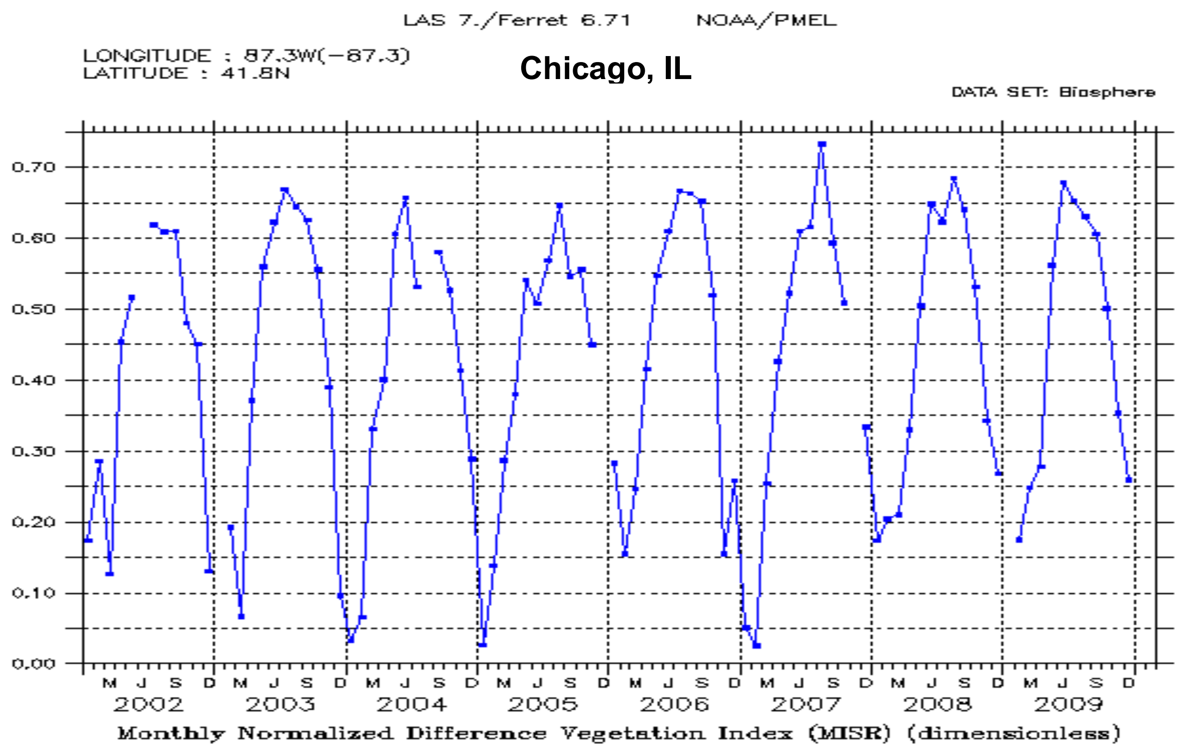
6. Students should understand that NDVI doesn't only vary by season, but also by climate and geography (temperature, precipitation levels, and elevation). You can either go over both maps and make the comparison between winter and summer as a class, or let students figure out the differences as they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

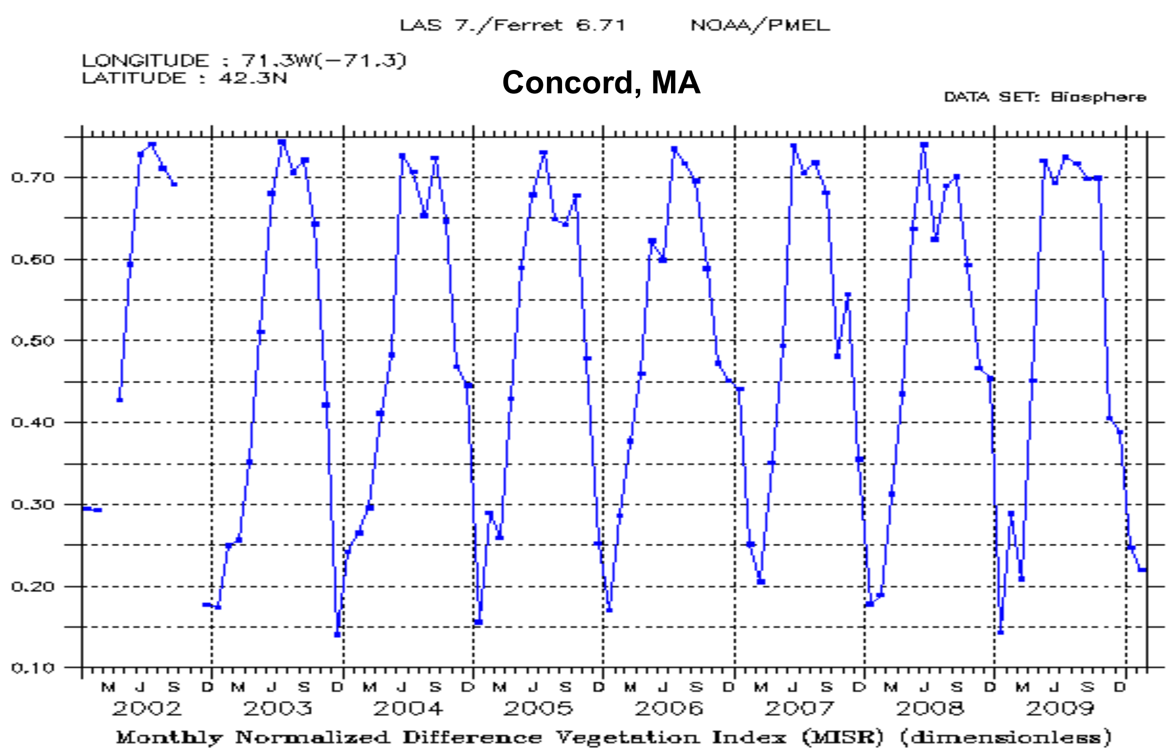
7. Demonstrate how the website works by walking through the first example, and projecting it using an LCD projector. Answer any questions students have. Depending on the ability level of your students you may want to complete the entire data sheet as a class, or break students into groups to complete the data sheet after the first example.



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 over 500 species of plants in Concord Massachusetts. 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.

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 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 classes to college students on plant biology and conservation biology. He also researches the effects of climate change on plant flowering in Concord, Massachusetts, and in Japan and South Korea. Primack has studied plant flowering in Concord 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 from 2003 to 2008 to study how plant flowering in Concord has changed over time.

Name ___________________________________Teacher/Class _______________________

Questions:

1. Why do you think these individuals all kept records of the first flowering dates of plants?

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

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

4. 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, Massachusetts, 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

Name ____Teacher/Class __________________________

Prediction, Part 1: If you were to graph the first flowering date of these five plant species, what pattern would you expect to see? Why?

Figure 1: Temperatures near Concord, Massachusetts, from 1852 to 2006.

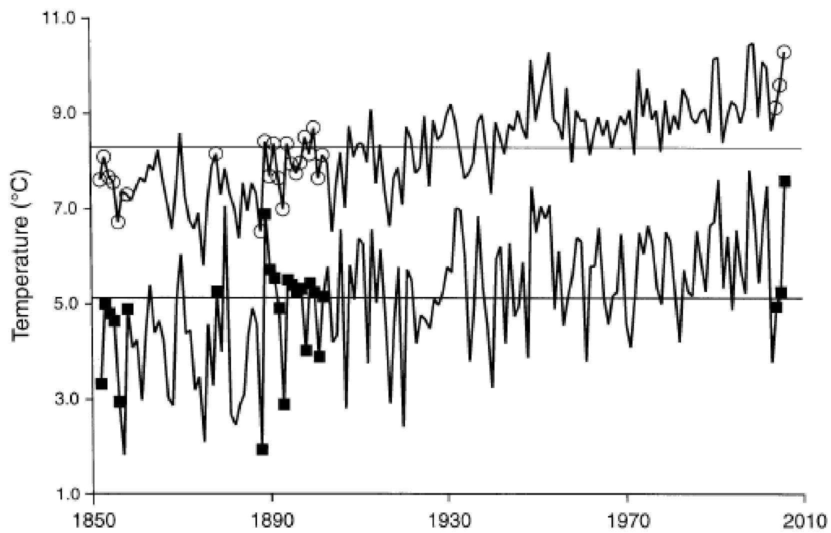


FIG. 1. Temperatures at Blue Hill Meteorological Observatory (33 km southeast of Concord, Massachusetts, USA) from 1852 to 2006. The upper line and open circles represent mean annual temperatures. The lower line and solid squares represent mean monthly temperatures in January, April, and May, temperatures 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)

Prediction, Part 2: Describe the graph in Figure 1, above. Focus on just the top curve, which shows average (mean) yearly temperatures for Concord. Use the information contained in this graph to refine the prediction you made in Part 1.

Name ____________________________________Teacher/Class ________________________

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.

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

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

Graphing the Data

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

Name ___________________________________ Teacher/Class _______________________

Name ___________________________________Teacher/Class _______________________

After you have completed your graph, answer the questions below:

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?

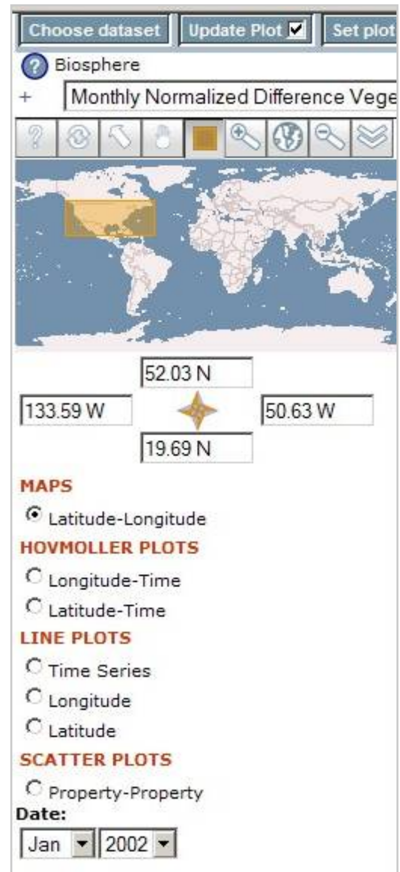
3) Do you think the first flowering date for your species was influenced primarily by day length, temperature, or some other factor? Explain your answer.

4) 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.

5) **Brainstorm:** What are benefits and risks to plants of flowering earlier in the season?

Part 3: Creating Maps using MY NASA DATA Live Access Server

Part 3.1: 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/
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 4 identical maps. Under each map you can select the month and year. Modify the months, so that you can see Feb, Mar, Apr, and May of 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 data sheet. Once you have answered the questions, move on to Part 3.2.

Part 3.2: Creating Graphs using MY NASA DATA Live Access Server

Part 3.2 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.

Part 3: 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, Massachusetts, 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: _________________________

1. Follow the instructions outlined on the sheet "**How to create maps and graphs using MY NASA DATA Live Access Server,**" **Part 3.1,** to generate four comparison maps of the monthly normalized difference vegetation index (NDVI) index for 2009 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.

   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.

2. Follow the instructions outlined on the sheet **How to Create Maps and Graphs using MY NASA DATA Live Access Server," Part 3.2,** 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:
      v. Highest amount of light absorbed ______________________________________
      vi. Month/year of the highest amount of light absorbed _____________________
      vii. Lowest amount of light absorbed ______________________________________
      viii. 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.

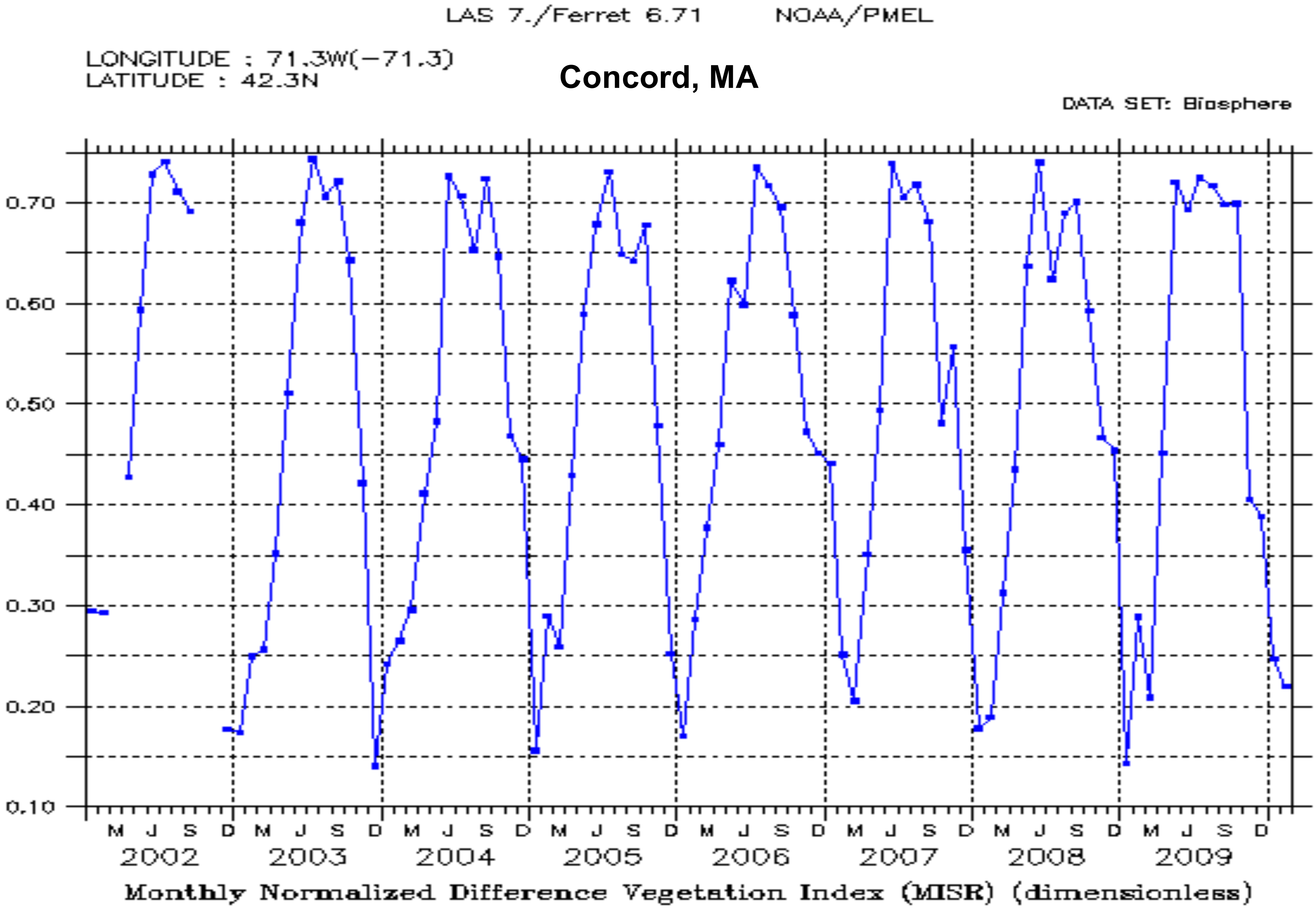
3. Look at your Concord, Massachusetts, species data on the phenology data table. What date did your plant bloom (remember, you will need to covert the day of the year back to the month/date)? How does the bloom time of your plant species compare to the overall monthly changes in vegetation shown on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

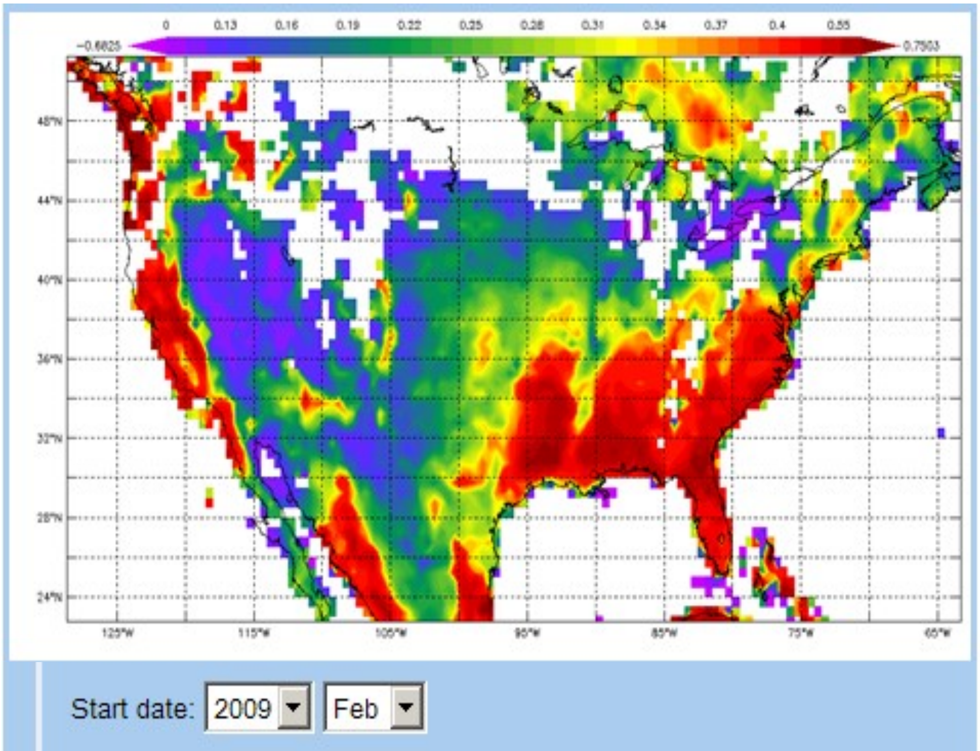
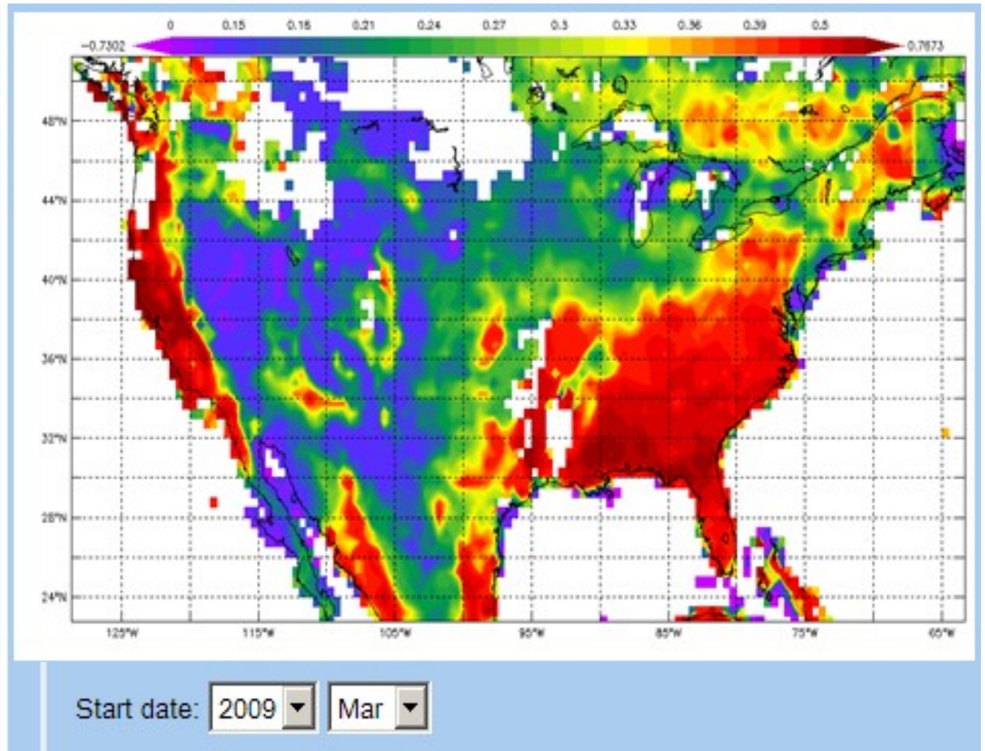
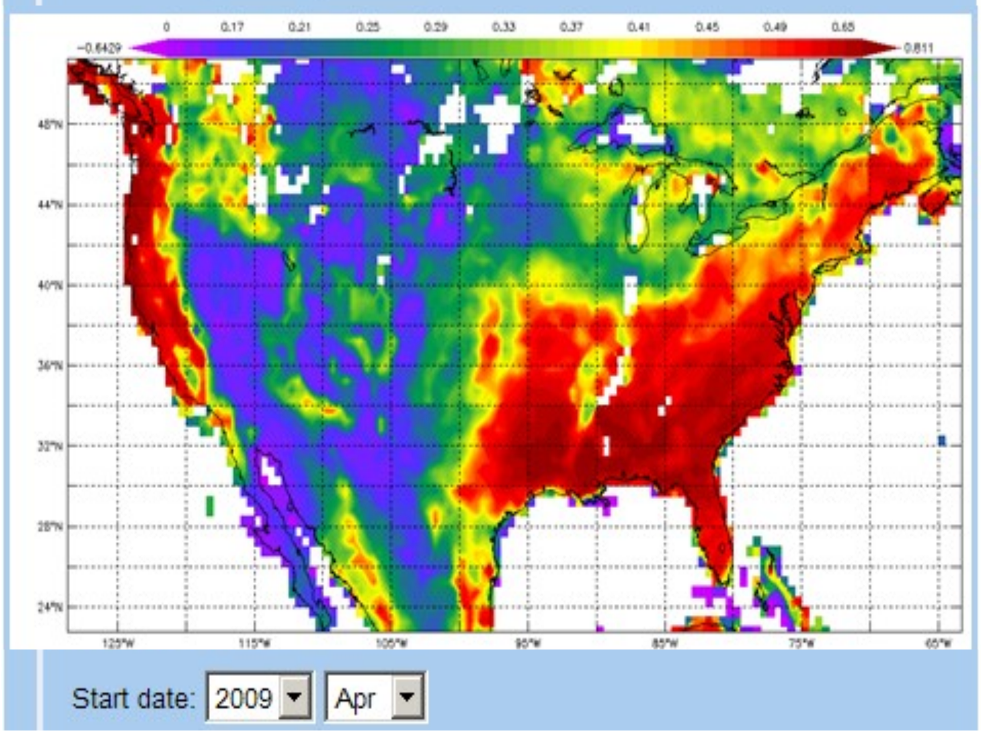
4. Look at your city's graph. Although the graph does not continue through 2011–2012, based on the pattern, explain how the bloom time of your BudBurst plant compares to the overall monthly changes in vegetation.

5. 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?

CHICAGO BOTANIC GARDEN

Concord, MA




Start date: 2009 Feb

Start date: 2009 Mar

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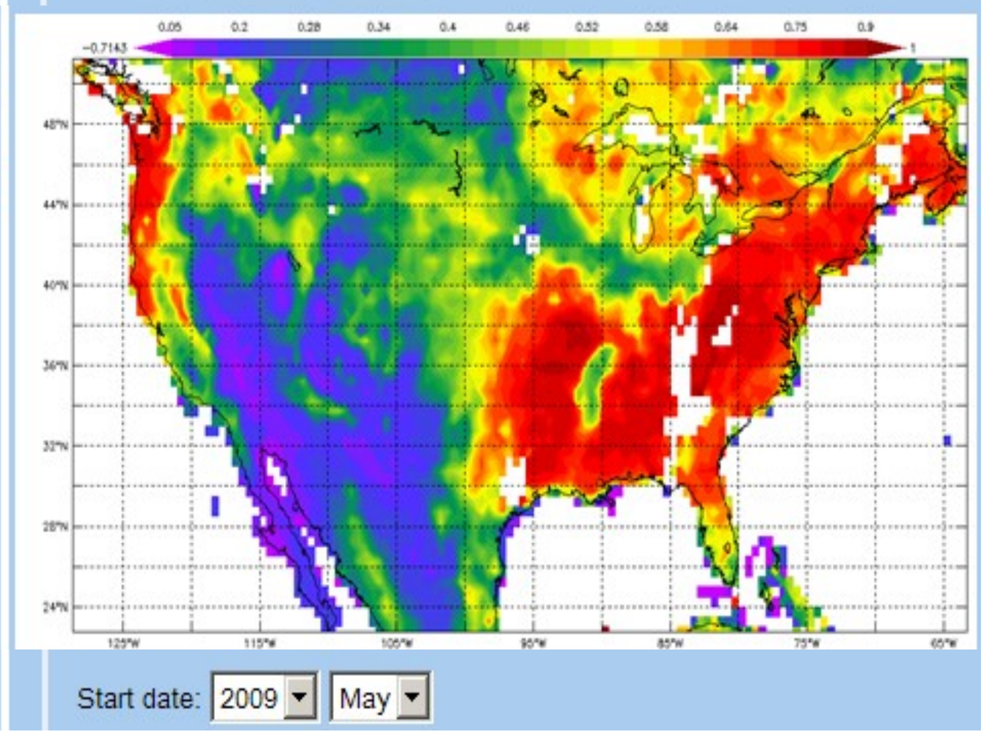
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