Budburst Protocol

Purpose

To observe budburst on selected trees at a Land Cover Sample Site, or a designated Phenology Site

Overview

In places where there are trees, students will select at least two trees and observe when budburst occurs.

Student Outcomes

Students will be able to,

- observe when buds burst open at the beginning of the growing season;
- examine relationships between budburst and climate factors;
- communicate project results with other GLOBE schools;
- collaborate with other GLOBE schools (within your country or other countries);
- share observations by submitting data to the GLOBE archive;
- compare phenological patterns among species; and
- predict the timing of budburst for upcoming seasons (advanced).

Science Concepts

Earth and Space Sciences

Weather changes from day to day over the seasons.

The sun is a major source of energy at the Earth's surface.

Life Sciences

Organisms can only survive in environments where their needs are met.

Organisms' functions relate to their environments.

Organisms change the environment in which they live.

Plants and animals have life cycles.

Energy for life derives mainly from the sun.

Living systems require a continuous input of energy to maintain their chemical and physical organizations.

Scientific Inquiry Abilities

Estimate dominant plant species.

Identify plant species (advanced).

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Time

Selection of site and trees (not including times to and from site): 1 hour

Daily visits (not including times to and from site): 15 min

Level

All

Frequency

Initially, twice a week beginning two weeks prior to anticipated budburst. After leaves start to emerge, daily visits until budburst is observed.

Materials and Tools

Budburst Data Sheet

Budburst Site Definition Sheet

Budburst Site Definition Field Guide

Budburst Field Guide

GPS Protocol Field Guide (if using a new site)

GPS Protocol Data Sheet (if using a new site)

Binoculars (optional)

GPS receiver (if using a new site)

Local tree identification guide

Preparation

Review how to determine the dominant tree species in a *Land Cover Sample Site* in the *Land Cover/Biology Investigation.*

Familiarize students with the local tree identification guides.

Prerequisites

None

Teacher Support

Who can do the Budburst Protocol?

First, you must decide if you live in an area appropriate for the GLOBE *Budburst Protocol*. You must live in an area with trees. Both deciduous and evergreen trees have buds, so either type may be used. Areas dominated by shrub and bush vegetation also have phenology, but the annual patterns are so variable that accurate monitoring takes more time. If you live in a tropical area with a normally warm and wet climate, your vegetation may not have strong annual vegetation cycles. However, if you have a distinct dry season and most of the vegetation loses its leaves during the dry season, you should definitely participate. You probably live in the part of the world for which we have a very poor understanding of vegetation phenology.

Budburst is one of three plant phenology protocols. For a discussion on which protocol is more appropriate for your class, please look at the *Measurement Logistics* section in the *Introduction* section to the *Phenology Protocols.*

Site Selection

For your site selection, you have different options.

1. A convenient option would be to use a preexisting Land Cover Sample Site if frequent observations at such a site are practical.
2. Create a new Budburst Study Site. Since students will need to make many visits to the site, we suggest you select a site close to your school or to where students live. You may use your school grounds or any other site that includes native trees that are minimally watered or fertilized. Identify the latitude, longitude and elevation following the GLOBE *GPS Protocol*.

You want to observe trees that are as close to the general vegetation as possible. If you live in an area where most of the trees are watered or fertilized, then observing an irrigated tree is fine. However, if most of the trees are growing without irrigation, do not pick a watered tree for study.

Since the results of this protocol will be combined with temperature and precipitation data from the GLOBE *Atmosphere Investigation,* try to choose a site close to the Atmosphere Study Site.

Tree Selection at Your Site

Budburst measurements are quick and easy. Consequently, you can either take just a few minutes a day to make observations or you may try to design a more in-depth investigation. Based on your available time and interest, select one of the following three measurement strategies:

1. Budburst for the dominant overstory species.
If you are using a Land Cover Sample Site, select the dominant tree species in the canopy. If you are using a new site, visually inspect the canopy and estimate which species is dominant. Estimate coverage when plants are in full leaf. If you are selecting a site when leaves are not full, do the best you can to estimate which tree species would have the most canopy coverage. If you are in an area where two or more species are equally dominant, chose one of the species and record this information as metadata in the comments section in the *Budburst Data Sheet*.

2. Budburst for more than one overstory species.
If you would like to study the phenological patterns of different species, additional trees may be identified for budburst analysis.

3. Budburst for overstory and/or understory species.
In many forests or parks, there are two levels of woody plants (like trees or shrubs). Woody plants living underneath the highest layer of trees are called the understory. They often have a very different phenological cycle than do overstory plants. These understory plants, which may be shrubs or small trees, can also be measured. If your shrub or tree is living underneath the top layer of trees, it is considered to be an understory plant. This information should be entered in the metadata section of your *Budburst Site Definition Sheet*. The phenological difference between understory and overstory vegetation is scientifically important and schools are encouraged to measure both if possible.

Once you have decided on the measurement you wish to take, you need to decide which trees to observe. Observe at least two trees and numerically label each tree. The trees you select should meet several criteria:

- Trees should be easily accessible.
- Ideally, individual buds should be visible with the naked eye. Otherwise, binoculars may be used to observe the individual buds.
- If possible, select native tree species. Non-native species, called exotics, have phenological cycles that are not necessarily tied to the local climate. Fruit trees are a classic example. You may have heard on the local news that a late spring frost ruined a fruit crop in your area. Often this is because exotics have not evolved to survive in the local climate. If you are unsure which plants are natives, ask your teacher, a local greenhouse or agricultural extension agent, or the appropriate staff at a local college or university.

Measuring Budburst

The timing of budburst on individual branches can vary by several days within one tree. High branches also can be difficult to see. For these reasons, using the steps below, you will record the date on which budburst has occurred on at least three different areas of the tree.

- Since budburst is highly variable from year to year, you will need to start monitoring well before the average date of budburst. Ask a biology teacher or someone from your local community if they have any record of budburst for your area. You can try contacting local horticultural societies, or college or university biology departments. The date does not need to be exact. You are just trying to establish when, on average, leaves begin to appear.
- In the spring, two weeks or more before the average date of budburst, the entire class or at least all students who will be taking measurements, should visit the Budburst Study Site to determine which trees to monitor.
- Make trips to your site initially twice a week. Look at the buds all over the tree. Do the buds appear to be swelling or have any of the buds burst open? Can you see signs of tiny leaves emerging from inside the bud? If so, this is the beginning of the overall tree budburst and you should start visiting the site every day. When you have noticed three separate locations on the each tree where budburst has occurred, enter this as the date of budburst on the *Budburst Data Sheet*. Three buds on one branch do not count; you are looking for three different parts of the tree where budburst has happened. You should have one date for each tree.
- Budburst observations can be made at any time during the day.

Managing Students

It is very important that someone visits the site at least twice a week until budburst begins to occur. After this, make observations every day in order to accurately estimate the day when three parts of the tree have experienced budburst. Depending on how rapidly budburst occurs, this could mean many visits to the site; sharing this responsibility among several students should make this easier to accomplish. Try to make a schedule so that students can take turns visiting the site with their parents or another adult if necessary. This will lessen the chance of not visiting the site often enough. By reporting the date of the last observation before budburst occurred, everyone using your data will know how many days are missing (if any) immediately preceding the date of budburst and therefore of the time interval when budburst occurred.

Frequently Asked Questions

1. What happens when the tree I am observing is cut down or dies?

If a tree dies or is cut down, select another tree of the same species. Identify the new tree with the next number in your labeling sequence, for example, ‘tree 3’. Record the changes in tree selection as metadata.

2. Can we record more than one budburst measurement for the same Budburst Study Site?

Yes, as long as all the trees are within a 30 m x 30 m area you may use the same Budburst Study Site for all the trees. If you are observing trees outside a 30 m x 30 m area you will need to define another Budburst Study Site.

3. What is meant by three separate locations on each tree?

The purpose of this requirement is to avoid recording budburst of a single bud that does not represent the overall phenological development of the tree. You need to wait until you see at least one individual budburst on three separate places on the tree. Three budbursts on one branch does not count. Beyond this, you do not need to worry about height of the branches, orientation, or shading.

Budburst Site Definition
Field Guide

Task

To select one or more native trees in the canopy, identify the species and locate the latitude, longitude and elevation. Trees or shrubs in the understory can be selected too.

What You Need

- ❑ GPS receiver
- ❑ *GPS Field Guide*
- ❑ *GPS Data Sheet*
- ❑ *Budburst Site Definition Sheet*
- ❑ Pen or pencil
- ❑ Local tree identification guide
- ❑ Flagging Tape

In the Field

1. Fill out the top part of the *Budburst Site Definition Sheet.*
2. Use the GPS receiver and *GPS Data Sheet* to identify the latitude, longitude and elevation. You do not need to do this if using a defined Land Cover Sample Site.
3. Identify the dominant tree species. Record the genus and species.
4. Put flagging tape on the trees you selected.
5. Complete the comment section on the *Budburst Site Definition Sheet.*

Budburst Protocol
Field Guide

Task

To observe budburst on three locations on your tree

What You Need

- ❑ Binoculars (optional)
- ❑ Pen or pencil
- ❑ *Budburst Data Sheet*

In the Field

1. About two weeks before budburst visit Budburst Site and observe selected trees. Record date. Are there tiny green leaves emerging anywhere on one or both trees?
   a. If yes, start to observe trees each day. Go to step 2.
   b. If no, continue to visit site twice a week.
2. Each day observe trees until budburst can be seen on three locations in each tree. Record dates.

Budburst Protocol –Looking at the Data

Are the data reasonable?

Even though the timing of budburst varies among years, budburst occurs when trees sense temperature or moisture conditions that act as signals or “triggers”. In other words, the trees respond to the local environmental and not to the dates on a calendar. Moisture and temperature will affect the timing of budburst.

Budburst tends to show some general patterns that you can use to assess whether or not your data are reasonable. In general, budburst can vary by about one month from year to year. If your school records indicate that budburst occurred on March 1 in one year and June 30 in the next, this indicates a possible data entry error. For the same species, trees growing farther north tend to have a later budburst than more southern trees (for the northern hemisphere). Microclimates can also affect budburst. Trees on the north side of buildings or in topographic low spots will probably experience colder temperatures and be characterized by a later budburst. By setting up your own budburst measurements, you can test these kinds of phenomenon.

What do scientists look for in the data?

GLOBE data will be used to better understand how satellite data correspond to real ground conditions. Additionally, by using your observations of budburst along with your temperature and precipitation data, scientists will be able to accomplish several objectives. After mapping the annual dates of budburst across the continents and establishing weather patterns that control phenology in your area and across the world, scientists can examine the relative importance of temperature and moisture on the beginning of the growing season. Eventually, scientists will be able to map areas of the world where the growing season is controlled by temperature and where it is controlled by moisture. Over time, scientists will develop a better understanding of how global vegetation responds to inter-annual climate variability. This understanding of plant phenology is a critical component of computer models of the global climate system.

Here is an example of how scientists investigate the relationship between timing of budburst and climate conditions. To do this, you need the temperature and precipitation data preceding budburst so that you can estimate the amount of moisture available for the trees and how warm the conditions are.

Estimating Warming Conditions: Calculating Growing Degree Summation:

Many plants in different areas of the world require a set amount of warming to initiate growth and to minimize their risk of frost damage. Growing degree summation (GDS) is a common measure of warming used by scientists. For this method, you will need the maximum and minimum temperature data for your school from January 1st (if you live in the northern hemisphere) or July first (if you live in the southern hemisphere) up to and including the date of budburst. To calculate GDS:

1. First, for each day, calculate the daily average temperature (Tavg) by adding the maximum and minimum temperature for each day and dividing by two beginning on January 1 in the northern hemisphere and July 1 in the southern hemisphere.
2. Starting with January 1 or July 1, check to see if Tavg is greater than 0˚ C. If it is, record this temperature. If not, ignore it. Go to the next day. Again, check to see if the (Tavg) is greater than 0˚ C. If it is, add it to the temperature you recorded for the first. If not, again ignore it. Repeat this process for each subsequent day up to the day of budburst. The sum of the positive average temperatures is your GDS. Record value in Table EA-BB-3 on your *Work Sheet.*

For example, look at the following series of temperatures and the summation that would go with them:

Tavg (0˚ C):	-3	-2	2	3	-1	5	6
GDS:	0	0	2	5	5	10	16

Calculating Moisture Availability

Moisture availability is often measured by comparing the input of water to the surface with the amount of water that could leave the surface. In other words, inputs are compared with outputs. If inputs exceed potential outputs, the environment is moist. On the other hand, if potential outputs are much larger than inputs, drought conditions exist. The precipitation (both solid and liquid) measured at your school is the input. Outputs are evaporation and transpiration. Transpiration is the process of water loss from plants while they absorb CO_2 for photosynthesis. The sum of evaporation and transpiration is called **e**vapo**t**ranspiration, or ET. ET can be accurately estimated using fairly complicated equations. For this activity, a reasonable estimate can be made using a very simple method to calculate a related quantity: the potential amount of water that could leave the surface under the observed temperature and precipitation conditions. This is called **p**otential **e**vapo**t**ranspiration, or PET. The following steps show you how to calculate the input, output and moisture availability.

Inputs

1. To calculate inputs, you need to sum the daily precipitation values for the 29 days prior to budburst and the day of budburst (a total of 30 days). This includes the rainfall and the liquid-water equivalent of new snow. You can record your values for the 30 days in Table EA-BB-2 in the student data work sheet. Record the total value in Table EA-BB-3.
2. If snow was on the ground at the time of budburst, then you need the liquid-water equivalent of the total snow depth. Record the value in Table EA-BB-3.
3. If snow was on the ground on the 29th day before budburst, you need a measurement or estimate of the liquid-water equivalent of the snow pack for that day. This can be done easily by making a linear interpolation between the two dates closest to the 29th day before budburst. On a piece of graph paper plot the two known values; the date is on the x-axis, the water equivalent in mm is on the y-axis. Draw a straight line between the two points. Locate the date needed and find the corresponding y-value on the line. This will give you an estimate of the liquid-water equivalent of the snow pack for the 29th day prior to budburst. Enter the value in Table EA-BB-3.
4. Total input of water = sum of the rain + sum of the water equivalent of new snow + water equivalent of snow pack on the 29th day prior to budburst - water equivalent of snow pack on the day of budburst. Record the result of your calculation in Table EA-BB-3.

Outputs:

To estimate potential evapotranspiration (PET), we will rely on the concept that for a given temperature, air can only hold a certain amount of water. Warmer air can hold more water. This means that under warm conditions, PET is higher than under cold conditions. In reality, PET also depends on the amount of solar radiation, but we can still obtain useful estimates using only temperature. Table EA-BB-1 includes calculations of PET based on your measured temperature and a simple mathematical model.

1. Once you have detected budburst, use Table EA-BB-1 to get PET. For the day of budburst, find Tavg in Table EA-BB-1. Then look in the column to the right. This is PET in mm per day. Record this value with its corresponding date in Table EA-BB-2 on the student work sheet. Since plants respond to long-term moisture trends, record PET for the 29 days prior to budburst so that you have a total of 30 values of PET.
2. Sum the PET values for the 30 days recorded in Table EA-BB-2. Enter the 30-day total in Table EA-BB-3.

Water Difference:

1. Subtract the PET total from either the precipitation total or the total water inputs, if the liquid-water equivalents of snow pack are part of your calculations. We will call this the water difference (WD). If WD is positive, this indicates wet conditions. Negative WD values suggest dry conditions.
2. Record the value in Table EA-BB-3.

Table EA-BB-1

Tavg (˚C)	PET (mm)	Tavg (˚C)	PET (mm)
-20	0.15	16	2.3
-19	0.16	17	2.4
-18	0.18	18	2.5
-17	0.19	19	2.7
-16	0.21	20	2.9
-15	0.23	21	3.0
-14	0.25	22	3.2
-13	0.27	23	3.4
-12	0.30	24	3.6
-11	0.32	25	3.8
-10	0.35	26	4.0
-9	0.38	27	4.3
-8	0.42	28	4.5
-7	0.45	29	4.7
-6	0.49	30	5.0
-5	0.54	31	5.3
-4	0.58	32	5.6
-3	0.63	33	5.9
-2	0.68	34	6.2
-1	0.74	35	6.5
0	0.8	36	6.9
1	0.9	37	7.2
2	0.9	38	7.6
3	1.0	39	8.0
4	1.1	40	8.4
5	1.1	41	8.9
6	1.2	42	9.3
7	1.3	43	9.8
8	1.4	44	10.3
9	1.5	45	10.8
10	1.6	46	11.3
11	1.7	47	11.9
12	1.8	48	12.4
13	1.9	49	13.0
14	2.0	50	13.7
15	2.1		

Budburst Data Analysis

Work Sheet

List of Abbreviations:

GDS: growing degree summation

PET: potential evapotranspiration

Tavg: average temperature

WD: water difference

Observations:

GDS: The summation of values (temperature values above 0° C) between and including January 1 (northern hemisphere) or July 1 (southern hemisphere) and the day of budburst If the difference in elevation between your Atmosphere and Phenology Sites is greater than 500 meters, then you need to add a correction factor. This is 6° C for every 1000 meters (colder at higher elevations). For instance if the budburst site is 500 meters higher than the closest atmosphere site, you would subtract 3° C for each day with a value above 0° C and then sum all the new values above 0° C. Table 2 can be used for calculating PET and precipitation. The totals are the summations of the values for 30 days (29 days before budburst and the day of budburst). Tavg for each day is the sum of the daily maximum and minimum temperatures divided by 2. It may be easier to start with the day of budburst and work backwards for the 30 days.

If you have calculated the water equivalent of snow pack in the *Solid Precipitation Protocol* in the *Atmosphere Investigation*, you need the values of the water equivalents of the snow pack for the day-of budburst and the 29th day before budburst for each branch.

Total Water Inputs = Precipitation, *or*

= Precipitation + water equivalent 29th day prior - water equivalent at budburst

Water Difference (WD) = Total Water Inputs - PET

Table EA-BB-2

Day	Tavg (° C)	PET (mm)	Precipitation (mm)
Total	no total needed		

Table EA-BB-3: Phenology Data

					Water Equivalent of Snow Pack				
Tree	Budburst Date (YYYY/MM/DD)	GDS (° C)	PET (mm) A	Precipitation (mm) B	Start (-29 days) (mm) C	End (at budburst) (mm) D	Total Inputs (mm) E (B+C-D)	WD (mm) B-A or E-A	Missed Observations (days)

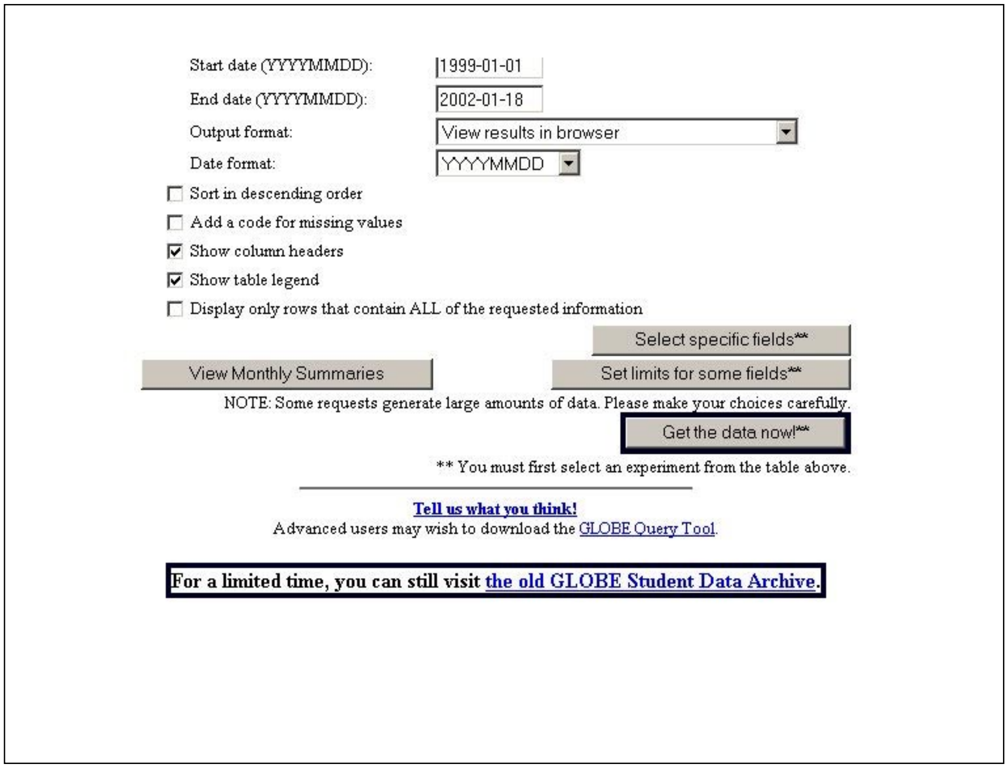
An Example of Student Research

Students in an Earth science class were assigned to do a project on phenology. So far, their class had not collected budburst data, but they intended to start this spring. To better understand the relationship between climate factors (particularly, temperature, precipitation and budburst), they decided to look at GLOBE data on the Web site. They predicted that budburst will occur earlier in warmer years and that it will occur earlier in years with more moisture. They first searched for a school on the Web site that had collected budburst data as well as consistently collected temperature and precipitation data so that they can estimate the warming conditions and moisture availability.

The students went to the data access page and selected "phenology" and entered the dates Jan. 1, 1999 and Jan. 1, 2002, as shown below:

Select an investigation, then press "Select specific fields" to specify the types of data you wish to retrieve, or press "Get the data now!" to get a pre-selected set of columns. [Help]

Investigation	First Measurement*	Last Measurement*	Measurements*	Schools*
All Measurements	1995-01-01	2002-01-27	7351385	5098
Atmosphere	1995-01-01	2002-01-27	6390075	4529
Air Temperature	1995-01-01	2002-01-27	2449014	4050
Cloud Observations	1995-01-01	2002-01-27	1777947	4411
Liquid Precipitation	1995-01-01	2002-01-27	1053441	4019
Solid Precipitation	1995-01-01	2002-01-27	1055716	3421
Humidity	1995-02-02	2002-01-27	33329	363
Ozone	2000-08-16	2002-01-24	4294	19
Aerosols	2000-07-02	2002-01-22	2649	9
Barometric Pressure	1995-02-02	2002-01-27	13685	189
Surface Water	1995-01-02	2002-01-26	638909	1806
Soil Moisture	1995-02-21	2002-01-25	58823	215
Soil Moisture (profile)				
Soil Moisture (by depth)				
Soil Temperature	1997-01-01	2002-01-26	71806	205
Soil Temperature (profile)				
Soil Temperature (by depth)				
Soil Characterization	1998-05-18	2002-01-23	10308	156
Soil Infiltration	1997-02-17	2001-11-24	1910	26
Land Cover/Biology	1995-04-19	2002-01-25	115827	642
Tree Biometry	1995-04-23	2001-11-26	42702	500
Grass Biometry	1995-05-16	2001-11-26	69716	238
Land Cover	1995-04-19	2002-01-25	3409	345
Phenology - Budburst	1998-03-30	2001-10-12	2021	100
Phenology - Lilacs	2000-03-25	2001-08-21	251	20
Lilacs (Common)				
Lilacs (Clonal)				
Green-up/Green-down	1999-09-26	2001-12-06	6048	18
Green-up	1999-09-26	2001-12-06	6048	18
Green-down	1999-09-26	2001-12-06	6048	18
Site Location	1996-10-19	2002-01-27	19749	2446
Go **Site Photos** Site photos are viewed using the GLOBE Site Photo viewer.	1995-04-19	2001-10-29	2031	98
[Metadata]	1995-05-01	2002-01-25	35658	2165



Start date (YYYYMMDD): 1999-01-01
End date (YYYYMMDD): 2002-01-18
Output format: View results in browser
Date format: YYYYMMDD

- [ ] Sort in descending order
- [ ] Add a code for missing values
- [x] Show column headers
- [x] Show table legend
- [ ] Display only rows that contain ALL of the requested information

Select specific fields**
View Monthly Summaries
Set limits for some fields**

NOTE: Some requests generate large amounts of data. Please make your choices carefully.

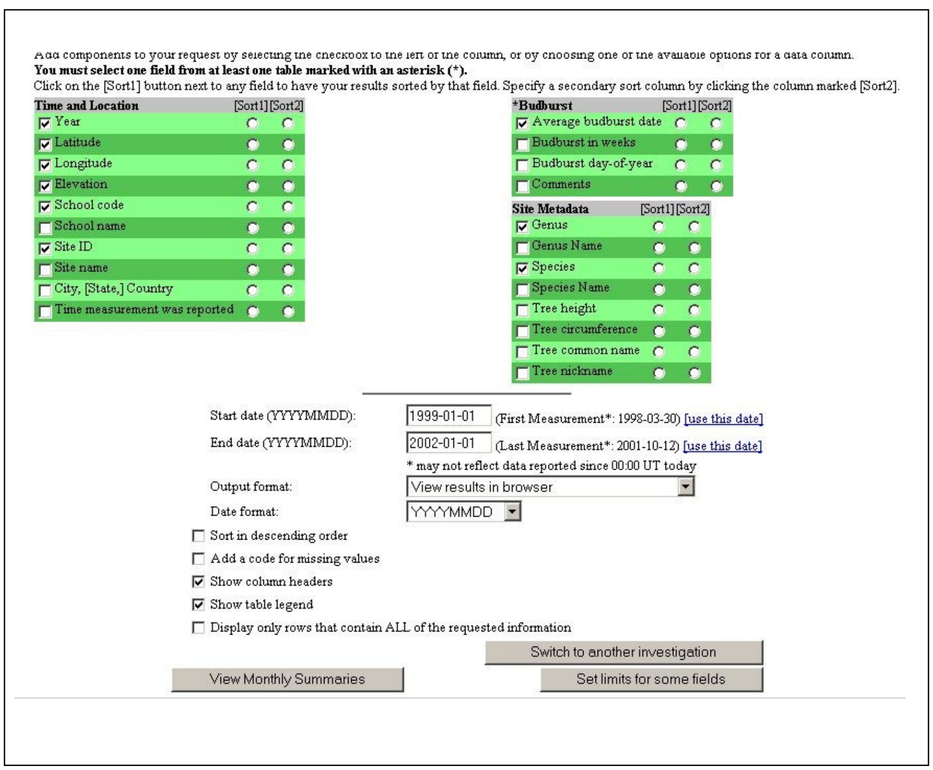
Get the data now!**

** You must first select an experiment from the table above.

Tell us what you think!
Advanced users may wish to download the GLOBE Query Tool.

For a limited time, you can still visit the old GLOBE Student Data Archive.

They then clicked on the "select specific fields" and a new page came up. The top of the web page was the same as before. However, the bottom of the page had different options from which to choose.



Add components to your request by selecting the checkbox to the left of the column, or by choosing one of the available options for a data column.
You must select one field from at least one table marked with an asterisk (*).
Click on the [Sort1] button next to any field to have your results sorted by that field. Specify a secondary sort column by clicking the column marked [Sort2].

Time and Location	[Sort1]	[Sort2]
[x] Year	○	○
[x] Latitude	○	○
[x] Longitude	○	○
[x] Elevation	○	○
[x] School code	○	○
[ ] School name	○	○
[x] Site ID	○	○
[ ] Site name	○	○
[ ] City, [State,] Country	○	○
[ ] Time measurement was reported	○	○

*Budburst	[Sort1]	[Sort2]
[x] Average budburst date	○	○
[ ] Budburst in weeks	○	○
[ ] Budburst day-of-year	○	○
[ ] Comments	○	○

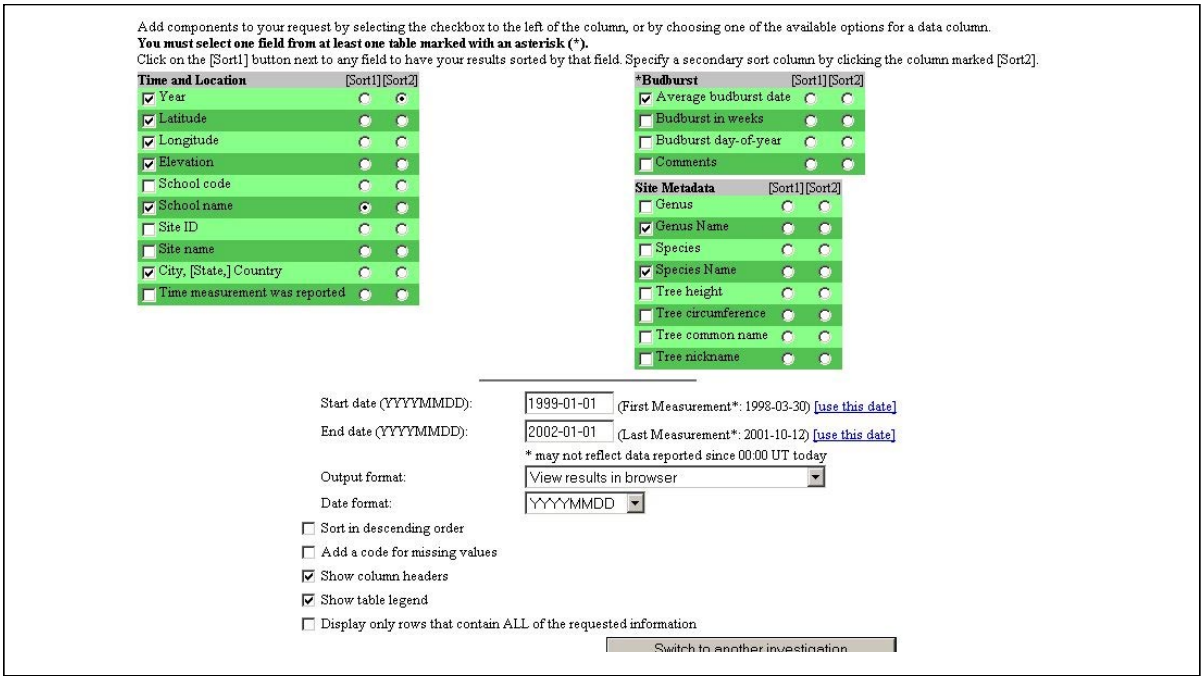
Site Metadata	[Sort1]	[Sort2]
[x] Genus	○	○
[ ] Genus Name	○	○
[x] Species	○	○
[ ] Species Name	○	○
[ ] Tree height	○	○
[ ] Tree circumference	○	○
[ ] Tree common name	○	○
[ ] Tree nickname	○	○

Start date (YYYYMMDD): 1999-01-01 (First Measurement*: 1998-03-30) [use this date]
End date (YYYYMMDD): 2002-01-01 (Last Measurement*: 2001-10-12) [use this date]
* may not reflect data reported since 00:00 UT today
Output format: View results in browser
Date format: YYYYMMDD

- [ ] Sort in descending order
- [ ] Add a code for missing values
- [x] Show column headers
- [x] Show table legend
- [ ] Display only rows that contain ALL of the requested information

Switch to another investigation
View Monthly Summaries
Set limits for some fields

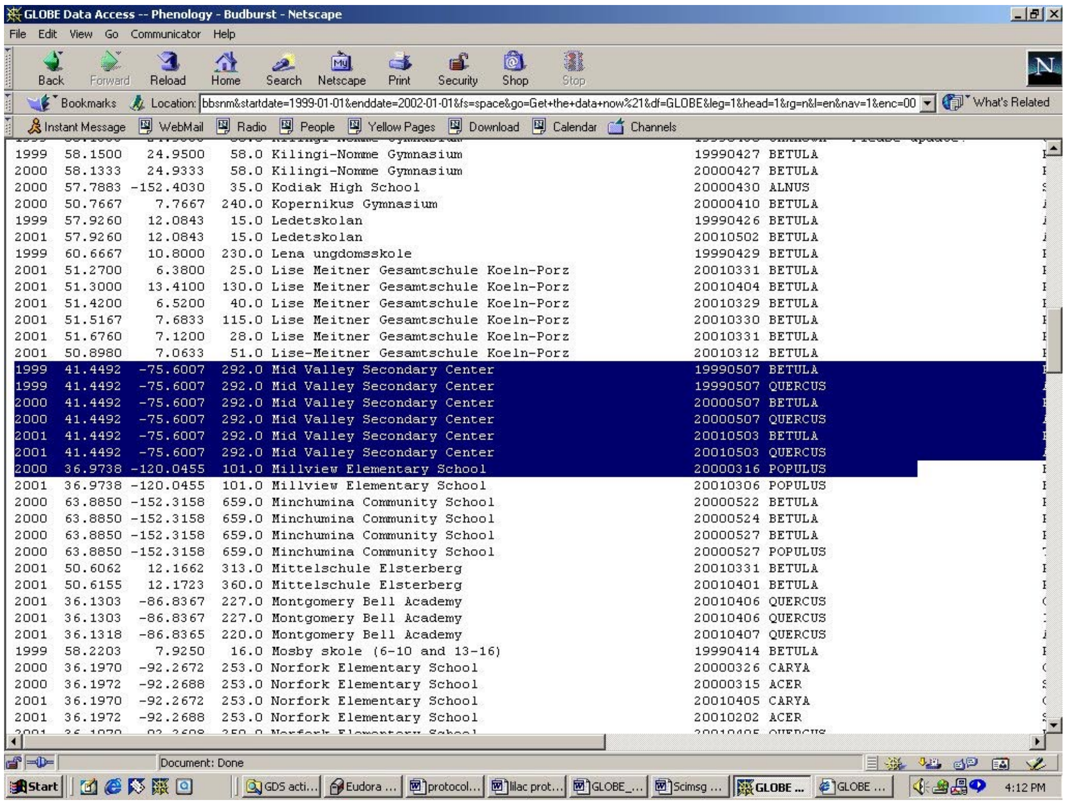
The students selected the columns they wanted to see (year, latitude, longitude, elevation, school name, average budburst date, genus name, and species name). Under the "sort 1" column, they selected "name of school" and under the "sort 2" column, they selected "year". By doing this, the data are organized so that they could quickly scan through the data to see which schools have three years of budburst data. They found two such schools - Vestvaagoey videregaaende skole and Mid Valley Secondary Center.

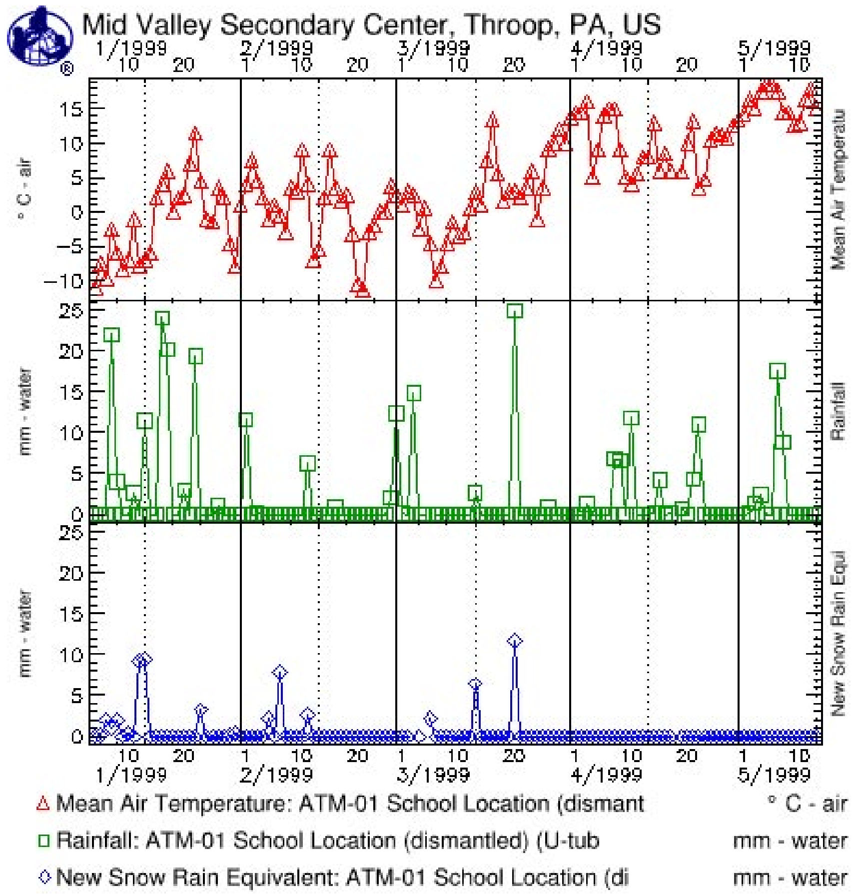


The students chose to examine Mid Valley Secondary Center and wrote down the tree species, *Betula populifolia* and *Quercus alba,* and the dates of budburst for each year.

Next, they needed the school's atmosphere data. At the navigation bar, they clicked on "Schools" under "GLOBE PARTNERS" and typed in "Mid Valley Secondary Center" for the "Find in school name". A new page with the school information appeared. This school has reported data from over 15,000 atmosphere measurements!

They clicked on "graph" and then created a graph of the mean temperature, rain, and liquid water equivalent between Jan 1, 1999 and May 10, 1999.





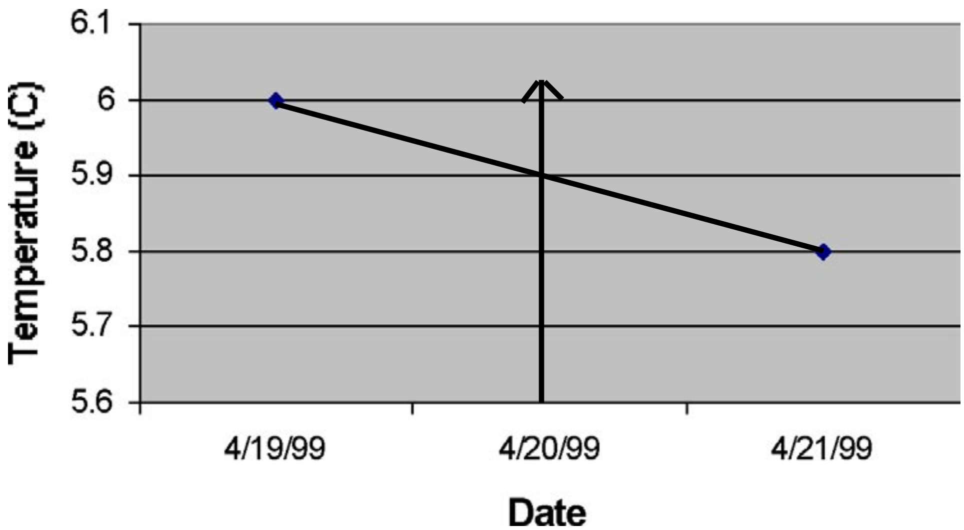
They then selected the "show table" option and a table with the data for the graph appeared at the bottom of the page and saved the file as a text file.

Next, they created a graph of temperature, rain and liquid water equivalent for snow between Jan. 1, 2000 and May 10, 2000; then a text file as they did for the 1999 data. They repeated these steps and created a text file for 2001 data.

The students opened a spreadsheet program on a computer and followed the instructions to open the 1999 text file.

In order to calculate Growing Degree Summation (GDS), they first examined the data to see if there were any missing days between Jan 1, 1999 and May 7, 1999 (the day of budburst). They found only one – April 20, 1999!! For that missing temperature date, they looked at the mean temperatures for the day before, April 19, and the day after, April 21. To estimate the mean temperature on April 20, they performed a linear interpolation, which is a technique often used by scientists to estimate the values of missing data. The graph below shows the mean temperature data for April 19 (6.0 C) and April 21 (5.8 C). They drew a line connecting these two points and then estimated the mean temperature for April 20 as 5.9 C.

They next calculated the GDS for 1999 for the two tree species observed by the students at Mid Valley Secondary Center. Both tree species had a budburst date of May 7. They started with January 1 and added all the temperature values greater than 0.0 C up to the day of budburst. They ignored the temperatures less than 0.0 C, as stated in the *What do scientists look for in the data?* section. They calculated a GDS of 619.1C. The table below shows their results.



Date	Mean Temperature	GDS
1/1/1999	-11.5	0
1/2/1999	-13	0
1/3/1999	-4.2	0
1/4/1999	-3.5	0
1/5/1999	-10.5	0
1/6/1999	-11	0
1/7/1999	-7.5	0
1/8/1999	-9.8	0
1/9/1999	-2.5	0
1/10/1999	-6	0
1/11/1999	-8.5	0
1/12/1999	-7	0
1/13/1999	-1	0
1/14/1999	-7.8	0
1/15/1999	-7	0
1/16/1999	-6	0
1/17/1999	2	2
1/18/1999	4	6
1/19/1999	6	12
1/20/1999	0	12
1/21/1999	2	14
1/22/1999	2.5	16.5
1/23/1999	7	23.5
1/24/1999	11.5	35
1/25/1999	4.5	39.5
1/26/1999	-1	39.5
1/27/1999	-1.5	39.5
1/28/1999	3.5	43
1/29/1999	2	45
1/30/1999	-4.5	45
1/31/1999	-8	45
2/1/1999	1	46
2/2/1999	4	50
2/3/1999	7.5	57.5
2/4/1999	4.5	62
2/5/1999	2	64
2/6/1999	-1.2	64
2/7/1999	1	65
2/8/1999	-0.5	65
2/9/1999	-3	65
2/10/1999	3.5	68.5
2/11/1999	3	71.5

Date	Mean Temperature	GDS
2/12/1999	9	80.5
2/13/1999	4	84.5
2/14/1999	-7	84.5
2/15/1999	-5.5	84.5
2/16/1999	2	86.5
2/17/1999	9	95.5
2/18/1999	3.5	99
2/19/1999	1.5	105.5
2/20/1999	2.5	108
2/21/1999	-3.2	108
2/22/1999	-10.5	108
2/23/1999	-11.5	108
2/24/1999	-3	108
2/25/1999	-2	108
2/26/1999	0	108
2/27/1999	0	108
2/28/1999	3.8	111.8
3/1/1999	2.5	114.3
3/2/1999	1	115.3
3/3/1999	3	118.3
3/4/1999	2.5	120.8
3/5/1999	-2.5	120.8
3/6/1999	0.5	121.3
3/7/1999	-4.5	121.3
3/8/1999	-10	121.3
3/9/1999	-8	121.3
3/10/1999	-4.5	121.3
3/11/1999	-1.5	121.3
3/12/1999	-3.5	121.3
3/13/1999	-3	121.3
3/14/1999	0.5	121.8
3/15/1999	3	124.8
3/16/1999	1	125.8
3/17/1999	7.5	133.3
3/18/1999	13.5	146.8
3/19/1999	5.5	152.3
3/20/1999	1.5	153.8
3/21/1999	3	156.8
3/22/1999	3	159.8
3/23/1999	2	161.8
3/24/1999	3.5	165.3
3/25/1999	6	171.3

Date	Mean Temperature	GDS
3/26/1999	-1	171.3
3/27/1999	3.5	174.8
3/28/1999	9.2	184
3/29/1999	10	194
3/30/1999	12	206
3/31/1999	10	216
4/1/1999	13.8	229.8
4/2/1999	14.5	244.3
4/3/1999	14.5	258.8
4/4/1999	16	274.8
4/5/1999	5	279.8
4/6/1999	9	288.8
4/7/1999	14	302.8
4/8/1999	15	317.8
4/9/1999	15	332.8
4/10/1999	9	341.8
4/11/1999	5	346.8
4/12/1999	4	350.8
4/13/1999	5.5	356.3
4/14/1999	8	364.3
4/15/1999	8	372.3
4/16/1999	13	385.3
4/17/1999	6	391.3
4/18/1999	8.5	399.8
4/19/1999	6	405.8
4/20/1999	est 5.9	411.7
4/21/1999	5.8	417.5
4/22/1999	10	427.5
4/23/1999	13.2	440.7
4/24/1999	3.5	444.2
4/25/1999	4.8	449
4/26/1999	10.5	459.5
4/27/1999	11.5	471
4/28/1999	11.1	482.1
4/29/1999	10.8	492.9
4/30/1999	12.5	505.4
5/1/1999	13.5	518.9
5/2/1999	14.2	533.1
5/3/1999	16.5	549.6
5/4/1999	15	564.6
5/5/1999	17.5	582.1
5/6/1999	18.5	600.6
5/7/1999	18.5	619.1

They then calculated the GDS for 2000 and 2001 following the steps described above. Both species of trees, *Betula populifolia* and *Quercus alba,* had the same date of budburst for each year. If the dates differed within the same year they would have had to calculate the GDS for each tree species. Here are their results:

Mid Valley Secondary Center -
Betula populifolia *and* Quercus alba

Year	**1999**	**2000**	**2001**
Budburst	May 7	May 7	May 3
GDS	619.1	734.4	493.4

It seems that the budburst dates are nearly the same for all three years but that the GDS values vary greatly. In fact the year with the earlier budburst date (May 3) had the lowest GDS of 493.4C. This is the opposite of what they predicted– a warmer spring, then an earlier budburst.

Next, the students looked at moisture availability – the difference of inputs and outputs of water available to the soil. Maybe that influenced when budburst occurred. They summed the precipitation data for the 29 days before budburst and the day of budburst (a total of 30 days). This includes both the rain and liquid water equivalent of melted snow. For rain, there was a total of 49.5 mm for the 30 days, although one day was missing (April 20). Rain could have fallen on that day. They checked to see if there were any liquid equivalent of new snow measurements. No snow fell during that time period.

Date	**Rain**	**Days**	**Equiv**	**Days**
19990408	0	1	0	1
19990409	6.8	1	0	1
19990410	6.6	1	0	1
19990411	0	1	0	1
19990412	11.8	1	0	1
19990413	0	1	0	1
19990414	0	1	0	1
19990415	0	1	0	1
19990416	0.1	1	0	1
19990417	4.2	1	0	1
19990418	0	1	0	1
19990419	0.1	1	0	1
missing				
19990421	0.7	1	0	1
19990422	0	1	0	1
19990423	4.3	1	0	1
19990424	11	1	0	1
19990425	0	1	0	1
19990426	0	1	0	1
19990427	0	1	0	1
19990428	0	1	0	1
19990429	0	1	0	1
19990430	0	1	0	1
19990501	0	1	0	1
19990502	0	1	0	1
19990503	0.1	1	0	1
19990504	1.4	1	0	1
19990505	2.4	1	0	1
19990506	0	1	0	1
19990507	0	1	0	1
Total	**49.5**			

Next, they calculated the outputs from evaporation and transpiration. The output values for each day in the 30 days was determined from a potential evapotranspiration (PET) table given in the What do scientists look for in the data? section. To find the PET value for each day, they looked at the average temperature value and found the corresponding PET value. If the temperature value for a given day fell between values listed in the table, they did a linear interpolation. The PET values for 30 days were added, shown below.

Date	Average Temperature	PET
4/8/99	15	2.1
4/9/99	15	2.1
4/10/99	9	1.5
4/11/99	5	1.1
4/12/99	4	1.1
4/13/99	5.5	1.15
4/14/99	8	1.4
4/15/99	8	1.4
4/16/99	13	1.9
4/17/99	6	1.2
4/18/99	8.5	1.45
4/19/99	6	1.2
4/20/99	est 5.9	1.2
4/21/99	5.8	1.2
4/22/99	10	1.6
4/23/99	13.2	1.9
4/24/99	3.5	1.05
4/25/99	4.8	1.1
4/26/99	10.5	1.65
4/27/99	11.5	1.75
4/28/99	11.1	1.7
4/29/99	10.8	1.7
4/30/99	12.5	1.85
5/1/99	13.5	1.95
5/2/99	14.2	2
5/3/99	16.5	2.35
5/4/99	15	2.1
5/5/99	17.5	2.45
5/6/99	18.5	2.6
5/7/99	18.5	2.6
Total		**50.35**

Next, they subtracted the outputs from the inputs for each year to see if there were moisture excesses or deficits. Negative difference values indicate a decrease in water, in other words, drying conditions. Positive difference values indicate an increase in water.

Year	1999	2000	2001
Total precipitation	49.5 mm	56.1 mm	37.4 mm
PET	50.35 mm	54 mm	56.35 mm
Difference (moisture availability)	-0.85 mm	2.1 mm	-18.95 mm

During the spring of 2001 there was a major decrease in the available moisture: –18.95 mm. The other two years moisture conditions remained steady. They then compared the moisture availability values with the budburst dates and GDS values in a table shown above.

Year	1999	2000	2001
Budburst	May 7	May 7	May 3
GDS	619.1	734.4	493.4

This is totally different than what they expected! Budburst occurred earlier in drier, colder conditions. They were not sure what to conclude. Perhaps for these species, the amount of daylight is more important than both moisture availability and temperature. They were curious to see if the same pattern resulted in 2002 and wanted to look at the data from another school to see if the same pattern is found. As well, they decided to go to the library and find out more about the tree species.