Phytoplankton are microscopic plants that form the base of the marine food chain. Though they are small, the energy they capture from the sun through photosynthesis helps to sustain almost all life in the ocean. They're also important to life on land: phytoplankton produce more than half of Earth's oxygen supply.

In this chapter, users learn about the variables that influence the abundance of phytoplankton. They apply this knowledge to make predictions about the timing of the spring phytoplankton bloom in the Gulf of Maine. Users obtain and graph data from buoy monitoring stations and interpret them to make their predictions. They check their predictions by examining chlorophyll concentration data at each buoy. Users also compare their predictions with reality by obtaining and examining MODIS satellite images to view the full extent of the bloom over time.

This chapter is part of the Earth Exploration Toolbook. Each chapter provides teachers and/or students with direct practice for using scientific tools to analyze Earth science data. Students should begin on the Case Study page.
Teaching Notes

Example Output

Users will produce and analyze graphs showing water temperature, salinity, density, and chlorophyll concentration for 2004 at four buoy locations in the Gulf of Maine. The multi-year graph of chlorophyll concentration below serves to illustrate the distinct fall and spring phytoplankton blooms that occur there each year.

The Gulf of Maine is outlined in the red box in the image below. The image shows chlorophyll levels recorded by the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor onboard the Terra satellite on April 23, 2003. The dark red pixels show areas where chlorophyll levels were 10.0 mg/cubic meter.
**Grade Level**
Grades 7-12

**Learning Goals**
After completing this chapter, users will be able to:

- Explain the ecological importance of phytoplankton
- Describe the components that influence a phytoplankton bloom
- Interpret satellite images in order to correlate buoy data
- Use the scientific process to predict the onset of the spring bloom based on background data
- Download and analyze graphs of oceanographic buoy data
- Identify geographic features in the Gulf of Maine

**Learning Contexts**
This chapter demonstrates how oceanographers study the phenomena of the spring phytoplankton bloom using a variety of different oceanographic technologies. Through understanding some of the basic factors that influence the productivity in the Gulf of Maine, students will be able to make educated guesses about when the spring bloom may occur based on buoy data and
satellite images. This inquiry based method will teach students to ask questions in order to solve a puzzle which scientists are also actively trying to answer. Depending on how much explanation and preparation is done for the students this could involve students from a variety of learning levels.

**Science Standards**

The following National Science Education Standards are supported by this chapter:

- **12ASI1.1** Identify questions and concepts that guide scientific investigations. Students should form a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding a hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and conceptual understanding of scientific investigations.

- **12ASI1.5** Recognize and analyze alternative explanations and models. This aspect of the standard emphasizes the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best. In other words, although there may be several plausible explanations, they do not all have equal weight. Students should be able to use scientific criteria to find the preferred explanations.

- **12CLS4.4** Living organisms have the capacity to produce populations of infinite size, but environments and resources are finite. This fundamental tension has profound effects on the interactions between organisms.

**Time Required**

Three 45 minute classes.

**Other Resources**

**Water temperature, salinity, and density graphs**

In the event that the GoMOOS server is down or running too slowly to provide the data for a large class situation, you can access graphs of
water temperature, salinity, and density for buoys B, E, I, and M at this link.

Chlorophyll graphs
Case Study: When is Dinner Served? Predicting the Spring Phytoplankton Bloom in the Gulf of Maine

To a fish, nothing beats phytoplankton. Small fish eat the microscopic plants for energy and nutrients. In turn, bigger fish eat the smaller fish. Even larger fish (and humans!) eventually eat the bigger fish. As phytoplankton are at the base of this food chain, it is not an exaggeration to state that phytoplankton sustain almost all life in Earth's oceans. (Bacteria in some deep sea ecosystems provide an additional source of food for marine life, but that process is not addressed in this chapter.)

Like all plants, phytoplankton need sunlight, carbon dioxide, water, and nutrients to grow. Because sunlight is most readily available near the surface of the sea, that's where phytoplankton develop. Phytoplankton contain chlorophyll-a, a pigment that gives the microscopic plants a greenish color. Depending on the phytoplankton species and their abundance in a region, the color of the ocean surface where they are growing actually changes color, ranging from green to brown to red. When these colors appear, the phytoplankton are said to be in "bloom." The blooms—essentially dense concentrations of chlorophyll—can be detected in satellite images. Scientists study these images to monitor the ocean's biological productivity. Commercial
fishermen and whale watching boats also access these images: where phytoplankton are blooming, dinner is served! Schools of juvenile fish, sand lance, mature fish, and whales may also be found in these areas.

Phytoplankton also play a critical role in the global carbon cycle. Phytoplankton consume carbon dioxide from the ocean during photosynthesis and emit oxygen as a by-product. In fact, more than half of the oxygen in Earth's atmosphere is produced by ocean phytoplankton. As a result of photosynthesis, the oceans are a net sink (or consumer) for carbon dioxide. If the amount of phytoplankton in the global ocean is reduced, as a result of climate change for example, atmospheric carbon dioxide could increase.

Since carbon dioxide and water are readily available at the ocean surface, the main factors that limit phytoplankton development are the availability of nutrients and sunlight. The nutrients phytoplankton need for growing (nitrate, phosphate, and silicate) are found in the colder, deeper areas of the ocean. Shifting ocean currents (called upwellings) and water mixing by wind bring these nutrients to the surface. When these nutrients are available at the surface and the amount of sunlight increases in the spring each year, the phytoplankton bloom.

In this chapter, you will gain an understanding of the critical role phytoplankton play in the marine food chain by predicting the timing of the spring phytoplankton bloom in the Gulf of Maine. You will access buoy data on water temperature, salinity, and density—variables that influence the timing of the spring bloom. These data are available from buoy monitoring stations in the Gulf of Maine Ocean Observing System (GoMOOS). You will graph these data and interpret them to predict when the bloom should occur. You will compare your predicted bloom date to the actual date by examining chlorophyll data. Finally, you will acquire MODIS (Moderate Resolution Imaging Spectroradiometer) satellite images of this region from the University of New Hampshire's Coastal Observing Center to see the phytoplankton bloom as viewed from 400 miles above Earth.
Part 1-What Causes a Phytoplankton Bloom in the Gulf of Maine?

Colorful phytoplankton blooms are complex phenomena that have attracted fishermen and perplexed scientists for decades. A phytoplankton bloom has been defined as a "high concentration of phytoplankton in an area, caused by increased reproduction; [this] often produces discoloration of the water" (Garrison, 2005). More generally, a bloom can be considered as a phytoplankton population explosion—blooms occur when sunlight and nutrients are readily available to the plants, and they grow and reproduce to a point where they are so dense that their presence changes the color of the water in which they live. Blooms can be quick events that begin and end within a few days or they may last several weeks. They can occur on a relatively small scale or cover hundreds of square kilometers of the ocean's surface. In the Gulf of Maine, spring and fall blooms occur on an annual basis. Smaller blooms have also been detected during other times of the year. Scientists have not yet been able to predict the exact date and location of a phytoplankton bloom before it occurs, but through the use of satellites, long term moored buoys and monthly oceanographic research cruises we are able to make better educated guesses. The data analysis you will do in this chapter is considered cutting edge research for the advancement of science!

Scientists consider many factors that influence where and when phytoplankton blooms occur. Some of the most important factors include water temperature, density, and salinity, hydrography of the region, availability of nutrients, what species and the amount of phytoplankton biomass that is present, what types of zooplankton are grazing on the phytoplankton, and available sunlight levels. There are very few "permanent" parameters (i.e. bathymetry/hydrography) in this system; the constantly changing values of most parameters make blooms somewhat difficult
to study. This primer is intended to focus only on the oceanographic principles that influence phytoplankton blooms that can be monitored by instruments on buoys and satellites.

Gulf of Maine
Scientists have been studying microscopic organisms in the oceans for decades using simple collection nets and collecting jars. Today, scientists study phytoplankton using research vessels, long term moored buoys, and satellite instruments. Based on oceanographic studies that utilize all of these methods, we now know that phytoplankton blooms occur around the world in regions of upwelling or along convergent currents known as fronts. In the Gulf of Maine, the dynamics are very unique. In studying the Gulf of Maine ecosystem, it is essential to understand how the bathymetry (depth and shape of the ocean floor) affects water movement in the region.
The Gulf of Maine is almost entirely enclosed by land. Three Canadian Provinces and three US states surround the Gulf of Maine creating a semi-circle shaped body of water that is still connected to the Atlantic Ocean.

A signature feature unique to the Gulf of Maine is the underwater ledges and banks that separate the water within the Gulf from the Atlantic Ocean. Before bathymetric maps, many people thought there was no separation between Atlantic waters and the Gulf but we now know that Georges Bank and Browns Bank are just two of the large underwater ledges that create a barrier between waters off shore and the inner Gulf of Maine. The Northeast Channel and the Great South Channel are the two main valleys that allow most of the water to enter and exit from the region. As seen in this picture, the red arrows indicate denser water flowing in through the Northeast Channel. This band of water can be both warm and cold depending on the current flow and can bring in new sources of nutrients trapped in this submerged layer of water. Water still flows continuously over the ledges creating nutrient mixing and fast moving currents which is why you will see a high chlorophyll reading in the satellite images in that area. Inside the Gulf, there are 3 prevalent basins known as Wilkinson Basin, Georges Basin, and Jordan Basin. These also play a large part in the physical dynamics of the Gulf of Maine. Because of the speed of the incoming currents as well as other forces, water in the Gulf of Maine circulates counterclockwise. Cold water from the north, known as the Labrador Current, and warm water from the south, known as the Gulf Stream, are mixed outside the Gulf before entering. The combination of these consistent currents, the direction of flow, the bathymetry and much more, makes the physical structure of the water column very different at each buoy location. This is why it is important to include different buoys in your study.
Stratification
The tilt of Earth's axis and its revolution about the sun cause seasons to change. We know the difference between summer and winter weather on land, but we are less familiar with how the weather changes underwater. The ocean experiences changes in seasons too! We can track how ocean "weather" changes by studying changes in the temperature, salinity, and density of columns of water from the ocean bottom to the surface. The concept of such a vertical sample of water is referred to as the water column.

In the atmosphere, air temperature, humidity, and pressure change with altitude. Similarly, various parameters underwater change with depth: these include water temperature, salinity, density, and pressure. The density (mass per unit volume) of seawater is controlled by its temperature and salinity (Spokes, 2003). The higher the salt content (salinity) of water, the higher the density. Conversely, the higher the water temperature, the lower the density. Differences in density are responsible for things sinking or floating: less dense things float on top of more dense things. Therefore, relatively fresh, warm water will float on top of salty, cool water. When ocean water becomes separated into layers of similar densities, it is said to be stratified or that stratification has occurred. Density stratification is the formation of layers, with each deeper layer being denser (weighing more per unit of volume) than the layer above it (Garrison, 2005). The Gulf of Maine, like the ocean, is divided into three density zones, the surface zone, the pycnocline—a layer in which the density increases significantly with an increase in depth, and the deep zone (Garrison, 2005). The depth of each zone varies with location.
In vertical profiles of water from the Gulf of Maine (above), cool, dense water is on the bottom and warmer, less dense water floats on top. This situation is most obvious in the spring and summer profiles. Both the color and the black lines in each graphic indicate water temperature at various depths. In winter, you can see that the water is generally uniform in temperature throughout the water column due to heavy mixing. In summer, water near the surface is warmer and therefore less dense than deeper water.

Just as storms mix the atmosphere, heavy winds, strong currents, and tidal forces mix water in the ocean. The mixing churns up relatively stable stratified water, bringing dense water water up and forcing less dense water down. This brings nutrients that were confined to the deep zone to the surface zone. In the winter months, the water column is fully mixed due to the prevalence of winter storms. Even if storms are absent, the cold atmospheric temperatures of winter chill the surface layers of the ocean. The result is that surface waters becomes too dense to be supported and they sink to the bottom, displacing the less dense, nutrient-rich water below, keeping the water mixed. Once spring comes, the higher atmospheric temperatures warm the surface waters, decreasing their density, and stratified layers develop again. This annual cycle of mixing and stratification repeats each year. The status of the water column is monitored by instruments on buoys: by analyzing these data, we can interpret if the water is mixed or stratified when blooms occur.

**Nutrients**

Nutrients play an essential role in supporting a phytoplankton bloom. Phytoplankton rely on sunlight and available nutrients for energy and growth. Carbon dioxide, water, and light are necessary for photosynthesis. Nitrate, phosphate, silicate, and carbonate are all important in the production of plant matter. Silicon, phosphorus, and nitrogen also play a key role in growing plants. Because their concentrations
fluctuate, nitrogen and phosphate influence the rates of phytoplankton production in the ocean. Concentrations of nutrients in the water column vary depending on the time of year, density of water, how they entered the ocean, and how much mixing has taken place during that season. In addition, each of these constituents have different residence times, or time remaining in the water column. This factor has a direct influence on the intensity of the phytoplankton bloom. In summary, nutrient availability is influenced by a range of complex factors in the Gulf of Maine.

How do we know what nutrients are available at different depths in the ocean? Currently, nutrient data is collected from water samples gathered on research vessels. Long term oceanographic buoys are not regularly equipped with the technology to measure nutrient levels, although research is currently being done to outfit buoys with real time nutrient sensors. What the water samples do tell us is that nutrient availability in the water column changes with the seasons. Winter mixing brings nutrients up from below, concentrating them near the surface. Spring warming creates a surface layer that floats on top, halting the supply of nutrients brought to the surface. As spring turns to summer, nutrients in the surface layer are consumed by phytoplankton, reducing nutrient availability at the surface. As summer sets in, phytoplankton die and drift to the bottom, taking the nutrients they ingested with them. Surface waters are now left with few nutrients available. Through the summer, this situation is reinforced as the surface waters are warmed and the stable situation of stratification sets in. Once autumn sets in with cooler days, a limited amount of vertical mixing brings nutrients up from below. In winter, heavy winds and plummeting temperatures cause strong mixing again. In general, when nutrients are found near the surface, they are not plentiful at deeper levels and vice versa. A more in-depth exploration of nutrient dynamics and how they influence phytoplankton blooms on a seasonal basis can be explored by studying ocean chemistry.

**Blooms**

Spring brings warmer temperatures and increased sunlight, creating a thermocline that traps nutrients at the ocean surface. This allows phytoplankton to absorb energy and take in the nutrients they need to photosynthesize and multiply. The warming of the surface layer keeps this water less dense, so it stays afloat. Phytoplankton respond very quickly when the right conditions occur, growing and reproducing as soon as a slight stratification of the water column occurs. As phytoplankton continue thriving in the nutrient-rich surface zone where they receive sunlight, they may become so plentiful that the ocean waters turn green, brown, or red from the chlorophyll they contain. As the phytoplankton use up the available nutrients
however, they begin to die and drift to the bottom. As autumn begins, cooler days cause some vertical mixing that may bring nutrients up from below resulting in a relatively smaller fall bloom. Once winter begins, plummeting temperatures and frequent storms cause heavy mixing. As phytoplankton do not remain at the surface in this mix, they do not have ready access to sunlight, so blooms do not occur in the winter.

**Major Spring Bloom Species**

The community structure of a phytoplankton bloom depends on the geographic location of the bloom as well as its timing and duration. In the Gulf of Maine, some of the common species found during the spring phytoplankton bloom are diatoms. These images show two species of diatoms, both are single celled organisms that are linked to form chains. Diatoms are often seen during the initial stages of a bloom. Generally, they consume nutrients and multiply before another plankton group, the dinoflagellates emerges. Diatoms grow faster than dinoflagellates. They generally bloom first if there is enough silicic acid in the water column. Diatoms use silica to produce their glass-like cell wall structure.

**Summary**

Phytoplankton blooms are created by an array of complex factors and influences that can combine to form conditions that cause a bloom, or a high concentration of phytoplankton in an area. Stratification of the water column with an influx of nutrients and sunlight can create an exciting display of blooming life. With an
introductory level of information and instructions on how to find and graph data, you are now better equipped to make educated guesses about when the spring bloom might happen. A few years ago, we did not have access to the amount of data that is now available because the necessary tools were not in place. With long term data sets collected from moored buoys such as the GoMOOS buoy system and an extensive library of satellite images, teachers and their students are now able to ask similar questions that can lead to conclusions that are useful to scientists. Understanding the ocean is difficult and complex yet with these new tools it is now more approachable than ever. Enjoy investigating the mystery of the spring bloom!

References:
Spokes, L. *Phytoplankton and nutrients in the oceans.* ESPERE. (16-October 2003).
Part 2—Explore GoMOOS

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

**Step 1—Learn about Buoys**

Oceans cover over 70% of Earth’s surface and contain 97% of Earth's water. The oceans regulate global carbon dioxide (CO₂) levels by absorbing roughly half of Earth's atmospheric carbon dioxide. They are also responsible for producing more than half of Earth's oxygen supply because they support photosynthesizing plants. Our oceans are home to hundreds of thousands of plant and animal species plus thousands or even millions of other species that have not yet been identified.¹ Additionally, ocean commerce is a multi-billion dollar industry: fishing, international trade, communications, recreation, and tourism all depend at least in part on our oceans.

Given the ecological and economic importance of Earth's oceans, it's vital that we collect and maintain information about them to monitor their health and identify potential threats. Data on such variables as wind direction, wave height, and air temperature, plus water temperature, salinity, and current speed and direction at different depths are now routinely collected by moored (anchored) buoys equipped with sensors at various depths along their tethers. These buoys transmit the data to shore as they are collected and the data become available right away via the Internet or phone. The ability to access "real-time" data on oceanographic conditions is beneficial to commercial fishermen, sailors, scientists, meteorologists, search and rescue personnel, and public health officials.

¹ We will know more about the number of aquatic plants and animals soon. A Census of Marine Life is currently underway. This 10-year global initiative involving researchers from more than 50 nations will help quantify the diversity and distribution of marine life and describe how it changes over time.

**Step 2—Explore the GoMOOS Buoys**

The Gulf of Maine Ocean Observing System (GoMOOS) is recognized as a leader in coastal ocean observing technology. GoMOOS deployed and maintains 10 buoys in the Gulf of Maine and provides access to real-time data from them plus 11 other
buoys (maintained by the National Oceanic and Atmospheric Administration) in the region.

Click this GoMOOS Hourly Data link to access an interactive map of the buoys in a new window. Click an individual buoy to obtain the most recent data for that buoy.

Click the "Description of station & location" link immediately to the right of the map to learn more about the buoy.

Take a quick look at the map to familiarize yourself with the locations of Buoys B, E, I, and M. These are the buoys for which you will request and analyze data to predict when the spring phytoplankton bloom will occur.

**Step 3-Compare data from GoMOOS Buoys**
Compare data from one buoy to another. Once you have chosen a station, click the "Compare this station to others" link at the right of the buoy map.

Keep the first buoy you chose or select a new one from the pull-down menu. Select a second and/or third buoy from their respective pull-down lists. Click the **show data** button to see the results. What can you tell about each location from the data?

![Compare Stations](image)
Part 3—Retrieve and Graph Buoy Data

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

Step 1—Request Water Temperature Data for Buoy B

Now that you know some of the basics about phytoplankton blooms and you've seen the types of data that are available from buoys, you'll set up several data requests. You'll request your data reports as graphs and use them to predict the spring phytoplankton bloom for 2004. Using a year that has already passed will allow you to check your prediction against reality.

Click the GoMOOS logo in the upper left of the interactive buoy map page to access the GoMOOS home page. Click the Graphing & Download link on the left to access the data request interface.

If this is your first visit to GoMOOS, you'll see a request to register as a user. GoMOOS can serve their customers better if they know a little about them—if you don't mind providing this registration information, enter it now and click the Register button. Or, you can click the Skip Registration button and proceed to the next step.

On the Introduction tab, click the Click Here to Begin button.
By examining water temperature, salinity, and density at various depths for several buoys, you'll be able infer when the water column at each location is mixed or stratified. The first location you'll examine is Buoy B, a near-shore buoy located northeast of Portsmouth, NH.

1. On the Data Types tab, select **Water Temperatures** from the pull-down list.
   - Select **Daily Average** and keep the default unit of measurement as **Degrees Centigrade**.
   - Click the **Add Data Type** button.
2. Click the **Time Periods** tab.
   - Check the box labeled **Custom Date** and enter **01/01/2004** to **12/31/2004**.
   - Click the **Add Time Period** button

3. Click the **Locations** tab and click the checkbox next to Buoy B. To get all the temperature data from different depths, keep all the default checkboxes GoMOOS has marked.
4. At the bottom of the list, click the Add Location button.
5. To request the dataset you've selected, click the Report tab and pause briefly while GoMOOS assembles the data.

Step 2-Graph the Water Temperature Data for Buoy B

GoMOOS offers several output format options. For our purposes, choose the Graph option. Since this is the default setting, simply click the Create Report button to generate the graph.
You'll be making a total of 12 graphs. You can print each window by clicking the **Print Window** link or you can save them electronically. To save them as bitmap images place your cursor over the graph, right-click your mouse button (on a Mac, press the control key (ctrl) on your keyboard and click the graph), and choose the **Save Picture As...** option. Save each graph with a descriptive name. For example, you might save this first file as *Buoy_b_water_temp.bmp*.

**Step 3-Retrieve and Graph Density and Salinity Data for Buoy B**

Set the water temperature graph aside for a moment. Set up requests and generate graphs of density and salinity data for the same location, Buoy B. Since the time period will stay the same, you only need to change the data type.

Click the **Data Types** tab and click the **remove all** link to clear your previous request. Select **Density** from the pull-down list. Specify **Daily Average** as the time step.
Click the **Report** tab and the **Create graph** button to graph density as a function of water depth. Print and/or save this graph and set it aside. Finally, obtain the salinity data for 2004 for Buoy B. On the **Data Types** tab, remember to click the **remove all** link under **Selected Data Type** setting before adding salinity. Graph these data, and print or save the graphs.

### Step 4-Retrieve and Graph Water Temperature, Density, and Salinity Data for Other Buoys

Repeat the steps above to obtain water temperature, density, and salinity data for 2004 for Buoys E, I, and M. Generate graphs of these data and save the graphs. When finished, you should have 12 plots: 3 graphs each for the 4 buoy locations.

**Special Note for Buoy M:** Buoy M has multiple depths available. Select only the 1 meter, 2 meter (where applicable), 20 meter and 50 meter depths.
Part 4—Analyze Graphs to Predict the Bloom

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

**Step 1-Group the Graphs by Buoy Location**

Examine the changes in water temperature, density, and salinity at each of the four buoy locations.

- Observe how each parameter changed at the surface and at depth over the year.
- Consider what you learned about stratification and mixing and how these conditions can be detected on your graphs.
- Compare your graphs with the vertical profiles for each season in Part 1. Do you see how each graph represents the annual cycle of mixing and stratification?

**Step 2-Analyze the Graphs to Predict the Timing of the Spring Bloom**

Interpret your graphs for each location to understand what was happening to the water column through the year and when a bloom might occur. Use the following questions to guide you in making a prediction about the timing and location of the spring bloom for 2004. Refer back to Part 1 or consult other resources as necessary.

1. Generally, how do water temperatures change with increasing depth?
2. How does salinity change with increasing depth?
3. How does density change with increasing depth?
4. What do your density graphs look like during times that the water column is mixed? How do the lines on the density graph change as the water becomes stratified?
5. Knowing that blooms occur when phytoplankton have ready access to sunlight and nutrients in a floating surface layer, make a prediction of the month or week that a bloom might occur for each buoy location.
6. Does your predicted bloom date vary by buoy location? Consider where each buoy is located in the Gulf. Can you explain any difference in predicted bloom dates based on the buoy locations?
Part 5—Retrieve and Graph Chlorophyll Data

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

**Step 1-Obtain and Graph Chlorophyll Data**

Chlorophyll is the pigment that plants use for photosynthesis. As such, measurements of chlorophyll concentration can serve as an estimate of the biomass (or quantity) of phytoplankton in the water. When a bloom occurs, chlorophyll concentrations increase dramatically. On a graph of chlorophyll concentration over time, bloom events are represented by vertical spikes in the graph.

Use the GoMOOS **Graphing and Downloading** pages again to generate graphs of chlorophyll levels for buoys B, E, I, and M. Select Chlorophyll as the data type and Daily Average as the unit of time.
How did your estimated date(s) of the phytoplankton bloom compare to the actual bloom as indicated in the chlorophyll graphs at each buoy location?
Step 2-A Closer Look at Buoy M

When this chapter was written in July, 2004 we noticed something very striking about the chlorophyll graph for Buoy M. We plotted chlorophyll at all four locations on the same graph.

![Daily Average Chlorophyll (ug/l) Jan-01 2004 to Dec-31 2004](chart)

We can see that chlorophyll levels at Buoy M are dramatically higher (roughly 15 times higher!) on April 24 than the chlorophyll levels reported the week before. These values greatly exceed the chlorophyll levels reported by any of the other buoys. They look suspicious! As you can imagine, moored ocean buoys are subject to a host of environmental influences such as wind gusts, storms, whales, and passing ships. All of these can affect the buoy’s ability to record and transmit accurate ocean measurements. A small collision with a ship, for example, might render a buoy inoperable for some length of time. Instruments on the buoy can also malfunction, resulting in erroneous measurements.

In assessing whether data are valid or not, it’s useful to consider all the information that’s available about the data in question. In this case, we can see that chlorophyll levels at Buoy M increased substantially in a short period of time. We can also see that these levels exceed all other readings at this and other buoys. Probably most importantly though, the buoy stops reporting data at all on May 17th, which suggests it was taken "off-line" at that time, possibly for repairs or replacement. Taken together, the information we have about the buoy suggests we should
probably disregard the chlorophyll data reported by Buoy M after mid-April when its values went well outside the normal range.

Science is messy. This example illustrates that every observation must be carefully considered and evaluated within the context of all the information that is known about the data.

If you requested a graph of this same data today, it may look quite different from this example. Data are routinely checked for quality and when problems are identified, corrections are made or the incorrect data are "thrown out." Still, the concept of evaluating all data before drawing any conclusions is a recurrent theme in science and an important concept to keep in mind.

In the next section, we will use satellite images to gain another perspective on ocean phytoplankton. This second set of chlorophyll measurements provides an additional check on questionable data values.
Part 6—Examine the Bloom in Satellite Images

In any step, click the Show me link to reveal extra information. If you prefer a printout of the full set of instructions for this part, choose Print from the File menu.

Step 1—What Does a Bloom Look Like From Space?

What does a phytoplankton bloom look like to a NASA satellite orbiting 400 miles above Earth's surface? Both NASA's Terra and Aqua satellites carry a MODIS (Moderate Resolution Imaging Spectroradiometer) instrument onboard. These satellites orbit the globe daily, providing images of Earth's land and ocean surfaces. Two MODIS data products that are useful for oceanography are chlorophyll concentration and sea surface temperature images.

The MODIS image below shows ocean chlorophyll on March 22, 2003. The Gulf of Maine is outlined in a red box. White patchy areas over the ocean in the lower right are clouds. The image was taken in early Spring before the phytoplankton bloom.

A month later, on April 23rd, 2003, the Gulf of Maine looked very different in the ocean chlorophyll image below. Note the yellow and red areas indicating higher chlorophyll levels.
Step 2-Obtain MODIS Images from WebCOAST

The MODIS images used in the previous step were acquired from WebCOAST at the University of New Hampshire (UNH). WebCOAST provides an array of coastal ocean observing data through their Coastal Observing Center. The WebCOAST satellite data holdings include 8 day composite images of chlorophyll-a and sea surface temperature for the years 2000 through 2004.

Go to the WebCOAST home page and click the Search and Retrieve Tool link in the middle of the right side of the page.

WebCOAST offers 5 methods (called filters) to select and order data from their database. You can search the database by Collection Name, Spatial Region, Temporal Range, Keyword, or Freetext, using one filter or a combination of filters to locate the data we want. Since we are interested in MODIS ocean images, click the Keyword Filter tab.

From the keyword list at the bottom center, select Satellite Data Products then click the Update Holding Count button.
After you click the **Update Holding Count** button, note the **Matching Holding Count** box in the upper right hand corner. This is the number of holdings (satellite data products) in the WebCOAST database that match your search criteria. Click the **View Matching Holdings** tab to see information about these images.

Find the holding labeled **MODIS_Aqua_chlorophyll_2004**. All of these satellite holdings are available in output formats that can be imported into image processing software such as *Image J*, we only want to look at the thumbnail images. Click the small camera icon under the correct holding.
The resulting page shows thumbnails of images produced every 8 days. These are composite 8 day images: that is, they are averages of all cloud-free measurements acquired during the 8 day period. Since clouds often prevent MODIS from imaging the ocean surface, compositing is a way of eliminating the clouds. Still, there are places where clouds persisted for 8 days. These areas appear white over the ocean on the thumbnail images.

Scroll through and examine images around the date you predicted the bloom would occur. Clicking any thumbnail image will bring up the full-size image. (Please Note: Your browser may shrink the full-size image to fit in the browser window, rendering it too small to see clearly. If you need to override this automatic resizing, use the tip that appears below the questions.

Use the images that show chlorophyll levels around your predicted bloom date to help you answer the following questions.

1. Can you identify the spring bloom in the chlorophyll images?
2. From the images, when would you say the bloom occurred? (you may be able to assign a beginning, peak, and end date for the bloom.)
3. Where in the Gulf of Maine was the bloom most evident? Did the data from the buoy(s) near that area indicate that the bloom might be more pronounced there than in other areas?
4. How long did the bloom appear to last?
5. Based on your understanding of phytoplankton blooms, describe what you would expect to find in the water column in the place where the bloom occurred.

**Tip**

**Does your browser shrink the images to fit in the browser window?**

Newer versions of the Netscape and Internet Explorer browsers include a default setting that automatically resizes images to fit in your browser window. Since these MODIS images are quite large (1300 x 1300 pixels) shrinking these images significantly reduces the clarity of the image. Here's how to change the default settings:

**Internet Explorer:**
- Tools Menu: choose **Internet Options**
- Click the **Advanced** tab
- Scroll down to the **Multimedia** section
- Deselect **Enable Automatic Image Resizing**

**Netscape:**
- Edit Menu: choose **Preferences**
- Click **Appearance**
- Deselect **Resize Images to fit in Browser Window**

**Step 3-Compare MODIS Images for 2001 through 2004**

Now let's compare the MODIS satellite images for this year to the previous three years.

▶ **Show me how**

▼ **Hide**

**Step 4-A Final Look at Buoy M**

Let's return to GoMOOS Buoy M, located roughly in the middle of the Gulf of Maine. As you'll recall, this buoy was reporting exceptionally
high chlorophyll values in mid-April, 2004. We found reasons to suspect that these observations aren’t valid and should be disregarded. The MODIS imagery provides an additional check on these questionable data.

Above, we superimposed the location of Buoy M onto the MODIS chlorophyll image taken on April 22, 2004. The image makes it clear that the highest chlorophyll values aren’t near Buoy M. The MODIS image of April 22 shows elevated chlorophyll levels throughout much of the region, with the highest levels in a large mass in the south-central region of the Gulf. Around Buoy M, chlorophyll levels appear to be approximately 2-5 mg chlor-a per cubic meter, nowhere near the measurements reported by that Buoy. When we consider all the information that we have about Buoy M, we can safely conclude that data from that buoy after mid-April, 2004 isn’t valid and should be ignored.
This chapter provided an overview of the factors that trigger a phytoplankton bloom as well as an introduction to the data, techniques, and analysis tools used to study these blooms. The Gulf of Maine is a complex marine ecosystem. Many factors interplay almost simultaneously to create a phytoplankton bloom and our understanding of these factors is incomplete. While we can't know precisely *When Dinner is Served* in the ocean, using the same data and tools scientists use to study these blooms we can make a reasonable prediction as to the timing, and in the process, gain a better appreciation of this unique oceanographic phenomenon.
About the Tool and Data

**Tool 1**

*Gulf of Maine Ocean Observing System (GoMOOS)*

The Gulf of Maine Ocean Observing System (GoMOOS) provides hourly real-time data on weather and oceanographic conditions in the Gulf of Maine.

**Tool Builder**

*Gulf of Maine Ocean Observing System*

P.O. Box 4919
Portland, ME 04112-4919

**Tool Cost**

Free

**Tool Help**

info@gomoos.org

---

**Tool 2**

*WebCOAST (a Web-based Coastal and Ocean Observing System)*

*WebCOAST* is a digital library of free coastal ocean observation data from the University of New Hampshire. A complementary data distribution system, *EOS-WEBSTER*, offers free, customized terrestrial Earth science data. *WebCOAST* is the portal for data and information products developed by researchers at the *Coastal Observing Center*. The Center's primary mission is to develop new methodologies for monitoring coastal marine ecosystems with a focus on the Western Gulf of Maine.

**Tool Builder**

*WebCOAST*

Dr. Annette Schloss, Project Manager
Complex Systems Research Center
Institute for the Study of Earth, Oceans, and Space
University of New Hampshire

**Coastal Observing Center**
Dr. Janet Campbell, Director
Ocean Process Analysis Laboratory
Institute for the Study of Earth, Oceans, and Space
University of New Hampshire

**Science advisor for this chapter:**
Dr. Ru Morrison
Ocean Process Analysis Laboratory
Institute for the Study of Earth, Oceans, and Space
University of New Hampshire

**Tool Cost**
Free

**Tool Help**
support@webcoast.sr.unh.edu
1-877-589-4909 (toll free)
Going Further

Other Data

Satellite Images of Phytoplankton Blooms from Around the World

20 spectacular images from NASA’s Visible Earth

Show me the list
Hide

Other Techniques

Create a Thermocline

As described in the primer, thermoclines are often viewed as temperature versus depth in vertical form. However, when many different depths are combined, the graph can look cluttered and confusing and can be difficult for students to understand. To give students a better understanding of the temperature/depth relationship in the ocean, have students draw a thermocline by using pencil and graph paper for a specific buoy at a specific depth either before or after they have created a GoMOOS graph. This may help orient them to the relationship of how temperature in the ocean can change as depth increases, depending on the season.

Other Tools

Phytopia: Discovery of the Marine Ecosystem

Phytopia is an educational CD-ROM produced by the Bigelow Laboratory for Ocean Sciences. The CD-ROM is free; shipping and handling for U.S. orders is $3.95. Learn more about Phytopia.
Ship Mates: Explore the Gulf of Maine As Oceanographers Do

Ship Mates, also from Bigelow Labs, is a suite of educational activities that interactively guide users through working with on-line oceanographic data.

"Seasons in the Sea"

Dr. Ann Michelle Morrison has written a terrific overview of seasonal change in the Gulf of Maine.

Educational Resources from the Coastal Observing Center

The Coastal Observing Center at the University of New Hampshire has a wide array of data products, visualizations, and curriculum materials available from their website. Check it out!

Background Resources: