

# Understanding Ocean Acidification

## Summary

Five lessons at increasing levels of sophistication incorporate real data from NOAA to help students understand the phenomenon of Ocean Acidification.

Grade Level: 10 – 12

Aligned to National Standards in Mathematics and Science, Ocean Literacy Essential Principles, Climate Literacy Essential Principles and selected state standards. See page 6.

This curriculum module was developed for the NOAA Ocean Data Education (NODE) Project by Caroline Joyce, Todd Viola and Andrew Amster in collaboration with the NOAA Coral Reef Conservation Program (<http://coralreef.noaa.gov>) and the National Oceanographic Data Center. This project has been made possible with support of the National Marine Sanctuary Foundation.

Scientific and technical advice was provided by Dr. Joseph Salisbury, Assistant Research Professor at the University of New Hampshire.

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## Prior Knowledge

This curriculum module is designed for students who are taking high school chemistry. Students should already have some experience with the following:

- Understanding and reading the pH scale.
- Knowledge of the carbon cycle.
- Using scientific notation to express large and small values.
- Reading chemical equations.

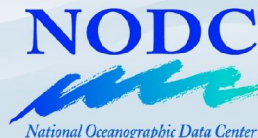
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Completed May 2011



NATIONAL  
ESTUARINE  
RESEARCH  
RESERVE  
SYSTEM



## Web Links

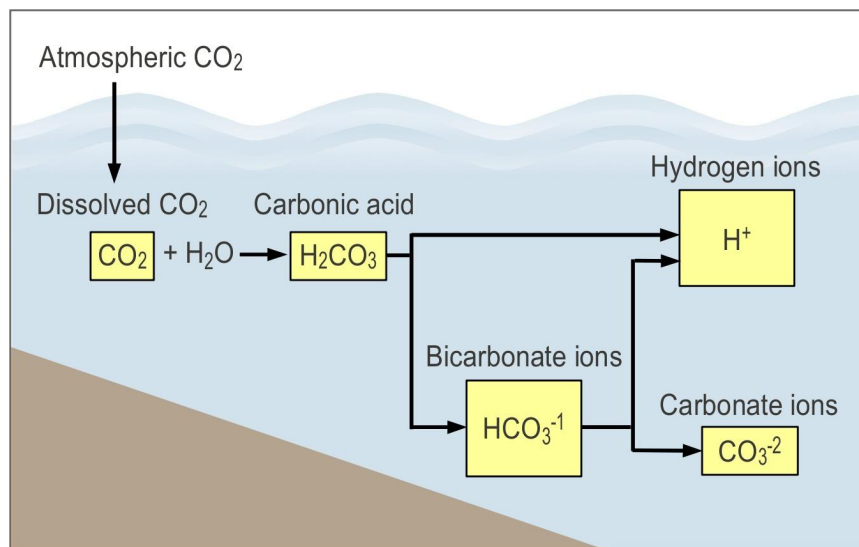
For links to helpful websites about Ocean Acidification, visit

[www.dataintheclassroom.org](http://www.dataintheclassroom.org).

## The Basics of Ocean Acidification

Burning fossil fuels releases carbon dioxide into Earth's atmosphere. This not only leads to a warmer Earth (i.e., global warming, the greenhouse effect), but also changes the chemistry of Earth's oceans.

The ocean is a "carbon sink," which means that it removes  $\text{CO}_2$  from the atmosphere. The ocean currently absorbs about one-third of the  $\text{CO}_2$  released by the burning of fossil fuels. However, beyond a certain level of atmospheric  $\text{CO}_2$ , the ocean can no longer act as a carbon sink without it having a negative impact on marine life. When  $\text{CO}_2$  dissolves in seawater, it leads to decreased pH levels. The ocean becomes less alkaline. This is referred to as ocean acidification.



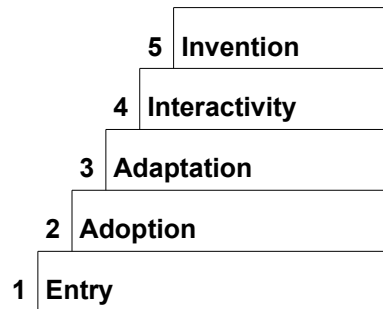
As the ocean water becomes less alkaline, there is a resulting decrease in the amount of carbonate ions available for many marine organisms to form their calcium carbonate hard parts. Coral polyps are less able to precipitate the mineral aragonite, which they use to build or rebuild their skeletons. This means that a coral reef might stop growing and become more vulnerable to erosion. Other marine organisms, such as oysters, might also be harmed.

Understanding ocean acidification is important for citizens engaged in debating global climate change issues, policies, and solutions. If

atmospheric CO<sub>2</sub> levels continue to rise, coral reefs may disappear from all of Earth's oceans by 2100.

## Lesson Overview

### Scaled Levels



This curriculum incorporates a scaled approach to learning. Each module offers activities at five different levels of student interaction, sometimes referred to as Entry, Adoption, Adaptation, Interactivity, and Invention. The early levels are very directed and teacher-driven, which provides important first steps when learning something new. The levels of Adaptation through Invention are more student-directed and open up opportunities to design lessons featuring student inquiry.

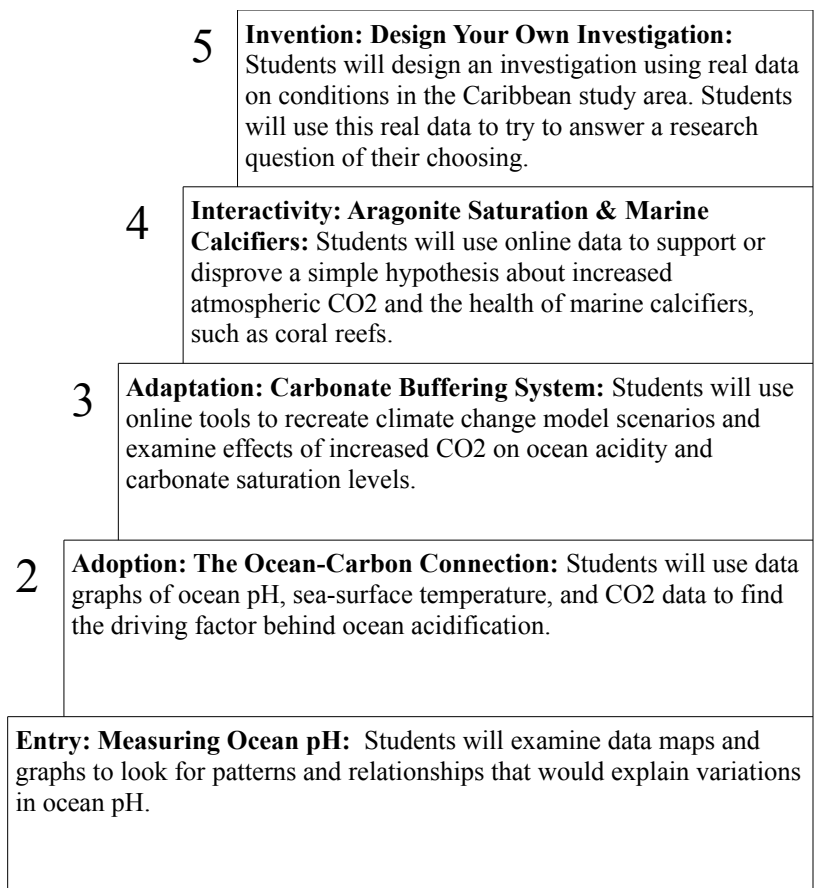
The levels serve a dual purpose. They are designed to engage students in increasingly sophisticated modes of understanding and manipulating data. They are also intended to help you, as a teacher, familiarize yourself with online tools for accessing data and to provide you with models for integrating the use of real data into your classroom practice.<sup>1</sup>

The chart below illustrates the five levels of this module, Understanding Ocean Acidification.

<sup>1</sup> For more information about the research behind this approach, consult these papers:

Dwyer, D. C., Ringstaff, C., & Sandholtz, J. H. (1990). Teacher beliefs and practices, Part I: Pattern of change. ACOT Report # 8. Cupertino, CA: Apple Classroom of Tomorrow Advanced Technology Group, Apple Computer, Inc.

Bransford, J.D., Goin, L., Hasselbring, T.S., Kinzer, C.K., Sherwood, R.D., & Williams, S.M. (1999). Learning with technology: Theoretical and empirical perspectives. Peabody Journal of Education. 5-26.



The levels provide a natural opportunity for you to adapt and customize the curriculum module as needed. For example, if students already have experience with the topic, you may find that you can skip the entry level activities.

## Using the Technology

Teaching using technology presents some challenges. Because this curriculum demonstrates strategies for using real scientific data available on the Internet, it assumes that you and your students will have access to the Internet at some point during the investigation. Because the level and availability of Internet access varies widely from setting to setting, however, you may need to adapt the activities to suit your particular situation. To help you, the activities are designed with flexibility in mind.

For example:

- When access to real data is needed, the Preparation section describes steps that can be performed outside of class. Data and results can be saved for use in class.
- Data can be accessed through the [dataintheclassroom.org](http://dataintheclassroom.org) Web site using special forms that have been designed for this project. While it is recommended that you familiarize yourself with how to access data using these tools, the early lessons also contain blackline masters of important maps, graphs, and other data products, which can be used in settings where live Internet access is not available.
- An important outcome of these activities, especially at the higher levels, is for students to learn how to access and manipulate data themselves. In the ideal case, students will access the Internet individually or in groups in order to generate maps and graphs using real data. In settings where this is not possible, the curriculum provides student masters, which can be reproduced and used in class. To fully explore the questions posed in the highest level activities, however, students in these settings will need to access the Internet in a library or computer center outside of class.

## National Education Standards

This curriculum module is aligned with the national education standards in science and mathematics for grades 9-12. The table below presents a list of core standards covered at each of the activity levels.

	Science <sup>2</sup>	Mathematics <sup>3</sup>
<b>Level 1</b> <b>Measuring Ocean pH</b>	<b>Content Standard A: Science as Inquiry</b> Scientists rely on technology to enhance the gathering and manipulation of data.	
<b>Level 2</b> <b>The Ocean-Carbon Connection</b>	<b>Content Standard B: Physical Science</b> A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms.	
<b>Level 3</b> <b>The Oceans &amp; Carbonate Chemistry</b>	<b>Content Standard D: Earth and Space Science</b> The earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical reservoirs. Each element on earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles.	<b>Data Analysis and Probability Standard:</b> Students should be able to use simulations to explore the variability of sample statistics from a known population and to construct sampling distributions.

<sup>2</sup> National Academy of Sciences. (1996). *National Science Education Standards*. Washington, D.C.: National Academy Press.

<sup>3</sup> National Council of Teachers of Mathematics. (2001). *Principles and Standards for School Mathematics*. Washington, D.C.

	Science	Mathematics
<p><b>Level 4</b> <b>Aragonite Saturation &amp; Marine Calcifiers</b></p>	<p><b>Content Standard C: Life Science</b> Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption.</p> <p><b>Content Standard C: Life Science</b> The distribution and abundance of organisms and populations in ecosystems are limited by the availability of matter and energy and the ability of the ecosystem to recycle materials.</p>	<p><b>Algebra Standard:</b> Students should be able to approximate and interpret rates of change from graphical and numerical data.</p> <p><b>Representation Standard:</b> Students should be able to create and use representations to organize, record, and communicate mathematical ideas.</p>
<p><b>Level 5</b> <b>Design Your Own Investigation</b></p>	<p><b>Content Standard A: Science as Inquiry</b> Design and conduct scientific investigations. Formulate and revise scientific explanations and models using logic and evidence</p>	<p><b>Representation Standard:</b> Students should be able to create and use representations to organize, record, and communicate mathematical ideas.</p> <p><b>Communication Standard:</b> Students should be able to communicate their mathematical thinking coherently and clearly to peers, teachers, and others.</p>

## **Selected States**

Correlations to selected state science standards can be downloaded from the Ocean Acidification teacher page at [www.dataintheclassroom.org](http://www.dataintheclassroom.org).

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## **Climate Literacy Essential Principles**

- The abundance of greenhouse gases in the atmosphere is controlled by biogeochemical cycles that continually move these components between their ocean, land, life, and atmosphere reservoirs.
- The chemistry of ocean water is changed by absorption of carbon dioxide from the atmosphere. Increasing carbon dioxide levels in the atmosphere is causing ocean water to become more acidic, threatening the survival of shell-building marine species and the entire food web of which they are a part.
- Environmental observations are the foundation for understanding the climate system. From the bottom of the ocean to the surface of the Sun, instruments on weather stations, buoys, satellites, and other platforms collect climate data.

## **Ocean Literacy Essential Principles and Fundamental Concepts**

- The ocean is a major influence on weather and climate. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.
- Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially.
- Humans affect the ocean in a variety of ways. Human development and activity leads to pollution (point source, non-point source, and noise pollution).



**Summary**

Grade Level: 10 - 12

Teaching Time: 40 minutes

Activities:

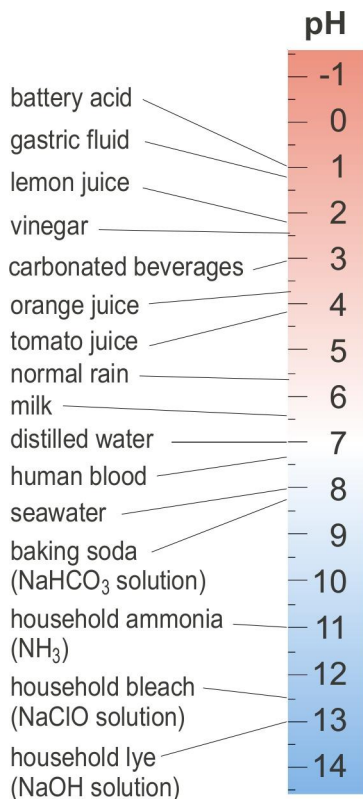
- Examine false-color maps to examine changes in pH within the study area.
- Compare time-series graphs to correlate changes in pH and sea-surface temperature over time.

**Objectives**

- Students will learn how to use online tools to access false-color data maps and graphs of ocean pH data.
- Students will examine data maps and graphs to look for patterns and relationships that would explain variations in ocean pH.

**Background**

Your students should be familiar with measuring the pH of solutions in the laboratory. pH is the measure of the hydrogen ion concentration in a solution. pH is used to express acidity or alkalinity on a scale of 0 to 14. Less than 7 represents acidity, 7 is neutral, and greater than 7 is alkaline. This illustration shows the pH values of common solutions:



pH is measured on a logarithmic scale, where small changes have increasingly greater effects. A solution with a pH of 3 is ten times more acidified than a solution with a pH of 4 and 100 times more acidified than solution with a pH of 5.

Earth’s oceans are naturally slightly alkaline. The pH of surface seawater is around 8.1. Ocean acidification refers to the observed, ongoing process by which the pH in Earth’s oceans is gradually decreasing, with the result that the water is becoming less alkaline. In this instance, “acidification” means that it the pH is becoming increasingly less alkaline and moving toward the acid end of the pH scale. The water in Earth’s oceans will never actually become acidic.

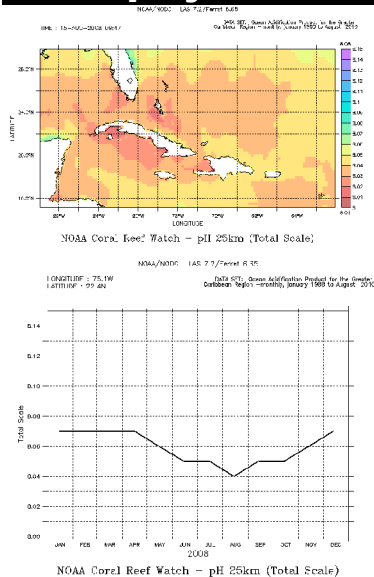
Scientists are not able to measure pH over vast expanses of ocean. Instead, they have created models based on satellite-imaging data to look at complementary data that allows them to better understand changes in pH over large areas of ocean. Results of these models are then checked

## Take Note

### What is a scientific model?

A scientific model is a representation of a complex phenomenon that helps us better understand the phenomenon. Models are approximations. Scientists start by proposing simple models that can be tested against actual phenomenon. The original model can then be rejected or modified. A good model becomes more accurate over time as it continues to be tested against observed data.

## To Display



Generate these images at  
[www.dataintheclassroom.org](http://www.dataintheclassroom.org)

with hands-on data collected by researchers on ships or from scientific instruments on buoys distributed within a study area. This is the type of data you will access and share with your students in this activity and which your students will access later in the Ocean Acidification module.

## Preparation

If you have access to a computer and projector, you can display a color version of the pH contour maps you create online. Use the following steps:

1. Visit [www.dataintheclassroom.org](http://www.dataintheclassroom.org) and click on the Ocean Acidification module link.
2. To access the data area for the Ocean Acidification module, select the “Get Data” link at the bottom of the left menu.
3. First you will create two pH maps for the entire study area in the Caribbean. In future data sets, you will be able to select a portion of the study area using the “Select a region” part of the screen. For now, leave this set for the default area.
4. Select “pH” in the “Which parameter?” pulldown.
5. Next select “Map” on the menu labeled “Which view?”
6. Specify the date by changing the date input to “January 2008.”
7. Select “Image” on the menu labeled “Select an output format.”
8. Finally, click the “Get Data” button. A new browser window will open that contains the pH map image you requested.
9. You may now save the pH map image to your local computer for later use. On a PC, right-click on the map with your mouse, select “Save Image as...” and provide a file name and local save destination. On a Mac, hold down the Ctrl key and click with the

## Vocabulary

**pH** – measure of the hydrogen ion concentration in a solution. pH is used to express acidity or alkalinity on a logarithmic scale of 0 to 14. Less than 7 represents acidity, 7 is neutral, and greater than 7 is alkaline.

**acidic** – a solution is acidic if it has an excess of hydrogen ions. Acidic solutions have a pH of less than 7.

**alkaline** – a solution is alkaline if it has a low concentration of hydrogen ions. Alkaline solutions have a pH greater than 7.

**ion** – an electrically charged atom or group of atoms formed when one or more electrons are gained or lost

**sea surface temperature** – the average water temperature of the uppermost layer of the ocean, measured from the air-water contact to only a few millimeters deep

**false-color map** – a map that uses colors to represent differences in measured values. The color is “false” in that the land, water, or other surface being shown is not really that color.

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mouse. When you have finished saving the map image, you may close that browser window.

10. Now create the second pH map. Change the date input to “August 2008” and click the “Get Data” button. Save the second pH map image to your local computer. When you have finished saving the map image, you may close that browser window.
11. Next you will create two time-series graphs. These will show changes in pH over time for a point location in the middle of the default study area. You do not need to change the parameter or output format selections.
12. First, change from “Map” to “Time series graph” on the menu labeled “Which view?”
13. Change the first date input to “January 2008.” A second date input will appear. Change it to “December 2008.”
14. Click the “Get Data” button. A new browser window will open that contains the pH time-series graph image you requested. This graph shows changes in pH during 2008 for a location at the center of default geographic area. When you have finished saving the graph image, you may close that browser window.
15. Finally, change the date inputs to “January 1995” and “August 2010.” Click the “Get Data” button. A new browser window will open that contains the pH time-series graph image you requested.
16. When you have finished saving the second graph image, you may close that browser window.
17. The last image to create is a time-series graph of sea-surface temperature (SST) for the year 2008. Select “Sea surface temperature” in the “Which parameter?” pulldown.
18. Change the date inputs to “January 2008” and “December 2008.”

19. Leave the view set to “Time series graph.”

20. Click the “Get Data” button. Save your new graph.

## Materials

- Computer or overhead projector
- Map and graph image(s) saved to your computer
- Copies of Student Master

## Procedure

Now that you have the images, you can either show them from your computer if it is connected to a projector, or make transparencies of the images for display using an overhead projector.

1. Show your students the map that displays monthly average pH for January 2008. Explain the key features of the map:
  - The map shows an area of the Caribbean Sea centered just northeast of Cuba and southeast of southern Florida.
  - X axis = longitude, degrees west of the Prime Meridian.
  - Y axis = latitude, degrees north of the Equator.
  - The map is a false-color map representing ocean surface water pH using colors. The key on the right correlates pH values to map colors. Have students look at the numbers at the top and bottom of the color key. These show the highest and lowest data points on the map. Therefore, while the color key goes up to pH 8.15, there are not data points above pH of 8.12. That is why there are no purple areas on the map. Similarly, while the color key goes down to a pH of 8.00, the lowest pH on the map is 8.06. That is why there are no orange or red areas on this map.
  - Map colors represent areas on the map with the same pH data readings. The light blue color on the map shows an area of ocean where the pH is 8.10. The blue-green color adjacent to the light blue area shows an area where the pH is 8.09.
2. The pH of ocean water is around 8.1. Students should know that, since pH 7 is considered neutral, a pH of 8.1 means that ocean water is slightly alkaline or basic. Discuss these questions: *Where on this map is the water more acidic? Where is the water more alkaline?* Students should know that lower pH values represent less alkaline conditions.

3. Now show students the pH data map for August 2008. Place the January 2008 and August 2008 pH maps side-by-side so that students can compare the two maps. Discuss these questions: *Is the water more basic or more acidic in August than in January? What evidence is there on the maps for this conclusion?* Students may give either colors or the data extremes at the top and bottom of the two map scales as evidence that the water in the study area was more acidic in August 2008 than it was in January 2008.
4. Next show students the time-series graph that displays pH change in the area over the entire year 2008. Explain the key features of the graph:
  - X axis = time, months of the year 2008.
  - Y axis = pH.
  - Students should notice that the graph contains only one data point per month which is plotted as occurring in the middle (15<sup>th</sup> day) of the month.
5. Students should also notice that the graph is for a single latitude/longitude location (top left above graph). This location is in the center of the geographic area specified when creating the false-color map.
6. Discuss the following questions: *Does the change in pH reflect what you observed on the two false-color maps for January and August 2008? In what months is the water the most basic (highest pH)? In what months is the water the most acidic (lowest pH)?* Students should suggest a seasonal explanation for the observed changes in pH.
7. Now show students the sea-surface temperature time-series graph for 2008. Place this graph side-by-side with the pH time-series graph for 2008 so that students can compare the two graphs. Discuss this question: *Does the temperature data support the idea that lower pH is linked to warmer surface water temperatures?* Students

should observe that the warmest water temperatures correlate to the lowest pH (most acidic water).

8. Review the importance of the log scale when measuring pH. Small changes in pH can represent larger and larger changes in H<sup>+</sup> ion concentration [H<sup>+</sup>], which can cause decreased alkalinity in Earth's oceans. A decrease of only 0.1 is equivalent to about a 26% increase in [H<sup>+</sup>]. For high school students, this would be a good time to review how to calculate [H<sup>+</sup>] from pH values using the formula: -  
$$\text{pH} = \log [\text{H}^+]$$
9. Give each student a copy of the Student Master, pH Time-Series Graph, 1988 to 2010. Students should use the graph to answer the questions on the Master:

Answers:

1. pH 8.10
2. pH 8.07
3. The graph shows a gradual decrease in pH over time.
4. The pH decreased from 8.10 to 8.07 between 1989 and 2009. The water is still alkaline, but it has become less alkaline.
5. On a logarithmic scale, changes increase by greater and greater values. A pH 0.1 change represents greater and greater [H<sup>+</sup>] as you move down the pH scale.

## Student Master

### pH Data

NOAA/NODC LAS 7.2/Ferret 6.65

LONGITUDE : 75.1W  
 LATITUDE : 22.4N DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly\_05 May  
 (1988-2009|10)



NOAA Coral Reef Watch – pH 25km (Total Scale)

### Questions

1. What was the average pH of water in the study area for the year 1989?
2. What was the average pH of water in the study area for the year 2009?
3. How would you describe the overall slope of the pH graph line?
4. For this time period, has the water become more acidic or more basic?

Look at the following table. pH is measure of the H<sup>+</sup> concentration in a solution. The second column shows the amount of concentration of H<sup>+</sup> ions for different pH values.

pH	[H <sup>+</sup> ]	[H <sup>+</sup> ](exp. as y x 10 <sup>-9</sup> )	Change in [H <sup>+</sup> ]
8.2	6.8 x 10 <sup>-9</sup> M	6.8 x 10 <sup>-9</sup> M	-----
8.1	7.9 x 10 <sup>-9</sup> M	7.9 x 10 <sup>-9</sup> M	1.6 x 10 <sup>-9</sup> M
8.0	1.0 x 10 <sup>-8</sup> M	10.0 x 10 <sup>-9</sup> M	2.1 x 10 <sup>-9</sup> M
7.9	1.3 x 10 <sup>-8</sup> M	13.0 x 10 <sup>-9</sup> M	3.0 x 10 <sup>-9</sup> M

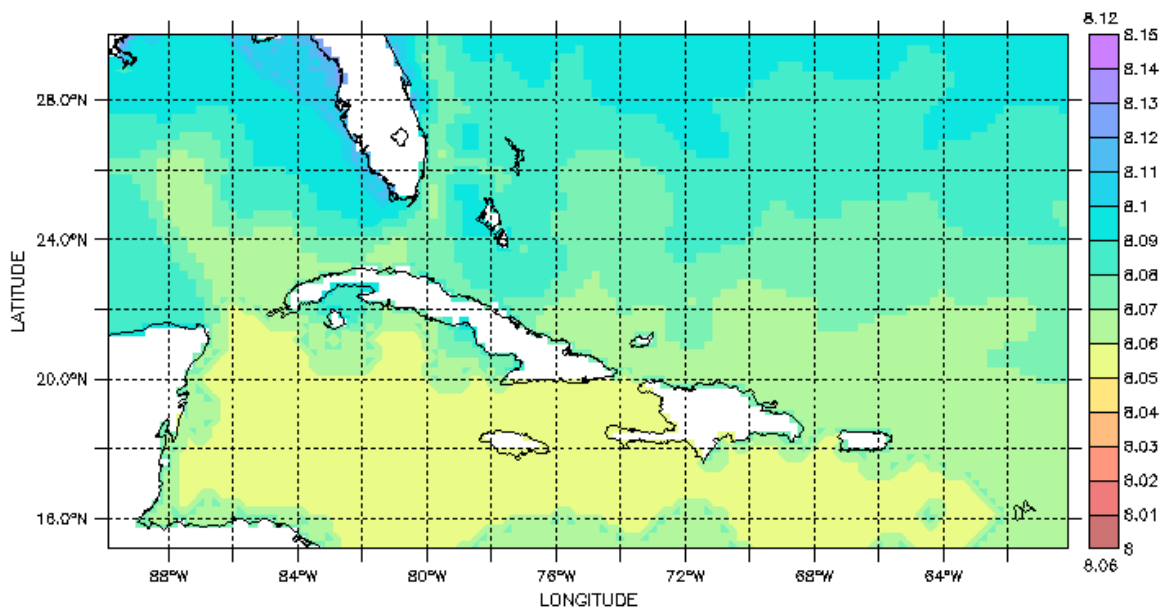
5. What evidence do you see in the table for pH being measured on a logarithmic scale?

# Teacher Master

NOAA/NODC LAS 7.2/Ferret 6.65

TIME : 15-JAN-2008 08:24

DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly, January 1995 to August 2010



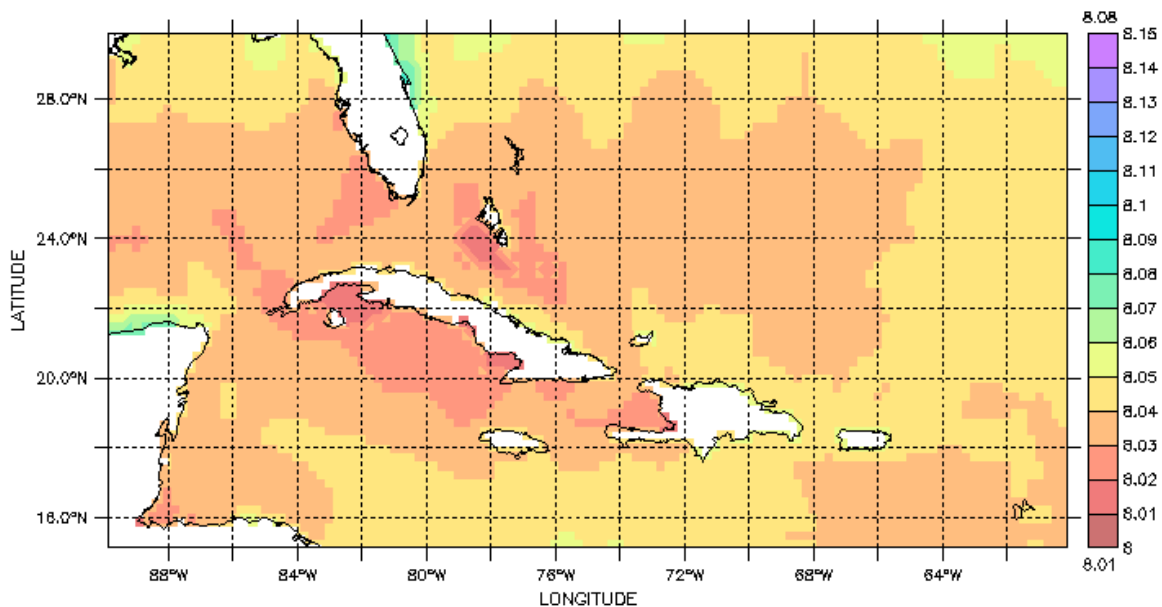
NOAA Coral Reef Watch - pH 25km (Total Scale)

pH January 2008

NOAA/NODC LAS 7.2/Ferret 6.65

TIME : 15-AUG-2008 09:47

DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly, January 1995 to August 2010



NOAA Coral Reef Watch - pH 25km (Total Scale)

pH August 2008

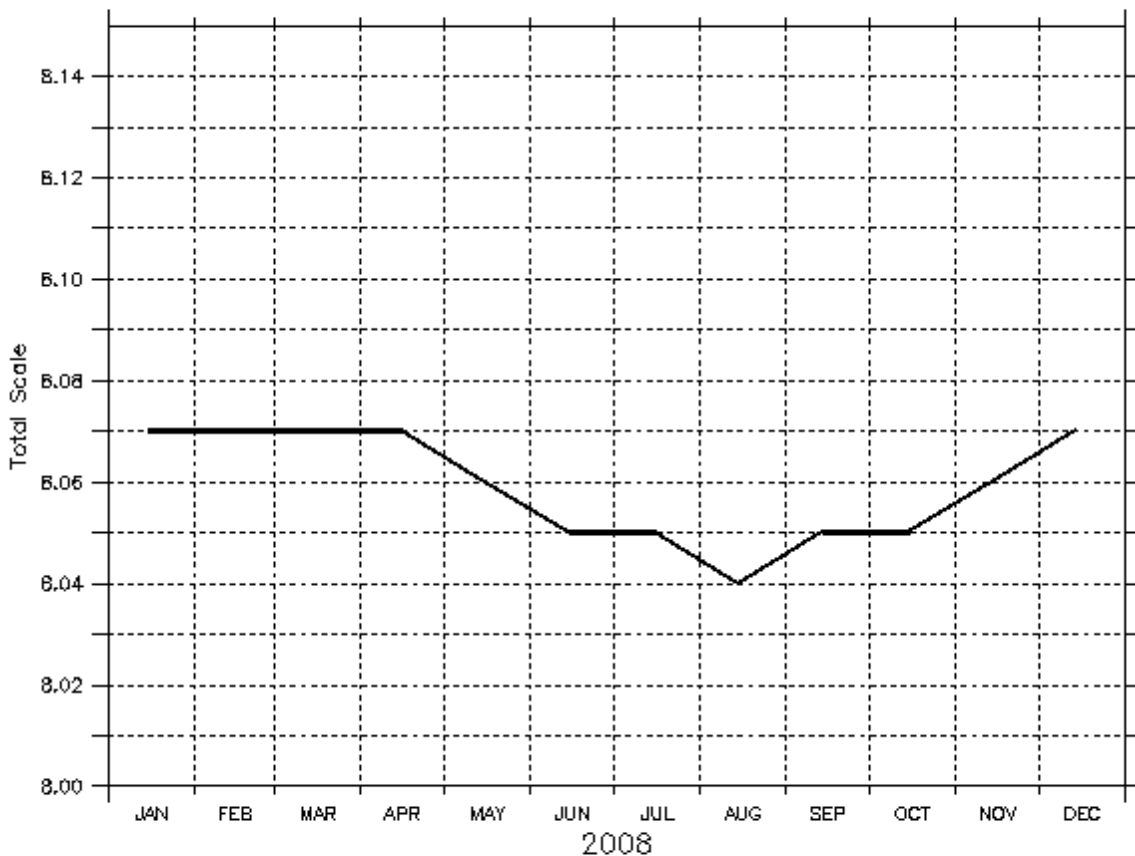


**Teacher Master**

NOAA/NODC LAS 7.2/Ferret 6.65

LONGITUDE : 75.1W  
LATITUDE : 22.4N

DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly, January 1988 to August 2010



NOAA Coral Reef Watch - pH 25km (Total Scale)

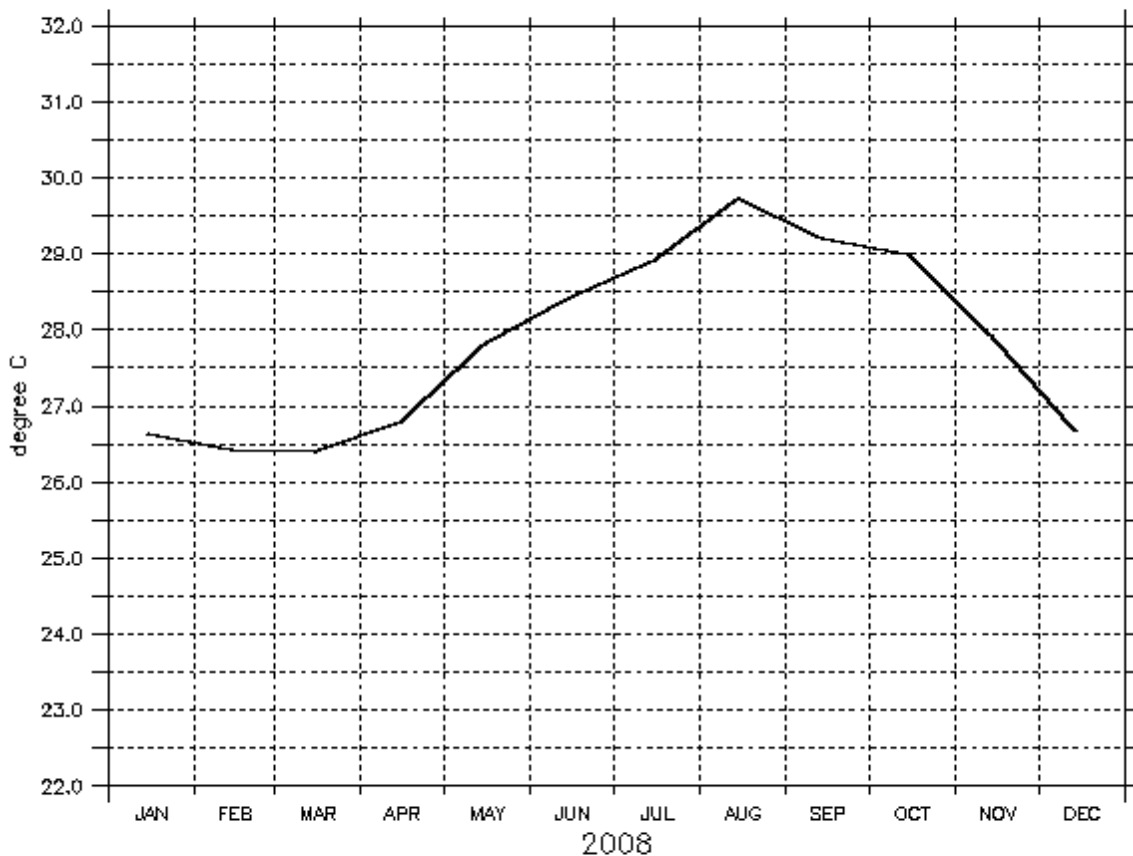
pH 2008

**Teacher Master**

NOAA/NODC LAS 7.2/Ferret 6.65

LONGITUDE : 75.1W  
LATITUDE : 22.4N

DATA SET: Ocean Acidification Product for the Greater  
Caribbean Region -monthly, January 1988 to August 2010



NOAA Coral Reef Watch - NOAA OI AVHRR-AMSRE SST 25km (degree C)

Sea surface temperature 2008

**Summary**

**Grade Level: 10 - 12**

**Teaching Time: 40 minutes**

**Activities:**

- **Examine graphs to examine changes in pH, sea-surface temperature, and dissolved CO<sub>2</sub> within the study area.**
  - **Correlate changes in pH to changes in CO<sub>2</sub> over time.**
- 

**Vocabulary**

**carbon cycle** – the recycling of organic and inorganic carbon as it moves between Earth’s biosphere, geosphere, hydrosphere, and atmosphere.

**carbonic acid** – a weak acid H<sub>2</sub>CO<sub>3</sub> formed when carbon dioxide dissolves in water.

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**Objective**

Students will use online tools to access data graphs of ocean pH, sea-surface temperature, and CO<sub>2</sub> data to find the driving factor behind ocean acidification.

**Background**

Carbon is essential to life on Earth. Carbon is a component of the tissues of both animals and plants. When animals breathe, they exhale carbon dioxide (CO<sub>2</sub>) into the atmosphere or the water. When plants respire, they take in CO<sub>2</sub>.

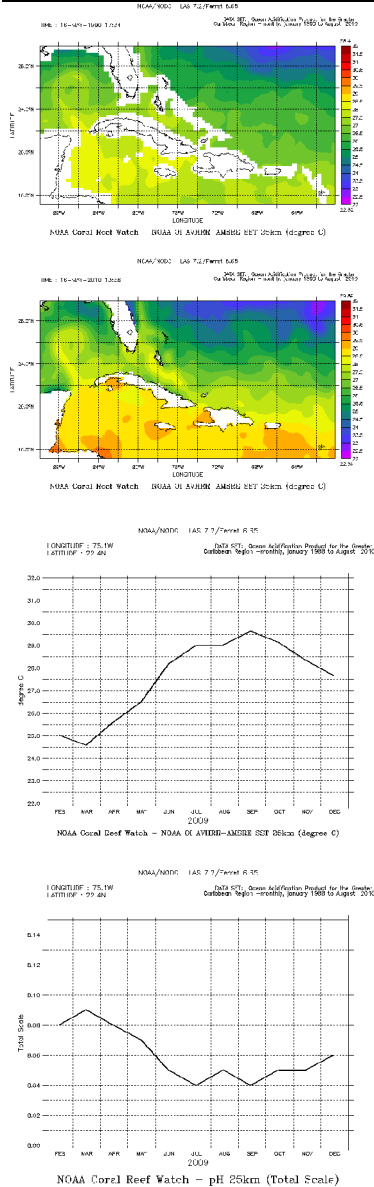
Carbon is stored in various reservoirs within the Earth system. Rocks store carbon. Soil stores carbon. Earth’s living organisms store carbon, as does Earth’s atmosphere and its ocean. However, that carbon does not stay in one place. As part of the carbon cycle, these reservoirs can either add carbon to the atmosphere or remove carbon from the atmosphere. Ideally, the amount of carbon moving into and out of the atmosphere would cancel each other out and overall levels would remain stable.

Human activity currently ensures that there is an excess of carbon moving through the cycle. Due to deforestation and modern industrial society’s use of fossil fuels, humans currently add more carbon to Earth’s atmosphere in the form of CO<sub>2</sub> than can be taken out of the atmosphere by natural processes. Earth’s ocean is one such carbon sink. The ocean absorbs approximately one-third of the CO<sub>2</sub> released into the atmosphere from human activities.

As CO<sub>2</sub> dissolves in seawater, the pH of the seawater decreases. The water becomes less alkaline. This process is called "ocean acidification." Because of the burning of fossil fuels since the start of the Industrial Age

(around 1880), Earth’s ocean is experiencing a drastic or rapid change in pH. Many ocean ecosystems may be unable to adapt to this change in ocean pH.

## To Display



**Generate these images at**  
[www.dataintheclassroom.org](http://www.dataintheclassroom.org)

## Preparation

If you have access to a computer and projector, you can display sea-surface temperature and pH time series graphs you create online. Use the following steps:

1. Visit [www.dataintheclassroom.org](http://www.dataintheclassroom.org) and click on the Ocean Acidification module link.
2. To access the data area for the Ocean Acidification module, select the “Get Data” link at the bottom of the left menu.
3. First you will create two sea-surface temperature (SST) maps for the entire study area in the Caribbean. In future data sets, you will be able to select a portion of the study area using the “Select a region” part of the screen. For now, leave this set for the default area.
4. Select “Sea surface temperature” in the “Which parameter?” pull-down.
5. Next select “Map” on the menu labeled “Which view?”
6. Specify the date by changing the date input to “May 1990.”
7. Select “Image” on the menu labeled “Select an output format.”
8. Finally, click the “Get Data” button. A new browser window will open that contains the SST map image you requested.
9. You may now save the SST map image to your local computer for later use. On a PC, right-click on the map with your mouse, select “Save Image as…” and provide a file name and local save

## Take Note

### Carbon Cycle Complexities

There are many factors that affect global, regional, and local transfer of carbon dioxide from the atmosphere to the ocean or vice-versa. Point sources (e.g., a large coal-burning power plant near the coast) may raise CO<sub>2</sub> in the atmosphere over the ocean locally, but that CO<sub>2</sub> is not tied to one location. The CO<sub>2</sub> disperses and gets spread out by air movements. Wind can also increase gas transfer from the atmosphere to the water. Bubbles formed in breaking waves can increase local transfer of CO<sub>2</sub> into the water. Photosynthetic marine organisms, such as an algal bloom, can use large amounts of CO<sub>2</sub> to grow and then store carbon in their cells until they decay.

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destination. On a Mac, hold down the Ctrl key and click with the mouse. When you have finished saving the map image, you may close that browser window.

10. Now create the second sea-surface temperature map. Change the date input to “May 2010” and click the “Get Data” button. Save the second SST map image to your local computer. When you have finished saving the map image, you may close that browser window.
11. Next you will create time-series graphs. The first graph will show changes in sea-surface temperature over time for a point location in the middle of the default study area. You do not need to change the parameter or output format selections.
12. First, change from “Map” to “Time series graph” on the menu labeled “Which view?”
13. Change the date inputs to “January 1988” and “August 2010.”
14. Click the “Get Data” button. A new browser window will open that contains the time-series graph image you requested. This graph shows changes in sea-surface temperature from 1988 to 2010 for a location at the center of default geographic area. When you have finished saving the graph image, you may close that browser window.
15. Now create the second time series graph. This graph will show changes in pH from 1988 to 2010 for the same point location as the SST time series graph.
16. Select “pH” in the “Which parameter?” pulldown. You do not need to change the view or output format selections. Make sure that the date inputs are still set to “January 1988” and “August 2010.”

17. Click the “Get Data” button. A new browser window will open that contains the pH time-series graph image you requested. When you have finished saving the second graph image, you may close that browser window.
18. Finally, create two more time-series graphs. This time, limit the time to the year 2009 by choosing “January 2009” and “December 2009” for the date inputs. Create a time-series graph for pH and another one for sea-surface temperature for this time period. Save the two graph images.

## Materials

- Computer or overhead projector
- Map and graph image(s) saved to your computer
- (for demo) container of tap water, blue pH indicator, small piece of dry ice or a straw
- Copies of Student Master

## Procedure

Now that you have the images, you can either show them from your computer if it is connected to a projector, or make transparencies of the images for display using an overhead projector. You may also choose to create maps or graphs in real time so that students see how to use the data access area of the module.

1. Show students the time-series graph that displays pH change in the area from 1988 to 2010. Explain the key features of the graph:
  - X axis = time in years
  - Y axis = pH
  - Students should also notice that the graph is for a single latitude/longitude location. This location is in the center of the geographic area specified when creating the graph.
2. The pH of ocean water is around 8.1, which is slightly basic. Students should know that lower pH values represent less alkalinity (and thereby more acidity). Discuss these questions with your students: *For this time period, has the water become more acidic or more basic? What do the regular pH increases and decreases each year represent?* Students should notice that pH has decreased gradually over the 22 year time period. Students should also notice that there is a seasonal effect each year, with pH being lower (seawater less alkaline) toward the end of summer.

3. Ask students what they would expect to find if they looked at a graph of pH change over a single year. Then show your students the time-series graph of pH for 2009.
4. Ask students what they would expect to find if they looked at a graph of sea-surface temperature (SST) over the same year. Then show your students the time-series graph of SST for 2009. If possible, show the two graphs (2009 pH and SST) side-by-side for easy comparison. *How do the two graphs correlate?* Students should notice that these two graphs are inversely proportional. As surface water temperature increases, pH decreases.
5. Discuss these questions with your students: *If every year shows the same seasonal effect on pH, why is the overall pH trending downward (i.e., less alkaline ocean) over time? What do you expect to see if you looked at a time series graph of sea-surface temperature for the longer, 1988 to 2010 time period?* Student answers to both questions will vary. Students are shown the 1988 to 2010 SST time series graph in the Student Master and will see that sea surface temperature is gradually increasing over time.
6. Show your students the time-series graph of SST for 1988 to 2010. If possible, show this graph side-by-side with the 1988 to 2010 pH graph. *How do the two graphs correlate? Do you think changes in sea-surface temperature are responsible for the long-term increase in ocean surface water acidity?* Students should notice that these two graphs are inversely proportional. As surface water temperature increases, pH decreases. However, this does not mean there is a cause-and-effect relation between the two factors. As they work through this and later activities, students discover that both SST and pH changes are caused by increased atmospheric CO<sub>2</sub>.
7. Now show your students the false-color maps that display monthly average SST for May 1990 and May 2010. If possible, show the two maps side-by-side. Explain the key features of the maps:

- The map shows an area of the Caribbean Sea centered just northeast of Cuba and southeast of southern Florida.
- X axis = longitude, degrees west of the Prime Meridian.
- Y axis = latitude, degrees north of the Equator.
- The map is a false-color map representing ocean surface water temperature using colors. The key on the right correlates temperature values in degrees Celsius to map colors. Have students look at the numbers at the top and bottom of the color key. These show the highest and lowest data points on each map.

Discuss the following questions with your students: *Why choose May when comparing temperatures from 1990 and 2010?* May represents a month that is more or less consistently a rough average between the seasonal SST highs and lows. Comparing May-to-May should help show long-term effects. *What differences in temperature do you observe between the two maps?* Southwest of Cuba and the Dominican Republic, the water is warmer in 2010 than it was in 1990. However, northeast of Cuba, water is cooler in 2010 than it was in 1990.

8. Acidity is a measure of H<sup>+</sup> concentration; the more free H<sup>+</sup> ions, the lower the solution's pH and the greater the acidity. Temperature change by itself cannot add H<sup>+</sup> ions. Where do they come from? Show your students the chemical equation:



Carbon dioxide reacts with water to form carbonic acid.



The carbonic acid then almost instantly dissociates in the seawater, releasing the H<sup>+</sup> ions and bicarbonate molecules.

You may demonstrate the formation of carbonic acid for your class using a container of water, blue pH indicator, and either a small piece



## Video



View this demonstration at  
[www.dataintheclassroom.org](http://www.dataintheclassroom.org)

of dry ice or a drinking straw. Use distilled water if possible as that will give you a neutral 7.0 pH to start. Add either Bromphenol blue or red cabbage indicator to the water in the container. The water will turn blue. This color will change when the acidity of the water changes. Bromphenol blue will turn yellow when the water becomes more acidic. The red cabbage indicator will turn more purplish. Observe what happens when you either add a small piece of dry ice (use safety gloves and goggles) to the container of water or blow into the water through a straw. In both cases, adding CO<sub>2</sub> to the water has created carbonic acid which, in solution, makes the water more acidic. If you do not want to do the demo yourself, you may show your students a video, Adding CO<sub>2</sub> to the Ocean, in which Dr. Jane Luchenco does the demo and discusses the impact of carbon dioxide on ocean water acidity.

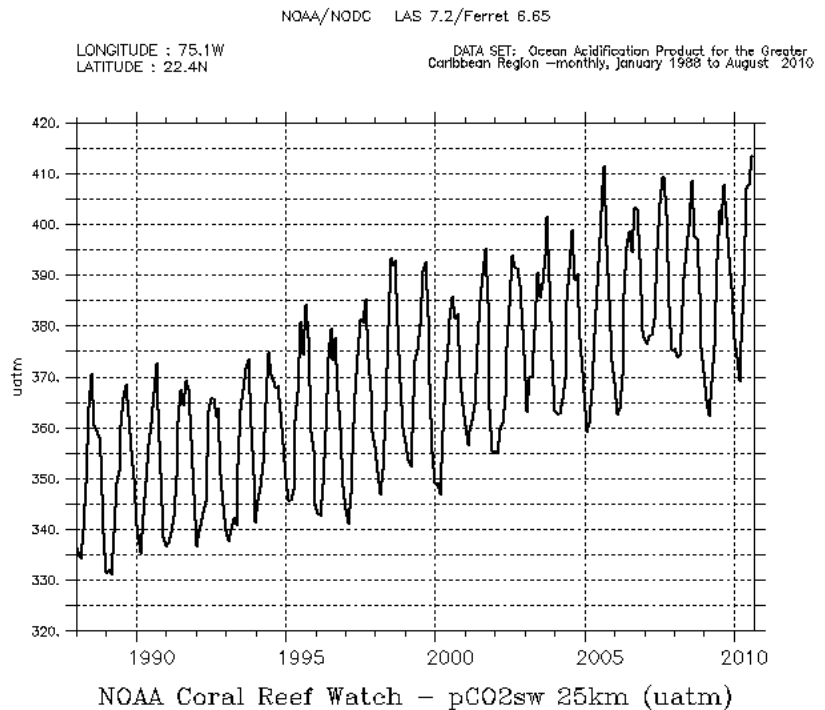
9. After your class has viewed the demonstration, discuss these questions with your students: *Why do you think that the average pH of a raindrop is 5.6? Could CO<sub>2</sub> be responsible for falling pH in the Caribbean study area and, if so, what is that CO<sub>2</sub>'s source?* Students should understand that water in contact with Earth's atmosphere is reacting with CO<sub>2</sub> in the air to form carbonic acid in the raindrop and in the ocean.
10. Briefly reintroduce your students to the global carbon cycle. Use the carbon cycle diagram provided on the Teacher Master or one you might find online or in an available text. Concentrate the discussion on the carbon exchange at the ocean-atmosphere boundary. Be sure students understand the significance of this being a cycle. Discuss these questions with students: *What sources add CO<sub>2</sub> to Earth's atmosphere? Do you think any of these CO<sub>2</sub> sources has changed considerably over time?*
11. Give each student a copy of the Student Master, Effects of CO<sub>2</sub> on Ocean Acidity. If possible, go online and show students how to create the two graphs shown on the Student Master. Students will

then follow instructions on the Student Master to create a third graph for comparison. Students should use the three graphs to answer the questions on the Master:

Answers:

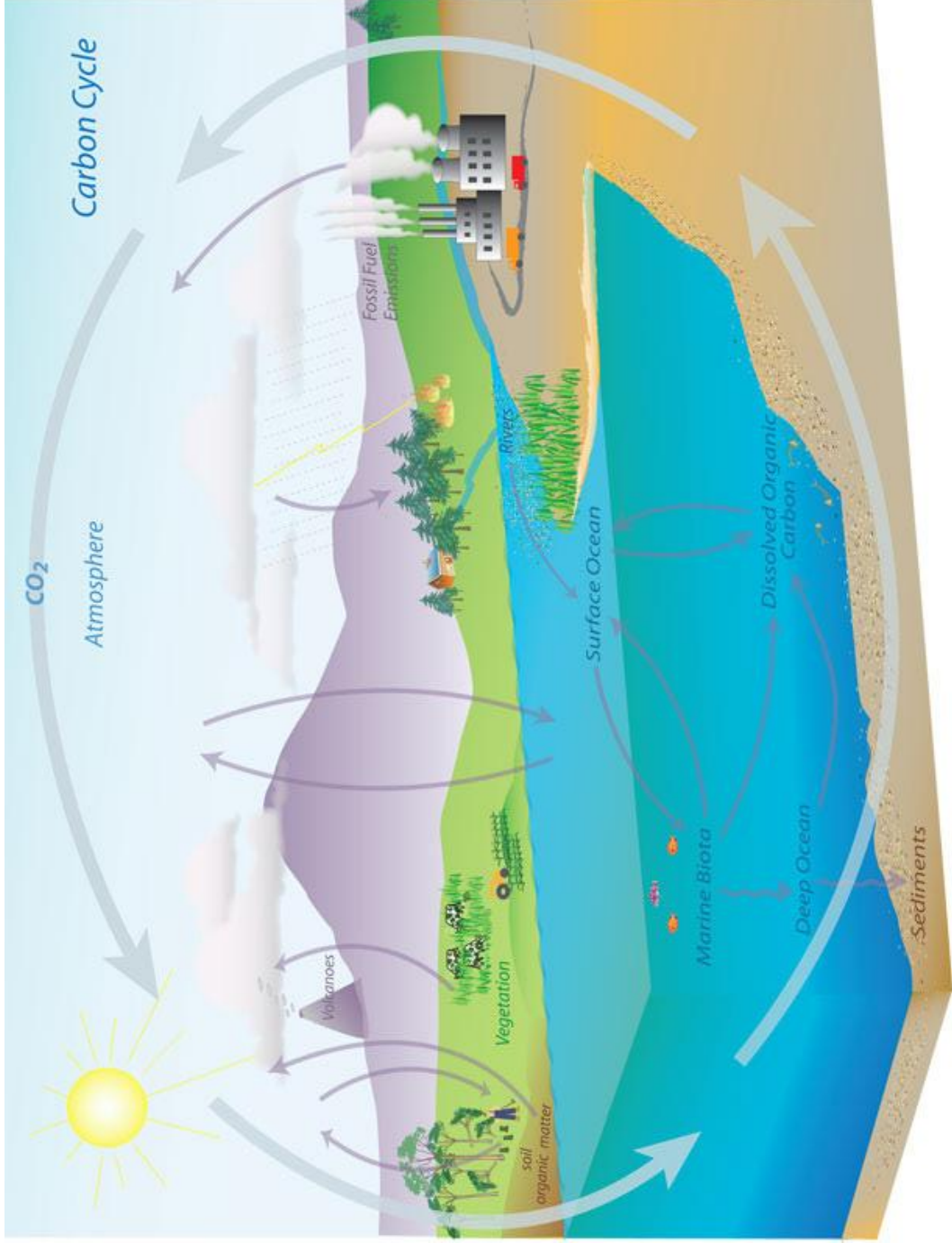
1. pH decreases over time (i.e., water becomes more acidic).
2. Sea surface temperature increases slightly over the 20 year period.
3.  $p\text{CO}_2\text{sw}$  increases over time.
4. To increase the amount of  $\text{CO}_2$  going into the water, you need to either lower the water's temperature and/or salinity, or increase the amount of  $\text{CO}_2$  in the air. Globally, increased amounts of  $\text{CO}_2$  in the air are responsible for ocean acidification.

This is the graph that students will create for the Student Master:



**Teacher Master**

**Carbon Cycle**



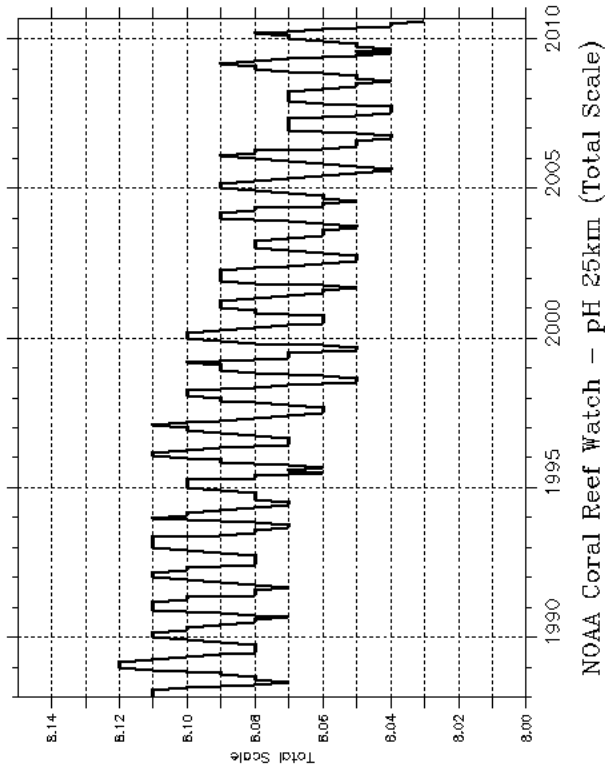
Source: NOAA

## Student Master

### Effects of CO<sub>2</sub> on Ocean Acidity

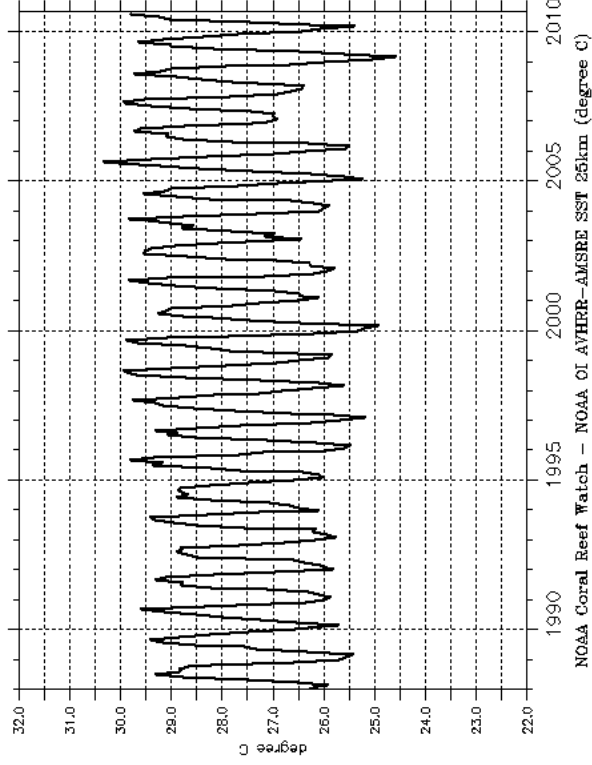
Look at the pH graph below. The graph shows that surface ocean waters in the Caribbean study area have become less alkaline over the last 15 to 20 years. Comparing the pH and sea-surface temperature graphs, you might also conclude that seasonal fluctuations in sea-surface temperature have some effect on pH. If increased H<sup>+</sup> ion concentration in the water is due to reactions between carbon dioxide in the atmosphere and water in the ocean, what would you expect to see if you graphed the amount of CO<sub>2</sub> dissolved in the water over time?

NOAA/NODC LAS 7.2./Ferret 6.65  
LONGITUDE : 75.1W  
LATITUDE : 22.4N  
DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly, January 1988 to August 2010



pH, 1988 to 2010

NOAA/NODC LAS 7.2./Ferret 6.65  
LONGITUDE : 75.1W  
LATITUDE : 22.4N  
DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly, January 1988 to August 2010



Sea-surface temperature, 1988 to 2010

For your purposes, partial pressure of carbon dioxide in sea water ( $p\text{CO}_{2\text{sw}}$ ) can be used as an approximation of dissolved  $\text{CO}_2$  in the water.

1. Visit [www.dataintheclasroom.org](http://www.dataintheclasroom.org), and find the Ocean Acidification module.
2. Follow the link to “Get Data.”
3. Leave the geographic area (latitude and longitude) set to the default study area in the Caribbean Sea.
4. Select “ $p\text{CO}_{2\text{sw}}$ ” under “Which parameter?”
5. Next select “Time series graph” on the menu labeled “Which view?”
6. Change the date inputs to “January 1988” and “August 2010.”
7. Click the “Get Data” button.
8. You may now save the graph to your local computer for later use. On a PC, right-click on the graph with your mouse, select “Save Image as...” and provide a file name and local save destination. On a Mac, hold down the Ctrl key and click with the mouse. If you have a printer available, you may also print the graph directly from the browser window. When you have finished saving or printing the graph, you may close that browser window.

## Questions

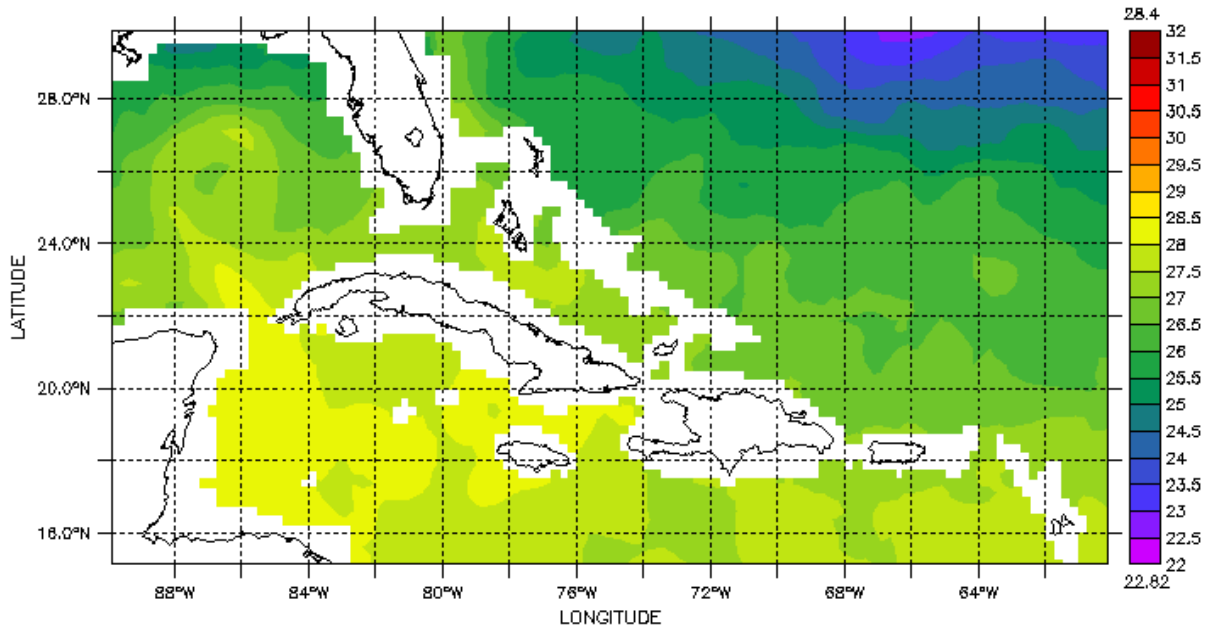
1. Ignoring the seasonal fluctuations, describe the overall trend in pH over time.
2. Describe the overall trend in sea-surface temperature over time.
3. Describe the overall trend in  $p\text{CO}_{2\text{sw}}$  over time.
4. What might cause an increase in dissolved  $\text{CO}_2$  in the ocean (and the resulting increased ocean acidity)?

# Teacher Master

NOAA/NODC LAS 7.2/Ferret 6.65

TIME : 16-MAY-1990 17:34

DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly, January 1995 to August 2010



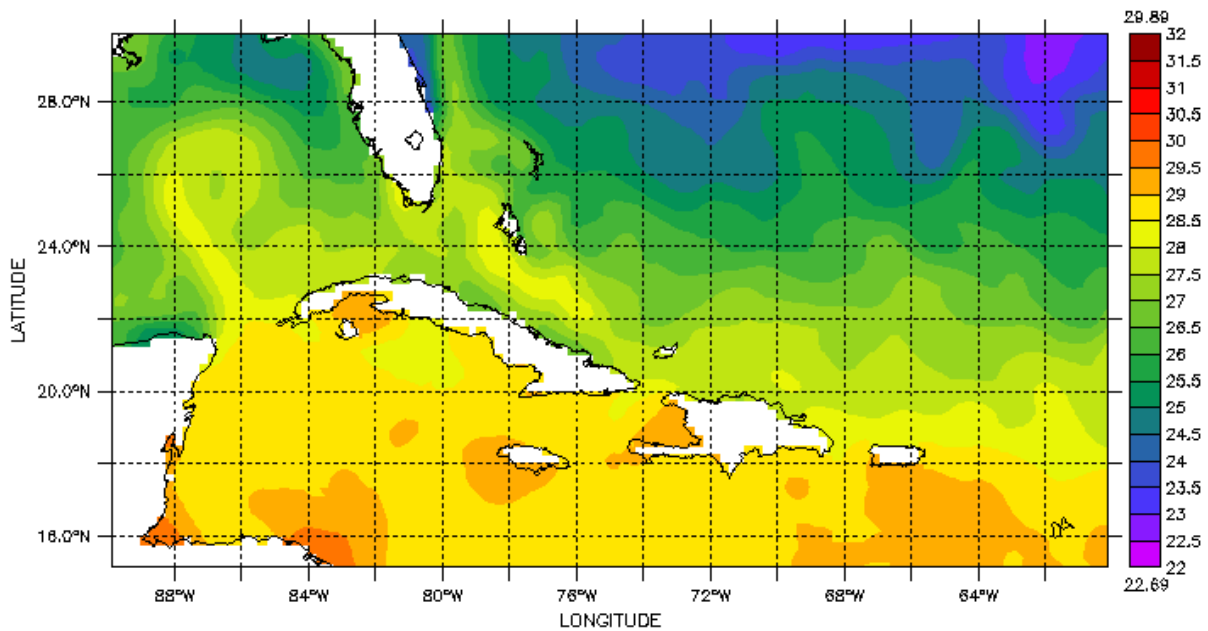
NOAA Coral Reef Watch – NOAA OI AVHRR-AMSRE SST 25km (degree C)

Sea surface temperature, May 1990

NOAA/NODC LAS 7.2/Ferret 6.65

TIME : 16-MAY-2010 13:58

DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly, January 1995 to August 2010



NOAA Coral Reef Watch – NOAA OI AVHRR-AMSRE SST 25km (degree C)

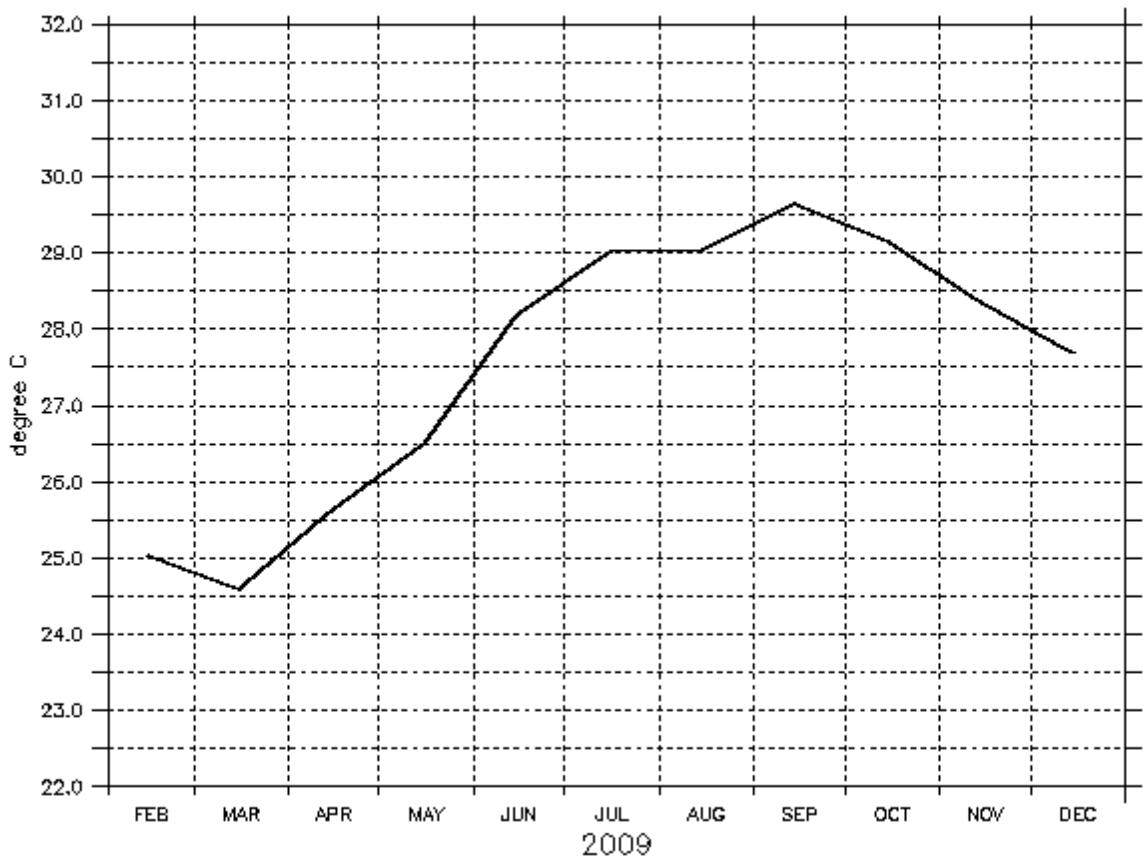
Sea surface temperature, May 2010

**Teacher Master**

NOAA/NODC LAS 7.2/Ferret 6.65

LONGITUDE : 75.1W  
LATITUDE : 22.4N

DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly, January 1988 to August 2010



NOAA Coral Reef Watch - NOAA OI AVHRR-AMSRE SST 25km (degree C)

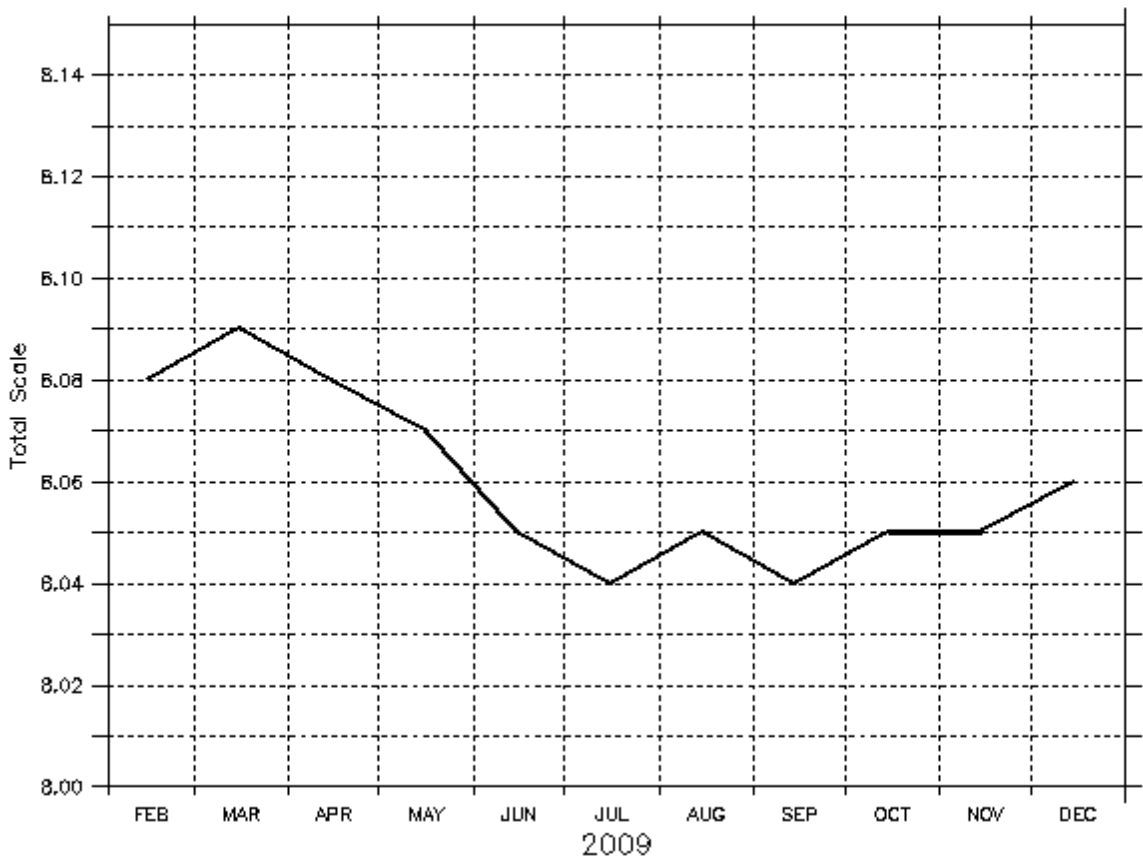
Sea surface temperature, January - December 2009

**Teacher Master**

NOAA/NODC LAS 7.2/Ferret 6.65

LONGITUDE : 75.1W  
LATITUDE : 22.4N

DATA SET: Ocean Acidification Product for the Greater Caribbean Region -monthly, January 1988 to August 2010



NOAA Coral Reef Watch - pH 25km (Total Scale)

pH, January - December 2009



**Summary**

**Grade Level: 10 - 12**

**Teaching Time: 40 minutes**

**Activities:**

- **Use an online simulation to examine the effects of changing atmospheric CO<sub>2</sub> and temperature on sea water pH and carbonate concentrations over time.**
  - **Apply simulation to different model-based scenarios of future CO<sub>2</sub> levels.**
- 

**Objective**

Students will use online tools to recreate climate change model scenarios and examine effects of increased CO<sub>2</sub> on ocean acidity and carbonate saturation levels.

**Background**

One reason models are useful is that they allow scientists to use what they know of the past and present to project possible future conditions. If the processes dependent on model parameters continue to work in the same way as they do now, what effects will changing those model parameters have in the future? For example, what would the effects be on ocean pH and on coral reefs if atmospheric CO<sub>2</sub> levels continue to rise?

Scientists worldwide have worked on many different models, attempting to use various types of current and historical data to predict future changes in atmospheric CO<sub>2</sub>, global temperature, sea-level increases, etc. Much of this work has been gathered in one place by the International Panel on Climate Change (IPCC). One result of the IPCC's work is the creation of several possible future scenarios for the changing amounts of atmospheric CO<sub>2</sub> over time and the predicted consequences.

## Vocabulary

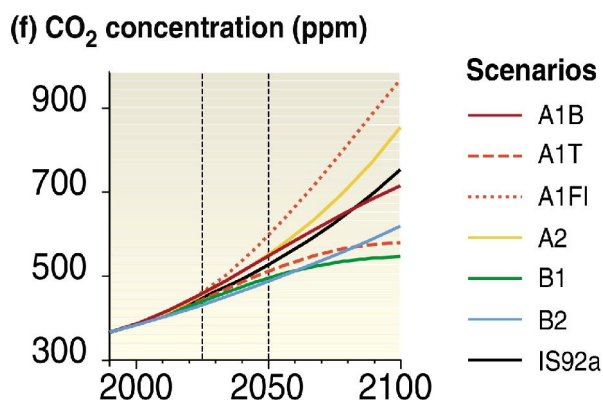
**bicarbonate** – an ion  $\text{HCO}_3^-$  formed when carbonic acid ( $\text{H}_2\text{CO}_3$ ) loses an  $\text{H}^+$  ion. A bicarbonate ion has a charge of negative one.

**carbonate** – an ion  $\text{CO}_3^{2-}$  formed when bicarbonate ( $\text{HCO}_3^-$ ) loses an  $\text{H}^+$  ion. A carbonate ion has a charge of negative two.

**aragonite** – a mineral form of calcium carbonate  $\text{CaCO}_3$  that is often used by marine life to form skeletons and shells.

**simulation** – a model that attempts to recreate how a real system or environment works.

**$\text{pCO}_2\text{atm}$**  – the partial pressure of carbon dioxide in the atmosphere.



Source: **IPCC, 2001**: Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp.

In the A1 scenarios, the IPCC model projects rapid worldwide economic growth. Population peaks mid-century. The A1Fi is the “worst case” scenario in which energy continues to be mainly derived from burning fossil fuels. A1T imagines energy as having moved to non-fossil fuels. A1B splits the difference between fossil and non-fossil fuels based scenarios.

The B scenarios imagine a somewhat rosier picture. In the B scenarios, world population still peaks mid-century. And, while these B scenarios see world and regional economies growing, they see that the types of economies move away from an emphasis on heavy industry and toward service and information economies. Emphasis is placed on cleaner, more efficient technologies.

## Preparation

Familiarize yourself with the online carbonate simulation, so that you can demonstrate it to your class using a computer and projector. The purpose of the interactive carbonate simulation is to help students see the generalized effects of rising atmospheric  $\text{CO}_2$  and changing water temperature on ocean pH and carbonate levels necessary for reef development.

## Vocabulary

**bicarbonate** – an ion  $\text{HCO}_3^-$  formed when carbonic acid ( $\text{H}_2\text{CO}_3$ ) loses an  $\text{H}^+$  ion. A bicarbonate ion has a charge of negative one.

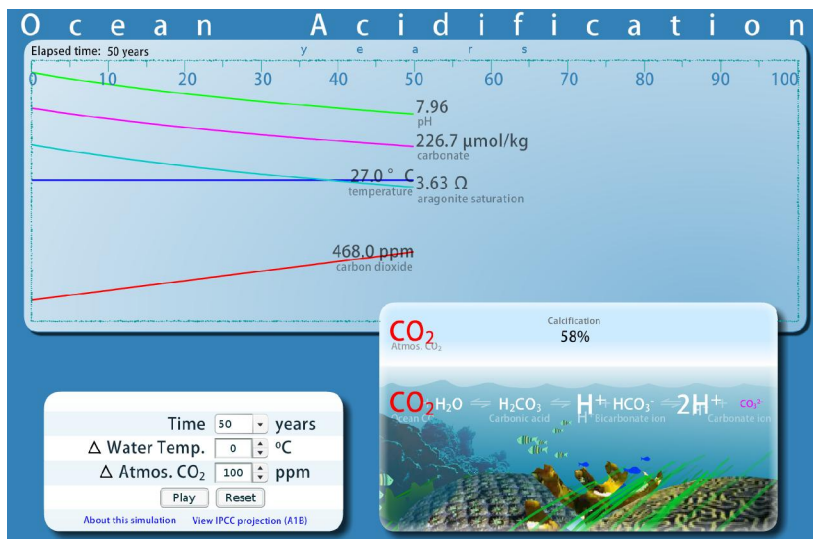
**carbonate** – an ion  $\text{CO}_3^{2-}$  formed when bicarbonate ( $\text{HCO}_3^-$ ) loses an  $\text{H}^+$  ion. A carbonate ion has a charge of negative two.

**aragonite** – a mineral form of calcium carbonate  $\text{CaCO}_3$  that is often used by marine life to form skeletons and shells.

**simulation** – a model that attempts to recreate how a real system or environment works.

**$\text{pCO}_2\text{atm}$**  – the partial pressure of carbon dioxide in the atmosphere.

1. Visit [www.dataintheclassroom.org](http://www.dataintheclassroom.org) and click on the Ocean Acidification module link.
2. Follow the link to “Carbonate Simulation.”
3. In this activity, students will be using the simulation to investigate how increased  $\text{CO}_2$  in the atmosphere affects pH and the carbonate buffering system reactions in seawater. The available inputs are time (in years), change in ocean surface water temperature (in degrees C), and change in atmospheric  $\text{CO}_2$  (in ppm). Note that the changes occur over the period of time chosen. An increase of 100 ppm  $\text{CO}_2$  over 10 years (10 ppm/year) is significantly greater than an increase of 100 ppm  $\text{CO}_2$  over 100 years (1 ppm/year). Also note that the atmospheric  $\text{CO}_2$  assumes a base value of 368 ppm. Changes in atmospheric  $\text{CO}_2$  are increases above that 368 ppm baseline, which was the level of atmospheric  $\text{CO}_2$  in the year 2000.



4. Change the “Time” setting to 50 years.
5. Change the “ $\Delta$  Water Temp.” setting to 0.5 °C. For the purposes of the simulation, water temperature has been separated from the  $\text{CO}_2$  input. Therefore, you will not see the water temperature change as a result of changing the  $\text{CO}_2$  levels. You may choose to change surface water temperature with the input, either in a

## Carbonate Buffer Model

The graphs and data seen in the simulation students use in this activity are based on the CO2SYS program, developed by researchers at the Brookhaven National Laboratory. **CO2SYS** performs calculations relating parameters of the carbon dioxide (CO<sub>2</sub>) system in seawater. Using known formulas, the program uses two of the four measurable parameters of the CO<sub>2</sub> system (total alkalinity, total inorganic CO<sub>2</sub>, pH, and partial pressure of CO<sub>2</sub>) to calculate the other two parameters, plus calcite and aragonite saturation levels, at a set of input and output conditions (temperature and pressure) chosen by the user.

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## Materials

- Computer or overhead projector
  - Copies of Student Master
  - Student access to computers with Internet connection
- 

positive or negative direction. However, in an atmosphere with increased levels of CO<sub>2</sub>, air temperature will increase over time (greenhouse effect, global warming), resulting in increased ocean surface water temperature. Average annual surface water temperature in the Caribbean Sea is expected to increase by 1.0 to 1.5 degrees Celsius by the end of this century.

6. Change the “Δ Atmos. CO<sub>2</sub>” setting to 100 ppm. This will increase CO<sub>2</sub> by 100 ppm over 50 years. This is equal to the current 2 ppm per year increase in atmospheric CO<sub>2</sub> observed by researchers.
7. Click the Play button to start the simulation. The simulation graph area shows the increasing atmospheric CO<sub>2</sub> accompanied by decreasing ocean pH (i.e., increased ocean acidity) and decreasing levels of carbonates.
8. Click the Reset button. Reenter your input choices to repeat the same simulation. This time, when you click Play, watch what happens in the inset window at the lower right of the simulation. The animated coral growth will be affected by the water conditions (i.e., pH, available calcium carbonate). In conditions that are bad for coral growth, the calcification rate will decrease, sea grass will increase, and fish populations decrease. The carbonate buffering system equations are also animated, with components increasing or decreasing in size to reflect what happens over time.

## Procedure

This activity uses guided inquiry to accomplish two objectives: 1) for students to become familiar with the complex carbonate buffering system present in Earth’s oceans; and 2) for students to understand the implications of increased atmospheric CO<sub>2</sub> on the ocean carbonate system, ocean acidity, and the ability of marine organisms to create their skeletons.

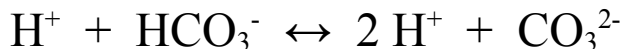
1. First show students the Teacher Master and go through the chain of chemical equations that make up the carbonate buffer system. Students may already be familiar with the first few steps if they have done Level 2 of the Ocean Acidification module. In the first chemical equation, carbon dioxide from Earth's atmosphere enters the ocean at the air/water contact and reacts with water to form carbonic acid:



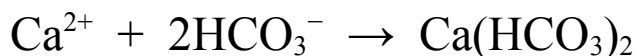
The carbonic acid almost immediately dissociates in water, releasing the hydrogen and bicarbonate ions:



The bicarbonate ions also dissociate, releasing additional hydrogen ions and forming carbonate ions:



Marine organisms that build calcareous shells use calcium carbonate in the form of the minerals, calcite or aragonite. That calcium carbonate is formed when some of the free bicarbonate ions react with calcium ions in the water to form calcium bicarbonate, which then is used to form calcium carbonate, with carbonic acid (dissociating to bicarbonate and hydrogen ions) as a byproduct:



2. These equations make up the carbonate buffer system. In chemistry, a buffer is an ionic compound that resists changes in its pH. Discuss

these questions with your students: *What is the significance of the equilibrium arrows in the carbonate equations? In what way do carbonate ions buffer the seawater against changes in pH?* Students should understand that the reactions in the carbonate buffer system work in both directions. Bicarbonate ions can dissociate to form carbonate and hydrogen ions; that increases hydrogen ion concentration. Going in the other direction, hydrogen ions can combine with carbonate ions to form bicarbonate; this decreases free hydrogen ions, thus buffering the solution by making it more alkaline.

3. Use a computer and projector to display the carbonate simulation found online at [www.dataintheclassroom.org](http://www.dataintheclassroom.org). Explain the inputs available. Set up the simulation with the inputs you used earlier (time 50 years,  $\Delta$  Water temp. 0.5 °C,  $\Delta$  Atmos. CO<sub>2</sub> 100 ppm) and click Play. Have students explain what they observe as outputs in the simulation window. Call attention to units:
  - Changes in CO<sub>2</sub> levels, both input and output, are reported as ppm (parts per million) CO<sub>2</sub>.
  - Dissolved carbonate is reported as  $\mu\text{mol/kg}$ , which is understood to mean micro-moles of carbonate dissolved in each kg of seawater.
  - Aragonite is reported as  $\Omega$ , which is the solubility ratio relating actual product of carbonate and calcium to the ideal product. An aragonite  $\Omega$  value greater than 1 means the seawater is oversaturated with ions necessary to form the mineral aragonite. An aragonite  $\Omega$  value less than 1 means the seawater is undersaturated with ions necessary to form aragonite.

Focus attention on trends in the lines. Which values go up and which go down? Click Reset and then run the simulation again. This time, have students observe the carbonate equation animation and the coral reef animation in the lower right area of the screen. What happens in each?

4. Give each student a copy of the Student Master, CO<sub>2</sub> and Carbonate Saturation. Students will then follow instructions on the Student Master to gather data online using the carbonate simulation and to answer a set of questions.

Answers:

1. The simulation shows minimal effect of increased seawater temperature on pH, and on carbonate and aragonite concentration. Increasing levels of CO<sub>2</sub> in the atmosphere leads to decreased pH (increased ocean acidity), decreased concentrations of carbonate ions, and decreased aragonite saturation levels.
2. For high  $\Delta$  CO<sub>2</sub>, the size of ions changes over time to indicate relative abundance. As time goes on, the concentration of H<sup>+</sup> ions increases (which decreases measured pH) and the concentration of carbonate ion decreases.
3. No, the pH of seawater never reaches the critical level of 7.66 in any of these three IPCC scenarios.
4. Calcification decreases with increased CO<sub>2</sub> levels. In the B2 scenario, calcification efficiency falls from 67 to 45 percent over 100 years. Carbonate and aragonite levels also decrease as CO<sub>2</sub> levels increase.

**Teacher Master**

**Carbonate Buffering Equations**



carbon dioxide

water

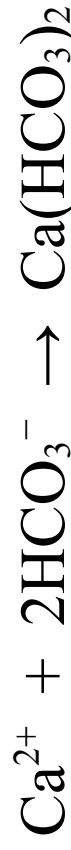
carbonic acid

hydrogen ion

bicarbonate ion

hydrogen ions

carbonate ion



Calcium ion

bicarbonate ions

calcium bicarbonate



calcium bicarbonate

calcium carbonate

bicarbonate ion

hydrogen ion

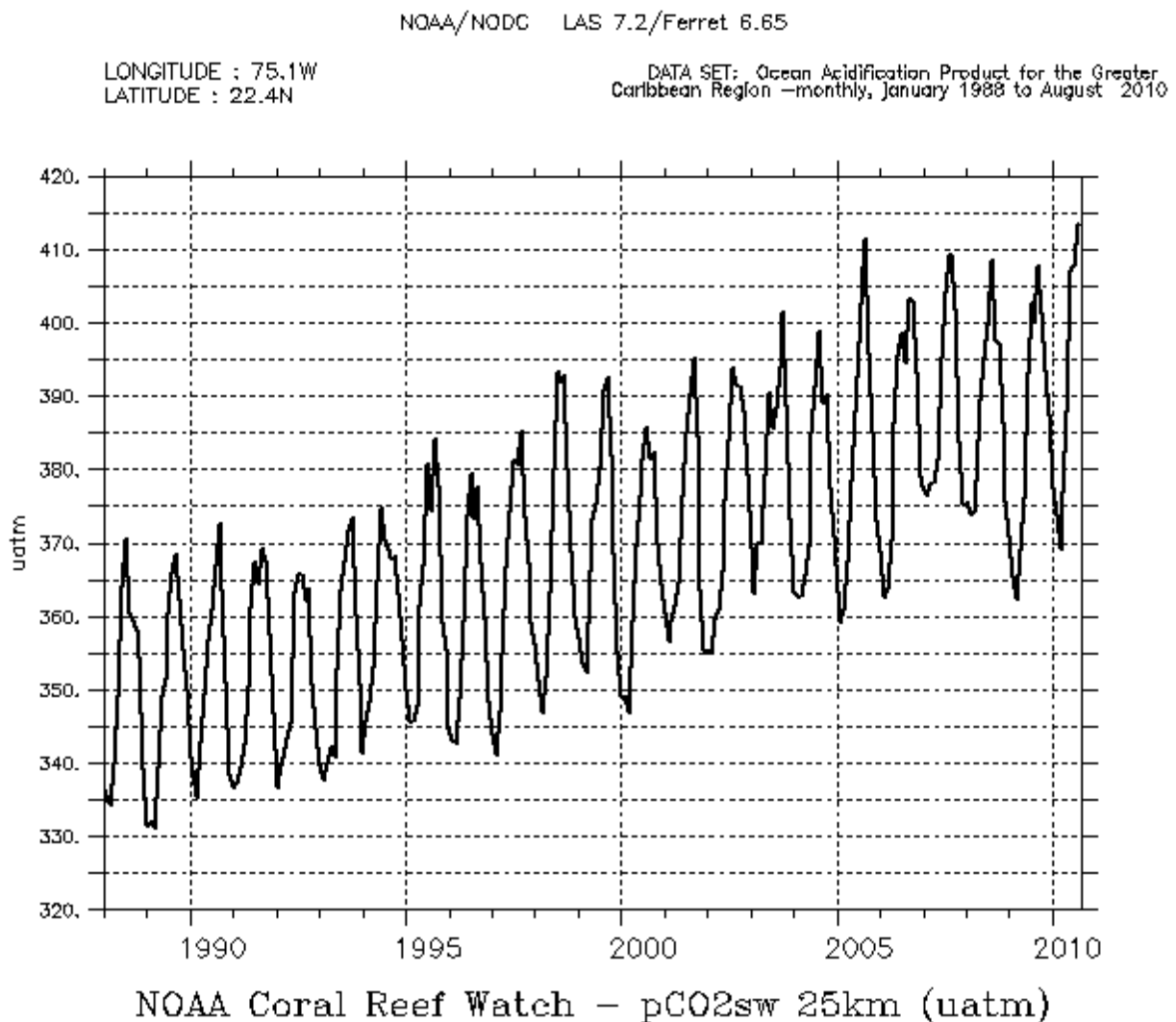


## Student Master

# CO<sub>2</sub> and Carbonate Saturation

If the IPCC best-case scenario for atmospheric CO<sub>2</sub> comes true over the next 100 years, what are the implications for ocean acidity and coral reef development?

The pCO<sub>2</sub>sw graph below shows that surface ocean waters in the Caribbean study area have experienced increased concentrations of dissolved CO<sub>2</sub> over the last 15 to 20 years. If atmospheric CO<sub>2</sub> continues to rise, what effect might that have on water pH and on the concentration of dissolved materials needed by marine life to form skeletons?



In this activity, you will use the online carbonate simulation to investigate the impact of changes in dissolved CO<sub>2</sub> and water temperature on pH and carbonate concentrations over time.

1. Visit [www.dataintheclassroom.org](http://www.dataintheclassroom.org) and click on the Ocean Acidification module link.
2. Follow the link to “Carbonate Simulation.”
3. This simulation is set up with inputs for time in years, change in surface water temperature, and change in CO<sub>2</sub> concentration just above the air/water contact. Set the time to 100 years and leave the other two inputs set to their default “0” values. Click Play. You should see that, if the CO<sub>2</sub> level remains at the default 368 ppm level, pH and dissolved carbonates (carbonate and aragonite) remain stable. The graphs “flat line.”
4. Let us see if water temperature has an effect. Select 50 years for “Time.”
5. To isolate the variables, pick a number for Δ CO<sub>2</sub> and leave that constant while you vary the change in water temperature. For now, use “50” for the “Δ CO<sub>2</sub>” input.
6. Now try different “Δ Temp” settings and run the simulation. Record the observed data in the table below.

Inputs			Outputs				
Time (years)	Δ Temp (°C)	Δ CO <sub>2</sub> (ppm)	Final water temp (°C)	Final CO <sub>2</sub> (ppm)	pH	Carbonate (μmol/kg)	Aragonite (Ω)
50	-1.0	50					
50	0.0	50					
50	+ 0.5	50					
50	+ 1.0	50					
50	+ 2.0	50					

7. Now repeat the process, except this time hold the “Δ Temp” constant at + 0.5 °C and vary the “Δ CO<sub>2</sub>” value. After each trial, click Reset and run the simulation a second time with the same settings. Watch the animated coral and animated chemical equations in the lower right window. Record the observed “Calcification” value in the table. The calcification rate displayed in this simulation is an approximation of the corals' calcification efficiency based on 100% efficiency in the year 1880, which was the beginning of the Industrial Era. A calcification rate of 67% means that an organism is only 67% as efficient at precipitating aragonite at that time as it was in 1880 when atmospheric CO<sub>2</sub> levels were much lower.

Inputs			Outputs				
Time (years)	$\Delta$ Temp ( $^{\circ}$ C)	$\Delta$ CO <sub>2</sub> (ppm)	Final CO <sub>2</sub> (ppm)	pH	Carbonate ( $\mu$ mol/kg)	Aragonite ( $\Omega$ )	Calcification
50	+ 0.5						
50	+ 0.5						
50	+ 0.5						
50	+ 0.5						
50	+ 0.5						

8. Finally, try approximating three of the IPCC model-based scenarios for CO<sub>2</sub> change in Earth's atmosphere. First look at the A1B "middle of the road" scenario. Click on the "View IPCC projection (A1B)" link at the bottom of the simulation to set the inputs. Click Play. Fill in your observations in the table below.

IPCC Scenario	Inputs			Outputs				
	Time (years)	$\Delta$ Temp ( $^{\circ}$ C)	$\Delta$ CO <sub>2</sub> (ppm)	Final CO <sub>2</sub> (ppm)	pH	Carbonate ( $\mu$ mol/kg)	Aragonite ( $\Omega$ )	Calcification
A1B	100	1.3	320					
B2	100	1.0	260					
A2	100	1.5	480					

9. Now run the B2 "environment" driven scenario. Use the input values in the table and click Play. Record your observations in the table.
10. Finally, run the A2 "economics" driven scenario and record your observations. Our simulator cannot show the effects of the "worst case" IPCC scenario (A1F1). In that "economic" scenario, our simulation would need to have an input of just over 553 ppm for  $\Delta$  CO<sub>2</sub>.

## Questions

1. Which has a greater effect on pH, change in temperature or change in CO<sub>2</sub>? Which has a greater effect on carbonate and aragonite concentration?
2. In the simulation, you observed the carbonate equation as the concentrations of ions changed over time. Describe the changes in the equation over time in trials run with high  $\Delta$  ppm CO<sub>2</sub>.
3. Below a pH of 7.40 to 7.66, coral organisms are unable to build their skeletons quickly enough to maintain a coral reef. Look at your data table. In any of these three scenarios, does the pH of seawater reach this pH level in 100 years?
4. Describe what you observed about calcification in the three scenarios. What other values decrease as CO<sub>2</sub> levels increase?

**Summary**

**Grade Level: 10 - 12**

**Teaching Time: Two 40 minute periods**

**Activities:**

- **Discuss how carbonate saturation and supersaturation affect marine life that requires calcium carbonate to form their shells and frameworks.**
  - **Use real data to understand how atmospheric CO<sub>2</sub> levels affect the health of marine calcifiers.**
- 

**Objectives**

- Students will examine the relationship between aragonite saturation levels and the health of marine calcifiers.
- Students will use online data to support or disprove a simple hypothesis about increased atmospheric CO<sub>2</sub> and the health of marine calcifiers, such as coral reefs.

**Background**

The calcium carbonate (CaCO<sub>3</sub>) in coral reefs and in the shells of other marine calcifiers comes in two different mineral forms: calcite and aragonite. The seawater at or near the ocean's surface in the tropics is supersaturated with the ions necessary to form these carbonate minerals. Ocean acidification reduces carbonate ion saturation, making it harder for marine organisms to produce the CaCO<sub>3</sub> that they use to form their shells and frameworks.

Studies of reef-building corals show a decline in the coral polyps ability to create CaCO<sub>3</sub> as aragonite saturation levels decrease. Even though the water continues to be supersaturated with the ions necessary to form aragonite, lower ion concentrations have a negative effect on the health of the coral organism. As aragonite saturation levels fall, the organism must divert energy from other important life functions to elevate ion concentrations within the immediate area of the coral tissue to allow it to continue creating its aragonite framework. If the coral polyps cannot produce CaCO<sub>3</sub> quickly enough, the coral reef as a whole will stop growing and begin to erode.

Corals mostly use aragonite to build reefs. Sea butterflies — pteropods — also produce shells made of aragonite, as do some mollusks. Two types of phytoplankton — coccolithophores and foraminifera — use

calcite, not aragonite, to form their shells. Increases in atmospheric CO<sub>2</sub> threaten the future of all these marine organisms as ocean acidity increases and carbonate ion concentrations decrease over time. For coral reefs, the effects of falling aragonite saturation levels include slower coral growth rates and decreased skeletal density.

## Vocabulary

**aragonite** – a mineral form of calcium carbonate CaCO<sub>3</sub> that is often used by marine life to form skeletons and shells.

**marine calcifier** – an organism that lives in the ocean and is able to form or accrete its own shell or framework using calcium and carbonate ions found in seawater.

**saturation state** – the degree to which a solution is saturated with a solute. A solution with saturation of 1  $\Omega$  is saturated. Solutions with  $\Omega$  greater than 1 are oversaturated (called supersaturated). Solutions with  $\Omega$  less than 1 are undersaturated.

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## Preparation

It is recommended that you do not show students examples of aragonite saturation maps and graphs before they begin this activity. A goal of this investigation is to encourage students to examine unknown data, and use skills and techniques they learned earlier to read and interpret that data.

You should still familiarize yourself with representations of this new data set, however, by following the instructions below.

1. Visit [www.dataintheclassroom.org](http://www.dataintheclassroom.org) and click on the Ocean Acidification module link.
2. To access the data area for the Ocean Acidification module, select the “Get Data” link at the bottom of the left menu.
3. Select “Saturation state (aragonite)” in the “Which parameter?” pulldown.
4. Next select “Map” on the menu labeled “Which view?”
5. Specify the date by changing the date input to “August 2010.”
6. Select “Image” on the menu labeled “Select an output format.”
7. Finally, click the “Get Data” button. A new browser window will open that contains the aragonite saturation map image you requested. When you have finished viewing the graph image, you may close that browser window.
8. Next create a time-series graph. The first graph will show changes

in aragonite saturation over time for a point located in the middle of the default study area. You do not need to change the parameter or output format selections.

9. First, change from “Map” to “Time series graph” on the menu labeled “Which view?”
10. Change the first date input to “January 1988” and the second date input to “August 2010.”
11. Click the “Get Data” button. A new browser window will open that contains the time-series graph image you requested. This graph shows changes in aragonite saturation ( $\Omega$ ) from 1988 to 2010 for a location at the center of default geographic area. When you have finished viewing the graph image, you may close that browser window.
12. Repeat the procedure to look at different dates or to generate different time-series graphs.

In this activity, students will be asked to create data tables and simple graphs using aragonite saturation data they find online at [www.dataintheclassroom.org](http://www.dataintheclassroom.org). Students may find it helpful to use spreadsheet software, such as Microsoft Excel or OpenOffice Calc, to work with and interpret the data.

## Materials

- Copies of Student Master, Research Project: Exploring Aragonite Saturation Data
- Copies of Student Master, Data Log Sheet
- Student access to computers with Internet connection
- Spreadsheet software (optional)
- Graph paper
- Ruler

## Procedure

This activity challenges students to think like scientists by designing a scientific investigation in which data collection and analysis are important parts of the process. Students are asked to use the scientific method, using real data to solve a problem.

1. Discuss the scientific method with your students. They will almost certainly have had exposure to the scientific method in their science classes in the past. However, they may not be familiar with the term “research question.” A research question is

## Video



View this demonstration at  
[www.dataintheclassroom.org](http://www.dataintheclassroom.org)

the question that the research sets out to answer. A hypothesis is one possible answer to that research question. It is the hypothesis that the researcher tests and evaluates as a possible answer to the research question.

2. Students should have as prior knowledge that adding  $\text{CO}_2$  to water creates carbonic acid and that increased  $\text{CO}_2$  levels in Earth's atmosphere are causing decreased alkalinity in Earth's oceans. The next important point is to connect ocean acidification with its effects on marine life. Show your students a video, *Impact of Acidification on Organisms*, in which Dr. Jane Luchenco demonstrates how lower pH affects marine life, including pteropods.
3. Near-surface ocean water is supersaturated with ions that marine organisms need to form their calcium carbonate (calcite and aragonite) shells or skeletons. You may want to review saturated solutions and the concept of supersaturation with your class at this time.
4. The saturation levels of the ions necessary for marine calcifiers to form shells and skeletons are an important measure of how marine life is reacting to ocean acidification. Show your students the graph on the Teacher Master. Call your students' attention to the following features of the graph:
  - The main x-axis is aragonite saturation measured in  $\Omega$ . An aragonite  $\Omega$  value greater than 1 means the seawater is supersaturated with ions needed to precipitate aragonite. An aragonite  $\Omega$  value less than 1 means the seawater is undersaturated with those ions.
  - The y-axis shows calcification rate. This is a measure of how efficiently a marine calcifier is able to form its shell or skeleton by precipitating aragonite. The unit on this axis is percent calcification efficiency based on 100% efficiency in the year 1880, which was the beginning of the Industrial Era



## Take Note

### Supersaturation & Precipitates

Some of your students may ask: “In the lab, I see precipitation occur in supersaturated solutions. Why doesn’t calcium carbonate just precipitate out of the tropical sea water until the aragonite saturation reaches 1?” One reason more precipitation of  $\text{CaCO}_3$  does not occur is because there are materials in the sea water (phosphate ions, magnesium ions, and organics) that get in the way. A seed crystal of  $\text{CaCO}_3$  cannot get large enough to precipitate out of solution because its surface is effectively cut off from the additional calcium and carbonate ions it needs to grow.

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when humans began pumping excessive amounts of  $\text{CO}_2$  into Earth’s atmosphere. Thus, 80% along the y-axis means that an organism is only 80% as efficient at precipitating aragonite at that time as it was in 1880 when atmospheric  $\text{CO}_2$  levels were much lower.

- The second x-axis is used to relate years to aragonite saturation and calcification data. Using this axis, students should see that at 1880, calcification rate was at 100% and aragonite saturation was over  $4.5 \Omega$ .
- Based on numerous experimental studies of marine calcifiers in varying aragonite saturation levels, the white line shows how the organism’s ability to calcify is affected by changes in aragonite saturation levels. Students should see that, as aragonite saturation levels decrease, the marine calcifier’s ability to form its shell or skeleton by precipitating aragonite also decreases. As aragonite saturation decreases, so does calcification rate.
- The amount by which the decrease in calcification rate affects the marine calcifier’s ability to form and maintain its shell or skeleton is indicated by the color areas. Levels above  $4.0 \Omega$  are optimal for aragonite precipitation. Levels of  $3.5$  to  $4.0 \Omega$  are considered only adequate for coral growth. Aragonite saturation levels of  $3.0$  to  $3.5$  are marginal or low. Below  $3.0 \Omega$ , conditions are extremely marginal, even critical. It is highly possible that corals would no longer exist as we know them at aragonite saturation levels of  $3.0 \Omega$  or lower.

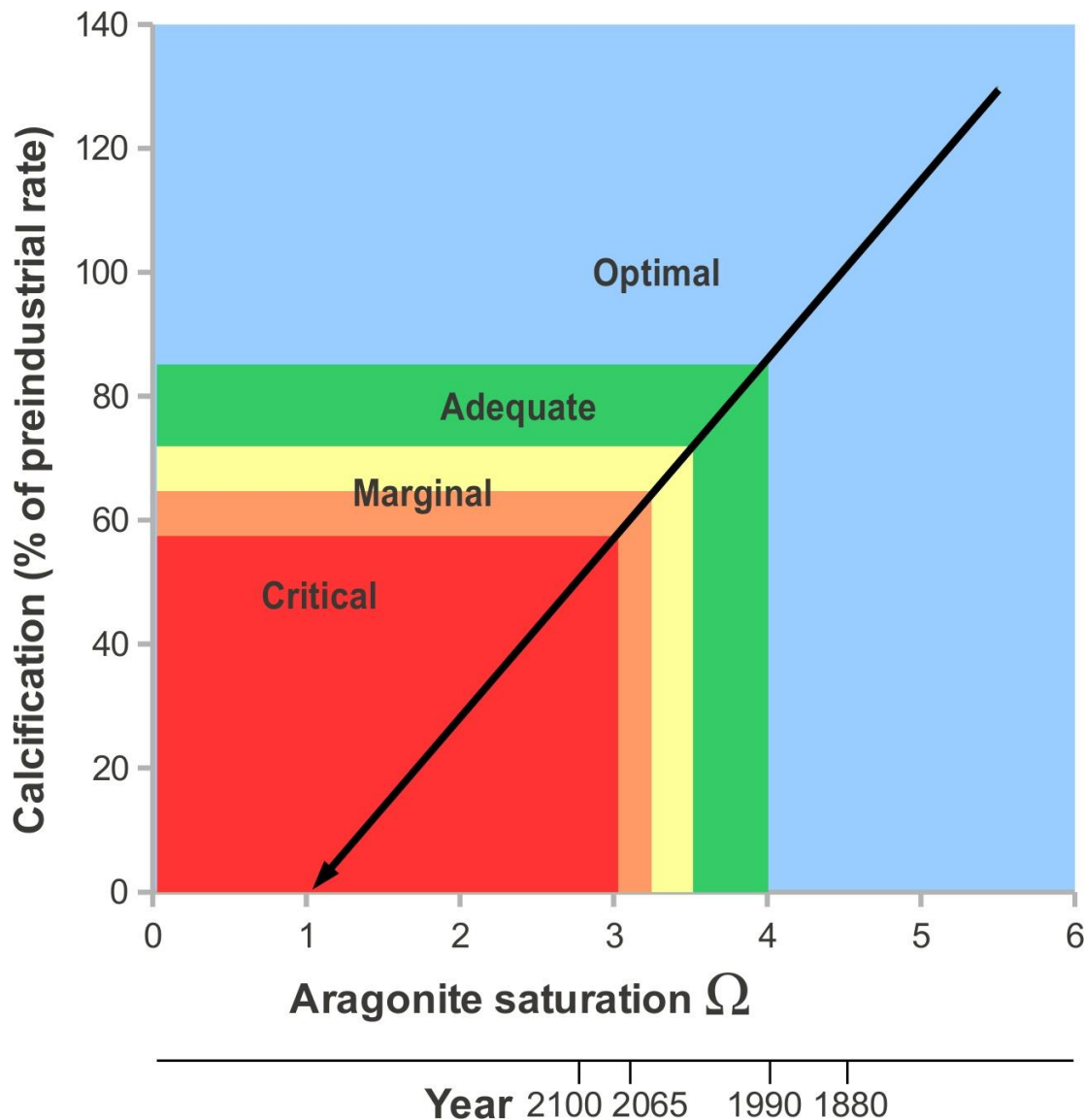
Focus student attention on the graph by asking the following questions: *Do marine calcifiers require water to be supersaturated with the ions necessary to form calcium carbonate? In what year did conditions change from Optimal to Adequate for corals?*

5. If you have additional time, you may choose to revisit the

carbonate simulation from Level 3 at this time. Visit [www.dataintheclassroom.org](http://www.dataintheclassroom.org) and click on the Ocean Acidification module link. Follow the link to “Carbonate Simulation.” Run the IPCC scenario and have students examine the aragonite saturation graph line relative to calcification. *How many years does it take for aragonite saturation to reach the 3.5  $\Omega$  marginal level? What is the calcification rate at that level?*

6. Assign students to work in teams of two. Give each team a copy of the Student Master, Research Project: Exploring Aragonite Saturation Data and the Student Master, Data Log Sheet.
7. Offer students a hint that they may want to look at historical data in order to predict the future. Online data for dissolved CO<sub>2</sub> can be used as a stand-in for atmospheric CO<sub>2</sub>. If they have not already, make sure students understand that aragonite saturation is one of the data parameters available online in the Ocean Acidification module’s “Get Data” area.
8. Students will need to access the Internet to generate and save data maps and graphs. Depending on the setting, this can be done in a computer lab or assigned as homework, assuming your students have access to the Internet at home, at a library, or in a computer center.
9. If students are using spreadsheet software, they may need guidance on setting up their spreadsheet and graphs. Show students that they can get raw data online to use in their spreadsheet by choosing “Data file for spreadsheet” under “Select an output format.”
10. Have students use the scientific method to carry out their investigation on the harmful effects of atmospheric CO<sub>2</sub> on marine calcifiers. When they have finished, have teams present their findings to the class.

## Carbonate Simulation



**Sources:**

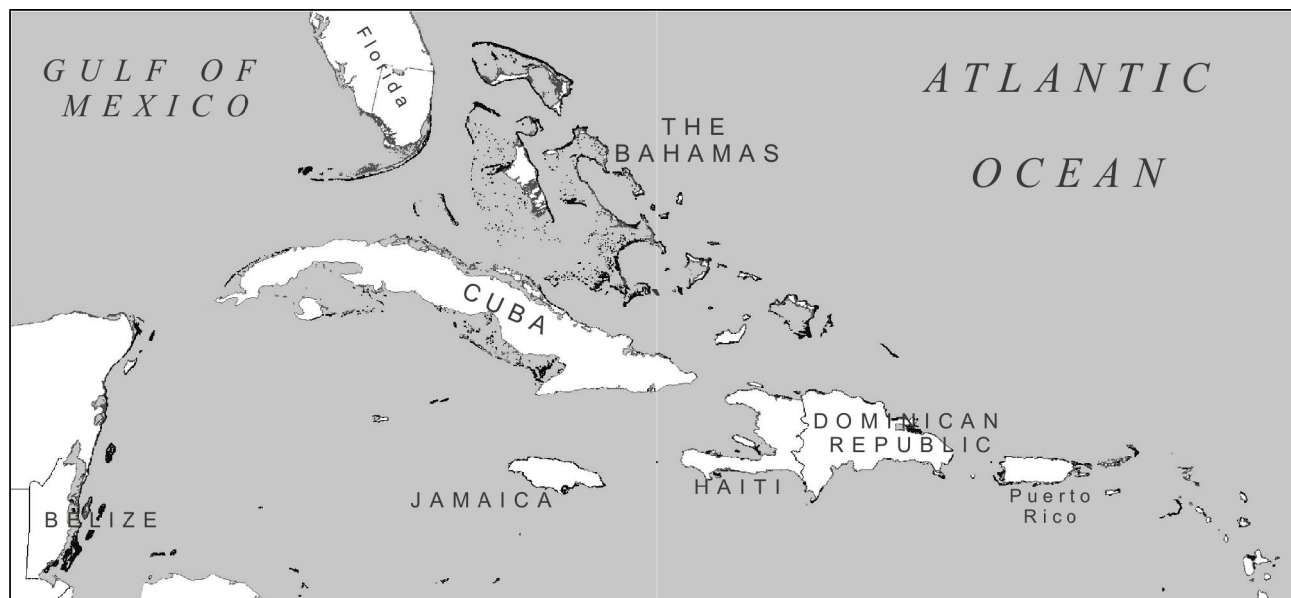
Langdon C, Atkinson MJ (2005) Effect of elevated pCO<sub>2</sub> on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment. *J Geophys Res* 110, C09S07.

J. M. Guinotte, R. W. Buddemeier, J. A. Kleypas, Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin. *Coral Reefs* (2003) 22: 551–558

## Student Master

### Research Project: Exploring Aragonite Saturation Data

You have joined a team of scientists who are studying the effects of atmospheric CO<sub>2</sub> on coral reefs in the Caribbean Sea. Coral reefs grow near the coasts of islands in the Caribbean (see map below), where the waters are warm, shallow, and rich in the dissolved materials coral organisms need to build the coral reefs.



Map provided by ReefBase. Coral reef location data provided by UNEP-WCMC. <http://www.reefbase.org/>

As aragonite saturation levels decrease, it becomes harder for marine calcifiers to precipitate the aragonite for their skeletons. Studies have shown that coral reef organisms are best able to build reefs when aragonite saturation in surface waters is greater than 4.0  $\Omega$ . Levels of 3.5 to 4.0  $\Omega$  are considered only adequate for coral growth. Aragonite saturation levels of 3.0 to 3.5 are marginal or low, with 3.3  $\Omega$  often called the critical threshold for reef growth. Major coral reef systems are not found in water with aragonite saturation below the critical 3.0  $\Omega$  level. At these levels, even though the water is still supersaturated in calcium and bicarbonate ions, the organisms cannot divert enough energy from their other life processes to precipitate adequate amounts of aragonite to form and maintain their framework.

Your task is to determine whether increased levels of CO<sub>2</sub> in Earth's atmosphere are affecting aragonite saturation levels in near-surface waters of the ocean, and, if so, at what point will decreasing aragonite saturation levels affect coral reefs in the Caribbean. First, you will prepare a research plan that describes what data you will need to examine and why, what investigation methods you will use, and how you will collect data. Once your plan is accepted, you will carry out your data collection, analyze your data, and report your findings to the team.

## **Planning your project:**

### **1. Form a hypothesis to answer the research question below.**

**Research Question:** Are increased levels of CO<sub>2</sub> in Earth's atmosphere affecting ocean chemistry in ways that are increasingly unfavorable for marine life, such as corals and pteropods, which create shells and skeletons from aragonite?

**Hypothesis:** As the concentration of CO<sub>2</sub> in Earth's atmosphere increases, aragonite saturation levels in the ocean will continue to fall, eventually reaching a level at which marine calcifiers, such as coral reefs, can no longer grow and maintain their shells or skeletons.

### **2. Design a plan to test your hypothesis and answer the research question.**

**What do you need?**

- a) More information: Do you need more information about aragonite, atmospheric CO<sub>2</sub>, the ocean's carbonate buffering system, or marine calcifiers?
- b) Specific data: When you go online to collect data, which of the following maps and graphs will you generate?
- c) Aragonite saturation maps
- d) Aragonite saturation time series graphs
- e) Dissolved CO<sub>2</sub> (pCO<sub>2sw</sub>) maps
- f) Dissolved CO<sub>2</sub> (pCO<sub>2sw</sub>) time series graphs
- g) Other?

### **3. Go online and get the data.**

- a) Visit [www.dataintheclassroom.org](http://www.dataintheclassroom.org), and find the Ocean Acidification module.
- b) Follow the link to "Get Data."
- c) Using the form, select the data and parameters you wish to look at.
- d) Click the "Get Data" button.

**4. Use the Data Log Sheet to keep a record of the data you select and/or save so you can refer to it later.**

Remember to save or print maps and graphs so that they can be used later for data analysis and then shown to your classmates when you present your findings.

**5. Analyze the data by answering the following questions:**

- a) Describe the pattern of change in dissolved CO<sub>2</sub> (pCO<sub>2sw</sub>) in the study area over time. How does dissolved CO<sub>2</sub> relate to levels of atmospheric CO<sub>2</sub>?
- b) Describe the pattern of change in aragonite concentration ( $\Omega$ ) in the study area over time.
- c) If you assume a steady rate of aragonite saturation decrease over time, when will coral reefs reach the critical 3.3  $\Omega$  level? (Hint: You can get raw data online by going online to create a time-series graph and selecting “Data file for spreadsheet” under “Select an output format.” Then you can graph the aragonite saturation data by hand using graph paper or use a spreadsheet.)
- d) Check your work using the carbonate buffering simulation. Assume a change in atmospheric CO<sub>2</sub> of +2ppm/year and increased sea-surface temperature of 1.3 °C over 100 years.

**6. Draw conclusions.**

Write down what you learned from your investigation. Use your data to help you decide whether your hypothesis is supported. If your hypothesis is not supported, think about other data you might need to collect.



**Summary**

**Grade Level: 10 - 12**

**Teaching Time: Three 40  
minute periods**

**Activity:**

- **Design an investigation using real data to examine a hypothesis.**
- 

**Objective**

Students will design an investigation into ocean acidification using real data on conditions in the Caribbean study area. Students will use this real data to try to answer a research question of their choosing. In reporting the outcome of their research, students must state what they have learned from the investigation, and use their findings to evaluate, explain, and prove (or disprove) their hypothesis.

**Background**

Coral reefs are the foundation for complex food webs. Abundant algae, sponges, coral, and other invertebrates form the base of the web. Small fish feed along the reef and are, in turn, eaten by larger predatory fish. The coral reefs also protect and support nearby ecosystems, such as mangrove and sea grass ecosystems.

Ocean acidification is one of many threats to coral reefs and their associated, fragile ecosystems. There are other threats to coral reefs associated with global climate change. Rising sea surface temperatures negatively affect coral reefs, as well as lead to rising sea levels. Warmer ocean water also means more storms as well as storms with increased intensity. These storms cause physical damage to the coral reefs. Increased water temperature can cause coral bleaching and stress-related disease, which also decrease the coral's viability. These threats are in addition to other human-caused threats to coral reef ecosystems, such as pollution, overfishing, and runoff from cities and agriculture.



In this activity, students should be encouraged to develop their own research questions and hypotheses. Here is one example:

**Research question:**

Does bicarbonate ion form at the same rate as carbonate ion concentration and aragonite saturation in sea water?

**Possible hypothesis:**

Bicarbonate ion concentration increases as carbonate ion concentration and aragonite saturation levels decrease over time.

## Materials

- Copies of Student Master, Design Your Own Investigation
  - Copies of Student Master, Data Log Sheet
  - Student access to computers with Internet connection
  - Spreadsheet software (optional)
  - Graph paper
  - Ruler
- 

## Procedure

This activity challenges students to think like scientists by designing a scientific investigation in which data collection and analysis are important parts of the process. Students are asked to use the scientific method, using real data to solve a problem.

1. Students may work individually or in teams of two. Give each student or team a copy of the Student Master, Design Your Own Investigation and the Student Master, Data Log Sheet.
2. Guide student selection of a research question (or have them make up their own) that is appropriate to their academic experience. Review your students' research question choices. You may find it useful to have multiple students/teams exploring the same research question using different or even the same hypotheses.
3. Next, have students develop a plan for designing a research project that will answer their research question. The plan should include: 1) the research question; 2) a testable hypothesis that addresses the research question; 3) a list of additional information needed; and 4) a list of the data that will be collected.

4. Check each research project plan before students begin to make sure that the project aligns with the research question and that the hypothesis is testable using the data resources available. Will your students be able to support or disprove their hypothesis using the data available to them?
5. Students will need to access the Internet to generate and save data maps and graphs. Depending on the setting, this can be done in a computer lab or assigned as homework, assuming your students have access to the Internet at home, at a library, or in a computer center.
6. If students are using spreadsheet software, they may need guidance on setting up their spreadsheet and graphs. Show students that they can get raw data online to use in their spreadsheet by choosing “Data file for spreadsheet” under “Select an output format.”
7. After students complete their research, provide time for them to present their findings to the class.
8. Use student presentations as an opportunity to relate their investigations about ocean acidification to current news and debate about global climate change. Ask: *From your own experience looking at real data, how do you view the question ocean acidification? Is ocean acidification a real problem? Are global climate change and ocean acidification related? Can ocean acidification be addressed without addressing global climate change?* This discussion can form the basis of an extension activity in which students explore the political and social implications of ocean acidification.

## Student Master

# Research Project: Design Your Own Investigation

The oceans' water is normally slightly basic/alkaline. Ocean acidification is the process by which the oceans' pH is lowered (made less alkaline) due to increased amounts of carbon dioxide entering seawater from the atmosphere. As atmospheric carbon dioxide levels continue to increase, the ocean becomes less alkaline. While the water in Earth's oceans will never become truly acidic (or even neutral), the decreased alkalinity threatens marine ecosystem more with each passing year.

You have used real data to begin to understand the phenomenon of ocean acidification, but there is still a lot you can learn from exploring the data. Using what you have learned, develop a research project about ocean acidification. Here are the steps to follow:

### Planning your project:

- 1. Develop a research question. Then form a hypothesis to investigate that helps answer that research question.**

Research Question:

Hypothesis:

- 2. Design a plan to test your hypothesis and answer the research question.**

What do you need?

- a) More information:
- b) Specific data:

- 3. Go online and get the data.**

- a) Visit [www.dataintheclassroom.org](http://www.dataintheclassroom.org), and find the Ocean Acidification module.
- b) Follow the link to "Get Data."
- c) Using the form, select the data and parameters you wish to look at.
- d) Click the "Get Data" button.

- 4. Use the Data Log Sheet to keep a record of the data you select so you can refer to it later.**

Remember to save or print maps and graphs so that they can be used later for data analysis and then shown to your classmates when you present your findings.

- 5. Analyze the data.**

- 6. Draw conclusions.**

**Student Master**

**Data Log Sheet**

As you use the online data access form to select data about conditions affecting reefs in the Caribbean study area, keep a record of the parameters you select on this data log sheet. Your data log will help you remember and keep track of the data you have looked at. Consider whether each new piece of data helps support or disprove your hypothesis.

	<b>Data set</b>	<b>Map or graph?</b>	<b>Region</b>	<b>Date(s)</b>	<b>Notes</b>