INVESTIGATING FUTURE CLIMATE SCENARIOS

WHO WILL BE AFFECTED BY SEA-LEVEL RISE?

by Chris Dempsey, Alec Bodzin, David Anastasio, Dork Sahagian, and Lori Cirucci

Over the span of geologic time, the Earth's climate has been both warmer and cooler than the present day, and over the last five decades the average annual global temperature has increased at an unprecedented rate. Scientists attribute much of this rise in Earth's climate temperature to anthropogenic greenhouse gas emissions (Frölicher and Joos 2010; IPCC 2007). No matter what the cause, there is clear evidence that shows Earth has been warming significantly over the last 100 plus years (Jin and Dickinson 2002) and will likely continue on this upward trend (Fu, Qian, and Wu 2011; IPCC 2007; Knutti et al. 2008; Ramanathan and Feng 2008; Weier 2002). One way scientists explore the ramifications of future global change is to construct numerical models of the Earth's climate that take into account Earth's radiative balance, land use, marine and terrestrial uptake of anthropogenic carbon dioxide emissions, and a multitude of feedbacks and interactions within the Earth system. (See also "Connecting the Earth Systems: Holistic Understanding Using the Earth-System-Science Model" in this issue.)

These climate models predict that the Earth's temperature will continue to rise (Meehl et al. 2005; IPCC 2007; Kacholia and Reck 1997; Yoshida, Maruyama, and Takahara 2008). These global circulation models are tested and calibrated by evaluating model predictions against past climate reconstructions.

Climate change produces worldwide impacts. For example, global warming is predicted to lead to increased sea-ice melting, rising sea levels, increased droughts, species migrations and extinction, and changes in weather patterns. The Intergovernmental Panel on Climate Change (IPCC) has compiled several future climate scenarios based on paleoenvironmental data, present climate conditions, and mathematical computer models (2007). Although these future climate scenarios are based on a number of assumptions and predictions, it is likely that Earth's entire population will be affected by a warmer climate in the future. These future climate scenarios are presented and discussed in the IPCC's Fourth Assessment Report (AR4) (2007).

One of the most alarming impacts of projected climate change is a significant rise in sea level. Sea level has varied by hundreds of meters over geologic time (Harrison et al. 1981; Sahagian and Watts 1991; Sahagian et al. 1996), yet these changes have generally been slow paced, allowing ecosystems to adjust to changing land surface and marine habitats. Since the Industrial Revolution, anthropogenic emissions have led to climate change that is causing sea level to rise rapidly in response to melting glacial ice and expansion of warming ocean water. During the 20th century, some of this sea-level rise was masked by the building of new dams that impounded water, which would otherwise have flowed downriver into the ocean (Sahagian 2000). In the 21st century, there has been a reduction in new dam building, and sea level has already been observed to rise much more rapidly than just a few decades ago. Furthermore, some acceleration in sea-level rise is expected to continue throughout the century, leading to disruption of coastal communities, where a large portion of Earth's human population resides.

This article describes an investigative "future worlds" learning activity we developed for eighth-grade students in which past and future climate scenarios are used to develop understandings regarding how the Earth and society may be affected by global change. The study of environmental issues, including those related to climate change, is often taught as part of the middle school science curriculum in U.S. schools and is included in many state standards, such as those in our state of Pennsylvania. In our local Bethlehem-area school district, four weeks in the school curriculum are devoted to teaching and learning climate change. The investigative activities described in this article are aligned to the 2012 *Framework for K–12 Science Education* disciplinary core ideas ESS2.D: Earth's Systems—Weather and Climate, and ESS3.D Earth and Human Activity—Global Climate Change, and incorporate crosscutting concepts of patterns and stability and change by illustrating how the outcomes of current climate models may have environmental consequences for the Earth (NRC 2012). The learning activities take advantage of Google Earth, a freely available technology application that has been found to be effective in promoting spatial thinking skills in addition to science content learning with appropriately designed instruction in middle school classrooms (Bodzin 2011; Kulo and Bodzin 2011). We developed the learning activities using a climate model scenario from the IPCC AR4 report that predicts a two-meter rise in sea level by the year 2100. It is important to note that critics of the AR4 report suggest that the IPCC panel's predictions are conservative in nature and that we may actually experience a rise in sea level that will be greater than 2m by the year 2100.

The Investigating Future Worlds With Google Earth activity is part of a larger climate-change curriculum that is freely available on the Environmental Literacy and Inquiry website at Lehigh University (*www.ei.lehigh.edu/eli/cc*). When we initially assessed our students' climate-change knowledge, we found they had relatively little understanding of global warming ramifications. After completing our climate change curriculum that includes the investigations discussed in this paper, our students' understandings of future climate scenarios increased.

Investigating Future Worlds With Google Earth

We implemented the Future Worlds investigations over the course of two consecutive 45-minute class periods. In part 1 of the study, students look at past indications of climate change to understand how climate has changed during the last 30 years. In part 2, students examine the impact of sea-level rise to understand how the coast and coastal plains may be affected within the next 100 years. We have students work in pairs on laptop computers, and we use a projected image from the teacher's computer that is displayed to the front of the classroom. This allows teachers to model the use of specific tool features in Google Earth that are employed in the investigation and to highlight specific data patterns during classroom discussions. If computers are not available to students, teachers can model the investigation at the front of the classroom and use questioning strategies and direct instruction to engage students with the learning tasks. We found this to be an effective pedagogical strategy in our classrooms with large numbers of students with disabilities.

All instructional and supporting materials for the two-day investigation are available online at *www.ei.lehigh.edu/eli/cc/sequence/day18.html* (part 1) and *www.ei.lehigh.edu/eli/cc/sequence/day19.html* (part 2). These materials include teacher and student guides, investigation sheets, the Google Earth files that are used in the investigations, assessments, and links to additional climate change content materials. To access the teacher guides and assessments, use login eliteacher and password 87dja92. The student Activity Worksheet, included with this paper, has embedded assessment information. (Note that Google Earth version 5.2 or later is needed to take advantage of the elevation profile tool that is described later in this article.) We recommend that teachers follow the guidelines in the investigation handouts. The learning activities are included in Word versions on the website so teachers may differentiate instruction to make questions easier or more challenging for their students. If time permits, we encourage teachers to augment the learning activities to include additional discussions with their students about the data and the environmental consequences explored in this activity.

Note: The data sets used in this activity are freely available online (*http://databasin.org*) and in some cases have been simplified to enhance the learning experience for middle school students. The ice-sheet data sets have been modified from the National Snow and Ice Data Center (*http://nsidc.org/data/virtual_globes/beta.html*).

Day 1

On the first day of learning activities, students use Google Earth to explore evidence of climate change from 1980 to 2010. First they use Google Earth to explore changes in the extent of Arctic sea ice over this 30-year period, and then they explore changes in the distribution of coral reefs in the Caribbean Sea over the same three decades. Before beginning the investigation, we recommend reading the Investigating Future Worlds With Google Earth (Part 1) Teacher Guide, as it provides some additional background material not covered in this article.

We begin the class by introducing students to the driving question: How has climate affected the environment in the last 30 years? At this point in our curriculum, our students have an understanding of important climate change concepts and have previously used Google Earth for other science learning activities. If students are not familiar with using Google Earth as a learning tool, we recommend showing them how to use some of the navigation and display features. Step-by-step instructions are located in the Investigating Future Worlds With Google Earth (Part 1) Teacher Guide and Student Guide. If your students have no prior experience with measuring distances in Google Earth, we recommend that you model how to use the measuring tool. To begin the investigation, students should turn on the gridlines in the Google Earth viewer.

We tell students they will be analyzing various authentic data sets using Google Earth by navigating around the world to understand how the environment has changed at various geographical locations. Students begin the activity by navigating to Hawaii to view the Keeling curve (Figure 1) (Tans and Keeling). Although CO_2 is a trace gas, making up 392 parts per million of the atmosphere (0.039%), it plays an important role in the greenhouse effect that warms the atmosphere, and its role has strengthened since

FIGURE 1 The Keeling curve depicts a detailed record of carbon dioxide concentrations as measured at the Mauna Loa Observatory in Hawaii (Tans and Keeling).

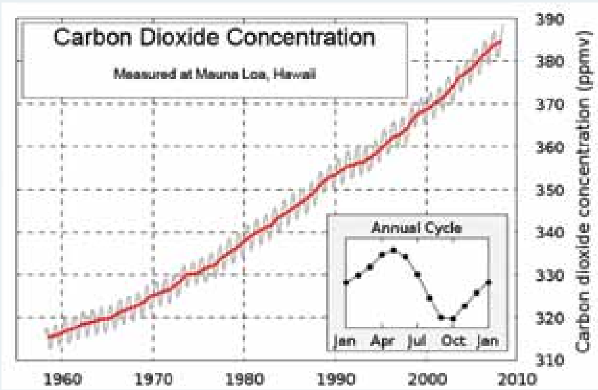
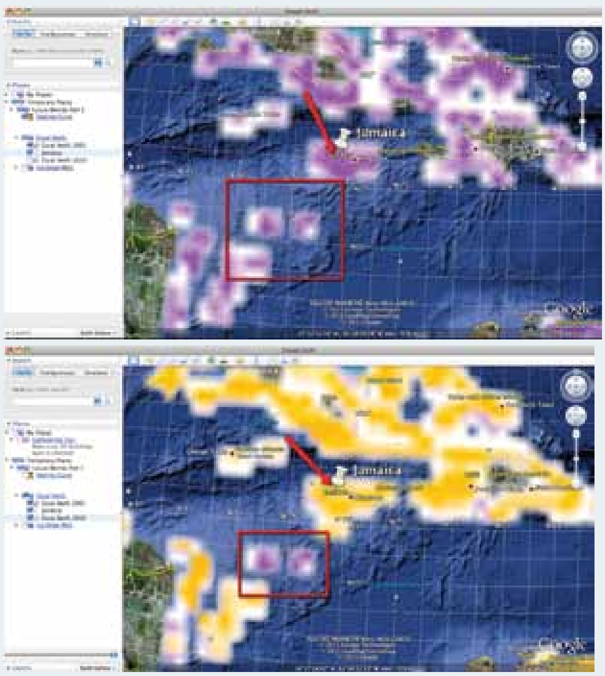


FIGURE 2 Location of coral reefs near the island of Jamaica in 2001 (purple) and 2010 (yellow); the red box indicates a coral reef population that was present in 2001 but not present in 2010.

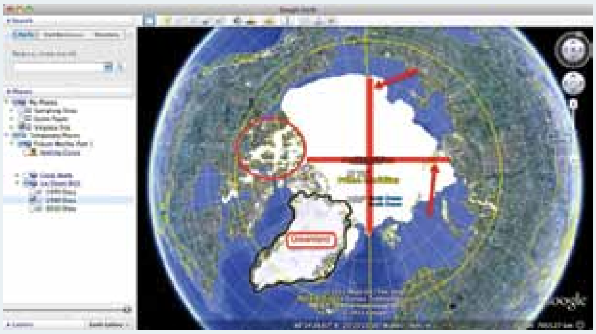


the Industrial Revolution due to its concentration increasing by 42% since that time. We ask students to observe the carbon dioxide (CO_2) concentration record taken at Mauna Loa, Hawaii, from 1960 to 2010 and to read some brief background information provided in Google Earth below the displayed figure. We explain to students that the interannual variability in the record is due to photosynthesis and decay processes in terrestrial ecosystems. Because land plants modulate atmospheric CO_2 and most of the Earth's land area is in the Northern Hemisphere, seasonality in the Northern Hemisphere controls atmospheric CO_2. We make sure students understand that during the Northern Hemisphere spring and summer, trees and plants absorb carbon when they undergo photosynthesis, reducing the amount of carbon in the atmosphere; during the fall and winter, they decay, releasing carbon back into the atmosphere. Students are then prompted to analyze patterns of CO_2 concentrations between 1980 and 2010 in the Keeling curve data and record observable trends in the data set on their Activity Worksheet (see questions 1 and 2).

Next students navigate to the Caribbean Sea to view changes in coral reef distribution between 2001 and 2010. Some background text along with a coral reef image are provided to introduce students to the idea that increasing ocean temperatures associated with climate change are the cause of coral bleaching. Students then use embedded data layers in Google Earth to analyze and compare coral reef distributions in 2001 and 2010. The warming climate has caused significant changes to ocean biogeochemistry, which can be observed in declining coral reef populations (Pandolfi et al. 2011). An area of dramatic change is to the southwest of Jamaica, where we can observe a 2001 coral reef with our spatial data. In 2010, this coral community is no longer present (see Figure 2). After students use Google Earth to analyze spatial patterns of coral reef distribution in the Caribbean Sea, they are prompted to answer a question on their Activity Worksheet (see question 3).

Students then navigate to the Arctic to view changes in sea-ice extent from 1979 to 2010. Students are presented with some background information about climate models and learn that modeling data from scientists show that increased ice-sheet melt will lead to increasing sea-level rise. Students are then instructed to display and measure the continuous Arctic Ocean ice sheet during three years: 1979, 1990, and 2010.

FIGURE 3 Google Earth display with measured red lines for length and width of the 1990 Arctic ice sheet. Greenland is outlined in a black color. The red-circled area is considered to be seasonal sea ice and should not be included in students' measurement of the continuous ice sheet.



Specific instructions are provided in both the teacher and student guides on how to use the Google Earth measurement tool for this task. We found it helpful to explicitly model the use of the measurement tool to measure the length of the ice sheet along the prime meridian and to measure the width perpendicular to the prime meridian. It is also helpful to show students areas where the ice sheet is continuous and where seasonality causes breaks (see Figure 3). We tell students that areas of the ice sheet that have breaks in it should not be included in their measurements. Additionally, students should not include the continental ice on Greenland in their measurements. We emphasize that only one time period (e.g., 1979) data layer should be displayed when taking measurements. After students complete their ice-sheet measurements, they calculate the area of the ice sheet for each year and record it in the chart on the Activity Worksheet (see number 4). Students' area calculations should show that the sea-ice extent in the Arctic has been decreasing since 1979. Students are then prompted to answer questions 5 and 6 on their Activity Worksheet.

Day 2

During the second day of the investigation, we ask students to think about the impacts of future climate change. Students are asked to explore a variety of geographic locations in Google Earth using the elevation profile tool and climate modeling data to determine the impact on the landscape if a 2m rise in sea level were to occur at those locations.

We begin this class period by asking students the following driving question: How will a 2m rise in sea level affect cities and low-lying areas near coastlines? In the first learning activity, students navigate to five different low-lying coastal areas: Wildwood, New Jersey; Folly Beach, South Carolina; the Greater New Orleans, Louisiana, area; Homestead, Florida; and the Maldives Islands. We start our activity at Wildwood because many of our students are familiar with this nearby coastal beach location. Teachers can alter the order in which students navigate through the activity, or they can have students create and label their own unique paths in Google Earth to explore coastal areas of interest to them in different geographical areas. A tutorial for making paths in Google Earth is available at *www.google.com/earth/outreach/tutorials/annotate.html*. We model how to use the elevation profile tool to examine the effects of sea-level rise on a particular location. This information is provided in the teacher guide. The elevation profile tool (Figure 4) in Google Earth allows students to determine how much land would succumb to a 2m rise in sea

FIGURE 4 An example of the elevation profile tool displayed for the Wildwood, New Jersey, study site. The beginning and end of the "path" are labeled. An arrow marks your location on the map when using the elevation profile tool.

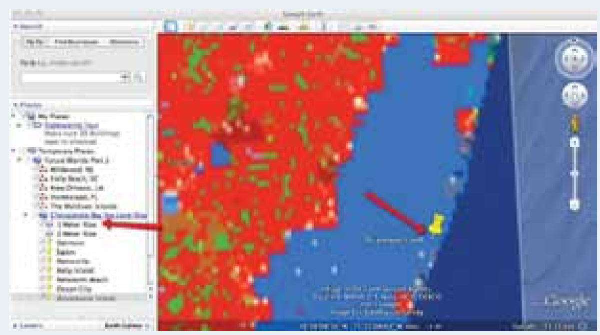


FIGURE 5 The example of Assateague Island shown with a 1m sea-level rise; the eastern portion of the island, as indicated by the blue color, would submerge with a 1m rise in sea level.

level. For this learning activity, we created a series of paths in Google Earth that appear as red line segments over a predetermined area. When one selects the elevation profile tool for a path, the bottom of the Google Earth viewer displays an elevation profile chart for that path (refer to Figure 4). The ordinate (*y*-axis) of the graph displays the elevation, and the abscissa (*x*-axis) of the graph displays distance. When you move the cursor through the various parts of the elevation profile, a corresponding arrow moves along the path and displays the elevation (left side of arrow) and cumulative distance (above the arrow). We tell students to look for the first location on the path away from the coastline where the change in elevation reaches 2m above sea level. This enables students to spatially visualize how the change in sea level will affect coastal-area communities. At each of the five locations, students measure and record the distance from the coastline that would be underwater if there were a 2m rise in sea level. Students are also prompted to examine the threatened land-use area and instructed to record the land-use cover for each location (refer to the first chart in part 2 of the Activity Worksheet). For example, in Wildwood, much of the submerged land with a 2m rise in sea level would be residential and marsh areas. Detailed instructions on how to use the elevation profile tool can be found in the teacher and student guides.

Next we instruct students to navigate to the Chesapeake Bay region. For this part of the investigation, students need to determine how a 1 or 2m rise in sea level would affect 13 different cities in the Chesapeake Bay area, which are marked with yellow pushpins in Google Earth. We model for our students how to navigate to each city location and how to display the one- and 2m rise data layers. In these data layers, the blue color represents water, and all other colors represent various types of land cover. We tell students to first examine a 1m rise in sea level at each location before examining the two-meter rise in sea level. If the point on the pin is completely surrounded by blue, the city would be submerged by the rise in sea level. The example of Assateague Island with a one-meter rise in sea level is shown in Figure 5. On their Activity Worksheet, students complete a table that identifies which locations will be underwater with a 1 or 2m rise in sea level (refer to the last chart in the Activity Worksheet). Once students have finished analyzing sea-level rise for each city, they are instructed to answer a series of questions associated with this learning activity (see questions 9–12 in the Activity Worksheet).

Conclusion

Sea level is likely to continue rising over the next 100 years. This two-day investigation allows students to explore how rapidly environmental conditions have been changing over the last 30 years and provides them a foundation of what the future might hold for various locations around the world. After day 1 of the activity, students should understand that the warming climate has already had significant impacts on the environment. Day 2 gives students an understanding of the implications associated with a 1 or 2m rise in sea level. We believe that incorporating these learning activities as part of our climate change curriculum helped our students gain a better understanding of climate change and realistic future predictions about global environmental change scenarios. Our students' climate change knowledge increased significantly on a climate change assessment measure from pre- to post-curriculum implementation. This activity illustrates that Google Earth can be used as an effective geospatial technology tool to provide students with spatially referenced scientific data sets that can be used for geospatial analysis and reasoning in the classroom to facilitate learning about climate change. ■

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Activity Worksheet Investigating Future Worlds With Google Earth (with embedded assessment information)

Part 1 [Answers in italic.]

1. Look at the Keeling curve. What is the concentration of atmospheric CO_2 in 1980 and 2010? Record your answers below. *1980: 338 ppm, 2010: 384 ppm*

2. Has the CO_2 concentration increased, decreased, or stayed the same over the past 30 years? Provide evidence for your answer. *The CO_2 concentration has increased over the last 30 years.*

3. What has happened to the reefs southwest of Jamaica between 2001 and 2010? Why do you think this has happened? Base your answers on your coral reef analysis. *Between 2001 and 2010, the coral reefs have disappeared from the area to the southwest of Jamaica. This is likely due to increased coral bleaching, which results from climate warming and human activities.*

4. Record the length, width, and areas of the continuous ice sheet from the three time periods below. Do not take into account the decimal points. Record whole numbers only. (*Answers will vary depending on students' length and width measurement locations. A range of possible answers is presented below.*)

Year	Length (km)	Width (km)	Area (km^2)
1979	2,880–3,494	2,581–3,788	7,433,280–13,235,272
1990	2,900–3,000	2,463–3,913	7,142,700–11,739,000
2010	2,807–3,073	2,150–2,784	6,035,050–8,555,232

5. Analyze the continuous ice-sheet area between 1979 and 2010. Are the ice sheets growing, melting, or staying about the same? Support your claim with evidence. What do you think is causing this to occur? *The ice sheets are melting. The continuous ice-sheet area has been reduced in size between 1979 and 2010. This is likely due to increased atmospheric temperatures, which have helped to melt the ice sheets.*

6. What do you think would happen to low-lying islands and coastal areas with very low land elevation (less than 2m) during the next 100 years? Why do you think this will occur? *As the ice sheets continue to melt during the next 100 years, sea level will start to rise. These low-lying islands would eventually submerge underwater. Coastal areas with very low elevation would begin to flood, especially during storm events.*

Part 2 [Answers in italic.]

In the data table below, record the farthest map distance inland that the shoreline would move if there were a 2m rise in sea level. Report your measurement in kilometers (km). Record the type of landscape cover that this water would cover. This may include farmland areas, residential areas (houses), or marsh areas (low-lying vegetated areas that are found in coastal areas). More than one land-cover type can be recorded in the chart below. You may need to zoom in to observe the land cover type.

Helpful hint: To measure the farthest distance inland to the shoreline, locate the first location in the elevation profile that has a 2m elevation. Note: *The values indicated in the table below indicate the first location in the elevation profile that had a 2m elevation. Acceptable student answers may be slightly higher than the distance indicated below.*

City	Distance inland (km)	Landscape cover (farmland, residential, or marsh)
Wildwood, New Jersey	5.7–6.0 km	Residential and marsh
Folly Beach, South Carolina	3.3–3.7 km	Marsh and farmland
New Orleans, Louisiana	124–126 km	Residential, farmland, and marsh
Homestead, Florida	22.9–23.6 km	Residential, farmland, and marsh
The Maldives Islands	2–2.3 km	Residential

7. Use the elevation profile data above to determine which of the five areas has the greatest amount of land that would be affected by a 2m rise in sea level. Which of the five areas has the least amount of land that would be affected by a 2m rise in sea level? *Greatest: New Orleans, with 126 km of land that would be underwater. Least: The Maldives Islands, with 0.88 km of land from the left side of the island path line, or 1.5 km of land from the right side of the island path line.*

8. Which of the five areas has the largest residential area that would be affected by a 2m rise in sea level? *Based on visual observations, New Orleans appears to have the most residential area that would be affected.*

Place an "x" in the table below if a location would be underwater if sea level were to rise one meter and 2m. Be sure to examine the 1m rise layer in Google Earth before examining the 2m rise layer.

Location	One-meter rise	Two-meter rise
Delmont, NJ	x	x
Salem, NJ		x
Pennsville, NJ		x
Kelly Island, DE	x	x
Rehoboth Beach, DE		x
Ocean City, MD	x	x
Assateague Island, MD	x	x

Location	One-meter rise	Two-meter rise
Somerset, MD	x	x
Fishing Creek, MD		x
Toddville, MD	x	x
Cobb Island, MD	x	x
Pooles Island, MD		
Shell Island, VA	x	x

9. How many of the above locations would be underwater if there were a 1m rise in sea level? How many of these locations would be underwater if there were a 2m rise in sea level? *Eight locations would be underwater if there were a 1m rise in sea level. All but one (Pooles Island) would be underwater if there were a 2m rise in sea level.*

10. What do you notice about the locations used in this activity that are projected to go underwater in the next 100 years? *All of these are located in low-lying areas along coastlines.*

11. If CO_2 concentrations continue to increase, why do you think sea level may continue to rise? *Sea-level rise can be most likely attributed to ice melt on land that has been melting at faster rates over the last several decades due to increased surface temperatures. If CO_2 concentrations continue to increase, global average temperatures will continue to increase, resulting in further land ice melt that will likely cause additional sea-level rise.*

12. The Chesapeake Bay region currently has a population of 16.6 million people. It is projected to grow to over 20 million people by the year 2030. If a 2m rise in sea level does occur, what would happen to a large number of people who live in the region? *Many of the people who live along the coastlines of the Chesapeake Bay region will likely be affected by sea-level rise. Many people will lose their homes, while others who are farther inland will be affected by saltwater intrusion, high tides, and surges of storm waves during hurricanes. This may increase the population density of this region because the area of dry land is decreasing.*