

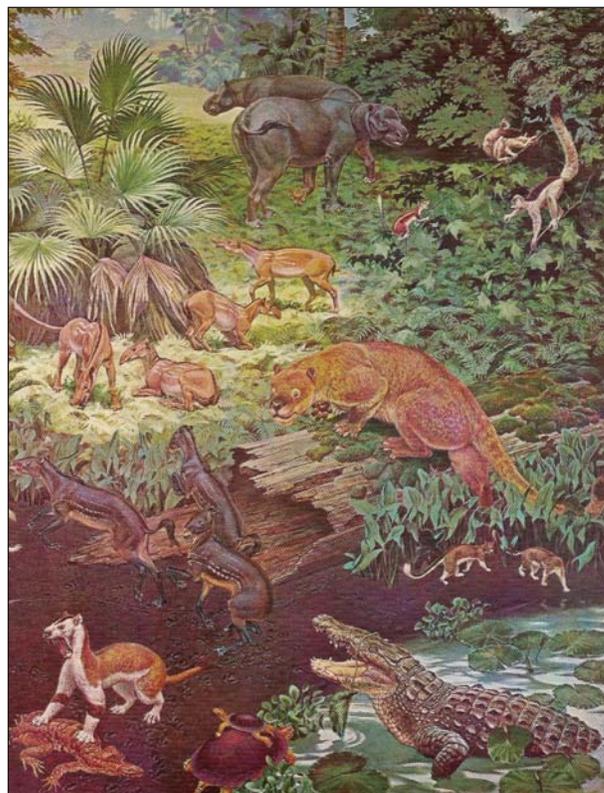
# Global Climate Change: What Does it Look Like?

by

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## Objectives

- Use the concept of average to distinguish between weather events, like El Niño and La Niña, and climate.
- Describe some of the data and methods that paleoclimatologists use to reconstruct ancient climates.
- Practice finding, graphing, and interpreting data about global climate change.
- Construct scientifically reasoned predictions about climate change.



## Part 1 – Weather and Climate: A Matter of Time

TV meteorologist Sara Fahrenheit, Ph.D., stood in a torrential downpour in front of the Channel 6 Weather Van. A hundred feet away, another house began sliding down the ridge. Sara wondered if this extreme weather was part of global climate change instead of a one-off occurrence. Weather, she knew, is the day to day change in temperature, precipitation, cloud cover, wind, visibility, barometric pressure, and humidity. Climate refers to a region's average weather conditions. Climate is normally predictable because rainfall, high and low temperatures, and seasonal storms repeat year after year.

The climate in Sara's hometown, Seattle, was generally mild, and winters had little ice and snow. But it had been quite different in the ancient past, and it was beginning to look different now.

Sara thought about the small perturbations in weather that over long periods of time accumulate in climate change. El Niño and La Niña, processes related to interactions of heat between the atmosphere and ocean, can cause brief periods of unusual weather throughout the world. In the continental U.S., El Niño brings cooler, wetter weather to the South, with warmer, drier conditions in most of the remaining areas. La Niña produces the opposite effects.

El Niño events were occurring more frequently and getting even more extreme, causing heavier rainfall and more flooding. Were these changes in weather happening frequently enough to change average weather conditions over the long term? Had the average rainfall over the last couple of decades changed significantly? Was the climate shifting? Scientists think so.



Because climate refers to the average weather over thousands of years, only drastic changes in weather can, in turn, cause climate change.

**Activity**

A classmate from North Carolina tells you that one of the warmest years on record included an El Niño event. Because El Niño events are examples of changes in weather, she concludes that they can't affect climate.

**Question**

Can you explain to your classmate why temperatures from only a single year are not enough to reach a conclusion about changing climate? Use Figure 1.1 to construct your argument, noting when El Niño events occur, but also which years have the highest temperatures. How has the average annual temperature shifted through time? How do the temperatures in the El Niño years compare to the 1950–1970 average? To the 1985–2005 average?

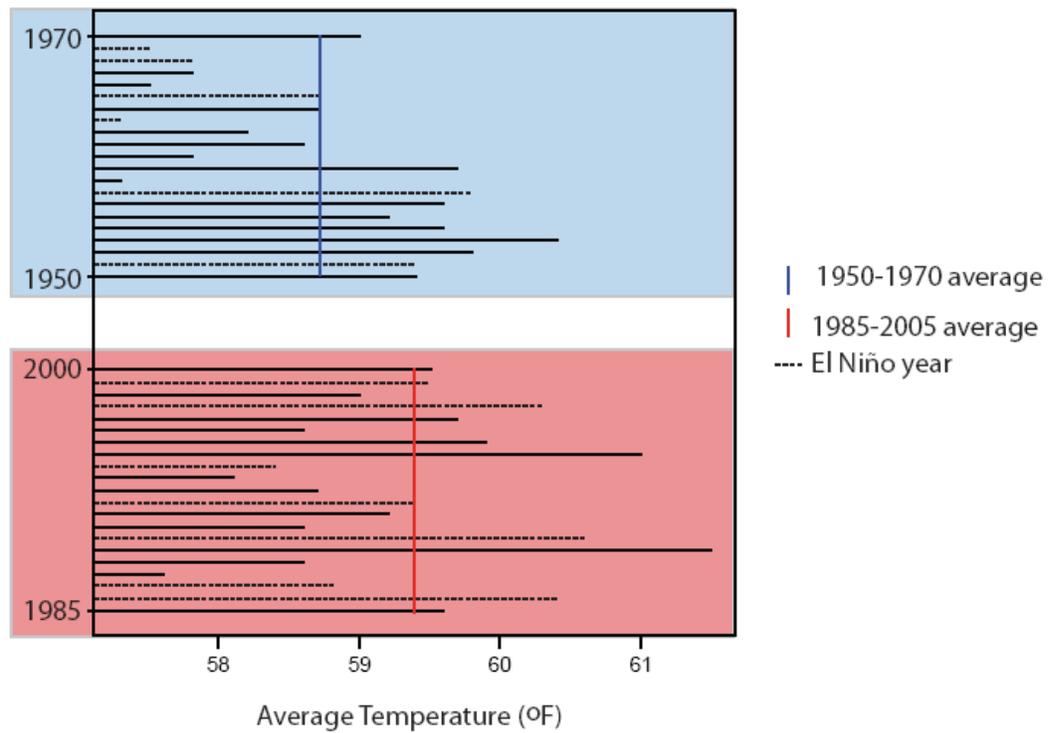


Figure 1.1. Average temperatures in the southeastern U.S., 1950–1970 and 1985–2005. Data from [http://www.cpc.noaa.gov/products/analysis\\_monitoring/ensostuff/ensoyears.shtml](http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml) and [http://www.sercc.com/climateinfo\\_files/monthly/North%20Carolina\\_temp.html](http://www.sercc.com/climateinfo_files/monthly/North%20Carolina_temp.html).

## Part 2 – The Past Repeated

“Take in that view, folks,” said Sara as she waited to go live. Trees groaned. The wind nearly ripped the hood off her raincoat. A glass earring, painted to resemble the Earth, flew from her earlobe. Sara cursed and shoved the other earring into her pocket.

The Chinook River was rising fast. Law enforcement vehicles were on their way to demand that Sara evacuate. Then the anchor from the studio appeared on the TV monitor with the word “LIVE” emblazoned across the upper right of the screen. “You there, Sara?”

“Yes! Let’s do this!”

Just then water gushed over Sara’s boots and up the wheel wells of the van. The monitor went blank. Sara jumped into the van, but by now the road was indistinguishable from the river. The van felt like a rudderless, rocking boat. And it was filling quickly with water and mud.

Law enforcement arrived just as the Channel 6 Weather Van’s tail lights disappeared below the surface of the raging Chinook River.

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Sara couldn’t move. Her eyes were open, but everything was dark. She felt a gentle tug on her hair, followed by a steady bristling sensation against her forehead, like someone was cleaning her face with a paintbrush. The brisk strokes reached her eyes and she felt the weight of what seemed like thick spa mud peeling from her face. A teenage boy stood over her, a paleontologist’s trowel in one hand and a paintbrush in the other.

“Can you move?” he asked. The teenager, relaxed and confident, helped Sara up. She glanced around, trying to get her bearings. Where was she?

“Hey. Are you with search and rescue? Where’s my van? Where am I?” she asked.

The Chinook River now seemed to be a gully of rock and mud, with giant ferns sprouting in several directions. The air was steamy and humid. And it was hot. It felt like being in the tropics. The Cascade Mountains were still in the east—but without a trace of snow. Sara realized with a shock that she was in the Chinook Valley, projected into a possible future. The climate had changed completely.

How had she gotten here, thrown into a future that looked so much like the past? Her head hurt as she plodded along next to the teenage boy. *Geez, this environment is like it was in the Early Eocene: higher temperature, more precipitation, and more humidity.*

The teenager emptied a pail of cold water over her head. “Ack! Okay. That’s good. Thanks. But, *please*, no more *water!* What’s going on here? I’m Sara Fahrenheit. Who are you?”

“I’m Odin,” the teenager said. He started walking and motioned for her to follow. “Tell me what you do.”

“I work as a television meteorologist, but my Ph.D. is in paleoclimatology; I am a paleoclimatologist,” replied Sara.

“What do paleoclimatologists do?” asked Odin.

“Well, we figure out what ancient climates were like by studying fossils and analyzing chemicals found in ice, rocks, and the ocean floor. We’ve found that solar and volcanic activity can change the climate. Different cooling and warming periods can last many thousands, even millions, of years. Throughout the history of the planet, fluctuations in the average temperature of the Earth have caused long-term changes to regional climates...” Sara drifted off when she realized Odin wasn’t listening. But she continued musing on the differences between weather and climate. During a warming spell, the weather in some regions could actually be colder than before, but the overall climate, averaged over the entire globe, would be warmer.

“It’s certainly warm here now,” continued Sara out loud. “Probably caused by a steady increase of greenhouse gases—not just carbon dioxide, but also methane, water vapor, nitrous oxide, and ozone. This weather is extreme. Do you have lots of intense, tropical storms and hurricanes?”

Just then the wind picked up and an electrified purple and black cloudscape up ahead promised a violent storm. Odin mumbled “Yeah,” but did not seem the least bit concerned. He beckoned her along.

“I studied extinct species and the places they lived to try to predict the future of our planet’s climate,” Sara continued as they passed columns of ferns and moss-covered trees. The young man seemed to be listening. “In fact, I know that this very place was once cooler, but because of factors both within and outside our control, you now live in a more *tropical* environment.”

As they continued walking, Sara thought more about her research on the climate of the Early Eocene (56 to 49 million years ago). She had studied sediment core samples from the ocean floor and learned that the global climate was hot and humid in the Early Eocene. The planet had been covered thick with plant life, much like what we see in today’s tropical regions. And much like what Sara now saw and felt all around her in this bizarre version of the Pacific Northwest.



*If global warming continues, Canada and the northern states in the U.S. could have the kind of weather we currently only see in the tropics.*

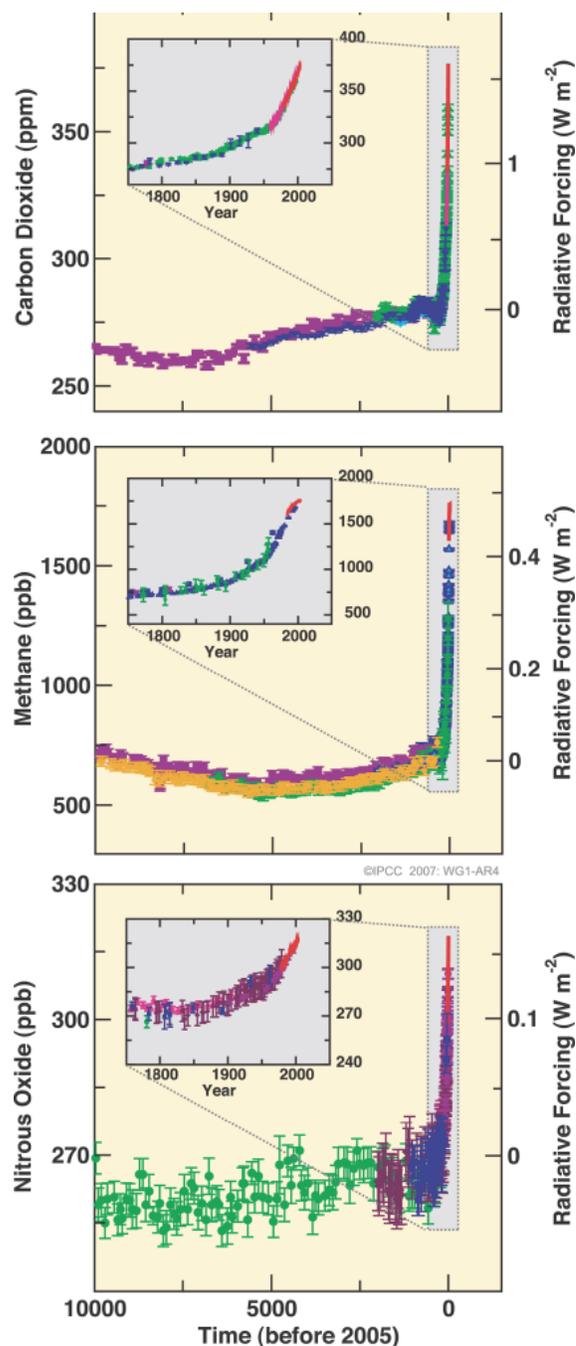
Atmospheric CO<sub>2</sub> has increased from approximately 280 parts per million (ppm) in 1850 to nearly 380 ppm today. The surest way to confirm this is through the measurement of *carbon isotopes*, which can be collected from ice cores.

Through computer models that use variables such as future population size, economic growth projections, and projected demands for increased energy use, the United Nations Intergovernmental Panel on Climate Change (IPCC) predicted that the average global temperature could increase by as much as 6.4°C.

### Activity

Use Figure 2.1 (taken from the IPCC report *Climate Change 2007*) to complete Table 2.1 below. Then graph the values from Table 2.1 into Figure 2.2.

Figure 2.1 Changes in Greenhouse Gases from Ice Core and Modern Data

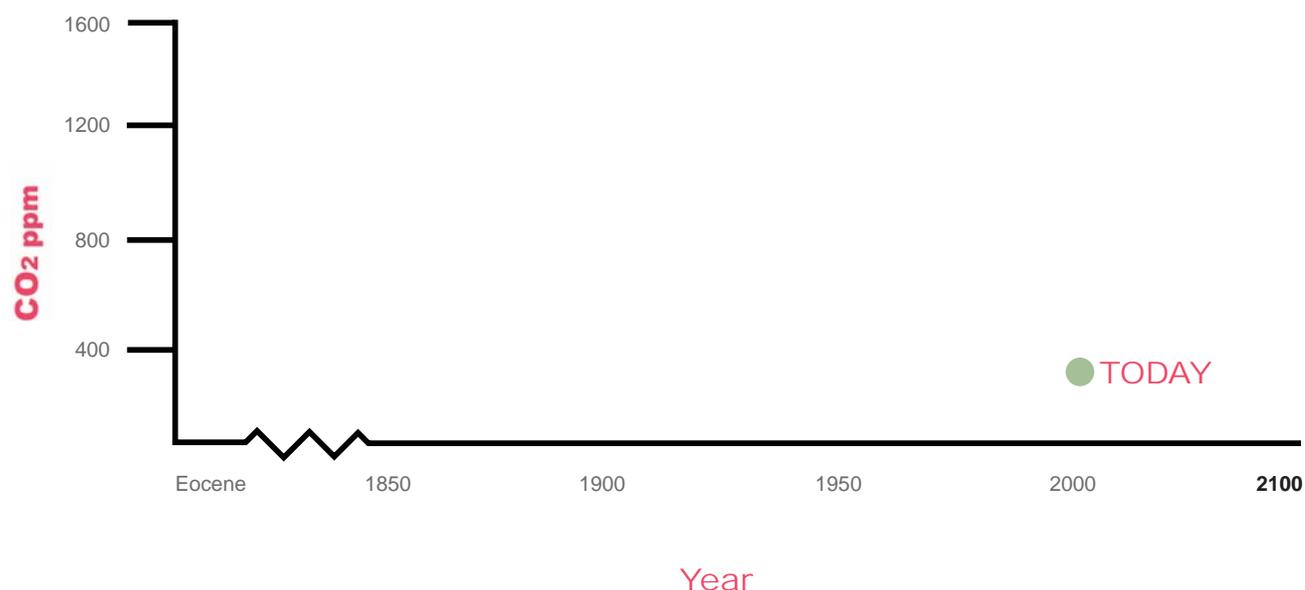


Source: Figure SPM.1 from IPCC Fourth Assessment Report: *Climate Change 2007*. Working Group I: The Physical Science Basis. [http://www.ipcc.ch/publications\\_and\\_data/ar4/wg1/en/figure-spm-1.html](http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-spm-1.html)

Table 2.1: Historical and extrapolated concentrations of CO<sub>2</sub> (in ppm)

Year	CO <sub>2</sub> ppm
Early Eocene (56–49 million years ago)	1,125*
1850	
1900	
1950	
2000	
2100	

Figure 2.2: The amount of carbon dioxide in the atmosphere, measured in parts per million, from the beginning of the Industrial Revolution to the year 2100.



### Questions

- Describe the trend in CO<sub>2</sub> levels that you have graphed.
- Compare your graph to Figure 2.1 from the 2007 IPCC Report, noting especially the scales on both axes.
  - What scale would you use in Figure 2.2 to exaggerate the changes in the amount of CO<sub>2</sub> that have occurred over the last 150 years?
  - What scale would you use in Figure 2.2 to obscure the changes in the amount of CO<sub>2</sub> that have occurred over the last 150 years?
- What change in human culture was well underway by 1850?
- Despite a steady upward trend since 1850, CO<sub>2</sub> levels predicted for 2100 are nowhere near Eocene levels. Still, why is this graph essential to scientists' argument that we urgently need to reduce CO<sub>2</sub> emissions now?

## Part 3 – The Power of a Toeprint

### *The Channel*

The storm reached them and a cedar tree crashed across the narrow trail. Sara lagged behind as Odin shouted out, “We’re almost there!” A long-fingered, weathered, and calloused hand appeared over the fallen cedar. Sara assumed it belonged to someone who had joined them on the trail to reach safety. But once over the fallen tree, she only saw Odin.

Odin motioned for Sara to follow him to a trail beside the Chinook River. As the wind and rain intensified, it became harder for them to stay on their feet. Sara nonetheless pushed ahead as Odin shouted, “To the channel!”

A shelter appeared downriver. Here they could stand on a narrow ledge with their backs to the cliff to wait out the heavy storm. Sara thought they were on the main tributary of the Chinook, not a channel. “Did you mean the river?” she asked. Odin was sitting a few steps away, his knees drawn up underneath his chin. “The channel,” he said. “It’s right there.” Sara saw the word “Channel” in faint blue letters across a panel of weather-beaten metal embedded in the cliff. With a few quick strokes of her sleeve, the number “6” appeared alongside it. It was her van.

As the storm raged, water cascaded off the cliff. “Um, can we uncover another part of the van...uh...channel,” said Sara, looking up and noticing that the now rushing sheet of water was edging closer. “It’s kind of hard for me to explain,” she said, as she faced the young man while clearing the portion of the rear doors. “But this is something I used before I...”

“I know,” interrupted Odin with a smile.

The side of the van emerged. Sara grabbed hold of the handle and swung the door open. The flash flood was eroding their shelter and the only option for safety was to enter the van. Sara got inside.

“Okay, here we go.” She turned to reach for Odin, but he was now in the distance, negotiating his way across the ledge toward the riverbank, a trail of footprints fading in the storm behind him. Just as Sara shouted for him to return, the side of the cliff gave way, crushing the door closed.

She fell backwards for a time. When she finally came to rest against the van’s dashboard, the glare of searchlight beams closed in.

“Dr. Fahrenheit, are you all right?” The badge on the man’s shoulder read *Chinook Valley Fire Department*.

### *Back Home*

Sara Fahrenheit listened from behind the curtain, waiting to deliver the commencement address for Chinook Valley College. She’d been heartened by the valedictorian’s speech—that young lady wanted to become an educator and had promised to do her part in taking American students back to the top of the developed world’s standings in math and sciences.

Over the past few years, Sara hadn’t thought much about what happened in the Chinook River, dismissing it as an odd dream. But it had inspired her to stop working as a TV meteorologist and write *Global Climate Change: Best and Worst Case Scenarios by 2100*. The book quickly became a bestseller.

The valedictorian introduced Sara, who walked to the podium and began her address:

*We’ve all heard about global warming and climate change. Some of the information might make us feel hopeless because it can make the problem sound insurmountable. There are more than likely a few of you who believe that global warming is such a vast problem that it’s hard to figure out what we can do as individuals to address it. Or you could be among those who believe it’s nothing of concern, because the levels of CO<sub>2</sub> and other greenhouse gases present in the atmosphere throughout certain periods of our planet’s history exceeded the levels we are experiencing today...*

The valedictorian started to daydream about what it would be like to teach high school. What could her students do to cut down on greenhouse emissions? She knew that as a teacher she would want her students to know that they could make a difference in the world.

*Reducing our own carbon footprints—even in small ways—will result in a large reduction in the total amount of CO<sub>2</sub> emitted.*

**Activity**

To get to high school, students can get dropped off, take the bus, ride their bikes, carpool, or drive themselves. If a student can afford her own car and gas, why shouldn't she enjoy the convenience and privacy of driving to school every day?

**Facts**

- Passenger cars in the United States contribute approximately 645 million tons of CO<sub>2</sub> emissions into the atmosphere each year.
- For every gallon of gasoline burned, 19.4 lbs. of CO<sub>2</sub> is emitted to the atmosphere.
- The average miles per gallon for passenger cars in the U.S. is about 22.

**Find your Carbon Toeprint**

So many resources that we use today—switching on our computers, driving our cars, recharging our cell phones—draw on power that potentially emits more CO<sub>2</sub>. Our carbon footprint is an estimate of how much CO<sub>2</sub> we use. Let's look at what might be considered a carbon toeprint: how much CO<sub>2</sub> high school students would emit during their commute to school if they were all to drive themselves.

**Questions**

1. Begin by using Figure 3.1 to complete Table 3.1. Record the total number of miles that each of the 25 students in Figure 3.1 would drive to and from school.

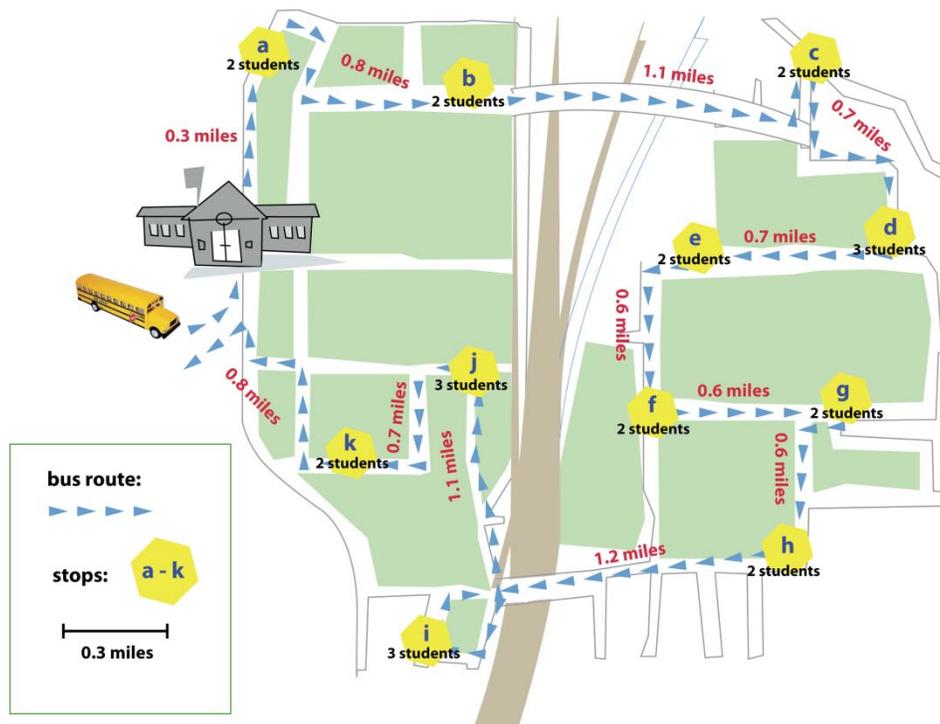


Figure 3.1. Students in this neighborhood all attend the same high school. How much CO<sub>2</sub> would be emitted if each student drove himself or herself to and from school each day? How much CO<sub>2</sub> would be saved if they all rode the bus together?

Table 3.1 Distance students would travel if they drove themselves

<i>Stop</i>	<i>Number of Students</i>	<i>Miles to and from school</i>	<i>Total miles driven by all students living near that stop</i>
A	2		
B	2		
C	2		
D	3		
E	2		
F	2		
G	2		
H	2		
I	3		
J	3		
K	2		
<i>Average:</i>			

2. Calculate the average distance traveled each week by all students in a school district:
  - a. Calculate the average number of miles traveled by the 25 students whose routes you studied.
  - b. Multiply the average distance traveled to school by the number of high school students in your school district.
  - c. Multiply that by 5 for each day of the school week.
3. Divide that number by 22 miles per gallon to calculate the average amount of fuel used throughout the week.
4. Now multiply that by 19.4 lbs of CO<sub>2</sub> per gallon emitted into the atmosphere.
5. How many tons is that?

Now let's suppose everyone takes the bus. More CO<sub>2</sub> is being emitted than if everyone were walking or riding a bike, so how much CO<sub>2</sub> would actually be saved each week? Let's assume these same 25 students ride a single bus.

6. Use Figure 3.1 to calculate the total number of miles that the bus drives to pick up and drop off students.
7. Calculate the average distance traveled each week by all students:
  - a. Divide the number of miles that the bus drives each day by 25 to find the distance traveled *per* student on the bus.
  - b. Multiply that result by the number of high school students in your school district.
  - c. Multiply that by 5 for each day of the school week.
8. Buses use more fuel than cars, so divide that number by 7 mpg to calculate the amount of fuel used by one bus throughout the week.
9. Now multiply that by 19.4 lbs of CO<sub>2</sub> per gallon emitted into the atmosphere.
10. How many tons is that?
11. How many tons of fuel are saved in a single school district each week if the students take the bus instead of driving?

The National Renewable Energy Laboratory, a federal laboratory under the auspices of the Department of Energy, reports that a number of school districts are paving the way for reducing the carbon emissions of school buses even more. Strategies include using alternative fuels like natural gas and biodiesel.

## Part 4 – Just a Few Degrees

Sara continued her address to the students of Chinook Valley College:

*Indeed, our planet is changing all the time. But how much change in our ecosystems can occur before they collapse, before they can no longer provide our most basic needs? Biodiversity is key. If we lose it, our environment may not be intact and varied enough to sustain us. Plant and animal species will continue to disappear. We are at a unique period in our planet's history, where slight changes in ocean levels and temperatures might soon return us to a global environment too inhospitable to preserve the abundance of life we know and depend on.*

*In my new book, I thoroughly investigate the science behind the best and worst case scenarios: access to clean water, food and energy distribution problems, population, and many other topics. My sources represent the studies from the best climate scientists around the world who collaborated to project what our world will be like as a result of climate change. And our climate is changing, right now. The consensus is in: whether we choose to curb CO<sub>2</sub> emissions from coal plants, automobiles, agriculture, and other sources, our grandchildren will inherit a more environmentally hostile and unpredictable world.*

*As the issue of climate change from global warming remains controversial, we're bound to hear a range of claims from skeptics. Some may suggest that an increase in temperature of just a single degree Celsius is not significant to create challenging conditions for humans or our biosphere. However, the most recent studies indicate that an average of one degree Celsius warmer by 2100 will have serious impacts on agriculture and coastal regions around the world.*

Sara paused, preparing to change to the more optimistic part of her speech, one targeted specifically towards the *carpe diem* enthusiasm of the new graduates.



*An increase in average global temperature of just 1°C (1.8°F) over the next 100 years will raise sea levels, hasten extinctions, and impact food production.*

When Sara Fahrenheit fell into the future, she found herself in a Western Washington climate similar to what Seattle was like in the Eocene. Just before the Eocene began, the Earth experienced the most rapid and extreme global warming event in geological history. Mass extinctions occurred, and the polar regions were much warmer, similar to today's summer climate in Seattle.

Here's the kicker: The average global temperature during that 20,000-year period increased by about 6°C. If CO<sub>2</sub> emissions continue at their current rate, by 2100 the planet could warm by as much as 3°C—in other words, we would experience half the levels we see in the Early Eocene, but the levels are increasing even faster than they did back then. So, if the Earth has experienced warmer temperatures in the past, what's so bad about warmer temperatures now? And 3°C doesn't seem like very much. Why should we be concerned about just a few degrees difference in temperature?

### *So How Does This Affect Me?*

Since 1900, the average global surface temperature of the planet has increased about 0.6°C. Throughout this time, we've seen increased frequency and intensity of hurricanes and El Niño seasons, increased plant and animal extinctions, higher temperatures and ocean levels, increased droughts, and extreme retreat of glacial cover. In contrast, throughout the past 10,000 years the average global temperature has not varied by more than 1°C in any one century. Based on the trend presented in the graph below, how close are we to surpassing this historical range in temperature?

### *Sea Levels*

We know that average global temperatures are on the rise and that ocean levels have risen 4–8 inches just over the last century. Seawater expands when heated, and NASA satellite images provide data for factoring ocean temperature and the melting of land ice into the rise of sea levels. The glaciers of Greenland are currently draining into the southern

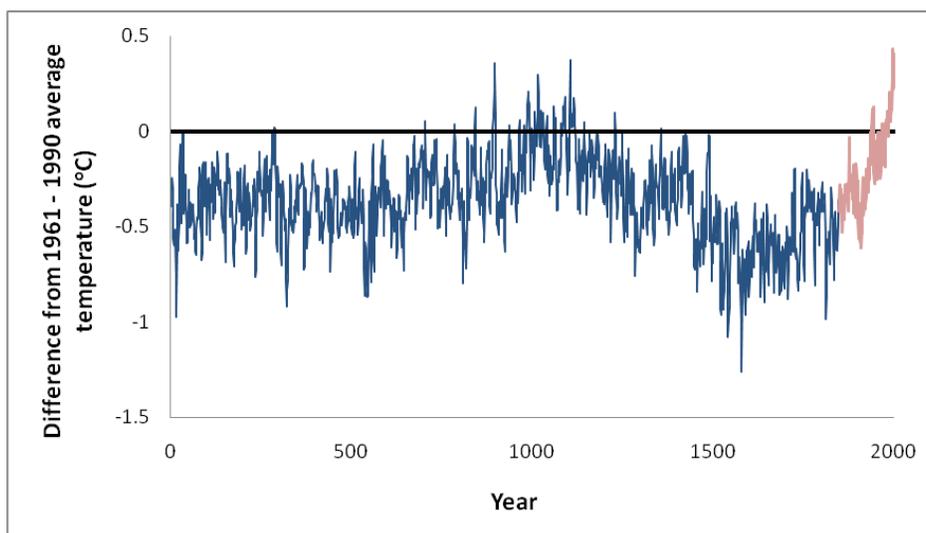
North Atlantic at a much faster rate than originally predicted. In fact, a 2008 study on glacial melt around Greenland predicts that the surrounding ocean will rise over two feet by 2100.

### Agriculture

Based on current predictions for climate change, global food production could actually increase. But only if your region is at higher latitudes and the mean temperature increase is no more than 3°C. For seasonally dry regions (like many parts of the Midwestern United States), crop productivity is projected to decrease with even relatively small increases in temperature, and resulting job losses from disappearing farms could devastate already strained farming communities. Globally, the news isn't as dire, but if average temperatures go much above 3°C, prolonged droughts, flooding, and other weather extremes will result in lower food production.

### Activity

The graph below depicts the way temperature (in °C) has fluctuated over the past 2,000 years.



*Figure 4.1* Estimated temperatures in every year of the Common Era. Blue values are inferred from paleoclimatological data, and red data, beginning with the year 1859, were measured directly.

### Questions

1. What do the  $x$  and  $y$  axes mean?
2. What does zero on the  $y$ -axis mean? What is the advantage of using this number as the zero?
3. Why do you think the average from 1961–1990 is a good baseline for comparison?
4. Highlight or shade the section of the graph with colder-than-average temperature in blue; highlight or shade the warmer-than-average section of the graph in yellow.
5. Locate the highest and lowest temperatures. When do they occur?
6. Compare the red temperatures (1859–2008) to the coldest and warmest blue temperatures calculated that were inferred from paleoclimatological data.
7. How has the climate changed since the year 1600?
8. What is the impact of just one degree Celsius change in temperature? Consider the difference between degrees Celsius and degrees Fahrenheit in your answer ( $1\text{ }^{\circ}\text{C} = 1.8\text{ }^{\circ}\text{F}$ ).
9. Based on the trend presented in the graph, how close are we to surpassing the highest temperature the Earth has experienced in the last 10,000 years (since before civilization)?

## Epilogue

Sara looked at the graduating class and smiled.

*So what can we do? First, educate ourselves about the causes of global climate change. Next, take action. We can start by taking an inventory of our own consumption and energy use, and deciding how we, as individuals, can get by with less. The next is to be informed voters so that, as citizens of the world, we can make larger changes in our community, region, and country that reduce our collective impact on the world's climate.*

*Simply put: the future environmental stability of our planet is ours to support, or ours to lose. We're counting on you. Best of luck to you all!*

The former paleontologist turned TV weather girl turned author was met with a standing ovation. After offering a short Q&A, Sara left the podium, turned a corner, and practically ran into the valedictorian. The shy girl thanked her and held out a copy of Sara's book to sign.

"That was quite a speech, by the way," said Sara, turning to the title page of the dog-eared book. As she spoke a teenage boy appeared beside the valedictorian. His smile and confident gaze were familiar, but she could not put his face to a time or place.

"Have we met, young man?"

"Not really," the young man replied.

He stretched out his closed fist and offered something to Sara. Into her open hand, he dropped a single round, glass earring, painted to resemble planet Earth.

"Oh, this is my little brother," said the girl, rolling her eyes.

"Always turning up at the appropriate times, right, Odin?"



*Credit:* Image on title page depicts restoration of Eocene fauna of North America, on a mural made for the US government-owned Smithsonian Museum by Jay Matternes, scan from the Time-Life book *North America*. Image available at <http://commons.wikimedia.org/wiki/File:Eocene.jpg>.

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