We are now in the first century in the thirty-five million centuries of life on Earth in which one species can jeopardize the planet's future. In *Riders in the Storm: Ethics in an Age of Climate Change,* Brian Henning is right that the identity of the twenty-first century will increasingly be defined by long-festering ecological crises, made worse by political and market failures. Here is a basic introduction, full scale across science, politics, and economics, seeing climate change as both ethical failure and opportunity. His analysis is well researched and documented, well presented, and quite readable. *Riders in the Storm* joins the most forceful voices in this keystone concern on the global agenda.

—Holmes Rolston III
Colorado State University

In *Riders in the Storm: Ethics in an Age of Climate Change*, Brian Henning shows that we are called to rethink everything in view of the catastrophe we face so as to engage together in the great work to which Thomas Berry has been calling us. Central to honorable pursuit of this work is personal morality, and this morality must shape our lives to the needs of our times. Like every truly wise morality, what it calls for is not miserable sacrifice but joyful, responsible life. Much that he describes is familiar to long-time participants in the environmental movement.

—John Cobb Jr.
Claremont School of Theology

The century's task—a task set for us by that implacable master physics—is to make ourselves smaller. This book is an eloquent reflection on that beautiful chore.

—Bill McKibben, author
Middlebury College

RIDERS IN THE STORM

ETHICS IN AN AGE OF CLIMATE CHANGE

BRIAN G. HENNING

ANSELM ACADEMIC

Author Acknowledgments

This project benefited greatly from the feedback and insights of the students in my Ethics of Global Climate Change at Gonzaga University from 2008 to 2014. The readability and flow of the initial manuscript was improved significantly thanks to the wise council of my wonderful development editor, Kathleen Walsh. The author extends his sincere thanks to the blind peer reviewers for their generous and exhaustive comments. Thanks go especially to all of the members of the production team at Anselm Academic for their professionalism, attention to detail, and hard work that made this volume a reality. Special thanks go to managing editor, Maura Hagarty, for her careful editor's eye and acquisitions editor, Jerry Ruff, for believing in the project from the start. Finally, I thank my wonderful spouse, Suzie Henning, without whose love, support, and encouragement this work would not be possible.

Some portions of this book originally appeared in journals or other books and are used with the permission of the publishers. Portions of chapter 1 and 4 were originally published as Brian G. Henning, "From Exception to Exemplification: Understanding the Debate over Darwin," in *Genesis, Evolution, and the Search for a Reasoned Faith*, edited by Mary Kate Birge et al. (Winona, MN: Anselm Academic, 2011). Portions of chapters 4 and 6 originally appeared as, Brian G. Henning, "Sustainability and Other Ecological Mistakes," in *Beyond Superlatives,* edited by Roland Faber, J. R. Hustwit, and Hollis Phelps, 76–89 (Newcastle upon Tyne: Cambridge Scholars Press, 2014). Portions of chapter 5 originally appeared as Brian G. Henning, "From Despot to Steward: The Greening of Catholic Social Teaching," in *The Heart of Catholic Social Teaching: Its Origins and Contemporary Significance*, edited by David Matzko McCarthy (Grand Rapids, MI: Brazos Press, 2009). The analysis in the appendix is an abbreviated version of Brian G. Henning, "Standing in Livestock's 'Long Shadow': The Ethics of Eating Meat on a Small Planet," *Ethics & the Environment* 16.2 (2011): 63–94.

Publisher Acknowledgments

Thank you to the following individuals who reviewed this work in progress:

Kendy Hess
College of the Holy Cross, Worcester, Massachusetts

Sarah Kenehan
Marywood University, Scranton, Pennsylvania

Created by the publishing team of Anselm Academic.

Cover images © *da-kuk/istockphoto.com* (stormy sea) and © *shayes17/istockphoto.com* (lighthouse)

Printed in the United States of America

7066

ISBN 978-1-59982-218-1

For Hope Philea and Nora Kalia.
May you take up the great work left to your generation.

Perhaps the most valuable heritage we can provide for future generations is some sense of the Great Work that is before them of moving the human project from its devastating exploitation to a benign presence. We need to give them some indication of how the next generation can fulfill this work in an effective manner. For the success or failure of any historical age is the extent to which those living at that time have fulfilled the special role that history has imposed upon them.

Thomas Berry, *The Great Work: Our Way into the Future*

1
CHAPTER

Climate Change Isn't Coming—It's Already Here

As I began to write this book in 2012 from the comfort of an air-conditioned neighborhood coffee shop in my little corner of the inland Northwest, much of the United States was baking in unprecedented temperatures.[1] Combined with lower-than-average precipitation, drought conditions covered 63% of the contiguous United States.[2] This mega-drought was so extensive that more than half (50.3%) of *all* US counties were declared disaster areas.[3] These hot, dry conditions and high winds also created the conditions for massive wildfires in many areas of the country. In July alone, more than 2 million acres (809,373 hectares) of forest burned nationwide. In Colorado, for instance, more than 34,500 people had to be evacuated from their homes, including entire towns; in the end, more than

1. Though the long-term trends are clear, climate change is difficult to describe because the data and literature are ever expanding. Readers are encouraged to consult the National Climatic Data Center to put current weather and climate patterns into historical context. See National Ocean and Atmospheric Administration, National Climatic Data Center, "State of the Climate," *www.ncdc.noaa.gov/sotc/*.

2. National Ocean and Atmospheric Administration, National Climatic Data Center, "State of the Climate: Global Analysis for July 2012," *www.ncdc.noaa.gov/sotc/global/2012/7*.

3. Michael Muskal, "As Drought Widens, 50.3% of U.S. Counties Declared Disaster Areas," *Los Angeles Times*, August 1, 2012, *http://lat.ms/1y0TbPL*.

350 homes were destroyed.[4] Although hot summers are nothing new, how does this one hot summer compare to the historical record?

It turns out that, for much of the country, July 2012 ranked among the warmest months on record. Figure 1.1 captures this temperature data. The closer the number on a state is to 118 (the number of years in the instrumental temperature record), the closer it is to being the hottest year on record for that state. According to the National Climatic Data Center (NCDC), the previous twelve months (August 2011 to July 2012) were the warmest since record-keeping began in 1895.[5] What is notable is not just the number of record-high temperatures, but just how high above normal they have been. For instance, the first six months of 2012 were 2.5°C (4.5°F) hotter than the average temperature and 0.83°C (1.5°F) hotter than the second hottest year on record (2006).[6]

This warming trend is not limited to the United States. The average land surface temperature in July 2012 for the Northern Hemisphere, where the majority of Earth's landmass is located, was the all-time warmest July on record. The Northern Hemisphere was 1.19°C (2.14° F) warmer than the twentieth-century average.[7] Thus putting the summer of 2012 in its historical context reveals that the increased temperature is not an isolated phenomenon. According to the NCDC, "July 2012 marks the thirty-sixth consecutive July and 329th consecutive month with a global temperature above the twentieth-century average."[8] Despite the day-to-day and season-to-season fluctuations, Earth *is* getting warmer. This is

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4. Jennifer Oldham, Amanda J. Crawford, and Tim Jones, "Colorado Wildfire Forces 34,500 to Evacute as Homes Burn," *BloombergBusinessweek*, June 28, 2014, *http://buswk.co/1vhyFrR*.

5. National Oceanic and Atmospheric Administration, National Climatic Data Center, "State of the Climate: National Overview for June 2012," *www.ncdc.noaa.gov/sotc/national/2012/6*.

6. Kelly Slivka, "Record High Temperatures in First Six Months of the Year," *Green* (blog), *New York Times*, July 9, 2012, *http://nyti.ms/TQE7ox*.

7. "State of the Climate: National Overview for June 2012." The report also states, "The average global temperature across land and oceans during July 2012 was 0.62°C (1.12°F) above the 20th century average of 15.8°C (60.4°F) and ranked as the fourth warmest July since records began in 1880. The previous three months—April, May, and June—also ranked among the top five warmest for their respective months."

8. Ibid., 6.

July 2012 Statewide Ranks[9]

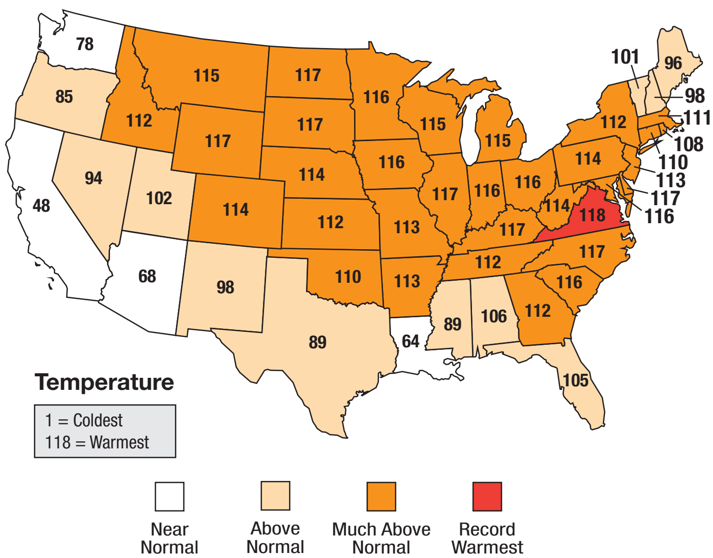


Figure 1.1. The closer the number on a state is to 118 (the number of years in the instrumental temperature record), the closer that state was to having the hottest year on record.

not disputable. Or, as the United Nations Intergovernmental Panel on Climate Change put it in their 2013 report, "Warming of the climate system is unequivocal."[10]

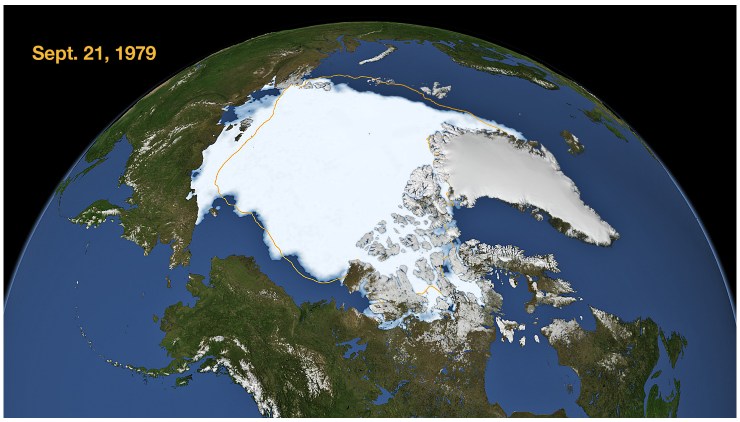
On Thin Ice

These persistently higher-than-normal global average surface temperatures are having detrimental effects on Earth's ecosystems. Nowhere is this more apparent than in the Arctic. Although the volume of ice has always fluctuated with the Arctic summer and winter, the ice cap at Earth's northern pole is steadily shrinking in

9. The data represented here is from the National Oceanic and Atmospheric Administration's National Climatic Data Center, *www.ncdc.noaa.gov*.

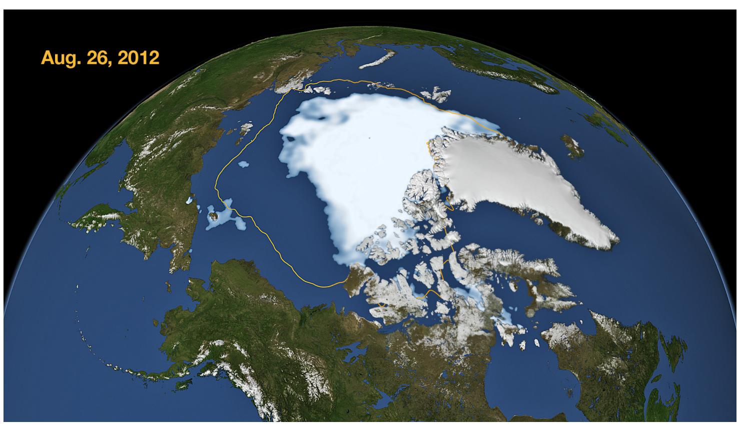
10. "Working Group I Contribution to the Fifth Assessment Report: Summary for Policymakers," *Climate Change 2013: The Physical Basis*, September 27, 2013, *www.climatechange2013.org/spm*.

size (see figs. 1.2 and 1.3). In fact, the summer of 2012 broke the previous record set in 2007 for the lowest volume of Arctic ice on record. This is no anomaly. Since satellite ice records began in 1979, the volume of ice has decreased steadily by 7.1% per decade. In other words, there is roughly 20% less sea ice now than thirty years ago.[11]



NASA/Goddard Space Flight Center Scientific Visualization Studio, The Blue Marble data is courtesy of Reto Stockli (NASA/GSFC).

Figure 1.2. This satellite image shows the concentration of sea ice in September 1979 compared to the average sea ice minimum from 1979 through 2010 (depicted by orange line).



NASA/Goddard Space Flight Center Scientific Visualization Studio, The Blue Marble data is courtesy of Reto Stockli (NASA/GSFC).

Figure 1.3. This satellite image shows the concentration of sea ice in April 2012 compared to the average sea ice minimum from 1979 through 2010 (depicted by orange line).

11. National Snow & Ice Data Center, "A Most Interesting Arctic Summer," 2012, *http://nsidc.org/arcticseaicenews/2012/08/a-most-interesting-arctic-summer/.*

Indeed, models created by researchers at the US Naval Postgraduate School estimate that there could be ice-free summers in the Arctic as early as 2016.[12]

While shipping, oil, and natural gas companies may benefit from the economic possibilities created by an ice-free or ice-diminished Arctic,[13] the people and creatures living in and around this area will not fare as well. For instance, without the sea ice to protect their coasts from the harsh winter waves, several Alaskan towns are at risk of falling into the ocean.[14] And animals such as walruses and polar bears, which hunt from ice floats, may become endangered or even extinct.

Reducing the **albedo** or whiteness of an area also raises concerns because a vicious warming cycle can be created (what scientists refer to as a **positive feedback** loop). Albedo relates to the reflectiveness of a surface. The higher the albedo, the greater the surface's reflectivity. Put simply, white surfaces reflect more of the incoming solar radiation into space than dark surfaces, such as green trees or open oceans, which absorb more of the Sun's rays. The warmer global temperatures shrink the surface area of the northern ice cap, revealing more open ocean, which has a lower albedo, which causes more of the Sun's rays to be absorbed, which increases warming, which further shrinks the amount of ice, continuing the cycle.

The Difference between Climate and Weather

Temperature records, both highs and lows, are broken every year. By its very nature, weather is variable. However, there is an important difference between **weather** and **climate**. Weather is the short-term, day-to-day variability within a particular geographical region that

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12. David Schmalz, "NPS Researchers Predict Summer Arctic Ice Might Disappear by 2016, 84 Years ahead of Schedule," *Monterey County Weekly*, November 27, 2013, *http://bit.ly/1opVPvk*.

13. For example, the melting ice opens up new areas for oil exploration and drilling.

14. Shishmaref is one example of a coastal Alaskan village threatened by erosion because of a reduction in sea ice. See "Human and Economic Indicators—Shishmaref," *www.arctic.noaa.gov/detect/human-shishmaref.shtml*.

meteorologists using satellites can forecast up to ten days into the future, often with limited success. Climate, on the other hand, refers to long-term weather trends and patterns over continents or the entire planet. Climatologists, who study climate, emphasize atmospheric chemistry and reconstructed historical trends during decades, centuries, or even millenniums.[15]

Because of the immense complexity of Earth's systems, it is not possible to demonstrate that climate change causes a particular event, such as Hurricane Katrina (2005) or Hurricane Sandy (2012). However, changes in climate can influence the severity or frequency of such events. The correlation between smoking and cancer serves as a helpful analogy. Although research showed a statistical correlation between cigarette smoking and lung cancer as early as the 1950s, it took decades to scientifically prove that smoking causes cancer.[16] Even now, one cannot *prove* that Uncle Al's smoking habit caused his lung cancer. Doctors can only say that smoking greatly increases the *likelihood* of getting cancer and that Al's pack-a-day habit is *very likely* the reason for his lung cancer.[17] Similarly, strictly speaking, it is not possible to *prove* that global warming causes a given weather event such as a hurricane or drought, if by "prove" one means "demonstrate with absolute certainty." However, one can accurately say that pollution makes the atmospheric blanket "thicker" and traps more heat from the Sun at Earth's surface and that this increased global average temperature increases the *likelihood* of extreme weather events.

So, it is theoretically *possible* that the record high temperatures of the summer of 2012 result from **natural variability**. It is also *possible* that Uncle Al's pack-a-day smoking habit didn't cause his lung cancer but that it resulted from something else, perhaps an unknown

15. Some data, such as data on the Arctic ice, has been measured only since 1979. The National Center for Atmospheric Research has recorded data on temperatures across the globe only since 1960.

16. For a detailed and articulate analysis of the tobacco industry's misrepresentation of the scientific findings, see Naomi Oreskes and Erik M. Conway, *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming* (New York: Bloomsbury Press, 2010).

17. See sidebar "The Definition of Scientific Certainty" in chapter 2 for a discussion of scientific certainty.

genetic defect or an undetected environmental toxin. However, the likelihood that the higher incidence of lung cancer in chronic smokers is just a coincidence is exceedingly small. Likewise, the chance that the recent extreme weather events are due entirely to natural variability are exceedingly low—so low that it would be irresponsible to base decisions on them. Referring to the increasing incidence of extreme weather events, James Hansen, who for decades served as the top climate scientist in the United States, argues, "These weather events are not simply an example of what climate change could bring. . . . The odds that natural variability created these extremes are minuscule, vanishingly small. To count on those odds would be like quitting your job and playing the lottery every morning to pay the bills."[18]

Rolling the Climate Dice

When Hansen first testified about climate change to Congress in 1988, he introduced the idea of "climate dice" to help explain the difference between natural weather variability and the long-term trends of climate change.[19] "Natural variability" of the weather refers to the fact that some summers are really hot while others are mild, and some winters are very cold while others are warmer.[20]

To represent this natural variability, imagine that two of the six sides of a die represent colder-than-normal temperatures, two sides represent normal or average temperatures, and two sides represent warmer-than-average temperatures. Given these ratios, rolling the "climate dice" again and again should result in an even distribution of record-high temperatures and record-low temperatures. Some summers prove brutal while others are quite temperate. That is natural variability.[21]

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18. James E. Hansen, "Climate Change Is Here–And Worse than We Thought," *Washington Post*, August 3, 2012, *http://wapo.st/1kHRrF6*.

19. Ibid.

20. Coincidently, while in 2012 nearly every state in the country experienced higher-than-normal temperatures, Washington was at or below the average of the last 118 years (see fig. 1.1).

21. Ibid.

However, as human pollution changes the composition of the atmosphere, extreme high temperatures become more and more likely, so much so that the die now has only one side with cooler-than-normal temperatures, one side with average temperatures, and *four* sides with warmer-than-normal temperatures. The climate dice are loaded. In fact, Hansen argues, the climate dice are now so loaded that one of those four warmer-than-normal sides represents not just hotter-than–normal temperatures but extremely hot temperatures: "Such events used to be exceedingly rare. Extremely hot temperatures covered about 0.1 percent to 0.2 percent of the globe in the base period of our study, from 1951 to 1980. In the last three decades, while the average temperature has slowly risen, the extremes have soared and now cover about 10 percent of the globe."[22]

This does not mean that there will no longer be severe, cold winters, or even record-setting ones. There will, but these events should not shift focus away from the overall trend, which clearly shows temperatures heading in an upward direction. The NCDC record shows the same trend. Statistically, in a climatically stable environment, the number of record-low temperatures should be about the same as the number of record-high temperatures over the course of a century. In the 1950s, record highs and lows, while not quite even, were fairly close (52 record highs with 48 record lows). However, when scientists at the National Center for Atmospheric Research (NCAR) examined millions of temperature readings from 1,800 weather stations across the United States over the six decades since 1950, they found that record highs outnumbered record lows, especially in the last thirty years. Between 2000 and 2009, scientists found twice as many record-high temperatures (291,237) as record-low temperatures (142,420).[23] This finding is notable not just for the

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22. Ibid.

23. *AtmosNews*, National Center for Atmospheric Research, "Record High Temperatures Far Outpace Record Lows across U.S.," November 12, 2009, *http://bit.ly/1pfvP5Y*. "The study team analyzed several million daily high and low temperature readings taken over the span of six decades at about 1,800 weather stations across the country, thereby ensuring ample data for statistically significant results. The readings, collected at the National Oceanic and Atmospheric Administration's National Climatic Data Center, undergo a quality control process at the data center that looks for such potential problems as missing data as well as inconsistent readings caused by changes in thermometers, station locations, or other factors."

number of record-high temperatures but for the fact that there were more than twice as many days with record-high temperatures than record-cold temperatures. Therefore, according to the instrumental record of the last century, the climate of Earth is getting warmer, and at an accelerating rate.

How much has Earth's temperature increased over the last century? The increased incidence of extreme weather—such as the mega-drought of summer 2012 or "Superstorm" Sandy in November 2012—correlates with only a 0.8° C (1.44° F) increase in the average surface air temperature of Earth in the last century. On average, the twentieth century was almost 1°C (1.8°F) warmer than the nineteenth century. "Only one degree Celcius?" you might think to yourself. "Surely that isn't anything to be concerned about. After all, the temperature varies far more than that in a single day!"

I experienced daily temperature variation on a summer camping trip to Glacier National Park. Early morning temperatures in the forties (Fahrenheit) (4.4°C to 9.4°C) required multiple layers of clothes and warm hats. However, by late afternoon, the temperatures approached 90°F (32°C). If a fifty-degree (Fahrenheit) (28°C) change in temperature in one day is not out of the ordinary, why should anyone be concerned by a couple degrees' change in a century? Again, the key lies in appreciating the difference between weather and climate.

While *weather* can vary considerably, *climate* changes very slowly over long periods of time, often tens of thousands or hundreds of thousands of years. Large temperature fluctuations are common with weather, but even a small change in climate can cause great damage. So the more important question is, "Is a change of 0.8°C in the twentieth century a significant *climatic* change?" The answer is an unambiguous "Yes!" To understand why requires knowledge of the long-term climate cycles of Earth's geological past and a look back into Earth's "deep time."

Our Holocene Home

According to the best evidence available from physicists, the universe is approximately 13.75 billion years old. Earth itself did not even arrive on the cosmic scene until 4.5 billion years ago. Our species,

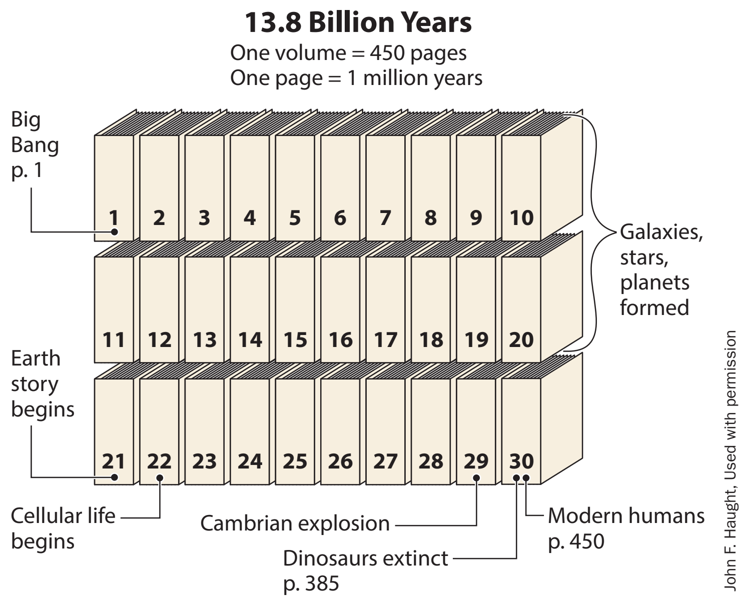

Figure 1.4. These volumes of books represent time from the Big Bang to today. Notice the late appearance of humans.

Homo sapiens, is a relative latecomer, appearing only just 200,000 years ago. These vast stretches of cosmic time are difficult to comprehend. Georgetown University theologian John Haught provides an illustration helpful in representing this concept.

Imagine time represented as a series of books in which each page represents 1 million years and each volume has 450 pages. The total history of the universe would be represented by thirty volumes. The first twenty volumes of the history of the universe contain essentially lifeless physical and chemical processes that formed the first galaxies, stars, and terrestrial bodies. The story of Earth does not even begin until volume 21. Primitive, single-celled life forms arrived on the scene in volume 22. The so-called Cambrian explosion, a period of rapid speciation during which most major animal groups are believed to have developed, occurs at the end of volume 29 (550 million years ago), and the dinosaurs become extinct on page 385 of volume 30 (65 million years ago). *Homo sapiens* do not appear until two-thirds of the way down the *last page* of volume 30. Recorded human history begins at the start of the last line of text of the last page of volume 30.

Looking forward, the Sun is expected to have enough fuel to burn for another ten or eleven volumes (5 billion years) before it swells into a red giant, swallowing Earth and many other planets in the process.[24] It is important to recognize that, no matter what human beings do, Earth's story has both a beginning and an end, although humanity's role in that story is still being written.

Scientists who have attempted to reconstruct Earth's climatic history have noted a pattern of ice ages. Since an ice age is defined in part by the presence of large, land-based ice sheets, such as those in Greenland and Antarctica, Earth is technically still in the Quaternary ice age, which began approximately 2.58 million years ago. However, this ice age includes subcycles of approximately 40,000 to 100,000 years during which glaciers advance (glacial periods) and retreat (interglacial periods).[25] The current interglacial period, called the Holocene, began some 11,000 years ago. The Holocene is humanity's "normal." All recorded human history has taken place during this period. All the plants and animals on which humans depend are adapted to thrive in the temperate and relative climatic stability of the Holocene.[26]

Remarkably, the difference in the average global air temperature between the height of a glacial period and a warmer, interglacial period is only a change of 5°C to 6°C (9°F to 10.8°F).[27] In other words, if the average temperature of the planet were 6°C colder—as it was some 20,000 years ago during the last glacial maximum[28]—my home in Spokane, Washington, would likely be covered by hundreds

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24. The previous two paragraphs originally appeared in Brian G. Henning, "From Exception to Exemplification: Understanding the Debate over Darwin," in *Genesis, Evolution, and the Search for a Reasoned Faith*, ed. Mary Kate Birge et al. (Winona, MN: Anselm Academic, 2011). See pages 92–94.

25. Chapter 2 will discuss what scientists believe might have caused these warming and cooling periods in the past and whether it is also the likely cause of the current warming.

26. Katherine Richardson et al., *Synthesis Report* from *Climate Change: Global Risks, Challenges & Decisions*, International Scientific Congress (March 10–12, 2009), 14, *http://bit.ly/1wwamru*.

27. John Houghton, *Global Warming: The Complete Briefing*, 4th ed. (Cambridge: Cambridge University Press, 2009), 13–14.

28. A "glacial maximum" is the "highest" point of a glacial period, after which ice starts to retreat.

Brian Henning, used with permission

Figure 1.5. Wild Goose Island, Saint Mary Lake, Glacier National Park.

of feet of ice. Indeed, during such a glacial period, pressure from massive ice floes carved the beautiful jagged peaks of Glacier National Park. These glaciers and ice sheets contained so much water that the oceans were some 400 feet (122 m) *lower* than they are today.[29] Some 125,000 years ago during the last warmer, interglacial period, Earth was even warmer than it is today and the oceans were some 13 to 19 feet (4 to 6 m) *higher* than they are today.[30] During these earlier glacial and interglacial periods, the contours of the present-day continents would have been unrecognizable. On this dynamic Earth, the only thing that remains constant is change.

Welcome to the Anthropocene

A better understanding of the climatic history of the planet can help answer the question raised earlier: "How do the current and projected

29. Houghton, *Global Warming*, 85.

30. Ibid.

changes in our climate compare to these historical changes?" The recent climate changes are extraordinary even in the context of such drastic changes in the past. The current change in climate is exceptional not merely for the increase in temperature—the temperature has been warmer in the past—but for the speed of change. The climate has gradually warmed since the end of the last glacial maximum some 20,000 years ago. According to climate scientist John Houghton, "The data indicate an average warming rate of about 0.2°C per century between 20,000 and 10,000 years before present (BP) over Greenland, with lower rates for other regions."[31] Therefore the 0.8°C (1.44°F) warming experienced in the twentieth century is at least four times the "background rate" of warming. Put differently, Earth experienced at least 400 years worth of warming in one century. Moreover, climate scientists project an *additional increase* in warming of 1.5°C to 6°C (2.7°F to 10.8°F) by the end of the twenty-first century.[32] That is, Earth will experience anywhere from one-third to an entire glacial period worth of temperature change—which normally takes many tens of thousands of years—in a single century.[33] Although a century represents a rather large increment of time for humans, this much temperature change in only one hundred years is truly extraordinary. Relating this to the shift in temperature experienced during my trip to Glacier National Park, it is as though the temperatures went from a chilly 40°F (4.4°C) to a toasty 90°F (32°C) in ten seconds, instead of ten hours.

Another, more personal analogy is to compare the difference in temperature fluctuation between weather and climate to the difference in temperature fluctuation between the body's surface (skin) temperature and the body's core temperature. In a sense, weather is to skin temperature as climate is to core body temperature.[34] In cold

31. Ibid., 88.

32. The Special Report on Emission Scenarios "shows increases for the different scenarios with best estimates for the year 2100 ranging from about 2°C to 4°C. When uncertainties are added, the overall likely range is from just over 1°C to 6°C—that wide range resulting from the large uncertainty regarding future emissions and also from uncertainty that remains regarding the feedbacks associated with the climate response to the changing atmospheric composition." Houghton, *Global Warming*, 143.

33. Ibid., 143–45.

34. The author thanks the students in his 2013 Ethics of Global Climate Change course at Gonzaga University for bringing this analogy to his attention.

weather, one's hands and feet can become quite chilled because as the body attempts to regulate a constant core temperature, the blood vessels in the extremities constrict, reducing blood flow. Thus the skin temperature of one's hands might be some 20°F to 30°F (9°C to 16°C) colder than one's core body temperature. On the other hand, core body temperature varies little, centering around 98.6°F (37°C). Thus large fluctuations in skin temperature are common, but even relatively small changes in core body temperature cause concern. For instance, if one were babysitting a young cousin and took her outside to play in the snow, her hands would be cold to the touch afterward. A thermal imaging camera might register their temperature at 60°F (15.5°C). A trip inside and a good mug of cocoa would quickly raise the skin temperature of her hands by 30°F (16.7°C). However, if that cousin starts to feel ill, one might take her core temperature. An increase of core body temperature (98.6°F or 37°C) of only a couple of degrees would cause worry; a change of 5°F (2.8°C) could prove life-threatening. The same holds true with climate.

Scientists predict that, were it not for the influence of humans, the climatic stability of the Holocene (that has made it possible for humans to thrive) would likely continue for several thousand years into the future.[35] However, the changes now underway are so large and so swift that some argue that the Holocene has prematurely ended and that Earth has entered a new climatic era. The Dutch atmospheric scientist Paul Crutzen has argued that, since **anthropogenic** (human-caused) changes now constitute the driving force behind changes on the planet, this new era should be called the "Anthropocene."[36] The author Bill McKibben argues that humanity no longer lives on the climatically stable and temperate planet called Earth but on a new, hotter, more dangerous planet, which he calls Eaarth.

> The planet on which our civilization evolved no longer exists. The stability that produced that civilization has vanished; epic changes have begun. . . . We *may*, with commitment and luck, yet be able to maintain a planet that will

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35. Johan Rockström et al., "A Safe Operating Space for Humanity," *Nature* 461, no. 7263 (September 24, 2009): 472.

36. *Anthropos,* the ancient Greek term for "human," comes from the same root as found in "anthropology" and "misanthropic."

> sustain *some kind* of civilization, but it won't be the same planet, and hence it can't be the same civilization. The earth that we knew—the only earth that we ever knew—is gone.[37]

Future Projections and Impacts

If the more intense heat waves, storms, and droughts *presently* experienced result from or are exacerbated by a 0.8°C (1.44°F) increase in Earth's average temperature, how much additional warming might occur this century, and how will it likely impact people and the planet?

At the beginning of the millennium, hundreds of scientists affiliated with the Intergovernmental Panel on Climate Change (IPCC) tried to answer this question. To aid world leaders responsible for making decisions for their countries, the IPCC created a "Special Report on Emission Scenarios." These forty scenarios are not predictions or forecasts but rather "projection scenarios" based on different possible courses of action this century. Extrapolating from correlations between past carbon dioxide (CO_2) levels, temperatures, and sea levels, scientists projected that, depending on the actions in the coming years, the average surface temperature would increase an additional 1.5°C to 6°C (2.7°F to 10.8°F) in the twenty-first century. Whether the final number ends up closer to one end of this range or the other depends largely on the policies adopted over the coming decades.

The average temperature of Earth has already increased by almost 1°C (1.8°F) during the last century, and at the current rate, will likely increase another 1.5°C to 6°C by the end of this century. That single degree has already brought about significantly warmer weather and increased the intensity of extreme weather events. If a single degree of warming has exacerbated the intensity of the droughts and storms, what will result from an increase of another 1°C to 6°C this century?

A planet with a changing climate will have regional winners and losers. While exile in Siberia will no longer be quite so bad, that Pacific island designated for an evil supervillain lair might disappear

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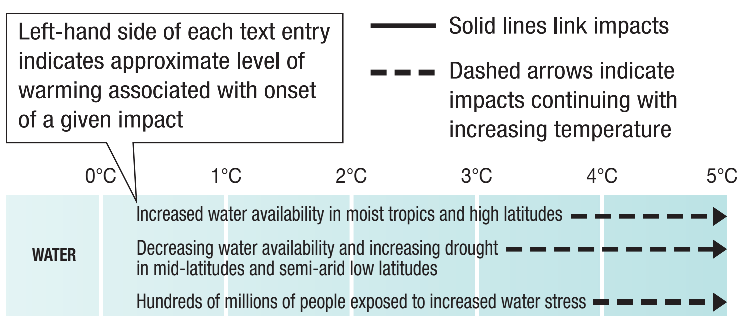
37. Bill McKibben, *Eaarth: Making a Life on a Tough New Planet* (New York: Time Books, 2010), 27, emphasis in original.

underwater.[38] Although benefits and damages will be unevenly distributed, in general, far more people and ecosystems will emerge as "losers" than "winners." These unevenly distributed benefits and damages will also likely disproportionately affect poor people in developing nations. Indeed, those least responsible for climate change stand to suffer the most significant impact.

Climate is a complex, dynamic, living system, not a static machine, which makes it difficult to project the likely impacts of an increase in the average temperature of Earth. While some impacts may occur in a smooth, linear fashion, others may be non-linear, occurring more suddenly as certain "thresholds" or "safe operating boundaries" are crossed. Indeed, new evidence suggests that gradual changes to the climate might "prove to be the exception rather than the rule. Many subsystems of Earth react in a nonlinear, often abrupt, way, and are particularly sensitive around threshold levels of certain key variables."[39]

Examples of Effects of Global Average Temperature Change[40]



Continued

38. Low-lying island nations are already confronting this problem. Indeed, those living on the Carteret Islands have become the first "climate refugees" to lose their nation to rising seas. The documentary *Sun Come Up* is an excellent resource for understanding the plight of the Carteret Islanders. See "Additional Resources" at the end of this chapter.

39. Rockström et al., "Safe Operating Space," 472.

40. The data represented in this chart is from the Intergovernmental Panel on Climate Change, "Fourth Assessment Report: Summary for Policymakers," *Climate Change 2007: Synthesis Report*, *http://bit.ly/SWzOXX*.

Examples of Effects of Global Average Temperature Change *Continued*

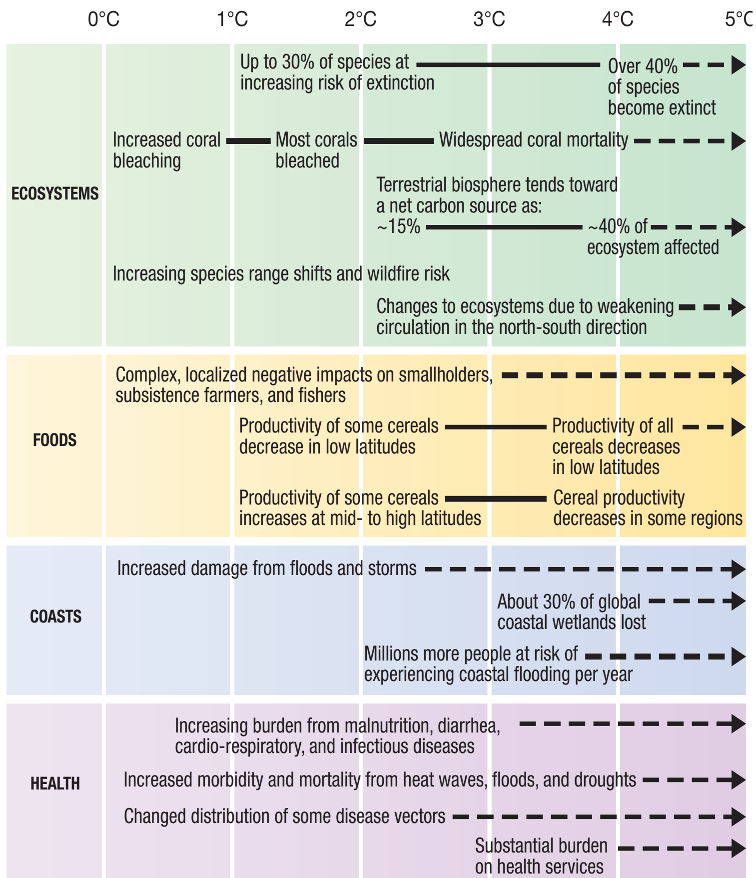


Figure 1.6. This chart presents examples of how different amounts of increased average global temperature changes—from 1 to 5 degrees Celsius—are expected to affect the world's climate in the twenty-first century. Scientists have a high level of confidence for all statements.

As indicated in figure 1.6, as the global average temperature increases, water availability will decrease and drought will increase in the mid-latitudes (the areas between roughly 25 and 65° North and 25 and 65° South, called the temperate zones) and semi-arid low latitudes (areas around the equator). As temperature increases, so does the rate of evaporation. Decreased water availability and increased evaporation will increase the risk and severity of wildfires. Increasing temperatures will also likely lead to increased human mortality from heat waves, floods, and droughts, as well as increasing malnutrition and diarrhea, cardio-respiratory, and infectious diseases. The combination of increased evaporation and decreased rainfall in some regions will also mean less water for agriculture and less run-off for waterways. In already semi-arid areas, this loss of rainfall will prove critical.[41] Beyond 2°C (3.6°F) warming, crops, which have adapted to the milder climate of the Holocene, will become less productive. For instance, rain-fed agriculture in Africa is expected to decrease 50% by 2020, exacerbating malnutrition.[42] Houghton notes that projected climate changes, combined with population increases, will double the number of people living in "severely stressed river basins . . . [from] 1.5 billion in 1995 to 3 to 5 billion" in 2050.[43]

Also, scientists expect the severity of storms to increase with each degree of warming: "For example, even with a modest increase in surface wind speed of 5 metres per second in tropical cyclones, possible with just a 1°C rise in ocean temperature, the number of the most intense and destructive cyclones [hurricanes] (Category 5) may double while the incidence of less intense cyclones would experience much smaller increases."[44] Although the regional effects will vary, many regions will experience less frequent but more severe precipitation events, resulting in damaging floods mixed with periods of intense drought, such as that experienced by more than half of the United States in 2012.[45]

Higher surface air temperatures, as well as higher concentrations of CO_2 in the atmosphere, also significantly impact Earth's oceans, which cover 70% of the planet. As the atmosphere becomes warmer, the oceans also become warmer. However, due to their size and the slow rate of turnover from the depths to the surface, the oceans respond more slowly than the atmosphere. These

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41. Houghton, *Global Warming*, 190–91.
42. IPCC, "Fourth Assessment Report."
43. Houghton, *Global Warming*, 193.
44. Richardson et al., *Synthesis Report*.
45. Houghton states, "The likely result of such a drop in rainfall is not that the number of rainy days will remain the same, with less rain falling each time; it is more likely that there will be substantially fewer rainy days and considerably more chance of prolonged periods of no rainfall at all. Further, the higher temperatures will lead to increased evaporation reducing the amount of moisture available at the surface—thus adding to the drought conditions. The proportional increase in the likelihood of drought is much greater than the proportional decrease in average rainfall." *Global Warming*, 158–59.

warmer temperatures have many significant effects on climate and sea life. One of the most important impacts for humans is that warmer water takes up more room than cold water. Scientists refer to this as "thermal expansion." Even apart from the possible impact of melting land-based ice, this thermal expansion will cause the oceans to rise. According to one estimate, an increase of 2°C to 3°C (3.6°F to 5.4°F) by 2050 could cause 2.29 feet (70 cm) of sea level rise due to thermal expansion alone.[46] As a report by the non-profit, non-partisan organization Architecture 2030 notes, "Beginning with just one meter [3.2 ft.] of sea level rise, our nation would be physically under siege, with calamitous and destabilizing consequences. The U.S. is a coastal nation with over 12,000 miles of coastline. With 53 percent of all Americans living in and around coastal cities and towns, it is important to understand the impact of climate-induced sea level rise on our nation."[47] According to scientists, a large portion of the West Antarctic ice sheet has already "gone into irreversible retreat" and has passed "a point of no return."[48] Over the course of the next two centuries these melting glaciers could cause the oceans to rise 1.2 meters (4 ft).

Beyond 2°C to 3°C warming, some low-lying island nations are expected to disappear entirely, while low-lying nations such as Bangladesh will be inundated, creating tens of thousands of climate change refugees. Moreover, the impacts visited on future generations increase in severity the longer these high temperatures are maintained. For instance, temperature changes of 2°C to 5°C (3.6°F to 9°F) maintained for several thousand years could result in the

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46. Oreskes and Conway, *Merchants of Doubt*, 178. Richardson and colleagues write, "An alternative approach is to base projections on the observed relationship between global average temperature rise and sea-level rise over the past 120 years, assuming that this observed relationship will continue into the future. New estimates based on this approach suggest a sea-level rise of around a metre [3.28 ft.] or more by 2100." *Synthesis Report*, 10. The IPCC reports, "Global average sea level has risen since 1961 at an average rate of 1.8 (1.2 to 2.3) mm/yr and since 1993 at 3.1 (2.4 to 3.8) mm/yr, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets." "Fourth Assessment Report," 1.

47. *Architecture 2030*, "Hot Topics: Nation under Siege," *http://architecture2030.org/hot_topics/nation_under_siege*. This website includes an interactive map showing the affects of a one-meter rise in sea level on different American cities. Another interactive map can be found at *Surging Seas*, Climate Central, *http://sealevel.climatecentral.org/*.

48. Justin Gillis and Kenneth Chang, "Scientists Warn of Rising Oceans from Polar Melt," *New York Times*, May 12, 2014, *http://nyti.ms/1iGkKCF*.

complete elimination of the Greenland ice sheet, which would result in a sea level rise of about 7 meters (23 ft).[49] As later chapters will discuss, the multigenerational nature of this challenge makes it all the more difficult to address.

Quite apart from the effect of increasing ocean *temperature* is the role that increased concentration of atmospheric CO_2 has on the *chemistry* of the oceans; as the oceans absorb atmospheric CO_2, they become increasingly acidic.[50] (Think of the acidity of a carbonated drink.) **Acidification** threatens much ocean life. In particular, a lower pH (signifying higher acidity) seems to negatively impact the formation of coral polyps that form coral reefs. Ocean acidification combined with higher water temperature has resulted in coral reefs dying or "bleaching." The bleaching of the oceans' reefs is of concern not only because it results in the loss of beautiful and unique ecosystems but also because reefs are among the most biologically rich ecosystems, relied on by millions of people for both commercial and subsistence fishing. Beyond 3°C (5.4°F) warming, the IPCC predicts "widespread coral mortality" (see fig. 1.6).

As the oceans expand and glaciers retreat, the salty seawater will increasingly encroach on freshwater (a phenomenon called **salinization**), further exacerbating shortages. Storms will further erode coastlines, and encroaching water will displace more people. Beyond 3° warming, 30% of all coastal wetlands, among the most biologically diverse habitats on the planet, will disappear.

While some impacts become more severe with each degree increase, some changes are expected to be *irreversible*.[51] (Recall the

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49. The IPCC reports, "The corresponding future temperatures in Greenland are comparable to those inferred for the last interglacial period about 125,000 years ago, when paleoclimatic information suggests reductions of polar and ice extent and 4 to 6 m of sea level rise." "Fourth Assessment Report," 13.

50. Houghton states, "The chemical laws governing this equilibrium are such that if the atmospheric concentration changes by 10% the concentration in solution in the water changes by only one-tenth of this: 1%." *Global Warming*, 40.

51. "Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change. Partial loss of ice sheets on polar land could imply metres of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands. Such changes are projected to occur over millennial time scales, but more rapid sea level rise on century time scales cannot be excluded." IPCC, "Fourth Assessment Report," 13.

analogy with the core temperature of the human body.) For instance, warming of 1°C to 3°C (1.8°F to 5.4°F) could lead to the extinction of 30% of all mammal, bird, and amphibian species in this century.[52] Warming beyond 4°C (7.2°F) would likely cause the extinction of more than 40% of all species on Earth. Species extinction is a natural part of the evolutionary process; biologists refer to this as the "background rate" of extinction. However, the current rate of species extinction is 50 to 500 times the typical background rate. Indeed, Earth may be in the midst of the sixth mass extinction event of its history:[53]

> There is growing understanding of the importance of functional biodiversity in preventing ecosystems from tipping into undesired states when they are disturbed. This means that apparent redundancy is required to maintain the ecosystem's resilience. Ecosystems that depend on a few or single species for critical functions are vulnerable to disturbances, such as disease, and are at a greater risk of tipping into undesired states.[54]

Given the magnitude and scope of the impacts of climate change, world leaders have agreed to try to limit warming to not more than an additional 2°C (3.6°F). They refer to this as the two-degree "guardrail,"[55] beyond which Earth would experience a "biodiversity catastrophe."[56]

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52. "Climate change is *likely* to lead to some irreversible impacts. There is *medium confidence* that approximately 20–30 percent of species assessed so far are *likely* to be at increased risk of extinction if increases in global average warming exceed 1.5–2.5oC" (relative to 1980–99) (IPCC, "Fourth Assessment Report," 13).

53. Rockström et al., "Safe Operating Space," 473. See also Elizabeth Kolbert, *The Sixth Extinction: An Unnatural History* (New York: Henry Holt, 2014).

54. Rockström et al., "Safe Operating Space," 474.

55. Richardson and colleagues write, "While there is not yet a global consensus on what levels of climate change might be defined to be 'dangerous,' considerable support has developed for containing the rise in global temperature to a maximum of 2°C [3.6°F] above pre-industrial levels. This is often referred to as 'the 2°C guardrail.' . . . Beyond 2°C, the possibilities for adaptation of society and ecosystems rapidly decline with an increasing risk of social disruption through health impacts, water shortages and food insecurity." *Synthesis Report*, 12.

56. Richardson et al., *Synthesis Report*, 14. Chapter 2 will discuss what it would take to limit warming to only an additional 2°C this century. One estimate entails reducing global greenhouse gas emissions by 60–80% just to *limit* warming to 2–2.4°C (ibid., 18).

To better convey the uncertainty in climate change prediction and the role of policy decisions, researchers at MIT developed "Greenhouse Gamble" roulette wheels. These two wheels—one representing the status quo (policymakers make no changes addressing climate change) and one representing the implementation of strict climate change policies—"depict the estimated probability, or likelihood, of potential temperature change (global average surface temperature) over the next 100 years. The face of each wheel is divided into colored slices, with the size of each slice representing the estimated probability of the temperature change in the year 2100 falling within that range."[57] The category ("pie slice") on the "no policy" wheel representing less than a 3°C increase in temperature is the smallest slice on the wheel and is barely visible, and the two categories representing a temperature increase of 4°C–6°C cover nearly two-thirds of the wheel. In contrast, the categories (slices) on the "policy" wheel that represent less than a 3°C increase in temperature cover nearly nine-tenths of the wheel.[58] These wheels show that although there is uncertainty in predicting the future, we can change the set of probabilities we are operating under by implementing climate change policies.

The magnitude of the challenges global warming will likely cause in this century and for centuries to come raises questions about whether increases in temperatures will more likely be at the low end of 1°C to 2°C (1.8°F to 3.6°F) or the high end of 4°C to 6°C (7.2°F to 10.8°F). How big is the challenge humanity faces? In a sense, it depends on what humanity does or does not do over the next few decades. The next question to consider is: What is causing the global atmosphere to warm? Only by understanding the causes underlying these changes can humanity hope to mitigate them.

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57. MIT Joint Program on the Science and Policy of Global Change Greenhouse Gamble Wheels, *http://globalchange.mit.edu/focus-areas/uncertainty/gamble*. On this interactive website you can "spin" the greenhouse gamble wheels to depict the estimated probability of potential temperature change over the next hundred years.

58. The "median value" of the "no policy" wheel is a 5.2°C (9.36°F) increase, while the median value of the "policy" wheel is an increase of 2.3°C (4.14°F). MIT Joint Program on the Science and Policy of Global Change Greenhouse Gamble Wheels. That is, without a climate change policy, there are only even odds (a 50/50 chance) of less than a 5.2°C temperature increase this century, which is at the very high end of the impact scenarios considered by the United Nations.

For Further Exploration

1. Visit one of these interactive maps and examine the expected flooding caused by rising sea levels:

   http://architecture2030.org/hot_topics/nation_under_siege

   Architecture 2030 includes an interactive map showing the effects of a one-meter rise in sea level on different American cities.

   http://sealevel.climatecentral.org/

   Surging Seas by Climate Central is an interactive map that allows users to look at effects of one to ten feet of sea level rise on coastal states.

   http://ngm.nationalgeographic.com/2013/09/rising-seas/if-ice-melted-map

   Rising Seas by National Geographic provides a view of the coastline of each continent should all the ice on the planet melt.

2. Review the latest US Global Change Research Program report (*http://ncadac.globalchange.gov/*) and identify the anticipated impacts of global climate change on your hometown.
3. Visit the MIT Joint Program on the Science and Policy of Global Change website (*http://globalchange.mit.edu/focus-areas/uncertainty/gamble*) and view the Greenhouse Gamble wheels. Then complete the following exercise, which the researchers described to Congress in 2007:

   > Imagine that you are playing "the greenhouse gamble" and have $100,000 in winnings. To end the game and collect your money, you must finally spin one of these two wheels. If you land on any of the sectors of the wheel corresponding to warming exceeding 3 degrees centigrade, you lose say $10,000 of your winnings. You can spin the "no policy" wheel for free but must pay to spin the "policy" wheel with its much lower odds of losing your money. In this game the $10,000 represents an (arbitrary) penalty for the damages caused by dangerous climate change and the money you are willing

to give up represents the cost of mitigating policy. How much of your $100,000 would you be willing to give up in order to spin the "policy" wheel?[59]

After deciding, spin the wheel and record your results and your reaction to your results.

Additional Resources

ORGANIZATIONS

350.org

This burgeoning global movement, co-founded by Bill McKibben and named for the amount of CO_2 scientists say will preserve a livable climate on Earth (350 parts per million), works to foster grassroots action to address climate change.

Intergovernmental Panel on Climate Change (IPCC)

The reports of this leading scientific body, which studies global climate change, are the most authoritative statements available. Its "Summary for Policymakers" documents are written in clear and accessible language that is understandable by non-scientists. See the following websites:

- IPCC website, *www.ipcc.ch/*
- IPCC's Fifth Assessment Report, *www.climatechange2013.org/*
- An interactive time line of the IPCC and its work, *unfccc.int/timeline/*

National Climatic Data Center (NCDC)

This center maintains the world's largest climate data archive and provides climatological services and data to every sector of

59. Ronald G. Prinn, "Climate Change: A Growing Scientific Impetus for Policy," Testimony to the Committee on Ways and Means, US House of Representatives (February 28, 2007), *http://globalchange.mit.edu/files/document/MIT_R.Prinn.CT07.pdf*.

the US economy and to users worldwide. Readers are encouraged to consult the NCDC to put current weather and climate patterns into historical context. (See *www.ncdc.noaa.gov/*.)

National Center for Atmospheric Research (NCAR)

This center plans, organizes, and conducts atmospheric and related research programs in collaboration with universities. (See *http://ncar.ucar.edu/*.)

National Snow and Ice Data Center (NSIDC)

This center supports research on Earth's frozen realms: the snow, ice, glaciers, frozen ground, and climate interactions that make up Earth's cryosphere. (See *http://nsidc.org/*.)

BOOKS

Houghton, John. *Global Warming: The Complete Briefing*. 4th ed. Cambridge: Cambridge University Press, 2009.

This textbook, written by the founding co-chair of the IPCC, is one of the most helpful and accessible on the science of global climate change. It is especially well suited for non-scientists.

Kolbert, Elizabeth. *The Sixth Extinction: An Unnatural History*. New York: Henry Holt, 2014.

Kolbert argues that human activity is causing the sixth mass extinction event in Earth's history. The last such event was 65 million years ago when the dinosaurs went extinct.

McKibben, Bill. *Eaarth: Making a Life on a Tough New Planet*. New York: Time Books, 2010.

McKibben's use of the word "Eaarth" to refer to our planet highlights that through global warming Earth has become a new and different planet. He argues that fundamental change is the only hope for establishing balance on the planet.

———. *Oil and Honey: The Education of an Unlikely Activist*. New York: Times Books, 2013.

McKibben provides accounts of two strategies for fighting global climate change: participating in large-scale action and finding small-scale local solutions. He chronicles a fight against the fossil fuel industry as well as the work of beekeeping.

Oreskes, Naomi, and Erik M. Conway. *Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*. New York: Bloomsbury Press, 2010.

Oreskes and Conway construct a detailed and articulate analysis of the powerful negative effects when industry scientists create campaigns to systematically mislead the public on issues such as the health effects of smoking tobacco and the science of global climate change.

DOCUMENTARY

Sun Come Up

This Academy Award–nominated documentary follows the plight of the Carteret Islanders, who became the world's first climate change refugees when their island nation had to be abandoned due to rising seas. (See *www.suncomeup.com/*.)