A Quick-Start Guide to

The Teacher-Friendly Guide™

to Climate Change

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Preface: The twelve pages of this booklet were selected by the authors to represent the contents of each of the twelve chapters of *The Teacher-Friendly Guide™ to Climate Change*. Each page discusses a key figure or key point that best represents the chapter as a whole. For super-busy teachers – or administrators, legislators, board-members, students, or parents – these twelve pages introduce you to important topics and invite you to pursue that subject as time allows in the full chapter.

Chapter 1: Why Teach About Climate Change?

Everyone we have ever known and loved lives on the speck we see in the photograph taken by the spacecraft Voyager 1 from outside the Solar System (see figure). People of all stripes treasure that speck deeply and want to preserve its richness, its diversity, and its life-supporting aspects. We are profoundly lucky to live on that speck, and we have a duty to preserve our luck for future generations. The state of the climate, locally and globally, is fundamental to that preservation.

Effective and up-to-date teaching of the science of climate change is of paramount importance to good science education and the science does make clear that the Earth's climate is changing through human activities. But simply sharing scientifically accurate content about climate change is not the same as good teaching, which facilitates deep learning about the interconnections of climate change with other 21st century human challenges such as food, energy, and water resources, and the many associated social issues.

Figure 1.1: View of Earth from outside the Solar System, at a distance of about 6 billion kilometers, from the Voyager 1 spacecraft. The image was taken at the request of astronomer and educator Carl Sagan.

But teaching climate change is challenging when the topic becomes socio-politically contentious in the classroom. Engaging students effectively requires attention not only to how science is learned, but how other facets of our lives influence our views. Thus teaching climate change requires mutual respect and reflection on how we come to accept the things that we do, what our own biases may be, and, more generally, why perhaps all of us believe some refutable ideas.

Understanding and teaching climate change is also challenging because climates are complex systems, with feedback loops, tipping points, long histories, and multiple scales of space and time. We must facilitate systems and temporal thinking.

And teaching about climate change is difficult because it means confronting challenges that are on a scale perhaps never faced by humanity. It is important, however, to maintain perspective. There are many examples in which increased scientific awareness, understanding, and societal change allowed people to work together to make a positive difference.

The Teacher-Friendly Guide to Climate Change explores all of these issues: the science of climate change, teaching about contentious issues, and maintaining hope and perspective.

Chapter 2: What Should Everyone Understand About Climate Change and Energy?

In this chapter, we approach the question in the chapter's title in three different ways:

- We provide responses from experts we surveyed—scientists both from the natural and social sciences, journalists, and educators—on what they think is most important for everyone to understand, and to boil it down to about 100 words or less.
- We review consensus documents written through collaborations of scientists and educators. These ideas were developed with input from many individuals.
- We share a framework of key ideas developed for this book but drawn from a series of Earth Science Overarching Questions and Bigger Ideas we have used in our programming for many years.

We also ask the reader to consider the question themselves, before and after digging into the content of the chapter.

A fairly small set of ideas appear again and again in these different views of climate change and energy. We believe that perhaps the most important of these is that climate change cannot be understood in isolation, and that a systems perspective is essential for developing deep understandings of our climate. Does this mean a learner should study the nature of complex systems before studying climate change? No. Studying climate change is a way to deepen one's understandings of systems and studying systems is a way to deepen one's understandings of climate change. These understandings can and should be developed in tandem.

Overarching Questions:
How do we know what we know? How does what we know inform our decision-making?

	Systems	*Energy*	*Life*	*Change*	*Models*
Earth System Science Bigger Ideas	**The Earth is a System of Systems.**	**The Flow of Energy Drives the Cycling of Matter.**	**Life, including human life, influences and is influenced by the environment.**	**Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system.**	**To Understand (Deep) Time and the Scale of Space, Models and Maps are Necessary.**

Figure 2.2 The Rainbow Chart (abbreviated)

Chapter 3: What is Climate?

The Greenhouse Effect is a metaphor that describes the way certain gases in the atmosphere keep the Earth warm. Analogous to the way glass over a greenhouse traps heat and keeps the contents warm, *greenhouse gases* trap heat and keep the planet warmer than it would be otherwise. Earth absorbs energy from the sun, and the law of conservation of energy requires that the same amount must be re-radiated back to space. The key difference is the wavelength of the incoming and outgoing radiation. Hot objects like the sun emit most of their energy as short-wavelength visible radiation, while cool objects like the Earth emit long-wavelength infrared energy. The atmosphere is transparent to short-wavelength incoming solar energy, thus it passes through the atmosphere, warms the Earth surface, and returns to space at longer wavelengths. Greenhouse gases absorb the IR energy emitted by the Earth. The gas molecules vibrate, warm up, and re-radiate the absorbed energy. The more greenhouse gases the more warming of the atmosphere before all the energy is radiated back to space. Scientists are especially concerned about the concentration of carbon dioxide gas because it absorbs exactly at the wavelength where Earth emits most of its IR energy.

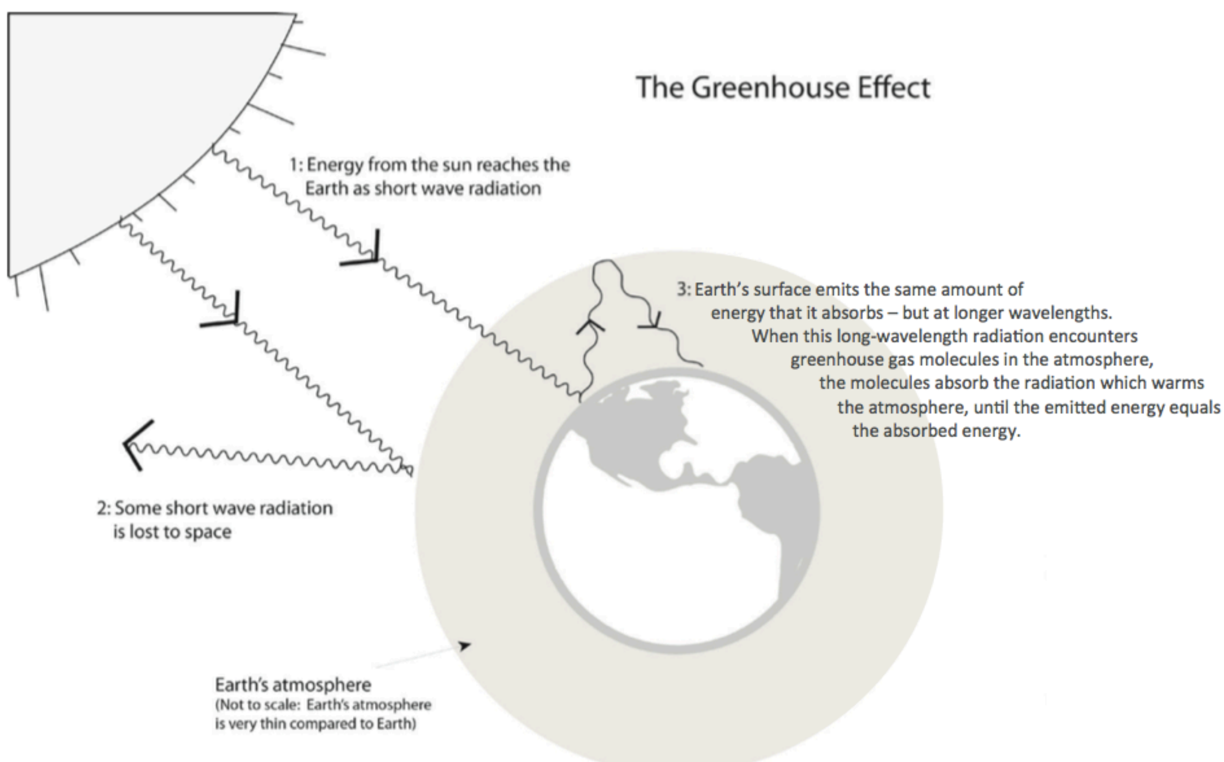

Figure 3.3: The greenhouse effect.

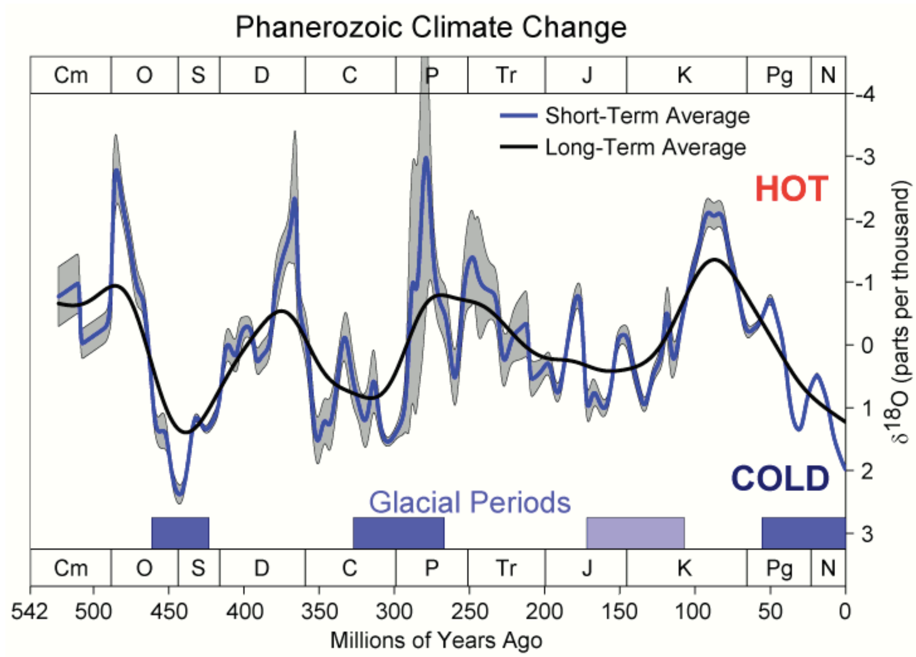

Figure 4.6: Changing global climate throughout the last 542 million years. These data were compiled using the ratios of stable oxygen isotopes found in ice cores and the carbonate skeletons of fossil organisms.

The Earth has throughout its history experienced wide swings in temperature and precipitation. Current climate change is not, however, just more of the same: it is, through its rapidity and extent, influencing humanity and the ecosystems upon which we depend. Rapid climate change is associated with some of the largest overturns in life throughout geologic time.

Understanding ancient climates may help students understand that climates *can* change, put the kinds of changes we see today into historical perspective, and help students understand how researchers use geological data to study our currently changing climate. Accepting the idea that the Earth does change has profound implications for how we see the Earth and its future.

It is helpful for students to know that past climates help scientists understand how the Earth *could* change by understanding how the Earth actually *has* changed. Computer models are essential for exploring how climate systems work, but there is no way to test global system models physically – we cannot experiment on the whole earth, but we can explore natural experiments the Earth has run for us in its geologic past.

Everything we know about the Earth's past is based on geologic records, in particular layers of sediments and their enclosed fossil and chemical data. In fact, we and our students can explore past climate change wherever we can find layers of sedimentary rocks. Layers that vary in their characteristics often reflect changes in climate that led to changes in weathering, environments, and sedimentation.

Chapter 5: Evidence for and Causes of Recent Climate Change

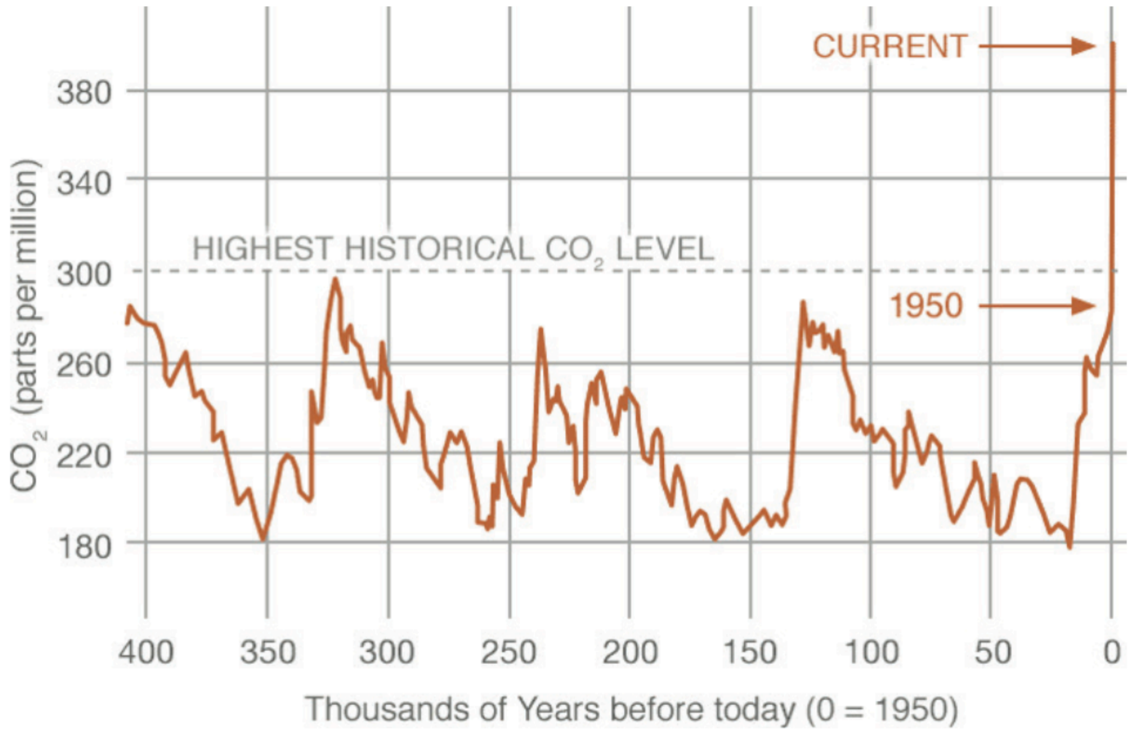

Figure 5.2: Atmospheric CO2 measurements from Antarctic ice cores and the NOAA Mauna Loa Observatory.

Long-term climate records document Earth's glacial and interglacial cycles. Over the last ~1 million years ice ages have occurred every 100,000 years, with the last glacial maximum at 18,000 years before present. The amount of carbon dioxide in the atmosphere rises and falls in step with the changes in global temperature. That CO_2 record comes from tiny samples of ancient atmosphere preserved in bubbles trapped in glacial ice. Since 1958 atmospheric scientists have made direct measurements of the amount of CO_2 in the atmosphere. Figure 5.2 shows these two CO_2 records together; ancient CO_2 concentrations from a core drilled through annual ice layers in the Antarctic ice cap and modern measurements made at the NOAA Mauna Loa Atmospheric Observatory in Hawaii. The ice core record extends back 400,000 years and shows the maximum CO_2 concentration no higher than 300 ppm. At the start of the industrial revolution atmospheric CO_2 was 280ppm. In the subsequent 150 years it has increased to the present value of 410ppm. This change is both larger and faster than any increase recorded in the geologic record. Typical glacial-interglacial CO_2 changes average 100ppm and occur over 10,000 years. Humans have accelerated that rate of change one hundred times.

Chapter 6: US Regional Climates

Though climate change is global, as individuals we are especially motivated to notice and act on changes that we see in our own communities, particularly if they affect the health and livelihood of people we know. Thus teaching about climate change and building resilience to it includes considering changes we can observe in our own region that are occurring now or are expected to occur in the future.

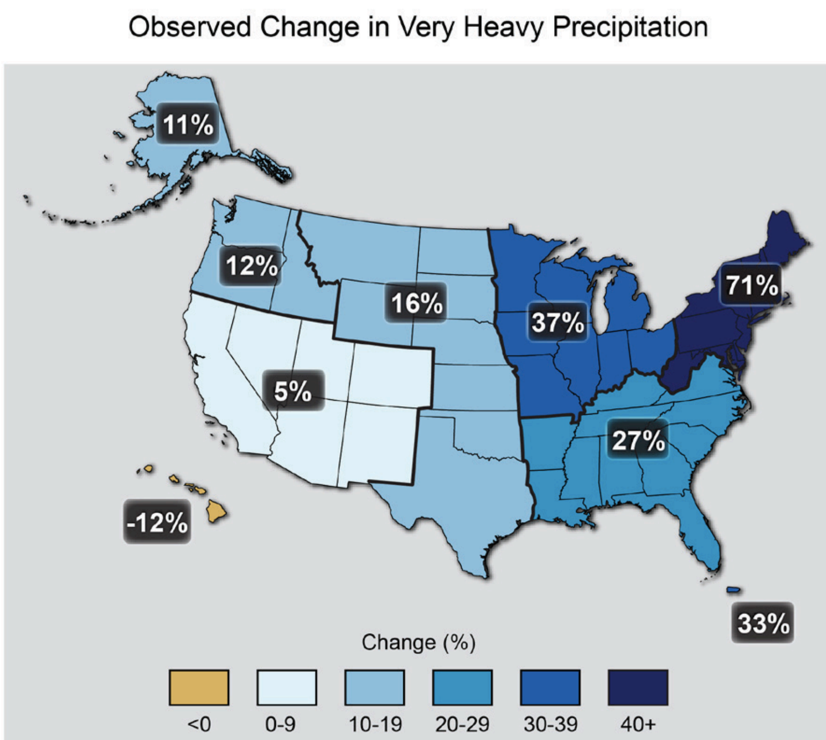

Figure 6.2: This map shows percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. These trends are larger than expected natural variations for the Northeast, Midwest, Puerto Rico, Southeast, Great Plains, and Alaska.

Each region of the country—from the equatorial wetlands of Florida to the arid deserts of Arizona—is impacted in some manner by the changing global climate. But the kinds and degrees of impacts differ. Coastal communities are being affected by rising sea levels and increased storm surges, while desert communities may be facing longer and more frequent droughts and heat waves. Ski resorts in the Rocky Mountains may have to adapt to less snowfall and smaller snow packs, while communities in the Northeast are experiencing more heavy rainfalls.

Teaching about regional variations in climate change is also an opportunity to help students consider how friends and family in other regions may be impacted in ways we do not experience first hand in our own region. Building effective understanding of climate change will depend on understanding that while climates and climate changes vary regionally, they are all connected through the larger Earth system.

Chapter 7: Climate Change Mitigation

The decisions made by humans over the past few centuries have already committed us all to unavoidable climate consequences, and we are going to have to adapt to these consequences. However, this does not mean that we are committed to the most catastrophic climate change scenarios. We have the capability to mitigate the factors that could lead to the worst climate changes by reducing our greenhouse gas emissions, thereby taking responsibility for the future of our planet and all the living things—including us—that live on it.

Climate change mitigation encompasses a wide range of strategies to reduce the sources of greenhouse gas emissions. These strategies involve different levels of effort and scope, from broad-ranging actions taken at the government level to actions by specific industries or companies, and to behavior changes made by individuals. A successful mitigation pathway will likely involve combinations of several strategies. Example strategies include reducing our energy use through energy efficiency and conservation—in buildings, transportation, industry, and water treatment and use; implementing low-carbon forms of energy production such as renewable and nuclear energy; carbon capture and storage from industrial processes; paying attention to the way we use land in forests, soils, and agriculture; and being smart about waste management.

Figure 7.7. Wind energy is an example of a renewable, low-carbon energy source.

Chapter 8: Geoengineering

Geoengineering, or climate intervention, is a large-scale technological effort to change the Earth's climate. It differs fundamentally from climate change mitigation, because instead of aiming to slow warming by decreasing carbon emissions, it involves either removing carbon dioxide from the atmosphere or decreasing heat received from the sun. Such methods could be used to supplement climate change mitigation, or used even while carbon emission rates continue increasing. Many scientists and policymakers are wary of geoengineering for this reason, because they are concerned that climate intervention will be seen as a magic bullet or easy solution that allows us to go on with business as usual, releasing more and more carbon. Geoengineering would be anything but easy, however, and could have tremendous financial and environmental cost. Intervening with Earth's climate systems also has great uncertainty at our current level of understanding, and could have harmful unintended consequences.

Given the concerns about geoengineering, why consider it at all? Some scientists view climate intervention as an undesirable but important method of last resort that deserves study. Others think that geoengineering methods that remove carbon dioxide from the atmosphere could contribute to emissions reduction efforts, and some methods may even cost less than certain types of mitigation. Other interventions which effectively block sunlight from reaching the Earth could theoretically begin to cool the climate within a few years of deployment, so they could be emergency options. If the climate approached a tipping point—a threshold beyond which the Earth would enter a vastly different climate state—then emergency measures would likely garner more serious attention. Major studies of geoengineering conclude that while research into climate intervention is prudent in order to be prepared for the worst, it is most important that we focus on reducing carbon emissions quickly.

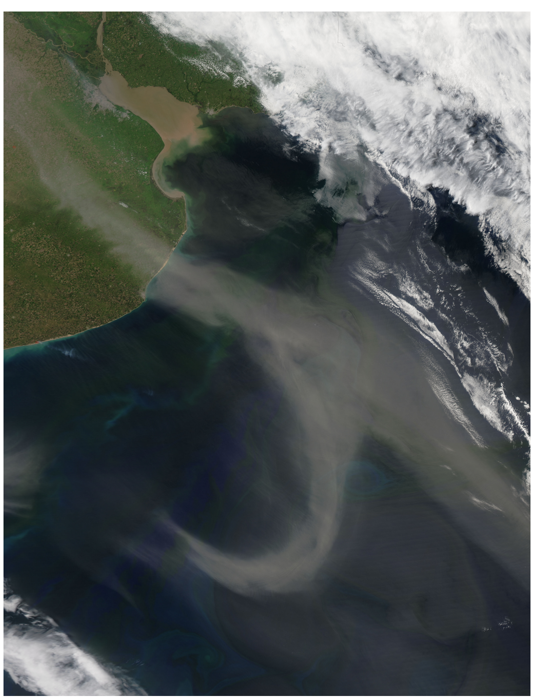

Figure 8.2: A pale brown plume of dust swept out of Argentina's Pampas, a heavily farmed grassland, and split into two plumes over the South Atlantic Ocean. The wind-blown dust carries iron and other nutrients that fertilize the ocean, promoting growth of surface-dwelling phytoplankton (blue and green regions in the ocean) that pull carbon out of the atmosphere through photosynthesis. Some scientists have proposed ocean fertilization as a geoengineering method.

Chapter 9: Climate Change Adaptation

The Earth's climate system generally changes slowly, and the greenhouse gases that we have already emitted are going to change the climate over the next decades and centuries even if we stop emitting all greenhouse gases tomorrow. This is why adaptation strategies are necessary. Mitigation strategies, on the other hand, ultimately are intended to reduce the severity of climate change impacts by reducing future emissions of greenhouse gases. Future adaptation will be much harder if we don't reduce greenhouse gas emissions today.

Communities are adopting a wide range of adaptation strategies. Some strategies are "win-win" or "no-regrets," that is, they have benefits beyond adapting to climate change and should probably be done anyway. Others can be seen as more drastic. Example strategies include:

- updating building codes to encourage construction of structures that are more storm- and flood-resistant
- relocating infrastructure out of flood-prone areas
- rebuilding coastal reefs to attenuate waves and storm surges
- building green infrastructure—rain gardens, green roofs, bioswales, etc.—to take advantage of Nature's ability to absorb and filter stormwater
- stabilizing shorelines and preventing erosion from increased flooding by planting deep-rooted, native plants along stream banks
- changing crop planting times and planting more heat-tolerant crop species
- providing more cooling centers for vulnerable populations during heat waves
- increasing distributed electricity generation to reduce the impacts of energy disruptions during heat waves and extreme storms.

Figure 9.2 Climate change is bringing more extreme storms and damage to coastal regions. Artificial oyster reefs parallel to the shoreline provide a way to slow the rate of coastal erosion by reducing incoming wave energy. They also restore habitat for oysters which have been over-harvested.

Chapter 10: Obstacles to Addressing Climate Change

All of us believe things that are not only untrue, but for which there is ample and clear evidence that these things are false. Understanding cognitive biases and logical fallacies – common ways our minds trick us into accepting falsehoods – are perhaps the most important ideas to understand in all of science. Such understandings can help keep us humble and empathetic and make us wiser.

Teaching about climate change and our changing energy system provides challenges not visible in teaching scientific topics like photosynthesis or the rock cycle. Climate change and energy, like all or most controversial topics, are highly interdisciplinary and complex. We have developed a set of rules of thumb for teaching or talking about controversial issues. In brief, these rules are: 1) Be nice (but there are limits); 2) Complexify the seemingly simple; 3) Evidence matters, but evidence alone is not enough; 4) Persistence matters; 5) Use one's place in the world as a starting point. These rules help make for more productive lessons and discussions, but they are not a panacea for building deep understandings of our climate and energy systems. Change is hard. Changing minds is hard. Changing behaviors is especially hard. But we can and must make progress.

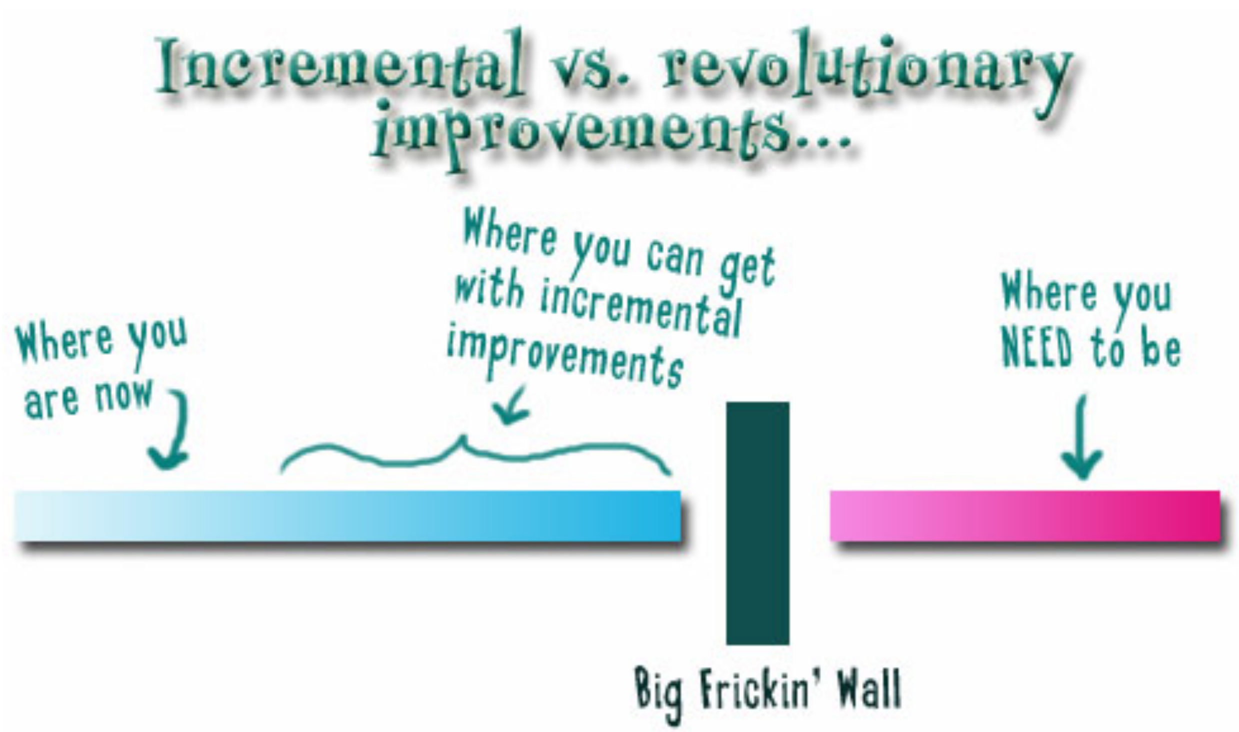

Figure 10.1: Barriers ("Big Frickin' Walls") to improvement of a system often require revolutionary improvement, rethinking the system, rather than incremental improvements within existing systems.

Chapter 11: Perspective

The ways in which humans have and are continuing to change atmospheric chemistry and therefore the ways in which our climate operates are, quite horrifying, but they will not bring the end of the world or civilization, or love and beauty. Also, for as long as humans have been telling stories, we have been telling apocalyptic stories and the world has not ended yet. There are powerful actions that we can to reduce negative consequences and these generally do not have expiration dates – but the sooner we take substantial action, the more effective and less painful those actions will ultimately be.

We will need to use numerous strategies make changes to mitigate climate change, some of which will be social and political. But at the core must be basic public understanding of the science of Earth systems, and of climate in particular, in order to facilitate good decision-making. No one is more important than teachers to help future generations understand Earth's systems, and to help students work with each other toward stewardship of the Earth's future climate.

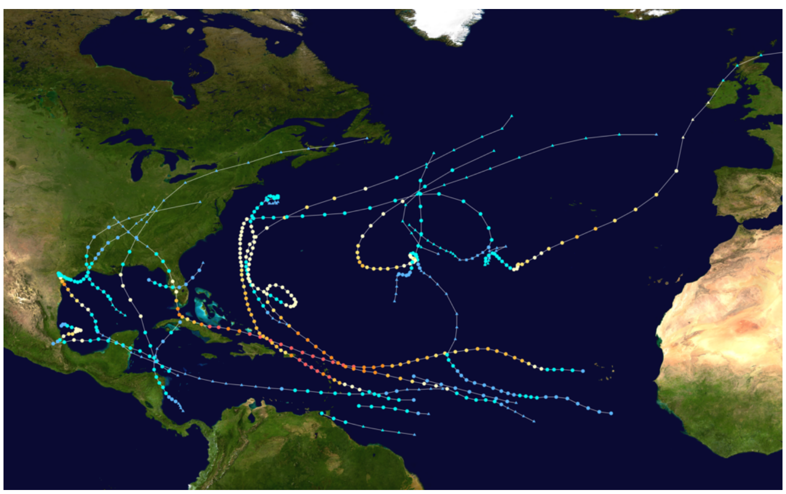

Figure 11: We live in wonderful horrible times and always have. The image on the left shows the tracks of all tropical cyclones in the 2017 Atlantic hurricane season. The points show the location of each storm at 6-hour intervals. The colors represents the storm's maximum sustained wind speeds. Category 5 hurricanes are shown in red, and category 4 storms are in orange. The 2017 season included the devastating Hurricanes Harvey, Irma, and Maria. At the start of the 2018 hurricane season, more than 50,000 people in Puerto Rico were still without power from Hurricane Maria the season before. The image on the right represents a happier side of the summer of 2017. Don, Kiana, and Nellie Duggan-Haas enjoyed Yellowstone's Grand Prismatic Spring in the days following the total solar eclipse visible across much of the US on August 21st.

Chapter 12: Frequently Asked Questions About Climate Change

What can be done by the average citizen?

The actions of individuals are where everything begins. We can, as individuals, reduce our reliance on fossil fuels in transportation, home heating and lighting, and consumption of goods. We can look for a zero-emission vehicle when its time for a new car. We can utilize public transportation. We can install energy-efficient appliances in our homes and businesses. We may be able to switch to alternative energy systems for home heating and electricity, or join a renewable energy co-op. We can make choices as consumers that minimize climate impact. For example, buying food in season and grown locally reduces the emissions that result from transporting food long distances. Beyond reducing our own emissions we can offset the emissions we cannot eliminate by supporting alternative energy technologies and reforestation efforts. Some corporations are beginning to act to offset their contributions to global warming. An individual might also think about the way a corporation is addressing global warming before making investment choices.

Individuals can work collaboratively to support communities and collective actions. Transportation, energy use, and other policies at the local, state, and federal levels will all influence greenhouse gas emissions. We can work for broad societal change, voting with our wallets when we make climate-friendly purchases, and at the ballot box when we choose representatives who will champion climate-neutral policies. Every step that we take – as an individual, as a community, or as a nation – to reduce our climate impact is a step that makes the problem a little smaller, a little less difficult. This is *enormously* important.

Shifting the world's economy away from its dependence on fossil fuels is the single step that would do the most to reduce anthropogenic climate change. This is also a huge challenge that will not be accomplished by any one change. It will require actions big and small by individuals, corporations, and governments around the world. Although people sometimes feel that nothing that they do matters, the only thing that ***does*** matter is what people do.

Figure 12.3: Aerial view of a solar farm near Austin, TX.

Figure Credits

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Figure 2.2: *Don Duggan-Haas*

Figure 3.3: Ingrid Zabel

Figure 4.6: Robert Rohde [CC-BY-SA-3.0] via Wikimedia Commons

Figure 5.2: NOAA

Figure 6.2: US Third National Climate Assessment (2014). Original source: updated from Global Climate Change Impacts in the United States (2009); Thomas R. Karl, Jerry Melillo, and Thomas C. Peterson, eds., US Global Change Research Program.

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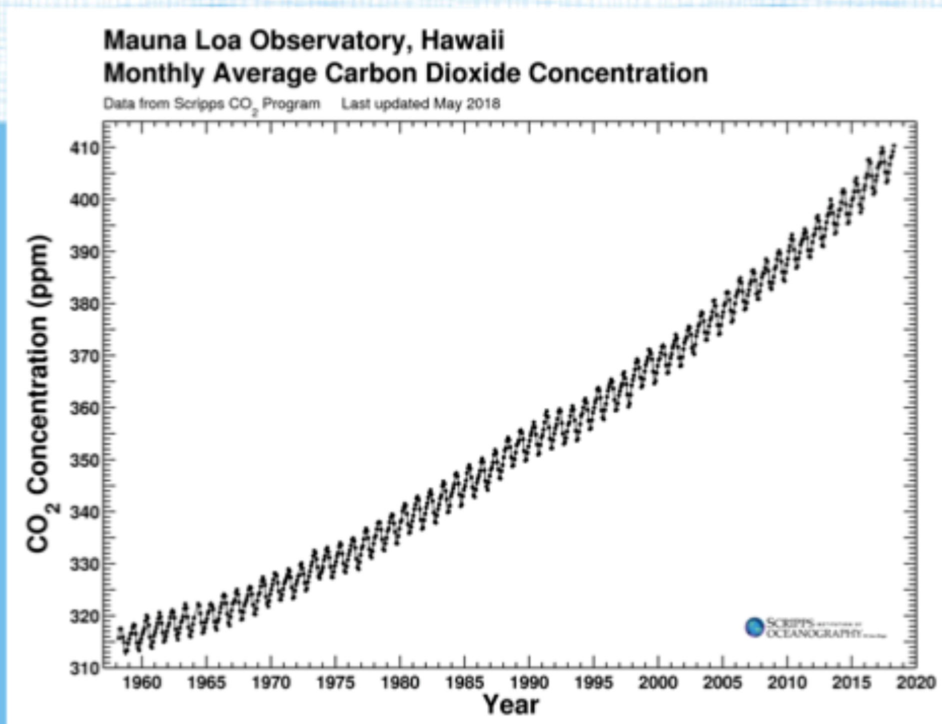

C. D. Keeling, S. C. Piper, R. B. Bacastow, M. Wahlen, T. P. Whorf, M. Heimann, and H. A. Meijer, Exchanges of atmospheric CO2 and 13CO2 with the terrestrial biosphere and oceans from 1978 to 2000. I. Global aspects, SIO Reference Series, No. 01-06, Scripps Institution of Oceanography, San Diego, 88 pages, 2001.