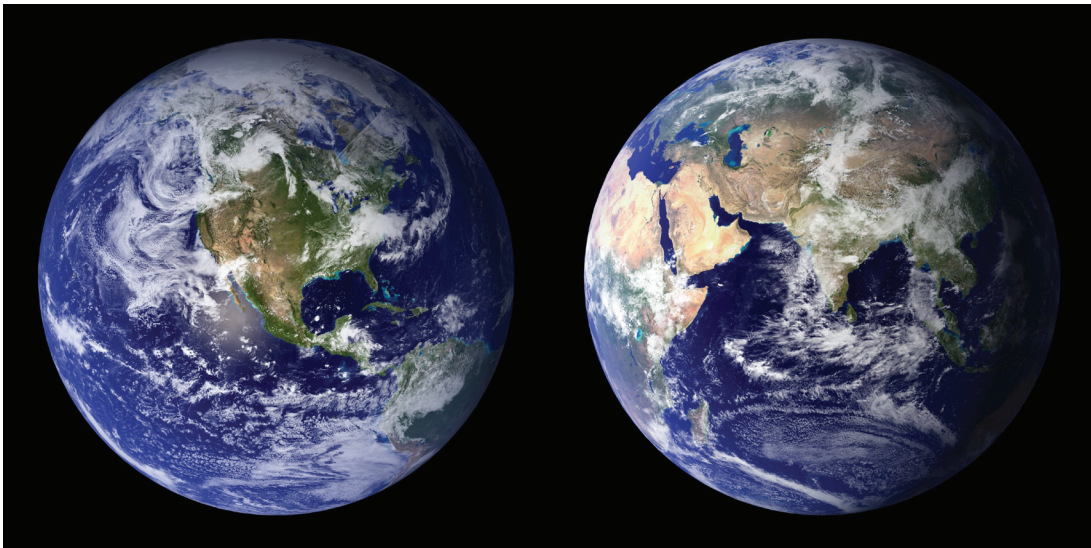


The  
**Teacher-Friendly**  
Guide™

to Climate Change



Edited by Ingrid H. H. Zabel, Don Duggan-Haas, & Robert M. Ross

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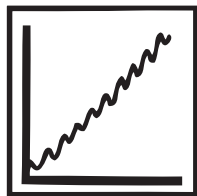
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On the front cover: the "Blue Marble." Composite images produced by NASA in 2001-2002.

On the back cover: Atmospheric CO<sub>2</sub> concentration at Mauna Loa Observatory from 1958 to 2014 (NOAA).



## Chapter 5: Evidence for and Causes of Recent Climate Change

Earth's climate has changed dramatically in the past, between extremes of hot and cold and over time scales ranging from millions of years to only decades (see Chapter 4). The rock record shows that at one time almost the whole planet was likely covered in ice, and at another time warm-loving palm trees grew in the present-day location of Alaska. These climate shifts were brought on by natural **forcings** such as changes in Earth's orbit around the sun, release of carbon dioxide (CO<sub>2</sub>) from volcanic activity, removal of atmospheric CO<sub>2</sub> through **rock weathering**, biomass of photosynthetically-active life, and changes in **ocean circulation**. One common feature of the shifts in Earth's climate is that warm and cool periods generally correspond to high and low atmospheric concentrations of CO<sub>2</sub>, respectively. CO<sub>2</sub> can be thought of as the "biggest control knob" for Earth's temperature.<sup>1</sup>

In Earth's very recent history—the last 100 to 200 years—CO<sub>2</sub> emissions have increased rapidly as industrial societies have grown. People discovered **fossil fuels** such as coal, oil, and natural gas, and invented clever ways to use them to heat and cool buildings, generate electricity, and power transportation. Industrialization also led to increased emission of other gases such as methane (CH<sub>4</sub>) and **chlorofluorocarbons**. In 1895 a Swedish physical chemist, Svante Arrhenius, calculated the effect of CO<sub>2</sub> on Earth's temperature and predicted that increased CO<sub>2</sub> in the atmosphere would lead to a warmer global climate (see Chapter 3 on the **greenhouse effect**). Today, datasets collected over many decades show evidence of recent rapid change in our atmosphere and climate. These are discussed here.

### Changing Temperatures and Carbon Dioxide

In the last 100 years both the ocean and land have warmed, and atmospheric CO<sub>2</sub> has risen sharply. *Figure 5.1* shows the global surface **temperature anomaly** over time from 1880 to 2015 (temperature anomaly is the difference in temperature relative to a reference time period, in this case 1951-1980).

As of the time this guide was written (2017), the ten warmest years on record have occurred since the year 1998. As of 2017, 2016 was the warmest year on record (a useful source for finding current climate summaries and reports is the

**forcing** • a change that has a directional impact on what is being changed (e.g., a solar forcing on the Earth directly impacts the Earth's heat absorption).

**rock weathering** • the breaking down of solid rock into small particles. See **CHEMICAL WEATHERING** and **PHYSICAL WEATHERING**.

**ocean circulation** • global-scale patterns of water movement throughout the world's oceans.

**fossil fuel** • a non-renewable, carbon-based fuel source like **OIL**, **NATURAL GAS**, or **COAL**, developed from the preserved organic remains of fossil organisms.

#### CHAPTER AUTHORS

Ingrid H. H. Zabel

and authors of

**A Very Short Guide  
to Climate Change**

<sup>1</sup> Richard Alley, the Evan Pugh Professor of Geosciences at Pennsylvania State University, uses this metaphor of a control knob in his excellent lecture, The Biggest Control Knob: Carbon Dioxide in Earth's Climate History. December 2009. 30 June 2016. [http://www.agu.org/meetings/fm09/lectures/lecture\\_videos/A23A.shtml](http://www.agu.org/meetings/fm09/lectures/lecture_videos/A23A.shtml).



## Temperature and CO<sub>2</sub>

**chlorofluorocarbons** • compounds of carbon, hydrogen, chlorine, and fluorine, usually ANTHROPOGENIC gases used as refrigerants or in aerosol cans. Released into the ATMOSPHERE, these compounds are GREENHOUSE GASES and are responsible for the OZONE HOLE.

**greenhouse effect** • the influence of GREENHOUSE GAS molecules in the Earth's atmosphere to retain heat (infrared radiation) radiating from the Earth's surface that would otherwise escape into space.

**remote sensing** • a method of scientific investigation that instruments on satellites or aircraft to make measurements of the Earth's surface. It is particularly useful for studying areas that are large in extent, difficult to access on the ground or ocean, and in some cases for areas that are dark for much of the winter.

**infrared light** • electromagnetic radiation in the part of the spectrum with wavelengths from 750 nanometers to 1 millimeter. People sense infrared radiation as heat.

**microwave radiation** • electromagnetic radiation in the part of the spectrum with wavelengths from about 0.1 to 100 centimeters.

# Recent Climate Change

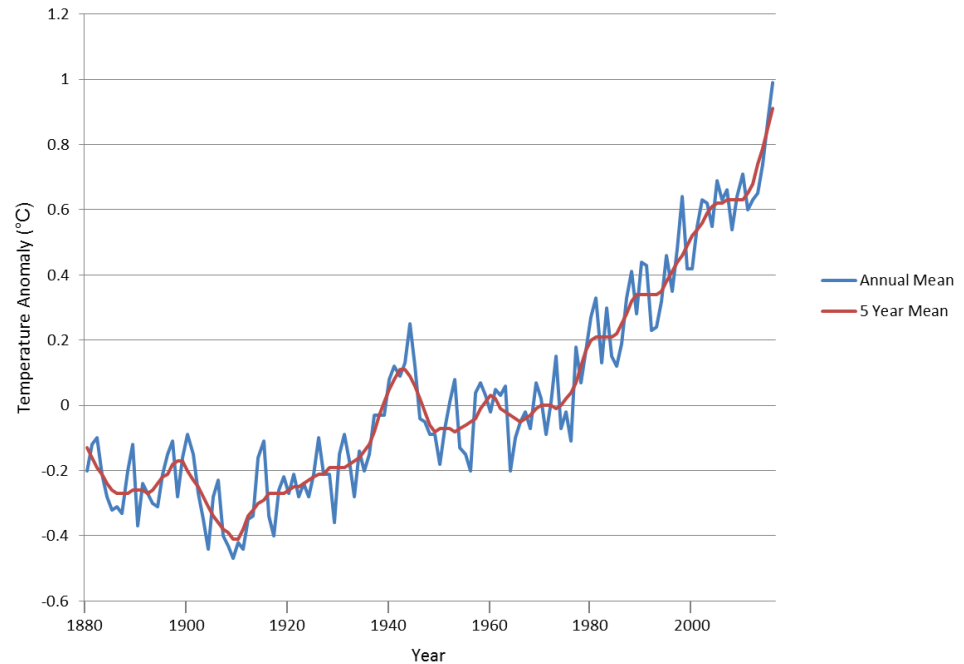


Figure 5.1: Global land-ocean surface temperature anomaly over time. Base period: 1951-1980. (See Teacher-Friendly Guide website for a full color version.)

National Centers for Environmental Information's *State of the Climate* website: <http://www.ncdc.noaa.gov/sotc/>). As Earth's temperature has increased, the ocean has been storing most of this heat energy. Scientists estimate that from 1971 to 2010 the oceans absorbed over 90% of the heat that has been added to our planet.

Global CO<sub>2</sub> also follows an upward trend in the recent past. The Mauna Loa, or Keeling, curve is a graph of atmospheric CO<sub>2</sub> measurements started by Charles David Keeling in 1958 at an observatory atop Mauna Loa, a mountain on the island of Hawai'i. Keeling's successors continue to make these measurements today, and the graph shows a steady upward trend and an annual oscillation which results from plants in the northern hemisphere taking in more CO<sub>2</sub> during the spring and summer than in the winter (Figure 5.2).

This recent increase in atmospheric CO<sub>2</sub> can be compared with CO<sub>2</sub> concentrations farther back in Earth's past. Figure 5.3, which plots the Mauna Loa data together with historic CO<sub>2</sub> data from an Antarctic ice core, shows how large the 20th century rise in CO<sub>2</sub> really is relative to pre-industrial levels.

See Chapter 4: Past Climates for information on how we can learn about past climates by analyzing ice cores.

Scientists measure land and sea surface temperatures through **remote sensing** from satellites, and using thermometers on land and on ships, coasts, and ocean buoys. The satellite sensors give a much broader coverage than point measurements, and they give access to areas that are difficult to access on the surface or are dark for much of the winter. Point measurements are used to check ("ground truth") the satellite data. The surface of the Earth emits **infrared light** and **microwave radiation** (see Box 5.1), and the intensity of that

# Recent Climate Change

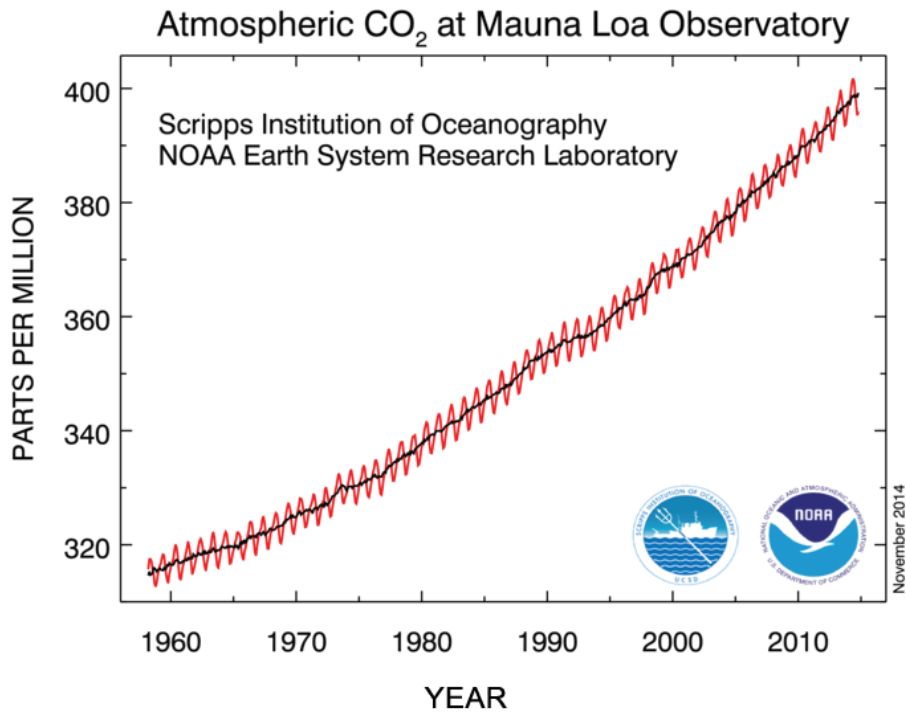


Figure 5.2: Atmospheric CO<sub>2</sub> concentration at Mauna Loa Observatory from 1958 to 2014.

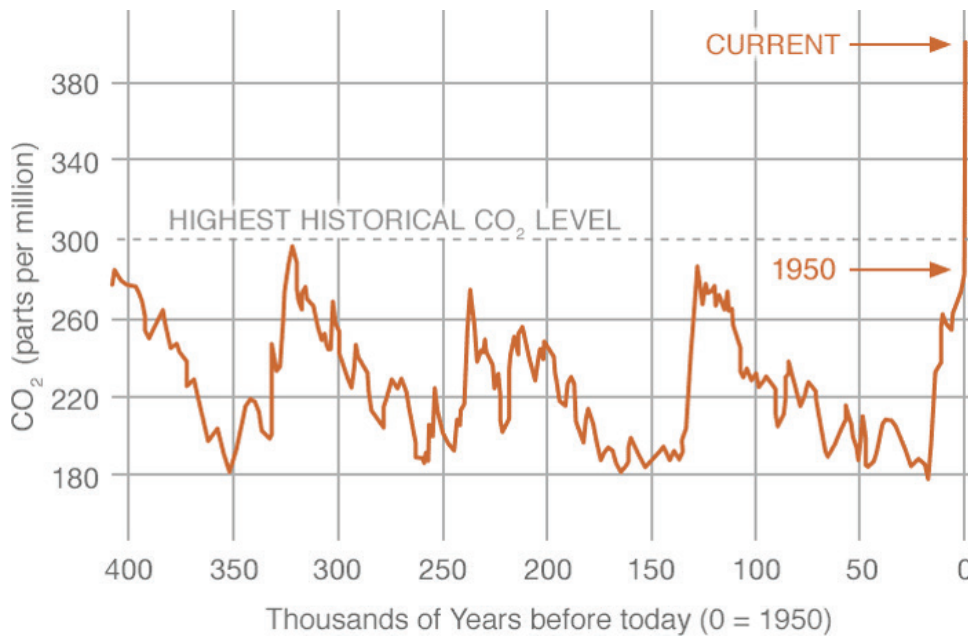


Figure 5.3: Atmospheric CO<sub>2</sub> measurements from Antarctic ice cores and Mauna Loa observatory.



## Shrinking Ice Sheets

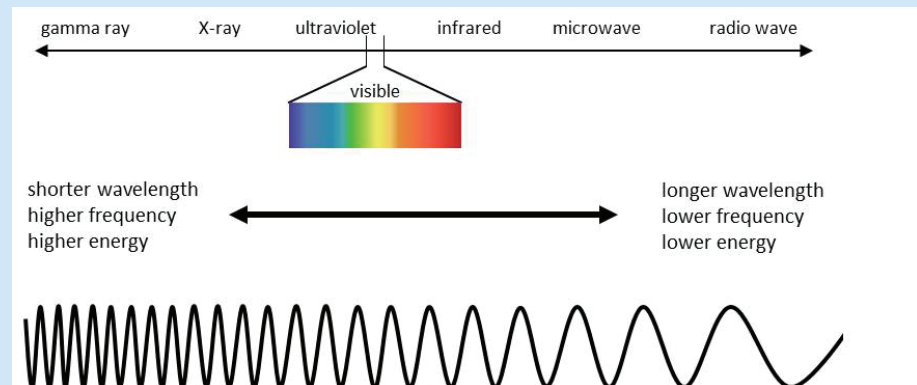
**ice sheet** • a mass of glacial ice that covers part of a continent and has an area greater than 50,000 square kilometers (19,000 square miles).

# Recent Climate Change

### Box 5.1: The electromagnetic spectrum and remote sensing

Electromagnetic radiation can be thought of as traveling waves of energy, being emitted, absorbed, scattered, and reflected all around us. There is a spectrum—a broad range—of these waves in the universe with different frequencies and wavelengths. In our everyday experience we are most familiar with visible light because we sense it with our eyes and it contains the colors that we see. But we have everyday experience with other parts of the spectrum as well, such as radiowaves (which carry radio broadcasts), infrared radiation (which we experience as heat), ultraviolet radiation (which can give us sunburn), x-rays (in medical tests), and microwaves (in microwave cooking and police radar).

Scientists measuring characteristics of the Earth's surface and atmosphere design sensors of electromagnetic radiation that fit the phenomena and conditions they want to observe. For example, scientists studying melting and freezing of the Greenland ice sheet have used microwave sensors on satellites because microwaves can penetrate clouds, they can be detected during the dark Arctic winter when visible light would not be useful, and they are sensitive to changes that occur on the ice sheet when the surface melts or freezes.



*The electromagnetic spectrum. Adapted from NASA's Imagine the Universe. (See Teacher-Friendly Guide website for a full color version.)*

radiation depends on the surface temperature in a known way. Instruments on satellites can detect this emitted radiation, from which scientists can calculate the surface temperature.

## Shrinking Ice Sheets and Glaciers

Although it may not feel like we are living in an ice age, when the Earth's current climate is viewed through the perspective of geological time scales it is evident that the Earth is in an interglacial period of an ice age (see Chapter 4), with the poles containing huge masses of ice. The Greenland and Antarctic **ice sheets** together store over 99% of the Earth's fresh water. The Earth's warming is having an effect on these ice sheets, however. *Figure 5.4* shows measurements of the mass of ice, in gigatonnes, lost from these two ice sheets since 2002. Diminished ice sheets can have a profound effect on regional and

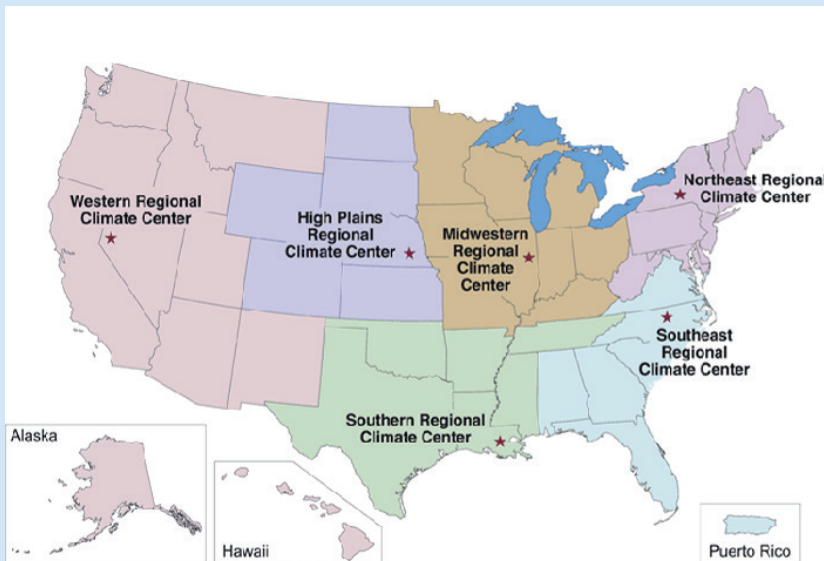
# Recent Climate Change



## Box 5.2: Climate and weather records from your backyard

You can find temperature and precipitation data, graphs, and maps for your region from your NOAA Regional Climate Center (<https://www.ncdc.noaa.gov/customer-support/partnerships/regional-climate-centers>). The lengths of the data records available to you vary by location, but you may be able to find data going back to the late 19th century.

Another source of historical climate data for the US is NOAA's Climate at a Glance website: <http://www.ncdc.noaa.gov/cag/>. Here you can generate maps and time-series plots of temperature, precipitation, and drought data for a broad choice of regions and time periods. Data are also available for cities, from two reliable sources: either the Global Historical Climatology Network or the US Historical Climatology Network.



Map showing geographic coverage of NOAA's Regional Climate Centers. (See Teacher-Friendly Guide website for a full color version.)

## Shrinking Ice Sheets

**albedo** • the fraction of solar energy that a surface reflects back into space.

global climate. For example, freshwater added to the ocean changes ocean surface salinity and thereby currents. Large amounts of water melted from land ice also raises sea level. Less ice cover decreases **albedo**: highly reflective sea ice is replaced by much less reflective open water, and loss of reflective land ice exposes darker soil and rocks beneath.

Scientists can measure the change in an ice sheet's mass in several ways: by using satellite and ground measurements to compare the amount of snow accumulating on the ice sheet to the amount of melted water flowing out, by using satellite and airborne instrument measurements to calculate the change in ice sheet elevation and volume, and by measuring changes in gravity over the ice sheet using very sensitive instruments on satellites.<sup>2</sup>

<sup>2</sup> This information and much more on ice sheets, sea ice, and glaciers can be found at the National Snow and Ice Data Center's website, <https://nsidc.org/>.



# Recent Climate Change

## Shrinking Ice Sheets

**ablation** • the loss of snow and ice from a GLACIER or ICE SHEET by melting, evaporation, sublimation (a phase transition from solid directly to gas), iceberg calving, and other processes.

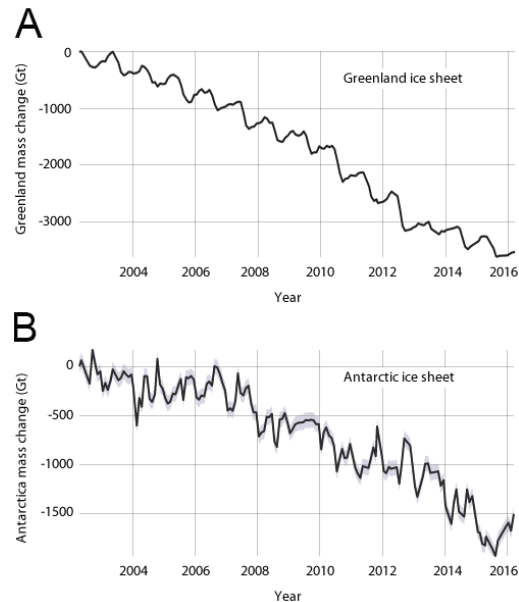


Figure 5.4: Measured mass change of A) the Greenland and B) Antarctic ice sheets, showing mass loss between 2002 and 2016.

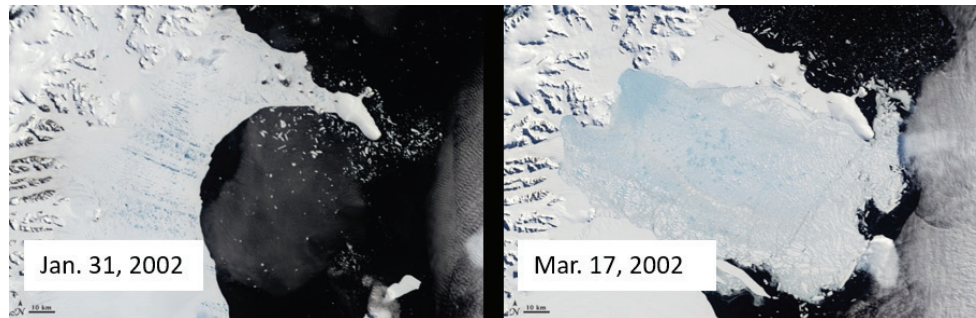


Figure 5.5: Satellite images showing the breakup of the Larsen B ice shelf in West Antarctica. Note the scale marker (10 km) in the lower left corner of the images.

Ice sheets lose mass in several ways: melting at the surface followed by runoff of meltwater to the ocean, melting when ice on the edge is in contact with seawater, **ablation**, and loss of solid ice when pieces of ice break off from the edge of the ice sheet and float in the sea. This breaking at the edge is called calving, and it is how icebergs form. Additionally, very large pieces of ice sheets sometimes break off, such as in 2002 when the Larsen B Ice Shelf disintegrated in Antarctica (Figure 5.5). The portion of the ice sheet that collapsed initially was about the size of Rhode Island.

Warmer air and water temperatures accelerate these processes, which lead to mass loss. The Greenland ice sheet has been breaking records in the last few years for the earliest onset of spring melting. In Antarctica, a recent study suggested that the ice sheet is actually gaining mass in some regions to the point where total mass losses are offset, but that increasing rates of mass loss will overtake this gain in a few decades.<sup>3</sup>

<sup>3</sup> See Vinas, Maria-Jose, "NASA Study: Mass Gains of Antarctic Ice Sheet Greater than Losses." 30 October 2015, <http://www.nasa.gov/feature/goddard/nasa-study-mass-gains-of-antarctic-ice-sheet-greater-than-losses>.



# Recent Climate Change



## Changing Sea Ice

*sea ice* • frozen seawater at the surface of the ocean.

Mountain glaciers have also been shrinking around the globe, although a few glaciers are holding steady or growing in mass. Generally, however, the trend is overwhelmingly towards glacial retreat and loss. Communities who depend on glacial meltwater for agriculture and drinking water are at risk as this trend continues. Water from melting glaciers also contributes to sea level rise, and is contributing at an accelerated pace in the last few decades. According to the latest Intergovernmental Panel on Climate Change (IPCC, see Box 5.3) report, most of the glacier mass loss around the world has taken place in the Arctic, the Southern Andes, and in Asian mountains.

### Box 5.3: The Intergovernmental Panel on Climate Change (IPCC)

The IPCC, founded in 1988 by the World Meteorological Organization and the United Nations Environment Programme, is a group of scientists from 195 countries who assess the state of the world's climate, climate science, impacts and risks of climate change, and options to respond to it. Over three thousand scientists are involved in writing and reviewing the IPCC's climate assessments approximately every six years, and these assessments are considered by many to be the authoritative source of information on climate change science. The assessments do not include policy suggestions, but they are intended to provide information to help government officials develop sound, research-based climate change policies.

## Changing Sea Ice Extent

The Arctic Ocean over the North Pole is covered by frozen seawater or **sea ice**, a feature of the Arctic that has long limited shipping and underwater exploration, and that is part of the natural environment of Arctic marine life, from plankton to polar bears. The area covered by sea ice grows in the winter when temperatures drop and seawater freezes, and shrinks in the summer as some of the new, thin ice melts during the warmest part of the year. Scientists can measure the extent of Arctic sea ice using remote sensing instruments on satellites, with records going back to the late 1970s. Measurements include total area, distribution, and thickness.

Arctic sea ice extent has decreased over the past few decades as the region has warmed, and decreased more rapidly since the turn of the 21st century. *Figure 5.6* shows images based on satellite data of Arctic sea ice extent, for the annual September minimum and March maximum, for 2000-01 compared with 2015-16. The decline in sea ice cover over fifteen years is evident, especially at the end of summer.

Around Antarctica, though some portions of the ice shelves have broken, total sea ice extent has shown the opposite trend to that seen in the Arctic, increasing on average since the late 1970s. The rate at which the Arctic has lost sea ice extent, in square miles per year, is about three times as big as the rate at which the Antarctic has gained sea ice extent. Scientists think the increase in sea ice extent is driven by cold continental winds and a strong, cold current that circles around Antarctica, isolating Antarctica from transport of heat from lower latitudes in ways that the Arctic is not.



# Recent Climate Change

## Thawing Permafrost

**permafrost** • a layer of soil below the surface that remains frozen all year round. Its thickness can range from tens of centimeters (inches) to a few meters (yards). Permafrost is typically defined as any soil that has remained at a temperature below the freezing point of water for at least two years.

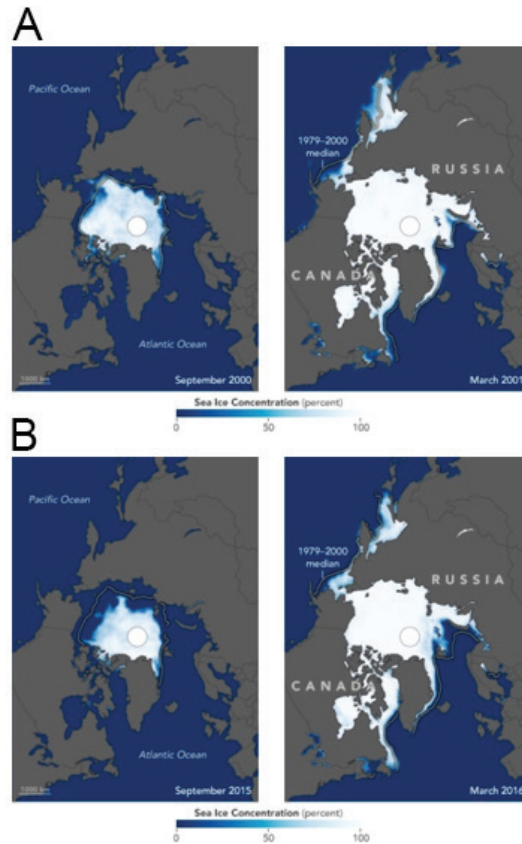


Figure 5.6: Arctic sea ice extent for the months of September (annual minimum extent) and March (annual maximum extent) for the years A) 2000-2001 and B) 2015-2016. (See Teacher-Friendly Guide website for a full color version.)

## Thawing Permafrost

About a quarter of the land surface in the Arctic is covered by **permafrost**: ground where a thick layer of soil is permanently frozen due to year-round cold temperatures. The Arctic is warming more rapidly than any other part of the world, and this means that permafrost is thawing. The IPCC's (see Box 5.3) latest report on global climate change concluded that it is "virtually certain" that permafrost extent in the Arctic will continue to decline, by 37% to 81% by the end of the 21st century, depending on the rate of carbon emissions from human activities.

As permafrost thaws the mechanical properties of the ground change, and structures such as roads and oil pipelines that have been built on frozen ground are at risk of damage. Another hazard from thawing permafrost is the release of  $\text{CO}_2$  and  $\text{CH}_4$  that have been frozen in the ground. These are powerful greenhouse gases, and  $\text{CH}_4$  in particular can have a large, short-term warming effect.

## Rising Sea level

Global sea level is rising, mainly as a result of a warming ocean. When water warms it expands, whether at the scale of a kettle of water on the stove or the

# Recent Climate Change



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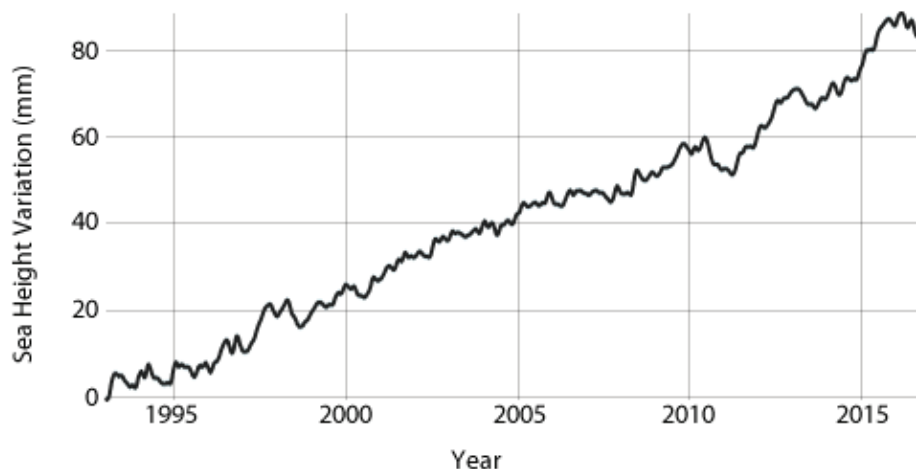


Figure 5.7: Global average sea level change as a function of time, with a base year of 1993.

vast volume of water that fills the world's ocean basins. Sea level is also rising as water is added to the ocean from melting glaciers and ice sheets. Melting glaciers (other than ice sheets) contributed to sea level rise at the rate of 0.76 mm per year (0.03 inches per year) from 1993 to 2009. Global average sea level has risen about 17.8 centimeters (7 inches) in the past 100 years (Figure 5.7). (Note that melting sea ice does not contribute to sea level rise because it's already displacing sea water as it floats.)

Sea level rise is close to, but not exactly, uniform everywhere. Ocean currents can pull water toward or away from coasts, effectively raising or lowering sea level. In some places the land is sinking (subsiding) or rising (being uplifted) because of geologic forces. In many places land uplift and subsidence occurs due to tectonic changes, which may occur over many millions of years. In high latitudes where glaciers covered the landscape, the ice sheet depressed the continental crust downward into the **mantle**; since melting back the land has been "rebounding" upward. This is happening wherever ice sheets covered the land, for example, across the northern part of North America. Land subsidence may occur over extended periods due to deposition of sediment from rivers, and over shorter time scales due to human activities such as groundwater and petroleum extraction. Where land is subsiding, such as along the US's East and Gulf coasts, the relative rate of sea level rise is higher than the global average. Where land is rebounding, sea level can be decreasing. Figure 5.8 shows a map of sea level trends along coasts worldwide. The highest sea level rise rates in North America are along the coast of Louisiana, where rates are in the range of 9-12 millimeters per year (3 to 4 feet per century).

## Causes of Recent Climate Change

How can we be sure that changes going on now are not just part of natural climate variation? It is worthwhile to consider the potential causes of recent climate change, both natural and anthropogenic (human-caused), and to evaluate the effects of each one.

### Causes of Change

**mantle** • the layer of the Earth between the crust and core. It consists of solid silicate rocks that, over long intervals of time, flow like a highly viscous liquid. Convection currents within the mantle drive the motion of plate tectonics.



# Recent Climate Change

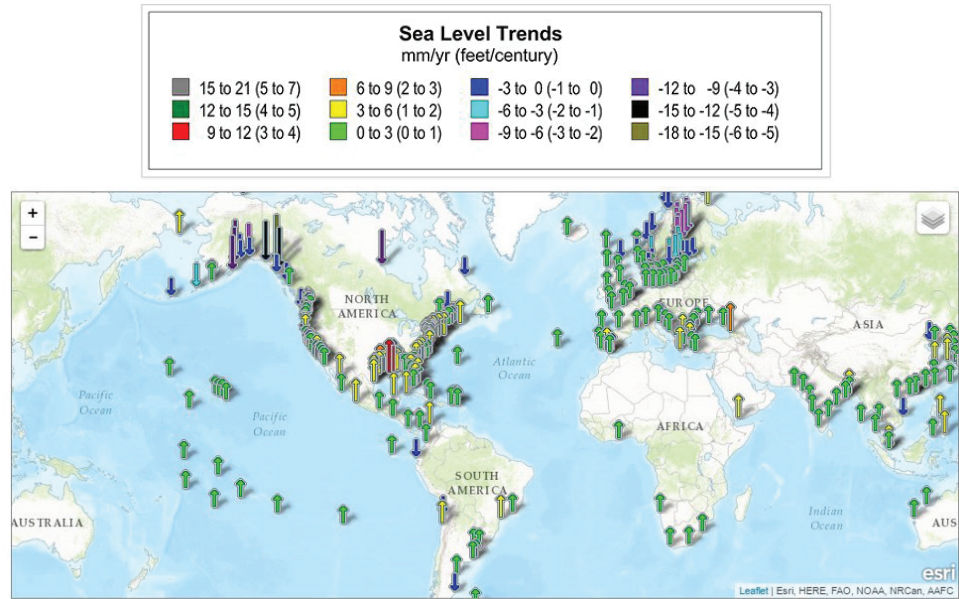


Figure 5.8: Regional sea level trends worldwide. The arrows represent the direction and magnitude of the change. (See Teacher-Friendly Guide website for a full color version.)

**Changes in Earth's orbit around the sun.** The Earth's tilt, wobble, and orbit around the sun go through predictable cyclical changes (Milankovitch cycles; see Chapter 3). These changes can have dramatic effects on the climate, and are thought to have brought on and ended glacial advances and retreats during the Ice Age (the ultimate long term cause of the Earth's transition to the Pleistocene Ice Age had separate causes). The changes in these cycles over last 200 years have been too small to have any significant effect on Earth's temperature, and over the next fifty to eighty thousand years would be expected to take the Earth toward another glacial advance.

**Changes in incoming solar radiation.** Changes in the energy output from the sun do not successfully account for the current warming trend. Eleven-year sunspot cycles have been consistently recorded, but these have risen and fallen as expected, never increasing their net output of energy. No other solar outputs correlate with the warming trend, either. So for the period for which we have direct, observable records, the Earth has warmed dramatically even though there has been no corresponding rise in any kind of solar activity.

**Volcanic eruptions.** Volcanos emit greenhouse gases when they erupt, which can lead to climate warming if the input of CO<sub>2</sub> to the atmosphere is sufficiently large. Volcanic eruptions can also have a short-term cooling effect because the sulfate particles they emit block incoming sunlight. The eruption of Mt. Pinatubo in 1991 led to an almost 0.6°C (1°F) decrease in average global temperatures over 15 months. The net long-term effect of volcanism over the last 200 years has not been significant enough to warm the climate. According to the IPCC (Box 5.3) "the emissions of CO<sub>2</sub> from volcanic eruptions are at least 100 times smaller than anthropogenic emissions, and inconsequential for climate on century time scales."<sup>4</sup>

<sup>4</sup> Stocker, T.F., et al., 2013, Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: NY. <http://www.ipcc.ch/report/ar5/wg1/>



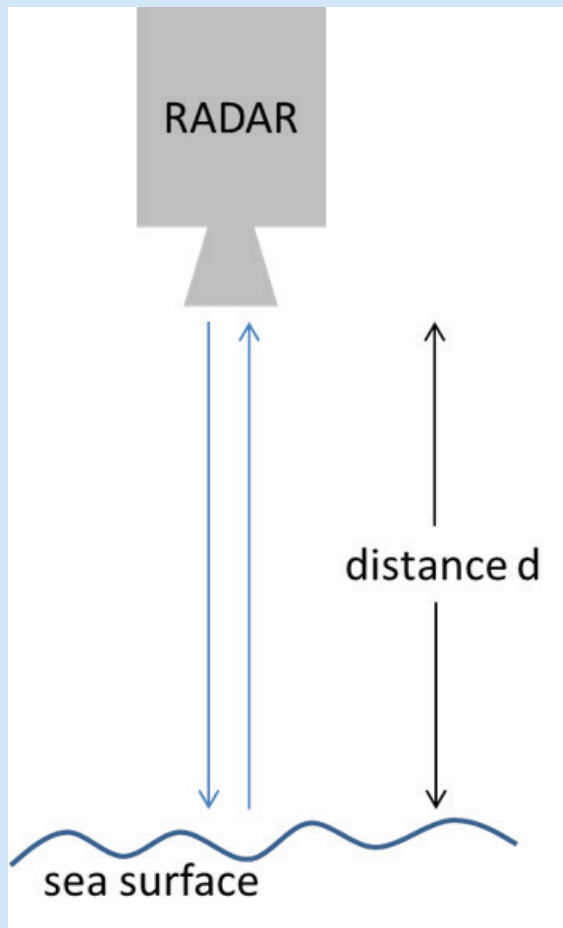
### Box 5.4: How do we measure sea level change?

Scientists measure sea level in two main ways: with tide gauges along the coasts, and with altimeters on satellites. Modern tide gauges use a radar fixed on a structure such as a pier or bridge, pointing down at the water to measure the distance from the surface of the sea to a fixed point. A detector measures the round-trip travel time  $t$  of the radar (microwave) beam between the instrument and the sea surface, and then distance is calculated in the following way:

$$d = ct/2$$

where  $t$  = round trip travel time and  $c$  = speed of light (i.e., the speed of the electromagnetic wave transmitted by the radar). Changing sea surface levels from waves and tides are averaged over time. GPS readings can be used to correct for any upward or downward motion of the land.

Since 1992, scientists have been able to measure sea level very accurately using data from altimeters on satellites. Altimeters work according to very similar principles to the radar tide gauge described above. Because they are on satellites they can gather data over large areas and in the middle of the ocean instead of just along the coast.



*Schematic of a radar-based tide gauge.*



# Recent Climate Change

**Land use changes.** When people cut down forests to plant crops, the physical properties of the land's surface change. Crops tend to be lighter colored than forests so they reflect away more incoming sunlight (i.e., they have a higher albedo), leading to cooling. Changes in the land surface roughness and water runoff from land use changes can also change the surface temperature. According to the 2013 IPCC report (Box 5.3) these changes tend to offset the albedo effect, but all these changes are hard to quantify and the scientific community does not have a good understanding on if these effects of land use change lead to a small net cooling or small net warming. It is clear that deforestation leads to increased CO<sub>2</sub> in the atmosphere because intact forests are carbon sinks. The loss of these carbon sinks, especially tropical rain forests, accelerated in the late 20<sup>th</sup> century.

**Aerosols.** Aerosols are tiny particles in the air, from both natural and human-made sources such as dust, volcanic eruptions, biomass burning, sea salt, and vehicle and factory emissions. Their presence in the stratosphere tends to have a net cooling effect on Earth's climate because they reflect incoming sunlight back into space. Aerosols can also serve as cloud nucleation sites and can alter the reflectivity of clouds. The impact of clouds on Earth's climate is not as well understood as other parts of the climate system, but according to the 2013 IPCC report (Box 5.3,) aerosols are thought to cool the climate.

**Greenhouse gases.** As discussed above and as seen in *Figure 5.9*, carbon emissions from human activity and concentrations of CO<sub>2</sub> and other greenhouse gases in the atmosphere have risen dramatically since the industrial revolution began in the early 1800s. Earth's average temperature has been rising in a way that cannot be accounted for by natural variation alone. Climate models that incorporate increasing CO<sub>2</sub> explain this warming trend better than any models based on natural variation alone. The pattern of the observed warming fits the pattern that we would expect from warming caused by the buildup of greenhouse gases, that is, almost all areas of the planet are warming; the Earth's surface and lower atmosphere are warming; and the temperature changes are greatest in the Arctic during winter.

We have seen natural variations in climate over the past several thousand years, some of which are not well explained. Is it possible that current changes are just one of those fluctuations? The reason most scientists do not think so is that (a) the magnitude of the current trend is larger than any that we have seen in the past several thousand years, and (b) the current trend shows strong directionality in not just warming, but *rate* of warming, through time. Such variation does not look like any of the temperature changes seen in the past 10,000 years or so. And there are no known sources of natural variation that would give rise to changes as rapid as those observed in global temperature over the past 150 years.

Could current changes just be unusually extreme variation that we do not yet understand? Yes. In science (by definition), all phenomena are open to new explanations, so scientists must always be ready to consider other options. Scientists do not, however, favor or give equal weight to random or unknown variation if another known explanation fits the available data. Some explanations are better than others, and it would be ineffective to act as if every explanation, no matter how unlikely, should receive equal treatment. The explanation of

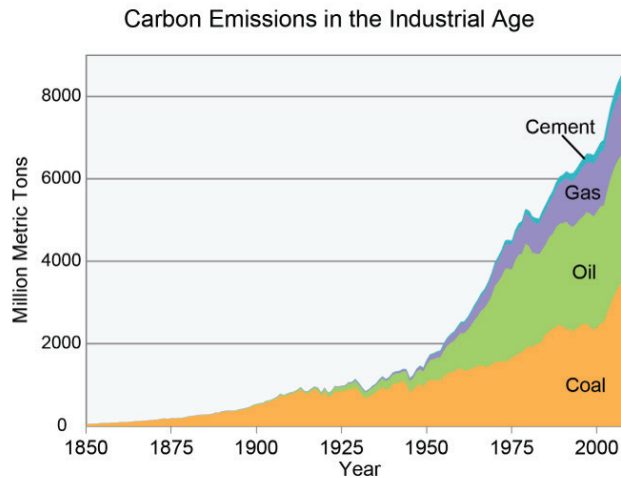


Figure 5.9: Global carbon emissions from burning coal, oil, and gas and producing cement (1850-2009). These emissions account for about 80% of the total emissions of carbon from human activities, with land-use changes (like cutting down forests) accounting for the other 20% in recent decades. (See Teacher-Friendly Guide website for a full color version.)

### Box 5.5: Carbon emissions from cement production

About 5% of global CO<sub>2</sub> emissions come from cement production. Making cement involves heating limestone to very high temperatures in kilns. The CO<sub>2</sub> escapes directly from limestone during heating, and it is also released in burning the fossil fuels used to run the kilns.

increased greenhouse gases in our atmosphere causing current warming fits the data extremely well.

## What are the Likely Effects of Climate Change Going to Be?

Over the past billion years, the Earth has experienced climates that were much warmer than those of today, as well as much colder periods. This fact, however, does not mean that future warming is nothing to worry about. The geological record tells us that these changes in Earth's past were usually much more gradual—occurring over thousands or millions of years—than many of the changes likely to occur in the very near future. And natural climate changes that have occurred rapidly have been linked to very rapid environmental change. Some periods of rapid climate change are associated with very large extinction events to organisms that had previously been thriving. The geological record, furthermore, tells us that our species—*Homo sapiens*—has not experienced since civilization developed about 10,000 years ago anything like what we are about to experience if current trends continue. Billions of people are and will be affected by the impacts of climate change, including coastal flooding, strained water supply, heat waves, and disease occurrence. It will change where and how we live and access food. We will need to learn how to adapt, and to act to limit further future warming.



# Recent Climate Change

## Online Resources

### Climate Data

Information, maps, plots, visualizations, and other multimedia on global climate change from NASA: <http://climate.nasa.gov/>

Time-series map animation showing the five-year average variation of global surface temperatures from 1884 to 2015: <http://climate.nasa.gov/vital-signs/global-temperature/>

State of the Climate (monthly summaries and reports, including news about when new records are set): <http://www.ncdc.noaa.gov/sotc/>

### Climate Indicators

Time-series plots of atmospheric CO<sub>2</sub> measurements, from Mauna Loa and ice core data, on time scales varying from the current week to 800,000 years ago to present: <https://scripps.ucsd.edu/programs/keelingcurve/>

Time series of maps of Arctic sea ice in September, from 1979-2014: [https://nsidc.org/cryosphere/sotc/sea\\_ice\\_animation.html](https://nsidc.org/cryosphere/sotc/sea_ice_animation.html). The visualization shows the decline of Arctic sea ice over the last few decades.

A section of a U.N. report on changes in mountain glaciers: <http://www.grid.unep.ch/glaciers/pdfs/5.pdf>

Interactive map of global sea level trends, showing variation in regional sea level changes: <http://tidesandcurrents.noaa.gov/sltrends/sltrends.html>

The Third National Climate Assessment: <http://nca2014.globalchange.gov/>

### Ways of Measuring Climate Indicators

Information about remote sensing of surface temperature from satellites: <https://podaac.jpl.nasa.gov/SeaSurfaceTemperature>

Information about satellite altimeters and how they are used to measure sea level: <http://www.star.nesdis.noaa.gov/sod/lsa/SeaLevelRise/>

An article about the history of measuring sea level and the evolution of tide gauges: <https://www.climate.gov/news-features/climate-tech/reading-between-tides-200-years-measuring-global-sea-level>



# Recent Climate Change

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Resources

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## **Causes of Climate Change**

An infographic on potential causes of climate change from 1880-2005 and their effects, based on datasets from NASA: <http://www.bloomberg.com/graphics/2015-whats-warming-the-world/>.

## **Other Visualizations and Teaching Resources**

Interactive, maps, graphics, videos, publications, and more on climate change: <http://www.climatecentral.org/>

Innovative visualizations of greenhouse gas emissions and other topics: <http://www.carbonvisuals.com/>

Reviewed collection of teaching resources: Climate Literacy and Energy Awareness Network (CLEAN) <http://cleanet.org/index.html>

