1.10: Lab 10 - Climate Change

This lab contains potentially inaccessible interactive resources. Please work with your instructor and local campus resources to identify accommodations for these resources.

Learning Objectives

- Explain the greenhouse effect.
- Differentiate among the major greenhouse gases based on their respective atmospheric concentrations and warming potential.
- Identify fluctuations of Earth's average temperature over the past 800,000 years.
- Explain the scientific consensus on anthropogenic climate change.
- Analyze carbon dioxide emissions data by country and world region in terms of time, population size, and economic development.
- Interpret global patterns of carbon dioxide emissions from a climate justice framework.

Introduction

Weather is the current atmospheric conditions in a given place and time. **Climate** is the long-term patterns of weather. Atmospheric conditions are recorded each and every day—by observation, instrument, or, in the long term, by Earth itself. Aggregate records of temperature and precipitation become climate data, revealing averages and extremes over extended periods of time. The Earth's climate system is a crucial life-sustaining system. It is complex and interdependent on the conditions of the oceans, ice sheets, atmosphere, and biosphere. In studying the Earth's climate, scientists strive to attain and analyze the longest continuous datasets possible, often spanning hundreds of thousands of years, to learn about climate controls and patterns of climate variability. Their goal is to understand one of the greatest global issues of our time: anthropogenic climate change.

This lab consists of four parts. In the first two sections, you will explore the basic processes and methods scientists use to understand the Earth's climate. This analysis will provide an understanding of the basis for the scientific consensus on anthropogenic climate change. In the last sections, a geographical analysis of four measures of global carbon footprints reveal patterns of global emissions and the disproportionate impacts of climate change.

Part A. Understanding Climate Science

The graphs below display the contemporary trends of global temperatures, based on the **instrumental record**, which is data directly recorded by instrumental measurement (Figures 10.1, 10.2, and 10.3). By comparing data sources, scientists can minimize measurement inconsistencies and create a generalized overview**.** Climate scientists often compute **temperature anomalies** the deviation from a set average temperature—to detect temperature trends despite the variability of geographical conditions that impact temperature recordings. For example, a mountain and a valley will have quite different absolute temperature recordings. Looking at anomalies for both locations might reveal that despite different geographical conditions both places were warmer than average. Because temperature anomalies reveal trends, anomalies are often used to understand patterns of climate change.

Exercise 1.10.1

1. In one to two sentences, explain why computed temperature anomalies are often used in global climate studies instead of temperature averages.

Figure 10.1 depicts near identical long-term warming trends from four independent data sources: NOAA s National Climatic Data Center (blue line), NASA s Goddard Institute for Space Studies (black line), the Japanese Meteorological Agency (green line), and the United Kingdom's Met Office Hadley Centre/Climatic Research Unit (orange line).

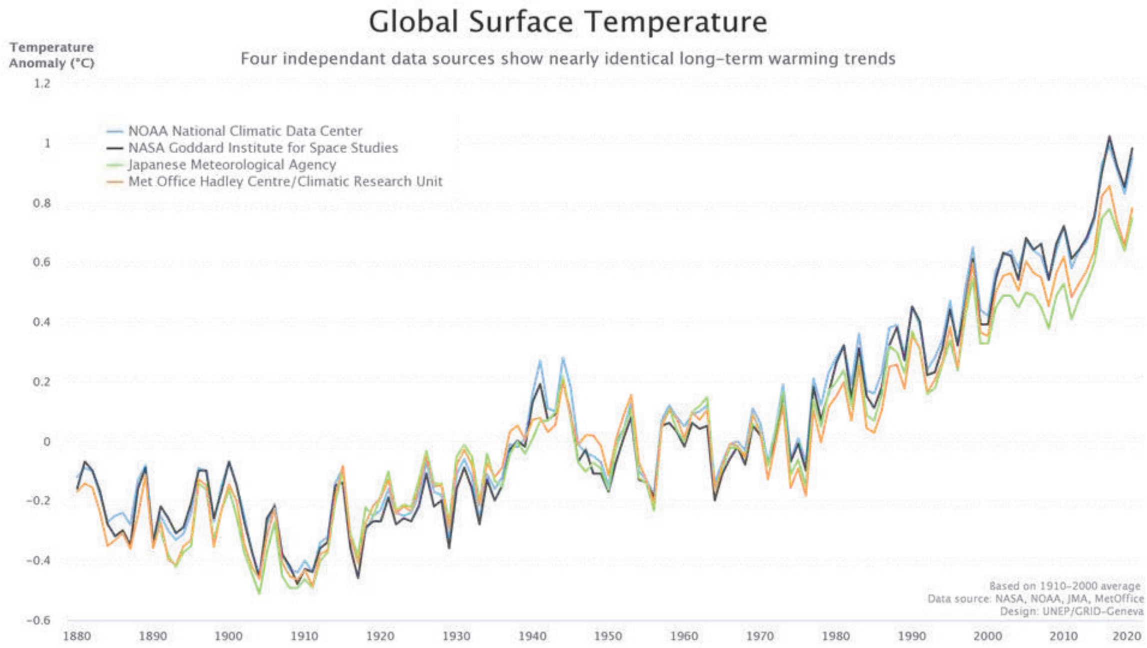

Figure 10.1: Global Surface Temperature Anomalies from Four Independent Instrumental Records Show Similar Trends, 1880-2020. Temperature anomalies are based on a 1910-2000 average. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure by UNEP/GRID is licensed under CC BY-NC-SA 2.0

Exercise 1.10.2

2. Refer to Figure 10.1.

   a. For what period of time are the displayed instrumental records available?

   b. How do the four different instrumental records compare?

Figure 10.2 shows the five-year average variation of global surface temperatures between 1880 and 2015. Before 1970, global surface temperatures were generally cooler than the 1910 to 2000 average. Since 1970, the years have been increasingly warmer than the 1910 to 2000 average. Nine of the ten warmest years during this time frame have occurred since 2000.

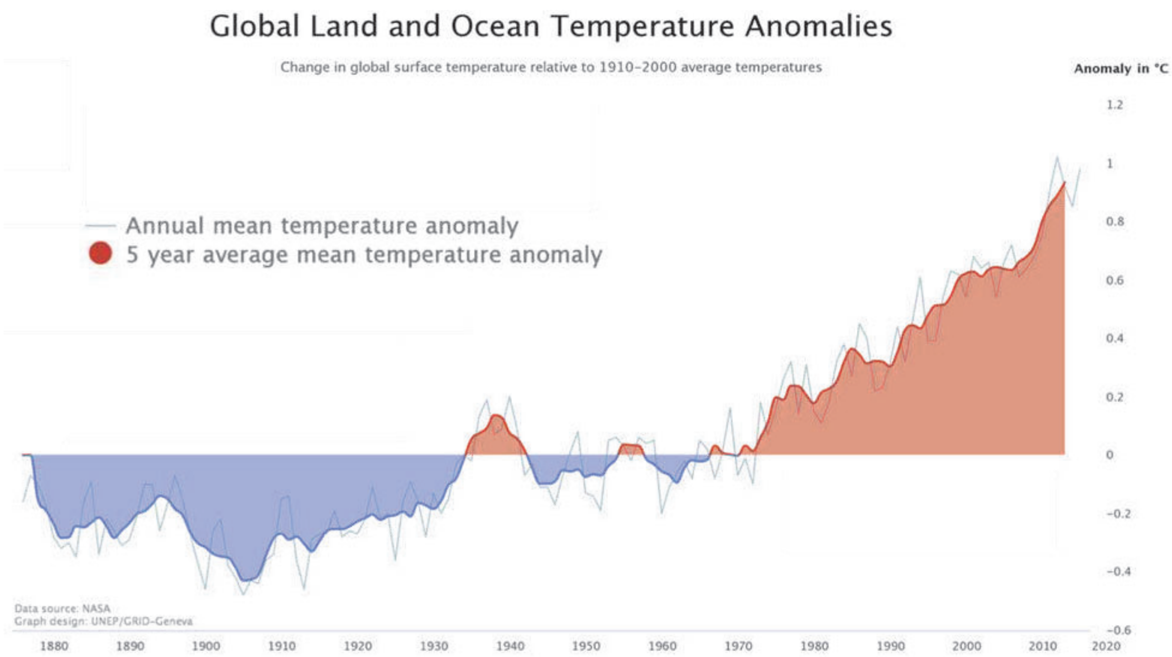

Figure 10.2: Change in Global Surface Temperatures Relative to the 1910-2000 Average. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

? Exercise 1.10.3

3. Refer to Figure 10.2.
    a. What does the 0 in the y-axis symbolize?
    b. How are temperature anomalies measured?
    c. What is the overall trend of global surface temperature anomalies?
4. Refer to Figures 10.1 and 10.2. What is the overall pattern of temperature anomalies since 1880? Tip: identify the data thresholds, which are the points in time that new data patterns emerge.

Figure 10.3 maps the temperature anomaly relative to the 1951-1980 average.

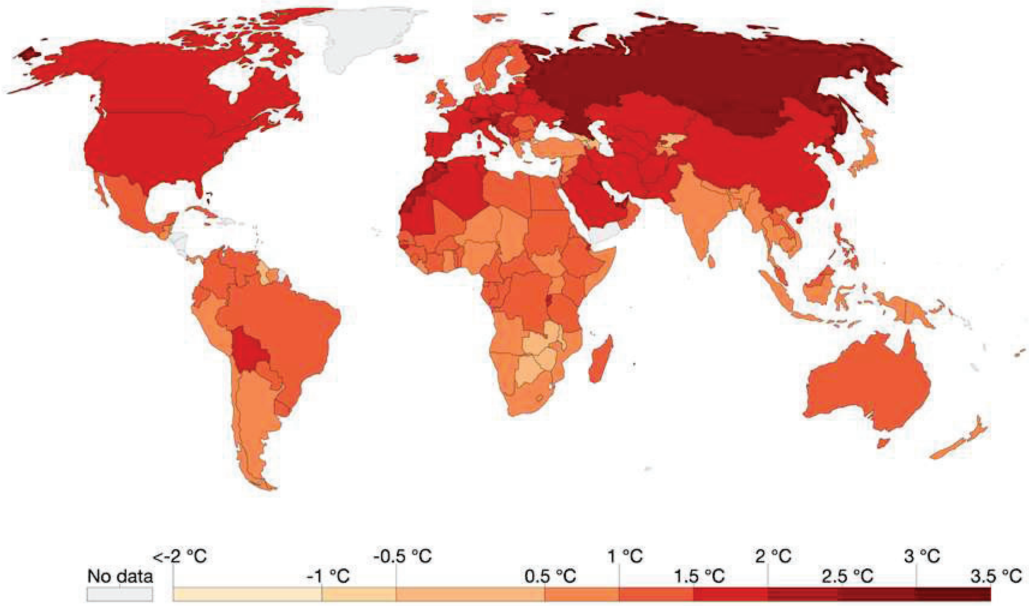

Figure 10.3: Trends in Global Surface Temperature Anomalies in 2017 Relative to the 1951-1980 Average. Tip: go to the Our World in Data website for an interactive version of this map. Figure from Our World in Data, with data published by NASA Goddard Institute for Space Studies, is licensed under CC BY 4.0

? Exercise 1.10.4

5. Describe the geographical distribution of temperature anomalies (Figure 10.3). What places have experienced the greatest temperature increases? Which have not?

An AccuWeather database of more than 3,800 global cities shows that 83% of cities experienced higher than normal temperatures in 2018.

6. How much warmer was your city in 2018 compared to normal? Search a database of your city (or a nearby city).
   a. Name your city (or nearby city):
   b. Was the temperature above or below normal?
   c. In °F, how much warmer or colder was the temperature?
   d. Click on °C; how much warmer or colder was the temperature?
7. Apply What You Learned: Before searching the database, rank the following cities from 1 to 3 with 1 being the city that warmed the most and 3 with the city that warmed the least.
   a. Irkutsk, Russia (52°N):
   b. Nome, Alaska (64°N):
   c. San Luis Potosí, Mexico (22°N):
   d. Now, search the database to find out if your ranking was correct. In one to two sentences, explain why you think your ranking was accurate.

Climate Forcings

The interactions of solar energy with land, air, and water shape Earth's climate system. Earth continuously receives energy from the Sun. A portion of the emitted solar energy that reaches the Earth is reflected back into space; some is absorbed directly by the atmosphere; but some moves through the atmosphere to the Earth's surface, heating land and water. These processes contribute to Earth's energy budget calculations that you analyzed in a previous lab. The atmosphere contains **greenhouse gases;** these gases act as a blanket and trap heat in the lower atmosphere. This process is called the **greenhouse effect**—it is natural and keeps Earth warm enough to support life (Figure 10.4).

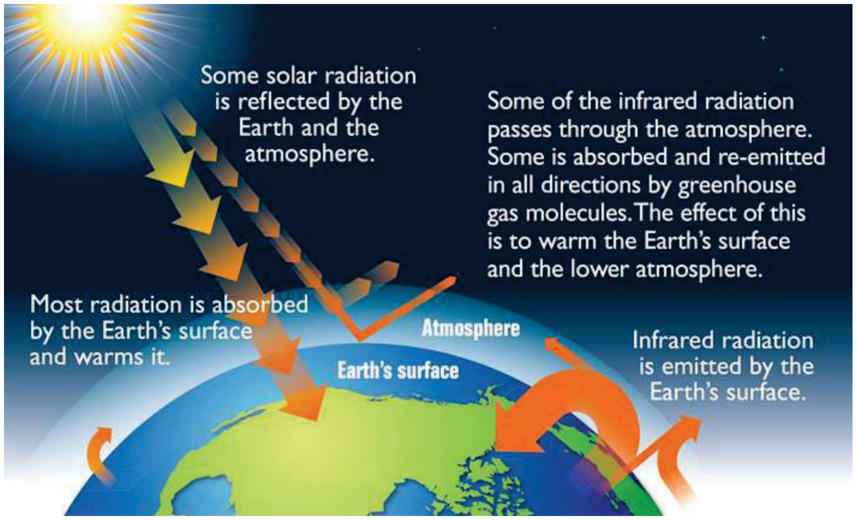

Figure 10.4: The Greenhouse Effect. Greenhouse gases absorb outgoing infrared radiation. Figure by U.S. Environmental Protection Agency is in the public domain

? Exercise 1.10.5

8. Do greenhouse gases absorb infrared radiation from the Earth?
9. Do greenhouse gases re-emit infrared radiation to the Earth?
10. Use Your Critical Thinking Skills: Do you think the greenhouse metaphor or the blanket metaphor best describe how greenhouse gases trap and re-emit longwave radiation? Explain your response in one to two sentences.

As the Earth absorbs energy from the Sun, it eventually re-emits it to space. The difference between incoming and outgoing radiation is known as a planet's **radiative forcing.** A climate forcing is a factor impacting this energy budget with the potential to change the climate system. When these factors result in incoming energy being greater than outgoing energy, the planet will warm. Conversely, if outgoing energy is greater than incoming energy, the planet will cool.

Incoming Energy – Outgoing Energy = Radiative Forcing

Climate scientists have identified a number of main factors that influence Earth's radiative forcing:

➢ Earth's orbit: The Earth wobbles on its axis, and its tilt and orbit change over thousands of years. These cyclical changes result in significant variations in the amount of solar energy reaching the planet and pushing its climate into and out of ice ages.

➢ Solar output: The amount of solar energy received by the Earth varies, increasing or decreasing by about 0.1% during Sun's natural 11-year sunspot cycle.

➢ Volcanic activity: Volcanic eruptions release greenhouse gases such as carbon dioxide into the atmosphere that result in warming. However, large volcanic eruptions can substantially increase atmospheric concentrations of sulfate aerosols and particles that shield the Earth from solar energy by reflecting sunlight and thereby cool the Earth's climate.

➢ Greenhouse gases: Atmospheric gases—such as water vapor, carbon dioxide, and methane—trap heat. While these are naturally occurring gases, burning fossil fuels to fuel industrialization resulted in a large increase of emissions of greenhouse gases. Increased greenhouse gas concentrations result in greater trapping of heat in the lower atmosphere, which increases global average temperatures.

? Exercise 1.10.6

11. Which of the main factors that influence Earth's radiative forcing are from solely natural causes?
12. Which of the main factors that influence Earth's radiative forcing are from both natural and anthropogenic causes?

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In order to better understand singular and combined factors' impacts on climate, climatologists at NASA s Goddard Institute for Space Studies (GISS) use climate models to test their assumptions and better understand controls of climate variability. As part of a contribution to an international climate research initiative called Coupled Model Intercomparison Project Phase Five CMIP5), GISS sought to combine results from climate models to see how well they could reproduce what's known about the climate from 1850 to 2012 and to estimate how the various climate forcings contribute to those temperatures.

Figure 10.5 shows the observed global temperatures from 1880 to 2000 in the blue line. Modeled factors include greenhouse gases, volcanic eruption, ozone, solar output, Earth's orbital changes, land use changes, and aerosols. The red line shows all of these forcings combined.

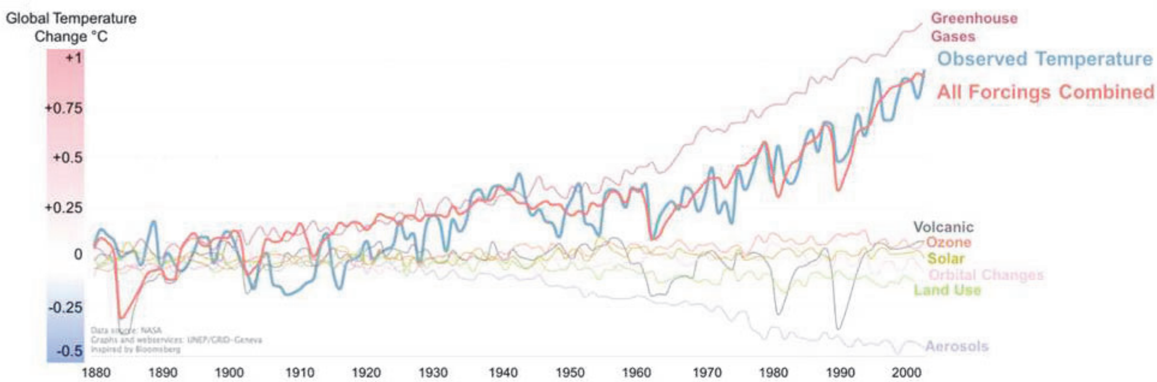

Figure 10.5: Modeled Individual Contributions to Global Temperature Changes. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

Figure 10.6 shows the same observed temperatures in blue and combined forcings in red as shown in Figure 10.5. It combines the anthropogenic contributions together in the black line and all of the natural contributions together in the green line.

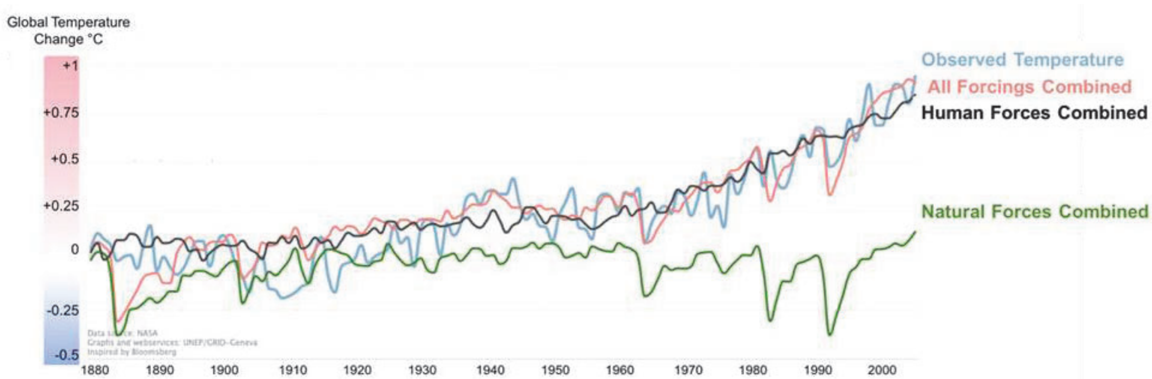

Figure 10.6: Modeled Human and Individual Contributions to Global Temperature Changes. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

? Exercise 1.10.7

13. Refer to Figures 10.5 and 10.6.

a. What is the overall observed pattern of temperature anomalies since 1880?

b. Describe the impacts of the following climate forcings on observed temperature changes.

i. volcanic eruptions:
ii. aerosols:
iii. orbital changes:
iv. solar output:
v. greenhouse gases:

c. Which of these forcings appear to have the greatest impact on current temperature patterns ?

d. When looking at human factors and natural factors combined (Figure 10.6), how does the correlation to global temperature patterns change? Which factors display stronger correlation to the global temperature anomalies? Explain your response in three to four sentences.

Paleoclimatology

On a planet that is more than 4.5 billion years old, human existence is a short glimpse of time. Amidst such vast natural history, scientists attempt to understand the human context by seeking records and clues to a distant past. The field of study dedicated to understanding long-term patterns of the Earth's climate beyond human records is called **paleoclimatology.** In order to reconstruct Earth's climate history, paleoclimatologists rely on **proxy data,** or preserved physical attributes that can be measured and analyzed to understand the past. Coral reefs, lakebed and ocean sediments, pollen, tree trunks, and ice cores are some of the natural recorders of climate indicators that scientists use to understand the Earth's climate beyond the instrumental record. Reading into the past allows us to better understand the present and the future.

Analyzing Ice-Core Data

Ice cores are cylinders of ice that paleoclimatologists drill from ice sheets and glaciers Figure 10.7). Layers of ice can act as high time-resolution capsules by freezing samples of the atmosphere in tiny air bubbles, thus allowing scientists to access and analyze atmospheric temperatures and composition well beyond the instrumental record. The deeper scientists drill, the older the ice and atmospheric samples that can be extracted.

Figure 10.7: Ice-core Sample Taken from Drill. Figure from NOAA is in the public domain

Under the European Project for Ice Coring in Antarctica (EPICA), scientists drilled and extracted an ice core that is about two miles long, the longest ice core sample as of 2020. The Dome C ice core enabled access to 800,000 years of continuous atmospheric data, revealing ancient atmospheric temperatures and greenhouse gas concentrations. Scientists can then test the data against other ice core data and other data proxies to create aggregate data sets such as the ones shown in Figure 10.8. These graphs represent proxy data from more than 63 locations interpolated by eight climate models with a 1,000-year resolution to reconstruct 800,000 years of Earth's climate.

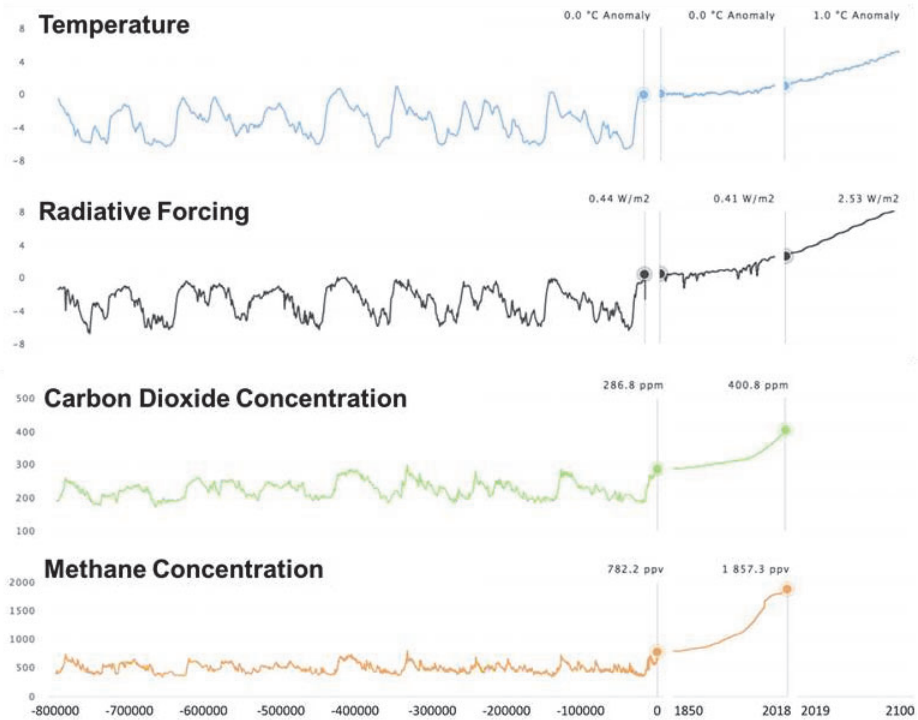

Figure 10.8: Trends in Global Atmospheric Changes from Aggregate Proxy Data. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

The trends in the mean global temperature anomaly based on the average temperature of the last 1,000 years are shown in Figure 10.9.

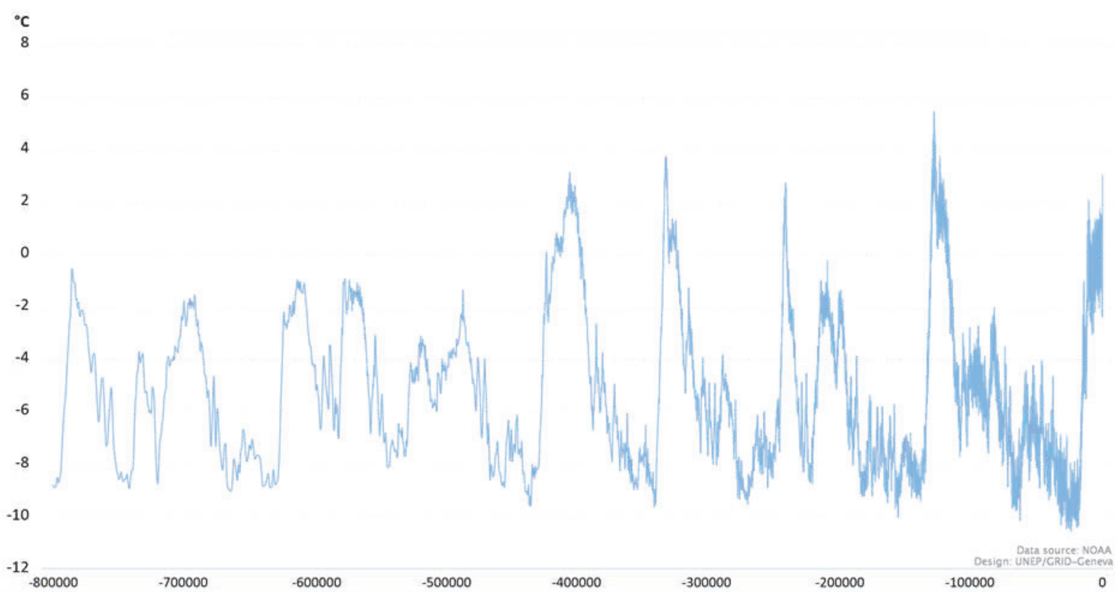

Figure 10.9: Trends in Global Temperature Change. Tip: go to the UNEP/GRID website for an interactive version of this graph. Figure adapted from UNEP/GRID is licensed under CC BY-NC-SA 2.0

? Exercise 1.10.8

14. Refer to Figures 10.8 and 10.9.

   a. How many years of climate data have been reconstructed? How do scientists construct such extensive datasets?

   b. Describe the patterns of global temperature, radiative forcing, and greenhouse gases displayed in the graphs above.

c. What are the maximum and minimum temperature anomalies recorded?

d. How many interglacial periods (times when the temperature deviation reached 0°C) can be detected in this dataset?

e. What is the correlation between temperature, radiative forcing, and greenhouse gas concentrations shown in this data record?

f. How do concentrations of carbon dioxide and methane of today compare to the patterns of this data record?

g. How do today’s recorded temperatures compare to temperature patterns of the past?

h. What changes are projected for 2100? What factors do you think explain such a projection?

Part B. Anthropogenic Climate Change

> *“Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.”*
>
> *IPCC 5th Assessment Report, 2014*

The term **climate change** refers to the climatic changes that occur over long periods of time. As observed from the datasets in previous sections, Earth’s temperatures varied from epoch to epoch. The paleoclimate record also shows a strong correspondence between temperature and the concentration of greenhouse gases in the atmosphere observed during the glacial cycles of the past several hundred thousand years. Furthermore, studies gauging radiative forcings Figures 10.5 and 10.6) suggest contemporary warming to be most attributed to increased greenhouse gases.

There is a strong scientific consensus that burning fossil fuels to power global industrialization has changed global atmospheric composition, increased greenhouse gas concentrations, and exacerbated the greenhouse effect. This is what scientists call **anthropogenic climate change,** or climatic change caused by humans. This change is defined by an increase in global average temperatures, or **global warming.** Global warming triggers a series of changes in the Earth’s climate system that disrupts life-supporting mechanisms, which will be discussed later in this lab.

Think About It…What is the Scientific Consensus on Climate Change?

Multiple studies in peer-reviewed scientific journals show that 97% of actively publishing climate scientists agree that warming trends of the past century are extremely likely to be anthropogenic NASA). More than 200 scientific organizations worldwide, including the most prominent American scientific organizations, agree that the Earth is warming due to human causes (NASA .

The Intergovernmental Panel on Climate Change (IPCC) is a United Nations body of hundreds of international scientists that gathered to produce a six-year literature review of the latest climate science to guide policy makers. This panel continuously asserts that human influence on the climate is clear and it is disruptive of Earth’s natural systems (IPCC .

Does the news media that you follow convey the scientific consensus on climate change? What motives do news media have to present biased information on climate change and the scientific consensus about its human causes?

Why CO_2 Matters

Carbon dioxide is an abundant greenhouse gas, a gas that absorbs and radiates heat. Different greenhouse gases have different **global warming potential GWP),** which is the relative ability to trap heat. Carbon dioxide absorbs less heat per molecule than other greenhouse gases such as methane or nitrous oxide (Figure 10.10). One tonne of methane has 28 times the warming impact as one tonne of carbon dioxide. Nonetheless, carbon dioxide is more abundant and it stays in the atmosphere much longer. In 2018, carbon dioxide accounted for 81% of all greenhouse gasses emitted through human activities in the United States.

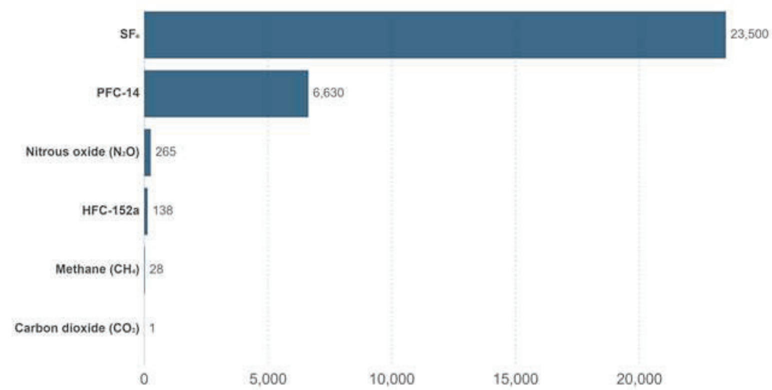

Figure 10.10: Global Warming Potential of Greenhouse Gases over 100 Years. Figure from Our World in Data, with data published in the IPCC 2014 Synthesis Report, is licensed under CC BY 4.0

NOAA s Annual Greenhouse Gas Index (AGGI) assesses the radiative forcing of long-lived greenhouse gases. The index compares the combined warming influence of these gases each year, starting in 1980 when NOAA s global air sampling expanded significantly. Figure 10.11 shows the heating imbalance in watts per square meter relative to the year 1750 caused by all major human-produced greenhouse gases: carbon dioxide, methane, nitrous oxide, chlorofluorocarbons 11 and 12, and a group of 15 other minor contributors. While the radiative forcing of the long-lived greenhouse gases increased 43% from 1990 to 2018, CO_2 has accounted for about 80% of this increase.

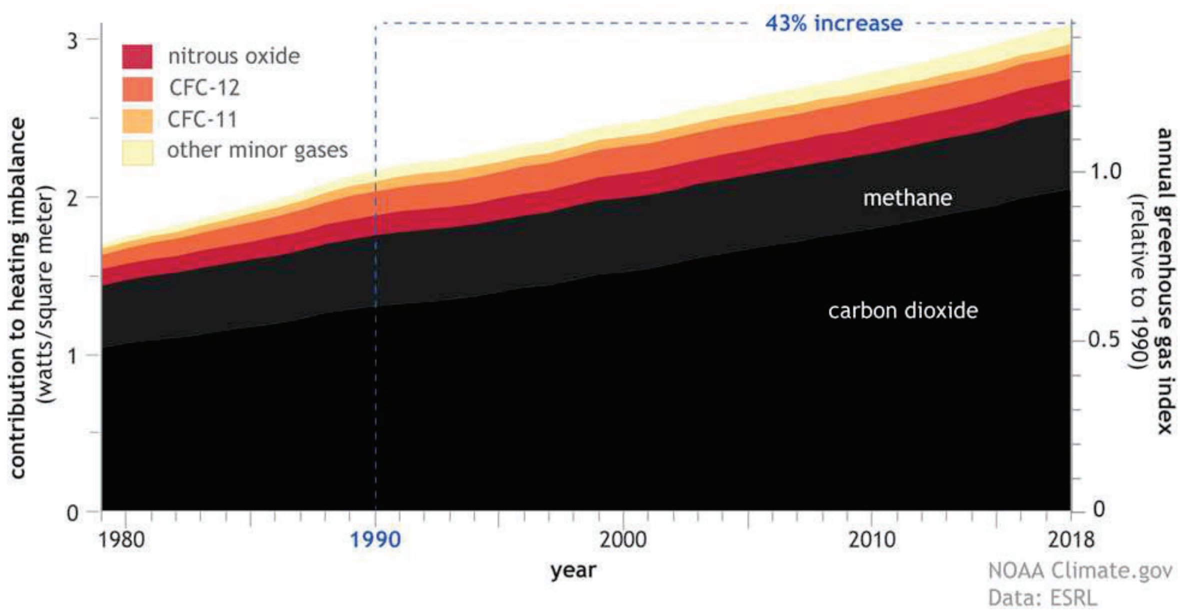

Figure 10.11: Influence of All Major Human-Produced Greenhouse Gases (1979-2018). Figure by NOAA is in the public domain

? Exercise 1.10.9

15. Refer to Figures 10.10 and 10.11.
    a. In your own words, explain GWP.
    b. In relation to CO_2, what is the relative GWP of methane and nitrous oxide?
    c. Based on NOAA s Greenhouse Gas Index, how has the radiative forcing attributable to greenhouse gases changed over time? Which gases contribute most to this heating imbalance? Explain your response in two to three sentences.

400pm Threshold

Scientists have long warned about the dangers of unprecedented CO_2 concentrations beyond 400 parts per million (ppm). The global average atmospheric carbon dioxide in 2019 was 409.8 ppm, with a range of uncertainty of plus or minus 0.1 ppm Figure 10.12).

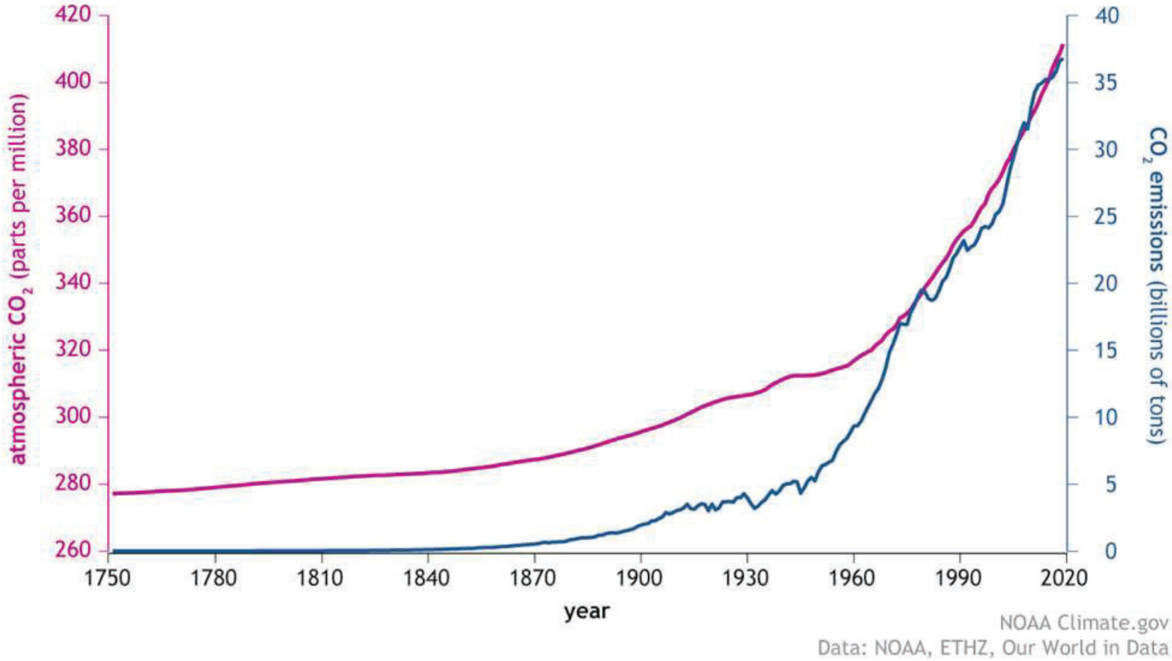

Figure 10.12: Atmospheric Carbon Dioxide (raspberry line) and Annual Emissions (blue line) from 1750-2019. Figure by NOAA is in the public domain

Exercise 1.10.10

16. Refer to Figure 10.12.

a. Figure 10.12 displays CO_2 atmospheric concentrations and CO_2 emissions. Why are such comparisons valuable? What patterns emerge from this data? Explain your response in two to three sentences.

b. What is the approximate concentration of CO_2 in the atmosphere in 2020 (in ppm)?

c. Compare and contrast early industrial atmospheric peak concentrations and emissions to contemporary data. List the similarities and/or differences.

Ice core proxy data provides evidence that carbon dioxide levels today are higher than at any point in at least the past 800,000 years Figure 10.13).

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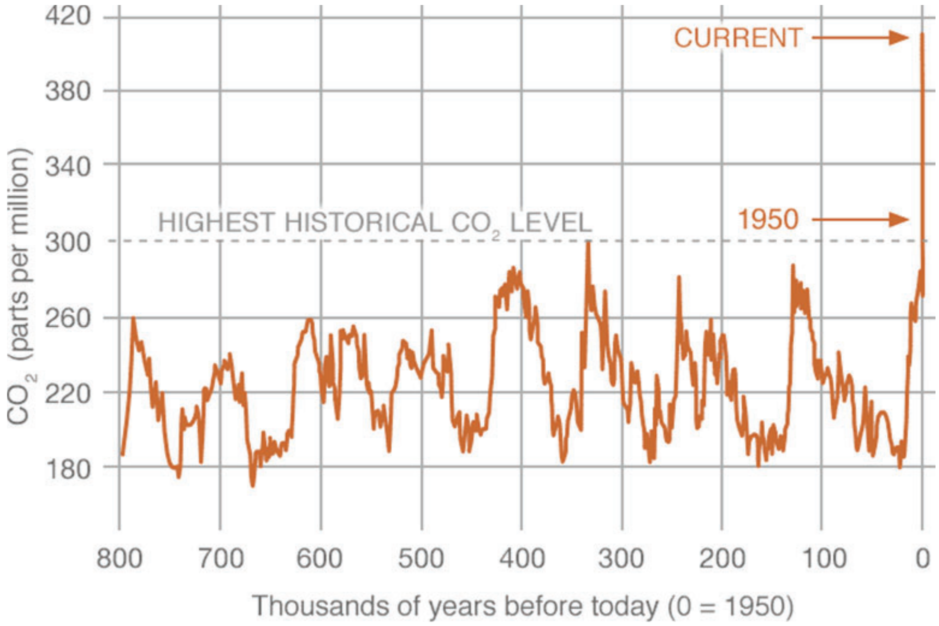

Figure 10.13: Global Atmospheric Carbon Dioxide Concentrations for the Past 800,000 Years. Figure by NOAA is in the public domain

? Exercise 1.10.11

17. Refer to Figure 10.13. What is the approximate highest CO_2 concentration recorded in the paleorecord? How does this compare to the 2020 value?

Direct observations and data collection at four observatories provide evidence of monthly average carbon dioxide concentrations since the 1970s (Figure 10.14). Note that in Figure 10.14, the annual oscillations at the two northern hemisphere sites (Barrow, Alaska and Mauna Loa, Hawai'i) are due to the seasonal imbalance between the photosynthesis and respiration of plants on land. The difference between Mauna Loa and the South Pole has increased over time as the global rate of fossil fuel burning, most of which takes place in the northern hemisphere, has accelerated.

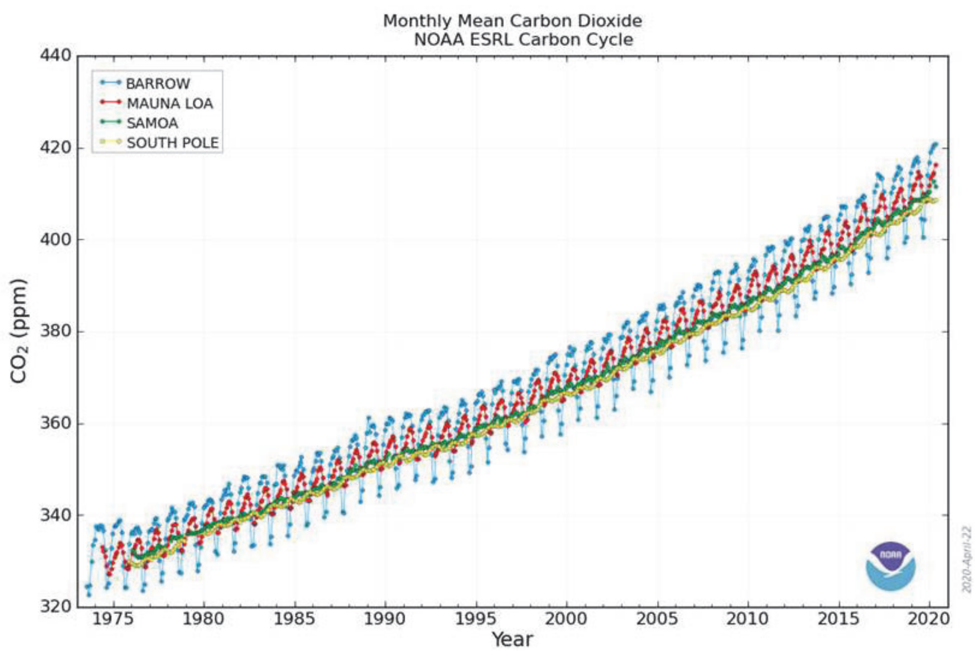

Figure 10.14: Monthly Average Carbon Dioxide from Four Baseline Observatories. Figure by NOAA is in the public domain

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Think About It…Why are the Baseline Observatories Located Where They Are?

Direct instrumental observations of carbon dioxide and methane occur at stations all around the world. Only four of these locations are called the baseline observatories. Figure 10.15 shows the locations: Barrow Alaska); Mauna Loa Hawai'i); American Samoa; and the South Pole (Antarctica). These observatories were established in order to provide sampling of the most remote air on the planet so that the true "background atmosphere" could be monitored.[171]

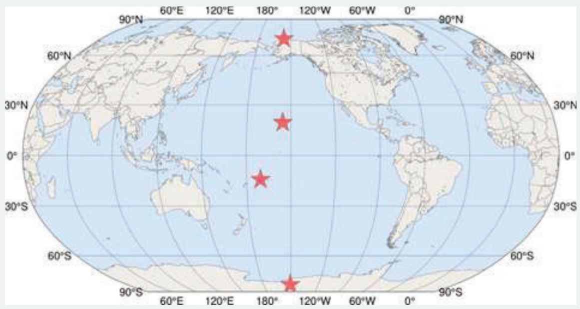

Figure 10.15: Locations of Baseline Observatories. Figure by NOAA is in the public domain

Exercise 1.10.12

18. Refer to Figure 10.14.

   a. Describe the overall trend shown.

   b. Approximately what year did all baseline observatories record 400 ppm concentrations?

   c. What CO_2 (ppm) value was the maximum-recorded concentration? When and where did this occur?

   d. Use Your Critical Thinking Skills: Why do you think this location recorded the highest concentration of carbon dioxide? Explain your response in at least one sentence.

Future Scenarios

Based on present patterns of increasing greenhouse gas emissions, scientists warn of diverse negative impacts of increased average global temperatures on natural and human systems. A warmer world threatens oceans, coastlines, biodiversity, and agriculture, and exacerbates extreme weather events and tensions over resources. Commitments to reduce greenhouse gases have evolved over a series of global agreements, all of which have shown limited results. What does the future look like? Climate policy matters.

The visualization below shows a range of potential scenarios modeled based on contemporary patterns (Figure 10.16). The graph's y-axis shows gigatonnes of carbon dioxide equivalents. Greenhouse gases are often normalized in measures of carbon dioxide equivalents, a standard unit based on the radiative forcing of a molecule of carbon dioxide over a time frame (often a 100-year period). Each scenario shows a range of shading due to the uncertainty of emissions—whether there are low or high emissions within each pathway is unknown. Here is a summary of each of the four scenarios:

➢ No climate policies: Represents expected emissions in a baseline scenario if countries had not implemented climate reduction policies. This would result in a warming of 4.1 to 4.8°C by 2100.

➢ Current policies: Represents emissions with current climate policies in place. This would result in a warming of 2.8 to 3.2°C by 2100.

➢ Pledges and targets: Represents emissions if all countries delivered on the reduction pledges they have made as of December 2019. This would result in a warming of 2.5 to 2.8°C by 2100.

➢ 1.5°C and 2°C pathways: Represents the goals outlined in the 2016 Paris Agreement by the United Nations Framework Convention on Climate Change. These pathways were developed based on more than 6,000 research papers to show that it is possible to limit warming and its ill-effects.