ESS.3.6 Global Climate History and Trends

Analyze and interpret data from global climate records to illustrate changes to Earth's systems throughout geologic time and make predictions about future variations using modern trends. Examples of data could include average sea surface temperature, average air temperature, composition of gasses in ice cores, or tree rings. (ESS2.D, ESS3.D)

In this section, focus on the idea that models can be used to infer and predict the behavior of Earth's past and future climate system.

Earth's Past Climate

The Earth's climate has changed throughout history. Just in the last 650,000 years there have been seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 7,000 years ago marking the beginning of the modern climate era — and of human civilization. Most of these climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives and natural changes to Earth's atmospheric composition .

Evidence of Past Climate

This section is adapted from What is proxy data? *by NOAA National Centers for Environmental Information; https://www.ncei.noaa.gov/news/what-are-proxy-data; public domain*

In paleoclimatology, or the study of past climates, scientists use what is known as proxy data to reconstruct past climate conditions. These proxy data are preserved physical characteristics of the environment that can substitute for direct measurements. Paleoclimatologists gather proxy data from natural recorders of climate variability such as corals, pollen, ice cores, tree rings, caves, pack rat middens, ocean and lake sediments, and historical data. By analyzing records taken from these and other proxy sources, scientists can extend our understanding of climate far beyond the instrumental record. The following paragraphs describe just a few examples of the environmental recorders scientists can use to learn about ancient climates.

Historical Data

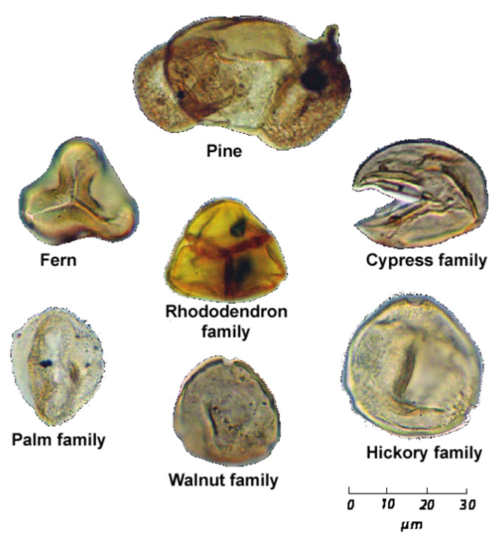
Historical documents, which are one type of proxy data, can contain a wealth of information about past climates. Observations of weather and climate conditions can be found in ship and farmers' logs, travelers' diaries, newspaper accounts, and other written records. When properly evaluated, historical documents can yield both qualitative and quantitative information about past climate. For example, scientists used historical grape harvest dates to reconstruct summer temperatures, between April and September, in Paris from 1370 to 1879.

Corals

Another type of proxy data, corals build their hard skeletons from calcium carbonate—a mineral extracted from seawater. The density of these calcium carbonate skeletons changes as the water temperature, light, and nutrient conditions change, giving coral skeletons formed in the summer a different density than those formed in the winter. The carbonate also contains isotopes of oxygen as well as trace metals that can be used to determine the temperature of the water in which the coral grew. Scientists can then use this information to reconstruct the climate when the coral lived.

Pollen Fossils

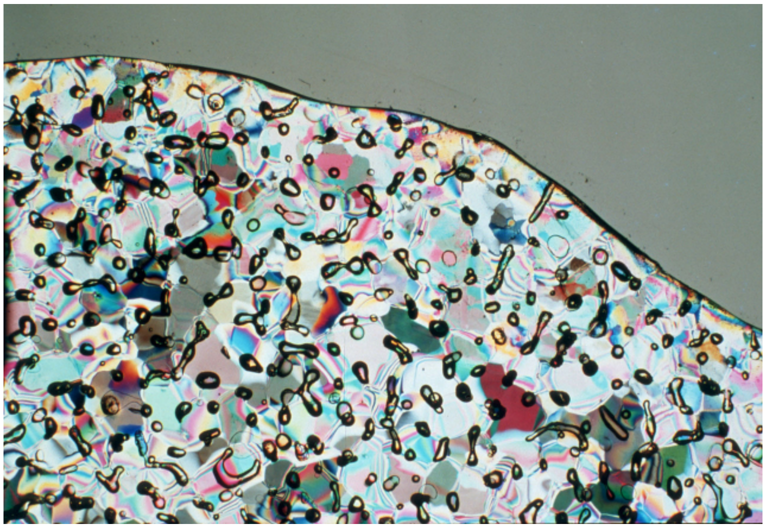
All flowering plants produce pollen grains, which are another type of proxy data. Scientists can use the distinctive shapes of pollen grains to identify the type of plant from which they came. Since pollen grains are well preserved in the sediment layers in the bottom of a pond, lake, or ocean, an analysis of the pollen grains in each layer tells scientists what kinds of plants were growing at the time the sediment was deposited. Scientists can then make inferences about the climate of the area based on the types of plants found in each layer since most plants will only grow under certain conditions.



Fossil pollen and spores preserved in sediments. *Image by USGS;* https://www.usgs.gov/programs/climate-research-and-development-program/science/paleoclimate-proxies; public domain

Ice Cores

Located high in the mountains and near the poles, ice—another type of proxy data—has accumulated from snowfall over many millennia. Scientists drill through the deep ice to collect ice cores, which often have distinct layers in them. These layers contain dust, air bubbles, or isotopes of oxygen, differing from year to year based on the surrounding environment, that can be used to interpret the past climate of an area. Ice cores can tell scientists about temperature, precipitation, atmospheric composition, volcanic activity, and even wind patterns.



Bubbles in an Antarctic ice sample illuminated with polarized light.

Image by CSIRO; https://en.wikipedia.org/wiki/Ice_core#/media/File:CSIRO_ScienceImage_518_Air_Bubbles_Trapped_in_Ice.jpg; CC BY 3.0

Tree Rings

Trees and their unique rings also serve as proxy data. Because climate conditions influence tree growth, patterns in tree-ring widths, density, and isotopic composition reflect variations in climate. In temperate regions where there is a distinct growing season, trees generally produce one ring a year, recording the climate conditions each year. If they depend heavily on warm temperatures or lots of moisture in the growing season, their rings will be wider when those conditions are present and narrower when they aren't. Trees can also grow to be hundreds to thousands of years old and can contain annual records of climate for centuries to millennia.

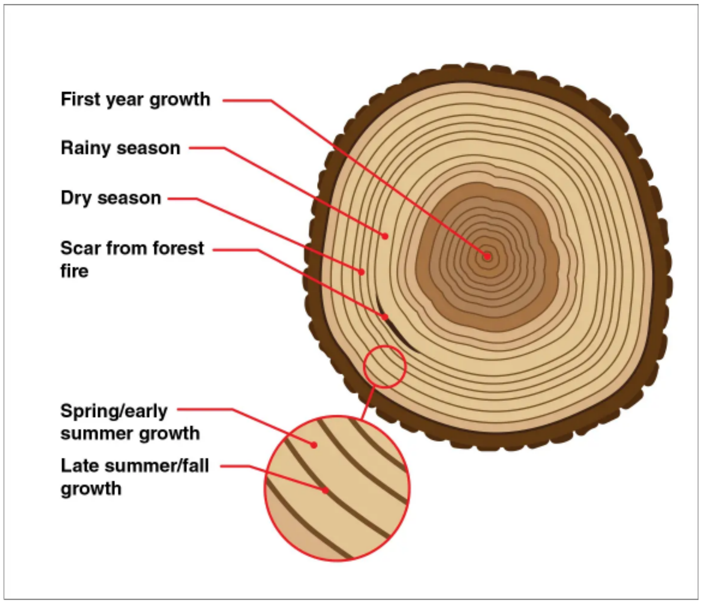


Image by NASA Global Climate Change; https://climate.nasa.gov/news/2540/tree-rings-provide-snapshots-of-earths-past-climate/; public domain

Cave Formations

Caves and the unique rock formations inside them also serve as proxy data. These underground chambers contain the secrets of Earth's climate in speleothems—also known as stalactites, stalagmites, and other formations. Speleothems grow over time as water drips down from a cave's ceiling or pools in its floor and mineral deposits build up in thin, shiny layers. Because the amount of water making its way into caves determines the amount speleothems grow, their layers can indicate times of both heavy precipitation and drought.

Sediment Samples

Another type of proxy data can be found on the floors of Earth's oceans and lakes. Billions of tons of sediment accumulate in ocean and lake basins each year, providing a vast amount of information about the environment. Scientists drill cores of the sediments from the basin floors and examine their contents, which include tiny fossils and chemicals, to interpret past climates.

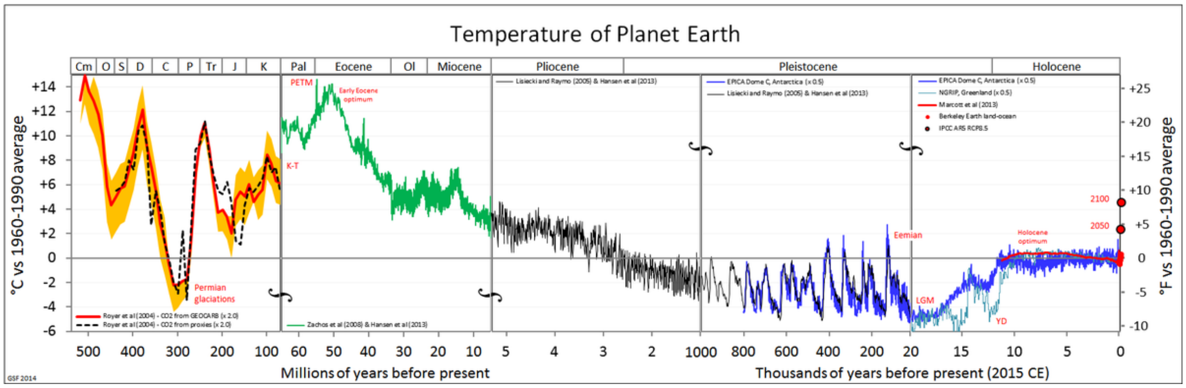


Image *Global average temperature estimates for the last 540 My* by Glen Fergus; https://commons.wikimedia.org/wiki/File:All_palaeotemps.png; CC BY-SA 3.0

The graph above shows estimates of global average surface air temperature over the ~540 million years. It was produced using proxy data. The temperature proxy measurements between 540 to 1 million years ago were produced by chemical measurements from the shells of microscopic marine organisms found in sediments. Measurements from 1 million to 20,000 years ago were taken from ice cores. Measurements from 20,000 years ago to the present were made by ice core analysis and other temperature proxies.

Natural Causes of Climate Change

Several natural processes have affected Earth's temperature throughout its history. The amount of energy the Sun radiates is variable. Sunspots are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle. When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is, and there is no known 11-year cycle in climate variability.

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents were joined into one supercontinent (such as Pangaea), nearly all locations experienced a continental climate. When the continents separate, heat is more evenly distributed. Plate tectonic movements may also help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age. Climate change caused by Plate Tectonics can take millions of years, much longer than the warming we are seeing today.

Plate motions trigger volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather. Massive eruptions of fluid lavas release much more gas and dust and can change climate for many years. This type of eruption is exceedingly rare and none has occurred since humans have lived on Earth.

Most significant changes in Earth's climate in the past are attributed by scientists to variation in the Earth's position relative to the Sun, known as Milankovitch cycles. The Earth goes through regular variations in its position relative to the Sun. When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Greenhouse gas levels have varied throughout Earth's history and can cause changes in climate. For example, CO_2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods, shown below.

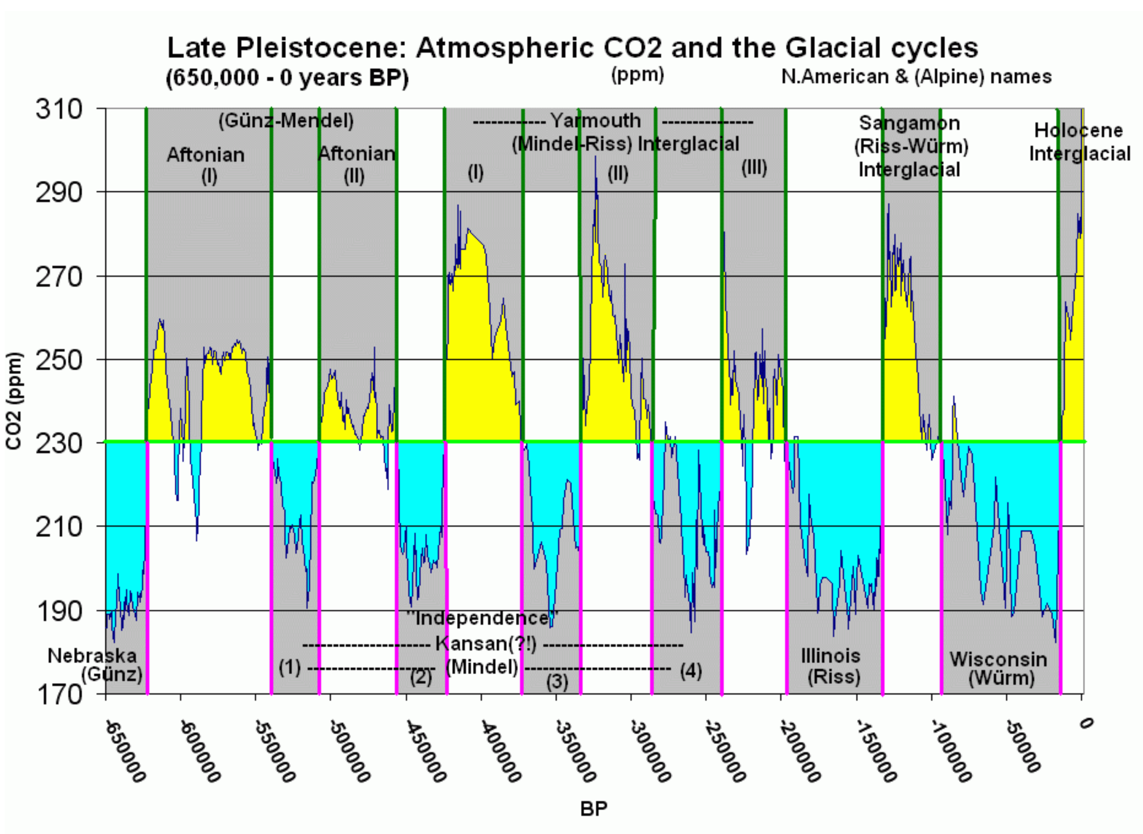
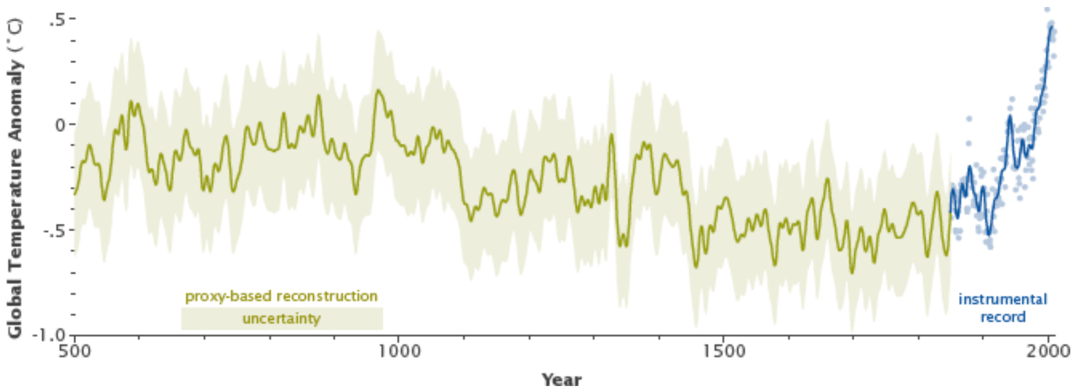


Image Atmospheric CO2 with glaciers cycles by Tom Ruen; https://commons.wikimedia.org/wiki/File:Atmospheric_CO2_with_glaciers_cycles.png; public domain

Current Climate Change

Paleoclimate records reveal that current warming of the climate is occurring much more rapidly than past warming events. In the past century alone, the temperature has risen roughly ten times faster than the average rate of ice-age-recovery warming. The predicted rate of warming for the next century is at least 20 times faster. This rate of change is extremely unusual and has never been seen before in Earth’s history.



NASA graph by Robert Simmon, based on data from Jouzel et al., 2007; https://earthobservatory.nasa.gov/features/GlobalWarming/page3.php; public domain

The graph above shows Temperature histories from paleoclimate data (green line) compared to the history based on modern instruments (blue line). The data suggests that global temperature is warmer now than it has been in the past 1,000 years, and possibly longer.

Evidence for Current Climate Change

This section is adapted from Evidence: How do we know climate change is real by NASA Global Climate Change https://climate.nasa.gov/evidence/; public domain.

The current warming trend is different because it is clearly the result of human activities since the mid-1800s, and is proceeding at a rate not seen over the past millions of years. Human activities have produced an abundance of atmospheric greenhouse gasses that have trapped more of the Sun’s energy in the Earth system. This extra energy has warmed the atmosphere, ocean, and land, and produced widespread and rapid changes in the atmosphere, ocean, ice cover, and biosphere.

The evidence for rapid climate change is compelling. First, global temperature is rising. The planet's average surface temperature has risen about 2 degrees Fahrenheit (1 degrees Celsius) since the late 19th century, a change driven largely by increased carbon dioxide emissions into the atmosphere and other human activities. Most of the warming occurred in the past 40 years. The years 2016 and 2020 are tied for the warmest year on record. The number of record high temperature events in the United States has been increasing, while the number of record low temperature events has been decreasing since 1950.

The ocean is getting warmer. The ocean has absorbed much of this increased heat, with the top 100 meters (about 328 feet) of ocean showing warming of more than 0.6 degrees Fahrenheit (0.33 degrees Celsius) since 1969. Earth stores 90% of the extra energy in the ocean. The graph below shows changes in heat content of the top 700 meters of the world's oceans between 1955 and 2020.

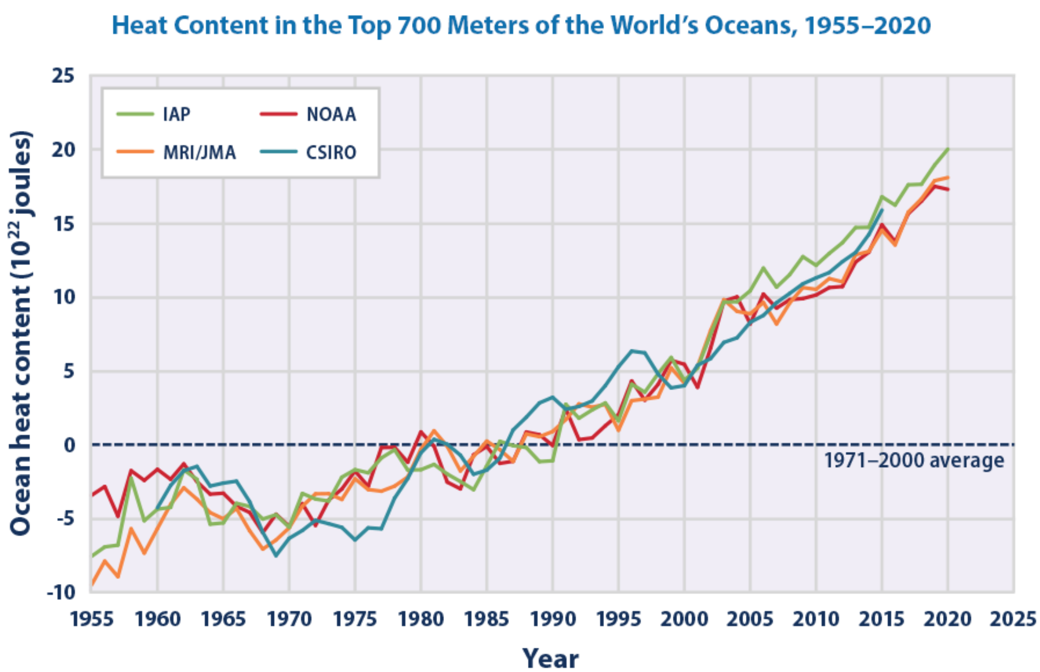


Image by EPA;
https://www.epa.gov/climate-indicators/climate-change-indicators-ocean-heat; public domain

Earth's ice, its cryosphere, is shrinking. The Greenland and Antarctic ice sheets have decreased in mass. Data shows Greenland lost an average of 279 billion tons of ice per year between 1993 and 2019, while Antarctica lost about 148 billion tons of ice per year. Glaciers are retreating almost everywhere around the world, including in the Alps, Himalayas, Andes, Rockies, and elsewhere. Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades. Satellite observations reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and the snow is melting earlier.

The first graph below shows the cumulative change in mass in the ice sheets of Greenland and Antarctica since 1992. The second graph below shows the cumulative mass of four U.S. reference glaciers since measurements began in the 1950s or 1960s. The third diagram below is a map of the western United States that shows trends in April snowpack, measured in terms of snow water equivalent. Blue circles represent an increased snowpack; red circles represent a decrease.

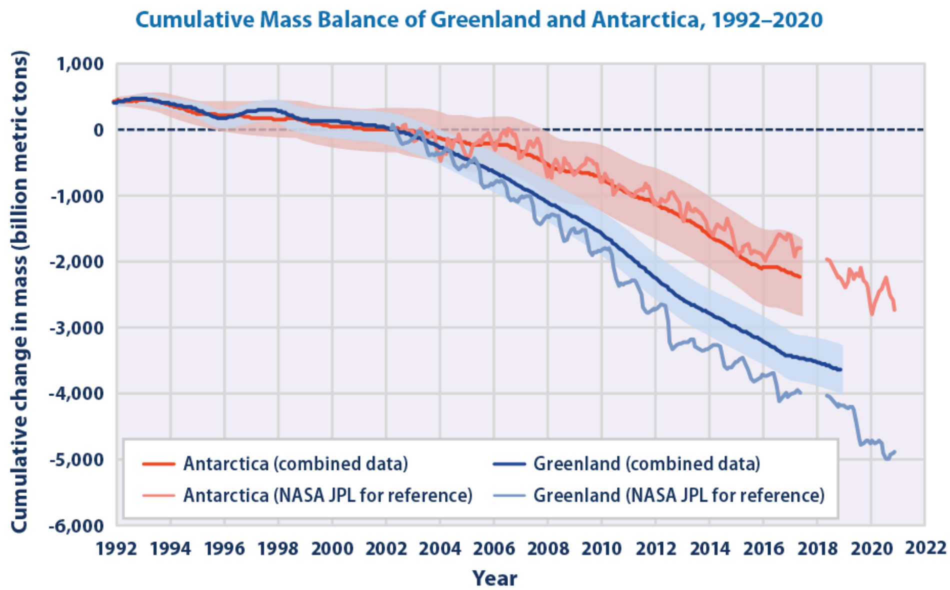


Image by EPA; https://www.epa.gov/climate-indicators/climate-change-indicators-ice-sheets; public domain

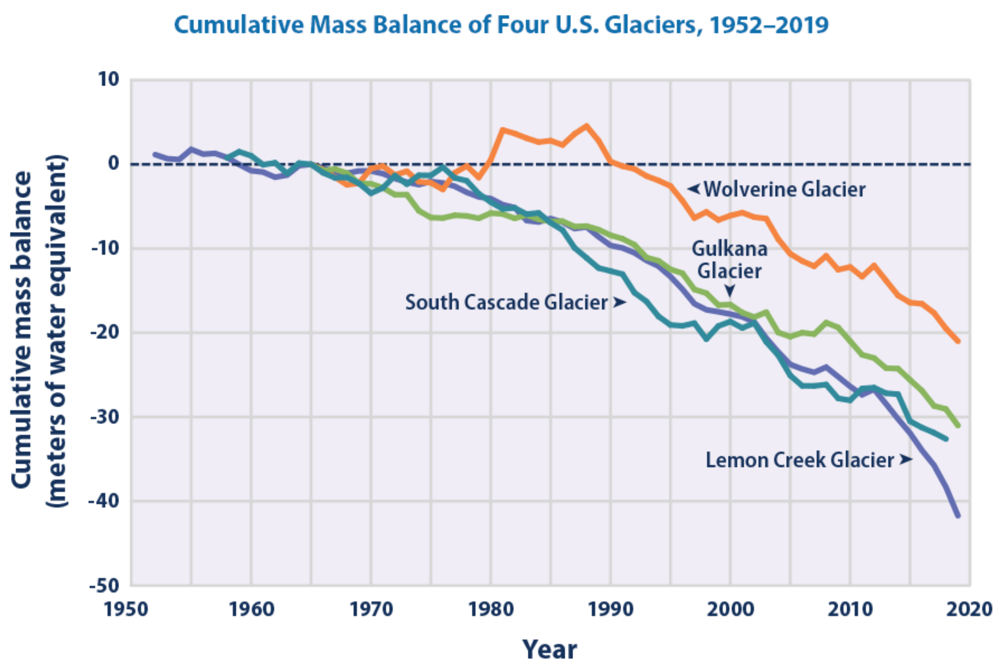


Image by EPA; https://www.epa.gov/climate-indicators/climate-change-indicators-glaciers; public domain

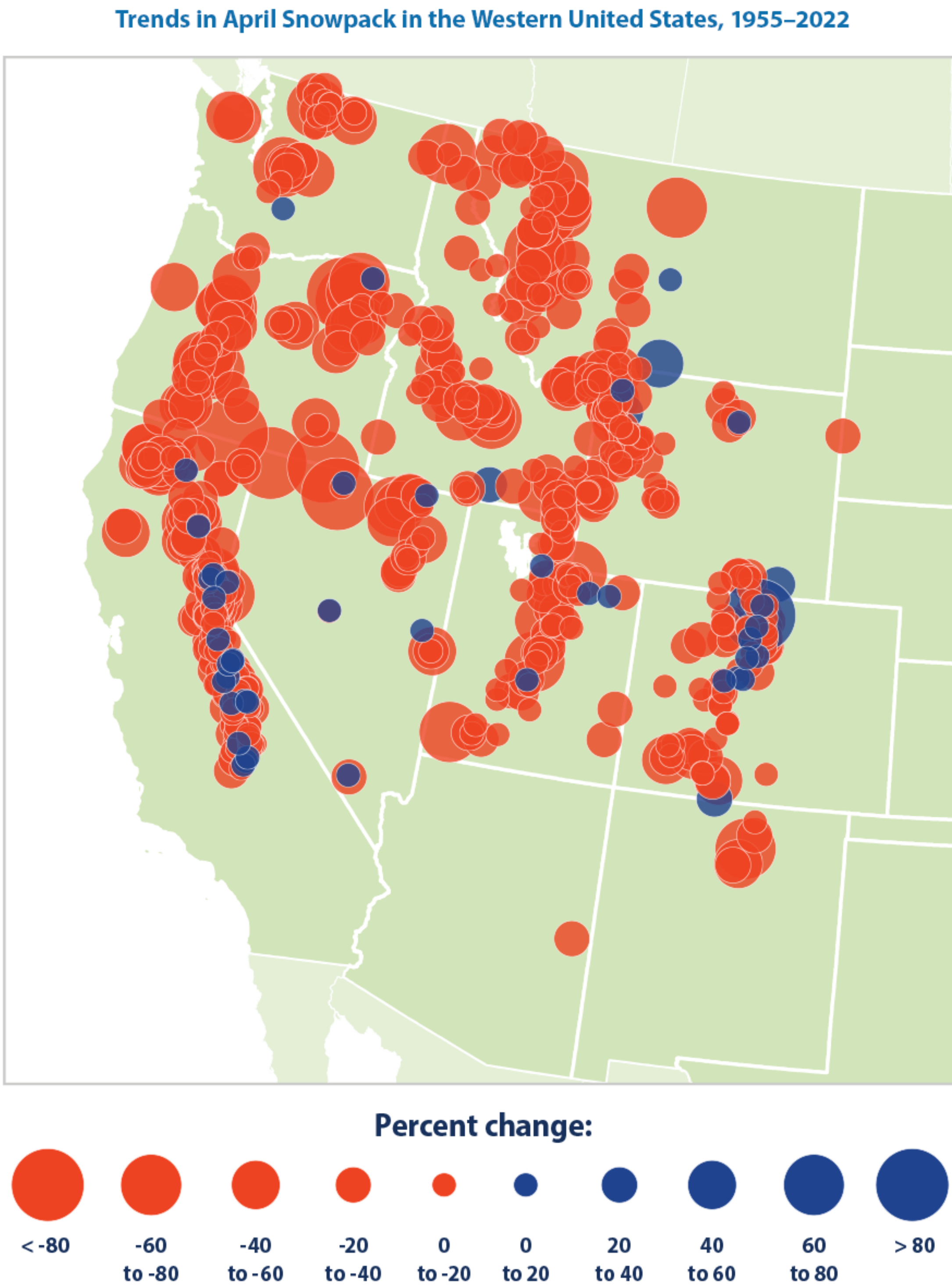


Image by EPA; https://www.epa.gov/climate-indicators/climate-change-indicators-snowpack; public domain

Ocean waters are changing in response to changes in climate. Global sea level rose about 8 inches (20 centimeters) in the last century. The rate in the last two decades, however, is nearly double that of the last century and accelerating slightly every year. Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30%. This increase is due to humans emitting more carbon dioxide into the atmosphere and therefore more being absorbed into the ocean. The ocean has absorbed between 20% and 30% of total human produced carbon dioxide emissions in recent decades (7.2 to 10.8 billion metric tons per year). The graph below shows cumulative changes in sea level for the world's oceans since 1880.

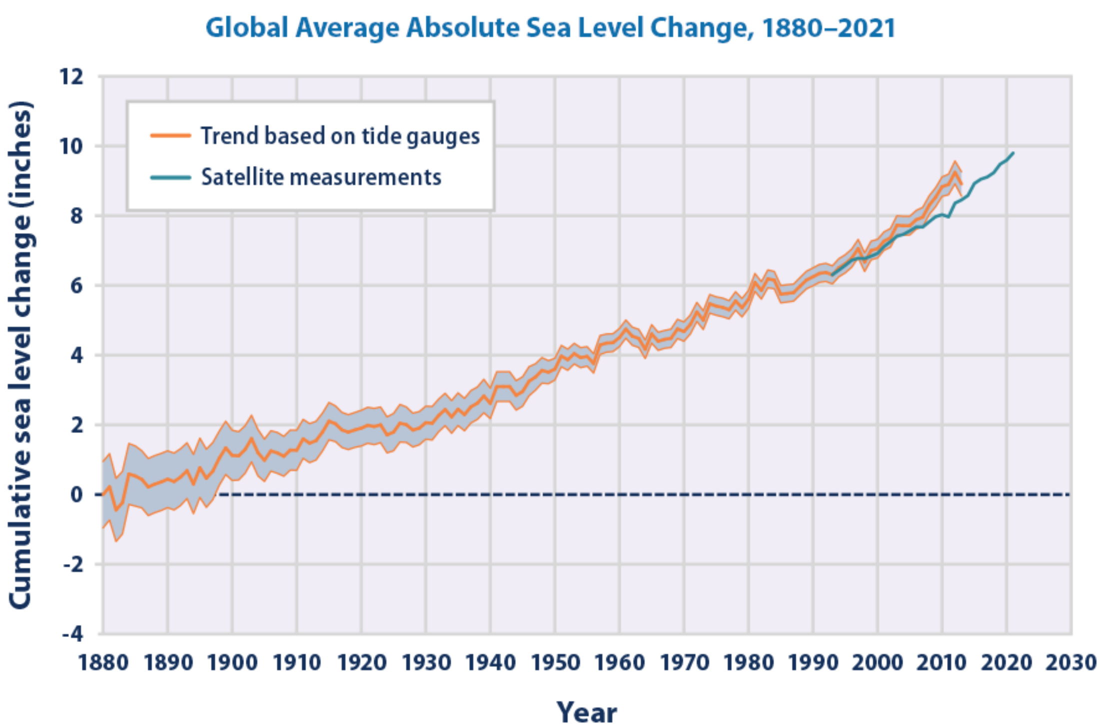


Image by EPA:
https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level; public domain

There is much more evidence of current climate change than is described above. The Earth's climate is changing. Temperatures are rising, snow and rainfall patterns are shifting, and more extreme climate events – like heavy rainstorms and record high temperatures – are already happening. Many of these observed changes are linked to the rising levels of carbon dioxide and other greenhouse gasses in our atmosphere.

Future Climate

Future climate is predicted using climate models. Climate models are complex. They use mathematical equations to characterize how energy and matter interact in different parts of the ocean, atmosphere, land. Once a climate model is set up, it can be tested by running the model from the present time backwards into the past. The model results are then compared with observed climate and weather conditions to see how well they match. This testing allows scientists to check the accuracy of the models and, if needed, revise its equations. Once a climate model is tested and performs well, its results for simulating future climate are also assumed to be accurate.

To predict climate in the future, models are run using different conditions and variables to represent different scenarios. Scenarios are possible stories about how quickly the human population will grow, how land will be used, how economies will evolve and affect climate policies, and the atmospheric conditions that would result for each storyline.

Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. They also show that human decisions and behavior we choose today will determine how dramatically the climate will change in the future.

The graphs and images below show the different pathways that climate could take based on greenhouse gas emissions and concentrations. Each different scenario produced by climate models is called a Representative Concentration Pathway (RCP). The trend lines of an RCP is dependent on the concentration of greenhouse gasses. More greenhouse gas emissions will result in warmer temperatures and sea level rise. Reduced greenhouse gas emissions will produce less extremes.

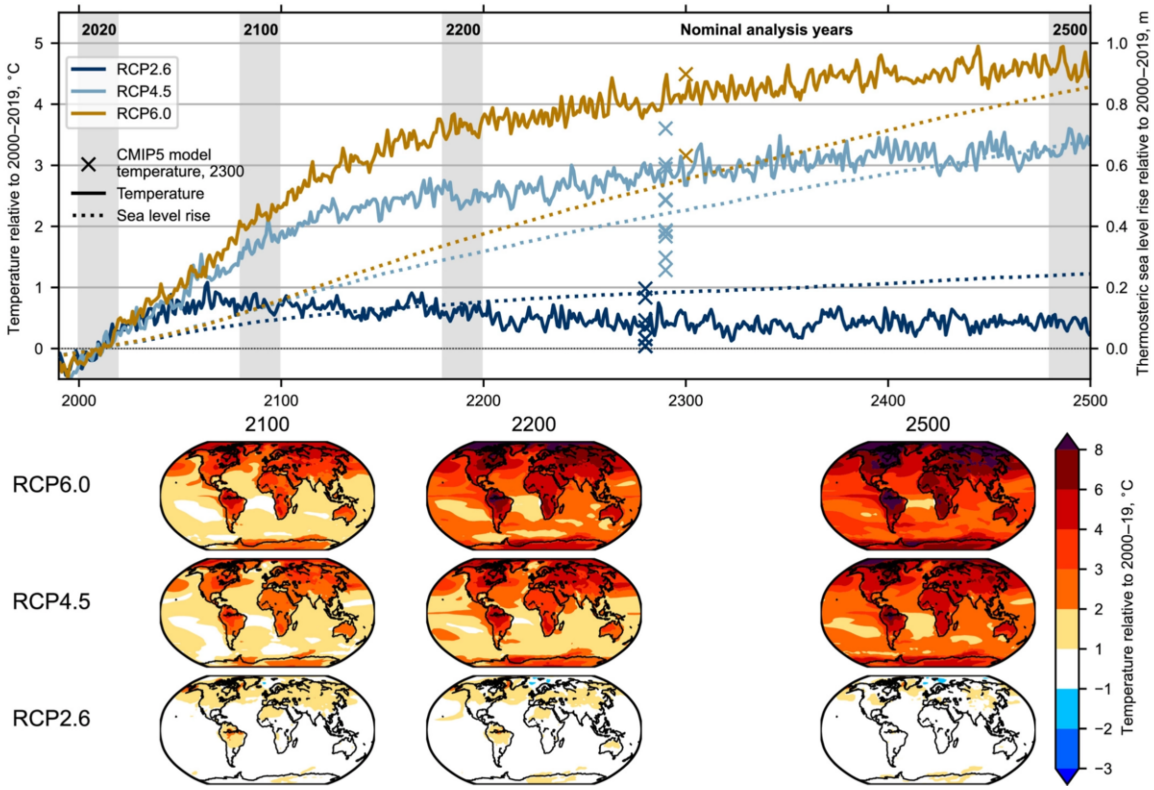


Image by Christopher Lyon, Erin E. Saupe, Christopher J. Smith, Daniel J. Hill, Andrew P. Beckerman, Lindsay C. Stringer, Robert Marchant, James McKay, Ariane Burke, Paul O'Higgins, Alexander M. Dunhill, Bethany J. Allen, Julien Riel-Salvatore, and Tracy Aze; https://en.wikipedia.org/wiki/File:Global_mean_near-surface_air_temperature_and_thermosteric_sea-level_rise_anomalies_relative_to_the_2000%E2%80%932019_mean_for_RCP_climate_change_scenarios.webp;