# CLIMATE CHANGE INDICATORS IN THE UNITED STATES 2016 FOURTH EDITION







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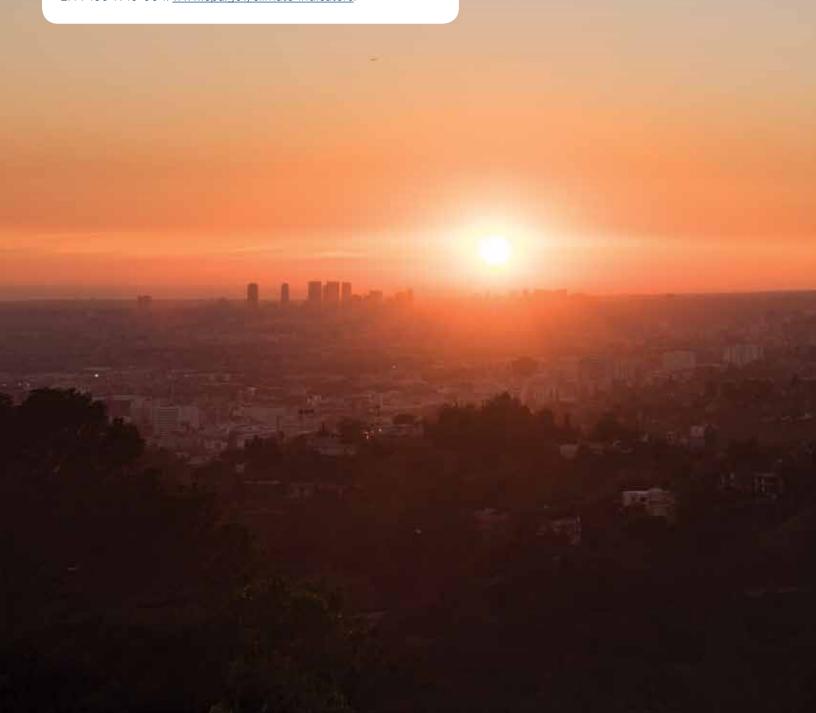
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# Introduction

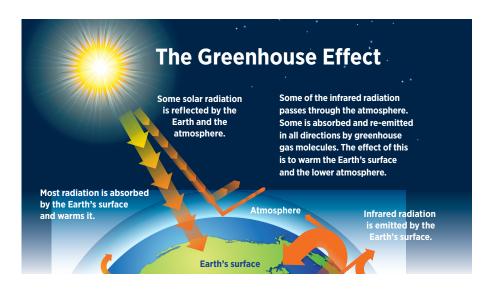
The Earth's climate is changing. Temperatures are rising, snow and rainfall patterns are shifting, and more extreme climate events—like heavy rainstorms and record-high temperatures—are already taking place. Scientists are highly confident that many of these observed changes can be linked to the levels of carbon dioxide and other greenhouse gases in our atmosphere, which have increased because of human activities.

#### **HOW IS THE CLIMATE CHANGING?**

Since the Industrial Revolution began in the 1700s, people have added a significant amount of greenhouse gases into the atmosphere, largely by burning fossil fuels to generate electricity, heat and cool buildings, and power vehicles—as well as by clearing forests. The major greenhouse gases that people have added to the atmosphere are carbon dioxide, methane, nitrous oxide, and fluorinated gases. When these gases are emitted into the atmosphere, many remain there for long time periods, ranging from a decade to thousands of years. Past emissions affect our atmosphere in the present day; current and future emissions will continue to increase the levels of these gases in our atmosphere for the foreseeable future.

"Greenhouse gases" got their name because they trap heat (energy) like a greenhouse in the lower part of the atmosphere (see "The Greenhouse Effect" below). As more of these gases are added to the atmosphere, more heat is trapped. This extra heat leads to higher air temperatures near the Earth's surface, alters weather patterns, and raises the temperature of the oceans.

These observed changes affect people and the environment in important ways. For example, sea levels are rising, glaciers are melting, and plant and animal life cycles are changing. These types of changes can bring about fundamental disruptions in ecosystems, affecting plant and animal populations, communities, and biodiversity. Such changes can also affect people's health and quality of life, including where people can live, what kinds of crops are most viable, what kinds of businesses can thrive in certain areas, and the condition of buildings and infrastructure. Some of these changes may be beneficial to certain people and places, as indicators like **Length of Growing Season** point out. Over time, though, many more of these changes will have negative consequences for people and society.<sup>1</sup>



#### What Is Climate Change?

Climate change refers to any substantial change in measures of climate (such as temperature or precipitation) lasting for an extended period (decades or longer). Natural factors have caused the climate to change during previous periods of the Earth's history, but human activities are the primary cause of the changes that are being observed now.

**Global warming** is a term often used interchangeably with the term "climate change," but they are not entirely the same thing. Global warming refers to an average increase in the temperature of the atmosphere near the Earth's surface. Global warming is just one aspect of global climate change, though a very important one.

#### Why Use Indicators?

One important way to track and communicate the causes and effects of climate change is through the use of indicators. An indicator represents the state or trend of certain environmental or societal conditions over a given area and a specified period of time. For example, long-term measurements of temperature in the United States and globally are used as an indicator to track and better understand the effects of changes in the Earth's climate.

# How Do the Indicators Relate to Climate Change?

All of the indicators in this report relate to either the causes or effects of climate change. Some indicators show trends that can be more directly linked to human-induced climate change than others. Collectively, the trends depicted in these indicators provide important evidence of "what climate change looks like."

#### **ABOUT THIS REPORT**

The U.S. Environmental Protection Agency (EPA) publishes this report to communicate information about the science and impacts of climate change, assess trends in environmental quality, and inform decision-making. *Climate Change Indicators in the United States, 2016*, is the fourth edition of a report first published by EPA in 2010. This report presents 37 indicators to help readers understand changes observed from long-term records related to the causes and effects of climate change, the significance of these changes, and their possible consequences for people, the environment, and society. While the indicators presented in this report do not cover all possible measures of the causes and effects of climate change, as might be found in the full body of scientific literature, they represent a wide-ranging set of indicators that show observed changes in the Earth's climate system and several climate-relevant impacts.

#### **About EPA's Indicators**

Each of EPA's 37 indicators covers a specific climate-related topic, such as **U.S. Greenhouse Gas Emissions**. Some indicators present a single measure or variable; others have multiple measures, reflecting different data sources or different ways to group, characterize, or zoom in on the data. EPA follows an established framework to identify data sets, select indicators, obtain independent expert review, and publish this report.

**Data sources:** All of EPA's indicators are based on peer-reviewed, publicly available data from government agencies, academic institutions, and other organizations. In addition to being published here, these data sets have been published in the scientific literature and in other government or academic reports. EPA also received input from scientists, researchers, and communications experts in nongovernmental and private sectors during the compilation of this report.

**Indicator selection:** EPA carefully screened and selected each indicator using a standard set of criteria that consider usefulness, data quality, and relevance to climate change. This process ensures that all indicators are based on credible data. For more information about EPA's indicator criteria and selection process, see the technical support document available at: www.epa.gov/climate-indicators.

**Expert review:** This report, along with all of EPA's climate change indicators and supporting documentation, was peer-reviewed by independent technical experts.

**Publication:** This report, the corresponding website, and the accompanying detailed technical documentation have been designed to ensure that the indicators are presented and documented clearly and transparently.

All of EPA's climate change indicators relate to either the causes or effects of climate change. Some indicators are more directly influenced by climate than others (e.g., indicators related to health outcomes), yet they all have met EPA's criteria and have a scientifically based relationship to climate. This report does not attempt to identify the *extent* to which climate change is causing a trend in an observed indicator. Connections between human activities, climate change, and observed indicators are explored in more detail elsewhere in the scientific literature.

EPA's indicators generally cover broad geographic scales and many years of data, as this is the most appropriate way to view trends relevant to climate change. After all, the Earth is a complex system, and there will always be natural variations from one year to the next—for example, a very warm year followed by a colder year. The Earth's climate also goes through other natural cycles that can play out over a period of several years or even decades. Thus, EPA's indicators present trends for as many years as the underlying data allow.

For more information, see "Frequently Asked Questions About EPA's Climate Change Indicators," available at: <a href="https://www.epa.gov/climate-indicators/frequent-questions">www.epa.gov/climate-indicators/frequent-questions</a>.

#### **How Is This Report Useful?**

Climate Change Indicators in the United States, 2016, is written with the primary goal of informing readers' understanding of climate change. It is also designed to be useful for the public, scientists, analysts, decision-makers, educators, and others who can use climate change indicators as a tool for:

- Effectively communicating relevant climate science information in a sound, transparent, and easy-to-understand way.
- Assessing trends in environmental quality, factors that influence the environment, and effects on ecosystems and society.
- Informing science-based decision-making.



#### A Roadmap to the Report

The indicators are grouped into six chapters: Greenhouse Gases, Weather and Climate, Oceans, Snow and Ice, Health and Society, and Ecosystems. Some chapters also include a "Community Connection," "Tribal Connection," or "A Closer Look" feature that highlights a specific region, data record, or area of interest. Several indicators highlight the important ways in which the observed changes can have implications for human health.

Each indicator in this report fills one or two pages, and contains:

- One or more graphics depicting changes over time.
- Background on how the indicator relates to climate change.
- What's Happening: Key points about what the indicator shows.
- About the Indicator: A description of the data source and how the indicator was developed.

Additional resources that can provide readers with more information appear at the end of the report (see Climate Change Resources on p. 84).

EPA's website provides a more complete version of each indicator, including more background information, additional graphs or maps in some cases, downloadable data, interactive maps and animations for selected indicators, and important notes to help readers interpret the data. EPA also compiles an accompanying **technical support document** containing more detailed information about each indicator, including data sources, data collection methods, calculations, statistical considerations, and sources of uncertainty. This document also describes EPA's approach and criteria for selecting indicators for the report. All of this information is available on EPA's website at: <a href="https://www.epa.gov/climate-indicators">www.epa.gov/climate-indicators</a>.

#### WHAT'S NEW IN 2016?

The 2016 report reflects previously reported indicators and has added the following new indicators and features:

- Seven new indicators: River Flooding, Coastal Flooding, Antarctic Sea Ice, Heat-Related Illnesses, West Nile Virus, Stream Temperature, and Marine Species Distribution.
- Three expanded indicators: Arctic Sea Ice was expanded to look at changes in the length of the melt season. Similarly, Snow Cover now examines changes in the length of the snow cover season. Heat-Related Deaths has a new graph that focuses on heat-related cardiovascular disease deaths, including trends for specific at-risk groups.
- **Updated indicators:** Nearly all indicators have been updated with additional years of data that have become available since the last report.
- Tribal connection: The report includes an example of stream temperature trends in the Pacific Northwest and highlights how changes may affect salmon, a tribally important resource.

#### **LOOKING AHEAD**

Indicators of climate change are expected to become even more numerous and to depict even clearer trends in the future. EPA will continue to work in partnership with coordinating bodies, such as the U.S. Global Change Research Program, and with other agencies, organizations, and individuals to collect and communicate useful data and to inform policies and programs based on this knowledge. As new and more comprehensive indicator data become available, EPA will continually update the indicators presented in this report.

#### Understanding the Connections Between Climate Change and Human Health

It can be tempting to think of climate change as something that affects other places, other people, or something in the distant future. However, climate change already poses a very real threat to the American people. One of the biggest concerns is its effect on human health.

Scientists' understanding of how climate change increases risks to human health has advanced significantly in recent years. In April 2016, the U.S. Global Change Research Program (USGCRP) published the largest-ever assessment of the state of the science.<sup>2</sup> Its conclusion: Every American is vulnerable to the health impacts associated with climate change.

As the impacts increase, and as we learn more about them and how best to track them over time, government agencies and communities are also finding new ways to respond to climate-related threats. In recognition of the growing body of evidence about the health risks of climate change, this edition of EPA's climate change indicators report includes new indicators on several health-related topics, along with a special section on the connections between climate change and health (beginning on p. 53). In addition, several indicators include boxes that highlight topics related to human health. These topics are highlighted with the following icon:

Note, however, that improved understanding of human health risks due to climate change does not necessarily correspond to increased long-term data for trend assessment. The USGCRP's Climate and Health Assessment identifies the importance of long-term environmental health data and monitoring.



## **Understanding Greenhouse Gases**

#### MAJOR GREENHOUSE GASES ASSOCIATED WITH HUMAN ACTIVITIES

The major greenhouse gases emitted into the atmosphere are carbon dioxide, methane, nitrous oxide, and fluorinated gases (see the table below). Some of these gases are produced almost entirely by human activities; others come from a combination of natural sources and human activities.

Many of the major greenhouse gases can remain in the atmosphere for tens to thousands of years after being released. They become globally mixed in the lower part of the atmosphere, called the troposphere (the first several miles above the Earth's surface), reflecting the combined contributions of emissions sources worldwide from the past and present. Due to this global mixing, the impact of emissions of these gases does not depend on where in the world they are emitted. Also, concentrations of these gases are similar regardless of where they are measured, as long as the measurement is far from any large sources or sinks of that gas.

Some other substances have much shorter atmospheric lifetimes (i.e., less than a year) but are still relevant to climate change. Important short-lived substances that affect the climate include water vapor, ozone in the troposphere, pollutants that lead to ozone formation, and aerosols (atmospheric particles) such as black carbon and sulfates. Water vapor, tropospheric ozone, and black carbon contribute to warming, while other aerosols produce a cooling effect. Because these substances are short-lived, their climate impact can be influenced by the location of their emissions, with concentrations varying greatly from place to place.

Several factors determine how strongly a particular greenhouse gas affects the Earth's climate. One factor is the length of time that the gas remains in the atmosphere. A second

factor is each gas's unique ability to absorb energy. By considering both of these factors, scientists calculate a gas's global warming potential, which measures how much a given amount of the greenhouse gas is estimated to contribute to global warming over a specific period of time (for example, 100 years) after being emitted. For purposes of comparison, global warming potential values are calculated in relation to carbon dioxide, which is assigned a global warming potential equal to 1. The table below describes sources, lifetimes, and global warming potentials for several important long-lived greenhouse gases.

#### Gases and Substances Included in This Report

This report focuses on most of the major, well-mixed greenhouse gases that contribute to the vast majority of warming of the climate. It also includes certain substances with shorter atmospheric lifetimes (i.e., less than a year) that are relevant to climate change. In addition to several long-lived greenhouse gases, the online version of the **Atmospher**ic Concentrations of Greenhouse Gases indicator tracks concentrations of ozone in the layers of the Earth's atmosphere, while Figure 2 of the Climate Forcing indicator on EPA's website shows the influence of a variety of short-lived substances.

#### **Major Long-Lived Greenhouse Gases and Their Characteristics**

Greenhouse gas	How it's produced	Average lifetime in the atmosphere	100-year global warming potential
Carbon dioxide	Emitted primarily through the burning of fossil fuels (oil, natural gas, and coal), solid waste, and trees and wood products. Changes in land use also play a role. Deforestation and soil degradation add carbon dioxide to the atmosphere, while forest regrowth takes it out of the atmosphere.	see below*	1
Methane	Emitted during the production and transport of oil and natural gas as well as coal. Methane emissions also result from livestock and agricultural practices and from the anaerobic decay of organic waste in municipal solid waste landfills.	12.4 years	28-36
Nitrous oxide	Emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.	121 years	265-298
Fluorinated gases	A group of gases that contain fluorine, including hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, among other chemicals. These gases are emitted from a variety of industrial processes and commercial and household uses and do not occur naturally. Sometimes used as substitutes for ozone-depleting substances such as chlorofluorocarbons (CFCs).	A few weeks to thousands of years	Varies (the highest is sulfur hexafluoride at 23,500)

This table shows 100-year global warming potentials, which describe the effects that occur over a period of 100 years after a particular mass of a gas is emitted. Global warming potentials and lifetimes come from the Intergovernmental Panel on Climate Change's Fifth Assessment Report.<sup>1</sup>

<sup>\*</sup> Carbon dioxide's lifetime cannot be represented with a single value because the gas is not destroyed over time, but instead moves among different parts of the ocean-atmosphere-land system. Some of the excess carbon dioxide is absorbed quickly (for example, by the ocean surface), but some will remain in the atmosphere for thousands of years, due in part to the very slow process by which carbon is transferred to ocean sediments.

# **Summary of Key Points**



**U.S. Greenhouse Gas Emissions.** In the United States, greenhouse gas emissions caused by human activities increased by 7 percent from 1990 to 2014. Since 2005, however, total U.S. greenhouse gas emissions have decreased by 7 percent. Electricity generation is the largest source of greenhouse gas emissions in the United States, followed by transportation.



**Global Greenhouse Gas Emissions.** Worldwide, net emissions of greenhouse gases from human activities increased by 35 percent from 1990 to 2010. Emissions of carbon dioxide, which account for about three-fourths of total emissions, increased by 42 percent over this period.



**Atmospheric Concentrations of Greenhouse Gases.** Concentrations of carbon dioxide and other greenhouse gases in the atmosphere have increased since the beginning of the industrial era. Almost all of this increase is attributable to human activities. Historical measurements show that the current global atmospheric concentrations of carbon dioxide are unprecedented compared with the past 800,000 years, even after accounting for natural fluctuations.



**Climate Forcing.** Climate forcing refers to a change in the Earth's energy balance, leading to either a warming or cooling effect over time. An increase in the atmospheric concentrations of greenhouse gases produces a positive climate forcing, or warming effect. From 1990 to 2015, the total warming effect from greenhouse gases added by humans to the Earth's atmosphere increased by 37 percent. The warming effect associated with carbon dioxide alone increased by 30 percent.



**U.S. and Global Temperature.** Average temperatures have risen across the contiguous 48 states since 1901. Average global temperatures show a similar trend, and all of the top 10 warmest years on record worldwide have occurred since 1998. Within the United States, temperatures in parts of the North, the West, and Alaska have increased the most.



**High and Low Temperatures**. Nationwide, unusually hot summer days (highs) have become more common over the last few decades. Unusually hot summer nights (lows) have become more common at an even faster rate. This trend indicates less "cooling off" at night. Although the United States has experienced many winters with unusually low temperatures, unusually cold winter temperatures have become less common—particularly very cold nights (lows).



**U.S. and Global Precipitation.** Total annual precipitation has increased over land areas in the United States and worldwide. Since 1901, precipitation has increased at an average rate of 0.08 inches per decade over land areas worldwide. However, shifting weather patterns have caused certain areas, such as the Southwest, to experience less precipitation than usual.



**Heavy Precipitation.** In recent years, a higher percentage of precipitation in the United States has come in the form of intense single-day events. The prevalence of extreme single-day precipitation events remained fairly steady between 1910 and the 1980s but has risen substantially since then. Nationwide, nine of the top 10 years for extreme one-day precipitation events have occurred since 1990.



**Tropical Cyclone Activity.** Tropical storm activity in the Atlantic Ocean, the Caribbean, and the Gulf of Mexico has increased during the past 20 years. Storm intensity is closely related to variations in sea surface temperature in the tropical Atlantic. However, changes in observation methods over time make it difficult to know for sure whether a longer-term increase in storm activity has occurred.



**River Flooding.** Increases and decreases in the frequency and magnitude of river flood events vary by region. Floods have generally become larger across parts of the Northeast and Midwest and smaller in the West, southern Appalachia, and northern Michigan. Large floods have become more frequent across the Northeast, Pacific Northwest, and parts of the northern Great Plains, and less frequent in the Southwest and the Rockies.



**Drought.** Over the period from 2000 through 2015, roughly 20 to 70 percent of the U.S. land area experienced conditions that were at least abnormally dry at any given time. However, this index has not been in use for long enough to compare with historical drought patterns.



A Closer Look: Temperature and Drought in the Southwest. The southwestern United States is particularly sensitive to changes in temperature and thus vulnerable to drought, as even a small decrease in water availability in this already arid region can stress natural systems and further threaten water supplies.



**Ocean Heat.** Three independent analyses show that the amount of heat stored in the ocean has increased substantially since the 1950s. Ocean heat content not only determines sea surface temperature, but also affects sea level and currents.



**Sea Surface Temperature.** Ocean surface temperatures increased around the world during the 20<sup>th</sup> century. Even with some year-to-year variation, the overall increase is clear, and sea surface temperatures have been consistently higher during the past three decades than at any other time since reliable observations began in the late 1800s.



**Sea Level.** When averaged over all of the world's oceans, sea level has risen at a rate of roughly six-tenths of an inch per decade since 1880. The rate of increase has accelerated in recent years to more than an inch per decade. Changes in sea level relative to the land vary by region. Along the U.S. coastline, sea level has risen the most along the Mid-Atlantic coast and parts of the Gulf coast, where some stations registered increases of more than 8 inches between 1960 and 2015. Sea level has decreased relative to the land in parts of Alaska and the Pacific Northwest.



A Closer Look: Land Loss Along the Atlantic Coast. As sea level rises, dry land and wetlands can turn into open water. Along many parts of the Atlantic coast, this problem is made worse by low elevations and land that is already sinking. Between 1996 and 2011, the coastline from Florida to New York lost more land than it gained.



**Coastal Flooding.** Flooding is becoming more frequent along the U.S. coastline as sea level rises. Nearly every site measured has experienced an increase in coastal flooding since the 1950s. The rate is accelerating in many locations along the East and Gulf coasts. The Mid-Atlantic region suffers the highest number of coastal flood days and has also experienced the largest increases in flooding.



**Ocean Acidity.** The ocean has become more acidic over the past few decades because of increased levels of atmospheric carbon dioxide, which dissolves in the water. Higher acidity affects the balance of minerals in the water, which can make it more difficult for certain marine animals to build their protective skeletons or shells.



**Arctic Sea Ice.** Part of the Arctic Ocean is covered by ice year-round. The area covered by ice is typically smallest in September, after the summer melting season. The annual minimum extent of Arctic sea ice has decreased over time, and in September 2012 it was the smallest ever recorded. The length of the melt season for Arctic ice has grown, and the ice has also become thinner, which makes it more vulnerable to further melting.



**Antarctic Sea Ice**. Antarctic sea ice extent in September and February has increased somewhat over time. The September maximum extent reached the highest level on record in 2014—about 7 percent larger than the 1981–2010 average. Slight increases in Antarctic sea ice are outweighed by the loss of sea ice in the Arctic during the same time period, however.



**Glaciers.** Glaciers in the United States and around the world have generally shrunk since the 1960s, and the rate at which glaciers are melting has accelerated over the last decade. The loss of ice from glaciers has contributed to the observed rise in sea level.



**Lake Ice.** Lakes in the northern United States are thawing earlier in spring compared with the early 1900s. All 14 lakes studied were found to be thawing earlier in the year, with thaw dates shifting earlier by up to 24 days over the past 110 years.



**Community Connection: Ice Breakup in Two Alaskan Rivers.** Regions in the far north are warming more quickly than other parts of the world. Two long-running contests on the Tanana and Yukon rivers in Alaska—where people guess the date when the river ice will break up in the spring—provide a century's worth of evidence revealing that the ice on these rivers is generally breaking up earlier in the spring than it once did.



**Snowfall.** Total snowfall—the amount of snow that falls in a particular location—has decreased in most parts of the country since widespread records began in 1930. One reason for this decline is that nearly 80 percent of the locations studied have seen more winter precipitation fall in the form of rain instead of snow.



**Snow Cover.** Snow cover refers to the area of land that is covered by snow at any given time. Between 1972 and 2015, the average portion of North America covered by snow decreased at a rate of about 3,300 square miles per year, based on weekly measurements taken throughout the year. There has been much year-to-year variability, however. The length of time when snow covers the ground has become shorter by nearly two weeks since 1972, on average.



**Snowpack.** The depth of snow on the ground (snowpack) in early spring decreased at more than 90 percent of measurement sites in the western United States between 1955 and 2016. Across all sites, snowpack depth declined by an average of 23 percent during this time period.





**Heat-Related Deaths.** Since 1979, more than 9,000 Americans were reported to have died as a direct result of heat-related illnesses such as heat stroke. The annual death rate is higher when accounting for deaths in which heat was reported as a contributing factor, including the interaction of heat and cardiovascular disease. People aged 65+ are a particular concern: a growing demographic group that is several times more likely to die from heat-related cardiovascular disease than the general population. Considerable year-to-year variability and certain limitations of the underlying data for this indicator make it difficult to determine whether the United States has experienced long-term trends in the number of deaths classified as "heat-related."



**Heat-Related Illnesses.** From 2001 to 2010, a total of about 28,000 heat-related hospitalizations were recorded across 20 states. Annual heat-related hospitalization rates ranged from fewer than one case per 100,000 people in some states to nearly four cases per 100,000 in others. People aged 65+ accounted for more heat-related hospitalizations than any other age group from 2001 to 2010, and males were hospitalized for heat-related illnesses more than twice as often as females.



**Heating and Cooling Degree Days.** Heating and cooling degree days measure the difference between outdoor temperatures and the temperatures that people find comfortable indoors. As the U.S. climate has warmed in recent years, heating degree days have decreased and cooling degree days have increased overall, suggesting that Americans need to use less energy for heating and more energy for air conditioning.



**Lyme Disease.** Lyme disease is a bacterial illness spread by ticks that bite humans. Tick habitat and populations are influenced by many factors, including climate. Nationwide, the rate of reported cases of Lyme disease has approximately doubled since 1991. The number and distribution of reported cases of Lyme disease have increased in the Northeast and upper Midwest over time, driven by multiple factors.



**West Nile Virus.** West Nile virus is spread by mosquitoes, whose habitat and populations are influenced by temperature and water availability. The incidence of West Nile virus neuroinvasive disease in the United States has varied widely from year to year and among geographic regions since tracking began in 2002. Variation in disease incidence is affected by climate and many other factors, and no obvious long-term trend can be detected yet through this limited data set.



**Length of Growing Season.** The length of the growing season for crops has increased in almost every state. States in the Southwest (e.g., Arizona and California) have seen the most dramatic increase. In contrast, the growing season has actually become shorter in a few southeastern states. The observed changes reflect earlier spring warming as well as later arrival of fall frosts.



**Ragweed Pollen Season.** Warmer temperatures and later fall frosts allow ragweed plants to produce pollen later into the year, potentially prolonging the allergy season for millions of people. The length of ragweed pollen season has increased at 10 out of 11 locations studied in the central United States and Canada since 1995. The change becomes more pronounced from south to north.





**Wildfires**. Of the 10 years with the largest acreage burned since 1983, nine have occurred since 2000. Fires burn more land in the western United States than in the East.



**Streamflow.** Changes in temperature, precipitation, snowpack, and glaciers can affect the rate of streamflow and the timing of peak flow. Over the last 75 years, minimum, maximum, and average flows have changed in many parts of the country—some higher, some lower. Most of the rivers and streams measured show peak winter-spring runoff happening at least five days earlier than it did in the mid-20<sup>th</sup> century.



**Stream Temperature**. Stream temperatures have risen throughout the Chesapeake Bay region—the area of focus for this indicator. From 1960 through 2014, water temperature increased at 79 percent of the stream sites measured in the region. Temperature has risen by an average of 1.2°F across all sites and 2.2°F at the sites where trends were statistically significant.



**Tribal Connection: Water Temperature in the Snake River.** Between 1960 and 2015, water temperatures increased by 1.4°F in the Snake River at a site in eastern Washington. Several species of salmon use the Snake River to migrate and spawn, and these salmon play an important role in the diet, culture, religion, and economy of the region's Native Americans.



**Great Lakes Water Levels.** Water levels in most of the Great Lakes appear to have declined in the last few decades. However, the most recent levels are all within the range of historical variation. Water levels in lakes are influenced by water temperature, which affects evaporation rates and ice formation.



**Bird Wintering Ranges.** Some birds shift their range or alter their migration habits to adapt to changes in temperature or other environmental conditions. Long-term studies have found that bird species in North America have shifted their wintering grounds northward by an average of more than 40 miles since 1966, with several species shifting by hundreds of miles.



**Marine Species Distribution**. The average center of biomass for 105 marine fish and invertebrate species along U.S. coasts shifted northward by about 10 miles between 1982 and 2015. These species also moved an average of 20 feet deeper. Shifts have occurred among several economically important fish and shellfish species. For example, American lobster, black sea bass, and red hake in the Northeast have moved northward by an average of 119 miles.



**Leaf and Bloom Dates.** Leaf growth and flower blooms are examples of natural events whose timing can be influenced by climate change. Observations of lilacs and honeysuckles in the contiguous 48 states suggest that first leaf dates and bloom dates show a great deal of year-to-year variability.



**Community Connection: Cherry Blossom Bloom Dates in Washington, D.C.** Peak bloom dates of the iconic cherry trees in Washington, D.C., recorded since the 1920s, indicate that cherry trees are blooming slightly earlier than in the past. Bloom dates are key to planning the Cherry Blossom Festival, one of the region's most popular spring attractions.







# **Greenhouse Gases**

Greenhouse gases from human activities are the most significant driver of observed climate change since the mid-20<sup>th</sup> century.¹ The indicators in this chapter characterize emissions of the major greenhouse gases resulting from human activities, the concentrations of these gases in the atmosphere, and how emissions and concentrations have changed over time. When comparing emissions of different gases, these indicators use a concept called "global warming potential" to convert amounts of other gases into carbon dioxide equivalents.

#### WHY DOES IT MATTER?

As greenhouse gas emissions from human activities increase, they build up in the atmosphere and warm the climate, leading to many other changes around the world—in the atmosphere, on land, and in the oceans. The indicators in other chapters of this report illustrate many of these changes. Such changes have both positive and negative effects on people, society, and the environment—including plants and animals. Because many of the major greenhouse gases stay in the atmosphere for tens to thousands of years after being released, their warming effects on the climate persist over a long time and can therefore affect both present and future generations.

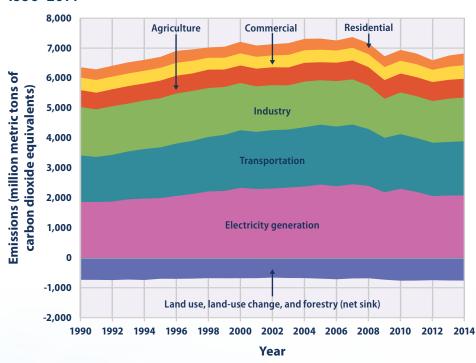


## **U.S.** Greenhouse Gas Emissions

This indicator describes emissions of greenhouse gases in the United States.

number of factors influence the quantities of greenhouse gases released into the atmosphere, including economic activity, population, consumption patterns, energy prices, land use, and technology. There are several ways to track these emissions, such as by measuring emissions directly, calculating emissions based on the amount of fuel that people burn, and estimating other activities and their associated emissions.

# U.S. Greenhouse Gas Emissions and Sinks by Economic Sector, 1990–2014



This figure shows greenhouse gas emissions (positive values) and sinks (negative values), by source, in the United States from 1990 to 2014. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents. All electric power emissions are grouped together in the "Electricity generation" sector, so other sectors such as "Residential" and "Commercial" show only non-electric sources, such as burning oil or gas for heating. The economic sectors shown here do not include emissions from U.S. territories outside the 50 states. Data source: U.S. EPA. 2016<sup>2</sup>

#### WHAT'S HAPPENING -

- In 2014, U.S. greenhouse gas emissions totaled 6,870 million metric tons (15.1 trillion pounds) of carbon dioxide equivalents. This 2014 total represents a 7-percent increase since 1990 but a 7-percent decrease since 2005.
- Among the various sectors of the U.S. economy, electricity generation (power plants) accounts for the largest share of emissions—31 percent of total greenhouse gas emissions since 1990. Transportation is the second-largest sector, accounting for 26 percent of emissions since 1990.
- Emissions sinks, the opposite of emissions sources, absorb carbon dioxide from the atmosphere. In 2014, 11 percent of U.S. greenhouse gas emissions were offset by net sinks resulting from land use and forestry practices. Growing forests remove carbon from the atmosphere, outweighing emissions from wildfires. Other carbon emissions and sinks result from crop practices, burning biofuels, or depositing yard trimmings and food scraps in landfills.

#### **ABOUT THE INDICATOR**

This indicator focuses on emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated gases. Data and analysis for this indicator come from EPA's annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. This indicator focuses on emissions associated with human activities, though some emissions and sinks from unmanaged lands are also included. Each greenhouse gas has a different lifetime (how long it stays in the atmosphere) and a different ability to trap heat in our atmosphere. To allow different gases to be compared and added together, emissions are converted into carbon dioxide equivalents using each gas's 100-year global warming potential. This analysis uses global warming potentials from the Intergovernmental Panel on Climate Change's Fourth Assessment Report. It starts in 1990, which is a common baseline year for global agreements to track and reduce greenhouse gas emissions. Other parts of this indicator available online track U.S. emissions by greenhouse gas, per capita, and per dollar of gross domestic product since 1990.



## **Global Greenhouse Gas Emissions**

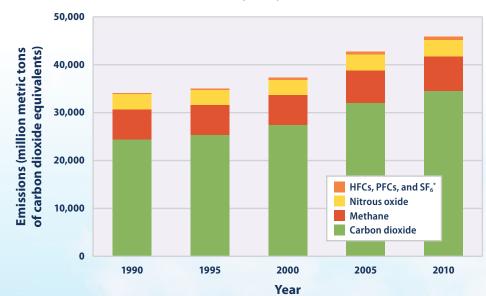
This indicator describes emissions of greenhouse gases worldwide.

ncreasing emissions of greenhouse gases due to human activities worldwide have led to a substantial increase in atmospheric concentrations of these gases (see the Atmospheric Concentrations of Greenhouse Gases indicator on p. 15). Every country around the world emits greenhouse gases into the atmosphere, meaning the root cause of climate change is truly global in scope. Some countries produce far more greenhouse gases than others, and several factors—such as economic activity, population, income level, land use, and climatic conditions—can influence a country's emissions levels. Tracking greenhouse gas emissions worldwide provides a global context for understanding the United States' and other nations' roles in climate change.

#### **ABOUT THE INDICATOR**

Data and analysis for this indicator come from the World Resources Institute's Climate Analysis Indicators Tool, which compiles data from peer-reviewed and internationally recognized greenhouse gas inventories developed by EPA and other government agencies worldwide. The Climate Analysis Indicators Tool includes estimates of emissions and sinks associated with land use and forestry activities, which come from global estimates compiled by the Food and Agriculture Organization of the United Nations. Each greenhouse gas has a different lifetime (how long it stays in the atmosphere) and a different ability to trap heat in our atmosphere. To allow different gases to be compared and added together, emissions are converted into carbon dioxide equivalents using each gas's global warming potential, which measures how much a given amount of the gas is estimated to contribute to global warming over a period of 100 years after being emitted. This analysis uses global warming potentials from the Intergovernmental Panel on Climate Change's Second Assessment Report. Other parts of this indicator available online track global greenhouse gas emissions by sector and region since 1990.

#### Global Greenhouse Gas Emissions by Gas, 1990-2010



This figure shows worldwide emissions of carbon dioxide, methane, nitrous oxide, and several fluorinated gases from 1990 to 2010. For consistency, emissions are expressed in million metric tons of carbon dioxide equivalents. These totals include emissions and sinks due to land-use change and forestry. Data sources: WRI, 2014;<sup>4</sup> FAO, 2014<sup>5</sup>

\* HFCs are hydrofluorocarbons, PFCs are perfluorocarbons, and SF<sub>6</sub> is sulfur hexafluoride.

#### ·WHAT'S HAPPENING

- In 2010, estimated worldwide emissions from human activities totaled nearly 46 billion metric tons of greenhouse gases, expressed as carbon dioxide equivalents. This represents a 35-percent increase from 1990. These numbers represent net emissions, which include the effects of land use and forestry.
- Between 1990 and 2010, global emissions of all major greenhouse gases increased. Net emissions of carbon dioxide increased by 42 percent, which is particularly important because carbon dioxide accounts for about three-fourths of total global emissions. Nitrous oxide emissions increased the least—9 percent—while emissions of methane increased by 15 percent. Emissions of fluorinated gases more than doubled.

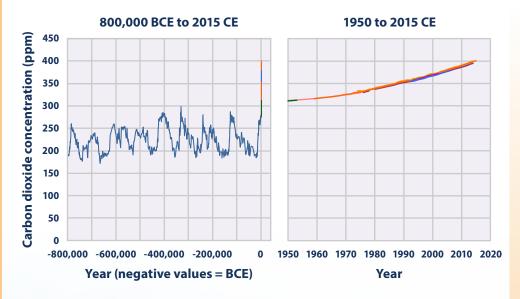


# **Atmospheric Concentrations of Greenhouse Gases**

This indicator describes how the levels of major greenhouse gases in the atmosphere have changed over time.

ince the Industrial Revolution began in the 1700s, people have added a substantial amount of heat-trapping greenhouse gases into the atmosphere by burning fossil fuels, cutting down forests, and conducting other activities (see the U.S. and Global Greenhouse Gas Emissions indicators on pp. 13 and 14). Many of these gases remain in the atmosphere for long time periods ranging from a decade to many millennia, which allows them to become well mixed throughout the global atmosphere. As a result of human activities, these gases are entering the atmosphere more quickly than they are being removed by chemical reactions or by emissions sinks, such as the oceans and vegetation, which absorb greenhouse gases from the atmosphere. Thus, their concentrations are increasing, which contributes to global warming.

#### **Global Atmospheric Concentrations of Carbon Dioxide Over Time**



This figure shows concentrations of carbon dioxide in the atmosphere from hundreds of thousands of years ago through 2015, measured in parts per million (ppm). The data come from a variety of historical ice core studies and recent air monitoring sites around the world. Each line represents a different data source. Data source: Compilation of 10 underlying datasets<sup>6</sup>

#### WHAT'S HAPPENING

- Global atmospheric concentrations of carbon dioxide have risen significantly over the last few hundred years.
- Historical measurements show that the current global atmospheric concentrations of carbon dioxide are unprecedented compared with the past 800,000 years.
- Since the beginning of the industrial era, concentrations of carbon dioxide have increased from an annual average of 280 ppm in the late 1700s to 401 ppm as measured at Mauna Loa in 2015—a 43-percent increase. This increase is due to human activities.

#### **ABOUT THE INDICATOR**

This indicator describes concentrations of greenhouse gases in the atmosphere. The graph above focuses on carbon dioxide, which accounts for the largest share of warming associated with human activities. Recent measurements come from monitoring stations around the world, while measurements of older air come from air bubbles trapped in layers of ice from Antarctica and Greenland. By determining the age of the ice layers and the concentrations of gases trapped inside, scientists can learn what the atmosphere was like thousands of years ago. Other parts of this indicator available online track global atmospheric concentrations of methane and nitrous oxide over the past 800,000 years and global atmospheric concentrations of selected halogenated gases and ozone over the last few decades. Ozone acts as a greenhouse gas in the lower atmosphere.

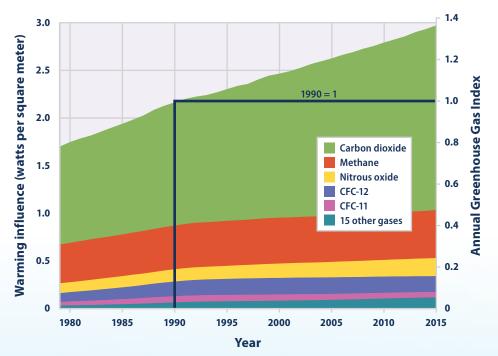


# **Climate Forcing**

This indicator measures the "radiative forcing" or heating effect caused by greenhouse gases in the atmosphere.

hen energy from the sun reaches the Earth, the planet absorbs some of this energy and radiates the rest back to space as heat. A variety of physical and chemical factors—some natural and some influenced by humans—can shift the balance between incoming and outgoing energy, which forces changes in the Earth's climate. These changes are measured by the amount of warming or cooling they can produce, which is called "radiative forcing." Changes that have a warming effect are called "positive" forcing, while those that have a cooling effect are called "negative" forcing. When positive and negative forces are out of balance, the result is a change in the Earth's average surface temperature. Greenhouse gases trap heat in the lower atmosphere and cause positive radiative forcing.

# Radiative Forcing Caused by Major Long-Lived Greenhouse Gases, 1979–2015



This figure shows the amount of radiative forcing caused by various greenhouse gases, based on the change in concentration of these gases in the Earth's atmosphere since 1750. Radiative forcing is calculated in watts per square meter, which represents the size of the energy imbalance in the atmosphere. On the right side of the graph, radiative forcing has been converted to the Annual Greenhouse Gas Index, which is set to a value of 1.0 for 1990. Data source: NOAA, 20168

#### WHAT'S HAPPENING-

- In 2015, the Annual Greenhouse Gas Index was 1.37, which represents a 37-percent increase in radiative forcing (a net warming influence) since 1990
- Of the greenhouse gases shown in the figure, carbon dioxide accounts for by far the largest share of radiative forcing since 1990, and its contribution continues to grow at a steady rate. Carbon dioxide alone would account for a 30-percent increase in radiative forcing since 1990.
- Although the overall Annual Greenhouse Gas Index continues to rise, the rate of increase has slowed somewhat since the baseline year 1990, in large part because methane concentrations have increased at a slower rate in recent years and because chlorofluorocarbon (CFC) concentrations have been declining as production of CFCs has been phased out globally.

#### **ABOUT THE INDICATOR**

This indicator measures the average total radiative forcing of 20 long-lived greenhouse gases, including carbon dioxide, methane, and nitrous oxide. The results were calculated by the National Oceanic and Atmospheric Administration based on measured concentrations of these gases in the atmosphere, compared with the concentrations that were present around 1750, before the Industrial Revolution began. Because each gas has a different ability to absorb and emit energy, this indicator converts the changes in greenhouse gas concentrations into a measure of the total radiative forcing (warming effect) caused by each gas. The right side of the graph shows the Annual Greenhouse Gas Index, which compares the radiative forcing for a particular year with the radiative forcing in 1990, which is a common baseline year for global agreements to track and reduce greenhouse gas emissions.





# **Weather and Climate**

Rising global average temperature is associated with widespread changes in weather patterns. Scientific studies indicate that extreme weather events such as heat waves and large storms are likely to become more frequent or more intense with human-induced climate change. This chapter focuses on observed changes in temperature, precipitation, storms, floods, and droughts.

#### WHY DOES IT MATTER?

Long-term changes in climate can directly or indirectly affect many aspects of society in potentially disruptive ways. For example, warmer average temperatures could increase air conditioning costs and affect the spread of diseases like Lyme disease, but could also improve conditions for growing some crops. More extreme variations in weather are also a threat to society. More frequent and intense extreme heat events can increase illnesses and deaths, especially among vulnerable populations, and damage some crops. While increased precipitation can replenish water supplies and support agriculture, intense storms can damage property; cause loss of life and population displacement; and temporarily disrupt essential services such as transportation, telecommunications, energy, and water supplies.

#### **WEATHER AND CLIMATE**

**Weather** is the state of the atmosphere at any given time and place. Most of the weather that affects people, agriculture, and ecosystems takes place in the lower layer of the atmosphere. Familiar aspects of weather include temperature, precipitation, clouds, and wind that people experience throughout the course of a day. Severe weather conditions include hurricanes, tornadoes, blizzards, and droughts.

**Climate** is the long-term average of the weather in a given place. While the weather can change in minutes or hours, a change in climate is something that develops over longer periods of decades to centuries. Climate is defined not only by average temperature and precipitation but also by the type, frequency, duration, and intensity of weather events such as heat waves, cold spells, storms, floods, and droughts.

While the concepts of climate and weather are often confused, it is important to understand the difference. For example, the eastern United States experienced a cold and snowy winter in 2014/2015, but this short-term regional weather phenomenon does not negate the long-term rise in national and global temperatures, sea level, or other climate indicators.



# **U.S. and Global Temperature**

This indicator describes trends in average surface temperature for the United States and the world.

armer temperatures are one of the most direct signs that the climate is changing. Concentrations of heat-trapping greenhouse gases are increasing in the Earth's atmosphere (see the Atmospheric Concentrations of Greenhouse Gases indicator on p. 15). In response, average temperatures at the Earth's surface are increasing and are expected to continue rising. Because climate change can shift the wind patterns and ocean currents that drive the world's climate system, however, some areas are warming more than others, and some have experienced cooling.

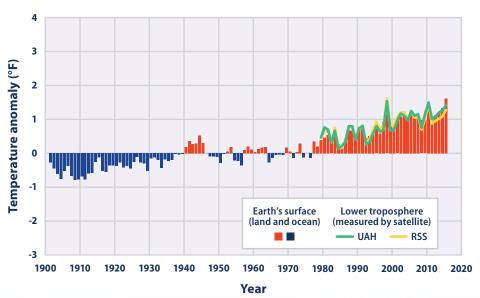
#### **ABOUT THE INDICATOR**

This indicator is based on daily temperature records from thousands of long-term weather monitoring stations, which have been compiled by the National Oceanic and Atmospheric Administration's National Centers for Environmental Information. The indicator was developed by calculating annual anomalies, or differences, compared with the average temperature from 1901 to 2000. For example, an anomaly of +2.0 degrees means the average temperature was 2 degrees higher than the long-term average. Daily, monthly, and annual anomalies have been calculated for each weather station. Global anomalies have been determined by dividing the world into a grid, averaging the data for each cell of the grid, and then averaging the grid cells together. For the map, anomalies have been averaged together and compared over time within small regions called climate divisions. The online version of this indicator also includes a graph of annual temperature anomalies for the contiguous 48 states since 1901. Hawaii and U.S. territories are not included, due to limitations in available data.

#### WHAT'S HAPPENING-

 Worldwide, 2015 was the warmest year on record and 2006–2015 was the warmest decade on record since thermometer-based observations began. Global average surface temperature has risen at an average rate of 0.15°F per decade since 1901.

#### **Temperatures Worldwide, 1901–2015**



This figure shows how annual average temperatures worldwide have changed since 1901. Surface data come from a combined set of land-based weather stations and sea surface temperature measurements. Satellite measurements cover the lower troposphere, which is the lowest level of the Earth's atmosphere. "UAH" and "RSS" represent two different methods of analyzing the original satellite measurements. This graph uses the 1901–2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time. Data source: NOAA, 2016<sup>1</sup>