OCEANS

Covering about 70 percent of the Earth's surface, the world's oceans have a two-way relationship with weather and climate. The oceans influence the weather on local to global scales, while changes in climate can fundamentally alter many properties of the oceans. This chapter examines how some of these important characteristics of the oceans have changed over time.

WHY DOES IT MATTER?

As greenhouse gases trap more energy from the sun, the oceans are absorbing more heat, resulting in an increase in sea surface temperatures and rising sea level. Changes in ocean temperatures and currents brought about by climate change will lead to alterations in climate patterns around the world. For example, warmer waters may promote the development of stronger storms in the tropics, which can cause property damage and loss of life. The impacts associated with sea level rise and stronger storms are especially relevant to coastal communities.

Although the oceans help reduce climate change by storing large amounts of carbon dioxide, increasing levels of dissolved carbon are changing the chemistry of seawater and making it more acidic. Increased ocean acidity makes it more difficult for certain organisms, such as corals and shellfish, to build their skeletons and shells. These effects, in turn, could substantially alter the biodiversity and productivity of ocean ecosystems.

Changes in ocean systems generally occur over much longer time periods than in the atmosphere, where storms can form and dissipate in a single day. Interactions between the oceans and atmosphere occur slowly over many months to years, and so does the movement of water within the oceans, including the mixing of deep and shallow waters. Thus, trends can persist for decades, centuries, or longer. For this reason, even if greenhouse gas emissions were stabilized tomorrow, it would take many more years—decades to centuries—for the oceans to adjust to changes in the atmosphere and the climate that have already occurred.

Summary of Key Points

Ocean Heat. Three separate 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 over the 20th century. Even with some year-to-year variation, the overall increase is clear, and sea surface temperatures have been 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 the world's oceans, sea level has increased 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 2013. Sea level has decreased relative to the land in parts of Alaska and the Northwest.

A Closer Look: Land Loss Along the Atlantic Coast. As sea level rises, dry land and wetland 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.

Ocean Acidity. The ocean has become more acidic over the past few centuries 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 skeletons and shells.

Ocean Heat

This indicator describes trends in the amount of heat stored in the world's oceans.

KEY POINTS

- In three different data analyses, the long-term trend shows that the oceans have become warmer since 1955 (see Figure 1).
- Although concentrations of greenhouse gases have risen at a relatively steady rate over the past few decades (see the Atmospheric Concentrations of Greenhouse Gases indicator on p. 20), the rate of change in ocean heat content can vary from year to year (see Figure 1). Year-to-year changes are influenced by events such as volcanic eruptions and recurring ocean-atmosphere patterns such as El Niño.

When sunlight reaches the Earth's surface, the world's oceans absorb some of this energy and store it as heat. This heat is initially absorbed at the surface, but some of it eventually spreads to deeper waters. Currents also move this heat around the world. Water has a much higher heat capacity than air, meaning the oceans can absorb larger amounts of heat energy with only a slight increase in temperature.

The total amount of heat stored by the oceans is called "ocean heat content," and measurements of water temperature reflect the amount of heat in the water at a particular time and location. Ocean temperature plays an important role in the Earth's climate system—particularly sea surface temperature (see the Sea Surface Temperature indicator on p. 48)—because heat from ocean surface waters provides energy for storms and thereby influences weather patterns.

Higher greenhouse gas concentrations are trapping more energy from the sun. Because changes in ocean systems occur over centuries, the oceans have not yet warmed as much as the atmosphere, even though they have absorbed more than 90 percent of the Earth's extra heat since 1955.[1,2] If not for the large heat-storage capacity provided by the oceans, the atmosphere would grow warmer more rapidly.[3] Increased heat absorption also changes ocean currents because many currents are driven by differences in temperature, which cause differences in density. These currents influence climate patterns and sustain ecosystems that depend on certain temperature ranges.

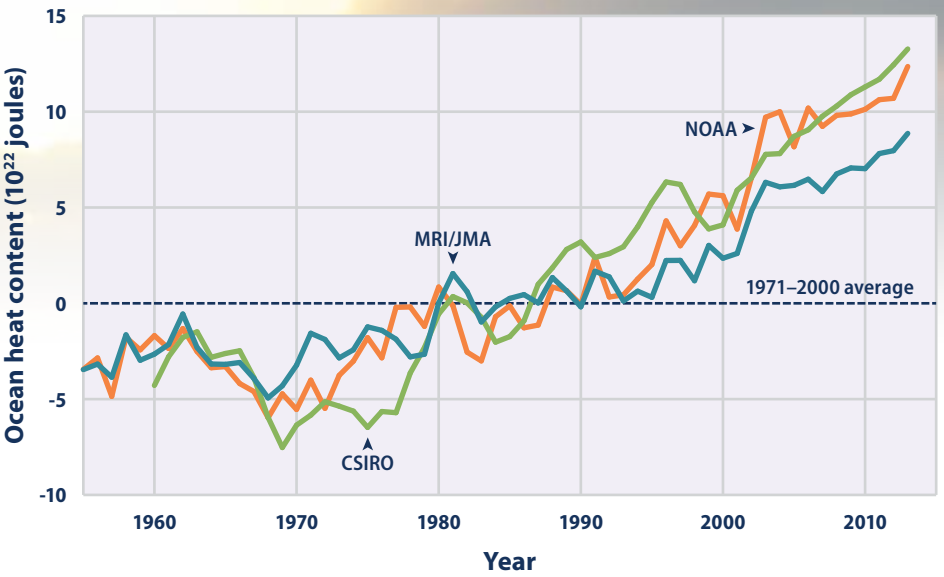
Because water expands slightly as it gets warmer, an increase in ocean heat content will also increase the volume of water in the ocean, which is one cause of the observed increases in sea level (see the Sea Level indicator on p. 50).

ABOUT THE INDICATOR

This indicator shows trends in global ocean heat content from 1955 to 2013. These data are available for the top 700 meters of the ocean (nearly 2,300 feet), which accounts for just under 20 percent of the total volume of water in the world's oceans. The indicator measures ocean heat content in joules, which are units of energy.

The National Oceanic and Atmospheric Administration has calculated changes in ocean heat content based on measurements of ocean temperatures around the world at different depths. These measurements come from a variety of instruments deployed from ships and airplanes and, more recently, underwater robots. Thus, the data must be carefully adjusted to account for differences among measurement techniques and data collection programs. Figure 1 shows three independent interpretations of essentially the same underlying data.

Figure 1. Ocean Heat Content, 1955–2013



This figure shows changes in ocean heat content between 1955 and 2013. Ocean heat content is measured in joules, a unit of energy, and compared against the 1971–2000 average, which is set at zero for reference. Choosing a different baseline period would not change the shape of the data over time. The lines were independently calculated using different methods by three agencies: the National Oceanic and Atmospheric Administration (NOAA), Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), and Japan Meteorological Agency's Meteorological Research Institute (MRI/JMA). For reference, an increase of 5 units on this graph (5 x 10^{22} joules) is equal to approximately 100 times the total amount of energy used by all the people on Earth in a year.[4]

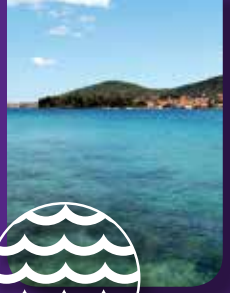
Data sources: CSIRO, 2014;[5] MRI/JMA, 2014;[6] NOAA, 2014[7]

INDICATOR NOTES

Data must be carefully reconstructed and filtered for biases because of different data collection techniques and uneven sampling over time and space. Various methods of correcting the data have led to slightly different versions of the ocean heat trend line. Scientists continue to compare their results and improve their estimates over time. They also test their ocean heat estimates by looking at corresponding changes in other properties of the ocean. For example, they can check to see whether observed changes in sea level match the amount of sea level rise that would be expected based on the estimated change in ocean heat.

DATA SOURCES

Data for this indicator were collected by the National Oceanic and Atmospheric Administration and other organizations around the world. The data were analyzed independently by researchers at the National Oceanic and Atmospheric Administration, Australia's Commonwealth Scientific and Industrial Research Organisation, and the Japan Meteorological Agency's Meteorological Research Institute.



Sea Surface Temperature

This indicator describes global trends in sea surface temperature.

KEY POINTS

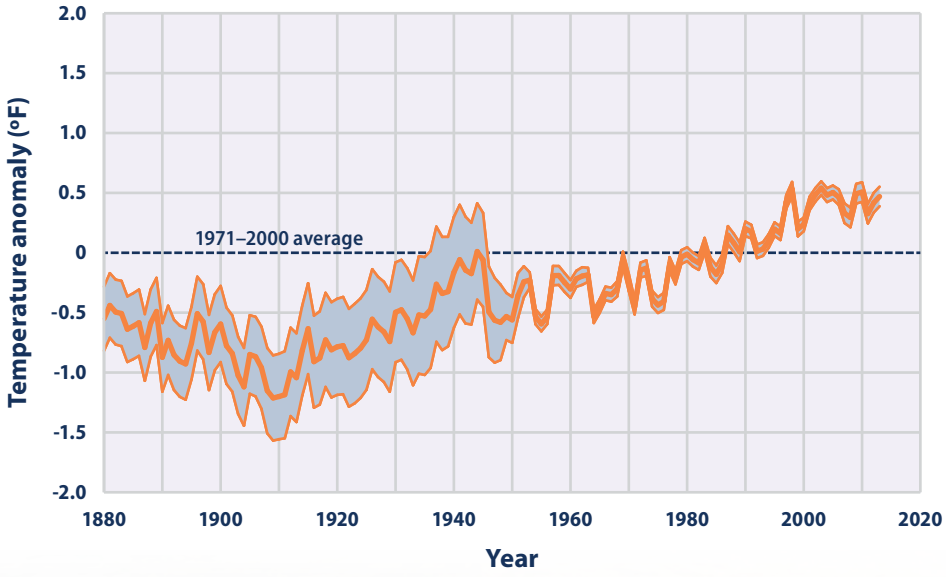
- Sea surface temperature increased over the 20th century and continues to rise. From 1901 through 2013, temperatures rose at an average rate of 0.13°F per decade (see Figure 1).
- Sea surface temperatures have been higher during the past three decades than at any other time since reliable observations began in 1880 (see Figure 1).
- Increases in sea surface temperature have largely occurred over two key periods: between 1910 and 1940, and from about 1970 to the present. Sea surface temperatures appear to have cooled between 1880 and 1910 (see Figure 1).
- Changes in sea surface temperature vary regionally. While most parts of the world's oceans have seen temperatures rise, a few areas have actually experienced cooling—for example, parts of the North Atlantic (see Figure 2).

Sea surface temperature—the temperature of the water at the ocean surface—is an important physical attribute of the world's oceans. The surface temperature of the world's oceans varies mainly with latitude, with the warmest waters generally near the equator and the coldest waters in the Arctic and Antarctic regions. As the oceans absorb more heat, sea surface temperatures will increase and the ocean circulation patterns that transport warm and cold water around the globe will change.

Changes in sea surface temperature can alter marine ecosystems in several ways. For example, variations in ocean temperature can affect what species of plants, animals, and microbes are present in a location, alter migration and breeding patterns, threaten sensitive ocean life such as corals, and change the frequency and intensity of harmful algal blooms such as "red tide."[8] Over the long term, increases in sea surface temperature could also reduce the circulation patterns that bring nutrients from the deep sea to surface waters. Changes in reef habitat and nutrient supply could dramatically alter ocean ecosystems and lead to declines in fish populations, which in turn could affect people who depend on fishing for food or jobs.[9]

Because the oceans continuously interact with the atmosphere, sea surface temperature can also have profound effects on global climate. Increases in sea surface temperature have led to an increase in the amount of atmospheric water vapor over the oceans.[10] This water vapor feeds weather systems that produce precipitation, increasing the risk of heavy rain and snow (see the Heavy Precipitation and Tropical Cyclone Activity indicators on pp. 36 and 42). Changes in sea surface temperature can also shift storm tracks, potentially contributing to droughts in some areas.[11]

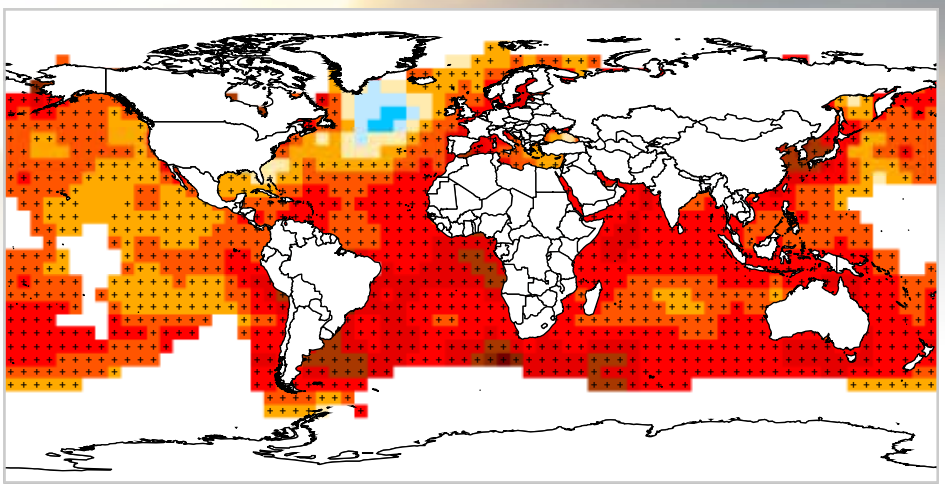
Figure 1. Average Global Sea Surface Temperature, 1880–2013

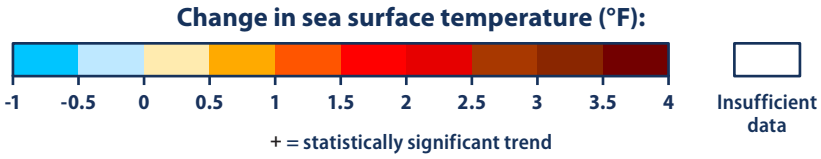


This graph shows how the average surface temperature of the world's oceans has changed since 1880. This graph uses the 1971 to 2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time. The shaded band shows the range of uncertainty in the data, based on the number of measurements collected and the precision of the methods used.

Data source: NOAA, 2014[12]

Figure 2. Change in Sea Surface Temperature, 1901–2012





This map shows how average sea surface temperatures around the world changed between 1901 and 2012. It is based on a combination of direct measurements and satellite measurements. A black "+" symbol in the middle of a square on the map means the trend shown is statistically significant. White areas did not have enough data to calculate reliable long-term trends.

Data source: IPCC, 2013[13]

ABOUT THE INDICATOR

This indicator tracks average global sea surface temperature from 1880 through 2013. It also includes a map to show how change in sea surface temperature has varied across the world's oceans since 1901.

Techniques for measuring sea surface temperature have evolved since the 1800s. For instance, the earliest data were collected by inserting a thermometer into a water sample collected by lowering a bucket from a ship. Today, temperature measurements are collected more systematically from ships, as well as at stationary and drifting buoys.

The National Oceanic and Atmospheric Administration has carefully reconstructed and filtered the data in Figure 1 to correct for biases in the different collection techniques and to minimize the effects of sampling changes over various locations and times. The data are shown as anomalies, or differences, compared with the average sea surface temperature from 1971 to 2000. The map in Figure 2 was developed by the Intergovernmental Panel on Climate Change, which calculated long-term trends based on a collection of published studies.

INDICATOR NOTES

Both components of this indicator are based on instrumental measurements of surface water temperature. Due to denser sampling and improvements in sampling design and measurement techniques, newer data are more precise than older data. The earlier trends shown by this indicator have less certainty because of lower sampling frequency and less precise sampling methods, as shown by the width of the blue shaded band in Figure 1.

DATA SOURCES

Data for Figure 1 were provided by the National Oceanic and Atmospheric Administration's National Climatic Data Center and are available online at: www.ncdc.noaa.gov/ersst. These data were reconstructed from measurements of water temperature, which are available from the National Oceanic and Atmospheric Administration at: http://icoads.noaa.gov/products.html. Figure 2 comes from the Intergovernmental Panel on Climate Change's Fifth Assessment Report (www.ipcc.ch/report/ar5/wg1), which gathers data from a variety of studies that provide the best available information about climate change.

Sea Level

This indicator describes how sea level has changed over time. The indicator describes two types of sea level changes: absolute and relative.

KEY POINTS

- After a period of approximately 2,000 years of little change (not shown here), global average sea level rose throughout the 20th century, and the rate of change has accelerated in recent years.[14] When averaged over all the world's oceans, absolute sea level increased at an average rate of 0.06 inches per year from 1880 to 2012 (see Figure 1). Since 1993, however, average sea level has risen at a rate of 0.11 to 0.12 inches per year—roughly twice as fast as the long-term trend.
- Relative sea level rose along much of the U.S. coastline between 1960 and 2013, particularly the Mid-Atlantic coast and parts of the Gulf coast, where some stations registered increases of more than 8 inches (see Figure 2). Meanwhile, relative sea level fell at some locations in Alaska and the Pacific Northwest. At those sites, even though absolute sea level has risen, land elevation has risen more rapidly.
- While absolute sea level has increased steadily overall, particularly in recent decades, regional trends vary, and absolute sea level has decreased in some places.[15] Relative sea level also has not risen uniformly because of regional and local changes in land movement and long-term changes in coastal circulation patterns.

As the temperature of the Earth changes, so does sea level. Temperature and sea level are linked for two main reasons:

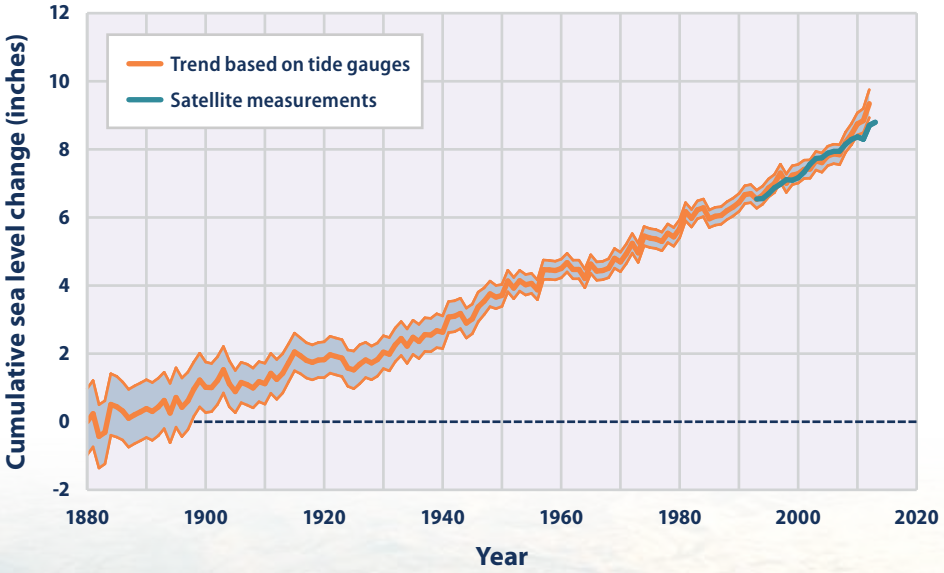
1. Changes in the volume of water and ice on land (namely glaciers and ice sheets) can increase or decrease the volume of water in the ocean (see the Glaciers indicator on p. 60).
2. As water warms, it expands slightly—an effect that is cumulative over the entire depth of the oceans (see the Ocean Heat indicator on p. 46).

Changing sea levels can affect human activities in coastal areas. Rising sea level inundates low-lying wetlands and dry land, erodes shorelines, contributes to coastal flooding, and increases the flow of salt water into estuaries and nearby groundwater aquifers. Higher sea level also makes coastal infrastructure more vulnerable to damage from storms.

The sea level changes that affect coastal systems involve more than just expanding oceans, however, because the Earth's continents can also rise and fall relative to the oceans. Land can rise through processes such as sediment accumulation (the process that built the Mississippi River delta) and geological uplift (for example, as glaciers melt and the land below is no longer weighed down by heavy ice). In other areas, land can sink because of erosion, sediment compaction, natural subsidence (sinking due to geologic changes), or engineering projects that prevent rivers from naturally depositing sediments along their banks. Changes in ocean currents such as the Gulf Stream can also affect sea levels by pushing more water against some coastlines and pulling it away from others, raising or lowering sea levels accordingly.

Scientists account for these types of changes by measuring sea level change in two different ways. *Relative* sea level change is how the height of the ocean rises or falls relative to the land at a particular location. In contrast, *absolute* sea level change refers to the height of the ocean surface above the center of the earth, without regard to whether nearby land is rising or falling.

Figure 1. Global Average Absolute Sea Level Change, 1880–2013



This graph shows cumulative changes in sea level for the world's oceans since 1880, based on a combination of long-term tide gauge measurements and recent satellite measurements. This figure shows average absolute sea level change, which refers to the height of the ocean surface, regardless of whether nearby land is rising or falling. Satellite data are based solely on measured sea level, while the long-term tide gauge data include a small correction factor because the size and shape of the oceans are changing slowly over time. (On average, the ocean floor has been gradually sinking since the last Ice Age peak, 20,000 years ago.) The shaded band shows the likely range of values, based on the number of measurements collected and the precision of the methods used.

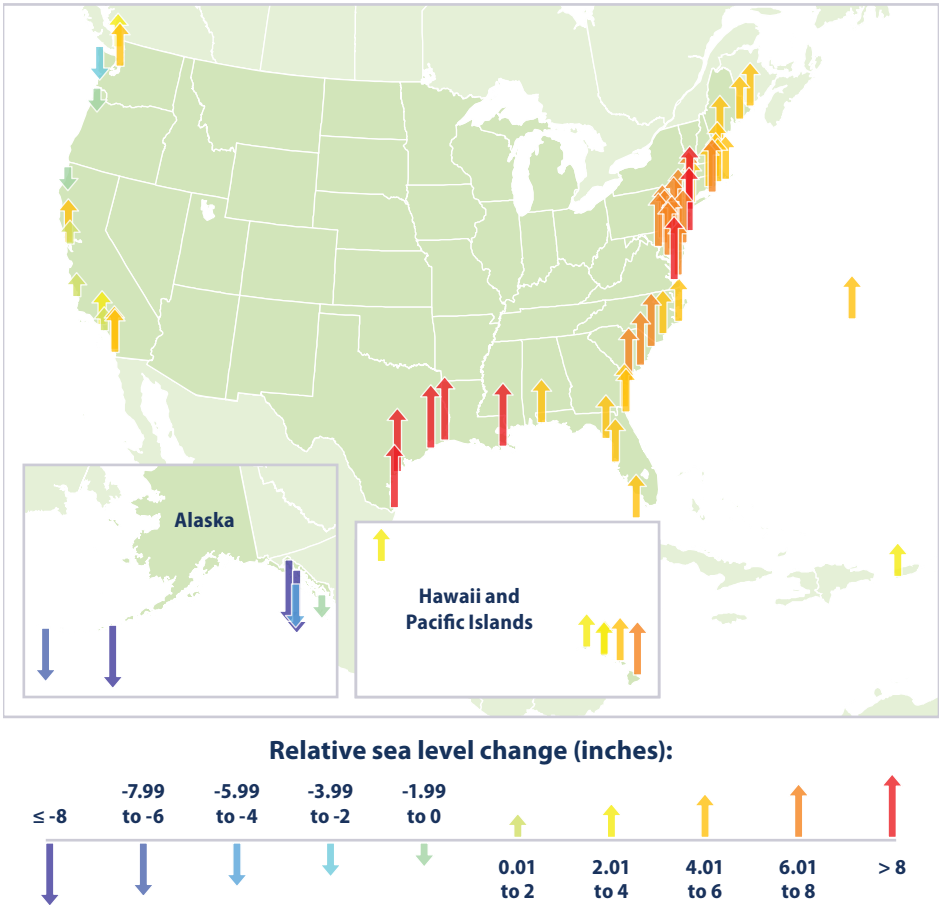
Data sources: CSIRO, 2013;[16] NOAA, 2014[17]

ABOUT THE INDICATOR

This indicator presents trends in sea level based on measurements from tide gauges and from satellites that orbit the Earth. Tide gauges measure relative sea level change at points along the coast, while satellite instruments measure absolute sea level change over nearly the entire ocean surface. Many tide gauges have collected data for more than 100 years, while satellites have collected data since the early 1990s.

Figure 1 shows annual absolute sea level change averaged over the entire Earth's ocean surface. The long-term trend is based on tide gauge data that have been adjusted to show absolute global trends through calibration with recent satellite data. This long-term data set has been calculated through 2012, while satellite data are now available through the end of 2013. Figure 2 shows trends at a more local scale, highlighting the 1960 to 2013 change in relative sea level at 67 tide gauges along the Atlantic, Pacific, and Gulf coasts of the United States.

Figure 2. Relative Sea Level Change Along U.S. Coasts, 1960–2013



This map shows cumulative changes in relative sea level from 1960 to 2013 at tide gauge stations along U.S. coasts. Relative sea level reflects changes in sea level as well as land elevation.

Data source: NOAA, 2014[18]

INDICATOR NOTES

Relative sea level trends represent a combination of absolute sea level change and any local land movement. Tide gauge measurements such as those in Figure 2 generally cannot distinguish between these two different influences without an accurate measurement of vertical land motion nearby.

Some changes in relative and absolute sea level can be due to multi-year cycles such as El Niño and La Niña, which affect coastal ocean temperatures, salt content, wind patterns, atmospheric pressure (and thus storm tracks), and currents. Obtaining a reliable trend can require many years of data, which is why the satellite record in Figure 1 has been supplemented with a longer-term reconstruction based on tide gauge measurements.

DATA SOURCES

Absolute sea level trends were provided by Australia's Commonwealth Scientific and Industrial Research Organisation and the National Oceanic and Atmospheric Administration. These data are based on measurements collected by satellites and tide gauges. Relative sea level data are available from the National Oceanic and Atmospheric Administration, which publishes an interactive online map (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml) with links to detailed data for each tide gauge.

Land Loss Along the Atlantic Coast

KEY POINTS

- Roughly 20 square miles of dry land and wetland were converted to open water along the Atlantic coast between 1996 and 2011. (For reference, Manhattan is 33 square miles.) More of this loss occurred in the Southeast than in the Mid-Atlantic (see Figure 1).
- The data suggest that at least half of the land lost since 1996 has been tidal wetland. The loss of dry land appears to be larger than the loss of non-tidal wetland (see Figure 2).

Rising sea level tends to make headlines during extreme events, like the storm surge that caused billions of dollars in damage during Hurricane Sandy in 2012. Yet rising sea level can also cause permanent changes in the landscape when it inundates (submerges) low-lying land. The Atlantic coast is particularly vulnerable because of low elevations and sinking shorelines.

The loss of coastal land can affect a large number of people, as nearly 10 million Americans live in a coastal floodplain.[19] Coastal ecosystems are also at risk. These environments provide habitat for many kinds of plants and animals, as well as services that ensure people's well-being, ranging from food production to recreation. Coastal wetlands provide valuable nursery, feeding, breeding, staging, and resting areas for many fish, shellfish, mammals, and birds, and they can buffer coastal areas against storm and wave damage.

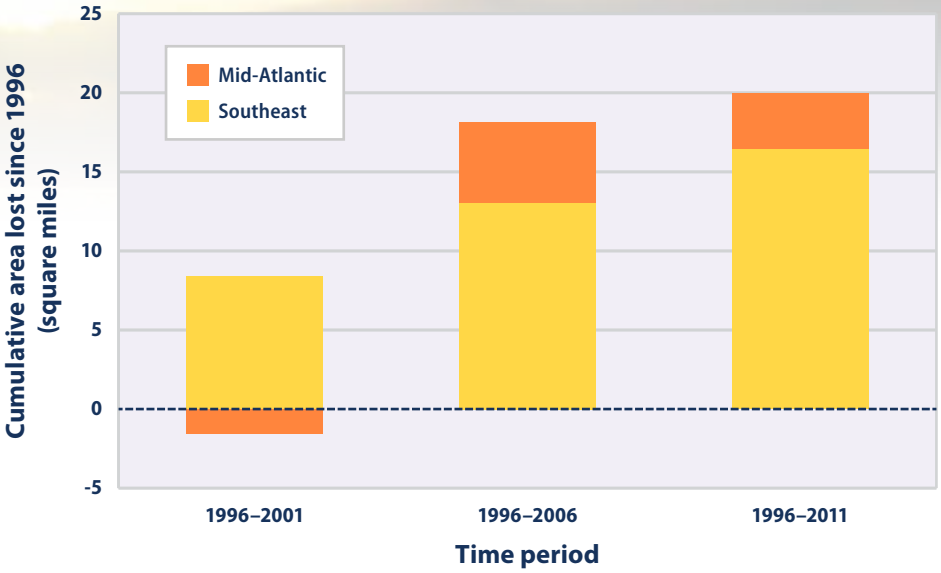
As sea level rises, dry land can turn into wetland or open water. Existing wetlands can be threatened, too, as salt marshes, mangrove forests, and other coastal wetlands are at risk of being converted to open water.

The Sea Level indicator (p. 50) shows that sea level is rising overall in connection with climate change, but the rate of change varies by region, as do the effects. To provide a useful regional perspective, this feature examines the amount of land lost to sea level rise along the Atlantic coast from Florida to New York. It is based on satellite data that have been collected and analyzed at five-year intervals since 1996. Figure 1 divides the Atlantic coast into two regions for comparison, while Figure 2 shows the different types of land that have been lost.

Why is the Atlantic coast particularly vulnerable to sea level rise?

Much of the land along the Atlantic coast is flat and close to sea level—including thousands of square miles of marshes and other productive wetlands, plus many low-lying cities. In addition, much of the land along the Atlantic coast is sinking, which magnifies the local effect of sea level rise. The land in North America is actually still adjusting to the loss of ice after the last ice age, which peaked about 20,000 years ago. Back then, thick sheets of ice covered areas of what is now Canada and the northern United States. The weight of all that ice depressed the land beneath it, but caused the land farther south (particularly the Mid-Atlantic region from North Carolina to New York) to bulge upward. After the ice melted and the extra weight was lifted, northern areas began to rise, and the Mid-Atlantic region started to sink. This very slow process continues today.

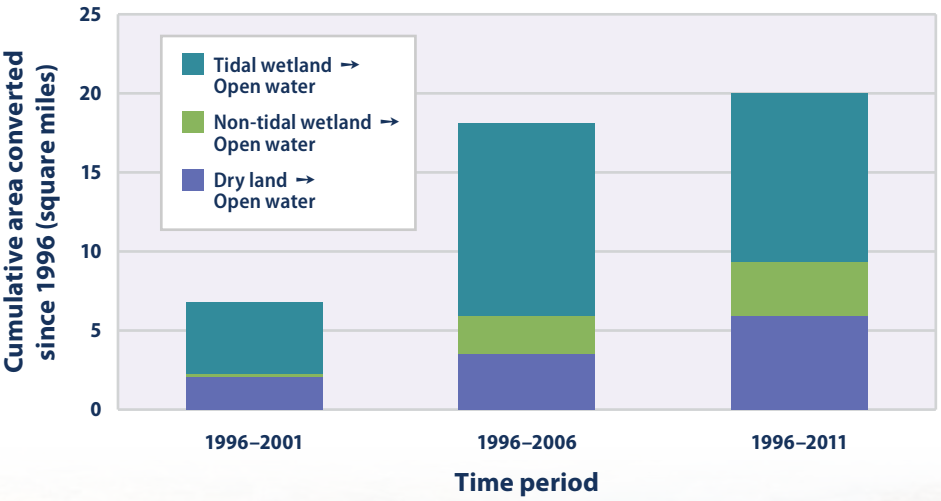
Figure 1. Land Loss Along the Atlantic Coast, 1996–2011



This graph shows the net amount of land converted to open water along the Atlantic coast during three time periods: 1996–2001, 1996–2006, and 1996–2011. The results are divided into two regions: the Southeast and the Mid-Atlantic (see locator map). Negative numbers show where land loss is outpaced by the accumulation of new land.

Data source: NOAA, 2013[20]

Figure 2. Land Submergence Along the Atlantic Coast, 1996–2011



This graph shows the net amount of land converted to open water along the Atlantic coast during three time periods: 1996–2001, 1996–2006, and 1996–2011. The results are divided into categories to show the type of land that has been converted to open water.

Data source: NOAA, 2013[21]

NOTES

Measurements of the change in coastal land depend on land cover and elevation data, which have significant limits in terms of accuracy and precision. Some results are field-checked for accuracy. The coastal land cover data are routinely compiled by the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program, and they represent the federal government's most comprehensive set of data on land use and land cover in the coastal zone.

Sea level rise is not the only factor that contributes to the loss of coastal land. In addition to the natural sinking of the shoreline in some areas, such as the Mid-Atlantic, coastal land loss has been made worse by human activities such as navigation and flood control structures that block wetland migration or the movement of sediment; withdrawal of ground water, oil, or natural gas in some regions; and boat traffic that accelerates wetland erosion.[22] Natural processes unrelated to current sea level rise can also cause shores to erode.

DATA SOURCES

This feature is based on land cover data from the Coastal Change Analysis Program, which is coordinated by the National Oceanic and Atmospheric Administration. For more information about this program, visit: http://csc.noaa.gov/digitalcoast.

Ocean Acidity

This indicator describes changes in the chemistry of the ocean, which relate to the amount of carbon dioxide dissolved in the water.

KEY POINTS

- Measurements made over the last few decades have demonstrated that ocean carbon dioxide levels have risen in response to increased carbon dioxide in the atmosphere, leading to an increase in acidity (that is, a decrease in pH) (see Figure 1).
- Historical modeling suggests that since the 1880s, increased carbon dioxide has led to lower aragonite saturation levels in the oceans around the world, which makes it more difficult for certain organisms to build and maintain their skeletons and shells (see Figure 2).
- The largest decreases in aragonite saturation have occurred in tropical waters (see Figure 2). However, decreases in cold areas may be of greater concern because colder waters typically have lower aragonite saturation levels to begin with.[23]

The ocean plays an important role in regulating the amount of carbon dioxide in the atmosphere. As atmospheric concentrations of carbon dioxide rise (see the Atmospheric Concentrations of Greenhouse Gases indicator on p. 20), the ocean absorbs more carbon dioxide. Because of the slow mixing time between surface waters and deeper waters, it can take hundreds to thousands of years to establish this balance. Over the past 250 years, oceans have absorbed about 28 percent of the carbon dioxide produced by human activities that burn fossil fuels.[24]

Although the ocean's ability to take up carbon dioxide prevents atmospheric levels from climbing even higher, rising levels of carbon dioxide dissolved in the ocean can have a negative effect on some marine life. Carbon dioxide reacts with sea water to produce carbonic acid. The resulting increase in acidity (measured by lower pH values) changes the balance of minerals in the water. This makes it more difficult for corals, some types of plankton, and other creatures to produce a mineral called calcium carbonate, which is the main ingredient in their hard skeletons and shells. Thus, declining pH can make it more difficult for these animals to thrive. This can lead to broader changes in the overall structure of ocean and coastal ecosystems, and can ultimately affect fish populations and the people who depend on them.[25] Signs of damage are already starting to appear in certain areas.[26]

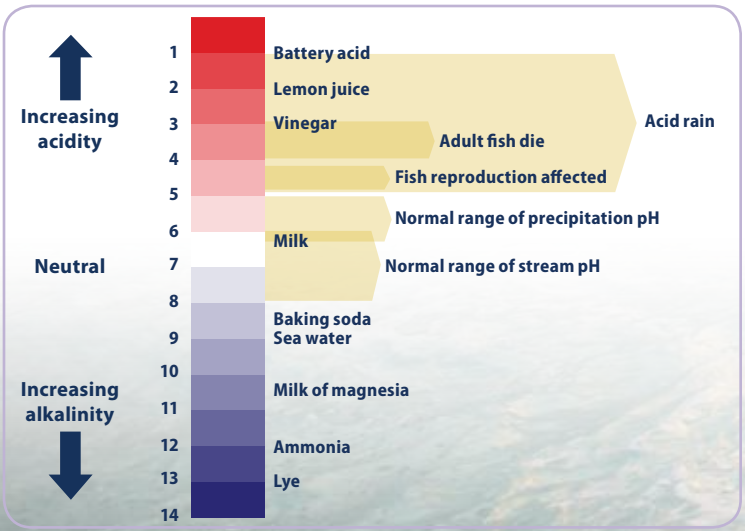
While changes in ocean pH and mineral saturation caused by the uptake of atmospheric carbon dioxide generally occur over many decades, these properties can fluctuate over shorter periods, especially in coastal and surface waters. For example, increased photosynthesis during the day and during the summer leads to natural fluctuations in pH. Acidity also varies with water temperature.

ABOUT THE INDICATOR

This indicator describes trends in pH and related properties of ocean water, based on a combination of direct observations, calculations, and modeling.

Figure 1 shows pH values and levels of dissolved carbon dioxide at three locations that have collected measurements consistently over the last few decades. These data have been either measured directly or calculated from related measurements, such as dissolved inorganic carbon and alkalinity. Data come from two stations in the Atlantic Ocean (Bermuda and the Canary Islands) and one in the Pacific (Hawaii).

The global map in Figure 2 shows changes over time in aragonite saturation level. Aragonite is a specific form of calcium carbonate that many organisms produce and use to build their skeletons and shells, and the saturation state is a measure of how easily aragonite can dissolve in the water. The lower the saturation level, the more difficult it is for organisms to build and maintain their skeletons and shells. This map was created by comparing average conditions during the 1880s with average conditions during the most recent 10 years (2004–2013). Aragonite saturation has only been measured at selected locations during the last few decades, but it can be calculated reliably for different times and locations based on the relationships scientists have observed among aragonite saturation, pH, dissolved carbon, water temperature, concentrations of carbon dioxide in the atmosphere, and other factors that can be measured. Thus, while Figure 2 was created using a computer model, it is based on measurements.

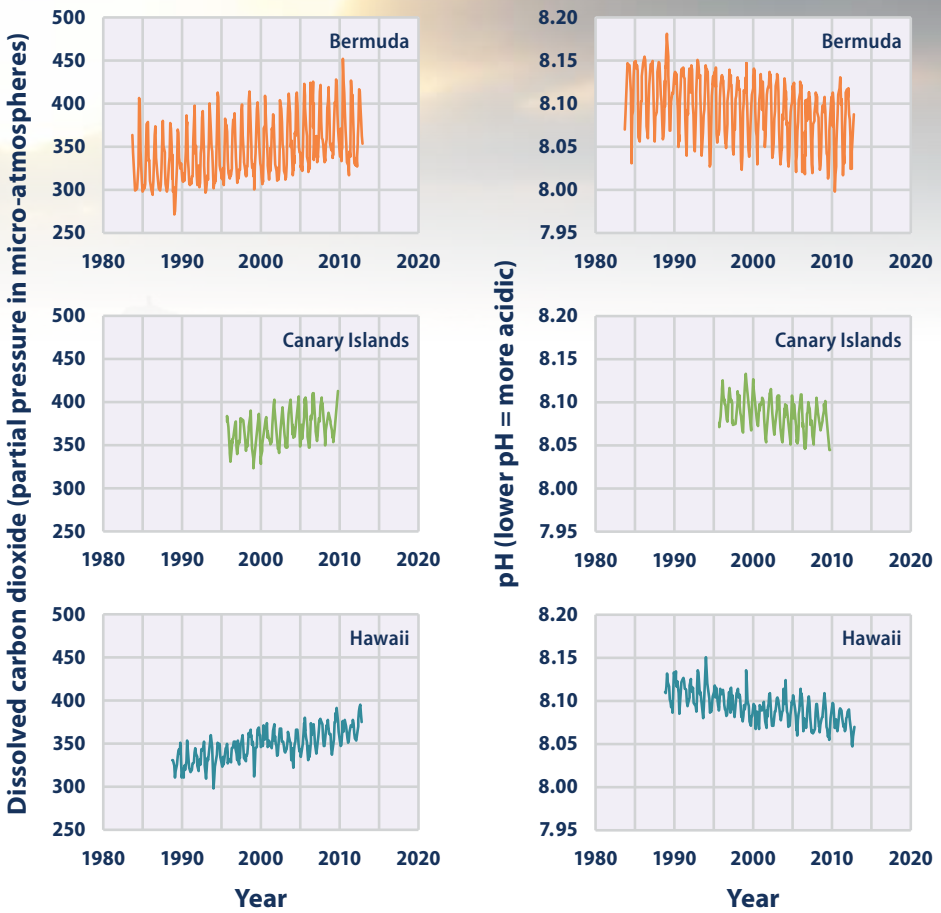


pH Scale

Acidity is commonly measured using the pH scale. Pure water has a pH of about 7, which is considered neutral. A substance with a pH less than 7 is considered to be acidic, while a substance with a pH greater than 7 is considered to be basic or alkaline. The lower the pH, the more acidic the substance. Like the well-known Richter scale for measuring earthquakes, the pH scale is based on powers of 10, which means a substance with a pH of 3 is 10 times more acidic than a substance with a pH of 4. For more information about pH, visit: www.epa.gov/acidrain/measure/ph.html.

Source: Environment Canada, 2008[27]

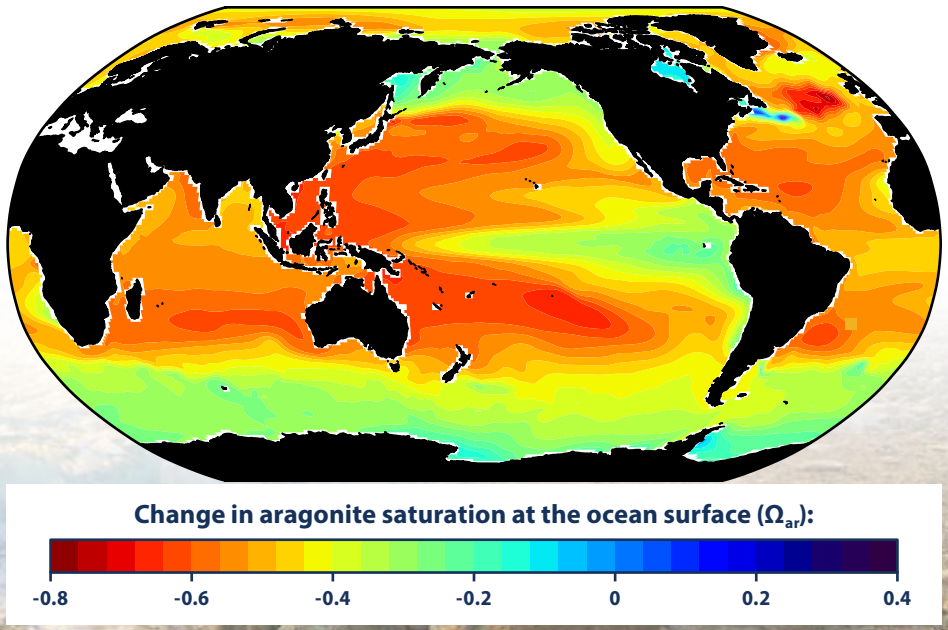
Figure 1. Ocean Carbon Dioxide Levels and Acidity, 1983–2012



This figure shows the relationship between changes in ocean carbon dioxide levels (measured in the left column as a partial pressure—a common way of measuring the amount of a gas) and acidity (measured as pH in the right column). The data come from two observation stations in the North Atlantic Ocean (Canary Islands and Bermuda) and one in the Pacific (Hawaii). The up-and-down pattern shows the influence of seasonal variations.

Data sources: Bermuda Institute of Ocean Sciences, 2014;[28] González-Dávila, 2012;[29] University of Hawaii, 2014[30]

Figure 2. Changes in Aragonite Saturation of the World's Oceans, 1880–2013



This map shows changes in the aragonite saturation level of ocean surface waters between the 1880s and the most recent decade (2004–2013). Aragonite is a form of calcium carbonate that many marine animals use to build their skeletons and shells. The lower the saturation level, the more difficult it is for organisms to build and maintain their skeletons and shells. A negative change represents a decrease in saturation.

Data source: Woods Hole Oceanographic Institution, 2014[33]

INDICATOR NOTES

This indicator focuses on surface waters, which can absorb carbon dioxide from the atmosphere within a few months.[31] It can take much longer for changes in pH and mineral saturation to spread to deeper waters, so the full effect of increased atmospheric carbon dioxide concentrations on ocean acidity may not be seen for many decades, if not centuries. Studies suggest that the impacts of ocean acidification may be greater at depth, because the aragonite saturation level is naturally lower in deeper waters.[32]

Ocean chemistry is not uniform around the world, so local conditions can cause pH or aragonite saturation measurements to differ from the global average. For example, carbon dioxide dissolves more readily in cold water than in warm water, so colder regions could experience greater impacts from acidity than warmer regions. Air and water pollution also lead to increased acidity in some areas.

DATA SOURCES

Data for Figure 1 came from three studies: the Bermuda Atlantic Time-Series Study, the European Station for Time-Series in the Ocean (Canary Islands), and the Hawaii Ocean Time-Series. Bermuda data are available at: http://bats.bios.edu. Canary Islands data are available at: www.eurosites.info/estoc/data.php. Hawaii data are available at: http://hahana.soest.hawaii.edu/hot/products/products.html.

The map in Figure 2 was created by the National Oceanic and Atmospheric Administration and the Woods Hole Oceanographic Institution using Community Earth System Model data. Related information can be found at: http://sos.noaa.gov/Datasets/list.php?category=Ocean.