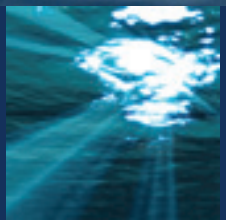
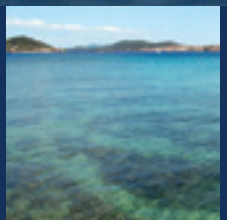
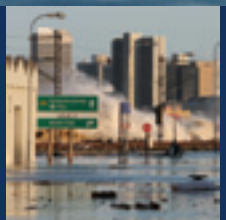
Oceans



Ocean Heat



Sea Surface Temperature



Sea Level

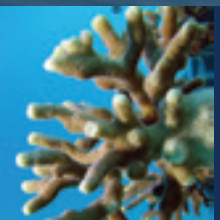
The oceans and the atmosphere interact constantly—both physically and chemically—exchanging heat, water, gases, and particles. This relationship influences the Earth's climate on regional and global scales. It also affects the state of the oceans.

Covering nearly 70 percent of the Earth's surface, the oceans store vast amounts of energy absorbed from the sun and move this energy around the globe through currents. As greenhouse gases trap more energy from the sun, the oceans will absorb more heat, resulting in an increase in sea surface temperatures, rising sea levels, and possible changes to ocean currents. These changes will very likely lead to alterations in climate patterns around the world. For example, warmer waters promote the development of more intense storms in the tropics, which can cause property damage or loss of life.

The oceans are also a key component of the Earth's carbon cycle. Over geological time, much of the world's carbon has come to reside in the oceans, either within plants and animals (living or dead) or dissolved as carbon dioxide. Although the oceans can help lessen climate change by storing a significant fraction of the carbon dioxide that human activities emit into the atmosphere, increasing levels of dissolved carbon dioxide can change the chemistry of seawater and harm certain organisms. These effects, in turn, could substantially alter the biodiversity and productivity of ocean ecosystems.

Even if greenhouse gas emissions are stabilized tomorrow, it will take many more years—decades or centuries—for the oceans to adjust to the climate changes that have already occurred.

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. The interactions between ocean and atmosphere occur slowly, over many years—even decades. For this reason, even if greenhouse gas emissions are stabilized tomorrow, it will take many more years—decades or centuries—for the oceans to adjust to the climate changes that have already occurred.



Ocean Heat

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

Background

When sunlight reaches the Earth's surface, the world's oceans absorb some of this energy and store it as heat. The amount of heat in the ocean, or ocean heat content, plays an important role in the Earth's climate system for several reasons. First, the amount of heat absorbed by the ocean affects its temperature. Sea surface temperature is especially important (see the Sea Surface Temperature indicator on p. 38) because surface waters exchange heat with the air and influence weather patterns. Deeper waters also absorb heat, however. Water also 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.

Greenhouse gases are trapping more energy from the sun, and the oceans are currently absorbing a significant fraction of this extra heat.[1] If not for the large heat storage capacity provided by the oceans, the atmosphere would grow warmer at a much faster rate.[2] Increased heat absorption can change the dynamics of the ocean, however, because many currents are driven by differences in temperature. These currents influence climate patterns and sustain ecosystems—for example, coastal fishing grounds that depend on upwelling currents to bring nutrients to the surface. 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. 40).

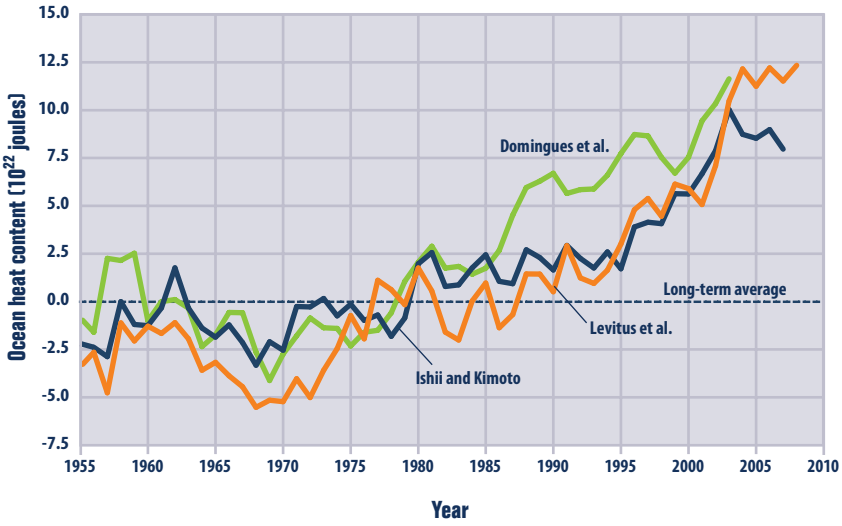
About the Indicator

This indicator shows trends in global ocean heat content to a depth of 700 meters (nearly 2,300 feet) from 1955 to 2008. The indicator measures ocean heat content in joules, which is a unit of energy.

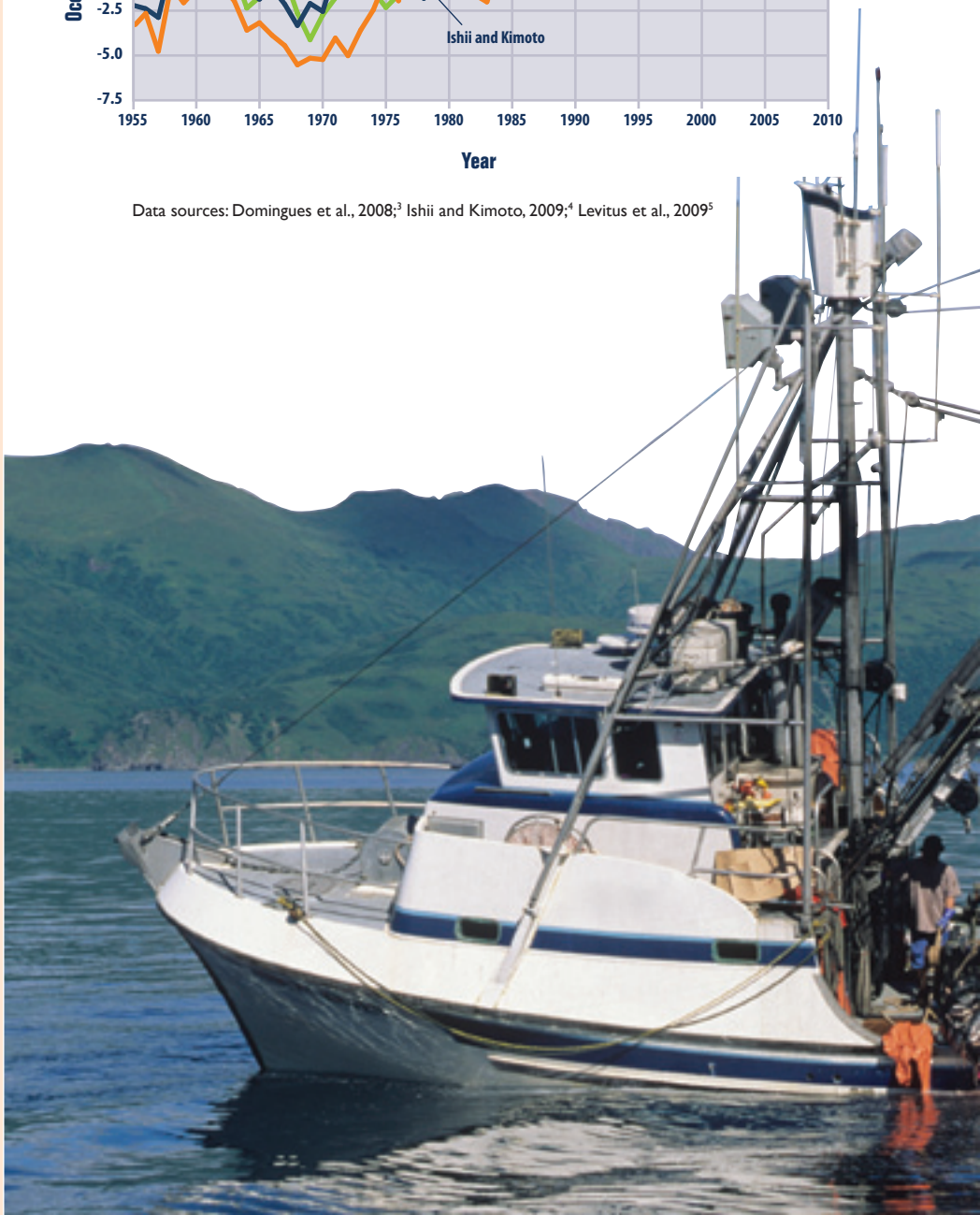
(Continued on page 37)

Figure 1. Ocean Heat Content, 1955–2008

This figure shows changes in ocean heat content between 1955 and 2008. Ocean heat content is measured in joules, a unit of energy, and compared against the long-term average, which is set at zero.



Data sources: Domingues et al., 2008;[3] Ishii and Kimoto, 2009;[4] Levitus et al., 2009[5]



Key Points

- In three different data interpretations, the long-term trend shows that ocean heat content has increased substantially since 1955 (see Figure 1).
- Although concentrations of greenhouse gases have risen at a steady rate over the past few decades (see the Atmospheric Concentrations of Greenhouse Gases indicator on p. 14), the rate of change in ocean heat content can vary greatly 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.

The National Oceanic and Atmospheric Administration and the National Aeronautics and Space Administration collected these data using a variety of ocean profiling instruments launched from ships and airplanes and, more recently, underwater robots. Thus, the data must be carefully adjusted to account for different measurement techniques. Scientists' understanding of how to correct the data has evolved over time, leading to changes in the trend line. Figure 1 shows three different interpretations of the same underlying data.

Indicator Limitations

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 the National Aeronautics and Space Administration, and were analyzed by Domingues et al. (2008),[6] Ishii and Kimoto (2009),[7] and Levitus et al. (2009).[8]

Sea Surface Temp

This indicator describes global trends in sea surface temperature.

Background

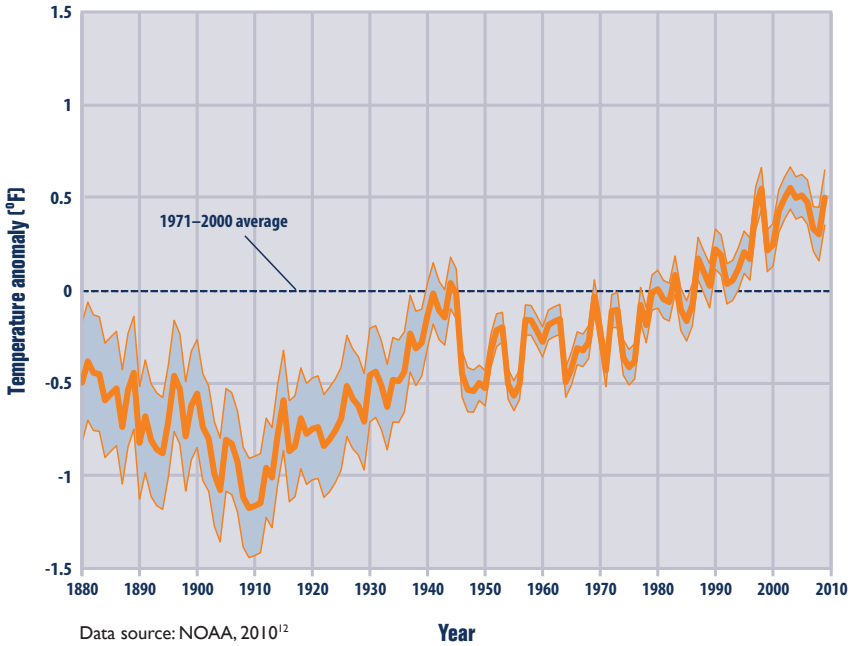
Sea surface temperature—the temperature of the water at the ocean surface—is an important physical attribute of the world's oceans. The surface temperature of the world's oceans varies mainly with latitude, with the warmest waters at the equator and the coldest waters in the Arctic and Antarctic regions. As air temperatures change, so can sea surface temperatures, as well as the ocean circulation patterns that transport warm and cold water around the globe.

Changes in sea surface temperature can alter marine ecosystems in several ways. For example, variations in ocean temperature can affect what species of plants and animals are present in a location, alter migration and breeding patterns, threaten fragile ocean life such as corals, and change the frequency and intensity of harmful algal blooms.[9] Over the long term, increases in sea surface temperature also can reduce the amount of nutrients supplied to surface waters from the deep sea, leading to declines in fish populations.[10]

Because the oceans constantly interact with the atmosphere, sea surface temperature also can have profound effects on global climate. Based on changes in sea surface temperature, the amount of atmospheric water vapor over the oceans is estimated to have increased by about 5 percent during the 20th century.[11] This water vapor feeds weather systems that produce precipitation, and the increase in water vapor increases the risk of heavy rain and snow (see the Heavy Precipitation and Tropical Cyclone Intensity indicators on p. 30 and p. 32, respectively). Changes in sea surface temperature can also shift precipitation patterns, potentially leading to droughts in some areas.

Figure 1. Average Global Sea Surface Temperature, 1880–2009

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 trend. The shaded band shows the likely range of values, based on the number of measurements collected and the precision of the methods used.

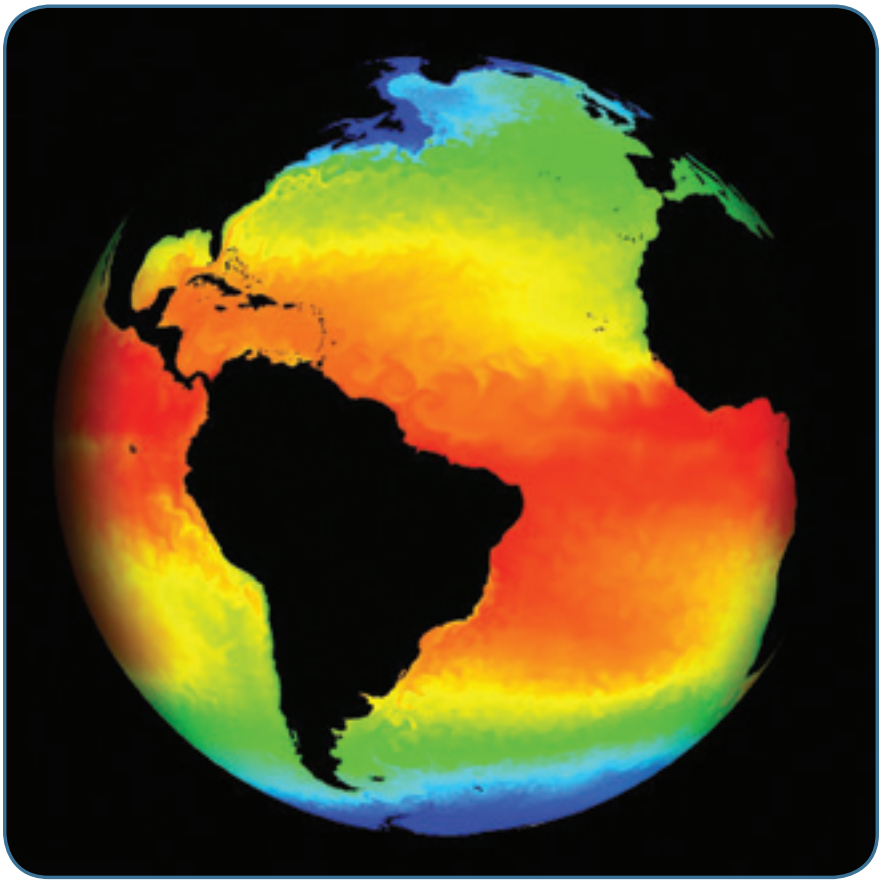


Data source: NOAA, 2010[12]

erature

Example of a Sea Surface Temperature Map

This image is an example of a sea surface temperature map based on satellite measurements and computer models. "Warm" colors such as red and orange indicate warmer water temperatures.



Source: NASA, 2008[13]

Key Points

- Sea surface temperature increased over the 20th century. From 1901 through 2009, temperatures rose at an average rate of 0.12 degrees per decade. Over the last 30 years, sea surface temperatures have risen more quickly at a rate of 0.21 degrees per decade (see Figure 1).
- Sea surface temperatures have been higher during the past three decades than at any other time since 1880 (see Figure 1).
- The largest increases in sea surface temperature occurred in two key periods: between 1910 and 1940, and from 1970 to the present. Sea surface temperatures appear to have cooled between 1880 and 1910 (see Figure 1).

About the Indicator

This indicator tracks average global sea surface temperature from 1880 through 2009 using data compiled by the National Oceanic and Atmospheric Administration. 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 buoys.

The data for this indicator have been carefully reconstructed and filtered 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.

Indicator Limitations

Because this indicator tracks sea surface temperature at a global scale, the data cannot be used to analyze local or regional trends.

Due to denser sampling and improvements in sample design and measurement techniques, newer data have more certainty than older data. The earlier trends shown by this indicator are less precise because of lower sampling frequency and less precise sampling methods.

Data Sources

Data for this indicator were provided by the National Oceanic and Atmospheric Administration's National Climatic Data Center and are available online at: www.ncdc.noaa.gov/oa/climate/research/sst/ersstv3.php. These data were reconstructed from actual measurements of water temperature, which are available from the National Oceanic and Atmospheric Administration at: http://icoads.noaa.gov/products.html.

Sea Level

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

Background

As the temperature of the ocean changes (see the Sea Surface Temperature indicator on p. 38), 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.
2. As water warms, it expands slightly—an effect that is magnified over the entire surface and depth of the oceans.

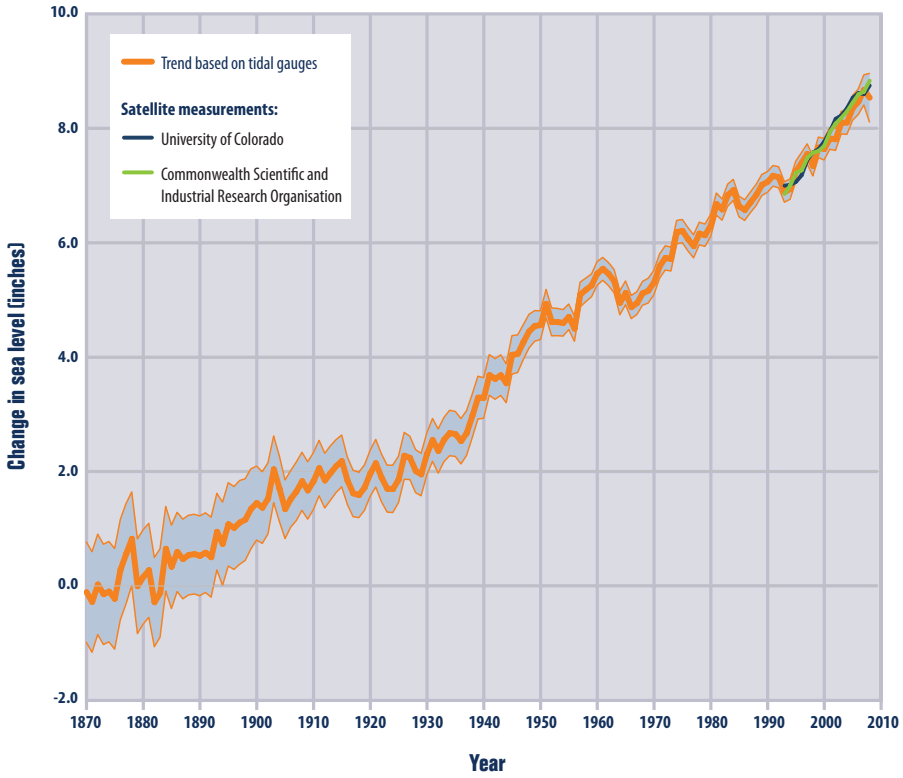
Changing sea levels can affect human activities in coastal areas. For example, rising sea levels can lead to increased flooding and erosion, which is a particular concern in low-lying areas. Sea level rise also can alter ecosystems, transforming marshes and other wetlands into open waters and freshwater systems to salt water.

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 Delta) and geological uplift (for example, over long timeframes as tectonic plates collide and build mountain ranges, and over shorter timeframes 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.

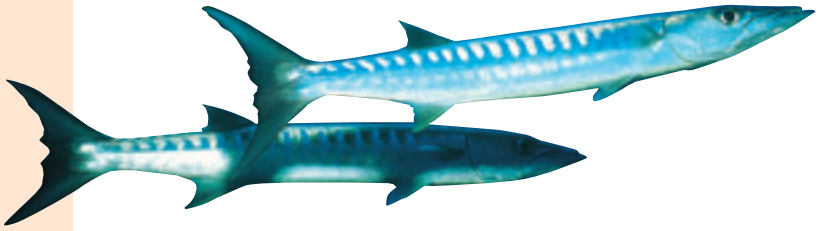
Scientists account for these types of changes by measuring sea level in two different ways. *Relative* sea level is the height of the ocean relative to the land elevation at a particular location. In contrast, *absolute* sea level strictly measures the height of the ocean surface above the center of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

Figure 1. Trends in Global Average Absolute Sea Level, 1870–2008

This graph shows how the average absolute sea level of the world's oceans has changed since 1870, based on a combination of long-term tidal gauge measurements and recent satellite measurements. Absolute sea level does not account for changes in land elevation. 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, 2009;[14] University of Colorado at Boulder, 2009[15]

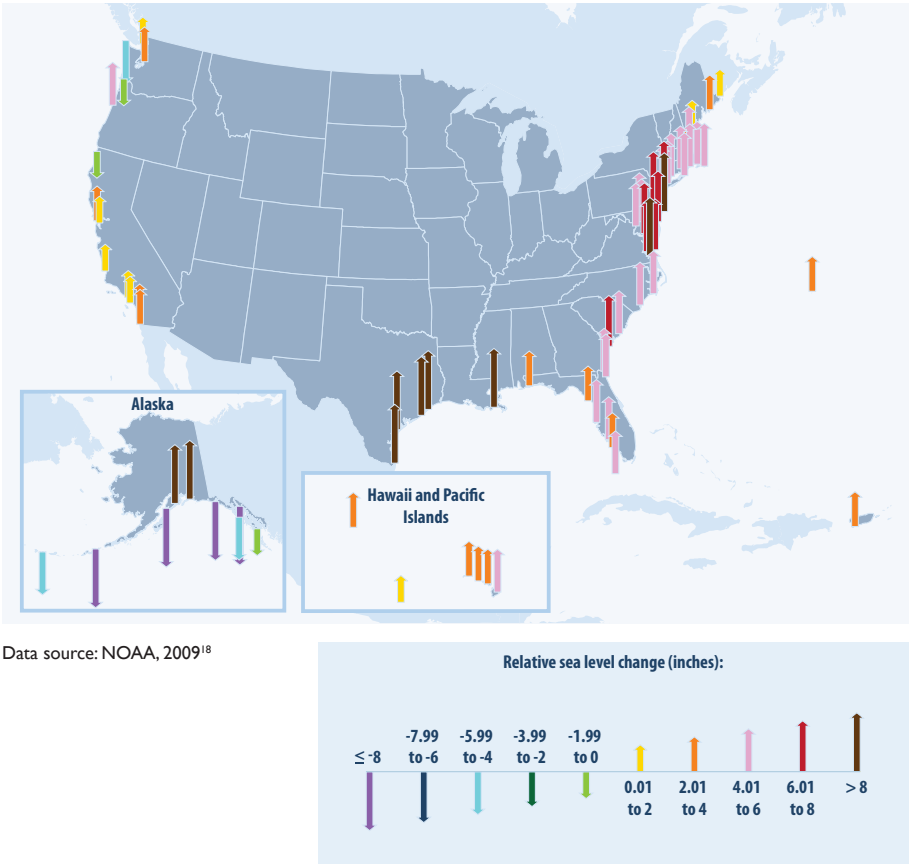


Key Points

- After a period of approximately 2,000 years of little change, average sea levels rose worldwide throughout the 20th century, and the rate of change has accelerated in recent years.[16] When averaged over all the world's oceans, absolute sea level increased at an average rate of 0.06 inches per year from 1870 to 2008 (see Figure 1). From 1993 to 2008, however, average sea level rose at a rate of 0.11 to 0.13 inches per year—roughly twice as fast as the long-term trend.
- Relative sea level rose along much of the U.S. coastline between 1958 and 2008, 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 if absolute sea level has risen, land elevation has apparently risen faster.
- While absolute sea level has increased steadily overall, particularly in recent decades, regional trends vary, and absolute sea level has decreased in some places.[17] 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.

Figure 2. Trends in Relative Sea Level Along U.S. Coasts, 1958–2008

This map shows changes in relative sea level from 1958 to 2008 at tidal gauge stations along U.S. coasts. Relative sea level accounts for changes in sea level as well as land elevation.



Data source: NOAA, 2009[18]

About the Indicator

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

Figure 1 shows trends in absolute sea levels averaged over the entire Earth's ocean surface. The long-term trend is based on tidal gauge data that have been adjusted to show absolute global trends through calibration with recent satellite data. Figure 2 shows trends at a more local scale, highlighting the 1958 to 2008 change in relative sea level at 76 tidal gauges along the Atlantic, Pacific, and Gulf coasts of the United States.

Indicator Limitations

Relative sea level trends represent a combination of absolute sea level change and any local land movement. Tidal 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, which affect coastal ocean temperatures; salt content; winds; atmospheric pressure; 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 tidal gauge measurements.

Data Sources

Absolute sea level trends were provided by Australia's Commonwealth Scientific and Industrial Research Organisation and the University of Colorado. These data are based on measurements collected by satellites and tidal 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/slrmap.html) with links to detailed data for each tidal gauge.

Ocean Acidity

This indicator shows acidity levels in the ocean, which are strongly affected by the amount of carbon dioxide dissolved in the water.

Background

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. 14), the ocean absorbs more carbon dioxide to stay in balance. Because of the slow mixing time of the ocean compared with the atmosphere, it can take hundreds of years to establish a balance between the atmosphere and the ocean.

Although the ocean's ability to take up carbon dioxide is a positive attribute with respect to mitigating climate change, these reactions can have a negative effect on marine life. Carbon dioxide from the atmosphere reacts with sea water to produce carbonic acid. Increasing acidity (measured by lower pH values) reduces the availability of chemicals needed to make calcium carbonate, which corals, some types of plankton, and other creatures rely on to produce their hard skeletons and shells. The effect of declining pH on shell-producing ocean organisms can cause changes in overall ecosystem structure in coastal ecosystems.[19]

While changes in ocean pH caused by the uptake of atmospheric carbon dioxide generally occur over long periods of time, some fluctuation in pH can occur over shorter periods, especially in coastal and surface waters. Increased photosynthesis during the day and during summer months, for example, leads to natural fluctuations in pH.

About the Indicator

This indicator presents ocean pH values based on direct observations and modeling. Scientists have only begun to directly measure ocean carbon dioxide and related variables (dissolved organic carbon, alkalinity, and pH) on a global scale during the last few decades.

While direct observations are important in monitoring recent ocean acidity changes, it is even more important to examine trends over longer time spans, given the slow rate at which sea water balances with atmospheric

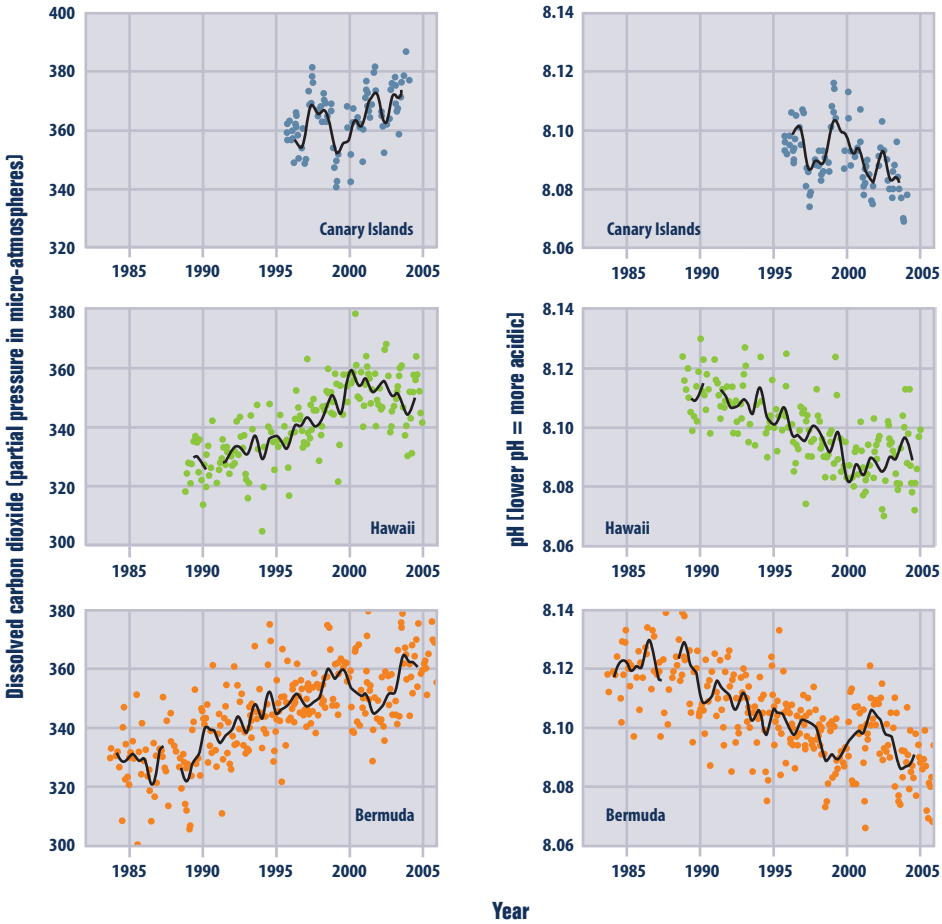
(Continued on page 43)

Key Points

- Measurements made over the last few decades have demonstrated that ocean carbon dioxide levels have risen, accompanied by an increase in acidity (that is, a decrease in pH) (see Figure 1).
- Modeling suggests that over the last few centuries, ocean acidity has increased globally (meaning pH has decreased), most notably in the Atlantic (see Figure 2).
- Direct observations show that pH levels fluctuate more frequently in some areas of the ocean than in others.[20] More measurements are needed to better understand the links between these natural fluctuations and long-term changes in ocean acidity.

Figure 1. Ocean Carbon Dioxide Levels and Acidity, 1983–2005

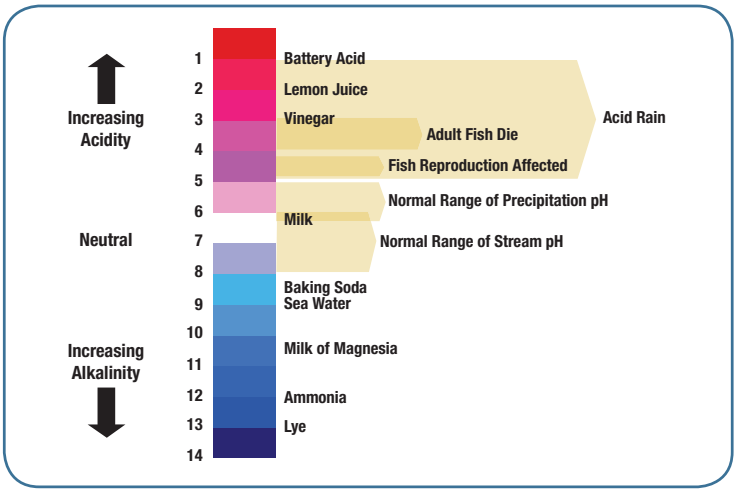
This figure shows changes in ocean carbon dioxide levels (measured as a partial pressure) and acidity (measured as pH). The data come from two observation stations in the North Atlantic Ocean (Canary Islands and Bermuda) and one in the Pacific (Hawaii). Dots represent individual measurements, while the lines represent smoothed trends.



Data source: Bindoff et al., 2007[21]

pH Scale

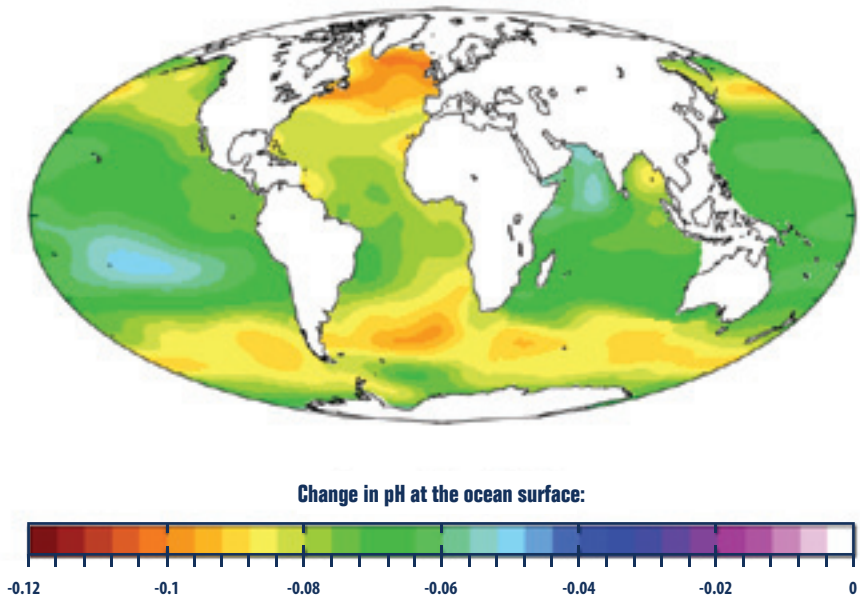
Acidity is commonly measured using the pH scale. Pure water has a pH of about 7, which is considered neutral. A substance with a pH less than 7 is acidic, while a substance with a pH greater than 7 is basic or alkaline. The lower the pH, the more acidic the substance. The pH scale is based on powers 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[22]

Figure 2. Historical Changes in Ocean Acidity, 1700s–1990s

This figure shows changes in ocean pH levels around the world from pre-industrial times to the present based on modeled data.



Data source: Yool, 2007[23]

carbon dioxide. Because of the lack of historical observation data, modeling has been used to make comparisons between pre-industrial times and the present.

Indicator Limitations

Changes in ocean pH caused by the uptake of atmospheric carbon dioxide tend to occur slowly relative to natural fluctuations, so the full effect of atmospheric carbon dioxide concentrations on ocean pH may not be seen for many decades, if not centuries.

Ocean chemistry is not uniform throughout the world's oceans, so local conditions could cause a pH measurement to seem incorrect or abnormal in the context of the global data.

Data Sources

Data for Figure 1 came from three ocean time series studies: the Bermuda Atlantic Time-Series Study, the Hawaii Ocean Time-Series, and the European Station for Time-Series in the Ocean (Canary Islands). Bermuda data were analyzed by Bates et al. (2002)[24] and Gruber et al. (2002).[25] Hawaii data were analyzed by Dore et al. (2003),[26] and Canary Islands data were analyzed by Gonzalez-Davila et al. (2003).[27] Bermuda and Hawaii data are available at: www1.whoi.edu. The map in Figure 2 was created using Global Ocean Data Analysis Project data, and the figure was provided by the Pacific Science Association Task Force on Ocean Acidification. This map and other information are available at: www.pacificscience.org/tfoceanacidification.html.