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Climate Change: Global Sea Level

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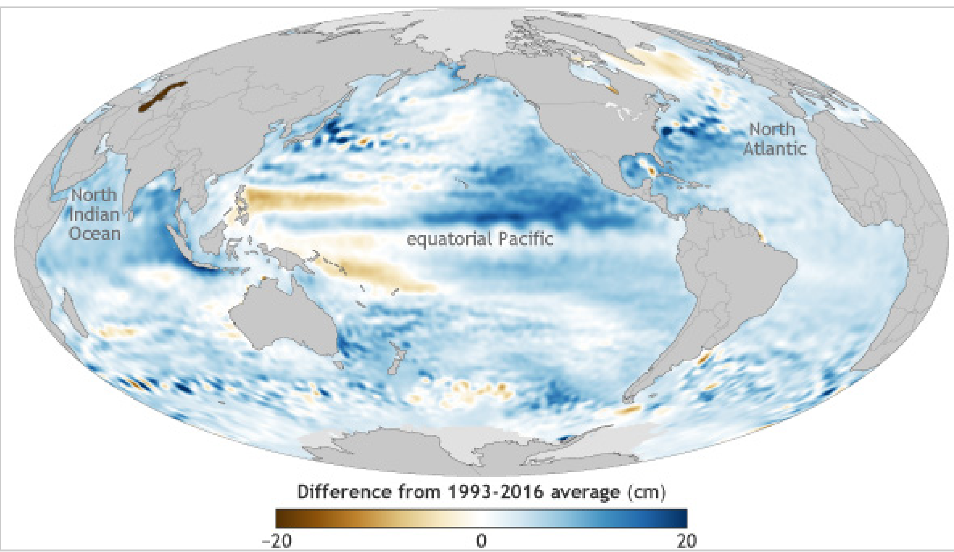
Sea level has been rising over the past century, and the rate has increased in recent decades. In 2016, global sea level was 3.2 inches (82 mm) above the 1993 average—the highest annual average in the satellite record (1993-present).

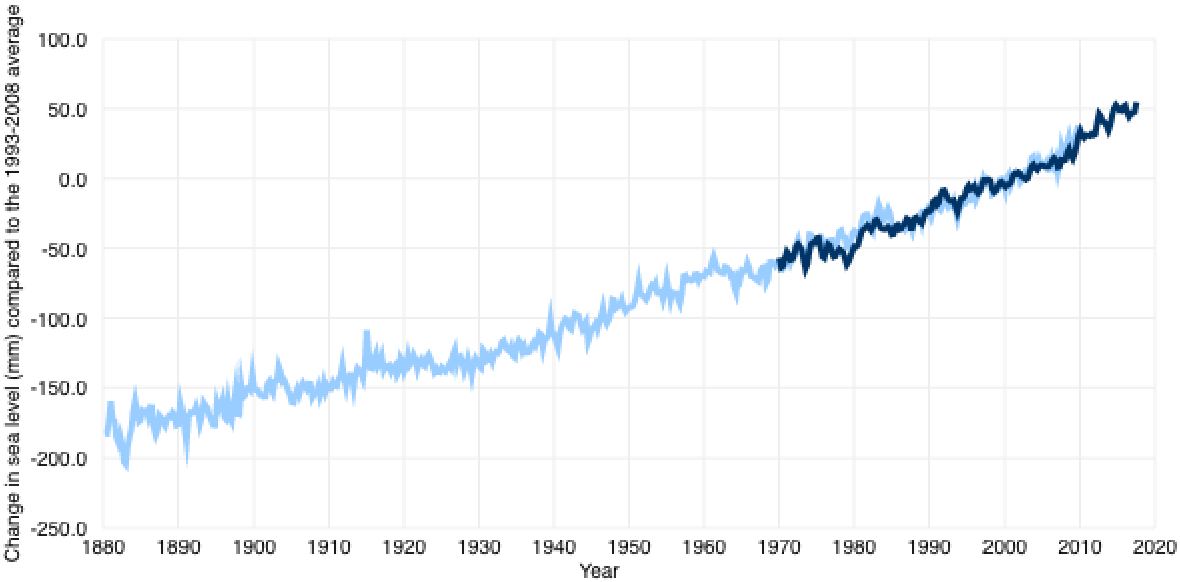


Sea level in 2016 compared to the 1993-2016 average. NOAA Climate.gov map, adapted from Figure 3.16a in State of the Climate in 2016. [(http://www.ametsoc.net/sotc2016/Ch03_GlobalOceans.pdf)](http://www.ametsoc.net/sotc2016/Ch03_GlobalOceans.pdf)

Sea level continues to rise at a rate of just over one-eighth of an inch (3.4 mm) per year, due to a combination of melting glaciers and ice sheets, and thermal expansion of seawater as it warms.

Global sea level since 1880

Explore this interactive graph: Click and drag either axis to display different parts of the graph. To squeeze or stretch the graph in either direction, hold your Shift key down, then click and drag.



The light blue line shows seasonal (3-month) sea level estimates from Church and White (2011) (http://www.cmar.csiro.au/sealevel/GMSL_SG_2011.html). The darker line is based on University of Hawaii Fast Delivery (http://uhslc.soest.hawaii.edu/data/?fd) sea level data. For more detail on the data sources, see the end of the article.

Why sea level matters

In the United States, almost 40% (http://oceanservice.noaa.gov/facts/population.html) of the population lives in relatively high population-density coastal areas, where sea level plays a role in flooding, shoreline erosion, and hazards from storms. Globally, 8 of the world's 10 largest cities are near a coast, according to the U.N. Atlas of the Oceans.

South Beach, Miami on May 3, 2007. Photo by Flickr user James WIlliamor (https://www.flickr.com/photos/bz3rk/), via a Creative Commons license.

In urban settings along coastlines around the world, rising seas threaten infrastructure necessary for local jobs and regional industries. Roads, bridges, subways, water supplies, oil and gas wells, power plants, sewage treatment plants, landfills—the list is practically endless—are all at risk from sea level rise.

Higher "background" water levels mean that deadly and destructive storm surges—like those associated with Hurricane Katrina or "Superstorm" Sandy—push farther inland than they once did. Higher sea level also means more frequent "nuisance flooding (https://www.climate.gov/news-features/understanding-climate/understanding-climate-billy-sweet-and-john-marra-explain)"—not deadly or dangerous, usually, but still disruptive and expensive.

Nuisance flooding in Annapolis in 2012. Around the U.S., nuisance flooding has increased dramatically in the past 50 years. Photo by Amy McGovern.

In the natural world, rising sea level creates stress on coastal ecosystems that provide recreation, protection from storms, and habitat for fish and wildlife, including commercially valuable fisheries. As seas rise, saltwater is also intruding into freshwater aquifers, many of which sustain municipal and agricultural water supplies and natural ecosystems.

What's causing sea level to rise?

Sea level is rising for two main reasons: glaciers and ice sheets are melting and adding water to the ocean and the volume of the ocean is expanding as the water warms. A third, much smaller contributor to sea level rise is a decline in water storage on land—aquifers, lakes and reservoirs, rivers, soil moisture—mostly as a result of groundwater pumping, which has shifted water from aquifers to the ocean.

From the 1970s up through the last decade, melting and thermal expansion were contributing roughly equally to the observed sea level rise. But the melting of glaciers and ice sheets has accelerated, and over the past decade, the amount of sea level rise due to melting—with a small addition from groundwater transfer and other water storage shifts—has been nearly twice the amount of sea level rise due to thermal expansion.

Melt streams on the Greenland Ice Sheet on July 19, 2015. Ice loss from the Greenland and Antarctic Ice Sheets as well as alpine glaciers has accelerated in recent decades. NASA photo (http://earthobservatory.nasa.gov/IOTD/view.php?id=86508) by Maria-José Viñas.

Glacier mass loss accelerated from 226 gigatons/year between 1971 and 2009 to 275 gigatons/year between 1993 and 2009. Ice loss from the Greenland Ice Sheet increased six-fold, from 34 gigatons/year between 1992-2001 to 215 gigatons/year between 2002 and 2011. Antarctic ice loss more than quadrupled, from 30 gigatons/year between 1992 and 2001 to 147 gigatons/year from 2002 to 2011.

The pace of global sea level rise doubled from 1.7 mm/year throughout most of the twentieth century to 3.4 mm/year since 1993.

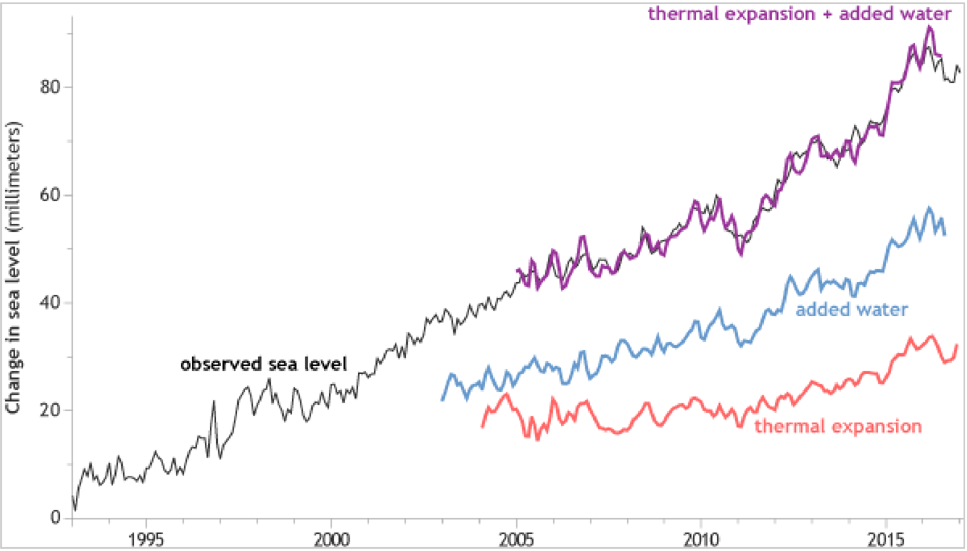
Sea level rise at specific locations (http://tidesandcurrents.noaa.gov/sltrends/sltrends.html) may be more or less than the global average due to local factors: subsidence, upstream flood control, erosion, regional ocean currents, and whether the land is still rebounding from the compressive weight of Ice Age glaciers.

Measuring sea level

Sea level is measured by two main methods: tide gauges (https://www.climate.gov/news-features/climate-tech/reading-between-tides-200-years-measuring-global-sea-level)and satellite laser altimeters. Tide gauge stations from around the world have measured the daily high and low tides for more than a century, using a variety of manual and automatic sensors. Using data from scores of stations around the world, scientists can calculate a global average and adjust it for seasonal differences.

Since the early 1990s, sea level has been measured from space using laser altimeters, which determine the height of the sea surface by measuring the return speed and intensity of a laser pulse directed at the ocean. The higher the sea level, the faster and stronger the return signal is.

To estimate how much of the observed sea level rise is due to thermal expansion, scientists measure sea surface temperature using moored and drifting buoys, satellites, and water samples collected by ships. Temperatures in the upper half of the ocean volume are measured by a global fleet of aquatic robots (https://www.climate.gov/news-features/features/argo-revolution).



Observed sea level since the start of the satellite altimeter record in 1993 (black line), plus independent estimates of the different contributions to sea level rise: thermal expansion (red) and added water, mostly due to glacier melt (blue). Added together (purple line), these separate estimates match the observed sea level very well. NOAA Climate.gov graphic, adapted from Figure 3.15a in State of the Climate in 2016. (http://www.ametsoc.net/sotc2016/Ch03_GlobalOceans.pdf)

To estimate how much of the increase in sea level is due to actual mass transfer—the movement of water from land to ocean—scientists rely on a combination of direct measurements of melt rate and glacier elevation made during field surveys, and satellite-based measurements (http://earthobservatory.nasa.gov/Features/GRACE/page2.php) of tiny shifts in Earth's gravity field. When water shifts from land to ocean, the increase in mass increases the strength of gravity over oceans by a small amount. From these gravity shifts, scientists estimate the amount of added water.

Future sea level rise

As global temperatures continue to warm, sea level will continue to rise. How much it will rise depends mostly on the rate of future carbon dioxide emissions and future global warming. How fast it will rise depends mostly on the rate of glacier and ice sheet melting.

The pace of sea level rise accelerated beginning in the 1990s, coinciding with acceleration in glacier and ice sheet melting. However, it's uncertain whether that acceleration will continue, driving faster and faster sea level rise, or whether internal glacier and ice sheet dynamics (not to mention natural climate variability) will lead to "pulses" of accelerated melting interrupted by slow downs.

In 2012, at the request of the U.S. Climate Change Science Program, NOAA scientists conducted a review (http://cpo.noaa.gov/AboutCPO/AllNews/TabId/315/ArtMID/668/ArticleID/80/Global-Sea-Level-Rise-Scenarios-for-the-United-States-National-Climate-Assessment.aspx) of the research on global sea level rise projections, and concluded that there is very high confidence (greater than 90% chance) that global mean sea level will rise at least 8 inches (0.2 meter) but no more than 6.6 feet (2.0 meters) by 2100.

About the data used in the interactive graph

The early part of the time series shown in the graph above comes from the sea level group (http://www.cmar.csiro.au/sealevel/index.html) of CSIRO (Commonwealth Scientific and Industrial Research Organisation), Australia's national science agency. The more recent part of the time series is from the University of Hawaii Sea Level Center. It is based on a weighted average of 373 global tide gauge records collected by the U.S. National Ocean Service, UHSLC, and partner agencies worldwide. The weights for each gauge in the global mean are determined by a cluster analysis that groups gauges from locations where sea level tends to vary in the same way. This prevents over-emphasizing regions where there are many tide gauges located in close proximity. The values are shown as change in sea level in millimeters compared to the 1993-2008 average.

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More sea level data and information from NOAA and partners

Global Ocean Heat and Salt Content (https://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/) page at NCEI

Tides and Currents Sea Level Trends (http://tidesandcurrents.noaa.gov/sltrends/sltrends.html) page at the National Ocean Service

Digital Coast Sea Level Rise Viewer (http://coast.noaa.gov/digitalcoast/tools/slr) at the Coastal Services Center

Coastal Flood Risk (https://toolkit.climate.gov/topics/coastal-flood-risk) page at the U.S. Climate Resilience Toolkit

Highlights:

- In 2016, global sea level was 3.2 inches (82 mm) above the 1993 average—the highest annual average in the satellite record (1993-present).
- Since 1993, sea level has been rising at a rate of 3.4 millimeters per year (just over one-eighth of an inch/year)
- In many locations along the U.S. coastline, nuisance flooding is now 300% to more than 900% more frequent than it was 50 years ago.
- Scientists are very confident that global mean sea level will rise at least 8 inches (0.2 meter) but no more than 6.6 feet (2.0 meters) by 2100.

Reviewer:

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