Mapping Choices: Which sea level will we lock in?

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Introduction

These maps are based on peer-reviewed scientific research led by Benjamin Strauss and Scott Kulp of Climate Centralin collaboration with Anders Levermann of the Potsdam Institute of Climate Impact Research, and published in Proceedings of the National Academy of Sciences of the United States of America. Application of this research to areas outside the U.S. is detailed in the Mapping Choices report.
These notes are intended to help explain the research, the maps, and how to use them.

Sea level lock-in

Carbon pollution casts a long shadow. It is expected to persist in the atmosphere long enough to prolong temperature increases for hundreds and thousands of years, long after we stop burning fossil fuels or clearing forest. And the seas will continue to rise.
That's what these maps are about. They do *not* show what sea levels will be in *this* century (see this map for near-term analysis). What they do show are scientific projections, taken from this paper, of the different post-2100 sea levels that could *lock in* this century, depending upon the carbon pathway we select. The areas colored blue are the areas below those levels – areas which will eventually be permanently underwater. These maps pose this question: which legacy will we choose?
Some research has suggested that the West Antarctic Ice Sheet has begun an unstoppable collapse, but the evidence is far from conclusive. The maps here do *not* assume inevitable West Antarctic collapse. If collapse has in fact begun, all locked-in sea levels would be higher than shown. Carbon emissions levels would still influence all outcomes.
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Sea level timing

There are two timeframes to these maps. The first is: When do we pass the point of no return, and lock in the future sea levels shown?
Maps that compare carbon scenarios show long-term sea level projections based on different pollution pathways through 2100 (default), 2050, or 2015 (historic pollution), depending on the settings chosen. Maps that compare temperature increases show sea level projections that lock in if and when enough carbon emissions add up to lock in each temperature increase. The answers depend on our carbon choices, and could easily fall within this century for any of the temperature options (see the scientific paper behind these maps and its Supporting Information, plus twoefforts that project warming based on "intended nationally determined commitments" for reducing emissions). The maps assume no pollution beyond the selected year or temperature.
The second timeframe is: When will the sea actually reach the heights shown?
The answer could be sooner than 200 years from now (see Table 1 in this scientific paper), or as long as 2,000 years (see this paper). Why the wide range? It is easier to estimate *how much* ice

will eventually melt from a certain amount of warming, than *how quickly* it will melt, which involves more unknowns. The same simple contrast would apply to an ice sculpture in a warm room.

The sea may rise higher still over longer timeframes, but those possibilities are beyond the scope of this analysis.

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Carbon choices, sea level choices

Temperatures | Unchecked pollution | Minor cuts | Moderate cuts | Extreme cuts

The sea level we lock in depends on the total amount of carbon we put into the atmosphere. Here is a guide to the possibilities that can be explored in these maps via different settings. Sea level projections are based on the expansion of ocean water as it warms; melting glaciers and ice caps; and the decay of Greenland and Antarctic ice sheets. Maps show local projections that can vary by several feet from the global average due mainly to changing gravity fields as the polar ice sheets lose mass. Local projections shown do not factor in the continuation of current land subsidence or uplift. (In most places, these might translate to a few centimeters or inches per century, but some places, such as southeastern Louisiana in the U.S., are sinking close to ten times faster.)

Temperatures. Warming of 2 °C (3.6 °F) is a long-standing international target, and corresponds to what many would consider successful global efforts to control greenhouse gas emissions. It also corresponds, in this analysis, to 4.7 meters (15.4 feet) of global sea level rise locked in to someday take place. Warming of 4 °C (7.2 °F) is close to our current path, would represent a breakdown in efforts, and corresponds to 8.9 m (29.2 ft) of locked-in global sea level rise. The span from 2-4 °C covers the likely range of possible outcomes from global climate talks at COP21 in Paris.

Warming of 3 °C (5.4 °F) corresponds roughly to the current sum of “intended nationally determined commitments” for reducing emissions, and 6.4 m (21.0 ft) of locked-in global sea level rise. Warming of 1.5 °C (2.7 °F) is the preferred goal of many island nations as compared to 2 °C (3.6 °F), and corresponds to 2.9 m (9.5 ft) of locked-in rise.

These are the four warming levels for which these maps visualize projections of committed sea level rise. The analysis behind the maps accounts only for warming caused by carbon dioxide, a long-term climate pollutant: in other words, as one example, the 2 °C (3.6 °F) scenario requires enough carbon emissions to cause this warming acting alone.

Other visualizations are based on carbon pathways, as opposed to set temperature increases, and are described just below.

Unchecked pollution. This is essentially the course we are on now. Technically, this option corresponds to a scientific scenario called RCP 8.5, which carbon pollution has been tracking closely so far. RCP 8.5 implies we emit a total of 2,430 gigatons of carbon by 2100 (or 3.67 times that weight of CO_2). That corresponds to 3.3 °C (5.9 °F) of eventual warming, and 7.1 meters (23.3 feet) of global sea level rise locked in to someday take place. These are central estimates within wider possible ranges, as are the further estimates in this section below. Note that in RCP 8.5, annual emissions are still rising in 2100, so locked-in sea levels will continue to increase. However, these maps and the analysis do not account for further pollution past 2100 under any of the four carbon pathways considered.

Minor carbon cuts. This option corresponds to RCP 6.0 and implies 1,678 GtC in total carbon pollution by 2100; 2.3 °C (4.1 °F) of warming; and 5.0 meters (16.4 feet) of locked-in global sea level rise. Under RCP 6.0, annual emissions peak in 2060 and then decrease, but remain above

current levels through 2100, so locked-in sea levels will continue to increase. However, these maps and the analysis do not account for post-2100 pollution.
Moderate carbon cuts. This option corresponds to RCP 4.5 and implies 1,266 GtC in total carbon pollution by 2100; 1.7 °C (3.1 °F) of warming; and 2.6 meters (11.8 feet) of locked-in global sea level rise. Under RCP 4.5, annual emissions peak in 2040 and then decrease, stabilizing at roughly half of current levels, so locked-in sea levels will continue to modestly increase. However, these maps and the analysis do not account for post-2100 pollution.
Extreme carbon cuts. This option corresponds to RCP 2.6 and implies 840 GtC in net total carbon pollution by 2100; 1.1 °C (2.0 °F) of warming; and 2.4 meters (7.9 feet) of locked-in global sea level rise. Under RCP 2.6, annual emissions rapidly peak in 2020, decline sharply to reach zero just after 2080, and become slightly negative after that. Negative emissions would require engineered active removal of carbon from the atmosphere at a massive scale, likely to be extremely difficult and expensive. However, negative emissions also suggest the possibility that some "locked-in" sea level rise might eventually be "unlocked," assuming unstoppable ice sheet decay is not already set in motion. These maps and analysis do not account for post-2100 negative emissions.
The historical scenario assumes we will be at 560 GtC by the end of 2015, which matches to 0.7 °C (1.4 °F) of warming and 1.6 meters (5.2 feet) of locked-in global sea level rise. Humanity is currently adding about 10 GtC to the atmosphere annually, a rate that has been increasing almost every year.
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Impacts threatened

Carbon emissions causing 4 °C (7.2 °F) of warming—what business-as-usual points toward today—could lock in 6.9 to 10.8 meters (23 to 35 feet) of global sea level rise, enough to submerge land currently home to 470 to 760 million people. Aggressive carbon cuts resulting in 2 °C (3.6 °F) warming, the well-established international target, could bring the numbers as low as 3.0 meters (10 feet) and 130 million people.
China, the world's leading carbon emitter, also leads in coastal risk, with 145 million people living on land ultimately threatened by rising seas if emission levels are not reduced. China further has the most to gain from limiting warming to 2 °C (3.6 °F), which would cut the total to 64 million. Twelve other nations each have more than 10 million people living on land at risk, led by India, Bangladesh, Viet Nam, Indonesia and Japan.
Next on the list is the U.S., where land inhabited by 25 to 34 million people could be affected, including the majority of residents in 1,500 or more municipalities and 25 or more cities with at least six-digit populations. Limiting warming to 2 °C (3.6 °F) could cut the total population numbers by more than 10 million, and reduce the damage inflicted on many iconic American cities and landmarks.
These are a few of the headlines from the Climate Central-led paper and report behind these maps. The Supporting Information at the end of the downloadable paper includes 12 tables with detailed and extensive results for each coastal U.S. state and majorly affected city with population exceeding 100,000. The Appendix at the end of the downloadable report includes two tables with results for every coastal nation in the world, and affected cities with total population over 1 million.
This analysis and the maps do not account for levees and other defenses that have been or might be built.
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Map sources and accuracy

Local locked-in sea level rise projections, which the maps show, differ slightly from global ones, because of gravitational and isostatic effects described in the research behind this project. Within the United States, these maps are based primarily on high quality lidar bare earth elevation data curated by NOAA, with roughly 5-meter (16-foot) horizontal resolution and a vertical accuracy (root mean square error) generally within 15 centimeters (6 inches). They also reference local high tide lines (mean higher high water, MHHW) based on high-resolution tidal modeling from NOAA, via the tool VDatum.

The map outside the U.S. utilizes elevation data on a roughly 300-foot (90-meter) horizontal resolution grid derived from NASA's Shuttle Radar Topography Mission (SRTM). SRTM provides surface elevations, not bare earth elevations, causing it to commonly overestimate elevations, especially in areas with dense and tall buildings or vegetation. Therefore, this map generally under-portrays, and our analysis underestimates, areas that could be submerged at each locked-in sea level.

SRTM data do not cover latitudes farther north than 60 degrees or farther south than 56 degrees, meaning that sparsely populated parts of Arctic Circle nations are not mapped here.

The map outside the U.S. (and for Alaska) also utilizes a different source for MHHW, and a global grid for MHHW provided by Mark Merrifield of the University of Hawaii, Manoa, Hawaii.

As one indicator suggestive of quality, our analysis of the U.S. based on SRTM elevation data and the global MHHW grid—plus a global population data source—underestimates exposure in the U.S. by 18% after 4 °C of warming, and by 36% after 2 °C of warming, as compared to our analysis based on lidar, VDatum, and U.S. Census data.

Graphical map tiles are by Stamen Design, under CC BY 3.0. Map data by OpenStreetMap, under CC BY SA.

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Help

Navigate the map. Navigate by typing any city or other place name or postal code through search, or using standard zooming and panning.

Change scenarios. These maps contrast different emissions and warming scenarios, over different time frames, which can be accessed and changed by clicking or tapping on the scenario/warming tabs, the settings icon above the map (three horizontal lines with dots), or the settings menu (select “See different futures”).

Share the map. Click on the share icon above the map, or tap on “Share this map” via the settings menu.

Embed the map. Click on the embed icon </> above the map, or tap on “Embed this scene” via the settings menu.

Take a screenshot. Click on the camera icon above the map, or tap on “Download map screenshot” via the settings menu.

See related content. Click on the “plus” icon above the map, or tap on “See more” via the settings menu.

Support our work. Click on the heart icon above the map, or tap on “Support our work” via the settings menu.

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Team

Benjamin Strauss and Scott Kulp of Climate Central led and conducted the research behind this project, in collaboration with Anders Levermann of the Potsdam Institute of Climate Impact Research. The entire Climate Central sea level rise group helped conceive and create this tool, its core design, and the associated materials. Please consider supporting our nonprofit efforts. Stamen Design in San Francisco designed and built the map and mobile tool.
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Funding

This effort is made possible thanks to the many organizations that have supported Climate Central and its sea level program, including the V. Kann Rasmussen Foundation, the Kresge Foundation and the Schmidt Family Foundation. Map development was also supported in part by U.S. National Science Foundation grant ARC-1203415.
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The purpose of this web tool is to provide a picture of post-2100 sea level rise threatened by different levels of carbon pollution, in order to inform public and policy dialogues about energy and climate. It is not meant as a planning tool or as a prediction for any precise location. All data and maps are provided “as is” without any warranty to their performance, accuracy or suitability for any particular purpose. All risks associated with any results, decisions and/or performance of the data made available on this website are borne entirely by the user. For more information visit Disclaimer |Terms of Use.