The source of a major refugee crisis for the U.S.: the Gulf Coast and Atlantic Coasts have many low-lying areas that will be flooded by a 6 m/20 ft rise in sea level. This is approximately the same territory that was underwater 125,000 years ago when the earth warmed several degrees above our present global average temperature—and that's equal to the most optimistic of the predictions for twenty-first-century fever.

Long before sea level reaches that height again, storm surges will reach much farther inland and destroy the homes of many millions. In Florida alone, 15 million people will be affected.

11

Come Hell and High Water

> Indeed, its ever spiraling insurance bill resulting from severe weather events and its growing water shortages in the west mean that the United States is already paying dearly for its CO_2 emissions.
>
> —biologist Tim Flannery, 2006

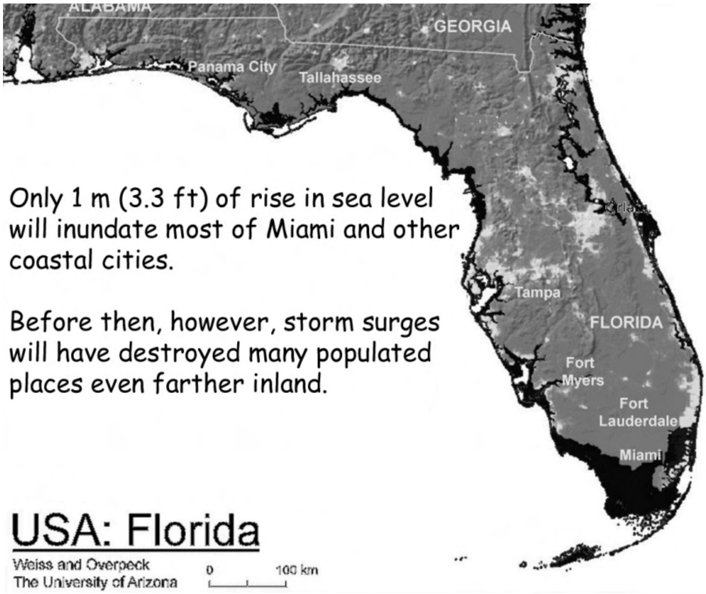
In terms of extreme weather events, it's worth noting that the United States already has the most varied weather of any country on Earth, with more intense and damaging tornadoes, flash floods, intense thunderstorms, hurricanes, and blizzards than anywhere else. With the intensity of such events projected to increase as our planet warms, in purely human terms the United States would seem to have more to lose from climate change than any other large nation.

Here I am going to address glacier-induced earthquakes and the speed of sea-level rise, but the shorelines illustrated in this chapter will mostly be those of the United States. I beg the indulgence of my international readers but, as you know, my country is most people's favorite candidate for the big country which has cumulatively contributed the most to the problem (though currently China adds more each year).

Let's start with the minimal sea-level rise for the twenty-first century, which is about 0.5 m (20 inches). The inundation is about two-thirds of that we'd get from a 1.0 m rise, given the way elevations rise near U.S. shorelines. And since most glaciologists I know think that the IPCC figure is an underestimate, I'll briefly mention what a 1 m rise will do.

About the first meter of sea-level rise will submerge the Maldives. Mali, the country's capital, is already a walled city. The country lost 10 percent of its land in the 2004 Indian Ocean tsunami. For scale, that's a cruise ship just behind the island, to the right of center.

It's the first meter (3.3 ft) that will destroy Miami and most coastal areas in Florida. Furthermore, the damage will occur in episodes such as storm surges, long before average sea level rises 1 m.



The black areas are those which are above sea level now but will be underwater later.

The insurance people talk of a "hundred year flood" and whether a community is protected against it. Communities with insufficient protection for a hundred-year flood are labeled as being in a flood zone—and so they pay more for insurance.

More than half of the U.S. population currently lives in counties located along the 20,000 km (12,000 miles) of coastline. Major cities such as New Orleans, Tampa, Miami, Baltimore, Philadelphia, New York, Boston and Washington, DC, will have to upgrade flood defenses and drainage systems. But are we going to build 8,000 miles of seawall along the Gulf and East Coasts?

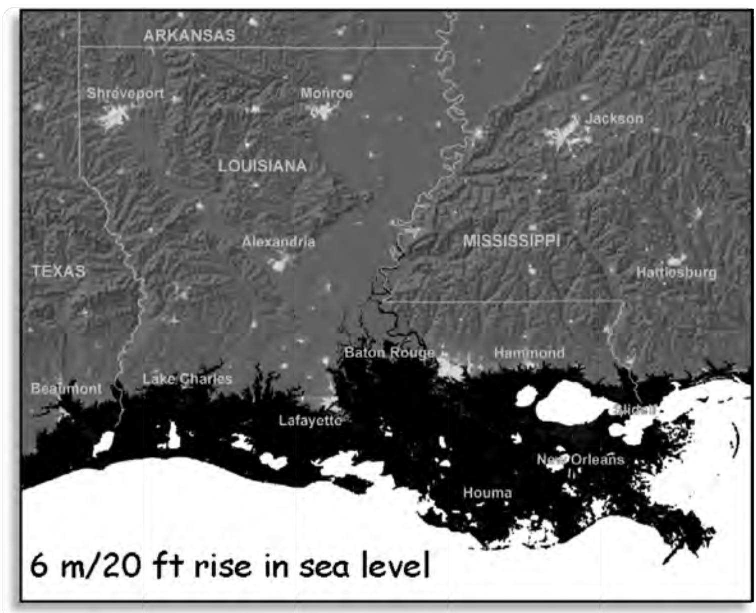
Storm surges that have occurred about every hundred years are going to become much more common, even for only a 1 m addition to sea level. For New York City, the hundred-year flood of the twentieth century will be experienced about every four years.

Now for the other end of the twenty-first century range of estimates, the 6 m / 20 ft of the last chapter. Most scientists who say 6 m is possible think that only 3 m of it could occur this century. But, since there has been a tradition of underestimates, I'll spell out the consequences of 6 m.

From home, I can walk down to the shoreline in a half hour—but I happen to live atop a hill over 100 m high, not likely to be flooded out. Yet like most Americans, I have relatives who live in places that will be ruined by a 6 m sea-level rise, such as out on the end of Cape Cod (the "arm" is going to be "amputated above the elbow" by rising sea level). Other relatives have a lovely new place on the Gulf of Mexico which will be totally underwater.

There's a sixth-floor family apartment in Florida which took a direct hit from three hurricanes in only two years. The bottom two floors of the building will be flooded. No more pool or parking lot. Initially I imagined looking down at a fleet of water taxis, maybe even gondolas a la Venice. Alas, the new shoreline would be miles away to the west and the building, exposed to the open ocean, would not last for very long before the waves pounded it apart. Perhaps we should put up posters in such areas, reminding people that where they stand was underwater the last time that the Earth ran a $3^{\circ F}$ fever.

Southern Florida is entirely gone when sea level rises by 6 m. Orlando loses its eastern suburbs. Most of the 15 million people now in fast-growing Florida will eventually find their property uninhabitable and worthless.



Louisiana will also lose its most heavily populated real estate and New Orleans will be permanently flooded. Chesapeake Bay will become twice as wide. Washington DC, New York City, and Boston will lose substantial areas unless massive earthworks are constructed.

William H. Calvin, GLOBAL FEVER (University of Chicago Press, 2008)

On page 133 is a simulated aerial view from Google Earth, looking west from Capitol Hill to the Washington Monument. The darkened overlay shows the inundation from a 6 m/20 ft rise in sea level, resulting from a $3^{\circ C}$ / $5^{\circ F}$ global fever. That's the White House at upper right.

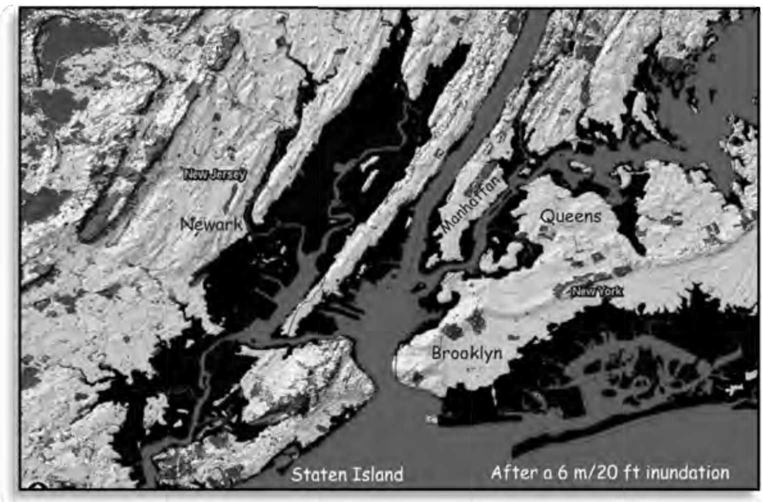
Storm surges will attack both Capitol Hill and the White House. Permanently flooded are most of the museums along the Mall, most war memorials, the National Academy of Sciences, and all of the major government buildings along Pennsylvania Avenue. Perhaps they will name the ruined swath for one of the party-now-pay-later politicians of the early twenty-first century who didn't take seriously the responsibility to future generations.

One can, of course, imagine that the Army Corps of Engineers will build giant dikes to channel the higher river, much like the ones looming over New Orleans that contain the Mississippi River. But I find it difficult to imagine continuous sea walls on open coastline all along the Atlantic and Gulf Coasts. And turning limestone into cement releases its carbon into the air—so both precautions and storm damage are likely to create more greenhouse gases, meaning that burning fossil fuels has to be reduced that much further.

Then there's New York City. Manhattan will lose half its width below Midtown. Queens and Brooklyn will lose substantial territory, as will western Staten Island. Large areas of New Jersey will be underwater, including Newark and Jersey City. All four major airports will be underwater, as will Yankee Stadium. Protecting Long Island's coastline from Brooklyn eastward is going to be difficult and expensive, requiring both dikes and storm barriers.

Even at the present sea level, there is similar vulnerability during a hurricane. "One of the highest storm surges possible anywhere in the country is where Long Island juts out at nearly right angles to the New Jersey coast. They could get 25 to 30 ft [about 8 m] of storm surge," said the director of the U.S. National Hurricane Center in 2006.

Proposals to build three storm surge barriers (and surely a fourth to protect Jamaica Bay and JFK airport), like the Thames Barrier in London, have gone nowhere even in the city of hedge funds where they ought to know about hedging their bets. A hurricane that came ashore somewhat north of Atlantic City, New Jersey, would most efficiently drive a storm surge right up the Hudson River.



But it isn't just hurricanes we have to worry about. Severe winter storms that sit offshore farther south create strong winds, initially out of the northeast (hence the name nor'easters). They can produce large storm surges. Unlike a hurricane whose storm surge is gone a few hours later, the spiral center of a nor'easter may sit there for days without moving, continuing to pile up water inland.

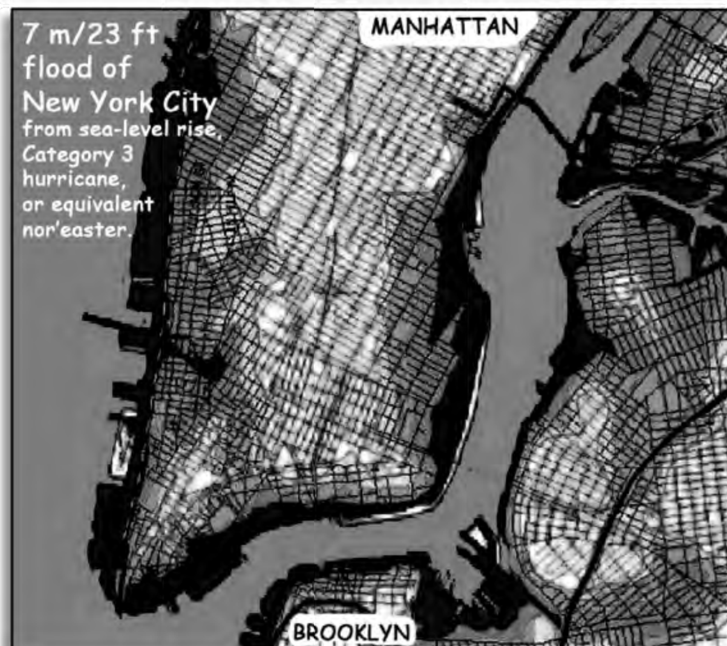
Like London, New York City has a great deal of underground infrastructure that is vulnerable to saltwater flooding now, and the floods will occur much more frequently later this century.

During the December 1992 nor'easter, ocean water flooded the Hoboken train station, short-circuiting the entire New York City subway system. It took ten days before service was fully restored.

If there are rivers behind them, surge barriers can only be closed for a short time. For example, the Thames begins to back up when the Thames Barrier is closed. This means that a constant sea-level rise must be handled differently, as when dikes are built inland along river banks to allow for a higher river.

"If just one flood broke through the Thames Barrier today, it would cost about £30 billion in damage to London, roughly 2 percent of the current UK GDP," observed Sir David King, chief science advisor to the British government.

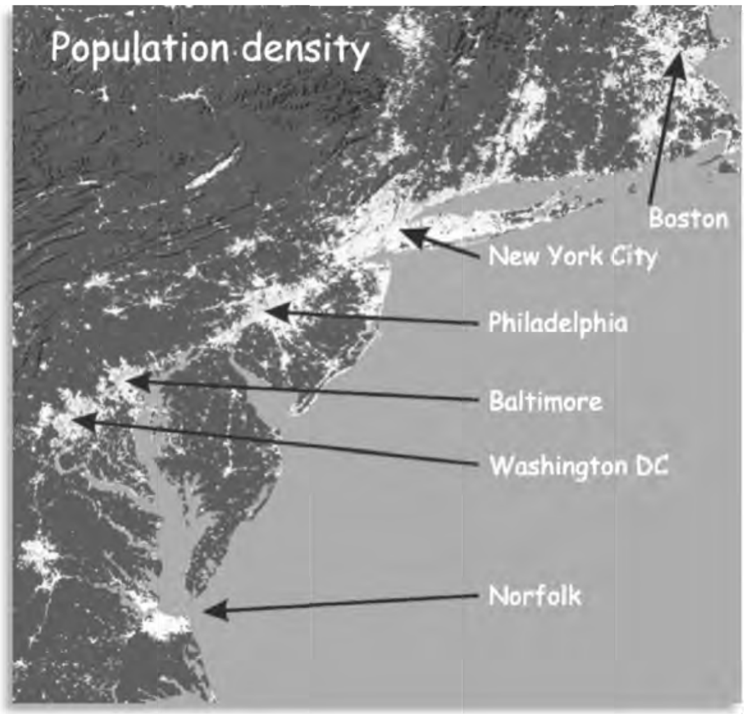

7 m
23 ft
sea level
rise
Lower Manhattan street level (World Trade Center, pre-2001)


7 m/23 ft
flood of
New York City
from sea-level rise,
Category 3
hurricane,
or equivalent
nor'easter.
MANHATTAN
BROOKLYN

Storm surges will be the immediate “cause of death” of the island nations without elevated land. Global warming from our pollution is what sets up the new high tide line, but battering waves will scour such islands long before high tide reaches the island’s high ground. It seems safe to predict that some climate change denialist will insist that the poor country was done in by a bad storm, not global warming.

To protect New York City and low-lying areas of New Jersey near the Hudson River, three Thames-like surge barriers have been proposed. A fourth could also protect Jamaica Bay and JFK airport, though it would also require a long seawall. Gray areas are the 100-year flood zones from before global fever.

The Thames Barrier is just downstream of Greenwich. This shows one of its smaller gates rotated into the upright position, blocking the storm surge from traveling farther upstream into London. The Thames Barrier is about 600 m wide; there is now a proposal to build a 16 km embankment, from Sheerness in Kent to Southend in Essex, containing similar gates to allow water to flow in and out of the Thames estuary.

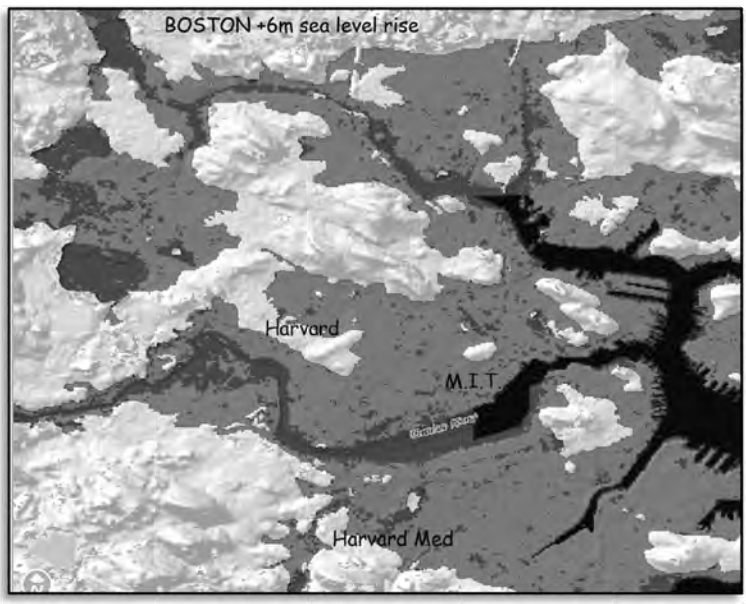


Population density (white dots) on the U.S. East Coast. The diagonal strip connecting Boston and Washington DC houses about one-fourth of the U.S. population. Economic disruptions in this corridor from hurricane (cyclone/-typhoon) storm surges would be widely felt elsewhere.

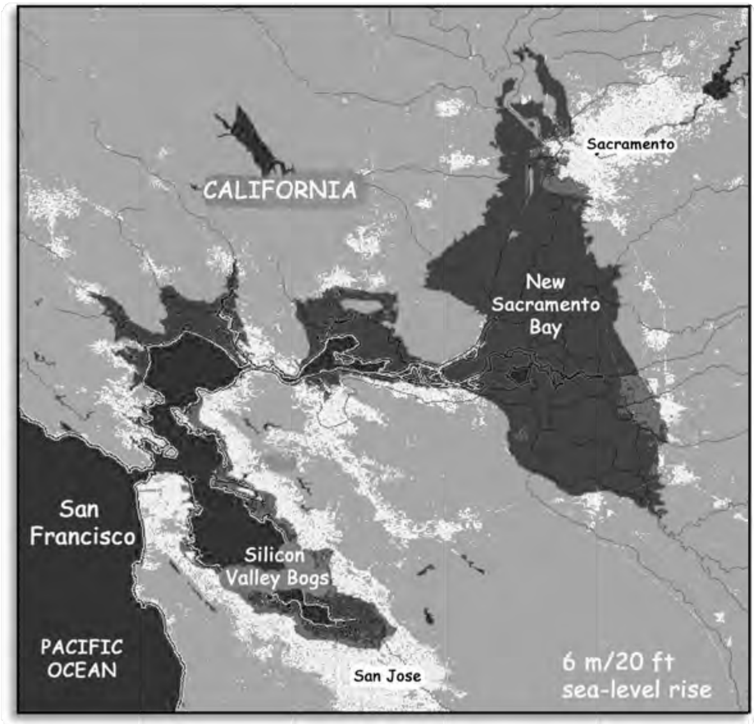
After a 6 m rise in sea level, many major population centers are partially flooded with saltwater (black areas). The Norfolk-Chesapeake-Newport area is underwater for about 50 km (30 miles) inland, continuing south into North Carolina and beyond.

That's Boston at top right; things don't look so bad on this scale of map.

But in fact eastern Massachusetts has a major problem when the sea rises 6 m/20 ft. The state capitol is still above it all on a new island, but MIT is underwater along with much of Boston. Harvard is waterfront on the new Harvard Peninsula (I used to live on its high point when I was at MIT and Harvard Medical School).



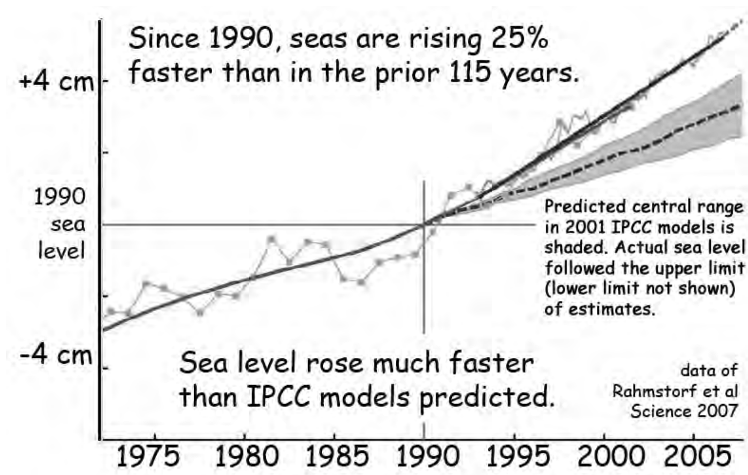
It isn't as bad on the west coast of North America because the shorelines rise more steeply. However, a mega version of San Francisco Bay will form, extending east into the Sacramento–San Joaquin delta. A large proportion of California's fresh water now flows through the delta; a salt disaster there would contaminate much of the drinking water for 32 million Californians and disrupt the world's seventh largest economy.



I have taken the privilege of naming some of the new marine features. New Sacramento Bay will be several times larger than the present San Francisco Bay. The Silicon Valley Bogs will enlarge San Francisco Bay to the south. Up north, some Napa Valley vineyards will become mangrove territory.

How soon can we expect the sea to rise by the entire 6 m? This century, the twenty-second, or just eventually?

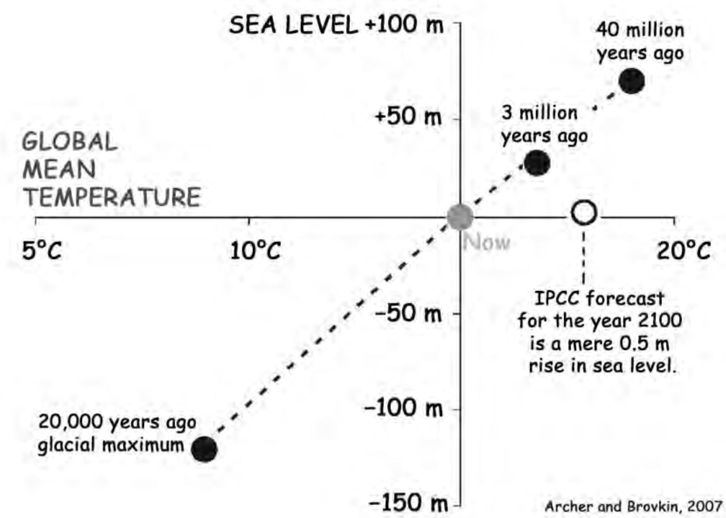
Most of the twentieth century rise in sea level was from the thermal expansion of the oceans and the melting of many mountain glaciers. In the 2007 IPCC projection for the twenty-first century, the annual rise in sea level is calculated from the thermal expansion of the warming oceans, to which is added a small amount from the summer melt of the surface layer of the ice sheets. For later this century, the estimate came out to about 0.3 m, just half again as much as the twentieth-century sea-level rise.



The Physical Sciences (WG 1) IPCC reports have a tendency to feature only what a giant spreadsheet can calculate. They downplay aspects for which no firm numbers can be attached because mechanisms are not yet understood.

Many climate scientists would say that the IPCC reports are too conservative, that they underestimate the trouble ahead for the policymakers who rely on the reports. As an example, they point to the model in the 2001 IPCC report which underestimated sea-level rise after 1990. And only the models' high-end predictions for temperature can match the actual data.

I suspect that the 2007 IPCC sea-level estimate of 0.3 m in this century is completely inadequate as guidance for policymakers. (A last-minute compromise was appended to the IPCC report that allowed that another 0.4 m could come from a faster melt of Greenland.) But 0.7 m doesn't add up to the 3 m this century that many climate scientists are worried about, just because of what's happened before. This shows the eventual sea level rise for past temperatures:



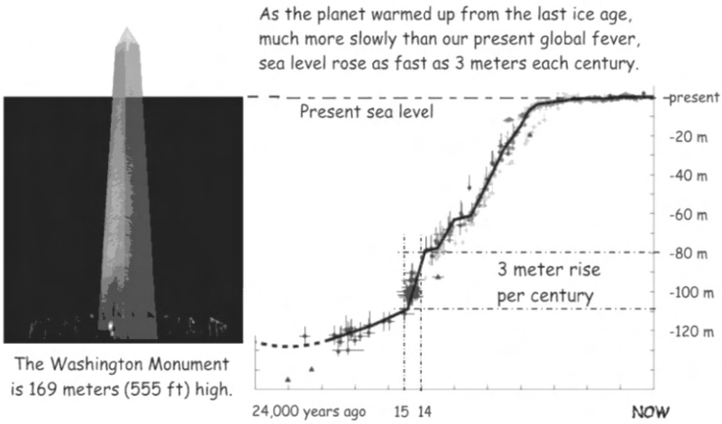
The diagonal line estimates the history of sea-level change as global temperature slowly varies. It suggests that a 3°C fever will eventually raise sea level by 50 m. That's only a hundred times more than the IPCC forecast for this century.

To flood coastlines worldwide, ice sheets don't have to melt in place. They only have to melt enough to grease the skids. Think collapse, not melt. Most of the sea-level rise may instead come from ice being pushed off the land into the ocean. A little melting can quickly lead to a lot of sea-level rise.

It is said that a 6 m sea-level rise won't happen as quickly as Greenland's temperature rises by 3°C (which will only take a 1.5°C rise in global temperature, likely to occur this century). But we don't know how fast Greenland will collapse, having neither a comparable collapse in the climate records nor a tested dynamic model of collapse. It's clear, however, that the hills and valleys underlying an ice sheet can play a crucial role in slowing collapse, by pinning the bottom of the ice sheet.

The current data isn't good enough to say how fast it rose 125,000 years ago, but when the last ice age melted off, it rose as fast as 3 m per century. Of course, it was then warming up more slowly than now, as the Milankovitch factors slowly crept along to produce hotter summers at the latitude of the Canada's, Greenland's and Scandinavia's ice sheets.

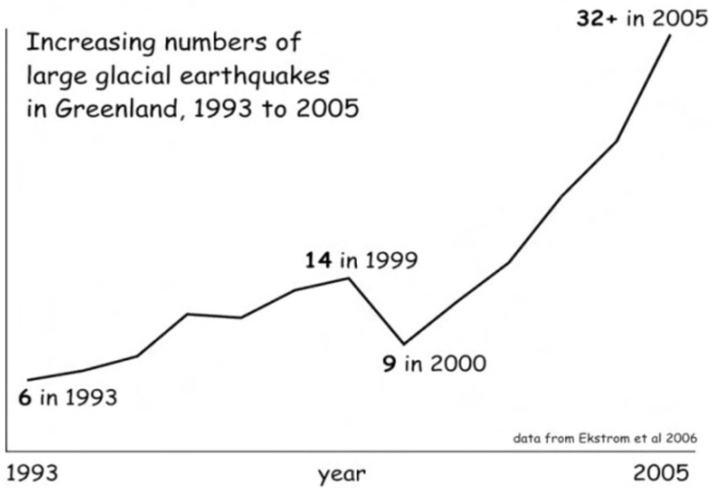
That means that our projected global temperature rise of 2 to 6°C during the twenty-first century is at least ten times faster than back then—so we will likely see faster melt-offs in both Greenland and Antarctica as the Earth spikes a fever. We might even see collapse happen in new ways. I may hope that the sea-level rise is only 0.3 m this century as in the 2007 IPCC report, but it would be foolish to count on it.



Had the Washington Monument been built near sea level 22,000 years ago, the bottom 130 m would now be underwater. The worry is that the present rate, 0.3 m per century, will increase as Greenland collapses. The speed record, 3 m per century, is thought to have had a major contribution from the collapse of ice shelves in Antarctica.

However, our current warming is also proceeding ten times faster than back then and collapse mechanisms may be sensitive to this speed. So, while you should take seriously the estimates of sea-level rise itself (6 m/20 ft), all bets are off regarding how soon. No scientist is going to be able to say, “We’re still safe for a century,” even though we’ll still see newspaper headlines like the Dutch one after the 2007 IPCC report was issued, saying “We’re Safe!”—

based on, of course, that conservative sea-level rise estimate of 0.3 m.



Earthquakes are occurring under the major outlet glaciers from Greenland's central ice sheet. Quakes increased in the late 1990s—and that was followed by a rapid increase from 2002 onwards.

Perhaps they come from the ice briefly lurching forward and cracking, or perhaps breaking off protruding bedrock. Between the mid-1990s and 2005, their numbers doubled and then doubled again. In the same decade, ice flow measurements from radar showed that the yearly amount of ice exported as icebergs had doubled by one estimate, tripled by another.

If all this can happen with less than 0.8°C of warming since 1910, what will 3°C bring? Such dynamics only emphasize that the present computer models may underestimate the trouble ahead. All that most people have heard about so far—if they've heard anything—has been based on the gradual extrapolation of present trends, not the more realistic scenarios. No one should count on the current melt being slow. When systems flip into new modes of operation, all bets are off.

I hope that it's obvious by now that serious sea-level rise is not controlled primarily by thermal expansion and by melting the ice surface at some predictable rate.

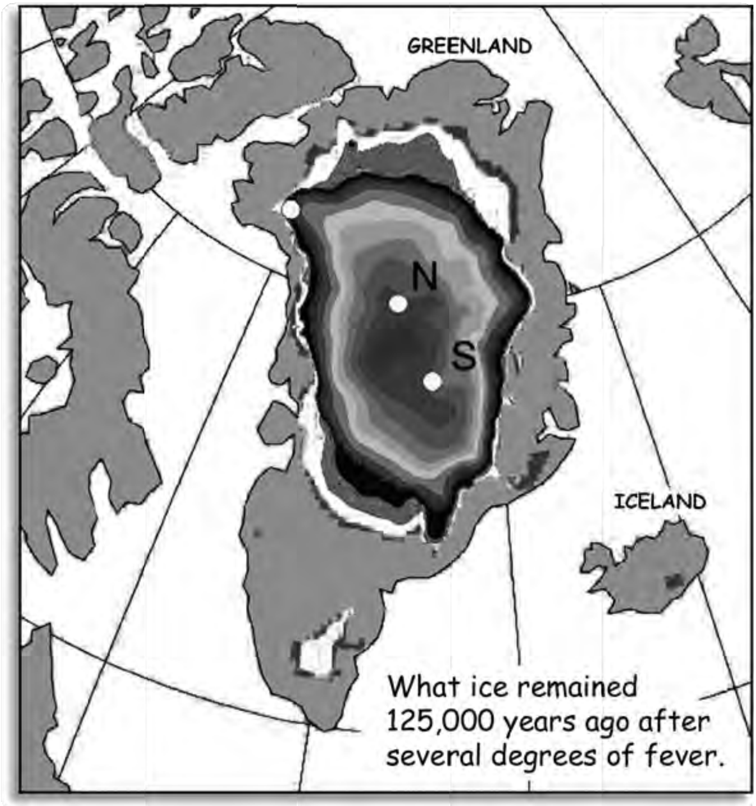
Rather, it is a matter of ice getting pushed off the land and instantaneously raising sea level. And how quickly ice gets pushed off the land depends on the ice mountain pancaking, spreading out sideways like that melting ice cream scoop on the sidewalk.

That in turn depends on what accelerates collapse, such as those water blisters that can form under the shoulders of the ice mountain, which create rotten ice and perhaps float the ice over obstacles.

This seems pretty obvious now, but in the IPCC reports, sea-level rise has been portrayed as slow, just one drip after another atop thermal expansion. It makes one wonder about how many other obvious things we are currently missing. Climate science is still a young science, akin to what neurophysiology was like in 1950 before positive feedback mechanisms were understood.

"May you live in interesting times" was an ancient Chinese curse, though I doubt that the collapse of Greenland or Antarctica was what they had in mind.

> With structural famine gripping much of the subtropics [at a 2.5°C fever], hundreds of millions of people will have only one choice left other than death for themselves and their families: they will have to pack up their belongings and leave. The resulting population transfers could dwarf those that have historically taken place due to wars or crop failures. Never before has the human population had to leave an entire latitudinal belt across the whole width of the globe.
>
> Conflicts will inevitably erupt as these numerous climate refugees spill into already densely populated areas. For example, millions could be forced to leave their lands in drought-struck Central American countries and trek north to Mexico and the United States. Tens of millions more will flee north from Africa towards Europe, where a warm welcome is unlikely to await them—new fascist parties may make sweeping electoral gains by promising to keep the starving African hordes out.
>
> Undaunted, many of these new climate refugees will make the journey on foot, carrying what they can, with children and old people trailing behind. Many of them will die by the wayside. Uprooted, stateless, and without hope, these will be the first generation of a new type of people: climate nomads, constantly moving in search of food, their varied cultures forgotten, ancestral ties to ancient lands cut for ever.
>
> —the writer Mark Lynas, 2007



Nearly all of Greenland is presently covered by ice. The overlay shows the ice that remained after the last time that local temperature rose about 3°C . This occurred 125,000 years ago. **S** is the summit of Greenland where a pair of deep ice cores were taken in 1993; **N** is the site of another, slightly deeper, ice core.

Unfortunately, it only takes a 1.5°C rise in the global average temperature to produce a 3°C rise in Greenland—and 1.5°C is the smallest, most optimistic greenhouse warming estimated for the twenty-first century. The sea-level rise may take longer but it reaches more than 6 m / 20 ft. It may also happen more quickly than 2100 if enough ice slides into the ocean.

GLOBAL

How to Treat Climate Change

FEVER

William H. Calvin

The University of Chicago Press
Chicago and London

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