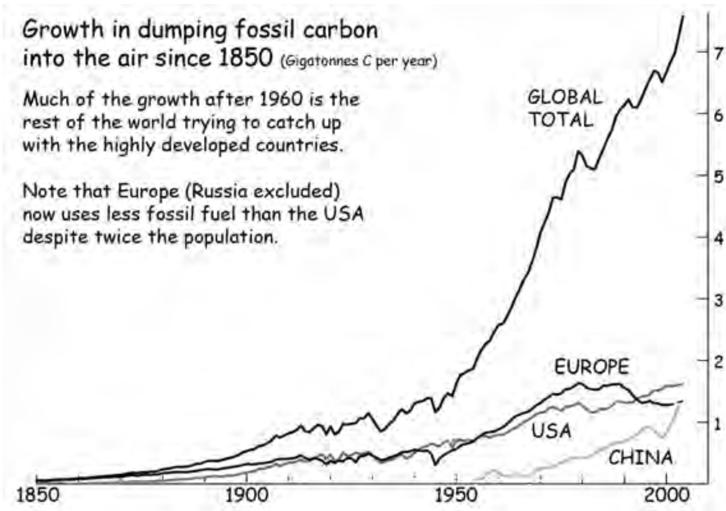
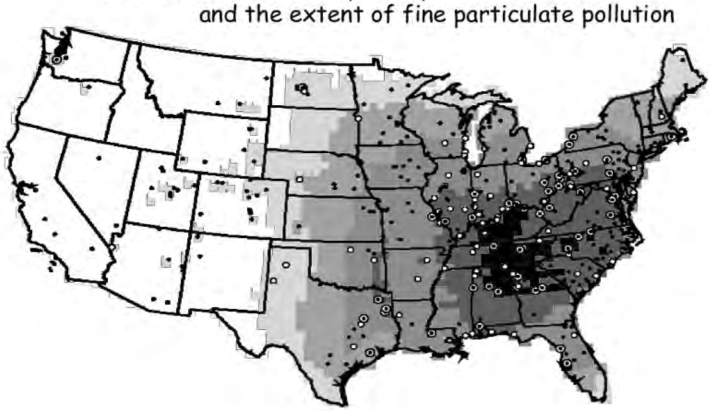


Location of coal-fired power plants in the U.S.
and the extent of fine particulate pollution



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

10

Slip Locally, Crash Globally

> Greenland is a different animal from what we thought it was just a few years ago. We are still thinking it might take centuries to go, but if things go wrong it could just be decades. Everything points in one direction, and it's not a good direction.
>
> —glaciologist Richard Alley

The common notion is that ice sheets build up, layer by layer, when it's cold. And that the reverse process works the same way, the sunshine melting the ice surface and slowly eating down through the accumulation. And so sea level slowly rises over the centuries.

Surface runoff and thermal expansion of the oceans is what, for the most part, is used to estimate sea-level rise in the 2007 report of the Intergovernmental Panel on Climate Change (IPCC), the major international body that evaluates the science for policymakers.

But this is seriously incomplete. It is merely the part of the problem which can be computed. Unfortunately, Greenland and Antarctica are big mountains of ice. Like a pancake, the melting ice sheet spreads out. An even better analogy is a scoop of ice cream fallen on the sidewalk. As it melts, the height goes down and the sides expand. That's what was happening the last time that ice sheets covered up Seattle and plowed into New York's Central Park. But most of the present-day ice sheets are close to saltwater and, when ice reaches the shoreline, it is pushed into the water and instantly raises sea level—even without melting. The dynamics of iceberg production are very different from those of melting in place.

The speedups in Greenland outlet glaciers—doubling and redoubling before 2006—were primarily from the removal of obstructions to downhill flow. A glacier may plow into the ocean without floating, perhaps freezing to the bottom. But terminal melting occurs because the sea water is warmer. Further, the sea water starts digging farther under the glacier's snout, dissecting back to form an ice shelf. Tides now lift and drop the overhang, opening up a hinge of fractured ice—and so eventually another iceberg breaks off and sets sail. The warmer the sea water, the faster this occurs, and so the faster the rest of the ice can flow downhill. That's primarily what's been going on.

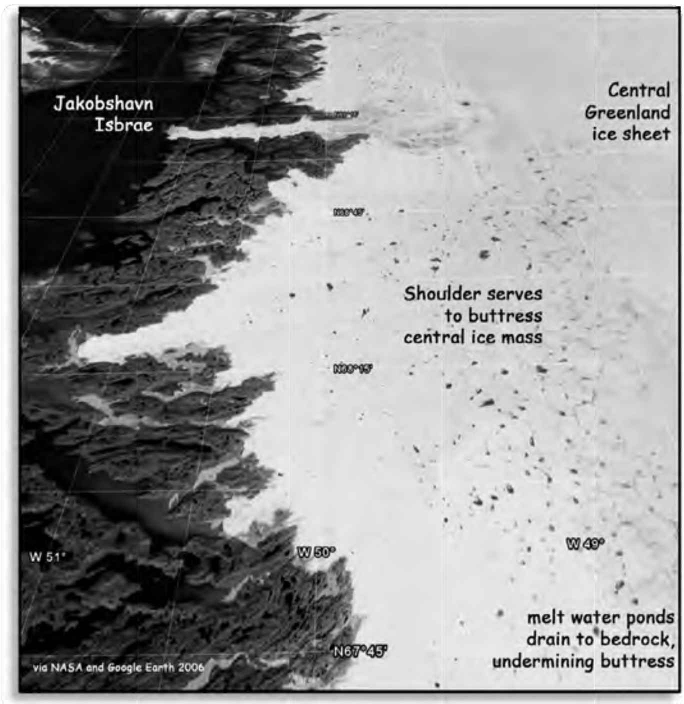
But if you fly over the Greenland ice cap (any summer nonstop between northern Europe and Vancouver, Seattle, or San Francisco will do, or you can use Google Earth), you will see a series of pretty blue lakes forming which are capable of speeding Greenland's collapse. Leading away from a nameless lake, you will see a nameless creek—that abruptly ends. That's because it found an express route to the bottom of the ice cap. Such a vertical channel, called a moulin, forms the world's tallest waterfall.

The water greases the skids, serving to float the ice sheet downhill to the ocean, where icebergs export the melting job to warmer places. When that happens, Greenland will not be merely melting, but collapsing. It will be like a runaway ice-cube machine.

Greenland melt water lake, draining down a crevasse. Some large lakes have disappeared overnight. (Photo by WHOI oceanographer Sarah Das, 2003).

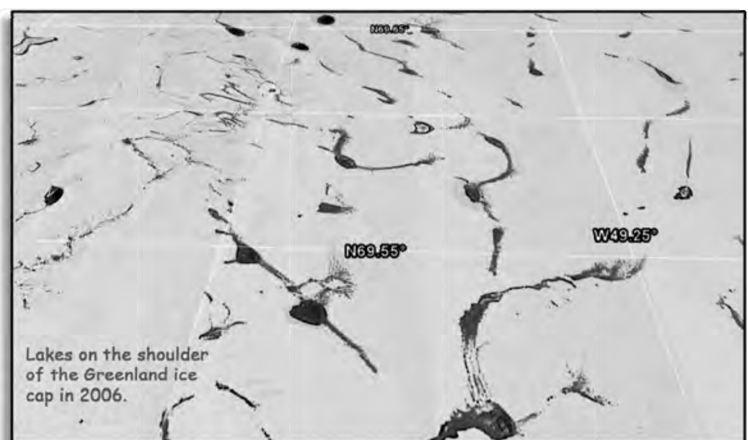
The ponds are located at the lower elevations where the temperature rises above freezing in the afternoons. And so the ponds and moulins are well positioned to affect the outlet glaciers that serve to buttress the central ice cap. Collapse the buttresses, and the rest can start flowing.

No amount of subsequent cooling can undo this structural damage to the base of the ice sheet. Stopping the melt will not stop the collapse and the iceberg production, though it can slow it somewhat.



Looking north above the west coast of Greenland. Because the summers have gotten hot enough (this shows 2006), the shoulders of the central Greenland ice mass are now covered with pretty blue lakes of melt water. They drain to bedrock and some of the water may become trapped underneath, like a blister. Enough such blisters would set up a collapse that would quickly push a lot of ice off the island, raising sea level long before it actually melted.

Some of the water under the ice sheet refreezes. That's what traps the rest of the water and keeps it from later shooting back up the hole like a geyser. If the trapped water comes under pressure from glacial movement, it may not refreeze. That's because liquid water has to expand when transforming into a solid form. With all that weight of the ice sheet bearing down from above, the trapped water remains supercooled. Soon part of the ice sheet is resting on a liquid cushion (rather like a blister on your foot), floating above the rock whose surface irregularities, called pinning points, usually anchor the ice sheet to the bedrock. (This process hasn't yet been studied in Greenland's moulins, but there are good studies in Iceland where the trapped water was melted on the bottom farther uphill by volcanic hot spots.)



Close-up of the shoulder's melt water lakes, each with its own vertical drain to bedrock. Richard Alley notes that because water is 10 percent heavier than an equal volume of ice, "Water-filled cracks, more than a few tens of meters deep, can be opened easily by the pressure of water. Ponding of water at the ice surface increases the water pressure, wedging cracks open."

Normally, ice flows by deforming midlevel ice, with the foundation staying stuck on the pinning points, like the spreading batter on a waffle iron. Unstuck and lubricated, the base of the ice sheet can now spread out like ice cream on a dish.

And so the ice mountain surges out at the edges at speeds that can reach a mile a month. I once thought that glacial advance meant that the ice was building up. True enough when an ice age begins, but most of the glacial advances in the world today are from breakup's pancaking.

What if it now cools down and no more pretty blue ponds form on the surface of the ice sheet? Surely, you say, that supercooled water forming the cushion will become lost over the years and the ice will settle back down on bedrock. Maybe, but by that time, the base of the ice will have been destroyed in other ways. As ice moves over bumps, cracks open up and the water, under very high pressure, jets into the openings and cuts channels. The friction from this heats up the place, making more holes to jet into.

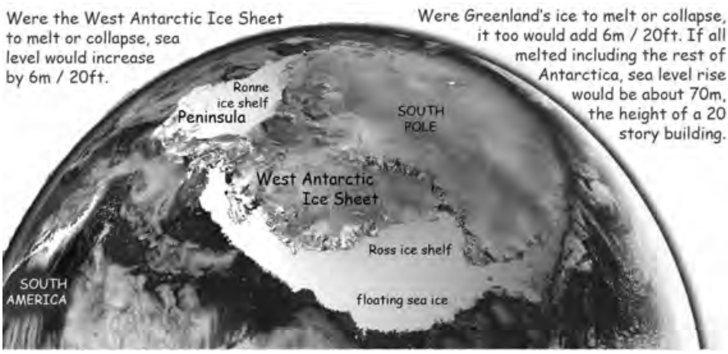
This process shatters the ice and turns the base into really rotten ice, the stuff that climbers hate for good reason. It is easily broken and nothing like the hard ice of the original base that was conveniently frozen to the irregular bedrock. Think of it as rotting away the foundations of the ice sheet.

So there is a legacy of the pretty blue ponds created by atmospheric warming. If the ice sheet is near a coastline, ice falls into the ocean in big chunks and sea level rises, a process which is much faster than Greenland melting in place.

Greenland's largest outlet glacier, draining 7 percent of the central ice sheet, is Jacobshavn Isbrae on the west coast. It's one of the galloping glaciers of Greenland, having doubled its speed between 1997 and 2003. The glacier itself is in the far background; what you see is the fjord, the icebergs, and the floating ice that is emerging into Baffin Bay. (Photograph by the glaciologist Koni Steffen.)

The water level in a glass of iced tea doesn't change when the ice melts. Ice shelves in Antarctica, when they break lose, get a lot of press. Then we see another round of talk-radio disinformation that suggests the scientists must be pretty dumb not to recognize that it doesn't change sea level by even an inch, ha-ha.

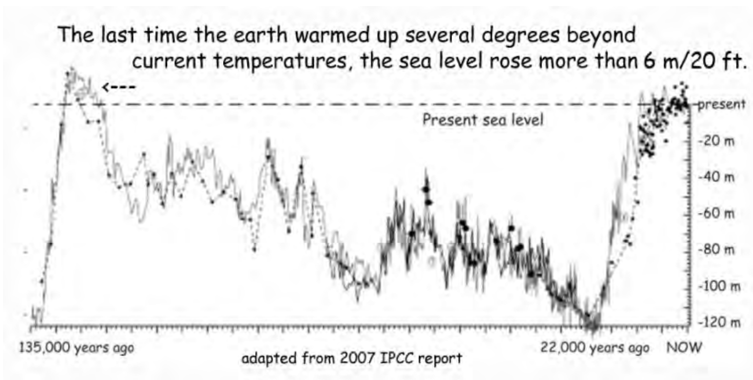
I used to be more understanding of this, reasoning that perhaps they didn't read far enough to realize that the big issue was making room for more ice to slide downhill, a plug having been removed. The crafters of disinformation always leave that out.



Saltwater can get beneath ice shelves and unstick them from the bottom, exposing them to the tides every day, and eventually breaking them up. While this doesn't raise sea level directly, it is like uncorking a bottle. The ice streams uphill now meet less resistance and speed up. More of the ice sheet is pushed into the sea, instantly raising sea level. (Image adapted from NASA's "A Tour of the Cyrosphere.")

Collapse, not melt, is the operative concept. The sea level is rising, mostly from thermal expansion but increasingly from ice additions. How fast that happens is, I suspect, largely a function of ice sliding sideways, not melt rate itself.

In the past, how fast did sea level rise? Climate scientists now have good records of the ups and downs of sea level for many millions of years. The downs are due to giant ice sheets slowly building up in the higher latitudes. The ups can be much quicker, thanks to collapse. The sea level fluctuates by about 130 m during an ice age. That's the height of a forty-story building.



When a lot of water was taken out of circulation and piled up as ice sheets at high latitudes in Alaska, Canada, Greenland, Scandinavia, and Antarctica, the oceans weren't as full as today. That exposed a lot of new real estate, much of which turned green. The cooler oceans also grew more phytoplankton, the little photosynthesizing plants at the bottom of the food chain known as marine algae. The high winds added more dust to fertilize their growth. The productivity increase helped haul down the CO_2 by one-third—and that's about what we need to do today to reverse climate change.

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

Later, when things warmed up starting about 15,000 years ago, some of that ice melted and the sea rose to near its present level by about 7,000 years ago. That's how we got our present shorelines and that's when complex human societies got started.

This rewarming occurred because the summers were hotter in the higher latitudes. The earth's axis was then tilted more than it was this last time around, putting the sun higher in the sky when beaming down on Greenland. While the winters were also colder up there, this didn't balance out the hotter summers. Even when more snow falls in winter, the summer days get hot enough to melt the surface and turn it gray, enabling three times as much heat to be absorbed rather than being reflected back out into space.

As skiers know, if the daytime temperatures get up above freezing, even for a day, the subsequent skiing will be inferior until it snows again—but at least the glare isn't so bad. In an era of global fever, glare is good.

> These [rapid Greenland ice] flows completely change our understanding of the dynamics of ice sheet destruction. We used to think that it would take 10,000 years for melting at the surface to penetrate down to the bottom of the ice sheet. But if you make a lake on the surface and a crack opens and the water goes down the crack, it doesn't take 10,000 years, it takes ten seconds. That huge lag time is completely eliminated.
>
> The way water gets down to the base of glaciers is rather the way magma gets up to the surface in volcanoes—through cracks. Cracks change everything. Once a crack is created and filled, the flow enlarges it and the results can be explosive. Like volcanic eruptions. Or the disintegration of ice sheets.
>
> —glaciologist Richard Alley

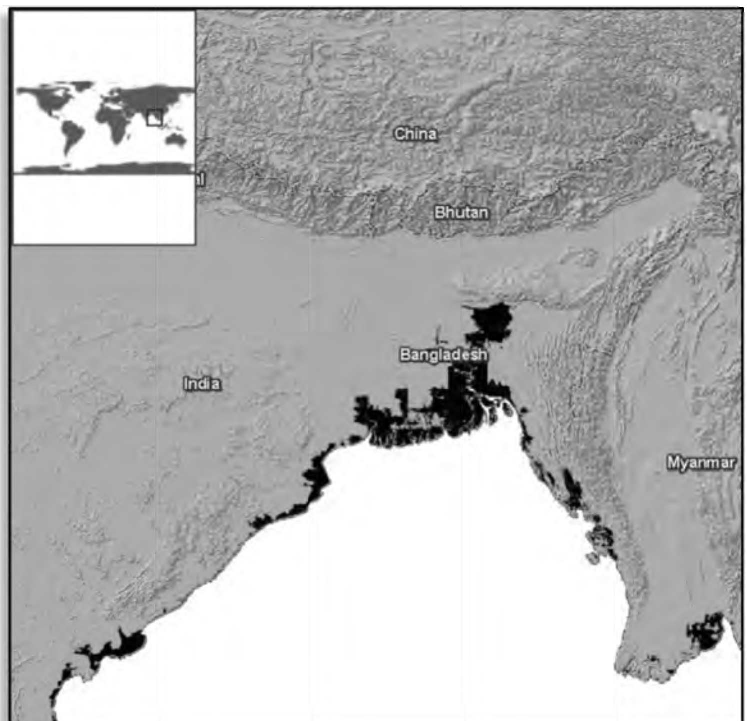
When things overheated several degrees about 125,000 years ago, much of Greenland melted and sea levels became at least 6 m higher than today, maybe 8 to 10 m judging from the coastal records from Brazil. That's probably an underestimate—I've seen estimates of 25 m for sea-level rise over the next century or two. It depends on how much the West Antarctic Ice Sheet contributes. It has two large ice shelves that could shatter much like Larsen B did in 2002. That would uncork the ice uphill.

But first let's take a look at what a mere 6 m rise in sea level will do to all of the people who live near the seashore. More than a third of the world's population now lives within commuting distance of the shoreline. Seven of the ten largest cities are situated on coastlines threatened directly by rising sea levels: Tokyo (34 million people, as many as all of California), New York, Sao Paulo, Mumbai (formerly Bombay), Los Angeles, Shanghai, and Jakarta (17 million). New Orleans and Miami are far down the list.

A lot of people live on river deltas, right on the front line of sea-level rise. The Netherlands, on the delta of the Rhine, has become the world's most densely inhabited country. Bangladesh is the fifth most populous country in the world with 144 million people, half living on the flood plain of the Ganges.

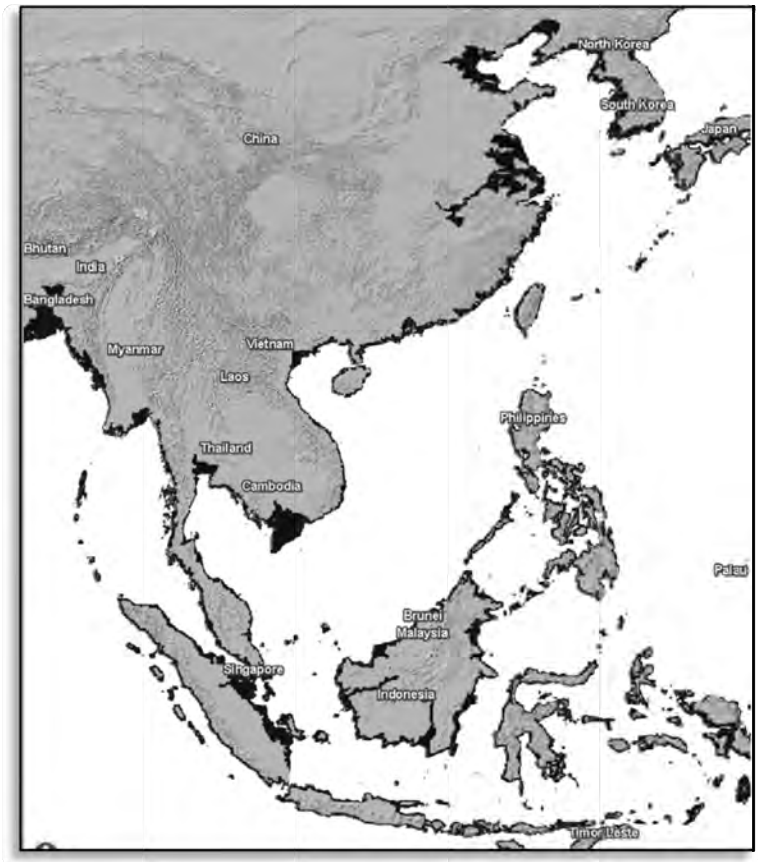
This analysis only addresses the creeping physical changes, not the associated societal leaps backward that result from resource wars and genocides. Climate change has been a major driver for wars and rebellions. In the pre-fossil-fuel-fiasco era, a cooling climate doubled their numbers in eastern China. In the present era of rapid warming, some of the same mechanisms will operate: instead of a shortened growing season from cooling, we'll see warming and drought eliminate that second crop per year.

Local slips, especially in Greenland and West Antarctica, have the potential to crash human populations.



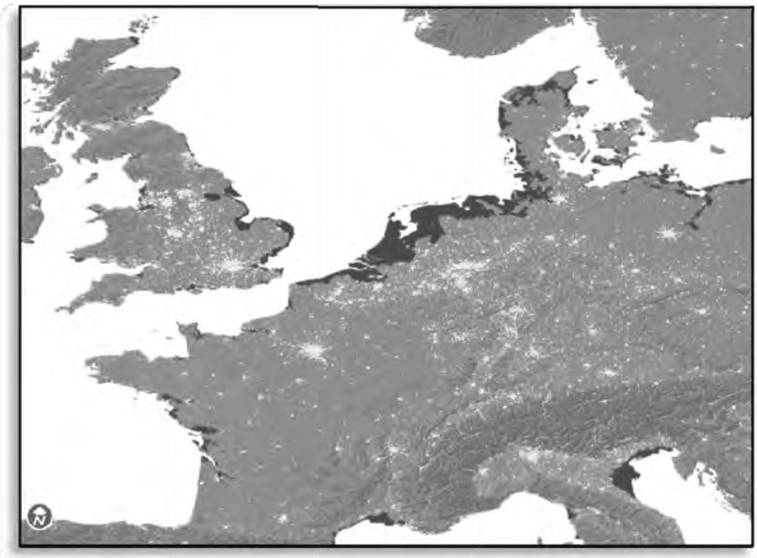
Much of Bangladesh, along with Calcutta in India, will be permanently flooded by a 6 m rise in sea level. This will displace seventy million people in a region already densely populated..

Bangladesh would lose 17.5 percent of its territory to a 1-m rise in sea level, displacing at least 13 million people.



With an extra 6 m, the major river deltas of Asia are underwater. They are heavily populated areas.

On China's river deltas, 72 million people would be threatened with increased coastal flooding by a 1-m sea level rise. Egypt and Vietnam, two other developing countries with large, unprotected river deltas, each have eight to ten million people living within 1 m of high tide.



The entire North Sea coastline of Western Europe is severely challenged by a 6 m rise in sea level, as is Venice and parts of the English and French coastline.

The Dutch control flooding from the Rhine by dikes but storm surges arrive on the northern coastline. The surges from the North Sea storm of 1953 flooded extensive areas of the Netherlands and the Dutch have since built a barrier system like that seen on the River Thames, which keeps London from temporarily flooding. The light areas are population centers (a 6 m rise covers the dark areas; you can still see the population dots as gray areas within the dark areas).

Most of the sea-level maps were produced with the digital elevation mapping software at the University of Arizona, thanks to Jonathan Overpeck and Jeremy Weiss.

The Netherlands is the most densely populated country in the world today. Land reclamation is a centuries-old practice. The Dutch meticulously construct coastal defenses to a 10,000-year storm standard and carefully restrict development. They will likely keep adding to their sea-wall system. If the dikes were to fail, this is what a 6 m rise in sea level would do to low-lying areas of the Rhine delta.

GLOBAL
How to Treat Climate Change
FEVER

William H. Calvin

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