The Secret of Sea Level Rise:
It Will Vary Greatly by Region

As the world warms, sea levels could easily rise three to six feet this century. But increases will vary widely by region, with prevailing winds, powerful ocean currents, and even the gravitational pull of the polar ice sheets determining whether some coastal areas will be inundated while others stay dry.

BY MICHAEL D. LEMONICK

For at least two decades now, climate scientists have been telling us that CO2 and other human-generated greenhouse gases are warming the planet, and that if we keep burning fossil fuels the trend will continue. Recent projections suggest a global average warming of perhaps 3 to 4 degrees C, or 5.4 to 7 degrees F, by the end of this century.

But those same scientists have also been reminding us consistently that this is just an average. Thanks to all sorts of regional factors — changes in vegetation, for example, or ice cover, or prevailing winds — some areas are likely to warm more than that, while others should warm less.

What’s true for temperature, it turns out, is also true for another frequently invoked consequence of global warming. Sea level, according to the best current projections, could rise by about a meter by 2100, in large part due to melting of the Greenland and West Antarctic ice sheets. But that figure, too, is just a global average. In some places — Scotland, Iceland, and Alaska for example — it could be significantly less in the centuries to come. In others, like much of the eastern United States, it could be significantly more.

And among the most powerful influences on regional sea level is a surprising force: the massive polar ice sheets and their gravitational pull, which will lessen as the ice caps melt and shrink, with profoundly different effects on sea level in various parts of the globe.

If the idea of local differences in sea level comes as a surprise, it’s probably because the experts themselves are only now beginning to fully realize what might cause such differences, and how significant they might be. One factor, which they’ve have been aware of for decades, is that the land is actually rising in some places, including northern Canada and Scandinavia, which are still recovering from the crushing weight of the Ice Age glaciers that melted 10,000 years ago. That makes sea-level increases less than the global average would suggest, since these land areas are rising a few millimeters a year.

Around the periphery of where the glaciers sat, by contrast — places like Chesapeake Bay and the south of England — the land was actually squeezed upward during the Ice Age by the downward pressure nearby. The resulting “glacial forebulge” has been sinking back ever since, also at an average rate of a few millimeters a year, so sea level rise is greater than average in these regions.

And in some coastal areas — most notably along the Gulf of Mexico in Louisiana — the land is falling as well: Thanks to massive oil and gas extraction, the continental shelf is collapsing like a deflated balloon. “The rate of subsidence measured at Grand Isle, Louisiana,” says Rui Ponte, of the private consulting firm Atmospheric and Environmental Research, Inc, “is
The polar ice caps keep sea level higher for thousands of kilometers around both land masses.

almost 10 millimeters per year, compared with two or three in other areas.” That’s especially problematic for a city like New Orleans, which already lies partly below sea level.

Ponte said that these local instances of rebound or subsidence will subtract or add a couple of inches to the global increase in sea level over the next century, depending on the region.

A bigger effect will come from changes in prevailing winds, which can push water consistently toward the land or keep it at bay. The trade winds that blow west across the tropical Pacific, for example, move water in the same direction, boosting average sea levels by as much as 24 inches on the western side of the ocean — in places such as the Philippines — compared with those in northern South America. If those winds shift with climate change, so would local sea levels.

Ocean currents can also create significant local effects. During preparations for the Intergovernmental Panel on Climate Change’s Second Assessment Report back in the mid-1990s, Ronald Stouffer — a climate modeler at the U.S. Geophysical Fluid Dynamics Laboratory in Princeton, NJ — and several colleagues were comparing projections of regional sea-level rise from different models.

“They were splattered all over the place,” he recalls, “and the differences had no rhyme or reason. We speculated that they had to do with differences in how the models treated changes in the prevailing winds.”

But a little more than a year ago, Jianjun Yin, now at Florida State University, suggested that it might be something else: a weakening of the “overturning” that drives major ocean currents. In the Atlantic, it works like this: Warm surface water — the Gulf Stream — flows north and east until it reaches the area between the United Kingdom and Greenland, where it cools, thus becoming denser, and sinks. It flows south and west, deep below the surface. Eventually, it rises again, warms, and heads back north.

If any part of this flow is significantly interrupted, the current will slow. Global warming has the potential to do just that, in two ways. First, a warmer North Atlantic won’t let the surface water cool so easily, interfering with its tendency to sink. Second, fresh water from Greenland’s shrinking ice cap dilutes the surrounding waters; since fresh water is less dense than salty water, there’s a further impediment to sinking.

Since the Gulf Stream warms northern Europe, the slowing could cool that part of the world. But the slowing would also force water to pile up behind what amounts to a partial blockage of the overturning current. That could force sea level along the U.S. coast to rise another 8 or so inches over the next century beyond the global average, given a medium-emissions scenario.

When he first heard about this idea, says Stouffer, “it was one of those ‘duh’ moments for me. I said, ‘Yeah, that makes sense.’” He ended up co-authoring a paper that appeared in Nature Geoscience last March, laying out the argument.

Then, however, Stouffer experienced another “duh” moment. “I’m somewhat embarrassed by that paper,” he says, “because here we were focused on this relatively little problem, and there’s this great big gorilla in the room, and I missed it. But I had a lot of company.” (This last point is crucial: Stouffer is among the most experienced and respected modelers in the world, so a “duh” moment for him means the surprise is widespread.)

The gorilla Stouffer refers to — an effect so large that it overwhelms the others — is something called the geoid. It’s an imaginary surface that maps the strength of Earth’s gravitational field, and it’s as bumpy as the surface of
mass, its pull on the surrounding ocean will lessen. The actual planet. Orbiting satellites don’t move around the Earth in perfect circles, or even perfect ellipses; their height changes when they go over the extra gravity exerted by a mountain range, and changes again when they orbit over a valley.

And because water is a liquid, the surface of the sea is also warped to follow the contours of the geoid. The extra gravitational attraction of an undersea mountain range pulls water toward it, creating a literal, permanent bump on the surface of the sea, while the deficit of gravity near an undersea valley creates a depression in the water up above.

The same sort of thing happens when there’s an excess of mass on land that lies near the ocean. A coastal mountain range pulls the water in its direction, raising sea level nearby. So do the massive icecaps that smother Greenland and Antarctica. Indeed, Antarctica’s polar ice sheet is so massive that it is three miles thick in places and covers an area one-and-one-half times the size of the United States, including Alaska.

These polar ice caps are Stouffer’s gorillas. They keep sea level higher than it would otherwise be for thousands of kilometers around both land masses, and correspondingly lower elsewhere.

If the polar ice sheets shrink, though — as they’re currently doing, especially in Greenland and West Antarctica — their gravitational pull weakens and so does their hold on the surrounding water. About a year ago, Jerry Mitrovica, a geophysicist who teaches an entire course on sea level at Harvard, co-authored a paper in *Science* that laid out what would likely happen if the West Antarctic ice sheet, the smaller of the two sheets that cover the Antarctic continent, were to melt. (Like a complete shutdown of the Gulf Stream, this is not considered likely anytime soon. But recent satellite measurements have shown that glaciers that drain the ice sheet have begun moving faster toward the sea).

If you simply spread the resulting increase in sea level evenly around the world, it would amount to about 5 meters’ worth. But the ice sheet’s gravity is currently keeping sea level artificially low in the Northern Hemisphere, so if it disappeared, the actual increase along the U.S. mid-Atlantic coast would be more like 6.3 meters. In other words, as the West Antarctic Ice Sheet melts and loses mass, its pull on the surrounding ocean will lessen. Seas will drop around Antarctica and parts of the Southern Hemisphere, and that water will be displaced to more northerly areas, such as the east coast of the U.S.

Now that the gorilla has made its presence known, Stouffer is working with Mitrovica to understand its effects in greater detail. A joint paper, due out in a few months, will look into the gravitationally driven sea-level changes a melting Greenland could trigger. “The signal is so large,” says Stouffer, “that if you own beachfront property in Iceland, and all of the ice on Greenland melts and adds seven meters to average sea level, you end up with more beach. But in Hawaii, you get your seven meters of sea-level rise plus an extra two or three on top of that. It’s phenomenal to me that it matters that much.”

Mitrovica agrees.

“When I give talks about this, people don’t believe me,” says Mitrovica. He doesn’t blame them, either. “It’s just wacky when you think about it, completely counterintuitive,” he says. “But it’s true.”

It’s even measurable, despite the fact that the melting of the ice sheets has barely begun. Even when you correct for other effects, says Mitrovica, you can still see that Europe’s sea level rise is less than you’d expect. “It’s profoundly puzzling,” he says, “until you realize you’re seeing the gravitational signal of Greenland melting.”

When he started looking at regional effects, Mitrovica recalls, some climate-change
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Deniers were noting that sea-level rise was happening at different rates in different regions, arguing that this proved there was no global trend, and thus no global warming. That was already a bogus argument, but now that he and others have begun investigating the gorilla in the living room, it’s even more absurd. The science is so straightforward, he says, that “if you saw that sea level was rising uniformly around the world, it would be proof that the big ice sheets are not melting.”

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ABOUT THE AUTHOR
Michael D. Lemonick is the senior writer at Climate Central, a nonpartisan organization whose mission is to communicate climate science to the public. Prior to joining Climate Central, he was a senior writer at Time magazine, where he covered science and the environment for more than 20 years. He has also written four books on astronomical topics and has taught science journalism at Princeton University for the past decade.

In other articles for Yale Environment 360, Lemonick has written about new evidence that makes the 2007 report by the Intergovernmental Panel on Climate Change already outdated and a recent report on the impacts of climate change in the United States.

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