Right Now

The expanding Harvard universe

DECIPHERING SEA LEVELS

The Gravity of Glacial Melt

Part of the Greenland Ice Sheet. The ice boulders (foreground) were left behind after a lake overflowed near the town of Kangerlussuaq.

In the popular imagination, sea levels rise in response to a warming climate in the same way water rises in a bathtub when the tap is turned on: evenly and uniformly around the globe.

Until nine years ago, many scientists also assumed the same thing. That's when professor of geophysics Jerry X. Mitrovica (then at the University of Toronto) and collaborators including Harvard College Observatory associate James L. Davis reported in *Nature* that incorporating glaciers' gravitational pull into the equations used to describe sea-level changes would help explain the extreme variation scientists were already seeing around the world. The equations then in wide use accurately described the trend in *average* sea level worldwide—a rise of about two millimeters per year in the twentieth century—but couldn't explain why actual observed conditions in many places did not conform to that average. Nevertheless, as long as the observed average rise was consistent with their equations, scientists tended to ignore the outliers, recalls Mitrovica (mi-tro-vi-tsa). "*We* were saying, 'Those are really important.'"

In fact, some places on Earth could find the local sea level *falling*. This is because the sheer mass of glaciers generates gravitational pull and draws water closer, raising the sea level nearby. As glaciers melt, though, this pull weakens and the adjacent sea level falls. At locations far from a given glacier, the most noticeable effect of its melting will indeed be the increased volume that meltwater has added to the sea; closer in, though, decreased gravitational pull becomes the predominant effect.

In a 2009 *Science* paper, Mitrovica and collaborators including doctoral student Natalya Gomez presented a "fingerprint" of future polar ice-sheet collapse.

Much depends on *which* ice sheets melt.

Photograph by Uriel Sinai/Getty Images

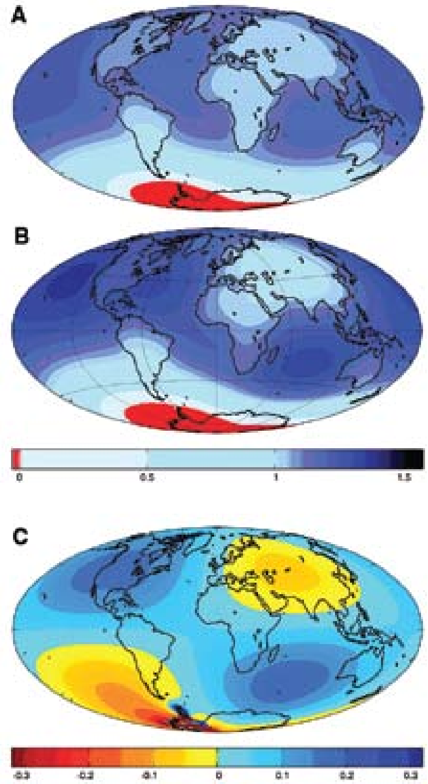
If glaciers near only one pole collapsed entirely and those near the other pole didn't melt much, the gravitational effects (and resulting sea-level drop) would be concentrated at that end of the world; if glaciers near both poles melted, sea levels at high latitudes would fall, while seas near the equator would rise at a much greater rate than the global average.

If only the Greenland Ice Sheet melted, sea levels would fall along the shores of Scotland, and the Netherlands would see only one-fifth the average sea-level rise worldwide. ("Of course, that's what they're hoping for, even as they plan for the worst-case scenario," says Mitrovica. "But if you're Australian, you have a very different hope.")

Conversely, if the West Antarctic Ice Sheet melted and Greenland's did not, "Tierra del Fuego on the southern tip of Chile might see sea levels fall," says Mitrovica. This wouldn't affect many local human residents—the Antarctic glacier is far from populated areas—but the United States might find itself in hot water. In all locations far from the Antarctic ice sheet—that is, in most of the Northern Hemisphere—sea levels would rise more than average, and more than older models have predicted.

But that's not all. When glaciers melt, the redistribution of their mass causes changes in the earth's rotational axis. "The earth isn't a perfect sphere," Mitrovica explains. "It's flattened because it's rotating. If you move the pole, the flattening adjusts." If the West Antarctic sheet collapsed, the pole would move such that sea levels would rise *even more* in North America. If this ice sheet—but none of the others—were to collapse, water levels at Boston, Washington, D.C., and other sites along the east and west coasts of the United States would rise *30 percent more* than the global average. Given a worldwide average rise of 5 meters in sea level, these cities would face seas higher by 6.5 meters.

Alarming though these projections may be, they are not immediate. "We're talking a scale of hundreds of years before this could ever happen," says Mitrovica. Predictions of what *will* happen are not his bailiwick; he leaves that to climate scientists and focuses instead on what he compares to "detective work." He and others working on the same problem start with the equivalent of four "fingerprints"



In 2001, Jerry Mitrovica and colleagues reported that the impact of glacial melting would not be distributed evenly around the world, because each glacier's individual gravitational pull affects the sea level nearby. These figures show the "fingerprint" of the melting of the West Antarctic Ice Sheet; sites in the Northern Hemisphere would see sea levels rise more than the worldwide average (Figure A). In 2009, Mitrovica's team updated their equations to include a shift of the earth's axis of rotation and other geological changes that would follow the glacial melt. The results show an even bleaker situation for the United States: Figure B shows the new distribution of sea-level rise (the scale indicates the factor of multiplication against the worldwide average); Figure C shows the difference between A and B (the scale represents percentage difference).

all laid down atop each other: they know how much sea levels have risen during the past century—or in some cases, several centuries—at various inhabited locations. From these observed changes, their work is to isolate the distinct impact—the individual fingerprint—of the melting of the West Antarctic Ice Sheet; the Greenland Ice Sheet; other glacier systems including that in Alaska; and thermal expansion (the seas' increasing volume as temperatures rise, an effect that would fade into the background if glacial melt, with its more severe effects, were to speed up). In this way, they are able to make an indirect observation of precisely how much volume and mass each ice sheet has lost. These calculations aid predictions of how the process will unfold in the years to come.

In climate science and throughout earth and planetary science, these "fingerprints" and the complex mathematical methods behind them have gained wide acceptance. But even now, when Mitrovica talks with scientists from other fields about the finding that sea levels will fall in some places, he is reminded that the idea is "so counterintuitive that sometimes they don't believe it. Or they think it must be dependent on some weird model parameter. But it isn't. It's just Newton sitting under the tree and the apple hitting him on the head."

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ELECTION BY ENCRYPTION

Secret Ballots, Verifiable Votes

THE TYPICAL VOTER experience, as Ben Adida sees it, involves too much trust. "There is a disconnect the moment you drop off your ballot," says the fellow of Harvard's Center for Research on Computation and Society and faculty researcher at Harvard Medical School. After a ballot is cast, voters can only wait for the results to appear on their smart phones, or on the evening news. Whether their own votes have been counted is never known, because they have entrusted a series of poll workers with their ballots. But "In voting, you cannot trust any other party," says Adida. "And you have to be able to be confident that everyone's voice has been heard."


Ben Adida

His solution is an online voting system called Helios that allows voters to track their ballots and opens the results for public auditing. Adida, a self-described "tech and policy geek," began building voting systems in 1997 as part of an undergraduate research project, well before "hanging chads" entered the American lexicon. He has been working on Helios—named for the ancient Greek sun god as a nod to the system's intended transparency—for nearly two years, and is on his third version of the open-source system, which will be made available to the public this summer.

A typical vote via Helios requires filling out an online ballot and then clicking a button that encrypts the vote, masking its content. Voters then receive individual tracking numbers—'fingerprints' of their votes; finally, they submit their votes by verifying their identities. In most cases, this is done by logging into an external platform that is appropriate for the election: voting for a Facebook group president, for instance, might require a Facebook login; electing Harvard's student body president, a University PIN system login. To double-check that their ballots have been counted, voters can then go to the election's ballot-tracking website, which allows them to match their specific tracking number to their name.

There is another layer of confirmation: a crowd-sourced verification measure called open auditing that allows anyone access to the election data. "We're not expecting every voter to be able to handle the auditing—you'll need someone who knows some college-level math to do it," says Adida, who admits that this is one of the chief criticisms of any such system. "But you expect every candidate, at least, to have access to one person whom they trust who is able to do the math."

Adida notes that Helios in its current form is not ready to handle elections for public office, even at the local level. "A government election is something that you don't want to do over the Internet," he says, citing both the potential for computer viruses to corrupt the voting and the possibility of voter intimidation. "I don't have an expectation that Helios ever becomes the system for government elections," he explains, "but I hope it paves the way for the open-audit system to become the standard in 10 to 15 years."

For now, he is happy to demonstrate Helios where the stakes are a bit lower. The campus-wide election of a president for Belgium's Université Catholique de Louvain last March offered a perfect opportunity. Because of preexisting tensions, a significant number of blank ballots were cast as protest votes, and neither of the two candidates won the majority needed to claim the presidency, though one fell short by just two votes. "We're pretty sure that in any other voting system, [the electorate] could have said, 'Oh, you didn't count right' or 'You lost a couple ballots,'" he says. But when third parties—including one affiliated with the candidate who fell just short—verified the election, there was little room for dispute.

Photograph by Toni Gauthier