There is essentially no debate among scientists about global warming’s “connection to the actions of mankind.”

Nor has there been a debate for years. Since at least 1995, the balance of evidence in climate science has indicated that human-caused greenhouse-gas emissions are behind the planet’s warming. Agreement on this question has only strengthened since. By 2012, an international panel of leading researchers in the field said there was at least a 95 percent chance that human activity has caused global warming since 1950.

There are active discussions in climate science—they’re just not about this. So before we all have to talk about a topic on which there is near total scientific agreement, I thought it might be fascinating to examine a real area of dispute in the field. And one of the most consequential disagreements is about something called the Atlantic Meridional Overturning Circulation, or AMOC.

In 1769, Ben Franklin became the first person to map the Gulf Stream when he made this chart. (NOAA)
Many Americans know AMOC as the Gulf Stream: the warm, surface-level current in the Atlantic Ocean that hugs the East Coast. You may have seen it in the old map by Ben Franklin, pictured above: It flows up the Carolinas, passes by New England and Nova Scotia, and then veers toward Europe. Eventually it arrives near the British isles and northwestern Europe.

The Gulf Stream is part of a much larger system, however. As that warm water flows northeast, it gradually cools, and in cooling, compresses and sinks. Eventually, in the Labrador and Greenland Seas, it becomes dense enough that it plunges down thousands of meters into the deep ocean. There it becomes a new current, running back south. It can remain in this deep-ocean current for many years until it eventually upwells at the equator or in the Southern Ocean.

This global conveyor belt of water is AMOC, and it is critical to the world’s climate. (Most scientists pronounce it as \textit{AY-mock}.)

When AMOC is strong, it sends millions of cubic meters of ocean water north everyday. A strong AMOC seems to shape the entire planet’s climate systems. It moderates the intensity of Atlantic hurricanes, lessens the risk of drought in North America, and assures the health of monsoons in India. AMOC also ferries warm weather from the equator to Western Europe, where it helps bring the region unusually mild winters. (Consider that temperate Berlin is about as far from the equator as the snowy Chilean city of Punta Arenas.)

Crucially, the entire AMOC system depends on cool, dense water “overturning” in the northwest Atlantic Ocean. Without cooled water plunging into the deep ocean near Greenland, and turning back south, the entire conveyor belt will stop.

About 30 years ago, climate researchers became concerned that AMOC could suddenly shut down as a result of anthropogenic climate change. The “paleoclimatic record”—that is, what the planet’s geology and fossil record reveal of previous global climates—showed that the AMOC has rapidly collapsed in the past. “Rapidly” here means “within the span of a human lifetime.”

The crumpling of AMOC could potentially cause big problems for the global economy. AMOC’s disappearance would quickly worsen sea-level rise on the U.S. East Coast and subject the Southeast to unusually intense tropical storms. It could upheave agriculture in India, Europe, and the African Sahel.

But as climate models improved, those fears dissipated. “No current comprehensive climate model projects that the AMOC will abruptly weaken or collapse in the 21st century,” wrote a team of NOAA researchers in 2008. “We therefore conclude that such an event is very unlikely.”
Thomas Delworth was the lead author of that report. Delworth is a researcher at the NOAA Geophysical Fluid Dynamics Laboratory and a professor of atmospheric and oceanic science at Princeton University. He says that scientists are now re-examining those old conclusions.

“Some recent work now is challenging that consensus. It suggests that the real climate system may be less stable than [the models] think,” Delworth told me.

The most attention-getting of this work: a paper last year by James Hansen and 18 other scientists that argued the AMOC’s collapse could threaten global civilization this century. The paper built on older work showing that huge injections of freshwater have historically destabilized AMOC, essentially by flooding the Atlantic with cold water and screwing up its finely tuned density cycle. Hansen and his colleagues argued that as the Greenland ice sheet melts, it would be able to provide exactly such a pulse—and that, crucially, climate models failed to account for this physical process.

The paper made headlines around the world. Though he now is a professor at Columbia University, Hansen led the NASA Goddard Institute for Space Studies for more than three decades. In 1988, he became one of the first scientists to warn Congress of the dangers of global warming.

This week, the consensus on AMOC was challenged again. A team of researchers have showed in Science Advances that a popularly used climate model may significantly overestimate the stability of AMOC. Once you account for this bias, AMOC proves much more likely to collapse, they argue. And this collapse could happen without any freshwater injection from Greenland.

In other words, they show that the stress of global warming can push AMOC into collapse all by itself in at least one model. Freshwater doesn’t need to pour in from Greenland for AMOC to fall apart; simply increasing the temperature of the ocean can do it.

That’s because climate models make AMOC more stable than it actually is in nature, said Wei Liu, an oceanography researcher at Yale University and one of the authors of the study. “In a stable routine, if you increase the CO2, then AMOC only weakens. But in an unstable routine, if you add global warming, then AMOC will collapse by itself,” he told me.

He argues that field observations of the Atlantic Ocean suggest that AMOC is in fact unstable. Between mid-2009 and mid-2010, AMOC appeared to weaken, with the current carrying only two-thirds of its usual volume of water. At the same time, sea-level rise on the East Coast accelerated and Europe experienced an unusually frigid winter.

In their study, Liu and his colleagues tried to make their model more unstable. Most models, they say, do a bad job of representing AMOC. They don’t have enough salty water entering the Atlantic at the equator, and they also don’t have enough freshwater leaving it in the deep ocean.
In their experiment, they fixed this extremely crudely. Instead of fixing the underlying physics, they told the model to add much more saltwater and freshwater to the simulation. Then they doubled the amount of carbon dioxide in the simulated atmosphere, stepped back, and watched to see what would happen.

What happened is that, between year 200 and 300 of their adjusted model, AMOC rapidly collapsed.

Delworth said that even though their experiment was crude, it was revealing. “It’s a very interesting and provocative work,” he told me. “I think they are opening up this topic and saying our models may be too stable.”

“In this new study, they’ve just put a bandaid on [this stability]. They’ve said, if we alter these characteristics, the model is much less stable. But sometimes it’s really good to have these simple ad hoc techniques to address, ‘What’s the sensitivity of our models?’” he said.

The paper alone didn’t overthrow the consensus, he added, but it did suggest it should be re-examined.

Hansen, on the other hand, was more dismissive of the study’s approach. “You can’t fix the climate model simulation via ‘bias removal’—you should fix what is wrong with the model physics,” he said in an email. “They are doubling CO2, letting that change the temperature, rainfall, etc. and seeing what that does to the AMOC in their model. It’s been more than 35 million years since we had that much CO2 in the air, and sea level was more than 200 feet higher then. If we (humanity) are so stupid as to double CO2, you can count on the AMOC to shut down much faster than 300 years.”

Other climatologists, especially those who study Earth’s past, were much more positive about the paper, describing it as a necessary improvement to how we understand current climate models.

“This is an important step forward,” said Jean Lynch-Stieglitz, a professor of Earth and atmospheric sciences at Georgia Tech. “This study identifies a specific property of the climate models that would tend to make the AMOC in the models more stable than in reality.”

“Importantly, it reminds us that even if most climate model projections agree on their projections for future AMOC changes, that doesn’t necessarily mean that the projections are correct,” she added.

People visit the beach at Slea Had in Ventry, Ireland, on December 27. Ireland benefits from a strong AMOC. (Clodagh Kilcoyne / Reuters)
The instability of AMOC is one of the great open questions remaining in our understanding of climate change, one of the ongoing explorations into global warming’s “degree and extent.”

It is, in other words, an active debate in climate science.

But I want to highlight how it does and doesn’t look like a political debate. To my eye, it looks more like an open investigation: Researchers share their results, compare the models to the field observations, make tentative corrections to the software and underlying assumptions, and move chaotically together toward a deeper understanding of how the planet works.

Sometimes, they may disagree about how best to proceed or about the validity of any one study. But they do not disagree about the underlying chemistry and physics of their enterprise—all of which show that people are warming the planet through their industrial greenhouse-gas emissions.

Martha Buckley, a research professor of oceanography at George Mason University, may have put it best.

“It is certainly a possibility that the AMOC is too stable in current [global climate models],” she said in an email. “The most obvious weakness of the paper is that the experiment is done for a single model.” She called the authors’ methods of fixing it “relatively crude.”

But then she went on. From what we know right now, the possibility that AMOC will shut down remains a “potential impact of climate change with significant consequences.”

“Yet other impacts are much more certain” to result from climate change, she said, listing “increased surface temperatures, sea level rise, and ice melt.” While some harms, like those of a collapsing AMOC, are still up for debate, it is almost completely certain that climate change will bring serious consequences for us in our time. Rampant drought, drier rivers, and vanished coasts are all ours to inherit.
The crack in this Antarctic ice shelf just grew by 11 miles. A dramatic break could be imminent.

By Chris Mooney January 6 at 4:30 PM

A crack in the Larsen C ice shelf as photographed Nov. 10. (John Sonntag/NASA)

This story has been updated.

An enormous rift in one of Antarctica’s largest ice shelves grew dramatically over the past month, and a chunk nearly the size of Delaware could break away as soon as later this winter, British scientists reported this week.

If this happens, it could accelerate a further breakup of the ice shelf, essentially removing a massive cork of ice that keeps some of Antarctica’s glaciers from flowing into the ocean. The long term result, scientists project, could be to noticeably raise global sea levels by 10 centimeters, or almost four inches.
It’s the latest sign of major ice loss in the fast warming Antarctic Peninsula, which has already seen the breakup of two other shelves in the same region, events that have been widely attributed to climate change.

The crack in the ice shelf, known as Larsen C, has been growing at an accelerating rate. Since the beginning of December, it has grown about 11 miles in length, after extending 13 miles earlier in the year. In total, the rift has grown about 50 miles since 2011 (it’s almost 100 miles long in total), and has widened to well over 1,000 feet. Now, only 12 miles of ice continue to connect the chunk with the rest of the ice shelf.

[In Greenland, a once doubtful scientist witnesses climate change’s troubling toll]

When it breaks away, the loss would be of nearly 2,000 square miles of ice, say the researchers with Project MIDAS, a British government-funded collaboration based at Swansea and Aberystwyth universities in Wales. That’s larger than Rhode Island and almost as big as Delaware.

The consequences of the break could be dramatic.

“When it calves, the Larsen C Ice Shelf will lose more than 10% of its area to leave the ice front at its most retreated position ever recorded; this event will fundamentally change the landscape of the Antarctic Peninsula,” said the researchers in a statement about the rift. “We have previously shown that the new configuration will be less stable than it was prior to the rift, and that Larsen C may eventually follow the example of its neighbour Larsen B, which disintegrated in 2002 following a similar rift-induced calving event.”

Here’s an image showing the apparently accelerating advance of the rift, per the Project Midas team:
The current location of the rift on Larsen C, as of January 2017. Labels highlight significant jumps. Tip positions are derived from Landsat (USGS) and Sentinel-1 InSAR (ESA) data. Background image blends BEDMAP2 Elevation (BAS) with MODIS MOA2009 Image mosaic (NSIDC). Other data from SCAR ADD and OSM.

The British Antarctic Survey also released a statement on the growing rift, saying a huge iceberg is “set to calve” from Larsen C.

“Because of the uncertainty surrounding the stability of the Larsen C ice shelf, we chose not to camp on the ice this season,” David Vaughan, the survey’s director of science, said in the statement.

The floating ice shelf is fed by the flow of ice glaciers that sit above sea level on the Antarctic Peninsula. As the shelf loses mass, these glaciers could flow more quickly — which would contribute to rising sea levels. Losses from the ice shelf alone, however dramatic, would not have that effect, as the shelf is already floating on water, just like an ice cube in a glass of water.
Fortunately, the Antarctic Peninsula does not contain nearly as much ice as other, thicker parts of Antarctica, such as the West and East Antarctic ice sheets. The potential sea level rise if Larsen C is lost would be measured in centimeters, not feet.

Still, it would subtract a major, enduring feature from the planet, and add to already dramatic changes that have been seen in the Antarctic Peninsula, the portion of the icy continent that extends northward towards South America.

Two scientists trek to remote Petermann glacier in northern Greenland to find out how quickly it is melting and what that means for global sea level rise. (Whitney Shefte/The Washington Post)

Two smaller ice shelves near Larsen C – Larsen A, and Larsen B – have already largely disintegrated. Larsen B retains a remnant of its former size, but scientists have determined that this ice, too, could vanish before too long. They have also documented that following the collapse of much of the Larsen B ice shelf in 2002, the glaciers behind it sped up their flow towards the sea. Now, the fear is the same process could be unleashed on the larger Larsen C shelf.

The Larsen C ice shelf is more than 1,000 feet thick, and in spatial extent, nearly the size of Scotland. It is the fourth-largest ice shelf in Antarctica, although nothing compared with the two largest, the Ross and Filchner-Ronne ice shelves.

NASA, during a flight in November, captured several spectacular photos of the rift, including the one at the top of this article and also the close-up below. But that was before further extension of the rift last month:
The Antarctic continent is ringed with ice shelves, which are the ocean-front portions of larger glaciers. But as the climate changes, these features have been thinning and in some cases breaking apart dramatically.

The Project MIDAS group did not immediately make a statement attributing the development at Larsen C to climate change, but the fact that the shelf would be “at its most retreated position ever recorded” after the break is certainly suggestive.

Previous research has also documented that the Larsen C ice shelf is becoming less thick, and so floating lower in the water, and this appears tied to the warming of the Antarctic Peninsula in recent decades. Warmer seas could also be playing a role.

Now, the wait for the anticipated break begins.
Swansea University’s Adrian Luckman, who heads up Project MIDAS, told the BBC that “If it doesn’t go in the next few months, I’ll be amazed.”

Daniela Jansen, a researcher with the Alfred Wegener Institute in Germany who collaborates with the Project MIDAS team, largely agreed in an email to The Washington Post.

“I think the iceberg will calve soon,” she said. “The jumps of the rift tip occurred in shorter time intervals the longer the rift got. This is probably due to the longer ‘lever’ for the forces acting to advance the rift, such as the up and down of the tides or strong winds towards the sea. Whether it will be months or maybe next year, I don’t know.”
IF ALL THE ICE MELTED

Explore the world’s new coastlines if sea level rises 216 feet.

The maps here show the world as it is now, with one difference: All the ice on land has melted and drained into the sea, raising it 216 feet and creating new shorelines for our continents and inland areas.

There are more than five million cubic miles of ice on Earth, and some scientists say it would take more than 5,000 years to melt it all. If we continue adding carbon to the atmosphere, we’ll very likely create an ice-free planet, with an average temperature of perhaps 80 degrees Fahrenheit instead of the current 59.