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The tip of the iceberg

Domino effect tips climate over edge

The instability of Arctic sea ice could be just the first in a cascade of tipping points

Michael Marshall

ONE climate domino has fallen, and it may start toppling others. A recent study outlined an interconnected web of climate tipping points, some of which make the next ones more likely. Now, an analysis of data from the last 23 years suggests we passed the first of these tipping points in 2007, when Arctic sea ice flipped into a new, less stable state. That may speed the world towards the next tipping point – the thaw of a vast expanse of Siberian permafrost.

When it comes to the consequences of climate change, few are more dramatic than tipping points – a small push unleashes a big change, which may be unstoppable. According to Tim Lenton of the University of Exeter, UK, and Valerie Livina of the UK's National Physical Laboratory, Earth saw its first tipping point in 2007 when the Arctic sea ice hit a record low. The pair analysed data on ice cover going back to 1979, and found that every year since then, the extent of sea ice in the summer has been hovering around a new, shrunken state (*The Cryosphere*, doi.org/kkq). "This wasn't a one-off, it was a permanent change," Lenton says. He notes that since 2007, the ice has consistently taken longer to recover from small changes, suggesting it has entered a new, less stable state.

The claim is controversial. Anders Levermann of the Potsdam Institute for Climate Impact Research in Germany argues that the ice loss cannot be called a tipping point because it could still be reversed. Peter Ditlevsen of the University of Copenhagen in Denmark says it is clear from the ice cover data that 2007 marked a dramatic turning point for Arctic sea ice.

"When the Arctic sea ice hit a record low in 2007, this wasn't a one-off, it was a permanent change"

A little further south, in the expanse of Siberian permafrost known as Yedoma, another tipping point could be looming. Ecologists predict that once the region begins to thaw, microbes will start breaking down the carbon-rich soil, producing heat and releasing greenhouse gases, which will accelerate the thaw.

Anton Vaks of the University of Oxford and colleagues used stalagmites in caves beneath Russia and China to reconstruct the 500,000-year history of the Siberian permafrost. Stalagmites cannot form when the soil is frozen, Vaks explains. "They only grow when water flows into caves." He found that those in the

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northernmost cave – nearest to modern-day continuous Siberian permafrost – only grew once, during a particularly warm period 400,000 years ago when global temperatures were 1.5 °C warmer than pre-industrial temperatures. That suggests the permafrost is likely to become vulnerable when we hit 1.5 °C of global warming (*Science*, doi.org/kkt).

Global temperatures have already risen by 0.8 °C. Even if humanity stopped all emissions tomorrow, temperatures would

> **"Even if we stopped all emissions tomorrow, temperatures would still rise another 0.3 °C"**

rise another 0.3 °C, suggesting the permafrost tipping point is likely to be reached.

These two tipping points – the Arctic sea ice and permafrost – are the first two in a network of points outlined recently by Lenton and Levermann (see diagram, right). The pair argue that periods of rapid ice loss in the Arctic change regional weather patterns, to warm Asia more quickly and speed up the thaw.

"No climate model has ever induced the tipping of one by tipping another," cautions Levermann. But he says that could be a quirk of the models, which climate modellers build to study aspects of climate that don't involve tipping points. "We observe more violent changes in the past than our models are capable of simulating," agrees Ditlevsen. "That points to the idea of dominoes."

In Lenton and Levermann's cascade, a critical point appears to be the shutdown of the Atlantic thermohaline circulation. This vast current pumps water around all the Earth's oceans, and interacts with many of the other areas susceptible to tipping points, including the Greenland and Antarctic ice. The good news is that this tipping point could act as a safety valve, slowing the progress of the others.

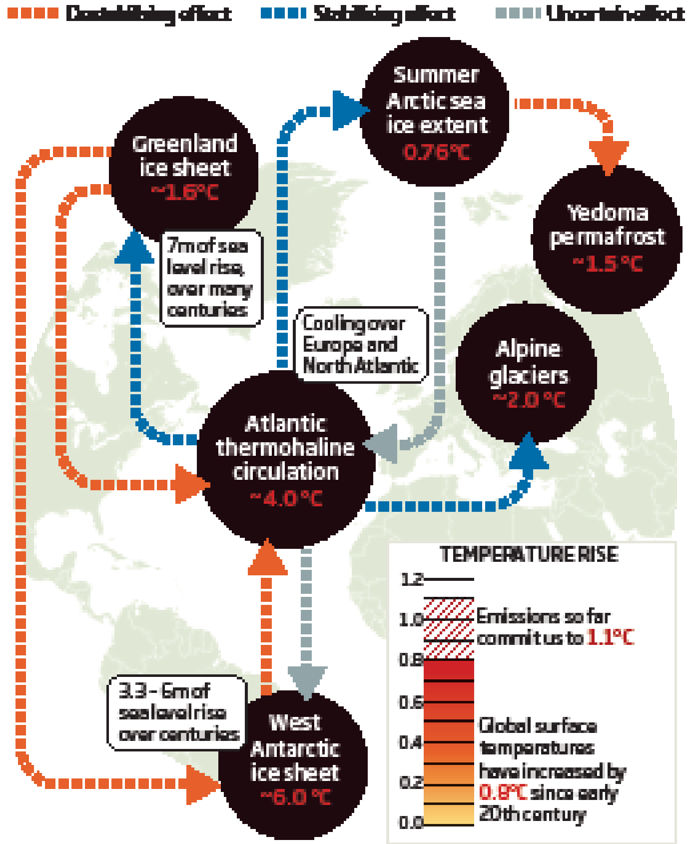
There are huge arguments over whether it will ever be hit. "All the models show the overturning circulation declining with global warming," says Levermann. But that doesn't mean it will collapse. Ditlevsen and Jan Sedlácek of ETH Zurich in Switzerland believe internal mechanisms would reboot the circulation in the event of a collapse – in part because so far, there is no evidence of a complete collapse in the past.

Perhaps the worst news of all is that there may be no warning of impending flips. Lenton has developed tipping point forecasts that look for warning signs. Historical records and chaos theory applied to ecosystem models suggest that as a system nears a threshold, it will struggle to bounce back from small disturbances. So if a system is approaching a tipping point, its response to extreme events should become more sluggish. The trouble is that the one tipping point we have already passed, according to Lenton – melting of the Arctic sea ice – gave us no such warning signs. Ditlevsen is not surprised. He found that there was no warning before similar events during the last ice age either (*Geophysical Research Letters*, doi.org/fd7vkj). Both researchers say the behaviour of other unstable systems, like the Amazon rainforest, glaciers and monsoons, may be more predictable.

So what's next? According to the temperatures on Lenton and Levermann's cascade, the collapse of Greenland's ice sheet would become inevitable shortly after the Yedoma permafrost thaws. This would raise sea levels 7 metres, over many centuries. A 2012 study (*Nature Climate Change*, doi.org/kkw) suggested it would only take 1.6 °C, because as soon as the south-eastern ice sheet starts losing surface mass, the entire sheet destabilises. ■

Web of tipping points

Big tipping elements may be interlinked. Models estimate the temperatures beyond which the breakdown of key climate systems becomes inevitable. They also suggest all except the loss of Arctic sea ice are irreversible



TRASHING SIBERIA

A mere 1.5 °C of warming may be enough to start the widespread thaw of Siberia's vast permafrost (see main story). We are already committed to 1.1 °C. What are the consequences?

The greatest concern, says Tim Lenton of the University of Exeter in the UK, is the regional landscape. Buildings and infrastructure are often built on hard permafrost, and will start to subside. "Ice roads won't exist any more," he says.

The increasingly soggy permafrost will also threaten the pipelines that transport Russian gas to Europe. "The maintenance and upkeep of that infrastructure is going to cost a lot more," says Ted Schuur of the University of Florida in Gainesville.

A study published last year predicted that the Russian cities of Nadym, Yakutsk and Salekhard would be worst affected. The amount of weight the ground underneath could support could fall 20 per cent or more (*Arctic, Antarctic and Alpine Research*, doi.org/kkz). The ecosystem will also change as plants move north.

The thawing permafrost will also release methane and carbon dioxide, which will warm the planet still further. Though Lenton says the effect will be small compared to humanity's emissions from burning fossil fuels.