Unfortunate timing and rate of change may be enough to tip a climate system

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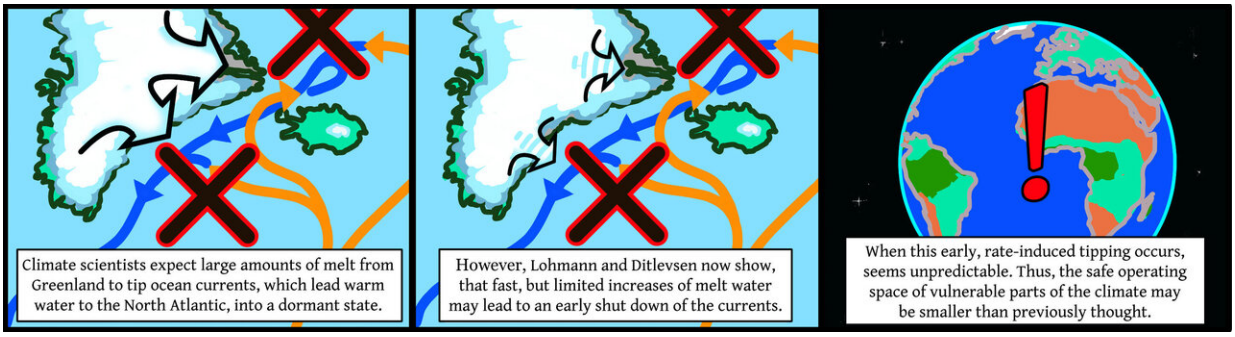

Credit: TiPES/HP

Imagine abrupt shifts of the tropical monsoons, reductions in Northern Hemisphere rainfall, and strengthening of North Atlantic storm tracks within decades. These are some of the impacts that climate scientists expect if the Atlantic Meridional Overturning Circulation (AMOC), which redistributes heat from equatorial regions to the Northern Hemisphere, suddenly tips into a dormant state as a result of global warming. The consequences would drastically alter conditions for agriculture, biodiversity, and the economy in large parts of the World.

A model study by Johannes Lohmann and Peter D. Ditlevsen from Physics of Ice, Climate, and Earth, The Niels Bohr Institute, the University of Copenhagen, Denmark, now suggests the AMOC, and potentially other climate sub-systems approaching tipping points might

tip long before anticipated because of rate-induced tipping. The work, published today in *PNAS* is part of the TiPES project funded by the EU Horizon 2020.

Time matters

There is a growing concern among climate scientists that several climatic sub-systems might tip irreversibly and abruptly to a new state if atmospheric CO_2-levels are pushed beyond still yet unknown thresholds. These sub-systems include the ice sheets of Antarctica and Greenland, the Amazon rainforest, the Asia-Australian monsoon, the sea ice of the Arctic Ocean, and the AMOC.

In addition, it is still uncertain whether rate-induced tipping effects might also occur. These effects manifest themselves as a tipping of the system to a new state even before a theoretical threshold in the external conditions (such as the atmospheric CO_2 levels) is reached. In rate-induced tipping, the rate of change—not the amount of change—is the important factor. This is because tipping occurs more readily when the system's conditions change rather quickly.

To study rate-induced tipping in the climate system Dr. Johannes Lohmann investigated the phenomenon in a complex ocean model, Veros.

Inherently unpredictable

First, the model's tipping threshold at very slow increases of North Atlantic freshwater input was identified. Then, a series of experiments were carried out, where the freshwater input was increased at varying rates, but only to levels below the tipping threshold. The results clearly showed the characteristics of rate-induced tipping.

Specifically, when the ocean model was subjected to increases in freshwater input to the North Atlantic, which simulated accelerating melt from the Greenland Ice sheet over time scales of 10 to 150 years, the AMOC had a strong tendency to tip to a dormant state before its threshold was reached.

It also appeared that due to the chaotic dynamics of the ocean model, the rate-induced tipping was highly sensitive to minute changes in the initial conditions and the rate of change of meltwater increase. This makes the tipping threshold fuzzy. Therefore the qualitative fate of the ocean circulation, i.e. whether it will collapse or remain like the modern state, remains inherently unpredictable.

Worrying, if real

The occurrence of rate-induced tipping in a global ocean model gives important evidence that one or more climate sub-systems may tip from being pushed too quickly as a result of global warming. Whether this is indeed a reality remains to be shown across more models in the climate model hierarchy.

However, the findings point to fundamental limitations in climate predictability and corroborate the need to limit CO_2 emissions in order to stay away from dangerous and unpredictable tipping.

"It is worrying news. Because if this is true, it reduces our safe operating space," says Johannes Lohmann.

More information: Johannes Lohmann el al., "Risk of tipping the overturning circulation due to increasing rates of ice melt," *PNAS* (2021). www.pnas.org/cgi/doi/10.1073/pnas.2017989118

Provided by University of Copenhagen