Emergency atmospheric geoengineering wouldn't save the oceans

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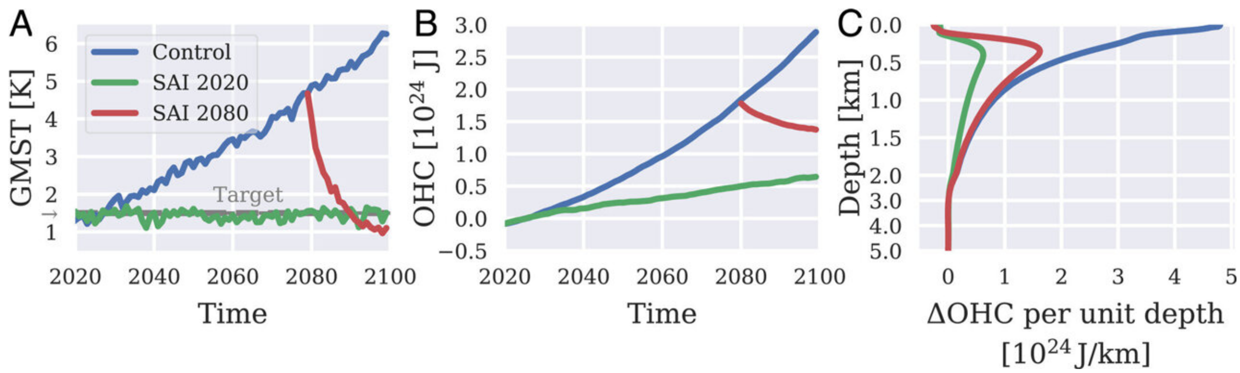

(a) Annual mean global mean surface temperature above pre-industrial reference temperature (b) Change in annual mean total depth ocean heat content (OHC) relative to 2020–2030 conditions in Control. (c) Difference in vertical OHC between end-of-simulation (2090–2100) conditions and present-day conditions in Control. Credit: *Geophysical Research Letters* (2024). DOI: 10.1029/2023GL106132

Climate change is heating the oceans, altering currents and circulation patterns responsible for regulating climate on a global scale. If temperatures dropped, some of that damage could theoretically be undone.

But employing "emergency" atmospheric geoengineering later this century in the face of continuous high carbon emissions would not be able to reverse changes to ocean currents, a new study finds. This would critically curtail the intervention's potential effectiveness on human-relevant timescales.

Oceans, especially the deep oceans, absorb and lose heat more slowly than the atmosphere, so an intervention that cools the air would not be able to cool the deep ocean on the same timescale, the authors found.

Stratospheric aerosol injection is a commonly discussed geoengineering concept based on the idea that adding particles to the stratosphere could help cool the surface of the planet by reflecting sunlight back into space.

This could help stabilize the planet if warming exceeds the 1.5 degree Celsius (2.7 degrees Fahrenheit) cap set by the Paris Climate Agreement, which the planet is on track to exceed under current emission rates. (Global temperatures surpassed that threshold for several months in 2023 due to a combination of factors in addition to climate change, such as El Niño.)

But whether the injections would work is still heavily debated.

Previous research hints that a steady trickle of aerosol injections would help cool the surface of the planet. But the new study suggests that while an abrupt aerosol injection later this century could provide some ocean cooling, it wouldn't be enough to nudge "stubborn" ocean patterns such as Atlantic meridional overturning circulation, which some research finds is already weakening.

In that case, preexisting problems resulting from a warmed deep ocean, such as altered weather patterns, regional sea level rise and weakened currents, would remain in place even as the atmosphere and surface ocean cooled.

"The big picture result is that we believe we can control the surface temperature of the Earth, but other components of the climate system will not be so fast to respond," said Daniel Pflüger, a physical oceanographer at Utrecht University who led the study. "We need to bring down emissions as fast as possible. We're only talking about geoengineering because the political will for emission mitigation is lacking."

The study was published in *Geophysical Research Letters*, AGU's journal for high-impact, short-format reports with immediate implications spanning all Earth and space sciences.

Warm planet, wild swings

Scientists know the surface of the planet can cool when large volumes of particles are added to the atmosphere because of events such as volcanic eruptions, which naturally emit gases and fine particles. For instance, in 1815, an eruption at Mt. Tambora in Indonesia launched so much material into the air that it cooled the planet the following year.

Aerosol injection is based on a similar principle whereby the atmosphere is made more reflective to send incoming solar radiation back into space, cooling the planet.

Because of this, Pflüger wanted to test how the atmosphere, shallow ocean, and deep ocean would respond to a steady trickle of aerosol injections over decades as opposed to a big, abrupt injection beginning later in the century. Would such an emergency measure be able to reverse ocean changes?

Pflüger and his colleagues simulated two aerosol injection scenarios, both with high carbon emissions. In one scenario, people started slowly adding particles into the atmosphere in 2020. In the other, beginning in

2080, people inject a large initial quantity of aerosols to bring the amount of warming back to 1.5 degrees Celsius and then continue to add enough aerosols to maintain that level of cooling.

The team found that in the 2020 scenario, gradual stratospheric aerosol injections maintain ocean temperatures, structure, and circulation patterns roughly similar to today.

In the 2080 scenario, the abrupt aerosol injection cooled the Earth's surface, including the top 100 meters (330 feet) of the ocean, to 1.5 degrees Celsius above the preindustrial average in about 10 years. However, the deep oceans remained warmer than average, and critical ocean circulation patterns remained altered. The intervention was not entirely successful.

The study shows that aerosol injection "might be able to slow down or prevent climate tipping points from happening in the first place," said Daniele Visioni, a climate scientist at Cornell University who was not involved in the research. But aerosol injection "cannot magically restore things."

"We cannot kick the can down the road forever," he said.

The extreme climate situations modeled here are neither desirable nor likely, Pflüger said. However, they provide a good baseline for understanding how Earth systems react to aerosol injections. Ultimately, geoengineering can be useful—but it cannot be the whole solution, he said.

Relying on geoengineering is "in a way, madness," Pflüger said. "But the situation is already quite mad."

The research is published in the journal *Geophysical Research Letters*.

More information: Daniel Pflüger et al, Flawed Emergency Intervention: Slow Ocean Response to Abrupt Stratospheric Aerosol Injection, *Geophysical Research Letters* (2024). DOI: 10.1029/2023GL106132

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