Thin the heat-trapping blanket of superpollutants and CO_2 to slow the rate of warming by half

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Abstract. With the collapse of the Atlantic Meridional Overturning Circulation (AMOC) revealed as rate-dependent, it is critical to quickly cut the rate of warming in half, which would require an ambitious combination of fast mitigation of short-lived climate pollutants, CO_2 mitigation, and removal of CO_2 and other GHGs.

Growing risk from accelerating rate of warming. The new paper by René M. van Westen, Reyk Börner & Henk A. Dijkstra, *Failure to track a stable AMOC state under rapid climate change* makes a persuasive case that rate of warming determines AMOC stability even more than warming level, and that at 0.3 °C decade^{-1} of warming, AMOC could collapse at as low as 2 °C, rather than at the 4 °C threshold with a more modest rate.[1] AMOC is a system of oceanic currents, including the Gulf Stream, covering the Atlantic Ocean that conveys warm surface water north while sending cold, dense water south deep below. AMOC collapse would amplify overheating in the tropics while plunging winter temperatures in Northern Europe as low as –48 °C in Oslo,[2] with a massive readjustment of the global winds and monsoon patterns billions depend on.

Van Westen and colleagues show in a series of clever model experiments that centennial-scale oceanic adjustments that move dense, salty water from one part of the ocean to another keep AMOC relatively stable even in a warmer climate, *if* the rate of warming is slow enough. But above a critical warming rate of about 0.3 °C decade^{-1}, lower-density water accumulating in the North Atlantic lowers the threshold for collapse to 2 to 2.5 °C.

These developments are alarming given that the current rate of warming is accelerating from about 0.18 ºC decade^{-1} from 2000–2013 to about 0.36 °C decade^{-1} from 2013–2024.[3] This is consistent with the observed increase in Earth's Energy Imbalance from 0.5 W m^{-2} in the first decade of the 21st century to 1 W m^{-2} in the second decade.[4]

This accelerating rate of warming coincides with planetary dimming: viewed from space, the planet is getting darker as it warms. This is due to a combination of factors, including primarily the removal of reflective aerosol pollutants as we clean up smokestacks and tailpipes, the loss of snow and ice, and the emergence of low-cloud feedbacks, all allowing the planet to absorb more solar energy. Continuing emissions of heat-trapping pollutants and other amplifying feedbacks are also contributing to the accelerated rate of warming.

As predicted by us in 2018,[5] the 1.5 °C barrier will be crossed by 2030, as now seems certain. With cooling aerosols likely to be further reduced by 30 percent by 2040 (ref. 6), we calculate that the rate of warming could soon exceed 0.5 °C decade^{-1} (V.R. and Y.X., in review), and that warming can surpass 2 °C before 2045 (Figure 1a), a prediction our world will test in suffering. When warming crosses 2 °C, the tropical thermodynamic forcing for global winds and rainfall will increase by an equivalent of 8 °C (ref. 7), driving weather extremes that push a good deal of humanity outside the stable Goldilocks climate of the Holocene.

Reducing superpollutants is the fastest way to slow the rate of warming. The fastest and most effective strategy to reduce the rate of warming is to cut four short-lived climate pollutants—hydrofluorocarbons (HFCs), primarily used as refrigerants; methane from fossil fuels, waste, and agriculture; tropospheric ozone, caused in large part by methane pollution; and black carbon soot. They are short-lived because their lifetimes range from weeks to two decades, compared to centuries for CO_2. If we rapidly cut emissions, their concentration will quickly reduce. They are referred to as climate superpollutants because they are tens to thousands of times more potent than CO_2 at trapping heat.

We previously showed how reducing climate superpollutants along with decarbonization to reduce CO_2 emissions can avoid up to four times more warming by mid-century than targeting CO_2 alone.[8] In that study, which assumed mitigation started in 2015, fast reductions of superpollutants could have cut the rate of warming from around 0.32 °C to 0.25 °C decade^{-1} within about 25 years of the start of aggressive mitigation (Figure 1b). Cutting CO_2 at the same time could have cut warming to about 0.2 °C decade^{-1} (blue dashed curve), based on an adjusted high-ambition scenario (SSP1-1.9).

Scaling these proven strategies to reduce superpollutants along with CO_2 by mid-century is essential to reduce the rate of warming and at least delay breaching 2 °C:

1) Reducing HFCs, as is now mandated by the Kigali Amendment to the Montreal Protocol, could be accelerated to reduce the warming rate by up to 0.02 °C decade^{-1} before 2040 (ref. 9). This year marks the 10th anniversary of the Kigali Amendment, and most countries are on schedule to implement the HFC phase-down, which will avoid nearly 0.5 °C by 2100.
2) Black carbon soot from diesel can be reduced by 80% by 2040, for example, through adoption of readily available diesel particulate filters.[10] Aggressive black carbon reductions contribute approximately 40% to the warming rate reduction in our study. This will also prevent millions of premature deaths and lung and heart-related diseases.
3) Reducing methane emissions by adopting best practices to stop wasteful "fugitive" emissions from the fossil fuel sector (about 35% of emissions), improving livestock productivity in the agriculture sector (about 40% of emissions), and preventing food loss and waste (about 20% of emissions) by separating and composting organic waste and keeping it out of landfill, could cut methane emissions while feeding the 3 billion poor. Ambitious methane mitigation can reduce the rate of warming by up to 0.06 °C decade^{-1} (about 40% of the reduction in our study) by mid-century and avoid nearly 0.3 °C over the next several decades.[11]
4) Measures targeting nitrogen oxides, carbon monoxide and volatile organic carbon emissions, for example through electrification of transportation, will further lower

ground-level ozone pollution and contribute about 10% to the warming rate reduction in our study, with additional health benefits to people and plants.

The cost of delay requires faster removal of CO_2. By delaying aggressive mitigation, reducing superpollutants may no longer, on its own, cut the warming rate fast enough to keep us below 2 °C by the 2040s and out of the danger zone of the rate-induced AMOC trigger. Aggressive mitigation (blue dashed line in Figure 1b) could slow warming by about 0.1 °C decade^{-1} over 20–25 years. Targeted superpollutant measures that go beyond aggressive fossil fuel decarbonization deliver about 80% of this. To slow warming by an additional 0.1 °C decade^{-1} to under 0.2 °C decade^{-1} by mid-century would require removing at least 60-70 $GtCO_2$ from the atmosphere over the next 20 years, not accounting for permanence and biogeophysical effects that could reduce the efficacy of negative emissions.

We are aware of uncertainties in model projections such as the ones made by van Westen and colleagues and by us in Figure 1. But uncertainties can go both ways. The no-regret solutions proposed here for cooling the planet still hold, since they help cap the warming below 2 °C, with significant co-benefits to human welfare.[1]

The need for speed. Leaders from local to global need to adopt the fastest and most effective solutions and move from voluntary efforts to mandatory action. The Montreal Protocol on Substances that Deplete Stratospheric Ozone succeeded in phasing out nearly 100 chemicals that were destroying the stratospheric ozone layer and also warming the atmosphere. That success should provide the inspiration to tackle methane next, as suggested by Barbados Prime Minister Mia Mottley, who is championing a binding methane agreement for the oil and gas sector, making it a priority for the 74-country Climate Vulnerable Forum she chairs.[12]

If we are going to continue to survive and thrive, we must recognize the cost of delay in increasing our risk of crossing irreversible tipping points. We can think of the challenge as a set of races run in parallel: a *sprint* to reduce superpollutants and cut the rate of warming by 0.1 °C decade^{-1} over 25 years; a *marathon* to phase out fossil fuels to avoid warming the planet beyond 3 °C; and an *ultramarathon* to massively scale up technologies to remove already emitted CO_2 and potentially methane.

The superpollutant sprint has little political-economic-international opposition, and has the governance mechanisms available to scale rapidly. Furthermore, reducing superpollutants will have major co-benefits, delivering $4 in benefits for every $1 invested in the first decade through reduced air-pollution-related health and economic costs and improved food and energy security for the three billion poor.[10] It is critical to reduce methane and the other superpollutants as quickly as possible, and simultaneously remove about 5% of the accumulated 1250 billion tons of CO_2 in the atmosphere, through binding measures whenever possible.

A well-informed public will make the right choice to hold tightly to the life preserver connecting us to the Goldilocks climate of the Holocene. This means redoubling efforts to inform the public

[1] While solar geoengineering has the potential to slow the rate of warming, we do not consider it here because there are many unresolved questions around efficacy, acceptability and governance, and broader considerations and research needs in the context of rate-dependent tipping of AMOC and potentially other systems.

about what the next 20-25 years holds. This can happen not just through the efforts of political leaders, but also through religious leaders,[13] and perhaps best of all, through a cadre of millions of citizen climate stewards and champions.[14]

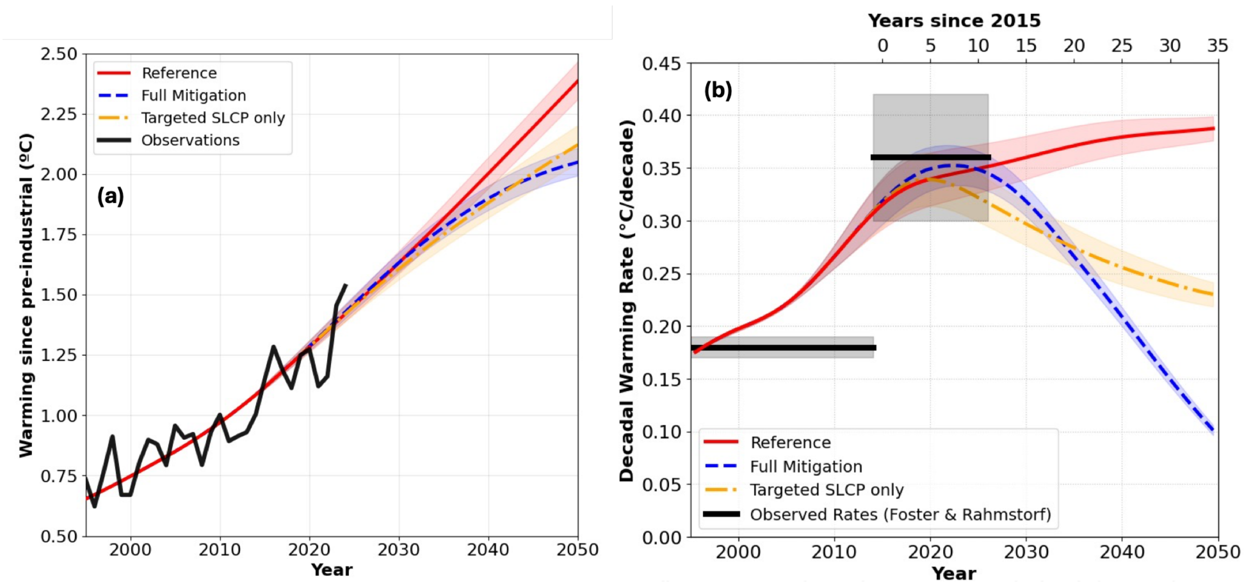

Figure 1. (a) Global mean surface temperature anomaly and (b) rate of warming from observations (black, Berkeley Earth Surface Temperature, Ref. [15], and warming rate from [3]) and projections[8] calculated using the RXM energy balance model using emissions from a reference scenario (red, adapted from SSP3-7.0), an aggressive decarbonization plus targeted SLCP mitigation scenario (dashed blue, modified from SSP1-1.9), and contribution of the targeted SLCP mitigation additional to decarbonization in the full mitigation scenario (dot-dashed orange). All mitigation scenarios assume reductions started in 2015.

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