Understanding the Urgent Need for Direct Climate Cooling

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Slides and Presentation

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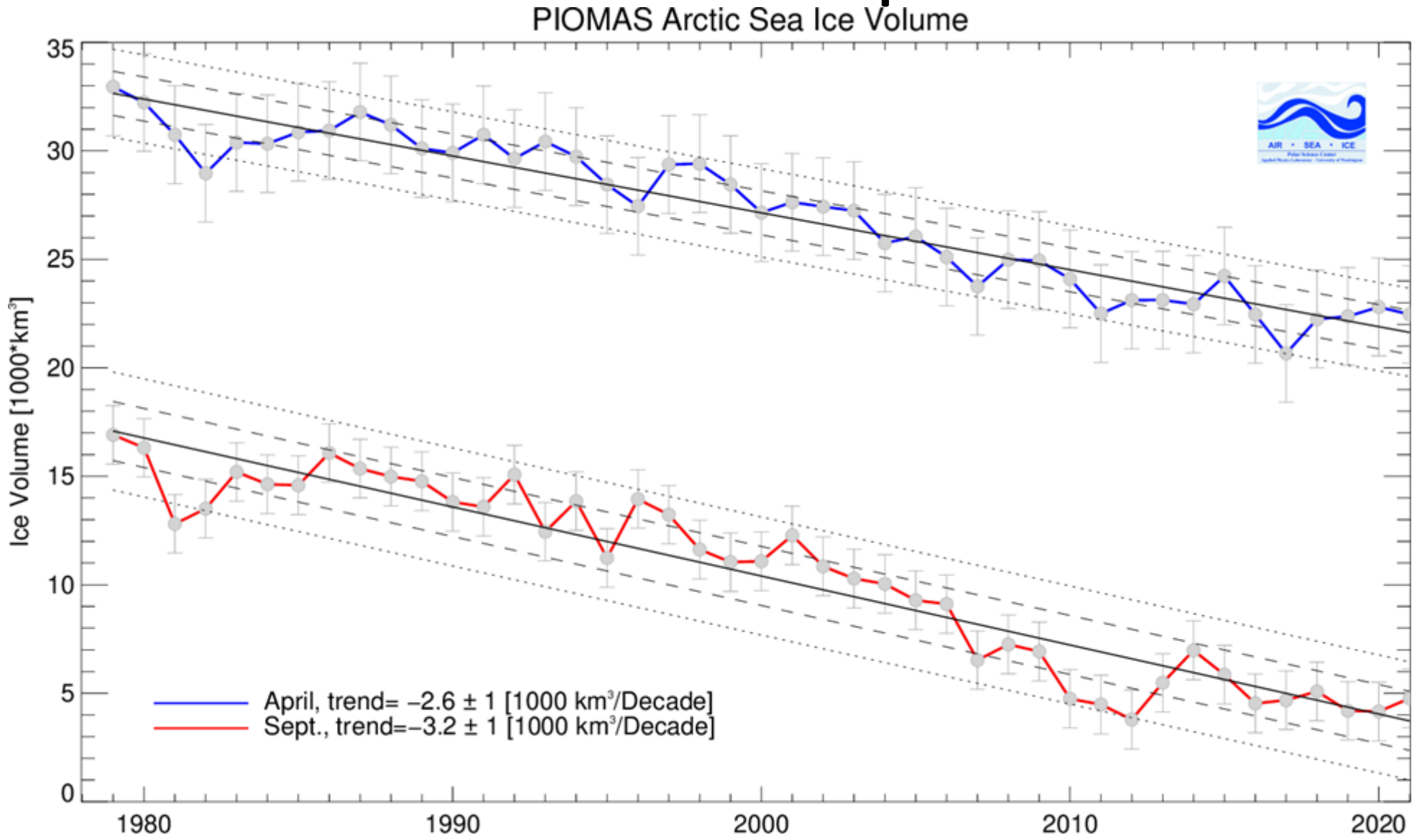
Natural Science

First Climate Tipping Point within two decades
Arctic ice-free September



Polar ice loss and warming underestimated

- Estimates included in Pistone et al. (2019) and corroborated by multiple other studies using different data and methodologies, suggest that lower albedo due to earlier surface melting and ice thinning and loss would lead to a global forcing impact increase from 1979 to the present equivalent to the warming effect of more than 20 years of GHG emissions at current rates.
- There has been a tendency over the past few decades for climate models to simulate less thinning and loss of Arctic sea ice than has been observed.
  - Pistone et al (2019) report that observed Arctic sea ice retreat per degree of global warming was 2.1 times larger than the mean of a large suite of models, with no model simulating as much reduction in sea ice cover as the observations.
  - A recent (2021) study found that from 2002 to 2018 Arctic ice has thinned 60% more than climate models have projected.
- From 1971 to 2019, the Arctic warmed three times, and from 1979 to 2021 nearly four times, faster than the rate of increase in the global average surface temperature anomaly.‴ Disproportionate warming has affected all three poles (i.e., including the Himalayan 'pole' at the top of the world, which is a critical source of water for 2 billion people ″). This "polar amplification" is contributing to the acceleration of losses of ice-sheet mass in Greenland, the Himalayas and Antarctica.
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IPCC Global Warming Metric understates Climate Change Impact

- The IPCC and COP's use of a 10 year moving average increase in global-average temperature change as their metric, a metric developed early on by scientists to get a strong signal-to-noise ratio, downplays the change being experienced by peoples and countries and fails to portray the seriousness of the changes in extreme weather that are being experienced.
- With respect to observations, averaging over time rather than calculating the present value from, say, a linear (or nonlinear) trend analysis significantly understates the amount of present warming and proximity to the Paris Agreement's warming goals.
- Averaging over time also fails to account for the year-to-year (and shorter-term) temperature excursions due to variability. Many types of impacts are most dependent on short-term excursions rather than decadal-averaged departures. Recent events are making clear that the worst impacts are from short-term weather extremes, such as flooding precipitation, prolonged heat waves, etc.

Spatially-averaged global temperature is a metric that virtually no one experiences

- Warming is greater over land than over the ocean, especially in mid- and high latitudes (and very especially in the Arctic), so most people are experiencing (and in the future will be experiencing) warming that is greater than the global average.
- And for those living in low-latitude regions that experience warming that is less than the global average, changes in precipitation are generally the most important impact, either as a result of prolonged heat waves and much drier conditions as the subtropics expand, or much wetter conditions because the trapped heat in low latitudes increases ocean evaporation and leads to more intense and prolonged precipitation.

Sea Level Rise is probably being Underestimated

- Neither the globally averaged temperature metric nor the focus on projections out to 2100 provides useful insight into the likely and ongoing amounts of sea level rise.
- Paleoclimatic analyses suggest an equilibrium sea level sensitivity exceeding 12 meters per degree change in global average temperature. The present rate of warming is at least 10 times greater than the average rate of warming during the deglaciation phase from the Last Glacial Maximum during which the average rate of sea level rise was 1.2 meters/century for 100 centuries while the global average temperature was rising at an average rate of one degree every 10 centuries.
- The recent IPCC assessment giving assurances that the rise in sea level by 2100 would be less than a meter is far from convincing given the increasing rate of flow of glacial streams coming off the Greenland and Antarctica and geological evidence that ice sheet decay occurs much more rapidly than ice sheet formation and would be very hard to stop once initiated.
- A 2022 NOAA technical report estimates that even if net-zero GHG emissions were reached now, existing levels of GHGs in the atmosphere and oceans will (in the absence of direct climate cooling or other countermeasures) lead to about 0.6 meters of sea level rise along the US coast by 2100.

Net-Zero anthropogenic emissions goals fail to recognize feedback increases in natural emissions

- As defined by the IPCC, the net-zero calculation refers only to direct human-induced emissions (i.e., emissions in national inventories).
- But already, the Arctic and Amazon basins have shifted from being natural sinks of CO_2 to natural sources, and the thawing of permafrost, warming of coastal sediments, ongoing forest conversion to farmland, occurrence of wildfires, and more, are reducing natural carbon uptake and storage and increasing natural emissions.
- By the time human-induced emissions reach net-zero, net natural emissions will be strongly positive and so global warming and climate disruption will continue.
- Counterbalancing these emissions with human-induced negative emissions will be very challenging given the magnitudes involved. NOAA has reported a super-linear increase in methane year over year that has a biogenic origin based on the stable isotope studies, a profound realization of a potential tipping point. Methane levels are now almost three times higher than they were pre-industrially.

DCC Climate Intervention is Needed Now

- Not everything needs to be learned and researched to its ultimate degree before starting intervention, as there should be learning along the way that is used to tune the intervention as it is ramped up. Perfection in understanding through modeling and analysis will be impossible and cannot be allowed to stop getting field research started. Basically, implementation and research must be tightly coupled.
- The relative benefit-detriment evaluation needs to be primarily with respect to the catastrophic conditions that are being avoided. In comparing the degree of return toward mid-20th century conditions, the comparison needs to determine how the envelopes of variability compare rather than just focus on differences in the time-averaged conditions. The better question is, will conditions with direct climate cooling interventions be more or less bearable than without intervention?
- A range of possible interventions exists in terms of season and location, and the patterns and intensities may well need to change over time. Deployment of options that permit adjustment would seem preferable to ones that cannot be readily adjusted.

Failure to begin DCC deployment in the very near-term will lead to greater harm and increased risk

- Recent modeling suggests that, in the absence of DCC if (anthropogenic and natural) net-zero emissions were to be achieved after 3667 Gigatons of CO2eq GHG (or 1000 Gigatons of carbon estimated to result in global warming of about 2.0° C) were accumulated in the atmosphere, global warming would remain at roughly 2.0° C for at least another 50 years due to continued thermal rebalancing from legacy ocean warming, even with continued ocean uptake of legacy CO2 from the atmosphere.'
- This suggests that after net-zero is achieved additional trillions of tons of legacy GHG would have to be directly removed from the atmosphere to reach atmospheric levels of CO_2 well below 350 ppm in order to cool the planet, remove carbon from the ocean, and restore the climate and ecosystem.'

Keeping warming below 1.5 °C, or “well below 2.0 °C”, without DCC is now practically impossible

- It is unrealistic to think global GHG emissions can be cut in half, or even a third, by 2030. But such such cutbacks would be necessary to have a greater than 66 percent chance of keeping global warming below 1.5 °C, or “well below 2.0 °C” (1.8 °C), through the 21st century.
- The World Meteorological Organization estimates that there is a 50 percent chance that the annual average global temperature increase will exceed 1.5 °C in at least one year by 2026 and Recent research suggests that even if emissions were stopped immediately in 2022, long term thermal equilibrium will produce above 2.0 °C warming before 2100.
- Existing Fossil-fuel generated aerosols exert an estimated 0.5° - 1.1° C cooling impact. Reducing these will likely cause the decadal-average increase in global average temperature to exceed 1.5° C, and possibly 2.0° C, until the stock of short-lived warming agents in the atmosphere decline.

Policy and Praxis

Climate Justice will not be possible without Direct Climate Cooling (DCC)

- The long-term average global temperature increase inadequately predicts the harm from regional or local extreme precipitation and heat events.
- Climate change, especially polar amplification, has already caused enormous damage and is likely to abruptly accelerate the risk of further catastrophic harm to humans and other species in the absence of urgent direct climate cooling efforts to slow or reverse it.
- At least eighteen potential direct climate cooling methods have been identified with the potential to address such climate disruptions.

Arguments against Direct Climate Cooling (DCC) are not persuasive

- The argument that any direct climate cooling method, whether localized or global, co-developed or not, should not be researched or implemented because it is a “moral hazard” that would slow GHG mitigation efforts has been put forth for several decades and with varied reasoning.
- But this argument as well as others about unanticipated consequences, “termination shock” or harmful climate destabilization if abruptly ended, and equitable governance, are concerns that in general, could be applied to many other efforts to reduce climate and environmental harm.
  - Climate adaptation, for example, was initially opposed as a potential moral hazard that could reduce pressure to cut emissions.
  - Regulations to reduce harmful sulfur emissions from cargo ship bunker fuel have reportedly had the unintended consequence of causing a global warming termination shock.
  - Equitable world governance is proving to be a challenge in achieving rapid, and at scale, global emissions reductions.

Delaying DCC has instead increased potentially avoidable harm and suffering and Climate Injustice

- While important considerations, the increasing pace of harmful climate impacts has so far not been sufficient to get a significant reduction in the share of global energy coming from fossil fuels, and meanwhile, the extent of impacts from extreme weather, for example, has consistently increased.
- Delaying direct cooling has instead led to greater harmful climate impacts, some now irreversible.
- There is little indication that this situation will change. Intervention related moral-hazard arguments cannot be settled *a priori* and do not properly compare the possible risks of some climate cooling methods against the convincingly projected impacts and risks that lie ahead if directly cooling the climate is not undertaken.
- Several climate cooling methods are local and low-tech and have few if any potential risks.

Many DCC Methods mimic natural processes and the need for DCC has increasingly been recognized

- Many of the approaches to offset climate warming mimic natural influences on the climate, or the impact of everyday human activity and can be quickly terminated if unanticipated adverse impacts arise.
- Delay in accelerating research, and then beginning to intervene to offset at least some of the global warming, as emissions continue at high levels, will lead to further warming, climate disruption and likely avoidable increases in human suffering and ecosystem disruption.
- These points have recently been recognized by many prominent national and international scientific and policy associations and think tanks, but unfortunately not yet by national or international climate decision-making bodies.

Prominent National and International Scientific and Policy Association and Think Tank endorsement of DCC Research

1. National Academy of Sciences. 2021. *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance.* Washington, D.C.: The National Academies Press,
2. A Policy Statement of the American Meteorological Society Adopted by the AMS Council on 2 February 2022: https://www.ametsoc.org/index.cfm/ams/about-ams/ams-statements/statements-of-the-ams-in-force/climate-intervention/ ,
3. Reflecting Sunlight to Reduce Climate Risk Priorities for Research and International Cooperation. Stewart M. Patrick. April 2022. Council on Foreign Relations: https://www.cfr.org/report/reflecting-sunlight-reduce-climate-risk ,
4. The Cambridge Center for Climate Repair: https://www.climaterepair.cam.ac.uk/restoring-broken-climate-systems , 5) The Climate Overshoot Commission: https://www.overshootcommission.org/

A Three Part Climate and Nature Restoration Plan: a) Cool, b) Reduce and c) Remove

To moderate global warming before key impacts become irreversible, a climate restoration plan with a goal of limiting global warming to well below 1° C in the near-term needs to be adopted and then promptly implemented. Such a plan would need to have three complementary components:

1. Deployment of near-term direct cooling influences, particularly focused at first on reducing amplified warming in the polar regions and the Himalayas,
2. Accelerated reductions of GHG emissions, including especially an early focus on methane and other short-lived warming agents, and
3. Building up capabilities for reducing the legacy concentration increases of CO_2, methane, and other GHGs by pulling down their loading in the atmosphere and oceans.

Direct Climate Cooling Methods Need to be Evaluated, Tested, and Deployed

- A precautionary approach would be to evaluate such direct climate cooling methods for their capacity to return our planetary trajectory towards known and healthy climate conditions.
- An evaluation framework could test and monitor small scale deployments under constrained conditions.
- Local methods with little or no risk could be immediately deployed if they are proven to be effective.
- This paper includes short summaries of eighteen of these methods, almost all written or reviewed by climate cooling experts from among those cited in the footnotes.

Eighteen potential DCC methods that merit early consideration, responsible investigation, and possible implementation and evaluation.

- Bright Waer
- Buoyant Flakes
- Cirrus cloud thinning (CCT)
- Extremely diluted Aqua Regia Aerosol (EDARA)
- Fizz Tops (Fiztops)
- Ice shields to thicken polar ice
- Iron Salt Aerosol (ISA)
- Making building and paving material more reflective and planting trees in urban areas
- Marine algal bloom stimulation

Eighteen DCC Methods (Continued)

- Marine Cloud Brightening (MCB)
- Marine Cloud Brightening (MCB)
- Mirrors for Earth's Energy Rebalancing (MEER)
- Ocean Thermal Energy Conversion (OTEC)
- Restoring natural upwelling and kelp forest ecosystem services offshore
- Restoring soil and vegetation
- Seawater atomization (Seatomizers)
- Stratospheric Aerosol Injection (SAI)
- Surface Albedo Modification (SAM)
- Titanium Oxide Aerosol (TOA)

Political Economy

The climate warming crisis timeline is shorter than that of social evolution so it needs to be solved largely within existing economic and political structures

- Although some fossil fuel interests have played an extraordinarily contrarian role in addressing the climate crisis (a role for which many think that they should be held accountable), fossil fuel use in general was not an "original sin," but was rather the basis for modern industrial development.
- Addressing the climate crisis is, at least in the short-term, primarily a practical environmental and technological problem that must be addressed within existing social and economic systems.
- Addressing the immediate aspects of the crisis by use of cooling approaches that can moderate global warming would allow for a more realistically feasible pace of emissions reductions while limiting further damage to many ecosystem resources, and perhaps providing a window for some degree of recovery.

But the longer-term (at least three decades) GHG reduction and removal and ecological regeneration opens up an opportunity for a more just economy and society

- Limiting further warming would thus provide an opportunity for societies to evolve from a fossil fuel and mineral mining based economy that is dependent on discovering and mining fossil fuels and minerals in particular locations, to a potentially more equitable, prosperous and ecologically sustainable civilization based on use of renewable energy and materials, able to harvest energy, and use minerals from the ocean and carbon from the air to synthesize needed materials, almost everywhere on the planet.
- Such a shift would replace today's wasteful and destructive practices with a circular economy where all waste is recycled as a resource. However the world proceeds, equity and environmental justice issues will need to be addressed to meet the Sustainable Development Goals that provide opportunity and a safety net for all.

Climate Justice is essential for a rapid transition to a more just and sustainable global economy over the long-term and DCC is essential to Climate Justice in the short-term

This will require addressing global climate issues such as:

- Providing a safe harbor for climate refugees,
- Assisting in overcoming loss and damage from climate disruption,
- Transferal of technology for climate restoration and ecological regeneration from rich to poor countries and individuals.

Doing this rapidly (within decades) will require significant funding and technology transfer and likely a mandatory global regime

- Over the 13 years from 2006 -2018 the Clean Development Mechanism that was part of the mandatory Kyoto accord transferred $303.8 billion from rich countries to poor countries for mitigation and adaptation.,
- In contrast the Paris agreement voluntary Green Climate Fund (GCF) had over the 8 years from 2014-2021 raised only $18.2 billion.
- Equitable reductions in GHG emissions would for example need to support economic development to offset the estimated $4 trillion in foreign exchange from oil and related products that countries comprising 1.1 billion people, or 14.2 percent of world population, depended on in 2019 for over 10% of their total export revenue. century levels.

Conclusion

Conclusion

- During at least the next several decades (and possibly much longer), direct cooling seems likely to be essential to limiting further warming and preventing human-induced climate change from spiraling out of control.
- Only the application of emergency cooling “tourniquets”, applied immediately or as soon as is reasonably advisable, has the potential to slow and even start to reverse ongoing climate disruption.
- Only direct climate cooling can slow or reverse Arctic sea ice loss, which seems near to flipping the Arctic Ocean into a summertime regime of very little, if any, sea ice.
- The very serious challenges imposed by increasing climate disruption and the economic opportunity of transforming the global energy system, must be urgently addressed together if unacceptable risks to society are to be minimized.
- Humanity has never faced an existential threat so critical for the long-term survival of human civilization and the ecosystems of the Earth on which society depends.