**Excerpt on Reaching Beyond the Averaged Global Warming Metric and Net-Zero Emissions**

Section 2: The Need for COP Policy to Reach Beyond Averaged Global Warming Metric and Net-Zero Emissions, from: Addressing the Urgent Need for Direct Climate Cooling: Rationale and Options, *Oxford Open Climate Change* 2024 forthcoming. Aug. 17, 2024, preprint.

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1. **The Need for COP Policy to Reach Beyond Averaged Global Warming Metric and Net-Zero Emissions**

The IPCC “Average Global Warming” metric, central to setting and publicizing policies dealing with climate change, is inadequate and misleading. Defined as “an increase in combined surface air and sea surface temperatures averaged over the globe and over a 30-year period,” the metric yields an approximation to global average temperature increase that is time-lagged by a decade behind the current level of warming [30]. This smoothing of data aims to provide a scientifically rigorous metric for determining when the Paris Accord peak-temperature goals are exceeded. However, by suppressing variability the metric defers recognizing essential thresholds that would indicate crossing of tipping points [10].

Though useful as a summary metric (as in figure 1), the Average Global Warming metric fails to convey the significance of the warming taking place in real time or reveal regionally important vulnerabilities. The oceans, which cover 71% of the Earth’s surface, have a very large heat capacity that keeps its average warming well below the increase occurring over land surfaces. Averaging ocean and land surface temperatures together understates the rapidly increasing impacts on people and the terrestrial biosphere [31].

In the Northern Hemisphere’s high latitudes, polar amplification is resulting in warming that is more than three times the global average, accelerating permafrost thawing, loss of sea ice, and loss of mass from the Greenland ice sheet [32]. In mid-latitudes, measures of the increases in extreme precipitation and duration of heat waves would better characterize the pace and significance of weather disruption [33]. The heat and discomfort index is a much more appropriate metric for indicating the significance of global warming in hot, humid regions [34]. Extremes in precipitation can cause the worst impacts on those living in wet, tropical regions where increased ocean evaporation leads to more intense rain and flooding [35]. Current events and observations are making it clear that short-term weather extremes [36] are increasing at a rate far faster than the slowly rising multi-decadal average of the global temperature increases.

Use of the global average warming metric, even with projections out to 2100, provides no direct insight into the ongoing and committed amounts of sea level rise. Paleoclimatic analyses suggest an equilibrium sea level sensitivity exceeding 12 meters per degree change in global average temperature [37]. The present rate of warming is at least 10 times greater than the average during the multi-millennial deglaciation following the Last Glacial Maximum. Sea level rise then averaged more than a meter per century for 100 centuries while the average temperature in Antarctica was rising at an average rate of one degree every 10 centuries [38].

The IPCC assurances that the rise in sea level by 2100 would be less than a meter [39] are questionable given the destabilization and increasing rate of flow of glacial streams from the Greenland and Antarctica ice sheets [40]. Geological evidence makes clear that ice sheet decay occurs much more rapidly than ice sheet formation and that melting is very hard to stop once it starts [41]. NOAA estimates in a 2021 technical report that even if net-zero GHG emissions were rapidly achieved, sea level rise along the US coast by 2100 would exceed half a meter [42], threatening destruction of all low-lying infrastructure. There is virtually no public understanding of committed future sea level rise and the impacts it will have on future generations [43].

The scientific community may view the global average warming metric, properly interpreted, as a suitable public and policy surrogate for climate change, but its use leaves many members of the public, most business leaders, and many lawmakers ill-informed about the urgency of effective climate action. Most citizens, and even political leaders, do not have access to expert climate advisors. A variety of more meaningful metrics and a revised approach to communicating the urgency of incorporating credible cooling research and responsible deployment into global climate change policy are needed.

**References**

1. UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE. 1992.

2. Hansen JE, Sato M, Simons L *et al.* Global Warming in the pipeline. *Oxford Open Climate Change* 2023;**3**:kgad008.

3. Climate Change 2022, Mitigation of Climate Change. Summary for Policymakers.

4. Tracking emissions by country and sector. *Brookings* 2022.

5. Global climate summary for January 2024 | NOAA Climate.gov. 2024.

6. Change NGC. Global Surface Temperature | NASA Global Climate Change. *Climate Change: Vital Signs of the Planet*.

7. Global Climate Highlights | Copernicus.

8. Smith AB. U.S. Billion-dollar Weather and Climate Disasters, 1980 - present (NCEI Accession 0209268). 2020, DOI: 10.25921/STKW-7W73.

9. Armstrong McKay DI, Staal A, Abrams JF *et al.* Exceeding 1.5°C global warming could trigger multiple climate tipping points. *Science* 2022;**377**:eabn7950.

10. Lenton TM, Rockström J, Gaffney O *et al.* Climate tipping points — too risky to bet against. *Nature* 2019;**575**:592–5.

11. Baiman R. In Support of a Renewable Energy and Materials Economy: A Global Green New Deal That Includes Arctic Sea Ice Triage and Carbon Cycle Restoration. *Review of Radical Political Economics* 2021;**53**:611–22.

12. Biermann F, Oomen J, Gupta A *et al.* Solar geoengineering: The case for an international non‐use agreement. *WIREs Climate Change* 2022;**13**:e754.

13. Diamond MS, Gettelman A, Lebsock MD *et al.* To assess marine cloud brightening’s technical feasibility, we need to know what to study—and when to stop. *Proc Natl Acad Sci USA* 2022;**119**:e2118379119.

14. Jebari J, Táíwò OO, Andrews TM *et al.* From moral hazard to risk-response feedback. *Climate Risk Management* 2021;**33**:100324.

15. McLaren D. Mitigation deterrence and the “moral hazard” of solar radiation management. *Earth’s Future* 2016;**4**:596–602.

16. MacMartin DG, Visioni D, Kravitz B *et al.* Scenarios for modeling solar radiation modification. *Proc Natl Acad Sci USA* 2022;**119**:e2202230119.

17. Montreal Protocol emerges as a powerful climate treaty | National Oceanic and Atmospheric Administration. 2023.

18. *Solar Radiation Modification in the United States: A Discussion*., 2024.

19. Baiman R. Our Two Climate Crises Challenge: Short-Run Emergency Direct Climate Cooling and Long-Run GHG Removal and Ecological Regeneration. *Review of Radical Political Economics* 2022;**54**:435–51.

20. Weitzman GW Martin L. Playing God. *Foreign Policy* 2012.

21. Diamond MS. Detection of large-scale cloud microphysical changes within a major shipping corridor after implementation of the International Maritime Organization 2020 fuel sulfur regulations. *Atmos Chem Phys* 2023;**23**:8259–69.

22. Yuan T, Song H, Oreopoulos L *et al.* Abrupt reduction in shipping emission as an inadvertent geoengineering termination shock produces substantial radiative warming. *Commun Earth Environ* 2024;**5**:281.

23. Baiman R, Baiman R, Bishop R *et al.* An Open Letter to the IMO Supporting Maritime Transport that Cools the Atmosphere While Preserving Air Quality Benefits. 2024, DOI: 10.22541/essoar.171690792.20111702/v1.

24. Manshausen P, Watson-Parris D, Christensen MW *et al.* Invisible ship tracks show large cloud sensitivity to aerosol. *Nature* 2022;**610**:101–6.

25. Simons L, Hansen J, Dufournet Y. *Climate Impact of Decreasing Atmospheric Sulphate Aerosols and the Risk of a Termination Shock*., 2021.

26. Hansen J, Kharecha P, Sato M. “A Miracle Will Occur” Is Not Sensible Climate Policy. 2023.

27. Harding AR, Belaia M, Keith DW. The value of information about solar geoengineering and the two-sided cost of bias. *Climate Policy* 2023;**23**:355–65.

28. McInnes CR. Space-based geoengineering: Challenges and requirements. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* 2010;**224**:571–80.

29. Van Wijngaarden A, Moore JC, Alfthan B *et al.* A survey of interventions to actively conserve the frozen North. *Climatic Change* 2024;**177**:58.

30. Betts RA, Belcher SE, Hermanson L *et al.* Approaching 1.5 °C: how will we know we’ve reached this crucial warming mark? *Nature* 2023;**624**:33–5.

31. Which parts of the planet are warming the fastest, and why? | MIT Climate Portal.

32. Arctic Climate Change Update 2021: Key Trends and Impacts. Summary for Policy-makers | AMAP.

33. Wu S, Luo M, Zhao R *et al.* Local mechanisms for global daytime, nighttime, and compound heatwaves. *npj Clim Atmos Sci* 2023;**6**:1–13.

34. Shulmeister J. Climate explained: will the tropics eventually become uninhabitable? *The Conversation* 2020.

35. Staff CB. Mapped: How climate change affects extreme weather around the world. *Carbon Brief* 2022.

36. Hersher R. Climate change exacerbates deadly floods in Libya and worldwide. *NPR*. https://www.npr.org/2023/09/13/1199273629/climate-change-exacerbates-deadly-floods-worldwide. Published September 19, 2023. Accessed July 24, 2024.

37. Center NGSF. Paleoclimate record points toward potential rapid climate changes.

38. Orbital and Millennial Antarctic Climate Variability over the Past 800,000 Years | Science.

39. Intergovernmental Panel On Climate Change (Ipcc). *The Ocean and Cryosphere in a Changing Climate: Special Report of the Intergovernmental Panel on Climate Change*. 1st ed. Cambridge University Press, 2022.

40. Hansen J, Sato M, Hearty P *et al.* Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming could be dangerous. *Atmos Chem Phys* 2016;**16**:3761–812.

41. Box JE, Hubbard A, Bahr DB *et al.* Greenland ice sheet climate disequilibrium and committed sea-level rise. *Nat Clim Chang* 2022;**12**:808–13.

42. Sweet WV, et al. *Global and Regional Sea Level Rise Scenarios for the United States*. National Ocean and Atmospheric Administration, 2022.

43. Moving To Higher Ground: Rising Sea Level and the Path Forward (Paperback) | Shakespeare & Co.

44. Climate at a Glance | Global Time Series | National Centers for Environmental Information (NCEI).

45. https://unfccc.int/sites/default/files/resource/cma2023\_L17E.pdf?download. 2023.

46. *Global Warming of 1.5 oC —*., 2018.

47. Von Schuckmann K, Cheng L, Palmer MD *et al.* Heat stored in the Earth system: where does the energy go? *Earth Syst Sci Data* 2020;**12**:2013–41.

48. Ritchie H, Rosado P, Roser M. Fossil fuels. *Our World in Data* 2024.

49. Arctic Shifts to a Carbon Source due to Winter Soil Emissions - NASA. 2019.

50. Gatti LV, Basso LS, Miller JB *et al.* Amazonia as a carbon source linked to deforestation and climate change. *Nature* 2021;**595**:388–93.

51. Lan X, Basu S, Schwietzke S *et al.* Improved Constraints on Global Methane Emissions and Sinks Using *δ* 13 C‐CH 4. *Global Biogeochemical Cycles* 2021;**35**:e2021GB007000.

52. Thoning K, Dlugokencky E, Lan X *et al.* Trends in globally-averaged CH4, N2O, and SF6. 2022, DOI: 10.15138/P8XG-AA10.

53. Ming T, Li W, Yuan Q *et al.* Perspectives on removal of atmospheric methane. *Advances in Applied Energy* 2022;**5**:100085.

54. Ditlevsen P, Ditlevsen S. Warning of a forthcoming collapse of the Atlantic meridional overturning circulation. *Nat Commun* 2023;**14**:4254.

55. Rahmstorf S, Box JE, Feulner G *et al.* Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. *Nature Clim Change* 2015;**5**:475–80.

56. Van Westen RM, Kliphuis M, Dijkstra HA. Physics-based early warning signal shows that AMOC is on tipping course. *Sci Adv* 2024;**10**:eadk1189.

57. Pistone K, Eisenman I, Ramanathan V. Radiative Heating of an Ice‐Free Arctic Ocean. *Geophysical Research Letters* 2019;**46**:7474–80.

58. Cao Y, Liang S, Chen X *et al.* Assessment of Sea Ice Albedo Radiative Forcing and Feedback over the Northern Hemisphere from 1982 to 2009 Using Satellite and Reanalysis Data. *Journal of Climate* 2015;**28**:1248–59.

59. Flanner MG, Shell KM, Barlage M *et al.* Radiative forcing and albedo feedback from the Northern Hemisphere cryosphere between 1979 and 2008. *Nature Geosci* 2011;**4**:151–5.

60. Hudson SR. Estimating the global radiative impact of the sea ice–albedo feedback in the Arctic. *J Geophys Res* 2011;**116**:D16102.

61. Mallett RDC, Stroeve JC, Tsamados M *et al.* Faster decline and higher variability in the sea ice thickness of the marginal Arctic seas when accounting for dynamic snow cover. *The Cryosphere* 2021;**15**:2429–50.

62. Heuzé C, Zanowski H, Karam S *et al.* The Deep Arctic Ocean and Fram Strait in CMIP6 Models. *Journal of Climate* 2023;**36**:2551–84.

63. harrisson thomas. Q&A: How is Arctic warming linked to the ‘polar vortex’ and other extreme weather? *Carbon Brief* 2019.

64. Rantanen M, Karpechko AYu, Lipponen A *et al.* The Arctic has warmed nearly four times faster than the globe since 1979. *Commun Earth Environ* 2022;**3**:168.

65. Change NGC. Ice Sheets | NASA Global Climate Change. *Climate Change: Vital Signs of the Planet*.

66. Lee E, Carrivick JL, Quincey DJ *et al.* Accelerated mass loss of Himalayan glaciers since the Little Ice Age. *Sci Rep* 2021;**11**:24284.

67. *Himalayan Glaciers: Climate Change, Water Resources, and Water Security*. Washington, D.C.: National Academies Press, 2012:13449.

68. Christian Aid. counting-the-cost-2022.pdf. 2022.

69. Dezember R. Blame Bad Weather for Your Bigger Bills. *Wall Street Journal*. https://www.wsj.com/articles/blame-bad-weather-for-your-bigger-bills-11640640525. Published December 28, 2021. Accessed July 25, 2024.

70. Equity Investors Must Pay More Attention to Climate Change Physical Risk. *IMF* 2020.

71. World Bank. World Bank Open Data. *World Bank Open Data* 2024.

72. Hansen J, Sato M, Ruedy R. The Climate Dice are Loaded. Now, a New Frontier? 2023.

73. Climate Action Tracker. Warming projections global update. 2023.

74. Environment UN. Emissions Gap Report 2023 | UNEP - UN Environment Programme. 2023.

75. *Zeke Hausfather*.

76. EDF. Methane: A crucial opportunity in the climate fight - Environmental Defense Fund.

77. Futerman G, Adhikari M, Duffey A *et al.* The interaction of Solar Radiation Modification and Earth System Tipping Elements. *EGUsphere* 2023:1–70.

78. MacDougall AH, Frölicher TL, Jones CD *et al.* Is there warming in the pipeline? A multi-model analysis of the Zero Emissions Commitment from CO2. *Biogeosciences* 2020;**17**:2987–3016.

79. Hausfather Z. Explainer: Will global warming ‘stop’ as soon as net-zero emissions are reached? *Carbon Brief* 2021.

80. White House Report, “Restoring the Quality of Our Environment,” Report of the Environmental Pollution Panel, President’s Science Advisory Committee, November 1965 | National Security Archive.

81. Committee on Developing a Research Agenda and Research Governance Approaches for Climate Intervention Strategies that Reflect Sunlight to Cool Earth, Board on Atmospheric Sciences and Climate, Committee on Science, Technology, and Law *et al.* *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance*. Washington, D.C.: National Academies Press, 2021:25762.

82. American Meteorological Society. A policy statement of the American Meteorological Society. 2021.

83. Reflecting Sunlight to Reduce Climate Risk | Council on Foreign Relations.

84. Refreeze | Centre for Climate Repair.

85. Climate Overshoot Commission. *Overshoot Commission*.

86. Zevenhoven R, Fält M. Radiative cooling through the atmospheric window: A third, less intrusive geoengineering approach. *Energy* 2018;**152**:27–33.

87. Wieners CE, Hofbauer BP, de Vries IE *et al.* Solar radiation modification is risky, but so is rejecting it: a call for balanced research. *Oxford Open Climate Change* 2023;**3**:kgad002.

88. Doherty. An open letter regarding research on reflecting sunlight to reduce the risks of climate change. *climate intervention research letter*.

89. Civillini M. Switzerland proposes an UN expert group on solar geoengineering. *Climate Home News* 2024.

90. Bradley S. Nations fail to back Swiss proposal to examine solar geoengineering tech. *SWI swissinfo.ch* 2024.

91. Congressionally-Mandated Report on Solar Radiation Modification | OSTP. *The White House* 2023.

92. Canada bets big on Bill Gates’ solar geoengineering initiative to tame global warming. *The People’s Network BNN* 2024.

93. Abnett K, Abnett K. EU calls for global talks on climate geoengineering risks. *Reuters*. https://www.reuters.com/sustainability/eu-calls-global-talks-climate-geoengineering-risks-2023-06-28/. Published June 28, 2023. Accessed July 25, 2024.

94. Research programme to model impact of solar radiation management. 2024.

95. *»Klima-Landschaften«, Walter Jehne, The Importance of Vegetation for the Water Cycle and Climate*., 2022.

96. Piao S, Wang X, Park T *et al.* Characteristics, drivers and feedbacks of global greening. *Nat Rev Earth Environ* 2019;**1**:14–27.

97. Evans D. Features. 2020.

98. Makarieva AM, Gorshkov VG. Biotic pump of atmospheric moisture as driver of the hydrological cycle on land. *Hydrol Earth Syst Sci* 2007.

99. Rohatyn S, Rotenberg E, Tatarinov F *et al.* Large variations in afforestation-related climate cooling and warming effects across short distances. *Commun Earth Environ* 2023;**4**:1–10.

100. Dekker SC, De Boer HJ, Koren GB *et al.* Targeted Climate Modification on land &#8211; A matter of scale. 2024, DOI: 10.5194/egusphere-egu24-4740.

101. Princeton Engineering - Planting forests may cool the planet more than thought. *Princeton Engineering*.

102. Andersson E, Barthel S, Borgström S *et al.* Reconnecting Cities to the Biosphere: Stewardship of Green Infrastructure and Urban Ecosystem Services. *AMBIO* 2014;**43**:445–53.

103. Wang T, Stewart CE, Sun C *et al.* Effects of biochar addition on evaporation in the five typical Loess Plateau soils. *CATENA* 2018;**162**:29–39.

104. Saco PM, McDonough KR, Rodriguez JF *et al.* The role of soils in the regulation of hazards and extreme events. *Philosophical Transactions of the Royal Society B: Biological Sciences* 2021;**376**:20200178.

105. Ban-Weiss GA, Bala G, Cao L *et al.* Climate forcing and response to idealized changes in surface latent and sensible heat. *Environ Res Lett* 2011;**6**:034032.

106. Griscom BW. Natural climate solutions. *PNAS* 2017, DOI: 10.1073/pnas.1710465114.

107. Clarke W. Clarke S. 2022 More Solutions. 2023;**1**, DOI: 10.17632/k6r7ycg7hk.1.

108. Strong AL, Cullen JJ, Chisholm SW. Ocean Fertilization: Science, Policy, and Commerce. *Oceanography* 2009;**22**:236–61.

109. Mitchell DL, Finnegan W. Modification of cirrus clouds to reduce global warming. *Environ Res Lett* 2009;**4**:045102.

110. Steffen W, Rockström J, Richardson K *et al.* Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences* 2018;**115**:8252–9.

111. Atkinson JD, Murray BJ, Woodhouse MT *et al.* The importance of feldspar for ice nucleation by mineral dust in mixed-phase clouds. *Nature* 2013;**498**:355–8.

112. Mitchell DL, Garnier A, Pelon J *et al.* CALIPSO (IIR–CALIOP) retrievals of cirrus cloud ice-particle concentrations. *Atmos Chem Phys* 2018;**18**:17325–54.

113. Tully C, Neubauer D, Omanovic N *et al.* Cirrus cloud thinning using a more physically based ice microphysics scheme in the ECHAM-HAM general circulation model. *Atmos Chem Phys* 2022;**22**:11455–84.

114. Tully C, Neubauer D, Villanueva D *et al.* Does prognostic seeding along flight tracks produce the desired effects of cirrus cloud thinning? *Atmos Chem Phys* 2023;**23**:7673–98.

115. Gryspeerdt E, Sourdeval O, Quaas J *et al.* Ice crystal number concentration estimates from lidar–radar satellite remote sensing – Part 2: Controls on the ice crystal number concentration. *Atmos Chem Phys* 2018;**18**:14351–70.

116. Lyu K, Liu X, Bacmeister J *et al.* Orographic Cirrus and Its Radiative Forcing in NCAR CAM6. *JGR Atmospheres* 2023;**128**:e2022JD038164.

117. Shi X, Liu X, Zhang K. Effects of pre-existing ice crystals on cirrus clouds and comparison between different ice nucleation parameterizations with the Community Atmosphere Model (CAM5). *Atmos Chem Phys* 2015;**15**:1503–20.

118. Gouveia DA, Barja B, Barbosa HMJ *et al.* Optical and geometrical properties of cirrus clouds in Amazonia derived from 1 year of ground-based lidar measurements. *Atmos Chem Phys* 2017;**17**:3619–36.

119. Dekoutsidis G, Groß S, Wirth M *et al.* Characteristics of supersaturation in midlatitude cirrus clouds and their adjacent cloud-free air. *Atmos Chem Phys* 2023;**23**:3103–17.

120. Irvine P. Global SRM Technologies - A Tier List. *Plan A+* 2023.

121. Lozano MM, Talu E, Longo ML. Dissolution of microbubbles generated in seawater obtained offshore: Behavior and surface tension measurements. *Journal of Geophysical Research: Oceans* 2007;**112**, DOI: 10.1029/2007JC004108.

122. Desch SJ, Smith N, Groppi C *et al.* Arctic ice management. *Earth’s Future* 2017;**5**:107–27.

123. Clarke W. Clarke S. 2021 Ice Shield Strategies. 2023;**1**, DOI: 10.17632/n6vsy3zgg6.1.

124. Zampieri L, Goessling HF. Sea Ice Targeted Geoengineering Can Delay Arctic Sea Ice Decline but not Global Warming. *Earth’s Future* 2019;**7**:1296–306.

125. Latham J. Amelioration of global warming by controlled enhancement of the albedo and longevity of low-level maritime clouds. *Atmospheric Science Letters* 2002;**3**:52–8.

126. Latham J, Rasch P, Chen C-C *et al.* Global temperature stabilization via controlled albedo enhancement of low-level maritime clouds. *Phil Trans R Soc A* 2008;**366**:3969–87.

127. Latham J, Bower K, Choularton T *et al.* Marine cloud brightening. *Phil Trans R Soc A* 2012;**370**:4217–62.

128. Parkes B, Challinor A, Nicklin K. Crop failure rates in a geoengineered climate: impact of climate change and marine cloud brightening. *Environ Res Lett* 2015;**10**:084003.

129. Parkes B, Gadian A, Latham J. The Effects of Marine Cloud Brightening on Seasonal Polar Temperatures and the Meridional Heat Flux. *ISRN Geophysics* 2012;**2012**:1–7.

130. Latham J, Parkes B, Gadian A *et al.* Weakening of hurricanes via marine cloud brightening (MCB). *Atmospheric Science Letters* 2012;**13**:231–7.

131. Latham J, Kleypas J, Hauser R *et al.* Can marine cloud brightening reduce coral bleaching? *Atmospheric Science Letters* 2013;**14**:214–9.

132. Liu F, Mao F, Rosenfeld D *et al.* Opposing comparable large effects of fine aerosols and coarse sea spray on marine warm clouds. *Commun Earth Environ* 2022;**3**:232.

133. Twomey S. The Influence of Pollution on the Shortwave Albedo of Clouds. *J Atmos Sci* 1977;**34**:1149–52.

134. Wood R. Assessing the potential efficacy of marine cloud brightening for cooling Earth using a simple heuristic model. *Atmos Chem Phys* 2021;**21**:14507–33.

135. Salter S, Sortino G, Latham J. Sea-going hardware for the cloud albedo method of reversing global warming. *Phil Trans R Soc A* 2008;**366**:3989–4006.

136. Salter S. Salter S. 2020 Sea Level Rise and Ice Recovery. 2024;**1**, DOI: 10.17632/3sb9zk9rc9.1.

137. Salter S. Salter S. 2021 Note for COP 26 on Marine Cloud Brightening. 2024;**1**, DOI: 10.17632/34tphk2yxz.1.

138. Salter S. Salter S. 2022 Simulations of a Demonstration of Cloud Albedo Change. 2024;**1**, DOI: 10.17632/8bmwp98786.1.

139. Mims C. “Albedo Yachts” and Marine Clouds: A Cure for Climate Change? *Scientific American* 2009.

140. Chamblee R. Putting the Great Barrier Reef marine cloud brightening experiment into context. *C2G* 2020.

141. Neukermans A, Cooper G, Foster J *et al.* Sub-micrometer salt aerosol production intended for marine cloud brightening. *Atmospheric Research* 2014;**142**:158–70.

142. Harrison DP. Cloud brightening reduces coral bleaching - Southern Cross University. 2023.

143. Jones A, Haywood J, Boucher O. Climate impacts of geoengineering marine stratocumulus clouds. *Journal of Geophysical Research: Atmospheres* 2009;**114**, DOI: 10.1029/2008JD011450.

144. Ricke K, Ivanova D, McKie T *et al.* Reversing Sahelian Droughts. *Geophysical Research Letters* 2021;**48**:e2021GL093129.

145. Seneviratne SI, Phipps SJ, Pitman AJ *et al.* Land radiative management as contributor to regional-scale climate adaptation and mitigation. *Nature Geosci* 2018;**11**:88–96.

146. Ortiz-Bobea A, Wang H, Carrillo CM *et al.* Unpacking the climatic drivers of US agricultural yields. *Environ Res Lett* 2019;**14**:064003.

147. Zhang Q, Bi G, Li T *et al.* Color Shade Nets Affect Plant Growth and Seasonal Leaf Quality of Camellia sinensis Grown in Mississippi, the United States. *Front Nutr* 2022;**9**:786421.

148. Li J, Jiang Y, Liu J *et al.* A photosynthetically active radiative cooling film. *Nat Sustain* 2024;**7**:786–95.

149. Cao M, Rosado P, Lin Z *et al.* Cool Roofs in Guangzhou, China: Outdoor Air Temperature Reductions during Heat Waves and Typical Summer Conditions. *Environ Sci Technol* 2015;**49**:14672–9.

150. McKuin B, Zumkehr A, Ta J *et al.* Energy and water co-benefits from covering canals with solar panels. *Nat Sustain* 2021;**4**:609–17.

151. Kim H, Gao Y, Moran E *et al.* High albedo daytime radiative cooling for enhanced bifacial PV performance. *Nanophotonics* 2024;**13**:621–7.

152. Hughes TP, Kerry JT, Álvarez-Noriega M *et al.* Global warming and recurrent mass bleaching of corals. *Nature* 2017;**543**:373–7.

153. Berg JT, David CM, Gabriel MM *et al.* Fluorescence signatures of persistent photosystem damage in the staghorn coral *Acropora* cf. *pulchra* (Anthozoa: Scleractinia) during bleaching and recovery. *Marine Biology Research* 2020;**16**:643–55.

154. Wild M, Folini D, Hakuba MZ *et al.* The energy balance over land and oceans: an assessment based on direct observations and CMIP5 climate models. *Clim Dyn* 2015;**44**:3393–429.

155. Thomson AM, Calvin KV, Smith SJ *et al.* RCP4.5: a pathway for stabilization of radiative forcing by 2100. *Climatic Change* 2011;**109**:77–94.

156. Hasselbring H. The Effect of Shading on the Transpiration and Assimilation of the Tobacco Plant in Cuba. *Botanical Gazette* 1914;**57**:257–86.

157. Laub M, Pataczek L, Feuerbacher A *et al.* Contrasting yield responses at varying levels of shade suggest different suitability of crops for dual land-use systems: a meta-analysis. *Agron Sustain Dev* 2022;**42**:51.

158. Archontoulis SV, Struik P, Danalatos N. Leaf photosynthesis of kenaf (cv. Everglades 41) as affected by different light intensity and temperature regimes. 2005.

159. Bauweraerts I, Mannaerts TBHL, Wertin TM *et al.* Elevated [CO2] and growth temperature have a small positive effect on photosynthetic thermotolerance of Pinus taeda seedlings. *Trees* 2014;**28**:1515–26.

160. Millstein DE, Fischer ML. Reflective ‘cool’ roofs under aerosol-burdened skies: radiative benefits across selected Indian cities. *Environ Res Lett* 2014;**9**:104014.

161. Trlica A, Hutyra LR, Schaaf CL *et al.* Albedo, Land Cover, and Daytime Surface Temperature Variation Across an Urbanized Landscape. *Earth’s Future* 2017;**5**:1084–101.

162. Munywoki JN. Influence of different coloured agronet covers on water use efficiency, insect pest populations, yield and quality of french bean (Phaseolus vulgaris l.). 2017.

163. Mohawesh O, Albalasmeh A, Deb S *et al.* Effect of Colored Shading Nets on the Growth and Water Use Efficiency of Sweet Pepper Grown under Semi-arid Conditions. *hortte* 2022;**32**:21–7.

164. Hartley IP, Hill TC, Chadburn SE *et al.* Temperature effects on carbon storage are controlled by soil stabilisation capacities. *Nat Commun* 2021;**12**:6713.

165. Barron-Gafford GA, Minor RL, Allen NA *et al.* The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures. *Sci Rep* 2016;**6**:35070.

166. Campra P, Garcia M, Canton Y *et al.* Surface temperature cooling trends and negative radiative forcing due to land use change toward greenhouse farming in southeastern Spain. *J Geophys Res* 2008;**113**:2008JD009912.

167. Caparas M, Zobel Z, Castanho ADA *et al.* Increasing risks of crop failure and water scarcity in global breadbaskets by 2030. *Environ Res Lett* 2021;**16**:104013.

168. Kornhuber K, Lesk C, Schleussner CF *et al.* Risks of synchronized low yields are underestimated in climate and crop model projections. *Nat Commun* 2023;**14**:3528.

169. Greene S. *Climate Adaptation and Democracy Support: Learning from One Another*. United Kingdom: International Institute for Environment and Development, 2023.

170. Villanueva D, Possner A, Neubauer D *et al.* Mixed-phase regime cloud thinning could help restore sea ice. *Environ Res Lett* 2022;**17**:114057.

171. Rangno AL. *A Critical Review of CRITICAL ISSUES IN WEATHER MODIFICATION RESEARCH*., 2003.

172. *Ulrike Lohmann on Clouds, Aerosols and Solar Radiation Modification - Challenging Climate*.

173. Baird J. Global warming, a global energy resource. *Thermal Science and Engineering* 2024;**6**:5268.

174. Rau GH, Baird JR. Negative-CO2-emissions ocean thermal energy conversion. *Renewable and Sustainable Energy Reviews* 2018;**95**:265–72.

175. Gleckler PJ, Durack PJ, Stouffer RJ *et al.* Industrial-era global ocean heat uptake doubles in recent decades. *Nature Clim Change* 2016;**6**:394–8.

176. NASA. Global Effects of Mount Pinatubo. 2001.

177. Smith W. The cost of stratospheric aerosol injection through 2100. *Environ Res Lett* 2020;**15**:114004.

178. MacCracken MC, Shin H-J, Caldeira K *et al.* Climate response to imposed solar radiation reductions in high latitudes. *Earth Syst Dynam* 2013;**4**:301–15.

179. Roose S, Bala G, Krishnamohan KS *et al.* Quantification of tropical monsoon precipitation changes in terms of interhemispheric differences in stratospheric sulfate aerosol optical depth. *Clim Dyn* 2023;**61**:4243–58.

180. Irvine PJ, Keith DW. Halving warming with stratospheric aerosol geoengineering moderates policy-relevant climate hazards. *Environ Res Lett* 2020;**15**:044011.

181. Tilmes S, MacMartin DG, Lenaerts JTM *et al.* Reaching 1.5 and 2.0&thinsp;°C global surface temperature targets using stratospheric aerosol geoengineering. *Earth System Dynamics* 2020;**11**:579–601.

182. world meteorological organization. *Scientific Assessment of Ozone Depletion: 2018*., 2019.

183. Visioni D, Pitari G, Aquila V *et al.* Sulfate geoengineering impact on methane transport and lifetime: results from the Geoengineering Model Intercomparison Project (GeoMIP). *Atmospheric Chemistry and Physics* 2017;**17**:11209–26.

184. Field L, Ivanova D, Bhattacharyya S *et al.* Increasing Arctic Sea Ice Albedo Using Localized Reversible Geoengineering. *Earth’s Future* 2018;**6**:882–901.

185. Restoring Arctic Ice: A New Way to Stabilize the Climate. *Arctic Circle*.

186. Johnson D, Manzara A, Field LA *et al.* A Controlled Experiment of Surface Albedo Modification to Reduce Ice Melt. *Earth’s Future* 2022;**10**:e2022EF002883.

187. Kalkstein LS, Eisenman DP, De Guzman EB *et al.* Increasing trees and high-albedo surfaces decreases heat impacts and mortality in Los Angeles, CA. *Int J Biometeorol* 2022;**66**:911–25.

188. Schneider S, McGarrell A. Enhancing Building Efficiency And Resilience With Solar-Reflective Walls. *IIBEC Interface* 2023.

189. Debbage N, Shepherd JM. The urban heat island effect and city contiguity. *Computers, Environment and Urban Systems* 2015;**54**:181–94.

190. MIT. Mitigating Climate Change with Reflective Pavement. 2020.

191. Oleson KW, Bonan GB, Feddema J. Effects of white roofs on urban temperature in a global climate model. *Geophysical Research Letters* 2010;**37**:2009GL042194.

192. Woo HY, Chae D, Son S *et al.* Passive daytime radiative cooling with thermal energy storage using phase change n-octadecane/SiO2 nanobeads. *Optical Materials* 2023;**139**:113812.

193. Munday JN. Tackling Climate Change through Radiative Cooling. *Joule* 2019;**3**:2057–60.

194. Forster PM, Smith CJ, Walsh T *et al.* Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence. *Earth Syst Sci Data* 2023;**15**:2295–327.

195. Henckel T, Jäckel U, Schnell S *et al.* Molecular Analyses of Novel Methanotrophic Communities in Forest Soil That Oxidize Atmospheric Methane. *Appl Environ Microbiol* 2000;**66**:1801–8.

196. Sand M, Skeie RB, Sandstad M *et al.* A multi-model assessment of the Global Warming Potential of hydrogen. *Commun Earth Environ* 2023;**4**:203.

197. Song X, Basheer C, Zare RN. Water Microdroplets-Initiated Methane Oxidation. *J Am Chem Soc* 2023;**145**:27198–204.

198. Lee JK, Han HS, Chaikasetsin S *et al.* Condensing water vapor to droplets generates hydrogen peroxide. *Proc Natl Acad Sci USA* 2020;**117**:30934–41.

199. Li K, Guo Y, Nizkorodov SA *et al.* Spontaneous dark formation of OH radicals at the interface of aqueous atmospheric droplets. *Proc Natl Acad Sci USA* 2023;**120**:e2220228120.

200. Vione D, Maurino V, Minero C *et al.* The atmospheric chemistry of hydrogen peroxide: a review. *Ann Chim* 2003;**93**:477–88.

201. Fischer H, Axinte R, Bozem H *et al.* Diurnal variability, photochemical production and loss processes of hydrogen peroxide in the boundary layer over Europe. *Atmos Chem Phys* 2019;**19**:11953–68.

202. Kastanek F, Spacilova M, Krystynik P *et al.* Fenton Reaction–Unique but Still Mysterious. *Processes* 2023;**11**:432.

203. Kremer ML. New kinetic analysis of the Fenton reaction: Critical examination of the free radical – chain reaction concept. *Progress in Reaction Kinetics and Mechanism* 2019;**44**:289–99.

204. Paulson SE, Gallimore PJ, Kuang XM *et al.* A light-driven burst of hydroxyl radicals dominates oxidation chemistry in newly activated cloud droplets. *Sci Adv* 2019;**5**:eaav7689.

205. Lee JK, Walker KL, Han HS *et al.* Spontaneous generation of hydrogen peroxide from aqueous microdroplets. *Proc Natl Acad Sci USA* 2019;**116**:19294–8.

206. Li Q, Meidan D, Hess P *et al.* Global environmental implications of atmospheric methane removal through chlorine-mediated chemistry-climate interactions. *Nat Commun* 2023;**14**:4045.

207. Li W, Liu Y, Yao X *et al.* Removal of Atmospheric Methane by Increasing Hydroxyl Radicals Via a Water Vapor Enhancement Strategy. 2023, DOI: 10.2139/ssrn.4590701.

208. Feister U, Cabrol N, Häder D. UV Irradiance Enhancements by Scattering of Solar Radiation from Clouds. *Atmosphere* 2015;**6**:1211–28.

209. Rohrer F, Berresheim H. Strong correlation between levels of tropospheric hydroxyl radicals and solar ultraviolet radiation. *Nature* 2006;**442**:184–7.

210. McCoy DT, Burrows SM, Wood R *et al.* Natural aerosols explain seasonal and spatial patterns of Southern Ocean cloud albedo. *Sci Adv* 2015;**1**:e1500157.

211. Mace GG, Benson S, Humphries R *et al.* Natural marine cloud brightening in the Southern Ocean. *Atmos Chem Phys* 2023;**23**:1677–85.

212. Svensmark H, Enghoff MB, Svensmark J *et al.* Supersaturation and Critical Size of Cloud Condensation Nuclei in Marine Stratus Clouds. *Geophysical Research Letters* 2024;**51**:e2024GL108140.

213. Loeb NG, Wielicki BA, Doelling DR *et al.* Toward Optimal Closure of the Earth’s Top-of-Atmosphere Radiation Budget. *Journal of Climate* 2009;**22**:748–66.

214. Nisbet EG, Manning MR, Dlugokencky EJ *et al.* Atmospheric Methane: Comparison Between Methane’s Record in 2006–2022 and During Glacial Terminations. *Global Biogeochemical Cycles* 2023;**37**:e2023GB007875.

215. Wu J, Luo S, Zeng Z-C *et al.* The Post-2020 Surge in Global Atmospheric Methane Observed in Ground-based Observations. 2024, DOI: 10.22541/au.171386602.26426238/v1.

216. Li M, Karu E, Brenninkmeijer C *et al.* Tropospheric OH and stratospheric OH and Cl concentrations determined from CH4, CH3Cl, and SF6 measurements. *npj Clim Atmos Sci* 2018;**1**:29.

217. Oeste FD, De Richter R, Ming T *et al.* Climate engineering by mimicking natural dust climate control: the iron salt aerosol method. *Earth Syst Dynam* 2017;**8**:1–54.

218. Oeste FD, Elsworth C. Oeste F. and Elsworth C. 2024 Tropospheric photosensitive Climate Catalyst Aerosols (CCAs) for climate cooling. 2024;**2**, DOI: 10.17632/pr38g8834g.2.

219. Haywood JM, Jones A, Jones AC *et al.* Climate intervention using marine cloud brightening (MCB) compared with stratospheric aerosol injection (SAI) in the UKESM1 climate model. *Atmos Chem Phys* 2023;**23**:15305–24.

220. Futerman G, Beard SJ. *Report of a Workshop on Managing the Contribution of Solar Radiation Modification and Climate Change to Global Catastrophic Risk*. University of Cambridge: University of Cambridge, Centre for the Study of Existential Catastrophic Risk, 2023.

221. ‎Challenging Climate: 29. Daniel Harrison on Marine Cloud Brightening and the RRAP on Apple Podcasts. *Apple Podcasts*.

222. ‎Reviewer 2 does geoengineering: Cloud seeding law - Simon on Apple Podcasts. *Apple Podcasts*.

223. Griffiths J. China to expand weather modification program to cover area larger than India. *CNN* 2020.

224. Baiman R. Baiman 2024 Incremental Polar SAI, the International Space Station, and Great Barrier Reef MCB. 2024;**1**, DOI: 10.17632/5z3t72n6rd.1.

225. Hausfather Z. Analysis: How low-sulphur shipping rules are affecting global warming. *Carbon Brief* 2023.

226. Morrissey W. Avoiding atmospheric anarchy: Geoengineering as a source of interstate tension. *Environment and Security* 2024;**2**:291–315.

227. Lee W, MacMartin D, Visioni D *et al.* Expanding the design space of stratospheric aerosol geoengineering to include precipitation-based objectives and explore trade-offs. *Earth System Dynamics* 2020;**11**:1051–72.

228. Smith W, Bhattarai U, MacMartin DG *et al.* A subpolar-focused stratospheric aerosol injection deployment scenario. *Environ Res Commun* 2022;**4**:095009.

229. Lee WR, MacMartin DG, Visioni D *et al.* High-Latitude Stratospheric Aerosol Geoengineering Can Be More Effective if Injection Is Limited to Spring. *Geophysical Research Letters* 2021;**48**:e2021GL092696.

230. *RFF Solar Geoengineering Futures | Solar Geoengineering’s Place in Broader Climate Strategy*., 2023.

231. Laboratory (CSL) NCS. SABRE Goals and Objectives.

232. ‎Reviewer 2 does geoengineering: Stratospheric dehydration - Schwarz on Apple Podcasts. *Apple Podcasts*.

233. *Solar Geoengineering/Sunlight Reflection Methods: Safe, Effective, Needed? W/ Doug MacMartin*., 2024.

234. Calculating Cooling. *Make Sunsets* 2022.

235. WMO update: 50:50 chance of global temperature temporarily reaching 1.5°C threshold in next five years. *World Meteorological Organization* 2022.

236. Zhou C, Zelinka MD, Dessler AE *et al.* Greater committed warming after accounting for the pattern effect. *Nat Clim Chang* 2021;**11**:132–6.

237. Ritchie H, Rosado P, Roser M. CO₂ and Greenhouse Gas Emissions. *Our World in Data* 2023.

238. Samset BH, Sand M, Smith CJ *et al.* Climate Impacts From a Removal of Anthropogenic Aerosol Emissions. *Geophysical Research Letters* 2018;**45**:1020–9.

239. Climate Change: Global Temperature | NOAA Climate.gov. 2024.

240. Dvorak MT, Armour KC, Frierson DMW *et al.* Estimating the timing of geophysical commitment to 1.5 and 2.0 °C of global warming. *Nat Clim Chang* 2022;**12**:547–52.

241. Baiman R. Financial Bailout Spending Would Have Almost Paid for Thirty Years of Global Green New Deal Climate: Triage, Regeneration, and Mitigation. *Review of Radical Political Economics* 2020;**52**:650–61.

242. Pörtner H-O, Roberts DC, Tignor MMB *et al.* eds. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.*, 2022.

243. Eisenberger P. REME -- Renewable Energy and Materials Economy -- The Path to Energy Security, Prosperity and Climate Stability. 2020, DOI: 10.48550/arXiv.2012.14976.

244. CDM. *Achievements of the Clean Development Mechanism: 2001-2018*. UNFCCC, 2019.

245. Fund GC. Status of Pledges (IRM, GCF-1 and GCF-2). *Green Climate Fund* 2024.