**Excerpt on Direct Climate Cooling Governance and Coordination**

Table 1: Typology of Approaches to Direct Climate Cooling (DCC), Table 2: Description of Direct Climate Cooling Approaches, and Section 6: Challenges and Opportunities 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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**Table 1: Typology of Approaches to Direct Climate Cooling (DCC)**

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**Table 2: Description of Direct Climate Cooling (DCC) Approaches** A white rectangular box with black text

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**Note:** Column headings from left to right refer to: a) name of the DCC approach, b) its potential near-term scalability or level of cooling impact, c) summary technological description of how the method would potentially work, d) where it would likely be most effective, e) its possible risks and side effects and f) current evidence for its DCC potential.

**6. Challenges and Opportunities**

With global warming near to exceeding the 1.5°C Paris Agreement target, there is a clear, urgent need to find approaches that could, if implemented, exert near-term cooling influences around the globe. We mean that within a decade, commitment to research and initiate deployment of such interventions must be incorporated into the Conference of the Parties policies and agreements if we hope to stabilize global temperatures and avert the most catastrophic climate change impacts.

The set of Direct Climate Cooling (DCC) approaches presented in Table 2 reflects the authors’ assessment of initially researched approaches that, appropriately deployed in the *near-term*, could be used to exert a local, regional, or global cooling influence. DCC methods designated as RG could be deployed to have ‘medium to large leverage’ as their influences would be broadly exerted in the stratosphere or via the troposphere’s clouds and winds. DCC methods designated as LR could be deployed to have ‘small to medium leverage’ as their influences would be generally confined to local or regional areas. Taken together, the approaches presented here exhibit a range of characteristics (e.g., low-leverage to high-leverage; low to higher cost; rapidly scalable to global scales or not; with or without major co-benefits; most useful at local to global scales; already initially deployed to only minimally researched; etc.).[[1]](#footnote-1) Here we simply present possibilities, leaving to further research and consideration which ones, deployed singly or together with others, would best be deployed as part of an integrated approach to complement the emissions reduction and removal and abate the intensifying climate emergency.

As indicated throughout Sections 1-5, and in view of the high likelihood that GHG emissions reduction and removal will not limit temperature rise and associated climate change impacts in this century, we argue that not trying to deploy DCC is the ‘moral hazard’ now confronting humanity. We acknowledge that the potential for unintended consequences merits attention and that further research and establishment of a governance structure are needed [144,219]. Our position is that the need for DCC is urgent and must immediately begin to be met.

Waiting until full governance is wholly in place to begin climate intervention will be too late. Delays in establishing critical globally agreed upon deployment protocols may lead to abrupt, unilateral, unjust, and/or non-transparent deployments of very high-leverage DCC methods by individual countries or coalitions to benefit themselves. Such actions could cause serious political or economic tensions and conflicts with powerful actors who do not judge the deployment to be in their own best interest [220]. We believe that in many cases national and local jurisdictions can apply protocols that enable transparent research and pilot testing to be conducted and establish a process for responsibly scaling up deployment to local and regional levels within their jurisdictions. For these and other reasons we do not believe it is necessary or prudent to restrict current DCC efforts to research and localized field trials, as proposed in many of the documents supporting DCC research [81–83,85,87,88].[[2]](#footnote-2)

As discussed in the DCC method summaries, several DCC methods can be applied at local scale to exert a cooling influence and provide other benefits at little to no risk. Some regional scale efforts seem unlikely to have significant “cross- boundary” impacts. For example, the ongoing efforts to “save the Great Barrier Reef” using MCB seem unlikely to have long-term effects [142,221]. These applications are of short duration and mainly targeted at limiting extreme ocean heating events. The gyre pattern of ocean currents around the Great Barrier Reef would also limit potential “cross-boundary” impact [142,221] It may also be possible to coordinate regional DCC interventions that could have ‘cross-boundary’ impacts by building upon current bilateral or regional legal frameworks that address concerns arising from “cloud seeding” that enhances precipitation in some locations but might increase harmful climate outcomes in others [222].

Climate interventions that are more likely to cross national boundaries pose a greater challenge [223]. But again, scaling DCC methods like MCB for regional application may be more easily coordinated across national boundaries than current common geophysical engineering projects such as building a dam on a major river that blocks or reduces the flow of water downstream.

It may be possible to pilot-test and gradually deploy high-leverage DCC methods, like SAI, at a regional scale without global governance and coordination by following the Great Barrier Reef MCB example. SAI could be pilot tested with consent from affected communities and authorities in accordance with an international, voluntary and transparent ‘coalition of the willing’ agreement. If successful, such an endeavor could build global trust and confidence in the same way as the international space station has done [224].[[3]](#footnote-3)

In some cases, sufficient authority to deploy a cooling mechanism may already be in place. The International Maritime Organization (IMO) could, for example, address the unintended global warming produced by its (well-intended to protect human health) maritime fuel sulfate content restrictions, under its existing authority [2,23,225]. First, it could immediately adopt an emergency regulation relaxing 2015 and 2020 shipping fuel sulfate content restrictions in the “high seas”. The intent would be to resume sulfate aerosol cooling over the high seas while avoiding significant human health impacts on coastal and island populations. Second, as a long-term solution, the IMO could support research and implement regulations requiring use of alternative fuels or power sources (see section 5) and the emission of aerosol precursors more benign than sulfates to human and environmental health, to replace the prior beneficial global cooling from using fossil fuels [23]. As noted in section 1, these measures alone could produce significant, urgently needed, DCC.

It is unlikely that high-leverage regional and global scale DCC methods could be effectively weaponized, as has been hypothesized by some [220,226]. The DCC method that is most often discussed in this context is SAI. However, modeling indicates that SAI could not be specifically targeted over nation states with reasonable accuracy. Although it might be possible to influence some geographic and seasonal variations in precipitation with carefully modulated SAI deployments, latitudinal and longitudinal mixing in the stratosphere make geographically specific outcomes exceedingly difficult, if not impossible [227,228]. It appears that only general latitudinal targeting is possible with SAI. That is why polar SAI deployment in the spring has been proposed as the most practical and efficient way to pilot regional-scale SAI efforts to produce summer polar cooling [16,229].

An additional practical impediment to weaponized deployment of SAI is that only a small number of countries either have, or have the capability to develop, aircraft that could loft the large payloads necessary for an effective SAI program, and the military propulsion technology necessary for this is not available for sale or purchase without at least tacit acquiescence by nations that have this technology such as the US, UK, EU and possibly a few others [228,230]. Also, it appears that only one country, the US, currently has aircraft that can loft large enough payloads to the stratosphere to initiate an effective pilot SAI program, though new customized planes would need to be developed to do this efficiently over a long period [177,228]. The US SABRE (Stratospheric Aerosol processes, Budget, and Radiative Effects) program is in fact currently using two high-altitude research aircraft that can loft payloads into the stratosphere, equipped with sampling instruments, to measure the properties of aerosols in the upper troposphere and lower stratosphere [231,232].

Finally, as with much of modern infrastructure, it might be possible to interrupt an SAI program by sabotaging its infrastructure or supply chain in hopes of ending the deployment.[[4]](#footnote-4) However, it is hard to understand what the incentive for this would be given the “shockingly strongly favorable” results from roughly a hundred studies that suggest pervasively beneficial impacts of SAI [18]. And, as with other critical infrastructure, this risk, and the possible “termination shock” risk that could result from an abrupt and complete cessation over an extended time, could be significantly reduced through redundancy and protective measures that make it more unlikely.

The ultimate goal and need is to develop comprehensive DCC governance and coordination for DCC efforts with significant cross-regional or global impact. Both implicit and explicit global coordination governance regimes are likely to evolve over time as the scale of DCC deployment grows larger. Building global, public, and political trust and confidence through gradual, local, and regional pilot testing of potential DCC efforts is critical to the development of comprehensive DCC global coordination and governance frameworks.[[5]](#footnote-5) Pilot testing and “learning by doing” to complement continued research will enable a fuller understanding of the potential impacts, positive and negative and near- and long-term, of large-scale DCC.

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1. Technical feasibility is not addressed in table 2 but is discussed in detail in many of the approach summaries. [↑](#footnote-ref-1)
2. These reports and open letters generally, and sometimes inaccurately, refer to DCC as ‘SRM’. For example, the National Academy of Science SRM report [81] labels CCT, MCB, and SAI as SRM though as noted in figure 3 CCT is based on thermal radiation modification (TRM) rather than SRM. They often also use the term SRM but implicitly or explicitly are focused on abrupt, or rapidly ramped up, large-scale global SAI deployment (commonly referred as ‘geoengineering’). These inaccuracies and ambiguities in nomenclature have unfortunately contributed to discussions that are not always well-informed with regard to the benefits or risks of SAI or DCC. [↑](#footnote-ref-2)
3. Pending further polar *winter* cloud cover research, gradual pilot testing of polar CCT or MCT might also be advisable as part of a comprehensive coordinated effort to ‘save the Arctic and Antarctic polar regions’ (and possibly these and other DCC methods in all three ‘polar’ regions including the Himalayan ‘third pole’). [↑](#footnote-ref-3)
4. Though this may be more difficult than with other critical technologies as, for example, there is an abundant supply of sulfur in the world [233]. [↑](#footnote-ref-4)
5. It should also be noted that, depending on the DCC approach, there are significant overlaps between the governance expected to be needed for deployment of DCC approaches, and of GHG emissions reduction and carbon removal programs. For example, the key issues for the latter efforts include the collective-action free-rider problem, and the need to mobilize massive resources rapidly and fairly through public and private mechanisms. The challenge of funding actions needed to achieve a global ‘public good’ through a negotiating process that lacks mandatory global governance and cannot mandate rapid resource transfers from rich to poor, has been a principal cause of our current inability to bring climate change under control [19]. To be deployed at scale, some forms of DCC similarly need large public and private resource mobilizations to exert a sufficient cooling influence, thus providing a global benefit with large externalities. However, initiating polar-focused SAI, and later, global SAI deployment would likely require a much smaller mobilization of public and private resources to achieve global benefits. As in the case of GHG emissions reductions and drawdown efforts, in the absence of a public effort private actors have begun filling the void by initiating DCC efforts based on ‘cooling credits’ that exploit the (almost) pure ‘public good’ characteristics of mid-latitude SAI [234]. However, this un-coordinated private sector approach to DCC only works in this case because it has an insignificant impact on global cooling. As noted, in the body of the paper above, only a small number of national actors have the potential ability to deploy or sanction the deployment of an *effective at-scale* SAI program. [↑](#footnote-ref-5)