CLIMATE INTERVENTION: THE CASE FOR RESEARCH

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Climate change policy needs to be able to anticipate and plan for the possibility of rapidly escalating or abrupt changes that dramatically escalate risks to public safety. Achieving net-zero emissions of greenhouse gases is essential to solving the climate change problem. However, due to the climate system's inertia, even rapid emission reductions may not produce a sufficiently fast response to prevent the climate system from crossing critical thresholds that lead to abrupt and possibly irreversible change. This paper argues that there is an urgent need for research on climate intervention as a potential means of addressing abrupt change, and counters common objections. It argues that research would (1) improve our understanding of the likelihood of abrupt changes and our ability to respond safely and effectively; (2) supply governments, stakeholders, and the public with the information needed to assess and make evidence-based decisions about climate interventions; (3) help address the risks of climate change for future generations and for vulnerable countries, especially those without resources to adapt; and (4) reduce the risk of geopolitical tensions over climate interventions due to uncertainties and mistakes.

INTRODUCTION

How can we best maximize the likelihood of a safe climate for present and future generations? Thus far, international climate policy has focused on limiting net emissions of greenhouse gases. From the standpoint of climate safety, this is clearly essential in order to stabilize greenhouse gas concentrations in the atmosphere and keep global warming within safe levels. But what if emission reductions prove insufficient? Given the risks, the world cannot afford to put all its eggs in one basket. It needs additional options.

This paper focuses on the risk that abrupt changes in the climate system – for example, due to thawing of Arctic permafrost or changes in ocean or atmospheric circulation patterns – could occur in the relatively near term and act as an accelerant to an unsafe climate.[1] Emission reductions, by themselves, do not adequately address this risk, since they influence global temperature quite slowly due to the climate system's inertia.[2] Instead, addressing the risk of abrupt, near-term climate change may require interventions that have the potential to reduce global warming rapidly – for example, by reflecting sunlight from the atmosphere ("solar climate intervention" or SCI).[3]

In an earlier paper, *Solar Climate Intervention: Options for International Assessment and Decision-Making*,[4] we considered a scenario in which a group of countries, concerned about avoiding dangerous climate impacts, sought a cooperative, science-based approach to decision-making regarding the potential use of SCI. The paper surveyed the existing institutional landscape to identify which international forum or forums would be in the best position (1) to produce a high-quality, scientific/technological assessment that would enable objective, minimally politicized decisions to be taken, and (2) to take such decisions, whether for or against the action in question. The paper posited that both the assessment and decision-making functions would need to consider "two safeties": the safety of the global climate

and the safety of SCI, if any, in response. Consideration of both safeties is essential, since decisions about whether or not to use SCI depend not only on the safety of using SCI, but also on the climate system's safety if SCI is not used to limit warming.

This paper complements the previous paper by examining, from the perspective of a prospective policymaker or member of the public, the information that would need to be "on the table" to allow a proper assessment of the two safeties and take science-based decisions. The paper explains the urgent need for research on climate intervention as a potential means of addressing abrupt change, and counters common objections, but does not address how research might be governed either nationally or internationally. In brief, it argues that research would:

- contribute to the goal of climate safety by improving our understanding of the likelihood of abrupt changes, and our ability to respond safely and effectively
- supply governments, stakeholders, and the public with the information needed to assess and make evidence-based decisions about climate interventions
- help address the risks of climate change for future generations and for vulnerable countries, especially those without resources to adapt
- reduce the risk of geopolitical tensions over climate interventions due to uncertainties and mistakes.

BACKGROUND ON ABRUPT CLIMATE CHANGES AND POSSIBLE RAPID RESPONSES

The global response to COVID-19 highlights the importance of advance planning for, and scientific understanding of, public safety threats arising from accelerating or abrupt changes. Countries such as South Korea that took seriously the possibility of a pandemic and planned in advance were able to ramp up testing quickly, prevent community transmission, and contain the disease. In contrast, countries that were unprepared and allowed the virus to spread had to rely on more disruptive and less effective mitigation measures such as sheltering in place.[5]

Climate change policy similarly needs to anticipate and plan for the possibility of rapidly escalating or abrupt changes that dramatically escalate risks to public safety. Currently, this is not the case. Climate models generally represent warming effects as relatively smooth, linear changes, which conventional mitigation could potentially address through emission reductions, perhaps in conjunction with carbon removal measures, given sufficient political will. The models predict that temperatures will increase gradually as greenhouse gas concentrations increase and that emission reductions will decrease the rate of global warming, albeit with a time lag due to the climate system's inertia.

But abrupt and rapidly escalating changes are also possible, if incremental warming causes parts of the climate system to reach critical thresholds, or "tipping points," that trigger major systemic changes that would not be reversible even if we were to return atmospheric concentrations of greenhouse gases to pre-industrial levels.[6] Such changes become increasingly likely as temperatures increase. For example, with continued warming:

- Thawing Arctic permafrost could release large amounts of carbon dioxide and methane, dramatically increasing the rate of global warming.
- The melting of Arctic and Greenland ice could cause a slowdown of the Atlantic meridional overturning circulation currents, leading to drought in the Sahel or disruptions to West African and Southeast Asian monsoons.
- El Niño could become a permanent condition, leading to drought in Southeast Asia.
- The West Antarctic ice shelf is likely to eventually disintegrate, raising sea levels by three meters and flooding coastal areas.[7]

The precise point at which each of these natural systems will move from incremental to abrupt change is currently uncertain. We might not reach some tipping points for many years or decades, or we could be on the brink of one right now. Our current level of uncertainty is still very high. When the Intergovernmental Panel on Climate Change (IPCC) first discussed tipping points in its Fourth Assessment Report, it estimated that most were unlikely to be realized unless global warming exceeded 5 degrees C.[8] But its more recent reports suggest that

1-2 degrees C warming could cause major parts of the climate system to change abruptly,[9] which means that the world may be approaching or crossing tipping points now – indeed, some suggest that Arctic ice may have already crossed a critical threshold, and there are also signs of structural weakening of the Pine Island and Thwaite Glaciers in West Antarctica.[10] Record extremes in many parts of the climate system support the possibility of increased abrupt change risks in the next 10-20 years. Moreover, evidence suggests that tipping points can interact – with major changes in one system causing others to tip, leading to a cascade of consequences.[11]

The possibility of abrupt, near-term climate change has two implications:

First, the global community needs to be prepared. That is why it is critically important to accelerate research in abrupt change risks and potential response alternatives now, rather than wait until catastrophic changes occur.

Second, decision makers need to identify practical response measures that will take effect quickly. The climate system's inertia means that conventional mitigation, focusing on the reduction of carbon dioxide emissions, would take decades or even centuries to reduce Earth's temperature.[12] By contrast, some potential climate interventions could lower temperature from within a few weeks, to a few months or years.[13] Possibilities include:

- increasing the reflection of sunlight from the atmosphere – for example, by scattering particles in the stratosphere or brightening marine clouds
- adding nutrients to the ocean surface to rapidly grow carbon dioxide-absorbing organisms to dramatically reduce the amount of carbon dioxide in the atmosphere, sometimes called "ocean fertilization"
- making deep cuts in emissions of short-lived climate forcers such as methane, refrigerant chemicals, and black carbon.

RESEARCH ACTIVITIES TO DATE

Although some scientists and scientific societies (such as the UK Royal Society) have been recommending research on climate interventions for more than a decade,[14] there has been considerable resistance to research due to concerns that it could lead to complacency in carbon mitigation and/or the use of risky technologies. As a result, there has been little climate intervention research to date, and the risks and benefits of different interventions remain poorly understood.[15]

As climate extremes and impacts mount, however, calls for more research are beginning to enter the political mainstream. The U.S. Congress in January 2020 appropriated $4 million for NOAA to study basic science and perform observations related to two solar climate intervention techniques: stratospheric aerosol injection and marine cloud brightening. In June 2020 , the majority staff report of the U.S. House Select Committee on the Climate Crisis called on the nation to follow recommendations of a forthcoming National Academy of Sciences study to establish a research program on solar climate intervention.[16]

Research on climate interventions, as a possible rapid response to address the risk of abrupt changes, can be classified along a number of dimensions, including:

- whether it examines basic physical processes (such as aerosol/cloud microphysics) or climatic/environmental effects
- where it takes place (in the laboratory or outdoors)
- if outdoors, its scale (small, medium, or large).

Types of research include:[17] study of observational data and natural analogues, such as volcanic eruptions;[18] computer modelling; laboratory/indoor studies; process studies, including small-scale, controlled-release experiments; large-scale outdoor testing of climate responses; and technology research and development.

Thus far, most research on climate interventions has been limited to the first two categories: study of natural analogues and computer modelling, although a few small-scale field tests have been undertaken.[19] The climate modelling research has focused on the effects of interventions, and has generally represented interventions by making assumptions about how primary processes associated with implementation would play out, using broad proxies like dimming the sun or turning up the number of cloud droplets.[20]

WHAT INFORMATION IS NEEDED TO MAKE INFORMED DECISIONS?

This section examines the information that a policymaker would want in order to consider the potential role of climate interventions in addressing the problem of abrupt change. It does not purport to set forth a detailed scientific research agenda, which should be developed by scientists. Instead, the perspective is that of an interested member of the public or a government decision-maker who is aware of the possibility of large-scale abrupt changes and extreme impacts and wants to understand the warning signs and potential responses. While research may never fully resolve the questions identified below and many uncertainties may remain, further research will help put decisionmakers in the best possible position to respond safely and effectively. Moreover, although social scientific research is also needed – for example, to allow integrated assessments of the physical, social, and economic impacts of abrupt climate change and possible rapid responses – this paper focuses on the natural science research that would be useful for policymakers and may be critical to informing social science research on the economic, social, and political implications of climate interventions.

Generally, the natural science information needed falls into five baskets:

UNDERSTANDING ABRUPT CHANGE, HIGH-IMPACT RISKS

First, decision makers need to better understand, and be better able to anticipate, abrupt changes. Important questions include:

- What evidence is there that the world is approaching abrupt changes in major natural systems?
- What is their regional heterogeneity (i.e., to what extent will they affect different regions differently)?
- Which of these are of greatest concern (e.g., due to their imminence, likelihood and/or severity)?
- What is our level of certainty regarding the timing, severity and consequences of each of these potential abrupt changes? Can we quantify the uncertainty of preventing catastrophic harm through mitigation or adaptation alone? Do we have adequate insurance against this uncertainty?
- What is the time scale of the processes leading to possible abrupt changes? How much and over what time frame would warming need to be limited in order to prevent serious harms, and at what point will it be too late? Do we still have time to avoid these harms through stronger mitigation or adaptation?
- Is the abrupt change irreversible? Or, if we reduce global temperatures, would the system return to its preexisting phase? How well do we understand this?
- What are the early indicators of an abrupt change for each at-risk major natural system?
- What is needed to monitor and forecast their state? Is it possible to establish an advance warning system for abrupt changes, e.g., by monitoring early indicators?

EFFECTIVENESS OF POSSIBLE RESPONSES IN PROMOTING CLIMATE SAFETY

Second, decision makers need information that will allow an evaluation of whether and how different climate intervention responses would benefit the safety of the climate system, either globally or regionally. Such information includes:

- Which interventions would produce what climate benefits, either globally or regionally? For example:
    - Which interventions, or combination of interventions, would produce a sufficiently rapid and large climate response to prevent or arrest an abrupt change?
    - Which interventions, or combination of interventions, could reduce or prevent catastrophic regional impacts of warming, such as the collapse of the Great Barrier Reef or cyclones of unprecedented intensity?
    - How large an intervention would be needed in order to achieve a given climate goal?
    - How predictable are these outcomes?
- How could each potential intervention be undertaken most effectively, in order to achieve a global or regional climate goal? For example:
    - **Stratospheric aerosol intervention (SAI)**: Which aerosols should be used? At what altitude and latitude should they be

injected into the atmosphere?

- **Marine cloud brightening (MCB)**: What is the optimal size of salt particles to achieve brightening effects on clouds (i.e. by serving as cloud condensation nuclei)? Where should MCB be undertaken in order to produce the maximum climate response? How much would be needed?
- **Ocean fertilization**: What nutrients might be used? Would ocean fertilization be successful in sequestering carbon long-term? Where in the ocean should it be undertaken?

- What are the potential interactions between different interventions? Could the climate benefits of an interaction be counteracted by another intervention by a country with a different climate objective?
- What models, analytical tools, and computational capabilities are required to adequately predict and manage climate effects of interventions?

TECHNOLOGICAL PRACTICABILITY OF POTENTIAL INTERVENTIONS

Third, research is needed on the technological feasibility and scalability of each potential intervention option. For example:

- **Stratospheric aerosol injection:** What materials have the optimum properties to maximize reflective effects and minimize side effects? What is required to generate them as aerosols at the required scale? Do the necessary technologies exist, or would they need to be developed? What are the technological options for transporting aerosols from the surface of the earth into the stratosphere? For example, is a new class of ultra-high-altitude cargo plane required? How scalable are the needed technologies? How much would they cost? How long would it take to ramp up deployment? What type of observation and measurement systems are needed to monitor and assess implementation and effects?
- **Marine cloud brightening:** What are the most effective technologies to generate sea salt mist and deliver it into the lower marine troposphere at the volume and particle size required? What information is required to target clouds and deliver mist at optimum times in optimum places? How many ships or autonomous platforms would be needed? What type of measurement systems are needed on the surface, in the air and from space to monitor the effects of the intervention?
- **Ocean fertilization:** What nutrients could be used to encourage the sustained growth of the right kind of organisms? How can they be made bioavailable in oceanic chemistries? How do these factors change in different regions, seasons, and ecosystems?

SAFETY OF POTENTIAL INTERVENTIONS

Fourth, research is needed on the second safety – the safety of the interventions themselves. For each potential type of intervention, important questions include:

- What are the most likely risks and how well are we able to characterize and reduce them?
- What, if any, low-probability, high-impact, risks are associated with the intervention and how well are we able to characterize and reduce them?
- What would be the effects of the intervention on regional climates (including effects on precipitation, temperature, etc.)?
- What would be its effects on other resources and ecosystems (the stratospheric ozone layer, the ocean, etc.)?
- What other physical risks, if any, does it pose?
- How long-lasting and reversible are the potential adverse effects?
- What is the range of unknowns?
- Are there ways of implementing the intervention to minimize the risks of adverse effects (for example, by injecting aerosols at a particular altitude or fertilizing the ocean in particular regions)?
- How might the intervention be monitored, for example, to get early warning of adverse effects? Are new instruments required? How can we monitor for the unexpected?
- How controllable is the intervention? How easy would it be to shut off the intervention, if it had adverse effects? What would be the adverse effects of stopping the intervention? Can these effects be mitigated and, if so, how?
- How do the various options for rapid intervention compare (in terms of risk and other characteristics)?

- Could different intervention options potentially be used in combination in order to reduce risks?

COMPARATIVE ANALYSIS OF SAFETY OF INTERVENTION VERSUS NON-INTERVENTION

Finally, using the information generated in the first four research baskets, extensive analysis is required to compare risks, projected outcomes, and uncertainties of intervention versus non-intervention scenarios with respect to:

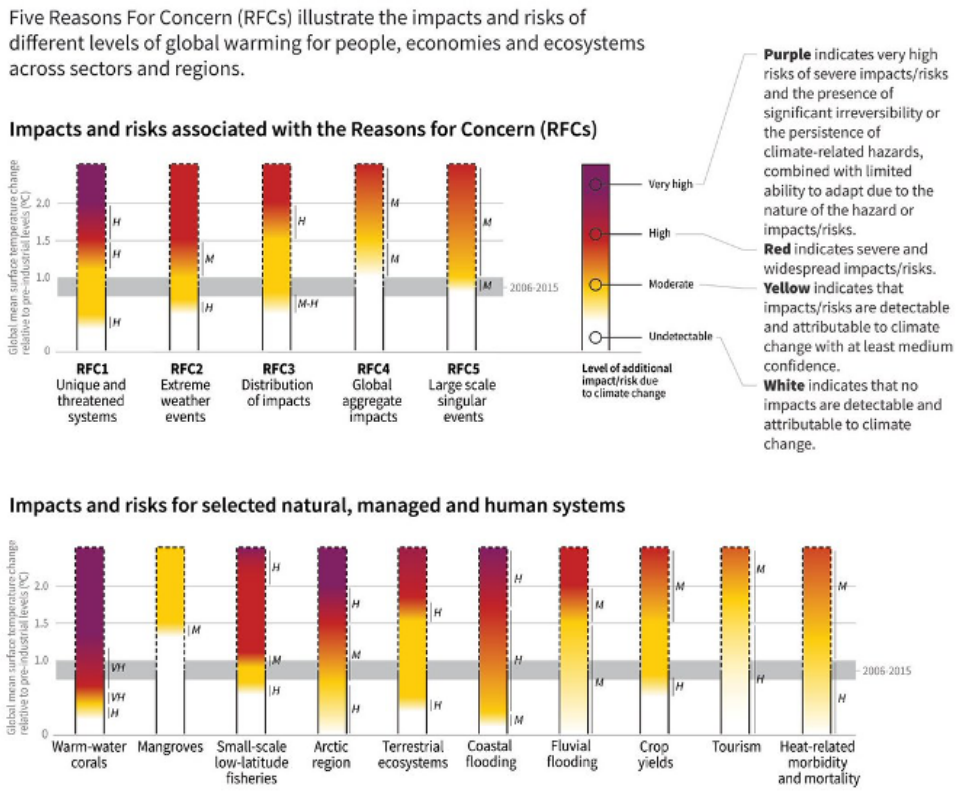
- projected global climate effects (including temperatures, precipitation, and the magnitude and distribution of weather extremes)
- projected impacts on the health of ocean and terrestrial ecosystems and on biodiversity
- the risk of abrupt changes in specific major natural systems
- projected regional and local impacts, including on hydrology, fire, flooding, and storms
- projected impacts on global and regional health and safety, migration and security, and the productivity and output of essential and major economic sectors.

REASONS WHY SCIENTIFIC RESEARCH IS ESSENTIAL

As noted above, research to answer the questions identified in the previous section is urgently needed for four reasons:

1. to promote the safest outcomes, taking into account both the risks of warming and the risks of possible interventions
2. to enable assessment and decision-making regarding climate interventions
3. to help protect vulnerable populations and future generations
4. to prevent avoidable geopolitical tensions resulting from a lack of information.

FIGURE 1: How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems



Source: IPCC, Special Report: Global Warming of 1.5° C (2018)

CLIMATE AND ENVIRONMENTAL SAFETY

Decisions about potential climate interventions will depend in large part on a comparative assessment of the benefits and risks of intervening versus not intervening.

On the one hand, climate change, if insufficiently addressed, will likely cause catastrophic harms. That is the context within which possible climate interventions need to be evaluated. The IPCC's most recent assessment projected, with high confidence, that climate change over the 21st century will:

- increase coastal flooding and erosion
- increase the risk of extreme weather events
- exacerbate risks to unique and threatened ecosystems
- increase the fraction of the global population experiencing water scarcity
- increase extinction risk for a large fraction of both terrestrial and freshwater species
- negatively impact food security
- exacerbate existing health problems
- displace people.[21]

The higher the level of warming, the greater the magnitude of these harms. As the IPCC *Special Report: Global Warming of 1.5° C* concluded, the risks of 2 degrees C warming are substantially higher than 1.5 degrees C warming.

On the other hand, climate interventions to reduce the risks of climate change also have potential risks. Among them, although some studies suggest that stratospheric aerosol injection would have limited harms, others conclude that it could hurt the stratospheric ozone layer, cause the Indian monsoon to fail, or have other adverse regional effects.[22] Marine cloud brightening could cause changes in weather patterns that adversely affect some regions. Ocean fertilization could cause harmful changes in the ocean food web. And other risks may not yet be identified.

Unless more robust research is undertaken on possible ways to identify and address tipping points, we risk incurring potentially avoidable harms because:

- We do not know the timing and magnitude of the risks of abrupt change in order to compare them with the costs and risks of various forms of response.
- We do not know the full range of possible responses, either globally or at the regional level (e.g., localized interventions to reduce coral bleaching of the Great Barrier Reef or melting of the Arctic).[23]
- We do not understand the adverse impacts of possible responses, including on regional climates.
- We do not know which responses can be undertaken most effectively and safely.
- We lack the technology and knowledge to be able to implement and scale a response quickly (within a few years), in order to respond to an emergency situation.

Research on the potential impacts, both good and bad, of climate interventions is necessary to make informed decisions about whether an intervention can be undertaken safely. Conversely, failure to study the possible impacts of climate interventions increases the likelihood that one or more states will overestimate the efficacy of an intervention, or underestimate its risks, and intervene in a manner that is ineffective and/or has significant adverse consequences.

Of course, even armed with information about the risks and possible responses, there is no guarantee that policymakers will make wise decisions, as illustrated by the response of some countries to COVID-19. But, as we also learned, undertaking research to fill existing knowledge gaps is likely to lead to better outcomes by those willing to apply the research results, and will thereby promote climate safety.

ASSESSMENT AND DECISION-MAKING

Information about the benefits and risks of climate interventions is essential for both assessment and decision-making, two key components of "governance" of climate interventions.

Assessment is a scientific and technical process, which requires information about the feasibility, effectiveness, and safety of possible climate interventions. Without research, the information necessary for a proper assessment of climate interventions will be lacking. Assessment, in turn, often involves multilateral scientific and technical cooperation, which also promotes communication and the development of expertise for decision-making.

Decision-making ultimately involves value-choices that cannot be answered by science. But to the extent

these value-choices depend on facts about the world—for example, about the risk of abrupt, near-term climate change and about the impacts of climate interventions—then decisions should be based on the best available information provided by science about these factual issues. In the absence of adequate research on near-term risks and climate interventions, decision-makers will not be able to make decisions about whether to intervene to promote safety in an informed manner, on the basis of science.

Moreover, assuming research results are made publicly available, research will give policymakers in all states (whether or not they undertake research), stakeholders of various kinds, and the public, information that allows them to make better-informed, evidence-based choices and to participate more effectively in the decision-making process. Research could thus promote more inclusive, more democratic decision-making on the use or non-use of climate interventions.

PROTECTION OF VULNERABLE POPULATIONS AND FUTURE GENERATIONS

Research on solar climate intervention would be especially beneficial to vulnerable populations and future generations.

Climate harms are expected to fall disproportionately on vulnerable developing countries that have contributed little to the climate change problem and have little capacity to respond. These include:

- small island developing states, which will be inundated by sea-level rise
- states with low-lying coastal areas, such as Bangladesh, which will experience severe flooding
- drought-prone states in Africa.

Research on climate interventions could help lessen or prevent these impacts on vulnerable states, by opening up additional options for limiting global warming, reducing near-term impacts and preventing near-term abrupt changes.

Climate harms will also fall disproportionately on future generations. Current and future children bear no responsibility for global warming but will suffer its consequences most. Given the climate system's inertia, some impacts (such as sea-level rise) will continue to worsen for centuries after emissions are reduced. Moreover, many large-scale abrupt changes in natural systems, should they occur, may be irreversible. Failure to pursue research now on possible climate interventions could deprive future generations of options to limit climate harms, should emission reductions prove insufficient.

REDUCING TENSIONS

As with any controversial issue, it may not be possible to avoid international tensions when it comes to either climate change or climate intervention. However, increased knowledge concerning the risks and benefits of climate intervention could have the effect of reducing tensions.

Uncertainty and ignorance can increase tensions by engendering unfounded fears, misinterpretations, and misunderstandings. Greater knowledge could work to reduce tensions in several ways. For example, if a group of states was planning to move forward with an intervention, research showing that the intervention would be ineffective or have dangerous side effects could help persuade the group not to proceed. Contrariwise, such a group might be able to use knowledge gained through research to assuage the concerns of others. In either case, by providing a better picture of the benefits and risks of an intervention, research could reduce the existence or severity of international conflict. Finally, scientific and technical cooperation in research and assessment can promote trust and constructive relationships that reduce tensions.

REASONS NOT TO DO RESEARCH ARE UNPERSUASIVE

Against these reasons to pursue research, there are a number of possible arguments against research, all of which are unpersuasive.

Objection: Climate intervention will not be needed, because we can avoid dangerous climate impacts through emissions reductions and/or adaptation

First, research on climate interventions would be unnecessary if we were completely confident that some combination of emission reductions and adaptation will prove sufficient to prevent abrupt change as well as dangerous climate change more generally. The history

of the last thirty years of international climate policy, however, provides no basis for confidence that states will reduce their emissions sufficiently to prevent dangerous climate change. Despite the political salience of the issue during that time period, the international community has made little progress in "bending the curve" of emissions. Since 1990, global emissions from fossil fuels have increased by more than 60 percent, and atmospheric concentrations of carbon dioxide have increased from 355 to 414 ppm.[24]

The Paris Agreement is the international community's latest effort to address the climate change problem. But as the parties to the Paris Agreement themselves recognize, the initial round of emission reductions pledged in Paris – although an improvement over business as usual – do not put the world on track to achieve the Agreement's temperature goals.[25] Although these pledges were understood as only a first step, and the Paris Agreement establishes an "ambition mechanism"[26] intended to ratchet up parties' nationally-determined contributions to reduce emissions over time, there is no certainty that this mechanism will prove successful. And even if countries ratchet up their ambition, there is no certainty that the increased emission reductions will be sufficient to prevent catastrophic changes in increasingly unstable natural systems.

The uncertainties associated with adaptation are also very high. As Joseph E. Aldy and Richard Zeckhauser note in *Three Prongs for Prudent Climate Policy:*

> *Adaptation will require considerable time and money… For example, if physical barriers are to be built to protect against rising sea levels and more intense storms, it will take years to figure out the engineering requirements, develop the plans, and secure the political will to produce the required resources.*[27]

Moreover, adaptations may ultimately be limited in the populations they can serve (for example, wealthy communities with the capacity to adapt) and the level of warming stress they can counter, given the increasingly unsafe environment, diminished natural resources, and widespread infrastructure failures caused by warming.

The argument that we should not engage in research because climate intervention will not be needed thus involves a huge risk. What if the assumption on which it is premised is wrong? It is difficult enough to predict changes in a complex physical system like the climate. It is much harder to predict the future of global politics and the global economy. Even the most aggressive mitigation measures may not be able to reduce warming rapidly enough to prevent catastrophic changes in some natural systems. Consequently, it is impossible to say with any certainty that, if research on rapid climate responses were off the table, the world would reduce emissions sufficiently to prevent dangerous climate change. Even if the risk of failure were small (which, in our view, is clearly not the case), this would still not undermine the rationale for research on climate interventions, given the importance of insuring against the risk of potentially catastrophic and irreversible impacts of abrupt climate change.

Objetion: Climate intervention should never be used, under any circumstances, even if the alternative was catastrophic climate change

Although we evaluate many actions in terms of their costs and benefits, some activities are viewed as wrong absolutely, regardless of their ultimate consequences, good or bad. If one views climate intervention as intrinsically wrong, then we should not engage in research about it, since, regardless of what the research showed, it should not be used.

The case of torture provides an illustration of this type of argument. There is considerable debate about whether, empirically, torture can produce useful intelligence – for example, about a ticking time bomb. But opponents of torture argue that it is intrinsically wrong and can never be justified, whatever the evidence shows about its effectiveness. On this view, we should not engage in research on whether torture produces true or false information, because the results of that research would be irrelevant to decision-making about whether or not to use torture. Indeed, research would be dangerous because it might put us on a slippery slope toward possible use of torture, if it showed that torture produced useful intelligence and thereby increased political pressure to engage in torture.

But spraying the atmosphere with particles to reflect sunlight from the earth bears no resemblance to torture, so the question is, what makes it intrinsically unethical, regardless of its consequences? In the case of torture, the reasons why it is viewed as intrinsically wrong are clear. Torture involves the direct infliction of immeasurable pain and suffering on the victim, which is an affront to

human dignity and shocks the conscience. By contrast, we do not know that climate intervention would cause any significant harm, let alone a level and type of harm that should rule it out absolutely, regardless of its possible climate benefits. If research established with a high degree of confidence that brightening marine clouds could reduce global warming with no harmful side effects, why would brightening marine clouds be immoral?

None of the answers to this question are persuasive. One possible rationale for ruling out climate intervention is religious, namely, that humans should not tamper with God's creation. Or we could attempt to give this argument a more secular flavor by characterizing it in terms of a moral imperative not to disrespect nature. But even if one accepted either of these views, it would not necessarily imply that we may not intervene in the climate system to ameliorate the disruptions humans are already inflicting on nature as a result of our greenhouse gas emissions. Even in the field of human rights, there are relatively few actions, such as torture, that are forbidden in all circumstances. Many rights may be abridged in times of emergency. If rapid climate interventions could help reduce the damage to vulnerable communities caused by climate change, then, from the standpoint of climate justice, this would seem to justify overriding whatever norms might otherwise exist against climate interventions.

Another possible argument for why climate interventions are impermissible, regardless of their consequences, is that they represent a "moral trespass"—they bring about changes in the world that affect all people and therefore require everyone's assent.[28] This is a variant of the argument that research cannot proceed without governance, and will be considered below.

Finally, even if one were to accept the argument that climate interventions are morally impermissible, not engaging in research cannot ensure that they will not be used unilaterally—for example, by a state wishing to avoid catastrophic climate impacts. It can ensure only that any interventions – as well as any responses to interventions—are undertaken in ignorance of the interventions' effectiveness and risks.

Objection: The risks of research are too great

Several specific arguments against research focus on its risks:

- Research could itself cause physical harms.
- Undertaking research might suggest to some people that climate intervention could "solve" the climate change problem and make them less willing to reduce emissions or undertake adaptation measures.[29] This argument that climate intervention research might undermine mitigation and adaptation efforts is sometimes characterized in terms of "moral hazard."[30]
- Climate intervention research will put us on a slippery slope toward deployment.

These arguments suggest that research should be pursued cautiously, not that it should not be pursued at all.

Physical harm: Since it is possible that some types of research could cause physical harm, researchers engaged in activities that create a meaningful risk of direct harm (generally large-scale, outdoor experiments) should be required to do advance assessments and to notify potentially affected groups or states, as is the case with other activities that may cause physical harm. Such assessment of the potential physical harms of large-scale research will depend, in part, on what smaller-scale research shows, so the importance of assessments is actually an argument for, rather than against, indoor research and small-scale outdoor research going forward.

"Moral hazard:" Although the moral hazard argument is often raised against climate intervention research, it suffers three weaknesses:

1. To the extent climate interventions pose a moral hazard, the mere prospect that an intervention could "solve" the climate change problem introduces the hazard, whether or not any research is undertaken. If research showed that a climate intervention is ineffective, difficult to implement, or dangerous, then this would lessen rather than increase the moral hazard associated with climate interventions.
2. The empirical evidence in support of the moral hazard argument is limited, at best, and the historical evidence points the other way. International developments that lowered the prospects for climate intervention (such as the so-called moratorium decision of the Convention on Biological Diversity in 2010 or the London Protocol amendment limiting ocean fertilization in 2013) did

not produce any apparent uptick in political will to engage in emissions mitigation.

3. It is not clear whether the imminent prospect of climate intervention would undermine or enhance political support for mitigation. Some suggest that research in climate intervention may send a signal to society of the gravity of the problem, propelling action on addressing the root cause (reducing greenhouse gases) rather than dampening it.[31]

Technological lock-in/slippery slope: Another argument against research is that research puts us on a slippery slope that leads inevitably to deployment. But this is clearly not always the case. Research can also quash a nascent technology by showing that it is infeasible or dangerous, as is often the case with drug trials.[32] If research shows the opposite – namely, that a climate intervention is feasible, effective, and safe – and thereby leads to its development and use, this would be problematic only if we accepted the previous argument that climate interventions are intrinsically wrong, regardless of their consequences.

Whatever the risks of pursuing research, they pale in comparison to the risks of not engaging in research:

- The international community might lack any means of responding quickly to abrupt climate change, because we have not sufficiently explored an adequate range of options.
- States might not be able to act quickly to reduce catastrophic impacts, because they have not researched and developed the necessary technologies.
- In response to a climate emergency, one or more states might decide to use a climate intervention approach that has not been adequately studied and that proves infeasible, ineffective, or dangerous.
- If a state decides to deploy a climate intervention that has not been thoroughly studied, other states will be less able to evaluate the potential implications in order to decide how to respond. Moreover, attributing environmental harms to the intervention, ex post, may be more difficult.
- The lack of information on the feasibility of interventions might lead to magical thinking about the likelihood that they can "solve" the climate change problem, making states complacent about the need to adapt and leading to misguided decisions, for example, about the management of infrastructure.

Objection: The benefits of research are illusory

A fourth argument is that the benefits of research will be immaterial since, no matter how much preparatory research is done, we still won't *really* know what the impacts of rapid responses will be without implementing at scale, which we should not do before safety issues have been resolved. The result is a chicken-and-egg problem: safety issues can be answered only through implementation; but implementation should not be undertaken unless safety issues have been answered.

There are two problems with this argument. First, we never have certainty about any policy question, so it is unreasonable to expect that of research on climate interventions. Second, we cannot know in advance the extent to which research will be able to reduce uncertainties. Although research will never fully resolve uncertainties about the safety of climate interventions, it could give us considerably more information about possible impacts and thereby allow more confident predictions. And if the level of confidence in the safety of an intervention was still insufficient after it had been researched, or if unacceptable risks had been identified, decision-makers could more readily decide not to proceed.

Objection: Because climate interventions would have global consequences, research should not proceed until a multilateral decision-making mechanism has been established

A final argument against climate intervention research is that there is no existing international mechanism to make decisions on research experiments at scales that produce significant environmental or climate impacts. Given the wide variety of views about whether climate interventions will be needed, are intrinsically wrong, and are too risky, individual states should not be able to decide on whether to engage in such research. Instead, these issues should be resolved collectively. Consequently, until an international decision-making mechanism has been established, research of this nature, and possibly of any kind, should not be allowed to proceed.

There are a number of possible responses to this argument:

First, research on climate interventions includes both research that is non-invasive (e.g. computer models, lab

work) or at a scale that produces only local impacts (e.g. plume experiments), and experiments at larger scales that have the potential to produce environmental effects that extend beyond national borders ("transboundary effects"). Even if one accepts that research with transboundary effects should be subject to international decision-making, the case for international decision-making is much weaker for research that has only local effects and even weaker for indoor research.

Second, multilateral decision-making is not a requirement for other research areas that have global or transboundary implications – for example, research on biotechnology,[33] artificial intelligence, and nanotechnology. Instead, individual states are free to make decisions about research in these areas. In most cases, such research is necessary to inform policy regarding these technologies. There is no good reason for treating climate intervention research differently.

Third, it may not be possible to get agreement internationally on a multilateral decision-making mechanism for climate intervention research. If so, requiring such a mechanism as a condition of research would be tantamount to banning research. This would be a good outcome only if the value of multilateral decision-making outweighed the value of understanding the feasibility, effectiveness and safety of climate interventions as a possible option to avoid abrupt, near-term climate change.

Fourth, the international community would be unable, in practice, to enforce a legal requirement for multilateral decision-making. A more effective and feasible means of influencing international behavior would be to establish a national research program that models responsible research, e.g., by stressing open science, international research cooperation, and robust scientific assessment. Although such a research program would arguably lack "input-based" legitimacy internationally (since it would be decided nationally, rather than through a "democratic" multilateral process), it could still have "output-based" legitimacy if it modeled norms of responsible research that were widely accepted as reasonable. In doing so, it would set a precedent for others and contribute to the development of international norms of responsible research.

CONCLUSION

Despite international efforts to address the climate change problem, the world's climate is becoming increasingly unsafe. Achieving net-zero emissions of greenhouse gases is essential to solving the problem. But, due to the climate system's inertia, even rapid emission reductions may not produce a sufficiently fast response to prevent the climate system from crossing critical thresholds that lead to abrupt and possibly irreversible change.

Climate interventions to reflect sunlight into space or to suck carbon out of the atmosphere are potential ways to lower the earth's temperature quickly in order to prevent abrupt, near-term change. But little has been done to research these technologies thus far. As a result, we know relatively little about their practicability, effectiveness, and risks.

In this context, ignorance is not bliss. Instead, ignorance about climate interventions:

- decreases climate safety by depriving us of potential options to address emergency situations
- decreases the safety of potential interventions due to lack of understanding of their potential harms
- exacerbates climate injustice by increasing the likelihood of climate harms that fall disproportionally on future generations and vulnerable countries lacking resources to adapt
- undermines good governance by ensuring that decisions are ill-informed
- increases the risk of conflict due to ignorance and miscalculation.

The answer to these ills is better knowledge about the risks and benefits of possible climate interventions. And that, in turn, requires that we undertake substantially more research than has occurred to date. Although research is unlikely to provide conclusive answers to all of our questions about climate interventions, it will put us in a better position to evaluate and make decisions about whether to intervene ourselves and how to respond to interventions by others.

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ENDNOTES

1 The paper focuses on the role of climate interventions in addressing the risk of abrupt climate change, but the arguments also apply to the risk of low-probability catastrophic impacts.

2 Thorsten Mauritsen and Robert Pincus, "Committed warming inferred from observations," *Nature Climate Change*, 7, 652–55 (2017), https://www.nature.com/articles/nclimate3357.

3 Paul U. Crutzen, "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?" *Climatic Change*, 77, 211-19 (2006), https://link.springer.com/article/10.1007/s10584-006-9101-y.

4 Susan Biniaz and Daniel Bodansky, *Solar Climate Intervention: Options for International Assessment and Decision-Making* (Arlington, VA: Center for Climate and Energy Solutions and SilverLining, 2020), https://www.c2es.org/document/solar-climate-intervention-options-for-international-assessment-and-decision-making/.

5 Maria Nicola et al., "Health Policy and Leadership Models during the COVID-19 Pandemic: A Review," *International Journal of Surgery*, 81: 122-29 (2020), https://dx.doi.org/10.1016%2Fj.ijsu.2020.07.026.

6 Tipping points occur "when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause." National Research Council, *Abrupt Climate Change: Inevitable Surprises* (Washington, D.C.: The National Academies Press, 2002), https://www.nap.edu/catalog/10136/abrupt-climate-change-inevitable-surprises.

7 Timothy M. Lenton et al., "Tipping Elements in the Earth's Climate System," *Proceedings of the National Academy* of Sciences, 105 (6): 1786-93 (2008), https://doi.org/10.1073/pnas.0705414105.

8 IPCC, *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, UK, and New York, NY: Cambridge University Press, 2007).

9 IPCC, *Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (2018), pp. 262-64.

10 Stef Lhermite et al., "Damage Accelerates Ice Shelf Instability and Mass Loss in Amundsen Embayment," *Proceedings of the National Academy of Sciences*, 170 (40): 24735-24741 (2020), https://doi.org/10.1073/pnas.1912890117.

11 Timothy Lenton et al., "Climate Tipping Points – Too Risky to Bet Against," *Nature*, 575: 592-96 (2019).

12 Thorsten Mauritsen and Robert Pincus, "Committed warming inferred from observations."

13 M. Granger Morgan and Katharine Ricke, *Cooling the Earth through Solar Radiation Management: The Need for Research and an Approach to Its Governance* (Geneva, Switzerland: International Risk Governance Council, 2010), https://irgc.org/wp-content/uploads/2018/09/SRM_Opinion_Piece_web.pdf.

14 E.g., M. Granger Morgan, "Why Goeengineering?" *Technology Review*, 14-15 (January/February 2009); David W. Keith et al, "Research on Global Sun Block Needed Now," *Nature*, 463(28): 426-27 (2010); Ken Caldeira and David W. Keith, "The Need for Climate Engineering Research," *Issues in Science and Technology*, 27(1): 56-62 (2010); Royal Society, *Geoengineering the Climate: Science, Governance and Uncertainty* (London: The Royal Society, 2009).

15 National Research Council, *Climate Intervention: Reflecting Sunlight to Cool Earth* (Washington, D.C.: National Academies Press, 2015). Thus far, funding in the United States has amounted to only about $8 million, and globally, total funding for research has been less than $10 million annually. Jesse L. Reynolds, "Solar Geoengineering to Reduce Climate Change: A Review of Governance Proposals," *Proceedings of the Royal Society*, 475: 20190255 (2019).

16 House Select Committee on the Climate Crisis Majority Staff, *Solving the Climate Crisis* (Washington, D.C.: U.S. House of Representatives Select Committee on the Climate Crisis, June 2020), https://climatecrisis.house.gov/report.

17 Solar Radiation Management Governance Initiative, *Solar Radiation Management: The Governance of Research* (2011); David W. Keith, Riley Duren and Douglas G. MacMartin, "Field Experiments on Solar Geoengineering: Report of a Workshop Exploring a Representative Research Portfolio," *Philosophical Transactions of the Royal Society*, 372: 20140175 (2014).

18 Alan Robock et al., "Studying Geoengineering with Natural and Anthropogenic Analogs," *Climatic Change*, 121: 445-58 (2013), https://doi.org/10.1007/s10584-013-0777-5.

19 Michael Burger and Justin Gundlach, "Research Governance," in Michael B. Gerrard and Tracy Hester, eds., *Climate Engineering and the Law: Regulation and Liability for Solar Radiation Management and Carbon Dioxide Removal,* p. 271 (2018).

20 Recently, representations of interventions are starting to become more sophisticated, for example, by exploring the impacts of factors such as the altitude of injections and investigating scenarios such as temporary "peak shaving" of warming in the context of parallel mitigation.

21 IPCC, *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, Switzerland: IPCC, 2014).

22 E.g., Katherine Dagon and Daniel P. Schrag, "Exploring the Effects of Solar Radiation Management on Water Cycling in a Coupled Land-Atmosphere Model," *Journal of Climate*, 29(7): 2635-50 (2016).

23 K. Ricke et al, "Regional Climate Response to Solar Radiation Management," *Nature Geoscience*, 3: 357-41 (2010).

24 Joseph E. Aldy and Richard Zeckhauser, *Three Prongs for Prudent Climate Policy* (Washington, D.C.: Resources for the Future, 2020).

25 "Adoption of the Paris Agreement," Decision 1/CP.21, para. 17.

26 One of the ways in which the Paris Agreement seeks to encourage Parties to ratchet up their levels of ambition over time is by providing for a global stocktake every five years to assess the Parties' collective progress toward meeting the Agreement's goals; the Agreement also calls for Parties to communicate a nationally determined contribution every five years and be informed by the outcomes of the global stocktake.

27 Aldy and Zeckhauser, *Three Prongs for Prudent Climate Policy.*

28 Benjamin Hale and Lisa Dilling, "Geoengineering, Ocean Fertilization and the Problem of Permissible Pollution," *Science, Technology and Human Values*, 36(2): 190-212 (2011).

29 E.g., Albert C. Lin, "Does Geoengineering Present a Moral Hazard?" *Ecology Law Quarterly*, 40(3): 673-712 (2013).

30 Gernot Wagner and Daniel Zizzamia, "Green Moral Hazards," (January 9, 2020), https://gwagner.com/green-moral-hazards/.

31 Aldy and Zeckhauser, *Three Prongs for Prudent Climate Policy.*

32 Daniel Edward Callies, "The Slippery Slope Argument against Geoengineering," *Journal of Applied Philosophy*, 36(4): 675-87 (2019). Some argue that climate interventions may face an uphill struggle rather than a slippery slope, as research identifies the challenges of implementation. Rob Bellamy and Peter Healey, "'Slippery Slope' or 'Uphill Struggle'? Broadening Out Expert Scenarios of Climate Engineering Research and Development," *Environmental Science and Policy*, 83: 1-10 (2018).

33 The Cartagena Protocol on Biosafety addresses the transboundary movement, transit, handling, and use of living modified organisms, but not research on biotechnology.

Other C2ES Resources:

Solar Climate Intervention: Options for International Assessment and Decision-Making
https://www.c2es.org/*document/solar-climate-intervention-options-for-international-assessment-and-decision-making/*

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