THINK GLOBALLY, GOVERN LOCALLY: DESIGNING A NATIONAL RESEARCH PROGRAM ON NEAR-TERM CLIMATE RISKS AND POSSIBLE INTERVENTIONS

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There is growing concern that the global response to climate change will be inadequate to avoid an unsafe climate. Current climate policy focuses on decarbonizing the global economy. This approach, although essential for climate safety, will not slow warming fast enough to address near-term climate risks. Research is therefore urgently needed to better understand these risks as well as the feasibility, effectiveness, and safety of possibly responses, including those that leverage earth system processes to reduce warming, such as increasing the reflection of sunlight from the atmosphere, or solar climate intervention (SCI).

While not endorsing or promoting the use of SCI, C2ES and SilverLining support expanding the knowledge base necessary to move toward the effective governance of SCI interventions in a manner that takes into account the safety of both the climate system and potential climate interventions, is science-based, and promotes cooperative international decision-making.

This paper is the third in a series exploring considerations and practical options for effective international cooperation and decision-making. The objective of the series is to explore considerations and develop practical possibilities for effective international cooperation and decision-making that engages the social justice issues and impacted communities. The first[1] and second[2] papers examined the ability of existing international bodies to evaluate and govern SCI and explored the nature of the research required to support science-based decision-making.

This paper argues for the establishment of a national research program on near-term climate risks and possible responses and outlines the elements of a model program aimed at providing information in a timely, safe, and open manner to allow for evaluation by policymakers and the public. A well-designed national research program could serve as a model for other national and international research programs and help provide information necessary for effective international governance. It uses the United States context as an example, since the United States has the sophisticated research capabilities necessary to explore near-term climate risks and interventions.

The U.S. National Academies of Sciences, Engineering, and Medicine (NASEM) recently published two related reports, one on a national agenda for climate research that emphasizes risk management[3] and one on research and governance for SCI that recommends a robust U.S. research program.[4] The model national research program described in this paper complements the recommendations from both NASEM reports.

INTRODUCTION

Climate change is not a distant problem—it is already here. Floods are occurring more frequently, droughts and wildfires are worsening, tropical storms and cyclones are becoming more intense, and coral reefs are dying. Recent extreme events, such as the 2003 heat wave in Europe, which killed more than 30,000 people; the 2013 Typhoon Haiyan in the Philippines, which killed upwards of 6,000 people; and the 2020 bushfires and forest fires in Australia and California, which burned more than 50 million acres combined, are among the many events attributable, at least in part, to climate change.[5] As the Arctic warms, we may cross thresholds that lead to much more rapid, abrupt change due to the release of greenhouse gases from thawing permafrost and reduced reflectivity of the Arctic caused by sea ice loss.[6] To address these risks, we need means of slowing or reducing global warming quickly.

To date, domestic and international climate policy have justifiably focused on decarbonizing the global economy.[7] But, given the climate system's inertia, emissions reductions—while essential—will not slow warming fast enough to address near-term climate risks. The reality is that no level of emissions reduction will influence warming sufficiently in the next 30–40 years, leaving a critical gap in society's efforts to address climate change, with potentially catastrophic effects, particularly for the world's most vulnerable people, and increasing risks of "tipping points" in natural systems in the near term.

To address this gap, a new approach is needed to assess near-term climate risks and potential responses that:

- is firmly grounded in the latest science;
- better represents complex risks, such as tipping points;
- accounts for uncertainties in the pace of human efforts to reduce greenhouse gas emissions;
- explores a range of approaches that extends beyond greenhouse gas emission reductions; and
- aids in the development of a portfolio of responses designed to dynamically optimize safety, as risks and solutions evolve over time.

One of the few potential ways to quickly reduce warming in response to near-term climate risks is through *solar climate intervention* (SCI), a term that encompasses various potential means to reflect sunlight from the Earth, such as by scattering reflective particles in the stratosphere or brightening marine clouds. SCI could, in theory, lower the Earth's temperature within a few years or less once developed; however, little research has been done on the topic, so the feasibility, safety, effectiveness, and associated costs are unknown. As a result, we do not know what role, if any, SCI might play as part of a portfolio of responses to near-term climate risks.

A previous paper[2] in this series explained why research is urgently needed on near-term climate risks and possible responses, including SCI. In brief, it argued that research would:

- contribute to climate safety, especially benefitting vulnerable countries and future generations;
- give governments, stakeholders, and the public information necessary for responsible decision-making; and
- reduce the risks of geopolitical tensions arising from ignorance, miscalculation, and asymmetric knowledge.

This paper argues for the establishment of a national research program and outlines the elements of a model program aimed at producing policy-relevant information about near-term climate risks and responses in a timely, safe, and open manner.[8] It addresses only governance of research and does not consider the issue of how any potential use of climate interventions should be governed, which will be subject of a separate paper. Given the urgency of the climate change problem, we cannot afford to wait for the development of an international regime to govern climate intervention research—we need to proceed now. A well-designed national research program would generate knowledge to support international scientific cooperation and set a precedent for responsible climate intervention research internationally, which could serve as a model for other future national and international programs.

The research program proposed here would sit within a broader policy framework for addressing rapidly escalating climate risks in a complex environment. To date, climate research and policy have centered on net

greenhouse gas emissions. As warming escalates, we need a more integrated systems-based approach that takes into account "the complex coupling between natural and human systems."[9] We must also better account for the likelihood that some responses do not work in the way they are projected. In risk management, this requires the design of a portfolio of policies that assumes some reasonable rate of failure and thus would be scoped to deliver, for example, 140% of the outcome required. With this in mind, the proposed national research program would be aimed at developing a strategy for managing near-term risks that involves a portfolio of responses.

Although this report focuses on guidance relevant to developed countries with the necessary capabilities for conducting climate research (e.g., super-computing, observational platforms, and large science programs), the proposed national research program would aim to build the scientific capabilities of other countries by making tools and data openly available as well as provide information for the benefit of the entire international community to support cooperative international assessment and decision-making about how to address near-term climate risks.

RATIONALE FOR A BOTTOM-UP APPROACH TO CLIMATE INTERVENTION RESEARCH

While much has been written about global governance of climate intervention research,[10] requiring the development of a global regulatory regime before proceeding with research would be ill-advised for several reasons:

- First, there is insufficient knowledge about climate interventions to intelligently design an international governance framework now. This ignorance could provoke proposals that are focused on the wrong risks (e.g., misunderstanding the relative risks of intervention versus the risks of warming for vulnerable communities) or that are overly restrictive, thereby reducing rather than enhancing safety (e.g., through premature efforts to ban or impose a moratorium on research).[11]
- Second, countries disagree on the need for global governance of research and on what types of governance would be appropriate. In 2019, a proposed United Nations Environment Assembly resolution[12] calling for an assessment of climate intervention technologies failed to achieve consensus due to differences about what technologies should be covered and who should undertake the assessment. Agreement on a research governance framework thus appears unlikely anytime soon.
- Third, even if agreement might eventually be possible, an international regime would take a very long time to negotiate, preventing useful and safe research from proceeding in the meantime.

Waiting for international agreement on research governance could be like waiting for Godot—not only is it unwise, but it is unrealistic. Except in cases where national research might have significant transboundary effects, other countries have no right to govern the research a country wishes to pursue. Even now, countries are pursuing research freely on a variety of other technologies with potential global impacts, such as artificial intelligence and nanotechnology, in the absence of international governance.[13] Although international governance could eventually play a useful role in promoting transparency, safety, and accountability, it is not a precondition for moving forward.

Accordingly, rather than focusing first on developing an international regime, this paper proposes an approach that builds from the bottom-up, starting with a nationally developed research program that could be internationalized through research collaboration and policy diffusion.[14]

Environmental policy diffusion is a common phenomenon—the experiences of first-movers can provide an information base for others to draw on in analyzing issues, designing programs, and developing local expertise. Policies that originate in one country can diffuse globally by serving as models for other countries. Examples of this include the establishment of national environment agencies, the regulation of water and air pollution, and the use of ecolabelling.[15] In some cases, environmental policy diffusion has eventually led to the development of international regimes. For example:

- National malaria eradication programs laid the groundwork for the World Health Organization's (WHO's) Global Malaria Eradication Program.

Specifically, the United States launched its National Malaria Eradication Program in 1947, India followed suit in 1953, and the WHO initiated its global program that same year.

- The propagation of national research stations in the Antarctic after World War II, starting with the establishment of research stations by the United Kingdom and Chile in 1947, followed by an Argentine station in 1951, an Australian station in 1954, and French and U.S. stations in 1956, led to the International Geophysical Year and the internationalization of Antarctic scientific research.
- Environmental impact assessments originated in the United States in 1970 in the *National Environmental Policy Act*.[16] This U.S. policy innovation was first emulated by other Western countries and now by more than 100 countries around the world.[17] Eventually, this convergent national practice became the basis for the Espoo Convention on Environmental Impact Assessment.[18]
- Regulation of hazardous waste and chemical exports began at the national level through laws such as the *Resource Conservation and Recovery Act*[19] and the *Toxic Substances Control Act*.[20] These national policies became the basis for international regulation through the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal[21] and the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade.[22]

Starting a model national research program focusing on near-term climate risks and interventions would have several benefits, including:

- generating scientific information necessary to assess risks and make responsible decisions;
- generating tools and skills that countries with less capacity could use in developing their own research programs, paving the way for international cooperation in science and technology;
- leading by example and thereby providing valuable insight for other national research programs; and
- providing a basis for the eventual development of an international framework for international cooperation and decision-making through the convergence of national approaches.

At present, the greatest danger is ignorance—without knowledge, we are ill-equipped to respond to abrupt, near-term climate change, with only untested, potentially ineffective, and unsafe options. Ignorance also makes international cooperation in decision-making harder and conflicts more likely. To remedy these problems, we should proceed expeditiously to develop a national research program that is effective, safe, and transparent.

GOALS AND FUNCTIONS OF A NATIONAL RESEARCH PROGRAM

A national research program that focuses on near-term climate risks and the associated feasibility, effectiveness, and risks of possible responses should be designed with the aim of developing an integrated systems-based approach to managing near-term climate risks.[23] This will require filling gaps in our knowledge, elaborating an analytical framework for assessing risks and responses, and providing decision-makers across the globe with the information they need to make informed choices about how to promote climate safety. To meet this goal, the proposed program should serve the following functions.

Promote rapid generation of knowledge. The model program's primary function should be to promote the generation, in policy-relevant time horizons, of information needed for assessment and decision-making about possible responses to near-term climate risks. In this context, research on SCI should be an important priority since it is potentially the most rapid and scalable option.

In order to serve this function, a national research program should:

- define a research agenda that identifies critical gaps in current knowledge, prioritizes research activities, and ensures appropriate coverage of the key issues;
- identify synergies among research by different agencies;
- prioritize and accelerate the development of relevant tools, technologies, and platforms;
- identify unintended overlaps in research that do not provide value added;
- support mechanisms for intercomparison and validation of research results;
- give researchers space for creativity and experimentation; and

- provide for ongoing assessment and review in order to facilitate revisions to the research program based on new information and experience.

Ensure the scientific quality and integrity of research. A national research program should ensure the scientific quality and integrity of research through ongoing expert assessment and review of research studies as well as through conflict-of-interest rules and transparency requirements. To the extent possible, it should also seek to ensure that the research program is insulated from political interference.

Ensure safety. Although modeling and laboratory studies do not raise safety concerns, outdoor experiments that release materials or non-native species into the environment could have physical effects that pose risks to the environment and to local communities. Therefore, a national research program should require advance assessments of environmental and other risks for medium-scale and impact-level release experiments.

Promote transparency and access to information. A national research program should provide for open access to research results to foster public trust, reduce international tensions, and give people access to the information necessary for informed, democratic decision-making.

Promote public engagement. A national research program should include mechanisms to engage the public and consider ethical and societal issues. These mechanisms might include:

- a notice-and-comment process for programmatic issues relating to the general design of the research program;
- support for outside centers to consider ethical, legal, and societal issues; and
- forums to consult with those who might be directly affected by medium-scale and impact-level research activities.

Provide a social license to researchers so that they feel more comfortable engaging in climate intervention research. To date, relatively few scientists have been willing to engage in climate intervention research, with some viewing it as almost a taboo subject. However, this is beginning to change. The design elements proposed in this paper—including authorization of a research program through a democratic, political process; elaboration of its strategy and standards through a notice-and-comment process that facilitates public input; and emphasis on transparency and environmental assessment—would help accelerate the legitimation of climate intervention research and break down social barriers to entry.

Promote international cooperation and trust. Finally, a national research program should promote international cooperation and trust and thereby help diffuse international tensions concerning possible use of climate interventions. To serve this function, the program should:

- require open access to data (as discussed previously) so that it is clear to the global community what the country is doing and what the research shows;
- promote collaborative international research activities;
- encourage participation by scientists from less developed countries, which may lack the technologies necessary for research on climate risks and responses (e.g., observational platforms and super-computing); and
- require notice to potentially affected countries of research activities that may have transboundary effects and provide consultations with them.

Finally, given concerns about climate intervention, it is worth emphasizing that establishing a national research program does not prejudge what might be included in a strategy to address near-term climate risks, in particular whether it might include climate intervention. The purpose of the research program is to provide information necessary to enable decision-makers to make informed decisions about that question.

LESSONS FROM OTHER NATIONAL RESEARCH PROGRAMS

Existing scientific research programs can help inform how a national research program on near-term climate risks and potential responses might be designed. In this section, we highlight two U.S. research programs: the U.S. Global Change Research Program (USGCRP) and the National Nanotechnology Initiative (NNI). These programs illustrate several design elements proposed in this paper, such as the use of steering committees for coordination, strategic plans to establish goals and

priorities, expert review of research results, and notice-and-comment requirements to facilitate public input.

USGCRP

The USGCRP was established in 1990 by the *Global Change Research Act*.[24] It is intended to provide strategic planning and coordination of research efforts across U.S. government agencies, as well as with private and international entities, and synthesize research results and share them with the public to assist "the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."[25] Currently, 13 U.S. government agencies and departments participate in the program. Important elements of the program include:

- an interagency committee to coordinate research, which is overseen by the White House Office of Science and Technology Policy;
- ten-year strategic plans, which are published 90 days in advance in the *Federal Register* to provide ample time for public comment;[26]
- inter-agency groups to coordinate and implement research activities within and across agencies;
- periodic national climate assessments, which integrate, evaluate, and interpret the findings of the program;[27]
- reviews of the program by the National Academies of Sciences, Engineering, and Medicine (NASEM) to identify significant accomplishments and potential lessons for future program planning;[28] and
- participation in international research initiatives, including the Group on Earth Observations, to promote international cooperation.

NNI

The NNI was established in 2001 to coordinate nanotechnology research and development across the U.S. government. Now embracing 20 Federal agencies interested in nanotechnology research, development, and commercialization, it has been called "arguably the best modern example" of transdisciplinary and interagency coordination in the United States.[29] Important features include:

- high-level coordination by a subcommittee of the White House National Science and Technology Council.
- technical and administrative support by the National Nanotechnology Coordination Office, which serves as the principal point of contact for participating federal agencies.
- a strategic plan that sets priorities and objectives and provides a framework for agency research and development (R&D) activities related to nanotechnology. Pursuant to the *21st Century Nanotechnology Research and Development Act*,[30] the strategic plan is updated every 3 years through a process that includes advance publication in the *Federal Register* and a period for public content.
- educational and public outreach through the National Science Foundation-sponsored Nanoscale Informal Science Education Network, which has involved more than 30 million people through its programs, events, and exhibitions.
- an environmental, health, and safety research strategy, adopted in 2011, to address the ethical, legal, and societal implications of nanotechnology, including through the support of two university-based research centers (i.e., Arizona State University and the University of California–Santa Barbara).
- use of grand challenges, student contests, webinars, web-based resource portals, communities of research (CORs), and other mechanisms to foster an NNI collaboration ecosystem that includes educational institutions, companies, foundations, and others engaged in nanotechnology R&D.
- international sharing of information and coordination, including through U.S.–European Union CORs.[31]

GENERAL CONSIDERATIONS IN DESIGNING A NATIONAL RESEARCH PROGRAM

A number of general considerations should inform the design of a national research program on near-term climate risks and possible responses, including:

The two safeties. Overall climate safety is a function of both the safety of the climate system (in light of rapidly escalating hazards) and the safety of potential responses (i.e., the "two safeties"). The program needs to address both elements of safety.

Science-based. The program should be science-based. It should be designed to produce information in policy-relevant time horizons that is objective, grounded in evidence, and as free as possible from political or normative influences.

Integration with other climate research. The program should be integrated with larger efforts in climate research and mitigation in order to generate a portfolio of potential responses to climate risks as well as the analytical tools needed to evaluate and compare different options.

Minimization of burdens. Requirements to ensure safety and scientific integrity should not impose undue burdens on research, given the aim of promoting the production of knowledge.

Research tiers. Different types of research warrant different tiers of governance. For example, modeling, laboratory work, and passive observation are very different from experiments that involve the release of material into the environment and do not warrant additional governance beyond existing requirements for government-funded research. Similarly, greater governance is appropriate for impact-level release experiments with potentially significant effects than small-scale release experiments with only minimal effects.[32]

Differentiation of systemic and project-specific issues. Different approaches to governance are appropriate for systemic/societal issues and project-specific issues. Systemic issues concern the research program as a whole, such as whether the program will discourage mitigation activities (often referred to as *moral hazard*) or lead to technology lock-in. These systemic issues are very different from project-specific issues, such as whether a particular research activity will have significant adverse effects. To ensure broad societal input and avoid burdening individual research activities, systemic issues should be dealt with at the outset for the program as a whole by institutions ultimately answerable to democratic processes. Established governmental mechanisms for public policymaking and scientific oversight are likely to be the most appropriate means of considering systemic/societal issues. In contrast, project-specific issues should be addressed on a case-by-case basis, along the same lines as research in other fields.

Research community. The program's functions of promoting and coordinating research would be furthered by building a research community that includes privately funded researchers.

Privately funded research. Although privately funded researchers should be free to pursue modeling, laboratory work, and passive observations, government oversight of privately funded outdoor release experiments is appropriate to promote transparency and safety. Accordingly, when a country establishes a national research program, its government should assert jurisdiction over privately funded outdoor release experiments involving possible climate interventions. This will require defining what experiments are covered, which will involve somewhat arbitrary line-drawing, since much of climate intervention research is also relevant to other areas of climate science.

National flexibility. A one-size-fits-all approach to a national research program is unrealistic, given differences in countries' capabilities, institutional structures, and circumstances. The proposed elements outlined in this paper are aimed at a country with high research capabilities and may be inappropriate for a developing country with limited research capacity. While this paper tries to identify best practices in research design, national research programs will understandably need to vary.

DESIGN ELEMENTS OF A MODEL NATIONAL RESEARCH PROGRAM

This section outlines the principal elements of a model national research program. Although some of these elements are appropriate for all countries (e.g., assessment of potential environmental impacts of medium-scale and impact-level release experiments), some may be feasible only for countries with advanced research capabilities, such as the United States.

AUTHORIZATION

Ideally, a national research program should be established through authorizing legislation or regulatory action to promote political buy-in and stability. The authorizing act should:

- set forth the program's mission and mandate;

- identify research goals, critical questions, and outputs;
- establish initial timelines and milestones for completion of the program's activities;
- create the program's institutional structure and delineate institutional responsibilities;
- provide mechanisms to fund the program's administration and research activities;
- support coordination of research among member institutions;
- support international scientific cooperation and future international cooperation in decision-making; and
- provide for the assertion of jurisdiction over all climate intervention experimental activities in the country's territory or by its citizens that involve the release of materials or non-native species into the environment in order to ensure public oversight of experiments that could raise potential environmental or safety risks.[33]

Examples of authorizing legislation for other research programs include the United States' *Global Change Research Act of 1990*[24] and the *21st Century Nanotechnology Research and Development Act*.[30] In democratic countries, establishing a national research program through legislation would serve not only a constitutive function but also provide the program with a social license.

INSTITUTIONS

Governance of a national research program will require overall policy direction and coordination, day-to-day management, and expert assessment. Given the differences between these functional tasks, they should ideally be performed by different institutions.

Steering Committee

Overall direction and oversight of the program should be provided by an inter-agency steering committee comprising research heads of participating agencies. In the United States, the USGCRP might serve this function, given its deep ties to the research community and its existing mandate "to gain a predictive understanding of the … processes that regulate the total Earth system and, hence, establish the scientific basis for national and international policy formulation and decisions…."[34]

Lead National Agency

A lead national agency should be designated to coordinate and oversee the development and operation of the program. An institution with relevant expertise in conducting and overseeing climate research in collaboration with public and academic institutions and that has existing mandates to inform and engage the public and international institutions (e.g., the National Oceanic and Atmospheric Administration in the United States) would be well-positioned to take this role.

Scientific and Technical Assessment Panel(s)

One or more scientific and technical assessment bodies should be designated by the program to:

- provide periodic assessments of the state of near-term risks and intervention alternatives;
- provide ad hoc expert review of new research;
- identify critical gaps for decision-making and implementation; and
- inform the development of additional governance mechanisms over time, as appropriate.

These assessment functions could be performed by an existing institution (e.g., in the United States by a committee of the NASEM) or by a newly created scientific and technical assessment panel.

RESEARCH AGENDA

The designated lead national agency, in collaboration with other participating agencies and private research institutions, should develop a research agenda aimed at driving and orchestrating all government-supported research. The research agenda should: (1) identify key questions and gaps in knowledge to ensure appropriate coverage, (2) prioritize research activities, and (3) identify synergies. Possible focus areas should include risk analysis and management, SCI, and nature-based, large-scale carbon removal interventions.

In developing the research agenda, the lead national agency and its collaborators should seek to consult with private researchers to promote coordination and synergies between privately and publicly funded research.

RESEARCH TIERS

Depending on the scale of an activity's potential impacts, different levels of governmental oversight and regulation

are appropriate. Accordingly, the lead national agency should define several research tiers, which would be subject to different requirements. These tiers might include:

- **Tier 1:** Modeling, laboratory work, and passive observations, which do not have any direct environmental effects.
- **Tier 2:** Small-scale outdoor release or biological system experiments, with only minimal, transient effects on the environment.
- **Tier 3:** Medium-scale release or biological system experiments, which could have environmental effects or pose safety risks over a relatively small area and relatively short period of time.
- **Tier 4:** Impact-level release or biological system activities, which are anticipated to have significant environmental effects or pose safety risks over a large geographical area or a long time period.[35]

The metrics used to distinguish "small-scale," "medium-scale," and "impact-level" release experiments/activities could be defined in various ways, such as the types or amounts of inputs into the environment (e.g., grams of sulfur injected into the atmosphere) or the environmental effects (e.g., changes in atmospheric circulation)[36] and should be informed by existing environmental regulations and requirements for related fields of research.

NATIONAL REGISTRY OF RELEASE EXPERIMENTS

The lead national agency should establish a national registry of outdoor experiments that involve the release of material into the environment. Researchers should be required to notify the agency in advance about planned release experiments and provide the following information for inclusion in the registry:

- a description of the experiment, including its nature, purpose, principals, location and timing, and funding sources;
- any environmental assessments of the proposed experiment;
- a summary of the research results after the experiment is completed; and
- observational data if findings and/or scientific claims are published.

The research registry should include all government-supported research as well as privately funded release experiments.

GOVERNMENT OVERSIGHT OF RELEASE EXPERIMENTS

The lead national agency and its collaborators should develop processes for oversight of release experiments, including through scientific and environmental reviews and local engagement. The processes should be informed by existing laws, regulations, and agency mandates and practices and should include factors such as the protection of scientific integrity, national security policies and practices, public safety, and the privacy and safety of researchers.

It is worth noting that publicly funded research is already subject to a variety of requirements relating to:

- scientific peer review;
- transparency through publication of methods, data, analysis, and findings; and
- documentation of compliance with applicable environmental and safety regulations.

As discussed previously, privately funded release experiments could raise safety and transparency questions and therefore should be subject to broadly the same oversight requirements as publicly funded research. This oversight should be designed in a manner that does not discourage research but simply ensures that it is carried out safely and transparently.

Public oversight of release experiments, irrespective of public or private funding, should include the following elements:

- **Definition of covered research:** The scope of climate intervention research should be defined either in the authorizing legislation for the national research program or in regulations promulgated by the lead national agency. In the United States, for solar climate intervention, one possibility would be to adapt the definition of "weather modification" in the *Weather Modification Reporting Act*, which defines weather modification as any activity performed with the intention of producing artificial changes in the composition, behavior, or dynamics of the atmosphere.[37] This definition would appear to cover SCI but would need to be modified to address other types of interventions, such as ocean fertilization.

- **Assertion of jurisdiction over covered activities:** The *Weather Modification Reporting Act* applies only to activities in the United States.[37] Given that climate intervention research might be undertaken in areas beyond national jurisdiction, such as the stratosphere or the high seas, jurisdiction should be asserted on a nationality as well as a territorial basis so that outdoor release experiments and activities by the country's nationals are covered no matter where they take place. This would fill a potential gap in existing national laws that allows researchers to escape regulation by engaging in activities in global commons areas outside the territorial jurisdiction of any country.
- **Advance notification and registration:** Given the importance of transparency in fostering public trust, all outdoor experiments involving the release of materials into the environment, regardless of their expected level of effects, should be registered in advance on the national registry of release experiments.
- **Scientific review:** Before any outdoor release experiment begins (whether privately or publicly funded), qualified experts from the lead national agency or the scientific assessment panel should review the experimental design (including whether the experiment might have more than *de minimis* environmental impacts). It should also review the published findings after completion. These scientific reviews should inform possible revisions to the classification of research tiers and to governance requirements and modalities.
- **Preliminary environmental assessment:** For medium-scale and impact-level release experiments (i.e., Tiers 3 and 4), researchers should be required to conduct a preliminary assessment of the environmental effects of the proposed experiment and make the assessment available to the lead national agency, relevant regulatory bodies, and the scientific assessment panel for its review.
- **Full environmental assessment:** If the preliminary assessment shows that a release experiment might have significant environmental or transboundary effects, researchers should be required to perform a full environmental assessment of the proposed research activity and notify the lead national agency of the results. The researchers should also develop a monitoring plan and provide a description of the experiment to the lead national agency.
- **Authorization/approval:** Impact-level release activities (Tier 4) should be permitted only with the explicit approval of the steering committee to ensure high-level review and approval. (In the United States and many countries, Tier 4 activities are part of a class of environmental release activities with established processes for review and approval from local and national authorities.)
- **Foreign relations:** The country's foreign ministry should be consulted in advance about any proposed experiment/activity that could have transboundary effects in order to allow time for notice to and consultation with potentially affected countries. Approval of such activities should require the concurrence of the foreign ministry.
- **Publication of research results:** Researchers who conduct medium-scale or impact-level release experiments (Tiers 3 and 4) should be required to publish or otherwise make available the results of their research.
- **Local engagement:** If the initial assessment identifies potential adverse environmental impacts on particular communities, researchers should be required to provide notice to those communities and consult with them.

PUBLIC ENGAGEMENT

The national research program should incorporate a notice-and-comment process to allow public input. The lead national agency should provide notice to the public of the principal design elements of the proposed research program, including the definition of research tiers and the environmental assessment and public engagement requirements for outdoor release experiments. In the United States, for example, notice could be provided by publication in the *Federal Register*, as is required for development of the *National Global Change Research Plan* for the USGCRP.[24] The public should then be given a period of time to comment on the proposal before final adoption of the research tier definitions and environmental assessment and public engagement requirements for outdoor release experiments.

INTERNATIONAL RESEARCH COORDINATION AND COLLABORATION

The steering committee should encourage international research coordination through new or existing scientific programs, such as the World Climate Research Program, the Inter-American Institute for Global Change, and the International Geosphere-Biosphere Program. Collaborative research activities should also be encouraged through national academies of science and on an agency-to-agency level.[38]

INTERNATIONAL REPORTING, NOTICE, AND CONSULTATION

The lead national agency should periodically report on the national research program and its results to relevant international institutions, such as the World Meteorological Organization, the World Climate Research Program, the UN Environment Programme, and the Montreal Protocol Scientific Assessment Panel, including information on research activities, analytic tools, and scientific reviews. The lead national agency (or the foreign ministry) should also provide advance notice to any country that might be adversely affected by an experimental activity and consult with them before proceeding with the experiment, as well as support mechanisms that further international scientific cooperation.

CONCLUSION

Research is urgently needed to better understand near-term climate risks and potential responses, including climate interventions. Establishment of a national research program would contribute to both climate safety and the safety of any possible climate interventions by providing national and international decision-makers with information needed to make cooperative, informed, and responsible decisions and would reduce the risk of international conflict due to ignorance or miscalculation. The program should be designed to promote the production of high-quality, policy-relevant scientific information in a safe, timely, and transparent manner. Such a program would set a precedent for responsible research and could serve as a model for other national and international research programs. Although a number of objections have been raised about researching climate interventions, including the possibility that such research could detract from efforts to limit greenhouse gas emissions (a concern that is not well-supported by evidence[39]), at least some countries are likely to pursue research on climate interventions regardless, given the threat posed by near-term climate change. Thus, the choice is not between research and no research, but between responsible and irresponsible research. This paper has attempted to outline what a responsible national research program that supports effective international cooperation and decision-making would entail.

ENDNOTES

1 Susan Biniaz and Daniel Bodansky, *Solar Climate Intervention: Options for International Assessment and Decision-Making*, DOI: 10.13140/RG.2.2.30746.36809 (Washington, DC: Center for Climate and Energy Solutions/SilverLining, 2020).

2 Daniel Bodansky and Susan Biniaz, *Climate Intervention: The Case for Research*, DOI 10.13140/RG.2.2.17324.59528 (Washington, DC: Center for Climate and Energy Solutions/SilverLining, 2020).

3 National Academies of Sciences, Engineering, and Medicine, *Global Change Research Needs and Opportunities for 2022–2031* (Washington, DC: National Academies Press, 2021), https://www.nationalacademies.org/our-work/advice-for-the-us-global-change-research-program.

4 National Academies of Sciences, Engineering, and Medicine, *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance* (Washington, DC: National Academies Press, 2021), https://www.nap.edu/catalog/25762/reflecting-sunlight-recommendations-for-solar-geoengineering-research-and-research-governance.

5 Peter Stott, D.A. Stone, and M.R. Allen, "Human Contribution to the European Heatwave of 2003," *Nature, 432*: 610–14 (2004). This estimates that anthropogenic climate change at least doubled the risk of a 2003-level heatwave. Izuru Takayabu et al., "Climate Change Effects on the Worst-Case Storm Surge: A Case Study of Typhoon Haiyan," *Environmental Research Letters*, *10*: 064011 (2015). This estimates that anthropogenic climate change increased the storm surge from the typhoon by 20%. Nicky Phillips and Bianca Nogrady, "The Race to Decipher How Climate Change Influenced Australia's Record Fires," *Nature*, *577*: 610 (2020).

6 Arctic Monitoring and Assessment Programme (AMAP), *Snow, Water, Ice, and Permafrost in the Arctic: Summary for Policymakers* (Oslo: AMAP, 2017), https://www.amap.no/documents/download/2987/inline.

7 E.g., the Paris Agreement, Article 4.1, adopted on December 13, 2015, U.N. Doc. FCCC/CP/2015/Add.1, *International Legal Materials*, *55*(4): 740–55 (2016). This establishes the global goal to achieve balance between emissions and removals of greenhouse gases by the end of the 21st century.

8 Earlier reports discussing the design of a national climate intervention research program include: House of Commons, Science and Technology Committee, *The Regulation of Geoengineering* (London, Stationery Office Limited: 2010); Bipartisan Policy Center, Task Force on Climate Remediation Research, *Geoengineering: A National Strategic Plan for Research on the Potential Effectiveness, Feasibility, and Consequences of Climate Remediation Technologies* (Washington DC: Bipartisan Policy Center, 2011); and National Research Council, *Climate Intervention: Reflecting Sunlight to Cool the Earth* (Washington, DC: National Academies Press, 2015).

9 See National Academies of Sciences, Engineering, and Medicine, *supra* note 1, p. 31.

10 E.g., Albert C. Lin, "Geoengineering Governance," *Issues in Legal Scholarship*, *8*(1): Article 2 (2009); Arunabha Ghosh, "Environmental Institutions, International Research Programmes, and Lessons for Geoengineering Research," in Jason J. Blackstock and Sean Low, eds., *Geoengineering Our Climate? Ethics, Politics and Governance* (London: Routledge, 2018); Edward A. Parson and Lia N. Ernst, "International Governance of Climate Engineering," *Theoretical Inquiries in Law*, *14*(1): 307–37 (2013); and Solar Radiation Management Governance Initiative, *Solar Radiation Management: The Governance of Research* (2011), https://www.srmgi.org/files/2016/02/SRMGI.pdf.

11 See House of Commons, Science and Technology Committee, *supra* note 7, p. 27 (summary of testimony of John Virgoe).

12 Jean Chemnick, "US Blocks U.N. Resolution Geoengineering," *Scientific American* (2019).

13 Dieter Ernst, *AI Research and Governance Are at Crossroads* (Waterloo: Center for International Governance Innovation, 2020), https://www.cigionline.org/articles/ai-research-and-governance-are-crossroads.

14 For broadly similar arguments for a bottom-up approach, see David B. Victor, "On the Regulation of Geoengineering," *Oxford Review of Economic Policy*, *24*(2): 322–36 (2008) and M. Granger Morgan, Paul Gottlieb, and Robert R. Nordhaus, "Needed: Research Guidelines for Solar Radiation Management," *Issues in Science and Technology*, *29*(3): 37–44 (2013).

15 Kristine Kern, Helge Jorgens, and Martin Janicke, *The Diffusion of Environmental Policy Innovations: A Contribution to the Globalization of Environmental Policy*, WZB Discussion Paper FS II 01-302 (Berlin: Wissenschaftszentrum Berlin Fur Sozialforschung, 2001), https://www.econstor.eu/obitstream/10419/48976/1/329601059.pdf.

16 *National Environmental Policy Act*, Pub.L. 91-190, 83 Stat. 852 (January 1, 1970), https://www.govtrack.us/congress/bills/91/s1075/text.

17 Neil Craik, *The International Law of Environmental Impact Assessment* (Cambridge: Cambridge University Press, 2008).

18 Convention on Environmental Impact Assessment in a Transboundary Context, adopted Feb. 25, 1991, 1989 UNTS 309.

19 *Resource Conservation and Recovery Act*, Pub.L. 94-580, 90 Stat. 2795 (October 21, 1976).

20 *Toxic Substances Control Act*, Pub.L. 94-469, 90 Stat. 2003 (October 11, 1976), https://uscode.house.gov/view.xhtml?req=(title:15%20section:2601%20edition:prelim).

21 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, adopted March 22, 1989, 1673 UNTS 126.

22 Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, adopted Sept. 10, 1998, 2244 UNTS 337.

23 National Academies of Sciences, Engineering, and Medicine, *supra* note 1, chapter 3.

24 *Global Change Research Act of 1990*, Pub.L. 101-606, 104 Stat. 3096 (November 16, 1990).

25 See § 101(b), *supra* note 23.

26 See § 104(f), *supra* note 23.

27 See § 106, *supra* note 23.

28 Committee to Advise the U.S. Global Change Research Program, *Accomplishments of the U.S. Global Change Research Program* (Washington, DC: National Academies Press, 2017).

29 National Academies of Sciences, Engineering, and Medicine, *A Quadrennial Review of the National Nanotechnology Initiative: Nanoscience, Applications, and Commercialization* (Washington, DC: National Academies Press, 2020).

30 *21st Century Nanotechnology Research and Development Act*, Pub.L. 108-153, 117 Stat. 1923 (December 3, 2003).

31 Subcommittee on Nanoscale Science, Engineering and Technology of the National Science and Technology Council, *National Nanotechnology Initiative: Strategic Plan* (Washington, DC: Executive Office of the President, 2016).

32 For a general discussion of categories of climate intervention research, see Solar Radiation Management Governance Initiative, *supra* note 9, pp. 25–28.

33 As noted earlier, this will require defining what constitutes a "climate intervention" experimental activity, which will be tricky, since much of the research relevant to climate interventions involves basic climate science.

34 Committee on Earth Sciences, *Our Changing Planet: The FY 1990 Research Plan* (Washington, DC: Office of Science and Technology Policy, 1989).

35 For a similar categorization, see Solar Radiation Management Governance Initiative, *supra* note 9, p. 26.

36 See House of Commons, Science and Technology Committee, *supra* note 7, pp. 17–18.

37 *Weather Modification Reporting Act of 1972*, Pub.L. 92-205, 85 Stat. 735 (December 18, 1971), https://www.govinfo.gov/app/details/USCODE-2010-title15/USCODE-2010-title15-chap9A-sec330.

38 Bipartisan Policy Center, *Geoengineering: A National Strategic Plan for Research on the Potential Effectiveness, Feasibility, and Consequences of Climate Remediation Technologies*, *supra* note 7, pp. 30–31.

39 Joseph E. Aldy and Richard Zeckhauser, "Three prongs for prudent climate policy," *Southern Economic Journal*, *87*(1): 3–29 (2020).