

Developing a Framework for an Interdisciplinary and International Climate Intervention Strategies Research Program

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Community Climate Intervention Strategies Workshop

What: Approximately 250 participants from 80 universities and government agencies across 30 countries joined online plenary and breakout sessions to discuss a framework and first steps for establishing a community-driven, interdisciplinary research program to assess a portfolio of climate intervention strategies.

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Where: Online

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Humanity faces growing risks due to climate change; however, there is no single near-term pathway that can limit warming to well below 2°C (IPCC 2018). A coordinated, large-scale collaboration between physical, life, and social science research, engineering, and practitioner communities is needed to understand and comprehensively assess how a portfolio of climate interventions would behave in real-world scenarios (Long and Shepherd 2014). Assessments of research and implementation strategies for carbon dioxide removal (CDR) and solar radiation modification (SRM) interventions, also known as geoengineering, have largely remained separated (National Research Council 2015b,a), while the need for investigating a portfolio of combined climate intervention scenarios including adaptation, mitigation, CDR, and SRM is becoming more evident (e.g., Jones et al. 2018; MacMartin et al. 2018; Lawrence et al. 2018; Tilmes et al. 2020; Buck et al. 2020).

The Community Climate Intervention Strategies (CCIS) Steering Committee was established to answer this call and to enhance collaboration between the disparate research groups needed to develop an interdisciplinary and international climate intervention research program. During the summer of 2020, CCIS hosted an eight-part webinar series that outlined the state of science of various climate intervention approaches and highlighted the need for portfolio-based assessments of climate interventions. A total of 27 international experts addressed the state of science information on future climate scenario development, integrated assessment modeling, SRM, CDR, observational needs, societal and ecological impacts, education and outreach, and ethics and governance. Over 16 h of the recorded presentations are available at www2.acom.ucar.edu/workshop/ccis-2020-webinars.

As a follow-up to the webinar series, the CCIS team convened the CCIS workshop in October 2020 with interdisciplinary and international participation of approximately 60% physical and biological scientists, and the remainder consisted of social scientists, communication and education specialists, local stakeholders, policymakers, and representatives from nonprofit organizations. Outcomes of the workshop included recommendations to 1) create seven science-themed working groups as part of the CCIS research framework, 2) develop a CCIS communication and resource hub to facilitate exchange between scientists, stakeholders,

and policymakers, and 3) integrate communication and interdisciplinary research design specialists within working groups and the CCIS program at large. These outcomes will be the basis for synergizing existing climate intervention research, identifying research priorities and needs, and initiating future interdisciplinary projects.

Day 1: Setting an interdisciplinary intervention research framework

The first day of the workshop began with context setting and exploratory questions by Antonio Busalacchi (UCAR President) and Bruce Hamilton (NSF), who both sponsored the workshop, Gyami Shrestha [Director, U.S. Carbon Cycle Science Program at U.S. Global Change Research Program (USGCRP)], Mark Rounsevell [Director, Analysis, Integration and Modeling of the Earth System (AIMES)], and David Fahey (Director, NOAA Chemical Science Laboratory). A common theme was the pressing need for the convergence of multidisciplinary research communities to adequately assess climate intervention strategies. The CCIS steering committee then presented workshop goals and objectives, a summary of the webinar series, and an overview of the proposed CCIS research framework.

The proposed CCIS research framework includes five main components, three of which are aligned with categories typically involved in climate research: 1) *human dimensions and drivers of change*, which considers demographic, economic, and technological changes, and social and ethical aspects of climate intervention strategies including governance; 2) *engineering and physical processes*, which includes stratospheric aerosol interventions, marine cloud brightening and cirrus thinning, sea ice, land, and industrial-based interventions, and ocean-based interventions, using modeling, observations, laboratory, and field studies; and 3) *impacts and adaptation*, which includes many biological and social impacts, including effects on water, food, energy, human health, and ecological processes and biodiversity. An additional component, 4) *education and outreach*, includes information exchange and outreach to stakeholders, policymakers, and the public, and social learning. Finally, a fifth component was included, 5) *interdisciplinary knowledge integration*, encompassing all components. This component is needed to facilitate and advance interdisciplinary collaboration and continuous knowledge exchange within and across the other components. The five components provided the basis for developing interdisciplinary science-themed working groups that would lay the foundation of the research framework going forward.

Day 2: Identification of science-themed topics to be discussed on day 3

Day-2 breakout group sessions (BGS) divided participants equitably into 10 diverse interdisciplinary groups based on their area of expertise, nationality, gender, and home organization. The first BGS task was to identify and prioritize the most urgent, high-level climate intervention science questions that require interdisciplinary collaborations. The second task was to describe how to best organize and coordinate activities within an overall framework structure that facilitates the needed collaborations. The goal of the day-2 BGS was to identify topics for the day-3 science-themed BGS that would engage interdisciplinary participation in each of these groups based on identified science questions and research needs.

One important topic among the day-2 BGS discussions was research governance and decision-making under uncertainty. The first science-themed day-3 BGS was therefore identified to cover societal decision-making including ethics and governance. This topic requires convergence of physical and social scientists as well as policy-makers and stakeholders to work toward science-based decision-making and governance. Of particular interest during the discussions was the development of realistic future scenarios relevant to policy-makers. A second breakout group was therefore identified to focus specifically on designing policy-relevant future scenarios to serve as input for Earth system models (ESM).

Other recommendations included the need to converge engineering and physical science, in particular, modeling approaches across scale and complexity, and observations, laboratory, and field experiments. The third science-themed breakout group topic was then identified to include all aspects of physical processes and engineering science. This topic requires the convergence of SRM and CDR experts on all levels, including observations and design of laboratory and field experiments. In particular, the need to identify opportunities and limitations of combined approaches, as well as the understanding of reaching and avoiding tipping points was noted. Advances in these areas will provide input for both future model development and societal decision-making, as well as for impact analysis and outreach activities.

Global risk and impacts to biological systems, such as effects on human health, water, food, air quality, ecological functions, and biodiversity in the context of climate intervention strategies, is a largely underresearched topic (Zarnetske et al. 2021), and constituted the fourth breakout group. This topic requires the convergence of climate scientists, including global and regional modelers, ecologists, and health experts. A subtopic emerged that includes targeted regional cross-cutting projects for addressing regional and local societal and ecological impacts and risks forming the fifth day-3 breakout group. This group requires convergence of physical and social scientists and regional stakeholders to identify what matters the most for specifically targeted regions in assessing combined approaches.

Day-2 BGS further highlighted the importance and challenges of interdisciplinary research and of communication and outreach efforts. A sixth day-3 breakout group was identified to tackle interdisciplinary communication and best practices for enhancing the usability of scientific products for decision-making. This group would also explore means to increase convergence and knowledge integration across disciplines and to identify how disparate disciplines approach and perform research. Finally, knowledge exchange beyond the sciences was identified as the topic for the seventh day-3 BGS. The full range of impacts of climate intervention strategies are not well known and limited education is leading to misinformation and skepticism among stakeholders and the public. Effective strategies for two-way exchange between researchers and stakeholders, policymakers, and the public will be critical to obtaining useful input for research design as well as to building public climate literacy.

The need for a comprehensive risk and benefit assessment, including the assessment of uncertainties, cuts across all topics. Uncertainty assessment needs to be ingrained in each of the science-theme breakout groups, and is also important for communication and education. Important uncertainties to consider include those in human behavior and decision-making (thereby affecting future scenarios), uncertainties in modeling, and uncertainties in impacts and adaptation efforts.

Day 3: Establishing science-themed working groups

Workshop day 3 explored details of the identified topics in BGS and discussions that will form a set of science-themed working groups for the CCIS framework. The tasks of the day-3 BGS were to identify the main science questions, list existing projects, and outline needed interdisciplinary collaborations within their theme.

Societal decision-making. This breakout group focused on developing frameworks for decision-making under risk, uncertainty, ignorance, and competing priorities and perspectives. One set of questions focused on the governance process itself, including mechanisms and coordination. Other questions centered around ethical issues, including who would participate in decision-making and the danger that the promise and hype of currently unproven and potentially risky interventions, e.g., SRM, could lead to reduced efforts in other, more proven, areas of intervention, e.g., mitigation. Key questions include how to achieve consensus if global approaches are to be applied, and what would happen if there is no con-

sensus, and who should decide? The need for holistic research to inform policy-makers was emphasized, starting from initial scenario design toward modeling, field studies, and impact assessment to identify the costs, benefits, and risks, and the role of a portfolio of climate intervention strategies. As research and potential implementation of climate interventions scale to the point where they may affect the climate and with that the general public, governance issues will become increasingly important. There is a need for communication with local stakeholders and vulnerable groups right from the start. The group acknowledged that existing work on societal decision-making is very decentralized and academic, often performed by individual researchers. However, a detailed assessment of research governance approaches to SRM has been performed by the National Academy of Science (National Academies of Sciences, Engineering, and Medicine 2021).

Building informed and combined scenarios. This breakout group addressed needs for building informed and combined scenarios and new interdisciplinary projects. The group recognized two purposes of scenario design: 1) exploring how the physical and natural system responds to single and combined climate intervention strategies, and 2) creating policy- and impact-relevant scenarios to directly inform stakeholders and policy-makers. Focus should be therefore given to both purposes, while exploring effects of a set of independent variables, which may include ecosystem and societal well-being metrics rather than global climate metrics. Reframing scenarios to more explicitly target informing decisions is necessary, with more specific emphasis on near-term and rapid-response scenarios. The process of developing policy and impact relevant scenarios requires convergence between policy—what decisions are there to be made and when and what information is needed to support those—and modeling using integrated assessment models (IAM) as well as ESM—what information can be provided and what are the opportunities, limitations, and risks of different climate intervention strategies. A science-themed working group needs the involvement of a wide range of disciplines to provide a scenario framework that can be used by the community for each of the scenario processes.

Physical process understanding. A thorough understanding of relevant physical processes is needed to ultimately allow accurate representation in ESM. This breakout group identified many existing projects mostly focusing on single intervention strategies. However, there is a need to explore a portfolio of combined climate intervention strategies including mitigation, SRM, and CDR. Many model improvements are needed to more accurately represent today's climate as well as proposed climate intervention approaches. Current model shortcomings include the inadequate representation of the carbon and nitrogen cycle, albedo, aerosol and cloud microphysical processes, permafrost, and representation of tipping points across different scales. A multimodel approach is needed to identify a possible range of outcomes. Accurately estimating uncertainties requires comparison to observations as well as laboratory studies. There is a need to understand the natural environment across multiple scales, ranging from fundamental microphysical and chemical processes to global-scale interactions. New convergence is further needed between physical science and engineering. The engineering community is indispensable to assess feasibility and uncertainties related to implementation, strategy development, and deployment needs, and needs to be engaged and connected with global modelers to identify reasonable options to develop the different climate intervention technologies.

Impacts of biological systems across scale. This breakout group focused on science questions around human health, water, food, air quality, ecological functions, and biodiversity. Main science questions were centered on how ecosystems and oceans will respond to

various climate intervention strategies. Little research has been done in this area and one major question is how to connect outcomes and identify metrics from currently existing large-scale climate model output toward small-scale ecological systems. Metrics like surface temperature or large-scale precipitation are often not sufficient, and new metrics have to be developed that will include relevant variables and scale. The need for analyzing the connection between ecosystem changes and economic risks and benefits has been pointed out, as well as changes in agriculture and health as the result of different climate intervention strategies. Effects and feedbacks of climate intervention, including SRM or CDR methods, on ecosystems and biodiversity are not included in current models or considerations for future scenarios. There is a need to explore existing observational networks to harness important data. Understanding of societal and ecosystem relevant impacts are important for scenario design and essential to future decision-making.

Targeted regional cross-cutting projects. The breakout group discussed a variety of different projects that cover ecologically and socially vulnerable communities and systems and how they respond to climate change, climate intervention, sea level rise, feedbacks, and tipping points. Two different aspects of targeted regional projects were discussed: 1) the regional effects of global intervention applications and 2) regional and local intervention applications and their effects, as well as a combination of both. Regions of special interest included the Arctic and Antarctica, developing countries that are already impacted by climate change, and ocean states. There is a need for the convergence of global and regional modelers to support those studies. Suggestions were made to learn from already-existing regional approaches. For example, weather modification has been researched for over 70 years and could be informative for marine cloud brightening approaches. Related questions on governance were discussed, including the need for a geopolitical analysis of how such an intervention would overlay on existing and future regional politics, including under accelerating climate change, for example, in connection with the Arctic Council work.

Coproduction and interdisciplinarity. The knowledge coproduction and interdisciplinary research breakout group focused on 1) what coproduction and interdisciplinarity looks like in practice, 2) challenges faced when practicing coproduction of knowledge, and 3) top priorities for designing models of coproduction and interdisciplinarity in this context. The group discussed how CCIS may learn from existing programs including IPCC or the Developing Country Impacts Modeling Analysis for SRM (DECIMALS). The meaning of coproduction was extensively debated, and the group concluded that, in the context of CCIS, it is important for interdisciplinarity and coproduction to be seen as the active creation of scientific products by different disciplines, rather than the mere transference of knowledge across the working groups and disciplines. Modeling and scenario development were identified as fruitful sites for coproduction, especially considering how the construction of models and scenarios are informed by particular goals and needs of the users. Regional impacts studies, identification of socioeconomic indices, and assessment of SRM scenarios were identified as potential activities to begin coproduction. Discussion included the need for multidisciplinary research teams to engage with stakeholders and policymakers, as well as the role early career scientists can play as integrators if they are embedded in disciplines other than their primary areas of expertise.

Knowledge exchange outside the sciences. The knowledge exchange outside the sciences group discussed communication, engagement, and education considerations regarding associated research communities, climate intervention stakeholders, and the public. The group identified that stakeholder and decision-maker needs would vary greatly and need

to be addressed at regional and local levels, in partnership with existing outreach efforts at that scale. This will be critical for areas especially vulnerable to climate change such as the Arctic. Embedded relationships leading to “trusted broker” status will become important and should be planned as part of larger communication plans. Communication plans should be created for each working group’s activities as well as for the larger CCIS program, at early stages of their formation. Public outreach and media awareness work can be done in partnership with larger existing climate change communication programs, and they can potentially collaborate to design tailored climate intervention outreach approaches, materials, and even continuing research on public perception. Pertaining to communication support of CCIS scientific staff, it was suggested that at least one communication specialist should be embedded within each working group to support interdisciplinary collaboration through common lexicon usage and facilitation of stakeholder needs assessments. The need for an online repository of CCIS research projects, products, and publications was identified as an important priority for the program.

Conclusions

In summary, the CCIS workshop made a significant contribution to refining a research framework for climate intervention strategies by assembling diverse experts and thought leaders. Next steps include 1) the further establishment of the CCIS science-themed working groups that will develop a research agenda with timelines and priorities, 2) creation of an online communication and research product exchange hub, and 3) continued workshops and webinar series that will bring researchers and stakeholders together in addressing the most urgent research questions. One of the most important challenges is to bring existing efforts in the community together, foster interdisciplinary interaction, and identify the most urgent research questions. Both benefits and risks of CCIS have to be explored holistically, requiring marginalized communities to have a voice and involving stakeholders starting during the design process. Clear relevance of such a community’s science- and technology-driven actions is reflected in recently issued priorities of the U.S. Government, such as Executive Order 13990 on Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis, Executive Order 14008 on Tackling the Climate Crisis at Home and Abroad, Reinstatement of the 2016 Presidential Memo on Climate Change and National Security, and the Launching of American Innovation Effort to Create Jobs and Tackle the Climate Crisis.

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