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Geoengineering

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Solar Geoengineering to Reduce Warming in the Earth System: The imperative for research

Insuring against catastrophic climate risks

Increased heat in the atmosphere is changing the earth system, with impacts that pose grave risks to communities, infrastructure, political systems and the ecosystems that sustain life. Larger more frequent wildfires are destroying communities in many parts of the west. Overwhelming storms are devastating our coastal communities, and extreme heat is threatening our heartland. Rapid and unpredictable changes threaten our way of life and critical parts of nature we rely on.

Efforts to reduce greenhouse gases may not be sufficient to address these risks, and adaptation measures may be insufficient for the scale and breadth of potential impacts. We may need options for reducing heat in the earth system to maintain stability and prevent catastrophic outcomes, allowing time to address underlying causes and transform our industries and practices.

The only known means of reducing warming in a timespan of years-to-decades is to increase the reflection of sunlight away from earth. – Ken Caldeira, Carnegie Institution for Science

The most promising approaches to reflecting sunlight (“solar climate intervention”) involve dispersing particles in the atmosphere to slightly increase its reflectivity: into the stratosphere, “stratospheric aerosol injection” or into low-lying ocean clouds, “marine cloud brightening”. Both approaches are based on phenomena observed in the earth system, and have been recommended by the National Academy of Sciences and US Global Change Research Program as priorities for research.¹

¹ *National Academy of Sciences 2015: [Climate Intervention: Reflecting Sunlight to Cool Earth](#)*

Kelly Wanser – written testimony (cont.)

The imperative for research

Today, we lack technical capabilities and scientific knowledge for any proposed approach to rapidly reducing heat in the earth system. It will likely take a decade of technology development, system modeling and process-level experimental research to determine if any options are feasible, and to understand them well enough to inform policy decisions. It may take another decade to scale any capabilities for deployment readiness. Work must commence soon to produce knowledge and options within a timeframe relevant to earth system risks (e.g. 10-20 years).

With damaging changes occurring around the world, it is likely, and may be inevitable, that others develop capabilities. With the potential to produce geographically variable climate outcomes, the U.S. has a security interest in understanding and controlling them.

The nature of the required research

Proposed interventions in the earth system require mission-driven interdisciplinary R&D efforts across multiple fields within geosciences, engineering, computing and operations, aligned with policy, social sciences and public engagement efforts. Even at small scales (by earth standards), technology challenges are substantial, and field research takes time.

A broad solar climate intervention research program should encompass major interdisciplinary efforts for each of the two recommended approaches, stratospheric aerosol injection and marine cloud brightening, and seed programs to explore other promising ideas.

Warming risks are a time-bound problem, and a research program should seek to provide a set of possible technology options, with understanding of their benefits and risks, within a timeframe relevant to decision making. For example, a 10-year program might be designed to deliver core technology and scientific understanding of viable options for reducing heat the atmosphere for policy-makers to assess possible development of capabilities for deployment.

Marine Cloud Brightening – dual purpose research with a well-defined pathway

Kelly Wanser – written testimony (cont.)

Marine cloud brightening is a promising entry point for solar climate research. It offers the potential for studying solutions ranging from local (coral reefs) to regional (dampening hurricanes) to global (warming), and research serves a dual purpose in accelerating understanding of the most significant uncertainty in understanding weather and climate— the effects of particles on clouds. Using natural materials (sea-salt) with short lived (2-3 days), localized effects, small-scale marine cloud brightening experiments can be highly controlled, and performed under existing regulatory and jurisdictional frameworks.

Early marine cloud brightening research is modeled on established designs for observations or other types of aerosol emissions into low-lying ocean clouds: ship-track studies and larger observational studies of pollution emissions such as the VOCALS study of industrial emissions emanating from Chile and ORACLES study of biomass emissions from Namibia. Marine cloud brightening researchers have published their experimental proposals, and engineering methods, and have only lacked funding and governance pathways to proceed.

Innovation is required; and presents an opportunity

Moving forward with research will help surface technical barriers and small-scale dynamics that are critical to assumptions about any forward possibilities, their costs, risks and policy dynamics. We need to know what particles we can generate, how they will behave, and what we can measure to input to models and forecasts of effects and risks.

Delivering aerosols with the right properties at sufficient scale is a hard engineering problem, and requires new technology for aerosol generation and innovative approaches to delivery. The first program to develop lab-scale technology, the marine cloud brightening project, took six years of work by a team of distinguished aerosol engineers and physicists to develop a nozzle to generate 80 nanometer particles at 1 trillion particles per second as required. Other materials proposed for aerosols in the stratosphere, such as calcium carbonate, may present a significantly harder engineering problem.

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Along with aerosol generation and delivery, measurement and detection is critical, and presents an opportunity to leverage disruptive new technologies for remote sensing. Ocean surface vehicles have the potential to make ocean surface, subsurface and lower atmosphere observations orders of magnitude less expensive than they are today, and support coverage of remote regions of the world, currently unobserved. Likewise, aerial unmanned vehicles carrying a new generation of miniaturized instruments and energy capabilities may replace airplanes for aerial atmospheric observations. And, a new generation of satellites may carry LIDAR and other sensitive instruments for detecting tiny particles from space. Companies like Saildrone, Spire Aerospace, Spaceflight and others may be partners in these efforts, working in tandem with existing platforms and programs.

To ensure effectiveness and manage risks, we will need to substantially improve our ability to understand and forecast weather and climate. We will need to use an array of approaches, from advanced data analysis via machine learning to advances in models and simulations. This will require increased computing capacity. Climate research is the largest consumer of computing resources on earth (only astrophysics has greater requirements). We will need to invest in the next generation of super-computing – exascale – and accelerate the adoption of cloud computing for dramatic increases in support for all types of data and analysis. Quantum and exascale computing start-ups, next-generation networking and chip companies and established players like IBM, Amazon Web Services, Google and others are potential partners in this innovation.

The current state of research

Today, the funding for research in the field is less than \$10M globally, concentrated in computer modeling and policy research. There are no significant experimental or technology R&D programs in the United States or any other country. In 2017, China announced a \$3m/year research program, currently comprised of modeling efforts. In recent international meetings in Berlin and Kenya, representatives from developing countries expressed interest in research on any solutions that might mitigate effects they are already experiencing, while communicating their lack of capabilities for doing so.

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The U.S. has the largest infrastructure for climate research in the world, encompassing observational platforms, computing, models, data and expertise. Solar climate engineering research efforts can build from these capabilities, but require new programs and resources for technology development, field trials, enhanced observation methods, and improved climate modeling.

Two major universities currently have programs in solar climate intervention: Harvard University, focused on stratospheric aerosols, and University of Washington, focused on marine cloud brightening and broader management of the atmosphere. These and other universities are likely to be important partners in any Federal research program.

The proposed path forward

Any capabilities for reducing heat in the atmosphere should ultimately be considered as part of a portfolio within an earth systems management framework that includes green-house gas removal, emissions reduction, land and ocean management, industrial practices, economic incentives, adaptation, and other activities with significant impact on the earth system.

Governance and regulatory efforts are needed that encourage and facilitate low-impact field research, while developing approaches for managing large-scale interventions. Oversight will help promote transparency, robust science and public engagement, and should be rapidly established.

Recognizing the importance of a carefully considered research agenda, a thoughtful and transparent approach to defining any program, such as a National Research Council study, may be a valuable initial step. This could be undertaken rapidly, in tandem with any smaller-scale grant programs and in advance of any larger national research program. With a clearly-defined research agenda, a similar process can be used establish a governance framework.

The solar geoengineering research community currently is currently comprised of a relatively small number of academic experts, concentrated in modeling, physics and social sciences. A process to define a program should expand the community to include engineering and systems,

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economics and risk and other disciplines, and include expertise in the management of long-term interdisciplinary science and innovation programs.

Initially, a grant-making program might be established to fund basic technology, science and modeling work in advance of a full program. To extend beyond modeling, such a program may require \$5-10m a year to enable early technology development and field work to inform models.

Solar geoengineering research is mission-driven and interdisciplinary, with basic science, applied science and national security characteristics. A full federal research program should be housed in an agency capable of all of these missions. With partnering roles for multiple agencies, universities, and private sector partners, a national laboratory structure may provide a useful point of integration for a larger, multi-faceted federal program.

Given the magnitude and urgency of the problem, and our current lack of knowledge and capabilities, defining a research agenda and developing funding pathways for research, may be important and beneficial investments for the country, of profound benefit to our communities and constituents.