To: Honorable Mayor and Members of the City Council

From: Jennifer Ott, City Manager

Date: March 24, 2024

Supplemental Memo regarding Item 7-B: Recommendation to Consider Granting Landlord Consent for Small-Scale Atmospheric Sea Salt Process Studies on the U.S.S. Hornet

SUPPLEMENTAL INFORMATION

This memo is being provided to supplement the staff report already published for the June 4, 2024 City Council meeting.

In addition to the information provided in the Staff report, Staff sought the outside expertise of Professor James W. Hurrell, of the Department of Atmospheric Science at Colorado State University on the following issues:

- An evaluation of potential impacts on the climate; and
- A summary of the ethical aspects of this type of climate intervention work.

Professor Hurrell's letter to the City is attached and includes his independent assessment of the potential for the activity - at the current scale - to have an impact on local weather patterns as well as his commentary on the larger ethical questions surrounding climate intervention research and experimentation such as this.

Respectfully submitted,

Abigail Thorne-Lyman, Base Reuse & Economic Development Director

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Alameda City Council May 24, 2024

It is my pleasure to write this letter in support of your dialogue regarding the Coastal Atmospheric Aerosol Research and Engagement (CAARE) Facility on the flight deck of the USS Hornet. I was asked to do so by Alesia Strauch, the Base Reuse Manager for the City of Alameda, CA. The views expressed below are solely mine and do not represent the views of Colorado State University or any other organization with which I am affiliated.

Professional Background

I am a Professor of Atmospheric Science and the Scott Presidential Chair of Environmental Science and Engineering at Colorado State University (CSU) in Fort Collins, CO. I received a PhD in atmospheric science from Purdue University in 1990, after which I joined the staff at the National Center for Atmospheric Research (NCAR) in Boulder, CO. In 2003 I was promoted to a Senior Scientist at NCAR – the equivalent of a full Professor at a university. I went on to become the Director of the Climate and Global Dynamics Laboratory at NCAR, the Director of the NCAR Earth System Laboratory, and finally the Director of NCAR. After 28 years at NCAR, I accepted a Presidential Chair position at CSU. Faculty named to Presidential Chair positions are selected for their key roles in advancing research and educational programs.

My personal research centers on empirical and modeling studies and diagnostic analyses to better understand climate variability, climate change and Earth system predictability. I have authored or co-authored more than 160 peer-reviewed journal articles, book chapters, and science planning documents, and I have given more than 250 professional invited and keynote talks. I have led numerous national and international science-planning efforts related to climate, and I have served the U.S. National Academies of Sciences, Engineering and Medicine (NASEM) extensively. I am currently a member of the NASEM Advisory Panel for the Division of Earth and Life Sciences, and I recently chaired NASEM workshops on Earth System Predictability Research and Climate Intervention in an Earth System Science Framework. I have served as the President of the Atmospheric Science Section of the American Geophysical Union (AGU) and as a Councilor of the American Meteorological Society (AMS), among many other roles in professional societies. I have also provided briefings and testimonies to both the U.S. Senate and the House of Representatives on climate science.

Affiliation with the University of Washington and the Marine Cloud Brightening Program (MCBP)

I am familiar with CAARE facility and its scientific objectives. I also know and have interacted professionally with several members of the MCBP team, including its Director (Sarah Doherty) and one of its lead researchers, Professor Robert Wood. I have published one paper with Dr. Doherty, but I have not published with Prof. Wood or any other MCBP members. I have no direct involvement with the CAARE facility, and I am not actively collaborating with any members of the MCBP team on research. I do serve

as one of six members of an external scientific review board of the MCBP, and I recently served on an external review panel for the Department of Atmospheric Science at the University of Washington.

Climate Intervention

In recent years I have become interested in the study of climate intervention. Climate Intervention (CI) refers to the possible deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change. CI includes both large-scale carbon dioxide removal (CDR) and sequestration technologies as well as solar radiation modification (SRM). CDR approaches are aimed at intervening in the Earth's carbon cycle to remove carbon dioxide from the atmosphere. Recent scientific assessments indicate that holding climate warming to below 2.0°C is implausible without significant, large-scale deployment of CDR. However, there are substantial environmental, technical, and cost challenges in using CDR at the scale needed to significantly halt or reduce global warming. These challenges, and the slow response of the climate system, make it unlikely that CDR could be implemented rapidly enough or at sufficient scale to avoid potentially dangerous levels of climate warming in the coming decades.

As a complement to long-term emissions reductions, adaptation, and CDR, SRM is being considered as an approach to rapidly counter near-term climate warming. SRM techniques are aimed at directly influencing Earth's radiation budget – such as by reflecting a small percentage of incoming solar radiation back to space or reducing the amount of infrared (longwave) radiation retained by Earth. Earth system and climate model simulations consistently show that a well-designed SRM strategy could offset many of the adverse effects of increasing greenhouse gas concentrations on global and regional climate, including reduced extreme heat and rainfall events and reduced loss of land ice and sea ice. However, since SRM does not reduce greenhouse gas emissions, the root cause of climate change, any potential SRM deployment would, at best, be an approach that could operate in parallel with ambitious mitigation measures.

National and International Calls for Research

The importance of research into CI as a tool to potentially reduce some of the growing impacts of climate change is now embraced by many professional organizations. The AMS "recommends an accelerated and robust climate intervention research program … to inform public policies" on climate, while a recent NASEM study concludes "the U.S. federal government should establish—in coordination with other countries—a transdisciplinary [SRM] research program" as part of an overall U.S. effort to respond to the risks posed by climate change. The international research community is also emphasizing the importance of CI research. The World Climate Research Programme (WCRP) recently launched an ambitious effort into CDR and SRM as part of its overall portfolio to rapidly advance the science and institutional frameworks needed to better manage climate risk and meet society's urgent need for robust and actionable climate information. Similarly, the United Nations Environment Programme (UNEP) released a report last year advocating for research into SRM given the possibility that it may be able to reduce climate damage and alleviate climate change impacts in the coming decades, while longer-term mitigation , adaptation and CDR efforts are accelerated.

Marine Cloud Brightening and the CAARE Facility

There are several SRM approaches that researchers are considering, but one of the most promising is marine cloud brightening (MCB). MCB is based on the idea of cooling Earth by increasing the reflectivity of low clouds over certain parts of the ocean. The clouds expected to be most susceptible to brightening are clean

stratocumulus clouds, which cover about 20% of Earth's oceans. As an analogue, under the right conditions, the aerosol pollution from ships leaves behind a "ship track" caused by the emitted aerosols (tiny solid or liquid particles suspended in the atmosphere) acting as additional cloud condensation nuclei. For the same total cloud water content, more droplets (from more nuclei) result in a higher surface area and a more reflective cloud. Yet, despite decades of research on aerosol and marine cloud interactions, including ship track studies, many uncertainties remain regarding the efficacy of MCB strategies. These uncertainties fundamentally center around our limited understanding of aerosol-cloud interactions, how these interactions affect a cloud's total water content and lifespan, and how aerosol-cloud interactions change under different meteorological conditions.

Importantly, a better understanding of aerosol and marine cloud interactions will not only help to determine whether MCB is a viable strategy to reliably and predictability slow future climate warming, but it will advance our basic understanding of the climate system and how it responds to changes in background aerosol conditions. Presently, climate forcing from anthropogenic aerosol emissions via aerosol-cloud interactions is estimated to be between 10% and 40% of anthropogenic forcing from greenhouse gases (GHG) and of opposite sign, thus providing an important but highly uncertain offset to GHG climate warming. Better quantifying cloud responses to aerosols is a "grand challenge" in climate science, and it is critical to predict future rates of planetary warming more accurately as greenhouse gas concentrations increase.

It is important to understand this "dual-purpose" aspect of MCB research. The CAARE facility on the flight deck of the USS Hornet will advance fundamental climate science through better observational constraints on aerosol-cloud interactions, even if MCB is determined to be unviable as an SRM strategy. Using an experimental aerosol-generation system called CARI (Cloud Aerosol Research Instrument), researchers will be able to use a consistent and well-characterized aerosol source to build statistical relationships between aerosol perturbations and marine cloud responses under different meteorological conditions. This, in and of itself, will be an important contribution to climate science, and the data produced by CAARE will be invaluable to climate researchers across the world.

Potential Impact on Local Weather and Climate

The study of SRM, including MCB, is heavily reliant on "what if" scenarios using climate models, data from laboratory-based studies, and data from natural and anthropogenic analogues of proposed SRM approaches. However, the national and international calls for research mentioned above also acknowledge that it will likely be necessary to conduct deliberate outdoor experiments to advance the study of certain core atmospheric processes that are critical for understanding SRM. Experiments that involve releasing substances into the atmosphere should be considered only when they can provide critical observations not already available and not likely to become available through laboratory studies, modeling, and experiments of opportunity (e.g., ship tracks). Moreover, there is a consensus that the amount of material emitted per experiment should be significantly less than other commonly accepted anthropogenic emissions to the atmosphere (e.g., from fireworks or commercial ships) with no ability to significantly alter climate or weather patterns.

It is my professional opinion that the small-scale and limited-duration release studies proposed for research at the CAARE facility meet these criteria. Specifically, the planned injections of sea salt aerosols using CARI for less than 30 minutes and no more than three runs per day, for a maximum of three or four days per week, are too small in scale to produce detectable effects on the local weather or climate. Reductions

in air polluting aerosols due to more stringent air quality standards in California are much larger in magnitude by comparison. The planned injections at CAARE would, however, produce high-quality and unique data that could be used by scientists worldwide to advance our understanding of marine cloud responses to aerosol perturbations under a range of meteorological conditions.

Ethical Considerations

Despite increasing calls for research into proposed SRM techniques, some scholars have argued against further research on the grounds that SRM may distract from the critical work of mitigation, slowing the pace of emissions reductions and the transition away from fossil fuels. The idea that SRM might undermine mitigation efforts is commonly known as the "moral hazard" argument. Whether and to what extent SRM research poses a moral hazard is difficult to assess. This is because a precise empirical measure of mitigation deterrence would require comparison to a counterfactual baseline. Other social science research has suggested the opposite: that individuals may increase their commitment to mitigation when the prospect of SRM is introduced. Regardless of whether SRM is likely to deter mitigation, the growing consensus in the climate research community is that SRM should be explored as a possible part of a broader set of strategies for addressing global climate change.

Other ethical issues include concerns about the environmental risks and impacts of SRM research; the potential that investment of time, effort, and financial resources in SRM research will create momentum in favor of SRM, facilitating a "slippery slope" toward deployment; and concerns that research will prematurely close consideration of a full range of options and instead generate path dependence and "sociotechnical lock-in" on a particular approach. A decision to deploy SRM to intentionally alter global climate would raise other ethical issues. For example, would such a decision be morally acceptable and, if so, who would determine the temperature at which the global "thermostat" would be set? Some scholars argue that SRM should be undertaken if the benefits significantly exceed the costs or if SRM would be expected to reduce the net harm associated with global climate change. However, others argue that it is not just aggregate benefits and costs that matter, but rather the distribution of benefits and costs (e.g., SRM might not be justified if the net benefits impose significant costs on some or if the costs are borne primarily by those who are already disadvantaged). From an ethical perspective, additional research is needed to identify the kinds of risks, harms, and benefits that matter most in relation to SRM, and how best to consider and evaluate these in research on SRM's technical and social feasibility.

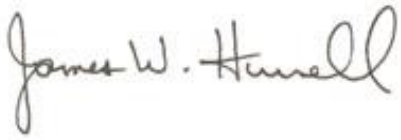
Closing Comments

In my view, the CAARE facility is a platform for valid and critically important scientific research. It has the potential to reduce one of the largest uncertainties in climate science: aerosol-cloud interactions and their impact on Earth's radiative balance. The research conducted at CAARE also has the potential to significantly improve climate models, through a better representation of aerosols and how they interact with the environment under a range of meteorological conditions. Such models are used to predict the future evolution of climate with many applications of clear relevance for society. Observational research into cloud-aerosol interactions is also required to assess the efficacy and viability of MCB as a potential tool in our collective toolbox to combat climate change. Ultimately, the data gathered through CAARE may prove that MCB should not be pursued. In the absence of such research, additional risks may arise, such as the possibility of unilateral MCB deployment by an individual country, a collection of parties, or an independent actor in the absence of sound scientific information.

Research on SRM, including MCB, is a growing part of mainstream climate science. As such, it must be carried out transparently and in a scientifically sound manner by highly qualified research teams. This includes deliberate, small-scale outdoor experiments that will advance understanding of core atmospheric processes central not only to SRM but also to climate science in general. The MCBT plans are to use the CAARE facility in exactly this way, and the data it will produce will be invaluable to researchers across the globe.

Please contact me if I can be of further assistance.

Sincerely,



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