AMS Community Synthesis on Climate Change Solutions

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Policy Program Study
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William Hooke
Paul A. T. Higgins
Keith Seitter

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The American Meteorological Society (AMS) is a scientific and professional society of roughly 12,000 members from the United States and over 100 foreign countries.

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Cover image photos:

Foreword

This AMS Policy Program study provides a summary of input from the AMS community on climate change solutions. It was carried out in an accelerated time frame in response to a request from the National Science Foundation for rapid community input. NSF was particularly interested in ideas from the AMS community on ways to address climate change that might be implemented and show progress relatively quickly (i.e., a 2–3-yr time frame), while having positive impacts that continued for much longer time frames. This work was supported by a small grant (NSF 2131848, awarded 10 May 2021), and NSF requested that the entire project be completed in just a few weeks.

As noted in this report, the process included input from many members of the AMS community. In that sense, this report is a compilation of the input of a wide range of individuals from the weather, water, and climate enterprise. The investigators acknowledge with deep gratitude these thoughtful and constructive suggestions for action and hope we have done justice to the contributors in reporting their comments here. We also wish to thank AMS Policy Program staff members Andy Miller, Katie Sullivan, Emma Tipton, and Lauren White for helpful edits of the final document.

William Hooke, Principal Investigator

Paul Higgins, Co-Principal Investigator

Keith Seitter, Co-Principal Investigator

Executive Summary

Scientific discovery and innovation are central to the advancement of humanity. This is even more true now as the scale of human activities have grown to be large relative to the planet and the life-support services the Earth system provides.

After decades of intensive scientific research, a great deal is understood about the climate system and the impact people are having on it. Scientific evidence relating to climate change spans dozens of fields of study and includes work from tens of thousands of individual scientists. The evidence has been rigorously assessed and independently corroborated hundreds of times. Many climate change solutions are already well understood, fully developed, and available for implementation. Nevertheless, humanity has been largely ineffective in addressing climate change.

This AMS Policy Program study provides a summary of input from the AMS community on climate change solutions. It was carried out in an accelerated time frame in response to a request from the National Science Foundation for rapid community input. Through these community discussions, this study identifies six key principles and seven solution areas for emphasis:

Principles:

- Progress is needed in *advancing* knowledge and understanding and *applying* knowledge with respect to mitigation (i.e., emissions reduction) and in adaptation (dealing with climate change impacts).
- Broad participation, involving all sectors of society and the vast majority of people, is necessary.
- Inclusion, equity, and justice are critical (these require unity, fairness, trust, and shared visions of success).
- Objective measures of progress are essential.
- Climate change is simultaneously a critical stand-alone problem, inextricably linked with a raft of other societal issues, and symptomatic of larger challenges and opportunities facing humanity.
- Efforts ranging from individual to global scales are needed to address climate change. These efforts must account for what contributions are possible at each particular scale.

Solution areas:

1. Develop a comprehensive plan for observations and monitoring
2. Enable broadly distributed efforts and public participation (i.e., place-based approaches)

3. Tailor scientific assessments for decision-making
4. Modernize climate science (i.e., upgrade computing infrastructure, workforce training, scientific practices, and rewards and incentives in research)
5. Develop the future workforce (education: informal/K–12, undergraduate/graduate, continuous education)
6. Develop effective strategies for public understanding and engagement for all audiences
7. Enable and strengthen partnerships

Human-caused climate change is extremely dangerous to all people everywhere. Addressing climate change effectively is challenging for a variety of reasons, including that it is embedded within additional problems and symptomatic of larger challenges facing humanity. However, success in addressing climate change is possible and represents an opportunity for humanity to chart a path forward on a much wider range of challenges and opportunities. Therefore, addressing climate change has the potential to usher in a more prosperous future—one that is more secure, inclusive, equitable, and just and that enables people and all life to thrive.

Background and context

The people of the United States are increasingly turning serious attention to the importance of innovation to America's future. If a country representing only 4% of the world's population aspires to be Madeleine Albright's "indispensable nation," it must not only embody the noblest ideals but also be the most innovative.

Innovation is more than the advance of science and knowledge; it extends to harnessing such advance to the benefit of life. With that in mind, a national conversation is underway on the future of the National Science Foundation (NSF), among other agencies, that has the potential to broaden the NSF portfolio to include more emphasis on application of known science and on technology.

As NSF contemplates such future possibilities, it has asked a handful of science and professional societies to suggest initiatives that would substantially accelerate national and world progress toward coping with climate change—initiatives that, though longer term, would begin to make noticeable progress in as little as 2–3 years. The details are captured in the NSF 16 April charge (Appendix 1). Societies were asked to submit proposals, carry out the work, and report back by 1 June 2021. NSF outreach included the American Meteorological Society (AMS).

The AMS process

AMS membership includes some 12,000 professionals, spanning meteorology, climatology, hydrology, oceanography, and space weather; the full range of the social sciences; and related technologies, including instrumentation, observing platforms, and all aspects of IT. AMS is both a scientific and a professional society. Its membership includes expert practitioners as well as scientists: service providers, operational forecasters, broadcast meteorologists, consulting meteorologists and climatologists, K–12 teachers, social scientists, and public-, private-, and academic-sector institutions. Through these members and local chapters, AMS has a visible and respected place-based footprint nationwide. Membership, though concentrated in the Americas, is truly global.

These broad and diverse elements, spanning every aspect of basic science and application for both public good and commercial profit, made the task a good fit. In response to the NSF request, AMS proposed and received one such small grant, which was awarded on 10 May 2021.

AMS then sought input and ideas from its membership. Some were provided through small focus group sessions. These involved members representative of the diverse professional perspectives described above, as well as the gender-, racial-, ethnic-, and other dimensions characterizing the diversity of the larger society. Representation included early and mid-career professionals in addition to those later in their careers. The focus groups included members from the private sector, academia, and government, including some who worked in the energy sector, broadcast meteorologists, teachers, and a variety of researchers. More senior participants include those who are either currently in or had recently held leadership positions in all three sectors, some at the highest levels. The inputs are provided in Appendix 2. In addition, AMS created a dedicated web portal to allow written input from individuals and requested and encouraged input from the full membership, to the extent the compressed time frame allowed (Appendix 3). The investigators have then provided this synthesis of the inputs.

Despite the tight time frame for this project, the investigators feel that they were able to organize an adequate number of focus group sessions and achieve a sufficient diversity of participants. Reviewing the notes from Appendices 2 and 3 revealed a number of common themes, stated in different ways.

The AMS synthesis: A basket of initiatives

A set of principles emerged organically during and from the AMS conversations:

- Progress is needed in two overlapping directions: *advancing* knowledge and understanding and *improving* application of knowledge with respect to mitigation (i.e., emissions reduction) and in adaptation (dealing with climate change impacts).
- Broad participation, involving all sectors of society and the vast majority of people, is necessary.
- Inclusion, equity, and justice are critical (these in turn require unity, fairness, trust, and shared visions of success).
- Objective measures of progress are essential.
- Climate change is simultaneously a critical stand-alone problem, inextricably linked with a raft of other societal issues, and symptomatic of larger challenges and opportunities facing humanity.
- Efforts ranging from individual to global scales are all needed to address climate change. Effectiveness depends on accounting for what contributions are effective at each particular scale (e.g., what individuals can contribute when acting alone or within their communities and what requires national approaches or global cooperation).

Participants brought up the opportunity and need for initiatives in seven broad areas that advance scientific knowledge and understanding itself, society's ability to use scientific information, or both.

1. Develop a comprehensive plan for observations and monitoring

After decades of intensive research and monitoring, climate sciences have revealed an enormous amount about Earth's climate system, the impact people are having on it, and implications for humanity and all life. Nevertheless, the observations and monitoring available are insufficient for addressing all dimensions of climate change risks, opportunities, and solutions. Therefore, we need a comprehensive plan to identify, obtain, maintain, and evolve the observations and monitoring systems that are necessary for understanding all dimensions of climate change and for enabling climate change solutions.

First steps: Convene scientists, practitioners, policy experts, and leaders from the private sector to develop a more robust strategic plan for observations and monitoring. Such a plan would recognize that observations and monitoring have multiple objectives, needs, and constraints. These include the need for spatial and temporal coverage; accuracy, and sustained calibration needed to detect small but persistent climate trends in the presence of large short-term variability in a variable Earth system; to reveal consequences; to enable solutions; and to monitor progress. The planning should include collaborators from other federal agencies and local and state governments. In addition to developing a comprehensive strategy, the plan might also provide priority ranking for observing instrumentation, platforms, and networks, and consider the needs for research and modeling to advance a predictive understanding of climate change and to enable solutions.

2. Enable broadly distributed efforts and public participation (i.e., place-based approaches)

The climate change challenge is both global (requiring both national and internationally coordinated responses) and local. Impacts will occur everywhere and at least some solutions can originate from anywhere. Furthermore, work on climate solutions is already underway and are a priority for many people, communities, and countries. However, if resources were made more readily available, more progress would be possible.

First steps: Enable multiple pilot projects distributed throughout the country designed to address a wide range of climate change–related challenges. These would be broadly dispersed and focused on local community efforts. A combination of peer-reviewed articles and new forms of communication may be best suited to ensure quick societal uptake. NSF could provide funding for such projects, as well as infrastructure, mechanisms, and incentives for the early detection of success and failure as well as the widespread and rapid sharing of lessons learned, particularly with respect to solutions that can be replicated or applied at scale.

3. Tailor scientific assessments for decision-making (e.g., for the energy sector and infrastructure)

Current scientific assessments generally take knowledge, understanding, and advances in science as the starting point that considers implications for society. This process needs to be maintained but complemented with assessments that focus, from the start, on key decisions relating to social and economic well-being. What are the key climate-sensitive decisions? What actionable information is already available? Where are better understanding and greater knowledge needed? How might these be acquired? How might existing knowledge be applied most effectively?

Tailored scientific assessments would focus on key decisions, in particular social or economic sectors (e.g., agriculture, energy, transportation, water resource management, public health, disaster preparedness and response, etc.) or for cross-cutting societal needs (e.g., infrastructure investments and for underserved communities).

In the discussion groups, an emphasis emerged on three topics: on the potential for tailored assessments to meet the future needs of the energy sector, infrastructure investments, and the needs of historically underserved communities. Each of these areas appear to be among those of the highest priority.

In the energy sector, policy makers need to better recognize that increasing the contribution of solar and wind energy is coupled with a greater dependence on weather and weather variability. Additional research is needed on how to build a network of renewable sources designed from the outset in order to provide a large fraction of the required energy reliably. For illustration, the current grid is inadequate to address the transmission requirements for carbon-free energy. A tailored assessment of science for the future energy sector would help identify the research and innovation needed over the next decade and help ensure more efficient investments in energy infrastructure.

The need for investments in infrastructure more generally is widely recognized, including the modernization of the nation’s transportation (roads, bridges, rail lines, airports, and ports) in addition to the electrical grid, and much more. Such investments are weather sensitive and will remain in place for decades. Therefore, infrastructure investment is both sensitive to climate change and a key component of our response.

Two factors of this much needed investment are often overlooked. First, the return-on-investment (ROI) of many of the individual projects depends on how effectively and accurately the designers and builders anticipate and accommodate the influence of climate change on the performance of the new infrastructure over its lifetime. Second, U.S. domestic infrastructure is not merely a sunk cost—a bill that must grudgingly be paid. It is not merely a domestic jobs program either. It is both of these things, but it is also “a demonstrator on the showroom floor.” To the extent America succeeds in modernizing its own infrastructure, it provides a powerful incentive for other countries to imitate the U.S. model, and draw on America's capabilities, across every aspect of the private sector. And that global market is huge. The World Economic Forum estimates the world will invest more than 25 trillion dollars in water infrastructure over the next 20 years. The International Energy Agency estimates the world will invest 55 trillion dollars in energy infrastructure over the same period. The UN Food and Agricultural Organization foresees a corresponding investment of 15 trillion dollars in agricultural infrastructure.

The benefit of scientific information will be greatest if shared equitably among all people. Historically, access to needed information and services among different people and groups has been profoundly unequal. Furthermore, vulnerability to climate change, while a serious concern for all people, is particularly urgent for low-income families and Black people, Indigenous communities, and people of color (BIPoC). As a result, there is a great need and opportunity for the assessment of information needs of historically underserved communities.

First steps: NSF could, in partnership with other agencies, build on and enable tailored scientific assessments to support decision-making. This could begin with a number of pilot programs that focus on key economic sectors or cross cutting initiatives that are then rapidly scaled up. Note that the American Meteorological Society, in partnership with NOAAs Climate Program Office, is in the process of one such pilot study focused on coastal resilience and intends to conduct a second pilot project over the next few months that will likely focus on the energy system. These initial pilots could help inform more comprehensive and wide-ranging efforts. AMS will strive to disseminate lessons learned and seek to support any such efforts.

4. Modernize climate science (i.e., upgrade computing infrastructure, workforce training, scientific practices, and rewards and incentives in research)

The problems of *tomorrow* cannot be solved with *yesterday's* tools alone. Tomorrow's ever-increasing demands will likely need both more effective use of the tools we have along with those only now becoming available and with novel capabilities in prospect that as yet remain undeveloped.

Much of the input our members provided addressed this point, either explicitly or implicitly. They included advice that scientists of the future should be using state of the art programming languages and methods to master exascale and even quantum computing platforms, and that much more support is needed for data analytics and artificial intelligence. They brought up funding needs for novel measurements of specific parameters, platforms, and networks for making and assimilating such observations with requisite global coverage and temporal and spatial resolution, for extended periods. They included requests for the formal study of science *application*. They included requests for more social science to unpack keys to develop an innovative society and culture, a society enjoying inclusion and equity with respect to both knowledge production and access to its benefits. Similarly, institutions will need to evolve with respect to function and the ways they collaborate. For example, universities are often structured around specific disciplinary research and incentive structures that fail to reward convergent research appropriately.

Additionally, we need capacity to more fully disseminate data and make it more accessible across the whole of society. We need to enable distributed contributions to science (i.e., democratize the practice of science, open the practice of science to all people everywhere.

There is an opportunity to prioritize research on industrial ecology, cradle-to-cradle manufacturing approaches, and the application of scientific knowledge.

First steps: Reexamine rewards and incentives to better encourage and recognize cross-disciplinary research, co-production of knowledge, applications, and public engagement. Devise approaches to better enable and fully support convergent research. Provide funding to update computing infrastructure to match state-of-the-art efforts in computer sciences.

5. Develop the future workforce (education: informal/K–12, undergraduate/graduate, continuous education)

The U.S. educational system must evolve in order to produce the workforce we need to maintain global leadership, to meet the general population needs, and participate in meaningful and productive ways with our government, industry, and educational institutions. AMS members have emphasized appreciation for our national scientific and technical capability and recognition of the need to develop a new shared vision and sense of purpose. Any society, but especially a democratic society, needs highly effective innovation to sustain itself. Therefore, we need to:

- Make continuous career-long training and retraining a way of life.
- Strengthen STEM education, and in particular ensure that education in the geosciences is an essential and not incidental part of that education. Partner with the private sector to build on current efforts and initiate new starts on identifying gaps in educational preparation of students for tomorrow's jobs.
- Foster public capacity, across all elements of our society for critical thinking, embracing fairness, respect, equity, diversity, and inclusion. Create a society that is more open to innovation (S&T advance *plus* implementation), a society comfortable with continuous change, and a

society and culture that learns from mistakes versus endures repetitive loss.

- STEM education alone cannot accomplish this vision. It needs balanced attention to humanities, ethics, and philosophy.

First steps: Historically in the United States, public education has been the province of state and local governments and could remain so. But NSF could convene a national dialog: (phase 1) convene other stakeholders in STEM education (including NASA, NOAA, USGS, the Department of Energy, the Department of Education, and the National Science Teachers Association, among others) to formulate plans; (phase 2) reach out to state and local governments to initiate a richer and sustained conversation on these topics within the first year.

6. Develop effective strategies for public understanding and engagement for all audiences

Climate solutions become possible when scientific information is available to and actionable for all people everywhere.

Early on in the COVID pandemic, The Johns Hopkins University constructed a web-based capability for monitoring new cases and morbidities. Though not official and both flawed and incomplete, it was widely respected and performed a useful function of keeping millions of concerned people engaged and aware of important trends.

Something similar could be done for all aspects of climate change, including measures of human-caused disturbance of the climate system (e.g., global CO_2 levels), key Earth system functions (e.g., local sources and sinks), climate change responses and impacts, and societal efforts to address climate change. Such scorekeeping would, ideally, inform and engage the public; foster calls and ideas for improving monitoring efforts; enable solutions; and hold nations accountable. It would also foster development and tracking of other indices: other greenhouse gases, landscape changes; ocean and atmospheric temperatures, and much, much more.

First steps: NSF could fund a handful of distributed efforts to identify and create exploratory public communication projects that seek to inform and engage broad audiences. This could involve many pilot projects or promote collaborative efforts that bring together physical, natural, and social scientists, communication experts (including broadcast meteorologists), and teachers to identify communication needs and opportunities (or both).

7. Enable and strengthen partnerships

Collaboration and partnerships are needed throughout society among scientists, decision-makers, information users, and the public; across scientific disciplines; among public, private, academic, and NGO communities; in support of inclusion, equity, and justice; and for the purposes of co-production and co-application of knowledge.

This effort is one small illustration of this key need. At this point, it would be natural for NSF to accept the reports from the handful of science societies involved in this first, exploratory outreach, thank us for the efforts, and then switch to an internal process to develop a program. But we urge NSF to consider the possibility of continuing to involve all of us, and others, in this next step of consolidation and synthesis, and even as we do so, continue to receive input from our respective communities going forward. Many of the individuals involved in the focus groups we held, as well as several of those who submitted input through the online portal AMS created, indicated that they would be happy to participate in follow-on activities. In a first-step effort to address this concern, we could imagine a sequence of workshops involving several societies working with NSF to build a more complete roadmap for next steps.

More generally, this engagement might reach out to communities on the front line of climate change impacts and include experts, who, historically, have not worked on NSF grants. The importance of the breaking down of silos throughout the research enterprise was a recurring theme during the input process.

Related to the need for breaking down silos, a theme emerging from the AMS feedback is that NSF and other funding agencies need to take steps to encourage would-be proposers and institutions for convergent research and broaden the pool of participants in scientific research. As an example, NSF requirements to meet certain criteria to ensure such convergence (fully accredited expertise in different fields, etc.) may create barriers to entry, thus diminishing inclusiveness and inhibiting innovation. Innovative convergent research (indeed all research) can benefit from greater participation among non-traditional groups. This might be done now in the spirit of the grants that have been made to individual Americans in dire need occasioned by the pandemic. Exploration of mechanisms that can provide flexibility in funding to agency program managers could prove useful.

Conclusion

In its charge (Appendix 1 below), NSF identifies climate change as "the most pressing challenge facing society today." That challenge is daunting in and of itself, but it is made even more so by the myriad ways climate change is embedded within and threaded through additional problems and even larger challenges facing humanity. That said, the prospects for success in addressing climate change are reasonable, promising even, precisely because NSF and other federal agencies have sustained high levels of funding for the relevant geosciences and related social sciences for several decades. It is that past sustained support that allows the current NSF quick-response request to yield useful results. The inputs gathered here, when synthesized with the complementary inputs from other geosciences societies, have revealed a range of possible ways for humanity to usher in a more prosperous future—one that is more secure, inclusive, equitable, and just, and one that enables people and all life to thrive.

Appendix 1: The NSF's CHARGE for Earth-to-Economy Climate-Change Solutions

Date: April 16, 2021

Preamble: Climate change is the most pressing challenge facing society today. Geoscientists can play an important leadership role in ideating and designing use-inspired solutions that preserve the environment through engagement with stakeholders across the realm of industry, government, and academia. We now have an opportunity to translate advances in science, technology, and engineering to society and the economy to create a thriving earth enterprise that culminates in actions and programs focused on identifying and implementing practicable climate change solutions.

The charge is to crowdsource, through the communities you represent, ideas, focus areas, and research and development roadmaps where the most impacts can be made in the shortest amount of time (2 to 3 years) for creating a thriving planet in a warming world where change, sometimes dramatic, is the norm not the exception. A critical element of this charge is development of conversations on the value of translation of research results to society and the economy because this expedites how we move forward in a changing climate while still protecting the environment and transforming the well-being and safety of people and driving prosperity, health, and national security.

Additional Consideration: A serious issue facing the geosciences academic community is the relatively low understanding of translational and use-inspired research and what that means and how it is done. We need to mobilize the geoscience academic community to take the scientific outcomes of foundational research on climate change to the next level to help inform adaptation, and mitigation strategies using cutting-edge technology and engineering. As part of your charge, NSF is looking for ideas and activities/programs for how this limitation can be overcome, especially in work focused on the climate sector and ideas on how our communities and institutions can incentivize this behavior, accelerating the development of an entrepreneurial mindset so geoscience is positioned to benefit from potential future funding opportunities.

Charge:

Mobilize and energize your community(ies): Use whatever tools/utilities/ input gathering process you feel will be most effective to collect the required information in the time allotted but ensuring significant early career and underrepresented group input. The report can be in whatever format you wish, but prefer it be direct and to the point with no superfluous text.

Roadmap/Innovation Report deadline: June 1

Resources: NSF will provide $50k award to your geoscience organization to generate input, as you feel you can most effectively collect the required information**.**

Issues to be addressed:

1. Identify the biggest, more important interdisciplinary/convergent challenges in climate change that can be addressed in the next 2 to 3 years and a list of corresponding stakeholders, potential partners, and high impact deliverables to society and the economy. Do not limit your ideas to a single theme or topic. Longer terms topics will be considered but should include what critical and impactful products/concepts can be delivered in the 2–3-year time frame.

2. Create 2-yr and 3-yr roadmaps to address the identified challenges and provide solutions, keyed to proposed milestones and the timing of delivery of high impacts results and technology. Indicate partnerships required to deliver on the promise.

3. Provide ideas on the creation of an aggressive outreach/communications plan to inform the public and decision makers on the critical importance of geoscience to providing solutions, tools, utilities, and technologies to help overcome/address identified challenges/problems in climate change.

4. Identify information, training, and other resources needed to embed a culture of innovation, entrepreneurialism, and translational research in the geosciences.

Appendix 2: Stream-of-consciousness notes from the brainstorming sessions

These notes were captured in a series of brainstorming sessions with a broad cross-section of AMS members. Each session involved 6–12 participants.

7 May session

Need more research investigating the urban heat island and its alignment with historic redline districts.

Need reach out to general population to better inform them on the kinds of actions each person can take to have an impact.

- Many companies have avenues to reach out to their users, how can those platforms be utilized to get climate change information to the public. (For example, smart phones are a platform to get messages to people, but it is not limited to that.)

- Existing private sector networks already work to gain public engagement so need to try to use those networks.

Look broadly at partnerships.

- Linking to environmental justice groups is important.

- Focus on vulnerable communities.

- The "last mile" issue is huge and requires reach into local networks, such as faith-based groups.

An audit of data gaps would be useful.

Climate science is built on "western science" and more could and should be done with other types of knowledge input, such as from indigenous peoples.

- This is especially important when looking at climate solutions, and there is a lot more that could be done on this.

Important to partner with community-based organizations because there must be local connections to be effective.

Need to be careful about how personal actions may not have much impact even if it makes people feel good.

- Need to be honest.

Framing this as a "mission based" approach may be helpful.

Need to keep in mind that “labor” is a notion that is different than public/private/academic sectors.

- When jobs are formed in a green economy, make sure it is not just profiting the few, but providing equitable solutions for labor to serve social justice.

The current administration seemed more focused on mitigation, but needs to do more to emphasize adaptation.

Workforce issues are important, and NSF could help ensure investment in interdisciplinary training needs.

- Tech colleges could form partnerships with corporations to build needed workforce (emphasis on BS and MS rather than Ph.D.).

- More work needed in social sciences to have people trained in the right way to address climate solutions.

Need to challenge NSF to work more broadly to help support effective tech transfer.

- NSF may need to adjust its approach to have the desired impact (embrace more R2O than it has).

Corporations are largely on board with the need to mitigate and adapt, but may not know how to use available research effectively.

- May not need as much new fundamental knowledge as more on how to use what we have.

Need to think not so much about R2O, but rather “Research to Applications” as a paradigm.

Need to ensure that IP issues do not constrain growth.

Actual decision making is still hampered by lack of knowledge on how to use available knowledge more effectively.

Voices from HBCUs, indigenous peoples, etc., need to be heard.

We have learned from Covid-19 that we cannot tackle global problems in isolation and international partnerships will be critical.

- Climate diplomacy will be important.

- We need workforce trained in working within international partnerships.

There is risk of having too many uncoordinated activities and therefore a lack of collective effectiveness.

- Finding better ways to coordinate could be critical.

<u>12 May session</u>

The recent NAS report on climate issues has some important recommendations on mitigation and geoengineering (including carbon capture).

Use the lessons from the pandemic to reimagine workforce development.

- Increase the role of "apprenticeships"

- Use public-private partnerships

- Look at ways for community colleges to train practitioners to provide climate services

There is a need to remove data silos and encourage greater cooperation

- Need to coordinate across various data types (geospatial data, observations, etc.)

The jobs act can be seen as a climate bill wrapped in infrastructure.

- Important to have new infrastructure be resilient.

- Increased mass transit investments need to be sensitive to their impact on urban areas.

Need to look more at carbon capture in addition to mitigation.

- Determine what carbon capture at scale would look like.

Need better consistency in "carbon counting" as a necessity for implementing a carbon tax.

- Need more research on how to do the counting, but also how to present approaches to policymakers so that it is clear and leads to good policy. (As an example, it is not clear how to count trees since their impact depends on their full life cycle, such as whether they are eventually burned or buried.)

- Natural climate solutions need more research, such as impact of reforestation.

Need a more operational workforce.

- Fewer Ph.D.s and more applied people.

- This could link to Biden Administration's "climate corps" in terms of having opportunities for apprenticeships.

- This connects with inclusivity goals because it may be attractive for diverse communities to pursue STEM fields that connect directly to societal needs.

There are opportunities for NSF to increase societal benefit by adjusting "broader impacts" definition.

- For example, could focus more on urban impacts for environmental justice issues.

Important to do social science research with local communities, from urban communities to indigenous populations.

- Provides lots of opportunities for place-based research that expands change to engage underserved populations.

- Place-based approaches allow pilot projects with rapid adjustment.

- Adaption and resilience are automatically local.

NSF needs to show ability to respond on the tight time frames required to hit the 2030 mitigation goals.

- May include supporting non-peer-reviewed publications for rapid pilot-project dissemination on short time frames (followed by more traditional peer-reviewed publication).

- Allow broader scope for Criteria 2 that values early results prior to peer-review.

- Could redefine success in a rigorous way that still allows more rapid progress.

An approach is doing assessments of key decision needs and working back to what that implies on research needs.

- Current AMS Policy Program pilot projects are examples of this approach.

- Work by Richard Moss is similar to this, but needs to be expanded.

There is room for more research on the hazards connections to climate change, and this naturally connects with work being done at NOAA.

Consider septennial assessment for Earth system sciences and services.

There should be periodic assessment of the assessment process to ensure that it is as impactful as possible.

13 May session

Transmission is limiting effective use of renewables.

Energy demand is very weather dependent, but renewable generation is also very weather dependent.

The observational needs for renewables need additional work.

- Partnering with NREL would be good.

Local municipal networks may not be getting the observations they need for effective operation.

There are issues in doing adaption of the built environment.

- There is not always good coordination across political districts to ensure equal protection (e.g., the height of a sea wall).

- Unequal protection in built environment becomes an equity issue.

At city level, plans to reduce carbon may not always fit into a true mitigation plan. Good planning could push goals to be more effective.

Need to find ways to get major emitters to address emissions.

- This gets to role of a cap-and-trade approach versus carbon tax.

Carbon capture for high-carbon emitters (such as cement) has a large payoff compared to other efforts.

Need to do more to look at supply-chain and it impacts on carbon footprint of products.

Providing characterizations of air quality, such as particulate load and health issues, with attribution of sources can be useful.

- There are co-benefits to doing this to address environmental justice issues.

We are at an inflection point in the U.S. for both climate change action and diversity, equity, and justice issues, and if we can find ways to combine the two it could be powerful and should be pursued.

The largest discrepancies in climate impacts is till between rich and poos countries, not between different areas within a rich country.

Building resilient infrastructure in the U.S. can be a demonstration to the rest of the world on best practices.

- Helpful to developing world

- Should relate to public-private partnerships

- May translate into opportunities for U.S. companies to work internationally

The U.S. should consider a sort of “skunk works” for energy innovation and mitigation approaches.

Need to get message out that working in the geosciences will be one of the most rewarding professions in coming years as we address climate change.

<u>14 May session</u>

It is not clear that we have the right diagnostics to know which actions provide the greatest return on investment in reducing carbon.

- As an example, would more attention to wildfires provide a large reduction in carbon release.

We need to do a lot of measurement to be able to assess progress.

- Also need to have more measurements to feed into models.

- (Analogy: If you don’t get on the scale, how do you know if your diet is working?)

There is a lot of hope in the younger generation, and they are very interested in working on climate change issues.

- This is true even in traditionally conservative areas and in families with conservative parents, and this could help move the needle in terms of broader public support for action.

- Having more weather and climate education in high school could be valuable to increase awareness.

Should make effort to make carbon and its impacts more visible and “real” to the general population.

More research is needed on carbon offset strategies because many are not based on robust science and it is not clear that the offset actually has the intended impact.

Climate models still have large uncertainties, and improvements in the models over the past couple of decades have not significantly reduced the uncertainties for future projections.

- We don’t yet have what planners need in terms of “the answer” because of the uncertainties in model projections.

The applications community is still using very simplistic models for water resources (in terms of how things like evapotranspiration and snowpack feed into future water resources).

- Need more research to create more sophisticated water resource tools.

It is not clear we know the actual impact of a company like Ford going from producing 95% of its line as gas-fueled vehicles to just 15% in the next 5-7 years.

Should look into creating a "dashboard" on CO_2 emissions and other climate change indicators that is updated in real time so we can see if we are moving things in the right direction or not (analogous to the Johns Hopkins dashboard on Covid-19 indicators).

- This could be similar to air quality monitoring in real time that we do now.

We should be looking to NIST for rigorous standards for carbon offsets.

We need public-private partnerships, but this needs to be ecosystem.

The Bureau of Reclamation has run contests with prizes for the best streamflow forecasts, so perhaps similar approaches could be employed for best mitigation strategies for specific situations.

Carbon offsets and the trading of offsets represents a area of potential growth for businesses, which increases need for good science on offsets so we know they do what is expected of them.

Carbon pricing and the economics that go with it require that we push the boundaries in bringing together economists and physical scientists to work on this.

- Market-based approaches should have more success than command and control ones.

- The risk assessment you get depends on the discipline of the person doing the assessment (the assessment from an economist is not the same as from an ecologist).

In terms of workforce, the private sector finds that it can get great people when it concentrates on the value of the mission, such as serving society, helping the developing world, etc.

- We need to push the excitement and value of the how working in these areas has great impact.

NSF has not traditionally supported environmental monitoring (mostly leaving that to NOAA, etc.), but much more monitoring is needed to address the issue.

- Climate reference network should be at least tripled, especially on global scales, and that is outside the purview of NOAA and other U.S. agencies.

Need to find ways to continue to show the public that we are seeing the changes in climate that had been projected to occur to help build more support for taking action.

- Broadcasters often “sneak in” information on climate change, but could do more.

We need to re-energize and expand the GLOBE program as a way to have school kids take home to their families more about the environment.

- When kids get energized, they push their parents to be also.

- Maybe GLOBE could be expanded to a broader citizen science initiative instead of only inside schools (especially now that it is cell-phone based).

Need to be careful on using wildfires as a measure of climate change impacts because humans have artificially lowered acreage burned compared to what would be “normal” historically.

A citizen science network has the potential to draw in current climate change skeptics.

- Doing citizen science directly with CO_2 measurements is tough because there are no cheap sensors that can be widely used.

At the precollege level, more needs to be done with the Next Generation Science Standards.

- The atmospheric science community needs to get louder because we are not pushing weather and climate enough in precollege curriculums.

- Need to do better to show how doing weather and climate can provide a way to build physics, biology, chemistry, etc. into curriculum.

- In math, pushing probability and statistics instead of pre-calculus would be good.

- There is a lot of inertia among teachers to change.

18 May session

We should put focus on addressing short-lived climate pollutants because they represent about a quarter of the range of climate change.

- Monitoring greenhouse gases other than CO_2 and identifying sources.

- Making progress on reducing these can lead to more rapid improvement since they are short-lived.

- There are lots of technology ideas on hose to do this, but work needed on how to scale them.

We need better observations, both ground and space-based, of greenhouse gases for monitoring and tracing.

- Need work on what kinds of observations can best be assimilated into models.

- This is important for policy work.

Funding levels for work on science or adaptation have been much to low to allow the progress needed.

- Monitoring impacts is needed.

- Work on learning systems.

- Monitoring intended and also unintended consequences needs focus.

The insurance industry has done "catastrophe modeling" for many years, but it is largely based on historical databases and is just now beginning to build in climate change.

- These tend to be proprietary models so not accessible to the scientific community.

- Should be broadened beyond insurance industry use, but will need a lot of work on model downscaling and bias removal.

There is sort of a "wild west" right now of start-up companies offering to help planners address adaptation, but there is a need for more scholarly input to get the science right.

- Federal funding in academia could help a lot and allow the creation of open-source tools that would be valuable to entire community.

NCAR had an important webinar series on modeling climate intervention (geoengineering).

- More work is needed in modeling geoengineering solutions with high-resolution models to test viability.

More work needs to be done with indigenous and marginalized communities.

In terms of workforce, a lot more is needed in getting people to do the software engineering to be ready for exoscale computing.

- Universities do not offer courses in the software tools being used in the models.

- It may be that the models have to be rewritten to use the tools current software engineers are trained in, rather than needing to retrain the engineers, so that it is easier to get really good people to work on the issue.

Industries are concerned about resilience, such as insurance and reinsurance industries, but not limited to them.

- Companies are asking for greater certainties to help guide investment.

- Companies may not know what to do, however, even if they had low uncertainties.

Companies may be interested in creating tools to guide investment but are reluctant pay for solutions that are open source and then benefit competitors.

There are opportunities to build partnerships between private sector and academia for creating planning tools to support local governments.

- Local governments, especially in marginalized communities, need capacity building.

The ability to trace greenhouse sources could help mitigation by “shaming” large sources into action.

- International monitoring of short-lived greenhouse gases (halocarbons) has shown some success in part because such trace-back has been possible.

- Still need to define better what observations would be needed to allow accurate tracing.

Carbon sequestration in oceans and wetlands through enhanced uptake could have noticeable impact, but a lot more science is needed to see if this would work.

- On land, genetically modified root mass could have potential for carbon sequestration.

- Need a lot more science because very optimistic estimates are floating around now without adequate confirmation.

Need research on possible plants that are effective in absorbing carbon and that could be planted on unused land as a way to commercialize carbon offsets.

- This could lead to market-driven solutions.

The geoscience and engineering communities need to collaborate more because scaling is not well understood and we would need good studies on scaling up geoengineering solutions before moving forward with them.

- Studies of unintended consequences are also needed.

- (See: https://www.nationalacademies.org/news/2021/03/new-report-says-u-s-should-cautiously-pursue-solar-geoengineering-research-to-better-understand-options-for-responding-to-climate-change-risks)

- (See: https://www.nap.edu/read/26055/chapter/1)

The energy industry oversimplifies the releases of greenhouse gases in energy production.

- Need better modeling of entire process (extraction through energy production).

- Leaks are not verified well.

- Monitoring and verification is a real problem and needs work.

Need to do carbon capture at the source and sequestration close, as well, in order to be economical.

- In some ways, this is less a technical issue than one of economy and logistics.

We need more social science on how to explain things in ways that get public support for action.

- This is not just for U.S. but other countries, as well.

- Getting the message right is important.

Social science has a lot to offer this topic. But social science budget in NSF is SO small that this important topic gets on minor attention in comparison with other very important topics like education., health, etc. But social science work on many aspects of the economic impacts of climate change, or whether claims about jobs and green economy are correct, etc., would be very helpful.

Need to do more to expose K-12 children to nature to build an appreciation for the need to protect the planet.

- This is hard to do without seeming to tell parents what to do.

- May be especially hard for some communities.

For both observations and monitoring, remote platforms like drones may offer solutions.

Programs to expose kids to nature can be powerful.

- Happens at community-based level, and good coordination can leverage this, but it tends to be funded as level that are much too small.

- Modest increases in funding for this could have a large return on investment.

The Do Not Litter campaign turned littering around in about 7 or 8 years. They concentrated on school children. The children then chided their parents when they littered. And littering decreased dramatically. Not sure this would work these days because climate is so politicized that skeptics or those who feel that it's too expensive to address will push back against having anything about this in the curriculum.

Things like ozone gardens at schools could be a way to expose K-12 kids to the idea that what we do makes a difference without transporting them elsewhere. You can see with your own eyes the damage to leaves and then discussions like the impacts of other gases are a natural follow up.

Artificial intelligence and machine learning may have important roles to play (and get some emphasis in the New Frontiers Act).

Need an integrated assessment model at the regional level.

19 May session

Focus on cities. Most cities are not large enough to have resources to implement known improvements at scale. Mayors of small- to medium-sized cities want to know: 1) what systems are impacted by climate change, 2) what is the frequency the city will violate air quality standards due to increased heat events, and 3) what can they do to reduce impacts.

- City planners are largely looking at the 2-4 year timeframe for action.

- Creating open tools that could be easily used by cities could have real value.

- creating an NGO that could bring together private sector investment in addition to leveraging government resources could amplify success.

Create a national climate adaptation certification program.

- Word has been done at UCAR to create a rough curriculum and a business model that would allow a university to offer a certificate program and cover its costs.

Look at megacities, internationally, for adaption efforts.

Local decision-makers are key for adaptation. Mitigation is often best done through national efforts at larger scale, but adaptation must be done locally so local leaders are critical.

A sticking point is always political will. This means more work needs to be done in the social sciences on who to better create networks of like-minded people who can help generate the necessary political will. This requires full engagement of practitioners and operational people in addition to researchers.

Create and arena where adaptive governance can play a role:

1) do not punish political action, only punish inaction (work toward implementation of no regrets strategies)

2) do lots of pilot projects and take small steps, picking up those that work, discarding those that don't (small activities can be a low cost, so the you can afford even those that do not work)

3) harvest experience to more broadly replicate successes (create networks of practitioners who can propagate success strategies)

It you tie an improving economy to the politics, it is easier to bet broad buy-in.

Create climate reference network stations to universities. This allows opportunities to bring advocacy to the populations served by those universities.

- Having the science in the neighborhoods gets people involved in the issue and makes it real for them.

- Invest in the infrastructure required to get installations in cities.

University of Oklahoma did a strategic plan on energy and sustainability that went into the role of cities and other communities and looked at the risk of not diversifying energy sources. Showed that there is risk reduction for communities in expanding energy sources beyond fossil fuels.

It is difficult to get funding for "convergent research" because agencies (including, but not limited to NSF) are so siloed. So much of the work toward climate change solutions requires multidisciplinary teams across science, engineering, and the social and economic sciences, but funding agencies have trouble making that work.

Funding for "convergent" work is of key importance, but not just funding. There are also problems with those doing that kind of research in terms of the reward structures (tenure, etc.), finding journal to publish in, and even find the right home in a university structure. (And even finding a common language between researchers coming together in convergent teams can be a challenge.)

Focusing on extremes is important. They are hard to study because they are rare events, but they have large and lasting impacts and are therefore critical to understand and become resilient to.

Look at the successes and failures of air quality work in the 1960s and 1970s for analogs that might be useful for climate work. Air quality improvements required both top-down and bottom-up strategies to achieve success.

- Top-down and bottom-up approaches are not mutually exclusive.

In the 1970s, there was a "Coordinating Research Council" in which there was collaboration between the EPA and the auto ad electricity generation industries on research investments and operational implementation. This was very successful in making progress on air quality problems, but was later prohibited by legislation because of concerns that the collaboration represented conflict of interest.

Getting students into field projects, internships, or other experiences that deal with climate change issues can have a big impact by giving them first-hand knowledge that will stick with them as they go on in their careers, no matter what those are.

More research is needed on possible impacts of geoengineering ideas, especially unintended consequences.

Internationally, promoting science-based decision-making for those affected by climate change has moved the needle toward climate services.

- There has been success in putting decisionmakers in the lead to tell scientists what they need.

- That has usually been framed in terms of statements of risk.

- Most are concerned with impacts to infrastructure.

- Often those impacted most do not have the capacity to take action even when it is clear what needs to be done.

- "Twinning" (pairing a country with higher capacity with one that has low capacity) has had some success.

- There should be lessons in these international efforts that would translate to success in this country.

Need to do more to communicate with those working in various economic sectors on ways they can build in stronger resilience. In particular, companies responsible for infrastructure improvement may be able to make small additional investments that greatly improve resilience of the resulting infrastructure. Having those private sector companies recognize this might lead to them increasing investment on their own as a way to show commitment to problem if the awareness is high enough in the public (good public relations for the company to be putting science to work to improve their local community, etc.).

More emphasis should be put on research driven by engagement, An NSF report will be released soon on "coproduction of knowledge" that addresses results showing the coproduction leads to better scientific results compared to more traditional models – there are more innovations in the coproduction model.

- Pushes researchers see impacts and that sharpens focus

- Improves implementation of research results

- Involvement of stakeholders means that research results have “staying power” within communities of those stakeholders

The way we train scientists needs to expand to allow better engagement across disciplinary boundaries.

Working with stakeholders helps develop decision support tools more effectively. Scientists working alone may not provide a tool that actually meets the needs of the users.

Focusing on solutions can help avoid some of the political pushback.

AMS (and other similar societies) provide a good bridge to bring together stakeholders.

Climate services are taking hold internationally but not as quickly in U.S.

- AMS could help develop networks to expand that.

- May need new networks in addition to current ones.

- Need to look more at how to get knowledge into the hands of decisionmakers.

Community-based efforts have great potential.

- An “inverted” model of working from decisionmaker to researcher can help meet needs more quickly.

- Much of the required info is already available but not known by the decisionmakers

- Sharing results among communities to spread best practices is a fundamental requirement.

- Can be a grass-roots effort, which often improves ability to seek philanthropic support within local communities.

- This may be valuable reference along these lines:

https://carnegieeurope.eu/2021/04/22/novel-approach-to-local-climate-action-in-france-pub-84363

20 May session

Georgia has implemented a private-academic partnership model called “Draw Down Georgia” (based on the Paul Harkins book *Draw Down*). The academic partners looked at 100 climate change solutions and their applicability to

Georgia, and came up with 20 solutions that were robust in providing possible impact for the state. They also developed a “carbon tracker” tool and tools to support an inventory effort in the state. (See: https://www.drawdownga.org)

Another model is the Georgia Climate Project, which is a university coalition that created a portfolio of activities that would have impact and that are available to pursue if and when funding for them becomes available. (See: https://www.georgiaclimateproject.org)

Also in Georgia, there is an NSF proposal in process for an engineering research center to address issues related to the urban heat island, with special emphasis on the social justice issues. It is called “Engineering Cities for Thermal Justice.” (See: https://scholarworks.gsu.edu/usi_sfl/8/)

Approaching climate issues at the state level can be effective because it allows connection with local and regional networks, including local private sector groups and faith-based groups.

An approach to get climate science information into the hands of decision-makers is to work with city planners. The American Planning Association provides certifications to city planners and that certification now requires work in sustainability and climate change issues.

- In many cases, tools exist that would be valuable for city planners, but they don’t know how to take advantage of them, so scientists (such as those from AMS community) can be a huge help.

- The American Planning Association provides a straightforward avenue into the city planner community since so many of them are members and are certified by APA.

Need to layer in environmental justice information with that used to make investments in infrastructure.

- At the planning stage, it is not hard to make sure investments also address social justice issues, it just needs to be factored into the decision process.

- Often the data to do this exists and is readily available, but decisionmakers may not be aware of it.

Need to address all these issues from a systems engineering point of view.

- Addressing one issue, such as rainstorm runoff and the storm sewer network, in isolation may lead to investments that miss opportunities to address other important issues at the same time.

- Treating the system as a whole is harder, but results in much greater resilience and can also address social justice issues implicitly as part of the process.

- And similarly, not all cities addressing urban issues of social justice, such as housing issues, are thinking about how to integrate infrastructure changes in ways that lead to improved community resilience.

Science needs to break the mold on how it is done. Instead of the normal model of ever deeper knowledge in more and more narrow areas of investigation, there needs to be much more effort to look at the connecting tissues between areas of research.

More emphasis needs to be placed in recognizing that we have one atmosphere and one global ocean and that they are intrinsically connected and influence each other.

Climate service practitioners still use tools based largely on assuming a stationary climate, such as the most recent “normal” (recognizing that those do change over time).

- Tools need to change to build in more recognition of nonstationarity and allow for futures based on IPCC projections.

A certification program in climate services (by an organization like AMS) would be really useful.

There is a need for new research on the social sciences of climate change that mirrors the social science work on how the population responds to severe weather hazards and warnings.

- Could follow a model similar to the Weather-Ready Nation efforts

- Requires funding agencies to overcome silo issues

- Needs to be an integrated systems approach

There may be only one university in the U.S. that offers a Ph.D. in “Climatology” (Univ. Delaware).

- Given need for applications work in climate change, that may not be enough.

While there are some great examples of climate action at the local level, there are still not a lot of them.

- Tend to be driven by key individuals in cities.

- Some real success stories are in areas that are politically aligned in ways that would suggest climate action would be opposed.

- Need social science work to better understand how to encourage replication on a broader level by other cities.

Climate is an “anthropologic issue” and should be studied with that perspective.

We do not need breakthroughs in technologies on how to address climate change, but we do need to get the psychology right to achieve buy-in.

- More research on how to educate the population on the causes of greenhouse gases can help. (As an example, people feel good about bringing their own reusable bags to the grocery store, but are unaware of how the choices they make in the products they purchase have many times more impact on carbon emissions.)

- Having people understand the issues can help lead to more robust policies.

We should not spend a lot on trying to find new climate solutions, but instead work toward how to effectively implement what we know.

- But there are still important issues with scaling up current solutions due to their dependence on rare earth minerals.

- These are abundant in total, but difficult to extract.

- Need research on how to better recycle rare earth elements out of used tech to move toward a “circular economy.”

A driver for the climate change issue is global population.

- This is one of several “beyond carbon” issues that cannot be ignored.

Scaling up electrical energy production is key, but policymakers need to understand that in the future weather is the key to every aspect of that.

- Weather needs to be integrated in the planning of systems

- Weather data will be needed to make the grids more efficient

- Weather largely determines both demand and supply

Dynamically consistent datasets will be needed for all aspects of the system, including placement and storage decisions, not just forecasting output.

- Grid operators need to better understand how weather impacts both load and generation.

- At policy level, there is not enough understanding on this and we need to make more progress on that.

Planners tend to be more concerned with possible climate impacts to infrastructure.

- They have not made the mental shift to an energy system that is completely weather dependent.

If planning is done poorly, stresses to the grid will cause failures and that will impeded further progress on the transition.

Offshore wind can play a major role, including floating systems, but a lot more needs to be done to deal with transmission limitations.

- Need to expand transmission capability and need research on how to do that effectively.

- Understanding of the atmospheric science is not up to the task for massive wind deployment, with one example being that wake effects are not understood nearly well enough.

- More research on modeling atmosphere also needed for solar since cloud shading is huge issue and cloud forecasting in models is not as good as needed to help.

- Cloud uncertainties continue to be a major issue (for example, afternoon fair-weather cumulus that can impact solar significantly).

- Basic research in cloud-resolving models may be able to help.

Hydrogen can be created with excess wind and store energy for long time periods. Europe is investing millions in hydrogen for storage with renewables.

University curriculums may need to be developed specifically to address future jobs in renewable.

- Need programs to support "weather-driven energy"

- What had been "coal, oil, and gas" as sources for energy is replaced by "wind, solar, and water" (including hydro, which is also strongly weather-dependent).

Grid operators do "integrated resource plan" that looks out 10 or 20 years at supply and demand, but they are now looking at adding climate change rather than using current "normal" climatologically.

- More work is needed on this.

- It is not just changes in climate that will impact demand (such as for HVAC), but also the uptake of EVs that need charging.

Based on current knowledge, getting to 100% carbon-free by 2050 probably not possible.

- Still need research on improving renewables.

- Still need research in storage (batteries, and other approaches such as hydrogen generation as a storage approach).

More research on attribution also needed.

- Current “big heat” and “big rain” attribution does not go far enough.

- Need research into “impact attribution” that partners climate scientists with others, such as health professionals, to look at these other impacts.

Appendix 3: Individual inputs in response to membership-wide request for ideas submitted through online portal

Note: In some cases, submissions are provided verbatim. For many, however, the submission text is summarized or paraphrased to increase consistency with other entries. Some separate comments were combined due to similar themes, and some were omitted if they were deemed unhelpful.

Climate change and climate solutions tend to be approached on long timescales, and adaptive management timescales of sub-seasonal to seasonal and multiyear are not getting due attention.

- The S2S project under WCRP and the Ready-Set-Go framework needs to be implemented in a much more rigorous and end-to-end system.

- All societal climate information needs broadly fall into food, water, energy and health sectors but the main challenge is to avoid making them silos.

- Models must include AI/Ml approaches to merge all data and models to deliver decision dashboards that take care of the last mile issues in every aspect of food, water, energy and health management and their interdependencies.

Produce high-quality graphics of simple actions that can be done at the individual level for energy conservation as a way to get the broader population to make changes that can be impactful in the long run.

- Get the ideas into the population early with science classrooms and activities kids can do at home with the adults that are focused on energy use and reduction.

- Activities like 4H, scouts, any community organizations, churches could help too.

- Focus on recycling and reducing individual energy use.

Deploy dense networks of meteorological stations to allow better real-time weather observations that can be used to better understand impacts of a changing climate.

The meteorological community as a whole must ensure hazardous weather and climate are considered in the design and operation of critical infrastructure such as transportation and energy. Our community could leverage these possible future NSF funds to undertake the necessary scoping and assessment analyses in order to determine barriers to future construction and appropriate mitigation activities. Furthermore, with the prospects of autonomous vehicles and zero-emissions vehicles, it will be essential to ensure these technologies can operate in a variety of conditions while also accounting for the non-stationarity of a changing climate. We must not forget that the implementation of new technology and infrastructure/public works projects is seldom done equitably. There is often emphasis and focus on more affluent neighborhoods and/or central business districts. This is another arena in which our community, as stewards of future NSF funding, must ensure that these applied endeavors also account for the needs of marginalized communities.

More detailed and frequent measurements of emissions of greenhouse gases are necessary to 1) understand the processes that generate GHGs, 2) to verify emission compliance and 3) to find leaks. There are huge uncertainties today.

- Case in point: https://online.ucpress.edu/elementa/article/doi/10.1525/elementa.358/112487/Estimation-of-methane-emissions-from-the-U-S

- Smaller and cheaper sensors are needed, in particular methane. (For example, the work of Aeris and SenseAir.) Sensors can then be carried by small drones and map emissions over areas.

- With further integration, non-experts can conduct such measurements.

- The effect would be a much lower cost of acquiring actionable data compared to today, when specialized companies offer measurement services using time-consuming techniques. By lowering the cost, more companies can measure their emissions more often. Both the development of smaller and cheaper sensors and the development of easy-to-use drone platforms would benefit a lot from public funding given that the business case is weak, not matching the potential of the positive environmental impact.

- A firmer grasp of the emission situation can lead to more stringent and rational regulations of various sectors where GHG emissions occur.

There are a number of opportunities to consider in exploring short-term high-impact climate solutions where research and mobilization from the geoscience community can be of service.

- Nature-based solutions: there is a large range of nature-based options to consider depending on location and scale of deployment. Further research could be useful in: evaluating how different NBS could be used in different communities, understanding intervention level vs impact, and understanding co-benefits

- Stormwater management: further research could be useful in adapting sewage/ drainage systems and developing catchment-scale planning resources

- Air quality: further research could be useful in better characterizing relationship between emissions and ambient concentrations (which are complicated by geographic vulnerability/meteorological processes), particularly for particulate matter

- Developing metrics to measure adaptation success

National Centers for Environmental Information should conduct a campaign to add as much good and valid data as possible to the Global Historical Climatology Network and the hourly data catalogs. This campaign should involve at minimum:

- Add National Ocean Service data from buoys, coastal-marine automated network, and other stations to the GHCN databases and Integrated Surface Hourly on an ongoing basis. (If the quality of these data are insufficient to add to the GHCN database, then fix or enhance these stations until they begin to produce data of adequate quality and reliability.)

- Develop a national or international database of hourly precipitation data, going back as far as possible, using all available networks and data catalogs, would prove very useful in assessing short bursts of very heavy rainfall and characterizing trends in their frequency of occurrence. These data exist at least at Weather Bureau sites before World War II.

- Add high-quality data from various stable state and local Mesonet stations to GHCN Daily, monthly, and where appropriate to the Integrated Surface Hourly dataset. This dataset should allow easy comparison to weather models and data assimilation. It also should allow statistics on windstorms to be calculated. For Weather Bureau sites, Army Signal Corps forts, and whatever other sites are available, this dataset should extend well before World War II and preferably into the 19th century., even if the "hourly" data include measurements only a few times a day.

- For the utilization of old wind data, a current study of primitive anemometry methods, exposures, and instruments may be expedient to enable the best and most accurate comparison to current measuring practices.

- Add more foreign data. For example, Mexico makes a large catalog of climate data available on its website here: https://smn.conagua.gob.mx/es/climatologia/informacion-climatologica/informacion-estadistica-climatologica

Additional data are occasionally profiled in old editions of Monthly Weather Review but not always included in GHCN.

- A special effort to digitize 19th-century (and earlier) data from forts, the Smithsonian Institution, and primitive cooperative sites, especially before 1893. Much of this data may have been digitized or at least scanned several years ago, but it is still not publicly available and is not in the GHCN Daily dataset.

- Extending the official NClimDiv monthly averages backward as far as possible before 1895 for parts of the country with reasonable coverage of weather stations.

- An effort to find some climatic data for the period of the War between the States, especially in the area under the control of the Confederate States of America. This effort may involve scholars of the war and require examination of documentary sources not traditionally considered in climate research.

- An investigation into records of weather and climate events during the Spanish colonial era

- An extension of the hurricane database for years before 1851 in the Atlantic Ocean and to develop a comprehensive database of tropical cyclones in the Pacific Ocean before 1966 and if possible well into the 19th century, including at least those that hit Mexico or New Spain. This effort should attempt to uncover and to use as many relevant documentary sources as possible, including those in Spanish, French, Dutch, and other languages as appropriate.

- These projects and others will enhance the nation's climate databases and enable easy comparison between current events and those of the 19th century. A better picture of the 19th century climate of and beyond the United States of America will bring more extreme and low-probability events into our documentary memory and enable people to prepare for their recurrence. It also enables the identification of long-period cyclical modes of climate variability.

In most of the eastern U.S., the past few decades have witnessed a significant increase in precipitation. A comprehensive national flood mitigation plan is in order. Such a plan may include:

- The climate database enhancements to improve our understanding of locally heavy rainfall and widespread heavy rain events.

- A comprehensive reassessment and remapping of flood plains nationwide with calculations of 1-year, 10-year, 100-year, and 1000-year flood events. (In highly urbanized areas and other areas of extensive land-use changes, reassessment once a decade or more frequently may be appropriate.)

- Enhancement of urban drainage systems, construction and repair of floodwalls, other flood mitigation infrastructure.

The increasing population of the coastal South increases vulnerability to hurricanes. Development of technology to strengthen housing could reduce damage.

- Should include methods of retrofitting older or historic homes.

- Technology would be valuable in other parts of the country that experience damaging windstorms.

Improve the energy efficiency of homes and of commercial and institutional buildings with respect to HVAC.

- Explore using wood heat in rural areas where trees thrive through high-efficiency, low-particulate-emission wood stoves since wood is sometimes considered a carbon-neural source.

A recent letter to the European Commission and European Space Agency, signed by over 600 global climate scientists, raises significant concern about a potential gap in polar satellite altimetry measurements for changes in the polar oceans, including the thickness of land and sea ice. At issue is the longevity of ESA's aging CryoSat-2 and NASA's IceSat-2 missions. In addition to climate change research and monitoring, polar ocean and sea ice data is also important for operational users such as Defense (e.g., U.S. Navy sea ice thickness surveys), USCG (operational icebreakers, search and rescue), commercial maritime shipping (e.g., efficient Arctic routing), commercial fishing, and oil and mineral exploration. GNSS reflectometry observations have the potential to cost-effectively measure sea ice properties such as height and extent, delineate marginal ice zones, and classify sea ice types with high temporal and spatial resolution. These observations also have the potential to serve as "gap-fillers" in the event of loss of either CryoSat-2 or IceSat-2.

There is need for applied, interdisciplinary, user-motivated work on climate risk, including especially extreme event risk. This is the kind of work advocated by the recent NASEM report advising USGCRP: A large fraction of climate risk is extreme weather event risk. The insurance industry has pioneered this in the past, developing so-called "catastrophe models" --- semi-empirical models which characterize the risk of financial losses from various kinds of extreme events. But the insurance industry is now behind the curve because they are only just starting to think seriously about how to incorporate climate change. Their existing "catastrophe models" can't handle it well because they're too empirical and tightly based on historical data. They're also proprietary, very costly to license, and not peer-reviewed; plus they are underdeveloped to nonexistent for places where there isn't a lot of insurance, i.e. poor countries. Climate models, on the other hand, don't work for extreme event risk either, because they are too biased in a number of respects, and don't capture the extremes well enough, in part due to inadequate resolution. So there's a big gap, now being recognized, but only very few groups so far are working in this space. It takes combinations of physics and empiricism, with the right combinations depending on the type of event (floods are different than droughts, etc.). Here's couple of recent conversations I was part of about this. These are a bit insurance industry focused but much of it applies more broadly: https://oasislmf.org/oasis-information-library/section-5-oasis-community-discussions and https://mcrf.milliman.com/MCRF/Mind-the-gap-How-cat-models-need-to-evolve. This kind of work also requires an understanding of the uses to which the results will be applied, and that requires some interaction with users themselves. In this respect it is different than the basic science most of us have done up until now. This issue is becoming more and more relevant to much of the private sector (not just insurance), as the need to assess climate risk is becoming a bigger and bigger deal and a cottage industry --- with no well-defined standards or regulation, and a lot of proprietary, non-peer reviewed science --- is springing up around it. But it's also very relevant to the public/nonprofit sector. In fact, having publicly funded solutions is even more important for such applications than for the private sector, since the private sector can pay for the science it needs but other users (arguably esp. those in greatest need) mostly can't. I'd argue that providing usable science to communities most affected by climate change is an essential part of climate justice, in fact. Thus far, no federal agency seems to have much interest in this kind of work, but I hope that changes. Private sector companies will always be concerned about getting competitive advantage; yet peer-reviewed, open-source tools are what is needed, not just to make the science as good as it can be but to make it as widely available as possible, which serves equity and climate justice. An investment from NSF could have a huge impact here, not just in the work that would be supported itself, but in getting more of our colleagues interested in doing this kind of research, which is different from what most of us have done historically. The time frame of 2-3 years is long enough to have a considerable impact, particularly to the extent that it draws in new players, builds new collaborations, and starts new efforts, some of which will be sustained. This kind of work is relevant to climate adaptation, and I'd argue that that's where climate science currently can do the most for human society. Mitigation (reducing emissions) is critically important, but science is not what's holding it back, politics is. Adaptation can make more use of new climate science, at this point. I make this argument at greater length here: https://rdcu.be/cj9b3. Partners in this work should include (non-exhaustive list, no particular order): 1. academic/ government climate scientists 2. Insurance/reinsurance companies 3. Other private sector companies that need climate risk information (the financial sector is probably the biggest immediate market) 4. Utilities 5. State/local governments 6. NGOs: e.g., World Bank, World Food Programme, Red Cross/Red Crescent, etc. 7. Environmental/climate justice organizations Existing organizations that are currently focused on this specific problem include Oasis, Insurance Development Forum, and the Geneva Association.

One of the keys to addressing climate change is convergent research.

- This is not something that most people learned in graduate school.

- We need training on what it means and how to do it with concrete examples of how to overcome challenges.

Convective Permitting Climate Modeling is the best way to address future climate change at the local scales. This would require a number of ensemble members of the CMIP6 runs being downscaled to the U.S. CONUS scale. This is close to possible now, but would require additional HPC time and storage, even greater than the current capability at NCAR. GPUs are a possible solution, but code needs to be adapted. We are currently performing simulations over the Continental U.S. and South America using a simplified climate forcing call Pseudo Global Warming in which only the monthly averaged CMIP6 thermodynamic climate change is added to the reanalysis and the WRF model forced by the so created files on the boundary. We are also working with the Department of Interior in a project called HyTest to perform a forty year historical CONUS run from 1979 to 2020. The next phase is a PGW simulation. If more computer time and storage is available we could do 5 ensemble members from CMIP6 and downscale current and future over the Continental U.S. for selected decades.

1. Additional research is needed on to determine how land-use/land-cover change may interact with and influence climate change. This includes research on how land-use/land-cover may be used to mitigate climate change. 2. Funding for the continuation of the North American Coordinated Regional Downscaling Experiment (NA-CORDEX.org). NA-CORDEX has provided high-resolution projections of climate change for public use across all of North America (our U.S issues do not stop at the boarder, and our international partners help expand and enhance the dataset). The dataset includes enhancements that make the data easier to use for a wide research audience, and particularly for those interested in examining climate change impacts and adaptation. CORDEX is a WCRP endorsed MIP as well. Published literature shows us that the NA-CORDEX dataset has been heavily used in the impacts and adaptation community, in the climate change research community, and ensembles of simulations from all international CORDEX efforts, including North America, have been used heavily in the upcoming IPCC WG1 AR6 report. NA-CORDEX is housed and co-lead at NCAR (the other co-lead is at Ouranos, in Canada). Funding to 1. continue the

data archive and experiment and 2. expand the NA-CORDEX effort with, e.g., state-of-the-art simulations and additional future scenarios, including mitigation scenarios of interest to stakeholders and researchers, would help us serve a larger audience further into the future, helping many researchers and stakeholders further address multiple climate change issues.

Look into regenerative agriculture, with incentives for organic farming, growing cover crops, planting trees, and raising livestock in open grazing lands that can't be used for organic farming.

In addition to solar and wind energy, we need more work on geothermal, tidal, hydro, and (safer) thorium nuclear energy.

Education is a key piece in getting people to make smarter personal choices that will help with climate change (transportation, plant-based foods, waste solutions, efficient energy usage, etc.) and become climate activists.

- Younger generations especially need to be taught about the environment, nature conservancy, food & nutrition, waste management and climate science in schools, from Pre-K to University.

Consider the elements of Project Drawdown at https://drawdown.org/solutions/table-of-solutions

which highlights many of the solutions we need.

Given the severity of climate impacts being already experienced, there is a need to explore how a portfolio of combined climate intervention strategies including mitigation, carbon dioxide removal and solar radiation management could achieve a climate-resilient future. UCAR and NCAR are currently leading a new program to target these needs in the wider research community through the Community Climate Intervention Strategies (CCIS) program https://www.ccis.ucar.edu/. The stated aim of the program is to develop the scientific capabilities to extensively evaluate portfolios of climate intervention strategies that are societally-relevant, assessing their impacts and benefits to human and natural systems, and developing strategies to communicate the findings of these studies to decision makers and the wider public. The CCIS program has identified three main objectives: 1) Advancing the state-of-science climate intervention studies through exploring the assumptions, model deficiencies, interactions and impact assessment methods through a preliminary case study that focuses on scenarios that restricts warming to 1.5 degrees C from CMIP6 baseline pathways when combined with climate intervention methods already developed by the project investigators; 2) The development of a generalized methodological approach, based on the findings from the case study and extensive stakeholder engagement of values and priorities, to further research into combined climate intervention scenarios and their evaluation; and 3) The development of mechanisms for designing research projects into combined climate intervention strategies that are responsive to stakeholder priorities and needs, i.e evaluations of proposed scenarios that capture fundamental metrics for decision making and reflect the evolving climate pathway.

- The CCIS program brings together multiple areas of research and disciplines that are currently working in isolation to investigate climate intervention strategies.

- The interdisciplinary approach is aiming to transform the climate interventions research landscape, moving it to more integrated approaches for research and assessments, specifically through the establishment of a new generalized approach for interdisciplinary development and assessment of policy-relevant combined climate intervention scenarios.

- The CCIS program has initiated a research framework for answering each of these objectives.

The following capture the full range of climate change issues with solutions that can be scaled appropriately: https://impactclimate.mit.edu/ and https://climategrandchallenges.mit.edu

Ordinary citizens, residents, homeowners, and small businesses need access to actionable climate science. Such information should be provided via portals and apps (via APIs) to provision decision support services which are localized to a user's specific location and property/structure characteristics. As an example, prospective home buyers should be able to get a full climate risk report for the property under consideration which takes into account historical and future projected climate risks for flood inundation, severe local storms, hurricanes, wildfire, extreme temperatures, and drought/water scarcity. Researchers at the National Center for Atmospheric Research (NCAR) have developed a concept for how such services could be provided to the real estate sector. Separate work is developing a "Hurricane Risk Calculator" to provide such services for real-time weather hazards. The concept of actionable climate science should be extended to small businesses. In such a paradigm, small businesses should have access to sector-specific climate indices and indicators so that they can intersect the climate risks to translate these into financial risks. Once businesses and homeowners have such information, they can begin to make risk-informed decisions.

Explore potential unanticipated contributors to climate change through positive feedback loops with soil C. Harness the tens of thousands of archived soil samples in the NRCS (USDA) soil sample archive, and resample location in critically warming regions to directly observe how (and how fast) soils are changing as a result of warming. The science community (soil C science) has been waffling for a decade or so about IF soils (outside of the arctic) will respond. This really needs to be a first order question to brace ourselves for unanticipated (and uncontrollable) feedbacks to the CO_2 cycle this century. Resampling, combined with radiocarbon measurements and other geochemistry should be a high intensity, near term, goal and objective.

The Private sector is capable of developing some mind-blowing technologies. The challenge for the "open innovation" aspect of this is that most of these are proprietary and only discussed under NDA.

- The government can easily fund development of technology at either government labs or universities, and that is a great basis for allowing private sector to take it in a more applied direction. NOAA has a Joint Technology Transfer Initiative (JTTI) for doing this.

- Getting private sector to share innovative ideas openly (read: to their competitors) could be tricky. The result is you run the risk of having government invest in developing technology that already exists in industry.

- Sometimes federal agencies will post RFIs asking if industry is opposed to them (the government) developing some capability. Many times industry intentionally won't reply because they don't want word getting out to their competitors that they have that capability. …but then the government agencies are left thinking industry simply doesn't care.

- This is unfolding in the climate realm with respect to both resilience and mitigation. I'm not sure if many of the thought leaders in our field who've been in public service or academia most of their careers are really aware of this dilemma.

Climate change is a real a present danger and it needs to be tackled. One of the best ways to reduce emissions is the energy transition; electrify everything and generate electricity with non-CO_2 emitting resources. The majority of those carbon free generation sources will be weather driven. This is the real risk to the grid. If the electric sector does not understand and properly account for complete paradigm shift that needs to occur to have a system that is largely weather dependent there is going to be a train wreck. You cannot shoehorn a non-dispatchable resource into a system designed for dispatchable thermal and hydro units. We can do it to a point, but when we get to about 50% by energy it will become harder, and it will get increasingly harder from there.

More work needs to be done on what the grid needs to look like in order to allow more dependence on renewables. Must of the discussion assume we just replace gas plants with wind and solar in an ad-hoc fashion where solar and wind farms are just placed wherever they can generate the most kwh's per year to achieve lowest cost of energy. Even the federal level tax incentives are set up this way. This simply won't work as penetration increases and more things are electrified. The storage technologies that would be needed do not exist and aren't likely to become viable for several decades.

- Policy makers largely do not understand that policy around transmission and generation planning is incredibly complicated and in some cases will take decades to change.

- Policy support for a national HVDC grid will be critically important

- To transition to renewables in the electric sector, and to electrify the other sectors requires a redesign of how the electric system is planned and operated. Fossil fuels are local stores of energy that we have a high degree of certainty over the availability of and where consumption is mostly (not completely) separated from the capability to provide supply. A weather dependent energy economy requires interconnectedness at geographic scale that can mitigate the worst case that the atmosphere can throw at us.

- The energy transition requires planners and policy makers have a comprehensive and intellectually honest appraisal of what a decarbonized energy economy looks like where 80%+ of all the energy (including transportation and space conditioning) is coming from renewable sources, and 72%+ comes from wind and solar, and they need that from within the context of understanding how the same weather that drives extreme usage will at times drive low resource.

- The datasets and tools need to be in place to analyze these impacts and plan the new economy accordingly.

More scientific research is needed on how restoring nature can reduce the carbon footprint by restoring their abilities to capture carbon -- abilities that have eroded because of agriculture, forestry, water allocations, ocean and coastal land use (mangrove, sea grass destruction), and loss of coral reef capabilities. There is a lot of research NSF could be doing in these categories as well.

We should be cautious about direct air capture of CO_2, as well as artificially cooling the planet (geoengineering). All of these solutions will require not just the basic research but also the research that would bring these solutions to large scale -- and the impacts that would have on the planet.

It will be very hard for solar and wind to fully to address the entire climate change problem. And in addition, those technologies will require much better weather forecasting as well as long-term forecasts (i.e. seasonal) for operations and planning.

Tomorrow.io, a weather forecasting and intelligence company, will launch starting in late 2022 a constellation of miniaturized precipitation radar satellites to provide global coverage with revisit times of an hour or less. Weather radar is one of the most important tools to track precipitation and provide short-term forecasts and warnings, but the coverage of ground-based weather radar is limited, with roughly 5 billion people worldwide living outside of radar coverage.

This first-of-its-kind constellation builds on the heritage of NASA's GPM, TRMM, and RainCube satellites, leveraging advances in small satellite and sensor technologies to affordably field a constellation of precipitation radars providing equal coverage across the developed and developing worlds, with the temporal resolution needed for operational applications.

The dramatic increase in precipitation data, ranked by the U.S. Group on Earth Observations as the highest priority Earth observation out of 152 parameters, will enable reliable forecasts of precipitation and extreme weather to help countries, businesses, and individuals mitigate the weather impacts of climate change.

Please see http://tomorrow.space for more information.

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