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A FRAMEWORK FOR SUSTAINED CLIMATE ASSESSMENT IN THE UNITED STATES

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This significantly condensed version of the full report on implementation of a sustained National Climate Assessment in the United States is published here for the benefit of the wider AMS membership. Readers interested in full details are encouraged to seek the full report in Weather, Climate, and Society.

The recent Fourth National Climate Assessment (NCA4) (USGCRP 2017a, 2018a) shows that extensive changes in climate have been observed in all regions of the country. The report states that climate change "creates new risks and exacerbates existing vulnerabilities…presenting growing challenges to human health and safety, quality of life, and the rate of economic growth." And it concludes that without additional large reductions in emissions, "substantial net damage to the US economy [will occur] throughout this century…"

As a result of growing public concern (Leiserowitz et al. 2018), efforts to reduce human contributions to climate change ("mitigation") and to adjust systems and practices to uncertain future climate conditions ("adaptation") are gaining traction. These efforts notwithstanding, multiple assessments have concluded that mitigation is not taking place nearly rapidly enough to stabilize atmospheric GHG concentrations at safe levels (e.g., IPCC 2014, 2018). Assessments of the state of adaptation have found that adaptation is progressing, but not fast enough (e.g., Hansen et al. 2012; Bierbaum et al. 2014; Vogel et al. 2016). Practitioners are making long-term plans and investments without consideration of future climate changes and impacts likely to affect the lives and livelihoods of U.S. citizens.

To better meet Americans' needs to increase preparedness and resilience in the face of climate change, in 2016 the National Oceanic and Atmospheric Administration (NOAA) and the Office of Science and Technology Policy of the White House convened a Federal Advisory Committee (FAC) to develop recommendations on how to accelerate development of a *sustained national climate assessment*. The basic idea of a sustained NCA (Buizer et al. 2013) is to better inform decision-making by providing access to knowledge of climate change and its potential impacts in a more flexible and ongoing way than through a series of reports. The FAC was addressing how to advance implementation of the sustained assessment when, in August 2017, NOAA announced it would not be continued. However, most FAC members reconvened and joined with eight additional experts in early 2018 as the Independent Advisory Committee on Applied Climate Assessment (IAC) to complete their report.

The complete report, available in *Weather, Climate, and Society* (Moss et al. 2019) is summarized here. IAC members (the main authors of the report) consulted broadly with practitioners, researchers, professionals, and science translators and received inputs from a number of related efforts including a "Science to Action" collaborative of some 100 organizations and individuals.

The IAC's report presents an ambitious agenda of ideas and initiatives addressed to the full range of stakeholders interested in improving climate change resilience and preparedness. These include federal agencies, state/local/tribal governments, the research sector including universities, professional associations, non-governmental organizations, and philanthropies. The IAC sunsets at the completion of this report, but as described below, with a broader coalition of groups it calls for establishing a new civil-society-based consortium for climate assessment to work towards implementation of these ideas.

OVERVIEW OF MAIN FINDINGS. ***Practitioners need new types of scientific support for adaptation and mitigation.*** The IAC analysis begins by assessing the needs of practitioners, defined here as individuals in state/local/tribal governments, non-governmental and private sector organizations, and other settings across the country where actions to limit and adapt to changing climate conditions are planned or occurring. The IAC highlights multiple ways to increase support for practitioners to apply climate-relevant science, including by framing results so they can be integrated into existing decision frameworks and used in adaptation and mitigation.

Practitioners identified a number of ways that assessments could provide value:

- Assessing how climate and impacts science can be embedded directly into existing policies, plans, operations, and budget structures;
- Signaling the need for transformative action (as opposed to incremental adjustments), including substantial departures from current policies, infrastructure, institutions, and governance structures;
- Providing scientific resources to support governments and organizations in creating and implementing codes and policies that integrate future climate considerations;
- Developing methods for incorporating climate risk in financial analysis, bond rating, supply chain risk assessment, and other financial tools;
- Supporting the building and training of a workforce that understands and uses climate information, especially in small and rural communities;
- Helping develop methods and information that effectively communicate the current and future impacts of climate change, including conveying confidence and uncertainty;

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- Expanding methods and building capacity for state and local governments to engage the public in two-way communication so that planning processes are more robust and support is generated for implementation; and
- Aggregating, analyzing, and refining indicators for measuring change in conditions and evaluating effectiveness of adaptation and mitigation.

The United States lacks a comprehensive national climate information system. Practitioners want definitive information on a number of climate adaptation science issues. For example, what are the most regionally robust sources of climate information for assessing specific hazards such as future flood risks, potential for wildfires, recurrence of heat waves, or persistence of drought conditions? How should uncertainty associated with projections of different variables in different regions be taken into account? Can future impacts and avoided damages from adaptation be incorporated in benefit-cost analyses? Which approach to downscaling is appropriate for which applications?

Some communities and decision-makers do have access to the resources needed to integrate climate change information into their work. But in most cases, those who are attempting to improve resilience to climate impacts and better manage risks lack the resources to do so. A recent study by the Government Accountability Office (GAO) notes that "the climate information needs of federal, state, local, and private sector decision-makers are not being fully met" and that federal climate information efforts could be improved by establishing a focused and accountable organization that assists in providing authoritative data and needed technical assistance (USGAO 2015). GAO's analysis reviews options for providing climate information and concludes that "a national system to provide climate information to U.S. decision makers could have roles for federal and non-federal entities…"

Assessments can provide missing authoritative information and engagement opportunities. Assessments can establish authoritatively how to use science in making and implementing decisions. Assessments bring together experts and produce consensus summaries of "the state of the science" and the degree of certainty that the experts have in their conclusions. In the United States, Congress placed responsibility for conducting assessments of global environmental issues such as climate change with the U.S. Global Change Research Program (USGCRP), a consortium of 13 agencies. Four National Climate Assessments (NCAs) have been conducted since the passage of the 1990 Global Change Research Act (GCRA 1990). A few states and a small number of cities/counties conduct assessments for their own jurisdictions (Bedsworth et al. 2018; NPCC 2015). For the most part, assessments have not undertaken the challenge of assessing the "state of practice" in using science, traditional knowledge, and other information to manage climate risk. Comparative evaluation of different applications to determine which are robust and can be transferred from one setting or user group to another would help address GAO concerns and provide stakeholders with authoritative and tested information on the effective use of climate science in practical applications.

RECOMMENDATIONS. The IAC reaffirms the conclusion by others (Buizer et al. 2013) that it is important to transition national climate assessments to a more sustained, user-oriented process. The IAC recommends that future assessments meet the need for authoritative information on how climate-relevant knowledge can be applied. In this report, the IAC uses the term "applied climate assessment" to describe this emphasis. The following is an overview of the IAC's recommendations.

Recommendation #1: Establish a civil-society-based climate assessment consortium. The IAC recommends that national, sub-national, and private institutions join together to establish and maintain a civil-society-based climate assessment consortium. The consortium would bring together practitioners with scientists, professionals, and science intermediaries to evaluate how to use knowledge to adapt to and mitigate climate change. The consortium would provide ongoing partnerships focused on shared challenges rather than produce one-off reports. It would create opportunities for users to query science in the context of community discussion of the tradeoffs and opportunities that come with adaptation and mitigation. The consortium would assess climate change information quality and usability based on scientific analysis integrated with the experiences of groups managing climate threats. It would inform best practices for implementation challenges such as designing infrastructure, using citizen science and artificial intelligence, and reflecting the benefits of resilience measures in bond ratings.

Blend civil-society and federal contributions. The term "civil-society-based" is intended to convey an expanded responsibility in governance and agenda setting by non-governmental institutions. This

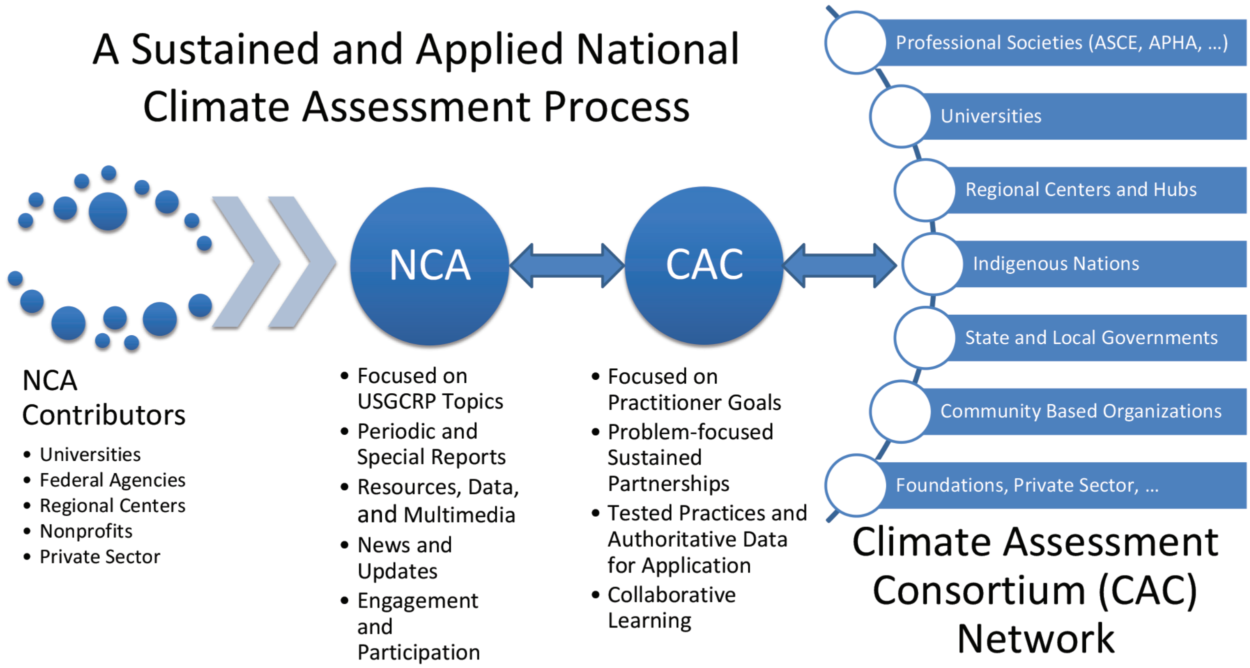

Fig. 1. Conceptual structure of the climate assessment consortium and its relationship to the ongoing National Climate Assessment.

increased role is essential to facilitate and support sustained dialogue, elevate user perspectives, and thus widen the community that shapes, accesses, and uses information in mitigation and adaptation. However, the federal government, through the USGCRP and its participating agencies, must continue to lead in organizing and funding global change research as well as conducting state-of-science assessments as mandated in legislation. There are a variety of options for ensuring an appropriate division of labor between federal assessments and the work of the consortium.

Provide a "backbone organization" for existing networks and organizations. The IAC recommends a consortium approach because a large number of groups are working together on an ongoing basis to apply climate information to adaptation and mitigation. These include non-federal government agencies (state/local/tribal), NGOs (professional societies, think tanks, civic groups, CBOs), research organizations (academic centers, universities, regional science and assessment hubs), and businesses (corporations and other private companies) (see Fig. 1). A consortium could be a "backbone organization" by facilitating a common agenda and mutually reinforcing activities for collaborative learning and access to authoritative knowledge and applications (Kania and Kramer 2011; Klempin 2016).

Urgently focus on limiting, and adapting to, climate change. To accelerate progress in limiting and preparing for climate change, the consortium needs to rapidly mobilize to support local climate action. It could inform implementation of a broad range of climate risk management strategies. Mitigation-related topics could include issues associated with managing carbon in the environment. For example, building on recent NCA products such as the recently released Second State of the Carbon Cycle Report (USGCRP 2018b), the consortium could assess standards for durable carbon sequestration; measurement, reporting, and verification of commitments; and the benefits and tradeoffs of managing different forms of carbon (soils, methane vs. carbon dioxide). Example adaptation topics would include improving preparations for overt climate threats; updating infrastructure for non-stationary conditions; addressing social and environmental justice considerations of climate change; and incorporating climate risk into budgeting.

Convene partners to establish the consortium and secure funding. To establish the consortium, prospective consortium partners will need to organize to establish a set of guiding principles (e.g., for participation and quality assurance), develop a business plan, evaluate organizational alternatives, and if necessary, incorporate a new entity.

Table 1. Overview of how "applied assessment" would extend the current National Climate Assessment process.

Current National Climate Assessment	Added Dimensions of Extended "Applied" Climate Assessment
Organized by sector and region	Organized by practitioner-defined challenges and problems, with attention to cross-sectoral interactions
Produces reports and other products	Supports sustained partnerships (e.g., communities of practice) and produces authoritative "tested practices" and information to support project implementation
Assesses vulnerabilities and risks	Adds assessment of applicability and usability of knowledge and support tools in different stages of implementing projects and improves access and guidance on their use for practitioners
Convened and governed by the federal government with inputs from science community	Coordinated by a consortium of states, local governments, tribes, and scientific/technical groups (research centers, professional societies, NGOs, CBOs) in collaboration with federal government

Information on initial leadership and engagement opportunities are provided at an interim website, www.climateassessment.org/. Resources will be required to support the governance process, a coordinating secretariat, and the activities and products of a consortium. Initially, a consortium would depend on contributions from visionary institutions, but following this start-up phase (expected to be three to five years), a self-sustaining long-term business model has been proposed but requires further development.

Recommendation #2: Assess knowledge in the context of how it is applied. To respond to needs identified by practitioners, the IAC advises that a new climate assessment consortium assess the quality and effectiveness of information and tools being applied to adaptation and mitigation. Assessments could be based on the practitioner input and independent analysis contained in the research literature and case studies. Table 1 summarizes how the applied climate assessment proposed here would complement and extend the current NCA process.

Focus on practitioner challenges. Assessments would address recurring challenges across state/local/tribal jurisdictions of the United States. Prioritizing challenges that recur in multiple locations would open the possibility of structured comparative analysis of how groups in these different places are developing information to support decision-making and implementation. More importantly, such a focus would provide practical benefits to a large number of practitioners. An assessment focused on practitioner challenges would be an efficient way to learn in order to scale up information services and identify innovation and research requirements.

Sustain partnerships through co-production and communities of practice. The mechanism and context for conducting these applied assessments would be a sustained and collaborative consensus process based on principles for effective engagement and co-production (Lemos et al. 2012; Fujitani et al. 2017). Co-production involves researchers and users alike and promotes mutual learning and growth for all participants, not just knowledge users (Meadow et al. 2015). Co-production increases knowledge use and allows for tailoring to specific needs of users. It also builds capacity and relationships for the production of usable knowledge and decision-making (Voorberg et al. 2015). As promising as co-production is, it is not a panacea, and additional work is required to understand effective practices (Lemos et al. 2018). Another model for sustaining partnerships is based on the concept of Communities of Practice (CoPs) (Probst and Borzillo 2008). CoPs share practical knowledge among individuals with a common interest who are separated by geography, expertise, or organization. They can build relationships, trust, and capacity and facilitate communication. In the context of the sustained assessment, CoP participants would evaluate information needed to implement solutions to shared challenges, as well as the scientific validity and usability of different approaches for meeting these information needs.

Assess information for implementation. Because practitioners indicate that action plans commonly stall at the implementation stage, the IAC explored structuring applied assessments around information needed and used in project implementation. Figure 2 provides a stylized depiction of an adaptive management process that a practitioner might use to plan and implement an adaptation or mitigation project. The

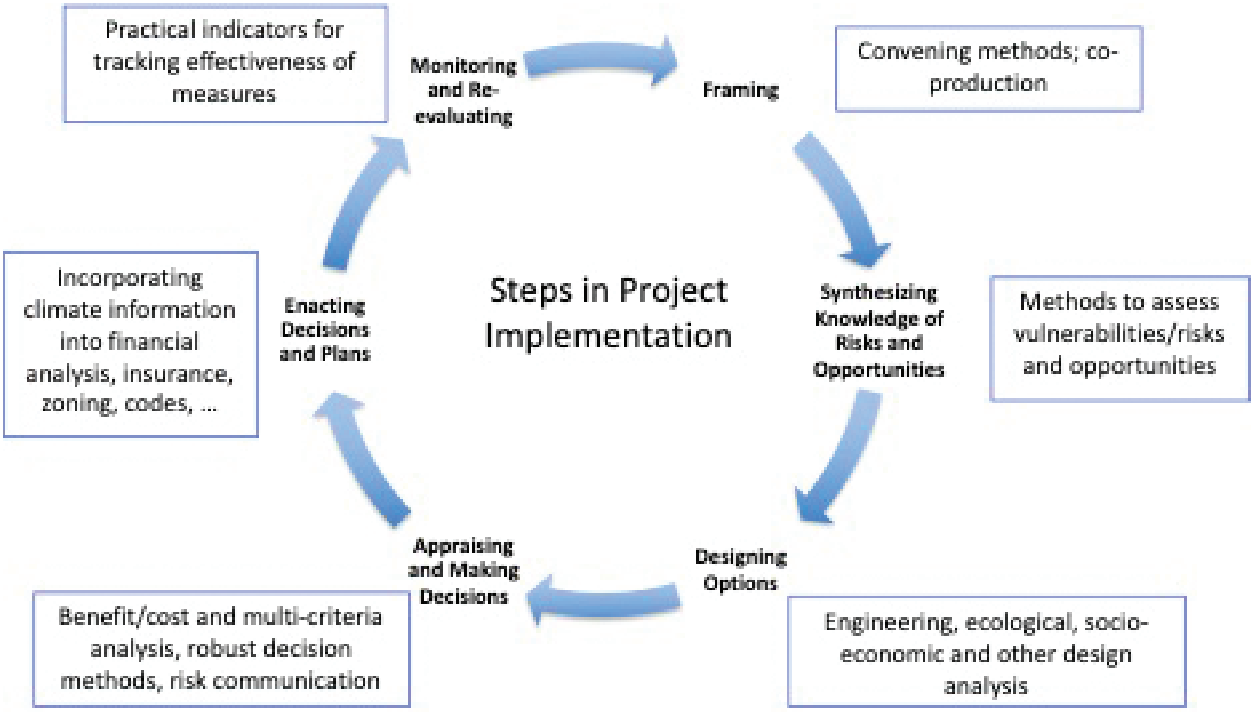

Fig. 2. These are the typical steps practitioners are likely to take—with the corresponding climate knowledge they would identify and assess at each step—in a process of implementing adaptation and mitigation. This is not a literal process, but it illustrates the range of issues that an applied assessment could address if it focused on evaluating information needed to frame a problem and implement solutions.

figure should not be interpreted literally but rather used to identify the different methods and types of information needed to frame problems, design options, make a decision, obtain financing, facilitate action through legal and financial incentives, and complete other implementation steps. The text boxes that ring the figure provide example topics that the applied assessment would explore.

Scale up a problem-focused national network. The proposed consortium would pilot a variety of approaches based on sustained dialogue and communication, sharing of experience and information, and rigorous assessment of competing methods. By starting with a small number of pilot projects, the consortium would analyze the effectiveness of its own efforts and develop a workable approach. Over time, it would establish additional CoPs and/or other processes for different goals or problems, leading to a distributed, sustained national effort focused on an array of high-priority adaptation and mitigation challenges.

The IAC acknowledges that standardization is not always desirable and can sometimes do more harm than good, as when tools unfit for a particular application lead to poor decisions. The applied climate assessment must experiment with strategies that lead to customization.

Recommendation #3: Advance methods for climate risk management. The IAC identifies six areas of opportunity for groups working in climate risk management to accelerate innovation and adoption of promising methods and technologies.

Evaluate climate information in the context in which it is used. A large array of climate information produced using a range of methodologies is freely available, including many methods for translating Global Climate Model (GCM) information from coarser- to finer-scale resolution. But different methods can appear to provide conflicting information or be inappropriate for a particular application (NAS 2012; USGCRP 2017a). Conversely, many locales do not have much or even any geographically specific, relevant data available. How can practitioners choose the information that is most suitable? Does the range of available information characterize legitimate scientific uncertainty and is it credible for a given application? This problem has been coined the "practitioner's dilemma" (Barsugli et al. 2013).

The IAC recommends increasing efforts to evaluate GCMs and the various methods of producing finer-scale climate information in the context of particular adaptation challenges to help users make informed decisions about what climate information and which analysis methods may be fit for particular adaptation challenges. This type of evaluation presents substantial scientific and technical challenges that have only recently begun to be addressed (Shepherd et al. 2018; Hackenbruch et al. 2017; CADWR 2015). Next steps include:

- Developing approaches for producing and evaluating climate science for applications that involve close coordination between scientific and user communities;
- Establishing a trusted and reliable process for providing ongoing guidance to the climate information user community regarding which means of producing climate information are suited to which kinds of adaptation challenges;
- Convening a multi-institutional and multidisciplinary technical committee to identify good practices, high-priority research gaps, standards for evaluating progress, and measures for promoting effective scientist-practitioner engagement; and
- Training and certifying a new generation of scientific and technical experts capable of effectively and ethically applying climate science in support of decision-making.

Assess methods for appraising adaptation and mitigation options and making decisions. Benefit-cost analysis (BCA) is often used to evaluate whether an adaptation or mitigation proposal's overall benefits are greater than its costs in the process of making decisions about financing and implementation. A range of tools and methods are available (e.g., Neumann et al. 2015; Moser et al. 2014; Cervigni et al. 2017; Ahouissoussi et al. 2014). As discussed in this report's findings, BCA generally fails to consider all relevant costs and benefits and is challenged by uncertainty, attitudes toward risk (especially regarding irreversible damages), questions about discount rates and time preference, and longer than usual time horizons. These shortcomings and the desire to consider the implications of uncertainty in climate projections have led to an interest in alternative risk-based decision-analysis frameworks for adaptation, such as robust decision-making (Hallegate et al. 2012) and multi-criteria analyses.

Building on insights from research, experience, and guidance documents on applying BCA methods, the IAC recommends:

- Assessing currently available tools and approaches and how they can be applied to support diverse adaptation decisions and actions in a special report and related guidance and training materials;
- Disseminating tools and knowledge—for example, by providing online access to spreadsheet tools, available climate scenarios and other relevant data, and by providing training; and
- Providing feedback to the research community, tool developers, and grant-making agencies and foundations about gaps in knowledge or capabilities to foster research on improving application of BCA to climate adaptation projects.

We note the importance of addressing the needs of staff and individuals in small communities (i.e., under 250,000 people) who lack technical expertise and resources to access even basic tools and methods.

Foster collaboration of local and national indicator initiatives. Indicators are seen as critical to support mitigation and adaptation planning and to evaluate the effectiveness of climate-related actions. The interest in locally driven indicator systems (e.g., NPCC 2015; NYC Office of the Mayor 2018; USDN 2016) follows on efforts to establish a National Climate Indicators System (NCIS) during and after the Third National Climate Assessment (e.g., Janetos et al. 2012; Buizer et al. 2013; Kenney et al. 2014; Kenney et al. 2016). The goal of the NCIS was to provide means to detect the status, rates, and trends of climate, environmental, and socioeconomic conditions. Implementation was to occur by piloting a subset of nationally relevant indicators first, then following up with a larger set, refining and adding indicators where necessary. Efforts to develop climate indicators and apply them have become widespread, and the need for such indicators is only growing as investors and other decision-makers seek to understand the effectiveness of potential interventions. To support these applications, research is needed to determine what indicators help communities in adaptation and to explore whether these indicators can be scaled up (aggregated) to provide useful information to support national scale assessments and decision-making.

The IAC recommends using the applied assessment process to examine the need for and use of locally developed indicators, and to identify potential convergence between national, regional, and local scale indicators that could shape the future direction of the NCIS. One option is to focus on urban infrastructure indicators as an initial test case, given their widespread relevance and potential for application. This pilot activity could, for example:

- Take stock of existing climate indicator efforts;
- Extend ongoing work on indicators and partner with local communities to establish a shared framework for further research and assessment;
- Conduct pilot urban infrastructure indicator studies using the shared framework, focusing on feasibility, applicability, and scalability;
- Analyze results from pilot studies and other ongoing initiatives to identify useful and feasible approaches for different local and regional settings, and to inform changes to the NCIS.

Accelerate the use of artificial intelligence to support climate resilience building. Artificial intelligence (AI) offers opportunities to change how society responds to climate risks and to improve resilience to climate change. Subdisciplines of AI, such as machine learning (ML) and robotics, have already been applied in climate science and engineering and are being used to identify impacts, insights, and options that would be difficult to otherwise discover (Ganguly et al. 2018). Recent advances have touched three broad areas: earth-systems science and modeling (Rasp et al. 2018); assessment and management of risks and adaptation (Chavez et al. 2015); and mitigation (Mascaro et al. 2014). ML depends heavily on the availability of volumes of heterogeneous data. Some of these data come from satellite remote sensors and large-scale numerical models that are openly shared, while adaptation-specific data, such as those for critical infrastructures and key natural resources, may be restricted due to privacy or security concerns.

Potential risks and challenges will need to be thoughtfully explored and addressed, including development of ethical principles to undergird development and adoption of AI applications (Floridi 2018). Challenges include maintaining transparency, transferring the capacity of individuals to act to automated processes, and societal resistance and restrictions on new technologies that can be seen as "taking over" interactions and environments.

- The IAC identifies opportunities for the applied assessment process:
- Convening and developing partnerships that include academia, the private and public sectors, and other groups to map applications related to climate risk management;
- Assessing actual usage in decision contexts, including the perspective of practitioners and citizens;
- Identifying applications that can be conducted in a test-bed mode to provide the greatest advancement in shared, scalable, actionable information; and
- Preparing a special report, potentially produced jointly with the federal NCA process, to synthesize knowledge and identify productive frontiers.

Launch a rigorous citizen and community science initiative to improve data on impacts and responses. In "citizen and community science," people who are not trained as scientists can participate in science. With their diversity and focus on real-world problems, citizen and community science programs are particularly promising for applying climate science to climate adaptation and mitigation (e.g., flooding in New Orleans or urban heat in New York City). The NCA3 report (Melillo et al. 2014) notes "There are opportunities to take advantage of citizen science observations…for data-poor regions, focusing on inadequately documented socioeconomic, ecological, and health-related factors, and under-observed regional and sectoral data." A recent NAS report also suggests that citizen science can be "a pathway for introducing new processes, observations, data, and epistemologies to science," including climate science (NAS 2018).

In spite of this potential, citizen and community science is currently underused in climate science and assessment. Increasing its use could help to fill many long-standing data gaps related to: local climate extremes and conditions; the impacts of these events; and needs for different types of adaptation measures. A particular opportunity is to document and improve understanding of the interactions of climate change with pre-existing challenges such as poor air and water quality, exposure to toxic wastes, lack of resources for coping and adapting, and other historical problems. Benefits of citizen science projects can include improving data, informing model development and solutions, monitoring results, and building community awareness and public engagement.

The IAC recommends that the applied assessment coordinate with citizen science groups and programs to expand the use of citizen science in climate risk management, prioritizing underserved regions and communities. A variety of near-term initiatives would support this broad effort:

- Assess current usage of citizen and community science in climate adaptation and mitigation;

- Develop standards and protocols to ensure rigor and consistency in data collection, including harnessing emerging technologies such as AI;
- Identify ways that citizen and community science provide local contextualization to supplement climate projections and models;
- Adapt the participatory methods of citizen and community science to enable climate research to inform community participation in climate policy debates;
- Use citizen and community science to better connect climate research to the short-and long-term priorities of historically underserved, marginalized, or oppressed communities.

Facilitate use of geospatial analysis. Geospatial analysis, including GIS and other mapping tools, enables practitioners to determine how climate extremes have impacted or will impact things they care about (such as property, infrastructure, and communities) as well as to explore the effectiveness and implications of adaptation options (for example, tradeoffs across ecosystem- and infrastructure-based approaches to flood control). GIS methods are particularly useful for integrating climate data (both observations and projections) with socioeconomic and environmental data on vulnerability and risk. Technological innovation has facilitated a transition from maps available at only national and regional scales to the provision of analysis, services, and reports at state, county, and municipal levels. Better and more accessible tools have some potential pitfalls including the potential to overlay unrelated data. There are also issues of access: large and medium-size cities can access these methods, but small cities, historically disadvantaged communities, and rural areas usually lack needed financial resources, capacity, or data.

The IAC recommends accelerating efforts to assess different methods and applications and develop tested practices on how to apply these tools in specific settings, specifically:

- Facilitate ongoing public-private partnerships with regional climate centers and adaptation professional groups and convene CoPs around specific mapping approaches;
- Collaborate with ongoing efforts to develop and apply a rigorous framework to assess practices and methods for applying geospatial data and tools to specific problems, building on the explosion of case studies and applications; and
- Prioritize capacity building and access to local climate assessments for small, historically disadvantaged, and rural communities.

CLOSING THOUGHTS AND NEXT STEPS. The IAC has identified a very ambitious agenda of initiatives that it believes can advance a sustained assessment and increase the application of climate science and knowledge by practitioners. Its central strategy is establishing a new and more inclusive applied assessment consortium. This approach is recommended for a variety of reasons, including the fact that the federal government alone cannot prepare the nation for change. The consortium would build on and augment federal climate assessments by synthesizing and evaluating knowledge from science, traditional ways of knowing, and collaborative learning from the experience of on-the-ground practitioners. The consortium would expand the scientific foundations for risk management by building on previous assessments. It would also address shared challenges and opportunities, including communication, engagement, and capacity building. The IAC urges a range of partners to join forces to address climate adaptation and mitigation issues, including the USGCRP and other federal programs and agencies, as well as the many non-federal groups working in this area.

REFERENCES

Ahouissoussi, N., J. E. Neumann, and J. P. Srivastava, 2014: Building resilience to climate change in the South Caucasus region's agricultural sector. World Bank Rep. 87601, 167 pp, https://doi.org/10.1596/978-1-4648-0214-0.

Barsugli, J. J., and Coauthors, 2013: The practitioner's dilemma: How to assess the credibility of downscaled climate projections. *Eos, Trans. Amer. Geophys. Union*, **94** (46), 424–425, https://doi.org/10.1002/2013EO460005.

Bedsworth, L., D. Cayan, G. Franco, L. Fisher, and S. Ziaja, 2018: California's fourth climate change assessment: Statewide summary report. Climate Assessment Rep. SUM-CCCA4-2018-013, 132 pp, www.climateassessment.ca.gov/state/docs/20180827-StatewideSummary.pdf.

Bierbaum, R., and Coauthors, 2014: Adaptation. Climate change impacts in the United States: The third National Climate Assessment, J. M. Melillo, T. C. Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 670–706, https://doi.org/10.7930/J0H12ZXG.

Buizer, J. L., P. Fleming, S. L. Hays, K. Dow, C. B. Field, D. Gustafson, A. Luers, and R. H. Moss, 2013: Preparing the nation for change: Building a sustained national climate assessment process. National Climate

Assessment and Development Advisory Committee (NCADAC) Rep., 73 pp, https://sncaadvisorycommittee.noaa.gov/Portals/0/Meeting-Documents/NCA-SASRWG_Report_Print.pdf.

CADWR, 2015: Perspective and guidance for climate change analysis. California Department of Water Resources Climate Change Technical Advisory Group Rep., 142 pp, www.water.ca.gov/LegacyFiles/climatechange/docs/2015/Perspectives_Guidance_Climate_Change_Analysis.pdf.

Cervigni, R., A. Losos, P. Chinowsky, and J. E. Neumann, 2017: Enhancing the climate resilience of Africa's infrastructure: The roads and bridges sector. World Bank Rep., 136 pp, http://documents.worldbank.org/curated/en/270671478809724744/Enhancing-the-climate-resilience-of-Africa-s-Infrastructure-the-roads-and-bridges-sector.

Chavez, E., G. Conway, M. Ghil, and M. Sadler, 2015: An end-to-end assessment of extreme weather impacts on food security. *Nat. Climate Change*, **5**, 997–1001, https://doi.org/10.1038/nclimate2747.

Fujitani, M., A. McFall, C. Randler, and R. Arlinghaus, 2017: Participatory adaptive management leads to environmental learning outcomes extending beyond the sphere of science. *Sci. Adv.*, **3**, e1602516, https://doi.org/10.1126/sciadv.1602516.

Ganguly, A. R., E. Kodra, U. Bhatia, M. E. Warner, K. Duffy, A. Banerjee, and S. Ganguly, 2018: Data-driven solutions. *Climate 2020: Degrees of Devastation*, United Nations Association, 82–85, www.una.org.uk/climate-2020-degrees-devastation.

GCRA, 1990: Global Change Research Act Public Law 101-606(11/16/90), 104 Stat. 3096-3104, www.gpo.gov/fdsys/pkg/STATUTE-104/pdf/STATUTE-104-Pg3096.pdf.

Hackenbruch, J., T. Kunz-Plapp, S. Müller, and J. Schipper, 2017: Tailoring climate parameters to information needs for local adaptation to climate change. *Climate*, **5** (2), 25, https://doi.org/10.3390/cli5020025.

Hallegatte, S., A. Shah, R. Lempert, C. Brown, and S. Gill, 2012: Investment decision making under deep uncertainty: Application to climate change. World Bank Policy Research Working Paper 6193, 39 pp, http://hdl.handle.net/10986/12028.

Hansen, L., R. M. Gregg, V. Arroyo, S. Ellsworth, L. Jackson, and S. Snover, 2012: The state of adaptation in the United States: An overview. EcoAdapt Rep., 118 pp, http://ecoadapt.org/programs/state-of-adaptation/US-state-of-adaptation.

IPCC, 2014: *Climate Change 2014: Mitigation of Climate Change*. O. Edenhofer et al., Eds, Cambridge University Press, 1435 pp, www.ipcc.ch/report/ar5/wg3/.

——, 2018: *Global Warming of 1.5°C*. V. Masson-Delmotte et al., Eds., World Meteorological Organization, 243 pp, www.ipcc.ch/report/sr15/.

Janetos, A. J., and Coauthors, 2012: National climate assessment indicators: Background, development, and examples. NCA3 Tech. Input Rep., 59 pp, https://doi.org/10.7916/D8RB7D2T.

Kania, J. and M. Kramer, 2011: Collective impact. *Stanford Social Innovation Review*, accessed 18 Feb 2019, https://ssir.org/articles/entry/collective_impact.

Kenney, M. A., and Coauthors, 2014: National climate indicators system report. National Climate Assessment Development and Advisory Committee (NCADAC), 157 pp, https://scholarworks.umt.edu/ntsg_pubs/376/.

Kenney, M. A., A. C. Janetos, and G. C. Lough, 2016: Building an integrated US National Climate Indicators System. *Climatic Change*, 135, 85–96, https://doi.org/10.1007/s10584-016-1609-1.

Klempin, S., 2016: Establishing the backbone: An underexplored facet of collective impact efforts. CCRC Research Brief, 60, 6 pp, https://drive.google.com/drive/u/0/folders/14UyST3pjqUw_IL1mc6bdUbrMdH6aeDpy.

Leiserowitz, A., E. Maibach, S. Rosenthal, J. Kotcher, M. Ballew, M. Goldberg, and A. Gustafson, 2018: Climate change in the American mind: December 2018. Yale Program on Climate Change Communication and George Mason Center for Climate Change Communication Rep., 49 pp, http://climatecommunication.yale.edu/publications/climate-change-in-the-american-mind-december-2018/.

Lemos, M. C., C. J. Kirchhoff, and V. Ramprasand, 2012: Narrowing the climate information usability gap. *Nat. Climate Change*, **2**, 789–794, https://doi.org/10.1038/nclimate1614.

——, and Coauthors, 2018: To co-produce or not to co-produce. *Nat. Sustainability*, **1**, 722–724, https://doi.org/10.1038/s41893-018-0191-0.

Mascaro, J., G. P. Asner, D. E. Knapp, T. Kennedy-Bowdoin, R. E. Martin, C. Anderson, M. Higgins, and K. D. Chadwick, 2014: A tale of two "forests": Random forest machine learning aids tropical forest carbon mapping. *PLOS ONE*, **9**, e85993, https://doi.org/10.1371/journal.pone.0085993.

Meadow, A. M., D. B. Ferguson, Z. Guido, A. Horganic, G. Owen, and T. Wall, 2015: Moving toward the deliberate coproduction of climate science knowledge. *Wea. Climate Soc.*, **7**, 179–191, https://doi.org/10.1175/WCAS-D-14-00050.1.

Melillo, J. M., T. C. Richmond, and G. W. Yohe, 2014: Climate change impacts in the United States: The third National Climate Assessment. U.S. Global

Change Research Program, 841 pp, https://doi.org/10.7930/J0Z31WJ2.

Moser, S. C., M. A. Davidson, P. Kirshen, P. Mulvaney, J. F. Murley, J. E. Neumann, L. Petes, and D. Reed, 2014: Coastal zone development and ecosystems. Climate change impacts in the United States: The third National Climate Assessment, J. M. Melillo, T.C. Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 579–618, https://doi.org/10.7930/J0MS3QNW.

Moss, R.H., and Coauthors, 2019: Evaluating knowledge to support climate action: A framework for sustained assessment. *Wea. Climate Soc.*, https://doi.org/10.1175/WCAS-D-18-0134.1, in press.

NAS, 2012: *A National Strategy for Advancing Climate Modeling*. National Academies Press, 294 pp, https://doi.org/10.17226/134.

Neumann, J. E., K. Emanuel, S. Ravela, L. Ludwig, P. Kirshen, K. Bosma, and J. Martinich, 2015: Joint effects of storm surge and sea-level rise on US coasts: New economic estimates of impacts, adaptation, and benefits of mitigation policy. *Climatic Change*, **129**, 337–349, https://doi.org/10.1007/s10584-014-1304-z.

NPCC, 2010: Climate change adaptation in New York City: Building a risk management response. *Ann. N.Y. Acad. Sci.*, **1196** (1), 354 pp., https://nyaspubs.onlinelibrary.wiley.com/toc/17496632/1196/1.

——, 2015: Building the knowledge base for climate resiliency. New York City Panel on Climate Change 2015 report. *Ann. N.Y. Acad. Sci.*, **1336** (1), 150 pp., https://nyaspubs.onlinelibrary.wiley.com/toc/17496632/1336/1.

NYC Office of the Mayor, 2018: Infrastructure and sustainability. Mayor's Management Rep., 257–286, www1.nyc.gov/assets/operations/downloads/pdf/mmr2018/2018_mmr.pdf.

Probst, G., and S. Borzillo, 2008: Why communities of practice succeed and why they fail. *Eur. Manage. J.*, **26**, 335–347, https://doi.org/10.1016/j.emj.2008.05.003.

Shepherd, T. G., and Coauthors, 2018: Storylines: an alternative approach to representing uncertainty in physical aspects of climate change. *Climatic Change*, **151** (3–4), 555–571, https://doi.org/10.1007/s10584-018-2317-9.

USDN, 2016: Developing urban climate adaptation indicators. Urban Sustainability Directors Network Rep., 24 pp., http://us.iscvt.org/wp-content/uploads/2017/01/Urban-Adaptation-Indicators-Guide-2.9.16.pdf.

USGCRP, 2017a: *Climate Science Special Report: Fourth National Climate Assessment (NCA4)*, Vol. 1, D. J. Wuebbles et al., Eds., U.S. Global Change Research Program, 470 pp, https://doi.org/10.7930/J0J964J6.

——, 2018a: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment (NCA4)*. Vol. 2, D. R. Reidmiller et al., Eds., U.S. Global Change Research Program, 1515 pp, https://doi.org/10.7930/NCA4.2018.

——, 2018b: *Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report*. N. Cavallaro et al., Eds., U.S. Global Change Research Program, 878 pp, https://doi.org/10.7930/SOCCR2.2018.

Vogel, J., and Coauthors, 2016: Climate adaptation: The state of practice in US communities. Abt Associates Rep., 260 pp, https://kresge.org/sites/default/files/uploaded/climate-adaptation-the-state-of-practice-in-us-communities-full-report.pdf.