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Understanding, Forecasting, and Communicating Extreme Weather in a Changing Climate

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on Science, Space, and Technology

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Thank you Chairwoman Johnson and Ranking Member Lucas for your invitation to testify on the urgent matter of extreme weather events and climate change. I am Ann Bostrom, Weyerhaeuser Endowed Professor of Environmental Policy in the Daniel J. Evans School of Public Policy at the University of Washington. I study risk perception, communication, and decision making under uncertainty in applied contexts like climate change and extreme weather, usually with interdisciplinary teams. In addition to climate change and extreme weather events, my research investigates other hazards, and the perception and communication of what we know and can do about the risks they pose, as well as scientific and management uncertainties. I also teach research methods, decision making, and environmental policy, with the aim of informing and improving the analysis and management of environmental and health risks. Achieving this requires advances in social and behavioral sciences along with advances in other sciences, and bridging science and society to ensure that investments in basic sciences are benefitting our communities. I have also contributed to National Academies reports that pertain to this hearing,

including *Communicating Science Effectively: A research agenda*[1], and I had the pleasure of co-chairing with the eminent William Hooke the National Academies 2018 report *Integrating Social and Behavioral Sciences Within the Weather Enterprise*.[2]

Changing perceptions, yet still unanticipated extremes

Thirty years ago in my first studies of climate change risk perception, communication and decision making, scientists and lay people voiced their expectations of more extreme weather as CO_2 emissions from our fossil fuel use warm the planet.[3] Our survey respondents in the early 1990's thought that a rise in mean sea level from climate change would increase the severity of storm surge incursions into coastal areas, but they did not anticipate that New York might flood.[4] When we replicated this survey a decade ago (2009), almost half (42%) of our respondents though it was true or possibly true that global warming would cause the ocean to flood all of the city of New York.[5] Seven years ago this October, superstorm Sandy flooded New York streets and subways, with climate change at least partly to blame.[6] The scientific evidence is now overwhelming that anthropogenic climate change has contributed to extreme weather events in

[1] National Academies of Sciences, Engineering, and Medicine. 2017. Communicating Science Effectively: A Research Agenda. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/23674

[2] National Academies of Sciences, Engineering, and Medicine. 2018. Integrating Social and Behavioral Sciences Within the Weather Enterprise. Washington, DC: The National Academies Press. https://doi.org/10.17226/24865

[3] Bostrom, A., Morgan, M.G., Fischhoff, B. and Read, D. "What do people know about global climate change?: 1. Mental models." Risk Analysis, 14(6), 959-970, 1994

[4] Read, D., Bostrom, A., Morgan, M.G., Fischhoff, B. and Smuts, T. "What do people know about global climate change?: 2. Survey studies of educated laypeople." Risk Analysis, 14(6), 971-982, 1994.

[5] Reynolds T.W., Bostrom, A., Read, D. and Morgan, M.G. "Now What Do People Know About Global Climate Change? Survey Studies of Educated Laypeople." Risk Analysis, 30(10), 1520-1538, 2010.

[6] Trenberth, K. E., Fasullo, J. T., & Shepherd, T. G. (2015). Attribution of climate extreme events. *Nature Climate Change*, *5*(8), 725.

recent years, increasing their severity and frequency.[7,8] Yet as suggested by the flooding in New York, the weather extremities climate change is bringing are still likely to exceed many plans and expectations.

Failures to forestall catastrophe: social and behavioral sciences insights and opportunities

Despite the phenomenally improved forecasts that government research investments have enabled over recent decades, we have failed to forestall catastrophic damages to many of our communities from hurricanes, floods, heatwaves, droughts, and wildfires. There is no single reason for this:

- Interdisciplinary policy research by economists and atmospheric scientists has estimated that hurricanes striking the U.S. cause over ten times the damage that would be caused by an equivalent storm striking another OECD country, due to lack of adaptation in the U.S.[9] In other developed countries, higher income tends to be associated with decreased damages, but not in the U.S.
- In a 2013 survey of U.S. residents in fire-prone areas who had faced fire events (including in Chelan County, WA, Horry County, SC, and Montgomery County, TX) most reported that they had decided to wait and see (65%), rather than evacuate early (24%); 11% had decided to stay and defend.[10] In this study, as in others, receiving an

[7] National Academies of Sciences, Engineering, and Medicine. 2016. *Attribution of Extreme Weather Events in the Context of Climate Change*. Washington, DC: The National Academies Press. doi: 10.17226/21852.
[8] According to Munich Re, the number of extreme weather events globally has more than tripled since the 1980s (https://natcatservice.munichre.com/events/1).
[9] Bakkensen, L.A. and Mendelsohn, R.O., 2016. Risk and Adaptation: Evidence from Global Hurricane Damages and Fatalities. Journal of the Association of Environmental and Resource Economists 3(3): 555-587
[10] McCaffrey, S., Wilson, R., & Konar, A. (2018). Should I stay or should I go now? Or should I wait and see? Influences on wildfire evacuation decisions. Risk analysis, 38(7), 1390-1404.

official cue, such as a voluntary or mandatory government evacuation notification, increased the odds of having evacuated. In the Camp fire, many Paradise residents never received an official evacuation order; 84 people died.

- In superstorm Sandy, despite accurate forecasts, 72% of the 240,000 residents living in mandatory evacuation zones in New Jersey decided to stay in their homes. Across the northeastern U.S. coastline, 117 people died in Sandy, with the most common cause of death being drowning. Half of these drownings were in flooded homes where mandatory evacuation orders were in place a day before the storm's landfall. Red Cross volunteers also noted about the superstorm Sandy drownings that people were "afraid of looters," "thought Hurricane Irene was mild," and "unable to leave because did not have transportation."[11]
- Despite the demonstrably increased influence of online and social media in this era,[12,13] police and fire were largely absent from online media during superstorm Sandy, and government largely absent from Twitter. [13]
- More than five million car crashes happen each year in the U.S., and weather contributes to over a fifth of them. Almost six thousand people are killed annually due to weather-related vehicle accidents, which is almost ten times the 600 adverse weather fatalities that are not related to vehicle accidents. While impressive advances have been made in

[11] CDC. (2013). Deaths associated with Hurricane Sandy—October-November 2012. Morbidity and Mortality Weekly Report, 62(20), 393. See the discussion in NASEM

[12] Demuth, J. L., Morss, R. E., Palen, L., Anderson, K. M., Anderson, J., Kogan, M., ... & Henderson, J. (2018). "Sometimes da# beachlife ain't always da wave": Understanding People's Evolving Hurricane Risk Communication, Risk Assessments, and Responses Using Twitter Narratives. Weather, climate, and society, 10(3), 537-560.

[13] Lachlan, K. A., Spence, P. R., Lin, X., & Del Greco, M. (2014). Screaming into the wind: Examining the volume and content of tweets associated with Hurricane Sandy. Communication Studies, 65(5), 500-518.

traveler information systems, these vary widely from state to state, suggesting the need for research on how best to convey the impact and risks of extreme weather events in these systems. Further, while there have been advances in crowd-sourced data and use of citizen reporting about road conditions, little is known about how drivers value and use them.[14]

- Decades of warning studies show that when a storm, heatwave or wildfire threatens people need to know what to do to be safe, how to do it, and the time until impact of the event. Should they evacuate? If so, how, and when? Where is it safe for them to drive? In addition to key content, the social and environmental contexts affect warning effectiveness, as do the source of the warning, characteristics of the person receiving the warning, and the message delivery method.[15] Although there is a substantial body of knowledge about what makes warnings effective, new challenges have emerged with Wireless Emergency Alerts (WEA), social media, and the entire rapidly evolving ecosystem of information and communication technologies and practices.
- People intuitively understand that there are uncertainties in weather forecasting. Further, the careful experimental research that has been conducted to date shows that people can make better decisions if they are given explicit uncertainty information based on the best scientific forecasts, and tailored to their decision context. They do not, however, always interpret visual and other forecast uncertainty information in the way that forecasters and emergency managers wish or expect.[16] Numerous studies and editorials have highlighted

[14] Chapter 4 in National Academies of Sciences, Engineering, and Medicine. 2018. Integrating Social and Behavioral Sciences Within the Weather Enterprise. Washington, DC: The National Academies Press.
[15] National Academies of Sciences, Engineering, and Medicine. 2018. Emergency Alert and Warning Systems: Current Knowledge and Future Research Directions. Washington, DC: The National Academies Press. https://doi.org/10.17226/24935
[16] Savelli S and Joslyn S. 2013. The advantages of predictive interval forecasts for non-expert users and the impact of visualizations. Appl Cognitive Psych 27:527–41. See the discussion in: Bostrom, A., Joslyn,

misinterpretations of the cone of uncertainty that the National Hurricane Center uses to show the probable track of the center of a tropical cyclone. For example, sometimes it is interpreted as the area likely to be affected. But less has been said about how specific misinterpretations influence decisions, which is as or more important to study and understand. There have been suggestions that it might be better to present a spaghetti-type diagram of multiple possible paths for the hurricane center. Presenting an ensemble of paths, that is, a suite of possible future paths, may reduce the tendency for people to see the cone itself as a spatial representation, for example of the size or intensity of the storm. But related research suggests an ensemble graphic could pose other challenges, such as people putting too much weight on a specific possible path.[17]

These examples illustrate a few of the ways that social and behavioral sciences can help identify where there are opportunities to save lives and property, and how to best realize those opportunities. To protect lives and property, and to realize the full value of the investments we've made in the physical sciences, we need to invest in the social and behavioral sciences of extreme weather and climate change.

S., Pavia, R. Hayward Walker, A., Starbird, K., & Leschine, T.M. (2015) Methods for Communicating the Complexity and Uncertainty of Oil Spill Response Actions and Tradeoffs, Human and Ecological Risk Assessment: An International Journal, 21:3, 631-645, DOI: 10.1080/10807039.2014.947867

[17] K. Broad, A. Leiserowitz, J. Weinkle, M. Steketee, Misinterpretations of the Cone of Uncertainty in Florida During the 2004 Hurricane Season, 88 Bulletin of the American Meteorological Society, 2007, pp. 651–667.

Ian T. Ruginski, Alexander P. Boone, Lace M. Padilla, Le Liu, Nahal Heydari,Heidi S. Kramer, Mary Hegarty, William B. Thompson, Donald H. House & Sarah H. Creem-Regehr (2016) Non-expert interpretations of hurricane forecast uncertainty visualizations, Spatial Cognition & Computation, 16:2, 154-172, DOI:10.1080/13875868.2015.1137577.

Wu, H. C., Lindell, M. K., & Prater, C. S. (2015). Strike probability judgments and protective action recommendations in a dynamic hurricane tracking task. Natural Hazards, 79(1), 355-380.

Beyond messaging individuals: integrating social and behavioral sciences throughout the weather enterprise

This research is needed to inform not only personal decisions and behaviors, like evacuation, but also the decisions of emergency management and planning organizations, and of the professionals who develop and operate our forecast and warning systems, and the professionals and volunteers who oversee and assist with response and recovery. Such research opportunities are illustrated in Figure 1, which is suggestive rather than comprehensive.

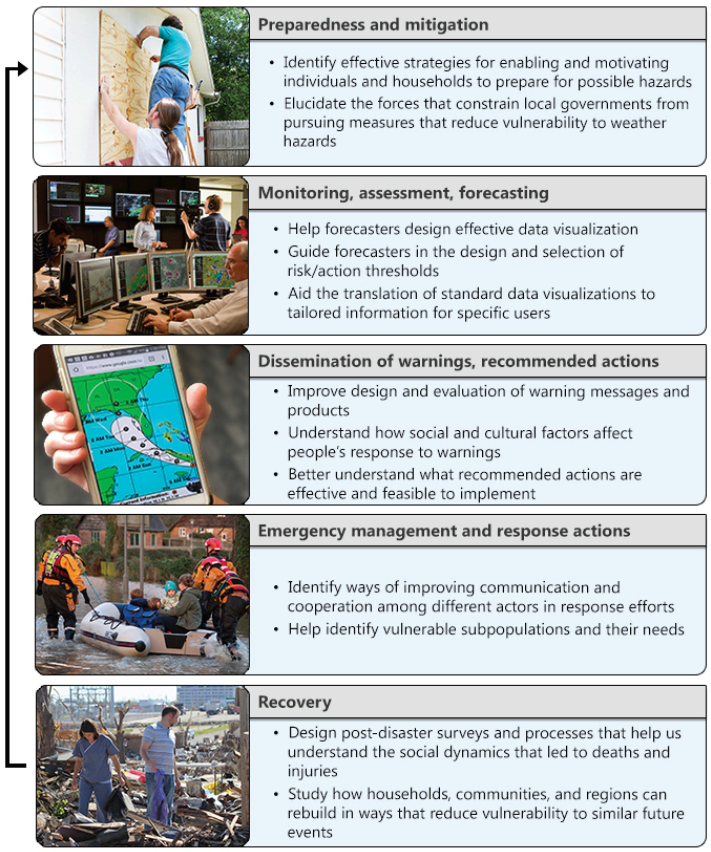

Figure 1. From the National Academies of Science, Engineering and Medicine report, Integrating social and Behavioral Sciences in the Weather Enterprise, Figure 2.1.[18] Stages of communication and decision support that must be addressed under the Weather Ready Nation paradigm, with examples of how social and behavioral sciences (SBS) research can provide critical insights and understanding in each of these stages.

[18] National Academies of Sciences, Engineering, and Medicine. 2018. *Integrating Social and Behavioral Sciences Within the Weather Enterprise*. Washington, DC: The National Academies Press.

People tend to be more prepared for an event when they have prior experience of it, but the type of experience they've had makes a difference.[19] While a plurality of people in the U.S. have long thought climate change will lead to more extreme weather events, their experiences may not be predictive of the weather extremities climate changes will bring. In my home state of Washington, the Climate Impacts Group has highlighted 2015 as a year that may presage climate change. In 2015 snowpack was 70% below normal, leaving the state with irrigation shortages, agricultural losses, fish die-offs, and problems stemming from the state's reliance on hydropower. More shocking for residents was the wildfire, as 2015 was the most severe wildfire season on record for the state.[20] In a more recent example of unexpected extremes, in Texas, tropical depression Imelda dumped three feet of rain in 24 hours, which caught people by surprise, despite Harvey.

Much remains to learn about how best to communicate forecasts and forecast uncertainties in these circumstances. There is a very large need for additional empirical research on communicating uncertainty for different decision contexts, research that brings social, behavioral, and other scientists together to determine how climate and weather information can

[19] E.g., Lazo, J. K., Bostrom, A., Morss, R. E., Demuth, J. L. and Lazrus, H. (2015). Factors Affecting Hurricane Evacuation Intentions. Risk Analysis, 35:10, 1837–1857. doi: 10.1111/risa.12407

[20] Engel, R. A., Marlier, M. E., & Lettenmaier, D. P. (2019). On the causes of the summer 2015 Eastern Washington wildfires. *Environmental Research Communications*, *1*(1), 011009.

Snover, A.K., C.L. Raymond, H.A. Roop, H. Morgan, 2019. "No Time to Waste. The Intergovernmental Panel on Climate Change's Special Report on Global Warming of 1.5°C and Implications for Washington State." Briefing paper prepared by the Climate Impacts Group, University of Washington, Seattle. Updated 02/2019

May C., C. Luce, J. Casola, M. Chang, J. Cuhaciyan, M. Dalton, S. Lowe, G. Morishima, P. Mote, A. Petersen, G. Roesch-McNally, and E. York, 2018: Northwest. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lew¬is, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1036–1100. doi: 10.7930/NCA4.2018.CH24

most effectively be integrated, analyzed and delivered to help forecasters, emergency managers, planners, drivers—indeed, all of us—make better decisions.

Building leadership and capacity

The *Weather Research and Forecasting Innovation Act of 2017* (Pub.L. 115-25) as amended by the *National Integrated Drought Information System Reauthorization Act of 2018* (Pub. L. 115-423) is a big step in the right direction, including, for example, specific attention to "Improving the understanding of how the public receives, interprets, and responds to warnings and forecasts of high impact weather events that endanger life and property" [Section 102(b)(2)]; incorporating risk communication research to create more effective hurricane watch and warning products [Section 104(b)(3)]; and mandating collaboration between the public and private sectors to identify the research necessary to enhance the integration of social science knowledge into weather forecast and warning processes, in Section 105(4)).

The National Science Foundation, the National Oceanic and Atmospheric Administration, and other agencies appear to have increased their investments in social and behavioral sciences addressing weather hazards over the last decade, but these investments have been highly variable, and have constituted only a very small proportion – on the order of less than 10% -- of their weather-related research investments to date. Such investments have funded pilot programs like the Collaborative Adaptive Sensing of the Atmosphere (CASA) Dallas-Fort Worth Living Lab program, which provides timely, tailored, human-scale forecasts on personal devices, and collects input from users to achieve continuous improvement. While recent initiatives such as *Convergence,* and *Coastlines and People (CoPe),* at the National Science Foundation appear promising, other more obviously closely related funding initiatives, such as Hazards Science, Engineering and Education for Sustainability (SEES), have ended. The

investments to date have not comprised the sustained resources required to achieve the advances our nation needs from the social and behavioral sciences in the interdisciplinary domain of weather and climate hazards and risks, or to encourage newly trained scholars to commit to work in it.

In order to fully realize these and other life-saving advances nationally and to achieve international leadership on understanding, forecasting and communicating extreme weather and climate will require **scientific leadership** and **capacity building** in the social and behavioral sciences across the public and private sectors, as well. Congressional support is essential. Successfully integrating social and behavioral sciences into an agency or other organization requires senior-level agency leadership,[21] high-level staff to coordinate top-down, bottom-up staff-led working groups, and a commitment to building and sustaining social and behavioral science capacity, through both professional development as well as education, training, and hiring. Detailed suggestions on each of these points can be found in the National Academies 2018 report on Integrating Social and Behavioral Sciences in the Weather Enterprise.

[21] Fischhoff, B. (2017). Breaking ground for psychological science: The US Food and Drug Administration. American Psychologist, 72(2), 118.