NATIONAL ACADEMIES *Sciences Engineering Medicine*

Enabling US Leadership in Artificial Intelligence for Weather

Board on Atmospheric Sciences and Climate Spring Board Meeting

May 13, 2024

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NATIONAL ACADEMIES Sciences Engineering Medicine

BOARD ON ATMOSPHERIC SCIENCES AND CLIMATE

Enabling US Leadership in Artificial Intelligence for Weather

Board on Atmospheric Sciences and Climate Spring 2024 Meeting

MAY 13, 2024

Virtual | **National Academy of Sciences Building** (2101 Constitution Ave NW Washington DC, 20418)

Additional information available on the event page

Advances in artificial intelligence (AI) are rapidly transforming the landscape for weather forecasting—expanding prediction capabilities and presenting new challenges for ensuring forecasts are trustworthy. The Board on Atmospheric Sciences and Climate (BASC) spring meeting will provide an overview of the current landscape of weather and AI in the US today, and the resources needed for the US to lead in this space in the future; consider cross-sectoral perspectives on developing trustworthy AI-informed weather forecasts for different end users; and explore opportunities and challenges of facilitating novel partnerships across academia, government, and industry.

10:30–10:45 **Introduction and Overview of AI and Weather Forecasting**

Amy McGovern, Elizabeth Barnes, and **Brad Colman**, BASC Board Members

10:45–12:15 **Session 1: Integrating AI into Weather Forecasting: Opportunities for Federal Leadership**

Moderator: Mary Glackin, BASC Chair

8-10-minute remarks + 10 minute Q&A for each speaker

- **Tsengdar Lee**, National Aeronautics and Space Administration (NASA)
- **Gary Geernaert**, Department of Energy
- **Eric DeWeaver**, National Science Foundation
- **Isidora Jankov**, National Oceanic and Atmospheric Administration (NOAA)

12:15–13:15 **Lunch**

13:15–15:15 **Session 2: Developing Trustworthy AI-informed Weather Forecasts for End Users**

Moderators: Elizabeth Barnes and Amy McGovern, BASC Members

Panel 1: Focus on Utilizing AI Tools to Enhance Forecast Capabilities

7-minute talks + 20 minutes Q&A/discussion

- **Chris Karstens**, NOAA
- **Jason Levit**, NOAA
- **Tom Hamill**, The Weather Company
-

Panel 2: Focus on Trust in AI for Weather Forecasts

7-minute talks + 20 minutes Q&A/discussion

- **Reva Schwartz**, National Institute of Standards and Technology
- **Ann Bostrom**, University of Washington

- **William Livingston**, University of Oklahoma
- **Scott Mackaro**, Vaisala Xweather

25-minute discussion with all Session 2 panelists

15:15–15:30 **Break**

15:30–16:20 **Session 3: Facilitating Novel Partnerships Across Sectors**

Moderators: Brad Colman and Andrea Lopez Lang, BASC Members

5-minute lightning talks + 25 minutes Q&A/discussion with all speakers

- **Matthew Chantry**, European Centre for Medium-Range Weather Forecasts
- **Daniel Rothenberg**, OpenEarthAI
- **Ryan McGranaghan**, NASA Jet Propulsion Laboratory
- **John Kreider**, Kreider Consulting LLC/NOAA Science Advisory Board
- **Angel Farguell**, San Jose State University

16:20–16:30 **Synthesis and Closing Remarks**

Amy McGovern, Elizabeth Barnes, and **Brad Colman**, BASC Board Members

16:30 **ADJOURN**

Guidance for Asking Questions Via Slido

How to join the conversation

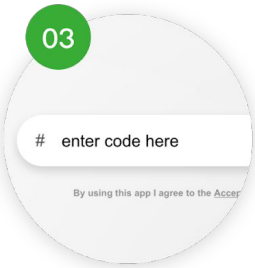
Access the link directly: https://app.sli.do/event/daPBZKAAwkQivkA3LdTxRe

OR

Go to slido.com and enter the event code: **# AI4Weather**

Open browser

Go to slido.com



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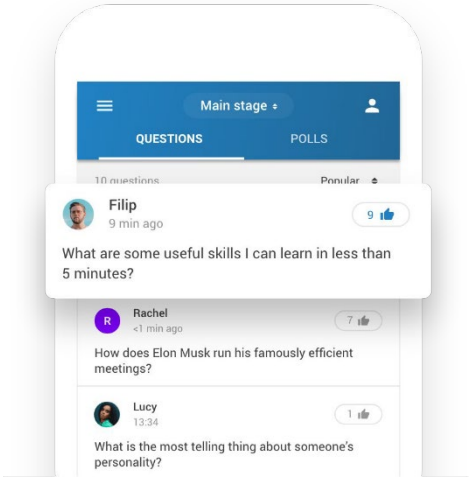
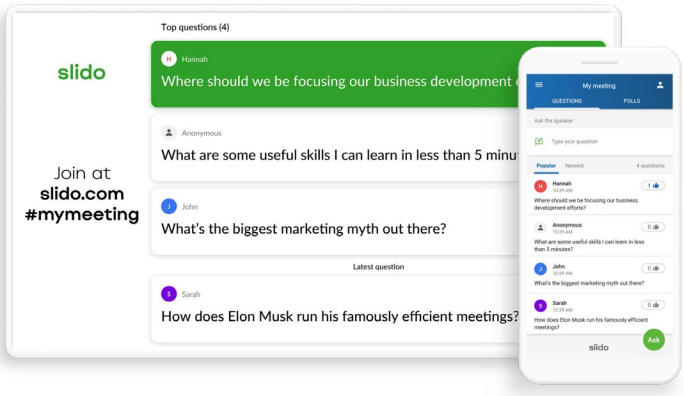


Questions and votes will appear in real-time on an interactive wall



For more information: https://community.sli.do/

Speaker Bios

Ann Bostrom is the Weyerhaeuser endowed Professor in Environmental Policy at the Evans School of Public Policy & Governance, University of Washington, Seattle. She studies risk perceptions, risk communication, and mental models of hazards: how people understand and make decisions under uncertainty about, for example, climate change, extreme weather, and earthquakes. She co-directs the NSF-funded Cascadia Coastlines and Peoples Hazards Research Hub and co-leads risk communication research in the NSF Artificial Intelligence (AI) Institute for Research on Trustworthy AI in Weather, Climate and Coastal Oceanography. Bostrom co-chaired the National Academies of Sciences, Engineering, and Medicine consensus report on Integrating Social and Behavioral Sciences Within the Weather Enterprise, and contributed to Communicating Science Effectively: A Research Agenda. She also served as the task team co-lead for the NOAA Science Advisory Board 2021 report on “Priorities for weather research."

Matthew Chantry is a Machine Learning Coordinator at the European Centre for Medium-Range Weather Forecasts (ECMWF). Chantry’s work at ECMWF focuses on the use of machine learning in generating forecasts and comparing the accuracy of AI models such as WeatherBench, Pangu-Weather and FourCastNet and with conventional Numerical Weather Prediction (NWP) models. Prior to joining ECMWF in 2021, Chantry was a Postdoctoral Research Associate at the University of Oxford where he assessed where developments in machine learning, and associated hardware, have value in improving weather and climate forecasting. Chantry holds a PhD in applied Mathematics from the University of Bristol and a Master of Mathematics from the University of St. Andrews.

Eric DeWeaver is a Program Director for the NSF Climate and Large-scale Dynamics Program, which funds research on atmospheric circulation from synoptic to planetary scales as well as the dynamical processes that determine mean climate, climate variability, and the response of the climate system to external forcing. Eric’s primary task is managing the review process for proposals submitted to the program. He is also the primary point of contact at NSF for the Community Earth System Model (CESM), the Center for Learning the Earth with Artificial intelligence and Physics (LEAP, a Science and Technology Center based at Columbia University), and the COSMIC radio occultation group at UCAR. He has served in the CLD program since 2009.

Angel Farguell is a post-doctoral research associate working at the San José State University as part of the Wildfire Interdisciplinary Research Center, a National Science Foundation Industry-University Cooperative Research Center (IUCRC). He holds a B.S. in Mathematics, an M.S. in Modeling for Science and Engineering, and a Ph.D. in Computer Science from the Universitat Autònoma de Barcelona (Spain). His main research interests focus on coupled atmosphere-fire modeling, statistical learning, remote sensing, and geographic information systems. He is a co-developer of the coupled atmosphere-fire model WRF-SFIRE, as well as the fire forecasting system WRFx, which is capable of real-time wildfire forecasting and prescribed burn applications. He is currently working on multiple projects improving the WRFx system and WRF-SFIRE, as well as applying artificial intelligence methods to support fire-atmosphere simulations using remote sensing data conducted by the WIRC fire modeling group.

Gary Geernaert is Director, Climate and Environmental Sciences Division, in the Office of Biological and Environmental Research, Office of Science, US Department of Energy. With a budget of approximately $310M, he oversees DOE funding to research projects carried out by Universities and National Laboratories. In addition, he is the federal official responsible for two DOE scientific user facilities, i.e., the Atmospheric Radiation Measurement (ARM) research facility and the Environmental Molecular Science Laboratory (EMSL). Besides his DOE duties, Geernaert serves as Vice-Chair of the US Global Change Research program and is

DOE principal to three other NSTC Subcommittees. Dr. Geernaert earned a B.S. degree in Atmospheric Sciences from the University of California, Davis; and he received a PhD degree in Atmospheric Sciences from the University of Washington. Before joining DOE in 2010, Dr. Geernaert spent 8 years as Director, Institute of Geophysics and Planetary Physics, at Los Alamos National Laboratory (LANL); prior to LANL, he spent 8 years as Director, Atmospheric Environment Department, Danish National Environmental Research Institute. Geernaert's other responsibilities have included national (Danish) representative to the Nordic Council of Ministers Air-Sea Policy Group; President, Danish Atmospheric Research Society; and Program Manager at the US Office of Naval Research. As a practicing scientist, he conducted research at the US Naval Research Laboratory, Scripps Institute of Oceanography, and Danish National Environmental Research Institute. He has written and published 4 technical books and over 100 journal articles and reports throughout his career; and he is a Fellow of the American Meteorological Society.

Tom Hamill joined The Weather Company two years ago and is its Head of Innovation, responsible for their deep learning NWP development and collaborations. Prior to that, Tom spent more than two decades with NOAA Research working on all things ensemble, from data assimilation to reanalysis and reforecasting to statistical postprocessing, forecast verification, and methods of treatment of model uncertainty. Tom has been a frequent visitor to ECMWF and has served in the World Meteorological Organization on the Working Group for Numerical Experimentation and as the co-chair of the Data Assimilation and Observing Systems working group.

Isidora Jankov is the Deputy Chief of the Earth Prediction Advancement Division and Chief, Scientific Computing and Novel Architectures Branch at NOAA. Her research is mainly focused on ensemble-based data assimilation, the design of ensemble forecasting systems, and ensemble statistical post-processing. As a part of research related to an ensemble forecasting design, for both data assimilation and ensemble forecasting application, Jankov have been extensively involved in the development and testing of the stochastic physics application within HRRR Ensemble (HRRRE) and HRRR DA system (HRRRDAS). The evaluated stochastic approaches have been proven as beneficial and have been recommended, upon further evaluation, for inclusion into the next-generation Rapid Refresh Forecasting System (RRFS). Additional data assimilation activities include the development of approaches and algorithms for dynamical localization of background error covariance matrix. Jankov was previously the HPC Branch Chief and Scientist of the Advanced Technology Division, and the Scientist III/Project Lead/Data Assimilation Liaison for the Cooperative Institute for Research in the Atmosphere (CIRA) at NOAA.

Chris Karstens has been a Techniques Development Meteorologist at the Storm Prediction Center (SPC) since 2017. His research involves developing a variety of tools that allow SPC forecasters to do their job better, and plays a key role in transitioning and supporting such tools for daily use by SPC forecasters. His interests include the application of SPC products and information residing within the watch/warning gap and working with both the physical and social science research communities in those efforts. Dr. Karstens has served as an Affiliate Associate Professor with the OU School of Meteorology since 2016. Chris has been involved in the American Society of Civil Engineers Wind Speed Estimation in Tornadoes Standards Committee since 2014 as a steering committee member, voting member and subcommittee chair. He earned his Bachelors, Masters and Ph.D. degrees from Iowa State University.

John Kreider has 50 years' experience as an ocean engineer and leader developing and operating mission-critical ocean systems and performing projects in unforgiving environments for commercial and government customers. Through 2018, Mr. Kreider was Senior Vice-President of Oceaneering Advanced Technologies (ADTECH) and an Executive Officer of Oceaneering International, Inc. In this position, he led an organization of 1500 employees and had broad P&L responsibility for all non-oilfield businesses, including manned and unmanned projects in space, undersea, and on land. Prior to Oceaneering, he was Vice-President at two small firms and manager at Shell Development Company. Mr. Kreider has chaired the NOAA Science

Advisory Board since 2020 and previously chaired the NOAA Ocean Exploration Advisory Board. He also serves as a Trustee on the Board of Woods Hole Oceanographic Institution and on the advisory board of Aegis Aerospace. He is an avid fly fisherman and diver, and with his wife enjoys time with their two sons and five grandchildren.

Tsengdar Lee is the Program Manager for the R&A Weather Focus Area, the High-End Computing Program, and for NASA's Data for Operation and Assessment. For the Weather Focus Area, he is responsible for the advanced planning for the weather research and development priorities. He is also the manager of the NASA Weather Data Analysis Program, focusing on the transition of research results into the operational forecast centers and the acceleration of operational use of research data. Two major activities include the multi-agency Joint Center for Satellite Data Assimilation and the Short-term Prediction Research and Transition Center. For the High-End Computing Program, he is responsible for maintaining the high-end computing capability to support the agency's aeronautics research, human exploration, scientific discovery, and space operations missions. Dr. Lee serves as co-chair for the Interagency Weather Research Coordination Committee (IWRCC). Lee joined NASA in 2001 as the High-End Computing Program Manager for the Earth Science Enterprise. He was responsible for the Earth science computational modeling needs, primarily focusing on weather and climate modeling. Between 2002 and 2006, Lee also managed the Earth Science Global Modeling Program. He funded research efforts to study the global climate change, weather forecasting, and hurricane prediction problems.

Jason Levit is the Chief of the Verification, Product Generation, and Product Generation Branch at the NOAA Environmental Modeling Center. Prior to joining EMC in 2017, he has worked at various research and development positions within the federal government, academia, and the private sector since graduating with a B.S. and M.S. in Meteorology from the University of Oklahoma in 1996 and 1998, respectively.

William Livingston serves as a Postdoctoral Research Associate at the Institute for Public Policy Research and Analysis, University of Oklahoma. His research primarily explores the interface between Public Policy and advanced technology, focusing on Artificial Intelligence and nuclear energy. Dr. Livingston holds a Ph.D. in Public Policy from the University of Oklahoma, where he developed a profound understanding of technological impacts on policy formulation and implementation. His work is aimed at bridging the gap between technological advancements and policy-making, ensuring sustainable and ethical integration of emerging technologies in society.

Scott Mackaro (Ma – care – oh) is the Head of Insights and Innovation for Vaisala. He is an established leader in the Atmospheric Science community, specializing in areas of predictive modeling, machine learning, and environmental monitoring. At Xweather, he brings together science, business, and technology to develop innovative solutions to some of humanity's greatest challenges. Mackaro received his Bachelor of Science degree in Meteorology from Millersville University of Pennsylvania in 2001 and his Master of Science and Doctor of Philosophy degrees from the University of Alabama in Huntsville in 2003 and 2008 respectively.

Ryan McGranaghan is a Data Scientist and Research Scientist at the NASA Jet Propulsion Laboratory, where he works with the Machine Learning and Instrument Autonomy group to apply data science techniques robustly and responsibly for breakthrough discovery in the Earth and Space Sciences, to cultivate cross-institution collaborations, and to explore more cohesive and plural scientific communities. In all of his work, Ryan takes a multi-disciplinary approach, bringing together traditional scientific inquiry with innovation from the fields of data science and sociology. Ryan's belief in transdisciplinarity and openness extends beyond science and into society, moonlighting as the creator, producer, and host of The Origins Podcast, and the founder and facilitator of The Flourishing Salons, gatherings that embrace liminality and plurality of thought and give rise to new connections, communities, and capabilities for flourishing systems. Ryan's transdisciplinary passions have led to involvement across many remarkable groups, executive councils, working groups, and steering committees,

filtered mostly by those that adopt an ethos of radical openness, transdisciplinarity, and creation.

Daniel Rothenberg is an atmospheric scientist and co-founder of OpenEarthAI. Following his PhD and post-doctoral work at MIT, Dr. Rothenberg served as the Chief Scientist of Tomorrow.io, where he led an applied research team to develop and operationalize novel techniques for sensing and forecasting the weather using non-traditional observations such as terrestrial microwave telecommunications. He later served as a Technical Lead at Waymo, working to develop ways for autonomous vehicles to sense the weather and ultimately achieve safe driving in all-weather and road conditions; he also collaborated on AI-for-weather applications at Google Research as a Staff Software Engineer. As a co-founder of OpenEarthAI, he is working to develop new and powerful approaches leveraging AI for analyzing and forecasting weather and climate. Dr. Rothenberg has also advocated for and contributed to the development of open-source tools for large-scale weather and climate data analysis through the Pangeo community.

Reva Schwartz is a research scientist in the Information Technology Laboratory (ITL) at the National Institute of Standards and Technology (NIST) where she serves as Principal Investigator on Bias in Artificial Intelligence for NIST's Trustworthy and Responsible AI program. Her research focuses on evaluating the societal impacts of AI systems, improving organizational practices, and driving understanding of socio-technical systems within computational environments. Her background includes a forensic science posting for almost 15 years at the United States Secret Service and adjunct researcher at the Johns Hopkins University Human Language Technology Center of Excellence. She has advised federal agencies about how experts interact with automation to make sense of information in high-stakes settings.

Board on Atmospheric Sciences and Climate (BASC)

WHO WE ARE

The issues addressed by BASC are at the forefront of contemporary concerns. Climate change and impacts, global climate models and the implications of their results, air pollution, and severe weather are topics discussed not just by scientists, but in Congress and in headlines every day. Our understanding of these issues directly affects the nation's environmental policies, energy choices, manufacturing decisions, construction codes, and agricultural methods. In addition, there are implications for human health and emergency management. BASC's interests include:

- advancing methodologies and technologies for supporting weather and climate science;
- enhancing structure, operation, and optimization of weather and climate observing and forecasting systems and approaches;
- improving understanding and prediction of weather and climate variability and related impacts on society;
- understanding climate variability, change, impacts, and adaptation;
- understanding atmospheric composition and chemistry, including transport and impacts of air pollution;
- facilitating research on atmospheric/land interactions, atmospheric/ocean interactions, and atmosphere/cryosphere interactions;
- advancing methods to communicate uncertainty in weather and climate information;
- improving understanding of atmospheric and climate sciences (including supporting technologies and services) and helping make this understanding relevant to national needs.

HOW BASC WORKS

BASC carries out its mission through the activities of volunteer committees and panels charged with providing independent advice on critical scientific issues, from narrowly defined, highly technical problems to broad public policy concerns. Studies are undertaken at the request of federal agencies, Congress, or other sponsors, or upon the BASC's own initiative. The end product can take many forms, but most often consists of written reports with careful conclusions and recommendations.

BASC activities are overseen by a volunteer Board of experts selected for their breadth and depth of knowledge and experience. They come from academia, industry, and government, and offer a diverse range of expertise and perspectives in fields such as climatology, atmospheric chemistry, meteorology, oceanography, and the social sciences. BASC members usually meet two times a year to review the progress of ongoing projects, consider topics for future study, and discuss issues with members of the atmospheric science and climate communities.

SOURCES OF SUPPORT

BASC receives support from the National Science Foundation, the National Oceanic and Atmospheric Administration, and the National Aeronautics and Space Administration. Individual projects receive support from these and other sources.

CONTACT BASC

National Academies of Sciences, Engineering, and Medicine
500 5th St NW, Washington DC 20001
https://www.nationalacademies.org/basc

Standing Activities

- Advice to the U.S. Global Change Research Program
- Climate Security Roundtable
- Roundtable on Macroeconomics and Climate-Related Risks and Opportunities

Current Activities

Consensus Studies

- Atmospheric Methane Removal: Development of a Research Agenda
- Modernizing Probable Maximum Precipitation Estimation
- Potential Environmental Effects of Nuclear War
- Developing a Strategy to Evaluate the National Climate Assessment
- Review of Draft Chapters of the National Biodiversity and Climate Change Assessment

Workshops

- Greenhouse Gas Emissions from Wildland Fires: Toward Improved Monitoring, Modeling, and Management
- Integrating Public and Ecosystem Health Systems to Foster Resilience
- Advancing Risk Communication with Decision-Makers for Extreme Tropical Cyclones: Learning from Extreme and Unprecedented Weather Events

Selected Recent Reports

- Review of the Draft Fifth National Climate Assessment (2023)
- Greenhouse Gas Emissions Information for Decision Making (2022)
- Biodiversity at Risk: Today's Choices Matter (2022)
- Global Change Research Needs and Opportunities for 2022-2031 (2021)
- Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance (2021)

BASC Board Member Bios

Mary Glackin (*Chair*) is the Past-President of the American Metrological Society (AMS). She is currently the Co-Chair of the Ocean Research Priorities Panel to the U.S. government. From 2015-2019 she was the Vice President for Weather Business Solution at The Weather Company, an IBM Business. Glackin had a long and distinguished career in public service, including 20 years in the National Weather Service and a five-year tenure as Deputy Under Secretary of Commerce for National Oceanic and Atmospheric Administration operations. She is an honorary member of AMS. Glackin received a B.S. in computer science from the University of Maryland. She previously Co-Chaired the National Academies of Sciences, Engineering, and Medicine's Committee on Sustaining Ocean Observations to Understand Future Changes in Earth's Climate

Joseph Árvai is the Dana and David Dornsife Professor of Psychology, Professor of Biological Sciences, Professor of Environmental Studies, and Director of the Wrigley Institute for Environment and Sustainability in the Dornsife College of Letters, Arts and Sciences at the University of Southern California. His research unfolds on two fronts: First, Árvai and his research team conduct interdisciplinary research aimed at improving our understanding of how people instinctively—and often in a biased fashion—approach judgment and decision-making in situations where environmental, social, and economic priorities intersect. Second, Árvai and his team develop and test critical reasoning and decision-support tools aimed at helping policy-makers, business leaders, and consumers to make better, science-based judgments and choices. He is a member of the U.S. Environmental Protection Agency's Science Advisory Board. Árvai received a Ph.D. in judgment and decision-making, an M.S. in oceanography, and a B.S. in ecology from the University of British Columbia. He previously served on the National Academy of Sciences, Engineering, and Medicine's Board on Environmental Change and Society.

Cynthia Atherton was most recently the director of the Science program at the Heising-Simons Foundation, where she oversaw a portfolio of research in climate change science, physics and astronomy, as well as an initiative to increase the number of women in physics and astronomy in the U.S. research academy. She was previously a science program director at the Gordon and Betty Moore Foundation, where she oversaw portfolios that included astronomy, condensed matter physics, seismology, and other physical sciences. She conducted research in atmospheric chemistry and physics at the Lawrence Livermore National Laboratory prior to joining the Moore Foundation. Atherton received a B.S. in engineering and applied science from the California Institute of Technology, M.S. in chemical engineering from the Massachusetts Institute of Technology and Ph.D. in atmospheric science from the University of California, Davis.

Elizabeth Barnes is a Professor of Atmospheric Science at Colorado State University. Barnes' research is largely focused on climate variability and change and the data analysis tools used to understand them. Topics of interest include earth system predictability, jet-stream dynamics, Arctic-midlatitude connections, sub-seasonal-to-decadal prediction, and data science methods for earth system research, with an emphasis on explainable machine learning. In addition to being a lead of the U.S. Climate Variability and Predictability Working Group: Emerging Data Science Tools for Climate Variability and Predictability and a funded member of the National Science Foundation (NSF) Artificial Intelligence Institute for Research on Trustworthy AI in Weather, Climate and Coastal Oceanography, Barnes recently finished led the National Oceanic and Atmospheric Administration Modeling, Analysis, Predictions and Projections Program Subseasonal to Seasonal Prediction Task Force. She received the American Geophysical Union's (AGU) Macelwane Medal and became a Fellow of the AGU in 2021, received the AGU Turco Lectureship for 2020, the American Meteorological Society Clarence Leroy Meisinger Award for 2020, an NSF CAREER grant in 2018, the George T. Abell Outstanding Early-Career Faculty Award in 2016, and the AGU James R. Holton Junior Scientist Award for 2014. Barnes has also been recognized for teaching and mentoring as the Outstanding Professor of the Year Award in 2022 and 2016 by the graduate students of the Department of Atmospheric Science at CSU and was awarded an Honorable Mention for the CSU Graduate Advising and Mentorship Award in 2017.

Barnes received a Ph.D. in atmospheric science from the University of Washington. She is a member of the National Academies of Sciences, Engineering, and Medicine Committee on Earth Science and Applications from Space.

Brad R. Colman is currently serving as President of the American Meteorological Society (AMS). Prior to this role he served as Director of Weather Strategy for Bayer/The Climate Corporation where he oversaw and guided the design and execution of the Bayer Enterprise weather programs. Before joining Bayer/Climate, Colman worked on a new Microsoft consumer weather service team to serve weather information across the entire Microsoft ecosystem. Previously, Colman had a diverse career with the National Oceanic and Atmospheric Administration (NOAA) where he worked at The National Weather Service's forecast office in Seattle, Washington; NOAA's Environmental Research Laboratory; and was the Acting Director of NOAA's Meteorological Development Laboratory. Colman is a member and Fellow of the AMS, a member of the Washington State Academy of Sciences, and is currently co-chair of NOAA's Science Advisory Board's Environmental Information Services Working Group. Colman received a B.S. in Earth sciences and mathematics from Montana State University and an Sc.D. in atmospheric sciences from the Massachusetts Institute of Technology. He currently serves on the National Academy of Sciences, Engineering, and Medicine's Roundtable on Macroeconomics and Climate Change and the workshop planning Committee on Advancing Risk Communication with Decision-Makers for Extreme Tropical Cyclones.

Bart E. Croes is the retired Chief of the Research Division for the California Air Resources Board, with former responsibilities for California's ambient air quality standard reviews; health, environmental justice, exposure, emissions, atmospheric processes, and emission mitigation research; indoor air quality program; short-lived climate pollutant science; and mitigation of high global warming potential gases. Croes has published peer-reviewed articles on air quality simulation modeling, emission inventory evaluation, reactivity-based volatile organic compound controls, toxic air contaminants, acid deposition, the weekend effect for ozone and particulate matter, air quality data analysis and trends, greenhouse gas emissions, and climate change impacts on California. He received a B.S. in chemical engineering from the California Institute of Technology and an M.S. in chemical engineering from the University of California, Santa Barbara. He previously served on the National Academies of Sciences, Engineering, and Medicine Committee for the Review of the Bureau of Ocean Energy Management "Air Quality Modeling in the Gulf of Mexico Study," Committee on Research Priorities for Airborne Particulate Matter, and the Committee on Energy Futures and Air Pollution in Urban China and the United States, a joint collaboration between the National Academy of Engineering, National Research Council, Chinese Academy of Engineering, and Chinese Academy of Sciences.

Minghui Diao is an Associate Professor of Meteorology and Climate Science at San Jose State University (SJSU). Her research focuses on cloud and aerosol processes based on aircraft in-situ measurements, remote sensing observations, and climate model simulations. In addition, her group examines the impacts of climate change and air pollution on communities in California and supports the decision-making activities of stakeholders using high-resolution climate model simulations. Diao is the recipient of the Lawrence Livermore National Laboratory Faculty Mini-Sabbatical Fellowship, SJSU Research Foundation Early Career Investigator Award, National Center for Atmospheric Research Advanced Study Program Postdoctoral Fellowship, National Aeronautics and Space Administration Earth and Space Science Fellowship, and the Princeton Francis Upton Fellowship. Diao received a B.S. in environmental sciences from Peking University and a Ph.D. in civil and environmental engineering from Princeton University. She previously served on the National Academies of Sciences, Engineering, and Medicine's Committee on Technology Developments to Advance Antarctic Research: A Workshop.

Neil Donahue is the Thomas Lord University Professor of Chemistry in the Departments of Chemistry, Chemical Engineering, and Engineering and Public Policy at Carnegie Mellon University, where he has been on the faculty since 2000. Prior to that, he spent a decade as a research scientist at Harvard University studying gas-phase radical molecule reaction kinetics of reactions important to stratospheric and tropospheric chemistry. Donahue studies oxidation chemistry in Earth's atmosphere, recently emphasizing the interactions

between organic oxidation mechanisms and thermodynamics of partitioning between the gas and condensed phases that drive formation and growth of atmospheric aerosols. He currently studies aerosol nucleation and growth as part of the Cosmics Leaving Outdoor Droplets collaboration at European Organization for Nuclear Research. Donahue has received the Pittsburgh, Esselen, and Creative Advances in Environmental Science and Technology awards from the American Chemical Society as well as the David Sinclair award for sustained excellence from the American Association for Aerosol Research (AAAR) and the Charney lectureship from the American Geophysical Union (AGU). He is a fellow of AAAR and AGU. Donahue received an A.B. in physics from Brown University and a Ph.D. in meteorology from the Massachusetts Institute of Technology.

Lesley-Ann Dupigny-Giroux is a Professor of Climatology in the Department of Geography & Geosciences at the University of Vermont, the Vermont State Climatologist since 1997, and the immediate Past President of the American Association of State Climatologists. In 2020, she was appointed by the Vermont House of Representatives to the Vermont Climate Council as the member with expertise in climate change science. An applied climatologist by training, Dupigny-Giroux's research interests intersect a number of interdisciplinary fields including hydroclimatic natural hazards and climate literacy, geospatial climate and land-surface processes, all within the context of our changing climate. She is an expert in floods, droughts and severe weather and the ways in which these affect the landscape and peoples of Vermont and the US Northeast. A Fellow of the American Meteorological Society, Dupigny-Giroux was invited by the White House Office of Science and Technology Policy Program to be a presenter on the "Climate Science Leading the Way" panel at the COP26 meeting in Glasgow, Scotland in 2021. She has contributed to all five National Climate Assessments (NCAs), serving as the lead author for the Northeast Chapter of NCA4, and is an author on the national Water chapter of NCA5. Dupigny-Giroux received a B.Sc. in physical geography and development studies from the University of Toronto and an M.Sc. in climatology and hydrology and Ph.D. in climatology and geographic information systems from McGill University. She currently serves on the National Academies of Sciences, Engineering, and Medicine’s Committee to Advise the U.S. Global Change Research Program.

Efi Foufoula-Georgiou (NAE) is a Distinguished Professor and the Samueli Endowed Chair in Civil and Environmental Engineering and Earth System Science at the University of California, Irvine. From 1989-2016 she was a McKnight Distinguished Professor at the University of Minnesota, Director of the St. Anthony Falls Laboratory and of the National Center for Earth-surface Dynamics. Foufoula-Georgiou studies hydrology and geomorphology with an emphasis on understanding the space-time organization and multiscale structure of precipitation and landforms for improving modeling and prediction. She has served on the National Science Foundation Advisory Council for Geosciences, National Aeronautics and Space Administration Earth Sciences Subcommittee, and as president of American Geophysical Union’s (AGU) Hydrology Section. Her awards include the European Geophysical Union John Dalton Medal, American Meteorological Society (AMS) Hydrologic Sciences Medal, and AGU Robert Horton Medal. She is a fellow of AGU, AMS, American Association for the Advancement of Science and member of the European Academy of Sciences, American Academy of Arts and Sciences, and National Academy of Engineering. She received a diploma in Civil Engineering from the National Technical University of Athens, Greece, and a Ph.D. (1985) in Environmental Engineering from the University of Florida, Gainesville. She currently serves on the National Academies of Sciences, Engineering, and Medicine’s Committee on Modernizing Probable Maximum Precipitation Estimation and a former member of the Water Science and Technology Board.

Kevin Gurney is a professor in the School of Informatics, Computing, and Cyber Systems at Northern Arizona University. Prior to NAU, Gurney was an Associate Professor at Arizona State University and Assistant/Associate Professor at Purdue University. He is also co-founder of Crosswalk Labs, a company aimed at providing greenhouse gas emissions data to governments, businesses, and civic society. Gurney is trained as an atmospheric scientist, ecologist and public policy expert currently working in the areas of carbon cycle science, climate science, and climate science policy. The emphasis of his research over the past two decades has included inverse estimation of greenhouse gas (GHG) fluxes, bottom-up GHG flux estimation, urban carbon dioxide dynamics, and climate policy. Gurney is an Intergovernmental Panel on Climate Change

lead author, an National Science Foundation CAREER award recipient, Sigma Xi Young Scientist recipient, and a Fulbright scholar. Gurney received a B.A. in physics and M.P.P. in public policy from University of California, Berkeley, an M.S. in meteorology from Massachusetts Institute of Technology, and a Ph.D. in ecology from Colorado State University. He previously served on the National Academies of Sciences, Engineering, and Medicine's Committee on Development of a Framework for Evaluating Global Greenhouse Gas Emissions Information for Decision Making.

Andrea Lopez Lang is currently a visiting faculty member in the Department of Atmospheric and Oceanic Sciences at the University of Wisconsin–Madison. For 12 years, Lang has been a professor in the Department of Atmospheric and Environmental Sciences at the State University of New York at Albany. Her research expertise spans synoptic to large-scale atmospheric dynamics on the weather to seasonal timescales, where she explores these timescales in the context of variability in the troposphere and stratosphere. Beyond research, she is committed to bridging the gap between student academic experiences and the breadth of careers opportunities for atmospheric scientists. Lang was in the inaugural 2018 class of the American Meteorological Society's (AMS) Early Career Leadership Academy and was the recipient of a 2008 Ford Foundation Fellowship. She is currently on the Council of the AMS and serves as Chair of its Board of Enterprise Economic Development. Lang received a B.S., M.S., and Ph.D. in atmospheric and oceanic sciences from the University of Wisconsin-Madison.

Maria Carmen Lemos (NAS) is a professor at the School for Environment and Sustainability and Principal Investigator of the Great Lakes Sciences and Assessments Center at the University of Michigan. Her research focuses on the use of scientific knowledge in environmental public policymaking in Latin America and the U.S., especially related to climate change (adaptation and adaptive capacity building) and the co-creation of actionable knowledge to solve sustainability problems. She was a lead author of the Intergovernmental Panel on Climate Change Fifth Assessment Report. Lemos was elected to the National Academy of Sciences in 2023. She received a B.S. in economics from the Universidade Federal de Juiz de Fora and an M.Sc. and Ph.D. in political science from the Massachusetts Institute of Technology. Lemos has served on numerous National Academies of Sciences, Engineering, and Medicine Committees including Restructuring Federal Climate Research to Meet the Challenges of Climate Change, America Climate Choice Science Panel, the Board on Environmental Change and Society, Committee to Advise the U.S. Global Change Research Program, the Societal Experts National Network.

Zhanqing Li is a distinguished university professor of Atmospheric and Oceanic Science at the University of Maryland. He was previously a research scientist at Natural Resource Canada. His research interests include remote sensing, atmospheric physics and chemistry, climate, and the environment with a focus on aerosols, clouds, the radiation budget, precipitation, biomass burning, and air pollution. Li is a fellow of the American Meteorological Society, American Geophysical Union (AGU), and American Association for the Advancement of Science. His awards include AGU's Kaufman Award, Humboldt Research Award of Germany, and the Head of Public Service Award of Canada. He has served on numerous committees including the Atmospheric Observation Panel for Climate of the World Meteorological Organization, the Atmospheric Chemistry Committee and Satellite Meteorological Committee of AMS, and an award committee of the AGU's Atmospheric Science Section. Li received a Ph.D. from McGill University.

Amy McGovern is the Lloyd G. and Joyce Austin Presidential Professor in the School of Meteorology and the School of Computer Science at the University of Oklahoma. She is also the Director of the National Science Foundation Artificial Intelligence (AI) Institute for Research on Trustworthy AI in Weather, Climate, and Coastal Oceanography (AI2ES). McGovern has worked in the intersection of artificial intelligence and meteorology since 2005. She became a fellow of the American Meteorological Society in 2021. McGovern received a B.S. in math and computer science from Carnegie Mellon University, and an M.S. and Ph.D. in computer science from the University of Massachusetts. She previously served on the National Academies of Sciences, Engineering and Medicine Committee on Machine Learning and Artificial Intelligence to Advance Earth System Science: Opportunities and Challenges - A Workshop.

Linda Mearns is the Head of the Regional Integrated Sciences Collective within the Research Applications Laboratory and Senior Scientist at the National Center for Atmospheric Research, Boulder, Colorado. She served as Director of the Weather and Climate Impacts Assessment Science Program for 15 years and served as Director of the Institute for the Study of Society and Environment for three years until April 2008. Mearns has performed research and published mainly in the areas of regional climate change, climate change scenario formation, quantifying uncertainties, and climate change impacts on agro-ecosystems. She has particularly worked extensively with regional climate models and has worked with resource managers (e.g., water resource managers and ecologists) to form climate change scenarios for use in adaptation planning.. She has been an author on the Intergovernmental Panel on Climate Change 1995, 2001, 2007, 2014, and 2021/22 Assessments regarding climate variability, impacts of climate change on agriculture, regional projections of climate change, climate scenarios, and uncertainty in future projections of climate change. She has also led the multi-agency supported North American Regional Climate Change Assessment Program, which has provided multiple high-resolution climate change scenarios for the North American impacts community. Mearns received a Ph.D. in geography/climatology from the University of California, Los Angeles. She has previously served on the National Academies of Sciences, Engineering, and Medicine's Committee on a National Strategy for Advancing Climate Modeling and the Panel on Adapting to the Impacts of the Committee on America's Climate Choices and currently serves of the Committee to Advise the U.S. Global Change Research Program.

Jonathan Patz (NAM) is the Vilas Distinguished Achievement Professor and John P. Holton Chair of Health and the Environment and, from 2011-2022, served as the inaugural director of the Global Health Institute at the University of Wisconsin–Madison. His faculty appointments are in the Nelson Institute for Environmental Studies, Center for Sustainability and the Global Environment, and the Department of Population Health Sciences in the School of Medicine and Public Health. Patz co-chaired the health report for the first Congressionally mandated U.S. National Assessment on Climate Change and for 15 years, served as a lead author for the United Nations Intergovernmental Panel on Climate Change—the organization that shared the 2007 Nobel Peace Prize. Some of his other awards include: the Aldo Leopold Leadership Fellows Award; the shared Zayed International Prize for the Environment; the Fulbright Scholarship; the American Public Health Association's Homer Calver Award for environmental health leadership; Case Western School of Medicine Alumni Special Recognition award; Johns Hopkins Society of Scholars; Chanchlani Global Health Research Award; and he is an elected member of the National Academy of Medicine. Patz earned medical boards in both Environmental & Occupational Medicine and in Family Medicine. He received his M.D. from Case Western Reserve University and his M.P.H. from Johns Hopkins University. Patz has served on numerous National Academies of Sciences, Engineering, and Medicine Committees, including the Committee on Accelerating Decarbonization in the United States: Technology, Policy, and Societal Dimensions

Kevin Reed is a Professor in the School of Marine and Atmospheric Sciences at Stony Brook University where he leads the Climate Extremes Modeling Group, which focuses on investigating how societally-relevant extreme events, such as hurricanes, may change in the coming decades. This research aids in advancing scientific understanding of the impacts of climate change, as well as developing new methodologies to better translate state-of-the-art science for climate adaptation applications and policies. Reed is also the Interim Director of Academic, Research, and Commercialization Programs at the New York Climate Exchange, a new non-profit focused on open exchange and collaboration that empowers sustainable solutions to climate change for New York City and the world. He leads the strategic direction and facilitates the co-development of academic, research, and community programs with a diverse set of academic, industry, and community partners. Reed received a B.S. in physics and M.S. and Ph.D. in atmospheric science from the University of Michigan, where he also completed a Graduate Certificate in Science, Technology, and Public Policy.

James Marshall Shepherd (NAS/NAE) is a leading international expert in weather and climate and is the Georgia Athletic Association Distinguished Professor of Geography and Atmospheric Sciences at the University of Georgia. Shepherd was the 2013 President of American Meteorological Society (AMS). He is frequently asked to advise key leaders at the National Aeronautics and Space Administration (NASA), the

White House, Congress, Department of Defense, officials from foreign countries and major media outlets. Dr. Shepherd previously chaired the NASA Earth Sciences Advisory Committee and served on National Oceanic and Atmospheric Administration's Science Advisory Board. Shepherd has received numerous awards including: Mani L. Bhaumik Award for Public Engagement with Science from the American Association for the Advancement of Science (2020), American Geophysical Union Climate Communication Prize (2019), AMS Helmut Landsberg Award for pioneering and significant work in urban climate (2018), AMS Brooks Award (2017), the Protector of the Earth Award from Ted Turner and his Captain Planet Foundation (2014), and a Presidential Early Career Award for Scientists and Engineers from President Bush (2004). In 2021, Shepherd was elected to the National Academy of Engineering and National Academies of Sciences. He received a B.S., M.S., and Ph.D. in physical meteorology from Florida State University. He currently serves on the National Academies of Sciences, Engineering, and Medicine's Space Studies Board and Committee on Advancing Risk Communication with Decision-Makers for Extreme Tropical Cyclones, and previously served on the workshop planning Committee on Extreme Weather Events and Climate Change Attribution, among others.

Aradhna Tripati is a Professor in the Institute of the Environment and Sustainability; Department of Earth, Planetary, and Space Sciences; Department of Atmospheric and Oceanic Sciences; and California Nanosystems Institute, and is the founder and director of the Center for Diverse Leadership in Science at the University of California, Los Angeles. She is an American geoscientist, climate scientist, and advocate for inclusive diversity, equity, justice, and belonging. Her research includes advancing new chemical tracers for the study of environmental processes and studying the history of climate change and Earth systems. She is recognized for her innovative research on climate change and clumped isotope geochemistry, including chemical tracer development, the evolution of atmospheric carbon dioxide levels and the impacts on temperature, the water cycle, glaciers and ice sheets, and ocean acidity. She is a Fellow of the Geochemical Society, European Association of Geochemistry, and Geological Society of America, and received a Presidential Early Career Award in Science and Engineering under President Obama. She held the Chair International D'Excellence in Stable isotopes and paleoceanography, was a Distinguished Lecturer at the National Science Foundation, and received the American Geophysical Union Presidential Citation for No Time for Silence Contributing Author, led by Vernon Morris. Tripati received a Ph.D. in Earth sciences from the University of California, Santa Cruz. She is a member of the U.S. National Committee for the International Union for Quaternary Research.

Bernadette Woods Placky is Climate Central's Vice President for Engagement, Chief Meteorologist, and director of the Climate Matters program where she helps the public understand the importance of climate change science, impacts, and solutions. At Climate Central, she develops partnerships with media organizations, non-profits, and academic institutions; leads a team that creates weekly, local data and other reporting resources for a large and growing network of media professionals; and serves as an expert on the links between climate change and weather. Woods Placky previously worked for more than a decade as a TV meteorologist, where she won an Emmy for Best Weathercaster. She is an American Meteorological Society (AMS) Fellow and Penn State Earth and Mineral Science Fellow. Woods Placky serves on the AMS Council, chairs the Penn State Meteorology and Atmospheric Science advisory committee, is on The Weather Channel's Pattrn Board, and is a science advisor for C-Change Conversations. She previously served on the Penn State GEMS and Watershed Institution Boards. Woods Placky received a B.S. in meteorology with a minor in French from Penn State University.

NATIONAL ACADEMIES *Sciences Engineering Medicine*

PREVENTING DISCRIMINATION, HARASSMENT, AND BULLYING:
POLICY FOR PARTICIPANTS IN NASEM ACTIVITIES

The National Academies of Sciences, Engineering, and Medicine (NASEM) are committed to the principles of diversity, inclusion, integrity, civility, and respect in all of our activities. We look to you to be a partner in this commitment by helping us to maintain a professional and cordial environment. **All forms of discrimination, harassment, and bullying are prohibited in any NASEM activity.** This policy applies to all participants in all settings and locations in which NASEM work and activities are conducted, including committee meetings, workshops, conferences, and other work and social functions where employees, volunteers, sponsors, vendors, or guests are present.

Discrimination is prejudicial treatment of individuals or groups of people based on their race, ethnicity, color, national origin, sex, sexual orientation, gender identity, age, religion, disability, veteran status, or any other characteristic protected by applicable laws.

Sexual harassment is unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature that creates an intimidating, hostile, or offensive environment.

Other types of harassment include any verbal or physical conduct directed at individuals or groups of people because of their race, ethnicity, color, national origin, sex, sexual orientation, gender identity, age, religion, disability, veteran status, or any other characteristic protected by applicable laws, that creates an intimidating, hostile, or offensive environment.

Bullying is unwelcome, aggressive behavior involving the use of influence, threat, intimidation, or coercion to dominate others in the professional environment.

REPORTING AND RESOLUTION

Any violation of this policy should be reported. If you experience or witness discrimination, harassment, or bullying, you are encouraged to make your unease or disapproval known to the individual at the time the incident occurs, if you are comfortable doing so. You are also urged to report any incident by:

- Filing a complaint with the Office of Human Resources at 202-334-3400 or hrservicecenter@nas.edu, or
- Reporting the incident to an employee involved in the activity in which the member or volunteer is participating, who will then file a complaint with the Office of Human Resources.

Complaints should be filed as soon as possible after an incident. To ensure the prompt and thorough investigation of the complaint, the complainant should provide as much information as is possible, such as names, dates, locations, and steps taken. The Office of Human Resources will investigate the alleged violation in consultation with the Office of the General Counsel.

If an investigation results in a finding that an individual has committed a violation, NASEM will take the actions necessary to protect those involved in its activities from any future discrimination, harassment, or bullying, including in appropriate circumstances **the removal of an individual from current NASEM activities and a ban on participation in future activities**.

CONFIDENTIALITY

Information contained in a complaint is kept confidential, and information is revealed only on a need-to-know basis. NASEM will not retaliate or tolerate retaliation against anyone who makes a good faith report of discrimination, harassment, or bullying.

Updated December 2, 2021

NATIONAL ACADEMIES Sciences Engineering Medicine

A GUIDE TO THE

Harassment Complaint Process for Participants

AT THE NATIONAL ACADEMIES

Review the Policy here.

Complaints regarding violations of the National Academies anti-harassment policies should be reported by:

- Filing a complaint with the Office of Human Resources at 202-334-3400 or hrservicecenter@nas.edu or
- Reporting the incident to an employee involved in the activity in which you are participating.

Complaints of harassment, discrimination, or bullying should be filed as soon as possible after an incident. The Office of Human Resources will investigate the alleged violation in consultation with the Office of the General Counsel.

When reporting an incident, please provide as much of the following information as is possible and applicable:

- Name and role of the person or persons allegedly causing the harassment;
- Description of the incident(s), including the dates, locations and the presence of any witnesses;
- Steps taken to try to stop the harassment; and
- Any other information that may be relevant.

If the National Academies determines that a participant in a National Academies activity has violated this policy, the National Academies will take action as it deems appropriate to address the situation and to prevent the participant from engaging in future discrimination, harassment, or bullying in National Academies activities, up to and including banning that individual from current or future participation in National Academies activities.

All inquiries, complaints, and investigations are confidential, and information is revealed only on a need-to-know basis. Information contained in a complaint is kept confidential. The National Academies will not retaliate or tolerate retaliation against anyone who makes a good faith report of discrimination, harassment, or bullying. or participates in a complaint investigation.

For more information, please watch the following videos from our Expert Volunteer Orientation:

- Making a Commitment to Diversity, Equity, and Inclusion
- Preventing Discrimination, Harassment, and Bullying