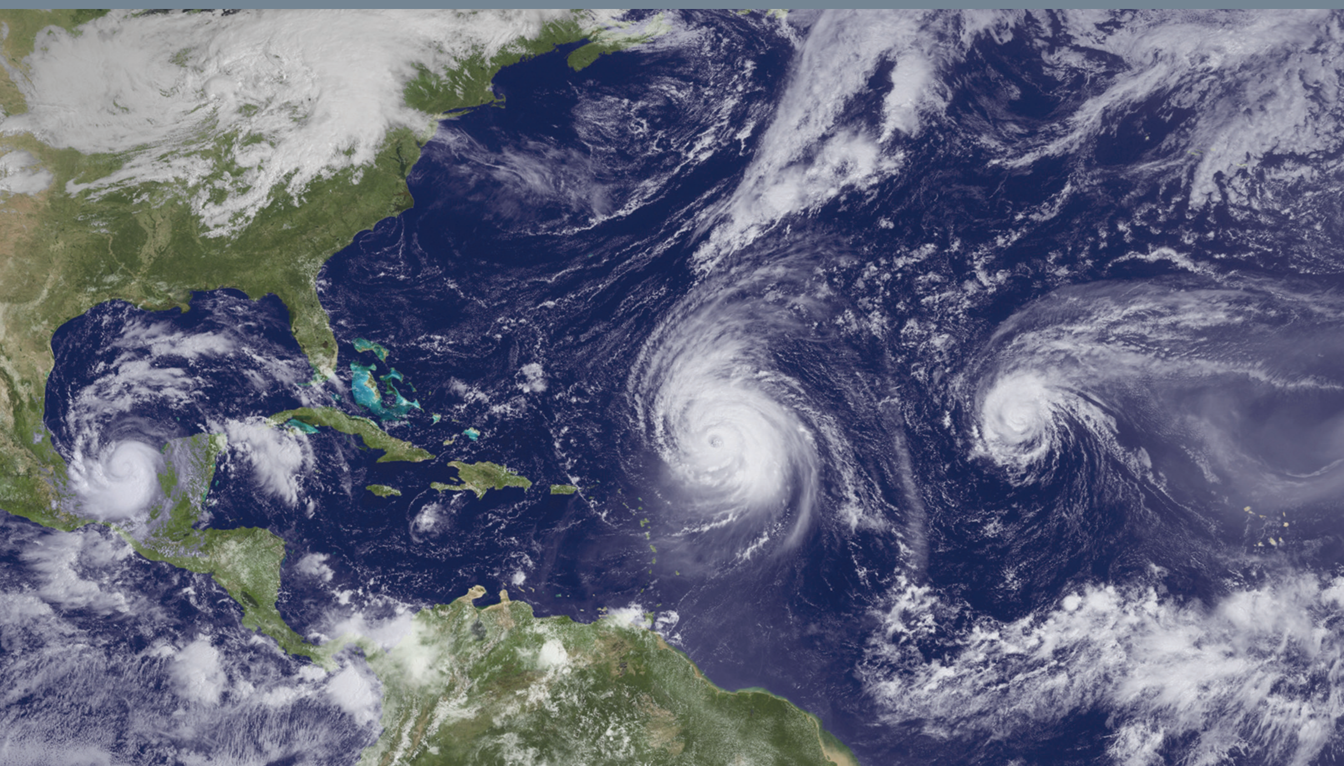
Science During Crisis:
Best Practices, Research Needs, and Policy Priorities



Rita R. Colwell and Gary E. Machlis

AMERICAN ACADEMY OF ARTS & SCIENCES

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Cover image: Hurricanes Karl, Igor, and Julia (from left to right) churn in the Atlantic Basin in September 2010. National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service (NESDIS), September 2010.

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Preface

From earthquakes, hurricanes, tornadoes, and landslides to oil spills, wildfires, and floods, major disasters place profound stresses on the ability of our society to respond quickly and effectively to safeguard lives, health, and property. Scientists from a broad range of disciplines are critical for mounting an effective response to such crises: their knowledge is essential for shaping and understanding the options available to crisis responders and for communicating that information to decision-makers. Yet while there has been considerable research on the role of science in predicting and preparing for disasters, less attention has been given to the application of science during disasters, including data collection, community engagement, and the integration of scientists into crisis response teams.

How, then, could the application of science during crisis be improved? In this report, Rita R. Colwell and Gary E. Machlis provide a clear, concise, and insightful analysis of the most pressing needs related to the practice of science during crisis, including new research directions, procedural changes, and policy reforms.

The report draws on a workshop held at the headquarters of the American Academy of Arts and Sciences in Cambridge, Massachusetts, at which a diverse group of experts representing many fields gathered to share their knowledge and experience and to debate what changes are needed to better enable scientists to contribute to the understanding and resolution of disasters. I join Dr. Colwell and Dr. Machlis in thanking this distinguished group, particularly Dr. Kristin Ludwig, who cochaired the workshop at the American Academy. I also thank the American Academy staff who provided strong intellectual and logistical support for this project, especially John Randell, the John E. Bryson Director of Science, Engineering, and Technology Programs, and Alison Leaf, Hellman Fellow in Science and Technology Policy.

This report on science during crisis was produced under the auspices of the Academy's Public Face of Science initiative, which is examining how public attitudes toward scientists are shaped and how science could be better applied to individual and institutional decision-making. I would like to express my appreciation to the foundations that have supported the project, including the Gordon and Betty Moore Foundation, the Rita Allen Foundation, and the Alfred P. Sloan Foundation, as well as the many American Academy members and other experts who have contributed to its success.

Jonathan F. Fanton
President, American Academy of Arts and Sciences
December 2018

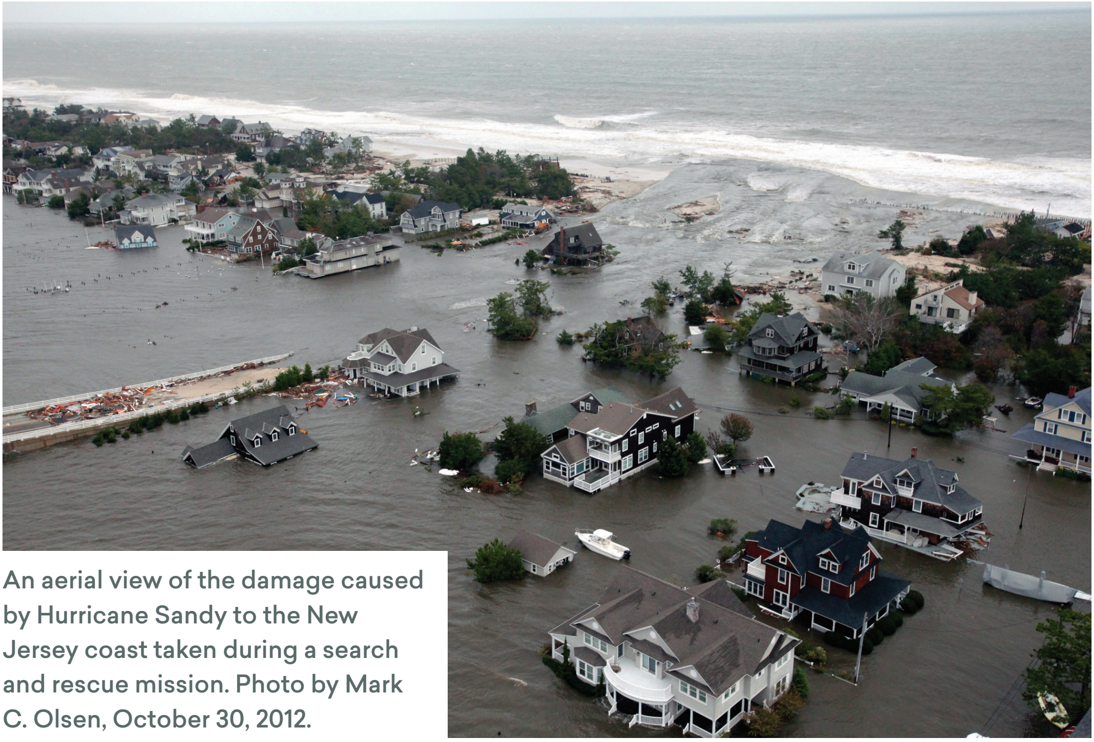
Introduction

Since 1980, the United States has experienced over 230 major weather and climate disaster events that collectively have caused nearly $1.6 trillion in damages and costs.[1] In 2017 alone, the United States was hit by sixteen separate billion-dollar disaster events, costing a total of $306 billion. These weather and climate disasters—along with natural hazards such as earthquakes, public health crises arising from disease outbreaks, and human-caused disasters such as contaminant spills—threaten human lives and pose challenges to relief efforts, restoring ecosystems, and rebuilding communities.

Science—including biological, physical, social, behavioral, cultural, engineering, and medical disciplines—plays an important role in responding to such crises. Physicians and geochemists collaborated in assessing the short- and long-term health impacts of dust from the September 11, 2001, attacks on the World Trade Center.[2] In 2010, scientists and engineers with expertise in oceanography, geology, engineering, physics, public health, and ecology helped contain the Deepwater Horizon oil spill and assess the extent of its damage to the Gulf Coast. When Hurricane Sandy made landfall in 2012, scientists and engineers were summoned to evaluate structural damage, assess health and environmental risks, and provide direction for response and recovery efforts. The Oso Landslide in Washington State in 2014 drew researchers who served side-by-side with emergency managers to evaluate the stability of the nearby slope and landslide dam, sharing technical information with both decision-makers in the field and the public. In 2016, when the Zika virus threatened the well-being of Caribbean, South American, and U.S. citizens, experts from a variety of scientific fields worked together to assess human-health and environmental impacts and develop interventions ranging from genetically modified mosquitoes to

1. National Oceanic and Atmospheric Administration, National Centers for Environmental Information, "Billion-Dollar Weather and Climate Disasters: Overview," https://www.ncdc.noaa.gov/billions/; and Adam B. Smith, "2017 U.S. Billion-Dollar Weather and Climate Disasters: A Historic Year in Context," January 8, 2018, https://www.climate.gov/news-features/blogs/beyond-data/2017-us-billion-dollar-weather-and-climate-disasters-historic-year.

2. Geoffrey Plumlee, "Report from Ground Zero: How Geoscientists Aid in the Aftermath of Environmental Disasters," *Earth Magazine*, October 2009, https://www.earthmagazine.org/article/report-ground-zero.



An aerial view of the damage caused by Hurricane Sandy to the New Jersey coast taken during a search and rescue mission. Photo by Mark C. Olsen, October 30, 2012.

chemical spraying.[3] In each case, science during crisis was essential to an effective response.

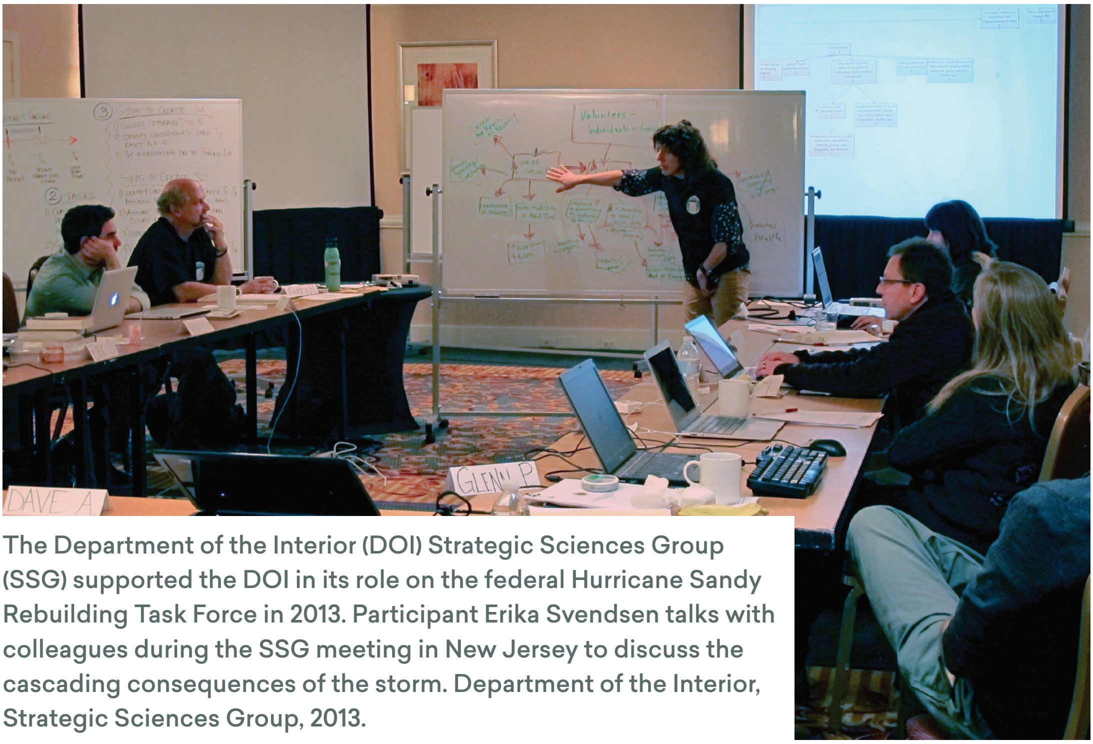
A rich literature on preparing for crises exists, but strategic deployment of scientific expertise and application of scientific information *during* crisis events is understudied. There is a critical need to develop best practices to collect relevant data; work together with affected communities; establish interdisciplinary teams; coordinate scientists, engineers, crisis managers, and decision-makers when disaster strikes; and ensure their collaboration through the crisis, response, and recovery.

What Comprises Science During Crisis?

Science during crisis includes conducting scientific research and analyzing data, as well as organizing, staffing, communicating, and archiving scientific and technical resources during a crisis event.[4] Crisis events are most

3. Committee on Science of the National Science and Technology Council, *A Strategy for Integrating Best Practices with New Science to Prevent Disease Transmission by Aedes Mosquito Vectors* (Washington, D.C.: Executive Office of the President of the United States, 2016).

4. Gary E. Machlis and Kristin Ludwig, "Science During Crisis: The Application of Interdisciplinary and Strategic Science During Major Environmental Crises," *Understanding Society and Natural Resources*, ed. Michael J. Manfredo, Jerry J. Vaske, Andreas Rechkemmer, and Esther A. Duke (Dordrecht, The Netherlands: Springer, 2014), 47–65.



The Department of the Interior (DOI) Strategic Sciences Group (SSG) supported the DOI in its role on the federal Hurricane Sandy Rebuilding Task Force in 2013. Participant Erika Svendsen talks with colleagues during the SSG meeting in New Jersey to discuss the cascading consequences of the storm. Department of the Interior, Strategic Sciences Group, 2013.

often acute disruptions and place-specific, with consequences for both natural and human systems.

Science during crisis requires the engagement of scientists and engineers across a broad range of disciplines, as well as emergency managers, resource managers, policy-makers, business owners, and the public. Because crises impact people and infrastructure and/or environmental assets of societal value, science during crisis is necessarily human-centric. Science during crises helps guide decision-making, from search and rescue operations and environmental remediation plans to health monitoring and evacuation planning. Further, scientific work done in emergency response directly impacts the lives and livelihoods of survivors in a crisis-affected area. Hence, crisis response may turn litigious despite being informed by science, with scientists called to testify in local, state, or federal courts.

For scientists serving in a crisis response, the protocols and timescales of conducting research during the crisis differ from the usual practice of science. Scientific research typically is deliberate and iterative, with peer-reviewed publications the hallmark of success. In contrast, science in support of emergency management is rapid, decisive, and typically moves forward necessarily based on more limited information. Success is gauged by lives saved, injuries reduced, ecosystem and infrastructure services restored, speed of recovery, and development of mitigation tools for future disasters. These differing strategies and goals can impair coordination and information-sharing during response.[5] They can also jeopardize careful consideration of challenges, risks, and ethical protections inherent in scientific undertakings. Little formal training in emergency response, ethical issues, or legal obligations is available for scientists to inform their work during crises. Similarly, there are few examples available of technical training in the sciences or the application of science for emergency managers.

The Importance of Science during Crisis

Weather and climate crises, natural hazards, public health crises, and technological disasters are inevitable, as are their cascading consequences across social, economic, and environmental systems. The challenges are exacerbated by significant human population growth, socioeconomic disparities, environmental factors including climate change, and diminishing natural resources. As the complexity of events increases, interdisciplinary science during crisis becomes increasingly important, and scientists will face new challenges in problem-solving, communicating results, and coordinating with response managers and decision-makers. Significant advances are needed in developing best practices, a research agenda for response, and policy reforms for science during crisis.

A persistent problem in responding to a crisis event is the temptation to "fight the last war." For example, a common initial assumption is that a new oil spill is similar to one that occurred previously. Yet every disaster is in some ways unique, and every disaster is local. Scientists, emergency managers, policy-makers, and response personnel must maintain flexibility, recognize both new and experienced voices from a variety of backgrounds and disciplines, and encourage creativity in identifying solutions and possible interventions as quickly as possible.

Actions taken during crisis are likely to come under intense scrutiny, with pressure from a 24/7 news cycle, demanding politicians, and the looming threat of litigation. Science can support legally defensible, evidence-based decisions during crisis and play an important role in informing emergency managers, policy-makers, and the public. While the threat of liability or even prosecution—such as the conviction (and later acquittal) of scientists for manslaughter in the aftermath of the deadly 2009 L'Aquila, Italy, earthquake—is a potential deterrent to scientists who wish to contribute

5. Lindley A. Mease, Theodora Gibbs-Plessl, Ashley L. Erickson, et al., "Designing a Solution to Enable Agency-Academic Scientific Collaboration for Disasters," *Ecology and Society* 22 (2) (2017): 18.

An aircraft from the U.S. Air Force Reserve 53rd Weather Reconnaissance Squadron "Hurricane Hunters" approaches the edge of Hurricane Florence, providing critical and timely weather data to the National Hurricane Center. Photo by Chris Hibben, September 12, 2018.

their expertise during crisis, scientists must be ready to engage during crisis and support fellow scientists lending expertise to response efforts.[6]

Science has played an important role during crisis for decades, and the scope of that work is broadening. The Office of Strategic Services (OSS) recruited scientists and engineers to provide expertise and support intelligence efforts during World War II. More recently, National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinators have served as technical experts to support the response to oil and chemical spills in U.S. waters.[7] Similarly, the National Weather Service (NWS) created Incident Meteorologist positions to transmit critical weather forecasts to firefighters.[8] In the public health arena, the National Institutes of Health (NIH) launched a Disaster Research Response Program (DR2P) to "create a disaster research system consisting of coordinated environmental health disaster research data collection tools and a network of trained

6. Edwin Cartlidge, "Earthquake Experts Convicted of Manslaughter," *Science*, October 22, 2012, http://www.sciencemag.org/news/2012/10/earthquake-experts-convicted-manslaughter.

7. National Oceanic and Atmospheric Administration, Office of Response and Restoration, "OR&R Field Staff Locations and Contact Information," http://response.restoration.noaa.gov/about/orr-field-staff.html.

8. National Oceanic and Atmospheric Administration, National Weather Service, "A Day In The Life of a NWS Meteorologist: Incident Meteorologists," https://www.weather.gov/jkl/Day_In_The_Life_Day13.

General William Donovan with members of the OSS Operational Groups at Congressional Country Club in Bethesda, Maryland, which served as an OSS training facility. Office of Strategic Services, c. 1942.

research responders," supported by library resources coordinated by the National Library of Medicine.[9] The Centers for Disease Control and Prevention (CDC) created Global Rapid Response Teams offering technical and scientific advice in the face of global public health crises.[10] Incident management at the Department of Health and Human Services routinely includes scientists from the CDC and NIH. The Department of the Interior (DOI) established the Strategic Sciences Group (SSG), modeled after the OSS, to be deployed during crises to provide interdisciplinary scientific assessments to DOI leadership. Agencies like the U.S. Geological Survey (USGS) coordinate with the Federal Emergency Management Agency (FEMA) to ensure scientists are on site during exercises to provide situational awareness.

In academia, the Stanford-led Science Partnerships Enabling Rapid Response (SPERR) project analyzed relationships between academic scientists and federal responders during the Deepwater Horizon oil spill and proposed solutions for improved coordination during future crises.[11] In

9. U.S. Department of Health and Human Services, NIH Disaster Research Response (DR2), "About the Program," https://dr2.nlm.nih.gov/about.

10. Centers for Disease Control and Prevention, "CDC Global Rapid Response Team," https://www.cdc.gov/globalhealth/healthprotection/errb/global-rrt.htm.

11. Mease et al., "Designing a Solution to Enable Agency-Academic Scientific Collaboration for Disasters."

addition, organizations such as the Geotechnical Extreme Events Reconnaissance (GEER) Association mobilize engineering experts to support initial reconnaissance efforts after disaster events, while On-call Scientists at the American Association for the Advancement of Science respond to requests from human rights organizations to advise on and assess response measures in disaster-struck areas.[12] Though not an exhaustive list, these examples of organizational responses highlight the vital and growing role of science and scientists during crisis.

About This Report

In April 2017, the American Academy of Arts and Sciences held a workshop to address issues surrounding science during crisis, focusing on the United States. The workshop engaged a diverse and interdisciplinary group of scientists, decision-makers, and communicators (see Appendix A for a list of participants). Workshop participants made presentations and engaged in extensive dialogue and discussion. The discussions centered on the experiences of the participants during crises and recent advances in improving the application of science for preparedness, response, and recovery.

With the workshop presentations and discussions as foundation, this report provides recommendations to:

- Identify best practices for employing, facilitating, communicating, and conducting science during crisis;
- Describe critical research needed to strengthen science during crisis; and
- Identify and prioritize policy recommendations to promote and facilitate science during crisis.

12. The Geotechnical Extreme Events Reconnaissance Association, "About GEER," http://www.geerassociation.org/about-geer; and The American Association for the Advancement of Science, "On-call Scientists," https://oncallscientists.aaas.org/en.

Emerging Best Practices for Science During Crisis

Best practices can advance "mission-ready" capabilities and streamline the process of employing science during crisis. This includes best practices for funding, staffing, execution, analysis, communication, and archiving of the resulting science. Such practices must reflect a range of scientific disciplines and professional organizations, meet accepted ethical standards, and protect the rights of affected persons and communities.

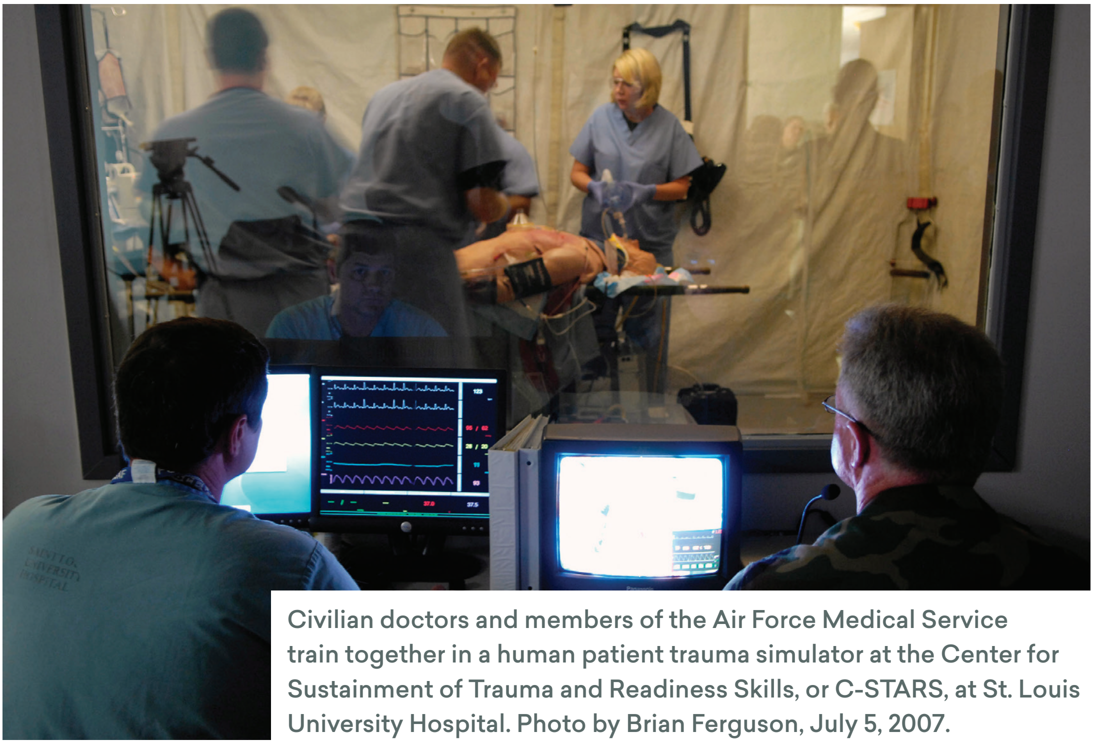
Recommendations for Improving Best Practices

Federal, state, and local agencies should have available emergency funds for science during crisis. Expedited funding is necessary to enable rapid deployment and capture ephemeral and time-critical data. Dedicated funding should be set aside for research during emergency response. Administrative requirements within government agencies, universities, and other institutions should be flexible enough to enable rapid deployment of funds for science during crisis.[13]

The emergency-response and scientific communities should expand joint training and outreach/education. Mutual understanding of well-articulated priorities, protocols, practices, and responsibilities will improve the capacity of emergency managers and scientists to coordinate activities and work safely. For some dimensions of training, such as ethics and community engagement, this may require the development of new standards and best practices. Opportunities for joint training include scenario-building and emergency response exercises.[14]

13. Currently, the NSF grants for Rapid Response Research (RAPID) provide a good example. This funding mechanism allows short proposals to be processed and awarded within one to two weeks of receipt.

14. Christopher M. Reddy, David L. Valentine, and Jason Ziebold,, "Academia and the Military Can be Valuable Partners," *Eos*, November 10, 2016, https://doi.org/10.1029/2016EO062795.



Civilian doctors and members of the Air Force Medical Service train together in a human patient trauma simulator at the Center for Sustainment of Trauma and Readiness Skills, or C-STARS, at St. Louis University Hospital. Photo by Brian Ferguson, July 5, 2007.

At the onset of a crisis, a central curated clearinghouse developed in advance should be activated to collect, disseminate, and coordinate relevant scientific information. Access to information during crises facilitates research. In addition, emergency managers can leverage available information to improve situational awareness, facilitate decisions, and inform the public. The optimum set of information should include existing baseline data, data collected during the crisis, decision-support tools, standardized tools for rapid data collection, models, forecasts, and preexisting research literature. Appropriate protocols should be put in place to ensure data security, particularly protection of personally identifiable information.

Research Needs for Improving Science During Crisis

Science during crisis must constantly evolve to incorporate new technologies, methods, data, and information, and to improve the delivery of usable knowledge. Supporting this process requires an interdisciplinary research agenda that takes into account both basic and applied questions regarding science during crisis. This research agenda can and should be implemented by the academic, public, private, and nongovernmental sectors.

Recommendations for a Research Agenda

Establishing baseline information

When crisis strikes, baseline environmental, human-health, social, and economic data are critical to understanding both the short- and long-term effects of the disaster. Such data provide scientists with the ability to present robust information on crisis-induced changes to decision-makers and the public. Key questions for the research agenda include:

1. *What is the best way to identify and/or update baseline information needed for science during crisis in anticipation of future disasters?*
2. *How can the collection of baseline health data for disaster responders, including scientists, be integrated into disaster preparedness protocols?*
3. *What are the best methods for collecting, archiving, and sharing baseline data relevant to a crisis?*

Understanding cascading consequences to document and predict the complexity of environmental and social disasters, and to improve response and rebuilding strategies

Disasters create cascading consequences for coupled human-natural systems, and understanding these consequences is essential for both emergency response and restoration of human communities, local economies, and ecosystems. Key questions include:

1. *What are the environmental, health, social, and economic cascading consequences of disasters, and can they be predicted?*
2. *What are the consequences of repetitive disasters (such as repeated hurricanes) in one location?*
3. *What are the best ways to forecast cascading consequences to support decision-making during a crisis?*
4. *How has engagement between scientific institutions and affected communities advanced or hindered long-term resilience and public trust in science?*

Addressing divergent scientific opinions, data, and results during crisis

During a crisis, decision-makers may be faced with studies with different or conflicting results. Such disparate findings can complicate evidence-based decision-making. Researchers should develop effective protocols and methodologies for addressing divergent scientific opinions and communicating uncertainty that may result from science during crisis. Key questions include:

1. *What methods are most effective for addressing divergent scientific views during crisis?*
2. *To what extent should data be proven reproducible during crisis? Do different standards apply?*
3. *What are the best methods for synthesizing divergent scientific findings and associated uncertainty?*

Communicating science during crisis

The delivery and presentation of scientific information during a crisis—to decision-makers, the media, and the public—can significantly affect emergency response, public safety, and restoration activities. Key questions include:

1. *What visualization techniques and methods of delivery or presentation are best-suited to communicating scientific information to different audiences?*
2. *What is the best way to: a) streamline technical communications for different audiences at different times; b) account for a variety of scientific perspectives and findings; c) address potential ethical concerns in the communication of sensitive data; and d) avoid information overload, misinterpretation, and unnecessary confusion?*

The Tomahawk Fire, in the northeast section of Camp Pendleton, San Diego County, burned more than six thousand acres, forcing evacuations of housing areas and schools. Photo by Joshua Murray, May 14, 2014.

Assessing how science-based decisions are made

Understanding what information is used by decision-makers and how it is used to make decisions is important to advancing the applicability of science during crisis. Key questions include:

1. *How and to what extent is scientific and technical information used in decision-making during crisis?*
2. *What are the ethical, moral, and legal considerations that need to be considered as scientists inform decision-making processes?*
3. *What are the best ways to ensure science is effectively considered in crisis decision-making?*

Using big data to support science during crisis

Big data sets such as those derived from social media and complex models are important complements to data collected on the ground during a crisis, and can contribute to both situational awareness and, in some cases, quality control and assurance.[15] At the same time, reliance on big data, particularly data generated by local communities, can give rise to inherent biases in the data, given varying degrees of technological capability and access of segments of the population. Key questions include:

1. *How can multiple streams of data from disparate sources (including government data, published data, gray literature, unpublished data, models, and social media) be identified and quality-assured to respond effectively and rapidly to research needs during a crisis?*

2. *What advances in computing and data visualization are necessary to streamline the collection, analysis, and delivery of crowd-sourced data and/or information gleaned from social media?*

3. *What ethical and practical challenges need to be considered when relying on big data sources, particularly those generated voluntarily by local communities?*

15. See Eleanor Starkey, Geoff Parkin, Stephen Birkinshaw, et al., "Demonstrating the Value of Community-Based ('Citizen Science') Observations for Catchment Modelling and Characterisation," *Journal of Hydrology* 548 (2017): 801–817; and Giles M. Foody and Doreen S. Boyd, "Using Volunteered Data in Land Cover Map Validation: Mapping West African Forests," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 6 (3) (2013): 1305–1312.

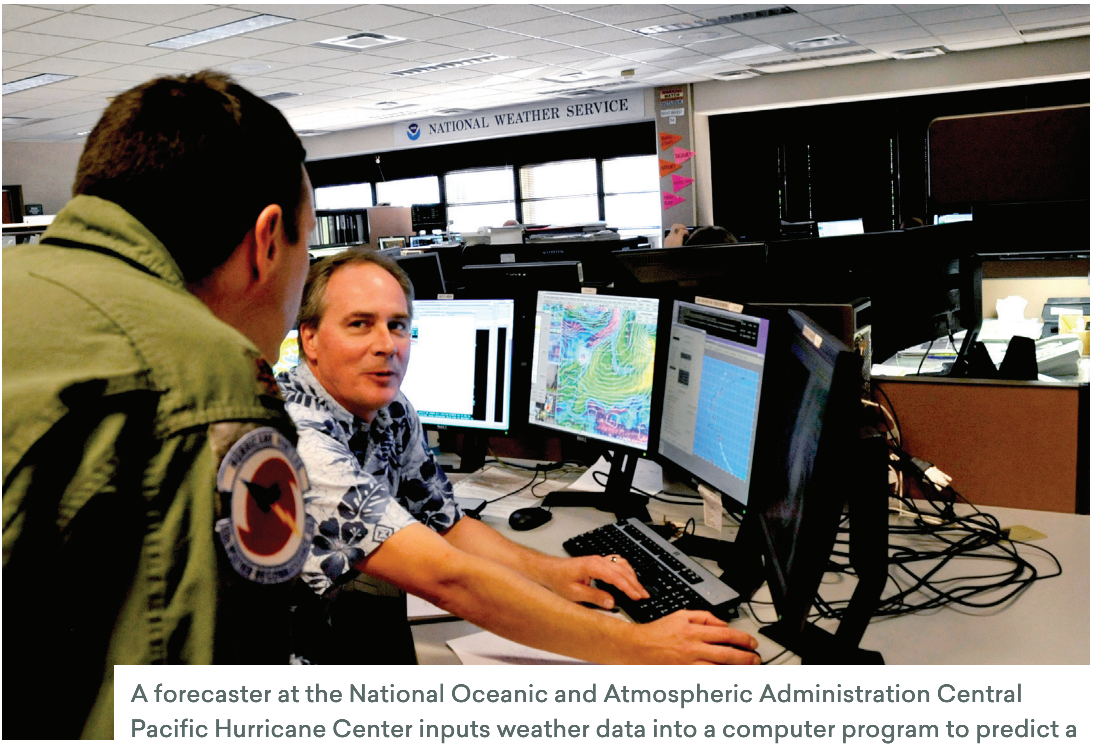
Policy Recommendations to Improve Science During Crisis

Changes in current federal, state, and local policies are needed to improve science during crisis. These changes will advance the conduct of science, access to and use of scientific data, and the role of science in decision-making, as well as improve crisis response and recovery. In addition to federal, state, and local government policies, improvements are needed in policies governing academic institutions, communities of practice, nongovernmental organizations, and private industry.

State governments should create a Chief Science Officer position to facilitate science during crisis. Gaps or lack of understanding between different professional cultures can lead to a mismatch between scientific activity, emergency response, and on-the-ground needs. It can also lead to a lack of institutional support for science during crisis at a state, regional, and local level. Creating a Chief Science Officer position within state government would reduce confusion and facilitate effective conduct and application of science during crisis. The Chief Science Officer would serve as a critical liaison between state and local government offices, emergency responders, and the scientific community.

FEMA should refine language referencing the Science and Technology Advisor position outlined in the 2017 National Incident Management System (NIMS) revision, as well as associated supplemental guidance and tools. Given that NIMS defines standard command and management structures for use nationwide by the entire FEMA and disaster-response community, the integration of science into this national doctrine is essential. The inclusion of the Science and Technology Advisor role supports effective delivery and application of science during crisis response operations: to inform decision-making, enhance safety, integrate wider scientific community input, and improve the collection and application of scientific data. The responsibilities of the Science and Technology Advisor should include facilitating site access for properly equipped and trained scientists, setting standards for data collection, and acting as a liaison between the scientific community and incident command.

Publishers of scientific journals and books should develop and implement policies that improve accessibility of scientific information during a crisis. During a crisis, access to up-to-date research is critical for



A forecaster at the National Oceanic and Atmospheric Administration Central Pacific Hurricane Center inputs weather data into a computer program to predict a hurricane's trajectory. Photo by Jessica Kendziorek, August 10, 2014.

the scientific community to identify gaps that need immediate attention and to find scientific solutions to pressing problems. Further, the rapid dissemination of data collected during a crisis but prior to publication is often critical for decision-making and to avoid unnecessary duplication of effort. Publishers should adopt a policy of providing free, publicly available, full-text access to journals, e-books, and databases with relevant information during and immediately following major crises. Recent advances within the biomedical community provide a potential model.

The scientific community should develop a code of conduct that addresses ethical and professional practices to which scientists engaged in science during crisis would adhere. A science during crisis code of conduct would describe scientists' distinct ethical responsibilities during a major crisis. The code of conduct should favor altruism over competition in scientific research and should recognize the primacy and rights of the communities and sovereign tribes immediately affected by the crisis. The code of conduct would recognize that science during crisis operates differently than science during noncrisis times, and should be developed and agreed upon by the burgeoning science during crisis community of practice.

Federal agencies and academic institutions should ease and/or expedite administrative restrictions on collaboration, information sharing, and data collection to enable more effective science during crisis. Administrative restrictions such as the Federal Advisory Committee Act

Health workers test samples for the presence of infectious viral particles. U.S. Centers for Disease Control and Prevention.

(FACA) and Paperwork Reduction Act (PRA) can serve as barriers to efficient conduct of science during crisis at a federal level: the FACA can prevent rapid access to needed expertise and advice, and the PRA can slow the rapid collection of critical human subject data. In addition, the sometimes lengthy (weeks- or months-long) process of Institution Review Board (IRB) approval does not always align with the compressed timelines typical of rapidly unfolding crises.[16] Reform of these policies that provide limited exemptions for science during crisis, while protecting the public's "right to know" and preventing unnecessary intrusions of privacy, can improve the conduct of science during crisis. Because federal agencies have varying FACA guidelines and policies, pilot reforms in selected and critically important agencies (such as FEMA, NOAA, and others) can create realistic opportunities for progress.

16. Recently, the NIH has made progress toward improving efficiency in the IRB process by introducing a single IRB for multisite research; additional policies are needed to expedite IRB approvals for scientists supported by, conducted by, or regulated by different federal agencies.

A Call to Action

Environmental and technological disasters cannot be eliminated. Each disaster and its legacy will be characterized by a unique combination of location, timing, size, duration, losses, decisions, and response. Yet risks and damage can be reduced and responses improved by the timely application of scientific knowledge. Science across all relevant disciplines will continue to play an important role in informing critical decisions and helping to guide response and recovery. The scientific community, in partnership with the emergency management community and decision-makers at all levels, has been involved in conducting, organizing, staffing, communicating, and archiving science during crisis. But further progress is needed. Best practices must be defined, a research agenda put in place, and policy reforms initiated.

Science during crisis has many long-term benefits. It can foster interdisciplinary collaborations within and among the scientific community, emergency response managers, local communities, federal, state, and local governments, and the private sector. Effective engagement of local communities and citizens—particularly those underrepresented or highly vulnerable—can improve trust, risk perception, communication, and coordination during crisis, as well as improve long-term outcomes. The scientific community can provide more efficient and effective scientific responses to future crises.[17]

This report is a call to action for federal, state, and local agencies, academic institutions, professional organizations, and stakeholders who rely on and contribute to science during crisis. Future climate and weather disasters will only be more frequent, severe, costly, and deadly; the communities affected by these events will need the very best science during crisis supporting them. We hope the recommendations in this report will contribute toward that important goal.

17. Marcia K. McNutt, "Convergence in the Geosciences," *GeoHealth* 1 (1) (2017): 2–3; and Mease et al., "Designing a Solution to Enable Agency-Academic Scientific Collaboration for Disasters."

Appendix A: Workshop Participants

Science During Crisis Workshop
April 19–21, 2017
American Academy of Arts and Sciences
Cambridge, Massachusetts

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Gary E. Machlis, *Cochair*
Former Science Advisor to the Director, U.S. National Park Service; University Professor of Environmental Sustainability, Clemson University

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San Jose State University

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President, American Academy of Arts and Sciences

Jeffrey Fox
Independent Science Writer and Editor

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Chief of the Emergency Response Division, National Oceanic and Atmospheric Administration

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Former Assistant Secretary for Preparedness and Response, U.S. Department of Health and Human Services

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Interim Director of the Scientific Responsibility, Human Rights, and Law Program, American Association for the Advancement of Science (AAAS)

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Shalin Jyotishi
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* While Dr. Symmes participated in the workshop discussions, the views and recommendations contained in this report do not necessarily represent the view of the National Academies of Sciences, Engineering, and Medicine or any of its constituent units.

Appendix B: About the Authors

Rita R. Colwell, a Fellow of the American Academy since 2002, is the former Director of the National Science Foundation and Distinguished University Professor at the University of Maryland. Her research interests are focused on global infectious diseases, water, and health. She is currently developing an international network to address emerging infectious diseases and water issues, including safe drinking water for both the developed and developing world. She is the recipient of both the Stockholm Water Prize (2010) and the Lee Kuan Yew Water Prize (Singapore, 2018).

Gary E. Machlis is the former Science Advisor to the Director of the U.S. National Park Service and University Professor of Environmental Sustainability at Clemson University. He founded and co-led the Department of the Interior's Strategic Sciences Group, which responded to both the Deep Water Horizon oil spill and Hurricane Sandy. He has written numerous books on issues of ecology and conservation, including *The Structure and Dynamics of Human Ecosystems: Toward a Model for Understanding and Action* (with William R. Burch Jr. and Jo Ellen Force, 2017) and most recently *The Future of Conservation in America: A Chart for Rough Water* (with Jonathan B. Jarvis, 2018).

The Public Face of Science

The Academy's Public Face of Science initiative (www.publicfaceofscience.org) addresses various aspects of the complex and evolving relationship between scientists and the public, and examines how trust in science is shaped by individual experiences, beliefs, and engagement with science. The project is also looking at the role of science in the legal system and the coordination and deployment of scientific teams as part of crisis response. The initiative has brought together a broad range of experts in communication, law, humanities, the arts, journalism, public affairs, and the physical, social, and life sciences. While this project does not directly address scientific literacy in K-12 and adult education, it will inform such efforts by fostering a greater understanding of the public's attitude toward science.

The first project report, *Perceptions of Science in America*, was published in February 2018 and summarizes the existing data on the current understanding of how Americans view science, scientists, and the impacts of scientific research.

Subsequent reports will highlight the numerous ways that individuals encounter science in their everyday lives and present recommendations for improving the practice of science communication and engagement.

Project Chair

Richard Meserve (Covington & Burling LLP; formerly, Carnegie Institution for Science)

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Robert Hauser (American Philosophical Society)
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"Science & the Legal System," *Dædalus*, edited by Shari Seidman Diamond & Richard O. Lempert (2018)

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