SCIENCE DURING CRISIS: THE ROLE OF SCIENCE IN DISASTER RESPONSE

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ABSTRACT

The number, scale, intensity, impact, and cost of environmental and technological disasters is increasing, from Category 5 hurricanes/typhoons to earthquakes in dense and growing urban spaces. Since 2014, the international community has experienced 1,639 man-made and natural disaster events that collectively have caused over 75,000 fatalities and US$917 billion in damages and recovery costs. Protecting human health, reducing risk, and improving outcomes requires science-informed decision-making. Hence, science during crises is of critical importance, and improved collaboration between scientists and disaster-response practitioners is essential. In this paper, based on the recent US Academy of Arts and Sciences report *Science During Crisis*, a set of best practices, research needs, and policy priorities are presented, along with case examples. Best practices range from the creation of interdisciplinary research teams, expanded joint training of emergency response and scientific communities, to central, curated clearinghouses for available data and insights deliverable in ways that response practitioners can use. Research needs to include improved baseline information, scenario-building to better understand cascading consequences, and more effective communication of science to managers, decision-makers, and the public during a disaster event. Policy priorities range from improving accessibility through to published scientific information and developing a code of conduct for scientists engaged in response. Case examples include the Gulf of Mexico Deepwater Horizon oil spill (2010), the Haitian earthquake (2010), the Fukushima Daiichi nuclear accident in Japan (2011), Typhoon Haiyan in the Philippines (2013), the South American and Caribbean zika virus emergency (2016), and Hurricane Maria in Puerto Rico (2017). A call to action is presented to improve the management, operation, and application of science during crises, in ways that increase the use, applicability, and value of science to disaster-response personnel.

Keywords: science, crisis, best practices, research needs, policy priorities.

1 INTRODUCTION

The number, scale, intensity, impact, and cost of environmental and technological disasters is increasing, from Category 5 hurricanes/typhoons to earthquakes in dense and growing urban spaces. The types of large-scale disasters range from the Gulf of Mexico Deepwater Horizon oil spill (2010), the Haitian earthquake (2010), the Fukushima Daiichi nuclear accident in Japan (2011), Typhoon Haiyan in the Philippines (2013), the South American and Caribbean zika virus emergency (2016), to Hurricane Maria in Puerto Rico (2017) and more. Since 2014, the international community has experienced 1,639 man-made and natural disaster events that collectively have caused over 75,000 fatalities and US$917 billion in damages and recovery costs [1]. 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 and industrial accidents – 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. Immediately following the 2010 Haitian earthquake, the European

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Commission's Joint Research Council analyzed satellite imagery to produce a rapid damage assessment to inform prioritization of emergency response actions [3]. When Hurricane Sandy made US 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. During the emergency response to the 2013 Typhoon Haiyan in the Philippines, the UN Office for Coordination of Humanitarian Affairs coordinated crowd-sourced mapping along with satellite and other data to develop emergency response maps. In 2016, when the Zika virus threatened the well-being of Caribbean, South American, and US 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 chemical spraying [4]. 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.

2 WHAT COMPRISES SCIENCE DURING CRISIS

Crisis events are most often acute disruptions (such as a 5.9 Richter magnitude earthquake) and place-specific (such as the L'Aquila earthquake in the Abruzzo region of Italy), with consequences for both natural and human systems. Science during crisis includes conducting scientific research and analyzing data, as well as organizing, staffing, communicating, and archiving scientific and technical resources during the crisis event – which for many events like earthquakes can last far beyond when the main shock and intense aftershocks end [5].

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, 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 in emergency response directly impacts the lives and livelihoods of survivors in a crisis-affected area.

Science during crisis has distinctive characteristics. For scientists serving in a crisis response, the protocols and time-scales of conducting research during the crisis differ from the usual practice of science. Typically, scientific research 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 delivers results necessarily based on more limited and uncertain 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 [6]. 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.

3 THE IMPORTANCE OF SCIENCE DURING CRISIS

While weather and climate crises, natural hazards, public health crises, and technological disasters are inevitable, so 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 in the US – the signature of and response to the Exon Valdez oil spill of 1989 (a surface spill) slowed understanding of the Deepwater Horizon oil spill's (a spill 1,500 meters below the surface) potential impact. 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 constant 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 their expertise during crisis, scientists must be ready to engage during crisis [7].

Science has played an important role during crisis for decades, and the scope of that work is broadening. The US experience is instructive. During World War II, the Office of Strategic Services (OSS) recruited scientists and engineers to provide expertise and support intelligence efforts. 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 US waters [8]. Similarly, the National Weather Service (NWS) created Incident Meteorologist positions to transmit critical weather forecasts to firefighters [9]. 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 research responders," supported by library resources coordinated by the National Library of Medicine [10]. 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 [11]. 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 US Geological Survey (USGS) coordinate with the Federal Emergency Management Agency (FEMA) to ensure scientists are on site during exercises to provide situational awareness.

Other examples exist – science is embedded in the Italian Department of Civil Protection's Augustus Method support functions, the UK's guidance documents "Emergency Preparedness" and "Emergency Response and Recovery", and Australia's Emergency

Management Manual. The Disaster Risk Management Knowledge Centre (DRMKC) fosters EU-level disaster science networks to support the European Response Coordination Centre and provide science-based advice to policy-makers. Though not an exhaustive list, these examples of organizational responses highlight the vital and growing role of science and scientists during crisis. It is to advance and improve the delivery of science during disaster events that the report "Science During Crisis: Best Practices, Research Needs, and Policy Priorities" was prepared [12].

4 ABOUT THE REPORT

In April 2017, the American Academy of Arts and Sciences held a workshop to address issues surrounding science during crisis. The Academy, founded in 1780, has served the United States as a champion of scholarship, civil dialogue, and useful knowledge. One of the nation's oldest learned societies and independent policy research centers, the Academy convenes leaders from the academic, business, arts, and government sectors to address critical challenges facing global society and provide decision-makers with authoritative and nonpartisan policy advice. The workshop on science during crisis was convened through the Academy's Public Face of Science Project, which is addressing various aspects of the complex and evolving relationship between science and the public in the United States.

The workshop engaged a diverse and interdisciplinary group of scientists, communicators and decision-makers. 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, the report provides recommendations to:

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

Selected recommendations with relevance both for and beyond the United States are described below.

5 RECOMMENDATIONS FOR IMPROVING BEST PRACTICES

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.

International, national, 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. 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.

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. Some dimensions of training, such as ethics and community engagement, may require the development of new standards and best practices. Opportunities for joint training include scenario-building and emergency response exercises.

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 relevant to the event and plausible cascading consequences. Appropriate protocols should be put in place to ensure data security, particularly protection of personally identifiable information.

6 RECOMMENDATIONS FOR A RESEARCH AGENDA

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.

6.1 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 pre-send 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?

6.2 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 in order 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?

6.3 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 a 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?

6.4 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?

6.5 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 for advancing the applicability of science during a crisis. Key questions include:

1. How and to what extent is scientific and technical information used in crisis decision-making?
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?

6.6 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. 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, grey 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?

7 POLICY RECOMMENDATIONS TO IMPROVE SCIENCE DURING CRISIS

Changes in current international, national, 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, the role of science in decision-making, and improve crisis response and recovery. In addition to government policies, improvements are needed in policies governing academic institutions, communities of practice, nongovernmental organizations, and private industry. Implementation of policy recommendations will vary by country, province/state, and local political institutions.

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 the regional and local level. State and provincial governments should create a Chief Science Officer position (and/or strengthen existing positions) to facilitate science during crisis. Creating a Chief Science Officer position would reduce confusion and facilitate effective conduct and application of science during crisis. The Chief Science Officer would serve as a critical liaison between national, state or provincial, and local government offices, emergency responders, and the scientific community.

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 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 non-crisis times and should be developed and agreed upon by the burgeoning science during crisis community of practice.

8 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, national, state/provincial, and local governments, and the private sector. Effective engagement of local communities and citizens – particularly those who are 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.

The Academy report is a call to action for government agencies, academic institutions, professional organizations, and stakeholders who rely on and contribute to science during crisis. Future 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. The recommendations in the American Academy of Arts and Sciences report, if acted upon, will contribute toward that important goal.

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REFERENCES

[1] Swiss Re Institute, Sigma Research, Sigma 1/2018: Natural catastrophes and man-made disasters in 2017: A year of record-breaking losses. www.swissre.com/institute/research/sigma-research/sigma-2018-01.html. Accessed on: 15 May 2019.

[2] Plumlee, G., Report from ground zero: How geoscientists aid in the aftermath of environmental disasters. *Earth Magazine*, 1 October 2009. www.earthmagazine.org/article/report-ground-zero. Accessed on: 16 May 2019.

[3] European Commission, European Commission supports relief efforts in Haiti with first damage assessment: Facts and Maps. http://europa.eu/rapid/press-release_IP-10-25_en.htm?locale=en. Accessed on: 20 May 2019.

[4] 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, Executive Office of the President of the United States: Washington, DC, 2016.
[5] Machlis, G. & Ludwig, K., Science during crisis: The application of interdisciplinary and strategic science during major environmental crises. *Understanding Society and Natural Resources*, eds M.J. Manfredo, J.J. Vaske, A. Rechkemmer & E.A. Duke, Springer: Dordrecht, pp. 47–65, 2014.
[6] Mease L., Gibbs-Plessl, T., Erickson, A., Ludwig, K., Reddy, C. & Lubchenco, J., Designing a solution to enable agency-academic scientific collaboration for disasters. *Ecology and Society*, **22**(2), p. 18, 2017.
[7] Cartlidge, E., Earthquake experts convicted of manslaughter. *Science Magazine*, 22 Oct. 2012. www.sciencemag.org/news/2012/10/earthquake-experts-convicted-manslaughter. Accessed on: 16 May 2019.
[8] National Oceanic and Atmospheric Administration, Office of Response and Restoration, OR&R field staff locations and contact information. response.restoration.noaa.gov/about/orr-field-staff.html. Accessed on: 20 May 2019.
[9] National Oceanic and Atmospheric Administration, National Weather Service, A day in the life of a NWS meteorologist: Incident meteorologists. www.weather.gov/jkl/Day_In_The_Life_Day13. Accessed on: 20 May 2019.
[10] US Department of Health and Human Services, NIH Disaster Research Response (DR2), About the program. dr2.nlm.nih.gov/about. Accessed on: 20 May 2019.
[11] Centers for Disease Control and Prevention, Global Health Protection and Security, Global Health Protection and Security: CDC Global Rapid Response Team. www.cdc.gov/globalhealth/healthprotection/errb/global-rrt.htm. Accessed on: 20 May 2019.
[12] Colwell, R.R. & Machlis, G., *Science During Crisis: Best Practices, Research Needs, and Policy Priorities*, American Academy of Arts and Sciences: Cambridge, MA, 2019.