J Extreme Events, Vol. 4, No. 3 (2017) 1771001 (8 pages)

DOI: 10.1142/S2345737617710014

Learning to Expect Surprise: Hurricanes Harvey, Irma, Maria, and Beyond

L Dilling[*,§], R Morss[†] and O Wilhelmi[‡]

[*]*Environmental Studies Program,*
Western Water Assessment,
Center for Science and Technology Policy Research,
and Cooperative Institute for Research in Environmental Sciences,
University of Colorado, Boulder, CO, USA

[†]*Mesoscale and Microscale Meteorology Laboratory,*
National Center for Atmospheric Research, Boulder, CO, USA

[‡]*Research Applications Laboratory,*
National Center for Atmospheric Research,
Boulder, CO, USA

Published 20 February 2018

Extreme events often bring unexpected situations and impacts, as the sequence of hurricanes and other natural disasters in summer and fall 2017 demonstrated. To reduce the risks associated with such events, many have focused on reducing uncertainty in prediction or reducing vulnerability. Although both are worthy goals, we suggest that the research community should also be focusing on the nature of surprise itself, to investigate the role of surprise in extreme events and its implications. Surprise arises when reality differs from people's expectations. Multiple factors contribute to creating surprise, including the dynamic nature of natural and human systems, the limitations of scientific knowledge and prediction, and the ways that people interpret and manage risks, not to mention climate variability and change. We argue that surprise is an unavoidable component of weather and climate disasters — one that we must acknowledge, learn to anticipate, and incorporate into risk assessment and management efforts. In sum, although it may seem paradoxical, we should be learning how to expect surprise.

Keywords: Adaptation; hazards; disasters; surprise; climate; interdisciplinary.

[§]Corresponding author's email: ldilling@colorado.edu

In 2017, once again the world's attention was focused on the astonishing power of weather and climate extremes and their devastating impacts. In India, Nepal, and Bangladesh, over 1,000 people died from widespread flooding during the summer monsoon. In August, Hurricane Harvey and its aftermath caused "unprecedented" flooding and an estimated $200B in damage along the US Gulf Coast. Harvey was followed closely by Hurricanes Irma and Maria and the California wildfires, each of which again caused devastating damage and loss of lives in the Americas.

These events have already provoked the usual debates about whether climate change is affecting weather extremes, as well as highlighting how development patterns, inequalities, and population and infrastructure vulnerabilities contribute to catastrophic outcomes. These topics are all important and useful foci for analysis and reflection as well as policy. Here, we focus on another important topic, one that intersects with science and policy, but is not often discussed: what can and should we be learning about the role of surprise in these events and its implications?

People are surprised "when perceived reality departs qualitatively from expectation" (Holling 1986, as cited in Kates and Clark 1996: P. 8). During the last century, scientific and technological advances have revolutionized weather and climate risk assessment and prediction capabilities (Bauer *et al.* 2015; IPCC 2012). It may seem paradoxical, then, to assert that in the 21st century, we must learn to expect surprise. We argue, however, that surprise is an unavoidable component of extreme events — one that we must acknowledge, learn to anticipate, and incorporate into risk assessment and management efforts.

The former US Secretary of Defense Donald Rumsfeld famously quipped that information about the future could be grouped into "known knowns, known unknowns, and unknown unknowns". The "known knowns" of weather and climate disasters include increasing exposures due to growing population and property near coastlines and the vulnerabilities of poorer communities and other populations (Morss *et al.* 2011; Thomas *et al.* 2013). Much of the scientific effort related to extreme events aims to make the "known unknowns" and "unknown unknowns" more known, by building new understandings, improving risk estimation and prediction, and characterizing and quantifying uncertainties (Stein and Geller 2012). Yet, inevitably some unknowns remain, leading to surprise. Some surprises occur because known uncertainties are not well characterized, communicated, or understood by those in harm's way. Some surprises occur because aspects of the system are simply not fully knowable in advance.

Surprises arise in part from the variable and changing natural environment, its interdependent components, and its increasingly complex interactions with the built environment and social systems (Morss *et al.* 2011; Merz *et al.* 2015). For example, predictions of future weather are inherently uncertain, due to the nonlinear and multi-scale nature of atmospheric motions combined with fundamental limitations in atmospheric observing and modeling. This was illustrated by the changes in the "best-guess" track forecast for Hurricane Irma as the storm evolved: although the general track of the hurricane across the Caribbean and towards the US coast was well-predicted days in advance, the areas that would be most affected by the storm were uncertain until closer to landfall. In the complex earth system, such uncertainties cannot be fully eliminated or predicted, leaving the potential for surprise. Moreover, they can rapidly amplify and cascade into unanticipated hazardous conditions, physical damages, and societal impacts, especially in the modern world with its complex infrastructure and interconnected systems.

Another major contributor to surprise is the cognitive biases and shortcuts that humans use to make sense of the world and manage risks (Merz *et al.* 2015). People's risk perceptions and their responses to risk information are influenced by a complex mix of cognitive processes, affect and emotion, experience, trust, worldviews, and other factors (Slovic 2016; McComas 2006; Demuth *et al.* 2016). Thus, in event after event, people are unable or unwilling to imagine the dramatic flooding or other hazardous conditions that can happen to them — or even believe that they are possible — until they occur (Kuhlicke 2010). Furthermore, even trained experts experience biases that lead to surprise. For example, in the 1997 Red River floods in the US and the 2002 Elbe River floods in Europe, engineers and authorities did not acknowledge the potential for catastrophic dike failures, nor did their safety procedures encompass worst case scenarios (Pielke 1999; Merz *et al.* 2015). While Hurricane Katrina (2005) has been called "the most predicted disaster in American history," its impacts and devastation in New Orleans, Louisiana, USA and surrounding areas were nonetheless profoundly surprising to many (Cigler 2007).

Surprise can also be created at the science–policy interface, when risk information available in expert domains is not well communicated with publics — or in some cases, not communicated at all. In Hurricane Irma, for example, even though forecasters understood that the storm's track was uncertain, many in western Florida, USA were surprised when the storm's track shifted from southeastern to southwestern Florida before landfall. This lack of clear information about risk can also affect longer-term decision-making such as moving at-risk property before a flood or purchasing homes or flood insurance. For example, when Hurricane Harvey affected the US Gulf Coast in August 2017, heavy rainfall from the storm flooded thousands of homes that, unbeknownst to homeowners, were built in reservoir "flood pools" behind dams designed by the US Army Corps of Engineers to hold water to protect downtown Houston, Texas from flooding (Olsen 2017).

This "manufactured" surprise can be exacerbated when risk information products, such as weather warning polygons and floodplain maps, give people a false sense of accuracy about risk in any given location due to how the risks are estimated and mapped (Monmonier 2014).

Floodplain maps, for example, are often based on highly uncertain estimates of flood risk (Downton *et al.* 2005). They also do not reflect the full extent and complexity of possible flooding scenarios, ranging from local interactions with the built environment to the dynamics of blocked stream courses to larger-scale streambed realignments. More fundamentally, maps designating areas at risk from flooding are designed to estimate the extent and magnitude of flood with a specified exceedance level, such as a "100-year" (or 1% chance) flood, yet more extreme floods can and do occur. However, members of the public can come to view floodplain maps as absolute designations of the potential for a location to flood, and thus are surprised when their property, understood by them as "safe", ends up being flooded (Soden *et al.* 2017).

As these examples illustrate, surprises are a ubiquitous and important feature of disasters, arising from physical, socio-behavioral, or policy components of a system or combinations of all the three. Therefore, we must integrate the potential for surprise and its realities into how we frame, study, and manage extreme events, from the questions we choose to study to the ways that we assess, predict, and communicate about the risks.

First, we must incorporate the lessons of surprise discussed above into our research and risk management agendas. One key area is improving communication and preparation for the "known knowns" of disasters that nevertheless end up being surprising to some, such as the vulnerability of New Orleans, Louisiana and Houston, Texas to extensive flooding and the vulnerability of the Caribbean islands of Dominica and Puerto Rico to a direct hit from a major hurricane like Maria. At the same time, since surprises are inevitable, we must maintain a focus on risk reduction efforts such as evacuation planning and poverty reduction to help reduce the impacts of extreme events when they occur. It is also important to continue building understanding about extreme events and improving risk estimates and predictions to help reduce unknowns. In order for such work to be more fully useful and pragmatic, however, we must acknowledge and communicate that parts of the earth system are not currently predictable and may not be for the foreseeable future. These predictability limitations are further exacerbated by nonstationarity associated with climate change. Only by expanding awareness of the possibilities of "the unthinkable", can we prepare the society for the inevitable surprises of the 21st century.

Second, further research on the concept of surprise in extreme events is needed, in order to better characterize and communicate that which we know well, that which we cannot know in advance, and the implications of each of these situations (Kates and Clark 1996). By studying what is surprising across events, we can detect larger patterns in how and why societal expectations do not match up with reality, whether in the way that physical events play out, or in the way complex social impacts cascade in the aftermath. Schneider *et al.* (1998) suggest ways of "imagining surprises" in a changing climate, and highlight, for example, the role of shared expectations and how different interpretations, salience of impacts, and interests can affect the outcomes that might be imaginable. We agree with Schneider *et al.* (1998) that "improving the anticipation of surprises is an interdisciplinary enterprise" (p. 165) and thus cuts across the otherwise inherently limited view from within individual disciplines of how disasters are produced and manifested. Within individual fields, it is important to investigate and be more explicit about what an analysis or model cannot predict, due to the fundamental and practical limitations of the science to give certain types of guidance. By connecting knowledge about these limitations across fields, we can then understand where the limits of predictability and potential surprise points are at the intersections across fields and incorporate that understanding into disaster risk management.

Third, we need to have different conversations about what might be possible and surprising in order to open up new action spaces for creative and resilient planning and preparation. Not all risk can be removed, reduced, or known in advance. More than a decade ago, the US National Weather Service (NWS) aimed to be "America's No Surprise Weather Service". No longer in use, this slogan at the time provided plenty of fodder for media critique of the NWS when forecasters failed to forecast a major snow storm in Washington, DC. Rather than "no surprises", we argue that we should be talking more about what kinds of unprecedented events may occur and how to incorporate that potential into our thinking and planning. As argued by Lagadec (2004) in his analysis of the 2003 European heat wave that led to thousands of deaths, today's crises are often unique, rapidly evolving, multi-faceted, and interconnected. These types of extreme events require scientists, policy-makers, and communities to conceive the "inconceivable" and operate under new paradigms. Experts and lay publics alike seek certainty and simplicity whenever possible — but omission of information about the possibility of surprise can, over the longer term, lead to devastating consequences when the inevitable occurs. The sea level risk community, for example, is engaging in these types of discussions by working to understand the potentially catastrophic issues associated with rapid ice melt scenarios due to climate change (Rahmstorf 2010).

Ultimately, the public's trust in science and other societal institutions rests on acknowledging that surprises can and will occur. Public attitudes toward technical knowledge vary widely: some place too much faith in the ability of science to predict the future and overestimate the control that is possible, while others do not believe or respond to warnings. In the end, discussing a full range of possible outcomes on a regular basis, including the potential for surprises, may be a more honest and ultimately more trustworthy stance for scientists and managers helping prepare members of the public for extreme events (LaPorte 2007). This includes acknowledging that technical experts sometimes are not able to know what is going to happen. Such a position may be uncomfortable for knowledge providers and decision-makers, but the transparency may lead to new ways of creating flexibility for managing increasingly complex weather and climate risks (Dilling *et al.* 2015).

With modern advances in science and technology, society increasingly relies on scientists to understand and predict weather and climate extremes so that people can act. Without the earth observations, numerical modeling, and forecast and warning systems available today, the 2017 hurricane season in the Caribbean and the US would almost certainly have caused much greater loss of life and an even more devastating series of disasters. Yet, when people suffer needless harm from knowable surprises, as they did in Hurricanes Harvey, Irma, and Maria, it is clear that new approaches are needed.

Incorporating surprise into extreme event risk assessment, prediction, and management means framing research, risk communication, and public engagement differently. Surprises provide a research opportunity to better understand not only how to get the science "right", i.e., the most precise specific answer, but also what can be known, with what types of uncertainties, and what cannot. The 2017 Atlantic hurricane season reveals that our understanding and ways of coping with risk are far from complete. Surprises also have important implications for the types of risk estimation and prediction tools we build and the ways that we communicate the resulting risk information. And, they have consequences for which types of risk management strategies should be adopted and how the public should be engaged in making those choices. As researchers and warning system partners, we must become more cognizant of what we are promising to deliver to society — and what we simply cannot.

Overall, we must learn to accommodate the potential for surprise in our thinking, study the realities of surprise, and communicate about these realities across areas of expertise and with public. Only then experts from different fields can work together and with publics to co-produce and co-utilize the knowledge that is urgently needed to reduce the impacts from extreme events and build sustainable futures in our increasingly complex and interconnected world.

Acknowledgments

L. Dilling acknowledges support from the Leverhulme Trust, UK, and R. Morss and O. Wilhelmi acknowledge support from NSF award 1331490. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

References

Bauer, P, Thorpe A and Brunet G (2015). The quiet revolution of numerical weather prediction. *Nature*, 525(7567): 47–55.

Cigler, BA (2007). The “big questions” of Katrina and the 2005 great flood of New Orleans. *Public Administration Review*, 67(s1): 64–76.

Demuth, JL, Morss RE, Lazo JK and Trumbo C (2016). The effects of past hurricane experiences on evacuation intentions through risk perception and efficacy beliefs: A mediation analysis. *Weather, Climate, and Society*, 8: 327–344.

Dilling, L, Daly ME, Travis WR, Wilhelmi OV and Klein RA (2015). The dynamics of vulnerability: Why adapting to climate variability will not always prepare us for climate change. *Wiley Interdisciplinary Reviews: Climate Change*, 6(4): 413–425.

Downton, MW, Morss RE, Wilhelmi OV, Gruntfest EC and Higgins ML (2005). Interactions between scientific uncertainty and flood management decisions: Two case studies in Colorado. *Global Environmental Change Part B: Environmental Hazards*, 6: 134–146.

Holling, CS (1986). Resilience of ecosystems; local surprise and global change. In: Clark, WC and Munn RE (eds.), *Sustainable Development of the Biosphere*. Cambridge, UK and New York: Cambridge University Press, pp. 292–317.

IPCC (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

Kates, RW and Clark WC (1996). Environmental surprise: Expecting the unexpected? *Environment: Science and Policy for Sustainable Development*, 38(2): 6–34.

Kuhlicke, C (2010). The dynamics of vulnerability: Some preliminary thoughts about the occurrence of ‘radical surprises’ and a case study on the 2002 flood (Germany). *Natural Hazards*, 55(3): 671–688.

Lagadec, P (2004). Understanding the French 2003 heat wave experience: Beyond the heat, a multi-layered challenge. *Journal of Contingencies and Crisis Management*, 12(4): 160–169.

LaPorte, TR (2007). Critical infrastructure in the face of a predatory future: Preparing for untoward surprise. *Journal of Contingencies and Crisis Management*, 15(1): 60–64.

McComas, KA (2006). Defining moments in risk communication research: 1996–2005. *Journal of Health Communication*, 11: 75–91.

Merz, B, Vorogushyn S, Lall U, Viglione A and Blöschl G (2015). Charting unknown waters — On the role of surprise in flood risk assessment and management. *Water Resources Research*, 51(8): 6399–6416.

Monmonier, M (2014). *How to Lie with Maps*. Chicago: University of Chicago Press.

Morss, RE, Wilhelmi OV, Meehl GA and Dilling L (2011). Improving societal outcomes of extreme weather in a changing climate: An integrated perspective. *Annual Review of Environment and Resources*, 36: 1–25.

Olsen, L (2017). Many homeowners unaware they lived in reservoir ‘flood pools’: Officials knew major storm could inundate homes. *Houston Chronicle,* September 26, 2017. http://www.houstonchronicle.com/news/houston-texas/houston/article/Many-homeowners-unaware-they-lived-in-reservoir-12231188.php.

Pielke, Jr. RA (1999). Who decides? Forecasts and responsibilities in the 1997 Red River flood. *Applied Behavioral Science Review,* 7(2): 83–101.

Rahmstorf, S (2010). A new view on sea level rise. *Nature Reports Climate Change*, 4: 44–45.

Schneider, SH, Turner BL and Garriga HM (1998). Imaginable surprise in global change science. *Journal of Risk Research*, 1(2): 165–185.

Slovic, P (2016). *The Perception of Risk*. London: Routledge.

Soden, R, Sprain L and Palen L (2017). Thin Grey Lines: Confrontations with Risk on Colorado’s Front Range. *Proceedings of the 2017 ACM Conference on Human Factors in Computing Systems (CHI 2017),* Denver, Colorado, US, pp. 2042–2053.

Stein, S and Geller RJ (2012). Communicating uncertainties in natural hazard forecasts. *Eos, Transactions American Geophysical Union*, 93(38): 361–362.

Thomas, DSK, Phillips BD, Lovekamp WE and Fothergill A (2013). *Social Vulnerability to Disasters*. Boca Raton, FL and New York: CRC Press.