21. CONCLUSIONS AND EPILOGUE

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To help understand the difficulty of determining the anthropogenic contribution to specific extreme events, consider this driving analogy (UCAR 2012). "Adding just a little bit of speed to your highway commute each month can substantially raise the odds that you'll get hurt some day. But if an accident does occur, the primary cause may not be your speed itself: it could be a wet road or a texting driver." Similarly, while climate models may indicate a human effect is causing increases in the chances of having extremely high precipitation in a region (much like speeding increases the chances of having an accident), natural variability can still be the primary factor in any individual extreme event. The difficulty in determining the precise sensitivity of, according to our analogy, driving speed on risks of accidents in particular conditions (wet roads, texting drivers) can explain why somewhat different analyses of the same meteorological event can reach somewhat different conclusions about the extent to which human influence has altered the likelihood and magnitude of the event.

For example, one assessment of seasonal changes in heavy five-day precipitation events in Australia finds little modeled evidence of long-term changes in such events once ENSO is factored in, while another analysis that examined the human influence on total monthly precipitation for March in roughly the same area found that it increased the probability of above average rainfall by 5%–15% ("Limited Evidence of Anthropogenic Influence on the 2011–12 Extreme Rainfall over Southeast Australia" and "An Attribution Study of the Heavy Rainfall over Eastern Australia in March 2012" in this report). These differences arose despite the two analyses having an author in common. However, the bottom line of the event attribution was basically the same: that the heavy rain last year in eastern Australia was predominately due to natural variability. But for rare events, the results of these analyses of Australian rainfall illustrate how attribution studies that examine the effects of human influences on an extreme event can be dependent on both the methodology used in the assessment as well as the choice of metrics.

Among all the extreme events that occurred around the world in 2012, the subset of events analyzed in this paper was not chosen at random. While "The Extreme March–May 2012 Warm Anomaly over the Eastern United States: Global Context and Multimodel Trend Analysis" (in this report) used objective criteria to search the globe to determine the event to analyze, other analysis topics were selected based on a variety of factors similar to what drives a great deal of scientific research, including the researchers' interests and subjective estimation of what events present tractable problems. It is likely no accident that the majority of the submissions focus on events related to temperature and precipitation, given that these are two variables where the observational record is strong. We also see a natural bias towards addressing local events as scientists in Australia, China, France, Japan, the Netherlands, New Zealand, Spain, the United Kingdom, and the United States examined extreme events impacting themselves, their friends, and their neighbors. A few groups examined events in distant locations, including Arctic sea ice and drought in the Horn of Africa, which they deemed important. It is also noteworthy that only one group examined a cold event, which global warming might theoretically be expected to decrease in frequency or intensity. So, there is a danger in drawing too strong a conclusion from a small sample of 19 analyses of 12 events that were not chosen at random. That said, approximately half of the analyses found some evidence that anthropogenic climate change was a contributing factor to the extreme event examined, though the effects of natural fluctuations of weather and climate on the evolution of many of the extreme events played key roles as well.

In this second issue of the annual *BAMS* attribution report, an important innovation is that we have now included multiple analyses of a single event. The differences in the results also provide insights into the structural uncertainty of event attribution, that is, the uncertainty that arises directly from the differences in analysis methodology. For example, there are four different studies of the wet summer in northern Europe using different methodological approaches, observational datasets, and climate models. While these studies provide complementary perspectives into the possible roles of North Atlantic sea surface temperatures, Arctic sea ice reduction, atmospheric circulation, and an enhanced moisture carrying capacity of the atmosphere, these studies also highlight certain deficiencies of current models, observations, and methods. As a result, the attribution conclusions

for such relatively complex events remain somewhat equivocal. The results in general contained in this special issue are not necessarily the final word nor the definitive treatments on these cases. Other studies, using different and perhaps improved tools (e.g. new models) will undoubtedly come forth and will further test the efficacy of surmised and plausible causal factors. In the manner that has become common in our field to "re-analyze" historical data as new data, analysis methods and models come forward, so too we foresee a rich science enterprise of "re-attribution". A priority for further research is to develop modeling systems that have been shown to be sufficiently reliable with respect to the specific type of extreme being assessed to generate less equivocal and more robust results for such complex events.

With the increasing sophistication of event attribution studies comes a greater focus on assessing the capability of the various current approaches to provide robust answers to such difficult questions as whether there is a link between anthropogenic climate change and the extremely wet summer in northern Europe in 2012, which was not only an extreme event in itself but also the sixth summer in a row in which UK rainfall was higher than the 1981–2010 average.

Where does the work on event attribution go from here? At the September 2012 workshop on the Attribution of Climate and Weather Extremes: Assessing, Anticipating and Communicating Climate Risks, which was held at Oxford University, it became clear that there was a broad range of stakeholders interested in the results of this science. For example, the insurance and legal sectors are keenly interested in understanding how the risks associated with extreme events are changing (Stott and Walton 2013, manuscript submitted to *Weather*). Climate forecasting services are likewise keenly interested in knowing the causes of extreme events. The process of clarifying the proximate and underlying causes is seen as key to providing a narrative of their origins, which advances predictive understanding. It is here where the dual challenges of improved prediction and improved explanation of causes intertwine.

This information is critical to preparing for future events, and the need to make this information accessible, timely, and relevant for the user is broadly recognized. For example, one of the key drivers of the Global Framework for Climate Services (GFCS) is to mainstream the provision of "information that governments, organizations, and individuals can use to manage climate risks and opportunities" (WMO 2012). One-fourth of the World Meteorological Organization (WMO) Commission for Climatology is dedicated to improving climate information for adaptation and risk management (WMO 2013). And, this is in addition to action being taken at the national and local scales by various governmental and nongovernmental groups. Extreme events are, of course, a key source of climate risk (Schiermeier 2011).

As the science underpinning the attribution of extreme events matures, it will nurture and make possible the creation of operational climate attribution systems (Stott et al. 2013). Then, as attribution of extreme events become part of routine climate services and part of the GFCS, scientists will need to continue outreach into our stakeholder communities. Climate risk reduction is a key driver of many climate adaptation activities (van Aalst et al. 2008). Therefore, many communities will need to better understand exactly what attribution of extreme event science can and cannot say. To return to the opening analogy, this means answering the question of how the change in the driver's speed was responsible for changing the odds of colliding with a texting driver on a wet road, which would be the extreme event we are trying to attribute.