CONCLUSIONS

Peter A. Stott—Met Office Hadley Centre, Exeter, United Kingdom; Thomas C. Peterson—NOAA National Climatic Data Center, Asheville, North Carolina; Stephanie Herring—Office of Program Planning and Integration, NOAA, Silver Spring, Maryland

"Climate is what a boxer trains for but weather throws the punches" (D. Arndt 2012, personal communication). Attribution analyzes, such as those in this article, have the potential to inform the necessary training and adaptation options for societies in dealing with the punches weather and climate extremes throw their way.

The section on historical context summarizes the evidence that human influence has affected trends and long-term behavior of temperature and precipitation extremes around the globe, thus altering the types and frequencies of punches for which our boxer must train. This is to be anticipated from theoretical expectations of a warmer world. The recent IPCC SREX report (Field et al. 2012) concluded that "it is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperature at the global scale" and that "there is medium confidence that anthropogenic influences have contributed to intensification of extreme precipitation at the global scale." But even if human influence is making a particular type of event more likely on average, because of natural variability it does not necessarily follow that its likelihood is greater every year. So while it has been argued that in the anthropocene[4] all extreme weather or climate events that occur are altered by human influence on climate (Trenberth 2011), and although it is difficult to prove that a particular extreme weather or climate event was not in some way influenced by climate change, this does not mean that climate change can be blamed for every extreme weather or climate event. After all, there has always been extreme weather.

The contributions in this article examining some of the specific extreme weather or climate events of 2011 demonstrate the importance of understanding the interplay of natural climate variability and anthropogenic climate change on their occurrence. We should not expect that climate change plays the major role in every extreme weather or climate event and indeed the rainfall associated with the devastating Thailand floods was not especially unusual. In this case, nonclimatic factors such as changes in land use and water management probably played a bigger role in the disaster. Thus attribution of the impacts of weather-related events to climate variability and change requires careful consideration

[4] The anthropocene is the most recent geological era in which human activities have had a significant global impact on the Earth's ecosystems (Crutzen 2002).

of possible confounding factors not related to climate (Hegerl et al. 2010).

The development of a regular attribution service whose results are available shortly after the month or season in question depends on the implementation of an established methodology. For example, the same circulation regime–based technique used to analyze the very cold northwestern European winter of 2009/10 (Cattiaux et al. 2010a) was used to investigate European seasonal temperatures in 2011. All four seasons were warmer in many parts of Europe than would be expected from the average of previous years with similar atmospheric flow conditions. While 2011 had the warmest annual mean temperatures in western Europe since the start of the analysis in 1948, temperatures expected from the observed atmospheric flow conditions would not have been unusual. The implication is that without long-term warming, 2011 would not have been a record breaker by this measure.

Another approach that supports a regular attribution service is based on estimating the changed probabilities of extreme weather or climate events from ensembles of atmosphere only climate models with different sea surface temperatures (SSTs) and altered concentrations of greenhouse gases and other climate forcings. This technique has been used to show that human-induced greenhouse gas emissions have increased the risk of the UK flooding seen in 2000 (Pall et al. 2011). A similar analysis of the cold UK winter of 2010/11 determined that temperatures as cold as seen in the early part of the winter were less likely as a result of human influence on climate and when looking at combined December/January temperatures they were half as likely. Examining the unique multicentury record of central England temperatures allows a simple verification of such statistics for the United Kingdom.

An important future development of such attribution systems is to allow the changed risk of extreme weather or climate events to be calculated quickly and disseminated on a regular basis. The Weather Risk Attribution Forecast (WRAF) system, which is based on a seasonal forecasting modeling system, has been trialled in this way, providing regularly updated estimates of risks of temperature and precipitation extremes. It will be crucial to understand the strength and limitations of such systems for the weather and climate events to which they are being applied. This should include an assessment of the reliability of the models being used (Christidis et al. 2012, manuscript submitted to *J. Climate*).

Providing such attribution results in time for this issue has proved extremely challenging given the delays involved in collecting observations, running models and analyzing data. Two analyzes presented here used preexisting climate model simulations to compare event statistics for recent years with years from the 1960s. While this approach does not explicitly calculate the extent of changes attributable to human influence because natural external forcing and natural internal variability could have contributed to the change in the likelihood of events since the 1960s, it does address how the long-term warming trend has affected weather odds. By carefully choosing years with patterns of SSTs similar to those of 2011, it was possible to determine that heat waves such as the one that affected Texas have become distinctly more likely than they were 40 years ago. In the United Kingdom there has been a much greater increase in the likelihood of the very warm November temperatures seen in 2011 than the reduction in likelihood of the very cold December temperatures seen the previous winter. This interesting seasonal asymmetry in the change of extreme climate and weather odds seems worthy of further investigation.

It has been questioned whether attribution studies might neglect many of the regions most vulnerable to extreme weather because of the greater difficulties of collecting climate observations and undertaking climate modeling in developing countries (Hulme 2011). Therefore the analysis of the East African drought of 2011 is particularly interesting because it demonstrates the potential for attribution in tropical regions that lack robust international exchange of climate observations. Low-latitude regions generally have higher ratios between the signal of climate change in temperature and variability than other regions (Mahlstein et al. 2011) and there appears to be potential skill in seasonal forecasting of impact-relevant metrics such as the onset of seasonal rains in Africa (Graham and Biot 2012). While La Niña had a large role to play in the failure of the rains in East Africa, there is evidence that warming in the western Pacific–Indian Ocean warm pool has contributed to an increased frequency of droughts in this region. While such a conclusion is supported by a deeper body of literature, the hypothesis of a link between ocean warming and a greater risk of drought in this region remains controversial. All attribution assessments are necessarily subject to change as science advances. A key challenge for attribution assessments remains to accurately characterize their levels of confidence given current understanding.

2011 was a year during which the weather threw plenty of punches [see Blunden and Arndt's (2012)

supplement to this issue]. While much work remains to be done in attribution science, to develop better observational datasets, to improve methodologies, to make further progress in understanding and to assess and improve climate models, the contributions in this article demonstrate the potential that already exists for meaningful assessments of the connection between specific extreme weather or climate events that occurred in a particular year and climate change. Whether readers react with excitement at the possibilities already demonstrated, or with irritation at the gaps and limitations still present, our hope as editors is that this initial selection of investigations encourages further development of the capability to produce timely and reliable assessments of recent extreme weather or climate events. Such an enterprise is much further advanced for climate monitoring—as shown by the maturity of the annual State of the Climate report (e.g., Blunden and Arndt 2012)—but even there important uncertainties exist and new assessments of past years will emerge, just as they will for attribution as understanding develops. By developing the scientific underpinning, the ability to put recent extreme weather or climate events into the longer-term context of climate change should improve as each year goes by.

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