Attribution and prediction of extreme events: Editorial on the special issue

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Editorial

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1. Introduction

The investigation of extreme events and their relation to climate change and variability is arguably one of the most challenging areas in climate research. Extremes are also of continual concern amongst policy and decision makers, and in the media, because of the devastating impacts that can result from their occurrence. As highlighted in the recent IPCC Special Report on "Managing the risks of extreme events and disasters to advance climate change and adaptation" (SREX), climate extremes are by definition rare, often difficult to define, not well observed, and pose substantial challenges in their characterization (IPCC, 2012; Seneviratne et al., 2012). The scientific challenges are multidisciplinary, and point to the need for improved statistical analysis tools, deeper process understanding, and more extensive assessments of the societal and ecosystems impacts of extreme events. Despite, or maybe because of these issues, research on extremes is vibrant and is advancing rapidly (Seneviratne et al., 2012; Zwiers et al., 2013; Herring et al., 2014). Nevertheless, the magnitude and importance of research on extremes is so large that even greater levels of effort and amounts of expertise are urgently required across a broad range of disciplines.

Accordingly, the World Climate Research Programme (WCRP) has chosen the theme "Understanding and predicting weather and climate extremes" as one of their six "grand challenges" (Zhang et al., 2013; Alexander et al., 2015). Research questions addressed under this grand challenge are related to the development of observational products on extremes based both on in-situ and satellite data, the understanding of large-scale vs regional-scale mechanisms leading to the occurrence of extremes, the prediction and simulation of extremes in climate models, as well as the possible attribution of extreme events to anthropogenic climate forcing (Alexander et al., 2015).

This special issue of *Weather and Climate Extremes (WACE)* includes a series of articles initiated during the 2014 WCRP summer school on the "Attribution and Prediction of Extreme Events". The two-week summer school took place from 21st July to 4th August 2014 at the International Center for Theoretical Physics (ICTP) in Trieste, Italy, and was organized in the context of the WCRP Grand Challenge on Extremes.

2. WCRP Summer School on the Attribution and Prediction of Extreme Events

The 2014 WCRP summer school, a unique event in terms of its scope and output (including the seven articles in this issue!), was focused on capacity building and the training of a new generation of scientists working in research on climate extremes. Thirty-six students with outstanding research potential, including a large number from developing countries, attended the summer school. The students were selected from amongst more than 220 applicants from all continents using a process that attempted to balance educational backgrounds, career stage, region of origin and gender, within the limits of the unequal regional distribution of applications.

The school was organized around three broad topic areas:

(1) statistical theory underpinning extreme value analysis,
(2) detection and attribution of observed changes in the frequency and/or intensity of extremes, and
(3) event attribution, and the physical mechanisms that are involved in amplifying and/or extending the duration of some specific extreme events such as heat waves.

Furthermore, the school educated students in the development of key data resources that are used to place current extremes into a historical context, and provided insights into some of the emerging thinking on the near-term prediction of the likelihood of extreme events. Finally, it also taught the importance of understanding the physical mechanisms that produce many of the most impactful extreme events, including complex hydrologic extremes such as drought and the role of land-atmosphere feedback mechanisms in amplifying extreme temperature events.

The school was subdivided in two main parts, one consisting of lectures and exercises, the other consisting of the development of seven independent research projects by respective working groups, each supervised by one or two lecturers. In planning the school, we expected that *some*, but certainly not all, of the working groups might be able to develop interesting enough research projects to write peer-reviewed publications on their results. It is an outstanding outcome that *all* of the working groups were able to complete innovative publications, as can be seen in the present special issue. The seven articles span a wide range of topics in climate and weather extremes, following the overall framework of the summer school, and thereby illustrate the breadth of themes relevant to this research area. These articles, together with the large collection of lecture notes, tutorials, and other resources that are available from the school's website (http://www.wcrp-climate.org/ictp2014-about) represent an enduring legacy that contributes to the body of knowledge and expertise on extremes.

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3. Articles of the special issue

Station data are a fundamental source of information about extremes that are used all over the world both to place current events into a historical context and as a basis for the calculation of extreme indices and return values (e.g. Alexander et al., 2006; Donat et al., 2013). These indices have many applications, including the estimation of long-period return values that are used as design criteria for the infrastructure sustaining our everyday lives. However, there are a number of scientific issues associated with the processing of such observations. The first two articles of this special issue, by Avila et al. (2015) and Bador et al. (2015), contribute to this research area by addressing questions related to the processing of station data and how to relate point-scale with regional-scale information. Avila et al. investigate the impact of interpolation methods and gridding, as well as their order, on regional statistics of extremes. They identify that grid resolution has limited effect when considering regional averages, but that the interpolation method and order of operations in the processing of station data can substantially influence the gridded values of extreme-value statistics. Nevertheless, they find that variations in the order of operations do not strongly affect long-term trends and inter-annual variability. Bador et al. investigate for their part the potential for spatial clustering of summer temperature maxima in observational and modeling datasets. The approach they tested yields valid information on extremes, while greatly reducing the size of the data set. It thus opens interesting options for data processing and future analyses of climate extremes.

When impactful extreme events occur, an unavoidable question from media and policy makers is whether human influence on the climate has somehow influenced the occurrence of the event. This question has become the focus of a rapidly developing branch of the science on extremes that is called *event attribution* (Allen, 2003; Stott et al., 2004; Herring et al., 2014). Event attribution uses a range of approaches that span the gamut from purely empirical approaches (e.g., van Oldenborgh et al., 2012) to methods that are heavily dependent upon ensembles of climate simulations (e.g., Pall et al., 2011). In parallel, the question of the attribution of long-term changes in climate to anthropogenic and other external influences, termed *detection and attribution,* is another fundamental and rapidly developing climate research area (e.g. Hegerl et al., 2007; Zwiers et al., 2011; Bindoff et al., 2013). The three studies in this issue by Sippel et al. (2015), Bellprat et al. (2015), and Mueller et al. (2015), contribute to these research areas by addressing applications related to extreme events attribution (Sippel et al. and Bellprat et al.), and detection and attribution and its implications for extreme growing season lengths (Mueller et al.). Sippel et al. provide a theoretical investigation assessing differences in two commonly applied techniques for quantifying the return period of given extreme events, i.e. Extreme Value Theory (EVT)-based statistical methods vs large model ensembles, focusing on cold extremes and heavy rainfall in winter in Europe. They identify biases in EVT-based estimates of the intensity of extremes when extrapolating far beyond the available data range. In particular, statistical inferences made about “rare” events (i.e. with a return period of >100 years) based on “moderate” events (e.g. annual extremes) are found to have pronounced biases in regions with high climatic variability. Bellprat et al. provide an attribution study for recent dry and wet rainy seasons that caused severe socio-economic damage in Southern Africa and Southern South America, based on climate model simulations from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The investigation shows that, while no attribution statement can be made in Southern South America due to lack of climate model performance, assessments can be derived for South Africa, with global warming making one event (2002/2003 dry summer) more likely, but the other (1999/2000 wet summer) less likely. Mueller et al. provide an assessment of changes in temperature-based calculations of growing season length and their possible attribution to anthropogenic climate warming. Their results show that climate change has increased the probability of extremely long growing seasons by a factor of 25, and decreased the probability of extremely short growing seasons, with important potential impacts for agriculture management. This result constitutes a first formal detection and attribution assessment related to growing season length.

While the above questions – i.e. the use of observations for the study of extremes statistics and the attribution of single extreme events or trends in extremes to anthropogenic forcing – are now well established in research on climate extremes, the consideration of mechanistic and predictive (in addition to statistical) aspects is equally essential. Indeed, it is imperative that we better understand the physical processes that contribute to and/or modulate the development of extreme events (e.g. Seneviratne et al., 2006; O'Gorman and Schneider, 2009; Pitman et al., 2012) for predicting these extremes on time scales of weeks to centuries (Mueller and Seneviratne, 2012; Martius et al., 2013, Kharin et al., 2013), as well as for robustly detecting changes (Sheffield et al., 2012; Greve et al., 2014; Seneviratne et al., 2014). In addition, it is necessary to better evaluate and develop tools that can be used to forecast the occurrence of extreme events (e.g. Weisheimer et al., 2011; Doblas-Reyes et al., 2013; Kidston et al., 2013), both to improve resilience to present-day climate variability as well as to foster adaptation to changes in climate extremes (Wilby et al., 2009). The final two studies in this issue, by Whan et al. (2015) and Pepler et al. (2015), contribute to these objectives by addressing previously unexplored questions related to the impact of soil moisture-temperature feedbacks on extreme temperatures and the ability of climate models to forecast extremes. Whan et al. assess the role of soil moisture-temperature feedbacks for monthly summer temperature maxima in Europe, accounting for the dependency of temperature on soil moisture content in a Generalized Extreme Value (GEV) framework. Their results highlight the importance of soil moisture for such extremes providing a quantification of this effect in southern-central and southeastern Europe. From the derived statistical model, hot temperatures extremes are estimated to be about 1.6 °C warmer per 100-mm increase in soil moisture deficit. Pepler et al. investigate the ability of a multi-model ensemble to forecast the 90^{th} and 10^{th} percentiles of seasonal temperature and precipitation, identifying that forecast skill for extremes is related to, but lower than, the skill in predicting means. These results highlight the specific difficulties associated with capturing extremes and the need for further investigations of the skill of forecasting systems in predicting extremes.

Overall, these studies highlight the diversity of research on extremes and the number of challenges faced – but also the potential rewards yielded – in bridging the gaps across the disciplines contributing to this field (e.g. statistics, climate modeling, process-based analyses). They also point to the range of topics that need to be considered in meeting the WCRP Grand Challenge on Extremes and in developing our capability to interpret extreme events with confidence, ranging from the fundamental data, to analysis techniques and the framing of questions, and to the supporting process understanding. In the years to come, and building (among others) upon this collection of articles, we expect that major advances can be reached from furthering such interactions.

4. Conclusions

It should be considered a major success of the summer school that such a high number of innovative publications – all led by the students themselves – could be completed, and we hope that this outcome will serve as an inspiration for future summer schools on related topics. The approach used at the summer school combined lectures by leading experts and hands-on tutorials with the engagement of students in well-designed research projects over an intense two-week period. In this approach, students can begin to immediately and successfully apply new knowledge and concepts, allowing them to develop analytical skills but also practical experience in the development of scientific research, while addressing innovative and exciting new research questions.

In conclusion, we would like to thank all the persons and institutions that allowed this summer school and special issue to be so successful. In particular, all the lecturers and their institutions; Anna Pirani and Roberta Boscolo, without whose impetus and perseverance the school would not have occurred; WCRP and ICTP for the institutional support; Petra Krizmancic, and Adrian Tompkins for the coordination and local organization; Lisa Alexander for the efficient coordination of this special issue; and last but not least, the participating students for their motivation, dedication and enthusiasm in working on these projects and so efficiently completing the respective publications. It was a pleasure for us to co-chair this summer school and see the successful outcome in the form of this special issue, and we herewith invite the readers to enjoy this very special collection of publications on climate extremes research.

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