SECOND DRAFT

WCRP Grand Challenge: Prediction and Attribution of Extreme Events

David Karoly, with input from GEWEX, CLIVAR, ETCCDI, WGSIP, WGCM and ACE

Context

Weather and climate-related extreme events have major impacts on human and natural systems, including loss of lives, damage to buildings and other infrastructure, and damage to ecosystems. There are many different types of extreme events, including heat waves, drought, cold outbreaks, flooding, blizzards, storm surges and severe storms. They span a very wide range of temporal scales, from minutes to years, and spatial scales, from a few kilometres to thousands of kilometres. Such extremes are rare in any one location, which increases the difficulty in obtaining robust and reliable observational data and model simulations for extremes.

Climate variations, such as associated with common modes of variability like El Niño-Southern Oscillation and the North Atlantic Oscillation, affect the frequency and intensity of extreme events on seasonal to interannual timescales. Anthropogenic climate change is already changing the frequency and intensity of some extreme events and will have a greater influence on extremes in the future (IPCC, 2012).

Improved understanding and prediction of extreme events, as well as reducing societal vulnerability to extremes, requires scientific inputs from and collaboration among all the WCRP research projects and working groups.

This Grand Challenge is the focus of the recent IPCC Special Report on Extremes (IPCC, 2012), as well as being a key GEWEX and CLIVAR Science Question and the topic for two Community Papers at the WCRP Open Science Conference in 2011 (Stott et al., 2012; Zwiers et al., 2012). There is already much research activity on extreme events and coordinated efforts will be more likely to reap greater rewards. This Grand Challenge builds on the existing
research efforts previously coordinated through the WCRP Crosscut on Extremes.

Scientific frontiers

F1: Observations and Analyses

Limitations on the availability and quality of observational data sets for extreme events have seriously undermined the capabilities for describing past variations in extremes, for understanding the causes of extremes and for developing modeling systems for prediction of future variations and changes in extremes. There are many opportunities for improvements.

Higher time and space scale observations are needed, as well as improved observations of key processes, including land-atmosphere, ocean-atmosphere and land-ice interactions. Free and open international exchange of existing high time resolution data would improve global coverage of daily and sub-daily observations for temperature and precipitation extremes. Data archaeology of historical undigitized weather observations holds the prospects for greatly expanding extremes data for the late 19th century and early 20th century, markedly extending the duration of extremes observations in some continents and over the oceans. Improved integration of remotely sensed and in situ data sources through data assimilation and reanalyses provides the opportunity to greatly improve the current and future monitoring and attribution systems for extremes. Improved data assimilation for the ocean, land, sea ice and atmosphere is key for improving initial state specification for prediction of extremes at subseasonal to interannual timescales.

F2: Modelling and Prediction
Many phenomena that are responsible for extremes are not well simulated in models; some because of resolution (such as tropical storms and highly localized precipitation events), but also others that are resolved (such as blocking anticyclones and some large-scale modes of variability). Models have difficulty in simulating aspects of the hydrologic cycle and they typically have problems handling the diurnal cycle. Model parameterizations addressing precipitation, convection and clouds are insufficient for accurate simulation and timing of many extreme events. There are conceptual difficulties in evaluating model results using observations, associated with (but not limited to) co-location in space and time, and grid cell data versus point measurements.

Models need to be confronted with the new observational products in innovative analyses and with appropriate metrics of extremes to evaluate model performance. This includes numerical weather prediction and climate models. As well as statistical analyses, studies should examine the phenomena responsible for extremes, whether and how well they are replicated in models, whether models represented the observed relationships between phenomena and extremes, and how to overcome incompatible resolution requirements. Routine verification of sub-seasonal to interannual predictions of extremes is needed to quantify uncertainties and biases, as well as opportunities for improvement. Quantification of chaotic uncertainties in the prediction of extremes needs to be estimated through the appropriate generation of forecast ensembles.

F3: Attribution of climate-related extreme events
Extreme weather and climate-related events are of great public concern and interest, yet there are often conflicting messages from scientists about whether such events can be linked to specific modes of climate variability, to anthropogenic climate change, or to both. The development of carefully calibrated physically-based assessments of observed weather and climate-related extreme events has been proposed, to identify any changed risk of such events attributable to particular factors. Event attribution is tightly connected to attributing large-scale changes in the frequency and intensity of events, which has an important role in placing extreme events into context and identifying systematic model biases in simulated changes in extreme events (see Peterson et al., 2012). Event-specific assessments have so far only been attempted for a relatively small number of specific cases, as described in the Community Paper at the recent WCRP Open Science Conference (Stott et al, 2012) and the recent report on attribution of some extreme events in 2011 (Peterson et al, 2012). This latter report is the first example of near real-time attribution of a number of important extreme events occurring in one year.

There are strong links between the development of routine event attribution methods and those used to make sub-seasonal to interannual predictions. Errors in the simulation of modes of variability and teleconnections hamper both initialised predictions and regional attribution of past events, and may lead to overconfident seasonal forecasts or misattribution of past climate events. Both activities are also constrained by the need for near real-time observational information and the operational constraint of regular and timely production. It is therefore important that near real-time attribution and operational climate prediction out to years ahead are developed in parallel. The use of the same models across these activities, using similar methods to present forecasts as well as attribution statements, and the routine evaluation of forecast skill offers great potential benefit for simplifying and better presenting the climate information provided to users.

F4: Informing decision makers and risk managers
There are many different potential users for information on weather and climate-related extreme events, including emergency managers, the public, decision makers, the insurance industry, in legal contexts, and to inform adaptation responses. While there may be many common requirements, different groups of users are likely to use different terminology and have different requirements concerning the specific questions they wish to see addressed. The differences in terminology and interpretation of information on extremes between different user groups has been a severe limitation. The development of readily understandable language for describing extremes, based on user needs, is key to better informing stakeholders and managing the risks of extreme events (IPCC, 2012). Monitoring, prediction and attribution of extreme events form a key component of any climate information service, such as is planned in the Global Framework for Climate Services.

Initiatives

I1: Improved observational and reanalysis data
Key initiatives are needed across a range of different issues to improve the quality and availability of observational data on extremes. Access to historical data from data-sparse regions can often be obtained through regional collaborations and capacity building, as demonstrated by ETCCDI and the CLIVAR regional projects. A substantial effort should be directed at data rescue for old data sets not in digital form, and especially high frequency (better than once daily) data sets. Priorities should be set for these data rescue efforts to ensure that the most critical records are secured first.

Guidelines for the archiving of higher temporal (hourly) and spatial (5km over land) resolution for observational data—both remotely sensed and in-situ—should be determined that take into account the falling costs of very large data storage and efficient data processing systems. Such guidelines need to target the most important meteorological and oceanographic variables, taking into account the impacts of different extreme events.

The synthesis of remotely sensed and in situ observations through data assimilation and reanalysis systems to produce high-resolution data for extreme events is critical to improved monitoring, understanding and prediction. It is already part of the GEWEX research plans.
Reanalysis products used in studies of extremes should be evaluated against in-situ observations for different circumstances and regions (high data density regions, low data density regions, short duration events, longer-duration events, etc) to assess the quality of the reanalyses.

I2: Sub-seasonal to interannual prediction of extremes
Skilful and reliable predictions of the frequency and intensity of extreme events on regional scales is a key aim for monthly to decadal climate predictions and is a key WGSIP initiative.
Although little is currently known about the predictability of the frequency of extremes at long lead times, the literature is beginning to suggest that there is some predictability, particularly for temperature extremes and when regional drivers such as ENSO are active.
Similarly, long-lived extremes such as extended periods of high temperature show some

predictability in tropical regions on seasonal timescales. Much work is needed to take careful account of uncertainty when delivering forecasts of extremes to users.

A number of operational centres are developing and improving their capabilities for prediction of sub-seasonal to interannual anomalies in the frequency of extremes. Such activities should be coordinated under by WGSIP, in collaboration with WGNE and WGCM. Quantification of the skill of model simulations and forecasts of extremes using appropriate metrics is very important. These include reliability metrics of prediction skill, as well as metrics of the simulation of extremes such as the extremes indices developed by the ETCCDI.

Coordinated intercomparisons of the representation of key processes in models, and intercomparisons of NWP model simulations with initialized climate model simulations are critical to improving process understanding and representation in models. Such intercomparisons of processes, weather systems and modes of variability in models need to be linked with the activities under the other WCRP Grand Challenges. Regional modelling initiatives as part of the *Regional Climate Information* Grand Challenge need to be linked to provide more useful regional predictions of changes in extremes.

I3: Attribution of Climate-related Extremes (ACE)

The foundations of attribution of extreme events involve real-time monitoring and climate analysis capability, and availability of historical data sets, such that current events can be placed into a reliable and physically consistent historical context, as well as model simulations and experimentation to establish plausible cause-and-effect relationships. An initiative for the production of timely and scientifically robust attribution assessments of extreme weather and climate events has been proposed as part of the international Attribution of Climate-related Extremes (ACE) project (Stott et al., 2012). Such a comprehensive attribution activity would require enhanced collaboration and coordination of numerous partners in order to provide a test bed for evaluating and applying data, theories, and computational methods.

A wide range of climate model simulations are planned at multiple modelling centres to provide a large database of simulations for use in ACE. These will include:

- ensembles of atmospheric model simulations run with prescribed observed SSTs for 1950-the present, as part of the CLIVAR C20C project;
- very large ensembles of perturbed physics and perturbed initial condition simulations run as part of the distributed computing project weather@home; and
- multi-model ensembles of coupled climate model simulations, including CMIP3, CMIP5 and other WGCM experiments, with and without prescribed changes in greenhouse gases and other forcings.

An important aspect of such an initiative would be to pre-determine thresholds for defining extreme weather and climate events, and to pre-define observational datasets and experimental protocols that minimize the influence of subjective post-hoc reasoning and the attendant risks of cherry picking and selective use of evidence. Some extreme situations of known high impact are amenable for *a prior* analysis of their probability of occurrence (for instance, droughts and heat waves), given expectations of near-term changes in boundary (e.g., ENSO, PDO) and/or external radiative forcings. This may thus involve assessments for the coming season or year to decade, and could be conducted for regional scales with suitable methods. As with weather forecasting, a regular attribution process would potentially lead to a continued improvement in reliability and could enhance the prospects for early warning of extreme events through enhanced understanding of predictability.

The frequency and intensity of local extreme events, such as annual maximum daily temperature or annual maximum precipitation amount, have been shown to change at large scales in response to modes of variability or external forcing (IPCC, 2012; Petersen et al., 2012). These changes are reasonably well sampled and can be readily evaluated against model simulations, thus identifying model biases and shortcomings. These may also be used to estimate risks of such events if a specific mode of variability is predicted. Key questions remain as to why climate models appear to overestimate some yet underestimate other extreme events, to what extent changes in extremes are linked to changes in mean climate, and what processes drive both apart. Systematic model shortcomings, such as in the representation of blocking or convection may lead to seasonal differences in the ability of models to simulate extremes. Sea surface temperature patterns and modes of variability and their teleconnections influence both mean and extreme climate, and the influence on extremes is regionally more complex than due to a simple shift in the mean.

I4: Drought Analysis and Prediction

[GEWEX requested that the Drought Interest Group be continued as part of this Grand Challenge. I leave a decision on that up to the JSC. I cannot write material on new initiatives by the DIG, if it is to be included in the Extremes Grand Challenge.]

The WCRP Crosscut on Extremes led to the development of the joint CLIVAR and GEWEX Drought Interest Group (DIG) in 2008.

http://www.clivar.org/organization/extremes/resources/dig

References

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Implementation Strategy

The Grand Challenge on Extremes will be coordinated through the International GEWEX Project Office, with each of the three (four) Initiatives coordinated separately. The Initiative on Improved Observational Data for Extremes will be coordinated by GEWEX, in close collaboration with the ETCCDI project in CLIVAR. The Initiative on Sub-seasonal to Interannual Prediction of Extremes will be coordinated by WGSIP. The Initiative on Attribution of Climate-related Extremes (ACE) has been developed initially through a US and UK collaboration, and does not have a WCRP parent, but is closely linked to CLIVAR, WGCM, WGSIP and ETCCDI. It appears that this Initiative would fit best within CLIVAR. The joint CLIVAR and GEWEX Drought Interest Group should continue to be coordinated through CLIVAR, if it is identified as an Initiative in this Grand Challenge.

Initially, a workshop should be held in 2013, bringing together representatives from all the Initiatives to discuss research gaps and opportunities, and to develop plans for research activities for the next one to three years. After this initial workshop, separate meetings should be held for each of the Initiatives separately, to develop specific Implementation Plans in each of the different areas. A workshop on ACE is already planned for 2013 and other workshops on Observations for extremes (GEWEX) and sub-seasonal to interannual prediction of extremes (WGSIP) should be held in 2013 or 2014.