FIRST DRAFT

WCRP Grand Challenges

Science underpinning the prediction and attribution of extreme events

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Needs consultation and feedback

Introduction

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, from heat waves, droughts and wild fires to 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 Nino-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 adapting to extremes and 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 a recent IPCC Special Report (IPCC, 2012), as well as being a key GEWEX 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.

Scientific frontiers

F1: Observations

Limitations on the availability and quality of observations 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 early 20th century and late 19th century, markedly extending the duration of extremes observations in some continents. Improved integration of satellite, reanalysis and conventional data sources provides the opportunity to greatly improve the current and future monitoring and attribution systems for extremes.

F2: Modelling

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). Models have difficulty in simulating 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. Models need to be confronted with the new observational products in innovative analyses and with new diagnostics and metrics of performance. This includes numerical weather prediction and climate models. There are conceptual difficulties in validating model results against observations, first of all associated with (but not limited to) co-location in space and grid cell data versus point measurements. As well as statistical analyses, studies should examine the phenomena responsible for extremes, whether and how well they are depicted in models, and how to overcome incompatible resolution requirements. Developmental needs should be used to focus field programs, process studies, and numerical experimentation.

F3: Attribution of climate-related 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 or to anthropogenic climate change. The development of carefully calibrated physically-based assessments of observed weather and climate-related events has been proposed, to identify any changed risk of such events attributable to particular factors. Such 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 operational attribution and detection systems and those used to make monthly to decadal predictions. For example, both activities suffer from the same climate model errors. Errors in modes of variability and teleconnections hamper both initialised predictions and regional attribution of past events and the errors that lead to overconfident seasonal forecasts can also lead to 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 operational detection and attribution and operational climate prediction out to years ahead are developed in parallel. The use of the same models across these activities and using similar methods to present forecasts as well as detection and attribution statements 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. Monitoring, prediction and attribution of extreme events will form a key component of any climate information service.

Imperatives and science topics

I1: Improved observational 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. Regional modeling initiatives need to partner with regional data providers, leading to collaborations as part of the *Regional Climate Information* Grand Challenge that will also improve data availability on extremes.

Guidelines for the archiving of higher temporal (hourly) and spatial (5km) resolution for observational data 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 weather variables, taking into account the impacts of different extreme events.

The synthesis of satellite, analysis and conventional weather observations 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.

I2: Improved understanding of process interactions important for extremes
Improved process understanding is critical to the better representation of key processes in prediction models. There are important connections between the processes studies planned in the other Grand Challenges, including on *Water Availability*, on *Clouds, Aerosols and Precipitation*, on the *Cryosphere* and on *Sea Level Rise,* and the improved prediction of extreme events. Particular emphases include land surface interactions with drought and temperature extremes, as well as with flooding, cloud and precipitation processes with rainfall extremes and flooding, cryosphere and sea level interactions with storm surges, and ocean-atmosphere coupling interactions with persistent extreme events, such as droughts and long-lived precipitation anomalies.

I3: Operational seasonal prediction capabilities
Skilful and reliable predictions of the frequency or 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 daily 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 seasonal to interannual anomalies in the frequency of extremes. Such activities are should continue to be coordinated under the auspices of WGSIP.

I4: Improved longer term predictions
Projections of changes in weather and climate-related extreme events due to anthropogenic climate change have been based on the series of coupled model experiments coordinated by WGCM, as described by IPCC (2012). Further improvements in longer term predictions of changes in the frequency and intensity of extreme events requires improved representation of key processes in climate models, higher spatial resolution simulations including regional modelling, initialization of coupled modeling systems so that they can be used for decadal and longer term prediction, and archiving of high temporal and spatial resolution output from these simulations. Such improvements can only take place through continued participation of national modeling centres in coordinated experiments, such as CMIP5 and CORDEX under the auspices of WGCM.

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 need to be linked with the activities under the other Grand Challenges as outlined in I2 above. 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.

I5: Operational attribution of climate events
The foundations of operational 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-effect relationships. An initiative for the production of timely and scientifically robust attribution assessments of extreme weather and climate events is being coordinated as part of the international Attribution of Climate-related Events (ACE) project (Stott et al., 2012). Such a comprehensive and authoritative attribution activity will demand 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.

Pre-determined thresholds for defining extreme weather and climate events, and pre-defined observational datasets and experimental protocols 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, 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.

ACE does not have a WCRP parent, but is closely linked to CLIVAR, WGCM, WGSIP and ETCCDI.

I6: Translation of extremes data into information relevant for stakeholders
The theme of “Actionable science” from the WCRP Open Science Conference is a key objective arising from the prediction and attribution of extreme events. It is likely that the translation of data on monitoring, attribution and prediction of extremes into information relevant to stakeholders can be best achieved through active collaborations with the Regional Climate Information Grand Challenge and with national climate information services.

In addition, research on effective communication of information on extremes, including on uncertainties, needs to be undertaken across a wide range of stakeholder cultures and communities to ensure that the information is utilized well for disaster risk management and adaptation to extremes in all countries.

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