Implementation Plan for WCRP Grand Challenge on Understanding and Predicting Weather and Climate Extremes

Version 3rd February 2015 by co-chairs
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The White Paper on the WCRP Grand Challenge on Understanding and Predicting Weather and Climate Extremes (http://www.wcrp-climate.org/index.php/gc-extreme-events) posed 8 'Grand Science' questions to the scientific community to be addressed over the coming decade. These are:-

1. How can we improve the collation, dissemination and quality of observations needed to assess extremes and what new observations do we need?

2. Can models be further improved to better simulate, predict and project extremes?

3. What do we understand about the interactions between large-scale drivers and regional-scale land-surface feedbacks that affect extremes and how can these processes be improved in models?

4. To what extent can detected changes in extremes be attributed to forcing external to the climate system and/or to internal factors such as modes of variability?

5. What factors have contributed to the risk of a particular observed event?

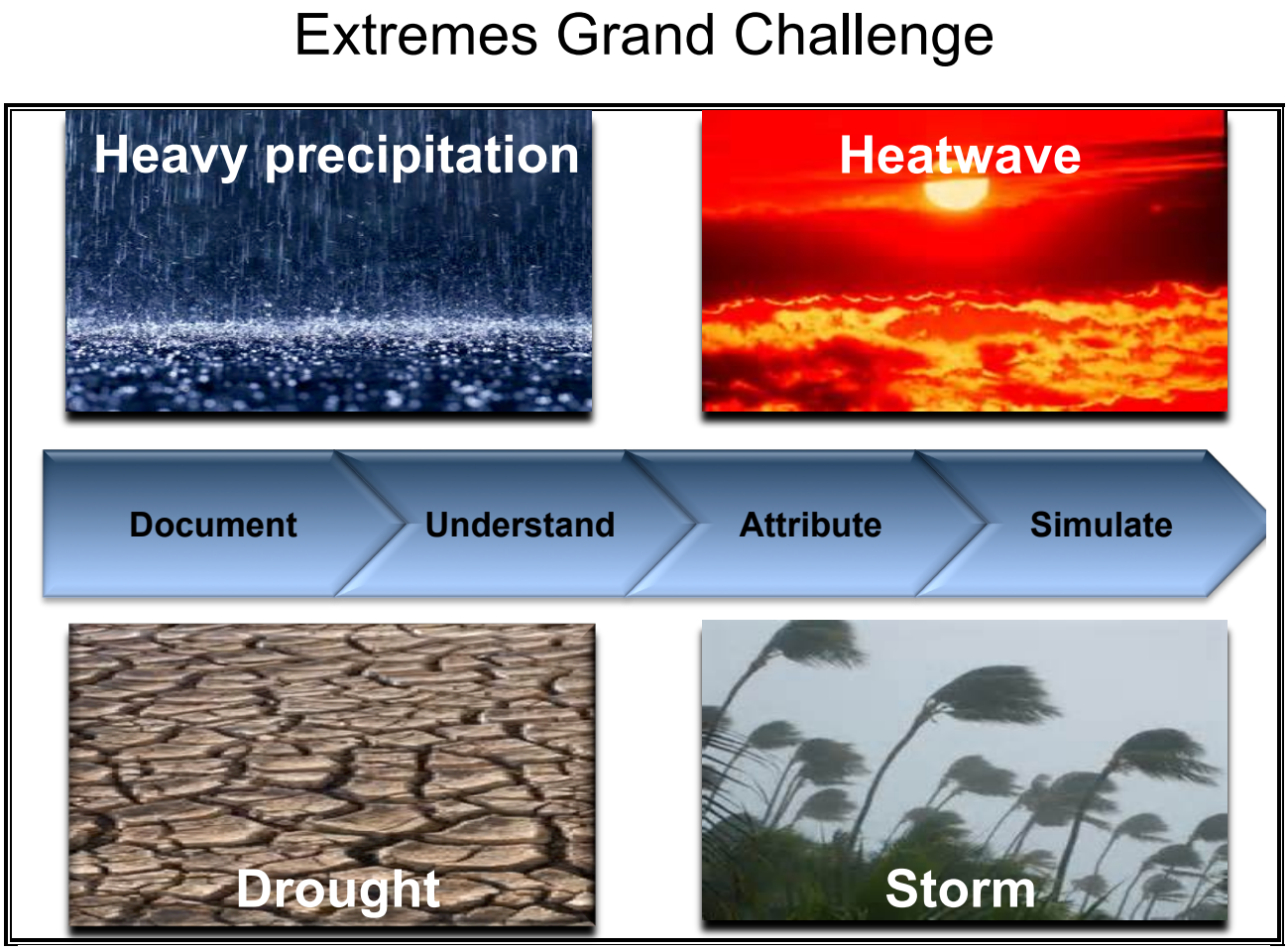
6. How has drought changed in the past and what were the causes, and how will it change in the future?

7. Are changes in the frequency and intensity of extremes predictable at seasonal to decadal scale and if so, how can we best realize that potential, and how can society best use such forecasts?

8. How will large-scale phenomena such as monsoons and modes of variability change in the future, and how will this affect extremes?

Of the Grand Science Questions, Q5-8 already have international community and coordination activities in place and thus this document primarily focuses on the implementation plan for Q1-4 although cross-cutting activities for all questions are outlined on Page 12. In order to best progress each of these grand science questions, we suggest that all questions can be thought of as covering **four overarching themes**: 1. Document 2. Understand 3. Attribute and 4. Simulate. All of the themes interact and are both led by and contribute to the Grand Challenge. We recommend that a small team of people (both established and emerging leaders) coordinate each theme and who will be tasked with pushing implementation forward. For each theme we split the implementation into two; one section which deals with coordination needs across and between existing activities and one which highlights what new activities, research or data gathering needs to be undertaken. In addition, cross-cutting activities are proposed that address several of the grand science questions and link to several of the other WCRP Grand Challenges. The implementation plan currently focuses on what is *doable*. For that reason our main implementation strategy focuses on **four core events**: 1. heatwaves, 2. droughts, 3. heavy precipitation and 4. storms. All activities will be closely aligned to the research activity on High Impact Weather within the World Weather Research Programme (WWRP) and so fits primarily into our cross-cutting activities on Page 12. The idea for implementation can be best summarized in the following schematic.

Fig 1: Schematic showing the four research themes and four core events that will be addressed as part of the Extremes Grand Challenge.



THEME 1: DOCUMENT

Lead Coordinators: Lisa Alexander, Ali Behrangi

This theme deals with documenting and assessing past changes in extremes. Observations are the key foundation for understanding long-term climate variability and change but observations are often not well-constrained and critical gaps exist in the amount, quality, consistency and availability of observations especially with respect to extremes. The current suite of climate extremes datasets is inadequate to properly assess climate variability and change and to provide the required underpinning for detection and attribution studies and model evaluation. This is due to data limitations (in time and space), differences in how extremes are defined, the spatial representativeness of point-based measurements, scaling issues between observations and models and uncertainties in variable estimates from satellite retrievals. There is a need to collate and better disseminate data from all existing sources that are relevant for extremes and to identify regions and time periods where we can fill in gaps and assess uncertainties.

Extremes are by definition rare. This means it takes longer time periods and better resolution in both space and time to properly characterize long-term changes in extreme events. This also means that some extreme values (e.g., amount of short duration rainfall) may be prone to be filtered out by the usual data quality control (QC) procedures. It is important to instigate efforts to undertake new and novel QC / homogenisation algorithms and benchmark their performance at daily and sub-daily timescales, work to create an integrated set of holdings of *in situ* data over global land areas which combines hourly, daily and monthly series across all elements including building datasets of parallel measurements to measure changes in observation systems including from satellite retrievals, to digitize data in as cost effective manner as possible and to improve data provision. This represents a monumental task (grand challenge) in itself but where the required data already exist, a minimal coordinated effort could reap enormous benefits. WCRP should work with other organizations such as GCOS and WMO to promote free and open access to meteorological and climate data.

Another issue for extremes is the general mismatch in the spatial scales between observations (usually taken at point locations) and model simulations (typically interpreted as representing an area of a model grid), making it difficult to conduct a like-with-like comparison between observations and models. Various techniques have been used to grid or to interpolate station data to aid observation and model comparison. There are several intertwined issues including spatial averaging, uneven number of stations/observations across the space, the order of operation (i.e., gridding anomalies, first difference or absolute values etc.) and many other parametric and structural uncertainties. Work is required to understand these effects and if possible rule out certain approaches to avoid artificial spread. Some data sources may have been under-used (e.g. reanalyses, various satellite and radar data products) and could allow better characterization of the spatial footprint of extremes. Work is required to evaluate those products especially for extremes and with a particular focus on precipitation extremes that will require extensive coordination with the Water Availability and Regional Climate Information Grand challenges.

The main advance for this theme will be based on continuing and strengthening existing data gathering activities in order to fill gaps and better match the available data with what is required for diagnostics, model evaluation and detection/attribution. This should be done in close coordination with other grand challenges and data initiatives and should include:-

Coordination of existing and forthcoming activities

- Collation and quality control of all existing *in situ* daily data sources for temperature and precipitation (and sub-daily for precipitation) e.g. GHCN-Daily, GPCC, HadISD, ECA&D etc. and raw data collection from HydroMet services and researchers stored in central repository. This should be organized in such a way to also encourage new international data initiatives such as EUSTACE and INTENSE to be added and to follow the example for quality and accessibility from the International Surface Temperature Initiative (ISTI). Coordination should also ensue with existing data rescue initiatives e.g. ACRE to ensure that 'old weather' records are incorporated into above activities. Ensure, to the extent possible, that data adhere to common data quality assurance and metadata standards, and that they are disseminated using a common format, thereby improving the exchangeability of existing data and promoting development of community data analysis tools. WCRP will continue to encourage free and open international exchange of existing high time resolution data to improve global coverage of daily and sub-daily observations for temperature and precipitation extremes in particular, and identify steps that would improve data sharing. [coordinate with GDAP, GHP]

- Collation of all ETCCDI *in situ* data including HADEX2, GHCNDEX and regional indices identified via a literature review. Similarly to above should be stored in a central repository and disseminated via a web portal such as climdex.org.

- **Workshop (**Pasadena, Dec 2014): A global drought information system (GDIS) workshop with a key goal of developing a concrete implementation plan towards realizing practical continental scale pilots that will mesh with actual users (such as the agriculture/food security community). This will bring together existing initiatives that focus on drought e.g. WMO GFCS task teams, ETCCDI, DIG.

- **Workshop (**Sydney, Feb 2015): To assess the data requirements within and between existing observations of extremes (e.g. *in situ* and remote sensing, existing and future datasets). Thus this workshop provides interaction between communities that have not previously worked together before. In addition, it would deliver a strategy for data collection and indices calculation, coordination and best practice which may ultimately lead to requirements for new initiatives, software etc.

New research/activity/data gathering requirements

- ETCCDI indices to be reviewed and new indices added, especially those that better represent capture long-term precipitation surplus and deficit, soil moisture, drought, heatwaves, and more impacts-relevant indices. This would also include a few more indices to capture changes in the shape of the temperature distribution.

- Standardised software and an associated manual will be developed to ensure that all ETCCDI calculations are calculated in the same way for intercomparison. Coordination should then ensue between other groups who are already working towards the Global Framework on Climate Services. Input data formats should be coordinated across various communities. [coordinated with WGRC, ET-CRSCI, GDIS]

- A 'best practice' guidance document to be produced on gridding data to best represent extremes and address scaling issues between observations and models. The recommendations to be used to produce revised global climate extremes datasets with better spatial and temporal coverage and uncertainty estimates than existing ones.

- A coordinated intercomparison of existing and new datasets should be conducted including the standard calculation of precipitation extremes from satellite retrievals. This intercomparison would provide a formal framework to address uncertainty and scaling issues with a recommended primary focus on the first three core events i.e. heatwaves, droughts and heavy precipitation. The data requirements for the fourth core event "storms" to be coordinated through WWRP.
- **Workshop** (Columbia University, 2016) with a focus on the data needs for high impact weather (including tropical and extra tropical cyclones) coordinated with WWRP research activity on High Impact Weather. WMO IWTC has a meeting every 4 years within its climate chapter. This would represent a scoping workshop on tropical cyclones/severe local storms and climate such that common threads between TCs and severe local events would be identified and outcomes related to TCs and climate change and the potential for extreme TCs. Part-funding would come from Columbia University. This will also be a **cross-cutting activity**.
- While most of the above activities relate to land-based extremes, additional activities which focus on ocean extremes e.g. heatwaves, extreme wave height storm surges will be encouraged and supported (see cross-cutting activities on Page 12).

THEME 2: UNDERSTAND

Lead Coordinators: Sonia Seneviratne, Olivia Martius, Robert Vautard

A range of mechanisms can lead to the occurrence of extreme events such as heat waves, droughts or floods. Recent investigations have shown that the interaction between large-scale drivers and regional-scale land-atmosphere feedbacks or forcings can be critical. For instance soil moisture-temperature feedbacks amplify heat waves in many regions, and were shown to play an important role in recent extreme hot events, such as the 2003 European heat wave, the 2010 Russian heatwave, or the 2012/2013 Australian summer. Moisture evaporated from the land was also identified as a major contributor to the precipitation events that led to the Pakistan floods in 2010. Additionally forcing from land cover and land use changes can be important for either amplifying or damping the occurrence of extreme events. Similarly, the role of the melting Arctic sea ice for weather extremes in Europe also needs to be clarified. Finally, there is an additional need to understand which events lead to specific impacts and which features of given events are of most relevant to these impacts.

A better quantification of these processes, thanks to interactions between research communities working both on large-scale atmospheric drivers and regional land-atmosphere feedbacks is essential to reduce uncertainties in projections, improve sub-seasonal to decadal predictability of extremes as well as the attribution of past trends and single events. The role of internal climate variability for the occurrence of extremes also needs to be carefully evaluated, in particular for past recent trends and in order to assess their contribution to projections' uncertainty. This will be done in connection to the attribution and model evaluation parts of the implementation plan.

Many of the activities will be cross-cutting, providing links to the "document", "simulate" and "attribute" themes.

Coordination of existing and forthcoming activities

Coordinated model experiments and analyses considering the respective role of large-scale vs regional/land drivers of extremes will be conducted in various frameworks:

- LS3MIP CMIP6 experiment: Coordinated experiment between GEWEX and CliC addressing the role of soil moisture- and snow-climate feedbacks in for historical simulations and climate projections (building upon GLACE framework)
- Dedicated experiments coordinated among contributors to grand challenge (e.g. focused on predictability issues, land cover and land use aspects (e.g. LUMIP), land geoengineering (LandGeoMIP testbed experiment), regional-scale CORDEX-type experiments, and the investigation of case studies coordinated with regional climate information grand challenge
- EU-FP7 EUCLEIA project: Experiments targeted at isolating the role of large-scale drivers versus regional-scale feedbacks and forcings for climate extremes attribution
- ERC DROUGHT-HEAT project (ETH): Experiments assessing the role of land-climate feedbacks for extremes in present and future climate, in particular addressing event attribution and land climate engineering
- ERC A2C2 project (LSCE): Use of atmospheric flow analogues to assess the impact of large-scale circulation drivers for extremes
- GDIS project: Evaluation of role of respective drivers leading to drought
- European initiative to link drivers and impacts (J. Sillmann)
- Process evaluation study (GEWEX-PROES): As part of the proposed GEWEX-PROES initiative (Jakob et al.) the implementation of diagnostics focusing on the process-based evaluation of extremes will be considered

Summer schools are essential tools to foster in-depth understanding of underlying mechanisms leading to extremes and to train and develop young scientists:

- WCRP/ICTP summer school Trieste, summer 2014: Definition of extremes, Attribution of extremes, Physical drivers of extremes, Observations of extremes
- This school represented a cross-cutting activity to train the next generation of leaders in this field, enhancing capacity. The workshop has resulted in 7 student-led papers based on the research problems tackled by the students during the workshop. These papers will be included in a special issue for the journal "Weather and Climate Extremes" in 2015
- Swiss International Summer School on extremes, summer 2015
- This summer school is a further activity to train future leaders in the field of extremes research. This summer school will also specifically include an interface to impacts research with presentations and workshops by representatives of the impacts community (Red Cross and Red Crescent, SwissRe, MeteoSwiss)
- Cargese fall school, fall 2015 (organization P. Yiou): Mathematical and statistical tools for investigation of extremes and climate variability, definition of extremes, processes leading to extremes

Workshops and conferences:

- GDIS Workshop (Pasadena, Dec 2014): Drought drivers in various regions of the world will be reviewed as part of the Global Drought Information System workshop
- Pan-GLASS land modeling meeting in 2015 (tentative venue: Leipzig or Zurich, October 2015)
- Workshop (TBA, 2016): workshop synthesizing results of first modeling experiments and dedicated analyses, and planned special issue and review article
- IDAG meeting January 2015; EUCLEIA meeting, summer 2015: both bring the event attribution communities together where mechanisms for extremes will be discussed in depth.
- M-CLIX workshop, October 2015: One theme of the workshop is dedicated to the investigation of land vs large-scale drivers for extremes

New research/activity/data gathering requirements

- Modeling experiments conducted by WCRP projects can contribute to better determine the role of distinct drivers and feedbacks for extremes. Such experiments should be complemented with the analysis of observational datasets newly compiled within the grand challenge, as well as the respective validation activities. A database of reference modeling experiments will be made available for the research community, including within CMIP6.

- Links between GEWEX, CLIVAR and CliC are already established and will be built upon. SPARC will be newly integrated (Olivia Martius). Some activities will be coordinated with other WCRP bodies (e.g. WGRC for CORDEX-type experiments, WGSIP for predictability experiments, WGCM for CMIP6 experiments). Links with the event attribution community are also already established through IDAG and EUCLEIA.

THEME 3: ATTRIBUTE

Lead coordinators: Xuebin Zhang, Frederike Otto

A key challenge for the community is to provide access to the latest information on how extremes have varied or are likely to vary under a changing climate and a range of likely greenhouse gas emissions scenarios. The extent to which humans are responsible for changes in extremes and particularly individual extreme weather is a challenging topic. They are addressed both by evaluating change in the global or large-scale pattern in the frequency or intensity of extremes (e.g., observed widespread intensification of precipitation extremes attributed to human influence, increase in frequency and intensity of hot extremes) and by event attribution methods. Interaction with both these activities is ongoing through the International Detection and Attribution Group (IDAG; with Zhang and Hegerl in the steering committee) and in several worldwide event attribution activities (US activities; European projects e.g. EUCLEIA). We will ensure that these communities are engaged in the activities in Themes 1-3 and can provide input.

This theme will be discussed at the next IDAG meeting (Boulder, January 2015), and at the next EUCLEIA meeting.

Coordination of existing and forthcoming activities

- **Summer School** (Trieste, July 2014): Definition of extremes, Attribution of extremes, Physical drivers of extremes, Observations of extremes. This school represented a cross-cutting activity to train the next generation of leaders in this field, enhancing capacity. The workshop has resulted in 7 student-led papers based on the research problems tackled by the students during the workshop. These papers will be included in a special issue for the journal "Weather and Climate Extremes" in 2015.

- Questions that should be specifically addressed include
    - How can event attribution and large-scale attribution results be better cross-linked in order to improve the robustness of event attribution results?
    - How can detection and attribution (both events and large-scale) make better use of understanding of physical mechanisms for changes in extremes in order to make results more robust, physically meaningful and easier to be evaluated in

climate models? Examples are diagnostic of disparate changes in P-E positive and negative regions in extreme rainfall and drought; a joint diagnostic of precipitation deficit and sensible heat; or a recent publication showing that changes in heat indices combining temperature and moisture are more robustly predicted in models than temperature individually.

- How can attribution methods be adapted to extreme events? Work on this is already ongoing but further method development is required, for example, it is important to develop an extreme value theory based method that is equivalent to the optimal fingerprint.

These questions can be addressed to a large extent by building on the existing IDAG and Event attribution communities.

Close links will be developed to CLIVAR Dynamics Panel activities focusing on modes of climate variability.

New research/activity/data gathering requirements

The GC team will continue to actively engage in the annual Bulletin of the American Meteorological Society (BAMS) report on attribution of climate-related events from the previous year and entrain collaborators on it (e.g., Christidis) into the grand challenge team.

Meeting (IDAG January 2015): A brainstorming session at the IDAG meeting in Boulder will be held in order to provide a list of necessary steps, supported by the community, as to how CLIVAR/GEWEX can support and coordinate detection and attribution and ensure the robustness of results. The topic will also arise during the EUCLEIA meeting in spring 2015. The activities will be reviewed in subsequent IDAG meetings.

Workshop (Banff, June 2016): A workshop on "uncertainty modeling in the analysis of weather, climate and hydrological extremes" has been funded by the Banff International Research Station (BIRS). This workshop will bring together over 50 researchers from atmospheric and hydrological sciences on the one hand, and statistics and probability on the other with a strong focus on multivariate extreme value theory and its application in the context of climate and hydrological extremes.

THEME 4: SIMULATE

Lead coordinators: Gabi Hegerl, Erich Fischer, Jana Sillmann

There is a lack of understanding in the types of events that current models can provide credible and robust simulations for, and in the identification of key processes for climate models to capture in order to produce credible simulations of weather and climate extreme events and thus improve prediction of those events. Furthermore, the ability of models to simulate particularly small-scale extremes depends on resolution and sometimes requires downscaling. We propose the following three-pronged approach:

Evaluation of extremes at the level of storylines or processes (also in coordination with theme "understand"). Storylines that lead to extremes can be analyzed and the models' ability to simulate the conditions leading to extremes can be evaluated. Understanding the interplay of various processes including atmospheric, land, and oceanic processes that lead to prolonged droughts or wet seasons may shed new light to guide model development. Contributions to the changing probability of extremes by anomalous sea surface and ice conditions, and by changing

radiative forcing need to be quantified and evaluated in climate models. It is important to select a set of priority events/case for comprehensive comparison, with an aim to understanding interactions of large-scale drivers and local (e.g. land-surface) feedbacks, using various approaches including event attribution. Events that are of large spatial-temporal (continental and seasonal) scales and that involve heavy precipitation or heat waves may provide better opportunity to advance. The selection of such events should consider geographical balance such that events that occurred in less developed world get selected and studied, although it is recognized that availability of data may be a more challenging issue in less developed world. Spatial scale may be important here as well, for example, blocking in some seasons is better simulated in high-resolution models.

There is a need to assess the benefit of high-resolution models in predicting/simulating extremes at small spatial scales at the margin of what can be resolved by present models, or beyond. Statistical methods to downscale unresolved processes also need to be evaluated. Strategies to address events that require high resolution, such as tropical cyclones, need to be compared and evaluated. Where models do simulate the fundamental underlying processes that produce extremes, dynamically based scaling approaches need to be developed in order to be able to better link processes at model scales with local scales. It needs to be considered that observations provide point-data, and statistical methods to quantitatively compare those with model data need to be improved and disseminated.

In addition it is important for all these points to continue to provide the data for model evaluation and detection and attribution: long-control simulations to characterize the variability in both circulation states and extremes; single-forcing sensitivity experiments, and other MIPS to save and archive high frequency data. The conditions leading to rare extremes in observations inevitably pose a sampling problem in model-data comparison. This could be addressed to some extent by model evaluation using moderate extremes and through the use of large ensembles of model simulations covering the period of historical observations, and will also benefit from extending the record of historical observations. The forced simulations should provide large ensembles to sample variability in extremes, which is a challenge from the relatively short observational record alone. It would be ideal if high frequency data were pre-processed to extract information relevant to extremes so that they are easier accessible to wider user community. Intra-seasonal to seasonal prediction, near-term prediction of probability of extreme events at impact relevant space/time scales will play increasingly important role for climate service. This requires the Extremes GC to work and engage with other groups such as WGSIP and CFHP so that high resolution model data are made available and models are also evaluated using new metrics that explicitly taking extremes into consideration.

Coordination of existing and forthcoming activities

- **Workshop** (Norway late 2015): An already funded workshop (M-CLIX), planned for late 2015 will be an excellent opportunity to discuss the following issues that need to be addressed for evaluating and improving the simulation of changes in extremes. This is important because climate model evaluation stops short of extremes generally, except for very simple diagnostics. The workshop will also bring together many of the contributors to this challenge. We aim to illustrate model evaluation focusing on extremes by them illustrating it with key examples. The following questions will be specifically addressed:-
    - Can climate models be evaluated for more moderate extremes for which ample data are available (such as the ETCCDI indices), and what do we miss for more rare extremes (e.g., do we miss a stronger role of land surface feedbacks for rare

hot extremes)? The latter can be addressed by linking to the individual event attribution community that determines what led to an event as well.
    - Can we use 'storylines' that link specific high impact events to large-scale circulation situations to evaluate the ability of models to simulate the key mechanisms for extremes, including blocking, for example? What does this mean for model evaluation?
    - What standard model diagnostics are important for extremes, and which of many possible choices of implementation should be compared (example: which blocking index)?
    - How can the scale problem be overcome? Statisticians can advise on what new techniques are available to address the point versus area problem that particularly hampers the evaluation of precipitation extremes; and we need to link to regional modelling using e.g. embedded tropical cyclones models.
    - Which features of extremes can be forecasted for the next years/decade using initialized forecasts or forcing?
    - What data are needed to better support model evaluation of extremes?

By bringing together dynamicists/severe weather specialists with statisticians and people analyzing models, best practice can be developed for model evaluation, possibly to be published as a white or review paper based on CMIP5 data analysis

New research/activity/data gathering requirements

Develop storylines involved in observed extremes and a set of metrics needs to be developed for assessing the models' ability to simulate dynamical conditions conducive to extremes (e.g., for example, blocking). Propose metrics to compare and measure local feedbacks to extremes (e.g., dry conditions enhancing heatwaves). This should be coordinated with the Regional Climate Information Grand Challenge.

Determine methods to quantify feedbacks involved in extremes in models and data: In connection with Theme 2, observational diagnostics representative for physical drivers of extremes will be derived to allow the evaluation of climate models in both present and future climate.

The next step is:

- Preparing for the M-CLIX workshop, including proposing preparatory analysis to illustrate methods
- Input from the detection/attribution and event attribution community by participation in the IDAG meeting (Jan 2015) and in the next EUCLEIA meeting (spring 2015) where this challenge will be discussed where many of the key players get together and the Grand Challenge agenda will be further discussed

Develop methods to evaluate small-scale extremes.

Cross-cutting activities

A WCRP Summer School on climate extremes was held in July 2014 to train **the next generation of leaders** in this field, enhancing capacity. The summer school is expected to produce a special issue for the journal "Weather and Climate Extremes" based on the research problems that were tackled by the students during the workshop.

Three to four focused workshops over the next 1-2 years will be organized with the objective to **bring the appropriate communities together to make significant progress in strategic areas of Grand Challenge Questions** (1) to (8) over the next few years (see timeline). This would include workshops addressing the "Document", "Understand" and "Simulate" themes in addition to a cross-cutting workshop on drought (led by GDIS) and one on high-impact weather organized in conjunction with WWRP.

Statistical tools based on extreme value theory can be very powerful to aid in the analysis and understand the long-term changes in extremes that are rare values. These tools are being further developed including theory of spatial extremes or multivariate extremes in the statistical sciences. However, the interactions between statistical and climate sciences communities are not sufficient and the statistical tools are not very accessible to climate community. It is important to instigate **enhanced interactions between the statistical and climate communities** through joint meetings and workshops, to provide two-way communities between the communities. It is also important to develop guidance and tools for the analyses of extremes for wider climate research community. The 13th International Meeting on Statistical Climatology to be held in western Canada will have a large and dedicated session on extremes to facilitate such communication. A workshop on "uncertainty modeling in the analysis of weather, climate and hydrological extremes" has been proposed to the Banff International Research Station to be held in 2016. This workshop, if funded, will bring together researchers from atmospheric and hydrological sciences on the one hand, and statistics and probability on the other with a strong focus on multivariate extreme value theory and its application in the context of climate and hydrological extremes.

If possible, opportunities at large international conferences such as AGU and EGU annual meetings as well as IUGG assemblies will be used. **Capacity building and data gathering workshops** such as those coordinated by the ETCCDI are ongoing and need to be continued. Two symposia are planned for the IUGG 2015 in Prague on hydrological extremes and on high-impact weather and climate events.

A further important step is to **identify funding opportunities** for research on extremes, and to provide guidance to funding agencies for addressing these research needs. On the European level, a multi-institution project on the attribution of extreme events was recently funded (EU-FP7 EUCLEIA). Avenues to help foster research in this area on other continents will be investigated.

A **WCRP-wide open science conference on climate extremes** will be organized in 2017. This will review our achievements within the Grand Challenge and provide valuable input into the next IPCC Assessment.

In the implementation plan, a conscious effort was made to define activities so as to address interfaces between the recommended four research themes and four core events in addition to theme-specific topics. This would aim to coordinate work on marine and atmospheric heatwaves, for example, much of which is currently being carried out in an ad hoc manner.

Particular focus should be given to providing “actionable information” in order that research remains interesting and relevant and sparks the public’s imagination.

Timeline of proposed activities

Date	Activity	Title	Location	Coordinator(s)	Expected concrete outcomes
July 2014	Summer school	Attribution and Prediction of Extremes Events	Trieste, Italy	Sonia Seneviratne, Francis Zwiers	Special Issue Weather and Climate Extremes
Sep 2014	Workshop	Lessons learnt for Climate Change Research and WCRP (invitation-only)	Bern, Switzerland	Xuebin Zhang, Gabi Hegerl	Break out group summary
Dec 2014	Drought workshop	An International Global Drought Information System Workshop: Next Steps (invitation only)	Pasadena, USA	GDIS – Siegfried Schubert et al.	TBA
Feb 2015	Data workshop	Data requirements to address the WCRP Grand Challenge on Weather and Climate Extremes: Observations and Models (invitation-only)	Sydney, Australia	Lisa Alexander, Xuebin Zhang, Gabi Hegerl, Sonia Seneviratne, Ali Behrangi	Data inventory. Best Practice documentation for gridding data. Data intercomparison
Mar 2015	RClimdex/FClimdex updates	ETCCDI software updated to incorporate new relevant indices	N/A	Xuebin Zhang, Lukas Gudmundsson	Standardised, tested and documented software available for the community
May 2015	Process understanding and model evaluation workshop	Advancing our understanding and modeling of climate extremes by combining physical insights with statistical methodology	Oslo, Norway	Jana Sillmann	Storylines and set of metrics developed
Jun 2015	IUGG 2015	Joint Symposium on Extreme Hydrological Events and IAMAS Symposium on Understanding and Predicting High Impact Weather and Climate Events	Prague, Czech republic	Christophe Cudennec, Richard Swinbank	TBA
Jul 2015	2015 United Nations Climate Change Conference	Proposed sessions on extreme events research	Paris, France	Session 1: Robert Vautard, Peter Stott, Fredericke Otto; Session 2: Jana Sillmann	TBA
Aug 2015	Summer School	Climate extremes	Ticino, Switzerland	Sonia Seneviratne, Reto Knutti	TBA
?? 2015	Summer School	Climate extremes: statistical methods	France	Pascal Yiou	TBA
Dec 2015	AGU	Special Session on extremes	San Francisco, USA	TBA	TBA
Jun 2016	Workshop	Uncertainty modeling	Banff,	Francis Zwiers,	TBA

		in the analysis of weather, climate and hydrological extremes	Canada	Philippe Naveau, Peter Guttorp	
2016	TC and the severe local weather workshop	Tropical Cyclones and High impact weather and climate change (small targeted but not closed)	New York, USA	Adam Sobel, WWRP	TBA
2016	Conference	13th International Meeting on Statistical Climatology	Vancouver, Canada	Xuebin Zhang	TBA
2017	Open Science conference (similar to WCRP OSC but focusing only on extremes)	Grand Challenge on Extremes	TBA	TBA	Input to IPCC AR6

The following four questions are already being well coordinated under existing activities but we should ensure that we are across what is happening here.

5. What factors have contributed to the risk of a particular observed event?

Coordinated by ACE (Myles Allen, Peter Stott).

6. How has drought changed in the past and what were the causes, and how will it change in the future?

Coordinated by water availability GC (GEWEX, Graeme Stephens and Sonia Seneviratne: climate change perspective, remote sensing observations) and GDIS (Siegfried Schubert: monitoring, seasonal prediction)

7. Are changes in the frequency and intensity of extremes predictable at seasonal to decadal scale and if so, how can we best realize that potential, and how can society best use such forecasts?

Coordinated by Seasonal/decadal forecasting WGSIP (Francisco J Doblas Reyes, Adam Scaife).

8. How will large-scale phenomena such as monsoons and modes of variability change in the future, and how will this affect extremes?

Coordinated by CLIVAR/GEWEX Monsoons Panel (MP) (Andy Turner – Reading University, Paul Dirmeyer COLA)