WCRP Grand Challenge: Understanding and Predicting Weather and Climate Extremes

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Summary

Weather and climate extremes are an inherent part of climate. There is overwhelming evidence that the climate and its extremes are changing. As extremes affect every aspect of our society, decision- and policy makers, and stakeholders are increasingly asking for reliable predictions of extremes on time scales from days to seasons and centuries. To meet this societal need, the world climate research community is challenged by underlying science questions and the quality and coverage of the observational data that are used to monitor and understand extremes. Both the science questions and the data need urgent attention in order to better identify the factors and mechanisms that determine the location, intensity, and frequency of various climate extremes including droughts, floods, heavy precipitation events, heat waves, cold spells, tropical and extratropical storms, coastal sea level surges and extreme ocean waves. This information is needed in the near-term (from a season to a year) to mitigate risks to society and ecosystems, and in the longer term (from a decade to centuries) for effective adaptation planning. Despite the importance of the topic, progress has been fairly slow. However, recent developments suggest that the prospects for more rapid advancement of this WCRP Grand Challenge are excellent. These developments include:

- recent substantial advances in modelling (including but not limited to model resolution)
- advances in the understanding of the physical mechanisms leading to extremes
- increased efforts to extend the historical observational record, including planned climate quality reanalyses over longer historical periods
- expected improvements in remote sensing products, which now extend long enough to document trends and sample extremes
- recent world wide coordinated efforts to attribute the causes of individual extremes, and other research activities already underway and planned.

This white paper explains the challenges and opportunities, suggesting activities that can help move the community forward more rapidly, making use of above advances.

Context

Weather and climate extremes have enormous impacts on society and the environment. Direct impacts on humans are often negative, but some types of extremes can also have beneficial impacts, such as wildfire, which is an integral aspect of the perpetuation of some types of ecosystems. The occurrence, intensity and character of many types of extremes are already changing and will very likely change in the future, as the climate continues to change due to human influences (IPCC, 2013). The growing impacts from extreme weather and climate events adds an additional imperative for the support of the Global Framework of Climate Services through the development of skillful short-term predictions of individual events to limit damage, injury and fatalities. It also requires the understanding of past changes in, and longer-term predictions and projections of the frequency and intensity of extremes in order to assess risks of natural hazards associated with climate extremes, to plan risk management actions and enable effective adaptation.

Weather and climate extremes are of many types and they result in various physical and environmental impacts. Extremes occur at different spatial and temporal scales, from continental-scale multi-year drought, to large-scale heat-waves that last days to several weeks, and to localized short duration events such as flash floods and tornadoes due to short-lived severe storms. The physical and environmental impacts of weather and climate events are also complicated by many other factors. For example, the severity of flooding or drought can be very different for a similar storm or precipitation deficit depending on antecedent soil moisture conditions. Compound events, the combination of different extreme events or even a series of events that are not individually extreme (e.g. IPCC 2012, Seneviratne et al. 2012), can have far reaching devastating impacts. For example, coastal inundation can be caused by local precipitation, high wind and wave, high tide, and combinations of some or all these factors; extreme temperatures in heat waves soar under low-moisture conditions, causing substantial impacts, for example, on vegetation, such as observed for the 2003 European heat wave.

Improvements in modelling and observations (including data rescue and better remote sensing products) will allow for substantial progress in predicting, projecting and understanding extremes. These recent developments have taken place within various core projects of the WCRP (GEWEX, CLIVAR, CliC) and in WCRP activities such as WGCM, WGSIP, and ETCCDI, and thus this Grand Challenge on extremes provides a framework to further coordinate research on extremes across the climate research community and make use of and accelerate the momentum of this research question.

Specific scientific questions with good prospects for advancement over the next 5-10 years are listed below, along with some recommended first steps to answer these questions (order does not indicate priority):

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

Major challenges exist in the derivation of suitable and reliable observational datasets for extremes. Despite continuous improvement in most observing systems, the high-frequency information (e.g. daily, sub-daily and even finer time scale precipitation, temperature, wind, waves, and sea level records) and high quality that is required to properly assess many high-frequency extremes remains unavailable for many regions. In addition, observations for hydro-climatic extremes (e.g. soil moisture for droughts, runoff for floods) are still very sparse and not yet fully collected in respective databases. New remote sensing datasets (e.g. new Global Precipitation Measurement (GPM) mission, soil moisture remote sensing products, Gravity Recovery and Climate Experiment (GRACE) and reanalysis products (e.g. the new ERA-CLIM project) offer promising perspectives. However, they need to be evaluated with respect to their performance in capturing extremes. Joint GEWEX and CLIVAR activities need to address this challenge by investigating ways to best derive reliable and adequate observational datasets and making them available for the assessment of extremes and their validation in climate models.

Actions: Current efforts in the development of new observational datasets for extremes started within GEWEX (GHP, GDAP) and ETCCDI are to be encouraged, including the comparison of remote sensing and ground observational data, the evaluation of new reanalysis products, and the development of new reference ground-based products. The selection of indices that are collected by the ETCCDI needs to be continuously discussed and improved. GEWEX panels (in particular GLASS and GHP) could help broaden the scope of the ETCCDI to include additional water-cycle related extreme indices (e.g. drought reconstructions, datasets relevant for the water cycle, and sub-daily as well as daily precipitation extremes), and indices that are more directly related to impacts in various sectors such as human health, agriculture, transportation, etc. The WCRP Working Group on Regional Climate (WGRC) could also be especially helpful in this regard. Effort should be made to ensure that, as much as possible, 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.We also need to continue to request 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, and identify steps that would improve data sharing. The coordination of existing digitization of weather observations that reside in paper archives (sometimes referred to as "data archaeology") holds prospects for greatly expanding the availability of high-quality historical extremes data for the late 19th and early 20th centuries, enhancing our understanding of long-term variability in extremes. New satellite observations, including those that will be obtained from the GPM, and synthesis products that blend all observations will help to achieve the necessary spatial cover and, with limitations, temporal resolution. It is necessary to determine which regional and national observing systems requirements are close to being satisfied and which are not. It is also necessary to continue to develop and improve the design of observing networks and systems. All of the above should be discussed in the context of 'best practice' for constructing the resulting observational datasets for extremes through the development of a guidance document.

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

While some improvements are evident in CMIP5 relative to earlier CMIPs, model resolution, process representation and parameterizations remain insufficient for simulating the dynamical and physics processes of relevance to many extremes of interest. In particular, climate models have difficulties in capturing some relevant phenomena (e.g. tropical cyclones, blocking anticyclones, some large-scale modes of variability, monsoons, droughts, convective systems, winter storms). Models need to be confronted with more complete historical data and new observational products in innovative analyses and with new diagnostics and metrics of performance. Validating extremes simulated by models with observations is inherently difficult because there is often a mismatch in spatial and temporal scales between phenomena that are of interest and their representation in models.

***Actions**:* New techniques should be developed to address scaling issues, and data products that are being developed (see question 1) can provide valuable input. The multiple scales involving extremes and supporting processes (e.g. from large-scale heat waves and drought to local intense rainfall) need to be better understood, and methods to evaluate adequacy of observations and to assess models at those scales need to be developed. A dedicated workshop on this topic will be useful. A set of metrics needs to be developed for assessing the models' ability to simulate extremes and the dynamical conditions conducive to them, for example, blocking, with the aim to identify strengths and weaknesses in model simulations of conditions conducive to extremes, and in extremes themselves. 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. Focused investments by space agencies to make the observational products consistent and inter-comparable is quite timely. A further challenge is that 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.

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?

The occurrence of different extreme events, such as droughts, heat waves, heavy precipitation events, and floods are often the result of a combination of large-scale drivers (e.g., sea surface temperatures, sea ice extent, Rossby waves) and regional-scale feedbacks (e.g. soil moisture, vegetation and snow conditions). Research shows that changing temperature extremes can in part be attributed to changing land surface conditions (modified soil moisture availability, changes in land use and land cover), and that land-atmosphere feedbacks can help to intensify temperature extremes (e.g. from GEWEX-sponsored GLACE, GLACE-2, GLACE-CMIP5, and LUCID experiments). Disentangling the processes leading to extremes is essential in order that they will be better represented in models and consequently the improvement of respective predictions/projections. The role of past and future land use forcing for the occurrence of extremes on land is still poorly quantified, although first results indicate that it has had a detectable role on changes in temperature extremes. Systematic model biases in the representation of land surface processes and respective feedbacks need to be addressed to improve the potential for predictions of extremes, in particular thanks to the development of improved land water and energy cycle datasets from remote sensing and ground observations (e.g. within GDAP and GHP, see item #1 above). Progress in this area is also of high relevance for the development of new attribution techniques for extremes, by allowing a better identification of the physical causation chain leading to the occurrence of extreme events.

Actions: This question requires coordination with GEWEX GLASS activities, in particular the GLACE-CMIP5, LUCID, GSWP3, and LUMIP multi-model projects (including those performed or planned as part of CMIP5 and CMIP6), as well as with CLIVAR on ocean heat content activities. Also of relevance are potential follow-up initiatives to the GEWEX-CLIVAR (GLASS-WGSIP) GLACE-2 experiment. 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 WCRP (e.g. GEWEX products developed within GDAP and GHP, as well as collaborations with IGBP community). CORDEX could help physical understanding of links between large-scale drivers and regional-scale responses.

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?

Observations have shown changes in the frequency and intensity of many kinds of extremes such as extreme temperatures and precipitation, or severity of ocean winds and waves. There is also evidence indicating that some of these changes can be attributed at least in part to forcing external to the climate system, such as increased greenhouse gases. Pinpointing causes and delineating the relative importance of external drivers such as greenhouse gas increases against internal drivers, such as modes of variability, which themselves might be influenced by external drivers, is necessary in order to improve confidence in models and future projections. There is also a growing body of research that links changes in the probability of extremes to inter-decadal climate variability. Both strands of research need to work closely together.

Actions: This area of research has made substantial advances recently (IPCC, 2012; 2013). However, challenges remain particularly associated to data availability, quality and consistency when targeting daily or sub-daily events, and when addressing changes in the SH and tropics (see also item #1). The WCRP community needs to continue to engage with the International ad-hoc detection and attribution group (IDAG), which has been coordinating detection and attribution studies for many years, with a focus on relevant variables including extremes at impact relevant scale. This activity confronts changes simulated by models with observations, and results can be used to quantify predictions. IDAG also has a close link with ETCCDI, which coordinates in situ data for the characterization of some extremes, as well as with the modelling groups. This activity also links closely to CLIVAR activities focusing on modes of climate variability. CMIP and CORDEX provide foundational modelling support to this effort.

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

Event attribution is tightly connected to attributing large-scale changes in the frequency or intensity of events (see question 4), but is fundamentally different in its focus to individual regional events rather than large-to-global-scale changes in the probability of events. The scientific underpinning of event attribution is being actively developed and plays an important role in model evaluation, including identifying systematic model biases in simulating changes in extreme events; in characterizing the contributors to events (see also #s 2,3,4) and in testing our physical understanding.

Actions**:** Engage with ‘event attribution’ activities that are underway worldwide and rapidly gaining steam (e.g., ACE group; EU project EUCLEIA; activities in the US, e.g. at NOAA and DOE). An initiative for the production of timely and scientifically robust attribution assessments for individual extreme weather and climate events has been proposed as part of the international Attribution of Climate-related Extremes (ACE) project with activities in many regions (US, Europe, Africa, Asia). The goal is to provide robust information to society on the extent to which the probabilities of specific observed extreme events have been affected due to human activity.

This topic is highly visible and provides important communication challenges as well as opportunities. As results depend on assumptions and questions asked, coordination is vital, and the framework needs to be continually tested, including with historical events. 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 their mechanisms and predictability. Factors that compound the impacts of specific observed extreme events, such as the coincidence of blocking and drought combined with heatwaves, and their relevance for event attribution also needs to be identified and quantified. The annual BAMS issue on climate events, published first for 2011, is an important step towards making this area of research visible that needs to be supported. CLIVAR and GEWEX panels can strongly contribute to the development of the underlying science, in particular in coordination with the research developed under #4. The WGRC can contribute substantially to alleviating communication challenges while also identifying extremes that have special societal importance and therefore should have high priority for research.

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

This question is very topical as recent advances have highlighted the dependency of trends in drought on the drought index used, and also how much it is affected by data uncertainty in forcing data. Progress will be achieved through links to the existing GEWEX-CLIVAR Drought interest Group (DIG) as well as to the GEWEX GLASS activities (e.g. GSWP3).

Actions**:** Develop tractable actions on monitoring, quantification and understanding of the global distribution of droughts and their trends using observational information, model development, land area factors governing drought, and societal interactions. Within WCRP, this involves DIG, WGRC and the GEWEX and CLIVAR panels and they need to collaborate and integrate with similar activities under WMO such as ETCRSCI. DIG is currently developing its Global Drought Information System (GDIS) activity that identifies a number of scientific and technical issues of critical importance to improving our ability to cope with this particular type of extreme. In addition, the GEWEX GSWP3 activity aims at producing a reanalysis of land conditions over the 20^{th} century. These new developments need to be sustained and more interaction with other extremes-related activities is required. The WGRC can promote activities that characterize the variety of droughts (e.g., precipitation, agricultural, etc.) and their societal interactions.

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?

Several challenges are found in this area, ranging from short-term predictions to seasonal forecasting (e.g. of droughts and heat waves), as well as to decadal forecasting (see Meehl et al., 2009). The short-term prediction of extreme events, with lead times of hours to days in advance, will continue to improve as a consequence of the continuing efforts of the World Weather Research Program to improve global numerical weather prediction capabilities. Individual short term weather extremes are likely not predictable beyond the general limit of predictability of weather events (i.e., ~10-12 days), but it should be possible to predict the statistical properties of short-term extreme events. Also, it may be possible to predict individual long-duration large-scale extremes, such as sub-continental scale drought, months or longer in advance, using initial conditions for "slow" variables of the climate system (e.g., ocean temperatures, soil moisture, snow, vegetation activity). Large-scale modes of variability such as ENSO or interdecadal modes influence the statistical properties of extremes (e.g. frequency of extreme precipitation in different parts of the world; see (1)) and affect the occurrence and intensity of large-scale drought (e.g. Sahel, Australian examples). Near-term predictions attempt to make use of these connections between extremes and climate state, but require an accurate representation of the 3-D state of ocean, and of land, atmosphere, and cryosphere in order to investigate and realize potential long-term predictability. The CMIP5 database has provided coordinated decadal forecasts and hindcasts (as proposed by WGCM) and WGSIP has coordinated experimentation with shorter-term seasonal to interannual hindcasts. Literature based on these efforts and on individual modelling group pilot projects suggests that there is some predictability, particularly for temperature extremes and when regional drivers such as ENSO are active. In addition, the joint WGSIP-GEWEX experiment GLACE-2 allowed the evaluation of the predictability potential that can be gained from land initialization. Long-lived extremes such as extended periods of high temperature and drought show some predictability in both tropical and extratopical regions on seasonal timescales, and they also show potential predictability based on external forcing such as greenhouse gas increases. However, the potential for predictability needs to be critically evaluated in order to determine the most effective method to predict near-term changes in extremes.

Actions: 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 (Working Group on Seasonal to Interannual Prediction) initiative. Much work is needed to take careful account of uncertainty when delivering forecasts to users (see 9). Activities by forecasting centres in seasonal to decadal predictions have been coordinated by WCP. Linkage should be established with WGSIP, in collaboration with WGNE (Working Group on Numerical Experimentation) and WGCM, as well as with GEWEX with respect to land-based predictability (GLACE and GLACE-2). Quantification of the skill of model simulations and forecasts of extremes using appropriate and comparable metrics is very important, and US CLIVAR has provided guidance (Goddard et al., 2012). The extremes indices developed by the ETCCDI and CLIVAR can provide metrics for extremes, and these need to be expanded to include metrics from the water cycle community (e.g. for drought assessment, as is being provided by GEWEX). This area has excellent potential for imminent progress and needs to be supported and coordinated. This is also an area that is ideal for implementing the 'seamless' paradigm, bridging from weather to climate research. The US-CLIVAR activity on decadal predictions that has provided guidance on evaluating predictions should be resumed and undertaken as a worldwide activity in order to ensure that metrics used to evaluate predictions are comparable and critical, and to further understanding of the causes of intermodal-differences in predictability. A further important step is to identify suitable datasets of the state of lands, ocean and cryosphere for the initialization of forecasts for a season to a decade.

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

As large scale phenomena such as monsoons and modes of variability influence the frequency of extremes, regional predictions and projections of changes in extremes are strongly influenced by changes in, for example, the frequency and intensity of ENSO. It is presently unclear if and how, for example, El Nino, may change its behaviour under global warming, and what the implications are of such changes for extremes, and their predictability. Nevertheless, it is *very likely* that ENSO will continue to be the dominant mode of interannual variability in the future (Christensen et al., 2013 – AR5 WG1 Ch14). For other modes of variability and circulation regimes the physical understanding of causes in their long-term change remains limited, and uncertainty is large, making this an area where rapid progress is unlikely.

Actions*:* This question requires and offers opportunity for coordination with the newly founded Monsoon panel, and with traditional CLIVAR activities, as well as with GEWEX (hydroclimatological variability), SPARC (role of stratosphere on modes of variability), and CliC (for example, influence of cryosphere changes on storm tracks) activities. In some aspects of this, such as changes of ENSO in the future, there is little prospect for rapid advances at present. For other aspects, such as the role of the stratosphere, of land-sea contrasts, of dynamics overall and its interaction with forcing as well as the influence of changing sea ice on storm tracks are highly visible open questions that require rapid progress and rigorous evaluation.

Strategy for implementation

Weather and climate extremes are cross-cutting across WCRP projects. For example, the development of this document is based on large community efforts including the 2010 workshop on extremes (Zolina et al. 2010), the IPCC SREX (IPCC 2012) and AR5 WGI assessments (IPCC 2014), the WCRP Open Science Meeting (Zwiers et al. 2013), and the development of GEWEX research questions on changes in extremes (GEWEX 2012), and the CLIVAR research focus on extremes.

Because of its complexity and cross-cutting nature, a joint CLIVAR/GEWEX Expert Team on Extremes would be required to coordinate extreme related activities across WCRP projects (GEWEX, CLIVAR, SPARC, CliC) and working groups (WGSIP, WGCM), and to communicate the ongoing activities of this Grand Challenge to key organizations including WMO, GEO, Future Earth and national organizations to ensure that progress leads to the development of improved climate services and that feedback is given. This could possibly be established by expanding the charge to the current ETCCDI, which would be coordinated under both CLIVAR and GEWEX, or directly at the WCRP level, with additional membership such that the existing ETCCDI activities would be a subset of the new expert team to maintain two-way communication between WCRP and its users CCl and JCOMM[1]. Initially, the team working on the grand challenge will be expanded in strategic areas for topics (1)-(8) by adding a few key individuals with different perspectives (e.g., from the seasonal and decadal forecasting communities).

A more detailed plan should be available at the time of the pan-CLIVAR and pan-GEWEX meetings in July 2014, where several sessions on extremes are planned that can provide further

[1] If the ETCCDI is expanded as suggested, the organizational structure would need to be discussed with CCl and JCOMM.

input from the wider community. The white paper will be presented and next steps developed immediately after the Science meeting. The focus will be on identifying near-term opportunities including improving cross-links by adding additional members of this grand challenge group, and on identifying funding opportunities. Several sessions at the GEWEX Science Conference will address the topic of extremes; and sessions and invited presentations will cover questions that are identified above. In addition, extremes will be a main topic of the joint Pan-GEWEX and Pan-CLIVAR meeting in The Hague (July 2014) and related journal special issues are planned on this topic (led by X. Zhang and L. Alexander).

A WCRP Summer School on climate extremes is planned for July 2014 to train the next generation of leaders in this field, enhancing capacity. Two to three focussed 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 challenges (1) to (8) over the next few years (topics to be determined no later than at the GEWEX/pan CLIVAR meetings in The Hague, ideally by spring 2014). Preference will be given to topics that offer opportunities for rapid progress (such as the topic of near-term predictability, the investigation of physical mechanisms leading to extremes and their relevance for attribution, and the development of new datasets for sub-daily extremes), or topics that have not been highlighted in this document (such as the question of scales of extremes, or the comparison of satellite and ground observational datasets for extremes). The insights gained will be formulated in an engaging way either for CLIVAR/GEWEX newsletters, or where possible, in high profile journals (e.g., Nature, Science, BAMS).

If possible, opportunities at large international conferences such as AGU and EGS 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.

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. First steps will be undertaken prior to the Pan-CLIVAR/Pan-GEWEX meeting. On the European level, a multi-institution project on the attribution of extreme events was recently funded (EU-FP7 EUCLEIA). Avenues to help fostering research in this area on other continents will be investigated.

References:

GEWEX 2012: GEWEX Plans for 2013 and beyond, GEWEX Document Series No. 2012-2.

Kunkel, K.E. et al., 2013: Monitoring and understanding trends in extreme storms. Bull. Amer. Meteor. Soc., 94, 499-514.

IPCC 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, pp. 109-230.

IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, pp. 109-230.

Goddard, L., A. Kumar, A. Solomon, D. Smith, G. Boer, P. Gonzalez, C. Deser, S. Mason, B. Kirtman, R. Msadek, R. Sutton, E. Hawkins, T. Fricker, S. Kharin, W. Merryfield, G. Hegerl, C. Ferro, D. Stephenson, G.A. Meehl, T. Stockdale, R. Burgman, A. Greene, Y. Kushnir, M. Newman, J. Carton, I. Fukumori, D. Vimont, T. Delworth (2012): Verification Framework for Interannual-to-Decadal Prediction Experiments. Climate Dynamics, Clim Dyn 40:245–272 [originating from a US CLIVAR white paper)

Meehl, G.A., L Goddard, J Murphy, R.J. Stouffer, G Boer, G Danabasoglu, K Dixon, MA Gorgetta, AM Greene, E. Hawkins, G Hegerl, D Karoly, N Keenlyside, M Kimoto, B Kirtman, A Navarra, R Pulwarty, D Smith, D Stammer and T Stockdale (2009): Decadal Prediction: Can it be skillful? BAMS, doi: 10.1175/2009BAMS2778.1.

Zolina, O., S. Demuth, V. Detemmerman, S. Gulev, W. Gutowski, A. Klein Tank, D. Stephenson, R. Stewart, K. Trenberth, F.W. Zwiers, 2010: Workshop on “metrics and methodologies of estimation of extreme climate events” sponsored by WCRP (GEWEX/CLIVAR) and UNISCO (IHP), Paris, UNESCO headquarters, 27-29 Sept. 2010.

Zwiers, F.W., L.V. Alexander, G.C. Hegerl, T.R. Knutson, J.P. Kossin, P. Naveau, N. Nichools, C. Schar, S.I. Seneviratne, X. Zhang, 2013: Challenges in Estimating and Understanding Recent Changes in the Frequency and Intensity of Extreme Climate and Weather Events, Climate Science for Serving Society: Research, Modelling and Prediction Priorities. G. R. Asrar and J. W. Hurrell, Eds. Springer.