Workshop on "*Metrics and methodologies of estimation of extreme climate events*" *sponsored by* WCRP(GEWEX/CLIVAR) and UNESCO (IHP)

(Paris, UNESCO headquarters, 27-29 September 2010)

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Executive Summary

The aim of the workshop (27-29 September 2010, Paris, UNESCO) was to facilitate an open dialogue of atmospheric scientists, climatologists and climate modellers from different regions, data producers, statisticians, and users (e.g., insurance companies) on the future strategy for the development of robust and reliable characteristics of extremes and optimal methodologies for their estimation. General workshop recommendations are as follows:

- WCRP, through its core projects, should enhance efforts to develop improved high temporal resolution (sub-daily) datasets that can be used to assess changes in extreme rainfall, drought, heat waves, floods, and storms.
- WCRP, and in particular, the Working Group on Coupled Modelling, should include in the agenda of model evaluation the focus on the model's ability to replicate extremes and to better compare model output with observations.
- WCRP core projects (foremost GEWEX and CLIVAR) should place a high priority on determining the main phenomena responsible for extremes and improving understanding of the relevant physical processes.
- Special action is required on the development of robust statistical methods for assessing extremes and their uncertainties and on making these tools available for wide-spread use.
- An activity on analysis of extremes utilizing data archived by the WCRP Coupled Model Intercomparison Project should be planned and launched in the near future.

Discussions during the workshop also produced many more specific recommendations from the break out groups on Data requirements and availability, including data policy, Representation of extreme events in climate and operational models, including consideration of scaling and spatial scales of extremes and Methodologies for estimation of extremes across areas and disciplines. These recommendations summarized in the report below and provide specific guidance for future actions in these areas as well as on the synergy between the areas for a better estimations and quantification of climate extremes.

1. Introduction: Workshop organization and scope

The WCRP-UNESCO (GEWEX/CLIVAR/IHP) Workshop on "*Metrics and methodologies of estimation of extreme climate events"* was held in Paris at UNESCO Headquarters 27-29 September 2010. The workshop was organized by WCRP, hosted by UNESCO and co-sponsored by Willis Research Network. The workshop Scientific Organizing Committee consisted of Olga Zolina (chair), Siegfried Demuth, Valery Detemmerman, Sergey Gulev, William Gutowski, Albert Klein Tank, Anna Pirani, David Stephenson, Ron Stewart, Kevin Trenberth (ex-officio) and Francis Zwiers. Local organizers were Siegfried Demuth and Barbara Lwanga of UNESCO/IHP. 132 participants from 32 countries attended the Workshop (see Annex 1). Of these 38 (29%) were female scientists and 34, (26%) were from developing countries and countries with economies in transition. The workshop consisted of oral and poster sessions, discussions, and breakout groups. Altogether there were 35 oral presentations and 82 posters.

The Workshop organization was motivated by a desire to synthesize and build on the outcomes of a sharply growing number of activities and meetings targeting different aspects of extreme events. Firstly, the IPCC WG-I and WG-II were developing a Special Report on "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation", and the second revision of this report was due in February 2011. Secondly, regional impacts of weather and climate extremes were recently addressed in a number of documents, such as the U.S. Climate Change Science Program (CCSP) report on extremes, "Weather and Climate Extremes in a Changing Climate (Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands)," published as CCSP Synthesis and Assessment Product 3.3 in 2008. Thirdly, the joint CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) had recently developed comprehensive "Guidelines on Analysis of extremes in a changing climate in support of informed decisions for adaptation" (*A. M.G. Klein Tank, F. W. Zwiers and X. Zhang, 2009, Climate Data and Monitoring WCDMP-No. 72, WMO-TD No. 1500, 56pp.*) addressing issues of data homogeneity, derivation of the set of indices quantifying extreme events and observed variability of the occurrence and intensity of extremes. Finally, it must be mentioned that numerous activities overseen by the International Hydrological Programme (IHP) of UNESCO, aimed at water resource management and capacity building, pose additional requirements for accurate estimation of extreme events in a changing climate.

In addition to the above mentioned activities, several other related meetings and projects took place during the past two years and these all contributed to the Workshop profile. Their outcomes and status were presented and discussed during a special briefing session.

The workshop **aim** was to facilitate an open dialogue among atmospheric scientists, climatologists, oceanographers and climate modellers from different areas as well as data producers, statisticians and users (e.g. insurance companies) on the future strategy for the development of robust and reliable characteristics of extremes and optimal methodologies for their estimation.

Specific **objectives** of the Workshop were to:

- Review and assess the existing metrics of extreme weather and climate events and identify their strengths and weaknesses;
- Assess critically the variety of methods for estimation of climate extremes and their uncertainties, involving cross-pollination of experience from different areas;
- Assess the reliability of representation of different extremes in different data types and model simulations;
- Identify critical gaps in quantitative estimation of climate and weather extremes in data and model experiments, particularly spatial aspects of extreme events and the nature of the "compound" events;

- Develop an optimal strategy for improving the estimation of climate and weather extremes and their projection in future climate through the implementation of well justified characteristics of extremes and accurate methodologies of their estimation;
- Assess critically the synergy between different extremes (e.g., precipitation, temperature and flooding) and their impacts.

The WCRP Joint Scientific Committee had launched several years back a cross-cutting activity on climate extremes. Outcomes of this Workshop were to contribute to the development of the future strategy of the WCRP and its core projects in the realm of extremes.

2. Workshop science sessions

Workshop was opened by welcoming remarks from UNESCO by Alberto Tejada-Guibert (Director of the Division of Water Sciences and Secretary of the International Hydrological Programme UNESCO/IHP)) and by Jorge Luis Valdes Santurio (Head of the Ocean Science Section UNESCO/IOC). A welcome from WCRP was presented by Valery Detemmerman (Senior Scientific Officer of the Joint Planning staff of WCRP).

The Workshop programme was organized in five major topical sessions (see Workshop programme, Annex 2). The opening session on "*Hydrological extremes (precipitation, flooding and river discharge), including compound hydroclimate extremes*" considered the physics and origins of hydroclimate extremes (Trenberth), observed climate variability in heavy precipitation and flooding (Lettenmaier, Easterling, Kunkel, Dong) and abilities of climate models to accurately simulate changes in extreme precipitation (Soden, Emori, Le Treut). A following session on "*Extremes in temperature conditions, heat waves and dry spells*" consisted of talks on regional analyses of heat waves and droughts (Schär, Gershunov, Stewart, Blender, Lawford) as well as regional and global studies on attribution of temperature extremes (Alexander and Zwiers). The session on "*Extreme tropical and extratropical cyclones and associated wind waves and storm surges*" analysed structure and global statistics of tropical (Kossin, Knutson) and extratropical (Gulev, Leckebusch) storms, stressing particularly the uncertainty of the definition of extreme cyclones. This session also considered storm surges representing a compound extreme phenomenon originating from many factors (von Storch). The following session on "*Methodologies for estimation extremes*" addressed different mathematical aspects of the estimation of events of rare occurrences (Panorska, Smith, Davison) and problems in estimation and detection of climate extremes in climate projections (Wang, Wehner) and in observations (Ren, Zolina). The concluding session on "*Risk assessment*" addressed issues of requirements for decision making (Goodess), downscaling and of climate extremes (Wood) and risks of sea-level extremes (Hunter). During this session there was a presentation by Gero Michel (Willis Research Network) reviewing the scope of activities of Willis RE in quantifying risks of different climate extremes worldwide.

Poster sessions (see Annex 2) supplemented oral sessions with specific regional and case studies on each topic. Of the total of 82 posters, 38 were presented in the session dealing with hydrological extremes covering a wide spectrum of hydrology-related topics, such as extreme precipitation, flooding, extreme river discharges, and changes in the drought frequency and duration. Many posters addressed the different space and time scales of hydrological extremes. With a few exceptions, most poster studies presented results based on daily data, which shows that the use of high-resolution data has become a common practice in dealing with extremes. A number of posters featured regional foci: 7 posters dealt with extremes in South America; 8 posters presented results for Western Europe; 6 for Africa; and 4 for Southeast Asia. Several posters employed not only in-situ data and numerical weather prediction (NWP) products, but also satellite observations of precipitation, thereby demonstrating the continuously growing capability of these data for quantification of hydrological extremes. Seven posters in the session "Extremes in temperature conditions, heat waves and dry spells" primarily covered variability of temperature extremes, with one dealing with a more comprehensive analysis of heat waves. Regionally these studies were spread throughout Europe, India and South America. Methodologically, the emphasis was on the analysis of multiyear trends in the time series of temperature extremes. Posters under the session on tropical and extratropical cyclones, wind waves and storm surges (14) were equally spread between mid-latitude storm activity, its changes, and associated impacts, and variability in the extreme wind events. A few posters presented case studies of tropical cyclones using model diagnostics. Twenty posters displayed at the session on methodologies presented different approaches applied to quantification of climate extremes (extreme indices, regression quantiles, and area-related definition of extreme floods). Some of these addressed issues related to regionalization and downscaling of extremes. Three posters presented at the “Risk assessment” session addressed socio-economic impacts of extremes in developing regions such as Ethiopia, Central America and Iran.

3. Briefing session on the recent meetings and activities in the area of extreme events

A special briefing session during the Workshop reviewed the outcomes from meetings and ongoing activities that occurred during 2009 and 2010 (see Annex 2). Several smaller scale workshops were targeted at the improvement of methods of estimation of extreme events. These included the GEWEX/WCRP Workshop in Vancouver in 2008, and subsequent workshops in Banff, Diessenhofen, and Bonn, each delivering new approaches for quantifying extreme climate events and also providing intercomparison of statistical methodologies. Workshops in Ashville, Winnipeg, Exeter, and Grand Forks were targeted at the provision of new data sets and platforms for monitoring of extreme events, including droughts. The Storm Surge Congress in Hamburg comprehensively addressed different aspects of hindcasting and forecasting of storm surges as a typical compound extreme event. Different aspects of the analysis of climate extremes, such as their origin, uncertainties in quantification, and impacts are being addressed in the IPCC Special Report on extreme events and disasters (to be published in 2012). The IMILAST project consolidates the effort of about 20 teams worldwide to intercompare different schemes for cyclone identification and tracking, and to establish more robust analysis of cyclone activity. Overall, this session revealed that different approaches for quantifying extremes are closely related to each other and, thus, consolidated effort is needed to provide cross-pollination of ideas and an effective strategy for the analysis of climate extremes in the future. Considering the methodological aspects of estimation of climate extremes, there are several issues for which all above mentioned meetings identified considerable gaps of knowledge. In particular, these are precise estimation of the timing of extreme events, comparisons of grid cell estimates (from e.g. models) to point data and estimation of the joint impact of different factors on the magnitude of compound extreme.

4. Break-out groups and discussions

Break-out group (BOG) sessions were introduced by three key-note talks by Albert Klein Tank (Data requirements and availability, including data policy, BOG-1), William Gutowski (Representation of extreme events in climate and operational models, including consideration of scaling and spatial scales of extremes) and David Stephenson (Methodologies for estimation of extremes across areas and disciplines).

4.1. BOG-1 (Data requirements and availability, including data policy)

BOG-1, led by Zolina and Lawford, examined the needs for real-time data for dealing with the impacts of extreme events as they occur. This BOG considered in particular:

1) issues related to the availability of data for use in the analysis of extremes;
2) requirements for homogeneous and interoperable data sets for the analysis and prediction of extremes;
3) the relative roles of satellites and models in providing data of use in understanding and characterizing extremes.

While the first reaction to a discussion of data needs was that it would be ideal to have data for all times at all locations around the globe, the group also had a practical perspective, recognizing that it was necessary to improve data holdings and availability without large increases in costs.

Additionally, it was recognized that large flows of historical data on a global basis are often beyond the capabilities of small organizations and even small countries to absorb and analyze and hence making data accessible was also a major issue. The discussion about improving data completeness, quality and relevance without introducing large budget increases led to proposals for more strategic investments in observational data. As part of this process there is a need for analysis of the marginal benefits of adding an additional station or an additional satellite when developing the rationale for support for network enhancements.

BOG-1 participants stressed that modelling skills are reaching levels of sufficient quality that in some highly data sparse areas the output of simulations by these models may be as reliable as analysis being carried out using the sparse data. However, many of these models are tuned to predict average conditions rather than the extremes. A particular focus of this BOG was the need for long term data sets to examine trends in extremes. Some extremes (e.g., drought) appear to have long term cycles with frequent intense events in some decades and only a few weak events in other decades. In other cases the frequency and intensity of events appears to be increasing monotonically. Long term records are needed to help separate the frequency of occurrence signal into natural and anthropogenic components. It was agreed that records of at least one hundred years are needed to establish the long-term characteristics of extremes. However, these long-term data sets are rarely available in digital form, even in developed countries, because the older records are still in slowly deteriorating paper archives.

The BOG-1 stressed that there is a need to complete historical data rescue and to homogenize the existing records for tropical cyclones. Typically records of cyclones are developed subjectively in operational environments without reference to the needs for research quality data for climate trend analysis. Formal documentation identifying operational changes that affect data quality and accuracy is needed to enable historical data and future data to be compared. Estimating factors such as size and structure metrics, which strongly modulate storm threat, is also important. This would be helped by maintaining satellite-borne scatterometers such as ASCAT and QuikSCAT and providing data continuity. More generally, reprocessing of the entire satellite record for tropical storms and their characteristics would improve knowledge of how such storms have changed over time.

Considering extremes in sea level, the group recognized that long-term records (>100 years) exist for some fields such as Mean Sea Level (MSL) pressure even though other climatological records may not be available. Such long-term records could be calibrated and used as proxies for indices related to specific extremes. Furthermore, once calibrated these proxies may allow one to use MSL pressure distributions from climate models to produce projections of drought indices. For the analysis of long-term climate time series of SLP and associated indices, the recently available 20th century Reanalysis (1871-2008) developed by Gill Compo (University of Colorado) and colleagues gives an opportunity to extend the existing time series.

BOG-1 stressed that studies of historical extreme events are often limited by the fact that it is very difficult to access historical data sets after the event has passed. Members of the group indicated that studies of extreme events have been impeded by the lack of understanding of the mechanisms linking sea surface temperature (SST) and regional surface temperature anomalies during heat waves and the lack of surface water storage and streamflow data during floods. There is a requirement to obtain a wide range of in-situ data that can provide insights on specific extreme events. In some cases, efforts are on-going to develop inventories of extremes in the available data. WCRP supports these efforts and wishes to have access to the data inventories at its earliest convenience to support its own research programmes. There is a need to ensure that data on the remote factors involved in an extreme should be identified and the relevant data archived and made freely available for analysis in the future. In this respect a number of issues related to data sets to support the analysis of extremes are being addressed through the results of a workshop held recently in Exeter that aimed at the recovery of high frequency datasets for temperature and many other variables. Issues related to data quality, homogeneity of data sets, metadata, and formats for data transfers are being addressed through this effort. While this working group agreed that these are critical issues for temperatures, it felt that any effort made to follow up on the Exeter workshop should deal with a wider range of variables, i.e. going far beyond surface temperatures. It is concerned that the opportunity to use the Exeter workshop arguments for more variables than surface temperatures over land should not be lost.

Weather radars constitute a rich source of data for the study of extremes. However, in many countries operational meteorological services do not archive radar data and in some cases do not have radars. In other countries the derived precipitation fields are not compared among the radars and ground truth of results is essential. Furthermore the status of metadata for radars appears to be unknown.

Strong feelings were expressed about countries and organizations that were not willing to share their data and were accordingly slowing the progress of research on extremes. This includes simply describing how extremes have changed as well as validating models, which benefit the countries themselves and is in their own self interest. One suggestion for bringing attention to this issue was to establish a web page to provide updates on the countries that are not providing data to global data centres and WCRP projects. While there is interest in seeing WMO/WCRP address a request to countries to share data, there was scepticism as to the effectiveness of doing this without having a strong statement about the benefits of data sharing.

The group supported the projects like ClimDEX which intends to update the ETCCDI extremes indices and develop and update their global daily gridded datasets. Different issues can be consider, particularly closely related to the estimation of climate extremes, although it was concerned about the net benefit of the project and its contributions to the science of extremes.

BOG-1 discussed potential roles of different WCRP core projects in a better quantification, description and prediction of extremes. In particular, the group discussed a number of issues related to the cryosphere and extremes including the lack of standardization in snowfall measurement and corrections among countries. The efforts of GEWEX in carrying out assessments of its long-term satellite data products were welcomed. However, there was concern that some of the issues related to extremes, such as the handling of saturated pixels and the effects of these pixels on the reporting of extremes, has not been fully dealt with. The efforts of Space Agencies in generating new data sets for the ECVs were recognized as being valuable contributions to climate science. Satellite data sets that can be used for identifying extremes such as wildfires and floods also need to be exploited. The needs for ground-truthing and reducing of false alarm rates for extremes derived from satellite data for extremes were discussed. Some space agencies have open data sets while others, such as ESA, are just starting to make their data sets more open. However, more needs to be done using currently available data products that relate to extremes.

Regional Reanalysis projects have made significant advances in the past decade. Although it is recognized that these reanalyses can assist in identifying areas where there have been extremes, there are concerns about their ability to represent the intensity of single severe events and detect trends in extremes. However, in some areas where there are few measurements, regional reanalyses may be the only viable method available for assessing some extremes. However, global reanalyses now have comparable to the resolution of regional reanalyses of a few years ago.

In many cases the archives of products from the IPCC model runs are not optimized for studies of extremes. As a result some of the variables most critical for the analysis of trends in extremes are not archived. BOG-1 also stressed that the climate community has not always been quick to take advantage of novel approaches to acquiring data on extremes. Innovations discussed in this group included using archives of ship radar for the analysis of waves and developing drop disdrometers for use on wind shield wipers to collect data during intense rain storms.

Lively discussions on these topics resulted in the following recommendations from this BOG:

- International agencies (WMO and GEO) and nations should promote and sponsor studies to assess the value of adding new observations of certain types in data sparse regions on both a global and a regional scale.
- Research organizations such as WCRP should continue to foster development of models that can reliably simulate extreme events and test them to see how useful they can be for estimating the occurrence and characteristics of extremes in areas where measurements do not exist.
- A substantial effort should be directed at data rescue (in line with the Exeter meeting recommendations) 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.
- Steps should be taken by WMO and WCRP to develop a comprehensive data base of tropical cyclones that will be useful for assessing the trends in the frequency and intensity of these events. Promoting reprocessing of the satellite data would help enormously in this regard.
- The research to explore the feasibility of using MSL pressure as a proxy of drought should be undertaken and promoted by WCRP.
- WCRP, perhaps working with GEO and CEOS, should take some specific actions to encourage nations to share their data at original space-time resolution, in particular: a) developing some success stories for nations on the benefits of sharing data; b) making efforts to provide specific products of special interest to those nations who take steps to make their data available; and c) developing a small educational campaign relying on in-country experts and experts from other countries to educate data providers and data policy personnel of the benefits of sharing data.
- The focus of projects like ClimDEX should be on more advanced techniques for data analysis.
- A review of data requirements to support case studies of extreme events should be undertaken so that steps can be taken in a timely way to ensure all of the data required to study an extreme are archived and accessible. Specifically, an overview of the needs for data to support the analysis of cryospheric extremes should be undertaken. It was also recommended that the concerns of the communities dealing with extremes in wind, precipitation and streamflow should be added to any WMO/WCRP letter that might be sent to NHMSs.
- The range of variables provided through reanalysis should be increased to address the needs for a wider range of data products related to extremes (e.g., soil moisture). It is further recommended that current reanalysis products that could be used in studies of extremes be validated against in-situ observations for several different circumstances and regions (high data density regions, low data density regions, short duration events, longer-duration events, etc).
- WCRP should foster one or more projects involving the development of radar data and intercomparison and analysis of radar data fields with other products to examine extreme events.
- WCRP working with CEOS and space agencies should help to determine ways in which the satellite data sets related to extremes could be refined and made more readily available. It was also recommended that WCRP develop information products, including articles for its E-zine, Newsletters, and brochures, to make more people aware of freely available data sets for studies of extremes in different parts of the world.
- Finally it was recommended that WCRP convene a task group, or charge an existing group, to study possible innovative techniques for the acquiring and distributing data on extremes and other climate phenomena.

4.2. BOG-2 (Representation of extreme events in climate and operational models, including consideration of scaling and spatial scales of extremes)

Major issues addressed by BOG 2 led by Gutowski and Syktus, included:

1) Comparison of models with observations and, in particular, appropriate comparisons of model output from grid boxes with observations, whether station (point) or gridded values.
2) Consideration of physical processes raised questions about the most pressing directions for improving simulation of extremes when updating models.
3) Consideration of scales and physical processes raised additional questions for modelling and data assimilation.

Comparison of models with observations raised issues concerning appropriate comparisons of model output from grid boxes with in-situ observations, whether with stations (i.e. in a point) or with gridded values developed from the point data. Underlying this was recognition that spatial and temporal scales simulated by a model govern the character of extremes a model can produce, especially short-term, high intensity extremes. The discussion also recognized that archives of model output often lack the temporal and spatial resolution needed to assess simulations of such extremes. In addition, model definitions of variables may differ from what is observed, especially for fields needed to understand physical processes leading to extremes. For example, a model may provide a 2-m temperature through an assumed surface-layer interpolation, whereas the observed 2-m temperature may be measured directly. Moreover, the surface may not be at the same altitude and the topography may be quite different from reality. Limitations in scales simulated and archived also contribute to uncertainty in simulating, forecasting and projecting extremes.

Consideration of physical processes raised questions about the most pressing directions for improving simulation of extremes when updating models. For example, higher resolution may be important for improving simulation of intense extremes, such as sub-daily precipitation and its governing processes, but goals of expanding the scope of processes modelled, such as including atmosphere and ocean chemistry, may restrict the ability to apply advances in computing power toward significant increases in resolution. Similarly, trade offs between ensemble simulation and higher resolution affect decisions about how to best deploy available computing power. The ability to assess model processes governing extremes is affected by the issues of temporal and spatial scales that are resolved and archived, but it is also affected by how well processes, especially complex nonlinear processes, are simulated in climate and weather models. Closely related to this point is the availability and quality of observations suitable for assessing physical processes producing extremes. Understanding well the nature of processes leading to extremes is also important for determining the inherent uncertainty due to nonlinear internal variability that affects the occurrence of extremes.

Consideration of scales and physical processes raised additional questions for modelling and data assimilation. Data assimilation is typically a stochastic process that may limit extremes in analysis products, both when applying quality control to outlier observations that may be judged bad, and thus discarded, and when regressing input data to grid point values. On the other hand, hybrid combinations of physical and statistical models may extend the ability of models and data assimilation products to represent extremes. Finally, metrics are needed for assessing the quality of extremes in climate model output, numerical forecasts and data assimilation products, which will help focus analyses aimed at improving simulation and representation of extremes.

Summarizing the discussion on these issues the following general recommendations were given:

- The group noted that analyses needed to consider more thoroughly how well models simulated credible climatologies of weather phenomena that yield extremes. This would include, for example, statistics of blocking highs, cut-off lows, frontal systems extratropical cyclones, and monsoons.
- The group argued that such assessments of phenomena and processes yielding extremes should become more commonly part of model development in addition to the usual efforts to improve means and variability of fields. More thorough comparison of simulated and observed extremes would require developing appropriate methodologies for comparing models with observations in light of model-observation comparison issues.

Besides these general recommendations, the discussion targeted several issues related to model capabilities of simulating extremes. In particular, the break-out group felt that a key issue for simulating extremes was not simply assessing the extremes themselves but also how extremes are impacted by the realism of the environmental conditions leading to the extreme behaviour. As well as resolved phenomena, consideration should also be given to the climatology of environments conducive to extremes that may not necessarily be resolved by a model, i.e., environments producing tropical cyclones, tornadoes, hail, etc. Environmental conditions would also include factors such as the role of land-surface processes leading up to events such as floods and droughts. Physical processes yielding extremes often involve interactions across a range of spatial and temporal scales. For example, mesoscale systems producing extreme rainfall may be governed by large-scale factors such as teleconnections and synoptic disturbances. Analyzing scale interactions with respect to extremes is thus an important part of assessing model capability for simulating extremes.

Assessing biases in simulations of extremes and their processes would be especially important for determining how extremes will change with changing climate and what uncertainty should be attached to those changes. The methodologies may well change as model resolution continues to increase, allowing for more intense behaviour in models but also raising issues of optimum model-observation comparisons for extremes in data-sparse regions. Additional fields at higher temporal resolution are also needed from models in order to learn more about the shortcomings and strengths of their simulations of extremes.

Based on these specific discussions, BOG-2 produced several recommendations aimed at the modelling community and WCRP's mission over the next 5-10 years to understand and simulate better the physical behaviour of climate:

(i) Prediction & projections

- The modeling community should work to develop skillful prediction on ENSO time scales of the variability of extremes.
- The emerging decadal forecasts should be assessed for their ability to produce decadal predictions of the behavior of extremes.
- Initial conditions and forcing datasets for long-term projections of climate should be improved with an eye toward reducing uncertainties in the evolution of extremes.
- Climate models are tending to become more complex through the addition of more processes that make them more complete renderings of the earth system. These processes include, for example, socioeconomic behavior, agriculture, and ocean biogeochemistry. When additional complexity is added to climate models, the impact of new feedbacks in the system on extremes needs to be understood.

(ii) Climate model output

- Output archives need to be established that are more suitable for analysis of extremes and their processes. This would include establishing requirements for appropriate fields in addition to those already saved, such probability-distribution functions of key fields, frequency of threshold exceedances and other complex diagnostics that match observing system output.
- Statistical models should be used more to reconcile model output with observations.

(iii) Methodologies for extremes:

- The community needs to learn how to construct appropriate ensembles of simulations for analysis, forecasting and projection of extremes, accounting for trade-offs between resolution and number of ensemble members.
- The community needs to learn how to best utilize multi-model ensembles for assessment of extremes.

- Data assimilation for models and reanalyses needs to be designed to represent extremes well, including ensemble approaches to better capture uncertainty.
- Greater application of statistical models is needed to aid the physical interpretation of extreme events, to make model output more applicable for integrated assessment, and to understand error propagation in model simulations. Error propagation for extremes would include propagation through statistical and dynamical downscaling, through sub-models receiving climate-model output, and through boundary conditions for global and regional models.

4.3. BOG-3 (Methodologies for estimation of extremes across areas and disciplines)

Discussions of BOG-3 (Stephenson and Stewart) aimed at assessing the current statistical methodologies used to define and estimate extremes and to suggest actions for moving forward. These discussions addressed the following key-issues:

1) Statistical methods used in climate science;
2) Capabilities of simplified indices to capture extremes, importance of sampling size and spatio-temporal considerations;
3) Transfer of knowledge and wider distribution of advanced statistical methodologies and making extreme event research societally relevant.

It has been stressed that good statistical methods are essential for exploring, defining, and estimating weather and climate extremes. Several statistical approaches for extremes are now being routinely employed in climate science such as:

- Simple sample statistics: so-called “extreme” indices (or “metrics”);
- Relating changes in extremes to changes in the bulk properties of the probability distribution (i.e. location/scale/shape);
- Stochastic process models e.g., modelling of duration and intensity of droughts;
- Basic extreme value modelling of tails of the distribution such as Generalized Extreme Value (GEV) modelling of block maxima, Generalized Pareto Distribution (GPD) modelling of excesses above high threshold, and Point process models of exceedance above high thresholds.

In addition, more recent studies have started to develop and apply more complex Extreme Value Theory (EVT) models capable of dealing with non-stationarity in time and space. For example, the following directions of this development were mentioned:

- EVT models that include explanatory covariates to account for non-stationarities such as linear and non-linear trends;
- EVT models that exploit spatial pooling over neighbouring locations;
- Max stable processes and Bayesian hierarchical EVT models.

Discussion on application of advanced statistical methodologies to estimation and quantification of climate extremes raised several critical questions that need to be addressed through the consolidated actions of the community:

- What can extreme indices (metrics) tell us about extremes?
- How should we develop well-specified extreme value models that account for non-stationarity (non-identical distributions) caused by natural and climate change processes?
- How should we deal with large sampling uncertainty due to the rarity of events and shortness of available observational records?
- How should we develop robust estimation in the presence of outlier events?
- What is the best way to model spatio-temporal trends and dependency?
- What can imperfect climate models tell us about real world extremes? How should we bias correct errors in model simulated extremes?

- How should we develop and test well-specified inferential frameworks for prediction and attribution of real world extremes from multi-model ensembles?

During the discussion, BOG-3 identified several outstanding methodological issues that need to be addressed with urgency:

- Transfer of knowledge on statistical tools from the mathematical to the climate community and the need for sustained cross-pollination of ideas between the two in order to concentrate on the development of more appropriate statistical methods.
- Enhanced emphasis on methodologies applicable for estimation of compound events (especially those not amenable to EVT, e.g., drought) and on spatio-temporal scales of extreme events.
- Development of fit-for-all definitions of “climate trend”.
- Making estimation of uncertainties (confidence and prediction intervals) and sampling errors a general practice.
- An accurate estimation of the sensitivity of different methods to the choice of thresholds and potentially development of recommendations on a proper choice of regional thresholds.
- Activities aiming on making the analysis of extremes societally-relevant, including operational context (e.g., real-time attribution in the future).

The breakout group came up with several recommendations on actions that would help the community progress. In no particular order, these included:

- WCRP should develop a statement about the existing problems of definition of extremes to help avoid misinterpretations in the diverse communities concerned. Examples include large meteorological values (maxima, exceedances over high thresholds, record breakers), rare events in the tail of the distribution, events that create large losses. These are not synonymous.
- WCRP should consider ways of engaging statisticians to collaborate with climate scientists. Mechanisms need to be created to help entrain and engage environmental statisticians in climate research on extremes.
- Joint activities on extremes with World Weather Research Programme (WWRP) should be developed such as joint activity on hurricanes and heavy precipitation events.
- Long control runs for use in detection and attribution studies of extremes should be produced by climate centres and made readily available.
- Capacity building regional workshops on methodologies for extremes should be organized.

5. General recommendations of the Workshop

The final discussion summarized the recommendations of the BOGs and delivered consolidated general Workshop recommendations as follows:

- WCRP, through its core projects, should enhance efforts to develop improved, high temporal resolution (sub-daily) datasets that can be used to assess changes in extreme rainfall, drought, heat waves, floods, and storms.
- WCRP and in particular, the Working Group on Coupled Modelling, should include in the agenda of model evaluation the focus on the model’s ability to replicate extremes and to better compare model output with observations.
- WCRP core projects (foremost GEWEX and CLIVAR) should place high priority on determining the main phenomena responsible for extremes and improving understanding of the relevant physical processes.
- Special action is required on the development of robust statistical methods for assessing extremes and their uncertainties and on making these tools available for wide-spread use.
- An activity on analysis of extremes utilizing data archived by the WCRP Coupled Model Intercomparison Project should be planned and launched in the near future.

6. Outputs and concluding remarks

Initial information on the Workshop was published in EOS Transactions (Zolina et al. 2010). The workshop web site (www.extremeworkshop.org) contains all presentations and posters as well as Workshop recommendations and will be maintained until at least 2012. The outcomes of the Workshop will be this extended Workshop report, to be published by WCRP and made available at the Workshop web site, and a white paper to be prepared to develop more detailed recommendations for action based on the workshop discussions. These outcomes are expected to feed into a larger WCRP cross-cutting effort targeted at climate extremes. The overall strategy will be discussed in more detail at the upcoming WCRP Open Science Conference (http://www.wcrp-climate.org/conference2011) that will be held in October 2011. A consolidated vision of the problems of estimation of climate extremes and potential strategy should be presented in a BAMS paper to be drafted in the coming months.

7. Acknowledgments

The successful organization of the Workshop was largely by courtesy of the support of WCRP and its Joint Planning Staff in Geneva, contributions by Willis Research Network and the organizational support of IHP of UNESCO, in particular Siegfried Demuth and Barbara Lwanga.

8. Annexes

8.1. Annex 1 – List of participants

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8.2. Annex 2 – Workshop programme

Monday 27 September 2010

08:00 – Registration
09:00-09:10 – Workshop objectives (***Olga Zolina**, MIUB, Germany*)
09:10-09:30 – Welcome

***Alberto Tejada-Guibert** (Director a i. of the Division of Water Sciences and Secretary of the International Hydrological Programme UNESCO/IHP))*
Jorge Luis Valdes Santurio (*Head of the Ocean Science Section UNESCO/IOC)*
***Valery Detemmerman** (WCRP)*

Session 1 Hydrological extremes (precipitation, flooding and river discharge), including compound hydroclimate extremes (Chairperson: ***Olga Zolina***)

09:30 Physics and origins of hydroclimate extremes *(**Kevin Trenberth**, NCAR, USA)*
10:00 Atmospheric warming and the amplification of precipitation extremes (***Brian Soden**, University of Miami, USA*)
10:20 Investigating mechanisms of future changes in precipitation extremes simulated in GCMs (***Seita Emori**, Center for Global Environmental Research Tsukuba, Japan*)
10:40 How much can global models tell us about future changes in drought and flood conditions? *(**Herve Le Treut**, Institut-Pierre-Simon-Laplace, France)*

11:00 – 11:30 – coffee*

Session 1 continues (Chairperson: ***Ron Stewart***)

11:30 Precipitation extremes and flooding: Evidence of nonstationarity and hydrologic design implications (***Dennis Lettenmaier**, University of Washington, USA)*
11:50 Observed changes in heavy precipitation events and extratropical cyclones (***David Easterling**, NCDC, USA*)
12:10 Trends in U.S. extreme snowfall seasons since 1900 (***Kenneth Kunkel**, Desert Research Institute, USA*)
12:30 Investigation of the 2006 drought and 2007 flood extremes at the Southern Great Plains through an integrative analysis of observations (***Xiquan Dong**, University of North Dakota, USA)*

12:50 – 14:00 – lunch

Session 2 Extremes in temperature conditions, heat waves and dry spells (Chairperson: ***Albert Klein Tank***)

14:00 Past and future changes in temperature extremes in Australia: a global context (***Lisa Alexander**, University of New South Wales, Australia*)
14:20 Detecting anthropogenic influence on extreme daily temperature at regional scale (***Francis Zwiers**, Meteorological Service of Canada, Canada*)
14:40 European heat waves in a changing climate (***Christoph Schär**, ETH Zurich, Switzerland*)
15:00 Heat waves in Mediterranean climate regimes (***Alexander Gershunov**, Scripps Institute of Oceanography, USA*)
15:20 The structure of drought (***Ron Stewart**, University of Manitoba, Canada*)

15:40 - 16:10 – coffee*

Session 2 continues (Chairperson: ***Sergey Gulev***)

16:10 Storms, drought, and wetness: Meteorological extremes on different time scales (***Richard Blender**, University of Hamburg, Germany*)
16:30 Contributions of drought studies to the Global Earth Observation System of Systems (GEOSS) (***Rick Lawford**, University of Manitoba, Canada*)

Briefing and discussion session (Chair and moderator: ***Sergey Gulev***)

16:50 Briefing on the recent workshops and activities on extreme events (5 minutes each)

- GEWEX/WCRP Extremes Workshop, Vancouver, Canada, May 2008 (***Ron Stewart***)
- IPCC Special Report of extreme events and disasters, Oslo, Finland, March 2009 (***Francis Zwiers***)
- Workshop on Extreme events in climate and weather, Banff, Canada, 22-27 August 2010 (***Peter Guttorp***)
- Weather and Climate Extremes During the Past 100 years, Diessenhofen, Switzerland, 7-9 June 2010 (***Urs Neu***)
- IMILAST project (Intercomparison of mid latitude storm diagnostics) (***Urs Neu***)
- Workshops on North American and global drought monitoring, Asheville, USA, April 2010 (***Rick Lawford***)
- GEO-DRI workshop Winnipeg, Canada, May 2010 (***Rick Lawford***)
- Storm Surge Risk and Management Congress, Hamburg, Germany, 13-17 September 2010 (***Hans von Storch***)
- Workshop on Extremes in Weather and Climate, Bonn, Germany, June 2010 (***Petra Friederichs, Douglas Maraun***)
- Creating surface temperature datasets to meet 21st Century challenges, Exeter, UK, September 2010 (***Albert Klein-Tank***)
- NASA NEWS extreme workshop, Grand Forks, ND, USA, 15-16 July 2010 (***Xiquan Dong***)

17:50 – **Discussion**
18:30 – **Reception (Sponsored by Willis Research Network)**

Tuesday 28 September 2010

Session 3 Extreme tropical and extratropical cyclones and associated wind waves and storm surges (Chairperson: ***Francis Zwiers***)

08:30 Observed tropical cyclone variability (***James Kossin***, *University of Wisconsin, USA*)
08:50 Extreme extratropical cyclones and their characteristics (***Sergey Gulev***, *IORAS, Russia*)
09:10 Perceived as a regional phenomenon, but really of global concern: storm surges (***Hans von Storch***, *GKSS, Germany*)
09:30 Atlantic hurricanes and climate change: modeling studies (***Thomas Knutson***, *GFDL, USA*)
09:50 Quantitative assessment of wind storms and extreme extra-tropical cyclones under climate change (***Gregor Leckebusch***, *Freie University Berlin, Germany*)

10:10 – 11:00 – **coffee*, special poster session**

Session 4 Methodologies for estimation extremes (Chairperson: ***David Stephenson***)

11:00 Stochastic models for weather extremes (***Anna Panorska***, *University of Nevada, USA*)
11:20 Extreme value theory and single-event attribution (***Richard Smith***, *University of North Carolina, USA*)
11:40 Statistical inference for space-time extremes (***Anthony Davison***, *EPFL, Switzerland*)
12:00 Extreme value analysis and projection in light of the changing climate (***Xiaolan Wang***, *Environment Canada, Canada*)

12:20 – 14:00 – **lunch, posters**

Session 4 continues (Chairperson: ***William Gutowski***)

14:00 Uncertainty in rare event statistics and the difficulties in comparing climate models to observations (***Michael Wehner***, *Lawrence Berkeley National Laboratory, USA*)

14:20 An objective identification technique for regional extreme events (***Fumin Ren***, *Beijing Climate Center, China*)
14:40 Advanced metrics of extreme precipitation events (***Olga Zolina***, *University of Bonn, Germany*)

Session 5 Risk assessment (Chairperson: ***Ivan Kuhnel***)

15:00 Estimation of future changes in extreme climate events for the user and decision-making communities (***Clare Goodess***, *Climatic Research Unit, University of East Anglia, UK*)
15:20 Future risk of global drought from downscaled, bias corrected climate projections (***Eric Wood***, *Princeton University, USA*)

15:40 - 16:10 – coffee*, posters

Session 5 Risk assessment (Chairperson: ***Ivan Kuhnel***)

16:10 Risk Assessment and future sea-level extremes (***John Hunter***, *Antarctic Climate & Ecosystems Cooperative Research Centre, Australia*)
16:30 ***Gero Michel***, *Willis Research Network, UK*

Discussion and introduction to breakout groups (Chairperson and moderator: ***Kevin Trenberth***)

16:50 – 17:00 Introduction of break-out groups (***Olga Zolina, William Gutowski, Ron Stewart***)
17:00 – 18:00 General discussion - 1

Proposed discussion topics:

- What is your view about how natural variability and global climate change intersect in producing extremes?
- What is the relationship among different extremes? This includes how droughts relate to heat waves, snow melt and early runoff relate to temperatures, or more generally how temperatures relate to precipitation and flooding.
- How do we translate or communicate these changing risks to the general public?
- Is there commonality between tropical and extratropical cyclone risk factors and changes?
- What changes in extremes are "global" vs what are regional?
- How do perceptions of extremes depend on time-scale?
- What is considered extreme? How much is it dependent on impact sector, geography, season, etc.?
- What risks are posted by compound extremes (e.g., heavy rains immediately after a drought)?

Wednesday 29 September 2010

Special session: Key-note kick-offs for breakout groups (Chairperson: ***Valery Detemmerman***)

08:30 What data do we require for extremes analysis and what is available? (***Albert Klein-Tank***, *KNM, the Netherlands*)
08:50 Precipitation Extremes in the NARCCAP Simulations (***William Gutowski***, *Iowa State University, USA*)
09:10 Statistical methodologies for exploring and quantifying extreme weather and climate (***David Stephenson***, *University of Exeter, UK*)

09:30 - 13:00 Breakout groups with coffee* served at 10:30

- Data requirements and availability, including data policy (Chair: ***Olga Zolina***, rapporteur: ***Rick Lawford***)
- Representation of extreme events in climate and operational models, including consideration of scaling and spatial scales of extremes (Chair: ***William Gtuowski***, rapporteur: ***Jozef Syktus***)
- Methodologies for estimation of extremes across areas and disciplines (Chair: ***Ron Stewart***, rapporteur: ***David Stephenson***)

13:00 – 14:30 – **lunch, posters**

<u>**Discussion session on break-out groups**</u> (Chairperson and moderator: ***William Gutowski***)

14:30 Report of breakout group "Data requirements and availability, including data policy" (***Rick Lawford, Olga Zolina***)
14:40 Report of breakout group "Representation of extreme events in climate and operational models, including consideration of scaling and spatial scales of extremes" (***Jozef Syktus***, ***William Gutowski***)
14:50 Report of breakout group "Methodologies for estimation of extremes across areas and disciplines" (***David Stephenson***, ***Ron Stewart***)
15:00 Discussion on breakout group reports

15:30 – 16:00 – **coffee*, posters**

<u>**General discussion – 2**</u> (Chairperson and moderator: ***Francis Zwiers***)

16:00 Final discussion, Workshop recommendations
18:00 Workshop ends

*** Coffee breaks sponsored by Willis Research Network**

Poster programme

<u>Session 1</u> Hydrological extremes (precipitation, flooding and river discharge), including compound hydroclimate extremes

1.1 **Ines Camilloni** *Future flood scenarios in the Paraná and Uruguay Rivers*
1.2 **Iracema Cavalcanti** *Monthly and seasonal extreme precipitation over South America – observations and simulations from CPTEC AGCM and HADCM3/HADLEY centre AOGCM*
1.3 **Tereza Cavazos, S. Arriaga-Ramirez and C. Turrent** *Regional trends of extreme daily precipitation indices in Northwest Mexico and the Southwest USA*
1.4 **Johanna Danneberg** *Effects of climate change on hydrological extremes in Thuringia*
1.5 **Guillaume Drapeau** *Extreme discharge values in the Amazon basin: observation and simulations by ORCHIDEE*
1.6 **Moira Doyle** *Extremes of monthly precipitation in La Plata basin*
1.7 **Alaa El-Sadek** *An application to the extreme value theory: two case studies in the Nile basin*
1.8 **Abeer El-Saharty** *Radionuclide concentrations in shallow water sediments off the Nile delta, Egypt*
1.9 **Nobuhiko Endo and Jun Matsumoto** *Tends in precipitation extremes over Southeast Asian*
1.10 **Petra Friederichs** *Spatial modeling of peak wind speed observations*
1.11 **Stephanie Hänsel** *Changes in drought frequency, severity and duration in the 21st century, model region Dresden, REGKLAM project*
1.12 **Koji Ishihara** *Assessment for the 30-year daily precipitation change due to global warming using regional frequency analysis*
1.13 **Doerte Jakob** *Variability in frequency and magnitude of intense rainfall events*
1.14 **Toshiharu Kojiri** *Comparison of extreme water variation in river basin scale due to global warming*
1.15 **Lisako Konoshima** *Changes in extreme rainfall characteristics of various temporal and spatial scales under a global warming climate*
1.16 **Maarit Lockhoff** *How capable are satellite-based products in representing precipitation extremes?*
1.17 **Mong-Ming Lu** *Variations of annual frequency of extreme rainfall events in Taiwan during the period of 1951-2009*
1.18 **Ewa Lupikasza** *Various approaches to calculating extreme precipitation indices for frequency analysis – an example based on Polish station data*
1.19 **Yaoming Ma** *Third Pole Environment (TPE) Programme*

1.20 **Luca Molini, A. Parodi, N. Rebora, F. Siccardi and G.C. Craig** *Predictability and predictive ability of severe rainfall events over Italy*
1.21 **Gustavo Naumann** *Droughts in the River Plata Basin: an analysis of dry spells using daily data*
1.22 **Shadananan Nair** *Climate extremes: Environmental and socio-economic impacts and hurdles in adaptation and preparedness in India*
1.23 **Tan Thanh Nguyen Thi** *An composite observing system for early extreme events warning*
1.24 **Pardeep Pall** *Anthropogenic greenhouse gas contribution to UK autumn flood risk: pilot application of a Probabilistic Event Attribution framework for weather extremes*
1.25 **Christiana Photiadou** *An extended reference precipitation and temperature dataset for the river Rhine*
1.26 **Juan Rivera** *Hydrological response to meteorological drought: a case study in La Plata Basin*
1.27 ***Simone Russo, A.Sterl and S.Speich*** *Global changes of seasonal extremes and mean from precipitation daily climate model data*
1.28 **Mohamed Said** *Climatic change and sea level variations off Alexandria, Egypt*
1.29 **Abdoulaye Sarr** *Modeling and observational study of an extreme off season rain case over Western Sahel*
1.30 **Mxolisi Shongwe** *Projected changes in mean and extreme precipitation in Africa under global warming*
1.31 **Asher Siebert and M. Neil Ward** *Estimating future occurrence statistics of threshold-crossing seasonal rainfall totals: methodology and application to sites in Africa*
1.32 **Brian Soden** *Atmospheric warming and the amplification of precipitation extremes*
1.33 **Jozef Syktus** *Projections of droughts and extremes in Australusing AR4 models 1*
1.34 **Oliver Elison Timm** *Projecting future rainfall extremes for Hawaii in the 21st century*
1.35 **Andrea Toreti** *Extreme precipitation in the Mediterranean region*
1.36 **Yves Tramblay** *Heavy rainfall events in the Languedoc region (France): relation with synoptic patterns and frequency analaysis*
1.37 **Patrick Willems and Meron Terefi Taye** *Statistical precipitation downscaling for small-scale hydrological impact investigations of climate change*
1.38 **Markus Ziese** *New version of GPCC Full Data Reanalysis Product (V.5) available and its application to estimate trends and extremes in monthly precipitation*

Session 2 Extremes in temperature conditions, heat waves and dry spells

2.1 **Sushil Dash** *Changes in the characteristics of temperature over India*
2.2 **Peter Guttorp** *Looking for climate change signal in a long temperature series*
2.3 **Emily Hamilton** *The predictability of daily temperature extremes on a seasonal timescale using dynamical seasonal prediction systems*
2.4 **Andreas Hoy** *Extremes in surface climate parameters and atmospheric circulation patterns in Estonia and eastern Germany*
2.5 **Jan Kysely** *Temperature extremes in climate change simulations estimated by the peaks-over-threshold method with a non-stationary threshold*
2.6 **Madeleine Renom** *Interannual variability of extreme temperature events in South eastern South America after 1976 climate shift*
2.7 **Andrea Toreti** *Heat waves in the eastern Mediterranean area*

Session 3 Extreme tropical and extratropical cyclones and associated wind waves and storm surges

3.1 **Kehinde Ajayi** *Wind speed measurement and Its distribution*
3.2 **Madeleine-Sophie Déroche** *Extreme European windstorms in the ERA-Interim Reanalysis*
3.3 **Jong-Dao Jou and Yung-Ming Chen** *Extreme heavy rainfalls associated with landfall typhoons in the Taiwan Area*
3.4 **Thomas Knutson** *Has there been a long-term increase in Atlantic tropical storms?*
3.5 **Margarida L. R. Liberato** *Extreme extratropical storms in the Euro-Atlantic region and associated impacts*
3.6 **Kathleen McInnes** *Investigation of climate change driven variations in wave climate along the east coast of Australia*

3.7 **Nobuhito Mori** *Statistical modeling of future typhoons under a climate change scenario*
3.8 **Urs Neu** *Intercomparison of mid latitude storm diagnostics (IMILAST) - A project overview*
3.9 **Grigory Nikulin** *Uncertainties in the simulated wind extremes over Europe*
3.10 **Roberto Ranzi** *A hydrometeorological reanalysis of the century 1966 Florence and Venice flood*
3.11 **Hans von Storch Frauke Feser, Matthias Zahn, Monika Barcikowska, Fei Chen and Lan Xia** *Changing statistics of polar lows and typhoons in the past and foreseeable future*
3.12 **Wenqing Tang** *Assessment of Extreme Weather Events from the Synergy of Earth Remote Sensing Satellites*
3.13 **Tomohiro Yasuda** *Projection of extreme wave climate change*

Session 4 Methodologies for estimation extremes

4.1 **Simon Brown** *The prediction of future extreme rainfall and temperatures from a perturbed physics ensemble of regional climate models*
4.2 **Julie Carreau** *Spatial Kernel interpolation for annual rainfall maxima*
4.3 **Cheng-Ta Chen** *Regionalization of future projections on the high-impact weather and climate extremes*
4.4 **Rosemary Eade** *Interannual to decadal predictions of extreme temperature and precipitation from a global climate model*
4.5 **Malaak Kallache** *Non-stationary probabilistic downscaling of extreme precipitation*
4.6 **Shaw Chen Liu** *Changes of precipitation intensity in the tropics in a warming globe*
4.7 **Douglas Maraun** *Atmospheric circulation and precipitation extremes. Observed relationships and regional climate model evaluation*
4.8 **Miloslav Muller** *Area-related definition of extreme floods and weather events*
4.9 **Luci Hidalgo Nunes** *Evaluation of empirical and statistical techniques for identification of precipitation extremes for the coast of the state of Sao Paulo, Brazil*
4.10 **Leonard N. Njau** *Monitoring and prediction of extreme climate events using tropospheric indices*
4.11 **Jan Picek** *Extremes based on regression quantiles*
4.12 **Federico Ariel Robledo** *Intensity of extreme rainfall in south-eastern South America*
4.13 **Sai R.Rao** *Extreme Events over Southern India during Northeast Monsoon Season*
4.14 **Seyni Salack** *Implications of the low frequency dryspell types in intra and inter seasonal rainfall variability of Senegal*
4.15 **Barbara Tencer** *Temperature extremes represented by a Southeastern South American daily gridded data set of observed surface minimum and maximum temperature for 1961-2000*
4.16 **Mai Dang Thi** *Clime extreme events in Central part of Vietnam*
4.17 **Robert Twardosz** *Maximum hourly precipitation depth in Kraków (Poland). A synoptic and probabilistic approach*
4.18 **Duane Waliser** *Development and use of observation-based metrics of tropical variability in GCMs*
4.19 **Christopher White** *Modelling extreme precipitation events and severe wind gusts in a changing climate using Regional Dynamically-Downscaled Climate Projections*
4.20 **Vidyunmala Veldore** *Regional climate change and extremes in temperature and rainfall in observations and IPCC AR4 simulations over Indian region*

Session 5 Risk assessment

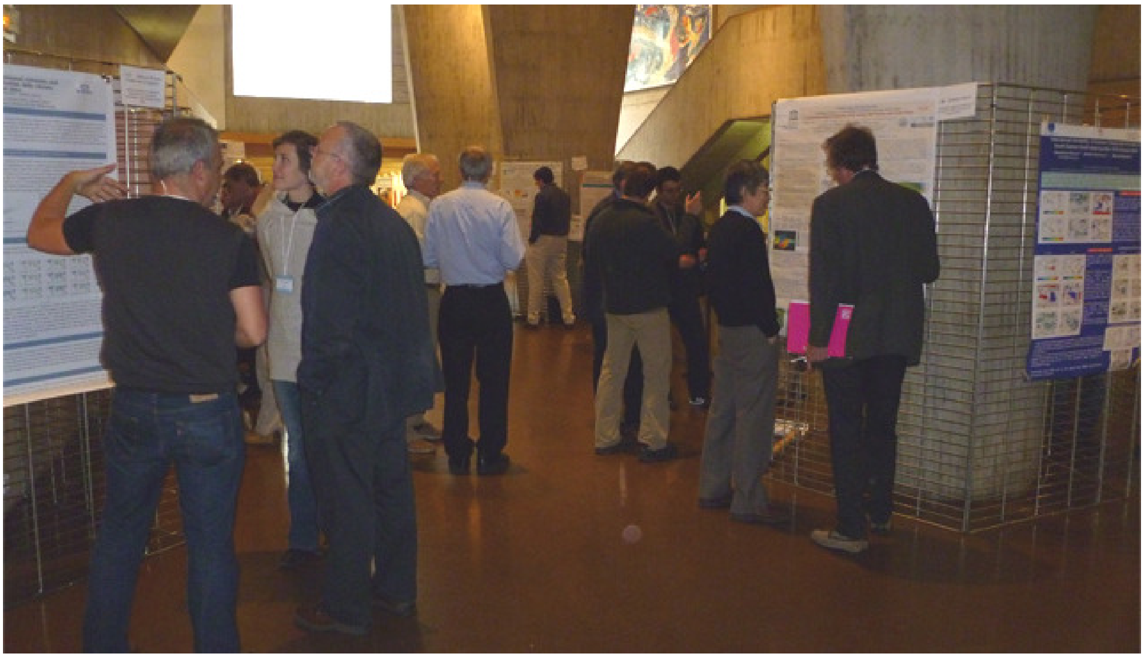
5.1 **Rajeevan Moothal** *Estimation of extreme climate events in developing countries from the socio-economic impact studies: a projected model for the next 25 years for Ethiopia*
5.2 **Alex Ruane** *Climate change impacts on agriculture in Central America and the Southeast US: changes in mean climate and new behavior of climate extremes*
5.3 **Amir Sadoddin** *Agricultural drought management using a Bayesian decision model for rainfed wheat farmlands in east of Golestan Province, Iran*

8.3. Annex 3 – Workshop programme

ASCAT: Advanced Scatterometer
BAMS: Bulletin of the American Meteorological Society
BOG: Break-Out Group
BOG-1: Break-Out Group discussed data requirements and availability, including data policy
BOG-2: Break-Out Group discussed representation of extreme events in climate and operational models, including consideration of scaling and spatial scales of extremes
BOG-3: Break-Out Group discussed methodologies for estimation of extremes across areas and disciplines
CCI: WMO Commission for Climatology
CCSP: Climate Change Science Program
CEOS: Committee on Earth Observation Satellites
ClimDEX: Climate inDices of EXtremes
CLIVAR Climate Variability and Predictability Project (WCRP core project)
CMIP: WCRP Coupled Model Intercomparison Project
ESA: European Space Agency
ECV: Essential Climate Variables Data Access Matrix
ENSO: El Nino-Southern Oscillation
ETCCDI: joint CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices
EVT: Extreme Value Theory
GEO: Group on Earth Observations
GEV: Generalized Extreme Value distribution
GEWEX: Global Energy and Water Cycle Experiment (WCRP core project)
GPD: Generalized Pareto Distribution
IHP: International Hydrology Programme
IMILAST: Intercomparison of MId LAtitude STorm diagnostics
IOC: UNESCO's Intergovernmental Oceanographic Commission
IPCC: Intergovernmental Panel on Climate Change
IPCC WG-I: IPCC Working Group I assesses the physical scientific aspects of the climate system and climate change
IPCC WG-II: IPCC Working Group II assesses the scientific, technical, environmental, economic and social aspects of the vulnerability (sensitivity and adaptability) to climate change
JCOMM: Joint Technical Commission for Oceanography and Marine Meteorology
JSC: WMO/ICSU/IOC Joint Scientific Committee (for WCRP)
NASA: National Aeronautics and Space Administration
NHMS: National Hydro-Meteorological Services
NWP: Numerical Weather Prediction
QuikSCAT: NASA's Quick Scatterometer
SLP: Sea Level Pressure
SST: Sea Surface Temperature
UNESCO: United Nations Education, Scientific and Cultural Organization
WCRP: World Climate Research Programme
WGCM: Working Group on Coupled Modelling
WMO: World Meteorological Organization
WWRP: World Weather Research Programme

Workshop participants at the UNESCO Headquarters

Briefing and discussion session



Workshop poster session