



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

# IPCC Workshop on Changes in Extreme Weather and Climate Events

Beijing, China

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## WORKSHOP REPORT

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## INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

# IPCC Workshop on Changes in Extreme Weather and Climate Events

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# 1 Introduction

The opening ceremonies were chaired by Prof. Ding Yihui, outgoing co-chair of IPCC Working Group I. Talks were given by:

Madame Deng Nan, Vice Minister, Ministry of Science and Technology, China  
Sir John Houghton, outgoing Co-chair of IPCC Working Group I, UK  
Dr Susan Solomon, incoming Co-chair of IPCC Working Group I, USA  
Prof Qin Dahe, incoming Co-chair of IPCC Working Group I, China

The texts delivered by Madame Deng Nan and Prof Qin Dahe are given in Annex A.

Sir John then gave a brief explanation of the role and mode of operation of the IPCC, as participants at this workshop included many who had no previous involvement with IPCC. He highlighted the IPCC Third Assessment Report's conclusions on extremes (see Annex B - Scoping paper), and explained that it is hoped the IPCC Fourth Assessment Report (4AR) will do better in this respect.

He described the main objective of the workshop - that the 4AR should deal better with extremes than did the TAR - in particular, what information might be provided about changes in frequency and intensity of extremes at different locations?

It was explained that on Day 2 of the meeting, a number of breakout groups (BG) would meet, each addressing one of the following types of extreme event:

- BG1 Temperature
- BG2 Precipitation
- BG3 Tropical cyclones
- BG4 Extra-tropical cyclones
- BG5 Small-scale Severe Weather Phenomena

In addition, a sixth breakout group (BG6) met to discuss statistical methods, as this had been identified by the scientific steering committee early on as a cross-cutting issue.

Sir John explained that these breakout groups should identify *what needs to be done*, especially:

- in indices & indicators of extremes,
- in observations,
- in understanding of processes,
- in model simulations & projections,
- in relation to impact studies, and
- in relation to disaster preparedness.

A fuller description of the background to the workshop, and its aims and limitations, is given in the scoping paper, at Annex B. This was prepared with input from the Scientific Steering Committee and the Working Group I and II Bureaux. The workshop continued with a series of presentations giving overviews of the main subject areas to be discussed. The workshop programme, listing all of the speakers, can be found at Annex C, while the abstracts of the presentations given during Day 1 of the workshop are at Annex D. Prior to the workshop, all delegates were sent some background material intended to guide discussions in the breakout groups. This background material was

prepared by the breakout group chairs, and is at Annex E. The list of participants in the workshop is at Annex F. A list of acronyms and abbreviations used in this report can be found at Annex G.

On Day 2, the meeting divided into the first five of the breakout groups as listed above. After a short plenary session in the afternoon, the groups reconvened, and the sixth group, on statistical methods, met in parallel. This arrangement was intended to ensure that those who so wished could attend one of the first five groups, *and* the statistical methods group. Sections 2 to 7 of this report briefly summarise the issues discussed and the conclusions reached by each of these groups. In reaching these conclusions, delegates were continuously aware of the critical factor of the timing of the IPCC 4AR.

During Day 2 of the workshop, it was recognised that delegates would find it useful to meet in Regional Groups, i.e. groups defined by WMO region. These groups were:

- BG7 Region I – Africa
- BG8 Region II – Asia
- BG9 Region III – South America
- BG10 Region IV – Central and North America
- BG11 Region V – Australasia and South Pacific
- BG12 Region VI – Europe

A very specific question was asked to be considered within each of the regional groups, namely, "what types of extremes (if any) in each region are moving from "qualitative" to "semi-quantitative" understanding?" These six groups met on the morning of Day 3 of the workshop to address this question. The conclusions reached by these groups are included in sections 8 to 13 of this report.

Several common concerns emerged from all of the breakout groups. These included

- Data availability (due to the format of archived data, and cost).
- Declining numbers of observing stations.
- Data quality (homogenisation).
- Short duration of datasets; i.e. need to be extended by digitisation and palaeo-data.
- Key role of local scientists in interacting with modellers to understand the successes and failures of models in each region.
- Need for capacity building, i.e. need more trained scientists in some developing countries.
- Need to study "complex climate events" where several component variables combine with severe consequences.
- Consistency of reporting, e.g. of tropical cyclones, needs to be ensured.
- Need for improved communications between WGI and WGII.
- Need for careful choice of statistical methods to study extremes.

An important factor, which the workshop recognised, was the importance of IPCC relationships with national and international research programmes. It was acknowledged that there are already close links between IPCC and international research programmes, such as those associated with the World Climate Research Programme (WCRP), the WMO Commission for Climatology/CLIVAR Working Group on Climate Change Detection, Monitoring and Indices, the WMO Working Group on Tropical Cyclones, and the Global Climate Observing System (GCOS). The importance of these relationships was stressed, and it was recommended that these links be further strengthened.

No attempt was made to standardise reports between subgroups. Each subgroup determined its own procedure and report structure.



## 2 Temperature (BG1)

Chair: Thomas C. Peterson

Rapporteurs: Francis Zwiers, Albert Klein-Tank

### 2.1 Introduction

The WGI objectives for research on extremes preparatory to the Fourth Assessment Report are likely to include:

- (a) document quantitatively the intensity, frequency and duration of a variety of extreme phenomena on a range of space and time scales in the climate of the past century;
- (b) assess whether recent changes in the intensity, frequency and duration of extremes are unusual in the context of instrumental and proxy records;
- (c) assess the role of human activity in these changes;
- (d) project future changes in extremes that may result from the human influence on climate; and
- (e) express those changes in the form of scenarios that can be applied in impact research.

This ambitious set of objectives will require the careful definition of extremes and indices of extremes that are computable from available data, the assessment of extremes in observations and models, innovative approaches that utilize available data resources in the most efficient way, and, most importantly, a concerted effort to provide easy access to high quality observational data to the broad community of researchers.

### 2.2 Utilization of monthly mean data for assessment of extremes

Analyses of short period extremes in the present climate and the detection of evidence of changes in their frequency and intensity generally require high quality high frequency (daily or sub-daily) data sets. The limited availability of such data hampers research on extremes. Monthly mean temperature and precipitation data are exchanged routinely on the GTS and are generally much more readily available than daily temperature and precipitation data. Approximately 1,200-1,400 stations globally report monthly mean minimum and maximum surface air temperatures at present, and it is anticipated that this number will soon increase to approximately 5,000 stations when CLIMAT reports are transmitted by the Regional Basic Climate Network (RBCN). Simple statistical reasoning suggests that a shift in the mean of the daily temperature distribution will result in changes in the likelihood of extreme temperatures in both the warm and cold tails of the distribution. Thus the low frequency variations that are reflected in monthly means should also provide information on variations in the frequency and intensity of extremes. Observational and theoretical research is therefore required to establish the relationships between means and extremes in order to extract information on changes in the intensity and frequency of short duration extremes from the relatively widely available monthly mean data record. Such relationships can be used both to interpret the historical climate record, and if they are based on sound statistical principles, should be helpful in inferring changes in the risk of extremes from projections of change in the mean climate.

Longer duration extremes, such as extended periods of above normal temperatures that result in large sustained demands for water and energy, are also of great interest. Thus it seems appropriate that substantially more study of the extremes of monthly means, including their intensity, frequency and duration, should be undertaken.

### **2.3 Changes in the seasonal cycle**

Changes in the climate resulting from external forcing on the climate system, of either anthropogenic or natural origin, will result in changes in the annual cycle of surface temperature. Such changes can be detected by monitoring changes in the amplitude of the annual cycle and in the dates of the annual maximum and annual minimum temperatures. As above, slow variation in the climatological mean, as indicated by changes in the amplitude and shape of the annual cycle, will impact the frequency and intensity of extremes on both daily and monthly time scales. Additionally, changes in the annual cycle could affect the onset and withdrawal of monsoons, which in turn could affect the timing of intense monsoon precipitation variability, resulting in damages to agriculture and infrastructure beyond that to which monsoon affected societies are presently adapted. The TAR presented information on changes in the seasonal cycle from the impacts point of view. For example, changes in the timing of phenological events, freezing and thawing of lakes and rivers, and changes in the duration of the growing season. Additional studies are likely to be available for the 4AR. Thus it would seem appropriate to focus additional research on observed and model-simulated changes in the annual cycle, its links with changes in monsoon circulations and relationships with local climate variability and extremes.

### **2.4 The influence of circulation variations on extremes**

There is a growing appreciation that variations in circulation, including large-scale circulations such as the North Atlantic Oscillation, Pacific Decadal Oscillation, blocking situations, and the Southern Oscillation, affect the frequency, intensity and duration of temperature and hydrologic extremes on a number of time and spatial scales. Many palaeo records have been shown to be sensitive to these circulation features and can, in principle, be used to extend the records of circulation variation back in time, particularly for the “recent” 1,000-2,000 years. While these records will be far from perfect, they will nonetheless be very useful for putting recent trends and variations in circulation related extremes in the context of a longer history of natural variations unaffected by anthropogenic forcing.

### **2.5 Complex extreme events**

Extreme events are often the consequence of a combination of factors that may not individually be extreme in and of themselves. Such events can occur on a range of scales in space and time. For example, drought is a relatively large scale, long duration phenomenon that is often the combined result of above normal temperature and below normal precipitation over an extended period of time. Complex extreme events are often preconditioned by a pre-existing, non-extreme condition, such as the flooding that may result when there is precipitation on frozen ground. In addition, non-climatic factors often play a role in complex extreme events, such as air quality extremes that result from a combination of high temperatures, high emissions of smog precursors, and a stagnant circulation.

Complex extreme events often have very high socio-economic and environmental impacts. The definition of these events and indices that can be used to monitor their frequency and intensity over time are likely to be regionally specific. Complex extreme events that have high impacts in, for example, Bangladesh, are likely to be quite different from those that have high impact in Europe or North America. Research is required to clearly define the events of greatest concern, to develop indices for monitoring these events using available data, and to investigate variation in their frequency and intensity. Research is also required to assess whether such indices can be derived from climate model data, whether indices calculated from model data have realistic variability, and if so, how the behavior of these indices changes in transient climate change simulations.

## 2.6 Scales of interest

As already noted, extremes occur on a range of space and time scales. High impact events may be of short duration, but could also extend over several days, several months, or perhaps even years. Similarly, there is great variation in the spatial extent of high impact extremes. Assessment of temperature related extremes should therefore be made on a range of space and time scales using methods and observations that are appropriate to the combination of scales that are of interest. These will be quite different for phenomena such as drought with large spatial and temporal scope than for short duration, location specific extremes.

Palaeo data is likely to play an important role in the assessment of changes in the variation and intensity of extremes, particularly on the larger space and time scales. Such data are becoming increasingly available, and can help to set rare events in the 20<sup>th</sup> century into a longer historical context. More effort is required to analyze the available palaeo records and to assess the information they contain on extremes.

Climate models may also be able to provide a perspective on the natural variability of extremes and may offer opportunities to evaluate the mechanisms that operate to produce extremes. Several groups have performed long coupled control simulations (from 1,000 to as long as 10,000 years in length) that could be analyzed for interannual, decadal and centennial variations in simulated extremes.

Increasingly regional climate models (RCMs) are being used as dynamical downscaling tools to provide impacts researchers with climate change information on smaller scales than can be represented in global coupled models. However, most RCM simulations have been of limited duration, and thus this modelling methodology, with a few exceptions, has yet to contribute greatly to the assessment of possible changes in extremes. Ensembles of moderately long runs (e.g., 30 years) would help to alleviate this situation.

## 2.7 Coordination of regional analyses of extremes

There is broad interest in extremes at the regional level, and agencies in many developed and developing countries will be conducting analyses of extremes using their own data holdings. It is necessary to coordinate these studies so that they make a useful contribution to a global body of knowledge on extremes, and to ensure that they receive the constructive peer review and dissemination necessary so that this knowledge can contribute to the Fourth Assessment Report. The joint Commission on Climatology / CLIVAR Expert Team on Climate Change Detection, Monitoring and Indices is a body that is well positioned to assist in this process.

Continuing regional initiatives such as the series of regional climate change workshops, sponsored by the WGCCD, AIACC project and the APN, in developing countries would also help in this process. Such workshops provide a means for capacity building and allow for a two-way exchange of knowledge and information between developing and developed world scientists on methodology, climate variations and extremes.

## 2.8 Interactions with other IPCC Working Groups

It is anticipated that WGII will have some specific requirements for extremes scenarios, to assess, for example, the impact of surface air temperature extremes on agriculture or sea-surface

temperature extremes on coral bleaching or algae blooms. To meet these needs it will be necessary to provide guidance on the incorporation of extreme climate events in scenario construction. In addition, dialogue with WGII scientists will be necessary to devise appropriate impacts-relevant indices of extremes that are computable from available observational data and global or regional climate model outputs. While it is recognized that many of these indices will be regionally specific, it is highly desirable that they be as generic and broadly applicable as possible. It is also recognized that active dialogues are required between WGI, WGII, and WGIII on the interpretation and application of global and regional climate model outputs, particularly as they relate to extremes.

## 2.9 General data considerations

It goes without saying that above all else, high quality data is THE indispensable resource that is required to quantitatively assess changes in extremes, and to assess whether human activity is changing the intensity, frequency and duration of extremes.

The importance of activities such as quality control (that does not throw out real extremes), careful homogenization to account for instrument and site changes, and data rescue to digitize records that are still in paper form, cannot be overstated. These efforts should be continued and expanded in the years leading up to the Fourth Assessment Report to ensure the availability of the most complete possible in situ instrumental record for the assessment of extremes.

There is a clear need for additional research on homogenization techniques for daily data, and for the broad application of such techniques to create high quality temperature data sets for the assessment of extremes. There is also a requirement for the assessment of gridded data products with respect to extremes, and for additional research on the development of these products, including methodological research, and the assessments of the underlying station density required to produce reliable gridded products with good representations of extremes.

The current decline in the coverage of in situ networks is of grave concern. High density networks are required to ensure confidence in extremes that might otherwise be removed by quality control procedures (i.e., does the extreme also occur at neighboring stations) and high frequency (at least daily) data are required to ensure that extremes can be detected. Data continuity is very important to ensure that changes in the frequency, intensity and duration of extremes can be detected. Therefore it is important that climate stations consistently adhere to GCOS guidelines.

Equally crucial is the free and open exchange of data. Indeed, the more that data are used and scrutinized, the more valuable they become, both for the originator and all subsequent users. The best way to increase the availability of new, quantitative results on extremes for the Fourth Assessment Report is to ensure that the global research community, in both the developed and developing world, has broad access to long-term, high quality, high frequency temperature and precipitation data. Therefore, a fully implemented GCOS Surface Network would be of great benefit. Also, an additional approach that could improve data availability would be to create a repository like the IPCC Data Distribution Centre (DDC) for research quality temperature and precipitation data sets contributed by national agencies for use in the 4AR. The stature that is derived from having a data set meeting pre-defined quality standards acceptable for posting on a DDC like site might be one of the carrots that would help to motivate countries to contribute their data.

## 2.10 Summary of recommendations

- Observational and theoretical research is required to establish the relationships between means and extremes.
- Substantially more study of the extremes of monthly means, including their intensity, frequency and duration, should be undertaken.
- Additional research should be undertaken on observed and simulated changes in the annual cycle, its links with changes in monsoon circulations and relationships with local climate variability and extremes.
- Palaeo circulation records for the “recent” 1,000-2,000 years, while far from perfect, should be developed and used to put recent trends and variations in circulation related extremes in the context of a longer history of natural variations unaffected by anthropogenic forcing.
- Research is required to clearly define the complex multi-parameter events of greatest concern, to develop indices for monitoring these events using available data, and to investigate variation in their frequency and intensity.
- Research is required to assess whether multi-parameter indices can be derived from climate model data, whether indices calculated from model data have realistic variability, and if so, how the behaviour of these indices changes in transient climate change simulations.
- More effort is required to analyze the available palaeo records and to assess the information they contain on extremes.
- Long coupled control simulation (from 1,000 to as long as 10,000 years in length) should be analyzed for interannual, decadal and centennial variations in simulated extremes.
- Ensembles of moderately long (e.g., 30 years) Regional Climate Model runs should be performed in order to provide information on smaller scales than can be represented in global coupled models.
- Analyses of extremes in developed and developing countries should be coordinated, disseminated and peer-reviewed so that this knowledge can contribute to the Fourth Assessment Report.
- Regional initiatives such as the series of regional climate change workshops, sponsored by the WGCCD, AIACC project and the APN, in developing countries should be continued.
- Dialogue with WGII scientists should be fostered to devise appropriate impacts-relevant indices of extremes that are computable from available observational data and global or regional climate model outputs.
- Active co-operation between WGI and WGII is needed to facilitate the incorporation of extreme climate events in scenario construction. Also, active dialogues are required between WGI, WGII, and WGIII on the interpretation and application of global and regional climate model outputs, particularly as they relate to extremes.

- Efforts to digitize records should continue and be expanded in the years leading up to the Fourth Assessment Report to ensure the availability of the most complete possible in situ instrumental record for the assessment of extremes.
- There is a clear need for additional research on homogenization techniques for daily data, and for the broad application of such techniques to create high quality temperature data sets for the assessment of extremes.
- Additional research should be conducted into the development of gridded products to ensure good representation of extremes.
- High-density observational networks should be maintained to ensure confidence in extremes that might otherwise be removed by quality control procedures (i.e., does the extreme also occur at neighboring stations?).
- Observing stations should adhere to the GCOS guidelines for climate stations.
- Broad access to long-term, high quality, high frequency (daily or sub-daily) temperature and precipitation data should be provided through improved data exchange.
- The GCOS Surface Network should be fully implemented.
- A repository like the IPCC DDC for research quality temperature and precipitation data sets, contributed by national agencies for use in the Fourth Assessment Report, should be created.

## • Precipitation (BG2)

Chair: David Easterling  
Rapporteurs: Lisa Alexander, Kumar Kolli

### 3.1 Introduction

The aim of the breakout group was to determine gaps in the IPCC Third Assessment Report (TAR) in relation to precipitation extremes, and to make recommendations for future research and analysis for the Fourth Assessment Report (4AR) in 2007. It was obvious from our discussions that the complex statistical properties of precipitation were appreciated and therefore understanding its distribution is a key element for understanding its 'extremes'. It was also clear that the space-time variation of precipitation extremes (both wet and dry) is useful for many areas of climate research from understanding observed extreme climate variations to model comparisons, detection and attribution studies, impacts and future projections of changes in such events. Therefore, given the wide ranging research interests within the breakout group session, we have tried to summarise the main points.

### 3.2 Gaps in IPCC TAR

It was clear that there was not enough information about precipitation extremes in the TAR due to:

1. Lack/inaccessibility of high temporal resolution/long records.  
Especially with regard to daily and sub-daily records. Often where there was high temporal resolution data it had a short period of record.
2. Incomplete and declining spatial coverage.  
Most of the results that were presented in the TAR were from developed countries. Data from other regions were unavailable due to a number of reasons including lack of digital records, international access and country contacts. Station numbers are declining in many parts of the world.
3. Lack of consistent analyses - definition of extremes may be inappropriate for different climates.  
Although there was an effort to produce a coordinated approach to the analysis of precipitation extremes in TAR, there were time limitations on what was possible. Indicators were chosen that were not always relevant in all parts of the world. Also a lack of indices relevant to impacts analyses.
4. "Best" statistical methods not used.  
The distribution of precipitation extremes is not likely to be globally unique and was not well documented. Statistics were used without a fundamental understanding of the distributions.
5. Lack of gridded high resolution data.  
Gridded data are required for looking at spatial variability patterns, detection and attribution studies, and model/data comparisons. The high resolution is needed on both temporal and large spatial scales.
6. Few studies of large-scale extremes.

For instance, there are few studies of large-scale droughts on seasonal to longer time scales e.g. large scale drying of Africa. A number of studies do exist around the world but were not properly synthesized in the report.

7. Lack of understanding of mechanisms related to extremes.

For instance, there is inadequate understanding of how extremes are related to large-scale circulation.

8. TAR conclusions subject to limited confidence.

The above points have led to limited confidence not only in the variability and distribution of observed precipitation extremes but also in any future scenarios of change. There was some confidence in these results in the TAR, but they were based on spatially and temporally incomplete data.

Given the gaps in the TAR the following questions need to be addressed:

- What is the frequency distribution of precipitation and how is it changing?
- As we cannot adequately define existing extremes in many parts of the world due to lack/inaccessibility of data - how do we determine changes?

### 3.3 Recommendations

We recommend that the above gaps could be bridged by putting the following recommendations in place. The recommendations are split into three main groups.

#### 3.3.1 Research recommendations

##### *Data*

- More analyses of the statistical properties of precipitation and extreme values of precipitation. These should be consistent with the recommendations of the statistical methods breakout group.
- Revisit reanalysis methods. Reanalysis data should be as homogeneous as possible, including in-situ data where available. Spatial availability of data changes through time.
- Need to better define seasonal and interannual variability of hydrological cycle both in observations and models.
- Identify extremes important to impacts assessment.
- Gridding methods: model/data comparisons. Need to develop an approach that is widely accepted and maintains spatial physical relationships.
- Development of statistical methods for precipitation analysis less sensitive to missing data and better methods for estimating missing data.
- Quantification, confidence limits on extreme value estimations.



### *Modelling*

- Higher resolution in both time and space.
- Regional evaluation of GCMs and RCMs by scientists from respective regions with direct interaction with modellers. Including workshops for regional dissemination of results both in regions and at modelling centers.
- Verification of precipitation simulations with high quality observations consistent with data needs.
- More experiments are needed on model sensitivity to changes in both natural and anthropogenic forcings and decadal variability.
- Improve understanding of Atmospheric/Ocean oscillations (e.g. ENSO, monsoons, NAO, Indian Ocean).
- Review whether precipitation extremes from simulations of future climate are credible. Are results from models realistic given observations and our physical understanding?
- Parametrization techniques in models need to be re-evaluated to ensure that extremes are well simulated.
- Identify methods to use and/or combine GCM with RCMs/statistical-dynamical downscaling to address issues requiring high resolution and large numbers of ensembles.
- Model intercomparisons and quantification of uncertainties.

### *3.3.2 Specific precipitation recommendations*

- Define appropriate global and regional indices, (e.g. frequency, place, seasonality, intensity).
- Fixed locations and numbers in network of stations needed for homogeneous data.
- Need research on drought indices appropriate for different climates.
- River basin approach to the analysis of very heavy precipitation in relation to stream flow/flooding.
- More analysis needed on snow/solid precipitation extremes.  
This should include time distribution of snow, model resolution issues and snow vs. rain changes.

### *3.3.3 General recommendations*

- Provide consistent methods/software/hardware to encourage in-country analyses as needed. User friendly software (e.g. improved CLICOM) should include user input. Define consistent methods and supply guidelines to provide consistent global picture of extremes. A small working group could define a simple common methodology and hence suggestions for optimal density of stations and length of record. Explore ways to transfer ideas to researchers in countries.

- Encourage collection of data in global data centers where possible.
- Request that all participants assess data holdings in relation to GCOS, etc. and provide results to a pre-defined central clearinghouse (web site).  
What data is available that is not in GCOS on National Meteorological Services and other websites etc. and what mechanism is available for this to be uploaded/linked and accessed. Consolidate information on what data and model simulations are currently available and provide information on capacity building assistance.
- Improved interaction between modelling groups and users/modellers in developing countries. This is to help improve modelling capabilities in general by involving regional participants in the modelling process.
- More interactions within and between *in situ* and satellite climate communities.  
Considering the importance of satellite precipitation observations for climate research, input should be supplied on the scientific needs of the general climate community at the beginning stages of a satellite project, in order that satellites adequately address the needs of climate research.
- Need more palaeo-type records/analyses.  
These should include all available proxy indicators of extremes during the pre-instrumental period e.g. PAGES/CLIVAR intersect.
- As much metadata as possible should be retained with the data.  
This is critical for quality and homogeneity issues.
- Need to show value in maintaining long-term stations in countries through in-country analyses.
- Encourage WMO regional training centers to impart training in data methods and modelling in developing countries.  
This would enhance institutional infrastructure and technical assistance in developing countries.
- Organize one chapter on extremes in 4AR covering observational analysis, model comparisons and future scenarios.  
Sections could be arranged geographically or by climate type as well as by individual extremes.

## 4 Tropical cyclones (BG3)

Chair: T. Knutson  
Rapporteurs: K. McGuffie, A. Noda

### 4.1 Introduction

The Tropical Cyclones (TC) breakout session focused its discussions on identifying gaps in existing knowledge on TCs and climate change and on recommending research needed to fill those gaps. The topic areas covered included TC observations, frequency, intensity, precipitation, tracks, location, storm surge, land-use effects, and impacts. The following summarises the group's conclusions with regard to these issues.

### 4.2 Gaps in existing knowledge

#### *Frequency of tropical cyclones*

Frequency of tropical cyclones (TC) has been used as an indicator of climate change in general circulation models. The group identified a number of key gaps in our existing knowledge.

- Method of counting TCs in global models
- Unrealistic present-day climatology
- Inconsistent sign of change in enhanced CO<sub>2</sub> environment
- Mechanisms of TC genesis in large-scale models

Some climate models show an increase and some a decrease in TC frequency as a result of climate change. The changes are not uniform across TC basins. Considering all published TC frequency studies there is no consensus among the models even on the sign of the change in global frequencies. In the case of higher resolution global models (T106), there appears to be a decrease or no change in the frequency of TCs. There is a lack of consistency in the techniques used for counting TCs in climate models and results may be sensitive to the method used. Unrealistic features of TC climatologies of GCM control simulations need to be addressed. It is important to understand the mechanisms of TC genesis in climate models (particularly regional differences) and the mechanisms responsible for changes in simulated frequency in climate change experiments. Currently our understanding of the genesis process is poor both for models and the real atmosphere, in particular the impact of vertical wind shear.

#### *Observations of Tropical Cyclones*

- Short record length (~30 years for satellite observations).
- Quality of observations is uneven across different basins.
- Inconsistency between satellite-derived estimates and surface observations of intensity.
- Inconsistency between basins in the definition of TCs.
- Palaeo records of cyclone activity are sparse.

Observed records of tropical cyclone activity are short and there are many problems with homogeneity. Consistent satellite data are only available since the 1960s and regions where longer-term statistics are available show large interdecadal variability in cyclone activity. Palaeo-reconstruction of tropical cyclone activity has a number of problems but has potential relevance to the climate change issue. Inhomogeneities in the historical records of environmental variables, such

as atmospheric temperature, limit the extent to which we can assess historical activity via maximum potential intensity (MPI) analyses.

### *Tropical Cyclone Intensity*

- Eye-eyewall interactions and secondary eyewall cycles
- Boundary layer exchange
- Ocean circulation changes
- Feedback of TCs on the climate system?
- Regional uncertainties
- Interaction of TCs with ocean eddies
- Interaction with vertical wind shear in the environment

The group noted the importance of mesoscale vorticity mixing processes occurring between eye and eyewall. Also important is the influence of eyewall cycles and boundary layer processes, especially uncertainties in momentum and energy transfer coefficients at high wind speed (e.g. sea spray). The extent to which TCs feed back on the climate system is also poorly understood. We need to understand the nature of tropical cyclone response to changes in the upper ocean (e.g. ocean eddy fields and mixed layer depth which are currently poorly understood) in climate change scenarios. At regional levels, there are gaps in our knowledge of future changes in ENSO and other large-scale climate features, which may affect regional TC frequency and/or intensity. Other sources of regional uncertainties include lapse rates, the interaction of TCs with vertical wind shear, and general regional climate scenario uncertainties. The impact of vertical wind shear in the environment in particular is not well understood and is probably poorly implemented in climate models.

### *Precipitation associated with tropical cyclones*

The group identified this as a crosscutting issue. There are few studies that address the precipitation aspects of TCs in climate models and our knowledge of how well models simulate the observed tropical cyclone precipitation is limited. Observations of tropical cyclone precipitation are also limited. Realism of physics parameterizations, particularly convective and precipitation schemes in the new generation of high-resolution models will be important.

### *Impacts*

The group was asked to consider factors important for climate change impact studies. These factors include rainfall rates, wind speed distribution and likelihood of mesoscale features affecting gusts (e.g. tornadoes, boundary layer turbulence, boundary layer rolls and mesovortices) and factors affecting storm surge. Return period of strong systems is poorly known.

### *Land use effects*

Land use changes could plausibly have an effect on tropical cyclone intensity near landfall through changes in surface properties. These changes may have influenced the historical record of cyclones and may influence cyclones in the future. We have very little information on the nature of any such effects.

### *Storm-surge*

Tropical cyclone induced storm surge assessment requires the integration of many modelling components. Knowledge of drag coefficient, cyclone track, cyclone wind field, cyclone translation, coastal bathymetry, tides, river flow and coastal geometry all have an influence on the storm surge. There are significant gaps in our knowledge of many of these factors in a climate change context.

### *Tracks and location*

Currently there is little information on how tracks and locations of tropical cyclones will change in future climate scenarios. The ability of current global models to simulate TC tracks has not been adequately assessed. Current confidence in modelled TC tracks is insufficient to justify assessment of future changes in tracks with current models.

## **4.3 Research needed to fill those gaps**

### *Tropical Cyclone Frequency*

- There is a need for a common methodology for counting tropical cyclones in large-scale climate models. At a minimum, investigators should demonstrate the robustness of conclusions to any arbitrary components of TC counting techniques.
- High resolution studies (e.g. regional climate models, timeslices) could provide means to study the mechanisms of genesis in climate models.
- It is recommended to test model interannual and interdecadal variability of TCs when forced by historical SSTs. Similarly, empirical genesis predictors (such as Gray's) need to be assessed in the context of interannual to interdecadal variability.
- Examine carefully the genesis mechanisms that are operating in large-scale models and compare with hypotheses and observations in different basins.

### *Observation of tropical cyclones*

- There is a need to achieve more uniform coverage of TC characteristics across basins via deployment of buoys, other in situ measurements and by remote sensing techniques.
- Encourage use of palaeo-techniques for reconstruction of the long-term tropical cyclone record and other methodologies for historical times.
- Encourage the reconstruction of homogeneous environmental data that are important for TC retrospective studies.
- It is recommended the WMO Working Group on Tropical Cyclones address the issue of inhomogeneous thresholds for tropical cyclones among basins.

### *Tropical Cyclone Intensity*

- There is a need to narrow the uncertainties identified above associated with TC intensity.
- There is a need for improved model physics of energy exchange in boundary layer.
- The group recommended the continued use of very high-resolution models to understand intensity issues such as eye-eyewall interactions and eyewall cycles.
- The group recommended that CMIP and AMIP simulations be evaluated for their value to the TC-climate change issue (e.g. using MPI analyses).
- A larger number of models and/or careful single model studies should be used to clarify model dependency issues.
- There is a need for greater understanding of the role of vertical wind shear and oceanic eddies in the development or suppression of TCs.

### *Precipitation associated with tropical cyclones*

- Modellers should study TC precipitation and test robustness of results.
- Need to evaluate the physics schemes associated with prediction of cyclone precipitation field.

- Need to evaluate the applicability of current satellite-based precipitation retrieval techniques for deriving the tropical cyclone precipitation, including improved spatial coverage and knowledge of precipitation through the lifetime of the storm.
- TC precipitation should be extracted from the regional precipitation records.
- NWP community should provide evaluations of simulations of present-day TC precipitation.

### *Tracks and Location*

- Need to evaluate carefully the skill of models to simulate tracks in present climate.
- High resolution modelling studies may provide improved simulations of cyclone tracks.

### *Land use change*

- Estimate the likely magnitude of land use effects at TC landfall using historical records and models.

### *Impacts*

- Recommend that WGII provide a realistic wish list of tropical cyclone parameters that can be provided by the TC community.

### *Storm surge*

- Need for integrated assessment experiments involving tidal processes, sea-level rise, river discharge and TC parameters.
- There is a need to couple storm surge models with tropical cyclone models.
- Possibly there is a need to revisit definition of storm surge to include superimposed waves.

## 5 Extra-tropical cyclones (BG4)

Chair: Jean Palutikof

Rapporteurs: Hans von Storch, Catherine Senior

### 5.1 Introduction

The aims of the group were to identify gaps in observations and modelling of extra-tropical cyclones (ETCs) in the TAR and to make recommendations as to what should be done prior to and as part of the Fourth Assessment Report (4AR). The group started by identifying what we felt were the main reasons for studying ETCs: the processes driving them, the weather elements arising from them, and the impacts associated with these weather elements.

#### *Processes*

We need to understand the key processes causing ETCs and to explore the behaviour in those processes that underlies variability and changes in ETCs. In order to detect changes in ETCs that lie outside of the range of natural variability we need to quantify the signal-to-noise ratio. For attribution, we need to accurately model the response to changes in anthropogenic and natural effects. A key impact of changes in ETCs will be through so-called combined events (where extremes in two or more variables occur together, e.g., heavy rainfall and high winds). We will need to identify the key processes underlying these.

#### *Weather elements*

The most important physical characteristics of ETCs in terms of their impacts are,

- Wind
- Precipitation and runoff
- Combined events (e.g. wind storms and heavy rainfall)
- Storm surges and waves

#### *Impacts*

The most significant resulting impacts of these weather elements are potentially:

- Injuries and deaths
- Damage to the built environment and infrastructure
- Damage to the natural environment and agriculture

We identified five key headings under which to discuss major gaps in the TAR, and to make recommendations as to how these gaps might be filled. These are Observations and palaeo-tempestology, Methodologies, Modelling, Processes and Impacts.

### 5.2 Observations & palaeo-tempestology

The major issues in this area are:

1. Inhomogeneity. The lack of long, homogeneous observational records of relevant variables such as sea-level pressure (SLP), wind extremes and wave heights
2. Length of record. For identifying trends in data, it is necessary to have as long records as possible. Ideally, wherever possible these should be at least 100 years.
3. Important regional effects are poorly observed. Examples of these are; Mediterranean storms, polar lows, and Australian east-coast lows.

4. Southern Hemisphere. There is a major lack of observational data covering ETCs in the Southern Hemisphere.

We recommend;

1. Where observational data exist in non-digitised form, all efforts should be made to digitise such data and to make it available to the community.
2. Exploitation of documentary and palaeo-material.
3. Identification and exploitation of local reliable homogenized data sets such as surface air pressure or proxy data such as sea level and tidal records and microseismic data.
4. Identification of the relationships between observations of extremes and large-scale patterns in the atmospheric circulation.

### 5.3 Methodologies

The major issues in this area are;

1. A variety of different methods have been used to describe extremes and to track cyclones, so that inter-comparison is difficult.
2. Sometimes, statistical methods are used beyond a reasonable range, e.g. calculation of extremes with very long return periods and the extrapolation of trends.
3. Re-analyses are affected by inhomogeneities related to changing data densities and types.
4. The observational record is of insufficient length to reliably determine the statistics of very rare events. Also, when only one realisation of a climate change simulation is available, the determination of the changing statistics of rare events is in most cases impossible.
5. Often changes in extremes are only characterized by changes in the rate of occurrence, while other informative measures are rarely applied.

We recommend;

1. Establishing a meta-database of statistical techniques for analysis of extremes and identification and tracking methodologies for ETCs.
2. Running different storm tracking algorithms over the same re-analysis/model outputs for the intercomparison of both the tracking methodologies and the model trends.
3. Avoidance of excessive extrapolation of return values.
4. Cautious interpretation of trends for predictive purposes.
5. Studying the sensitivity of the re-analysis data to changing data density and type, with respect to extremes.
6. The use of long runs and ensembles of runs to identify present-day (and past/future) statistics of very extreme extremes.
7. In addition to changes in the rate of occurrence, use of other appropriate statistical measures such as the mean excess, variance of excess and measures of clustering.

### 5.4 Modelling

The main purpose of global models is to do process studies and to provide global scenarios, whereas regional models are most useful for impact analyses.

The major issues in this area are;

1. Model data are often not saved or made available on sufficiently high temporal resolution for studies of extremes and their impact on climate sensitive systems.
2. Model intercomparison is difficult because of the use of different storm identification and tracking algorithms and statistical analysis techniques.



3. Little effort has been made so far in comparing the occurrence of extremes in different model simulations.

We recommend;

1. Model output should be made available at appropriate scales (temporal and spatial) for impact analysis (regional studies; hourly data) and process analysis (global studies, 12-hourly to daily data).
2. Intercomparisons of models are needed, notably in looking at regions sensitive to key processes and impacts.
3. There is a need to explore whether differences in storm track algorithms/analysis techniques are responsible for apparent differences in model projections.

## 5.5 Processes

The major issues in this area are;

1. Any projected changes in the climate models should be interpretable in terms of their physical causation.
2. Models may not agree in their present-day simulations and projections of the future behaviour of extreme events.
3. Processes driving the occurrence of ETCs in nature, and their feedbacks with the climate system, are not well understood.
4. It is not well understood how the statistics of extremes relate to measures of low-frequency variability.

We recommend;

1. In order to understand better the differences between model simulations of extremes, model intercomparison is required. There should be a focussed IPCC exercise in model intercomparison targeted at ETCs and extreme ETC processes, variability and impacts. Modelling groups should be encouraged to generate model output from past, present-day and future model scenarios for this purpose.
2. Efforts should be made to relate the physical processes in the models to those underlying observed extreme events.
3. Analysis of long (multi-century/millennia) model runs is required to better understand the influence of low-frequency variation on the occurrence of ETCs.
4. Analysis of how the formation of extreme cyclones (and associated extreme wind speeds and heavy rainfall) is related to the ambient environment.

There are two approaches to looking at processes in the real-world and model atmospheres that lead to climate change. One approach emphasises the dynamical approach, and the other emphasizes the needs of impact analysts. The purpose of the first, in the context of the IPCC process, is to establish the reliability of the models, and to quantify (and reduce) uncertainty in the model projections. The purpose of the second is to provide relevant information to end-users. We recognize the need to take a balanced position.

## 5.6 Impacts

A major issue in the preparation of the TAR was the less than optimal communication between WGI and WGII. It is recommended that we make special efforts to improve this communication.

WGI believes that it can provide WGII with physical characterizations of ETCs at the present day and in the future, such as:

- Intensity, frequency, duration and clustering of ETCs
- Position of ETCs – latitudinal; landfalling cyclones
- Issues of scale and uncertainty
- Local climatology of wind; patterns of extreme wind speeds in relation to storm tracks

WGI would welcome the specification of the additional needs of the impacts community from WGII. Our understanding of some relevant issues related to ETCs are;

- Will cyclone-related precipitation change?
- Will storm surges and large-scale winds change?
- Will waves and ocean climate change?
- Will combined events (e.g. extreme coastal rain and storm surges, drifting snow, dust, ice storms) change?
- Will gust factors change?
- What would be the impacts of a reduction in ETC numbers e.g., frosts in polar outbreaks of cold air, blocking anticyclones, air pollution, heat waves?

To improve the communication between the two working groups, we recommend;

1. Joint integrating case studies (e.g., special reports, chapters in 4AR) on e.g. marine weather, loss potentials, hydrology.
2. The formation of transdisciplinary working groups to facilitate transfer of knowledge.
3. Communication to the impacts community of what can't be achieved yet.
4. The assessment and characterization of extremes as provided by WGI should better meet the demands and needs of climate impact research as discussed in WGII.

## 6 Small-scale Severe Weather Phenomena (SCSWP) (BG5)

Chair: Rudolph Brazdil  
Rapporteurs: Gaston Demaree, Harold Brooks

### 6.1 IPCC discussion to date

Small-scale severe weather phenomena (SCSWP) are weather events that are sparse in space and time and may have important impacts on societies, such as loss of life and property damage. Their temporal scales range from minutes to a few days at any location and typically cover spatial scales from hundreds of meters to hundreds of kilometers. The Technical Summary of the Working Group I Report of the TAR describes SCSWP with the following:

“Recent analyses of changes in severe local weather (e.g., tornadoes, thunderstorm days, and hail) in a few selected regions do not provide compelling evidence to suggest long-term changes. In general, trends in severe weather events are notoriously difficult to detect because of their relatively rare occurrence and large spatial variability.”

### 6.2 Addressing the problem for the Fourth Assessment Report

In spite of the difficulty in detecting changes, these events are critical to societies around the world, resulting in half of the total economic costs of extreme weather events globally. Individual events can be catastrophic to substantial numbers of people while the cumulative effects of relatively large numbers of less-intense events can lead to major impacts. In addition, the combination of different events at the same location in a short period of time can have complex results.

Small yet extreme weather-related events tend to be excluded from many statistical records, and receive considerably less attention in climate modelling and impacts analysis. In addition, data-gathering conventions can result in omission of certain types of events, e.g., weather-related vehicle losses or business interruptions from electric power disruptions. In some cases, definitions set high minimum thresholds for inclusion so many events go unrecorded (Cohen et al. 2001: IPCC/TAR/WGII/Ch15). In one important example, land subsidence losses from two droughts during the 1990s in France resulted in losses of 2.5 billion US\$--a cost on a par with large hurricanes. Subsidence losses have been observed to triple during drought years in the UK, with a cost approaching \$1 billion annually. Similarly, permafrost melt is also expected to result in damage to human infrastructure.

In some cases, a large fraction of economic losses are concentrated in a small number of events, causing major disruption in the risk management community when they do occur. For example, tornadoes in the U.S. result in a mean annual loss of \$400 million, but individual events causing \$1 billion in damage occur approximately once per decade. The intermittency of very large damage amounts makes providing sufficient capital for insurance purposes difficult for the private sector.

A fundamental limitation in addressing SCSWP is our lack of knowledge of the distribution of events in space and time. Reliable observational records are limited, and events are rare at any particular location. As a result, we are unable at present to say much about SCSWP in relation to global climate. Analyses of fluctuations and possible changes in SCSWP are limited to very few countries and have had very narrow audiences, usually from the country for which the analysis was done.

In addition to our lack of knowledge about the occurrence and magnitude of events, successful efforts to model them on the scale at which environmental observations are typically taken have also been limited. In some cases, this is a result of our lack of understanding of the physical processes involved or physically accurate parametrization schemes. In other cases, it's a result of our lack of systematic and reliable observations of the events.

Because of the rarity of SCSWP, comprehensive climatologies are available in only some regions of the world for some phenomena, e.g., tornado data in the U.S. In order to estimate global-scale characteristics of extreme events, it is necessary to determine the relationship between these characteristics and their large-scale environments. This approach will enable global climatologies of extreme events to be inferred, and enable the probability of occurrence to be modelled through diagnostic downscaling.

In order to address these shortcomings, we propose the following recommendations for dealing with SCSWP. Most of the recommendations hold true for all SCSWP. We have included some additional phenomena-specific recommendations for selected events (thunderstorms, tornadoes, hail, fog), and phenomena that become important because of a combination of meteorological and other factors (dust storms and smoke, wildfires, soil subsidence/permafrost melt). These pose unique challenges that, given more information, could provide great benefits to societies around the world. The list of phenomena is not exhaustive but merely illustrative. The phenomena of most concern will vary from location to location and with the particular vulnerabilities of different societies.

## 6.3 General recommendations

### *Observations*

1. Strongly recommend funding for retrieval of historical data (instrumental and documentary) and metadata on occurrence and, when possible, magnitude and impacts of SCSWP. After quality control and homogenization of data, make it available for analysis and research. This will require capacity building for developing countries.
2. National Meteorological Services need to maintain long-term observational records including consistent, traditional observations at key stations, and cross-calibration needs to be done between traditional observations, present methods, and future methods.

### *Modelling*

1. Determine appropriate parameters and relationship of large-scale observed and modelled parameters to SCSWP and how those parameters have changed and/or will change in time and space.
2. Exploit synergies between operational and research modelling of SCSWP and climate change studies.
3. Promote analysis of large-scale forcing (e.g., ENSO) on temporal and spatial variability of SCSWP (also related to observations).

### *Impacts*

1. Assess relationship between impacts and meteorological events because even with no change in meteorological conditions, societal vulnerability changes in space and time.

## 6.4 Phenomena-specific recommendations

1. Thunderstorms
  - Explore ways to carry out long-term global monitoring of lightning.
  - Research how satellites may provide globally consistent analyses of detection and estimation of intensity of thunderstorms.
2. Tornadoes
  - Work towards internationally accepted, meteorological classification that serves impacts community.
3. Hail
  - Research how radar and satellites may provide globally consistent detection and estimation of intensity of hail.
4. Dust storms and smoke
  - Supplement routine visibility and humidity observations with particle concentrations from air quality networks.
5. Fog
  - Improved boundary layer modelling.
6. Fire weather
  - Recommend global fire monitoring from satellite.
  - Recommend linkage of fire models and climate models.
7. Soil subsidence/permafrost melt
  - Improve historical database, correlating loss data with weather conditions.
  - Develop relevant output parameters for impact analysis, e.g., soil moisture and building stock characteristics.



## 7 Statistical methods for extreme weather and climate events (BG6)

Chair: David Stephenson  
Rapporteurs: Rick Katz and Tahl Kestin

### 7.1 Introduction

The breakout group on statistical methods explored how statistical methods for extremes might be more extensively utilized in research on changes in extreme weather and climate events. The aim is to enable the 4AR to better quantify changes in extremes, including associated uncertainties, than was possible in the TAR.

### 7.2 Gaps

1. Many of the descriptive indices fail to summarise ALL the important attributes of extremes: rate (frequency), intensity, volatility and clustering (both temporal and spatial).
2. Several studies have modelled extremes poorly by fitting to the WHOLE distribution (e.g. gamma distribution fits to all rainfall values fails to capture heavy tail behaviour of rainfall extremes).
3. Very few studies have used extreme value theory to model, detect, or project trends in extremes of weather and climate (e.g. only one cited in TAR!). This tail modelling approach has many potential advantages over existing descriptive approaches to extremes.
4. Many unanswered questions on how do we compare extremes in model simulations to observed extremes e.g. How to interpret the values at a grid point?
5. Are current statistical and numerical downscaling techniques appropriate for extremes? (the disaggregation problem)

### 7.3 Research Needs

1. Develop homogenization techniques that are appropriate for dealing with extremes. For example, how do we separate genuine extremes from outliers? How do we identify jumps in indices of extremes?
2. Implement and apply methodology for dealing with multivariate dependent extremes – such as sea level rise and storm surge, ice storms, and droughts. Multivariate extremes are important because extreme situations can occur when two not so extreme events occur simultaneously.
3. Explore spatial pooling (regional analysis) as a way for increasing sample sizes. Can also use this technique with high-resolution models by combining several grid points.
4. Develop optimal methods for extracting information about extremes from ensembles of weather/climate simulation.
5. Develop methods for treating spatio-temporal dependence of extremes (e.g. clustering in time and in space caused by complex events such as storms).
6. Extend extreme value methods for application to nonstandard cases such as extreme crossing rates of thresholds that can lead to large impacts (e.g. freeze-thaw damage).

7. Develop methods for designing data observation networks necessary for extreme event monitoring.

#### 7.4 Recommendations

1. Quantify uncertainty on all stated quantities by providing standard errors (interval estimates) e.g. estimates of trends should also give error on slope  $1.0 \pm 0.2^\circ\text{C}/\text{yr}$ .
2. Describe attributes of extremes more completely by making indices of rate (frequency), intensity, volatility, and clustering.
3. Analyse and quantify variations and trends in variance (e.g. daily values) in addition to means.
4. Attempt to explain changes in descriptive indices in terms of changes in the mean and variance of observed and model simulated data. Determine whether this is sufficient or whether there is also a structural change in the tail shape.
5. Summarise the extreme behaviour (both temporal and spatial) completely by doing proper modelling of tails using extreme value theory and other methods. This approach is also useful for summarizing a lot of information (at all different thresholds) in a small number of parameters. Instead of tailoring indices especially for different uses (e.g. in impact studies), this provides precise summary information for impact modelers.
6. Apply estimation techniques that make better use of the observed and model simulated data (e.g. peaks over threshold rather than annual maxima).
7. Take advantage of knowledge already gained in other disciplines (e.g. hydrology, engineering, seismology, and risk assessment industries such as nuclear waste disposal).
8. Where possible attempt to interpret statistics in terms of physical processes e.g. dynamical/physical mechanisms that led to extreme behaviour.
9. Identify mechanisms by which IPCC could fill identified gaps in statistical methods available to researchers for dealing with trends in weather and climate extremes. Possible suggestions could include: a focused training workshop on methodology, a repository for statistical software, dissemination of indices software (e.g. via NCDC START's Climdex mechanism), a good practice guidance report. A prototype method site has already recently been established at [www.met.rdg.ac.uk/cag](http://www.met.rdg.ac.uk/cag).



## 8 WMO Region I – Africa (BG7)

Chairs: Joshua Wairoto, Andrew Oniarah

The group considered:

- Gaps in the Third Assessment Report (TAR)
- Actions required
- Recommendations

Its findings were as follows:

### Gaps in the Third Assessment Report (TAR)

#### *GCM models*

It was noted that the General Climate Models (GCMs) and Regional Climate Models (RCMs) models used in the climate modelling and projections chapters did not capture the climate scenarios and trends in many areas of Africa. This was mainly due to:

- i) failure to use valid data for some of the areas (e.g. for equatorial areas of East Africa, rainfall data for Long Rains Season (March, April and May), and Short Rains Season (October, November and December) should have been used instead of rainfall data for June, July, August and September, and December, January and February periods, which are dry months in the area.
- ii) failure to incorporate the role of aerosols in climate studies in Africa.

#### *Data availability*

Researchers found it difficult to access data from Africa due to:

- i) format of archived data,
- ii) cost recovery charges
- iii) decreasing number of data observation stations.

#### *Capacity building*

The Region lacked sufficient capacity for meteorological data:

- i) observations,
- ii) communications,
- iii) data processing,
- iv) sufficient well trained scientists in the various disciplines of climate change.

#### *Research*

There was not sufficient research done on:

- i) Rainfall variability,
- ii) Aerosols,
- iii) Extreme phenomena,
- iv) Role of oceans, inland water, lakes and river basins in climate modelling.

## **Actions required**

Re-run the GCM/RCM with valid data sets.

Incorporate information on aerosols.

Improve on data availability as follows:

- i) Improve on data archiving facilities,
- ii) Increase number of observation stations
- iii) Use data generated by other methods (e.g. remote sensing, radar etc.)

Cost recovery charges for data required by Research Institutions should be waived.

## **Capacity building**

Employ partnerships with users to address

- i) Maintenance of observation stations and expansion of the stations network
- ii) Communications
- iii) Data processing
- iv) Increasing the number of African professionals in climate modelling

## **Research**

Enhance research on:

- i) Rainfall variability
- ii) Aerosols
- iii) Extreme weather and climate phenomena
- iv) Role of oceans, inland water, lakes and river basins in the African Region

## **Recommendations**

The Fourth Assessment Report (4AR) of the IPCC should ensure that:

- i) Valid data is used in re-running the GCM models for climate modelling and projection
- ii) Role of aerosols is incorporated in the re-run experiments

Countries and IPCC should encourage partnership between national meteorological services and users of meteorological data. The users are both those in the countries and the International Community.

IPCC should ensure that studies are undertaken to establish the role of oceans, inland water lakes and river basins in the climate of Africa.

IPCC should participate in the strengthening of Regional Centres (Drought Monitoring Centre, Nairobi and Harare), and the African Centre for Meteorological Development (ACMAD) to help address the above noted problems.

## 9 WMO Region II – Asia (BG8)

Chairs: Yihui Ding, Kansri Boonpragob

Major focus: Semi-quantitative study of extreme events. The group discussed the following issues:

- Review of the current knowledge on extreme events, and identify the gaps in TAR: data, observation, definition, new finding, model and projection.
- Major extreme events in Asia.
- Recommendations: How to study extreme events on semi-quantitative basis.

To achieve the objective of transition from empirical study toward semi-quantitative study of extremes, three pre-conditions are required:

- Sufficiently long data sets with quality control and good resolution (temporal and spatial).
- Reasonable definition of extremes and appropriate methodology.
- Quantitative illustration. Data availability is very fundamental and crucial. An investigation is as follows:

Daily data available for extreme studies in various Asian countries

Country	Daily data elements	No. of Stations	Periods
China	T, R	~700	1951-2000
Japan	T, R	10-50 ~200 840 (automated stations)	~100 years ~20 years 1974-today
Tajikistan	T, R	~72	1950-today
Iran	T, R	~300	1961-today
India	T, R	~200	1880-2000
Nepal	T, R	~65	1965-today
Uzbekistan	T, R, $T_{max}$ , $T_{min}$	~72	~5 <sub>st</sub> -1900; ~30 <sub>st</sub> -1927; ~50 <sub>st</sub> -1950
Bangladesh	T, R	~40	1948-today
Thailand	T, R	~70	1950-today

- Each country has made extreme studies using their national data sets, mainly temperature and rainfall.
- Length of data sets is not sufficiently long to cover decadal variability very well. Palaeo-data need to be added.
- Data quality is satisfactory for extreme studies, but improvements need to be done in the future, including elimination of urban biases, inhomogeneities etc.
- Some areas are faced with a decline in the number of stations, a potential impact in the study of extremes.

### Major extreme events

- Extra-tropical cyclones, cold waves/heat waves, length of growing season, cold injury, monsoon (winter and summer), heavy rainfall (Meiyu, Baiu, Changma), flood/drought, dust storms, snow melting and avalanche, mountainous disasters, storm surges and other extremes.

## **Modelling work**

- Earth simulator: 20km resolution; performing for 3 years. Input to IPCC 4AR in the area of extremes (Japan).
- CGCM: China, Korea, Japan and other countries. Input to IPCC 4AR by 2005.
- Regional climate model: Many countries use nested models within CGCM to study specific extremes in their countries and regions.

## **Recommendations**

1. Inter-comparison of modelling results on major extreme events in Asia (Earth Simulator, CGCM, RCM).
2. Capacity building, different level from the developed countries.
3. Data and software exchange and transfer to enhance cooperation with other regions.
4. Workshop and training with special emphasis on Asia.

## 10 WMO Region III – South America (BG9)

Chair: Luis Mata

The aims of the group were to identify topics related to extreme events as they have been typified in this workshop. A number of issues in relation to temperature (higher maximum and minimum temperatures, more hot days, heat waves and frost), precipitation (rainfall, flood and droughts) and mid-latitude storms have been recognised from the semi-quantitative and qualitative point of view. The table below gives details of the issue in every case.

<b>Type of extreme events</b>	<b>(qualitative)</b>	<b>(semi-quantitative)</b>
<b>Temperature:</b> -- (higher maximum temperatures, more hot days, and heat waves) -- (minimum temperatures, fewer cold days, cold days)	Forecast of frost occurrence in Colombia.	Glaciers melting in tropics and Mid-latitude. (rate increase) Higher maximum temperature and lower minimum temperature in Argentina (1959-1998). Increase in the numbers of hot days and heat waves in Argentina and Brazil. Studies of probability of frost occurrence in Colombia, Argentina and Southern Brazil, for impacts purposes. Regional modelling and downscaling of temperature and precipitation for Argentina using the MM5 model.
<b>Precipitation</b> --(more intense precipitation events) --intensified droughts and floods (associated with El Niño)	Increase of spatial variability of rainfall in Venezuela in the last twenty years. Intensification of floods in Peru and Ecuador. Anomalies of rainfall in Colombia  Increase of the frequency of mudflow in Northwest Argentina	Intensification of floods in La Plata River basin during the last 30 years. Decrease of number of droughts in Argentina. Anomalies of rainfall in Colombia Studies of drought and floods in Chile. Rainfall and runoff anomalies in the Caroni basin (Venezuela). Rainfall anomalies in Venezuela.
<b>Mid-latitude storms</b> --(increased intensity of mid latitude storms)		Trends and variability analysis of cyclones in the Southern Hemisphere based in reanalysis. Evaluation of anticyclones.
<b>Tropical Cyclones</b>	-	-
<b>Small-scale Severe Extreme Events</b>	Hailstorm increase in Central and West Argentina.	



## 11 WMO Region IV – Central and North America (BG10)

Chair: John Stone

Not surprisingly, for a region that stretches from the Equator to the North Pole, the range of extreme events is large - from hurricanes to droughts. These extreme events impact a number of economic sectors such as water quantity, agriculture and infrastructure as well as environmental systems such as coral reefs.

The state of knowledge suggests that there is considerable room for improvement in understanding of past extremes as well as projected changes. It is not always clear that there has been any increase in frequency and intensity of some extreme events. An example of this is droughts on the Great Plains and Prairies and hurricanes in the Atlantic basin. In addition, there has been little coherent analysis of precipitation deficits in the Caribbean and Central American area.

Although there has been some improvement in our understanding of the meteorological conditions that precondition some extreme events, there are still significant problems in model development. This is particularly true in small-scale events such as severe thunderstorms. Thus, we may not be able to make more confident statements in the 4AR.

There was considerable interest in “complex climate events” such as ice storms, repeated precipitation events, sea level rise and storm surges, and heat indices. In these events none of the component variables may in themselves be extreme but in combination the impacts can be severe. For example, heat indices are expected to increase faster than temperature.





## 12 WMO Region V – Australasia and South Pacific (BG11)

Chair: Michael Manton

### Current state of data and regional research relevant to extreme weather

#### *Background*

The climate of the region is dominated by the El Niño – Southern Oscillation (ENSO) phenomenon, and this leads to significant interannual variability in the frequency of many extreme weather types, such as tropical cyclones, monsoons, floods, droughts, sea-surface temperature, and fire weather. Moreover the analysis of the interdecadal variability in ENSO and related climate phenomena has highlighted limitations in the quality and length of the climate record throughout the region.

Countries of the Asia Pacific region have collaborated through workshops sponsored by the Asia Pacific Network for Global Change Research (APN) and System for Analysis Research and Training (START) to carry out consistent analyses of climate extremes across the region. The indicators are based on daily temperature and rainfall data, and the project is described at <http://www.bom.gov.au/bmrc/csr/apn>.

This report considers the current state of our understanding of regional extreme weather, based on analysis of climate data, and of the priorities for future modelling studies on extreme weather across the region. Extreme events are classified as short-term, with durations up to some hours, or persistent, with durations up to some days.

#### *Short-term events*

The reporting of short-term events across the region is considerably affected by variations in the population density. The low population density of much of Australia and the South Pacific means that some events will probably never be directly observed. Moreover there have been few analyses of the existing data, and this means that there is uncertainty about the quality and quantity of the data, in addition to uncertainties in the climatologies of short-term extreme weather events.

The types of short-term extremes that affect the region include hailstorms, thunderstorms, tornadoes, dust storms, and frost. There has been some work on the climatologies of some extreme events, such as tornadoes and frost in Australia.

#### *Persistent events*

Because of their longer duration, there has been some analysis of several types of persistent extreme events across the region. Tropical cyclones (TCs) occur over much of the region, and they often have storm surges associated with them. Over the last few years there have been studies to characterise the trends in TCs. It is noted that there are some issues of data digitisation and availability in the South Pacific. Moreover, it is not clear that there is complete consistency in the reporting of TCs across the region and the world, and this impairs attempts to generalise results.

The analysis of storm surges is limited by the relatively short duration of sea-level data in the region. Studies of sea-level data could assist in the understanding of trends in severe storms in the Pacific region.

Other persistent events in the region are associated with monsoon surges. Some long-term but sparse data sets have been used for climatological studies, but high-resolution modelling is seen as the future means for achieving the required spatial coverage for comprehensive analysis of the monsoon system.

There have been some climatological analyses of extra-tropical cyclones and Australian east coast lows. Fire weather and the associated wild fires and smoke are significant extreme events in many parts of the region. Smoke is often associated with severe drought in the Indonesian archipelago, and further studies (especially based on satellite data) should improve understanding of its characteristics.

Droughts related to ENSO are common across the region. In the South West Pacific, drought can occur at both extremes in ENSO (El Niño and La Niña). Daily rainfall data support analyses across the region, but issues of data digitisation and availability remain.

Based on daily climate data, there have been some studies of heat waves in Australia.

There are sizable interannual variations in sea-surface temperature (SST), which can lead to coral bleaching and other impacts on marine ecology. Broad-scale studies of these phenomena are supported by historical SST data and palaeodata from corals.

### **Priorities for future modelling of extremes**

Because of the rare occurrence of many extreme events in the population centres across the region, traditional climate data are unlikely ever to be adequate to support comprehensive analyses of extreme weather in the region. On the other hand, current modelling (generally for numerical weather prediction purposes) has demonstrated the capability to diagnose the probability of occurrence of short-term extreme events. Thus the development of statistical downscaling methods to diagnose the occurrence of extreme events in models is seen to be very important for simulation and projection studies on short-term extreme events in the region.

The influence of ENSO and associated decadal variability on the climate of the region means that modelling the future climatologies of most extreme phenomena in the region will be limited by the capability of models to represent ENSO. The characteristics of droughts will be especially important aspects of such modelling studies.

The modelling of intraseasonal fluctuations, such as monsoon surges, is also important for the region. Other persistent extremes that should be modelled include storms and tropical cyclones (both tracks and intensities). These studies would be combined with estimates of sea-level rise to simulate the characteristics of storm surges.

## 13 WMO Region VI – Europe (BG12)

Chair: Albert Klein Tank

The breakout group considered the question: what type(s) of extremes (if any) are moving from “qualitative” understanding in IPCC TAR to more “quantitative” understanding in IPCC 4AR? The discussion focused on both our confidence in observed changes (observations) and our confidence in projected changes (modelling).

### Observations

Improved understanding is expected from observed changes in extremes of temperature, precipitation, wind and other variables due to concentrated Europe-wide, regional and national efforts to assemble and analyse (sub)daily instrumental data and historical documentary evidence.

### Modelling

Because of the large variety of projects funded by the European Commission, national institutions and other agencies, progress in quantifying changing climate statistics and impacts is expected. The intrinsic uncertainties may be better quantified when cascading information through a chain of global models, regional climate models and specific impact models. The relative uncertainty is expected to be larger for precipitation and wind than for temperature extremes, but the improvement may be larger for wind and precipitation.



## 14 Acknowledgements

This IPCC workshop on “Changes in Extreme Weather and Climate Events” was held at the kind invitation of the Government of China. The workshop was hosted by the China Meteorological Association. Thanks are also due to the Government of Venezuela, who offered to host the workshop; circumstances in the spring of 2002 meant that this offer could not be accepted.

This report was prepared by the chairs and rapporteurs of the breakout groups together with the IPCC Working Group I Technical Support Unit.

The workshop was organised by the IPCC Working Group I Technical Support Unit. The staff of the Technical Support Unit would like to thank all of the following:

- the staff of the China Meteorological Association, for their superb local organisation,
- the members of the scientific steering committee, who provided plentiful advice on the scope, structure and planning of the workshop,
- the outgoing Working Group I and II Bureaux, who provided advice in the early stages of planning the workshop,
- the outgoing and incoming Working Group I co-chairs and the incoming Working Group I Bureaux members, who chaired some of the plenary sessions,
- the speakers, who set the scene for the subsequent break-out group discussions,
- the chairs and rapporteurs of each of the breakout groups, who ensured the groups run smoothly,

and all others who generously contributed their time and effort to the planning and implementation of the workshop.



## **Annex A: Speeches given at the opening ceremony**

**Madame Deng Nan**  
**Vice Minister**  
**Ministry of Science and Technology, China**

Distinguished Guests,  
Ladies and Gentlemen,

First of all, please allow me, on behalf of the Ministry of Science and Technology, to express our warm welcome to you all for participating in the IPCC Workshop on Changes in Extreme Weather and Climate Events.

The extreme weather and climate events have a great impact on national economy and people's daily life. Therefore, these events go against people's well being as well as national interests. Human societies and natural ecological systems are vulnerable to these extreme events. This has been proved by the economic losses, miseries and casualties as result of such disasters induced by droughts, flooding, and avalanche. Although there are still some uncertainties, the frequency and intensity of these extreme events in the 21st century are most likely to increase due to the climate change and climate variations. Consequently, it is predicted, as has gone global warning, their impacts as well as their severity tend to further increase. China is one of the countries that have been hit by extreme weather and climate events, especially by droughts, low and high temperature, tropical cyclones, thunderstorms and dust storms.

The Chinese climate community has made an outstanding contribution in addressing these issues in past decades, due to the great efforts exerted by all Chinese scientists. The climate research is one of the fields, in which the Chinese scientific and technological communities are most directly involved with the international research communities. The Ministry of Science and Technology has always given a high priority to the climate research, and my ministry will continue to do so in the future. In the 10<sup>th</sup> 5-year-plan period, the climate research has been listed as one of the important projects. Moreover, arrangements have been made at various stages in the national plan. In next 10 years, the major targets in the research of climate prediction theories and techniques in China will focus on furthering our understanding the physical, chemical processes, etc., that determine the climate predictability, improving the climate prediction skills and capability, tracking the proactive issues confronted by the world climate research community and organizing associated research activities in accordance with the national needs and interests. To better carry out these researches, we need to work hand-in-hand with all scientists of the world.

I am convinced, this workshop will contribute to better understanding and increasing the knowledge on climate change and to the preparation for the next IPCC assessment report.

Finally, I wish the workshop a great success, and a pleasant stay in Beijing. Thank you!

**Dahe Qin**  
**IPCC WGI Co-chair**  
**China Meteorological Administration**

Distinguished Guests,  
Dear participants,  
Ladies and Gentlemen,

I am very pleased to attend the IPCC Workshop on Exchanges in Extreme Weather and Climate Events. On behalf of the China Meteorological Administration, I am now extending our most warm welcome to all participants.

It is well known to all, extreme weather and climate event is one of most severe natural disasters. Human societies seem to be so vulnerable to such extreme events. The theme of the WMO World Meteorological Day this year was reducing vulnerability to weather and climate extremes. By selecting this theme, WMO appeals all countries in the world to take necessary measures aimed at mitigating the impacts of extreme weather and climate events.

In order to reduce the threat of the extreme events, WMO and other international agencies have done enormous amount work in monitoring and forecasting such events. Moreover, all countries in the world have been making great efforts to improve their monitoring, forecasting and warning systems. These systems are one of the most effective methods in preparing for and mitigating the impacts of weather and climate extremes.

China is one of the countries suffering from extreme weather and climate events, especially drought, heavy rain, low temperature injuries, hot weather, typhoon, extra-tropical storms, thunderstorms and sand/dust storms, etc. Each year, the economic loss and human casualties are quite noticeable. In summer of 1998, the prolonged heavy rainfall caused a loss of 180 billion Yuan RMB (equivalent to about 21.7 billion US dollars). Some research outcome indicates that along with the enhancement of global warming, the frequency and intensification of the extreme events tend to be increasing. For an example, the Northern China suffered from continuous drought in 4 consecutive years since 1997. Therefore, the Chinese government attaches great importance to the research, monitoring and forecasting of the extreme weather and climate events. CMA has created a drought/flood monitoring and early warning system, a dust storm monitoring and forecasting system and a meteorological and geological disaster monitoring, forecasting and warning system. Some encouraging results have been achieved in the research on these extreme events, including the study of the impacts of El Niño on the precipitation in China. To further promote the research on climate change, including extreme weather and climate events, and to strengthen the international cooperation in this area. China plans to hold the International Symposium on Climate Change in Beijing from 31 March to 3 April 2003, organized by the National Committee on Climate. I wish to take this opportunity to invite the experts from all countries to participate in the symposium.

It should be noted that although all countries have made great effective efforts in reducing the vulnerability to weather and climate extremes. The situation we are now faced with is not quite optimistic. We are still confronting with many challenges to reduce weather and climate-induced disasters. In this process, IPCC has played and will continue to play an important role. I believe, this workshop will make an useful contribution to better understanding and knowledge of climate changes. This workshop is also a very important contribution of WGI of IPCC, and also very much help to prepare the IPCC Fourth Assessment Report in the future.



It was my honour to be elected co-chair of the IPCC Working Group I at the 19th Session of IPCC Plenary Meeting. To fulfill my responsibility, I shall work actively and closely with another Co-chair Dr. Susan Solomon. We shall make the joint extensive efforts in preparing for the IPCC Fourth Assessment Report in the WGI. Susan and I have had a discussion about the future works during the past days. We are going to think about the structure of the new scoping outline of the assessment report. Efforts will be made with the main aim at achieving new findings in the next assessment report, among them extreme weather and climate events will be one of the priorities. We are also think about the new team, in which the high-level lead authors will be invited and more outstanding scientists including young scientists will be chosen to participate in it, so as to ensure the scientific high-quality and authority of the report. We hope more scientists from the developing world will be encouraged to participate in and make more contributions to the process. Necessary conditions will be created to enable their participation. We discussed a lot, and both believe that the success of the Fourth Assessment Report very much depends on the close collaboration and active participation of all involved scientists. Anyway, I have the confidence and responsibility to fulfill the task.

In conclusion, I wish the workshop a complete success, and may you enjoy your stay in Beijing.

Thank you!



## Annex B: Scoping paper

### IPCC Workshop on Changes in Extreme Weather and Climate Events 11-13 June 2002, Beijing, China

#### Background

Changes in severe weather due to climate change will have particular impacts on society and the natural environment. Hence the importance of understanding the mechanisms of extreme weather events and, if possible, projecting future changes. The impacts of climate change will be particularly felt through changes in extreme events because they will stress or exceed our present day adaptations to climate variability.

For possible changes in extreme weather events due to increasing CO<sub>2</sub>, the most robust conclusions of the IPCC WGI Third Assessment Report (TAR) are: (a) an increased probability of extreme warm days and decreased probability of extreme cold days, (b) an increased chance of drought for mid-continental areas during summer, (c) more intense precipitation events over many areas, and (d) an increase in tropical cyclone peak wind intensities. In addition, the TAR SPM states “Even with little or no change in El Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño events in many different regions.”

The TAR also concluded that the analysis of extreme events faces two major challenges:

- Data: Lack of adequate data
- Scales: Small temporal and spatial scales of the events and mismatch of scales resolved by models and that of validating data

And finally, the TAR also identified some specific areas that needed development in order to study changes in severe weather due to climate change:

- Improvement of datasets for severe weather monitoring
- Establishment of common indices and indicators of extreme weather and climate
- Development of a systematic approach regarding analysis of extremes in simulated climate
- Agreement on consistent methodologies
- Improvement of the access to high frequency (daily) model data
- Reduction of spatial resolution in climate models – use of Regional Climate Models
- Improvement of the simulation of tropical cyclones
- Development of the understanding of extremes associated with the land surface (flood and droughts)
- Detection and projection of small-scale phenomena such as thunderstorms, tornadoes, hail and lightning.

#### Aim

To assess the state of the science in detection and attribution of changes in extreme weather and climate events and in projecting future changes in the occurrence of extreme events due to human influence.

#### Issues

- Definition of extremes (starting with that used in the TAR)
- Have we observed an increase in severe weather events and can we establish common indices and indicators of extreme weather and climate events in order to detect them in the future?
- Are observational data available and suitable for requirements?
- How well do we understand the processes leading to extreme events, and what developments in modelling or in process studies need to be pursued to improve the representation and projection of extremes?
- How well do the models simulate severe weather events and can we aim for a consistent methodology for analysing these extremes?
- How confident are we in the model projections of severe weather, and can we quantify the uncertainties?
- What can climate modellers learn from experience gained with weather prediction models?
- Exactly what model projections are needed for impacts purposes, i.e. which types of extreme, and where?
- How can projected changes in extreme events be most usefully characterised for infrastructure planning, design and related applications?
- To what extent will forecasting of severe events become possible?
- What are the main uncertainties and future needs in the study of severe weather events from both the observations and the modelling perspectives?

These questions will be addressed under the following headings taking into account observed and projected changes:

**A. Temperature**

Maximum and minimum, length of hot or cold spells, heat index.

**B. Precipitation**

Precipitation intensity and frequency (droughts and wet spells) (large scale and small scale, seasonal and sub-seasonal timescale), availability of soil moisture

**C. Tropical and Extra-tropical Cyclones**

Tropical cyclones (indices/diagnostics include e.g. intensity, track, frequency, location, max wind speed, precipitation, size, storm surge at land fall, maximum potential intensity, some measure of damage potential)

Extra-tropical cyclones, stormtracks (indices/diagnostics include e.g. intensity, frequency, SLP gradients, winds, water levels, wave height)

**D. Thunderstorms and other small-scale severe weather phenomena (SCSWP)**

Thunderstorms and tornadoes and related phenomena such as hail, lightning, wind, dust, water spouts, downpours, cloudbursts, fog, ice storms and blizzards.

**Participation**

WGI community plus a few key WGII scientists to provide the crossover between the science of severe weather events and the impacts of such events.

**Limitations of the Workshop**

The workshop will deal with extreme events mainly from the WGI perspective (i.e. assessing the observations and modelling needs but not assessing the impacts of severe weather events). Nevertheless, inputs from some WGII participants will be required in order to specify the type of variables and scales that the impact community needs to analyse the impacts of extreme weather.

**Programme outline**

Day 1: Plenary session with overview lectures on “Why is it difficult to detect and project extremes?” and “Which extremes are most important from the impact perspective?”

Presentations on workshop themes A-D (two or three lectures covering each theme).

Day 2: Breakout into groups to discuss workshop themes A-D in detail. Summary reports for each session to be circulated at the end of the day.

Day 3: Plenary session for discussion and update of summary reports that will be presented by chairpersons of breakout groups.

**Deliverables**

- Assessment in the form of a Workshop Report of present-day knowledge on changes in severe weather due to climate change.
- Recommendations for the IPCC Fourth Assessment Report (4AR): What are the areas where efforts should be focussed and what should we aim to develop in time for the 4AR?

The Workshop Report could be distributed to UNFCCC bodies, WMO/CCI/CLIVAR Expert Team on Climate Change Detection, Monitoring and Indices, START group on Monitoring Extreme Climatic Events (START-MECE), WCP (CLIPS) and IGBP (PAGES), among others.

**Scientific Steering Committee**

	<b>Observation</b>	<b>Models</b>	<b>Processes</b>	<b>Impact</b>
<b>Temperature</b>	T Peterson (USA)	F Zwiers (Canada)	G Meehl (USA) Qing Cun Zeng (China) D Stephenson (UK)	L Mearns (USA)
<b>Precipitation</b>	T Karl (USA) B Garanganga (Zimbabwe) R Kolli (India)	A Henderson-Sellers (Australia) L R Pericchi (Puerto Rico)		T Carter (Finland)
<b>Tropical and Extra-tropical Cyclones</b>	N Nicholls (Australia) (Tropical) M Manton (Australia) P Jones (UK) (Extra-tropical)	T Knutson (USA) (Tropical) C Senior (UK) (Extra-tropical)		L Mata (Venezuela)
<b>Small-scale severe weather phenomena</b>	R Brazdil (Czech Republic)	C Price (Israel)		

Organisers: L Bravo (Venezuela), M Noguer and C Johnson (IPCC WGI TSU)

## Annex C: Workshop programme

Tuesday, June 11 - 2002	
09:00	Opening remarks, Workshop objectives <i>Ding Yihui (outgoing IPCC WGI Co-chair), Deng Nan (Vice Minister, Ministry of Science &amp; Technology), Qin Dahe (Administrator of CMA, incoming IPCC WGI Co-chair), Sir John Houghton (outgoing IPCC WGI Co-chair)</i>
Session 1: Setting the Scene: The issues to be addressed <i>Chair: Dahe Qin, IPCC WGI Co-chair</i>	
09:30	Methods for estimating and attributing climate change in extreme events <i>David Stephenson, University of Reading, UK</i>
09:50	Model projections and types of extremes needs for impacts studies <i>Luis Jose Mata, ZEFc (Germany), Venezuela</i>
10:10	Dust storm and its possible relationship to climate change in East Asia <i>Ding Yihui, CMA, China</i>
10:30	Storm surges and flood defense: impacts at the interference of hydrological and coastal regimes <i>Pieter Jacobs, RIZA, The Netherlands</i>
10:50 – 11:10	Coffee/tea
Session 2: Global trends in temperature and precipitation <i>Chair: Kansri Boonpragob, IPCC WGI Vice-chair</i>	
11:10	Global/European analysis of extremes – recent trends <i>Albert Klein Tank, KNMI, The Netherlands</i>
11:30	Extremes of temperature and precipitation in AMIP models <i>Francis Zwiers, CCCMA, Canada</i>
11:50	Modelling changes in extreme events <i>Catherine Senior, Hadley Centre, UK</i>
12:10	Temperature data issues <i>Thomas Peterson, NOAA/NCDC, USA</i>
12:30	Model-simulated CO <sub>2</sub> -induced changes in seasonal precipitation extremes <i>Jouni Räisänen, SMHI, Sweden</i>
12:50 - 14:00	Lunch
Session 3: Small-scale Severe Weather Phenomena (SCSWP) <i>Chair: Maria Martelo, IPCC WGI Vice-chair</i>	
14:00	Severe thunderstorms: climatology and modelling challenges <i>Harold Brooks, NOAA/NSSL, USA</i>
14:20	SCSWP (observations, processes, climatology) – a European view <i>Dario Camuffo, CNR ISAC, Italy</i>
14:40	Global lightning and thunderstorms: observations and modelling related to climate change <i>Colin Price, Tel Aviv University, Israel</i>
15:00 - 15:20	Coffee/tea
Session 4: Tropical and Extra-tropical cyclones <i>Chair: Jean Jouzel, IPCC WGI Vice-chair</i>	
15:20	Tropical cyclones and global climate change: An observational perspective <i>Thomas Knutson, NOAA/GFDL, USA</i>
15:30	Tropical cyclones – theoretical aspects: understanding extreme intensity <i>Michael Montgomery, CSU, USA</i>
15:50	Modelling the impact of future warming on tropical cyclone activity <i>Thomas Knutson, NOAA/GFDL, USA</i>
16:10	Changes in mid-latitude cyclones and storm tracks in reanalysis results, historical analyses and <i>in-situ</i> data <i>Nick Graham, Scripps Institution of Oceanography, USA</i>
16:30	Modelling changes in Northern Hemisphere storms under climate change <i>Uwe Ulbrich, University of Koln, Germany</i>
16:50	Review of presentations. Introduction of Break-out Groups topics <i>John Houghton, UK Cathy Johnson and Maria Noguer, TSU</i>
17:15	Plenary close
18:30	Buffet reception. New Century Hotel
Wednesday, June 12 - 2002	
Breakout Group Sessions	
09:00 - 13:00	(Coffee/tea in the Breakout rooms)
BG1	Temperature Chairperson: <i>Thomas Peterson</i> Rapporteurs: <i>Albert Klein Tank, Francis Zwiers</i>
BG2	Precipitation Chairperson: <i>David Easterling</i> Rapporteurs: <i>Lisa Alexander, Kumar Kolli</i>
BG3	Tropical cyclones Chairperson: <i>Thomas Knutson</i> Rapporteurs: <i>Kendal McGuffie, Akira Noda</i>
BG4	Extra-tropical cyclones Chairperson: <i>Jean Palutikof</i> Rapporteurs: <i>Catherine Senior, Hans von Storch</i>
BG5	SCSWP Chairperson: <i>Rudolf Brazdil</i> Rapporteurs: <i>Gaston Demaree, Harold Brooks</i>
13:00 - 14:00	Lunch
Plenary Session <i>Chair: Susan Solomon, IPCC WGI Co-chair</i>	
14:00 - 16:00	Main conclusions from the Breakout Groups
15:30 - 16:00	Coffee/tea
Break-out Group Sessions	
16:00	Continuation of Breakout Groups 1-5, plus new BG6 on Statistical methods
BG6	Statistical methods Chairperson: <i>David Stephenson</i> Rapporteurs: <i>Rick Katz, Tahl Kestin</i>  (Draft of Reports to be ready by 08:00 on 13 June)
18:30	Breakout Group Sessions close
Thursday, June 13 – 2002	
Plenary Session <i>Chairs: Susan Solomon, IPCC WGI Co-chair, John Houghton, Ding Yihui</i>	
09:00	Regional Groups
10:00	Final discussion on BG Reports
11:00	Coffee/tea
11:30	Final discussion on BG Reports (continue)
13:00	Workshop Close
13:00 - 14:00	Lunch
Breakout Group Sessions <i>(Chairs, Rapporteurs, TSU and others)</i>	
14:00	Final drafting of Workshop Report



## Annex D: Abstracts

### **Methods for estimating and attributing climate change in extreme events**

David B. Stephenson, Department of Meteorology, University of Reading, UK

### **Model projections and types of extremes needs for impact studies**

Luis J. Mata, ZEFc (Germany), Venezuela

### **Dust storm and its possible relationship to climate change in East Asia**

Ding Yihui, CMA, China, and Zeng Qingcun, Institute of Atmospheric Physics/CAS, China

### **Storm surges and flood defence: impacts at the interface of hydrological and coastal regimes**

Pieter Jacobs, RIZA – Institute for Inland Water Management and Waste Water Treatment, The Netherlands

### **Global/European analysis of extremes – recent trends**

Albert Klein Tank, KNMI – Royal Netherlands Meteorological Institute, The Netherlands

### **Extremes of temperature and precipitation in AMIP models**

Francis W. Zwiers, Canadian Centre for Climate Modelling and Analysis, Canada

### **Modelling changes in extreme events**

Catherine Senior, Hadley Centre for Climate Prediction and Research, Met Office, UK

### **Temperature data issues**

Thomas C. Peterson, NOAA/National Climatic Data Center, USA

### **Model-simulated CO<sub>2</sub>-induced changes in seasonal precipitation extremes**

Jouni Räisänen, Rossby Centre, SMHI, Sweden

### **Severe thunderstorms: Climatology and modelling challenges**

Harold E. Brooks, NOAA/National Severe Storms Laboratory, USA

### **Small-scale Severe Weather Phenomena (observations, processes, climatology): A European view**

Dario Camuffo, Michele Colacino, Giovanni Sturaro, Emanuela Pagan, National Research Council, Italy

### **Global lightning and thunderstorms: Observations and modelling related to climate change**

Colin Price, Tel Aviv University, Israel

### **Tropical cyclones and global climate change: An observational perspective**

Thomas Knutson, NOAA/Geophysical Fluid Dynamics Laboratory, USA

### **Tropical cyclones – theoretical aspects: Understanding extreme intensity**

Michael Montgomery, Department of Atmospheric Science, Colorado State University, USA

### **Modelling the impact of future warming on tropical cyclone activity**

Thomas Knutson, NOAA/Geophysical Fluid Dynamics Laboratory, USA

### **Changes in mid-latitude cyclones and storm tracks in reanalysis results, historical analyses and *in-situ* data**

Nicholas Graham, Scripps Institution of Oceanography, USA

### **Modelling changes in Northern Hemisphere storms under climate change**

Uwe Ulbrich, Universität zu Köln, Germany





## Methods for estimating and attributing climate change in extreme events

David B. Stephenson,  
Department of Meteorology, University of Reading, UK

This plenary talk will briefly summarise the main methodological issues involved in detecting and projecting weather and climate extreme events and their changes due to human influences on climate.

The “definition problem” of extremes will be introduced and explained in terms of exceedances above high thresholds. The unifying point process stochastic model for exceedances will be presented and will be used to interpret the four main properties of extreme events: rate, intensity, volatility (shape), and dependency.

Various methods used for estimating extreme value parameters will then be briefly reviewed in terms of their abilities to get the most out of limited data samples. The need for interval (rather than point) parameter estimates will be highlighted as a means for addressing the problem of detecting climate change signals against the background uncertainty caused by sampling from limited-size samples.

Finally, various hypotheses about how extremes are likely to change due to climate change will be reviewed: the “no change” hypothesis, the “mean effect” hypothesis, the “variance effect hypothesis”, and the “structural change hypothesis”. The talk will conclude with a summary of possible recommendations that can be discussed in the breakout groups. The extreme value analysis in the talk will be illustrated using cold extremes in daily Central England Temperature historical values from the period 1772-2002.

## **Model projections and types of extremes needs for impact studies**

Luis J. Mata,  
ZEFc (Germany), Venezuela

An attempt is made to describe the needs for assessing the impact and adaptation to changes in extreme weather and climate events. Environmental vulnerability can be used as the crossing point (interface) between diverse systems elements or sectors. Vulnerability has been defined in the IPCC Third Assessment Report (TAR) as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including variability and extremes. Thus, vulnerability being a function of the character, magnitude, rate of climate variation, sensitivity and adaptive capacity is suggested as the link concept between model projection and impact studies.

The presentation will describe methodological questions faced by impact assessors, by means of revising conclusions of TAR from Chapter 13 (WGI) and Chapter 3 (WGII) in order to provide the information needed for how we assess the impacts of extreme events. An example of an effort to incorporate changes in extreme events into impact assessment will be evaluated. Although it is clear that other methods for incorporating such changes into qualitative climate scenarios remain to be developed, further advances in this area of research should be expected over the next few years. Also, it is intended to address a question such as: What types of extreme climate events have important impacts on natural and human systems?

Perceived needs in opposition to actual information requirements of the impacts community should be analysed. Impacts assessors need to look carefully at the extent to which changes in variability and extremes are covered implicitly by changes in averages; when this is not the situation, the impact assessor must incorporate possible changes in extreme phenomena into the scenario.

A table (3-10 from Chapter 3 WGII) with representative examples of projected impacts (all with high confidence of occurrence in some areas) resulting from extreme climate phenomena with very likely or likely likelihood projected during the 21<sup>st</sup> century will be presented.

An evaluation of the advantages or disadvantages of climate scenario tools such as regional models and weather generators regarding extreme events according to the five criteria (consistency, physical plausibility and realism, appropriateness, representativeness, and accessibility) recommended in the TAR for use in impact assessments are considered in the presentation.

Adaptive capacity to climate change including variability and extremes would refer to both the ability inherent to coping range and the ability to move or expand the coping range with new or modified adaptations. One can think that how weather prediction and climate forecasting of extremes can assist adaptation strategies is an important issue that should be included when we try to evaluate the need of impact assessors from model climate projections. A proper question might be: How can climatological analysis assist in developing adaptation strategies?

## Dust storm and its possible relationship to the climate change in East Asia

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National Climate Center/CMA, China  
Zeng Qingcun,  
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Sand and dust weather is classified into three categories (drifting sand or dust, blowing dust or sand, sand or dust storm) based on the horizontal visibility and the size of suspended particles. Three requirements for occurrence of the dust storm have been identified sustained high wind at low level, thermally unstable atmospheric stratification and thick dry soil or sand layer. Most of Xinjiang province and southwest Qinghai province (Takela Magan Desert), west Gansu Province and Inner Mongolia (Gobi desert) are two regions of high frequency (>10-15 days). The southern Xinjiang and west Inner Mongolia have maximum dust storm days (20-30 days). Maximum frequency season is spring (March-May) with peak month of April; the second peak season is winter; the minimum occurrence season is summer. Conditions of occurrence of dust storms are active cold waves bringing high wind; dry climate condition with little precipitation; thicker dry and soft soil layer and strong thermal instability. Main tracks of dust storms indicate three paths: north-westerly, westerly and north-northwesterly.

Long-term variation of the frequency of dust storms and its possible link to climate change or variability in East Asia have been further discussed. Time-series of annual total days of dust storm from 1954 to 2001 show significant decadal variability: high frequency period: 50's-70's, decreasing frequency period: 1982-1997 and recent increase since 1997. High frequency period is characterized by cold temperature, active cold wave, and high wind and dry condition. Low frequency period is characterized by warm temperature, inactive cold waves, weak wind and wet condition. The recent increase in dust storms is believed to be linked to development of drought events in North and Northwest China. Occurrence areas for most of dust storm show decreasing trend for the recent 50 year, only with a few moderate areas having increasing trend. In addition, the number of occurrence of dust fall has shown a centennial-scale variability, with high frequency periods of 1060-1360 AD, and 1470-1970 AD, corresponding to dry spells.

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## **Storm surges and flood defence:**

### **Impacts at the interface of hydrological and coastal regimes**

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In recent years, much progress has been made in the development and improvement of climate models and subsequent downscaling techniques to arrive at scenarios used for impact assessment studies. These impact studies have been applied to estimate the effects of climate change on e.g. precipitation patterns and resulting river discharge (hydrological regime) as well as on sea level rise and the occurrence of storm surges (coastal regime). Such impact studies are relevant for flood protection in coastal and fluvial areas. Flood defence in regions surrounding river deltas, estuaries and lagoons is often designed to curb the effects of extreme events in both the hydrological and coastal regimes, whether these events occur simultaneously or not.

To develop impact assessment studies at the interface of hydrological and coastal regimes, the occurrence of extreme events in both regimes is often assumed to be uncorrelated. Even when this assumption is true for the present day situation (which, in some cases, is not so), it is unknown how climate changes affect the correlation between relevant parameters in the hydrological and coastal regimes in the future. Part of the uncertainty arises from the fact that different downscaling techniques are used to arrive at estimates for parameter ranges for future hydrological regimes on one hand (statistical downscaling) and coastal regimes on the other hand (deterministic techniques, e.g. nested models).

A case study for the Rhine-Meuse delta in The Netherlands shows that high water levels in this region can be quite sensitive to increases in storm intensity and duration, in combination with increasing (winter) river discharges. In the near future, this study will be extended to incorporate sensitivity to the correlation between storm surges and river discharges. In order to develop reliable scenarios for such case studies, downscaling techniques for hydrological and coastal regimes should leave the structure of such correlation functions unchanged.

## **Global/European analysis of extremes – recent trends**

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KNMI – Royal Netherlands Meteorological Institute, The Netherlands

### Acknowledgements:

Lisa Alexander, Hadley Centre for Climate Prediction and Research, Met Office, UK  
Janet Wijngaard, Aryan van Engelen and Günther Können, KNMI  
36 participants from the European Climate Assessment project (Europe and Middle East)

An overview will be given of recent trends in observational series of climate extremes. The overview will be based on the results of the European Climate Assessment project (see: <http://www.knmi.nl/samenw/eca>) and related work in other parts of the world. Rather than studying changes in very rare extreme events such as those characterised by the size of their societal or economic impacts or analysing the parameters of extreme value distributions, we focus on: trends in observational series of phenomena with a daily time scale and typical return period < 1 year.

Extremes are defined using derived climate indices as proposed by the joint CCL/CLIVAR Working Group on Climate Change Detection (Peterson et al., WMO-TD No. 1071, 2001). Most of the indices refer to counts of days crossing a threshold. Either absolute (fixed) thresholds or percentile (variable) thresholds relative to local climate are used. Standardisation enables comparisons between results for Europe and elsewhere (e.g. Frich et al., *Clim. Res.* 2002; also in IPCC-TAR, 2001). The choice of indices is motivated by the fact that the detection probability of trends depends on the return period of the extreme event and the length of the observational series. In order to be able to draw conclusions for daily extremes in observational series with typical length ~50 years, the optimal return period of extremes is 10-30 days rather than 10-30 years. Examples of indices trends will be given for temperature and precipitation.

Questions for discussion are raised related to the availability of good quality observational series with daily resolution; the need for gridding the data; the required quality control and homogenisation methods and, finally, the applicability of the indices for trend analysis in climate models and for impact assessment.

## **Extremes of temperature and precipitation in AMIP models**

Francis W. Zwiers,  
Canadian Centre for Climate Modelling and Analysis, Canada

We describe and discuss estimates of long period (e.g., 20-year) "return values" of daily minimum and maximum temperature, and daily and pentadal precipitation simulated by models participating in AMIP2. Comparisons are made between models, and with results obtained from several data sets that are in some way informed by observations. A projection of future changes in these types of extremes is also briefly described and discussed.

## **Modelling changes in extreme events**

Catherine Senior,  
Hadley Centre for Climate Prediction and Research, Met Office, UK

Global climate models show modest skill in simulating extreme temperature and precipitation events. The largest source of errors in predictions of extreme events are probably associated with the relatively low horizontal and vertical resolution of global coupled models; deficiencies in the representation of physical processes that are important for extremes and the lack of a robust signal under climate change due to the often small number of extremes in an experiment for a particular forcing. Regional models show considerably greater skill in capturing extremes, even over small catchment areas.

Projections of changes in extreme events in both global and regional models under climate change are affected by the wide range of global and regional predictions of mean temperature and precipitation for a given forcing scenario. Nevertheless, the IPCC TAR shows a degree of consensus on qualitative changes in extreme temperature and rainfall and some consistent statements are beginning to emerge. Many of these are consistent with changes we would expect on physical grounds. For example, a rise in mean temperature increases the probability of extreme warm days and decreases the probability of extreme cold days. Enhanced evaporation due to higher temperatures leads to a more vigorous hydrological cycle with more precipitation on average, and this is generally associated with increased frequency of heavy precipitation events in model projections. In addition, a number of changes in weather and climate extremes projected in climate models have been seen in observations in various parts of the world.

## Temperature data issues

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Over the last couple of decades, a great deal of work has been done on monthly mean station temperature data to make them suitable for climate change analyses. This work includes basic data archaeology of locating historical records and digitizing them (e.g., Peterson and Griffiths, 1997), merging them together into global databases (e.g., Jones, 1994; Peterson and Vose, 1997), developing appropriate quality control checks (e.g., Peterson et al., 1998a) and adjusting the data for inhomogeneities (see Peterson et al., 1998b for a review of homogeneity adjustments in monthly data). However, to assess changes in temperature extremes, daily or sub-daily observations are needed. Unfortunately, daily datasets are nowhere near as far advanced as monthly datasets.

Part of the problem is that daily data have more complex issues than monthly data. For example, while homogeneity assessments need to be done to account for the effects of changing from one type of instrument shelter to another, the proper daily adjustment depends not only on whether it is summer or winter, but whether the day was clear or overcast and windy or calm. This is particularly true when one wants to use the adjusted data to assess changes in extremes. Because of this complexity, the issues involved in homogeneity adjustments for daily data are just beginning to be addressed (e.g., Vincent *et al.*, 2002; Trewin and Trevitt, 1996). Daily data are also far less available than monthly means. "Global" datasets have large portions of South America, Central America, Africa and Southwest Asia lacking long-term daily observations (Gleason, 2002). Even the assessment of what constitutes "long-term" data is different. Daily observations are often considered long-term if they are several decades long while monthly observations are widely available on century time scales.

However, a variety of efforts are underway to improve this situation. The Global Climate Observing System Surface Network is slowly growing (Peterson et al., 1997), regional climate change workshops (e.g., Asia-Pacific, Manton et al., 2001; Caribbean, Peterson et al., 2002; Africa, in Peterson et al., 2001) are providing climate change assessments and climate change indices derived from daily data (see Frich *et al.*, 2002 for more on these indices) for under assessed areas of the world, and individual research projects are building regional (e.g., Klein Tank et al., 2002) and global (e.g., Gleason, 2002) databases. Yet much remains to be done. A great deal of data still needs to be digitized. Political concerns need to be overcome so more data can be exchanged. And additional work is required to develop robust homogeneity adjustments to daily data.

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## Model-simulated CO<sub>2</sub>-induced changes in seasonal precipitation extremes

Jouni Räisänen,  
Rossby Centre, SMHI, Sweden

High and low extremes of seasonal time scale precipitation are of interest for their impact on large-scale flooding and droughts. Seasonal precipitation extremes (especially lack of precipitation) have a larger spatial scale than many other types of extreme events, but as with all extremes, sampling variability makes it difficult to get robust statistics from single model simulations.

In this talk, simulated CO<sub>2</sub>-induced changes in seasonal precipitation extremes are studied using 19 models participating in the second phase of the Coupled Model Intercomparison Project (CMIP2; Meehl et al. 2000). Changes in both the magnitude (largest or smallest seasonal precipitation within a 20-year period) and the risk of occurrence (how often precipitation is above or below a threshold derived from the control runs) of extremely high and low seasonal precipitation are investigated using this multimodel ensemble.

As a rule of thumb, changes in 20-year seasonal precipitation extremes follow the changes in mean precipitation, with the wet extremes becoming more and the dry extremes less severe where the mean precipitation increases (and vice versa). However, in a globally averaged sense, there are hints of increased variability, with a larger difference between the wet and dry extremes in a warmer climate. As theoretically expected, changes in the risk of extremely wet or dry seasons are much larger than the changes in the magnitude of the extremes. As also expected, the changes in risk are in relative terms larger for more (e.g., once in 80 years in control runs) than for less (e.g., once in 20 years) extreme events.

The occurrence of flooding and droughts is not determined by precipitation alone. It may also be affected by other greenhouse gas induced changes in the hydrological cycle, such as changes in snow conditions and evaporation, and by non-climatic factors such as changes in land use.

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## Severe thunderstorms: Climatology and modelling challenges

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Severe thunderstorms (tornadoes, large hail, strong winds) are threats throughout the inhabited world. Changes in demographics and urbanization are changing the hazards to societies around the world. Unfortunately, descriptions of the climatological distributions of severe thunderstorms are typically based on small sample sizes. This is due to the rare nature of the events and the fact that data collection is a part of the national weather service responsibility in only a few countries. The most complete and accurate official dataset, the record of F2 and greater (approximately the 10% strongest) tornadoes in the United States is only about 30 years old. Given these limitations, it is unlikely that climate-related trends, if any, can be detected in the raw observations of events.

Recently, research has shown some hope for improvements in climatological estimates of the threats. Specifically, it appears that the distribution of strong and violent tornadoes (F2 and greater) by intensity is the same throughout most of the world, implying that the same physical processes are important everywhere. A working hypothesis is that the reason for the difference in number of tornadoes in different areas is the difference in the frequency of occurrence of environments conducive to tornadoes. Detailed studies of radiosonde and reanalysis data in the vicinity of severe storms in the United States have delineated the environmental conditions in which severe storms are most likely to form. It may be possible to take advantage of these studies to make “pseudo-climatologies” of severe weather by mapping the frequency of environments. Given that the period of record of consistent environmental observations is longer in most locations than the period of consistent storm observations, the environmental conditions may hold the key to producing reasonable climatologies. Possible changes in the frequency of environmental conditions associated with severe thunderstorms may be detectable.

Finally, the crucial parameters for discriminating between tornadic and non-tornadic environments are associated with the planetary boundary layer (PBL). Current parameterizations of the PBL for numerical weather prediction models are primitive and are unlikely to reproduce the discriminatory power of the observations. Without improvements in those parameterizations, it is doubtful that we will be able to model possible changes in the frequency of severe thunderstorm environmental conditions in GCMs.

## Small-scale Severe Weather Phenomena (observations, processes, climatology): a European view

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### Summary

This presentation discusses climatic trends and evolutions of Small-scale Severe Weather Phenomena (SCSWP) in Europe and over the Mediterranean Basin. The SCSWP include floods in Venice (I), extreme daily temperatures, short and long lasting extreme heat waves, meteorological bombs, gale winds, rivers overflowing, fog, hail and thunderstorms. Not all the above phenomena have the same quality and quantity of long-term observations, especially at daily or shorter scale. This makes difficult or sometimes uncertain the interpretation of present-day change. In particular, in some cases the actual value of the trend critically depends on the length of the available series. This is particularly relevant in view of depicting sound scenarios.

Due to its geographical position, and because it was built at sea level, **Venice** is extremely sensitive to climate changes and, in the future, risks being submerged as a consequence of the expansion of oceanic water in response to global warming. A key problem is the increasing frequency of **storm surges** with the sea flooding the city (locally named *acqua alta*) that has reached an unsustainable level (Fig. 1). Factors influencing the flooding tides in Venice are: meteorology (Sirocco surges and air pressure), climate change (sea level rise), land subsidence, sea surface oscillations, astronomical forces, human factors.

Paradoxically, the flooding frequency is increasing although the Sirocco storms are decreasing (Fig. 2). The strong decrease in gale Sirocco frequency (almost 50%) was not sufficient to reduce the flood tides in Venice that on the contrary are increased by more than 100% in the same period. Extreme phenomena originated by complex interactions between human and natural factors require a special approach because they are particularly relevant for the society of tomorrow.

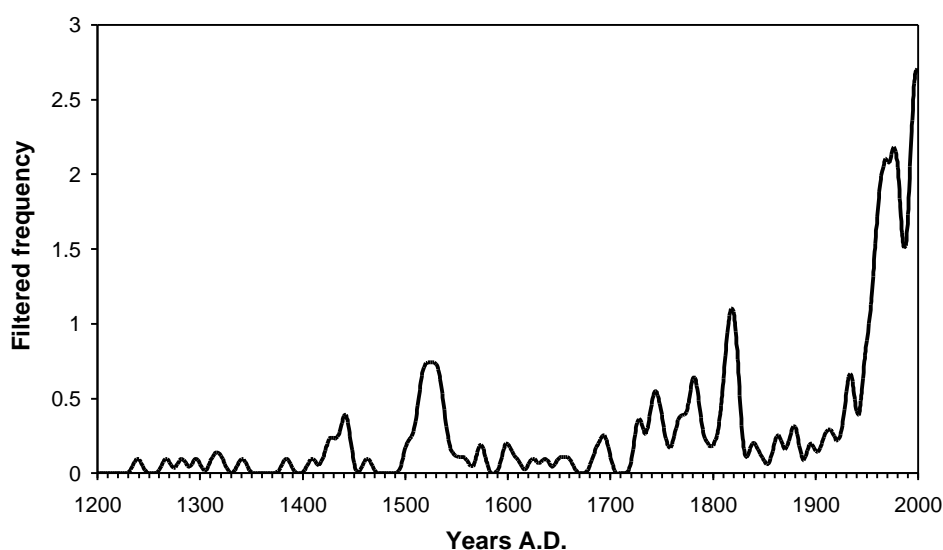


Figure 1: Frequency distribution of flooding surges in the documentary (1200 – 1871) and instrumental (1872-today) periods. The data have been handled with the Hamming-Tuckey filter with 19-yr window and 2-yr step. In order to show the present-day situation and to avoid the filter truncation at 9.5 yr before present, the data 1991-2000 have been repeated for 2001-2010, assuming unchanged conditions.

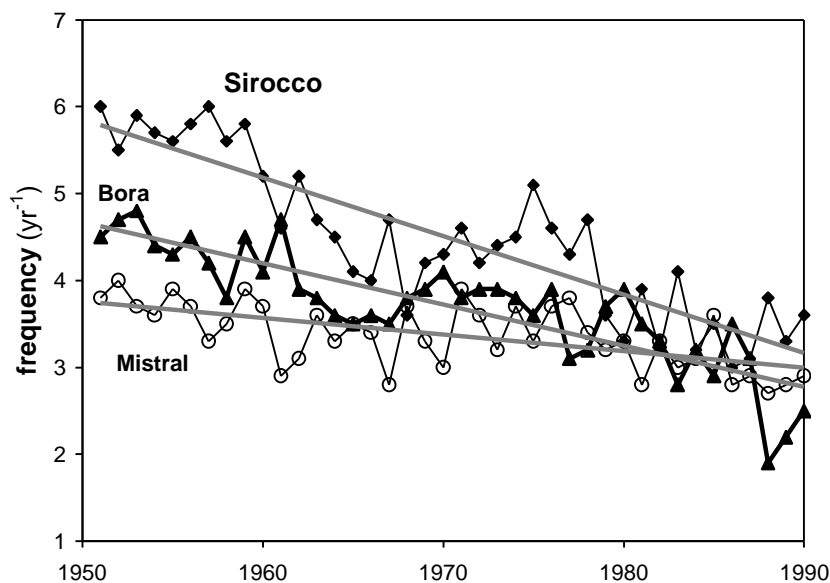


Figure 2: Gale winds in the Mediterranean Basin (speed > 25 kt for > 6 hr).

The three main **winds** (Sirocco, Mistral and Bora) at **gale force** in the Mediterranean Basin are presented for the period 1950-1990 (Fig. 2). They are considered at gale force when blowing at a speed > 25 kt for > 6 hr. The trends are different, but markedly decreasing. To find a strong decrease in gale Sirocco frequency (almost 50%) does not necessarily imply a future scenario without Sirocco, but only that the analysis has been performed in a time period (40 years) that may be short in comparison with the natural variability of this phenomenon (Piervitali et al., *Theor Appl. Climatol*, 58, 1997).

**Extreme daily temperatures** were computed from the secular daily series produced in the framework of the European project IMPROVE (Camuffo & Jones, *Clim. Change*, 53, 2002), i.e. Padova (Italy, 1725-1998), Milan (Italy, 1763-1998), Central Belgium (1767-1998, temperature only), Uppsala (Sweden, 1722-1998), Stockholm (Sweden, 1756-1998), San Fernando/Cadiz (Spain, 1776-1996) and St Petersburg (Russia, 1743-1996, temperature only). These series have been augmented with Central England (UK, 1772-1999). They constitute the longest and the most accurate documentation of the past temperature and its variability in Europe.

The **extreme heat waves** in the Mediterranean Basin are presented for the period 1950-1995. Two types of heat waves occur: (a) Short-lasting Heat Waves, characterised by a duration of 3-5 days, and a temperature increase  $\Delta T$  generally of 7-15°C above the seasonal average; (b) Long lasting heat waves, with more than 10-day duration and  $5^{\circ}\text{C} \leq \Delta T \leq 7^{\circ}\text{C}$ . The trend of extreme heat waves shows a strong variability and the future evolution is difficult to forecast.

“**Meteorological Bombs**” are defined as extra-tropical depressions deepening at rate of 1 hPa/hr (geostrophically adjusted), at least for 24 hr, i.e. 1 Bergeron (Sanders & Gyacum, *Mon. Weat. Rev.*, 108, 1980). Their geographical distribution within the Mediterranean Basin, and their trend for the period 1965-1995, are shown. The frequency of the total number of bombs over the Central and Western Mediterranean is anticorrelated to the trend of the average pressure field at 500 hPa. The long-term evolution was computed for the IMPROVE series Uppsala (60°lat North), Stockholm (59.5°), Milan (45.5°), Padova (45.4°), and San Fernando/Cadiz (36.5°). The number of events is the smaller the lower the latitude. Other comments are: (1) A good correlation is found between the stations Padova and Milan, 230 km afar (Fig. 3). Differences are justified as effects of Eastern circulations influencing Padova as well as effects of lee-Alps cyclogenesis in Milan. (2) On

the contrary, a better correlation was expected between Uppsala and Stockholm, only 70 km afar. This may be explained in terms of the data quality, which is a very general problem. (3) By analysing the trends in the period 1800 - today, and looking at the last part of the trendline, i.e. since 1950, this part is sometimes found different from the trend computed only for the most recent 50-year period, ignoring the previous data. The difference in the trends, determined by both the presence of fluctuations and the length of the time interval, makes ambiguous the interpretation of results computed over short periods. This stresses the need for very long series.

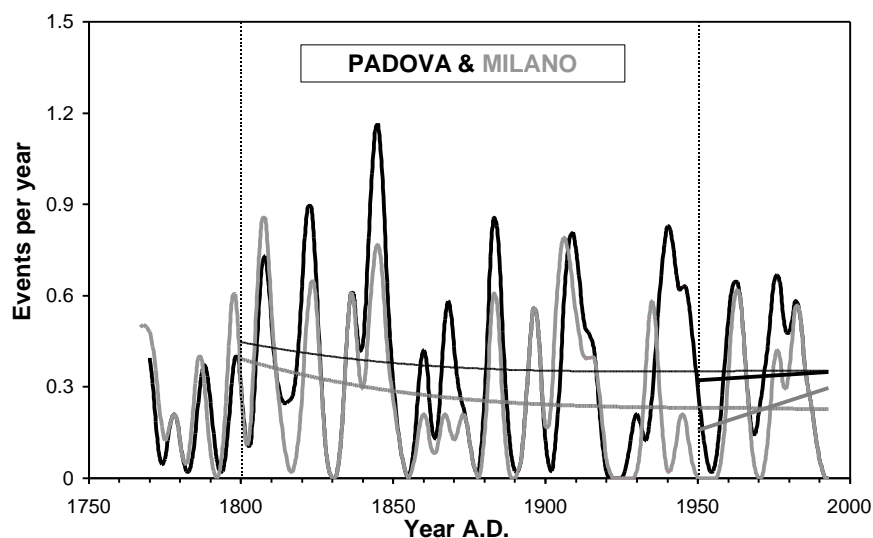


Figure 3: Long series of the number of meteorological “bombs” in Padova and Milano, Northern Italy, estimated from the daily pressure series. At these latitudes, “bombs” are defined as extra tropical depressions deepening at rate of 19.8 hPa/day. Data are filtered with an 11-yr binomial filter.

An opposite teleconnection between the **rivers Tiber (Italy) and Tagus (Iberian Peninsula) overflowing** is found for the last six centuries. The river Tiber is in flood mainly with Meridional Circulation, in the presence of Mediterranean Depressions, while the Tagus with Zonal Circulation, and Atlantic Depressions. The dependence on two different weather situations explains why the two rivers flooding are anti-correlated.

The Po Valley (Northern Italy) is one of the foggiest regions within Central and Southern Europe. The **fog** in Milan and Venice is studied for the last 50 years. The phenomenon is conditioned by both meteorological and anthropogenic factors, i.e. winter high pressure and air pollution. In Venice, near the coast, the fog events seem more or less unchanged. In Milan, in the hinterland, the accumulation of pollution is dominant and a strong difference in behaviour is found after 1973. In this year the fuel for domestic heating was switched from oil to methane, reducing the fog frequency in Milan that now approaches the Venice level.

An interesting problem concerning **hail and thunderstorm** frequency in Padova is presented. The series shows apparently different values with discontinuities at the passage between different observational styles during the course of the centuries.

In the past centuries, **hailstorms** were recorded when they occurred in the wider area in which the observer had certain information. At present, the phenomenon is recorded only when it occurs in the limited site where the weather station is located. The frequency seems to be under-evaluated in the recent times. In the past, the recorded number of **thunderstorms** was higher than the actual number, because the observers included also all the case in which they observed lightning without hearing the thunder. A correction made on the ground of the original registers was not sufficient to

reconcile the difference. The data homogeneity is a key problem for a correct interpretation of the data. The problem is particularly significant for visual observations.

Hailstorms, tornadic storms, deep convective episodes are being monitored and studied with more modern approaches: remote sensing (satellites and polarimetric radar) assisted by numerical modelling. They focus on intense meteorological phenomena in the Mediterranean (orographic effects, orographic cyclones, heavy precipitation, baroclinic/convective systems, role of latent heat release and surface fluxes). Numerical modelling, based on hydrostatic and non hydrostatic models, are applied to forecasting of extreme events (coupling of meteorological and hydrological models for flood forecast), to regional weather forecasting and data assimilation.

## Conclusions

Knowing the past is the key to interpret the climate processes and changes. To this aim the research needs are:

- to seek to produce the still unknown or unexploited long-term data series;
- to give priority to the series with high resolution (daily or shorter);
- to control the data quality and work to homogenise and correct the long series;
- to support recovering of existing long-term observations scattered in different countries in the Mediterranean Area, which is extremely important for the passage, deepening and genesis of mid-latitude cyclones and that is scarcely documented.
- Instrumental meteorological data cover at maximum the last two centuries and part of the previous one. Proxy data cover a wider scale, and documentary data which cover one millennium or more are widespread in Europe and can add new light to the knowledge of the past climate ages. They merit more attention in view of the high benefits they offer.
- The choice of the best indices for SCSWP is dramatically conditioned by the availability of data according to the above items.

## **Global lightning and thunderstorms:**

### **Observations and modelling related to climate change**

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Thunderstorms are constantly active around the globe, producing ~50 lightning flashes every second. These thunderstorms can result in heavy precipitation, flash floods, hail damage, wind damage, as well as igniting forest fires. It is therefore extremely important to know if, and how, these thunderstorms will change as the earth's climate changes. In the last decade a number of studies have looked at the relationship between observed lightning activity and surface temperatures. All these studies, covering diurnal, weekly, monthly, seasonal and interannual time scales, show a statistically significant positive correlation between surface temperature and local/regional/global lightning activity. Furthermore, modelling studies using the NASA GCM climate model indicate that for a doubled CO<sub>2</sub> atmosphere the global lightning activity could increase dramatically by 30-50%. Unfortunately, there are no long-term statistics on regional or global thunderstorms. Some industrialised countries have ground networks for continuously detecting lightning, although these cover small areas of the globe and cannot be used for long term studies. Satellites provide global coverage, but none have lifetimes longer than a few years, although lightning sensors on geostationary satellites have been proposed. However, there is a method of continuously monitoring regional/global lightning activity via an electromagnetic phenomenon called the Schumann resonance. This method needs only a few monitoring sites around the globe, and observations can be absolutely calibrated, allowing for a cheap method to continuously monitor global thunderstorm activity indefinitely. A number of such stations are already in operation.



## **Tropical cyclones and global climate change: An observational perspective**

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The status of tropical cyclone observations relevant to the global climate change problem is briefly reviewed. Three related topic areas include: analysis of tropical cyclone climatological records for evidence of long-term trends; examination of relationships in observed data between tropical activity and large-scale environmental parameters; and attempts to reconstruct prehistoric tropical cyclone activity using proxy palaeoclimate data.

Observed climatological records of tropical cyclone activity are of limited duration due, for example, to lack of complete coverage of basins in the pre-satellite era. The most complete records exist for the Atlantic and Northwest Pacific basins, extending back into the 1940s. The time series of tropical storm frequency for the Atlantic basin shows no clear evidence for long-term trends; intense Atlantic hurricane frequency appears to vary substantially on interdecadal timescales. The maximum hurricane intensity recorded each year in the Atlantic shows no evidence for a long-term trend. Shorter tropical cyclone records from the Australian basin indicate a downward trend since 1970 in the frequency of moderate and strong storms. In the Northwest Pacific basin, the occurrence of tropical storms and typhoons since 1960 has shown a decrease followed by an increase.

Tropical cyclone intensity distributions, stratified by sea surface temperature, indicate that the strongest storms occur only over relatively warm ocean surfaces. However, many weak storms also occur in the high SST region, such that there is only a weak relationship between SST and the mean tropical cyclone intensity occurring at that SST. Recent work by Emanuel has indicated that observed tropical cyclones, once attaining hurricane strength, are equally likely to attain any intensity from minimal hurricane strength up to, but not exceeding, their potential intensity as determined from the thermodynamic environment. (This empirical finding applies when considering storms whose maximum intensity is not limited due to decreasing potential intensity, as occurs for example when storms begin to track over cooler ocean surfaces.) The implication is that potential intensity theories may provide information on the entire distribution of tropical cyclone intensities under climate change, and not just the upper limit intensity.

To enhance the relatively short observational record of tropical cyclone activity, researchers have begun to explore the use of palaeoclimate reconstruction of prehistoric tropical cyclone activity. Although such “palaeo-tempestology” work is still at a relatively early phase, this technique may provide important tests for climate models by providing information on tropical cyclone activity under climate conditions quite different from those of the present-day tropics.

## Tropical cyclones - Theoretical aspects: understanding extreme intensity

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The maximum intensity that a hurricane can attain in a given atmospheric environment is called the maximum potential intensity (MPI). Recent theoretical work has contributed much to understanding the thermo-mechanical processes that govern MPI. On the applied side, for example, the MPI places an important constraint on the magnitude of intensity changes possible in a climate warming scenario. While the theory is largely supported by current observations, we consider here the role of coherent vortex structures in the MPI problem and the modification that may be required to incorporate these phenomena.

We begin by reviewing the basic Carnot model of MPI as developed by Emanuel (1986, 1995; *J. Atmos. Sci.*). Pertinent to a theme of this workshop, the theory predicts that the maximum wind speed will increase in a greenhouse-induced warming scenario. This prediction has been verified recently using the NOAA/GFDL hurricane modelling system (Knutson and Tuleya 1998; *Climate Dyns.*). Although the Carnot theory appears to successfully capture many aspects of the intensity problem, we argue that it has not been thoroughly tested at high spatial and temporal resolution sufficient for resolving real clouds and related mesoscale vortex structures. To address this issue we undertake a comprehensive test of MPI theory at an unprecedented resolution using the Rotunno and Emanuel (1987; *J. Atmos. Sci.*) axisymmetric hurricane model. At cloud resolving scales "super intense" hurricanes are found to emerge that greatly exceed the corresponding intensity prediction of the Carnot theory (Persing and Montgomery 2002; submitted to *J. Atmos. Sci.*).

We explain the superintensity phenomenon by showing that super intense hurricanes access a second source of heat in the lower troposphere of the hurricane eye. This heat source is not accounted for in the Carnot model. A model diagnosis shows that the eye reservoir is maintained by fluxes of latent heat from the underlying ocean in the eye. The heat surplus in the eye is transported radially outward and injected into the eyewall cloud by coherent mesovortices residing at the interface between the eye and the eyewall.

Our results are supported by recent flight-level and GPS dropsonde data obtained with NOAA WP-3D aircraft of the eye/eyewall region. These observations provide evidence that the super intensity mechanism operates in real hurricanes. We suggest that in nature the super intensity mechanism acts to help offset the adverse effects of vertical shear and shear-induced cooling of the oceanic mixed layer underneath the cyclone.

To further elucidate the fluid dynamics of the eyewall mesovortices described above a novel experimental study has been carried out (Montgomery, Vladimirov, and Densissenko 2002; *J. Fluid Mech.*). Here we summarize some of the main findings of this study. The experimental flow is designed to possess both a tangential (primary) and transverse (secondary) circulation similar to a real hurricane vortex. The eye/eyewall region of the experimental flow supports two primary quasi-steady mesovortices and secondary intermittent vortices. Relative to the parent vortex that supports them, the experimental mesovortices generate a 50 % local enhancement in the horizontal velocity. Current high resolution hurricane simulations using the Penn State/NCAR MM5 demonstrate a horizontal velocity enhancement of approximately 30 % in association with the eyewall mesovortices.

Our work suggests that extreme intensities in hurricanes occur in association with low-level vortex structures in the eye/eyewall region of the cyclone. We advocate further observational, experimental, and theoretical research of this phenomenon. The potential relevance of these findings to climate change scenarios is not yet known.

## Modelling the impact of future warming on tropical cyclone activity

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Attempts to model the impact of climate warming on tropical cyclone activity have used several methods, including direct global climate model simulation, empirical downscaling, theoretical estimates of Maximum Potential Intensity (MPI), and nested high resolution simulation of storm cases.

Using global climate models to directly simulate tropical cyclone activities, the results have been quite inconsistent among models in the studies to date. Published results have varied from ~50% increase to ~50% decrease in global tropical cyclone frequency. There are many differences among the models that could contribute to these discrepancies, including differences in model physics and in experimental design. Although global models appear to simulate a tropical cyclone climatology that is realistic in some respects, further opportunities for evaluating their performance in the current and historical record exist. The ability of global models to realistically simulate tropical cyclone genesis has been questioned, and the simulation of tropical cyclogenesis in general remains an active research topic.

An alternative to simulating tropical cyclones explicitly is to use meteorologically based empirical methods, such as Gray's genesis parameters, to infer tropical cyclogenesis using relatively large-scale information on the tropical climate from a global model. While this method appears useful for the present climate, modifications are necessary to apply such a method to a climate change scenario. At least one study has attempted to do so, and finds relatively modest increase of tropical cyclone frequency (4-7% at the time of CO<sub>2</sub> doubling), although it is not clear how to evaluate the reliability of such altered empirical methods.

To investigate tropical cyclone intensity changes under different climate conditions, high-resolution models have been used to simulate case studies. For example, samples (order 50) of individual tropical cyclone cases have been derived from multi-year climate model integrations and nested into high resolution regional models. One such study found marginally significant increases of intensity (~5-11 %) for a 2.2°C sea surface warming in the tropical NW Pacific, while a second lower resolution study (Australia region) found changes that were mostly not statistically significant. More idealized case study experiments, with tropical cyclones embedded in uniform zonal flows, show increased intensities (~3 to 10% in various basins) that are quite statistically significant. The idealized experiments show a similar degree of intensification when ocean coupling is included in the simulation. These experiments show substantial increases in storm-related precipitation (~18 to 28%) in the warmer climate cases. The robustness of these results to the use of different models needs to be examined. The percentage increase in storm intensity computed in the higher resolution studies mentioned above is roughly similar to that estimated using theoretical (Maximum Potential Intensity) methods.

## Changes in mid-latitude cyclones and storm tracks in reanalyses results, historical analyses and *in-situ* data

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Frontal cyclones are an important defining characteristic of cool-seasons mid-latitude climate. From a human perspective winter frontal systems are most strongly associated with precipitation, rapid temperature changes, strong winds, and, at sea and in coastal locations, high waves. These eddies are also an important dynamical element in the general circulation and a key diagnostic of climate variability through changes in Meridional fluxes of heat, moisture and momentum.

Recent studies using reanalysis results indicate there have been substantial changes in the climatology of mid-latitude cyclones over the past 50 years. These studies, conducted using both explicit tracking of cyclones and gridded eddy statistics, highlight the following results relevant primarily to the mid-latitude maritime storm tracks:

### Over the **Northern Hemisphere**:

- Increasing numbers of cyclones
- Increasing numbers of intense cyclones, with associated increases in extreme surface winds
- Upward trends in eddy statistics. Over the North Pacific these trends have been produced by southward and eastward expansion of the storm track.
- Coincident decadal fluctuations in both the North Pacific and North Atlantic superimposed on the trends noted above.
- Increased deepening rates and translation speeds.
- Associated changes in the mean circulation at the surface and aloft.

### Over the **Southern Hemisphere**

- Decreasing frequencies of surface cyclones.
- Larger, deeper cyclones.
- Increasing frequencies of 500 hPa cyclones downstream of major land masses - especially south of Australia and into the western South Pacific Ocean.

An obvious question concerns the degree to which these changes are real as opposed to a) the effects of changes in the types, location and density of observations, b) the effects from spurious trends in observations, or d) artifacts of the reanalysis procedures themselves [likely interacting with a) and b)]. To address this issue some studies have attempted to corroborate the reanalysis results using direct comparisons with *in-situ* data from radiosonde sites, weather ships reports, and other types of analyses. The results of these studies support the conclusion that there has been substantial regional intensification of winter mid-latitude cyclones in the Northern Hemisphere during the past half-century (and perhaps longer). These corroborative investigations are considerably hampered by the sparse availability of high quality data over the oceans, and the removal of key observing stations over the years. Most notably, analyses of radiosonde data show some regional biases between low frequency variability in reanalysis results and radiosonde data

(though this is not the case for at least one key site on the southern fringes of the Pacific storm track). Thorough objective studies of the impacts of changes in data density and type on storm track intensity in reanalysis results have yet to be conducted and require substantial resources to complete.

Some studies have also considered impacts of these changes in climate – most notably on ocean waves. These studies have shown that the increasing frequency of mid-latitude cyclones has led to significant increases in both median and extreme wave heights in the North Atlantic and Pacific. Initial analyses suggest that these changes may be associated with apparent increases in coastal erosion along the west coast of the US (and by extension the British Isles). Some of these changes can be corroborated since approximately 1980 using buoy measurements (seismic reconstructions of spectral wave data offer the possibility to extend these records back to the 1920s or earlier).

It is notable that an intensification of the mid-latitude storm tracks is decidedly counter to the results of greenhouse warming modelling studies. Further although more frequent major El Niño episodes have likely contributed to the observed changes over the North Pacific, this contribution appears to be secondary.

There are some activities that offer the potential to improve the resolution and understanding of past changes in cyclone environments, and thus better establish whether the changes seen in the reanalysis results are accurate.

1. Systematic examination of the effects of changes in observation densities and types on reanalysis results.
2. Direct comparisons between the results of different reanalysis and analysis products.
3. Availability of high time resolution fields from control and GHG coupled model simulations or at the least eddy statistics.
4. Further comparisons between in situ data and reanalysis results, especially marine surface reports, aircraft reports, and radiosondes. Given the changes in types and numbers of observations over the years, marine SLP observations from both weather ships and the Volunteer Observing Ships (VOS) may offer the most consistent and plentiful source of data.
5. The use of novel techniques – (e.g., seismic reconstructions of coastal wave heights and spectral characteristics, reanalyses using only surface data, targeted investigations using bulk statistics of VOS reports).
6. Where possible compare inferred to observed impacts – e.g. by matching reconstructed or measured data with reanalysis driven hindcasts (e.g., storm surge, ocean waves).

Other actions will improve our ability to resolve future changes in cyclone activity – indeed it would be unfortunate should similar questions exist in future decades. Some of these are listed below:

1. Re-establishment and extension of marine surface observing platforms over the mid-latitude oceans with a commitment to multi-decadal maintenance.
2. Re-establishment and extension of radiosonde sites.
3. Establishment of “fixed-position” aircraft reporting locations.
4. More continuous spatial and temporal coverage by satellite measurements (e.g., scatterometer winds / waves, precipitation).

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## **Modelling changes in Northern Hemisphere storms under climate change**

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Local extreme wind gusts are the main reason for storm damages. As this parameter cannot be realistically simulated by global coupled Atmosphere-Ocean General Circulation Models (AOGCMs), a direct evaluation of changing storm impacts is not possible. As a consequence, indirect larger-scale indicators like cyclones or upper tropospheric waves are often considered in scenario simulations. The justification for this approach is that the close relation between the occurrence of extreme winds and such indicators, which should be reproduced more realistically by AOGCMS.

Results from climate change simulations from some models (in particular ECHAM, HadCM) are presented, which suggest a greenhouse gas forcing induced change of winter cyclone activity and extreme winds over the North Atlantic and European sector. An increase in deep and a decrease in weak cyclones are found associated with a northward shift of activity in this area (ECHAM). Extreme winds produced by the models are increasing at the same time. The changes are largely consistent with modifications of parameters like baroclinicity and latent heat content of the atmosphere. While this result may be interpreted in terms of a tendency towards an increasing storm risk, a quantitative interpretation in terms of changing local gust occurrence can only be based on downscaling techniques or on (nested) high resolution model runs. Regional models are able to give fairly realistic simulated storm fields when forced with suitable (storm-) boundary conditions. It has recently become possible to perform 30 year time-slice runs with regional models. Still, these runs are affected by long term climate variability (as produced by the AOGCMs) which might disguise climate trends.

Dynamical-statistical downscaling has also been employed to study changing storm risk under climate change. The procedure is based on a number of historical storm events, which can, for example, be simulated under the boundary conditions available from archived analysis data. A change of local storm risk can then be estimated from a change in the occurrence of the specific large scale fields leading to storms. This will, however, not give a good coverage of all possible storms that could develop from a given situation. One way that might be explored in the future is to estimate storm risk of large-scale weather situations with the help of ensemble weather forecasts. The storm risk of a situation could be estimated from the number of ensemble members leading to a severe storm. With respect to climate change, one could consider changes in the occurrence of these situations.



## **Annex E: Breakout Groups – Background information**

### **Breakout Group**

BG1 Temperature  
BG2 Precipitation  
BG3 Tropical cyclones  
BG4 Extra-tropical cyclones  
BG5 SCSWP  
BG6 Statistical methods

### **Chair**

Thomas Peterson  
David Easterling  
Thomas Knutson  
Jean Palutikof  
Rudolf Brazdil  
David Stephenson



## Background material for the breakout group on:

### Temperature (BG1)

**Thomas C Peterson,  
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The purpose of the breakout groups is to identify areas and mechanisms whereby extreme weather and climate events could change under climate change, describe the status of research on these areas and mechanisms, give an assessment of the uncertainties involved and provide recommendations on these topics for the IPCC Fourth Assessment Report (4AR). The following are some of the issues we should consider in the Temperature breakout group.

Phenomena creating temperature extremes:

- What types of weather conditions are we assessing?
  - High extremes, low extremes, discomfort extremes (temp + moisture).
- What are their space scales?
  - This impacts the density of the networks needed to thoroughly observe them.
- What are their time scales?
  - What data are necessary to assess them?
    - Monthly means? Daily Tmax, Tmin? Hourly? Synoptic?
  - Persistence of the phenomena.
    - Temporal correlation.
      - Definition of a heat wave is often dependent on its duration.
  - What impact does missing data have on assessing these phenomena?

Analysis of the observations:

- Are long-term changes in temperature extremes spatially cohesive?
- How sensitive are the analysis techniques to data problems such as homogeneity?
- How robust are the changes?
  - E.g., do slightly different ways to calculate an extreme index yield similar results?
- How is the distribution of temperature observations changing?
  - Extremes, mode, all percentiles.
    - How do the tails of the distribution move relative to the mean/median?
- Impact-relevant analyses.
- International coordination of indices that track changes in extremes.
- Globally relevant indices versus regionally specific. For example:
  - Analysis of the number of days below freezing can NOT be applied globally.
  - Changes in bottom or top 10% can be applied globally.
- How to deal with the seasonal cycle.
  - Independent so extreme high temps occur any time of year.
  - Dependent, so extreme high temps are purely a summertime phenomenon.

Data types:

- In situ land-surface weather observations usually come to mind first.
- What other types of data are relevant?
  - Reanalyses?
  - Radiosondes?
  - SSTs
    - What do we want to know over the oceans?
      - Coral bleaching
    - Are the data good enough?
- Data needed for assessing extremes are different than understanding their causes.
  - Understanding their physics may require:
    - Cloud cover, snow cover, surface albedo, near surface wind speed, relative humidity, soil moisture, soil and vegetation type, rooting depth, etc.
    - Many of which are not commonly observed.

## Data problems:

- Quality control typically removes outliers.
  - Yet valid outliers are the extremes we seek to assess.
  - Physical implausibility versus statistical implausibility.
- Homogeneity of the data.
  - Particularly at the tails of the distributions or during specific weather conditions.
  - Little data in the tails to be used to develop statistically based adjustments.
  - Homogeneity adjustments to monthly data are well documented by many groups.
  - But that isn't the case for daily and certainly not hourly data.
  - Significant human resources will be required to develop techniques to adequately homogenize daily or sub-daily data.
- Availability and exchange of metadata is often quite limited.
  - Yet when the type of thermometer changed is important information.
  - For interpreting results.
  - For homogenising the data.
  - How best to encourage additional metadata archaeology and digitization?
- Length of observations.
  - Limited century-scale data available.
  - How best to encourage additional data archaeology and digitization?
- Missing data.
  - The spatial density of the observations.
  - Would the GCOS Surface Network be adequate?
- How best to encourage additional data exchange?
- Exchanging indices rather than original data.
  - May produce greater exchange of information.
  - But we will never be able to go back and critically assess indices derived from data which are not exchanged.
- Producing gridded data sets.

## Modelling of temperature extremes:

- Evaluation of model climatology of extremes.
  - In regions where high quality long-term in situ observations exist.
  - In very data sparse regions.
- Can the model scale capture the phenomena creating extremes?
- Projections of the future.
  - Global, regional.
  - Differences between models.
  - Dependent on modelling of land surface processes?
- In addition to extremes:
  - Mean, variance, stochastic behavior, persistence, etc.
- How few stations in a grid box are acceptable for comparisons to model grid boxes?
- Can we validate models with reanalysis or remotely sensed data?

## Understanding causal mechanisms:

- Separating temperature changes from precipitation.
  - Are extreme high temperature observations due solely to a dry spell?
- Separating long-term changes from short-term oscillations.
  - Which have different causal mechanisms.
  - Particularly difficult where the period of record is short.
- Mechanisms that can cause changes in persistence or temporal correlation.
- Relationships with land surface processes.

## Background material for the breakout group on:

### Precipitation (BG2)

**Dave R Easterling,  
NOAA/National Climatic Data Center, USA**

Definition of precipitation extremes, both wet and dry, what are we talking about here?

Statistically defined precipitation extremes.

- a) parametric statistics: distributions such as log-normal, gamma, normal. What is the appropriate distribution for what time scale.
- b) percentiles: non-parametric, extremes defined by percentile thresholds (e.g. 90<sup>th</sup> percentile threshold might equal 90mm per day).
- c) return period thresholds (e.g. 20 year return period threshold might equal 150mm per day).
- d) indices (Palmer Drought Severity Index, Standardized Precipitation Index (SPI), others?) These can be used for both wet and dry spell analysis.

Event-driven Extremes.

- a) droughts
- b) storm-driven (e.g. thunderstorms, hurricanes, etc.)

Observations.

Scale: both spatial and temporal scales.

- a) spatial scale, local-regional-national-continental-global: what are phenomena and data needed to analyze on each spatial scale?
- b) temporal: hourly, daily, multi-day, monthly, seasonal, annual, decadal, century. What are phenomena and data needs for analysis on each temporal scale.

Data Issues: Availability and Quality.

Instrumental Records. Availability, temporal and spatial resolution.

- a) networks: GCOS, data exchange, maintenance, data poor regions.
- b) quality issues
- c) homogeneity issues.
- d) metadata.

Palaeoclimatology Records:

- a) data type and availability (tree rings, ice cores, written records, etc.).
- b) reliability: strength of association with precipitation extremes (wet and dry).

Physical Mechanisms/Relationships.

- a) Atmosphere/Ocean Oscillations (ENSO, Monsoons, etc.).
- b) Storms: time and space scales: convective storms, tropical cyclones, mid-latitude cyclones, polar lows.
- c) Droughts: surface/atmosphere feedbacks, relations with A/O Oscillations
- d) atmospheric water vapor changes in relation to changes in precipitation extremes.

- e) heavy precipitation and streamflow.

Modelling Issues. GCMs and Regional Climate Models.

Temporal and Spatial Resolution Issues.

- a) access to simulations with appropriate temporal resolution for examining extremes.
- b) spatial resolution necessary to resolve storms.

How well do models simulate mean precipitation?

- a) do they produce a realistic annual cycle?
- b) do they produce realistic numbers of rain-days?
- c) do they produce realistic AO oscillations (monsoons, ENSO, etc.) that may affect extremes?

Do models reproduce observed relationships between mean precipitation and extremes?

- a) on a climatological basis?
- b) under climate change scenarios (e.g. over 20<sup>th</sup> century)?

Are we seeing similarity in changes in model extremes and observed extremes (e.g. climate change detection).

Long-term variability: in limited long (e.g. 1,000 year) simulations do model simulations compare favorably with palaeoclimate results (e.g. palaeo-drought in U.S.)?

Forecasting of precipitation extremes.

Prospects for future modelling efforts.

Other Issues.

Downscaling approaches for extremes: statistical, regional climate model.

Impacts of precipitation extremes.

## Background material for the breakout group on:

### Tropical cyclones (BG3)

**Thomas Knutson,  
Geophysical Fluid Dynamics Laboratory / NOAA, USA**

#### Overall Objectives

- identify areas/mechanisms of extreme weather change
- describe status of research in the areas/mechanisms
- assess uncertainties involved
- provide recommendations on the topics for the Fourth Assessment Report (4AR)

In short, how can scientists provide improved information on possible future Tropical Cyclone behaviour related to anthropogenic climate change for the IPCC 4AR?

#### Tropical Cyclone (TC) related topics:

intensity (maximum wind speed), track, frequency, location, size, precipitation, storm surge, damage potential (impacts based measure), etc. Others?

#### Summary of previous TC/climate change assessments:

- Henderson-Sellers et al. (1998) – for 2xCO<sub>2</sub> – TC intensity: maximum intensity increase of 0 to 20%, although some factors may mitigate this increase, and the changes are small compared to natural variability. TC frequency: no reliable information at present. Note: don't use 26°C isotherm to define region of cyclogenesis in a changed climate. TC damages in U.S. have increased rapidly, mainly due to increasing infrastructure in TC-affected areas.
- IPCC 2001 – for 21<sup>st</sup> century -- TC intensity: peak wind intensities will increase (Likely, over some regions). TC precipitation: mean and peak precipitation intensities will increase (Likely, over some regions). TC frequency and location: past and future changes are uncertain

#### Observations of TCs and TC-related fields:

- Little evidence of significant long-term trends in TC intensity, frequency.
- Prospects for improved historical coverage in terms of time period and different basins?
- Data homogeneity/availability issues in TC historical records (Landsea/Nicholls)
- Historical data quality of TC-related variables – SST, atmospheric temperature, moisture, wind shear; Radiosondes vs. reanalysis issues.
- Retrospective view: Given historical changes in various factors (e.g., SST, atmospheric temperature) how much change in various TC measures would be expected?
- Can Gray's genesis parameters (infer TC frequency from large-scale characteristics of the tropical climate) or MPI theories be further evaluated using interannual variability in the present observational record?
- Can palaeo-reconstruction provide information relevant to the climate change/TC behavior issue?
- Land-use change effects on TCs? (a modelling issue as well)

### Future intensity of TCs:

- Maximum Potential Intensity (MPI) and nested simulations indicate greater upper limit intensities. For nested simulations the intensity change is of the order of 5-10%/100yr. It is only marginally significant in one set of case studies, and mostly not significant in another set of case studies with lower resolution nested model (Walsh), but quite statistically significant in more idealized simulations. Using global models, TC intensity results vary from ~no change to some intensification at high-intensity end of distribution.
- Do MPIs have applicability to the entire frequency distribution of storm intensities, i.e., mean vs. maximum achievable intensity (Emanuel)?
- Status of MPI research/issues (e.g., ocean spray effects)?
- How robust are nested simulations or MPI results to use of different models? Both host GCM and the MPI method or nested model? Resolution and physical parameterization effects?
- Regional dependence? El Niño-like warming and future ENSO still uncertain but can impact results.
- Atmospheric temperature and moisture are important for TC intensities, not just SSTs (Shen et al., MPI theories). How reliable are profiles of atmospheric temperature and moisture changes in global climate change experiments?
- How important are dynamical effects vs. thermodynamical effects? Do present models adequately simulate the effects of wind shear on TCs?
- Small signal relative to observed variability – difficult to detect changes?

### Future frequency of TCs:

- Little consistency so far between global model results (even sign of change varies).
- Are all model simulations for climate change equally plausible or are some studies more reliable than others?
- Sources of differences among studies: Differences in SST changes (magnitude and regional structure), physical parameterizations, methods of counting storms, experimental design (specified vs. computed SSTs; mixed layer vs. coupled models), model resolution, radiative forcing, sample size, etc.
- Opportunities for evaluating models: seasonal cycle and spatial pattern of TC occurrence by basin. TC spatial structure, intensity, tracks. Interannual or interdecadal variability of TC frequencies in AMIP integrations.
- Gray's genesis parameters: Should it be used more routinely to evaluate tropical part of GCM control runs? How can it be modified for use in climate change context?
- Windspeed extremes – an alternative to counting storms in GCMs (e.g., Kharin and Zwiers maps)
- Is there a preferred method of assessing TC frequency changes in current generation models?
- Tropical cyclogenesis still very much a research topic: is simulated cyclogenesis in GCMs realistic i.e., does it occur for the right reasons?

### Future TC-related precipitation

- Larger percentage increases in TC-related precipitation than in TC wind speeds according to nested hurricane model simulations
- Changes in precipitation from TCs have potentially large societal impact.
- TC-related precipitation changes not evaluated in most TC/climate change simulation studies.



- How can global model or regional model TC precipitation simulation best be evaluated for the present climate?
- Robustness of precipitation changes to different models (either host GCM or nested model)?
- Precipitation change may potentially be more detectable with larger signal, but is data adequate? How large would the change need to be in order to be detectable?

#### TC tracks/location

- More poleward occurrence of TCs- still limited to Walsh study for S. Pacific region. Robustness of result?
- Tracks/location can have important societal effects
- Resolution effects on TC track simulations?

Storm surge – sea level rise influence, TC intensity influence

Experimental design issues – recommendations for consistent methodologies?

Observing systems for the TC/climate problem – critical needs and recommendations?

Working Group I (Science) / Working Group II (Impacts) integration issues?

## Background material for the breakout group on:

### Extra-tropical cyclones (BG4)

Jean Palutikof,  
Climatic Research Unit (UEA), UK

#### Definitions

##### How to define extra-tropical cyclone severity?

Pressure characteristics: central pressure, pressure gradient

Cyclone characteristics: size, speed of movement, length of life

Wind speed characteristics: gust speed, maximum daily mean wind speed etc.

Impact: property damage, forest damage, insured vs. economic damage

- Association of cyclones with heavy rainfall/snow
- Track position relative to high density population clusters
- Regionally-specific definitions of cyclone severity (relative to, for example, building standards)

##### How to identify and track extra-tropical cyclones?

Manual tracking from charts

Automated tracking schemes

Can we apply more widely the experiences gained/techniques developed for weather forecasting?

##### Other approaches to defining storm events.

Pressure triangles, e.g. as used by the WASA group, to calculate geostrophic wind

Construction of site-specific time series based on indices such as:

- annual lowest recorded pressure,
- number of days when pressure drops below defined thresholds
- Jenkinson gale index

Storm catalogues (e.g. as compiled by Lamb and Risk Management Solutions)

Can we define best practice for identifying climate change-related trends in storminess? e.g., the 'best' tracking algorithm, the best measure of site-specific storminess.

#### Data considerations

##### Data sets for the development of cyclone climatologies (past and future)

Present-day:

Re-analysis datasets for the present day and historical past (NCEP, ECMWF)

Forecasting charts

Campaigns e.g., the three one-month Special Observing Periods of the Antarctic

First Regional Observing Study of the Troposphere (FROST) project

Satellite data

Future

GCM/RCM data for the future

##### Data requirements for construction of cyclone climatologies:

What variables should be used?

- Sea level pressure
- Geopotential height
- 500 hPa bandpass geopotential height variability

What time step is necessary to ensure cyclones are correctly identified?

What grid resolution is necessary to ensure cyclones are correctly identified?

Data for site-specific time series of storm indices:

Pressure data for calculation of:

- geostrophic wind,
- gale indices
- indices of extreme low pressure

Wind data – gust speeds, mean wind speeds, maximum daily wind speed

Data accuracy in the historical record

How homogeneous are these data sets in time?

How likely is it observed trends are spurious?

What methods are available for testing for inhomogeneities?

Can we define best practice in testing for inhomogeneities?

Data accuracy in the climate models

What variables should we be evaluating? Sea level pressure, geopotential height (and variability), wind speed?

How should we validate these variables – what statistical techniques should be used?

Can we make use of statistical downscaling techniques?

Can we define a set of the ‘best’ statistical measures for evaluating the performance of climate models?

Analyses of cyclone occurrence

What measures of change are important? Need to consider these measures in the light of extra-tropical cyclone impacts e.g., shift in position of tracks, shift in direction of approach of storms may be as important as size and intensity.

How can the storminess analyses be used to look at the impacts on secondary (mainly oceanographic) characteristics such as storm surge, wave height etc.?

Do we need to analyses storminess taking into account related variables such as rainfall? A ‘wet’ storm will cause more damage than a ‘dry’ storm.

How can we identify and meet the needs of colleagues working in WGII?

Can we establish globally consistent methodologies for detecting changes in observations and analysing changes in models?

What statistical techniques are useful? Can we define best practice? Can we develop software for statistical analyses?

Understanding causal mechanisms

Relationships to, for example, sea surface temperatures, NAO, AO, AAO etc

What are the underlying mechanisms which might lead to future changes in storminess?

Regional issues

Need to explore change outside the most studied regions e.g., Mediterranean, Arctic, and especially the Southern Hemisphere.

Need to enlarge scientific community addressing these issues through, for example, developing capacity to analyse local data on windstorms. Useful in this context to develop a globally consistent approach.

What are the critical needs from the climate observing system. How can this system be maintained/enhanced? Where are the critical needs?

## **Background material for the breakout group on:**

### **Small scale Severe Weather Phenomena (SCSWP) (BG5)**

**Rudolf Brazdil,  
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The breakout group SCSWP should concentrate on evaluation of existing knowledge concerning SCWSP from the point of view of selection of SCSWPs, their observations, data and its quality, methods of analysis, existing results and their regional up to global presentation, mechanisms and modelling, relation to global warming and recommendations for the IPCC Fourth Assessment Report (4AR). The following topics should be addressed in the SCSWP breakout group:

#### **1) Definitions**

- What phenomena and events should be selected as SCSWP?
- What SCSWP have the potential to be studied in local, regional, supra-regional and global scales?
- What SCSWP are relevant for study of the global climate change?
- What is definition of “extreme event” in the case of selected SCSWP (according to frequency, intensity, impacts or damage)?

#### **2) Observations and data**

- What are the potential and limitations of contemporary observations of SCSWPs at the national networks of meteorological stations?
- What is availability of data about SCSWP at national meteorological services and agencies from point of view of its characteristics, quality and lengths of observations?
- What methods should be used for homogenisation of SCSWP records?
- What physical relations between different SCSWPs might be used for improvement of quality of data?
- What homogeneous long-term series of SCSWPs are recently available?
- What new observing methods and systems, including global ones, might be used for observing of SCSWP?
- Is there any potential for creation of SCSWP monitoring and database at the international or global levels?
- Is there any potential for including data about SCSWP from sources outside of meteorological services (such as insurance industry and other special agencies or institutes)?

#### **3) Analysis**

- What are basic characteristics of SCSWPs for their statistical analysis (occurrence of events – frequency, number of days with events, number of days with damage, intensity of event – classification)?
- What are the spatial correlations between the same and different SCSWPs and how it can be used for improvement of data quality?
- How to analyse extremely spatially and temporally discontinuous information about SCSWPs (station series – regional series – supra-regional series)?
- For what characteristics of SCSWP is it useful to develop their series in the regional up to global scales?

**4) Contemporary knowledge**

- Do we know well the climatology of SCSWP in different regions of the world and in different scales (from regional to global ones)?
- Do we have analysis of long-term series of SCSWPs showing their trends for the last decades?
- Are there any consistent trends in characteristics of SCSWPs in different areas of the world?
- What are the main physical mechanisms contributing to similar/opposite trends of SCSWP characteristics in different areas of the world?
- Is there any evidence of changes in SCSWP characteristics in relation to the observed global warming?
- What factors are potentially the most important for future changes in SCSWPs?

**5) Modelling of SCSWP and climate scenarios**

- What is the potential of recent climate models for modelling of occurrence and intensity of SCSWPs?
- What is the potential of recent climate models for modelling of climatology of SCSWPs in different temporal and spatial scales?
- What is the potential of climate models for projections of future SCSWP (occurrence, seasonality, intensity, impacts) for continuation of global warming?
- What information about SCSWP is useful for impact studies?
- What can downscaling bring for including SCSWP into the regional climate scenarios?

**6) Recommendations for the IPCC Fourth Assessment Report**

- Focus on selected SCSWP with high quality data and important impacts.
- Monitoring and storing of data about SCSWPs on national and international scales.
- Selection of long-term series of SCSWP in different parts of the globe.
- Study of recent trends of SCSWPs in different spatial and temporal scales (selection of model areas).
- Relation of SCSWPs to global warming.
- Modelling possibilities of SCSWPs.
- Future projections of SCSWPs and their inclusion in climate impact scenarios.

## Background material for the breakout group on:

### Statistical diagnostic methods and techniques (BG6)

**David Stephenson,  
University of Reading, Department of Meteorology, UK**

The four main aims of this breakout group are listed below together with suggestions for some of the most important issues that need to be addressed:

1. To identify areas and mechanisms whereby extreme weather and climate events could change under climate change:
  - Response of extremes to changes in the mean
  - Response of extremes to changes in variance – trends in variance?
  - More complicated structural change leading to changes in shape, dependency, etc.
2. To describe the status of research on these areas and mechanisms:
  - Review previous ideas on how climate change might change extremes
  - Identify areas that need to be addressed (e.g. trends in variance)
  - Discuss a common strategy for analysing extreme events statistically
  - Status of research concerning optimal indices for monitoring extremes
3. To give an assessment of the uncertainties involved:
  - Uncertainties due to sampling (that can be quantified by providing interval estimates)
  - Uncertainty due to small sample size and poor estimation methods (e.g. block maxima)
  - The need for Extreme Value Theory (EVT) probability modelling as well as descriptive empirical approaches
  - Uncertainties caused by changes in variance and how it is handled by homogenization
4. To provide recommendations on these topics for the IPCC Fourth Assessment Report (4AR):
  - Use parametric EVT modelling in addition to descriptive empirical techniques
  - Use improved estimation methods rather than data wasteful approaches
  - Use spatial pooling (regional analysis) to increase sample sizes
  - Interpret the four main attributes of extremes rather than focusing solely on rate
  - Diagnose changes in terms of changes of location (mean) and scale (variance)
  - Address extreme dependency using extremal index, and regression on large-scale covariates and time parameter.
  - + any others that may arise ...





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## Annex G: Acronyms and Abbreviations

4AR	IPCC Fourth Assessment Report
AAO	Antarctic Oscillation
AIACC	Assessments for Impacts and Adaptations to Climate Change
AMIP	Atmospheric Model Intercomparison Project
AO	Arctic Oscillation
AOGCM	Atmosphere-Ocean General Circulation Model
APN	Asia Pacific Network
BG	Breakout Group
CLICOM	Climate Computing Project
CLIVAR	Climate Variability and Predictability
CMIP	Coupled Model Intercomparison Project
DDC	IPCC Data Distribution Centre
ECA	European Climate Assessment
ECHAM	ECMWF/MPI Atmospheric GCM
ENSO	El Niño-Southern Oscillation
ETC	Extra-Tropical Cyclones
EVT	Extreme Value Theory
GCM	General Circulation Model
GCOS	Global Climate Observing System
GTS	Global Telecommunications System
HadCM	Hadley Centre Coupled Model
IPCC	Intergovernmental Panel on Climate Change
MPI	Maximum Potential Intensity
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
PAGES	Past Global Changes
PBL	Planetary Boundary Layer
RCM	Regional Climate Model
RBCN	Regional Basic Climate Network
SCSWP	Small-scale Severe Weather Phenomena
SST	Sea Surface Temperature
START	System for Analysis Research and Training
TAR	IPCC Third Assessment Report
TC	Tropical Cyclones
UNFCCC	United Nations Framework Convention on Climate Change
WASA	Waves and Storms in the North Atlantic
WCP (CLIPS)	World Climate Programme (Climate Information and Prediction Services)
WCRP	World Climate Research Programme
WGI	IPCC Working Group I
WGII	IPCC Working Group II
WGIII	IPCC Working Group III
WGCCD	WMO Commission for Climatology/CLIVAR working group on climate change detection
WMO	World Meteorological Organization