US CLIVAR Working Group Prospectus:
Large Scale Circulation Patterns Associated With Extremes

1. Motivation

Extremes have large societal and economic consequences. Heat waves cause a larger annual number of weather related deaths (170) than hurricanes (117) or flooding (74) in a 10-year average (1997-2006). While many heat waves are short-lived (e.g. Chicago, 12-15 July 1995, 500-1000 fatalities) longer events can have a large economic cost (e.g. $55B heat wave in the central part of the US during much of the summer of 1980). Cold air outbreaks (CAOs) tend to be short-lived but carry large economic losses: $5.5B 20-30 December 1990, $1.4B 13-17 January 2007 in California; while in Florida: $4.2B in 1983 and $2.3B in 1995. Timing of the cold can be more important than the minimum temperatures of the freeze; during 4-10 April 2007 low temperatures across the South caused $2B in agricultural losses since many crops were in bloom or had frost sensitive buds or nascent fruit. The event also exemplifies how monthly means can be misleading: April 2007 average temperatures were near normal. In Florida during December 1989, 2 days of subfreezing weather wiped out half the citrus *trees*, though the monthly mean temperature was above normal. In short, several types of extremes that have high impact are short term events that do not necessarily appear in monthly mean data.

Here we focus on short-term (five-day or less) extreme precipitation and temperature events for North America to keep the problem manageable and reduce overlap with existing efforts. The societal and economic impacts of such events can be severe and may become worse in a warming climate. Such events in both observations and models are receiving considerable attention (including research papers, e.g. Meehl and Tibaldi, 2004; and active websites: http://www.esrl.noaa.gov/psd/ipcc/extremes/ and http://gmao.gsfc.nasa.gov/research/subseasonal/atlas/Extremes.html). However, the large-scale circulation patterns (**LSCP**s) and underlying dynamical mechanisms associated with such extreme events are less well-known. As a starting point, precipitation extremes will be considered in terms of both daily and five-day means, which captures most of the big impact single events. Additional narrowing will exclude tropical cyclone related events and the emphasis will be upon the cold season when LSCPs are likely to be better defined. Defining extremes is not straightforward and will be one of the focus areas of the workshop. Similarly, temperature extremes will include both short-term hottest days (warm season) and CAOs (winter and spring) though the greater amount of research literature predicts an emphasis on extreme hot events. Our region is North America. While extreme events of interest to the WG occur over smaller regions and we expect participants to select such regions based on their interest and experience, we seek to maximize participation by not imposing a regional filter at the start.

A few studies have shown that extreme events are associated with LSCPs that have a spatial scale bigger than mesoscale systems but smaller than the near-global scale of some modes of climate variability. The LSCs are distinct from named climate modes (such as the NAO) though such modes may influence an extreme event. . Several studies (Carrera et al., 2004; Grotjahn and Faure, 2008) identified the LSCPs associated with specific extreme hot and CAO events. In addition, several studies (Lackmann and Gyakum, 1999; Bosilovich and Schubert, 2001; Grotjahn and Faure, 2008) have shown LSCPs associated with situations of heavy precipitation. An extreme precipitation event on 1998/02/02 in Grotjahn and Faure (2008) is related to a so-called atmospheric river (AR; Ralph and Dettinger, 2011) phenomenon, which is related to the MJO (Guan et al. 2011). So the extreme precipitation event is not simply viewed as a result of a vigorous extratropical cyclone but also with high water vapor content concentrated in an AR. Parts of these LSCPs tend to be uniquely associated with the corresponding extreme weather and those parts have some predictability (Grotjahn, 2011; Jones et al. 2011). Extreme events have also been linked to circulation indices like the NAO (Guirguis et al., 2011) and the MJO (Mo and Higgins 1998; Moon et al. 2011; Guan et al. 2011).

Establishing a link between extreme events that are rare, and occur on a smaller space and time scale, with LSCPs provides a means of utilize climate model simulations to study variability of extremes under a changing climate. However, the overall relationships between extreme events and LSCPs for North America are not well known -- and we can anticipate large variations by variable (precipitation and temperature), by climatic region, and by season. Also, interactions with local topography probably play key roles for at least some extreme precipitation events. In addition, there is a knowledge gap in how well climate models simulate these LSCPs, including ARs; if a model simulates them poorly then the model may not develop extreme weather adequately or for the wrong reason. This is a critical question for understanding the uncertainty of future projections and for driving model improvements.

Now is an opportune time to examine the critical issues discussed above and identify key knowledge gaps in the understanding of climate extremes and their variability and trend because: 1) we don't know if the current climate models used for future projections are producing extremes with the correct dynamical mechanisms, which reflects directly on the appropriate confidence in the projections, and 2) knowledge of the circulations may be used for downscaling – global models which can't reproduce the extremes accurately may still be able to capture the correct LSCPs. Finally, there is now sufficient preliminary work to make the proposed effort reasonable.

The key organizing questions are: Do current climate models produce extremes for the right reasons? Further, can they be used for predicting and projecting climate extremes?

2. Objectives

The main objectives of the working group are:
1) Assess and synthesize existing knowledge base on the links between LSCPs and extremes, and
2) Identify key questions and knowledge gaps;
3) Establish a methodology and research protocols for using the LSCP approach to analyzing extremes in observations and model output;
4) Provide a preliminary assessment of the ability of current models to reproduce the correct relationship between extremes and LSCs for North America

The first two objectives will be accomplished by the working group itself and will result in a journal review article. The third objective will be accomplished by developing expert opinion through a workshop and will result in a CLIVAR Exchanges article. The fourth objective will be accomplished in part by the workshop (as participants are likely to share examples of their assessment work with specific: models and extreme events) and in part by post-workshop efforts to apply knowledge gained (in the third objective) to refine such assessments. It is anticipated that a journal article making a preliminary assessment will arise as a collaborative effort by working group members and participants in the workshop.

The proposed specific tasks are:
1. *Assess and synthesize existing research and identify key knowledge gaps.* This task will be led by the working group and will result in the submission of a review article. The article will examine different ways of identifying extremes, establishing relationship between extremes and LSCPs, limitations of data sets, identification of knowledge gaps (dynamical mechanisms, geographic regions, seasonality, etc.).

2. *Convene a workshop to establish methodology and research protocols for the LSC approach, and to help build a network of "extremes" researchers*. One of the foci of the workshop will be to develop research protocols and enhance knowledge sharing amongst the research community for this topic. There are many different ways to identify and analyze extremes so comparing different results is hard; data sets

have a range of limitations that aren't always widely known or appreciated; data sets for the short time scales of extremes are not always easy to obtain, especially for long modeling runs. There is value and opportunity to either come up with data protocols (data needed for this kind of work) or with trying to identify appropriate data. Related topics as an outcome of the workshop will include: how to choose between different methods of defining and identifying extremes? What may be different possible techniques to establish connection between extremes and LSCs? (composites, regressions, etc.) What observational data is there? (station observations and large scale reanalysis) What statistical methods are there to identify and assess the extreme events and the LSCPs associated with them including multivariate statistics.

We will also consider the 'synoptic-dynamics' of why a particular large scale pattern fosters a given extreme event. Beyond physical mechanisms that relate a certain extreme to a certain LSCP, there are issues of seasonal variation and so forth. As part of the proposed activity, we may consider interactions with other short-term extremes with longer-term fluctuations. We will liaise with the hurricane working group for tropical cyclone impacts.

3. Provide a preliminary assessment of where the current climate models stand in their simulation of LSC and possibility for downscaling. This task will draw on the results of the workshop, and include other interested researchers from the workshop. How does the current generation of climate models (e.g., CMIP3 or CMIP5) stack up in the assessment of some key features of the LSCPs associated with extremes? Assessing the ability of models to simulate the upper air LSCPs keeps the task focused, since simulation of the surface extreme values needs both the large scale pattern and proper simulation of many other things: surface energy balance, precipitation physics parameterization, etc. The WG will weigh in on the proper ways to apply analysis of LSCPs to understand model performance in creating extreme events. This includes how to resolve potential criticisms about how to properly identify the LSCPs in model data, for example, when dealing with a trend in the upper air variables, either an area-wide one or a distortion of the mean pattern. Another potential line of criticism concerns a shift in the probability density function (PDF)of surface values so that exceeding some absolute temperature becomes 'easier' and hence the LSCP may not be so distinct. At the simplest level, finding LSCPs in the models becomes analogous to work done in other contexts to look for some other type of circulation pattern such as looking for AO/NAO/MJO patterns in climate model simulations and discussing how a model's AO/NAO/MJO climatology compares with observations. At higher levels of sophistication, the WG could provide some valuable insight on how to proceed.

The impact of LSCP simulation upon downscaling by a regional model will also be considered.

Timeline of activities

<u>Year 1:</u>

-WG drafts review paper on previous work, identifies key questions
-WG develops plans and early organization of the workshop to be held in Year 2
-WG identifies possible approaches for a preliminary assessment of current model skill at capturing LSCP-extreme events links

<u>Year 2:</u>

-Review paper submitted
-Organize and hold the workshop to develop methodology and research protocols
-Based on workshop, WG and other interested researchers draft a paper that uses the developed methodology to provide a preliminary assessment of current model skill

Anticipated outcomes and benefits to US CLIVAR

The ***outcomes*** of the proposed effort will provide a direction for research efforts that will enable advancements to our understanding of variability of extremes under a changing climate. This goal will be achieved by: (a) a review paper that will assess and synthesize previous work, and will identify key questions and knowledge gaps; (b) developing a LSCP-based methodology to link extremes with LSCPs that can be used to assess climate models; and (c) providing a preliminary assessment of current model skill at capturing the LSC-extreme relationship and the associated potential for downscaling.

The ***benefits*** to US CLIVAR will be an organized effort that targets a key problem of societal importance, and development of a new methodology for examining extreme events and assessing future projections, and a preliminary assessment of the ability of current climate models to accurately represent extremes over North America. The activities will also build a community of researchers interested in the analysis and simulation of extreme events. The efforts of the WG will directly contribute the US CLIVAR goals of "*Identifying and understanding the major patterns of climate variability*" from the perspective of the patterns important to extremes, and "*Evaluating and enhancing the models used to project climate change due to human activity,*" through the model assessment. The potential for downscaling may also contribute to shorter-term intraseasonal to decadal projection as well.

3. Publications and Outreach

The publications resulting from the proposed effort will be:
1)a review paper that summarizes previous research;
2) a CLIVAR Exchanges paper that summarizes new methodology developed through workshop and key questions identified; and
3) a paper that demonstrates methodology and provides a preliminary assessment of current model skill and potential for downscaling. The primary outreach will be through a workshop.

4. Reporting Plan

This WG has relevance to the PPAI, POS, and PSMI panels. Indeed, the idea for this WG was jointly created by several members of the POS and PPAI panels. Hence we propose to report our progress to both of these panels and seek their advice and support. We propose to report on our progress at the annual US CLIVAR summit.

5. Leadership and Suggested Membership

The following lists indicate the proposed membership of the working group. The WG core members were actively involved with the development of this prospectus and the core members sample the broad expertise being gathered for this effort. Additional lists of people who should be considered for membership follow as indicated. Working group members will be encouraged to include any junior colleagues (e.g., graduate students and post docs) to participate in all aspects of the working group's activities.

<u>WG core members</u>

Richard Grotjahn – Co-Chair (UC Davis): Climate and large-scale dynamics, synoptics of hot and cold extremes and extreme frontal cyclone precipitation, climate modelling of extremes

Mathew Barlow – Co-Chair (UMASS Lowell): Influence of large-scale climate variability and change on local conditions, contribution of tropical cyclone-related variability to North American extreme precipitation

Michael Bosilovich (GMAO, NASA/GSFC): Reanalysis and data issues

Alexander Gershunov (Scripps; UC San Diego): Global and regional climate variability on daily to multi-century time scales; extreme events; teleconnections; long-range seasonal predictability of extreme weather statistics

Arun Kumar (CPC NCEP/NOAA): Seasonal climate variability and predictions; weather-climate connection; diagnostics of climate models
Joshua Xiouhua Fu (U. Hawaii): Tropical dynamics, modeling and prediction of monsoon, MJO, and extreme events

Other suggested members
Nick Bond (U. Washington): LSCPs in NW heat waves and extreme air pollution events now and in future climate
Rick Katz (NCAR) or *Eric Gilleland* (NCAR) Experts in extreme statistical methods applied to meteorological data
Robert Black (Georgia Tech):LSCPs and extreme weather in SE US
Martin Hoerling (NOAA): Analysis of extreme events
Siegfried Schubert (NASA): Analysis of extreme events
Claudia Tibaldi (Climate Central): Analysis of extremes, statistical techniques, projections
Russ Schumacher (CSU): Causes of US extreme rainfall
William Gutowski (Iowa State): Changes in extremes, regional assessment
Arthur DeGaetano (Cornell): Trends in temperature extremes, Director of Northeast Regional Climate Center

International Contributing Members
Tereza Cavazos (CICESE, Mexico): Extreme rainfall events associated with the North American monsoon and tropical cyclones; observed trends; extremes under climate change conditions. Member of extremes working group of CLIVAR-VAMOS panel.
John Gyakum (McGill U., Canada): Synoptic-dynamic meteorology, extreme precipitation from midlatitude systems.

6. Resource Requirements

-Travel support for two annual WG meetings
-Publication chargers for two journal articles
-Organizational support for a 50-participant workshop
The WG will meet once per year for 2-3 days and will hold monthly teleconferences.

References available on request