Working Group on:
Large Scale Circulation Patterns Associated With North American Short-term Temperature and Precipitation Extreme Events

Co-Chairs: Richard Grotjahn and Mathew Barlow

26 May 2015

Working Group Members

US Members	Institution
Matt Barlow (co-chair)	U. Massachusetts
Robert Black	Georgia Tech
Joshua Xiouhua Fu	U. Hawaii
Alexander Gershunov	UC San Diego/SIO
Richard Grotjahn (co-chair)	UC Davis
Bill Gutowski	Iowa State U.
Rick Katz	NCAR
Arun Kumar	NOAA/NCEP
Lai-Yung (Ruby) Leung	PNNL
Young-Kwon Lim	Florida State U.
Russ Schumacher	Colorado State U.
Michael Wehner	UC Berkeley/LBL

US Contributing Member

Mike Bosilovich	NASA/GSFC
Tony Barnston	Columbia U.

International Contributing Members

Teresa Cavazos	CICESE, Mexico
John Gyakum	McGill U., Canada

Main Activities of the Extremes WG

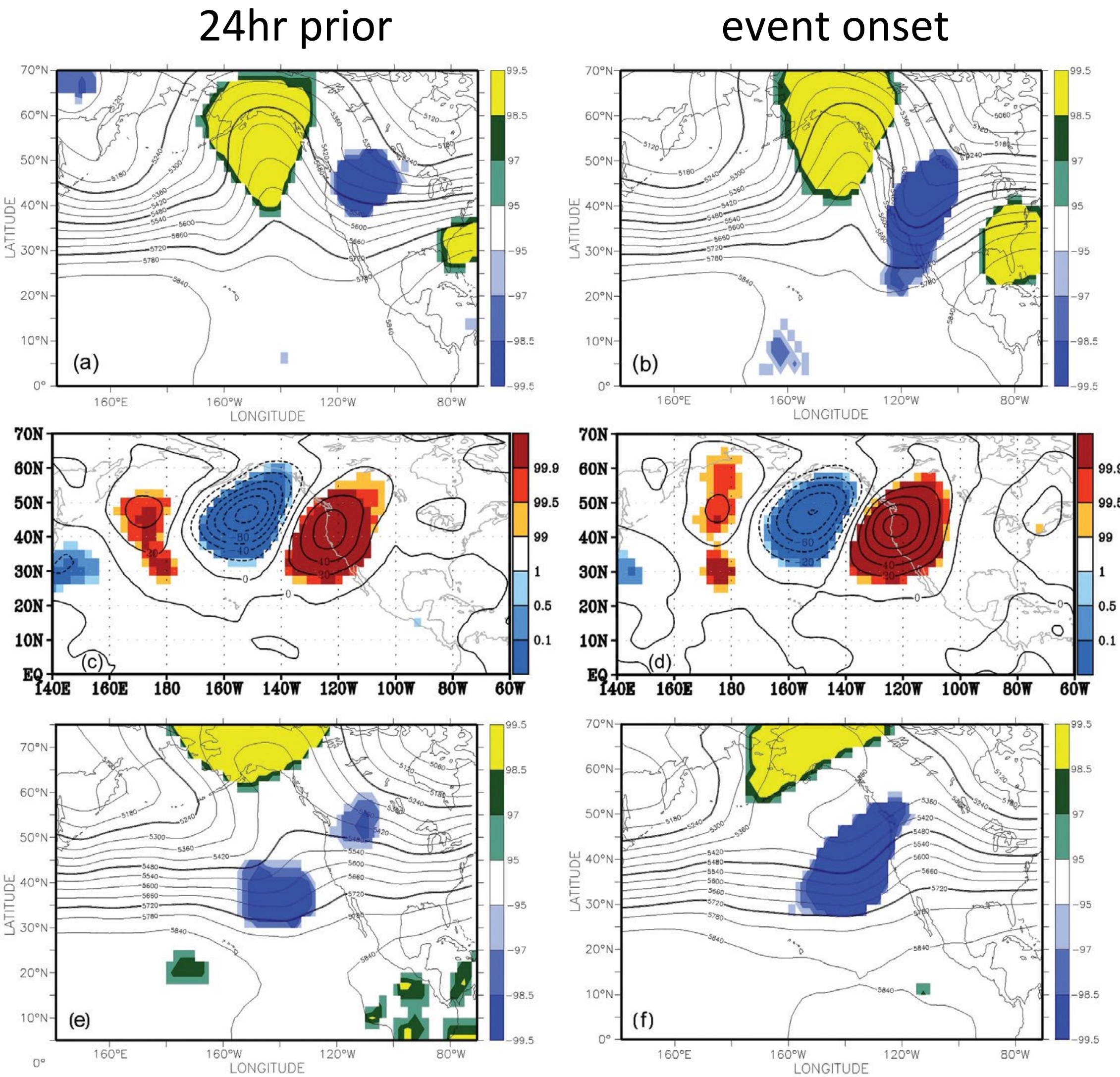
1. Workshop held in Berkeley, August 2013
2. Special issue of US CLIVAR *Variations* (Winter 2014)
3. Workshop report, with detailed recommendations, published June 2014
4. Contributions relating to extreme events in the US CLIVAR Science Plan (summer/fall 2014)
5. Input to CMIP6 planning
6. Major publication in *Climate Dynamics* on temperature extremes over North America
7. Major publication in preparation on precipitation extremes over North America (drafted)

Jargon: LSMP

1. Large Scale Meteorological Patterns (LSMPs)
2. LSMPs are the synoptic patterns in atmospheric variables at multiple levels that cause the extreme event.
3. Synoptic time scale (a few days)
4. Tend to be equivalent barotropic
5. Have ocean basin and/or continental scale
6. Differ from low-frequency modes

Examples: California LSMPs in Z_{500}

- Shading indicates unusual values
- Top row: CAOs
- Middle row: *anomaly fields* for heat waves
- Bottom row: extreme P
- Left column: 24 hours before onset; Right column at onset



Berkeley Workshop, 20-22 August 2013

- Analyses, Dynamics, and Modeling of Large Scale Meteorological Patterns Associated with Extreme Temperature and Precipitation Events
- Objectives:
  - Establish methodology and protocols for using LSMPs in statistical, dynamical, and synoptic analyses
  - Preliminary assessment of climate model simulation and downscaling connection to T & P extreme events
- Topics: 1) Data, 2) Statistics, 3) Synoptics and Dynamics, 4) Modeling

Special Issue of Variations

- Winter 2014 issue
- 6 articles plus a summary introduction
- Based on selected workshop presentations

US CLIVAR
Climate Variability & Predictability
VARIATIONS
Winter 2014 • Vol. 12, No. 1

Diagnosing temperature and precipitation extremes

Mathew Barlow
University of Massachusetts Lowell, Guest Editor

Extreme events have large societal impacts and are an important part of understanding the effects of climate change. Short-term events lasting less than a week can have important impacts but are not well-represented by typical monthly or seasonal analyses. To focus on these events and their dynamics, US CLIVAR established a working group in 2012 on the large-scale meteorological patterns (LSMPs) associated with short-term extremes of temperature and precipitation for North America. The large-scale patterns can be well-resolved in current models and observational data, and allow for an assessment of model dynamics as well as the possibility of downscaling. Two key motivating questions are: what are the dynamics of these events and how well do current models capture the dynamics?

The working group held a workshop in Berkeley, CA in August 2013, with an emphasis on combining the areas of statistics, observational data, modeling, and dynamics to explore methodologies for identifying and analyzing the large-scale patterns and to identify key issues.

Extreme precipitation events: Data issues and meteorological causes

Kenneth E. Kunkel[1,2] and David R. Easterling[2]
[1]NOAA Cooperative Institute for Climate and Satellites, North Carolina State University
[2]National Climatic Data Center

Numerous papers have documented an increase in extreme precipitation events in the US over the past 30 years or so. The fundamental cause of this trend is a subject of active research. The purpose of this study is to examine the meteorological factors that underlie the trend, specifically to determine the contributions of the major types of meteorological precipitation-producing systems to the observed secular variations in heavy precipitation event frequencies. The analysis of the meteorological causes covers the period of 1908-2009.

A set of 930 long-term stations from the US National Weather Service's Cooperative Observer Network (COOP), distributed throughout the US, is used to identify extreme daily heavy precipitation events. A recent project has undertaken the keying of pre-1948 data, which hitherto has been mostly in paper form only (Dupigny-Giroux et al. 2007). A subsequent project has undertaken the quality control of the newly-keyed data (Kunkel et al. 2005). The dataset used for identification of extreme precipitation events is a combination of this newly-available quality-controlled data and the post-1947 data that has been routinely quality-controlled through the years by the National Climatic Data Center.

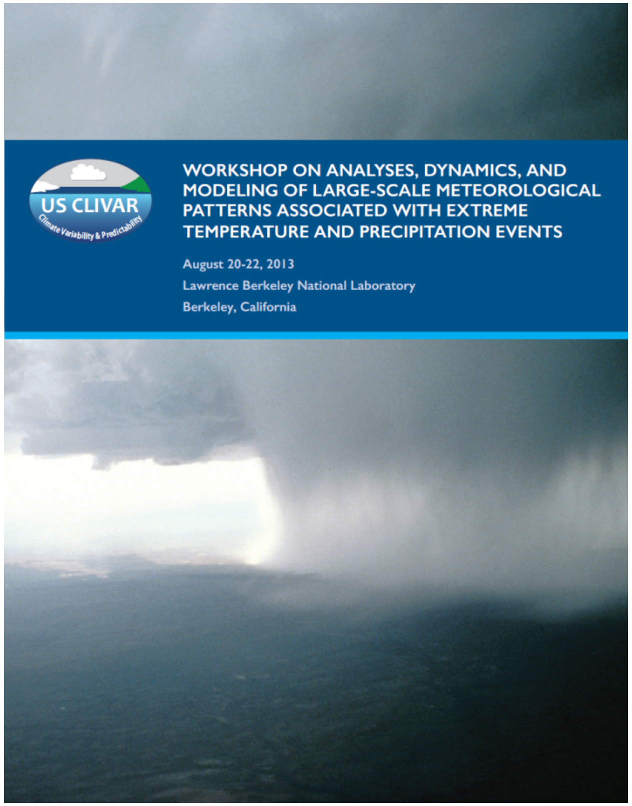
Extreme events are defined as daily precipitation totals exceeding the threshold for a 1 in 5 year recurrence. A total of 18,322 events are examined. The meteorological cause of each event is identified as one of the following: extratropical cyclone near a front (ETC-FRT), extratropical cyclone not near a front (ETC-NFRT), tropical cyclone (TC), mesoscale convective system (MCS), air mass convection (AMC), North American Monsoon (NAM), and upslope flow (USF). The effort has been intensive, because the assignment of a cause is done by expert judgment using several supporting pieces of information, including surface pressure fields

IN THIS ISSUE

Extreme precipitation events: Data issues and meteorological causes 1
Statistical methods for relating temperature extremes to Large-Scale Meteorological Patterns 4
Self-Organizing Maps: A method for analyzing
Large-Scale Meteorological Patterns associated with extreme events 7
Diagnosing Large Scale Meteorological Patterns associated with temperature extremes
in models and observations 11
The low frequency modulation of anomalous temperature regimes during winter 13
The making of an extreme event: Putting the pieces together 17

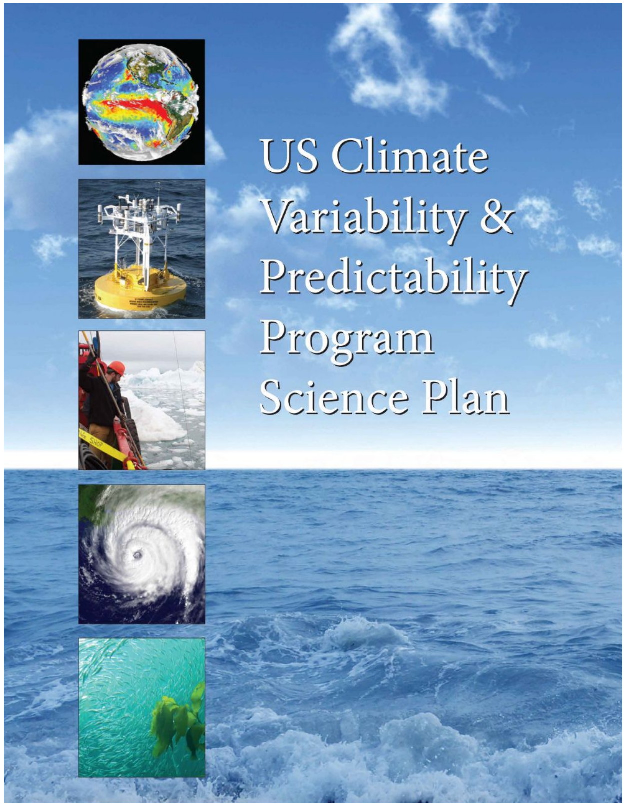
Berkeley Workshop Report, 10 June 2014

- Summarizes present state of knowledge and methodologies in:
  - Data and methodologies
  - Statistical methods and applications
  - Synoptic-dynamics methods and applications
  - Modeling approaches and issues
- Detailed recommendations
  - Data needs
  - Statistical tools needs
  - Synoptic-dynamic knowledge gaps
  - Modeling needs
  - Other general recommendations



US CLIVAR Science Plan, 2013

- Mainly section 5.2:
  - on climate extremes.
  - one of four research challenges
  - Definition
  - Significance: scientific, societal
  - Dynamics of: droughts, hurricanes, precipitation, temperature
  - Future research: observational & model issues, infrastructure, applications, focused efforts



CMIP6 , 2014

- WG commented on CMIP6 planning
- Primary issue:
  - providing adequate data to study simulated extremes (higher spatial and time resolution than in the past)

Temperature extremes paper

1. Covers 5 major topics:
    1. Data issues
    2. Methodologies for identifying the LSMPs
    3. Synoptic-Dynamics of LSMPs
    4. Model simulation of LSMPs and T extremes
    5. Trends in T extremes
2. Knowledge gaps identified and key, targeted questions listed
3. 13 authors, 34 journal pages
4. Published **Open Access** in *Climate Dynamics*, 22 May 2015.
5. DOI: 10.1007/s00382-015-2638-6

Clim Dyn
DOI 10.1007/s00382-015-2638-6

CrossMark

North American extreme temperature events and related large scale meteorological patterns: a review of statistical methods, dynamics, modeling, and trends

Richard Grotjahn[1] · Robert Black[2] · Ruby Leung[3] · Michael F. Wehner[4] · Mathew Barlow[5] · Mike Bosilovich[6] · Alexander Gershunov[7] · William J. Gutowski Jr.[8] · John R. Gyakum[9] · Richard W. Katz[10] · Yun-Young Lee[1] · Young-Kwon Lim[11] · Prabhat[4]

Received: 7 August 2014 / Accepted: 4 May 2015

Abstract The objective of this paper is to review statistical methods, dynamics, modeling efforts, and trends related to temperature extremes, with a focus upon extreme events of short duration that affect parts of North America. These events are associated with large scale meteorological patterns (LSMPs). The statistics, dynamics, and modeling sections of this paper are written to be autonomous and so can be read separately. Methods to define extreme events statistics and to identify and connect LSMPs to extreme temperature events are presented. Recent advances in statistical techniques connect LSMPs to extreme temperatures through appropriately defined covariates that supplement more straightforward analyses. Various LSMPs, ranging from synoptic to planetary scale structures, are associated with extreme temperature events. Current knowledge about the synoptics and the dynamical mechanisms leading to the associated LSMPs is incomplete. Systematic studies of: the physics of LSMP life cycles, comprehensive model assessment of LSMP-extreme temperature event linkages, and LSMP properties are needed. Generally, climate models capture observed properties of heat waves and cold air outbreaks with some fidelity. However they overestimate warm wave frequency and underestimate cold air outbreak frequency, and underestimate the collective influence of low-frequency modes on temperature extremes. Modeling studies have identified the impact of large-scale circulation anomalies and land–atmosphere interactions on changes in extreme temperatures. However, few studies have examined changes in LSMPs to more specifically understand the role of LSMPs on past and future extreme temperature changes. Even though LSMPs are resolvable by global and regional climate models, they are not necessarily well simulated. The paper concludes with unresolved issues and research questions.

✉ Richard Grotjahn
grotjahn@ucdavis.edu

1 Atmospheric Science Program, Department of L.A.W.R., University of California Davis, One Shields Ave., Davis, CA 95616, USA

2 School of Earth and Atmospheric Sciences, Georgia Institute of Technology, 311 Ferst Drive, Atlanta, GA 30332-0340, USA

3 Pacific Northwest National Laboratory, Richland, WA 99352, USA

4 Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

5 University of Massachusetts Lowell, Lowell, MA 01854, USA

6 NASA GSFC Global Modeling and Assimilation Office, Greenbelt, MD 20771, USA

7 Climate, Atmospheric Science and Physical Oceanography (CASPO) Division, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093, USA

8 Department of Geological and Atmospheric Sciences, Iowa State University, Ames, IA 50011, USA

9 Department of Atmospheric and Oceanic Sciences, McGill University, Montreal, QC H3A 0B9, Canada

10 Institute for Mathematics Applied to Geosciences, National Center for Atmospheric Research, Boulder, CO 80307, USA

11 NASA Goddard Space Flight Center, Global Modeling and Assimilation Office, Goddard Earth Sciences Technology and Research/I.M. Systems Group, 8800 Greenbelt Rd, Greenbelt, MD 20771, USA

Published online: 22 May 2015

Precipitation extremes paper

1. Covers 6 major topics:
   1. Data and extreme P event identification
   2. Types of extreme P events
   3. Synoptics of LSMPs
   4. Remote influences on extreme P events
   5. Trend detection: observed and projected
   6. Simulation of extreme P events and their LSMPs
2. A first draft of the sections above has been written.
3. To be submitted to *Climate Dynamics*

WG Findings

1. The dynamics underlying short-term extreme temperature and precipitation events are not well understood over most of the US.
2. Consequently, the extent to which current climate models are able to capture the dynamics underlying extreme events is also not well understood – a critical limit on confidence in future projections.
3. Analyzing the **large-scale meteorological patterns (LSMPs)** associated with short-term extreme events is very useful for investigating event dynamics and can provide a basis for downscaling.
4. Understanding and predicting extremes requires interaction between researchers in these different topical areas: extreme value statistics, observations, synoptic-dynamics, modeling, and application sectors. The Berkeley workshop facilitated interaction amongst the first four areas, and there was much interest in follow-on activities that also involved the fifth, application sectors. More details and recommendations in the workshop report, Variations special issue, and two refereed papers.

WG Recommendations (1 of 3)

- Details in Workshop Report, gaps & questions in refereed papers
- Extremes involve multiple subjects, so, many recommendations

1. Data: (EWE=extreme weather event)
    1. Increase investment in Big Data infrastructure to manage & process large amounts of model data and catalog EWEs identified
    2. Better quantify and display uncertainties in observed datasets
    3. Promote efforts to maintain current observing networks, including cooperative networks, especially those with long records
    4. Develop grid versus station data comparison protocols
2. Statistical Tools:
3. Synoptic-dynamic gaps & knowledge:
4. Modeling:
5. Other:

WG Recommendations (2 of 3)

1. Data:
2. Statistical Tools: (EVS=extreme value statistics)
    1. Promote multiple LSMP analysis techniques
    2. Develop and promote LSMP prediction uncertainty & reliability assessment techniques, including use in projections
    3. Develop multivariate EVS, including trends, low frequency influences, surface factors, seasonality
3. Synoptic-dynamic knowledge: (EWE=extreme weather event)
    1. Characterize EWE LSMPs in an objective, uniform and simple manner
    2. Leverage atmospheric blocking events studies as LSMP prototypes
    3. Fund developing simple, effective and concise metrics related to EWE LSMPs
    4. Fund engaging atmospheric dynamics community in studies of EWE LSMPs, including: deducing physical mechanisms responsible for LSMPs and for LSMP-Low Frequency modes linkages
4. Modeling:
5. Other:

WG Recommendations (3 of 3)

1. Data:
2. Statistical Tools :
3. Synoptic-dynamic knowledge: (EWE=extreme wx event)
4. Modeling: (RCM=regional climate model)
    1. Archive higher time (≤6 hrs) and vertical resolution for dynamical study and LSMP identification
    2. Fund dynamics and modeling communities to develop & apply analysis of model output for LSMP: biases, frequency, duration, and trends. This includes: metrics, time evolution prior to onset through event end, changing variability of LSMPs, and separating ways an EWE is created.
    3. Fund developing metrics that assess how good is ‘good enough’ LSMP simulation for adequate RCM simulation of the EWE
5. Other:
    1. Follow on workshop(s) such as: dynamical LSMP metrics (beyond ETCCDI), application sector needs, applied EVS, predictability of extremes

WG Recommendations (Condensed)

1. Data:
    1. Increase investment in Big Data infrastructure re LSMPs
    2. Better quantify and display uncertainties
    3. Protocols for grid to station comparisons
    4. Promote efforts to maintain current observing networks,
2. Statistical Tools :
    1. Promote multiple LSMP analysis techniques
    2. Develop and promote LSMP prediction uncertainty techniques
    3. Develop multivariate EVS, including trends, low frequency influences, surface factors
3. Synoptic-dynamic knowledge: (EWE=extreme wx event)
    1. Standardize LSMPs analyses
    2. Leverage atmospheric blocking events studies to LSMPs
    3. Fund developing metrics related to EWE LSMPs
    4. Fund dynamical studies of EWE LSMPs and LSMP-LF linkages
4. Modeling:
    1. Archive higher time and vertical resolution output
    2. Fund analysis of model output for LSMP properties, metrics, time evolution, changing variability, and separating ways an EWE can be created.
    3. Fund assessing ‘good enough’ LSMP simulation
5. Other:
    1. Follow on workshop(s)

Follow-on Activities: Summary of Funding Recommendations

- Increase investment in **Big Data infrastructure** to manage & process large amounts of model data and catalog EWEs identified

- Fund developing simple, effective and concise **metrics** related to EWE LSMPs

- Fund engagement of **atmospheric dynamics** community in studies of EWE LSMPs, including: deducing physical mechanisms responsible for LSMPs and for LSMP-Low Frequency modes linkages

- Fund dynamics and modeling communities to develop & apply **analysis of model output** for LSMP: biases, frequency, duration, and trends. This includes: metrics, time evolution prior to onset through event end, changing variability of LSMPs, and separating ways an EWE is created.

- Fund developing **metrics** that assess how good is 'good enough' LSMP simulation for adequate RCM simulation of the EWE

- Support **follow-on workshops**: dynamical LSMP metrics (beyond ETCCDI), application sector needs, applied EVS, predictability of extremes

Follow-on Activities: Programs and Organizations

- US CLIVAR
  - Science plan research challenge 5.2. Have had WGs on the four hazards there: TCs, Drought, and now T&P extremes. Revisit these? Shift focus?
- International CLIVAR
  - WCRP Grand Challenge: Science Underpinning the Prediction and Attribution of Extreme Events. Share this WG expertise with International CLIVAR effort?
- USGCRP Third National Climate Assessment
  - Extremes included in chapters 2, 6, and 20. Research from funding requested above would better inform these (and other chapters in the next NCA)
- IUGG activities
  - (biennial meetings) High-Impact weather and climate extremes sessions (forecasters, statisticians, and climate modelers) mainly through IAMAS' ICDM
  - (quadrennial meetings) Hydrological extremes mainly through IAHS but also IAMAS
- NSF PREEVENTS
  - (1) understand better fundamental processes underlying geohazards and extreme events on various spatial and temporal scales, & their variability; (2) improve models of geohazards, extreme events, and their impacts; (3) develop new tools to enhance societal preparedness and resilience.

Follow-on Activities: Possible Specific Project

Regional evaluations of how well current models capture the dynamics of short-term precipitation and temperature extremes over the US.

This addresses a critical national problem--how much confidence to have in projections of extreme activity (e.g., as in NCA, IPCC)--and would do it regionally, which is both dynamically appropriate and most useful for applications.

Such an effort would lead to several extremely useful outcomes: evaluation of confidence in the projections, of course, but also: downscaled projections via the LSMP approach, model evaluation, better understanding of the basic dynamics of the events, and information relevant to predictability at different scales. The effort could take advantage of existing models runs, but a key part of the work would be making the right information from those runs (daily, multiple levels) easily available for analysis. It is essential for the community to have access to the full set of metrics produced by the extensive number of model runs. These metrics should be available at sufficiently high frequencies to provide the opportunity to analyze extreme episodic events that occur on both the mesoscale and synoptic scales. The effort could tie-in with existing efforts to diagnose and attribute extreme events.

With the regional emphasis, it could also perhaps link to applications/decision makers/vulnerability efforts within each region -- maybe some workshops to focus on what types/indices of extremes are most important to understand.

There are some possible parallels to the DRICOMP effort but with the set-up effort focused on data availability rather than new model runs.