# Toward Understanding and Predicting Regional Climate Variations and Change

*Findings from the NOAA Science Challenge Workshop*

*September 20-22, 2011*

## *Workshop Organizing Committee*

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|---|---|
| Harold Brooks | OAR/NSSL |
| Randall Dole (chair) | OAR/ESRL/PSD |
| Leo Donner | OAR/GFDL |
| David Fahey | OAR/ESRL/CSD |
| Mitch Goldberg | NESDIS/STAR |
| Wayne Higgins | NWS/NCEP/CPC |
| Martin Hoerling | OAR/ESRL/PSD |
| Arun Kumar | NWS/NCEP/CPC |
| Robin Webb | OAR/ESRL/PSD |

## *Workshop Program Committee*

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| Harold Brooks | OAR/NSSL |
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| Leo Donner (co-chair) | OAR/GFDL |
| Lisa Goddard | IRI |
| James Kinter | COLA |
| Siegfried Schubert | NASA GMAO |
| Claudia Tebaldi | Climate Central |
| Scott Weaver | NWS/CPC |
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## *Workshop Support*

| | |
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| Ann Keane | OAR/ESRL/CSD |
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Submitted on behalf of the workshop participants, the Workshop Organizing Committee and the Workshop Program Committee.

Randall M. Dole (Workshop Chair)

February 24, 2012

# Executive Summary

This report summarizes findings of the NOAA Science Challenge Workshop *Toward Understanding and Predicting Regional Climate Variations and Change*. The workshop follows on the earlier NOAA Science Workshop on Strengthening NOAA Science. Over forty scientists from across NOAA, from other agencies and institutions, academia and the private sector participated in this workshop. The participants included experts in atmosphere and ocean dynamics, atmospheric composition including aerosols, atmosphere-land surface interactions, climate modeling and science communication. They assessed current assets, capabilities, and needs for developing improved understanding, predictions and projections of regional climate variability and change. The participants identified high priority science topics and opportunities within these areas, and recommended steps for achieving near-term progress that can be used to inform the development of the new NOAA 5-year Research Plan.

One overarching grand challenge emerged from this workshop:

*Develop a more holistic understanding of the causes of regional climate variability and change by integrating knowledge of the coupled ocean-atmosphere-land system, biological processes and changing atmospheric composition including effects of aerosols.*

Three specific opportunities for progress that received especially strong emphasis in the workshop were:

- Explaining regional climate trends and multi-decadal variations
- Understanding climate-extreme event linkages at regional scales
- Determining mechanisms for Arctic climate change and relationships with other regions

The participants recommended steps toward achieving near-term progress in these three areas. They also stressed the need to build a true climate observing system and advance high-end modeling for use at regional scales.

In addition, several crosscutting challenges were identified:

- Role of aerosols in regional climate
- Ocean observations and predictions
- Organized tropical convection, including tropical-extratropical interactions
- Interface and boundary layer interactions

The workshop findings suggest two complementary and interconnected research strategies: a *problem-focused strategy* to address specific high priority opportunities on science questions of central interest to NOAA and the Nation, and *a strategy aimed at building foundational capabilities* in observations and modeling together with focused process research to address key science crosscuts.

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# 1 Introduction

## A. Background and Organizational Context

This workshop follows recommendations from an earlier NOAA Science Workshop held in April 2010 in which scientists and science managers from across NOAA provided their perspectives on the grand science challenges facing NOAA and suggested opportunities for improving how NOAA conducts its science. Outcomes from this NOAA Science Workshop are summarized in a white paper *"Strengthening NOAA Science: Findings from the NOAA Science Workshop"*. Among the key recommendations from participants was that further science workshops be held on focused topics. Further, these focused workshops should move from science challenges toward solutions, and involve external partners as well as NOAA participants.

In response to these recommendations, the NOAA Research Council (NRC) proposed a series of thematic workshops to explore topic-specific and crosscutting science challenges in more depth. These workshops are intended to inform research priorities and directions for development of the new NOAA 5-year Research Plan. The NRC identified "Climate Variability and Change" (CVC) as one of four broad thematic areas. Nominees from different Line Offices served as an initial Organizing Committee for the CVC Workshop (members listed on inside cover). With approval of the NRC, the Organizing Committee refined this general theme to a more specific, focused topic: "Toward Understanding and Predicting Regional Climate Variations and Change". The committee also identified extreme events in a variable and changing climate as a major sub-theme, as such extremes often have strong regional manifestations. A Program Committee consisting of NOAA scientists and external partners (listed on inside cover) then recommended and invited participants (Appendix 1) and developed the Workshop Agenda (Appendix 2).

## B. Drivers for Topic

***"...adaptation to a changing climate needs to occur at regional-to-local scales."***

Regional climate trends and extreme events during the last century have greatly influenced public perceptions of climate variability and change. Trends or extremes that are unanticipated leave decision-makers and the public poorly prepared for planning and adaptation, with potentially disastrous consequences. Recognizing the critical need for improved regional-scale climate information, the 2007 IPCC Working Group II Report on "Impacts, Adaptation and Vulnerability" identified as one of its two most important climate science related research needs "knowledge regarding the nature of future changes, particularly at the regional scale and particularly with respect to precipitation changes and their hydrological consequences, and changes in extreme events..." (IPCC WGII, p. 78).

As noted in the "Vision and Strategic Framework for NOAA Climate Services", adaptation to a changing climate needs to occur at regional-to-local scales. One particularly important requirement in adaptation planning is information on changes in weather and climate extremes. The Strategic Framework document also emphasizes the importance of this issue, designating changes in extremes of weather and climate as one of four critical societal challenges where NOAA has mission responsibility and expertise, and where demands for climate information from stakeholders are very high. Extreme events often have strong regional manifestations and corresponding regional needs. For example, hurricanes and storm surges are a key concern on the U.S. Gulf and East coasts, while in much of the Midwest tornadoes and other severe convective storms are of especially high interest. Understanding the relationships between regional climate variations and change and weather and climate extremes was therefore identified as a major sub-theme in this workshop.

***"...it is imperative that understanding and predictions of regional climate variations and change be improved and placed on a firm scientific foundation."***

To provide a fundamental underpinning for NOAA climate services, as well as to improve support for other NOAA services, it is imperative that understanding and predictions of regional climate variations and change be improved and placed on a firm scientific foundation. Achieving this objective will contribute directly to meeting NOAA's science mission "To understand and predict changes in climate, weather, oceans and coasts". Science challenges at regional scales are complex and diverse. Addressing these challenges will require multi-disciplinary expertise, necessitating strong partnerships across NOAA and with external partners. This workshop was intended to serve as one step in this process, by synthesizing recommendations from NOAA and external scientists on how significant progress in understanding and predictions of regional climate variations and change can be achieved over the next several years.

### C. Workshop Organization and Process

The workshop was organized as a working meeting, with the bulk of the time devoted to breakout groups. Plenary presentations during the first day introduced the current state of scientific understanding and identified key challenges in several areas. For most of the remaining workshop, breakout groups met to further refine the challenges and identify gaps, needs and opportunities for achieving significant progress. A synthesis of workshop findings is presented in the following sections, with breakout group reports provided in Appendix 4.

## 2 Priority Topics and Key Science Questions

The overarching challenge emerging from this workshop is:

***Develop a more holistic understanding of the causes of regional climate variations and change by integrating knowledge of the coupled ocean-atmosphere-land system, biological processes and changing atmospheric composition including the effects of aerosols.***

The issues of system complexity and the needs to develop more integrated knowledge articulated in this challenge were also central to the overarching grand science challenge identified at the April 2010 NOAA Science Workshop. The issue of scale articulated at that Workshop is also fundamental to addressing regional science challenges, with significant implications for observations, process understanding and modeling. Moving from global to regional scales requires consideration of an increasing number of processes and interactions. For example, while factors such as land use and land cover change do not contribute strongly to global-mean temperature trends (IPCC 2007), they can be a major contributing factor in driving trends at regional-to-local scales. Similarly, spatial and temporal variations in sea surface temperatures or aerosols can play first-order roles in regional climate variations and trends, reducing or even offsetting trends anticipated from global increases in greenhouse gas concentrations.

Within the context of this overarching regional grand challenge, three specific research opportunities received particularly strong emphasis for their importance and potential for near-term progress. These areas are discussed briefly below. The following section then provides recommendations and priorities for achieving progress.

## 2.1 Explaining Regional Climate Trends and Multi-Decadal Variations

Comparisons of observed global and continental scale trends with model simulations show broad agreement over the past century (IPCC 2007). However, at regional scales there are some large discrepancies. For instance, observed and modeled precipitation trends over the U.S. since 1950 show little agreement in many regions (CCSP, 2008a). Such discrepancies between model and observed behaviors, when not understood or explained, reduce confidence in model projections of future regional climate changes. They can have important implications for adaptation planning, for which most decisions must be based on regional or even local considerations. Understanding the causes for such discrepancies, and resolving them to the extent possible, will be crucial for establishing levels of confidence in model projections of future regional changes to be used in adaptation planning.

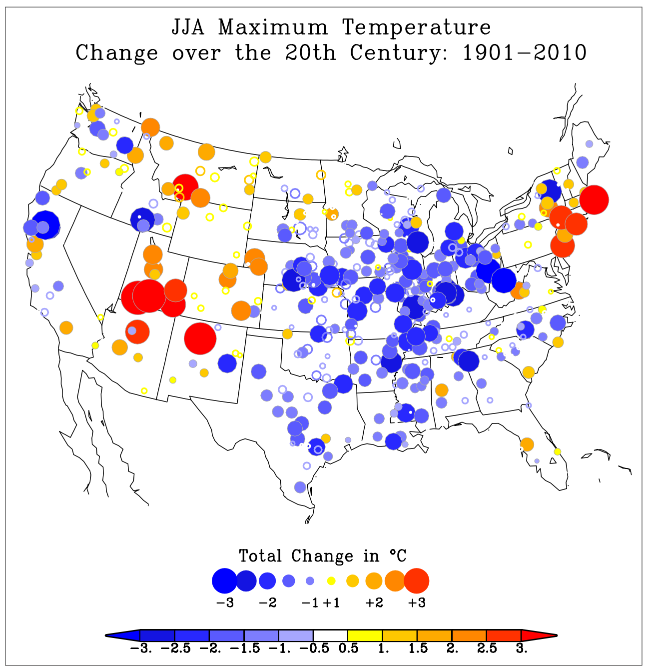


*Figure 1. The trend in seasonal summertime (June, July, August) daily maximum surface temperatures for the period 1901-2010. The trend is plotted as total change/100 yrs. Each circle denotes a station location based on the USHCN data set. Cooling (warming) trend plotted in blue (red), and the larger trends are denoted with larger circles. The figure illustrates the large regional variations in maximum temperature trends, including a marked cooling trend over this period over much of the Midwestern U.S. Courtesy M. Hoerling.*

From a national perspective, the lack of a warming trend over the central and southern United States during the past century, sometimes called the U.S. "warming hole", is especially noteworthy (e.g., Kunkel et al. 2006, Knutson et al. 2006). Particularly striking is a cooling trend in summertime maximum temperatures at almost all meteorological observing stations located between the Rocky and Appalachian Mountains since the early part of last century (Fig. 1). Simulations used in the Fourth Assessment Report indicate that central North America would have been expected to be a "climate change hot spot", with warming appreciably exceeding the global-mean temperature increase over this period. Further, while coupled climate model simulations forced by increasing greenhouse gas concentrations produce relatively uniform warming over all seasons, observed regional temperature trends vary greatly by season (Fig. 2, from Wang et al. 2009).

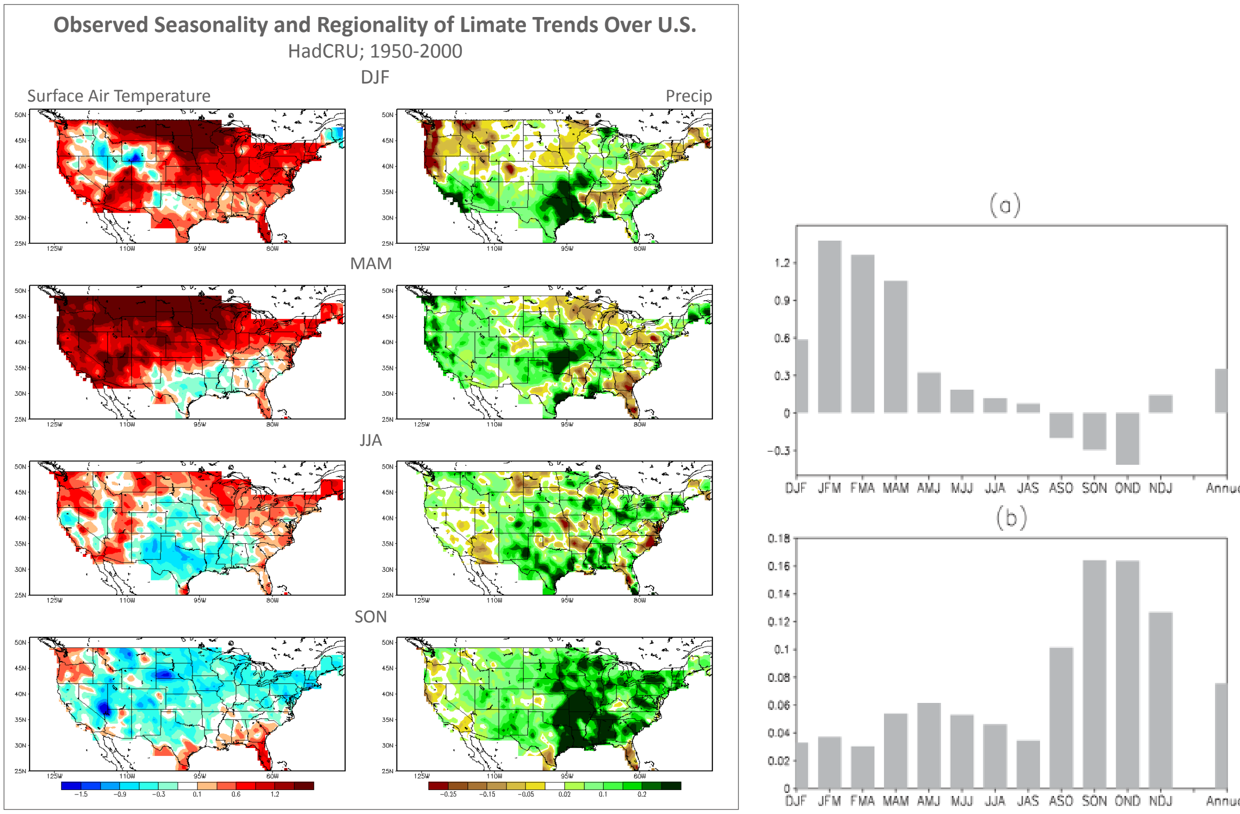


*Figure 2. Observed seasonal trends in surface temperature and precipitation over 1950-2000 from Wang et al. (2009). The maps on the left show regional temperature and precipitation trends for the standard winter (DJF), spring (MAM), summer (JJA) and fall (SON) seasons, while those on the right show contiguous U.S. averages for running-three month seasons and the annual-average trend (far right bar) for (a) temperature and (b) precipitation. The figure shows strong seasonal as well as regional variations in trends, which can differ markedly from annual average values.*

Regional trends outside the U.S. are also not well understood but have enormous societal and economic implications. One such region is that affected by the Asian monsoon, which includes roughly half of the world's population. An observed weakening of the South Asian summer monsoon during the second half of the 20th century has been simulated in recently developed models which include both direct and indirect (cloud-aerosol interactions) effects of aerosols (Bollasina et al., 2011). These results suggest that increases in anthropogenic greenhouse gases tend to strengthen the monsoon, while changes in aerosols and natural forcing weaken it. The treatments of aerosols in models remain very rudimentary, implying uncertainty in regional trends related to aerosols.

> ***"...[there is a] need for a more comprehensive assessment on the causes of regional and seasonal differences in climate trends that considers multiple possible contributing factors..."***

Indeed, while the model employed by Bollasina et al. (2011) captured key features of the observed weakening of the south Asian summer monsoon, it also incorrectly indicated reduced summer precipitation over eastern portions of China. Aerosol effects on regional climate change in the tropical Atlantic (Chang et al., 2011), Sahel (Ackerley et al., 2011), and the boreal winter extra-tropics, including the position of the Aleutian low (Ming et al., 2011), are also possible.

Such examples illustrate the need for a more comprehensive assessment on the causes of regional and seasonal differences in climate trends that considers multiple possible contributing factors, including atmospheric dynamics and coupled ocean-atmosphere processes, land surface and biological processes, changes in atmospheric chemical composition and effects of aerosols.

*Figure 3. U.S. Billion Dollar Weather and Climate Disasters in 2011 (source, NCDC). Disaster type and approximate locations are illustrated. Initial NOAA estimates indicate there were 14 weather and climate-related disasters with impacts exceeding $1B in the U.S. last year, a record high number over the period extending back to 1980. There is strong public interest in understanding whether such disasters are connected to climate variability and change, and to what extent climate change might be a factor in driving a change in frequency of occurence of such disasters in the future.*

## 2.2 Understanding Climate—Extreme Event Linkages at Regional Scales

Within the context of regional climate variability and change, extreme weather and climate events attract enormous public attention and can have major economic impacts. For example, in 2011, a NOAA assessment identified 14 weather and climate-related disasters having impacts exceeding $1B (Fig. 3), a record high number of such events over the period extending back to 1980. Among the questions posed to scientists are what relationships (if any) were there between these events and human-caused climate forcings? Does the unusually high number of events over this past year portend a trend, or might it be a transient anomaly? Were these events related to natural climate variations such as El Niño or La Niña? Could similar events be anticipated and early warning provided? If so, what kinds of information could be provided, and at what lead times?

As a specific example of the challenge in understanding climate-extreme event relationships, consider the 2011 Texas drought and summer heat wave (Fig. 4). This example illustrates the challenge

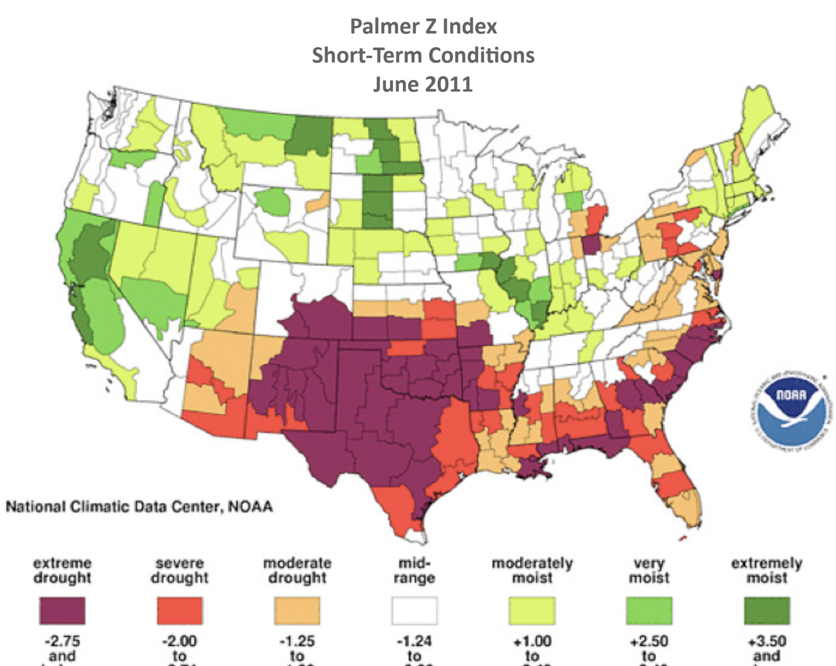


*Figure 4. Short-term drought conditions as of June 2011 (source NOAA NCDC). Extreme drought affected a large portion of the Southern Plains in 2011, with extreme heat as well centered over Texas and Oklahoma. These areas had not experienced long-term trends toward either drought or substantial warming (cf. Fig. 2), raising science challenges for explaining causes, and the possible effects of anthropogenic climate change.*

> ***"...extreme weather and climate events attract enormous public attention and can have major economic impacts."***

of reconciling previous regional climate trends, which did not show a long-term tendency toward increased heat or drought in this region (cf. Fig. 2), with a heat wave and drought event of record proportions. It also illustrates the need to consider multiple possible contributing factors, including human-caused climate changes, effects of ocean variations and local land-atmosphere interactions, including the role of vegetation. There is a compelling public interest in understanding whether this past year reflects variability that is likely to revert to previous conditions, or rather is the harbinger of a new long-term regional climate trend.

Addressing such questions poses many science challenges, but also outstanding opportunities. Because of the great diversity of phenomena, ranging from severe convective storms and hurricanes to sustained droughts, there is a need to consider numerous potential factors, human-caused and natural. A science opportunity for NOAA in moving toward a more holistic understanding is to identify and document multiple cascading effects associated with extreme events, such as those connecting drought, changes in runoff, and offshore hypoxia, with consequent human, economic and ecological impacts. Identifying systematic relationships also requires a greatly improved understanding of the connections between weather and climate. The potential payoffs to society from gains in understanding weather-climate connections are enormous, ranging from improved early warning of extreme events to providing information that is essential for longer-term adaptation decisions.

## 2.3 Determining Mechanisms for Arctic Climate Change and Relationships with Other Regions

Arctic warming and the concurrent reduction in Arctic sea ice pose another regional climate challenge with large consequences for local inhabitants and natural ecosystems, as well as for public perceptions of climate change. Over the past few decades the rates of loss in Arctic sea ice extent and thickness have been extremely rapid (Fig. 5), exceeding the rates simulated in most models used in the IPCC Fourth Assessment (e.g., Stroeve et al. 2007). Regional warming is strongly

August Sea Ice Extent %

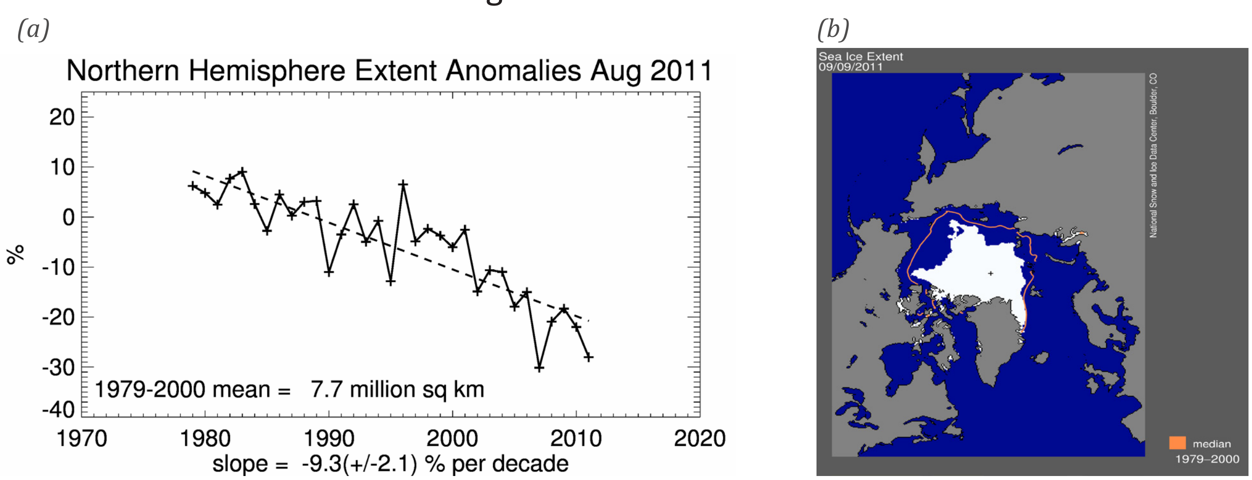


*Figure 5. (a) August sea ice extent (%) from 1979-2011 (source NSIDC). (b) Minimum sea ice extent in September 2011, compared with 1979-2000 mean (red curve). Sea ice extent has declined very rapidly over this period, with the causes for the rapid rate of loss not fully understood.*

coupled with other climate system changes over the Arctic basin, with the Arctic amplification in surface warming largely related to feedbacks produced by sea ice losses (e.g., Serreze and Francis 2006; Kumar et al. 2010). The physics of this relationship appears to be consistent with sea ice-Arctic climate relationships inferred from historical data (Bekryaev et al. 2010). Unanswered questions include the relative roles of human caused climate change and natural variability in both the atmosphere and ocean in explaining rapid sea ice losses, and more generally, rapid Arctic warming. Remote influences, either human-caused or natural, are being increasingly recognized for their potential to strongly influence Arctic regional climate trends. In addition, the potential role of the Arctic on other regions has emerged as a major science question with important implications for climate predictions and projections.

***"...[Arctic climate change has profound] consequesnces for local inhabitants and natural ecosystems, as well as for public perceptions of climate change."***

# 3 Addressing Research Gaps – Problem-Focused Strategies

Workshop participants identified the following areas as priorities and opportunities for progress. The following give specific *problem-focused strategies*.

## 3.1 Explaining Regional Climate Trends and Multi-Decadal Variations

To make significant advances in addressing this key challenge, participants recommended that NOAA

*Adopt a problem-focused strategy with coordinated research to explain specific regional trends*.

- Causes for regional and seasonal differences in U.S. temperature and precipitation trends
- Relation between trends in means and in extremes
- Relative roles of local processes and remote effects
- Implications for predictions and projections

## 3.2 Improving Understanding of Climate-Extreme Event Linkages at Regional Scales

To make significant advances in this area, participants recommended that NOAA could

*Conduct or lead an intensive assessment of the relationships between climate variations and change and extreme events over a particular time period; e.g., "Understanding the Extreme Weather and Climate Events of 2011: The Year of Living Dangerously".*

- Conducting coordinated, intensive research focused on a limited time period can lead to significant advances in addressing major science challenges. Examples of time-focused intensive research efforts include the International Polar Year, the Year of Tropical Convection, and FGGE. Such a focused effort could be performed retrospectively, for example, over a recent period having events of great public interest and known high impacts, or planned prospectively, e.g., for 2015. An alternative approach is to focus intensively on a specific phenomenon and question(s), as, for example, the recent "Droughts In Coupled Models Project" organized through U.S. CLIVAR.

Such an intensive effort could, for example,

- Assess current observational capabilities, state of understanding and predictive capabilities on climate-extreme event relationships for events observed over a recent time period. Determine what can be said based on the best available science at that time, on questions such as: What is the potential impact of global warming? What are the roles of land-atmosphere feedbacks, SST forcing, aerosols? What are relationships to large-scale modes of climate variability? What are the implications for predictions and projections?
- Determine gaps that limit understanding and predictions, assess what would be possible with improvements in observations, models, and process understanding.
- Identify directions for developing extreme event information and services.
- Use the knowledge and develop the capacity to deliver timely information about trends, attribution and impacts of extreme events.
- Participants also recommended:
- Increasing emphasis on warm and transitional season relationships
- Fully mining existing data sets to better estimate historical variability and change.

## 3.3 Determining Mechanisms for Arctic Climate Change and Relationships with Other Regions

*It is recommended that NOAA strengthen efforts to improve observations and understanding of the physical and dynamical processes influencing the Arctic Ocean, including an assessment of heat transports between various ocean basins. Advances in sea ice modeling are essential to identifying what factors caused the recent rapid declines and whether they should be expected to continue.*

- Maintain and improve the Arctic observing system
- Conduct focused research on key Arctic processes
    - » Sea ice, aerosol effects, black carbon, clouds, surface and boundary layer exchange processes and energetics, interactions among components
    - » Assess connections of Arctic climate variability and change with other regions; effects of declining sea ice on extratropical climate; Arctic Oscillation
- Advance Modeling
    - » Focus on overall rate of sea ice loss and interannual variability

# 4 Crosscutting Challenges

Workshop participants also identified several high-priority crosscutting challenges where focused research by NOAA in collaboration with partners is needed to help address multiple problems. These are summarized below.

- *Roles of aerosols in regional climate variations and change* **–** effects on both temperature and precipitation can be quite important and can occur through multiple mechanisms. Aerosols represent a major source of uncertainty for both global and regional climate trends. A key challenge is aerosol-cloud interactions. There is a strong need for much better understanding of the multiple indirect effects of aerosols. Improved observations of spatial distribution of aerosols, vertical distribution, and aerosol properties are high priority needs.
- *Ocean observations and predictions* **–** There are continuing uncertainties in historical sea surface temperature (SST) analyses, and major uncertainties in the evolution of temperatures at depth. *SST patterns matter!* There is very good evidence that decadal variations and trends in regional climate and tropical cyclone activity are significantly influenced by SST patterns, and are likely to be sensitive to details of the distributions. Can we attribute the causes for regional SST trends? Are they a manifestation of a forced response to human-caused climate change, or internal variability on multi-decadal time scales?
- *Organized tropical convection, including tropical-extratropical interactions* – organized tropical convection is a pervasive weakness in weather and climate models. It is a (the) major source of potential predictability on time scales of a few weeks to a season. Take advantage of results from ongoing or planned field campaigns, e.g., Dynamics of the Madden-Julian Oscillation (DYNAMO)
- *Interface and boundary layer interactions* – These are essential for understanding the coupled Earth system. Major areas of uncertainties where progress can be made include: land surface feedbacks; climate-biology feedbacks, e.g., dynamic vegetation, ocean biology and feedbacks.

# 5 Build the Scientific Foundation

Participants strongly stressed the need to build scientific foundations in climate observations and modeling where focused NOAA efforts are needed.

## 5.1 Develop, Support and Sustain a Climate Observing System

As stated by E. Sarachik, "Without a sustained climate observing system, climate is not a science." In cooperation with others, NOAA can play a key role in:

- Starting the design of a global climate system
- Sustaining what we have and building from what we have

  The following priorities were called out:

***"Without a sustained climate observing system, climate is not a science."***

» High quality observations of adjacent ocean regions
» Develop coupled data assimilation and a coupled reanalysis for climate
» Observations of the coupled Arctic system
» Aerosol observations

### 5.2 Develop Models for Regional Science and Applications

Understanding and prediction regional climate variations and change pose major demands on climate models, which NOAA can take actions to address:

- Improvements will be necessary in coupled ocean and atmosphere models to simulate regional climate change and variability
- Increased complexity will be necessary to simulate climate change associated with aerosols and clouds
- Increased resolution and improved physics will be required to simulate extreme events and regional climate
- Investments will be needed in model development and analysis (computational and human requirements)
- Need modelers and observational and process scientists working more closely together; e.g., "Climate Process Teams" to implement new knowledge of physical processes important in climate into climate models and teams to conduct focused diagnostic efforts to identify and minimize model biases
- Need to facilitate access to models and provide capacity for scientists outside modeling centers to conduct experiments
- Need capacity to develop large ensembles and development of ensemble methods, and engaging multiple models to address high priority problems (e.g., GFDL, NCEP)
- Need to strengthen collaborations, including with information users, e.g., as in the National Climate Predictions and Projections Platform (NCPP)

# 6 Conclusion

The topic of this Workshop, "Toward Understanding and Predicting Regional Climate Variations and Change", is central to improving NOAA's climate services, especially at regional scales, as well as to supporting other NOAA services. Improving knowledge and capabilities will be imperative for providing a sound scientific underpinning to inform public preparedness and adaptation to a variable and changing climate. These considerations argue strongly for a focused NOAA research strategy on problems of regional climate variability and change, with an important emphasis on trends and variations in extreme events.

The workshop participants provided many thoughtful, creative and constructive suggestions on directions for progress. They are to be commended for their numerous contributions. As intended

> ***"Improving knowledge and capabilities will be imperative for providing a sound scientific underpinning to inform public preparedness and adaptation to a variable and changing climate."***

for such workshops, the participants helped NOAA begin the process of moving from science challenges toward solutions in a specific, high-priority area. Similar to the 2010 Science Workshop, the diverse backgrounds of scientists who participated contributed to looking at various problems – and potential solutions – from broader perspectives than might have otherwise occurred. In this respect, all of those who participated benefitted.

The ultimate success of this workshop will depend on whether ideas put forward in this workshop influence NOAA's research strategy over the next several years in significant ways. In this respect, the findings suggest two complementary and interconnected strategies:

- A problem-focused strategy to address specific high priority opportunities on questions of central interest to NOAA and the nation
- A strategy aimed at building foundational capabilities in observations and modeling together with focused process research to address key crosscuts.

The recommendations summarized here provide starting points for further development of NOAA's research plan. The extent to which NOAA follows up and develops the strategies and recommendations will provide NOAA and external participants with a strong indication of the value of their workshop contributions.

# Appendix 1

## Workshop Participants

| Name | Affiliation |
|---|---|
| Randy Dole | NOAA ESRL/PSD, chair |
| Harold Brooks | NOAA NSSL |
| Leo Donner | NOAA GFDL |
| David W. Fahey | NOAA ESRL/CSD |
| Lisa Goddard | IRI, Columbia University |
| Wayne Higgins | NOAA NWS/CPC |
| Martin Hoerling | NOAA ESRL/PSD |
| Arun Kumar | NOAA NWS/CPC |
| Siegfried Schubert | NASA GSFC |
| Claudia Tebaldi | Climate Central and NCAR |
| Scott Weaver | NOAA NWS/CPC |
| Robert Webb | NOAA ESRL/PSD |
| Michael Alexander | NOAA ESRL/PSD |
| Don Anderson | NOAA CPO |
| Julio Bacmeister | NCAR |
| Clara Deser | NCAR |
| David G. DeWitt | IRI, Columbia University |
| David Easterling | NOAA NESDIS/NCDC |
| Graham Feingold | NOAA ESRL |
| Andrew Freedman | Climate Central |
| Jim Hurrell | NCAR |
| V. Krishnamurthy | Institute of Global Environment and Society, U. MD. |
| K. Kumar | CIRES (sabbatical from India) |
| Kenneth Kunkel | NOAA Cooperative Institute for Climate and Satellites |
| Shian-Jiann Lin | NOAA GFDL |
| Greg McCabe | USGS |
| Christopher Miller | NOAA CPO |
| Raghu Murtugudde | University of Maryland |
| John A. Ogren | NOAA ESRL/GMD |
| David Parrish | NOAA ESRL/CSD |
| Kathy Pegion | CU CIRES |
| Richard B. Rood | University Michigan |
| Ed Sarachik | University of Washington |
| Amy Solomon | CU CIRES |
| Eugene S. Takle | Iowa State University |
| Jim Todd | NOAA CPO |
| Michael Trainer | NOAA ESRL/CSD |
| Jeff Trapp | Purdue University |
| Gabriel Vecchi | NOAA GFDL |
| Steve Zebiak | International Research Institute for Climate and Society |

# Appendix 2

## Agenda

### NOAA Climate Variability and Change Science Challenge Workshop

**Toward Understanding and Predicting Regional Climate Variations and Change**

**September 20-22, 2011**

**NOAA/Earth System Research Laboratory**

**Boulder, Colorado**

Meeting Strategy

*Approach:* Focus on specific high priority regional science problems where significant scientific progress is possible over the next 5-6 years. In the plenary sessions, introduce examples of outstanding problems in understanding and predicting regional climate variations and change, including extreme events. These plenary presentations are intended to help focus breakout discussions on key challenges, gaps, needs and opportunities in observations, process understanding, and modeling of regional climate variations and change. The findings of this workshop will inform the development of research priorities and directions in NOAA's new Five-Year Research Plan.

**Day 1: Regional Climate Science: Identifying the Challenges**

*Plenary Presentations*

8:30 am Welcome and Introduction - Meeting Background, Objectives and Organization (Randy Dole)

Overview presentations (Randy Dole, Chair)

8:45 am - Serving society: Benefits of regional climate information (Steve Zebiak)

9:15 am - Outstanding challenges in regional climate trends and variations (Marty Hoerling)

9:45 am - Regional climate and extreme events: severe convective storms (Harold Brooks)

10: 15 am - *Break*

Toward Understanding Regional CVC (Leo Donner, Chair)

10:30 am - Tropical climate variations and change and regional implications (Gabe Vecchi)

11:00 am - Heat waves, droughts, and regional climate trends: Ocean and land influences (Siegfried Schubert)

11:30 am - Impacts of aerosols on climate (John Ogren)

12:00 pm - Arctic climate variations and change (Clara Deser)

Lunch, including presentation (12:30 pm – 1:30 pm)

12:45 pm - A climate observing system for global and regional science and applications (Ed Sarachik)

*Plenary Session (Robin Webb, Chair)*

Toward Predicting Regional CVC (Robin Webb, Chair)

1:30 pm - Overview of global modeling issues (Leo Donner)

1:50 pm - High-resolution global models for simulation and prediction of extreme events and their applications to regional climate (S-J Lin)

2:10 pm - Key regional challenges from the CPC perspective (Wayne Higgins)

2:30 pm - Predictability, predictions and the role of attribution (Lisa Goddard)

3:00 pm - Open discussion, with presenters as panelists

3:25 pm - Charge to breakout groups (Randy Dole)

3:30 pm - Break

3:45 pm - ***Breakout group discussions***

Focus on refining key challenges, end-to-end perspective – take advantage of cross-disciplinary expertise in discussions.

Are there specific high priority problems where near-term progress is feasible?

What are the critical gaps limiting progress?

Are there common challenges that cut across several problems that, if addressed, would allow progress on multiple problems?

5:15 pm - *Plenary* – Brief summary of day, next steps (Randy Dole)

5:30 pm - End of day 1

6:30 pm - Group dinner for those interested (Chautauqua)

**Day 2: Regional Climate Science: Key Gaps, Needs and Opportunities**

Breakout sessions (continued)

8:30 am - Breakout groups reconvene on science challenges and gaps

10:00 am - Break

*Plenary session*

10:30 am - Breakout group report out – science challenges, high-priority problems and gaps

11:30 am - Open discussion and synthesis

Lunch, including presentation (12:00pm – 1:30 pm)

12:30 pm - Challenges in Communicating What Know - and Don't Know - About Regional Climate Variations and Change: A Perspective from the Front Lines (Andrew Freedman)

1:30 pm - ***Breakout group discussions***

What steps are needed to address key gaps in observations, process understanding and modeling?

What are opportunities to address regional science challenges and improve regional climate understanding and predictions, especially over the next ~5-6 years?

How can NOAA work together with partners to address these challenges?

3:30 pm - Break

3:45 pm - Breakout group discussions (cont.)

Begin summarizing/drafting findings on needs and opportunities for advances.

5:30 pm - End of day 2

**Day 3: Regional Climate Science: Recommendations for Advances**

*Plenary session*

9:00 am - Breakout group summaries – opportunities, needs and partnerships

10:00 am - Break

10:30 am - Open discussion - Initial summary of findings; next steps

12:00 pm - Meeting Conclusion

# Appendix 3

## Acronyms

| | |
|---|---|
| CCSP | Climate Change Science Program (now U.S. Global Change Research Program) |
| CLIVAR | Climate Variability and Predictability project (under WCRP, see below) |
| CVC | Climate Variability and Change |
| FGGE | First GARP Global Experiment |
| GARP | Global Atmospheric Research Programme |
| IPCC | Intergovernmental Panel on Climate Change |
| NRC | NOAA Research Council |
| WCRP 2 | World Climate Research Programme |

# Appendix 4

## Breakout Group Reports

### Day 1 Reports

Breakout Group 1

» *What are key challenges in understanding and predicting regional climate variations and change?*

» *Are there specific high priority problems where significant near-term progress is scientifically feasible?*

- Improved understanding and prediction of extratropical short term climate extremes (e.g., heat waves, flooding, changes in tornadic activity)
    - » targeting the transition/warm seasons
    - » what are the large-scale teleconnections associated with such events?
    - » what is the role of land-atmosphere feedback; SST forcing; aerosols?
    - » what is the (potential) impact of global warming?
    - » what is their predictability (issues of SST predictability in all ocean basins are relevant here)?
- Improved understanding/prediction of changes in of tropical cyclone activity
    - » can we predict changes in frequency, tracks (land-falling), intensity?
    - » what is the role of the MJO?
    - » what is the role of local and remote SST forcing?
    - » what is the (potential) impact of global warming?
    - » are there periods that are more predictable (forecasts of opportunity)?
- Continue to improve seasonal forecasts.
    - » will add to improvements in subseasonal - including impacts on extremes and decadal predictions
    - » still much to be gained from improved simulation of ENSO as well as variability in other ocean basins
    - » work to develop conditional forecasts that take advantage of periods of enhanced predictability and/or enhanced information about the initial state
- Improved understanding and prediction of intraseasonal and interannual variations of regional monsoon activity (e.g., India, Africa, Americas, Australia).
    - » onset, demise, intensity, active/break
    - » take advantage of cloud resolving models

- Assess the role of decadal oscillations, aerosols, and non-modal changes in the mean state parameters (e.g., ocean) in regional climate anomalies

Gaps: *What are critical gaps in observations, process understanding and modeling that limit progress in addressing these high priority regional problems and challenges?*

- Model deficiencies
  - » Inadequate representation of aerosols (direct/indirect effects) in climate prediction models
  - » Inadequate representation of the atmospheric annual cycle (mean state)
  - » Uncertainties in the representation of land/atmosphere and ocean/atmosphere coupling
  - » Inadequate representation of the stratosphere
  - » Deficiencies in the simulation of the relevant atmospheric teleconnections (MJO, ENSO, etc. this includes issues of organized tropical convection and how to best parameterize that in increasingly higher resolution climate models)
  - » Insufficient interactions between climate system and ecosystems/agriculture
- Observational Deficiencies
  - » Inadequate soil moisture and snow observations (need for improved satellite and in situ observations)
  - » Better (objective) observational database of small-scale severe weather events (e.g., tornados and hail)
  - » Continued support for and enhancement of ocean observing system (e.g., TAO), abd upper air observing system (especially upper troposphere and lower stratosphere)
  - » Improved spatial and vertical distributions of aerosols
  - » Improved reanalysis of historical SST (improved consistency across time scales), non-traditioanl sources of SST data including e.g., from the fishing industry.
  - » Improved estimates of surface and subsurface ocean (e.g., coupled atmosphere/ocean reanalyses)
- Research/Analysis Needs
  - » Research focus on warm season basic state (annual cycle)
  - » Process studies on aerosol impacts (direct and indirect)
  - » Diagnostic studies of the environmental conditions associated with short term climate extremes and links to large scale forcing
  - » Coordinated and targeted model experimentation including use of dynamical downscaling and emerging high resolution global models (e.g., CPTs)
  - » Targeted and timely attribution of recent high profile events
  - » Leverage off recent and on-going community programs (e.g., DYNAMO)
- Other

- » Insufficient computing resources to run high resolution models for extended periods
- » Timeliness of predictions and hindcasts
- » Impacts assessments (e.g., land fall risks, flooding versus high wind risks)
- » Archive and access to data and model output

## Breakout Group 2

*Q1 What are key challenges in understanding and predicting regional climate variations and change? Are there specific high priority regional problems and challenges?*

Overarching Challenge:

- Create a holistic assessment of observed regional climate patterns of variability and change that combines physical science understanding of the coupled ocean-atmosphere-land system, land surface and biologic processes, and chemical understanding of aerosols and their interactions with clouds.

Regional Case study opportunities to address specific regional challenges:

1. Arctic Climate Change: Has a tipping point been reached regarding prospects for a recovery of Arctic climate/cryospheric conditions to pre-1980 levels? What is the “contagion effect” of Arctic sea ice loss?

2. The U.S. Warming Hole: What has been the contribution by natural climate variability? What has been the role of human induced land coverage change? What rol for aerosols? What is the region’s sensitivity to anthropogenic greenhouse gas forcing? What do the next 2 decades portend for central US temperatures?

3. Hurricanes: Event scale predictability as a hazard warning; seasonal scale predictability as an outlook; climate change impacts and sensitivity to ocean changes.

4. Aerosols and Asian/Indian Monsoon: Has a change in Indian summer monsoon rains been detected? How have aerosol change impacted Asian/Indian monsoon rains, with concerns for food security.

5. Current Extremes: Understanding the Extreme events of 2011: The Year of Living Dangerously In the U.S. Early warning for early action. When were certain extremes predicted/predictable? (Texas drought/heat wave, Ohio Valley floods, Missouri Basin floods).

Provide an integrative assessment of the sensitivity of regional variability and extremes within a context of global climate and the non-uniform aspects of externally forced signals.

- Characterize the climate variability that can be explained as a consequence of known “modes” of variability, such as ENSO, PDV/AMV, external radiative forcing.
- Describe and quantify the predictability of climate variability and extremes given current observational systems and model systems.

Sub themes:

» How non-stationary is regional climate?

» What is the "signal to noise ratio" of regional internal variability to the xternally forced signal?

» How sensitive are internal modes of variability to with anthropogenic change?

» Are there distinct physical time scales for the internal variability of seasonal to decadal time scales.....is this just red noise? What implications for predictability?

» To what extent does instrumental record capture modes of unforced variability, e.g. mega-droughts? Do current coupled models generate such unforced variability?

» What aspects of the modeling of regional climate variability are especially sensitivie to (and improved by) enhanced model resolution? Improved physical process representation (e.g., aerosol/clouds)

» How well do we monitor the ocean conditions needed for climate prediction?

» How well are observed SST variations and trends known to permit detection studies and interpretations of evolving climate conditions?

» How do we quantify the relative impacts of aerosols, land use changes, ocean impacts, and other forcings at regional scales?

» How do we know if, and to what degree, current regional trends are likely to continue?

» Why has seasonal fcst accuracy for t,p not improved, if it hasn't?

- Provide an integrative assessment of the sensitivity of regional variability and extremes within a context of global climate and the non-uniform aspects of externally forced signals.

Have 4 challenges, 5 case studies

To address challenges, use case studies to provide motivation and focus:

Prioritize main sources of variability/change (predictability

- aerosols & clouds
- ocean-atmosphere interaction
- land-atmosphere interaction ( soil moisture, LULCC)

Need good observations (How to identify optimal design??)

Process understanding

Represent in models

» to what extent does having X in models improve our predictions?

GAPS:

» Modellers and observationalists working together

- » Models don't do well on both mean state & variability (together)
- » Observing networks e.g. extend TAO array
- » gap in obs/monitoring & process understanding
- » Arctic observing sysem
- » US is under-resourced to provide their domestic and international obligations in terms of observations and modeling and collaborations of modeling centers with the community

Q3:

Requirements:

- » KEEP WHAT WE HAVE in terms of observations
- » Also applies to prediction tools that go into forecasts
- » Investment in CPTs
- » Undertake research with multiple models (e.g. NCAR, GFDL)
- » Need aerosol climatologies – how dense should network be?
- » Improve aerosol observation network; leverage field campaigns
- » Need to do better with what we have
- » Provide (and synthesis) existing data that is not currently available to scientific community, including synthesis of disparate observational data sets and metadata. This will require infrastructure, as well as a relatively small amount of human resources.
- » Seasonal – keep TAO
- » Actual GCOS design and requirements (Academy report?)
- » Arctic observing systems

Opportunities:

- » Physical processes; high resolution; analysis & experimentation with new models (GFDL developing ESMs with biogeochemistry etc, high resolution models, new

## Breakout Group 3

Question 1: Challenges

A. Climate Observing System:

How to integrate the observing systems to provide climate information?

Needed for

- Initializing climate models
- Long-term observations of natural variability and climate change on global and regional scale

- Quantifying fundamental climate variables, ex. Planetary albedo
- To advance regional understanding, predictions, and projections

B. Foundational Science

- Identifying sources of predictability
- Quantifying uncertainty in projections
- Ocean vs. land-surface impact on CVC
- Improving modeling of fundamental processes that are important for CVC, ex. Clouds, convection, MJO (need for a coordinated effort across NOAA)
- Parameterization of boundary layer and surface processes, both observations and modeling efforts are needed, ex. uncertainty in the atmospheric boundary layer height.
- Focused diagnostic efforts to identify and improve (minimize) model biases (application of decadal predictions experiments?)
- Integrating multiple sources of information in forecast systems
- Integrating components of the earth system: coupling of scales, ex. Land surface-atmosphere, ocean-atmosphere
- Adding value to downscaling: Improving understanding and modeling of scale interaction/ coupling, ex. large scale forcing.

C. Involving users in modeling, predictability, and validation studies: Will help guide priorities, improvements in models, use of forecasts and data

## Day 2 Reports

### Group 1 – Questions 1-4

Challenges:

» What are key challenges in understanding and predicting regional climate variations and change?

» Are there specific high priority problems where significant near-term progress is scientifically feasible?

1. Improved understanding and prediction of extratropical short term climate extremes (e.g., heat waves, flooding, changes in tornadic activity)

    - targeting the transition/warm seasons
    - what are the large-scale teleconnections associated with such events?
    - what is the role of land-atmosphere feedback; SST forcing; aerosols?
    - what is the (potential) impact of global warming?
    - what is their predictability (issues of SST predictability in all ocean basins are relevant here)?

2. Improved understanding/prediction of changes in of tropical cyclone activity

    - can we predict changes in frequency, tracks (land-falling), intensity?
    - what is the role of the MJO?
    - what is the role of local and remote SST forcing?
    - what is the (potential) impact of global warming?
    - are there periods that are more predictable (forecasts of opportunity)?

3. Continue to improve seasonal forecasts.

    - will add to improvements in subseasonal - including impacts on extremes (link to bullet) and decadal predictions
    - still much to be gained from improved simulation of ENSO as well as variability in other ocean basins
    - work to develop conditional forecasts that take advantage of periods of enhanced predictability and/or enhanced information about the initial state

4. Improved understanding and prediction of intraseasonal and interannual variations of regional monsoon activity (e.g., India, Africa, Americas, Australia).

    - onset, demise, intensity, active/break
    - take advantage of cloud resolving models

5. Assess the role of decadal oscillations, aerosols, and non-modal changes in the mean state parameters (e.g., ocean) in regional climate anomalies

Gaps: What are critical gaps in observations, process understanding and modeling that limit progress in addressing these high priority regional problems and challenges?

Model deficiencies:

- Inadequate representation of aerosols (direct/indirect effects) in climate prediction models
- Inadequate representation of the atmospheric annual cycle (mean state)
- Uncertainties in the representation of land/atmosphere and ocean/atmosphere coupling
- Inadequate representation of the stratosphere
- Deficiencies in the simulation of the relevant atmospheric teleconnections (MJO, ENSO, etc. this includes issues of organized tropical convection and how to best parameterize that in increasingly higher resolution climate models)
- Insufficient interactions between climate system and ecosystems/agriculture

Observational Deficiencies:

- Inadequate soil moisture and snow observations (need for improved satellite and in situ observations)
- Better (objective) observational database of small-scale severe weather events (e.g., torna-

dos and hail)

- Continued support for and enhancement of ocean observing system (e.g., TAO), abd upper air observing system (especially upper troposphere and lower stratosphere)
- Improved spatial and vertical distributions of aerosols
- Improved reanalysis of historical SST (improved consistency across time scales), non-traditioanl sources of SST data including e.g., from the fishing industry.
- improved estimates of surface and subsurface ocean (e.g., coupled atmosphere/ocean reanalyses)

Research/Analysis Needs:

- research focus on warm season basic state (annual cycle)
- process studies on aerosol impacts (direct and indirect)
- diagnostic studies of the environmental conditions associated with short term climate extremes and links to large scale forcing
- coordinated and targeted model experimentation including use of dynamical downscaling and emerging high resolution global models (e.g., CPTs)
- Targeted and timely attribution of recent high profile events
- Leverage off recent and on-going community programs (e.g., DYNAMO)

Other:

- insufficient computing resources to run high resolution models for extended periods
- Timeliness of predictions and hindcasts
- Impacts assessments (e.g., land fall risks, flooding versus high wind risks)
- Archive and access to data and model output

Opportunities and Needs:

*What are the near-term opportunities and requirements for addressing high priority problems in advancing understanding and predictions at regional scales?*

- Opportunities (Linked to Grand Challenges)

  Key:

  » Climate Extremes

  » Tropical Cyclones

  » Seasonal Forecasts

  » Regional Monsoons

  » Decadal, Aerosols

Regional input to National Climate Assessment. 1, 2

Statistical and dynamical downscaling techniques, sustaining assessment, NCPP

NASA AO on support for Assessment; NASA provides early IESA capability and products.

National and International Multi-model Ensemble Prediction Systems 1, 3, 4

NMME will have 30 years of hindcasts completed by August, 2012

CMIP5 simulations, some high resolution. 1, 3, 4, 5

WCRP efforts to develop an International Drought Early Warning System. 1, 3, 4

Operational early warning system;

Drought atlas;

Coordinated research on high profile events engaging user community.

Events of 2011 as organizing theme for research activities (e.g. MW floods, TX drought, cold, snowy winter in East, April tornado outbreak, etc.). 1, 2

Partering with the Hurricane Forecast Improvement Project to link weather and climate prediction of TC's. 2

Link DYNAMO and Yr of Tropical Convection 1, 4

New reanalysis efforts (CFS, 20th Century, MERRA/aerosols, ERA). 1-5

Observations

Satellite obs (SMAP, NPP, JPSS, GOES-R, AQUARIUS). 1-5

In situ: GRUAN, CRN, RCRN. 1-5

Radar (Dual Polarization). 1, 2

Partnerships:

*How can NOAA work together with our partners to more effectively address these challenges?*

The following example illustrates the types of coordination required to make progress on one of the Group 1 challenges, specifically:

1. Improved understanding and prediction of extratropical short term climate extremes (e.g.,flooding)

   Stakeholders and users can engage through portals (e.g. Climate.gov), National Data Centers and Climate Prediction Centers. Key issues include development and delivery of climate products; web pages; user friendly formats; translational information on flooding. Includes workshops, training, surveys, etc.

   Private sector partners can engage in many ways (e.g. through NOAA grants programs, including the Small Business Innovation Research (SBIR) program; NOAA Needs Assessments; customer service)

Academic partners can engage in collaborative research through CI's, RISA's, NOAA's grant programs, including test bed activities (e.g., Climate Test Bed) and CPTs

Take advantage of National Climate Predictions and Projections (NCPP) Platform as umbrella to facilitate connections, and build communities that link users, infrastructure developers and climate scientists across the categories above.

Strengthen partnerships by incentivizing coordination for key priorities

Management approaches that lead to functioning, sustainable coordination

- » Make all stakeholders feel they have something to contribute
- » Set up task force research areas (e.g. like drought task force)

Service Level Agreements (internal) and MOUs (external)

## Day 2 – Breakout Group 2

*Q3 – What are near-term opportunities and requirements for addressing high priority problems in advancing understanding and predictions at regional scale?*

Opportunities:

- Improved physical processes and high resolution models allows analysis & experimentation to understand high priority problems
- Do prediction experiments (SI, hurricane, climate extremes) to test impact of resolution and of improved physical parameterizations
- Obtain improved estimates of predictability with high resolution models
- New satellite cloud observations; field campaign for aerosols to improve cloud-aerosol interaction
- Experimentation of NWP models for climate and climate models for Wx prediction to assess strengths and weakness of each
- Develop objective drought monitoring and prediction system
- Generate timely "a"ssessments of high impact climate and weather events
- Fully mine existing datasets, such as climate data modernization program data, for perspectives/estimates of historical variability and change

*Q4 – How can NOAA work together with our partners to more effectively address these challenges?*

- Increase availability of results of integrations with NOAA models to research groups outside of model-developing institutions.
- Increase availability and support for NOAA models outside of model-developing institutions.
- Provide facility for partner-generated experiments to be run using NOAA models.

- Maintain strong communications with model-developing institutions outside of NOAA, nationally and internationally.
- Maintain strong links between model developers and process-study communities, e.g, GCSS (Global Cloud System Studies).
- Maintain strong links with NSF, NCAR, NASA, DOE regarding foundational studies, satellite observations, and process studies, e.g., DOE Atmospheric Systems Research (ASR).
- Generate merged (NOAA and other) observational datasets. Use NOAA models to interpret and analyze observations.
- Increase NOAA intra-mural targeted partnerships, e.g., HFIP, Climate Testbed, NCEP-GFDL joint model evaluation.
- Maintain strong links within NOAA and between NOAA and other agencies in intensive field programs.
- Strengthen strategy for requirements of applications stakeholders to enter strategic research planning and planning for transition of research to service. Build on current mechanisms, e.g., RISAs (Regional Integrated Science Assessment) and PACE (Postdocs Applying Climate Expertise). RISAs offer potential in this regard but need stronger integration with other elements of NOAA. NOAA requires permanent mechanisms for integrated science assessment.
- Develop relationships between regional climate service offices (NOAA, Interior) and NOAA broadly.
- Maintain and strengthen academic partnerships via grant programs.
- Maintain relationships for international scientific programs and observing systems.
- Maintain CLIVAR involvement.
- Implementation of these recommendations will require enhanced resources.

## Day 2 – Breakout Group 3

**Question 3: Opportunities and Needs -1**

*What are near-term opportunities and requirements for addressing high priority problems in advancing understanding and predictions at regional scales?*

- Timely responses on analysis and attribution of individual extreme events within 3 months – start with implementation for 2011
- Better characterization of radiative impacts of aerosols over the USA through field campaign planned for 2013
- Clarify the influence of aerosols on the spatial and temporal distribution of precipitation
- Work across the NOAA silos (aka LOs) to communicate climate information on impacts for health, marine eco and agriculture.
- Establish credibility for intraseasonal to interannual climate information before engaging at decadal and century timescales

- Understand the decision process and use of seasonal hurricane outlooks. Need to document and get systematic feedback
- Use Observing System Simulation Experiments (OSSEs) for ocean, land, and atmosphere in designing the Climate Observing System
- Exploit the national multimodel ensemble data streams on monthly predictions to achieve better skill at seasonal timescales
- Intraseasonal timescale application of multimodel ensemble approach, process understanding of predictability to know how interannual to multidecadal variations modulate teleconnections
- Better coordinate observing, modeling and forecasting capabilities for intraseasonal outlooks - more than just MJO
- Apply high resolution multimodel ensembles for seasonal convective outlooks (risk assessments for tornado/high precip)
- Explain and contrast big and small climate extreme seasons
- Improve reanalysis derived products such as CAPE for understanding and predictability of convective weather
- Arctic is a region experiencing rapid change – observations (including field campaigns and trace gas emissions) are needed to monitor changes in climate and inform development of indicators
- Extreme nighttime temperatures are having impacts on natural, agriculture and built resources: advance understanding, predictability and modeling of impacts such as wildfire potential
- Understanding sources of predictability through initialized decadal climate predictions: Improved predictability of rapid warming of North Atlantic with improved initialization of overturning circulation and overall state of the ocean as well as reduction of model biases
- Maximize use of existing resources through product enhancements such as conditional skill masks for existing climate forecast system models (e.g., La Niña/El Niño/neutral)
- Provide access to the necessary suite of CFS data to support hindcasts and forecasts that can be used to downscale output and to run nested regional climate and other impact models
- Explore linking 'research to decision making' to leap frog over the valley of death challenge in transitioning 'research to operations'

**Question 4:**

*How can NOAA work together with our partners to address these challenges more effectively?*

- RISAs
- Connecting users with climate services/needs
- Feedback to NOAA on climate products
- Invest more in state/regional climate info
- RISA, state climatologists (state epi model), regional climate centers

- Integrate climate info into river forecasts
- Climate Process Team model
- Partnership across branches on NOAA with outside partners
- Well-defined goal with definite time table
- Partnership with universities-integrating uni scientists via CIs, grants
- Model output access as a point for working together

# References

Ackerley, D., and Co-Authors, 2011: Sensitivity of twentieth-century rainfall to sulfate aerosol and CO2 forcing. J. Climate, 24, 4999-5014.

Bekryaev, R. V., I. V. Polyakov, V. A. Alexeev, 2010: Role of polar amplification in long-term surface air temperature variations and modern arctic warming. J. Climate, in print, doi: 10.1175/2010JCLI3297.1

Bollasina, M. A., Y. Ming, and V. Ramaswamy, 2011: Anthropogenic aerosols and the weakening of the South Asian summer monsoon. Science, 334, 502-505.

Chang, C. -Y., J. C. H. Chiang, M. F. Wehner, A. R. Friedman, R. Ruedy, 2011: Sulfate aerosol control of tropical Atlantic climate over the twentieth century. J. Climate, 24, 2540-2555.

Cook B.I., R. L. Miller, R. Seager, 2009: Amplification of the North American ''Dust Bowl'' drought through human-induced land degradation. Proc. Natl. Acad. Sci. , 106:4997–5001.

CCSP, 2008a: Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of observed Change. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. R. M. Dole (ed.), M. Hoerling, S. Schubert, P. Arkin, E. Kalnay, G. Hegerl, D. Karoly, A. Kumar, J. Carton, R. Koster, A. Kumar, R. Pulwarty, D. Rind. Dept. of Commerce, NOAA National Climatic Data Center, Washing, D.C., USA, 132. pp.

CCSP, 2008b: Climate Projections Based on Emissions Scenarios for Long-Lived and Short-Lived Radiatively Active Gases and Aerosols. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. H. Levy II, D.T. Shindell, A. Gilliland, M.D. Schwarzkopf, L.W. Horowitz, (eds.). Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA, 100 pp.

CCSP 2009: Atmospheric Aerosol Properties and Climate Impacts, A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.)]. National Aeronautics and Space Administration, Washington, D.C., USA.

Deser, C., R. Tomas, M. Alexander, D. Lawrence, 2010: The seasonal atmospheric response to projected arctic sea ice loss in the later twenty-first century. J. Climate, 23, doi: 10.1175/2009JCLI3053.1.

Diffenbaugh, N., 2005: Atmosphere-land cover feedbacks alter the response of surface temperature to CO2 forcing in the western United States Climate Dynamics (2005) 24, 237–251, doi: 10.1007/s00382-004-0503-0.

Giannini A., R. Saravanan, P. Chang, 2003: Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales. Science, 302, 1027–1030.

Giannini A., M. Biasutti, M. M. Verstraete, 2008: A climate model-based review of drought in the Sahel: desertification, the re-greening and climate change. Glob. Planetary Change, 64, 119–128.

Hoerling M., J. Hurrell, J. Eischeid, A. Phillips, 2006: Detection and attribution of twentieth-century northern and southern African rainfall change. J. Clim., 19, 3989–4008.

IPCC, Climate Change 2007: The Physical Science Basis. Contribution of Working 263 Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate 264 Change [Solomon, S.D. et al. (eds.)]. Cambridge University Press, Cambridge, 2007.

Knutson, T., and Coauthors, 2006: Assessment of twentieth-century regional surface temperature trends using the GFDL CM2 coupled models. J. Climate, 19, 1624–1651.

Kumar, A., J. Perlwitz, J. Eischeid, X. Quan, T. Xu, T. Zhang, M. Hoerling, B. Jha, and W. Wang (2010), Contribution of sea ice loss to Arctic amplification. Geophys. Res. Lett., 37, L21701, doi:10.1029/2010GL045022.

Ming, Y., V. Ramaswamy, and G. Chen, 2011: A model investigation of aerosol-induced changes in boreal winter extratropical circulation. J. Climate, 24, 6077-6091.

National Research Council, 2005: Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties. National Academies Press, Washington, DC.

National Research Council, 2010: Assessment of Intraseasonal to Interannual Climate Prediction and Predictability. National Academies Press, Washington, D.C., pp. 181.

Pan, Z., R. W. Arritt, E.S. Takle, W. J. Gutowski Jr., C J. Anderson, and M. Segal, 2004: Altered hydrologic feedback in a warming climate introduces a‘‘warming hole’’. Geophys. Res. Lett. L17109, doi:10.1029/2004GL020528.

Polyakov, I., J. Walsh, and R. Kwok, 2012: Recent changes of Arctic multiyear sea ice coverage and likely causes. Bull. Amer. Met. Soc., doi: 10.1175/BAMS-S-11-00070.1.

Rotstayn L. D., Lohmann U. Tropical rainfall trends and the indirect aerosol effect. J. Clim. 2002, 15, 2103–2116.

Schubert S. D., Suarez M. J., Pegion P. J., Koster R. D., and Bacmeister J. T., 2004: On the cause of the 1930s Dust Bowl. Science, 303, 1855–1859.

Serreze, M. C., and Francis, J. A., 2006: The Arctic amplification debate. Climatic Change, 76, 241–264.

Serreze, M. C., M. M. Holland, and J. Stroeve. 2007. Perspectives on the Arctic's shrinking sea ice cover. Science 315(5818): 1533-1536, doi:10.1126/science.1139426.

Screen, J. A., and I. Simmonds, 2010: The central role of diminishing sea ice in recent arctic temperature amplification. Nature, 464, doi:10.1038/nature09051.

Stroeve, J., M. M., Holland, W. Meier, T. Scambos, and M. Serreze, 2007: Arctic sea ice decline: faster than forecast. Geophys. Res. Lett. 24, L09501, doi:10.1029/2007GL029703.

Stroeve, J. M., and co-authors 2008. Arctic sea ice plummets in 2007. Eos, Trans. Am. Geophys. Un. 89, 13–20.

Wang, X., J. R. Key, 2005: Arctic Surface, Cloud, and Radiation Properties Based on the AVHRR Polar Pathfinder Dataset. Part II: Recent Trends. J. Climate, 18, 2575–2593.

Wang, H., S. Schubert, M. Suarez, J. Chen, M. Hoerling, A. Kumar, P. Pegion, 2009: Attribution of the seasonality and regionality in climate trends over the United States during 1950-2000. J. Climate, 22, 2571-2590.

Wild, M., 2012: Enlightening Global Dimming and Brightening. Bull. Amer. Meteor. Soc., 93, 27–37.

Williams A. P., C. Funk, 2011: A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa. Clim. Dyn., doi: 10.1007/s00382-010-0984-y.