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1 Introduction

In March 2011, 139 attendees from over 30 countries participated in the WCRP Workshop on Drought Predictability and Prediction in a Changing Climate (please refer to Appendix 2 for a list of participants). The workshop was a collaborative effort, coordinated by WCRP core projects CLIVAR (Climate Variability and Predictability) and GEWEX (Global Energy and Water Cycle Experiment).

The workshop objectives were to:

1. Determine user requirements for drought prediction information on sub-seasonal to centennial time scales;
2. Assess current understanding of the mechanisms and predictability of drought on sub-seasonal to centennial time scales;
2. Assess current drought prediction/projection capabilities on sub-seasonal to centennial time scales; and
3. Recommend actions needed to advance regional drought prediction capabilities for variables and scales most relevant to user needs on sub-seasonal to centennial time scales.

The workshop ran over three days and was organized into five different sessions, each of which featured a series of talks and poster presentations, culminating in a discussion session (please refer to Appendix 3 for the agenda). On the fourth day, the Workshop Scientific Organizing Committee (Siegfried Schubert, Sonia Seneviratne, Wenju Cai and Xavier Rodo), invited speakers, and members of the WCRP Drought Interest Group met to discuss the outcomes of the discussion sessions and to develop an action plan.

Section 2 summarizes the discussion sessions that took place, and Section 3 outlines the key recommendations that arose from the Workshop. Appendix 1 contains the latest versions of the post-workshop scoping documents outlining the plans for how to move forward on the key recommendations.

2 Discussions

The workshop discussion summaries are organized into two broad and intertwined topics of Prediction and Predictability (section 2.1) and User Needs (section 2.2).

Figure 1 denotes the linkages between these two topics. The schematic, of spatial scales versus temporal scales, shows the extent of the overlap between current skill, users needs and predictability. The key message is that whilst the overlap between current capabilities (limited to large spatial scales, and relatively short timescales) and user needs is relatively small, there is considerable room for improvement (i.e. we are still far from the limits of predictability). Also, user needs tend to involve substantially smaller scales than we are currently capable of predicting with any skill, and some may involve the unpredictable components of drought and hence might never be met.

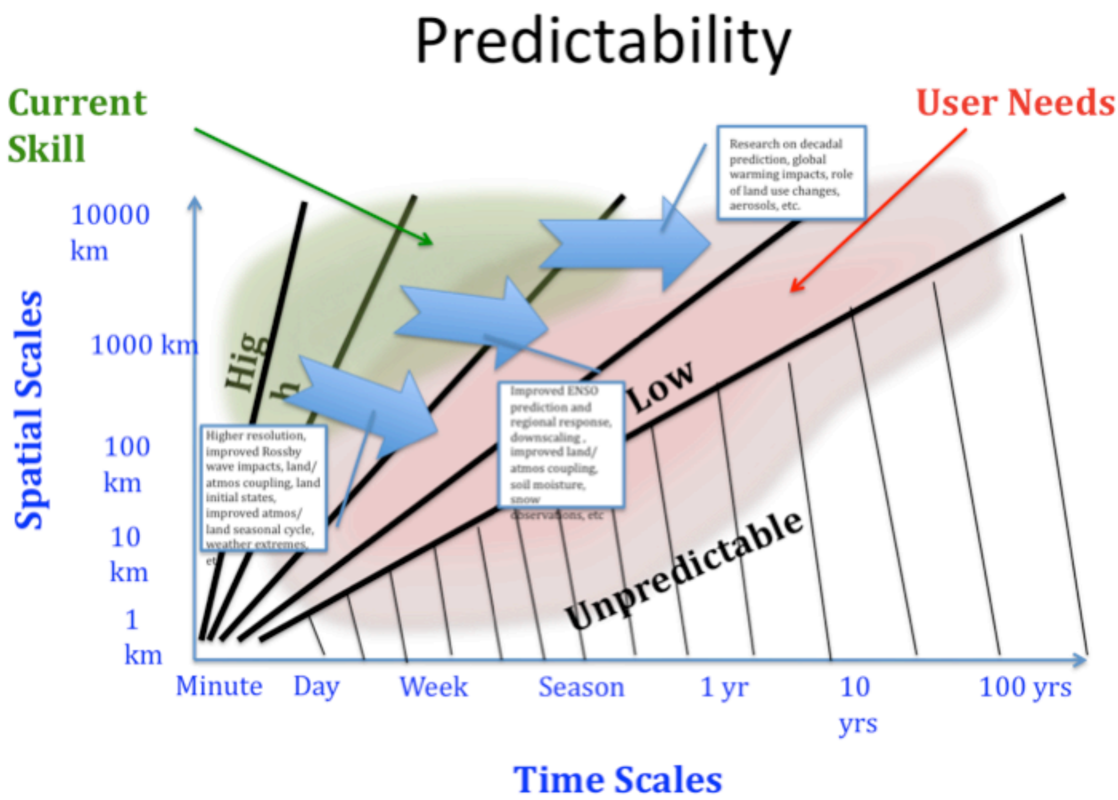

Figure 1: Schematic of drought predictability, current skill, and user needs as a function of space and time scales. The text indicates possible areas of focus for making progress on our prediction capabilities at the different time scales.

2.1 Prediction and Predictability

The discussions on prediction and predictability have been summarized under the two sections below:

- Mechanisms, Predictability and Prediction (section 2.1.1); and
- Modeling Issues (section 2.1.2).

In terms of the scope of the discussions, the issue of flooding was raised. Some participants advocated a focus on wet cycles as well as dry cycles, on the basis that floods can be just as devastating (if not more so) as droughts.

2.1.1 Mechanisms, Predictability and Prediction

Current prediction capability varies with time/space scales and location. In particular, our skillful predictions tend to be limited to the larger spatial scales and shorter time scales. It is not clear the extent to which model improvements and improvements in observations will impact prediction skill, but these should be prioritized based on user needs, and linked to drought susceptibility in particular regions (see section 2.1.2 below).

In terms of drought predictability, it was suggested that there is a need to determine what our ocean observing system is providing; there needs to be a comprehensive assessment of the role of the ocean.

With regards to mechanisms, certain variables were discussed, including sea surface temperatures (SSTs), soil moisture, ground water and Rossby waves. Case studies and cataloguing drought was also discussed, in addition to data availability. These points are expanded upon in the following paragraphs.

At seasonal and longer time scales precipitation is largely tied to SSTs. However, even where the correlation with SST is relatively high (say 0.5), this only explains a small fraction of the variance, therefore much of the variability is unpredictable. In particular, individual weather events can reduce the skill of seasonal forecasts that are otherwise very good. Scientists need to communicate effectively the probabilistic nature of the forecasts, and also address the fact that such forecasts are often conditional (e.g. forecasts may be more skillful when there is an ENSO).

Soil moisture (as well as snow) is an emerging area of focus for initializing subseasonal and seasonal forecasts. New measurements of near-surface soil moisture from satellites appear promising; however it was pointed out that soil moisture should be measured to greater depths, particularly if longer timescales are the subject of prediction.

The question was raised as to whether ground water is also necessary for prediction. Various water table measurements are being carried out by geologists, but these data are not readily available to climatologists. Groundwater modeling could indeed be useful for seasonal agricultural production and regional climate projection. However, it was noted that in some regions groundwater has been so depleted by pumping in recent years that levels are no longer linked to climate variability.

At subseasonal and seasonal timescales, mid-latitude Rossby waves appear to play a major role in triggering and maintaining extreme events such as heat waves and short-term drought. It is important to ascertain what the needs are for initializing the atmosphere/land/ocean at these timescales.

Case studies can be effective tools to assess mechanisms and predictability. They also provide a means of connecting to stakeholders. A key caveat is that with the emerging global change signal, the past may not be a very good predictor of the future. It is important to distinguish between global change-related drought (the "fingerprints" of such droughts), and those linked with other drivers of climate variability. On the subject of case studies, one recommendation was to identify regions that are prone to drought and build institutional partnerships in these areas to generate more information and further case studies.

Alongside case studies, a catalogue of past droughts and their mechanisms can be a valuable tool, since the skill of drought predictions depends to some extent on what initiates them. It was suggested that an annual drought outlook should be assembled, synthesizing information from across regional groups. This exercise could also serve to identify case studies.

Further discussions took place regarding barriers to obtaining datasets, which impacts on the ability to monitor drought. Where this is the case, scientists should be more vocal with regard to open access to data for climate research. Europe is an example of where data accessibility can be limited owing to the multi-national nature of the region. However the situation does appear to be improving for certain countries (e.g. Netherlands, Norway, Slovenia, Check Republic and Spain). It was noted that countries are more likely to make available derived quantities (e.g. indices), rather than the raw data.

2.1.2 Modeling Issues

Modeling issues were discussed in terms of the uncertainty inherent in global climate change projections and how models can be improved. Currently there are only very limited areas where climate models reasonably agree (>66% of projections) on even the sign of changes in drought patterns. Also, there are large uncertainties over predicted changes in the strength and overall features of the global water cycle especially over land areas.

In terms of reducing the uncertainties, the following methods were addressed:

- Validation;
- Hindcasts;
- Model resolution;
- Observation data;
- Paleo data; and
- Factor separation.

There were a couple of methods highlighted by which models can be validated in order to assess the reliability of model projections. One approach is to look at the performance of the models at shorter time scales. Another is to assess the realism of the phenomena/mechanisms at the process level. Also, models should be tested in response to changes in forcing, to allow for calibration of the responses.

It was noted that multi-model seasonal hindcast data sets are being made available, for example though the Climate-system Historical Forecast Project, (CHFP), and the Coupled Model Intercomparison Project, Phase 5 (CMIP 5) in which high resolution decadal simulations are going to be available, and that these should be exploited. There were also calls to continually assess current predictions and capabilities in the current generation of models, and a re-examination as new models are released.

On the issue of model resolution, it is not necessarily the case that enhanced resolution at the smaller scale will lead to improvements at the larger scale. It is also unclear whether high-resolution models have improved because the large-scale is better simulated or whether it is because the small-scale has improved. There is evidence to suggest that major improvements are possible, down to a resolution of 10 km. The fundamental character of the solutions changes when you start to resolve clouds. One particular problem is that high elevation topography is not resolved in current climate models, which is important for river flow (snow). This highlights a need to link high-resolution models to very fine scale hydrologic models.

The issue was raised regarding whether good observational data are available to evaluate the high-resolution models. Comparisons between low and higher resolution models show that large-scale features are actually relatively similar, which is positive, as this was not necessarily assumed to be the case.

The use of paleo data was discussed in relation to whether droughts are sufficiently represented that paleo datasets can be used to improve model capabilities. A few paleo drought products currently exist or are being developed that describe the temporal and spatial evolution of drought in the last 1 k years. These products could potentially be useful for assessing the dynamics and root causes of drought.

One participant emphasized that factor separation should be employed when considering multiple factors, to assess the non-linear interactions between factors. It was noted, however, that substantial computational cost is tied to separating factor interactions in high-resolution models.

2.2 User Needs

There was a general consensus that research priorities need to have a stronger links to user needs. However, the degree of interaction with the user community, and the issues that need to be communicated was more contentious. Capacity building was also addressed during the discussions.

2.2.1 User Interface

There was broad agreement that a direct link between scientists and the end users was not feasible, but that instead there should be some intermediate organization/group (e.g. IRI). It was suggested, for example, that the national Climate Services could act as an interface between scientists and users. Expertise from other disciplines could be brought in to assess the implications of forecasts, for example how the price of food would vary in response to predicted conditions.

Local agencies in charge of links to user needs could also feed information back to the climate scientists. This would enable models to be harmonized, as larger scale studies may not reflect regional characteristics.

Even if there is some intermediary organization, it is important to understand who the users actually are. In the case of hydrology this is clear, but in terms of health or social impacts it is less so. Concern was raised that users in water resources may predominantly fall into a category where there is no predictability. Another issue is that social scientists and physical scientists speak different languages and it is important that the two disciplines learn how to communicate.

A contrasting view was that the science agenda is being 'watered down' by requiring scientists to connect with all different sectors, and that the onus should not be placed on the scientists. This point was backed up by the example that ENSO research was curiosity driven science.

2.2.2 Communication with Users

The means by which the community communicates with users was discussed. One participant held the view that communication with users is more associated with embedding information and practices through risk management, rather than it being a two-way process in practice. The use of nowcasting and indices were also covered, and are expanded upon below.

Nowcasting can be very useful to users in relation to decadal timescales. In particular, it would be beneficial to be able to communicate what part of the cycle we are in and how long we are likely to stay in that phase. Also, whilst there is a clear need for seasonal and longer-term forecasts, intraseasonal variations of rainfall are also important for management. In two different droughts, for example, even if the total annual rainfall is similar, one may be more conducive to farming than the other if the precipitation happens to occur at the opportune stage of the growing cycle.

The scientific community has been struggling to define drought indices for some time. There is very little agreement amongst users in terms of useful indices, of which there are many; there is perhaps a need to assess the independence of the various indices. It was suggested that efforts should initially focus on precipitation and temperature, and then encompass soil moisture and run-off. There is currently a bilateral study being undertaken on drought indices and definitions across USA and Canada.

Two mechanisms were put forward, which would both help to define indices:

1. WMO Regional Outlook Fora to identify the indices that are most relevant for their regions and stakeholders, identify the current skill, and educate users on what can and cannot be achieved; and
2. A drought impacts database, to help refine useful products, to calibrate indices, and to aid drought response.

2.2.3 Capacity Building

Young scientists could be trained to better understand the language and needs of users, exploiting facilities that users have (e.g. hydro-power visits). Capacity building is also necessary amongst users, to train users how to use climate information, which could be achieved through workshops. Education can help to alleviate the impacts of drought by addressing misconceptions about drought, as has been done extensively in Canada.

3 Recommendations / Action Items

The key recommendations of the workshop are outlined below. Following the workshop, volunteers carried out a more detailed scoping of these action items. The resultant reports are provided in Appendix 1.

ACTION 1. Develop a drought catalogue that summarizes our current understanding of the causes of drought world-wide. For example, a map summarizing the important time scales (e.g. subseasonal, seasonal, decadal, centennial) and mechanisms (e.g. ENSO, PDO, land feedbacks, global warming) for each region, with links to relevant publications.

Initial Volunteers: Ron Stewart, Wenju Cai, Sumant Nigam, Richard Heim

ACTION 2. Define case studies and carry out a coordinated analysis of the mechanisms, predictability and prediction skill. Cases will have a high profile and strong links to user needs (e.g. the 2010 Russian heat wave, the 2011 Australian drought). This could evolve into a regular annual assessment of worldwide drought.

Initial Volunteers: Vikram Mehta, Bart van den Hurk, Sonia Seneviratne, Paul Dirmeyer, Roberto Mechoso, Robert Vautard

ACTION 3. Actively contribute to the development and improvement of drought early warning systems (DEWS) taking advantage of our current capabilities in drought prediction and monitoring (with links to the NIDIS drought portal and other national and regional drought monitoring activities).

Initial Volunteers: Marty Hoerling, Richard Heim, Kingtse Mo, Eric Wood

4 Presentations

Please follow the following weblink to access the presentations from the Workshop:

http://drought.wcrp-climate.org/workshop/Agenda

Appendix 1 Post-workshop Scoping Documents (as of 11 May 2011)

Note that these are initial scoping documents that, along with the membership, are expected to evolve as the efforts begin to take shape. The versions included here are current as of 25 May 2011.

A1.1 Group One: Cataloguing Drought, Drivers and Features

Wenju Cai, Richard Heim, Sumant Nigam, Ron Stewart

1. Objectives

Develop a drought catalogue that summarizes our current understanding of the causes of drought world-wide. For example, a map summarizing the important time scales (e.g. subseasonal, seasonal, decadal, centennial) and mechanisms (e.g. ENSO, PDO, land feedbacks, global warming) for each region, with links to relevant publications.

2. Actions

- Identify colleagues who could contribute information to this study.
- By surveying the literature and existing publications, acquire current information and maps of drought worldwide and update these as needed. This would utilize relevant drought and relevant climate indices and would also include intensity and temporal and spatial scales of drought in different regions.
- Assess means through which drought is initiated, evolves and ends including combinations of factors. Examples of large scale factors include SAM, the IOD, ENSO, PDO whereas regional factors include land surface and land area feedbacks. Factors would also include those linked with climate change forcing (for example, increasing CO2, ozone depletion, and enhanced aerosol concentrations).
- Document droughts as to structural features including nearby and/or internal precipitation events and explain common and unique features.
- Hold a workshop on this issue, probably in conjunction with a larger event, in order to exploit linkages and to save costs.

3. Linkages

This activity can link with others being undertaken in different regions. Two examples include the following:

- U.S.-Canadian GEO Bilateral Drought Indices and Definitions study. This study is preparing an inventory of drought indices used across North America and a bibliography of drought definitions for the diverse climates of North America. The results of this study can feed into this drought catalogue activity, and the results of the WCRP DIG workshop drought catalogue can feed into the North American study.

- Global Drought Monitor Portal (GDMP) and the Global Drought Early Warning System (GDEWS), where the WCRP drought catalogue can serve as an educational information component.

4. Outcomes

- An updated pictorial view of drought around the world. Associated graphs would illustrate key drivers and there would be a consistent examination of the structure of droughts to illustrate common and unique features.
- Recommendations for prediction and adaptation requirements at a variety of time scales.
- Material would be made available for use in educational activities.
- Listing of appropriate publications.

5. Resources

This activity is based on volunteers but funding is needed. Although no specific cost is known, the effort would benefit greatly from a dedicated post-doctoral fellow or research associate working for at least a year on this topic; the location is quite flexible. In addition, a workshop should be held on this issue and it would ideally be linked with a larger event.

A1.2 Group Two: A Draft Program to Conduct Case Studies of Causes, Mechanisms, and Societal Impacts of Interannual and Decadal Droughts, and User Information Needs for Adaptation[1]

Vikram Mehta, Bart J.J.M. van den Hurk, Sonia Seneviratne, Paul Dirmeyer, Roberto Mechoso, Norman Rosenberg, Robert Vautard

1. Objectives

- To identify causes and mechanisms of major, interannual and decadal droughts in past, instrument-based observations in various regions of the world;
- To assess impacts of identified droughts on major societal sectors such as water, agriculture, public health; and on natural ecosystems;
- To assess drought information needs of stakeholders to cope with/adapt to future droughts; and
- To develop the needed climate and impacts information, and provide it experimentally to stakeholders in a timely and actionable manner.

2. Actions

- Survey of major interannual and decadal droughts in past data (precipitation, temperatures, soil moisture) to prepare a "portfolio" of observations-based drought cases for further studies.
- Classification of types of droughts via analyses of global and regional climate (ocean-atmosphere-land) conditions before, during, and after the identified droughts to associate climatic conditions with droughts (e.g. spring precipitation deficit in midlatidutes; ENSO-, PDO-, tropical Atlantic SSTs-, and Indian Ocean Dipole-related related droughts; cold/dry air intrusions in high latitudes).
- Collection and analyses of stream flow and crop yield data during major drought episodes.
- Identification of a few (4-6?) case studies, based on results from the above (and possibly new cases if/when they occur); possible, recent drought cases to be studied (but not limited to): Russia and Amazon (2010), Australia (2009-10), Europe (2003).
- Identification of interested collaborators for interdisciplinary studies (climate scientists, hydrologists, drought specialists, agricultural and social scientists, stakeholders such as farmers and water managers, and policymakers) from the identified countries, volunteering to work on centralizing information on identified drought cases (and possibly new cases if/when they occur), by committing some of their time on in-depth investigations; involvement of other appropriate WMO entities, FAO, USAID as necessary.
- Simulation experiments with climate, hydrology, and land use models to replicate causes and impacts of past droughts on water and agriculture; and also of projected, future droughts according to IPCC scenarios.
- Interactions with in-country specialists and stakeholders via regional workshops and other fora (1) to assess impacts of past droughts and remedial actions taken; (2) to

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[1] Last revision on 21 March 2011

assess their current and future drought (climate in general) information needs; and (3) to generate feedback for climate scientists.

For each drought event, activities may include, but not be limited the following:

i. Review

- What happened during the particular event (drivers/mechanisms of initiation, intensification, ending of event)?
- What is the potential predictability of this event, and was it actually forecasted well? How far in advance?
- What were the impacts (*society*: health, traffic, power supply, agriculture; *nature*: vegetation carbon sink, phenology)?
- How do you place this event in the context of climate change and future climate?
- Lessons learned (e.g. drought management)

ii. Modeling (Multi-Model Experiments)

- Identify key drivers & feedbacks
- SST forcing, snow and soil moisture, vegetation
- Climate change: CO_2, aerosols
- Evaluate predictability & skill
- Coupling to hydrological/agricultural impact modeling

iii. Future Climate

- Assess future return time and impacts, using AR5 organized climate model archive
- Development of an experimental program to provide nowcast and forecast drought information to stakeholders, according to their needs, in successful case study areas
- Preparation and publication of reports and papers

3. Outcomes

- Development of models and methodologies for assessing causes, mechanisms, and impacts of interannual and decadal droughts
- Development of networks of stakeholders and scientists in case study regions
- Estimation of interannual and decadal drought impacts in selected case study regions and countries
- Assessment of current drought simulation and prediction capabilities
- Assessment of drought information needs of stakeholders in societally-important sectors
- Experimental drought prediction and information-delivery systems, with potential for applications to an expanded number of regions in the world

4. Resources

- Approximately US$ 500,000 per case study; $3 million for six case studies
- Climate, hydro-meteorological, stream flow, agricultural, public health, and AR5 data sets
- Access to uncoupled and coupled climate models; and hydrology, land use, and other impacts models

A1.3 Group Three: Develop an Experimental Global Drought Early Warning System

1. Objectives

- To determine who the target "audience" is for the DEWS and assess their needs with the goal of developing tools that supplement what the nations meteorological agencies/communities are already doing;
- To perform risk assessment for droughts in different countries;
- To establish global drought monitoring based on improved historical and near real-time observations and the outputs from calibrated land surface models;
- To combine drought monitoring, multi-model ensemble forecasts, and our understanding of the causes of drought, into a framework that will serve as the technical footing for an experimental Global Drought Early Warning System (GDEWS); and
- Where needed and requested, transfer DEWS technology to national services and regional drought centers for assessment, and carry out training in using the systems.

2. Work Plan

i. Drought Indices

- Drought will be monitored according to drought indices. Meteorological drought: the 1, 2, 3, 6 , 12 and 24 -month standardized precipitation indices (SPI) will be used to monitor drought on different time scales. The base period for precipitation will be 30-years or longer (preferably 50 years or longer).
- In addition to the SPIs, other indices such as the SPEI or indices recommended by the WMO drought index working group and the CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) should be considered
- Currently, the NCDC is developing in situ SPIs using the GHCN data. The CPC is developing SPI using the CPC unified precipitation at the horizontal resolution of 0.5 degrees for the base period from 1979 to the present. The system should be designed to incorporate local precipitation and other hydrometeorological data that may be unavailable to CPC. This will lead to improved country and regional monitoring.
- For agricultural drought, soil moisture at the root zone and total soil moisture will be used. Because no global soil moisture data available, the soil moisture from calibrated land surface models (LSM) will be used.
- For hydrologic drought, streamflow data or runoff from calibrated LSMs will be used to develop runoff indices for monitoring.

ii. Land surface modeling systems, LSMS

Products from the LSMS will be essential for developing the Global DEWS. Because the ensemble means are more representative than individual members, products from multi- model LSM produces will be used. The major forcing variable to drive the LSM models is precipitation followed by radiative forcings (primarily solar). Better precipitation analyses (see below) will improve soil moisture and runoff from the LSMS for drought monitoring.

iii. Satellite Derived Products

There are many satellite derived products for drought monitoring. For example, the evaportranspiration (ET) based index derived from the thermal infrared-based surface energy balance model can serve as an independent index in addition to indices derived from the LSMs. Additionally, soil moisture drought indices based on satellite retrieved soil moisture (e.g. SMOS and/or AMSR-E) can also provide information useful for the DEWS. By synthesizing the Gravity Recovery and Climate Experiment (GRACE) data and other observations within a land surface model, one can overcome the data latency and resolution problems to produce a high resolution near real time soil moisture and ground water storage. These products can be used for drought monitoring.

Here we will consider two focus areas: a) improving near real-time global precipitation analyses through the use of satellite information and b) evaluation of additional remotely sensed variables relating to soil moisture (e.g., ET).

iv. Develop Seasonal Drought Forecasts

A true drought early warning system, should include a forecasting component. In order to achieve an integrated system, the forecasts of drought indices need to be consistent with the drought monitoring.

For meteorological drought, the SPI forecasts can be based on the dynamical model forecasts of precipitation or statistical models that takes into consideration the persistence of the SPI in its design. Here we will pursue ensemble methods by taking advantage of current national multi-model efforts to provide experimental near-real time global subseasonal to seasonal and longer predictions.

To predict agricultural and hydrologic drought, hydrologic prediction of soil moisture and runoff on the subseasonal to seasonal time scales is needed. Currently, most hydrologic prediction for the United States is based on global forecasts. Soil moisture and runoff are products of the hydrologic model outputs. The forcing to drive a hydrologic model is derived from downscaled and bias corrected precipitation and surface temperature from a global model forecast

The challenge is to develop a multi- model ensemble hydro -climate production system based on both multi global and hydrologic models. Most statistical bias correction methods will only correct the models climatology and standard deviations. Hydrologic models will not correct errors of a global model. Key issues that need to be investigated are how to: (a) optimally combine the global model forecasts for hydroclimate applications, (b) improve downscaling and bias correction methods , and (c) best form ensembles of soil moisture and runoff predictions from the hydrologic model products.

v. Product Delivery

The Global Drought Monitor Portal (GDMP) developed by the NCDC can be used as a foundation for a Global DEWS. The GDMP is a monitoring product that integrates continental Drought Monitors which are created by Member Countries of each continent. The GDMP/GDEWS concept is to provide global drought indicators, such as satellite-derived ET, precipitation, etc., and global model-based indicators, and other global in situ indicators such as the GHCN-based SPI, for consistent global coverage (indicators computed over a common calibration period and methodology for the entire world), which are used as guidance for the continental DMs; but the actual drought depiction on each continent is determined by those on the continents experiencing their droughts first-hand.

Similar to the monitoring produces. The forecasts of the global drought indices will be provided. The WMO Global Framework for Climate Services (GFCS) Climate Services Information System (CSIS) has global mechanisms for regional climate services and global forecasts that may be beneficial for this effort to hook up with. Our GDEWS global drought forecasts could be provided as guidance to the regional/continental/national entities who may make their own forecasts.

A Global Drought Information Service (GDEWS) should be put together from participating countries around the world as well as through established UNESCO drought centers.

vi. Education and Outreach Activity

The global DEWS should be transferred to county hydrological/meteorological services and regional drought centers when requested. This offers the opportunity for local services to assess the system at country to regional scales. Sufficient training needs to be provided so the country services and regional centers can effectively use the system

vii. Linkages to other projects/programs

The GDEWS will network and coordinate with other organizations/projects doing global and regional drought monitoring and forecasting. This includes the Group on Earth Observations (GEO), the US National Integrated Drought Information System (NIDIS), WMO, and various other research projects.

It is recognized that understanding the causes of ongoing drought can also be an important part of a GDEWS. As such, this effort will contribute to and link to other activities that focus on the attribution of drought.

3. Members

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Raeed Hassan	Presidency of Meteorology and Environment
Richard Heim	NOAA NCDC

Zaida Hernández-Guillén	University of Murcia
Stefanie Hess	WSL
Hugo Hidalgo	Universidad de Costa Rica
Martin Hoerling	NOAA, ESRL, PSD
Anahit Hovsepyan	Armstatehydromet
Marjolein Huijgevoort	Wageningen UR
Bart Hurk	KNMI
Malaak Kallache	LSCE/IPSL (Paris, France)
Sarat Kar	National Centre for Medium Range Weather Forecasting, Ministry of Earth Sciences
Shahram Khorasanizadeh	Regional Centre on Urban Water Management-Tehran (under the auspices of UNESCO)
Randal Koster	GMAO, NASA/GSFC
Henny Lanen	Wageningen University
Dennis Lettenmaier	university of washington
Yaohui Li	Institute of Arid Meteorology
Maria-Carmen Llasat	University of Barcelona
Anne Van Loon	Wageningen UR
Joan Lopez-Bustins	University of Barcelona
Ruth Lorenz	ETH Zurich
Jorge Lorenzo	CSIC
Teresa Losada	Universidad Complutense de Madrid
Lifeng Luo	Michigan State University
Bradfield Lyon	IRI, Columbia University
Zhuguo Ma	Institue of Atmospheric Physics,CAS
Victor Magaña	Universidad Nacional Autónoma de México
Ramona Magno	IBIMET-CNR
Rodrigo Maia	FEUP-Faculty of Engineering of the University of Porto

Erwin Makmur	Indonesia Agency of Meteorological Climatological and Geophysical (BMKG)
Jose Marengo	INPE
Annarita Mariotti	University of Maryland/ESSIC
Javier Martin-Vide	WCRP Spanish Committee
Carlos Mechoso	University of California Los Angeless
Vikram Mehta	The Center for Research on the Changing Earth System
Vikram Mehta	The Center for Research on the Changing Earth System
Joaquín Meliá	Universitat de València
Adérito Mendes	INAG - National Water Institute
Kingtse Mo	Climate Prediction Center/NCEP/NOAA
Robert Molinari	CLIVAR
Franco Molteni	ECMWF
Josep Anton Morguí	IC3 - Institut Català de Ciències del Clima
Asif Muhammad	Catalan Institute of Climate Sciences
Wolfgang Müller	Max Planck Institute for Meteorology
Omar Müller	Universidad Nacional del Litoral
Abdalrahman Mushtaq	Presidency of Meteorology and Environment
Nasrin Nasrollahi	University of California, Irvine
Gustavo Naumann	CONICET - UBA
Carolina Neri	UNAM
Sumant Nigam	Univesity of Maryland, Dept. of Atmospheric & Oceanic Science
Leonard Njau	African Centre of Meteorological Applications for Development (ACMAD)
Taikan Oki	IIS The University of Tokyo
Rene Orth	ETH Zurich
Oriol Palom Rico	Institut Català de Ciències del Clima
Olga Penalba	Departamento de Ciencias de la Atmósfera. FCEN. UBA

Saskia Pietzsch	Deutscher Wetterdienst
Jan Polcher	CNRS-LMD
Vera Potop	Czech University of Life Sciences in Prague
Roger Pulwarty	NOAA
Xavier Rodó	Institut Català de Ciències del Clima
Luis Ricardo Rodrigues	Institut Català de Ciències del Clima
Belén Rodríguez de Fonseca	Departamento de Geofísica y Meteorología, Universidad Complutense
Richard Rosen	NOAA Climate Program Office
Joseph Santanello	NASA-GSFC
João Santos	ESTIG, Instituto Politécnico de Beja
Jae-Kyung Schemm	CPC/NCEP/NWS/NOAA
Siegfried Schubert	NASA/GSFC
Richard Seager	Lamont Doherty Earth Observatory of Columbia University
Sonia Seneviratne	ETH Zürich
Ge Shi	University of Southern Queensland
Mahesh Shinde	Institut Català de Ciències del Clima
Frank Sienz	CliSAP, University of Hamburg
Jailan Simon	Malaysian Metorological Department
Andrew Singleton	European Commission Joint Research Centre
Soo-Jin Sohn	APEC Climate Center
Soroosh Sorooshian	University of California, Irvine
Kerstin Stahl	University of Freiburg
Maria Staudinger	University of Zurich
Ronald Stewart	University of Manitoba
Jozef Syktus	Queensland Climate Change Centre of Excellence
Lena M. Tallaksen	University of Oslo
Marivi Tello	IC3 - Institut Català de Ciències del Clima

Ryan Teuling	Wageningen University
James Todd	NOAA CLIMATE PROGRAM OFFICE
Seydou Traore	AGRHYMET Regional Centre
Adrian Trotman	Caribbean Institute for Meteorology and Hydrology
Marco Turco	University of Barcelona
Gerard Van der Schrier	Royal Netherlands Meteorological Institute
Hamza Varikoden	Indian Institute of Tropical Meteorology
Robert Vautard	LSCE CEA/CNRS/UVSQ
Sergio Vicente-Serrano	Instituto Pirenaico de Ecología (CSIC)
Danila Volpi	Institut Català de Ciències del Clima
Zunya Wang	Natinal Climate Center, China Meteorological Administration
Jinsong Wang	Institute of Arid Meteorology
Hui Wang	NOAA CPC and Wyle IS
Michael Wehner	Lawrence Berkeley National Laboratory
Don Wilhite	University of Nebraska
Eric Wood	Princeton University
Richard Wood	Natural Environment Research Council
Elena Xoplaki	University of Bern / Institute of Geography
Ramesh Yadav	Indian Institute of Tropical Meteorology
Med Zegrar	Centre of spaces techniques
Xukai Zou	National Climate Center of CMA

Appendix 3 Agenda

Wednesday 2nd March 2011

08:30 Xavier Rodó and Franziska Ewald: Welcoming remarks and logistics

08:40 Ghassem Asrar: Opening Remarks

08:50 Siegfried Schubert: Understanding and predicting drought on subseasonal to decadal and longer time scales: An overview

09:10 Ileana Blade: CLIVAR Spain

09:20 Josep Enric Llebot i Rabagliati, Secretary for Environment and Sustainability of the Goverment of Catalonia: Welcoming remarks

Session I Understanding Drought and its Predictability

Chair: Siegfried Schubert and Robert Vautard

09:30 Sonia Seneviratne: Drought in a changing climate: Feedbacks and uncertainties

09:50 Robert Vautard, C.Cassou, J Cattiaux, P. Ciasis, F. D'Anrea, Y. Fan, M. Kageyama, N. de Noblet, J. Polcher, B. Quesada, N. Viovy, A. Provenzale, P. Yiou, M. Zampieri: The Development of summer heat and drought in Europe

10:1 Marty Hoerling**:** On the increased frequency of Mediterranean drought

10:30 Coffee Break

11:00 Contributed talk – Mathew Barlow and Andrew Hoell: Seasonal and subseasonal predictability of drought in Central-Southwest Asia

11:15 Contributed talk – A.J. Teuling, C. C. van Heerwaarden, and S. I. Seneviratne: The role of land-atmosphere interaction in controlling forest and grassland evapotranspiration during drought

11:30 Contributed talk – P.A. Dirmeyer, Benjamin A. Cash, James L. Kinter III, Thomas Jung, Lawrence Marx, Peter Towers, Nils Wedi, Deepthi Achuthavarier, Jennifer M. Adams, Eric L. Altshuler, Bohua Huang, Emilia K. Jin, and Julia Manganello: Evidence for enhanced land atmosphere feedback in a warming climate

11:45 Contributed talk – W. Müller, H. Pohlmann, D. Smith, E. Burke, S. Hagemann, D. Matei, C. Reick: The potential of current decadal climate prediction systems for multi-year drought forecasts

12:00 Richard Seager and Naomi Naik: A mechanisms-based approach to detecting recent anthropogenic hydroclimate change

12:20 Lunch

13:20 Discussion Session

Discussion Leads: Sonia Seneviratne, Richard Seager, Martin Hoerling

Rapporteur: Catherine Beswick

Session II Prediction of Drought

Chair: lleana Bladé and Randal Koster

14:20 Ronald Stewart: The structure of drought and implications for prediction

14:40 Randal Koster, Sarith Mahanama, Ben Livneh, Dennis Lettenmaier, and Rolf Reichle: Prediction of hydrological drought: What can we learn from continental-scale offline simulations?

15:00 Eric Wood: Utility of remote sensing products for drought monitoring and retrospective analysis

15:20 Taikan Oki, Naota Hanasaki, Shinta Seto, Kei Yoshimura, and Shinjiro Kanae: Quasi-real time offline simulation of land surface model coupled with anthropogenic activities

15:40 E. Hugo Berbery, D. Alcaraz-Segura, S.-J. Lee, O. V. Muller: The effect of the surface conditions on extreme events: Regional model simulations using Ecosystem Functional Types

16:00 Break

16:30 Contributed talk – Roberto Mechoso: Sahel Rainfall: Before and after the 1970's

16:50 Contributed talk – Bart van den Hurk, Francisco Doblas-Reyes,

Gianpaolo Balsamo, Randal D. Koster, Sonia Seneviratne and Helio Camargo Jr: Soil moisture effects on seasonal temperature and precipitation forecast scores in Europe

17:05 Contributed talk – H. Douville, B. Decharme, A. Ribes, R. Alkama:

Detection of recent changes in land evapotranspiration and implications for drought projections

17:20 Contributed talk – Cheng-Ta Chen and Shou-Li Lin: Are the more extreme seasonal drought conditions easier to predict?

17:35 Contributed talk – Jozef Syktus: Projections of drought during the 21st century using representative concentration pathways and CSIRO Mk3.6 climate mode

17:50 Poster Session and Ice-Breaker

Thursday 3rd March 2011

Session II Prediction of Drought – Continued

Chair: Randal Koster

08:30 Soroosh Sorooshian, Amir AghaKouchak, Kuolin Hsu, Xiaogang Gao:

Application of PERSIANN satellite precipitation estimates to drought analysis

08:50 Dennis Lettenmaier: The role of initial conditions and weather forecast skill in seasonal drought prediction

09:10 Discussion Session

Discussion Leads: Siegfried Schubert, Hugo Berbery, Bart van den Hurk

Rapporteur: Catherine Beswick

10:10 Coffee Beak

Session III Regionality of Drought and its Prediction

Chair: Annarita Mariotti, Hugo Hidalgo

10:30 Wenju Cai, Tim Cowan, and Peter van Rensch: The cause, nature, and impact of the recent Australian drought

10:50 Xavier Rodó, Mariví Tello, Joan Ballester and Josep Anton Morguí:

Spatiotemporal evolution of drought-associated energy over the last century.

Regionalization and prospects for predictability

11:10 Hugo G. Hidalgo: Model calibration and retrospective analysis of

Drought Variability in Central America

11:30 Contributed talk – Michael Wehner, David R. Easterling, Jay H.

Lawrimore, Richard R. Heim Jr., Russell S. Vose, Benjamin D. Santer: Projections of future drought in the continental United States and Mexico

11:45 Contributed talk - A. Weisheimer, F. Doblas-Reyes, T. Jung and T.

Palmer: On the predictability of the extreme summer 2003 over

Europe

12:00 Contributed talk – Kerstin Stahl and Lena M. Tallaksen: Large-scale droughts in Europe: A comparison between streamflow observations and WATCH multi-model analysis of extremes

12:15 Lunch

13:10 Poster Session

14:10 Pinhas Alpert: Droughts prediction over the Mediterranean and a proposed new method for monitoring precipitation with commercial cellular communication systems

14:30 Annarita Mariotti: Decadal climate variability and drought in the

Mediterranean region

14:50 TelCo José Marengo: Regional drought in the Amazon region: mechanisms, prediction challenges and user needs

15:10 Tayeb El Hassani: Drought preparedness in the Near East region: Current challendes and user needs

15:30 Break

16:00 Contributed talk – Sumant Nigam, Bin Guan, Alfredo Ruiz-Baradas: Reconstruction of 20th century North American Droughts reveals a key role for Atlantic basin temperatures

16:20 Contributed talk - Vicente-Serrano, Sergio M., Juan I. López-Moreno, Luis Gimeno, Raquel Nieto, Enrique Morán-Tejeda, Jorge Lorenzo-Lacruz, Santiago Beguería and Cesar Azorin-Molina: A multi-scalar global evaluation of the impact of ENSO on droughts

16:35 Contributed Talk - Tim Cowan: The impact of the Indian Ocean on Australian Droughts and Bushfires

16:50 Discussion Session (End 17:35)

Discussion Leads: Pavel Groisman, Paco Doblas, Ron Stewart

Rapporteur: Catherine Beswick

20:00 Workshop Dinner (for registered participants)

Restaurant "Can Cortada", Avinguda de l'Estatut de Catalunya 55, 08035 Barcelona, Metro line L3, station "Valldaura." (walking distance to restaurant 500m, aprox. 8 minutes)

Friday 4th March 2011

Session IV Monitoring Drought

Chair: Brad Lyon

08:30 Don Wilhite: Drought monitoring and early warning: The pathway to improved mitigation and preparedness

08:50 Kingtse Mo: Monitoring many faces of drought over the United States: Progressed and challenges

09:10 Xukai Zou, Fumin Ren, Donglin Cui: An objective identification technique for persistent regional meteorological drought events

09:30 Leonard Njau: Drought monitoring and early warning for Southern, Eastern Africa and the Sahel using tropospheric indices as predictors

09:50 Contributed talk – Li Yaohui: Methods of drought monitoring and prediction used in the Institute of Arid Meteorology, CMA

10:05 Contributed talk – G. van der Schrier, P.D. Jones, K.R. Briffa: A global dataset of self-calibrating Palmer Drought Severity Index dataset

10:20 Contributed talk – Pavel Ya. Groisman, Richard W. and Vyacheslav N. Razuvaev: Observational evidence of changes in precipitation Spectra over Northern

Extratropics related to extreme rainfall and droughts: New tendencies emerging during the last decades

10:35 Coffee Break

11:00 Brad Garanganga: Circulation characteristics associated with largescale droughts across Southern Africa

11:20 Richard Heim Jr and Michael J. Brewer: The development of an international drought clearing house and summary of the April 2010 Global Drought Assessment Workshop

11:40 Gao Ge, Zhang Peiqun, and Liao Yaoming: Drought Monitor Operational System and Early Warning in China Meteorological Administration

12:00 Contributed talk – Michael Ek, Youlong Xia, Eric Wood, and the NLDAS team: Evaluation of long-term, high-resolution NLDAS products using in-situ observations, and application of these products to the U.S. Drought Monitor

12:15 Contributed talk – Andrew Singleton, Blaz Kurnik, Paulo Barbosa, Jürgen Vogt and Stefan Niemeyer: Needs and options for medium range probabilistic forecasting of meteorological drought as part of the European Drought Observatory

12:30 Lunch

13:30 Poster Session

Session V Linking User Needs with Current and Expected Prediction Capabilities

Chair: Kingtse Mo

14:30 Bradfield Lyon: Drought prediction to drought decision.

14:50 Henny van Lanen: Need for prediction of hydrological drought to improve water resources management

15:10 Contributed talk – Vikram Mehta, Norman Rosenberg, Katherin Mendoza, Cody Knutson, J. Rolf Olsen, Nicole Wall, Tonya Bernadt, and Michael Hayes: Impacts of decadal droughts on water and agriculture, and consequent climate information needs of stakeholders and policymakers for decision support: A case study of the Missouri River Basin in the U.S.A

15:25 Contributed talk - Roger Pulwarty: The U.S. National Integrated Drought Information System - A prototype for national and global climate services

15:40 Break

16:00 Discussion Session

Discussion leads: Brad Lyon, Kingtse Mo, Wenju Cai

Rapporteur: Catherine Beswick

17:00 Adjourn

Saturday 5th March 2011

8:30 Summaries of Workshop Discussions (20 minutes each)

Session 1: Sonia Seneviratne and Martin Hoerling

Session 2: Siegfried Schubert and Hugo Berbery

Session 3: Xavier Rodó, Ron and Pavel Groisman

Sessions 4/5: Wenju Cai, Brad Lyon and Kingtse Mo

10:00 Discussion and Next Steps

12:00 Adjourn