

THE INTERNATIONAL RESEARCH
INSTITUTE FOR CLIMATE PREDICTION

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LINKING SCIENCE TO SOCIETY



**Joint International Workshop on
Applicable Methods for Use of
Seasonal Climate Forecasts
in Water Management**

November 6-8, 2002
Palisades, New York, USA

Bryson C. Bates
Editor

COLUMBIA UNIVERSITY

IRI

International Research Institute for Climate Prediction

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DWC

Dialogue on Water and Climate

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Preface

Rapid population growth, increasing urbanization, and industrialization and pollution along with natural climate variability and human-induced climate change pose a threat to water resources. This is particularly the case in developing countries where the impacts are potentially great and yet the capacity to cope is the weakest. Hydro-meteorological disasters such as floods and droughts have major impacts in terms of human life, economic and environmental losses, and social upheaval. New understandings of the climate and its variation on seasonal and inter-annual scales, together with a growing ability to predict seasonal variations like the El Niño provides a new means to reduce vulnerability and improve coping capacity.

Water management involves issues of supply, quality, allocation, distribution, equity, resource vulnerability and reliability, sustainable use, and ecosystem health. Effective management demands an approach linking technological, social and economic development with the protection of natural ecosystems. Therefore there is a need to mobilize expertise across several disciplines to establish the knowledge and methods necessary to assess the climate risk connected with rural and urban water cycles, and to develop adaptive management strategies that can respond easily to emerging climate fluctuations and mitigate adverse affects. This includes the connections between climate prediction, climate-related hazards, climate change, and the planning, design, operation, maintenance, and rehabilitation of water-related infrastructure. Assessments of appropriate measures for proactive management need to be carried out to preempt and avoid crises whenever possible, and to devise effective responses to crises when they occur. Changes in water quality, water demand and availability due to climate fluctuations will affect users' perceptions, preferences and behavior. The socio-economic relationship between cost and risk prevention, and social preferences for risk levels need to be integrated into water management.

Experience in many parts of the world has shown that substantial efforts are needed to develop a strong recognition by water managers of the potential value of scientific prediction of seasonal and inter-annual climate variability, and to advance the adoption of modern forecasting methods and products. A number of factors are responsible: inaccessibility of climate information and forecasts; inadequate communication between water managers and climate scientists, differences in perceptions and research priorities; the complexity of the problems faced by water managers and the effects of political and institutional constraints on their decisions; the probabilistic and uncertain nature of seasonal forecasts and skepticism about their accuracy; limited training and/or experience; lack of suitably tailored tools and methodologies to make use of forecast products; and insufficient advocacy at local to international levels.

The co-sponsors of the three-day seminar and workshop *Applicable Methods for Use of Seasonal Climate Forecasts in Water Management*, held in Palisades, New York, on November 6-8, 2002, bring complementary interests – science and dialogue – to bear on the above issues. The International Research Institute for Climate Prediction (IRI) works to develop the scientific basis for the generation and application of seasonal forecasts, and

undertakes research and demonstration projects in different sectors – water, health, and agriculture for example, especially in vulnerable developing countries. It produces global forecasts and undertakes specialized capacity building activities. The Dialogue on Water and Climate (DWC), on the other hand, works to improve the interactions between the water and climate communities and to establish better access to information bases, in order to develop the capacity of water policymakers and managers to cope with climate variability and change.

The main aim of the Workshop was to produce a digestion of knowledge and practical lessons from case studies that could guide the water sector on how to approach the issue of seasonal forecasts. The specific objectives were the:

- Dissemination of latest developments in climate forecasting science.
- Integration and sharing of state-of-the art knowledge about the linkages between climate and water that are relevant to the water sector.
- Identification of the core issues for the practical adoption of seasonal and inter-seasonal climate forecasts in management policies and decisions.
- Definition of climate information, tools, methodologies, and learning experiences available, as well as their accessibility.
- Definition of a joint international agenda for future research and development.

Workshop participation was by invitation only. Participants were people who have direct expertise and experience in developing and applying seasonal forecasts in the water sector, and representatives of selected stakeholders in developing and developed countries. The Workshop provided a unique and exciting opportunity for climate scientists, hydrologists and water resource managers to work collectively to share and integrate state-of-the art knowledge about the application of seasonal and inter-seasonal climate forecasts to management policies and decisions.

It is intended that this workshop report will be a key document to inform current international efforts to build a new dialogue between climate scientists and water managers in response to emerging global climate-water issues. The Workshop is part of a series of events that will culminate in a special session at the 3rd World Water Forum to be held in Japan, from March 16-23, 2003. It will provide direct input to the DWC's Synthesis Workshop to be held at Dhaka, Bangladesh, from December 17-18, 2002. It will also provide a foundation for presentations of information and project opportunities for institutional participants at the 3rd World Water Forum.

An IRI organizing committee consisting of Roberto Lenton, Reid Basher, Upmanu Lall, and Bryson Bates developed the Seminar-Workshop in collaboration with DWC's Henk van Schaik. I wish to express my gratitude for the tireless efforts of the IRI's support staff, particularly those of Sandy Vitelli and Brendon Hoch, in planning and hosting the event. My

great appreciation goes to the authors of the presentations, session moderators and workshop rapporteurs, and the members of the Water Managers Panel. These people contributed generously of their time and expertise.

A good measure of the success of any workshop is the level and nature of the subsequent dialogue and the number of new partnerships between climate scientists and water managers that emerge and grow. True success will be evident when the quality and standard of living of ordinary people in developing countries improves through the astute usage of seasonal climate forecasts. I challenge you to build on the momentum of this Workshop by taking responsibility for continuing the dialogue, building capacity and encouraging training within your organization, and fostering partnerships with other Workshop participants.

Bryson C. Bates
Visiting Research Scientist, IRI
Senior Principal Research Scientist,
Water Security and Sustainable Communities
CSIRO Land and Water, Australia

Executive Summary

A workshop titled *Applicable Methods for Use of Seasonal Climate Forecasts in Water Management* was held in Palisades, New York, between 6th and 8th November 2002. The Workshop was co-sponsored by the International Research Institute for Climate Prediction (IRI) and the Dialogue on Water and Climate (DWC). It was designed to become a contribution to the DWC's Synthesis Workshop to be held in Dhaka, Bangladesh, on 17-18 December 2002, and the 3rd World Water Forum to be held in Kyoto, Japan, on 16-23 March 2003.

The Workshop consisted of 1½ days of presentations and one day of break-out group meetings and joint discussion sessions. It brought together the broad community of climate scientists; water researchers who have close linkages with the water industry, and professional water managers from developing and developed countries. Participation was by invitation only. The main objective of the Workshop was to produce a digestion of knowledge and practical lessons from case studies that could guide the water sector on how to approach the issue of seasonal forecasts.

There were three factors that justified holding the Workshop. First, experience in many parts of the world has shown that substantial efforts are needed to develop a strong recognition by water managers of the potential value of scientific prediction of seasonal and inter-annual climate variability, and to advance the adoption of modern forecasting methods and products. Second, the dialogue on climate forecasting has tended to be one way, from climate scientists to water managers. Third, scientists need to pay more attention to what water managers think and want. Otherwise, the water sector's uptake of climate forecasts will remain low.

This report summarizes the various stages that were undertaken to establish a firm dialogue between scientists and water managers. Workshop participants identified six key points about climate forecasting and its application in water resources management:

- The net benefits of using seasonal climate forecasts in water management have not been demonstrated. The consequences and benefits associated with actions based on or without climate forecasts must be assessed and compared. This must take place within operational settings so that the focus is on user needs rather than those of climate scientists. Demonstration projects that use hindcasts as well as forecasts are essential.
- Users require authoritative, objective, dependable, explicit, user-friendly forecasts at temporal and spatial scales that are appropriate for their needs. They also require applicable information about forecasting error and uncertainty.
- Problems and issues are more difficult in developing countries, and there is a need to strengthen their local meteorological communities.
- Scientists need to use appropriate mechanisms for technology transfer, such as: (1) a terminology that is comprehensible to water managers; (2) the development of tools and

methodologies that are acceptable to users and distinguish between research and application areas; (3) outreach, education and training activities; and (4) expert consultation.

- The socio-economic aspects of forecasting are crucial. Users and stakeholders need: (1) better education on climate issues and processes, forecasting techniques and probability; (2) to overcome their resistance to the use of new information; (3) economic mechanisms that can improve water use efficiency; and (4) to develop no-regret policies that account for the presence of uncertainty and error in climate forecasts. Scientists, on the other hand, need to recognize: (1) the effects of institutional, political and cultural constraints on policy formulation and decision-making; (2) that the value of forecasts depends on the level of engagement, resilience and technological sophistication of users and stakeholders, as well as forecast quality; (3) that climate information needs vary between users; and (4) the importance of incorporating feedback from the user community into research strategies.
- There is a need for a long-term commitment to dialogue between climate forecasters and users of climate information.

Climate forecasts have the potential to increase water security in developing and developed countries. To realize the full extent of the potential benefits, scientists and water managers must enter into and maintain partnerships that incorporate the needs and aspirations of the communities they serve. Climate information is not enough, but when combined with adaptation strategies that are acceptable to stakeholders and the general public, seasonal forecasts can serve as a valuable tool for water management.

Overview of Technical Presentations

SESSION 1: Recent Developments in Climate Forecasting Science (1)

Steve Zebiak opened the first technical session by describing the nature of climate and the basis for predictability, current understanding of prominent patterns of variability, and prediction of the El Niño - Southern Oscillation (ENSO), North Atlantic Oscillation, Pacific Decadal Oscillation (PDO), and Indian Ocean Dipole. He noted that sea surface temperatures (SSTs) nudge the atmosphere, and that study of the coupling of the oceans and atmosphere leads to predictability. Climate forecasts describe the predictability of the statistics of weather, not its day-to-day evolution. The degree of predictability changes over a variety of time scales and with location, and it has become appreciated that 'noise' is an important driver in the climate system. Climate prediction, he noted, is a probabilistic game. At present, only the modeling of ENSO exhibits long-lead prediction skill though other less prominent phenomena also hold promise. Steve concluded by stating that there is a need for: (1) better understanding (through observations and analysis) of prominent patterns of variability; (2) efforts to address systematic errors, model initialization, and 'noise' on forecasts; and (3) the development of better ensemble (multi-model) methods and downscaling techniques (statistical, dynamical or hybrid) is needed to realize the potential benefits of seasonal forecasts.

Tony Barnston described the IRI's climate forecast system. Although SST anomalies are largely responsible for predictability, he noted that predictions of SST are the weakest part of any forecasting system. In preparing forecasts, the IRI currently uses persisted global SSTs (as SSTs tend to change slowly) and forecasted SSTs (which generally have no better skill than persisted SSTs except in the tropical Pacific Ocean). Persisted SSTs are only usable out to 3 to 4 months lead. Tony described the IRI dynamical climate forecasting system, which is based on an ensemble approach. Forecasts typically offer 3- to 6-month leads and use a tercile system (above-, near- and below-normal). Although there is low predictability for many regions and most seasons, there is very usable predictive skill in a few regions in certain seasons. He concluded by asking whether the production of cumulative distribution function for precipitation would be of more use to water managers than the tercile system and asking, "How can the IRI's forecast products better serve the hydrological community?"

Neil Ward reviewed statistical and dynamical approaches to downscaling. He noted that the short lengths of reliable records limit the usefulness of statistical methods. Purely dynamical models exhibit skill with respect to seasonal means in some cases. They offer the potential for weather within a climate forecast to be better represented. The statistical transformation of GCM and RCM output was also described.

SESSION 2: Recent Developments in Climate Forecasting Science (2)

Upmanu Lall made a clear distinction between climate variability and climate change. Climate variability was defined as the structured inter-annual or longer variations that arise

as a consequence of internal feedback processes in the climate system. These variations exhibit large spatial scales of organization. Climate change was defined as secular changes due to anthropogenic causes and included changes in modes of climate variability. Manu made three key points: (1) climate is non-stationary, and may exhibit irreversible changes or a set of regimes; (2) adaptive rather than static strategies for resource management need to be adopted in practice; and (3) prediction problems relate to the statistics of hydroclimatic state variables, and the development and application of methods for change detection, forecasting and record reconstruction. He concluded with three closing thoughts: (1) climate forecasting is a low frequency story, and we need to characterize and understand the signal carrier; (2) the use of climate information and analyses will revolutionize water management through the assessment of dynamic flood, drought and environmental risks, and the use of seasonal to inter-annual forecasts; and (3) innovative dynamical and statistical methods are being developed, and that tremendous changes in current practices will result when these methods are incorporated into decision support systems and socio-economic analyses.

Bryson Bates used a case study in southwestern Australia to examine the utility of applying stochastic downscaling techniques to climate model forecasts. He focused on the Perth water supply system, which has been under climatic stress since the mid-1970s. A non-homogenous hidden Markov model (NHMM) was used to relate multi-site daily rainfall to large-scale atmospheric variables. The model was fitted to Reanalysis data for 1978 to 1992, and was tested against Reanalysis data for 1958 to 1977 and 1993 to 1998. The model was found to perform well for these two independent periods, and no degradation in model performance was found despite the marked changes in regional-scale atmospheric circulation that have taken during the 1958 to 1998 period. The model was then used to downscale atmospheric fields from climate model control runs (125 km and 500 km horizontal resolution). The downscaled simulations were shown to reproduce the statistics of observed daily rainfall at 30 sites. The NHMM was then applied to dynamical forecasts (300 km resolution) for the five winter half-years (May to October) in the period 1997-2001. The downscaled GCM forecasts showed improved skill in predicting seasonal rainfall occurrence relative to that of mean station climatology in four out of the five winter half-years examined.

Ashish Sharma presented a new statistical method for medium- to long-term forecasting. The method is based on nonparametric statistics and uses an ensemble approach. The utility of the procedure was demonstrated through two applications. The first consisted of forecasting the Southern Oscillation Index (SOI) over a specified time period, and the second, annual reservoir inflows at six locations in the state of Cear , Brazil. In both applications the multiple models used predictors selected from prior lags of climate indices and globally distributed, gridded SST anomaly data. The model's performance was assessed by cross-validation and by forecasting the entire period of the record that was left out in model formulation. The results indicated that the consideration of uncertainty in climatological observations and the use of an ensemble of model outputs result in probabilistic forecasts that are more reliable and accurate than is the case otherwise.

SESSION 3: Case Studies in Water Resources Management (1)

Francisco de Assis de Souza Filho opened the first session on case studies in water management. He described the approaches to water resources management in the state of Ceará, Brazil: the inflow forecasts used, reservoir operations, and the challenges faced. Assis listed six principles: (1) water management should be institutionally integrated and involve public participation; (2) surface water management should use the watershed as its basis for decision making; (3) water is scarce and priority should be given to public water supply; (4) water pricing has implications for socio-economic development; (5) water management involves the resolution of conflicts between multiple and competitive uses; and (6) non-transferable licensing of individual water users is essential. He described the use and performance of statistical, dynamical and statistical-dynamical forecasting techniques in Ceará.

Pi-Jaw Sheu described a statistical analysis of rainfall variability in Taiwan and the 2001-2002 drought. An attempt was made to identify severe drought events in a 50-year period and their links to large-scale oscillations. Two indices were identified: one to indicate the strength or duration of the two monsoon seasons, namely northeasterly and southwesterly winds; the other exposure to severe drought periods. In the same presentation, Ming-Hsu Li described the ongoing development of a drought warning system. The system incorporates dynamical, regional-scale climate forecasting and basin-scale hydrological modeling to provide quantitative estimates of future water supply as well as water demand by human, industrial, and agricultural usages. Whether a drought warning should be issued or not is determined by comparing the amount of predicted water shortage with the probability distribution of water deficit amounts generated by past drought events. The lead-time of this drought warning system will be limited by the skill of regional climate prediction. A 12-week forecast is expected to be sufficient for Taiwan.

Madduma Bandara provided an overview of water resources and the seasonality of rainfall in Sri Lanka. He focused on the information needs of users, and quizzed forecasters as to whether they can provide information about the timing, magnitude and spatial distribution of rainfall for existing and proposed water supply schemes. Sri Lanka suffers from severe water shortages, with one part of the country wet and the other dry.

SESSION 4: Case Studies in Water Resources Management (2)

Pradeep Mujumdar gave a brief introduction on irrigated agriculture in India, the single largest user of water in that nation. He followed this by a description of the use of hydrologic forecasts and a suite of mathematical tools for optimizing the operation of surface water irrigation systems and water allocation to maximize crop yield. Deterministic and stochastic optimization techniques were considered. The approach was demonstrated through the study of a drought prone region in southern India. Pradeep highlighted the gaps between theory and practice in the developing world. These included: (1) institutional constraints; (2) the lack of interaction between academia and the real world; (3) the high level of conflict amongst multiple water users over allocation decisions; (4) and water allocation decisions that are driven by strong socio-political considerations.

Erich Plate stated that forecasting was a multidimensional problem. There are different time scale and lead-time requirements for different purposes. Uncertainty increases with the length of the forecasting period, but can be reduced by taking an average over a long period.

Forecast requirements change with regional differences. Erich noted application areas that could benefit from seasonal climate forecasts: (1) flood forecasting (e.g., forecasting the start of the flood season) and flood protection; (2) reservoir operations for flood control and water supply; and (3) irrigated agriculture (with respect to decisions about what to plant and when to sow). He also noted that it is important to examine whether the use of climate forecasts leads to better decisions.

Alan Hamlet gave a brief overview of the hydrologic characteristics of the Columbia River basin and commented that its water yield is heavily influenced by the ENSO and PDO. He described the application of two methods: (1) resampling from a 50-year historical record to produce a forecast of the coming winter's climate; and (2) coupled climate and hydrologic models. A major obstacle in the development of the second forecast system has been the lack of consistent precipitation forecast skill from the climate model used (NCEP Global Spectral Model). Alan reported the results of two case studies involving retrospective forecasts from the resampling technique. The first involved improvements to basin-wide non-firm energy revenue (made feasible primarily by the long lead-time of the forecasts), and the second involved hedging rules for winter flood control evacuation at Libby Dam (a headwater project in Montana) that are designed to improve the likelihood of refill and availability of reservoir storage for fish flow releases in spring and summer.

Jocelyn Gaudet discussed the role of seasonal climate and dam inflow forecasts in optimization of water use for hydropower generation, assessments of the hydrologic safety of dams, financial planning, and enhancing profitability. Spring inflows due to snowmelt and floods due to autumn storms are of particular concern. A better inflow forecast for spring assists estimation of the overall power generation expectancy for the year, since about half of the yearly inflow occurs during that period. It also helps decisions regarding the reservoir air space needed to accommodate spring floods. A better forecast of fall inflows helps in managing reservoir filling before the high power demand and low inflow period. It is also useful for financial and security considerations as this is the time of the year when reservoirs are at their highest levels. At present, inflow forecasts are based on recent hydrological and meteorological conditions. Plausible climate scenarios are drawn from a database and used to drive a conceptual hydrologic model. In collaboration with the IRI, HydroQuébec are investigating the use of seasonal climate forecasts to bias climate scenario selection, and the development of stochastic models for seasonal inflows that use oceanic and atmospheric variables. It is envisaged that this work will lead to improvement in the treatment of forecast error and uncertainty.

SESSION 5: Case Studies in Water Resources Management (3)

In the context of climate forecasting for water management, Nilson Campos described the path from data to wisdom through analysis, information, synthesis, knowledge, and judgment. He stated that it was more important to know what to do with data than to have

them. This point was well illustrated by the impact of the forecast for 1992-1993 on the state of Ceará. In 1992 rainfall was low, water levels in the reservoirs that supply water to the city of Fortaleza were low, and the city was suffering from a Cholera epidemic. A forecast of 'normal' precipitation for 1993 led to a 'do nothing' response from water managers. However, the drought of 1993 was among the worst of the 20th century and river flows were very low throughout that year. This example brought home several messages: (1) there is always a margin for error in any forecast; (2) if the consequences of accepting a given forecast are high (e.g., water supply collapse in a major city), the forecast should be treated with caution; and (3) always have ready a Plan B! Nilson also described the impact of the forecast for 1998 (below-average precipitation) and the subsequent drought. At the time of the forecast the water levels in the reservoirs were low, but not critically so. A technical committee formed by meteorologists, water managers and the Secretariat of Water Resources briefed the Governor. A decision was made to invest in repairs of the Trabalhador's canal, built in the 1993 drought to transfer water from Oros Reservoir to the reservoir system. A widespread drought came to Northeast Brazil, but Fortaleza was not subjected to the water shortages suffered by many big cities in the region. In time it was shown that the correct decision had been taken, and that some lessons had been learnt from the 1993 drought.

Josh Foster summarized the report "Connecting Science, Policy, And Decision-Making: A Handbook for Researchers and Science Agencies" written by Katharine Jacobs, Arizona Department of Water Resources, under contract with the National Oceanic and Atmospheric Administrations' Office of Global Programs. The presentation highlighted the problems in integrating research and practice and the differences in perspective of water managers and scientists. Issues that were addressed included: (1) opportunities for the use of climate information in water management; (2) the keys to establishing a dialogue between the climate and water communities; (3) conditions for providing useful information and services; (4) conditions for encouraging innovation in water management; and (5) measures of success in collaboration.

Jayantha Obeysekera described the South Florida Water Management District's experience with incorporating climate forecasts in the development of operating rules for Lake Okeechobee. Management of this system requires a multi-objective approach that considers water supply for urban areas, agriculture and the restoration of the Everglades ecosystem, and the need control the maximum lake level during the hurricane season (flood protection). Jayantha described the many indicators and methods that are used for predicting climate outlooks. The methods use forecasts made by the Climate Prediction Center, historical data and Artificial Neural Network models. The weekly operating rules of the system have been modified to include climate outlooks. A risk-based simulation technique known as Position Analysis is used to evaluate the seasonal and multi-seasonal performance of the water management system. Jayantha listed a number of challenges for water managers who want to use climate forecasts: (1) stakeholder buy-in can be a problem; (2) updating forecasting methods within a legally-binding framework can be difficult; (3) operators prefer a cook-book approach rather than flexibility because of legal liability issues; (4) decision makers do not like uncertainty; and (5) the public loses confidence quickly after a single erroneous forecast.

Panel Discussion – What Do Water Managers Want?

Introduction

Bryson Bates introduced the session by noting that several participants had expressed the view that the dialogue on forecasts tended to be one way, from climate scientists to water managers, and that there needed to be more attention paid to what water managers think and want. It was in response to this sentiment that an ad hoc panel was formed of those at the Workshop who were closest to management concerns – the panel comprised professional water managers from several countries and a water applications researcher who has very close linkages with the water industry.

The panel members were: Madduma Bandara (National Water Resources Authority of Sri Lanka); Jocelyn Gaudet (HydroQuébec, Canada); Alan Hamlet (University of Washington, USA); Jayantha Obeysekera (South Florida Water Management District, USA); and Francisco De Assis De Souza Filho (FUNCEME, Brazil). As the moderator to this panel discussion, Bryson identified a few issues and questions that he hoped the panelists might choose to address:

- In your experience, what factors have prevented successful collaboration between climate scientists and water managers?
- If successful collaborations between water managers and climate scientists have taken place, what factors and processes have led to this success?
- From a water manager's perspective, what are climate scientists doing that is wrong or misguided?
- What are your experiences with adopting seasonal climate forecasts? For example, are the costs of using a poor forecast too high? Do seasonal forecasts have sufficient skill? As water managers, what are the institutional and political constraints that inhibit your use of seasonal forecasts?
- How do you deal with issues of probability and uncertainty in your decision-making, and in your interactions with stakeholders?

Response

Jocelyn Gaudet stated that the reasons for his attendance were that he wanted to see what others doing, to identify common issues across regions and case studies, and to look for new ideas. Jayantha Obeysekera noted that the use of stochastic optimization in water allocation decision-making had "died" in practice, and that seasonal climate forecasting could be in similar danger.

Erich Plate stated that the evaluation of forecasts is a key issue. He then went on to pose four questions:

- For seasonal forecasts, what are the forecast lengths and lead-times that you require for decision-making?
- How do you assess the value of forecasts? How good are they and what is their worth? Erich emphasized that society has a need to know what is happening during or happened after major climatic events, and will form opinions about the usefulness of climate forecasts by comparing the forecasts to actual events.
- What are the decisions that we want to support with forecasts? Erich noted that water allocation and reservoir management came immediately to mind, but what about institutional arrangements and societal expectations? Another point worthy of consideration was the development of policies in regions where no water management exists.
- What is the degree of overlap in core climate issues and core water issues?

Jocelyn Gaudet responded that the value of forecasts could be assessed by the extent to which they decrease uncertainty. He noted that in hydropower generation a decrease in uncertainty meant a decrease in contingencies (less money held in reserve). Other benefits would be better use of the resource, and a decrease in the number of possible events that have to be planned for.

Alan Hamlet reported on feedback from Pacific Northwest (PNW) water managers collected during outreach workshops conducted by the Climate Impacts Group at the University of Washington. PNW water managers complain frequently that the uncertainties in forecasts are too large, that the spatial and temporal scale of the forecasts do not match the existing decision processes closely enough, that the source of the forecasts is not aligned with professional practice (i.e. the forecast needs come from an "official" source), and that the risks and professional liability associated with use of the new forecasts are not adequately specified. Water managers want to be able to employ the tools that they currently use to assess the risks involved and make decisions, but don't necessarily have appropriate input pathways for long-lead ensemble forecasts, and frequently lack operational experience using probabilistic forecasts and information (current operational forecasts are almost universally interpreted as deterministic information). Alan noted that water managers tend to adopt risk adverse behaviour due to institutional constraints and societal expectations, which translate to perceptions of professional risk associated with using new forecast products. Alan also commented that potential benefits, impacts, and risk tolerance are very different for different users (e.g. hydropower–high risk tolerance vs. flood control–low risk tolerance) and the usefulness of experimental forecasts will probably have to be evaluated on a user-by-user basis.

Jayantha Obeysekera added that there are more restrictions placed on decisions in the public than in the private sector, and that the proponents of a new forecasting method must be able

to demonstrate accuracy and benefits. The method must be robust with respect to objective scrutiny. For reliability considerations, there is a need for a common terminology and clear and repeatable decision paths. Users must assess the consequences of wrong forecasts. Jayantha stated that climate variations at decadal scales are important for planning. Water management decisions must have stakeholder involvement and involve risk communication. Better forecasts would lead to a better balancing of risks.

Erich Plate posed two challenges to the panelists: (1) life involves risk: why is it that water managers do not accept this; and (2) why do water managers not use insurance to hedge against losses due to inaccurate forecasts? He pointed out that forecasting is a small component of an integrated decision process. Its value depends on: financial capability, technological sophistication and resilience of the population; geographical location; and the level of public involvement.

Jayantha Obeysekera countered that water managers are slowly becoming less risk adverse, and that getting insurance against environmental damage is hard. Jocelyn Gaudet noted that water managers are not risk adverse if they have a reasonable idea of forecast skill and risk. Francisco De Assis De Souza Filho added that there needed to be good communication with respect to risks and impacts. Decisions made on the basis of seasonal forecasts can be changed as new information comes to hand. He reminded the audience that politicians represent society, and thus they reflect societal expectations.

Several panelists commented on desirable lengths and lead-times for seasonal forecasts. Jocelyn Gaudet stated that he wanted a 6-month forecast with lead-times of 1 to 3 months. Madduma Bandara indicated lead-times ranging from 2 weeks to at least 3 months, and Francisco De Assis De Souza Filho lead-times of 1 to 9 months. Jayantha Obeysekera indicated that he was interested mainly in multi-year drought. He stated that the 2-year drought was of particular concern in southern Florida.

Madduma Bandara highlighted three issues that are pertinent to developing countries: (1) the trade-off between food security and water for power generation; (2) the need to make decisions irrespective of data availability; and (3) the inability to build technological capacity to a level similar to that of an organization such as the IRI. Francisco De Assis De Souza Filho raised two issues that are relevant to any nation: (1) water management is about conflict resolution between multiple and competitive users of the resource; and (2) information needs and the level of information uptake vary between stakeholders.

Upmanu Lall emphasized the need for changes to water engineering curricula to improve the climatological skills of future water managers. Such changes could lead to better management practices through a better understanding of the climate system and the state-of-the-art in climate prediction. This view was supported by other participants and was raised several times during subsequent discussion.

Summary Reports From Break-Out Groups

Group A

Core Issues

- Demonstration projects are essential. The consequences associated with actions based on or without climate forecasts must be assessed: is there any value added by using forecasts?
- Forecasting has to be seen as one of several integrated issues: it is not a magic bullet!
- The value of forecasts depends on the people you are dealing with, their level of engagement, resilience, and sophistication; and on forecast quality.
- There is a need for a long-term commitment to dialogue between climate forecasters and users. This will require the building of partnerships between the climate forecasting community and local water managers and organizations. It will in turn lead to the successful use of forecasts as climate scientists learn with users and evaluate applications.
- There is a need to:
 - Establish the level of confidence of forecasts before promoting their use. (The level of skill varies across regions and with time of year.)
 - Evaluate the value of forecasts to the people involved.
- The relationship between climate variability and climate change is not clear.
- Social aspects of forecasting are crucial:
 - Need better education on climate issues.
 - Need to overcome resistance to the use of new information.
 - Economic mechanisms can improve efficiency of water demand management.

Climate Information, Tools and Methodology

- Focus on 1- to 3-month lead forecasts as these have the highest skill.
- Seasonal forecasts tend to be qualitative - this needs improvement.

Capacity Building

- Need to strengthen local meteorological communities, particularly in developing countries.
- Need broad and project-based training of personnel at the agencies that make decisions.

Group B

Core Issues

- Water sector is not organized, and skill in adopting new forecasting techniques is low.
- Institutional structures for water management are complex:
 - Water Ministry, regional/local government.
 - Stakeholders - water user associations.
 - Structures are specific to location and application, and can change with time.
- Problems/issues are more difficult in developing countries.
- Need concise mapping with respect to use of climate information:
 - Decisions - allocation and/or operational problems.
 - Actual user - public/private.
 - Existing technology.
 - Scope for improvement.
 - Linkage with other sectors/ information uses (e.g., agriculture and human health).
- Communication and outreach:
 - Language and information that is explicit and understandable to local community.
 - Engagement of the public in decision-making process.
 - Increasing awareness of uncertainty in forecasts.
 - Education and training of users.
- What if forecasts are wrong? Need to have contingency plan(s), disaster mitigation, insurance, and liability coverage.
- Engagement of local educational institutions and in-line (extension) agencies.
- Opportunity for integrated water management through climate information.

Climate Information, Tools and Methodology

- Need sector specific products and estimates of their uncertainty:
 - Require mean, variability, distribution, and extremes.
 - Quantification of predictive skill.
 - Explanation/definition of climatic context (different regimes/variability).
- Time-scale of product: long-lead (> 1 year), seasonal-operational (0.1 to 2 years).
- Need maps of areas that are vulnerable to climate variability.
- Linkage of climate information to different user variables/sectors.

- Need acceptance of the principle that multiple methods that lead to best results.
- Incorporation of non-stationarity information into models.
- Verify historical products and decisions - retrospective forecasts.
- Robust system performance:
 - Develop no-regret policies to account for uncertainty.
 - Quantify risk involved in adopting climate information.
 - Decision-making processes can be flexible.
- Real-time operation of the system:
 - Change operation based on system response.
 - Carry out monitoring and forecasting together.
 - Update models and parameters based on monitored information - Bayesian methods.
- Decision support systems with integrated components:
 - Carry out scenario analysis with economic value.
 - Integrate systems with monitoring database.

Group C

Core Issues

- Research to generate better understanding of the climate and better prediction skill.
- Consideration of institutional, political, or cultural constraints.
- Identification of the need for monitoring and forecast updating.
- Generation of and access to necessary data (e.g., validation data).
- Improvement in the skill of regional forecasts. Need authoritative, objective, dependable, user-friendly forecasts at appropriate temporal and spatial scales. The desired scales are case specific.
- Error characteristics of forecasts, leading to tools for quantitative risk assessment.
- Metrics for assessing skill and value of forecasts:
 - Comparison with existing decision processes.
 - Quantitative hindcasts for historical periods of interest.

- Incorporation of feedback from user community into research strategies.
- Extension of focus beyond reservoir management and water availability to include other water-related issues such as ecological management and human health.

Climate Information

- Background information on weather, climate processes, forecasting and probability.
- Need forecast and hindcast information at seasonal, multi-seasonal, and interannual scales, and at the temporal and spatial scales that users need.
- Provision of data for 'end-to-end' applications.

Tools and Methodologies

- For developing countries:
 - Use appropriate atmospheric-oceanic predictors for the regions of interest.
 - Translation of climate forecasts into decision-making.

Accessibility

- Outreach, education, training, and availability for expert consultation.
- Use of appropriate mechanisms for technology transfer:
 - Documentation of basic methods.
 - Development of a common terminology between water managers and scientists.
 - Tools and methodologies that are acceptable to users and distinguish between research and application areas.
 - Appropriate presentation of qualitative and quantitative information to the user community.

Joint Workshop – Research Agenda and Discussion

Reid Basher summarized how the IRI expected to produce workshop proceedings and to present the results of the Workshop to the DWC Synthesis meeting in Dhaka, Bangladesh, December 2002. This would be followed up with a further presentation and project proposals to the 3rd World Water Forum in Kyoto in 2003. Pavel Kabat proposed that a review publication was needed for Kyoto and that the IRI could coordinate input to this.

Several participants volunteered to contribute to a publication that would be essentially an expansion of the proceedings. Some emphasized the need to get moving on a research agenda and on actual projects, and not get bogged down in international program management. A comment was made that although Memoranda-Of-Understanding were useful for formalizing collaborative relationships between organizations, they do not necessarily lead to action.

In identifying practical applications of forecasts, no consensus emerged about particular paths that water managers should follow. Nevertheless the following specific approaches were reported:

- *Analogue years:* In Québec, Canada, hydrological models used to predict electricity production are based on historical records of climate. The selection of the years to be used in an analysis can be biased toward those years that are most like the predicted season.
- *Scenario production:* In Ceará, Brazil, hydroclimatologists produce a set of forecast-based scenarios of the hydrological system. The scenarios are presented at public meetings to facilitate consensus on water allocation decisions. If the meeting participants are not satisfied with these, further scenarios may be run. In the Columbia River, USA, water managers have computer-based decision tools at hand that enable them to use what-if scenarios to test the consequences of possible decision options.
- *Decision trees:* In South Florida, USA, a multi-level decision tree that includes seasonal climate outlook information is used to determine controlled discharges from Lake Okeechobee to neighboring estuaries. Stakeholders have endorsed the decision tree as a regulatory instrument.
- *Information only:* In the Mahaweli Basin, Sri Lanka, a variety of information on ENSO impacts and current climate forecasts are made available but are not yet formally introduced at stakeholder water allocation meetings.

Synthesis

The Workshop has demonstrated that a two-way dialogue between climate scientists and water managers is already underway. Nevertheless, climate scientists need to gain a better appreciation of the operational environment in water management and a clearer picture of the information needs of water managers. Similarly, water managers need to gain a better appreciation of the latest developments in climate science and prediction, the knowledge gaps, and the potential utility of seasonal climate forecasting. Bridging this gap in communication will require the development of a common terminology, an appreciation of the complexity of the issues faced by each sector, and a continuing spirit of cooperation and trust.

It is apparent that apart from a small number of exceptions, the net benefits of using seasonal climate forecasts in water management have not been demonstrated. The reasons for this situation were mentioned repeatedly throughout the Workshop. Amongst the most important are: (1) assessments of the value of forecasts must take place within operational settings so that the focus is on user needs rather than those of climate researchers; (2) forecast and hindcast information should be provided at the temporal and spatial scales that practitioners need; (3) the lack of suitable information about forecasting error and uncertainty; (4) the lack of mechanisms for expert consultation and training; and (5) climate information needs to be explicit and in a language that is understandable to the local community.

A recurring theme throughout the Workshop was that users must assess the consequences of erroneous forecasts. Consideration must be given to the development of contingency plans and measures for disaster mitigation so that societal expectations regarding water security are met. These expectations include water allocation for the environment as well as public, industrial and agricultural supplies. Failure to meet these expectations could pose a threat to food and water security, impact human health and lead to litigation.

The output of this Workshop will provide useful information for organizations such as the IRI. Within the IRI it will be used to define the terms of reference for a research program focused on the use of seasonal climate forecasts and improved knowledge about climate variations at decadal scales in water management. It will also be used to scope climate prediction experiments, training and capacity building activities. Hopefully it will encourage changes to the water engineering curricula at educational institutions so the climatological skills of future water managers are improved.

Appendix A – Program

Day 1 - Presentations (Auditorium)

8:30 to 9:00 **WELCOME**

Opening Statements From the IRI, *Stephen Zebiak, Reid Basher and Bryson Bates*

9:00 to 10:30 **SESSION 1 – Recent Developments in Climate Forecasting Science (1)**
Chair: *Francisco de Assis de Souza Filho*

Seasonal Climate Variability and Predictability, *Stephen E. Zebiak*

The IRI's Climate Forecasting System, and its Current Precipitation Forecasts,
Tony Barnston, Lisa Goddard and Simon Mason

Downscaling of Seasonal to Interannual Climate Predictions, *M. Neil Ward*

11:00 to 12:30 **SESSION 2 – Recent Developments in Climate Forecasting Science (2)**
Chair: *P.-J. Sheu*

Climate Variability and Change: Assessment and Forecasting, *Upmanu Lall*

Stochastic Downscaling of Climate Model Forecasts: A Case Study from
Southwestern Australia, *Bryson C. Bates*

Probabilistic Forecasts of Hydroclimatic Variables,
Ashish Sharma and Upmanu Lall

14:00 to 15:30 **SESSION 3 – Case Studies in Water Resources Management (1)**
Chair: *Upmanu Lall*

Water Management and Clima in Ceará, *Francisco de Assis de Souza Filho*

The Climate Prediction for the Recent Drought and the Water Resources
Management in Taiwan,
C.-H. Sui, P.-J. Sheu, M.-H. Li, C.-P. Tung, and M.-M. Lu

Water Resources and Seasonality of Rainfall in Sri Lanka With Special Reference to
the Mahaweli Region, *C.M. Madduma Bandara*

Day 1 - Presentations (continued)

16:00 to 18:00 SESSION 4 – Case Studies in Water Resources Management (2)
Chair: C.M. Madduma Bandara

Use of Hydrologic Forecasts in Irrigation Water Management,
Pradeep P. Mujumdar

Long and short term forecasting needs in water resources management,
Erich J. Plate

Long-Range Streamflow Forecasting Products and Water Resources Management
Applications in the Columbia River Basin,
Alan F. Hamlet, Andy Wood and Dennis P. Lettenmaier

Seasonal Forecasts and Power Generation at Hydro-Québec, *Jocelyn Gaudet*

Day 2 - Presentations and Panel Discussion (Auditorium)

9:00 to 9:30 INTRODUCTION

The Dialogue on Water and Climate, *Pavel Kabat*

9:30 to 10:30 SESSION 5 – Case Studies in Water Resources Management (3)
Chair: Bryson C. Bates

The Climate Forecasting Science and Water Resources Management,
José Nilson B. Campos

The Decision-Making Perspective: Bridging the Gap Between Science and Water
Management, *Katherine Jacobs and Josh Foster*

11:00 to 12:30 SESSION 6 – Case Studies in Water Resources Management (4)
Chair: Bryson C. Bates

Use of Climate Outlook for Water Management in South Florida,
Jayantha Obeysekera

What do Water Managers Want?
Panel Discussion

Day 2 - Workshop Sessions (Break-Out Groups)

14:00 to 15:30 SESSION 7 – Workshop

What Are The Core Issues For The Practical Adoption Of Seasonal And Inter-Seasonal Climate Forecasts In Management Policies And Decisions?

16:00 to 18:00 SESSION 8 – Workshop

Definition of Climate Information, Tools, Methodologies, and Accessibility Required By Water Resource Managers.

Day 3 - Workshop and Synthesis (Auditorium)

8:30 to 8:45 INTRODUCTION

Statement from the IRI, *Reid Basher*

**8:45 To 10:00 SESSION 9 – Workshop Group Reports and Synthesis
Chair: *Reid Basher***

Report from Group A Rapporteur, *Ariaster Chimeli*

Report From Group B Rapporteur, *Sankar Arumugam*

Report From Group C Rapporteurs, *Rashed Chowdhury and Oli Sveinsson*

**10:30 to 12:00 SESSION 10 – Joint Workshop
Chair: *Upmanu Lall***

Developing A Joint International Agenda For Future Research And Development

11:30 to 12:00 CLOSE

Closing statements from the IRI, *Reid Basher and Stephen E. Zebiak*

Appendix B – List of Abstracts

Seasonal Climate Variability and Predictability

Stephen Zebiak

*International Research Institute for Climate Prediction, Palisades, New York, USA
(steve@iri.columbia.edu)*

Over the past 15 years significant progress has been made in the understanding of seasonal climate variability and predictability. The principal gains have been made in recognizing the strong feedbacks between the atmosphere and the oceans in the tropics, responsible for such phenomena as the El Niño/Southern Oscillation, which in turn impact significant regions of the globe. Physical models that capture the salient features of El Niño have been developed, and are now routinely being used to predict El Niño evolution with some degree of skill. Yet numerous challenges exist in current capabilities, especially in reducing systematic biases and initializing forecast models. Other modes of climate variability, including the North Atlantic Oscillation, the Pacific Decadal Oscillation, and patterns in the tropical Atlantic and Indian Ocean, are less well understood, but may well contribute to additional predictability.

The nature of climate predictability on seasonal time scales is essentially probabilistic: the likelihood of particular characteristics of the weather - for example seasonal means, variances, frequency of extreme weather events - changes in certain regions and seasons due to persistent influence of large-scale ocean surface temperature anomalies or land surface anomalies. Accordingly the appropriate form for seasonal climate predictions should be probabilistic. Such products are now being produced. Assessments of performance over recent years show modest skill in some regions of the world, particularly the tropics.

The IRI's Climate Forecasting System, and the Precipitation Outlook for the Forthcoming Two 3-Month Seasons

Tony Barnston, Lisa Goddard and Simon Mason

*International Research Institute for Climate Prediction, Palisades, New York, USA
(tonyb@iri.columbia.edu)*

The International Research Institute for Climate Prediction (IRI) makes forecasts for the global temperature and precipitation for the globe each month. The forecasts are based mainly on the indications of five dynamical atmospheric general circulation models, whose behaviors are governed mostly by predicted global sea surface temperature anomalies. As a sensitivity check for the predicted changes in sea surface temperature anomaly from those existing at the time of the forecast, the atmospheric models are also run using a continuation of the most recently observed sea surface temperature anomalies, damped with lead time.

The IRI's forecast procedure is outlined and described in some detail, including the prediction of sea surface temperature, subsequent prediction of the climate over land, and the correction of model systematic error. The historical skill of the models in hindcast mode is summarized. An examination of the real-time precipitation forecasts for the two coming 3-month periods will then be used as an illustration, both for the globe as a whole and with a more focused view toward certain regions expected to experience climate anomalies.

An important feature of the IRI's forecasts is the manner in which they are expressed -- i.e., as probabilities of pre-defined tercile categories for both temperature and precipitation. A probabilistic forecast is necessary because of the substantial degree of uncertainty inherent in most climate forecasts. The meaning and utility of such forecasts will be discussed in view of the users' cost/loss contingencies, combined with the normally somewhat "flat" probability densities of the forecasts.

Forecast formats that would be most suitable for the largest proportion of the user communities will be explored, together with prospects for their production. One such format would be an estimation of the entire forecast probability distribution function, such as a probability of "exceedance" curve. The flexibility of such a forecast format would make it more universally applicable, as different users are interested in different aspects or portions of the forecast distribution.

Downscaling of Seasonal to Interannual Climate Predictions

Neil Ward

*International Research Institute for Climate Prediction, Palisades, New York, USA
(nward@iri.columbia.edu)*

Climate Variability and Change: Assessment and Forecasting

Upmanu Lall

*Earth & Environmental Eng., Mail Code 4711
Columbia University, New York, NY, 10027
(ula2@columbia.edu)*

Stochastic Downscaling of Climate Model Forecasts: A Case Study From Southwestern Australia

Bryson C. Bates^{1,2} Stephen P. Charles², I. Smith³, and J.P. Hughes⁴

¹*International Research Institute for Climate Prediction, Palisades, New York, USA
(bryson@iri.columbia.edu)*

²*CSIRO Land and Water, Perth, Western Australia, Australia*

³*CSIRO Atmospheric Research, Aspendale, Victoria, Australia*

⁴*Department of Biostatistics, University of Washington, Seattle, USA*

Recent advances in the science of weather prediction have led to growing interest in the use of climate model forecasts for water resources management. Although general circulation and regional climate models (GCMs and RCMs) perform reasonably well in simulating synoptic atmospheric fields, they tend to over-estimate the frequency and under-estimate the intensity of local-scale precipitation. Stochastic downscaling techniques provide a means of overcoming these limitations as they link local- and regional-scale weather to large-scale atmospheric fields. A case study in southwestern Australia involving a non-homogeneous hidden Markov model (NHMM), historical daily atmospheric fields and daily precipitation data for 30 sites, the NCEP-NCAR reanalysis dataset that spans the period 1958–2001, GCM (R21 resolution) and RCM (125 km) simulations for present day (control) conditions, and GCM (T63 resolution) forecasts forced by persisted sea surface temperature fields, will be presented and discussed. The NHMM defines stochastic conditional relationships that link daily multi-site precipitation to a discrete set of weather states (patterns). The transition from one state to another is conditioned on a relatively small number of atmospheric variables (predictors) derived from the reanalysis dataset. The NHMM is fitted to the Reanalysis data for 1978–1992 and evaluated for 1958–77 and 1993–1998. Downscaled climate forecasts are compared with observed at-site precipitation data for the winter half-years in the period 1997–2001. It will be shown that: (1) the out-of-sample performance of the NHMM is credible at a daily time step, even across periods that exhibit marked changes in atmospheric circulation; (2) the NHMM reproduces historical daily precipitation statistics from coarse-resolution GCM or RCM atmospheric fields for control conditions, and (3) that the potential predictive skill of 1-month ahead downscaled GCM forecasts is high, but the actual increase in skill is marginal relative to mean climatology. The directions for future research are discussed.

Probabilistic Forecasting Of Hydroclimatic Variables

Ashish Sharma¹ and Upmanu Lall²

¹*School of Civil and Environmental Engineering, The University of New South Wales, Sydney, Australia
(ashish@iri.columbia.edu)*

²*Earth and Environmental Engineering and the International Research Institute for Climate Prediction,
Columbia University, New York, USA
(ula2@columbia.edu)*

Probabilistic forecasts of hydroclimatic variables can be useful in increasing the efficiency and reliability of existing water resources systems. Three drawbacks of long-term statistical probabilistic forecasting approaches are addressed in this work. These are: (a) the use of methods that avoid assumptions about the form of dependence or the distributional attributes governing the variables being modelled, (b) use of methods that can recognise the varying levels of reliability associated with climatological observations, particularly relevant for data that are interpolated from the relatively scarce (in both space and time) observations available for the 19th and early 20th centuries, and (c) use of ensemble averaging that involves combining outputs from several models (each model being restricted to have a relatively independent basis) so as to reduce the chance of model misspecification, a common occurrence when the dependence is highly random and the system too complex to be explained by a limited number of predictors.

The usefulness of the procedure is demonstrated through two applications. The first application consists of forecasting the Southern Oscillation Index (SOI) over a specified time period, and the second, the reservoir inflows at selected locations in the state of Ceará, Brazil. In both applications the multiple models are formulated using predictors selected from prior lags of climate indices and globally distributed, gridded sea surface temperature anomaly data. The model is assessed by evaluating its performance both in cross-validation as well as by forecasting an entire period of the record that was left out in model formulation. The results indicate that the consideration of uncertainty in climatological observations and the use of an ensemble of model outputs result in probabilistic forecasts that are more reliable and accurate than is the case otherwise.

Water Management and Climate in Ceará

Assis De Filho

*FUNCEME, Fortaleza, Brazil
(AssisFilho@funceme.br)*

The Climate Prediction for the Recent Drought and Water Resource Management in Taiwan

C.-H. Sui¹, P.-J. Sheu¹, M.-H. Li¹, C.-P. Tung², and M.-M. Lu³

¹*Institute of Hydrological Sciences, National Central University, Taiwan
(sui@cc.ncu.edu.tw; pjs@ihs.ncu.edu.tw; mli@cc.ncu.edu.tw)*

²*Department of Bioenvironmental Systems Engineering, National Taiwan University, Taiwan;
(cptung@ccms.ntu.edu.tw)*

³*Central Weather Bureau, Taiwan
(lu@rdc.cwb.gov.tw)*

Taiwan experienced a prolonged dry climate from late last year (2001) till this past spring when water supply was severely restricted. This episode has brought lots of attention on the skill of climate prediction, and hot debates on current water resource management. This event motivated us to perform a collaborative research to investigate three aspects of the recent drought: global climate, regional rainfall and hydrological variability, and relevant current water resource managements.

At this early stage of the study, a preliminary analysis of the regional rainfall variability is performed based on the empirical orthogonal functions analysis of half of a century of rain data from twenty stations over the island of Taiwan. We attempt to identify severe drought events in this time span and their links to the large-scale oscillations. The results provide three principal components account for 75% of the total variance. The spatial distribution of the first mode shows a near-uniform pattern, indicating that, climatologically, Taiwan should be regarded as one region. The second and third modes seemingly reveal two major seasonal precipitation patterns due to topography and monsoon, respectively. The exact causes of the corresponding variability are yet to be determined. We would like to establish two indices: one to indicate the strength or duration of the two monsoon seasons, namely northeasterlies and southwesterlies; the other to expose severe drought periods. Combing these indices, basin-scale hydrological data like water level and inflow of a reservoir, we are performing an analysis to link regional drought occurrence with climate and monsoon variability.

On the side of water resource management, we report the ongoing development of a drought warning system. The system incorporates regional climate forecasting and basin-scale hydrological modeling to provide quantitative estimates of future water supply as well as water demands by human, industrial, and agricultural usages. Whether a drought warning should be issued or not is determined by comparing the amount of predicted water shortage with the probability distribution of water deficit amounts generated by past drought events. The lead time of this drought warning system will be limited by the skill of regional climate prediction. A twelve-weeks forecast is expected to be sufficient for Taiwan.

Water Resources And Seasonality Of Rainfall In Sri Lanka With Special Reference To The Mahaweli Region

C M Madduma Bandara

*Chairman, Natural Resources Management Services, Mahaweli Authority of Sri Lanka,
Dam Site, Polgolla, Sri Lanka
(mbandara@slt.lk; iriefcd@sltmet.lk)*

The modern phase of Mahaweli Development began only in the 1960s with the development of the UNDP/FAO sponsored Mahaweli Master Plan. This plan, to be implemented within a period of 30 years, envisaged the development of land and water resources of nearly one-third of the total land area of Sri Lanka. In 1977, the Government accelerated the whole programme and telescoped it into a short period of six years. This involved the rapid development of land and water resources of the project areas including resettlement of people affected by the project as well as creating new settlements in the hitherto undeveloped areas. Apart from increasing agricultural productivity, the project also significantly enhanced hydropower generation through a number of large-scale power projects such as Victoria and Kotmale. It has also done much to offset some adverse environmental implications through the creation of a network of national parks and wildlife sanctuaries, the total area under which exceeded the total area that had been brought under agriculture and settlement development. Today, the country is reaping the benefits of this gigantic programme that was made possible through massive international funding among which the contributions of UK, Sweden, Germany, Canada, Japan and U.S.A and the World Bank stand out. The total investment up to now exceeds 90 billion rupees (nearly a billion US Dollars). In terms of returns, the latest estimates indicate that nearly 25% of the total rice production and over 50% of the total power generation in Sri Lanka result directly from the Mahaweli Project. The total investment on the project had been recovered within its first fifteen years, from hydropower generation benefits alone. Among the adverse impacts were the large-scale displacement of people particularly from the hill country reservoir sites such as Victoria and Kotmale, and the environmental implications of clearing large areas for agriculture and human settlement. On the balance it could be contended that the project had done more good to the country than any other development project in recent history.

The challenge today, is to protect these massive investments as well as the sacrifices made and to attain high levels of sustainable productivity through better resources management. The present Ministry of Irrigation and Water Management since its inception, has taken steps to develop a new vision for Mahaweli in particular and the water resources development in the country in general. This included a division of the country into five river basin-based regions for water sector planning, development and management. Of these, the Mahaweli Region, that covers the largest land extent (36%) encompasses Mahaweli Basin as well as all adjacent river basins that are fed with Mahaweli waters through trans-basin canal systems. Water allocation at system level in the Mahaweli is customarily undertaken before the beginning of every major cultivation season by the Mahaweli Water Management panel (WMP) at kanna (season) meetings attended by all stakeholders. One of the major issues at these meetings is the inability to forecast the timing, magnitude and the spatial pattern of agriculturally significant rainfall, thereby creating serious impediments in the implementation

of strategies for conjunctive water use. A more reliable predictive capacity of seasonal rainfall would go a long way in resolving the crises that often ensue and also would have significant economic and social implications.

Several examples provided establish clearly the link between water resources development and rainfall seasonality in Sri Lanka with special reference to the Mahaweli and Northwestern Regions. They demonstrate the importance of forecasting seasonal rainfall for the water allocation decision-making processes. It also brings out the economic and social significance of such an exercise to water resources management in Sri Lanka. It is therefore argued that, seasonal rainfall forecasting is not only useful to the present projects, but also to those proposed for the future. In the latter case it is contended that it is best to assess and incorporate rainfall-forecasting capability early in the project cycle.

Use Of Hydrologic Forecasts In Operational Management Of Irrigation Systems In India

Pradeep Mujumdar

*Department of Civil Engineering,
Indian Institute of Science, Bangalore 560 012 India
(pradeep@civil.iisc.ernet.in)*

A brief introduction to the overall surface water scenario in India will be presented. It will be emphasized that irrigation water management in the country has significant socio-economic implications. An overview of the models developed at the Indian Institute of Science (IISc) for operational management of irrigation systems will be provided. Most of these models use short-term streamflow/rainfall forecasts for applications in real-time. Through a case study, use of seasonal forecasts along with appropriate stochastic disaggregation techniques to obtain forecasts for operational time periods of ten days, and an integration of such forecasts with decision models, will be demonstrated. Country-specific issues that need to be addressed for implementation of the models and methodologies developed will be discussed. Perspectives on gaps between theory and practice in developing countries will be presented.

Long and Short Term Forecasting Needs in Water Resources Management

Erich J. Plate

*Am Kirchberg 49, 76229 Karlsruhe, Germany
(plate@iwk.uka.de)*

Introduction.

Among the most important applications of hydrological sciences is the problem of forecasting future hydrological events. Consequently, there exists a vast body of literature on the subject. Hydrologists have tended to see forecasting purely as the problem of extending an existing time series into the future and to make a statement on what the future will bring.

Recently, we have learned to understand that hydrological forecasting must be application oriented. Application oriented forecasting is only one of many tasks related to the societal objective for which it is done. Nevertheless, progress in forecasting is one of the most important success stories for many applications of hydrology.

Forecasting is a task with many components: obtaining data, interpreting data, application of models to convert basic data into suitable forecasts - for which suitable model components have to be developed. It seems that the most important part of the forecast is its reliability, and therefore the performance of a forecasting model has to be tested in hindsight on as many data as possible. The result should be a forecast which is not only a crisp number, but which gives error bounds of the estimates, and leaves the responsibility of final judgment on what decisions to take to the decision makers. A need exists to develop a clear terminology for forecasting and warning, which needs to be universally understood, and for developing a criterion that can be used to quantify the quality of a forecast, by comparison with forecasting the present value as continuing as a constant into the future. This criterion will be stated, and some of the general problems associated with forecasting are discussed.

Then three problems are discussed for which improved seasonal forecasts are needed. They are taken from the experience of the former Institute for Hydrology and Water Resources Planning of the University of Karlsruhe. The first concerns forecasting needs for flood protection, as will be illustrated by showing how flood forecasts must be seen in the context of flood risk management, as a link in the chain of the early warning process (Plate, 2002). For some parts of the chain long term and seasonal forecasts are useful and may help to improve flood protection. This will be illustrated by means of a flood protection system involving reservoirs. A model for operating a multi-purpose reservoir in the Ruhr district is presented that was developed to serve the primary need of water supply and also for flood storage (Goeppert, et al., 1998). This model can be combined with a model developed by Bardossy (Bardossy & Caspari, 1990), which allows to estimate long term changes in the water situation by using the weather pattern associated with flooding situations as a conditioning input - conditioning the probability distribution for floods, so that climate change scenarios can be included in the long term forecast by providing the conditioning probabilities for extreme weather situations.

The other two problems illustrate the potential for application of seasonal forecasts for agriculture in semi-arid lands, shown by unusual examples from the Mekong countries in South East Asia and from Saudi Arabia. The Mekong situation is characterized by annual floods which usually are beneficial to the farmers, but which harm crops and people if the flood level exceeds a certain critical height. Seasonal forecasts may be a very helpful aid in deciding on the onset of the flood season, which may be important for deciding on whether or not to plant a third crop of rice. Flood forecasting systems for the Mekong are discussed in Tanaka (1999) and Plate & Insisiengmay (2002).

The Saudi Arabian situation is characterised by enough land that could be irrigated, but the limiting factor is the availability of water. Based on a project that we did for Saudi Arabia (Hiessl & Plate, 1990, Schmidt & Plate, 1985), we developed a model that very much depends on forecasting the future seasonal water supply -here is a potential application of seasonal forecast that may make the difference between drought for the fields and abundant crops. The result of this study has to be a set of operating rules for reservoirs, both for the release strategy, and for the flood protection strategy.

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Long-Range Streamflow Forecasting Products and Water Resources Management Applications in the Columbia River Basin

Alan F. Hamlet¹, Andy Wood, and Dennis P. Lettenmaier

¹*Center for Science in the Earth System
Box 352700, University of Washington, Seattle, WA 98195
(hamleaf@u.washington.edu)*

Advances in long-range forecasts of the El Niño - Southern Oscillation (ENSO) and in the understanding of decadal scale climate variability associated with the Pacific Decadal Oscillation (PDO) have made feasible streamflow forecasts with lead times of as much as 12 months in the snowmelt dominated Columbia River basin. Since 1997-1998 the Center for Science in the Earth System (CSES) at the University of Washington has been producing experimental long-range streamflow forecasts for the Columbia River in real time, as well as retrospective simulations used to assess the error characteristics of the forecasts. This forecasting technique makes use of the Variable Infiltration Capacity (VIC) macro-scale hydrologic model implemented over the Columbia basin and an observed 50-year climate record. The forecast incorporates an estimate of the current hydrologic state and a forecast the coming winter's climate. Typically, about 1/3 of the streamflow probability distribution is eliminated when long-range climate information informs the forecast, a result that has been shown to have important applications for water management in the Columbia basin.

Over the past several years, a more sophisticated experimental streamflow forecasting technique based on linked climate and hydrologic models has also been developed at the University of Washington. This forecasting system, which is currently being implemented over most of the western US, uses the same hydrologic simulation tool as the retrospective resampling approach described above, but incorporates forecasts of meteorological variables generated by bias corrected and downscaled global climate model simulations. These kinds

of forecasting tools are of considerable interest because they have the potential to produce better forecasts of rapidly evolving changes in climate (e.g. climate change) or unusual climate variability. In the Columbia basin, a major obstacle in the development of this forecast system has been the lack of consistent precipitation forecast skill for the climate model used in the pilot project (NCEP Global Spectral Model). As a result, most of the demonstrable forecast skill in the Columbia basin using this forecasting system is at present derived from persistence of the hydrologic state (soil moisture and snow) and temperature forecasts from the climate model.

To illustrate potential application of these kinds of forecasting products to water management problems, two case studies in the Columbia River basin are described using retrospective forecasts from the resampling technique described above. The first involves improvements to basin-wide non-firm energy revenue (made feasible primarily by the long lead time of the forecasts), and the second involves hedging rules for winter flood control evacuation at Libby Dam (a headwater project in Montana) designed to improve the likelihood of refill and availability of reservoir storage for fish flow releases in spring and summer.

Seasonal Forecasts and Power Generation at HydroQuébec

Jocelyn Gaudet

*Prévisions et ressources hydriques, HydroQuébec, Montréal, Canada
(gaudet.jocelyn@hydro.qc.ca)*

HydroQuébec relies on water for about 95% of its yearly power generation. For the corporation to be efficient and competitive, accurate inflow forecasts are essential. Such forecasts are required for a variety of needs: for the optimization of resources and generation planning, for installation and population safety in case of extreme weather events, and for financial planning and profitability. Given the weather conditions typical of the province of Québec, roughly 50% of yearly inflows depend on the spring freshet, accompanying snowmelt over the northern drainage basins, and there is an increase in inflows during the fall. These periods are then of uttermost importance forecast wise. In recent years, there has also been an increasing need for the improvement of water resources optimization. The consequence of this situation is the requirement for a better, more accurate inflow forecast, and an improvement in the treatment of forecast uncertainty and error. Significant forecast gains were evaluated to be dependent on improvements to the freshet volume forecasts, and to autumn storms flood volumes. A better freshet forecast helps evaluate the overall power generation expectancy for the year, since about half of the yearly inflows comes from that period, and helps plan reservoir emptying to accommodate the spring flood. A better forecast of the fall storms will help manage reservoir filling before the high power demand and low inflow period, for financial and security considerations, as this is the time of the year when our reservoirs are at their highest levels. Since both these events are large on the temporal and spatial scales, and since both need to be forecasted months ahead of time, it is believed that seasonal climate forecasts can bring an important plus-value to our inflow forecast scheme. The approaches we are implementing with the IRI rely on the use of seasonal

climate forecasts to bias the climate scenario we use with our inflow model, and on building seasonal stochastic models which use climate prediction. Our expectations are to obtain a more accurate forecast of actual inflows, and a better quantification of forecast uncertainty. That would make the use of water resources at HydroQuébec more efficient, improving in turn profitability, decreasing the amount of water needed to produce the required power, and generally bettering the use of the water resources.

The Climate Forecasting Science And Water Resources Management

José Nilson Beserra Campos

Fundação Cearense de Meteorologia e Recursos Hídricos

Fortaleza, Ce, Brazil

(nilson@fortalnet.com.br)

The climate forecast, as a whole, can be thought as communication process having the nature as a primary emitter, some sensors to capture the emitted signals, a decoder to translate the captured signals in an user understandable message, and a message to send to the users. That steps also can be seen a transformation process. Firstly, the collected data is transformed in information by analysis; following, information is transformed in knowledge by synthesis; finally knowledge becomes wisdom by judgment. The decisions to be taken using forecast information depend on the available hydraulic structures and on the society activities affected by the climate. That structure of the climate forecast helps in analyzing past decisions to improve the decision process in future.

Two experiences forecast use in Ceará's State, located in Northeast of Brazil, are presented. In 1993, the city of Fortaleza, with more than two millions of inhabitants, was close to have a water system collapse. An over trust on the forecast made the decision makers postpone some necessary actions to be taken as a precaution for a unexpected drought, which happened to come. As a result, it was necessary to build an one hundred kilometers canal in six months. In 1998, the forecast, based in El Niño, was for low precipitation. A meeting among meteorologists, hydrologists, decisions makers and the state Governor discussed the situation. The decision was to invest a considerable amount of money to make the hydraulic structures works properly. The drought came and the hydraulics structures were ready on time. Fortaleza gets rid from another severe water shortage.

Connecting Science, Policy, And Decision-Making: A Handbook for Researchers and Science Agencies

Kathy Jacobs¹ and Josh Foster²

¹*Arizona Department of Water Resources,*

²*NOAA Office of Global Programs/Office of Strategic Planning
(kljacobs@adwr.state.az.us, Josh.Foster@noaa.gov)*

There is well-documented need to improve the flow of information in both directions between scientists and decision-makers. Improved access to scientific information and to the hands-on experience of decision-makers has multiple benefits from the perspective of developing new management options and adaptive capacity. At present, it is clear that many of the products and tools scientists have developed for water managers are not as fully utilized as they might be. This is at least partly because the scientists who have developed them do not fully appreciate the institutional, economic, and cultural circumstances within which decisions are made. It is partly because decision-makers frequently do not actively seek new sources of information or initiate contacts with experts who could be helpful to them in making more informed decisions. It is common for researchers to develop products and tools that they believe will be useful, then make them available for use without verifying whether these are really the products needed. This “loading doc” mentality is generally the result of one-way communication, without sufficient evaluation of the needs of stakeholders. The result is that, at least in the context of federal agencies, millions of dollars are being spent on research that has the potential for utility but in fact may currently have little tangible societal benefit.

A number of scientists have recognized the need to achieve more integration among disciplines in order to address emerging social and environmental problems. In fact, there is general acknowledgement that decision-making in the context of an increasingly complex and inter-related global system will require more interdisciplinary research and more involvement from decision-makers and stakeholders. This handbook provides practical, hands-on suggestions for researchers and science agencies about ways to improve the focus of scientific research that is intended to be useful to decision-makers. These suggestions are based on interview with researchers who study science and decision-making, federal agency science and policy personnel, and decision-makers and stakeholders.

It is hoped that this handbook will be useful in a number of contexts, and for that reason some of the considerations are identified through questions rather than answers. The handbook is intended to assist physical science researchers in developing successful relationships with stakeholders and decision-makers, but is deliberately not prescriptive in terms of providing answers to many of the important questions. The report focuses on the ingredients of successful interaction from multiple perspective and identifies:

- Conditions for producing useful services and products
- Keys to communication and collaboration
- Incentives for change
- Mechanisms for evaluation and feedback, and measures of success in collaboration.

Use of Climate Outlook for Water Management in South Florida

Jayantha Obeysekera, Ph.D., P.E.

*Director, Hydrologic Systems Modeling Division
South Florida Water Management District, West Palm Beach, Florida
(jobey@sfwmd.gov)*

Longer-lead (seasonal and multi-seasonal) climate forecasts can significantly benefit the operation of regional water management systems which include lakes and storage reservoirs for flood control, water supply, energy, and environmental enhancement. In South Florida, the water management system is extremely complex. Management of this system requires a multi-objective approach that considers water supply for urban and agricultural users in the region, and the restoration of the Everglades ecosystem. The primary storage component in the water management system is Lake Okeechobee, the second largest freshwater body located wholly within the continental United States. Accurate seasonal and multi-seasonal forecasts can be extremely valuable for the management of Lake Okeechobee. This presentation will address many indicators and methods that were used for predicting climate outlook. The methods use the forecasts made by the Climate Prediction Center, historical data, as well as Artificial Neural Network models. The weekly operating rules of the system have been modified to include climate outlooks. A risk-based simulation technique known as Position Analysis is used to evaluate the seasonal and multi-seasonal performance of the water management system. The process that is used to receive input from scientists and engineers from a variety of disciplines will also be discussed.

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Appendix C – List of Participants (Non-IRI)

Madduma C. M. Bandara

Chairman, Natural Resource Management Services,
Mahaweli Authority of Sri Lanka
Dam Site, Polgolla
Sri Lanka
EMAIL: mbandara@slt.lk
PHONE: + 94 8 388 397
FAX: + 94 8 389 003

Gilberto Camara

Instituto Nacional de Pesquisas Espaciais (INPE)
Divisao de Processamento de Imagens
(Image Processing Division)
Caixa Postal 515
Sao Jose dos Campos Sao Paulo 12201-097
Brazil
EMAIL: gilberto@dpi.inpe.br
PHONE: + 55 12 345 6499 or + 55 12 345 6444
FAX: + 55 12 345 6468

José Nilson Beserra Campos

Fundacao Cearense de Meteorologia e Recursos
Av. Padre Antônio Tomás 3646
Apto. 1120
Fortaleza Ce 60.190-020
Brazil
EMAIL: nilson@funceme.br
PHONE: + 55 85 23 0967 (H) + 55 85 433 1803
FAX: + 55 85 433 1809

Josh Foster

Program Development Specialist/Strategic Planner
NOAA/Office of Global Programs/CSI-OSP
1100 Wayne Ave., Ste. 1225
Silver Spring, MD 20910
USA
EMAIL: josh.foster@noaa.gov
PHONE: + 1 301 427 2089, x173
FAX: + 1 301 427 2082

Jocelyn Gaudet

Hydro-Quebec
Prévisions et ressources hydriques
75 West René- Lévesque, 9 étage
Montréal Québec H2Z 1A4
Canada
EMAIL: gaudet.jocelyn@hydro.qc.ca
PHONE: + 1 514 289 2211, x4142
FAX: + 1 514 289 4687

Alan F. Hamlet

CSES/CIG, University of Washington
Box 352700
Seattle WA 98195
USA
EMAIL: hamleaf@u.washington.edu
PHONE: + 1 206 685 1796
FAX: + 1 206 685 3836

Pavel Kabat

Dialogue on Water and Climate
Science Support Office
Lawickse Allee 11
IAC Building, Room 159
Wageningen, 6200
The Netherlands
EMAIL: P.Kabat@Alterra.wag-ur.nl
PHONE: + 31 317 47 43 14
FAX: + 31 317 49 55 90

Ming-Hsu Li

Institute of Hydrological Sciences,
National Central University
No. 300, Jung-da Road
Jungli City, Taoyuan Taiwan
Republic of China
EMAIL: mli@cc.ncu.edu.tw
PHONE: + 886 3 422 2964
FAX: + 886 3 422 2894

Edwardo Savio Passos

Rodrigues Martins

FUNCEME
Av. Rui Barbosa 1246
Aldeota, Fortaleza/Ceará
Brazil, 60115221
EMAIL: esm9@funceme.br
PHONE: + 55 85 433 1842
FAX: + 55 85 433 1805

Pradeep Mujumdar

Indian Institute of Science
Department of Civil Engineering
Bangalore Karnataka 560 012
India
EMAIL: pradeep@civil.iisc.ernet.in
PHONE: + 91 80 360 0290; or 94 2324
FAX: + 91 80 360 0404; 683

Jayantha Obeysekera

South Florida Water Management District
3301 Gun Club Road
West Palm Beach FL 33416
USA
EMAIL: jobey@sfwmd.gov
PHONE: + 1 561 682 6503
FAX: + 1 561 682 5503

Erich Plate

Universitat Karlsruhe (TH)
Am Kirchberg 49
76229 Karlsruhe
Germany
EMAIL: plate@iwk.uka.de
PHONE: + 49 721 468 752
FAX: + 49 721 946 3985

Pi-Jaw Sheu

Institute of Hydrological Sciences,
National Central University
No. 300, Jung-da Road
Jungli City, Taoyuan Taiwan
Republic of China
EMAIL: pjs@ihs.ncu.edu.tw
PHONE: + 866 03 422 2445
FAX: + 866 03 422 2894

**Francisco De Assis De Souza
Filho**

Presidente Da Funceme, FUNCEME
Rua Barbosa De Freitas, 1910,
Apto 301
Bairro Aldeota CEP 60.170-021
Brazil
EMAIL: assisf@funceme.br
PHONE: + 55 85 433 1803 or
+ 55 85 433 1804
FAX: + 55 85 433 1805

Appendix D – List of Participants (IRI staff)

Sankar Arumugam

EMAIL: sankar@iri.columbia.edu
PHONE: + 1 845-680-4471
FAX: + 1 845-680-4864

Tony Barnston

EMAIL: tonyb@iri.columbia.edu
PHONE: + 1 845-680-4447
FAX: + 1 845-680-4865

Reid Basher

EMAIL: rbasher@iri.columbia.edu
PHONE: + 1 845-680-4455
FAX: + 1 845-680-4866

Bryson Bates

EMAIL: bryson@iri.columbia.edu
PHONE: + 1 845-680-4460
FAX: + 1 845-680-4464

Ariaster Chimeli

EMAIL: chimeli@iri.columbia.edu
PHONE: + 1 845-680-4504
FAX: + 1 845-680-4864

Rashed Chowdhury

EMAIL: rashed@iri.columbia.edu
PHONE: + 1 845-680-4505
FAX: + 1 845-680-4864

Upmanu Lall

EMAIL: ula2@columbia.edu
PHONE: + 1 845-680-4421
FAX: + 1 845-680-4866

Roberto Lenton

IRI Secretariat, 61 Rt. 9W, Lamont Hall
EMAIL: rlenton@iri.columbia.edu
PHONE: + 1 845-680-4414

Ashish Sharma

EMAIL: ashish@iri.columbia.edu
PHONE: + 1 845-680-4438
FAX: + 1 845-680-4866

Oli Sveinsson

EMAIL: oli@iri.columbia.edu
PHONE: + 1 845-680-4464
FAX: + 1 845-680-4866

Neil Ward

EMAIL: nward@iri.columbia.edu
PHONE: + 1 845-680-4446
FAX: + 1 845-680-4865

Stephen E. Zebiak

EMAIL: steve@iri.columbia.edu
PHONE: + 1 845-680-4497
FAX: + 1 845-680-4865

Lareef Zubair

EMAIL: lareef@iri.columbia.edu
PHONE: + 1 845-680-4424
FAX: + 1 845-680-4864

IRI Postal Address (unless otherwise shown)

International Research Institute for Climate Prediction
The Earth Institute at Columbia University
61 Rt. 9W, Monell Building
Palisades, New York 10964
USA

Appendix E – Acronyms

CSES/CIG	Center for Science in the Earth System/Climate Impacts Group (United States)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DWC	Dialogue on Water and Climate
ENSO	El Niño - Southern Oscillation
FUNCEME	Fundação Cearense de Meteorologia e Recursos Hidricos (Meteorology and Water Resources Ceará Foundation)
GCM	General Circulation Model
IRI	International Research Institute for Climate Prediction
NCAR	National Center for Atmospheric Research (United States)
NCEP	National Centers for Environmental Prediction (United States)
NHMM	Nonhomogeneous hidden Markov model
PDO	Pacific Decadal Oscillation
PNW	Pacific Northwest (United States)
RCM	Regional Climate Model
SOI	Southern Oscillation Index
SST	Sea surface temperature

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Organizing Committee

Roberto Lenton
Reid Basher
Upmanu Lall
Bryson C. Bates

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Brendon Hoch

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Dialogue on Water and Climate

Report Production

Tricia Ramsey