AGU CHAPMAN CONFERENCE

Portland, Oregon USA | 28-31 July 2013

Seasonal to Interannual Hydroclimate Forecasts

AGU Chapman Conference on Seasonal to Interannual Hydroclimate Forecasts

Portland, Oregon
28-31 July 2013

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Note: Attendees at the Chapman conference may be photographed by AGU for archival and marketing purposes. No photography will be permitted during scientific sessions.

AGU Chapman Conference on Seasonal to Interannual Hydroclimate Forecasts

Meeting At A Glance

Sunday, July 28

12:30 p.m. – 5:30 p.m.	Optional Field Trip to Bonneville Dam
6:00 p.m. – 7:30 p.m.	Welcome Reception

Monday, July 29

8:20 a.m. – 10:00 a.m.	Session – Climate to Streamflow Forecasting at Seasonal to Interannual Time Scales I
10:00 a.m. – 10:30 a.m.	Coffee Break
10:30 a.m. – 12:30 p.m.	Session - Climate to Streamflow Forecasting at Seasonal to Interannual Time Scales II
12:30 p.m. – 1:30 p.m.	Group Lunch
1:30 p.m. – 3:30 p.m.	Poster Session - Climate to Streamflow Forecasting at Seasonal to Interannual Time Scales
3:00 p.m. – 3:30 p.m.	Coffee Break
3:30 p.m. – 4:10 p.m.	Climate to Streamflow Forecasting at Seasonal to Interannual Time Scales III
6:30 p.m. – 8:30 p.m.	Banquet Dinner and Program

Tuesday, July 30

8:20 a.m. – 10:00 a.m.	Session – Streamflow Forecasting at Seasonal to Interannual Time Scales
10:00 a.m. – 10:30 a.m.	Coffee Break
10:30 a.m. – 12:30 p.m.	Session – Risk Management Tools and Probabilistic Frameworks for Water Management I
12:30 p.m. – 1:30 p.m.	Group Lunch
1:30 p.m. – 3:30 p.m.	Poster Session – Climate Forecasts Applications and Risk Management Framework
3:00 p.m. – 3:30 p.m.	Coffee Break
3:30 p.m. – 4:10 p.m.	Session – Risk Management Tools and Probabilistic Frameworks for Water Management II

Wednesday, July 31

8:20 a.m. – 10:00 a.m.	Session – Water Supply and Quality Management Applications of Climate and Streamflow Forecasts
10:00 a.m. – 10:30 a.m.	Coffee Break
10:30 a.m. – 11:50 a.m.	Session – Moving Forward: What is Required to Make Better use of Medium-range Weather and Climate Information in Water Resources Management? I
12:00 p.m. – 1:00 p.m.	Group Lunch
1:00 p.m. – 2:00 p.m.	Session – Moving Forward: What is Required to Make Better Use of Medium-range Weather and Climate Information in Water Resources Management? II
2:00 p.m.	Adjourn

Poster Presentation Guidelines

Poster sessions are active on Monday, 29 July and Tuesday, 30 July, 1:30 p.m. – 3:30 p.m.

The poster dimensions are 4 feet high by 8 feet wide. All boards will be marked with the appropriate poster number and category.

Those presenting their posters on Monday are asked to set up their posters on Sunday, 28 July between the hours of 4:00 p.m.-6:00 p.m. Posters must be removed by 7:00 p.m., on Monday, 29 July.

Those presenting their posters on Tuesday are asked to set up their posters on Tuesday, 30 July between the hours of 8:00 a.m.-12:00 p.m. Posters must be removed by 12:00 p.m. on Wednesday, 31 July.

SCIENTIFIC PROGRAM

SUNDAY, 28 JULY

12:30 p.m. – 5:30 p.m. **Optional Field Trip - Bonneville Dam**

6:00 p.m. – 7:30 p.m. **Welcome Reception**

MONDAY, 29 JULY

Climate to Streamflow Forecasting at Seasonal to Interannual Time Scales
Presiding: Andrew W. Robertson, Hamid Moradkhani
Columbia Falls

8:20 a.m. – 8:40 a.m. **Lisa Goddard** | Seasonal-to-Interannual Forecasts for Use in Decision Systems

8:40 a.m. – 9:00 a.m. **Lifeng Luo** | Seasonal streamflow prediction with VIC and Climate Forecast System version 2

9:00 a.m. – 9:20 a.m. **Joshua K. Roundy** | The optimal time and space scale for downscaling the CFSv2 forecast for seasonal hydrologic predictions

9:20 a.m. – 9:40 a.m. **Carly Tozer** | Identification of Drivers of Rainfall Variability for Informing Seasonal Forecasting Schemes

9:40 a.m. – 10:00 a.m. **Xing Yuan** | The role of climate models in global seasonal hydrologic forecasting

10:00 a.m. – 10:30 a.m. **AM Coffee Break (Monday)**

Climate to Streamflow Forecasting at Seasonal to Interannual Time Scales II
Presiding: Ashish Sharma, Lifeng Luo
Columbia Falls

10:30 a.m. – 10:50 a.m. **David Gutzler** | Hydroclimatic Forecasting in Southwestern U.S. River Basins

10:50 a.m. – 11:10 a.m. **Chetan Pandit** | Introducing EHP in India

11:10 a.m. – 11:30 a.m. **Julien Boé** | Theoretical and practical predictability of decadal variations in river discharges in France and implications for water management

11:30 a.m. – 11:50 a.m. **Mohammed Bari** | Operational streamflow forecasting at different time scales – hours to seasons to decades

11:50 a.m. – 12:10 p.m. **Mohammad Reza Najafi** | Evaluating Multi-Modeling Techniques with Varying Complexities for Seasonal Hydrologic Forecasts

12:10 p.m. – 12:30 p.m. **Andrew J. Newman** | Impacts of Hydrologic Model Uncertainty on the Skill of Seasonal Streamflow Forecasts

12:30 p.m. – 1:30 p.m. **Group Lunch (Monday)**

1:30 p.m. – 3:30 p.m. **Climate to Streamflow Forecasting at Seasonal to Interannual Time Scales Posters**
Poster Hall

M-1 **Li-Chuan Chen** | Seasonal Runoff Forecasts Based on the Climate Forecast System Version 2

M-2 **Takeshi Doi** | Why was the prediction of the 2012 positive Indian Ocean Dipole Mode difficult?

M-3 **Thomas Mosier** | Downscaling Global Climate Data: Production and Optimization of 30 Arc-Second Surfaces

M-4 **Shraddhanand Shukla** | Forecasting East Africa Spring rainfall at Seasonal Scale using a Hybrid Approach

M-5 **Julie Vano** | Mapping the diversity of hydrologic responses to seasonal climate in the Pacific Northwest

M-6 **Mengqian Lu** | Space-time structure of tropical moisture exports and their precursors associated with high precipitation induced floods

M-7 **Shahrbanou Madadgar** | A Probabilistic Framework for Predicting the Spatial Variation of Future Droughts

M-8 **Mohammad Reza Najafi** | The Impact of Climate Change on Runoff Extremes Based on Regional Climate Models and Hierarchical Bayesian Modeling

M-9 **Andrew M. Chiodi** | An OLR perspective on La Nina and El Nino precipitation impacts over North America

M-10 **Moty Cohen** | Depth-Area-Duration analysis for an Eastern Mediterranean basin

M-11 **Tanvir H. Bhuiyan** | Ensemble Methods for Seasonal Streamflow Prediction

M-12 **Lianne Daugherty** | Probabilistic Operational Forecasting in the San Juan Basin using Stochastic Weather Generator based Seasonal Ensemble Streamflow Forecasts

M-13 **Caleb M. DeChant** | Understanding the Effects of Initial Condition and Model Structural Uncertainty in Seasonal Hydrological Forecasts with Data Assimilation and Bayesian Model Averaging

M-14 **Ben Livneh** | From catchments to regional scales: Hydrologic impacts of land cover disturbances in the Upper Colorado River Basin

M-15 **Katherine Lownsbery** | Development of Seasonal Forecasting of Upper Niger River Streamflow

M-16 **Golnazalsadat Mirfenderesgi** | A Comparative Assessment of Particle Filtering-Markov Chain Monte Carlo and Particle Smoothing Methods for Seasonal Hydrologic Forecasting and Uncertainty Quantification

M-17 **Sarah Whateley** | Seasonal Hydrologic Forecasting in the Northeastern United States

M-18 **Hongxiang Yan** | A Regional Bayesian Hierarchical Model for Flood Frequency Analysis in Oregon

M-19 **Ying Zhang** | Development of a rainfall type prediction model for NYC

M-20 **Nina Caraway** | Advancing Ensemble Streamflow Prediction with Stochastic Meteorological Forcings for Hydrologic Modeling

M-21 **Rajarshi Das Bhowmik** | Multivariate Downscaling of Decadal Climate Change Projections Over the Sunbelt

M-22 **Seung Beom Seo** | Near-term Climate Change Impacts on Surface Water and Groundwater Interactions Over the Sunbelt

3:00 p.m. – 3:30 p.m. **PM Coffee Break (Monday)**

Climate to Streamflow Forecasting at Seasonal to Interannual Time Scales III
Presiding: David Raff, Edith Zagona
Columbia Falls

3:30 p.m. – 3:50 p.m. **Ashish Sharma** | THE DO'S AND DON'T'S OF COMBINING MODEL PREDICTIONS FOR SEASONAL HYDROLOGIC FORECASTING

3:50 p.m. – 4:10 p.m. **Andrew W. Wood** | The potential value of NCEP climate forecasts for hydrologic prediction in the Pacific Northwest

4:20 p.m. – 5:00 p.m. **Climate to Streamflow Forecasting a Seasonal to Interannual Time Scales III**

Dinner Program Introductions - Sankar Arumugam
Welcome - Hamid Moradkhani
Presiding: Sankar Arumugam
Willamette Ball Room

6:30 p.m. – 7:30 p.m. **Upmanu Lall** | The Columbia Global Flood Initiative — from Climate Causal Modeling to Supply Chain Risk Management

TUESDAY, 30 JULY

Streamflow Forecasting at Seasonal to Interannual Time Scales
Presiding: Martyn Clark
Columbia Falls

8:20 a.m. – 8:40 a.m. **Jan Danhelka** | IMPLEMENTING THE EXTENDED HYDROLOGICAL PREDICTION: A PAST AND FUTURE WMO ACTIVITIES

8:40 a.m. – 9:00 a.m. **Christian Zammit** | Effect of initial conditions of a catchment on seasonal streamflow prediction using ensemble streamslow prediction technique (ESP) for 2 river basins on New Zealand's South Island

9:00 a.m. – 9:20 a.m. **Daehyok Shin** | Seasonal Hydrologic Forecasting for Water Resources Management

9:20 a.m. – 9:40 a.m. **Bart Nijssen** | Relative Contributions of the Sources of Uncertainties in Seasonal Hydrologic Prediction Globally

10:00 a.m. – 10:30 a.m. **AM Coffee Break (Tuesday)**

Risk Management Tools and Probabilistic Frameworks for Water Management I
Presiding: Ximing Cai, Levi Brekke
Columbia Falls

10:30 a.m. – 10:50 a.m. **Carlos H. Lima** | SEASONAL STREAMFLOW FORECASTS FOR THE BRAZILIAN HYDROPOWER NETWORK: PRESERVING THE SPATIO-TEMPORAL VARIABILITY IN STATISTICAL MODELS

10:50 a.m. – 11:10 a.m. **Tushar Sinha** | Experimental Inflow and Storage Forecasts Portal for Major Reservoirs in the Southeastern US

11:10 a.m. – 11:30 a.m. **Mengqian Lu** | Multi-time scale Climate Informed Stochastic Hybrid Simulation-Optimization Model (McISH model) for Multi-Purpose Reservoir System

11:30 a.m. – 11:50 a.m. **Andrew W. Robertson** | Combining seasonal climate forecasts with stochastic simulation of interannual-to-interdecadal streamflow variability for reservoir Optimization over NW India

11:50 a.m. – 12:10 p.m. **Leon Basdekas** | STOCHASTIC STREAMFLOW GENERATION FOR INTER-ANNUAL MUNICIPAL WATER SUPPLY PLANNING

12:10 p.m. – 12:30 p.m. **Nathalie Voisin** | Improved Medium Range to Seasonal Streamflow Forecasts Through Simultaneous Assimilation of Snow and Streamflow Observations: Evaluation Over the Feather River Basin, CA

12:30 p.m. – 1:30 p.m. **Group Lunch (Tuesday)**

1:30 p.m. – 3:30 p.m. **Climate Forecasts Applications and Risk Management Framework Posters**

Poster Hall

T-1 **Indrani Pal** | Detecting the Shift in Timing of Seasonal Hydrological Cycle in India and Understanding the Dynamical Associations

T-2 **Kara DiFrancesco** | Inclusion of climate change projections into flood frequency analysis to assess the robustness of proposed management actions – application to the American River, California, USA

T-3 **Leon Basdekas** | Using Multi-objective Optimization for Interdecadal Drought Planning

T-4 **Yeonjoo Kim** | A robust decision making framework for integrated watershed management under climate change: a case study in a Korean urban watershed

T-5 **Maria C. Mateus** | Vulnerability of water resources with changing land use, and climate in the Santiam River Basin, Oregon

T-6 **James L. McCreight** | Global Positioning System (GPS) observations of hydrologic variables for water management: current and future applications

T-7 **Augustina Odame** | Water-Saving Technology Adoptions under Ecological and Economic Uncertainty

T-8 **Sunal Ojha** | Role of snow cover and its Hydrological impact on Himalayan River basins

T-9 **Adriana D. Piemonti** | ANALYSIS OF STAKEHOLDER ATTITUDES ON OPTIMIZED WATERSHED MANAGEMENT PLANS

T-10 **Mehmet U. Taner** | Use of seasonal forecasting for improving reservoir operations in the Niger River Basin

T-11 **Logan Callihan** | A Robust Decision Making Technique for Water Management Under Uncertainty Due to Climate Variability

T-12 **Ashish Sharma** | AN UPPER LIMIT TO SEASONAL STREAMFLOW PREDICTABILITY?

T-13 **Amirhossein Mazrooei** | Inter-model Comparison of Seasonal Streamflow and Soil Moisture Forecasts for the US Sunbelt

T-14 **Maryam Pournasiri Poshtiri** | Understanding the Droughts in the Major River Basins of the U.S. and their Dynamical Connections: Implications for Water Resources Management

T-15 **Majid Shafiee-Jood** | Assess the value of seasonal forecast to mitigate farmers' losses from drought

T-16 **Pablo A. Mendoza** | A multisite ensemble seasonal streamflow forecasting framework for semi-arid Andean basins

T-17 **Juan J. Nieto** | Establishment of a regional Hydrological Outlook for the West Coast of South America

T-18 **Zhaohui Lin** | Seasonal Hydrological Ensemble Prediction System Over Huaihe River Basin and Its Preliminary Verification

3:00 p.m. – 3:30 p.m. **PM Coffee Break (Tuesday)**

Risk Management Tools and Probabilistic Frameworks for Water Management II
Columbia Falls

3:30 p.m. – 3:50 p.m. **Edith Zagona** | Tools and Techniques for Complex Water Management Models on Interannual to Multidecadal Time Scales

3:50 p.m. – 4:10 p.m. **Upmanu Lall** | Innovations in Climate Informed Water Supply and Demand Forecasts and Water System Management

4:20 p.m. – 5:20 p.m. **Climate Forecasts Applications and Risk Management Framework Panel**

WEDNESDAY, 31 JULY

	Water Supply and Quality Management Applications of Climate and Streamflow Forecasts Presiding: Andrew W. Robertson Columbia Falls
8:20 a.m. – 8:40 a.m.	**Laila B. Parker** | Adaptively managing variable environmental flow releases from a water supply reservoir into First Herring Brook, Scituate, MA, in response to unexpected climactic conditions
8:40 a.m. – 9:00 a.m.	**Tirusew Asefa** | Challenge and opportunities in using Hydroclimate Predictions to drive weekly to seasonal scale decisions: A water supply utility's perspective
9:00 a.m. – 9:20 a.m.	**Benjamin L. Harding** | A Probabilistic Seasonal Forecasting System for Water Utilities
9:20 a.m. – 9:40 a.m.	**Daniel P. Sheer** | Using Forecast Information to Improve Water Management
10:00 a.m. – 10:30 a.m.	**Coffee Break (Wednesday)**
	Moving Forward: What is Required to Make Better use of Medium-range Weather and Climate Information in Water Resources Management? Presiding: Hamid Moradkhani, Lisa Goddard Columbia Falls
10:30 a.m. – 10:50 a.m.	**Alan Roberson** | Improving Municipal Water Demand Forecasting
10:50 a.m. – 11:10 a.m.	**Erik Pytlak** | Water Supply Forecast Techniques and Challenges on the Columbia River
11:10 a.m. – 11:30 a.m.	**Kevin Werner** | Forecasting the Life Blood of America's Southwest: Challenges for the Next Decade
11:30 a.m. – 11:50 a.m.	**Paul Trimble** | Application of Seasonal and Multi-seasonal Climate Outlooks for Water Management in South Florida
1:00 p.m. – 2:30 p.m.	**Group Lunch (Wednesday)**
1:00 p.m. – 2:00 p.m.	**Moving Forward: What is Required to Make Better Use of Medium-range Weather and Climate Information in Water Resources Management?**

ABSTRACTS

listed by name of presenter

Asefa, Tirusew

Challenge and opportunities in using Hydroclimate Predictions to drive weekly to seasonal scale decisions: A water supply utility's perspective

Asefa, Tirusew[1]; Adams, Alison[1]

1. Tampa Bay Water, Clearwater, FL, USA

Tampa Bay Water is the largest wholesale water provider in the Southeast U.S. and with its Member Governments (Hillsborough, Pasco and Pinellas Counties and Cities of New Port Richey, Tampa, and St. Petersburg) serves over 2.3 million water customers. It provides potable water using a unique blend of ground water, surface water and seawater sources. Over the past decade, average annual delivery has ranged between 222 mgd to 262 mgd. In the last three years, 45% to 65% of supply came from groundwater sources, 35% to 45% from surface water sources and 1% to 9% from desalinated seawater. As an "on demand" water provider, the utility forecasts water supply availability and expected water demands from weekly to seasonal scales. It has developed a suite of decision support tools, several of which are probabilistic, to account for uncertainties in input, such as rainfall, and the process being modeled. Its short-term models use forecast product such as Weather Prediction's Center's (WPC) Quantitative Precipitations Forecast (QPF), whereas seasonal models make use of established large-scale teleconnections and ENSO ensemble outlooks. The short-term operational objective, given the seasonal outlook and surface water availability, is optimizing well field operations to meet projected demand. Seasonal to annual objectives, based on planning and management of different supply sources, include cost-efficiency and environmentally sustainability goals. This presentation highlights the use of hydroclimate predictions to manage a complex water supply system and identifies the space-time gaps, accuracy, and uncertainty of forecast products as they propagate through various decision support tools.

Bari, Mohammed

Operational streamflow forecasting at different time scales – hours to seasons to decades

Bari, Mohammed[1]; Tuteja, Narendra[1]; Enever, David[1]; Perkins, Jeff[1]; Jayasuriya, Dasarath (Jaya)[1]; Feikema, Paul[1]

1. Climate and Water Division, Bureau of Meteorology, West Perth, WA, Australia

The Australian Government has assigned the Bureau of Meteorology with national responsibilities for water forecasting services through a legislative mandate under the Water Act 2007. These forecasting services complement and add to other services for weather, climate and oceans. The prolonged drought in recent decades has been followed by three successive very wet years since 2010 in eastern Australia. Demands for domestic, agricultural and industrial water use have increased significantly over the past few decades. These factors have made improved water availability forecasts more important for water resources planning and operations. Water availability forecast services at the Bureau range from hours to days to seasons to several decades. The hourly forecasting service includes extremes of rainfall and flood. This service provides real time operational forecasts of river heights and enables the public to take protective action across Australia (http://www.bom.gov.au/australia/flood/). The short-term (up to 7 days) streamflow forecast service is an extension of the flood forecasting service. This service combines hydrologic and weather forecasts and provide advanced notice of high flow events, emergency storage management and environmental water releases. The seasonal forecasting service is currently delivering 3-months total streamflow outlooks at 50 key water supply catchments across eastern Australia (http://www.bom.gov.au/water/ssf). Many water sectors currently benefit from the seasonal forecasting service, including water allocations, cropping strategies development, water markets planning, reservoir operations, setting restrictions and environmental release. The long term forecasting service covers time spans of years to decades. This service is being developed to provide water availability forecasts with an emphasis on the next 10 to 30 years and focus on regions considered more vulnerable to extremes in water availability. As a precursor of the long term water forecasting service, a set of 221 Hydrologic Reference Stations has been identified for streamflow change detection and attributions (http://www.bom.gov.au/water/hrs/). Using climate projections from the Fifth Assessment Report of the IPCC, the Bureau plans to make a comprehensive national statement on the long-term trends in water availability for all Hydrologic Reference Stations and major water source catchments. These hydrological forecasting services are being used for enhancing the existing drought service (http://www.bom.gov.au/climate/drought/), including the monitoring and prediction of meteorological, agricultural and hydrological drought. Important elements of the operational services include partnership development and active and cooperative engagement of users and stakeholders. The Bureau is also leveraging complex research and development collaboration – in particular with CSIRO through the Water Information Research and Development Alliance (WIRADA). Other collaborators include Centre for Australian Weather and Climate Research (CAWCR), eWater CRC, and academic institutions.

Basdekas, Leon

STOCHASTIC STREAMFLOW GENERATION FOR INTER-ANNUAL MUNICIPAL WATER SUPPLY PLANNING

Basdekas, Leon[1]; Stewart, Neil[1, 2]; Balaji, Rajagopalan[2]

1. Colorado Springs Utilities, Colorado Springs, CO, USA
2. University of Colorado Boulder, Boulder, CO, USA

During periods of drought, near term (season to 24 months) planning by municipal water supply providers is one of several tools used to assess and address risk. Generation of stochastic flows used to inform decision makers on potential near term risk is an important step in this process. In this process, climate-based seasonal streamflow forecast for the near term are combined with historical averages for the subsequent 18 months or so to produce a streamflow sequence that is 24 months long. Thus, a produced sequence is used to drive water resources systems model for planning and management decisions. The main drawback of this approach is that often historical averages are wetter than the near term seasonal forecasts, thus suggesting an optimistic future to the planners thereby, biasing the planning process. We propose two different methods to simulate streamflow sequences for the 2-year period following the current seasonal forecast that better captures potential variations. These methods are the K-nearest neighbor (KNN) and a variation of the K-nearest neighbor approach (KNN Plus) that uses the recent hydrologic conditions as the feature vector to select historical neighbors and consequently the simulations. For example, if the recent hydrologic state is drier then the stochastic simulations will be biased towards drier flows. Thus, it can produce consecutive dry years such as those produced in current climate can be simulated, which are importance for risk based planning. By adding in a memory component, this potential new climate regime can be better captured even without a similar situation in the observed record. As part of continuing drought response measures, Colorado Springs Utilities (CSU) is interested in modeling the variation in potential future flows, which is not captured well with typical methods. We apply these methods for CSU water resources near term planning.

Basdekas, Leon

Using Multi-objective Optimization for Interdecadal Drought Planning

Basdekas, Leon[1]; Stewart, Neil[1, 3]; Triana, Enrique[2]

1. Colorado Springs Utilities, Colorado Springs, CO, USA
2. MWH Americas, Ft. Collins, CO, USA
3. University of Colorado Boulder, Boulder, CO, USA

Colorado Springs Utilities (CSU) is currently engaged in an Integrated Water Resource Plan (IWRP) to address the complex planning scenarios currently faced by CSU. The modeling framework developed for the IWRP uses a flexible data-centered Decision Support System (DSS) with a MODSIM-based modeling system to represent the operation of the current CSU raw water system coupled with a state-of-the-art multi-objective optimization algorithm. The long term planning effort and the ongoing drought in the Western U.S. provided an opportunity to utilize analytical tools not previously available for CSU drought planning. We describe a new drought metric that captures duration and intensity. This drought metric was then used to filter over 20,650 10 year time series down to 2328 potential drought time series for system modeling. Those timeseries that produced system demand shortages were further analyzed in order to select a stochastic ensemble of timeseries for multi-objective optimization. Of CSU's 37 reservoirs or reservoir accounts, nine high priority reservoirs were identified for use as preferred storage sites during drought periods. A sophisticated mutli-objective optimization approach was used to identify individual and system storage pool volumes, identify drought response triggers and associated drought policy responses. We utilize multiple system performance metrics such as demand shortage, volume of water saved during restrictions, and reservoir reliability as optimization objective functions to be either minimized or maximized. The goal of this multi-objective optimization is creating a set of non-dominated solutions for which the multiple objective metrics collectively could not be improved and for which the trade-offs in satisfying the different objectives can be quantified. There is opportunity for adapting this methodology to an interannual time frame.

Bhuiyan, Tanvir H.

Ensemble Methods for Seasonal Streamflow Prediction

Bhuiyan, Tanvir H.[1]; French, Mark N.[1]

1. Civil & Environmental Engg., University of Louisville, Louisville, KY, USA

Hydrological extremes such as floods and droughts are two of the more hazardous natural disasters in context of economic loss and human impact. The frequency and the severity of these events are related to precipitation extremes and linked to climate variation. Prediction of floods and droughts is challenging yet can provide benefits in terms of managing irrigation water requirements, reservoir operations, and planning for recovery. Accurate forecasts depend on identification of relevant variables and uncertainties involved in prediction methodologies. Uncertainties in seasonal flow predictions can be considered in ensemble forecast methods which combine a variety of model predictions and allows the variability of estimation to be considered. In this study, methods including time series and neural network (NN) are evaluated for seasonal flow forecasts ensembles. Forecasts based on persistent characteristics are included as a baseline performance criterion. Initially, relationships between the seasonal flow variations of the five selected rivers namely Congo, Yangtze, Rhine, Columbia, and Parana, and fluctuations of external environmental variables such as El Niño, La Niña episodes, sun spot numbers, Pacific Decadal Oscillation, and North Atlantic Oscillation are quantified. River flows and external

variables (forcing variables) are incorporated in stochastic time series and NN methods to examine the ability to reproduce seasonal variability evident in historical flows. The forcing variables are expected to contribute to natural streamflow conditions. Model performance is evaluated for improvement in prediction skills, while including multivariate approaches with river flow and external variables. Overall model performance indicates inclusion of river flows and forcing variables on average improve model performance. To further assess model efficiency for predicting seasonal flow, both stochastic and NN model forecasts are categorized into high, average and low flow levels. Persistence model results are often comparable to more complex multivariate approaches, indicating the inclusion of multiple variables does not always improve model performance. An ensemble approach merging stochastic and the NN based forecasts with persistence are developed to forecast seasonal river flow. Results indicate ensembles forecasts are useful to improve seasonal flows estimates. Variation of forecast magnitudes based on model-type underscores the usefulness of utilizing multi-model ensembles. The ensembles of the time series and the NN model predictions indicate seasonal flow variations are well-captured in the ensemble range. The ensemble approach appears promising for seasonal flow predictions in flow extremes associated with climate variation.

Boé, Julien

Theoretical and practical predictability of decadal variations in river discharges in France and implications for water management

Boé, Julien[1]; Habets, Florence[2, 3]

1. CNRS/CERFACS URA1875, Toulouse, France
2. Geosciences Department, MINES ParisTech, Fontainebleau, France
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River discharges in France exhibit large decadal variations, especially in spring. The existence of such low-frequency variations raises two important questions in the water management context. (i) Are we able to evaluate correctly and take into account the uncertainties that are associated with those decadal variations for water management. (ii) Are those decadal variations theoretically and practically predictable? A positive answer to the second question would open the door to the elaboration of more efficient water management strategies at the inter-annual and decadal time-scales. If decadal variations are not predictable, it is even more important to answer the first question. For example, internal decadal variations in streamflows can either seriously aggravate or moderate the impact of global warming on water resources during the next decades, and the entire possible range of variations has to be taken into account in the water management context. As a first step to answer those questions, it is necessary to understand the mechanisms responsible for the decadal variations in river discharges in France. We show that the decadal variations in streamflows are principally related to the modulation of large-scale atmospheric circulation by the Atlantic Multidecadal Oscillation (AMO), the main mode of decadal climate variability in the North Atlantic region. This result suggests that it is theoretically possible to predict a part of the the decadal variations in streamflows, thanks to decadal climate predictions. Decadal climate prediction is a new and experimental branch of climate modelling that consists in using observations to initialize the ocean in coupled climate simulations in the hope to predict the internal low-frequency variations of the climate system. We will assess whether a state-of-the-art decadal prediction system (based on the CNRM-CM5 coupled climate model from the Coupled Model Intercomparison Project Phase 5) shows any skill in the retrospective prediction of precipitation over France and/or of large-scale circulation, that could then be used with a statistical downscaling method to obtain the atmospheric forcing necessary to simulate river discharges. As current decadal prediction systems generally show more skill for oceanic variables, an alternative approach will be tested, using the prediction of the AMO and the observed link between the AMO and river discharges. Finally, a purely statistical method, based on the lagged relationship between the AMO and river discharges will be investigated. If none of the approaches described previously exhibit any skill, it is even more crucial to evaluate as well as possible the whole possible range of variations associated with internal low-frequency variability in river discharges during the next decades. The capacity of current coupled climate models to represent correctly the amplitude of decadal variations in French hydroclimate will be assessed in order to determine whether the uncertainties they cause in the projections for the next decades are correctly captured.

Callihan, Logan

A Robust Decision Making Technique for Water Management Under Uncertainty Due to Climate Variability

Callihan, Logan[1, 2]; Zagona, Edith[1, 2]; Rajagopalan, Balaji[1, 3]

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2. CADSWES, University of Colorado, Boulder, CO, USA
3. CIRES, University of Colorado, Boulder, CO, USA

Robust decision making, fundamental to managing water resources in light of deep uncertainties associated with climate variability at inter-annual to multi-decadal time scales, is an analytical framework that detects when a system is in or approaching a vulnerable state, and implements strategies to address the vulnerabilities that perform well over a wide range of plausible future scenarios. Various techniques have been developed to identify vulnerable conditions and to select the options that are most favorable in given situations. To characterize strategies in terms of their potential success given various system states requires extensive modeling of a wide range of conditions. Recent research(1) that increases our understanding of decadal scale variability has the potential to improve decisions made in this framework. This research develops a comprehensive robust decision making framework that utilizes the power of extensive modeling to develop relationships between climate indicators and future system performance to identify the type and severity of vulnerable conditions, and evaluate a set of options and strategies in terms of benefits, costs, likelihood of mitigating vulnerable conditions, as well as the resiliency of system performance under a range of eventual conditions. The research utilizes the RiverSMART suite of software modeling and analysis tools developed under Reclamation's WaterSMART initiative and built around the RiverWare modeling environment. To provide a wide range of possible hydrologic futures, the framework generates stochastic streamflow scenarios using a K-nearest neighbor nonparametric method, resampling observed and paleo reconstructed hydrology; other data sets can be produced that combine characteristics of the paleo, historic and climate change projections using various Markov Chain techniques(2). A case study is developed for the Gunnison Basin of the upper Colorado River. Various demand scenarios are projected and system performance indicators measure the ability of the system to meet water demands for agriculture, municipalities, environmental flows, hydropower and recreation. Options and strategies for addressing vulnerabilities include such measures as conservation, reallocation, and adjustments to operational policy. Projections that utilize teleconnections with decadal scale signals such as AMO are evaluated for improving the efficacy of the decisions. Results of extensive simulations provide both guidance for decision-making and evaluation of the effects of the decisions on performance and resiliency of the systems. This methodology can also be readily adapted to inter-annual and multi-decadal time scales. References: 1. Nowak, Kenneth C. (2011), Stochastic Streamflow Simulation at Inter-decadal Times Scales and Implications for Water Resources Management in the Colorado River Basin, Civil, Environmental, and Architectural Engineering Ph.D. Dissertation, University of Colorado. 2. Prairie, J., K. Nowak, B. Rajagopalan, U. Lall, and T. Fulp, (2008), A Stochastic Nonparametric Approach for Streamflow Generation Combining Observational and Paleo Reconstructed Data, Water Resources Research, 44.

Caraway, Nina

Advancing Ensemble Streamflow Prediction with Stochastic Meteorological Forcings for Hydrologic Modeling

Caraway, Nina[1]; Wood, Andrew[2]; Rajagopalan, Balaji[3]

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3. CIRES, University of Colorado, Boulder, Boulder, OR, USA

River Forecast Centers of National Weather Service (NWS) produce seasonal streamflow forecasts via a method called Ensemble Streamflow Prediction (ESP). NWS ESP forces the temperature index SNOW-17 and conceptual Sacramento Soil Moisture Accounting model (SAC-SMA) models with historical weather sequences for the forecasting period, starting from models' current watershed initial conditions, to produce ensemble streamflow forecasts. Among several serious drawbacks of this method, two are: (i) the ensembles are limited to the length of historical record, limiting ensemble variability; and (ii) incorporating seasonal climate forecasts (e.g., related to the El Nino Southern Oscillation) relies on adjustment or weighting of ESP streamflow sequences. These drawbacks motivated the research presented here, which has two components: (i) a multi-site stochastic weather generator and (ii) generation of ensemble weather forecast inputs to the NWS models to produce ensemble streamflow forecasts. We enhanced the K-nearest neighbor bootstrap based stochastic generator include conditioning the weather forecasts on probabilistic seasonal climate forecast. This multi-site stochastic weather generator runs in R and the NWS models run within the new Community Hydrologic Prediction System (CHPS), a forecasting sequence we label 'WG ESP'. The WG ESP framework was applied to generate ensemble forecasts of runoff season (April-July) streamflow in the San Juan River Basin, one of the major tributaries of the Colorado River, USA, for the period 1981-2010. The hydrologic model requires daily weather sequences at 66 locations in the basin. Runoff season ensemble forecasts stepped through November to April lead times for the period 1981-2010 and were made from both WG ESP and traditional ESP. The WG ESP approach provides a skillful and comprehensive variety of flow ensembles compared to the ESP. Furthermore, it exhibited higher skill in predicting seasonal and monthly flows at long lead times, particularly in wet years. The flexible and robust framework augments the ESP framework, and provides a new linkage between climate and streamflow prediction, two developments that will be valuable for water resources management.

Chen, Li-Chuan

Seasonal Runoff Forecasts Based on the Climate Forecast System Version 2

Chen, Li-Chuan[1]; Shukla, Shraddhanand[2]

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2. Department of Geography, University of California, Santa Barbara, Santa Barbara, CA, USA

In this study, we conduct an assessment of the hydrological drought predictability as derived by the use of the Climate Forecast System version 2 (CFSv2) forecasts. We found that direct runoff forecasts from CFSv2 not only have large biases but also limited skill to be used for operational drought prediction. Climatological analysis has revealed that the partition between the water balance components (e.g., runoff and soil moisture) in Noah model, the only land surface model employed in CFSv2, needs improvements. We further investigate the usability of CFSv2 forecasts in hydrological drought prediction by evaluating the forecast skill of standardized cumulative runoff index simulated by a macroscale hydrologic model (the Variable Infiltration Capacity model) forced with daily precipitation, temperature, and wind forecasts from CFSv2 (i.e.

hydroclimate forecasts denoted as CFSv2_VIC). The skill of CFSv2_VIC forecasts is compared with respect to baseline forecasts generated using the Ensemble Streamflow Prediction (ESP) method (i.e. ESP_VIC), that derives its skill solely from the knowledge of the initial hydrologic conditions. We observed that the relative skill of CFSv2_VIC (w.r.t ESP_VIC) varies throughout the year and with the location. In general, the skill of CFSv2_VIC forecasts is greater than ESP_VIC over the areas where precipitation is driven by large-scale circulation or dynamical forcing is active, such as the Southwest monsoon region in July and the eastern United States in the fall. The skill of CFSv2_VIC forecasts is mostly increased from the baseline ESP_VIC forecasts when and where precipitation forecasts are skillful. CFSv2-based hydroclimatic forecasts are a useful tool for real-time hydrological drought prediction; however, their skill is limited to specific seasons and regions.

Chiodi, Andrew M.

An OLR perspective on La Nina and El Nino precipitation impacts over North America

Chiodi, Andrew M.[1]; Harrison, Don E.[2, 1]

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El Niño-Southern Oscillation (ENSO) impacts on seasonal weather anomalies form the basis for skillful statistical seasonal weather prediction in the regions around the globe where the statistical links between ENSO and seasonal weather anomalies are strong. A warm-ENSO (El Niño) index based on outgoing longwave radiation (OLR) conditions in the tropical Pacific has recently been proposed and found to have a stronger statistical linkage to seasonal weather anomalies over the contiguous U.S. than the commonly used ENSO indices, which rely on sea surface temperature (SST) or sea level pressure (SLP) conditions. A complimentary OLR-based cool-ENSO (La Niña) index is proposed and this pair of OLR-based ENSO indices is evaluated for their respective connections to interannual precipitation and atmospheric circulation anomalies over North America using composite analysis. We find that over the period for which satellite-based OLR observations are available, almost all of the useful (statistically significant and consistent from event to event) ENSO impacts on seasonal precipitation are due to the years distinguished by the OLR-based ENSO indices ("OLR El Niño"; "OLR La Niña"). On the other hand, composites based on other years with ENSO status based on the current NOAA definition ("non-OLR El Niño"; "non-OLR La Niña") do not have nearly as robust or statistically significant anomaly patterns as the OLR ENSO events. To the extent this observed behavior holds in the coming decades, OLR diagnostics can serve as indicators of times in which greater confidence can be placed in seasonal forecasts than has perhaps been previously realized. It should be noted also, however, that such times occur only in a subset of the conditions now commonly identified as ENSO years.

Cohen, Moty

Depth-Area-Duration analysis for an Eastern Mediterranean basin

Cohen, Moty[1]

1. Soil and Water, Faculty of Agriculture, The Hebrew University of Jerusalem, Rehovot, Israel

The eastern Mediterranean climate is characterized (Goldreich, 2003) by winter rainfall ranging between 600 mm (north) to 200 mm (south) isohyets. Several factors determine the intra-annual variability of rainfall levels in this region. The occurrence of Cyprus lows is the dominant factor, and the Mediterranean oscillation index (MOI2) is also a significant factor. Another key factor is an enhanced tendency of upper-level troughs to be oriented in a southwest–northeast direction. Alpert et al. (2004) proposed that rainfall may increase as a function of the number of days characterized by the Red Sea Trough, a system mainly impacting the rainfall potential in southern Israel. Being situated in the margins of these systems leads to high variability and intermittency of rainfall. Knowledge of rainfall depth and its temporal and spatial occurrence is essential for all hydrological research performed with the goal of mitigating flood hazards. These include the physical basis of rainfall-runoff phenomena, as well as the design of hydraulic structures. One approach is to assess meteorological and synoptic parameters (Ziv et al. 2013), however from an engineering point of view, the use of empirical tools is more practical. Traditionally, intensity-duration-frequency (IDF) curves are derived using point values of the rain gauge measurements. This approach is not useful for describing the spatial distribution of the rain, nor the areal reduction resulting from the averaging of rain values over the whole area. To generate this type of analysis, depth-area-duration (DAD) analysis is used to correlate rainfall areal averaged depth with the size of the rainfall event area. Analysis of a large number of storms of varying duration enables one to assess the probable rainfall depth for a given watershed size and response time. In addition to the ability to accurately compute rain volumes and flood discharge (critical for engineering/environmental design), this DAD analysis serves as a tool to characterize storm patterns prevailing in a given area as a result of different climatologic regimes (Jolly et al. 2008). An extensive study of this type has been carried out in the US (Svensson and Jones, 2010), but scant research of this sort has been done in Israel. This type of research is of particular interest since flood discharge in areas such as the Yarkon watershed (800 km2) near Tel-Aviv, Israel may be catastrophic from an environmental, political, and economic standpoint as they are very densely populated (with over 1.5 million residents). In this study, the 24-hr rainfall measured at 32 stations over 59 years via gauge data was analyzed to derive fixed area DAD curves. Thus, to characterize the spatial distribution of rainfall events occurring over the Yarkon watershed Results of the analysis show that the maximal daily rainfall for the Yarkon watershed is 172 mm. The areal reduction factor for the entire watershed may reach 39% and 47% for a 2-year and a 10-year return period, respectively. In a forthcoming study, such areal reduction functions based on point "ground truth" measurements will be compared to similar functions derived from radar measurements which may be a more appropriate database with which to achieve this goal.

Danhelka, Jan

IMPLEMENTING THE EXTENDED HYDROLOGICAL PREDICTION: A PAST AND FUTURE WMO ACTIVITIES

Danhelka, Jan[1]

1. Czech Hydrometeorological Institute, Praha, Czech Republic

Extended hydrological prediction (EHP) has the potential to bring a wide range of benefits in water management and other fields. The successful implementation of EHP will require the bridging of several gaps between various communities and groups as well as development of reliable operational procedures and tools and training of hydrologists and water managers. WMO organized workshop and trainings on EHP in the Western Coast of South America 2010 and an Expert meeting on EHP in Melbourne in 2011. The recommendations from a Melbourne meeting include the compilation of case studies and guidance on the needs and justification of EHP, its scientific basis, the issue of service delivery mechanisms and formats, stakeholder consultation and finally the transfer from research to operation. Based on the outcomes of the Melbourne meeting, the Commission for Hydrology (CHy) of WMO has included in its working plan (2013–2016) an aim to compile case studies and provide guidance on the application of EHP to water resources management. The overall aim is to increase the ability of National Hydrological Services (NHSs) to provide and make use of EHP. The chain of activities within the field of EHP usually starts with climate observations and/or outlooks, proceeds with hydrological modeling and ends at user's interpretation or processing of the prediction output and finally, decision making. From the institutional point of view these activities present National Meteorological Services as climate information providers, the NHSs (hydrological modeling) as conduits for service delivery and water managers and others as service users. The WMO has established the Global Framework for Climate Services (GFCS) as the framework for the delivery of climate data, information and services. The water sector is one of the key focus areas of the GFCS. It is assumed that hydrologists and water managers will be the users of the GFCS and will provide user's input and feedback through the User Interface Platform (UIP). EHP could benefit from the feedback and guidance provided through the UIP. However the EHP is also an excellent example of possible product provided by the hydrological community through the GFCS. Relevant climate drivers of stream flow and their variability differ among various regions significantly. Accordingly the optimal method of extended hydrological prediction may differ from basin to basin. Approach used for reservoir inflow forecast does not include climate variables of future period but rely on simplified empirical water balance method of observed snow and rain. Monthly EHP in the Czech Republic accounts for 9 different combinations of expected future temperature and precipitation (below-normal, normal, and normal) based on ECMWF monthly forecast evaluation to select 40 ensemble members from synthetic 1000 y daily weather time series and its spatial and temporal downscaling to produce flow simulations. Australia approach includes basin specific statistical models using various climate and ocean oscillation indices as predictors. This contribution will present a template for case studies compilation and proposed structure of guidance for NHSs on implementing EHP and using GFCS. The participants of the conference will be encouraged to contribute to the case studies catalogue and guidance.

http://www.wmo.int/pages/prog/hwrp/chy/index.php

Das Bhowmik, Rajarshi

Multivariate Downscaling of Decadal Climate Change Projections Over the Sunbelt

Das Bhowmik, Rajarshi[1]; Arumugam, Sankar[1]; Patskoski, Jason[1]

1. North Carolina State University, Raleigh, NC, USA

Statistical downscaling of precipitation and temperature is commonly required to bring the large scale variables available from GCMs to a finer grid-scale that can be ingested watershed models. Most of the currently employed procedures on statistical downscaling primarily consider a univariate approach by developing a statistical relationship between large-scale precipitation/temperature with the local-scale precipitation/temperature ignoring the interdependency between the two variables. In this study, a Bayesian K-nearest neighbor (K-NN) approach is proposed that obtains the posterior distribution of precipitation and temperature at the local scale by preserving spatio-temporal correlation structure among these two variables. The study also shows an upper bound on the correlation between the downscaled variables that are obtained based on univariate downscaling using simple and asynchronous regression techniques. The proposed Bayesian K-NN approach will also be compared with simple univariate downscaling and asynchronous regression in preserving the multivariate correlation structure at the local scale by downscaling climate models inter-comparison project-45 (CMIP5) projections over the Sunbelt.

Daugherty, Lianne

Probabilistic Operational Forecasting in the San Juan Basin using Stochastic Weather Generator based Seasonal Ensemble Streamflow Forecasts

Daugherty, Lianne[1, 2]; Zagona, Edith[1, 2]; Rajagopalan, Balaji[1, 3]; Grantz, Katrina[4]; Miller, Paul[5]; Werner, Kevin[5]

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Projections of reservoir conditions and operations of major projects in the Colorado River Basin have been generated each month for many years by the Bureau of Reclamation (Reclamation) using the 24-Month Study, a monthly timestep deterministic model that incorporates streamflow forecasts produced by the National Weather Service (NWS), Colorado Basin River Forecast Center (CBRFC). Using an Ensemble Streamflow Prediction (ESP) method and a physically based hydrologic model, the CBRFC produces an ensemble of streamflow forecasts by sampling historical weather sequences conditioned on 3-7 month seasonal climate forecasts starting from the model's current initial conditions. Subsequent months use statistical average conditions. The 24-Month Study is used mainly to provide only the most probable (based on the 50% exceedance) reservoir operations projection and requires manual monthly reservoir operations input.(1) The two main drawbacks of this forecasting process are i) the ESP method is limited by the limited variability of the historical meteorological record; and ii) the deterministic nature of the operations model does not provide a probabilistic range of the forecast. The goal of this research is to join the enhanced ESP technique and a probabilistic version of the monthly reservoir operations model to demonstrate improved forecasting skill at long lead times along with quantified uncertainty that can be used in decision-making. Caraway (2) developed an enhanced ESP method that uses a K-nearest neighbor bootstrap based stochastic weather generator (WG) combined with a probabilistic seasonal climate forecast. The generated weather sequences are coupled with the SAC-SMA model within the NWS Community Hydrologic Prediction System (CHPS) to produce a weather-generated ensemble streamflow forecast, referred to as WG based ESP which showed improved long lead skills compared to the traditional ESP2. Reclamation is developing an ensemble-based operations model referred to as the Mid-Term Operations Model (MTOM), which is capable of incorporating multiple hydrologic traces, simulating reservoir operations, and thus producing probabilistic projections of reservoir conditions. We apply the forecasting techniques in the San Juan River Basin (SJRB) using a portion of the Colorado River MTOM. The spring streamflow ensembles from ESP, WG based ESP and those conditioned on seasonal climate forecasts, issued at six different lead times, are proposed to be incorporated into yearly MTOM simulations from 2000-2010, using historical values as initial conditions. Ensembles of reservoir levels and releases at Navajo Reservoir will be obtained and their skills evaluated against variables obtained using historical streamflow (i.e., baseline). Reference: 1. http://www.usbr.gov/uc/rm/crsp/wtrops.html 2. Caraway, Nina Marie, 2012, Stochastic Weather Generator Based Ensemble Streamflow Forecasting, Masters thesis, University of Colorado at Boulder.

DeChant, Caleb M.

Understanding the Effects of Initial Condition and Model Structural Uncertainty in Seasonal Hydrological Forecasts with Data Assimilation and Bayesian Model Averaging

DeChant, Caleb M.[1]; Moradkhani, Hamid[1]

1. Portland State University, Portland, OR, USA

Uncertainties are an unfortunate but inevitable part of any forecasting system. Within the context of seasonal hydrologic predictions, these uncertainties can be attributed to three causes: our imperfect characterization of initial conditions, an incomplete knowledge of future climate and errors within computational models. In order to effectively manage these uncertainties, each of these three factors must be managed, providing a framework to reduce uncertainty and accurately convey persistent predictive uncertainty. To date, only partial accounting of uncertainty has been performed. Understandably, research and operational forecast systems have emphasized climate uncertainties in seasonal predictions. Forecasted climate is arguably the dominant source of uncertainty in a hydrologic forecasting system, but the other sources of uncertainty are significant. Since these uncertainties are significant, a complete representation of forecast uncertainty requires direct consideration of both initial condition and model structural uncertainties, in addition to climatic uncertainties. Recent research has examined the use of data assimilation to characterize initial condition uncertainty, but this has still ignored aspects of uncertainty related to model errors. In order to manage all three sources of uncertainty, this study utilizes a combined data assimilation, to characterize initial condition uncertainty, and model averaging system, to examine model structural errors, to give a complete description of seasonal hydrologic forecasting uncertainty. This presentation will highlight the need to advance the description of hydrologic uncertainty. An assessment of the reliability of current and proposed methods will be provided, along with an estimate of the relative uncertainty in the different sources of uncertainty. Overall this assessment will quantify the importance of accounting for state and model uncertainties in seasonal hydrologic forecasting.

DiFrancesco, Kara

Inclusion of climate change projections into flood frequency analysis to assess the robustness of proposed management actions – application to the American River, California, USA

DiFrancesco, Kara[1]; Tullos, Desiree[1]

1. Biological and Ecological Engineering, Oregon State University, Corvallis, OR, USA

The scientific community currently lacks both reliable climate projections at the temporal and spatial resolution required for flood frequency analysis as well as methods to incorporate multiple, highly uncertain future scenarios into flood frequency analysis. This study addresses the later issue by applying a new method using Bayesian statistics to assess the potential changes in flood frequency and flood risk under climate change. With this method, we calculate Expected Annual Damages over a range of plausible future flood frequency curves derived from a Monte Carlo Markov Chain algorithm and use this information to determine the portion of future scenarios under which the system can maintain damages below a threshold. We apply this method to the American River Basin in California, USA to assess the robustness of proposed management approaches in the 2012 Central Valley Flood Protection Plan. Each of the proposed approaches meets the performance threshold under a smaller portion of projected future scenarios than under current conditions and are vulnerable to greater than 70% of the plausible range of future conditions. While the future projections align with historic trends of increasing flood magnitude and variability, due to the uncertainty associated with the currently available downscaled projections, the results do not represent a predictive model of future flood conditions in the American Basin per say. Rather, the method represents a general technique to incorporate multiple sets of future projections into flood risk studies.

Doi, Takeshi

Why was the prediction of the 2012 positive Indian Ocean Dipole Mode difficult?

Doi, Takeshi[1]; Sasaki, Wataru[1]; Behera, Swadhin[1]; Masumoto, Yukio[1]; Yamagata, Toshio[1]

1. JAMSTEC, Yokohama, Japan

The Indian Ocean Dipole Mode (IOD) is now known to have impacts on climate forecasts and water management of the world, in particular, Indian Ocean rim countries such as Australia, India, and several east African countries. The seasonal prediction system based on the SINTEX-F ocean-atmosphere coupled model has so far demonstrated good performance of prediction on the IOD. However, the system has failed to predict the 2012 positive IOD event 1-season ahead for the first time since it became operational. We have explored the reason, and found that the ocean subsurface temperature initialization in April was the key. The observation showed warmer-than-normal temperature below 50 m depth in the western equatorial Indian Ocean in April 2012. This sustained the warmer-than-normal sea surface temperature (SST) there in May. The active convection associated with this warm SST anomaly in the western pole favored a positive IOD condition, which evolved through ocean-atmosphere coupled feedback from June, to reach a mature state in August. The SST-nudging initialization, however, could not capture the unique subsurface precondition off East Africa and hence negatively influenced the 2012 IOD prediction.

Goddard, Lisa

Seasonal-to-Interannual Forecasts for Use in Decision Systems

Goddard, Lisa[1]

1. International Research Institute for Climate & Society, Columbia University, Palisades, NY, USA

This talk will provide an overview of research and development efforts for seasonal climate forecasts at the International Research Institute for Climate & Society (IRI). The IRI has been producing probabilistic multi-model forecasts since 1997, and the methodology behind those forecasts has evolved considerably over the past 15 years. The methodology has always sought to emphasize past performance of the models, by region and season, and to minimize model-related errors. The goal is to extract the maximum useful information from multiple dynamical models and construct reliable probability forecasts. I will discuss our current approach to correct and combine the model output and to construct the probability density functions (PDFs). The methodology involves a penalized regression approach, which can account for sampling error where skill is low and the historical record is short. The availability of full PDFs, rather than the more standard formats of tercile categories or a deterministic best-guess, allows us to disseminate the forecast in a much more flexible format. This enables forecast consumers to view forecasts pertinent to their specific category or threshold. As an example, results from a study of hydropower in Ethiopia show that the use of reliable probabilistic forecasts keyed on user-defined thresholds yield improved hydropower reliability and economic benefit.

Gutzler, David

Hydroclimatic Forecasting in Southwestern U.S. River Basins

Gutzler, David[1]

1. Dept of Earth & Planetary Sciences, Univ of New Mexico, Albuquerque, NM, USA

Major rivers in the southwestern U.S., such as the Colorado and Rio Grande and their major tributaries, derive much of their annual flow from snowpack that falls at high elevation near their headwater catchments. The downstream reaches of these rivers extend through the climatic domain of the North American monsoon system, which exhibits a pronounced summer season precipitation maximum that can provide a significant flood pulse several months after the spring snowmelt season. Streamflow forecasts on these rivers are largely based on observations of winter snowpack, with some additional predictability possible early in the water year based on seasonal prediction skill for winter precipitation. In recent decades, however, some (but not all) of the most severe winter precipitation and snowpack deficits were followed by extremely wet monsoon seasons. Seasonal prediction skill for summer precipitation is still problematic, so water managers receive minimal guidance of summer hydroclimatic conditions beyond knowledge of climatology that would allow them to plan for severe deficits or high flows associated with pronounced anomalies in monsoonal precipitation. Projected climate change magnifies the significance and current uncertainties inherent in summertime hydrologic forecasts. Streamflows in southwestern rivers are projected to decline in association with warmer temperatures, due principally to decreasing snowpack and increasing warm season evaporation. Although precipitation itself shows no significant long-term trend, the ratio of (observed spring runoff)/(observed winter precipitation) is decreasing as temperatures have risen in recent decades. Summer precipitation projections represent a major uncertainty in adapting global climate model simulations to streamflow projections, especially on low flow tributaries in smaller drainage basins that can be especially strongly affected in strong monsoon seasons. The current hydrologic situation in the Southwest unfortunately provides an excellent example of the dilemma faced by water managers. Poor snowpack and low streamflow means that difficult surface water allocation decisions are now being made at the beginning of the growing season. More reliable guidance on summer precipitation, if it were available and trusted by stakeholders and hydrologic forecasters, could affect these decisions.

Harding, Benjamin L.

A Probabilistic Seasonal Forecasting System for Water Utilities

Harding, Benjamin L.[1]; Gangopadhyay, Subhrendu[2]; Rajagopalan, Balaji[3]; Rodriguez, Alfredo[4]

1. AMEC Environment & Infrastructure, Boulder, CO, USA
2. Bureau of Reclamation, Lakewood, CO, USA
3. University of Colorado, Boulder, CO, USA
4. Aurora Water, Aurora, CO, USA

Currently available climate and streamflow seasonal forecasts provide general guidance for water basin management at a basin or sub-basin scale. However, to make operational planning and management decisions, managers of water-supply systems could greatly benefit from site-specific forecasts of relevant system variables (e.g., end-of-water-year reservoir contents). Direct forecasting of relevant system variables requires the use of system-specific data and methods that are not currently available in large-scale forecasts. These shortcomings motivated the development of a Probabilistic Seasonal Forecasting System (PSFS) for water utilities. The PSFS uses large scale climate data, local hydrologic data and system data as the basis to develop a probabilistic statement about the degree to which conditions over a forecast period (i.e., through the end of an upcoming or current runoff season) will be similar to previous years. The methodology for deriving the probabilistic forecasts is based on the notion of similarity of years, which is derived using nearest neighbor algorithms from non-parametric statistics. The PSFS produces a cumulative distribution function (CDF) of system state variables (e.g., reservoir contents). The PSFS can generate a forecast for streamflows or for any system variable that is calculated by a system simulation model. The system has been used to generate forecasts for water utilities along the Front Range of Colorado since water year 2008 (October 1, 2007 through September 30, 2008) at five lead-times, October, and January through April. Cross validation of forecasts for the four utilities showed that the forecasts had substantial skill at certain lead times when forecast conditions are in the lower (dry) and upper tercile (wet), but no skill in the middle tercile (average). A significant component of forecast skill comes from antecedent reservoir states. The skill exhibited by the PSFS, and other existing forecasts, is useful to water system managers, but is sufficient only to condition operating decisions in the context of other information.

Kim, Yeonjoo

A robust decision making framework for integrated watershed management under climate change: a case study in a Korean urban watershed

Kim, Yeonjoo[1]; Chung, Eun-Sung[2]

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2. Seoul National University of Science and Technology, Seoul, Republic of Korea

An robust decision making framework has been developed for integrated watershed management (IWM) to rehabilitate the distorted cycles of water quantity and quality in a changing climate. The procedure consists of nine steps and includes several engineering, economic, and social techniques, which are multi-criteria decision making, sustainable development index, a continuous rainfall runoff simulation model and stakeholder involvement. Based on the driver-pressure-state-impact-response concept, the index is used to assess spatial vulnerability with various management alternatives. A stakeholder participates in the quantification of preferences with regard to management objectives. This procedure was applied to the Korean urban watershed, which has suffered from streamflow depletion and water quality deterioration. As a result, robust strategies are selected according the proposed framework. This research provides a useful IWM tool for incorporating such quantitative and qualitative information into the evaluation of various policies with regard to water resource planning and management.

Lall, Upmanu

The Columbia Global Flood Initiative — from Climate Causal Modeling to Supply Chain Risk Management

Lall, Upmanu[1]

1. Earth & Environmental Eng, Columbia Univ, new york, NY, USA

This talk introduces the Columbia Global Flood Initiative with an invitation to the community to join in an effort to bring hydroclimatic science and financial risk management together to provide sustainable solutions to the Earth's most damaging natural hazard. The key building blocks for the initiative are: 1) the need to understand and predict the causal mechanisms of extreme floods so that we are better prepared to adapt to climate variability; 2) the development of a Lagrangian framework for understanding the role of atmospheric circulation mechanisms on moisture transport and convergence associated with extreme, persistent flooding; 3) an understanding of the global concordance of flood and drought and its probabilistic representation; 4) the application of this knowledge to coordinated financial risk management and infrastructure development; and 5) the application to global and local supply chain risk management in addition to local damage assessment. My thesis is that we need a transformation in the thinking on these issues and we are close to where these ideas can be brought together for an exciting synergy of hydrology, climate, and the risk management community

Lall, Upmanu

Innovations in Climate Informed Water Supply and Demand Forecasts and Water System Management

Lall, Upmanu[1]

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Over the last two decades, many approaches to forecasting climate and streamflow have evolved. There has been some corresponding effort to translate these forecasts into application. Some new innovations for management have also emerged. I plan to discuss some ways by which market mechanisms and financial securitization can be brought into play to address water quantity and quality goals in a hierarchical framework from regional planning to reservoir operation to user opportunity and risk management. The approach may offer benefits even where forecasts are not skillful.

Lima, Carlos H.

SEASONAL STREAMFLOW FORECASTS FOR THE BRAZILIAN HYDROPOWER NETWORK: PRESERVING THE SPATIO-TEMPORAL VARIABILITY IN STATISTICAL MODELS

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Hydropower plants play a major role in energy production in Brazil, being responsible for almost 100 % of the electricity yield during wet periods. Nearly all plants consist of large storage and multipurpose water reservoirs that are unequally distributed across the country, with most of them located in the South and Southeast regions. Thousands of kilometers of transmission lines interconnect all major hydropower plants into four hubs of energy production (North, Northeast, South and Southeast) that supply the electricity demand across the country. Based on multi-scale streamflow forecasts, the System National Operator (ONS) defines the optimal operational policy for each hydropower reservoir in order to maximize the system efficiency and avoid unnecessary energy losses due to water spills and evaporation from the reservoirs. Most current streamflow forecast models employed by ONS are of the auto-regressive (AR) class of statistical models and are built individually for each site by considering, given the covariates used in the model, that the streamflow series are mutually independent. Although this assumption may hold for short lead time forecasts, when the persistence of the streamflow series and the use of past information may lead to a conditional independence across the series, it may not be valid for larger lead times, where persistence explains little, if any, of the variance of the future inflows. Since there is about 50 streamflow series with a limited number of data to be modeled, it becomes a challenge to derive a joint probability distribution for the entire set of streamflow sites which accounts for all details of the inherent spatio-temporal variability and still keeps the uncertainty of the parameter estimates at a satisfactory level of confidence. Here in this work we explore the concept of dynamic Bayesian networks and we factorize the joint probability distribution of the entire set of the streamflow series into a set of conditionally independent distributions that are more tractable and robust in terms of parameter estimates. Particularly, we consider the spatial arrangement of the streamflow sites in order to define the nodes of the Bayesian network and the associated conditional independent distributions. The most upstream sites are considered the parent nodes and climate information (climate indices from the Pacific and Atlantic Oceans) is used to factorize the joint distribution of streamflow sites that are not in the same river network, i.e., sites that are not hydraulic connected. The proposed model is tested on 54 monthly streamflow series from the major hydropower reservoirs in Brazil. A LASSO regression framework is used to shrink the model parameters and avoid overparameterization. Preliminary results shows an improvement of the proposed model over classical periodic auto-regressive and principal component analysis (PCA) based models in predicting the streamflow series up to 6 months lead time while preserving the main correlation structure across and within streamflow sites.

Lin, Zhaohui

Seasonal Hydrological Ensemble Prediction System Over Huaihe River Basin and Its Preliminary Verification

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The Seasonal Hydrological Ensemble Prediction System (SHEPS) over Huaihe River basin will be introduced firstly in this paper, which is based on the Coupled Land surface-Hydrology Model System (CLHMS) developed at IAP, CAS, and the dynamical seasonal prediction system (CFSV2), is aimed to predict the monthly streamflow anomalies over the basin. Besides the dynamical model system, the meteorological ensemble preprocessor system is another important component of the SHEPS, which includes the Bayesian merging pre-processor, the historical-analog criterion ensemble selection pre-processor and the temporal matching pre-processor. Using the observation data over Huaihe river basin, it's found that the preprocessors effectively improve the probability distribution of the reforecast rainfall and temperature by CFSv2 (CFSRR) and the forecast skill of summer precipitation and temperature over the Huaihe River basin can be improved significantly with lead time of 1-3 months. The seasonal prediction skill of summer streamflow over the Huaihe River basin will be evaluated through the 25-year hindcasts by SHEPS during 1982 to 2006, and comparison with the results from Extended Streamflow Prediction (ESP) will also be conducted. Preliminary verification results show that, the ensemble mean forecast skill of streamflow by SHEPS is relatively higher when lead time is one or two months, the Pearson Correlation Coefficient (PMC) of the June-averaged streamflow between the observation and forecast can reach 0.81 in Bengbu station with lead time of one month, increased by 0.11 when compared with ESP hindcast. With the lead time of 2 months, the Pearson Correlation Coefficient (PMC) between the observation and SHEPS forecast is 0.49, however, the PMC between the observation and EPS hindcast is -0.12. For the probabilistic forecasts for above-normal, normal and below-normal events, the hindcast skill of SHEPS are also higher than that of ESP hindcast. The ranked probability score (RPS) for June streamflow forecasts by SHEPS hindcast is 0.19 in Wangjiaba station with lead time of one month, which is significantly lower than the value of 0.24 for ESP hindcast. Moreover, it's found that the skill of ensemble streamflow forecasts by SHEPS is remarkably higher for wet years than that for dry years. Finally, further efforts on the improvement of seasonal hydrological prediction over China will be discussed. Key words: Seasonal hydrological prediction, Land surface-hydrology model, Huaihe River basin, Downscaling, Bias correction

Livneh, Ben

From catchments to regional scales: Hydrologic impacts of land cover disturbances in the Upper Colorado River Basin

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The U.S. Southwest and surrounding areas rely on the Colorado River Basin to irrigate roughly 5.5 million acres of farmland, and to supply a population of 5.5 million people in 7 states. The majority of water originates as snowfall in the headwaters region, which has experienced widespread forest mortality due to bark beetle infestation across a range of forest types, elevation, and latitude. Further episodic disturbance from deposition of dust from regional dryland sources on the mountain snowpack strongly alters the snow surface albedo and influencing snowmelt runoff magnitude and timing. In this study, we investigate the relative impacts of competing streamflow drivers through assessing system sensitivities to individual and combined disturbances. We begin at the catchment-scale by training the Distributed Hydrology and Vegetation Model (DHSVM) over the baseline historical period, and simulate hydrologic conditions over a set of 4 catchments within the headwaters region that offer a gradient in bark beetle impacts, dust-deposition, elevation, and forest coverage. The observational data sets include meteorological forcings of precipitation, maximum and minimum temperature, aerial survey forest disturbance data, time series maps of MODIS-derived leaf area index (LAI), as well as other ecological indices derived from MODIS forest phenology products. In the second stage of the analysis we apply these parameterizations and results to larger areas of the headwaters region, using a meso-scale hydrologic model, the Variable Infiltration Capacity (VIC) Model. Experiments are aimed at quantifying the system sensitivity and hydrologic impacts of changing LAI (from forest disturbance) and reduced snowpack albedo (from dust deposition and forest litter) on streamflow and hydrologic states. Preliminary catchment-scale results suggest beetle kill-induced canopy loss leads to slightly greater snow accumulation as a result of less snow interception and reduced sublimation canopy sublimation, which outweigh increases in sub-canopy ablation fluxes. Combined with reduced transpiration during the warm season, the increased soil moisture availability translates into an overall increase in water yield (i.e. streamflow) on the order of 3 - 15%, depending on disturbance severity and extent. Dust-on-snow exerts a primary control on the timing and rate of melt, with earlier and more rapid melt rates associated with more extreme dust deposition. It is anticipated that the final results will lead to a clearer understanding of system

components and will better inform mitigation strategies and planning efforts.

Lownsbery, Katherine

Development of Seasonal Forecasting of Upper Niger River Streamflow

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The Upper Niger River basin is characterized by a sub-Sahelian to Sahelian climate, with distinct wet and dry seasons. Selingue Dam, the largest dam in the region located on a tributary to the Niger River, is operated for three purposes: hydroelectricity generation, large scale irrigation and sufficient flood waters to the Niger Inner Delta. Operations decisions to maximize the value of dam releases could be more optimal when informed by seasonal forecasting of wet season (July – September) streamflow. West African Sahelian rainfall during the wet season is generally predicted with low skill by general circulation models (GCMs); however, using model output statistics (MOS) with regional wind flow has been shown to improve predictions. It has also been shown that depending on the sign of rainfall anomalies in the Sahel and Guinea Coast regions, Sahelian rainfall is negatively correlated to El-Nino Southern Oscillation sea surface temperatures and the Southern Oscillation Index. This study extends seasonal forecasting of rainfall to investigate the predictability of Upper Niger River streamflow for use in dam operations decision-making processes. Specifically, the skill of seasonal forecasting from GCM outputs, MOS corrections of GCM outputs and direct statistical prediction from climate indices is evaluated.

Lu, Mengqian

Space-time structure of tropical moisture exports and their precursors associated with high precipitation induced floods

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The recent extreme floods in the United States (1993, 2011), China (1998), United Kingdom (2000, 2003), Pakistan (2010), Europe (1995, 2010) and Thailand (2011) highlight the importance of understanding the hydrometeorological processes responsible for these extreme floods events and the associated temporal and spatial characteristics of sequences of the associated precipitation events. The intensity of extreme precipitation is projected to increase under global warming in many parts of the world. However, these arguments are driven largely by considerations of the moisture holding capacity as a function of temperature, as indicated by the Clausius-Clapeyron equation. One needs to also consider the attendant atmospheric circulation and moisture transport dynamics that lead to persistent extreme precipitation and subsequent flooding as evidenced in the recent major floods cited earlier. Although the climate mechanisms governing precipitation vary by location, extreme precipitation events in the mid-latitudes are typically associated with anomalous atmospheric moisture from warmer tropical or subtropical oceanic areas. Atmospheric Rivers (AR) are associated with direct poleward transport of tropical moisture along the AR bands from the Tropics all the way to the extratropics. For meridional transport at middle latitudes, ARs account for a substantial part of the moisture transport. The AR concept indicated a direction to track the moisture from warmer oceanic source to the heavy precipitated regions. Stationary Rossby waves account for a substantial fraction of summertime monthly mean surface temperature and precipitation variability over a number of regions of the Northern Hemisphere middle latitudes. Tropical moisture exports (TMEs) to the Northern Hemispheric extratropics are an important feature of the general circulation of the atmosphere and link tropical moisture sources with extratropical precipitation and occasionally with explosive cyclogenesis. Here, a case study that classifies N. Hemisphere tropical moisture export (TME) tracks using a clustering method, and relates the spatial flood incidence across the regions to the persistence and spatial structure of these tracks. The origins and pathways of moist and warm tropical air masses, which are the fuel for the heavy precipitation events and rapid cyclogenesis in the extratropics, are examined with water vapor content along the tracks considered be a mass attribute for a mass moments analysis of centroid and variance. The clustered TME tracks, thus, help identify different moisture sources and climate dynamics, which govern and drive the movement of water vapor to the frequent-flooded areas, together with an atmospheric circulation pattern that leads to persistent multi-day convergence and precipitation in those regions. The genesis location of TME can be linked to the seasonality and sea surface temperature; while the variance or the second moments of the tracks recognize the water vapor contents and most importantly monitor the lease of the moisture, which may directly induces intensive precipitation, that are potentially attributable for flooding events followed.

Lu, Mengqian

Multi-time scale Climate Informed Stochastic Hybrid Simulation-Optimization Model (McISH model) for Multi-Purpose Reservoir System

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In order to mitigate the impacts of climate change, proactive management strategies to operate reservoirs and dams are needed. A multi-time scale climate informed stochastic model is developed to optimize the operations for a multi-purpose single reservoir by simulating decadal, interannual, seasonal and sub-seasonal variability. We apply

the model to a setting motivated by the largest multi-purpose dam in N. India, the Bhakhra reservoir on the Sutlej River, a tributary of the Indus. This leads to a focus on timing and amplitude of the flows for the monsoon periods. The flow simulations are constrained by multiple sources of historical data and GCM future projections, that are being developed through a NSF funded project titled "Decadal Prediction and Stochastic Simulation of Hydroclimate Over Monsoon Asia". The model presented is a multilevel, nonlinear programming model that aims to optimize the reservoir operating policy on a decadal horizon and the operation strategy on an updated annual basis. The model is hierarchical, in terms of having a structure that two optimization models designated for different time scales are nested. The two optimization models have similar mathematical formulations with some modifications to meet the constraints within that time frame. The first level of the model is designated to provide optimization solution for policy makers to determine contracted annual releases to different uses with a prescribed reliability; the second level is a within-the-period (e.g., year) operation optimization scheme that allocates the contracted annual releases on a subperiod (e.g. monthly) basis, with additional benefit for extra release and penalty for failure. The model maximizes the net benefit of irrigation, hydropower generation and flood control in each of the periods. The model design thus facilitates the consistent application of weather and climate forecasts to improve operations of reservoir systems. The decadal flow simulations are re-initialized every year with updated climate projections to improve the reliability of the operation rules for the next year, within which the seasonal operation strategies are nested. The multi-level structure can be repeated for monthly operation with weekly subperiods to take advantage of evolving weather forecasts and seasonal climate forecasts. As a result of the hierarchical structure, sub-seasonal even weather time scale updates and adjustment can be achieved. Given an ensemble of these scenarios, the McISH reservoir simulation-optimization model is able to derive the desired reservoir storage levels as a function of calendar date, and the associated release patterns. The multi-time scale approach allows adaptive management of water supplies acknowledging the changing risks, meeting both the objectives over the decade in expected value and controlling the near term and planning period risk through probabilistic reliability constraints. For the applications presented, the target season is the monsoon season from June to September. The model also includes a monthly flood volume forecast model, based on a Copula density fit to the monthly flow and the flood volume flow. This is used to guide dynamic allocation of the flood control volume given the forecasts.

Luo, Lifeng

Seasonal streamflow prediction with VIC and Climate Forecast System version 2

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Decisions regarding water resource management, agricultural practice, and energy allocation often require information about future climate conditions weeks to months in advance. Skillful and reliable subseasonal and season climate prediction have the potential to significantly facilitate and benefit the decision making process. For streamflow predictions, the extended streamflow prediction (ESP) method heavily relies on the initial hydrological conditions such as soil moisture and snow water equivalent in the basin. During the forecast period, historical records of meteorological conditions are used as possible future outcomes to produce a multi-member ensemble streamflow prediction. Earlier studies have shown that potential improvement in the seasonal streamflow forecast skills can be achieved by incorporating precipitation and temperature forecast from dynamic climate models. In this study, we use the precipitation and temperature forecasts from the NCEP Climate Forecast System version 2 (CFSv2) and the VIC hydrological model to quantify the usefulness of the climate forecast information in seasonal streamflow forecasting. The central piece of the work is the bias correction and downscaling method that continuously updates the posterior distribution of future conditions based on daily CFSv2 forecast. For a given day, the posterior distributions of temporally aggregated temperature and precipitation are derived within a Bayesian framework. This new approach can take advantage of the operational configuration of CFSv2 and combine many of its forecast runs in a consistent way to maximize the skill of temperature and precipitation forecast, and thereby improve the streamflow forecast. This presentation discusses the application of the system to the Colorado River Basin. Streamflow forecast skill will be evaluated in both realtime and retrospective contexts, with a focus on several key drainage basins that are important for water management.

http://drought.geo.msu.edu/research/forecast/

Madadgar, Shahrbanou

A Probabilistic Framework for Predicting the Spatial Variation of Future Droughts

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Spatial variation of future droughts across the Gunnison river Basin in CO, USA is studied using a recently developed probabilistic forecast model. The Standardized Runoff Index (SRI) is employed to analyze the drought status across the spatial extent of the basin. To apply SRI in drought forecasting, the Precipitation Runoff Modeling System (PRMS) is used to estimate the runoff generated in the spatial units of the basin. Then, the statistical forecast method, whose main core is the copula functions, models the joint behavior between the correlated variables of accumulated runoff over the forecast and predicting periods. Given the drought status of the predicting period, the probability of different drought conditions in the forecast period is evaluated. Moreover, runoff variation over the basin with the particular chance of occurrence is obtained. The forecast model also provides the uncertainty bound of future runoff produced at each spatial unit across the basin. Our results indicate that the statistical method developed in this study is a useful procedure in presenting the probabilistic forecasting of droughts given the spatio-temporal characteristics of droughts in the past.

Mateus, Maria C.

Vulnerability of water resources with changing land use, and climate in the Santiam River Basin, Oregon

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The distribution of water supply and demand are likely to vary across river basins and across water users in the future as the climate and land use change, though some areas are certain to be more sensitive than others to the changes. This paper analyzes the influence of climate change and land use change on the future availability of water resources across two sub-basins with different hydrogeological characteristics within the Santiam River Basin (SRB), in Oregon. The objectives of this study are to: 1) Investigate how patterns in hydrologic responses vary with subbasin characteristics that contribute to hydrologic sensitivity to climate and land use change; 2) Identify subbasins likely to experience vulnerability to water scarcity in the future; and 3) Explore how hydrologic sensitivity relates to water scarcity vulnerability in the basin. Results demonstrate that water demand exerts the strongest influence on basin's vulnerability to water scarcity regardless of basin characteristics. Results also demonstrate that basins characterized by higher permeability, with greater groundwater recharge and storage (North Santiam Basin), are less sensitive to climate and land use changes when compared to basins characterized by a mixed groundwater and surface-water system (South Santiam Basin). There is the need for water managers to take into account hydrologic variability and basin characteristics when allocating and distributing water to different users within the basin.

Mazrooei, Amirhossein

Inter-model Comparison of Seasonal Streamflow and Soil Moisture Forecasts for the US Sunbelt

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Seasonal streamflow and soil moisture forecasts, contingent on climate forecasts, could provide valuable information to improving water resources management such as optimizing hydroelectric power generation and agricultural operations. However, the uncertainty in climate forecasts poses a serious challenge in utilizing streamflow and soil moisture forecasts information in real time operations. Several studies have utilized Land Surface Models (LSMs) to develop seasonal streamflow and soil moisture forecasts using observed or climatological forcings, but only fewer studies have used monthly updated climate forecasts. Furthermore, very limited studies focused on rainfall-runoff regimes, where precipitation forecasts play an important role than initial hydrologic conditions (IHCs), as opposed to snowmelt-driven regimes. Therefore, our objectives are: 1) To develop seasonal streamflow and soil moisture forecasts for the rainfall-runoff mechanism dominated region - the US Sunbelt, by implementing multiple LSMs with climate forecasts from ECHAM4.5 General Circulation Model (GCM), and 2) Compare and evaluate performance of different LSMs under different climatic (humid and semi-arid) and hydrologic (flood and drought) conditions. In this study, we will implement widely used LSMs such Noah, Catchment, Variable Infiltration Capacity (VIC) and CLM, available through NASA's Land Information System (LIS) framework, with ECHAM4.5 climate forecasts. Updated IHCs will be estimated, prior to the forecasting period, by forcing each of the LSMs with North American Data Assimilation phase – 2 (NLDAS-2) forcings. We will statistically downscale monthly updated ECHAM4.5 precipitation forecasts (up to 3 months lead time) to 0.25° scale using Canonical Correlation Analysis (CCA) and then temporally disaggregate to a daily time step using K-Nearest-Neighbor (KNN) approach. Hourly climatology for all other forcing variables will be estimated from NLDAS-2 dataset over the 1981-2010 period. Then all the LSMs will be implemented with monthly updated precipitation forecasts and hourly climatological forcings during the 3-month forecasting period to develop retrospective seasonal streamflow and soil moisture forecast over the period 1993-2012. Finally, the performance of different land surface models in forecasting streamflow and soil moisture under different climatic and hydrologic conditions will be analyzed over the US Sunbelt.

McCreight, James L.

Global Positioning System (GPS) observations of hydrologic variables for water management: current and future applications

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The indirect, or reflected, (L-band) microwave GPS signal is sensitive to water in the environment. We have used the signal to noise ratio of the direct and reflected GPS signals (at an antenna) to measure 3 variables of acute interest to water supply forecasting. 1) Snow depth observations are critical to forecasting runoff volume in subsequent months. 2) Volumetric soil moisture directly affects recharge rates and runoff at seasonal timescales. 3) Vegetation water content observations inform the timing of transpiration. (Unlike green-up measures, such as NDVI, GPS measures when plants increase their water content.) Estimates of these variables have been validated against in situ observations and found to be accurate. Improvement of methods is on-going. GPS provides high-frequency data at an intermediate spatial scale (between point and satellite): daily observations have spatial footprints of roughly 1000 square meters. We have produced estimates of these hydrologic variables using the Plate Boundary Observatory (PBO - originally intended to measure tectonic activity) in the Western United States and our data are freely available online (http://xenon.colorado.edu/portal/). GPS antennas designed for positioning intentionally suppress the "noise" of reflected signals and are extremely expensive. We are developing inexpensive GPS receivers for hydrologic purposes to expressly measure reflected signals. Future hydrologic and agricultural applications will be discussed.

http://xenon.colorado.edu/portal/

Mendoza, Pablo A.

A multisite ensemble seasonal streamflow forecasting framework for semi-arid Andean basins

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In Chile, the rivers with headwaters in the Andes Cordillera are the main source of water for human consumption, irrigation, industry, mining and energy generation, and there is a strong need for streamflow forecasts to help optimize scarce water resources. In this paper, we develop a multisite ensemble streamflow forecasting method to predict average streamflow for spring/summer in 10 basins located in the semi-arid Andean region between 30° and 34° S, where most of the surface runoff comes from the water accumulated during winter as snowpack and glaciers, which melts during the spring/summer seasons. The framework tested here is based on the following steps: (i) Principal Component Analysis (PCA) over average Oct-Mar flows to find the most significant patterns in the data (i.e., leading Principal Components or PCs), (ii) climate diagnostics to find appropriate predictors for the dominant streamflow modes, (iii) selection of the best models using the Generalized Cross Validation (GCV) score, (iv) streamflow prediction in cross-validation mode by using all models and then back transforming to flow space, and (v) final ensemble forecast generation by resampling results from the models based on weights computed using their associated GCV scores. We perform probabilistic verification by computing the Rank Probability Skill Score (RPSS) for each year using three categories obtained from the 33% and 66% flows observed at each location. As the first PC in spring/summer flows explains 88 % of the total variance, model development is based on testing several combinations of predictors for this pattern. Our results demonstrate the advantage of applying a framework like this in areas where meteorological data is quite sparse, with skill scores between 0.2 and 0.7. Future tests will include forecast evaluation with increasing leading times and the exploration of temporal disaggregation techniques.

Mirfenderesgi, Golnazalsadat

A Comparative Assessment of Particle Filtering-Markov Chain Monte Carlo and Particle Smoothing Methods for Seasonal Hydrologic Forecasting and Uncertainty Quantification

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The need for effective assimilation of useful hydrologic data into the forecast model is becoming increasingly emphasized. Application of ensemble data assimilation methods to hydrologic forecasting provides a framework for improving the accuracy of initial states and parameters, and simultaneously estimating their respective uncertainties. Among all the assimilation methods, approaches like particle filtering (PF) and particle smoothing (PS) are becoming popular for assimilation of a wide range of hydrologic variables, while algorithmic developments are making these techniques increasingly effective for hydrologic applications. This study provides a comparison of the recently developed PF-Markov chain Monte Carlo (MCMC) and PS methods for state-parameter estimation, within the coupled Sacramento Soil Moisture Accounting (SAC-SMA) and Snow-17 models for seasonal streamflow forecasting. The experiment is performed over several watersheds within the upper Colorado RiverBasin. In this study, both a synthetic and a real experiment were performed to study and compare the effectiveness and efficiency of the two data assimilation techniques.

Mosier, Thomas

Downscaling Global Climate Data: Production and Optimization of 30 Arc-Second Surfaces

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This study compares variations of static downscaling methods for applications with spatially distributed hydrologic models. The most physically representative downscaling procedure is then implemented using globally available data as inputs, resulting in 30 arc-second resolution surfaces for monthly precipitation and mean temperature with global land coverage. Both the Delta and Bias Correction Spatial Disaggregation downscaling methods are implemented; however, the Delta downscaling method appears to produce more physically representative results and therefore analysis focuses on optimization of the Delta method. The primary step within the Delta method which differs between implementations is the anomaly interpolation step. Bilinear, cubic spline, and piecewise cubic Hermite interpolating polynomials (PCHIP) are examined for the step of interpolating the anomaly field. The resulting grids are then compared to Global Historical Climatology Network station records to assess the grids' accuracy, which shows that use of PCHIP anomaly interpolation with the Delta method produces the most physically representative downscaled surfaces. This downscaling procedure is implemented using the 30 arc-second WorldClim climatologies and 0.5 degree time-series grids by Willmott & Matsuura as inputs. The Delta downscaled grids are compared to the corresponding Parameter-elevation Regressions on Independent Slopes Model (PRISM) data using Oregon, USA as a test region. In the case of precipitation, the Delta grids have a root mean square error (RMSE) of 15.6 mm compared to PRISM's RMSE of 12.9 mm. In the case of mean temperature, though, the Delta data performs slightly better than PRISM, with an RMSE of 0.8 deg C compared to PRISM's RMSE of 1.4 deg C. A strength of the Delta downscaled dataset discussed herein is that it is freely available for all global land surfaces at a spatial resolution of 30 arc-seconds. Analysis for additional test regions distributed globally indicate that the Delta downscaled grids have a relatively consistent level of accuracy across regions.

Najafi, Mohammad Reza

Evaluating Multi-Modeling Techniques with Varying Complexities for Seasonal Hydrologic Forecasts

Najafi, Mohammad Reza[1]; Moradkhani, Hamid[1]; Wood, Andy[2]; Garen, David[3]

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Seasonal water supply forecasts (WSFs) are required by decision makers for managing water deliveries, determining industrial and agricultural water allocation, and operating reservoirs. Several operational agencies issue seasonal water supply outlook forecasts of naturalized or unimpaired flow. This is commonly done using statistical and ensemble streamflow prediction (ESP) methods. Recent work has shown the potential for WSF improvement through improved forecasting of seasonal atmospheric forcings as well as from the combination of a suite of prediction approaches, including statistical and dynamical (i.e., physical or conceptual models), with benefits to streamflow forecast skill at both short- and long- lead times. We present results from a project to incorporate several multi-model combination approaches that optimally merge forecasts from different sources, including ensemble hydrologic forecasts. The complexities of the applied techniques vary from simple averaging to Bayesian model average approaches. Given that a multi-model contains information from all participating models, including the less skillful ones, the increase in forecast accuracy is assessed in comparison with the available best and worst prediction. The uncertainty related to each multi-model method is also estimated. The study is performed over four different river basins in the western US. The results indicate that multi-modeling methods can produce forecasts with a greater skill

than any one of the individual forecasts, but, of course, the skill of the combined forecast is limited by the skill of the individual forecasts.

Najafi, Mohammad Reza

The Impact of Climate Change on Runoff Extremes Based on Regional Climate Models and Hierarchical Bayesian Modeling

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Climate change would impact the spatiotemporal variability of hydrologic extremes especially in regions with topographical variations. We investigate the runoff extremes over the Pacific Northwest (PNW) using a spatial hierarchical Bayesian approach. The changes in extremes in the future period (2041-2070) are compared to the historical period (1971-2000). Different regional climate model projections are analyzed and the seasonal variations of runoff extremes are studied. Climate scenarios are provided by the North American Regional Climate Change Assessment Program (NARCCAP) including nine regional climate model (RCM) simulations. Hydrologic modeling is performed after downscaling the precipitation, maximum and minimum temperature and wind speed to 1/8th degree resolution using the quantile-mapping approach. Variable Infiltration Capacity (VIC), a distributed hydrologic model is used to provide daily runoff estimates (mm) for each cell. Spatial hierarchical Bayesian model was then applied on the cell-wise extreme runoff (mm) for both time periods and for all seasons. The estimated spatial changes in extreme runoffs over the future period vary depending on the RCM driving the hydrologic model. The hierarchical Bayesian model characterizes the spatial variations in the marginal distributions of the General Extreme Value (GEV) parameters and the corresponding 100-yr return level runoffs. Results show an increase in the 100-yr return level runoffs for most regions in particular over the high elevation areas during winter. However, reduction of extreme events in several regions is projected during summer.

Newman, Andrew J.

Impacts of Hydrologic Model Uncertainty on the Skill of Seasonal Streamflow Forecasts

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The National Weather Service (NWS) operational approach to streamflow forecasting involves (i) running a hydrologic model up to the start of the forecast period to estimate basin initial conditions; and (ii) running the model into the future with probabilistic weather forecasts and climate information. Forecast skill depends on both the accuracy of the basin initial condition estimates and their impact on the basin response, the accuracy of the weather and climate forecasts, and the hydrologic model. A key shortcoming of this approach is that it only accounts for uncertainty in climate forecasts, and neglects uncertainty in the estimates of the basin initial conditions and uncertainty in the hydrologic model (e.g., Schaake et al., 2007). The purpose of this study is to examine the spatial variability in the performance of the operational NWS SNOW-17/SAC-SMA hydrologic modeling system in different hydroclimate regions (e.g., regions with/without substantial snow storage; regions with varying degrees of climate predictability), and at different forecast initialization times throughout the year (e.g., forecasts initialized on October 1st versus April 1st). To accomplish this, the SNOW-17/SAC modeling system is configured and calibrated for the 629 United States Geological Survey's Hydro-Climatic Data Network 2009 (HCDN-2009, Lins 2012) conterminous U.S. basin subset (gages having at least 10 years of flow data since 1990). The calibration is based on existing retrospective forcing datasets (e.g. Daymet, Thornton et al. 2012) and is performed using the shuffled complex evolution optimization strategy (Duan et al. 1993). Relationships between model parameters, skill and basin characteristics (climate, topography, vegetation, soils), and station density are examined and presented.

Nieto, Juan J.

Establishment of a regional Hydrological Outlook for the West Coast of South America

Nieto, Juan J.[1]

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In response to the need for an operational hydrological seasonal forecast, it was established an exploratory and consultative work plan with experts from NMHSs of the region, IRI, CIIFEN in a coordinating role, and the contribution of the Hydrology and Water Resources Department of the World Meteorological Organization. After the evaluation process of the most appropriate approach, considering the circumstances of the region that allow to take advantage of the seasonal climate forecast mechanism, which remains operationally since 2003, was decided to establish a common methodology in demonstration basins in Bolivia (Achacachi), Chile (Maule), Ecuador (Paute), Peru (Coata) and Venezuela (Caroní). The methodology consist in generate areal precipitation and evapotranspiration in the whole basin by the inclusion of time series data from representative meteorological stations located within or nearby the basin. With the use of a hydrological model that receives as input, quarterly areal precipitation, evapotranspiration, and flow data, a scheme that correlates flows and seasonal accumulated rainfall is constructed. From seasonal climate forecasts operationally performed by the six countries, expected accumulated precipitation is included to the hydrological model to estimate expected values of quarterly flow for the basin. With the use of the method of analogue years, the quarterly flow forecast is disaggregated into monthly expected flow values. The process is now in a demonstration phase in some countries of Western South America, to achieve and consolidate a regional mechanism that contributes to a seasonal operational decision making and planning for various sectors and water resource users.

Nijssen, Bart

Relative Contributions of the Sources of Uncertainties in Seasonal Hydrologic Prediction Globally

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Skillful seasonal hydrologic prediction is crucial to mitigating the impacts of droughts and floods. Sources of uncertainties in hydrologic prediction at seasonal lead times (1–6 months) are the initial hydrologic conditions (IHCs – primarily soil moisture and snow) and seasonal climate forecast skill (FS). In this presentation we report on the relative contributions of these two sources of uncertainty to seasonal hydrologic prediction skill globally as a function of time of year, as well as on the development of a global system for estimating IHCs in near real-time. We conducted two model-based forecast experiments using the Variable Infiltration Capacity (VIC). In the first experiment, Ensemble Streamflow Prediction, we combined a single set of IHCs with ensembles of atmospheric forcings (based on observed forcings during the period 1961–2007) to generate hydrologic forecasts for the target forecast period. In the second experiment, Reverse-ESP (rESP), we combined an ensemble of IHCs with a single time series of atmospheric forcings (observed atmospheric forcings for the target forecast period) to generate forecasts. By construct, the ESP experiment derives its skill from the knowledge of the IHCs only, whereas the rESP experiment derives its skill solely from the observed forcings. We compared cumulative runoff (CR), soil moisture (SM) and snow water equivalent (SWE) forecasts obtained from each experiment with a control simulation of the VIC model forced with observed atmospheric forcings over the reforecast period (1961-2007) and estimated the ratio of Root Mean Square Error (RMSE) of both experiments for each forecast initialization date and lead time. The contributions of IHCs are greater than the contribution of FS to forecast skill over the Northern (Southern) Hemisphere during the forecast period starting in October and January (April and July). Over snow-dominated regions in the high latitudes of the Northern Hemisphere, the IHCs dominate the CR forecast skill for up to 6 months lead-time during the forecast period starting in April. Based on our findings we argue that despite the current low levels of seasonal climate forecast skill (mainly for precipitation), better estimates of the IHCs could lead to improvement in the current level of seasonal hydrologic forecast skill over many regions of the globe at least during some parts of the year. To produce IHCs globally in near real-time, we describe the implementation of a multi-model drought monitoring system, which provides near real-time estimates of soil moisture conditions for the global land areas between 50S and 50N with a latency of about one day. The global system we describe uses satellite-based precipitation as well as temperature estimates based on global weather model analysis fields to track the evolution of soil moisture in near real-time at a spatial resolution of 0.5 degree using multiple land surface models.

http://www.hydro.washington.edu

Odame, Augustina

Water-Saving Technology Adoptions under Ecological and Economic Uncertainty

Odame, Augustina[1]; Sims, Charles[1]

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This study employs the real options approach to evaluate the decision to invest in water-saving technology in the face of economic and ecological uncertainty in the Wasatch Range Metropolitan Area. An agent, who employs water in production, must determine whether and when to invest in water-saving technology in order to maximize his water-use efficiency and subsequent water savings gains. The agent's decision to invest in water-saving technology and thus make a switch from his current (inefficient) technology depends on the trade-off between the expected value of the investment, and the cost of investment. The net-benefit of investing in water-saving infrastructure is estimated by the market-value of any water savings which may accrue to the investor minus the cost of investment. This depends on the price of water which is determined by its availability relative to demand. Thus the evolution of investment benefits (V) depends on the evolution of water-price (P) and water-supply (W). The availability, and hence the price of water is uncertain due to changing hydro-climatic conditions in the region. Both water price and water supply are believed to evolve according to a Geometric Brownian Motion, a stochastic process employed in explaining uncertainty-laden evolutions over time. The two processes interact via a shared Weiner process associated with stochastic changes in water-supply. Technology adoption is considered largely irreversible due to the prohibitive costs of reversal and the limited use and resale value given the specialized nature of the technology. Considering the uncertainty of future water supplies in the region and the largely irreversible nature of technology adoption, the option to delay investment in water-saving technologies may be valuable. By waiting to invest, an investor can observe whether water-prices increase or decrease before committing to the substantial sunk investment cost. This tends to delay investment longer than suggested by traditional cost-benefit analysis. Carey and Zilberman (2002) apply real-option theory to a farm's decision to adopt new irrigation technology, and is the premise spurring this more general study. This study extends Carey and Zilberman (2002) in four ways: First, it generalizes their farm-specific model to allow consideration of infrastructure investments by other agents such as canal company operators. Second, it explicitly considers ecological uncertainty. Using hydrological stream-flow data to estimate trends and volatility in water-supplies that may compromise the ability of water-users to perceive predictable water-supplies, the study investigates how ecological uncertainty from uncertain future water-supplies impacts the potential benefits from investing in water-saving infrastructure and subsequently, the decision to invest in these infrastructures. Third, it allows for impulse-control where the agent may incrementally upgrade technology, investing where he can make the greatest efficiency-gains first, with possible future expansion. Finally, it considers the impact of policy-induced jumps in investment costs to verify the hypothesis that while policies like subsidies aim to hasten technology adoption, uncertainty about the timing of such policy may delay investment by increasing the value of waiting to invest.

Ojha, Sunal

Role of snow cover and its Hydrological impact on Himalayan River basins

Ojha, Sunal[1]

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Satellite remote sensing is an effective tool for monitoring snow covered area. However, complex terrain and heterogeneous land cover and the presence of clouds, impose challenges to snow cover mapping. This research analyzes snow cover and glaciers with a perspective of climate change in Himalayan Regions using remote sensing techniques. The remote sensing snow cover data from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite from 2000 to 2010 have been used to analyze some climate change indicators. In particular, the variability in the maximum snow extent with elevations, its temporal variability (8-day, monthly, seasonal and annual), its variation trend and its relation with temperature have been analyzed. The snow products used in this study are the maximum snow extent and fractional snow covers, which come in 8-day temporal and 500m and 0.05 degree spatial resolutions respectively. The results showed a tremendous potential of the MODIS snow product for studying the spatial and temporal variability of snow as well as the study of climate change impact in large and inaccessible regions like the Himalayas. The snow area extent (SAE) (%) time series exhibits similar patterns during seven hydrological years, even though there are some deviations in the accumulation and melt periods. The analysis showed relatively well inverse relation between the daily mean temperature and SAE during the melting period. Some important trends of snow fall are also observed. In particular, the decreasing trend in January and increasing trend in late winter and early spring may be interpreted as a signal of a possible seasonal shift. However, it requires more years of data to verify this conclusion. Significant coverage of lake ice was found in lower elevation zone which is due to flat terrain in this zone. Key Words: Climate change, Himalayas, MODIS, remote sensing, snow, lake ice.

Pal, Indrani

Detecting the Shift in Timing of Seasonal Hydrological Cycle in India and Understanding the Dynamical Associations

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Determining when, where, and how much moisture is available for hydrological cycle is important for water resources management, planning and development. India receives almost two-thirds of its annual precipitation during the Indian summer monsoon (ISM) (Das, 1986), with some expected spatial variability, whereas east coastal and southeastern states receive precipitation due to northeast monsoon (NEM) (Rao, 1999). Reported changes in magnitude, frequency, and timing of monsoon precipitation in India due to various reasons (for example, climate change, land use changes, aerosol, etc), and increase in post-monsoon precipitation and reduction in June-July precipitation (Krishnakumar et al., 2009) especially in Kerala, the state known as the “Gateway of ISM”, imperative question comes that “is there a shift-in hydrological cycle and its timings?” and if yes, “what is the magnitude of those changes and how it can be explained?”. As India’s precipitation pattern is highly seasonal, it is expected that the maximum moisture influx will be concentrated during the monsoon season over most region. Therefore, this research tries to detect the shift in timing and the corresponding amount of moisture delivered. To understand such shifts, we also carry out an in depth analysis of the dynamical connections. The initial results showed that there have indeed been significant ‘shifts’ in moisture influx timing towards the end of the monsoon season (traditionally defined as June-July-August-September) and that the shift could be explained by the large-scale intra-seasonal dynamics related to large-scale climatic factors. This study also demonstrates that it is important to consider shift in timing of moisture availability for water resources management. References: Das PK. 1986. Monsoons. Geneva, Switzerland: World Meteorological Organization, Fifth WMO lecture, WMO No. 613. Krishnakumar KN, Prasada Rao GSLHV and Gopakumar CS. 2009. Rainfall trends in twentieth century over Kerala, India. Atmospheric Environment 43 : 1940-1944. Rao GN. 1999. Variations of the SO relationship with summer and winter monsoon rainfall over India: 1872–1993. Journal of Climate 12 : 3486–3495.

Pandit, Chetan

Introducing EHP in India

Pandit, Chetan[1]

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This paper attempts to derive lessons for future success, from analysis of past failures. 335,160 SqKm of area in India is prone to floods and some 80,000 SqKm is annual affected by floods. The annual flood damages are 575 mn $, affecting 41 million people. The Central Water Commission (CWC) conducts hydrologic observations at 945 sites and provides Flood Forecasts (FF) at 175 sites, with a lead time of 12 to 24 hours. The India Meteorological Department (IMD) is providing QPF. CWC is set to double the number of hydrologic observation stations, using telemetry. India is ready to start EHP, yet previous attempts to introduce EHP have failed. CWC continues with vintage practice of computing the forecast at each of these 175 locations. CWC can not provide hydrologic modeling experts at 175 locations; and the divisional engineer is required to spend more time in administrative work, leaving forecast computing to junior staff with no training even in basics of hydrology. As a result, forecasting was, and continues to be, carried out by primitive methods such as gauge to gauge correlation. Following actions are necessary to introduce EHP in India. - Local forecast computation must end. Transmit all hydro-met data in real time to a central forecast computing facility, manned by trained experts, capable of using advanced models. - With catchments ranging from arid zones to humid tropics to snow mountains to rain forests, FF softwares with a single option for rainfall-runoff modeling just won't do. This is a major obstacle in using conceptual models. Develop FF packages with several options for rainfall-runoff model, so that with all other things (data I/O, channel routing, user interface) remaining the same, a rainfall-runoff model can be selected suitable for each catchment. Even better, user should be able to tweak the rainfall-runoff model at source code level. - A major obstacle is user's question "is EHP more accurate?" Unfortunately, it isn't. The QPF based forecast with lead time of 96 hours will necessarily be less accurate than the G-to-G correlation forecast with 12 to 24 hours lead time. The only way to convince the user is, develop reservoir operation models and do a "shadow reservoir operation" in real time using the EHP, to compare 'with EHP' and 'without EHP' operations, and demonstrate that despite less accuracy, more lead time results in better performance in terms of power generation, water supplies, flood moderation. This by itself is a major task. But unavoidable. EHP also makes a change from discrete forecasting of only the peak flow rate during extreme events, to forecasting the continuous hydrograph; and from a deterministic forecast to probabilistic forecast. Considerable user education is necessary to demonstrate the utility of all this. The author is presently working as a 'mentor', trying to assemble a group comprising hydrologists, river engineers, and software writers, to generate a forecasting package with above named specifications; also develop reservoir simulation package to demonstrate the utility of EHP; bring together the main actors – the CWC, the IMD, and the State Government (users of forecast); arrange the resources to do all this; and convince at least one user to try it out. With some resources, and some luck, the aim is to try out the first EHP in India during the monsoon of 2015.

Parker, Laila B.

Adaptively managing variable environmental flow releases from a water supply reservoir into First Herring Brook, Scituate, MA, in response to unexpected climactic conditions

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In the fall of 2011, the Town of Scituate (MA) began implementing an environmental flow release program from its water supply reservoir system into First Herring Brook. Scituate Water Division staff had worked with non-governmental organization and state and federal agency partners for years to come up with this approach, which involved bio-period flow targets designed to ensure adequate water supply while improving conditions for aquatic life. Water Division staff and partners found themselves confronting the feasibility of implementing the plan sooner than expected, as streamflows around the Northeast were considerably below normal for much of that first year, particularly during the two key periods for herring migration. By early April 2012, the season when river herring begin to migrate upstream, discharge at a local gage was about 20-40% that usually seen at that time of year. The Water Division found that they were having trouble meeting their flow targets while ensuring adequate water supply. After much consultation, Water Division and watershed association staff agreed to lower the flow target in mid-April. Dam operators were able to meet that revised target regularly as measured at the fish ladder itself; although stage data collected downstream suggested less success in meeting the target. The benefits of these efforts were demonstrated later that month, when volunteer fish counters saw river herring swimming into the lower reservoir for the first time in decades. By fall streamflows were still low and partners came up with an approach to use a notched weir board that allowed for releases that met the targets for both fish ladder water depths and downstream flows. Although partners felt 2012 was a relative success, they are nervous as to how this effort will fare as the local climate changes. In this presentation, we will describe how the environmental flow release program came to be, and how partners adaptively managed this program through a very dry inaugural year. Looking forward, we will also discuss the challenging of using multiple targets (flow over fish ladder, stage at downstream staff gage) and how local data collected by the town and the watershed association are being used to improve those targets. We will seek input from Chapman participants on how to better use regional forecasting tools to plan ahead for allowing downstream flows and adequate supply reservoir levels.

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Piemonti, Adriana D.

ANALYSIS OF STAKEHOLDER ATTITUDES ON OPTIMIZED WATERSHED MANAGEMENT PLANS

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The lack of a sustainable planning for land resources has led to the alteration of hydrological cycles creating a series of threatening and challenging problems (such as climate change, water scarcity, floodings, etc.) in the modern societies. It has been suggested that a distributed network of ecological systems (conservation practices) may provide a solution for such problems, restoring some of the benefits that nature uses to maintain a natural balance. But where and how this distributed network should be placed is one of the most important challenges current land planners should consider conservation practices have been widely studiedfrom a multi-objective optimization perspective in order to explore the most optimal alternative that will meet physical, ecological or/and economic requirements to provide the highest benefits from an implemented system plan in a particular community. However, direct participation of stakeholders is not considered during the design plan, delaying the adoption and implementation of practices, and avoiding the so important insightful learning of the different processes that will help to solve a particular problem. In this research, we focus our attention towards the influence that a certain attitude may bring to a proposed optimal design. An evaluation of socio-economic studies has been performed to estimate possible outcomes of preferred sets of conservation practices depending on different stakeholder's attitudes. Using a weight approach system we separate a set of 4 (four) significant land operator preferences and evaluate the effects that these preferences have over a plan design that includes a complete set of conservation practices. . To perform the optimization, we used a NSGA algorithm assuming uniform distribution of land tenure type. Our results showed that, for example, when landowner decisions are driven by economic profits, then the modified alternatives experienced a decrease in nitrate reduction by 2-50%, and decrease in peak flow reductions by 11-98 %, and decrease in sediment reduction by 20-77%. Other decision drivers such as flood control, erosion control and fertilizer lost were also evaluated. Interactive surveys and tests have been proposed in order to corroborate the hypothesis built and obtain a more accurate evaluation of the preferences from different land operators.

Pournasiri Poshtiri, Maryam

Understanding the Droughts in the Major River Basins of the U.S. and their Dynamical Connections: Implications for Water Resources Management

Pournasiri Poshtiri, Maryam[1]; Pal, Indrani[1]

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Drought is one of the most expensive natural disasters worldwide and the United States is not an exception. During the past 2000 years, U.S. has experienced widespread and prolonged droughts with devastating negative impacts on the society and environment. According to the IPCC, the occurrence of more severe, warmer and drier conditions is expected to continue in the 21st century within the U.S., which we might already be experiencing at these earlier decades. Despite much progress in seasonal, annual, and longer-term (e.g. decadal and multi-decadal to some extent) hydro-climate predictions, we need further understanding on how climate and region specific water sustainability are linked at different spatio-temporal scales. Rivers are one of the important and key water resources for many parts of the U.S., which sustains vast portion of total freshwater needs in this country with notable spatial and temporal variations. This research aims to study the characteristics of different types of droughts (agricultural, hydrological, and meteorological) occurring in the Major River basins within the U.S. and affecting the water sustainability, and also to understand their spatio-temporal links with large-scale climatic patterns, which ultimately helps determining the optimal combinations of predictors. These findings will be useful to not only have a basic dynamic and thermodynamic understanding of the linkages between different category of droughts in the major river basins in the U.S. but will also contribute enhancing the predictive capacity of the same.

Pytlak, Erik

Water Supply Forecast Techniques and Challenges on the Columbia River

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Water supply forecasting in the Columbia River Basin is crucial for supporting the many commercial, treaty-trust and cultural uses of this river system, and protecting the region's infrastructure, economy, and ecology. The Columbia River Forecast Group (CRFG) was established in 2008 as an interagency (i.e., Federal, State, Tribal) effort to collectively identify ways to improve long-range streamflow forecasting and water supply forecast accuracy in the Columbia River Basin. Since that time, the participating agencies have shared their statistical and Ensemble Streamflow Prediction techniques and verification results, evaluated the comparative strengths and weaknesses of each technique, and in a few cases proposed and implemented changes in the forecasting techniques. The Group has also identified locations where better and more frequent observational data, particularly in the wilderness areas of southeast British Columbia, may help improve situational awareness, forecast responsiveness, and forecast reliability. Meanwhile, the CRFG has continued to support the existing regional observational network, despite growing budgetary pressures and a loss of human observing capabilities. In this presentation, the CRFG will share the forecast techniques the member agencies currently use for their long range and water supply forecasts, their verification and validity, and which situations and locations the Group sees the techniques providing more or less value for planning purposes. The presentation will also identify some of the challenges going forward as hydrologic model skill evolves, and new challenges develop in the region, including a growing population, increasing ecological pressure, and climate change. The CRFG hopes to share our forecast challenges with the hydrologic research community and help guide discussions on the current and future hydrometeorological research opportunities, which in turn could be used to improve regional decision-making.

Roberson, Alan

Improving Municipal Water Demand Forecasting

Roberson, Alan[1]

1. American Water Works Association, Washington, DC, USA

Water utility managers face increasing risk in matching water supply and demand due to increasing uncertainties in predicting future demand due to several factors, including the potential impacts of climate change. Climate change presents many challenges to the water sector. The impacts of climate change on water supply include changes in the quantity and intensity of precipitation events, changes in snowpack and resultant runoff events, lowering of aquifer levels, and seawater infiltration into coastal aquifers. As such, existing research on potential impacts to water resources has focused on water supply and less is known about climate change's potential impacts on water demand. Utility managers need accurate tools to both forecast changes in water demand, and be able to respond accordingly. Accurate water demand forecasting is critical, as water demand equals water sales equals revenues for water systems. This presentation will summarize the results from a recently completed research project - Decreasing Risk Thought Improved Municipal Water Demand Forecasting. A stakeholder process was used to develop a gaps analysis and research plan to address the impacts of climate change on water demand. This research started with an evaluation of the state of the science for municipal water demand forecasting and then identified research gaps. The stakeholder group developed several specific recommendations for water utilities for reducing risk through improved demand forecasting, and developed strategies for demand forecasting that would appropriate address several factors such as the penetration into the market place of low-flow plumbing fixtures, Xeriscape landscaping, installation of automatic sprinklers, smaller-scale lifestyles, among others. These recommendations fell into six general categories that need further investigation by water utilities to determine the appropriate means of implementation at their system: 1. Collecting the necessary data; 2. Analyzing water use and related data ; 3. Evaluating potential changes in demand; 4. Evaluating potential changes in demographics; 5. Understanding and incorporating uncertainty; and 6. Planning for and coping with drought This presentation will go into detail on each of the above recommendations. This research should increase utility managers' better understanding of how to plan for and adapt to the potential impacts on water demand forecasting from climate change.

Robertson, Andrew W.

Combining seasonal climate forecasts with stochastic simulation of interannual-to-interdecadal streamflow variability for reservoir Optimization over NW India

Robertson, Andrew W.[1]; Cook, Edward[3]; Greene, Arthur[1]; Kondrashov, Dmitri[4]; Lall, Upmanu[2]; Lu, Mengqian[2]

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Multi-year storage reservoirs must be managed in the face of weather and climate variability across timescales ranging from daily weather to interannual climate. While seasonal climate may contain a predictable component associated with the El Nino-Southern Oscillation (ENSO), longer timescales are not yet usefully predictable. It is thus of interest to develop strategies that combine together predictive seasonal climate information with stochastic simulation of interannual-to-decadal reservoir inflow variability based on historical or proxy records. For the Bhakra reservoir in northern India, we develop seasonal streamflow forecasts based on GCM seasonal climate forecast models for the spring snow-melt season and summer monsoon. Stochastic simulations of interannual-to-interdecadal variability are constructed using a nonlinear noise-driven multi-level autoregressive model, trained on ensembles of tree-ring based 500-yr reconstructions of reservoir inflow, incorporating the reconstruction uncertainties. This stochastic model is shown to reproduce the main characteristics of the reconstructed flow series including its interdecadal spectral peaks. We investigate the extent of seasonally predictive information in the context of longer timescale stochastic information for input into a reservoir optimization model.

Roundy, Joshua K.

The optimal time and space scale for downscaling the CFSv2 forecast for seasonal hydrologic predictions

Roundy, Joshua K.[1]; Yuan, Xing[1]; Wood, Eric[1]

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Extreme hydrologic events in the form of droughts and flood are a significant source of social and economic damage in many parts of the world. Having sufficient warning of these extreme events allows managers to prepare for and potentially reduce the severity of their impacts to society. A hydrologic forecast system can give seasonal predictions that can be used by mangers to make better decisions; however hydrologic predictions rely on the skill of the climate model in order to predict the hydrologic state at seasonal timescales. The skill of climate forecast models diminishes in the first month due to chaotic nature of the climate system. Nevertheless, the gradual improvement of climate models in the last decade has lead to the skill of these models now exceeding that of statistical models in El Niño-Southern Oscillation (ENSO) prediction. The extent to which this skill propagates to the key forcing variables that are used in driving seasonal hydrologic prediction is not well understood, especially given that the forcing variables from climate models need to be downscaled in order to match the finer resolution of the hydrologic model. For most seasonal hydrologic forecasts systems the downscaling is done at a monthly time step for convenience in operational procedures. The optimal time and spatial scale at which to downscale the climate model is unknown and most likely varies with space and time. In this work we explore the optimal space and time events of climate models for the use in downscaling the key drivers of the hydrologic forecast system. This work analyzes NCEP's Climate Forecasts System version 2 (CFSv2) for its optimal events for downscaling the forcing variables to the NLDAS domain during the hindcast period from 1982-2009. The optimal events are determined by considering the correlation of daily precipitation and minimum and maximum temperature between the CFSv2 forecasts and the NLDAS version 2 dataset while changing the temporal and spatial scale of averaging of the forecast variables. The change in optimal events due to initialization time and spatial location is also analyzed and its implication to downscaling and producing better hydrologic forecasts is discussed.

Seo, Seung Beom

Near-term Climate Change Impacts on Surface Water and Groundwater Interactions Over the Sunbelt

Seo, Seung Beom[1]

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Recent Climate Change Projections from Climate Models Inter-comparison Project-5 (CMIP5) provide opportunities for incorporating climate change information in planning and management. Most of the climate change studies primarily focus on either surface water or groundwater resources alone. In this study, we utilize one of the fully coupled surface water and groundwater models – Penn-State Integrated Hydrologic Model (PIHM) to analyze impacts of near-term climate change over selected basins in the Sunbelt. The study will evaluate different approaches for quantifying the changes in surface water and groundwater interactions by effectively capturing the interactions between them. We intend to evaluate the proposed methodologies by first validating using the hindcasts from CMIP5 and then comparing them with the observations. The difference in performance between a simple downscaling to an improvised bivariate downscaling scheme that captures the interdependency between precipitation and temperature will also be quantified. The primary goal of this study is to assess sustainability of both surface water and groundwater resources utilizing both the hindcasts and future near-term climate change projections over four selected basins that belong different hydroclimatic regimes across the Sunbelt.
Keywords: Hydrologic Model, Streamflow, Groundwater, Streamflow generation, Climate Change

Shafiee-Jood, Majid

Assess the value of seasonal forecast to mitigate farmers' losses from drought

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In recent years, drought has turned into a widespread concern in the United States and farmers are now facing with adverse impacts of droughts more frequently. This situation is exacerbated by the U.S. Midwest drought of 2012, one of the worst droughts in the history of the country. This concern has raised again the question of what is available and what is needed from science and engineering communities to help mitigate drought impacts, especially on farmers. The 2012 Midwest drought hurt most the rainfed agriculture, for which short-term forecast is not useful since once a crop is planted, what farmers can do is very limited when a drought is predicted or actually occurs. It is the mid-term seasonal forecast, if it provides some meaningful information, that can assist farmers' decisions right before the crop season. For example, farmers in Midwest decide the crop pattern (e.g., corn or soybean), contract with ethanol industry, etc., which can considerably affect farmers' income when a serious drought occurs. Indeed farmers who made a large contract to ethanol industry are among the group which was most seriously hurt by the 2012 drought. On the other hand, seasonal climate forecast has low skill score, which is usually too unreliable to be used. Furthermore,

assuming the forecast includes some useful information, there lacks an approach to convey the information to farmers. In this study seasonal forecast data are generated using the regional climate extension of Weather Research and Forecasting (CWRF) model driven by multiple general circulation models (GCMs) and initial soil states as well as multiple physics configuration. The driving GCMs include the Climate Forecast System version 2 (CFSv2), the ECHAM version 4.5 and the European Center for Medium-Range Weather Forecasts (ECMWF) Reanalysis-Interim (ERI). The planning framework is based on a stochastic optimization model coupled with a crop growth simulation model (SWAP). Utilizing the seasonal forecast data, the optimization-simulation framework determines the optimal decision for crop type (i.e. corn or soybean), farmers' contract and amount of fertilizer for a rainfed agriculture system. The model and forecast (hindcast in this case) will be applied to the US Midwest 2012 drought. As the outcome, this study specifically attempts to address the following issues: 1) reliability of utilizing seasonal forecast to mitigate farmers' loss from drought, 2) what useful information can be obtained from the proposed framework for both farmers (information users) and modelers (information providers), and 3) assessment of effective forecast horizon (e.g., 2-, 3-, 4-month or an even longer period) for practical use of climate forecast for drought mitigation.

Sharma, Ashish

THE DO'S AND DON'T'S OF COMBINING MODEL PREDICTIONS FOR SEASONAL HYDROLOGIC FORECASTING

Sharma, Ashish[1]; Khan, Mohammad Z.[1]; Mehrotra, Raj[1]; Chowdhury, Shahadat[1]; Amurugam, Sankar[2]

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2. Department of Civil, Construction and Environmental Engineering, North Carolina State University, Raleigh, NC, USA

The use of ensemble combinations for formulating improved climate forecasts is now well established. These methods have recently been extended for seasonal hydrologic predictions, with applications showing a range of situations where the advantages can be significant. This talk reviews some of the approaches for combining model predictions, with a view of identifying when such combinations are especially of use. The talk then proceeds to present a basis for combining model predictions when inter-model correlations at each grid location are significant, illustrating the improvements that can be achieved if procedures for factoring this dependence are utilised. The talk concludes with a case study on forecasting one-month-ahead global (gridded) sea surface temperature anomalies (SSTA), the commonly used basis for formulating seasonal hydrologic and climate forecasts the world over. The study includes forecasts from five dynamical and statistical models used by various modelling groups around the world, and proceeds to demonstrate the improvements that result when the forecasts are combined without considering inter-model dependence, and then again when inter-model dependence is taken into account. It then proceeds to speculate on the nature of improvements that will be possible when these combinatorial methods put to use by hydrologic and meteorological organisations over the world.

Sharma, Ashish

AN UPPER LIMIT TO SEASONAL STREAMFLOW PREDICTABILITY?

Sharma, Ashish[1]; Taormina, Riccardo[2]; Westra, Seth[3]

1. School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW, Australia
2. Coastal and Hydraulic Engineering, Hong Kong Polytechnic University, Hong Kong, Hong Kong
3. School of Civil, Environmental and Mining Engineering, The University of Adelaide, Adelaide, SA, Australia

In a recently published paper, Westra and Sharma (2010) concluded that "asymptotic predictability of global precipitation was 14.7% of its total variance", with this predictability reducing to just 2.1% using standard cross-validation techniques when a long dataset (1900-2007) was considered. This finding posed serious questions to the viability of seasonal rainfall prediction, especially the part of the prediction that involves using climate information that extends beyond its largest mode of low-frequency variability - the El Nino Southern Oscillation. This presentation builds on the abovementioned work, using the methodology to ascertain whether an upper limit to predictability of global seasonal streamflow exists. As with the above study, it uses the global sea surface temperature anomaly (SSTA) field to represent the low-frequency variability of the climate system, and an assumed Markov order one representation characterising the catchment storage mechanism for the flows. It goes on to assess the variability that is obtained with and without the Markov order one assumption, and as a function of various catchment related attributes. The results show that a similar upper limit can be formulated in the context of streamflow, but that this limit varies considerably on a regional basis, often as a function of relevant catchment attributes. Reference: Westra, S., and A. Sharma (2010), An Upper Limit to Seasonal Rainfall Predictability?, Journal of Climate, 23(12), 3332-3351, doi:10.1175/2010JCLI3212.1.

Sheer, Daniel P.

Using Forecast Information to Improve Water Management

Sheer, Daniel P.[1]

1. Hydrologics Inc., Columbia, MD, USA

Forecast based operating rules have and have the potential to greatly increase the benefits derived from the management of water resources in the United States and internationally. This paper will present examples of how point forecasts, probabilistic forecasts, and ensemble forecasts can be incorporated in the rules used to guide the operations of water management facilities. It will also describe some of the forms of rules best suited to improving management with regard to specific uses, including water supply, hydropower, navigation, recreation, fisheries, and environment and riparian habitat. Examples will be drawn from the author's experience and include New York City water supply, Apalachicola/Chattahoochee/Flint (Atlanta water supply and Alabama/Florida/Georgia Water Wars), Roanoake Basin, and South Florida/Everglades. Displays which illustrate the benefits gained in both economic and non-economic terms will be shown.

Shin, Daehyok

Seasonal Hydrologic Forecasting for Water Resources Management

Bari, Mohammed[1]; Shin, Daehyok[1]; Tuteja, Narendra[1]; Feikema, Paul[1]; Zhou, Senlin[1]; Kabir, Aynul[1]; Kent, David[1]; Laugesen, Richard[1]; Lee, Bat[1]; Hawksworth, Clare[1]; MacDonald, Andrew[1]; Jayasuriya, Dasarath (Jaya)[1]

1. Climate and Water Division, Bureau of Meteorology, West Perth, WA, Australia

A seasonal water forecasting service has been needed in Australia for many years, and the Australian Government's recent investment in water information is addressing this need. Skilful and reliable seasonal forecasts of streamflows are highly valuable for providing water allocation outlooks, informing water markets, planning and managing water use and managing drought. The opportunity for the Bureau to expand its seasonal forecasting service is a result of its new responsibilities, which largely came about because of the impacts of the prolonged drought. In early 2007, the Australian Government announced 'Water for the Future', a $12.9 billion water investment program. This included $450 million for the 'Improving Water Information Program' administered by the Bureau and backed by the Commonwealth Water Act 2007 and key stakeholders. The Bureau launched a new Seasonal Streamflow Forecasting (SSF) service in December 2010. The service delivers probabilistic forecasts of streamflow volumes for the next three months at a site or total inflows into major water supply storages (http://www.bom.gov.au/water/ssf). The seasonal water availability prediction service of Australia relies on the development and integration of the statistical and dynamic modelling approaches. A statistical prediction system is based on a Bayesian joint probability modelling approach (BJP), and it provides reliable forecasts of 'seasonal' streamflow over the next three months. In parallel, a dynamic modelling approach has been developed whereby outputs from climate models are downscaled to a catchment scale to provide inputs to hydrological models of various degrees of complexity. The key climate models are the Centre for Australian Weather and Climate Research's (CAWCR) Predictive Ocean Atmosphere Model for Australia (POAMA). All prediction systems are accompanied with verification systems that measure skill and reliability of the forecasts. In delivering on these responsibilities, the Bureau relies on considerable research, particularly through CAWCR, the Water Information Research and Development Alliance (WIRADA) between the Bureau of Meteorology and CSIRO, and the university sector.

Shukla, Shraddhanand

Forecasting East Africa Spring rainfall at Seasonal Scale using a Hybrid Approach

Shukla, Shraddhanand[1]; Funk, Christopher[1]; Husak, Geg[1]; McNally, Amy[1]; Hoell, Andrew[1]

1. University of California, Santa Barbara, Santa Baraba, CA, USA

East Africa ranks among one of the most food insecure regions in the world. This region experiences to two main rainfall seasons: March-April-May (MAM, "Long Rains", spring rainfall) and October-November-December ("Short Rains"). The agriculture in this region is mostly rainfed. Low levels of technological advances and poverty make this region particularly vulnerable to interannual variability of rainfall during both seasons. Skillful rainfall predictions for this region can help inform timely efforts to mitigate socio-economic losses. The relationship between "Short rains" and ENSO conditions is well established, leading to reasonable levels of predictability. "Long rains" predictability has proven to be a challenge. In recent years, a few studies have identified a potential link between MAM rainfall and a warming trend in the western Pacific warm pool and eastern Indian Ocean. While MAM decreases in rainfall and a warming trend have been attributed to the impact of warming sea surface temperatures (SSTs), this link could potentially provide greater levels of MAM rainfall predictability. This presentation explores this relationship using a hybrid approach that combines the state-of-the-art Climate Forecast System version-2 (CFSv2) dynamical forecasts with statistical downscaling methods to predict spring rainfall in East Africa. Specifically, we used CFSv2 precipitation and SSTs forecasts over the Indian and Pacific Oceans as predictors of East Africa spring rainfall. We implemented two statistical approaches for this analysis: (1) Constructed analogue and (2) Matched filter regression. Both methods essentially perform a linear regression between the CFSv2 forecasts and observed spring rainfall over hindcast years (i.e. the training period) and use that relationship to predict spring rainfall in real-time based on the CFSv2 forecasts. We found that the hybrid approach was able to identify ~75% of spring drought events between 1996-2012 about a month in advance, and the correlation value between the Z-score of the predicted and observed MAM rainfall for that period was about 0.7. We also noted that CFSv2 precipitation is a better predictor of the East Africa spring rainfall than the CFSv2 SST forecast. We conclude with a brief exploration of this technique applied to boreal spring and winter precipitation in western North America.

Sinha, Tushar

Experimental Inflow and Storage Forecasts Portal for Major Reservoirs in the Southeastern US

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Increase in water demand due to urbanization and population growth has threatened the reliability of existing water supply systems. In addition, increase in seasonal to interannual variability in streamflow enhances the vulnerability of these systems. Given that most of the reservoirs in the eastern and southeastern US are designed as within-year storage systems, they intend to capture only the seasonal variability in streamflow, as opposed to reservoirs in the West, which typically carryover the deficit/surplus from year to year. Thus, relatively lower storage of reservoirs in the Southeast and increasing urban demand underscore the importance of utilizing climate based information to develop inflow and storage forecasts. Such forecasts can adaptively be used to update monthly to seasonal water allocations to better manage existing reservoirs, particularly during prolonged droughts. As a part of recently funded projects by North Carolina (NC) Water Resources Research Institute and NC Urban Water Consortium, we have developed fully automated experimental monthly to seasonal inflow and storage forecasts for the two major reservoirs, Falls Lake and Jordan Lake, located in the rapidly growing Triangle Area of NC (http://www.nc-climate.ncsu.edu/inflowforecast). These experimental reservoir inflow forecasts are developed by downscaling the precipitation forecasts available from ECHAM4.5 General Circulation Model using Principal Components Regression (PCR) model. This prognostic information, which is available as shift in probabilities of streamflow, is converted to experimental reservoir storage forecasts by combining the inflow forecasts with a reservoir simulation model. The inflow forecasts portal is customized to project monthly to seasonal storage scenarios for any user prescribed releases. Both the inflow and storage forecasts can be generated for individual years as well as for multiple years on a retrospective basis. These probabilistic forecasts can be generated from 1990 to present on monthly or seasonal basis for up to 3 months lead time using climatological or PCR models. Further, several skill evaluation metrics are estimated to compare the performance between utility of precipitation forecasts and climatological forecasts. These inflow and storage forecasts will be extended to major reservoirs in the southeastern US. Finally, the existing experimental inflow forecasts will be enhanced to an operational streamflow and soil moisture forecasts using multiple semi-distributed models.

http://www.nc-climate.ncsu.edu/inflowforecast

Taner, Mehmet U.

Use of seasonal forecasting for improving reservoir operations in the Niger River Basin

Taner, Mehmet U.[1]; Lownsbery, Katherine[1]; Brown, Casey[1]

1. Civil and Environmental Engineering, Umass Amherst, Amherst, MA, USA

Managing water resources in the Niger River Basin is a challenging task due to the high climate variability and the uncertainties in the future climate. The use of seasonal forecasting in an adaptive management framework is a promising option for improving reservoir operations, particularly for multi-objective planning. This study presents a sampling stochastic dynamic program (SSDP) for deriving optimal seasonal operation policies, and a simulation model for using the SSDP derived policies in the real-time operations. A Bayesian approach is used for employing seasonal forecasting to update the probabilistic streamflow descriptions in the SSDP model and to update reservoir release decisions in the real-time simulation model. The proposed framework is demonstrated in the Upper Niger Basin, which consists of Selingue Reservoir and a large irrigation scheme, "Office Du Niger". The system performance with proposed framework is compared against the existing operation policies in terms of reservoir reliability, irrigated acreages in rainy (June to October) and dry (February to May) seasons, and environmental flow reliability at the Niger Inner Delta, located downstream of Office Du Niger. The approach is considered as an adaptation strategy to climate change using plausible projections of future climate for the region.

Tozer, Carly

Identification of Drivers of Rainfall Variability for Informing Seasonal Forecasting Schemes

Tozer, Carly[1]; Verdon-Kidd, Danielle C.[1]; Kiem, Anthony S.[1]

1. Environmental & Life Sciences, University of Newcastle, Callaghan, NSW, Australia

A key challenge in the development of skilful seasonal rainfall forecasts is the identification of the atmospheric and oceanic processes that drive the rainfall variability. Seasonal rainfall forecasts for South Australia (SA) currently have low predictive skill and we hypothesise that this is because the key drivers of SA's rainfall variability have yet to be fully identified and therefore are not adequately represented in the forecast models. Previously, much of the focus in Australia has been on determining the causes of seasonal and annual rainfall variability in eastern and Western Australia, with little research conducted on SA's rainfall variability. Therefore the aim of this this study was to identify relationships between a host of potential climate drivers (such as the El Niño Southern Oscillation, Indian Ocean Dipole, Southern Annular Mode etc.), and seasonal

rainfall across South Australia. A threshold method is used that accounts for the inherently non-linear nature of the links between large scale climate phenomena and hydroclimatic variability. This will provide a set of metrics against which dynamical forecasting schemes can be tested and may also lead to the development of new statistical forecasting schemes.

Trimble, Paul

Application of Seasonal and Multi-seasonal Climate Outlooks for Water Management in South Florida

Trimble, Paul[1]

1. Hydrologic & Environmental Systems Modeling, West Palm Beach, FL, USA

Incorporation of seasonal to multi-seasonal climate outlooks for improved hydrologic forecasting is important for operational planning in the management of large-scale water resources systems. The South Florida Water Management District (SFWMD), regional agency responsible for management of water resources in South Florida, has effectively employed the seasonal and multi-seasonal climate outlooks for operational planning. Since the agency has embarked on a major infrastructure improvement project to facilitate Everglades Restoration while meeting the water supply for agriculture and increasing urban population, the issue of climate change and decadal to multi-decadal climate variability in water resources planning has come to the forefront as a major consideration in future investments. This presentation provides an application of the research to develop operational rules for Lake Okeechobee, the liquid heart of South Florida, as well as the real-time implementation of rules based on climate outlooks. The current research to address the questions of climate change and the decadal to multi-decadal climate variability in infrastructure planning is also discussed. The South Florida Water Management Model (SFWMM), a distributive hydrologic model applied to the SFWMD hydrologic system, is one of several decision tools in operational planning. The model is reinitialized to current conditions on the same day for every year in the simulation period. Model results are presented as stage and discharge time series of percentile traces for Lake Okeechobee and other impoundments in the system. Conditional position analysis is obtained when a given climatic shift (dry or wet) is incorporated into the analysis. Discussion of the possible application of the national Climate Forecast System Model to drive the SFWMM will be considered.

Vano, Julie

Mapping the diversity of hydrologic responses to seasonal climate in the Pacific Northwest

Vano, Julie[1]; Lettenmaier, Dennis[1]

1. University of Washington, Seattle, WA, USA

Temperature and precipitation changes will lead to fundamental changes in the seasonal distribution of streamflow and consequently for water management in the Pacific Northwest. Basin-specific implications of these changes are, however, complicated by the wide range of projections of future temperature and precipitation from global climate models, the spatial resolution of which is coarse from a hydrologic perspective, and therefore do not easily translate to local water management applications. To better understand local impacts of regional climate changes at basin scales, we conducted experiments to determine basin-scale hydrologic sensitivities (to imposed annual and seasonal temperature and precipitation change) of seasonal and annual streamflow. We did so using the Variable Infiltration Capacity (VIC) land-surface hydrologic model applied at one-sixteenth degree latitude and longitude spatial resolution, over the Pacific Northwest, a scale sufficient to support analyses at the hydrologic unit code eight (HUC-8) basin level, a scale at which there are ~200 basins within the region. Our results allowed us to determine basin-specific transfer functions to estimate future changes in long-term mean seasonal responses that can provide viable first-order estimates of the likely range of streamflow changes without performing detailed model simulations. These estimates of long-term changes allow for projections of streamflow changes and mapping of those portions of the river basins and portions thereof within the region that are most sensitive to temperature and precipitation changes. The approach we suggest also provides a basis for exploring sources of uncertainties in future hydrologic change across the region.

Voisin, Nathalie

Improved Medium Range to Seasonal Streamflow Forecasts Through Simultaneous Assimilation of Snow and Streamflow Observations: Evaluation Over the Feather River Basin, CA

Voisin, Nathalie[1]; Nijssen, B.[2]; Wigmosta, M.[1]; Lettenmaier, D. P.[2]

1. Hydrology Group, PNNL, Seattle, WA, USA
2. University of Washington, Seattle, WA, USA

The Pacific Northwest National Laboratory and the University of Washington are collaborating on the development of a streamflow forecasting system that is fully integrated into the DOE Water Use Optimization Toolset (WUOT). which can be used to inform reservoir and power operations and guide decisions that affect environmental performance decision making. WUOT adresses the unique forecast requirements of DOE and the hydropower industry in the face of increasing competition for water. The toolset takes into consideration traditional objectives such as flood control and water supply, as well as emerging needs for renewable energy integration and environmental requirements. The streamflow forecast system uses the semi distributed Variable Infiltration Capacity (VIC) model, medium-range ensemble forecasts from the Global Forecast System (GFS), as well as ensemble seasonal climate forecasts from CFS v2 and climatological resampling. Forecasted hydrologic variables include gridded fields of runoff, snow water equivalent, soil moisture and unregulated ensemble flow and side-flow forecasts at points of interest. The system also generates 14-day hourly meteorological forecasts, including precipitation, air temperature, air and vapor pressures, relative humidity, solar and longwave radiations, and wind speed. Forecasts are enhanced through assimilation of two sources of information: i) streamflow observations are assimilated to improve modeled soil moisture states, which leads to improved forecasts at short to medium range time scales, ii) snow water equivalent observations to improve snow pack storage, which results in reduced errors at medium to longer time scales. The challenge in combining the two methods is that it may result in an inconsistency at intermediate time scales with potentially a deterioration in forecast skill. The system is evaluated at multiple time scales with multiple combinations of data assimilation approaches over the Feather River, CA over the 1990-2012 period. We conclude with a discussion of the best-performing implementation of the forecast system over this rain-snow transition basin.

Werner, Kevin

Forecasting the Life Blood of America's Southwest: Challenges for the Next Decade

Werner, Kevin[1]

1. CBRFC, NWS, Salt Lake City, UT, USA

Demand on fresh water resources in major river basins in the Southwestern United States have reached parity with supply in recent years. This has placed tremendous pressure on water managers and the forecast agencies that support them. NOAA's Colorado Basin River Forecast Center (CBRFC) provides forecasts from timescales of hours out to a year or more in the future to support water managers in the Colorado Basin but also in the Great Basin of Utah. CBRFC relies on a hydrologic modeling and forecast system composed of hydrologic and snow models, extensive data quality control, ingestion of weather and climate forecasts, as well as the considerable forecaster expertise at the CBRFC. CBRFC strives to continually improve its forecast processes and methods through both through internal developmental projects and in collaboration with the greater science community. This talk describes major areas ripe for improving CBRFC forecasts including linking to and improving climate prediction, improving snow modeling, leveraging data assimilation techniques to improve data quality control, and connecting to stakeholder decision support systems. This talk describes the current state and near term opportunities for water supply forecasting in support of water management in the Colorado River Basin. In particular, stakeholders have worked with the US Bureau of Reclamation to design more sophisticated management models and techniques in order to optimize operations. One major aspect has been the development of a probabilistic operations model (the Mid Term Operations Model or MTOM) intended to provide stakeholders with probabilistic projections of management activities to support risk based decision making. The MTOM is intended to supplement the long standing 24 month study run by USBR. The MTOM presents an opportunity for the NOAA Colorado Basin River Forecast Center (CBRFC) to apply its existing ensemble forecast technique. It also presents significant opportunities to test NOAA's next generation streamflow ensemble forecast system, the Hydrologic Ensemble Forecast System (HEFS) and other ensemble forecast techniques that leverage climate and weather forecasts. Forecast skill in weather and climate forecasts has steadily improved over the last several decades as its underlying science and technology has advanced. While these improvements have yet to be systematically leveraged into improved water supply forecasts for the Colorado Basin, HEFS and other techniques under exploration by CBRFC and its partners present opportunities to advance the state of water supply forecasting.

Whateley, Sarah

Seasonal Hydrologic Forecasting in the Northeastern United States

Whateley, Sarah[1]; Brown, Casey[1]

1. Department of Civil and Environmental Engineering, University of Massachusetts Amherst, Amherst, MA, USA

In many parts of the United States, seasonal hydrologic forecasts are critical to water resource management. Numerous studies have demonstrated significant skill in predicting regional hydrology and river flows, namely in the western and southeastern US, using both initial hydrologic conditions (IHC) (i.e. soil moisture and snow water-equivalent measures) and climate indices that characterize aspects of the geophysical system. However, efforts to produce skillful seasonal hydrologic forecasts in the Northeast US have been limited. As such, long-range streamflow forecasts are often not incorporated into seasonal operating policies of reservoir systems in this region as they are in the West. Increasing concern for drought and flood management in the water resources community under a changing hydrologic regime emphasizes the need for improved understanding of the influence of IHC and large-scale atmospheric-oceanic circulation patterns on seasonal hydrologic forecast skill. This work will illustrate our efforts toward creating a hydrologic forecast in the Northeast beneficial to water management. Current efforts focus on predicting spring peak and summer low streamflows in major river basins throughout the Northeast US using soil moisture and snow water-equivalent anomalies and atmospheric-ocean circulation patterns related to the North Atlantic. Further exploration of the relationships between hydroclimatology (i.e. the influence of the climate system on time and space variations of the hydrologic cycle), anomalous antecedent hydrologic conditions, and hydrologic extremes in the region is needed. This presentation will present the current state of understanding of the variability and predictability of the hydroclimate system in the Northeast US, evaluate forecast skill, and assess its applicability to water resource management.

Wood, Andrew W.

The potential value of NCEP climate forecasts for hydrologic prediction in the Pacific Northwest

Wood, Andrew W.[1]; Schaake, John[2]

1. NOAA/NWS Northwest River Forecast Center, Portland, OR, USA
2. Consultant, Annapolis, MD, USA

Seasonal climate forecasts have been produced operationally by NCEP for over a decade. NCEP has recently upgraded to version 2 of the Climate Forecast System (CFSv2), and also participates in the new National Multi-Model Ensemble (NMME) prediction capability which combines ensemble forecasts from a multiple modeling centers. Operational streamflow predictions at the NOAA/NWS Northwest River Forecast Center (NWRFC) that support water management in the Pacific Northwest (PNW) do not currently make use of climate forecast information, but are slated to do so in the near future via the new NWS Hydrologic Ensemble Forecast Service (HEFS), which uses NCEP Global Ensemble Forecast System (GEFS) short to medium range predictions and CFSv2 climate predictions. The weather and climate predictions are downscaled by a statistical technique to provide calibrated inputs to catchment level streamflow prediction models. This presentation summarizes skill assessments at the coarse and catchment scales for these weather to climate prediction datasets, and discusses their potential to improve seasonal operational streamflow prediction.

Yan, Hongxiang

A Regional Bayesian Hierarchical Model for Flood Frequency Analysis in Oregon

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1. Portland State University, Portland, OR, USA

In this study, we propose a regional Bayesian hierarchical model for flood frequency analysis. The Bayesian hierarchical method is an alternative to the traditional regional flood frequency analysis. Instead of relying on the delineation of implicit homogeneous regions, the Bayesian model describes the spatial variability and dependence in its inner structure. Our model has two levels. The first level of the hierarchical model introduces the independent fitted distributions (identified by L-moments) to the maximum streamflow data. The second level of the hierarchical model presents the spatial variability of the parameters by considering different covariates (watershed size, elevation, etc.). The performance of the Bayesian model is assessed in a case study over the Pacific Northwest region. The uncertainty of different quantiles can be quantified from the posterior distributions using Markov Chain Monte Carlo algorithm. Temporal changes for different quantiles are also examined using a 10 year moving window method. The calculated shifts in flood risk can facilitate future water resource management.

Yuan, Xing

The role of climate models in global seasonal hydrologic forecasting

Yuan, Xing[1]; Wood, Eric F.[1]

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Using NCEP's Climate Forecast System version 2 (CFSv2), we recently found that climate models can provide better seasonal hydrologic forecasts over CONUS than the Ensemble Streamflow Prediction (ESP) approach through appropriate downscaling procedures, but significant improvements are heavily dependent on the variables, seasons and regions. Now we are extending such investigation from CONUS region to global land areas and from a single CFSv2 model to multiple climate forecast models. Based on the joint probability distribution between observations and model hindcasts, we bias correct the monthly precipitation and temperature forecasts from nine climate forecast models (COLA, GFDL, IRI-AC, IRI-DC, GMAO, CFSv1, CFSv2, CanCM3, CanCM4), downscale them to a daily time scale, and use them to drive the Variable Infiltration Capacity (VIC) land surface hydrologic model to produce a set of seasonal hydrologic hindcasts globally at one degree resolution. The hindcasts are initiated on the 1st of each calendar month during 1982-2009 and run out to 6 months with 20 ensemble members. For comparison, a parallel run using the ESP forecast method is also carried out. Analysis is being conducted for the predicted soil moisture and runoff over global major river basins, and is targeted to explore the global baseline hydrologic predictability from ESP, and to see whether there are added values from climate models in specific regimes.

http://hydrology.princeton.edu/~xingy/

Zagona, Edith

Tools and Techniques for Complex Water Management Models on Interannual to Multidecadal Time Scales

Zagona, Edith[1, 2]; Rajagopalan, Balaji[2, 3]; Jerla, Carly[4]; Prairie, James[4]

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3. CIRES, CU, Boulder, CO, USA
4. Bureau of Reclamation, Boulder City, NV, USA

Managing water for an uncertain future - whether flood forecasting over the next hours or days, or planning for unknown climate change impacts over many decades – benefits from the ability to quickly and efficiently simulate many possible realizations, organize and analyze out put data, and securely archive decision-producing results. A new suite of modeling and analysis tools developed at the University of Colorado Center for Advanced Decision Support for Water and Environmental Systems facilitates this type of activity, from generating stochastic hydrology to statistical analysis of outputs. The tools, developed under

Reclamation's WaterSMART initiative, were designed to facilitate Basin Studies - comprehensive water studies to explore options for meeting projected imbalances in water supply and demand under future climate change and variability. Possible flow scenarios are produced by the Hydrology Simulator, which uses non-parametric K-nearest neighbor resampling techniques to generate ensembles of hydrologic traces based on historical data, optionally conditioned on long paleo reconstructed data using various Markov Chain techniques. Resampling can also be conditioned on climate change projections from e.g., downscaled GCM projections to capture increased variability. The simulations produced are ensembles of hydrologic inputs to the RiverWare operations/infrastucture decision modeling software. Alternative demand scenarios can be produced with the Demand Input Tool (DIT), an Excel-based tool that allows modifying future demands by groups such as states; sectors, e.g., agriculture, municipal, energy; and hydrologic basins. The demands can be scaled at future dates or changes ramped over specified time periods. Resulting data is imported directly into the decision model. Different Model Files can represent infrastructure alternatives and different Policy Sets represent alternative operating policies, including a means to identify unacceptable vulnerabilities that trigger dynamically executing changes in operations or other options. The over-arching Study Manager provides a graphical tool to create combinations of future supply scenarios, demand scenarios, infrastructure and operating policy alternatives; each scenario is executed as an ensemble of RiverWare runs, driven by the hydrologic supply. The Study Manager sets up and manages multiple executions on multi-core hardware. The sizeable output files are typically direct model outputs, or post-processed indicators of performance based on model outputs. Post processing statistical analysis of the outputs are possible using the Graphical Policy Analysis Tool or other statistical packages. Several Basin Studies undertaken have used RiverWare to evaluate future scenarios. The Colorado River Basin Study, the most complex and extensive to date, has taken advantage of these tools and techniques to generate supply scenarios, produce alternative demand scenarios and to set up and execute the many combinations of supplies, demands, policies, and infrastructure alternatives. The tools and techniques will be described with example applications.

Zammit, Christian

Effect of initial conditions of a catchment on seasonal streamflow prediction using ensemble streamslow prediction technique (ESP) for 2 river basins on New Zealand's South Island

Zammit, Christian[1]; Singh, Shailesh[1]; Hreinsson, Einar[1]; Woods, Ross[1, 4]; Hamlet, Alan[3]; Clark, Martyn[2]

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Increased access to water is a key pillar of the New Zealand government plan for economic growths. Variable climatic conditions coupled with market drivers and increased demand on water resource result in critical decision made by water managers based on climate and streamflow forecast. Because many of these decisions have serious economic implications, accurate forecast of climate and streamflow are of paramount importance (eg irrigated agriculture and electricity generation). New Zealand currently does not have a centralized, comprehensive, and state-of-the-art system in place for providing operational seasonal to interannual streamflow forecasts to guide water resources management decisions. As a pilot effort, we implement and evaluate an experimental ensemble streamflow forecasting system for two major river basins in on New Zeland's South island (Waitaki and Rangitata River basins) using a hydrologic simulation model (TopNet) and the familiar ensemble streamflow prediction (ESP) paradigm for estimating forecast uncertainty. To provide a comprehensive database for evaluation of the forecasting system, first a set of retrospective model states simulated by the hydrologic model on the first day of each month were archived from 1972-2009. Then, using the hydrologic simulation model, each of these historical model states was paired with the retrospective temperature and precipitation time series from each historical water year to create a database of retrospective hindcasts. Using the resulting database, the relative importance of initial state variables (such as soil moisture and snowpack) as fundamental drivers of uncertainties in forecasts were evaluated for different seasons and lead times. The analysis indicate that the sensitivity of flow forecast to initial condition uncertainty is depend on the hydrological regime and season of forecast. However initial conditions do not have a large impact on seasonal flow uncertainties for snow dominated catchments. Further analysis indicates that this result is valid when the hindcast database is conditioned by ENSO classification. As a result hydrological forecasts based on ESP technique, where present initial conditions with histological forcing data are used may be plausible for New Zealand catchments.

Zhang, Ying

Development of a rainfall type prediction model for NYC

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Predicting precipitation in the Northeast US has directly application to urban drainage, urban supply, runoff water quality, recreational activities, etc. We develop a season-ahead prediction system for New York City focused on forecasting the frequencies of precipitation type. Precipitation types during the June-August season are categorized by rain-forming mechanisms through a cluster analysis. The ensuing prediction system is statistically-based, using sea surface temperatures as predictors. After that, the precipitation type frequencies are converted into precipitation depths through bootstrapping. Preliminary results indicate skillful predictive capabilities.