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Late 20th Century Hydrologic Change in Western North America: Regional Impacts and the Role of Climate

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Final Report for Period: 07/2009 - 06/2010

Submitted on: 12/10/2010

Principal Investigator: Jain, Shaleen .

Award ID: 0732309

Organization: University of Maine

Submitted By:

Jain, Shaleen - Principal Investigator

Title:

Late 20th Century Hydrologic Change in Western North America: Regional Impacts and the Role of Climate

Project Participants

Senior Personnel

Name: Jain, Shaleen

Worked for more than 160 Hours: Yes

Contribution to Project:

As the PI of this project, advising graduate and undergraduate students has been a key task, as well collaboratively working with Jon Eischeid and Jong Kim to prepare two manuscripts on project-related topics. The research from the projects have been presented at national and international meetings.

Post-doc

Graduate Student

Name: Chandler, John

Worked for more than 160 Hours: Yes

Contribution to Project:

John Chandler completed his MS thesis in December 2008. His research focused on the project-related foci.

Name: Sen Gupta, Avirup

Worked for more than 160 Hours: Yes

Contribution to Project:

Avirup Sen Gupta will be looking at the western North American hydroclimatic extremes, especially the droughts. Using AMIP and CMIP simulations of 20th and 21st century climate, his work will seek to clarify the role of tropical oceans and global change in engendering regionwide extremes.

Undergraduate Student

Name: Foster, Samuel

Worked for more than 160 Hours: No

Contribution to Project:

Sam was a member of the undergraduate researcher team that developed the SimStream system and the website.

Name: Eisenberg, Zev

Worked for more than 160 Hours: No

Contribution to Project:

Zev was a member of the undergraduate researcher team that developed the SimStream system and the website.

Name: Skiold-Hanlin, Sarah

Worked for more than 160 Hours: No

Contribution to Project:

Sarah was a member of the undergraduate researcher team that developed the SimStream system and the website. She also developed the poster presentation for the University of Maine Center for Undergraduate Research Symposium in April 2010. Sarah led the concept and implementation of the artwork for the various sprites in SimStream.

Name: Pepin, Nathan

Worked for more than 160 Hours: No

Contribution to Project:

Nate was a member of the undergraduate researcher team that developed the SimStream system and the website.

Name: Smith, Seth

Worked for more than 160 Hours: No

Contribution to Project:

Seth was a member of the undergraduate researcher team that developed the SimStream system and the website.

Name: Simpson, Jonathan

Worked for more than 160 Hours: No

Contribution to Project:

Jon was a member of the undergraduate researcher team that developed the SimStream system and the website.

Name: Baker, Timothy

Worked for more than 160 Hours: No

Contribution to Project:

Tim led the Simstream undegraduate Research Team through the various phases of model development, testing, demonstration, and website development. He also traveled with PI Jain and University of Maine New Media Lab Director Mike Scott to present the Simstream at the 2010 MIT Scratch Conference in Cambridge, MA.

Name: Hendrickson, Kyle

Worked for more than 160 Hours: Yes

Contribution to Project:

Technician, Programmer

Name: Eischeid, Jon

Worked for more than 160 Hours: Yes

Contribution to Project:

Jon has been involved in the acquisition and collation of the observational, atmospheric and coupled GCM data archive for the project. He has also worked on data analysis and processing. Finally, he assists the diagnostics studies by preparing data, programming and visualization support.

Other Participant

Research Experience for Undergraduates

Organizational Partners

NOAA/Climate Diagnostics Center

The project has benefitted from access to computing facilities and data archives at NOAA Earth System Research Laboratory, Boulder. Jain collaborates with CDC researcher Martin Hoerling on regional climate change issues that overlap with the research focus on this project.

Other Collaborators or Contacts

Please see attached report

Activities and Findings

Research and Education Activities:

Please see attached report

Findings:

Please see attached report

Training and Development:

Please see attached report

Outreach Activities:

Please see attached report

Journal Publications

Jain, S., and J. K. Eischeid, "What a difference a century makes: Understanding the changing hydrologic regime and storage requirements in the Upper Colorado River basin", Geophysical Research Letters, p. L16401, vol. 35, (2008). Published, 10.1029/2008GL034715

Kim, J.-S. and S. Jain, "High-resolution streamflow trend analysis applicable to annual decision calendars: a western United States case study", Climatic Change, p. 699-707, vol. 102, (2010). Published, 10.1007/s10584-010-9933-3

Books or Other One-time Publications**Web/Internet Site****URL(s):**

http://tok.asap.um.maine.edu/watershed_sustainability/

Description:

A team of undergraduates researchers supported by this project worked collaboratively to develop watershed sustainability model in the programmable multimedia environment, Scratch. The website continues to be developed and will be used to watershed and climate education for middle school students.

Other Specific Products**Contributions****Contributions within Discipline:**

See attached document

Contributions to Other Disciplines:

Noted in the Progress Report Document

Contributions to Human Resource Development:

Graduate Research Assistant, John L. Chandler was supported on this project, and has successfully completed a MS thesis in Decemebr 2008.

Contributions to Resources for Research and Education:

Noted in the Progress Report (Water Managers Workshop in Nevada 2008)

Contributions Beyond Science and Engineering:

Noted in the attached report (Research from this project used in workshops focusing on adaptive water management and policy in the western United States)

Conference Proceedings

Categories for which nothing is reported:

- Any Book
- Any Product
- Any Conference

Final Report

Late 20th hydrologic change in western North America: Impacts and the role of climate

National Science Foundation Grant Number: AGS 0732309

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Major Goals and Objectives

This research project is motivated by: (a) the need to understand climate-related causative factors that underpin the systematic changes in the western North American regional streamflow, and (b) river basin sensitivities and impacts on managed systems and riverine ecosystems. Observed increases in the variance of regional streamflow and frequent, synchronous extremes across the four major river basins in this region—Fraser, Columbia, Sacramento-San Joaquin, and Upper Colorado—further illuminate the broad implications of hydrologic change on a range of dependent human and natural systems. Two critical concerns related to changing water supplies and systems management are: (i) assessment of the long-term reliability of water supplies in the upper Colorado River Basin, and (ii) the water supply, hydropower and stream ecosystems (e.g., Pacific salmon) relationships in the Columbia River Basin.

The research pursued within this project can be categorized as:

- (a) based on observational and coupled and atmospheric model simulations (CMIP and AMIP respectively), pursue diagnostic studies to characterize the recent and future changes in the WNA hydroclimate
- (b) develop analysis and modeling frameworks for river-basin specific studies to understand and explicate the sensitivity to and impact of decadal and longer-term variations in hydroclimate on infrastructure and ecosystems
- (c) develop methods for the effective use of climate model-based information for river basin scale water supply assessment by water managers and stakeholders, and
- (d) engage undergraduate researchers in developing computational models of watershed sustainability using programmable multimedia that highlight the complex interactions of climate-water-ecosystems in natural and urbanizing regions.

Key Results and Accomplishments

A brief summary of the seven interlinked studies were completed as part of this work is provided here:

1. *Late 20th-century trends in the western North American hydroclimatic regime: Observations and atmospheric GCM simulation results*
A number have illustrated the critical role of sea surface temperatures (SSTs) in engendering regional-scale hydroclimatic change. In this study, we used NSIPP atmospheric GCM (AGCM) simulations with prescribed global SSTs and 9-ensemble members, for the 1950-2004 period. A multivariate analysis of river basin precipitation was used to assess the relative preponderance of a synchronous precipitation pattern (one where all four river basins exhibit anomalies with same sign). We discovered that 6 out 9 runs show a robust synchronous principal component (PC). Furthermore, ensemble mean also shows a synchronous PC. Analysis of changes in variance of time confirms the increasing trend noted by Jain et al. (2005) in observations. This AGCM-based attribution of the role of SSTs as a driver of regional change is an important step in our ability to distinguish trends stemming from natural fluctuations versus ones that may have

anthropogenic origins. In this case, tropical Pacific SSTs show high correlation with the observed changes. A followup analysis using a large prescribed SST simulation ensemble using 4 AGCMs and ~50 members revealed that Sacramento-San Joaquin River basin shows the highest level of robustness in the signal towards increasing variance. A manuscript is being submitted to *Climate Dynamics*.

2. *A new multimodel weighting scheme for coupled atmosphere-ocean model ensemble simulations: The Robust Dependence Method*

The availability of a large set of coupled ocean-atmospheric model simulations for the 20th and 21st century for various IPCC scenarios afforded a unique opportunity to assess regional patterns of variability and change. As contrasted with numerous approaches in the literature that use statistical bias correction and regression, we tested a set of nonlinear and linear dependence methods with a goal to assess the joint distribution of ENSO-regional precipitation distribution in models and observations. This study developed a new method that exploits the nonparametric kernel density estimation methods, and uses Monte Carlo simulations to assess the similarity in the joint structure of 20th century model and observed teleconnections. This approach is further use for weighting model projections across 18 coupled climate models to develop river basin specific probabilistic estimates of precipitation and temperature change in the 21st century (based on the SRES A1B scenarios). Both these variables have enormous implications for the seasonality and magnitude of water supplies. A manuscript reporting this work is being finalized for submission to *Physical Review E*.

3. *Projected hydroclimatic change in western North America: Adaptation considerations for water resources management*

A 18-model, 42-member ensemble of IPCC AR4 CMIP3 suite (SRES A1B) was analyzed for systematic changes in the empirical probability distributions for the four major river basins in the WNA region. Using nonparametric kernel density estimators, we examined the shifts in both probability distributions and the incidence in synchronous extremes. Furthermore, a moving window analysis of ENSO-related teleconnections was also pursued. This is particularly important for the use of seasonal forecasts(also note the study 4 below). Results of multi-model assessments for 2001-2098 forecast increasing average annual wet-season precipitation for the Columbia, Fraser, and Upper Colorado basins and significantly more frequent and intense droughts for the Sacramento-San Joaquin basin. While future drought synchronicity may become less frequent than during 1902-2000, more synchronous flooding may occur. Manuscript is being prepared for submission to *International Journal of Climatology*.

4. *Potential usability of probabilistic climate forecasts in water resources management*

The water management sector is often thought of as a primary beneficiary of improved climate forecasts. Given the probabilistic nature of climate forecasts, however, the potential impacts of uncertain climate information on, say, reservoir

decisions are not well understood. A conceptual statistical framework is used here to understand the conditional forecast distribution of runoff volume based on a climate forecast. Two contributing factors are examined: (1) the correlation between the climate precursor (for example, El Niño-Southern Oscillation) and the target variable (here, runoff volume), and (2) the forecast uncertainty itself, which can be strongly case-dependent. The impact of climate forecast-type (long-term mean or climatology, climate information with no uncertainty, and climate information with uncertainty) on the forecast distribution of runoff volume is quantified for a simple one-reservoir system. Combining knowledge of the runoff forecast uncertainty with reservoir operation constraints also enables an a priori identification of cases when the probabilistic forecast is likely to be most or least useful for a particular reservoir system. (Manuscript to be submitted to the *Journal of American Water Resources Association*)

5. *High-resolution streamflow trend analysis applicable to annual decision calendars: A western United States case study*

Changes in the seasonality of streamflow in the western United States have important implications for water resources management and the wellbeing of coupled human-natural systems. An assessment of changes in the timing and magnitude of streamflow resolved at fine time scales (days to weeks and seasons) is highly relevant to adaptive management strategies that are responsive to changing hydrologic baselines. In this paper, we present a regional analysis of the changes in streamflow seasonality through a broad classification of streams and quantification of increases and decreases in flow, based on a quantile regression methodology. This analysis affords a useful research product to examine the diversity of trends across seasons for individual streams. The trend analysis methodology can identify windows of change, thus revealing vulnerabilities within decision calendars and species lifecycles, an important consideration for adaptation and mitigation efforts. (Published in the journal *Climatic Change*).

6. *What a difference a century makes: Understanding the changing hydrologic regime and storage requirements in the upper Colorado River basin.*

The changing hydrologic regime of the Upper Colorado River Basin presents a daunting challenge for water resources management. A major source of concern is that of ascertaining the nature of runoff variability and re-calibrating the systemic management and planning based on a more reliable envelope of water supply variations to meet societal needs. In this letter, we examine the long-term variability and change in the Upper Colorado annual runoff volume—quantified as shifts in the mean, interannual variability, and persistence—in a recent tree-ring based reconstruction extending back to 762AD. A simple model for reservoir storage requirement shows sensitivity to the changing hydrologic regime, with episodes of abrupt shifts toward significantly higher storage requirements, often not readily evident in runoff statistics. The results also suggest that benchmarking of climate models for regional water resources assessment should focus on the runoff statistics that are most relevant for storage requirement computations. (Published in the journal *Geophysical Research Letters*)

7. *Alteration of the Columbia River basin hydrologic regime by nonstationary climate and flow regulation*

Western North American river systems exemplify a unique blend of complexity—highly managed and dammed, heavy reliance on water supplies, climatic influences, increasing water demand, and at-risk ecosystems. A retrospective analysis to quantify the progressive alteration of the flow regime by regulation and response to climatic extremes illuminates the sensitivity of Columbia River and systems to climate and flow regulation due to human activities. The availability of daily streamflow and unimpaired version were used to understand the commingling effects of climate and flow regulation on a suite of streamflow metrics, particularly ones belonging to the Indicators of Hydrologic Alteration, known to reflect in health and integrity of stream ecosystems. Future integrative work is likely to incorporate climatic variations in environmental flow assessment. This study is likely the first of this kind for a major river basin. We plan submit this manuscript to *Water Resources Research*.

Project Publications (to date)

Jain, S., and J. K. Eischeid (2008), What a difference a century makes: Understanding the changing hydrologic regime and storage requirements in the Upper Colorado River basin, *Geophysical Research Letters*, 35, L16401, doi:10.1029/2008GL034715.

Kim, J.-S. and S. Jain (2010), High-resolution streamflow trend analysis applicable to annual decision calendars: A western United States case study. *Climatic Change*, Volume 102, Numbers 3-4, 699-707. doi:10.1007/s10584-010-9933-3

Student Training

Graduate Student (2)

Undergraduate Students (8)

One MS thesis

Broader Impacts

1. Watershed Sustainability using Programmable multimedia (Undergraduate students developed these models and website):

http://tok.asap.um.maine.edu/watershed_sustainability/

2. *Conference Presentations*

American Geophysical Union Fall and Spring meetings

American Meteorological Society Annual meeting

Climate change: Global risks, Challenges & Decisions, 2009, Copenhagen, Denmark

3. Organized Sessions at the AGU Spring and Fall meetings

4. Incorporated research results in to graduate course material and developed a new graduate course with a focus on water resources sustainability
5. Undergraduate and Graduate Student mentoring and student participation in project research.
6. *Jain and Eischeid (2008)* paper in *Geophysical Research Letters* selected to be American Geophysical Union Editor's Highlight Paper: AGU Press Release Storage requirements in the Upper Colorado River basin: Drastic changes through time.
7. *Jain and Eischeid (2008)* paper noted on the Front cover of the *Geophysical Research Letters*. Also covered on www.EurekaAlert.org
8. *Jain and Eischeid (2008, GRL)* paper was used as a key example of research seeking to produce usable knowledge for climate-informed water resources management at the workshop titled, "Tree-ring reconstructions of streamflow and climate and their application to Colorado River Basin water management - November 13, 2008, Boulder City, Nevada." This meeting was attended by 50 water managers in the western United States. PI worked closely with one of workshop organizers, Prof. C. A. Woodhouse (University of Arizona) to make the project research results accessible to water managers in the West, within the context of regional hydroclimatic variability and change. Workshop report available at: http://www.colorado.edu/treeflow/docs/Boulder_City_report.pdf

Impact of this project on PI's Professional Career

As PI's first NSF grant, this project provided graduate support to John Chandler, who completed a Master's thesis. PI plans to publish four journal articles based on results reported in the graduate thesis. The research completed under this grant is also paving the way towards follow-up research questions that emanate from the results. One particular focus is that of understanding the role of central Pacific SST anomalies on the cold season hydroclimatic variability over the North American region. Furthermore, for 21st century climate projections (from the impending IPCC AR5 projects), an important focus would be to assess the decadal predictability over the North American region and a framework to augment the use of predictive information for resource management. PI plans to pursue this under a future submission to the NSF.

Furthermore, the undergraduate research done under this grant focused on developing watershed sustainability education modules in the programmable media, Scratch with a focus on middle school students. This work has contributed directly to PI's Education and Outreach plan in his pending NSF CAREER program application. To broaden this work with middle school students, PI have developed partnerships with Stillwater Montessori School in Maine, as well as University of Maine's Wabanaki Center. A research proposal to initiate this work during the 2011-2012 is now being funded by the US Geological Survey Water Resources Research Institute program.

At the University of Maine, PI has developed a cross-disciplinary graduate course, titled “CIE 598: Managing our Water Resources.” This course has attracted graduate students from various disciplines. Case studies (including research on western North American hydroclimate pursued in this grant) have been pursued on several topics emerging from research completed as part of this project with high salience to environmental sustainability concerns. Key topics include: (a) the analysis of decision calendars and their relationships with multiscale climate variability, (b) the use of climate forecasts and attendant uncertainty for water resources management, and (c) the impact of nonstationary climate on water resources and environmental flow management concerns. This is a unique course offering at the University of Maine with climate and water as the integrating theme. PI plans to develop this course further as part of the pending NSF CAREER program proposal’s Education and Research plan.