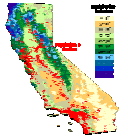
Regional Probabilities of Climatic Change for Decision Making



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ABSTRACT

Probability Distribution Functions (PDFs) of precipitation and temperature change over Northern California are produced using a Bayesian statistical approach, based on the output of 21 Global Circulation Models. These PDFs can be used outright to yield a general message regarding the kinds of overall regional climate changes suggested by GCMs over decades and seasons. The use of these probabilistic projections in natural resource management is attractive, representing a big step forward when compared to the traditional approach to decision making in the face of climate change that uses single model output. We use these distributions to derive synthetic time series using a K-nearest neighbor (K-nn) resampling scheme to produce alternative climate data sets at a local scale conditioned upon projected seasonal changes at a larger regional scale. Thus, we create ensembles of climate scenarios, guided by the densities derived from multiple GCMs, which are then used in a water resource management model of the Sacramento Basin, California. The water management model has been applied to several specific decision-making processes that are well suited for climate change analysis based on the application of a 3S (Sensitivity, Significance, and Stakeholder support) standard.

Quantifying Precipitation and Temperature Change with a Bayesian Approach

The change in precipitation and temperature represented by the PDFs from the Bayesian model are to be interpreted as the average change over the region of Northern California, for specific seasons and (multi-)decades. The statistical treatment summarizes projections from an ensemble of different Global Climate Models (GCMs), under a specific SRES emission scenario. In the formulation of the statistical model two criteria of model reliability are brought to bear:

1) BIAS, i.e. GCMs that are better at reproducing current climate are weighted more in the final result than GCMs that present a large bias

2) CONVERGENCE, i.e. GCMs that agree with each other when it comes to future projections are weighted more than GCMs that appear as outliers with respect to the ensemble "consensus".

The results shown are based on 21 GCMs contributing runs to the IPCC AR4 archive. The transient simulations assume SRES scenario A1B (considered a middle-of-the-range scenario in terms of the hypothesized rate of greenhouse gas emissions).

Let X_0 be the observed average climate (temperature or precipitation), X_j the current climate simulation from the *j*-th GCM, Y_j the corresponding future climate projection from the same GCM. Let s_0 be the natural variability estimated from observations over the region and s_j a measure of each model's variability. Let *m* and *n* be the true climate means for current and future periods, respectively. We treat them as uncertain, as we do with the 21 "s_j" and through the statistical model we derive posterior PDFs for them. The likelihood assumptions for the data are as follows:

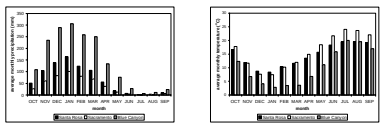
$X_0 \sim N(m,s_0)$

$X_j \sim N(m,s_j)$ $j=1,\ldots,21$

$Y_j \sim N(n+b*(X_j - m),l*s_j)$ $j=1,\ldots,21$

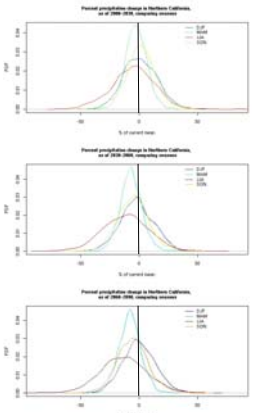
where $N(.,.)$ indicates a Normal distribution. The prior assumptions for all the uncertain parameters are "uninformative", letting the data drive the estimate of the posterior PDFs. As an example of the results of our statistical model, the figures at top of column 2 show PDFs of percent precipitation change and temperature change by season, as three-month averages. The baseline period is taken as 1980-1999 and the change shown is for 3 periods along the 21st century, 2000-2030; 2030-2060 and 2060-2090.

Avg. Climate of Northern California



Regional PDFs for the Sacramento Basin

Fig. 2a Precipitation change densities as 30-year averages, for the four seasons, relative to the 1980-1999 mean.



30-Year Average Changes

Seasonal Changes in Precipitation

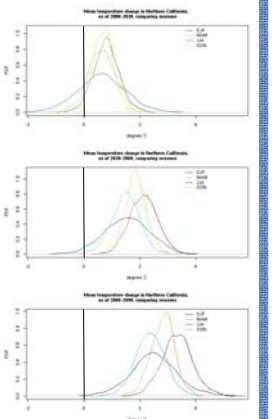
Seasonal Changes in Temperature

There appears to be more agreement among models regarding temperature predictions, although the flatter distribution of the change in winter temperatures suggests less agreement among models about the magnitude of that increase. The density spread for fall temperature in each 30year period is much tighter, suggesting more agreement among models. There is clearly a forecast warming trend in all models over the 90-year period, as noticeable across the three panels.

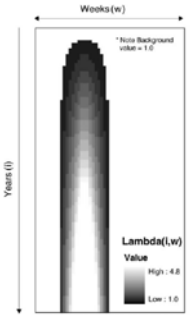
Changes in winter and spring precipitation are the most important, since the Sacramento Basin as well as most of California have a Mediterranean climate with most precipitation occurring in the winter months, followed by warm, dry summers (Fig 1).

From 2000-2030, the Bayesian results suggest about a 50% likelihood of either more or less precipitation, but the density for the spring months of that same period is slightly shifted towards negative changes (decreasing rainfall). The 2030-2060 decades are somewhat similar, while Bayesian results for the 2060-2090 period suggests a substantially higher likelihood of drier springs, on the order of 15%.

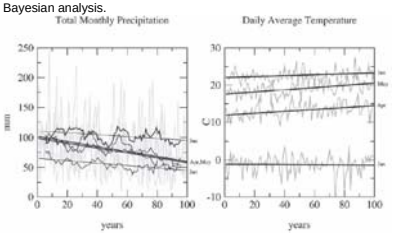
Fig. 2b Temperature change densities as 30-year averages, for the four seasons, relative to the 1980-1999 mean.



Statistical downscaling using a biased K-Nearest Neighbor



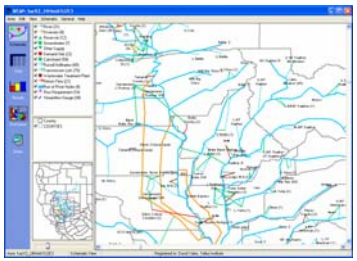
A bootstrapping technique, K-nearest neighbor, produces alternative climate data sets conditioned upon hypothetical climate scenarios, e.g., warmer-drier springs, warmer-wetter winters, etc. This technique allows for the creation of ensembles of climate scenarios that can be used in integrated assessment and water resource management models for addressing the potential impacts of climate change and climate variability. The k-nn technique is used to generate alternative climate scenarios based upon prescribed conditioning criteria, such as the kinds of changes suggested by the multi-model Bayesian analysis.



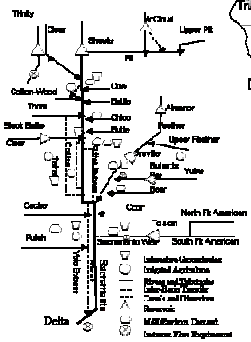
A Water Resources Management Model of the Sacramento Basin

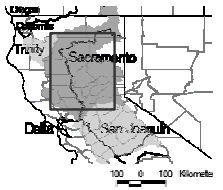
WEAP Schematic of Sacramento Basin

The Water Evaluation and Planning Version 21 (WEAP21) Integrated Water Resource Management (IWRM) model seamlessly integrates water supplies generated through watershed scale hydrologic processes with a water management model driven by water demands and environmental requirements, governed by the natural watershed and physical network of reservoirs, canals, and diversions.



Simplified Engineering Diagram





Model Includes:

Major and minor tributaries

Alluvial aquifers of the Central Valley

Trans-basin diversion from the Trinity River

Reservoirs (McCloud, Trinity, Shasta, Black Butte, Oroville, Almanor, Buzzard, and Folsom)

Main irrigation canals and demands

Major and minor municipal and industrial demands

Flood conveyance systems

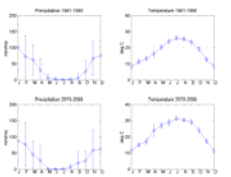
Decision Making

A comprehensive inventory of environmental decisions in the Sacramento Basin related to water quality and quantity and/or aquatic species and ecosystem health that are sensitive to climate change have been identified. This distillation was guided by the application of the 3S standard (Sensitivity, Significance and Stakeholder support) in consideration of each of the decision making processes (Purkey et al. 2005, Integrating a Climate Change Assessment Tool into Stakeholder-Driven Water Management Decision-Making Processes in California, J. of Water Management, in press).

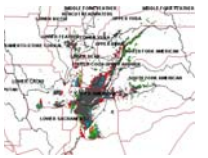
Decision Process	Decision Summary	Decision	Impact
Sacramento Flood Control Project	State of California is developing a policy related to the financial exposure to flood damage risk.	1-2 years	10-100+ years
Local Land Use Decision-making	Local developments must assure water supply exists over a 20-year planning horizon.	Ongoing	0-100+ years
Statewide Energy Planning	California Legislature requires an Energy Policy Report to recommend state policies	2 years	2-100+ years
Statewide Water Planning	The five year California Water Plan serves local water management decisions.	1-3 years	10-100+ years
Integrated Storage Investigations	Identify promising surface storage opportunities and to quantify both the costs and benefits	3-5 years	10-100+ years
Ecosystem Restoration Investments	The Ecosystem Restoration Program (ERP) is tasked to improve habitat and ecological function in the Bay-Delta system	3-5 years	5-100+ years
Yolo Bypass Shallow Water Habitat Restoration	Can the Yolo Bypass can be operated for improved environmental services without compromising agricultural and water supply?	1-2 years	5-100+ years
California Legislative Hearings	The Select Committee on California Water Needs to discuss how federal, state, and local water agencies are planning for climate change.	1-2 years	5-100+ years
Small Dam Removal (e.g. Battle Creek)	Pacific Gas and Electric, Department of Fish and Game, and community groups will decide whether full or partial dam removal is the most economically and ecologically beneficial.	1-2 years	5-100+ years
Hydropower Re-licensing (e.g. Yuba, American, and Bear)	Pacific Gas and Electric and community groups will define the best economical and ecological strategy for operation of reservoirs.	1-2 years	5-100+ years

Modeling environmental change throughout the Sacramento Basin

Climate Change Scenarios



Land Use Change



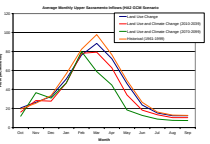
Land Use Projections for 1998 (gray), 2020 (green), 2050 (blue), and 2100 (red). Red solid lines are county demarcations. (Landis and Reilly, 2003)

Other forcing

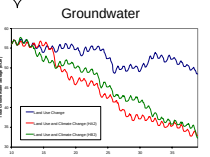
Other Changes in WEAP Model: M&I per capita demand; Population Growth; Agricultural production/cropping patterns Crop water use; Water use efficiencies; Dynamic reservoir operating rules; Changing water rights, Conjunctive use of Surface/Groundwater

output

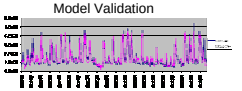
Surface Water



Groundwater



Model Validation



Water demand projections

References and Publications

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