Statistically Downscaling and Archiving WCRP CMIP3 Climate Projections for Planning Applications in the Contiguous United States

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ABSTRACT

Incorporation of climate change information into long-term evaluations of water and energy resources requires analysts to have access to climate projection data spatially downscaled to "basin-relevant" resolution. This is necessary in order to develop system-specific hydrology and demand scenarios consistent with projected climate scenarios. Analysts currently have access to "climate model" resolution data (e.g., from the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project 3 (CMIP3) multi-model data archive hosted by the Lawrence Livermore National Laboratory (LLNL) Program for Coupled Model Diagnosis and Intercomparison (PCMDI, http://www-pcmdi.llnl.gov/)). However, analysts do not currently have access to spatially downscaled translations of these datasets.

Motivated by a common interest to establish this data access, the U.S. Bureau of Reclamation and LLNL (through support from the DOE National Energy Technology Laboratory) have teamed to develop an archive of downscaled climate projections (temperature and precipitation) with contiguous U.S. geographic coverage, and a web-information service to provide Reclamation, LLNL, and other interested analysts free access to archive data. A contemporary statistical method was chosen for bias-correction and spatial downscaling of projections datasets, and applied to 112 WCRP CMIP3 climate projections (i.e. 16 GCMs and their multiple simulations of SRES A2, A1b, and B1 emissions pathways). Archive content will be stored and web-accessed at LLNL's Green Data Oasis (http://www.llnl.gov/icc/lc/gdo/). PCMDI's Climate Data Analysis Tools are being utilized to process custom data-retrieval requests.

OBJECTIVES (FY2007)

1. Downscale menu of climate projections (i.e. produce archive content):
   - monthly time series of 1950-2099; 1/8th degree spatial resolution within North American Land-Data Assimilation System domain (http://ldas.gsfc.nasa.gov/); average precipitation rate and mean temperature
2. Store archive content at LLNL; host web service at LLNL permitting free, public archive access.
3. Launch beta-version web service by 1 October 2007 with interface permitting regular-area or location-specific data retrieval of archive contents, plus documentation.

METHODS

Bias-Correction: Account for GCM tendencies (warm/cool, wet/dry)

1. Concatenate GCM time series (temperature and precipitation variables, monthly time step, gridded at GCM's spatial resolution) from simulations representing 1950-1999 (assuming estimated 20th Century forcings) and the 21st century (assuming projected forcings).
2. Spatially interpolate GCM time series to a common grid at 2° resolution (*GCM*).
3. Define reference climatology during 1950-1999 as observations aggregated to the same 2° grid (*OBS*).
4. Generate month-specific cumulative distribution functions (CDFs) of 1950-1999 conditions for both *GCM* and *OBS*, together serving as month-specific "Quantile Maps." (**Fig. 1**).
5. Use "Quantile Maps" to adjust *GCM* during 1950-1999 ("bias-correction" period) (**Fig 2**). Use same procedure to adjust *GCM* during the 21st century projection period (*Adjusted GCM*).

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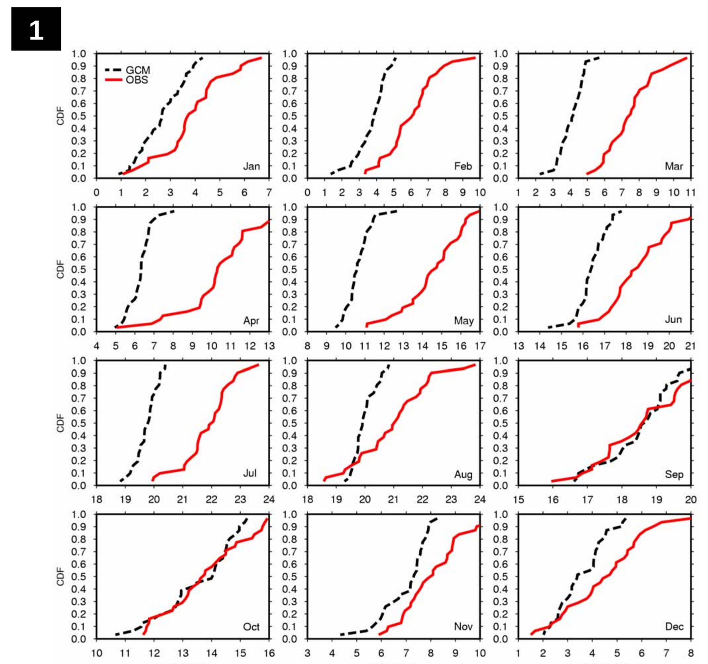
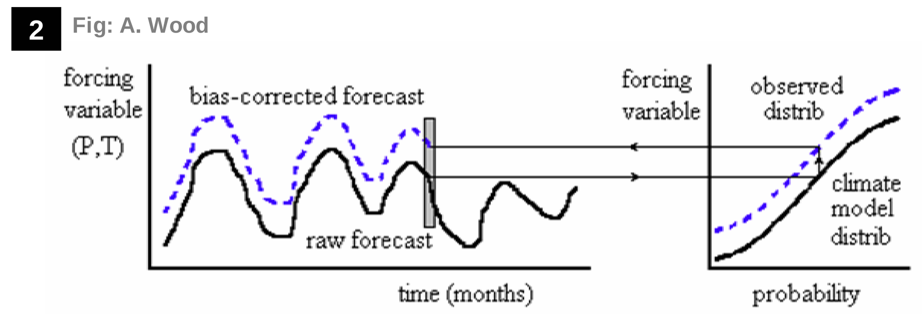


2 Fig: A. Wood



Notes:

For method details, see Wood et al. 2002, Wood et al. 2004, and Maurer 2007.

Adjusted GCM and *OBS* are forced to have the same mean and variance during the "bias-correction" period. GCM biases are assumed to have the same structure in 20th and 21st centuries.

Prior to bias-correction on *GCM* temperature, 21st century trends are identified and removed from *GCM*, then added to *Adjusted GCM* afterwards.

Relative changes in mean and variance in future period *GCM* output are preserved, mapped onto observed variance.

METHODS (continued)

Spatial Downscaling

1. Compute *Factor* time series from *Adjusted GCM* at each 2° location. For precipitation, *Factor* equals a given timestep's (month's) *Adjusted GCM* value divided by the monthly value (for the same month) from a randomly selected historical year (% ratio). For temperature, *Factor* equals *Adjusted GCM* minus the given month's 1950-1999 monthly mean. (e.g., **Fig. 3**, representing a time-step's precipitation *Factor* at each 2° location)
2. Spatially interpolate the 2° *Factor* time series to 1/8° resolution, and apply to the reference 1/8 gridded values for each day in the randomly selected historical month

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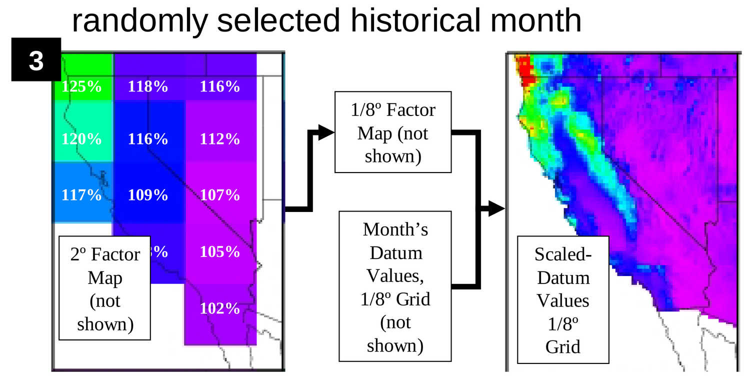

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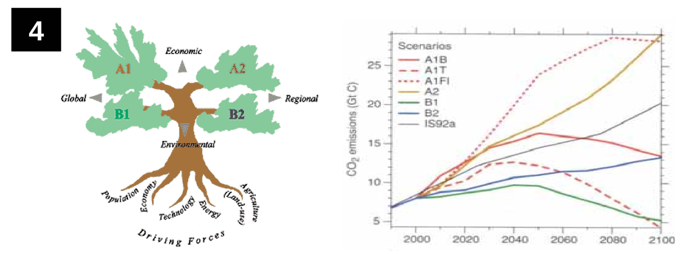

SRES A2: Technological change and economic growth more fragmented, slower, higher population growth (**Moderate to high path for 21st century**)

SRES A1B: Technological change in the energy system is balanced across all fossil and non-fossil energy sources, where balanced is defined as not relying too heavily on one particular energy source (**Mid-level estimate for 21st century**)

SRES B1: Rapid change in economic structures toward service and information, with emphasis on clean, sustainable technology. Reduced material intensity and improved social equity (**Lowest estimate for 21st century**)

Projections Scope

Bias-correction and spatial downscaling were applied to 112 WCRP CMIP3 projections and respective 1950-1999 simulations used for initialization, collectively produced by 16 GCMs (**Table 1**). GCM membership in the ensemble was *generally* based on the criterion of having simulated 20C3M (for bias-correction) and three future emission scenarios (SRES A1b, A2, and B1 (IPCC 2001) (**Fig 4**)).

Table 1. Scope of Archive Content

Modeling Group, Country	WCRP CMIP3 I.D.	SRES A2 runs:	SRES A1b runs:	SRES B1 runs:	Primary Reference [1]
Bjerknes Centre for Climate Research	BCCR-BCM2.0	1	1	1	(Furevik et al., 2003)
Canadian Centre for Climate Modeling & Analysis	CGCM3.1 (T47)	1…5	1…5	1…5	(Flato and Boer, 2001)
Météo-France / Centre National de Recherches Météorologiques, France	CNRM-CM3	1	1	1	(Salas-Mélia et al., 2006)
CSIRO Atmospheric Research, Australia	CSIRO-Mk3.0	1	1	1	(Gordon et al., 2002)
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0	1	1	1	(Delworth et al., 2006)
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.1	1	1	1	(Delworth et al., 2006)
NASA / Goddard Institute for Space Studies, USA	GISS-ER	1	2, 4	1	(Russell et al., 2000)
Institute for Numerical Mathematics, Russia	INM-CM3.0	1	1	1	(Diansky and Volodin, 2002)
Institut Pierre Simon Laplace, France	IPSL-CM4	1	1	1	(IPSL, 2005)
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	MIROC3.2 (medres)	1…3	1…3	1…3	(K-1 model developers, 2004)
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	ECHO-G	1…3	1…3	1…3	(Legutke and Voss, 1999)
Max Planck Institute for Meteorology, Germany	ECHAM5/ MPI-OM	1…3	1…3	1…3	(Jungclaus et al., 2006)
Meteorological Research Institute, Japan	MRI-CGCM2.3.2	1…5	1…5	1…5	(Yukimoto et al., 2001)
National Center for Atmospheric Research, USA	CCSM3	1…4	1…3, 5…7	1…7	(Collins et al., 2006)
National Center for Atmospheric Research, USA	PCM	1…4	1…4	2…3	(Washington et al., 2000)
Hadley Centre for Climate Prediction and Research / Met Office, UK	UKMO-HadCM3	1	1	1	(Gordon et al., 2000)

[1] See http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.php.

POTENTIAL APPLICATIONS

1) Location-Specific Assessment of Projection Consensus: Metric: "Change in 30-year Mean Annual" climate, 2041-2070 relative to 1971-2000. Assessment: survey archive contents at locations of interest (e.g., four shown on **Fig 5**), compute precipitation and temperature changes for each projection, fit distribution to member changes to permit consensus statements (e.g., nonparametric distribution shown in **Figs 6-9**).

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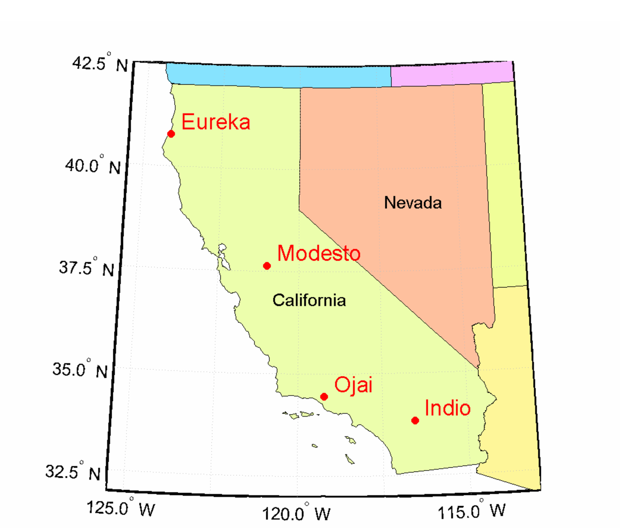

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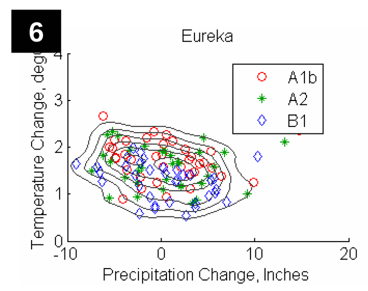

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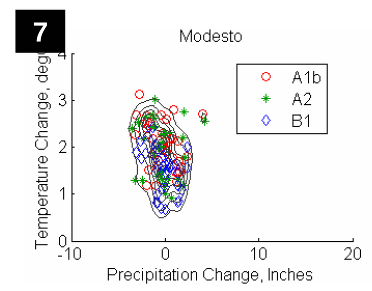

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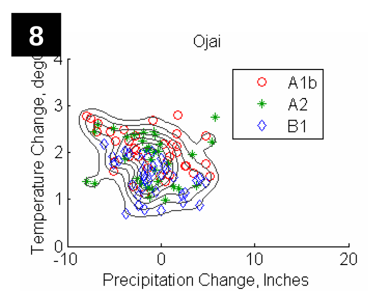

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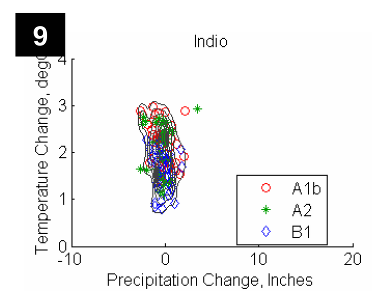
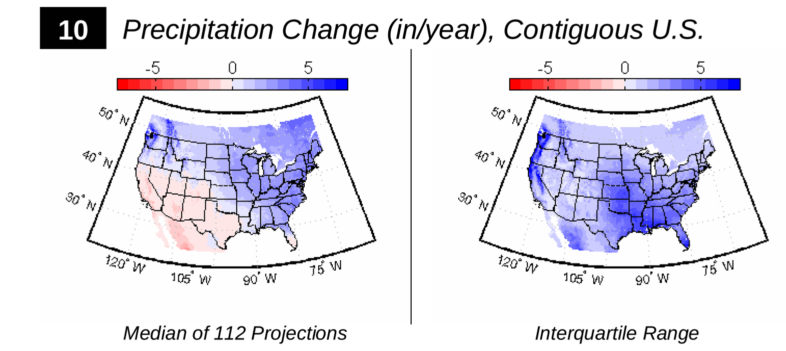


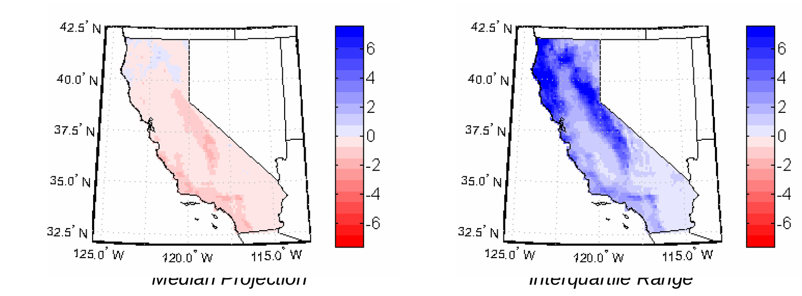
POTENTIAL APPLICATIONS (continued)

2) Large-Region Assessment of Projection Consensus: Metric: "Change in 30-year Mean Annual" climate, 2041-2070 relative to 1971-2000. Evaluate and map the ensemble median and interquartile range of projected change for the Contiguous U.S. (**Figs. 10-11**), a single state (**Figs. 12-13**), etc.

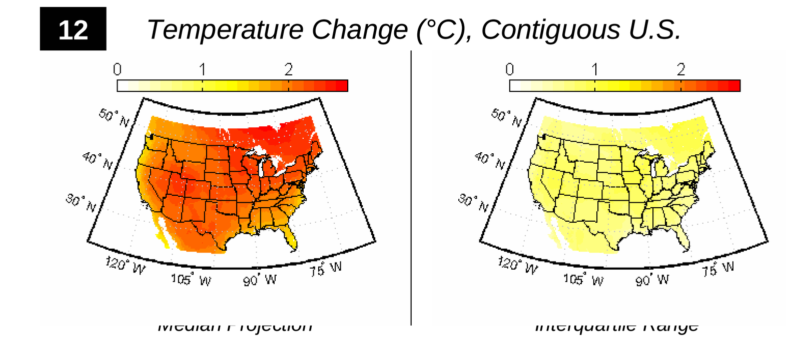
10 *Precipitation Change (in/year), Contiguous U.S.*



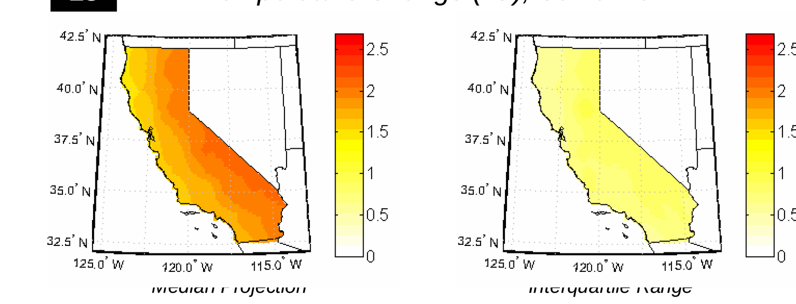
11 *Precipitation Change (in/year), California*



12 *Temperature Change (°C), Contiguous U.S.*



13 *Temperature Change (°C), California*



3) Regional Risk Assessment framed by Archive Content: Archive content can be used to frame water or energy resource risks associated with contemporary climate projections. Risk contrasts from impacts assessment in that scenario probabilities (*relative* in this application) are also estimated. The following is an example where the subject is risk to Sierra Nevada snowpack reduction:

- Downscaled climate projection data are used to drive a regional snow model (**Fig. 14**).
- Multiple projections are combined into an ensemble of possible futures (22 in this example).
- Results are used to form probabilistic statements about impact thresholds, useful for risk assessment at different locations (**Fig. 15**).

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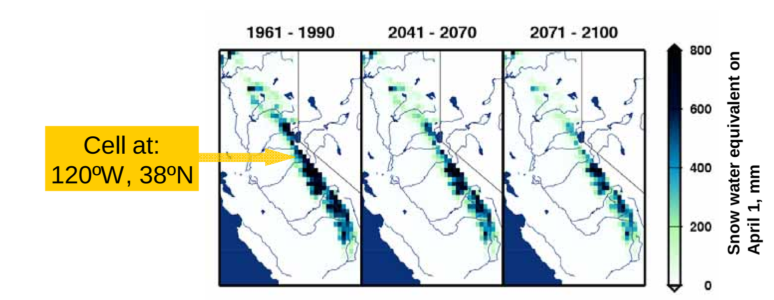
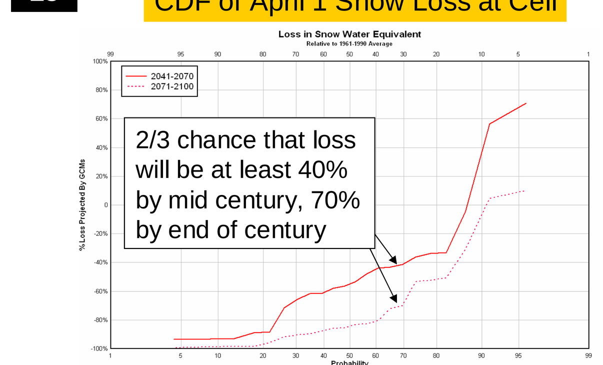


15 CDF of April 1 Snow Loss at Cell



STATUS AND FUTURE WORK

1. Archive Content: Downscaling has been completed, with content produced in netCDF format.
2. Web-Service: Under development. First-version interface will feature two versions of data-retrieval. The first is by ftp or pre-processed run-specific datasets. The second allows custom selection via web-form (spatially limited to regular area selections in this phase), data processing on GDO using CDAT tools, and email notification on where to get processed data via ftp. Irregular-area retrieval is being scoped.
3. User Evaluation: beta-version web service scheduled for launch in early FY08; user comments invited.

REFERENCES

Wood, A. W., E. P. Maurer, A. Kumar, and D. P. Lettenmaier, 2002. Long-range experimental hydrologic forecasting for the eastern United States, J. Geophysical Research-Atmospheres, 107(D20), 4429.

Wood, A. W., L.R. Leung, V. Sridhar, and D.P. Lettenmaier. 2004. Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs, Climatic Change, 15(62):189-216.

Maurer, E.P., 2007. Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California under two emissions scenarios, Climatic Change, 82, 10.1007/s10584-006-9180-9.

Intergovernmental Panel on Climate Change (IPCC). 2001. IPCC Third Assessment Report: Climate Change 2001.

ACKNOWLEDGMENTS

This project was jointly funded by the Department of Energy's National Energy Technology Laboratory and the U.S. Bureau of Reclamation Research and Development Office. We thank staff at LLNL PCMDI and Green Data Oasis for assistance with web-service scoping and development. We would also like to acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modeling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy.