Susceptibility of Colorado River Basin to Megadroughts in a Warming Climate

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1 Objective

The ongoing 2000s western U.S. drought has focused attention on drought susceptibility of the Colorado River Basin (CRB). There is a concern that many climate models predict permanently drier conditions for the next century over the CRB, however interpretation of these projections is complicated by their coarse spatial resolution, which does not resolve the role of the relatively small mountain headwaters area that is the source of much of the basin's runoff. Regional climate models (RCMs) are able to resolve these spatial scales, and for this reason arguably should be a preferred source of information about the future hydrology of the Colorado basin. The object of this work is two-fold:

1.To evaluate the performance of RCM and GCM simulations of the surface water balance of the CRB in comparison with observations.

2.To evaluate RCM predictions of the future land surface hydrology of the CRB

2 *Study area: the Colorado River Basin*

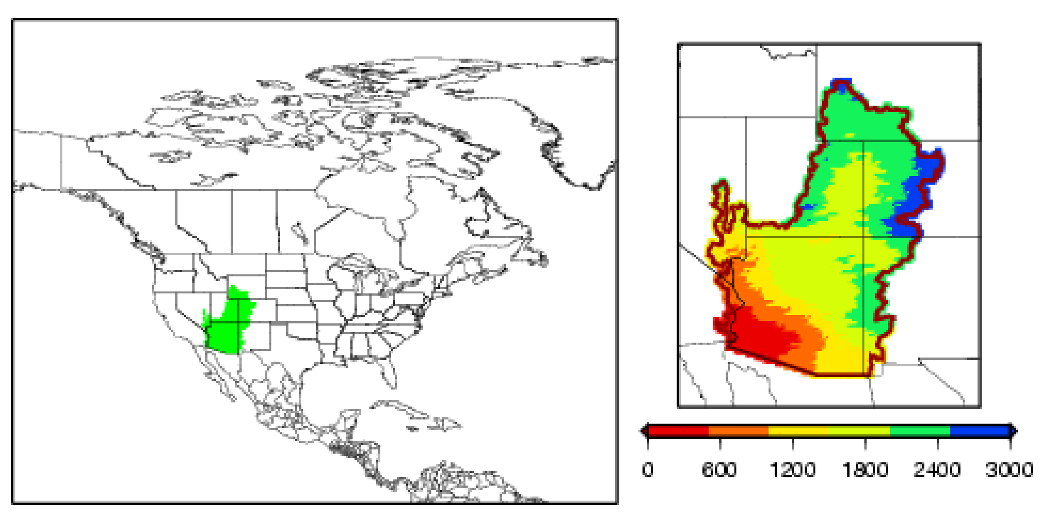

Figure 1 Location (left) and topography (right; unit: m) distribution for the Colorado River basin (CRB)

The Colorado River Basin (CRB) includes parts of seven U.S. states and Mexico. The headwaters lie in the Rocky Mountains of Wyoming and Colorado. 85% of the streamflow is generated from 15% of the area, while the lower basin contributes only 8% of the annual streamflow. With an annual average flow of roughly 15 million acre-feet, the Colorado River Basin (CRB) is not particularly large, especially when compared to other major U.S. rivers like the Columbia or Mississippi. But the Colorado River is the most important source of water in the vast, arid southwestern United States, and provides water for tens of millions of people from San Diego to Denver and a multitude of communities in between, as well as extensive irrigated agriculture. The CRB is especially vulnerable due to the sensitivity of discharge to precipitation and temperature changes (both of which affect snow accumulation and melt patterns as well as evapotranspiration), effects which are exacerbated by the semi-arid nature of the basin (Loaiciga, 1996).

3 Data and approach

I. NARCCAP

The North American Regional Climate Change Assessment Program (NARCCAP*) is intended to produce high resolution regional climate information that can address the issues outlined in Section 1. The simulations are being produced using multiple or single nesting of RCMs within both the host NCEP/DOE reanalysis, and several GCM simulations of future climate (see table below). The future climate simulations all use the IPCC SRES A2 global emissions scenario, over a domain covering the conterminous US and most of Canada (Figure 1).

NARCCAP is being conducted in two phases. Phase I (completed) consisted of 25-year simulations (1979-2004) using NCEP/DOE boundary conditions. In Phase II, multiple RCMs are being nested within four GCMs at 50 km spatial resolution for simulation periods 1971-2000 and 2041-2070. The RCM/GCM combinations are listed in Table 1. We focus here primarily on the Phase II runs that have been completed to date.

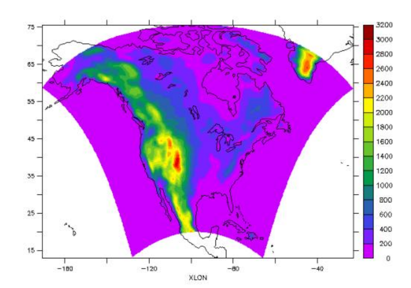

Figure 2 Elevation of the simulation region in NARCCAP

Table 2 Summary of NARCCAP data archived including RCM/GCM combinations

	Phase II				Phase I
	GFDL	CGCM3	HadCM3	CCSM3	NCEP/DOE
CRCM	--	finished	--	planned	finished
ECPC	running	--	planned	--	Finished
HRM3	planned	--	finished	--	Finished
MM5	--	--	planned	running*	Finished
RCM3	finished	finished	--	--	Finished
WRF	--	planned	--	finished	finished

II. Approach

•All calculations in this study used the seasonal and annual means based on the 3 hourly outputs from NARCCAP (http://www.earthsystemgrid.org) and monthly GCM output for 20C3M and A2 scenarios from CMIP3 (http://www-pcmdi.llnl.gov/ipcc/orientation.php), except for the HadCM3 run, which was produced for NARCCAP).

•We evaluated Performance of NARCCAP RCMs/GCMs and the host GCMs for current climate (1970-1999) through comparison with the 1/8-degree historical North American Land Data Assimilation System (NLDAS) data set (OBS for short; Maurer et al., 2002).

•The spatial resolution of the RCMs is 50 km. The resolution of the GCMs ranges from ~1.5 - 3.75 degrees latitude-longitude. For purposes of our analysis, we interpolated the GCM and RCM output to the 1/8-degree spatial resolution of OBS, and performed our comparisons using points only within CRB.

4a Results I. Evaluation for the historical period (1970-1999)

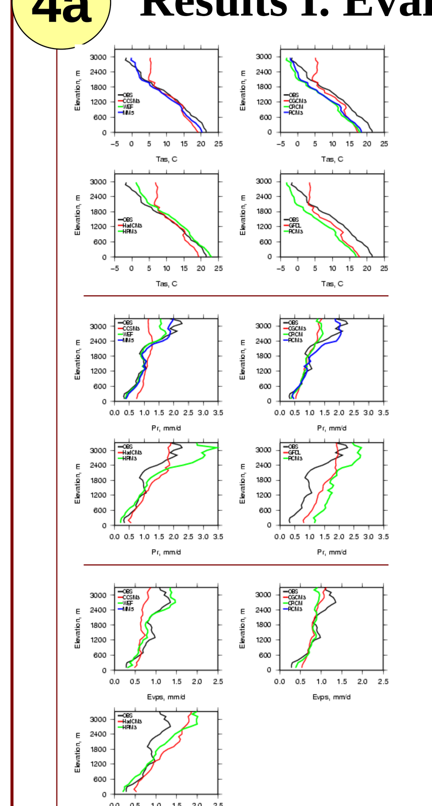

Figure 3 Surface air temperature (unit: ℃) as a function of elevation (unit: m) from RCMs and the host GCMs compared with the 1/8-degree historical North American Land Data Assimilation System (NLDAS) data set (OBS) over the CRB

Figure 4 The same as Figure 3, but for precipitation (unit: mm•d-1)

Figure 5 The same as Figure 3, but for evaporation (unit: mm•d-1)(E for RCM3 runs are not archived)

Table 2 Surface air temperature (T), precipitation (P), evaporation (E) and runoff (P-E) errors over Colorado River basin obtained from RCMs forced by their host GCMs (for example, MM5I/CCSM3 is MM5 integration driven by CCSM3) for 1971-2000. Spatial errors are measured in terms of Standard Deviation (SD), bias (BIAS), Root-Mean-Squared-Error (RMS) and pattern correlation (CORR). Temperature SDs, RMSs and biases are in units of °C and precipitation, evaporation and P-E are in units of mm/day.

Var	Models	SD	BIAS	RMS	CORR
T	CCSM3	4.9	-0.37	2.94	0.88
	MM5I/CCSM3	5.58	-1.08	1.93	0.95
	CGCM3	4.73	-1.2	3.11	0.86
	CRCM/CGCM3	5.80	-3.70	2.03	0.94
	RCM3/CGCM3	5.73	-3.25	2.07	0.94
	GFDL	5.03	-2.39	2.98	0.87
	RCM3/GFDL	5.56	-4.67	2.07	0.94
	HadCM3	4.45	0.56	3.04	0.88
	HRM3/HadCM3	5.7	1.4	1.98	0.95
P	CCSM3	0.14	0.14	0.51	0.22
	WRFP/CCSM3	0.35	-0.01	0.37	0.72
	MM5I/CCSM3	0.39	0.08	0.36	0.73
	CGCM3	0.23	-0.03	0.48	0.4
	CRCM/CGCM3	0.28	-0.02	0.42	0.62
	RCM3/CGCM3	0.48	0.16	0.45	0.6
	GFDL	0.34	0.6	0.52	0.34
	RCM3/GFDL	0.47	0.85	0.42	0.65
	HadCM3	0.44	0.38	0.57	0.31
	HRM3/HadCM3	0.82	0.34	0.65	0.62
E	CCSM3	0.11	-0.22	0.3	0.48
	WRFP/CCSM3	0.3	-0.04	0.24	0.71
	CGCM3	0.12	-0.06	0.29	0.5
	CRCM/CGCM3	0.16	-0.05	0.28	0.56
	HadCM3	0.38	0.42	0.41	0.34
	HRM3/HadCM3	0.47	0.22	0.38	0.59
P-E	CCSM3	0.17	0.35	0.33	-0.02
	WRFP/CCSM3	0.12	0.03	0.29	0.17
	CGCM3	0.15	0.03	0.29	0.26
	CRCM/CGCM3	0.19	0.03	0.25	0.50
	HadCM3	0.12	-0.04	0.31	0.06
	HRM3/HadCM3	0.47	0.11	0.42	0.46

RCMs in general are expected to capture the mean pattern of the host GCMs. However, their finer resolution should allow better representation of finer scale precipitation processes (especially those related to topographic variations). Our results show that the RCMs generally better reproduce OBS with respect to surface air temperature, precipitation, evaporation and runoff than do the host GCMs.

4b Results II: Climate change for RCMs

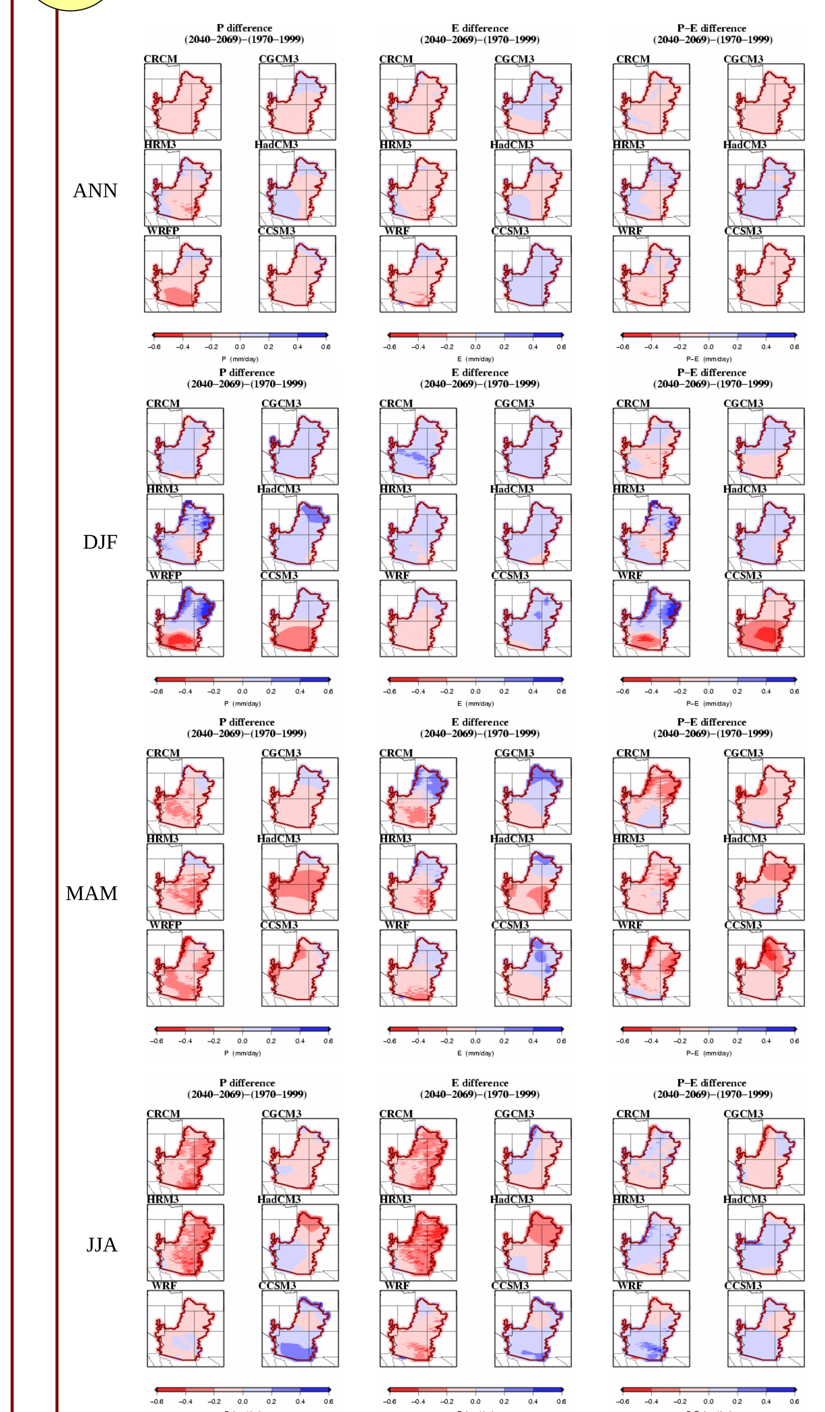

Figure 6 The distribution of annual mean precipitation (P), evaporation(E) and P-E change over CRB for RCMs and the host GCMs (2040-2069 mean minus 1970-1999).

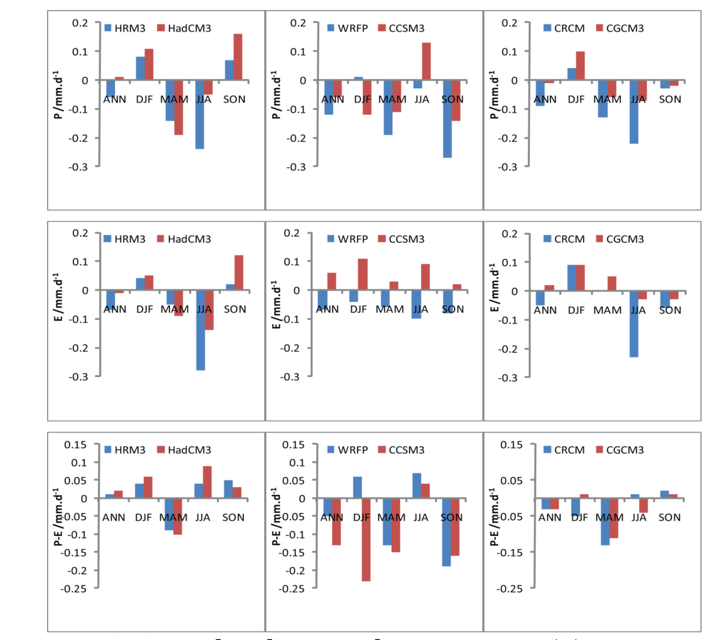

Figure 7. Annual and seasonal precipitation (P), evaporation (E) and P-E changes (2040-2069 mean minus 1970-1999 mean; unit: mm · d-1) for RCMs and the host GCMs averaged over the CRB

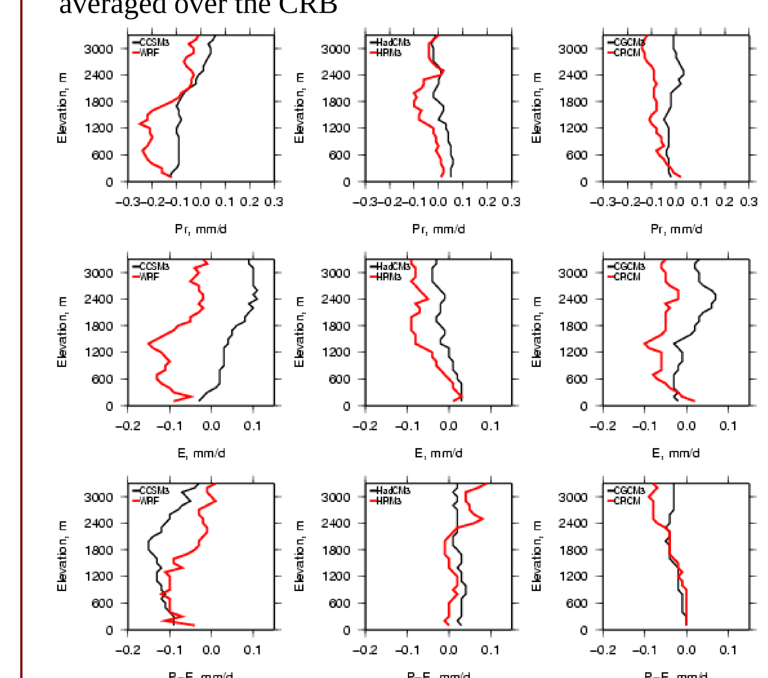

Figure 8. Variations of mean annual runoff change with elevation (2040-2069 mean minus 1970-1999 mean; unit: mm · d-1) for RCMs and the host GCMs averaged over the CRB

Averaged over the three RCMs and GCMs, the RCMs show slightly smaller annual P-E changes than do the host GCMs, although with considerable variations. Spring P-E dramatically decreases for all GCMs and RCMs due to reduced winter snow accumulation and spring melt. All but one GCM, and all RCMs, show increases in summer P-E, although the changes are small in some cases.

5 Summary

We analyzed the performance 3 RCM/GCM pairs archived by the North American Regional Climate Change Assessment Program (NARCCAP).

Changes in future climate projections of annual and seasonal surface air temperature, precipitation, evaporation and runoff for the RCMs are mostly consistent with the host GCMs.

RCM simulations of P-E changes for 2040-2069 are slightly smaller in magnitude than for the host GCMs, but with considerable variations among the RCM/GCM pairs. The higher spatial resolution of the RCMs accentuates changes at the highest elevation zones for most GCM/RCM pairs.

6 References

Loaiciga, H. A., Valdes, J. B., Vogel, R., Garvey, J., and Schwarz, H.: Global warming and the hydrologic cycle, J. Hydrol., 174, 83–127, 1996.

Maurer, E.P., A.W. Wood, J.C. Adam, D.P. Lettenmaier, and B. Nijssen, 2002: A Long-Term Hydrologically-Based Data Set of Land Surface Fluxes and States for the Conterminous United States, *J. Climate* 15, 3237-3251.

* http://www.narccap.ucar.edu/.