Assessment of Climate Change over Colorado River Basin as predicted by Regional Climate Models

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1. Objectives:

The 2000s western U.S. drought has drawn attention to drought susceptibility of the Colorado River Basin (CRB). 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 relatively small mountain headwaters that generate much of the basin's runoff. Regional climate models (RCMs) can resolve these spatial scales and, for this reason, should be a preferred source of information about the future hydrology of the CRB. The object of this work is two-fold:
To evaluate the performance of RCM and GCM simulations of the surface water balance of the CRB in comparison with observations.
To evaluate RCM predictions of the future land surface hydrology of the CRB.

2. Data and approach:

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 objectives. The simulations are being produced using multiple or single nesting of RCMs within both the host NCEP/DOE reanalysis (phase I), and several GCM simulations of future climate (Phase II). The future climate simulations all use the IPCC SRES A2 global emissions scenario, over a domain covering the conterminous US and most of Canada. The six RCMs participating in NARCCAP are WRF, MM5, CRCM, RCM3, ECPC RSM, and HRM3. The four GCMs are CCSM3, CGCM3, GFDL and HadCM3. Climate change projection is investigated for three RCMs/GCMs combinations (WRF/CCSM3, CRCM/CGCM3 and HRM3/HadCM3).

All calculations in this study used the seasonal and annual means based on the 3 hourly outputs from NARCCAP Phase II (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 customized 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 (NLDAS 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 NLDAS, and performed our comparisons using points only within CRB.

3. Evaluation

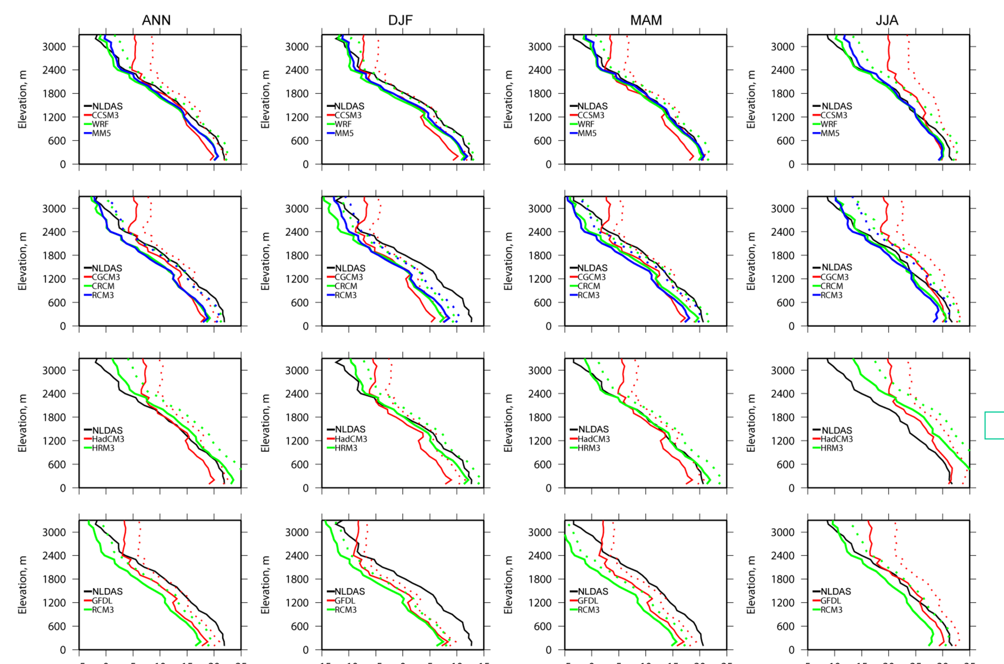

Figure 1 Variations in annual, winter, spring, and summer surface air temperature as elevation from RCMs/GCMs and the host GCMs comparing to the 1/8-degree historical NLDAS data set (NLDAS) over the CRB (the solid line is the historical period and the dash line is the future period)

Improvements in simulating surface temperature in mountainous regions have important effects on simulating ET, snowpack, and runoff, as indicated by the results. Such improvements seem essential for differentiating the climate change signals between that simulated by regional and global simulations.

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

4. Climate changes

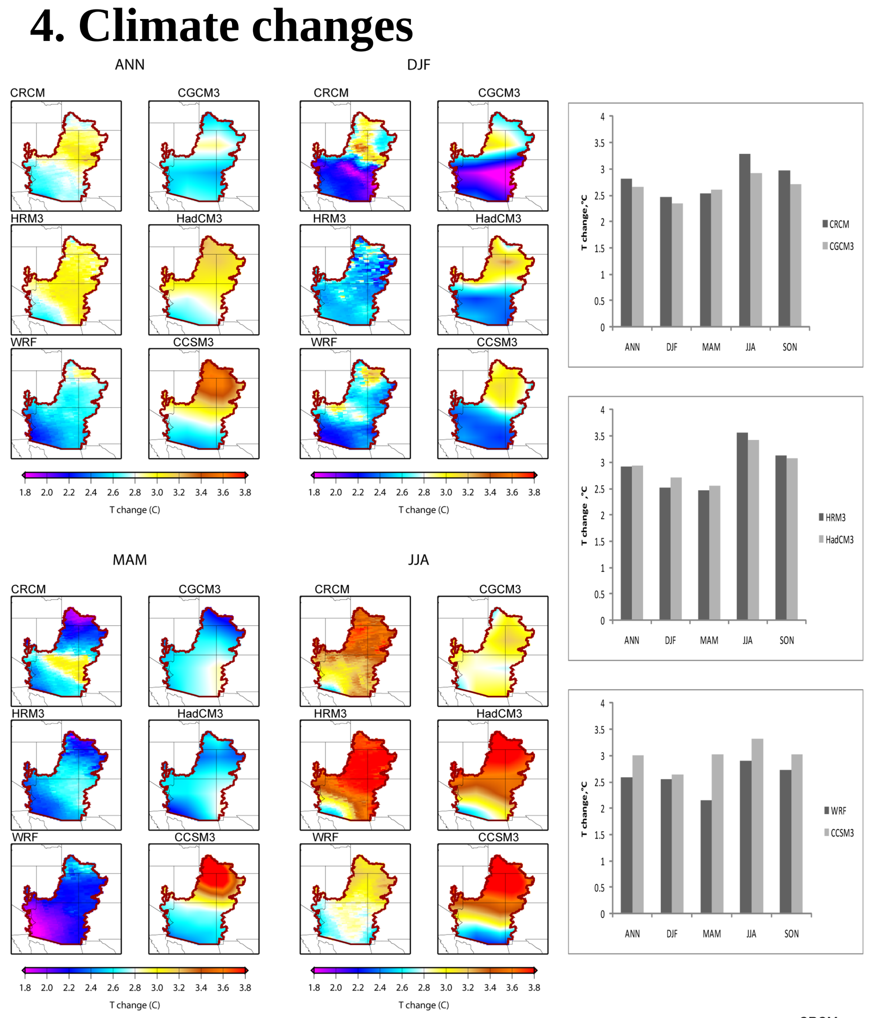

Figure 2. The distribution (left) and basin average (right) of annual, and seasonal surface air temperature (T) change over CRB for RCMs and the host GCMs for the future (2040-2069) minus current (1970-1999)

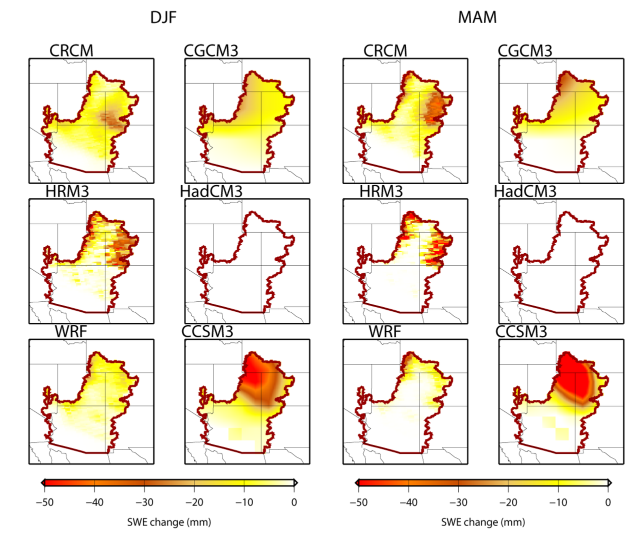

Figure 3. The distribution of winter and spring snow water equivalent (SWE) change for RCMs and the host GCMs for the future (2040-2069) minus current (1970-1999).

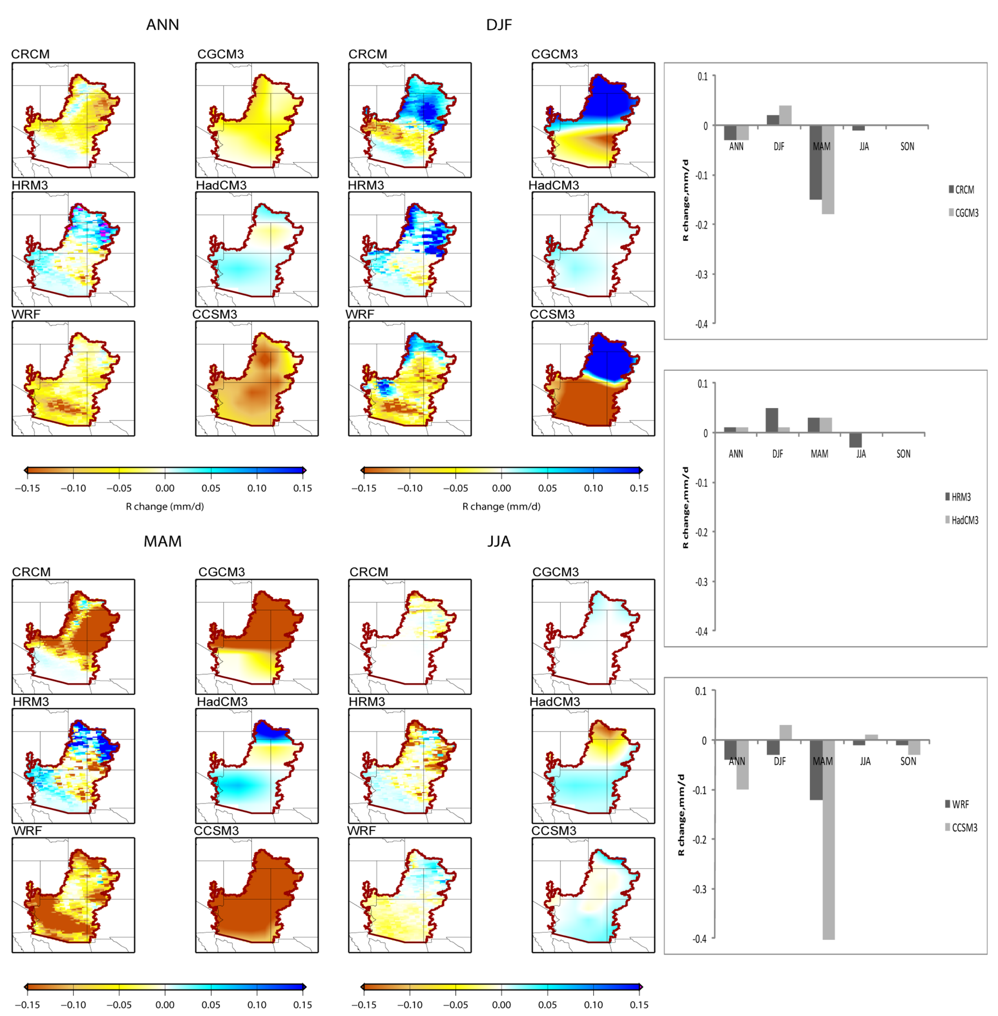

Figure 4. Similar to Figure 2, but for runoff (R) change

Changes in surface air temperature, runoff, and snow water equivalent at high elevations all indicate that headwater streams are less susceptible to a warming climate in climate change simulations that use RCMs than in simulations that only use GCMs.
Following Deque et al. (2005), the RMS spread (intermodal standard deviation) is measured as the dispersion of the RCMs or GCMs projection about their centroid. Table 4 shows that the GCM projection spread is greater than the RCM not only for annual temperature, but also for precipitation and runoff. Seasonal spread is apparently smaller for RCMs than GCMs in winter for temperature/precipitation and in spring for runoff. This indicates that the use of the RCMs leads to a reduction in the uncertainty of projections.

Table 4 Spread over CRB for temperature (℃), precipitation (mm d^{-1}), and runoff (mm d^{-1}) for RCM and GCM projected response.

		ANN	DJF	MAM	JJA	SON
T	**RCM**	**0.29**	**0.08**	**0.35**	**0.57**	**0.35**
	GCM	**0.32**	**0.33**	**0.44**	**0.46**	**0.34**
P	**RCM**	**0.05**	**0.07**	**0.10**	**0.19**	**0.10**
	GCM	**0.06**	**0.23**	**0.11**	**0.19**	**0.26**
R	**RCM**	**0.05**	**0.07**	**0.17**	**0.02**	**0.01**
	GCM	**0.10**	**0.03**	**0.38**	**0.01**	**0.03**

Table 1 Annual and seasonal surface air temperature (T) (T change, (2040-2069)-(1970-1999)) for area above 2250 m for RCMs and GCMs (unit: ° C)

	ANN		DJF		MAM		JJA		SON	
WRF	1.6	(2.71)	-9.71	(2.52)	1.16	(2.29)	13.49	(3.12)	1.44	(2.89)
CCSM3	5.26	(3.3)	-7.5	(2.85)	3.13	(3.4)	20.11	(3.73)	5.32	(3.21)
CRCM	0.11	(2.9)	-12.02	(2.75)	-1.23	(2.32)	13.57	(3.52)	0.11	(3.03)
CGCM3	4.92	(2.67)	-7.81	(2.59)	2.52	(2.46)	19.15	(2.96)	5.8	(2.69)
HRM3	4.3	(2.92)	-7.4	(2.43)	1.62	(2.37)	17.65	(3.79)	5.33	(3.08)
HadCM3	6.99	(3.09)	-5.58	(2.96)	5.45	(2.52)	20.34	(3.72)	7.74	(3.15)

Table 2 Annual and seasonal snow water equivalent (SWE) change (2040-2069)-(1970-1999) for RCMs and GCMs over the CRB (unit: mm (%))

	ANN		DJF		MAM		JJA		SON	
WRF	-1.9	(-32%)	-4.5	(-27%)	-2.3	(-41%)	--	--	--	--
CCSM3	-11.3	(-57%)	-15.4	(-51%)	-18.9	(-73%)	--	--	--	--
CRCM	-4.3	(-26%)	-7.9	(-21%)	-8.4	(-33%)	--	--	--	--
CGCM3	-4.0	(-36%)	-8.4	(-28%)	-7.2	(-50%)	--	--	--	--
HRM3	-3.8	(-28%)	-7.7	(-24%)	-6.7	(-32%)	--	--	--	--
HadCM3										

Table 3 Similar to Table 1, but for runoff (R) (unit: mm · d^{-1} (%))

	ANN		DJF		MAM		JJA		SON	
WRF	-0.03	(-16%)	0	(0%)	-0.11	(-19%)	0	(0%)	0	(0%)
CCSM3	-0.07	(-16%)	0.27	(61%)	-0.56	(-50%)	0.01	(17%)	0	(0%)
CRCM	-0.07	(-16%)	0.06	(200%)	-0.32	(-19%)	-0.03	(-75%)	0	(0%)
CGCM3	-0.04	(-13%)	0.12	(80%)	-0.3	(-27%)	0.01	(100%)	0	(0%)
HRM3	0.05	(5%)	0.15	(88%)	0.2	(7%)	-0.15	(-20%)	0.01	(5%)
HadCM3	0.01	(6%)	0.01	(20%)	0.04	(15%)	-0.02	(-9%)	0	(0%)

5. Summary

Although the RCMs do not significantly improve the simulation of precipitation, improvements in simulating surface temperature in mountainous regions have important effects on simulating ET, snowpack, and runoff, as indicated by the results. Such improvements seem essential for differentiating the climate change signals between that simulated by regional and global simulations.

Runoff generation and change in the CRB is highly elevation-dependent.

Although both RCMs and GCMs project decreases over the CRB, the RCMs project less warming in the spring and thus have smaller decreases in runoff in the spring (arising from smaller temperature changes and better topographic resolution), which results in smaller decreases in annual runoff as compared with the GCMs.

Surface air temperature, runoff, and snow water equivalent changes at high elevation all indicate that headwater streams are less susceptible to a warming climate in the RCM climate change simulations than in GCM simulations.

References:

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