A projection of the hydroclimate in California during the mid-21st century using the JIFRESSE Regional Earth System Model

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Abstract

The UCLA-JPL Joint Institute for Regional Earth System Science and Engineering (JIFRESSE) Regional Earth System Model (RESM) has been used to investigate the impact of the climate change induced by increased GHG on the cold season hydroclimate in California during the 20-year period 2035-2054 on the basis of the NCAR-CCSM3 global climate projection corresponding SRES-A1B emission. The results show that the low-level temperature in California will increase by 1–2.5 C, with larger increases in high-elevation regions and in winter. Noticeable decreases in snowfall, snow-water equivalent, and surface albedo in high-elevation regions in the projected mid-twenty-first century climate suggest that the temperature increases in the high-elevation regions are partially amplified by local snow-albedo feedback. Precipitation decreases over the entire cold season. The seasonal variations in the precipitation change pattern are primarily associated with the climate change signals in rainfall. Snowfall decreases in the warmer climate, most noticeably in winter. The changes in seasonal precipitation result in the reduction in snowmelt, seasonal-mean snow-water equivalent, and runoff during the cold season, especially in high-elevation regions. The decrease in the high-elevation snowpack is of a special concern, as it is among the main sources of warm season water supply in California.

1. INTRODUCTION

Observational and modeling studies strongly suggest that significant global climate change induced by an increase in greenhouse gases (GHGs) will occur in this century. Future changes in the regional hydroclimate in response to the global change is an important concern in California that is characterized by extreme contrasts in precipitation with wet cold seasons and dry warm seasons. California relies heavily on cold season precipitation and snow accumulation for the water supply in dry warm seasons. Observational studies (e.g., Stewart et al. 2005) revealed that global climate change appears to be affecting the snowpack and snowmelt-driven runoff in California's mountainous region. Thus, reliable assessments of the impact of the climate change on the future water resources in the region has been an important concern to the water managers in California (Anderson et al. 2008) . This being said, the amplitude and consequences of the changes to the global climate are still far from certain, particularly on regional and local scales. Figure 1a shows projections of the annual mean surface air temperature (SAT) change for southern/central California from 18 different GCMs that have contributed to the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Noteworthy is the fact that every model predicts increases in SAT for this region, albeit with an uncertainty factor of 3 at the end of the 21st century. More problematic for determining the consequences to society are the associated projections for precipitation change (Figure 1b). In this case, the models are not even in agreement whether California will become wetter or drier with the uncertainty ranging up to ± 20% of the annual mean rainfall.

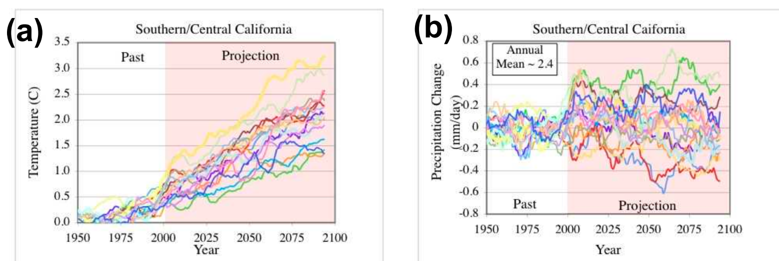

Figure 1 Model simulations of the changes in annual mean surface air temperature (a) and precipitation (b) for Southern/Central California relative to a climatology calculated for the period 1900-1999. Each line represents a different GCM contribution (N=17) for the IPCC' s 4th Assessment Report (2007).

A considerable part of the uncertainty and disagreement in Figure 1, especially precipitation, lies in the fact that the global models poorly, or do not, resolve important physical processes and terrain variations that are fundamental for a realistic simulation for regional scales. Thus downscaling of GCM-generated climate scenario is necessary for assessing regional impact of global climate change.

This study investigates the impact of the climate change induced by increased GHGs on the surface hydroclimate in California by dynamically downscaling a global climate from the NCAR CCSM3 on the basis the IPCC SRES-A1B emission profile.

2. MODELING SYSTEM AND EXPERIMENTS

To address the above needs, the UCLA Joint Institute for Regional Earth System Science and Engineering (JIFRESSE), a collaboration between UCLA and the Jet Propulsion Laboratory (JPL) to improve understanding and to develop projections of the impact of global climate change on regional climates and environments, has developed a comprehensive Regional Earth System Model (RESM) that contains advanced treatments of the physical and dynamical processes in the atmosphere, coastal ocean, and land-surface (**Figure 2**). The RESM is based on one-way and/or interactive nesting of the models for limited-area atmosphere (WRF), ocean (ROMS) and air quality (CMAQ).

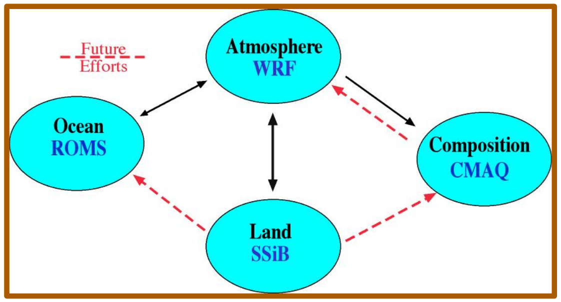

Figure 2. The UCLA Joint Institute for Regional Earth System Science and Engineering (JIFRESSE) Regional Earth System Model (RESM).

The dynamical downscaling is performed using the Weather Research and Forecast (WRF) model, version 2.2.1. Details of the WRF model can be found in the web site http://wrf-model.org. The physics options selected in this experiment includes the NOAH land-surface scheme (Chang et al. 1999), the simplified Arakawa Schubert (SAS) convection scheme (Hong and Pan 1998), the RRTM longwave radiation scheme Mlawer et al. 1997), Dudhia (1989) shortwave radiation, and the WSM 3-class with simple ice cloud microphysics scheme.

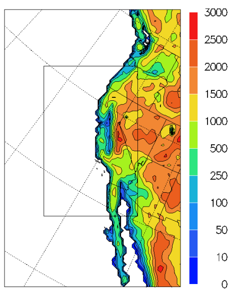

Figure 3 The model domain and the terrain (meters) represented at a 36km resolution.

The domain covers the western United States (WUS) region at a 36km resolution (Figure 3) and 27 σ layers. The inner box shows the California region for which the results are presented. At this horizontal resolution, the model terrain captures major orographic variations in the region; however, the high elevation regions in the Sierra Nevada and the narrow but steep coastal terrain is somewhat under-represented.

2. MODELING SYSTEM AND EXPERIMENTS-CONTINUED

Five sub-regions, Northern Coastal Range (NC), Southern Coastal Range (SC), Mt Shasta (SH), Northern Sierra Nevada (NS0, and Southern Sierra Nevada (SS), are selected for investigating more detailed spatial variations in the projected climate change signals within California. Among these, the three regions, SH, NS, and SS feed most of the major reservoirs in California. The wettest region in California (the Smith River basin) is located in the northern end of NC.

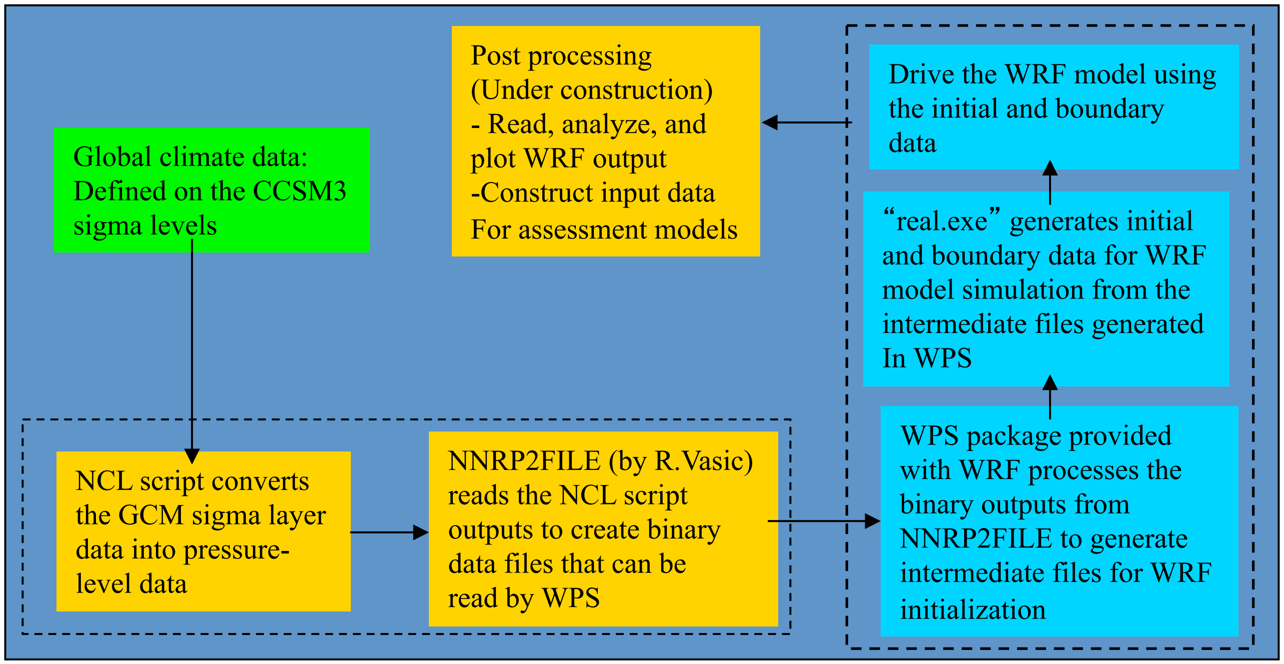

Figure 4. The data flow in the regional climate change projection.

The regional climate simulations are driven by an NCAR CCSM3 climate scenario generated according to the SRES-A1B emission profile. The climatology for the late 20th century and mid-21st century periods is calculated from the 20 cold season climatology for 1961-1980 and 2035-2054, respectively. The cold season covers the 6-mo period Oct-Mar and includes two seasons; fall (OND) and Winter (JFM).

3. RESULTS

3.1 Low-level temperature changes

The projected climate change signal shows that the low-level air temperature will increase in California by 1-2.5K with noticeable variations according to geography and season. Seasonally, the temperature signals are larger in winter (Fig. 5c) than in fall (Fig. 5b). Geographically, the projected warming signals vary according to latitudes, the distance from the coastline, and terrain elevation. The warming signals increase towards the north and away from the ocean. The warming signals also vary according to terrain elevation with the largest warming signals occurring in the high elevation Sierra Nevada region.

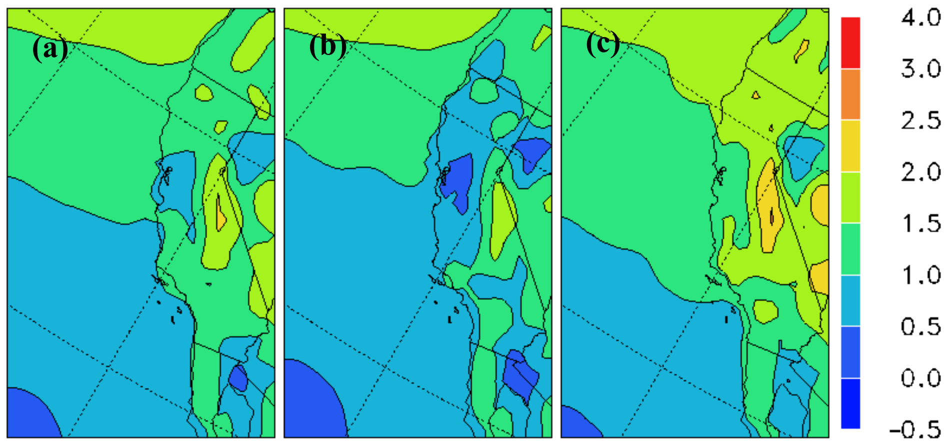

Figure 5. The climate change signals in the seasonal low-level air temperature: (a) Cold season (Oct-Mar), (b) Fall (Oct-Dec), and (c) Winter (Jan-Mar).

The projected changes in surface albedo decreases significantly in the high elevation regions in northern California and the Sierra Nevada (not shown). The changes in albedo are negligible in low elevation regions. The decrease in surface albedo is more pronounced in winter than in fall as well. In conjunction with the changes in snowfall and snowpack (Figure 8), the results show that the projected temperature change in the high elevation regions are partially augmented by local snow-albedo feedback.

3.2 Seasonal precipitation changes

The precipitation change signals also vary according to geography and season. In the early part of the cold season (i.e., fall), positive precipitation changes in northern California are contrasted by negative precipitation in southern California. This north-south pattern is reversed in winter. For the entire cold season, precipitation decreases in the entire California region.

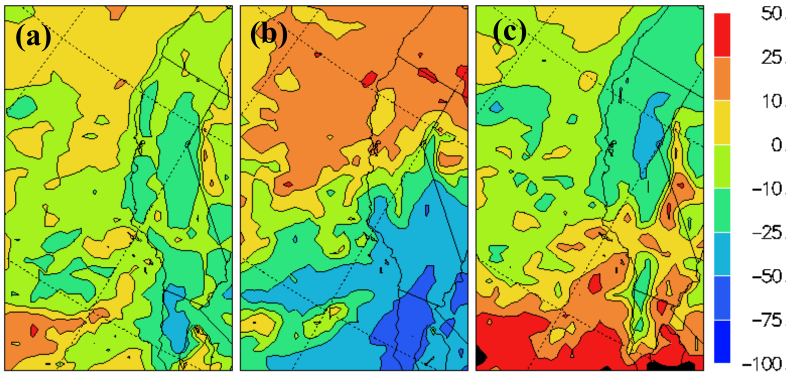

Figure 6. The climate change signals in seasonal precipitation (% of the control run values): (a) Cold season (Oct-Mar), (b) Fall (Oct-Dec), and (c) Winter (Jan-Mar).

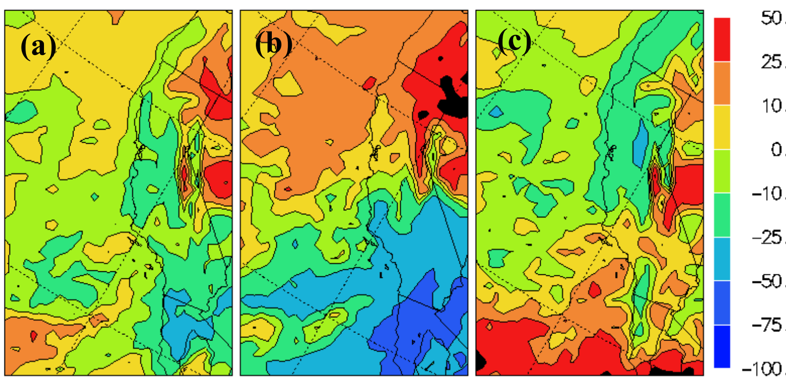

Figure 7. Same as Figure 6, but seasonal rainfall

The spatial variations in the precipitation changes in Figure 6 are associated chiefly with rainfall changes (Figure 7). The increase in rainfall in the northern Sierra Nevada region is one of the most important consequences of the low level warming; converting snowfall in colder climate into rainfall in warmer climate. Snowfall decreases everywhere in California except in the Sierra Nevada region in winter where the model terrain exceeds 2500m (not shown).

3.3 Snowpack changes

The seasonal-mean snow-water equivalent (SWE) in the Sierra Nevada region decreases by as much as 40% of the control climate in response to the low-level warming (Figure 8). The loss of winter snowpack in the Sierra Nevada is a crucial problem in the warm season water supply in California.

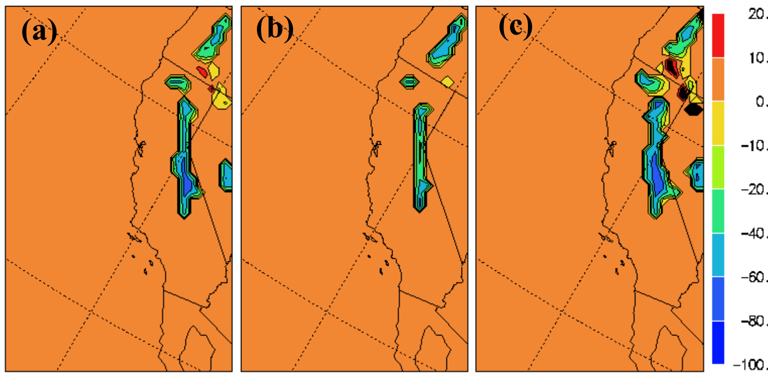

Figure 8. Same as Figure 6, but seasonal-mean snow-water equivalent (SWE).

3.4 Climate change signals: sub-regions in California

The seasonal-mean snow-water equivalent (SWE) in the Sierra Nevada region decreases by as much as 40% of the control climate in response to the low-level warming (Figure 8). The loss of winter snowpack in the Sierra Nevada is crucial problem in the warm season water supply in California.

Table 1. Climate change signals in key surface hydrologic variables within five sub-regions. The numbers in the parenthesis indicate the climate change signals in terms of the percent of the late 20th century RCM climatology.

	Season	NC	SC	SH	NS	SS
Precip (mm/mo)	Fall (OND)	22.5 (11.5)	-6.6 (-11.7)	23.5 (15.2)	16.1 (9.85)	-16.0 (-15.4)
	Winter (JFM)	-64.4 (-21.5)	-15.1 (-14.6)	-44.8 (-17.2)	-82.6 (-26.6)	-39.8 (-20.9)
	Oct-Mar	-21.0 (-8.46)	-10.9 (-13.6)	-10.7 (-5.2)	-33.2 (-14.0)	-27.9 (-19.0)
Rainfall (mm/mo)	Fall (OND)	25.4 (13.5)	-6.7 (-12.2)	34.8 (28.0)	29.6 (22.7)	-3.6 (-5.1)
	Winter (JFM)	-54.7 (-19.4)	-15.5 (-15.0)	-14.0 (-6.93)	-45.8 (-19.1)	-12.2 (-10.7)
	Oct-Mar	-14.6 (-6.23)	-11.2 (-14.0)	-10.4 (6.4)	-8.1 (-4.4)	-7.9 (-8.6)
Snowfall (mm/mo)	Fall (OND)	-2.9 (-41.7)	0.2 (n/a)	-11.3 (-40.5)	-13.5 (-40.5)	-12.5 (-36.5)
	Winter (JFM)	-9.7 (-53.1)	0.4 (n/a)	-30.8 (-51.3)	-36.8 (-52.6)	-27.6 (-36.5)
	Oct-Mar	-6.3 (-50.0)	0.3 (n/a)	-21.1 (-46.9)	-25.1 (-48.7)	-20.0 (36.5)
Runoff (mm/mo)	Fall (OND)	-0.1 (-0.4)	-0.2 (-11.2)	-0.7 (5.6)	-1.9 (-10.7)	-6.5 (-63.1)
	Winter (JFM)	-12.9 (-10.4)	-3.4 (-28.2)	-3.6 (-3.8)	-24.9 (-22.6)	-16.5 (-29.4)
	Oct-Mar	-6.5 (-50.0)	-1.78 (-26.7)	-1.4 (-2.7)	-13.4 (-21.0)	-11.5 (-34.6)
Snowmelt (mm/mo)	Fall (OND)	-2.89 (-42.0)	0.2 (n/a)	-10.1 (-36.4)	-11.3 (-37.7)	--8.5 (-29.9)
	Winter (JFM)	-9.75 (-52.8)	0.4 (n/a)	-32.3 (-51.9)	-39.4 (-54.0)	-30.7 (-38.6)
	Oct-Mar	-6.32 (-50.0)	0.3 (n/a)	-21.2 (-47.2)	-25.4 (-49.2)	-19.6 (-36.3)
SWE (mm)	Fall (OND)	0.1 (42.3)	0.0 (0.0)	-1.1 (-32.9)	-1.4 (29.9)	-3.1 (-42.7)
	Winter (JFM)	-1.3 (-78.5)	0.0(0.0)	-2.9 (-58.1)	-5.0 (-65.5)	-13.2 (-67.9)
	Oct-Mar	-0.6 (-60.8)	0.0 (0.0)	-3.2 (-52.0)	-3.21 (-52.0)	-8.2 (-61.1)
T2 (C)	Fall (OND)	0.87	0.59	0.95	0.98	1.38
	Winter (JFM)	1.73	1.42	1.77	1.94	2.09
	Oct-Mar	1.30	1.36	1.36	1.46	1.74

4 Conclusions

(1)The low-level air temperature will increase by 1-2.5K, with larger increases in high elevation regions during winter. The geographical variations in the projected warming signals are associated with the significant depletion of snowpack in the warmer climate and the prevailing westerlies.
(2)Surface albedo decreases notably in high elevation regions in northern California and the Sierra Nevada. The decrease in the surface albedo is more pronounced in winter than in fall.
(3)The cold season precipitation decreases in the entire region of California. The precipitation changes show strong interseasonal variations: Fall precipitation increases in the northern California and decreases in the southern California region. The winter precipitation changes show opposite features.
(4)Rainfall increases notably in high elevation regions in the northern Sierra Nevada where a significant portion of snowfall in the present-day climate falls as rain in the warmer climate.
(5)Snowfall decreases throughout the cold season by 25-50% of the amount in the present-day climate. The largest percent-decrease in snowfall occurs in winter.
(6)The snowpack in the high elevation Mt. Shasta and the Sierra Nevada regions decrease by over 40% in fall and nearly 70% in winter due to reduced snowfall. The reduced snowfall in the warmer climate also results in the reduction in snowmelt by 38% and 54% during fall and winter, respectively.
(7)The cold season runoff decreases in California due to reduced precipitation.
The climate change signals obtained in this study, especially the reduction in high elevation snowpack, suggests that the climate change will adversely affect the water resources in California. It must be noted that the results in this study represent only one of many global climate change scenarios that are equally plausible. The changes in the key surface hydroclimate fields projected in this study compares qualitatively with the results in previous studies (Kim et al. 2002); however, details in the projected climate change signals vary among these studies primarily due to the differences in the GCM climate projections used to drive an RCM.

5. Acknowledgement

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