5.5 LONG-TERM REGIONAL CLIMATE SIMULATIONS DRIVEN BY TWO GLOBAL REANALYSES AND A GCM FOR THE WESTERN U.S.

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1. INTRODUCTION

A major goal of the pilot project funded by the U.S. Department of Energy Accelerated Climate Prediction Initiative (ACPI) is to demonstrate an end-to-end assessment of climate change impacts on water resources in the western U.S. The project defines three elements of research to achieve the objective. First, ocean data assimilation is used to provide ocean conditions for initializing a coupled ocean-atmosphere model, the National Center for Atmospheric Research/ Department of Energy Parallel Climate Model (PCM). Second, the PCM is used to generate current and future climate scenarios. A total of three ensemble simulations were performed for the future conditions that extend from 1995 to 2100. Third, dynamical downscaling is performed to provide climate scenarios at the spatial scale needed for assessing climate change impacts on water resources in the western U.S (http://www.pnl.gov/ ccpp/acpi.html, http://www.cgd.ucar.edu/pcm/ACPI).

This paper focuses on the downscaling component of the pilot project using the Penn State/NCAR Mesoscale Model (MM5) (Grell et al., 1993). In this study, a 40-km spatial resolution domain covering the western U.S. is nested within a larger domain that covers the whole continental U.S. at 120 km resolution. Analyses and evaluation of the simulations are discussed in the sections below.

2. NUMERICAL EXPERIMENTS

To evaluate how well the RCM captures the regional climate features of the western U.S., two sets of simulations have been performed with the nested model configuration with 23 vertical levels using the NCEP/NCAR and ECMWF reanalyses. Both simulations were initialized on July 1, 1980, using conditions derived from the reanalyses. Lateral boundary conditions were updated every 6 hours based on large-scale conditions from the reanalyses. The simulation driven by the NCEP/NCAR reanalyses was performed for 1980-2000; the simulation driven by the ECMWF reanalyses lasts only 13 years between 1980-1993.

For climate sensitivity, the RCM was used to downscale the PCM control simulation and climate projections that were performed at T42 spatial resolution. The PCM control simulation was initialized using the assimilated ocean conditions of 1995 and run for 50 years while keeping emissions of greenhouse gases and sulfate constant at the 1995 level. Downscaling was performed for the first 20 years of the control simulation. For future climate projections, three ensemble simulations have been performed with the PCM, each initialized in 1995 and projected forward using the Business-As-Usual (BAU) scenario for greenhouse gases and sulfate for 1995-2100. Downscaling is being performed for each projection between 2040-2060 to elucidate mid-century effects of greenhouse warming.

To evaluate the model simulations, we used a dataset recently developed at the University of Washington by Dennis P. Lettenmaier and colleagues (http://www.hydro.washington.edu/Lettenmaier/gridded_data/). This dataset contains daily and monthly surface temperature and precipitation gridded at 1/8 degree. Our analyses focus mainly on precipitation, which is important for water resource applications.

3. MODEL EVALUATION

To evaluate the regional simulations driven by realistic large-scale conditions, Figure 1 compares the spatial distribution of precipitation as observed and simulated by the model using the NCEP/NCAR and ECMWF reanalyses for summer (JJA) and winter (DJF) averaged over the simulation period (1980-2000). Several model deficiencies are apparent in both simulations. First, although the simulations capture the larger amount of precipitation along the coastal mountains of the Cascades and the Sierra during wintertime, there is much less precipitation simulated along the low lying but hilly coastal zone. Furthermore, the simulations allow too much moisture to cross the coastal mountains and over simulate precipitation in the Columbia Basin and the intermountain zone. During summer, precipitation is lacking in the Northern Rockies and the southwest U.S. in both simulations.

Figures 2 and 3 compare the monthly precipitation averaged over the Columbia River (CRB) and Sacramento-San Joaquin (SSJ) River basins based on observations, RCM simulations, and reanalyses. Comparing the NCEP/NCAR and ECMWF reanalyses, precipitation is simulated more realistically by the latter in both basins. The NCEP/NCAR reanalyses often depict a seasonal cycle with strong peaks in late spring or early summer that are not found in the observations. Furthermore, the RCM simulation resembles much more the reanlyses precipitation in both basins when driven by the ECMWF than the NCEP/NCAR reanalyses. When driven by the ECMWF reanalyses, the RCM realistically captured the seasonal cycle and interannual variability of precipitation. When driven by the NCEP/ NCAR reanalyses, the RCM produced too much precipitation during winter. These results will have important implications in water resources applications.

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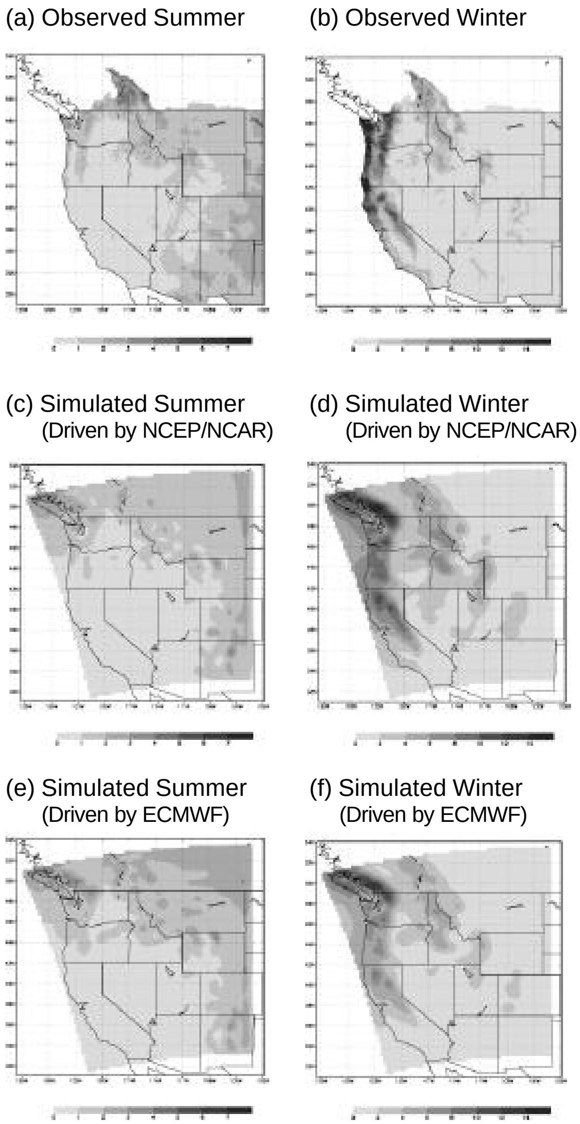

Figure 1. Observed and simulated seasonal mean precipitation for summer (JJA) and winter (DJF). Observations (a) and (b) are based on 1/8-degree gridded data for 1980-2000. Simulation driven by NCEP/NCAR reanalyses is shown in (c) and (d). Simulation driven by ECMWF reanalyses is show in (e) and (f).

For surface temperature, both simulations are within one degree C warmer than the observations in the river basins. Since the mean elevations of the basins at 1/8 degree are comparable to that of the model grids at 40 km resolution, the model biases cannot be explained by simple elevational differences.

4. CLIMATE SENSITIVITY SIMULATED BY GLOBAL AND REGIONAL CLIMATE MODELS

The control PCM simulation was initialized in 1995 and greenhouse gases and sulfate concentrations were

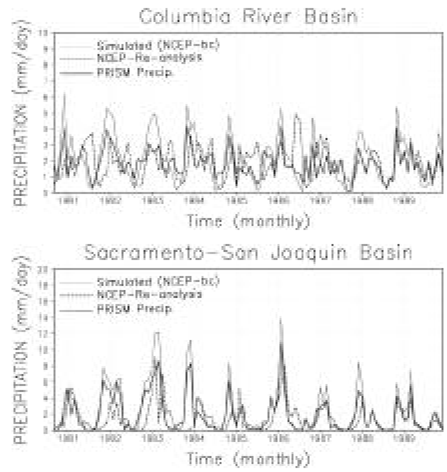

Figure 2. Basin mean observed and simulated monthly precipitation at CRB and SSJ. NCEP-bc refers to the RCM simulation driven by NCEP/NCAR reanalyses.

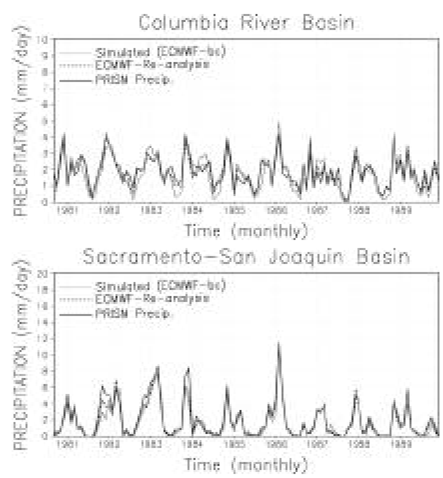

Figure 3. Similar to Figure 2, except ECMWF-bc refers to the RCM simulation driven by the ECMWF reanalyses.

kept constant during the 50-years simulation. The climate tends to reach a state that is in equilibrium with the 1995 forcings. By taking only the first 20 years of the control simulation, we are assuming that the control simulation is representative of the current climate conditions.

Figure 4 shows the mean summer and winter precipitation of the PCM and downscaled control simulations. During winter, the largest difference between the PCM and downscaled simulations are related to cold season orographic precipitation along coastal mountains. At a spatial resolution of 40 km, the downscaled precipitation has a more realistic spatial distribution which is similar to the simulations driven by reanalyses as shown in Figures 2 and 3. During the warm season, however, the regional climate simulation is distinctly different from the global simulations; this is more related

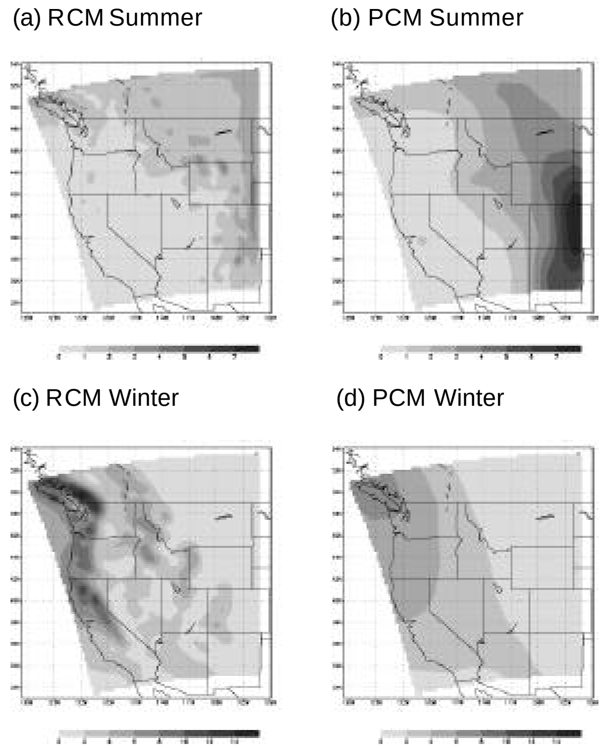

Figure 4. Seasonal mean precipitation (mm/day) simulated by the RCM [(a) and (c)] and PCM [(b) and (d)] driven by the PCM.

to differences in the physics parameterizations used in the models rather than spatial resolutions. Most notably, the downscaled simulation shows much less precipitation along the Rocky Mountain than the global simulation, and therefore is more realistic.

Figure 5 shows the mean seasonal cycle of precipitation based on observations of 1980-2000, PCM control simulation, and downscaled control simulation in the CRB and SSJ regions. The PCM simulated precipitation follows the observed seasonal cycle remarkably well in both basins. Because of the stronger orographic signature, the downscaled precipitation is much higher than the PCM simulation during the cold season at the SSJ. Although not shown, both global and regional simulations reproduce the seasonal variations of temperature very well within the two basins. Larger difference is found during spring where the simulations are up to 5oC too cold at the CRB. At the SSJ, the simulations are colder than the observation during spring and vice versa during summer.

5. CONCLUSIONS

This paper examines dynamical downscaling of climate conditions in the western U.S. Numerical experiments were performed with the MM5 for long-term climate simulations driven by the NCEP/ NCAR and ECMWF reanalyses. Results show that the ECMWF reanalyses and regional climate simulations driven by

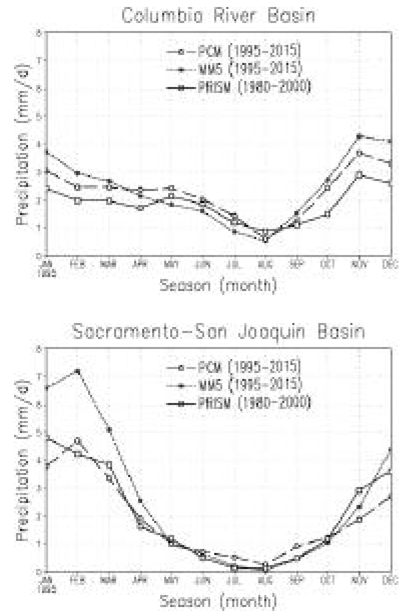

Figure 5. Monthly mean precipitation based on observed and simulated climatology.

the ECMWF reanalyses compare more favorably with observations than the NCEP/NCAR reanalyses. While the mean precipitation and surface temperature over the CRB and SSJ basin in the regional simulations are similar to that of the reanalyses used to drive the RCM, the spatial distributions in the RCM simulations are clearly more realistic and reflective of the topographic forcings of the western U.S. Model deficiencies identified will be addressed in future studies using sensitivity experiments with various domain configurations and physics parameterizations.

Similar conclusions can be drawn from the downscaling experiments using PCM runs. The PCM control simulation of precipitation and temperature are found to be very realistic at the river basins. However downscaling produces much more precipitation in the SSJ basin. Obviously bias correction must be applied to both the PCM and RCM simulations to realistically describe the spatial distribution of precipitation for simulating the hydrologic conditions of the river basins in the west. This issue is being addressed in the ACPI pilot project. Downscaling of the PCM BAU runs is being performed to examine differences between the PCM and downscaled climate signals and their implications to assessing climate change impacts on water resources in the western U.S.

6. REFERENCES

Grell, G., J. Dudhia, and D. R. Stauffer, 1993: A description of the fifth generation Penn State/NCAR mesoscale model (MM5). NCAR Tech. Note., NCAR/TN-398+IA, Nat. Cent. for Atmos. Res., Boulder, Colorado.