A Comparison of Orographic Precipitation Simulated Using High Spatial Resolution and a Subgrid Parameterization

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1. Introduction

Motivations

Orography exerts a major influence on precipitation and land surface processes including snowpack and runoff

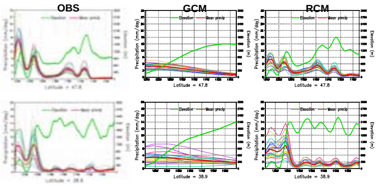
The impacts of large scale variability such as that associated with ENSO on the surface climate are modulated by the complex terrain to create important regional differences

Improved representation of orographic effects in climate models can lead to improved seasonal climate and hydrologic forecasting skill

Previous efforts in simulating orographic precipitation using mesoscale model and subgrid parameterizations have identified strengths and weaknesses in both approaches

This study compares these approaches with the goal to identify methods to improve the simulation of orographic effects on precipitation and surface hydrology in mountainous regions

Regional climate is determined by the interaction of forcings and circulations that occur at the planetary, regional, and local spatial scales



Numerical Experiments

(1) GCM simulation
The subgrid orographic precipitation scheme of Leung and Ghan (1996; 1998) has been implemented in the NCAR Community Atmosphere Model (CAM). A simulation has been performed at 1x1.25 degree explicit horizontal resolution with the subgrid scheme using the AMIP SST as lower boundary conditions.

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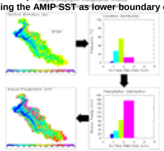


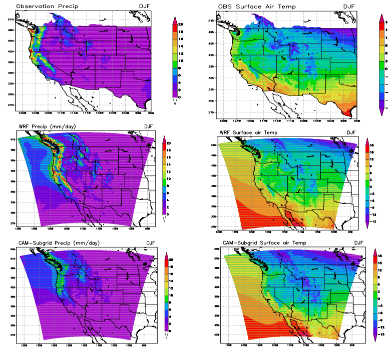
(2) RCM simulation (15km resolution)
The Weather Research and Forecasting (WRF) model has been applied at 15 km spatial resolution to the western U.S. The simulation was driven by the NCEP/DOE Reanalysis and AMIP SST for 1994-1999.

(3) RCM simulation (30km and 5km resolution)
Another set of WRF simulations has been performed using one-way nesting from 30km to 5km horizontal resolution for 1988-1993. All WRF simulations used the WSM6 cloud microphysics scheme, Noah LSM, and CAM shortwave and longwave radiation.

(4) Comparison
For comparison of the GCM and RCM simulations, the GCM simulation has been mapped to the RCM domain by linearly interpolating the GCM subgrid variables simulated at each elevation band for the GCM grid cell that overlaps with the WRF grid cell based on the surface elevation of the RCM grids.

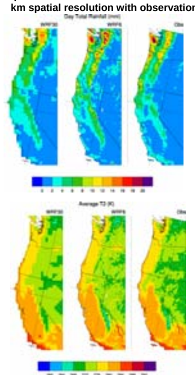
2. Comparison of Mean Climatology

Mean DJF Precipitation (mm/day) | **Mean DJF Surface Temperature (C)**



Note: Observations are based on a 1/8 degree gridded data developed by the Surface Hydrology Group at University of Washington

Comparison of WRF simulations at 30 km and 5 km spatial resolution with observations



(1) The WRF simulation has a general warm bias of up to 4C in the intermountain and Rockies. The CAM simulation has a small cold bias in the same regions, in addition to a cold bias in the Central Valley and the Southwest.

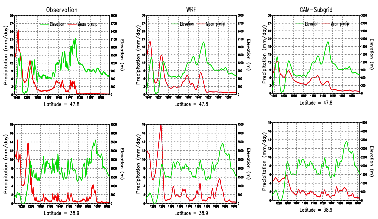
(2) The WRF simulated precipitation is comparable to the observed precipitation along the coastal range. The separation of the two precipitation bands along the coastal range and Cascades/Sierra is well captured. However, a wet bias is found along the Cascades and Sierra Nevada, as well as in the intermountain west and Rockies.

(3) The CAM simulated precipitation is generally much lower than the observed along the coastal mountains. Further inland, there is a wet bias in the Columbia basin and Rockies.

(4) At higher spatial resolution (WRF at 30 km, 15 km, and 5 km grid spacing), there is significant improvement in simulating precipitation along the coastal range. However, the wet bias in the Cascades and Sierra Nevada is amplified at higher spatial resolution.

3. Analysis on East-West Transects, Elevation-Precipitation Relationships, and Snowpack

Surface Elevation (m) and DJF Precipitation (mm/day) Across Two East-West Transects

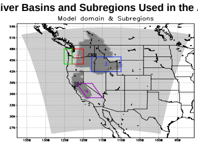


(1) The WRF simulation realistically captured the strong precipitation peak associated with the coastal range, but overpredicted precipitation in the Cascades and Sierra. The shift of the precipitation peaks towards the upwind slope side is well reproduced in all mountain ridges.

(2) The CAM subgrid simulation has a general dry bias associated with biases in the large scale circulation simulated by the GCM. Along both transects, the separation between the two precipitation bands associated with the coastal range and Cascades/Sierra is less clear.

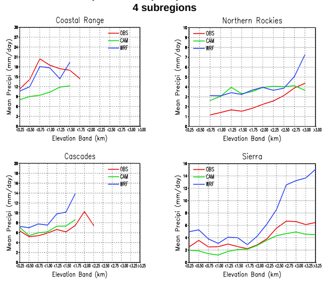
(3) The CAM simulation has a tendency for precipitation to maximize at the highest elevation rather than the upwind slopes. This reflects the neglect of rainshadow effects in the subgrid orographic precipitation treatment (i.e., areas belonging to the same subgrid elevation class receive the same amount of precipitation). Rainshadow is resolved at the explicit grid resolution (1x1.25 degree) and its effects are captured east of the Cascades and Sierra Nevada.

River Basins and Subregions Used in the Analysis



(1) Coastal Range
(2) Cascades
(3) Northern Rockies
(4) Sierra Nevada

Relationships between precipitation and elevation in 4 subregions



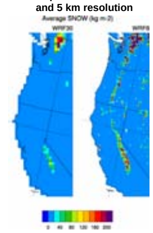
(1) There is a quasi-linear relationship between precipitation and surface elevation in the Northern Rockies, which are not directly under the influence of the maritime air mass.

(2) Near the Pacific coast, precipitation amount is influenced not only by topography, but the distance from the coast is an important parameter. This complicates the relationships in the coastal range, Cascades, and Sierra Nevada.

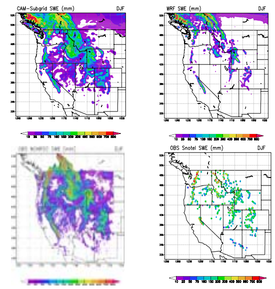
(3) At very high elevation, there is a tendency for the WRF and CAM simulations to show a wet and dry bias respectively compared to observations. In the subgrid parameterization, precipitation amount depends on moisture availability and orographic uplift. The increase in precipitation with altitude is reduced or even reversed at very high elevation.

(4) The amplification of precipitation at very high elevation in WRF could be a result of misrepresentation of orographic uplift associated with gravity waves. The wet biases at high elevation are found to be insensitive to the cloud microphysics schemes used.

DJF snowpack simulated at 30 km and 5 km resolution



Observed and simulated DJF mean snowpack



(1) Orography plays a dominant role in snow processes in the western US. The DJF mean SWE reaches as high as 800 mm in the northern Cascades, Sierra Nevada, and Northern Rockies.

(2) Snotel and remotely sensed SWEs are generally consistent, with slightly higher values in the snotel dataset.

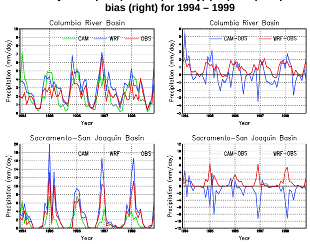
(3) Both simulations reproduced the elevation dependence, capturing the deeper snowpack along the Cascades and Sierra Nevada.

(4) The WRF simulation shows a larger negative bias as a result of a warm bias, particularly in the intermountain west and Rockies.

(5) Increasing spatial resolution has a large impact on snowpack, as the high terrain cannot be realistically represented at 30 km or even 15 km resolution.

4. Interannual Variations and Seasonal Cycle

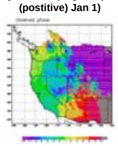
Monthly mean precipitation (mm/day) (left) and precipitation bias (right) for 1994 – 1999



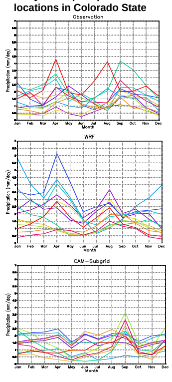
(1) Driven by realistic large scale circulation, the WRF simulation captures the interannual variations of precipitation very well compared to observations. The monthly biases shown on the right suggest an overprediction of moisture convergence into the river basins during the cold season that remains nearly constant from year to year. This results in a wet bias of 20-30% in the cold season basin mean precipitation.

(2) Driven only by AMIP SST, the CAM simulated large scale circulation does not reflect the interannual variations that were observed during 1994 – 1999. The dry bias in the Sacramento-San Joaquin basin suggests a bias in the location of the jet stream.

Observed seasonal phase of precipitation (each unit corresponds to 10 days before (negative) and after (postive) Jan 1)



Monthly mean precipitation at 20 locations in Colorado State



(1) The seasonal cycle of precipitation in the western US is dictated largely by the large scale circulation. However, topography also plays an important role in defining some regional differences.

(2) In the western US, precipitation usually peaks in the winter time, as abundant moisture is brought in from the Pacific Ocean. Further inland and in the Southwest, however, precipitation peaks in the summer as related to different moisture sources (e.g., monsoon).

(3) In Colorado, there is a large diversity in seasonality as airflow interacts with the complex terrain differently in the winter and summer.

(4) The figures on the left show the seasonality of precipitation in 20 different locations in Colorado State. The WRF simulation captures the diverse timing (single peak vs multiple peaks, summer vs winter peaks) of seasonal peak(s).

(5) In the CAM simulation, there is less diversity of seasonality precipitation. While some areas are dominated by a single peak in the summer, others show very little seasonal variations.

5. Summary and Future Work

(1) Two approaches to model cold season orographic precipitation have been compared: high resolution modeling using WRF and subgrid parameterization in a GCM. Results have been compared with observed precipitation, temperature, and snowpack in the western US.

(2) The WRF simulation realistically captured features including the two separated precipitation bands along the coastal range and Cascades/Sierra and a shift in the precipitation peak towards the upwind slopes. However, similar to the findings from previous studies (e.g., Leung and Qian 2003), precipitation is much higher than the observed on the windward slopes of the Cascades and Sierra Nevada. This effect is amplified as spatial resolution increases. Increasing spatial resolution, however, greatly improves the simulation along the coastal range.

(3) Driven by realistic large scale circulation, and with detailed representation of topography, the WRF simulation displays realistic variations at the seasonal and interannual time scales. This suggests is able to capture the interactions between large scale circulation and the topographic variations.

(4) The CAM simulation generally underpredicts precipitation as a result of large scale biases. Rainshadow effects are well captured at the larger scale by the explicit resolution, but not resolved at the smaller scale by the subgrid parameterization.

(5) Future work will investigate the wet biases along the Cascades and Sierra Nevada in the WRF simulation through more detailed analysis of the 3D atmospheric structures and precipitation under different large scale conditions, and sensitivity experiments using 2D simulations.

(6) We will perform WRF simulation driven by the CAM large scale circulation for more direct comparison of the orographic effects in the WRF and subgrid simulations.