REGIONAL CLIMATE SIMULATION USING THE WRF MODEL.

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1 INTRODUCTION

The methodology of nesting high resolution limited area models in global models has been used extensively for both research and operational numerical weather prediction (NWP). Dickinson *et al.* (1989) and Giorgi (1990) adapted this approach for regional climate simulation and its use is now widespread.

A regional climate model (RCM) provides high resolution climate scenarios important for impact assessment and resource management. High resolution allows for a more precise description of regional topographic forcings due to orography, land-sea contrasts and vegetation characteristics. Consequently, processes strongly forced by topography, such as orographic precipitation and monsoon circulations, improve at increased resolution (Giorgi and Marinucci, 1996) . Better resolved small-scale processes can have improved large-scale impacts and, in addition to downscaling climate information, RCMs can be used to study the upscale impact of regional forcings (e.g. the orographic shadowing effect) on the large-scale climate. In view of the anticipated decrease in climate model grid-spacing, it is important to assess the value of higher resolution (1-10km grid spacing) regional climate modeling. Higher resolution does not necessarily imply more accurate climate simulation (e.g. Boyle (1993), Sperber *et al.* (1994) and Senior (1995)). The sensitivity of physics parameterizations to model grid-spacing may overwhelm any benefits of higher resolution simulation (Duffy *et al.*, 2003) . There are also fundamental differences in how NWP model and RCM simulations depend on resolution.

The Weather Research and Forecasting (WRF) model was specifically designed for high resolution applications, and provides an ideal tool for assessing the value of high resolution regional climate modeling. The long-term goal of developing a RCM based on the WRF model builds on knowledge gained from previous regional climate research using the fifth-generation Pennsylvania State University-NCAR mesoscale model (MM5). This preliminary study represents a first step in assessing the value of high resolution (1-10km grid spacing) regional climate modeling by seeking to establish the validity of the WRF model for simulating regional climate. Our goal is not to perform a vigorous model intercomparison, but rather to determine any significant advantages that WRF may have over MM5.

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2 SUMMARY OF RECENT MM5 REGIONAL CLIMATE SIMULATIONS

Recent regional climate research has focused on the region of the Western United States where topographic forcings play an important role in defining the regional climate, and where it is thought regional climate modeling will have greatest impact. Since water resources in this region derive largely from cold season precipitation and snowpack, and accurate regional climate models are important in providing climate scenarios for impact assessment and resource management, model evaluation has focused on precipitation and surface temperature.

Leung and Gahn (1998) showed a RCM based on MM5 was able to produce regional climate features comparable to observations on regional scales. A 20 year regional climate simulation using MM5 nested to 40km grid spacing, and forced by NCEP-NCAR reanalyses, (Leung *et al.*, 2003) was able to capture many regional climate features of the Western United States. The 20-year mean December-January-February precipitation was well simulated over the northern Rockies, but was typically overestimated in the basins and the Intermountain West. The observed rain shadow effect downwind of the Cascades and Sierra Range was reproduced well, but at 40km grid spacing the model terrain height along the coastal hills was severely underestimated, as was precipitation in this region. The model added realistic mesoscale details to the large-scale distribution of surface temperature that compared well with observations. However, the model showed a warm bias, typically within 3°C, that was particularly pronounced along the northwest coast and mountains.

3 METHODOLOGY

Simulations of the cold-season regional climate of the Western United States are performed using a RCM based on the WRF model. The domain of 125$\times$150 grid points, shown in Fig1, includes the major river basins of the Columbia, Colorado and Sacramento rivers, and extends far enough south to allow simulation of the warm-season North American Monsoon climate (not presented here). Simulations are performed using a horizontal grid spacing of 30km and 31 vertical sigma levels. Initial condition and lateral and lower boundary conditions are derived from the NCEP-NCAR reanalyses interpolated onto the WRF model grid. Simulations are initialized on 1st October 1990 and run for 6 months over the cold season with

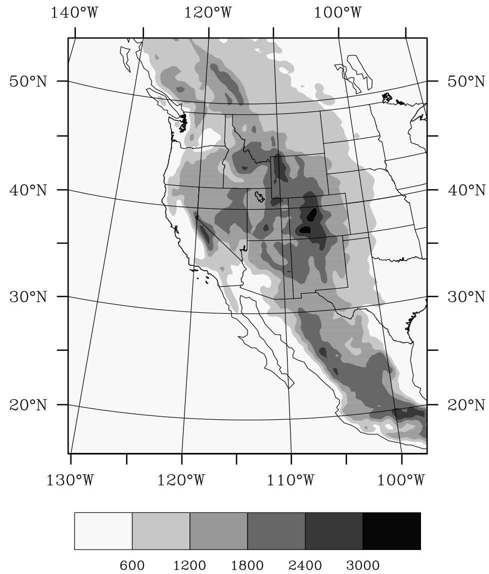

Figure 1: Terrain height (m).

boundary conditions updated every 6 hours. Boundary relaxation has a combined linear/exponential functional form over 10 grid points. The orography shown in Fig.1 includes terrain features on the smallest resolvable scales of the model. To aid long-term integrations sea surface temperatures are updated every 6 hours, and vegetation fraction is updated monthly.

Boundary and surface-layer processes are represented by the Monin-Obukhov surface scheme, the Oregon State University land surface model and the MRF boundary layer scheme. Convection is parameterized by the eta Kain-Fritsch scheme, and radiation is represented by the rapid radiative transfer model and the Goddard short-wave scheme. Sensitivity experiments are perfomed using the Ferrier and Lin microphysics schemes to examine the sensitivity of rainfall characteristics to the microphysics parameterization and guide future physics selection.

Surface temperature and precipitation are the two most important parameters for hydrological applications, and are therefore used to evaluate our WRF simulations. The dataset used to analyse the regional climate of the Western United States consists of daily precipitation accumulation and daily maximum and minimum surface temperature gridded at 1/8° for 1949-2000, developed by the Surface Water Modeling group at the University of Washington. This dataset is available from their web site at $http://www.hydro.washington.edu/Lettenmaier/gridded\_data/$ and is described by Maurer *et al.* (2002). A statistical topographic-precipitation relationship developed by Daly *et al.* (1994) is used during spatial interpolation to capture the mesoscale details of precipitation distribution in regions of complex terrain. For the purposes of evaluating the WRF model regional climate, the climate of the Western United States is determined from the observed precipitation and surface temperature gridded datasets interpolated onto the WRF model grid.

4 RESULTS

The simulated cold-season accumulated precipitation using agrees well with observations in terms of spatial distribution, as shown by a comparison of Fig. 2 and Fig. 3. The model captures the double band of precipitation along the coast of the northwest United States associated with the coastal hills and the Cascade Range, and produces enhanced precipitation over the higher terrain of the Rocky Mountains. The simulation compares less favorably in terms of magnitude, consistent with MM5 simulations. The models generally overestimate precipitation, and the WRF model overestimates precipitation amount by up to factor of 2. The simulated cold-season precipitation accumulation using the Lin microphysics scheme (not shown) shows very similar spatial distribution, but increased magnitude. Differences in magnitude are greatest over the northern Rocky Mountains and the Pacific Northwest, where increases above the simulation using the Ferrier microphysics scheme of up to 20% are widespread. Monthly mean accumulations (not shown) show the model is able to capture month-to-month variability in spatial distribution throughout the cold season.

The simulated cold-season mean surface temperature field compares well the observed field in terms of spatial distribution and magnitude, as shown by a comparison of Fig. 4 and Fig. 5. The regions of the Great Plains, the Rocky Mountains and the Pacific Northwest show a slight warm bias in the simulation, generally within 3°C consistent with MM5 simulations. In contrast to MM5 simulations, however, the WRF model simulation shows a cool bias over the low lying regions of the desert Southwest and along the Sacramento and San Joaquin Valleys in California. The monthly mean surface temperature fields (not shown) show the warm bias over the Rocky Mountains increases towards january and subsequently decreases, even turning to a slight cool bias during March. The warm bias over the coastal hills and Cascade Range of the Northwest United States follows a similar trend resulting in a more favorable agreement during March.

5 CONCLUSIONS

This preliminary evaluation has shown the WRF model to be a viable and potentially useful tool for regional climate modeling in downscaling research. No immediate benefits over MM5 are apparent from this simple evaluation; however, it is thought the benefits of the more accurate numerical methods will become apparent for higher resolution simulations.

6 FUTURE WORK

A more detailed evaluation of the cold-season WRF simulations is needed to identify any advantages WRF

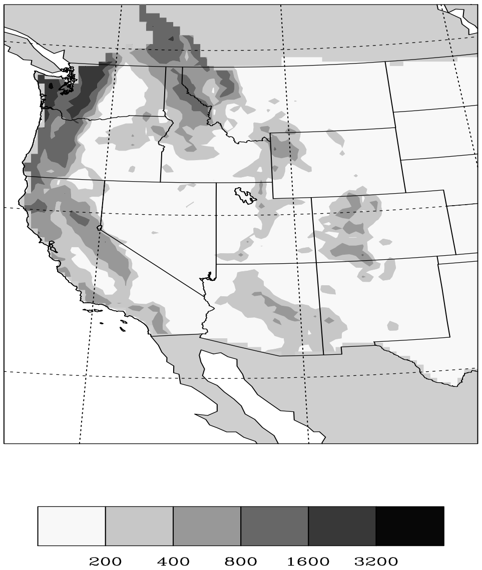

Figure 2: Observed cold-season accumulated precipitation (mm) calculated using a bilinear interpolation of the observed gridded dataset onto the WRF model grid, contoured using an exponential scale.

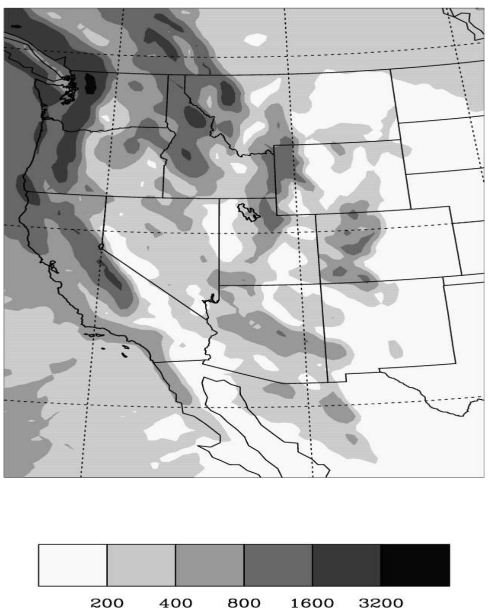

Figure 3: Simulated cold-season accumulated precipitation (mm) using the WRF model, contoured using an exponential scale.

may have over MM5. In particular, the topography-precipitation and temperature-precipitation relationships will be examined in more detail. The value of WRF over MM5 will then be assessed for higher resolution (1-10km grid spacing) regional climate simulations using a nested approach. Averages of seasonal simulations over a few years will determine the robustness of the preliminary results.

Attention will then focus on the warm-season North American Monsoon climate. Sensitivity studies will es-

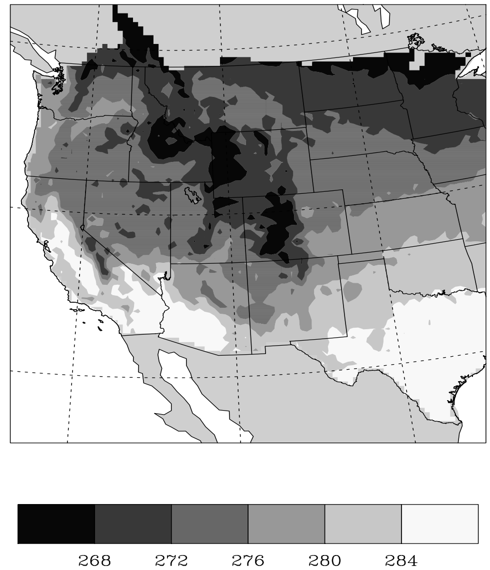

Figure 4: Observed cold-season mean surface temperature (K) calculated using a bilinear interpolation of the observed gridded dataset onto the WRF model grid.

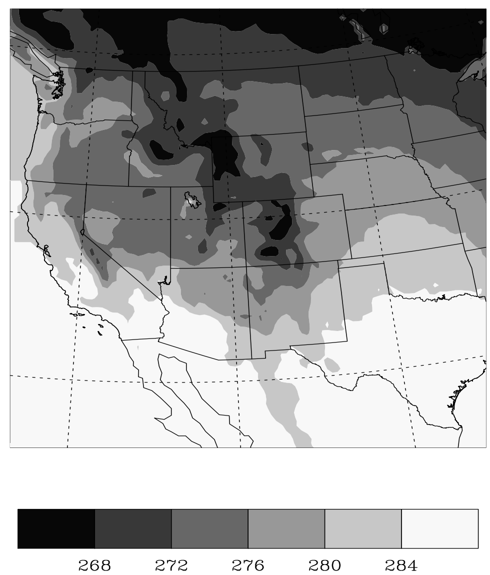

Figure 5: Simulated cold-season mean surface temperature (K) using the WRF model.

tablish those climate features sensitive to the convection scheme, and provide guidance for the choice of convection scheme. The monsoon climate will be evaluated based on the observational dataset described in this study and six month warm-season WRF simulations.

Finally, rather than using RCMs for downscaling climate information, their real value lies in the ability to study the interaction between regional topographic forcings and the large-scale climate signal. Our goal is to establish the validity of the WRF model for high resolution long-term simulation for upscaling research.

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