Climate downscaling for Arizona using WRF: Dependence of precipitation on model resolution and convective parameterization

Ashish Sharma* and Huei-Ping Huang

School for Engineering of Matter, Transport, and Energy, Arizona State University

*Corresponding author, Email: ashish.sharma.1@asu.edu

1. INTRODUCTION

Climate in Arizona is generally dry with intermittent seasonal rainfall in summer and winter that is spatially heterogeneous (e.g., Sheppard *et al.*, 2002). The large variation of rainfall in space is due in part to complicated topography in the region, which affects both summertime convection and mechanically induced rainfall by winter storms. Simulating precipitation in Arizona is challenging because it requires proper resolution of small-scale orography and its effect on moist convection. This provides an ideal background to test the performance of a mesoscale model in simulating the seasonal rainfall when the horizontal resolution and/or the detail of convective parameterization in the model are changed. Using the Weather Research and Forecast (WRF) Model, this study will perform a series of seasonal simulations with multiple nesting centered in Arizona to clarify the dependence of the simulated rainfall on the model resolution and the switching on/off of cumulus parameterization scheme.

While several recent studies have used a high-resolution mesoscale model to examine the variation of simulated rainfall with horizontal resolution or cumulus parameterization scheme (e.g., Gilliland 2007, Mercander *et al.* 2007), they mostly focused on short-term weather forecast. We will instead consider long simulations and study the sensitivity of seasonal mean precipitation on those key parameters of the model. Our simulations are constrained by the observed large-scale boundary conditions in the fashion of "climate downscaling" (e.g., Leung *et al.* 2003). The potential of using a high-resolution mesoscale model in climate downscaling to improve regional rainfall simulation has been demonstrated elsewhere (e.g., Caldwell *et al.* 2009). In addition to focusing specifically on Arizona, our study will refine the horizontal grid size to a partially cloud-resolving 3 km, which has not been done before in the context of seasonal downscaling for the southwest US. As we approach this resolution, the cumulus parameterization scheme begins to lose its validity. We will therefore perform experiments with the cumulus scheme switched on and off as another sensitivity test.

2. MODEL SETUP

We will use WRF Version 3.1 Model with multiple nesting, configuring the innermost domain to cover Arizona and the outermost domain to cover the whole western U.S. The horizontal grid size for the innermost domain is varied from 12 km to 6 km, then to 3 km. The 12 km runs are carried out with two layers of nesting, using 36 km resolution for the outer domain. The 6 km runs adopt a 3-layer nesting with 54 and 18 km for the outermost and intermediate domains. The 3 km runs also use a 3-layer nesting with 48 and 12 km for the outermost and intermediate domains. The innermost domains for these runs are shown in Fig. 1.

Six hourly NCEP Global Analysis data on 1 x 1 degree grid (FNL) are used to construct the initial and boundary conditions. We perform 2 sets of runs for the 6 km case and 1 set each for the 3 km and 12 km runs. Each set consists of seven 90-day runs for the 7 winter seasons (November-January) from 2003-2009. Winter is chosen because the model generally simulates the climatology of the cold season more accurately than the warm season. The 12 km runs are performed with the cumulus convective scheme turned on; the 3 km runs are with it turned off. Two sets of 6 km runs, one with cumulus parameterization turned on and one with it turned off (leaving grid-scale convection to produce all the rainfall), are performed. The Kain-Fritsch scheme is used for cumulus parameterization whenever it is switched on.

We will analyze only liquid-form precipitation based on the two major variables RAINC and RAINNC from the WRF model output. The former is the rainfall produced by cumulus parameterization and the latter is grid-scale rainfall. Our later analysis of the time series of local rainfall will focus on a sub-domain in southern Arizona (see the square box in Fig. 1a, defined as 111.78^{o}W-113.61^{o}W and 31.90^{o}N-33.69^{o}N) over which almost all precipitation is in the form of rain.

3. RESULTS & DISCUSSION

The seasonal (cumulative) rainfall for 1 November 2009-31 January 2010 from various sets of runs are shown in Fig. 1. Although we only show the results for a particular winter, the simulations for the other winter seasons are qualitatively similar to this case. The simulations captured the basic pattern of relatively more abundant rainfall over mountainous regions in central Arizona and scanty rainfall in southern Arizona. The small value of seasonal rainfall over northern Arizona reflects the dominance of snowfall (which we do not analyze) there in winter. Figures 1(a)-1(c) show the contour maps of RAINC (rainfall produced by cumulus parameterization), RAINNC (rainfall produced by grid-scale convection), and RAINC+RAINNC from the 6 km run with the cumulus parameterization turned on. Figure 1(d) is similar to Fig. 1(b) but for RAINNC from the 6 km run with cumulus parameterization switched off. (In that case, RAINC = 0.) From these results, we find that when cumulus parameterization is turned off, grid-scale convective rainfall increases to compensate for the absence of subgrid-scale rainfall. The RAINNC shown in Fig. 1(d) is as large as the combination of RAINC+RAINNC in Fig. 1(c).

Figures 1(e)-1(g) are similar to Figs. 1(a)-1(c) but for the 12 km run. Under this relatively coarse resolution, the rainfall produced by the subgrid-scale cumulus parameterization (Fig. 1(e)) becomes more prominent, while grid-scale rainfall (Fig. 1(f)) becomes weaker compared to the 6 km runs. The total rainfall, RAINC+RAINNC, is also generally weaker compared to the 6 km runs. While RAINC is smaller than RAINNC in most areas for the 6 km and 12 km runs, one can find a few exceptions such as the wet spot in northern Mexico just cross Arizona-Mexico border. This is likely due to the increasing importance of small-scale convection as one moves toward warmer and more humid latitudes. Figure 1(h) shows the grid-scale rainfall (RAINNC) for the 3 km run. Compared to the change in rainfall by refining the grid from 12 km to 6 km, the difference between the 6 km and 3 km runs is relatively small. (We should compare Fig. 1(d) to Fig. 1(h), both are with cumulus parameterization switched off.) The 3 km run sees a slight increase in the maximum rainfall over the mountains in central Arizona and emergence of more fine-scale structures in the rainfall pattern that reflects the influence of topography.

The eight panels in Fig. 2 show the time series of hourly rainfall averaged over the square box in southern Arizona indicated in Fig. 1(a). They are arranged in the same order as Fig. 1. (Notice the different vertical scales for different panels.) For instance, panel (a) is for RAINC from the 6 km run with cumulus parameterization. Over this box, we find that RAINC and RAINNC generally show a similar pattern in their temporal evolution; a rainfall event with a large RAINNC usually has a large RAINC. A detailed statistical analysis of RAINC vs. RAINNC will be performed in the future using the simulations for all 7 years.

4. CONCLUSION

From the series of simulations of wintertime rainfall over Arizona, we find a significant increase in the total rainfall when model resolution is refined from 12 to 6 km, and relatively mild increase in rainfall when the grid size is further refined to 3 km. At the 6 km resolution, turning the cumulus parameterization off resulted in about the same amount of total rainfall, due to the compensation by an increase in the grid-scale rainfall. This indicates that for climate downscaling for Arizona it may be appropriate to switch off cumulus convective scheme when the grid size of the regional model is refined to 6 km or smaller.

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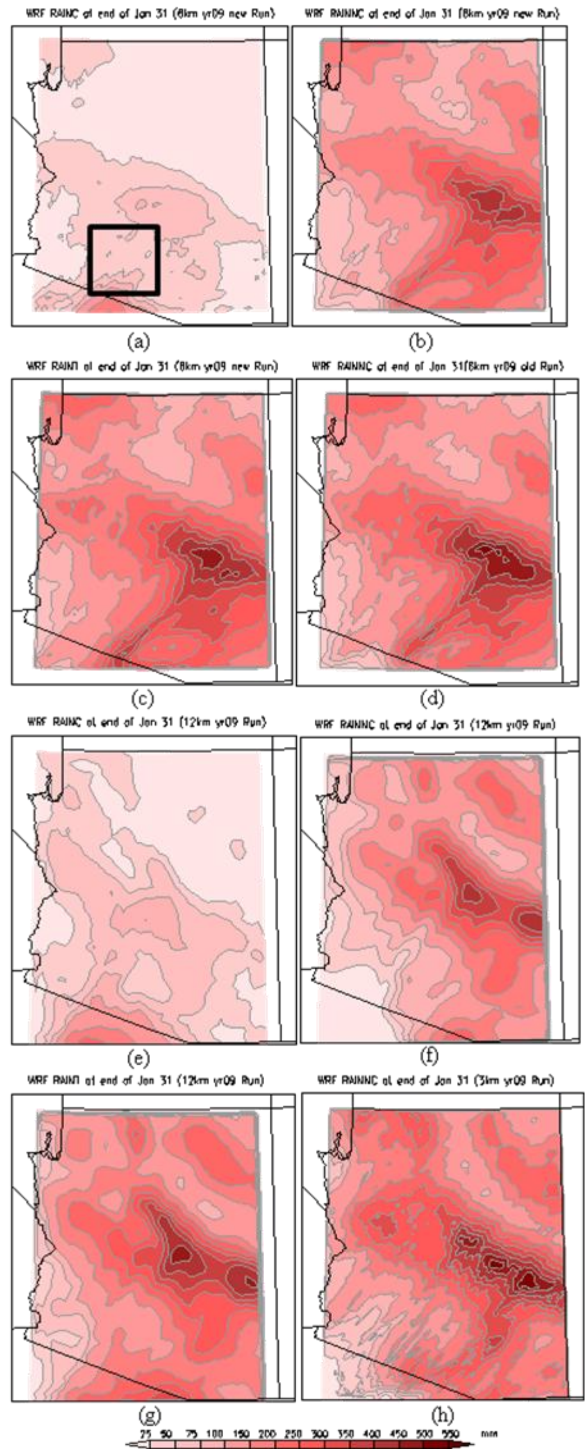

Fig. 1. Seasonal cumulative rainfall for November 2009-January 2010 from a series of runs. See text. The box in (a) shows the area chosen to construct the time-series of rainfall in Fig. 2.

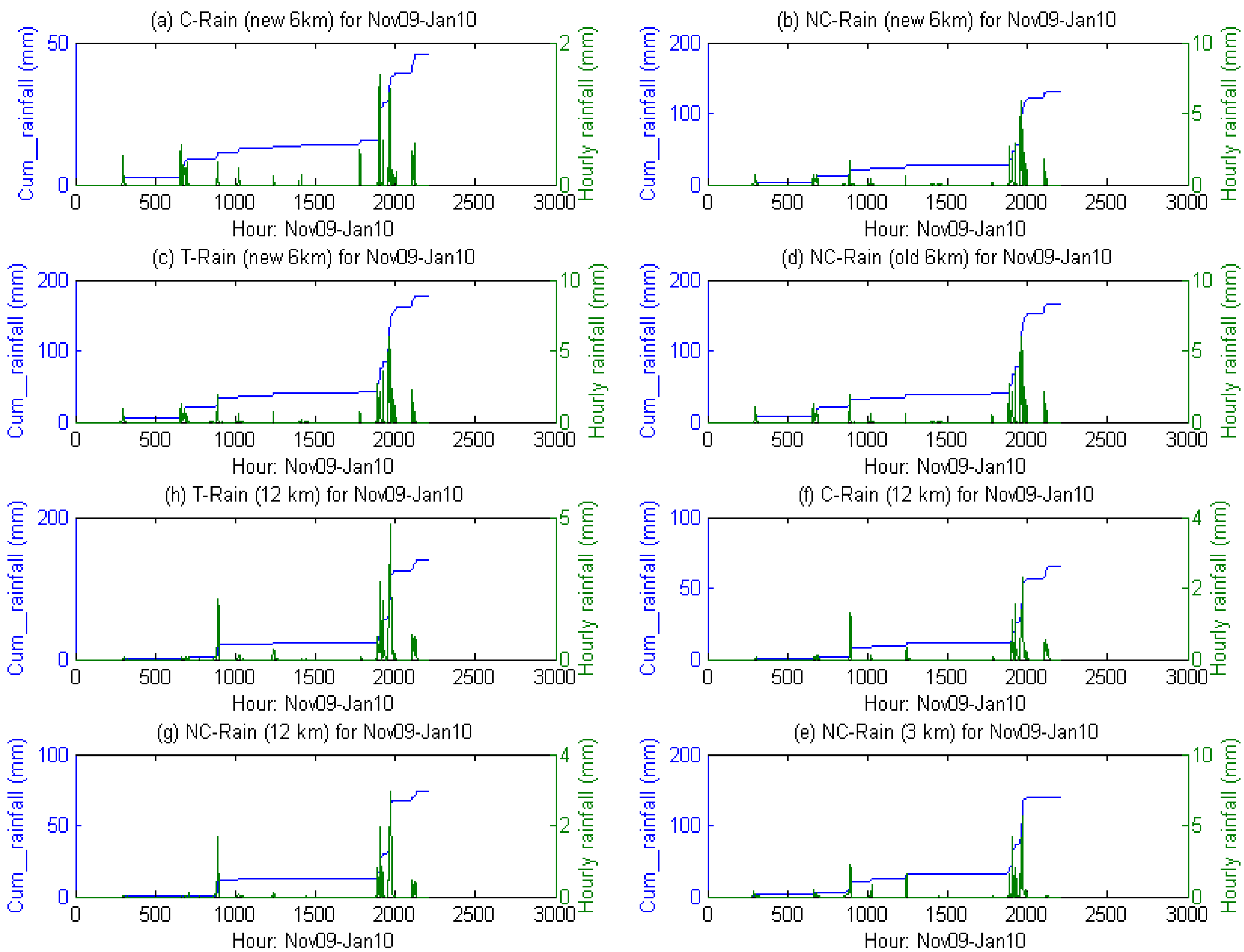

Fig. 2. Time-series of hourly rainfall averaged over the box in Fig. 1a for 1 Nov 2009-31 Jan 2010 for different set of runs that correspond to the 8 panels (arranged in the same order) in Fig. 1. Blue and green represent cumulative rainfall and hourly rainfall, respectively.

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