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QUANTITATIVE PRECIPITATION FORECASTING OF WINTERTIME PRECIPITATION IN THE SIERRA NEVADA

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1. INTRODUCTION

Topography is one of the most important local elements that controls the amount, spatial distribution and occurrence of precipitation. This is particularly true for the wintertime precipitation in the western United States that has a large impact on the local hydrologic cycle. Large mountain barriers such as the Sierra Nevada (average crest height of 2.2 km, a half width of 100 km) typically produce maximum of precipitation 10-20 km upstream of the crest accompanied by a strong shadowing of the lee side. The occurrence of heavy precipitation along the western slopes of the Sierra Nevada is mainly caused by orographic lifting of the oceanic inflow of air at the upslope of the mountain range. Consequently, cloud systems here evolve slowly and often persist for many hours within a single storm event (Rauber 1992).

The amount of orographic uplift and precipitation is quite dependent on the size and shape of the barrier as well as the distribution of moisture and static stability at lower atmospheric levels (Smith 1979). The Sierra Nevada is especially well suited for study of orographic wintertime precipitation processes due to its uniform upwind slope and absence of larger mountains upstream (aside from ~300 m high Coastal Range). This quasi-two dimensional mountain range slopes up uniformly from the Central Valley of California (at 0.1 km ASL) to approximately 2.2 km ASL over a horizontal distance of 100 km. The orientation of the range is north-northwest to south-southeast, and its length close to 600 km. There is a very small number of high passes that interrupt the compact ridgeline but a fairly large number of deep river valleys on the western slope oriented perpendicular to the mountain range [Fig. 1; see also Fig. 1 in Grubišić and Cardon (2002) in this volume)].

Accurately predicting the amount and spatial distribution of precipitation still poses a problem in this terrain. The accuracy of short-term precipitation forecasts is still relatively low, in part due to shortcomings of microphysical parameterizations of cloud and precipitation processes used in mesoscale numerical models. Existing modeling studies of orographic precipitation in the western U.S. show that there is a discrepancy between the observed and model-predicted precipitation such that there is an over-estimation of precipitation on the windward side and under-estimation on the lee side (e.g., Colle and Mass 2000).

Recently, the improvement of Quantitative Precipitation Forecasting (QPF) has been given a high priority by the U.S. Weather Research Program (USWRP) (Fritsch et al. 1998). The ultimate goal of

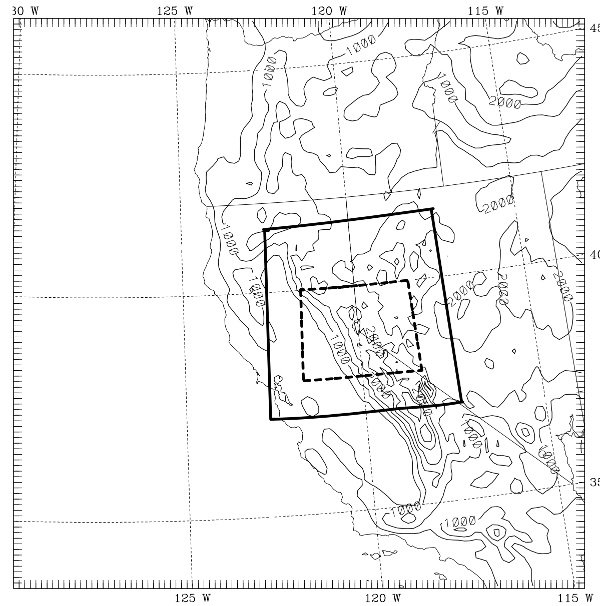

Figure 1: Model representation of orography within the first nested domain of the MM5 model simulations. Contouring interval is 500 m with the outline of the U.S. west coast displayed in place of the zero contour. The thick solid lines encircle the second nested domain. The dashed outline marks a portion of that domain displayed in Fig. 2.

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our research is to achieve an improvement in quantitative precipitation forecasting in complex terrain by improving the description of microphysical processes in mesoscale numerical models. In this paper, we report on the first part of our study in which we have investigated the skill of QPF in the Sierra Nevada using the existing microphysical schemes in a mesoscale model.

2. NUMERICAL MODEL

The numerical model used in this study is MM5 (Grell et al. 1994), a limited-area, non-hydrostatic, prognostic model with equations cast in the terrain-following pressure coordinates. The model has a capability of flexible, one- or two-way, multiple nesting. Advanced physical parameterizations for precipitation processes in MM5 include several cumulus parameterizations and microphysical schemes.

We have carried out high-resolution numerical simulations of selected winter storms in the Sierra Nevada employing two-way nesting within a triple nested-down domain. In the innermost domain, which covers a large portion of the Sierra Nevada (cf. Fig. 1), the numerical grid has a horizontal grid increment of 4.5 km with 29 unevenly distributed vertical levels. The model was initialized 12 hours ahead of the period of interest with NCAR/NCEP grid-point reanalysis fields, which were also used for the boundary conditions update every 6 hours. The period of integration ranged from 24 to 48 hours depending on the selected case. The only thing that was varied in the model set up was the choice of a microphysical scheme. The schemes selected for this study are: (1) Dudhia (DUDH) simple ice scheme (Dudhia 1989), which includes snow and cloud ice below 0° C, (2) Reisner's mixed phase schemes (REIS1-excluding graupel, REIS2-including graupel) (Reisner et al. 1998), which allow for supercooled water below 0° C and in which ice does not immediately melt above 0° C, (3) Goddard's mixed phase microphysical scheme (GSFC; Tao and Simpson 1993), and (4) Schultz's explicit microphysics (SCHZ; Schultz 1995).

3. OBSERVATIONAL DATA

Our validation data set consists of a selected number of high-impact winter storms from the 1980s, documented during the Sierra Co-operative Pilot Project (SCPP). This program, conducted from 1978 to 1987 in the central Sierra Nevada by the U.S. Bureau of Reclamation, was designed to document the physical processes associated with

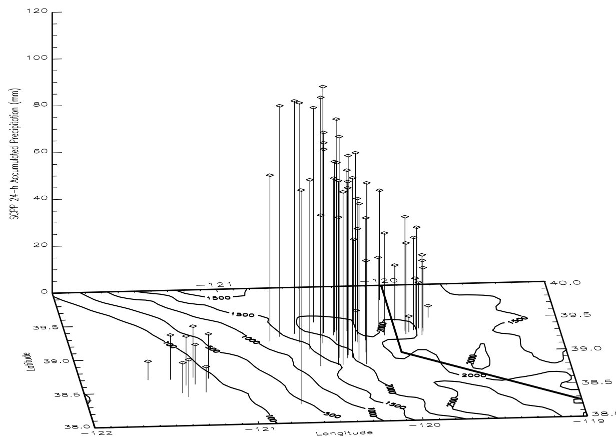

Figure 2: 24-hour accumulated precipitation from 12 UTC 12 February to 12 UTC 13 February at the SCPP observational sites. The outline of this portion of the model domain is shown in Fig. 1. The minimum and maximum length of pins is, respectively, 5.1 mm and 109.7 mm.

orographic wintertime storms with the goal of verifying and improving the weather-modification technology employed in the central California (Reynolds and Dennis 1986). We use the SCPP observational data sets of precipitation fields to verify the model forecasts. In addition to precipitation data, the SCPP data set includes upper-air soundings launched from two sites, one near the windward edge of the Sierra Nevada and the other slightly upwind of the crest line. Our study is limited to five SCPP cases listed in Table 1. Figure 2 shows the 24-hour accumulated precipitation amounts at SCPP stations during the 12–13 February 1986 storm.

Start DateTime (GMT)	End DateTime (GMT)	Max Precip (mm/day)
821217–0500	821218–0100	78.24
830310–2200	830311–1700	72.25
830330–2200	830331–1600	49.9
860212–0400	860213–1500	86.56
870103–1100	870104–0900	103.91

Table 1: SCPP cases selected for QPF validation in this study. The precipitation maxima in the thrid column reflect the total amount of precipitation at stations with a recorded storm maximum divided by the storm length (in days).

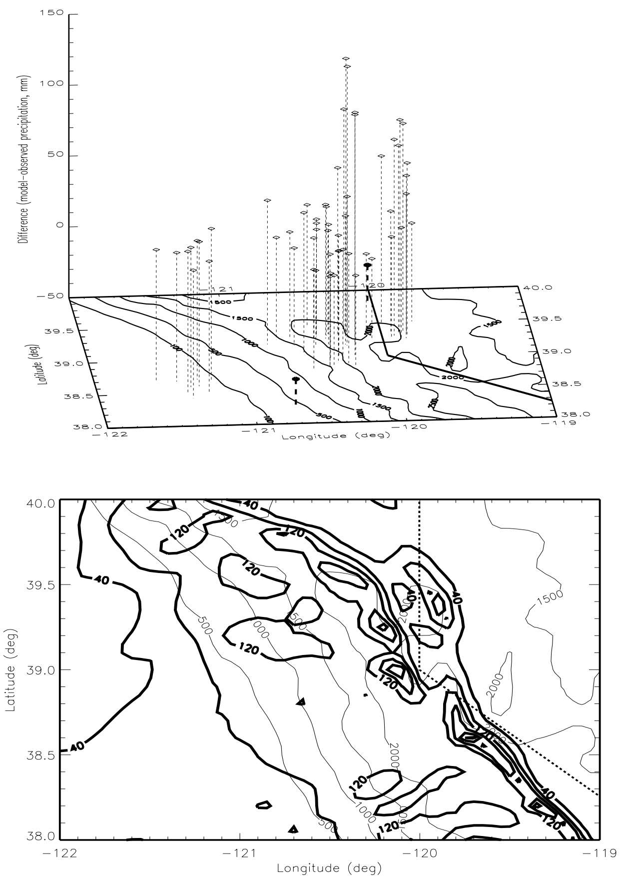

Figure 3: Results for DUDH scheme. Upper panel: Difference between model-predicted and observed precipitation displayed with vertical pins above terrain contours. Thin solid pins mark the positive values (over-prediction), and thick dashed ones mark the negative values (under-prediction). The maximum and minimum differences are, respectively, 128 mm and -31.45 mm. Lower panel: Contours (thick solid) of accumulated precipitation (c.i. 40 mm) for the period specified in Fig. 2 are superimposed over terrain contours (thin solid, c.i. 500 m). Thick dotted lines mark the California-Nevada border.

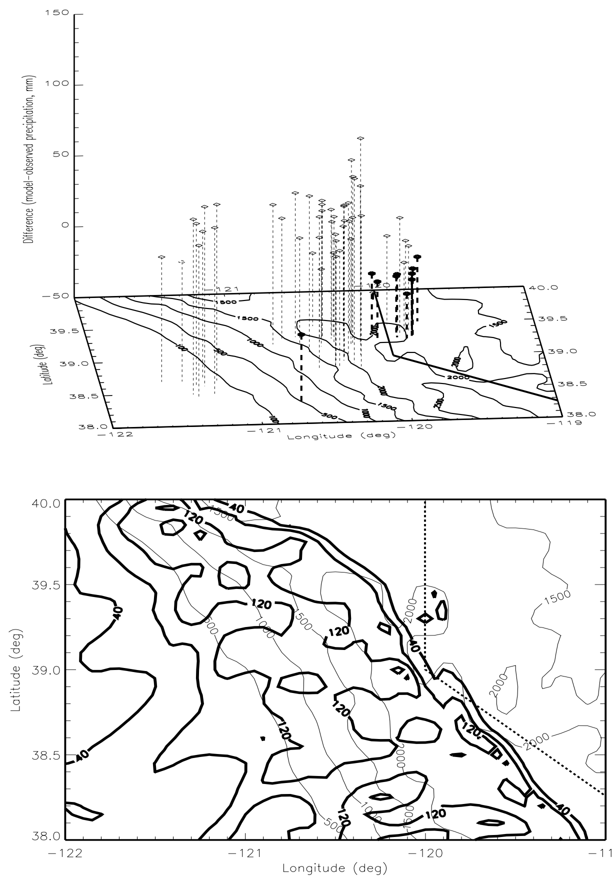

Figure 4: As in Fig. 3 but for REIS2 scheme. The maximum and minimum differences in the upper panel are, respectively 102 mm and -41.5 mm.

In the following, we limit our discussion to the February 1986 storm, which originated over the south-central Pacific, and was a significant weather event that caused heavy precipitation in the mountains and the Central Valley. A detailed synoptic analysis of this storm is presented in Rauber (1992).

4. RESULTS

Figures 3 and 4 display the model-predicted 24-h accumulated precipitation using DUDH and REIS2 schemes. The upper panels of these figures illustrate the difference between the predicted and observed precipitation at the SCPP sites. For the latter, the model predicted fields in the innermost domain were interpolated to the SCPP observational sites from the neighboring grid points.

In all the simulations of this case, it is found that the heaviest precipitation occurred between 03 UTC and 06 UTC on 13 Feb 1986, which is in good agreement with the SCPP reported and published observations (Rauber 1992). The 24-hour accumulated precipitation fields (between 12 UTC 12 February and 12 UTC 13 February) obtained with different microphysical schemes show comparable maximum amounts. For four of the five schemes this maximum was 200 mm, and the fifth one (GSFC) produced a 20% higher maximum value. However, locations of these maxima are quite different. While all the schemes produced a quasi-linear pattern of maximum precipitation, approximately paralleling the topography contours, the maximum for REIS and SCHZ schemes was located at approximately 1.7 km ASL, whereas for DUDH and GSFC schemes the maximum was very close to or right at the crest-line.

In the domain with the horizontal grid increment of 4.5 km, the precipitation is primarily produced by a cloud microphysical scheme. Thus, for the most part differences in the accumulated precipitation fields reflect differences in the complexity of microphysical parameterizations. The over-prediction of precipitation on the upwind side, and under-prediction on the lee side, was a hallmark of all the schemes, except for DUDH scheme, which tends to overpredict precipitation everywhere. All schemes predicted 20–25% more precipitation than observed at the lower windward elevations (cf. Figs. 3 and 4). Reisner's schemes (REIS1 and REIS2) produced the smallest errors in the accumulated precipitation, with REIS2 scheme (including graupel and additional prognostic equations for concentrations of hydrometeor species) being the superior of the two.

4. CONCLUSIONS AND FUTURE WORK

So far our results confirm the previous findings of the tendency of existing microphysical schemes in mesoscale models to produce the over-prediction of precipitation on the upwind mountain slopes and under-prediction on the lee slopes.

This analysis will be quantitatively substantiated and expanded with additional SCOO case studies listed in Table 1. The SCPP precipitation data will be supplemented with additional data from the archives of the Western Regional Climate Center at DRI in order to generate a denser observational grid to be used for determining the statistical skill scores of precipitation forecasts.

We also plan to carry out additional sensitivity model experiments using a fourth nested domain (with the horizontal grid increment of 1.5 km) to quantify the effects of resolution on the skill of these precipitation forecasts. The influence of topography and the associated airflow dynamics on cloud and precipitation processes will be given special attention in the analysis of these ultra-high resolution simulations.

Acknowledgments. This research has been supported by the National Science Foundation (NSF) USWRP grant ATM–9908995.

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