7.4

An Evaluation and Verification of the Simulated Microphysical Sensitivities during 13-14 December 2001 of IMPROVE 2

Brian A. Colle[1*], Matt Garvert[2], Justin Wolfe[1], Greg Thompson[3], and Clifford F. Mass[2]

[1]Institute for Terrestrial and Planetary Atmospheres, Stony Brook University/SUNY

[2] Dept. of Atmospheric Sciences, Univ. of Washington

[3] NCAR-RAP, Boulder

1. INTRODUCTION

The primary goal of the IMPROVE field experiment was to collect a dataset to verify and improve the bulk microphysical parameterizations (BMPs) in mesoscale models. This modeling study focusses on the second phase of IMPROVE, which occurred over the central Oregon Cascades during November-December 2001. On 13-14 December 2001, a landfalling frontal system resulted in strong (> 35 m s^{-1}) cross barrier flow and heavy precipitation over the Cascades. Woods et al. (2003) and Medina and Houze (2003) describe the observations from this event, and Garvert et al. (2003) presents the high resolution simulation and verification using the Penn State-NCAR Mesoscale Model (MM5).

As these BMPs are verified and improved using IMPROVE data, it is also important to understand which parameters and processes control the transfer of water mass from one species to another as well as their effect on the surface precipitation. This study investigates the BMP sensitivities within the Reisner2 scheme for the 13-14 December 2001 event. In particular, we discuss important microphysical pathways that contribute to the simulated orographic precipitation. This paper focusses on those few parameters which have shown to have some of the largest impact based on two-dimentionsal (2-D) and idealized studies (Zeng et al. 2003; Thompson et al. 2003). These other 2-D studies provide a more comprehensive evaluation of the BMP parameter sensitivities.

Garvert et al. (2003) describes the setup of the MM5 simulations for the 13-14 December event using v3.6 of the model, which were nested down to 1.33-km grid spacing over the central Oregon Cascades (Fig. 1). The control run of the MM5, was initialized at 0000 UTC 13 December using the NCEP AVN model, and used the Reisner2 microphysics (Reisner et al. 1998; Thompson et al. 2003), which includes graupel and super-cooled water processes.

The following questions will be addressed in this study:

- What are the important microphysical processes and pathways for simulated precipitation during the 13-14 December event?

- What are the microphysical process sensitivities using different slope intercepts for snow, fallspeeds, and autoconversions? Which of these process experiments will verify better when compared with the observations?

- How does the surface precipitation vary for each of the sensitivity simulations?

*Corresponding author address: Dr. Brian A. Colle, Marine Sciences Research Center, Stony Brook University, Stony Brook, NY 11794-5000. email: bcolle@notes.cc.sunysb.edu.

2. CONTROL SIMULATION

a. 1.33-km Precipitation Verification

Figure 1 shows the 1.33-km MM5 precipitation between 1400 UTC 13 December and 0800 UTC 14 December (14-32 h). There are large variations in surface precipitation, which is the result of fine-scale vertical motions by the individual ridges as shown in Garvert et al. (2003). Some of the heaviest precipitation fell in a few bulls-eyes over some of the steep windward slopes of the northern and central Cascades.

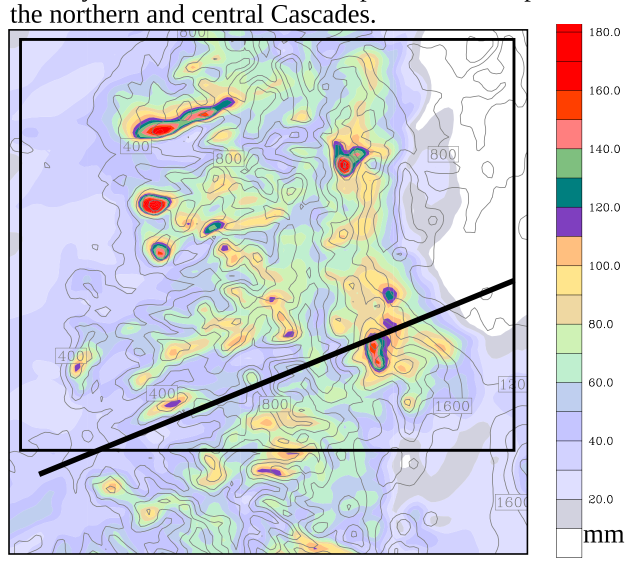

Figure 1. MM5 precipitation for a portion of the 1.33 km domain between 1400 UTC 13 December 0800 UTC 14 December (14-32 h). Terrain is contoured every 200 m.

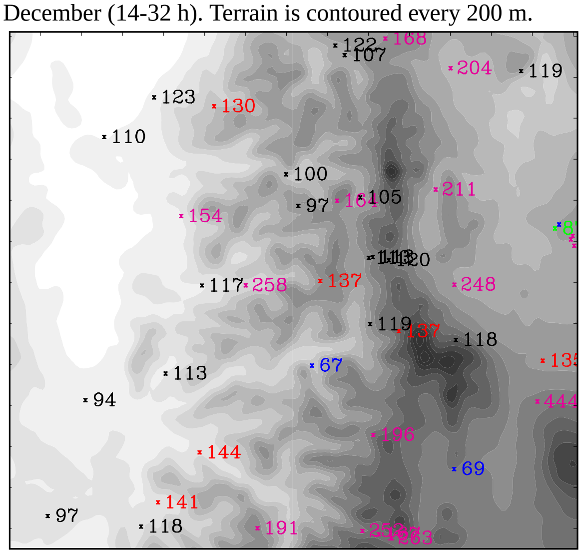

Figure 2. The 1.33 kmMM5 percent of observed precipitation for 1400 UTC 13 December 0800 UTC 14 December (14-32 h). Terrain is shaded for reference.

The 1.33-km MM5 precipitation was verified against all surface rain gauge locations and plotted as a percent of observed for the 14-32 hour forecast (Fig. 2). There is a large variability in the model verification numbers. Both upstream of the Cascades and in many of the narrow valleys of the windward Cascades, the MM5 is within 20% of the observed. In contrast, there is model overprediction over some of the higher terrain areas and to lee of the barrier. A rain gauge is located near one of the model precipitation bull-eyes over the lower windward slope (Fig. 1), and shows 154% of observed, thus suggesting that the simulated magnitude of this precipitation maximum is too large.

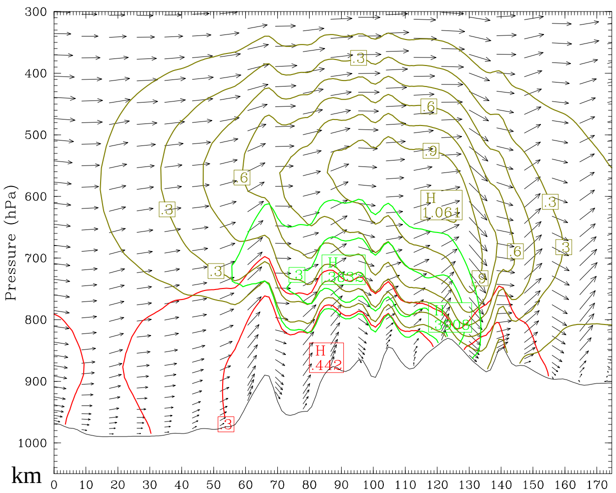

Figure 3. Average west to east cross section across the Cascades for the box in Fig. 1 showing mixing ratios of snow (dark yellow), graupel (green), and rain (red) every 0.15 g kg^{-1}. The average winds in the section are also shown.

b. Microphysical Budget

Figure 3 shows an average west-east cross section of the mixing ratios for snow, graupel, and rain averaged for 2300-0100 UTC 13-14 December for the inset boxed region in Fig. 1. During this two hour period there was a deep orographic cloud, with snow extending above 400 mb, graupel between 800 and 600 mb, and rain below 750 mb. Some of the individual peaks on the windward slope produced an enhanced upward motion and perturbations in the hydrometeor magnitudes. The snow maximum is around 600 mb over the crest and there is spillover into the lee.

Figure 4 shows the dominant microphysical processes averaged over a volume of atmosphere within the boxed region of Fig. 1 between 2300 and 0100 UTC. Each process is normalized by the water vapor loss rate within the volume. One large pathway to rain is from condensation (cond), which leads to accretion of cloud water by rain (racw) and snow (ssacw) and autoconversion to rain (ccnr). Another large pathway is snow deposition (sdep) and melting of snow to rain (smlt). Most of the graupel gain comes from accretion of cloud water by snow (gsacw) and accretion of rain (gacr).

The microphysical processes for snow and graupel gain are plotted spatially in Fig. 5, where each point in space shows the percentage weighting of each process. For snow (Fig. 5a), there is gain above 500 mb by autoconversion of cloud ice to snow (green) and

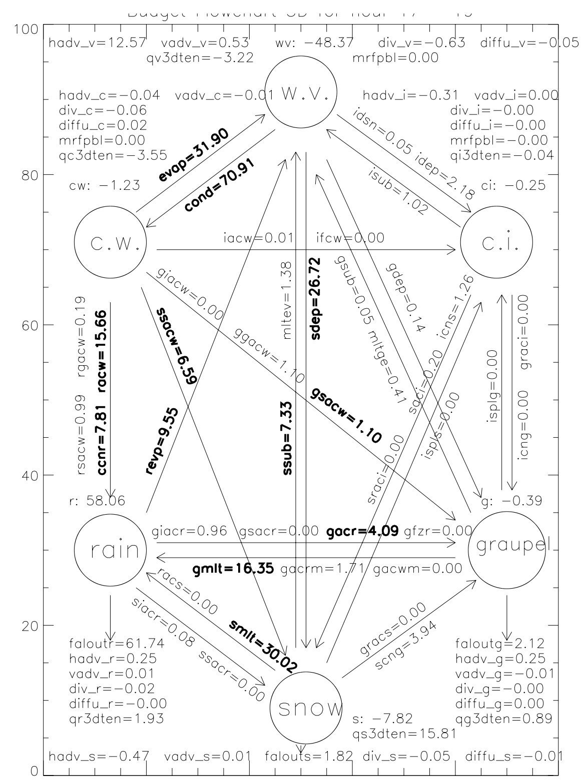

Figure 4. Microphysical budget over the box in Fig. 1 for the 23-25 hour period. The process rates are normalized by the water vapor loss rate, and the arrows point in the direction of the water/ice movement.

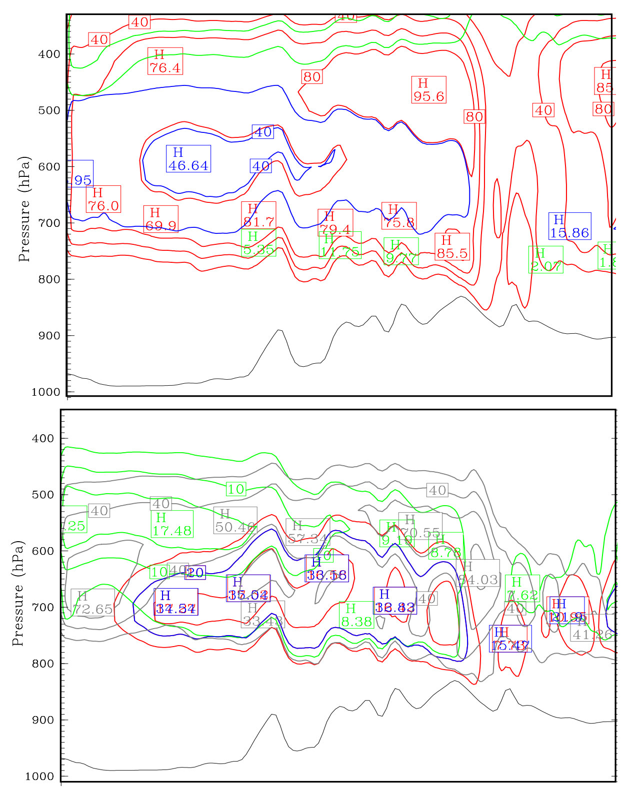

Figure 5. Spatial plot of dominant microphysical processes (in percent) for (a) snow gain and (b) grapuel gain at each point in space for the average west-east cross section within the box of Fig. 1. See text for details on the processes shown and labelling.

deposition (red). Snow grows primarily by deposition around 500 mb over the barrier, while both deposition and accretion of cloud water to snow (blue) occur over the lower windward slope between 600 and 500 mb. The graupel gain is concentrated around 700-600 mb, where there is collection of rain by graupel (30-35%), collection of cloud water by snow (30-35%), conversion of snow to graupel (10-15%), and collection of cloud water by graupel (10-15%).

3. SENSITIVITY SIMULATIONS

Additional simulations were completed in order to determine the Reisner2 sensitivities to a few different microphysical processes. Using two-dimensional idealized simulations, Zeng et al (2003) showed that the precipitation can be quite sensitive to the slope intercept for snow, snow fallspeeds, and cloud to rain water autoconversions for steep slopes.

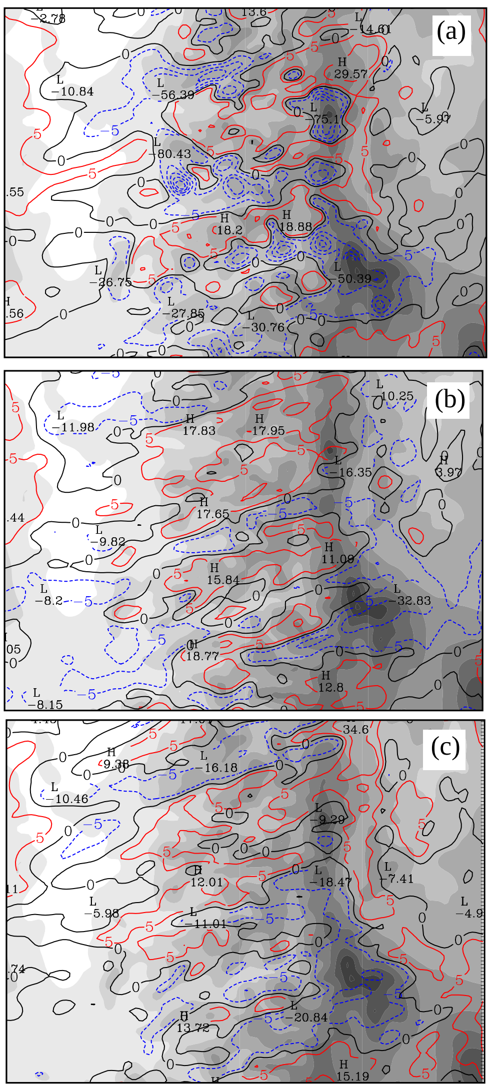

Figure 6. 1.33-km MM5 precipitation differences (14-32 h) in mm for the (a) KESS-CTL, (b) NOSQ-CTL, and (c) COXFS-CTL contoured very 20 mm starting at 5 mm. Red (solid) lines are positive differences and blue (dashed) are negative. The zero line is black. Terrain is shaded for reference.

Reisner2 can use either the Kessler (1969) or Berry and Reinhardt (1974) cloud to rain water autoconversion. The Kessler uses a threshold (0.35 g kg^{-1}) and a simple Heaviside function to do the conversion, while the Berry has a somewhat more complex form (Thompson et al. 2003). The control (CTL) MM5 uses the Berry method, and another simulation was completed using Kessler (KESS). The KESS run has significantly less precipitation (50-80 mm) over some of the steeper windward slopes (Fig. 6a), so there is less tendency for bulls-eyes as seen in the CTL (Fig. 1). The KESS run has more suspended cloud water than the CTL (Fig. 7); therefore, there is less liquid precipitation to fallout as rain over the steeper windward slopes. However, the larger amounts of cloud water in KESS increases the graupel and fallout over some of the less steep areas of the windward slope (Fig. 6a).

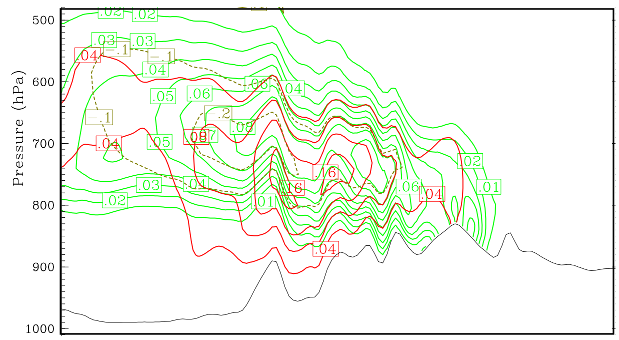

Figure 7.Average west-east cross section for the KESS-CTL showing snow (dark yellow every 0.10 g kg^{-1}), graupel (green every 0.02 g kg^{-1}), and cloud water (red every 0.04 g kg^{-1}) mixing ratio differences for the period between 2300-0100 UTC.

The CTL MM5 Reisner2 uses a variable slope intercept for snow (Nos), which is a function of temperature (Houze et al. 1979; Thompson et al. 2003). A previous version of Reisner2 used a variable slope intercept, which is a function of snow mixing ratio (Reisner et al. 1998). A mixing ratio version of Nos was completed (NOSQ run), and there is 5-15 mm more precipitation over the much of the windward slope region, and there is 5-15 mm less in the lee of the Cascades. The NOSQ run has 0.1-0.3 g kg^{-1} less snow and 0.02-0.10 g kg^{-1} more graupel and rain over the windward slope (Fig. 8). The larger amount of graupel and less snow results in more fallout over the windward slope and less in the lee.

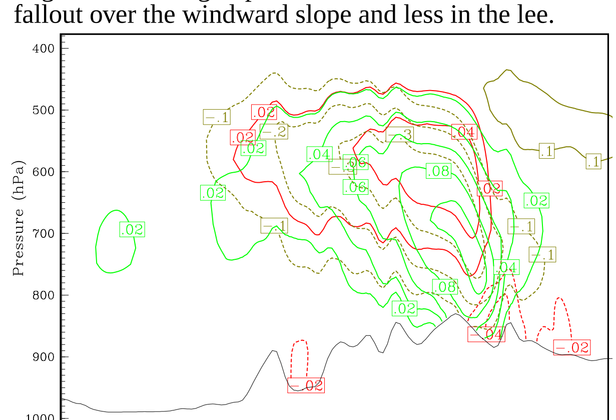

Figure 8. Average west-east cross section for the NOSQ-CTL showing snow (dark yellow every 0.10 g kg^{-1}), graupel (green every 0.02 g kg^{-1}), and rain (red every 0.01 g kg^{-1}) mxing ratio ratio differences for the period between 2300-0100 UTC.

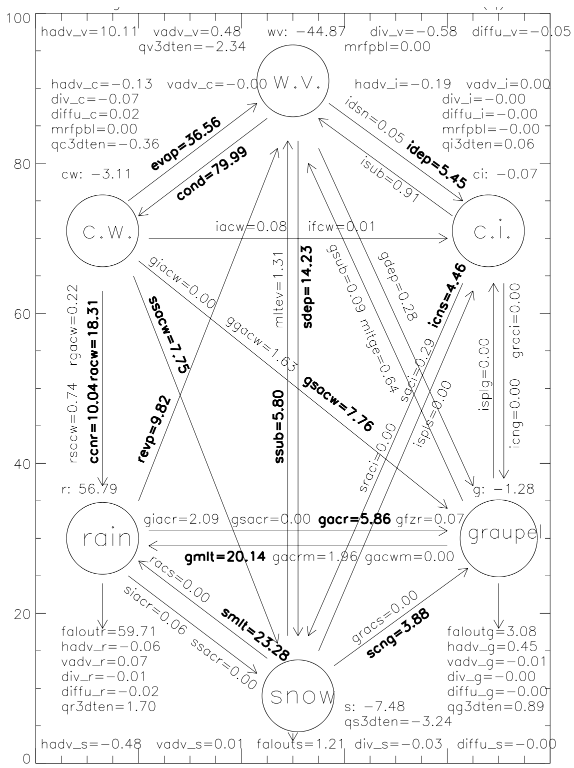

Figure 9. Same as Fig. 4 except for the NOSQ simulation.

Figure 9 shows the budget flowchart for the NOSQ simulation for the 2300-0100 UTC period. The snow deposition (sdep) is half that of the CTL (Fig. 4). As a result, there is more condensation to cloud water, which in turn results in more accretion of snow to form graupel and accretion of rain. Overall, the NOSQ results in a microphysical pathway that favors less snow and more liquid and graupel.

Both Colle and Mass (2000) and Zeng et al. (2003) showed that there is relatively large precipitation sensitivity to the snow fallspeed in the MM5. The CTL MM5 uses a snow fallspeed that is 20-30% larger than some other relationships, such as Cox (1988). A separate 1.33 km simulation (COX run) was completed using the slower Cox fallspeed. The slower fallspeed results in 5-15 mm less precipitation near the crest and 5-15 mm more precipitation in the lee.

Figure 10 shows the differences in trajectories for snow in the CTL (red) and COX (blue). The COX trajectories fallout 20-30 km farther downwind than the CTL. There is less snow falling out over the upper windward slope in the COX, which results in less riming and graupel (Fig. 11).

4. BRIEF SUMMARY AND FUTURE WORK

The goal of this modeling effort is too explore some of the sensitivities of the BMPs, by quantifying changes in how the water mass is transferred between processes and its effect on surface precipitation. From these experiments of changing the cloud water autoconversion, slope intercept for snow, and snow fallspeed, it is clear that there are relatively large uncertainties in the some of the BMP parameters. In particular, the partition between cloud water and its autoconversion to rain versus snow

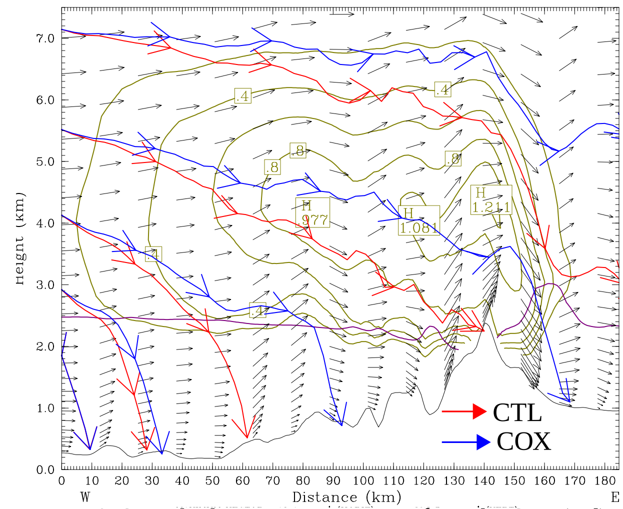

Figure 10. Snow hydrometeor trajectories from the CTL (red) and COX (blue) simulations. The wind vectors and snow mixing ratios from the CTL are show for reference. The cross section location is given by the line in Fig. 1.

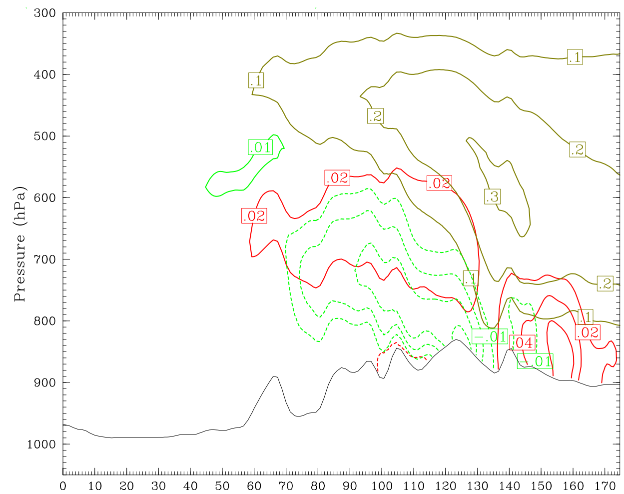

Figure 11. Average west-east cross section difference for the COX-CTL showing snow (dark yellow every 0.10 g kg^{-1}), graupel (green every 0.02 g kg^{-1}), and rain (red every 0.01 g kg^{-1}) between 2300-0100 UTC

deposition appears to be sensitive pathways within the BMPs, since the amount of riming determines how much graupel there will be and in turn the overall fallout efficiency of the hydrometeors. For example, it appears the Berry autoconversion depletes too much cloud water and results in bull-eyes over the steeper windward slopes.

These sensitivities studies as well as others will be verified using the aircraft and in situ data to quantify the errors in cloud water and snow number concentrations and amounts. Some of these results will be reported at the conference as well as future papers.

5. ACKNOWLEDGEMENTS

This research is supported by the National Science Foundation (Grant No. ATM-0094524). Use of the MM5 was made possible by the MMM Division of the National Center for Atmospheric Research (NCAR).

6. REFERENCES

Berry, E.,X., and R.L. Reinhardt, 1974: An analysis of cloud drop growth by collection. Part IV: A new parameterization. *J. Atmos. Sci.*, **31**, 2127-2135.

Colle, B.A., and C.F. Mass, 2000: The 5-9 February 1996 flooding event over the Pacific Northwest: Sensitivity studies and evaluation of the MM5 precipitation forecasts. *Mon. Wea. Rev.*, **128**, 593-617.

Cox, G.P., 1988: Modeling precipitation in frontal rainbands. *Quart. J. Roy. Meteor. Soc.*, **114**, 115-127.

Garvert, M., B. A. Colle, and C. F. Mass, 2003: Modeling of the 13-14 December 2001 IMPROVE case. *10th Conference on Mesoscale Processes*, Portland, OR, Amer. Meteor. Soc., this issue.

Houze, R.A., P.V. Hobbs and P.H. Herzegh, 1979: Size distributions of precipitation particles in frontal clouds. *J. Atmos. Sci.*, **36**, 156-162.

Kessler, E.,III, 1969: On the distribution and continuity of water substance in atmospheric simulations. *Meteorol. Monogr.*, No. 32, Amer. Meteor. Soc., 84 pp.

Medina, S.m and R.A. Houze Jr., 2003: A possible role for turbulence in the enhancement of orographic precipitation: Results from IMPROVEII. *10th Conference on Mesoscale Processes*, Portland, OR, Amer. Meteor. Soc., this issue.

Reisner, J., R.M. Rasmussen, and R.T. Bruintjes, 1998: Explicit forecasting of supercooled liquid water in winter storm using the MM5 mesoscale model. *Quart. J. Roy. Meteor. Soc.*, **124**, 1071-1107.

Thompson, G., R.M. Rasmussen, and K. Manning, 2003: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part I: Description and sensitivity analysis. *Mon. Wea. Rev.*, In review.

Woods, C.P., M.T. Stoelinga, J.D. Locatelli, and P.V. Hobbs, 2003: Cloud and precipitation processes observed in the 13-14 December 2001 storm studied over the Oregon Cascades in IMPROVE. *10th Conference on Mesoscale Processes*, Portland, OR, Amer. Meteor. Soc., this issue.

Zeng, Y., B. A. Colle, and J. Wolfe, 2003: An investigation of the orographic precipitation sensitivities within a sophisticated bulk microphysical parameterization in the MM5. Preprints, *10th Conference on Mesoscale Processes*, Portland, OR, Amer. Meteor. Soc., this issue.