# EVALUATION OF MM5 PRECIPITATION AND MICROPHYSICS OVER THE WASATCH MOUNTAINS DURING IPEX IOP3

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## 1. INTRODUCTION

The Intermountain Precipitation Experiment (IPEX) is a field and research program designed to improve the understanding, analysis, and prediction of precipitation in complex terrain, with an emphasis on the Intermountain West of the United States. Participants include the University of Utah, National Severe Storms Laboratory, National Weather Service, Desert Research Institute, NOAA Air Operations Center, University of Oklahoma, Storm Prediction Center, Hydrometeorological Prediction Center, and SUNY-Stony Brook. The field phase of IPEX was held in February 2000, during which seven Intensive Observing Periods (IOPs) were conducted, several of which examined precipitation and microphysical processes associated with the narrow, steeply sloped Wasatch Mountains of northern Utah.

Recent verification studies of the Penn State/NCAR Mesoscale model (MM5) and National Centers for Environmental Prediction (NCEP) Eta model have revealed deficiencies in high resolution quantitative precipitation forecasts over complex terrain (Colle et al. 1999; Colle et al. 2000). Therefore, a major goal of IPEX is to use field observations to verify and improve the bulk microphysical parameterizations (BMPs) within mesoscale models. This paper presents some preliminary results from IPEX IOP3, during which a major winter storm produced up to 90 cm of snow in the Wasatch Mountains from 0600 UTC 12 Feb - 0600 UTC 13 Feb 2000.

## 2. PRELIMINARY ANALYSIS OF IPEX IOP3

IOP3 was associated with the passage of a forward-tilting trough (i.e., the 700-hPa trough axis preceded that at the surface) and featured large-scale southwesterly crest-level flow that gradually veered to westerly, weak low-level warm advection, and a near-saturated upstream environment. The 700-hPa trough axis is evident over the Great Salt Lake (GSL) in the cross section presented in Fig. 1. Lapse rates were initially slightly more stable than moist adiabatic and gradually increased to moist adiabatic.

With crest-level winds oriented roughly normal to the Wasatch Mountains, substantial orographic precipitation

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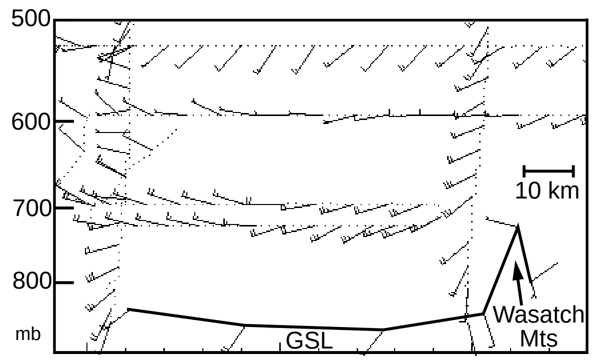


Figure 1. Cross section of flight-level winds, mobile sounding vertical profiles, and MesoWest surface observations from 1700–1900 UTC 12 Feb 2000. Cross section oriented roughly along line AB of Fig. 2. Full and half barbs denote 5 and 2.5 m $s^{-1}$, respectively.

enhancement was observed along the entire Wasatch Crest (Fig. 2). North of Salt Lake City (SLC) lowland precipitation increased as one moved across the Great Salt Lake towards the Wasatch Mountains (Fig. 2a). Observations from the P-3 tail doppler radar showed a broad region of high reflectivity extending well upstream of the Wasatch Mountains in this region (Fig. 3a). This region of enhanced lowland precipitation appeared to be associated with a convergence zone that formed 20-30 km upstream of the lower Wasatch slope (not shown). Several factors may have contributed to the formation of the convergence zone, including topographic blocking, as observed upstream of coastal mountain ranges (e.g., Overland and Bond 1995; Ralph et al. 1999), and frictional convergence associated with land–lake roughness contrasts. Precipitation decreased dramatically to the lee of the Wasatch, with accumulations decreasing by at least a factor of 3 just 15 km downstream of the crest (e.g., Fig. 2a). As illustrated in Fig. 3a, the region of maximum reflectivity during the event sloped strongly downward to the lee of the Wasatch, suggesting that a region of intense leeside subsidence may have limited downstream hydrometeor transport.

This IOP was simulated down to 1.3-km grid spacing using MM5 version 3.3.The simulation featured four one-way nested domains with grid spacings of 36, 12, 4, and 1.3 km. In the vertical, 36 half-sigma levels were used with the levels at approximately 10-hPa intervals near the surface and 30-hPa intervals in the middle and upper troposphere. Precipitation processes were parameterized

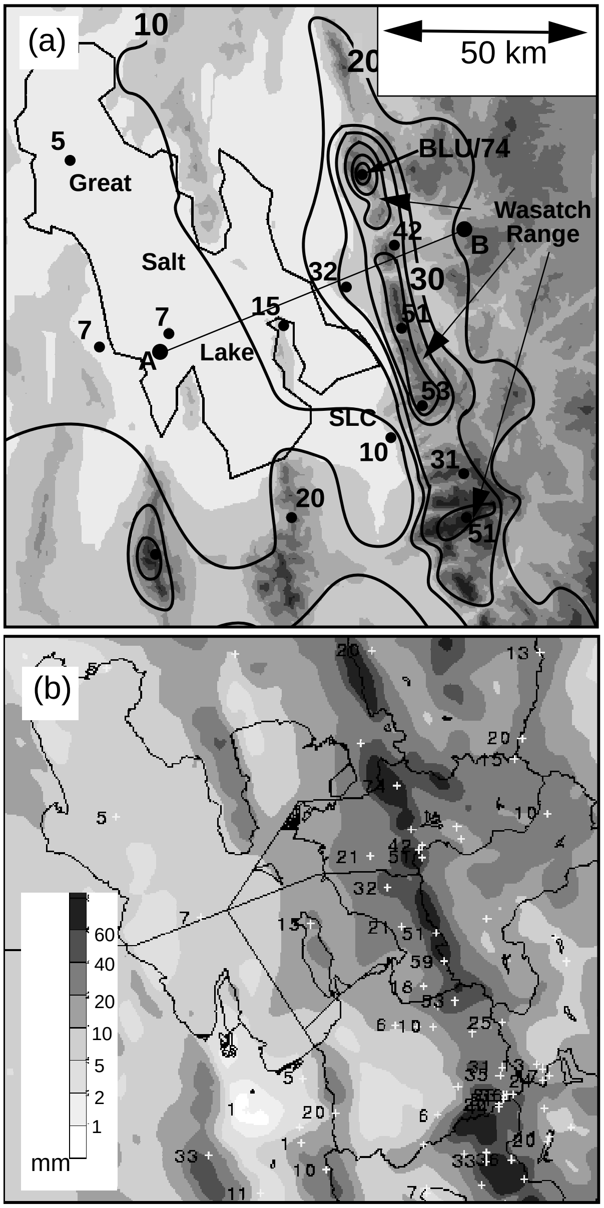


Figure 2. (a) Observed storm-total precipitation (liquid equivalent, contours every 10 mm) from 06 UTC 12 Feb – 06 UTC 13 Feb 2000. Accumulation at selected sites annotated (courtesy Linda Cheng, University of Utah). (b) MM 5 precipitation (shaded using the inset key) for a portion of the 1.3 km domain from 06 UTC 12 Feb – 06 UTC 13 Feb 2000 (18-42 h.). Observed totals for the period are shown at the plus signs.

using the Reisner-II cloud scheme, with the Kain-Fritsch cumulus parameterization used on the 36- and 12-km domains. Other parameterizations included the MRF PBL, Dudhia cloud-interactive radiation scheme, and Klemp and Durran radiative upper-boundary condition.

Using 3-h analyses from the NCEP Eta Data Assimilation System (EDAS), which incorporated special IPEX regional soundings, four-dimensional data assimilation was used to "spin-up" the 36- and 12-km domains from 1200 UTC 11 Feb - 0000 UTC 12 Feb. At 0000 UTC 12 Feb, data assimilation ended on the 36- and 12-km domains and the 4- and 1.3-km nests were activated. The Great Salt Lake temperature on the 4- and 1.3-km domains was set to 6$^{o}$C, roughly the mean lake temperature at the Hat Island mesonet site during the simulation period.

Overall, the 1.3 km MM5 realistically simulated the precipitation around the Wasatch (Fig. 2b). The model predicted the maximum precipitation near the crest, with enhanced precipitation extending ~20 km upwind of the barrier. There is also a sharp gradient of precipitation in the lee associated with the lee side subsidence. One weakness of the simulation is that there is less reverse shear (winds weakening with height above 700 hPa) than observed (Fig. 1); therefore, the model is missing an ingredient that favors greater mountain wave amplification (Colle and Mass 1998).

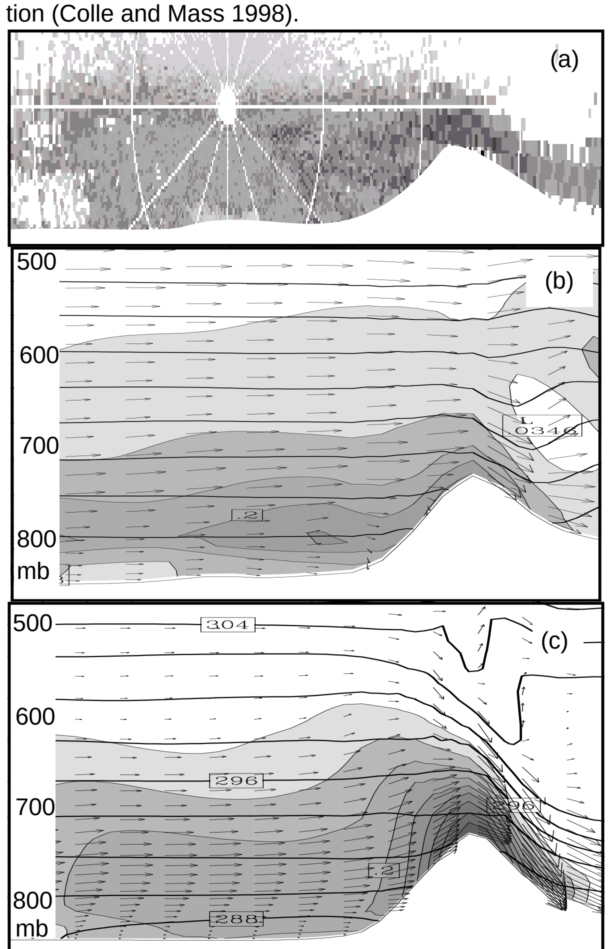


Figure 3. (a) P-3 tail radar reflectivity cross section (along orientation of line AB of Fig. 2a showing windward enhancement and lee side spillover. Range rings every 5 km. (b) MM5 cross section AB from the 1.3 km domain showing winds in the section, potential temperature, and total mixing ratio (shaded every 0.05 g/kg). (c) Same as (b) but for the 2-D Reis2 simulation..

## 3. 2-D MM5 SENSITIVITY TESTS

Additional 2-D MM5 simulations were completed to explore some of the microphysical sensitivities associated with this event. The 2-D MM5 at 1 km resolution (1000 km long domain) was initialized using an observed upstream sounding (near point A on Fig. 2a) at 1800 UTC 12 February 2000. The MRF PBL (but no surface fluxes) and the Reisner2 microphysical scheme were used for the CTL 2-D run.

Figure 3c shows the 2-D flow and precipitation for section AB averaged for the 6-12 h simulation period. In agreement with the 3-D run, there was precipitation enhancement upstream of the barrier, with a maximum near the crest. However, the 2-D had more precipitation near the crest and a more robust lee wave, which is likely the result of having significant reverse shear and the 2-D nature of the simulation (Doyle et al. 2000). Since the 2-D still captures the essential flow and precipitation distribution across the barrier, it was used to explore the sensitivities of a few microphysical parameterizations within the MM5.

Figure 4 shows the 6-12 h accumulated precipitation for 6 different microphysical runs using the same initial conditions. Overall, there is a significant variability in the precipitation distributions across the barrier for the various schemes/versions. Both the simple ice scheme (SICE) and older version of Reisner2 (V2.3) have an anomalous spike in lee side precipitation. This problem has also been identified for 3-D simulations at less than 5-km resolution in the lee of steep barriers (Colle and Mass 2000; C. Mass, personal communication 2001). Both Reis2v2.3 and SICE use a fixed-slope intercept for snow number concentrations, which favors large amounts (>1.0 g/kg) of snow over the barrier. The snow near the crest is brought downward along the lee slope with the mountain circulation. The Reis1V2.6 and uses a variable slope intercept for snow, resulting in less snow generation aloft (not shown). This, combined without graupel processes over the crest, results in significantly less precipitation in the lee than Reis2v2.6. Both Reis1 and the latest Reis2 (V3.3) have more precipitation 10-20 km upstream of the barrier since both schemes predict more cloud water, which auto-converts to rain and falls out rapidly.

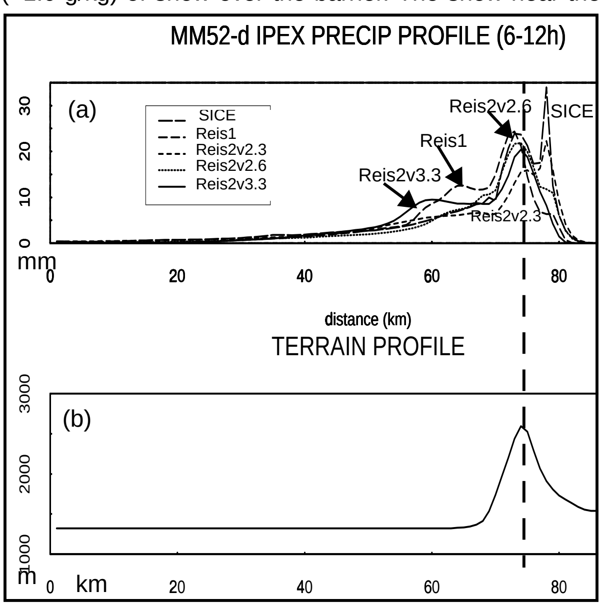


Figure 4. (a) Total 6-12 h precipitation (mm) from the 2-D MM5 for the various microphysical schemes defined in the inset key. (b) Terrain profile used by the 2-D simulations.

## 4. SUMMARY AND FUTURE WORK

High resolution observations and MM5 simulations from IPEX IOP3 illustrate the important role of local terrain-induced circulations in controlling the mesoscale distribution of precipitation. The development of a low-level convergence zone upwind of the initial Wasatch slope resulted in precipitation enhancement over lowland regions, and the lee wave circulation helped advect hydrometeors into the lee. The 2-D MM5 simulations suggest that there are large sensitivities of orographic precipitation to the cloud microphysical schemes used in the MM5. The recent modifications to the Reisner schemes have helped eliminate the anomalous spike of precipitation in the lee; however, there have been no long term verification studies of this scheme. Future work will further detail the kinematic and microphysical aspects of IOP-3, as well as validate and improve the model microphysical parameterizations.

## 5. ACKNOWLEDGEMENTS

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## 6. REFERENCES


Colle, B. A., and C. F. Mass, 1998: Windstorms along the western side of the Washington Cascade Mountains, part II: characteristics of past events and three-dimensional idealized simulations. *Mon. Wea. Rev.* **126**, 53-71.

_________, K. J. Westrick, and C. F. Mass, 1999: Evaluation of MM5 and Eta-10 precipitation forecasts over the Pacific Northwest during the cool season. *Wea. Forecasting.* **14**, 137-154.

_________, C.F. Mass, and K.W. Westrick, 2000: MM5 precipitation verification over the Pacific Northwest during the 1997-1999 cool seasons, *Wea. Forecasting* **15**, 730-744.

Doyle, J. D., and co-authors, 2000: An intercomparison of model predicted wave breaking for the 11 Jan. 1972 Boulder windstorm. *Mon. Wea. Rev.*, **128**, 901-914.

Overland, J. E., and N. A. Bond, 1995: Observations and scale analysis of coastal wind jets. *Mon. Wea. Rev.*, 123, 2934-2941.

Ralph, F. M., and co-authors, 1999: Blocking by coastal mountains in land-falling Pacific winter storms. *Preprints, Third conference on Coastal Atmospheric and Oceanic Processes*, New Orleans, LA, 368-373.