CHAPTER 6

SUMMARY AND CONCLUSIONS

The IPEX field program took place in the Salt Lake City area during February 2000 to study the dynamics, kinematics, and microphysics of precipitation in the intermountain West. The goals of the IPEX program included research to validate and improve model forecasts of precipitation in complex terrain. Precipitation data from an extensive network of surface observations were utilized along with radar reflectivity to study the evolution and distribution of precipitation for the six IOPs that took place in the Salt Lake City area. The precipitation data were also used to validate the QPF performance of three models during IPEX.

Precipitation data from 90 surface stations throughout the Salt Lake City area were successfully collected and quality controlled for the IPEX period, and a data set was created to obtain 6- and 24-h totals. The quality-control process was successful even for stations in the SNOTEL network, which are designed primarily to measure snow accumulation over entire winter seasons. Despite large diurnal fluctuations that vary from gauge to gauge, it was possible to extract meaningful hourly precipitation totals from the SNOTEL data.

The precipitation data set was used to show the spatial distribution of precipitation during the IOPs. Because of the different characteristics of the storms that occurred during February 2000, the precipitation distribution varied greatly between events. These distributions were fairly complex, with different areas more favorable for heavy precipitation than other areas within the IPEX domain. The integration of median radar reflectivity with the gage data was beneficial to understanding the evolution of the precipitation bands and the spatial distribution of precipitation, especially in areas with no available surface observations.

Significant orographic enhancement of precipitation was observed during IOP 3 and IOP 7, with large variations in precipitation totals evident over short distances near the mountain ranges. The northern part of the Wasatch Range received more precipitation than the southern Wasatch during IOP 3, but the opposite was true for IOP 7. Furthermore, during IOP 7, climatologically arid areas such as the Great Salt Lake and the western desert received relatively significant amounts of precipitation. Orographic enhancement was also evident but to a much lesser extent during the other events, which include the fast-moving squall line of IOP 4 and the convective event of IOP 6. The storms that occurred during IOP 2 and IOP 5 showed more localized precipitation. Precipitation was limited mainly to the southern part of the IPEX domain during IOP 2, but the Tooele Valley and several small areas of the Wasatch Range and Wasatch Front received the largest totals during IOP 5.

Precipitation forecasts from the AVN, Eta, and MM5 models were interpolated to the locations of four representative gauges during the IPEX period. The results showed the differences in skill that exist between the three models and between locations. The coarser-resolution AVN and Eta models underforecast precipitation at the mountain sites and overforecast precipitation at the valley sites. These trends are likely due to the inadequate resolution of the model output grids upon which the analysis is based coupled with the relatively coarse resolution of the models' grid. In the AVN and Eta, differences in model terrain elevation between the four stations are small, resulting in little variation between precipitation forecasts in the mountains and valleys. The performance of the MM5 differed from that of the AVN and Eta. The MM5 underforecast the total precipitation at Ben Lomond Peak in the northern Wasatch, but overforecast the precipitation at Alta Guard House in the southern Wasatch. The model overforecast precipitation at both valley sites, but the Sandy site was more significantly overforecast. There was also a significant variation in the skill of the models for the different events. There were periods when the AVN and Eta performed better than the MM5, even though the MM5 generally had better cumulative totals over the course of the entire IPEX period. Evaluation of the point forecasts made by the IPEX forecast team for the Salt Lake Airport and Alta Guard House showed that the forecasters were able to improve upon the model forecasts, but there were also instances when their forecasts were worse.

Spatial maps were constructed from the Eta and MM5 to examine the predicted distribution of precipitation for the entire IPEX domain. The MM5's finer resolution led to forecasts with more detailed structure than the Eta. However, the distribution of forecast precipitation is related to the model terrain, and because the models are unable to properly resolve some of the smaller-scale topographical features, areas of enhanced precipitation are shifted away from the observed precipitation maxima. Even in the higher-resolution MM5, the crest of the northern Wasatch is not fully resolved, so precipitation maxima in that area were commonly forecast further east where the model terrain is higher. This shift appears to be one reason why the point forecast for Ben Lomond Peak had significantly less precipitation than observed. Large precipitation totals were usually forecast by the

MM5 in the Cottonwoods area of the southern Wasatch, even when the observed maximum was located elsewhere, due to the local maximum in elevation of the model terrain. This could explain the MM5 overforecasting at the Alta Guard House station, since it is located in the Cottonwoods area. Although the MM5 was better able to forecast the variability of precipitation totals that existed during each precipitation event, the Eta produced forecasts of precipitation totals that were comparable to the MM5 forecasts over most of the IPEX domain, particularly in the valley regions. Therefore, the Eta should not be viewed as having less skill than the MM5, even though its lower resolution may not allow for the prediction of fine-scale features in the precipitation distribution.

A simple objective technique based upon the Student’s t test for the difference of two means was used to contrast the observed variability of precipitation in different climatological zones to the forecast variability of precipitation from the MM5. This approach was necessary since many of the commonly used objective measures of precipitation forecast skill, such as the equitable threat score, are inappropriate for such a small sample of forecasts over a small domain. This method also bypasses the competing arguments often raised in precipitation validation studies regarding whether observed precipitation should be interpolated to the model grid or the model grid point values should be interpolated to gauge locations.

The most significant drawback to the approach used here arises from the disparity in distribution of observed gauges compared to the regular lattice of model grid points. It is likely that the sample mean of observed precipitation from the available gauges is not completely representative of the population mean for the entire climatological zone. Nonetheless, it is still possible to assess the likelihood that the available observed and forecast samples arise from the same population. If the two samples deviate substantially from one another, then it can be stated objectively that the forecast over- or underpredicts the observed precipitation. The definition of a skillful forecast in this context is one in which it is impossible to distinguish objectively the forecast sample of precipitation on the model grid points from the observed sample of precipitation at the gauges.

The evaluation of precipitation error from the real-time MM5 forecasts provides an objective baseline for future modeling studies. Several clear baseline indicators include: the Northern Wasatch Mountains zone tends to be underforecast while the Southern Wasatch Front and Wasatch Mountain Valleys tend to be overforecast, low skill is evident in the Northern Wasatch Front, and the greatest skill is evident in the Southern Wasatch Front. Combining the zones located along the Wasatch Front and those in the Wasatch Mountains to obtain a larger sample size shows that large errors arise due to both under- and overforecasting along the Wasatch Front, but the largest errors in the mountains are due primarily to overforecasting.

The IPEX precipitation data set provides a manageable sample of variable weather conditions for future model sensitivity studies. This study focused only on the observed distribution of precipitation and the skill of models of different resolutions and physics to predict these distributions. The causes of any errors in the forecasts were not considered. Many factors can contribute to poor precipitation forecasts. One of these factors is the low resolution of the current operational models. Different model physics and parameterizations can also influence precipitation forecasts. Furthermore, errors in the large-scale forecast can affect the amount and timing of precipitation forecast for local regions. To improve precipitation forecasts in complex terrain would require further work in model development, as well as the improvement of the understanding of the characteristics and behavior of precipitation bands impacted by orography.

The skill of models to forecast precipitation is expected to improve if the models are better able to resolve the fine scale of the terrain features and dynamical processes that contribute to such complex distributions of precipitation as those observed during IPEX. However, the precipitation forecast errors are due, in some cases, to large-scale forecast errors that will not necessarily be reduced by increasing the resolution. Large-scale forecasts may be improved by increased observations, which would provide better initial conditions for the models. Furthermore, ensemble techniques would help capture the uncertainties inherent to any one model run. These model improvements are expected in the near future as technological developments allow for the computational power necessary for their implementation.

Current operational and research models incorporate a wide range of physical schemes. Some are more complex than others, but the increased complexity of model physics does not necessarily result in better forecasts, since forecasts are produced based on the interaction of the various physical schemes with each other as well as the model itself. For example, Colle and Mass (2000) studied the sensitivity of different cloud microphysical schemes on the MM5 precipitation forecast during a winter storm in the Pacific Northwest. They found that the most sophisticated schemes did not produce better forecasts than some of the simpler ones, especially at resolutions lower than 20 km, since most of the errors in those cases are due to low terrain resolution. With increased model resolution, model physical schemes and parameterizations become more important, and errors caused by inadequate physical representations are more evident at higher resolution.

Therefore, it is necessary to develop schemes that can more accurately represent the fine-scale aspects of the physical processes that occur.

Data collected during IPEX will allow for a comprehensive study of precipitation processes in complex terrain. Results from these studies will hopefully create a better understanding of the causes of the complex distributions of precipitation that were observed. The results will also help determine the processes responsible for the errors in the model forecasts, and models can then be improved. Even if model forecasts are slow to improve, results from these studies will allow operational forecasters to gain a better understanding of the limitations and forecast tendencies of the models so that better value-added forecasts can be made.