CHAPTER V

SUMMARY AND CONCLUSIONS

During weak synoptic conditions, mesoscale processes can have significant impact on regional weather. Examples of these processes include local surface heat flux gradients caused by differences in evaporation and transpiration from the earth's surface, and circulations caused by topography. Surface characteristics can also play a dominant role in the development of the planetary boundary layer and in cloud and precipitation patterns. Uncertainty in the specification of surface characteristics can impact regional scale predictability. For example, soil moisture and texture and the land use itself are deemed to be the dominant surface characteristics that affect surface forcings. Correctly treating these land surface forcings is important for capturing and properly simulating terrain and land-use induced mesoscale circulations. The effect of these land surface forcings and mesoscale processes on the boundary layer structure has significant implications in the understanding of circulation patterns and regional scale interactions. These processes and characteristics were studied using a high-resolution numerical model.

The PSU/NCAR 5th generation mesoscale model (MM5) is used to perform numerical simulations of these case studies. A one-way triple nested domain was centered over North Carolina with a resolution of 45 km / 15 km / and 5 km for the coarse, intermediate, and inner domains, respectively. The

Oregon State University (OSU) land surface model (LSM) was used with 1 km terrain and land-use data to capture the dynamics of land-surface forcing. This simulation was performed for two independent cases during summer conditions, a non-precipitation case and a convective case with precipitation. In which synoptic conditions were weak for both cases. Model integration was performed for 72-hours from 0000Z August 15, 2000 to 0000Z August 18, 2000 for the non-precipitation case and 0000Z August 1, 2000 to 0000Z August 4, 2000 for the convective case with precipitation. The model employed MRF PBL physics, the Kain-Fritsch cumulus scheme, and Dudhia's simple ice explicit scheme.

Model performance was validated using surface observations, rawinsonde data, and SODAR measurements in North Carolina. Point-to-point comparisons of surface observations with the closest model grid point values were performed using the 5 km model domain. Evaluation and validation of multiple surface parameters were performed using qualitative measures as well as quantitative statistical analysis.

In general, complex regions such as heterogeneous land use and soil type combined with extensive topography were more difficult to model in terms of surface parameters such as wind speed, heat fluxes, temperature, and specific humidity. Nocturnal near-surface temperatures and wind speeds were poorly simulated, particularly in the mountains. However, the general flow speed and direction in the PBL was better simulated. Large differences in the surface temperature simulation may be due to incorrect parameterization of the surface energy budget affecting radiational cooling and non-regional representative observation stations. The model has difficulty capturing the sub-grid scale heterogeneity, especially in the mountains.

Overall, the general flow patterns over the domain are well simulated by the model. When compared with sounding data at heights below 2 km in the PBL, the model appears to be in good agreement with the observations. The 5 km domain does simulate more mesoscale variability in the wind fields than in the EDAS analysis and the 15 km domain. The maxima and minima are typically less in the model output fields when compared with observations, especially during night.

Observed surface winds are light and variable at night while the model tends to over predict wind speeds. This is noted in the mountains where sub-grid scale heterogeneity is obviously the major source of error in the simulation of winds. More observations are needed in areas of complex topography areas in order to simulate regionally consistent flow patterns. In the mesoscale precipitation event, the rapid variations in the winds and the mesoscale variability are not picked up well by the model.

Initialization errors can be extremely detrimental at high resolutions since complex mesoscale interactions are dramatically affected by surface characteristics. One small point-value error can impact surrounding areas in terms of model integration. Soil temperatures are overestimated by the model during daytime hours, especially in the coastal plain. Although the model appears to simulate the soil moisture changes fairly well, initial soil moisture fields are too uniformly distributed and could impact the development of gradients and hence have an impact on the boundary layer structure as well as the formation of clouds and convective precipitation.

One interesting and possible implication for errors is the soil type classification over the domain. MM5 uses Zobler and STATSGO data for soil type information in the model. After careful examination, this dominant soil type classification appears to be based almost entirely on the surface soil characteristics only and not a volume average of soil type. This is evident in Figure 2.4 where there is no specification of clay in North Carolina.

Observed nocturnal temperatures in both simulations are always cooler than the model predicted temperatures at the grid points closest to the stations. Radiational cooling seems to be a major factor in nocturnal temperature errors that are not well simulated by the model. This problem could be related to improper representation, specification, and initialization of surface features including soil moisture, land-use and texture as well as the surface energy budget. In the precipitation case, there doesn’t appear to a considerable difference in the model bias for temperature during the daytime and nighttime as was seen in the non-precipitation case study.

When spatially comparing point-to-point values of near surface temperature and specific humidity, there is consistent evidence that regional biases in these fields may exist in the model. Overall, model performance for both case studies appears to increase from west to east. This finding is reinforced by statistical analysis. In the mountains, there is difficulty in simulating surface characteristics in regions of complex topography. The model performs well in the coastal plain region where the terrain is relatively flat and the soil and vegetation type are somewhat homogeneous. The model simulation over the piedmont region, in the non-precipitation case, fairs well for maximum temperatures. The model has trouble in this region in the precipitation case. This inconsistency could be directly related to the precipitation patterns where a majority of the precipitation accumulations were in the piedmont region.

Comparison of near surface specific humidity between the model and observations presents similar spatial patterns as seen in the temperature comparisons. Overall the model appears to be somewhat dryer than the observations in the surface layer. Comparison of the model and observations show initialization errors in the near surface specific humidity fields during the precipitation case. Although this is not especially apparent in the non-precipitation case, the time series for specific humidity in Chapter 4 indicate initial errors of 3 to 5 kg at many stations.

Transverse vertical circulations are simulated in areas of complex topography and in regions with contrasting gradients in land-use and soil type. At the coast, during the non-precipitation case, diurnal variation in the wind direction is evident in the observations and model simulation along the land-ocean boundary generating a well-defined sea breeze circulation during the day and off shore flow at night. During the precipitation case a defined sea breeze is not evident during the majority of the simulation possibly due to a stronger synoptic flow from the south that was not present in the non-precipitation case.

Topographic induced circulations are simulated in the mountains of NC. The model appears to develop a return flow circulation on the leeward slope providing a possible “trapping zone” for particulates. This could result in higher concentrations in this area during the daytime. The leeward mountain circulations quickly erode and are replaced by a strong katabatic flow as simulated during the nighttime. Unfortunately, observational evidence for this diurnal cycle in the mountains is lacking. In the precipitation case, a south-southwesterly wind pattern is prominent bringing in warm moist air. This flow is converging with the northwesterly down-slope flow in the mountains, showing strong vertical motions in this region. The divergence of winds aloft may help contribute to the vertical motion and hence the heavy precipitation observed in this region during the case study.

Mesoscale circulations are simulated in the sand hills region of the piedmont in NC. Sharp gradients in land-use and soil type in this region may play a dominant role in the development of these simulated circulations. In addition to the land-use induced transverse vertical circulations seen in this region, a moderate southerly flow in the precipitation case providing ample moisture may contribute to the potential increase in convective precipitation. Continued studies in this region may help quantify the effect of gradients in surface characteristics on the development of transverse circulations.

Simulated latent and sensible heat fluxes seem to be well-correlated to the land cover and soil type. These heat fluxes may be attributed to the soil moisture availability in the region as well as the field capacity of the soil types. Significant gradients in the latent and sensible heat fluxes in the sand hills area may contribute to the development of mesoscale circulations seen in this region. Heat fluxes in the precipitation case have more variability indicative of cloud cover over the domain.

Diurnal variation of the boundary layer structure is well simulated. Nocturnal boundary layer heights appear to be simulated fairly well by the model when compared with sounding and SODAR observations. The timing of the convective boundary layer growth also matches the observations well. The rate of growth, however, is somewhat overestimated by the model. This would leave one to believe that convective daytime boundary layer heights are more than likely overestimated by the model. Unfortunately SODAR observations do not exceed 600m in the study.

Overall, precipitation patterns are better simulated by the model in the 15 km domain and in the 5 km domain when cumulus parameterization is used in conjunction with explicit cloud physics. Interestingly, in the 5 km domain, the precipitation amounts and the overall precipitation pattern is not well represented when using explicit cloud physics only. Daily totals of observed and modeled precipitation patterns match fairly well. These results suggest that model performance is reasonably accurate in simulating precipitation, not only in cumulative totality during the entire simulation, but also in the timing and placement of precipitation occurrences.

Future work involving four-dimensional data assimilation may improve model results by initializing the model with the latest surface and upper air observations in addition to the NCEP analysis data. Sensitivity studies involving different radiation schemes, cumulus parameterizations, and land surface schemes may improve model results. Additional case studies are needed to develop a regional strategy for improving model performance in a complex heterogeneous environment.