

***A Cooperative Project
Between the Milwaukee/Sullivan NWS Forecast Office and
the University of Wisconsin-Madison: Final Report***

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Project Number: S98-98361

I. Introduction

During the final phase of COMET project S98-98361 with the National Weather Service (NWS) Milwaukee/Sullivan office, significant advancements have been made in both the operational and educational aspects of the collaborative project. Our primary objective was and continues to be the improvement of the availability and accuracy of University of the Wisconsin Nonhydrostatic Modeling System (UW-NMS) mesoscale numerical guidance to the National Weather Service Milwaukee/Sullivan and the surrounding offices while also assessing the feasibility of accurate high resolution operational predictions of subtle, yet important precipitation inhomogeneities using current data assimilation and model initialization techniques. Expanding upon this objective, the growing interest in local mesoscale prediction throughout the Western Great Lakes National Weather Service Offices has supplied the necessary impetus and framework for our most recent and exciting endeavor

with the Cooperative Institute for Meteorological Satellite Studies (CIMSS) which includes the assimilation of GOES 8/9 derived products into the operational UW-NMS. As a supplement to the operational venture, we have responded both formally and informally to numerous questions posed by the NWS staff regarding the behavior of the UW-NMS. The ensuing paragraphs describe the activities in which we have been involved during this final year of the collaborative project.

II. Improvements to the UW-NMS Operational Production Runs

The UW-NMS continues to be executed twice per day using a two grid configuration with 60 km and 30 km horizontal resolutions for the outer and inner grids respectively. We also employ 32 vertical levels with a minimum grid spacing of 10 m near the ground. Figure 1 illustrates the spatial dimensions of our current operational run. A major goal put forth by Milwaukee/Sullivan was to provide a 48 hour forecast in GRIB format to the office by 18/6 UTC. As discussed in our previous COMET report, the NWS had been having some difficulty decoding the UW-NMS GRIB files. This decoding problem was quickly alleviated, and we have been routinely placing the UW-NMS output on the Central Region server since June of 1997. We are providing the UW-NMS on both the AWIPS 211 (80 km) and the AWIPS 215 (20 km) grids. With the encoding/decoding issues settled, the matter of timeliness needed to be resolved. In order for the forecasters to consider and include the UW-NMS in the afternoon/morning zone package, it is essential that the GRIB files arrive at the NWS office by no later than 6 hours after synoptic time. This time constraint, however, could not be met using the technology that we had available (HP-755). The solution was the purchase of a \$110,000 4 processor SGI Origin 2000 workstation which was cost shared by Tripoli's research group and CIMSS. Despite the increased horsepower, the accelerated operational production runs were not a reality for nearly 6 months. During this six month period, countless hours were spent by Greg Tripoli and Brad Hoggatt restructuring and in

many cases rewriting large blocks of code to most efficiently accommodate the SGI's parallel architecture. Upon successful completion of this enormous task, the UW-NMS operational forecasts were and continue to be supplied to the NWS within the allotted time constraint.

Local Spherical Grid

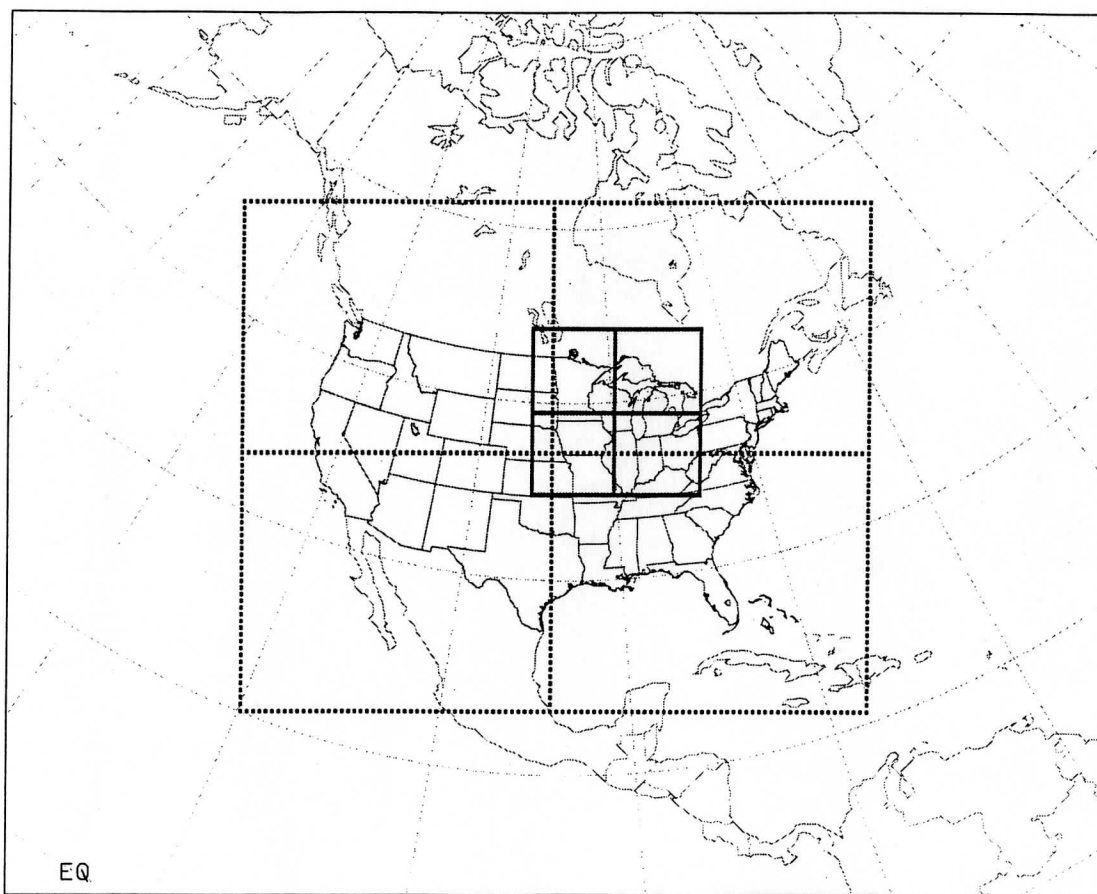


Figure 1. Current UW-NMS operational grid configuration. The outer grid (60 km horizontal resolution) encompasses all of the continental United States, southern Canada, and northern Mexico while the inner grid covers all of the Upper Midwest (30 km horizontal resolution).

During the rewrite, numerous upgrades to the UW-NMS were performed which included: 1) modification of the Emanuel cumulus parameterization to include downdrafts, energy conservation, the ice phase, and vertical momentum transport, 2) implementation of a vertically implicit boundary layer turbulence scheme, 3) replacement of the Chen and Cotton radiation scheme with the more robust Ackerman and Panegrassi scheme, and 4) reformulation of the vertical coordinate system to include a variable vertical grid spacing near the ground. Given the uniqueness of the quasi-terrain following step topography vertical coordinate, the importance will be elaborated upon.

The UW-NMS employs step topography usually referred to as the Eta coordinate system. In the Eta coordinate system, topography is represented by a series of discrete blocks. The step topography can be compared to Lego building blocks. The step topography has attractive numerical properties over the terrain following sigma coordinate system (NGM, AVN, RUC, MM5). Since the sigma vertical system by definition follows the ground, the contact layer as well as those directly above have both a horizontal and vertical component which demands the use of the chain rule and the associated approximations to calculate derivatives and model tendencies. The Eta vertical coordinate, however, is orthogonal; so one does not need to utilize the chain rule to compute horizontal derivatives.

The pure Eta coordinate system is not without its deficiencies, however. The Eta coordinate system unfortunately cannot resolve topographical differences less than the vertical grid spacing. For instance, if a model employed 500 m vertical grid spacing in the lowest layer, the model would not be able to differentiate between the Great Lakes and the surrounding states unless the elevation was greater 500m. In fact, the model would think Wisconsin was located at sea level! We have historically used 200 m vertical resolution which does differentiate between Lake Michigan and Wisconsin, but we are not able to capture some of the subtle topographical features which fall between 200-400 m of elevation across WI. These slight topographical undulations no doubt have important meteorological significance eg. nocturnal slope flows (cold air drainage).

In order to combat the Eta coordinate's inadequacy, Greg Tripoli rewrote the model to utilize a variable vertical grid spacing near the ground. The model can now resolve any terrain change while still maintaining the orthogonality of the vertical coordinate system.

The UW-NMS is the first model to use the concept of horizontally varying vertical grid spacing in the context of an Eta coordinate system. The enhanced topographical resolution should allow for a more accurate representation of atmosphere/topography interaction and ultimately a better numerical prediction.

Beyond the vertical coordinate modification and the other aforementioned improvements, we have recently upgraded the initialization procedure to incorporate: 1) high resolution real-time sea surface temperature data set which includes the Great Lakes, 2) spatially varying albedo, 3) variable surface roughness, and 4) evapotranspiration soil moisture availability. These four real-time data sets will greatly improve our ability to simulate boundary layer processes. We are currently in the process of changing our initialization procedure to utilize the 3 hour 40 km AWIPS 212 Eta GRIB files which will allow us to reduce the size of outer domain and increase the horizontal resolution of the inner mesh to 10 km. Moreover, we are designing a new operational production cycle initialization procedure which will incorporate a 12 hour 4D data assimilation cycle. A simple nudging approach using an extended Rayleigh Friction zone will be applied to the UW-NMS during the $T=-12h$ to $T=0h$ time window using the previous Eta initialization (00/12 UTC) and the new Eta initialization (12/00 UTC) to calculate the nudging coefficients. The 12 hour spinup cycle is crucial for the accurate depiction of meso- β scale structures within the 0-12 hour regime.

III. Quantitative Verification of UW-NMS Forecasts

We have historically relied upon qualitative verification of UW-NMS forecasts. We have now, however, implemented an automated statistical verification scheme which calculates threat, equitable threat, and bias scores for a plethora of parameters including: precipitation, temperature, mixing ratio, winds, etc. In order to verify UW-NMS quantitative precipitation forecasts (QPF's), a successive correction objective analysis methodology is applied to analyze "truth" from observation space to model space. Precipitation "truth" is

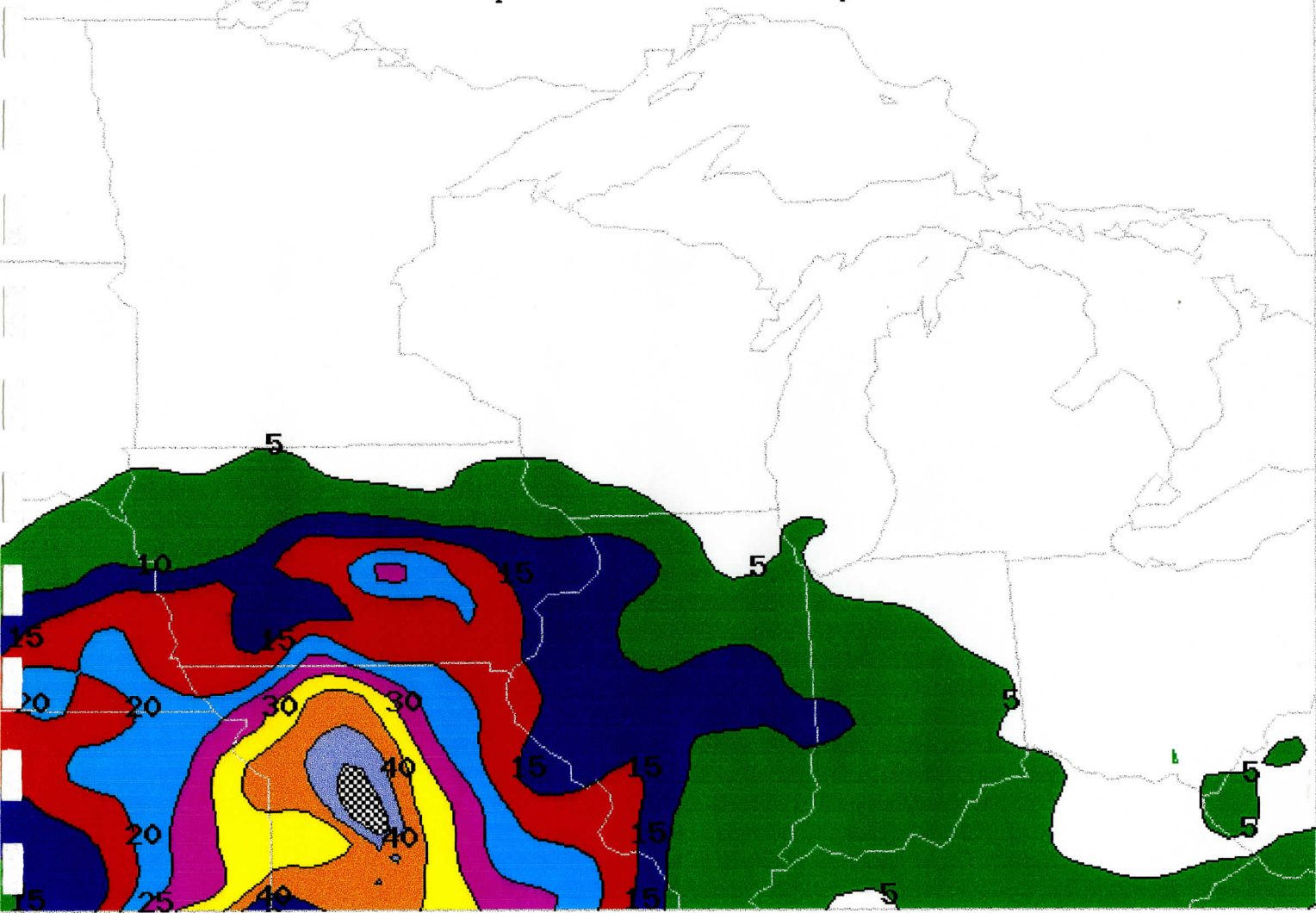
determined by the tipping bucket network of automated (ASOS) plus manual observations (NWS Cooperative Observers) while the RAOBS provide "truth" for the 3-D fields. The QPF verification algorithm calculates numerous performance parameters; however, we are focusing upon two: equitable threat and bias. The equitable threat is the fraction of the time that an observed precipitation event was correctly forecast (awarded for hits while penalized for misses and false alarms) with an adjustment included to remove any contamination introduced by random chance. Bias measures the tendency to overforecast (Bias > 1) or underforecast (Bias <1). We are performing quantitative verification on both the 60 km and 30 km grids. An example of the statistical verification including the analyzed 24 hour precipitation totals and the 24 hour UW-NMS quantitative precipitation forecast is shown in figure 2a, 2b, and 2c respectively.

Figure 2a. Validation of the twenty-four hour UW-NMS forecast valid 12 UTC March 8, 1998 for the inner grid domain as defined in figure 1.

Lower Precipitation Limit (mm)	Upper Precipitation Limit (mm)	Hits	Misses	False Alarms
1.00	600.00	2136	205	397

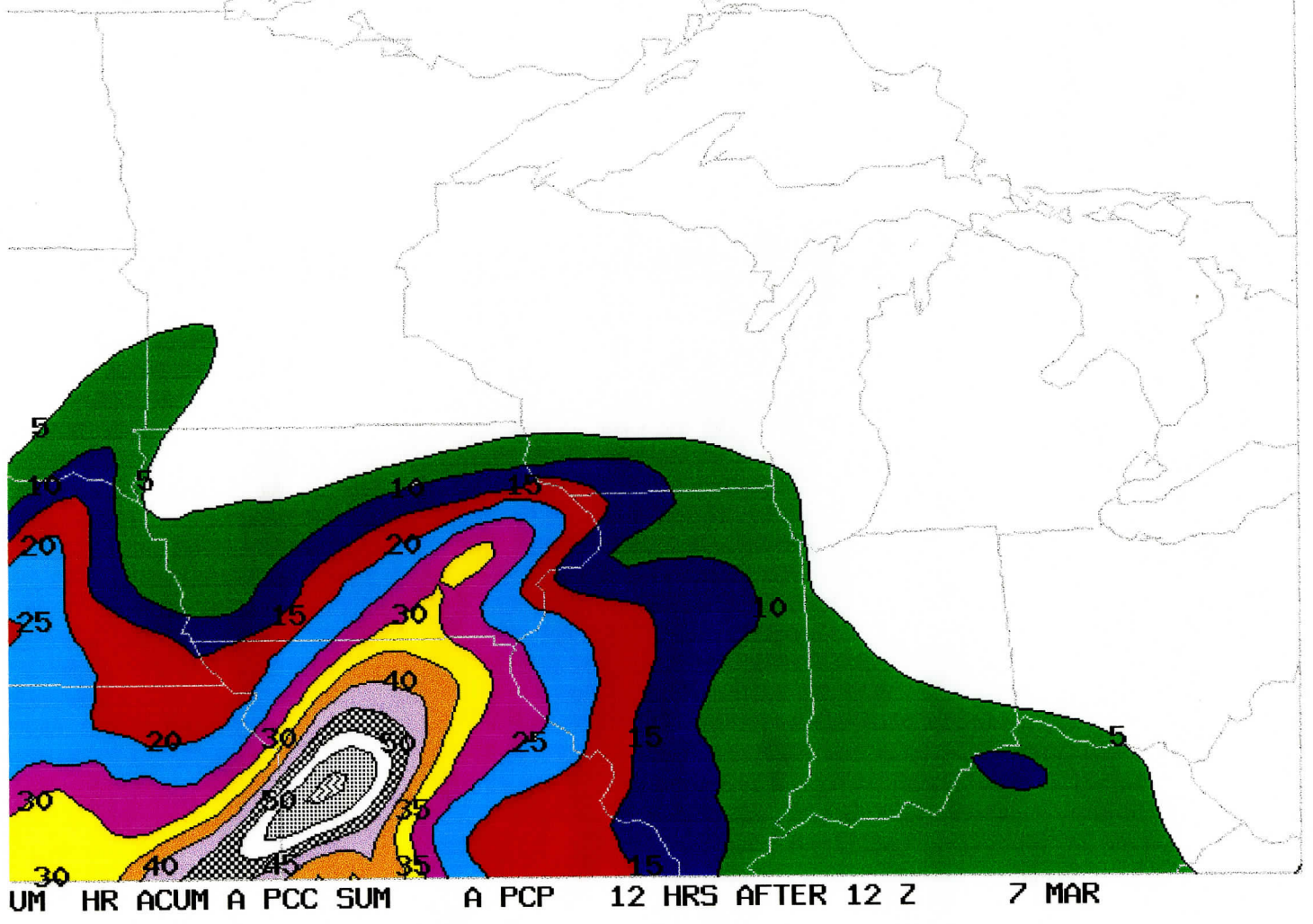
Threat Score	Equitable Threat Score	Forecast Points	Observed Points	Bias
.7801	.5725	2533	2341	1.08

Figure 2b. Twenty-four hour precipitation analysis which was utilized to verify the 24 hour UW-NMS forecast. Precipitation is contoured every 5mm.



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Figure 2c. Corresponding twenty-four hour UW-NMS quantitative precipitation forecast valid 1200 UTC March 8, 1998. Contours are every 5 mm.



The validation statistics shown in figure 2 only represent a single case that produced heavy snow across southern Wisconsin. An unbiased evaluation of model performance, however, necessitates that a running temporal average of model performance be calculated. Therefore, we have developed an automated UW-NMS verification algorithm which will generate statistics averaged over various discrete time intervals and spatial dimensions.

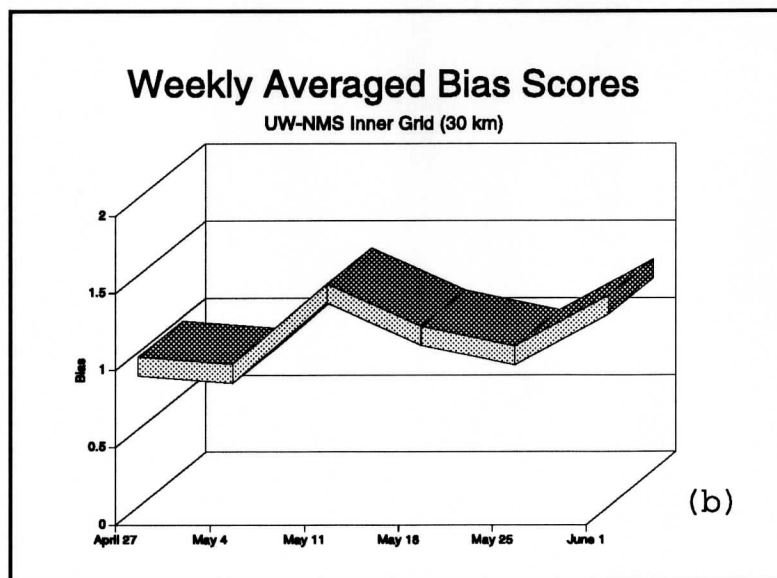
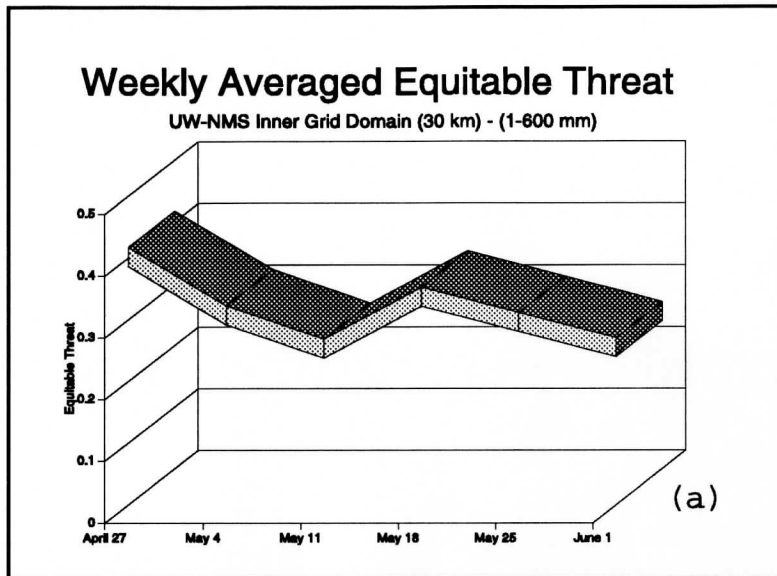


Figure 3. a) Weekly averaged QPF equitable threat scores calculated from the UW-NMS for precipitation values ranging from 1-600 mm. b) Weekly averaged UW-NMS QPF bias scores calculated for the same precipitation range. The verification domain was the current operational run's inner 30 km mesh as defined in figure 1.

IV. Collaborations with Duluth, Marquette, and Grand Forks

We continue to work closely with the Duluth and Marquette NWS offices to investigate a peculiar lake-effect and/or lake enhanced lake-effect snow event. Dan Lennartson, a graduate student, has been performing sensitivity studies in support his Masters Thesis for the December 18, 1996 case to determine the roles of: 1) large scale forcing, 2) topography, 3) thermal forcing, and 4) the land/lake frictional gradient. His preliminary results indicate a positive resonance between the large scale cyclone's occluded structure and the thermal forcing provided by Lake Superior. The latent and sensible heat fluxes provided by Lake Superior acts to increase the intensity of the warm occlusion resulting in a more vigorous thermally direct circulation. The more robust frontal circulation manifested itself in the form of enhanced lake-effect snow along Lake Superior's North Shore. The impact of Lake Superior's thermal forcing can be demonstrated by comparing a "no lake" simulation with the control. The "no lake" simulation yielded up to 40 % less snowfall than the control simulation and the verifying observations.

Another collaborative venture has been initiated between the UW the Grand Forks NWS office. Brad Hoggatt has been interacting with both Philip Schumacher and Bradley Bramer to investigate the origin and evolution of an usually robust convective complex which caused extensive damage across eastern North Dakota and Minnesota last summer. We plan to present our results at the AMS Severe Local Storms Conference in September.

V. Future Collaboration

With the successful acquisition of a second COMET grant, the University of Wisconsin-Madison Nonhydrostatic Modeling System group looks forward to expanding our collaborative work with the surrounding National Weather Service Offices to develop and assess local meso- β scale prediction. The planned work focuses upon bringing new technologies designed to assimilate data on the meso- β scale into operations and assess their impact, especially on the short term forecast which now suffers from "spin-up" problems. Future goals include:

- ◆ Continued execution of a real-time meso- β scale model (10 km horizontal resolution) and the dissemination of the forecast product to the field offices via the frame network.
- ◆ Incorporation of new technologies to better define meso- β scale structures in the initial condition from non-conventional data sources including satellite cloud depictions, water vapor winds, and 3-layer total precipitable water derived from the GOES 8/9 sounders.
- ◆ Simultaneous qualitative and quantitative evaluations of model performance with and without the assimilated satellite information via written evaluations by the local NWS field offices (Milwaukee/Sullivan, Marquette, Duluth, and LaCrosse) and local computation of THREAT, Equitable THREAT, and BIAS scores.
- ◆ Case study analyses with the local NWS offices which exemplify particularly unusual situations or forecast problems which need to be understood ie. cases which deviate substantially from the accepted "rules of thumb".