7B.1 QUANTITATIVE PRECIPITATION FORECAST FOR THE COUPLED OCEAN/ATMOSPHERE MESOSCALE PREDICTION SYSTEM (COAMPS^{TM})[1]

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1. Introduction

The quantitative precipitation forecast (QPF) has long been a tough problem to solve in the history of numerical weather prediction. The reason for this is related to the difficulty of accurately parameterizing the atmospheric moist processes (especially convective and explicit microphysics) for a wide range of weather phenomena that produce precipitation on different time and space scales. Model output statistics (MOS) or ensemble techniques have been developed to enhance the operational model's QPF skill (Antolik 2000). Improvement in the forecast model initialization, physics, numerics, and resolution to explicitly model the precipitation processes with higher horizontal and vertical grid resolutions are also able to provide better QPF skill (Damrath et al. 2000). Various statistic techniques such as bias, threat, Heidke skill, and equitable threat scores have long been used to validate the QPF. These methods are derived from the contingency table for the evaluation of dichotomous (e.g. Yes/No) forecasts. However, these methods are sensitive to the precipitation timing and location errors. New statistical measures have been developed to gain additional information on the QPF verification problem in recent years. By comparing the observed versus forecast three directional components (latitude, longitude, and diagonal) of the rain fluctuation scaling parameters over time, Zepeda-Arce et al (2000) were able to quantify the spatial and temporal variability of a high resolution mesoscale forecasts. Object oriented approaches have also been developed to examine QPF. Ebert and McBride (2000) adapted the pattern matching technique to find the best match between the observed and forecast rain pattern and to derive the model root mean square error (RMSE) in terms of location, size, and intensity. Nachamkin (2001) took the event verification approach to compare model versus observed spatial distribution climatology. A composite method (Nachamkin 2002) was also developed to extend the usage of partially observed events to obtain the probability of forecasted Mistral event over the Mediterranean. A recent effort has been undertaken to upgrade the Naval Research Laboratory (NRL) COAMPS physics, including the explicit microphysics, convective parameterization, radiation, and planetary boundary layer (PBL).

Validation of the model QPF and other model statistics are important to gauge the improvements of the model performance. COAMPS has been the operational mesoscale model of the US NAVY since 1997. It is running daily at the US Navy's central and regional forecasting centers over many different regions of the world with horizontal grid resolution ranging from 81 to 5 km. The COAMPS CONUS forecasts were obtained from the US Navy's Fleet Numerical Meteorology Oceanography Center (FNMOC) at 27km horizontal resolution. The purpose of this paper is three fold: (1) establish base line QPF statistics for the future model improvements, (2) test the new verification techniques developed at NRL (Nachamkin 2001 and 2002), and (3) identify areas of model deficiencies for QPF improvements.

2. Model physics and grid setup

COAMPS is a non-hydrostatic terrain following sigma coordinate mesoscale model (Hodur 1997) that can be run on a wide variety of computer platforms including the massive parallel distributed memory and the shared memory systems. The current operational version at FNMOC uses the message passing interface and two dimensional domain decomposition techniques to achieve the parallelism. The horizontal grids use an Arakawa C-staggering. A fixed 3:1 ratio is used to define the grid spacing. Multiple nests are allowed at the same nest levels. The nests can be moved or initialized at any given time during the forecast. The current operational version of COAMPS contains only the atmospheric component. The tightly coupled atmosphere and ocean system is expected to transition to operations in 2008. The full model physics is used for all the operational forecasts. The operational CONUS domain at FNMOC consists of two grids (81 and 27 km). The operational 27 km COAMPS model forecasts at 24 and 48 hours from the 1200 UTC cycle are used to compute the 2001 cold season statistics. For the case studies, two additional grids with 9 km horizontal resolution are added to the operational 27 km domain (Fig.1)

Fig. 1. The 27 and 9 km COAMPS domain configuration.

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[1] COAMPS^{tm} is a trademark of the Naval Research Laboratory.

3. Observational data

The grided 24 hour accumulated stage 4 gauge precipitation analysis at 4 km resolution from the National Center for Environmental Prediction (NCEP) River and Forecast Center (RFC) have been routinely collected at NRL since November 2001 for the COAMPS QPF studies. Since the COAMPS forecast grid resolution is coarser than the RFC rain analysis, the RFC rain analysis is remapped to the COAMPS 27 km model grid points using an upscale discrete type algorithm. The effect of the upscale aggregation is shown in Fig 2. Smaller scale features can be seen at 9 km compared to the 27 km resolution rain analysis but the overall patterns are similar. The area coverage of precipitation from these two different scales is almost identical. The errors resulting from the upscale aggregation is small and can be ignored for the one-week case study.

4. COAMPS precipitation statistics

The COAMPS precipitation statistics for the 2001 cold season were computed over the 27 km COAMPS domain using eight different thresholds of rain rate. The time period is from mid November 2001 through 30 April 2002. Due to various data collecting problems, 111 days statistics are actually used for the average. Fig. 3 shows the averaged equitable threat score (ETS) and the bias score. The comparison of the averaged COAMPS rain area coverage (represented by the bias score in Fig. 3a) with the observation indicate: for light rain amount (<10 mm/day) the COAMPS rain area coverage has good agreement with the observed (bias is close to 1); for medium rain amount (10-35 mm/day) the area was over-predicted; for heavy rain amount (>35mm/day) the rain area was under-predicted.

Comparison of the 0-24 and 24-48 hour forecasts bias scores (Fig. 3a) shows the model has positive precipitation bias with increasing forecast time. The COAMPS relative humidity (RH) field also showed the same bias trend indicating the precipitation problem was related to the increase moisture in the model atmosphere with time. The possible causes for the RH and precipitation bias are currently under investigation.

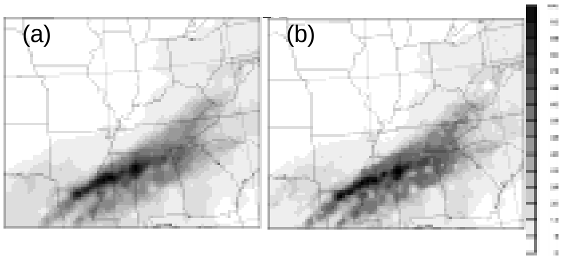


Fig. 2. Example of remapping the RFC 24 hours accumulated rain analysis at 1200 UTC 25 January, 2002 to the (a) 27 km and (b) 9 km COAMPS grid.

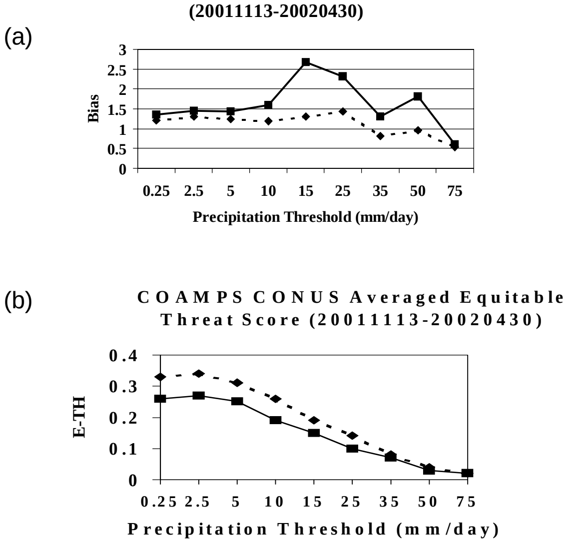


Fig. 3. The averaged 27 km COAMPS CONUS (a) bias and (b) equitable threshold scores for precipitation thresholds of 0.25 to 75 mm/day. The dotted line represents the 0-24 hour forecast and the solid line represents the 24-48 hour forecast.

The COAMPS 27 km equitable threat scores shown in Fig. 3b are a little over 0.3 for the light rain rates and decrease linearly to about 0.04 in the heavy rain categories. Since the bias scores are close to one for rain rate <50 mm/day, the low ETH score seems to indicate the COAMPS forecasts do not produce enough “exact” rain coverage suggesting a possible phase shift problem. For a rain rate > 75 mm/day, both the bias and ETH scores are low suggesting the model does not forecast enough heavy precipitation. The averaged equitable threat and bias scores provide useful guidance on identifying the problems of model bias in precipitation but provide little information to the user as to where such biases may exist geographically on the model grid unless the scores are computed separately in different geographical locations. Additional information in this regard can be drawn from the statistics by plotting the frequency distribution for each precipitation category over an extended period of time (Nachamkin, 2001) on the model grid. To try out the event based verification method, the precipitation event is defined for each rain threshold if there is at least four observed grid points exceeding that threshold. The total number occurrence at each grid point from the observed and forecast events are shown in Fig. 4. Subjective inspections of these plots show the model rain distribution climatology is remarkably similar to the observed.

The correlations in the Pacific Northwest (PNW) and the lower Mississippi River Basin (MRB) is shown in Fig. 5. In general, COAMPS orographically induced precipitation forecasts are good along the PNW. However it tends to over-forecast the occurrence of precipitation in this region that is also reflected in the lower correlation values for the light and heavy rain categories. Over the MRB, COAMPS consistently under-forecasted the precipitation occurrence for rain rate > 15 mm/day. The winter time precipitation in the MRB region is mostly associated with synoptic scale frontal passages with embedded mesoscale convection. Further examination shows that less than 20% of the total model forecast rain is convective for the rain rate > 35 mm/day category in both the Pacific Northwest and MRB regions.

Since the 27 km horizontal resolution is too coarse to explicitly model the precipitation process, more precipitation contribution should come from the model subgrid scale processes (mainly the convective scheme). The lack of convective rain at 27 km resolution suggests one of the possible causes for the model QPF deficiency.

5. Case Studies:

To further understand whether the 27 km COAMPS precipitation bias come from the explicit or the convective schemes, additional model runs were performed for a one-week period (1200 UTC 25 January to 1 February 2002) using a research version of the model. Two 9km domains, one over the PNW and the second one over the MRB (Fig. 1) regions are added to the operational CONUS domain. The precipitation for the 9 km domains is explicitly resolved by the model microphysics scheme (e.g. convective scheme is not turned on). A bench run using the current version of microphysics and a sensitivity run using the improve microphysics (schmidt 2001) are examined.

A synoptic front swept through the CONUS from the Pacific Northwest during this one-week period producing moderate precipitation. The one week averaged ETH scores from the 1200 UTC forecasts show higher scores at 9 km than at the 27 km in both the PNW and MRB regions (Fig. 6). In addition, the 9km ETH score on the PNW region is higher than the MRB region similar to the 27 km cold season results discussed in the previous section.

Encouraging results are obtained when using the new improved microphysics scheme for this one-week period. The ETH and bias scores for both the 27 km and the 9km grid resolutions are much better across all the rain categories (Fig. 7). Visual inspection of the 24 hour accumulated convective precipitation for this one-week period shows the convective precipitation amounts are roughly the same for the improved microphysics runs. These results indicate possible precipitation deficiency with the current COAMPS convective scheme. An effort to implement a new version of KF scheme that is used in the Weather Research and Forecasting (WRF) model into COAMPS is currently underway to improve the QPF.

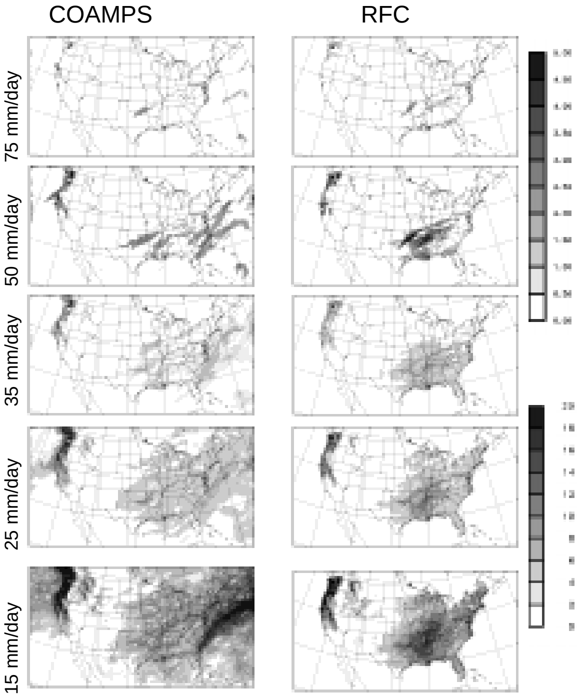
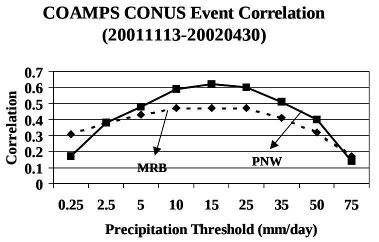


Fig. 4. Comparison of the COAMPS and the observed cold season 2001 24 hour accumulated rain event climatology. The shaded areas represent the number of event occurrence. The maximum scale of shading for the rain rate >50 mm/day is 5 events and for the rain rate < 50 mm/day is 20 events.



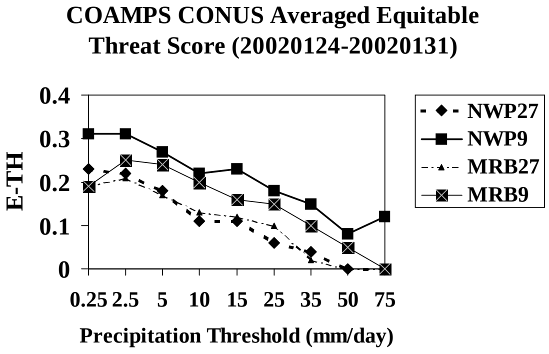


Fig. 6. COAMPS equitable threshold scores at 9km (the top two solid lines) and 27 km resolution during the one week test period.

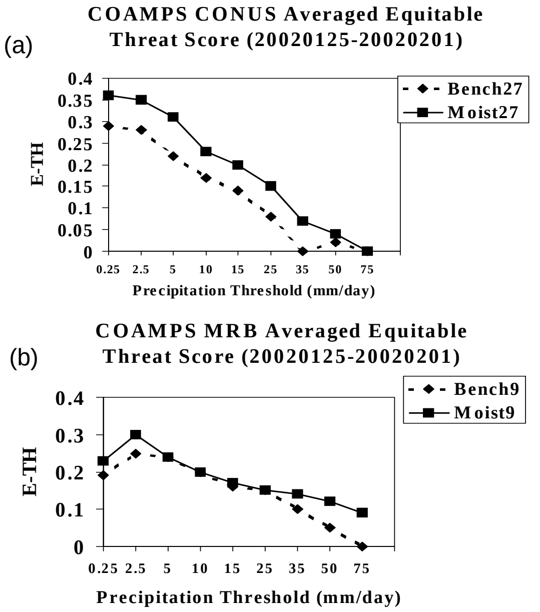


Fig. 7. Comparison of COAMPS equitable threat scores between the standard (bench) and the improved microphysics (moist) runs (a) at 27 km resolution over the CONUS region and (b) at 9 km resolution over the MRB region during the one week test period.

6. Conclusion

Evaluation of COAMPS QPF has been conducted for the winter 2001 season over the CONUS region using the 4 km resolution RFC rain gauge analysis from NCEP. Traditional techniques, such as the equitable threat and bias scores, along with an event verification technique (Nachamkin 2001) are used to validate COAMPS QPF skill. Horizontal plots of the regional distribution help to isolate geographical areas that have the greatest impact on the overall threat and bias scores. Such information can be helpful in identifying weaknesses in the model physics, which directly impact the QPF. Some preliminary results showed the COAMPS cold season 27 km QPF biases are close to one for most of the rain thresholds except for the very heavy precipitation categories (35mm and above). The distribution plots suggest that model has similar climatology compared to the observed. The model over-forecasts the precipitation along Pacific Northwest and consistently under-forecast the precipitation over the lower Mississippi River Basin at 27 km grid resolution. For the 35 mm/day and above rain thresholds, less than 20% of the total precipitation was contributed by the COAMPS convective scheme.

The one-week case studies show increasing resolution improved the model QPF. When using the new microphysics, even more QPF improvements are obtained. This microphysics scheme is currently being tested for a wide range of weather phenomena that produce cloud and precipitation. The new scheme will be transitioned to operations later this year. Similar to the 27 km cold season QPF results, the case studies indicate possible precipitation deficiency from the COAMPS convective scheme. Studies to examine COAMPS special and temporal distributions of the warm season QPF are planned for the near future.

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