13.5 ENSEMBLE MEMBER FORECAST SPREAD AND ITS IMPLICATION FOR ROAD WEATHER FORECASTING

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1. INTRODUCTION

The Federal Highway Administration (FHWA) began an aggressive research and development program in 2000 to develop a prototype winter Maintenance Decision Support system (MDSS) designed to support state departments of transportation snow and ice control operations. The MDSS utilizes state-of-the-art weather forecasting and data fusion techniques and merges them with computerized winter road maintenance rules of practice. The result is a set of guidance aimed at maintenance managers that provides a forecast of surface conditions and treatment recommendations customized for specific routes.

Several weather models (including Eta, GFS, RUC, MM5, WRF, and MOS) are used by the Road Weather Forecast System (RWFS), which generates a consensus forecast used within other MDSS components (Myers et. al 2002). A time lagged ensemble approach of the mesoscale models was also utilized so that the MM5 and WRF runs from the most current run, as well as the two runs prior to that were all used. The RWFS then uses these ten model members to come up with its final consensus forecast. A winter 2004-2005 field demonstration was conducted over Colorado with an emphasis on four areas: the E-470 highway around the eastern side of Denver, a section of I-70 near Genesee in the foothills west of Denver, a section of I-25 south of Denver, and I-70 in the mountains near Vail Pass. The overall forecast spread observed by the ensemble model members of the RWFS, for a moderate snow event on 27-29 November 2004 is presented to illustrate the large differences often found between model members.

It is important to be aware of the forecast differences for each weather parameter. The large spread that is evident between all of the models lends credence to the ensemble forecasting approach utilized in the RWFS, which results in a final consensus forecast that is better on average than many of the individual models.

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2. 27-28 NOVEMBER 2004 SNOW EVENT

2.1 Synoptic Overview

The first significant snow storm to impact the Denver metro area occurred over Thanksgiving weekend 2004, one of the busiest travel weekends of the year. The snow began around 02 UTC on 28 November 2004. There was approximately 1 inch of accumulation followed by a lull in the storm from 05-14 UTC. The snow started falling again at 14 UTC and continued all day and into the next, through 15 UTC on 29 November. A total of 5-8 inches of snow fell in the area by the end of the event.

For this event, three RWFS runs, each out 24 hours, are examined and compared for the meteorological parameters, including air temperature, dewpoint temperature, wind speed, and cloud cover. Quantitative precipitation forecasts (QPF) are also explored.

The first run from 18 UTC on 27 November 2004 is examined to address how the individual models predict the approach of the storm and the start of the precipitation. The next run is from 12 UTC on the 28th, and it shows how the system performed during the heart of the storm. Finally, the forecast valid at 06 UTC on the 29th is used to look at how accurately the end of the event was forecasted, especially with regard to the precipitation end time.

2.2 Parameter Forecast Prediction

2.2.1 Air Temperature

The 18 UTC forecasts from each of the ten RWFS input modules show a very large spread in the predicted air temperature for the entire 24 hr period (Fig. 1). The models are as far apart as 6°C at times. The mesoscale models (MM5 and WRF) start too warm, while the Eta is too cold. The GFS starts out fairly close to the observed temperature but gets much too warm a few hours later when it fails to forecast the frontal passage. In spite of this, the final RWFS consensus forecast is within 1°C of the observations for much of the time, with a maximum difference of 1.5°C for a short period. The frontal passage is forecast by all the models, with the exception of the GFS, to come through the area at 00 UTC on 28 November, which was approximately two hours earlier than the observed frontal passage. This also corresponds to the time of the maximum temperature difference between the RWFS consensus forecast and the Denver ASOS observation. Between the initial onset of snowfall and the second, longer-lived snow period (as seen in the next run), the models show significant differences in their respective air temperature forecasts. In spite of the conflicting forecasts, the RWFS weighted ensemble technique results in a good consensus forecast overall, and this continues through the first 24 hours.

When looking at the 12 UTC run from 28 November (Fig. 2), all of the models except the Eta warm the air during the afternoon hours, whereas the observed air temperature steadily decreases throughout the day. This over-forecast of air temperatures causes the RWFS to be about 2°C high during the afternoon and evening hours, but the differences decrease around midnight, as the individual models come into agreement. During the remainder of the forecast period, the RWFS is within 1°C of the observed temperature.

The 06 UTC system run from 29 November (Fig. 3) shows better agreement between the models and the observations until the end of the period. The RWFS air temperature is within about 0.5°C until about 00 UTC on the 30th. The errors increase again during the evening and overnight hours due to the large spread between the model forecasts, which were all too warm, possibly because the skies cleared more than the models forecast (see Fig. XX) and with the fresh snow on the ground the radiational cooling was higher than forecast.

2.2.2 Dewpoint Temperature

An incredibly large spread in dewpoint temperature between the models is apparent in the comparisons for both the 18 UTC and 12 UTC runs (Figs. 4 and 5). For the first run, all of the MM5 runs perform fairly well, while during the second run the MM5_4 and the GFS are the closest. Again, in spite of the large differences between the models, the RWFS final consensus forecast is within 1-1.5°C most of the time for both runs.

For the third run examined (Fig. 6), the NCEP models (GFS and Eta) perform better early on, and then the mesoscale models do better later in the time series. The RWFS dewpoint temperature forecast for this run is very good through the end of the snow event.

2.2.3 Wind Speed

The wind speed forecasts from the entire forecast module suite for the 18 UTC 27 November run (Fig. 7) started out about 5 m/s too low; however, the forward error correction scheme (FEC) applied within the RWFS increased winds in the consensus forecast, so it compared quite closely to the observations in the first few hours. After the frontal passage (~22 UTC), forecast wind speeds from all of the models and the consensus were consistently low compared to the observations through the end of the first run and through 00 UTC on 29 November, as shown in Fig. 8. After that time, the wind speed decreased and all the forecast models were much more in line with the observations during the middle and end of the snowfall period, as seen in Fig. 9. However, after the snow ended, the winds became calm, but the models predicted the winds to remain higher.

2.2.4 Cloud Cover

All of the models appear to have difficulty forecasting complete overcast (100% cloud cover) and completely clear (0% cloud cover) conditions. For this case, all of the models predicted conditions closer to broken skies when completely overcast skies were observed (Fig. 10).

At the start of the 12 UTC run on 28 November (Fig. 11), some of the models forecasted scattered cloud cover during completely cloudy conditions. The models were allowing more solar radiation to penetrate the clouds than was actually occurring, impacting air temperature forecasts, which were too high during the afternoon of the 28 November, as illustrated in Fig. 2. Toward the end of the snow event (end of the 12 UTC 28th and beginning of the 06 UTC 29th runs), the models do trend towards overcast conditions, but they never reach 100% (see Figs. 11 and 12). Because of the FEC process, the final RWFS consensus forecast valid at 06 UTC on November 29th starts out at 100% overcast and remains near 100% for the first five hours. By the end of the period, the observations have quickly dropped to clear, whereby the models are slow to respond and change only to scattered sky conditions.

2.2.5 Quantitative Precipitation Forecast

Within the RWFS there are set thresholds for hourly probability of precipitation (POP) and quantitative precipitation forecast (QPF) values that must be met before precipitation will be declared by the system. For the 2004-2005 winter field demonstration the POP threshold was set at 25% while the QPF threshold was 0.05 mm/hr.

A GEONOR precipitation gauge, located at Denver International Airport as part of an FAA sponsored project, was used as the observational dataset for liquid equivalent precipitation. This precipitation gauge has a Double Fence Intercomparison Reference (DFIR) shield surrounding it in order to minimize the affects of the wind during snow falls. According to Rasmussen, et al. (2001), this snow gauge and wind shield combination measures within 5% of manual (ground truth) observations. A higher confidence is placed in the accuracy of the GEONOR liquid equivalent precipitation measurements than the hourly automated precipitation measurements made at ASOS sites.

As previously mentioned, the start time of this event was about 02 UTC on 28 November 2004, as indicated by the DIA GEONOR precipitation gauge observation (black line in Fig. 13). The models differed on the start time, most of which were earlier than actual and a few missed the initial very light snow event altogether and just forecasted the start of the heavier snowfall that began about 8 hours later. It is interesting to notice that the older mesoscale model runs (MM5_3, MM5_4, WRF_3, and WRF_4) actually do better than the newest runs for the start time of the first light event. The Eta also did very well on the earlier start time. The RWFS consensus forecast (red line) predicted the start time of the first very light event about two hours early. The forecast rate of snowfall was fairly close to the actual, though. Because the consensus RWFS forecast had the break in the snowfall forecast later than observed, the predicted amounts at the end of the time series were high by approximately 0.03 inches.

At the end of the first time series, the RWFS has snow beginning again around 16 UTC when the observations show it started two hours earlier. In the 12 UTC 28th run (Fig. 14), the Eta and GFS models had a start time of 12 UTC; however, the mesoscale models all delayed the snow until much later. The RWFS did not meet the threshold for declaring precipitation until 00 UTC on the 29th, approximately 9 hours late.

The final run from 06 UTC 29th (Fig. 15), shows the RWFS forecast tracking below the GEONOR precipitation observations because the forecast rate is slightly low. The RWFS then predicts a break in the snowfall at 11 UTC, which was actually observed at 14 UTC. This break lasts only a few hours, while the RWFS had it lasting six hours. The short-lived snow shower that moved through at 17 UTC was forecast by the WRF and final consensus forecast.

3 SUMMARY

This case study illustrates several issues that need additional investigation. It was surprising to see such large discrepancies between the weather models in predicting air and dewpoint temperature, wind speed, cloud cover, and precipitation. This result was repeated many times throughout the winter season. None of the models consistently outperformed the others for any parameter.

All the models were too dry (low dewpoint temperatures) and most had difficulty predicting 100% cloudy conditions. The models also had a low wind speed bias overall. Some of these deficiencies can be traced to the fact that the Denver area often experiences shallow, moist frontal systems that are not well captured by the models. The fronts often arrive hours before they are predicted bringing along moist, cool air and thin, shallow cloud layers.

These findings support the conclusion that an intelligent data fusion system should be used to optimize an ensemble of forecasts. The RWFS was able to demonstrate more skill overall than any of the individual forecast members. There is ongoing research on how to best configure the RWFS to make it more responsive to rapidly changing conditions and how to select the appropriate type and number of forecast members.

The findings also support the concept of presenting weather prediction results in probabilistic terms because there are clearly times when the atmosphere is more predictable than others. Users should be made aware of the certainty of specific predictions that are important and relevant to their operations and decision making. More research is required to determine the best approaches to use to present this uncertainty to end users.

4 REFERENCES

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Rasmussen, R., et al. 2001: Weather Support to Deicing Decision Making (WSDDM): A Winter Weather Nowcasting System. *Bull. Amer. Soc*, **82**, pp. 579-595.

5 ACKNOWLEDGEMENTS

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The development of the MDSS functional prototype is a team effort involving several U.S. national laboratories including CRREL, MIT/LL, NOAA/GSD and NOAA/NSSL. Each national laboratory has contributed by providing technologies that support MDSS objectives.

6 FIGURES

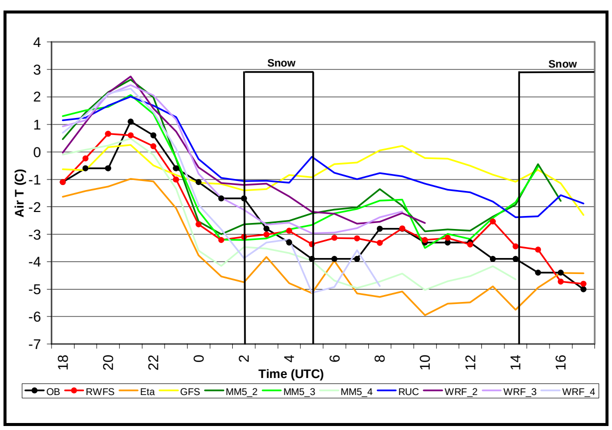

Fig. 1: *18 UTC 27 November 2004 model runs showing air temperature (ºC) forecasts versus the Denver METAR observations.*

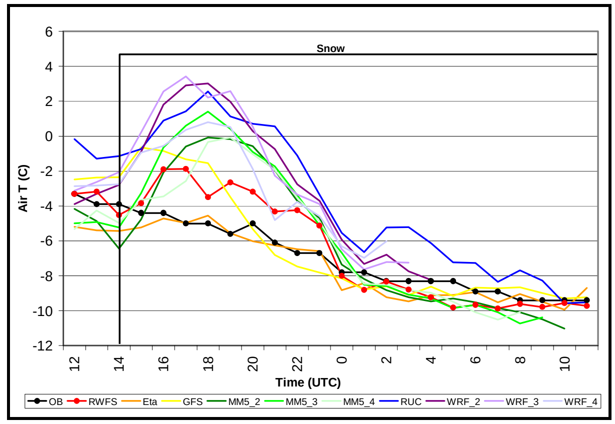

Fig. 2: *12 UTC 28 November 2004 model runs showing air temperature (ºC) forecasts versus the Denver METAR observations.*

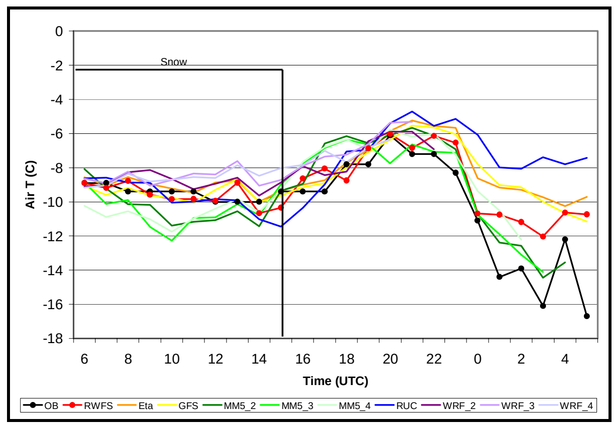

Fig. 3: *06 UTC 29 November 2004 model runs showing air temperature (ºC) forecasts versus the Denver METAR observations.*

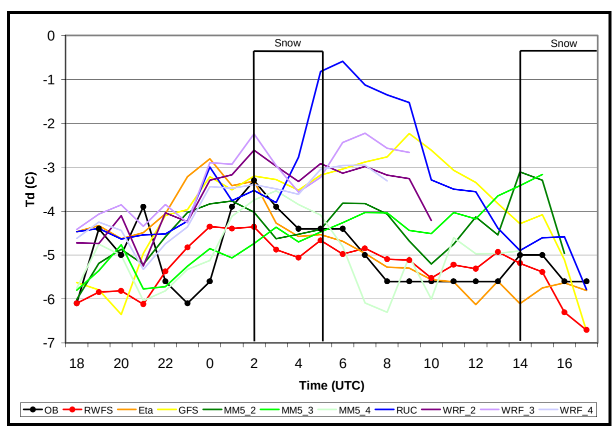

Fig. 4: *18 UTC 27 November 2004 model runs showing dewpoint temperature (ºC) forecasts versus the Denver METAR observations.*

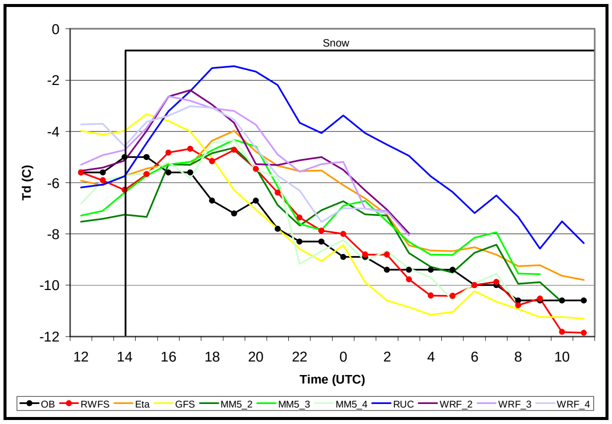

***Fig. 5:** 12 UTC 28 November 2004 model runs showing dewpoint temperature (ºC) forecasts versus the Denver METAR observations.*

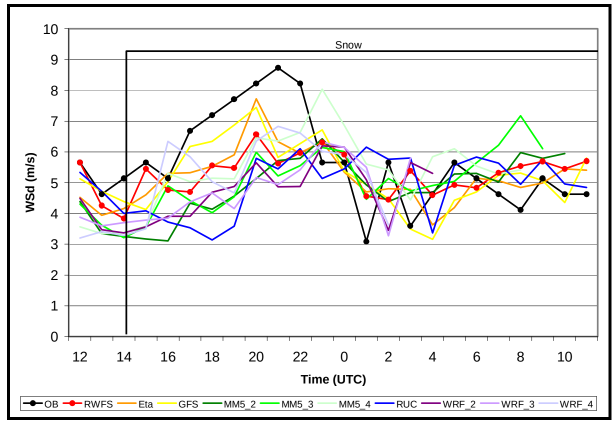

***Fig. 8:** 12 UTC 28 November 2004 model runs showing wind speed (m/s) forecasts versus the Denver METAR observations.*

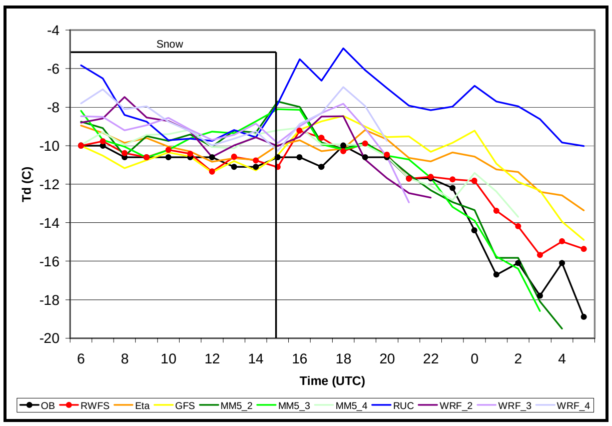

***Fig. 6:** 06 UTC 29 November 2004 model runs showing dewpoint temperature (ºC) forecasts versus the Denver METAR observations.*

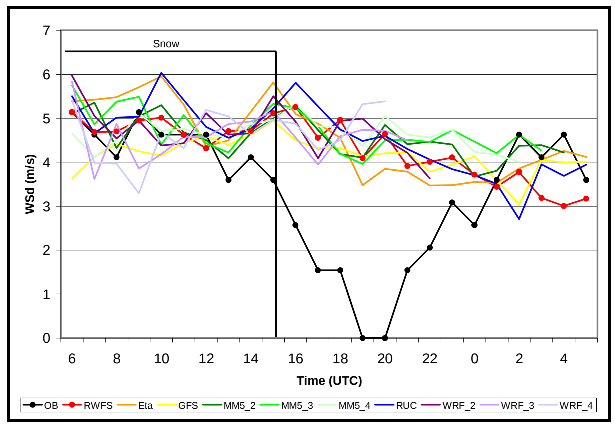

***Fig. 9:** 06 UTC 29 November 2004 model runs showing wind speed (m/s) forecasts versus the Denver METAR observations.*

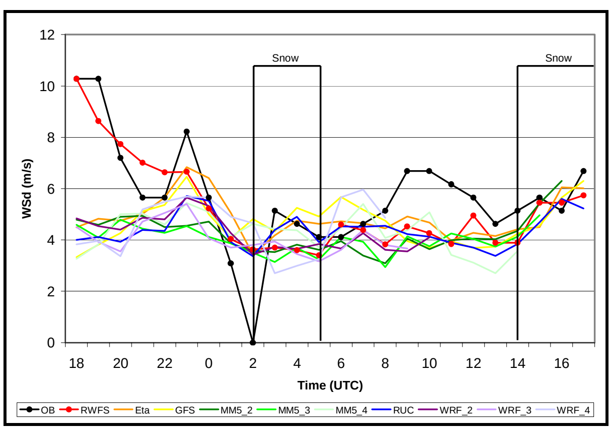

***Fig. 7:** 18 UTC 27 November 2004 model runs showing wind speed (m/s) forecasts versus the Denver METAR observations.*

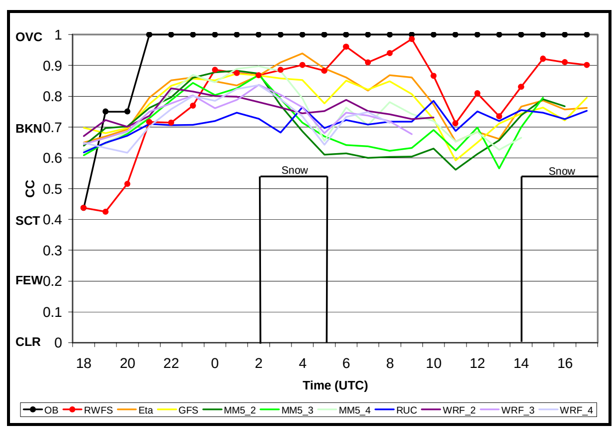

***Fig. 10:** 18 UTC 27 November 2004 model runs showing cloud cover forecasts versus the Denver METAR observations.*

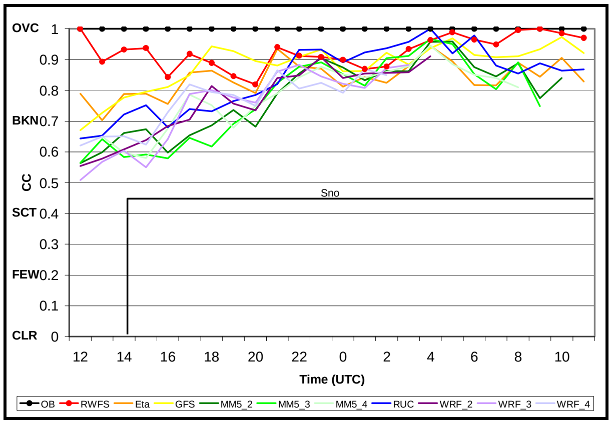

Fig. 11: *12 UTC 28 November 2004 model runs showing cloud cover forecasts versus the Denver METAR observations.*

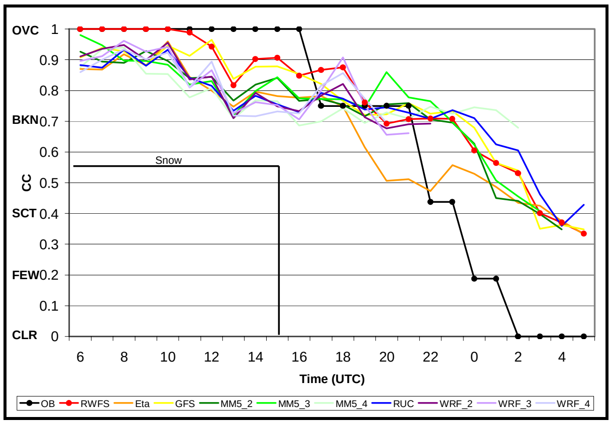

Fig. 12: *06 UTC 29 November 2004 model runs showing cloud cover forecasts versus the Denver METAR observations.*

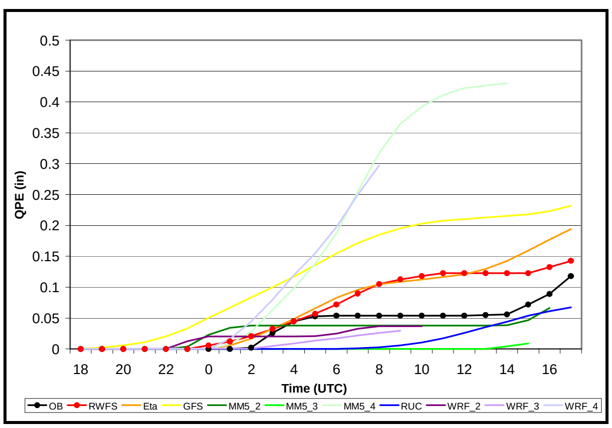

Fig. 13: *18 UTC 27 November 2004 model runs showing quantitative precipitation forecasts versus the GEONOR observations at Denver International.*

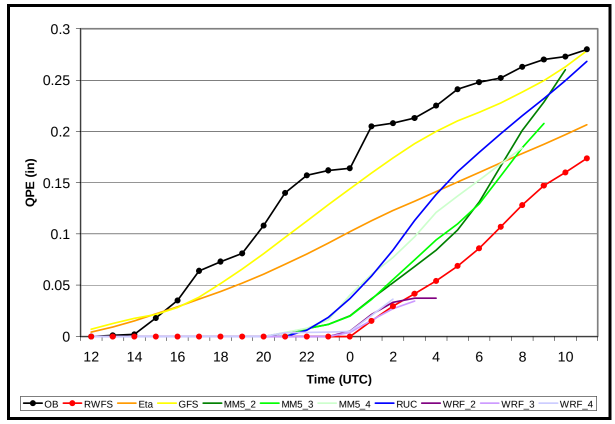

Fig. 14: *12 UTC 28 November 2004 model runs showing quantitative precipitation forecasts versus the GEONOR observations at Denver International.*

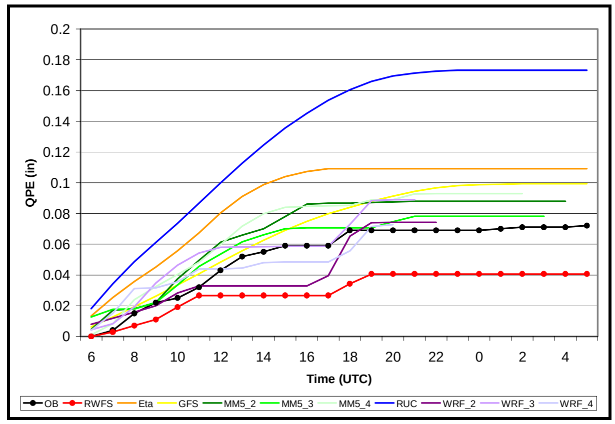

Fig. 15: *06 UTC 29 November 2004 model runs showing quantitative precipitation forecasts versus the GEONOR observations at Denver International.*