2A.5 INITIAL ANALYSIS OF MODEL GUIDANCE FOR THE COLORADO FRONT RANGE BARRAGE OF SNOWSTORMS NOV. 2006-FEB. 2007

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1. INTRODUCTION

During the period extending from late Nov. 2006 through late Feb. 2007, the Colorado Front Range was subjected to a barrage of snow events (Fig. 1), some high-impact in nature, and some that were not only climatologically anomalous but difficult to forecast. Snowfall was significant in the region for at least 9 events during the period (details for 4 events will be included in this article), and aggregate totals for many locations on the west side of the urban corridor easily exceeded 4 meters for a period that is typically prior to the climatologically snowiest season (springtime). The heaviest snowfall of Dec. 20-21 (20.7" at the Stapleton Airport site) shut down major ground and air transportation systems throughout the region for 2+ days, and also severely impacted the Great Plains region (eg. 10,000-15,000 dead cattle). Another event (Feb. 28) produced a 50-car pileup on a major highway south of Denver. Other storms also produced enormous snowdrifts over the plains, and east of CO, several inches of ice from freezing rain, with communities losing power, communications, supplies, and food for extended periods. However, this paper focuses on conditions along the Front Range.

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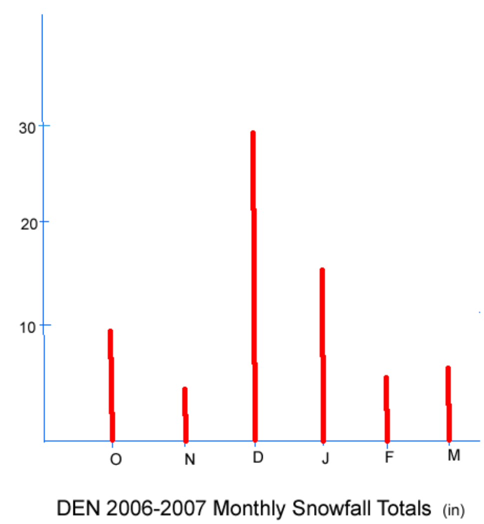

Fig. 1: DEN snowfall data

The transition of the NOAA/NWS primary numerical guidance from the Eta model to the WRF-NMM (non-hydrostatic mesoscale model; Rogers et al. 2005) resulted in this period being an adjustment phase for operational forecasters. Mesoscale Eta guidance was not available to forecasters during the cool season for the first time in many years, as the NAM grids utilized the hybrid sigma-pressure coordinate rather than the Eta-coordinate.

NAM12* and GFS40** (the latter being the spectral model with equivalent grid-point spacing of 35-40 km; see NOAA/NCAP/EMC, 2005) forecasts were the primary operational tools on the AWIPS systems. Problems with the new NAM resulted in NCEP implementing changes on 19 Dec. 2006, perhaps affecting the forecast of the largest event in this study, which will be discussed in detail later. Experimental 5km NMM guidance was available via the Web, but these model results are not the emphasis of this study. Results of these higher-resolution runs will be presented in a companion paper at the conference. (Szoke et al. 2007).

The authors noted during the forecast periods for several of these storms that performance of the NAM12 was inconsistent, and occasionally poorer than that of the coarse resolution GFS40 spectral model. This investigation takes an initial look at 36-72 hour guidance and verification for these storms, both on a case-by-case basis and in aggregate. The event descriptions are relatively brief and general with the exception of two storms. Model pressure-level data (primarily height and winds) as well as some moisture fields are evaluated during the 2-3 day period ahead of the storms. Examples of actual forecasts (data and watches/warnings) will be shown for one of the events, as well as some insight towards what model guidance the forecasters were emphasizing and why. Ensemble data (SREF) available from NCEP for these models will be evaluated, as presentation time allows.

Generally, when a potentially significant winter storm is lurking, 2-3 day forecasts are critical to public, emergency, and private sector officials who require some accuracy in order to perform their jobs. Recently, debate in the NWS and the modeling research community has centered on whether the human forecaster adds value during the 2-4 day forecast period. Numerical guidance improvements have generally enabled the community to make strides towards automation. This study will attempt to provide some relevant baseline data for forecasting wintertime storms in complex terrain 2-3 days ahead of time.

The multitude of plots in this paper show predicted and analyzed 500 mb heights and 700 mb winds for Denver, Colorado, during the peak snowfall period of several of the storm events. These fields are useful to indicate the synoptic pattern present and because 700 mb upslope or easterly winds indicate deep upslope flow, serving as a preliminary signal to the forecaster that there is potential for significant snowfall. Nearly all of Denver's very heavy snowfalls involve a closed low situation at 500 mb. Note that while simulations initializing at 06z and 18z are available to the WFOs, only those beginning and 00z and 12z are shown in this manuscript.

Additionally, 24-hour precipitation forecasts from the two models are shown together with two different precipitation analyses, the NCEP Stage IV multisensor product which is essentially a radar estimate bias-corrected using gauge data, and the Climate Prediction Center (CPC) analysis of gauge data. The plots were compiled from images at http: // www.emc.ncep.noaa.gov/ mmb/ylin/pcpverif/daily/. Note that the multisensor product has a different color scale than all of the others in the plots. The GFS has coarser resolution than both observed precipitation estimates while the NAM is coarser than the multisensor product, thus a correct forecast of the grid-box precipitation volume may result in smaller peak accumulations than in these analyses. Because the NAM has much sharper delineation of terrain features along the Front Range than the GFS has, a similarly good forecast of synoptic features by both models ought to yield better prediction of orographic precipitation from the NAM than from the GFS.

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*NAM12 is post-processed output on a 12-km grid from the NAM WRF-NMM run at 12-km grid spacing

**GFS40 is post-processed output on a 40-km grid interpolated from ½-deg lat-lon post-processed output from the T382 spectral GFS model

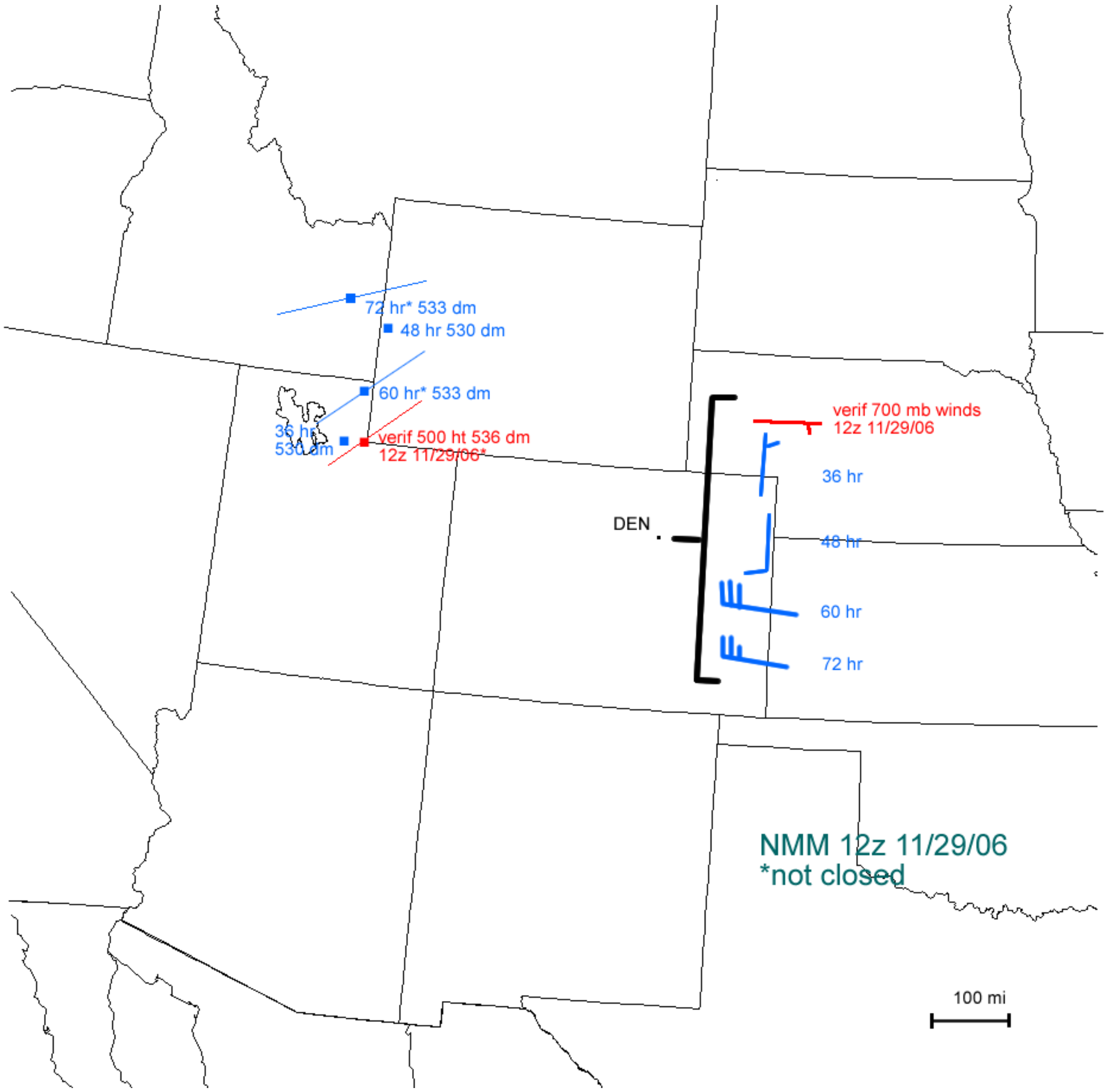


Fig. 2: NAM12 500 mb heights and 700 mb winds, analyzed (red) and predicted (blue) at 36, 48, 60 and 72 hours for the time shown. Red and blue lines denote the orientation of the predicted trough axis, when not closed at 500 mb.

2. 28-29 NOVEMBER 2006 EVENT

The first event produced 5-15 inches of snowfall over the urban corridor. While NAM12 500 mb predictions (Fig. 2) were relatively good, serious problems existed for the 72 and 60 hr forecasts of 700 mb winds; these indicated strong downslope winds that would result in dry conditions for the area in the absence of a low-level air mass of Canadian or Arctic origin. Indeed, all of the NAM forecasts confined precipitation amounts of more than 5 mm to the west side of the mountains (Fig 4).

The GFS40 model did not have this problem for the 60 hour forecast, and even at other lead times indicated potential for more significant upslope flow at 700 mb. As shown in Fig. 3, northeasterly 700 mb winds were predicted at 72, 60, 48 and 36 hours ahead of the peak snowfall time. The GFS did have more precipitation east of the Continental Divide than the NAM.

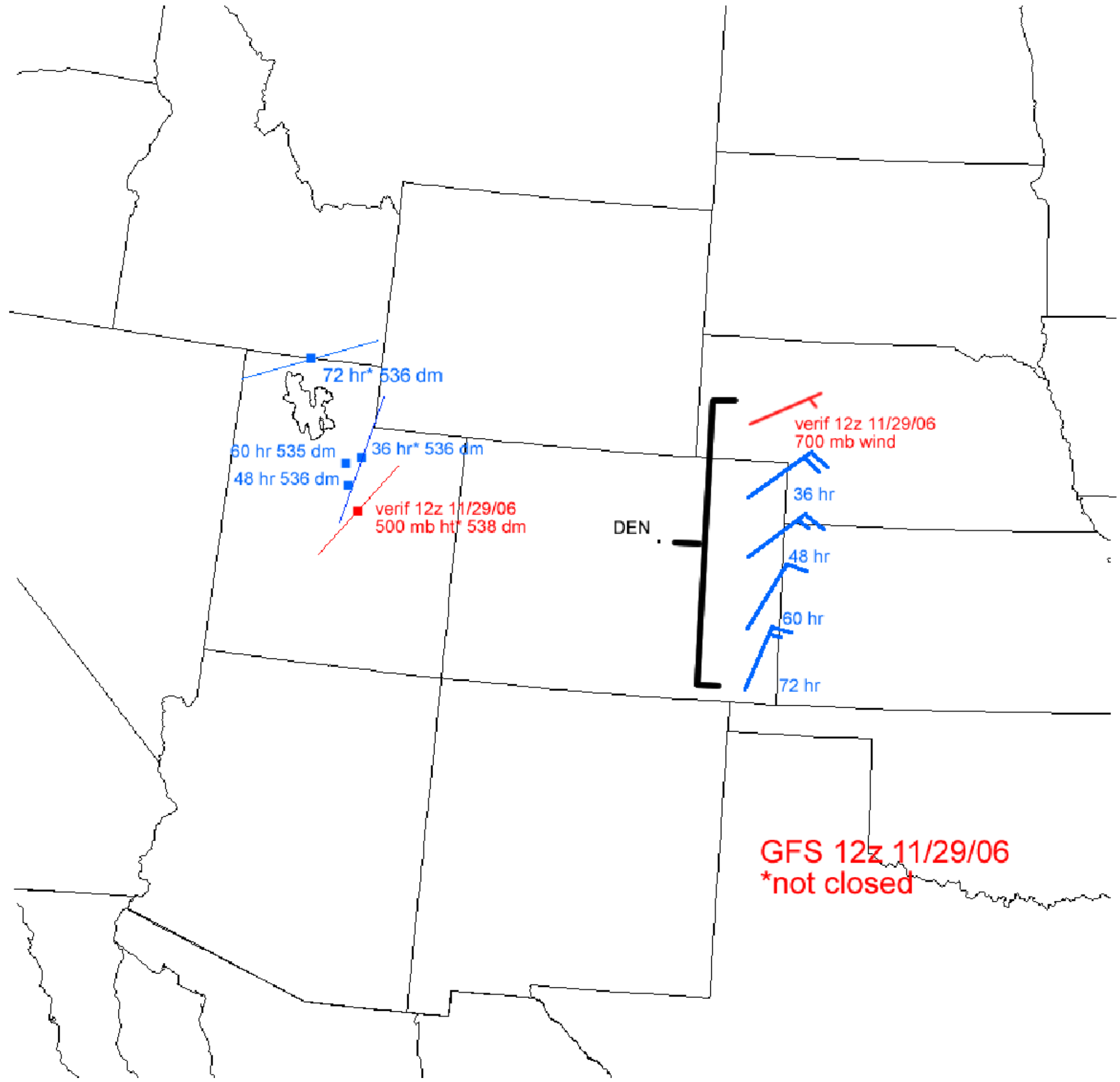


Fig. 3: GFS 500 mb heights and 700 mb winds, analyzed (red) and predicted (blue) at 36, 48, 60 and 72 hours for the time shown. Red and blue lines denote the orientation of the predicted trough axis, when not closed at 500 mb.

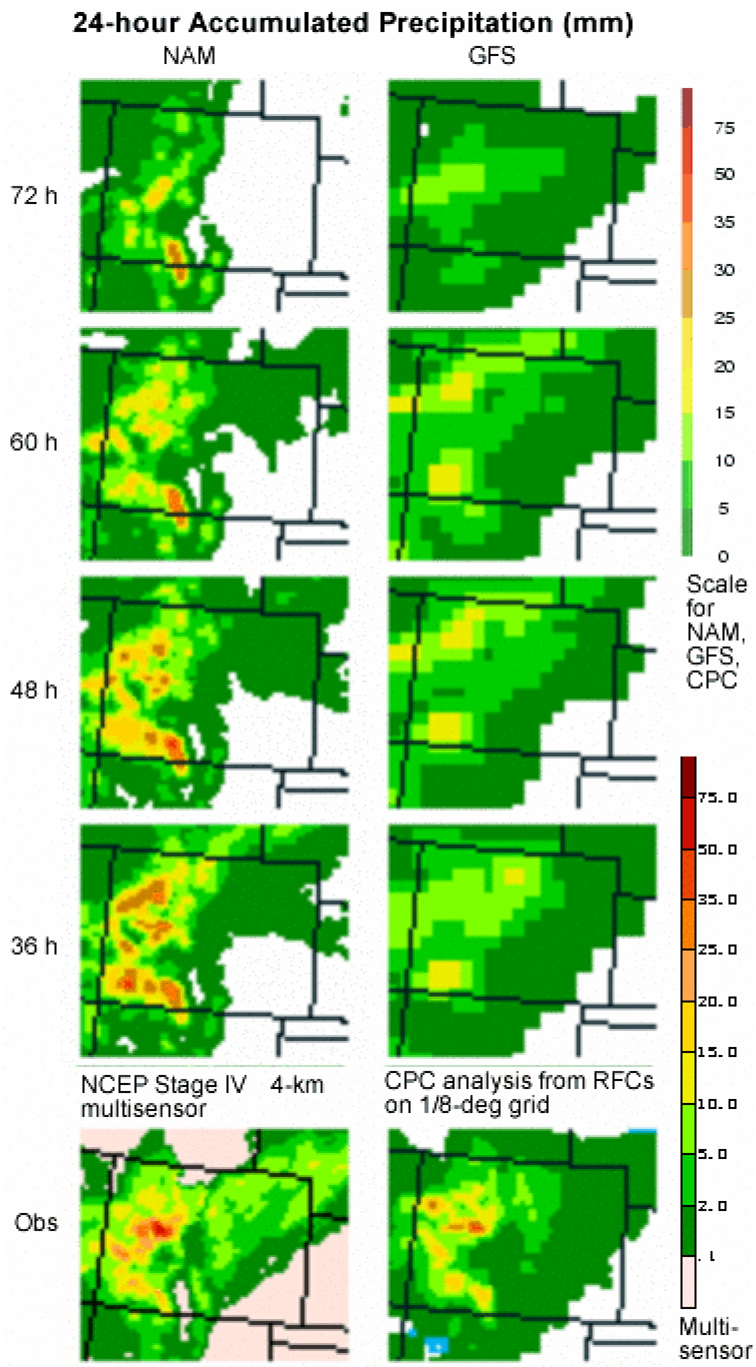


Fig. 4: GFS40 and NAM12 precipitiation forecasts and NCEP/CPC observed precipitation analyses, valid 12z 29 Nov. 2006.

3. 20-21 DECEMBER 2006 EVENT

The second event studied here was the heaviest snowfall of the winter for the Front Range of Colorado, 20-21 Dec. 2006. This event included extensive devastating impacts on the public in a large portion of eastern CO, southeastern WY, western KS, and western NE (Szoke et al., 2007).

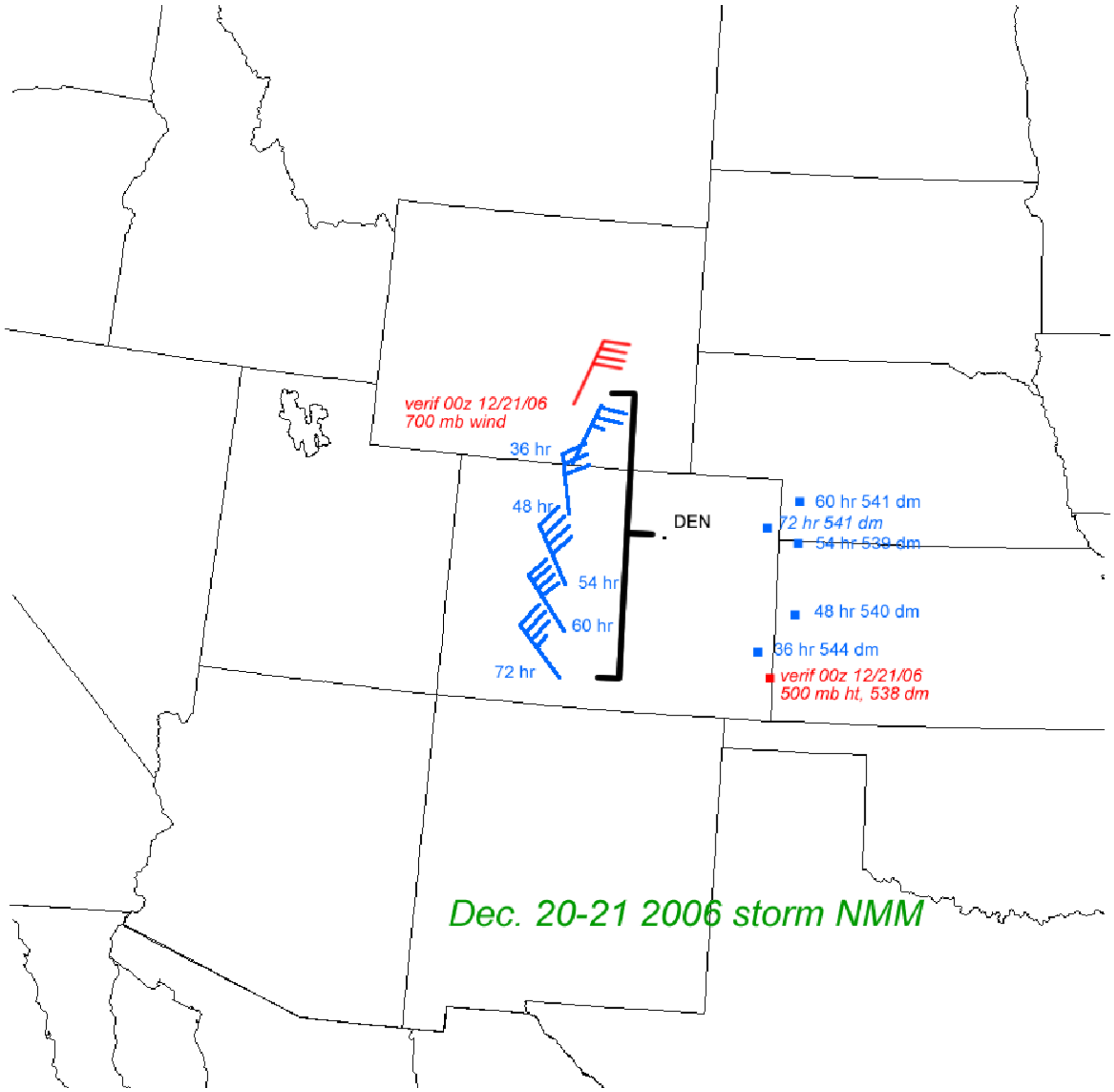


Fig. 5: NAM12 500 mb heights and 700 mb winds, analyzed (red) and predicted (blue) at 36, 48, 60 and 72 hours for the time shown. Red and blue lines denote the orientation of the predicted trough axis, when not closed at 500 mb.

As shown (Fig. 5), accuracy of 700 mb NAM12 predictions increased markedly as the event approached. Upslope at this level was not predicted until 36 hrs. prior to the peak snowfall. Serious problems existed for the 500 mb closed low location also, with progression to the south in the model as the event approached and a verified location slightly south of the 36 hr forecast. Nonetheless, the model predicted significant precipitation even in the model run listed as 60-hours here, which had a 48-72 hour accumulation (24-hour period) exceeding 15 mm along and east of the Front Range. NAM model runs from the next day (36 hr forecasts, for example; also see Fig. 10) predicted a storm of historic proportions (corresponding to the now strong upslope 700 mb wind component) and even highlighted the peak amounts in a north-south axis along the Front Range and then extending east along the Palmer Divide.

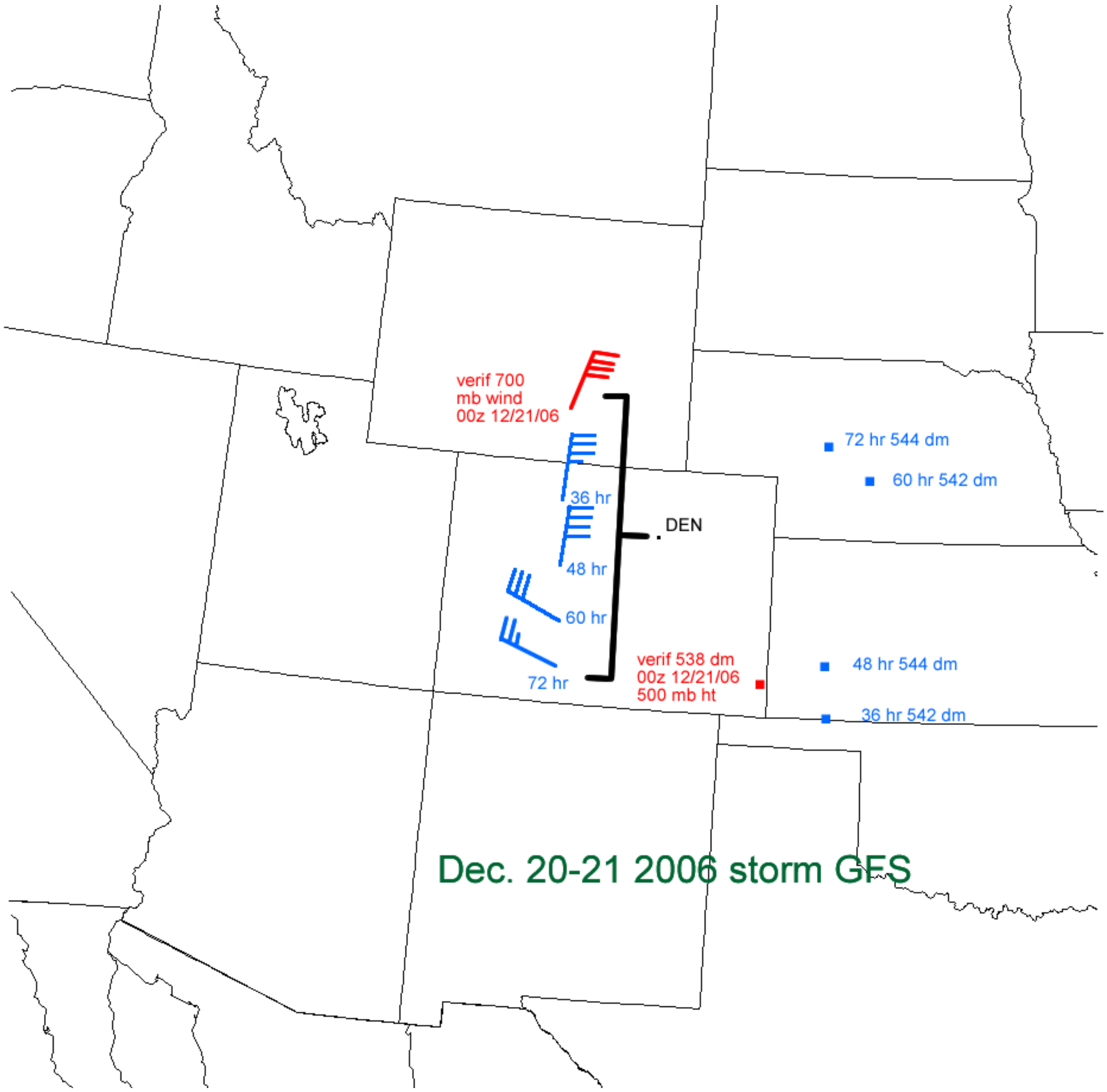


Fig. 6: GFS40 500 mb heights and 700 mb winds, analyzed (red) and predicted (blue) at 36, 48, 60 and 72 hours for the time shown. Red and blue lines denote the orientation of the predicted trough axis, when not closed at 500 mb.

Problems with the GFS were initially similar in nature but worse at 72 and 60 hr; these errors seemed to be corrected by 48 hr, at both 700 mb and 500 mb (Fig. 6). The GFS precipitation forecasts began predicting significant amounts with 12 hours *less* lead time than the NAM forecasts and did not show the heaviest amounts well east, on the plains (Fig. 10).

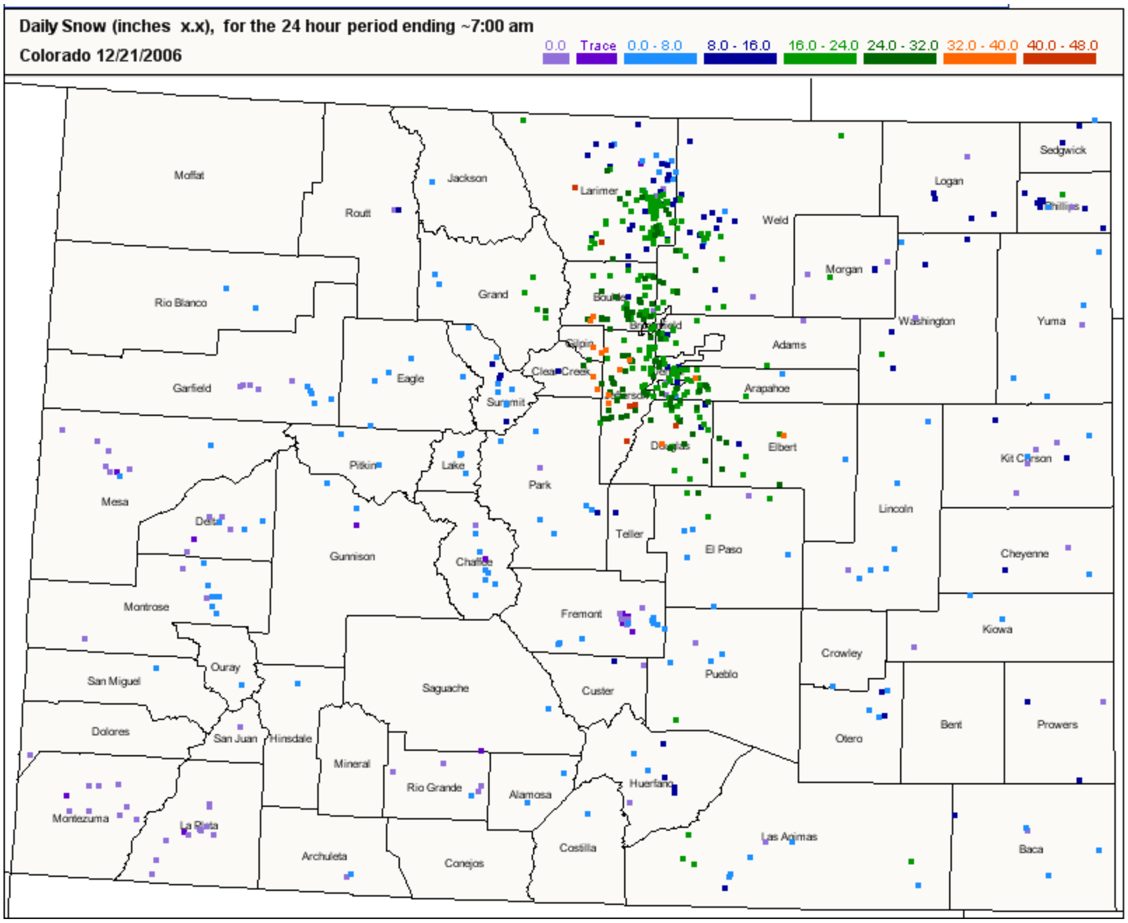
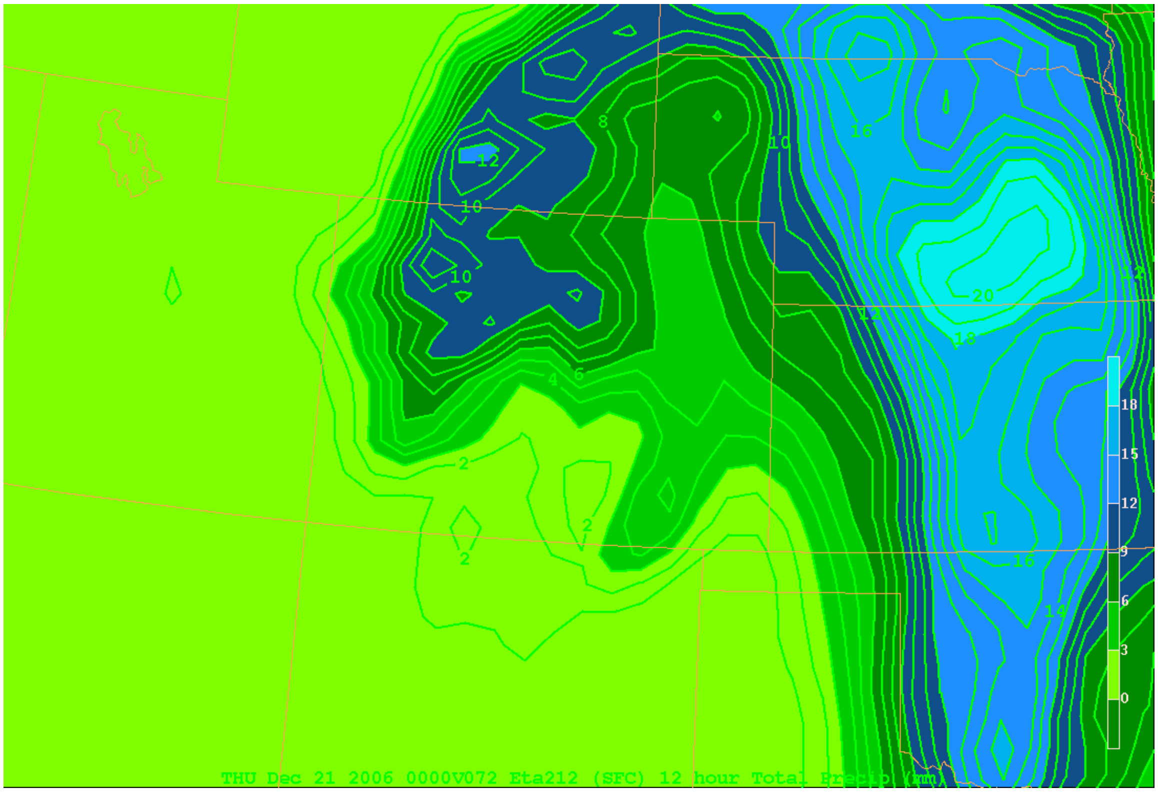


Fig. 7: Snowfall observations for the 24 hr period ending at 7:00 am local time on Dec. 21, 2006, from the CoCoRaHS observation network.

The CoCoRaHS observations (Fig. 7) over Colorado revealed extensive areas with more than 18” snowfall accumulation over and east of the Front Range. Fig. 8 shows a sample of NAM12 precipitation forecasts for the storm.



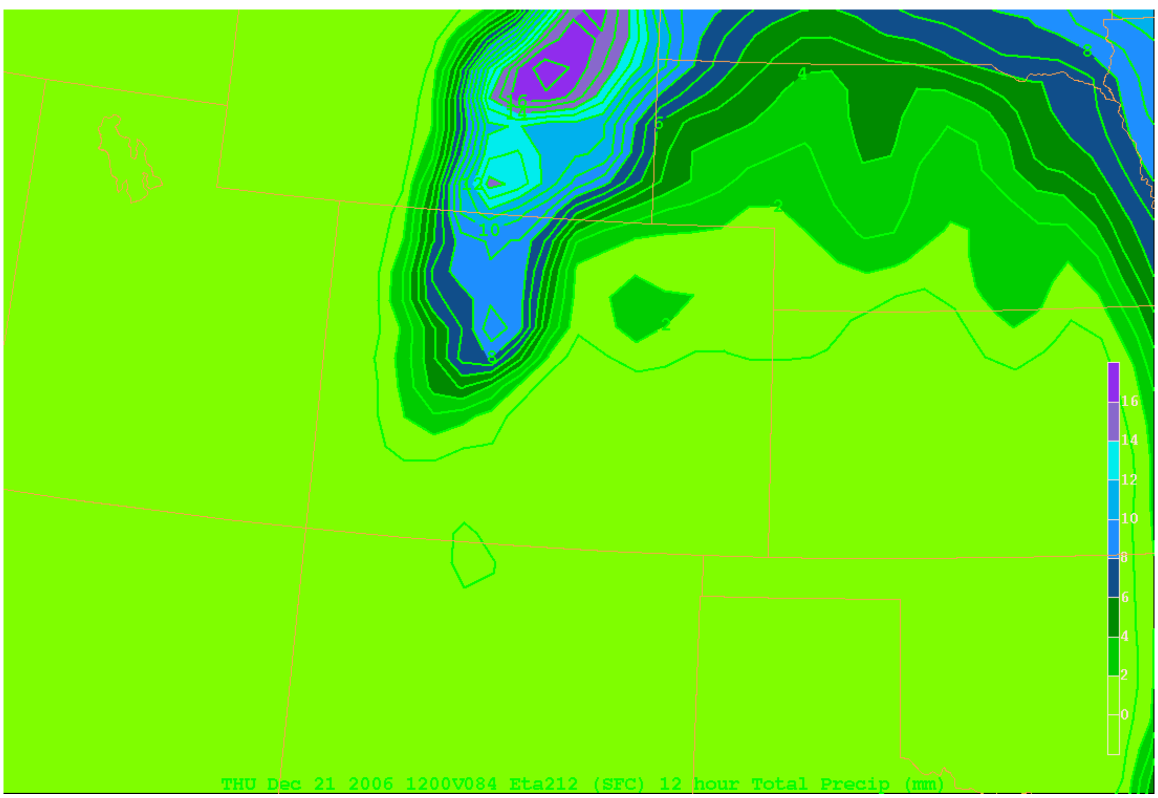
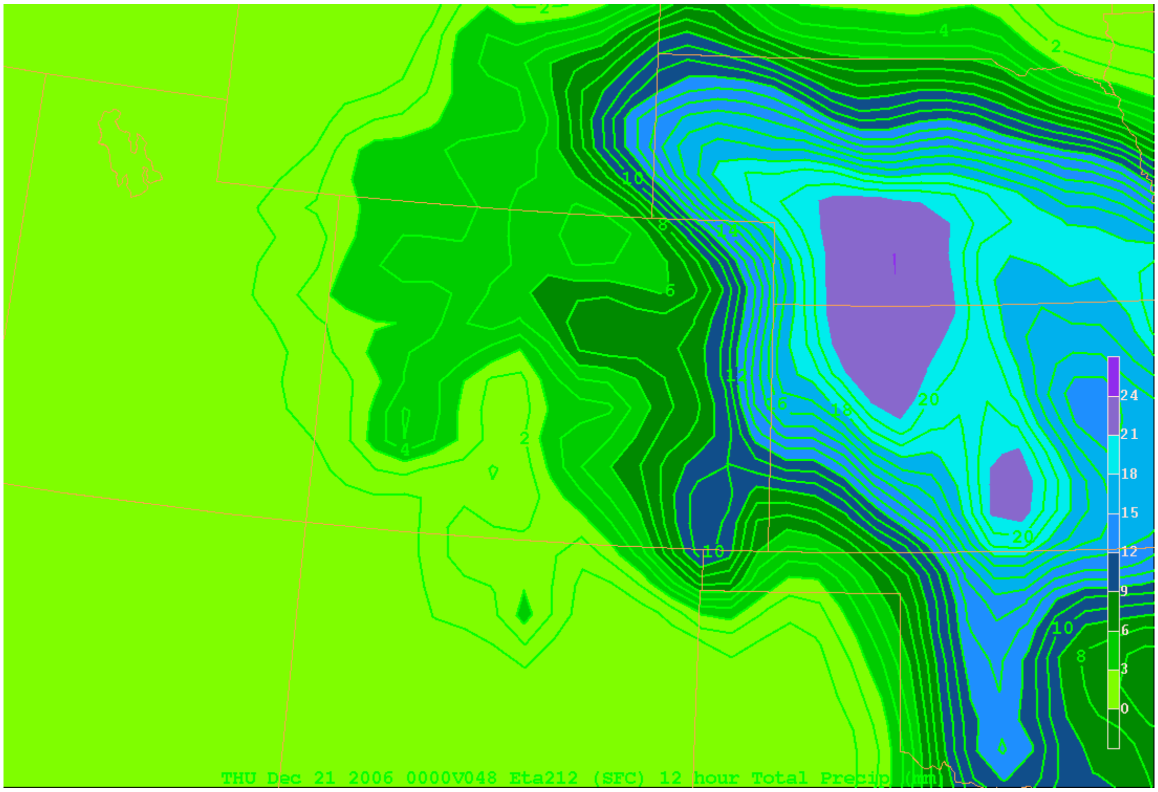


Fig. 8: 12hr precipitation totals (mm) for NAM12 72- and 84-hr forecast ending 00z 12/21/06 (top) and 12z 12/21/06 (bottom).

Approximately 10 mm of liquid equivalent was forecast during this period for the Front Range corridor, with somewhat larger (15-20 mm) for the foothills to the west. Observations (Fig. 7) revealed that these values were severely underpredicted. Fig. 9 shows the NAM12 predictions for the 48- and 60-hr forecasts.



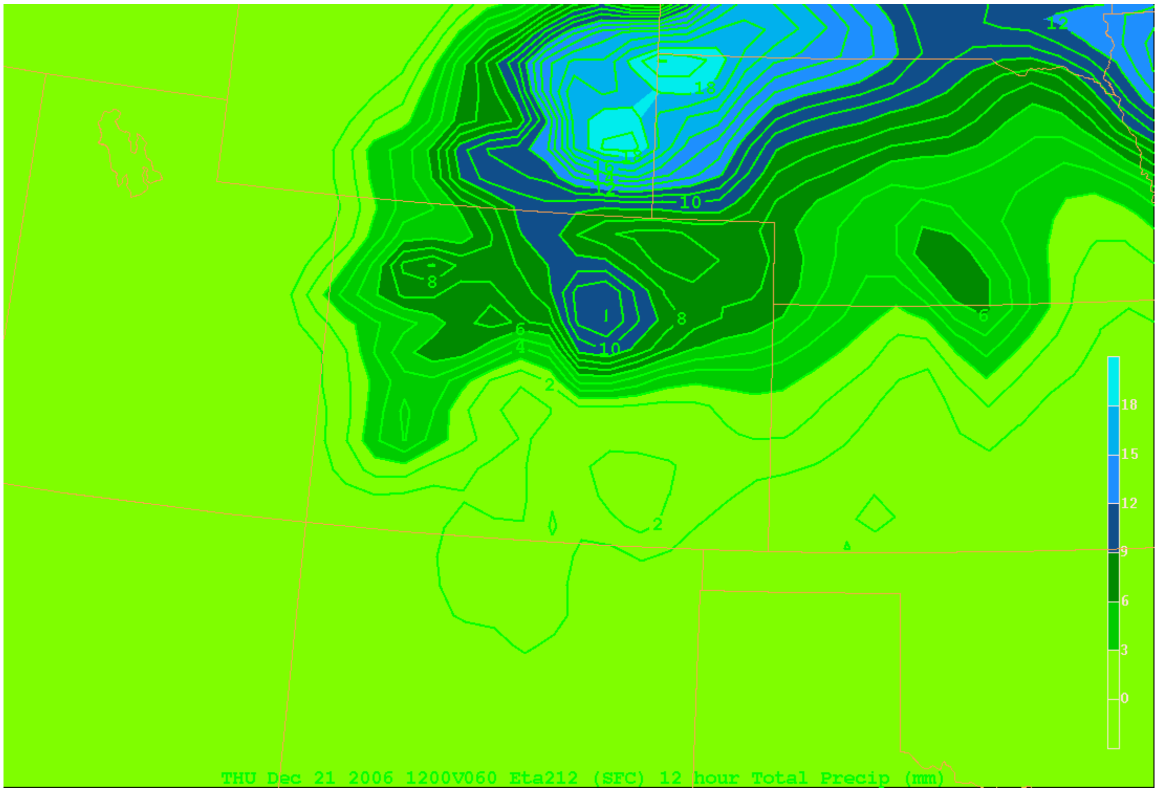


Fig. 9: 12hr precipitation totals (mm) for NAM12 48- and 60-hr forecast ending 00z 12/21/06 (top) and 12z 12/21/06 (bottom).

Only slight improvement is noted for these forecasts, with 15-20 mm over the area of interest. Again, the discrepancies were expected considering the problems with the large-scale dynamic predictions even at 48 hr noted previously. Comparisons with GFS precipitation predictions for this storm will be shown at the conference.

Fig. 10 shows a series of the model and analyzed precipitation values for both models, centered on CO, valid 12z Dec. 21. Most notable is the trend with time towards much heavier precipitation in both models, especially comparing the 72/60 hr plots to those at 48/36 hr. For the NAM, the changes from 60 to 48 hr are very large; the GFS's largest increase is in the 72/60 hr transition. Note that the period of heavy snow for these forecasts and in the observations began closer to the beginning of the 24-hour periods, so the lead time prior to storm onset was considerably less than the forecast hour of the valid time for the 24-hour amounts.

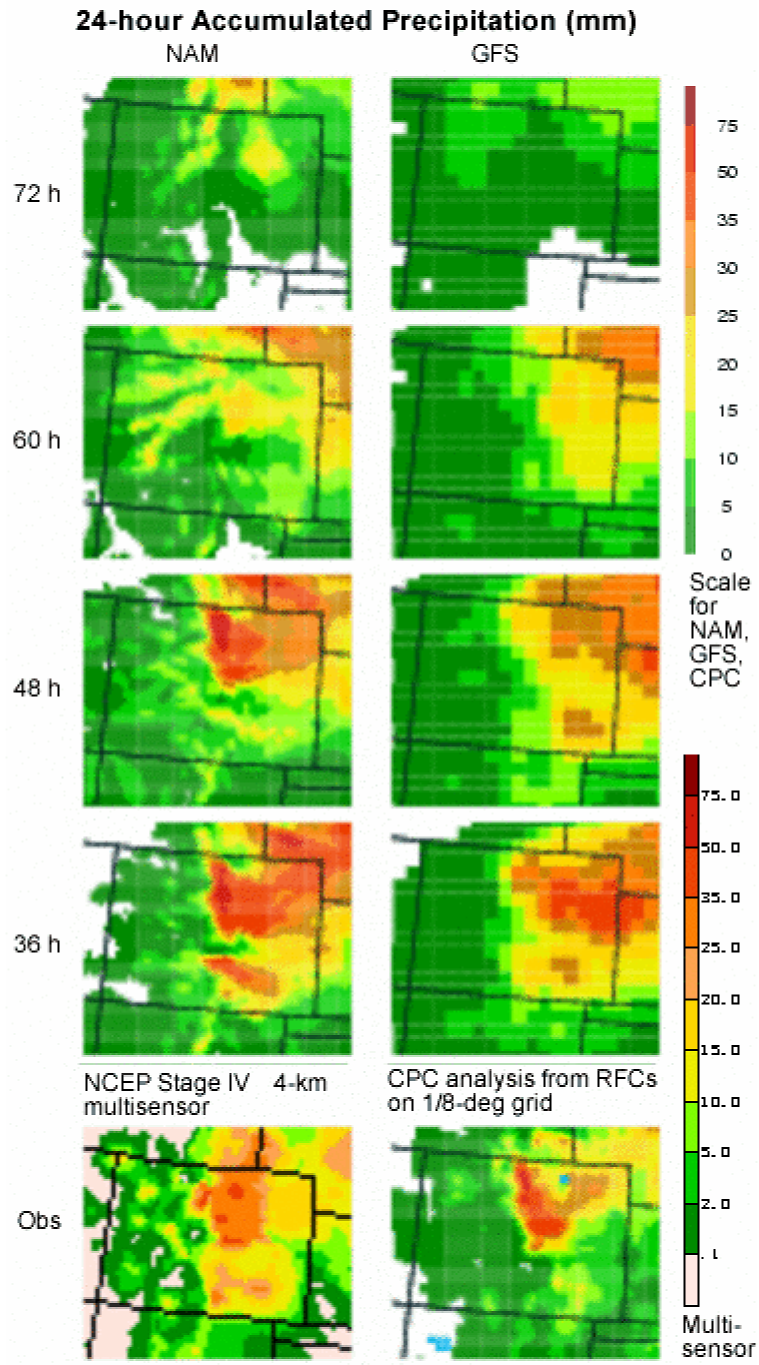
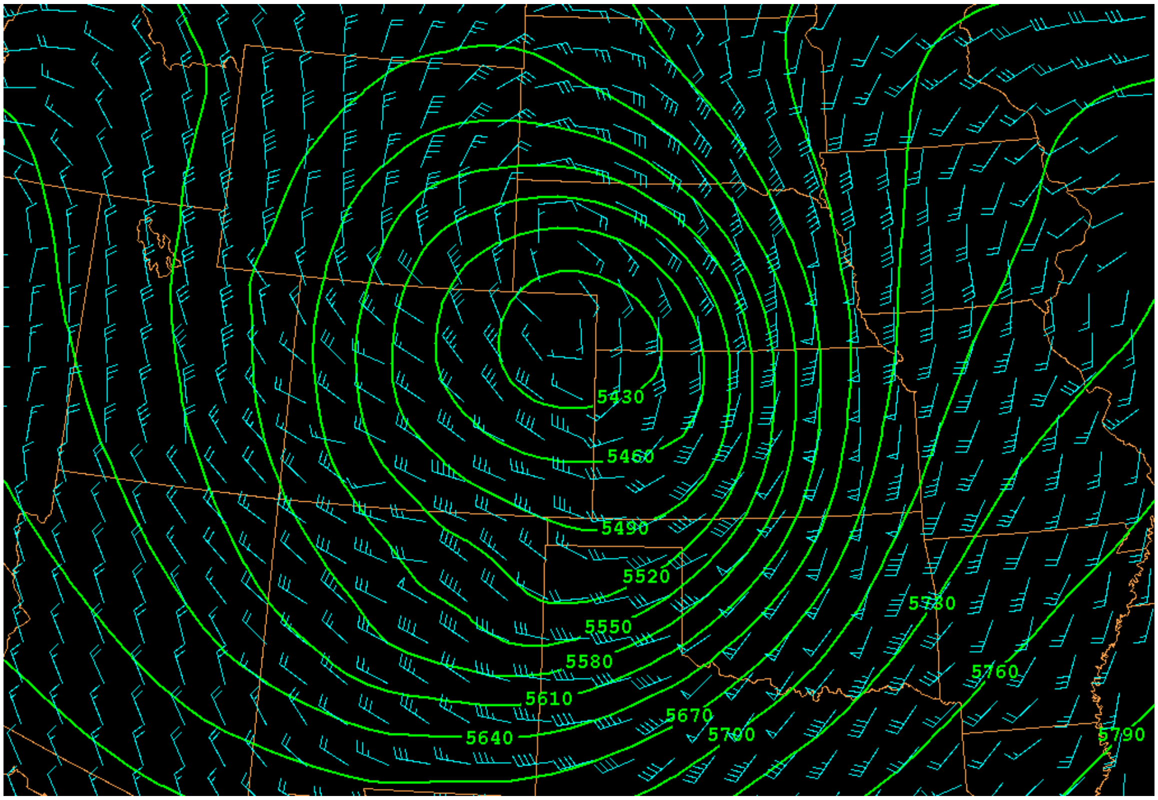


Fig. 10: GFS40 and NAM12 precipitation forecasts and NCEP/CPC observed precipitation analyses, valid 12z 21 Dec. 2006.

A closer look at 500 mb height and 700 mb wind predictions at 72 hours revealed more detail in the large-scale problems with the predictions of both models (Figs. 11-12).



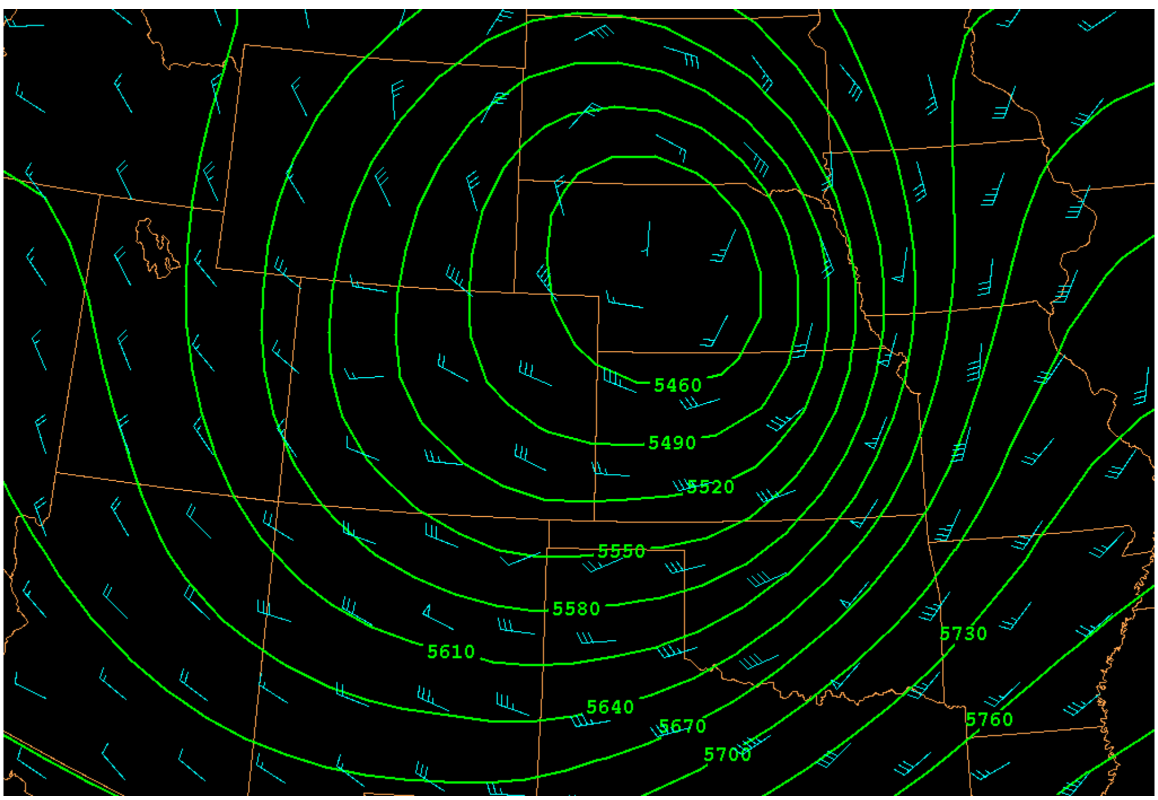


Fig. 11: Top: NAM12 72-hr forecast, 500 mb ht. and 700 mb wind, for 00z Dec. 21, 2006
Bottom: same as top portion, for the GFS model.

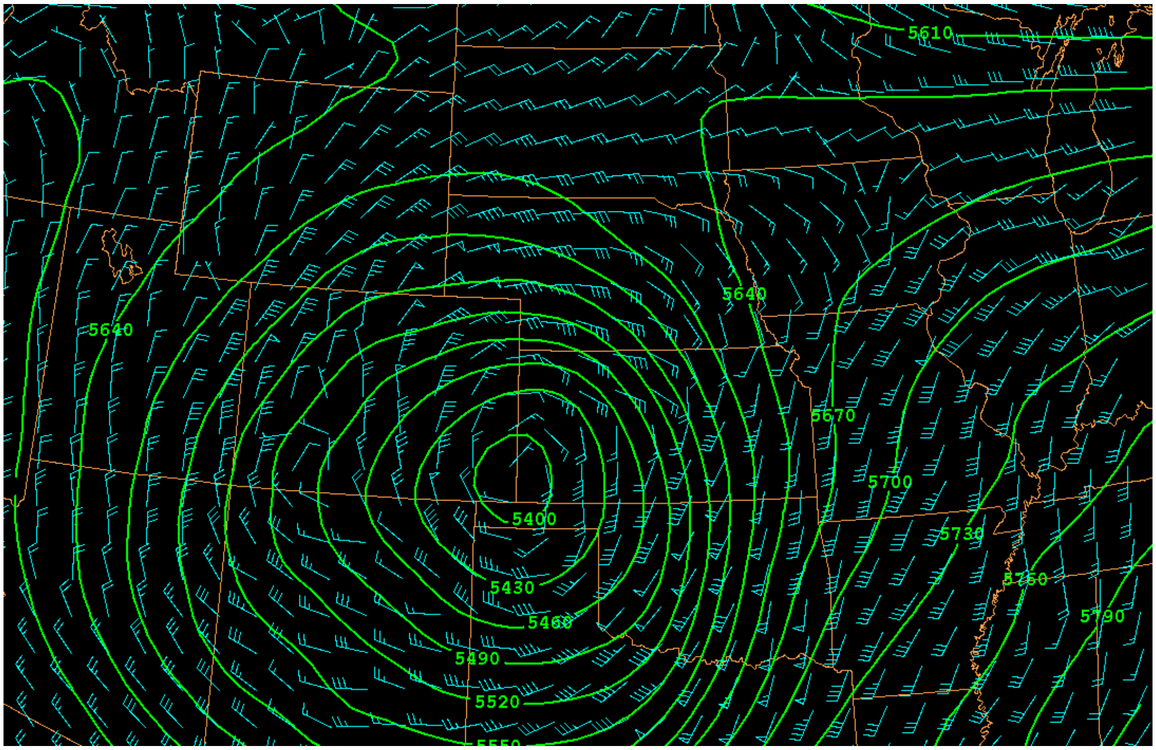


Fig. 12: NAM12 analysis for 00z 21 Dec. 2006

Major differences in the predicted location and strength of the strong closed low over the central High Plains exist between the analysis and both model predictions, leading to, essentially, a prognosis of strong 700 mb downslope flow vs. an analysis of very strong northeasterly flow at 700 mb. In other words, the numerical guidance indicated cold, windy, dry conditions, while, of course, heavy snowfall and strong wind conditions developed. Critical challenges thus existed for more than 5 local forecast offices in this case due to large errors in model guidance 3 days out.

3.1 A look at the SREF for this storm

We will now discuss the Short Range Ensemble Forecasts (SREFs) for this storm. The SREF is a multi-model, 21-member ensemble using the Eta with two differing convective schemes, the WRF-NMM and the WRF-ARW (Du et al. 2006) run at NCEP operationally since 2001, which has been used for probabilistic prediction in the 0-3 day forecast range. It is a probabilistic companion to the deterministic WRF-NAM.NMM. In this context, we will see if the SREF picked up on the probability of a very large snowfall in the Denver area, as expressed in probability of exceedance, mean and spread, and spaghetti diagrams.

The 75-hour forecasts from the 21 UTC 17 December 2006 SREF run correspond operationally to the 72 hour forecasts from the GFS and the WRF-NMM valid at 00 UTC 21 December 2006. Fig. 13 shows the forecast mean and spread of 500-hPa heights valid at that time. Note that the mean position of the 500-hPa cutoff low is well north of the verification (compare to Fig. 11) and that most uncertainty is north and northeast of the ensemble mean center, rather than south toward the eventual verification.

One of the complaints about previous implementations of the SREF has been the tendency for model clustering. Spaghetti plots of the 500-hPa heights from the same run for the WRF-NMM and WRF-ARW (6 members), and RSM (5 members) are shown in Fig. 14. Model clustering seems to be less of a problem in the 20-21 December 2006 case than in the past. At 500-hPa, one Eta member (the red solid contour) indicates a cutoff low close to the

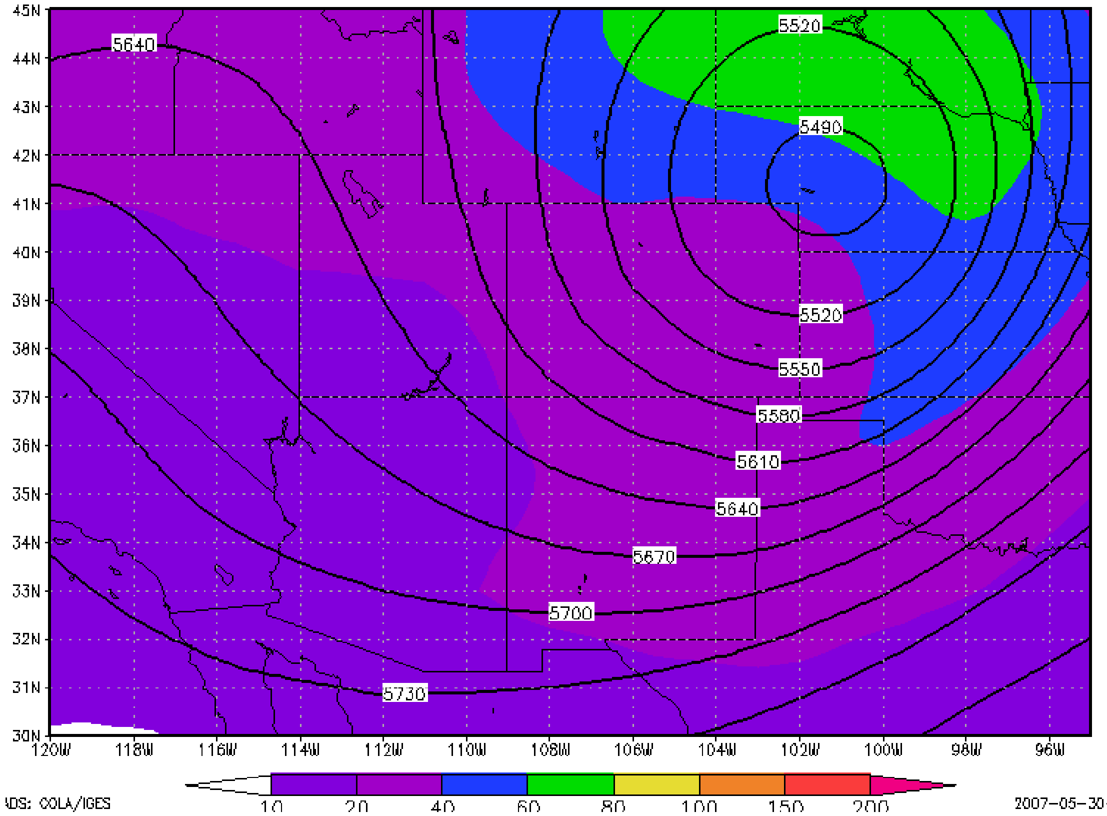
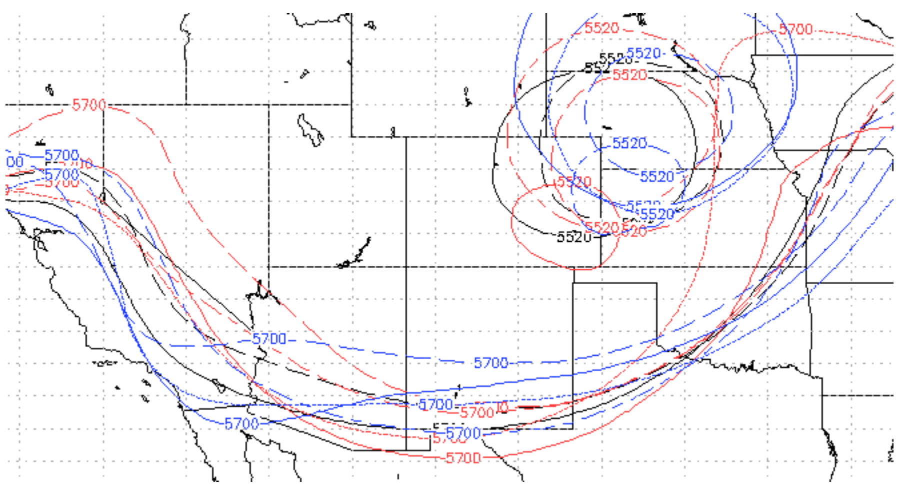


Fig. 13: SREF ensemble mean (contoured) and spread (shaded, values in color bar) for 500-hPa heights (m) from 09 UTC 17 December 2006 valid 00 UTC 21 December 2006 (an 87-hour forecast).



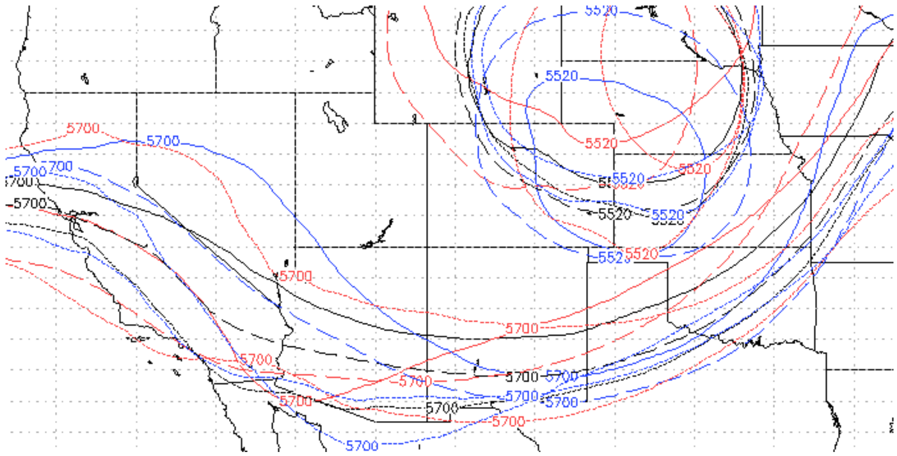


Fig. 14: SREF spaghetti plot of 5520 and 5700 500-hPa height contours for Eta SREF members (top); and WRF-ARW, WRF-NMM, and RSM SREF members (bottom) from 21 UTC 17 December 2006 valid 00 UTC 21 December 2006. On the top, solid, long dash, dotted, and long-short dashed contours represent the first through fourth positive and negative perturbation pairs. On the bottom, the WRF-ARW members are solid, WRF-NMM contours are long dashed, and the RSM contours are dotted. In both panels, control members are black, positive perturbations are red, and negative perturbations are blue.

eventual verification (Figure 11). Another has the cutoff low in northwest KS (blue long-short dashed contour). None of the ensemble members produce 1” or more of liquid equivalent close to the CO Front Range for the 24 hour period ending 12 UTC 21 December 2006 (not shown), though the two Eta members with the most southerly 500-hPa cutoff lows do produce between 0.5-1” of liquid equivalent (not shown). Since none of the WRF or RSM members produce as much as even 0.25” liquid equivalent for this period, this gives a probability of exceeding 0.5” of liquid equivalent in the 24 hours ending 12 UTC 21 December of about 10% .

The 09 UTC 18 December SREF (63 hours prior to mid-event) did no better than at 75 hours; in fact, there were no 500-hPa cutoff lows south of the northeast corner of CO. For the 21 UTC 18 December SREF cycle, the companion 00 UTC 19 December operational WRF-NMM was broadcasting an historic event for the CO Front Range down to the Palmer Divide, with 24-hour liquid equivalents of 35-50mm (1.3-2”). The SREF, however, only had one of 21 ensemble members indicating more than 1” of liquid equivalent.

In Fig. 15, we see that the SREF finally begins to reflect the final verification in its precipitation field, with eight of 10 Eta members and 3 of 11 WRF/RSM members indicating more than 1” of liquid equivalent.

Why the SREF failed to better indicate the potential severity of the 20-21 December 2006 event is beyond the scope of this paper. There may have been problems with the initial conditions affecting the evolution of this system upstream over the Pacific Ocean. Model resolution may also have played an important role in the forecast; the SREF is run at more than three times coarser resolution than the operational WRF-NMM. The point to take away from this case is that the SREF must be evaluated in the forecast process just as the operational NWP models must be, including physical reasonableness of the forecast evolution and evaluation of the initial conditions displayed by the SREF models.

4. OTHER EVENTS

The third event occured 28-29 Dec. 2006. This event produced generally 6-16 inches of snow for the Front Range and adjoining foothills, with markedly higher amounts in the higher foothills. Run-to-run consistency was much higher for this event for both operational models.

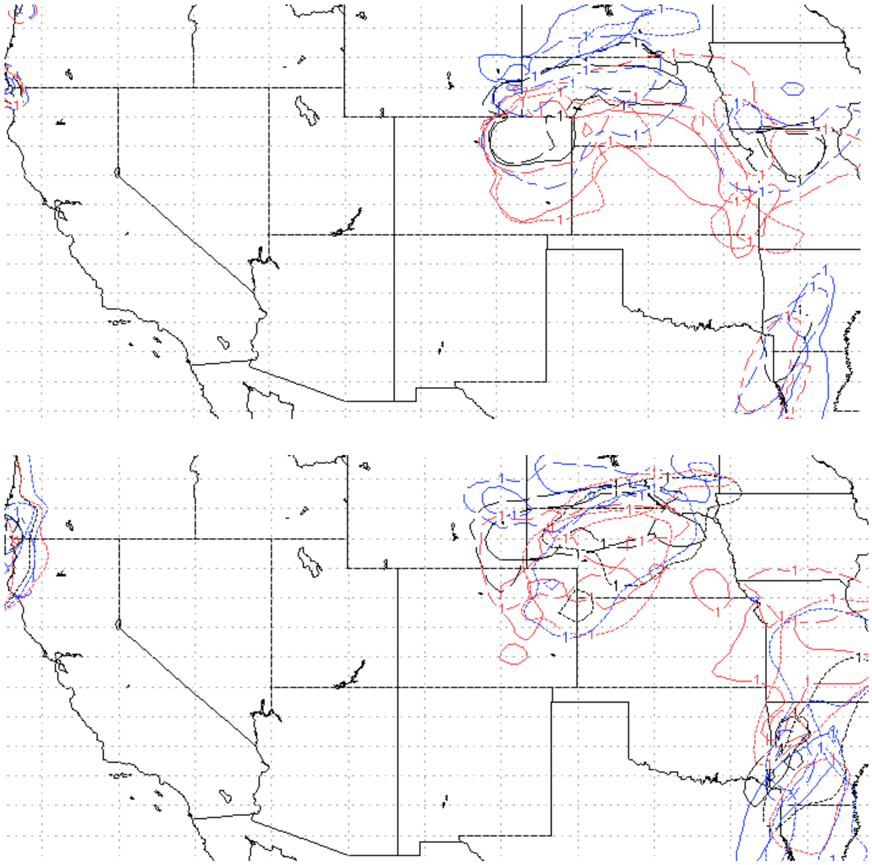


Fig. 15: Same as Figure 20, except SREF spaghetti plot of 5520 except for 24-hour accumulated precipitation of 1" from 09 UTC 19 Decmeber 2006 valid 12 UTC 21 December 2006.

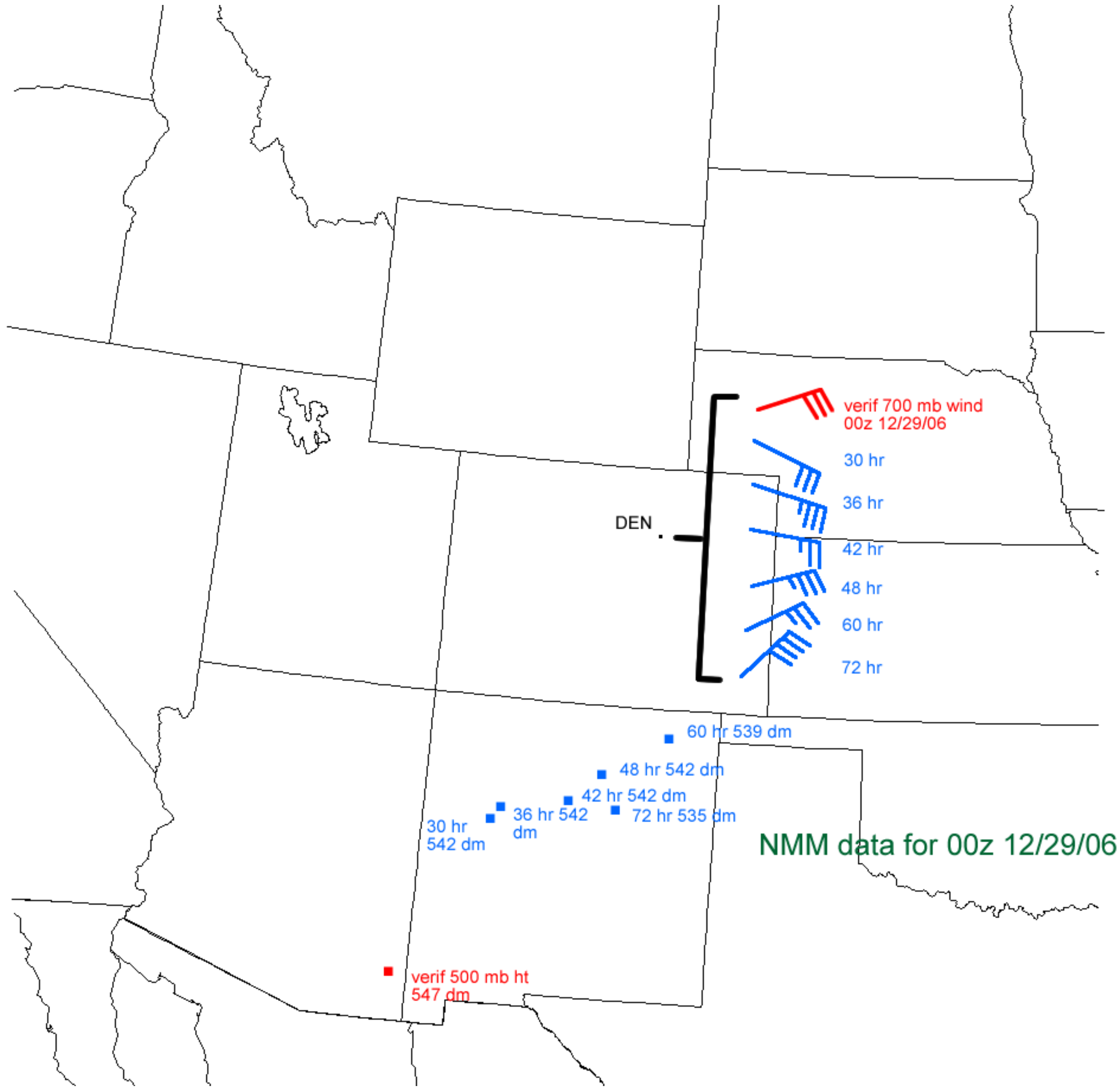


Fig. 16: NAM12 500 mb heights and 700 mb winds, analyzed (red) and predicted (blue) at 36, 48, 60 and 72 hours for the time shown.

Significant 700 mb upslope flow was indicated by the NMM well ahead of the event (Fig. 16), even at 72 hr. Problems were more serious for the 500 mb closed low position and strength, with the analyzed positions well south of the predictions and the analyzed strength much less.

Fig. 17 shows a specific forecast from the NAM12 for this event, a 72-hr prognosis initializing at 00z 12/26/06.

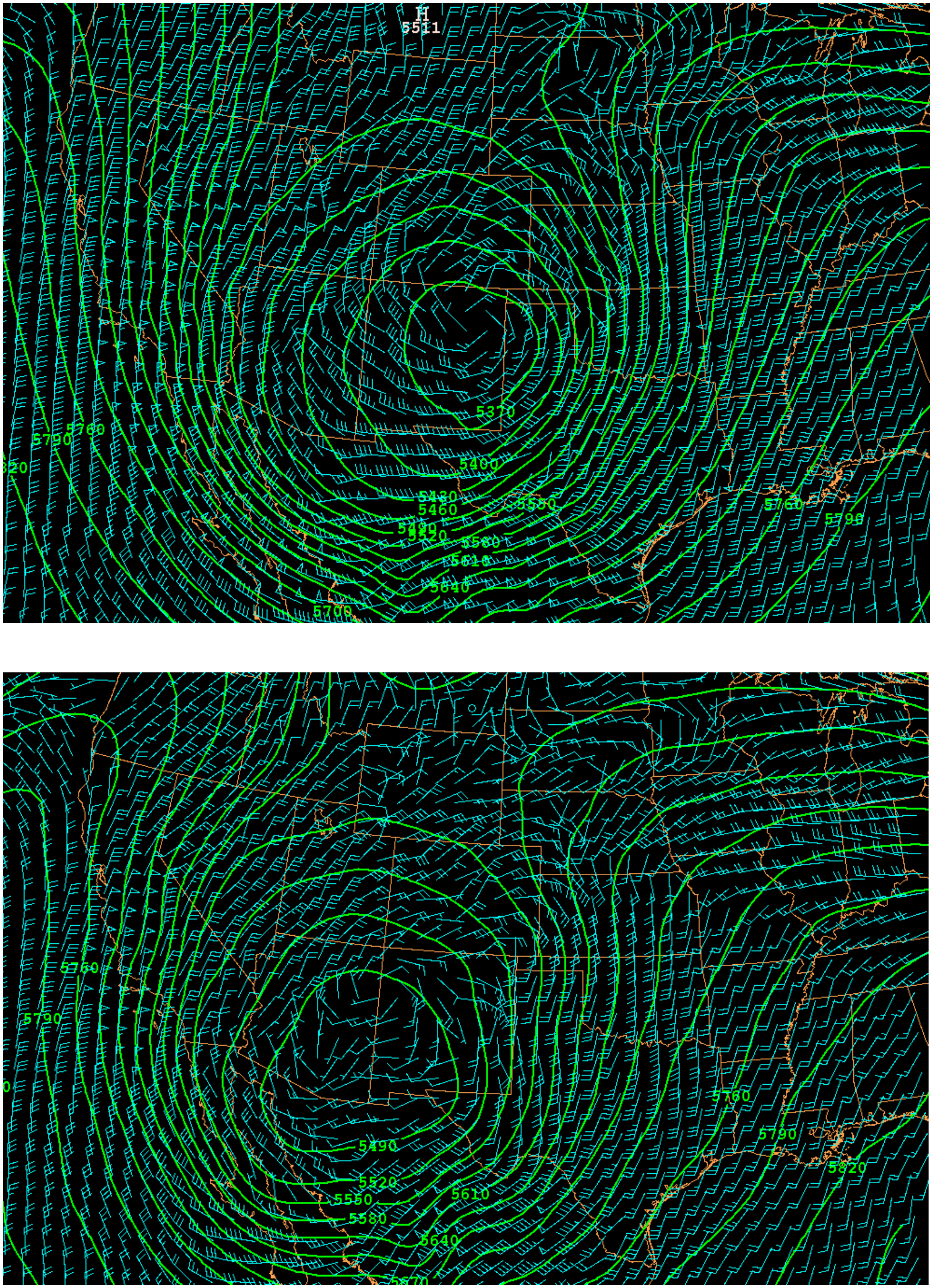


Fig. 17: NAM12 72 hr forecast for 00z 29 Dec. 2006, 700 mb winds and 500 mb heights. Bottom: NAM12 analysis for that time.

While the position of the 500 mb closed low has some error, generally the flow features over the high plains are predicted well 72 hours in advance. Human forecasters were able to infer a threat of heavy snowfall in this case well in advance with the NAM12 forecasts. Here is the progression of portions of the worded zone forecasts and other products during this period for the Front Range:

COZ039-262300-
BOULDER AND JEFFERSON COUNTIES BELOW 6000 FEET/WEST BROOMFIELD COUNTY-
INCLUDING
ARVADA...BOULDER...GOLDEN...LAKEWOOD...LONGMONT
1154 AM MST TUE DEC 26 2006

.THURSDAY...CLOUDY WITH SNOW LIKELY. HIGHS IN THE LOWER 30S. NORTH WINDS 15 TO 25 MPH IN THE AFTERNOON. CHANCE OF SNOW 60 PERCENT.
.THURSDAY NIGHT...CLOUDY WITH SNOW LIKELY. LOWS AROUND 17. CHANCE OF SNOW 60 PERCENT.
.FRIDAY AND FRIDAY NIGHT...MOSTLY CLOUDY WITH SNOW LIKELY. HIGHS IN THE UPPER 20S. LOWS AROUND 10. CHANCE OF SNOW 60 PERCENT.

URGENT - WINTER WEATHER MESSAGE
NATIONAL WEATHER SERVICE DENVER CO
909 PM MST TUE DEC 26 2006

...ANOTHER MAJOR WINTER STORM ON TRACK TO BLAST COLORADO...

.A POTENT WINTER STORM WAS TAKING AIM ON COLORADO. THIS STORM WAS

PLAINS BY END OF PRD. SYS HAS STG DYNAMICS AND UPWRD Q-G OMEGA. SYS WILL PRODUCE DEEP LYRD MOIST UPSLP FLO AGAINST ERN SLP OF MTNS AND HI PLAINS BEGINNING BY MID-DAY THU AND CONTINUE THRU FRI. SNW WILL DCRS ACRS AREA FRI NGT. COLD CANADIAN AMS WILL SPRD S OVR HI PLAINS THU MRNG. STG WNDS WITH SYS MAY PRODUCE MUCH BLWG SNW AND NR BLIZZARD CONDITIONS OVR PLAINS WHEN SYS GET WOUND-UP E OF MTNS ON THU NGT AND FRI. WILL GO WITH THE CURRENT SLOWER...BY 6 HRS...GFS
33>36..38>51.

PRESENTLY MOVING INTO CALIFORNIA AND WILL TRACK INTO ARIZONA BY WEDNESDAY EVENING. FROM THERE...THE STORM IS EXPECTED TO MOVE SLOWLY EASTWARD ACROSS NEW MEXICO AND INTO THE TEXAS PANHANDLE THURSDAY AND FRIDAY.

THIS TRACK WOULD BE VERY FAVORABLE FOR HEAVY SNOWFALL ACROSS MUCH OF NORTHEAST AND NORTH CENTRAL COLORADO. IN ADDITION...STRONG NORTH WINDS ARE EXPECTED TO DEVELOP DURING THE COURSE OF THE STORM PRODUCING CONSIDERABLE BLOWING AND DRIFTING SNOW. IT IS TOO EARLY TO PREDICT THE EXACT TRACK AND INTENSITY OF THIS STORM...BUT AT THIS TIME THE STORM HAS POTENTIAL TO PRODUCE BLIZZARD CONDITIONS.

PEOPLE PLANNING TO TRAVEL ACROSS NORTHEAST AND NORTH CENTRAL COLORADO THURSDAY AND FRIDAY SHOULD BE PREPARED FOR HAZARDOUS DRIVING CONDITIONS...AND SHOULD CONSIDER AVOIDING TRAVEL ON THOSE DAYS.

THE STORM MAY ALSO DELAY OR POSSIBLY PREVENT AIR TRAVEL FROM DENVER INTERNATIONAL AIRPORT. ALL HOLIDAY TRAVELERS SHOULD CHECK AIRLINE SCHEDULES FOR DELAYED OR CANCELED FLIGHTS.

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE DENVER CO
205 PM MST TUE DEC 26 2006

.LONG TERM...WED NGT-FRI...MDLS FAIRLY CONSISTENT IN TRACKING CLSD UPR LO FM 4 CORNERS ACRS CNTRL AND SRN RCKYS ONTO CNTRL AND SRN GRT ON STARTING SNW ON THU...BUT TYPICAL SLO MOVEMENT OF DIGGING SYS MAY DELAY START LATER. THUS SYS MAY BE SLOWER EXITING AREA ON FRI NGT. TEMPS WILL BE QUITE COLD THRU PRD.

.BOU WATCHES/WARNINGS/ADVISORIES...WINTER STORM WATCH...FRONT RANGE MTNS...ERN FTHLLS...AND ALL OF PLAINS FM THU AFTN THRU FRIDAY...

COZ040-271200-
NORTH DOUGLAS COUNTY BELOW 6000 FEET/DENVER/WEST ADAMS AND
ARAPAHOE COUNTIES/EAST BROOMFIELD COUNTY-
INCLUDING AURORA...BRIGHTON...CITY OF DENVER...DENVER
INTERNATIONAL AIRPORT...HIGHLANDS RANCH...LITTLETON...PARKER
922 PM MST TUE DEC 26 2006

...WINTER STORM WATCH IN EFFECT FROM THURSDAY AFTERNOON THROUGH
FRIDAY AFTERNOON...

.WEDNESDAY NIGHT...MOSTLY CLOUDY. LOWS AROUND 20.
.THURSDAY...SNOW SHOWERS LIKELY IN THE MORNING...THEN WIDESPREAD
SNOW WITH AREAS OF BLOWING SNOW IN THE AFTERNOON. COLDER. HIGHS
AROUND 30. WINDS BECOMING NORTH 10 TO 20 MPH WITH GUSTS TO 30 MPH.
.THURSDAY NIGHT...WIDESPREAD SNOW. WINDY WITH AREAS OF BLOWING SNOW.
POSSIBLE HEAVY SNOW ACCUMULATIONS. LOWS AROUND 14. NORTH WINDS 20 TO
30 MPH WITH GUSTS TO 40 MPH.
.FRIDAY AND FRIDAY NIGHT...WIDESPREAD SNOW. WINDY WITH AREAS OF
BLOWING SNOW. POSSIBLE HEAVY SNOW ACCUMULATIONS. SNOW DECREASING
FRIDAY NIGHT. HIGHS IN THE MID 20S. LOWS AROUND 11.

COZ038-039-281200-
LARIMER COUNTY BELOW 6000 FEET/NORTHWEST WELD COUNTY-BOULDER AND
JEFFERSON COUNTIES BELOW 6000 FEET/WEST BROOMFIELD COUNTY-
INCLUDING FORT COLLINS...HEREFORD...LOVELAND...NUNN...ARVADA...
BOULDER...GOLDEN...LAKEWOOD...LONGMONT
909 PM MST WED DEC 27 2006

...WINTER STORM WARNING IN EFFECT FROM 12 PM THURSDAY TO 6 AM MST
FRIDAY...

.THURSDAY...CHANCE OF SNOW IN THE MORNING...THEN SNOW IN THE
AFTERNOON. SNOW ACCUMULATION OF 2 TO 5 INCHES. HIGHS IN THE MID
30S. NORTH WINDS 10 TO 15 MPH IN THE AFTERNOON.
.THURSDAY NIGHT...SNOW WITH AREAS OF BLOWING SNOW. SNOW MAY BE HEAVY
AT TIMES WITH ACCUMULATIONS OF 5 TO 12 INCHES. LOWS AROUND 15. NORTH
WINDS 10 TO 20 MPH WITH GUSTS TO 30 MPH.
.FRIDAY...SNOW WITH AREAS OF BLOWING SNOW. HIGHS IN THE MID 20S.
NORTH WINDS 15 TO 25 MPH WITH GUSTS TO 35 MPH.
.FRIDAY NIGHT...SNOW WITH AREAS OF BLOWING SNOW. POSSIBLE HEAVY SNOW
ACCUMULATIONS. LOWS AROUND 9. NORTHWEST WINDS 10 TO 20 MPH WITH
GUSTS TO 30 MPH.
.SATURDAY AND SATURDAY NIGHT...AREAS OF BLOWING SNOW. MOSTLY
CLOUDY WITH A 50 PERCENT CHANCE OF SNOW. HIGHS IN THE LOWER 20S.
LOWS AROUND 10.

With this improved model guidance for at least the initial portion of this storm, forecasters were able to communicate expectations of heavy snowfall (within one week of the major storm Dec. 20-21) in the 48-60 hr time period ahead of the onset of significant snowfall.

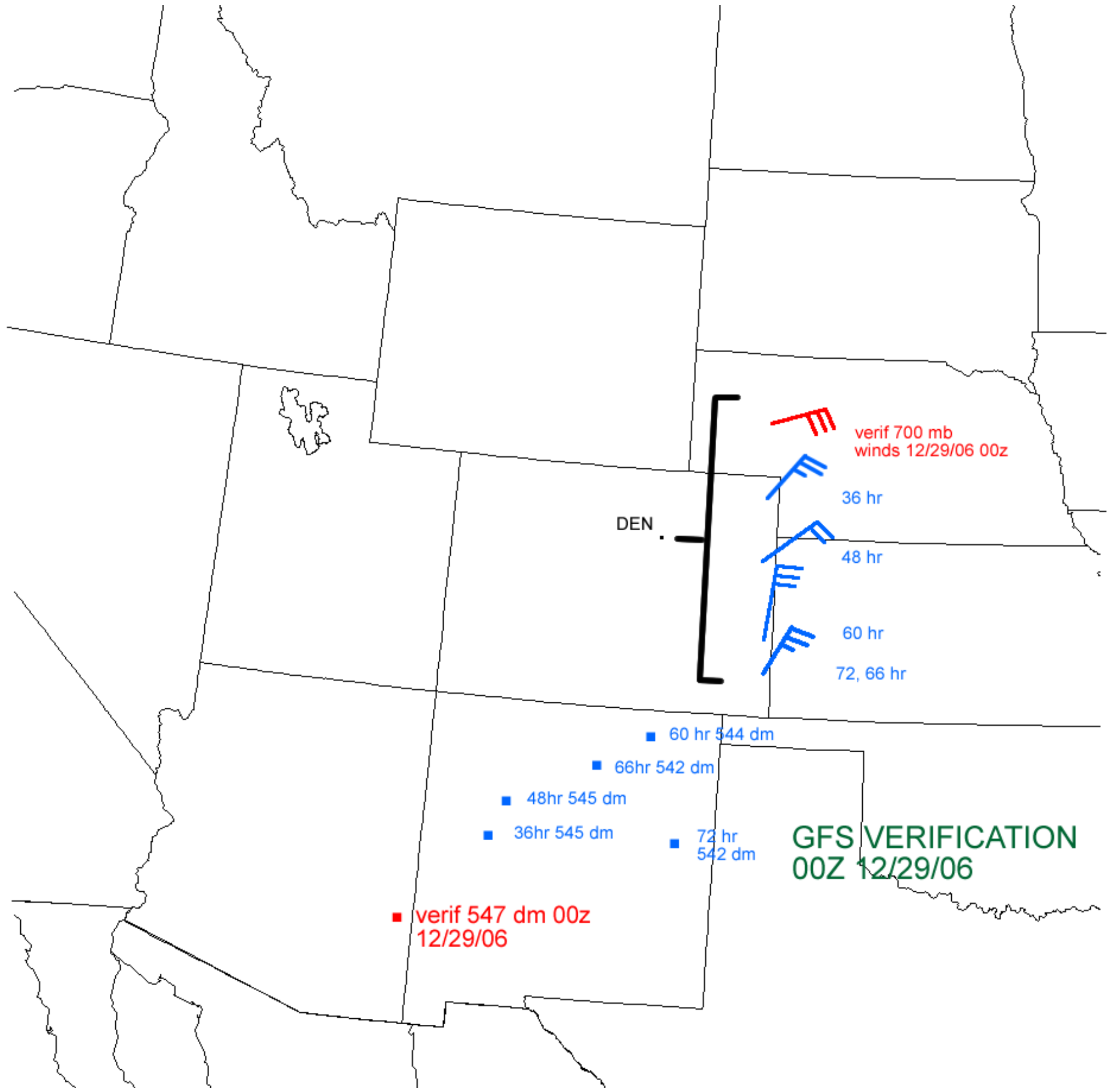


Fig. 18: GFS 500 mb heights and 700 mb winds, analyzed (red) and predicted (blue) at 36, 48, 60 and 72 hours for the time shown.

Generally, the 700 mb wind predictions by the GFS (Fig. 18) were reasonable, especially at 48 and 36 hrs., but not as accurate as those of the NAM12. The 500 mb height predictions fared a bit better than those of the NAM12, but the positional problems were similar. Overall, the GFS supported the scenario of moderate to heavy Front Range snowfall in the 48-72 hr period ahead of the event.

Because this was almost entirely an orographic event, the upslope flow was the primary factor, and the models did predict significant snowfall, actually over a somewhat too broad an area. Fig. 19 shows the precipitation forecasts and analyses for 12z 29 Dec., or 12 hours later than the previously-discussed dynamic fields.

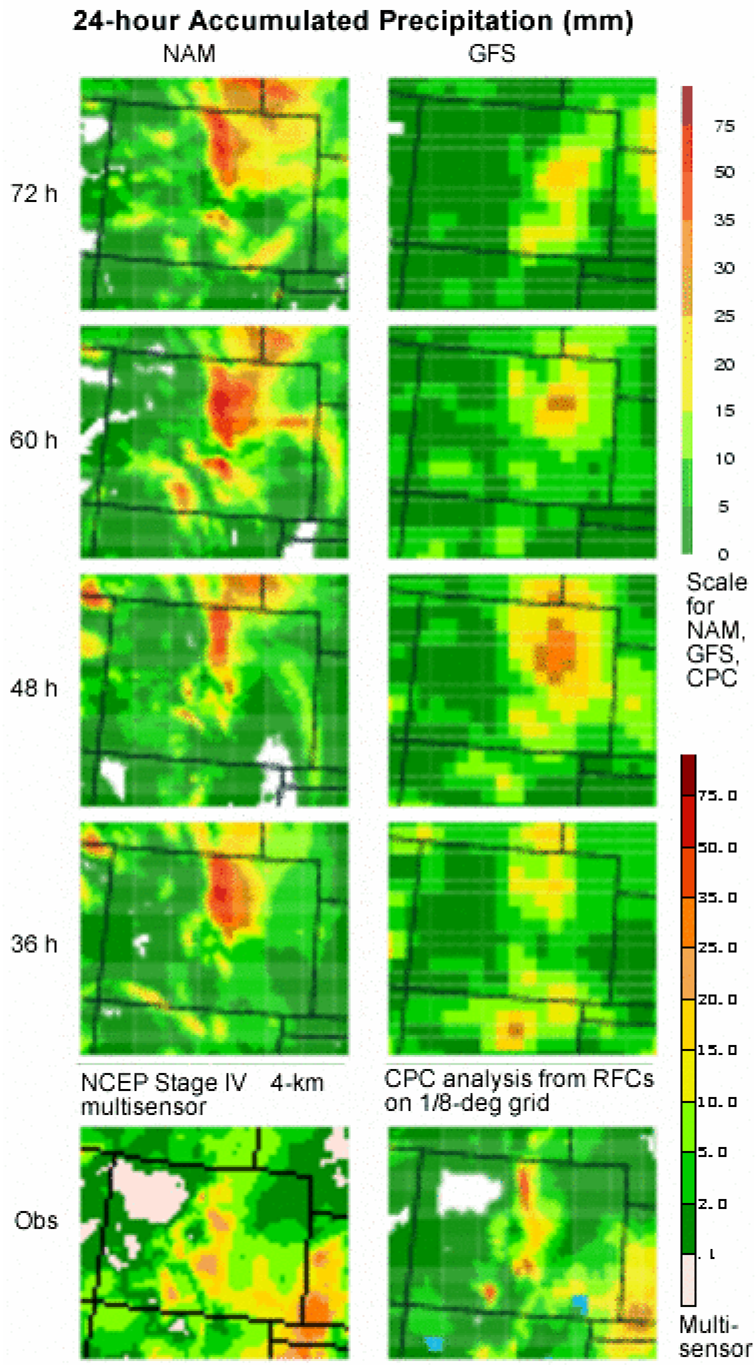


Fig. 19: Accumulated model and analyzed precipitation valid at 12 UTC 29 December 2006.

As noted previously, run-to-run consistency was much higher for the models in this storm compared to the previous event. The NAM12 predictions of much more precipitation in the western urban corridor/foothills emulated the model's improved ability to handle the orographic enhancement of precipitation, compared to the GFS40.

An important aspect of the model forecasts for the latter portion of 29 Dec. into 30 Dec. was the threat of the primary mid-level closed low to move northeastward and

Induce redevelopment of the cyclone over extreme eastern/southeastern CO, leading to a regeneration of heavy snowfall and wind over the Front Range. This was included in several 3-day model predictions and had an operational impact, but it did not actually happen. This portion of the predictions will be discussed in more detail at the conference.

Forecasters had the SREF guidance available operationally, utilizing simulations from the Eta, NAM12, other WRF-NMM versions, and the spectral model (Du et al. 2004, 2006). A brief look here at the products available shows mixed results in comparison to the operational runs. Fig. 20 shows the 63 hr SREF product for 00z 29 Dec. 2006. The averaged product was somewhat improved over the GFS operational simulation (Fig. 18) in terms of the orientation of the 700 mb height gradient/winds, but these winds likely lacked the magnitude of the easterly component at that level that was forecast by the operational NAM12 run at 60 hr. Also, like the operational runs, SREF did not predict well the southwestward extent of the location of the mid-level closed low.

The SREF at 500 mb is shown in Fig. 21. A better forecast for the closed low in comparison with the NAM12 is evident (Fig. 16) but not so with the GFS (Fig. 18).

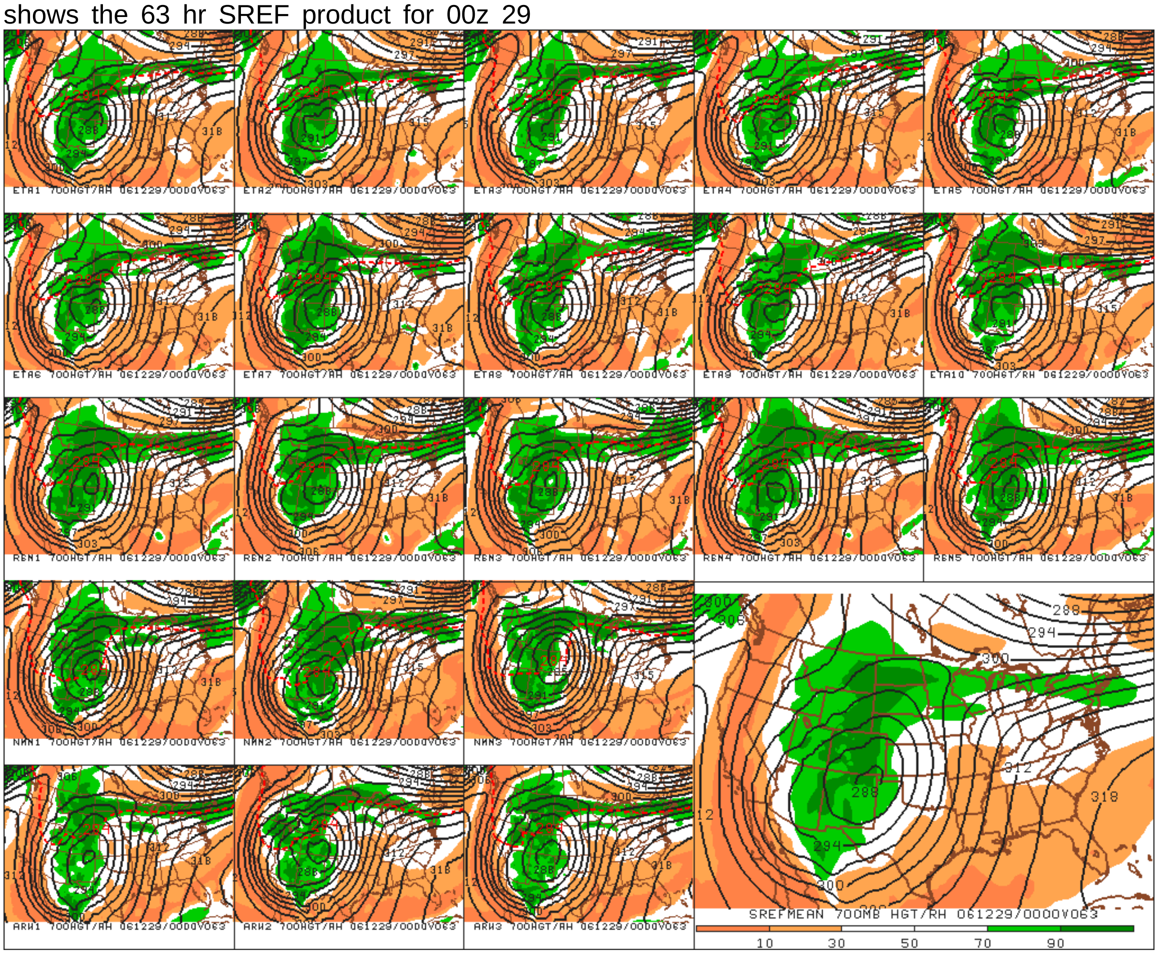


Fig. 20 SREF 700 mb heights and relative humidity for the 63-hr forecast at 00z Dec. 29.

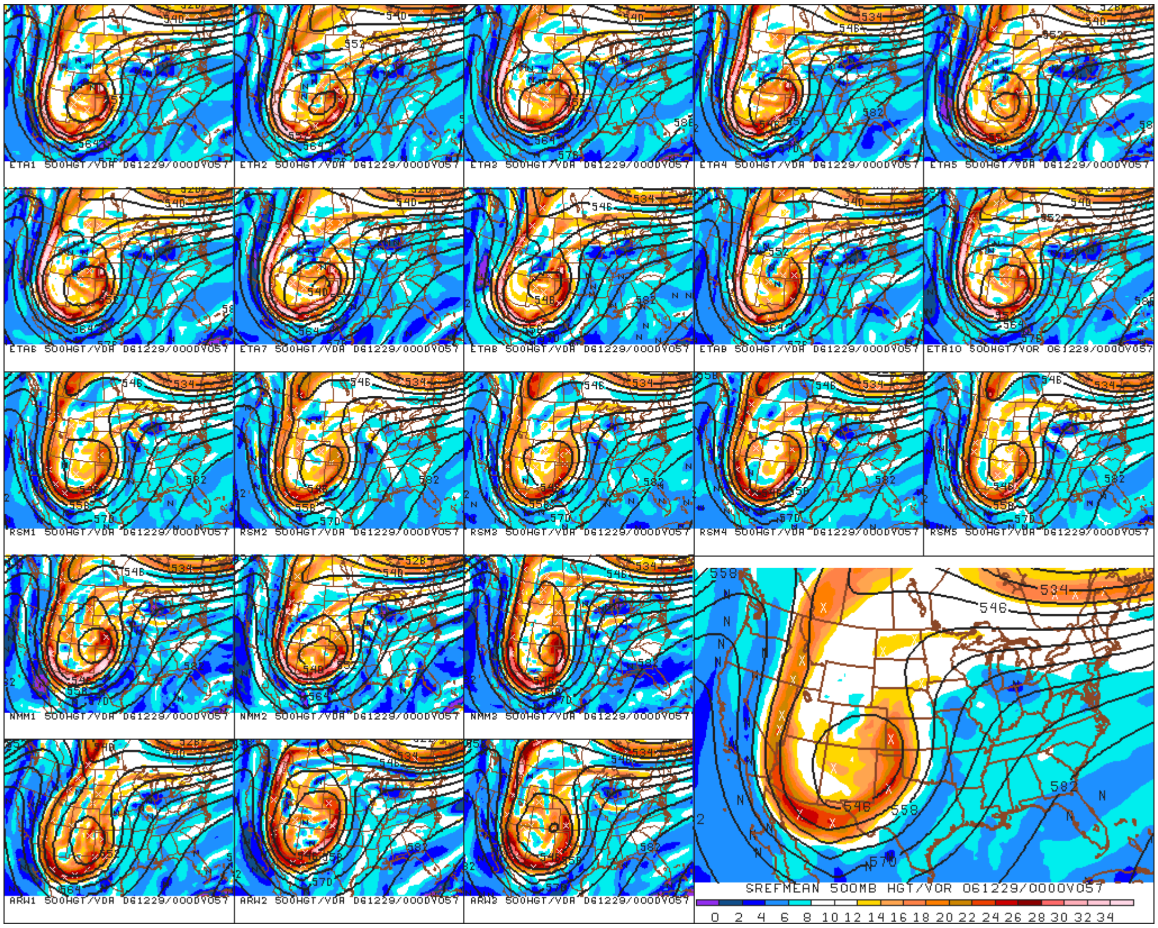


Fig. 21: SREF 57-hr forecast (500 mb heights and vorticity) for 00z 29 Dec. 2006.

The final case in this study occurred 4-5 Jan. 2007, an event exhibiting 6-12" observed snowfall amounts. This storm did not include closed-low characteristics at 500 mb, but did exhibit moderate upslope conditions at 700 mb.

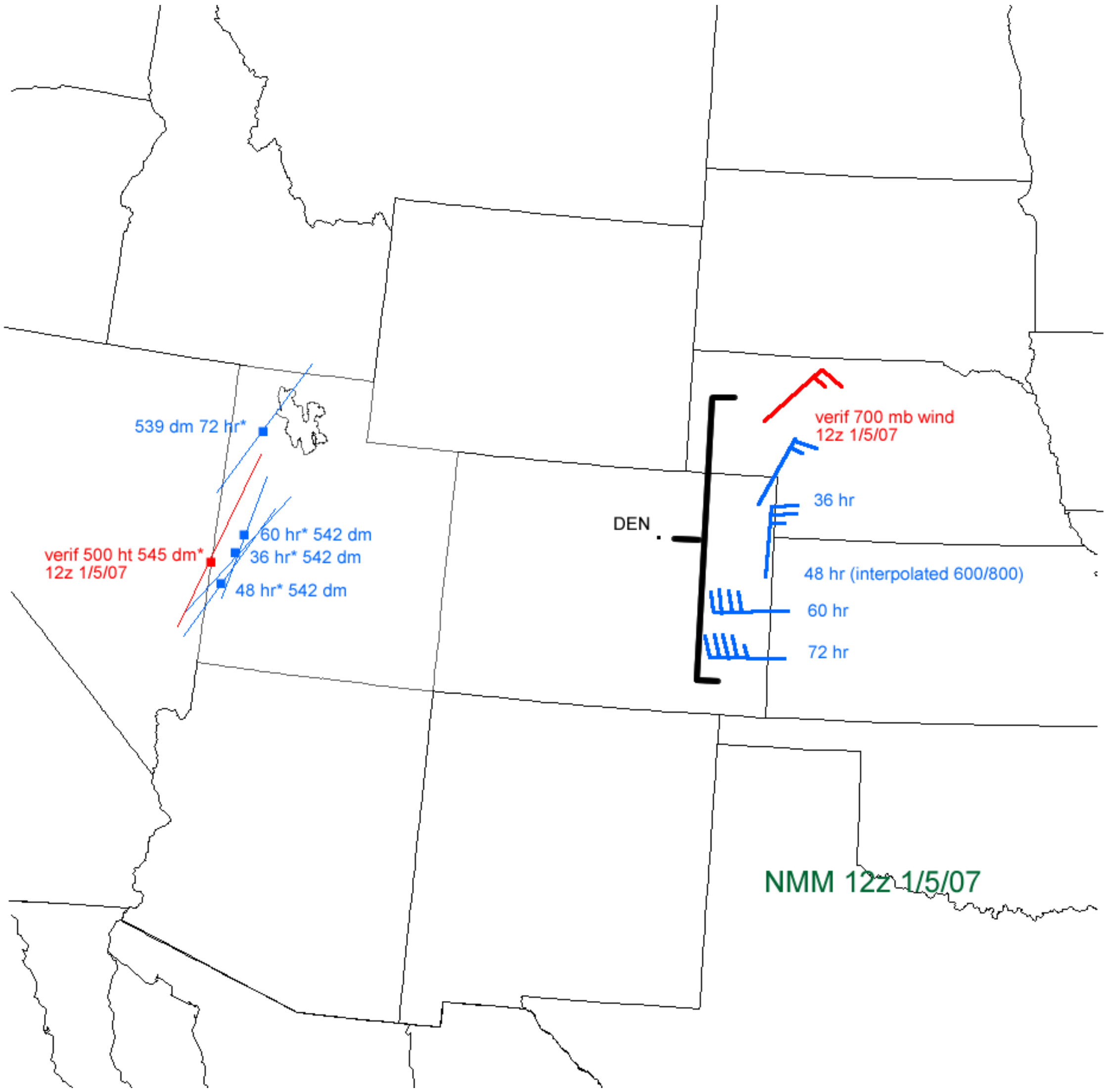


Fig. 22: NAM12 500 mb heights and 700 mb winds, analyzed (red) and predicted (blue) at 36, 48, 60 and 72 hours for the time shown. Red and blue lines denote the orientation of the predicted trough axis, when not closed at 500 mb.

The NAM12 (Fig. 22) did not foresee upslope 700 mb conditions until approximately 48 hours before the event, but the upper trough position fared fairly well throughout the forecast. Strong 700 mb westerly winds were predicted at 60 and 72 hr, compared with northeasterly winds at 15 kt in the analysis.

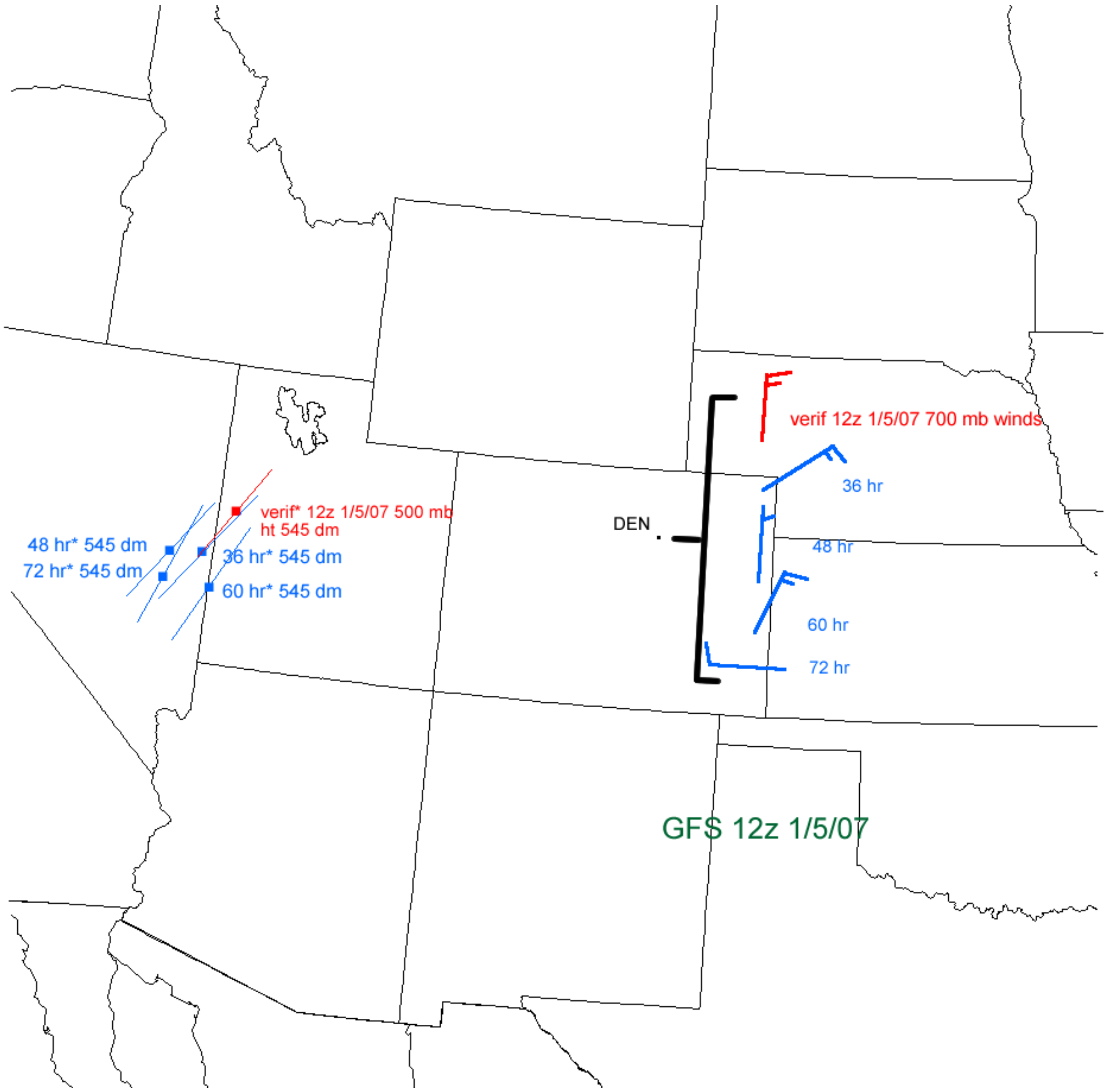


Fig. 23: GFS12 500 mb heights and 700 mb winds, analyzed (red) and predicted (blue) at 36, 48, 60 and 72 hours for the time shown. Red and blue lines denote the orientation of the predicted trough axis, when not closed at 500 mb.

Generally, the GFS (Fig. 23) fared a bit better than the NAM12 for 700 mb winds, with upslope conditions predicted at 60 hr. 500 mb trough location and orientation were forecast very well in this case by the GFS. Figs. 24-25 show the modeled and observed precipitation amounts, centered on CO, with 2 days shown due to continuation of Front Range snowfall past 12z 5 Jan..

Interestingly, though both models underpredicted Front Range snowfall significantly, the NAM12 overall indicated much higher precipitation values for the urban corridor for the 36/48 hr predictions during the second period. The trend of precipitation moving southward in time was correctly handled by both models.

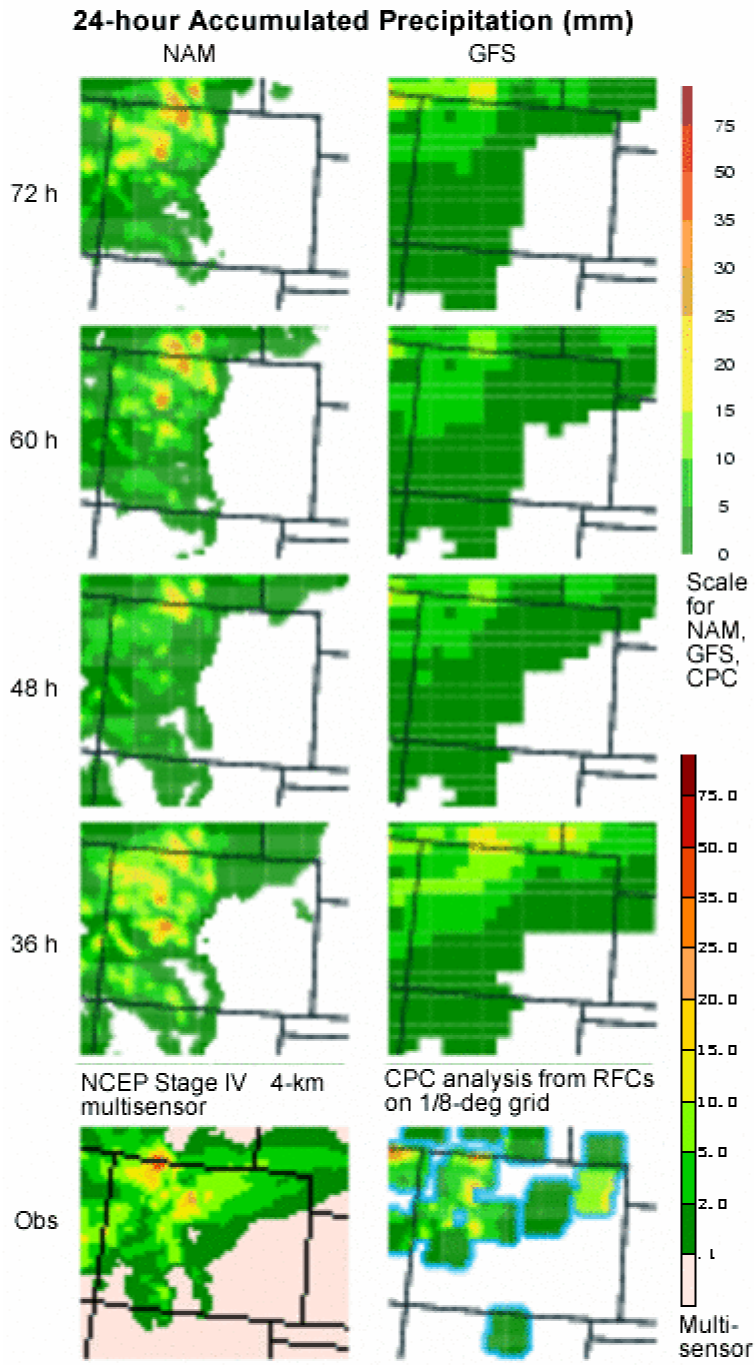


Fig. 24: Accumulated model and analyzed precipitation valid at 12z 5 Jan. 2007.

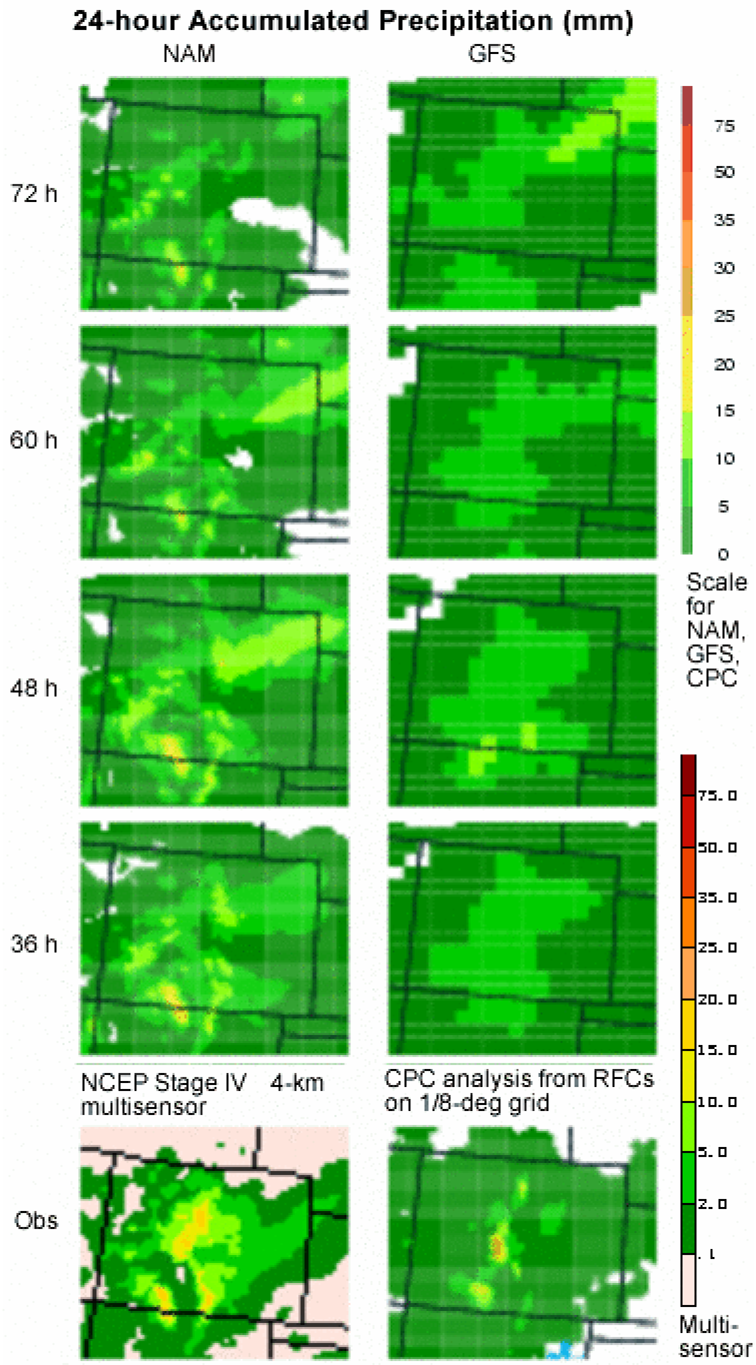


Fig. 25: Accumulated model and analyzed precipitation valid at 12z 6 Jan. 2007.

5. DISCUSSION

The primary issues addressed in this study beg the question of how predictable the atmosphere really is from a modeling standpoint on the 1-3 day time scale. The moderate to major winter events studied indicated that significant uncertainty existed in 2- or 3-day forecasts for both operational models, including SREFs. One important general aspect of GFS vs. NAM performance comparisons was the GFS predicting the position of 500 mb closed low centers more accurately than the NAM12 predictions for these storms. The “dprog/dt”-type plots indicated that the GFS obtained a relatively high level of accuracy quicker than the NAM as the storms approached, in

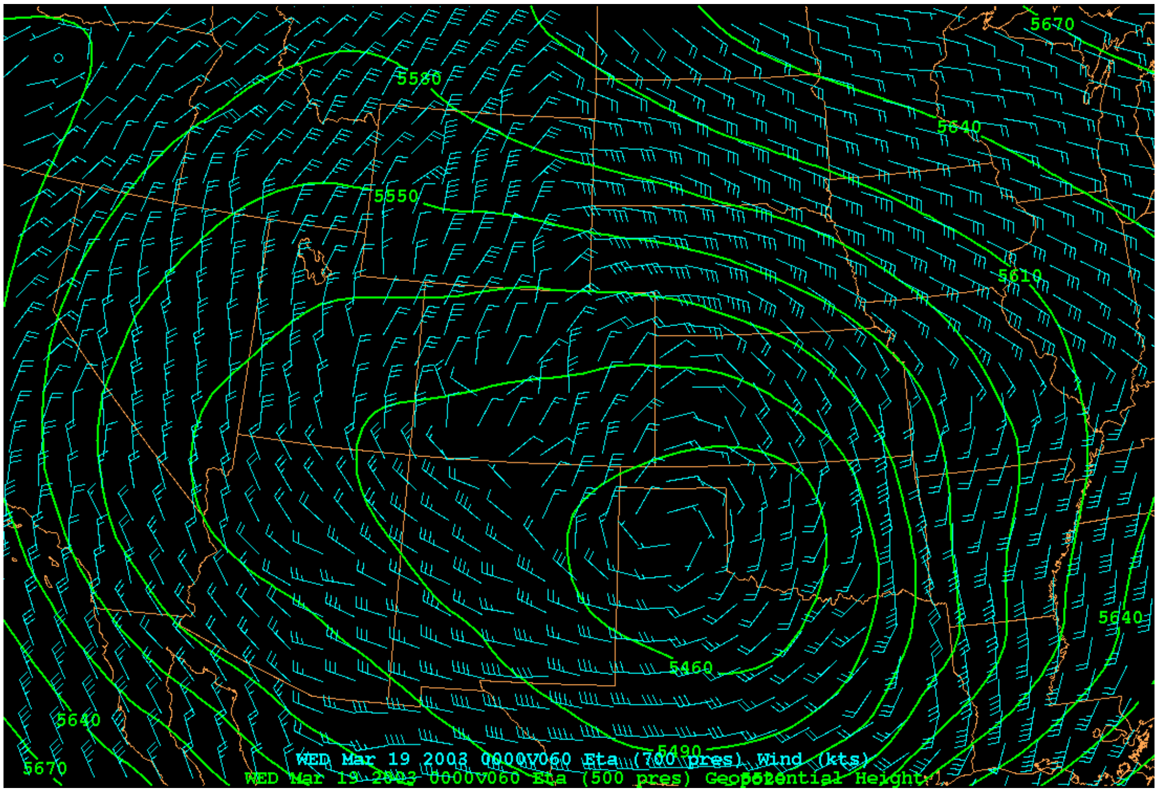


Fig. 26: Eta12 72-hr forecast of 500 mb heights and 700 mb winds for 00z 19 March 2003.

concurrence with operational forecasters noting the higher level of inconsistency in 500 mb closed-low positioning in the NAM.

Past studies of major, highly anomalous events, like the March 2003 Front Range superstorm (Weaver, 2003), indicated a relatively high degree of accuracy at 72 hours for Eta12-model forecasts of many events (see Fig. 26 for an example). Such a forecast proved extremely critical in warning the public well ahead of time of severe winter conditions for an extreme event. Whether this could be stated for forecasts in general is unknown.

For the 2006-7 winter, the NAM was utilized in operations for the first time and the model itself was being updated during the winter season. As stated previously, Eta guidance was no longer available except the 80km version via the SREF. During a transition period such as this, a phase in which both models are being run operationally and made available routinely to forecasters is useful for several reasons:

1. enables forecasters to begin to accustom themselves with new model characteristics and nuances while still having a familiar model available.
2. detailed side-by-side comparisons are easier to conduct operationally.
3. while the new model is still undergoing major adjustment, the old model simulations are always available.
4. more comparative studies can be undertaken from a model research standpoint.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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