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EVALUATION OF THE NCEP WRF NMM AND ARW MODELS FOR SOME RECENT HIGH-IMPACT WEATHER EVENTS

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1. INTRODUCTION

At the last Weather Analysis and Forecasting/Numerical Weather Prediction Conference in Washington, D.C. in the summer of 2005, a number of presentations were made (Session 7) on the Developmental Testbed Center (DTC) Winter Forecast Experiment (DWFE), conducted during the winter of 2005. The goal of that experiment was to run and evaluate two versions of the Weather Research and Forecasting (WRF) model at high resolution (~5-km horizontal grid resolution) on the CONUS scale, and distribute the output in real-time to National Weather Service (NWS) forecasters. Evaluation of the DWFE models by forecasters was generally quite positive, and the overall success of the effort prompted the National Centers for Environmental Prediction (NCEP) to announce, during the conference, that they would start running the two models again on a daily basis. This has been done now since late in 2005, with ~5-km horizontal grid resolution versions of the WRF Nonhydrostatic Mesoscale Model (NMM) and WRF version of the Eulerian Mass core model (ARW) run in four different sub-CONUS windows, each once per day. A set of graphics is distributed via the NCEP web page at http://www.nco.ncep.noaa.gov/pmb/nwprod/analysis/ and at another web site located at http://www.emc.ncep.noaa.gov/mmb/mmbpll/nestpage/.

During the past winter we examined the performance of these two new models for a number of cases, comparing the forecasts to the operational North American Mesoscale (NAM) and Global Forecast System (GFS) models. In this paper we will show a couple of the cases, looking at the performance of these models for two high-impact weather events during the winter season. Our focus will be on precipitation forecasts from the operational and high-resolution models. One of the cases will be the first of two major storms that crippled Colorado and nearby states around the Christmas holiday in late 2006, resulting in major travel delays and other critical impacts. A companion paper (Wesley et al. 2007) will examine the guidance at longer ranges from the operational models for this and other Colorado events. We will try to determine whether the high-resolution models provided improved guidance for operational forecasters.

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2. MODEL SPECIFICATIONS

According to the NCEP Environmental Modeling Center (EMC) notes (online at http://wwwt.emc.ncep.noaa.gov/mmb/mmbpll/eric.html#TAB4), the concept of special high-resolution window runs began with a high-resolution (10-km horizontal grid resolution) version of the Eta model run in five separate windows in March of 2001. About a year later (February 2002) the high-resolution model was switched from the Eta to the NMM, and the horizontal grid resolution was decreased to 8 km. Another upgrade to the high-resolution runs occurred in September 2004 with the WRF version of the NMM run at 8-km horizontal grid resolution replacing the NMM. In addition, a second model run was added, the WRF ARW, with a horizontal grid resolution of 10 km. The change that was announced at the last conference is listed as occurring in June 2005, with the high resolution window locations and the initialization times of the different runs shown in Fig. 1. The horizontal grid resolution was improved to 5.1 km for the WRF NMM, and 5.8 km for the WRF ARW. This reduction in horizontal grid resolution allowed the convective parameterization to be turned off in both models, justified by

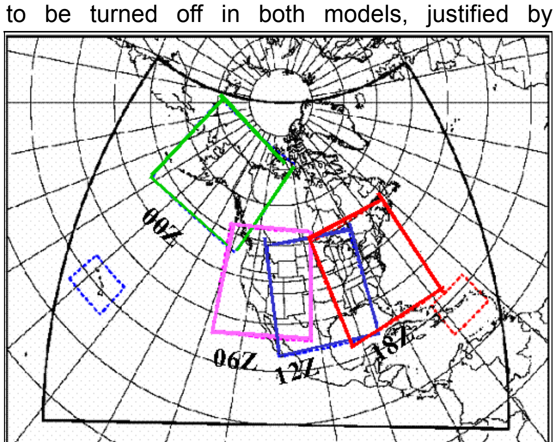

Fig. 1. Window locations and start times.

experience from the DWFE and other model experiments. These resolutions are still in place for the high-resolution window models, which are run out to 48 h.

In this paper the WRF NMM and ARW high-resolution runs are compared to the operational NAM and GFS models. In Table 1 some characteristics of these four models are listed. A major difference between the operational models and the high-resolution WRF runs, besides the horizontal grid resolution, is the fact that the NAM and GFS are run four times per day, at 0000, 0600, 1200, and 1800 UTC, while each of the WRF windows in Fig. 1 are only run once per day.

Table 1. Model Characteristics.

Model	Horizontal Grid Resolution (km)	Number of Vertical Levels	Convective Parameterization?
NAM	12	60	yes
GFS*	35km (T382)	64	yes
WRF-NMM	5.1	35	no
WRF-ARW	5.8	35	no

*Since the GFS is a spectral model, the equivalent horizontal grid resolution is given.

3. CASES

Two impressive winter storms buried Colorado just before and just after Christmas 2006. Both were high-impact events, the first one (discussed here) causing major travel disruptions with highway and airport closures. The post-Christmas storm was not as severe for the Front Range, but resulted in huge snowfalls over the far eastern Plains into Kansas, leaving a number of ranches isolated for weeks, killing many livestock, and causing major highway closures. A brief final case is for a particularly perplexing April storm that the first author unfortunately worked at the Boulder NWS Weather Forecast Office (WFO).

3.1 *20-21 December 2007 blizzard.*

This huge storm guaranteed a white Christmas for much of Colorado, with the Front Range and portions of the nearby Eastern Plains particularly hard hit. By early on 22 December snowfall from the storm spread from southeastern Wyoming south to northeastern New Mexico, then eastwards across most of Nebraska and the western half of Kansas. We will focus on the Boulder NWS WFO forecast area of northeastern Colorado for the verification of the models for this case. A snowfall map compiled by the Boulder WFO is in Fig. 2. Topography often plays a large role in modulating the snowfall, and Fig. 3 gives an image of topography with important features and locations labeled. The heaviest snows fell from the Palmer Divide south of Denver northward across the

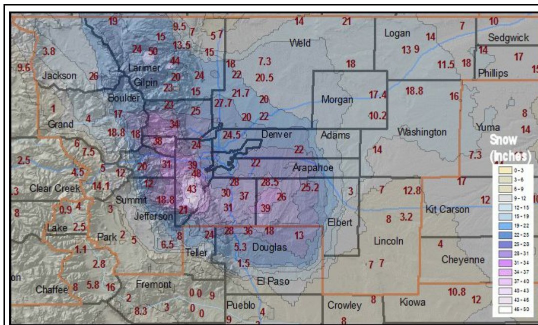

Fig. 2. Storm total snowfall (inches) as compiled by the Boulder WFO for northeastern Colorado.

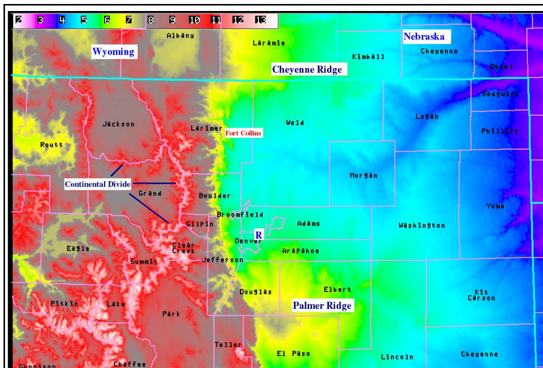

Fig. 3. Topographic map (image, in kft) with important features labeled. Also labeled are counties, the city of Fort Collins, and "R" for the Denver upper-air site.

Denver area, particularly in the western suburbs, then north to the Wyoming border. In the mountains snowfall peaked in the foothills and then decreased higher up as one approached the Continental Divide from the east, with much less snow west of the Divide. Most of the snow fell in less than 24 h, with heavy accumulation along the Front Range cities beginning abruptly between 0700 to 0900 Local Time (1400-1600 UTC) as a "wall of snow" moved in from the east. The storm reminded the first author of some of the great Nor'Easters of his youth, with strong winds present even before the snow began. The headlines in Fig. 4 give an indication of the major impact of the


Online | Flight info, road conditions and videos denverpost.com

THE DENVER POST

Voice of the Rocky Mountain Empire

THE BLIZZARD OF '06

WHAT A MESS

DIA: Flights to resume, but what took so long? | Commute: Expect gridlock and delays | Cleanup: Denver struggles to clear roads after blizzard

SNOW REPORT

20.7 inches

Fig. 4. Front page headlines from the Denver Post for 22 Dec 2007.

storm. Travel both by land and air was disrupted, with the Denver International Airport (DIA) shutting down by ~1600 UTC on 20 December and not reopening until ~1900 UTC 22 December. Major highways quickly closed as well, as many roads became impassable, with snow removal complicated by the high volume of snarled traffic as employers sent workers home early. Many of them were caught at the height of the storm that lasted well into the night.

For a comparison with the model forecasts, the precipitation (instead of snow) totals are needed. These are available from a number of sources, including a volunteer observing network (the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) (Cifelli et al. 2005)). National sources of precipitation totals include those from the NOAA National Operational Hydrologic Remote Sensing Center (NOHRSC), which specializes in snowfall and snow water equivalent, the NWS National Precipitation Verification Unit (NPVU), and a different NWS Precipitation Analysis. Unfortunately, none of the sites allow one to display 2-day precipitation totals. Examination of the single day estimates from the three national sites indicates reasonable agreement, with 2-day maximum precipitation estimated in the 2.0 to 2.80 in range. The precipitation estimates from the NOHRSC are given in Fig. 5. These estimates nearly cover the storm duration for Northeastern Colorado, while in Southeastern Colorado (south of Limon in Fig. 5) additional snow precipitation of up to ~0.25 in fell by 0600 UTC on 20 December, as the storm was moving from south to north.

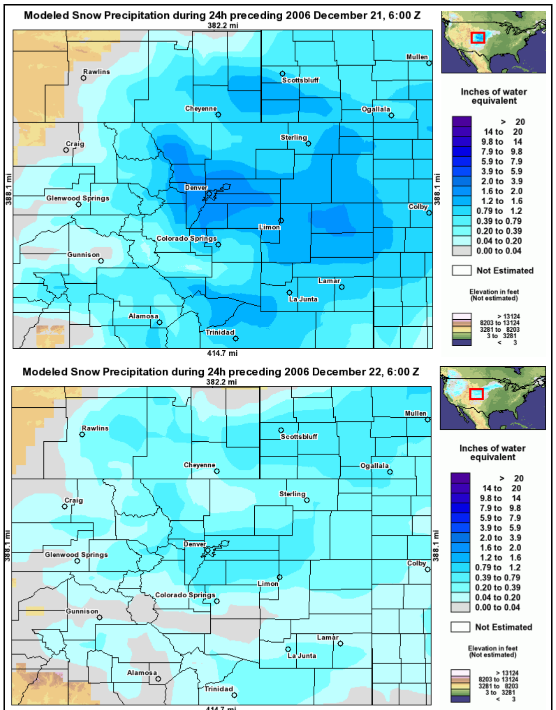

Fig. 5. Snow precipitation estimation from NOAA NOHRSC for the 24-h periods ending at 0600 UTC on 21 Dec (top) and 22 Dec (bottom), in inches.

For comparison to the above estimates we compiled storm totals from the daily CoCoRaHS volunteer network and official NWS Cooperative observers (some of these overlap), yielding the map in Fig. 6. Note that snowfall is not necessarily easy to measure, especially in conditions of strong winds, which existed in this case. The equivalent precipitation from the snow is even harder to accurately measure in strong wind conditions, and can be unreliable without some kind of shielding mechanism for the guage. This likely explains some of the large variations in precipitation from this storm by the CoCoRaHS observers, and to a lesser extent the COOP observers. Both of these sources were carefully examined in the process of arriving at our best estimate of the total storm precipitation in Fig. 6. From these data we estimated that maximum precipitation amounts likely ranged from 3-3.5 in over the Palmer Divide southeast of Denver to 2.6-3 in over the western portion of the Palmer Divide. In the city of Denver and nearby suburbs a general consensus for much of the city would be near 2.0 in (at the official site at the old airport known as Stapleton Airport, a COOP observer recorded 1.43 in of precipitation with 20.7 in of snow, but this precipitation amount seems low compared to many surrounding observations), ranging to as much as 3.0 in over the southeastern suburbs where the elevation increases approaching the Palmer Divide. Maximum precipitation amounts generally ranged from 1.80 to 2.2 in to the northwest of Denver in Boulder County. Farther north through Larimer County similar ranges of precipitation totals were found in the city of Fort Collins, but some observers recorded somewhat more snow just to the east, with precipitation totals ranging up to 2.6 in. Another area with a greater maximum was in the foothills of Larimer County, with several reports exceeding 2.0 in of liquid equivalent, and a maxima of 2.83 in, with snowfall totals of up to 32 to 40.5 in.

It is difficult to be certain if some of the heavier amounts of precipitation observed are accurate, or

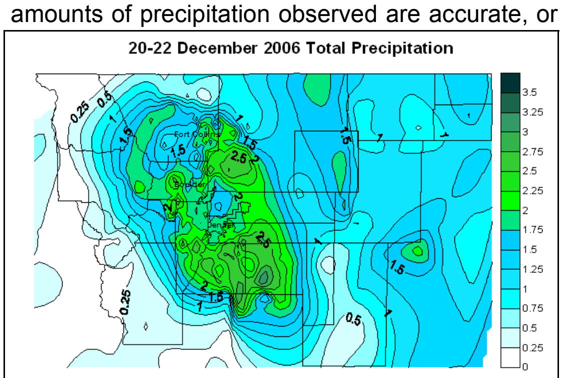

Fig. 6. Storm total precipitation compiled from CoCoRaHS and COOP observer reports, in inches.

if the strong winds and drifting snow resulted in erroneous measurements. Our best estimation is that in general at least 1.7 to 2.4 in of precipitation fell in the heavier snowfall areas, with as much as 3.0 and perhaps 3.5 in falling in some local areas. These are the amounts that will be used when comparing to the model forecasts.

In terms of an overview of the synoptic setup for the blizzard, the storm took a very southern track after coming onshore on 16 December (Fig. 7a). By 19 December (Fig. 7b) the 500 mb closed low nearly plunged into northern Mexico before lifting to the northeast the following day (Fig. 7c). This was a bit like the post-Christmas blizzard of 1987 (Barnes and Colman 1993) in Colorado that dropped even farther south well into Mexico before lifting to the northeast and deepening, much like this storm does on 20-21 December (Figs. 7c and 7d). Often storms that pass so far south of Colorado end up too far south or east to produce much snow in northeastern Colorado. Numerical models seem to have more than the usual amount of difficulty with such systems, perhaps because of limited upper level data in Mexico and the eastern Pacific. Indeed, this was the case for this event, with forecasts from the operational models earlier in the week predicting that most of the snow/precipitation with this storm would pass to the east of the Front Range (Wesley et al. 2007, this conference).

The first set of model forecasts considered here are from the initialization at 1200 UTC on 18 December 2006 (Fig. 8). The 700 mb forecasts are shown for this time to note that all models were still having difficulty predicting how the upper low would lift out (see the verification in Fig. 9). Both WRF window runs are initialized using the NAM model, so their forecasts of the main upper-level features will often mirror those of the NAM. That is the case for the set of forecasts in Fig. 8, with the operational NAM, and GFS for this case, both having an elongated 700-mb low that extended back into Wyoming. This configuration is quite different from the more concentrated 700-mb low that verified farther south (Fig. 9). This difference, while not great in distance or intensity from the forecast, is huge in the resulting winds along the Front Range, as seen by the 700-mb winds from the northwest along the Front Range in Figs. 8a and 8b. While the 700-mb height forecasts from both WRF models also have an elongated low, close examination of these forecasts indicates a more north to northeast flow along the Front Range, with the suggestion of a center to the 700-mb upper low more to the east of Denver. This is at least somewhat closer to the observed conditions.

The next set of forecasts initialized 18 h later at 0600 UTC on 19 December (this is the next WRF initialization time that includes Colorado within the domain) allow us to examine precipitation

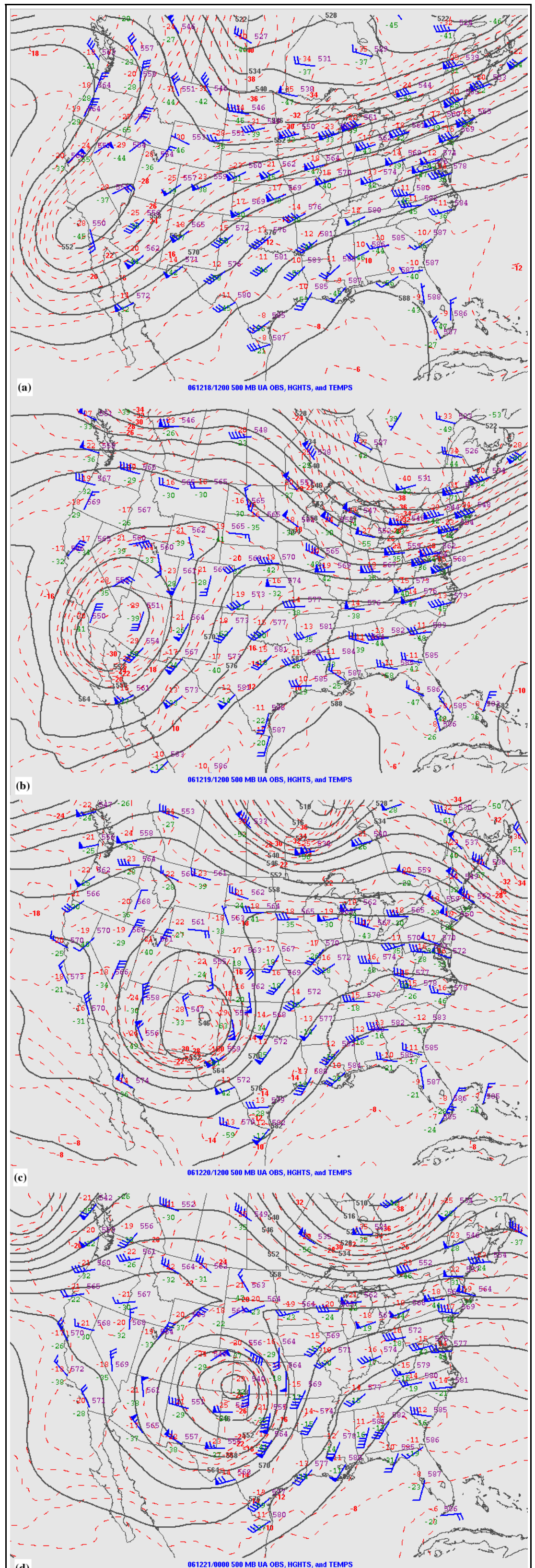

Fig. 7. 500 mb analyses and data from the Storm Prediction Center website, for 12 UTC on 18 (a), 19 (b), and 20 Dec (c), and 00 UTC 21 Dec.

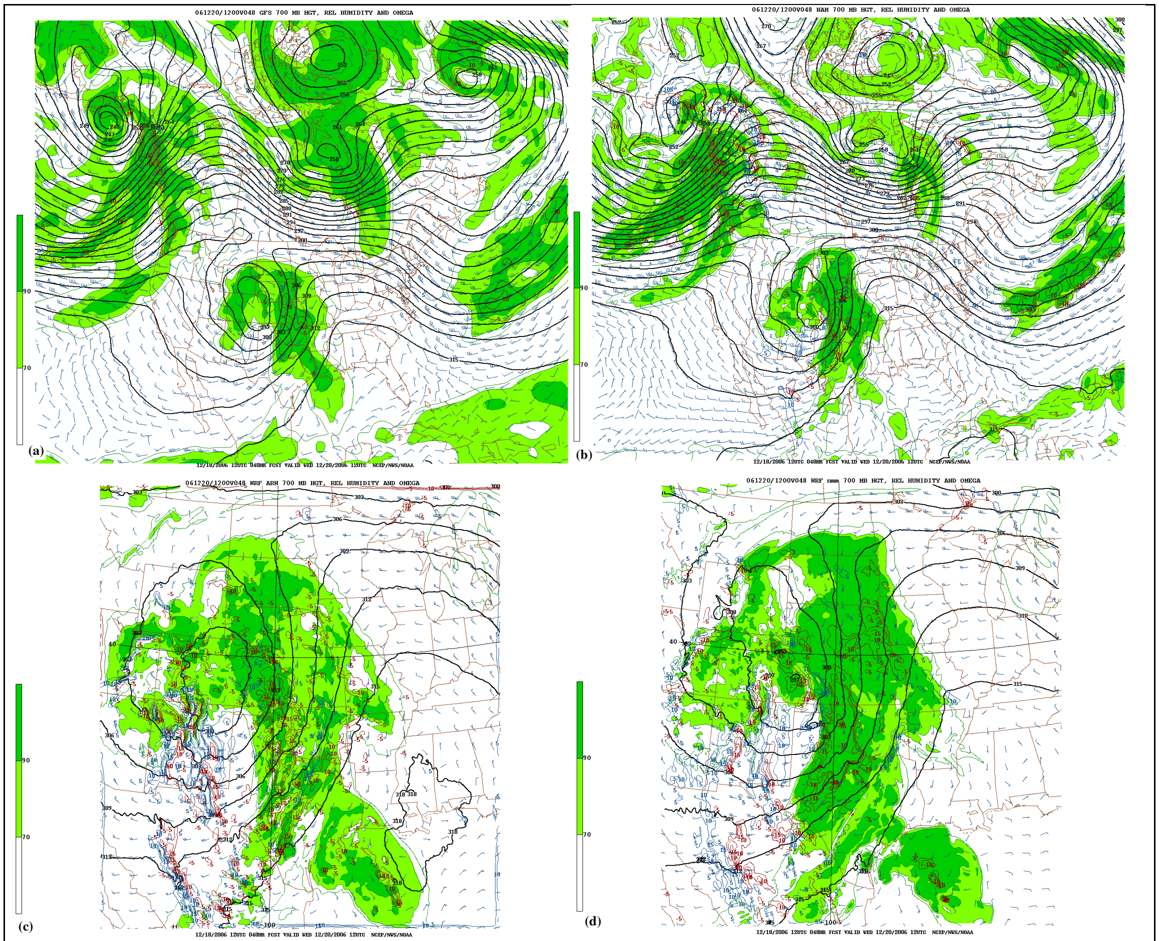

Fig. 8. 48-h 700 mb forecasts valid at 1200 UTC on 20 Dec 2006 of height (dm), relative humidity (contour at 50%, shading at and above 70%), wind (barbs, in knots), and omega (c and d only), from the GFS (a), NAM (b), WRF-ARW (c), and WRF-NMM (d).

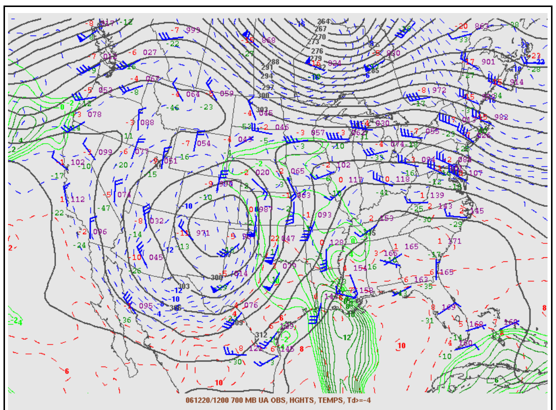

Fig. 9. As in Fig. 7, but for 700 mb on 1200 UTC 20 Dec 2006.

forecasts for most of the period of the storm. First we examine the 42-h 700-mb forecasts in Fig. 10, valid at 0000 UTC 21 December, when the storm was at its maximum intensity. The 700-mb analysis for this time is given in Fig. 11.

All the models have a much better forecast for the position and intensity of the 700-mb upper-level low than for the forecasts from the earlier runs shown in Fig. 8. The position of the upper low in all the forecasts is, however, too far to the north, and this translates into too much northerly to northwesterly flow at 700 mb in the GFS and NAM forecasts. The observed flow at the Denver RAOB site was from 020° at a strong 40 knots. As with the previous forecast period, both WRF models have important differences in the 700-mb flow near the Front Range, with a north to northeast flow in both models at close to the observed speed.

The difference in the flow allows for much more precipitation to wrap around and be forced by the higher topography west of the Front Range cities. This explains the differences in the accumulated precipitation forecasts as seen in Fig. 12. The difference between the two operational forecasts along the highly populated Front Range is significant. The GFS produces a small maximum of precipitation of 1.25-1.50 in shifted to the east of the Front Range, while the Front Range area was in the zone of 0.50-0.75 in. The heaviest precipitation was forecast over central Nebraska south to western Kansas. The NAM has a maximum of precipitation, but narrower and not as

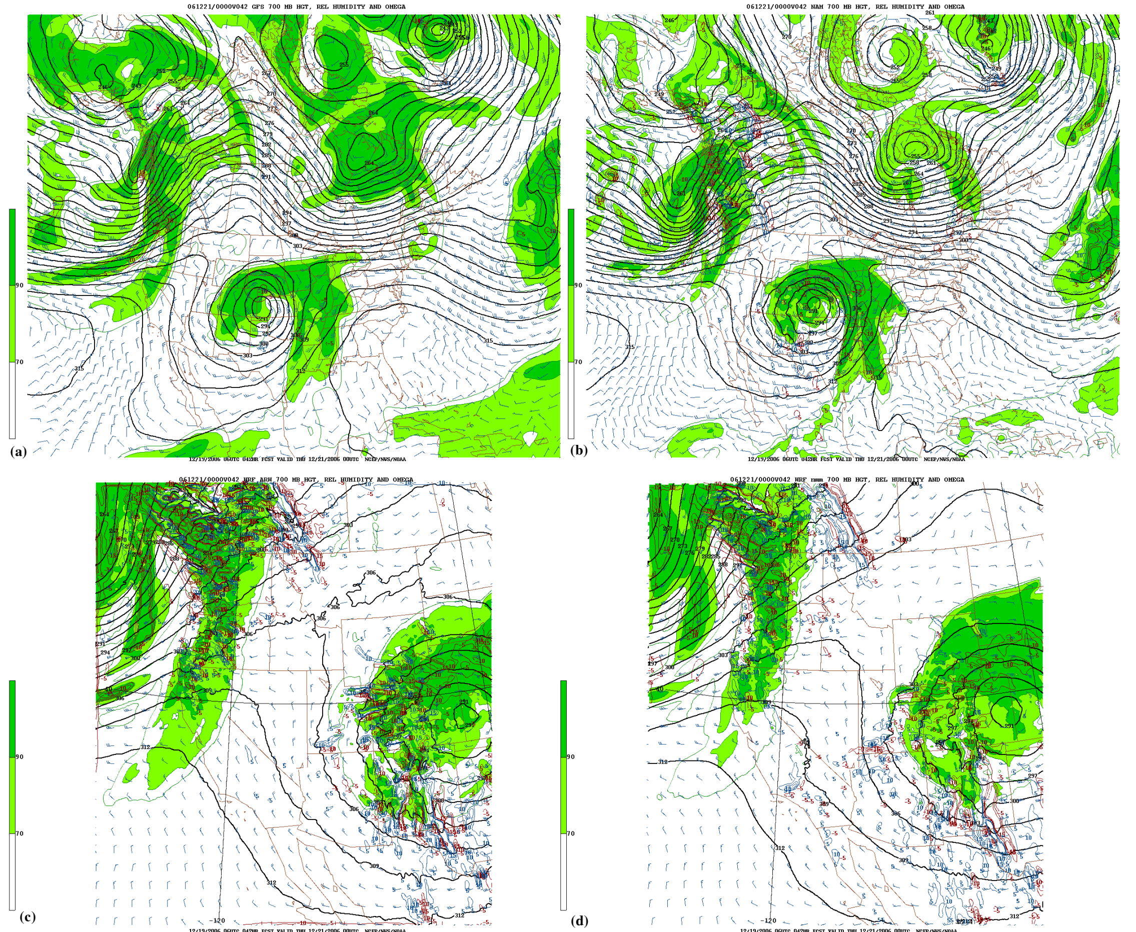

Fig. 10. 42-h 700 mb forecasts valid at 0000 UTC on 21 Dec 2006, as in Fig. 8, from the GFS (a), NAM (b), WRF-ARW (c), and WRF-NMM (d).

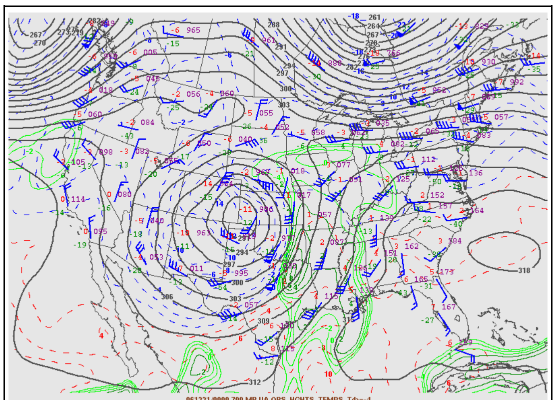

Fig.11. 700 mb analysis, as in Fig. 9, for 0000 UTC 21 Dec 2006.

much as in the GFS, in western Kansas and western to central Nebraska. However, the heavier precipitation wraps westward across southeastern Wyoming and then down the Front Range, with a small maximum of 1.25-1.50 in near Fort Collins. The WRF models are similar to the NAM with the area of precipitation extending back into Wyoming and down the Front Range, except both runs have more precipitation focused in the area where the maximum was observed. Comparing the two WRF runs, there is clearly more precipitation in the WRF-ARW than the WRF-NMM, with small maxima of 2-2.5 in for the ARW, versus 1.75-2.0 in for the NMM. The greater amount of precipitation found in the WRF-ARW is a general characteristic for all of Colorado, and probably farther east as well. However, this is not possible to determine from this set of runs as the maximum of precipitation from Nebraska to Oklahoma is shifted quite a bit farther to the west in the NMM run and is east of the window domain in the ARW.

A big difference between the WRF runs and the two operational runs is the amount of detail in the high-resolution precipitation forecasts compared to the operational runs. The NAM forecast does have a sharp gradient of precipitation from near the Continental Divide westward, but not much on the Colorado eastern plains. The WRF models have even more detail along the mountains near and east of the Continental Divide. Additionally, the models are able to capture the lower level downslope flow over portions of the eastern plains

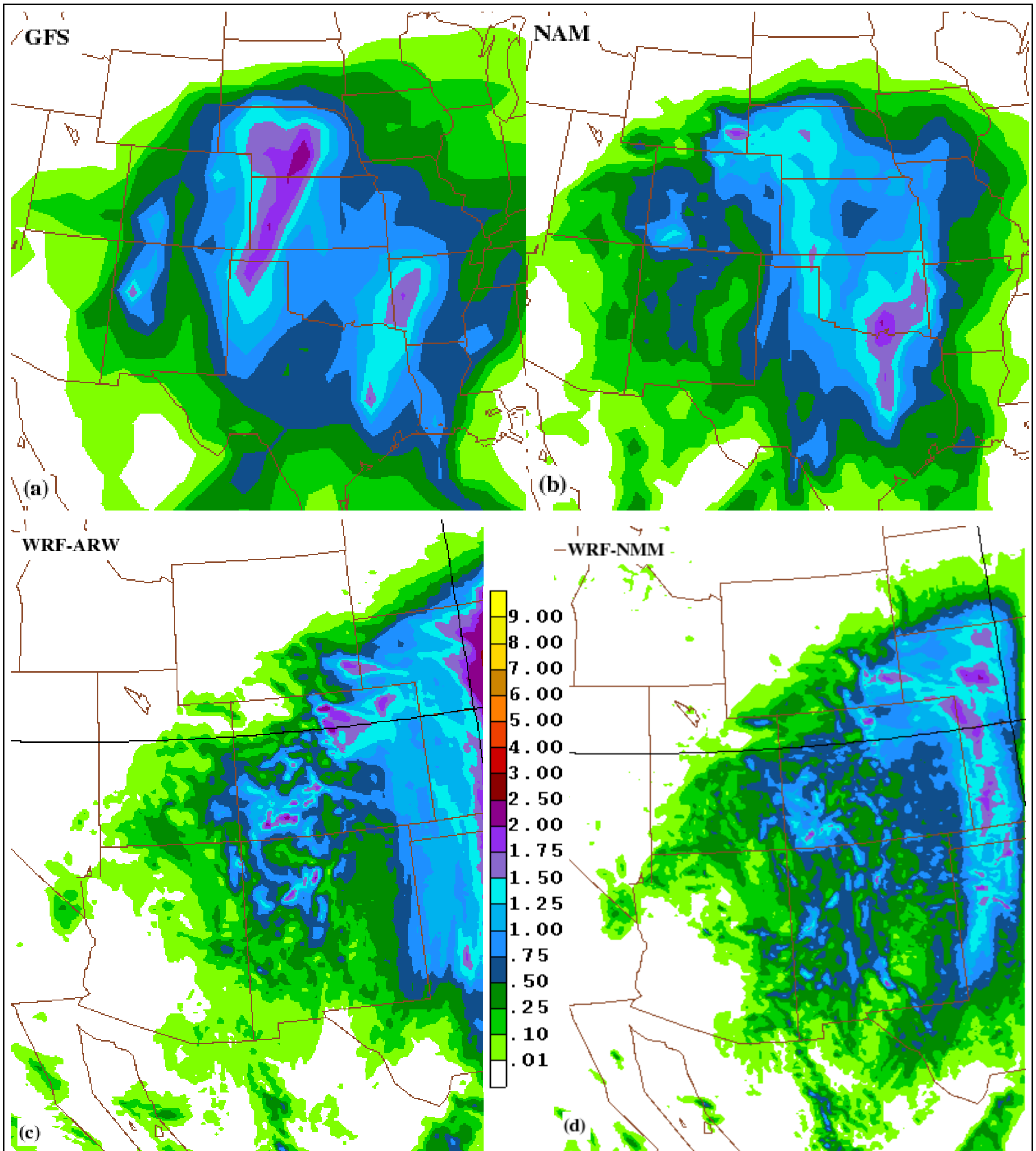

Fig. 12. 48-h forecasts of accumulated precipitation ending at 0600 UTC on 21 Dec 2006 from the GFS (a), NAM (b), WRF-ARW (c), and WRF-NMM (d). Precipitation scale, in inches, is the same for all runs.

that created local areas of less precipitation, such as south of the Cheyenne Ridge (see Fig. 3 for topography). Overall, for this time period the WRF-ARW was the better forecast, with the larger area of heavier precipitation verifying closer to the observed amounts.

The Colorado area has the advantage of being in more than one of the high-resolution windows, as seen in Fig. 1, and the next set of high-resolution runs would be 6 h later at 1200 UTC. Unfortunately, these high-resolution runs are not available to examine for this case. The operational forecasts initialized at 1200 UTC on 19 December 2006 are shown in Fig. 13. The relatively subtle difference in the 700-mb wind, with a more northerly flow in the GFS down the Front Range, results in a significant shift in the precipitation maximum (of 1.47 in at its peak value) to east of the Front Range, similar to the 0600 UTC run. The NAM, by contrast, continues to predict far heavier precipitation pushing back into the Front Range, with the heaviest amounts (a maximum value of 3.23 in) found just to the northwest of Fort Collins, bordering the eastern edge of the foothills. This heavier amount verifies well, but as in the previous

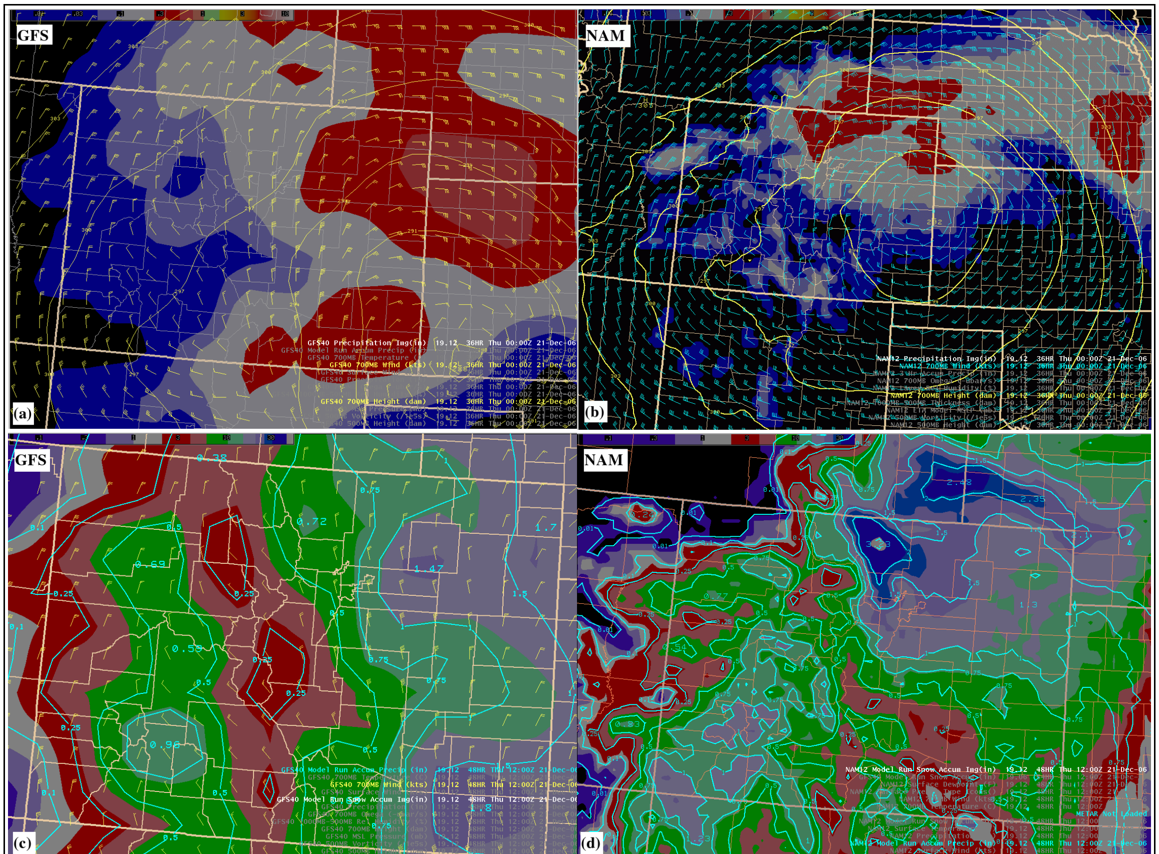

Fig. 13. Forecasts from the 1200 UTC 19 Dec operational runs. In (a) and (b) 36-h forecasts valid 0000 21 Dec of 700 mb wind and height from the (a) GFS, with 6-h precipitation (image), and (b) NAM, with 3-h precipitation (image). In (c) and (d) 48-h accumulated precipitation (contours) and 48-h accumulated snow (image) ending at 1200 UTC on 21 Dec 2006 from the (c) GFS, with 700 mb winds, and (d) NAM.

forecast from the NAM, forecast precipitation decreases too rapidly to the southeast, especially in areas west and south of Denver.

In the next set of forecasts initialized at 1800 UTC (not shown), the NAM forecast precipitation area did expand southward to more closely match what was observed. The GFS also finally came around to a more northeast component flow at 700 mb along the Front Range, resulting in a forecast precipitation maximum a little farther west, in closer (but not as good as the NAM) agreement with the observations. As the operational models came into better agreement that a major storm was imminent, watches and warnings were hoisted by several WFOs (Fig. 14). Overall, even though the confidence in the storm being a big event was not high far in advance, the event was well predicted in the shorter term (24 to 36 h in advance).

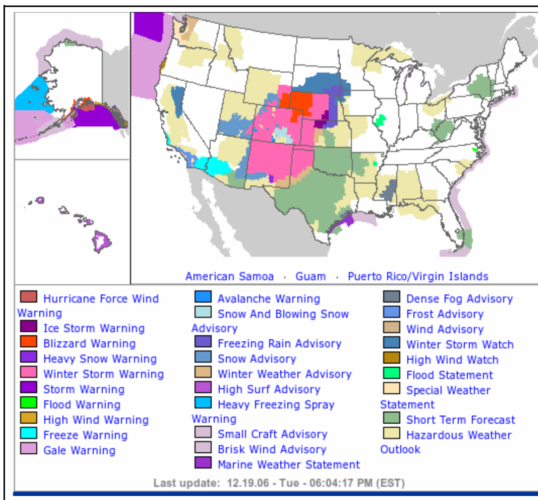

Fig. 14. NWS watches and warnings in effect as of 2300 UTC 19 Dec 2006.

The final set of forecasts examined for this case is from the runs initialized at 0600 UTC on 20 December, about 6 to 9 h before the heavy snows hit the Front Range. For this time only the precipitation forecasts are shown (Fig. 15), for the 48-h period ending 0600 UTC on 22 December. Although this is a different period than shown in Fig. 12 (48-h period ending 0600 UTC on 21 December), most of the snow had ended by 0600 UTC 21 December, so the two run total forecasts can be compared reasonably well. Both operational models have more precipitation wrapping back towards the Front Range than in the forecasts from 24 h earlier, with a maximum of about 2 in for the GFS near the Denver area, and 3

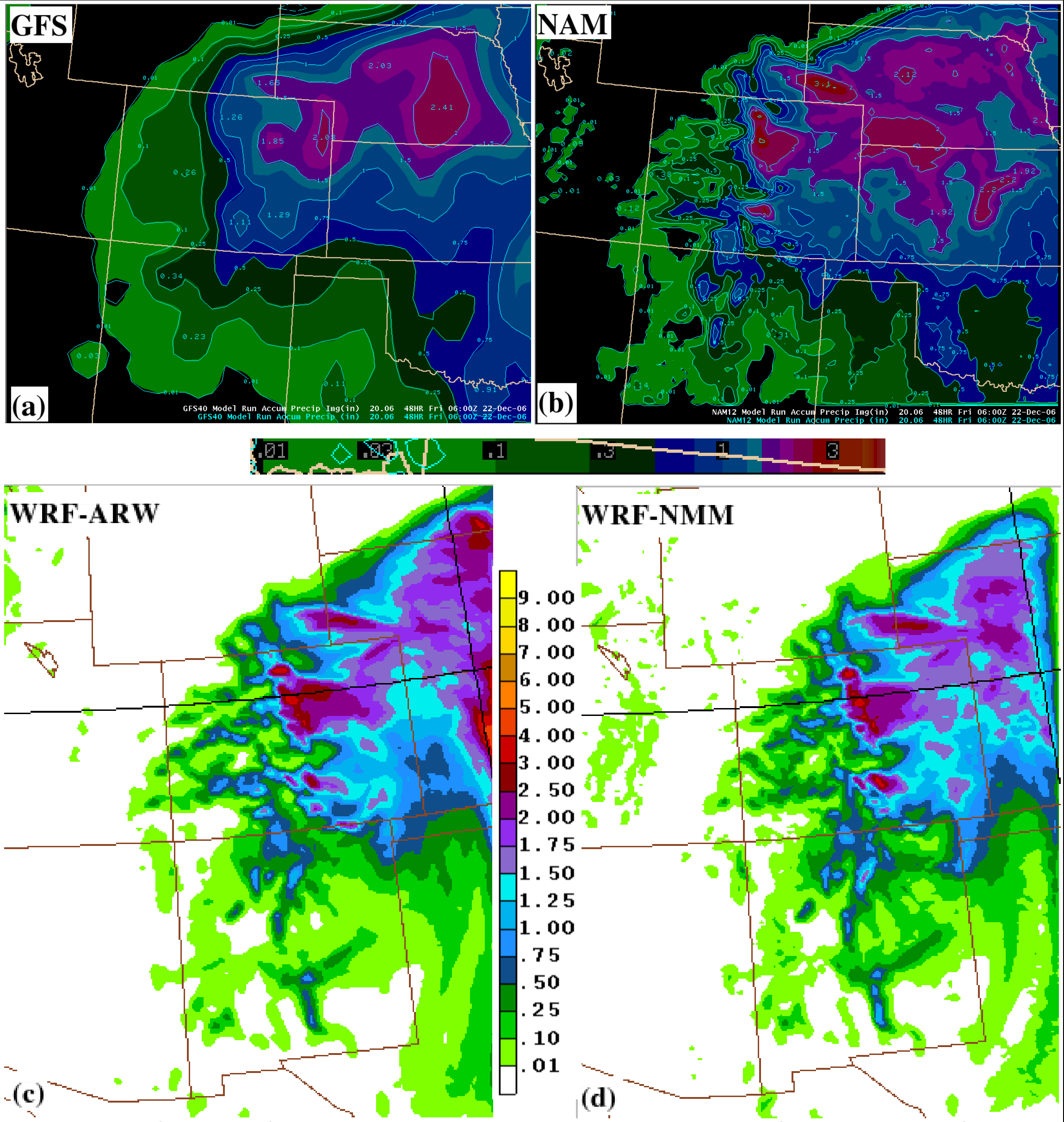

Fig. 15. Model forecasts of 48-h accumulated precipitation ending at 0600 UTC on 22 Dec 2006 from the GFS (a), NAM (b), WRF-ARW (c), and WRF-NMM (d). Two precipitation scales, in inches, are given; one for the NAM and GFS, and the other for the WRF runs.

in for the NAM, embedded within a relatively large area of greater than 2 in along the Front Range. (We discovered some discrepancies in the precipitation amounts when comparing the web graphics with those captured from AWIPS. For the GFS, the online precipitation generally agreed closely with the AWIPS graphics for the "GFS40", the highest resolution AWIPS display from the GFS. However, the maximum precipitation amounts from the AWIPS NAM12 precipitation graphics exceeded those from the web. For the time period shown in Fig. 15b, the maximum precipitation from the web graphics was in the 2-2.5 in range, whereas the AWIPS graphics (Fig. 15b) yield a maximum of just over 3 in.) Inspection of the 700-mb forecast winds (not shown) from the GFS indicated more north to northeast flow into at least the northern portion of the Front Range, though not as strong as observed, but still a component of northwest flow farther to the south. The other models more correctly forecast stronger (40 to 50 knot) northeast flow into the Front Range, similar to what was observed (Fig. 11).

The NAM also has the maximum precipitation area extending farther to the west and even south of the Denver area, as was observed. The NAM's horizontal grid resolution of 12 km is sufficient to produce a minimum of precipitation (in the 0.25-0.5 in range) downstream of the Cheyenne Ridge (see Fig. 3 for topography), extending into northeastern Colorado to the east-northeast of Fort Collins. This type of detail is not found in the GFS forecast, while on the other hand it is even more apparent in both high-resolution forecasts. The high-resolution models have a minimum of precipitation in the 0.10-0.25 in range in this area of low-level downslope as northerly flow passes over the Cheyenne Ridge. The NOHRSC precipitation estimate (Fig. 5) has ~0.4-0.6 in storm total precipitation in this area, but there was a CoCoRaHS report of only 0.28 in, close to the upper end of the model minimum. Close inspection of the model forecasts indicates the minimum in precipitation is shifted a bit west of where it was actually observed. Still, the high resolution models are able to capture the extraordinary gradient in precipitation between this minimum and a local maximum forecast in the 3-3.5 in range to the west of Fort Collins. The distance between these extremes is roughly 40 km in the observations. The NAM does nearly as well with this strong gradient of precipitation.

A similar minimum of precipitation is also forecast by both high-resolution models, and to nearly the same extent, by the NAM, south of the Palmer Divide. This topographic feature is similar to the Cheyenne Ridge but is located to the south and southeast of Denver. The city of Colorado Springs is near this forecast minimum, and indeed, a large gradient of precipitation was observed between a minimum of less than 0.5 in across portions of Colorado Springs to more than 2.5 in to the north just downstream of the Palmer Divide. Even more precipitation was observed on the upstream side of the Palmer Divide, with some observations of 3-3.5 in. The high-resolution models also do a good job of capturing this gradient. The NAM has this same gradient, but is not quite as extreme as what was observed, both in the minimum and the maximum precipitation amounts.

Aside from these and other sharp gradients of precipitation associated with topography that are best resolved by the high-resolution models, these models also forecast an area of heavier precipitation extending eastward from the Denver-Boulder area, near 40° north latitude. This maximum was also observed (Figs. 2, 5, and 6), generally in the 2-2.5 in range. This was a persistent feature in the high-resolution runs, and is seen in the forecast from 24 h earlier (Fig. 12).

3.2 *13-14 April 2007: Miss for the Front Range.*

The last case is a brief look at a storm that had great potential but ended up missing the Front Range, with significant snows over southeastern Colorado and western Kansas. Winter Storm Watches were hoisted for a large area including the Front Range at least 48 h in advance of the storm, and upgraded to warnings more than 24 h in advance. The first author had the misfortune of working a shift at the Boulder WFO on 12 April, when most signs still pointed to a significant snow storm for northeastern Colorado. Things began to go astray as the afternoon of 12 April progressed, with the 1800 UTC runs of the operational models finally indicating that the main storm was continuing to dive to the south, and would end up passing too far south and east to bring significant snows to the Front Range. One initialization time will be shown for this case, with the main point being that if the model providing the boundary conditions has a busted forecast, then the high-resolution models will likely err as well. This point has been noted by NCEP meteorologists in their assessment of the high-resolutions models (NCEP documentation, 2005, available online at http://www.emc.ncep.noaa.gov/mmb/mmbpll/June2005.HRWUpgrade/June2005.HRWupgrade.html).

A 48-h, 700-mb forecast from the 11 April 1200 UTC NAM is shown in Fig. 16, with the verification for 1200 UTC 13 April in Fig. 17. The observed 700-mb low verified well to the south of where it was forecast, and was also weaker than forecast. Together this resulted in a light northwest wind at the Denver RAOB site, instead of a 10-20 kt northeast wind.

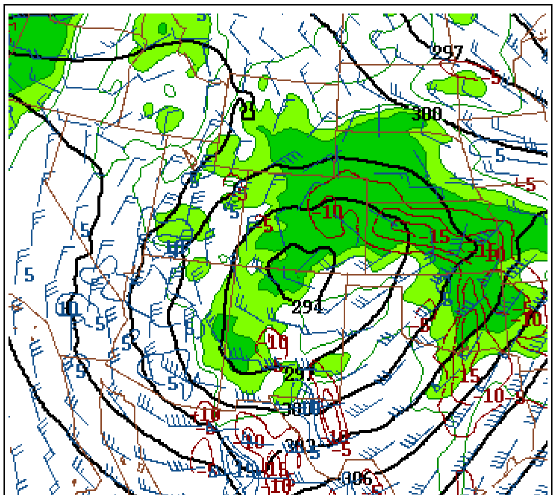

Fig. 16. NAM 48-h 700 mb forecast of wind, height, and omega, with relative humidity at and above 70% shaded, valid at 1200 UTC 13 April.

The 48-h, 700-mb forecasts from the high-resolution runs valid for 1200 UTC 13 April focused the best northeast upslope flow into southeastern Wyoming. This resulted in the precipitation forecasts shown in Fig. 18, which actually had the heaviest precipitation, at least through 1200 UTC 13 April, falling north of the Front Range. Verification for the 24-h period ending at this same time is in Fig. 19. This 24-h period encompasses

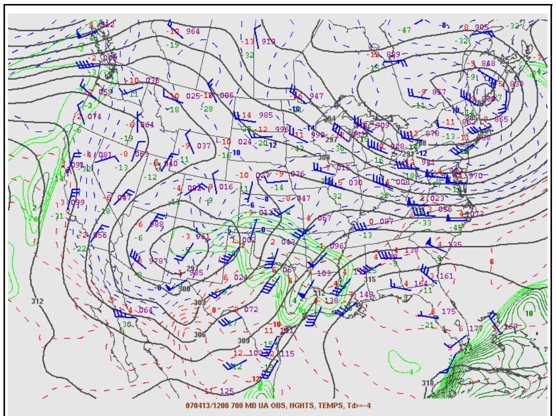

Fig. 17. As in Fig. 7, for 700 mb on 1200 UTC 13 April 2007.

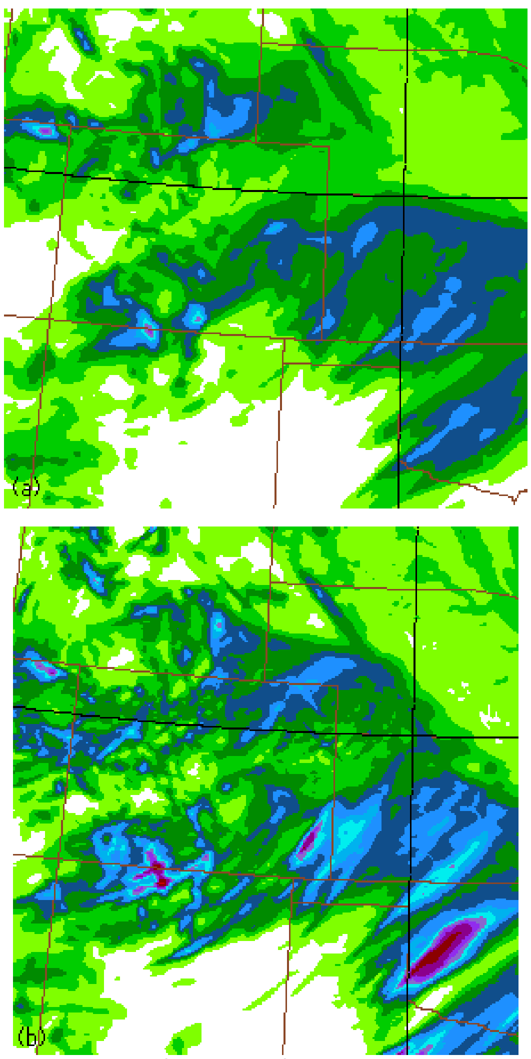

Fig. 18. Model forecasts of 48-h accumulated precipitation ending at 1200 UTC on 13 April 2007 from the WRF-ARW (a) and the WRF-NMM (b). Precipitation scale is given in Fig. 15.

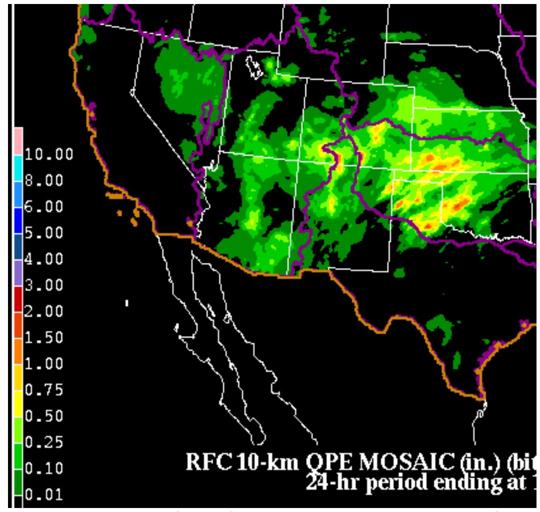

Fig. 19. NPVU QPE for 24-h ending 1200 UTC on 13 April 2007, in inches.

most of the precipitation that fell in the 48-h prior to 1200 UTC 13 April. Both forecasts predicted far too much precipitation across southeastern Wyoming, where little if any precipitation fell, since the main area of precipitation was shifted well to the south.

It is interesting that the two high-resolution model forecasts are different in other areas, most notably that the NMM had a swath of precipitation from near Denver extending to the northeast into Nebraska. Much of this precipitation occurred with a separate shortwave trough that lifted out across northeastern Colorado on the afternoon of 12 April, the amounts being over-forecast by the NMM in this area.

4. SUMMARY AND CONCLUSIONS

Many cases were saved over the last winter season comparing the two high-resolution window runs by NCEP with the operational models, the GFS and NAM. Two cases were shown here that demonstrate some of the characteristics of the runs and issues in interpreting the forecasts. Some general subjective impressions of the forecasts from the high-resolution runs examined are summarized here, mainly for the precipitation forecasts.

The most obvious characteristic of the high-resolution runs is the greater detail in the forecast precipitation, as would be expected, compared to the operational runs. For areas like Colorado, where terrain is an important factor, the precipitation distribution and amount can be heavily influenced by the topography. For the great pre-Christmas blizzard, the topographic influences shown in the high-resolution model forecasts were largely confirmed by observations. The operational NAM, at a 12-km horizontal grid resolution, is able to resolve many of the same features, but not to the level of detail of the high-resolution runs. The GFS for the most part smooths out the terrain-influenced precipitation patterns. We have not carefully done a systematic look at the forecast orographic precipitation in the mountains of Colorado, but our general impression is that the high-resolution models, while certainly providing excellent detailed forecasts, tend to over-predict precipitation in the mountains for most events, particularly weakly forced ones.

An interesting aspect of the blizzard case discussed here is the slightly different 700-mb flow forecast by the high-resolution models compared to the NAM and especially the GFS. A more northeast-component flow near the Front Range in the high-resolution models resulted in a better precipitation forecast for the Front Range and nearby eastern plains than in the operational models. This occurred even as the overall position of the 700-mb upper low became similar in all the forecasts, suggesting that the combination of the better resolved terrain with the higher resolution of the model may influence the flow. This may have been a factor in why the GFS tended to be too far east with the precipitation maximum even when it finally correctly forecast the position of the 700-mb low.

Lastly, with the second case we confirmed a point noted by NCEP, that if the “parent” model errs significantly, the forecast from the high-resolution models will also be bad. This point can sometimes be forgotten, as forecasters become mesmerized with some of the detail in the high-resolution model forecasts. This can be especially true when fields such as model reflectivity are displayed, with hourly forecast reflectivity fields revealing entirely realistic-looking patterns. The “forecast funnel” approach remains a useful one to employ.

A final issue involves how much NWS forecasters make use of the current high-resolution runs. During the DWFE, we made a great effort to get the high-resolution model output to forecasters via AWIPS, or through an AWIPS-like display system known as FX-Net (Madine et al. 2002). Output was also available on the web, but response to a survey conducted indicated a large preference for AWIPS or at least FX-Net (Koch et al. 2005). A recent informal survey of some WFOs suggests this is still true, with most forecasters in the offices surveyed not using the high-resolution runs at this time. Another factor in their lack of use could be that the models are only run once per day (although for some areas, such as Colorado, overlapping windows allow for two runs per day). This means that the high-resolution model forecasts often become “old”, compared to the operational runs made every 6 hours. Another factor noted by some WFOs is the use of on-site local models that are directly available on AWIPS at high-resolution, run more frequently, and able to be input into the Graphical Forecast Editor (GFE, Wier et al. 1998), the main tool for NWS forecasters to produce their forecast.

NCEP does plan to make changes in the near future to the high-resolution runs that will include new fields, such as simulated model reflectivity, which was very popular during the DWFE. In addition, the horizontal grid resolution will be increased to approximately 4 km, which will allow convective precipitation to be better resolved. The windows will be reconfigured to a larger size, with two windows covering the CONUS domain, and a greater effort made to get the forecasts into AWIPS. In addition, runs will be made twice daily for the eastern window, which covers much of the CONUS. All these efforts should improve the use of the high-resolution runs by forecasters.

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