P4.21 AN EXAMINATION OF THE OPERATIONAL PREDICTABILITY OF MESOSCALE TERRAIN-INDUCED FEATURES IN EASTERN COLORADO FROM SEVERAL MODELS

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1. INTRODUCTION

With the improvement of radar and surface observations, forecasters have become increasingly aware of the importance of mesoscale circulations, which can have a significant impact on the sensible weather. In the past such features were difficult to observe with real-time data and were seldom captured by operational numerical models. However, with increased grid resolution of operational models and the availability of locally run smaller-scale models, it is now possibile to resolve and predict features on the mesoscale. In this study we look at the predictability of two well-known mesoscale features that occur in northeastern Colorado by examining forecasts from the latest versions of the Eta and RUC models, as well as from a local model run quasi-operationally at the NOAA Forecast Systems Laboratory (FSL) for the collocated Boulder Weather Forecast Office (WFO).

The features of interest are known locally as the "Denver Cyclone" and the "Longmont Anticyclone," both of which have been well-documented at conferences and in the literature, through observational studies and numerical modeling using various research models (see, for example, Szoke et. al. 1984, Szoke 1991 and the references in that paper, and Wesley 1995). Both features are induced by the interaction of the synoptic flow with terrain. The resultant weather changes that can arise in association with these features range from dramatic variation in the wind field to mesoscale distribution of precipitation and localized occurrence of severe weather during winter and convective seasons. Clearly, there is high interest in trying to make operational forecasts of these features. Before the advent of higher resolution models, forecasters generally used synoptic flow forecasts and their understanding of the potential mesoscale features that could develop under such flow conditions to predict the occurrence of the two flow features. Numerical models provide the possibility for more accurate predictions of the occurrence of these important phenomena.

Although local-scale models have been running at FSL (and made available to the Boulder WFO) for years, there has not been a consistent verification effort aimed at these two northeast Colorado flow features. Also, a recent change of the local-scale model to a version of the MM5, with somewhat better resolution of the lower levels, has improved the overall ability to forecast the circulations. Meanwhile, the reduction of the grid resolution of the operational Eta to 22 km allows it to make better forecasts of both features. The new 20-km version of the Rapid Update Cycle (RUC-2) model (Benjamin et. al. 2000) has also demonstrated predictability of these features. Here we present a subjective examination of the three models' predictions of the Denver Cyclone and Longmont Anticyclone. Comparison is made with sensible weather using detailed observations (METAR and local mesonet), coupled with the Local Analysis and Prediction System (LAPS, McGinley et al. 1991) analysis for the verification times. In addition, we examine the model point forecasts for some of the sites where the Boulder WFO is required to make a Terminal Aviation Forecasts (TAF), as a further test of model performance and utility. We mainly concentrate here on predictions of the Denver Cyclone, and hope to show additional cases that include the Longmont Anticyclone at the poster session during the conference.

2. OVERVIEW OF THE MODELS

FSL has been testing the potential of running a local-scale model at a WFO for years (Shaw et al. 2001), using the Boulder (formerly Denver) WFO as a test site. FSL's key idea behind local modeling is to initialize the model utilizing a local analysis based on a variety of data, some of which may only be available at a WFO (as opposed to a national center). In this regard, LAPS has been used to initialize various models that have been run locally at FSL at a grid resolution of 10 km, including the Eta, SFM (Scalable Forecast Model, a version of the Colorado State University RAMS model), and MM5 (NCAR/Penn State University Mesoscale Model-Version 5). Since the mid-1990s all three of the local models were run, usually twice daily, with output to the FSL Webpage (Szoke et al. 1998). To better demonstrate the feasibility of local modeling at a WFO, over the last two years one local model (the SFM) was run within the Boulder WFO, using a separate multiprocessor computer connected inside the firewall to their Advanced Weather Interactive Processing System (AWIPS, Wakefield 1998) workstation. The project successfully demonstrated the capabilities of such an approach, using

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LAPS analyses to initialize the model for four runs per day out to 18 h.

More recently (over the last year) FSL has made a few changes to the local modeling system, including replacing the SFM with the NCAR/PSU MM5 model, employing a “hot-start” through LAPS to initialize the model (Shaw et al. 2001), and running the model over an expanded domain that is considerably larger than the WFO forecast area (still at 10-km horizontal grid resolution) of 125 by 105 points. The vertical grid consists of 41 levels, with the highest resolution contained within the boundary layer. The Schultz explicit microphysics and the Kain-Fritsch convective parameterization are employed. The rapid radiative transfer model (RRTM) scheme is used as the longwave radiation package, and the Blackadar scheme is used for the PBL parameterizations. Although the model conceivably could still run on the same machine that was used for the SFM, with the availability of the new FSL supercomputer and collocation of the Boulder WFO, the model was run by FSL using some nodes of the supercomputer with the results transmitted to the WFO for display on their AWIPS. Four runs are made each day, with output expanded to go out to 24 h. The model output is also available online through the FSL LAPS homepage at http://laps.fsl.noaa.gov.

Although they are not run at the same 10-km grid resolution, two other models are applicable for the forecast problem of mesoscale circulations and were used in this study. One is the new 20-km RUC-2 model (online documentation and access to this model is available at http://ruc.fsl.noaa.gov/). The RUC model provides high-frequency mesoscale analyses and short-range forecasts for the domain of the continental United States (CONUS). Extensive documentation of the RUC model can be found at the Web site and through Benjamin et al. (2000). The RUC is quite a different model than the MM5 or Eta, being an isentropic model with sigma levels closer to the surface (40 levels are used in the new 20-km RUC (“RUC20”)). Another aspect of the RUC model is its ability to ingest off-synoptic-time data from sources like ACARS, satellite, and surface data in its analysis scheme. Some of the model characteristics, such as radiation and microphysics schemes, are versions of those used in the MM5, but other schemes are designed especially for the RUC. For this paper we used output from the “RUC20” that was available online, concentrating on predictions of the surface wind. The RUC is updated hourly, with forecasts made hourly out to 3 h, and out to 12 h at 6-h intervals. In addition, 24-h forecasts (made twice per day) were also available online. As of this writing, the 20-km RUC is still considered experimental (with the 40-km RUC operational at the National Center for Environmental Prediction (NCEP)), but is sceduled for implementation soon.

The final model that was used for comparison is the Eta model, which for the period of comparison (beginning in the fall of 2000) was being run by NCEP at a resolution of 22 km (Black 1994). Output from this model is available out to 48 or 60 h for runs every 6 h at WFOs nationwide through AWIPS, with the best resolution output distributed for a subsection of the CONUS under the title of “Mesoeta” (Black 1994). The 22-km output is actually interpolated to a 20-km grid, with surface output transmitted for display on AWIPS at this highest resolution. An online description of the mesoeta can be found at http://nimbo.wrh.noaa.gov/wrhq/96TAs/TA9606/ta96-06.html. Note that for the MM5 and RUC-2 models, their native output of 10 km and 20 km grids (respectively) were used.

3. OVERVIEW OF THE DENVER CYCLONE AND LONGMONT ANTICYCLONE

Because of limited space here, we concentrate on the modelling of the Denver Cyclone, but hope to also show cases of the Longmont Anticyclone feature at the conference.

3.1 Denver Cyclone

The Denver Cyclone is a mesoscale flow feature that was documented when data became available from a mesonetwork of automated surface stations installed by FSL in 1980 for the purpose of testing the utility of such data. A schematic of the feature is shown in Fig. 1. Also known as the Denver Convergence-Vorticity Zone (DCVZ), because it may appear as an approximate north-south zone of low-level convergence and cyclonic vorticity rather than a full fledged circulation, it is a relatively common feature, appearing on 20 to 30% of warm season days (Szoke et al. 1984). Numerous successful modeling studies (summarized in Szoke 1991) with

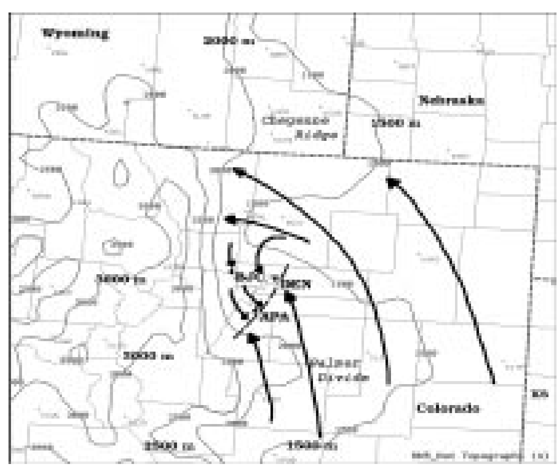

Fig. 1. Schematic of the DCVZ, along with terrain (m) and METAR sites. Background map shows county outlines.

research models have helped establish a likely cause of the feature, which is the response of southerly component flow passing over the terrain feature known as the Palmer Divide (the east-west ridge south of Denver depicted in Fig. 1) under conditions of appropriate stability. One of the reasons the DCVZ is important for local weather in the Boulder WFO forecast area is its influence on winds, which can be important enough to determine the takeoff/landing configuration at Denver's International Airport (DIA), since this site often lies close to the DCVZ and so at times can either experience 20-25 knot plus southerly flow, or north to northwest flow at around 10 knots (airport LLWAS sensors have even documented cases where a portion of a runway experienced one flow while the opposite end had the other). Also, the DCVZ is often the location of initial convection and later severe storms (particularly nonsupercell tornadoes, because of its association with regions of localized cyclonic vertical vorticity). For this paper we use the wind forecast problem associated with the Denver Cyclone as a test of the model, verifying the various models against the observed winds at the sites where the Boulder WFO has responsibity for issuing TAFs (see Fig. 1).

In addition to the various modeling studies of the DCVZ noted above, many years ago the RUC model was used in a nested grid formulation of 80 km (the operational RUC at that time) for the outer domain and 20 km for the inner domain to successfully model a single Denver Cyclone case (Benjamin et al. 1986). Because of the larger grid used for that study, it was the first modeling demonstration of a DCVZ-like feature north of two east-west terrain ridges along the Front Range that are similar to the Palmer Divide, the Raton Mesa near the Colorado-New Mexico border, and the Cheyenne Ridge near the Colorado-Wyoming border.

3.2 Longmont Anticyclone

The Longmont Anticyclone is another flow feature that results from the interaction of the lower level flow with the terrain in the area. In this case, northwesterly flow across southern Wyoming apparently interacts with some of the higher terrain of the Rockies and the Cheyenne Ridge, causing the flow to turn to north or northeast as it enters Colorado and moves southward along the Front Range (Wesley et al. 1995). In more extreme cases the flow will turn all the way to the southeast along the Front Range, with the center of the circulation sometimes located near the town of Longmont (~20 km northeast of Boulder), hence the name. The feature is sometimes associated with enhanced precipitation near the Front Range, and of course is important for determining low-level wind direction and speed.

4. A DCVZ FORECAST EXAMPLE

A Denver Cyclone case from 24 March 2001 is used to illustrate the ability of the three models considered to predict the feature. This date happened to be when FSL was running the "RUC20" out to 24 h in support of the Pacific Land-falling Jets Experiment (PACJET), so we took advantage of this opportunity to compare 24-h forecasts from the three models, all initialized on 23 March 2001 at 1800 UTC. It is useful to recall that one of the differences among the models is the initialization scheme, with the LAPS analysis used for the "MM5hot" run, with boundary conditions provided by the Eta model (in this case the 1200 UTC run). The verifying LAPS analysis for 1800 UTC on 24 March is shown in Fig. 2. Comparison of the analysis to surface observations (shown later in Table 1) reveal that the LAPS analysis does a good job of depicting the location of what is a full Denver Cyclone circulation for this case, centered about 15-20 km to the east of Denver. The different 24-h forecasts are shown in Figs 3a-c, with all the runs valid for the time of the LAPS analysis in Fig. 2.

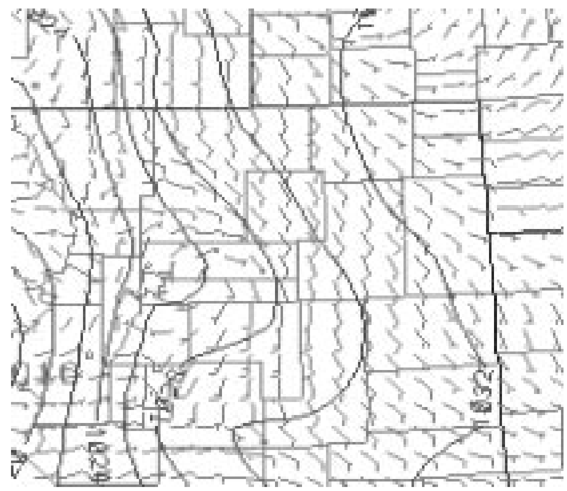

Fig. 2. LAPS analysis of surface wind (long barb = 10 kts) and MSL pressure for 1800 UTC on 24 March 2001.

As an overview, perusal of the three predictions in Fig. 3 indicates that all three models were able to forecast a Denver Cyclone. Considering that these are 24-h forecasts, this result alone is considered to be quite impressive, and nicely shows the capabilities of modeling at finer grid resolution. Although all three models generally show the Denver Cyclone in approximately the same area, there are some differences. The "MM5hot" solution shows an elongated circulation in the east-west direction rather than more circular, and appears to be centered about 30 km too far east. While there is some possibility that the actual circulation could be a little farther east than the LAPS analyses indicates (since observations become more spotty east

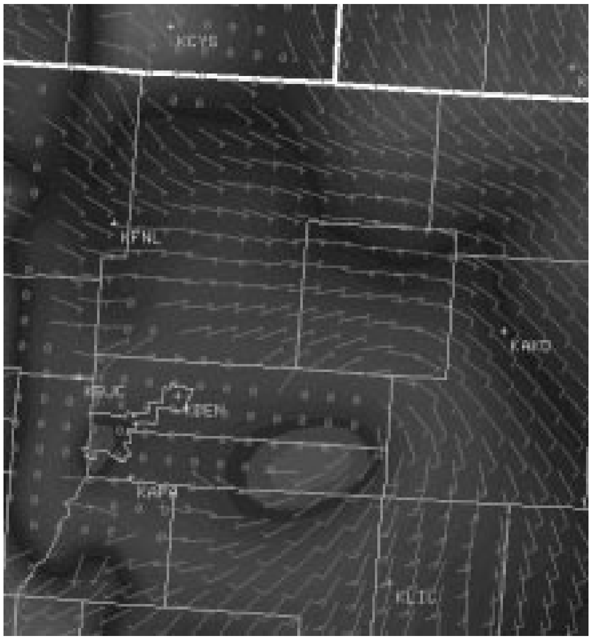

Fig. 3a. "MM5hot" 24 h forecast of surface winds (background is temperature) valid 1800 UTC 24 March.

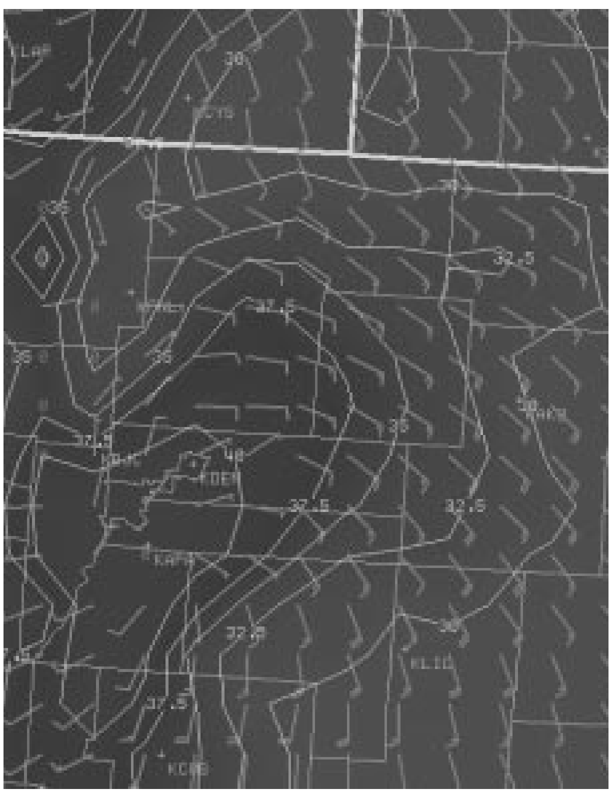

Fig. 3b. As in Fig. 3a but for the Mesoeta.

of DIA), we believe the LAPS analysis is a close representation of where the Denver Cyclone was located in this case. The Mesoeta forecast in Fig. 3b has a more circular Denver Cyclone and its position is farther west than the "MM5hot" fore-

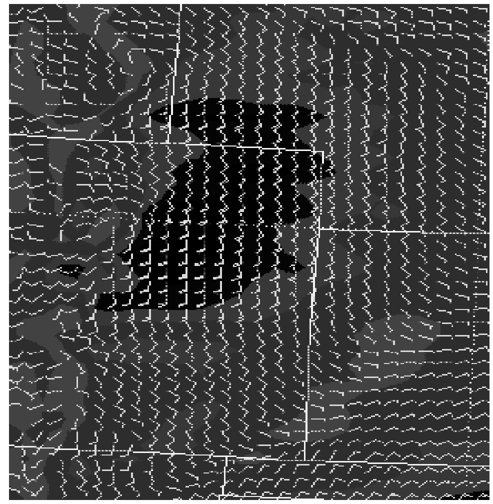

Fig. 3c. As in Fig. 3a but for the RUC-20 km run. Note that the background color in this case is wind speed.

cast, actually positioned a bit too far west and south but really quite a good forecast. The "RUC20" forecast shown in Fig. 3c is presented without the county background map shown in the other figures, as it was captured from a Web presentation at a larger scale. However, it is possible to get an indication of where its forecast of the Denver Cyclone is by comparing it to Fig. 3b (using the state boundaries), since the wind barbs in both figures are displayed at 20-km intervals and positioned in approximately the same location. Such a comparison indicates that the forecast position of the center of the Denver Cyclone from the "RUC20" is about 20 km northwest of the Mesoeta position in Fig. 3b, with a similar circular shape. Comparison of each forecast with the LAPS analysis in Fig. 2 again indicates that all are good forecasts, with the best forecast perhaps a consensus location from the three models for this time.

Examination of other times (not shown) using the LAPS analyses indicates that at 1200 UTC on 24 March the Denver Cyclone was centered more over southern portions of Denver, and then moved slowly east-northeastward through midafternoon (2100 UTC). The model forecasts varied on this evolution; the "MM5hot" came fairly close to forecasting what was observed at 1200 UTC, and moved the circulation off correctly to the east-northeast, but was somewhat premature compared to what was observed. The Mesoeta tended to anchor the circulation close to the position indicated in Fig. 3b, while the "RUC20" moved the circulation in a manner like the MM5 between 1200 and 1500 UTC, but then strengthened the circulation with some retrogression to the position in Fig. 3c, before moving it somewhat northeastward by 2100 UTC. In the experimental simulation by Crook et al. (1990) the Denver Cyclone circulation moved north-northeastward with time, but observations suggest that while this may be true in some cases (Szoke 1991), there are many variations that include a relatively stationary circulation. For this case it appears the "MM5hot" may have been closest to simulating the observed motion of the circulation. To get a better idea how the different models actually verified for point wind forecasts, we examined some forecast hours for this and other cases for the DEN METAR site, which is located at DIA, and is therefore of interest to operational forecasters who are required to issue TAFs for this and other locations. The results are shown in Table 1.

Table 1: Verification of point wind forecasts

Date (all 2001) & Time (UTC) & station	METAR Obs	Model Forecast Wind (direction and speed (kts))		
		MM5hot	RUC20	Mesoeta
DCVZ case, for models initialized at 1800 UTC 23 Mar				
24 Mar/12/DEN	10011	10005	12010	09010
24 Mar/15/DEN	08009	calm	19010	08005
24 Mar/18/DEN	05008	calm	18005	06005
DCVZ case, for models initialized at 1200 UTC 17 Apr				
17 Apr/18/DEN	14006	12005	16005	14005
17 Apr/21/DEN	14007	12010	19005	13005
18 Apr/00/DEN	18007	14010	16005	15005
DCVZ case, for models initialized at 1200 UTC 17 Apr				
17 Apr/18/BJC	27005	09005	06005	calm
17 Apr/21/BJC	03003	11005	12005	calm
18 Apr/00/BJC	34006	05005	10005	18003
LGM Anticyclone; models initialized at 1800 UTC 30 Apr				
30 Apr/21/DEN	30013	32015	31520	32005
1 May/00/DEN	09006	34010	34010	26005
30 Apr/21/BJC	30012	34005	30015	29005
1 May/00/BJC	18006	11005	30010	24005

The trends discussed for the first case (24 March) are reflected in the point wind forecasts for DEN. The second case was more of a DCVZ rather than a circulation, with the convergence zone starting out near DIA then gradually moving slightly westward with time. There are no major differences in the wind forecasts for this case for DEN listed in Table 1, though examination of the individual forecasts showed that the "MM5hot" best captured the position of the DCVZ, with the "RUC20" pushing the southeast flow too far west and the Mesoeta too weak without much turning of the wind. This is generally reflected in the verification for station BJC (Broomfield-Jeffco Airport), south of Boulder, which remained on the west side of the DCVZ. The final case shown is for a Longmont Anticyclone, which as seen by the wind observations created a turning of the flow to south/east from the prevailing northwest flow between 2100 and 0000 UTC. For this case, only the "MM5hot" captured this wind turning, perhaps because this is a rather weak case that could not be handled well at 20-km grid resolution.

5. SUMMARY AND CONCLUSIONS

In general all three models showed skill in resolving the Denver Cyclone, with an edge to the finer resolution MM5hot for the weaker cases. These limited results are encouraging, and suggest that local models can provide significant support to forecasting even at the 24-h range.

6. ACKNOWLEDGMENTS

We wish to thank Nita Fullerton and Joe Golden of FSL for reviews of this paper.

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