Weather Forecast Model Grid Spacing – Is Smaller Better

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ABSTRACT: The Colorado Avalanche Information Center (CAIC) implemented an in-house numerical weather prediction model in 2011. Computer-generated forecast products designed specifically for the Colorado snow safety community are updated four times per day. These products have proven valuable to operational forecasters and backcountry users. CAIC is considering a computer hardware upgrade allowing increased model resolution, which provides better representation of mountainous terrain and potentially improved computer-generated forecasts This paper investigates whether smaller grid spacing is better for the Colorado application. Case study results indicate a small overall improvement in snowfall and wind forecasts. More significant improvements are noted in small areas where higher-resolution model terrain likely had a greater influence.

KEYWORDS: Numerical weather prediction, operational forecasting.

1. INTRODUCTION

The U.S. National Weather Service provides a wide range of weather forecast products. Many of these products are derived from Numerical Weather Prediction (NWP) computer models such as the North America Model (NAM) and Global Forecast System (GFS). Operational weather and avalanche forecasters depend on these models to generate local weather predictions. The NWS models, however, do not typically provide enough detail in mountainous terrain to describe small spatial-scale variability in weather phenomena. Examples are large changes in snowfall accumulations across short distances and highly-variable winds over complex terrain. The operational forecaster must use experience and other resources to tailor weather forecasts for the local environment.

Low cost compute power has made it possible for local centers to run their own computer forecast models. The models are configured to meet the specific needs of the local forecast office; hence, providing an additional resource to add value to NWS predictions. The Colorado Avalanche Information Center (CAIC) implemented an in-house numerical weather prediction model in 2011 (Snook, et. al, 2005). Computer generated forecast products designed specifically for the Colorado snow safety community are updated four times per day. These products have proven valuable to operational forecasters and backcountry users.

The computer model, called the Weather Research and Forecast Model (WRF) (Skamarock and Klemp, 2007), is configured with a 4-km grid spacing, which at the time was three times smaller than the highest resolution NWS forecast model. Smaller model grid spacing provides better representation of mountainous terrain and captures smaller-scale weather features, which should provide improved computer-generated forecasts (eg. Colle, et al., 2005).

Compute power generally doubles every 1.5 years. Benchmark results using 2016 hardware indicate that even smaller model grid spacing is possible at a reasonable cost. This paper investigates whether 2-km grid spacing improves predictions for the Colorado application. Several case studies were selected from the 2015-2016 winter season during which significant weather occurred including heavy snowfall and high winds. The WRF model, configured with a 2-km grid, was rerun for each case study period. The operational 4-km and the experimental 2-km computer-generated forecasts are then compared to observations.

2. WRF MODEL CONFIGURATION

The CAIC operational WRF domain configuration uses a nested grid approach (Fig. 1) where the outer domain covers the Western U.S. with a 12-km spaced grid and the inner domain covers the mountainous areas of Colorado and eastern Utah with a 4-km spaced grid. The operational model runs four times per day with forecasts provided to

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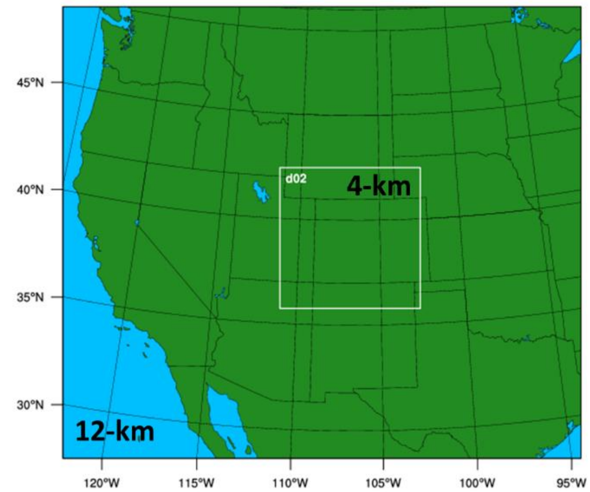


Fig. 1: Operational WRF model domain configuration.

84 hours. The case study domain configuration uses the same areal extents with half the grid spacing, i.e. 6-km and 2-km. Hence, each grid cell in the case study domain covers 25% of the area when compared to the 4km operational domain. Figure 2 illustrates the improved model representation of terrain.

3. CASE STUDY ANALYSIS AND RESULTS

Four case study periods during winter 2016 were selected based on interesting weather conditions. Model simulations to 84-hour forecast were completed for the following initial times: 1) Jan. 23-25 – localized heavy snow, 2) Jan. 29-Feb. 3 – heavy snow, 3) Feb. 16-17 - high wind, and 4) Mar. 13-15 – widespread heavy snow. Two WRF model simulations were completed for each case study day initialized at 0000 and 1200 UTC. A total of 26 runs were completed for each domain configuration. The latest available WRF model version 3.8 was utilized, which is an update since the 2015-16 winter season. Therefore, 4-km domain simulations were completed to provide a fair comparison.

Table 1 shows 24-hour height of snow (HN24) ski area observations during the heavy snow case study periods. Data were collected from Colorado Ski Country USA reports except for Telluride and Vail, which were obtained from ski patrol.

Case studies 4), 1) and 2) are presented with more detail followed by summary statistics for all completed case studies simulations.

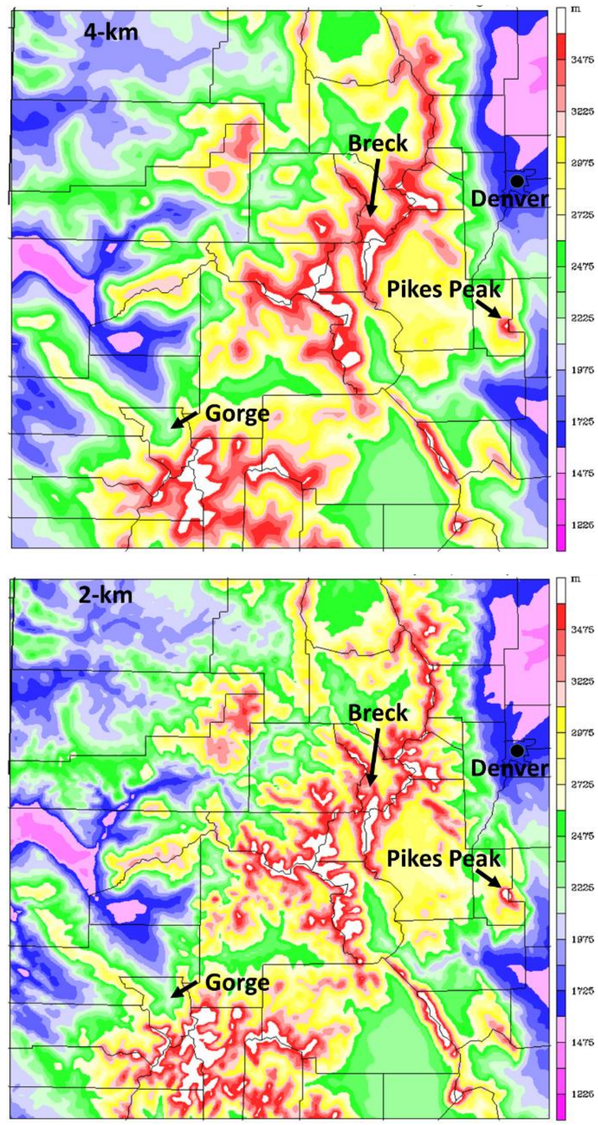


Fig. 2: Model topography (m) for the 4-km and 2-km domains.

Tbl 1: Ski area reports of 24-hour height of snow (HN24) ending at 0500 local time.

HN24 (in)	1/25	1/31	2/1	2/2	2/3	2/4	2/5	3/15	3/16	3/17	3/18
A-Basin	2	8	4	2	0	1	1	10	4	3	5
A-Highlands	6	12	11	10	1	0	1	10	6	0	
Crested Butte	2	10	12	7	0	0	0	7	4	0	0
Copper	5	9	5	3	2	1	1	7	5	5	6
Eldora	3	4	3	10	1	0	0	8	7	12	12
Loveland	3	10	6.5	3.5	1	1	1.5	11	6	8	6
Monarch	4	13	7	10	2	2	1	5	6	0	0
Steamboat	7	10	3	7	7.5	1	4	5	4	5	12
Sunlight	5	9	6	5	1	1	2	9	5	0	0
Telluride SP	11	3.6	15	3.4	0.7	0.2	0.6	2.1	0.8	0	0
Vail SP	4.2	12	3	14	2.3	1.2	2.2	9.2	3.7	0	0
Wolf Creek	7				0	0	0	0	0	0	
Winter Park	2	8.5	2.5	1	1.5	0	1	14	10	6	13

3.1 Mar. 13 – 15 (widespread heavy snow)

An extended period of heavy snow occurred during a 4-day period starting on March 14. Heaviest snow fell across the Northern and Central Colorado Mountains. Four-day storm total accumulations included 109 cm (43 in) at Winter Park, 94 cm (37 in) at Eldora, and 79 cm (31 in) at Loveland. Figure 3 shows a comparison of WRF 84-hour forecast snow accumulation ending at 1200 UTC (0600 local time) on March 18.

Areal snowfall coverage is similar with several areas of maximum snowfall forecast at 60-75 cm (25-30 in) along the Continental Divide. While the 2-km grid model simulation generated somewhat higher snowfall amounts, neither simulation produced the greater than 75 cm (30 in) reported at several locations. The WRF model does not generate snowfall amounts directly, but rather produces liquid water equivalent (SWE). An ad-hoc procedure assumes a 15:1 snow to water ratio when forecast temperatures are lower than 5C and then ramps down to 10:1 ratio at freezing. Some of the difference in forecast vs actual snowfall may be due to differences in actual snow to water ratios. It would be better to verify the model with SWE, but available SWE reports are scarce.

3.2 Jan. 24 through 25 (Gorge storm)

The Uncompahgre Gorge is a narrow north-south oriented canyon feature located south of Ouray, Colorado. Although not high in elevation compared to surrounding terrain, the Gorge can receive significant snowfall in a short time period. The difficult forecast problem typically occurs after a cyclonic storm system moves east of the area resulting in northerly flow moving up the canyon. If wrap-around moisture is available, then the Gorge often receives much greater snowfall than higher surrounding terrain.

This situation occurred around on January 25 with storm total (HST) of 48.3 cm (19 in) recorded at Monument near the top of the Gorge while 33 cm (13 in) was reported at Red Mountain Pass (RMP) to the south.

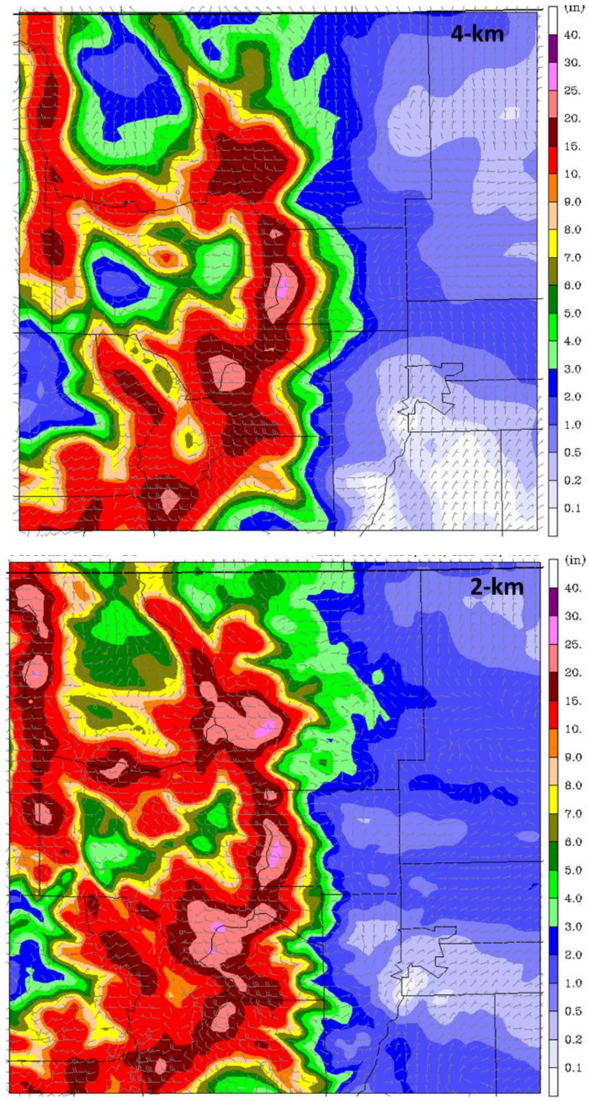


Fig. 3: 84-h WRF HST (in) forecast valid at 1200 UTC, 18 March 2016.

Figure 4 shows a comparison of the WRF model simulations initialized at 0000 UTC (1700 local time) Jan. 23, about 36 hours ahead of storm onset. The 4-km simulation predicted uniform HST across the area north of RMP while the 2-km simulation successfully generated larger HST in the vicinity of the Gorge. The results suggest that the 2-km grid configuration can provide greater skill in micro-scale situations where small-scale topography changes are significant.

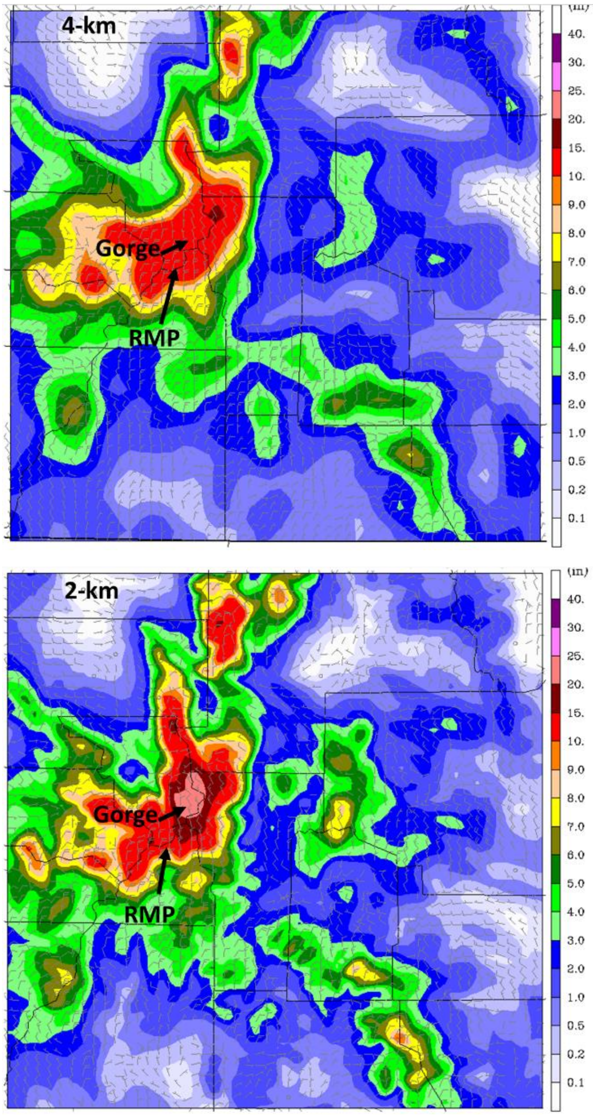


Fig. 4: 51-h WRF HST (inches) forecast valid at 0300 UTC, 26 Jan 2016.

3.3 *Feb. 16 through 17 (high wind)*

An approaching trough of low pressure west of Colorado generated very strong south to southwest winds on Feb. 18. Recorded wind gusts exceeded 150 km/h at several locations including: Eagle (south of Red Mt Pass) 192 km/h, Telluride (Dynamo) 161 km/h, Snowmass (Baldy) 156 km/h, and Breckenridge (Peak 6) 156 km/h. The strong winds brought the first significant dust event of the season to the San Juan Mountains in southwest Colorado.

Figure 5 shows a comparison of WRF forecast winds initialized at 0000 UTC Feb. 16 (1800 local time) about 3 days ahead of the strongest recorded winds. The 2-km wind gusts are generally stronger and closer to observations. The 2-km run predicted a peak gust of 163 km/h (101 mph) while the 4-km predicted 135 km/h (84 mph). 2-km wind vectors during the peak gust period remained more westerly in direction (closer to observed), which likely resulted in a prediction closer to observed than the 4-km results.

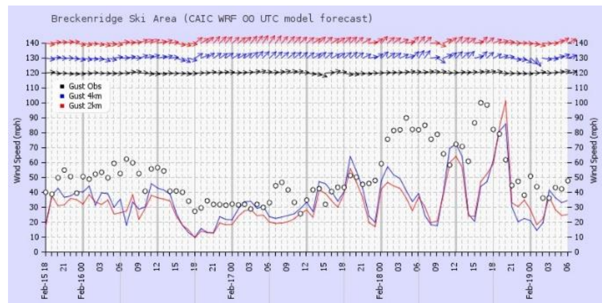
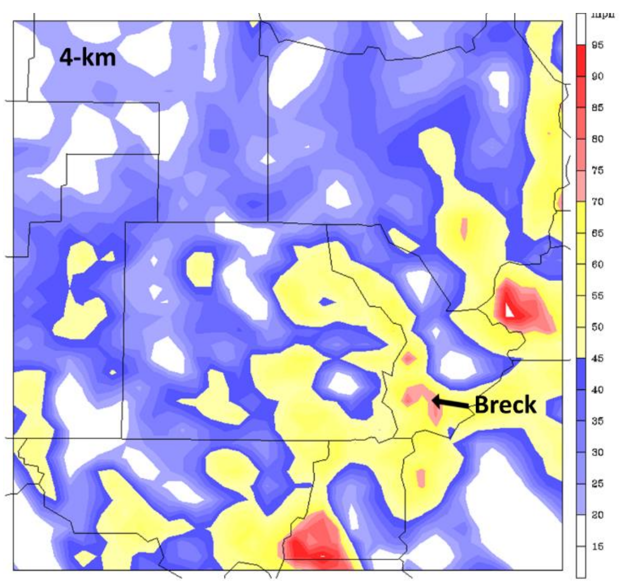


Fig. 5: Wind observations from Breckenridge Ski Area – Peak 6 (black) compared to 4-km (blue) and 2-km (red) WRF forecasts. Vectors are wind direction. Wind gusts speeds (mph) are plotted. Times are local (UTC-7).

Figure 6 shows a comparison of the 74-hour WRF wind gust forecast. Note that the 2-km simulation generated several small areas exceeding 153 km/h (95 mph) while greatest 4-km wind gust speeds are about 30-40 km/h less.



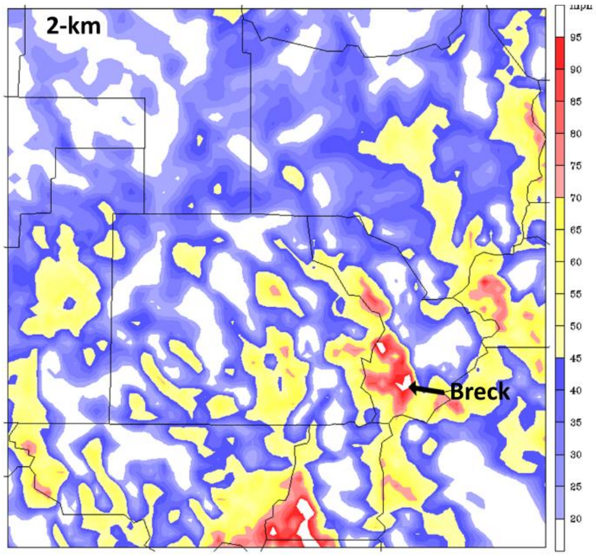


Fig. 6: 74-h WRF wind gust forecast (mph) valid at 0200 UTC, 19 Feb 2016.

3.4 <u>Case studies HN24 summary</u>

A comparison of WRF forecast HN24 to observations (Tbl. 1) was completed for all simulations with forecast data available on the 11 days of significant recorded snowfall. Table 2 shows bias and mean absolute error (MAE) results at forecast lengths ranging from 24 to 84 hours. In nearly all cases, HN24 was under-forecast, although less so for the 2-km simulations. MAE results are close, but generally the 2-km simulations show a small improvement.

Table 3 shows the same comparison but only for HN24 observations >= 10.2 cm. Bias results indicate a somewhat greater under-forecast of HN24 ranging from 2-10 cm and MAE values in the 7-13 cm range. Results are quite close for the shorter time range forecasts, but 2-km starts to show greater skill at forecast times beyond 60 hours.

4. CONCLUSIONS

The CAIC is considering upgrading computer hardware for the upcoming winter season, which would allow an increase from 4- to-2 km grid spacing for the CAIC operational NWP weather model predictions. Four case study periods with heavy snow and high wind were evaluated with 26 WRF model simulations using grid spacing of 4- and 2-km.

Results indicate that the 2-km simulations show a small improvement in overall forecast quality. In specific areas where model terrain representation is important, more significant improvements are noted. All the chosen case studies contained significant weather events. Follow-on case study experiments are proposed with smaller snowfall intensity events such as prolonged weak orographically-induced snow events. It is hypothesized that the 2-km grid configuration will show greater skill during these weakly-forced events.

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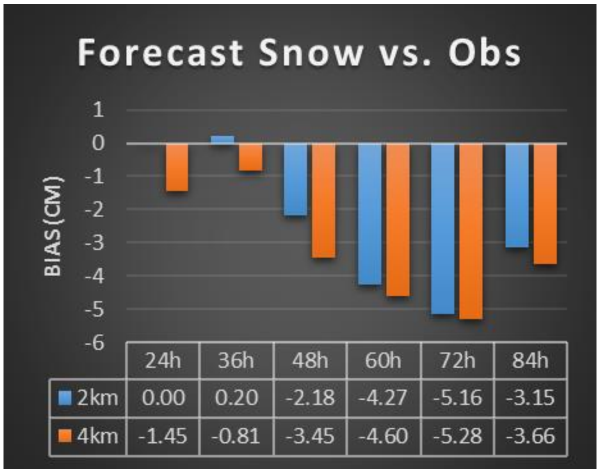
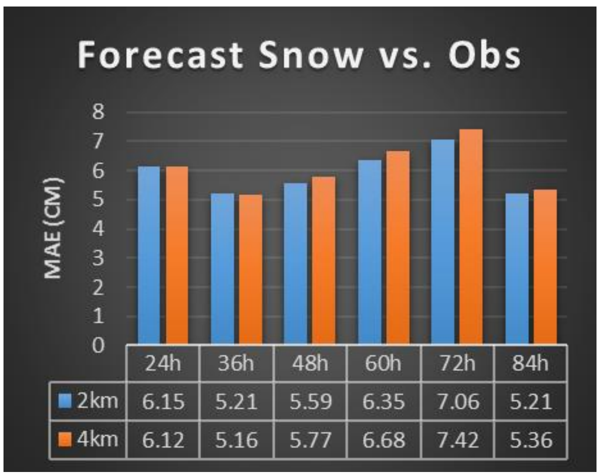
Tbl 2: WRF forecast comparison to HN24 observations for 11 days shown in Table 1.





Tbl 3: WRF forecast comparison to HN24 observations >= 10.2 cm (4 in).