CASE STUDY OF THE 12-13 NOVEMBER WINDSTORM IN SOUTH CENTRAL COLORADO

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1. INTRODUCTION

During the evening and early morning of 12-13 November 2011, a damaging downslope windstorm struck the eastern slopes of the mountains of south central Colorado. Windstorms in the lee of high mountain barriers of south central Colorado are not uncommon, and a couple local studies on windstorms have been done previously (Wolyn, 2000 and Wolyn, 2002). The 12-13 November 2011windstorm is a unique high wind event in that damaging winds occurred in locations which do not typically observe high winds. Damaging wind gusts were reported intermittently over a distance of around 250 km along the lee slopes of various mountain ranges in south central Colorado, and wind speeds in excess of 45 m/s (~100 mph) were observed.

This extended abstract will first discuss the observed wind speed and damage associated with this windstorm. Next, the synoptic pattern which produced the windstorm will be shown. Finally, output from the WRF model run locally at WFO Pueblo will be presented, demonstrating the usefulness of a locally run nonhydrostatic model for forecasting windstorms.

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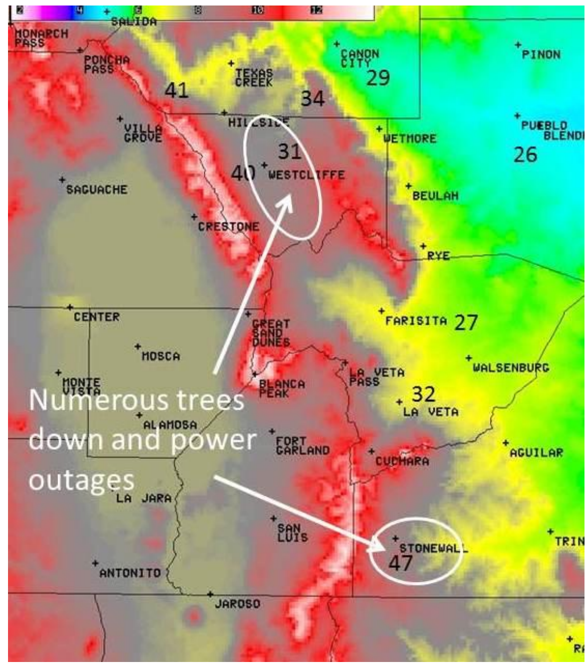

Figure 1. Topographic map of south central Colorado showing observed wind speed (m/s). The elevation is in thousands of feet. 1000 feet = 304.8m.

2. DESCRIPTION OF EVENT

Figure 1 shows a topographic map of south central Colorado with approximate locations of reported wind gusts (m/s). (The population and wind equipment are sparse in this region and this map should not be interpreted as a detailed plot of wind speeds.) The two ovals show areas where widespread damage occurred, and these regions typically do not experience damaging winds.

The southern oval is located in the vicinity of Stonewall, Colorado. Stonewall is at an elevation of around 2.4km (~7900 feet) and the crest of the Sangre de Cristo Mountains is over 3.8km (~12500 feet) roughly 13 km (8 miles) west of Stonewall. There was widespread tree and roof damage in the Stonewall area (as demonstrated by an example Figure 2). A mesonet site approximately 9 km

Figure 2. Example of widespread tree and property damage near Stonewall, Colorado.

south-southeast of Stonewall reported a peak wind gust of 47 m/s (105 mph). The Stonewall region appears not to be susceptible to damaging winds. The residents commented this was the worst windstorm they ever experienced, and the National Weather Service Forecast Office (WFO) in Pueblo has not received similar high wind reports from this region since the office became a WFO in 1995.

The second area of widespread wind damage was near Westcliffe, Colorado. Strong winds are fairly common west of Westcliffe in the immediate lee of the Sangre de Cristo Mountains (Wolyn 2002); however, damaging winds in the town of Westcliffe and locations farther to the east are uncommon. Westcliffe is at an elevation around 2.4km (~7900 feet). The Sangre de Cristo Mountains rise to over 3.8km (~12500 feet) around 18 km (11 miles) to the west. Numerous trees and power lines were knocked over in the vicinity of Westcliffe. A roof was blown off of a barn and trailers were toppled. One mesonet site just east of Westcliffe reported a wind gust of 31 m/s (71 mph), and sites to the northwest of Westcliffe reported wind gusts in excess of 40 m/s (90 mph).

The two areas highlighted by the ovals in figure 1 will be examined in more detail when the local WRF simulations are discussed. The WRF simulations will show the atmospheric structure associated with the windstorm and demonstrate the utility of a local model in forecasting downslope windstorms.

3. SYNOPTIC SITUATION

Figures 3 a-e show the height, wind, and temperature from 300 hPa to 700 hPa at 1800 UTC 12 November 2011, which is about 10 hours before the windstorm started. These plots were created using the initial fields of the RUC simulations mapped to an 80 km grid. Figure 3f shows observed sea level pressure and surface winds. The 300 hPa chart (Figure 3a) shows a split flow. In the northern stream, a trough is moving across the northern Rockies, and in the southern stream a deep trough is located off the southern California coast. A region of light winds extends northeast from the center of the low off the California coast to the trough axis across Idaho. The subtropical jet is across the southern Rockies, centered across southern Arizona and southern New Mexico.

The trough across the northern Rockies has a slight eastward tilt with height. At 300 and 400 hPa (figures 3 a-b), the colder air is slightly ahead of the trough axis, while 500 hPa and 600 hPa (Figures 3c-d) the cold air is coincident with the trough axis. At 700 hPa (Figure 3e), the cold air is slightly west of the trough axis. At the surface (Figure 3f), a lee trough is present with gusty west winds over much of the region east of the mountains.

Figures 4a-f show the synoptic pattern at 0800 UTC 13 November 2011, which is during the windstorm. At 300 hPa (Figure 4a) south central Colorado is between the northern branch and southern branch of the flow. The trough, which was over the northern Rockies earlier at 1800 UTC 12 November (Figure 3a),

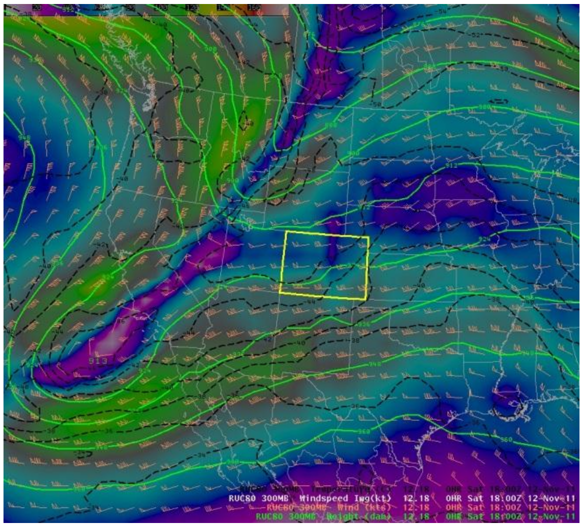

Figure 3a. 300 hPa

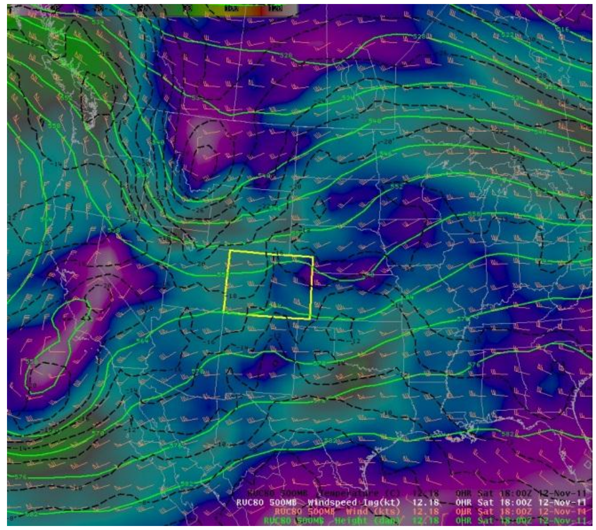

Figure 3c. 500 hPa

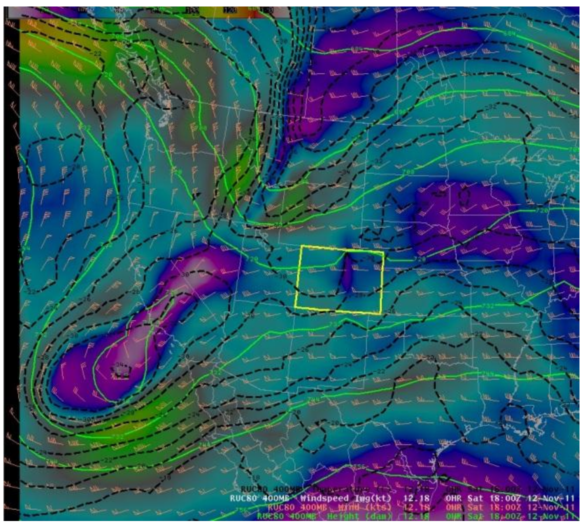

Figure 3b. 400 hPa

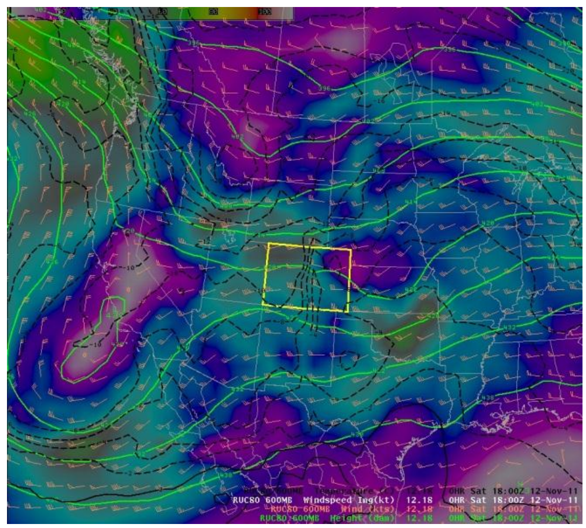

Figure 3d. 600 hPa

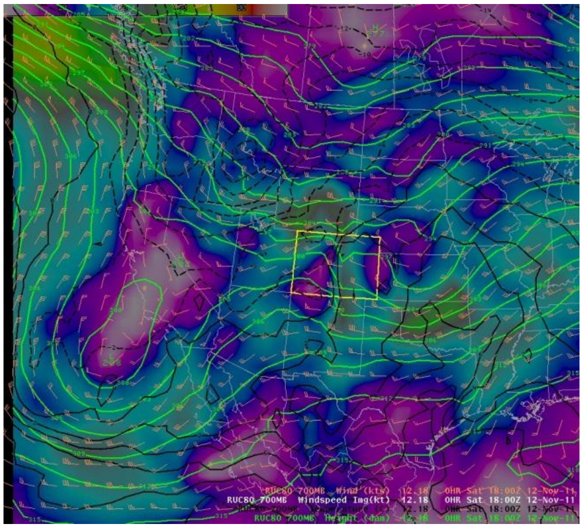

Figure 3e. 700 hPa

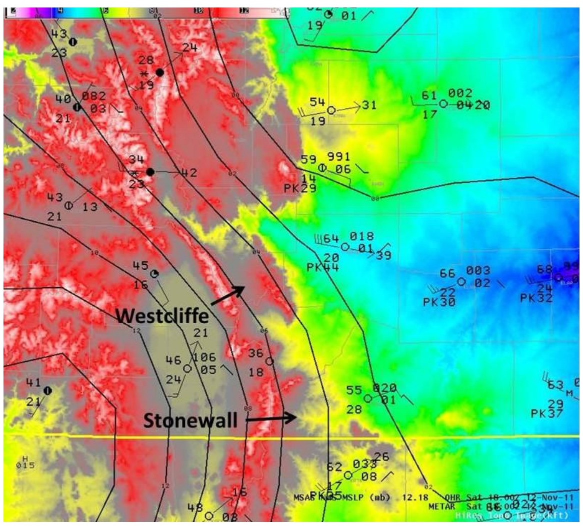

Figure 3f. Sea level pressure and observations.

Figures 3a-f.: Plots at 1800 UTC 12 November 2012

3a-e: Plots of height in dm (green lines), temperature in ºC (black lines), winds in knots (orange barbs) and wind speeds in knots (image). Winds are plotted in knots with a half feather = 5 knots, full feather = 10 knots and flag = 50 knots. 1 knot = 0.51 m/s. Data are from the RUC initial conditions. Colorado is highlighted in yellow.

3f: Plot of observed mean sea level pressure, surface observations, and topography map for south central Colorado and parts of the surrounding states. Sea level pressure is in mb, 1mb = 1 hPa. Winds are plotted in knots with a half feather = 5 knots, full feather = 10 knots and flag = 50 knots. Wind gusts are also knots. 1 knot = 0.51 m/s. Temperature and dewpoint are in ºF. Topography map is in thousands of feet. 1000 feet = 304.8 m.

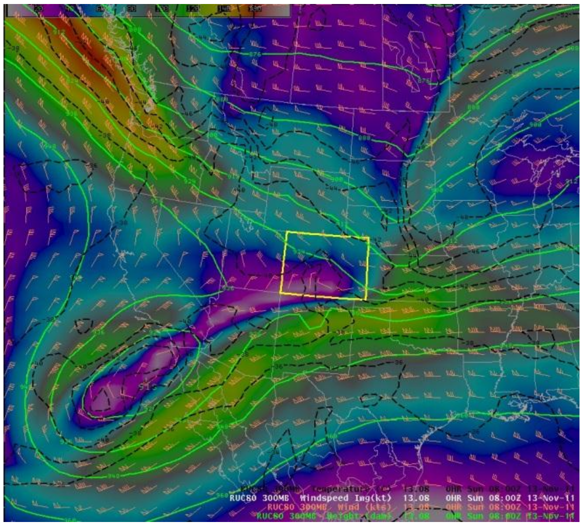

Figure 4a. 300 hPa

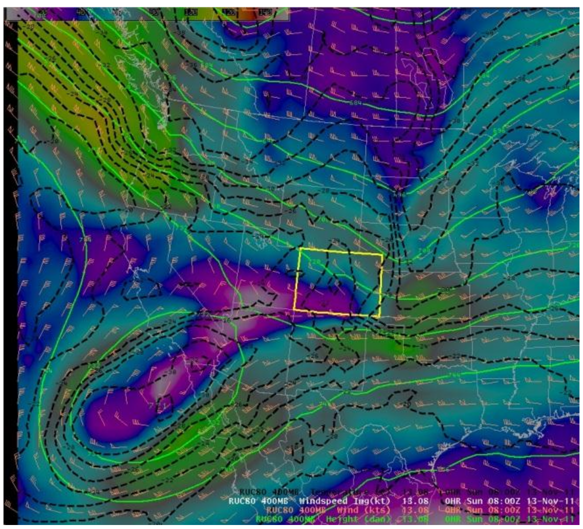

Figure 4b. 400 hPa

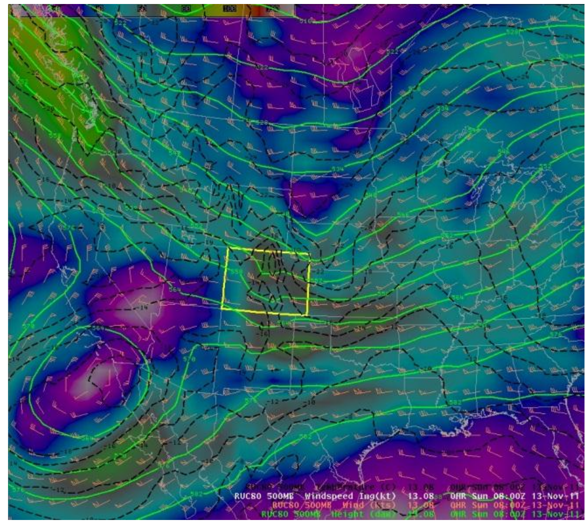

Figure 4c. 500 hPa

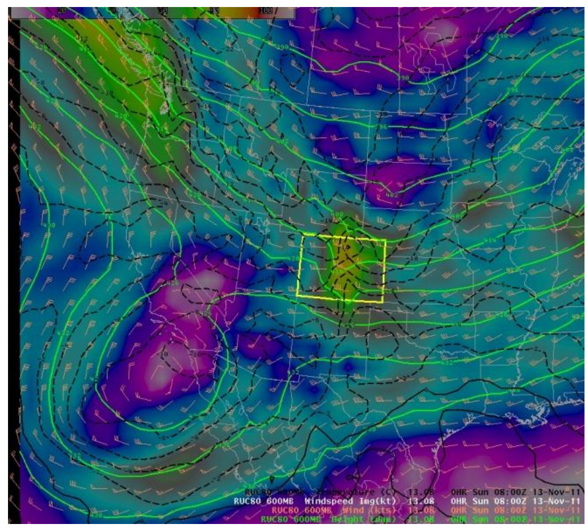

Figure 4d. 600 hPa

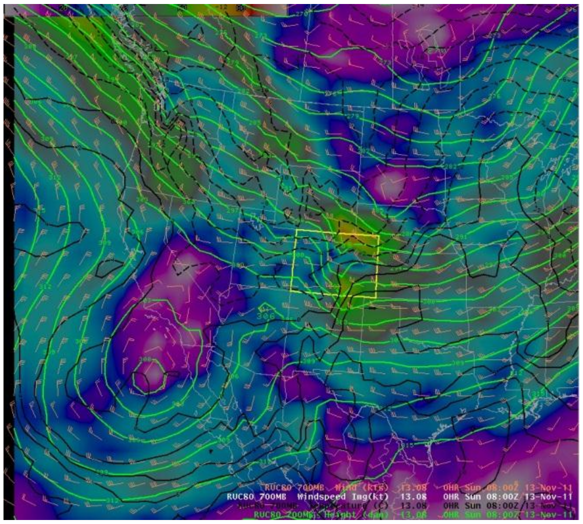

Figure 4e. 700 hPa

Figures 4a-f.: Plots at 0800 UTC 13 November 2012

4a-e: Plots of height in dm (green lines), temperature in ºC (black lines), winds in knots (orange barbs) and wind speeds in knots (image). Winds are plotted in knots with a half feather = 5 knots, full feather = 10 knots and flag = 50 knots. 1 knot = 0.51 m/s. Data are from the RUC initial conditions. Colorado is highlighted in yellow.

4f: Plot of observed mean sea level pressure, surface observations, and topography map for south central Colorado and parts of the surrounding states. The dashed white line shows the approximate location of a cold front. Sea level pressure is in mb, 1mb = 1 hPa. Winds are plotted in knots with a half feather = 5 knots, full feather = 10 knots and flag = 50 knots. Wind gusts are also knots. 1 knot = 0.51 m/s. Temperature and dewpoint are in ºF. Topography map is in thousands of feet. 1000 feet = 304.8 m.

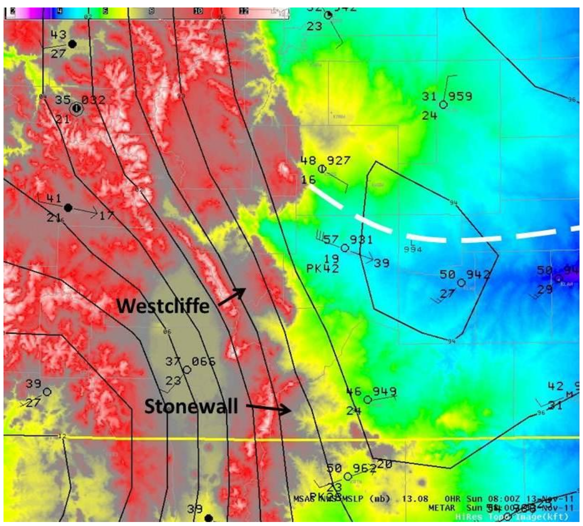

Figure 4f. Mean sea level pressure and observations.

has moved to the east of Colorado. Behind the trough, the winds become lighter and from a more northwesterly direction. A col extends from the center of the cutoff low off the California coast to central Colorado. There is a sharp decrease in speed on the northern edge of the subtropical jet, which is just south of Colorado.

This trough across the northern high plains has a clear eastward tilt with height from 500 hPa to 300 hPa (Figures 4 a-c) with a pool of cold air ahead of the trough axis. Between 300 hPa and 500 hPa, winds veer to a more northwesterly direction as the trough passes, and the veering of the wind becomes more pronounced with height. The vertical structure of the trough from about 500 hPa to 300 hPa is similar to a “warm front aloft”. As the trough passes, there is pronounced warming and the winds become lighter from the northwest.

At 600 hPa and 700 hPa (Figures 4 d-e), the cold air is closer to the trough axis, and a south to north thermal gradient is evident across Colorado. The winds at 600 hPa are the strongest over Colorado and are associated with the pronounced south to north thermal gradient across Colorado. At the surface (Figure 4f) a west to east front is over eastern Colorado and the general location is given by the dashed line. To the north of the front, the winds are generally light and from the east to southeast.

Reverse wind shear above mountain top can help induce downslope windstorms in the lee of mountain barriers. Even when the cross barrier flow does not become zero, a mountain wave induced critical layer above the mountain can develop. During the 12-13 November 2012 windstorm, the atmosphere over south central Colorado has substantial reverse shear from around 600 hPa to 300 hPa. Cross barrier flow (west to east) at 300 hPa was around 5 to 10 m/s (10-20 knots). The cross barrier flow increased to around 33 m/s (65 knots) by 600 hPa. (Cross sections from a high resolution WRF simulation will be presented in the next section and they show a mountain wave induced critical layer).

An increase in mountain top stability is another factor enhancing the chances for a downslope windstorm. The northern branch trough tilted eastward with height and the cold air was ahead of the trough. The passage of this trough would result in a layer of warming which would descend from 300 hPa to near 500 hPa. This layer of warming would tend to increase the stability above the mountain top.

The synoptic situation very uncommon for windstorms in the lee of the Rockies. A unique feature of the synoptic situation is the presence of the col near the location of the windstorm. The col between the subtropical jet and the northwesterly flow in the northern branch resulted in light winds around 300 hPa with stronger cross barrier flow below. The author could not find any documentation of a similar synoptic pattern resulting in a damaging windstorm along the eastern slopes of the Colorado Rockies or other major mountain ranges. It is the author’s experience that windstorms in the lee of the southern Colorado Rockies are typically not associated with such strong reverse shear. Typically, the shear above mountain top is near neutral or there is weak reverse shear.

Windstorms with strong reverse shear typically occur on the west side of mountain barriers. Low level cold air flows towards the west over a barrier and westerly flow occurs above the layer of cold air. A mean state critical layer occurs where the ambient cross barrier flow is zero. Windstorms with this pattern have been documented in several areas, such as Colle and Mass, 1998 in the Cascades .

4. LOCAL WRF SIMULATIONS

At WFO Pueblo, a nonhydrostatic version of the WRF model is run locally twice daily out to 36 hours. The NAM218 grids are used for initial conditions and for lateral boundary conditions every 3 hours. Bob Rozmulaski wrote a software package which allows WFO’s to fairly easily download initial data, run the WRF, and post process the model output.   The output is displayed on AWIPS so forecasters can utilize the model in operations.

The local model at WFO Pueblo has three nested grids. The outer grid has a grid spacing of 36km, and it covers much of the CONUS and extends well into the Pacific Ocean. The second grid has a grid spacing of 12km and is centered over Colorado. The inner most grid has a grid spacing of 4km, and it covers the forecast area of WFO Pueblo and some surround areas (see Figure 5). The grid spacing of 4km was chosen because it is grid spacing which can reasonably simulate mountain waves.

Output from the model is sent directly from the computer running the simulation to AWIPS with a vertical resolution of every 25 hPa. Other high resolution models, such as the HRRR and NSSL WRF, are run outside of WFO Pueblo. However, only limited output from these high resolution models is available in AWIPS because of bandwidth restrictions. A large amount of bandwidth is needed to obtain these data in sufficient vertical resolution for mountain wave analysis in AWIPS. Available fields from these models are limited to surface data and possibly a few mandatory levels.

Local WRF cross sections on the inner most grid, initialized from the 0000 UTC 13 November 2011 NAM, will first be examined to determine if the local WRF model could accurately simulate the downslope windstorm and to provide the best estimate of the vertical atmospheric structure associated with the windstorm. The initial time of this model run is about 4 hours before the windstorm began. Figure 5 shows the model terrain and 600 hPa winds for the entire innermost domain (with a 4km grid spacing) at 0800 UTC 13 November. The southernmost black line shows the orientation of the cross section through Stonewall and the middle solid black line shows the orientation of the cross section through Westcliffe. (The northernmost line is the location of the cross section through another location with damaging winds, which will not be

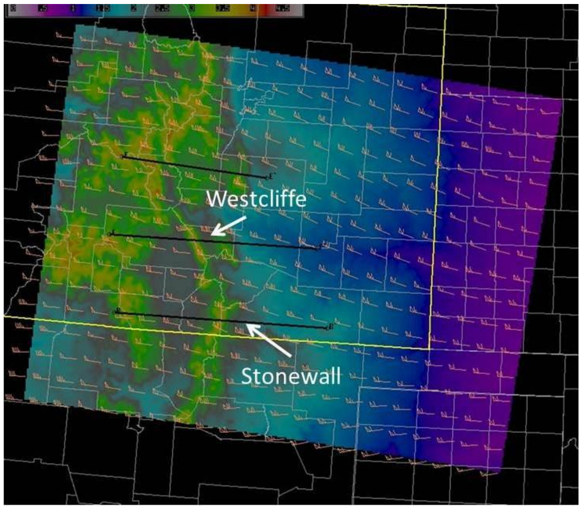

Figure 5. Plot showing the innermost domain (4km grid spacing) of the WRF run locally at WFO Pueblo. Image is elevation in thousands of feet. 1000 feet = 304.8 m. Barbs show 600 hPa winds at 0800 UTC 13 November from 0000 UTC 13 November model run. Winds are in knots. Half feather = 5 knots, full feather = 10 knots and flag = 50 knots. 1 knot = 0.51 m/s. Solid black lines show cross section orientations.

discussed in this paper. The model also successfully simulated a downslope windstorm at this location).

Figure 6 shows a cross section through the Stonewall region at 0800 UTC 13 November. The cross section shows a classic downslope windstorm signature. A local critical layer is evident just to the lee of the mountain between 400 and 500 hPa (labeled 400 to 500mb in the plot). In the lee of the mountain, the model simulated winds in excess of 51 m/s (100 knots), just above the surface, near the location of Stonewall. Upstream of the barrier, the strong reverse shear is clearly evident. Winds at 550 hPa (550 mb) are 33 m/s (65 knots) and the winds decrease to 10 m/s (20 knots) of cross barrier flow by 350 hPa (350 mb). The isentropes show a modestly more stable layer near and below the mountain top level of around 600 hPa.

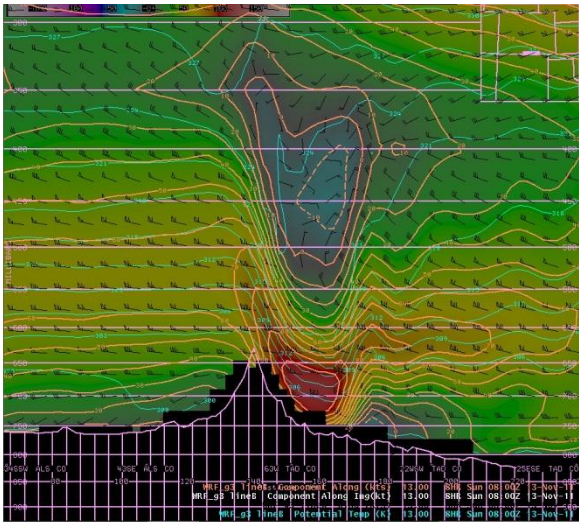

Figure 6. Cross section on innermost grid of local WRF model through Stonewall (most southern black line in figure 5) at 0800 UTC 13 November from 0000 UTC 13 November. Green lines are isentropes (K). Orange lines are winds along the cross section (knots). Black wind barbs are in knots. Half feather = 5 knots, full feather = 10 knots, and half = 50 knots. 1 knot = 0.51 m/s. Vertical axis are in mb. 10 mb = 10hPa.

Figure 7 shows a similar cross section passing through Westcliffe, Colorado. The substantial reverse shear is evident upstream of the barrier. A local critical layer, with cross barrier flow of less than 5 m/s (10 knots), is present at around 500 hPa (500 mb) in the lee of the barrier. The model simulated wind speeds near 51 m/s (100 knots) in the lee of the mountains, just above the surface. This cross section also shows the region of strong winds in the lee of the Wet Mountains, which is the smaller mountain barrier to the east. Some sites in the Wet Mountains and just to the east of the Wet Mountains reported wind gusts in excess of 31 m/s (70 mph).

The 4km grid spacing is sufficiently small to simulate downslope windstorms for operational concerns. How well did previous model runs identify the potential for these damaging winds? Figures 8a and b show cross sections for Stonewall and Westcliffe from the locally run WRF initialized from 1200 UTC 12 November NAM. The cross sections indicated that a windstorm was likely at some locations along both cross sections. The simulated windstorm for Stonewall cross section (Figure 8a) was slightly weaker than the 0000 UTC 13 November simulation (figure 6) with the maximum wind speed about 5 m/s (10 knots) weaker. The 1200 UTC 12 November simulation had the northern edge of the subtropical jet slight farther north than what occurred. This weakened the magnitude of the reverse shear which could influence the structure of the mountain wave.

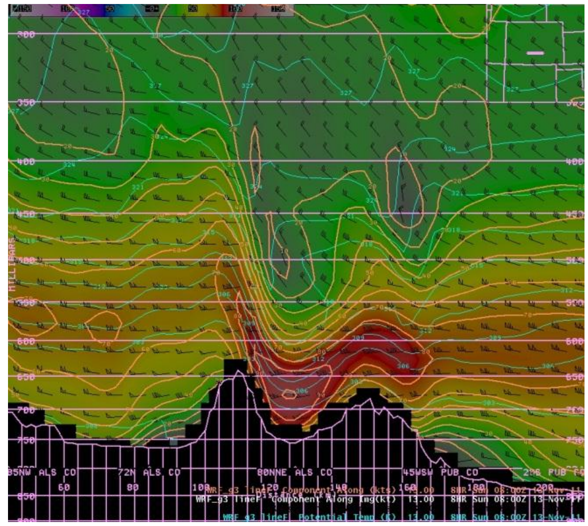

Figure 7. Same as Figure 6 but for cross section through Westcliffe in Figure 5.

Along the Westcliffe cross section, the magnitude of the winds was about 5 m/s (10 knots) weaker in the 1200 UTC 12 November simulation (Figure 8b) than the 0000 UTC 13 November simulation (Figure 7). The location of the wind maximum was farther west in the 1200 UTC 12 November simulation. The magnitude of the reverse shear upstream of the barrier is less than in the 0000 UTC 13 November simulation which could affect the mountain wave dynamics.

In the local WRF runs from the 0000 UTC 12 November NAM runs (Figures 9a and b), the maximum wind speeds are stronger than the 1200 UTC 12 November runs and they

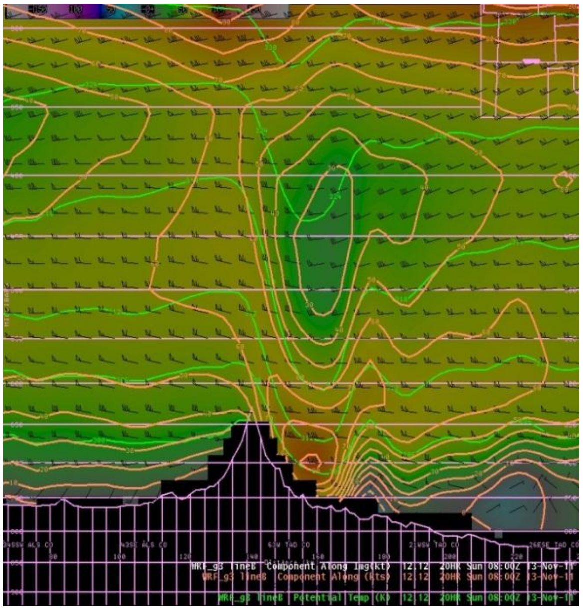

Figure 8a. Same as figure 6 but for 1200 UTC 12 November model run. Time of cross section is the same at 0800 UTC 13 November.

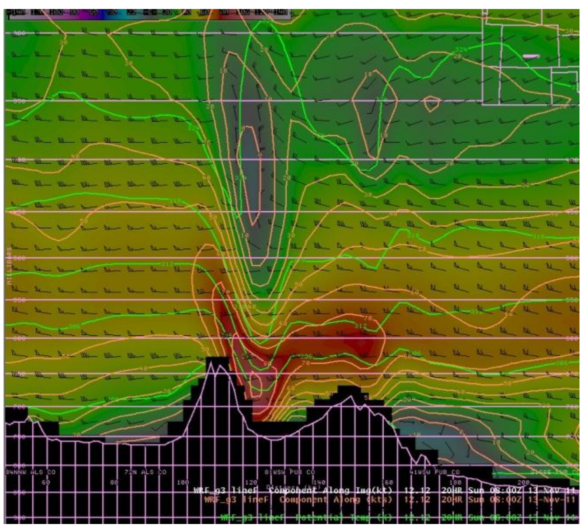

Figure 8b. Same as figure 7 but for 1200 UTC 12 November model run. Time of cross section is the same at 0800 UTC 13 November.

agree more closely with the 0000 UTC 13 November simulations.

The maximum forecast wind speeds for Stonewall and Westcliffe will briefly be examined. The “maximum” wind speeds are not exactly the maximum wind speeds from the

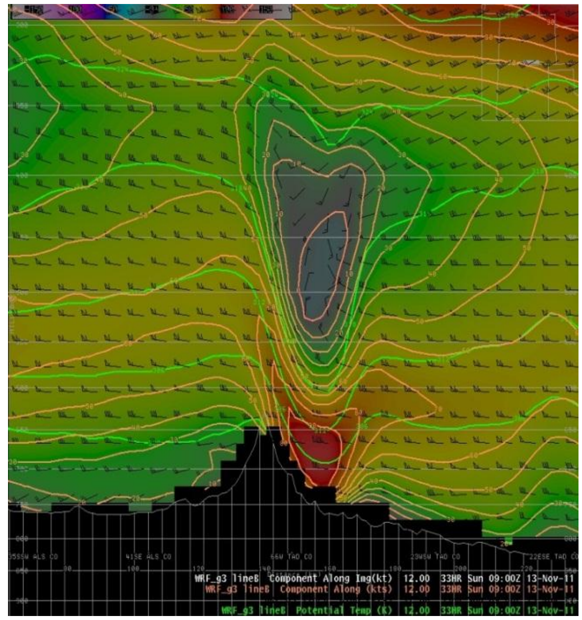

Figure 9a. Same as figure 6 but for 0000 UTC 12 November model run. Time of cross section is the same at 0800 UTC 13 November.

model because output from the local WRF simulation is only available at hourly intervals. These “maximum” wind speeds are similar to sustained wind speeds. Wind gusts would be much higher and there could be local periods of enhanced sustained winds. Table 1 shows that the local WRF runs consistently predicted strong winds for Stonewall. However, the earlier model runs did not predict damaging winds in Westcliffe. In the 0000 UTC 12 November and 1200 UTC 12 November runs, the area of high winds was just west of Westcliffe.

This brief point analysis highlights another difficulty of forecasting downslope windstorms. The region of damaging winds often is confined narrow regions and subtle changes in the atmosphere can affect whether or not a town experiences damaging winds.

Overall, the local WRF model run at the WFO provides very useful guidance for the potential of a windstorm in lee of the south central Rockies. Subtle differences in the synoptic scale pattern can affect the strength of the winds. In addition, the dynamics of the model can also affect the forecast. The outer domain is initialized with the NAM218 grid, then the NAM218 grids only provide lateral boundary conditions at the edges of the outer grid every 3 hours. Even minor differences on how the local WRF simulates the synoptic scale evolution (in the outer grid) compared to the NCEP NAM simulation could also affect the forecast magnitude of the event.

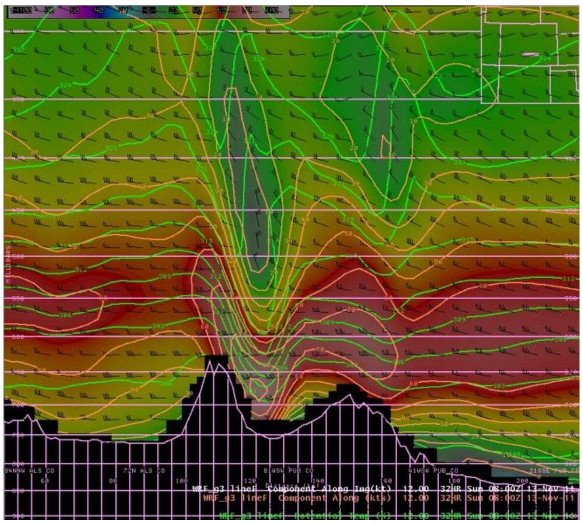

Figure 9b. Same as figure 7 but for 0000 UTC 12 November model run. Time of cross section is the same at 0800 UTC 13 November

Table 1

Maximum surface wind speed obtained from runs of the local WRF model. Values are from the innermost grid.

Simulation	StoneWall	Westcliffe
00 UTC 13th	28.9 m/s (56 knots)	26.8 m/s (52.1 knots)
12 UTC 12th	23.7 m/s (46 knots)	11.0 m/s (21.3 knots)
00 UTC 12th	25.8 m/s (50.1 knots)	10.9 m/s (21.2 knots)

5. REFERENCES

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