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AN APPLICATION OF THE MM5 TO MODELING HIGH WINDS IN COMPLEX TERRAIN: A CASE STUDY IN THE EASTERN SIERRA

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[Editors Note: Figures 1, 2 and 11 are included with the printed version of this Technical Attachment. The other figures are available via the Western Region Web page http://nimbo.wrh.noaa.gov/wrhq/TA98.html/]

Introduction

Weather prediction in western Nevada is often very complex due to mesoscale variations induced by the topography of the eastern slope of the Sierra Nevada. Current operational models are often found to miss significant local events, such as high winds, due to resolution problems. The National Weather Service Forecast Office in Reno, Nevada has recently begun to run the Pennsylvania State University/National Center for Atmospheric Research Fifth-Generation Mesoscale Model (MM5; Anthes and Warner 1978; Grell et al. 1993) to look at various effects of using higher model resolutions. We are asking two questions: 1) Is a higher resolution model able to more accurately predict surface winds, and what resolution is necessary to do so?; and 2) If the model can accurately predict high surface winds events where verification is available, what can we conclude about wind-prone areas where observations (and thus verification) are sparse?

In an effort to explore these questions, several simulations using the MM5 were run for the eastern Sierra high wind event of 29 December 1996.

Model Description and Case Overview

The MM5 configuration consisted of three domains over western North America with horizontal resolutions of 27 km (89x71), 9 km (88x76), and 3 km (64x55) (Fig. 1). The nesting was one-way. Twenty-seven half-sigma levels (ground-100 mb) provided the vertical resolution. The initialization and lateral boundary conditions were derived from NCEP gridded data from the operational 48 km Eta model (Black 1994). The 27 km MM5 output provided input for the 9 km and 3 km runs. The model physics package consisted of the simple ice scheme, Grell cumulus scheme (for the 27 and 9 km runs), Blackadar PBL, and a simple cloud radiation scheme with an upper radiative boundary condition. The physics did not include a multi-layer soil temperature scheme, nor shallow convection.

Figure 2 shows the synoptic scale pattern associated with the event of 29 December 1996. Wind speeds of 50-65 kts (25-33 ms^{-1}) in Reno were common, and peak gusts of up to 80 kts (41 ms^{-1}) were observed. Trucks were blown over and power outages occurred over a large area surrounding Reno.

The MM5 simulations were run on an HP C110 with 224 MB of RAM. All simulations ran in the background since the C110 is used operationally. The 27 km run took about an hour for each hour of output (not counting initialization time). The smaller 3 km grid took 2 hours for every hour.

Terrain Considerations

The terrain in and around the Sierra Nevada Mountains and western Nevada is more complex than the terrain resolved by synoptic scale and operational mesoscale models. Figure 3 shows the actual terrain. Lake Tahoe is crudely colored in blue here and the "R" to the northeast represents Reno. The terrain used with the 27 km run of the MM5 is shown in Fig. 4. It is similar to the terrain of the 29 km Meso Eta although a little smoother. This is probably due to the fact that eta coordinates allow steeper mountain slopes at a given resolution than sigma coordinates. As with the 29 km Meso Eta, Reno is located too close to the crest of the Sierra Nevada, and South Lake Tahoe, CA (TVL) and Truckee, CA (TRK) are on the wrong side of the crest. Figure 5 is the terrain (zoomed in from Fig. 4) used by the 9 km MM5 run (red shows elevations below 1500 m and green elevations above 2000 m). The Sierra Mountains are better defined and RNO is now in relatively flat terrain to the east. TVL and TRK are east of the crest and Lake Tahoe is hinted at but "leaks". There are still no mountains east of Reno. The 3 km MM5 terrain overlaid on a terrain image (Figs. 6 & 7) shows the realistic detail that comes through at this resolution. Lake Tahoe and surrounding mountains are now well defined. TVL and TRK are between mountain crests and Reno is properly placed in a basin with surrounding mountains and valleys. The red line in Fig. 7 shows the location of a cross section that will be discussed below.

Results

Figures 8-10 show select output from the 27, 9, and 3 km runs. The 27 and 9 km winds are the lowest sigma level (.995), while the 3 km winds are at 850 mb and have winds from the 29 km Meso Eta overlaid. Wind forecasts from the 27 km run were similar to the 29 km Meso Eta. Increasing the resolution to 9 km brought an increase in winds just southwest and west of Reno (where most of the strong wind reports came from) and a well-defined shear line appeared south southeast of Reno. At 3 km, forecast winds increased (60-70 kts) southwest and west of Reno with more shear lines appearing over the forecast area. We found that these shear lines were associated with mountain waves.

Figure 11 shows 3 km run output at 1800 UTC along the cross section defined in Fig. 7. Terrain is depicted in white along the bottom. The green and blue lines are potential temperature. This cross section clearly shows mountain waves. Figure 12 is the same cross section but with 9 km (solid) and 27 km (dashed) output valid at 2000 UTC. There is one well-defined wave at 9 km which lines up fairly well with the strongest waves at 3 km. For comparison, Fig. 13 shows the 29 km Meso Eta. There is little sign of a mountain wave.

Adding lower level winds to the cross sections shows their relation to the waves. Figures 14-16 are from the 3 km MM5. Note the wind shifts that follow the wave through the Reno area as it progresses east as well as the tight packing of the isentropic field that develops on the west side of Reno. How real are these waves? Compare a 1 km visible GOES-9 satellite image taken at 1800 UTC (Fig. 17) with the positive portion of the vertical component of the wind at 500 mb from the 3 km MM5 forecast valid at the same time (Fig. 18). Many of the waves do not line up with the model waves but the wave length and orientation are similar especially from around Reno north. The model did less well SE of Reno. This may be due to boundary effects since this area is near the south and east side of the 3 km MM5 grid.

The next sequence of images (Figs. 19-24) shows the lowest sigma level (.995) winds (in green) from the 3 km MM5 around the greater Reno area along with some actual wind observations (yellow). The number plotted at the upper left of the observations is the peak wind measured at +/- 10 min to the hour. Note the wind shifts and speed increases that occur as the shear line passes several sites.

Figure 25 is similar to those in the preceding sequence but isotachs have been added. Note the strongest flow is on the southwest and west side of Reno. This is where the tight packing of theta surfaces was indicated in the cross sections, and where most of the strong wind and damage reports came from. Note also that the model did not fill the whole area with strong winds.

There were several successes and failures resulting from this study. These are highlighted below.

Successes

- The strongest near surface level winds from the 3 km (and 9 km) MM5 runs occurred in the part of town that reported the strongest winds and the most damage.
- The 3 km output did not fill the whole area with high winds but also showed much lighter winds in areas that had relatively light flow during this portion of the wind event.
- The strongest wind gusts were similar to the wind speeds shown by the lowest sigma level winds.
- At least some of the mountain wave-related shear lines in the model output were real and moved at realistic speeds.

Failures

- Some sites on the crest of the Sierra Nevada near Lake Tahoe measured sustained winds well over 100 kts (51 ms^{-1}) during this event. This is not unusual. The model forecasts did not show this, possibly due to the limited number of vertical levels used or the very small horizontal scale of these winds.
- A wind shift similar to the one observed at Reno occurred at a RAWS site between Reno and Fallon, NV. The model did not show this. This is the same area where the MM5 did not model the mountain wave structure well. It is also close to the edge of the 3 Km grid.

Conclusions

The high wind case in the eastern Sierra was simulated by the MM5 in order to explore the basic question of "Are higher resolution models more accurate?" It was found that MM5 simulations at a resolution of 3 km were needed to resolve the important details of the wind fields in the complex terrain of the Sierra Nevada and western Nevada. The output from the 3 km MM5 run showed a significant improvement in the depiction of the details of the wind flow around Reno compared to operational models. To a lesser extent, this is also true of the 9 km run. In addition, the strongest winds in this case, around Reno, were found to be associated with mountain waves, a feature which was reasonably modeled by the MM5.

The question of model accuracy in areas where little is known about the observed winds was not resolved by this study. It is hoped this winter will bring a case where observations are available to study this problem. Future model runs with more levels in the vertical and more complex physics are planned. Another possibility is the initialization of the MM5 using the Local Analysis and Prediction System (LAPS). The office plans to collaborate with the Desert Research Institute in Reno for future mesoscale model experimentation.

References

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Grell, G.A., J. Dudhia and D.R. Stauffer, 1993: A description of the fifth-generation Penn System/NCAR Mesoscale Model (MM5). NCAR Tech. Note, NCAR/TN-398+1A, 107 pp.

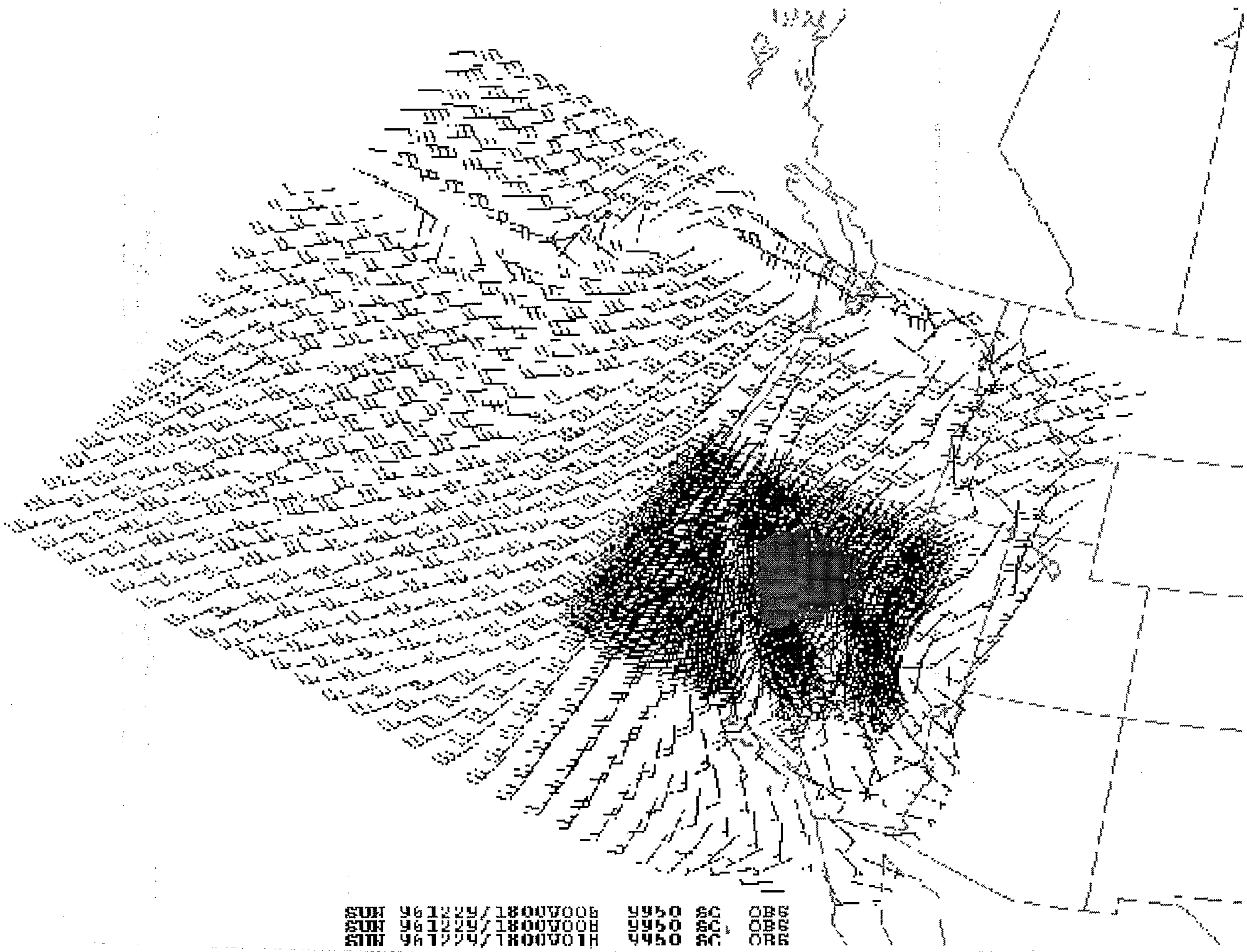

Figure 1 The MM5 configuration of three domains over western North America with horizontal resolutions of 27 km (89x71), 9km (88x76), and 3 km (64x55).

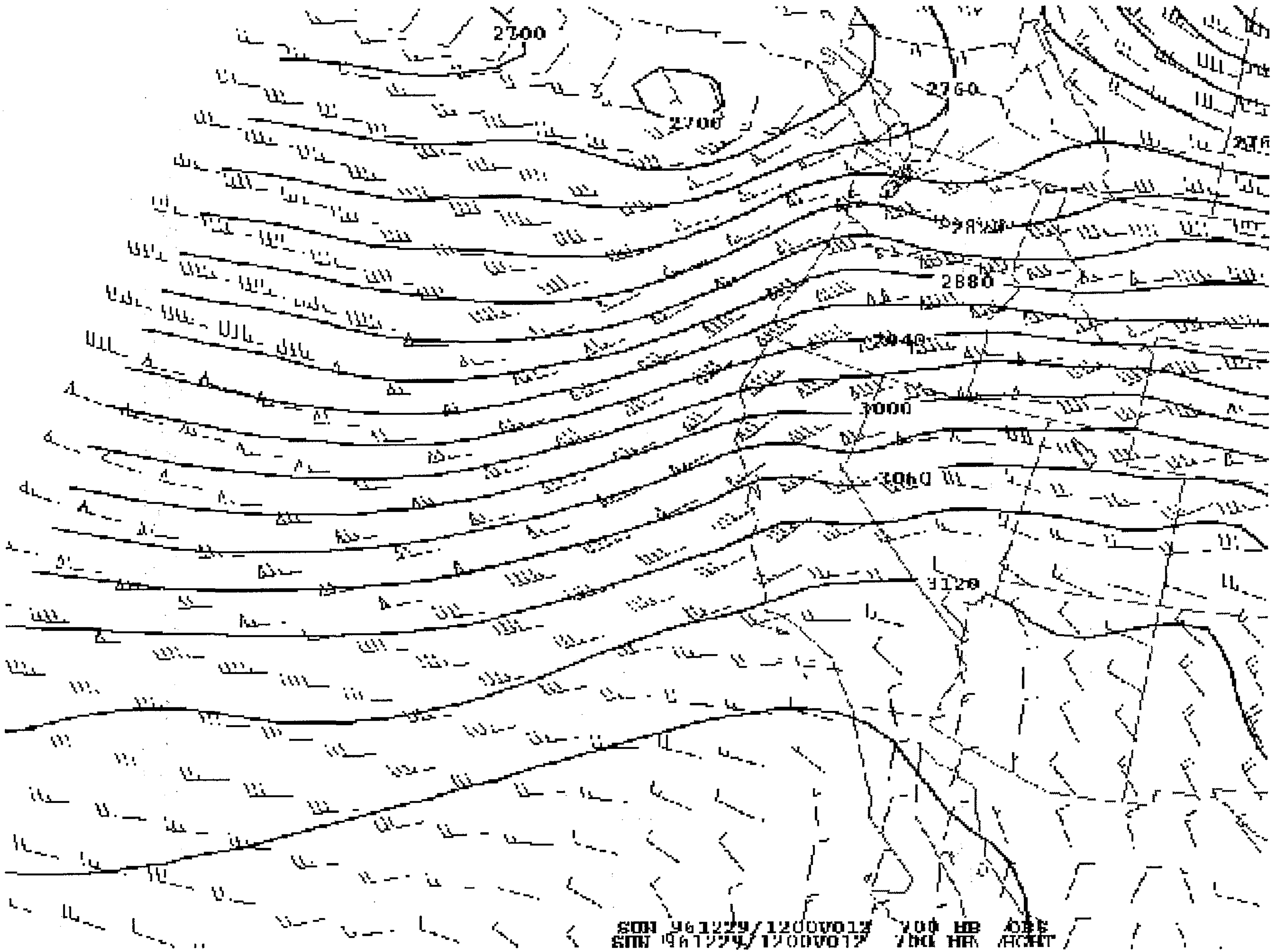

Figure 2 700 kPa heights (dm) and winds (kts) for 1200 UTC 20 December 1996.

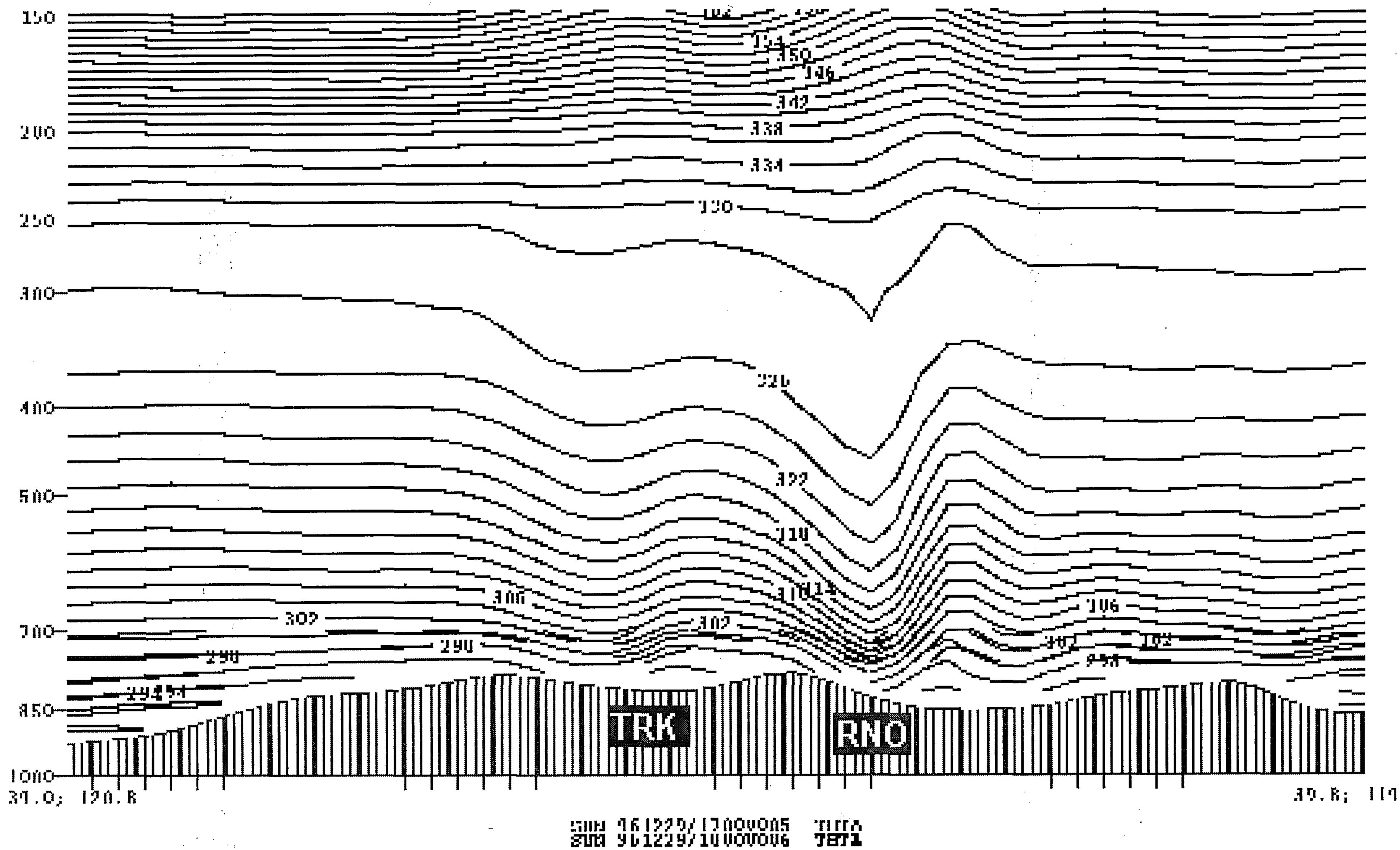

Figure 11 Model cross-section of potential temperature (K) for the 3 km run valid at 1700 UTC 29 December 1996. Truckee, CA (TRK) and Reno, NV (RNO) are indicated. The terrain is depicted by the area of vertical bars along the bottom.