Analysis of Thermal Inversions across the Albuquerque Metro Area

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Introduction

The complex terrain characterizing much of New Mexico makes for unique weather forecasting challenges year round. The Rio Grande River Valley which stretches nearly 400 miles from south central Colorado southward to the Mexican border is one such area. Dramatic mountain ranges, rising to over 10000 feet in some areas, lie parallel to this river valley through its entire journey through New Mexico. The Albuquerque Metro area is situated within the Rio Grande Valley and elevations within the city range from around 4800 feet along the valley floor to over 6000 feet in the foothills beneath the Sandia Mountains. During clear, calm and dry nights nocturnal inversions can develop, creating large thermal gradients across the city. This study will examine the variability of minimum temperatures across the Albuquerque metro area on days with surface inversions present and compare this variability to the strength and depth of the inversion.

Methodology

For this study, 12Z upper air sounding data from Albuquerque (KABQ) for 1996 were obtained from the Earth Systems Laboratory sounding archive web page http://raob.fsl.noaa.gov/. Each sounding was visually inspected to determine whether a surface inversion was present. Soundings with inversions during precipitation events and/or where the temperature and dewpoint curves met at any level of the sounding were thrown out to avoid precipitation and cloud cover contamination. There were 130 inversion cases retained for this study representing around 36% of the entire year. Minimum temperature data for each corresponding inversion day was collected from the South Valley (COOP station, 1510 meters), the Heights (KABQ, 1619 meters), and the Foothills (COOP station, 1865 meters). The inversion events were then filtered using two methods.

The first method categorized the inversion events by the standardized anomaly of the inversion thickness. The standardized anomaly was calculated for each sounding by subtracting the mean inversion thickness ($\overline{Z} = 323.2$ meters) from the observed thickness for an individual day then dividing by the standard deviation ($\sigma_Z = 278.6$ meters). The inversion events were then divided into five standard anomaly intervals; -1 to 0, 0 to 1, 1 to 2, 2 to 3, and 3 to 4. The mean temperature difference between the Foothills station and the Valley station, the Heights station and the Valley station, and the Foothills station and the Heights station was calculated for each corresponding standardized anomaly category.

The second method categorized the inversion events by the standardized anomaly of the inversion lapse rate. The standardized anomaly was calculated for each sounding by subtracting the mean inversion lapse rate ($\overline{\Gamma} = 20.2\,\mathrm{C/km}$) from the observed lapse rate for an individual day then dividing by the standard deviation ($\sigma_\Gamma = 15.9$ C/km). The inversion events were then divided into five standard anomaly intervals; -2 to -1, -1 to 0, 0 to 1, 1 to 2, and 2 to 3. The mean temperature difference between the

Foothills station and the Valley station, the Heights station and the Valley station, and the Foothills station and the Heights station was calculated for each corresponding standardized anomaly category.

Discussion

Table 1 summarizes the mean temperature difference between each station by standardized anomaly category for the thickness method and Table 2 summarizes the same results using the lapse rate method. The number of cases and percent distribution within each category are shown in the tables along with the mean thicknesses and mean lapse rates. The temperature differences between the Foothills station and the Valley station for the thickness method range from 5.8ºC for shallow inversions to 12.7ºC for deep inversions (difference of 6.9ºC). The temperature differences between the Heights station and the Valley station are nearly constant regardless of inversion depth with variations ranging from 8.0ºC to 8.5ºC. This data suggests there is an important relationship between the inversion depth and the resultant minimum temperatures across the city, especially at the Foothills station. The average inversion depths for the 0 and greater standard anomaly categories are greater than the height difference between the Heights and Foothills stations (246 meters) therefore temperature is still increasing with height above the Foothills station. Given an inversion depth a forecaster should be able to predict whether the Foothills station will be warmer or cooler than the Heights station and to what degree. Note that for all 130 inversion cases; 62% account for shallow inversions with average depths around 155 meters, 25% account for deeper inversions with average depths around 439 meters, and 13% of all cases account for inversions with average depths greater than 664 meters.

THICKNESS METHOD	-1 to 0	0 to 1	1 to 2	2 to 3	3 to 4
Number of Cases	80	33	9	5	3
Percent Distribution (%)	62	25	7	4	2
Average Thickness (m)	155	439	664	974	1409
Average Lapse Rate (C/km)	27	10	8	8	4
Heights – Valley (F)	+ 8.2	+ 8.5	+ 8.5	+ 8.4	+ 8.0
Foothills – Valley (F)	+ 5.8	+ 7.6	+ 8.6	+ 11.2	+ 12.7
Foothills – Heights (F)	- 2.4	- 0.9	+ 0.1	+ 2.8	+ 4.7

Table 1. Summary of mean temperature difference between the Foothills, Heights, and Valley by standardized anomaly category for the thickness method.

The temperature differences between the Heights station and the Valley station are still nearly constant for the lapse rate method ranging from 8.0ºC to 9.1ºC. Unlike the thickness method, the temperature differences between the Foothills station and the Valley station vary little for the lapse rate method ranging from 6.5ºC and 7.8ºC (difference of 1.3ºC). While the data calculated using the lapse rate method further support the average 8.0ºC to 9.0ºC temperature difference between the Heights and Valley stations, there is little additional information supporting a forecast decision on temperature at the Foothills station when the lapse rate is known. Therefore, the thickness method offers more insight into the possible temperature variability between the Foothills and Valley stations. Note that for all 130 inversion cases; 57% account for average lapse rates around 12 C/km, 18% account for average lapse rates around 27 C/km, 17% account for very steep lapse rates greater than 43 C/km, and 8% account for very weak lapse rates around 3 C/km.

LAPSE RATE METHOD	-2 to -1	-1 to 0	0 to 1	1 to 2	2 to 3
Number of Cases	10	74	24	15	7
Percent Distribution (%)	8	57	18	12	5
Average Lapse Rate (C/km)	3	12	27	43	63
Average Thickness (m)	790	440	188	110	111
Heights – Valley (F)	+ 8.3	+ 8.0	+ 8.5	+ 9.1	+ 8.4
Foothills – Valley (F)	+ 6.8	+ 6.5	+ 7.8	+ 6.5	+ 7.0
Foothills – Heights (F)	- 1.5	- 1.5	- 0.7	- 2.6	- 1.4

Table 2. Summary of mean temperature difference between the Foothills, Heights, and Valley by standardized anomaly category for the lapse rate method.

In order to determine whether these qualified inversion events can serve as a conceptual model to more accurately predict the thermal variability across the metro area, the minimum temperatures for all three stations were examined for each day of 1996. The Heights station was warmer than the Valley station 86% of the time, the Foothills station was cooler than the Heights station 80% of the time, and the Foothills station was warmer than the Valley station 60% of the time. The 130 inversion cases were then subtracted from the remainder of the year. In this case, the Heights station was warmer than the Valley station 52% of the time, the Foothills station was cooler than Heights station 55% of the time, and the Foothills station was warmer than the Valley station 41% of the time. Therefore, the qualified inversion days represent a significant contribution to determining the degree of thermal variability between the Heights, Valley, and Foothills stations. After filtering out the qualified inversion days, there were still 48 cases where the temperature differences between the Heights, Valley, and/or Foothills stations exceeded 8.0ºC. The majority of these non-qualified inversion events occurred during the late spring, summer, and early fall months even when the 12Z RAOB displayed thinly saturated layers at 500mb and/or 300mb.

Now that a conceptual model of the thermal variability across the metro area during qualified inversion events has been established we can examine the seasonal variability. A scatter plot of minimum temperatures versus date for all three stations is illustrated in Figure 1. The Valley station is represented by the blue circles, the Heights station green, and the Foothills station orange. Not all points are visible in the chart where overlap occurs. There is a high concentration of inversion events during the spring, fall, and winter seasons with a relative lull during the summer. For most inversion cases the Heights and

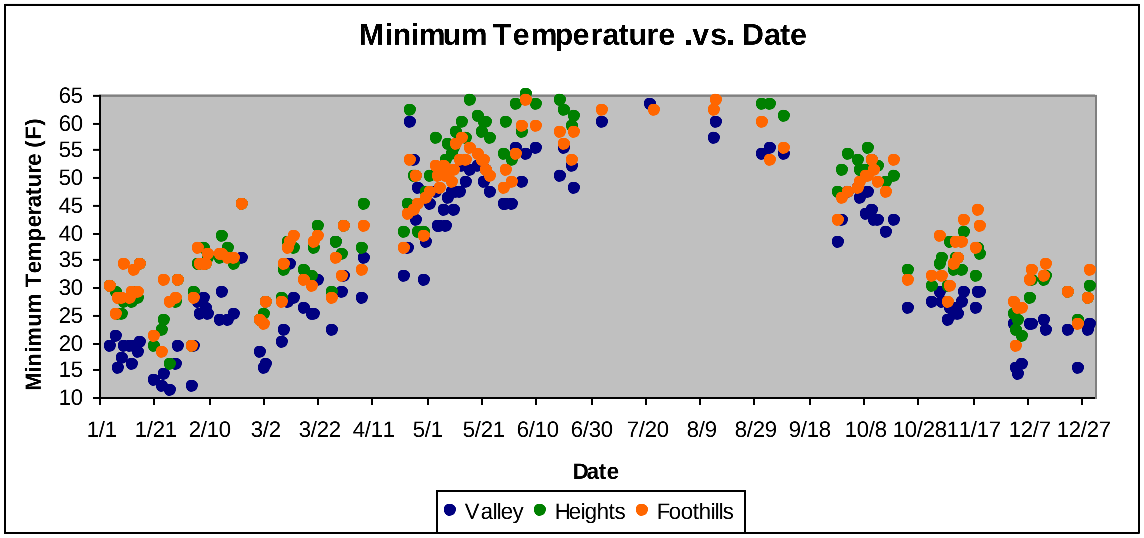

Figure 1. Scatter plot of minimum temperature versus date for all inversion cases.

Foothills stations are warmer than the Valley station and this is supported by the above frequency calculations. However, it is more difficult to observe a relationship between the Heights and Foothills stations at any particular time of year although the above frequency calculations suggest the Foothills stations will likely be cooler than the Heights station.

The same scatter plots are presented in Figures 2 - 6 for each standardized anomaly category of the thickness method. Figure 2 reveals relatively the same distribution of inversion events as Figure 1 but with fewer cases observed during the winter season. This suggests shallower inversion events ($\overline{Z}$ = 155 meters) can occur at any time of year and are relatively frequent. As the average inversion depth increases ($\overline{Z}$ = 439 meters) the concentration of events decrease, especially during the spring season (Figure 3). As the average inversion depth continues to increase (Figures 4 and 5) the frequency of events dramatically decrease and shift into the winter season, with the exception of two events in April. Once the average inversion depth increases to 1409 meters there are only three inversion events remaining confined to January (Figure 6). Therefore, the deepest inversion events occur mainly during the winter season and are infrequent, whereas, shallower events can occur at any time of year and are relatively frequent. Charts for the inversion events categorized by the lapse rate method are not shown because the events occurred during any time of year regardless of lapse rate strength.

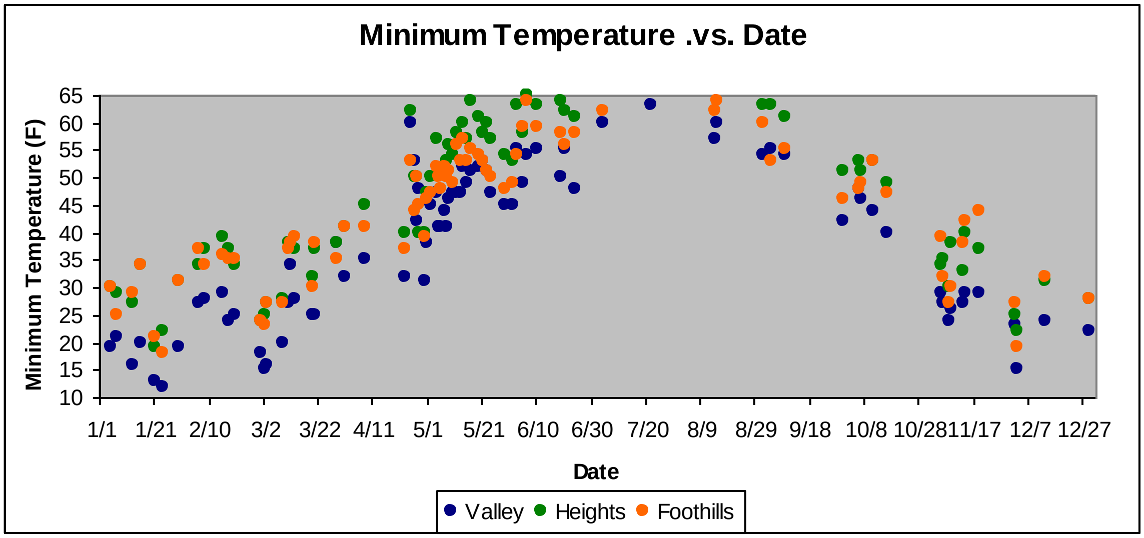

Figure 2. Scatter plot of minimum temperature for -1 to 0 standardized anomaly inversion cases ($\bar{Z}$ = 155 meters) using the thickness method.

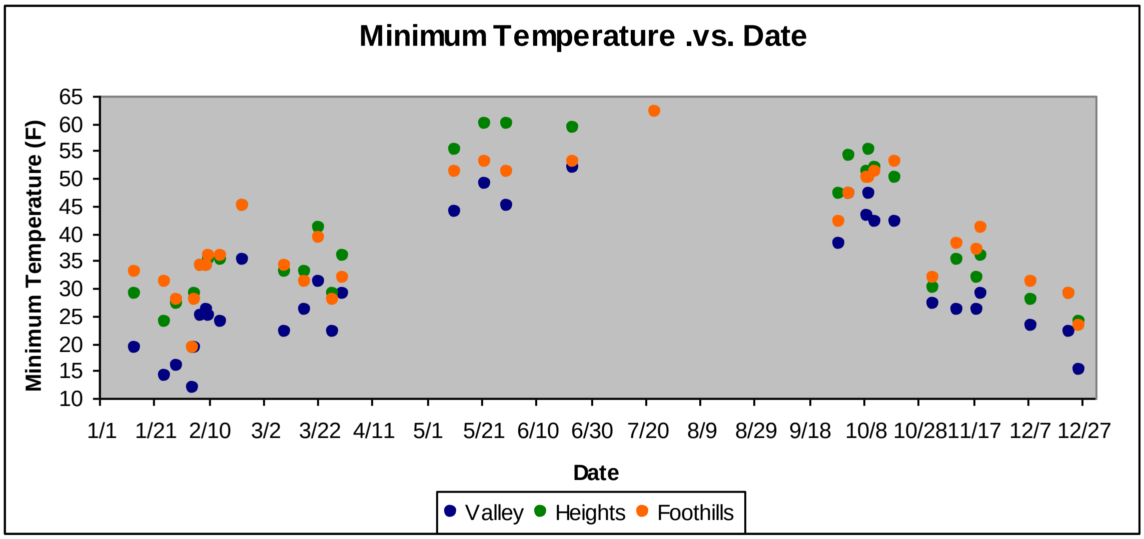

Figure 3. Scatter plot of minimum temperature for 0 to 1 standardized anomaly inversion cases ($\bar{Z}$ = 439 meters) using the thickness method.

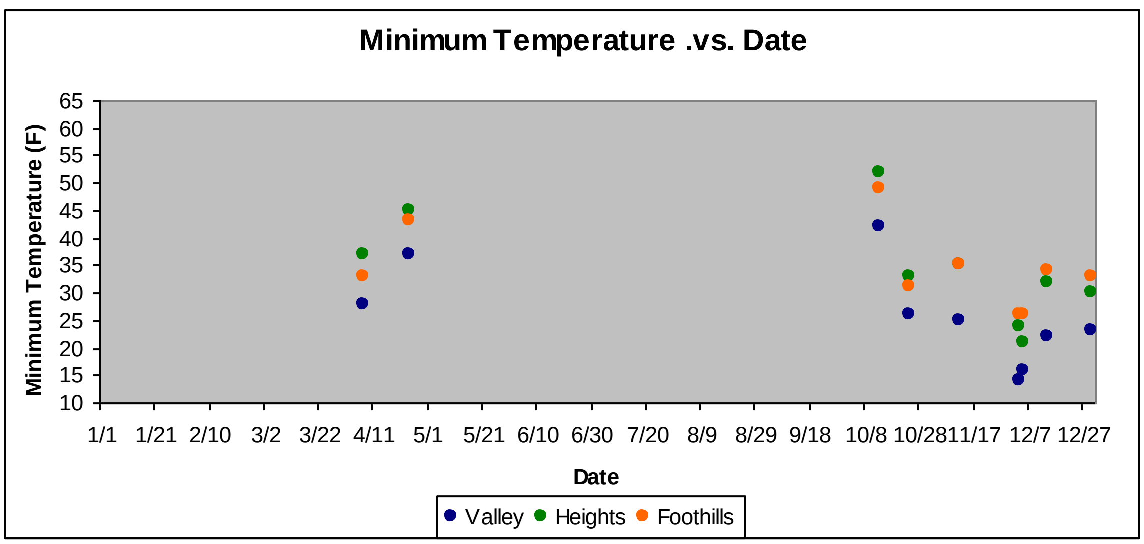

Figure 4. Scatter plot of minimum temperature for 1 to 2 standardized anomaly inversion cases ($\bar{Z}$ = 664 meters) using the thickness method.

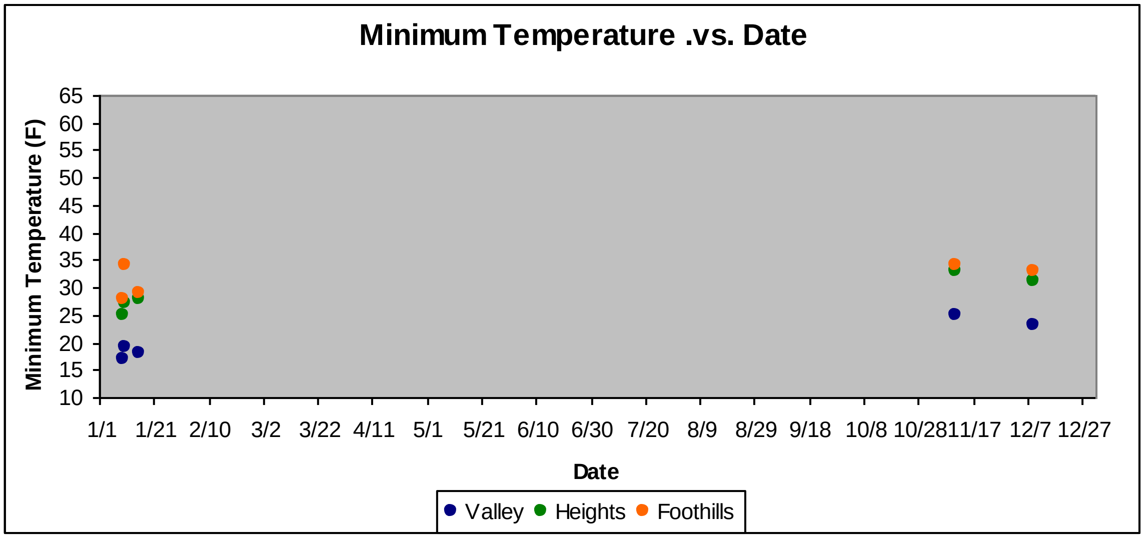

Figure 5. Scatter plot of minimum temperature for 2 to 3 standardized anomaly inversion cases ($\bar{Z}$ = 974 meters) using the thickness method.

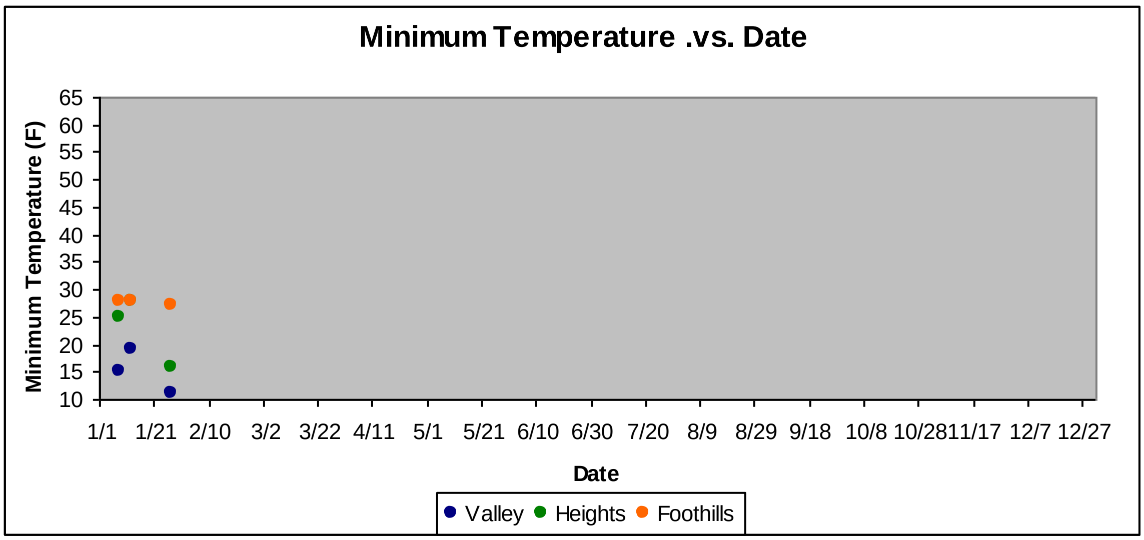

Figure 6. Scatter plot of minimum temperature for 3 to 4 standardized anomaly inversion cases ($\bar{Z}$ = 1409 meters) using the thickness method.

Case Studies

Two soundings are presented in Figures 7 and 8. Figure 7 is an example of a shallow inversion from March 9, 1996 at KABQ and Figure 8 is an example of a deep inversion from November 20, 1996 at KABQ. The November 20th inversion occurred beneath strong westerly flow of 30 to 40 knots below 500mb within a dry atmospheric column. Notice the light southeasterly flow in the lowest level indicating the boundary layer has decoupled from the mid level wind field. The southeast flow may represent drainage from the higher terrain to the southeast of the Heights station. The Foothills station reported a low temperature of 41ºF and the Valley reported a low of 29ºF (12ºF difference). The shallower inversion on March 9th occurred beneath light northerly flow below 500mb within a dry atmospheric column. There is no indication that the boundary layer has actually decoupled from the mid level wind field. The Foothills station reported a low temperature of 27ºF and the Valley station reported a low of 20ºF (7ºF difference).

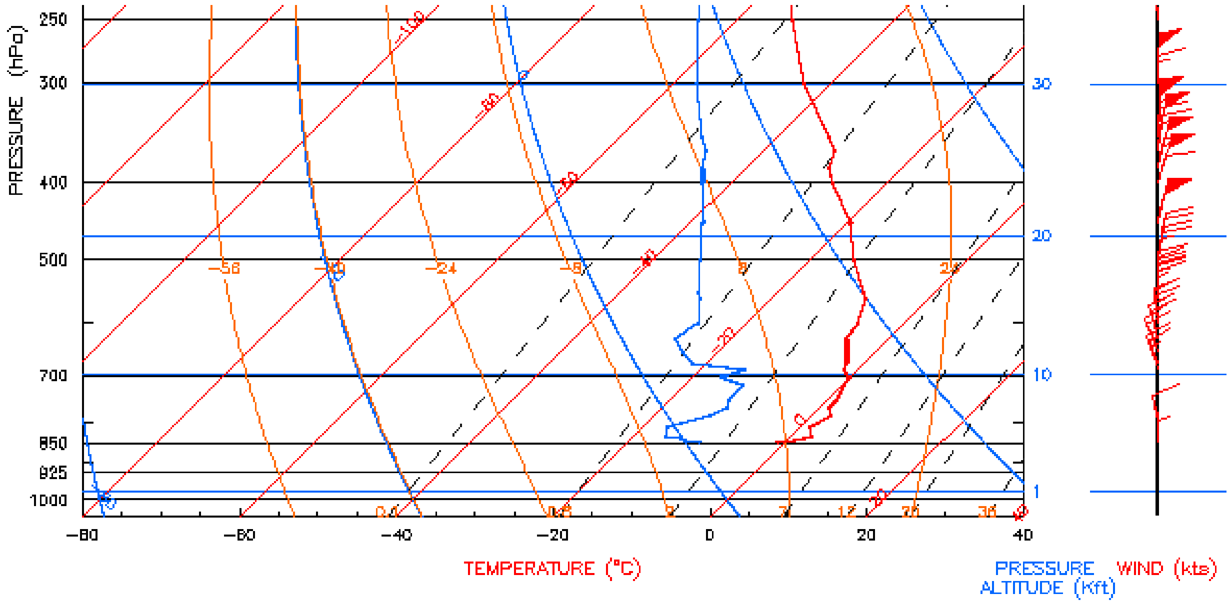

Figure 7. NOAA/FSL 12Z RAOB for KABQ March 9, 1996 showing a thermal inversion from 845mb to 832mb with a thickness of 123m. An 8ºF temperature difference occurred between the Heights and Valley stations with a 7ºF temperature difference between the Foothills and Valley stations.

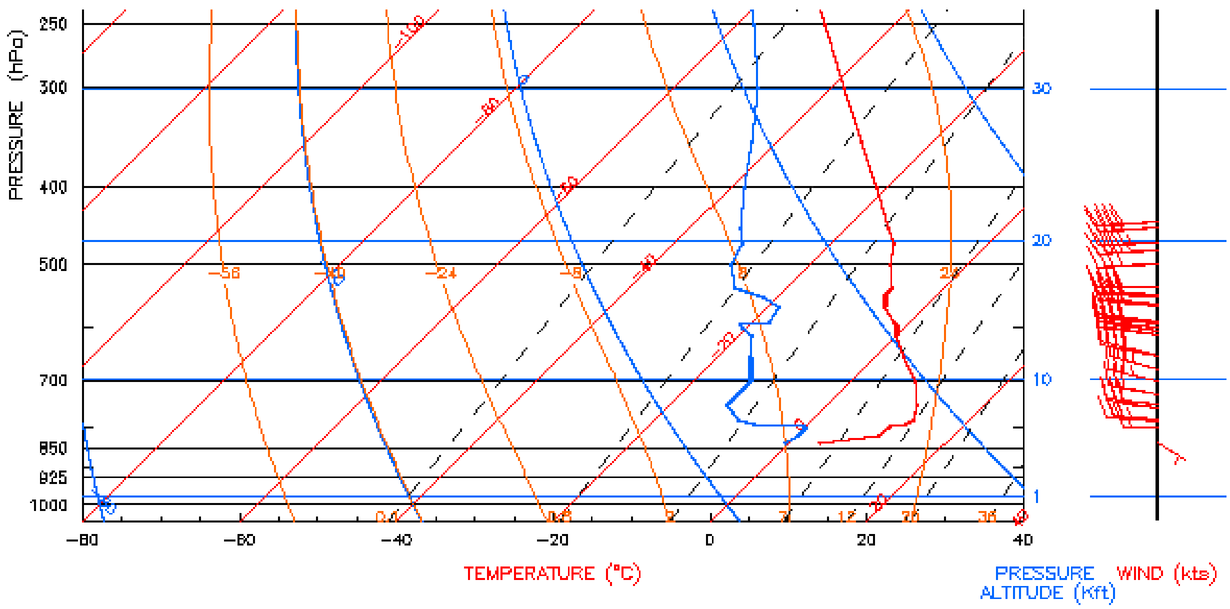

Figure 8. NOAA/FSL 12Z RAOB for KABQ November 20, 1996 showing a thermal inversion from 836mb to 781mb with a thickness of 565 meters. A 12ºF temperature difference occurred between the Foothills and Valley stations with a 7ºF temperature difference between the Heights and Valley stations.

To complete the conceptual model let us examine a case from January 21, 2008. Figure 9 shows the corresponding 00Z GFS 12-hour forecast BUKFIT profile at KABQ. The red curve represents the temperature profile, the green curve the dewpoint, horizontal dashed white lines are height, and vertical dashed blue lines are temperature. BUFKIT provides an active readout so the user can hover over the profile and obtain the desired data. Point A indicates the top of the inversion temperature, point B is the corresponding height at Point A, and Point C is the surface temperature (left) and surface dewpoint (right). In this case, the temperature at the top of the inversion is 0.0ºC and the depth is 1800 feet (549 meters). The height of the top of the inversion is greater than the height difference between the Foothills and Heights stations (246 meters, 807 feet) therefore we should expect the minimum temperature at the Foothills station to exceed that of the Heights station. By examining Table 1 we should expect that for a forecast inversion depth of 549 meters from the BUFKIT profile the temperature difference between the Heights and Foothills stations should be about equal and the temperature difference between the Heights and Valley stations should be around 8.5ºF.

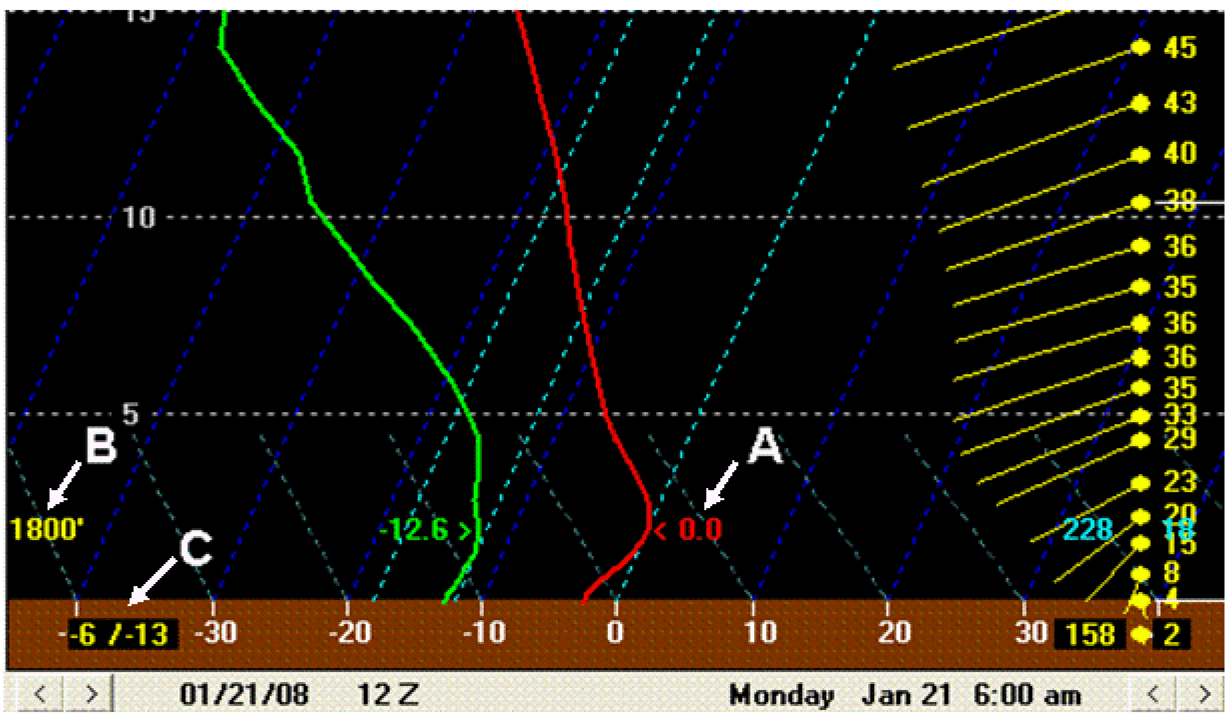

Figure 9. 00Z GFS 12-hour forecast BUFKIT profile at KABQ for January 21, 2008. Note the top of the inversion is higher than the Foothills station therefore the temperature is still increasing with height above that site. The lapse rate for this sounding from the top of the inversion to the surface is forecast to be 9.5ºC/km.

Figure 10 shows the 12Z RAOB for KABQ for January 21, 2008. The vertical wind profile and the temperature profile are similar to Figure 9. However, by visual inspection the low-level lapse rate appears to be weaker in the BUFKIT profile and the temperature at the top of the inversion is also slightly cooler. The Foothills station reported a low temperature of 30ºF, the Heights station 22ºF, and the Valley station 13ºF. That is a 17ºF temperature difference between the Foothills and Valley stations. The actual inversion depth was 433 meters, inversion top temperature 1.0ºC, and the lapse rate 9.5ºC/km. Once again, the results from Table 1 suggest that for an inversion depth of 433 meters we should expect the temperature difference between the Foothills and Heights stations to be near 1.0ºF and the difference between the Heights and Valley stations to be around 8.5ºF.

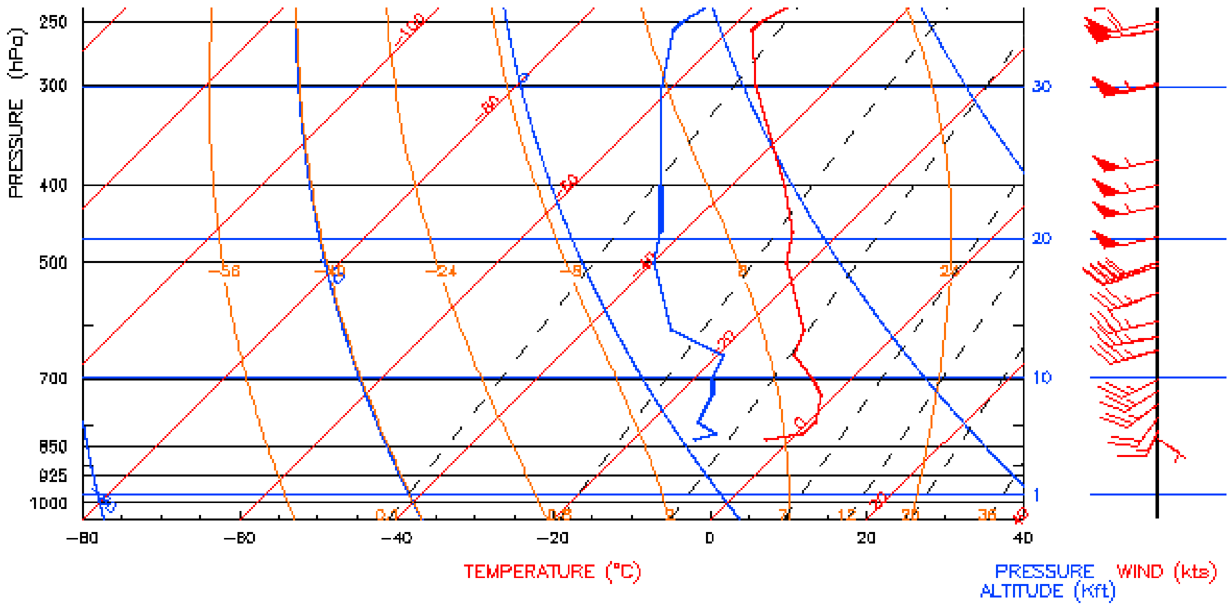

Figure 10. NOAA/FSL 12Z RAOB for KABQ January 21, 2008 showing a thermal inversion from 833mb to 789mb with a thickness of 433m. A 17ºF temperature difference occurred between the Foothills and Valley stations with a 9ºF temperature difference between the Heights and Valley stations.

To understand why the actual temperature differences far exceeded expectations we need to look a little further. Figure 11 is a plot of the minimum temperatures across central New Mexico for January 21, 2008. Notice farther to the east there is an 18ºF temperature difference within the Estancia Valley between the Moriarty station (MRY, elevation 6220 feet) and the Cedar Grove station (CCE, elevation 6910 feet). There is also a 13ºF difference between the Moriarty station and the Clines Corners ASOS (CQC, elevation 7052 feet). By interrogating the ASCII-text output from the 12Z RAOB it was found that the winds at inversion top level were between 15 and 18 knots. This suggests that while the inversion did build to a height greater than that of the Foothills station the atmospheric mixing was enough to prevent minimum temperatures from decreasing over the higher elevations. Figures 12 and 13 are screen captures of the GFE surface wind and minimum temperature observation grids at 12Z January 21, 2008. The wind grid indicates stronger winds across the Sandia and Manzano Mountains as well as the higher terrain near Clines Corners.

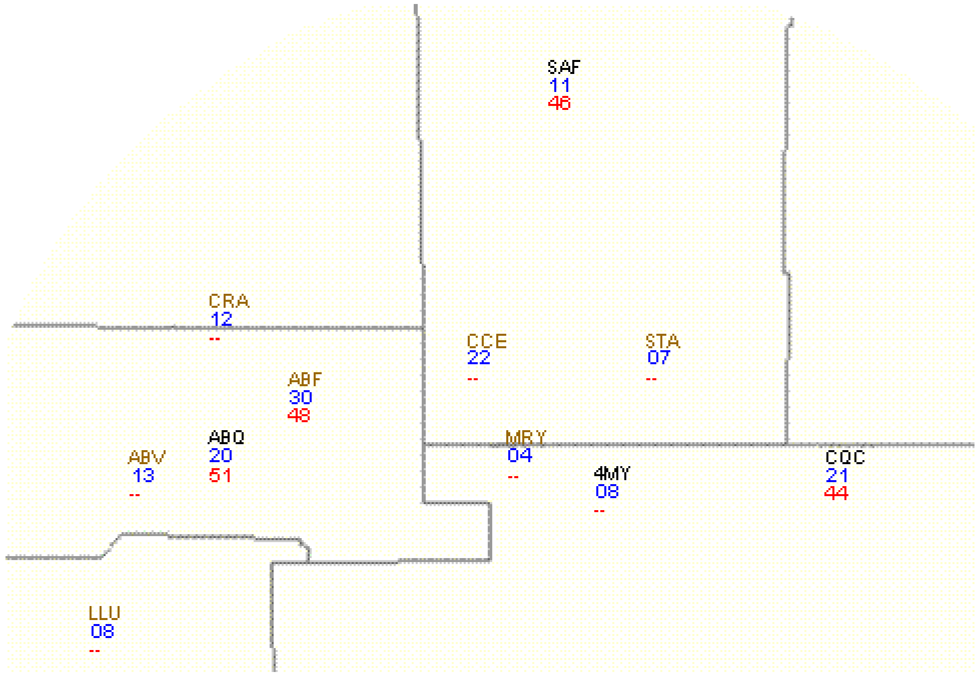

Figure 11. Plot of minimum temperatures across central New Mexico from January 21, 2008. ABV identifies the Valley station, ABQ the Heights station, and ABF the Foothills station. Notice the 17ºF temperature difference between the Valley and Foothills stations.

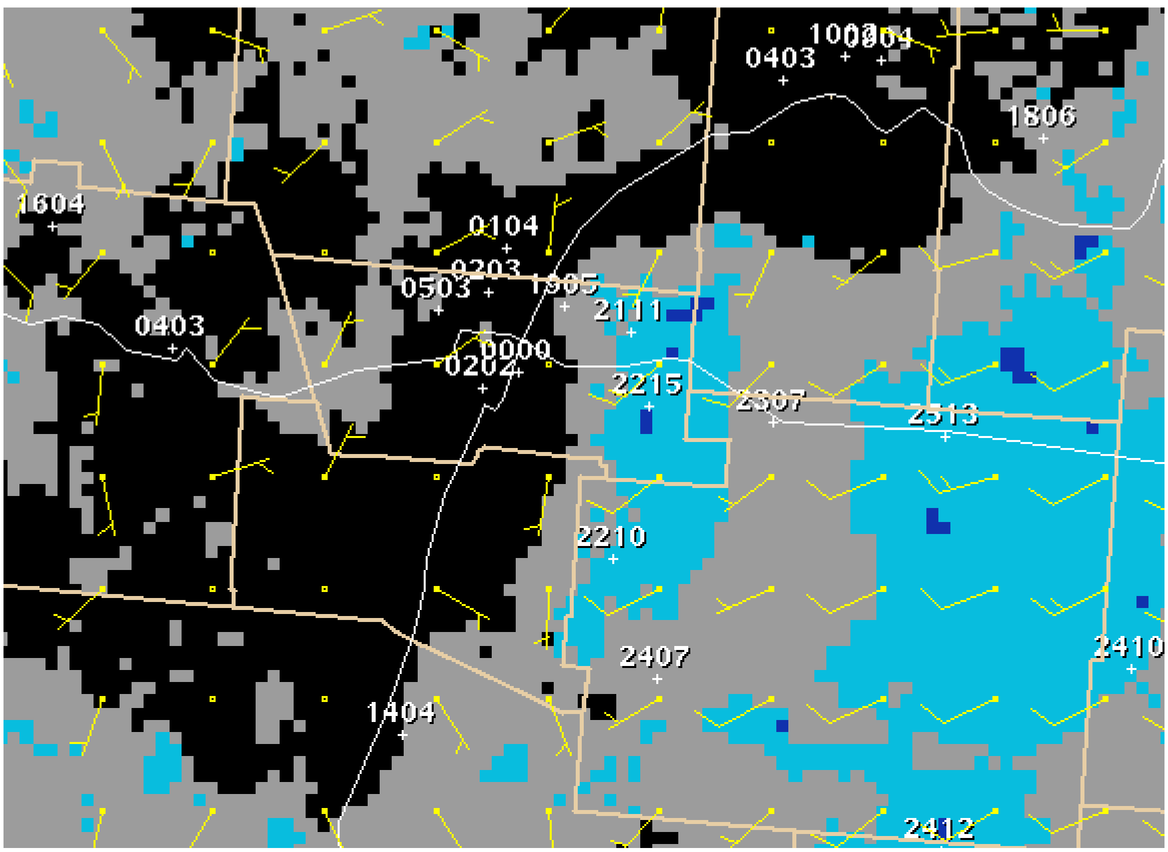

Figure 12. GFE surface wind observation grid at 12Z January 21, 2008.

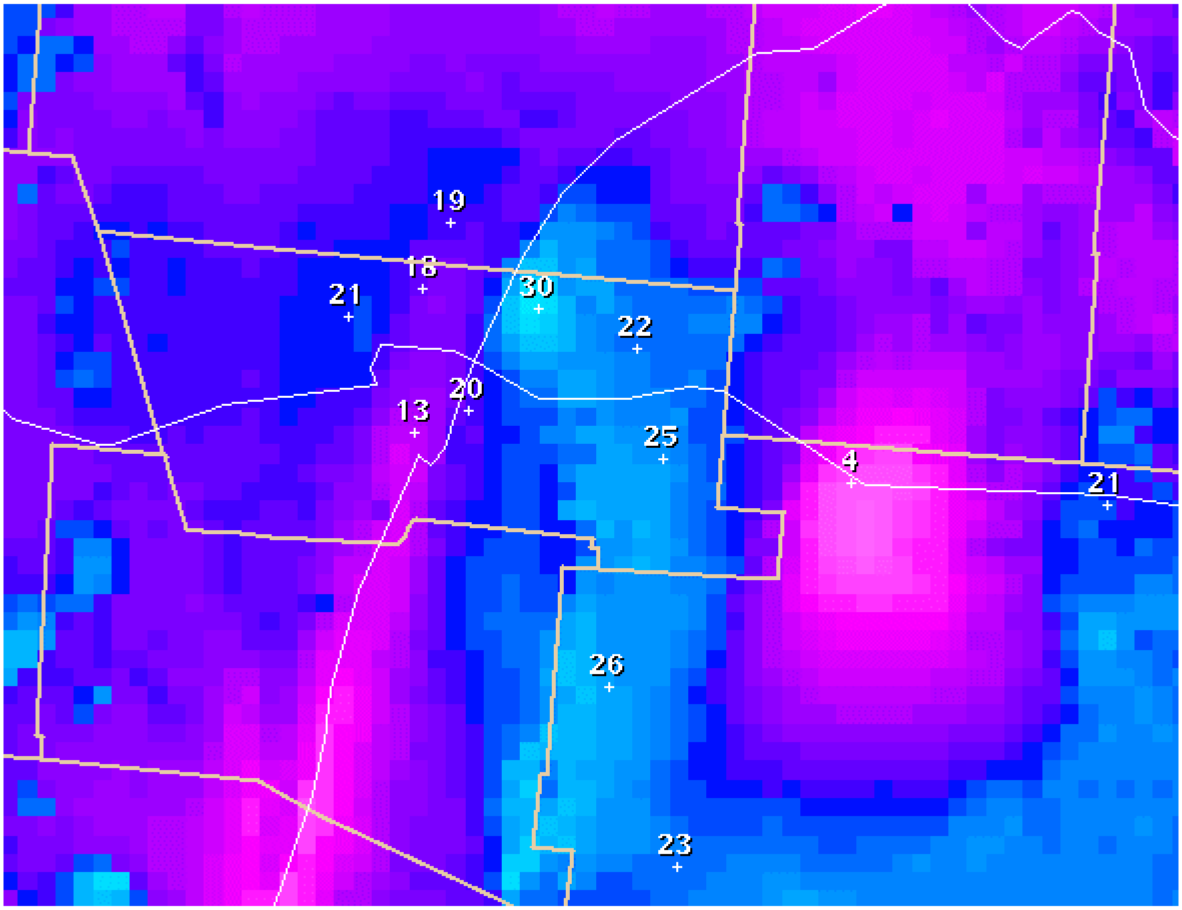

Figure 13. GFE minimum temperature observation grid at 12Z January 21, 2008.

Conclusions

The thermal variability across the Albuquerque metro area may be more accurately inferred using BUFKIT sounding analysis during nights when qualified inversion events are expected. There is a quantifiable relationship between the inversion depth and the variance of minimum temperatures between the Foothills, Heights, and Valley stations as illustrated by the thickness method. The case studies from March 9, 1996 and November 20, 1996 are ideal inversion events however as the case study from January 21, 2008 suggests there are more complicated factors at play when making a minimum temperature forecast. The results of this study are particularly useful since there is little statistical guidance available to the forecaster for the Foothills and Valley stations. Given the wealth of statistical guidance available at the Heights station the forecaster should be able to more accurately predict the corresponding minimum temperatures at the Foothills and Valley stations during inversion events. Since the data gathered for this study covered only one year it is likely the conclusions made will be more robust if several more years of sounding analysis are performed.