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# INTELLIGENT USE OF A LAPSE RATE SMART TOOL IN THE GRAPHICAL FORECAST EDITOR

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## 1. Introduction

The production of high quality National Digital Forecast Database (NDFD) grids across complex terrain can be greatly facilitated by the use of Smart Tools in the Graphical Forecast Editor (GFE). Care must be taken, however, to ensure that Smart Tools are used in a scientifically valid manner. This paper will examine the use of a lapse rate Smart Tool, "LapseRate " (Mazza 2002), on maximum and minimum temperature fields across the varying elevations of western North Carolina.

"LapseRate " requires the forecaster to first create a temperature grid as it would appear if elevated terrain did not exist. (The base elevation within the WFO Greenville-Spartanburg (GSP) forecast area is around 500 feet MSL.) The tool then uses a user-defined lapse rate across this temperature field, in combination with the GFE terrain field, to generate a temperature grid that accounts for the terrain differences. In lieu of better guidance, forecasters have generally adopted default lapse rates that are used daily to create temperature grids. To examine whether or not the use of such default temperature lapse rates adds demonstrable value to the gridded maximum and minimum temperature fields, a seasonal climatology of lapse rates between two observing stations in the North Carolina mountains was developed. Where mean default values were shown to be inadequately skillful, regression equations to predict lapse rates based on Eta model data were developed to serve as guidance in selecting the most appropriate lapse rate.

## 2. Methodology

Calendar year 2001 daily maximum and minimum temperatures were gathered from the Asheville Regional Airport (AVL), at an elevation of 2140 feet above Mean Sea Level, and from the Cooperative Observer Station at Flat Top Mountain (Swannanoa 2 SSE), at 4320 ft MSL. This station is approximately 13 statute miles northeast of AVL (Fig. 1), and also reports maximum and minimum temperatures on a midnight-to-midnight basis. Lapse rates[1] from AVL to Flat Top Mountain were then computed in

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[1] Although lapse rates are traditionally defined as the vertical rate of change of temperature at a point, here they are used to denote the rate of change with elevation between maximum or minimum temperatures that are separated horizontally by some distance. This approach assumes there is no horizontal temperature gradient between the two locations.

units of degrees F per 1000 feet in order to match the input units of the "LapseRate" GFE Smart Tool.

Eta model data were also gathered from the 00 and 12 UTC runs- with approximately 1200 potential predictor variables from the 12, 18, and 24-hour projections from each run. The Eta data were extracted from the full resolution BUFR sounding data at AVL. The computed lapse rates were then compared to the Eta model data by associating the maximum temperature lapse rates with the 12 to 24-hour projections of the 00 UTC Eta model run, and by associating the minimum temperature lapse rates with the 12 to 24-hour projections of the 12 UTC Eta model run. The data were then stratified into a cool season consisting of cases from January through March and October through December, and a warm season with cases from April through September.

Each dataset was quality-controlled to eliminate cases where the maximum or minimum temperature did not occur in the usual diurnal time periods. Cases where the AVL minimum temperature occurred after 1800 UTC on the day in question, or where the maximum temperature did not occur between 1200 UTC and 0000 UTC, were rejected. This might happen, for example, if the daily minimum temperature is recorded in the evening following a strong cold frontal passage. It was necessary to assume that cases satisfying the AVL quality control check were also acceptable at Flat Top Mountain. The resulting four datasets contained between 118 and 156 cases each. Simple statistical summaries were created of the distribution of lapse rates in each dataset. These are discussed in Section 3.

## 3. Analysis

The distribution of cool season maximum temperature lapse rates depicted in Fig. 2 shows a roughly normal distribution. The majority of the cases are clustered near the population mean of 3.43 °F/1000 ft. Approximately 80 percent of the cases fall in the 2 to 5 °F/1000 ft range, with a narrow interquartile range of 1.3 °F/1000 ft. A very small number of cases in the sample exhibited negative lapse rates (where temperatures increased with height). The high lapse rate tail above 6.0 °F/1000 ft likewise contained very few cases- as one might expect since the dry adiabatic lapse rate in the standard free atmosphere is 5.5 °F/1000 ft. Thus, one could feel reasonably confident that using a value of 3.4 °F/1000 ft as the lapse rate in the smart tool for maximum temperatures during the cool season should add value to the gridded forecast (compared to not accounting for terrain) the vast majority of the time. It is interesting to note that this value is quite close to the moist adiabatic lapse rate in the standard free atmosphere of 3.3 °F/1000 ft.

The same cannot be said, however, for the distribution of cool season minimum temperature lapse rate cases (Fig. 3). This sample exhibited a multi-modal distribution with cases rather evenly distributed from -5 to +5 °F/1000 ft, with rather large tails at both extremes. The spread evident in the interquartile distance of 6.4 °F/1000 ft makes it apparent that no single value of minimum temperature lapse rate will suffice as a default during the cool season. Clearly, using the same default value for minimum temperatures day after day, through changing weather regimes, would add little or no value to the NDFD grids. In fact, the -.01 mean value of the sample suggests that, in the absence of other guidance, no lapse rate factor should be applied at all.

To produce some basic lapse rate guidance, a multiple linear regression equation was developed to model cool season minimum temperature lapse rate as a function of several Eta model predictor variables. Each potential predictor in the dataset was tested in linear regression via the $R^2$ statistic (coefficient of determination) to assess the percentage of the total variation in the observed lapse rate that could be explained by that particular independent variable. Additional predictors were subsequently added in a step-wise fashion to create a multiple linear regression equation such that $R^2$ would be maximized while the residual standard error would be minimized. (Wilks 1995)

The selection and regression process produced the following equation for cool season minimum temperature lapse rate between AVL and Flat Top Mountain:

$$\textbf{(1)}\ \mathbf{LR = 1.162 - .426(T24_3\text{-}ST24) - .405(T18_2\text{-}ST18) + 5.88(OMEG24_1) + .020(SKNT24_{27})}$$

where:

**LR** = Lapse Rate (degrees F per 1000 feet)
**$T24_3$** = Temperature (C) at hour 24 in Eta model layer 3 (approximately 888 mb)
**ST24** = Skin Temperature (C) at hour 24
**$T18_2$** = Temperature (C) at hour 18 in layer 2 (approximately 903 mb)
**ST18** = Skin Temperature (C) at hour 18
**$OMEG24_1$** = Vertical Velocity ($10^{-6}$ m/s) at hour 24 in layer 1 (approximately 916 mb)
**$SKNT24_{27}$** = Wind Speed (kt) at hour 24 in layer 27 (approximately 340 mb)

The regression statistics indicated an $R^2$ value of 0.87 with a residual standard error of 1.38. Thus, the regression model depicted in Fig. 4 appears to "explain" about 87% of the variation of the lapse rate. The reduction in residuals was achieved with an associated p-value less than .01. It is thus highly likely that the model relationship depicted is not random, but has genuine predictive value.

To assess the equation's performance, a separate verification dataset was constructed from January 2002 data. A plot of observed lapse rate overlaid with forecast lapse rate from the verification period is included in Fig. 5. Subjectively, the forecast trace does appear to generally follow the observed lapse rate trace. The mean observed lapse rate in the verification dataset was -0.72 °F/1000 ft. Fifty-seven percent of the cases exhibited a positive lapse rate with 43% negative. It was determined that the forecast produced the proper sign in 93% of all cases and in 100% of the negative lapse rate cases. The Mean Absolute Error (MAE) associated with the forecast lapse rate was 1.77 °F/1000 ft. The MAE produced by using a default lapse rate of zero between AVL and Flat Top Mountain was 3.95 °F/1000 ft.

The distributions for the warm season cases are depicted in Figs. 6 and 7. The maximum temperature lapse rate cases once again exhibited little spread- with an interquartile range of 1.3 ° F/1000 ft about a mean value of 3.4 °F/1000 ft. With respect to the maximum temperature lapse rate cases, the seasonal stratification appears to be unnecessary with the 3.4 default value proving adequate year-round. It should be noted, however, that a few negative lapse rate cases did appear in the cool season sample, while warm season lapses stayed universally positive.

Once again, the spread was much higher for the warm season minimum temperature lapse rate cases, albeit much less stark than for the cool season, with an interquartile spread of 2.2 °F/1000 ft about a sample mean of 1.65. The rather thick tail on the negative lapse rate end suggests that the forecast could benefit from additional guidance. As for the cool season, multiple linear regression was employed to develop the following Eta guidance:

**(2)** $\mathbf{LR = 1.618 - .275(T18_2\text{-}TD18_2) + .171(SKNT24_1) - .365(T24_2 - ST24) - .001(BRCH18)}$

where:

$\mathbf{LR}$ = Lapse Rate (degrees F per 1000 feet)
$\mathbf{T18_2}$ = Temperature (C) at hour 18 in Eta model layer 2 (approximately 900 mb)
$\mathbf{TD18_2}$ = Dewpoint (C) at hour 18 in layer 2
$\mathbf{SKNT24_1}$ = Wind Speed (kt) at hour 24 in layer 1 (approximately 914 mb)
$\mathbf{T24_2}$ = Temperature (C) at hour 24 in layer 2
**ST24** = Skin Temperature (C) at hour 24
**BRCH18** = Bulk Richardson Number at hour 18

The regression statistics indicated an $R^2$ value of 0.61 with a residual standard error of 1.12. Thus, this equation appears to "explain" much less of the variation of the lapse rate than did the cold season equation. A separate verification dataset was constructed from July 2002 data. The mean observed lapse rate in the verification dataset was 1.26 °F/1000 ft. The Mean Absolute Error associated with the forecast lapse rates derived from eq. (2) was 1.18 °F/1000 ft. The MAE produced by using the mean lapse rate of 1.65 °F/1000 ft between AVL and Flat Top Mountain (see Figure 7) was 0.97 °F/1000 ft. Thus, the guidance equation for warm season minimum temperature lapse rate exhibited no demonstrable skill, for the month in question, over simply using a climatological default value.

## 4. Summary

A climatology of maximum and minimum temperature lapse rates between the Asheville Regional Airport and the Cooperative Observing Station at Flat Top Mountain was developed for the warm and cool seasons. From the climatology, it was determined that a default lapse rate of 3.4 °F/1000 ft provides reasonable input to the GFE "LapseRate" Smart Tool for maximum temperature grids. This value was found to be very consistent and reliable from season to season. The minimum temperature lapse rates, however, exhibited considerable spread and showed a highly non-normal distribution, especially for the cool season. In an attempt to improve the guidance for forecasters for the minimum temperature lapse rates, multiple linear regression equations were developed for each season, with predictor variables taken from the Eta model and with the observed lapse rate serving as the predictand. A one-month independent verification dataset demonstrated that such a regression technique can produce qualitative and quantitative improvements in the cool season minimum temperature lapse rates over simply using a default lapse rate near the climatological mean. No improvement was achieved, however, for the less variable warm season minimum temperature lapse rates.

It must be acknowledged that this statistical guidance is only valid for the lapse rate between the stations used in its derivation. The forecast area of the Greenville-Spartanburg, SC WFO covers terrain spanning some 6,300 feet in elevation. It may not be valid to assume that lapse rates between Asheville and Flat Top Mountain are indicative of lapse rates from Asheville down to the lower mountain valleys, or down into the adjacent Piedmont. The lapse rate could likewise be unrepresentative for higher elevations extending upward to Mount Mitchell (6,684 ft).

Finally, verification needs to be done to assess the performance of forecasts created by populating the grids with raw Eta temperature fields. The Eta model makes gridded surface temperature forecasts (not specifically maximum and minimum) that account for terrain as depicted in the model. However, these model grids currently have a coarser horizontal resolution than the GFE grids. If it can be demonstrated, either via a gridded verification scheme, or a robust point verification system, that these data provide an adequate representation of lapse rates across complex terrain, then strategies for selecting the proper lapse rate will be largely unnecessary.

## References

Mazza, T., 2002: LapseRate Version 1.0. NOAA/NWS IFPS Smart Tool Repository.

Wilks, D. S., 1995: Statistical Methods in the Atmospheric Sciences. 467 pp.

## Figures

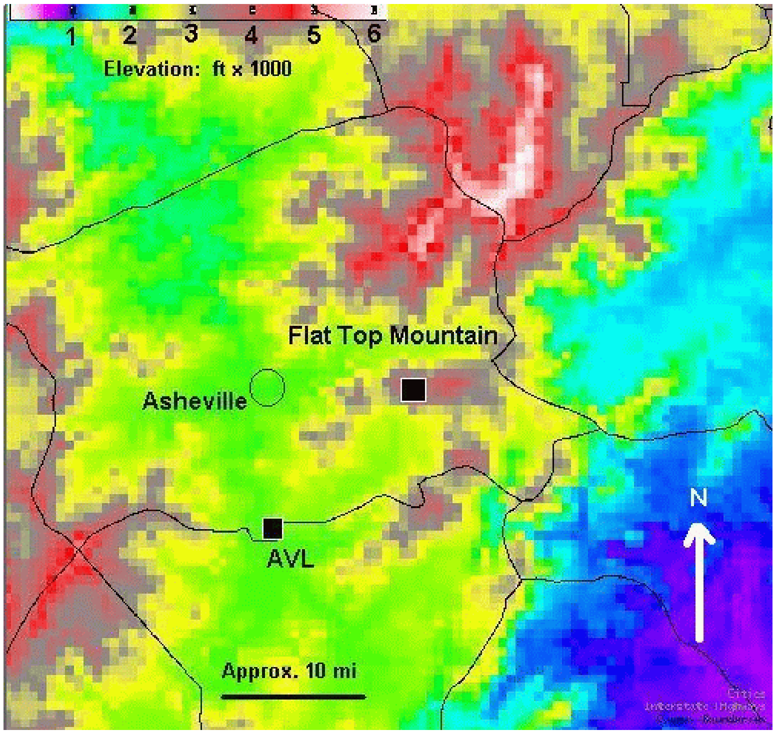

**Figure 1**: Topographic map of the Asheville, NC vicinity showing the observing locations of AVL and Flat Top Mtn.

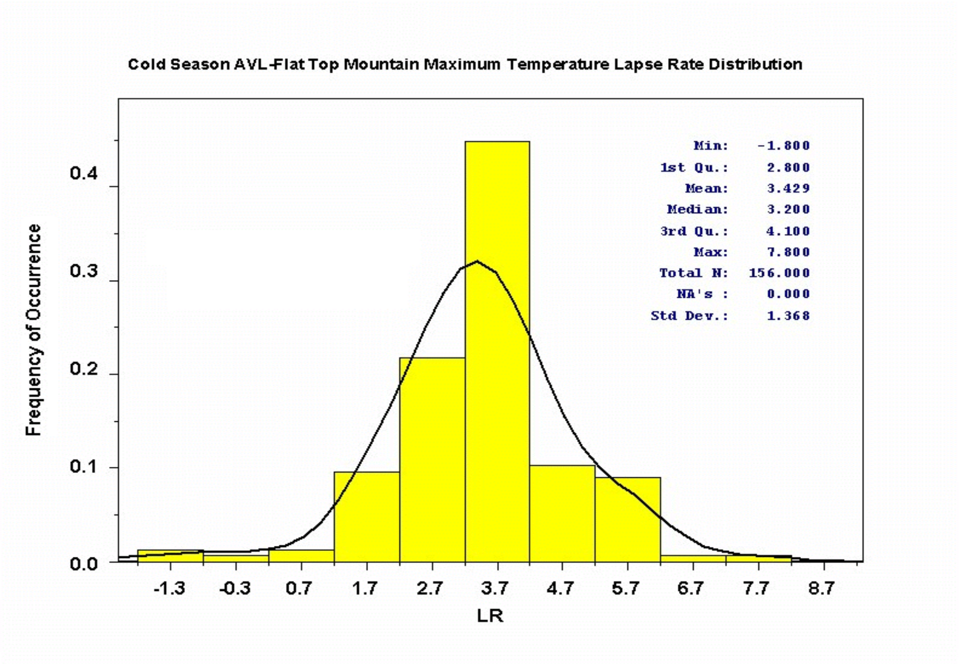

**Figure 2**: Cool season maximum temperatures lapse rate (LR), with best-fit distribution curve. (°F/1000 ft.)

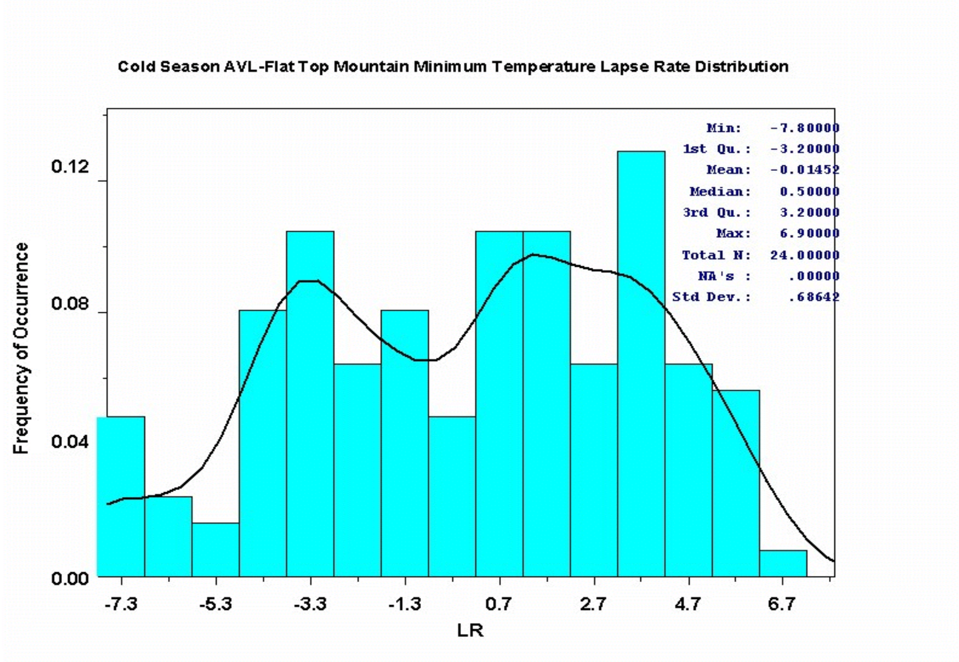

**Figure 3**: Cool season minimum temperature lapse rate (LR). (°F/1000 ft.)

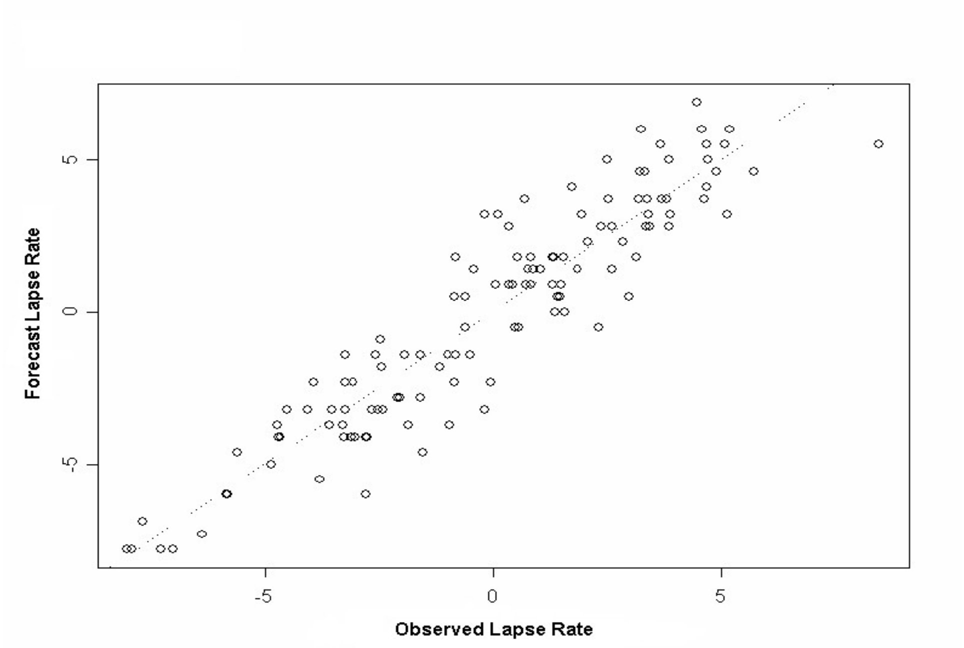

**Figure 4**: Multiple linear regression fit for cool season minimum temperature lapse rate.

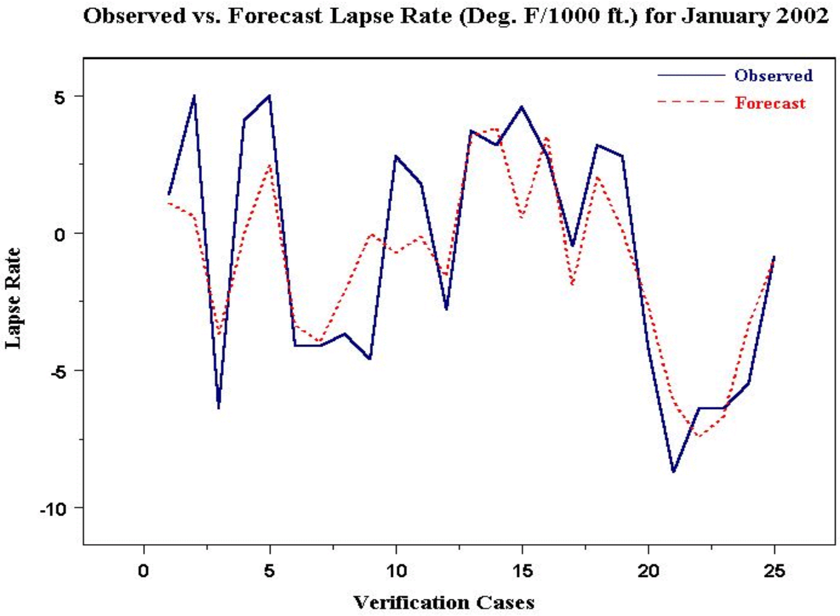

**Figure 5**: Cool season minimum temperature lapse rate forecast verification.

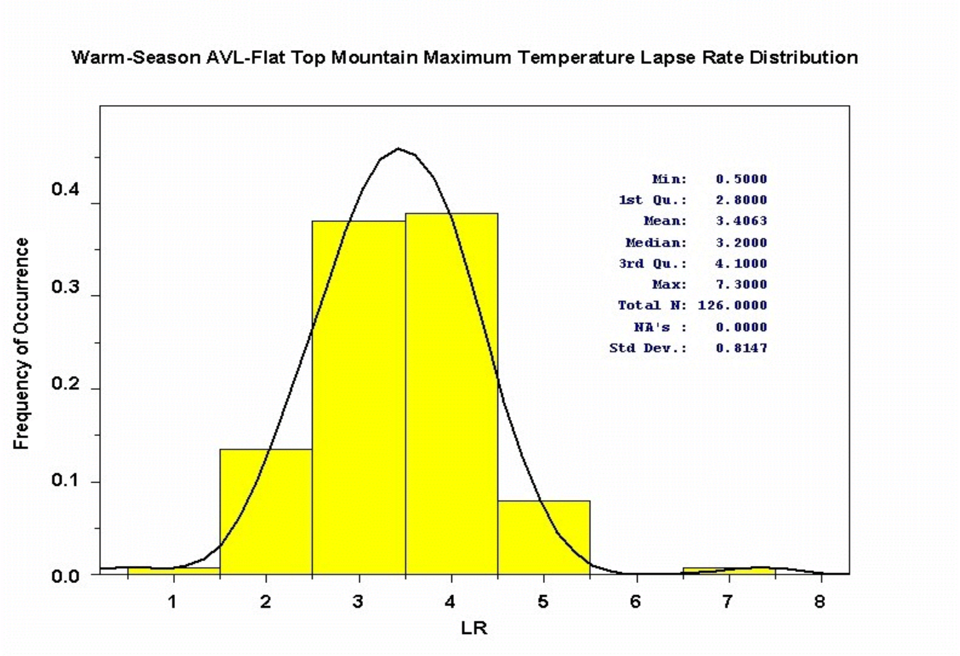

**Figure 6**: Warm season maximum temperature lapse rate (LR). (°F/1000 ft).

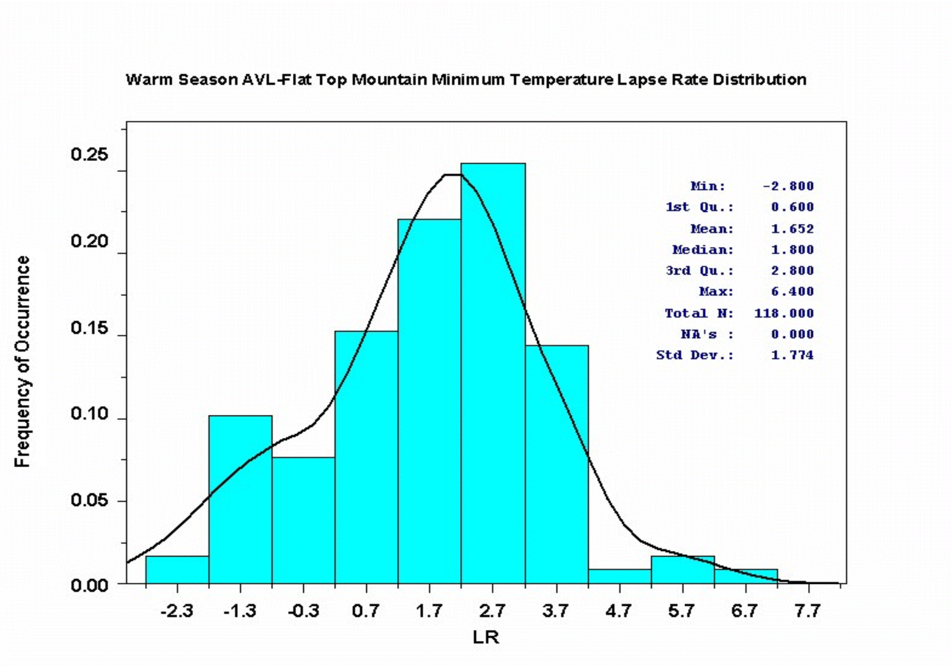

**Figure 7**: Warm season minimum temperature lapse rate (LR). (°F/1000 ft.)