Using Thermal Gradients between the Sierra and Western Nevada to Forecast the Strength of the Washoe Zephyr

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Introduction

The Washoe Zephyr is a thermally induced downslope wind frequently observed in the summer during the late afternoon and early evening across the Sierra Front in western Nevada and northeast California (Kingsmill 2000, Zhong et al. 2008). The zephyr wind develops along the eastern slopes of the Sierra Nevada and moves to the east across the Reno-Carson City area before weakening as it reaches the Carson and Humboldt sinks near the cities of Fallon and Lovelock (see Fig. 1 for locations). Maximum wind speeds are typically measured prior to sunset near U.S. Highway 395/Interstate 580.

The term Washoe Zephyr first appeared in literature in Mark Twain's book "Roughing It" (1871). Twain wrote about the Washoe Zephyr during his time in Carson City around 1870,

> *"It is a pretty regular wind, in the summer-time."*

He further describes how the wind impacted the residents,

> *"now and then blows a stage-coach over and spills the passengers; and tradition says the reason there are so many bald people there is, that the wind blows the hair off their heads while they are looking skyward after their hats."*

The Washoe Zephyr plays a large role in defining the summer time weather across western Nevada. It affects fire weather, travel along north-south routes and can serve as a surface boundary to enhance convection (Brong 2004). The diurnal cycle of the Washoe Zephyr is apparent in the Reno Airport (RNO) wind rose (Fig. 2). The Washoe Zephyr is a west wind that usually begins within 2 hours of 21 UTC (2pm local, Fig. 2b), with peak sustained wind speeds between 12 and 20 knots (Fig. 2c). The wind diminishes in the evening by 06 UTC (9pm local, Fig. 2d).

The need for this study began from a string of missed red flag events during 2007 and 2008, where forecasters were routinely underestimating the strength of the Washoe Zephyr and its impact on fire weather. The initial study was completed in 2009, and then expanded in 2013 to develop a more reliable climatology. The Sierra Front lies within the urban-wildland interface where the Washoe Zephyr can quickly turn a fire start into a large and destructive wildfire. The Waterfall (Carson City July 11-14th, 2004) and Andrew Fires (Pleasant Valley and Virginia Foothills south of Reno Aug 26th, 2004), were fanned by the Washoe Zephyr. Several homes were lost during both fires and two injuries resulted from a burn over of a staging area during the Waterfall Fire (Anderson 2004).

Data and Methods

Since the Washoe Zephyr occurs during the summer, data collected for this study was limited to the months of June, July and August from 2004-2012. The thermal gradients were calculated using daily high temperature data from Truckee (TRK), South Lake Tahoe (TVL), Lovelock – Derby Field (LOL) and the Fallon Naval Air Station (NFL). Three of the sites (TVL, LOL, and NFL) are Automated Surface Observation Systems (ASOS) and one site (TRK) is an Automated Weather Observations System (AWOS). The gradients were compared to daily peak wind gusts from the Reno (RNO) ASOS.

Four different thermal gradients were calculated between the Sierra Nevada (TRK and TVL) and the Carson and Humboldt Sinks (LOL and NFL) by subtracting the daily high temperature at LOL and NFL from TRK and TVL. The distribution of the thermal gradients is shown in histogram format in Fig. 3. In general, all of the histograms showed a normal Gaussian distribution. The mean and standard deviation for each data set is shown in Table 1.

To filter wind gusts associated with thunderstorm outflows, days when the RNO peak gust values exceeded two standard deviations from the mean were removed from the dataset. It is likely that this filter did not remove all of the days contaminated by thunderstorm outflows. Thunderstorms frequently occur along the Sierra Front on days with a zephyr wind present (Brong 2004). Thunderstorm outflows can travel a long distance, meaning storms do not have to develop in the vicinity of RNO for it to be affected by outflow winds. In addition, low thermal gradient days occur during favorable synoptic patterns for thunderstorms. One in particular is the Great Basin High pattern (Brong 2005), which is characterized by hot, dry and unstable conditions with light winds in the boundary layer. Most of these thunderstorm events probably occur when gradient values are near or just below the mean and with thunderstorm outflow wind gusts at RNO of 30 to 40 mph.

Discussion

Scatterplots depicting the relationship between the thermal gradients and RNO peak wind speed are shown in Fig. 4. In all of the scatterplots, there is a noticeable upward trend of the peak wind gust values with higher thermal gradients. This supports the theory that the Washoe Zephyr is a thermally induced wind, such that larger thermal gradients result in stronger peak wind gusts along the Sierra Front.

Since there is a considerable difference (as much as 20 mph) between the maximum and minimum RNO peak wind gust for each gradient value, the 25^{th}, 50^{th} and 75^{th} percentiles for the RNO gusts were found for each LOL-TRK gradient value and plotted (Fig. 5). This is a simpler way to show the increasing trend of higher peak wind gusts with higher thermal gradients. In addition the breakdown gives operational forecasters the lowest, median and highest possible range of values for the peak wind gust at RNO based on the data collected from 2004 to 2012.

The linear relationship between the peak gusts at RNO and the observed thermal gradients is not statistically significant as r-squared scores for all 4 cases is less than 0.25 (as shown on Fig. 4). Even though the r-squared score is not statistically significant, the trend shows an increased potential for stronger gusts when the thermal gradient over western Nevada is higher. The relationship of stronger wind gusts due to a higher thermal gradient can be used as an initial starting point to forecasting peak gusts along the Sierra Front. This is especially true for fire weather applications where critical fire weather conditions are defined as gusts of 30 mph or more combining with relative humidity below 15 percent. Other data sets need to be interrogated such as, position of the jet stream and strength of ridge level winds which were shown to mix downward and/or factor into the duration of the zephyr wind event to the surface by Kingsmill (2000) and Zhong (2008).

Applications for Operational Meteorology

The purpose of this study is to provide forecasters with an additional tool for assessing the strength of the Washoe Zephyr and the potential for critical fire weather wind gusts (>30 mph) along the Sierra Front. Table 2 shows the potential for peak wind gusts to exceed 30 mph at KRNO for the LOL-TRK gradient values below the mean, greater than the mean, greater than one standard deviation and two standard deviations above the mean. The study shows that two-thirds of the events where the LOL-TRK thermal gradient exceeds the mean value of 15^{o}F produce peak gusts of 30 mph or more at RNO. The chance of gusts exceeding 30 mph increases to 84% when the LOL-TRK gradient reaches 19^{o}F or 1 standard deviation above the mean. The gradient-RNO peak wind gusts correlations are similar for the other gradient pairs, LOL-TVL, NFL-TRK, and NFL-TVL. These results provide forecasters with statistical confidence on the wind gusts at RNO exceeding Red Flag thresholds.

Following the study a tool was created for the Graphical Forecast Editor (GFE) to help raise forecaster awareness of the correlation between the strength of the thermal gradient and forecast wind gusts along the Sierra Front. The tool calculates four days of thermal gradients for LOL-TRK, LOL-TVL, NFL-TRK and NFL-TVL by using all available model and official maximum temperature forecasts. The output is displayed in a color coded table based on where the gradient falls in relation to the mean, +1 standard deviation and +2 standard deviations derived from in the study. The tool also searches the official wind gust grids and displays the number of points in the Sierra Front exceeding 25, 30 and 35 mph (Fig. 6).

After running the tool, forecasters can quickly access the potential strength of the thermal gradients and how they correspond to the wind gust forecast. This information gives forecasters an initial idea on how to modify the forecast if wind gusts are too low in the presence of model agreement on a high thermal gradient day.

Acknowledgments

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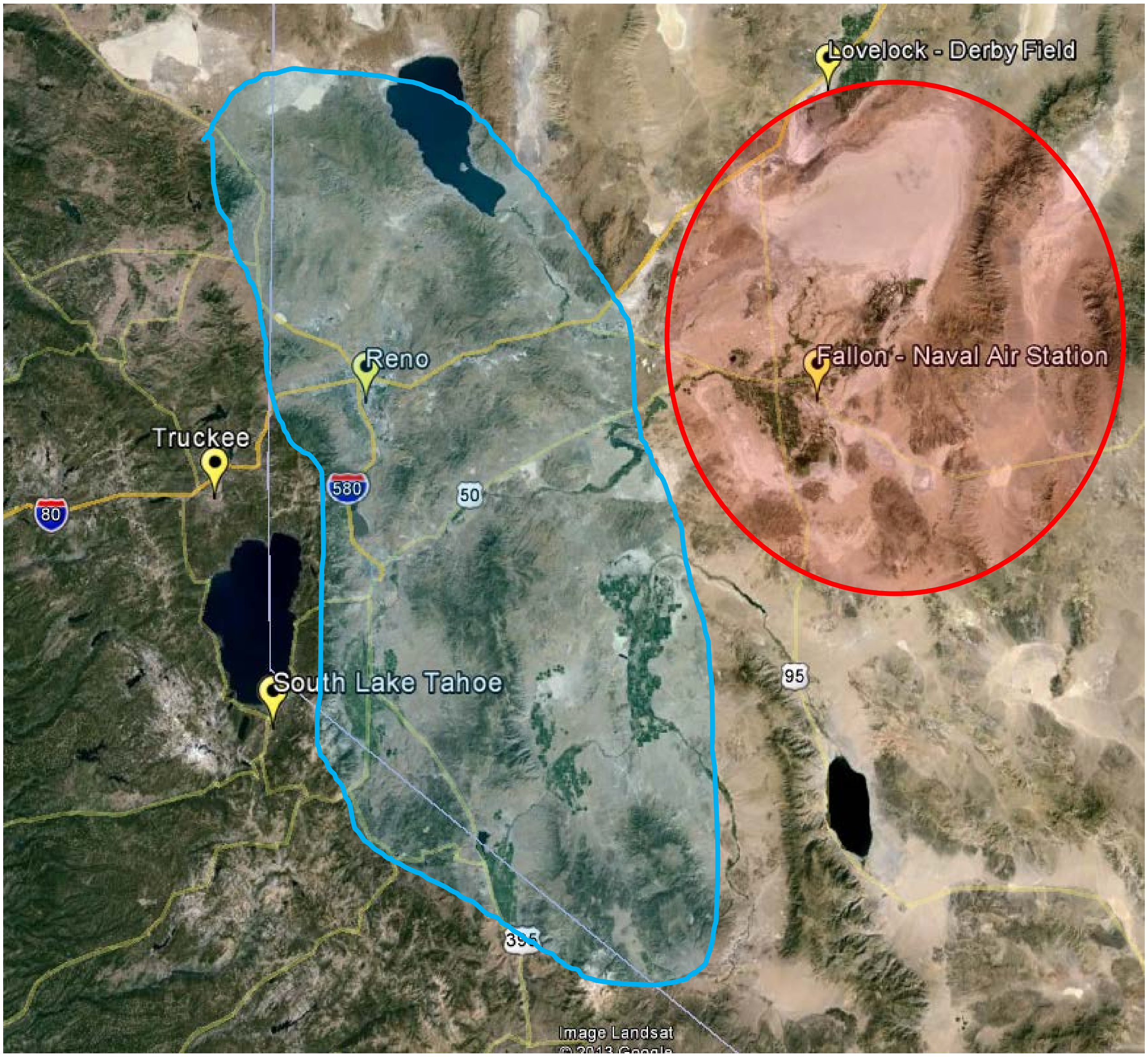

Figure 1. Map of the Sierra Nevada and western Nevada with the Sierra Front region shaded in blue and the Carson and Humboldt Sinks shaded in red. Observation sites used in this study are denoted by yellow markers.

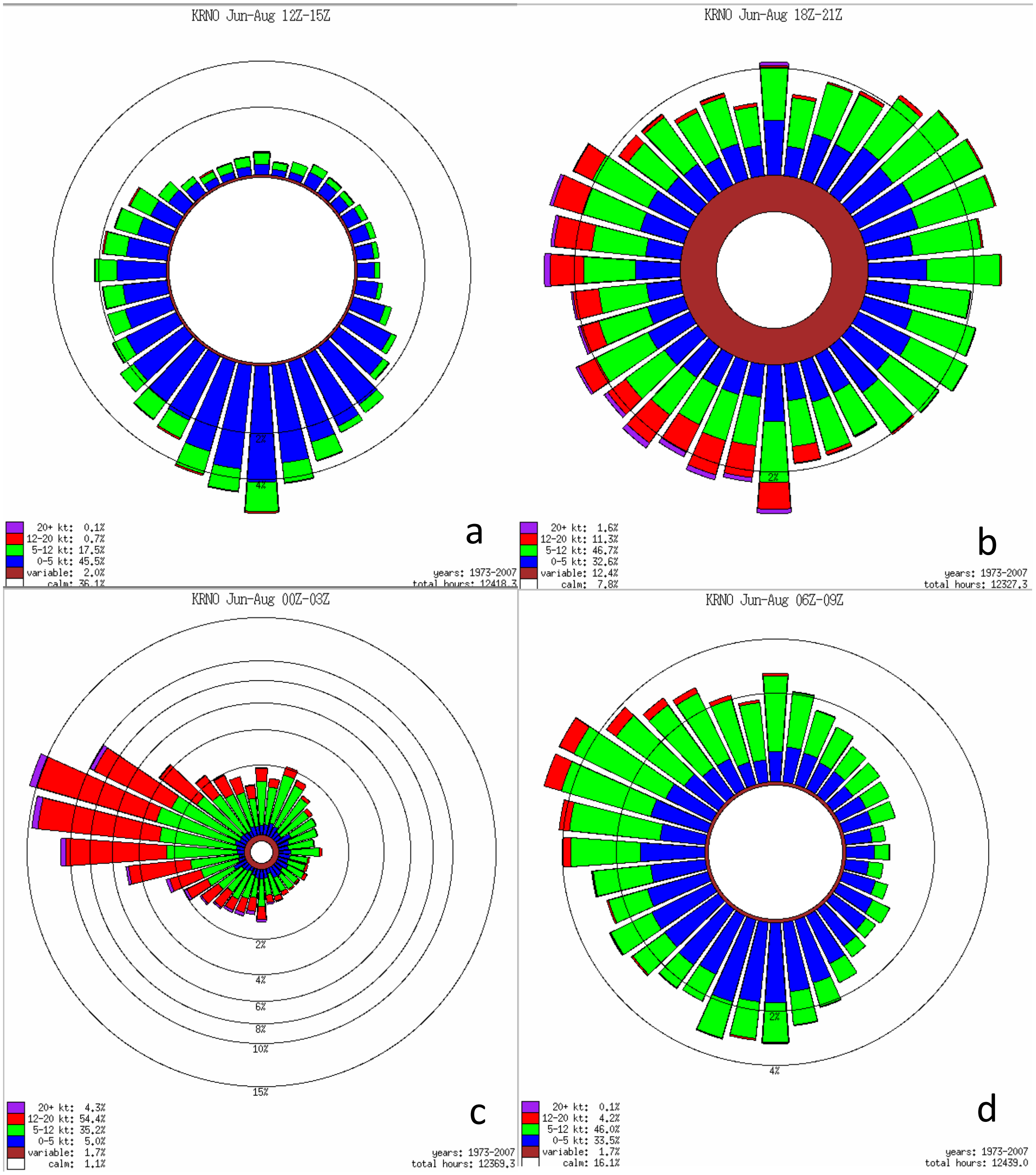

Figure 2. RNO wind roses (speed in knots) valid June- August 1973-2007. (a) 12-15 UTC, (b) 18-21 UTC, (c) 00-03 UTC and (d) 06-09 UTC.

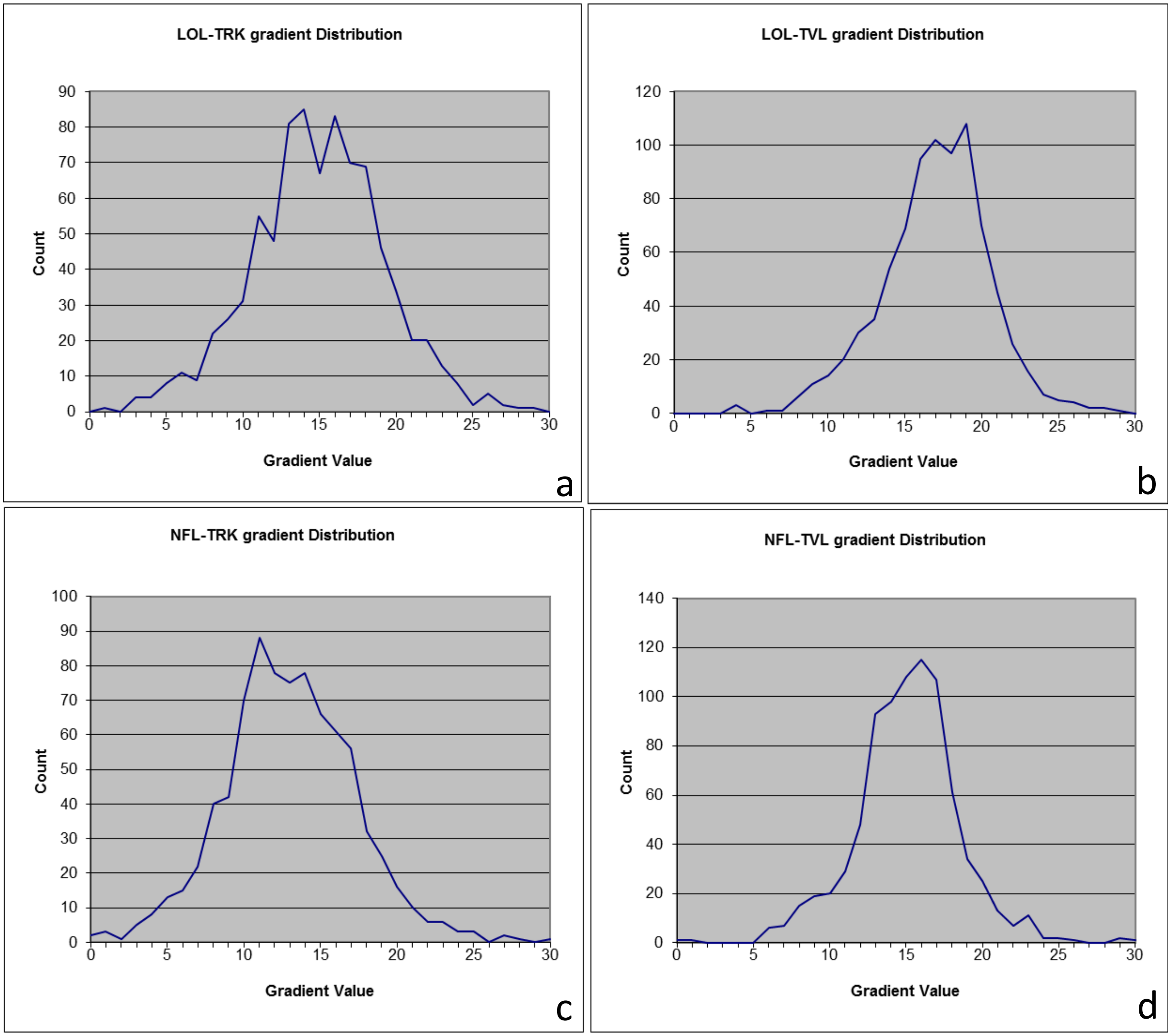

Figure 3. Histograms of the of the (a) LOL-TRK, (b) LOL-TVL, (c) NFL-TRK and (d) NFL-TVL thermal gradients (^{o}F) for June, July and August 2000-2012.

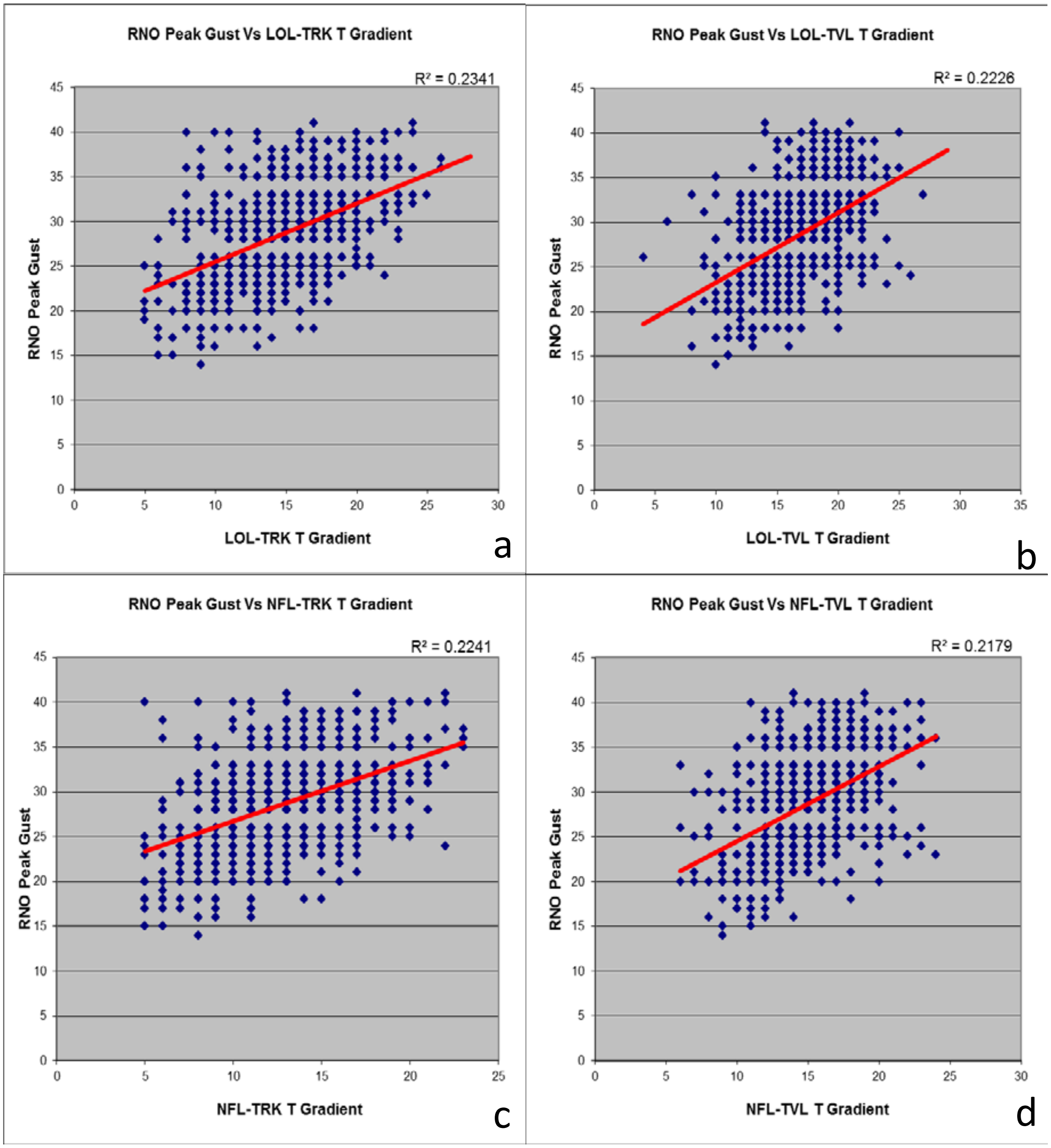

Figure 4. Scatter plots of the thermal gradients (°F) for (a) LOL-TRK, (b) LOL-TVL, (c) NFL-TRK and (d) NFL-TVL against the RNO peak wind gust (mph). The red line in each graph is the linear regression with the r-squared score to the upper right of the graph.

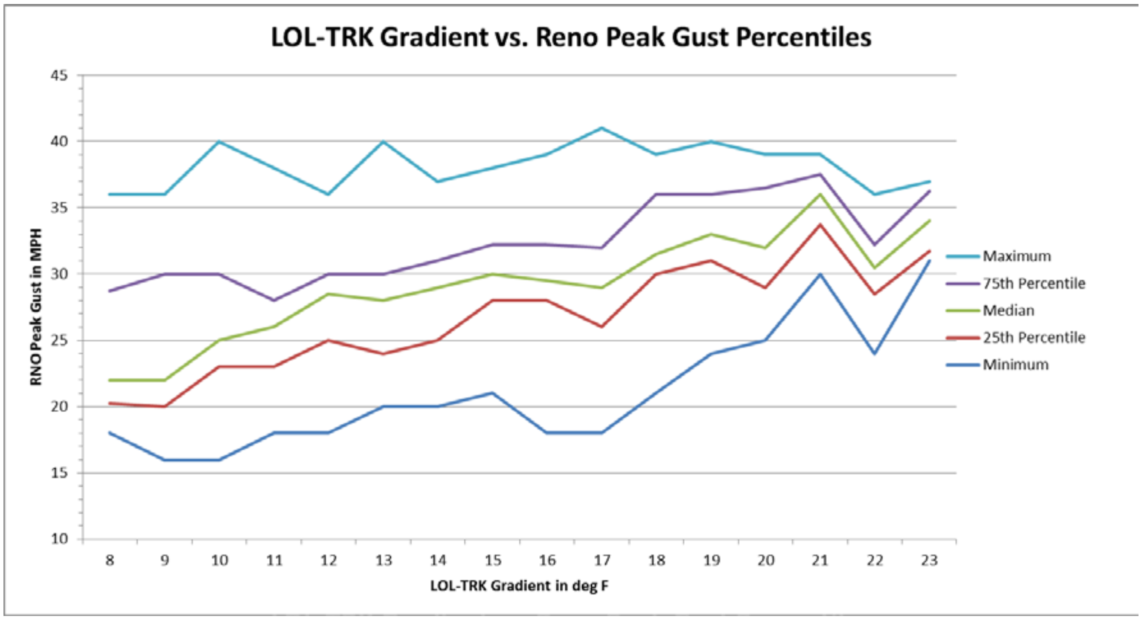

Figure 5. Percentile values of the RNO peak gusts for each value of the LOL-TRK thermal gradient.

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+++++  Sierra Front Thermal Gradients for Wednesday 08-07
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 Model                LOL-TRK    LOL-TVL    NFL-TRK    NFL-TVL
 ADJECE                    19         23         17         21
 ECMWF                     17         21         17         21
 ECMWFBC                   17         18         16         17
 ADJECEBC                  16         19         16         19
 BCCONSAll                 16         18         15         17
 BCCONSRaw                 16         18         15         17
 GFS40BC                   15         18         13         16
 BCCONSMOS                 15         17         15         17
 WModel                    15         17         15         17
 ADJMEXBC                  15         17         14         16
 BCAllBlend                15         17         14         16
 Fcst                      15         17         13         15
 CONSRaw                   14         18         14         18
 AllBlend                  14         17         13         16
 CONSAll                   14         17         13         16
 CONSMOS                   13         17         11         15
 GFS40                     13         16         13         16
 ADJMEX                    13         14         12         13
 NAM12                      0          0          0          0
 NAM12BC                    0          0          0          0
 ADJMET                     0          0          0          0
 ADJMETBC                   0          0          0          0
 MOSGuide                   0          0          0          0
 MOSGuideBC                 0          0          0          0
 MOSG25                     0          0          0          0
 MOSG25BC                   0          0          0          0
 SREF                       0          0          0          0
 SREFBC                     0          0          0          0
*** Percent of points Exceeding Gust Value
 Gust > 25 mph              0
 Gust > 30 mph              0
 Gust > 35 mph              0
 Max Gust                   0
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Figure 6. Sample output for the Graphical Forecast Editor Sierra Front Thermal Gradients tool, showing the columns for the gradients pairs and the gradient value (^{o}F) for each model source. At the bottom is the percentage of points in the Sierra Front where the forecast gust values exceed 25, 30 and 35 mph.

	LOL-TRK	LOL-TVL	NFL-TRK	NFL-TVL	RNO Peak Wind Gust
Mean	15	17	13	15	29
Standard Deviation	4.4	3.6	4.3	3.4	6.5

Table 1. Mean and standard deviation values (^{o}F) for the thermal gradient pairs and the RNO peak wind gusts (mph).

LOL-TRK Gradient	Gradient < mean	Gradient >= mean	Gradient >= 1 Std. Dev.	Gradient >= 2 Std Dev.
Total Days	233	202	57	13
Days Peak Gusts >=30	69	131	48	12
% Gusts >=30	30	65	84	92

Table 2. The number of events and the percent chance of peak gusts exceeding 30 mph at RNO for the LOL-TRK gradient values below the mean, greater than or equal to the mean, one standard deviation above the mean and two standard deviations above the mean.