# HOUR-BY-MONTH" CLIMOGRAMS AS A PLANNING, DECISION-AID, AND GENERAL INFORMATION TOOL IN THE VISUALIZATION AND INTERPRETATION OF EXTREME TEMPERATURE, WIND SPEED, AND RELATIVE HUMIDITY DATA

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## 1. INTRODUCTION

The following describes and illustrates the use of "hour-by-month" climograms as a means of visualizing and interpreting single-station extreme hourly temperature, wind speed, and relative humidity data. A visual analog to the topographic map, the climogram scheme has calendar month comprising the y-axis, and hour of the day the x-axis. Upon the grid, a parameter of interest's diurnal/monthly variation is depicted by contours, shadings, vector arrows, etc. In addition, sunrise/sunset demarcation lines are overlain, lending an extra physical perspective to the patterns.

Previous studies (Fisk, 2004, 2008, 2009, and 2010) demonstrated hour-by-month climograms' use in portraying monthly and diurnal variations in means, percent occurrence frequencies, mean vector wind orientations, median ceilings' heights, and other types of statistics. Climatological extremes, however, were not explored, and these may be of interest in some cases. Accurate construction of such charts, however, is potentially more complex, as the uncertain nature of some parameters' distributions, (bounded on one side?, skewed?), which express themselves to a large degree in the tail regions, implies that application of conventional "rule-of-thumb" standard deviation multiples (e.g., "plus or minus two-sigma", "plus-or-minus three sigma, etc.) to produce exceedance threshold estimates may not be realistic or valid. Indeed, arising from real, natural physical causes, a wide range of parameter shape/ spread distributional properties might be present across the 288 possible "hour"/"month" combinations whose statistics make up a given climogram. Therefore, to attempt to insure a more representative identification of parameter values at specified threshold levels, some sort of pre-processing approach is necessary. One strategy might be *percentile rankings*, by hour and month (288 separate arrays of ranked values with percentiles attached to each individual observation). The extremes' climogram for a given percentile level (e.g., "upper 99$^{th}$ percentile") would be based on data extractions for that level from each of the 288 arrays, such as to create a single array of 288 "upper 99$^{th}$ percentile" magnitude statistics for each hour/month combination.

To demonstrate examples, climograms of extremes in temperature, relative humidity (low), and sustained wind speed (high) will be constructed at the 99th and 1st percentile levels for a selection of stations.

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The original motivation for the study came from familiarity with a number of coastal California stations' extreme temperature characteristics relative to month and hour. The State's physical setting, including coastal mountain ranges/ passes bordered by interior basins on the east and a cold ocean current on the west, results in some unusual hour/month extreme temperature patterns (especially warm ones) over the course of the year for localities immediately along the coast. To portray these patterns through the climogram approach, specifically, and to demonstrate the method in general as a graphical analysis tool, a series of charts focusing on upper 99th percentile threshold hour vs. month temperatures are constructed for a selection of stations. Not to exclude anomalously low temperatures, a series of lower 1st percentile climograms are presented also, but they do not show the same peculiar bent, at least for those few stations at which they were experimented with.

Temperature, of course, is not the only meteorological parameter, the extremes of which are of operational interest and importance, so the scope of the investigation is expanded to include relative humdities (low) and sustained wind speeds (high). A collection of both domestic and international stations' data are included for this purpose.

## 2. METHODS AND PROCEDURES

Hourly observations for a given station of interest were downloaded, decoded, and quality controlled from the online NCDC Integrated Surface Hourly Data Set. Those for the parameter of choice were then sorted by month and hour with percentile rankings assigned. Finally, those values corresponding to the 99th or 1st percentile rankings, respectively, were identified, extracted, and assembled into 99th and 1st percentile files that would serve as input for the climograms. In the graphs, the extremes were positioned at month number midpoints (1.5 for January, 2.5 for February, etc.) by hour, smoothed slightly, and spherically kriged. For comparison purposes, included also would be climatological Hourly Means Climograms

Contrasting color schemes are adapted for the three different parameters (Temperature, Relative Humidity, and Sustained Wind Speeds), and for the Relative Humidity and Sustained Winds variables, different color schemes are also utilized for their respective extremes and climatological means charts. The customary sunrise/sunset demarcation curves appear for all the climograms.

## 3. RESULTS

### *3.1. Extreme Hourly Temperatures' Climograms*

For the hourly temperature extremes application, five sample climogram sets are described and discussed, those for the four California stations Point Mugu Naval Base, Los Angeles International Airport (LAX), Santa Maria Municipal Airport, San Francisco International Airport, plus Boston, MA. International Airport (Logan). Mean Hourly Temperature climograms are included along with the 99th and 1st Percentile charts to afford additional interpretative insights.

#### *3.1.1 - Point Mugu Naval Base , CA. (near Oxnard) Lat: 34° 07' N; Lon: 119° 07' W; Elev: 13*

Point Mugu, CA. is a Naval Base situated on the southeastern edge of the Oxnard Plain in Ventura County, adjacent to the Santa Monica Mountains' western terminus. The contour patterns of its upper 99th percentile extreme warmth climogram (Figure 1) are visibly more complex than that of its counterpart mean hourly chart (Figure 2), with displacement of

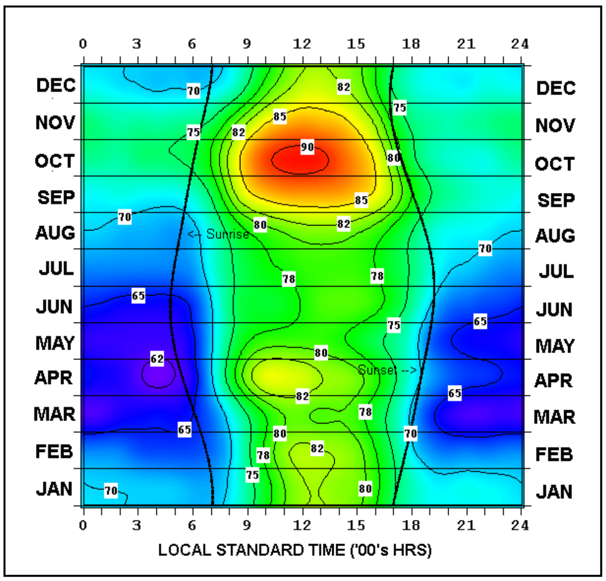


**Figure 1**. Upper 99th Percentile Temperature Climogram (Deg F) for Point Mugu, CA (1946-2013 Period of Record)

high temperature contour magnitudes to times of the year not customarily associated with warm levels. Highest isopleth (90F) is centered in approximately mid-October for the hours 10AM to 2PM at the widest, a calendar interval several weeks *after* the autumnal equinox. Isopleths of 80 F or higher extend over a wide range of hours through the close of the calendar year, into January and through April; none, interestingly, are present for June and July (at least not for the 99th percentile level).

Inspecting Figure 2, a seasonal lag feature in maximum mean hourly temperature is evident (71 F contour covering roughly early August to mid-September for the early afternoon hours), but no indication of the October extreme 99th percentile maximum , or the secondary maxima features over January to April. Some of April's 82 F coverage extends to as early as 9AM, just several hours after sunrise.

Much of this pattern incongruity is related to the seasonal occurrence frequencies of Santa Ana winds, strong, extremely dry downslope offshore winds that affect coastal Southern California. They can be hot or cold, depending on the prevailing temperatures in the Great Basin and upper Mojave Desert source regions. Their frequencies vary by month, being highest in Fall and Winter, but have occurred in all months except July and August at Pt.Mugu.

Santa Ana episodes in Fall can produce very warm temperatures at the coast as the source regions are still quite warm themselves, the resulting adiabatic warming associated with the descending flows through the passes and canyons frequently producing the highest temperatures of the year. For example, based on the 1946-2013 period of record at Point Mugu, the record highest temperatures for October and November are 105 F and 100 F, respectively; that for July is only 93 F.

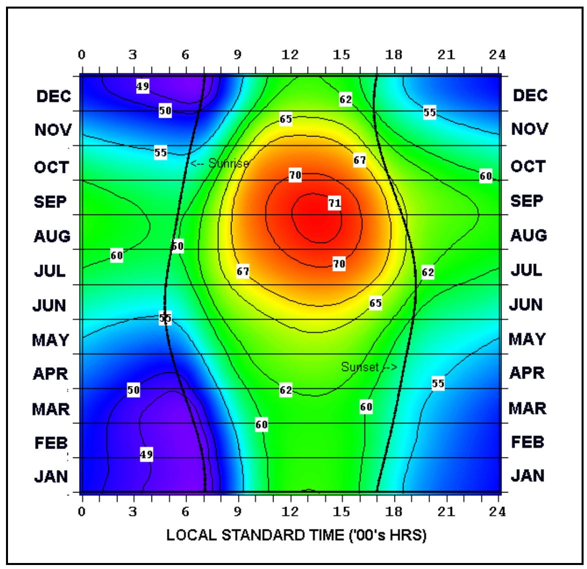


**Figure 2**. Mean Hourly Temperature Climogram (Deg F) for Pt. Mugu (1946-2013 Period of Record)

Highest extreme temperatures for the non-daylight hours at the 99th percentile level (70 F to 75 F ) are seen not in summer, but fall and winter! (see Figure 1), reflecting carryover effects of Santa Ana warm wind episodes that have persisted through midnight of the preceding day or whose onset have come prior to sunrise. Curiously, the lowest isopleth (62 F) is situated for the pre-dawn hours (0400 and 0500 LST) in April, attributable to the fact that mean sea surface temperatures offshore are at their climatological coolest levels at this time of year, coupled with the much rarer likelihood (at the 99th percentile level) of overnight Santa

Ana episode carryovers or onsets prior to dawn. April Santa Ana's frequently commence in the mid-morning hoursl, reflected by the secondary maximum 82F isopleth encompassing roughly 9AM to 1PM. While typically more short-lived diurnally at this late season, they are potentially warmer than those in the preceding months, as sun angles are higher and the source regions warmer

Point Mugu's Figure 1 pattern is one of the best case examples of the effects of downslope wind incidence in "skewing" individual hours' temperature distributions,

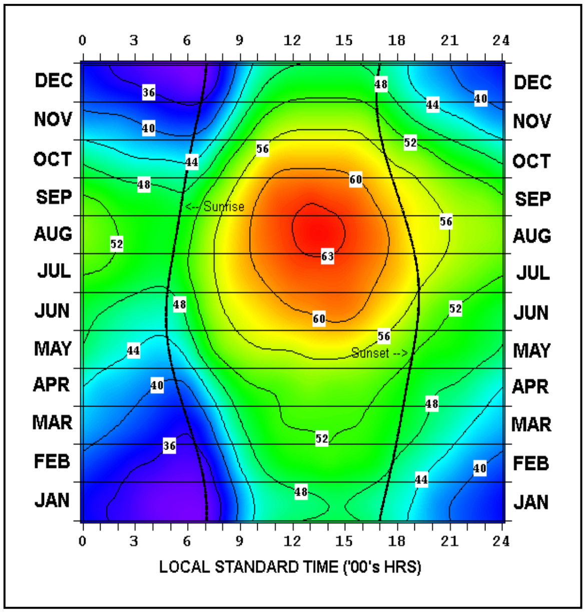


**Figure 3**. Lower 1st PercentileTemperature Climogram (Deg F) for Pt. Mugu (1946-2013 Period of Record)

especially in the warm direction. Interestingly, the one-on-one correlation of the 288 individual 99$^{th}$ percentile data points with those of the hourly means is only +.768; a more typical figure should be well above +.900.

Figure 3 shows the Lower 1st Percentile Temperature Climogram for Point Mugu. Its configuration shows a much greater alignment to the Figure 2 pattern, as different primary processes are at work (mostly radiative cooling as opposed to adiabatic warming) in producing the opposite character extreme temperature data points. Minimum 1st Percentile isopleth (36 F) covers the early morning hours of December to February, no surprise here as these are the winter months. The maximum contour (63 F), matches very well in placement with the corresponding feature in the Figure 2 chart. Correlation with the hourly means is much higher: +.968.

As an additional illustration of the asymmetric nature of Point Mugu hourly temperature distributions across the 288 hour/month combinations, Figure 4 is a climogram depiction of the actual skewness coefficients. Except for an area covering most of the pre-sunrise mid-May through August hours back to midnight, along with an hour or so extension past the daylight side of sunrise, all of the contours reflect positive values, indicative that the character of the hourly temperature anomalies are skewed to the warm values. Some of the contour magnitudes are quite pronounced, exemplified by the +1.70 isopleth situated for the late-morning hours over much of April.

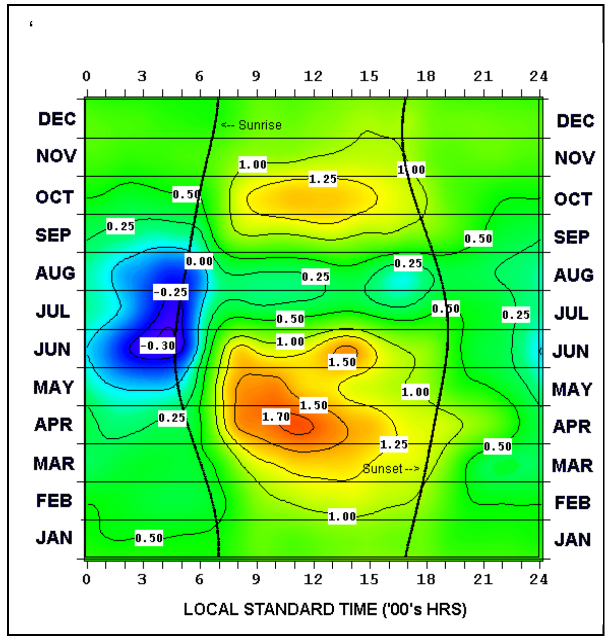


**Figure 4**. Skewness Coefficients' Climogram for Pt. Mugu Hourly Temperatures (1946-2013 Period of Record)

### *3.1.2 - Los Angeles International Airport (LAX) - Lat: 33° 56' N; Lon:118° 23' W; Elev: 100*

The Los Angeles International Airport (LAX) station is located about 50 miles southeast from Point Mugu, along the Pacific Ocean coastline. Subject to the same general seasonal offshore flow tendencies, it displays a similar configuration of upper 99$^{th}$ percentile contours (see Figure 5 below) but with a few minor contrasts..

Highest (warmest) contour (94 F) encompasses the mid-September to mid-October calendar interval, but at a more oblique orientation (1000 to 1200 LST contour boundary in mid-September, a 1100 to 1300 LST one for mid-October), possibly reflection of a stronger sea-breeze effect in September. Like Point Mugu, this feature is not hinted at from the LAX Mean Hourly Temperature Climogram (Figure 6), which displays a maximum mean contour of 74 F covering August, essentially, for the hours 1100 to 1400 LST, inclusive. In further contrast to Point Mugu, the LAX minimum contour (64 F) is not localized to April, but instead covers the pre-sunrise hours of December to March back to about 2AM. Also, the "suppression" of June and July higher magnitude 99th percentile temperatures for Point Mugu is not seen for LAX. A secondary maximum late-morning April feature (84 F) is present also for LAX, but a duplicate 84 F magnitude contour is also evident covering a significant number of June and July hours as well. Linear correlation between LAX's 99th percentile values and its climatological hourly means is +.869.

The Lower 1st Percentile contours for LAX (Figure 7), like those for Point Mugu, are very much aligned in form with those of the Mean Hourly Temperature chart (Figure 6). Magnitudes range from 38 F (several hours immediately preceding sunrise in January) to 64 F (late July through August for roughly 11AM to 3PM). The correlation figure is up to +.934.

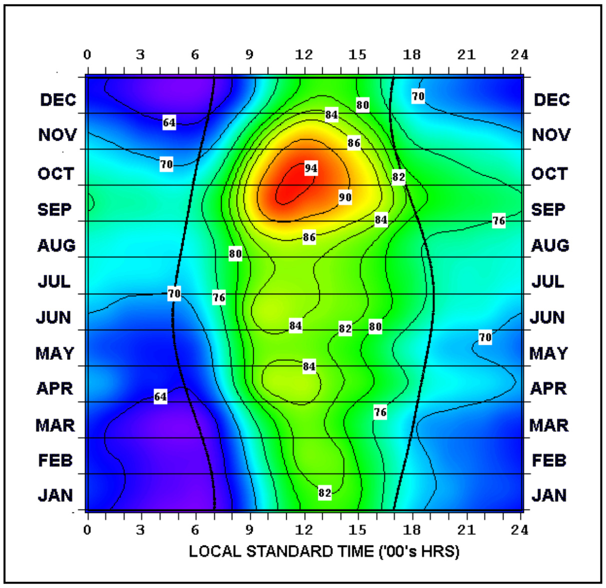


**Figure 5**. Upper 99th Percentile Temperatures Climogram (Deg F) for LAX (1949-2013 Period of Record)

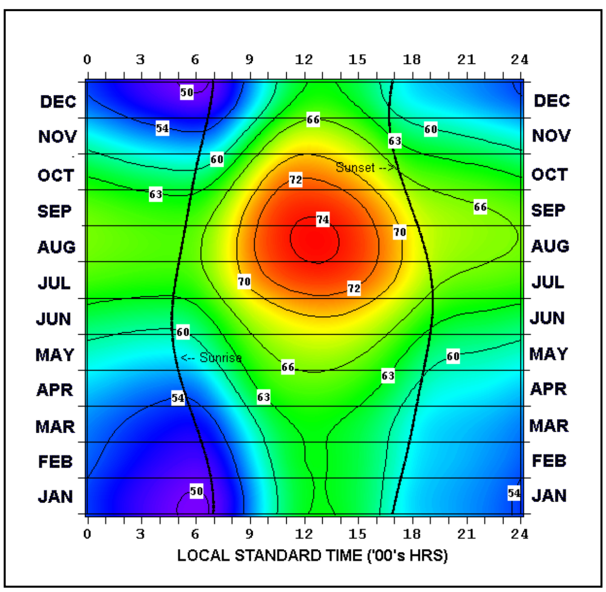


**Figure 6**. Mean Hourly Temperature Climogram (Deg F) for LAX (1949-2013 period of record)

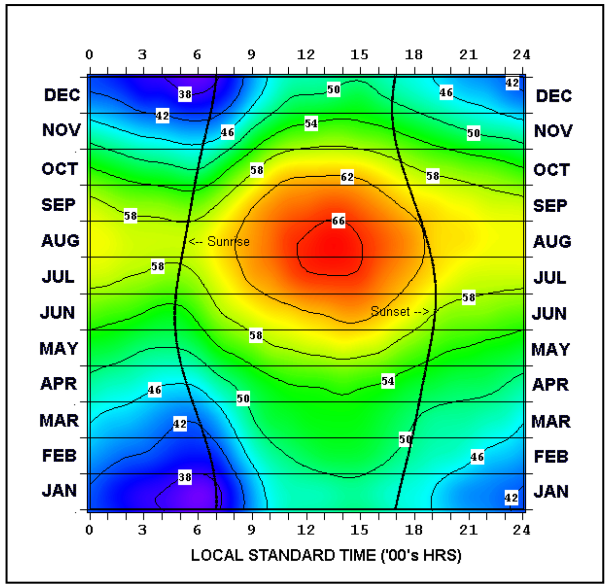


**Figure 7**. Lower 1st Percentile Temperatures Climogram (Deg F) for LAX (1949-2013 Period of Record)

### *3.1.3 –Santa Maria Municipal Airport - Lat: 34° 54' N; Lon: 120° 27' W; Elev: 269 ft*

Santa Maria Airport, CA., located about 100 miles northwest of Point Mugu, is situated in a ten-mile wide valley, open to the Pacific Ocean about 15 miles to the west.

The Figure 8 Upper 99th Percentile Temperature climogram shows the same early Autumn warm feature seen for Point Mugu and Los Angeles, in the form of a 93 F contour covering late September to mid-October for the hours 1100 to 1300 LST. The secondary April maximum seen for Point Mugu and LAX has morphed into a more extensive feature extending towards summer, in particular the 88 F contour displayed for June, encompassing 0900 LST to just after Noon. The June feature likely reflects infrequent offshore flow episodes from the interior areas (of which are quite hot in June), coming down the Santa Maria river valley. Sea-breeze influences, however, are responsible for confining the maximum contours to Noon or earlier, especially for June. The slightly lower isopleths for July and August reflect the greater predominance of onshore flow during these months, lessening the likelihood of high 80's occurrences in Santa Maria at the 99% level.

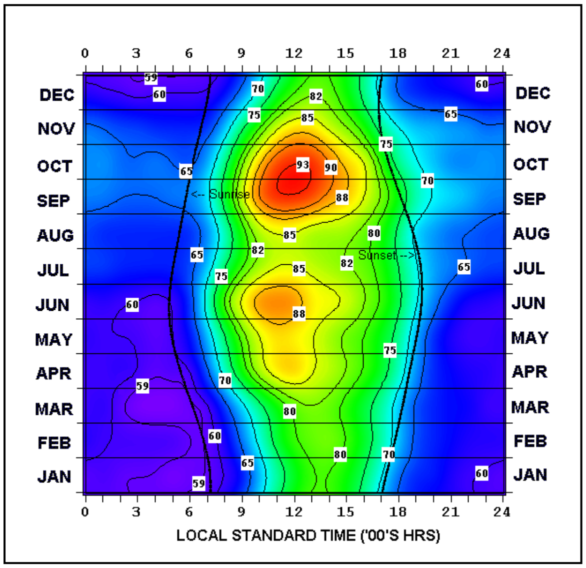


**Figure 8**. Upper 99th Percentile Temperature Climogram for Santa Maria, CA (1948-2013 Period of Record)

Lowest magnitude contour in Figure 8 (59 F) extends back from sunrise to about 3AM, especially for January and March. The 60 F boundary extends a few hours further back hourwise, and stretching seasonally all the way into June, reflecting the climatologically cool sea sea-surface temperatures, and their gradual warmup tendencies over this time of the year.

Comparing Figure 8 to the Mean Hourly Temperature Chart in Figure 9 below, the early autumn maximum feature could perhaps be deduced, but not the Spring to early Summer secondary one. It's not likely either that the relatively late seasonal extension of the (cool) 60 F contours could be inferred from Figure 9's config-urations. Nonetheless, the correlation between the Santa Maris upper 99th percentile temperature figures and those of the climatological means (+.936) is higher than that either Point Mugu or Los Angeles.

The Lower 1st Percentile climogram (Figure 10 below) essentially displays the same contour pattern form as that of Figure 9 (one-on-one correlation: +.962), although Figure 10's maximum contour (62 F) extends only to early September, that for Figure 9 extending into early October. Santa Maria has the potential for freezing temperatures in winter, as indicated by the fairly expansive 30 F contour area covering a number of pre-dawn hours in December, January, and February, not to mention a smaller 27 F area encompassing a few hours immediately preceding sunrise over late December thru early January.

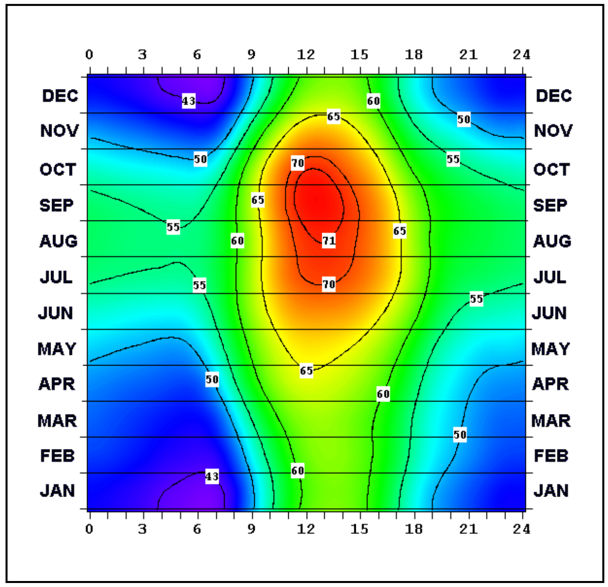

**Figure 9**. Mean Hourly Temperature Climogram (Deg F) for Santa Maria, CA (1948-2013 Period of Record)

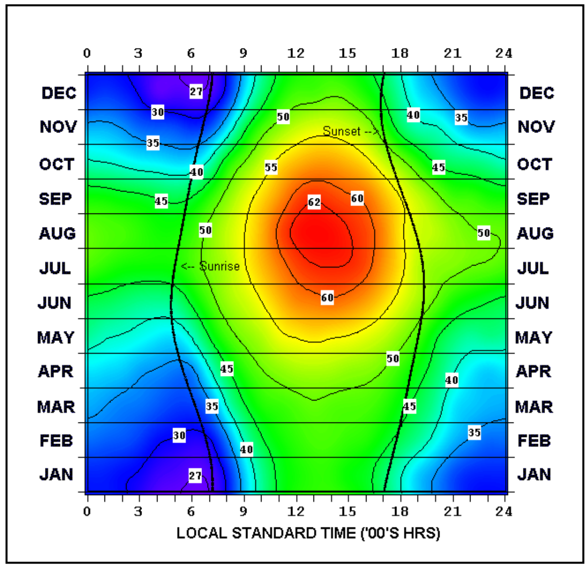


**Figure 10**. Lower 1st Percentile Temperature Climogram (Deg F) for Santa Maria, CA (1948-2013 Period of Record).

*3.1.4 : - San Francisco WSO- Lat: 37° 37' N; Lon 122° 23' W; Elev: 21 ft. (San Francisco Int'l Airport).*

San Francisco International Airport, located 260 miles northwest of Santa Maria, experiences warm offshore flow also, almost exclusively originating from the California Central Valley.

Its Upper 99th Percentile Temperature Climogram (Figure 11) displays a further pattern morphing to a "double-pole" of 90 F contours, three hours wide at the greatest extent, for June and September. The June feature also appears to be centered (between 1300 and 1400 LST), about one hour earlier than September's. The likely explanation is that local surface pressure gradients are more predominantly onshore during July and August, and while there are occasional lulls in which flow might be offshore from the hot Central Valley, they are less frequent, thus 90 F and higher contours for July and August can only be expressed in a climogram depicting higher than 99 percent exceedance levels. Not to say that extreme heat cannot occur in July and August, record highest San Francisco Int'l Airport temperatures for the individual months June through September, inclusive, are 104 F, 104 F, 99 F, and 99 F respectively.

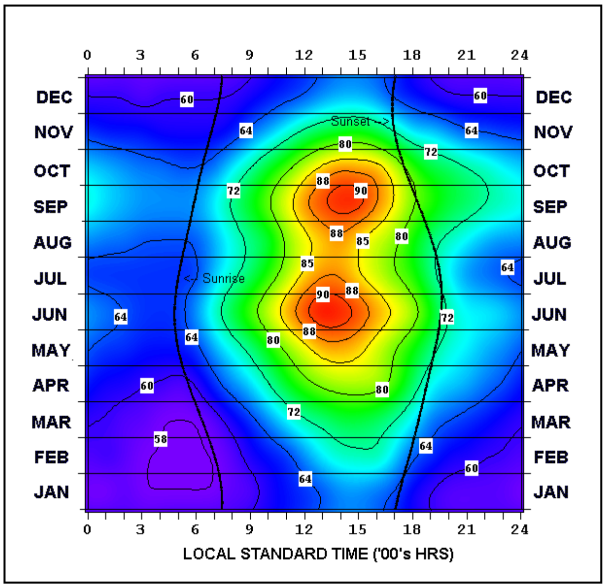


**Figure 11**. Upper 99th Percentile Temperature Climogram (Deg F) for San Francisco (1949-2013 Period of Record)

Lowest isopleth in Figure 11 (58 F) covers a collection of pre-dawn hours over roughly mid-January to mid-March. Compared to the San Francisco mean hourly chart (Figure 12 below), the 99th Percentile chart has its October relative maximum 90 F feature in alignment with the means' chart's 70 F relative maximum feature, but the June extremes element cannot be inferred from Figure 12. Aside from this, the appearances of the two charts are quite similar in form. One-on-one correlation of the 99th Percentile temperatures with the hourly means is +.949, a bit higher still compared to the figures for Point Mugu, Los Angeles, and Santa Maria.

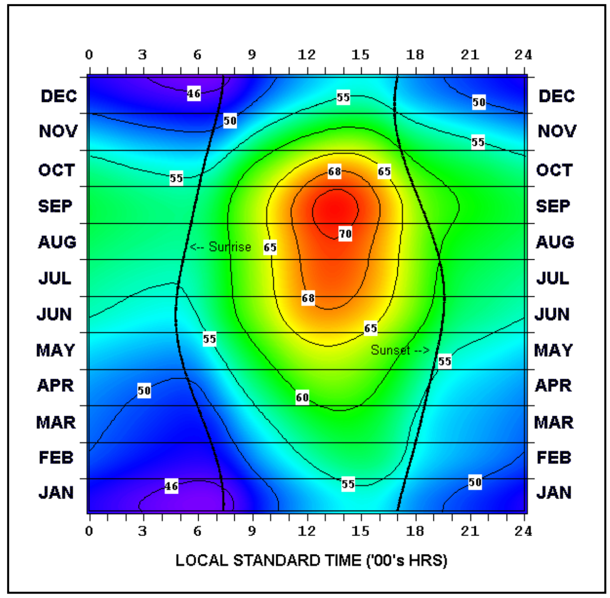


**Figure 12**. Mean Hourly Temperature Climogram (Deg F) for San Francisco (1949-2013 Period of Record)

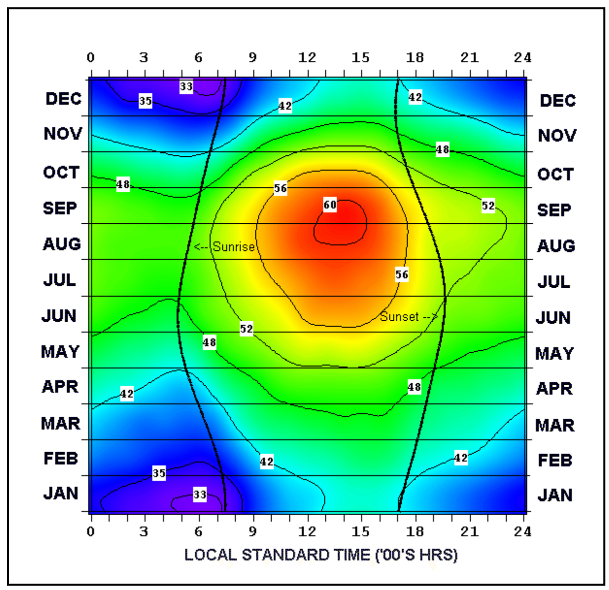


**Figure 13**. Lower 1st Percentile Temperature Climogram (Deg F) for San Francisco, CA (1949-2013 Period of Record)

The Lower 1st Percentile chart also has contour configurations similar to those of the means chart (Figure 12). Minimum relative contour (33 F) is confined to the late December to mid-January period for a several hour interval just before sunrise, and the maximum (60 F) covers mid-August to late September from about Noon to 1500 LST. Correlation of the San Francisco lower 1st percentile temperatures with the corresponding mean hourlies is +.960.

*3.1.5 - Boston (Logan Int'l Airport), MA Lat: 42° 36' N; Lon:71°00' W; Elev:20 ft*

Not to be confined to California stations only, the analysis moves Boston, MA (Logan Int'l Airport). Figures 14 to 16 show the Upper 99th Percentile, Mean Hourly, and Lower 1st Percentile Climograms respectively.

Figure 14 shows none of the pattern asymmetries evident for the coastal California stations. The Boston maximum contour (96 F) exhibits slight seasonal/diurnal lags, being offset to July (a bit after the summer solstice) and also into the afternoon hours. Minimum contour (53 F) is predominantly a February feature, extending from (2000 LST), overnight, and to 0900 LST of the "following" morning. Overall pattern of the chart also conforms very well to the hourly means chart in Figure 15, the one-on-one correlation +.968. The same holds true for the Lower 1st Percentile chart. Range of values is from 2 F for about 0300 to 0800 LST over early January to early February, to 62 F for mid-July to early August from 1100 to 1400 LST. The one-on-one correlation with the hourly means is +.991.

Although only an exhaustive study could confirm this for sure, it is probably true that the symmetries, lags, and high correlations exhibited by the Boston 99th and 1st percentile temperature extremes vs. corresponding mean hourly climatological figures are typical of most stations in the continental U.S., especially those not located in regions of complex topographies which feature occasional downslope winds from source regions of significantly higher elevation or those relatively similar in elevation but markedly different in temperature character.

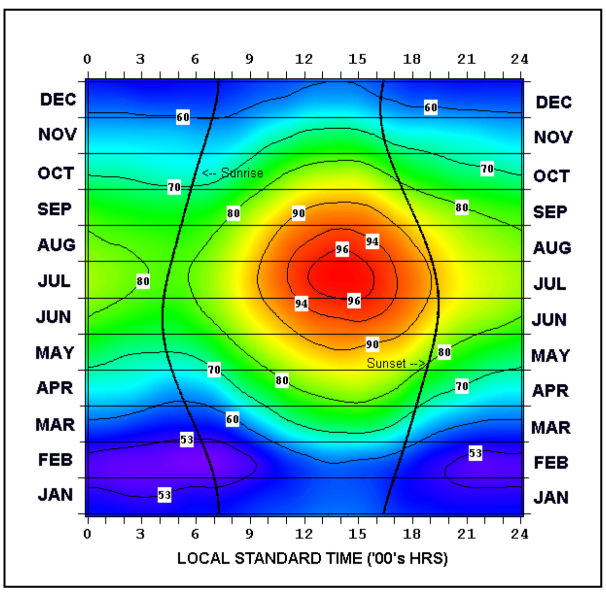


**Figure 14** Upper 99th Percentile Temperature Climogram (Deg F) for Boston, MA (1945-2013 Period of Record)

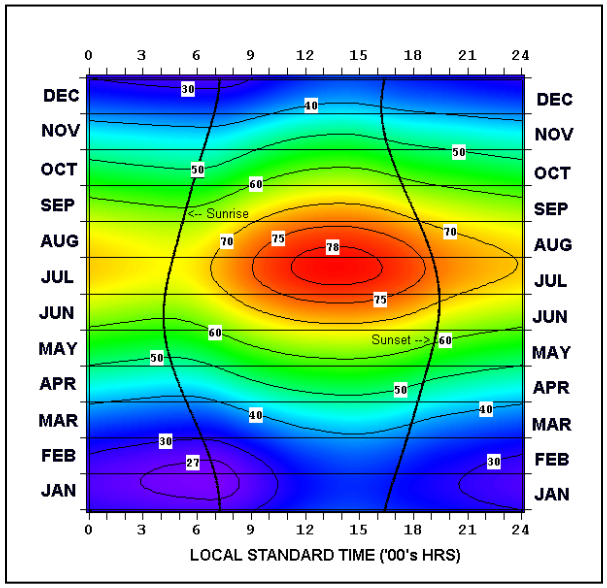


**Figure 15**. Mean Hourly Temperature Climogram (Deg F) for Boston, MA (Period of record 1945-2013)

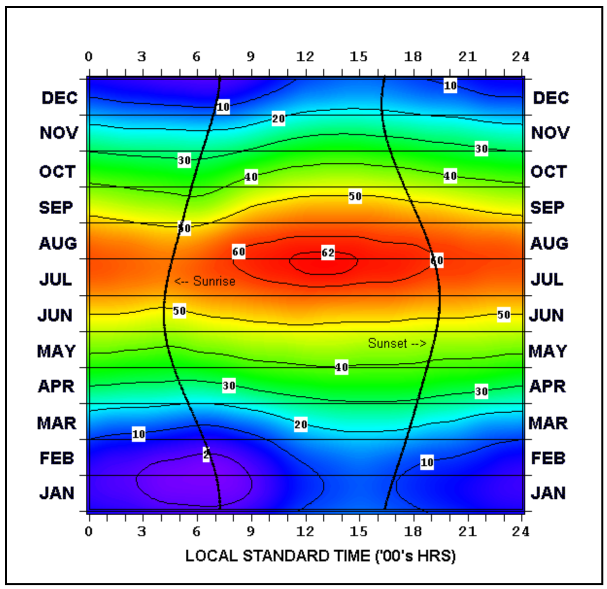


**Figure 16**. Lower 1st Percentile Temperature Climogram (Deg F) for Boston, MA (1945-2013 Period of Record)

*3.2. Extreme Hourly Relative Humidity Climograms*

The Relative Humidity variable lends itself readily to percentile ranking treatment as it is bounded on both sides (0 to 100 percent range) and is likely distributionally skewed or peaked frequently  Except for perhaps desert stations, an upper 99th percentile analysis would be likely trivial, as most stations' hour/month combinations attain100% humidity values (or values at least close to these) at frequencies that could not be considered rare. Extremely low relative humidity magnitudes, however, undoubtedly exhibit more variation by hour/month and between stations, so a Lower 1st Percentile chart should have greater illustrative and insightful value. Thus, to demonstrate, a set of Lower 1st percentile relative humidity climograms and companion hourly means charts are constructed for four stations: Los Angeles (LAX). Seattle-Tacoma Int'l Airport, Miami Int'l Airport, and Boston, MA. (Logan Int'l Airport).

*3.2.1 - Los Angeles International Airport (LAX) - Lat: 33° 56' N; Lon:118° 23' W; Elev: 100*

Figures17 and 18 below show the Lower 1st Percentile and Mean Relative Humidity climograms, respectively, for Los Angeles International Airport.

Large inter-season contrasts in magnitudes are shown in Figure 17. Most of the months, January through April, and October through December have the potential for extremely low humidities for all hours of the day , reflecting, of course, episodes of offshore flow. An exceptionally low 8% isopleth covers roughly late October to mid-November for the hours 1100 to 1300 LST, and the 10% contour is fairly expansive , encompassing October thru January from the late morning hours to late afternoon (1600 LST). For the early months of the year, the 15% isopleth, also, extends from 0900 LST to past sunset in January, but only to noon at the end of April, reflecting the greater tendency for offshore flow episodes to be cut short by sea-breeze intrusions. For the summer months (June-August) marine layer/sea-breeze influences exclusively hold sway, the extreme one-percent low humidities magnitudes not really "low" at all, as evidenced by the 74% isopleth for several pre-sunrise hours in July

From the Figure 18 hourly means pattern, there is no inferring of the exceptionally low levels over much of Figure 17. Mid-day average humidities from mid-November to December are somewhat lower (around 50 %) than those of the summer months (between 60% and 65%), nocturnal means down to the upper 60's to low 70's compared to the 80's in summer, but overall the Means' pattern seems more of a mixed diurnal/seasonal one. In consequence, The LAX one-on-one correlation of the 288 individual 1st percentile humidity data points with those of the hourly means is only +.700,

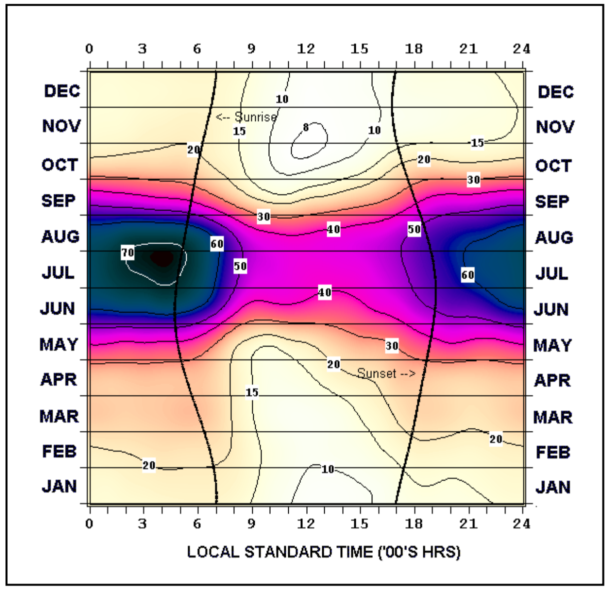


**Figure 17** Lower 1st Percentile Relative Humidity Climogram for LAX(1949-2013 Period of Record)

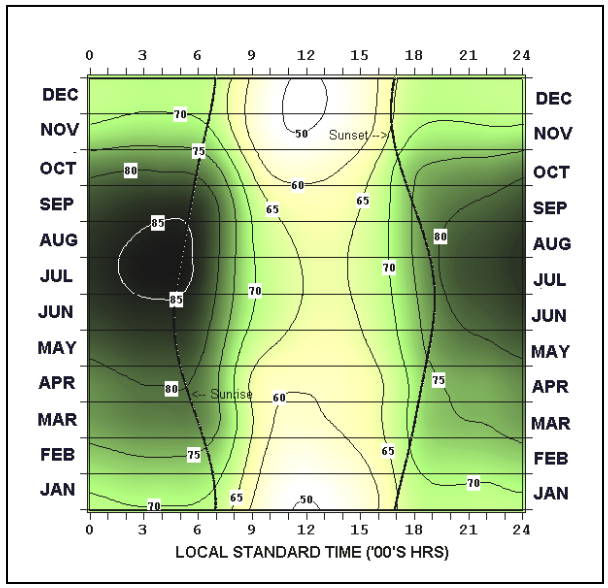


**Figure 18** Mean Hourly Relative Humidity Climogram for LAX (1949-2013 Period of Record)

*3.2.2 – Seattle-Tacoma Airport -* Lat: 47°27' N; Lon:122°18' W; Elev: 433 ft

Figures 19 and 20 are the Lower 1st Percentile and Mean Relative Humidity climograms, respectively, for Seattle-Tacoma International Airport.

From the Figure 20 Means chart, Seattle has relatively high climatological average humidities for many hours of the day across numerous months, as evidenced by the relatively large areas of the climogram colored green depicting comparatively high humidties relative to others on the chart.  A large area of 85 % or higher means covers the predawn and early morning hours for September to November, and mean hourlies for the winter months (December-February) are above 70% for all hours of the day. The lowest isopleth (50%) is a fairly localized feature, situated essentially for July in the late afternoon (1400 to 1700 LST).

Figure 19, however, shows that these above described relatively humid mean "regions" can experience quite low humidities at the one percent level. For example, a relatively expansive 23 % relative minimum contour, covering the mid to late afternoon hours, extends all the way from April to September. Within this "space" is the absolute minimum 21% isopleth covering early April to early May for about 1400 to 1600 LST. Also, aside from a few hours either side of sunrise in July through September, which retain relatively high magnitudes at the one percentile level (in the 60's), other hour/month combinations that displayed mean relative humidity values in the 80's show one percent exceedance levels in the 40's and lower.  The above described winter months which have mean figures in the 70's, even in the daytime, have one percent levels in the low 30's and even high 20's. Seattle-Tacoma is primarily a marine-influenced climate, but drier continental type air masses can occasionally make their presence felt.  Likely due to the above described feature contrasts between climograms, the first percentile vs. climatological means correlation is only +.697.

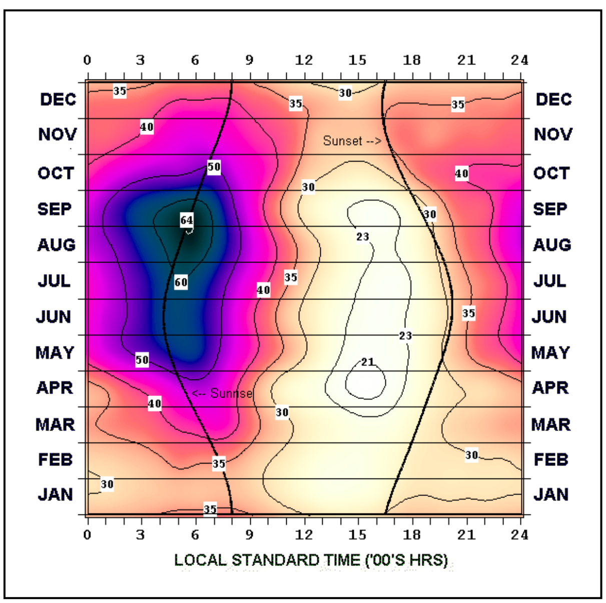


**Figure 19**.  Lower 1st Percentile Relative Humdity Climogram for Seattle-Tacoma Airport 1944-2013 Period of Record).

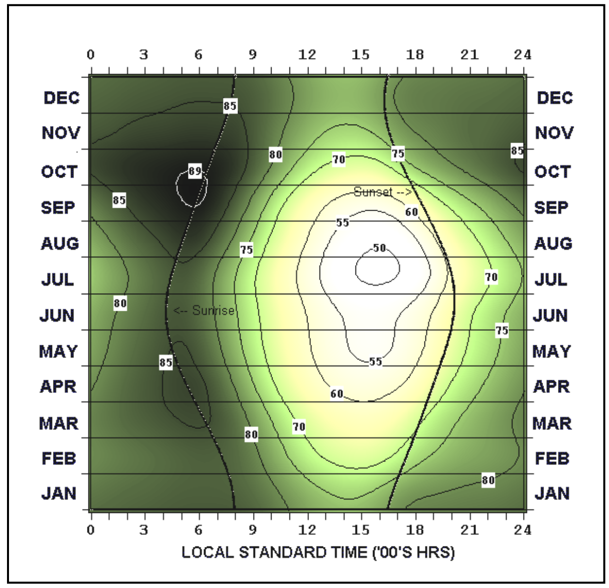


**Figure 20**.  Mean Hourly Relative Humidity Climogram for Seattle-Tacoma Int'l Airport (1944-2013 Period of Record).

*3.2.3 – Miami Int'l Airport- Lat: 25°48' N; Lon:118° 17' W; Elev: 7 Ft.*

Figures 21 and 22 show the Lower 1st Percentile and Mean Relative Humidity climograms, respectively, for Miami International Airport

The Lower 1st percentile chart (Figure 21) clearly shows the moist tropical influences on one percent exceedance levels in summer, none of the pre-sunrise magnitudes being lower than 60% over June through September, a several hour wide area with a 70% isopleth also evident straddling sunrise in July and August.  The chart also shows appreciable green-shaded areas, mostly for the nocturnal hours.

During the winter and spring drier periods, when continental flow is more frequent, one-percent magnitudes can dip to relatively low levels in Miami, a sizeable 30 percent isopleth area visible for the afternoon hours from December through April, a 23 percent contour contained within, encompassing early January to early February for a few late afternoon hours. This relative minimum feature deviates slightly from that of the hourly means chart (Figure 22), the minimum mean feature there being a 55 percent contour including late March and April from noon to 1600 LST at the widest.  Also, the hourly means maximum  isopleth (86%) bestrides sunrise in September, a bit later than the corresponding feature for the first percentile chart (72% contour for mid-July to mid-August, essentially overlaying the sunrise demarcation trace).  Correlation between the two charts' data is +.864.

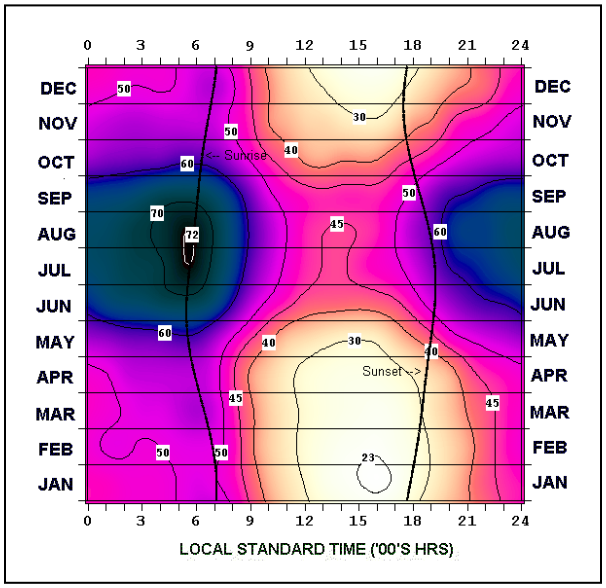


**Figure 21**. Lower 1st Percentile Relative Humidity Climogram for Miami International Airport (1973-2013 Period of Record).

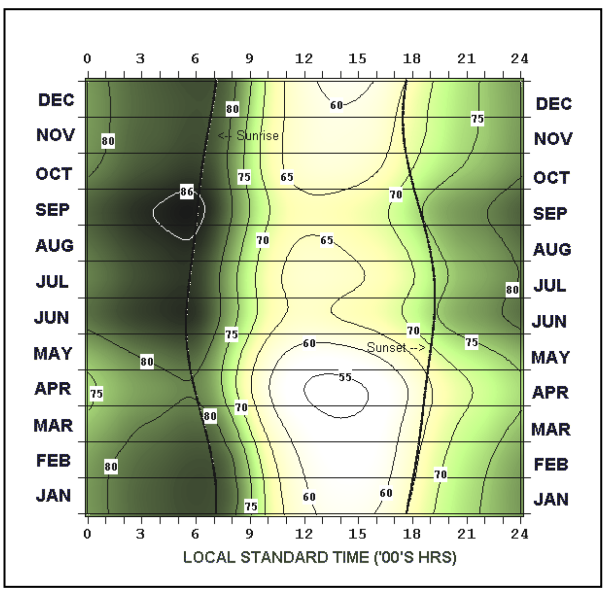


**Figure 22.** Mean Hourly Relative Humidity Climogram for Miami International Airport (1973-2013 Period of Record)

*3.2.4 – Boston (Logan Int'l Airport), MA Lat: 42° 36' N; Lon:71°00' W; Elev:20 ft*

Figures 23 and 24 display the Lower 1st Percentile and Mean Relative Humidity climograms, respectively, for Boston Int'l Airport.

The Lower 1st percentile chart shows a fairly simple pattern with the lowest magnitude contour (15%) covering late April for the late afternoons, highest contour (55%) overlaying the sunrise isopleth over late August to mid-September. Boston being a farther north location with potential for strong continental influences from the west and north, the potential for low relative humidity episodes exists throughout the year. None-theless, since it also borders the Atlantic Ocean, mean relative humidities are likely influenced by that proximity too. Lowest contour magnitude in Figure 24 is 55 %, for the early afternoon hours of late March to late April. The two charts' patterns are quite similar in form, as evidenced by the +.920 correlation figure.

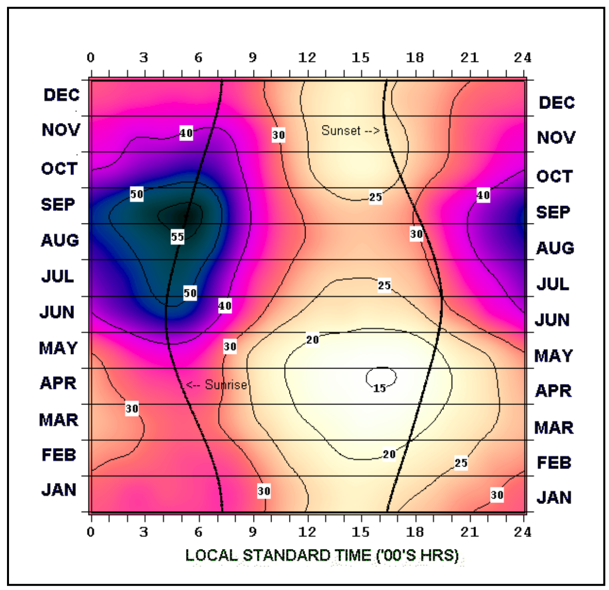


**Figure 23**. Lower 1st Percentile Relative Humidity Climogram for Boston International Airport (1945-2013 Period of Record).

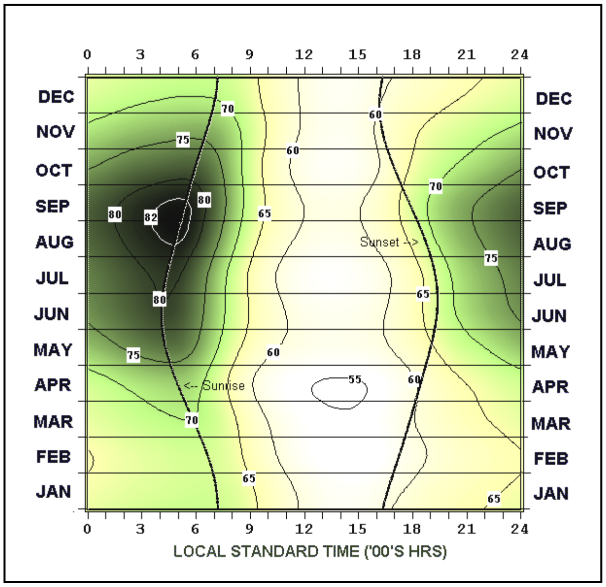


**Figure 24**. Mean Hourly Relative Humidity Climogram for Boston International Airport (Period of record 1945-2013)

*3.3. Extreme Hourly Sustained Winds Climograms*

The remaining variable to be covered is sustained winds magnitudes (high). For planning, scheduling, and safety considerations, it is obviously important to have knowledge of the character of high wind events for given stations/localities, namely the diurnal and seasonal variations in magnitudes for selected exceedance levels.

To demonstrate the climogram approach in this regard, sets of Upper 99th Percentile Sustained Wind Speed and companion Hourly Means charts are constructed for four stations: San Francisco International Airport, Chicago O'Hare International Airport, Wellington, New Zealand Airport, and Marignane Airport (near Marseilles), France

*3.3.1 - San Francisco WSO- Lat: 37° 37' N; Lon: 122° 23' W; Elev: 21 ft. .*

Figure 25and Figure 26 are the Upper 99$^{th}$ Percentile and Mean Hourly Sustained Winds climograms, repectively, for San Francisco Int'l Airport.

San Francisco exhibits an early summer afternoon maximum in mean wind speeds (Figure 26), a local diurnal feature reflecting onshore pressure gradients from the North Pacific High offshore to the thermal low feature in the San Joaquin Valley. Mean wind speeds are 16 knots or greater over a large swath of afternoon hours from May through August, and a very localized 18 knot absolute maximum is indicated for 1600 LST covering June. The 99th percentile maximum (31 knots – See Figure 25) is positioned a bit earlier, over all of May and early June, and the 30 knot feature stretches from late May into late June, spanning back to 1400 LST at the earliest to1800 LST at the latest. Upper 99$^{th}$ percentile sustained winds are at greater than 20 knots for most of Figure 25's "space", but mean speeds are actually quite light for many hours over certain seasons – mostly 6 knots or less for the autumnal months in the early A.M. Perhaps this helps explains the low +.661 one-on-one correlation statistic.

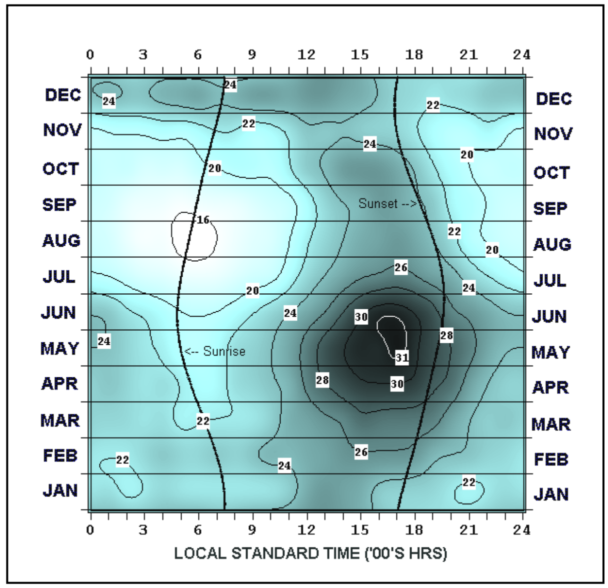


**Figure 25** - Upper 99$^{th}$ Percentile Sustained Winds Climogram (Knots) for San Francisco Int'l Airport (1949-2013 Period of Record)

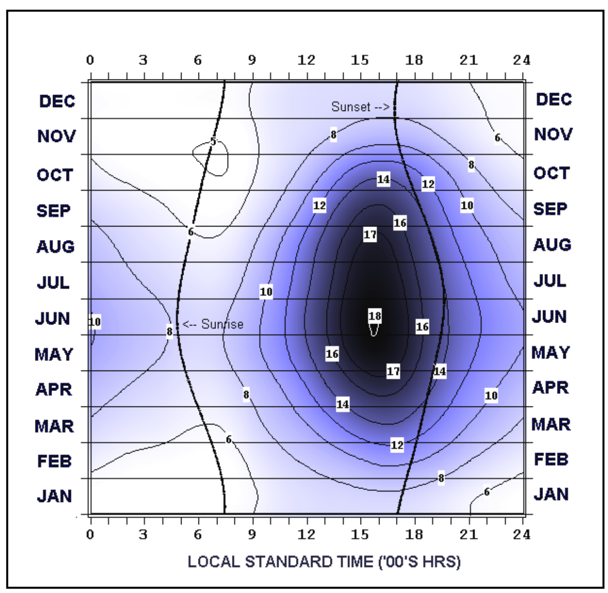


**Figure 26** – Mean Hourly Sustained Wind Speeds (Knots) for San Francisco Int'l Airport (1949-2013 Period of Record)

*3.3.2 - Chicago O'Hare Int'l Airport - Lat: 41°58 N;Lon 87° 54' W; Elev: 21 ft. .*

Chicago is known as the "Windy City", but in reality is exceeded in mean overall wind speeds by a number of other cities across the United States. Figures 27 and 28 show the Upper 99th Percentile and Mean Hourly Sustained Winds climograms, respectively.

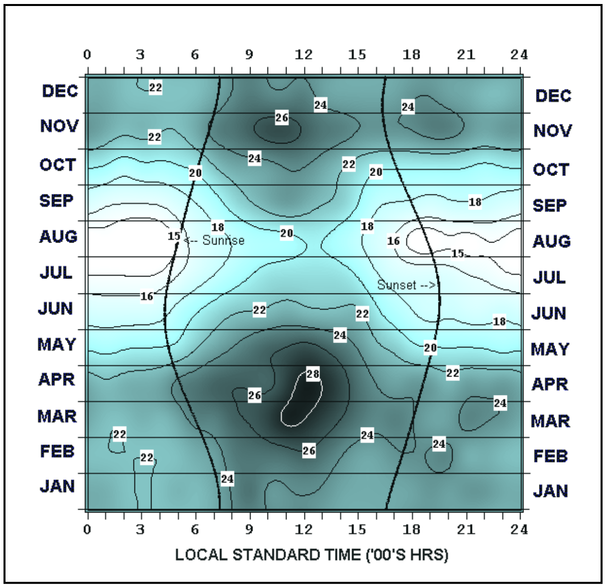


**Figure 27** - Upper 99th Percentile Sustained Winds Climogram (Knots) for Chicago O'Hare International Airport (1946-2013 Period of Record)

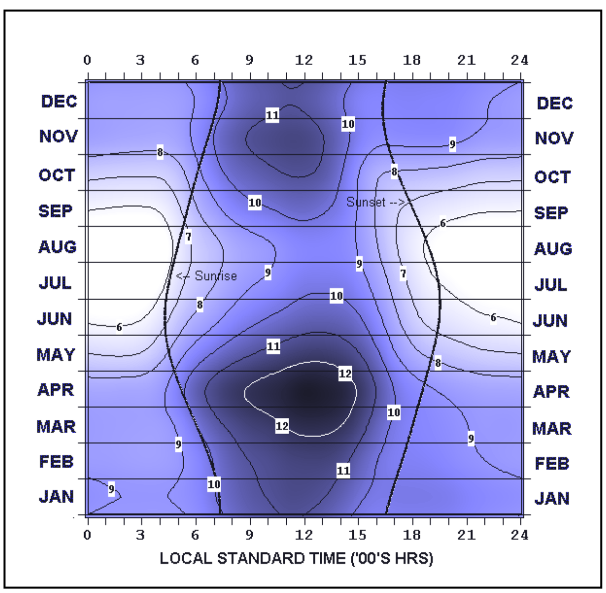


**Figure 28** – Mean Hourly Sustained Wind Speeds (Knots) for Chicago O'Hare Int'l Airport (1946-2013 Period of Record)

Chicago's maximum 99th percentile contour (28 knots) is several knots less than San Francisco's, and is positioned instead at mid-day, covering roughly March and April at several hours' width. A secondary maximum feature (26 knots) covers the late morning hours in November. The means chart (Figure 28) is quite similar in form, with a12 knot mean maximum contour including essentially mid-morning to mid-afternoon for March and April. Correlation between the two charts' data points is +.912.

*3.3.3 - Wellington, New Zealand Airport - Lat: 41°17 S;Lon 174° 46' W; Elev: 43 ft. .*

Wellington, New Zealand is known from some Internet sources as the windiest city in the world, and to portray this supposed character, Figures 29 and 30 are its Upper 99th Percentile and Mean Hourly Sustained Winds climograms, respectively.

From Figure 30, mean hourly wind speeds range from 12 to 18 knots, the maximum contour (18 knots) positioned in November over roughly the hours 1300 to 1500 LST. This is a late Spring feature, as this being the southern hemisphere, the Summer solstice occurs in December. The Upper 99th percentile contours (Figure 29) are much different, showing a basically uniform distribution of quite high magnitudes - all at 30 knots or greater, and as pronounced as 37 knots for small spaces in June (near midnight), and 1500 LST in May. This distribution of near gale force or higher sustained winds for virtually all hours and months of the year likely sets Wellington apart from most other cities of the world, thus the title of windiest city may be deserved. Not surprisingly, the means vs. extremes correlation figure is just .193.

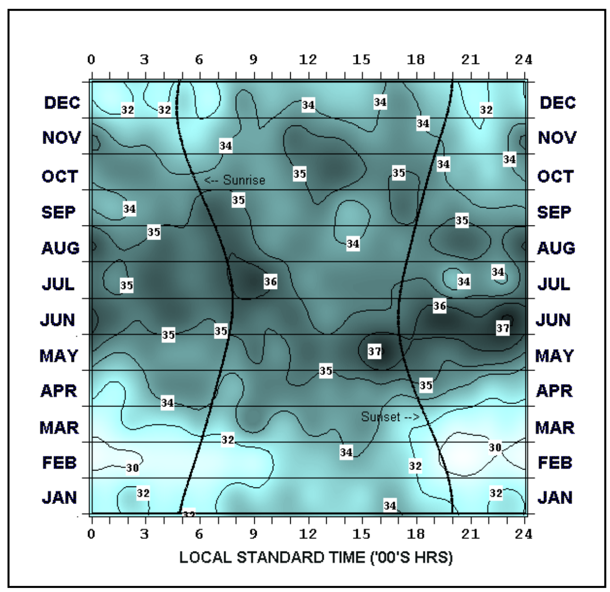


**Figure 29** - Upper 99th Percentile Sustained Winds Climogram (Knots) for Wellington, New Zealand Airport (1959-2013 Period of Record)

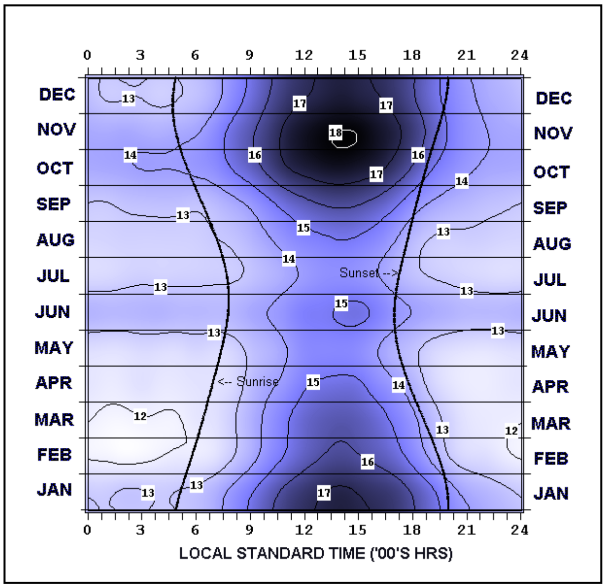


**Figure 30**. Mean Hourly Sustained Wind Speeds (Knots) for Wellington, New Zeland Int'l Airport (1959-2013 Period of Record

*3.3.4 - Marignane-Provence Airport, France (near Marseilles) - 43°5' S;Lon 26°13' W; Elev: 75 ft*

Marignane is a regional airport in France located 27 km northwest of Mareilles, on the Meditteranean coast. It is chosen for Climogram demonstration here because of its susceptibility to the Mistral, a very strong cold wind that flows down the Rhone River Valley on occasion. The mean hourly wind speed climogram (Figure 32) indicates that Marignane late afternoon wind speeds can be rather high, but not extraordinarily so, 14 knot contours visible covering late March through April and early June through July. At most other spaces on the climogram they are relatively light, frequently less than 10 knots, so in the mean, Marignane is not likely to be high on a list of the "windiest cities of the world".

The 99$^{th}$ Percentile climogram (Figure 31), however shows a much different character with frequent areas of 30 knot contours or greater. The maximum isopleth (39 knots), essentially an April feature from 1300 to 1600 LST exceeds all levels on the Wellington chart, and a fairly expansive 36 knot area is also present, covering February for several hours in the middle afternoon to April from 9AM to past sunset**.** The relative maxima contours for the hourly means chart provided some indications that there might be some non-specific high 99$^{th}$ percentile magnitudes, but not to the extreme levels actually seen in Figure 32. This higher than expected skewness, attributable to the atypical nature of the Mistral, is undoubtedly responsible for the reduced correlation between the charts' data points:+.756

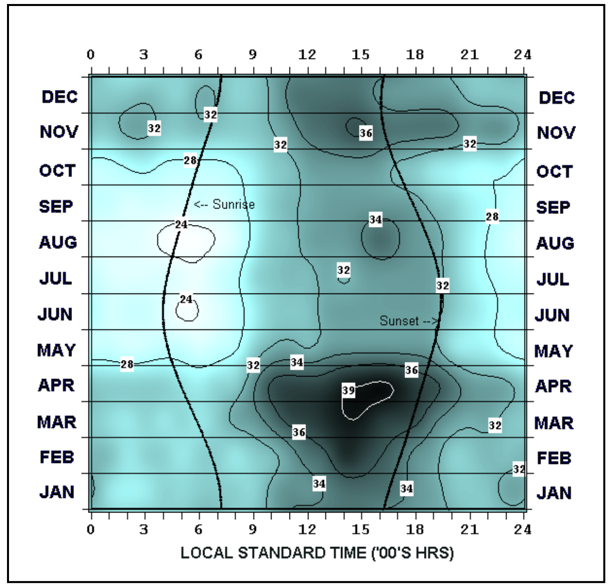


**Figure 31** - Upper 99$^{th}$ Percentile Sustained Winds Climogram (Knots) for Marignane Airport, France (1973-2013 Period of Record)

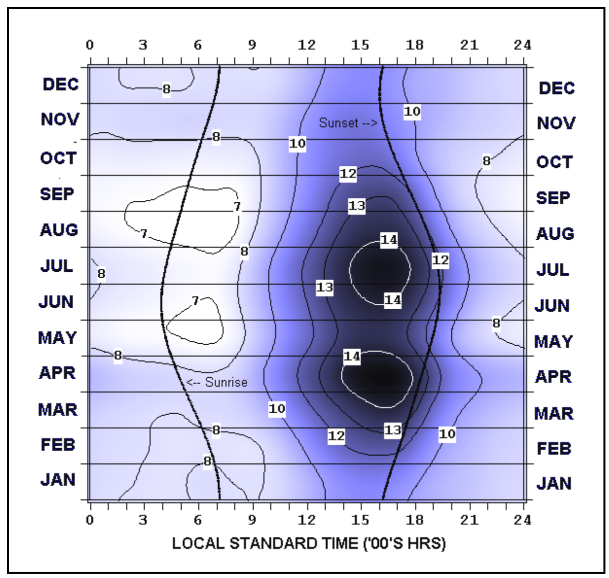


**Figure 32**. Mean Hourly Sustained Wind Speeds (Knots) for Marignane Airport, France (1973- 2013 Period of Record)

## 4. SUMMARY AND CONCLUSION

The foregoing illustrated the use of hour-by-month climograms in the depiction of extreme exceedance level patterns of temperature, relative humidity, and sustained wind speeds, based on a percentile-ranking methodology that attempts to work around the complications of suitable exceedance magnitude determinations from non-symmetric or bounded distributions. Ten different stations' data, all first-order with long periods of record were analyzed. The 99th and 1st percentile ranking levels were arbitrarily chosen as threshold levels. Results showed that hour-by-month patterns at high exceedance levels occasionally deviated significantly and unexpectedly from those of parameter mean values, the best example being perhaps Wellington, New Zealand sustained wind speeds. Ten stations, obviously, only represent a small fraction of those possibly suited for this kind of analysis, and there are of course many other appropriate exceedance level thresholds to consider. Hour-by-Month extremes climatological charts of these kind can be useful as quick-study tools for practical operational concerns as well as for providing insights for their own sake.

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