A COMPARATIVE CLIMATOLOGICAL ANALYSIS OF SANTA ANA WIND OCCURRENCES FOR TWO NEARBY COASTAL AND MOUNTAIN STATIONS IN SOUTHERN CALIFORNIA

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1. INTRODUCTION

The following is an in-depth comparative climatological analysis of wind character during Santa Ana offshore flow events at two nearby coastal and mountain stations in southern California near Oxnard: Point Mugu Naval Air Base and Laguna Peak (See Figure 1). Historical records of the former, located a mile from the Pacific Coast (altitude 13 ft), and the latter, a mountain station several miles east of Point Mugu, will be explored and studied for "Santa Ana Day" events, defined using wind/humidity criteria that are alternatively different and the same for the two stations.

Figure 1. – Map of Point Mugu Naval Air Base and Laguna Peak vicinity

A mix of climatological and graphical analyses are presented, including: 1.) monthly relative frequencies of Santa Ana day events (both at Mugu and Laguna Peak), 2.) yearly event totals (both at Mugu and Laguna Peak), 3.) comparisons of individual hours' tendencies for Santa Ana winds during Santa Ana "days" (both stations) 4.) relative frequency distributions of the number of Santa Ana hours' tallies for given Santa Ana "days" (both stations), and 5). frequency distributions of multi-day runs of Santa Ana "days" (both stations). On A calendar month unit basis (3.), (4.), and (5.) are performed for all months combined, and October thru April, inclusive. In addition, utilizing K-Means Clustering Analysis incorporating a special add-on feature called the V-fold Cross Validation algorithm, idealized hourly midnight-to-midnight wind patterns or "modes" will be created for Santa Ana Day events at Point Mugu and Laguna Peak, both on an individual and paired-station basis, utilizing midnight-to-midnight decomposed u and v individual hourly wind calculations as input. The resulting clusters' centroid mean u's and v's are recombined into hourly mean vector wind statistics that serve as the means of pattern interpretations. The focus is on identifying the nature and relative frequencies of the two stations' patterns, individually, month-to-month, and given their altitude differences, the contrasts and /similarities relative to one other.

The following operational definitions of a "Santa Ana Day" are employed. For Point Mugu, the definition is at least one hour with a wind direction between 10 degrees and 90 degrees, combined with a wind speed of >=10 knots; for Laguna Peak, it's at least two consecutive hours with wind directions between 10 degrees and 130 degrees, combined with wind speeds of >=15 knots and relative humidities of less than or equal to 30 percent. "Paired" analyses apply one or the other station's definition to both stations simultaneously.

Point Mugu (part of the Naval Base Ventura County Complex) is a Naval Air Station situated on the south-eastern edge of the Oxnard Plain in Ventura County, about 50 miles northwest of Los Angeles, and adjacent to the Santa Monica Mountains' western terminus. In the Santa Monicas, about 3 miles east of the Mugu weather station, is a 1450-foot mountain, Laguna Peak. For forecasting utility reasons, weather instruments have resided there at least back to the late 1960's. As Jay Rosenthal, Head Meteorologist at Point Mugu for many years writes [email communication, 2016], the Laguna Peak observations "…are one of the best sources of information to document Santa Ana conditions in southern California, as well as storm winds when the wind is out of the SE. The National Weather Service had originally requested the ongoing appendage of Laguna Peak data to the Point Mugu surface weather observations because data from the 1450-foot site was/is instrumental in observing early signs and onset of Santa Ana conditions capable of doing extensive damage to people and property as well as its implication in wildfire assessments" Hourly observations of Laguna Peak winds, temperature, and dewpoint were recorded on in-house paper forms to at least as far back as 1968, and transcriptions onto the Point Mugu daily log sheets in the remarks section became a regular duty about 1982.

In the mid 1990's, midnight-to-midnight hourly readings of wind direction, sustained wind speeds, temperature, and dewpoint were digitized for the 1982-1992 period, inclusive (more than 96000 obs); those

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after 1992 are available at NCDC but with few exceptions are not midnight-to-midnight, as the host Point Mugu weather station's diurnal scope was reduced to a less than 24-hour one.

The Point Mugu data included the years1963-2016; the entire record goes back to 1946, but 1963 was the first full year with the wind instruments at their present approximate height.

2. MORE ON THE WIND CLUSTERING METHODOLOGY

The STATISTICA Data Miner Clustering module was utilized to create the idealized wind pattern modes. As stated above the raw input were individual hours' u and v wind components, by day (in Excel files). . Traditional K-Means being a trial-and-error procedure, the V-Fold Algorithm is an automated, iterative training sample procedure that rapidly produces in ascending order, 2 to K cluster sets, the iterations ceasing at some "optimal" number K, depending on a choice of statistical distance metric (Squared Euclidean for this study), percent improvement cutoff threshold (5 percent default for this study), and other settings. The software that offers the K-Means/V-Fold capability, however, also gives the option of fixing the number of clusters, and one of the applications in the study goes this route.

Preliminary to the clustering, the software automatically normalizes the data internally, by hour, to reduce them to a common scale and lessen the effects of outliers. A single-station analysis would be one in 48-dimensional space (24 pairs of u and v-components) a two-station analysis one in 96-D space. In a one-station analysis, each of the individual cluster "clouds" would have midpoints or centroids in 48-D space, made up of mean u and v values for each hour of the day. These would then be un-normalized and recombined, hour-by-hour using the arctangent function, producing 24 sets of hourly mean vector wind statistics; The cluster arrays would be independent self-contained multivariable entities, depicting idealized progressions of mean vector wind character, hour-by-hour, over the course of a day.

Since the clustering process assigns diurnal wind observations of a very similar character to a given cluster, the individual hour mean vector wind direction results in many cases could be interpreted, with only slight loss of precision, as *average wind directions.* Also, the accompanying mean vector wind *speeds*, would be very similar (slightly less) than their counterpart mean scalar wind speed statistics,

The results, cluster by cluster, are depicted graphically on single-chart layouts, the hourly mean vector wind directions as arrows, proportional in length to their magnitude (the highest magnitude vector is annotated), "constancy" statistics (mean vector wind speed/mean scalar wind speeds*100; a measure of collective individual wind observational nomogeneity in a given cluster) as colored circles (ordered from dark blue to dark red). In other less ideal cases (with lower constancies), a results array might portray a diurnal pattern that had inherently lighter and more variable winds (for example, weak diurnal circulation regimes), and/or one with natural diurnal breaks (for example, land-breeze/sea-breeze transitions and vice-versa). The "average wind direction/wind speed" intepretation of the high constancy cases might not be as applicable here, but patterns of this nature, being an integral part of the given station's diurnal climatological "landscape" are, of course, no less important to present and describe.

The month-to-month cluster bars depict the percent of the given pattern's total cases that were included for each month.

3. RESULTS

3.1 *Point Mugu Results with Point Mugu Filter*

Figures 2 to 14 show the results for the various analyses performed on the 1963-2016 Point Mugu data, filtered for "Santa Ana Days" defined as at least one hour between midnight to midnight with a wind direction between 10 and 90 degrees, accompanied by a wind speed of >=10 knots (dubbed the "NTD Filter"). Figure 2 depicts the mean frequency of "Santa Ana Days", by month, conforming to this definition. Maximum climatological frequency (10.2 days) is seen for January, second highest for December (9.7 days). There are non-zero mean frequencies for July and August, but these likely reflect those rare east quadrant land breezes or eddies that attained speeds of greater than 10 knots. Using a more exacting "Santa Ana Day" definition that incorporates low relative humidities <=30 percent), "classic" Santa Anas have never been recorded at Point Mugu in July and August.

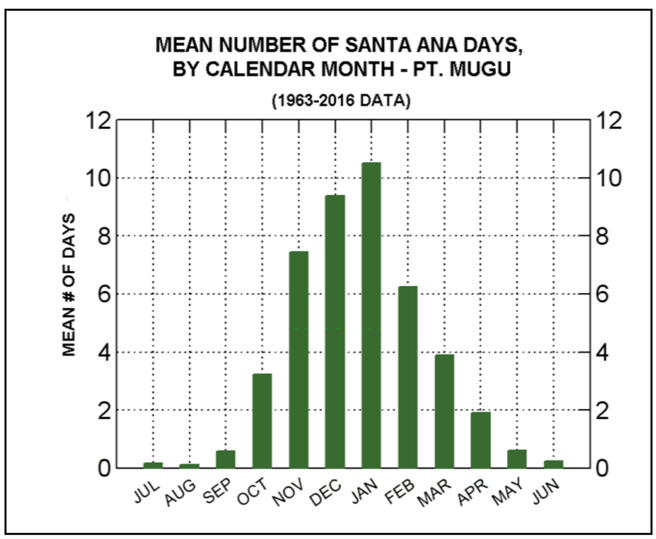

Figure 2. Mean Number of Santa Ana Days, by Calendar Month, using the NTD "Santa Ana Day" filter.

Figure 3 below is a graph of the total number of Santa Ana days per year over the 1963-64 to 2015-16 seasons; four of the seasons (1971-72, 1972-73, 1995-96, and 2015-16) are incomplete as to daily coverage. In recent years there seems to have been above average frequencies (four seasons at 50 or higher through 2014-15), probably because of the persistent dry winters and more offshore flow episodes. Nearly 70 events are noted for the 2011-12 season.

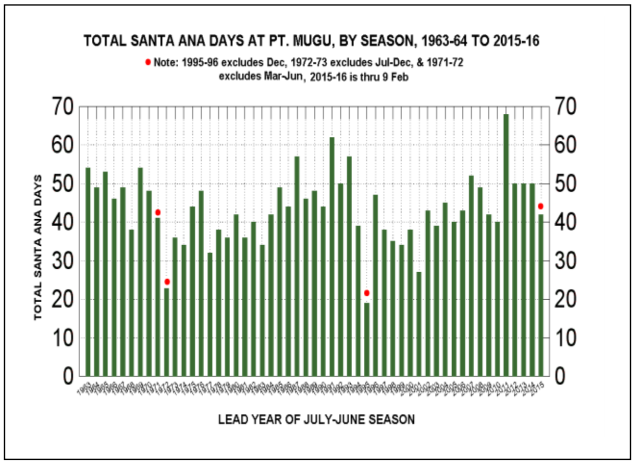

Figure 3. Total Santa Ana Days, by year, 1963-64 to 2015-16 (NTD "Santa Ana Day" filter)

3.1.1 Individual Hourly Tendencies for Santa Ana Winds on Santa Ana Days

A noticeable characteristic of Santa Ana Day occurrences at Point Mugu is the marked diurnal preference for certain times of the day to experience Santa Ana "hours" or those with East quarter winds at 10 knots or greater. In the upper-left chart in Figure 4 ("all months combined") the climatological percent frequencies increase rapidly from about 27% at midnight to a maximum 60 % at 10 AM, then fall off rapidly again to near 15 % at 6 PM, trending up again past Midnight and beyond. The October (upper-right) chart shows a more amplified pattern, the maximum exhibited at 9 AM (~65 %), the minimum (10 %) at 6 PM. November (lower-left) also displays a 9 AM maximum (~62 %), with December showing a 10 AM maximum again (~61 %) combined with a higher relative minimum (~22 %) at 6PM.

In Figure 5, January and February (upper-left and upper-right charts, respectively) each display 10 AM and 6 PM maxima and minima, respectively, January's range 60 % to 21 %, February's 60 % to 14 %. March and April (lower-left and lower-right, respectively) show noticeably different configurations than January and February, March exhbiting only four frequencies above 35 % (over the hours 0800 to 1100 LST, inclusive), April, with an even more amplified pattern than October's, frequencies at or near 65 % at 9-10 AM but many others under 10%. The relative affinity for the mid-to-late morning hours is quite evident for Pt. Mugu.

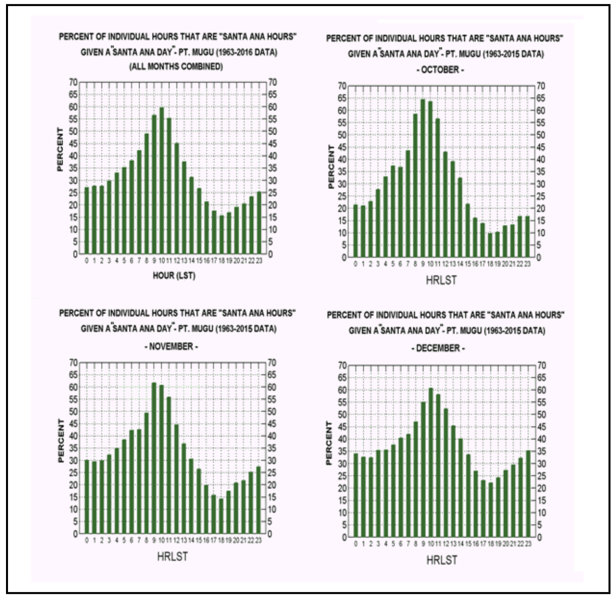

Figure 4. Hourly Tendencies for Santa Ana Winds on Santa Ana Days at Point Mugu – All Months Combined, October, November, and December (NTD filter)

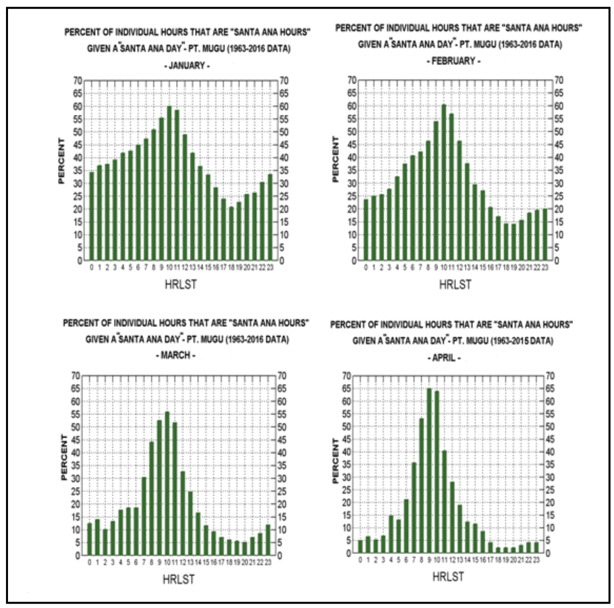

Figure 5. Hourly Tendencies for Santa Ana Winds on Santa Ana Days at Point Mugu – January, February, March, and April (NTD filter)

3.1.2 Distributions of Santa Ana Hours' Tallies on on Point Mugu Santa Ana Days

Another attribute considered is the number of hours with Santa Ana Winds per Santa Ana Day. Figure 6 shows the relative frequency distributions of Santa Ana hour tallies for All Months Combined (upper-left), October (upper-right), November (lower-left), and December (lower-right). The distributions are more similar then different – on an individual hourly basis, most Santa Ana days are one-hour affairs with relative frequencies at that level between 15 and 20 percent. The October chart shows a slight build-up of relative frequencies between 4 and 6 hours, at the expense of those immediately higher. There is also a slight elevation of relative frequencies at the 24 hour level for all the charts, reflecting all-day Santa Ana Day episodes.

Figure 7 exhibits the corresponding relative frequency charts for January (upper-left), February (upper-right), March (lower-left), and April (lower-right). January displays the most uniformily distributed pattern of any, the one-hour level frequency just under 15 percent with relative frequencies at higher levels (beyond 18 hours) much in evidence, including that at 24 hours. For the February, March, and April charts, there is a trend for increased one-hour only frequencies (nearly 30 percent for April). Also, relative frequencies at higher levels become increasingly scarce; there are no 24 hour cases for March and April.

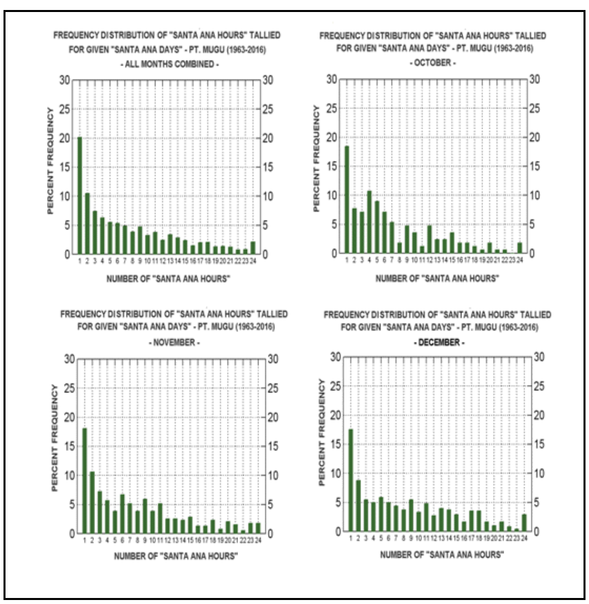

Figure 6. Frequency Distributions for "Santa Ana Hour Tallies" on Santa Ana Days at Point Mugu – All Months Combined - October, November, and December (NTD filter).

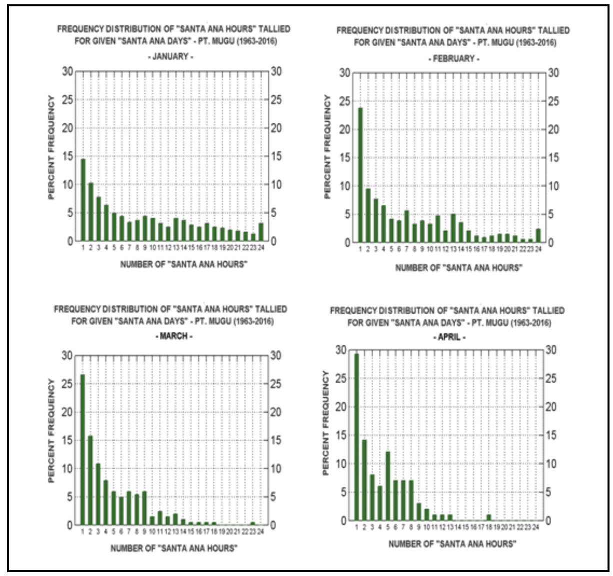

Figure 7. Frequency Distributions for "Santa Ana Hour Tallies" on Santa Ana Days at Point Mugu – January, February, March, and April (NTD filter).

3.1.3- Frequency Distributions of Santa Ana Multi-Day Runs at Point Mugu

Another climatological aspect to take into account is the nature and frequency of day-to-day runs of Santa Ana episodes. Figure 8 shows the frequency distributions of Santa Ana daily runs at Point Mugu for All Months Combined (upper-left), October (upper-right), November (lower-left), and December (lower-right). Overall (All Months Combined Chart), about 50 percent of Santa Anas at Point Mugu were single day events, the percent frequencies negligible beyond, say, four days, although some as long as 12 days were noted, in December.

Figure 9 shows the corresponding daily runs' frequencies charts for January (upper-left), February (upper-right), March (lower-left), and April (lower-right). January displays appreciable relative frequencies for 2 and 3 day runs (30 % and 20%, respectively) as well as for single day ones. Santa Ana durations become progressively shorter in length in March and April, the one-day length frequencies around 60 percent for March and 65 percent for April.

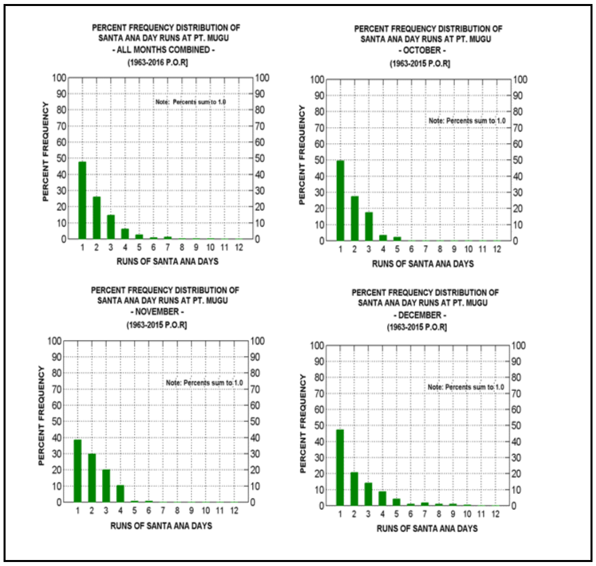

Figure 8. Frequency Distributions for Santa Ana Day Runs at Point Mugu – All Months Combined, October, November, and December (NTD filter).

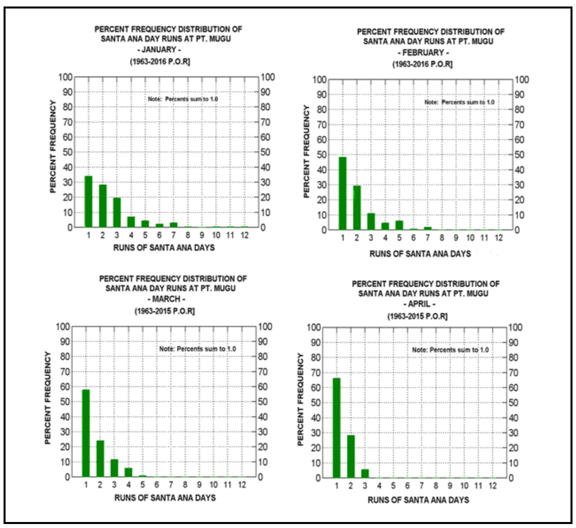

Figure 9. Frequency Distributions for Santa Ana Day Runs at Point Mugu – January, February, March, and April (NTD filter).

3.1.4- Wind Cluster Patterns or "Modes" for Pt. Mugu (NTD Filter)

Next, the wind clustering analysis was performed on the 1963-2016 Santa Ana Day subset to resolve idealized diurnal mean vector wind patterns for Point Mugu. Five modes were generated, ranging in relative frequencies from 30.8 to 13.1 percent.

Figure 10 shows the wind cluster chart for the most prominent mode, the "Light N'Easterlies – Brief W Sea-Breeze" Pattern. This depicts a diurnal mean vector wind pattern in which the NTD Santa Ana Day criterion is met for one hour or perhaps several more, but overall is likely portion of a weak rather than a strong event.

The mean vectors are light northeasterly from midnight to 1000 LST at green or blue constancy levels, transitioning to westerly over 1100 LST and Noon (note the brown or orange constancy colors which indicate a changeover interval in mean wind vector wind character) displaying westerly to west-northwesterly orientations through late afternoon, then turning back to light northeasterly for the evening hours. Highest magnitude mean vector is a 6.6 knot west-northwesterly for 1500 LST.

Highest bar frequencies are over November-January – about 55 percent of the cases grouped for this cluster confined to these months.

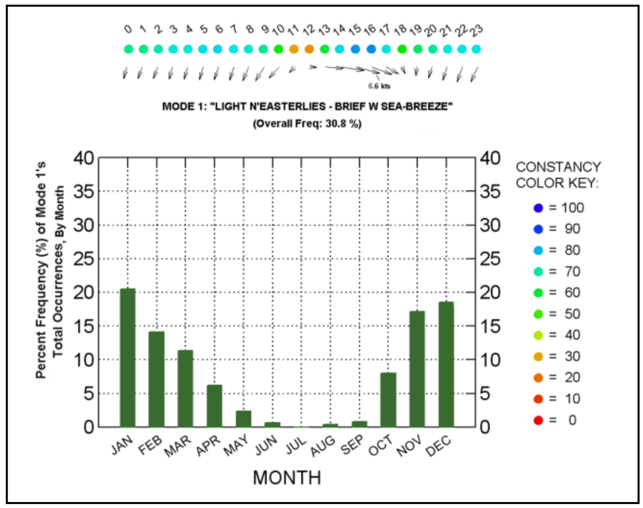

Figure 10 – Mean Vector Wind Cluster Diagram for Mode 1: "Light N'Easterlies – Brief W Sea Breeze Pattern" (incidence 30.8 %)

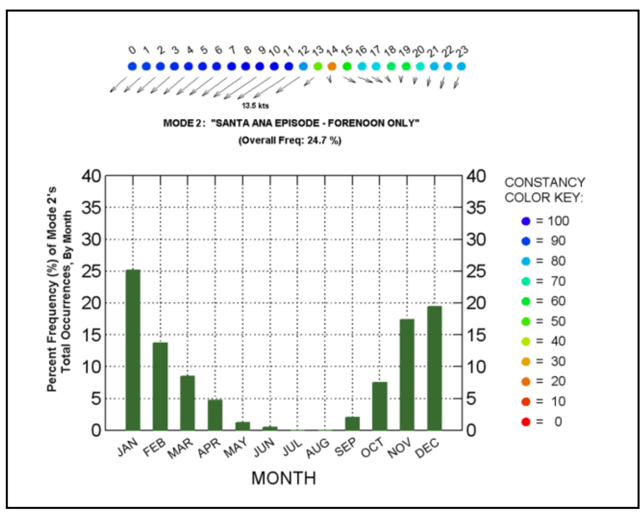

Figure 11 – Mean Vector Wind Cluster Diagram for Mode 2: "Santa Ana Episode – Forenoon Only" Pattern (incidence: 24.7 %)

Figure 11 displays the chart for the second most important mode, the “Santa Ana Episode – Forenoon Only” pattern. As the title indicates, this cluster includes those days that were parts of stronger events, the episodes, however, confined essentially to the pre-Noon hours. Maximum mean vector magnitude is a 13.5 knot northeasterly at 1100 LST; a sea-breeze transition then ensuing with light northwesterly vectors visible over the brief 1500-1700 LST interval. Some 25 percent of this pattern’s cases were January ones.

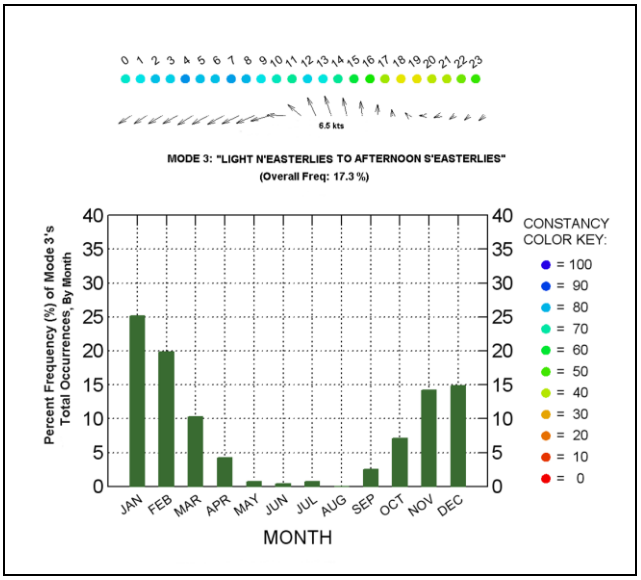

Figure 12 - Mean Vector Wind Cluster Diagram for Mode 3: “Light N-Easterlies to Afternoon S’Easterlies” Pattern (incidence: 17.3 %)

Ranking third in importance is the “Light N’Easterlies to Afternoon S’Easterlies” pattern (Figure 12). Like Mode 1, this cluster included daily observations that met the NTD Santa Ana Day criterion for one hour more, but were relatively weak. The mean vectors display (light) northeasterly orientations through about 0900 LST, then turn southeasterly to southerly over the 1100 LST to 1500 LST interval. Maximum magnitude vector is a 6.5 knot south-southeasterly at 1300 LST. Some 25 % of this pattern’s cases were confined to January, another 20 % to February. As the NTD filter did not include relative humidities, some of the cases in January and February could conceivably been Pacific Storms. Other cases might have been Catalina Eddies.

In fourth place is the “Santa Ana Episode – Mid-Morning Onset” pattern (Figure 13). This displays northeasterly oriented vectors for the whole day, the magnitudes stepping up after 0800 AM, reaching a maximum mean speed 13.5 kts at 1300 LST. Some 32 percent of these cases were confined to December, 27 percent to January.

Ranking fifth and last in importance is the “Santa Ana Episode – All Day” Pattern (Figure 14). This depicts a genuine and strong Santa Ana event that persists midnight to midnight. Maximum magnitude vector is a 18.5 knot Northeasterly for 1100 LST. Forty percent of the cases were grouped in January.

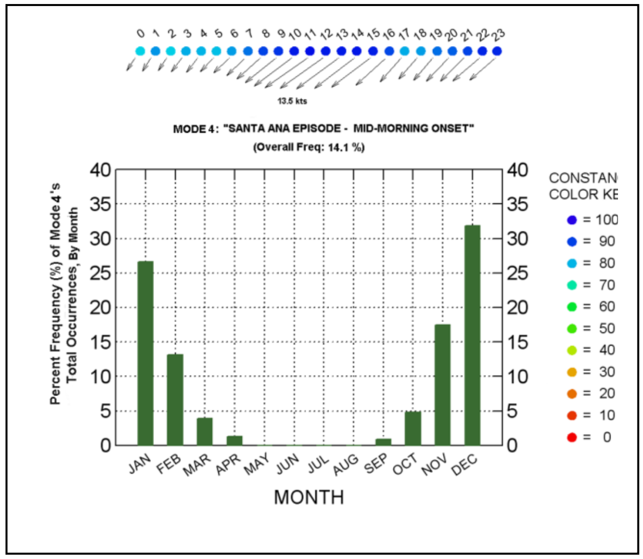

Figure 13 - Mean Vector Wind Cluster Diagram for Mode 4: “Santa Ana Episodes – Mid-Morning Onset” Pattern (incidence: 14.1 %)

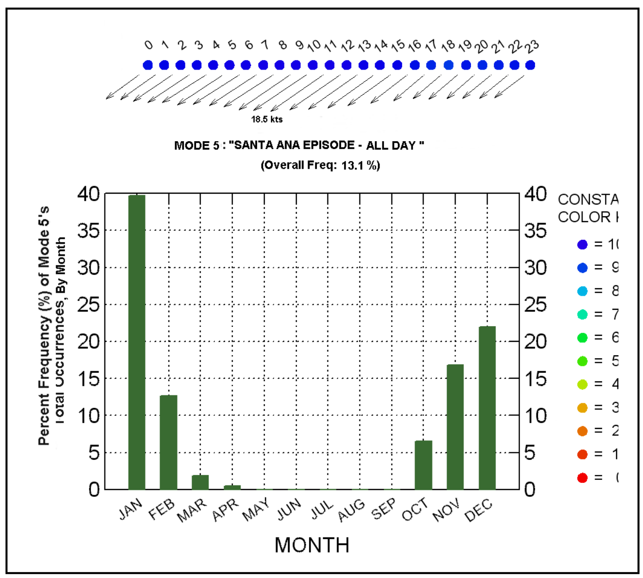

Figure 14 - Mean Vector Wind Cluster Diagram for Mode 5: “Santa Ana Episode – All Day” Pattern (incidence 13.1 %).

3.2. *Laguna Peak Results with Laguna Peak Filter*

In the identical manner as was done for Point Mugu, Figures 15 to 25 shows results for the various analyses performed on the Laguna Peak 1982-1992 and 2015-16 data, filtered for “Santa Ana Days” which were defined as at least two consecutive hours with a wind direction between 10 and 130 degrees, accompanied by a wind speed of >=15 knots and relative humidities of <=30 percent (dubbed the “LPK filter”).

Figure 15 depicts the mean frequency of “Santa Ana Days”, by month, at the Peak, conforming to this definition. Although the Santa Ana Day definition here is different, the configuration of bars looks much the same as that for Point Mugu’s chart (See Figure 2). Maximum climatological frequency (16.4 days) is seen for January, second highest for December (16.0 days).

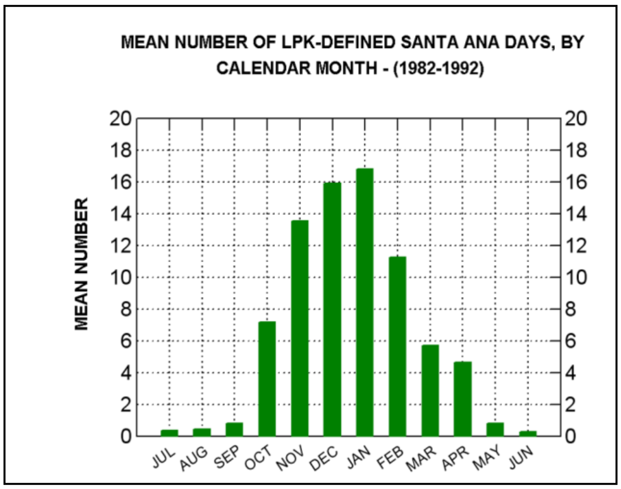

Figure 15. Mean Number of Santa Ana Days at Laguna Peak, by Calendar Month, using the “Laguna Peak” Santa Ana Day filter.

Figure 16 below is a graph of the total number of Santa Ana days per year at Laguna Peak over the 1982-1992 years. Given the abbreviated period of record, the tallies are done on a January-December basis – a July-June treatment, as was done for Point Mugu, would leave only ten years available (1982-3 thru 1991-92), Yearly frequencies range from 60 (1983) to 90 (1984 and 1988).

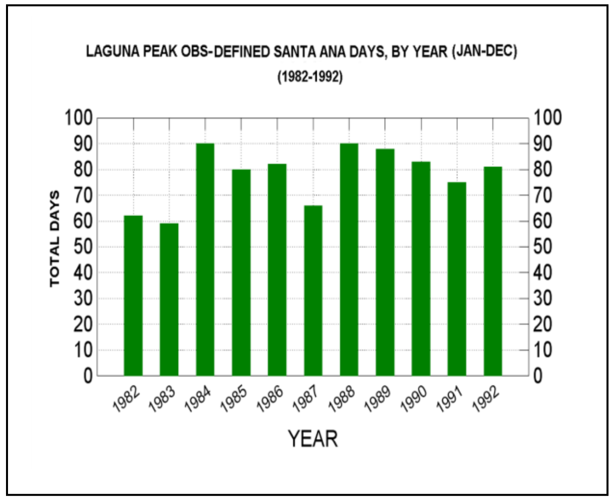

Figure 16. Total Laguna Peak Santa Ana Days, by calendar year, 1982-1992 (LPK “Santa Ana Day” filter)

3.2.1 Individual Hourly Tendencies for Laguna Peak Santa Ana Winds on Santa Ana Days (LPK filter”

As was seen for Santa Ana day occurrences at Point Mugu, there is also a significant diurnal preference atop Laguna Peak for certain times of the day to experience Santa Ana “hours”, or by definition, hours that are portion of at least a two consecutive hour run of wind directions between 10 to 130 degrees, wind speeds at >=15 knots, and relative humidities <=30 percent.

Figure 17 below plots the Hourly Tendencies for Santa Ana Winds on Santa Ana Days at Laguna Peak – All Months Combined (upper-left), October (upper-right), November (lower-left), and December (lower-right). Overall (“All Months Combined”) and in contrast with Point Mugu’s counterpart chart, the maximum magnitude bars are less concentrated over a narrow range of hours, the absolute maxima figures coming a few hours earlier. Maximum percent frequencies (60 %) are observed for three hours: 0000 LST, 0700 LST, and 0800 LST). In addition, the lowest frequencies come an hour or so earlier as well, the minimum values 23 % and 24 %, noted for 1700 LST and 1600 LST, respectively. October displays its maximum at 0600 LST (62 %), its minima at 1600 LST and 1700 LST (both 9 %). November has its maximum at 0000 LST (65 %), the minimum (20 %), at 1700 LST. Finally, December has its maximum (~65 %) at 0800 LST, its minimum, (~ 30 %) at 1400 LST.

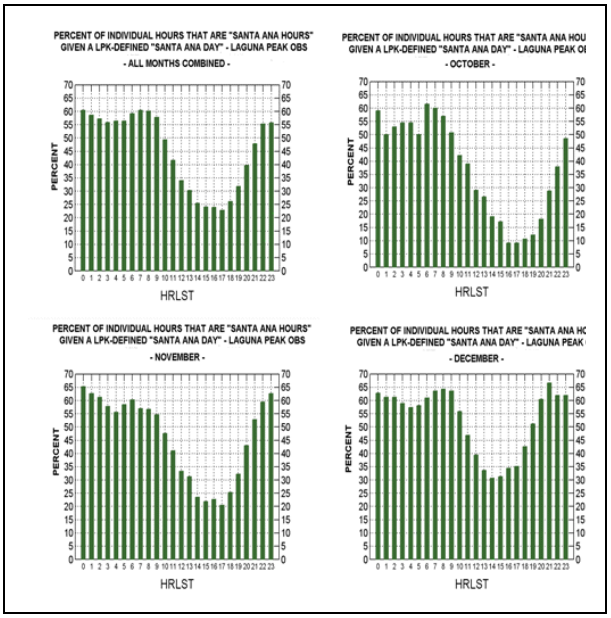

Figure 17. Hourly Tendencies for Santa Ana Winds on Santa Ana Days at Laguna Peak – All Months Combined, October, November, and December (LPK filter)

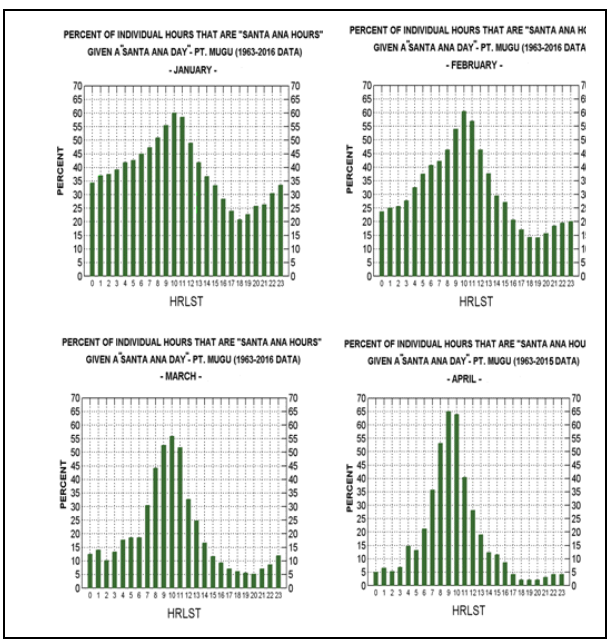

Figure 18. Hourly Tendencies for Santa Ana Winds on Santa Ana Days at Laguna Peak – January, February, March, and April (LPK filter)

Figure 18 above shows the hourly tendencies for Santa Ana Winds on Santa Ana Days at Laguna Peak – January (upper-left), February (upper-right), March (lower-left), and April (lower-right).

January displays uniformily high frequencies from 0000 LST to 0800 LST, all approaching or in some cases exceeding 65 %; the absolute maximum is occurs for 2200 LST (70 %). Lowest frequency is just 37 %, at 1600 LST. This month is obviously the height of the Santa Ana season at Laguna Peak, and to a much greater relative extent than at Point Mugu (see Figure 4).

In February, the frequencies drop off significantly, especially in the afternoons, as the sea-breeze regime is getting progressively stronger with the advancing season. March/April frequencies continue to decline for the afternoon hours, but a few early morning cases after sunrise exhibit respectably high percentages, such as March's 63 % and April's 59 % figures, both at 0800 LST.

3.2.2 Distributions of Santa Ana Hours' Tallies on On Laguna Peak Santa Ana Days

Figure 19 shows the relative frequency distributions of Santa Ana hour tallies atop the Peak for All Months Combined (upper-left), October (upper-right), November (lower-left), and December (lower-right). On an overall month basis, the most frequent tallies are, 3 hours (~11 %), 2 hours (~9 %), and 24 hours (7 %), the latter, of course, reflecting all-day Santa Ana episodes. Most October events are 3-hour affairs (not necessarily consecutive hours) , as are those for November, but curiously, for December, the peak frequency (10%), reflects 15 hours of Santa Ana winds, The 24-hour bar is relatively prominent for November and December, but not so much for October.

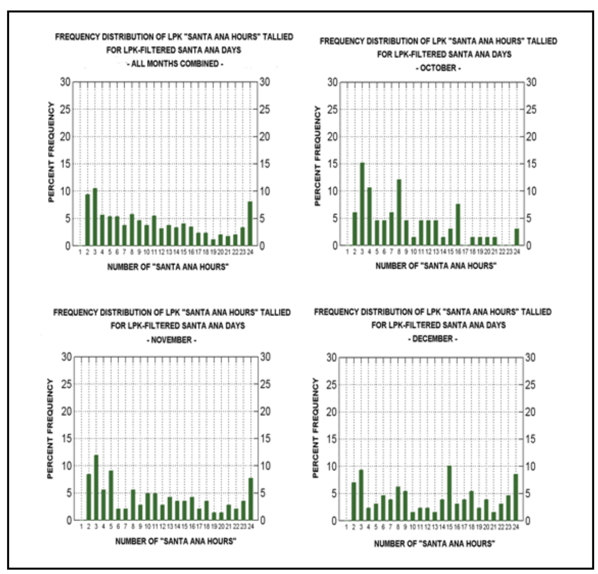

Figure 19. Frequency Distributions for "Santa Ana Hour Tallies" on Santa Ana Days at Laguna Peak - All Months Combined - October, November, and December (LPK filter).

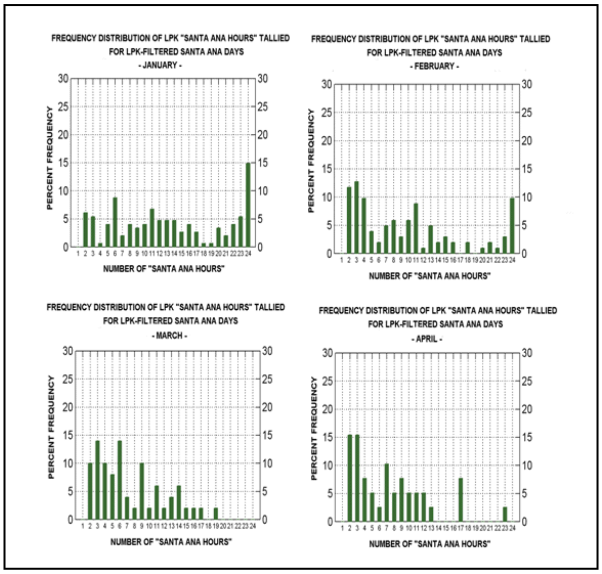

Figure 20. Frequency Distributions for "Santa Ana Hour Tallies" on Santa Ana Days at Laguna Peak – January, February, March, and April (LPK filter).

Figure 20 above exhibits the corresponding relative frequency charts for January (upper-left), February (upper-right), March (lower-left), and April (lower-right).

Interestingly, for the January chart, by far the most prominent individual frequency (15 %) is that for the 24-hour bar, signifying all-day Santa Ana's. The 24-hour bar is still ranks as 3rd highest for February (10 %), but is absent from the March and April charts, the land-sea breeze season too advanced at these months to allow all-day events. The most frequent individual tallies for February, March, and April are each 3 hours (frequencies between 10 and 15 %).

3.2.3- Frequency Distributions of Santa Ana Multi-Day Runs at Laguna Peak

Figure 21 below shows the frequency distributions of Santa Ana daily runs at Laguna Peak for All Months Combined (upper-left), October (upper-right), November (lower-left), and December (lower-right). On an overall basis, most runs are one or two day events, (frequencies each at 26-27%), but the three-day frequency is a respectable 19 %. Given the earliness of the season, most October events are single-day occurrences (38 %), November with 21-24 % frequencies for one, three, and four day events. December's distribution stretches out noticeably to the higher runs, including the absolute maximum: 14 days.

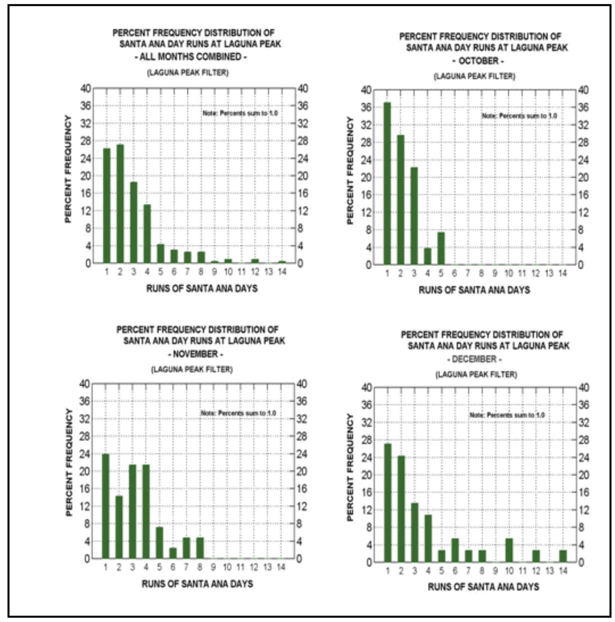

Figure 21. Frequency Distributions for Santa Ana Day Runs at Laguna Peak - All Months Combined, October, November, and December (LPK fllter).

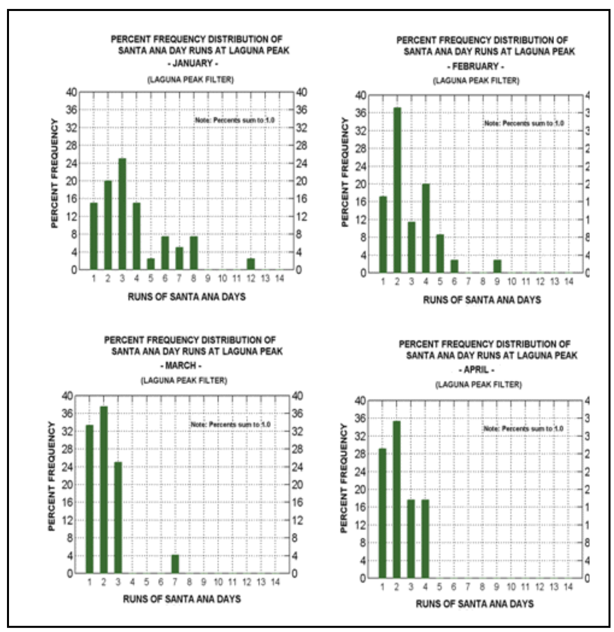

Figure 22. Frequency Distributions for Santa Ana Day Runs at Laguna Peak - January, February, March, and April (LPK fllter).

Figure 22 above presents the daily runs' frequencies charts for January (upper-left), February (upper-right), March (lower-left), and April (lower-right). January's modal frequency (25 %) is for 3-day runs, but given its status in the midst of the Santa Ana season, the distribution is stretched out noticeably to higher levels also. February, March, and April's each have very high frequencies for two-day runs - between 36 and 38 percent.

3.2.4- Wind Cluster Patterns or "Modes" for Laguna Peak (LPK Filter)

As was performed for Point Mugu, the next task was to perform a clustering analysis on the 1982-1992 and 2015-16 Laguna Peak subset to resolve its idealized diurnal mean vector wind patterns on Santa Ana Days. Three modes were generated, ranging in relative frequencies from 37.1 to 28.0 percent.

Figure 23 shows the wind cluster chart for the most important mode, the "Weak Santa Ana or Land Breeze Through Mid-Morning" Pattern. Not unlike the principal mode for Point Mugu, this depicts a mean vector wind pattern suggesting relatively weak episodes.

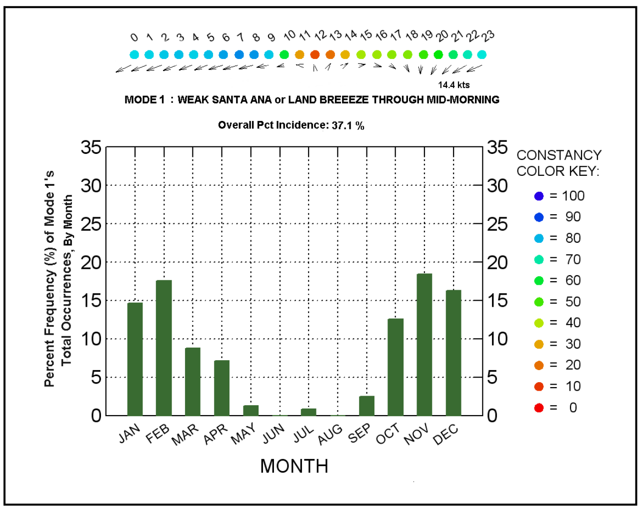

Figure 23 – Mean Vector Wind Cluster Diagram for "Weak Santa Ana or Land Breeze Through Mid-Morning" Pattern (incidence: 37.1 %)

The orientations are light northeasterly through about 1000 LST, but at sub-15 knot mean speeds (the maximum magnitude for the pattern is only 14.4 knots, that for a northeasterly mean vector later in the day at 2200 LST). Over 1100 LST to 1400 LST, the winds are variable in direction (low constancies), light westerly ones (semblance of a sea-breeze) then appearing about 1500 LST, becoming progressively more northwesterly into the early evening. About half of this mode's cases were confined to November, December, and February.

Ranking second in importance is the "Moderate Santa Ana Flow in Forenoon" pattern (Figure 24). This depicts a stronger Santa Ana event (including a mean vector wind speed of 26.2 kts noted for 0600 LST), one however, that is cut short in the afternoon by a sea-breeze intrusion, the changeover coming at 1300-1400 LST, as evidenced by the (low) constancy colorings. In the late evening, the orientations turn offshore again.

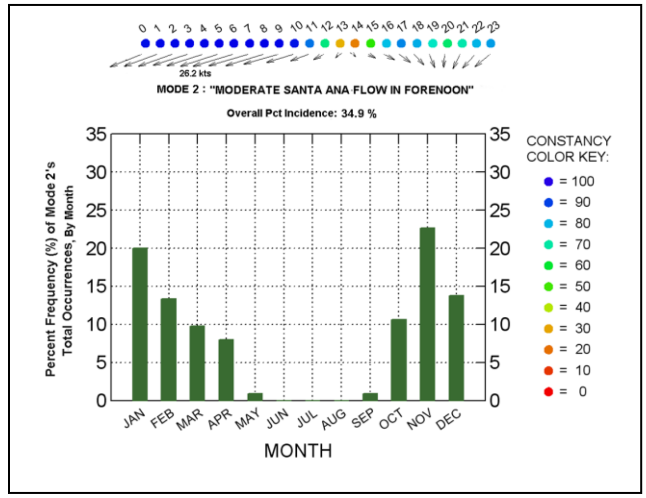

Figure 24 – Mean Vector Wind Cluster Diagram for "Moderate Santa Ana Flow in Forenoon" Pattern (incidence: 34.9 %)

The remaining cluster is the "Strong Santa Ana Day" pattern (Figure 25); this depicts an all-day event with strong northeasterlies throughout. Maximum magnitude speed (33.0 knots) is labeled for 0800 LST. This is a predominantly January and December pattern with 34% and 28 % of the cases, respectively, confined to those months

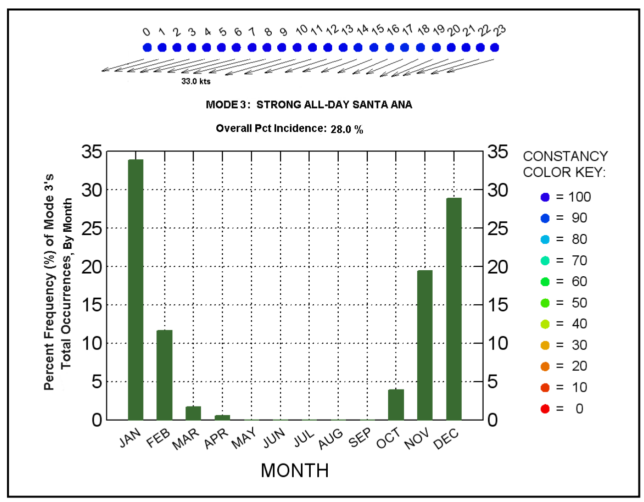

Figure 25 – Mean Vector Wind Cluster Diagram for "Strong All-Day Santa Ana" Pattern (incidence: 28.0 %)

3.3 – “Paired” Results: Two-station Wind Cluster Analyses of Point Mugu and Laguna Peak using The “NTD Filter” with a repeat analysis using the “LPK filter”

In this section the analysis is elevated to a two-station one, with the Point Mugu and Laguna Peak data analyzed as one with the “NTD Filter” applied (on Mugu data only) followed by similar treatment with the “LPK Filter” applied (on Laguna Peak data only). By necessity, the Mugu data’s period of record is reduced to match that of Laguna Peak’s (1982-1992 and late 2015/early 2016)

3.3.1 – Point. Mugu and Laguna Peak Paired Analysis utilizing the NTD Filter

Wind cluster analysis of the Pt. Mugu and Laguna Peak data subset after appilication of the NTD filter produced five patterns or “Modes”, ranging in relative frequency from 28.6 % to 12.8 %.

Figure 26 below presents the wind cluster diagram for the most frequent mode: “Santa Ana Episode – Forenoon Only”.

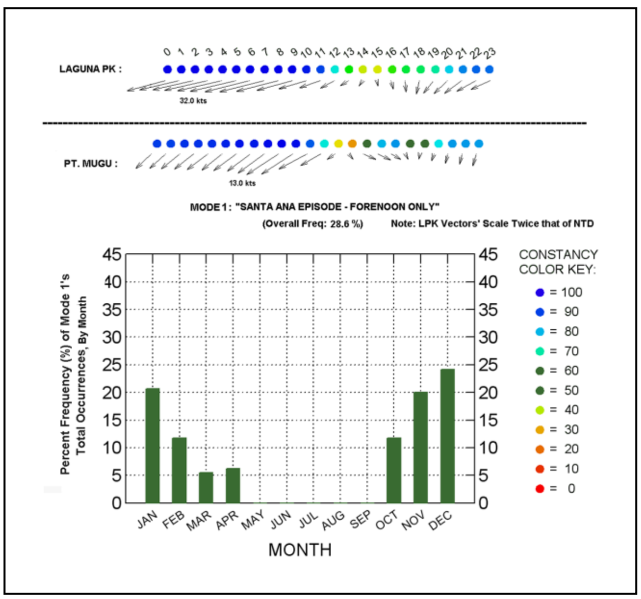

Figure 26 – Mean Vector Wind Cluster Diagram for the “Santa Ana Episode – Forenoon Only” (incidence: 28.6 %)

The mean vectors depict an abbreviated Santa Ana episode, terminated at both Point Mugu and Laguna Peak by a sea-breeze instrusion in the early afternoon. At Laguna Peak, the mean vectors are east-northeasterly at high magnitudes in the morning hours (including a maximum 32.0 knots at 0500 LST); at Mugu in the A.M., they are more northeasterly, and lighter, the maximum 13.0 knots for 0900 LST. The changeover to onshore flow at Mugu sets in about 1200-1300 LST (yellow and brown low constancy colors), while at Laguna Peak the shift is delayed to1400 LST to 1500 LST (yellow low constancy shadings). Thereafter, there’s a gradual shift back at both stations to light to moderate offshore flow for the evening. Some 25 % of this pattern’s cases were December ones, another 20 % January’s.

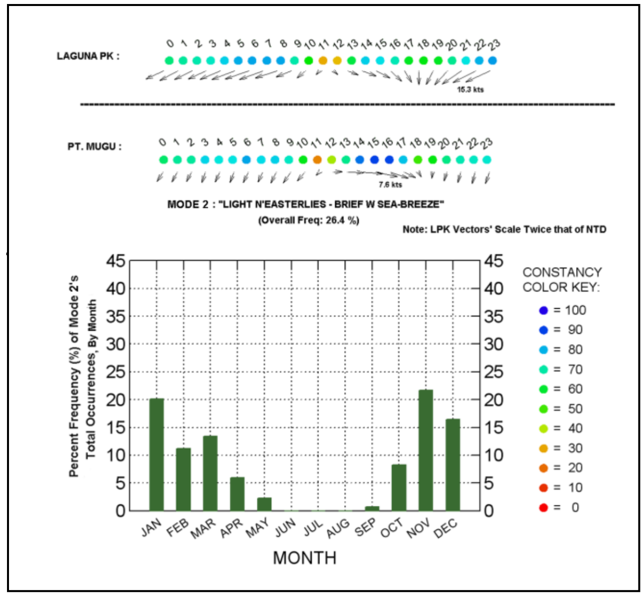

Figure 27 – Mean Vector Wind Cluster Diagram for the “Light N’Easterlies – Brief W Sea-Breeze” Pattern (incidence: 26.4 %)

Ranking second in frequency (26.4%) is the “Light N’Easterlies – Brief W Sea-Breeze” pattern (Figure 27 above). The mean vectors depict another alternating offshore/onshore mode, the light northeasterly quadrant vectors for the morning hours at both stations, however, suggestive of a weak episode at those times. Similar to Figure 26, the morning vectors at Laguna Peak are more east-northeasterly than those at Point Mugu. Around 1100 LST at both stations a transition to onshore flow sets in, that at Point Mugu more apparent visually, as the westerly mean vectors for 1400 LST to 1600 LST all have blue constancy shadings, including that for the maximum mean magnitude, 7.6 knots, at 1500 LST. At Laguna Peak, signs of a incipient Santa Ana appear just before midnight, the highest mean vector magnitude, 15.3 knots (northeasterly) noted at 2300 LST. A slight majority of this pattern’s cases were confined to November (22 %).

Third most frequent pattern (16.4 %) is the “Strong Santa Ana Episode – All Day” pattern (Figure 28 below) As the title indicates, high magnitude northeasterly-oriented vectors are present for all hours of the day at both stations, the maximum magnitude vector at Laguna Peak 39.9 knots for 0600 LST, that for Point Mugu 18.6 knots at 1100 LST. Some 45 % of the cases were January ones.

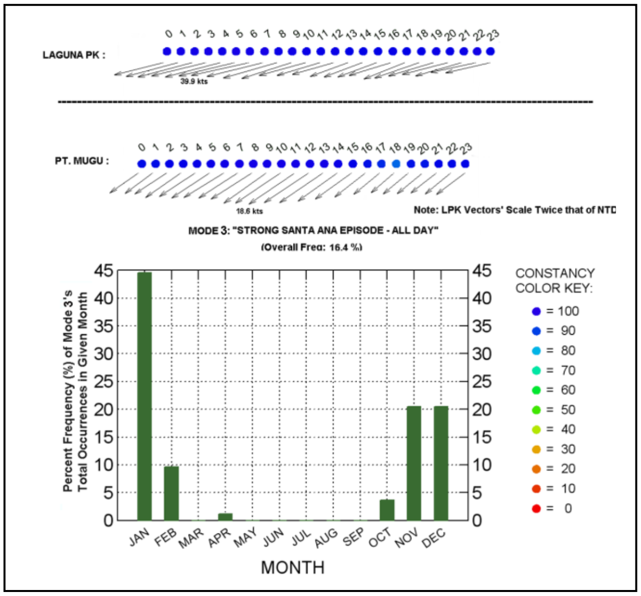

Figure 28 – Mean Vector Wind Cluster Diagram for the "Strong Santa Ana Episode – All Day" Pattern (incidence: 16.4 %)

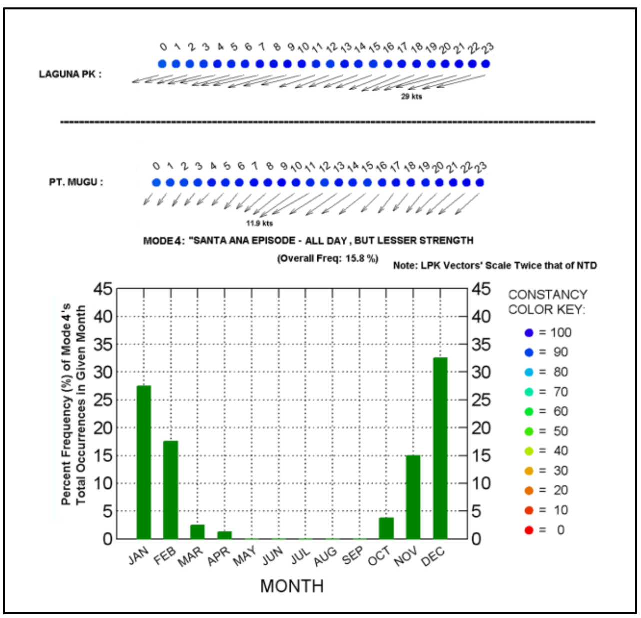

Figure 29 – Mean Vector Wind Cluster Diagram for the "Santa Ana Episode – All Day but Lesser Strength" Pattern (incidence: 15.8 %)

Fourth in rank is the "Santa Ana Episode – All Day but Lesser Strength" pattern (see Figure 29 above). The hourly vectors are again northeasterly for all hours of the day at both stations, the maximum magnitude at Laguna Peak (29.0 knots) noted for 2100 LST.

Maximum vector magnitude at Point Mugu is just 11.9 knots, at 1000 LST, so it appears that for much of the day, wind speeds there are just above the NTD filter criterion or in the case of hours prior to 0900 LST, below it. This may be a Santa Ana regime that struggles to get down from the altitude of the Peak to those near sea-level. Most favored calendar month for Figure 28's cases (32 %) was December.

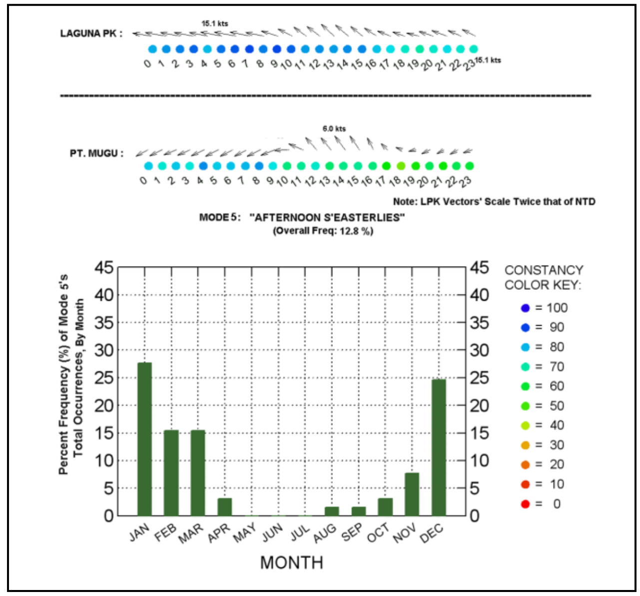

Figure 30 – Mean Vector Wind Cluster Diagram for the "Afternoon S'Easterlies" (incidence: 12.8 %).

In fifth place is the "Afternoon S'Easterlies" pattern (Figure 30 above). This cluster's group membership likely included a number of daily cases that met the NTD Santa Ana Day criterion for one hour or a few more with 10 knot or greater Northeast quadrant winds. Again, since the NTD filter does not include relative humidities, some of the cases in winter could conceivably be Pacific Storms that set in in the afternoon following the customary land-breeze earlier in the day, or to a lesser extent Catalina Eddies.

3.3.2 – Point Mugu and Laguna Peak Paired Analysis using the LPK Filter

Initial wind cluster analysis of the Pt. Mugu and Laguna Peak data subset after application of the LPK filter produced three clusters but as an additional exploratory action, the number was increased to four, utilizing a software feature that permits fixed cluster numbers to be produced. The resulting patterns ranged in relative frequency from 51.4 to 13.2 percent.

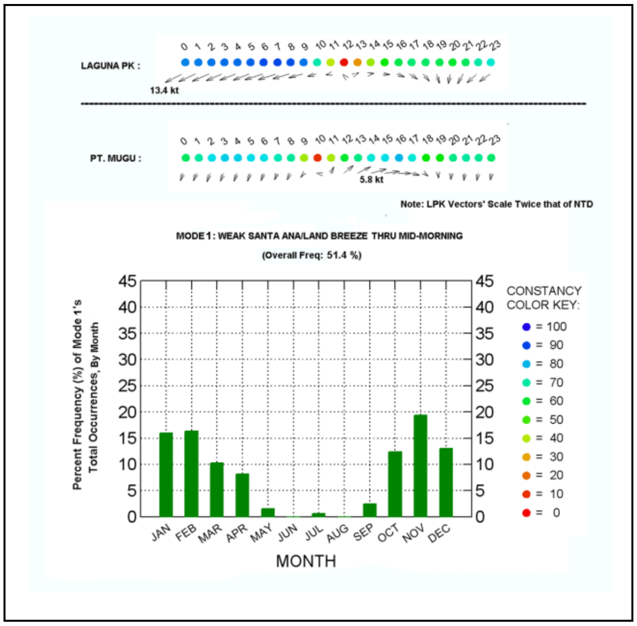

Figure 31. Mean Vector Wind Cluster Diagram for "Weak Santa Ana/Land Breeze Thru Mid-Morning" Pattern (Incidence: 51.4 %)

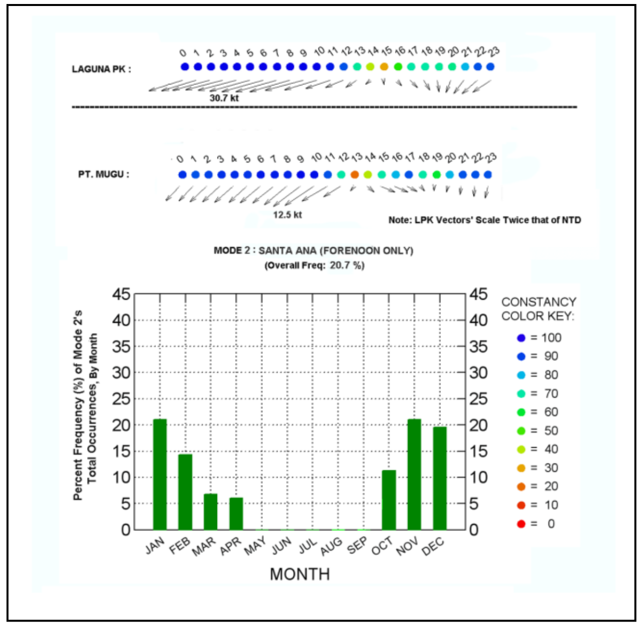

Figure 32. Mean Vector Wind Cluster Diagram for "Santa Ana (Forenoon Only)" Pattern (Incidence: 20.7 %)

Figure 31 above shows the wind cluster chart for the most prominent mode, the "Weak Santa Ana/Land Breeze thru Mid-Morning" Pattern.

This pattern's title reflects that fact the none of the mean vector magnitudes at Laguna Peak are more than 15 knots in magnitude, the absolute maximum figure, for 0000 LST, just 13.4 knots. So, like a few other cases examined previously, mean vectors are depicting weak Santa Anas (at least on the Peak) with early morning cutoff times. The mean vectors at Point Mugu are very light northeasterly through 0900 LST, indications of Santa Ana conditions uncertain there. At 1000 LST a changeover to onshore flow takes place (red constancy coloring), the same occurring at Laguna Peak some two hours later (red constancy coloring again). The onshore flow at both stations is relatively light, maximum vector magnitude at Mugu just 5.8 knots, a southwesterly at 1400 LST. In the evening hours at both stations the vectors switch back to (light) offshore again.

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Ranking second in importance is the "Santa Ana (Forenoon Only)" pattern (Figure 32 above, incidence 20.7 %). As the title indicates, the episode is confined to the morning hours, but there is an offshore "rejuvenation" of sorts on the Peak just before midnight. Mean vector magnitudes at both the Peak and Mugu in the A.M are at definite Santa Ana levels, including a 30.7 knot maximum at Laguna Peak for 0500 LST, and a 12.5 knot maximum at Mugu for 1000 LST. A changeover to onshore flow is seen at Mugu for 1300 LST (orange-brown constancy shading), a similar pattern switch (brown constancy shading) noted for the Peak two hours later at 1500 LST. Light offshore flow vectors at blue constancy magnitudes appear again for Mugu for 2000 LST to 2300 LST.

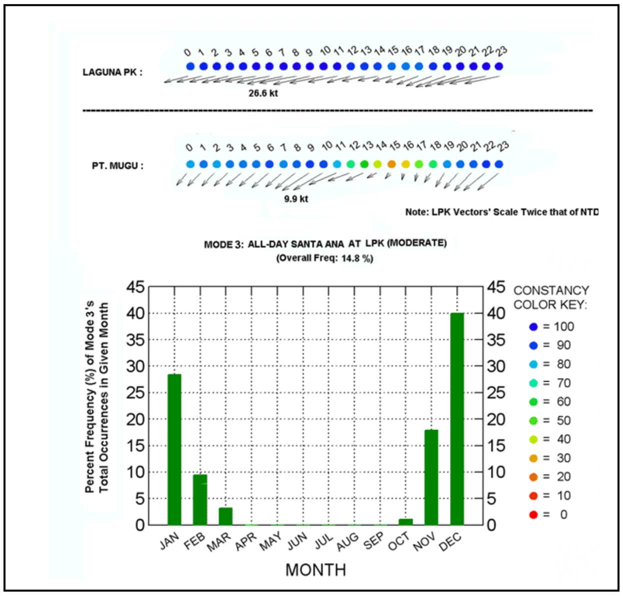

Figure 33. Mean Vector Wind Cluster Diagram for "All-Day Santa Ana at LPK (Moderate)" Pattern (Incidence: 14.8 %)

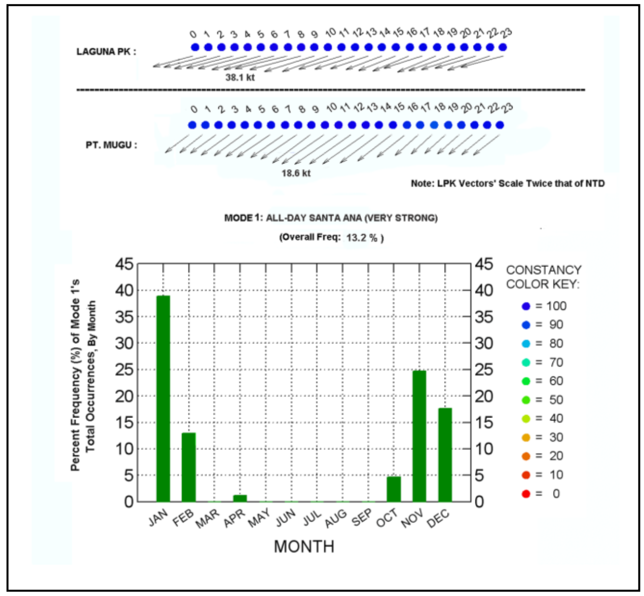

Figure 34. Mean Vector Wind Cluster Diagram for "All-Day Santa Ana (Very Strong)' pattern (Incidence: 13.2 %)

In third place is the "All-Day Santa Ana at LPK (Moderate)" Pattern (relative incidence: 14.8 % - Figure 33 above) . The "LPK" distinction is made because while the idealized Santa Ana regime persists all day at the Peak, it does not appear to extend down to the level of Mugu at mean wind magnitudes that would suggest that Santa Ana conditions are occurring there to the same relative degree (maximum mean vector magnitude at Mugu only 9.9 knots; in contrast, that on the Peak is 26.6 knots at 0900 LST). Also, there are hints of at least some sea-breeze intrusions at mid-afternoon (yellow and brown constancy shadings over the 1400 LST to 1600 LST interval at Mugu). Some 40 percent of this pattern's cases were confined to December.

Finally, ranking fourth, is the "All-Day Santa Ana (Very Strong)" Pattern" (incidence 13.2 % - Figure 34 below). This depicts high magnitude Santa Ana winds at both the Peak and Mugu for all hours of the day, mean values for the former as high as 38.1 knots (at 0800 LST), those for the latter at 18.6 knots at 1100 LST. Nearly 40 percent of this mode's cases were in January.

5. SUMMARY

Using a variety of analytical methods and tools, the nature of Point Mugu and Laguna Peak diurnal wind character during "Santa Ana Day" episodes was investigated to thorough extent. On an individual station basis, properties such as the relative frequencies of Santa Ana days per year and month were evaluated. Also, the relative frequencies of Santa Ana "hours", by hour and the distributions of total Santa Ana hours, by day, were studied; additionally, the frequency distributions of consecutive day Santa Ana runs were tabulated. The latter three were done on an all-months combined basis and for a selection of individual calendar months (October-April, inclusive). Anectodal notions of wind character at Point Mugu and Laguna Peak during Santa Ana episodes (such as the morning maximum in Santa Ana "hour" frequency) were confirmed in many instances, and these ideas are now established as factual, supplemented by objective and detailed statistical and graphical information.

Also, in a relatively new and original adaptation of clustering analysis on individual hourly wind observations (decomposed u and v midnight-to-midnight wind observations at both stations during defined Santa Ana Days events), idealized climatological mean vector wind hour-to-hour patterns or "modes" were produced. These provided useful, supplementary interpretative information on the varieties of contiguous hours' patterns experienced during Santa Ana day episodes and their relative frequencies, and in the case of the paired Point Mugu and Laguna Peak analyses (considered as one data set), contrasts between the two stations' patterns during the "same" Santa Anas. While the wind cluster patterns created (both in the individual and paired applications) in most cases appeared to be physically meaningful, it should be said that their numbers, form, and relative frequencies were influenced by the particular "Santa Ana Day" filtering definitions chosen, along with the software settings selected (default or otherwise) for the actual clustering operation.

6. REFERENCES

e-mail exchange with Jay Rosenthal, CCM, 14 Apr 2016

"The Santa Ana Winds"
http://people.atmos.ucla.edu/fovell/ASother/mm5/SantaAna/winds.html

Nisbet, R., Elder, J., and Miner, G., 2009: Handbook of Statistical Analysis & Data Mining Applications - Elsevier, 824 pp.