Summarizing Wind Climatologies Through the Use of Wind Roses

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1.0 Introduction

Of all the meteorological fields– temperature (T), pressure (P), horizontal winds (V) and humidity (q)– measured in a routine weather station observation, summarizing wind measurements presents a unique challenge. T, P ,and q are *scalar* fields in that they have a single value at each point in the atmosphere. By contrast, V is a *vector* field with two distinct components, *direction* and magnitude (*speed*). Typically, wind speed and wind direction are reported as two separate fields in the observation record. However, these two fields are obviously complementary, being two aspects of the same vector wind field V.

For a wide variety of reasons, it is useful to create a climatology[1] of meteorological variables. It is comparatively easy to calculate a climatology for a group of T, P, or q values by treating the group as a distribution and finding the moments (mean, standard deviation, etc.). By contrast, wind speed and wind direction (scalar fields when listed separately) are highly correlated in time. While it is possible to create climatologies of wind speed and wind direction separately, it is useful to implement a summary technique that retains the speed/direction relationship of the component observations of a collection of wind observations while still giving some kind of probability of occurrence. The *wind rose* is one such graphical representation of a wind climatology that incorporates both speed and direction in the same probability analysis.

The wind rose is also a graphical product. The outcome of a wind rose study is not moment-related, i.e., it does not provide strictly numerical values to summarize a sample of wind observations. Rather, the wind rose is a hybrid presentation that incorporates both visual and numerical attributes in one display.

2.0 Wind Observations

2.1 Observation height

There are several attributes of the wind, and wind measurements, worth noting. Being slowed at the surface by friction, wind speed varies with height, typically lowest in the first few meters above the surface and increasing with height. The default height above ground for taking wind measurements is 10 m (about 33 ft). above ground level (AGL). This is felt to be sufficiently high to overcome the strongest friction effects, while still adequately sampling the “uncontaminated” surface wind field. In reality, there is no obvious “best height” for wind measurements.

Most importantly, all of the observations of the wind sample should be measured the same site. Some older data sets have wind observations at 3 m. These data are not useless by any means, but they will tend to be slower than the higher 10 m wind observations, and should not be commingled with observations taken at higher levels.

2.2 Wind Direction

Wind direction is determined as the *direction the wind comes **from***, typically in 10° increments from true north (bearing consistent with the compass rose). For example an easterly wind (originating from the east)

1. The term “climatology” used in this sense to denote a summary study of a group of like meteorological variables

has a direction of 90°, and a NW wind (out of the NW) has a direction of 315°. In reality, the direction is typically reported to 10° of precision, usually rounded up. Thus, in the example above, a NW wind would be reported as 320 degrees.

Table 1 provides degree-equivalent direction angles for the acronym system.

N	NNE	NE	ENE	E	ESE	SE	SSE
0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°
S	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**
180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°

TABLE 1. Acronym directions and their degree equivalents

2.3 Wind Speed

The wind speed may be given in a variety of units, most commonly *nautical miles per hour* (*kt*) in the U.S. Other frequently used measurement units are *statute miles per hour* (*1 mph = 1.15 kt*) and meters per second (*1 m/s = 1.94 kt*).

Light winds are often quite variable in direction. Variable winds less than 6 kt are typically given a direction of "*vrb*" to denote this variability. Occasionally, higher wind speeds will be assigned a direction of *vrb,* but typically as wind speed increases, the direction becomes more constant over the relatively short time scales of the measurement.

2.3.1 Wind Speed Classifications

Current state of the art instruments are capable of obtaining discrete wind measurements several times per second. The values reported are not instantaneous observations but rather the average of several consecutive observations accumulated over a fixed sampling period. This fact makes it possible to define several different types of wind speed.[1]

Sustained Wind: Sustained wind speed is determined by averaging observed values over a two-minute period.

Wind Gust: Wind gusts are reported when the peak wind speed reaches at least 16 knots and the variation in wind speed between the peaks and lulls is at least 9 knots. Gusts usually last less than 20 sec.

Peak Wind: The definition of the peak wind varies depending on the source of the wind speed observations, but is generally either the highest instantaneous wind speed or the strongest wind gust over a given sampling time. This definition is probably the most variable from one observing program to the next, and perhaps the least useful.

1. The definitions given here are not absolute, and indeed the definitions of the wind speed types discussed here often vary somewhat from one observing program to the next. The best bet is to read the metadata that (hopefully) accompanies the observational data. Usually small (or even moderate) variations in sample size or averaging time do not make a great deal of difference *for most applications*.

Wind direction is usually not given for gusts or peak winds, implicitly assuming that wind direction is the same or similar to the sustained wind direction. This may or may not be justified, given the turbulent nature of strong winds near the surface.

Most data sources do not consistently report wind gust or peak wind speed if gust criteria are not met. With the exception of certain specialized applications (e.g. where peak winds are an important aspect of design criteria), sustained winds are usually considered the best characterization of windiness at a given site.

3.0 Components of the Wind Rose

3.1 Elements of the Wind Rose Graphic

The construction of a wind rose is conceptually simple. In this section, we will build a sample of a minimal wind rose using the data in Table 1.

sample number	dir (°)	spd(kt)	sample number	dir (°)	spd(kt)
#1	83	7	#6	55	7
#2	105	12	#7	86	15
#3	175	19	#8	195	17
#4	34	12	# 9	321	3
#5	325	1	#10	315	14

TABLE 2. A very small sample of wind direction/speed values

Note that there are (conveniently) 10 wind observations in Table 1,with a sample number for ease of reference. To start out, we reproduce the directional aspect of the well-known compass rose with its directional points (Figure. 1):

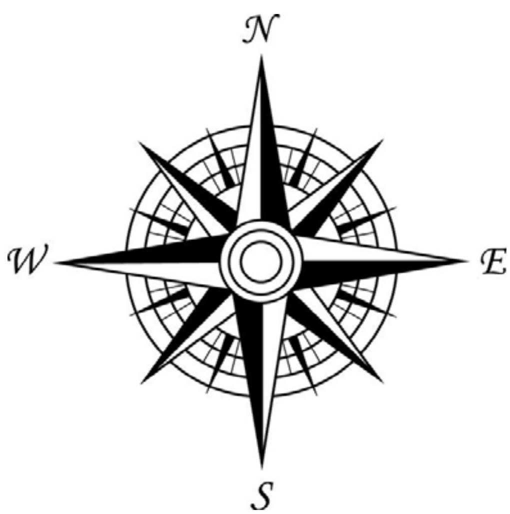

*Figure 1.*a A traditional compass rose.

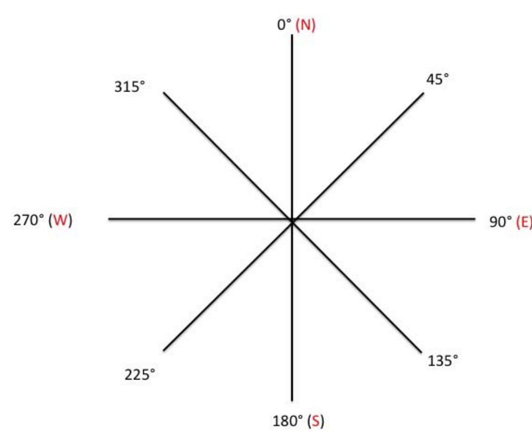

Figure 1.(b) The compass rose as used in creating wind roses.

From Figure 1 (a) and (b) we see the close relationship between the two figure types. For this example, the wind rose (Figure. 1b) has the 4 cardinal directions (N,E,S,W) as well as an intermediate value between each. Note that the direction starts at “0” at the top spoke of the wind rose, increasing in 45° increments as one proceeds around the rose clockwise, giving us eight equally-spaced spokes.

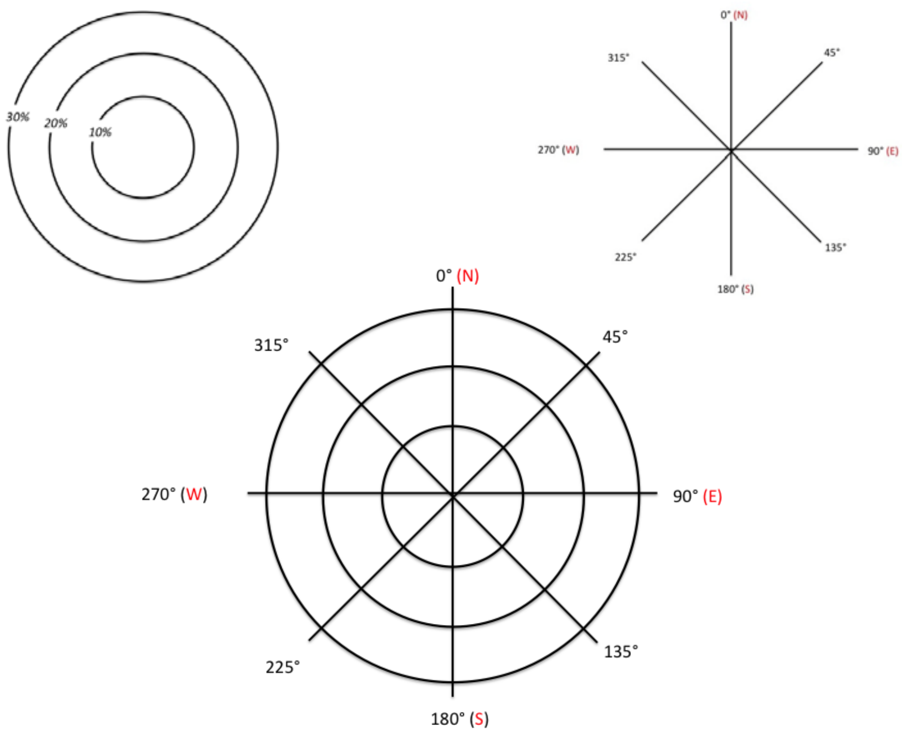

Figure 2. Upper left probability rings. Upper right, rose directional spokes. Bottom, empty wind rose structure.

The second set of lines are concentric rings (Figure 2, upper-right). These lines denote the probability of occurrence and are labeled with percentages increasing outward.

The final aspect of the wind rose are the bins of wind speed, given by bands (in this example called "tiles"). This requires a color bar, or some other way of assigning colors to wind speed bins. An example color bar is given in Figure 3.

The three components shown above– direction spokes, probability rings and colors for the speed bins– are the essential components of a wind rose.

3.2 Constructing a Sample Wind Rose

Referring to the data in Table 1, it is clear that there are many more directions than those labeled explicitly in Figure 1.

The wind rose we are constructing indeed provides information for only eight directions. This requires that we sort and "bin" the directional component of each wind observation so that we may talk about observed directions associated with the average direction denoted by each spoke[1].

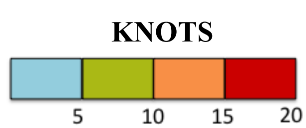

Figure 3. The color bar, with 5 kt bins. implemented for this example

1. In general, for a plot with N equally-spaced spokes over a range of $0°–359°$, the bin width $D = 360/N$. For a given spoke with a value θ, the bin ranges from $\theta - D/2$ to $\theta + D/2$.

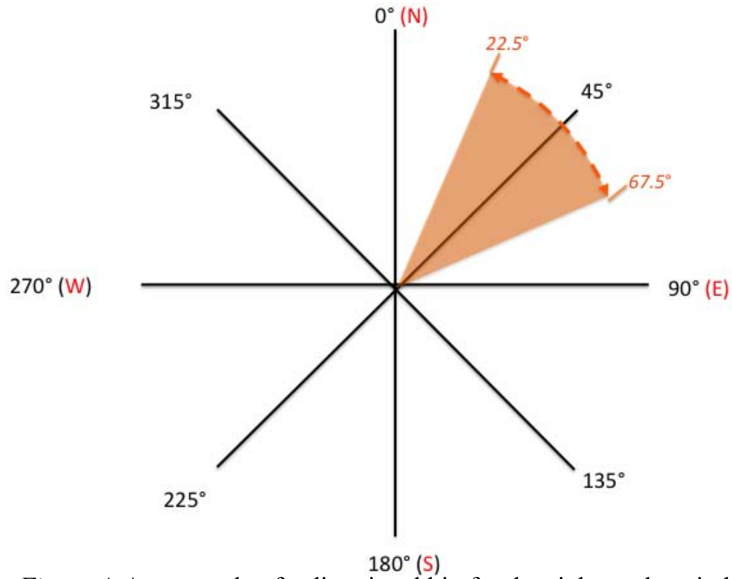

Figure 4. An example of a directional bin for the eight-spoke windrose, Centered on the 45°spoke, the edges of the bin 22.5°to either side. This leaves a sector bounded by 22.5° and 67.5°.

In Figure 4 we see an example of such a sector bin in orange, centered on 45° and bounded by 22.5°on the upper side and 67.5° on the lower boundary, forming a wedge-like bin. By inspection it is apparent that eight such bins will exactly fill the rose. Each observation in the entire data must be sorted by direction into the appropriate sector.

Thus far we have taken care of the directional part of the wind sorting but still need to sort wind speeds *within each sector bin* for the speed. If we consult Table 1, we find two observations that fall into the bin in Figure 4: #4 (34°, 12 kt) and #6 (55°, 7 kt). Referring back to the color bar (Figure 3) we see that sample #4 has a speed of 12 kt and thus falls into the orange bin bounded by 10 kt and 15 kt. Sample #6 is 7 kt, putting it in the green bin bounded by 5 kt and 10 kt[1] in the color bar.

For another value, consider the 315° (NW) spoke, with a sector bin of spanning 292.5° to 337.5°. Inspection of the Table 2 finds three values for this sector bin, #5 (325°, 1 kt); #9 (321°, 3 kt) and #10 (325°, 14 kt). In this instance, there are two values (#5 and #9) that fall in the speed bin 0-5 kt and one (#10) that falls in the 10-15 kt speed bin. The directions above have been given in two systems: an acronym method,e.g., NW for north west, and the degrees bearing system. Both systems are used extensively and often interchangeably as is done here.

1. If a speed happens to coincide with a boundary value, it is counted as a member of the bin to which the boundary value .pertains.

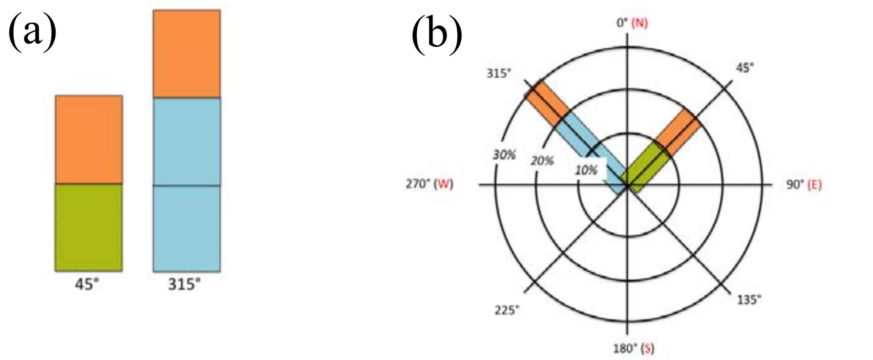

Figure 5. (a) Stacks of "speed" tiles for two of the spokes. (b) The tiles in A overlaid on the appropriate spokes.

Now, we consider each sample as a tile with its color the corresponding speed bin. If we make a stack of these tiles starting with the with the "slowest" ones on the bottom and increasing with speed upward, we get the "petal" for the corresponding spoke. Figure 5 shows two such stacks of tiles. All that is left now for this example is to superimpose the petal onto the requisite spokes making sure that the bottom of the stack is at the center of the plot. Figure 5A shows the stack of speed tiles and Figure 5 shows the tiles placed on the rose.

3.3 The Completed Example

If we repeat the process with the other 6 directions, we get the completed example wind rose displayed in Figure.

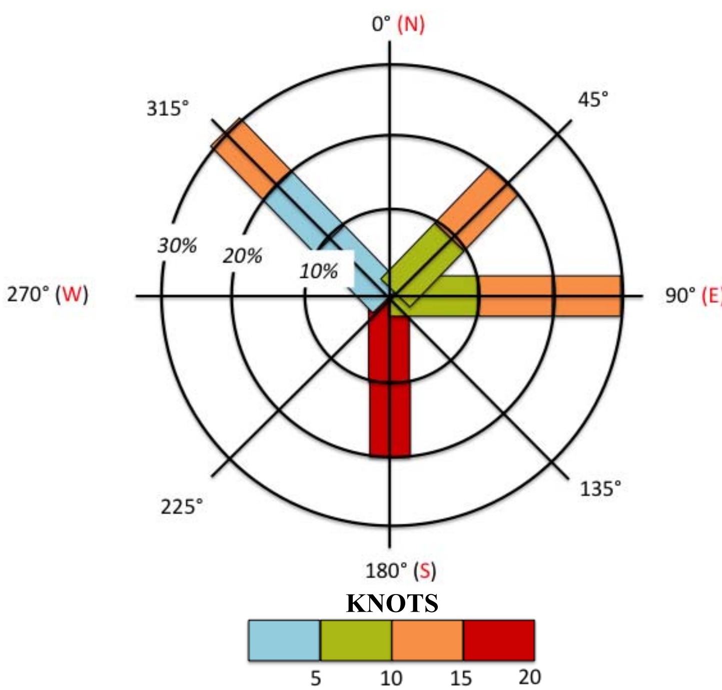

*Figure 6.*The complete example wind rose from the data in Table 1.

This example wind rose looks a bit rough around the edges, but it is also robust enough to show the salient benefits of the wind rose. The sample size of N = 10, is very convenient for the example, but is much smaller that the hundreds to thousands of samples usually used to build a wind rose. The other simplification is having only 8 directional sectors. It is probably more typical to have 16 sectors, giving more resolution to the directional component of the wind rose. The wind rose, after all is simply a plotting tool to make sense of aggregate wind data at s single location. More sophistication almost invariably comes with a more complicated and confusing plot... which is what we are trying to get away from.

3.3.1 Discussion

We can get a fair amount of information from the simple example of Figure 6. Just at first glance, we can see that, at least for the very short period of record (POR) there has been no wind from directions 0°, 135°, 225°, and 270°. The most common wind directions are 90° and 315°with 30% total likelihood in both directions Getting down into the weeds a little bit, we can look at the speed distribution for a single direction, say 315°. The blue section (0-5 kt) measures in at 20%. We can interpret this as “20% of the time (for the POR) the winds blow out of 315° at 5 kt or less. The orange section (10-15 kt) is 10% wide, allowing us to say “10% of the time the wind is from 315° at 11-15 kt. Note that we have no 6-10 kt speed bin on this petal, corresponding to green. That is fine– if we had more samples we would likely have some exemplars having this speed and direction. In a more summary sense we can make the more summary statement “The wind blows from 315° 30% of the time at 15 kts or less”. Inspecting widths of the color bands, we can also note that while winds from 315° are fairly common, they tend to be light. This is the great utility of the wind rose– the ability to summarize data at a glance.

Now take a look at the 180° sector. We see immediately that these winds occur only 20% of the time, but when they do blow, it is a stronger wind of 16-20 kts. Furthermore since there are no color bands below the maroon 16-20 kt one, we can make a stronger summary statement” winds blowing out of 180° occur 20% of the time and are strong, between 16-20 kt”.

4.0 A Complete Working Example

In this final section we will look at some wind roses– full-year and seasonal– from an actual data set. The data in this set represents hourly “observations” from five years of model data. These data are not observations, but rather a time-series collection of hourly forecast surface winds at one point in the model domain:

name	id	Longitude	Latitude
Valdez Duck Flats	#NE017	-146.322°	061.123°

Table 3. Location of wind time series.

Regardless of the origin of the data– observed or modeled– each point has both a direction and a speed. In the event that for some reason a point doesn’t have both components, the point is discarded from our data set.[1]

1. There are a host of reasons that wind data points may be missing one or both components– typically because of intermittent instrument or communication issues. Numerically simulated winds, are not true observations and seldom, have missing/incomplete points.

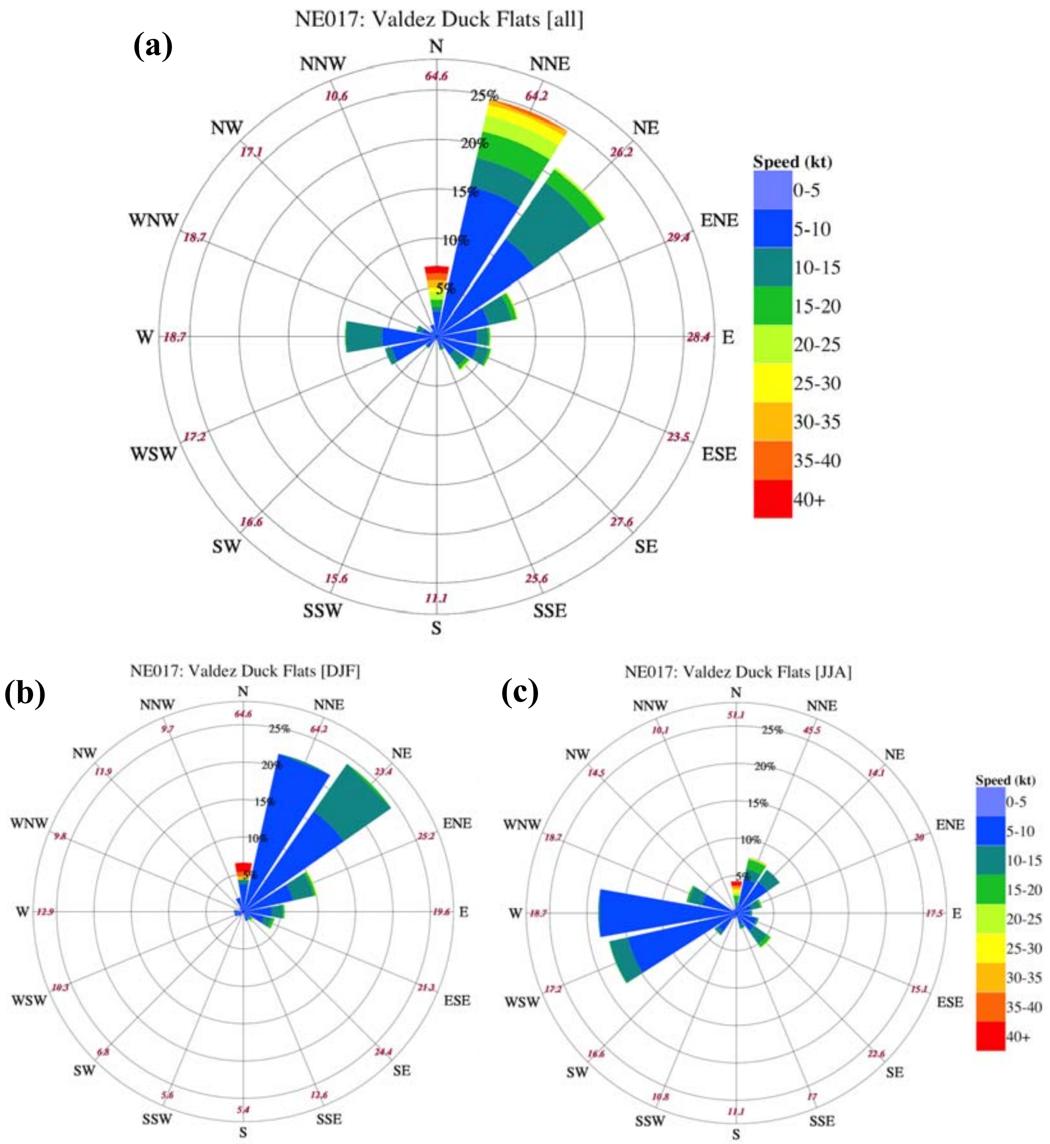

Figure 7. (a) The full-year wind rose from simulated surface wind observations. (b) A wind rose constructed only from winter winds (Dec, Jan, Feb.). (c) A wind rose constructed only from summer winds (Jun, Jul, Aug).

4.1 Valdez Duck Flats Wind Rose

Figure 7a shows a wind rose for all the available data points in the data set for the entire period of record. Note the differences between this figure and the more idealized example of Figure 6. There are now 16 directions rather than the 8 shown in Figure. 6 The percentage rings are spaced at 5% intervals rather than 10% intervals, and there are more color choices in the color bar of Figure 7, corresponding to a larger range of speeds (0–40+ kt). Also, in the outermost ring of each spoke the maximum speed for the corresponding direction over the POR is printed.

Winds of 5 kt or less are not plotted in Figure 7– both because the directions tend to be variable (even if an explicit direction is given) and because at most sites they occur such a great percentage of the overall time that they “swamp out” the stronger winds that are generally of greater interest to most users.

Finally, the figure is spruced up a bit for clarity's sake, with the rose petals tapering towards the base.

4.1.1 Discussion

One quick glance at Figure 7a shows that at this particular location, the winds are predominantly from the NNE and NE, about 45% of the time. Wind regimes that show a dominant direction are referred to as prevailing winds. (Not all wind regimes show a dominant direction. When this occurs, the term "prevailing winds" is ambiguous and should not be used.) There is a small secondary maximum showing westerly winds about 8% of the time. The other 47% of the time, the wind directions are scattered across the other directions.

What information does Figure 7a provide about the prevailing wind speeds? Looking at the colors on the NNE (22.5°) and NE (45°), we see that they are less than 10 kt. more that 20% or the time. On the higher end, note that about 5% of the time the site experiences prevailing winds from 15-20 kt. Only about 3% of the time does the prevailing wind exceed 20 kt. Looking at the highest speeds in this direction, it is clear that in certain, more uncommon situations, winds in this direction exceed 40 kt, with the highest wind speeds in this direction for the POR exceeding 64 kt.

The N (0°) spoke is of note as well. While quite short– winds only blow out of 0° about 7% of the time– this colorful spoke shows us that the highest winds are more likely to come from the N, exceeding 40+ kt about 1 % of the time. More than half the winds from this direction exceed 20 kt.

4.2 Seasonal Wind Roses

4.2.1 Seasonal wind roses: Winter

In understanding the wind regime for a given area, it is often useful to *subset* or separate the observational record by season. Such wind roses are instructive in understanding the winds displayed in the full-year wind roses. Figure 7b, the wind subsample for the climatological winter (Dec, Jan, Feb). Figure 7b matches the full-year sample (Figure 7a) to first approximation. The NNE/NE prevailing winds are again evident, though they are a bit more quiscent, with winds 20 kt or below about 45% of the time. The due N winds are another story, with winds exceeding 40 kt about 1% of the time, probably during sustained high-wind episodes. Another point of interest demonstrated by this seasonal rose is that the wind directions are strongly biased toward the first quadrant (N-E, 0°-90°), with about 75% of the winds originating from this quadrant.

4.2.2 Seasonal wind roses: Summer

The wind rose in Figure 7c pertains for the summer months of Jun, Jul, and Aug (JJA). From Figure 7c, it is apparent that the summer time wind regime is not typical of the full year. Significantly, there is only a small secondary maximum of winds in the direction of the annual prevailing winds. Rather, the predominant wind is clearly from the W/WSW, more than 35% of the time with winds occasionally occurring from almost any direction. The predominant westerlies are also generally light, < 10 kt over 50% of the time. As in the other two plots, high winds are clearly in the domain of the northerlies, where winds exceeding 40 kt do occur, albeit less than 1% of the time.

5.0 Summary

This document has provided a tutorial on the construction and use of wind roses as a way of summarizing wind climatologies. Clearly, the technique has its limitations. This graphical method depends strongly on the visual capabilities of the user. The wind rose technique is of less utility to those who are color weak or color blind.

Many modifications to this basic template can be made. For example, the color bar of Figure 7 could be extended above 40 kts. Also, for cases where the predominant wind occurs more than about 60 % of the time in a single direction, extra higher percentage rings may need to be added.

Finally the wind rose technique is not necessarily limited to wind observations– any collecion of 2-d vector observations can be displayed in a very similar manner. Fields as diverse as optics and ecology have adopted the wind-rose style display techniques to great advantage.

One of the issues in creating and using wind roses is a relative paucity of free graphical software to do the plotting across a number of computing platforms. The wind roses in this document were created using ggplot and the R statistical programming language. Another option is the NCAR Graphics NCL scripting language. Both R and NCL work well in Windows, OS-X, and the various flavors of Linux.