JP5.12 WIND CLIMATE ANALYSIS FOR A 61-M TOWER IN THE SOUTHEAST

Allen H. Weber, Robert L. Buckley, and Robert J. Kurzeja
Savannah River Technology Center, Aiken, South Carolina

1. INTRODUCTION

The Savannah River Technology Center's (SRTC) Atmospheric Technologies Group (ATG) has operated nine 61-m tower sites (Parker and Addis, 1993) including the Central Climatology (CC) tower which is located near the center of the Savannah River Site (SRS) since 1985. (See Fig. 1). Data from the weather instruments on this tower have provided answers to questions involving risk analyses, dose studies, forecast verifications, and wind/temperature conditions during extreme events and planned tests. Most recently, data from these towers are being used for initial and boundary conditions for computationally intensive numerical simulations using mesoscale forecasting models that are run on a three-hourly basis by ATG for SRS and the surrounding vicinity.

Weber et al. (2002a) found that a series of wind roses based on relatively short time scales (from two weeks to one hour) were a convenient method to depict the predominant wind speeds and directions at anemometer sites in the Southeast operated by the NWS. That report also revealed some interesting spatial and temporal relationships among thirteen NWS stations in the Carolinas, Georgia, and Florida. Our study here will focus on the CC tower to show changes in the wind speed and direction distributions with height during diurnal and annual cycles. This study will concentrate on mean wind speed and direction statistics since wind gusts and turbulence statistics were covered in an earlier publication (Weber et. al., 2002b).

Wind speed and direction are monitored at the CC Tower with sensors at 4, 18, and 36 m in addition to the SRS standard 61-m level. Parker and Addis (1993) described the siting and instrumentation on the CC tower. The tower is located at north latitude 33 degrees 14 minutes 43 seconds, and west longitude 81 degrees 39 minutes 0 seconds in N-Area near the center of the SRS (labeled CLM in Fig. 1). The tower stands in a flat area surrounded by grass out to about 83 m followed by a low-profile (< 1.5 m) storage yard/buildings, railroad, and scattered stands of pine trees.

**Corresponding author address*: A. Weber, Savannah River Technology Center, Bldg. 773A, Aiken, SC 29808.

The pine tree stands begin about 152 m from the tower. Beyond the isolated pine tree stands are areas of denser forest and cleared areas for roads, production sites, railroads, fields and streams.

Parker and Addis (1993) also described the cup anemometers and wind vanes mounted on the CC tower. The wind instruments consist of Teledyne-Geotech model 1585 bivanes and model 1564B cup anemometers that have been operated and calibrated on a regular basis since the tower was erected.

There has been one change in measurement height of the wind instruments at the lowest level of the tower. In May 1993 the anemometer and bivane were moved from 2-m to 4-m to avoid the wake effect of a junction box mounted on a tower leg.

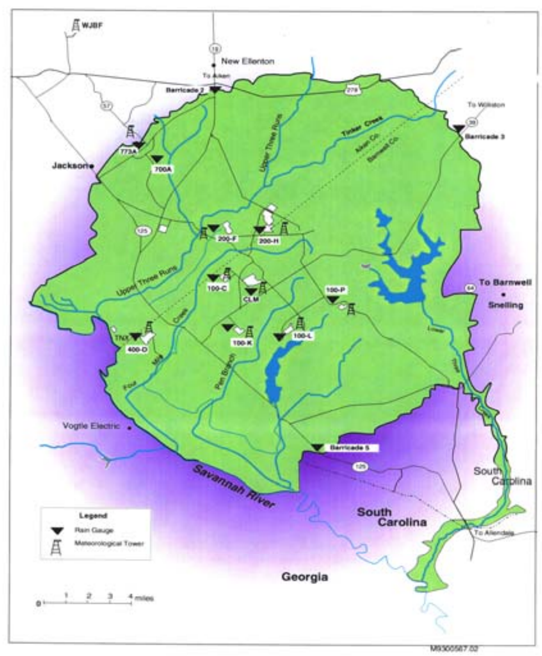
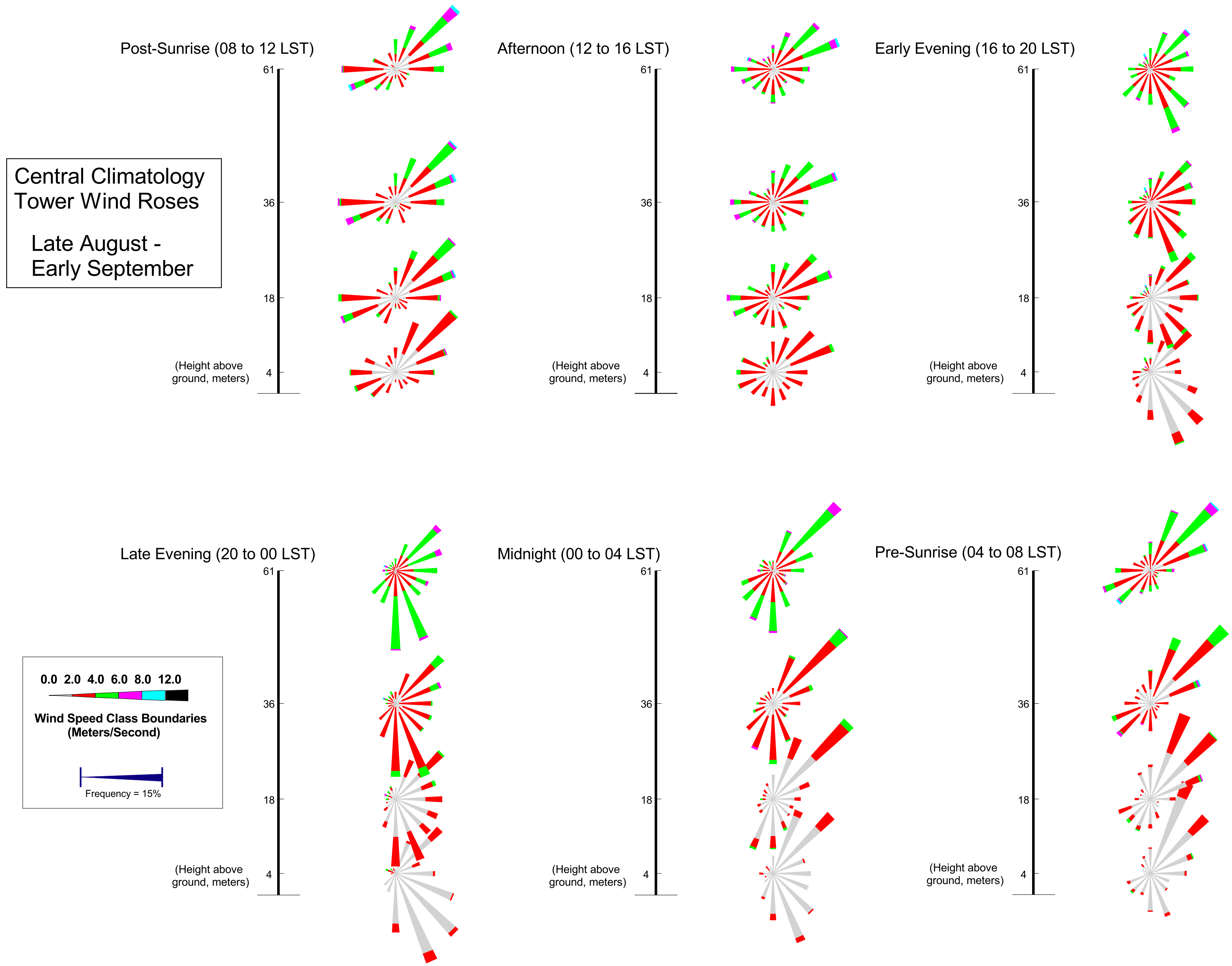


Figure 1: Map showing the CC tower's location (labeled CLM) on the Savannah River Site.

2. CC WIND SPEED AND DIRECTION DATA

Data from the first half of the 20-year period of CC's operation could not be copied from magnetic tapes to disk storage media so our effort in this

Figure 2: CC Wind roses for late August - early September.



study used the more recent data from the CC Tower's data span. The wind speed and direction data for use in this study were obtained for the four tower measurement levels (2-4, 18, 32, and 61-m) for a ten-year period between January 1, 1991 and December 31, 2000. These data records consist of 15-minute scalar averages of wind speed and vector averages of wind direction. Four fifteen-minute records beginning on each hour were combined to obtain one-hour averages of the wind speed (scalar average) and wind direction (vector average).

In order to show the wind speed and direction data at a given level for all 10 years on a single conventional wind rose plot it is necessary to convert the wind directions into 16-point compass-sector wind directions, since the original winds are recorded to the nearest degree. This was accomplished by rounding the wind direction to the nearest of sixteen 22.5-degree compass sectors (centered on N, NNE, etc.) No bias is introduced in the wind direction sectors using this process (as would be the case for stations that report to the nearest 10 degrees).

Using our 10-year data interval it was possible to average the data for the wind rose plots over relatively short time periods to examine climatic changes over a typical day and parts of the year. In this study the data were categorized using twenty-six two-week periods covering the annual cycle. (Each year was truncated at 364 days from the beginning). Six 4-hr time periods were defined to cover the diurnal cycle. The six 4-hr time periods selected were (midnight, 00:00-03:00 LST; pre-(sun)rise, 04:00-07:00; post-(sun)rise, 08:00-11:00; afternoon, 12:00-15:00; early evening, 16:00-19:00; late evening, 20:00-23:00). For the CC Tower during January 1, 1991 to December 31, 2000 (10 years) there are 87,672 hourly observations (350,688 fifteen-minute observations). For the 26 two-week periods and six 4-hr periods spanning a day (averaged over the 10-year data set) there are ~560 hours of data from the CC Tower represented in each individual wind rose plot. A complete set of 156 (26 x 6) wind roses will be available on the Internet at an address provided by the author (allen.weber@srs.gov). The Internet is being used to present the wind roses since there are such a large number of detailed color figures that need to be displayed. In this article a sample of the figures representing one of the 26 two-week periods and all six periods of the day is shown in Fig 2.

3. INTER ANNUAL WIND DIRECTION PATTERNS REFLECTED IN THE WIND ROSES

There seems to be a fairly coherent pattern of inter-annual wind direction patterns reflected in the wind roses repeated from the bottom to the top of the CC tower. The reasons for the inter annual shifts are not as apparent as the major shifts that are discussed in the earlier report on the Southeastern NWS stations, namely the Bermuda high in the summer months and the high pressure system over the Appalachians in the autumn.

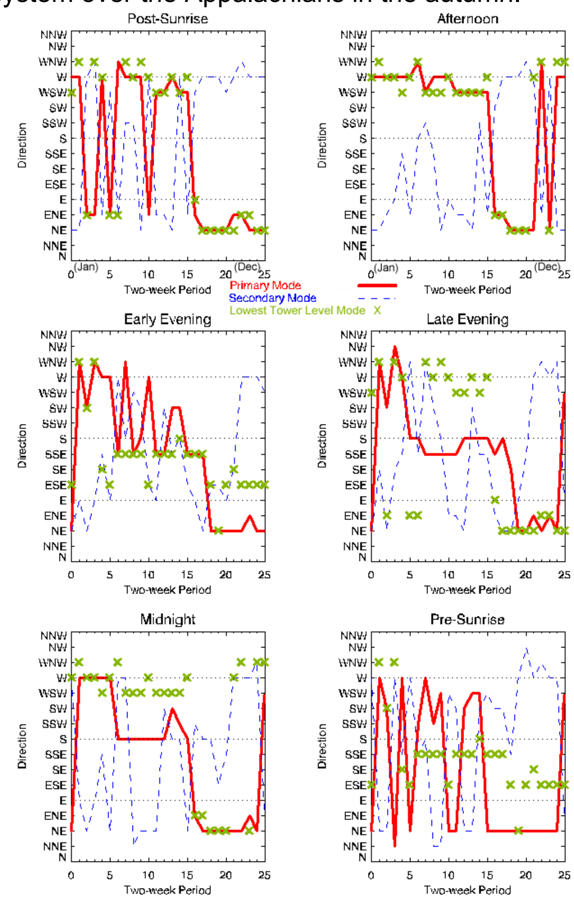


Figure 3: Wind direction modes for the 6 periods of the day over an entire year. The modes plotted in each figure are (1) primary mode (red): selected as representing the most frequent wind direction for the upper three levels of the tower, (2) secondary mode (blue): selected as representing the second most frequent wind direction for the upper three levels of the tower, and (3) surface mode (green): selected as representing the most frequent wind direction for the lowest tower level.

The inter-annual wind direction patterns are shown in Fig. 3 for each of the 6 periods within the diurnal cycle for 26 two-week periods. The modes plotted in the Fig. 3 are (1) primary mode: the most frequent wind direction for the upper three levels of the tower, (2) secondary mode: the second most frequent wind direction for the upper three levels of the tower, and (3) surface mode: the most frequent wind direction for the lowest tower level.

The figure shows some of the striking short-term changes in the primary wind direction mode which occur (in a climatological sense) over the two-week periods. In some cases these short-term fluctuations suggest that the winds “overshoot” and oscillate about some mean wind direction. This can be seen best in the figures for post-sunrise, early evening, and pre-sunrise. These oscillations seem to contain one-month and two-month periods in the wind direction within the annual cycle. The lowest CC tower level often shows a predominant wind direction that is quite different from the higher tower levels, especially for late evening, midnight and pre-sunrise. It is important to emphasize that these are climatologically averaged wind directions. So to think that the winds on a particular day necessarily exhibit strong wind shear could be misleading. Nevertheless, there ought to be occasions when the actual tower winds behave in this manner. Indeed, katabatic winds below 18 meters could cause such behavior.

4. SIMILARITY OF WIND ROSES BETWEEN CC AND AGS OR CAE

In some situations it would be helpful to be able to provide information on the similarity of wind roses between CC lower tower levels and the National Weather Service (NWS) stations at Augusta, Georgia (AGS) (~32 km distant) or Columbia, South Carolina (CAE) (~100 km distant). Unfortunately, the measurement levels at AGS have been changed (14 to10-m) while CAE’s have remained at 10-m during the ten-year period from 1991-2000. CC’s lower 2 levels have been at 2-m (or 4-m since May 1993) and 18-m, so AGS and CAE’s measurement heights are about midway between the lower two CC instruments. These differences make it difficult to compare the distributions in a statistically rigorous manner.

A subjective comparison of the annual wind rose for CAE and AGS with the CC tower by the authors showed that the top three tower levels resemble CAE whereas the bottom level resembles AGS. On shorter time scales, the CC tower usually resembles an average of the wind roses for AGS and CAE. For the two-week time scales neither AGS nor CAE are consistently similar to the lower two CC levels.

5. EL NIÑO’S APPARENT LACK OF INFLUENCE ON CC WINDS

The El Niño/Southern Oscillation’s (ENSO) influence on rainfall in the Southeast U.S. is now becoming more appreciated. (See Wolter, 1987 and Wolter and Timlin, 1993 and 1998, or http://water.dnr.state.sc.us/water/climate/sercc/. One might suspect that the various ENSO indexes are related to the wind speed and/or direction preferences in the Southeast and that effect would be reflected in the wind data collected at the CC tower site. In order to investigate this possibility we chose to use an index called the “multivariate ENSO index (MEI)” since it contains additional parameters (related to climate) that the ENSO index alone doesn’t contain (Wolter and Timlin, 1993). The MEI values were merged to the wind speed and direction data from the 10-years of CC data, and wind roses were computed for three subsets: El Niño (MEI > 0.1), La Niña (MEI < -0.1), and neutral (-0.1 < MEI < 0.1). These results are shown in Fig. 4. This figure indicates little, if any, relationship between the wind direction and the MEI.

The results of computing simple statistics for the wind speed at 61-m for El Niño (MEI > 0.1), La Niña (MEI < -0.1), and neutral (-0.1 < MEI < 0.1) are shown in Table 1. The mean speed for the El Niño case is 3.92 m/s versus 4.08 m/s in the La Niña case. This is a relatively small percentage difference in speed; it is one that is statistically significant because of the large number of observations in the 10-year period. There are also small statistically significant changes in the u and v-components (east-west and north-south components) of the wind vector.

Table 1. Simple statistics for the CC’s 61-m wind speed based on the MEI index, i.e., El Niño (MEI > 0.1), La Niña (MEI < -0.1), and neutral (-0.1 < MEI < 0.1). The statistics are the mean of the variable, standard deviation, minimum and maximum of the variable (all m/s), respectively.

Set	Var.	No.	Mean (m/s)	Std. Dev.	Min.	Max.
El Niño	Spd	48,502	3.92	1.74	0.017	30.83
	U	47,966	0.26	3.32		
	V	47,966	0.24	2.82		
La Niña	Spd	31,932	4.08	1.71	0.058	14.06
	U	31,840	0.225	3.39		
	V	31,840	0.164	2.93		
Neutral	Spd	1973	3.86	1.42	0.201	9.081
	U	1964	-0.287	3.12		
	V	1964	0.800	2.66		

6. NAO INDEX AND CC WINDS

The NAO index is a measure of atmospheric pressure patterns in the North Atlantic. The National Weather Service Climate Predictions Center's web site (no author listed, http://www.cpc.ncep.noaa.gov/data/teledoc/nao.html describes the NAO as follows:

"The positive phase of the NAO reflects below-normal heights and pressure across the high latitudes of the North Atlantic and above-normal heights and pressure over the central North Atlantic, the eastern United States and Western Europe. The negative phase reflects an opposite pattern of height and pressure anomalies over these regions. Both phases of the NAO are associated with basin-wide changes in the intensity and location of the North Atlantic jet stream and storm track, and in large-scale modulations of the normal patterns of zonal and meridional heat and moisture transport (Hurrell 1995). This in turn results in changes in temperature and precipitation patterns often extending from eastern North America to western and central Europe."

The relationship between the NAO index and CC winds was explored by categorizing the NAO into three subsets similar to the MEI, i.e., NAOo (NAO > 0.1), NAOa (NAO < -0.1), and NAOn (-0.1 < NAO < 0.1). These results are shown in Fig. 5.

The NAOo phase (Fig. 5a) is characterized by slightly fewer westerlies and southerlies, and slightly more northeasterlies and west-southwesterlies than the NAOa (Fig. 5b) phase. The NAOn (Fig. 5c, neutral phase) is characterized by more frequent southerlies than either the NAOo or NAOa phase.

Table 2. Simple statistics for the CC's 61-m wind speed based on the NAO index, i.e., NAOo (NAO > 0.1), NAOa (NAO < -0.1), and neutral (-0.1 < MEI < 0.1). The statistics are the mean of the variable, standard deviation, minimum and maximum (all m/s) of the variable, respectively.

Set	Var.	No.	Mean (m/s)	Std. Dev.	Min.	Max.
NAOo	Spd.	39,320	4.00	1.74	0.017	16.30
	U	38,929	0.29	3.36		
	V	38,929	0.17	2.88		
NAOa	Spd.	30,875	3.94	1.72	0.041	30.83
	U	30,686	0.25	3.33		
	V	30,686	0.25	2.83		
NAOn	Spd.	12,212	4.00	1.68	0.130	12.46
	U	12,155	0.008	3.33		
	V	12,155	0.322	2.87		

The results of examining subsets of the wind speed data are shown in Table 2. The mean speed for the case of NAOo is 4.00 m/s versus 3.94 m/s in the NAOa case. As in the comparison with the MEI index, this is a fairly insignificant percentage change in speed but one that is statistically significant because of the large number of observations in the 10-year period. There is a larger percentage change in the v-component (north-south component) of the wind. For the NAOo case the v-component is 0.17 m/s while for the NAOa case the v-component is 0.25 m/s

7. SUMMARY STATISTICS

The mean wind speeds for the ten-year period were determined by hour, two-week period and year. The highest wind speeds were seen at night at the top tower level. The lowest wind speed was found during the night at the lowest tower level. The maximum mean wind speed during the twenty-four hour period was 4.39 m/sec at the 61-m level at 22:00 LST. The minimum mean wind speed during the twenty-four hour period was 1.28 m/sec at the 4-m level at 04:00 LST.

The mean wind speeds for the twenty-six two-week periods showed the highest wind speeds (4.77 m/sec) are achieved in late February-early March at the 61-m tower level. The lowest wind speed (1.53 m/sec) is found during mid-August at the 4-m tower level.

The mean wind speeds for each year over the ten-year period showed that the highest wind speed was achieved during 1996 at the top tower level. The lowest wind speed was found during 1991 at the lowest tower level (which was 2-m at this time). The maximum mean wind speed during the ten-year period was 4.19 m/sec at the 61-m level in 1996. The minimum mean wind speed during the ten-year period was 1.62 m/sec at the 2-m level in 1991.

8. CONCLUSIONS

This paper has been written to present climatological summaries of the wind data at SRTC's CC Tower and to focus on short term climatological summaries of the wind speed and direction that may not have been widely appreciated in the past. In particular, short-term (two-week) wind roses provide a means to demonstrate the temporal and spatial relationships that wind speed and direction undergo using a ten-year database from the CC Tower. These relationships are best demonstrated by examining a complete set of figures or by looking at loops of computer-generated images.

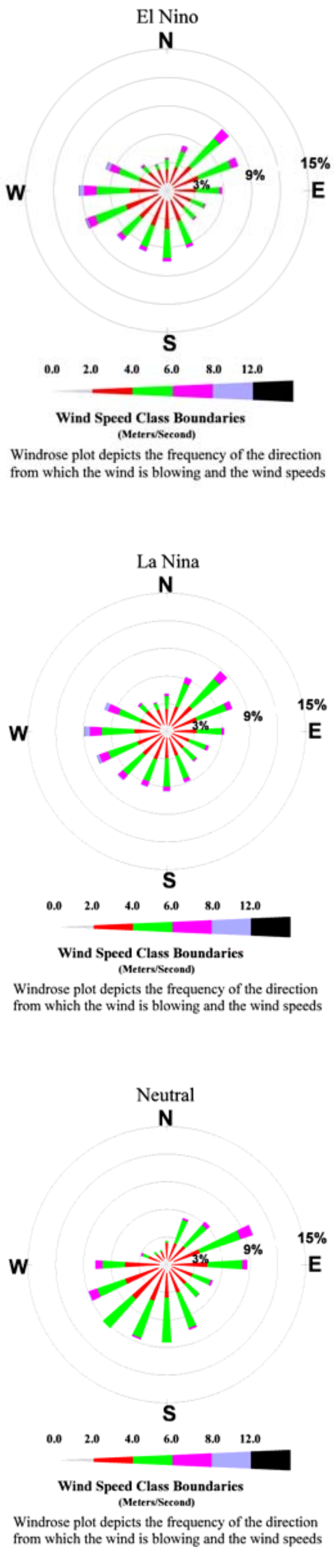


Figure 4: Wind rose description as in Fig. 2 for an individual level. These wind roses are (a) for El Niño (MEI > 0.1) (b)) for La Niña (MEI < -0.1) and (c) neutral (-0.1 < MEI < 0.1)conditions over the 10-year period.

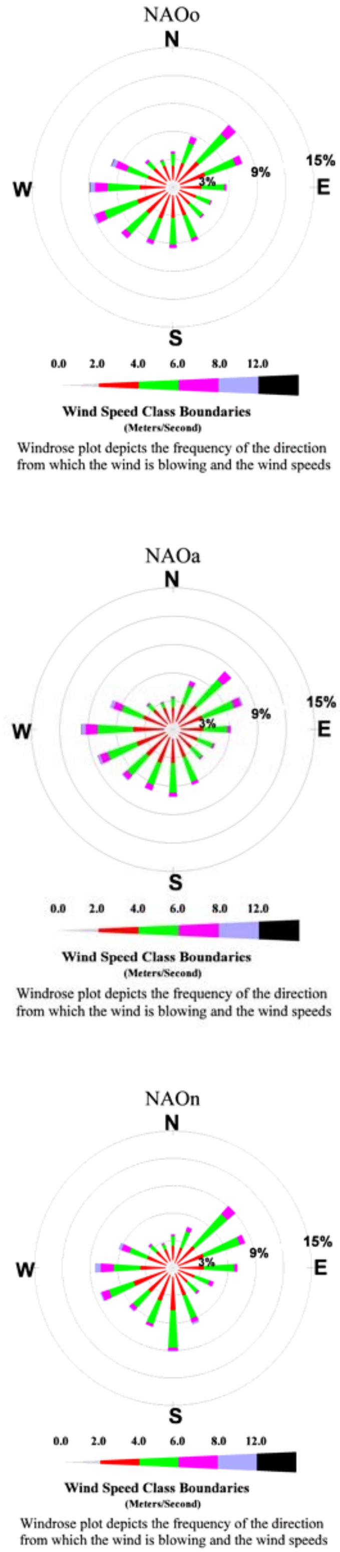


Figure 5: As in Fig. 4 except for NAOo (NAO> 0.1) conditions. (b) as in (a) except for NAOa (NAO< -0.1) conditions. (c) as in (a) except for NAOn (-0.1 < NAO< 0.1) conditions.

As was true for the NWS surface stations in the Southeast (Weber et al, 2002a), the Appalachian Mountains and the Atlantic Ocean are major influences of wind direction for the CC Tower. Terrain steering of the wind from the mountains is suggested in the seasonal and diurnal patterns of the wind. The CC Tower is strongly influenced by sea breezes in the evening hours (mainly in the spring and summer seasons) that penetrate from the coast up the Savannah River channel. In autumn all levels of the CC Tower are subject to northeasterly winds that arise from high-pressure systems to the north and northwest.

Wind roses can be used to aid wind direction forecasting applications at SRS, particularly when models predict light wind speeds. In cases when numerical models disagree on wind direction forecasts it is advisable to consider the CC tower wind roses.

Subjectively comparing the annual wind rose for CAE and AGS with the CC tower showed that the top three tower levels resembled CAE whereas the bottom level resembled AGS. On shorter time scales, the results of a subjective comparison were that the CC tower usually resembled an average of the two wind roses for AGS and CAE. Neither AGS nor CAE were consistently similar to the lower two CC levels for shorter time scales (e.g., two-weeks).

Statistical correlation between CC's 61-m wind speed and El Niño/La Niña conditions was very low. Furthermore, a significant statistical correlation between CC's 61-m wind speed and the NAO index was not found.

9. REFERENCES

Hurrell, J. W., 1995: Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. *Science*, **269**, 676-679.

Parker, M. J., and R. P. Addis, 1993: Meteorological Monitoring Program(U). WSRC-TR-93-0106, Westinghouse Savannah River Company, Savannah River Technology Center, Aiken SC. 87pp.

Weber, A. H., R. L. Buckley, and M. J. Parker, 2002a: Wind Climate Analyses for National Weather Service Stations in the Southeast (U). WSRC-TR-2002-00515, Westinghouse Savannah River Company, Savannah River Technology Center, Aiken SC. 60pp.

Weber, A. H., M. J. Parker, and J. H. Weber, 2002b: Surface Wind Gust Statistics at the Savannah River Site. *16th Conference on Probability and Statistics in the Atmospheric Sciences*, 13-17 January 2002, Orlando Florida. 120-125.

Wolter, K., 1987: The Southern Oscillation in surface circulation and climate over the tropical Atlantic, Eastern Pacific, and Indian Oceans as captured by cluster analysis. *J. Climate Appl. Meteor.*, **26**, 540-558.

Wolter, K., and M.S. Timlin, 1993: Monitoring ENSO in COADS with a seasonally adjusted principal component index. Proc. of the 17th Climate Diagnostics Workshop, Norman, OK, NOAA/N MC/CAC, NSSL, Oklahoma Clim. Survey, CIMMS and the School of Meteor., Univ. of Oklahoma, 52-57.

Wolter, K., and M.S. Timlin, 1998: Measuring the strength of ENSO - how does 1997/98 rank? *Weather*, **53**, 315-324.