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CITY OF VIRGINIA BEACH
SOUTHERLY WIND FREQUENCY ANALYSIS REPORT

Provided by MetStat, Inc.

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1. EXECUTIVE SUMMARY

The findings of this report suggest that recent "wind tide" events appear to be statistical irregularities, and that there are no apparent trends in the rate of occurrence. Other factors may be partially responsible for the relatively high number of "wind tides" in the 2017 to 2019 period. Increasing water levels and loss of marsh both contribute to allowing water to move faster into the Southern Rivers Watershed during period of sustained winds. Increased rainfall in recent years may also be a factor. For example, analysis of the relationship between rainfall-runoff and 30- to 60-day average water levels in Currituck Sound has found a high correlation with precipitation at Corolla, North Carolina. Further analysis would need to be completed to assess rainfall amounts in recent years, the influence on water levels, and any relationship to the wind tide occurrences. At this time, the increase in precipitation is not reflected in this wind frequency analysis.

This report summarizes a study of the statistical frequency of sustained southerly winds. Such wind conditions push water from the Currituck Sound, in North Carolina, and cause wind setup, or "wind tides" in to Back Bay and North Landing River in the Southern Rivers Watershed of Virginia Beach. Low lying land, roads, and buildings are flooded as a result of these conditions. Longer periods of southerly winds can result in flooding over multiple days. Between 2017 and 2018, four such events have occurred and increased concern within the City of Virginia Beach, as well as with residents and stakeholders in the affected areas. A computer model study has improved understanding of the response time of water levels to varying southerly wind conditions (CVB 2019); however, the frequency of such wind conditions, and any potential changes in their frequency, had not yet been examined.

Sustained southerly wind conditions were evaluated through examination of historical wind records at Oceana Naval Air Station (NAS), located in Virginia Beach, as well as Duck and Manteo, North Carolina. Hourly wind direction and wind speed time series data were evaluated from five gauges representative of and near the Virginia Beach area. Only the three gauges at Oceana, Manteo, and Duck had records long enough to be included in the analysis. Previous work (CVB 2019) has found that wind conditions from the Duck location are best suited for modeling water level response to southerly wind conditions. Wind speed data were retrieved and analyzed in units of knots, but have been converted to miles-per-hour (mph) to match other work. The approach considered 2, 3, and 4 day periods where southerly winds (winds from the southeast through southwest directions) were above 8 mph for 75% of the period of sustained winds.

Statistical analysis was performed to identify the return periods of wind speeds at defined durations (2, 3, and 4 days). Annual maximum series (AMS) of the events were identified, quality controlled, and used in a regional frequency analysis using L-moments to determine the return periods (or annual exceedance probabilities [AEPs]) for those durations. Return periods from the 2- to 1000-year occurrence were calculated. As expected, the exposed station on the barrier island (Duck) has the highest wind speeds, while the most inland station (Oceana NAS) has the lowest wind speeds (due to surrounding land and associated friction). Longer duration events are statistically less likely, and as such, the analysis showed that higher wind speeds are associated with the shorter duration events. For example, at the 10-year return period, a 2-day duration of sustained winds has a return period speed of 25 mph is associated with the 2-day duration, which drops to about 20 mph at the 4-day duration.

For insight into stormwater and floodplain management considerations, the return period wind speeds can be related to water elevation response times by wind speed from previous modeling work (Appendix A - CVB 2019). An example is provided below, using the wind speed return periods from Duck, and the water level elevation look-up table for Beggars Bridge Creek:

- Wind setup from sustained 2-day winds
  - 2-year return period: about 0.9 feet
  - 10-year return period: about 1.5 feet
  - 50-year return period: about 2.2 feet
  - 100-year return period: between 2.2 and 3 feet

- Wind setup from sustained 3-day winds
  - 2-year return period: between 0.8 and 1.2 feet
  - 10-year return period: about 1.3 feet
  - 50-year return period: between 1.5 and 2.3 feet
  - 100-year return period: about 2.3 feet

- Wind setup from sustained 4-day winds
  - 2-year return period: about 1.1 feet
  - 10-year return period: about 1.9 feet
  - 50-year return period: between 1.9 and 3 feet
  - 100-year return period: between 1.9 and 3 feet

From the determined wind return periods, as well as relationships above, it appears that the multiple "wind tide" events observed in 2017 to present (2019) resulting in water elevations over 2 feet, are statistical deviations. No further analysis was completed at this time to assess any climatological influences on recent events.

Further analysis was completed to assess the seasonality and number of sustained southerly wind events for the period of record. Seasonality was evaluated using the rarest 25 unique wind events in the AMS record. The strongest southerly sustained winds on record at the stations analyzed have tended to occur in the months of March through May. For historical context of the sustained wind events, a count of events for the 2, 3, and 4-day durations was completed. Counts were completed for the number of events between selected speeds of 10 to 30 knots (11.5 to 34 mph). There were no discernable trends in the rate of occurrence of sustained southerly wind events through time.

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2. PURPOSE

The purpose of this project was to provide southerly wind information in the form of return periods (or annual exceedance probabilities (AEPs)) to Dewberry with the purpose of analyzing wind tides for the City of Virginia Beach. The analysis was originally completed in knots, but units are shown in miles-per-hour or mph to match other work. Wind speeds in mph are equivalent to 0.869 knots.

Hourly wind direction and wind speed time series data were collected from gauges representative of and near the Virginia Beach area for use in the analysis. It was necessary to define sustained hourly winds in such a way as to capture the occurrence of wind tides and still ensure sufficient data for the analysis. Annual maximum series (AMS) of sustained southerly winds were identified for selected durations of 48-hour, 72-hour, and 96-hour; quality controlled; and used in a regional frequency analysis using L-moments (Hosking and Wallis, 1997) to determine return periods (AEPs) for those durations. Return periods provide a sense of the recurrence of wind speeds exceeding that magnitude over a duration.

For each station, a count (per year) of sustained winds that exceed selected speeds of 17.3 through 34.5 mph (15 through 30 knots) were determined to provide historical context for the wind climatology in the area.

This report provides a summary of the procedures employed and the findings obtained from the regional wind frequency analysis conducted for point wind speeds for stations within the project area and from the count of historical exceedances.

3. PROJECT AREA

The project domain covers Virginia Beach and includes coastal stations to the south, specifically focusing on the fetch for Virginia Beach which is comprised of the sound side of the Outer Banks. Figure 1 depicts the project area where results are most applicable at or near station locations.

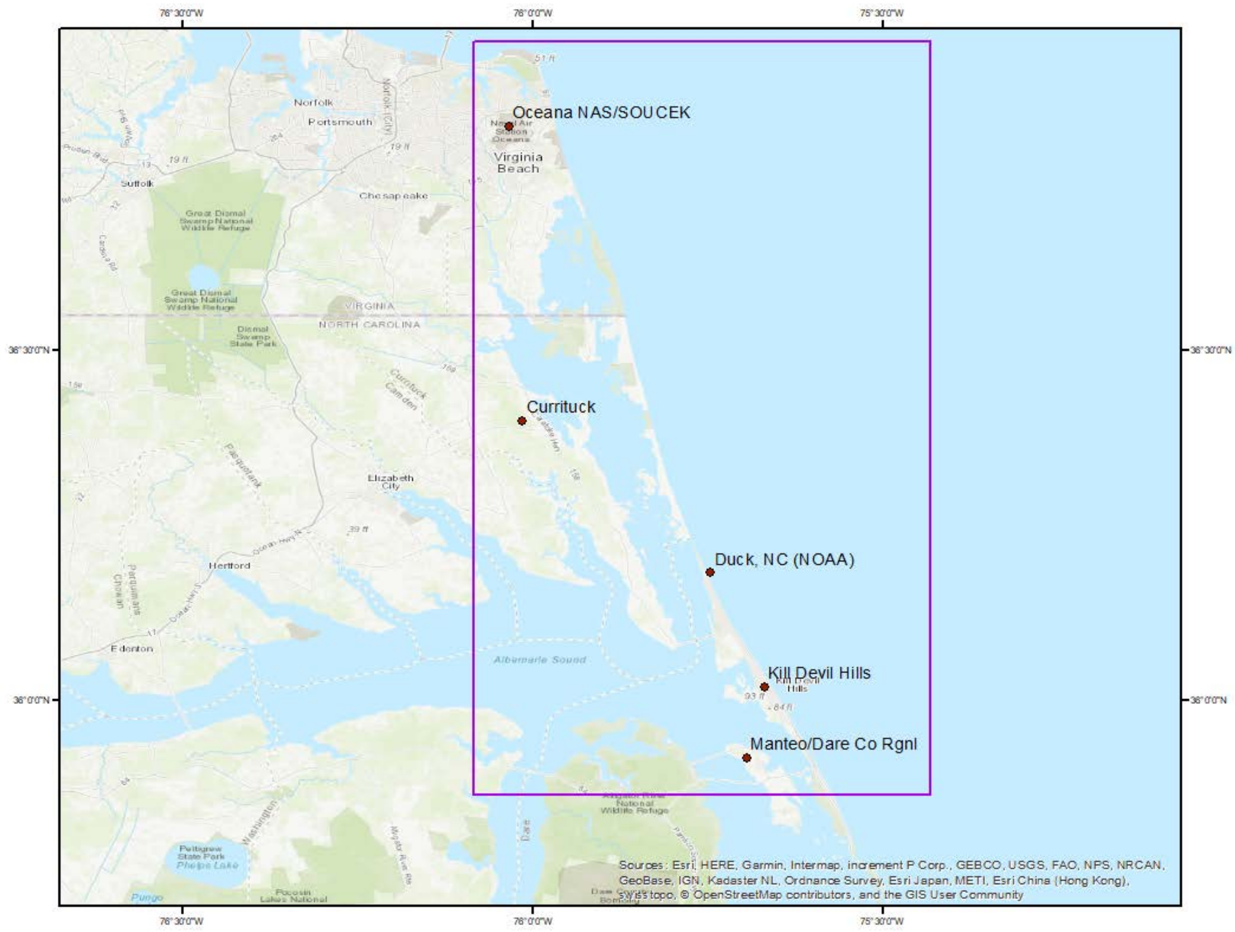

Figure 1. Project area for the Virginia Beach wind frequency analysis and station locations for potential wind data

4. WIND DATA

4.1 Point Wind Observation Data

Wind data were collected from Automated Surface Observing System (ASOS) and Automated Weather Observing System (AWOS) sites (collectively formatted as METeorolgoical Aerodome Reports, or METAR data) within the project area. METAR data are typically available from airports and operated by the Federal Aviation Administration (FAA). The data were downloaded from the Iowa State University's Iowa Environmental Mesonet website (https://mesonet.agron.iastate.edu/request/download.phtml).

An additional wind data (station 8651370 Duck, NC) were identified within the project area and collected from the National Oceanic and Atmospheric Administration's Center for Operational Oceanographic Products and Services (CO-OPS) (https://tidesandcurrents.noaa.gov/inventory.html?id=8651370).

These five wind stations nearest Virginia Beach in the direction of interest were downloaded (Figure 1, Table 1).

Table 1. Metadata for stations in the project area where 'Station Elevation' is the elevation of the ground above mean sea level and surface winds are measured at a standard height of 10 meters (32.8 feet) above that.

ID	Name	Lat	Long	Station Elevation (m)	Period of Record	Years of Record
NTU	Oceana NAS/SOUCEK	36.8207	-76.03354	7	1/1948 - 04/2019	70
ONX	Currituck	36.39994	-76.01544	5.5	8/2004 - 04/2019	14
MQI	Manteo/Dare Co Rgnl	35.91898	-75.69554	4	9/1985 - 04/2019	33
8651370	Duck, NC (NOAA)	36.1833	-75.7467	7.7	11/1995 - 04/2019	24
FFA	Kill Devil Hills	36.0200	-75.6700	4	2/2004 - 04/2019	14

Measurements of surface winds are standardized by taking them at a standard height of 10 meters (32.8 feet) above ground where the instrument is placed away from any vertical obstruction. METAR wind data are recorded at hourly intervals. Figure 2 shows a wind rose for all of the hourly observations in each station's record. Wind directions are reported as an angle in degrees, 0º through 360º; where 0º is from due north, 90º is from due east, 180º is from due south, and 270º is from due west. Wind direction nomenclature is the direction that the wind originates (i.e., a northerly wind is coming from the north). The data were formatted to 48-hour, 72-hour, and 96-hour mean wind speeds using a moving window corresponding to the time step. If more than 25% of the observations for a given time step were missing, the value was set to missing.

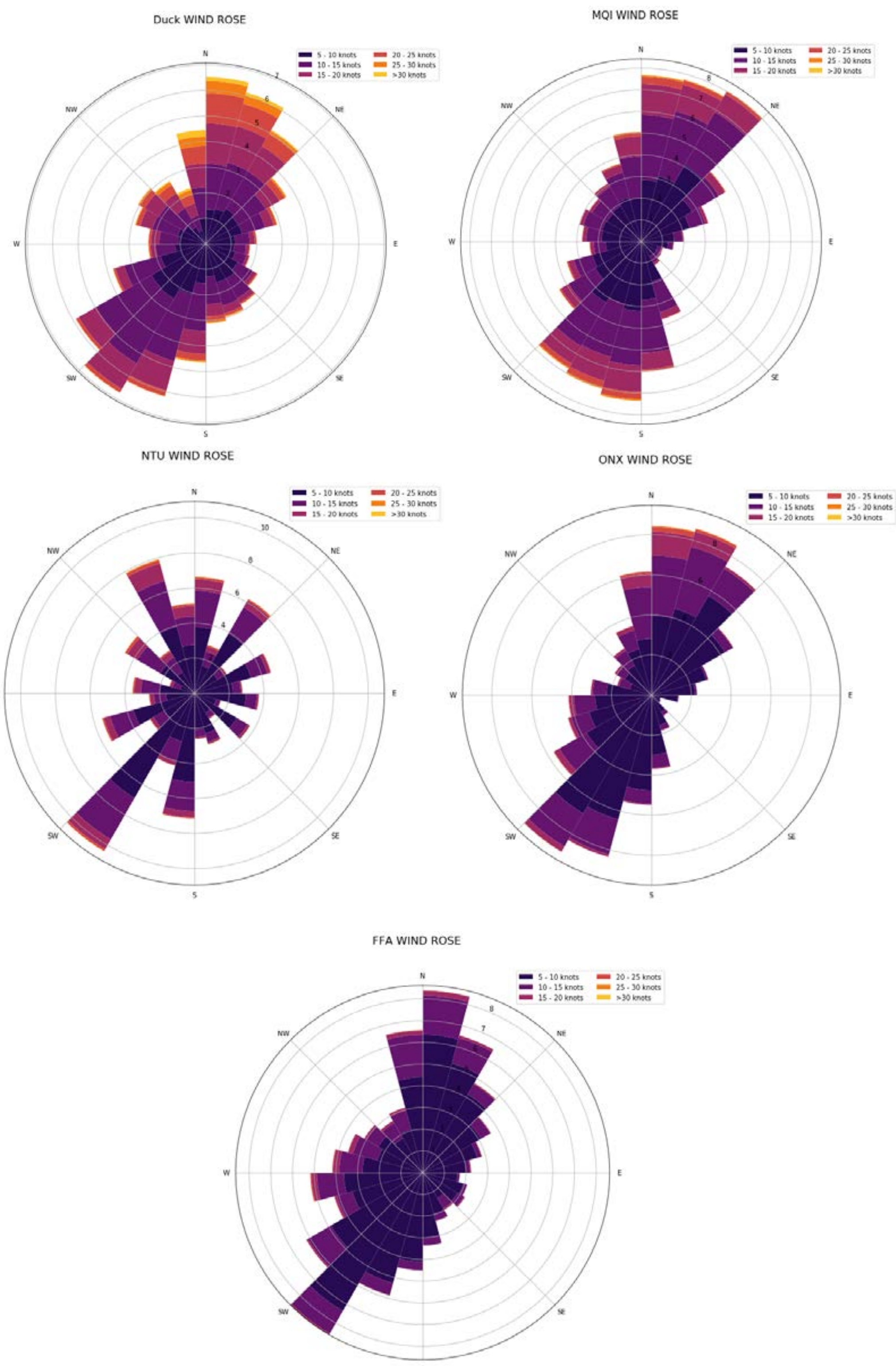

Figure 2. Wind Rose plots for all hourly data at each station where the circular axis represents the frequency of occurrence and the colors represent the proportion of winds at given wind speeds in knots for reference.

4.2 Definition of Sustained Wind

4.2.1 Key Durations

The key durations of interest necessary to cause wind tide flooding were defined as 2-day (48-hour), 3-day (72-hour), and 4-day (96-hour). The 2-, 3-, and 4-day durations were selected based on water level response times, as developed from a numerical modeling of the wind tides (CVB, 2019). Although sustained southerly winds can quickly raise water levels in a 24-hour period, a minimum 2-day duration was selected to focus the analysis on conditions that would result in water levels at the threshold for minor flooding. The maximum duration was set at 4-days, as the numerical modeling indicated that was the duration that the rate of water level increase slowed significantly and durations longer than 4 days did not have sufficient data that meet the criteria necessary to define a sustained wind over multiple days to allow reliable analysis.

4.2.2 Criteria for Sustained Southerly Wind

Because winds can vary in speed and direction over very short time intervals (minute to minute or hour to hour), it was necessary to establish a minimum acceptable speed and an allowance of winds from directions other than the direction of interest. To be considered a sustained wind from the southerly direction in this analysis, wind observations over the key durations were averaged and only winds that met the criteria outlined below were considered as a candidate annual maximum for a given key duration.

Thresholds were initially established to maintain a sense of conservatism (i.e., strictly define a sustained wind that could generate wind tidal flooding). After sensitivity testing to ensure sufficient annual maxima could be extracted for reliable statistical analysis, the criteria for a sustained southerly wind were defined as follows:

- Winds must be from the southeast through southwest directions, i.e., 135 to 225 degrees.
- Winds must be from the defined southerly direction for 75% of the duration.
- Winds must be 8 mph (7 knots) or above for 75% of duration (i.e., allow time with lower wind speeds or lulls in the wind).
    - Eight mph (7 knots) is the threshold on the Beaufort scale for measuring wind speeds that delineates light breezes from breezes capable of creating large wavelets over open water where crests can begin to break (https://www.spc.noaa.gov/faq/tornado/beaufort.html).

Several dates of flooding and road closures in Virginia Beach were also examined to ensure such wind events were captured by the criteria (Section 6).

4.3 Assembly of Wind Annual Maximum Series and Quality Checking

Annual maxima series (AMS) were used for the frequency analysis. Separate annual maxima datasets were assembled for each duration of interest.

The highest 48-hour, 72-hour, and 96-hour mean wind speeds were extracted for each year as AMS for each station. Only data that met the criteria outlined in Section 4.2 were eligible for extraction. The annual maxima dataset is stored in the L-RAP (Schaefer and Barker, 2009) ASCII Text format.

Data quality checking was conducted to eliminate false annual maxima. This was accomplished by examining the completeness of the record during each climatic year and scanning AMS (Figure 3). For the most part, AMS data across all three durations were deemed acceptable for use and did not require corrections. Verifying annual maxima included a double-check of the raw hourly station data to ensure no spurious recordings occurred during the duration, as well as a literature and historical search to determine what atmospheric events occurred during the duration, such as a tropical storm or a subtropical cyclone.

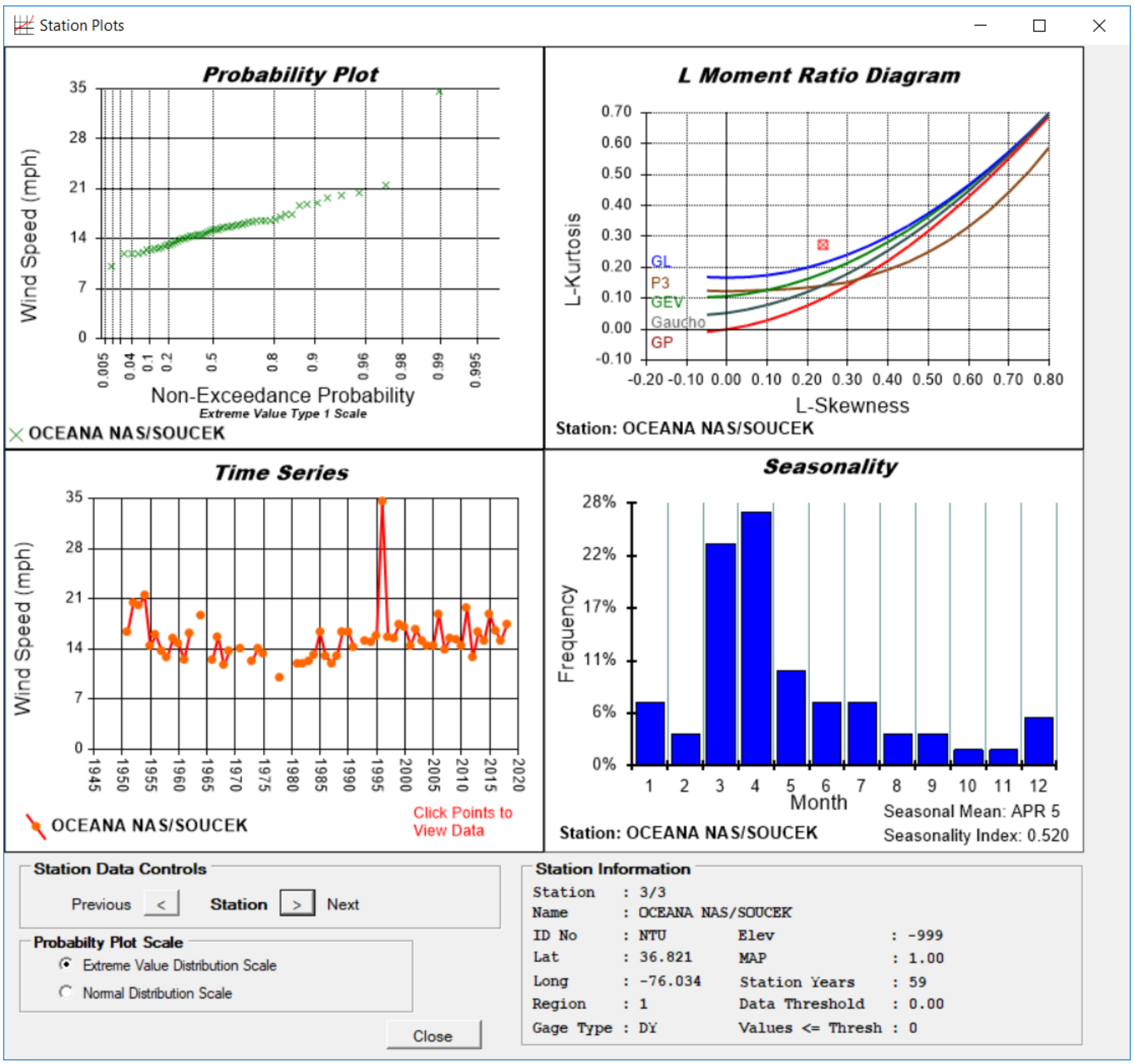

Figure 3. Example graphics from L-RAP of data quality control of 48-hour AMS at NTU (Oceana) showing station data probability distribution (top left); annual maxima time series (bottom left); diagram of L-Skewness of the data versus L-Kurtosis (top right); and seasonality of station data (bottom right)

5. REGIONAL WIND-FREQUENCY ANALYSIS

5.1 Description Of Basic Approach

Regional analysis is a methodology for the analysis of datasets comprised of measurements of the same phenomenon observed at multiple sites. The primary goal in a regional frequency analysis is to use the collective statistical information from all measurement sites to develop magnitude-frequency relationships that can be applied throughout the project area. This approach greatly reduces sampling variability present at any specific site and increases the reliability of magnitude-frequency estimates throughout the region. The regional methodology employed here is L-moments regional statistics (Hosking and Wallis, 1997).

Conventional statistical moments are used to define the shape of a probability distribution. The first two moments are the mean and variance, which provide information on the location and variability (spread, dispersion) of a set of numbers, respectively. Skewness, the third moment, is a measure of the symmetry of the shape of a distribution. If a distribution is symmetric, the skewness will be zero; if it is skewed toward higher values, it will be positive, and vice versa for negative. Kurtosis, the fourth moment, is a measure of the peakedness (or flatness) of a distribution.

L-Moment ratios are linear combinations of order statistics and are analogous to their conventional moment counterparts. L-moments are used for computing sample statistics, characterizing the shapes of probability distributions, and identifying a best-fit probability distribution. They are a significant improvement over standard product-moment statistics and are particularly well-suited for analyses of environmental data where small sample sizes are common and the data are often highly skewed. L-moment sample statistics provide dimensionless measures of variability (L-Cv), skewness (L-Skewness), and kurtosis (L-Kurtosis) for the wind AMS at each station.

The three stations had more than 20 years (at 48-hour) to be included in the analysis - Oceana NAS (NTU), Duck, and Manteo (MQI) (Table 1). These stations were grouped together as a region for analysis.

5.2 Homogeneous Region

The cornerstone of a regional analysis (Hosking and Wallis, 1997) is that data from sites within a homogeneous region can be pooled to improve the reliability of the magnitude-frequency estimates for all sites. This occurs because of the significant reduction in sampling variability of the statistical measures offered by a larger sample of the same phenomenon compared to the sampling variability for a single site. The regional approach works well for regional estimates of L-Cv typically resulting in only minor levels of uncertainty. The regional approach is particularly important for regional estimates of L-Skewness, which have inherently high levels of sampling variability.

L-moment heterogeneity measures H1 and H2 were used to assess the homogeneity of candidate homogeneous sub-regions. H1 uses L-Cv and H2 uses L-Skewness to test between-site variations in sample L-moments for a group of stations compared with what would be expected for a homogeneous region. These are based solely on statistical considerations of the sampling characteristics for L-Cv and L-Skewness. H1 and H2 values of 2.0 (per Hosking and Wallis, 1997) were used in this study for distinguishing between likely homogeneous and likely heterogeneous data where any value below 2.0 indicates a sub-region is acceptably homogeneous for statistical analysis. These threshold values account for additional variability that arises from difficulties in accurate measurement and recording of meteorological data (Schaefer and Barker, 2009). The three-station region was acceptably homogeneous for all three durations (Table 2).

Table 2. L-moment heterogeneity measures for the 48-hour, 72-hour, and 96-hour regional analyses.

Duration	H1	H2
48-hour	1.34	-0.52
72-hour	-0.47	0.20
96-hour	-0.32	0.13

5.3 L-Moment Computation

Regional values of L-Moment ratios were computed using the three stations that comprised the homogeneous region. The regional values are averages of the at-site statistics weighted by record length. Table 3 shows the L-Moment ratios for each of the durations

Table 3. Regional L-Moment ratios of the sustained southerly winds for each duration.

Duration	L-Cv	L-Skewness	L-Kurtosis
48-hour	0.087	0.201	0.206
72-hour	0.071	0.098	0.148
96-hour	0.095	0.038	0.027

5.4 Identification of Regional Probability Distribution

The L-Moment goodness-of-fit test (Hosking and Wallis, 1997) was used for identifying the best-fit regional probability distribution. L-RAP software (Schafer and Barker, 200) was used to execute the test which, in summary, utilizes monte carlo simulations of 1,000 synthetic data sets. The regional means of the simulations were then averaged and standardized so that the goodness-of-fit could be measured as the deviation (Z^{DIST}) from the simulated mean point to the theoretical distributions in the L-skewness dimension. Three-parameter probability distributions, such as Generalized Extreme Value (GEV) and Generalized Pareto (GP) were tested. The L-moment ratio diagram (e.g., Figure 4) provides a graphical depiction of the L-moment goodness-of-fit test by showing the nearness of regional L-Skewness and L-Kurtosis pairings to a specific three-parameter probability distribution. Regional values are weighted by station data length. GEV passed for the 90% confidence level ($|Z^{DIST}| <= 1.64$) for all durations and because it is commonly accepted as the best distribution for environmental data, the GEV distribution was selected to compute the annual exceedance probabilities for these data.

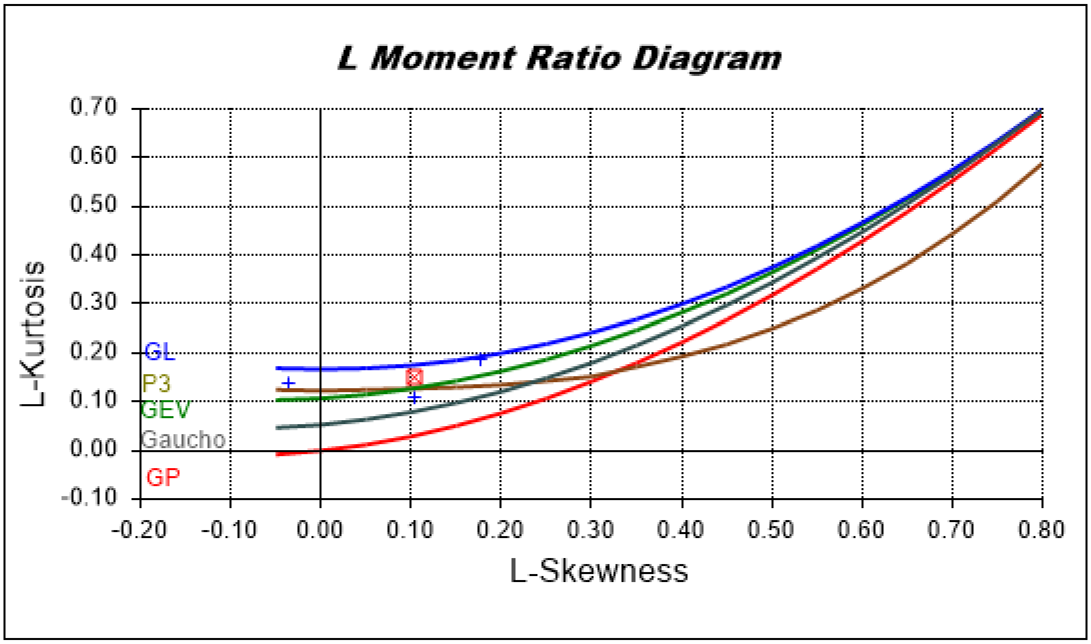

Figure 4. Example of an L-moment ratio diagram for the 72-hour data where the station values are represented as blue plus-signs and the regional average as a red square; the distributions are represented as follows: blue line is the generalized logistic (GL), brown is the pearson type III (P3), green is generalized extreme value (GEV), grey is Gaucho, and red is generalized pareto (GP)

5.5 Return Periods (Annual Exceedance Probabilities)

Return periods (AEPs) at stations were computed using the at-station mean, regional parameters, and GEV distribution.

Tables 4, 5, and 6 provide the resulting 2-year (1 in 2 AEP) through 1,000-year (1 in 1,000 AEP) wind speeds for each station for the 48-hour, 72-hour, and 96-hour durations. As expected the shorter durations sustain the higher wind speeds. Also as expected, the exposed station on the barrier island (Duck) has the highest wind speeds, while the most inland station (NTU) has the lowest wind speeds due to surface friction.

Table 4. Best-estimates of 48-hour mean wind speed (in knots) for selected return periods (AEPs) between 2-year (1 in 2 AEP) through 1,000-year (1 in 1,000 AEP) for the three stations in the Virginia Beach project area

	48-hr Best Estimate in mph (knots)		
Return Period (AEP)	**NTU**	**Duck**	**MQI**
2-year (1:2)	15.0 (13.0)	19.7 (17.1)	17.8 (15.5)
5-year (1:5)	17.1 (14.9)	22.6 (19.6)	20.5 (17.8)
10-year (1:10)	18.6 (16.2)	24.5 (21.3)	22.3 (19.4)
20-year (1:20)	20.3 (17.6)	26.6 (23.1)	24.2 (21.0)
50-year (1:50)	22.3 (19.4)	29.3 (25.5)	26.7 (23.2)
100-year (1:100)	24.1 (20.9)	31.6 (27.5)	28.8 (25.0)
200-year (1:200)	25.8 (22.4)	33.9 (29.5)	30.8 (26.8)
500-year (1:500)	28.2 (24.5)	37.2 (32.3)	33.7 (29.3)
1,000-year (1:1000)	30.2 (26.2)	39.7 (34.5)	36.1 (31.4)

Table 5. Best-estimates of 72-hour mean wind speed (in mph and knots) for selected return periods (AEPs) between 2-year (1 in 2 AEP) through 1,000-year (1 in 1,000 AEP) for the three stations in the Virginia Beach project area

	72-hr Best Estimate in mph (knots)		
Return Period (AEP)	**NTU**	**Duck**	**MQI**
2-year (1:2)	14.3 (12.4)	17.5 (15.2)	16.3 (14.2)
5-year (1:5)	15.9 (13.8)	19.6 (17.0)	18.2 (15.8)
10-year (1:10)	16.9 (14.7)	20.8 (18.1)	19.3 (16.8)
20-year (1:20)	17.8 (15.5)	22.0 (19.1)	20.4 (17.7)
50-year (1:50)	18.9 (16.4)	23.2 (20.2)	21.6 (18.8)
100-year (1:100)	19.6 (17.0)	24.2 (21.0)	22.4 (19.5)
200-year (1:200)	20.3 (17.6)	25.0 (21.7)	23.2 (20.2)
500-year (1:500)	21.1 (18.3)	26.0 (22.6)	24.2 (21.0)
1,000-year (1:1000)	21.6 (18.8)	26.7 (23.2)	24.9 (21.6)

Table 6. Best-estimates of 96-hour mean wind speed (in mph and knots) for selected return periods (AEPs) between 2-year (1 in 2 AEP) through 1,000-year (1 in 1,000 AEP) for the three stations in the Virginia Beach project area

	96-hr Best Estimate in mph (knots)		
Return Period (AEP)	**NTU**	**Duck**	**MQI**
2-year (1:2)	13.5 (11.7)	15.9 (13.8)	14.6 (12.7)
5-year (1:5)	15.5 (13.5)	18.3 (15.9)	16.8 (14.6)
10-year (1:10)	16.6 (14.4)	19.6 (17.0)	18.0 (15.6)
20-year (1:20)	17.4 (15.1)	20.5 (17.8)	18.9 (16.4)
50-year (1:50)	18.3 (15.9)	21.5 (18.7)	19.9 (17.3)
100-year (1:100)	18.8 (16.3)	22.2 (19.3)	20.5 (17.8)
200-year (1:200)	19.2 (16.7)	22.7 (19.7)	20.9 (18.2)
500-year (1:500)	19.8 (17.2)	23.2 (20.2)	21.5 (18.7)
1,000-year (1:1000)	20.0 (17.4)	23.6 (20.5)	21.7 (18.9)

5.6 Seasonality

A wind seasonality analysis was conducted using the 25 rarest 48-hour southerly wind events (on unique dates) for the entire project area. A frequency histogram representing the seasonality of extreme 48-hour duration southerly wind events is shown in Figure 5. Peak occurrence of high winds occurred between the months of March through May in the station records.

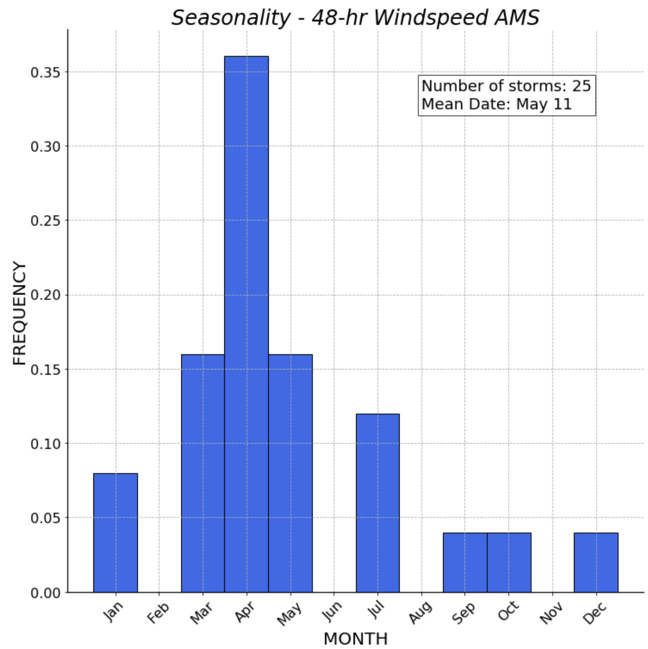

Figure 5. Frequency histogram for seasonality of extreme 48-hour duration southerly winds

6. CASE STUDIES

To provide some context, four historic flooding events and road closures in Virginia Beach were briefly examined. Each of four cases had at least one station with sustained 48-hour southerly winds. Tables 7 and 8 show the maximum sustained 48-hour winds during each case study compared to the annual maximum for that year, with Table 8 also showing the values for the 96-hour duration. Fewer sustained 96-hour southerly winds were observed at stations during the longer case studies (Table 8)

Table 7. 48-hour sustained southerly winds during Virginia Beach flooding case studies compared to the annual maximum for that year. "n/a" indicates that data were not available for that time period at that station.

Station	Max Sustained 48-hour Southerly Winds During Case	Annual Maximum Sustained 48-hour Southerly Winds (and date)
May 2, 2017		
Duck	22.4 mph (19.5 knots)	22.4 (19.5 knots) (5/2/2017)
MQI	n/a	16.0 mph (13.9 knots) (6/19/2017)
NTU	15.2 mph (13.2 knots)	15.2 mph (13.2 knots) (5/2/2017)
October 11, 2018		
Duck	23.5 mph (20.4 knots)	23.5 mph (20.4 knots) (10/12/2018)
MQI	12.7 mph (11.0 knots)	19.1 mph (16.6 knots) (5/20/2018)
NTU	n/a	17.4 mph (15.1 knots) (4/14/2018)

Table 8. 48-hour and 96-hour sustained southerly winds during Virginia Beach flooding case studies compared to the annual maximum for that year. "n/a" indicates that data were not available for that time period at that station.

Station	Max Sustained 48-hour Southerly Winds During Case	Annual Maximum Sustained 48-hour Southerly Winds (and date)	Max Sustained 96-hour Southerly Winds During Case	Annual Maximum Sustained 96-hour Southerly Winds (and date)
July 21-August 2, 2018				
Duck	17.5 mph (15.2 knots)	23.5 mph (20.4 knots) (10/12/2018)	16.5 mph (14.3 knots)	19.3 mph (16.8 knots) (4/17/2018)
MQI	15.4 mph (13.4 knots)	19.1 mph (16.6 knots) (5/20/2018)	13.8 mph (12.0 knots)	17.0 mph (14.8 knots) (5/20/2018)
NTU	n/a	17.4 mph (15.1 knots) (4/14/2018)	n/a	15.7 mph (13.6 knots) (4/16/2018)
September 15-18, 2018				
Duck	n/a	23.5 mph (20.4 knots) (10/12/2018)	n/a	19.3 mph (16.8 knots) (4/17/2018)
MQI	14.4 mph (12.5 knots)	19.1 mph (16.6 knots) (5/20/2018)	n/a	17.0 mph (14.8 knots) (5/20/2018)
NTU	n/a	17.4 mph (15.1 knots) (4/14/2018)	n/a	15.7 mph (13.6 knots) (4/16/2018)

7. COUNTS OF EXCEEDANCES

For each station, counts per year of sustained southerly winds that exceeded 11.5, 17.3, 23.0, 28.8, and 34.5 mph (10, 15, 20, 25 and 30 knots) over each duration were obtained to provide historical context for the wind climatology in the area. They were submitted in MS Excel worksheets. Figures 6 and 7 show the counts of 48-hour winds that exceeded 11.5 mph (10 knots) and 17.3 mph (15 knots), respectively. Note that data were not recorded or available during the period 1976-1982 at NTU. Plots of the number of exceedances through time; there were no noticeable relationships between the number of exceedances and time (Figures 6-9) to warrant additional testing for trends. Counts per year of 48-hour winds greater than 23.0 mph (20 knots) were minimal, with only one occurrence observed at the Duck monitoring station in 24-years. No occurrences were identified in the 48-hour data with speeds greater than 28.8 or 34.5 mph (25 or 30 knots).

Counts per year of 72-hour and 96-hour southerly winds greater than 11.5 mph (10 knots) are shown in Figures 8 and 9, respectively. Counts per year of 72-hour and 96-hour winds greater than 17.3 mph (15 knots) were minimal with only up to 2 occurrences in just a handful of years. No occurrences were identified in the 72-hour and 96-hour data with speeds greater than 23.0, 28.8, and 34.5 mph (20, 25, and 30 knots).

For reference, Table 7 shows the number of total exceedances at all stations over the period of record.

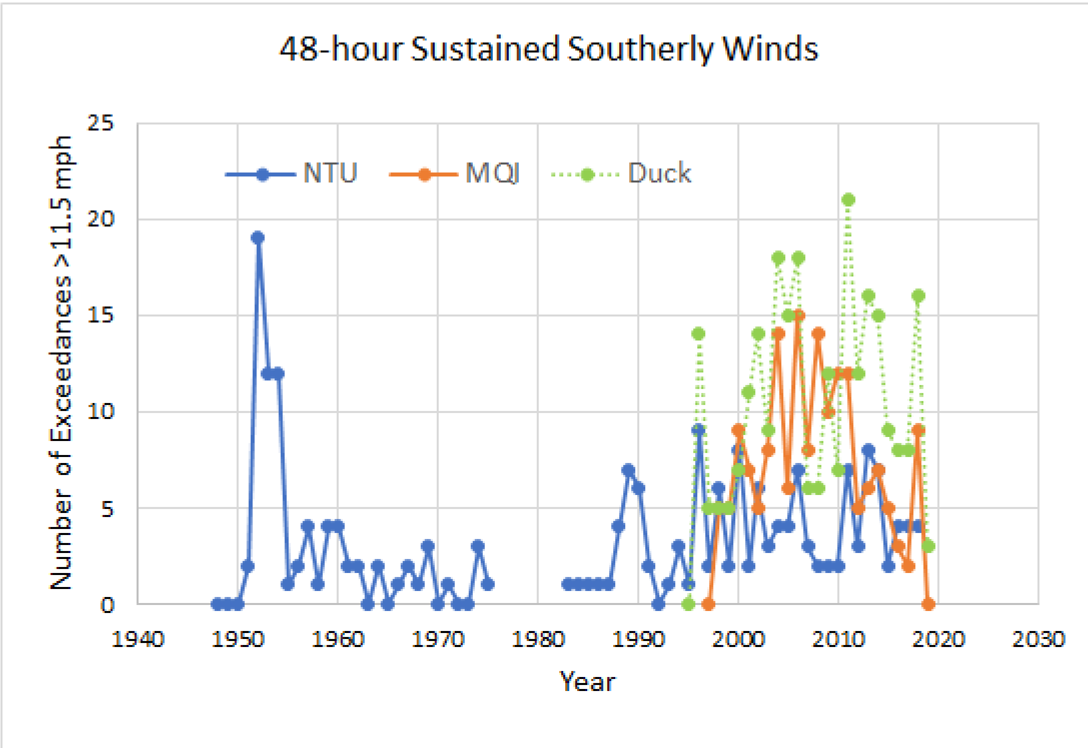

Figure 6. Count of defined southerly sustained 48-hour winds that exceed 11.5 mph (10 knots) in each year.

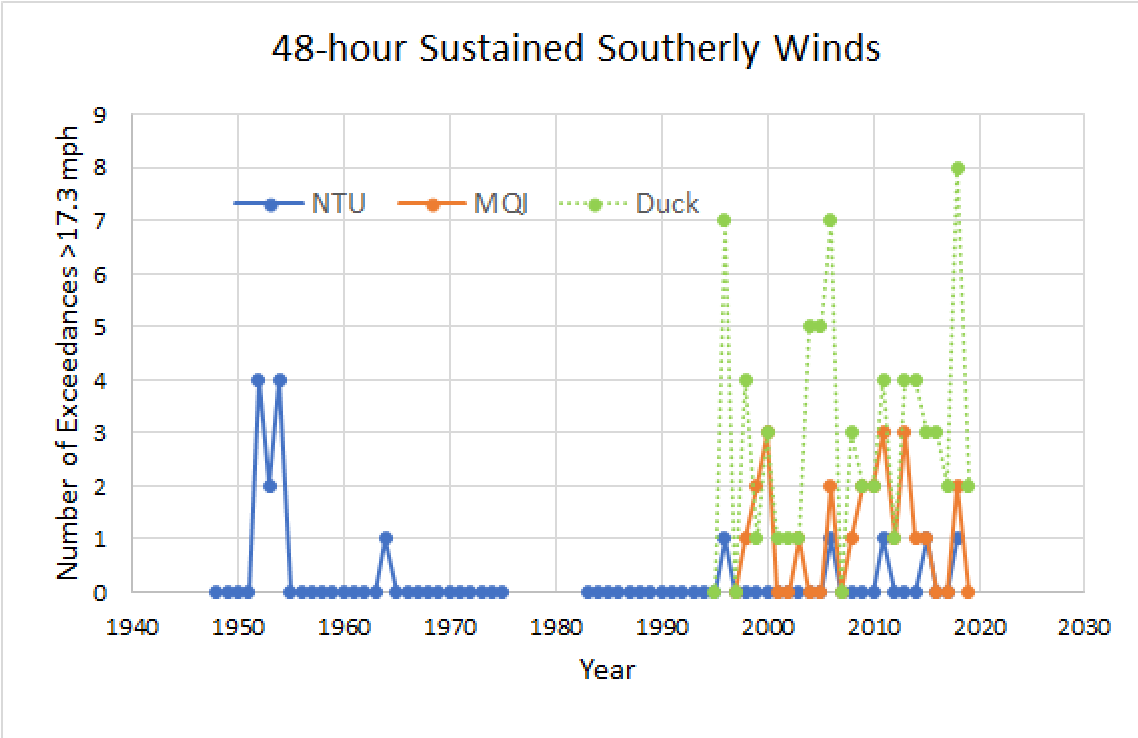

Figure 7. Count of defined southerly sustained 48-hour winds that exceed 17.3 mph (15 knots) in each year.

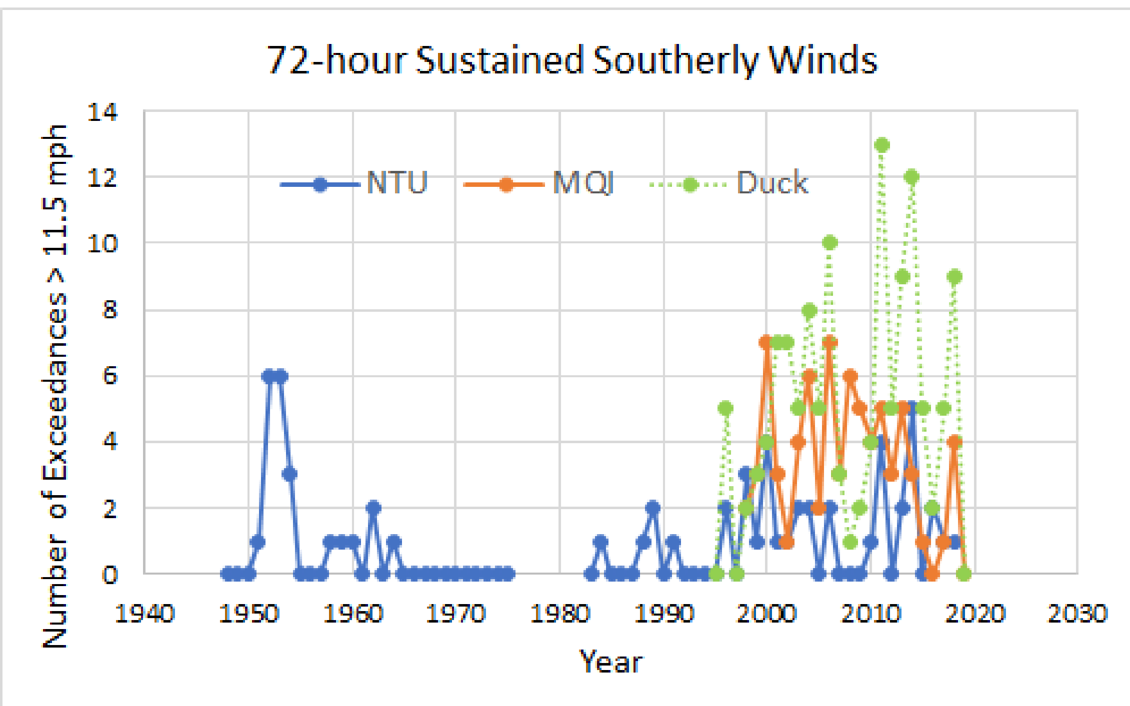

Figure 8. Count of defined southerly sustained 72-hour winds that exceed 11.5 mph (10 knots) in each year.

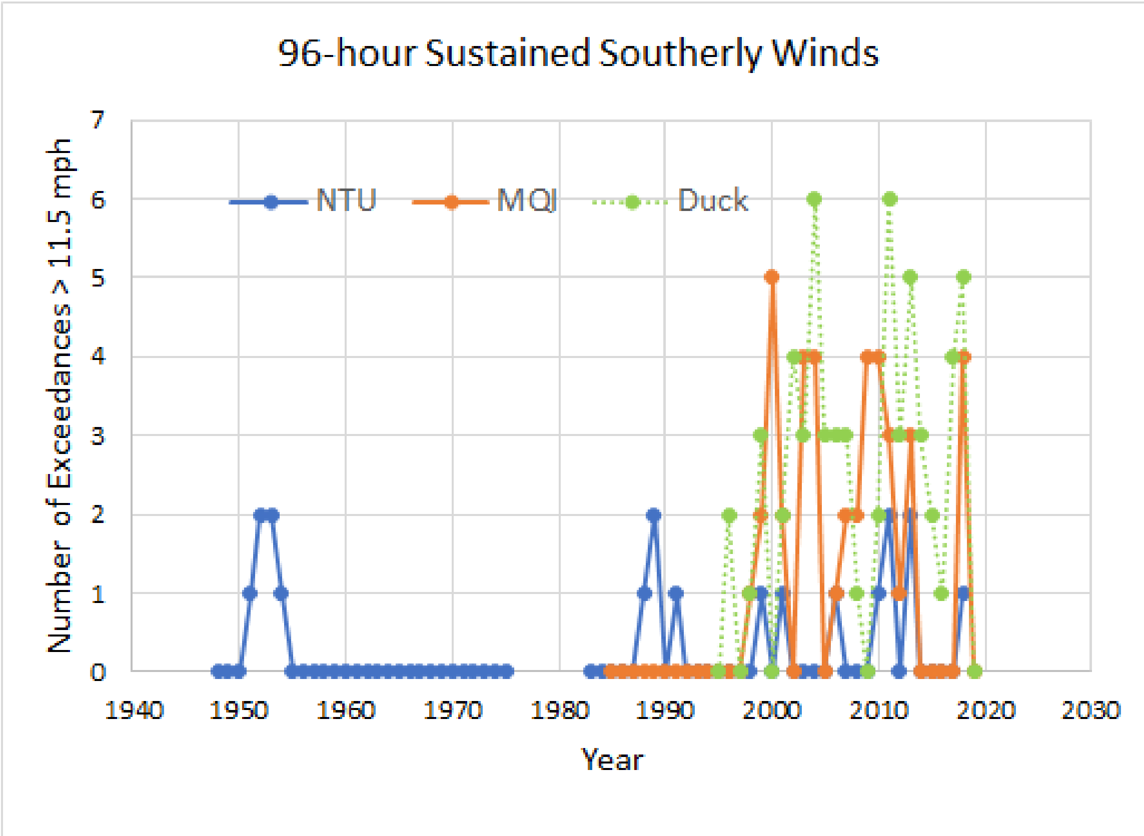

Figure 9. Count of defined southerly sustained 96-hour winds that exceed 11.5 mph (10 knots) in each year.

Table 7. Total number sustained southerly winds that exceed given thresholds at NTU, MQI, and Duck over the period of record.

Exceedance Threshold in mph (knots)	Count of 48-hour Winds > Threshold	Count of 72-hour Winds > Threshold	Count of 96-hour Winds > Threshold
11.5 (10)	636	262	123
17.3 (15)	114	25	11
23.0 (20)	5	0	0
28.8 (25)	0	0	0
34.5 (30)	0	0	0

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