NWTC M2 Wind Conditions

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08 November 2016 07:46

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About This Document

This document describes the analysis and interpretation of data from the M2 meteorological tower at the National Renewable Energy Laboratory (NREL) National Wind Technology Center (NWTC), near Boulder, Colorado.

The M2 tower is an 82-meter (270 foot) meteorological tower located at the western edge of the NWTC Site and about 11 km (7 miles) west of Broomfield, and approximately 8 km (5 miles) south of Boulder, Colorado. The tower is located at 39° 54' 38.34" N and 105° 14' 5.28" W (datum WGS84) with its base at an elevation of 1855 meters (6085 feet) above mean sea level.

More information about the M2 tower can be found at www.nrel.gov/midc/nwtc_m2/.

The analysis presented here uses data from a cup anemometer and wind vane mounted at 80 m above ground.

If you are reading the PDF, you are reading a document created from an R markdown file using *knit*. R markdown has been used to enable reproducible research. Replication files are available on the author's Github account[1,2].

[1] **Current version**: November 08, 2016

[2] **Repository**: https://github.com/AndyClifton/NWTCM2WindConditions

Preparing Data

Directory structure

This code stores data, figures, and other results in a directory structure at ~/Documents/public/code/R/NWTCWindConditions/N

Codes used for this analysis can be found in the Code directory.

Required Packages

The plots in this document work best with the developer versions of *ggplot2* and *scales* (the developer versions are required for captions). These packages can be found at https://github.com/hadley/. Installing these versions requires the *devtools* package. To install *devtools* and the developer version of *ggplot2*, type:

```
update.packages("devtools",
                repos = "http://cran.us.r-project.org",
                dependencies=c("Depends"),
                ask = FALSE)
devtools::install_github("hadley/scales",
                         dependencies=c("Depends"))
devtools::install_github("hadley/ggplot2",
                         dependencies=c("Depends"))
```

This code also uses *lubridate*, *MASS*, and *RColorBrewer*.

Read Data

This script reads all .csv files in ~/Documents/public/code/R/NWTCWindConditions/NWTCM2WindConditions/Data. These files are saved as *.Rdata* files for each year.

The processed *.Rdata* data are read in from ~/Documents/public/code/R/NWTCWindConditions/NWTCM2WindConditions/Data Importing pre-existing data means that the the time-consuming step of processing the raw data every time can be avoided.

```
## Reading 2001_10minData.Rdata
## Making new df.10min.all
## Reading 2002_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2003_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2004_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2005_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2006_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2007_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2008_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2009_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2010_10minData.Rdata
```

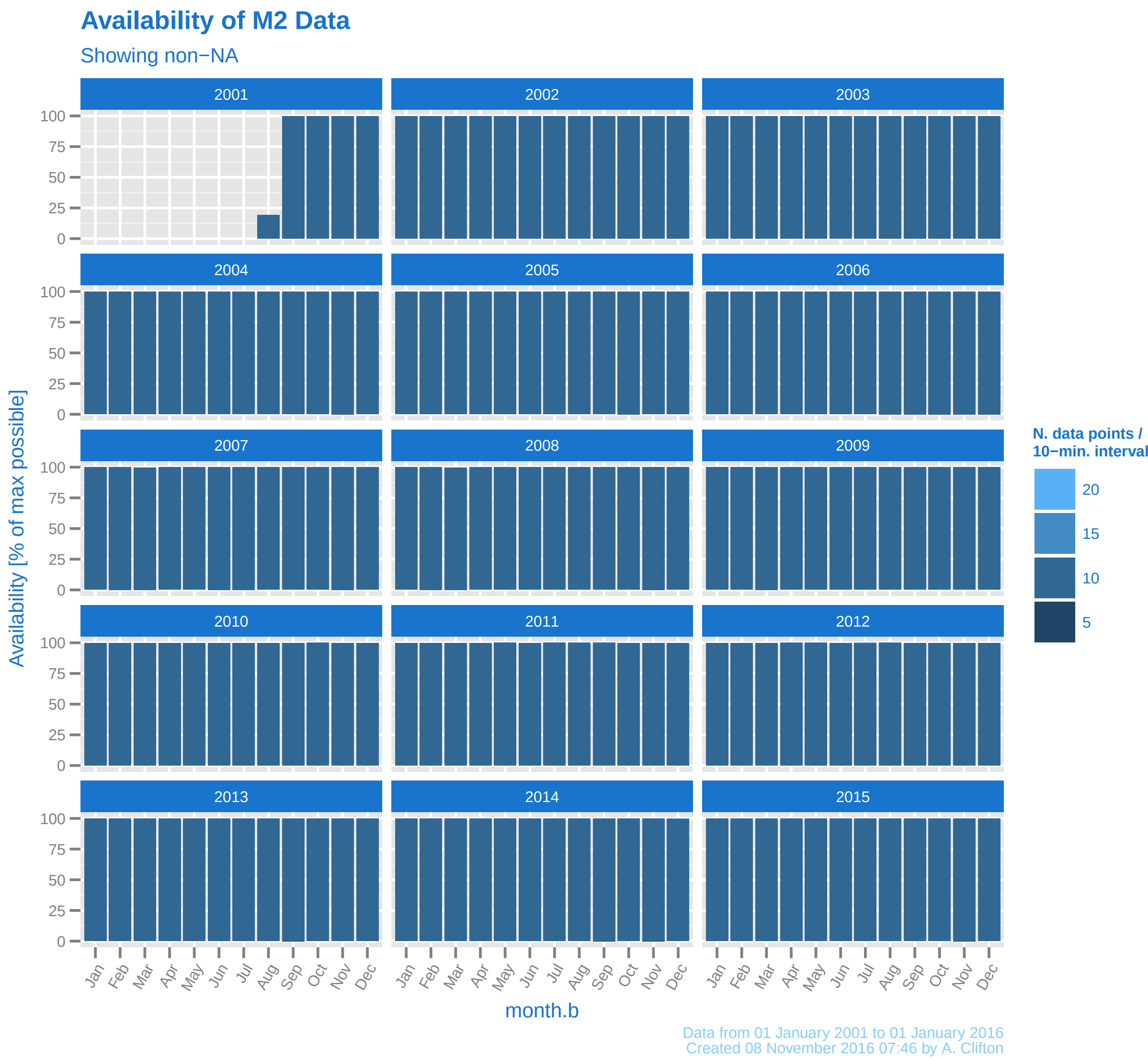
```
## Concatening data to df.10min.all
## Reading 2011_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2012_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2013_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2014_10minData.Rdata
## Concatening data to df.10min.all
## Reading 2015_10minData.Rdata
## Concatening data to df.10min.all
```

Results

The following results are based on data obtained during the period from 2001-01-01 to 2016-01-01.

Data Availability

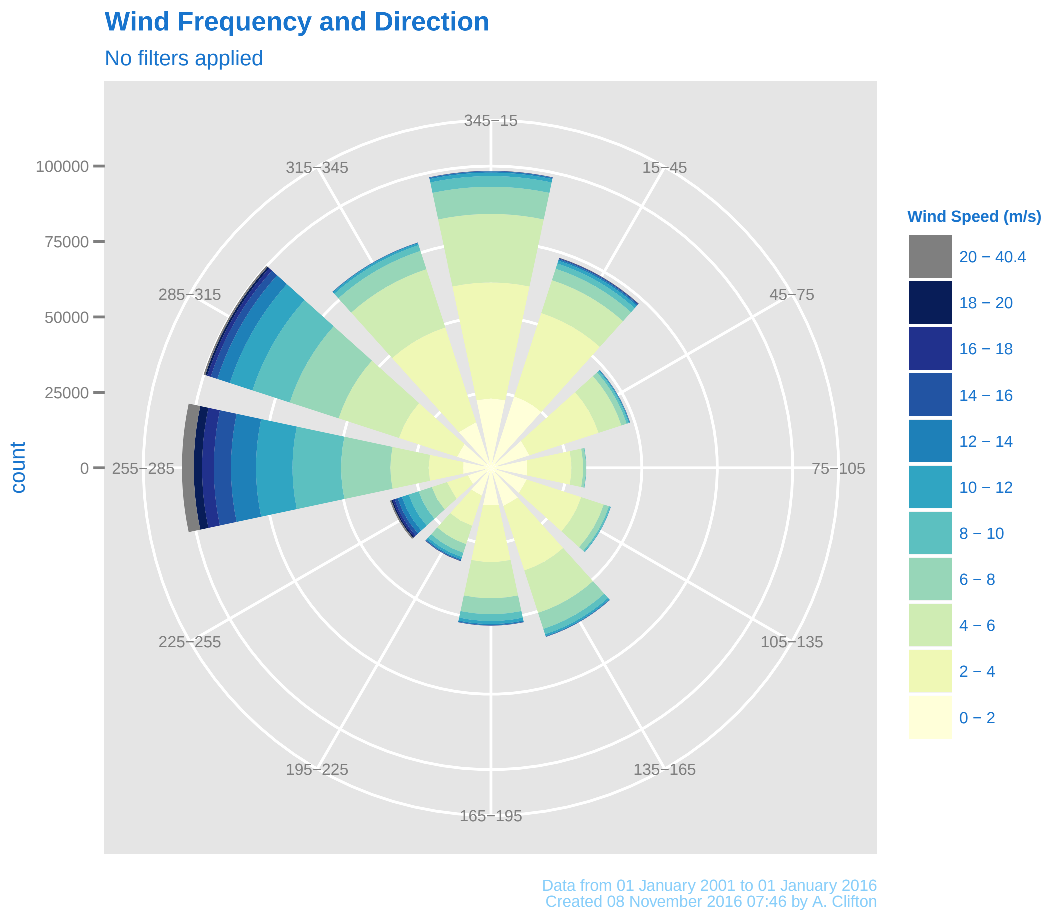
The following figure shows the availability of the data used in this analysis. Data are plotted as the number of non-NA 10-minute 80-m wind speed data points per month, expressed as a percentage of the maximum possible for that month.



Data in the plot are grouped by the number of datapoints that are averaged per 10-minute interval. This averaging process is required as the M2 data are recorded with varying temporal resolution; from 2011 onward, they were recorded at 1-minute intervals. Therefore, there should be a maximum of 10 samples per 10-minute period.

Wind Roses

The following figure shows the wind rose created from the entire data set. It covers the period from 2001-01-01 to 2016-01-01. This can be considered the climatic wind rose.

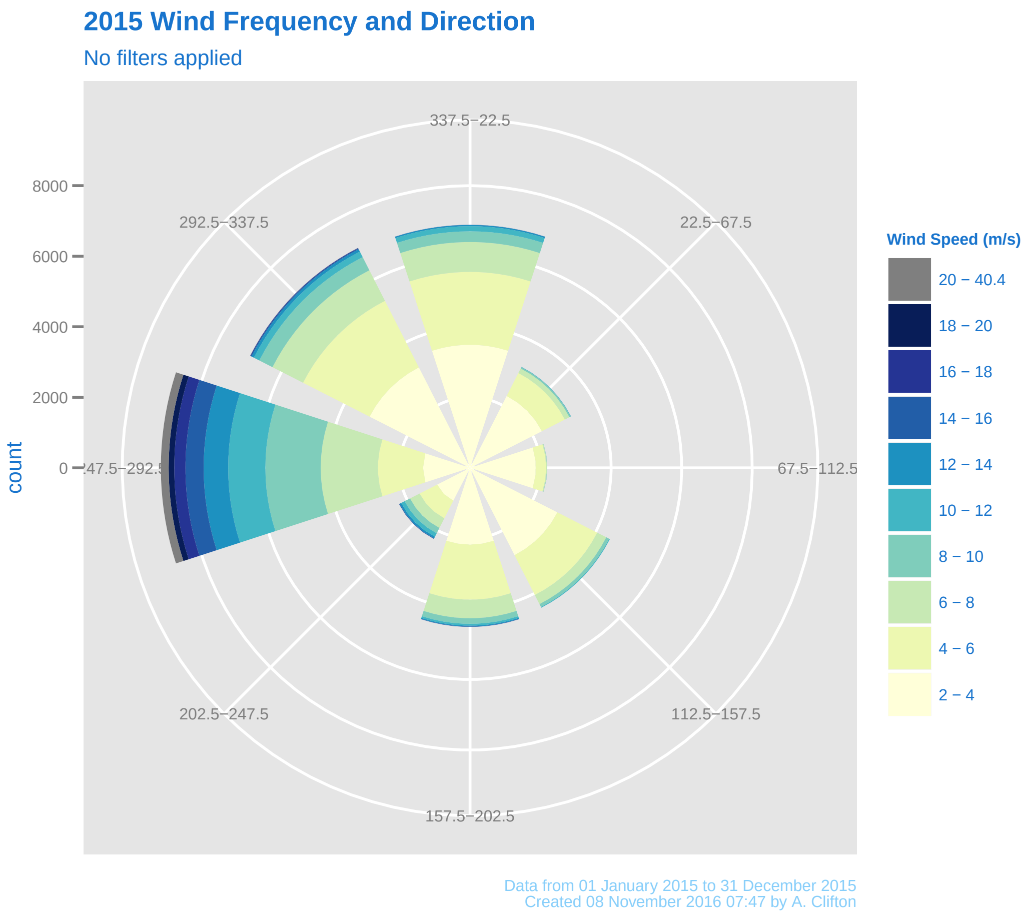


The following plot shows the wind rose in each year. There is some variability from year to year. Some of the reasons for the variability are explored in Clifton and Lundquist [2012].

Wind Frequency and Direction

No filters applied

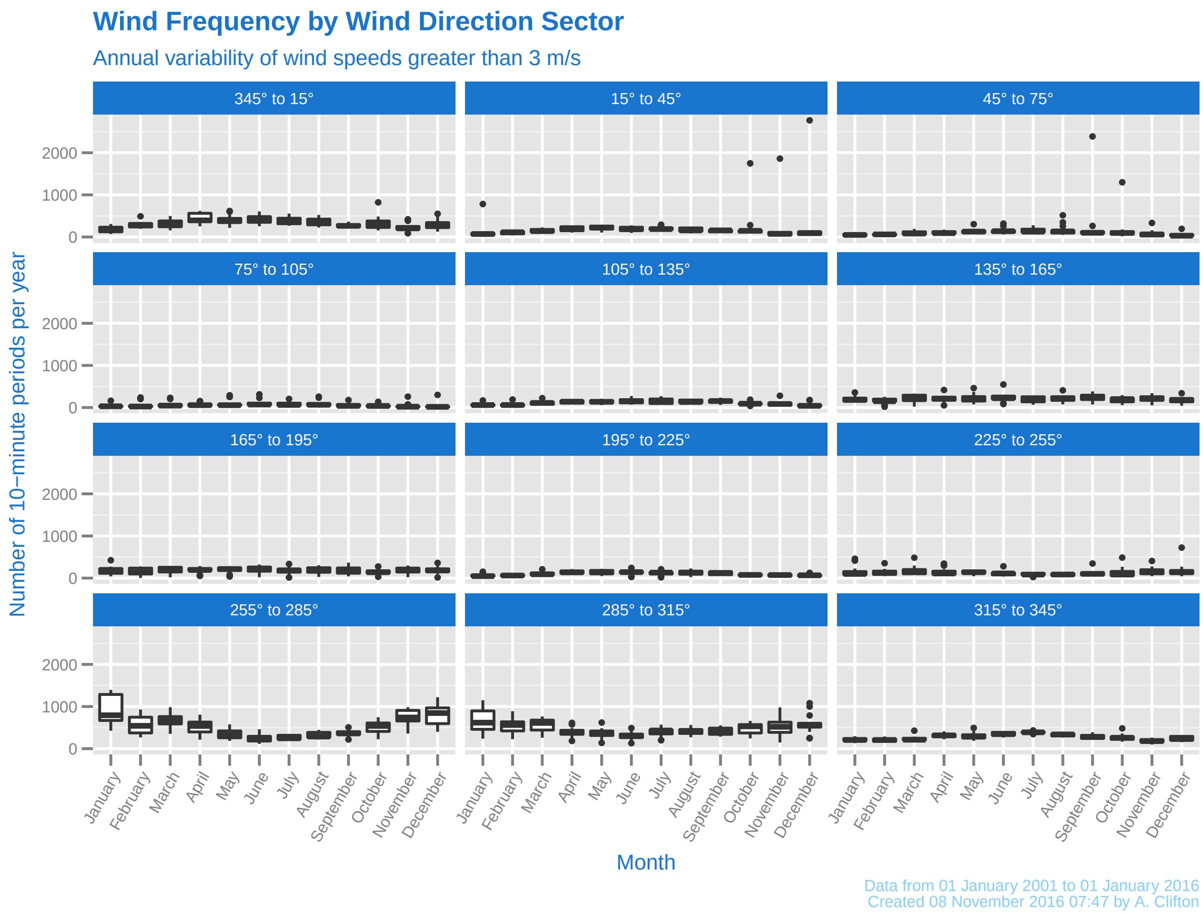
The following plot shows the wind rose for the 80-m level on the M2 tower in 2015. This plot is provided for comparison to data available through NREL's Measurement and Instrument Data Center, or MIDC. The MIDC version can be accessed via this link. Note that the MIDC plot uses 1-minute data and results are therefore slightly different to this plot.



Monthly Wind Characteristics

Winds at the NWTC show a clear seasonal cycle of direction and speed. This can be seen in the following figure, which shows the annual variaiblity of the number of 10-minute intervals where the wind speed exceeds 3 m/s, in each wind direction sector. In this analysis we use 30 degree wind direction sectors, centered on 0°.

As discussed in Clifton and Lundquist [2012], there is a clear annual cycle of wind direction, with westerly through north winds being more common in the winter months (October through April).



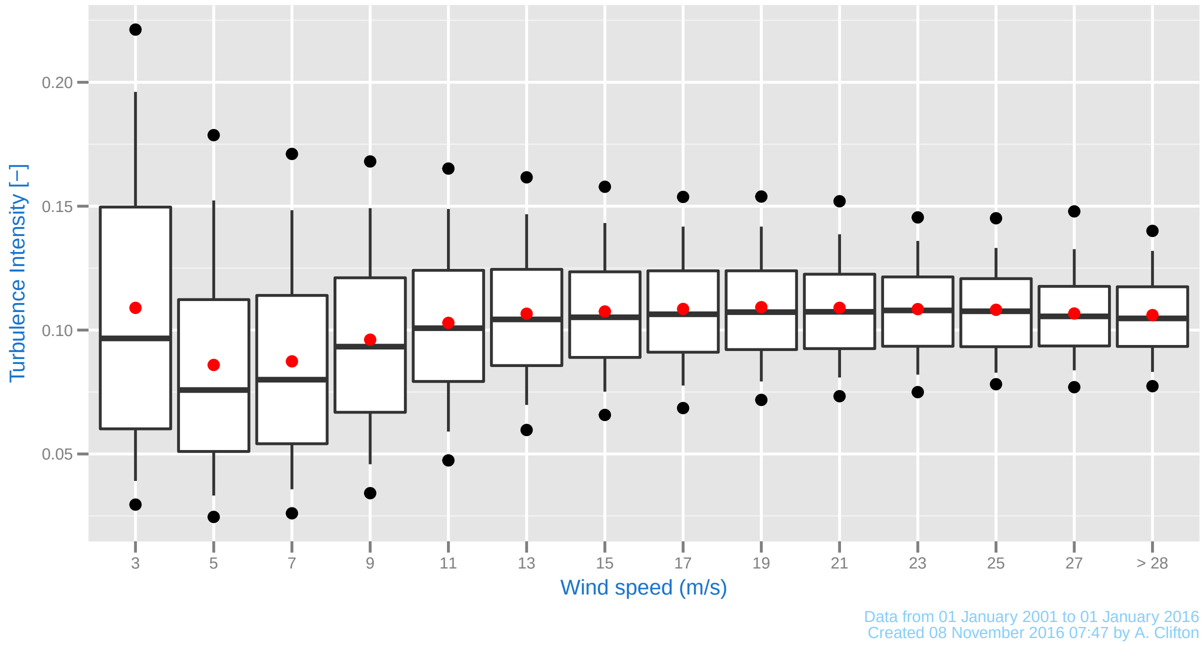
Turbulence Intensity

Turbulence intensity is the standard deviation of wind speed in a 10-minute interval, normalized by wind speed.

The following plot shows the turbulence intensity statistics in each wind speed bin. The data used in this plot are not filtered by direction. The plot uses the same convention as Kelley [2011].

Turbulence Intensity

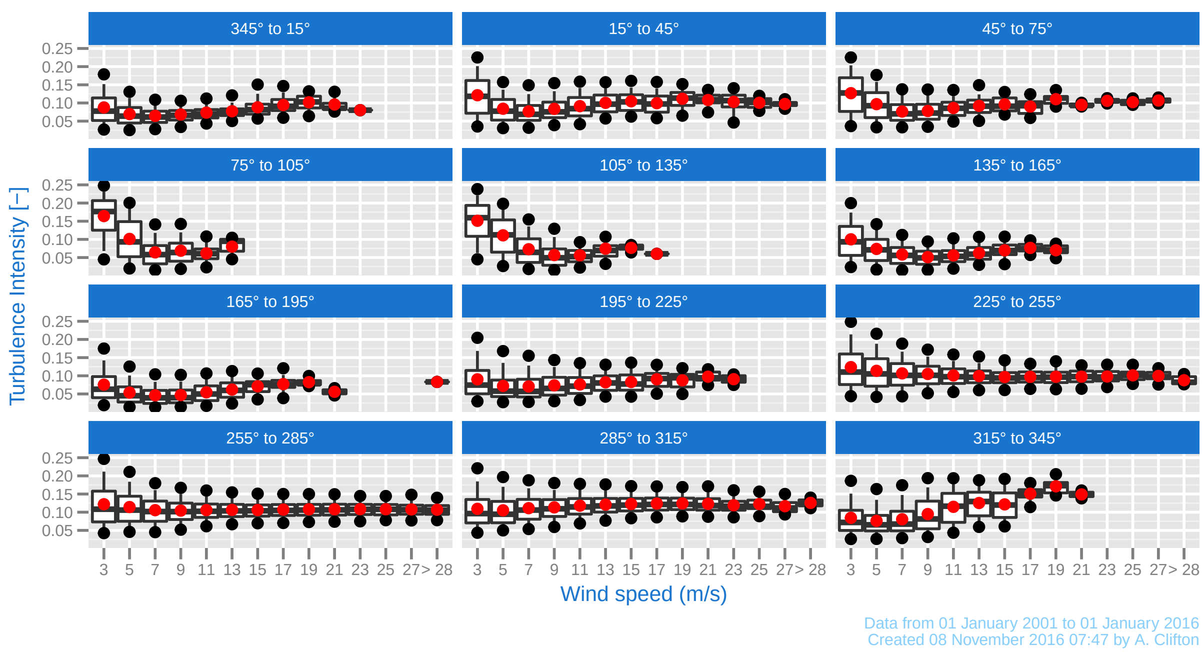
Wind speeds greater than 2 m/s



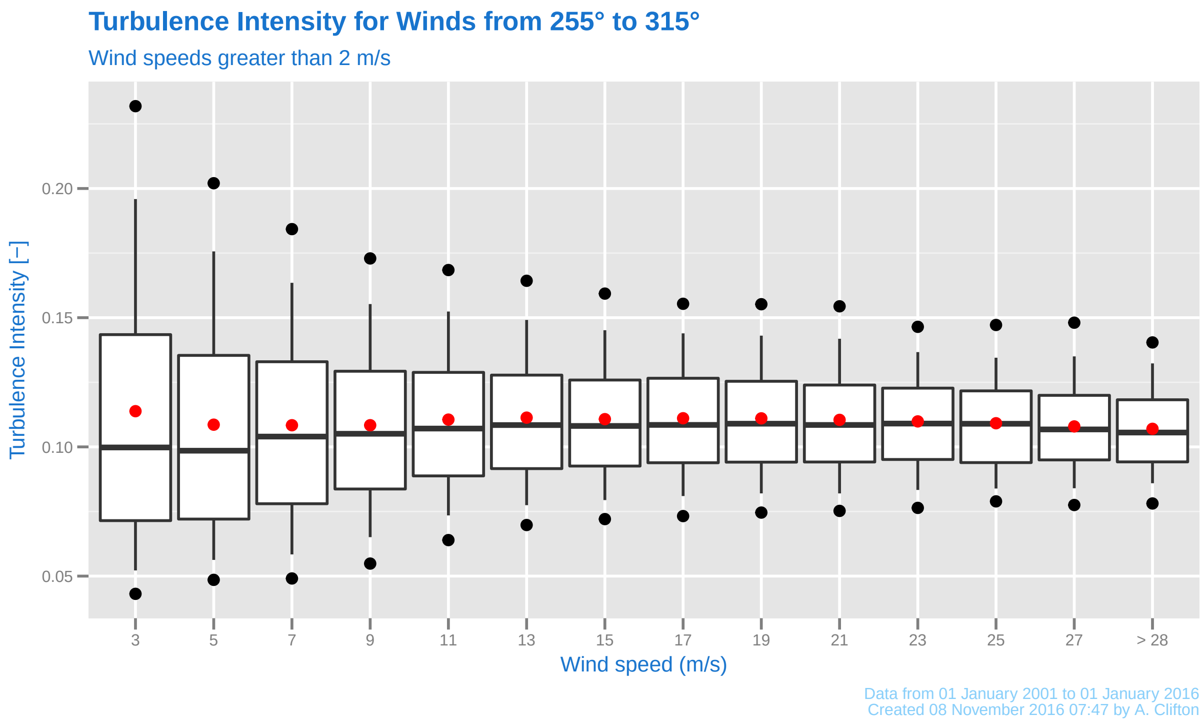
The following plots show the variation of turbulence intensity by wind direction sector. As seen earlier, there is clear variation by wind direction, which is a result of the variation in upwind conditions with direction at the NWTC.

Turbulence Intensity by Wind Direction

Wind speeds greater than 2 m/s



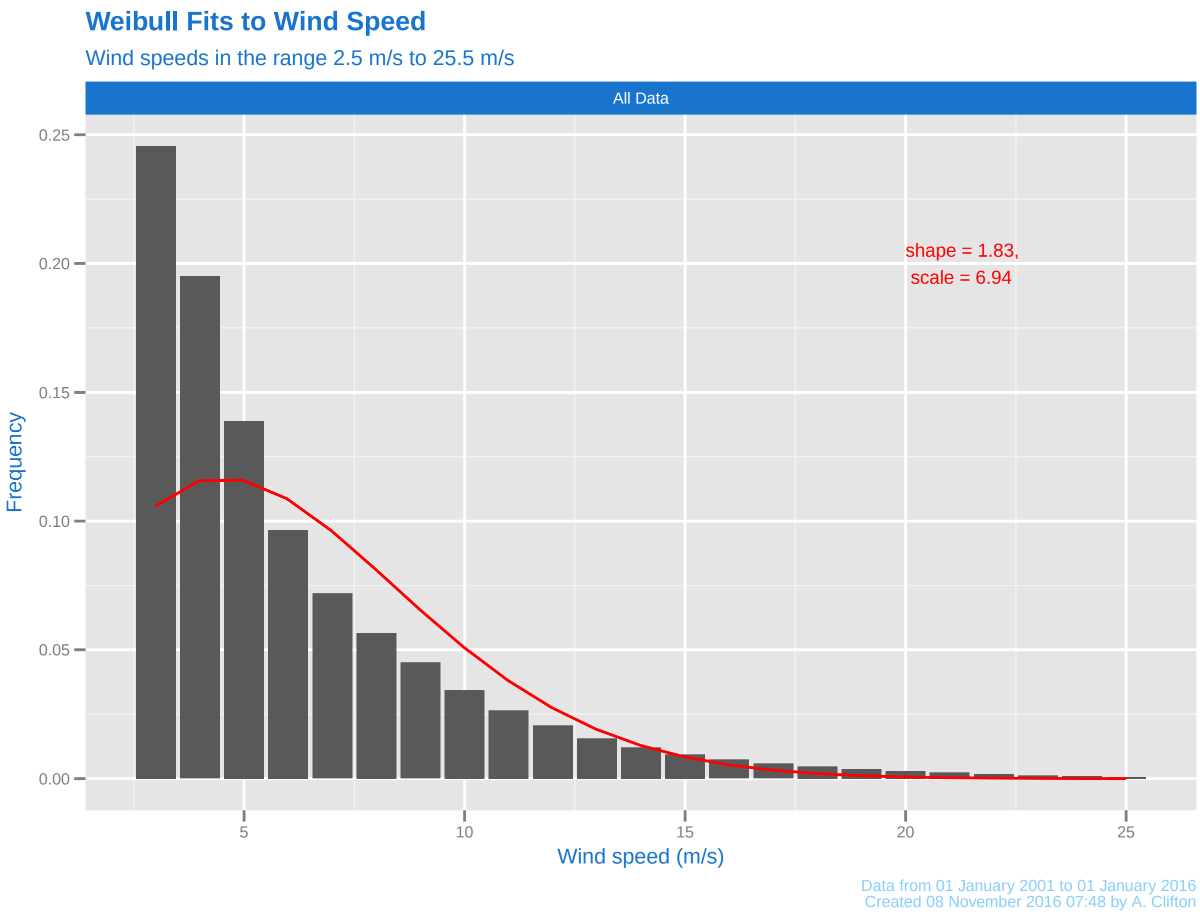
In the next plot, data are limited to the direction sector between 255° and 315° upwind of the M2 tower. This sector is the dominant wind direction during the winter months.



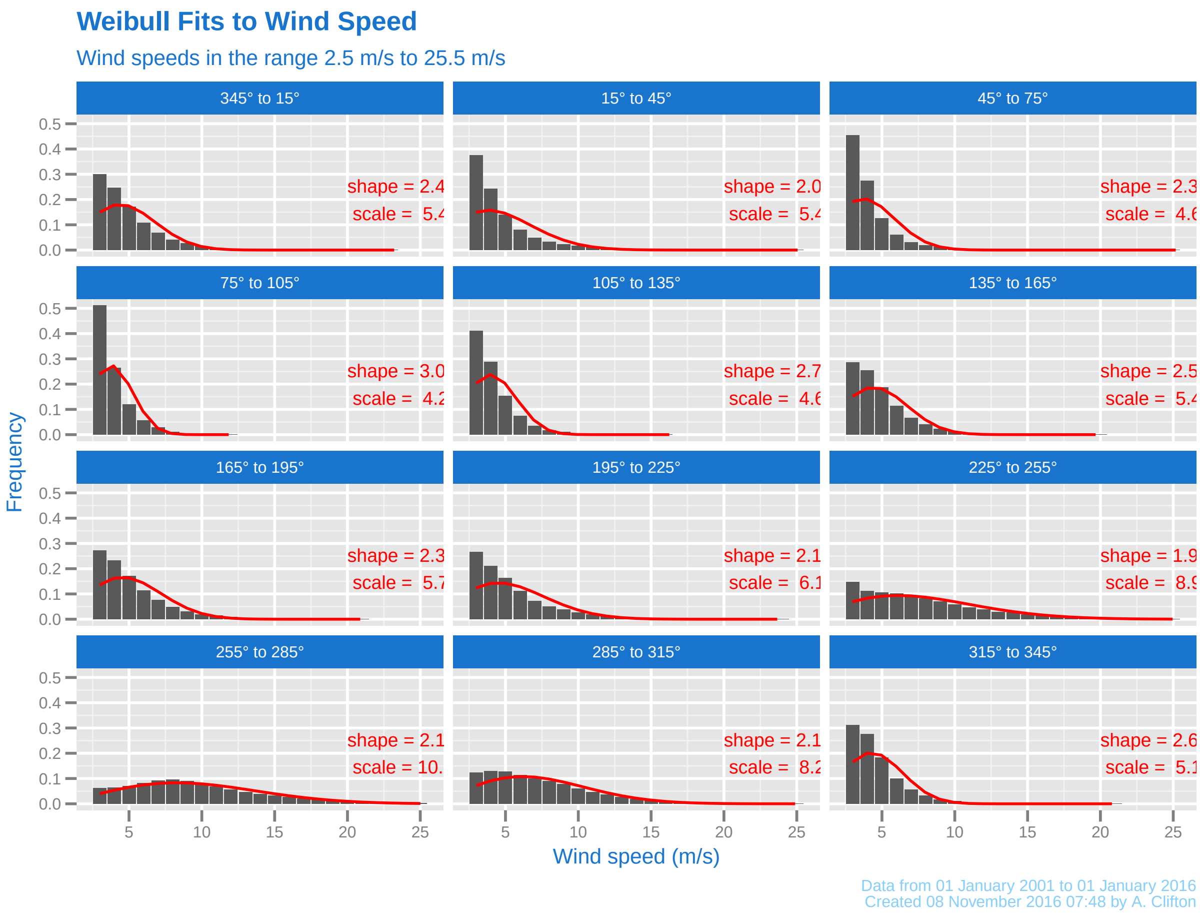
Wind speed distributions

The following plots show fits to wind speed data using a Weibull distribution. The fit is made to the raw data. The range of the data used is from 2.5 m/s to 30.5 m/s. It should be noted that fitting data with a weibull curve is recognized as being very difficult.

The fit in the following plot uses all data.



Fits in the next plot are made to the data in each wind direction sector.



Summary of NWTC M2 Conditions

The previous plots are based on data from 788,847 10-minute data records. During this period, the mean conditions measured by the tower were:

Parameter	Value	Notes
$V_{\text{ave (all)}}$	4.71	Average wind speed for all data
$V_{\text{ave (operating)}}$	6.15	Average wind speed for winds over 2.5 m/s
$f_{\text{(operating)}}$	66.0	Frequency of winds over 2.5 m/s
$V_{\text{(max, 10-minute)}}$	40.4	Maximum 10-minute average wind speed
WD (°T)	284.0	Mode of wind direction for winds over 2.5 m/s

Bibliography

Andrew Clifton and Julie K. Lundquist. Data clustering reveals climate impacts on local wind phenomena. *Journal of Applied Meteorology and Climatology*, 51:1547–1557, 2012. doi: 10.1175/JAMC-D-11-0227.1.

Neil D. Kelley. Turbulence-turbine interaction: The basis for the development of the TurbSim stochastic simulator. Technical Report TP-5000-52353, National Renewable Energy Laboratory, 2011.