7th Protocol: Wind

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There are many types of instruments used for measuring wind speed. Here some of them will be described.

Cup Anemometer : it consists of a set of three cups, crossing a vertical basement stick. This cross shape allows to measure the horizontal wind velocity at a specific height. The wind speed is derived from number of cycles/time or turning velocity. For measuring the wind direction, a wind vane is used. It points to the direction where the wind is coming. This is through a potentiometer to detect the right direction.

Propeller anemometer : the way this this instrument works is very similar to the cup anemometer. It points to the mean wind direction at that moment. With the use of three propeller anemometer pointing different direction, three dimensional wind can be measured.

Ultrasonic anemometer thermometer : This uses the speed of sound to measure the wind. Normally, it will be displayed in three directions to measuread all directions and get a more accurate measurement value. One of the advantages of using the ultrasonic anemometer is the small fluctuations detected on the measures. The speed of sounds depends on temperature and air humidity. Thus, the following equations allow the calculation of speed of sound and the temperature at high frequencies;

$$C_l = D/2 * ((1/timeA - A) + (1/timeB - A))$$
$$C_l = \sqrt{K_a * R_a * T_{av}}$$

* When

$$K_a = 1.4$$

,

$$R_a = 287.05 J/Kg * K$$

,

$$T_{av} = T(1 + 0.513 * q)$$

Hot wire anemometer : When a current flow is introduce within a wire, there is a release of heat. Then, the air flow goes throguh the wire and cools down removing the released energy. It can be apply in two different ways;

At a constant current, the change of temperature is measure with a thin thermocouple. This can be hard at a high speed wind.

At a constant temperature, with a temperature change the current is regulated, such that the temperature is held constant and thus, with a high wind there will be a high current as well.

Common errors with anemometer. The starting speed of cup and propeller anemometer is that it starts to rotate when speed is 0.5 m/s. When wind flow stops, but the cup anemometer keeps rotating a bit longer until it fully stops. In case of low wind speed, sonic anemometer are the best instruments to use but in case or rain, it cannot do measurements instead.

When installation the anemometers there are some tips to have into account. Better to set them far above ground,this way the roughness of the lower layer above soil's surface will not be affecting the measures. The same with any other object around in the area.In case of sonic anemometer, is important to protect it against birds or any type of instect that make small variation when measuring.

averaging suing vector average (Grange 2014)

Figure 1: Caption for the picture

4 Analysis

```
library(tidyverse)
```

```
## Warning: package 'tidyverse' was built under R version 4.0.5

## Warning: package 'tibble' was built under R version 4.0.5

## Warning: package 'tidyr' was built under R version 4.0.5

## Warning: package 'forcats' was built under R version 4.0.5
```

```
library(lubridate)
```

```
## Warning: package 'lubridate' was built under R version 4.0.5
```

```
library(clifro) # for windrose
```

```
## Warning: package 'clifro' was built under R version 4.0.5
```

```
library(patchwork)
```

```
## Warning: package 'patchwork' was built under R version 4.0.5
```

```
library(ggthemes)
```

```
## Warning: package 'ggthemes' was built under R version 4.0.5
```

```
theme_set(theme_bw()) # ggplot theme
```

```
wind <- read_csv(here::here("Data_lectures/7_Wind/Winddata_Botanical_garden.csv")) %>%
  drop_na() %>%
  rename(WS_0.5m = WS_05m, wd=WD_deg)
```

```
deg2rad <- function(deg) deg * pi / 180
rad2deg <- function(rad) rad * 180 / pi

# calculates the wind angular average over the provide input.
# intend to be used together with group_by and summarize
wind_dir_average <- function(wd){
  dir <- deg2rad(wd)
  # calc the vector components and then make the mean
  u <- cos(dir) %>% mean
  v <- sin(dir) %>% mean
  # convert back to a direction. Note atan2 uses y,x
  avg_dir <- atan2(v, u)
  # need to convert in 0 - 360 range
  avg_dir <- avg_dir %% (2*pi)
  return(rad2deg(avg_dir))
}
```

```r
# wind gathered
wind_g <- wind %>%
  gather("height", "windspeed", WS_0.5m, WS_1m, WS_2m, WS_5m, WS_10m) %>%
  # converts the height into a numeric value
  mutate(height = as.numeric(gsub(".*?([0-9]+).*", "\\1", height)))

wind_1d<- wind %>%
  mutate(Date = floor_date(Date, unit = "1 day")) %>%
  group_by(Date) %>%
  summarise(across(c(-wd), mean), wd = wind_dir_average(wd))

wind_g_1d <- wind_1d %>%
  gather("height", "windspeed", WS_0.5m, WS_1m, WS_2m, WS_5m, WS_10m) %>%
  # converts the height into a numeric value
  mutate(height = as.numeric(gsub(".*?([0-9\\.]+).*", "\\1", height)))
```

4.1 Wind averages

Calculate 1 hour averages of 10 minute mean wind speed and direction data.

```r
wind_1h <- wind %>%
  group_by(round_date(Date, unit = "1 hour")) %>%
  summarise(across(-wd, mean), wd = wind_dir_average(wd))
```

```r
wind %>%
  filter(between(Date, as_datetime("2021-01-15") , as_datetime("2021-01-17"))) %>%
ggplot()+
  geom_point(aes(Date, wd, colour="10 mins"), size=.8) +
  geom_line(aes(Date, wd, colour="1 hour"),
            data=filter(wind_1h, between(Date, as_datetime("2021-01-15"),
                                          as_datetime("2021-01-17")))) +
  labs(y="Wind direction", colour="") +
  scale_y_continuous(breaks = c(0, 90, 180, 270, 360),
                     labels = c('N (0°)', 'E (90°)', 'S(180°)',
                                'W(270°)', 'N (360°)'), limits = c(-10, 370))
```

The wind speed and direction have been averaged at 1 hour. Vectorial average has been used for wind direction. In figure 2 the average direction is compared with the original data. Between the 15th and the 16th of January there are some data points with a wind direction close to 0, but the average is around 350.

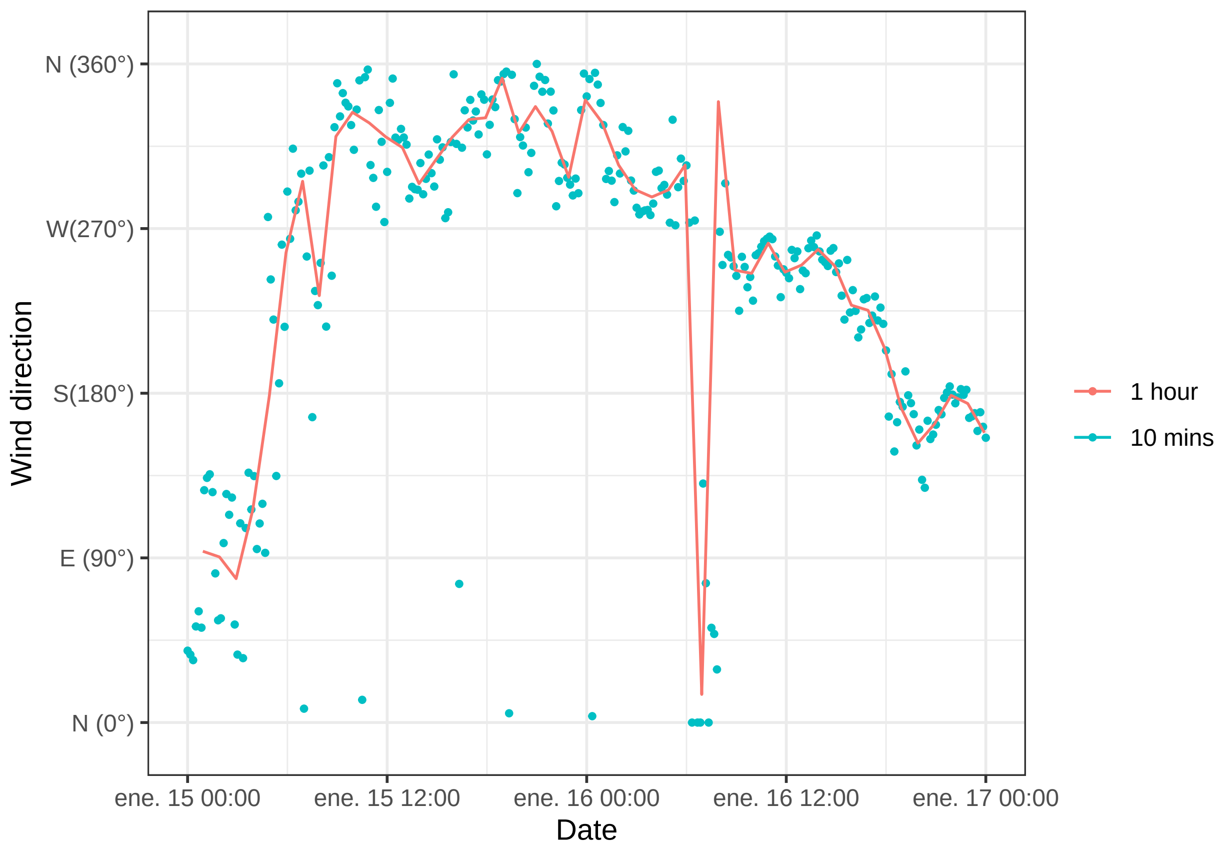


Figure 2: Comparison of wind direction original data (10 mins) and hourly average. Data from botanical gardern 15th-17th January 2021.

4.2 Wind speed and height

How does the wind speed change with height? Characterize the wind pattern in different heights at the botanical garden

```
## plotting the same thing using gather
(wind_g_1d %>%
  #just one month otherwise the plot is too compressed
  filter(between(Date, as_datetime("2020-01-15") , as_datetime("2020-02-15") )) %>%
  mutate(height = fct_reorder(as_factor(height), sort(height, decreasing = T))) %>%
  ggplot(aes(Date, windspeed, col=height))+
  geom_line() +
  scale_color_colorblind() +
  labs(y="Windspeed (m/s)", colour="Height (m)", title="(a) Winter month")) /
(wind_g_1d %>%
  #just one month otherwise the plot is too compressed
  filter(between(Date, as_datetime("2020-06-15") , as_datetime("2020-07-15") )) %>%
  mutate(height = fct_reorder(as_factor(height), sort(height, decreasing = T))) %>%
  ggplot(aes(Date, windspeed, col=height))+
  geom_line() +
  scale_color_colorblind() +
  labs(y="Windspeed (m/s)", colour="Height (m)", title="(b) Summer month")) +
plot_layout(guide="collect")
```

In Figure 3 .. As it is possible to appreciate in the graph, wind speed gets faster at 10m height. This makes sense when having in mind the vertical wind profile graph that increases with height.

```
wind_prof <- wind_g_1d %>%
  group_by(height) %>%
  summarize(windspeed=mean(windspeed))
#### fit logarithmic wind profile to data and estimate the parameters u*, z0 and d ####
# initial values
u_star_start <- 0.1
d_start <- 0.3
z0_start <- 0.05

log_prof_model <- nls(windspeed ~u_star/0.4*(log((height - d)) - log(z0)),
                 start = list(u_star=u_star_start,
                              d=d_start,
                              z0=z0_start),
                 na.action = na.exclude, data=wind_prof)
wind_prof <- mutate( wind_prof,
  pred_ws = predict(log_prof_model))
```

```
wind_g_1d %>%
  ggplot() +
  geom_boxplot(aes(windspeed, height, group=height)) +
  geom_line(aes(x=pred_ws, y=height, colour="Fitted log profile"),  data = wind_prof) +
  geom_point(aes(x=pred_ws, y=height, colour="Fitted log profile"), data = wind_prof, )
```

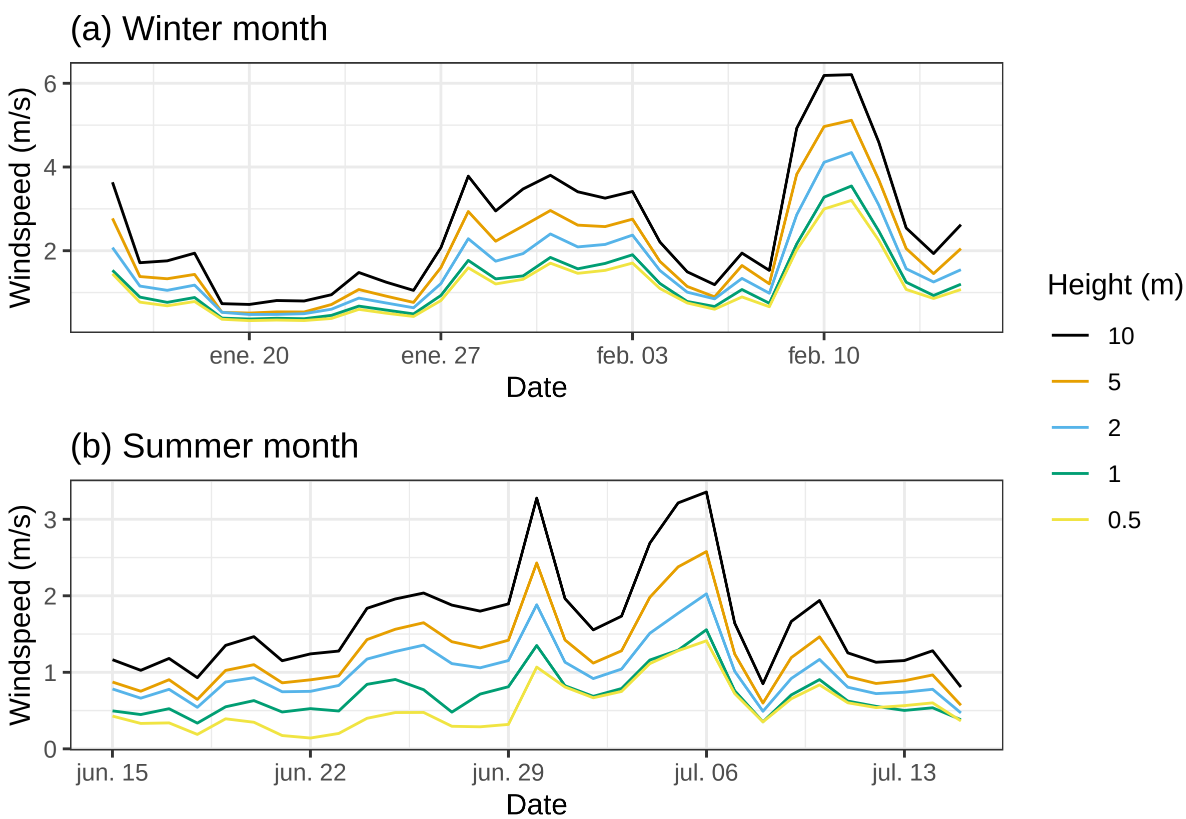
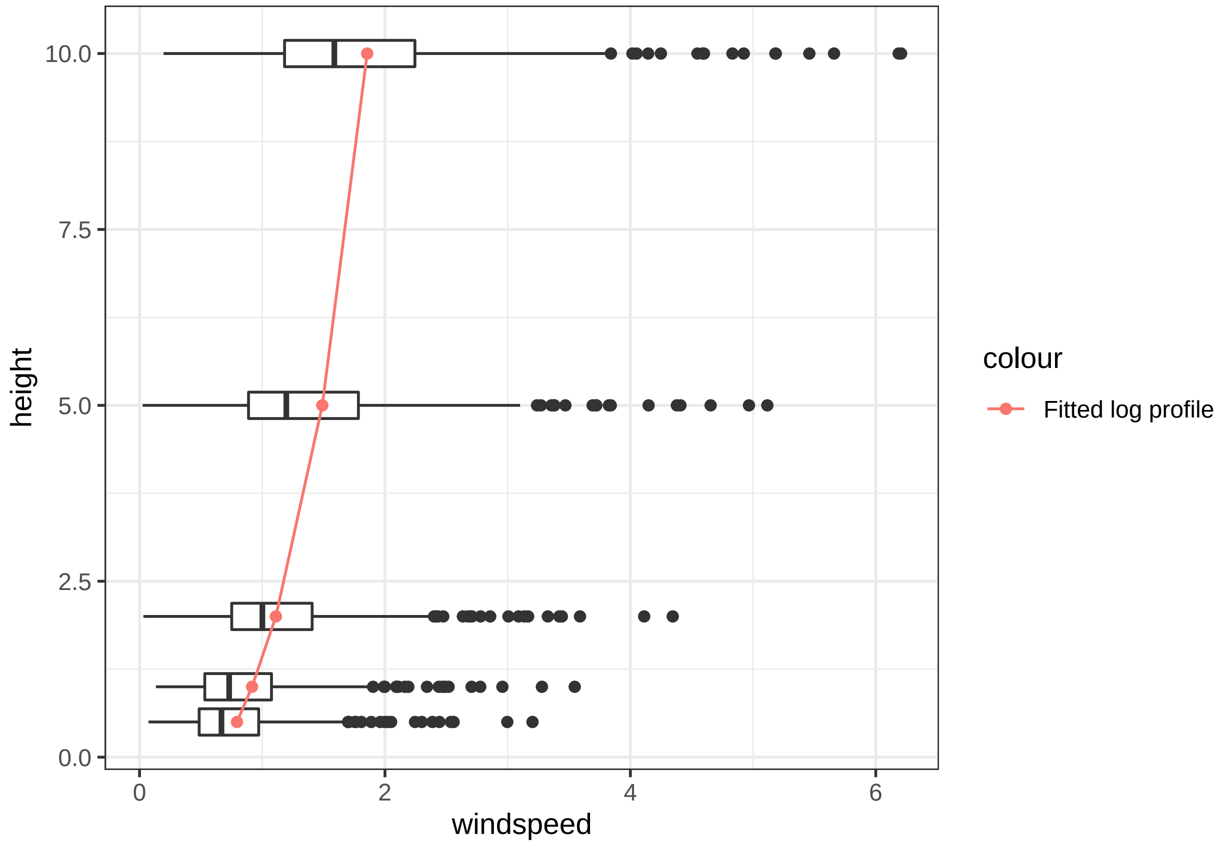


Figure 3: Time series of wind speed at different heigth. (a) is a summer month (15th Jan 2020 - 15th Feb 2020). (b) is a winter month(15th Jun 2020 - 15th Jul 2020). Data from botanical garden.

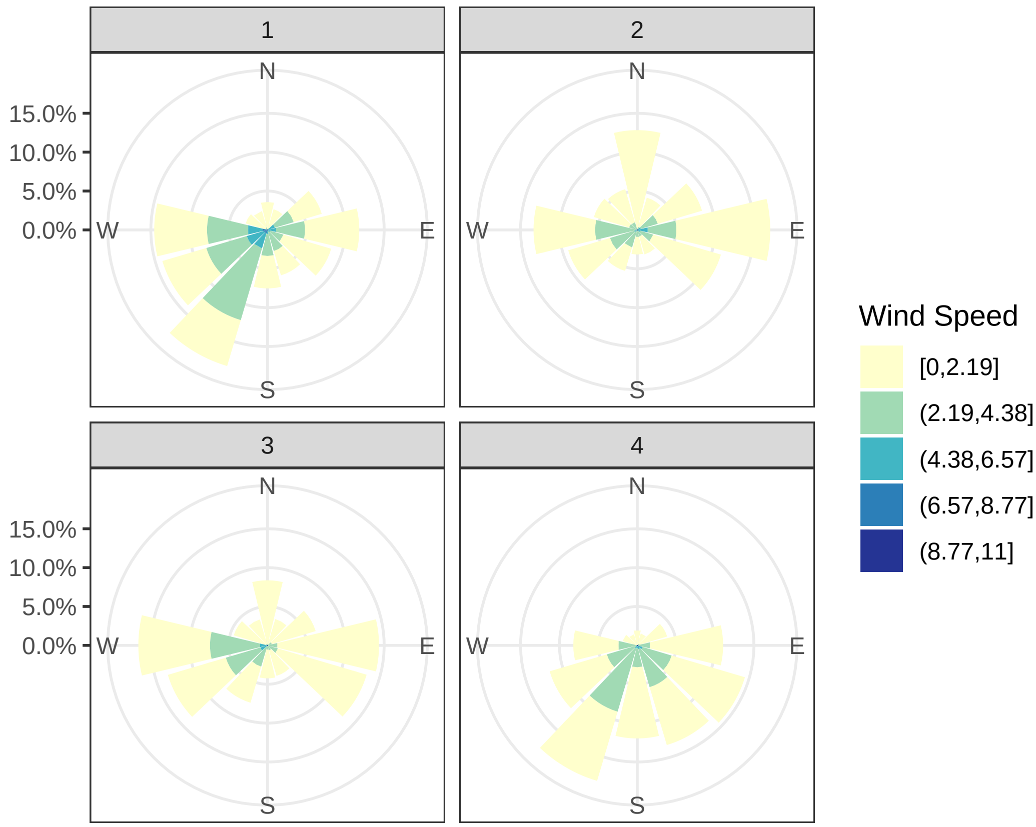


Boxplot and fitted curve

4.3 Windspeed over year

How does the wind speed varies over the year and what can explain the variability?

```
wind_q <- wind %>%
  mutate(quarter = quarter(Date) %>%
           as_factor)
windrose(wind_q$WS_10m, wind_q$wd, wind_q$quarter, n_col= 2, col_pal="YlGnBu",
         ggtheme = "bw")
```



```r
ggplot(wind_1d, aes(Date, WS_10m)) +
  geom_line() +
  labs(y="Wind speed (m/s)")
```

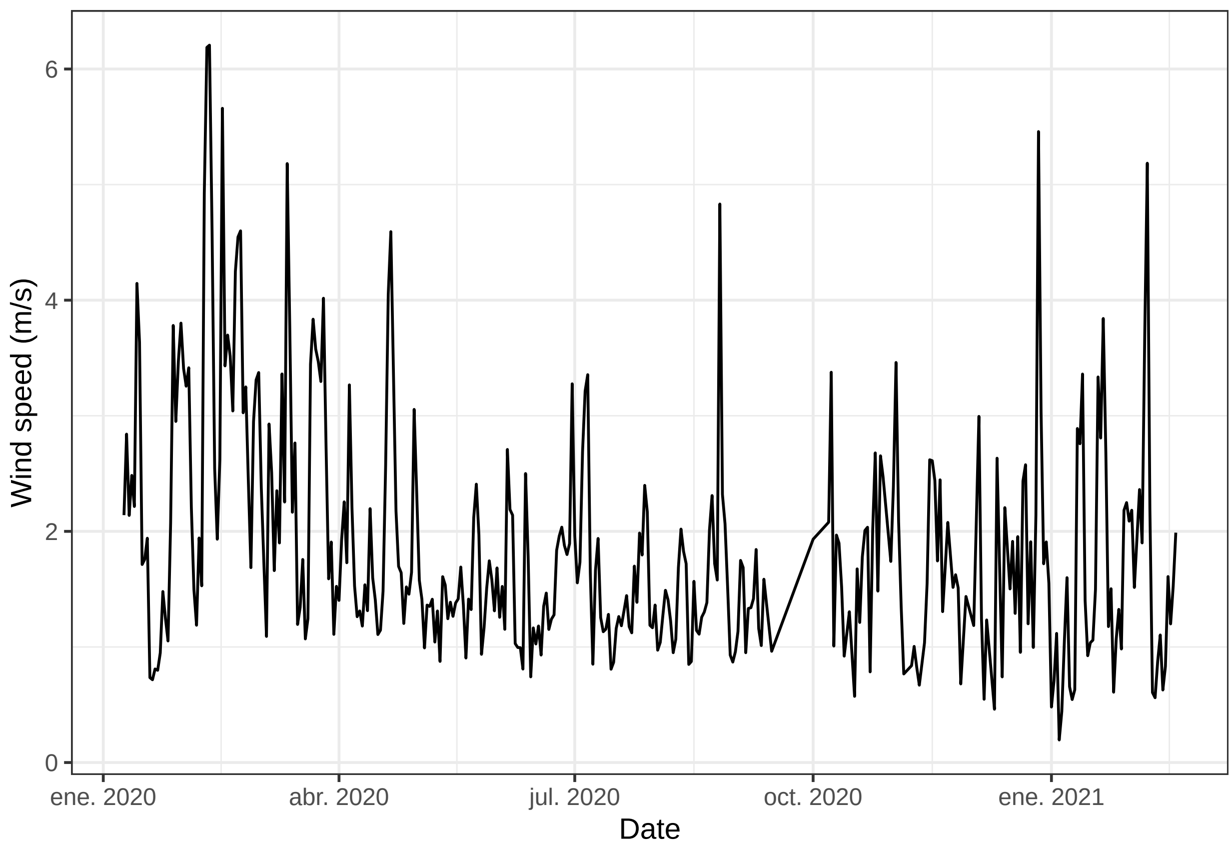


Figure 4: (#fig:ws_year)Daily averages of wind speed at 10 meters. Data from forest botanical garden January 2020 - February 2021.

During the spring and winter the wind is stronger. In summer daily average oscillates around 1.5 m/s

The graphs displays the variation of the wind speed along year. It is faster from end of december to beginning of april. During summer the mean wind speed is lower but some days it gets faster than others. This variability is originated depending on when the wind is coming from.

```r
# data frame with months start and end to draw background
months <- map_df(1:14, function(n_mon){
  start <- as_datetime("2020-01-01")
  # offset to the correct month start
  month(start) <- month(start) + n_mon - 1
  end <- start
  # adding one month to get to the end and removing one day
  month(end) <- month(end) + 1
  day(end) <- day(end) - 1
  tibble(start = start, end = end,
         month= month(start, label = T), quarter= quarter(start))
} )
```

```r
wind %>%
  group_by(round_date(Date, unit = "1 weeks")) %>%
  summarise(across(c(matches("WS"), Date), mean), wd = wind_dir_average(wd)) %>%
  ggplot() +
  geom_rect( #add months in the background to be able to read the figure
    aes(xmin = start, xmax = end, fill = month),
    ymin = -Inf, ymax = Inf, alpha = 0.6,
    data = months
  ) +
  scale_fill_brewer(palette = "Set3") +
  geom_point(aes(Date, wd)) +
  coord_polar(theta="y") +
  labs(y="Wind direction", fill="Month") +
    scale_y_continuous(breaks = c(90, 180, 270, 360),
                      labels = c('E', 'S', 'W', 'N' ), limits=c(0, 360))
```

References

Grange, Stuart. 2014. "Technical Note: Averaging Wind Speeds and Directions," June. https://doi.org/10.13140/RG.2.1.3349.2006.

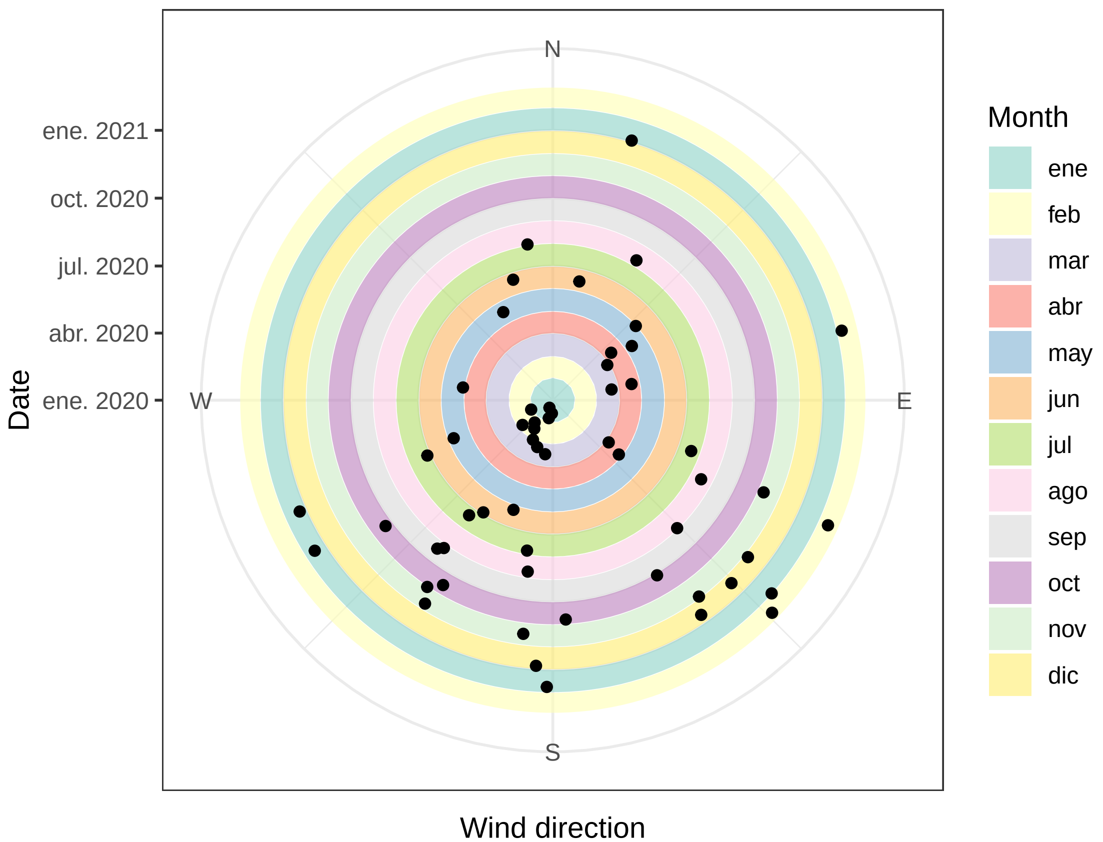


Figure 5: Weekly average of wind directions for the year. The distance from the center and the different background indicates the date, while the position in the circle the wind direction. Data from forest botanical garden January 2020 - February 2021.