Wave Height Forecasting

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24/06/2021

Introduction

Wave height forecasting plays a crucial role on supporting a country coastal development. Being able to correctly define your coastal conditions allows to correctly define the design parameters to create coastal protection structures such as: - Ports & Harbours - Jetty walls - Breakwaters

And even design some of the most complex and spectacular cities known to man, such as the Palm Jumeirah in Dubai.

The dataset considered for this analysis contains ocean wave information about Valencia, a coastal city in the east of Spain. The Buoy is placed on the Mediterratenan Sea, and the data can be extracted from http://www.puertos.es/en-us/oceanografia/Pages/portus.aspx.

On this project we will conduct an Exploratory Data Analysis (EDA) on the Coastal Data for the Valencia region and build a robust forecasting model on expected Significant (H_s) and Maximum (H_p) wave height, aiming to provide reliable forecasted values for the significant wave height.

Variables

The full description on the features and parameters can be found in the attached file "OPPE_Description.pdf", but given this is supplied by the Public Gov Organism State Ports and it is only supplied in Spanish, we will provide the following variables description,

Variable sample times

The values are aggregated on an hourly basis, however the buoy parameters they are not measured during the entire hour, for instance wind data is measured during a 10 minutes interval every hour, thus even though each hour has an average wind speed data point, this value has been calculated over a 10 minutes period.

Table below details the mean duration for each one of the observed agents:

Agent Observed	Measure Duration
Waves	30Min (Aprox)
Wind Speed	10 Min.
Current Speed	10 Min.
Air Temperature	Instantaneous
Air Preasure	Instantaneous
Water Salinity	Instantaneous
Water Temperature	Instantaneous

Variables description

- Date (GMT): Time Value was recorded at time zone GMT, Greenwich Mean Time
- Source of data: there are three columns and they seem to represent a change in the device being used to record the data, there is no information in the official documentation, but if we build a time series plot we can see how on the 2020-11-25 at 22:00:00 all the sources share the same value 3, and also how the number of missing values on some fields increases when compared to the previous periods.

Waves

- Scalar parameters of zero cross and espectral.
  - Significant Wave Height(m): the average wave height, from trough to crest, of the highest one-third of the waves. This is used to represent the wave height an trained observer will appreciate by simply looking where the wave is crossing (not from the coast).
  - Mean Period Tm02(s): Mean period (as an inverse of the wave length) of the measured waves, usually referred to as T_m
  - Peak Period(s): Period of the wave group with more energy, usually defined as T_p, when the more regular the waves are, the closer the T_p is to the T_m, however T_p is usually larger than T_m
  - Maximum Waves Height(m): Max Wave Height measured
  - Highest Wave Period(s):
- Directional parameters
  - Waves coming-from Direc.(0=N,90=E)
  - Wave coming-from direction(0=N,90=E)
  - Mean comming-from Direc. at Waves Peak(grados): Direction of the waves with largest energy

Meteorology

Measured 3m over the water surface - Atmospheric Pressure(hpa)
- Air Temperature(ºC)
- Wind Speed(m/s)
- Wind coming-from Direction(0=N,90=E) , mean direction of propagation

Oceanography

Measured 3m under the water surface - Sea Temperature(ºC)
- Salinity(Practical Salinity Units, psu), salt concentration (Sodium and Chlorure) in sea water.
- Currents Mean Speed(cm/s), mean speed of the water currents
- Currents propag. Direction(0=N,90=E), mean direction of propagation

Valencia Buoy information

- Longitude 0.20 E
- Latitude 39.51 N
- Data Sampling 60 Min
- Code 2630
- Mooring Depth 260m
- First record date: 2005-09-15
- Last record date: 2021-06-16
- Type of sensor: Directional Met-Oce
- Model: SeaWatch

- Data set: REDEXT

```
# Dimensions
dim(df)
```

```
## [1] 8757   21
```

```
# Structure
str(df)
```

```
## tibble [8,757 x 21] (S3: tbl_df/tbl/data.frame)
##  $ Date..GMT.                                  : POSIXct[1:8757], format: "2020-06-15 00:00:00" "2
##  $ Significant.Wave.Height.m.                  : num [1:8757] 0.62 0.58 0.53 0.44 0.41 0.36 0.31 0
##  $ Mean.Period.Tm02.s.                         : num [1:8757] 3.73 3.65 3.54 3.31 3.03 3 2.91 3.08
##  $ Peak.Period.s.                              : num [1:8757] 4.65 4.33 4.19 4.12 3.82 3.87 4 3.87
##  $ Maximum.Waves.Height.m.                     : num [1:8757] 1.09 0.89 0.85 0.7 0.54 0.54 0.42 0.3
##  $ Highest.Wave.Period.s.                      : num [1:8757] 4.45 4.34 3.99 4.27 4.27 4.7 4.83 4.4
##  $ Source.of.data                              : num [1:8757] 1 1 1 1 1 1 1 1 1 ...
##  $ Waves.coming.from.Direc..0.N.90.E.          : num [1:8757] 163 164 163 170 187 194 184 158 134 1
##  $ Wave.coming.from.direction.0.N.90.E.        : num [1:8757] 174 168 170 168 194 187 174 163 137 1
##  $ Mean.comming.from.Direc..at.Waves.Peak.grados.: num [1:8757] 32 25 34 28 49 46 46 67 50 52 ...
##  $ Source.of.data.1                            : num [1:8757] 1 1 1 1 1 1 1 1 1 ...
##  $ Sea.Temperature.Â°C.                        : num [1:8757] 21.7 21.6 21.6 21.6 21.5 ...
##  $ Salinity.psu.                               : num [1:8757] 37.7 37.7 37.7 37.7 37.7 ...
##  $ Currents.Mean.Speed.cm.s.                   : num [1:8757] 28.9 28.9 30 15.2 15.6 17.5 23 17.1 1
##  $ Currents.propag..Direction.0.N.90.E.        : num [1:8757] 182 187 208 213 233 265 271 309 343 3
##  $ Source.of.data.2                            : num [1:8757] 2 2 2 2 2 2 2 2 2 ...
##  $ Atmospheric.Pressure.hpa.                   : num [1:8757] 1018 1018 1018 1018 1018 ...
##  $ Air.Temperature.Â°C.                        : num [1:8757] 21.6 21.4 21.2 21.6 21.4 ...
##  $ Wind.Speed.m.s.                             : num [1:8757] 2.81 1.17 2.57 4.21 3.75 2.81 3.04 2
##  $ Wind.coming.from.Direction.0.N.90.E.        : num [1:8757] 67 36 326 329 320 315 317 309 300 320
##  $ Source.of.data.3                            : num [1:8757] 2 2 2 2 2 2 2 2 2 ...
```

```
# Summary
print(summary(df))
```

```
##    Date..GMT.                  Significant.Wave.Height.m. Mean.Period.Tm02.s.
##  Min.   :2020-06-15 00:00:00   Min.   :0.1100             Min.   :1.860
##  1st Qu.:2020-09-14 04:45:00   1st Qu.:0.4700             1st Qu.:3.320
##  Median :2020-12-14 14:30:00   Median :0.6600             Median :3.750
##  Mean   :2020-12-14 12:01:52   Mean   :0.7668             Mean   :3.863
##  3rd Qu.:2021-03-15 19:15:00   3rd Qu.:0.9400             3rd Qu.:4.220
##  Max.   :2021-06-15 01:00:00   Max.   :4.2200             Max.   :8.130
##  NA's   :1                     NA's   :68                 NA's   :68
##  Peak.Period.s.   Maximum.Waves.Height.m. Highest.Wave.Period.s.
##  Min.   : 1.750   Min.   :0.190           Min.   : 2.270
##  1st Qu.: 4.000   1st Qu.:0.620           1st Qu.: 3.960
##  Median : 4.920   Median :0.850           Median : 4.450
##  Mean   : 5.311   Mean   :1.044           Mean   : 4.696
##  3rd Qu.: 6.250   3rd Qu.:1.280           3rd Qu.: 5.260
##  Max.   :24.800   Max.   :6.480           Max.   :20.630
##  NA's   :68       NA's   :4833            NA's   :4837
```

```
##  Source.of.data  Waves.coming.from.Direc..0.N.90.E.
##  Min.   :1.000   Min.   :  0.0
##  1st Qu.:1.000   1st Qu.: 67.0
##  Median :3.000   Median :109.0
##  Mean   :2.104   Mean   :124.1
##  3rd Qu.:3.000   3rd Qu.:158.0
##  Max.   :3.000   Max.   :360.0
##                  NA's   :68
##  Wave.coming.from.direction.0.N.90.E.
##  Min.   :  0.0
##  1st Qu.: 66.0
##  Median :106.0
##  Mean   :125.8
##  3rd Qu.:161.0
##  Max.   :359.0
##  NA's   :68
##  Mean.comming.from.Direc..at.Waves.Peak.grados. Source.of.data.1
##  Min.   :14.00                                  Min.   :1.000
##  1st Qu.:28.00                                  1st Qu.:1.000
##  Median :35.00                                  Median :3.000
##  Mean   :36.93                                  Mean   :2.104
##  3rd Qu.:44.00                                  3rd Qu.:3.000
##  Max.   :80.00                                  Max.   :3.000
##  NA's   :4837
##  Sea.Temperature.ÂºC. Salinity.psu.   Currents.Mean.Speed.cm.s.
##  Min.   :13.51       Min.   :37.22   Min.   : 0.00
##  1st Qu.:15.00       1st Qu.:37.81   1st Qu.: 8.60
##  Median :18.57       Median :38.04   Median :13.60
##  Mean   :19.56       Mean   :37.97   Mean   :14.94
##  3rd Qu.:24.64       3rd Qu.:38.16   3rd Qu.:19.50
##  Max.   :28.34       Max.   :38.25   Max.   :64.10
##                                      NA's   :1
##  Currents.propag..Direction.0.N.90.E. Source.of.data.2
##  Min.   :  0.0                        Min.   :2.000
##  1st Qu.: 69.0                        1st Qu.:2.000
##  Median :153.5                        Median :3.000
##  Mean   :161.6                        Mean   :2.551
##  3rd Qu.:246.0                        3rd Qu.:3.000
##  Max.   :359.0                        Max.   :3.000
##  NA's   :1
##  Atmospheric.Pressure.hpa. Air.Temperature.ÂºC. Wind.Speed.m.s.
##  Min.   : 991.4            Min.   :11.09       Min.   : 0.000
##  1st Qu.:1013.6            1st Qu.:17.03       1st Qu.: 2.340
##  Median :1017.2            Median :18.75       Median : 3.980
##  Mean   :1017.2            Mean   :19.12       Mean   : 4.486
##  3rd Qu.:1021.3            3rd Qu.:21.09       3rd Qu.: 6.090
##  Max.   :1036.7            Max.   :26.56       Max.   :17.580
##  NA's   :5                 NA's   :5317        NA's   :81
##  Wind.coming.from.Direction.0.N.90.E. Source.of.data.3
##  Min.   :  0.0                        Min.   :2.000
##  1st Qu.: 64.0                        1st Qu.:2.000
##  Median :151.0                        Median :3.000
##  Mean   :161.3                        Mean   :2.551
##  3rd Qu.:250.0                        3rd Qu.:3.000
```

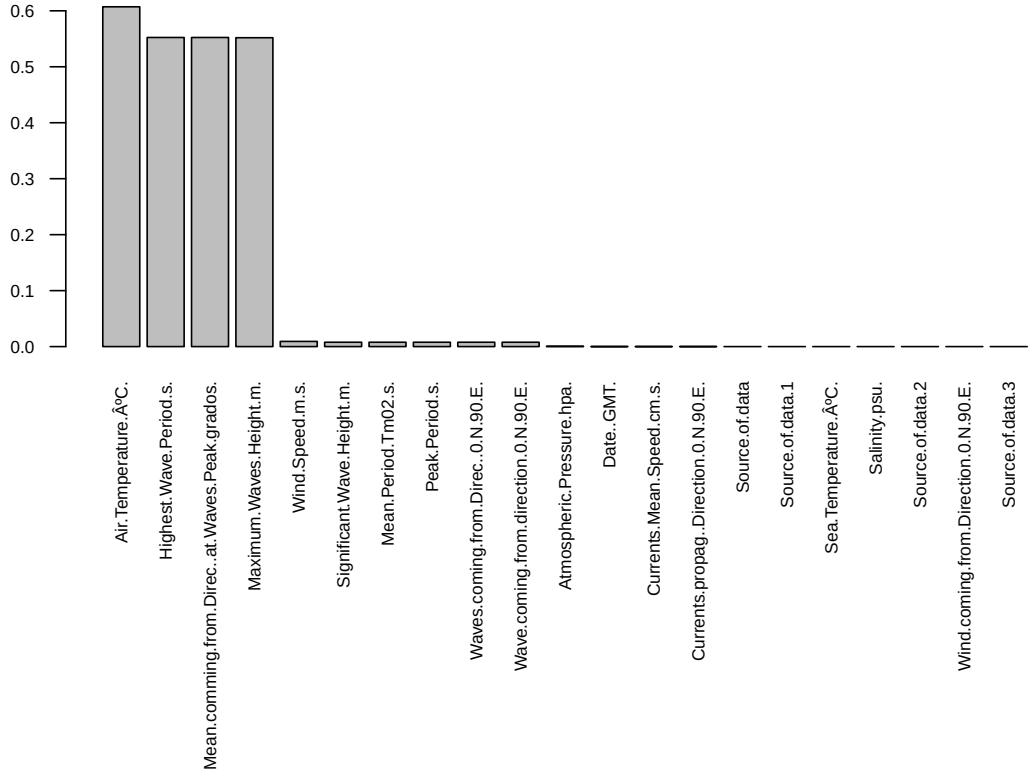
```
##  Max.   :357.0                        Max.   :3.000
##
```

Missing Values

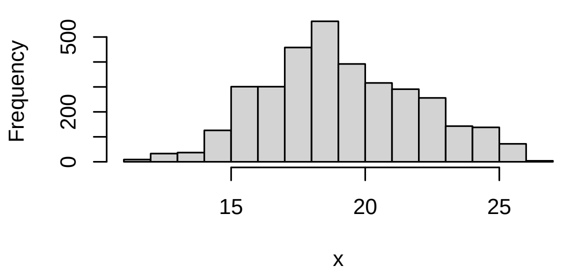
Below we can see the % of null values present in our dataset - Air Temperature(ºC) has 60.02% of its values missing in the considered time period The Highest Wave records present the 55% of their records missing for the considered time period - Highest Wave Period(s) - Mean comming-from Direc. at Waves Peak(grados) - Maximum Waves Height(m)

The remaining variables presenting missing values have a ratio of under 1% meaning we could probably exclude them and still have a good enough sample size to model. For the other 4 variables presenting high levels of missing values we will study them independently and assess what is the best or more reasonable missing values strategy.

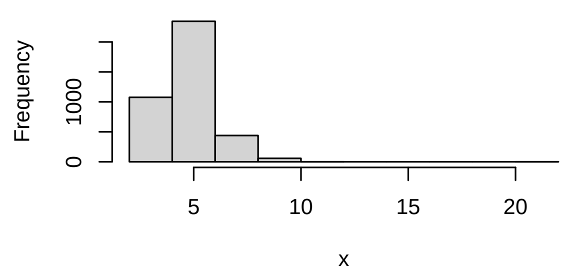
```
##  [1] "Air.Temperature.ÂºC."
##  [2] "Highest.Wave.Period.s."
##  [3] "Mean.comming.from.Direc..at.Waves.Peak.grados."
##  [4] "Maximum.Waves.Height.m."
##  [5] "Wind.Speed.m.s."
##  [6] "Significant.Wave.Height.m."
##  [7] "Mean.Period.Tm02.s."
##  [8] "Peak.Period.s."
##  [9] "Waves.coming.from.Direc..0.N.90.E."
## [10] "Wave.coming.from.direction.0.N.90.E."
## [11] "Atmospheric.Pressure.hpa."
## [12] "Date..GMT."
## [13] "Currents.Mean.Speed.cm.s."
## [14] "Currents.propag..Direction.0.N.90.E."
## [15] "Source.of.data"
## [16] "Source.of.data.1"
## [17] "Sea.Temperature.ÂºC."
## [18] "Salinity.psu."
## [19] "Source.of.data.2"
## [20] "Wind.coming.from.Direction.0.N.90.E."
## [21] "Source.of.data.3"
```


0.6
0.5
0.4
0.3
0.2
0.1
0.0
Air.Temperature.ÂºC.
Highest.Wave.Period.s.
Mean.comming.from.Direc..at.Waves.Peak.grados.
Maximum.Waves.Height.m.
Wind.Speed.m.s.
Significant.Wave.Height.m.
Mean.Period.Tm02.s.
Peak.Period.s.
Waves.coming.from.Direc..0.N.90.E.
Wave.coming.from.direction.0.N.90.E.
Atmospheric.Pressure.hpa.
Date..GMT.
Currents.Mean.Speed.cm.s.
Currents.propag..Direction.0.N.90.E.
Source.of.data
Source.of.data.1
Sea.Temperature.ÂºC.
Salinity.psu.
Source.of.data.2
Wind.coming.from.Direction.0.N.90.E.
Source.of.data.3

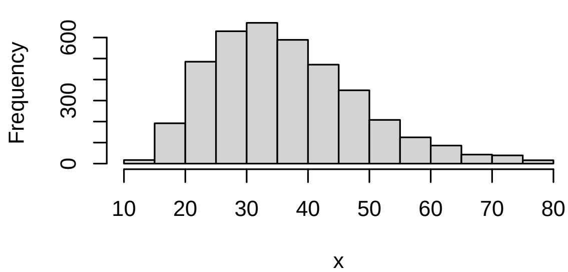
Histogram Air.Temperature.Â°C.



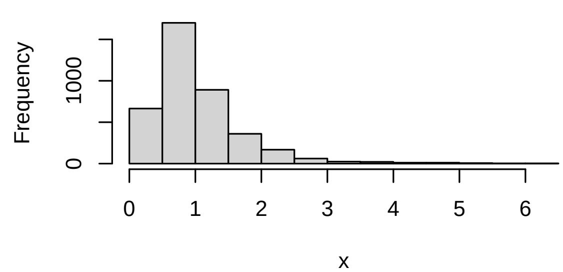
Histogram Highest.Wave.Period.s.



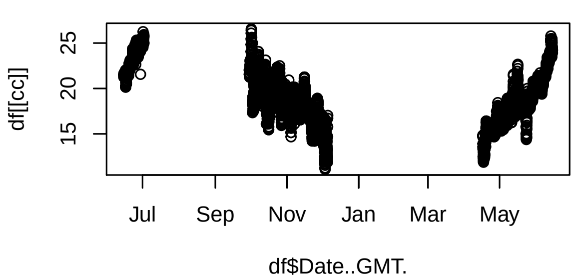
togram Mean.comming.from.Direc..at.Waves.Peak.



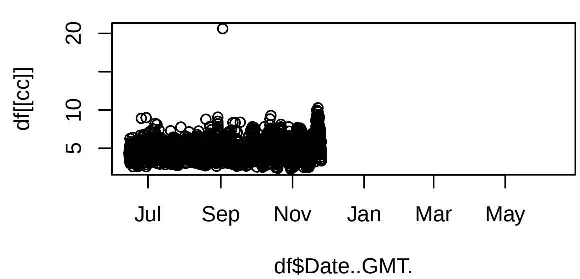
Histogram Maximum.Waves.Height.m.



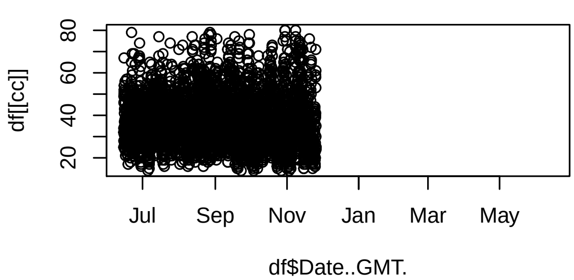
Time series Air.Temperature.Â°C.



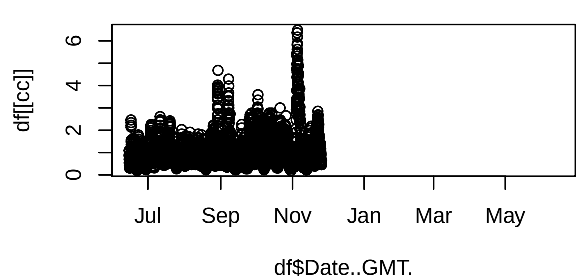
Time series Highest.Wave.Period.s.



e series Mean.comming.from.Direc..at.Waves.Peak.



Time series Maximum.Waves.Height.m.



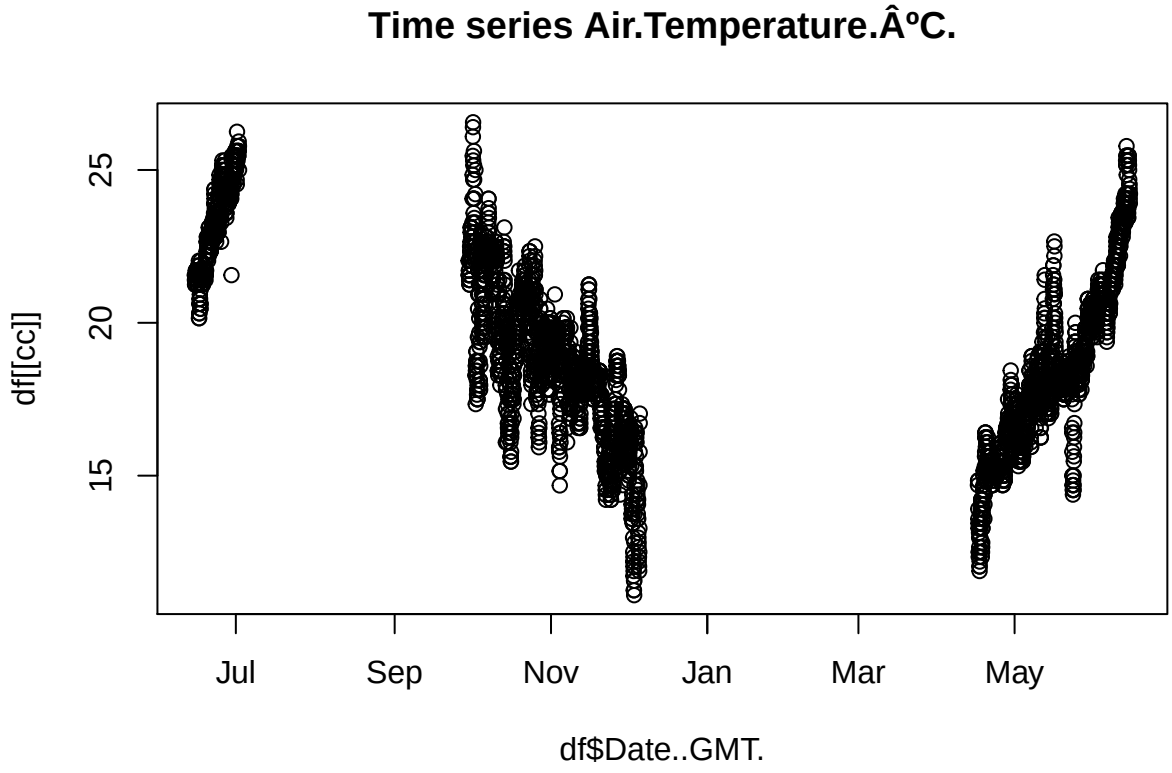

```
## # A tibble: 4 x 5
##   name                                                    mean     sd   skw   kurt
##   <chr>                                                  <dbl>  <dbl> <dbl>  <dbl>
```

```
## 1 Air.Temperature.Â°C.                              19.1   2.86  0.175 -0.446
## 2 Highest.Wave.Period.s.                            4.70  1.16  1.70  10.5
## 3 Mean.comming.from.Direc..at.Waves.Peak.grados. 36.9  12.1   0.733  0.367
## 4 Maximum.Waves.Height.m.                           1.04  0.694 2.52  10.1
```

After exploring the, probabilistic distributions one could argue most of them are right skewed except for the Air Temperature which is the one which presenst a closets similarity to a normal distribution (Skewness= 0.17, Kurt = -0.44). But given this is a time series, it might be possible to fit it to a trend function, so let's explore them from a time series perspective.

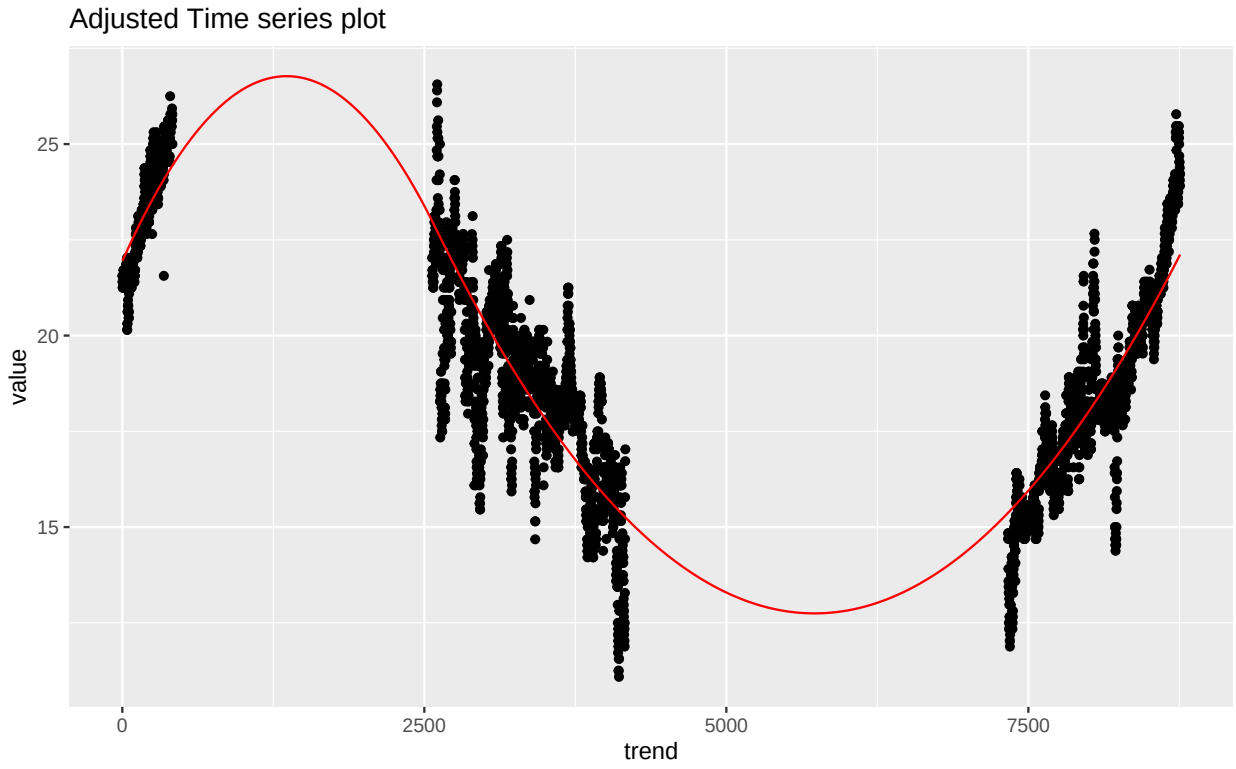
Air Temperature

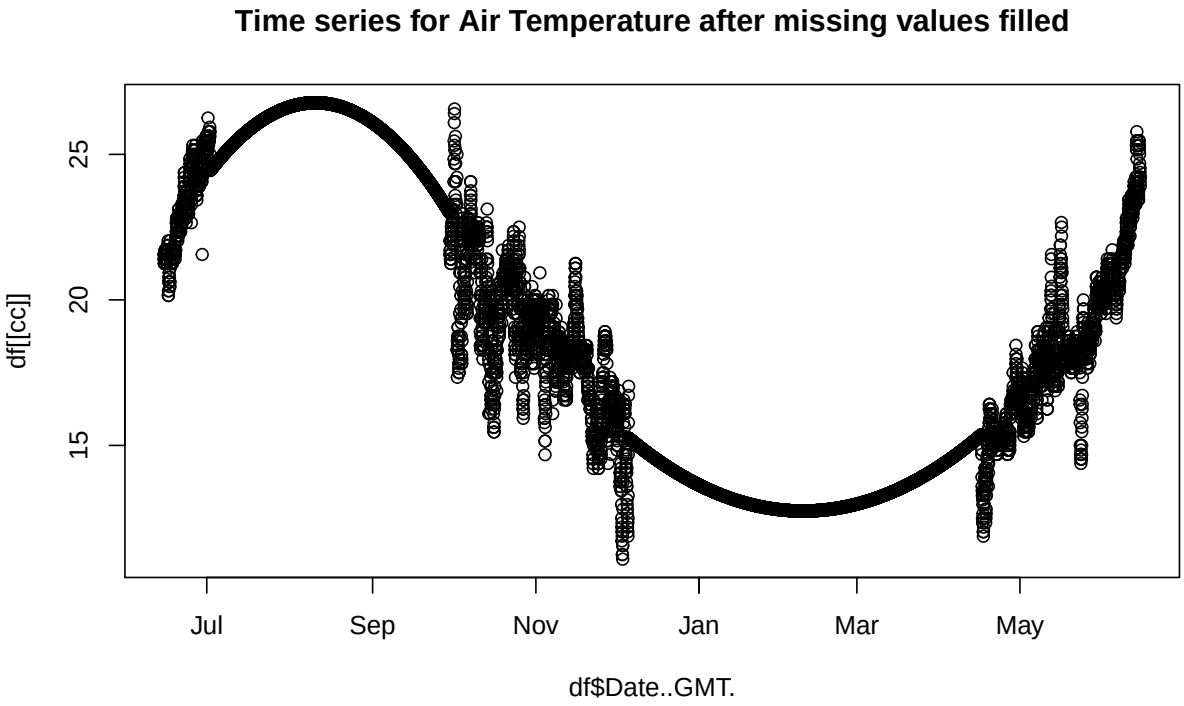
The variable seems to be following a cyclic pattern, which would make sense, the air temperature would be expected to be higher during the summer periods and lower during the winter, plot below shows how we have the trend points for the series, we have the initial increment from June 2020, then around October it starts to show a downward trend and after May it starts to pick up again.




```
## Warning: Removed 5317 rows containing missing values (geom_point).
```

```
## Warning: Removed 1 row(s) containing missing values (geom_path).
```


Adjusted Time series plot
value
25
20
15
0
2500
5000
7500
trend

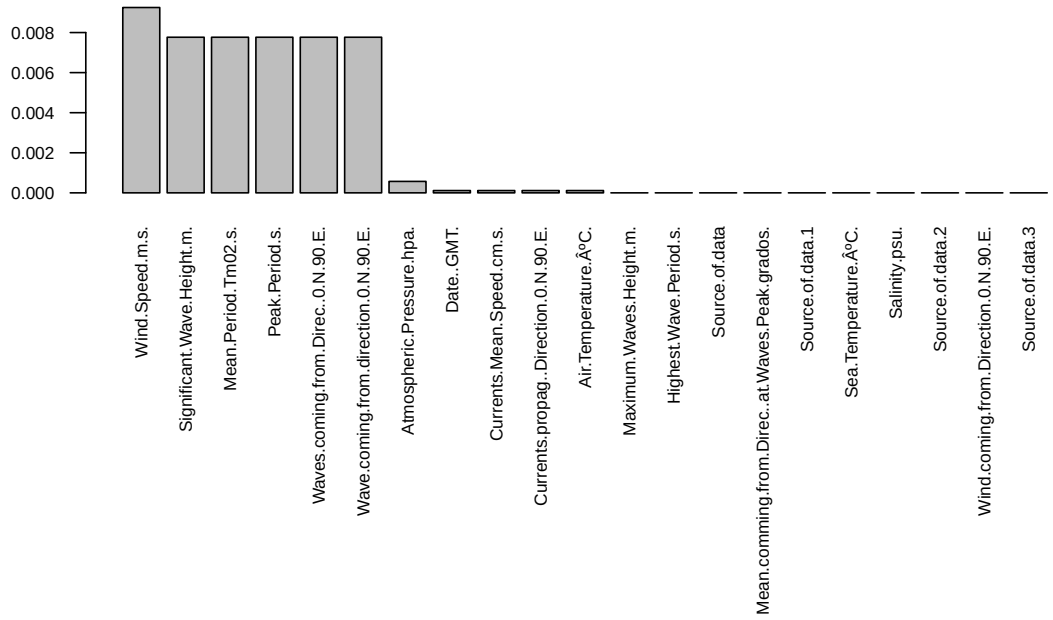

Time series for Air Temperature after missing values filled
df[[cc]]
25
20
15
Jul
Sep
Nov
Jan
Mar
May
df$Date..GMT.

Other three columns

The variables Highest Wave Period(s), Mean comming-from Direc. at Waves Peak(grados) and Maximum Waves Height(m) do not present any obvious overarching trend, therefore we will use the mean value to fill the missing values.

Remaining missing values

Given they represent less than 1% of the total values, we will use the mean value for all of them and drop all the records for the missing values of **"Significant Wave Height(m)"**, given this is our target value.



Analysing target variable

When plotting the variable it is quite obvious it is a time series which presents several levels of seasonality, the usual levels of seasonality experience by the sea state can be found in several nautical bibliography books, but as a rule of thumb waves in the ocean present at the very least the following levels of seasonality: - Every 12hrs - Daily (Mon to Sun) - Moon Cycles (every 28 days) - YearSeasons, which we will model with the per month indicator

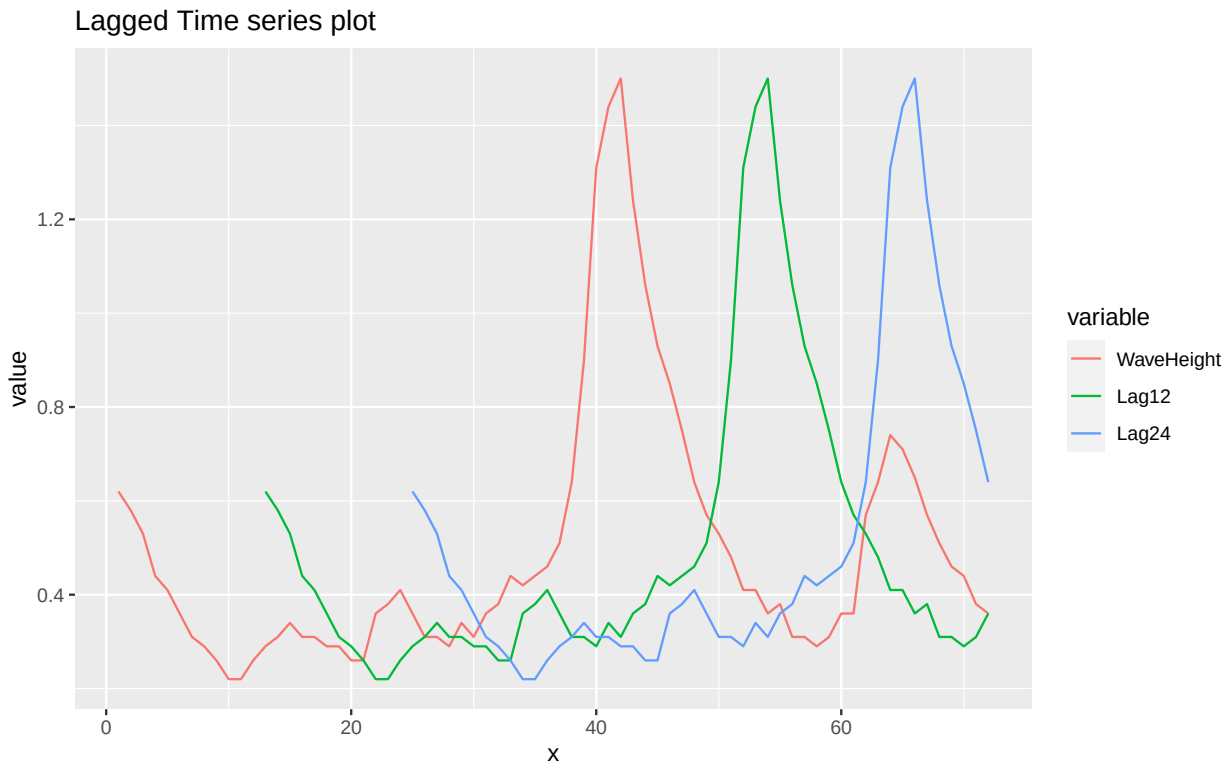
If we had longer tailed data spanning over several years we might be able to identify further seasonal information periods, but given our dataset spans for the lenght of 1 year, we will focus on the most frequently identifiable seasonal events a wave time series might experience over the course of a year.

Which means we will add those levels of information to our dataset to highlight those events

```
## Warning in melt(., id = c("x")): The melt generic in data.table has been passed
## a data.frame and will attempt to redirect to the relevant reshape2 method;
```

```
## please note that reshape2 is deprecated, and this redirection is now deprecated
## as well. To continue using melt methods from reshape2 while both libraries are
## attached, e.g. melt.list, you can prepend the namespace like reshape2::melt(.).
## In the next version, this warning will become an error.

## Warning: Removed 36 row(s) containing missing values (geom_path).
```




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

##
## Attaching package: 'mltools'

## The following object is masked from 'package:e1071':
##
##     skewness

## The following object is masked from 'package:tidyr':
##
##     replace_na
```

Model selection and cross validation

From a purest perspective, this is a time series forecasting model, whereby we aim to predict the wave height based on some seasonality and trend, however, what we've also got are some measurements of the sea state: Water Temperature, Salinity, Wind speed, Wave direction, which we could use to help improve our model and move away from a time series forecasting model towards a multivariate regression model.

Given we've got no baseline for our model we will build a baseline model which will consist mainly of the average:

$$\hat{y} \approx \bar{y}$$

And use it as the baseline to beat.

As output measures to consider model performance we will use two metrics: - Root mean square error

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} e_i^2}{n}}$$

- Mean absolute error

$$\text{MAE} = \frac{\sum_{i=1}^{n} |e_i|}{n}$$