PM2.5 Forecasting

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Load data

```
# Explanations for each variable
# No: row number
# year: year of data in this row
# month: month of data in this row
# day: day of data in this row
# hour: hour of data in this row
# pm2.5: PM2.5 concentration (ug/m^3)
# DEWP: Dew Point (°F)
# TEMP: Temperature (°F)
# PRES: Pressure (hPa)
# cbwd: Combined wind direction
# Iws: Cumulated wind speed (m/s)
# Is: Cumulated hours of snow
# Ir: Cumulated hours of rain
#create new data frame
setwd(datadir)
prsa <- read.csv('PRSA_data_2010.1.1-2014.12.31.csv', row.names = 1, colClasses = c("pm2.5"=
"numeric","DEWP"="numeric"))
summary(prsa)
```

```
##       year          month             day             hour      
##  Min.   :2010   Min.   : 1.000   Min.   : 1.00   Min.   : 0.00  
##  1st Qu.:2011   1st Qu.: 4.000   1st Qu.: 8.00   1st Qu.: 5.75  
##  Median :2012   Median : 7.000   Median :16.00   Median :11.50  
##  Mean   :2012   Mean   : 6.524   Mean   :15.73   Mean   :11.50  
##  3rd Qu.:2013   3rd Qu.:10.000   3rd Qu.:23.00   3rd Qu.:17.25  
##  Max.   :2014   Max.   :12.000   Max.   :31.00   Max.   :23.00  
##                                                                 
##      pm2.5             DEWP              TEMP             PRES     
##  Min.   :  0.00   Min.   :-40.000   Min.   :-19.00   Min.   : 991  
##  1st Qu.: 29.00   1st Qu.:-10.000   1st Qu.:  2.00   1st Qu.:1008  
##  Median : 72.00   Median :  2.000   Median : 14.00   Median :1016  
##  Mean   : 98.61   Mean   :  1.817   Mean   : 12.45   Mean   :1016  
##  3rd Qu.:137.00   3rd Qu.: 15.000   3rd Qu.: 23.00   3rd Qu.:1025  
##  Max.   :994.00   Max.   : 28.000   Max.   : 42.00   Max.   :1046  
##  NA's   :2067                                                      
##  cbwd            Iws               Is                 Ir         
##  cv: 9387   Min.   :  0.45   Min.   : 0.00000   Min.   : 0.0000  
##  NE: 4997   1st Qu.:  1.79   1st Qu.: 0.00000   1st Qu.: 0.0000  
##  NW:14150   Median :  5.37   Median : 0.00000   Median : 0.0000  
##  SE:15290   Mean   : 23.89   Mean   : 0.05273   Mean   : 0.1949  
##             3rd Qu.: 21.91   3rd Qu.: 0.00000   3rd Qu.: 0.0000  
##             Max.   :585.60   Max.   :27.00000   Max.   :36.0000  
## 
```

Change “cv”" in cbwd to “SW”

```
levels(prsa$cbwd)[1] <- "SW"
# sort it to NE, NW, SE, SW
prsa$cbwd <- factor(prsa$cbwd, levels = c("NE", "NW", "SE", "SW"))
summary(prsa$cbwd)
```

```
##    NE    NW    SE    SW
##  4997 14150 15290  9387
```

Create datetime from year, month, day and hour

Sort the dataframe by datetime

```
prsa <- prsa %>%
  mutate(date = make_date(year, month, day),
         datetime = make_datetime(year, month, day, hour)) %>%
  arrange(datetime)
summary(prsa)
```

```
##       year          month             day             hour      
##  Min.   :2010   Min.   : 1.000   Min.   : 1.00   Min.   : 0.00  
##  1st Qu.:2011   1st Qu.: 4.000   1st Qu.: 8.00   1st Qu.: 5.75  
##  Median :2012   Median : 7.000   Median :16.00   Median :11.50  
##  Mean   :2012   Mean   : 6.524   Mean   :15.73   Mean   :11.50  
##  3rd Qu.:2013   3rd Qu.:10.000   3rd Qu.:23.00   3rd Qu.:17.25  
##  Max.   :2014   Max.   :12.000   Max.   :31.00   Max.   :23.00  
##                                                                 
##      pm2.5             DEWP              TEMP             PRES     
##  Min.   :  0.00   Min.   :-40.000   Min.   :-19.00   Min.   : 991  
##  1st Qu.: 29.00   1st Qu.:-10.000   1st Qu.:  2.00   1st Qu.:1008  
##  Median : 72.00   Median :  2.000   Median : 14.00   Median :1016  
##  Mean   : 98.61   Mean   :  1.817   Mean   : 12.45   Mean   :1016  
##  3rd Qu.:137.00   3rd Qu.: 15.000   3rd Qu.: 23.00   3rd Qu.:1025  
##  Max.   :994.00   Max.   : 28.000   Max.   : 42.00   Max.   :1046  
##  NA's   :2067                                                      
##  cbwd            Iws               Is                 Ir         
##  NE: 4997   Min.   :  0.45   Min.   : 0.00000   Min.   : 0.0000  
##  NW:14150   1st Qu.:  1.79   1st Qu.: 0.00000   1st Qu.: 0.0000  
##  SE:15290   Median :  5.37   Median : 0.00000   Median : 0.0000  
##  SW: 9387   Mean   : 23.89   Mean   : 0.05273   Mean   : 0.1949  
##             3rd Qu.: 21.91   3rd Qu.: 0.00000   3rd Qu.: 0.0000  
##             Max.   :585.60   Max.   :27.00000   Max.   :36.0000  
##                                                                  
##       date               datetime                  
##  Min.   :2010-01-01   Min.   :2010-01-01 00:00:00  
##  1st Qu.:2011-04-02   1st Qu.:2011-04-02 11:45:00  
##  Median :2012-07-01   Median :2012-07-01 23:30:00  
##  Mean   :2012-07-01   Mean   :2012-07-01 23:30:00  
##  3rd Qu.:2013-10-01   3rd Qu.:2013-10-01 11:15:00  
##  Max.   :2014-12-31   Max.   :2014-12-31 23:00:00  
## 
```

Plot the distribution of each variable

```
which(colnames(prsa) == "pm2.5")
```

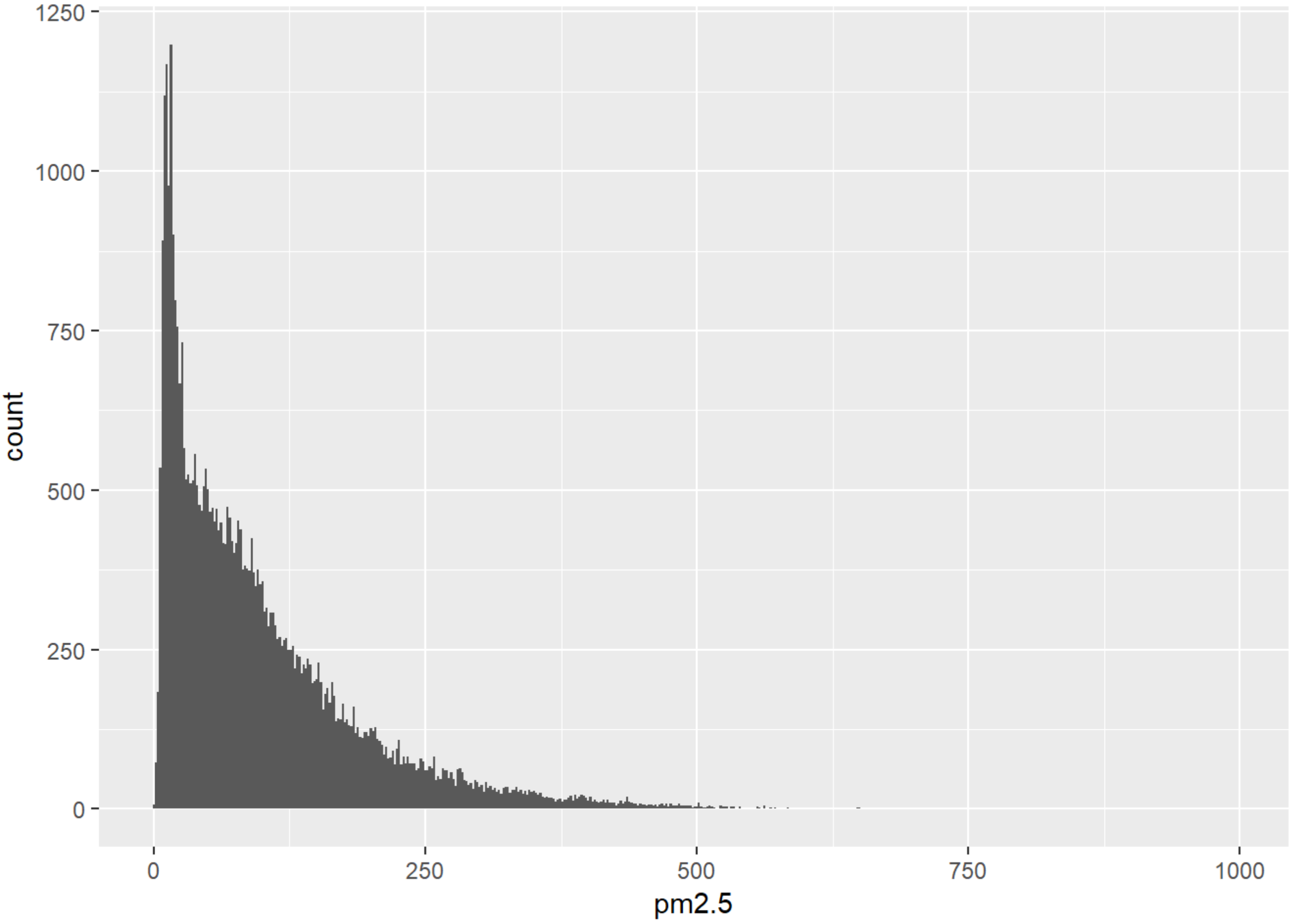
```
## [1] 5
```

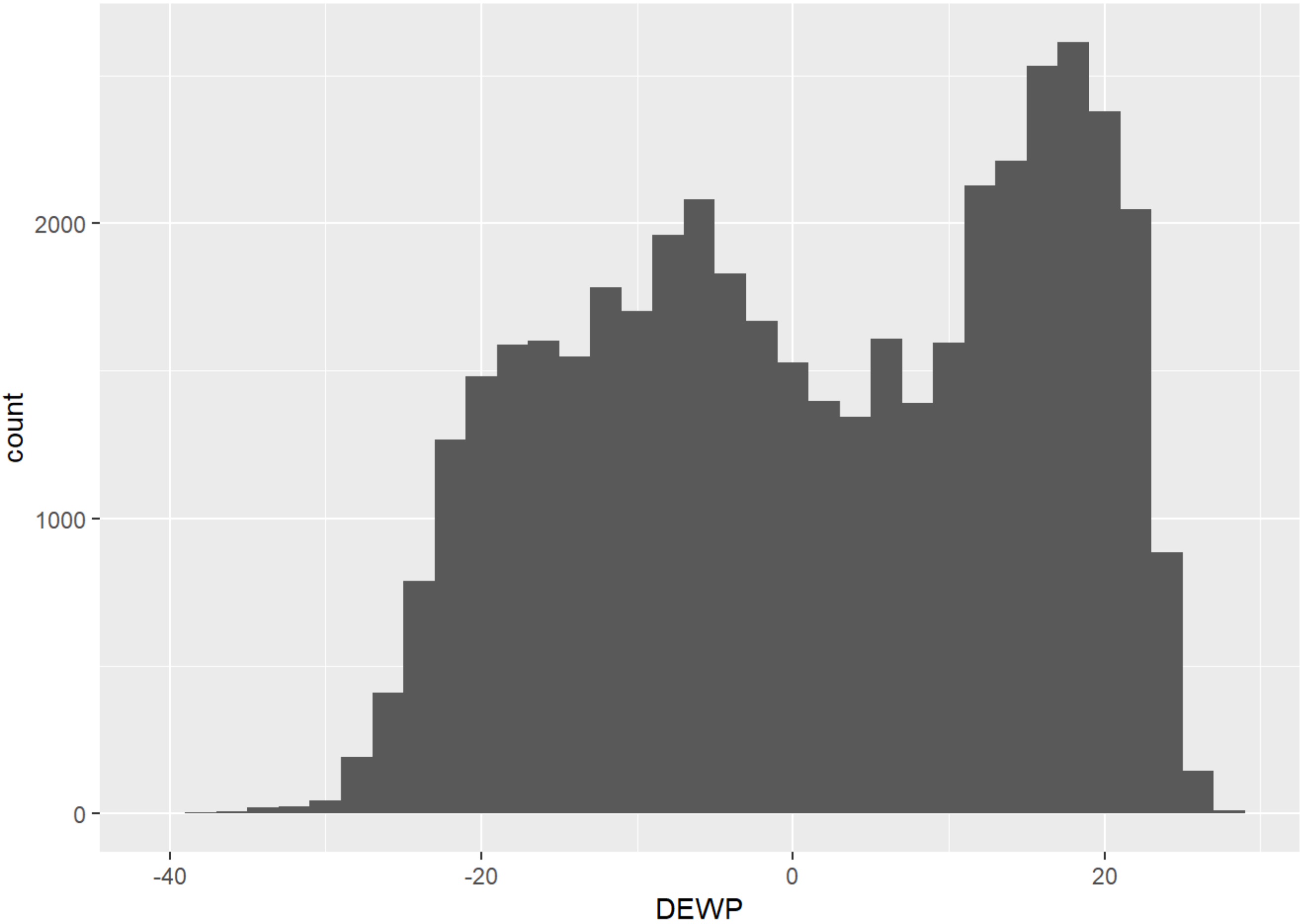
```
which(colnames(prsa) == "Ir")
```

```
## [1] 12
```

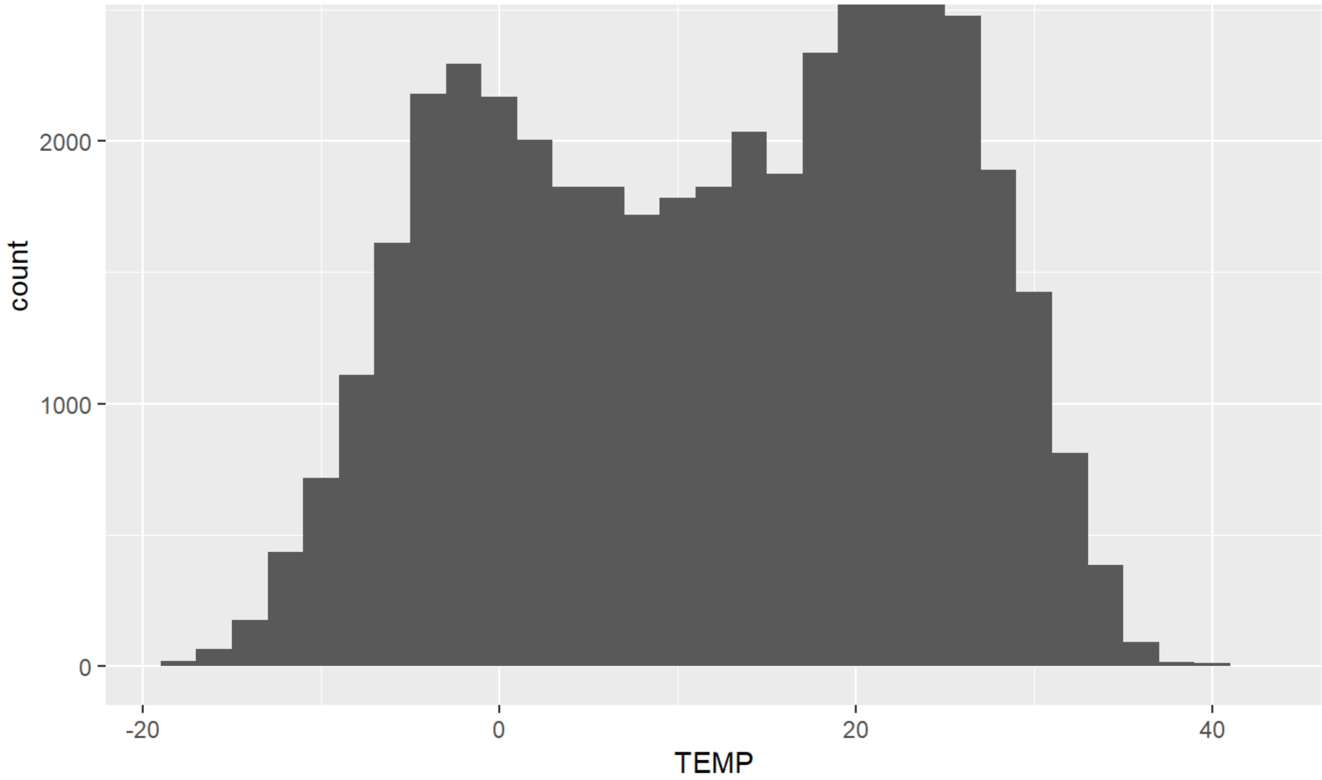
```
for(i in 5:12) {
  if(is.factor(prsa[,i])) {
    print(ggplot(prsa, aes(prsa[, i])) +
            geom_histogram(stat = "count") +
            xlab(colnames(prsa)[i]))
  }
  else {
    print(ggplot(prsa, aes(prsa[, i])) +
            geom_histogram(binwidth = 2) +
            xlab(colnames(prsa)[i]))
  }
}
```

```
## Warning: Removed 2067 rows containing non-finite values (stat_bin).
```

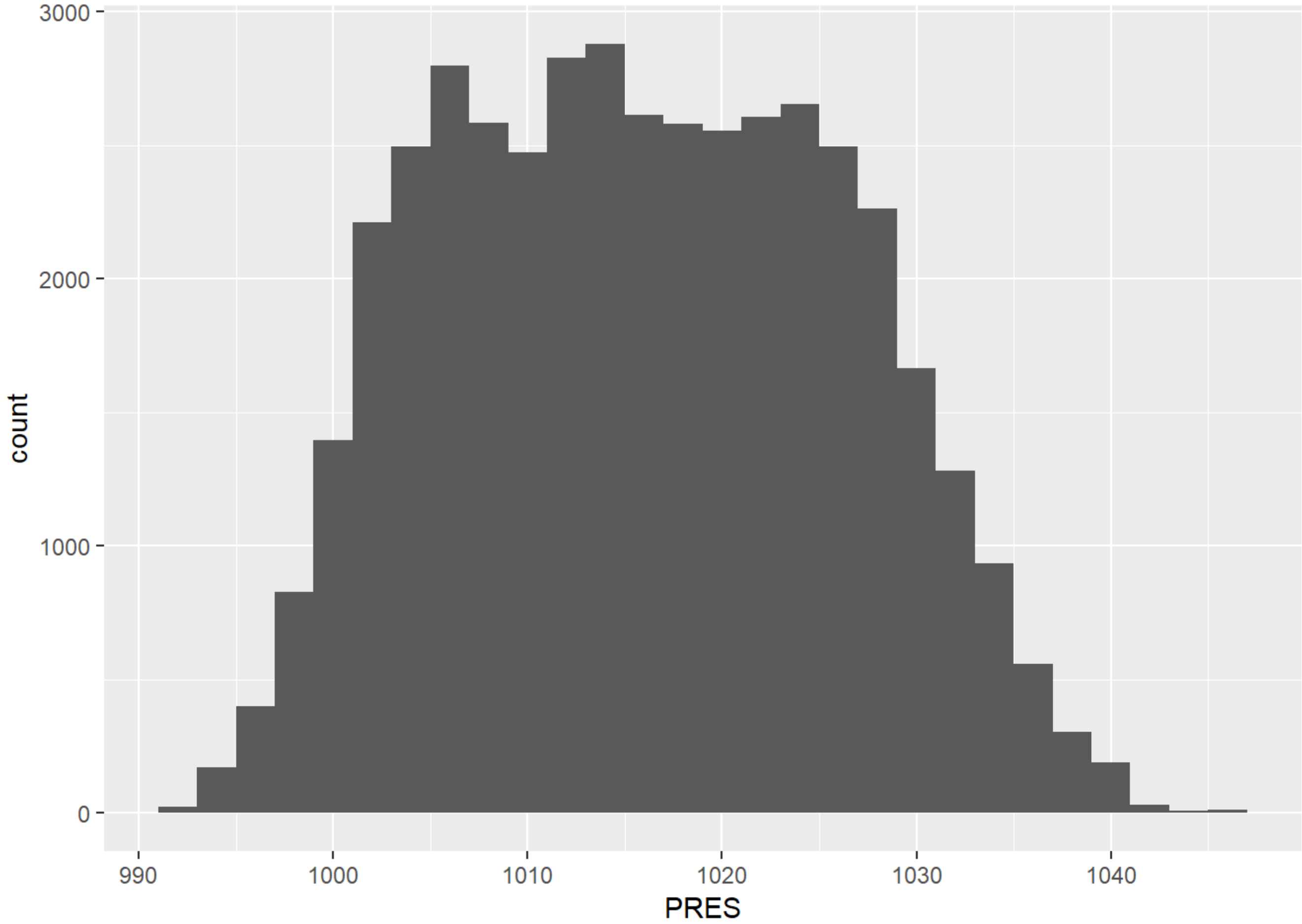

1250
1000
750
500
250
0
count
0
250
500
750
1000
pm2.5

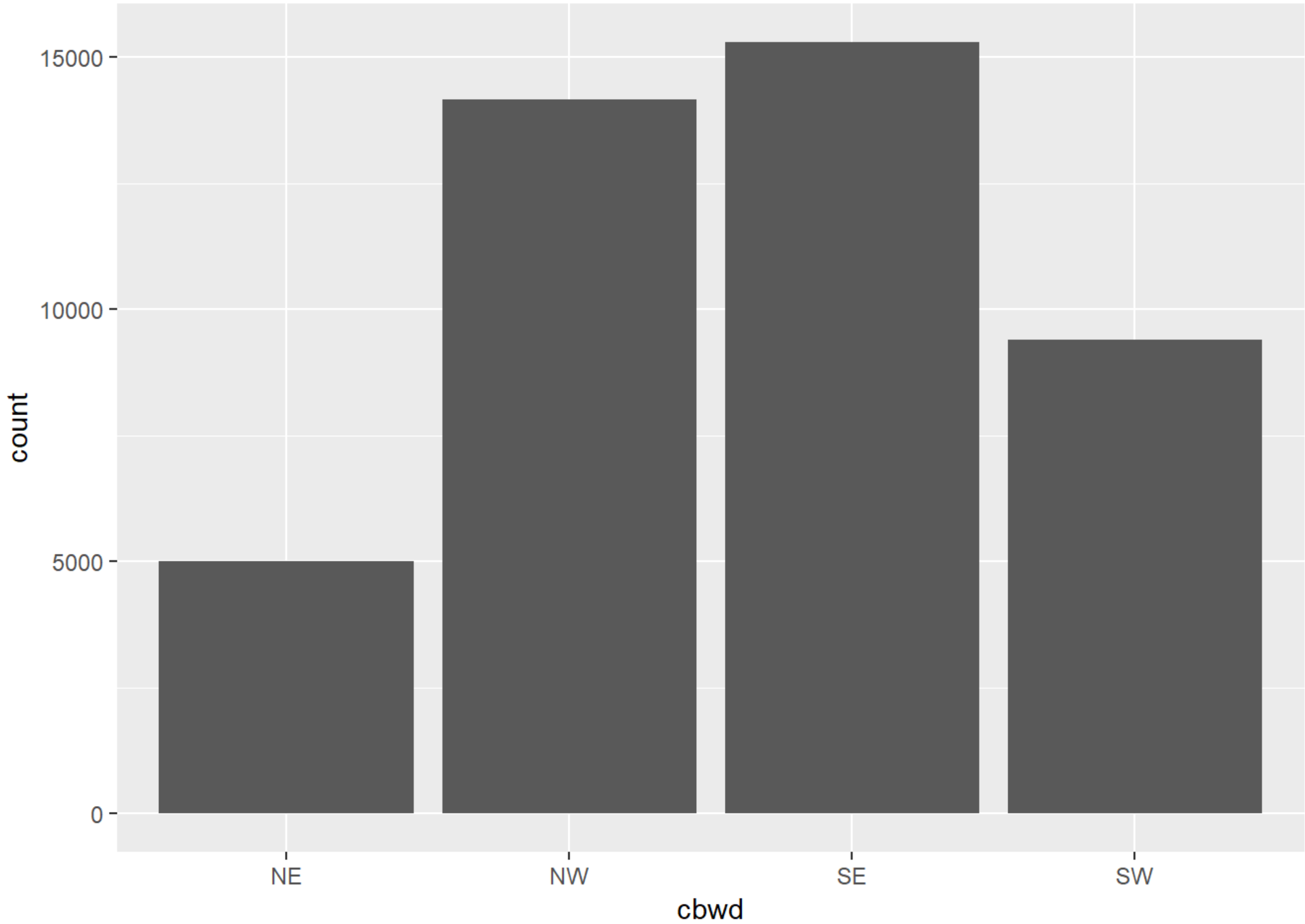

2000
1000
0
count
-40
-20
0
20
DEWP

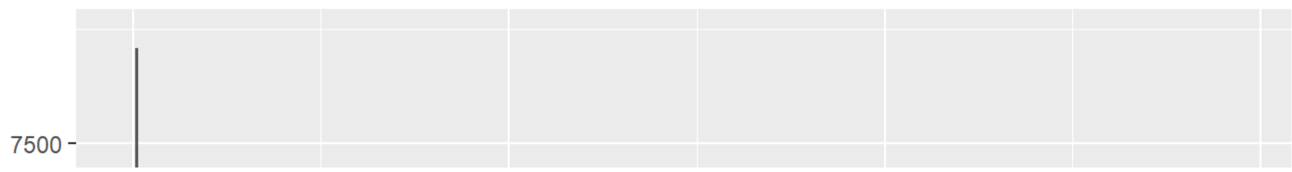

3000

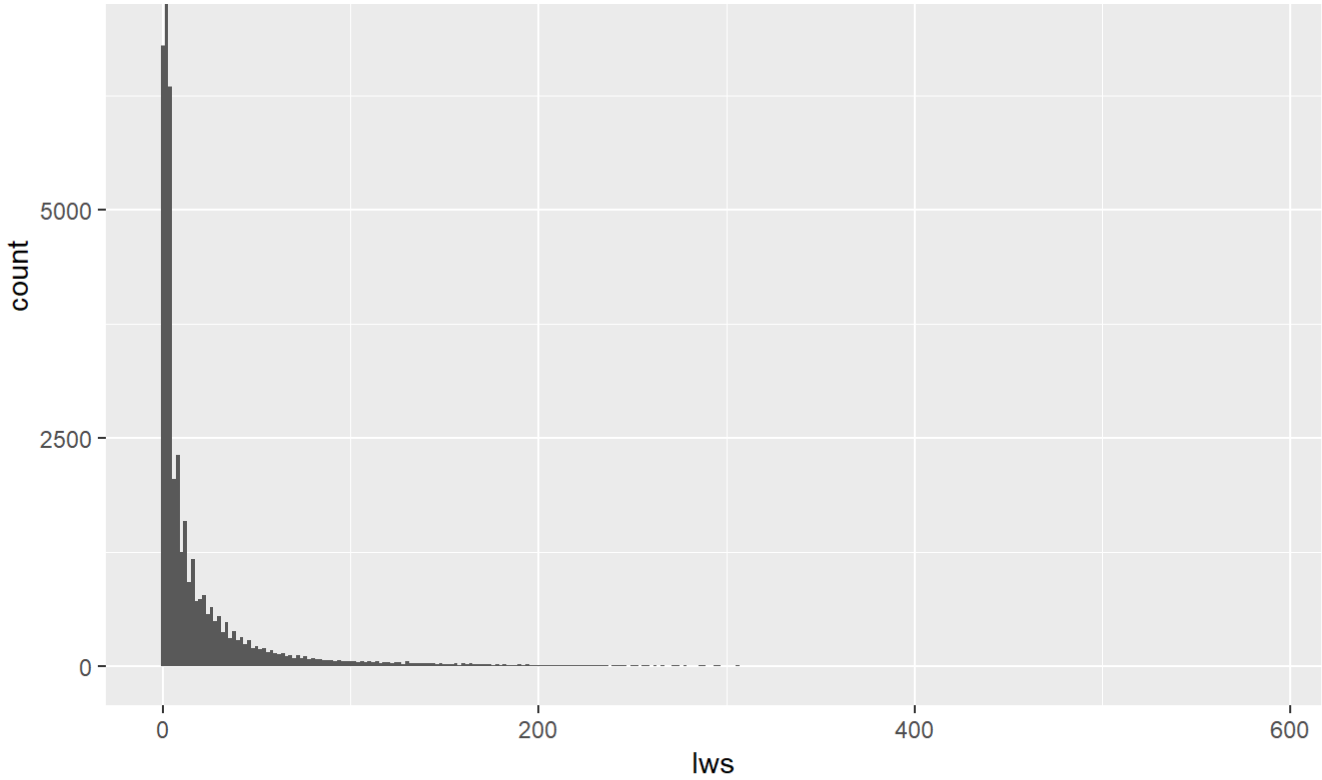


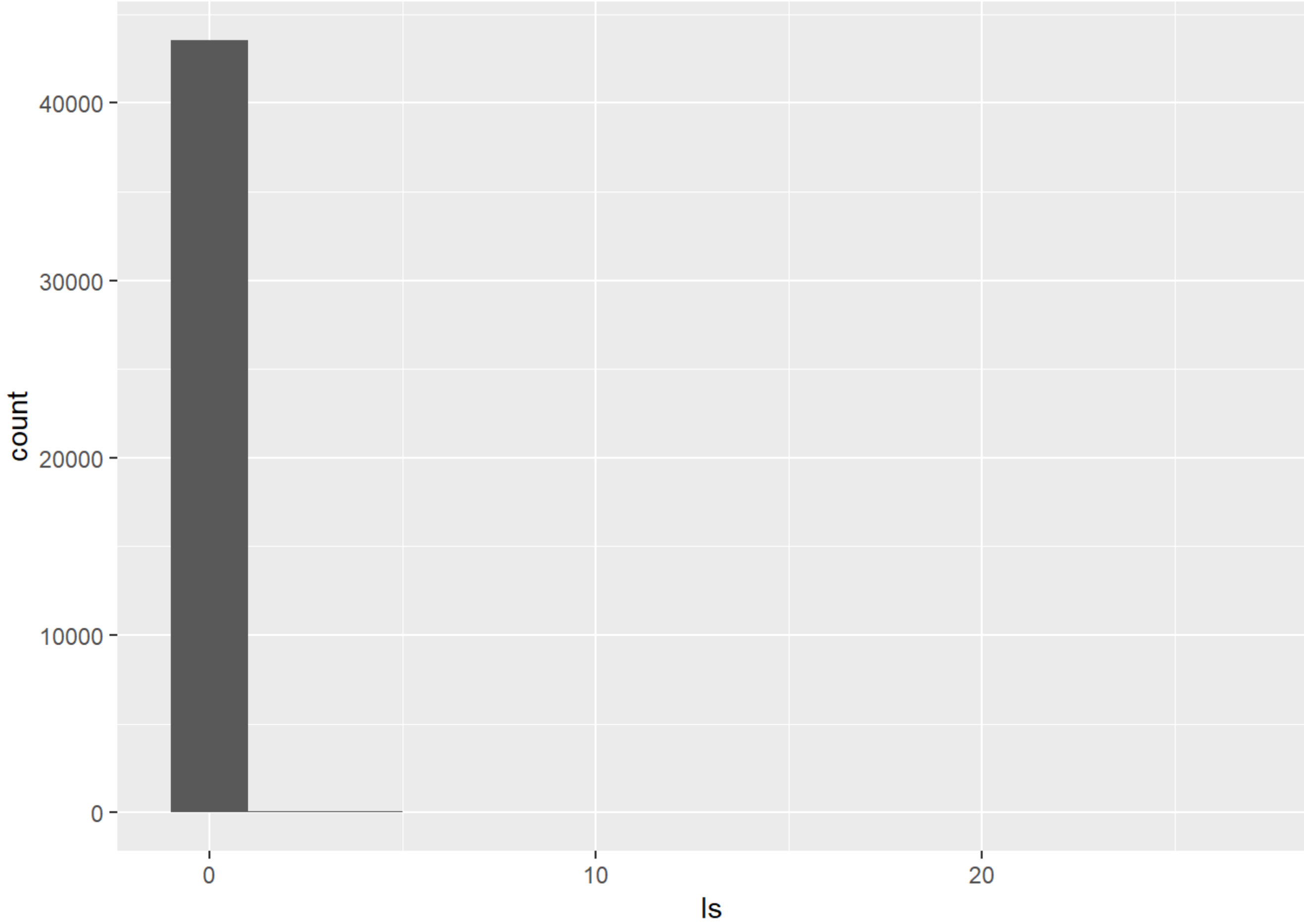

```
## Warning: Ignoring unknown parameters: binwidth, bins, pad
```

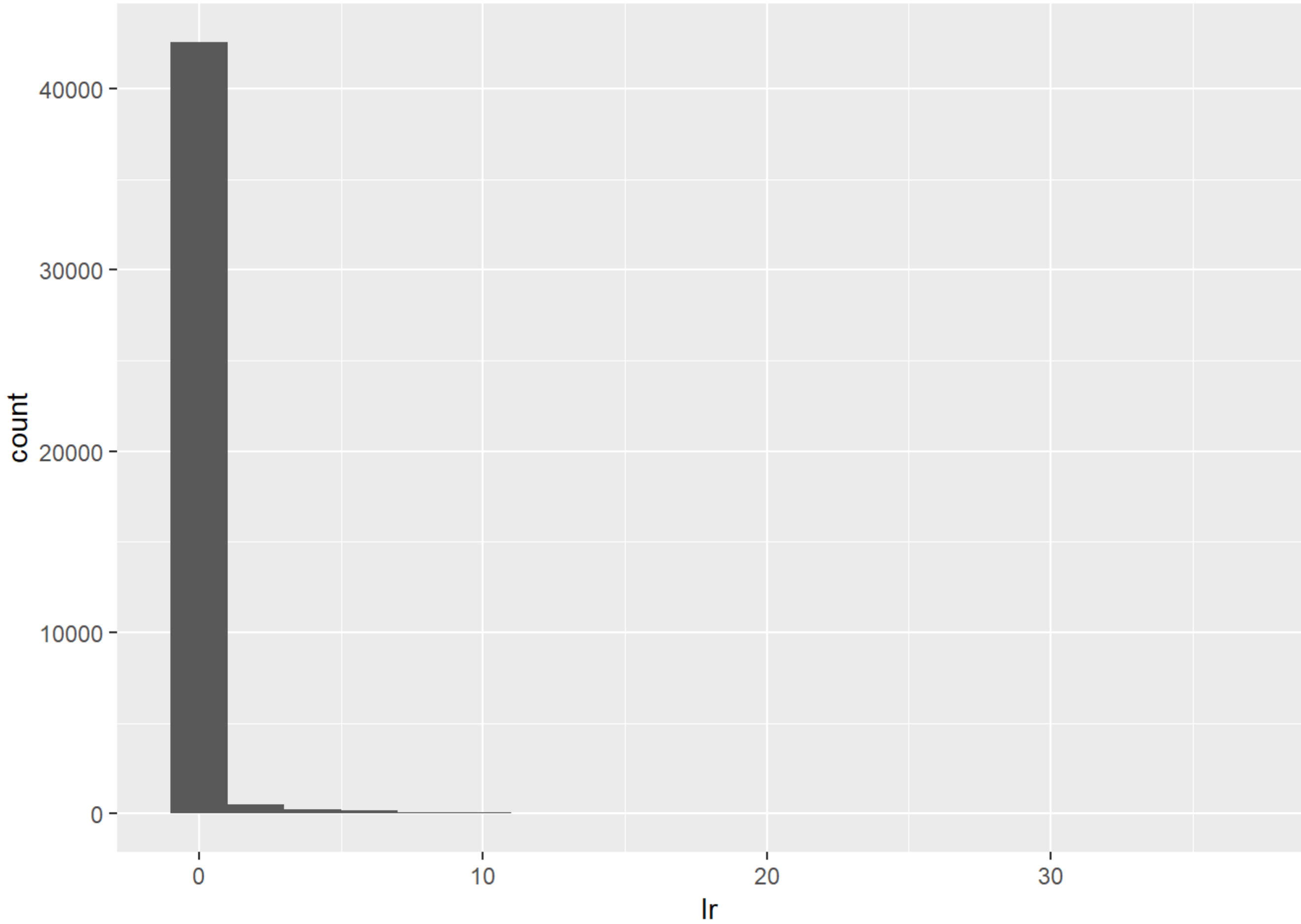

3000
2000
1000
0
count
990
1000
1010
1020
1030
1040
PRES


15000
10000
5000
0
count
NE
NW
SE
SW
cbwd


7500


count
5000
2500
0
0
200
400
600
lws


count
40000
30000
20000
10000
0
0
10
20
ls

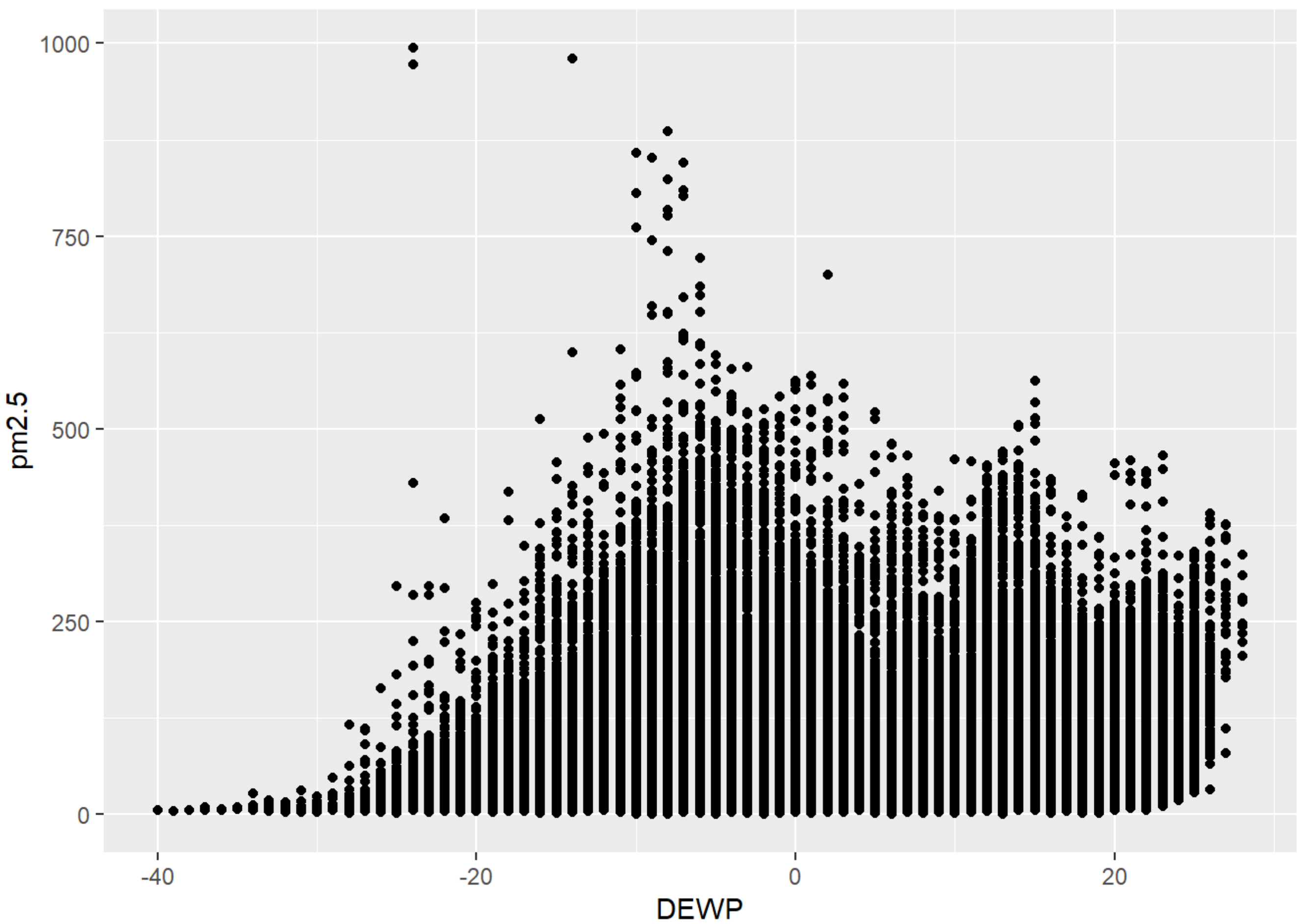

count
40000
30000
20000
10000
0
0
10
20
30
lr

Correlations between pm2.5 and other variables

```
for(i in 6:12) {
  if(!is.factor(prsa[,i])) {
    print(paste("pm2.5 & ", colnames(prsa)[i], sep = ""))
    print(cor(prsa$pm2.5, prsa[, i], use = "complete.obs"))
    print(ggplot(prsa, aes(prsa[,i], pm2.5)) +
            geom_point() +
            xlab(colnames(prsa)[i]))
  }
  else {
    print(ggplot(prsa, aes(prsa[,i], pm2.5)) +
            geom_boxplot() +
            xlab(colnames(prsa)[i]))
  }
}
```

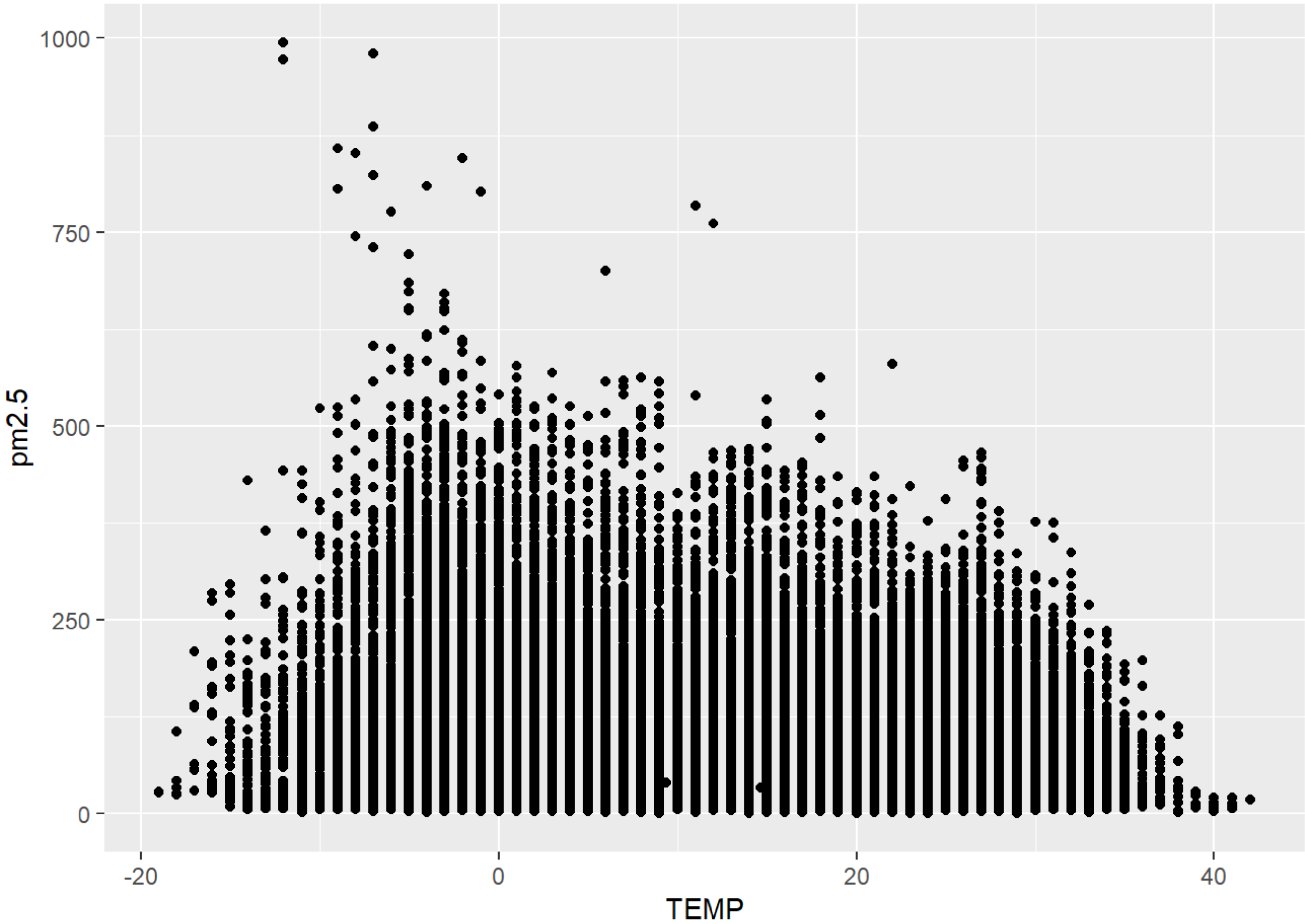
```
## [1] "pm2.5 & DEWP"
## [1] 0.1714233
```

```
## Warning: Removed 2067 rows containing missing values (geom_point).
```



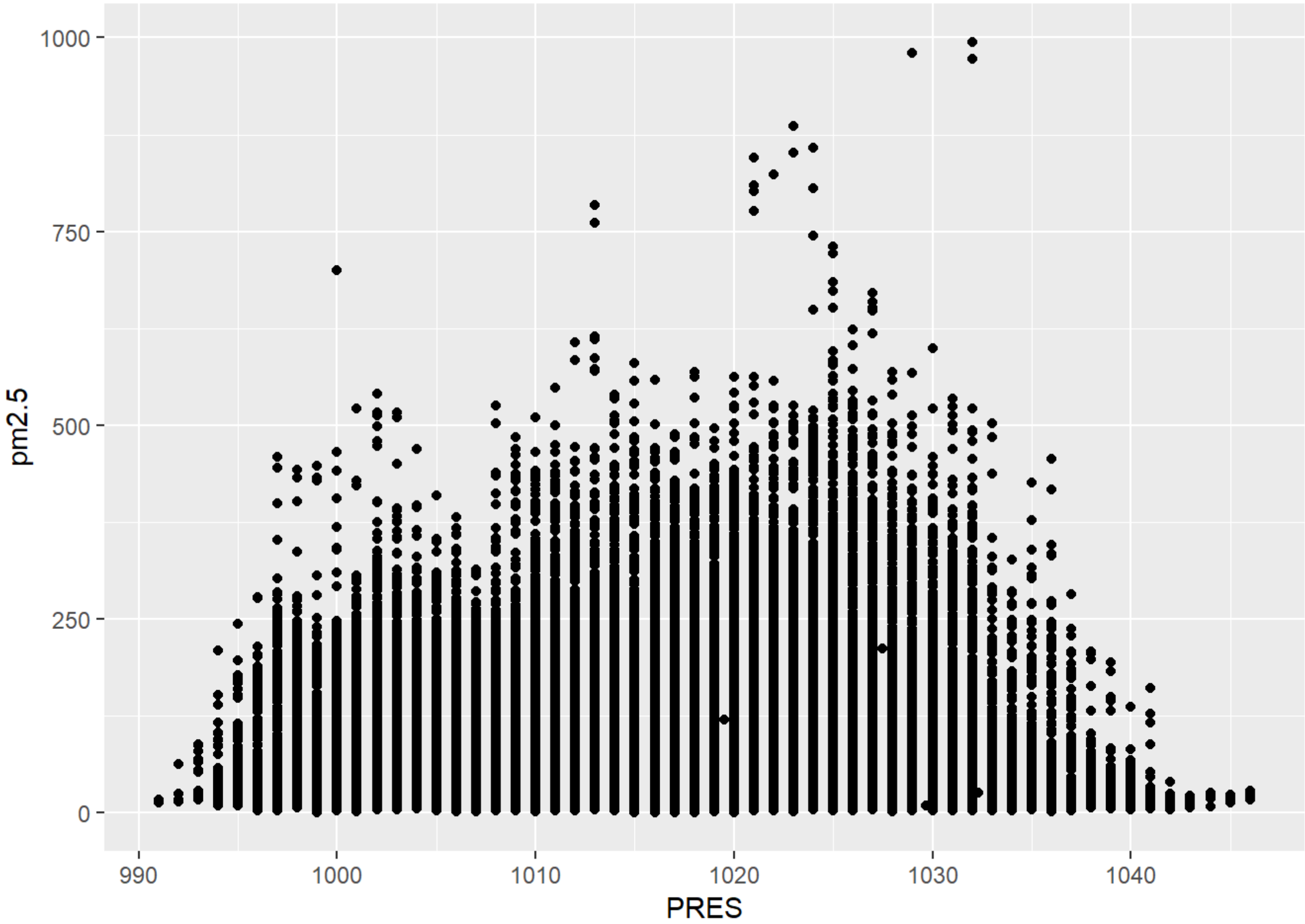

```
## [1] "pm2.5 & TEMP"
## [1] -0.090534
```

```
## Warning: Removed 2067 rows containing missing values (geom_point).
```

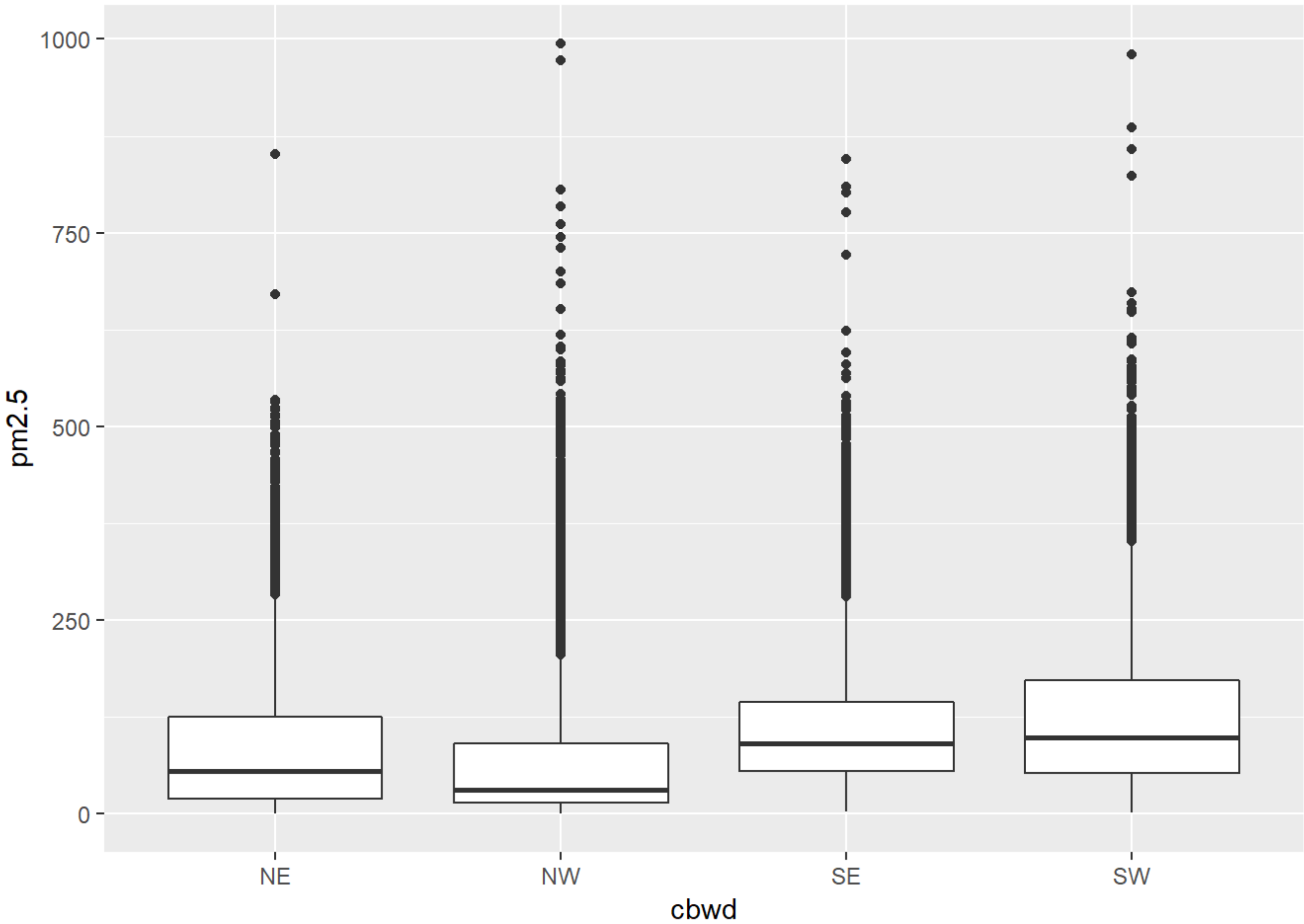



```
## [1] "pm2.5 & PRES"
## [1] -0.04728231
```

```
## Warning: Removed 2067 rows containing missing values (geom_point).
```

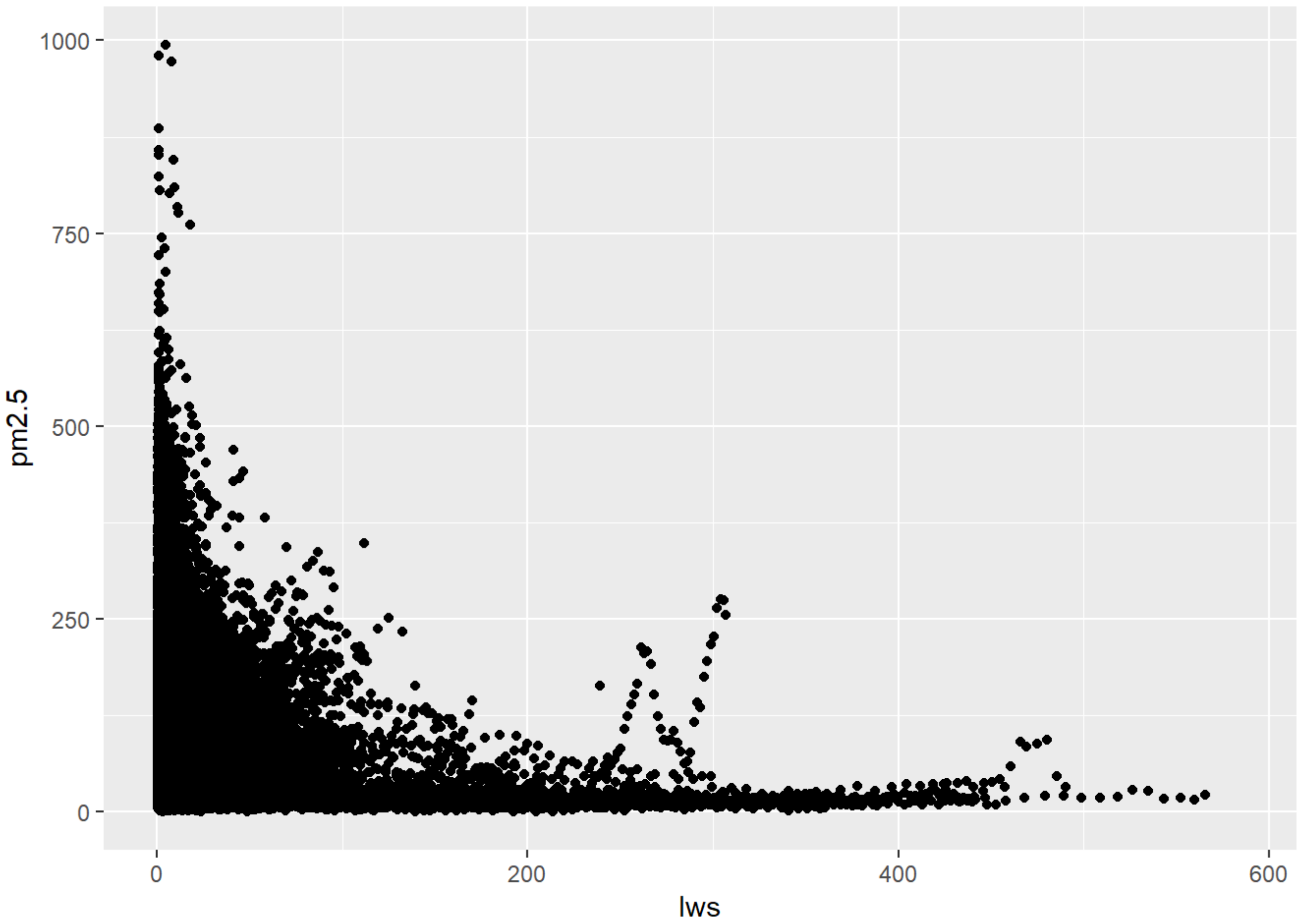



```
## Warning: Removed 2067 rows containing non-finite values (stat_boxplot).
```



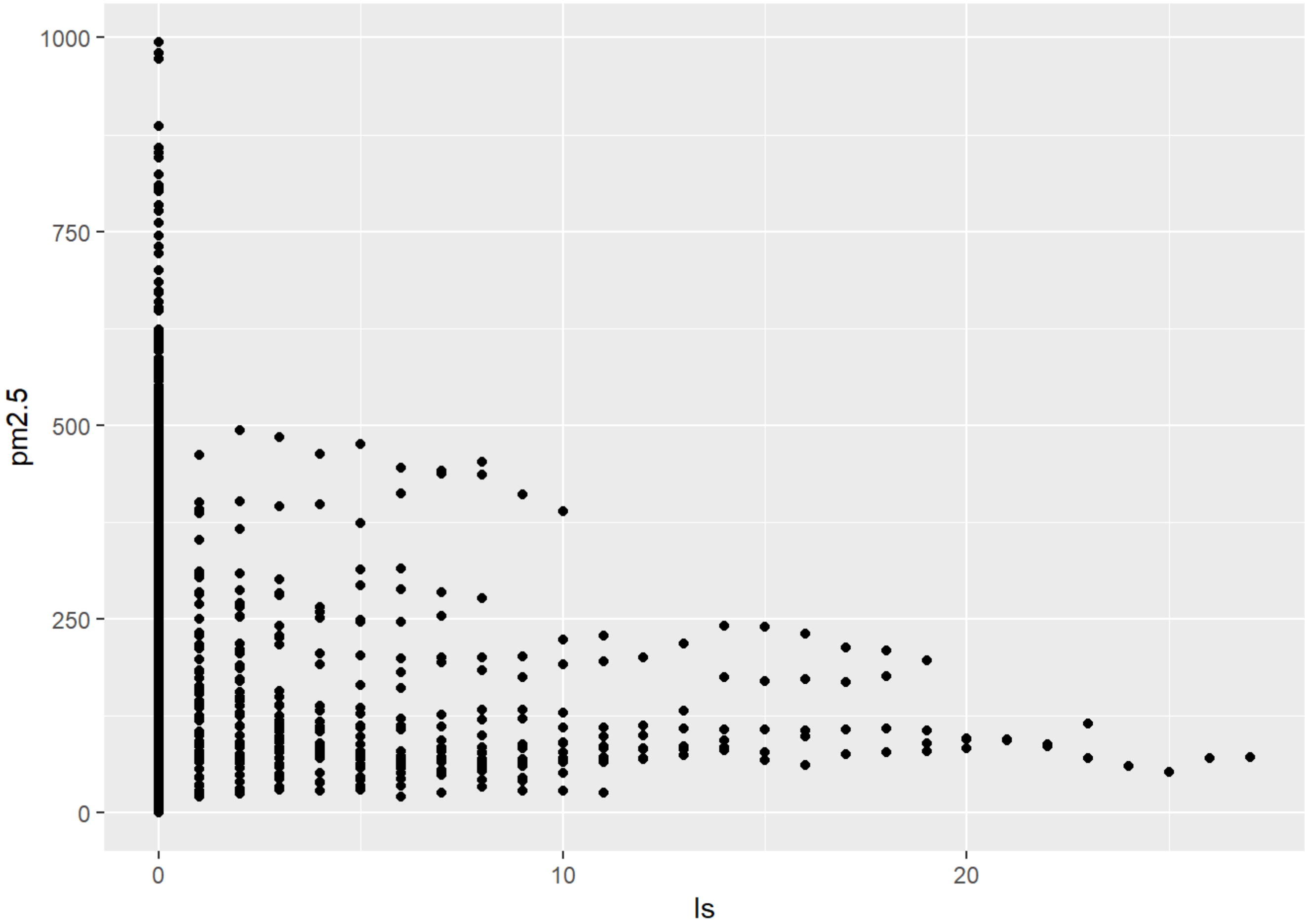
```
## [1] "pm2.5 & Iws"
## [1] -0.2477844
```

```
## Warning: Removed 2067 rows containing missing values (geom_point).
```



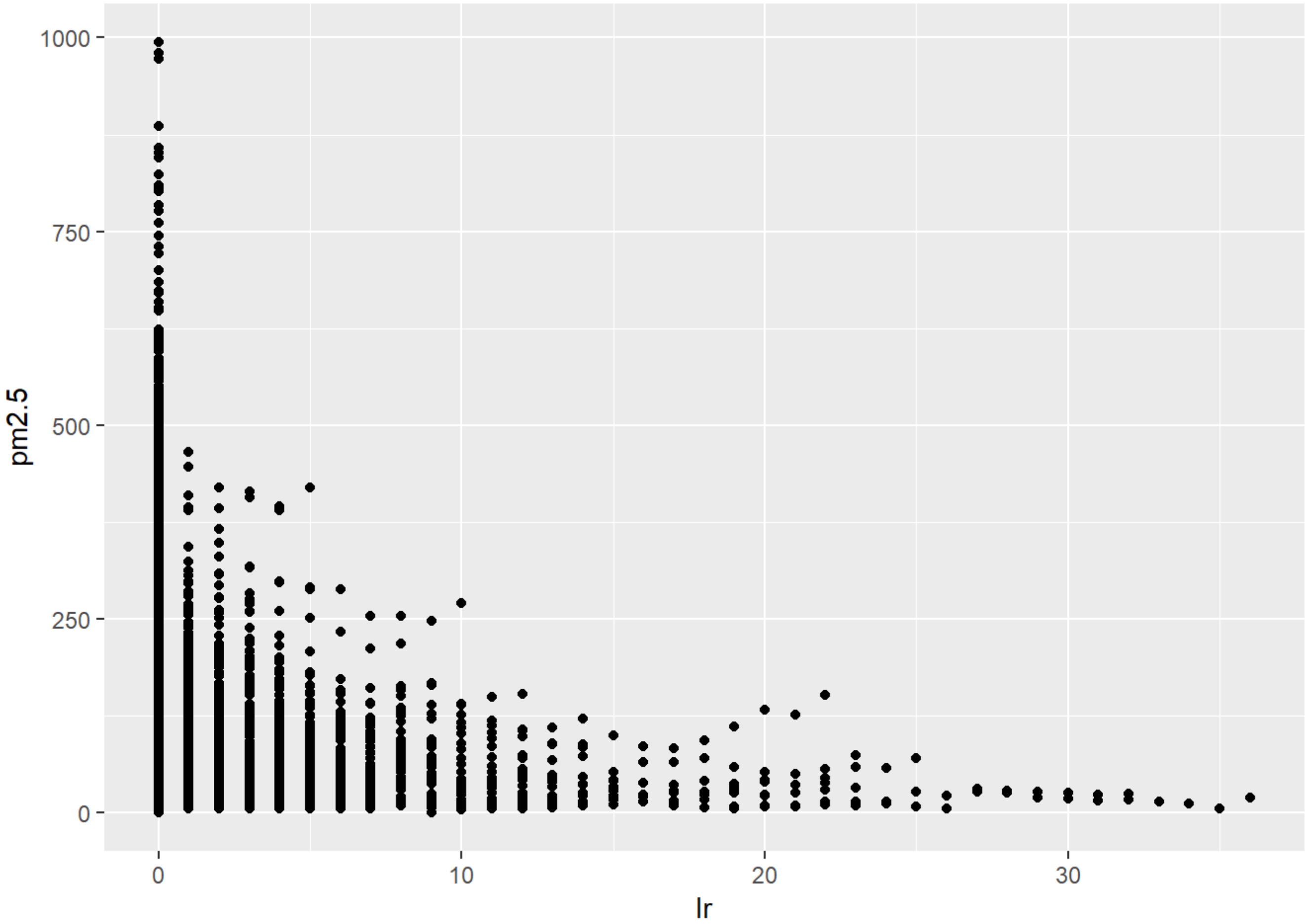

```
## [1] "pm2.5 & Is"
## [1] 0.01926558
```

```
## Warning: Removed 2067 rows containing missing values (geom_point).
```




```
## [1] "pm2.5 & Ir"
## [1] -0.05136871
```

```
## Warning: Removed 2067 rows containing missing values (geom_point).
```



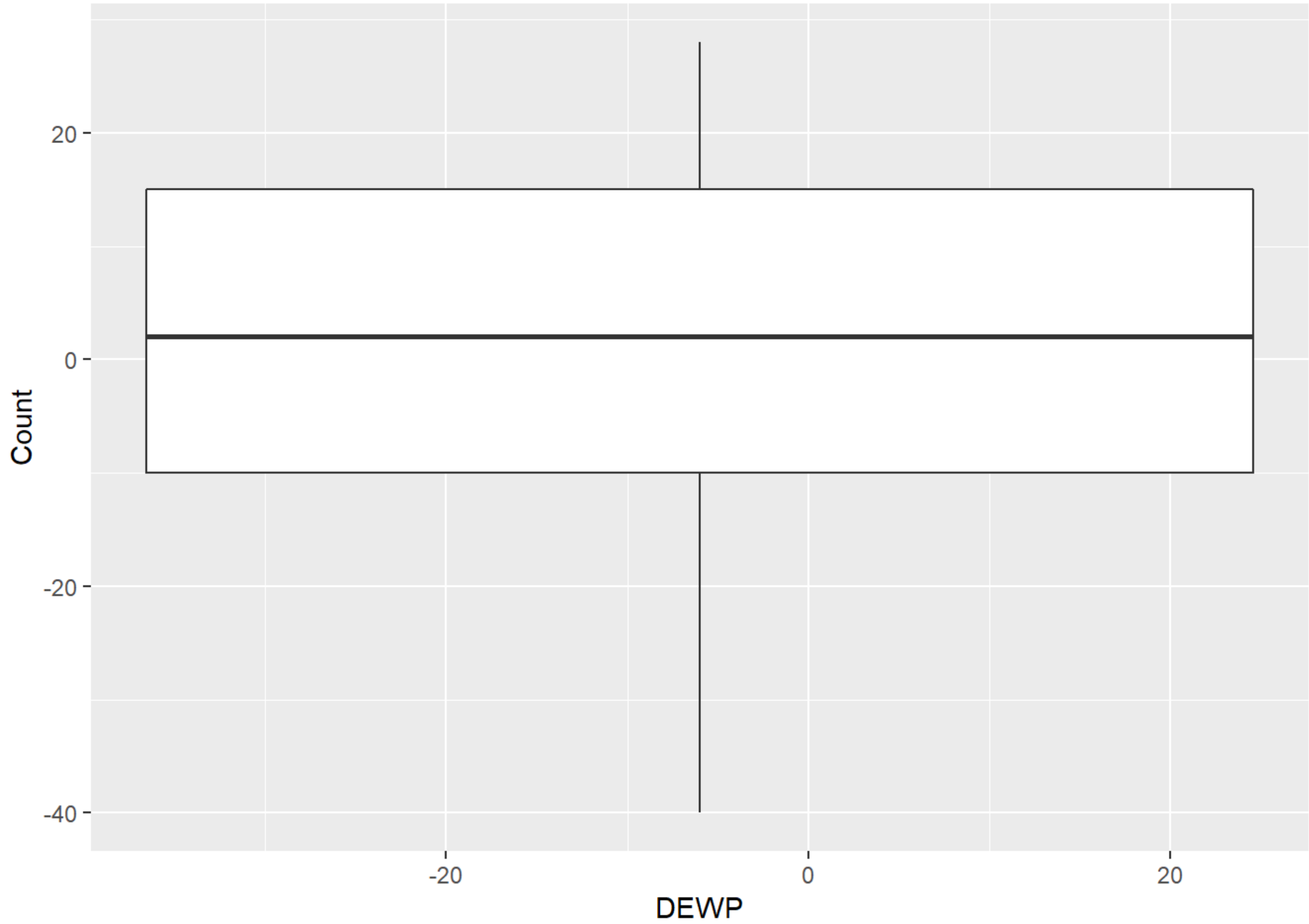
dewp has positive correlation, whereas lws, ls and lr have negative correlation

Why is there an N-shape in the plot of pm2.5 vs lws? Are they outliers?

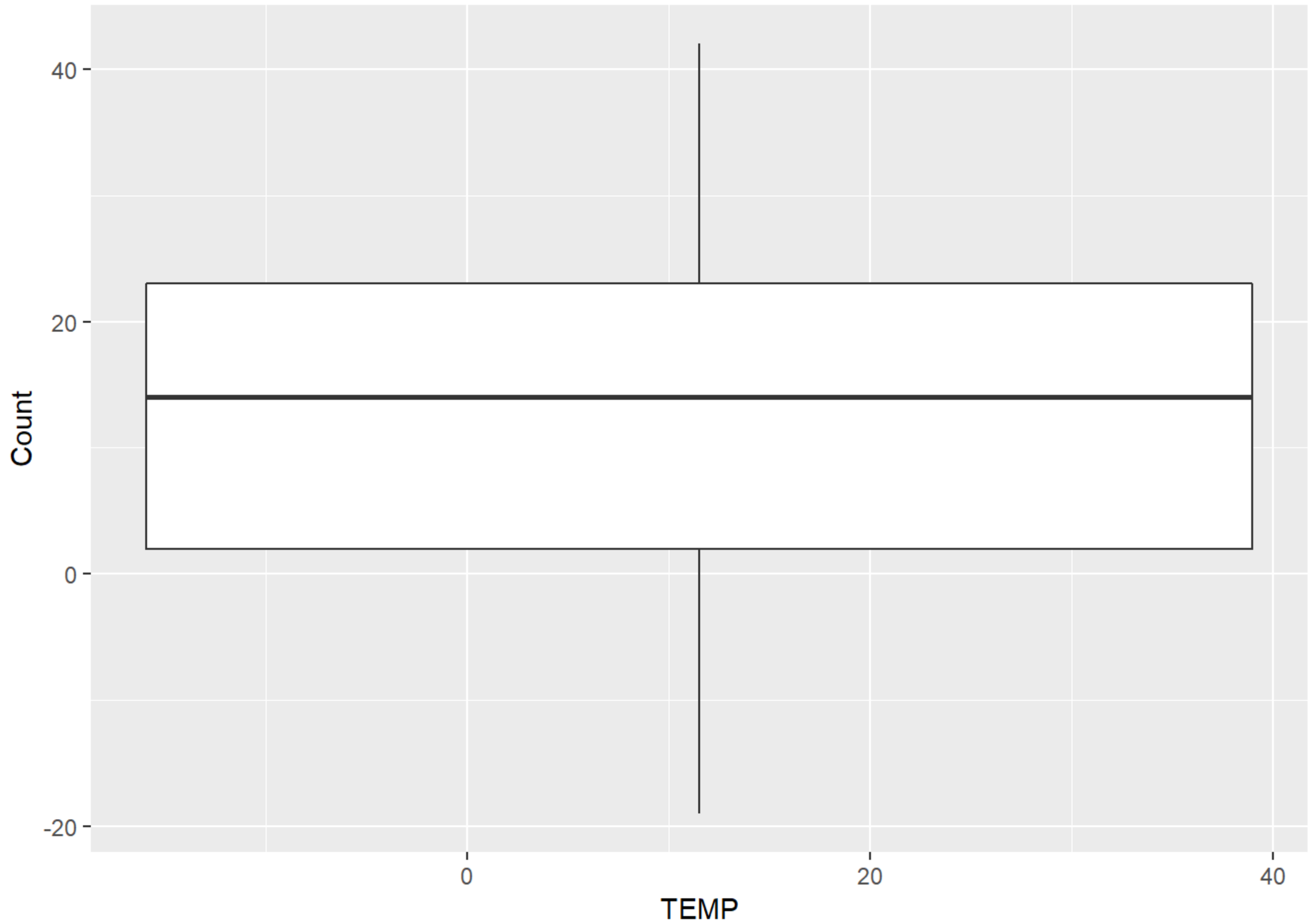
Boxplot of each variable

```
for(i in 6:12) {
  if(!is.factor(prsa[,i])) {
    print(ggplot(prsa, aes(prsa[,i], prsa[,i])) +
            geom_boxplot() +
            xlab(colnames(prsa)[i]) +
            ylab("Count"))
  }
}
```

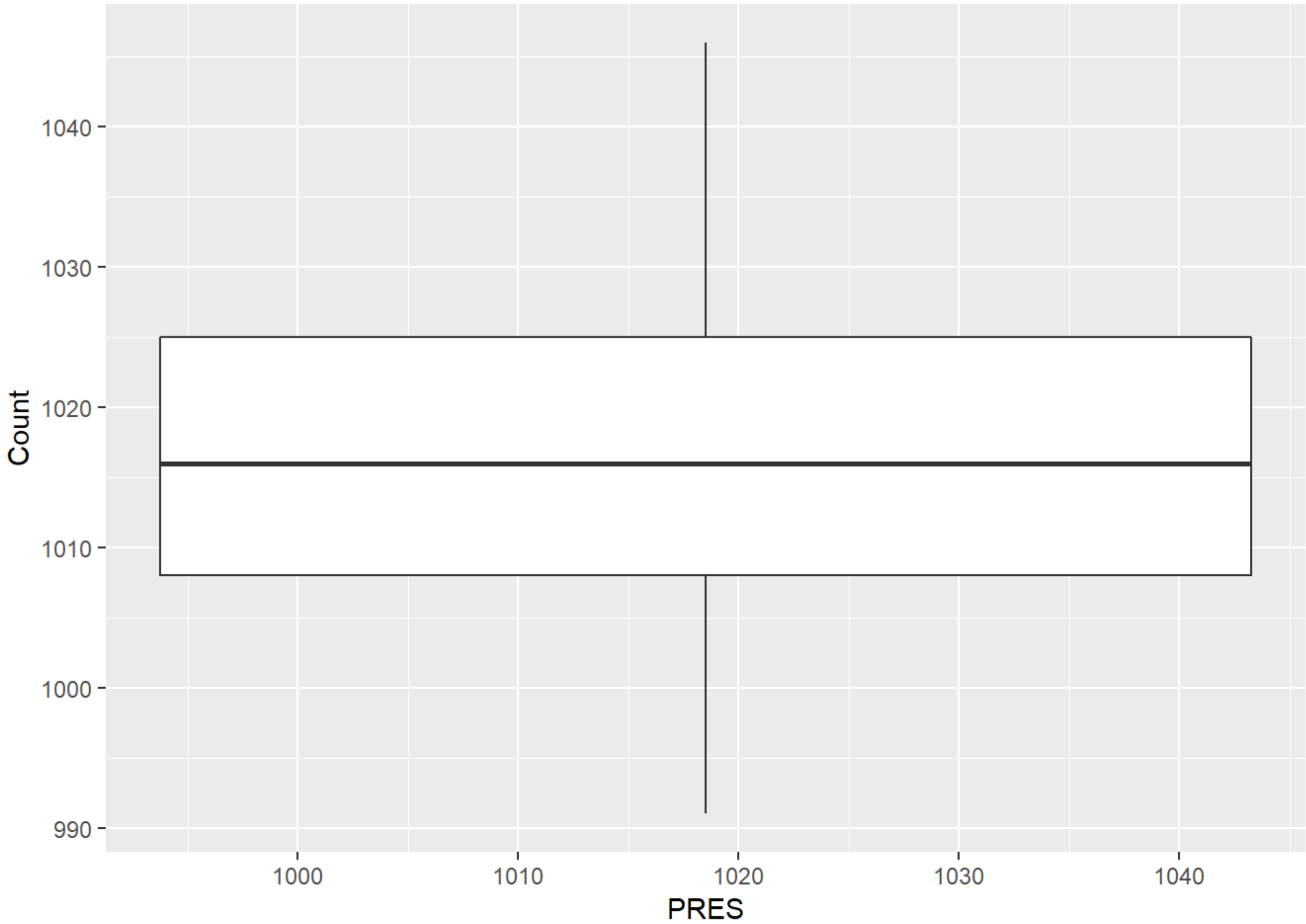
```
## Warning: Continuous x aesthetic -- did you forget aes(group=...)?
```



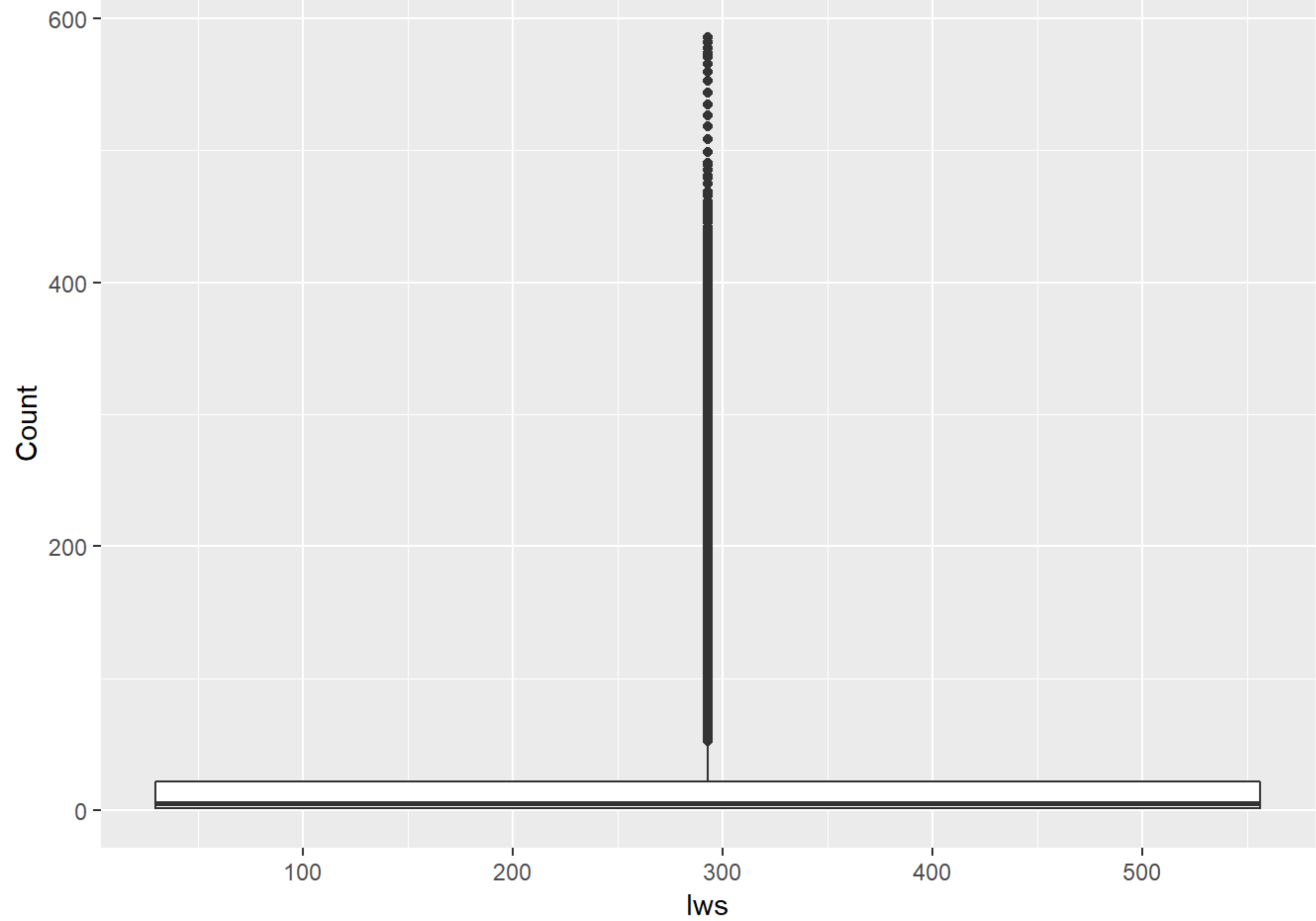

```
## Warning: Continuous x aesthetic -- did you forget aes(group=...)?
```



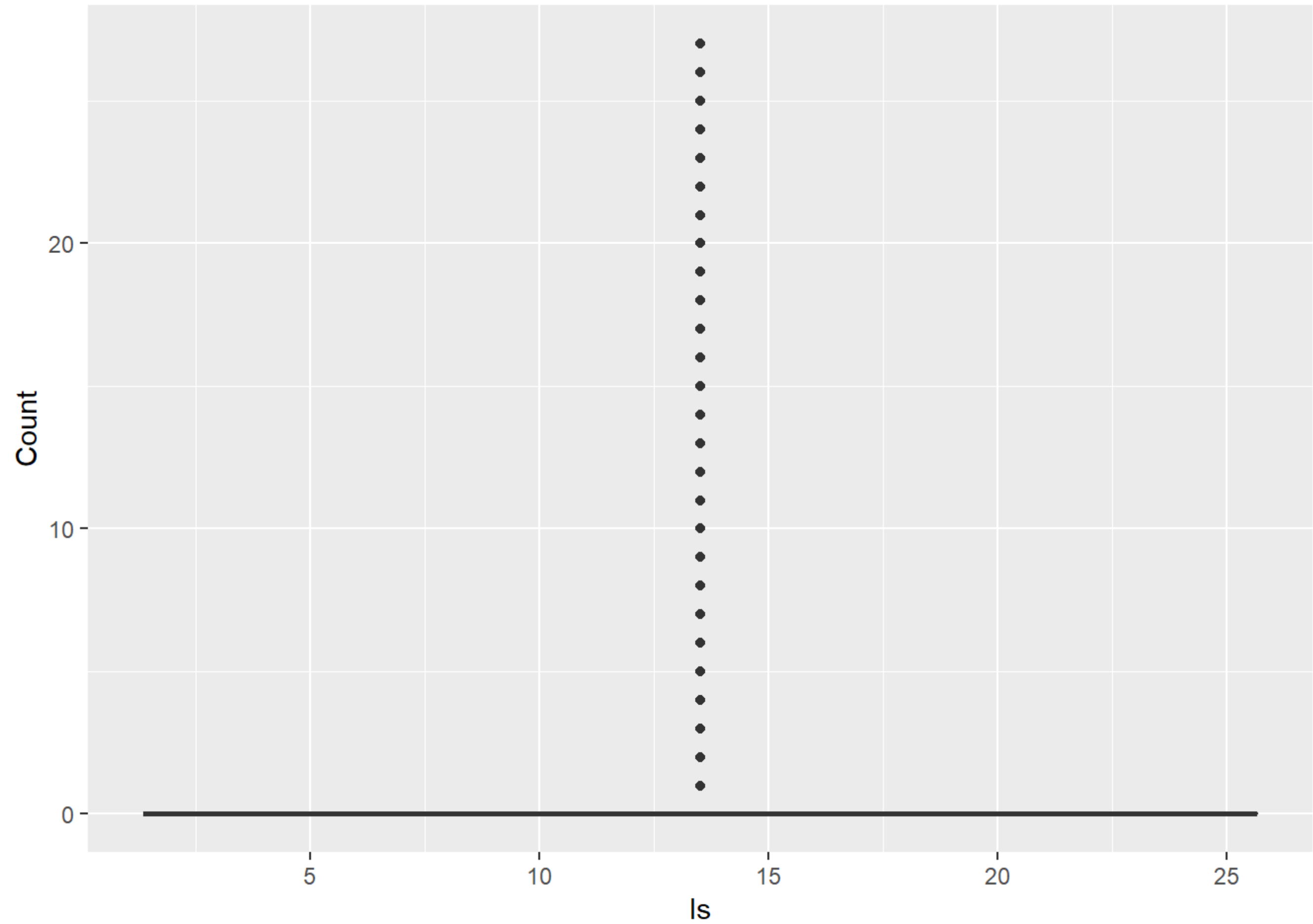
```
## Warning: Continuous x aesthetic -- did you forget aes(group=...)?
```



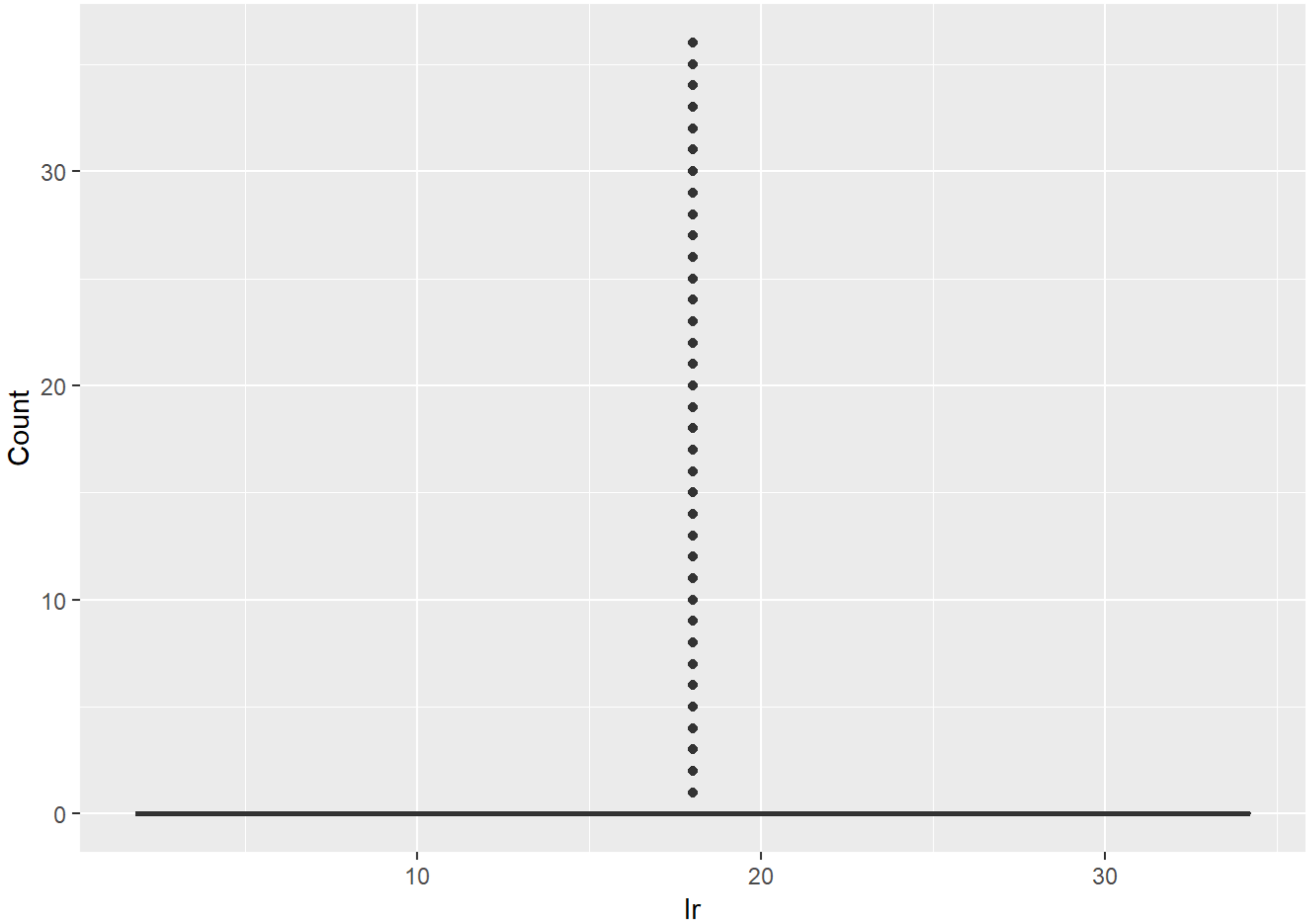

```
## Warning: Continuous x aesthetic -- did you forget aes(group=...)?
```




```
## Warning: Continuous x aesthetic -- did you forget aes(group=...)?
```



```
## Warning: Continuous x aesthetic -- did you forget aes(group=...)?
```

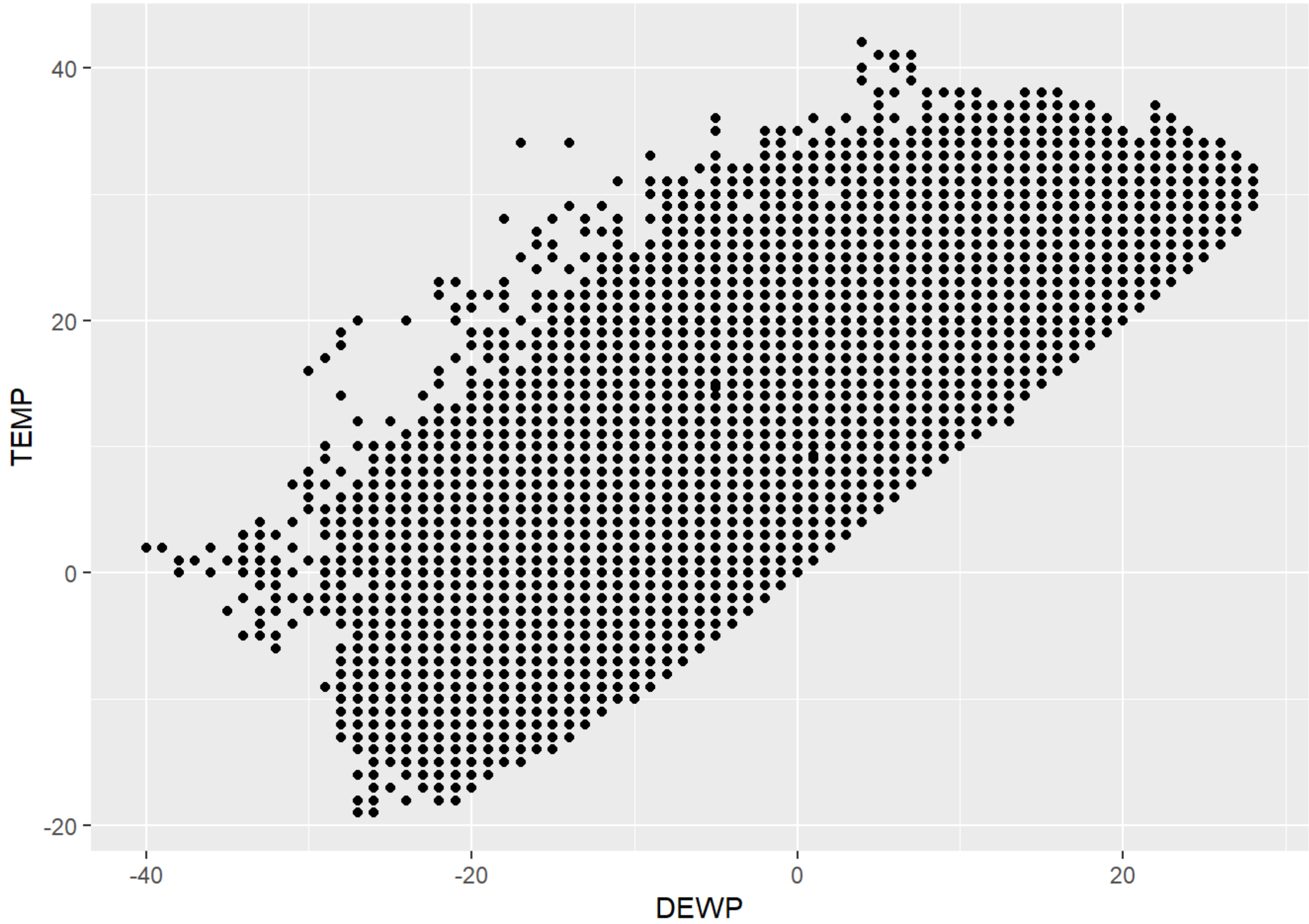


Iws has many outliers

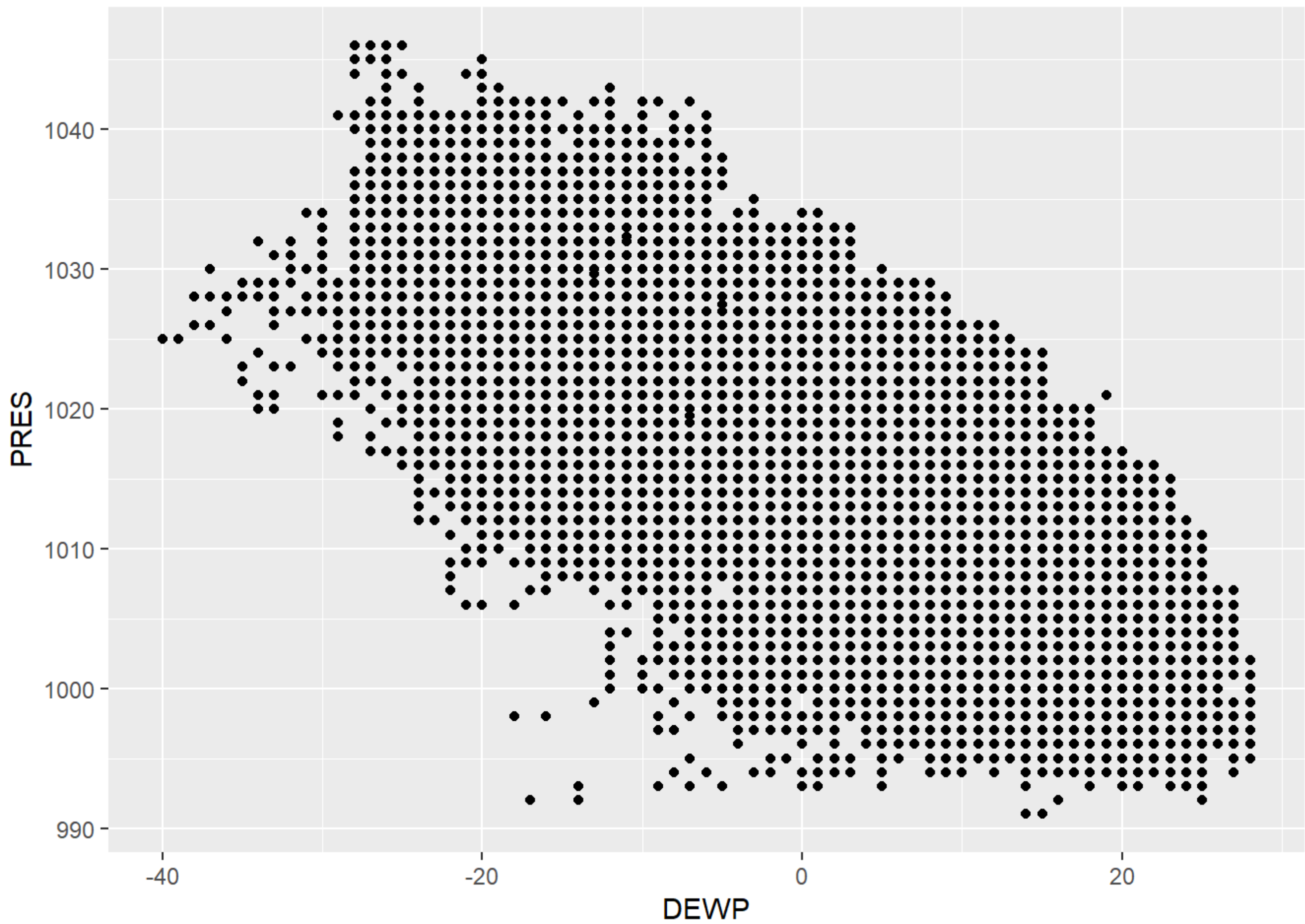
Are there any correlations between those weather variables?

```
for(i in 6:12) {
  for(j in (i+1):12) {
    if(j <= 12 & j > i & !is.factor(prsa[,i]) & !is.factor(prsa[,j])) {
      print(paste(colnames(prsa)[i], "&", colnames(prsa)[j], sep = " "))
      print(cor(prsa[,i], prsa[,j]))
      print(ggplot(prsa, aes(prsa[,i], prsa[,j])) +
              geom_point() +
              xlab(colnames(prsa)[i]) +
              ylab(colnames(prsa)[j]))
    }
  }
}
```

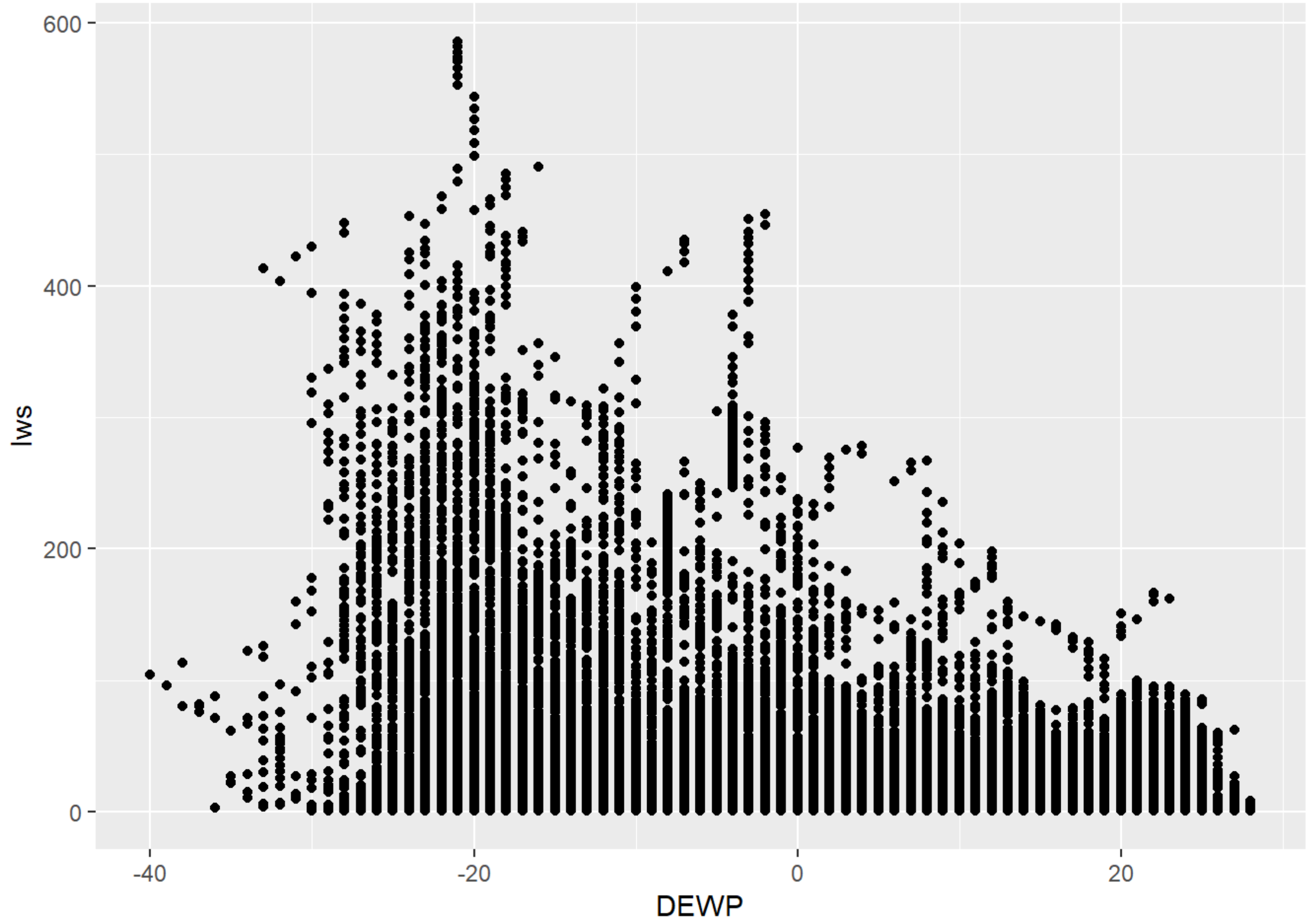
```
## [1] "DEWP & TEMP"
## [1] 0.8246331
```



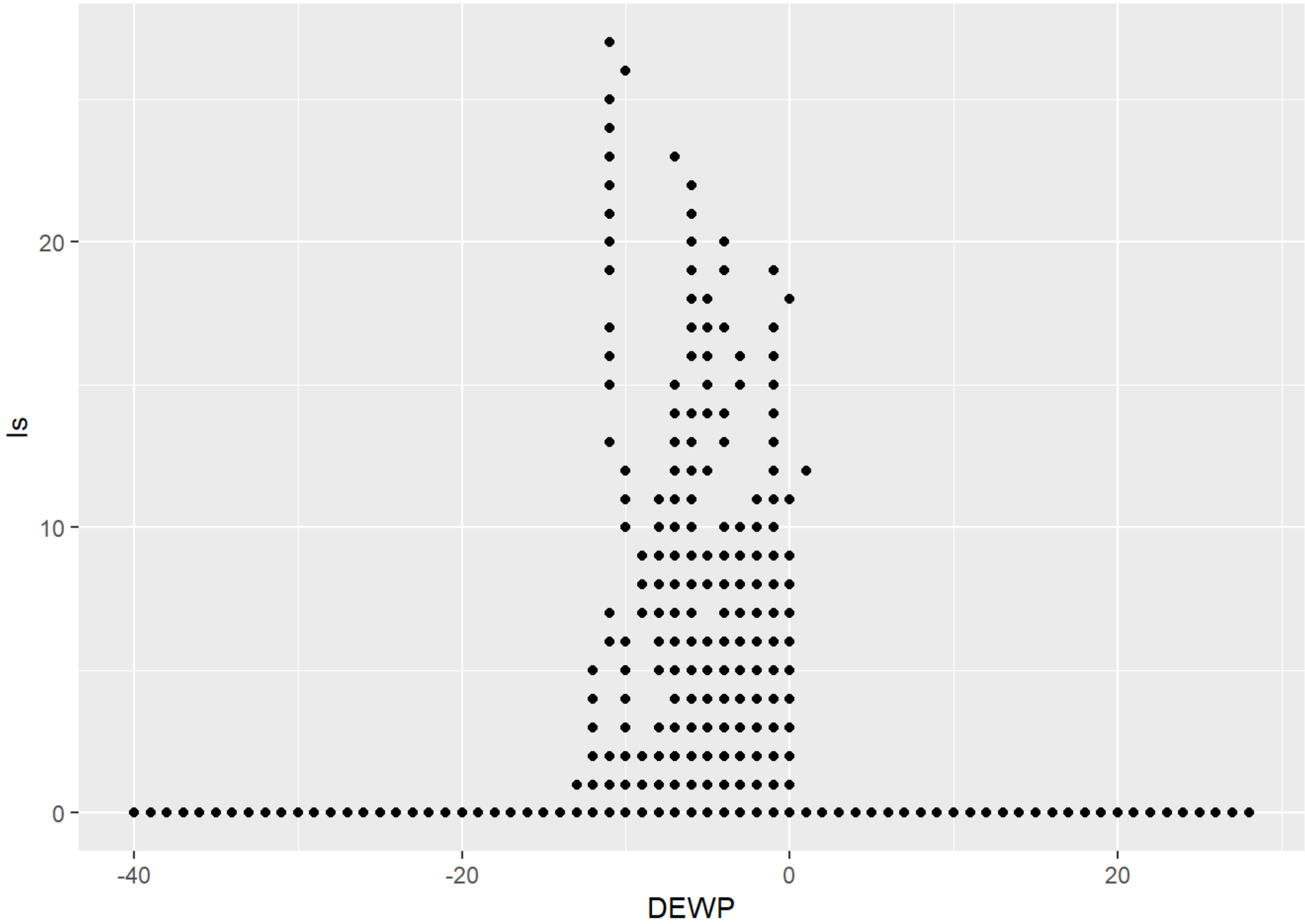

```
## [1] "DEWP & PRES"
## [1] -0.7783461
```



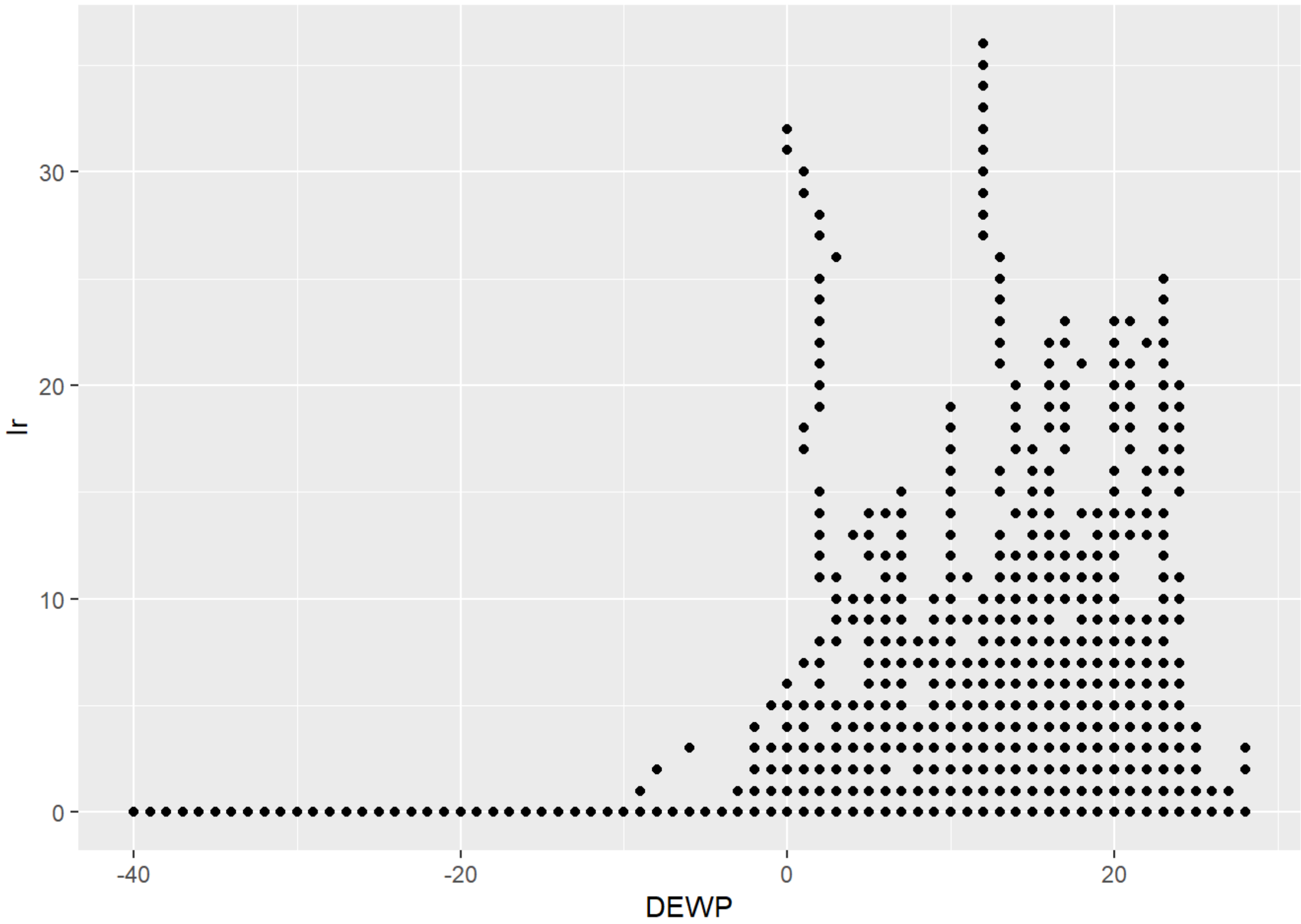
```
## [1] "DEWP & Iws"
## [1] -0.2963987
```



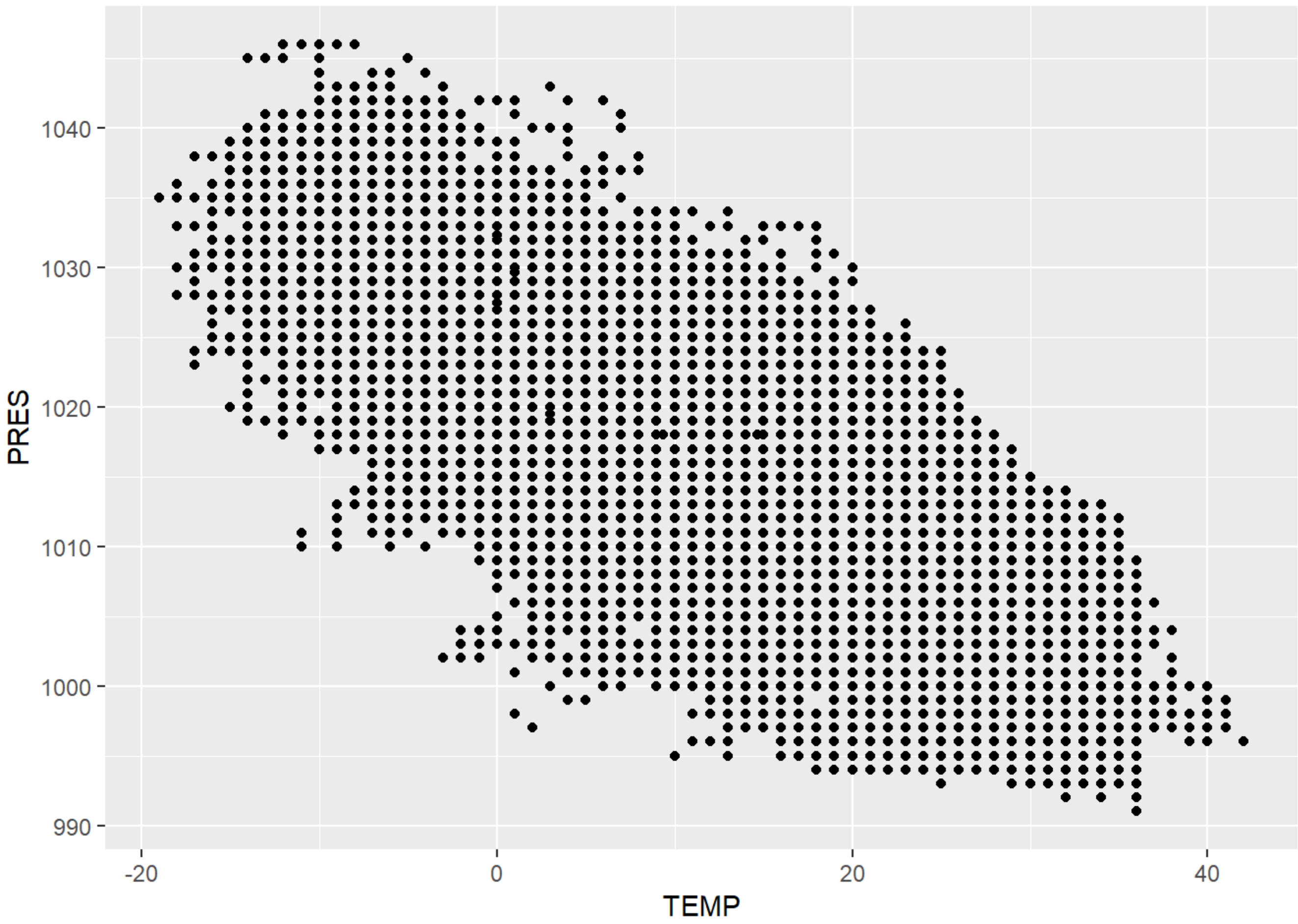

```
## [1] "DEWP & Is"
## [1] -0.03441037
```



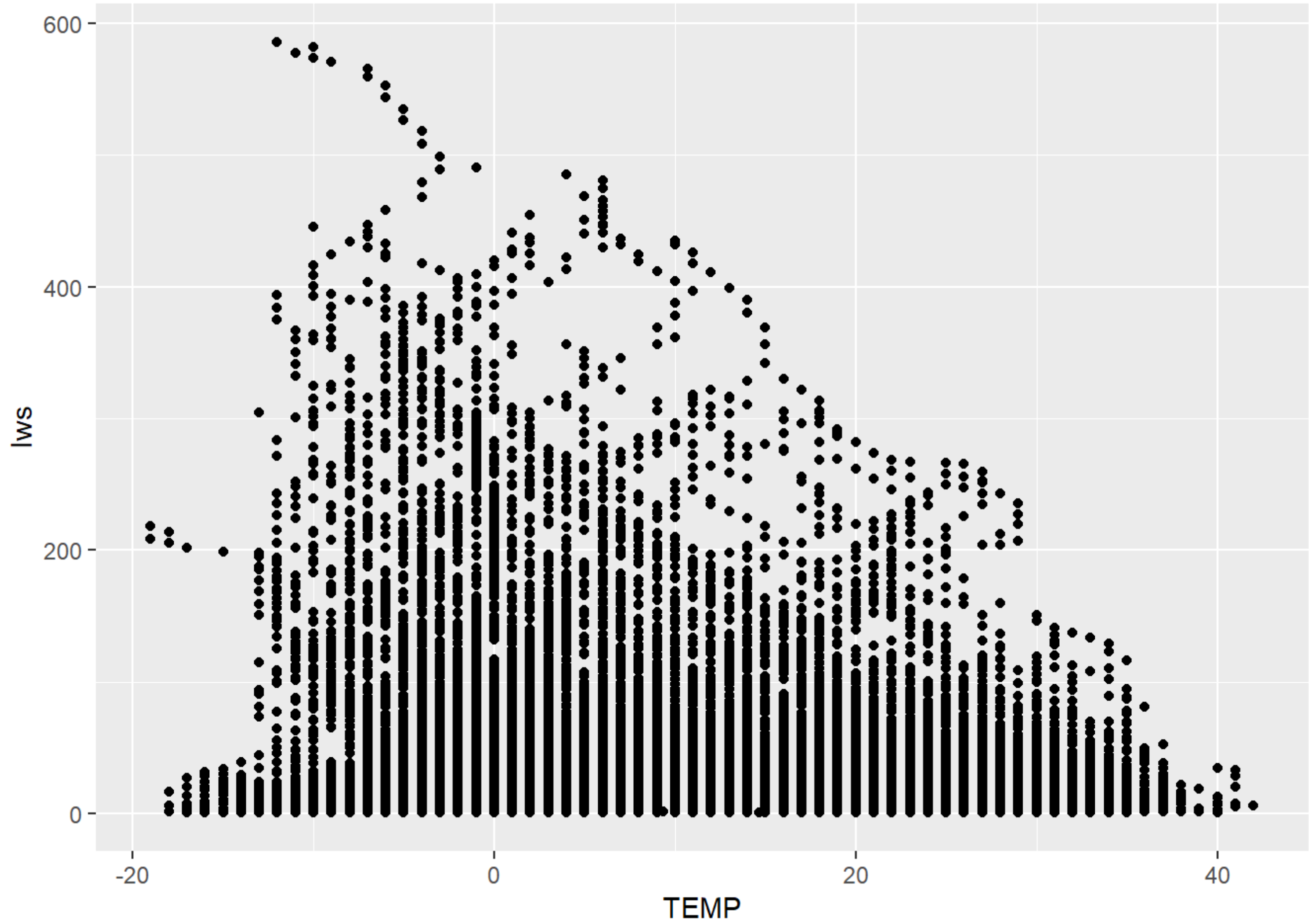

```
## [1] "DEWP & Ir"
## [1] 0.1250895
```



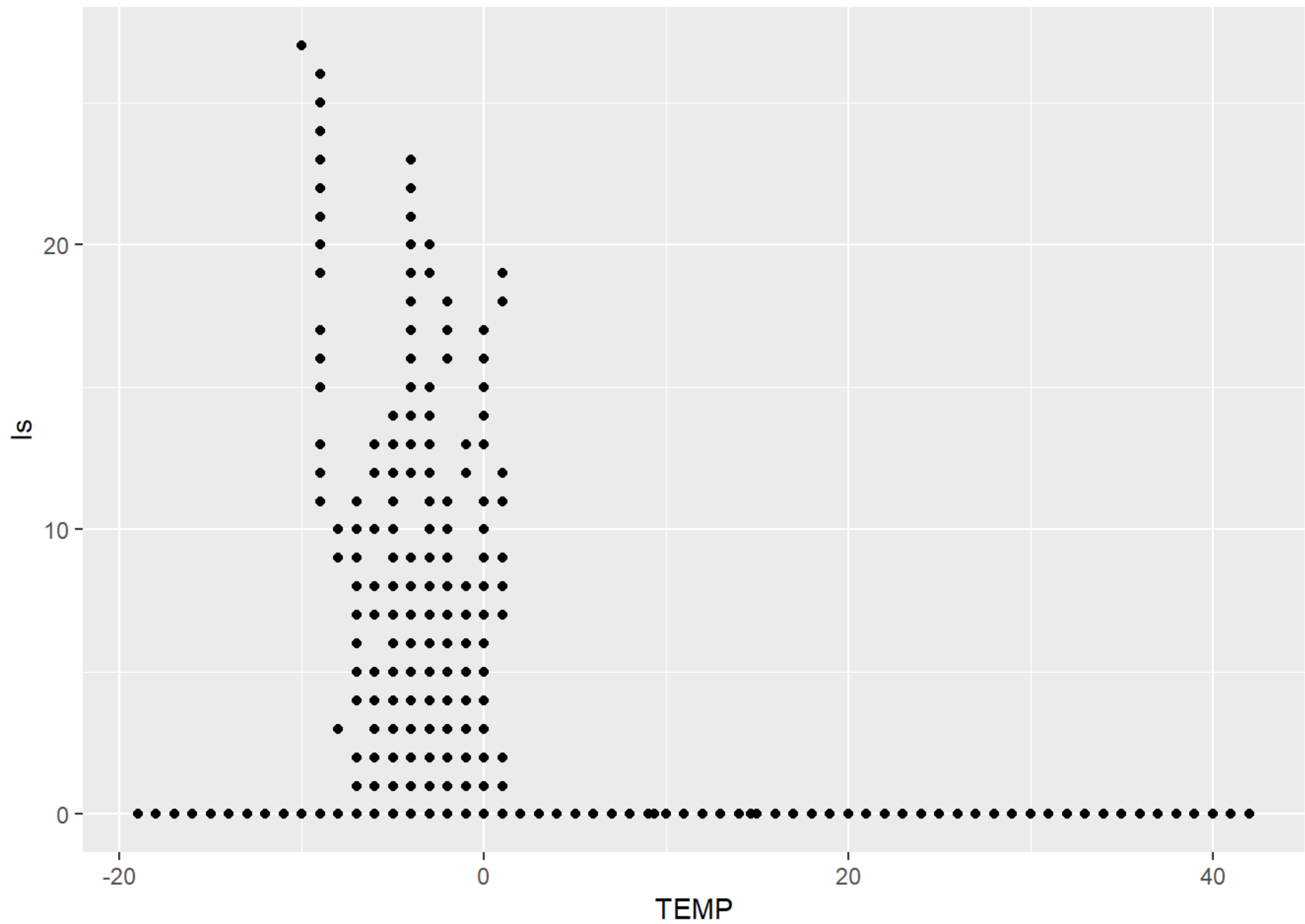
```
## [1] "TEMP & PRES"
## [1] -0.8266904
```



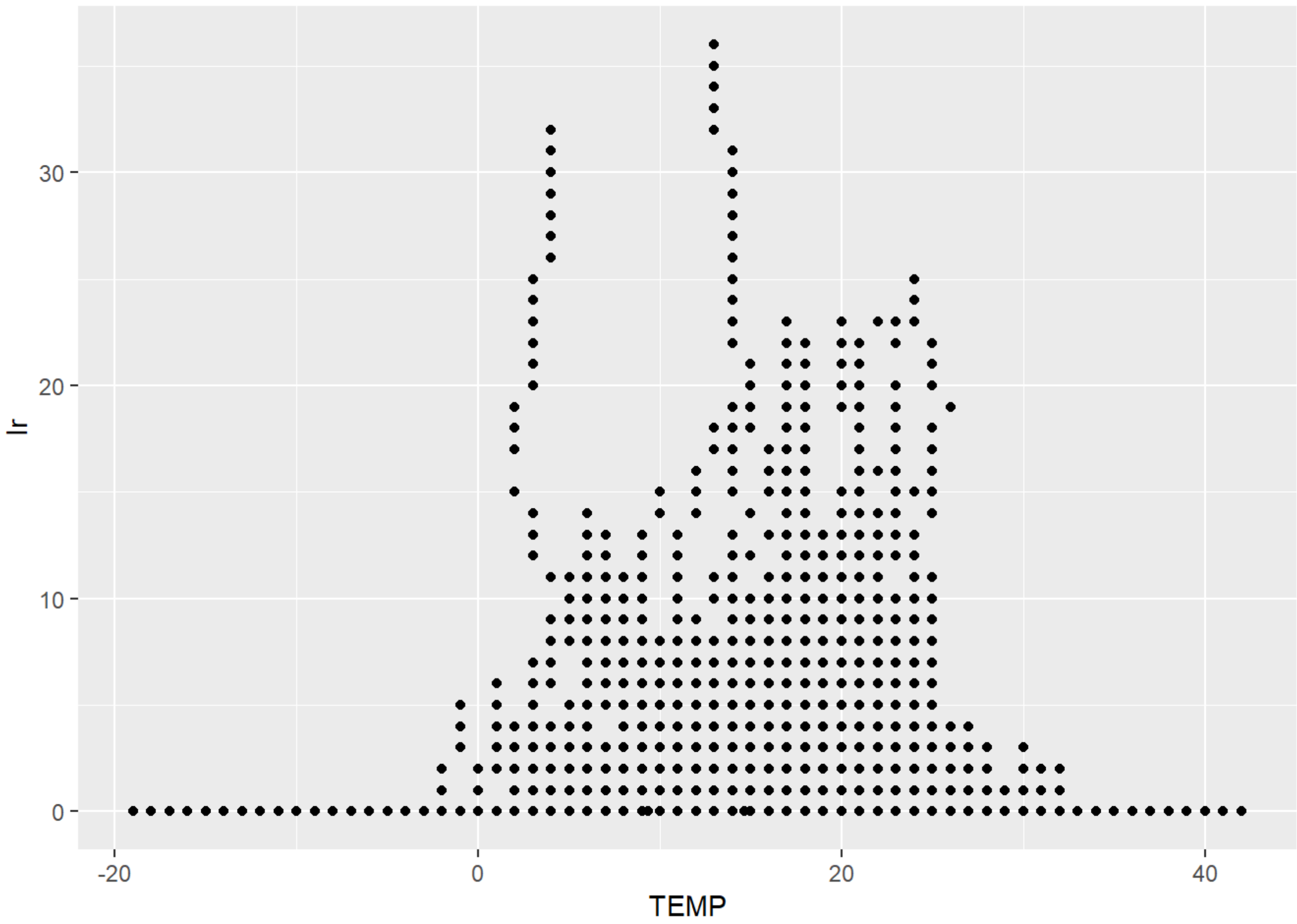

```
## [1] "TEMP & Iws"
## [1] -0.1546228
```



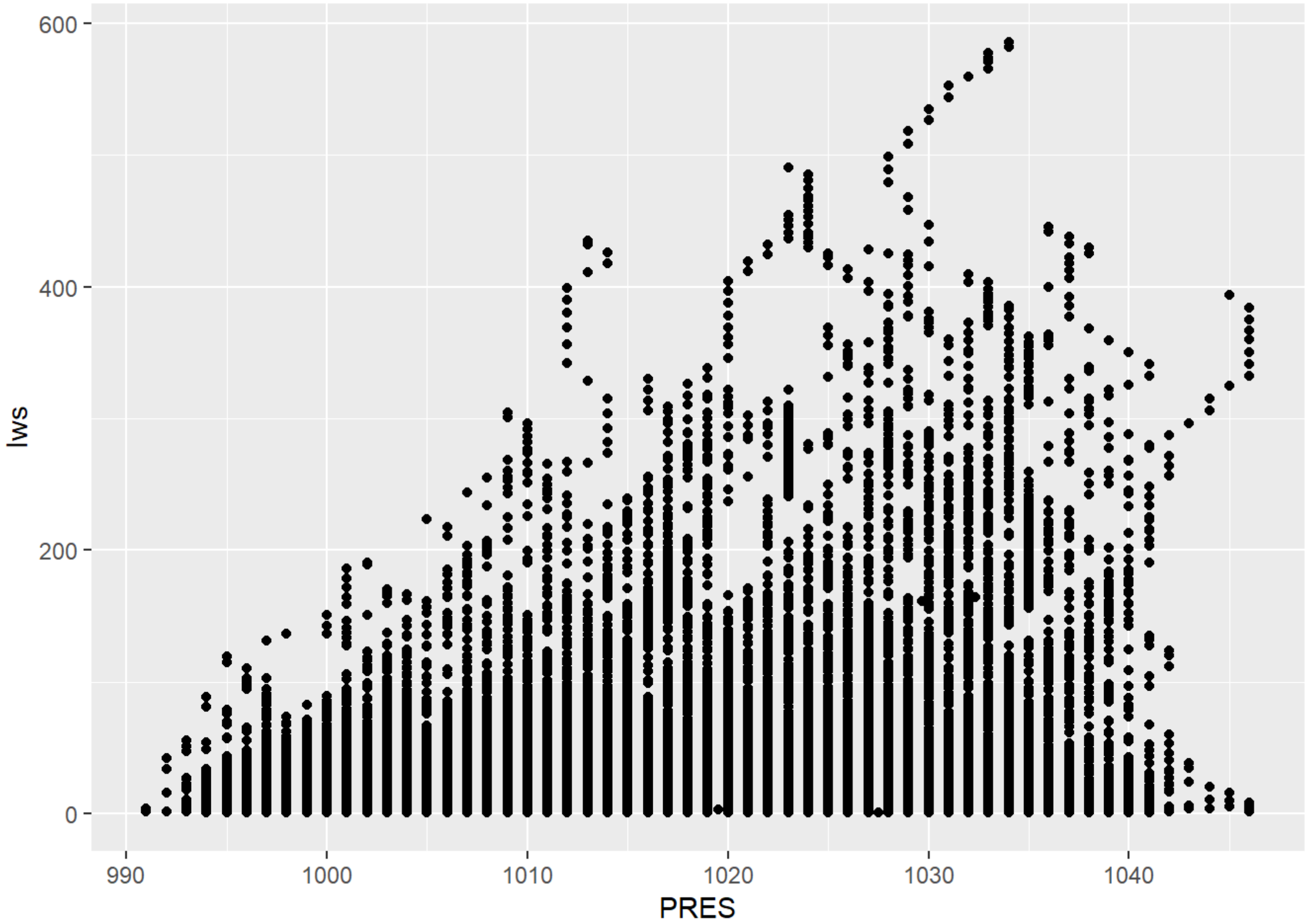

```
## [1] "TEMP & Is"
## [1] -0.09260097
```



```
## [1] "TEMP & Ir"
## [1] 0.04912147
```

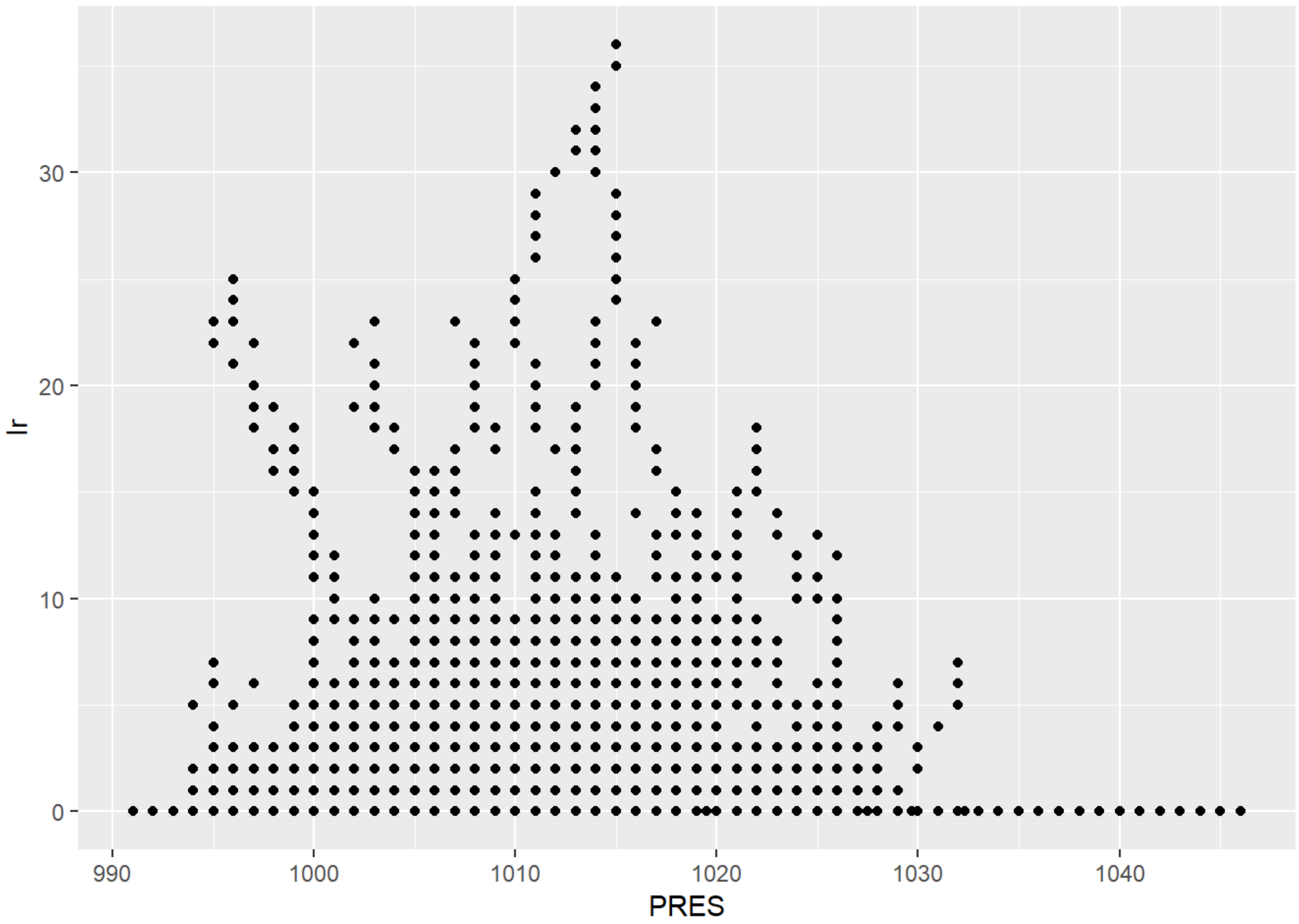



```
## [1] "PRES & Iws"
## [1] 0.1853547
```

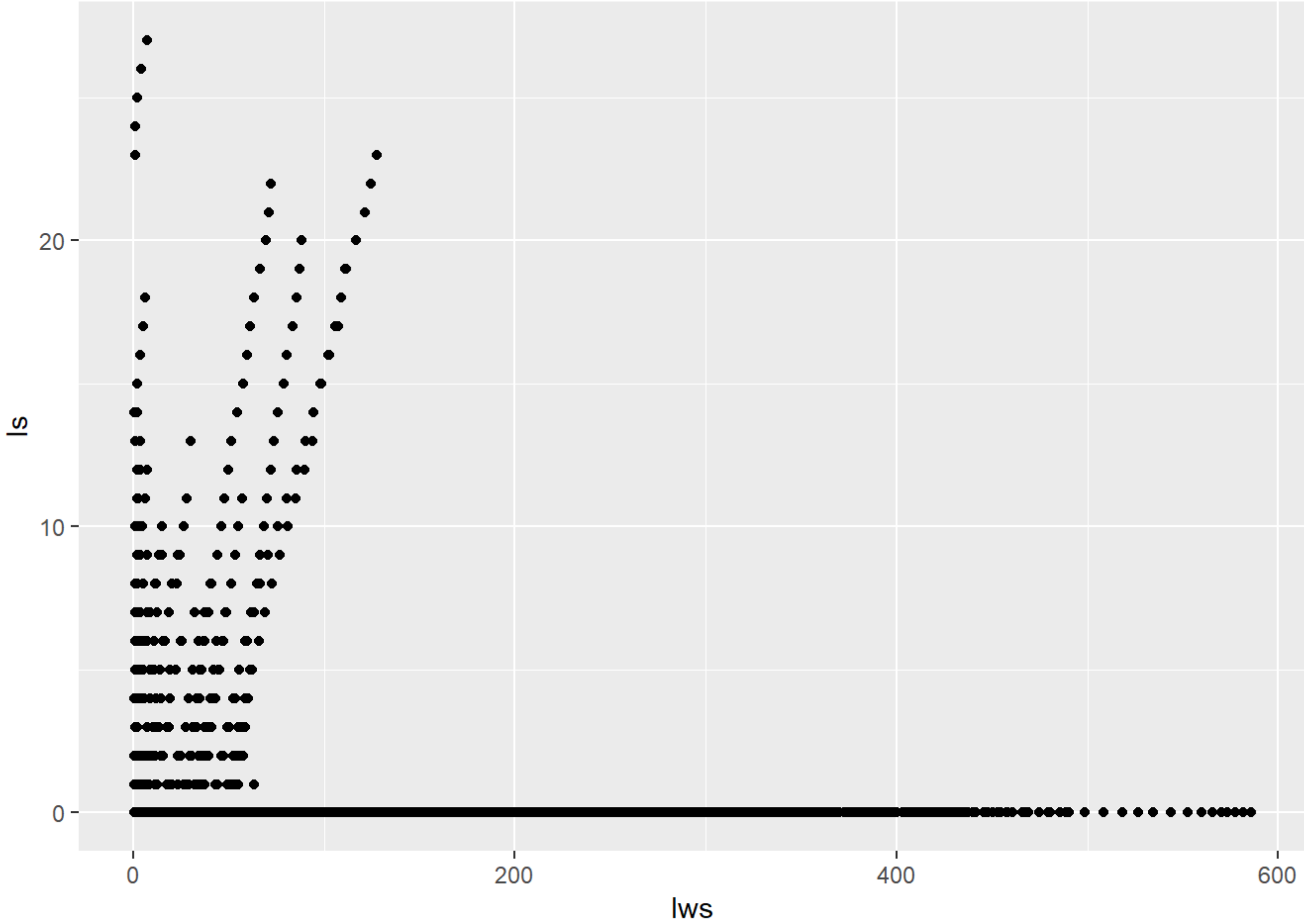



```
## [1] "PRES & Is"
## [1] 0.06902795
```

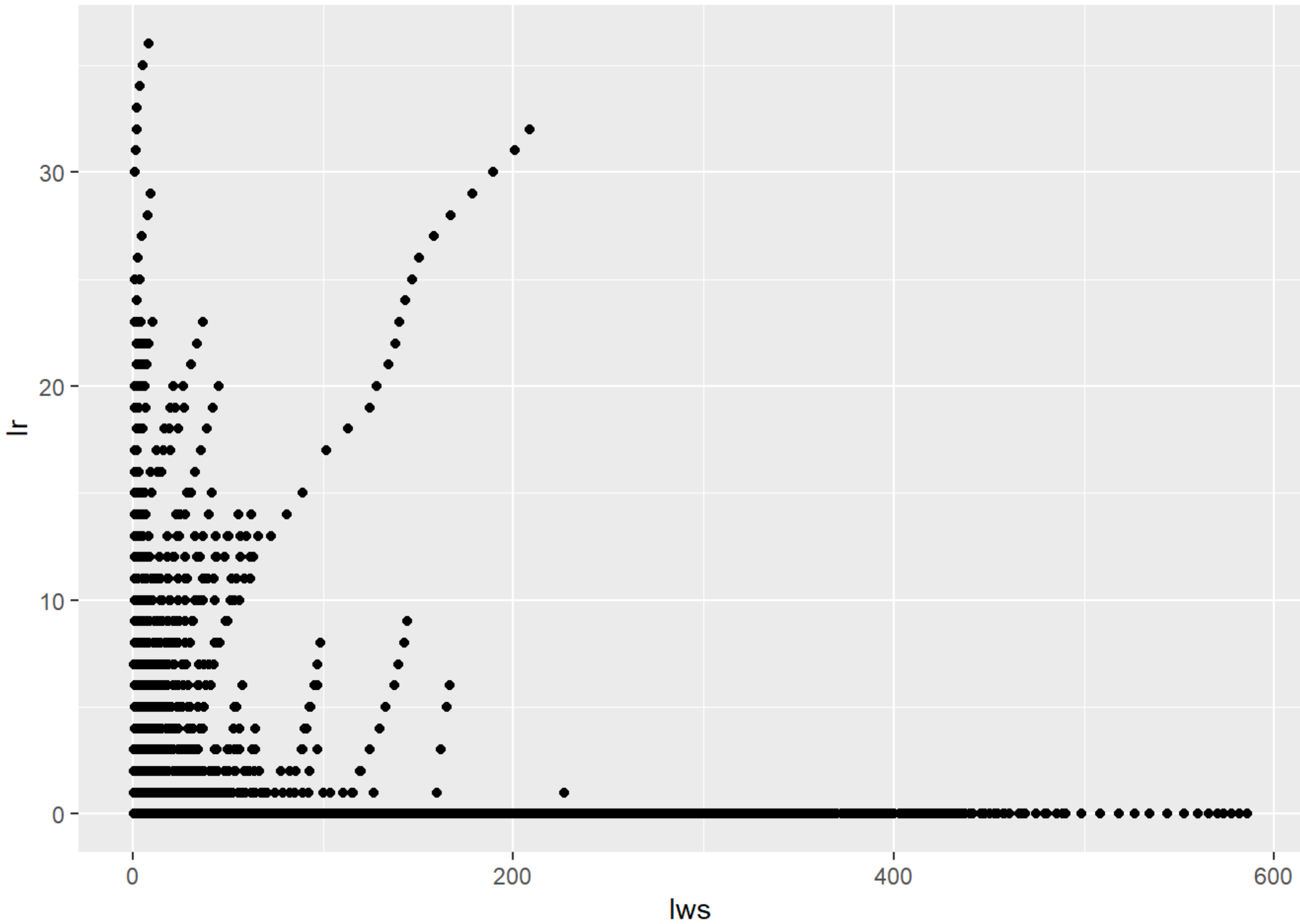
```
## [1] "PRES & Ir"
## [1] -0.07984317
```



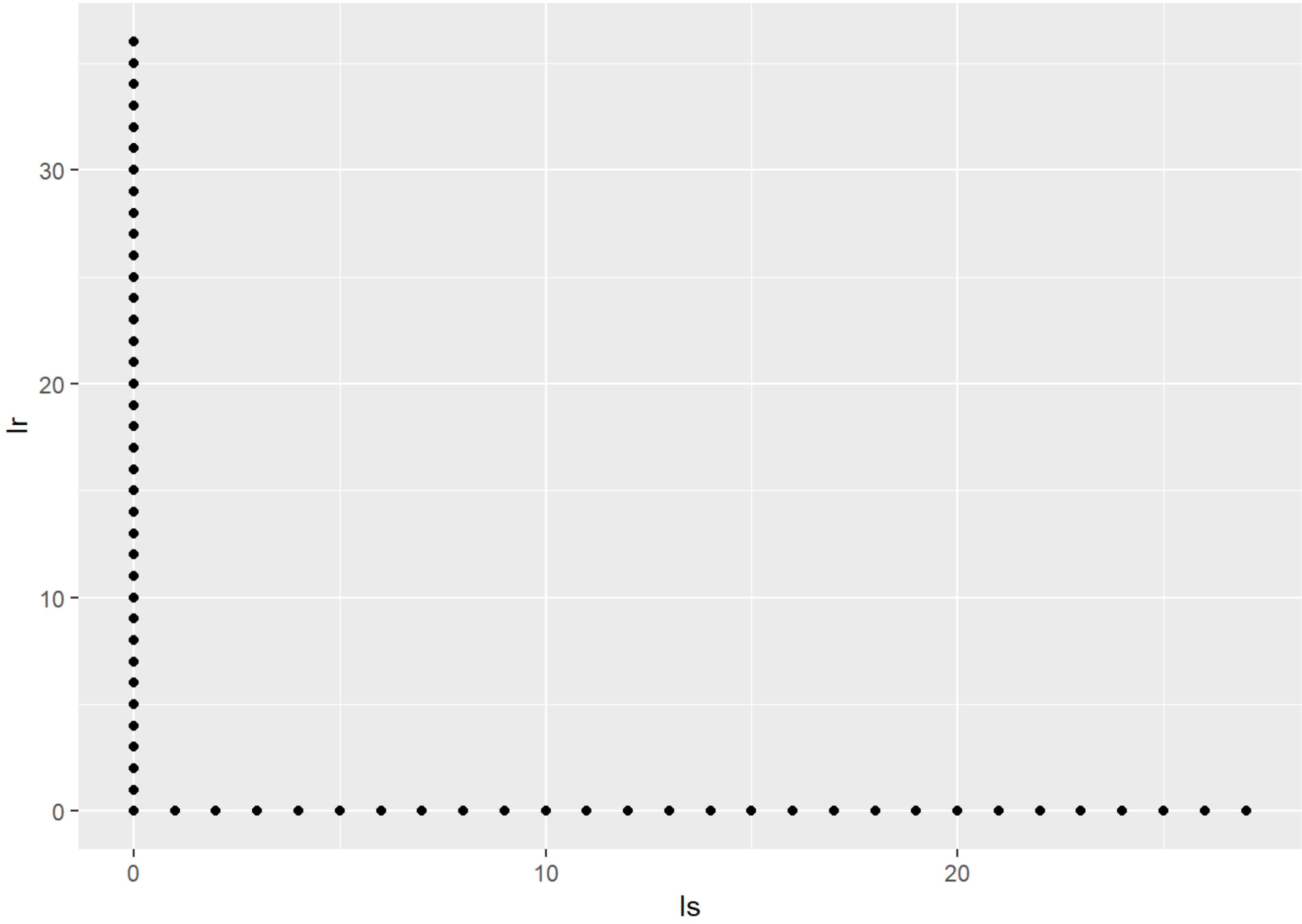

```
## [1] "Iws & Is"
## [1] 0.02188285
```




```
## [1] "Iws & Ir"
## [1] -0.01012205
```



```
## [1] "Is & Ir"
## [1] -0.009547625
```



dewp and temp have positive correlation

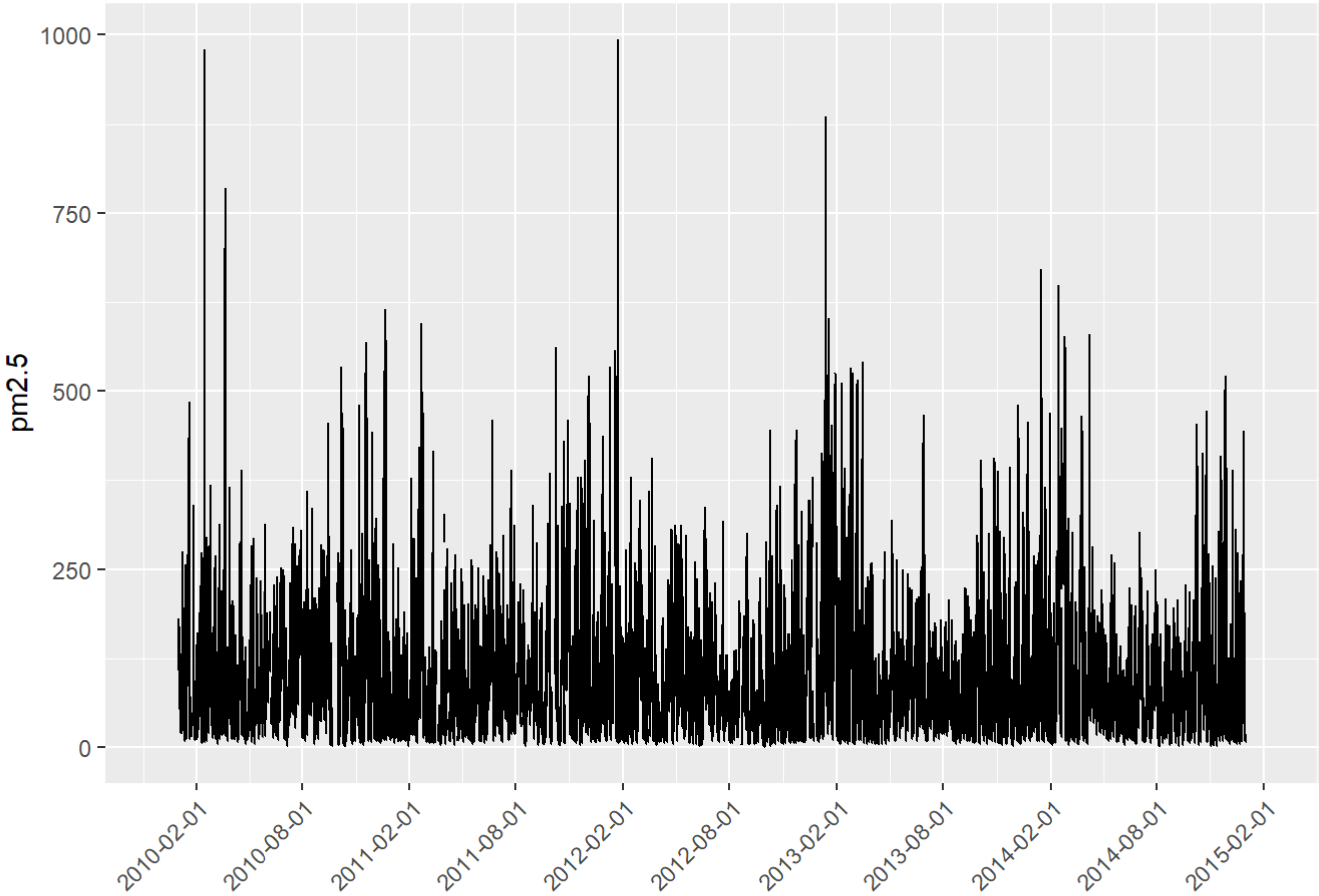
dewp and pres have negative correlation

temp and pres have negative correlation

plot time series of pm2.5

```
ggplot(prsa, aes(datetime, pm2.5)) +
  geom_line() +
  scale_x_datetime(date_breaks = "6 months", limits = c(as.POSIXct("2009-12-01"), as.POSIXct(
"2015-01-31"))) +
  xlab("") +
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
```

```
## Warning: Removed 24 rows containing missing values (geom_path).
```



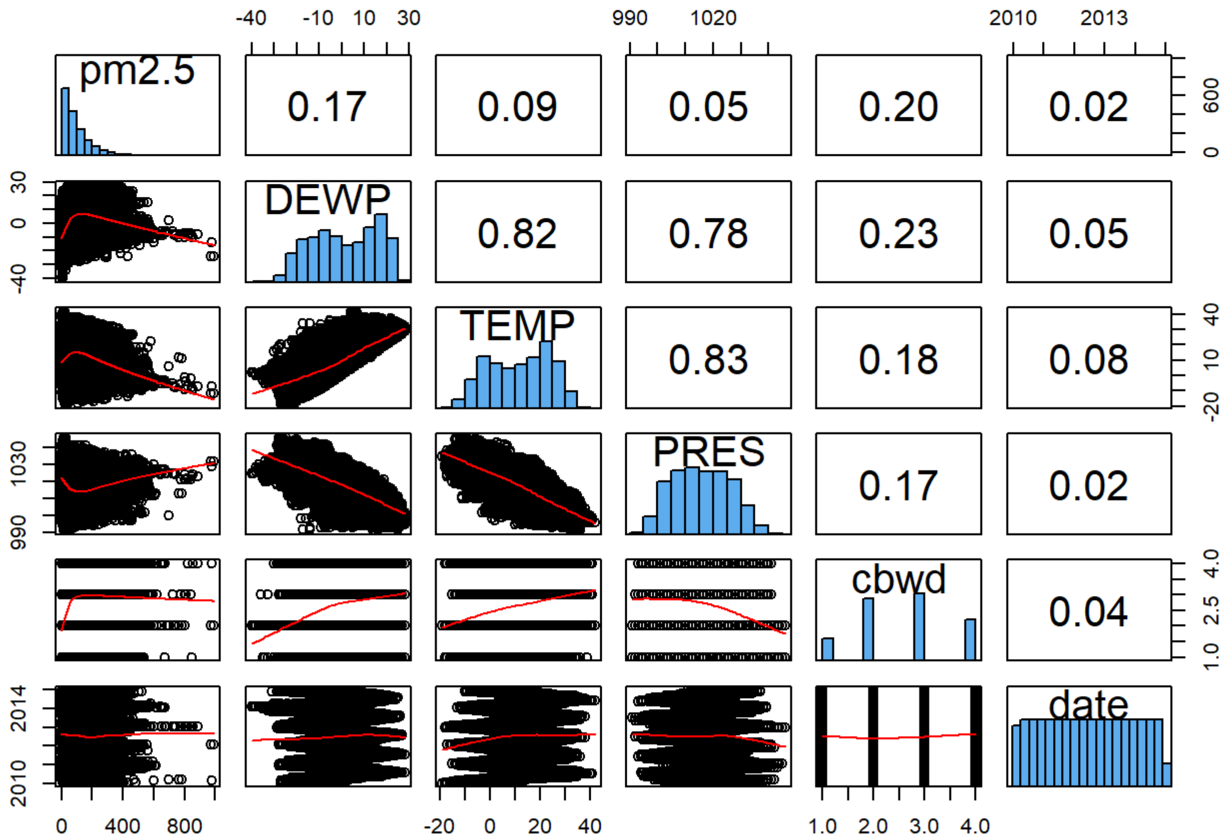
From the plots above, we can get that PM2.5 is highly correlated with Dew Point, Temperature, Pressure and cbwd

Build the new dataframe

```
prsa.omit <- prsa[,c(5,6,7,8,9,13)]
summary(prsa.omit)
```

```
##      pm2.5             DEWP              TEMP             PRES     
##  Min.   :  0.00   Min.   :-40.000   Min.   :-19.00   Min.   : 991  
##  1st Qu.: 29.00   1st Qu.:-10.000   1st Qu.:  2.00   1st Qu.:1008  
##  Median : 72.00   Median :  2.000   Median : 14.00   Median :1016  
##  Mean   : 98.61   Mean   :  1.817   Mean   : 12.45   Mean   :1016  
##  3rd Qu.:137.00   3rd Qu.: 15.000   3rd Qu.: 23.00   3rd Qu.:1025  
##  Max.   :994.00   Max.   : 28.000   Max.   : 42.00   Max.   :1046  
##  NA's   :2067                                                      
##  cbwd            date           
##  NE: 4997   Min.   :2010-01-01  
##  NW:14150   1st Qu.:2011-04-02  
##  SE:15290   Median :2012-07-01  
##  SW: 9387   Mean   :2012-07-01  
##             3rd Qu.:2013-10-01  
##             Max.   :2014-12-31  
## 
```

```
uva.pairs(prsa.omit)
```



Analysis of the missing data(NAs)

```
prsa.omit[!complete.cases(prsa.omit),]
```

```
##       pm2.5 DEWP TEMP PRES cbwd       date
## 1        NA  -21  -11 1021   NW 2010-01-01
## 2        NA  -21  -12 1020   NW 2010-01-01
## 3        NA  -21  -11 1019   NW 2010-01-01
## 4        NA  -21  -14 1019   NW 2010-01-01
## 5        NA  -20  -12 1018   NW 2010-01-01
## 6        NA  -19  -10 1017   NW 2010-01-01
## 7        NA  -19   -9 1017   NW 2010-01-01
## 8        NA  -19   -9 1017   NW 2010-01-01
## 9        NA  -19   -9 1017   NW 2010-01-01
## 10       NA  -20   -8 1017   NW 2010-01-01
## 11       NA  -19   -7 1017   NW 2010-01-01
## 12       NA  -18   -5 1017   NW 2010-01-01
## 13       NA  -19   -5 1015   NW 2010-01-01
## 14       NA  -18   -3 1015   NW 2010-01-01
## 15       NA  -18   -2 1014   NW 2010-01-01
## 16       NA  -18   -1 1014   SW 2010-01-01
## 17       NA  -19   -2 1015   NW 2010-01-01
## 18       NA  -18   -3 1015   NW 2010-01-01
## 19       NA  -18   -5 1016   NE 2010-01-01
## 20       NA  -17   -4 1017   NW 2010-01-01
## 21       NA  -17   -5 1017   SW 2010-01-01
## 22       NA  -17   -5 1018   NW 2010-01-01
## 23       NA  -17   -5 1018   NW 2010-01-01
## 24       NA  -17   -5 1020   SW 2010-01-01
## 546      NA  -18    2 1024   NW 2010-01-23
## 547      NA  -18    1 1024   NW 2010-01-23
## 548      NA  -17    0 1024   NW 2010-01-23
## 549      NA  -18    0 1024   SE 2010-01-23
## 550      NA  -15   -3 1024   SW 2010-01-23
## 551      NA  -16    0 1023   NW 2010-01-23
## 552      NA  -16    0 1023   NW 2010-01-23
## 553      NA  -15   -2 1022   NW 2010-01-24
## 554      NA  -14   -7 1022   SW 2010-01-24
## 555      NA  -14   -8 1021   NW 2010-01-24
## 556      NA  -16  -11 1021   NW 2010-01-24
## 557      NA  -14   -9 1019   NW 2010-01-24
## 558      NA  -15  -10 1019   SW 2010-01-24
## 559      NA  -16  -12 1019   SE 2010-01-24
## 560      NA  -15  -12 1019   SW 2010-01-24
## 561      NA  -16  -13 1019   NE 2010-01-24
## 562      NA  -13   -7 1020   SW 2010-01-24
## 563      NA  -12   -4 1019   SW 2010-01-24
## 564      NA  -13    0 1019   SW 2010-01-24
## 565      NA  -16    4 1018   NW 2010-01-24
## 566      NA  -19    5 1017   NW 2010-01-24
## 567      NA  -18    5 1017   NW 2010-01-24
## 568      NA  -19    5 1017   NW 2010-01-24
## 569      NA  -20    5 1018   NW 2010-01-24
## 570      NA  -19    3 1020   NW 2010-01-24
## 571      NA  -18    1 1023   NW 2010-01-24
## 572      NA  -20   -1 1027   NW 2010-01-24
## 573      NA  -20   -2 1028   NW 2010-01-24
## 574      NA  -21   -3 1029   NW 2010-01-24
## 575      NA  -25   -4 1030   NW 2010-01-24
## 576      NA  -26   -5 1031   NW 2010-01-24
## 577      NA  -25   -5 1031   NW 2010-01-25
```

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## 579      NA  -24   -6 1032   NW 2010-01-25
## 580      NA  -24   -6 1033   NW 2010-01-25
## 581      NA  -23   -6 1033   NW 2010-01-25
## 582      NA  -22   -7 1033   NW 2010-01-25
## 583      NA  -21   -7 1033   NW 2010-01-25
## 584      NA  -21   -7 1034   NW 2010-01-25
## 585      NA  -21   -6 1035   NW 2010-01-25
## 586      NA  -21   -4 1036   NW 2010-01-25
## 587      NA  -22   -3 1036   NW 2010-01-25
## 588      NA  -22   -2 1036   NW 2010-01-25
## 589      NA  -23   -1 1035   NW 2010-01-25
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## 591      NA  -25    2 1032   NW 2010-01-25
## 592      NA  -25    2 1031   NW 2010-01-25
## 593      NA  -24    2 1031   NW 2010-01-25
## 594      NA  -22    1 1031   SE 2010-01-25
## 595      NA  -19   -1 1031   SE 2010-01-25
## 596      NA  -19   -1 1031   SE 2010-01-25
## 597      NA  -17   -4 1031   SE 2010-01-25
## 598      NA  -18   -1 1031   SE 2010-01-25
## 599      NA  -18   -5 1030   SW 2010-01-25
## 600      NA  -18   -3 1030   SE 2010-01-25
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## 602      NA  -16   -8 1029   SW 2010-01-26
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## 604      NA  -16  -12 1029   SW 2010-01-26
## 605      NA  -16  -10 1028   NW 2010-01-26
## 606      NA  -17  -10 1028   NW 2010-01-26
## 607      NA  -17  -12 1027   NW 2010-01-26
## 608      NA  -17  -10 1027   NW 2010-01-26
## 609      NA  -18  -13 1028   NE 2010-01-26
## 610      NA  -16   -8 1028   NW 2010-01-26
## 611      NA  -16   -6 1027   NW 2010-01-26
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## 2120     NA    6    8 1018   SE 2010-03-30
## 2121     NA    6    8 1019   SE 2010-03-30
## 2122     NA    6    9 1018   SE 2010-03-30
## 2123     NA    6   10 1018   SE 2010-03-30
## 2124     NA    6   11 1018   SE 2010-03-30
## 2125     NA    6   10 1018   SE 2010-03-30
## 2127     NA    7   10 1016   SE 2010-03-30
## 2128     NA    7   10 1016   SW 2010-03-30
## 2129     NA    7    9 1015   SW 2010-03-30
## 2130     NA    7    9 1014   NE 2010-03-30
## 2131     NA    7    9 1014   NE 2010-03-30
## 2132     NA    7    8 1015   SW 2010-03-30
## 2133     NA    7    8 1015   SE 2010-03-30
## 2134     NA    7    8 1015   SE 2010-03-30
## 2135     NA    7    8 1016   NE 2010-03-30
## 2136     NA    8    9 1015   NW 2010-03-30
## 2137     NA    7    8 1015   NW 2010-03-31
## 2138     NA    7    8 1015   SW 2010-03-31
```

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## 2140      NA    6    7 1014   SW 2010-03-31
## 2141      NA    6    7 1014   SE 2010-03-31
## 2142      NA    5    7 1014   SW 2010-03-31
## 2143      NA    5    7 1014   SW 2010-03-31
## 2146      NA    7   10 1015   SW 2010-03-31
## 2147      NA    7   12 1015   SW 2010-03-31
## 2148      NA    7   12 1014   SE 2010-03-31
## 2149      NA    7   13 1013   SW 2010-03-31
## 2150      NA    6   15 1013   SE 2010-03-31
## 2151      NA    6   16 1012   SW 2010-03-31
## 2152      NA    4   16 1012   SW 2010-03-31
## 2153      NA    1   17 1012   NW 2010-03-31
## 2172      NA  -18   11 1021   NW 2010-04-01
## 2173      NA  -17   12 1020   NW 2010-04-01
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## 3283      NA   13   19 1008   SW 2010-05-17
## 3524      NA   16   18 1015   NE 2010-05-27
## 3525      NA   16   18 1015   NE 2010-05-27
## 3526      NA   16   18 1015   NW 2010-05-27
## 3527      NA   16   18 1015   SW 2010-05-27
## 3528      NA   16   18 1014   SW 2010-05-27
## 3641      NA   15   25 1013   SE 2010-06-01
## 3647      NA   16   21 1014   SW 2010-06-01
## 3648      NA   17   20 1014   SW 2010-06-01
## 3649      NA   16   20 1014   SE 2010-06-02
## 3650      NA   14   18 1014   SE 2010-06-02
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## 3652      NA   15   17 1014   SW 2010-06-02
## 3653      NA   15   17 1015   SW 2010-06-02
## 3654      NA   15   17 1015   SE 2010-06-02
## 3655      NA   16   17 1016   NE 2010-06-02
## 3656      NA   15   18 1016   SW 2010-06-02
## 3657      NA   15   18 1017   SE 2010-06-02
## 3658      NA   15   18 1017   SE 2010-06-02
## 3659      NA   15   20 1017   SE 2010-06-02
## 3660      NA   15   20 1017   SE 2010-06-02
## 3661      NA   15   22 1017   SW 2010-06-02
## 3662      NA   15   24 1017   SE 2010-06-02
## 3663      NA   15   23 1016   NW 2010-06-02
## 3664      NA   14   24 1016   SW 2010-06-02
## 3665      NA   14   24 1016   SE 2010-06-02
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## 3712      NA   10   29 1013   SE 2010-06-04
## 3713      NA    9   29 1013   SE 2010-06-04
## 3714      NA    8   28 1013   SE 2010-06-04
## 3715      NA    8   27 1013   SE 2010-06-04
## 3716      NA   11   26 1013   SE 2010-06-04
## 3717      NA   11   25 1013   SE 2010-06-04
## 3718      NA   11   24 1013   SE 2010-06-04
## 3719      NA   13   21 1014   SE 2010-06-04
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## 3721      NA   12   20 1014   SE 2010-06-05
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## 3723      NA   11   18 1014   SW 2010-06-05
## 3724      NA   11   17 1013   SW 2010-06-05
```

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## 3725      NA   12   17 1014   SE 2010-06-05
## 3726      NA   12   16 1014   SE 2010-06-05
## 3727      NA   14   18 1014   SE 2010-06-05
## 3728      NA   15   19 1014   SE 2010-06-05
## 3729      NA   15   21 1014   SW 2010-06-05
## 3730      NA   15   23 1014   SW 2010-06-05
## 3731      NA   14   24 1014   SW 2010-06-05
## 3732      NA   14   27 1013   SE 2010-06-05
## 3733      NA   13   28 1013   SW 2010-06-05
## 3734      NA   11   30 1011   SE 2010-06-05
## 3735      NA   11   30 1011   SW 2010-06-05
## 3736      NA   12   31 1010   SE 2010-06-05
## 3737      NA   12   30 1009   SE 2010-06-05
## 3738      NA   12   29 1009   SE 2010-06-05
## 3739      NA   11   29 1009   SE 2010-06-05
## 3740      NA    9   28 1009   SE 2010-06-05
## 3741      NA   11   26 1010   SE 2010-06-05
## 3742      NA   13   24 1010   SE 2010-06-05
## 3743      NA   12   23 1011   SE 2010-06-05
## 3744      NA   12   22 1011   SE 2010-06-05
## 3745      NA   12   21 1011   SE 2010-06-06
## 3746      NA   12   21 1011   SE 2010-06-06
## 3747      NA   11   20 1011   SW 2010-06-06
## 3748      NA   11   19 1011   SW 2010-06-06
## 3749      NA   12   17 1012   NE 2010-06-06
## 3750      NA   12   17 1012   SE 2010-06-06
## 3751      NA   13   18 1012   SW 2010-06-06
## 3752      NA   14   22 1013   SE 2010-06-06
## 3753      NA   14   22 1013   SE 2010-06-06
## 3754      NA   14   24 1013   SE 2010-06-06
## 3755      NA   15   26 1013   SE 2010-06-06
## 3756      NA   15   28 1013   SW 2010-06-06
## 3757      NA   15   29 1012   SE 2010-06-06
## 3758      NA   10   31 1011   SE 2010-06-06
## 3759      NA   10   32 1010   SE 2010-06-06
## 3760      NA   11   31 1010   SE 2010-06-06
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## 3762      NA   12   30 1009   SE 2010-06-06
## 3763      NA   11   30 1009   SE 2010-06-06
## 3764      NA   11   28 1009   SE 2010-06-06
## 3765      NA   13   26 1010   SE 2010-06-06
## 3766      NA   14   25 1011   SE 2010-06-06
## 3767      NA   14   24 1011   SE 2010-06-06
## 3768      NA   15   24 1011   SE 2010-06-06
## 3769      NA   16   23 1012   SE 2010-06-07
## 3770      NA   17   22 1012   SE 2010-06-07
## 3771      NA   17   21 1012   SE 2010-06-07
## 3772      NA   16   20 1012   SW 2010-06-07
## 3773      NA   16   20 1012   SW 2010-06-07
## 3774      NA   16   20 1013   SE 2010-06-07
## 3775      NA   17   21 1013   SE 2010-06-07
## 3776      NA   17   22 1014   SE 2010-06-07
## 3777      NA   18   23 1014   SE 2010-06-07
## 3778      NA   18   25 1014   SE 2010-06-07
## 3779      NA   17   26 1014   SW 2010-06-07
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## 3797      NA   14   20 1014   SW 2010-06-08
## 3798      NA   14   20 1014   SW 2010-06-08
```

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## 3803     NA   14   27 1015   SE 2010-06-08
## 3804     NA   15   28 1015   SW 2010-06-08
## 3805     NA   14   30 1014   SW 2010-06-08
## 3806     NA   11   31 1013   SE 2010-06-08
## 3807     NA   11   32 1013   SE 2010-06-08
## 3808     NA   11   33 1013   SE 2010-06-08
## 3809     NA   11   30 1012   SE 2010-06-08
## 3810     NA   10   30 1012   SE 2010-06-08
## 3811     NA   11   29 1012   SE 2010-06-08
## 3812     NA   12   29 1012   SE 2010-06-08
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## 3814     NA   11   26 1014   SE 2010-06-08
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## 3816     NA   12   24 1014   SE 2010-06-08
## 3817     NA   12   23 1014   SE 2010-06-09
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## 3820     NA   13   20 1014   SE 2010-06-09
## 3821     NA   14   21 1014   SE 2010-06-09
## 3822     NA   13   20 1014   SW 2010-06-09
## 3823     NA   14   20 1015   NE 2010-06-09
## 3824     NA   14   23 1015   NW 2010-06-09
## 3825     NA   13   24 1015   NW 2010-06-09
## 3826     NA   12   26 1015   NE 2010-06-09
## 3827     NA   11   28 1015   SW 2010-06-09
## 3828     NA   11   28 1015   SW 2010-06-09
## 3829     NA   11   29 1015   SW 2010-06-09
## 3830     NA   11   30 1013   SE 2010-06-09
## 3831     NA   10   30 1013   SW 2010-06-09
## 3832     NA   11   31 1013   SW 2010-06-09
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## 4089     NA   18   27 1009   NW 2010-06-20
## 4090     NA   17   29 1009   NW 2010-06-20
## 4139     NA   19   29 1005   SE 2010-06-22
## 4140     NA   19   30 1005   SE 2010-06-22
## 4141     NA   17   30 1006   SE 2010-06-22
## 4142     NA   16   29 1006   SE 2010-06-22
## 4143     NA   15   29 1005   SE 2010-06-22
## 4144     NA   16   30 1005   SE 2010-06-22
## 4145     NA   15   29 1005   SE 2010-06-22
## 4146     NA   15   29 1006   SE 2010-06-22
## 4147     NA   16   28 1006   SE 2010-06-22
## 4148     NA   15   26 1007   SE 2010-06-22
## 4149     NA   14   25 1008   SE 2010-06-22
## 4150     NA   13   24 1009   SE 2010-06-22
## 4151     NA   13   24 1009   SE 2010-06-22
## 4152     NA   14   23 1009   SW 2010-06-22
## 4153     NA   13   23 1010   SE 2010-06-23
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## 4159     NA   14   22 1011   SW 2010-06-23
```

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## 4161      NA    8   24 1011   SW 2010-06-23
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## 5398      NA   25   27 1001   SE 2010-08-13
## 5399      NA   25   27 1001   NE 2010-08-13
## 5400      NA   25   26 1000   SE 2010-08-13
## 5401      NA   24   26  999   SE 2010-08-14
## 5402      NA   24   26  999   SE 2010-08-14
## 5403      NA   24   25  999   NE 2010-08-14
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## 5405      NA   23   25  999   SW 2010-08-14
## 5406      NA   23   24  998   NE 2010-08-14
## 5407      NA   22   23  999   NW 2010-08-14
## 5408      NA   23   25  999   SW 2010-08-14
## 5409      NA   24   26  999   SW 2010-08-14
## 5410      NA   23   29  999   SW 2010-08-14
## 5411      NA   18   31  999   NW 2010-08-14
## 5412      NA   13   33  999   NW 2010-08-14
## 5413      NA   -1   35  999   NW 2010-08-14
## 5414      NA    0   35  998   NW 2010-08-14
## 5415      NA    1   36  998   NW 2010-08-14
## 5416      NA    3   36  998   NW 2010-08-14
## 5417      NA    2   35  998   NW 2010-08-14
## 5418      NA    5   35  999   NW 2010-08-14
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## 5422      NA    9   26 1002   SW 2010-08-14
## 5423      NA    9   28 1002   NW 2010-08-14
## 5424      NA    9   28 1003   NW 2010-08-14
## 5425      NA    9   27 1003   NW 2010-08-15
## 5426      NA    9   27 1003   NW 2010-08-15
## 5427      NA    9   26 1003   NW 2010-08-15
## 5428      NA    9   26 1003   NW 2010-08-15
## 5429      NA   10   25 1003   NW 2010-08-15
## 5430      NA   10   24 1004   NW 2010-08-15
## 5431      NA   12   21 1004   NW 2010-08-15
## 5432      NA   11   26 1005   NW 2010-08-15
## 5433      NA   12   28 1005   NW 2010-08-15
## 5434      NA   10   30 1005   NW 2010-08-15
## 5435      NA    9   31 1006   NW 2010-08-15
## 5436      NA    8   33 1005   NW 2010-08-15
## 5437      NA    9   34 1005   NW 2010-08-15
## 5438      NA    9   35 1004   SW 2010-08-15
## 5439      NA   10   33 1004   SE 2010-08-15
## 5440      NA   11   33 1004   SW 2010-08-15
## 5441      NA   12   33 1004   SE 2010-08-15
## 5442      NA   12   32 1004   SE 2010-08-15
## 5443      NA   13   31 1004   SE 2010-08-15
## 5444      NA   13   30 1004   SE 2010-08-15
## 5445      NA   13   29 1005   SE 2010-08-15
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## 5447      NA   15   25 1006   SW 2010-08-15
## 5448      NA   17   23 1006   SW 2010-08-15
## 5449      NA   17   23 1006   NE 2010-08-16
## 5450      NA   17   23 1006   SW 2010-08-16
## 5451      NA   17   22 1007   NE 2010-08-16
```

```
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## 5453      NA   17   21 1007   NE 2010-08-16
## 5454      NA   17   20 1007   NW 2010-08-16
## 5455      NA   17   20 1008   NW 2010-08-16
## 5456      NA   17   24 1008   NW 2010-08-16
## 5457      NA   15   26 1008   NE 2010-08-16
## 5458      NA   16   28 1008   NE 2010-08-16
## 5459      NA   15   31 1008   SW 2010-08-16
## 5460      NA   16   31 1008   SW 2010-08-16
## 5461      NA   16   33 1007   SW 2010-08-16
## 5462      NA   16   34 1007   SW 2010-08-16
## 5463      NA   14   35 1006   SE 2010-08-16
## 5464      NA   14   35 1005   SE 2010-08-16
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## 6080      NA   13   19 1010   NW 2010-09-11
## 6081      NA   13   23 1010   NW 2010-09-11
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## 6083      NA   11   27 1011   NW 2010-09-11
## 6084      NA   11   29 1010   NW 2010-09-11
## 6085      NA   11   31 1010   NW 2010-09-11
## 6086      NA   11   31 1009   NW 2010-09-11
## 6087      NA   12   31 1008   NE 2010-09-11
## 6088      NA   12   32 1008   SW 2010-09-11
## 6089      NA   11   32 1008   SE 2010-09-11
## 6090      NA   12   31 1008   SE 2010-09-11
## 6091      NA   14   28 1008   SE 2010-09-11
## 6092      NA   13   26 1008   SE 2010-09-11
## 6093      NA   14   23 1009   SE 2010-09-11
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## 17884    NA  -12   -9 1021   NE 2012-01-16
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## 17887    NA  -12   -7 1020   NW 2012-01-16
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## 35011    NA  -24    2 1016   SE 2013-12-29
## 35012    NA  -23    4 1017   SE 2013-12-29
## 35013    NA  -23    1 1017   SE 2013-12-29
## 35014    NA  -23    4 1017   SW 2013-12-29
## 35015    NA  -18   -3 1017   SW 2013-12-29
## 35016    NA  -17   -2 1017   SW 2013-12-29
## 35017    NA  -23    3 1017   NW 2013-12-30
## 35018    NA  -23    2 1017   NW 2013-12-30
## 35019    NA  -24    3 1017   NW 2013-12-30
## 35020    NA  -24    3 1017   NW 2013-12-30
## 35021    NA  -24    1 1016   NW 2013-12-30
## 35022    NA  -24    1 1016   NW 2013-12-30
## 35023    NA  -24    0 1016   NW 2013-12-30
## 35024    NA  -23    3 1016   NW 2013-12-30
## 35025    NA  -23    3 1017   NW 2013-12-30
## 35026    NA  -23    4 1017   NW 2013-12-30
## 35027    NA  -22    5 1017   NW 2013-12-30
## 35330    NA  -21   -1 1033   NW 2014-01-12
## 35331    NA  -24   -1 1034   NW 2014-01-12
```

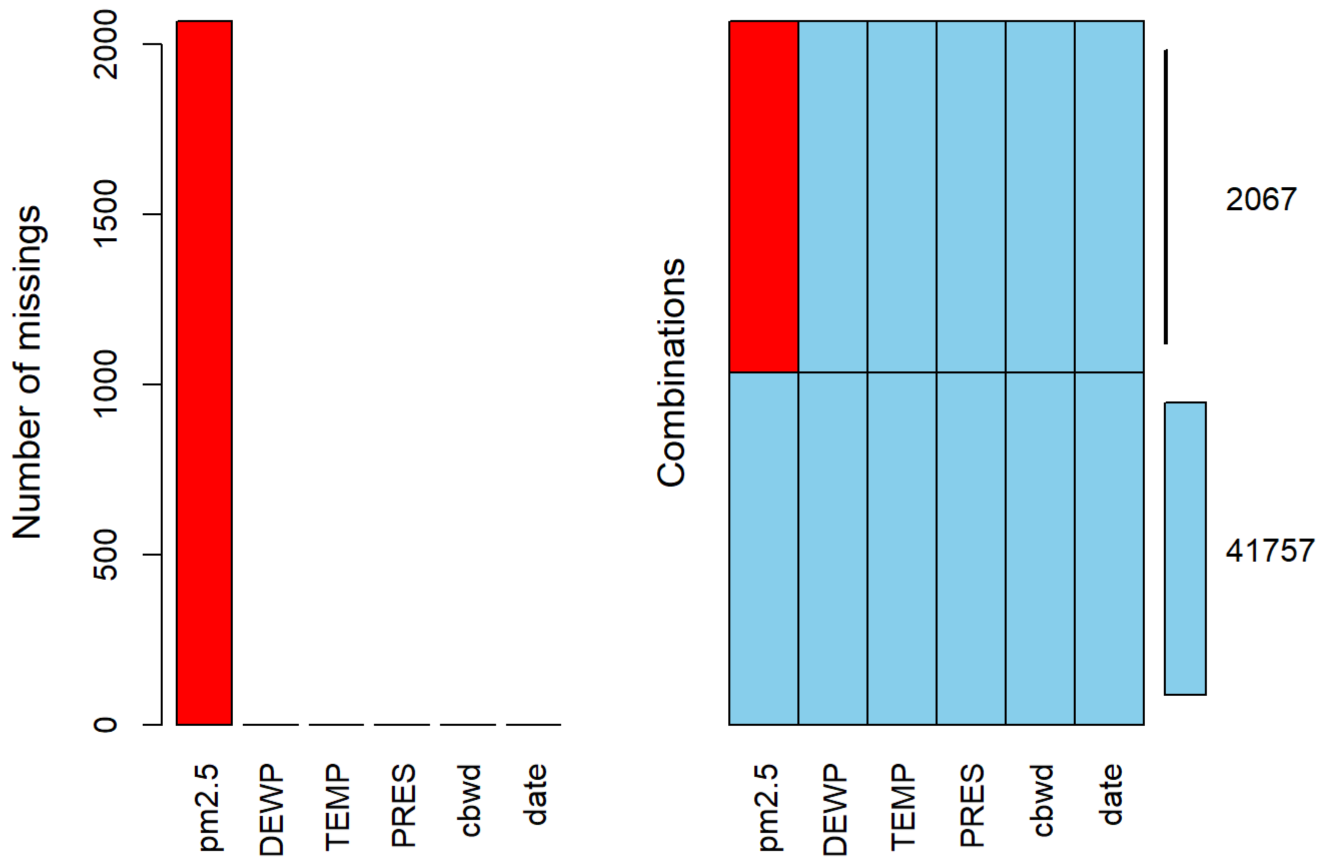
```
## 35332    NA  -22   -3 1035   NW 2014-01-12
## 35333    NA  -23   -6 1035   NW 2014-01-12
## 35334    NA  -22   -7 1035   NW 2014-01-12
## 35585    NA  -21    5 1021   SE 2014-01-22
## 35586    NA  -21    4 1021   SW 2014-01-22
## 36234    NA  -12    2 1028   SE 2014-02-18
## 36276    NA   -6    0 1032   SE 2014-02-20
## 36339    NA   -5    2 1032   SE 2014-02-23
## 36977    NA  -18   22 1016   SE 2014-03-21
## 37456    NA   -7   18 1021   SE 2014-04-10
## 37553    NA    9   26 1013   SE 2014-04-14
## 37554    NA    9   25 1013   SE 2014-04-14
## 38412    NA    8   28 1005   NE 2014-05-20
## 38413    NA    9   29 1005   SE 2014-05-20
## 38785    NA   15   26 1005   NW 2014-06-05
## 38809    NA   16   27 1003   SE 2014-06-06
## 38833    NA   14   16 1005   SW 2014-06-07
## 38857    NA   15   19 1003   SW 2014-06-08
## 38881    NA   14   17 1002   NW 2014-06-09
## 38883    NA   13   15 1002   NW 2014-06-09
## 38884    NA   13   15 1003   SW 2014-06-09
## 38885    NA   14   16 1004   NE 2014-06-09
## 38886    NA   13   14 1004   SW 2014-06-09
## 38887    NA   15   16 1005   NW 2014-06-09
## 38888    NA   14   19 1005   NW 2014-06-09
## 38889    NA   14   22 1005   NW 2014-06-09
## 38890    NA   14   24 1005   SW 2014-06-09
## 38891    NA   13   25 1005   SW 2014-06-09
## 39111    NA   16   30 1001   SW 2014-06-18
## 39113    NA   16   31 1000   SE 2014-06-18
## 39114    NA   17   30 1000   SE 2014-06-18
## 39686    NA   11   33 1002   NE 2014-07-12
## 39687    NA   10   33 1001   SE 2014-07-12
## 39688    NA   10   34 1001   SE 2014-07-12
## 39689    NA   10   34 1000   SE 2014-07-12
## 39690    NA   10   34 1000   SE 2014-07-12
## 39924    NA   17   29 1007   NE 2014-07-22
## 39925    NA   16   29 1007   NW 2014-07-22
## 40577    NA   18   30 1010   SE 2014-08-18
## 40578    NA   18   30 1010   SE 2014-08-18
## 40625    NA   17   33 1006   SE 2014-08-20
## 40626    NA   18   32 1006   SE 2014-08-20
## 40627    NA   18   31 1006   SE 2014-08-20
## 40628    NA   18   29 1007   SE 2014-08-20
## 40629    NA   19   28 1007   SE 2014-08-20
## 40630    NA   19   28 1007   SE 2014-08-20
## 40631    NA   19   27 1008   SE 2014-08-20
## 40632    NA   19   27 1008   SE 2014-08-20
## 40633    NA   19   26 1008   SE 2014-08-21
## 41264    NA    9   15 1019   SW 2014-09-16
## 41277    NA   14   18 1018   SE 2014-09-16
## 41348    NA   17   19 1010   SE 2014-09-19
## 41441    NA   17   18 1016   SW 2014-09-23
## 41444    NA   18   18 1016   SW 2014-09-23
## 42089    NA   13   17 1018   SE 2014-10-20
## 42491    NA   -8    9 1032   NE 2014-11-06
## 42666    NA  -13   12 1022   NW 2014-11-13
## 42838    NA   -2    0 1019   NE 2014-11-20
```

```
## 42839    NA   -1    0 1020   SW 2014-11-20
## 42840    NA    0    0 1020   SW 2014-11-20
## 42841    NA   -2   -2 1020   NW 2014-11-21
## 42842    NA   -3   -2 1020   NW 2014-11-21
## 42843    NA   -2   -1 1020   NW 2014-11-21
## 42844    NA   -2   -1 1019   NW 2014-11-21
## 42845    NA   -1    1 1019   SW 2014-11-21
## 42846    NA   -2    0 1019   NW 2014-11-21
## 42847    NA   -2    0 1019   NW 2014-11-21
## 42848    NA   -3    0 1020   NW 2014-11-21
## 42849    NA   -3    0 1020   SW 2014-11-21
## 43191    NA  -22    4 1025   NW 2014-12-05
## 43192    NA  -22    3 1025   NE 2014-12-05
## 43265    NA  -13    3 1033   SW 2014-12-08
## 43267    NA  -11   -2 1034   SE 2014-12-08
## 43268    NA  -11   -2 1035   SE 2014-12-08
## 43269    NA  -11   -4 1036   SE 2014-12-08
## 43270    NA  -11   -5 1036   SE 2014-12-08
## 43271    NA  -11   -5 1036   NE 2014-12-08
## 43274    NA  -11   -4 1037   SW 2014-12-09
## 43275    NA  -10   -5 1036   SE 2014-12-09
## 43276    NA  -10   -6 1037   SW 2014-12-09
## 43277    NA  -10   -7 1036   SW 2014-12-09
## 43278    NA  -11   -6 1036   SW 2014-12-09
## 43279    NA  -11   -7 1036   SW 2014-12-09
## 43280    NA  -11   -8 1036   SW 2014-12-09
## 43281    NA   -9   -6 1036   SE 2014-12-09
## 43282    NA   -8   -5 1037   NE 2014-12-09
## 43283    NA   -8   -4 1037   SW 2014-12-09
## 43284    NA   -8   -3 1036   NE 2014-12-09
## 43545    NA  -18   -4 1031   NW 2014-12-20
## 43546    NA  -17   -4 1031   NW 2014-12-20
## 43547    NA  -18   -2 1031   NW 2014-12-20
## 43548    NA  -17   -1 1031   NW 2014-12-20
## 43549    NA  -18    0 1030   NW 2014-12-20
## 43550    NA  -19    1 1029   NW 2014-12-20
## 43551    NA  -20    1 1029   NW 2014-12-20
## 43552    NA  -20    2 1028   NW 2014-12-20
## 43553    NA  -21    1 1028   NW 2014-12-20
```

```
sum(is.na(prsa.omit))
```

```
## [1] 2067
```

```
aggr(prsa.omit,prop=F,numbers=T)
```



The total number of NAs is 2067

Impute the missing data

```
newdata <- prsa.omit
data <- mice(newdata, m=5, method = 'pmm', maxit = 10, seed = 1)
```

```
##
##  iter imp variable
##   1   1  pm2.5
##   1   2  pm2.5
##   1   3  pm2.5
##   1   4  pm2.5
##   1   5  pm2.5
##   2   1  pm2.5
##   2   2  pm2.5
##   2   3  pm2.5
##   2   4  pm2.5
##   2   5  pm2.5
##   3   1  pm2.5
##   3   2  pm2.5
##   3   3  pm2.5
##   3   4  pm2.5
##   3   5  pm2.5
##   4   1  pm2.5
##   4   2  pm2.5
##   4   3  pm2.5
##   4   4  pm2.5
##   4   5  pm2.5
##   5   1  pm2.5
##   5   2  pm2.5
##   5   3  pm2.5
##   5   4  pm2.5
##   5   5  pm2.5
##   6   1  pm2.5
##   6   2  pm2.5
##   6   3  pm2.5
##   6   4  pm2.5
##   6   5  pm2.5
##   7   1  pm2.5
##   7   2  pm2.5
##   7   3  pm2.5
##   7   4  pm2.5
##   7   5  pm2.5
##   8   1  pm2.5
##   8   2  pm2.5
##   8   3  pm2.5
##   8   4  pm2.5
##   8   5  pm2.5
##   9   1  pm2.5
##   9   2  pm2.5
##   9   3  pm2.5
##   9   4  pm2.5
##   9   5  pm2.5
##   10   1  pm2.5
##   10   2  pm2.5
##   10   3  pm2.5
##   10   4  pm2.5
##   10   5  pm2.5
```

```
data$imp
```

```
## $pm2.5
##         1   2   3   4   5
## 1     345 129 170 148 101
## 2      94 286 198 178 179
## 3     149 119 114 255 328
## 4     129 133 266 111 148
## 5      39  77  34  23  83
## 6     189 121 113 124  33
## 7      48 200  70  29 167
## 8     153 138  21 175 132
## 9     194 138  96 171  91
## 10     86 129  82  87  89
## 11     81 164  59 109  22
## 12     21  72  61  56 148
## 13     48  15 123  39  84
## 14     19  63  20  60 222
## 15     93  39  73 146  92
## 16    317 226 176  94 168
## 17    183 457 286  54  51
## 18     49  40   7  81  13
## 19    118  72 185  66  66
## 20    258 113  52 240  80
## 21     60 201 433 124 162
## 22     59  46  55  53  86
## 23     77 102  89  47  59
## 24     28  60 172 123  67
## 546    18  19  64  12  61
## 547    57   9  39  19  20
## 548     9  19  10  16  32
## 549   303 119  12  34 136
## 550    89 172 190  77  31
## 551    32   8  90  71  55
## 552    32   6  49  19  19
## 553    79  62 113  24  58
## 554    91 252  90 141 346
## 555   233 176  64  41  40
## 556   331 169 225 205 160
## 557    90 198   9 168  98
## 558   318  77 398 183 253
## 559   170 192 151 132 227
## 560   304 322 304 469 322
## 561    24 115 195 397 140
## 562   253 459 227 159  81
## 563   191 259  86 140 259
## 564    13  61  32 290  57
## 565    58  24  12   6  93
## 566    86  54 121  15  44
## 567    44  59  75   2 106
## 568    87   9  19  17  11
## 569    15  16  11  15  11
## 570    11  45  10  18  26
## 571    11  24  16  15  22
## 572    12  52  32  11  86
## 573    14  98  68  45  82
## 574    73  34  22 110  15
## 575    27  13  17 165   8
## 576    23  26  12   7  31
```

```
## 577    24  11  40  48   6
## 578    75 148  11  50  58
## 579   190  23  38  39   9
## 580   148  22  14  30  18
## 581    22  22  53  22  10
## 582     9  69  62 110 144
## 583    93  76 133  16  16
## 584    74  76 202  30  11
## 585    47  18 194  67  14
## 586    45  11  42  31  41
## 587    24  18  14  62  20
## 588    50   9  13  16   8
## 589     9  63  18   9  13
## 590    38  17  13  20  41
## 591     9  14  22  22  13
## 592     8  31  10   8  34
## 593    12  13 165  24  12
## 594    32  10  15  78  46
## 595    11 105  90  54 210
## 596   249   9  68 104 139
## 597    76  30  32  69 113
## 598   141 192 230 246 117
## 599    62  29  31 101 284
## 600     9  50  26  49 194
## 601    95 147  68  68 125
## 602   218  71 153 141  99
## 603   353  97  80 144 493
## 604   286 196  64 115 115
## 605   130 221   1 152  70
## 606   208  54 118 160  25
## 607   142 250 160 163 143
## 608   126   9 119  17  28
## 609    78  95 142  31  80
## 610    91  87 124 152  63
## 611   295 107 141  17  53
## 612   139  17  75 115  88
## 1059   60 309 111  21  20
## 1878  415 391 132 824 247
## 1879   37 130  45  11  82
## 1944   59  17  15  59  67
## 2119  267  78  77 122 163
## 2120  267 222  97 230 187
## 2121   30  98  33 120 101
## 2122   84 104 107 346  99
## 2123  215  87  87 184 170
## 2124  121  92  51  81  50
## 2125  395  30 289  73 186
## 2127  191 204 124 315  17
## 2128  118 278  83 211  38
## 2129  158 113 152  57  77
## 2130   86  83  23 170 222
## 2131   75  83  23 244  58
## 2132  230  47 166  95 106
## 2133  176  77 178  73 154
## 2134  176  94 178 266 105
## 2135  209 225 232 117 167
## 2136   50 176  48  35 244
## 2137  115  69 141 167  92
```

```
## 2138  213  98 166 149 159
## 2139  321 184  89  91  78
## 2140   30 165 174 250  91
## 2141  164  76 286 273  30
## 2142   99 166  77  19 200
## 2143  112 166  60  19 595
## 2146  269 164 111 107  26
## 2147  111 198 154 277  25
## 2148  196  87  31  71 200
## 2149   93  93  66  88 189
## 2150  285  90  52  74 107
## 2151   36 197 103  69 128
## 2152   85 100  94  55  54
## 2153  128  39  77  47  47
## 2172   81  15   9  26  12
## 2173   14  34  48  14  15
## 3282   53 212  52 116 198
## 3283  362 255 169 324 205
## 3524  128  31  99 270  66
## 3525  120  31 213 144  98
## 3526   88  11  71  92  99
## 3527   91 228 152  63 352
## 3528  414 112 129 160 316
## 3641   87  57  69  12  40
## 3647  143 293 189  61  53
## 3648  290 113 137 193 147
## 3649   49 323 111 286 105
## 3650   47  37 150 100  80
## 3651   36 161   5 100 128
## 3652  206 210 140 245  46
## 3653   67 118 245 200  73
## 3654  282 167  30 235 126
## 3655   90  21 105  57 307
## 3656  324  73  57 106 125
## 3657  178  30  47  68  62
## 3658  183  51 105  16  62
## 3659   46 110 103 155  91
## 3660   75 111 113 146 134
## 3661  251  65  57  20  37
## 3662  153  79 109  21  95
## 3663   42  28  85  10   5
## 3664   21 104  57 145  78
## 3665   39  17  54  72  37
## 3709   27  15  30  24   8
## 3710  210  13   9  31  28
## 3711   12  74  12  16  73
## 3712   43  17  17  17  66
## 3713   40  56  59  59  15
## 3714   28  11  11  10  14
## 3715   19  79   3  36  52
## 3716  144  22  50  19 106
## 3717   64  27  13  64 215
## 3718   20  52  95  49  15
## 3719  172 317  52  62  74
## 3720    3  29  21  73  35
## 3721   80 152 170  48  90
## 3722  190 197  19 111 247
## 3723  173 135   9  44 111
```

```
## 3724   96  39  37  55  26
## 3725   48 137  70  43 131
## 3726  184 102 121 237 139
## 3727   55  61  97 117  51
## 3728  249 393 517  48 132
## 3729  255  35 128  36  57
## 3730  108  66 110  85  94
## 3731   58  74 153 193 121
## 3732   52  59  53  32  63
## 3733  113  50  82  75 222
## 3734    7  11  11  23   6
## 3735   32 183  12  16 156
## 3736   61   7  53  53  42
## 3737  130  13  48  61   8
## 3738    6  11  22  59  59
## 3739   48  17 104 100  24
## 3740   13  37  36  15  20
## 3741   18  38   6  41   9
## 3742   43  56 248  44  27
## 3743   52  55 119  38  52
## 3744   43 261 143 192  29
## 3745   66  89 114 217  22
## 3746  155  95  32 236  63
## 3747  208  55 180  42 236
## 3748   15 117  61  90 157
## 3749  213  44 179 104  25
## 3750  306 124  99  59 142
## 3751   77 187 213 107  83
## 3752  234  48  82  61  52
## 3753  234  69 180 238 289
## 3754  114  80  93 102 100
## 3755   29  97  14  36 242
## 3756   16 146  20 164  39
## 3757   16  26  14  10  92
## 3758   44   8  16  65  13
## 3759   11   8   9  12  31
## 3760    9  47  27  13  27
## 3761   22  20  34 129  69
## 3762   41  33  79  14   8
## 3763   80  39 116  13   9
## 3764   36  62  14  12  37
## 3765   42  18  42  30  88
## 3766   90  44  39  93 214
## 3767   17  42  57 136  51
## 3768  261  22  18  29 185
## 3769   66  73 320  42  72
## 3770   23  85  35 227 246
## 3771  144 315  81  62 373
## 3772   61 275 100 146 155
## 3773   22 224 109 109 155
## 3774  136  46 208  40  89
## 3775  140  38  99  17  20
## 3776  156 179 293 137  96
## 3777   52 157  87  64 324
## 3778   67  69 239 178 229
## 3779   37 137 119 118  16
## 3780   10  43 159  24  16
## 3797   54  74  69  60  82
```

```
## 3798   44  74 176  56  82
## 3799  108  55 109 201  96
## 3800  100 163 193  77  13
## 3801  112  18 117 175 128
## 3802   48   9  51 106 143
## 3803    9   5  51  46  54
## 3804   95  24  35  44  35
## 3805   75 106  11  16   9
## 3806   18  23  16  11  22
## 3807    8  11  25  23  13
## 3808   16  16   9  25   7
## 3809   11   7  30  79  12
## 3810   39  48  18  45  92
## 3811   82  10  53  20 167
## 3812   16  16  17  40 101
## 3813   19 158  43  27  19
## 3814  105 176  92 100  46
## 3815  175  15 150 107  97
## 3816   92  38  44  60 144
## 3817  273  88  48  98  64
## 3818  109 149  57  19  16
## 3819   87 114  69 151 140
## 3820   79  27  90 196   9
## 3821   93 196  88 167  79
## 3822  230  32  34  31 219
## 3823   34  23 151 250  50
## 3824    9  25  10  18 105
## 3825   38  18  15 108  92
## 3826  115  51  24  14  11
## 3827   18  34  20  21   7
## 3828  110  96 138   7  27
## 3829    3  14  32 105  20
## 3830   25  17  72  19  39
## 3831    8  48  28  15   8
## 3832   24  49  13   8  36
## 3833   12   9  10  43  16
## 4089   62  16  40  75  36
## 4090   12  34  37  15  45
## 4139   51  36  22  45  88
## 4140  134  85  27  73 117
## 4141   56  97  23 109  96
## 4142   79  60  32 149  21
## 4143   16  31  14  16  64
## 4144   32  10  77  14  56
## 4145  113  31 201  16  51
## 4146   11  14 118 156  49
## 4147   71  47 167  39  23
## 4148   53  96 137  39  19
## 4149  115 292 104  22 146
## 4150  112  12 131  14  13
## 4151  112  15 130  24 156
## 4152   12  97 467 107  53
## 4153   11  36  29  17  13
## 4154  151 184 132 201  41
## 4155   32  73 101  37 140
## 4156  212 110  49  58 139
## 4157   94 138  63  71 393
## 4158   55  68  10 184 309
```

```
## 4159   77 147  87  62  62
## 4160   78  10  10  43 242
## 4161   70  31  50 144 295
## 4162   47  63  45  16  41
## 5397  126 205  85 196  70
## 5398  148  60  66 245  44
## 5399   88  11  56  66  28
## 5400   29 174 223 164 805
## 5401   69  29  54 169  69
## 5402   69  42  54  83 140
## 5403   80  36  48 126 193
## 5404   37 231  68  98 229
## 5405   64 272 225 201  62
## 5406  246 123  76  98 111
## 5407   96  25   8  30 157
## 5408   75 178  63 109  79
## 5409  209  60 102  26 329
## 5410   63  80 133  39  50
## 5411   95  61   9  19  46
## 5412   29  25  38  10  59
## 5413   18  44  65  31  31
## 5414   10  11   7  70  10
## 5415    7   5  20  44  11
## 5416   15  14  17   5  25
## 5417   37   1   4  10   6
## 5418   15  15  10  27  18
## 5419   29   8  17  13  13
## 5420   33  31  18   3  12
## 5421   27  41  12  21  36
## 5422   24  10  11  63  79
## 5423   10  14  13  16  14
## 5424  115  59  11  26  10
## 5425   15  23  33  28  14
## 5426   33  13  92  43   6
## 5427   28   8  15  15   2
## 5428   28   8  34  16  45
## 5429   18   4  10  70  99
## 5430   16  83  47   9  61
## 5431  133  14   7 337  86
## 5432   14 120  13   8  29
## 5433   10  38  11  14  49
## 5434   89  20  54  17  23
## 5435    5   7  34  39  15
## 5436   23  36  33  67  15
## 5437    8  17   9   7  15
## 5438   42  12  13  17   6
## 5439   22  13  36  19  13
## 5440   99  14  17  75  12
## 5441   28  16  20   7  19
## 5442   19  61  15  41  24
## 5443   76  69  32  42 117
## 5444  168  63  26  41 223
## 5445   70  13  51  12  11
## 5446   17  51 157  24  29
## 5447  266  51  98  84 176
## 5448   98 135 124  74  82
## 5449  100 206  74  93  25
## 5450  112  71 135  25  96
```

```
## 5451   89  59  38  21  58
## 5452   22 113  20  34  38
## 5453   62  31  29 102  38
## 5454   36 166  85  57 185
## 5455   64  50 176 116  81
## 5456    9  21 117  15   6
## 5457  123  36  11   9  63
## 5458   52  20  61   5  46
## 5459   21  79   6   7  20
## 5460  188  47   8  18 114
## 5461   56  37  48  17  11
## 5462   71  11 129  72   6
## 5463   13  33   3   9  79
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## 6084   59   6  29  11  42
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## 6086   84   7  12  12  22
## 6087   10  13  39  83  29
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## 6286   78 171  62  45 119
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## 6330   55  21  86 238 118
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## 6340  307  92  25 196  23
```

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## 6397   27 140  51 146 130
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## 6514   71 138  70  33 110
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```

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```

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```

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## 10582 232 213  30  91  80
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## 22573  61  64  11  26  48
## 22574  33  10  24  14  12
## 22575  15  20  79  13  32
## 22576  28  32  21 102  77
## 22577  98  13  11  14   8
## 22578  27  34 205 245 115
## 22579 152  30   9  28  22
## 22580 108  20  28 118 217
## 22581  65 105 194 235 407
## 22582 105 198 240  40 138
## 22583 240  79 133  55  94
## 22584 193 107 195   8  79
## 22585  29 118  16 144 132
## 22586  12  17  69 140  89
## 22587 133  43 163  37  86
## 22588  41 193  90  67 397
## 22589  55  57 256  46  50
## 22590  88 320 309  88  66
## 22591  92  24 101 172   2
## 22592 246 226 121  10 154
## 22593 136  11  72 136  49
## 22594 171  10  16 230  22
## 22595  73  71  36  85  68
## 22596 154 231  61 112  18
## 22597  98 391  65  98  47
## 22630  88  39 244 195  51
## 22697  92 254  23  71  48
## 22890 188 139  78  81  64
## 22891  68  98 196  36  49
## 22892 115 150  69 104  21
## 22893 138 273 226 111 177
## 22894 112  88  36  18  65
## 22895  91  24 254  64  67
## 22896 128  38  50 216  97
## 22897 121 361 114 219  61
## 22898  26 361 114  88  94
## 22899  26  24  96 247 261
## 22900  43  24  96  52  86
## 22901 150 140  63 120  90
## 22902 159 121 114 219 261
## 22903 125 140 258 123  90
## 22904 145  81 169 107 132
## 22905  88  58  78 283  69
## 22906  61  82  84 410 367
```

```
## 22907  18  43  92  19  74
## 22908 185  99  99  25 357
## 22909  74  99 113  53 130
## 22910  42  16 470 227  42
## 22911 252  75  87  36  22
## 22912 131  47  87  36  52
## 22913  56 179 229  47 170
## 22914  90 215 120 220  45
## 22915  49  12  52  61  71
## 22916  81  19 573 479 149
## 22917  55 135 374 213  94
## 22918 263 143 234 446  85
## 22919  86  21 125  50 132
## 22920  50  82  98 153 190
## 22921  66 160 115 147 190
## 22922 148  63  80 197 170
## 22923 166  42  27  15 111
## 22924 300  25 153  15 113
## 22925 137 161 346 210  39
## 22926  89  83 342 210  35
## 22927  23  92  91  18 170
## 22928  65  17 128  43 176
## 22929  65  12 165  99   8
## 22930  50 131  13 115  70
## 22931  37 113  60  15  46
## 22945 335 105 117 140 104
## 23008  15 143  97  69  33
## 23009  37 109  16  62  34
## 23032  33  91  86 110 394
## 23052  95 112 222  90  31
## 23053 242 231 196 167 201
## 23054 242 231 196 184  49
## 23055 131  64  34 162 103
## 23056 359 291  56 134  28
## 23057 120  70  82 331  78
## 23058 115  32  79  22  47
## 23059 335 136  31  72 108
## 23060  46 145 208  77  91
## 23061  22 107 138  26  78
## 23062  87  82  62 197  47
## 23063 224 196  66  95 134
## 23064 185 205 311 214 184
## 23065  39 133  50  76 186
## 23066 140  78  45  61 321
## 23067  54  26  44 130  72
## 23068  81  49 263 165 160
## 23069  90 261 144  54  35
## 23070 153 450 129 181 174
## 23071 157 271 130 203  65
## 23072   8 134  39  69 107
## 23073 181  78 117  73  69
## 23074 144   6  14 147  29
## 23075  33  19  80   8  66
## 23076  48 117  15  19   9
## 23077  18 117  45 138  26
## 23078  85  26  19  12  84
## 23079  42  36  51  44  21
## 23080 115  18   6   4  39
```

```
## 23081  90 117  35 148 120
## 23082 163  26  37  65 266
## 23083  56  39  76  83  54
## 23084 129 104  20  69  69
## 23085 116 121 209 469 236
## 23086 335 356  19 262 109
## 23087  27  99 152  44  77
## 23088 198 307 129  26 367
## 23089 115 142 482  36 215
## 23090 112  56  45 392 262
## 23091  18  56  98  76 190
## 23092 284 141  24 353 438
## 23093  90 124  11  51 189
## 23094 119 181  56  71  59
## 23095 205 111  11  88 234
## 23096 284  71 422 169  40
## 23097 361  40 148 164  29
## 23098  58 176 202 110 276
## 23099 233 131  19  61 296
## 23100 320  82 164  69  26
## 23101  52  79  11  21  25
## 23102 242  37 111 117 130
## 23103 113 193 107  22  29
## 23104  73  93 105  62  25
## 23105  41  82 324 225 123
## 23106  62  59 201  72 259
## 23107  71  61  89 299 143
## 23108 136  52  94  16 129
## 23109  20  47  63  40  89
## 23110  27  28  17  10  74
## 23111  22   9  94  22  12
## 23112  14 112   9  17 279
## 23113  90 119  44  96  66
## 23114  75  51  46  24  30
## 23115  38  39  21  39  39
## 23116   7  77  88  11  22
## 23117  27  15  20 102  40
## 23118   9  58   6  46 134
## 23119  28  20  26  13 104
## 23120  15   8 107  42   6
## 23121  27   9  64 227  15
## 23122  32  29  15  16  71
## 23123  74  20  89  43   9
## 23124  14 115  19  16  23
## 23125  16  22  96   8   7
## 23711  23 281 211  19 183
## 23742 112  50  60 190 259
## 23981  43 143  64 239 103
## 24011 121 299  68  58  31
## 24012  23 151  35 129  87
## 24013 145  43 145  31  39
## 24148  84 121 109 221 388
## 24469  25  54 183  11  31
## 24569   6  16  42  70  21
## 24804  65  48  27  13  24
## 25293 103 266 146  77  93
## 25294  93  47  98  49 145
## 25295 494 135 196  64 207
```

```
## 25296 141 249 327  41  88
## 25297 230 401  43  87 109
## 25298 117  59 141 114 244
## 25299 118 159 268  79 126
## 25300 100 226  77  77 269
## 25301 125 172  84  49 268
## 25302  16 199  89  77 195
## 25303  55 165  44 208 145
## 25304 100 228  89 155 268
## 25305  29 144  28  70  67
## 25306  79  27 229 115 149
## 25307  20  18  10  12  51
## 25308 108  53   9  55  15
## 25309 117  34  43  12  14
## 25310  80   6  73  83  88
## 25311  34  13  14  34  38
## 25312 137 110  97  31  81
## 25457  37  52  11  36  36
## 25458  11  13  18  27  11
## 25759  83  82 507  80  72
## 26024 144 376 431  51 290
## 26049  50 125  70  68  37
## 26095  61  47  26  33  80
## 26096  36 147  48  16  23
## 26097  30  47   8  22  87
## 26098 210   6  40  61  78
## 26099  31  15  31  80  88
## 26100  11  23 105  52  31
## 26101  27   9 148  10  10
## 26102  35   8  30  80  10
## 26103  75   7  78 133  69
## 26104  38  36  36  30  55
## 26105  38  15  24  68  16
## 26106  60  66 121  62 157
## 26107  71  49 204  74  93
## 26108 315 122  38  17 123
## 26109 315 115  38  87  70
## 26110 337  85  87  63  43
## 26111 196  49 185 192 143
## 26112  94  28 124  28 434
## 26113 240 248  90 340 295
## 26114 233  28 201 263 144
## 26115 285 126 115 126 148
## 26116 502 587 180  96 151
## 26117 183 469 151 297 183
## 26118 168 293  72  73  80
## 26119  60 147 115 100  48
## 26120 206 356  25 107  99
## 26121  95  47 115  44  48
## 26122 168  30 164  87 332
## 26123 153 270 180  80  98
## 26124 199 147  25  33  66
## 26125  38 174  18 104  91
## 26126  87  78  89 423 202
## 26127 144  86 129 172 125
## 26128 356 121 187  78  73
## 26129 338 111 201  78  73
## 26130  28 206 126 124 175
```

```
## 26131  88  81  95  76  29
## 26132   5 121  45 234 210
## 26133  37  19  83  43 183
## 26134 128  38  58  94 189
## 26135  39  72   7  90  14
## 26136   9  89 109  69  14
## 26137  27  48  48  13 101
## 26138  39  61  31  15   7
## 26139   4  65 117  87  39
## 26140  97  94 350  13   7
## 26141  47  29  95  51  57
## 26142 102  14  43 206  27
## 26143  21 101  99  68 104
## 26144 106  93  66  16  38
## 26145  11  18  86  18  38
## 26146  24  30   8  13  44
## 26147  25 126 168  80 218
## 26148 129  10  30  22 107
## 26149  12  13  98  22  16
## 26150  25  14   7  29 310
## 26151  52  18  12  28 143
## 26152   7  12  64  12  79
## 26153  70  94  15  12  22
## 26154 146 156  16  94  55
## 26155 360  17 146  13  12
## 26156  29  20  83  27  19
## 26157 129  33  32 197 173
## 26158 362  20 206  59  45
## 26159  45 163 266 136  28
## 26160 189 161  95 300 152
## 26161  77  16  25 406 114
## 26162 103 157  51  59 229
## 26163 289  39  35  40  84
## 26164 322 122  80  86 143
## 26165 104  39 239 336  21
## 26166  69 204 156  91 184
## 26167 380 210 199  80 114
## 26168 122 174 205  75  67
## 26169 346  17 205 130  85
## 26170 129 235  68  38 124
## 26171 166 108  88  97 279
## 26172 324  18  74  84  40
## 26173 165  99  40 255 313
## 26174 135  93  65 202 144
## 26175  35 311  48  85  56
## 26176 312  48  78 198 221
## 26177 118 172  31   7 226
## 26178  55  76  65  60 121
## 26179  78 299  52 238 255
## 26180 845  41 151 238 131
## 26181 416  54  48  66 207
## 26182  58 282 184 167  80
## 26183 218 148  98 253  62
## 26184 213 118 373 386 192
## 26185 138 147 287 226  92
## 26186 176 166 128 335 244
## 26187 215 153 175 195  88
## 26188  89 160 204 184 286
```

```
## 26189 133 118 158 212 220
## 26190 183 278 122  84  59
## 26191 211  79 135 125 189
## 26192  83  51 218  16 348
## 26193 111 372  81 225  88
## 26194 186  57 218 178 375
## 26195  69  28  55  36 143
## 26196  12  69  31  69 126
## 26197 188  72  90  89  64
## 26198  49 179 238 273  23
## 26199  49 134  80 273 281
## 26200 302 116  42 172 122
## 26201 152 351  61  77  57
## 26202 141  75  63  45 111
## 26203 227 297  51 196  13
## 26204 100 114 326  63 104
## 26205  18  59  43 103 134
## 26206 248 164 212 346 181
## 26207 266 178  77 224 224
## 26208 253 277 136 111 134
## 26209 184 163 200  76 447
## 26210 109 196  88 105  84
## 26211 482 206 115 105 132
## 26212 112  71  37 166  63
## 26213  77  68 150 150 179
## 26214  35  91 106  38 155
## 26215 172 103 103  41 271
## 26216  52 103 172  41  38
## 26217  67  68 271  22 271
## 26218 113  27 532  76 368
## 26219  84  70 146  37  48
## 26220 183 205  35  34  45
## 26221 158  22  23  34 122
## 26578 106 162 247 294 247
## 26607 136 157 306 106 231
## 26656  15 356  43 105  23
## 26667 170 116 207 100 176
## 26982 258 214 351 357 508
## 27372  12  21  53  11  63
## 27804  10  49  24  10  21
## 27860  57 150 292  22 112
## 28045 225  43 293 502  60
## 28088 132  81  70  76  66
## 28309 107  92  75 117 118
## 28497  13 440 163  88   6
## 28715  15   8   9  19  21
## 28818  69  52 116  59 128
## 28836  33  13  56  12  23
## 28842  77  31 239  45 222
## 29585  34 123  70 185  18
## 29586  50 123  25  40  67
## 29587  10  57 147  11  22
## 29588  52  35  52 188  48
## 29589 286 248 113 115  10
## 29590 155 269  55 150  49
## 29591  59 327 259  67  25
## 29592  30 222 138  45  81
## 29593 194 186  76 206 259
```

```
## 29594 230 200  82  90 207
## 29595 731 100 266  92 104
## 29596 130 119  91  52 423
## 29597 307 128 335 365  47
## 29598  50  27  24  70 141
## 29599  39 354  45 365 166
## 29600 102 133  58 203 179
## 29846  26 149  39  73  85
## 30396  28  88  21  15  68
## 30397  14   9  28  28  27
## 31047  29 164  68  12  23
## 31164 164 102  71  25  88
## 31165  83  52 188 130  24
## 31166  45  26  28  11 204
## 31167  67  52 122 299  27
## 31168  22  36  73 106  42
## 31169 263  44  93 108  17
## 31825  32   7  18 104 525
## 31873  46 331  92 146  51
## 31902 107 182 298 153  83
## 31911  36  51 100  93  40
## 31912  36  51  91 130 109
## 32102  14  15   7  17  23
## 32103  21  24  30  29   9
## 32104  23  30 149  52  36
## 32105  12  27  12  25  28
## 32434  64 353 187 293 162
## 32435  59 515 177 324 286
## 32751  10  17  44  47  20
## 33039  15  71  12  57  34
## 33040  50  60   9 103  34
## 33041  50 185 155  16 110
## 33042  96 281  45  92  35
## 33376  36  26  19  14  29
## 33377 122 101 348 148  66
## 34049 106  16   7  93  26
## 34131  11 107  52 170  89
## 34794  30  26 115  19   9
## 34795  19  10  70  28  12
## 34989  54  12  72  46  17
## 35011  38  19  25  14 116
## 35012   8  36  19  13  27
## 35013 171  13 327  46 103
## 35014  42  73  20  21  35
## 35015  47 131 108 107 221
## 35016  35  72  43 231 156
## 35017  19  22  15  41  18
## 35018  18  29  23  43  10
## 35019  17  20  13  14  14
## 35020  17 204  12  10  14
## 35021  14  47  12  16  45
## 35022  20  58  15  13  45
## 35023  78  19  12   8  16
## 35024   7  10  85   8  20
## 35025   9  87  42  90   7
## 35026  66  19  20  12  34
## 35027  81  10  49  84  11
## 35330  58  38 108   3  15
```

```
## 35331  23  16  14   9  30
## 35332  21  88  21  41   9
## 35333  10  48  19   9  18
## 35334   5  50  22 150  21
## 35585  21  23  16  59   7
## 35586  13  23   9  12  31
## 36234  27  31 151  93 210
## 36276  41 105 123 128  13
## 36339  92 248  99  87  81
## 36977  38  24   8  14  15
## 37456  20  91  42  91   6
## 37553   8  16   9  50  16
## 37554  48  97  11  63  97
## 38412  94  94  16   8 107
## 38413   8  11  43  24  13
## 38785  11  27  56  24  16
## 38809 163  62 155  49  29
## 38833 346 351 129 105 490
## 38857 109 123  41 297  71
## 38881  36  57 129 291  64
## 38883  18  92  74  27  91
## 38884 192 287 397 303 177
## 38885  85  69 339 125 148
## 38886 443 314 345  31  77
## 38887  48  58 105 136  28
## 38888  64  73 229  91 103
## 38889  14  16  31  66  77
## 38890  41 213  53  90  97
## 38891 114   9  83  22 124
## 39111  46  24  22  27  57
## 39113  10   6   8  69 117
## 39114  13 153 108  48  17
## 39686  69 205   9  14   6
## 39687 160 108  29 109  82
## 39688  17  26  38  38  13
## 39689  19  21  17  16  24
## 39690  31 130  17  10  49
## 39924 110  70  15  60  33
## 39925  11  15 165   6  13
## 40577  12  85  43  48  22
## 40578 121 162 107 162  13
## 40625  84  48  14   8 153
## 40626 142 124  14  67 164
## 40627 146 126  77  30 101
## 40628 173  23  54 291  71
## 40629 202  79  37 280  16
## 40630  64 111  49  80 100
## 40631  34 298  87  18 155
## 40632 115 298 158  18  20
## 40633  50 207 246  38 281
## 41264  48  53 312 137 175
## 41277  24 101 125  54  18
## 41348 279 401  45  39 244
## 41441 148  42  36  82 151
## 41444 369  85 256 188  25
## 42089 178 245  62  90 156
## 42491  66  13  13  15  17
## 42666  20  43  62  45  10
```

```
## 42838 304  41 123 110 158
## 42839 114 164  70  50 138
## 42840  38  46 372 135 168
## 42841 178 148  86  87 190
## 42842 301  70  97 166 201
## 42843 405 203  67 234 142
## 42844 124 521 134  78 324
## 42845 329 213  74 185 213
## 42846 253 178  64 130  86
## 42847 121 551  73 130 106
## 42848  57 133  46 106  71
## 42849 124 238 283 412 248
## 43191  22  59  38  26  20
## 43192  42  23 104  81  36
## 43265  26  45  11  66  13
## 43267 199 335  71  71 196
## 43268  72  74  68 236  16
## 43269  57 372  76 155  95
## 43270 284 119  32  22  87
## 43271  97  89  96 100 147
## 43274 113  76  79 133  73
## 43275 119  93 253 257 290
## 43276 277 195 134 315 158
## 43277 126 190 101  50  75
## 43278  62  33  16  75 215
## 43279  99  62 383  74 125
## 43280  91 298 169  91 335
## 43281  44 107 290 180  85
## 43282  38  84 149  55  27
## 43283 128  77 162  67 119
## 43284 115  47 474 168 207
## 43545 212  19  11  22   6
## 43546  44  48  20 142  34
## 43547   9   9  27  10  32
## 43548  23  11  32  27  51
## 43549  37  20  17 159   9
## 43550  16   7  47  21  31
## 43551  17  12 106  55  15
## 43552  11  18  22   7  46
## 43553 158  36  11   8  20
##
## $DEWP
## [1] 1 2 3 4 5
## <0 rows> (or 0-length row.names)
##
## $TEMP
## [1] 1 2 3 4 5
## <0 rows> (or 0-length row.names)
##
## $PRES
## [1] 1 2 3 4 5
## <0 rows> (or 0-length row.names)
##
## $cbwd
## [1] 1 2 3 4 5
## <0 rows> (or 0-length row.names)
##
## $date
```

```
## [1] 1 2 3 4 5
## <0 rows> (or 0-length row.names)
```

```
pm2.5 <- complete(data)
summary(pm2.5)
```

```
##      pm2.5             DEWP              TEMP             PRES     
##  Min.   :  0.00   Min.   :-40.000   Min.   :-19.00   Min.   : 991  
##  1st Qu.: 29.00   1st Qu.:-10.000   1st Qu.:  2.00   1st Qu.:1008  
##  Median : 72.00   Median :  2.000   Median : 14.00   Median :1016  
##  Mean   : 98.71   Mean   :  1.817   Mean   : 12.45   Mean   :1016  
##  3rd Qu.:137.00   3rd Qu.: 15.000   3rd Qu.: 23.00   3rd Qu.:1025  
##  Max.   :994.00   Max.   : 28.000   Max.   : 42.00   Max.   :1046  
##  cbwd            date           
##  NE: 4997   Min.   :2010-01-01  
##  NW:14150   1st Qu.:2011-04-02  
##  SE:15290   Median :2012-07-01  
##  SW: 9387   Mean   :2012-07-01  
##             3rd Qu.:2013-10-01  
##             Max.   :2014-12-31  
```

Check the mode of each variable

```
sapply(pm2.5, class)
```

```
##     pm2.5      DEWP      TEMP      PRES      cbwd      date 
## "numeric" "numeric" "numeric" "numeric"  "factor"    "Date" 
```

The only apparent categorical variable in our dataset is cbwd, the wind direction

Create the dummy variables of wind direction

```
pm2.5 <- pm2.5 %>% mutate(SW = as.numeric(cbwd == 'SW'))
pm2.5 <- pm2.5 %>% mutate(NE = as.numeric(cbwd == 'NE'))
pm2.5 <- pm2.5 %>% mutate(NW = as.numeric(cbwd == 'NW'))
pm2.5 <- pm2.5 %>% mutate(SE = as.numeric(cbwd == 'SE'))
```

“SW”, “NE”, “NW”, “SE” are four new variables in the dataframe pm2.5

```
summary(pm2.5)
```

```
##      pm2.5             DEWP              TEMP             PRES     
##  Min.   :  0.00   Min.   :-40.000   Min.   :-19.00   Min.   : 991  
##  1st Qu.: 29.00   1st Qu.:-10.000   1st Qu.:  2.00   1st Qu.:1008  
##  Median : 72.00   Median :  2.000   Median : 14.00   Median :1016  
##  Mean   : 98.71   Mean   :  1.817   Mean   : 12.45   Mean   :1016  
##  3rd Qu.:137.00   3rd Qu.: 15.000   3rd Qu.: 23.00   3rd Qu.:1025  
##  Max.   :994.00   Max.   : 28.000   Max.   : 42.00   Max.   :1046  
##  cbwd            date                  SW               NE       
##  NE: 4997   Min.   :2010-01-01   Min.   :0.0000   Min.   :0.000  
##  NW:14150   1st Qu.:2011-04-02   1st Qu.:0.0000   1st Qu.:0.000  
##  SE:15290   Median :2012-07-01   Median :0.0000   Median :0.000  
##  SW: 9387   Mean   :2012-07-01   Mean   :0.2142   Mean   :0.114  
##             3rd Qu.:2013-10-01   3rd Qu.:0.0000   3rd Qu.:0.000  
##             Max.   :2014-12-31   Max.   :1.0000   Max.   :1.000  
##        NW               SE        
##  Min.   :0.0000   Min.   :0.0000  
##  1st Qu.:0.0000   1st Qu.:0.0000  
##  Median :0.0000   Median :0.0000  
##  Mean   :0.3229   Mean   :0.3489  
##  3rd Qu.:1.0000   3rd Qu.:1.0000  
##  Max.   :1.0000   Max.   :1.0000
```

Preparing for training and test set

```
#shuffle dataset and create train and test set
set.seed(1234567)
n <- nrow(pm2.5)
shuffled <- pm2.5[sample(n),]

train <- shuffled[1:round(0.7 * n),]
test <- shuffled[(round(0.7 * n) + 1):n,]

summary(train)
```

```
##      pm2.5            DEWP             TEMP             PRES     
##  Min.   :  0.00   Min.   :-40.000   Min.   :-19.00   Min.   : 991  
##  1st Qu.: 29.00   1st Qu.:-10.000   1st Qu.:  2.00   1st Qu.:1008  
##  Median : 73.00   Median :  2.000   Median : 14.00   Median :1016  
##  Mean   : 98.83   Mean   :  1.772   Mean   : 12.37   Mean   :1017  
##  3rd Qu.:137.00   3rd Qu.: 15.000   3rd Qu.: 23.00   3rd Qu.:1025  
##  Max.   :994.00   Max.   : 28.000   Max.   : 42.00   Max.   :1046  
##  cbwd            date                  SW               NE        
##  NE: 3477   Min.   :2010-01-01   Min.   :0.0000   Min.   :0.0000  
##  NW: 9940   1st Qu.:2011-04-03   1st Qu.:0.0000   1st Qu.:0.0000  
##  SE:10677   Median :2012-06-30   Median :0.0000   Median :0.0000  
##  SW: 6583   Mean   :2012-07-01   Mean   :0.2146   Mean   :0.1133  
##             3rd Qu.:2013-10-02   3rd Qu.:0.0000   3rd Qu.:0.0000  
##             Max.   :2014-12-31   Max.   :1.0000   Max.   :1.0000  
##        NW              SE       
##  Min.   :0.000   Min.   :0.000  
##  1st Qu.:0.000   1st Qu.:0.000  
##  Median :0.000   Median :0.000  
##  Mean   :0.324   Mean   :0.348  
##  3rd Qu.:1.000   3rd Qu.:1.000  
##  Max.   :1.000   Max.   :1.000
```

```
summary(test)
```

```
##      pm2.5            DEWP             TEMP             PRES     
##  Min.   :  0.00   Min.   :-37.000   Min.   :-19.00   Min.   : 991  
##  1st Qu.: 29.00   1st Qu.:-10.000   1st Qu.:  2.00   1st Qu.:1008  
##  Median : 72.00   Median :  2.000   Median : 14.00   Median :1016  
##  Mean   : 98.44   Mean   :  1.924   Mean   : 12.64   Mean   :1016  
##  3rd Qu.:138.00   3rd Qu.: 15.000   3rd Qu.: 23.00   3rd Qu.:1024  
##  Max.   :845.00   Max.   : 28.000   Max.   : 41.00   Max.   :1046  
##  cbwd           date                  SW               NE        
##  NE:1520   Min.   :2010-01-01   Min.   :0.0000   Min.   :0.0000  
##  NW:4210   1st Qu.:2011-03-30   1st Qu.:0.0000   1st Qu.:0.0000  
##  SE:4613   Median :2012-07-05   Median :0.0000   Median :0.0000  
##  SW:2804   Mean   :2012-06-30   Mean   :0.2133   Mean   :0.1156  
##            3rd Qu.:2013-09-29   3rd Qu.:0.0000   3rd Qu.:0.0000  
##            Max.   :2014-12-31   Max.   :1.0000   Max.   :1.0000  
##        NW               SE        
##  Min.   :0.0000   Min.   :0.0000  
##  1st Qu.:0.0000   1st Qu.:0.0000  
##  Median :0.0000   Median :0.0000  
##  Mean   :0.3202   Mean   :0.3509  
##  3rd Qu.:1.0000   3rd Qu.:1.0000  
##  Max.   :1.0000   Max.   :1.0000
```

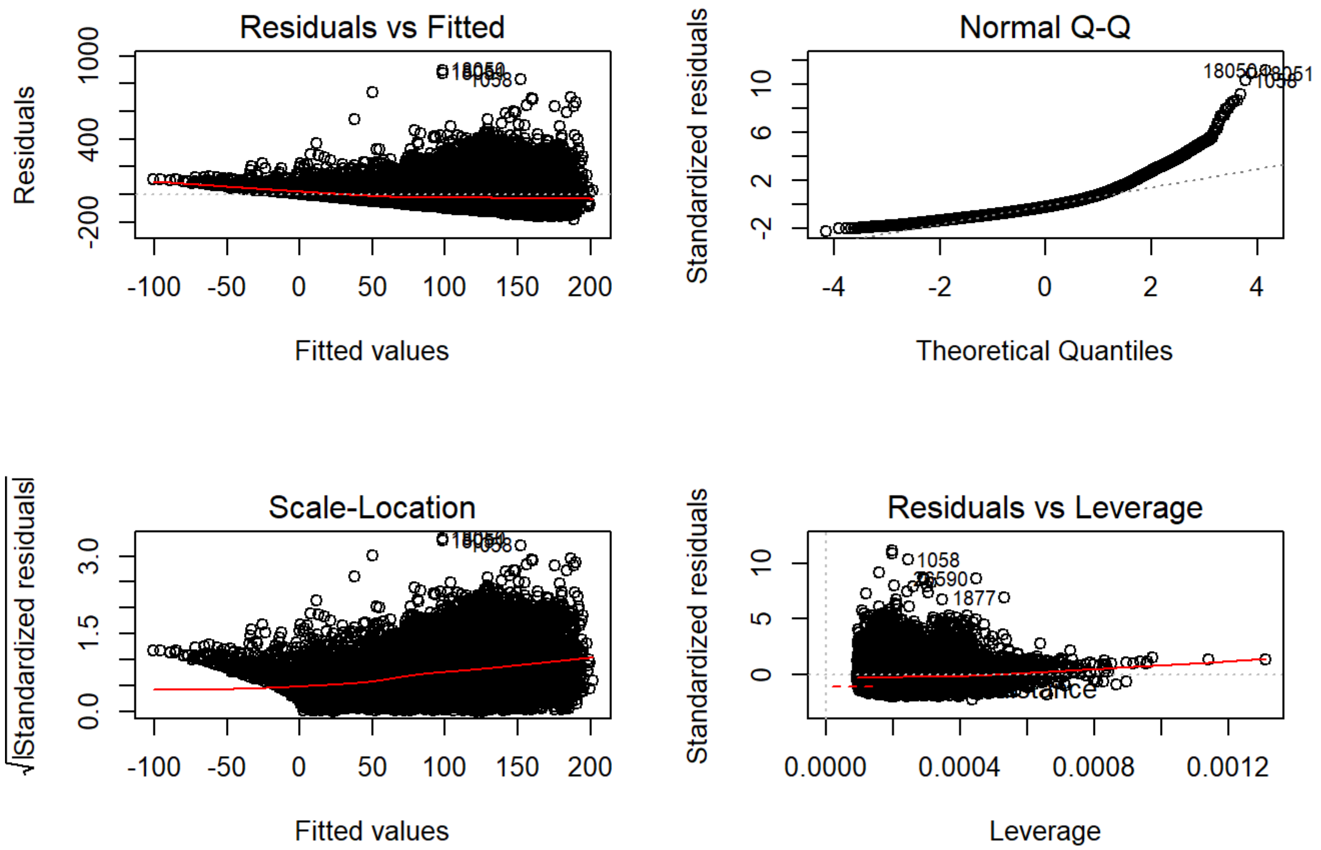
Build a main effects model

```
pm2.5.lm1 <- lm(pm2.5 ~ DEWP + TEMP + PRES + SW + NE + NW + SE, data = train)
summary(pm2.5.lm1)
```

```
##
## Call:
## lm(formula = pm2.5 ~ DEWP + TEMP + PRES + SW + NE + NW + SE,
##     data = train)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -179.78  -52.18  -16.68   31.30  895.99
##
## Coefficients: (1 not defined because of singularities)
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1929.10399   85.16635  22.651   <2e-16 ***
## DEWP           4.05070    0.06076  66.670   <2e-16 ***
## TEMP          -6.31482    0.07873 -80.208   <2e-16 ***
## PRES          -1.71474    0.08324 -20.601   <2e-16 ***
## SW             0.00393    1.28336   0.003    0.998
## NE           -29.48972    1.59660 -18.470   <2e-16 ***
## NW           -40.04735    1.20423 -33.256   <2e-16 ***
## SE                  NA         NA      NA       NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 80.45 on 30670 degrees of freedom
## Multiple R-squared:  0.239,  Adjusted R-squared:  0.2388
## F-statistic:  1605 on 6 and 30670 DF,  p-value: < 2.2e-16
```

Diagnose the model

```
par(mfrow = c(2,2))
plot(pm2.5.lm1)
```




```
par(mfrow = c(1,1))
save_data <- c()
for(i in 1:1000){
  result_test <- shapiro.test(sample(pm2.5.lm1$residuals,5000))
  save_data <- append(save_data,result_test[[2]])
}
length(save_data[save_data<=0.05])
```

```
## [1] 1000
```

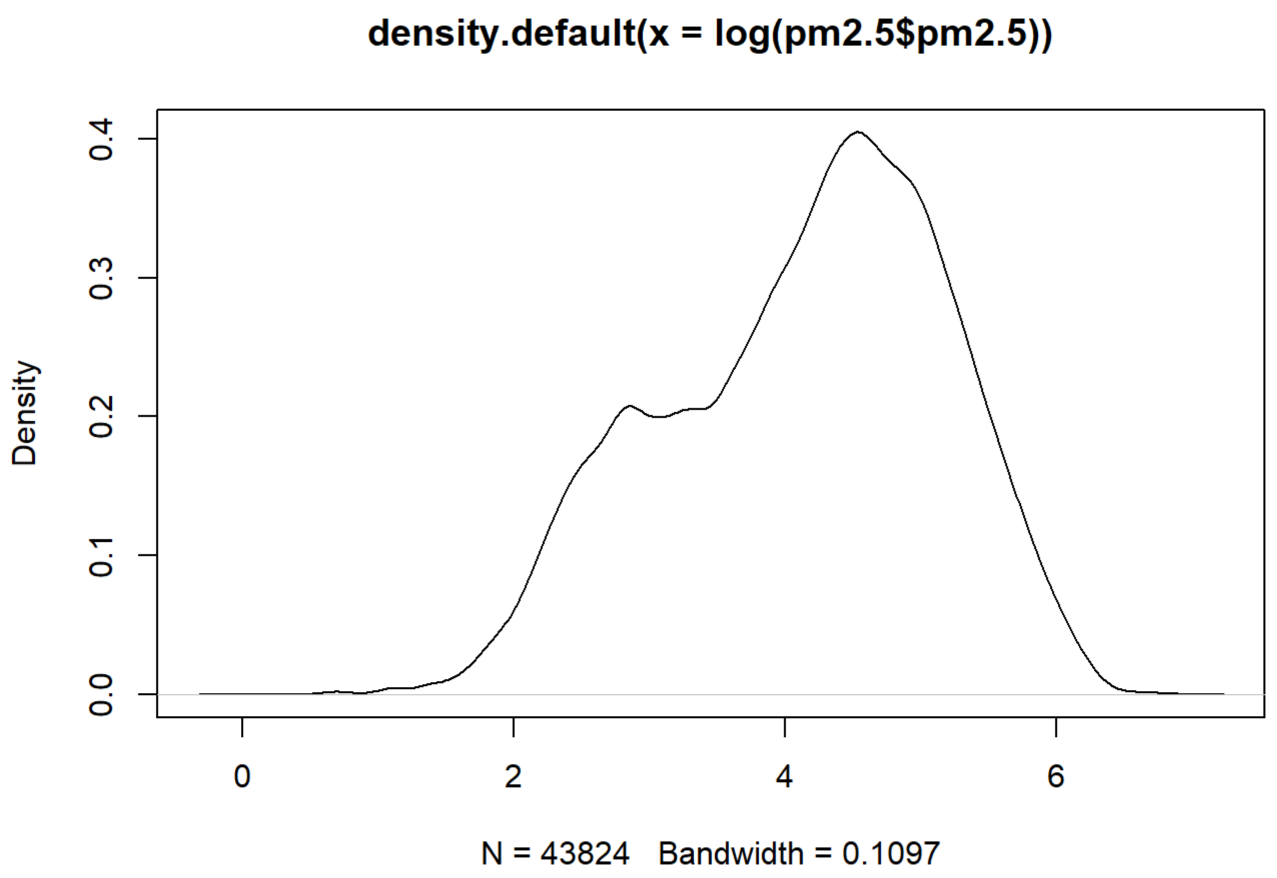
From Normal Q-Q plot and shapiro test result, we know that the residuals are not normally distributed. So we need do box-cox transformation

However, box-cox transformation cannot be applied here. From the density plot of pm2.5, we can know that the response variable can be negative. However, box-cox

transformation includes the log transformation as a particular case. So here, we introduce the IHS(Inverse Hyperbolic Sine) transformation

Density Plot of pm2.5 time series

```
plot(density(log(pm2.5$pm2.5)))
```




```
summary(pm2.5.lm1)
```

```
##
## Call:
## lm(formula = pm2.5 ~ DEWP + TEMP + PRES + SW + NE + NW + SE,
##     data = train)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -179.78  -52.18  -16.68   31.30  895.99
##
## Coefficients: (1 not defined because of singularities)
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1929.10399   85.16635  22.651   <2e-16 ***
## DEWP           4.05070    0.06076  66.670   <2e-16 ***
## TEMP          -6.31482    0.07873 -80.208   <2e-16 ***
## PRES          -1.71474    0.08324 -20.601   <2e-16 ***
## SW             0.00393    1.28336   0.003    0.998
## NE           -29.48972    1.59660 -18.470   <2e-16 ***
## NW           -40.04735    1.20423 -33.256   <2e-16 ***
## SE                  NA         NA      NA       NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 80.45 on 30670 degrees of freedom
## Multiple R-squared:  0.239,  Adjusted R-squared:  0.2388
## F-statistic:  1605 on 6 and 30670 DF,  p-value: < 2.2e-16
```

IHS(Inverse Hyperbolic Sine) transformation. The IHS transformation works with data defined on the whole real line including zeros. For large values of x, IHS behaves like a log transformation, and the transformation accommodates values of 0

```
ihs <- function(x) {
  y <- log(x + sqrt(x ^ 2 + 1))
  return(y)
}
```

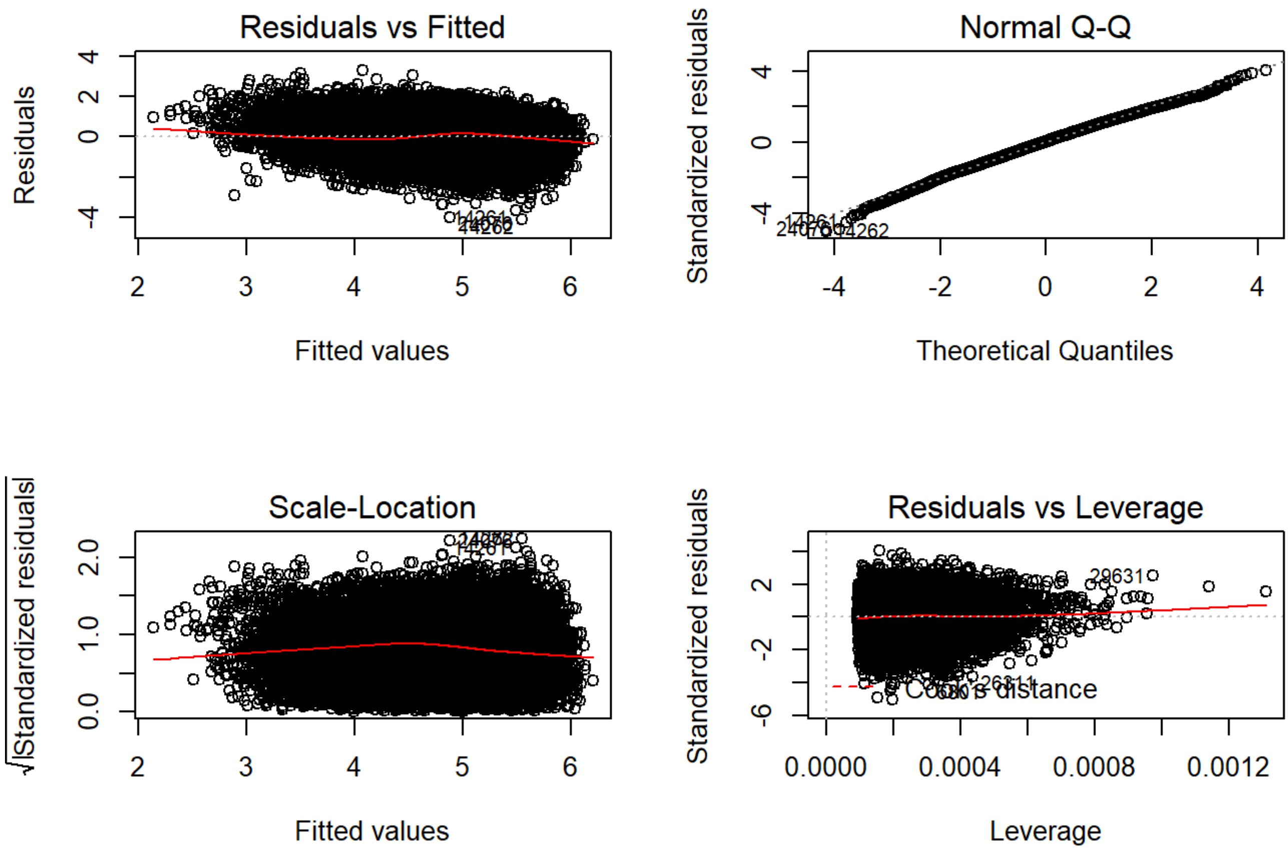
Take the IHS of the response variable pm2.5

```
pm2.5.lm1.ihs <- lm(ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE, data = train)
summary(pm2.5.lm1.ihs)
```

```
##
## Call:
## lm(formula = ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW +
##     SE, data = train)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.1007 -0.5456  0.0197  0.5687  3.2885
##
## Coefficients: (1 not defined because of singularities)
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept) 28.1526755  0.8618829  32.664   <2e-16 ***
## DEWP         0.0544473  0.0006149  88.551   <2e-16 ***
## TEMP        -0.0759813  0.0007968 -95.364   <2e-16 ***
## PRES        -0.0217879  0.0008423 -25.866   <2e-16 ***
## SW          -0.1175254  0.0129876  -9.049   <2e-16 ***
## NE          -0.5566304  0.0161575 -34.450   <2e-16 ***
## NW          -0.7411186  0.0121868 -60.813   <2e-16 ***
## SE                  NA         NA      NA       NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.8141 on 30670 degrees of freedom
## Multiple R-squared:  0.3752, Adjusted R-squared:  0.3751
## F-statistic:  3070 on 6 and 30670 DF,  p-value: < 2.2e-16
```

Diagnose the model

```
par(mfrow = c(2,2))
plot(pm2.5.lm1.ihs)
```




```
par(mfrow = c(1,1))
save_data <- c()
for(i in 1:1000){
  result_test <- shapiro.test(sample(pm2.5.lm1.ihs$residuals,5000))
  save_data <- append(save_data,result_test[[2]])
}
length(save_data[save_data<=0.05])
```

```
## [1] 1000
```

From the Normal Q-Q plot, we get that the residual is nealy normally distributed. So we can say that the ihs transformation rastically increased the adjusted R 2 and significantly improved the model assumptions.

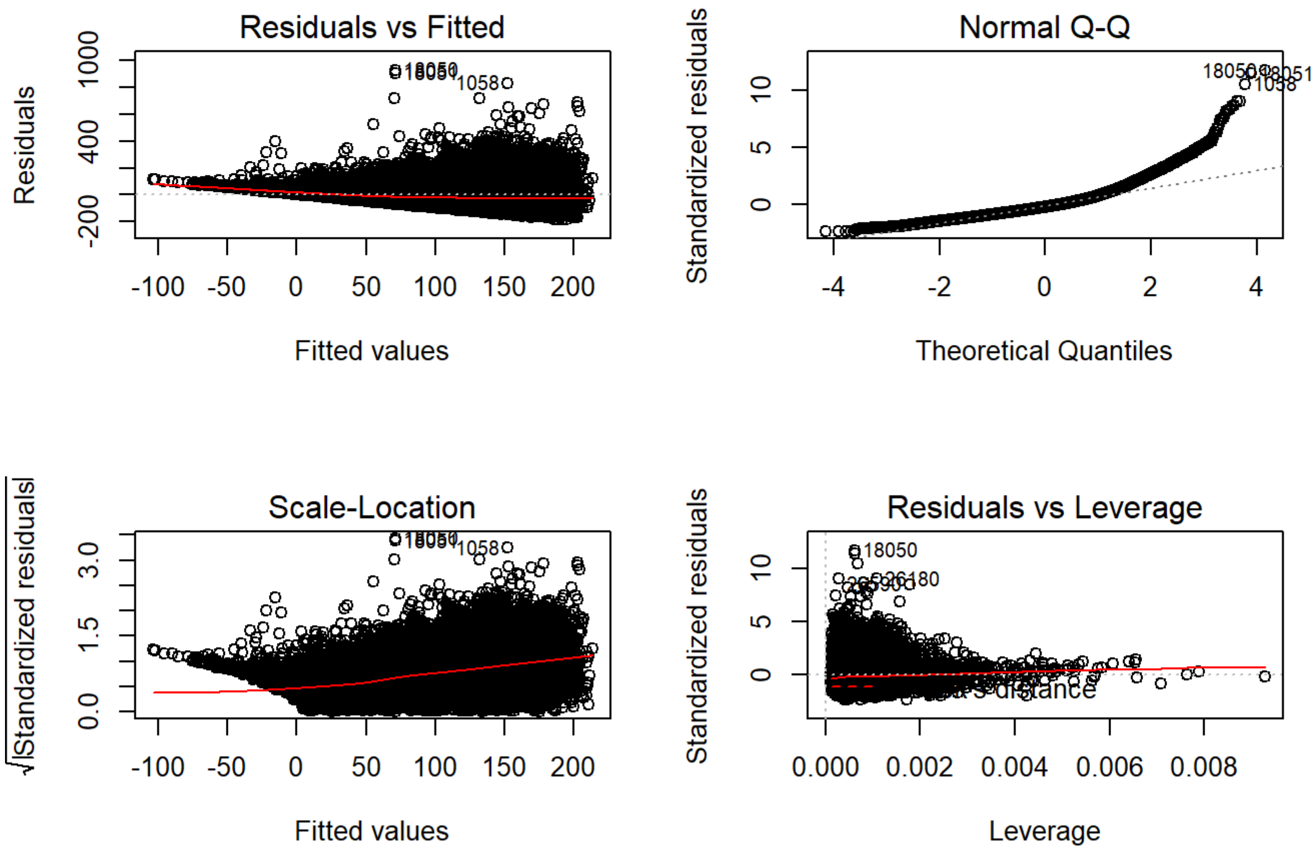
Build a main effects + interation model

```
pm2.5.lm2 <- lm(pm2.5 ~ (DEWP + TEMP +
    PRES + SW + NE + NW + SE)^2, data = train)
summary(pm2.5.lm2)
```

```
##
## Call:
## lm(formula = pm2.5 ~ (DEWP + TEMP + PRES + SW + NE + NW + SE)^2,
##     data = train)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -182.49  -50.13  -14.48   31.46  922.83
##
## Coefficients: (10 not defined because of singularities)
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  9.371e+02  1.841e+02   5.089 3.62e-07 ***
## DEWP        -1.256e+02  7.359e+00 -17.068  < 2e-16 ***
## TEMP         5.963e+01  7.255e+00   8.219  < 2e-16 ***
## PRES        -7.364e-01  1.802e-01  -4.086 4.39e-05 ***
## SW          -1.262e+01  2.343e+02  -0.054 0.957033
## NE           4.415e+02  2.945e+02   1.499 0.133835
## NW           5.673e+02  2.176e+02   2.607 0.009150 **
## SE                  NA         NA      NA       NA
## DEWP:TEMP   -4.435e-02  6.266e-03  -7.078 1.49e-12 ***
## DEWP:PRES    1.284e-01  7.205e-03  17.818  < 2e-16 ***
## DEWP:SW      2.666e-01  1.845e-01   1.445 0.148582
## DEWP:NE      3.434e-01  2.105e-01   1.631 0.102945
## DEWP:NW     -5.467e-01  1.447e-01  -3.777 0.000159 ***
## DEWP:SE             NA         NA      NA       NA
## TEMP:PRES   -6.426e-02  7.146e-03  -8.992  < 2e-16 ***
## TEMP:SW     -1.369e+00  2.245e-01  -6.101 1.07e-09 ***
## TEMP:NE     -1.526e+00  2.727e-01  -5.596 2.21e-08 ***
## TEMP:NW     -1.004e+00  1.976e-01  -5.082 3.77e-07 ***
## TEMP:SE             NA         NA      NA       NA
## PRES:SW      2.893e-02  2.291e-01   0.126 0.899517
## PRES:NE     -4.398e-01  2.878e-01  -1.528 0.126442
## PRES:NW     -5.820e-01  2.127e-01  -2.737 0.006210 **
## PRES:SE             NA         NA      NA       NA
## SW:NE               NA         NA      NA       NA
## SW:NW               NA         NA      NA       NA
## SW:SE               NA         NA      NA       NA
## NE:NW               NA         NA      NA       NA
## NE:SE               NA         NA      NA       NA
## NW:SE               NA         NA      NA       NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 78.73 on 30658 degrees of freedom
## Multiple R-squared:  0.2713, Adjusted R-squared:  0.2709
## F-statistic: 634.2 on 18 and 30658 DF,  p-value: < 2.2e-16
```

Diagnose the mdoel

```
par(mfrow = c(2,2))
plot(pm2.5.lm2)
```




```
par(mfrow = c(1,1))
save_data <- c()
for(i in 1:1000){
  result_test <- shapiro.test(sample(pm2.5.lm2$residuals,5000))
  save_data <- append(save_data,result_test[[2]])
}
length(save_data[save_data<=0.05])
```

```
## [1] 1000
```

From the Normal Q-Q plot and the shapiro test result, we know that the residuals are not normally distributed. So we need do IHS(Inverse Hyperbolic Sine) transformation

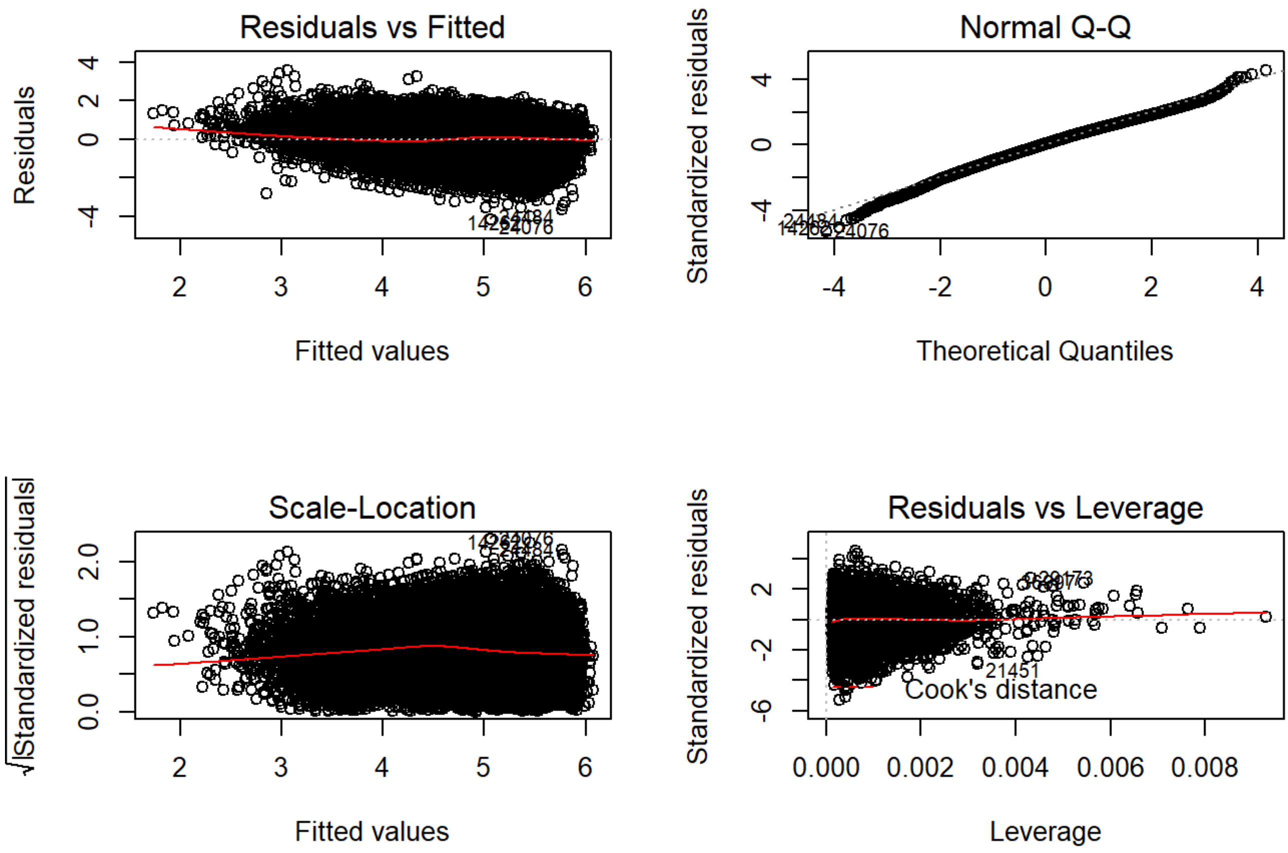
Take the IHS of the response variable pm2.5

```
pm2.5.lm2.ihs <- lm(ihs(pm2.5) ~ (DEWP + TEMP +
    PRES + SW + NE + NW + SE)^2, data = train)
summary(pm2.5.lm2.ihs)
```

```
##
## Call:
## lm(formula = ihs(pm2.5) ~ (DEWP + TEMP + PRES + SW + NE + NW +
##     SE)^2, data = train)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.1870 -0.5124  0.0384  0.5562  3.5788
##
## Coefficients: (10 not defined because of singularities)
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.529e+01  1.851e+00   8.260  < 2e-16 ***
## DEWP        -1.636e+00  7.397e-02 -22.115  < 2e-16 ***
## TEMP         5.926e-01  7.292e-02   8.126 4.61e-16 ***
## PRES        -9.209e-03  1.811e-03  -5.084 3.72e-07 ***
## SW          -1.410e+00  2.355e+00  -0.599 0.549412
## NE           1.025e+01  2.960e+00   3.461 0.000539 ***
## NW           1.182e+01  2.188e+00   5.405 6.53e-08 ***
## SE                  NA         NA      NA       NA
## DEWP:TEMP   -4.777e-05  6.298e-05  -0.758 0.448183
## DEWP:PRES    1.657e-03  7.242e-05  22.886  < 2e-16 ***
## DEWP:SW      5.755e-03  1.855e-03   3.102 0.001921 **
## DEWP:NE      1.867e-02  2.116e-03   8.822  < 2e-16 ***
## DEWP:NW      9.374e-03  1.455e-03   6.444 1.18e-10 ***
## DEWP:SE             NA         NA      NA       NA
## TEMP:PRES   -6.426e-04  7.183e-05  -8.946  < 2e-16 ***
## TEMP:SW     -1.337e-02  2.256e-03  -5.927 3.11e-09 ***
## TEMP:NE     -3.225e-02  2.742e-03 -11.763  < 2e-16 ***
## TEMP:NW     -2.608e-02  1.986e-03 -13.132  < 2e-16 ***
## TEMP:SE             NA         NA      NA       NA
## PRES:SW      1.435e-03  2.303e-03   0.623 0.533252
## PRES:NE     -1.022e-02  2.893e-03  -3.532 0.000412 ***
## PRES:NW     -1.203e-02  2.138e-03  -5.626 1.87e-08 ***
## PRES:SE             NA         NA      NA       NA
## SW:NE               NA         NA      NA       NA
## SW:NW               NA         NA      NA       NA
## SW:SE               NA         NA      NA       NA
## NE:NW               NA         NA      NA       NA
## NE:SE               NA         NA      NA       NA
## NW:SE               NA         NA      NA       NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.7914 on 30658 degrees of freedom
## Multiple R-squared:  0.4098, Adjusted R-squared:  0.4095
## F-statistic:  1183 on 18 and 30658 DF,  p-value: < 2.2e-16
```

Test the model

```
par(mfrow = c(2,2))
plot(pm2.5.lm2.ihs)
```




```
par(mfrow = c(1,1))
save_data <- c()
for(i in 1:1000){
  result_test <- shapiro.test(sample(pm2.5.lm2.ihs$residuals,5000))
  save_data <- append(save_data,result_test[[2]])
}
length(save_data[save_data<=0.05])
```

```
## [1] 1000
```

The residual of pm2.5.lm.ihs is nearly normally distributed and significantly improve the model assumption

Use stepwise regressio on your main effects + interation model

```
pm2.5.lm2.step <- step(pm2.5.lm2.ihs)
```

```
## Start:  AIC=-14334.99
## ihs(pm2.5) ~ (DEWP + TEMP + PRES + SW + NE + NW + SE)^2
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + DEWP:SE + TEMP:PRES +
##     TEMP:SW + TEMP:NE + TEMP:NW + TEMP:SE + PRES:SW + PRES:NE +
##     PRES:NW + PRES:SE + SW:NE + SW:NW + SW:SE + NE:NW + NE:SE
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + DEWP:SE + TEMP:PRES +
##     TEMP:SW + TEMP:NE + TEMP:NW + TEMP:SE + PRES:SW + PRES:NE +
##     PRES:NW + PRES:SE + SW:NE + SW:NW + SW:SE + NE:NW
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + DEWP:SE + TEMP:PRES +
##     TEMP:SW + TEMP:NE + TEMP:NW + TEMP:SE + PRES:SW + PRES:NE +
##     PRES:NW + PRES:SE + SW:NE + SW:NW + SW:SE
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + DEWP:SE + TEMP:PRES +
##     TEMP:SW + TEMP:NE + TEMP:NW + TEMP:SE + PRES:SW + PRES:NE +
##     PRES:NW + PRES:SE + SW:NE + SW:NW
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + DEWP:SE + TEMP:PRES +
##     TEMP:SW + TEMP:NE + TEMP:NW + TEMP:SE + PRES:SW + PRES:NE +
##     PRES:NW + PRES:SE + SW:NE
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + DEWP:SE + TEMP:PRES +
##     TEMP:SW + TEMP:NE + TEMP:NW + TEMP:SE + PRES:SW + PRES:NE +
##     PRES:NW + PRES:SE
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + DEWP:SE + TEMP:PRES +
##     TEMP:SW + TEMP:NE + TEMP:NW + TEMP:SE + PRES:SW + PRES:NE +
##     PRES:NW
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + DEWP:SE + TEMP:PRES +
##     TEMP:SW + TEMP:NE + TEMP:NW + PRES:SW + PRES:NE + PRES:NW
```

```
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + SE + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + TEMP:PRES + TEMP:SW +
##     TEMP:NE + TEMP:NW + PRES:SW + PRES:NE + PRES:NW
##
##
## Step:  AIC=-14334.99
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + TEMP:PRES + TEMP:SW +
##     TEMP:NE + TEMP:NW + PRES:SW + PRES:NE + PRES:NW
##
##             Df Sum of Sq   RSS    AIC
## - PRES:SW    1      0.24 19202 -14337
## - DEWP:TEMP  1      0.36 19202 -14336
## <none>                   19202 -14335
## - DEWP:SW    1      6.03 19208 -14327
## - PRES:NE    1      7.82 19209 -14324
## - PRES:NW    1     19.82 19221 -14305
## - TEMP:SW    1     22.00 19224 -14302
## - DEWP:NW    1     26.01 19228 -14296
## - DEWP:NE    1     48.74 19250 -14259
## - TEMP:PRES  1     50.12 19252 -14257
## - TEMP:NE    1     86.66 19288 -14199
## - TEMP:NW    1    108.00 19310 -14165
## - DEWP:PRES  1    328.03 19530 -13817
##
## Step:  AIC=-14336.6
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + DEWP:TEMP +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + TEMP:PRES + TEMP:SW +
##     TEMP:NE + TEMP:NW + PRES:NE + PRES:NW
##
##             Df Sum of Sq   RSS    AIC
## - DEWP:TEMP  1      0.43 19202 -14338
## <none>                   19202 -14337
## - DEWP:SW    1      5.84 19208 -14329
## - PRES:NE    1     10.14 19212 -14322
## - DEWP:NW    1     25.84 19228 -14297
## - PRES:NW    1     29.19 19231 -14292
## - TEMP:SW    1     30.29 19232 -14290
## - DEWP:NE    1     48.55 19250 -14261
## - TEMP:PRES  1     51.40 19253 -14257
## - TEMP:NE    1     91.85 19294 -14192
## - TEMP:NW    1    120.25 19322 -14147
## - DEWP:PRES  1    327.84 19530 -13819
##
## Step:  AIC=-14337.92
## ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW + DEWP:PRES +
##     DEWP:SW + DEWP:NE + DEWP:NW + TEMP:PRES + TEMP:SW + TEMP:NE +
##     TEMP:NW + PRES:NE + PRES:NW
##
##             Df Sum of Sq   RSS    AIC
## <none>                   19202 -14338
## - DEWP:SW    1      6.06 19208 -14330
## - PRES:NE    1      9.90 19212 -14324
## - DEWP:NW    1     26.98 19229 -14297
## - PRES:NW    1     28.98 19231 -14294
```

```
## - TEMP:SW    1     30.20 19232 -14292
## - DEWP:NE    1     49.22 19251 -14261
## - TEMP:PRES  1     52.89 19255 -14256
## - TEMP:NE    1     91.43 19294 -14194
## - TEMP:NW    1    123.50 19326 -14143
## - DEWP:PRES  1    475.98 19678 -13589
```

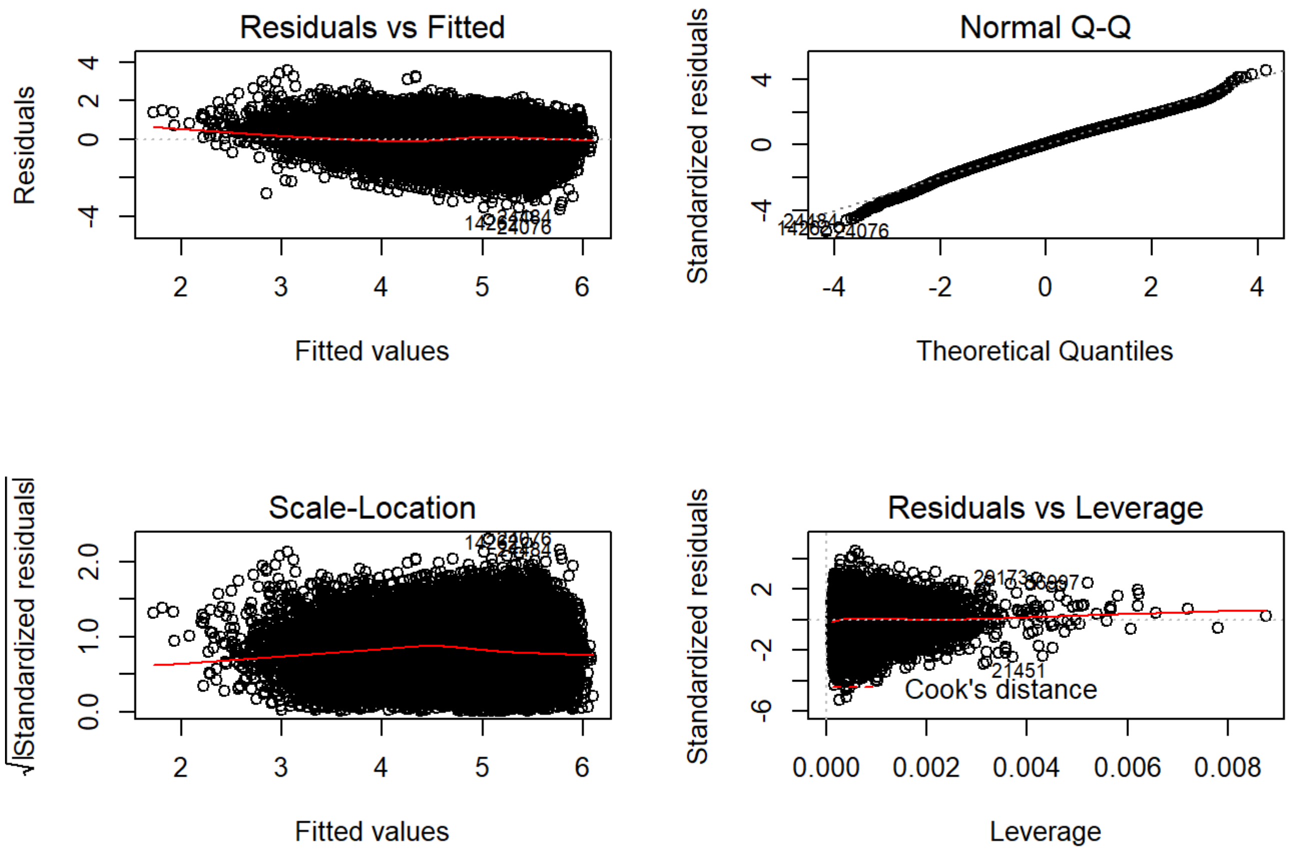
Choose the new model

```
summary(pm2.5.lm2.step)
```

```
##
## Call:
## lm(formula = ihs(pm2.5) ~ DEWP + TEMP + PRES + SW + NE + NW +
##     DEWP:PRES + DEWP:SW + DEWP:NE + DEWP:NW + TEMP:PRES + TEMP:SW +
##     TEMP:NE + TEMP:NW + PRES:NE + PRES:NW, data = train)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.1843 -0.5125  0.0381  0.5560  3.5821
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.490e+01  1.403e+00  10.619  < 2e-16 ***
## DEWP        -1.668e+00  6.208e-02 -26.876  < 2e-16 ***
## TEMP         5.808e-01  6.960e-02   8.346  < 2e-16 ***
## PRES        -8.829e-03  1.373e-03  -6.430 1.30e-10 ***
## SW           5.663e-02  2.484e-02   2.280  0.02264 *
## NE           1.075e+01  2.756e+00   3.900 9.66e-05 ***
## NW           1.217e+01  1.859e+00   6.545 6.05e-11 ***
## DEWP:PRES    1.689e-03  6.126e-05  27.568  < 2e-16 ***
## DEWP:SW      5.509e-03  1.771e-03   3.111  0.00187 **
## DEWP:NE      1.863e-02  2.102e-03   8.865  < 2e-16 ***
## DEWP:NW      9.375e-03  1.428e-03   6.564 5.32e-11 ***
## TEMP:PRES   -6.308e-04  6.864e-05  -9.190  < 2e-16 ***
## TEMP:SW     -1.398e-02  2.014e-03  -6.944 3.89e-12 ***
## TEMP:NE     -3.240e-02  2.682e-03 -12.082  < 2e-16 ***
## TEMP:NW     -2.606e-02  1.856e-03 -14.042  < 2e-16 ***
## PRES:NE     -1.071e-02  2.694e-03  -3.976 7.02e-05 ***
## PRES:NW     -1.237e-02  1.818e-03  -6.803 1.04e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.7914 on 30660 degrees of freedom
## Multiple R-squared:  0.4098, Adjusted R-squared:  0.4095
## F-statistic:  1331 on 16 and 30660 DF,  p-value: < 2.2e-16
```

Diagnose the model

```
par(mfrow = c(2,2))
plot(pm2.5.lm2.step)
```




```
par(mfrow = c(1,1))
save_data <- c()
for(i in 1:1000){
  result_test <- shapiro.test(sample(pm2.5.lm2.step$residuals,5000))
  save_data <- append(save_data,result_test[[2]])
}
length(save_data[save_data<=0.05])
```

```
## [1] 1000
```

From Normal Q-Q plot and shapiro test result, we know that the residuals are normally distributed.

Compare the AIC of the two model

```
AIC(pm2.5.lm1.ihs)
```

```
## [1] 74449.1
```

```
AIC(pm2.5.lm2.step)
```

```
## [1] 72721.64
```

```
anova(pm2.5.lm1.ihs)
```

```
## Analysis of Variance Table
##
## Response: ihs(pm2.5)
##              Df  Sum Sq Mean Sq F value    Pr(>F)    
## DEWP          1  3050.0  3050.0 4601.79 < 2.2e-16 ***
## TEMP          1  5912.3  5912.3 8920.38 < 2.2e-16 ***
## PRES          1   366.3   366.3  552.64 < 2.2e-16 ***
## SW            1   323.0   323.0  487.36 < 2.2e-16 ***
## NE            1   105.9   105.9  159.78 < 2.2e-16 ***
## NW            1  2451.2  2451.2 3698.26 < 2.2e-16 ***
## Residuals 30670 20327.7     0.7                      
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(pm2.5.lm2.step)
```

```
## Analysis of Variance Table
##
## Response: ihs(pm2.5)
##              Df  Sum Sq Mean Sq   F value    Pr(>F)    
## DEWP          1  3050.0  3050.0 4869.9424 < 2.2e-16 ***
## TEMP          1  5912.3  5912.3 9440.1855 < 2.2e-16 ***
## PRES          1   366.3   366.3  584.8412 < 2.2e-16 ***
## SW            1   323.0   323.0  515.7541 < 2.2e-16 ***
## NE            1   105.9   105.9  169.0950 < 2.2e-16 ***
## NW            1  2451.2  2451.2 3913.7616 < 2.2e-16 ***
## DEWP:PRES     1   849.4   849.4 1356.2210 < 2.2e-16 ***
## DEWP:SW       1    17.5    17.5   27.9762 1.237e-07 ***
## DEWP:NE       1     5.3     5.3    8.3917  0.003772 ** 
## DEWP:NW       1     2.3     2.3    3.6575  0.055826 .  
## TEMP:PRES     1    91.8    91.8  146.6145 < 2.2e-16 ***
## TEMP:SW       1     0.0     0.0    0.0026  0.959389    
## TEMP:NE       1    32.7    32.7   52.2416 5.022e-13 ***
## TEMP:NW       1    94.5    94.5  150.9462 < 2.2e-16 ***
## PRES:NE       1     3.0     3.0    4.8626  0.027452 *  
## PRES:NW       1    29.0    29.0   46.2789 1.044e-11 ***
## Residuals 30660 19202.1     0.6                        
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The second model has better performance to fit the data

Assessing test set performance

```
pred1 <- predict(pm2.5.lm1.ihs, test)
```

```
## Warning in predict.lm(pm2.5.lm1.ihs, test): prediction from a rank-
## deficient fit may be misleading
```

```
pred2 <- predict(pm2.5.lm2.step, test)
head(pred1)
```

```
##    29681     6080     6639    22972     4895    33369
## 4.794975 4.669995 4.573542 5.889805 5.141580 4.895222
```

```
head(pred2)
```

```
##    29681     6080     6639    22972     4895    33369
## 4.652420 4.703010 4.817894 5.612322 5.139300 5.175095
```

Plotting of train and test data against actural performance

```
train.pred1 <- predict(pm2.5.lm1.ihs)
test.pred1 <- predict(pm2.5.lm1.ihs, test)
```

```
## Warning in predict.lm(pm2.5.lm1.ihs, test): prediction from a rank-
## deficient fit may be misleading
```

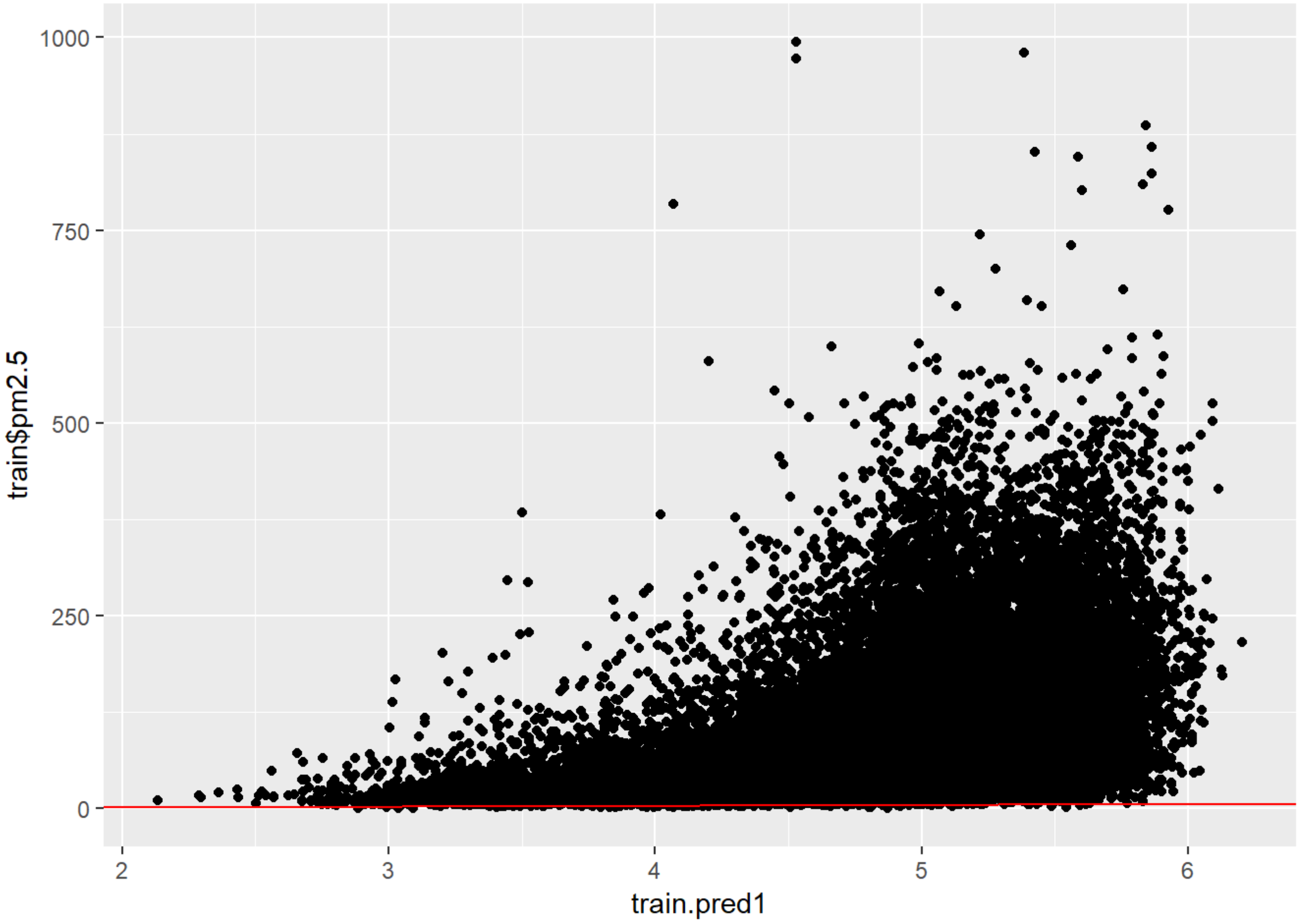
```
train.pred2 <- predict(pm2.5.lm2.ihs)
test.pred2 <- predict(pm2.5.lm2.ihs, test)
```

```
## Warning in predict.lm(pm2.5.lm2.ihs, test): prediction from a rank-
## deficient fit may be misleading
```

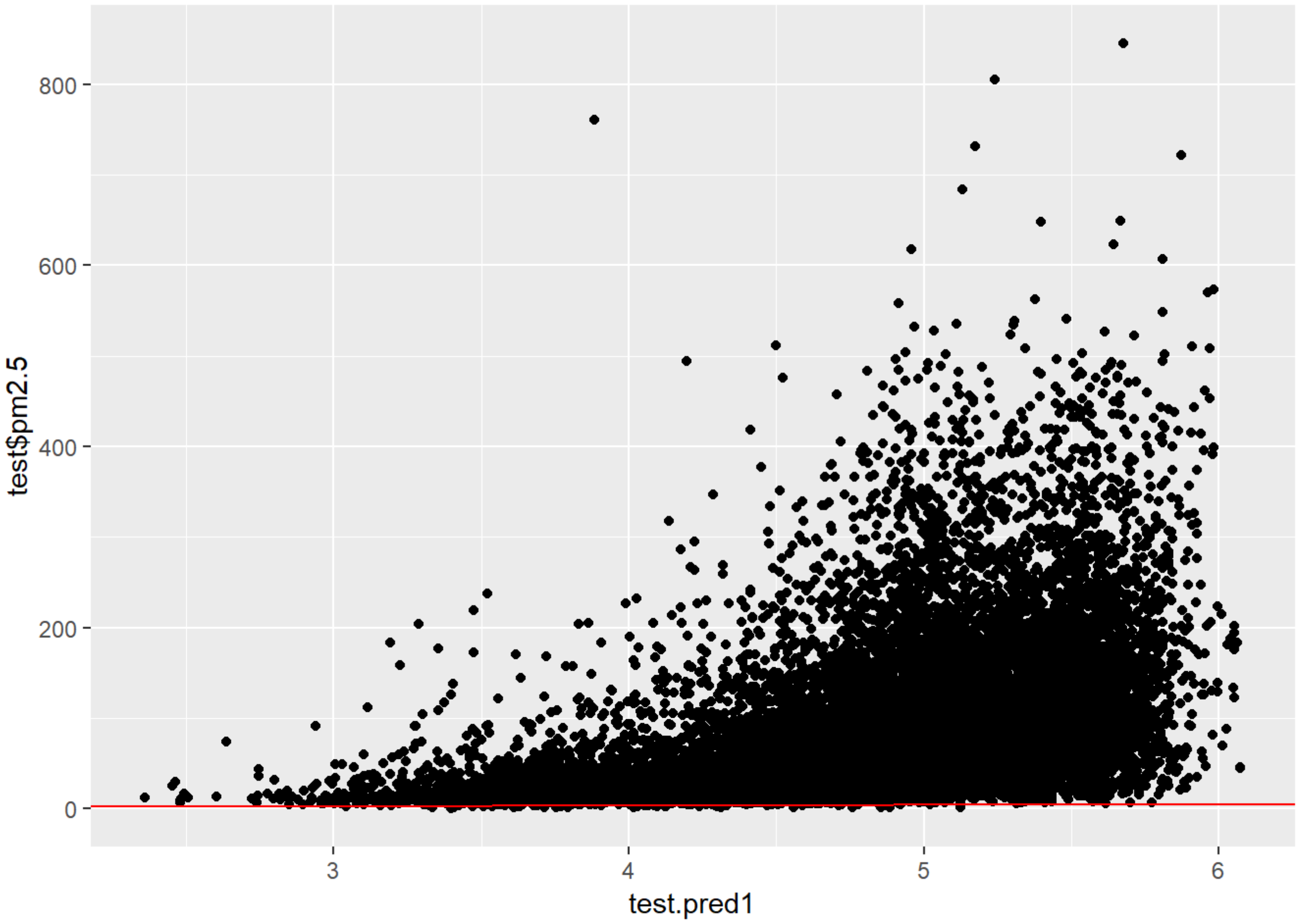
```
plot.train1 <- ggplot(train, aes(x = train.pred1, y = train$pm2.5)) +
  geom_point() +
  geom_abline(color = "red")

plot.test1 <- ggplot(test, aes(x = test.pred1, y = test$pm2.5)) +
  geom_point() +
  geom_abline(color = "red")

plot.train1
```


train$pm2.5
1000
750
500
250
0
2
3
4
5
6
train.pred1

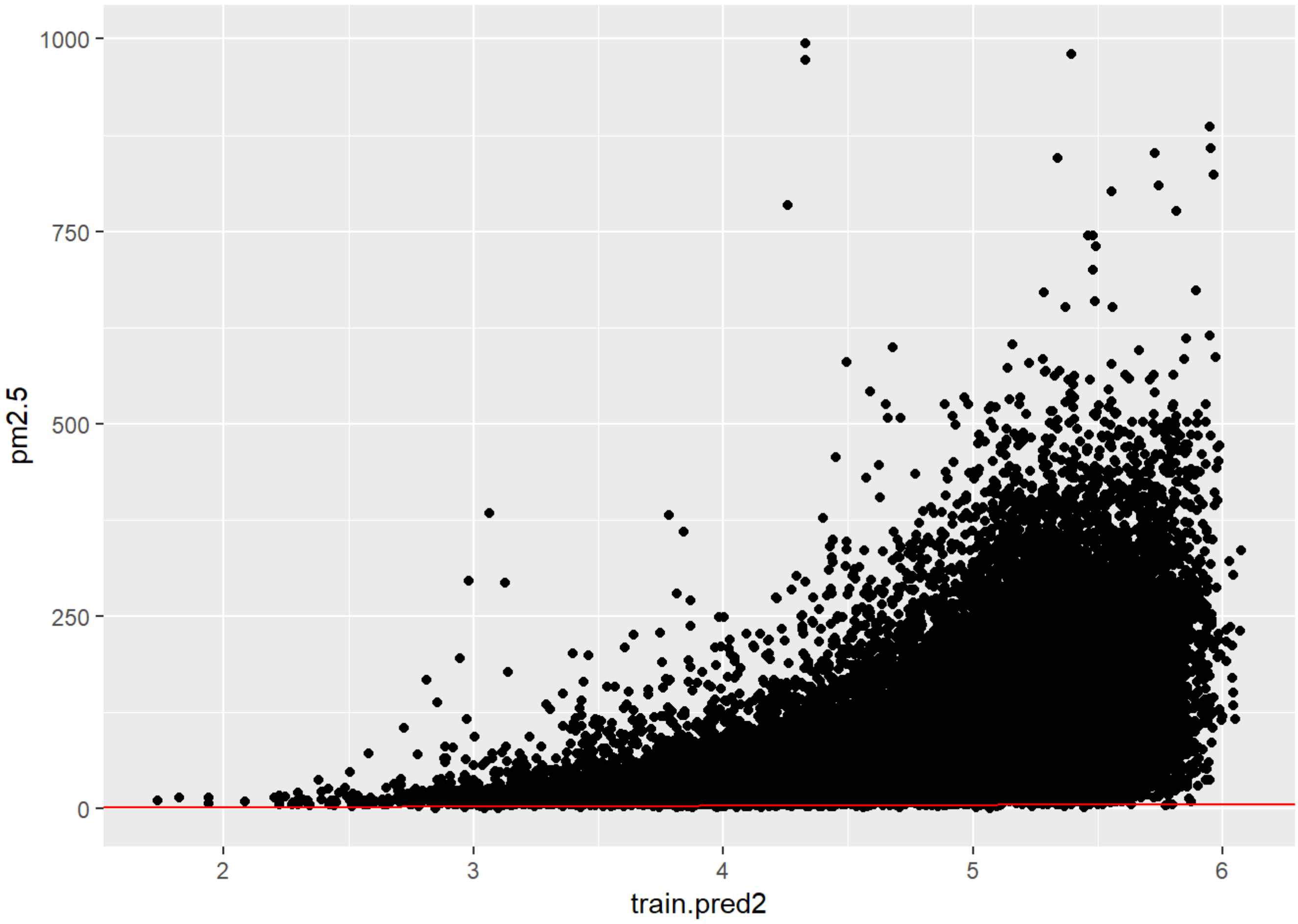
```
plot.test1
```


test$pm2.5
800
600
400
200
0
3
4
5
6
test.pred1

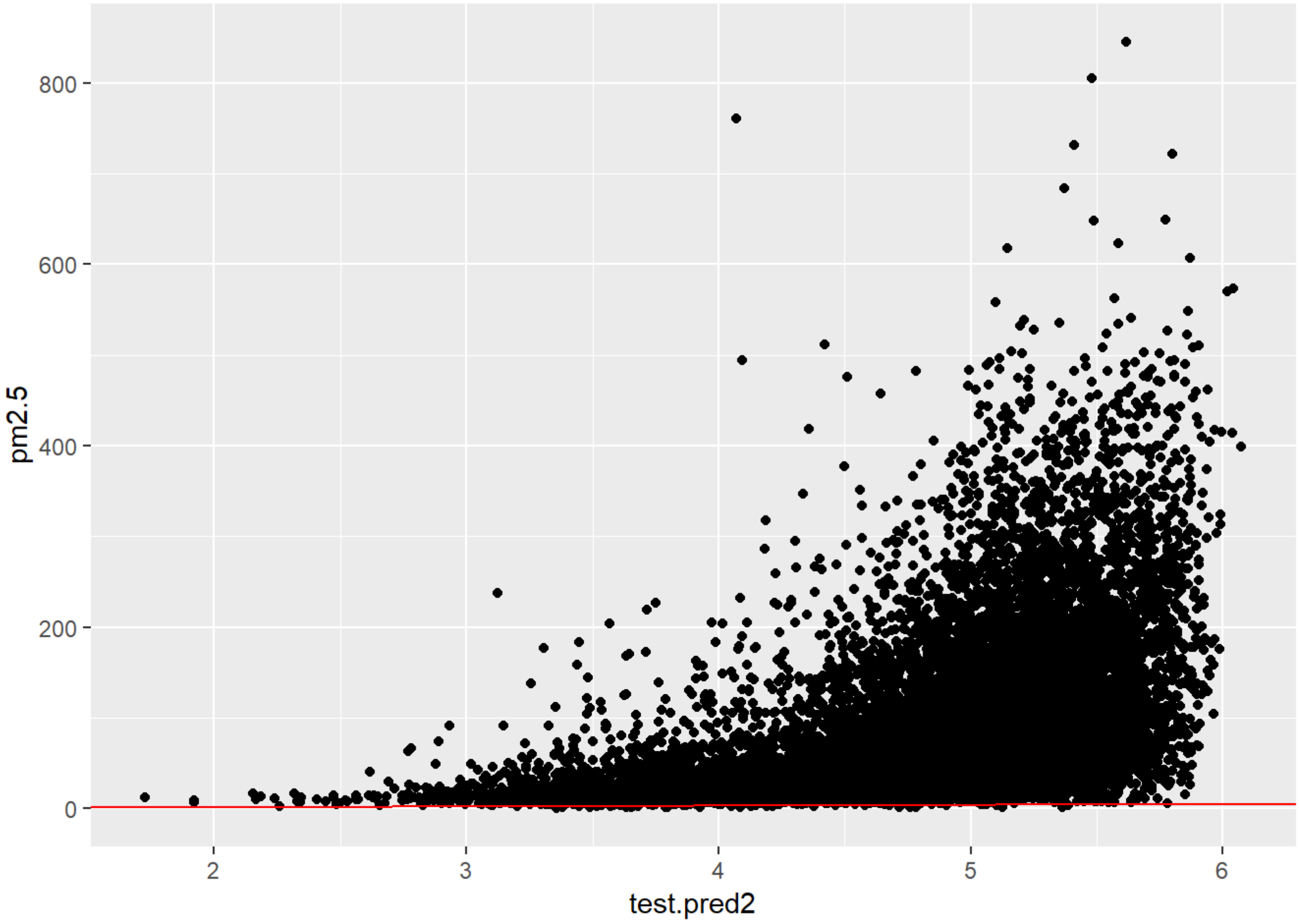
```
plot.train2 <- ggplot(train, aes(x = train.pred2, y = pm2.5)) +
  geom_point() +
  geom_abline(color = "red")

plot.test2 <- ggplot(test, aes(x = test.pred2, y = pm2.5)) +
  geom_point() +
  geom_abline(color = "red")

plot.train2
```




```
plot.test2
```



Check which model is fitting better

Test for pm2.5.lm1.ihs

```
predictions <- pm2.5.lm1.ihs%>% predict(test)
```

```
## Warning in predict.lm(., test): prediction from a rank-deficient fit may be
## misleading
```

```
data.frame( R2 = R2(predictions, test$pm2.5),
            RMSE = RMSE(predictions, test$pm2.5),
            MAE = MAE(predictions, test$pm2.5))
```

```
##          R2     RMSE    MAE
## 1 0.2326135 130.9954 93.623
```

Test for the pm.2.5.lm2.step

```
predictions <- pm2.5.lm2.step%>% predict(test)
data.frame( R2 = R2(predictions, test$pm2.5),
            RMSE = RMSE(predictions, test$pm2.5),
            MAE = MAE(predictions, test$pm2.5))
```

```
##         R2     RMSE      MAE
## 1 0.260747 130.9712 93.62059
```

Now we and see that the second model is more optimal model, but from the plot above, both models doesn’t have good performance. And to improve the performance, we need to check if the model has multicollinearity problem.

VIF and Conditional Number k

```
vif(pm2.5.lm2.step)
```

```
##         DEWP         TEMP         PRES           SW           NE 
## 39314.494844 35236.358062     9.781866     5.094843 37398.601676 
##           NW    DEWP:PRES      DEWP:SW      DEWP:NE      DEWP:NW 
## 37094.554141 39556.296408     6.031905     5.581207     6.861035 
##    TEMP:PRES      TEMP:SW      TEMP:NE      TEMP:NW      PRES:NE 
## 34893.435631    10.650441     9.714858     9.452146 37046.697804 
##      PRES:NW 
## 36885.430947
```

```
kappa(pm2.5.lm2.step)
```

```
## [1] 16862891
```

VIF is almost bigger than 5 or 10 and Condtional Number is bigger than 30, which implys that there exits severe multicollinearity problem

LASSO

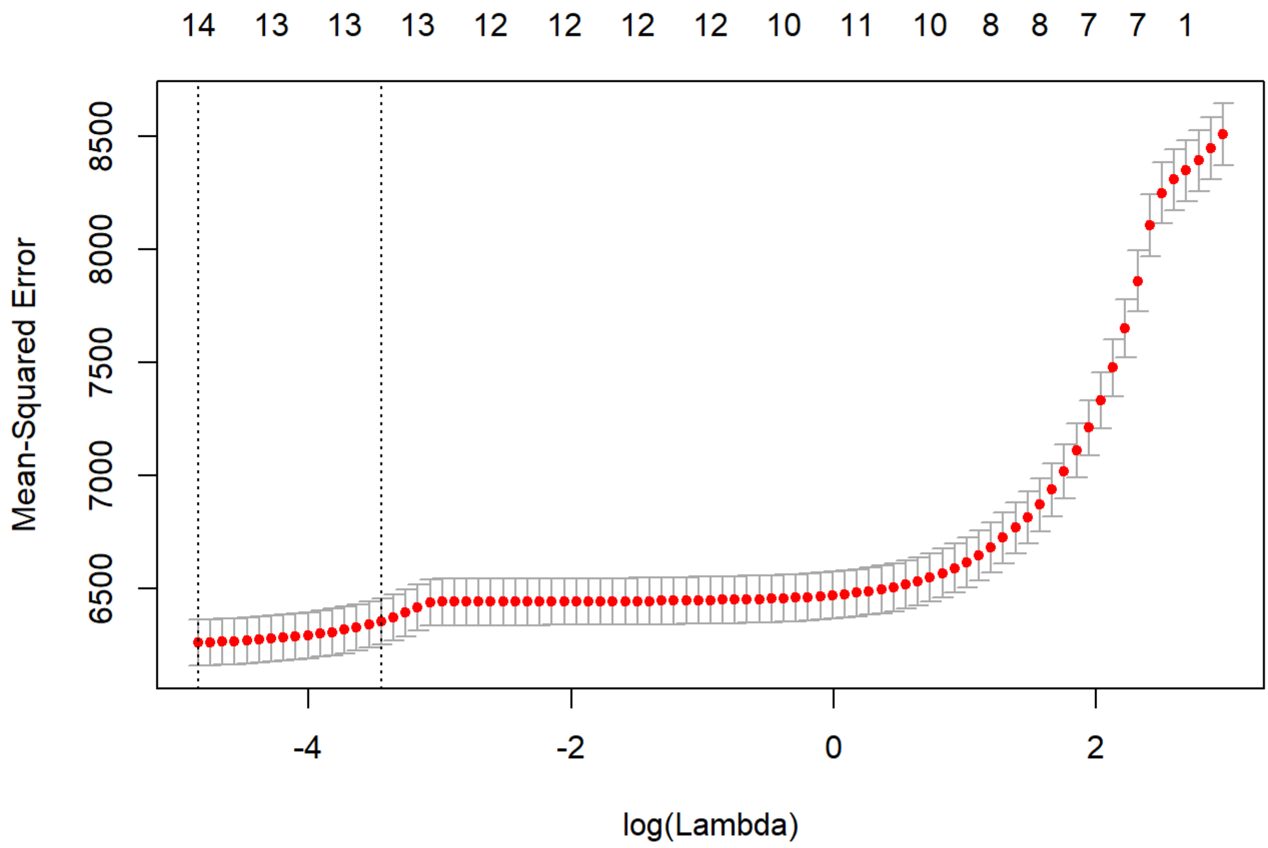
```
x = model.matrix(pm2.5.lm2.step)
y = train$pm2.5
```

Setting Parameters

```
set.seed(888)
train1 = sample(1:nrow(train), .7 * nrow(train))
test1 = (-train1)
ytest = y[test1]
lambda <- 10^seq(10, -2, length = 100)
```

Choosing Best lambda

```
cv.out <- cv.glmnet(x[train1, ], y[train1], alpha = 1)
plot(cv.out)
```

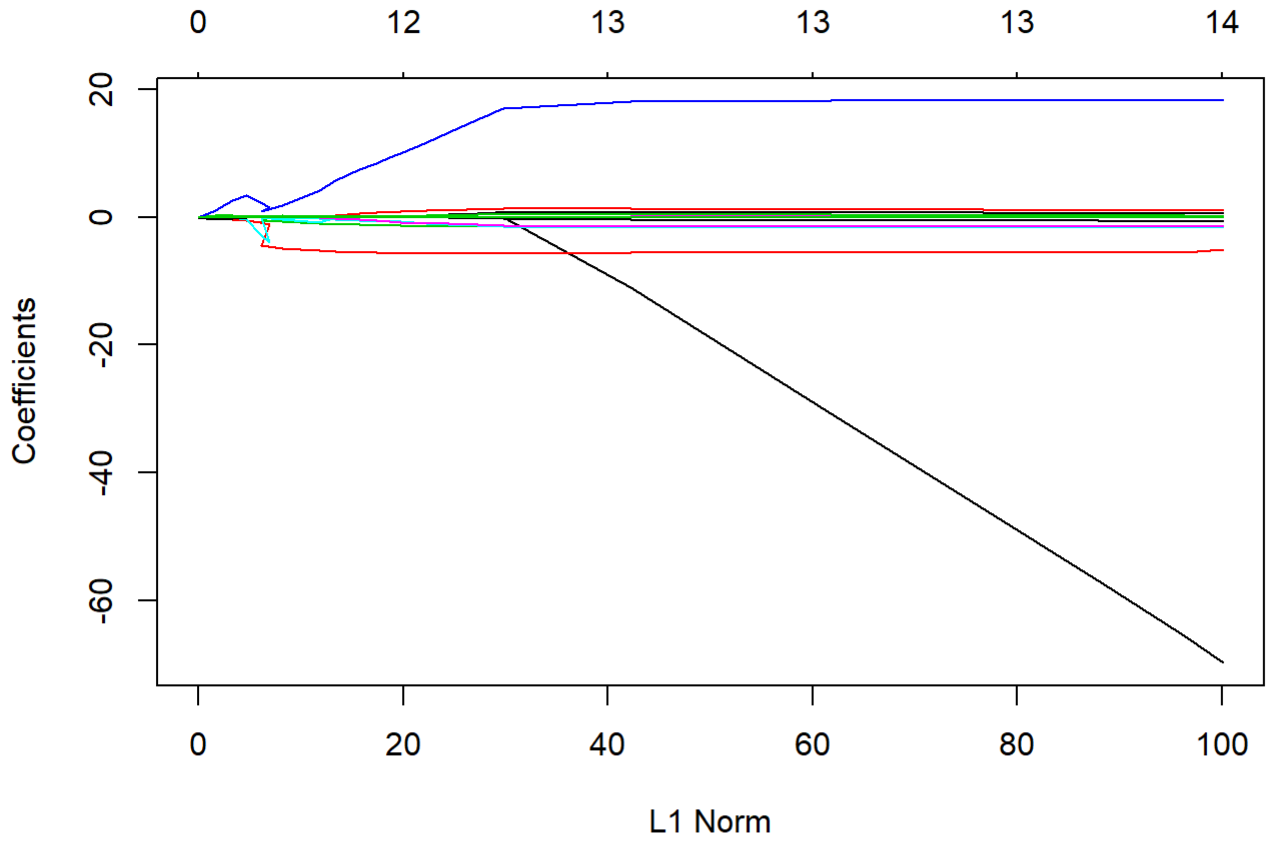



```
bestlam <- cv.out$lambda.min
```

The Plot of Lambda

Lasso Predictions

```
lasso.mod <- glmnet(x[train1, ], y[train1], alpha = 1, lambda = lambda)
plot(lasso.mod)
```




```
lasso.pred <-predict(lasso.mod, s = bestlam, newx = x[test1,])
mean((lasso.pred - ytest)^2)
```

```
## [1] 6237.932
```

The Plot of Coefficients Varying with Parameters in Lasso Regression

Coefficient Analysis

```
out = glmnet(x, y, alpha = 1, lambda = lambda)
lasso_coef = predict(out, type = "coefficients", s= bestlam)[1:16,]
lasso_coef
```

```
##   (Intercept)   (Intercept)          DEWP          TEMP          PRES 
##  1.870313e+03  0.000000e+00 -7.004265e+01 -5.456911e+00 -1.658496e+00 
##            SW            NE            NW     DEWP:PRES       DEWP:SW 
##  1.812503e+01  0.000000e+00  0.000000e+00  7.274563e-02  5.714234e-01 
##       DEWP:NE       DEWP:NW     TEMP:PRES       TEMP:SW       TEMP:NE 
##  9.260656e-01  1.102196e-02 -2.130212e-04 -1.573530e+00 -1.447454e+00 
##       TEMP:NW 
## -5.597322e-01
```

Aggregate to daily maxima for model building

```
summary(pm2.5)
```

```
##      pm2.5             DEWP              TEMP              PRES     
##  Min.   :  0.00   Min.   :-40.000   Min.   :-19.00   Min.   : 991  
##  1st Qu.: 29.00   1st Qu.:-10.000   1st Qu.:  2.00   1st Qu.:1008  
##  Median : 72.00   Median :  2.000   Median : 14.00   Median :1016  
##  Mean   : 98.71   Mean   :  1.817   Mean   : 12.45   Mean   :1016  
##  3rd Qu.:137.00   3rd Qu.: 15.000   3rd Qu.: 23.00   3rd Qu.:1025  
##  Max.   :994.00   Max.   : 28.000   Max.   : 42.00   Max.   :1046  
##  cbwd           date                  SW               NE       
##  NE: 4997   Min.   :2010-01-01   Min.   :0.0000   Min.   :0.000  
##  NW:14150   1st Qu.:2011-04-02   1st Qu.:0.0000   1st Qu.:0.000  
##  SE:15290   Median :2012-07-01   Median :0.0000   Median :0.000  
##  SW: 9387   Mean   :2012-07-01   Mean   :0.2142   Mean   :0.114  
##             3rd Qu.:2013-10-01   3rd Qu.:0.0000   3rd Qu.:0.000  
##             Max.   :2014-12-31   Max.   :1.0000   Max.   :1.000  
##        NW               SE        
##  Min.   :0.0000   Min.   :0.0000  
##  1st Qu.:0.0000   1st Qu.:0.0000  
##  Median :0.0000   Median :0.0000  
##  Mean   :0.3229   Mean   :0.3489  
##  3rd Qu.:1.0000   3rd Qu.:1.0000  
##  Max.   :1.0000   Max.   :1.0000
```

```
dailyPM2.5 <- aggregate(pm2.5$pm2.5, by = list(pm2.5$date), FUN = max)
colnames(dailyPM2.5) <- c("date", "pm2.5")
print(dailyPM2.5)
```

```
##           date pm2.5
## 1   2010-01-01   345
## 2   2010-01-02   181
## 3   2010-01-03   107
## 4   2010-01-04    79
## 5   2010-01-05   106
## 6   2010-01-06   132
## 7   2010-01-07   198
## 8   2010-01-08   275
## 9   2010-01-09   196
## 10  2010-01-10    88
## 11  2010-01-11    28
## 12  2010-01-12    37
## 13  2010-01-13    96
## 14  2010-01-14   257
## 15  2010-01-15   102
## 16  2010-01-16   271
## 17  2010-01-17   317
## 18  2010-01-18   435
## 19  2010-01-19   485
## 20  2010-01-20   389
## 21  2010-01-21    72
## 22  2010-01-22    49
## 23  2010-01-23   303
## 24  2010-01-24   331
## 25  2010-01-25   249
## 26  2010-01-26   353
## 27  2010-01-27   300
## 28  2010-01-28    34
## 29  2010-01-29    52
## 30  2010-01-30    94
## 31  2010-01-31   145
## 32  2010-02-01    78
## 33  2010-02-02   104
## 34  2010-02-03   161
## 35  2010-02-04   104
## 36  2010-02-05   126
## 37  2010-02-06   189
## 38  2010-02-07   164
## 39  2010-02-08   258
## 40  2010-02-09   273
## 41  2010-02-10    22
## 42  2010-02-11    24
## 43  2010-02-12    69
## 44  2010-02-13   267
## 45  2010-02-14   980
## 46  2010-02-15   116
## 47  2010-02-16   198
## 48  2010-02-17   247
## 49  2010-02-18   296
## 50  2010-02-19   191
## 51  2010-02-20   282
## 52  2010-02-21   261
## 53  2010-02-22   154
## 54  2010-02-23   282
## 55  2010-02-24   368
## 56  2010-02-25   266
```

```
## 57   2010-02-26   103
## 58   2010-02-27   138
## 59   2010-02-28   161
## 60   2010-03-01    99
## 61   2010-03-02   169
## 62   2010-03-03   247
## 63   2010-03-04   269
## 64   2010-03-05   248
## 65   2010-03-06   103
## 66   2010-03-07   134
## 67   2010-03-08    76
## 68   2010-03-09    51
## 69   2010-03-10   111
## 70   2010-03-11   224
## 71   2010-03-12   314
## 72   2010-03-13    82
## 73   2010-03-14   116
## 74   2010-03-15   220
## 75   2010-03-16    89
## 76   2010-03-17    85
## 77   2010-03-18   239
## 78   2010-03-19   250
## 79   2010-03-20   700
## 80   2010-03-21   121
## 81   2010-03-22   784
## 82   2010-03-23    86
## 83   2010-03-24   134
## 84   2010-03-25    69
## 85   2010-03-26   142
## 86   2010-03-27   134
## 87   2010-03-28   120
## 88   2010-03-29   366
## 89   2010-03-30   395
## 90   2010-03-31   321
## 91   2010-04-01    81
## 92   2010-04-02    77
## 93   2010-04-03   168
## 94   2010-04-04   206
## 95   2010-04-05   199
## 96   2010-04-06    34
## 97   2010-04-07   140
## 98   2010-04-08   158
## 99   2010-04-09   150
## 100  2010-04-10   102
## 101  2010-04-11    91
## 102  2010-04-12   116
## 103  2010-04-13    69
## 104  2010-04-14   100
## 105  2010-04-15   237
## 106  2010-04-16   289
## 107  2010-04-17   223
## 108  2010-04-18   351
## 109  2010-04-19   389
## 110  2010-04-20   110
## 111  2010-04-21    52
## 112  2010-04-22    53
## 113  2010-04-23    65
## 114  2010-04-24   122
```

```
## 115  2010-04-25   142
## 116  2010-04-26    26
## 117  2010-04-27    50
## 118  2010-04-28    38
## 119  2010-04-29    27
## 120  2010-04-30    54
## 121  2010-05-01    97
## 122  2010-05-02   151
## 123  2010-05-03   160
## 124  2010-05-04   228
## 125  2010-05-05   283
## 126  2010-05-06    41
## 127  2010-05-07   228
## 128  2010-05-08   203
## 129  2010-05-09   294
## 130  2010-05-10   132
## 131  2010-05-11    54
## 132  2010-05-12    55
## 133  2010-05-13    83
## 134  2010-05-14   216
## 135  2010-05-15   238
## 136  2010-05-16   185
## 137  2010-05-17   362
## 138  2010-05-18   105
## 139  2010-05-19    50
## 140  2010-05-20   113
## 141  2010-05-21   234
## 142  2010-05-22   229
## 143  2010-05-23   176
## 144  2010-05-24   100
## 145  2010-05-25    57
## 146  2010-05-26   139
## 147  2010-05-27   414
## 148  2010-05-28   206
## 149  2010-05-29   314
## 150  2010-05-30    97
## 151  2010-05-31   179
## 152  2010-06-01   290
## 153  2010-06-02   324
## 154  2010-06-03   190
## 155  2010-06-04   210
## 156  2010-06-05   255
## 157  2010-06-06   306
## 158  2010-06-07   172
## 159  2010-06-08   191
## 160  2010-06-09   273
## 161  2010-06-10    80
## 162  2010-06-11   100
## 163  2010-06-12   160
## 164  2010-06-13   198
## 165  2010-06-14   142
## 166  2010-06-15   229
## 167  2010-06-16   155
## 168  2010-06-17    51
## 169  2010-06-18   100
## 170  2010-06-19   120
## 171  2010-06-20   240
## 172  2010-06-21   132
```

```
## 173  2010-06-22   140
## 174  2010-06-23   212
## 175  2010-06-24   120
## 176  2010-06-25   231
## 177  2010-06-26   252
## 178  2010-06-27   163
## 179  2010-06-28   200
## 180  2010-06-29   249
## 181  2010-06-30   235
## 182  2010-07-01   241
## 183  2010-07-02    46
## 184  2010-07-03   100
## 185  2010-07-04   168
## 186  2010-07-05   132
## 187  2010-07-06    62
## 188  2010-07-07    80
## 189  2010-07-08    77
## 190  2010-07-09   123
## 191  2010-07-10   117
## 192  2010-07-11   231
## 193  2010-07-12   211
## 194  2010-07-13   206
## 195  2010-07-14   174
## 196  2010-07-15   286
## 197  2010-07-16   310
## 198  2010-07-17   196
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## 1516 2014-02-24   425
## 1517 2014-02-25   577
## 1518 2014-02-26   562
## 1519 2014-02-27    53
## 1520 2014-02-28   179
## 1521 2014-03-01   210
## 1522 2014-03-02   257
## 1523 2014-03-03   322
## 1524 2014-03-04   266
## 1525 2014-03-05    49
## 1526 2014-03-06    53
## 1527 2014-03-07   100
## 1528 2014-03-08   218
## 1529 2014-03-09   172
## 1530 2014-03-10   195
## 1531 2014-03-11   303
## 1532 2014-03-12    66
## 1533 2014-03-13    40
## 1534 2014-03-14    66
## 1535 2014-03-15   189
## 1536 2014-03-16   205
## 1537 2014-03-17   191
## 1538 2014-03-18    79
## 1539 2014-03-19    96
## 1540 2014-03-20    18
## 1541 2014-03-21    67
## 1542 2014-03-22   163
## 1543 2014-03-23   249
## 1544 2014-03-24   281
## 1545 2014-03-25   326
## 1546 2014-03-26   414
## 1547 2014-03-27   465
## 1548 2014-03-28   224
## 1549 2014-03-29   222
## 1550 2014-03-30    66
## 1551 2014-03-31   254
## 1552 2014-04-01   220
## 1553 2014-04-02   163
## 1554 2014-04-03    64
## 1555 2014-04-04    60
## 1556 2014-04-05    49
## 1557 2014-04-06   102
## 1558 2014-04-07   155
## 1559 2014-04-08   206
## 1560 2014-04-09   580
## 1561 2014-04-10   175
## 1562 2014-04-11   103
## 1563 2014-04-12   190
## 1564 2014-04-13   231
```

```
## 1565 2014-04-14   282
## 1566 2014-04-15   112
## 1567 2014-04-16   134
## 1568 2014-04-17   151
## 1569 2014-04-18   193
## 1570 2014-04-19    84
## 1571 2014-04-20   128
## 1572 2014-04-21    91
## 1573 2014-04-22   170
## 1574 2014-04-23   185
## 1575 2014-04-24   140
## 1576 2014-04-25   177
## 1577 2014-04-26    61
## 1578 2014-04-27   135
## 1579 2014-04-28   132
## 1580 2014-04-29   136
## 1581 2014-04-30   221
## 1582 2014-05-01   202
## 1583 2014-05-02    60
## 1584 2014-05-03   167
## 1585 2014-05-04    98
## 1586 2014-05-05    85
## 1587 2014-05-06   154
## 1588 2014-05-07   159
## 1589 2014-05-08   147
## 1590 2014-05-09    91
## 1591 2014-05-10    71
## 1592 2014-05-11    57
## 1593 2014-05-12    82
## 1594 2014-05-13   112
## 1595 2014-05-14    38
## 1596 2014-05-15   121
## 1597 2014-05-16   271
## 1598 2014-05-17   109
## 1599 2014-05-18   198
## 1600 2014-05-19   167
## 1601 2014-05-20   215
## 1602 2014-05-21   150
## 1603 2014-05-22   259
## 1604 2014-05-23   110
## 1605 2014-05-24   104
## 1606 2014-05-25   160
## 1607 2014-05-26    31
## 1608 2014-05-27   102
## 1609 2014-05-28    49
## 1610 2014-05-29    78
## 1611 2014-05-30   113
## 1612 2014-05-31   143
## 1613 2014-06-01    83
## 1614 2014-06-02    55
## 1615 2014-06-03    64
## 1616 2014-06-04   107
## 1617 2014-06-05   108
## 1618 2014-06-06   163
## 1619 2014-06-07   346
## 1620 2014-06-08   109
## 1621 2014-06-09   443
## 1622 2014-06-10    99
```

```
## 1623 2014-06-11   123
## 1624 2014-06-12    51
## 1625 2014-06-13   126
## 1626 2014-06-14   106
## 1627 2014-06-15   169
## 1628 2014-06-16   196
## 1629 2014-06-17   225
## 1630 2014-06-18   144
## 1631 2014-06-19   200
## 1632 2014-06-20    94
## 1633 2014-06-21    76
## 1634 2014-06-22    51
## 1635 2014-06-23    36
## 1636 2014-06-24    68
## 1637 2014-06-25   150
## 1638 2014-06-26   199
## 1639 2014-06-27    62
## 1640 2014-06-28    35
## 1641 2014-06-29    77
## 1642 2014-06-30   104
## 1643 2014-07-01   168
## 1644 2014-07-02   114
## 1645 2014-07-03   280
## 1646 2014-07-04   303
## 1647 2014-07-05   184
## 1648 2014-07-06   252
## 1649 2014-07-07   239
## 1650 2014-07-08   196
## 1651 2014-07-09    85
## 1652 2014-07-10    70
## 1653 2014-07-11    64
## 1654 2014-07-12   160
## 1655 2014-07-13    58
## 1656 2014-07-14    58
## 1657 2014-07-15    81
## 1658 2014-07-16   172
## 1659 2014-07-17   195
## 1660 2014-07-18   220
## 1661 2014-07-19    87
## 1662 2014-07-20    87
## 1663 2014-07-21    60
## 1664 2014-07-22   110
## 1665 2014-07-23    46
## 1666 2014-07-24   104
## 1667 2014-07-25   160
## 1668 2014-07-26   149
## 1669 2014-07-27   133
## 1670 2014-07-28   143
## 1671 2014-07-29   189
## 1672 2014-07-30   212
## 1673 2014-07-31   250
## 1674 2014-08-01   196
## 1675 2014-08-02   121
## 1676 2014-08-03   201
## 1677 2014-08-04    92
## 1678 2014-08-05    51
## 1679 2014-08-06    71
## 1680 2014-08-07   142
```

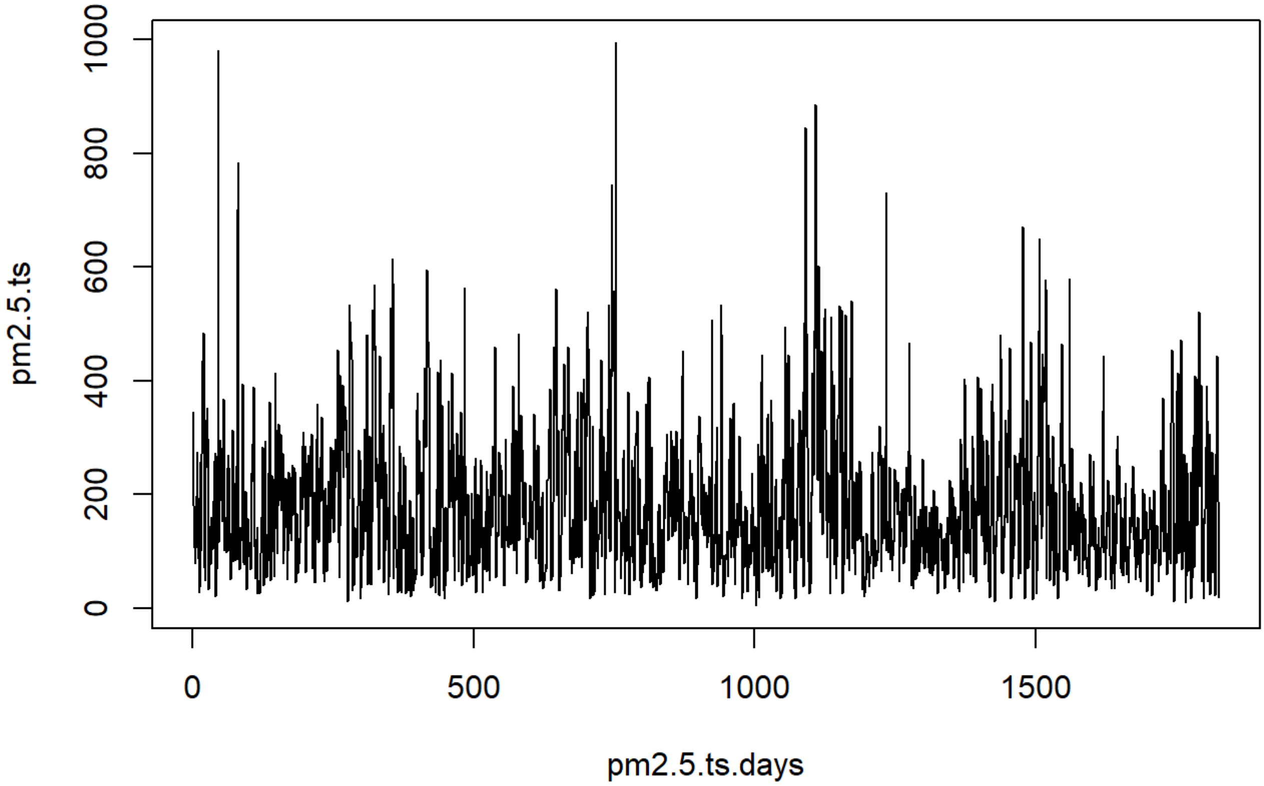
```
## 1681 2014-08-08   90
## 1682 2014-08-09  160
## 1683 2014-08-10   78
## 1684 2014-08-11   86
## 1685 2014-08-12   64
## 1686 2014-08-13   55
## 1687 2014-08-14   48
## 1688 2014-08-15  121
## 1689 2014-08-16   97
## 1690 2014-08-17  209
## 1691 2014-08-18  121
## 1692 2014-08-19  123
## 1693 2014-08-20  202
## 1694 2014-08-21  173
## 1695 2014-08-22  124
## 1696 2014-08-23  171
## 1697 2014-08-24   46
## 1698 2014-08-25   30
## 1699 2014-08-26   41
## 1700 2014-08-27   94
## 1701 2014-08-28  129
## 1702 2014-08-29  139
## 1703 2014-08-30  196
## 1704 2014-08-31  139
## 1705 2014-09-01  175
## 1706 2014-09-02   59
## 1707 2014-09-03   23
## 1708 2014-09-04   81
## 1709 2014-09-05  155
## 1710 2014-09-06  157
## 1711 2014-09-07  207
## 1712 2014-09-08  104
## 1713 2014-09-09   80
## 1714 2014-09-10  118
## 1715 2014-09-11  124
## 1716 2014-09-12  147
## 1717 2014-09-13  108
## 1718 2014-09-14  106
## 1719 2014-09-15   47
## 1720 2014-09-16   98
## 1721 2014-09-17   75
## 1722 2014-09-18  119
## 1723 2014-09-19  279
## 1724 2014-09-20  228
## 1725 2014-09-21  229
## 1726 2014-09-22  135
## 1727 2014-09-23  369
## 1728 2014-09-24  101
## 1729 2014-09-25  168
## 1730 2014-09-26  219
## 1731 2014-09-27  132
## 1732 2014-09-28  101
## 1733 2014-09-29  107
## 1734 2014-09-30   60
## 1735 2014-10-01  100
## 1736 2014-10-02  132
## 1737 2014-10-03  207
## 1738 2014-10-04  130
```

```
## 1739 2014-10-05    86
## 1740 2014-10-06    79
## 1741 2014-10-07   326
## 1742 2014-10-08   432
## 1743 2014-10-09   454
## 1744 2014-10-10   430
## 1745 2014-10-11   328
## 1746 2014-10-12    13
## 1747 2014-10-13    59
## 1748 2014-10-14   128
## 1749 2014-10-15   149
## 1750 2014-10-16    80
## 1751 2014-10-17   225
## 1752 2014-10-18   382
## 1753 2014-10-19   413
## 1754 2014-10-20   285
## 1755 2014-10-21    97
## 1756 2014-10-22   132
## 1757 2014-10-23   214
## 1758 2014-10-24   383
## 1759 2014-10-25   472
## 1760 2014-10-26   395
## 1761 2014-10-27    68
## 1762 2014-10-28    99
## 1763 2014-10-29   215
## 1764 2014-10-30   272
## 1765 2014-10-31   232
## 1766 2014-11-01   215
## 1767 2014-11-02    11
## 1768 2014-11-03    57
## 1769 2014-11-04   255
## 1770 2014-11-05   239
## 1771 2014-11-06    66
## 1772 2014-11-07    90
## 1773 2014-11-08    97
## 1774 2014-11-09   116
## 1775 2014-11-10   153
## 1776 2014-11-11   239
## 1777 2014-11-12    17
## 1778 2014-11-13    53
## 1779 2014-11-14    90
## 1780 2014-11-15   283
## 1781 2014-11-16   304
## 1782 2014-11-17    72
## 1783 2014-11-18   203
## 1784 2014-11-19   409
## 1785 2014-11-20   393
## 1786 2014-11-21   405
## 1787 2014-11-22   146
## 1788 2014-11-23   193
## 1789 2014-11-24   289
## 1790 2014-11-25   342
## 1791 2014-11-26   522
## 1792 2014-11-27   470
## 1793 2014-11-28   214
## 1794 2014-11-29   393
## 1795 2014-11-30   254
## 1796 2014-12-01    48
```

```
## 1797 2014-12-02   125
## 1798 2014-12-03   126
## 1799 2014-12-04    18
## 1800 2014-12-05   158
## 1801 2014-12-06   150
## 1802 2014-12-07   174
## 1803 2014-12-08   284
## 1804 2014-12-09   390
## 1805 2014-12-10   331
## 1806 2014-12-11    92
## 1807 2014-12-12    47
## 1808 2014-12-13   112
## 1809 2014-12-14   212
## 1810 2014-12-15   307
## 1811 2014-12-16    25
## 1812 2014-12-17   245
## 1813 2014-12-18   254
## 1814 2014-12-19   274
## 1815 2014-12-20   212
## 1816 2014-12-21    64
## 1817 2014-12-22   145
## 1818 2014-12-23   234
## 1819 2014-12-24    23
## 1820 2014-12-25    69
## 1821 2014-12-26   271
## 1822 2014-12-27   363
## 1823 2014-12-28   444
## 1824 2014-12-29   373
## 1825 2014-12-30   189
## 1826 2014-12-31    20
```

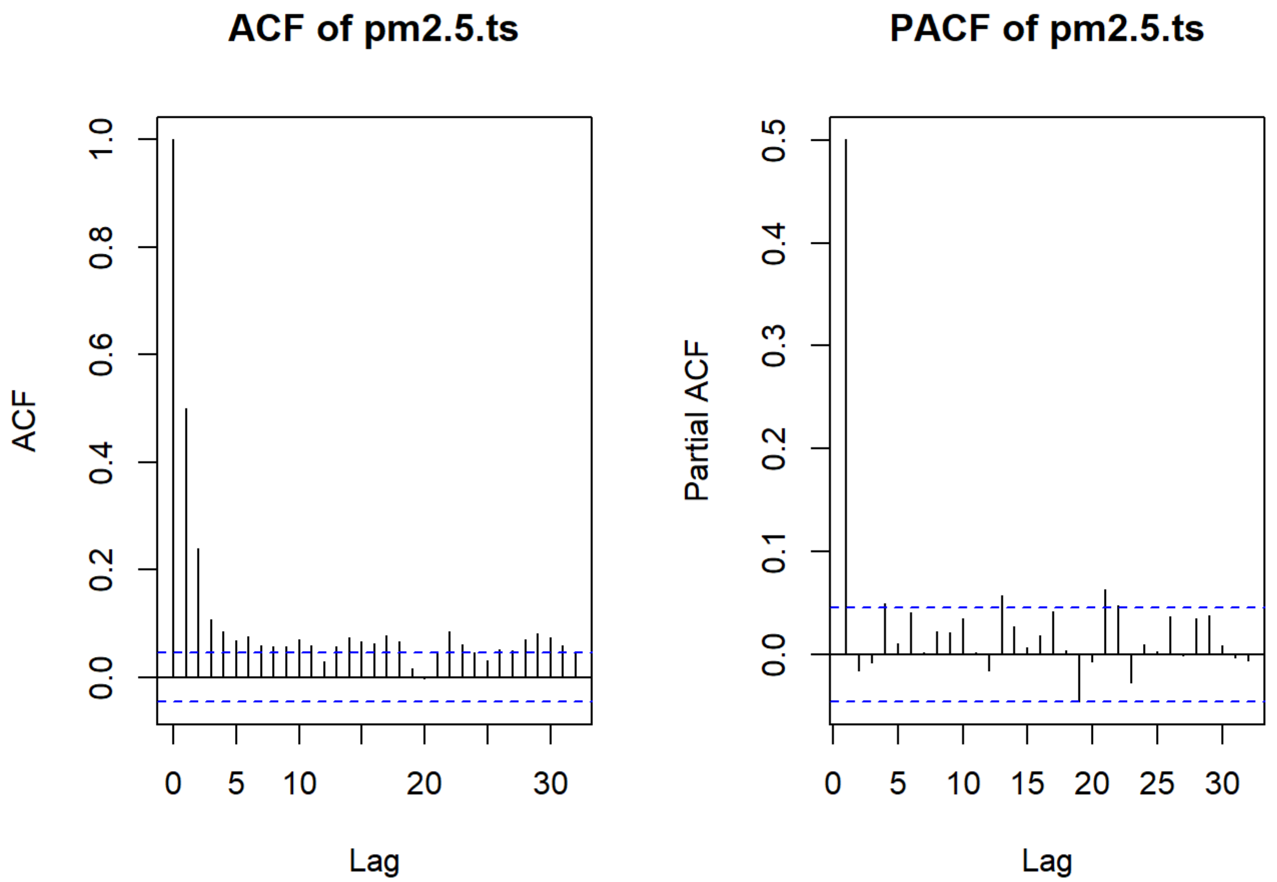
Create time series of pm2.5

```
pm2.5.ts <- ts(dailyPM2.5$pm2.5)
pm2.5.ts.days <- c(1:length(dailyPM2.5$pm2.5))
plot(pm2.5.ts.days, pm2.5.ts, type = "l")
```



ACF and PACF of the pm2.5 time series

```
par(mfrow = c(1,2))
acf(pm2.5.ts[pm2.5.ts.days], main = "ACF of pm2.5.ts")
pacf(pm2.5.ts[pm2.5.ts.days], main = "PACF of pm2.5.ts")
```




```
par(mfrow = c(1,1))
```

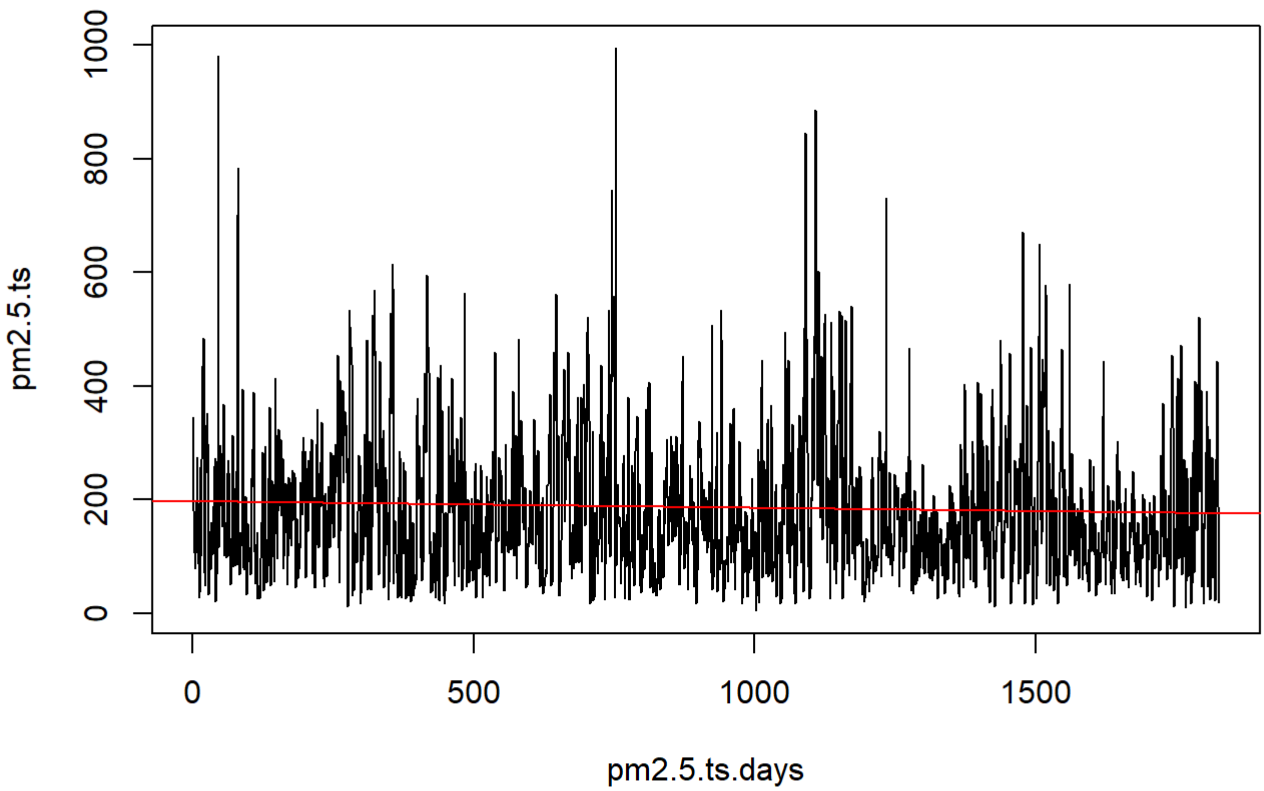
The pm2.5 time series is stationary

Model the trend of the pm2.5 time series

```
pm2.5.ts.trend <- lm(pm2.5.ts ~ pm2.5.ts.days)
summary(pm2.5.ts.trend)
```

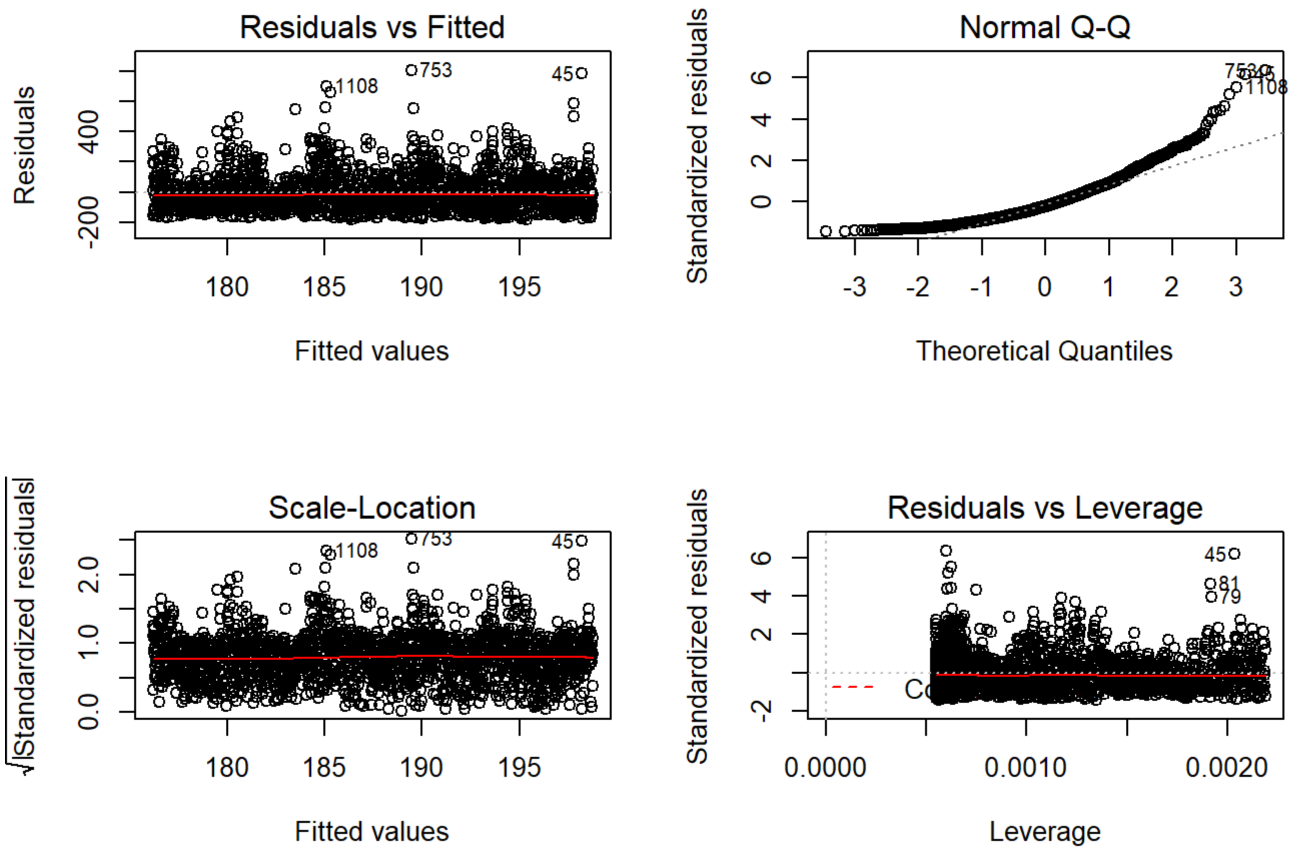
```
##
## Call:
## lm(formula = pm2.5.ts ~ pm2.5.ts.days)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -182.37  -93.31  -28.44   66.02  804.54
##
## Coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)   198.783067   5.935808  33.489   <2e-16 ***
## pm2.5.ts.days  -0.012375   0.005628  -2.199    0.028 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 126.8 on 1824 degrees of freedom
## Multiple R-squared:  0.002644,    Adjusted R-squared:  0.002097
## F-statistic: 4.835 on 1 and 1824 DF,  p-value: 0.02802
```

```
plot(pm2.5.ts.days, pm2.5.ts, type = "l")
abline(pm2.5.ts.trend, col = "red")
```

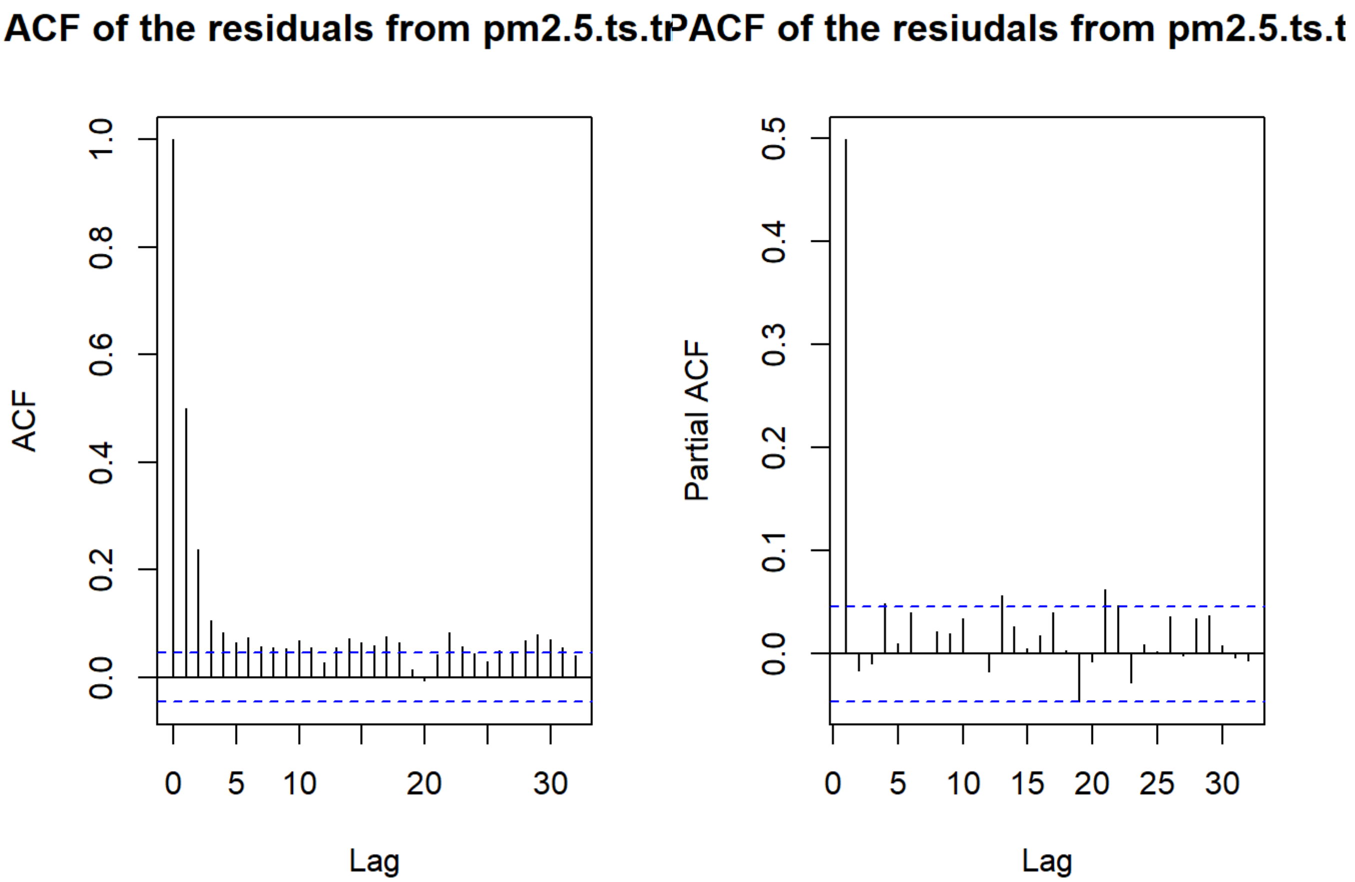


Test the result

```
par(mfrow = c(2,2))
plot(pm2.5.ts.trend)
```




```
par(mfrow = c(1,1))
par(mfrow = c(1,2))
acf(pm2.5.ts.trend$residuals, main = "ACF of the residuals from pm2.5.ts.trend")
pacf(pm2.5.ts.trend$residuals, main = "PACF of the resiudals from pm2.5.ts.trend")
```




```
par(mfrow = c(1,1))
shapiro.test(pm2.5.ts.trend$residuals)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  pm2.5.ts.trend$residuals
## W = 0.90284, p-value < 2.2e-16
```

The p-value of Shapiro-Wilk normality test is less than 0.05 implying that residual is significantly not normally distributed. No pattern is apparent on the plot of residuals against the predicted values, or the risiduals over time. As shown the ACF plot of pm2.5.ts, there exists a seasonality of 7 days. There are peaches in every 7 days and there are a lot of spikes in pacf plot. Thus we

consider to add seasonality components to our model.

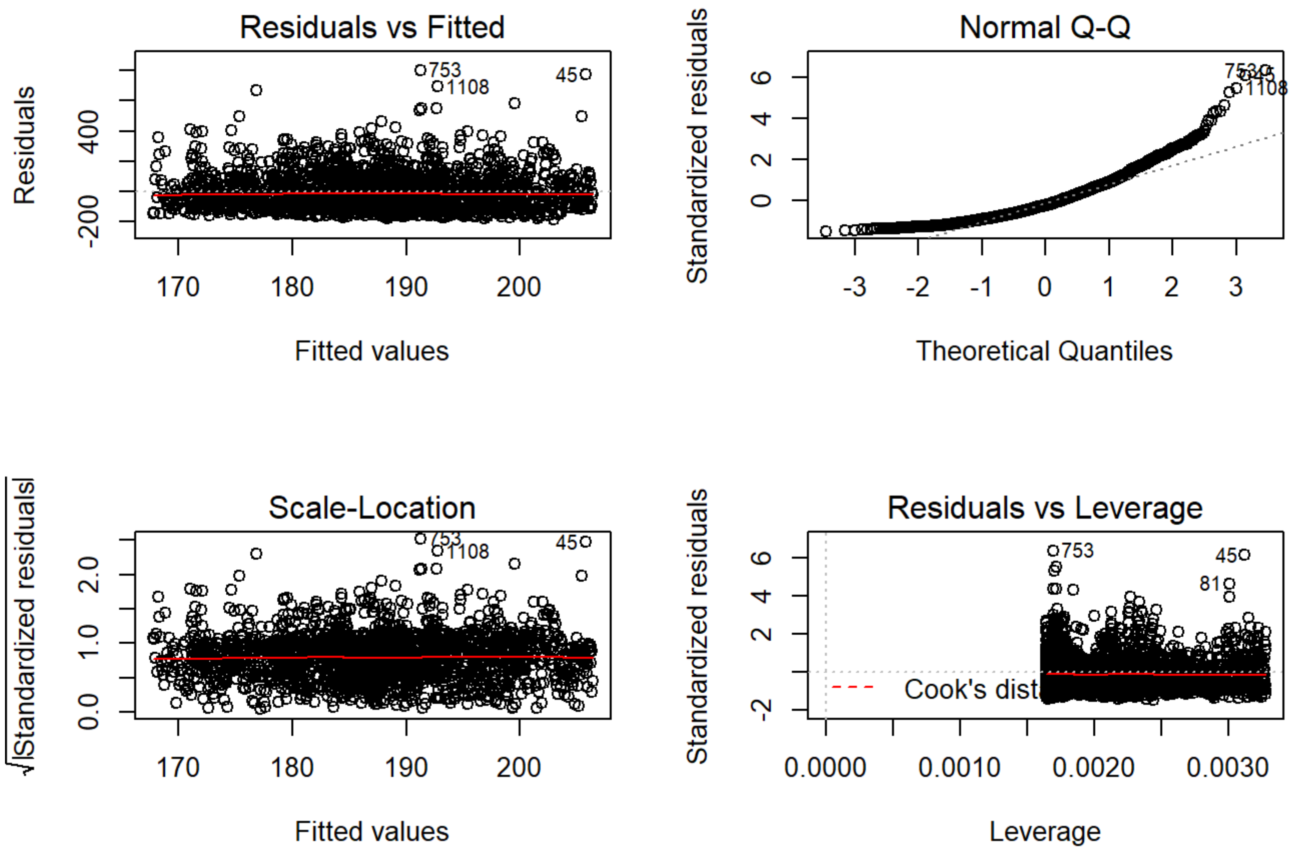
Model the seasonality of the pm2.5 time series

```
pm2.5.ts.trend.seasonal <- lm(pm2.5.ts ~ pm2.5.ts.days + sin(2*pi*pm2.5.ts.days/7) + cos(2*pi
*pm2.5.ts.days/7))
summary(pm2.5.ts.trend.seasonal)
```

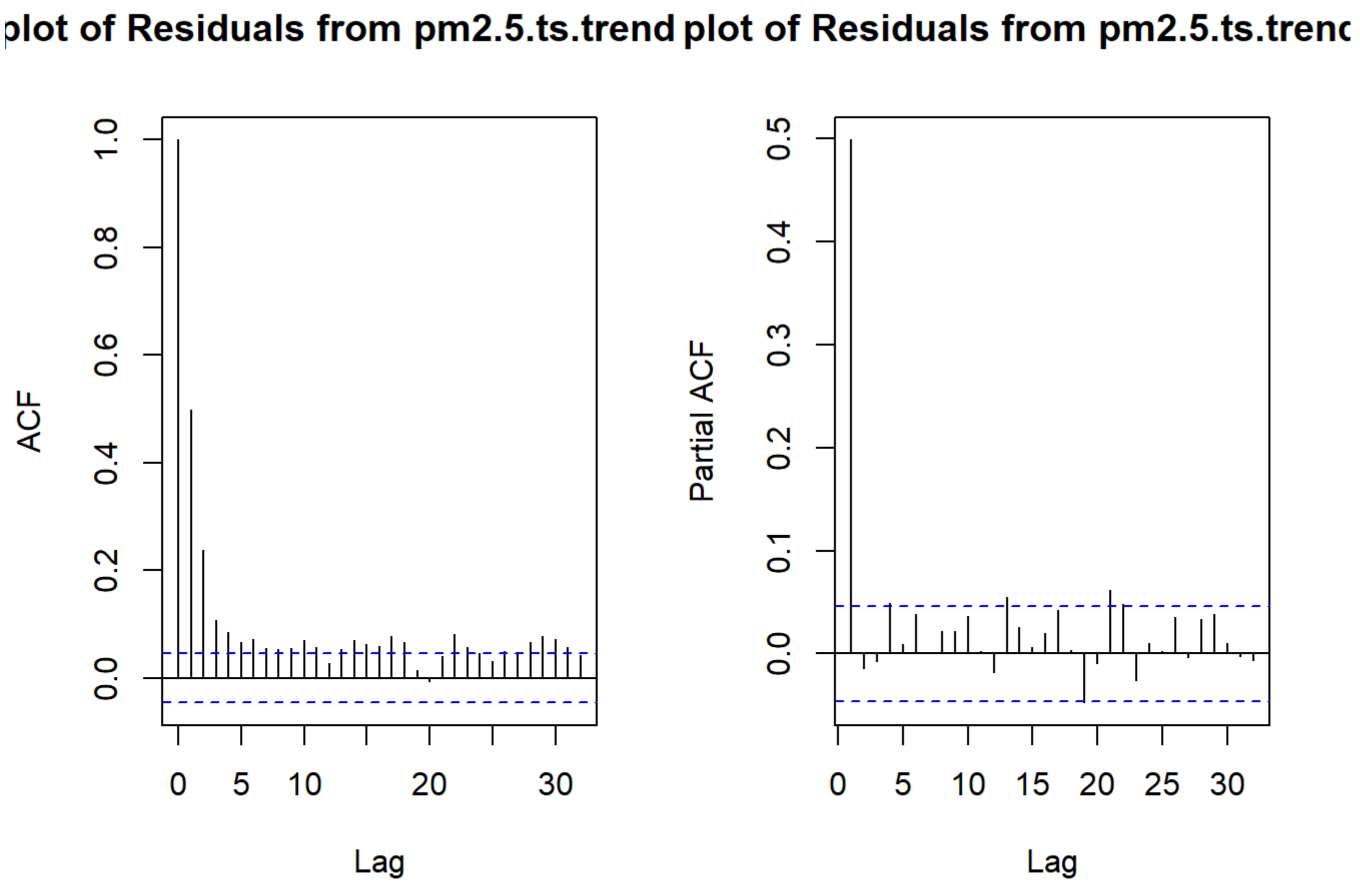
```
##
## Call:
## lm(formula = pm2.5.ts ~ pm2.5.ts.days + sin(2 * pi * pm2.5.ts.days/7) +
##     cos(2 * pi * pm2.5.ts.days/7))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -189.91  -91.81  -27.89   65.39  802.76
##
## Coefficients:
##                                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)                   198.757488   5.932490  33.503   <2e-16 ***
## pm2.5.ts.days                  -0.012350   0.005625  -2.196   0.0282 *
## sin(2 * pi * pm2.5.ts.days/7)   6.658060   4.192037   1.588   0.1124
## cos(2 * pi * pm2.5.ts.days/7)  -5.185897   4.194319  -1.236   0.2165
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 126.7 on 1822 degrees of freedom
## Multiple R-squared:  0.004856,   Adjusted R-squared:  0.003218
## F-statistic: 2.964 on 3 and 1822 DF,  p-value: 0.03104
```

Diagnose the result

```
par(mfrow = c(2,2))
plot(pm2.5.ts.trend.seasonal)
```




```
par(mfrow = c(1,2))
acf(pm2.5.ts.trend.seasonal$residuals, main = "ACF plot of Residuals from pm2.5.ts.trend.seas
onal")
pacf(pm2.5.ts.trend.seasonal$residuals, main = "PACF plot of Residuals from pm2.5.ts.trend.se
asonal")
```




```
par(mfrow=c(1,1))
shapiro.test(pm2.5.ts.trend.seasonal$residuals)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  pm2.5.ts.trend.seasonal$residuals
## W = 0.90259, p-value < 2.2e-16
```

The p-value of Shapiro-Wilk normality test is less than 0.05 implying that residual is significantly not normally distributed, which violates assumption of linear regression. Then we use box cox transformation to normalize the data, and then refit the linear model. And still acf plot shows potential seasonality.

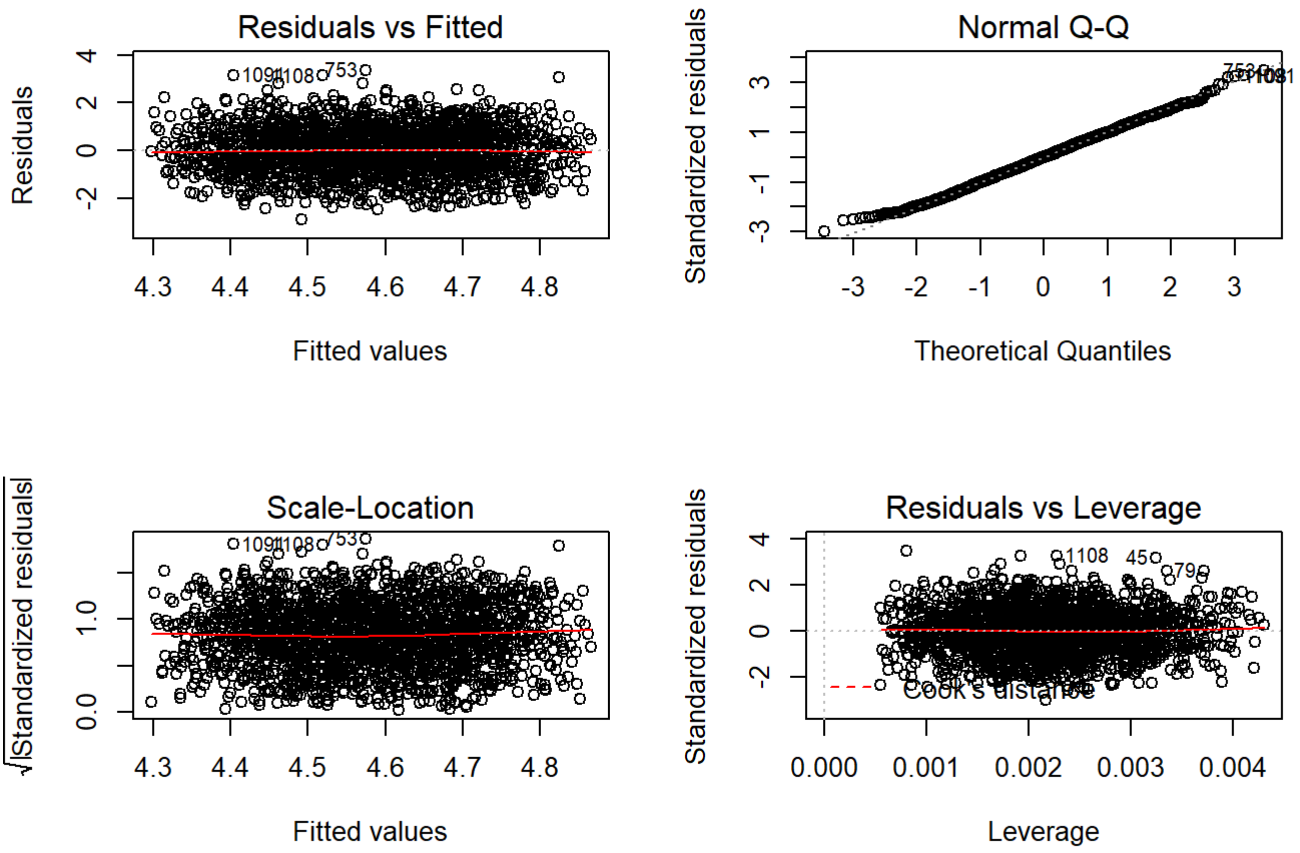
Box-cox transformation

```
L <- boxcox(pm2.5.ts.trend.seasonal, plotit = F)$x[which.max(boxcox(pm2.5.ts.trend.seasonal,
 plotit = F)$y)]
pm2.5.ts.trend.seasonal1 <- lm(pm2.5.ts^L ~ pm2.5.ts.days + sin(2*pi*pm2.5.ts.days/7) + cos(2
*pm2.5.ts.days/7))
summary(pm2.5.ts.trend.seasonal1)
```

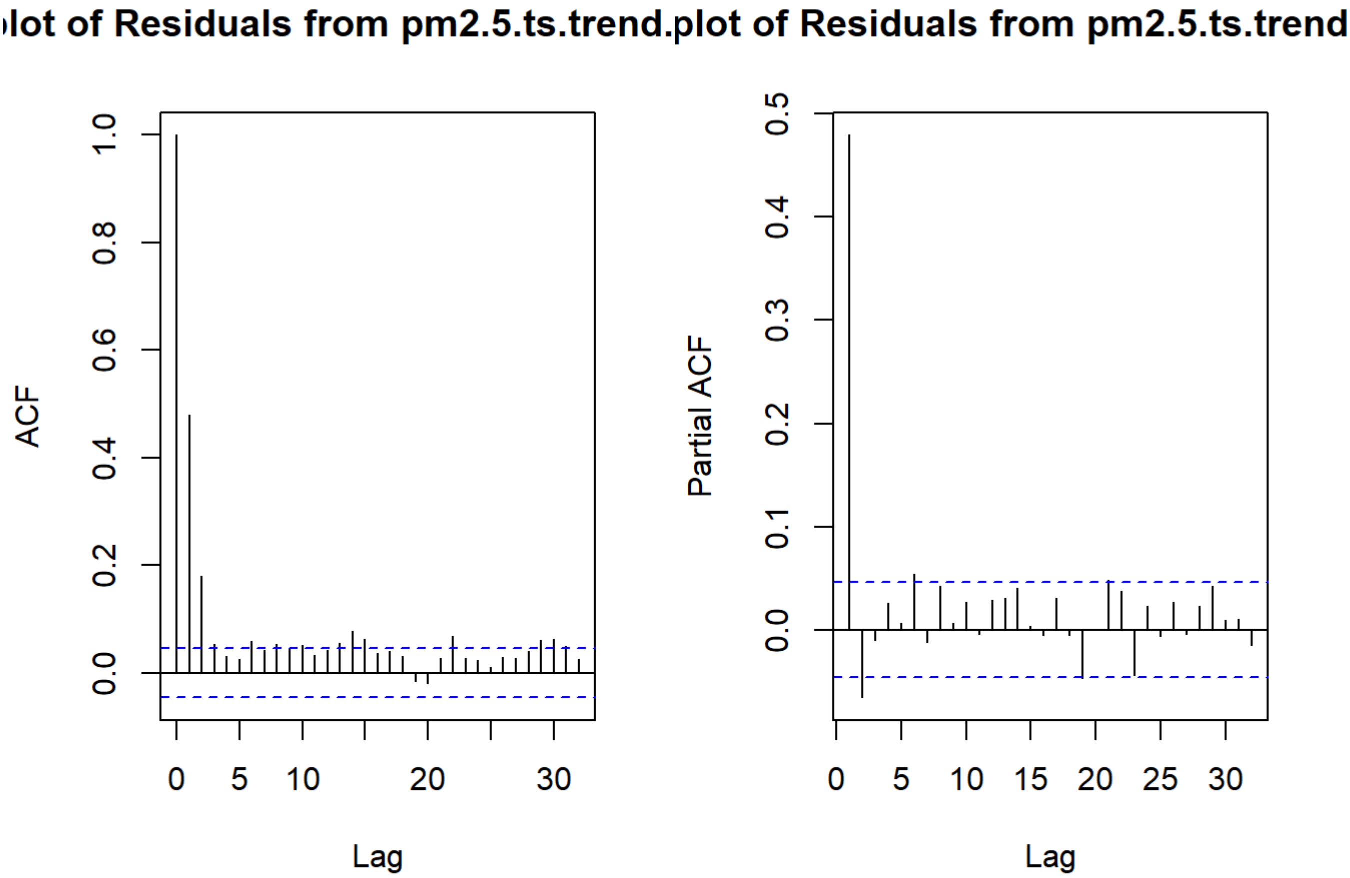
```
##
## Call:
## lm(formula = pm2.5.ts^L ~ pm2.5.ts.days + sin(2 * pi * pm2.5.ts.days/7) +
##     cos(2 * pm2.5.ts.days/7))
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -2.8710 -0.6531  0.0033  0.6640  3.3547
##
## Coefficients:
##                                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)                    4.664e+00  4.504e-02 103.562  < 2e-16 ***
## pm2.5.ts.days                 -9.280e-05  4.271e-05  -2.173   0.0299 *
## sin(2 * pi * pm2.5.ts.days/7)  6.513e-02  3.183e-02   2.046   0.0409 *
## cos(2 * pm2.5.ts.days/7)       1.419e-01  3.183e-02   4.459 8.72e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.9619 on 1822 degrees of freedom
## Multiple R-squared:  0.01555,    Adjusted R-squared:  0.01393
## F-statistic: 9.593 on 3 and 1822 DF,  p-value: 2.767e-06
```

Diagnose the model

```
par(mfrow = c(2,2))
plot(pm2.5.ts.trend.seasonal1)
```




```
par(mfrow = c(1,2))
acf(pm2.5.ts.trend.seasonal1$residuals, main = "ACF plot of Residuals from pm2.5.ts.trend.sea
sonal1")
pacf(pm2.5.ts.trend.seasonal1$residuals, main = "PACF plot of Residuals from pm2.5.ts.trend.s
easonal1")
```




```
par(mfrow=c(1,1))
shapiro.test(pm2.5.ts.trend.seasonal1$residuals)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  pm2.5.ts.trend.seasonal1$residuals
## W = 0.99828, p-value = 0.05453
```

The p-value of Shapiro-Wilk normality test is bigger than 0.05 implying that the residual confers to normal distribution, which agree with assumption of linear regression.

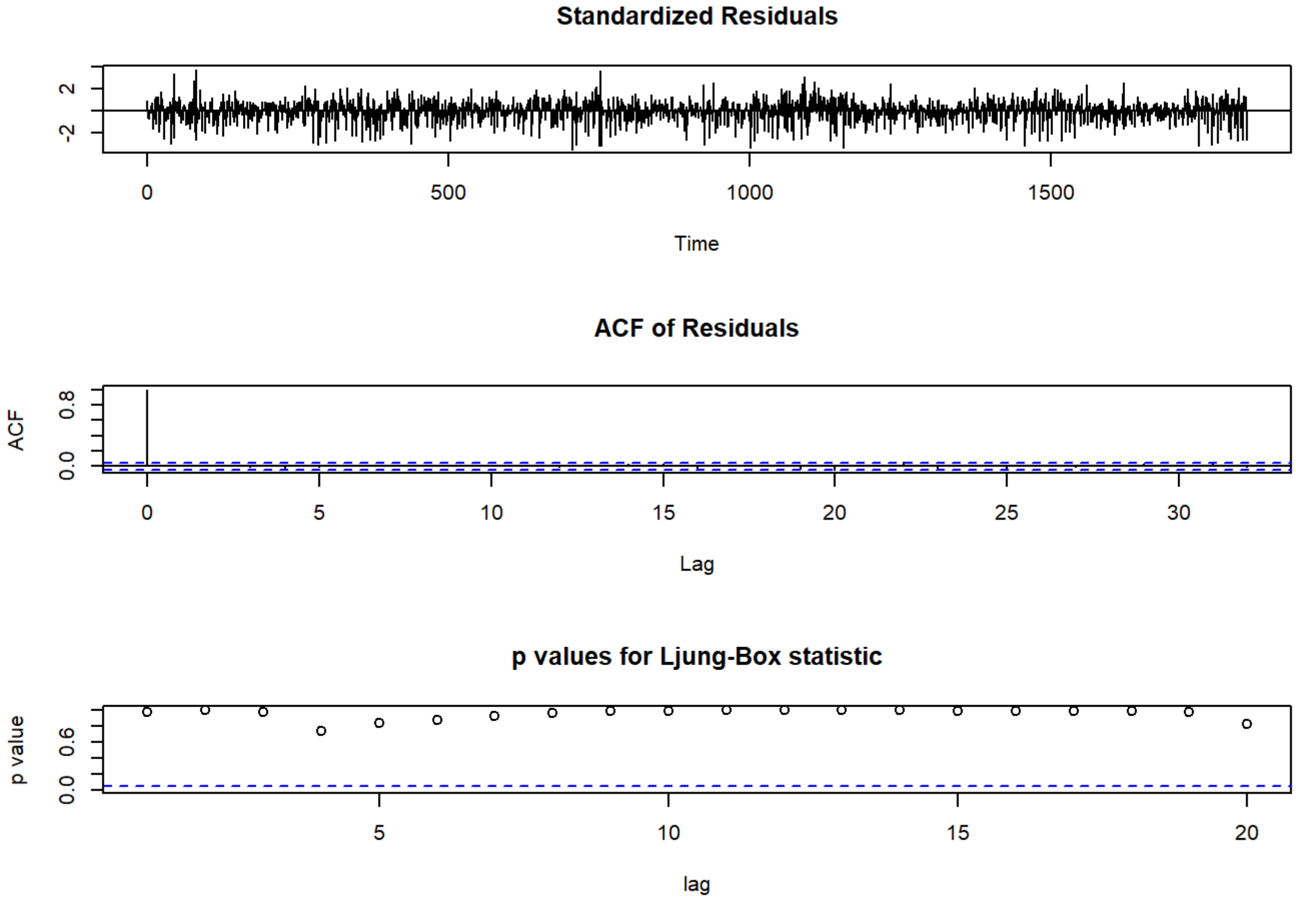
Build the arima model of the residual of the linear model of the pm2.5 time series

```
pm2.5.ts.autoarima <- auto.arima(pm2.5.ts.trend.seasonal1$residuals)
summary(pm2.5.ts.autoarima)
```

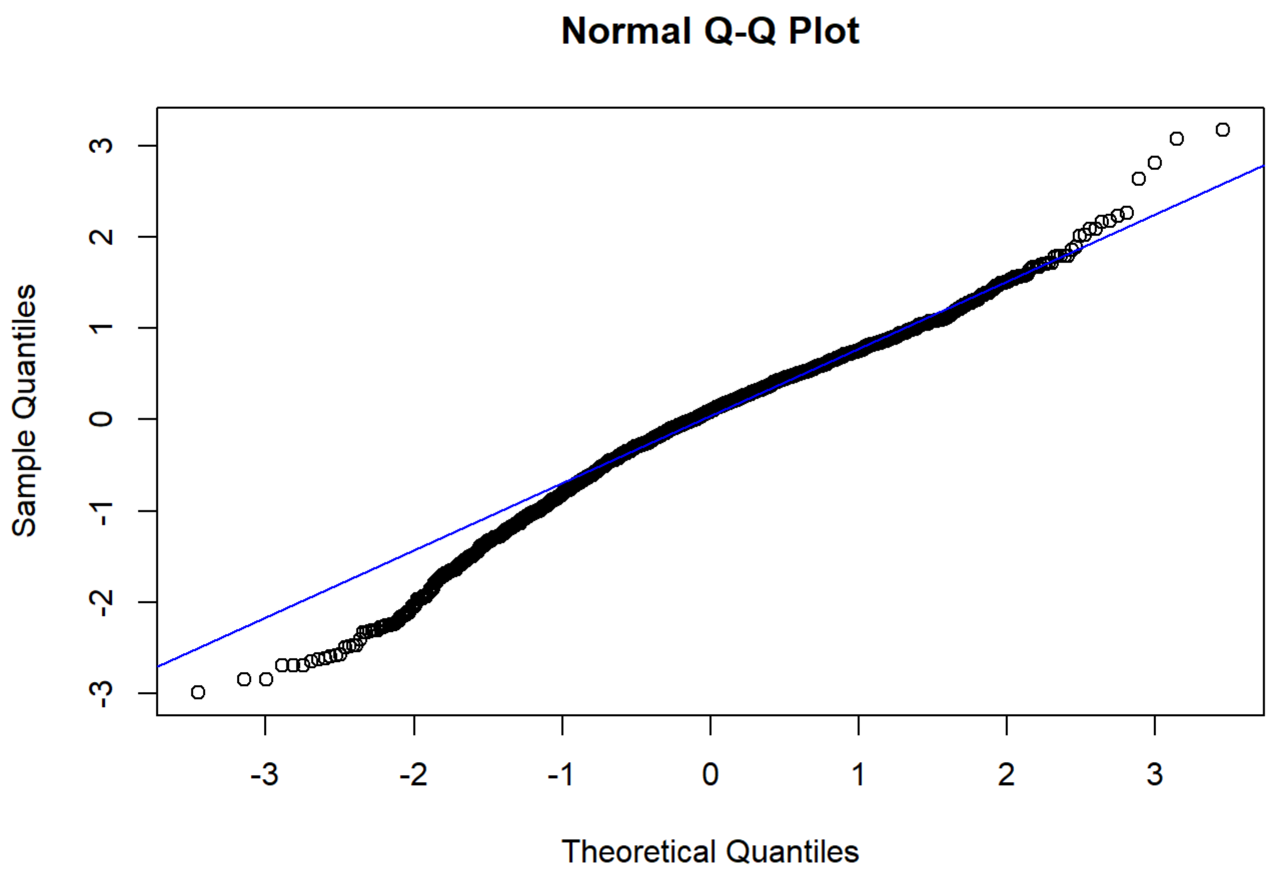
```
## Series: pm2.5.ts.trend.seasonal1$residuals
## ARIMA(3,0,3) with zero mean
##
## Coefficients:
##          ar1     ar2      ar3     ma1      ma2      ma3
##       0.3495  0.8731  -0.2568  0.1605  -0.8612  -0.2017
## s.e.  0.0725  0.0776   0.0559  0.0726   0.0584   0.0464
##
## sigma^2 estimated as 0.7037:  log likelihood=-2267.31
## AIC=4548.62   AICc=4548.68   BIC=4587.19
##
## Training set error measures:
##                        ME     RMSE       MAE     MPE     MAPE      MASE
## Training set -0.0001160445 0.837482 0.6462517 81.7431 227.1895 0.8889572
##                       ACF1
## Training set 0.0009836837
```

Diagnose the model

```
tsdiag(pm2.5.ts.autoarima,gof.lag=20)
```



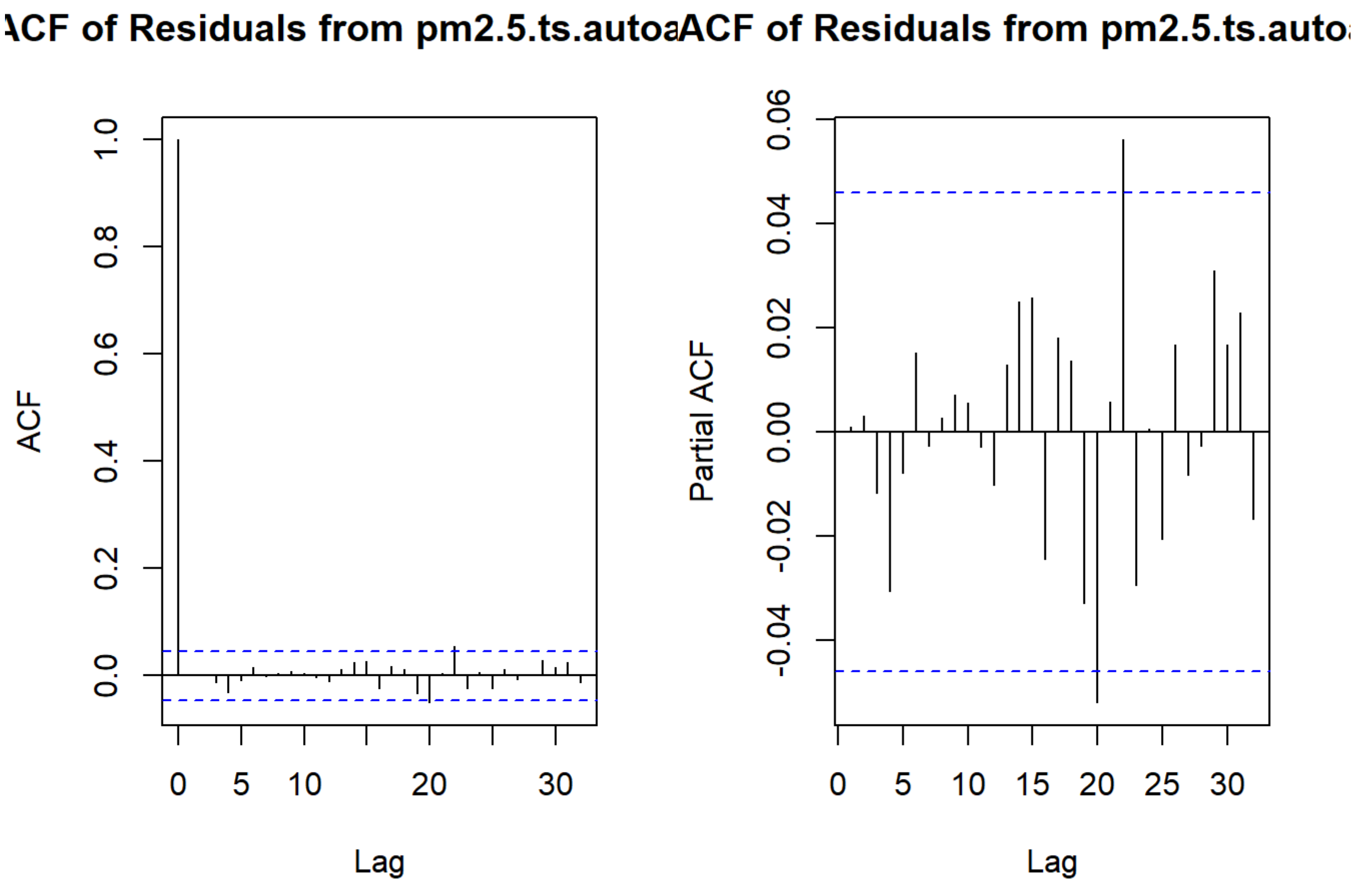

```
qqnorm(pm2.5.ts.autoarima$residuals)
qqline(pm2.5.ts.autoarima$residuals,col="blue")
```




```
shapiro.test(pm2.5.ts.autoarima$residuals)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  pm2.5.ts.autoarima$residuals
## W = 0.98002, p-value = 2.755e-15
```

```
par(mfrow=c(1,2))
acf(pm2.5.ts.autoarima$residuals, main="ACF of Residuals from pm2.5.ts.autoarima")
pacf(pm2.5.ts.autoarima$residuals,main="PACF of Residuals from pm2.5.ts.autoarima")
```




```
par(mfrow=c(1,1))
Box.test(pm2.5.ts.autoarima$residuals,type="Ljung-Box")
```

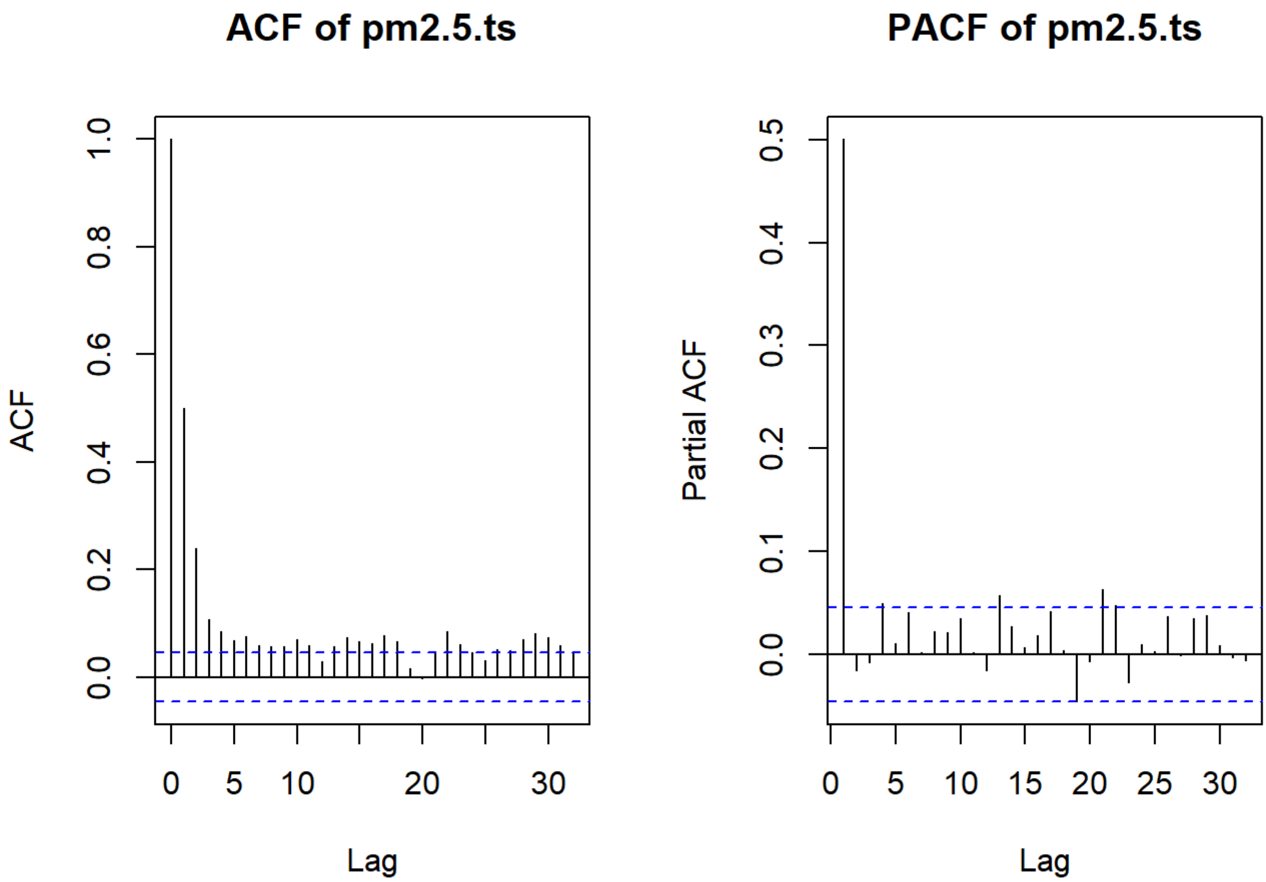
```
##
##  Box-Ljung test
##
## data:  pm2.5.ts.autoarima$residuals
## X-squared = 0.0017698, df = 1, p-value = 0.9664
```

Shapiro Wilk normality test and box Ljung test shows residual of the arima is normally distributed. In the ACF and PACF plot, nearly almost lags are within confidence interval implying that there isn't any autocorrelation.

Using just arima model

ACF and PACF of the pm2.5 time series

```
par(mfrow = c(1,2))
acf(pm2.5.ts[pm2.5.ts.days], main = "ACF of pm2.5.ts")
pacf(pm2.5.ts[pm2.5.ts.days], main = "PACF of pm2.5.ts")
```




```
par(mfrow = c(1,1))
```

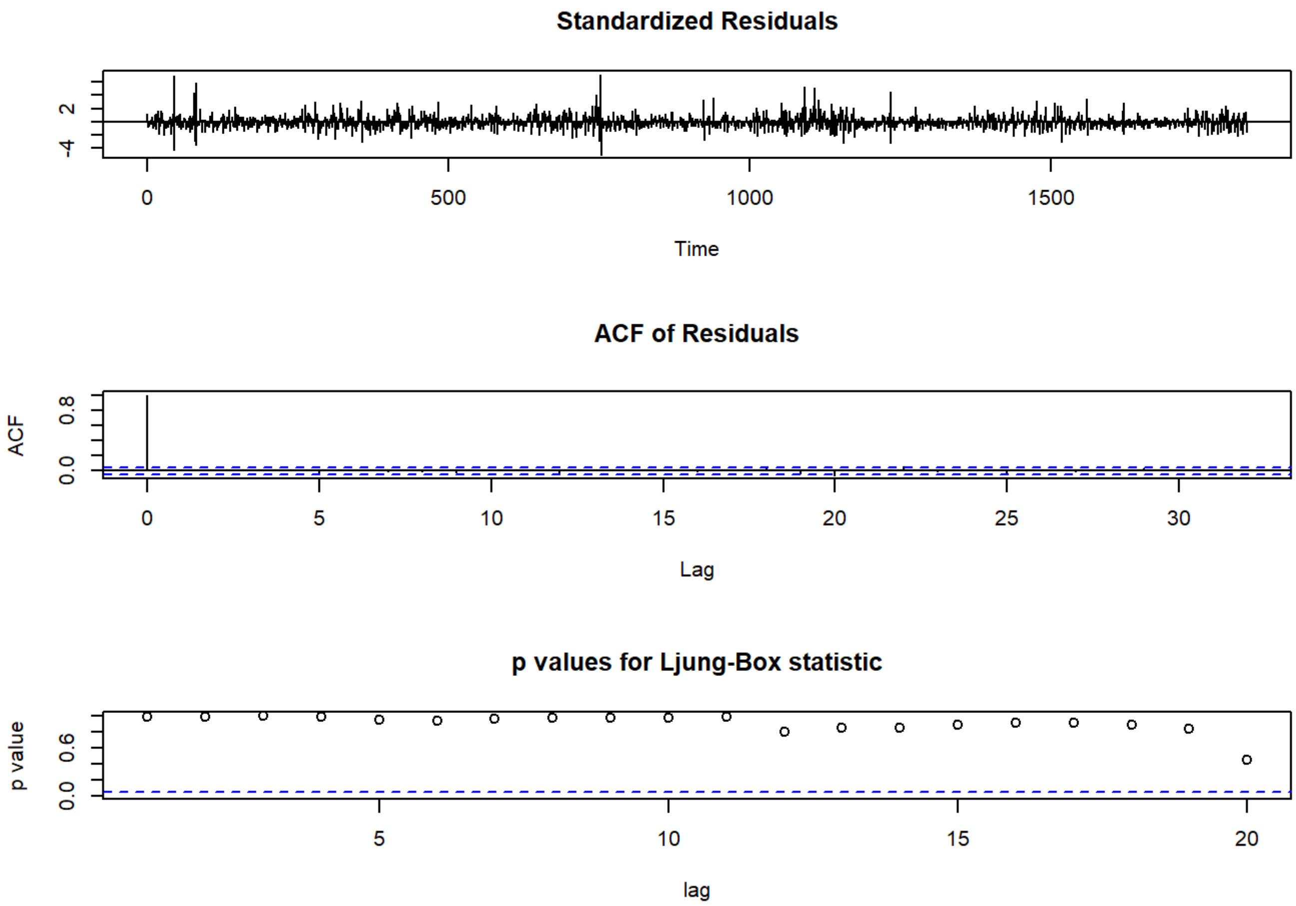
From the ACf and PACF plot of the pm2.5 time series, we can get that p=1 and q=4

```
arima1 <- arima(pm2.5.ts, order = c(1, 0, 4))
summary(arima1)
```

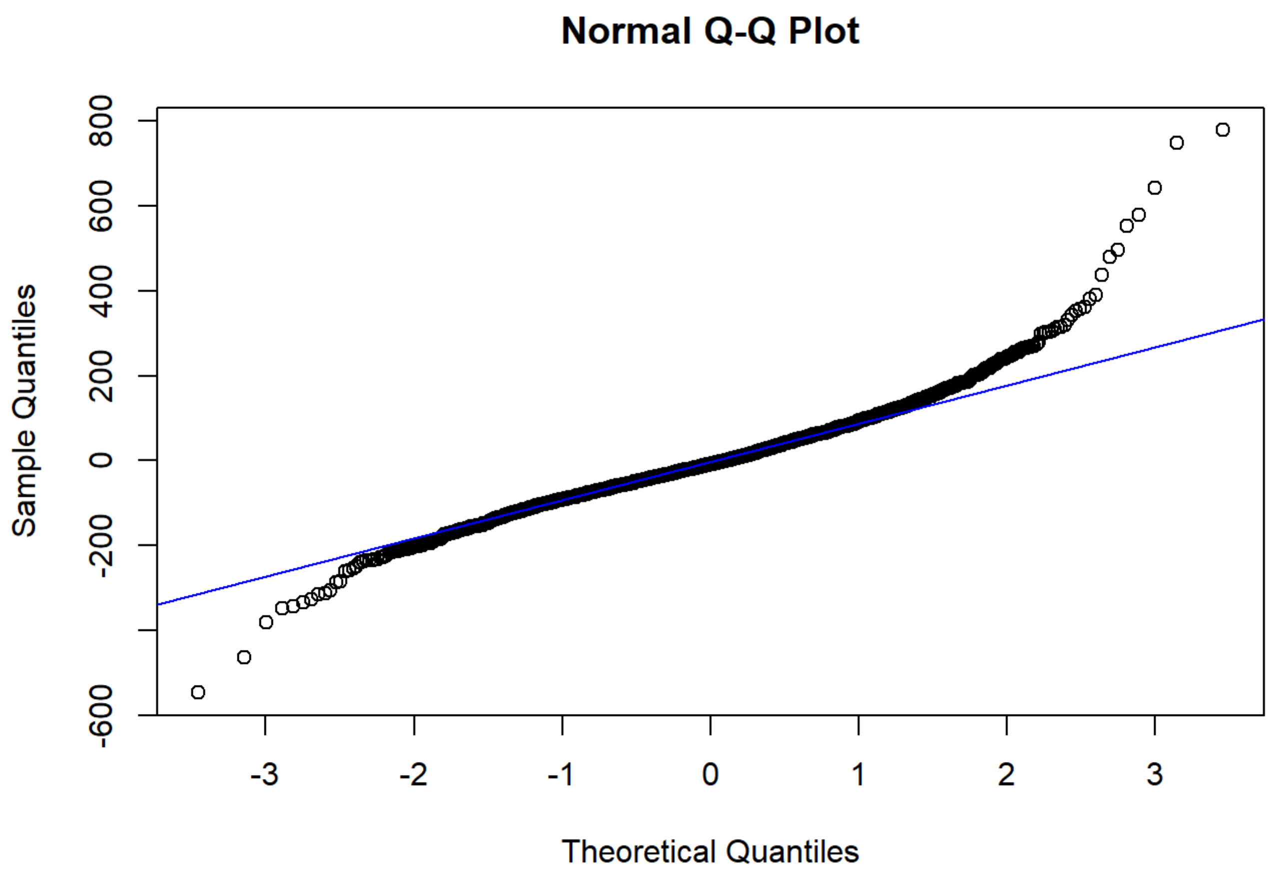
```
##
## Call:
## arima(x = pm2.5.ts, order = c(1, 0, 4))
##
## Coefficients:
##          ar1      ma1      ma2      ma3      ma4  intercept
##       0.9779  -0.4774  -0.2572  -0.1600  -0.0263   187.6623
## s.e.  0.0113   0.0260   0.0264   0.0252   0.0234     9.0426
##
## sigma^2 estimated as 11945:  log likelihood = -11162.46,  aic = 22338.93
##
## Training set error measures:
##                       ME     RMSE      MAE       MPE    MAPE    MASE
## Training set -0.04794343 109.2914 79.53181 -60.65098 84.9157 0.91944
##                      ACF1
## Training set 0.0004084028
```

ACF and PACF of arima1

```
tsdiag(arima1,gof.lag=20)
```



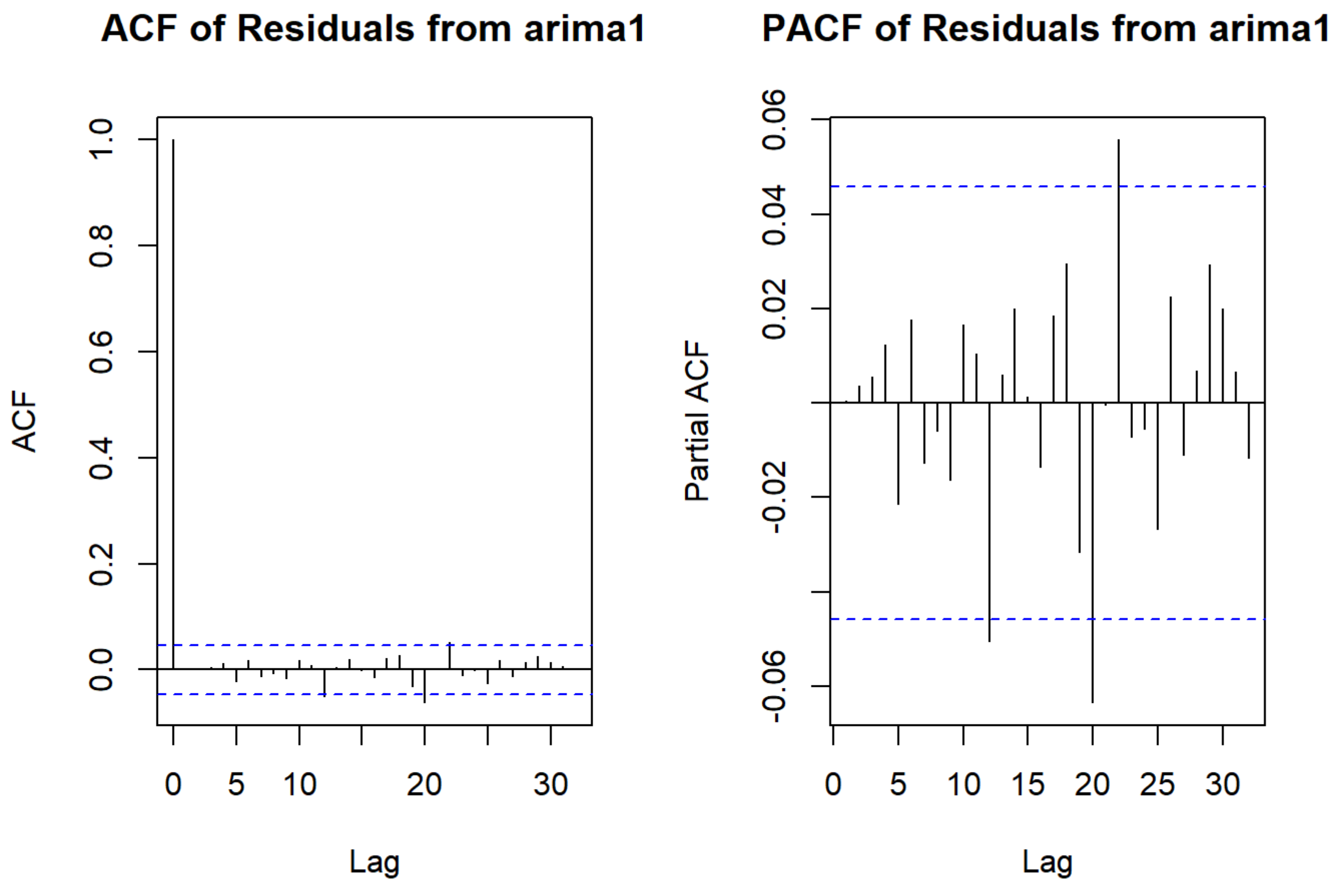

```
qqnorm(arima1$residuals)
qqline(arima1$residuals,col="blue")
```




```
shapiro.test(arima1$residuals)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  arima1$residuals
## W = 0.9497, p-value < 2.2e-16
```

```
par(mfrow=c(1,2))
acf(arima1$residuals, main="ACF of Residuals from arima1")
pacf(arima1$residuals,main="PACF of Residuals from arima1")
```




```
par(mfrow=c(1,1))
Box.test(arima1$residuals,type="Ljung-Box")
```

```
##
##  Box-Ljung test
##
## data:  arima1$residuals
## X-squared = 0.00030506, df = 1, p-value = 0.9861
```

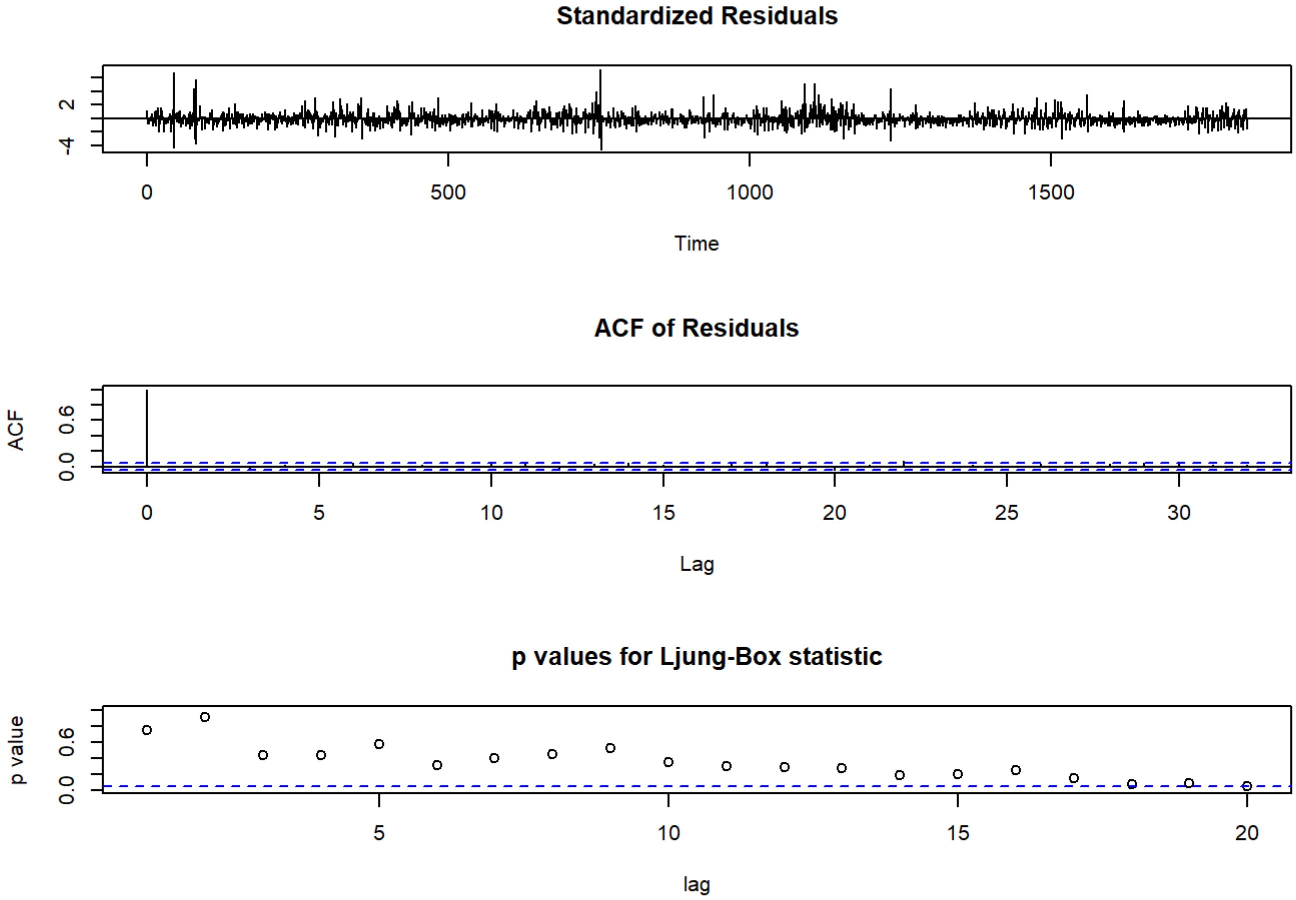
Use auto.arima() to model

```
autoarima1 <- auto.arima(pm2.5.ts)
summary(autoarima1)
```

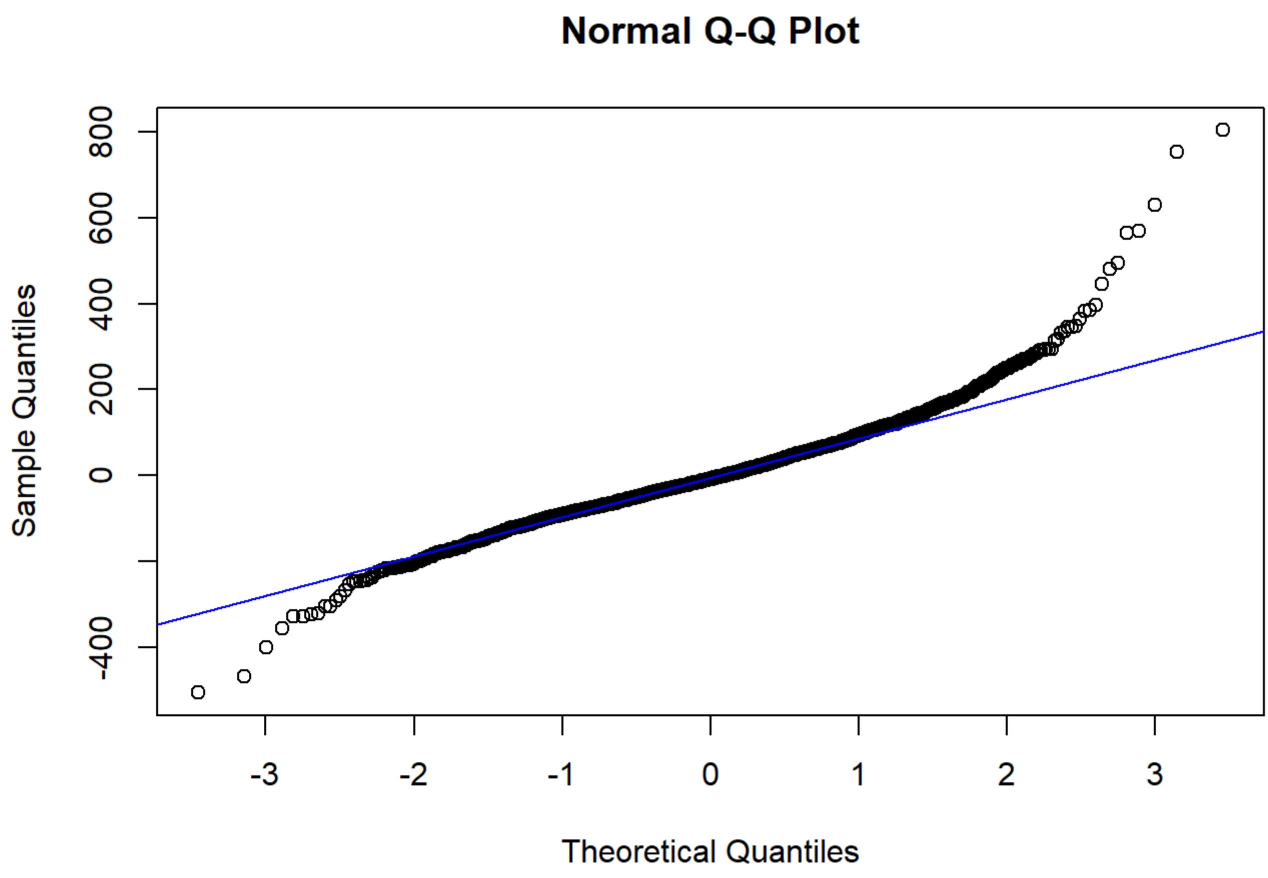
```
## Series: pm2.5.ts
## ARIMA(1,0,0) with non-zero mean
##
## Coefficients:
##          ar1      mean
##       0.5009  187.4646
## s.e.  0.0203    5.1461
##
## sigma^2 estimated as 12074:  log likelihood=-11171.22
## AIC=22348.44   AICc=22348.46   BIC=22364.97
##
## Training set error measures:
##                       ME     RMSE      MAE       MPE    MAPE      MASE
## Training set -0.05051918 109.8206 79.91543 -60.72288 84.9966 0.9238749
##                     ACF1
## Training set 0.007676786
```

Build ARIMA(1,0,0)

```
tsdiag(autoarima1,gof.lag=20)
```



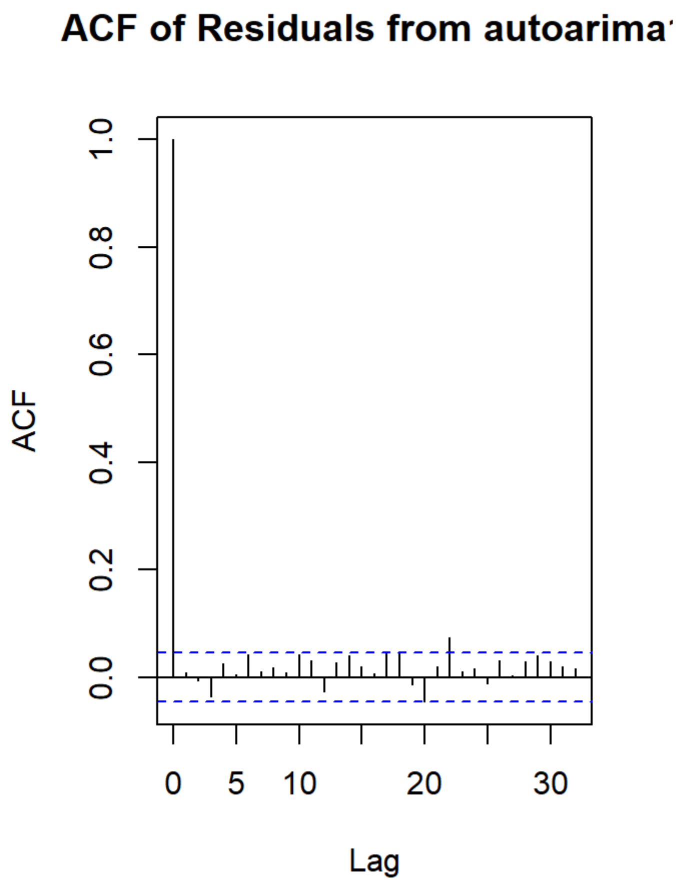

```
qqnorm(autoarima1$residuals)
qqline(autoarima1$residuals,col="blue")
```

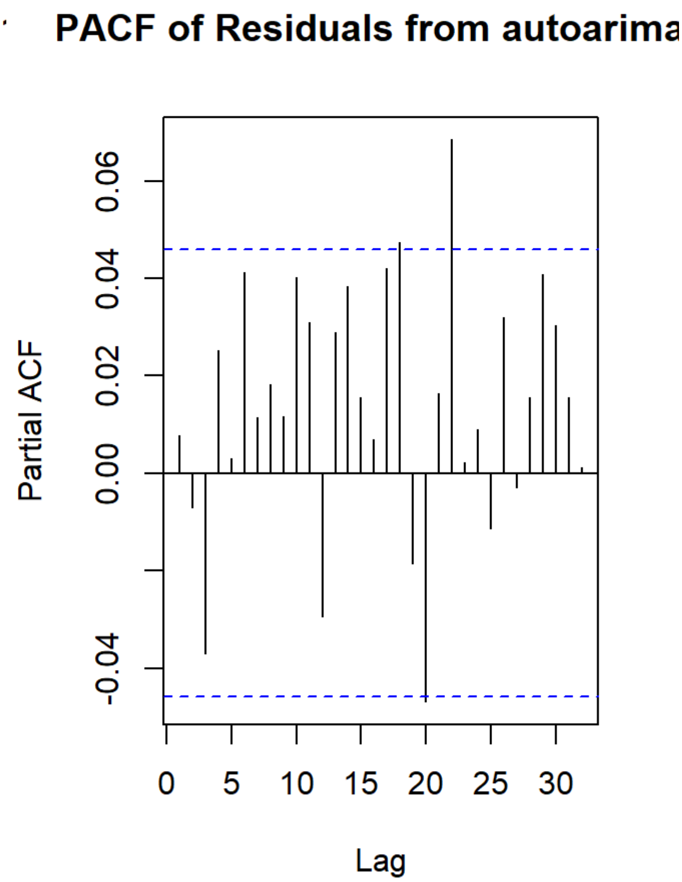



```
shapiro.test(autoarima1$residuals)
```

```
##
##  Shapiro-Wilk normality test
##
## data:  autoarima1$residuals
## W = 0.94893, p-value < 2.2e-16
```

```
par(mfrow=c(1,2))
acf(autoarima1$residuals, main="ACF of Residuals from autoarima1")
pacf(autoarima1$residuals,main="PACF of Residuals from autoarima1")
```






```
par(mfrow=c(1,1))
Box.test(autoarima1$residuals,type="Ljung-Box")
```

```
##
##  Box-Ljung test
##
## data:  autoarima1$residuals
## X-squared = 0.10779, df = 1, p-value = 0.7427
```

Comparision of the two just arima models

```
AIC(arima1)
```

```
## [1] 22338.93
```

```
AIC(autoarima1)
```

```
## [1] 22348.44
```

Since we choose the model with less AIC, so we choose the model arima1

Compare arima1 with pm2.5.ts.autoarima on forecasting the next 30 days

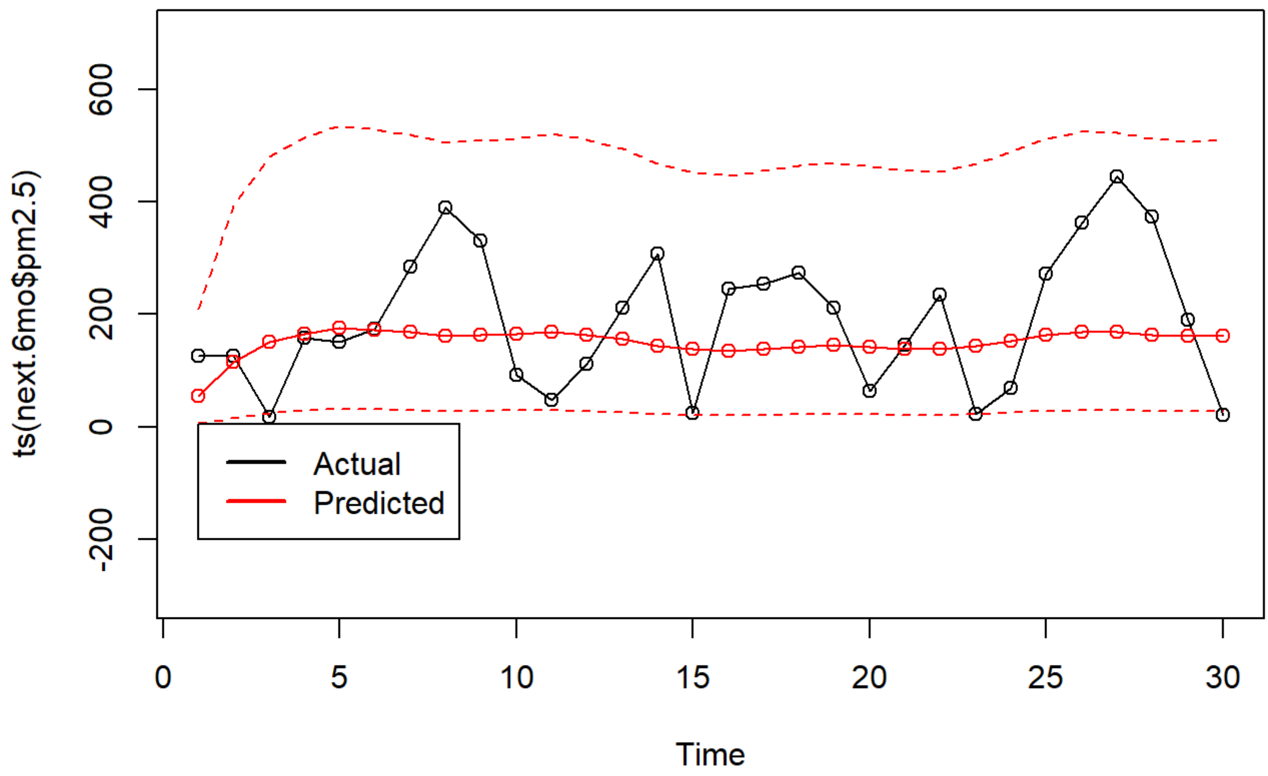
Prediction for the next 30 days by pm2.5.ts.trend .seasonal1 and its MSE

```
next.6mo.time <- c((length(pm2.5.ts)-29):(length(pm2.5.ts)))
next.6mo <- data.frame(pm2.5.ts.days = next.6mo.time, pm2.5 = pm2.5.ts[next.6mo.time])
next.6mo.ts <- ts(next.6mo$pm2.5)
E_Y.pred <- predict(pm2.5.ts.trend.seasonal1, newdata = next.6mo)
e_t.pred <- forecast(pm2.5.ts.autoarima, h=30)
next.6mo.prediction <- (E_Y.pred + e_t.pred$mean)^(1/L)
mean((next.6mo.prediction-next.6mo$pm2.5)^2)
```

```
## [1] 15189.54
```

Plot actual values and predicted values and confidence intervals

```
plot(ts(next.6mo$pm2.5),type='o',ylim=c(-300,700))
lines(ts(next.6mo.prediction),col='red',type='o')
lines(1:30, (E_Y.pred + e_t.pred$lower[,2])^(1/L), col = "red", lty = "dashed")
lines(1:30, (E_Y.pred + e_t.pred$upper[,2])^(1/L), col = "red", lty = "dashed")
legend(1,5, legend = c("Actual", "Predicted"), lwd = 2, col = c("black", "red"))
```



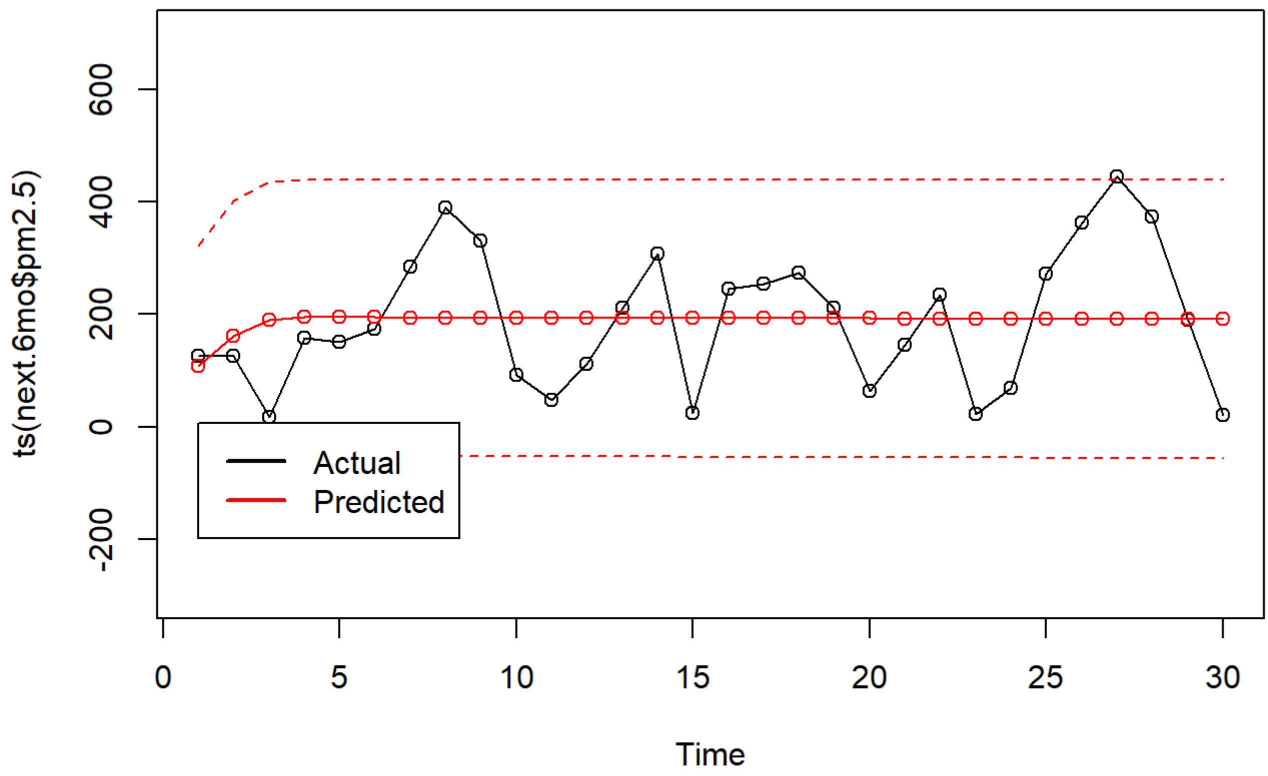
Prediction for the next 30 days by arima1 and its MSE

```
e_t.pred2 <- forecast(arima1, h=30)
next.6mo.prediction2 <- e_t.pred2$mean
mean((next.6mo.prediction2-next.6mo$pm2.5))
```

```
## [1] -2.027031
```

Plot actual values and predicted values and confidence intervals

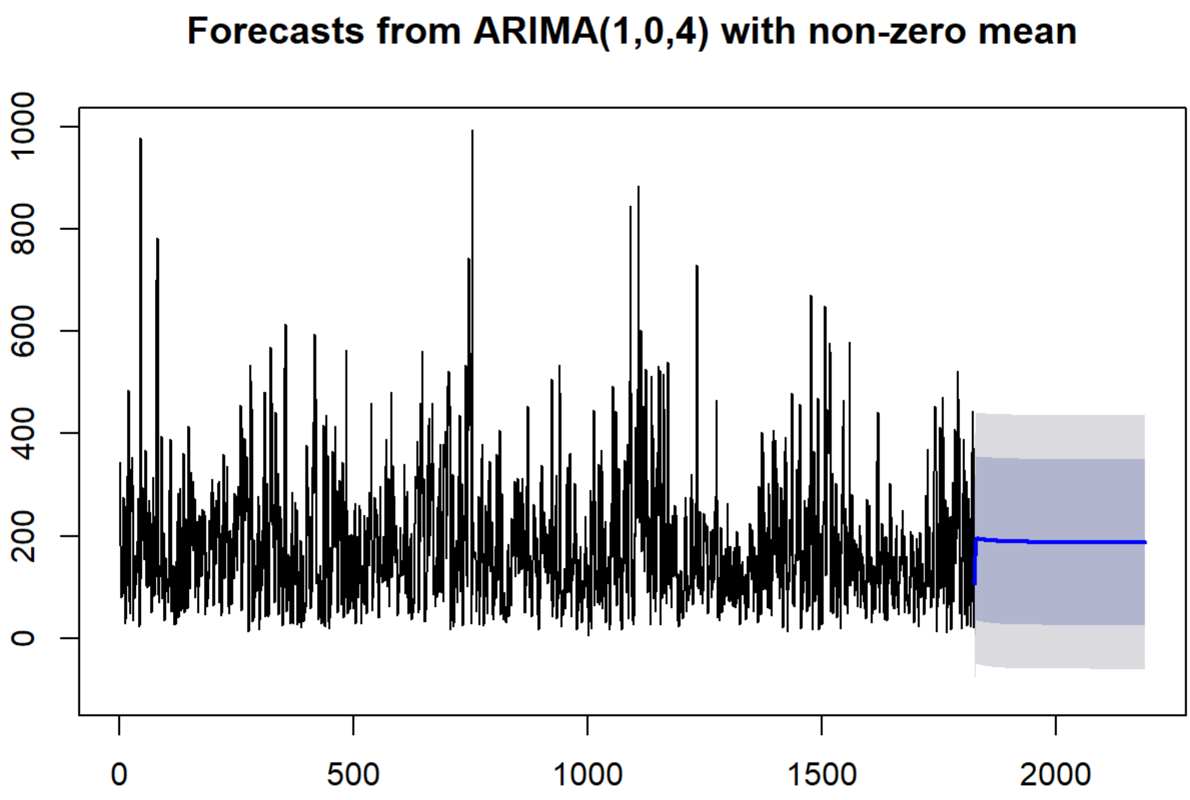
```
plot(ts(next.6mo$pm2.5), type='o', ylim=c(-300,700))
lines(ts(next.6mo.prediction2),col='red',type='o')
lines(1:30,e_t.pred2$lower[,2],col="red",lty="dashed")
lines(1:30,e_t.pred2$upper[,2],col="red",lty="dashed")
legend(1,7,legend=c("Actual","Predicted"),lwd=2,col=c("black","red") )
```



From the predicting plots and MSE, we can get that arima1 is more optimal

The forecasting plot of pm2.5 for the next one year

```
arima1.forecast <- forecast(arima1, h=365)
plot(arima1.forecast)
```



Using the powerful Facebook's Library Prophet for forecasting.¶

Prophet follows the sklearn model API. We create an instance of the Prophet class and then call its fit and predict methods.

```
pm2.5.temp <- pm2.5[,c("date","pm2.5")]
colnames(pm2.5.temp)<- c("ds","y")
summary(pm2.5.temp)
```

```
##        ds                   y
##  Min.   :2010-01-01   Min.   :  0.00
##  1st Qu.:2011-04-02   1st Qu.: 29.00
##  Median :2012-07-01   Median : 72.00
##  Mean   :2012-07-01   Mean   : 98.71
##  3rd Qu.:2013-10-01   3rd Qu.:137.00
##  Max.   :2014-12-31   Max.   :994.00
```

```
pm2.5.prophet <- prophet(pm2.5.temp,daily.seasonality = TRUE)
summary(pm2.5.prophet)
```

```
##                         Length Class      Mode     
## growth                      1  -none-     character
## changepoints               25  POSIXct    numeric  
## n.changepoints              1  -none-     numeric  
## changepoint.range           1  -none-     numeric  
## yearly.seasonality          1  -none-     character
## weekly.seasonality          1  -none-     character
## daily.seasonality           1  -none-     logical  
## holidays                    0  -none-     NULL     
## seasonality.mode            1  -none-     character
## seasonality.prior.scale     1  -none-     numeric  
## changepoint.prior.scale     1  -none-     numeric  
## holidays.prior.scale        1  -none-     numeric  
## mcmc.samples                1  -none-     numeric  
## interval.width              1  -none-     numeric  
## uncertainty.samples         1  -none-     numeric  
## specified.changepoints      1  -none-     logical  
## start                       1  POSIXct    numeric  
## y.scale                     1  -none-     numeric  
## logistic.floor              1  -none-     logical  
## t.scale                     1  -none-     numeric  
## changepoints.t             25  -none-     numeric  
## seasonalities               3  -none-     list     
## extra_regressors            0  -none-     list     
## stan.fit                    0  -none-     NULL     
## params                      5  -none-     list     
## history                     5  data.frame list     
## history.dates           43824  POSIXct    numeric  
## train.component.cols        5  data.frame list     
## component.modes             2  -none-     list     
```

Plot the forecast

Broken down the forcast into trend, weekly seasonality, and yearly seasonality

```
#pm2.5.prophet.future <- make_future_dataframe(pm2.5.prophet, periods = 12)
#tail(pm2.5.prophet.future)
#pm2.5.prophet.forcast <- predict(pm2.5.prophet,pm2.5.prophet.future)
#tail(pm2.5.prophet.forcast[c('ds', 'yhat', 'yhat_lower', 'yhat_upper')])
#plot(pm2.5.prophet.forcast)
#prophet_plot_components(pm2.5.prophet.forcast)
```

I haven’t compelte this part yet