

## PM2016\_2020.R

gulnaz.gabidinova

2021-02-07

*#Исследование случай-контроль: бронхиальная астма и РМ*

*#Г.Ф.Габидинова*

*#2 июля 2021 г.*

**library**(ggplot2)

**library**(knitr)

**library**(psych)

**library**(Hmisc)

**library**(ggpubr)

**library**(Rmisc)

**library**(tidyverse)

**library**(GGally)

**library**(car)

**library**(rstatix)

**library**(ez)

**library**(emmeans)

**library**(ROCR)

## Warning: package 'ROCR' was built under R version 3.6.3

**library**(sjmisc)

## Warning: package 'sjmisc' was built under R version 3.6.3

**library**(interplot)

## Warning: package 'interplot' was built under R version 3.6.3

## Warning: package 'arm' was built under R version 3.6.3

**library**(survival)

**library**(survminer)

## Warning: package 'survminer' was built under R version 3.6.3

**library**(lme4)

**library**(dplyr)

**library**(sjstats)

## Warning: package 'sjstats' was built under R version 3.6.3

**library**(cowplot)

**library**(nlme)

**theme\_set**(**theme\_bw**())

**Sys.setenv**(**LANG** = "en")

**data** <- **read.csv**('database\_full\_0207.csv', **header**=**TRUE**, **sep**=';', **dec** = ",")  
**data**\$**Year** <- **as.factor**(**data**\$**Year**)

```
data$Point <- as.factor(data$Point)
data$Time2 <- as.character(data$Time2)
data$Time2 <- strtoi(as.difftime(data$Time2, format = "%H:%M"))
```

```
#TSP
```

```
colSums(is.na(data))
```

```
##      Year      Point abs_risk_450 abs_risk_451 abs_risk_458      abs_risk
##      0         0      200         200         200         200
##      Date      Time      Time2      Daytime  Thermometer  Pressure
##      0         2         2         2         0         0
##      Humidity    Wind      Wind_V    Weather      TSP      TSPn
##      0         0         0         0         0         0
##      PM10      PM10n      PM2.5      PM2.5n      NO2      NO2n
##      0         0         0         0         0         0
##      C         Cn
##      0         0
```

```
data <- data[!is.na(data$Daytime),]
length(unique(data$Point))
```

```
## [1] 10
```

```
table(data$Point)
```

```
##
##  1  5  6  9 10 11 12 13 14 15
## 228 240 237 230 228 239 239 240 240 228
```

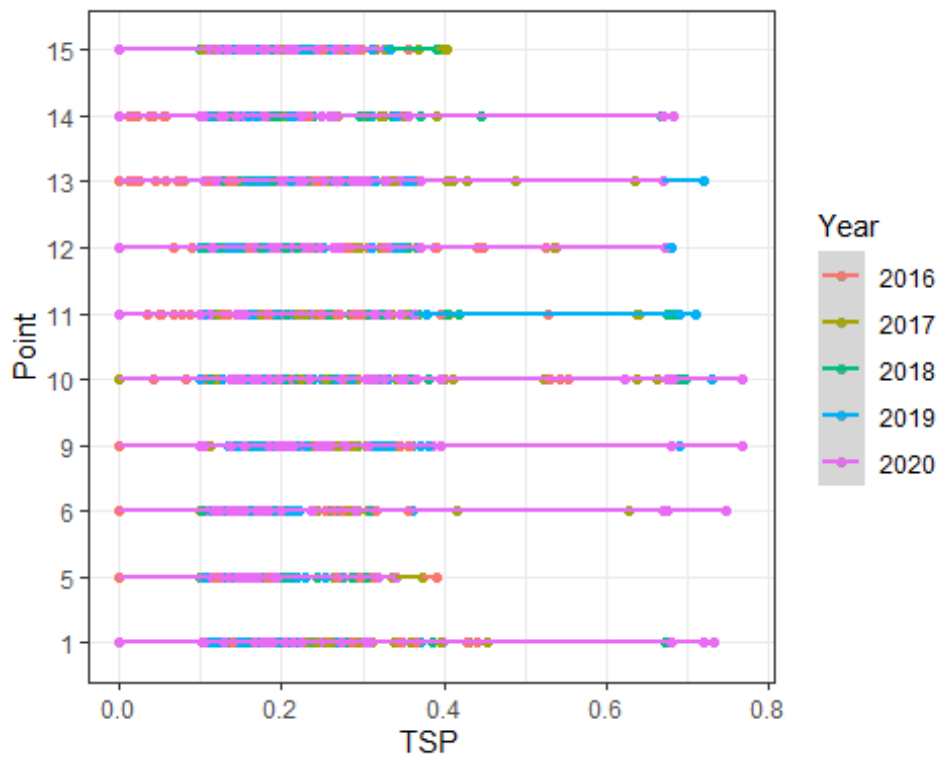
```
table(data$Year)
```

```
##
## 2016 2017 2018 2019 2020
##  199  540  530  540  540
```

```
with(data, table(Year, Point))
```

```
##      Point
## Year    1  5  6  9 10 11 12 13 14 15
## 2016 12 24 24 20 12 24 23 24 24 12
## 2017 54 54 54 54 54 54 54 54 54 54
## 2018 54 54 51 48 54 53 54 54 54 54
## 2019 54 54 54 54 54 54 54 54 54 54
## 2020 54 54 54 54 54 54 54 54 54 54
```

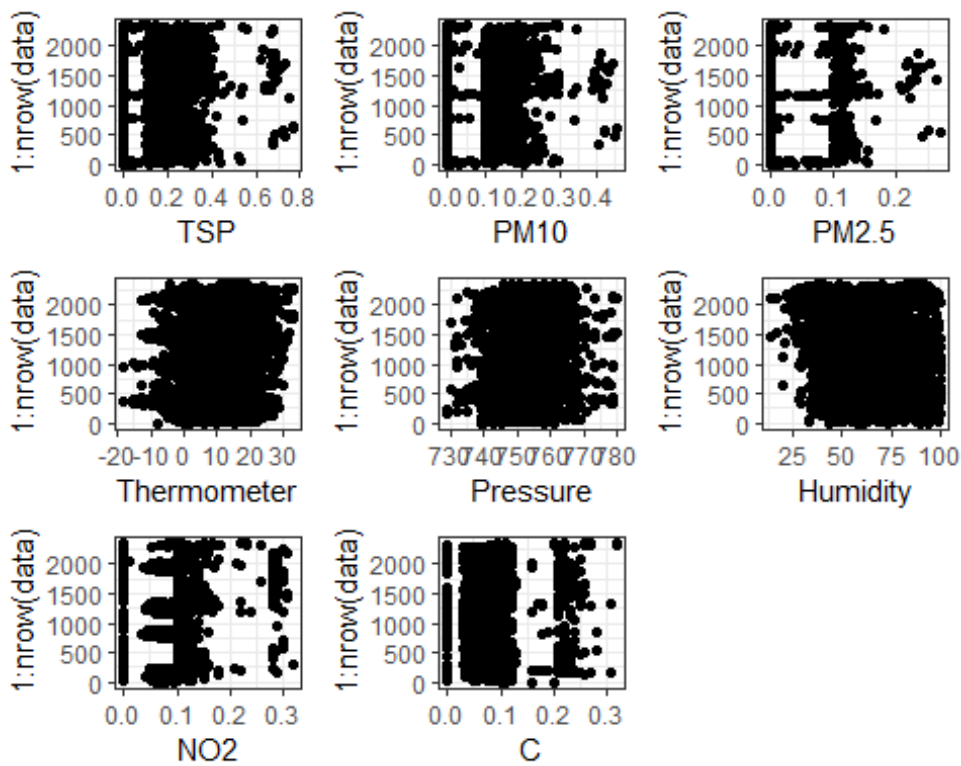
```
ggplot(data, aes(x = TSP, y = Point, color = Year)) +
  geom_point() +
  geom_smooth(se = TRUE, method = "lm", size = 1)
```



*#Нет ли выбросов? Строим диаграммы Кливленда*

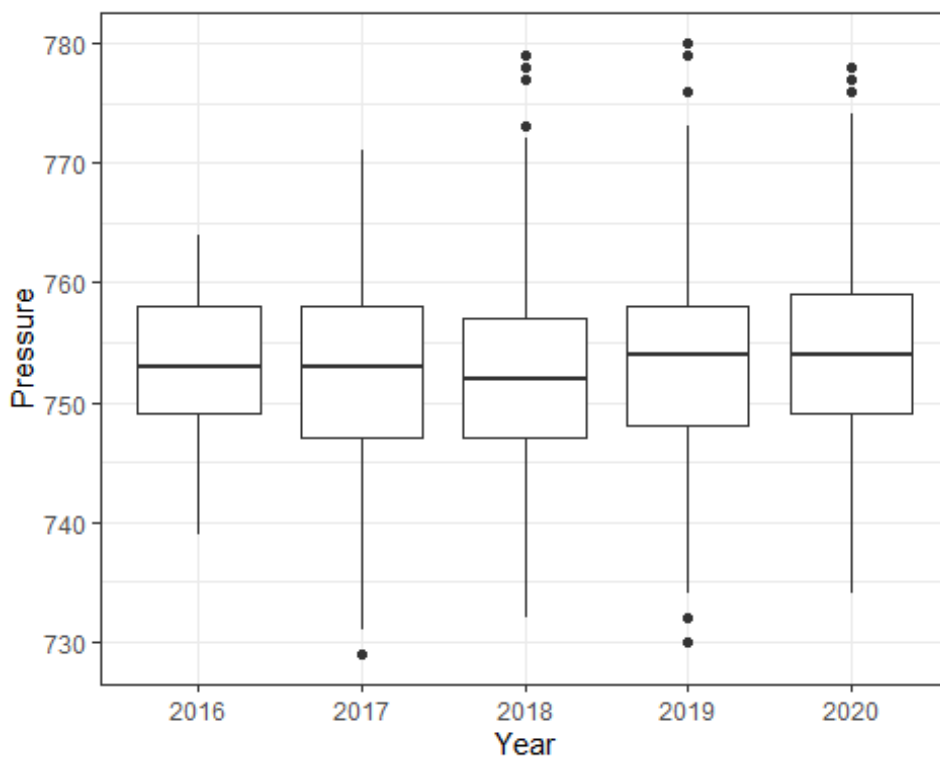
```
gg_dot <- ggplot(data, aes(y = 1:nrow(data))) + geom_point()
```

```
plot_grid(gg_dot + aes(x = TSP),
          gg_dot + aes(x = PM10),
          gg_dot + aes(x = PM2.5),
          gg_dot + aes(x = Thermometer),
          gg_dot + aes(x = Pressure),
          gg_dot + aes(x = Humidity),
          gg_dot + aes(x = NO2),
          gg_dot + aes(x = C))
```

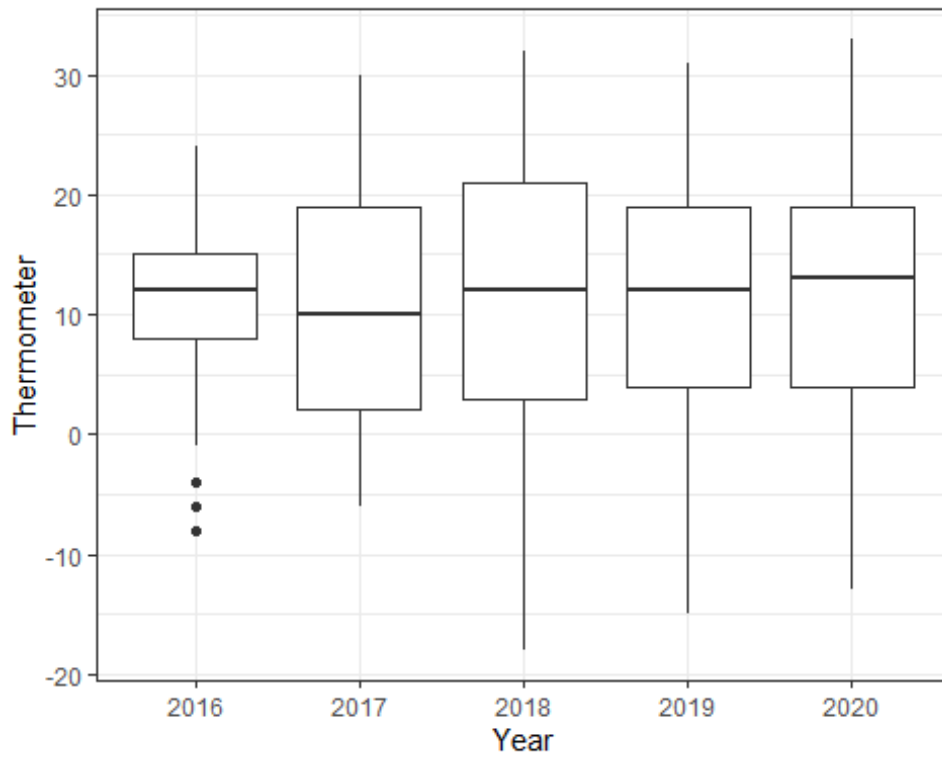


*#Нет ли коллинеарности дискретных и непрерывных предикторов?*

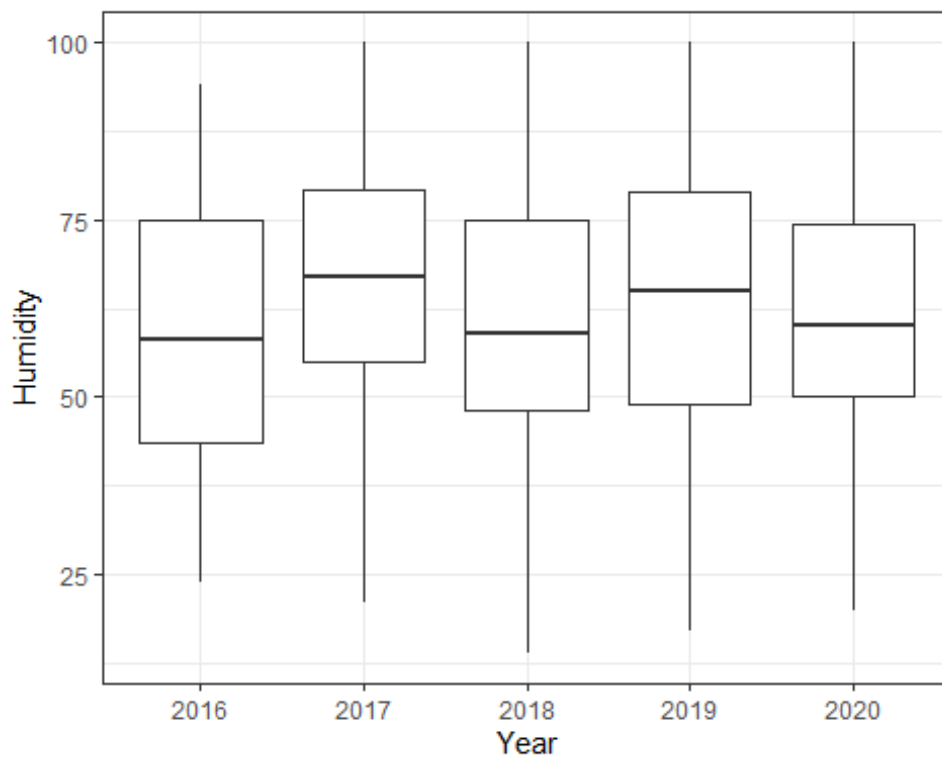
```
ggplot(data = data, aes(x = Year, y = Pressure)) + geom_boxplot()
```



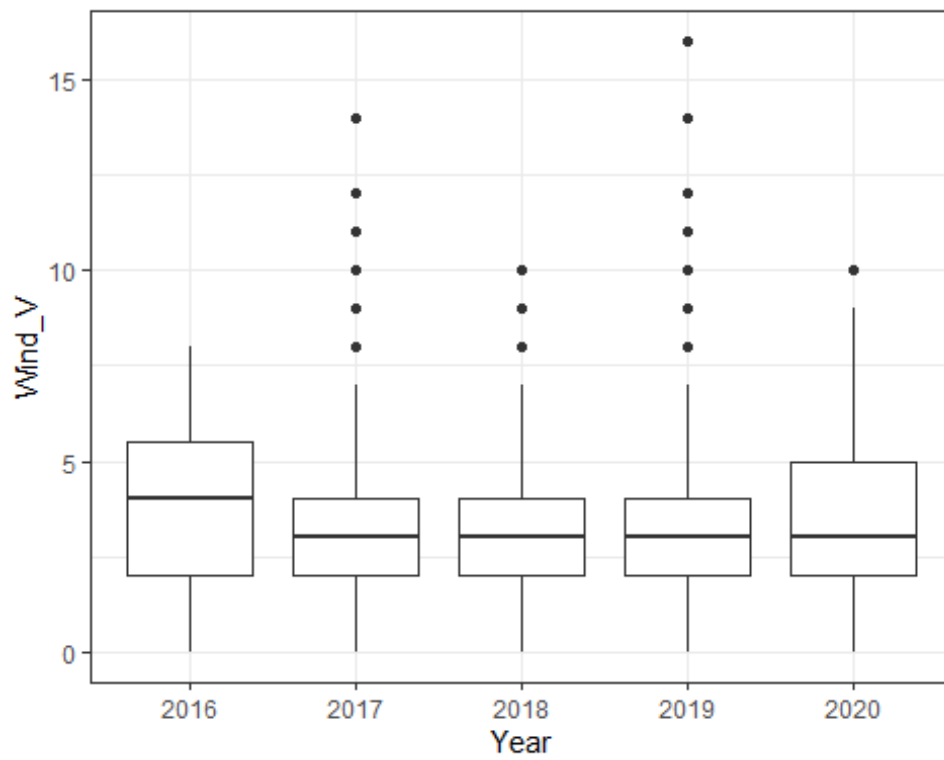
```
ggplot(data = data, aes(x = Year, y = Thermometer)) + geom_boxplot()
```



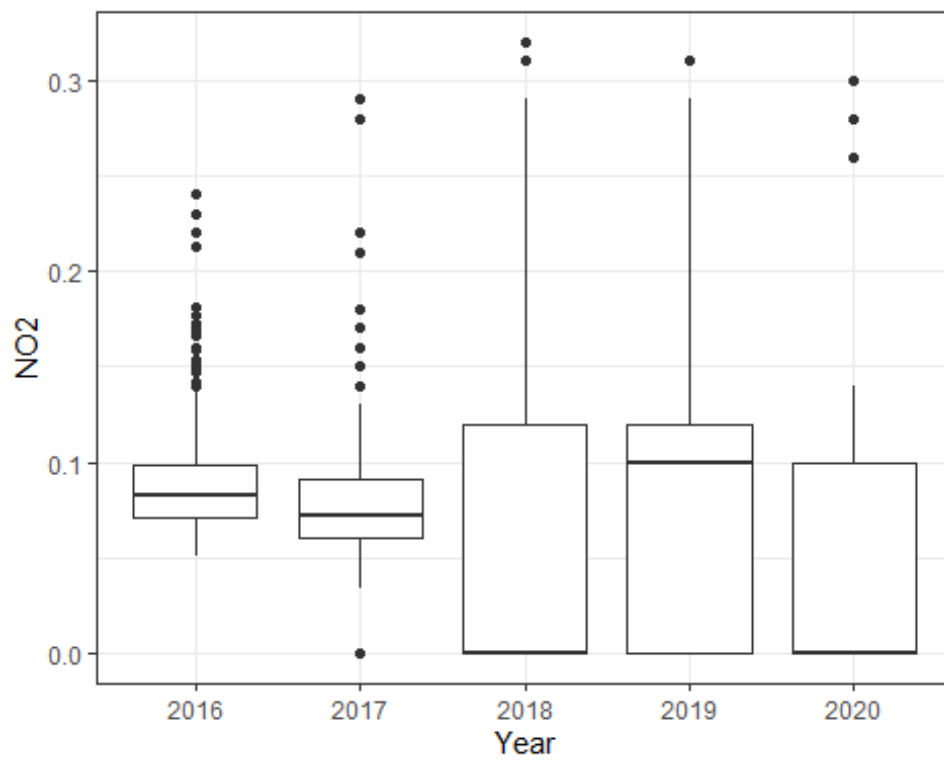
```
ggplot(data = data, aes(x = Year, y = Humidity)) + geom_boxplot()
```



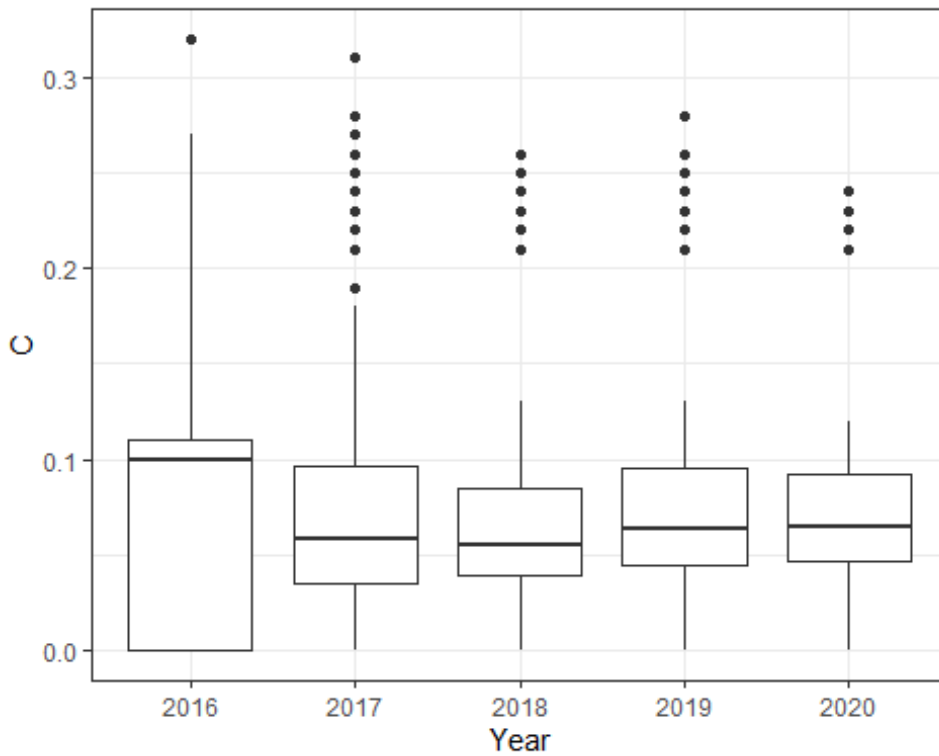
```
ggplot(data = data, aes(x = Year, y = Wind_V)) + geom_boxplot()
```



```
ggplot(data = data, aes(x = Year, y = NO2)) + geom_boxplot()
```



```
ggplot(data = data, aes(x = Year, y = C)) + geom_boxplot()
```



```
mod1 <- lm(TSP ~ Pressure * Thermometer * Humidity * Wind_V * NO2 * C, data = data)
Anova(mod1)
```

## Anova Table (Type II tests)

##

## Response: TSP

	Sum Sq	Df	F value	Pr(>F)	
## Pressure	1.1255	2	46.6428	< 2.2e-16	***
## Thermometer	0.6604	12	4.5612	2.510e-07	***
## Humidity	3.7660	10	31.2134	< 2.2e-16	***
## Wind_V	0.3916	14	2.3185	0.0036131	**
## NO2	0.6845	12	4.7280	1.117e-07	***
## C	0.6982	12	4.8227	7.047e-08	***
## Pressure:Thermometer	0.0009	1	0.0768	0.7817133	
## Pressure:Humidity	0.0033	1	0.2762	0.5992416	
## Thermometer:Humidity	0.3119	5	5.1701	0.0001010	***
## Pressure:Wind_V	0.0014	1	0.1155	0.7339503	
## Thermometer:Wind_V	0.0638	6	0.8808	0.5080500	
## Humidity:Wind_V	0.1412	5	2.3399	0.0394878	*
## Pressure:NO2	0.0006	1	0.0526	0.8186823	
## Thermometer:NO2	0.1834	6	2.5335	0.0190186	*
## Humidity:NO2	0.1409	5	2.3350	0.0398677	*
## Wind_V:NO2	0.0869	6	1.2006	0.3028912	
## Pressure:C	0.0178	1	1.4755	0.2246061	
## Thermometer:C	0.1284	5	2.1290	0.0592930	.
## Humidity:C	0.1425	5	2.3623	0.0378026	*
## Wind_V:C	0.0829	6	1.1452	0.3333273	
## NO2:C	0.2869	5	4.7551	0.0002514	***

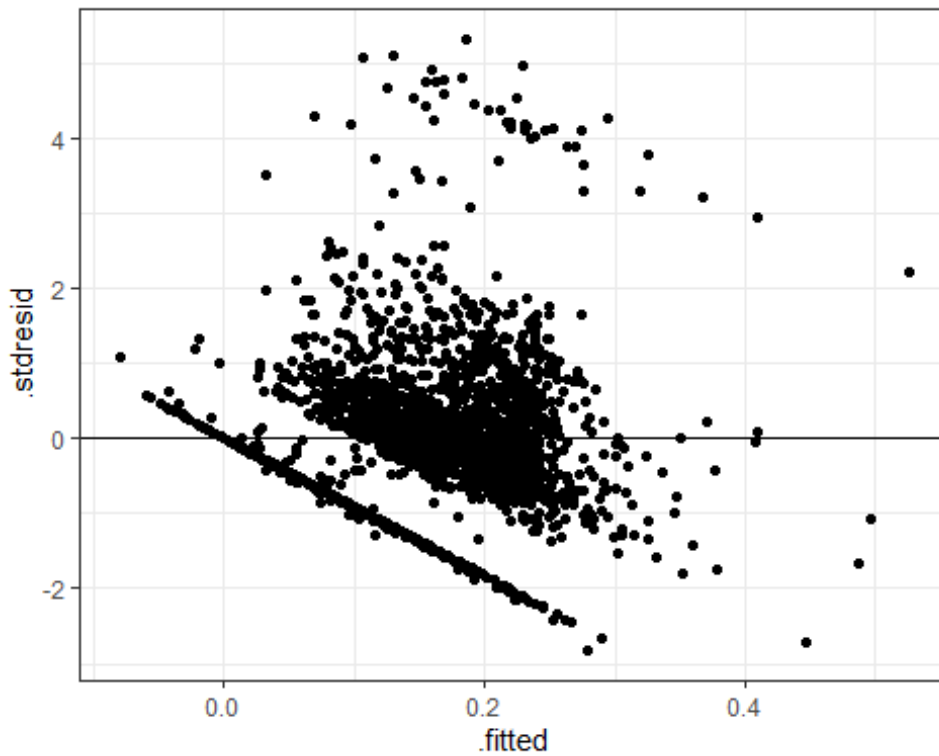
```

## Pressure:Thermometer:Humidity      0.1072    1  8.8842 0.0029069 **
## Pressure:Thermometer:Wind_V        0.0357    1  2.9589 0.0855391 .
## Pressure:Humidity:Wind_V           0.0196    1  1.6284 0.2020566
## Thermometer:Humidity:Wind_V        0.1028    3  2.8395 0.0366566 *
## Pressure:Thermometer:NO2           0.0027    1  0.2202 0.6389512
## Pressure:Humidity:NO2              0.0088    1  0.7286 0.3934241
## Thermometer:Humidity:NO2           0.0194    3  0.5367 0.6571529
## Pressure:Wind_V:NO2                0.1146    1  9.4946 0.0020854 **
## Thermometer:Wind_V:NO2             0.0414    3  1.1441 0.3298858
## Humidity:Wind_V:NO2                0.0321    3  0.8865 0.4472997
## Pressure:Thermometer:C              0.0073    1  0.6047 0.4368872
## Pressure:Humidity:C                 0.0000    1  0.0001 0.9927255
## Thermometer:Humidity:C              0.0344    2  1.4256 0.2405694
## Pressure:Wind_V:C                  0.1035    1  8.5771 0.0034378 **
## Thermometer:Wind_V:C               0.0499    3  1.3786 0.2474527
## Humidity:Wind_V:C                  0.0021    2  0.0856 0.9179241
## Pressure:NO2:C                     0.0008    1  0.0661 0.7971683
## Thermometer:NO2:C                  0.1509    3  4.1703 0.0059084 **
## Humidity:NO2:C                     0.1155    2  4.7848 0.0084399 **
## Wind_V:NO2:C                       0.0455    3  1.2576 0.2873517
## Pressure:Thermometer:Humidity:Wind_V 0.1087    1  9.0087 0.0027161 **
## Pressure:Thermometer:Humidity:NO2   0.0478    1  3.9631 0.0466276 *
## Pressure:Thermometer:Wind_V:NO2     0.0135    1  1.1189 0.2902687
## Pressure:Humidity:Wind_V:NO2        0.0017    1  0.1436 0.7047855
## Thermometer:Humidity:Wind_V:NO2     0.0076    2  0.3138 0.7306971
## Pressure:Thermometer:Humidity:C      0.0001    1  0.0079 0.9291493
## Pressure:Thermometer:Wind_V:C       0.0040    1  0.3291 0.5662715
## Pressure:Humidity:Wind_V:C          0.0001    1  0.0060 0.9384372
## Thermometer:Humidity:Wind_V:C       0.0150    2  0.6198 0.5381198
## Pressure:Thermometer:NO2:C          0.0000    1  0.0039 0.9499107
## Pressure:Humidity:NO2:C             0.0357    1  2.9575 0.0856159 .
## Thermometer:Humidity:NO2:C          0.0198    2  0.8189 0.4410360
## Pressure:Wind_V:NO2:C               0.0049    1  0.4069 0.5236036
## Thermometer:Wind_V:NO2:C            0.0375    2  1.5541 0.2116001
## Humidity:Wind_V:NO2:C               0.0205    1  1.7004 0.1923671
## Pressure:Thermometer:Humidity:Wind_V:NO2 0.0000    1  0.0000 0.9971404
## Pressure:Thermometer:Humidity:Wind_V:C 0.0018    1  0.1521 0.6965389
## Pressure:Thermometer:Humidity:NO2:C  0.0476    1  3.9484 0.0470363 *
## Pressure:Thermometer:Wind_V:NO2:C   0.0277    1  2.2953 0.1299012
## Pressure:Humidity:Wind_V:NO2:C      0.0052    1  0.4323 0.5109448
## Thermometer:Humidity:Wind_V:NO2:C   0.0015    1  0.1252 0.7234441
## Pressure:Thermometer:Humidity:Wind_V:NO2:C 0.0020    1  0.1653 0.6843273
## Residuals                          27.5693 2285
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

mod1_diag <- fortify(mod1)
ggplot(mod1_diag, aes(x = .fitted, y = .stdresid)) +
  geom_point() +
  geom_hline(yintercept = 0)

```

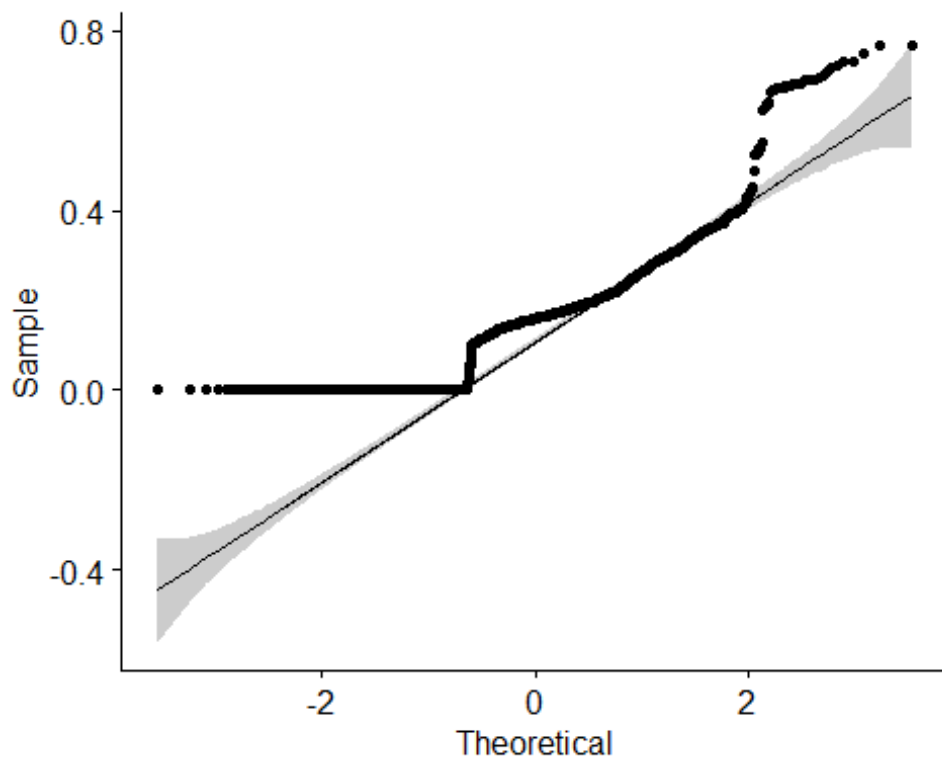




*#Присутствуют признаки гетероскедастичности*

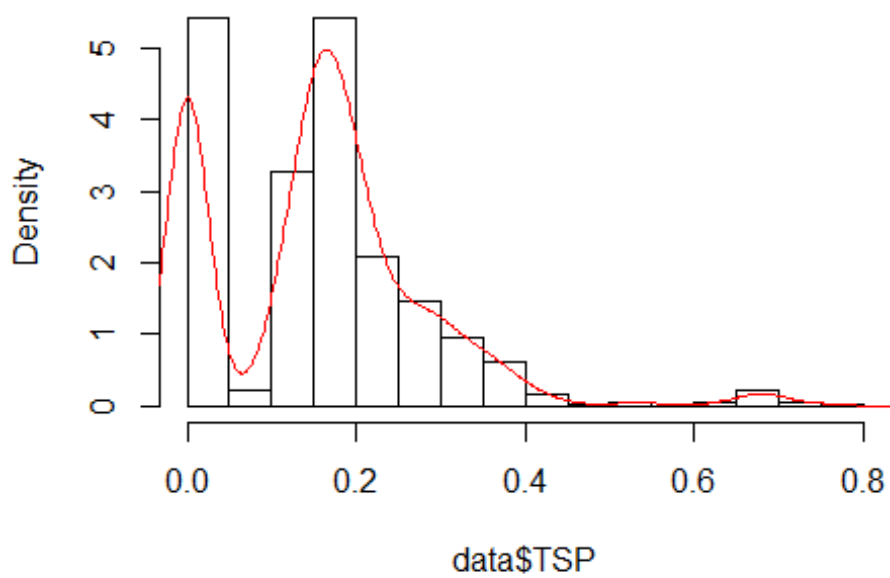
*#Наличие гетероскедастичности - нарушение условий применимости моделей, основанных на нормальном распределении отклика. Возможные пути решения: преобразовать зависимую переменную (Log), использовать более сложную модель, ввести ковариату дисперсии*

```
ggqqplot(data$TSP)
```

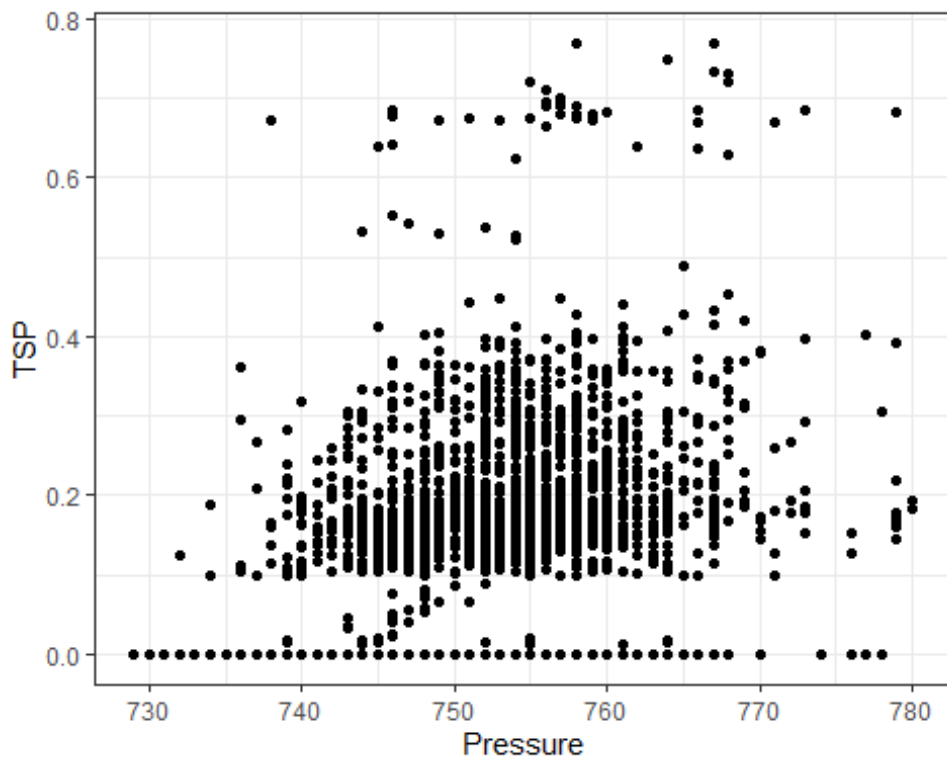


```
hist(data$TSP,probability=T)
lines(density(data$TSP),col=2)
```

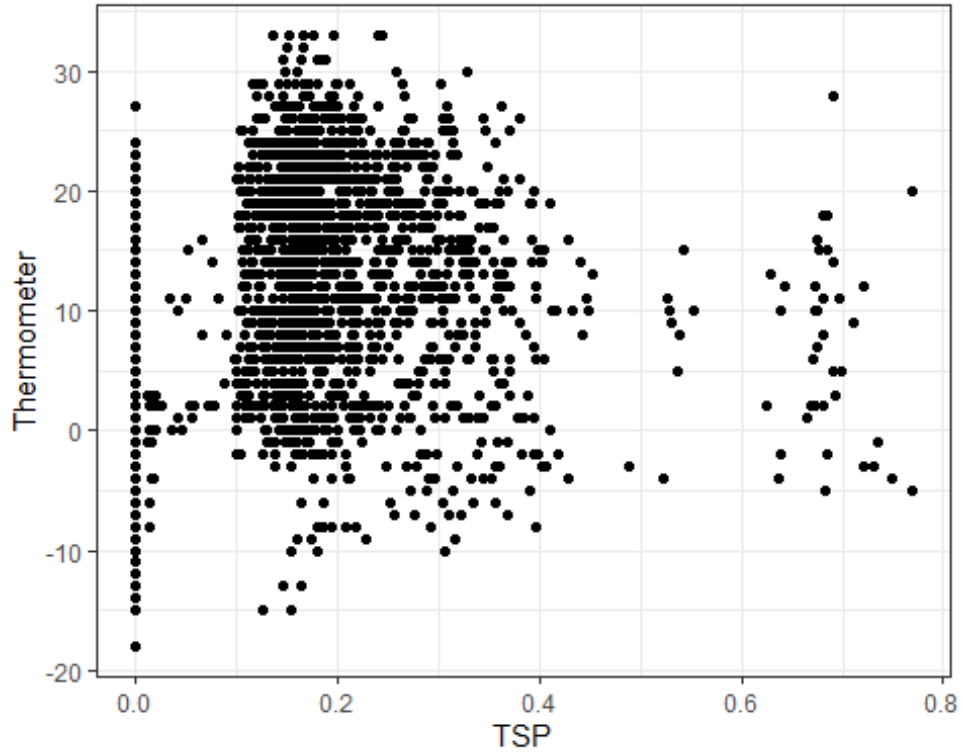
**Histogram of data\$TSP**



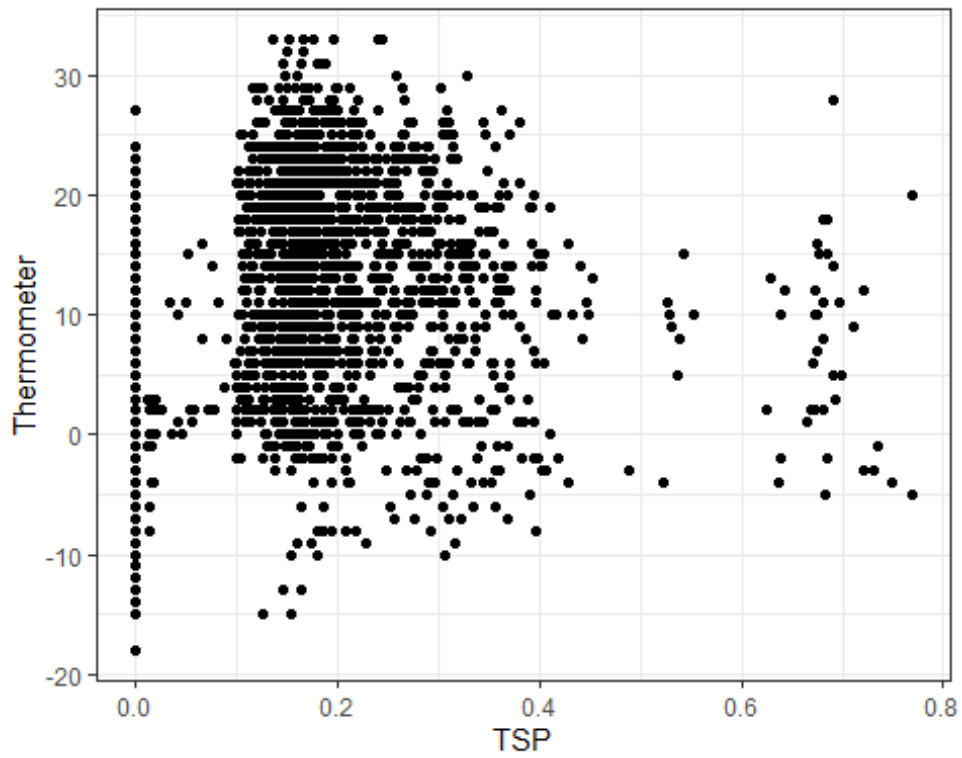
```
ggplot(data, aes(x = Pressure, y = TSP)) +
  geom_point()
```



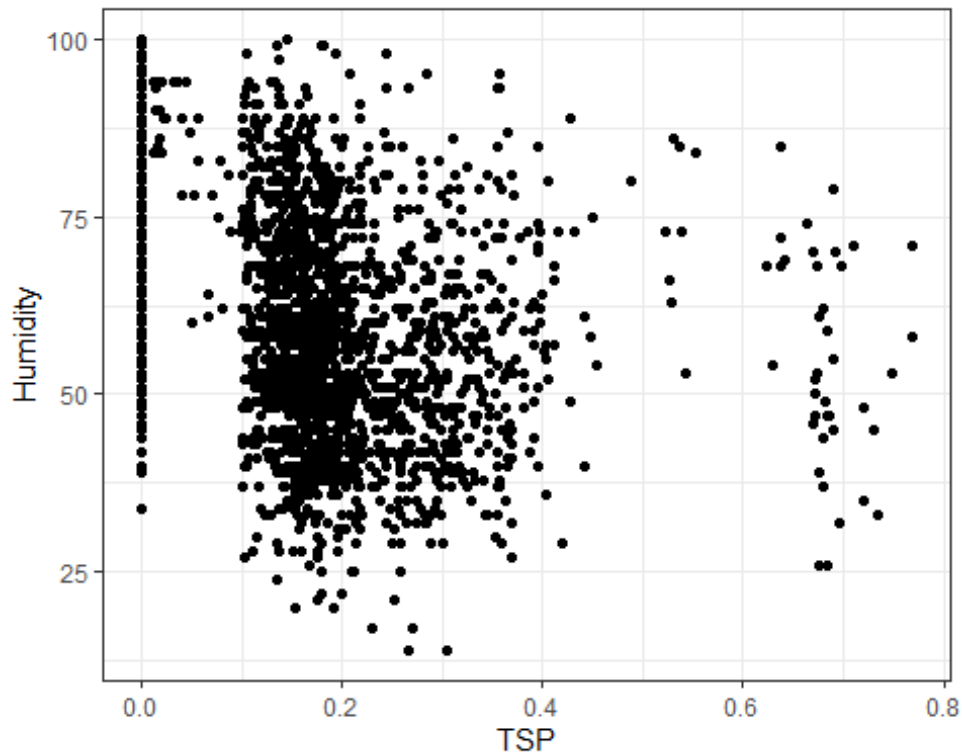
```
ggplot(data, aes(x = TSP, y = Thermometer)) +  
  geom_point()
```



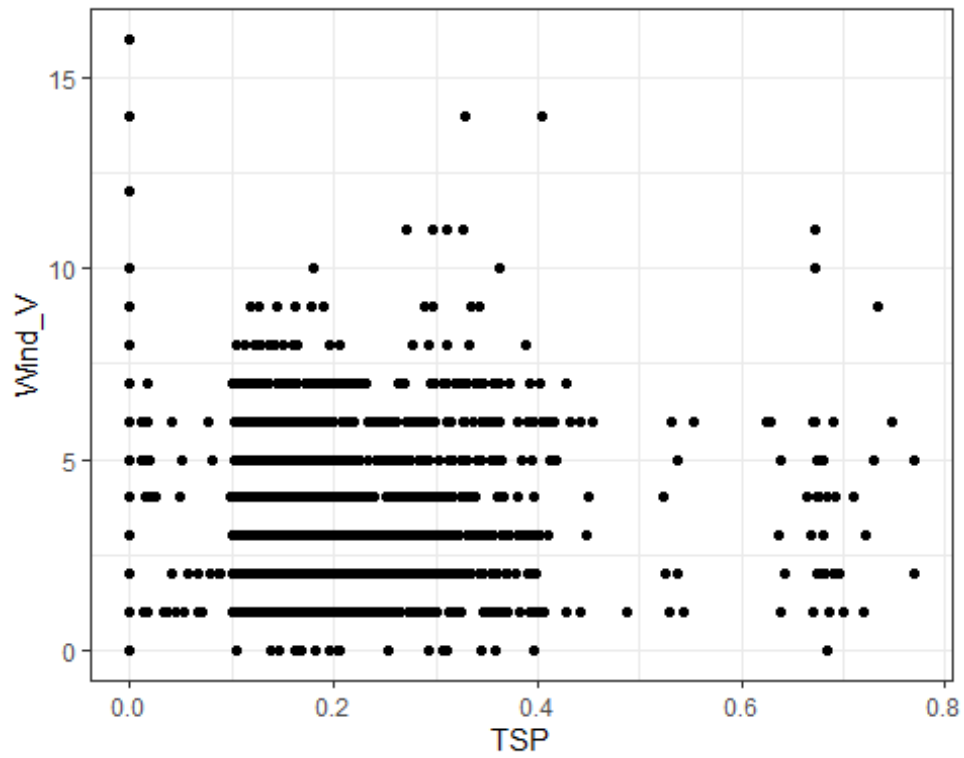
```
ggplot(data, aes(x = TSP, y = Thermometer)) +  
  geom_point()
```



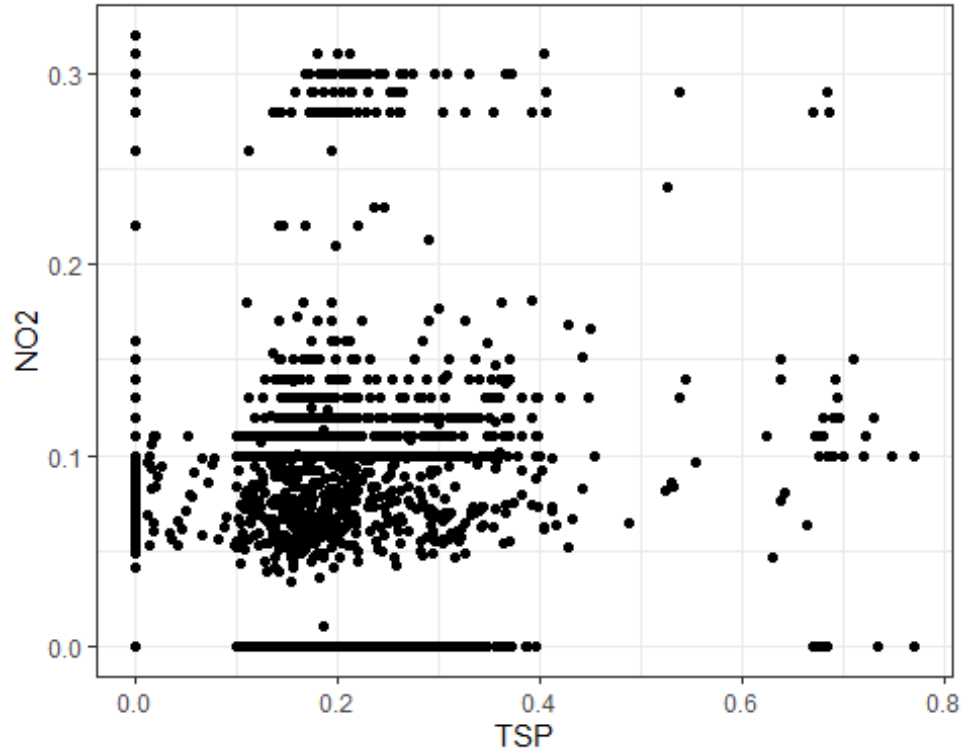
```
ggplot(data, aes(x = TSP, y = Humidity)) +  
  geom_point()
```



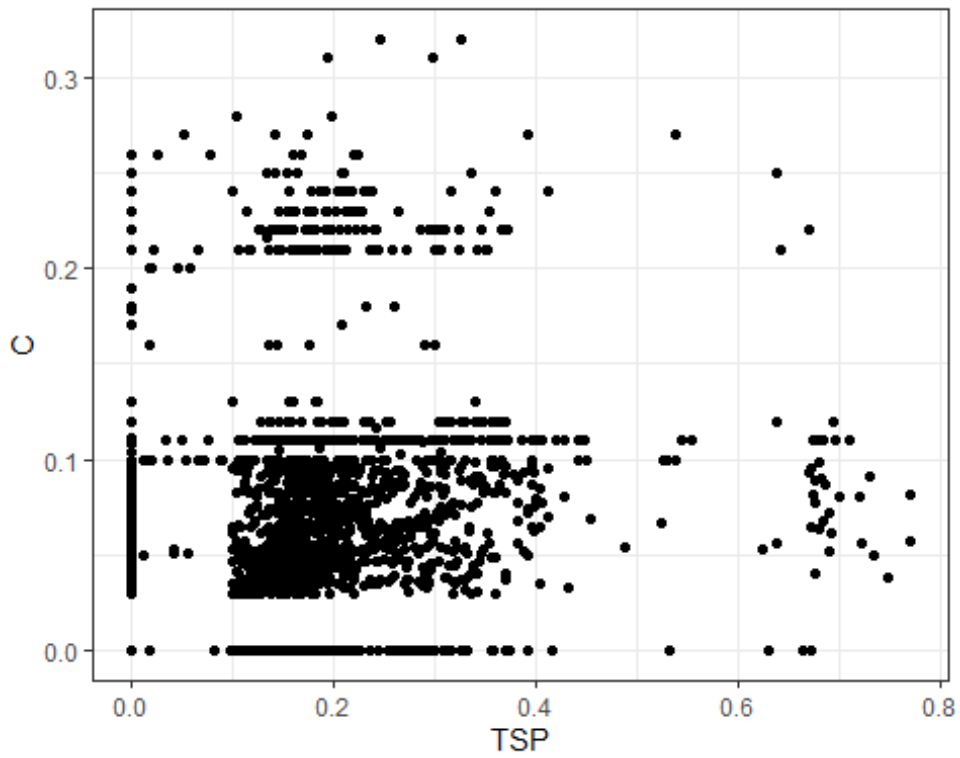
```
ggplot(data, aes(x = TSP, y = Wind_V)) +  
  geom_point()
```



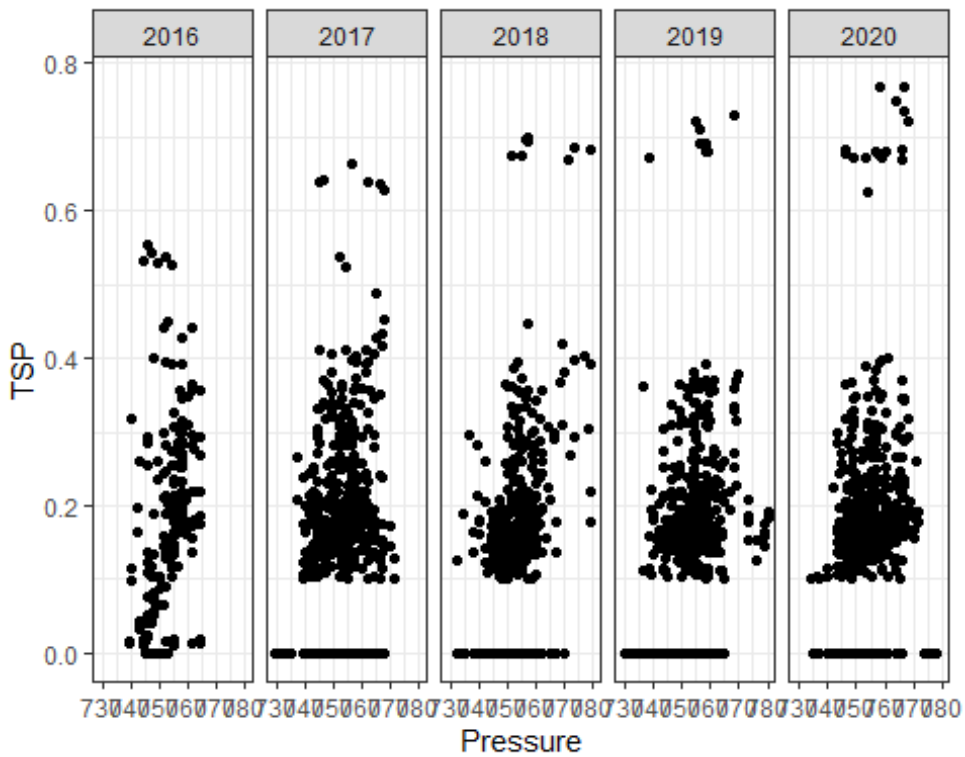
```
ggplot(data, aes(x = TSP, y = NO2)) +  
  geom_point()
```



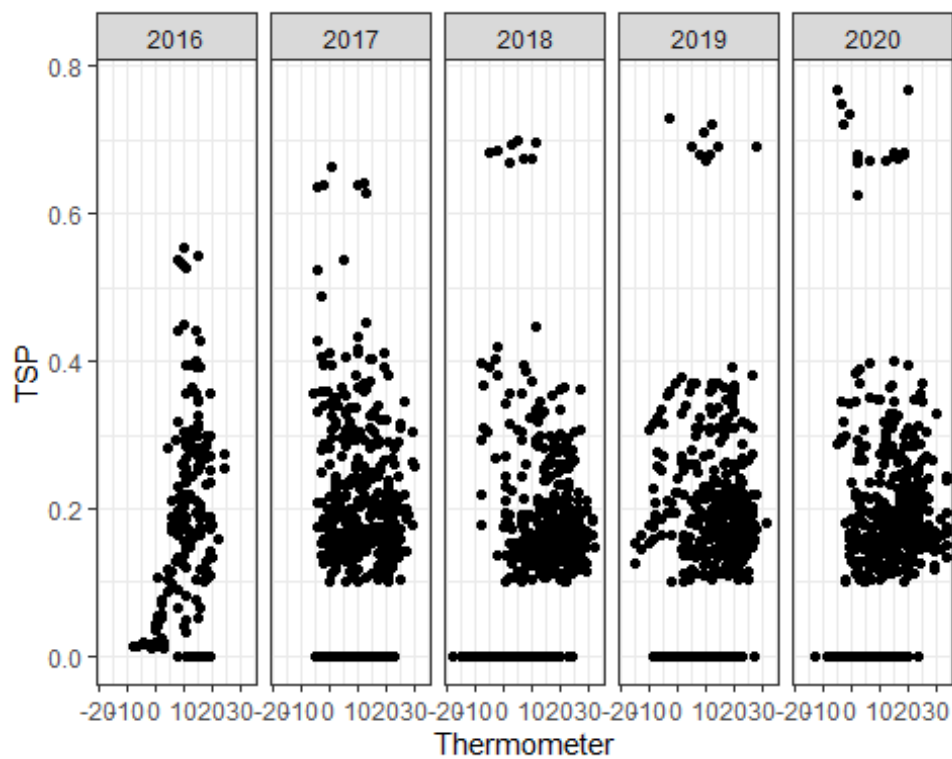
```
ggplot(data, aes(x = TSP, y = C)) +  
  geom_point()
```



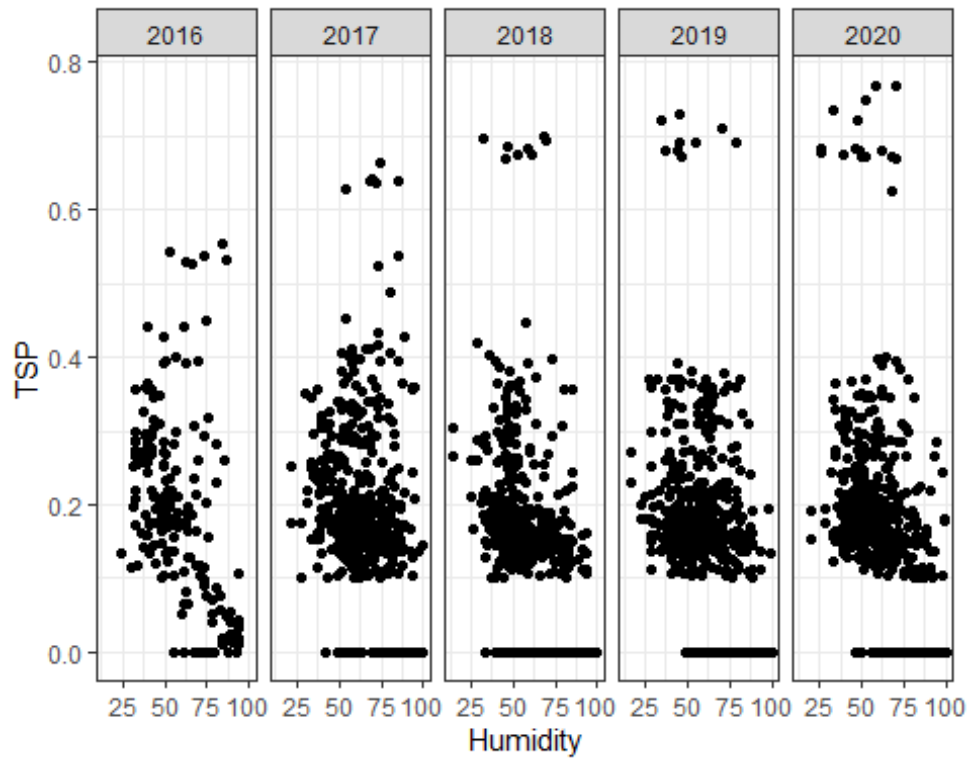
```
ggplot(data, aes(x = Pressure, y = TSP)) +  
  geom_point() +  
  facet_grid(~ Year)
```



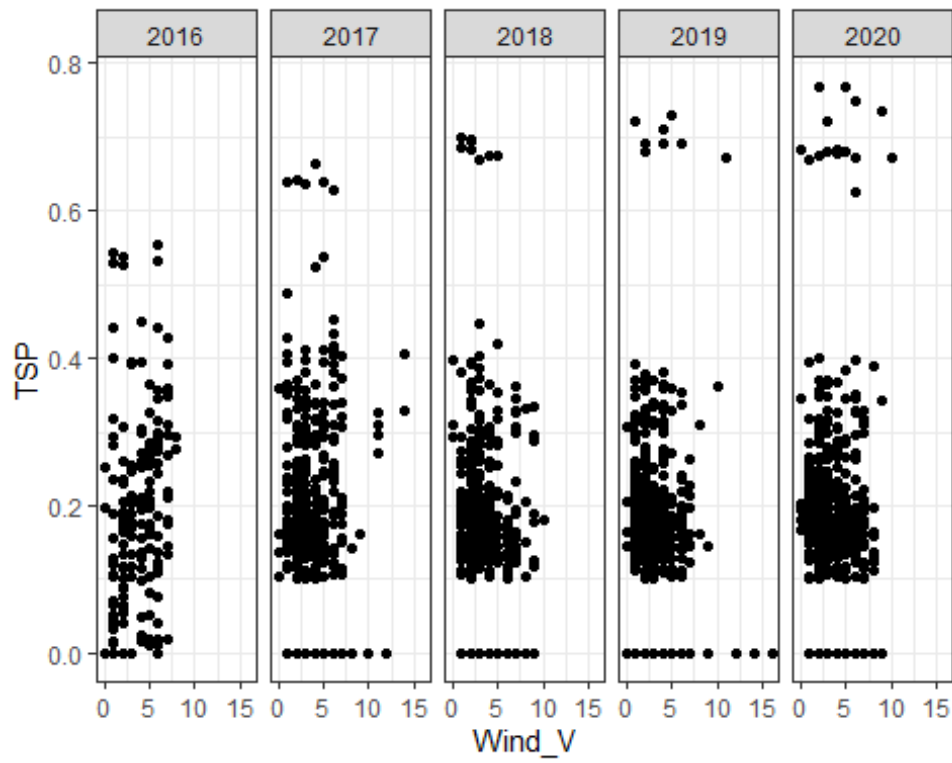
```
ggplot(data, aes(x = Thermometer, y = TSP)) +  
  geom_point() +  
  facet_grid( ~ Year)
```



```
ggplot(data, aes(x = Humidity, y = TSP)) +  
  geom_point() +  
  facet_grid( ~ Year)
```

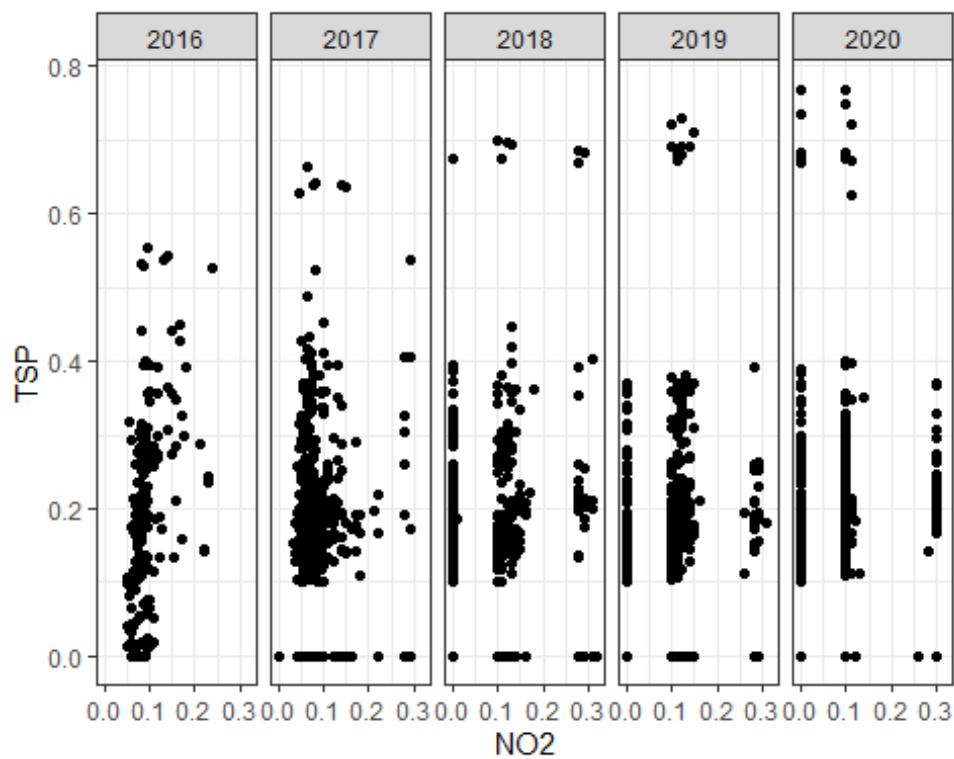


```
ggplot(data, aes(x = Wind_V, y = TSP)) +  
  geom_point() +  
  facet_grid(~ Year)
```

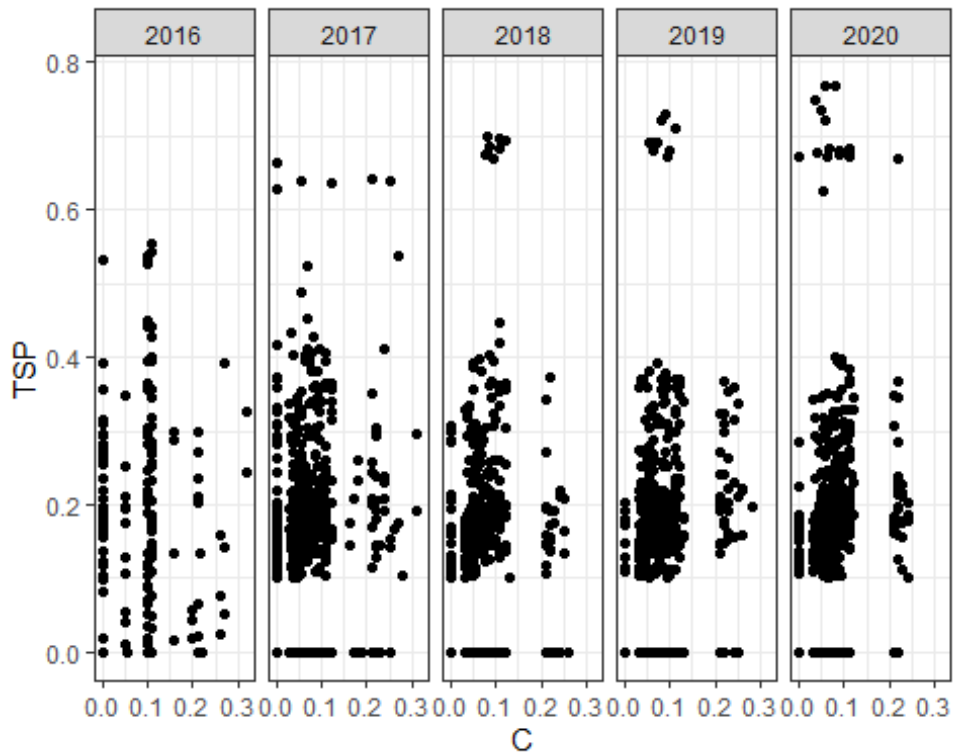




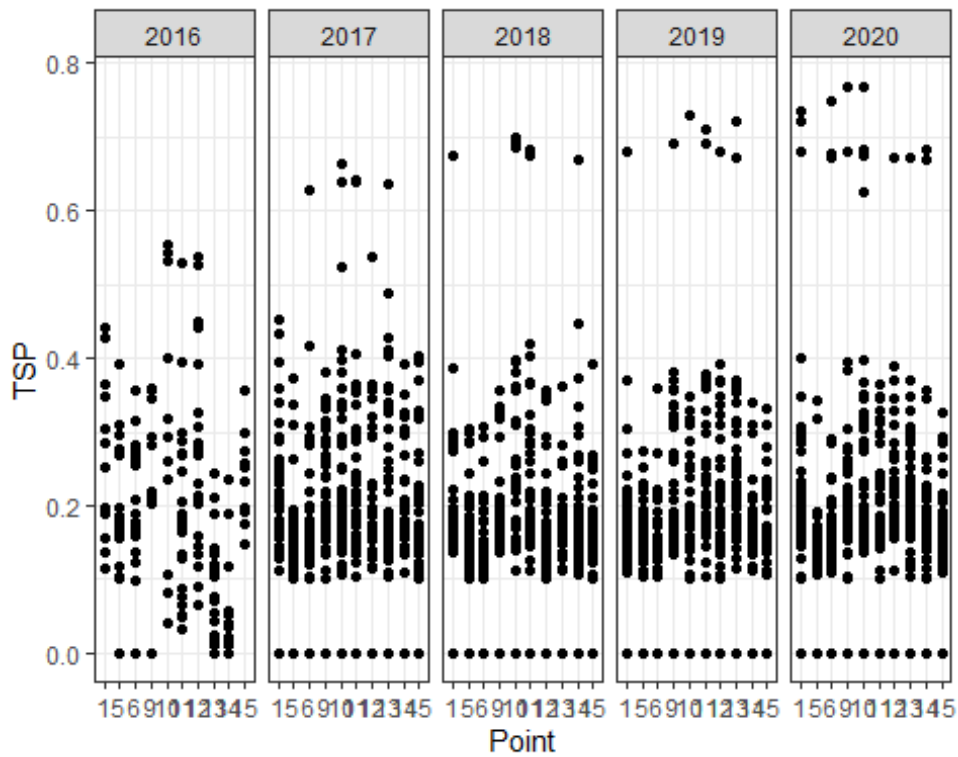
```
ggplot(data, aes(x = NO2, y = TSP)) +  
  geom_point() +  
  facet_grid( ~ Year)
```



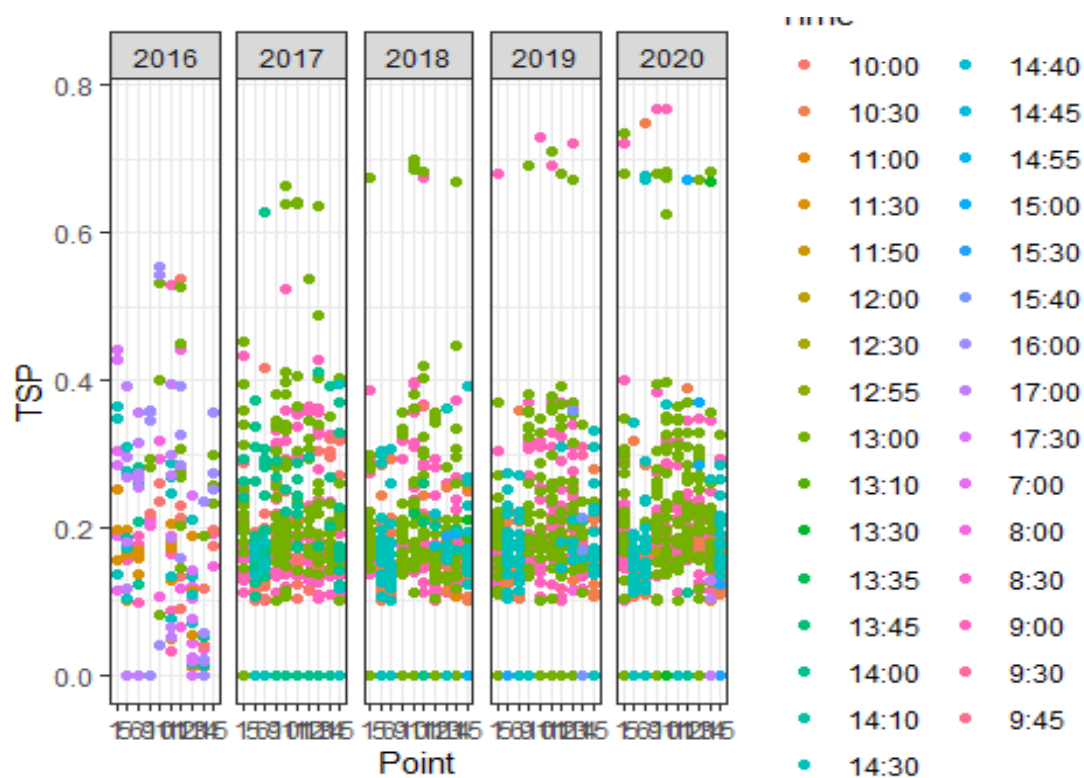
```
ggplot(data, aes(x = C, y = TSP)) +  
  geom_point() +  
  facet_grid( ~ Year)
```



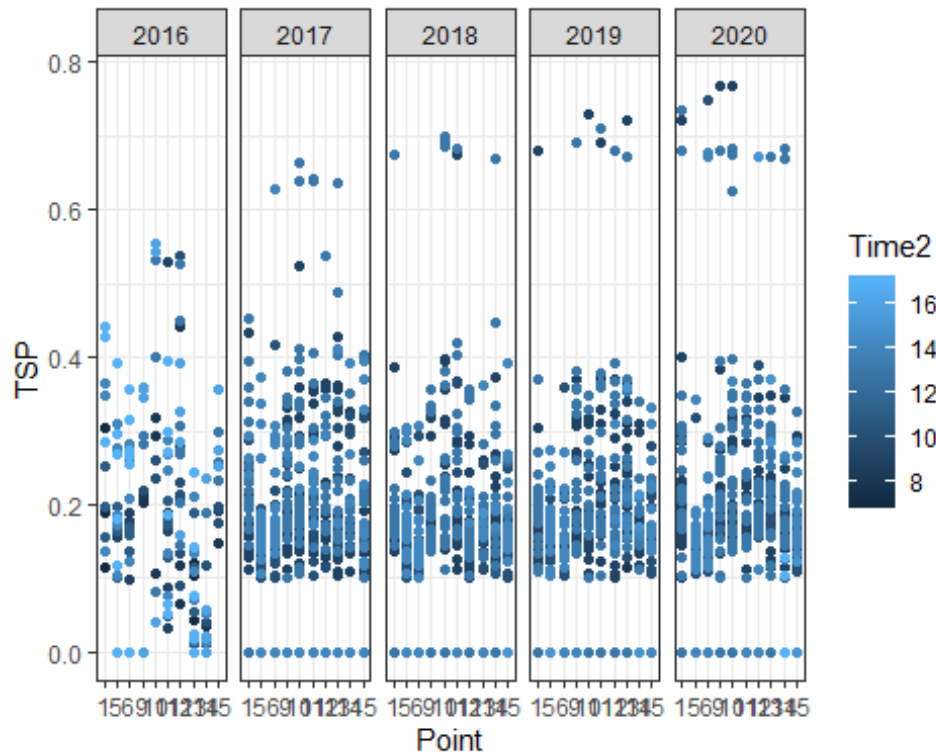
```
ggplot(data, aes(x = Point, y = TSP)) +  
  geom_point() +  
  facet_grid(~ Year)
```



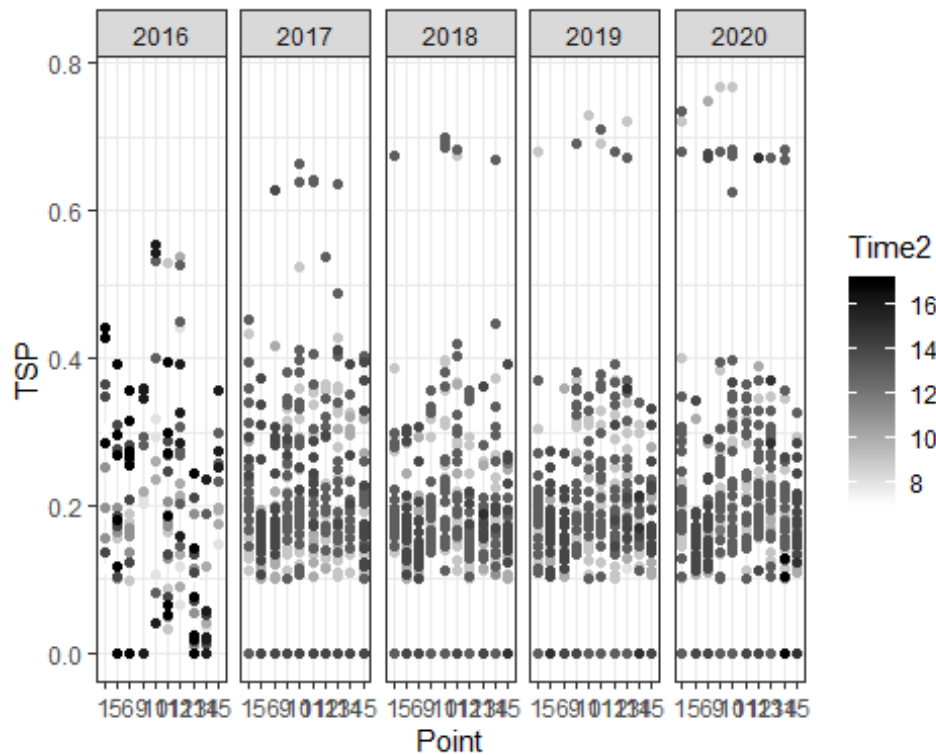
```
ggplot(data, aes(x = Point, y = TSP, colour = Time)) +
  geom_point() +
  facet_grid(~ Year)
```



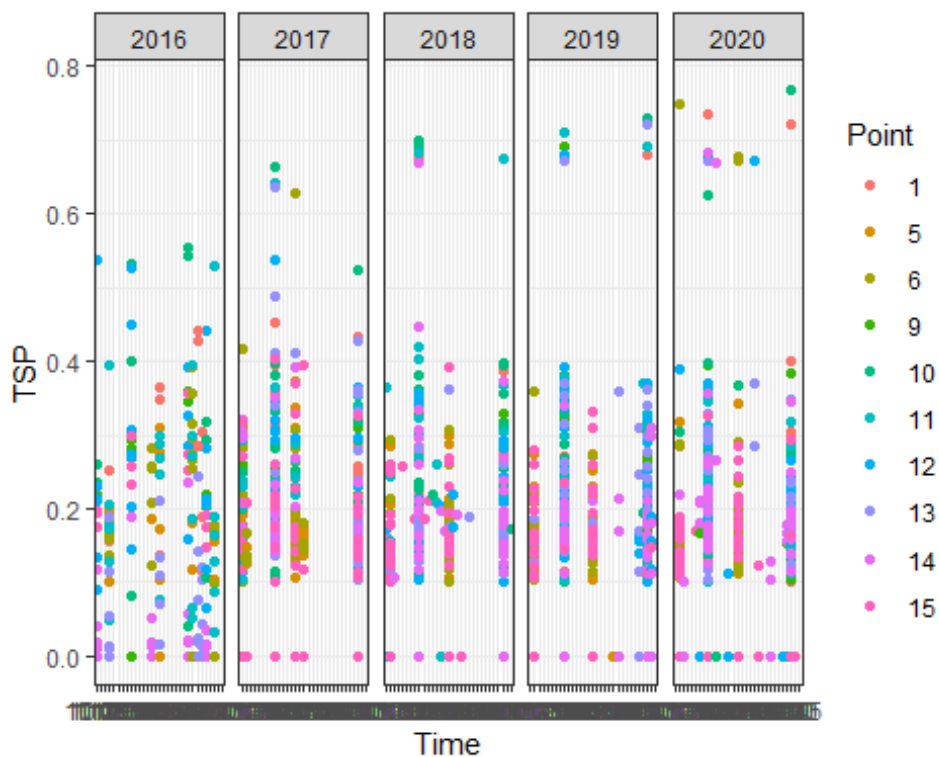
```
ggplot(data, aes(x = Point, y = TSP, colour = Time2)) +
  geom_point() +
  facet_grid(~ Year) +
  scale_color_continuous(breaks = c(8, 10, 12, 14, 16))
```



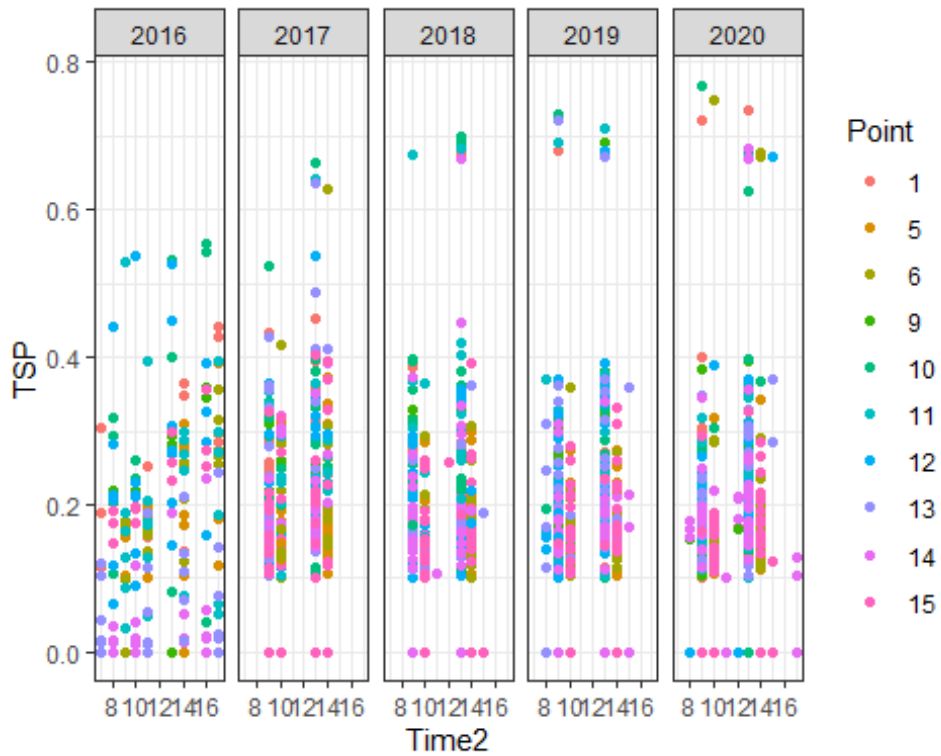
```
ggplot(data, aes(x = Point, y = TSP, colour = Time2)) +
  geom_point() +
  facet_grid( ~ Year) +
  scale_color_gradient(low = 'white', high = 'black', breaks = c(8, 10, 12, 14,
16))
```



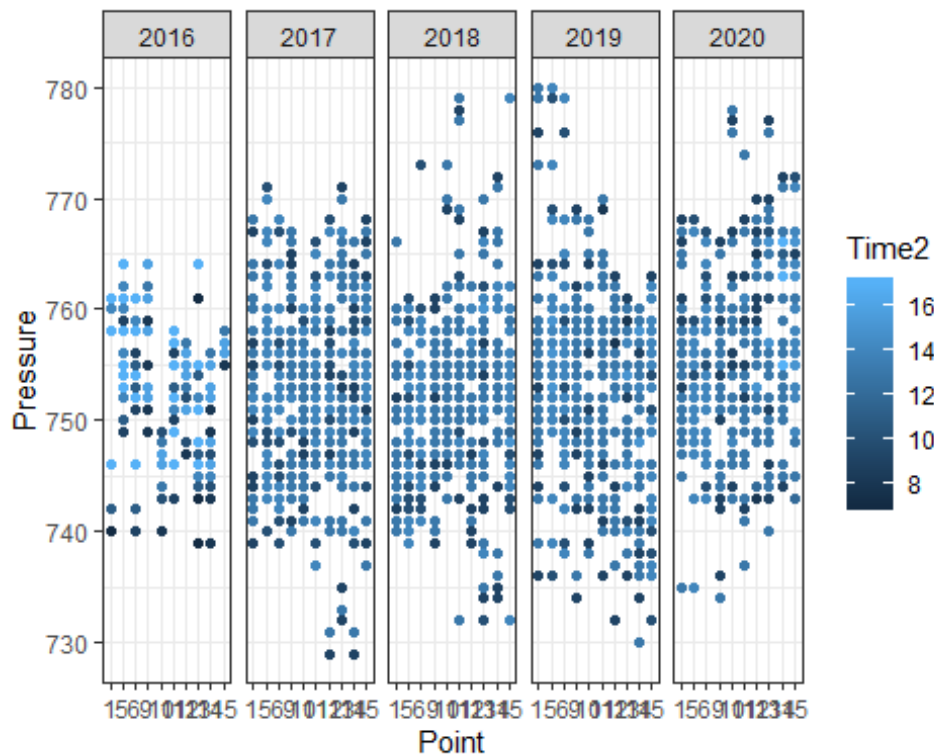
```
ggplot(data, aes(x = Time, y = TSP, colour = Point)) +  
  geom_point() +  
  facet_grid( ~ Year)
```



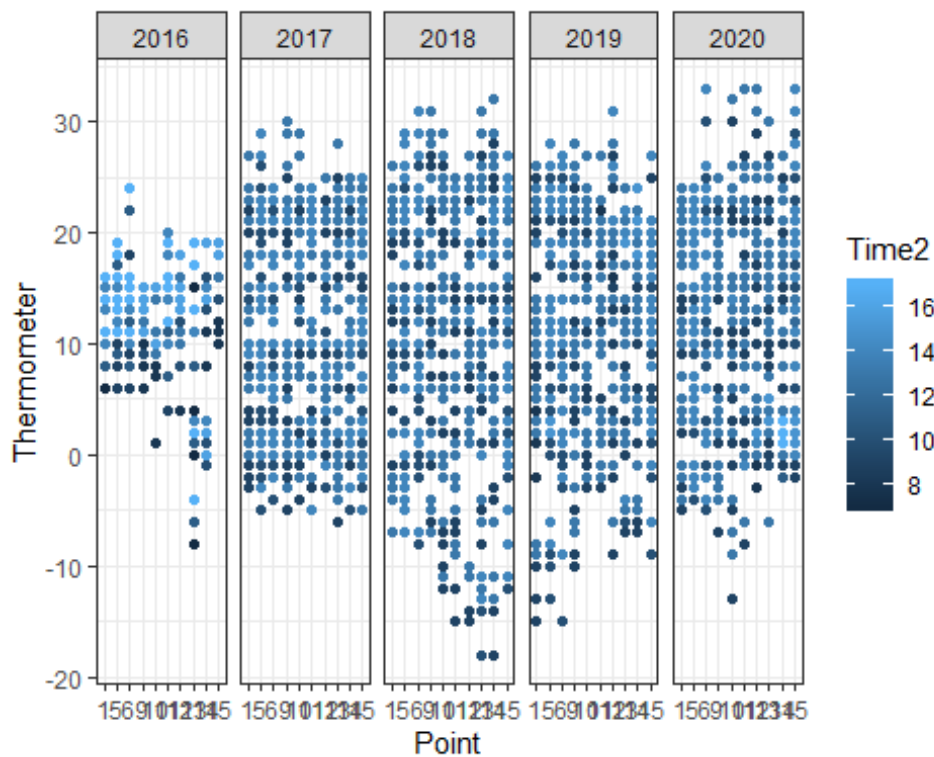
```
ggplot(data, aes(x = Time2, y = TSP, colour = Point)) +  
  geom_point() +  
  scale_x_continuous(breaks = c(8, 10, 12, 14, 16)) +  
  facet_grid( ~ Year)
```



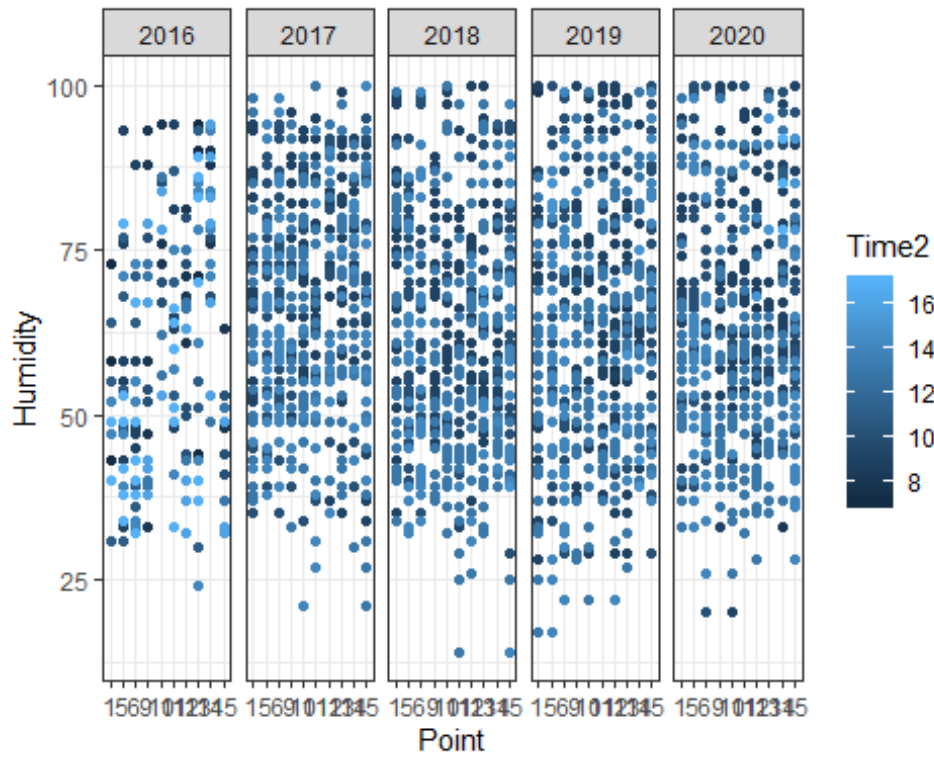
```
ggplot(data, aes(x = Point, y = Pressure, colour = Time2)) +
  geom_point() +
  facet_grid( ~ Year) +
  scale_color_continuous(breaks = c(8, 10, 12, 14, 16))
```



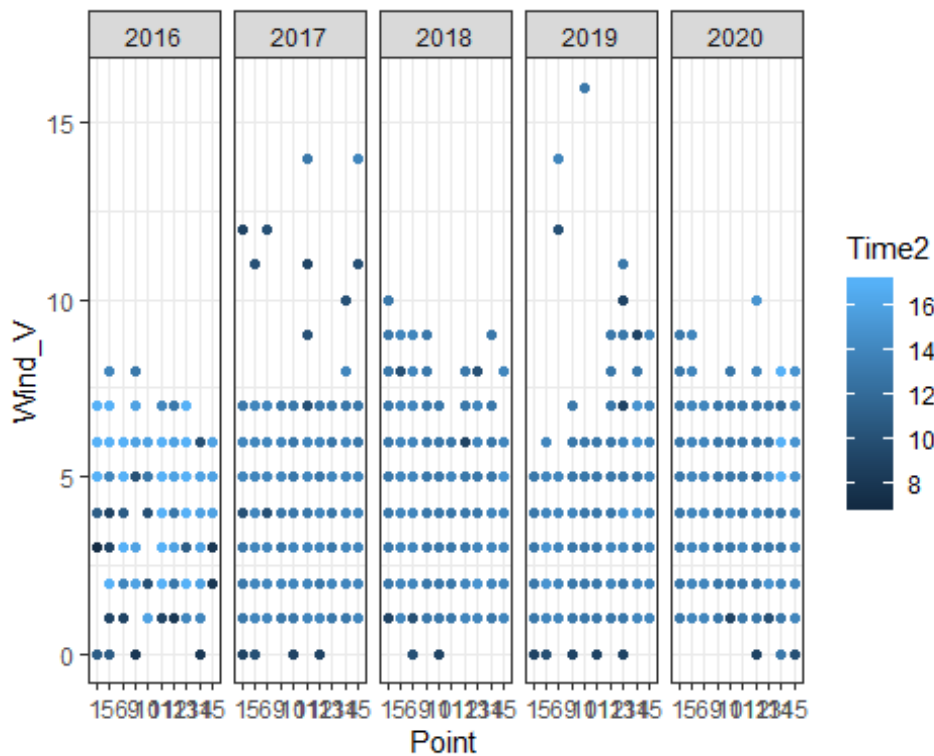
```
ggplot(data, aes(x = Point, y = Thermometer, colour = Time2)) +
  geom_point() +
  facet_grid( ~ Year) +
  scale_color_continuous(breaks = c(8, 10, 12, 14, 16))
```



```
ggplot(data, aes(x = Point, y = Humidity, colour = Time2)) +
  geom_point() +
  facet_grid( ~ Year) +
  scale_color_continuous(breaks = c(8, 10, 12, 14, 16))
```

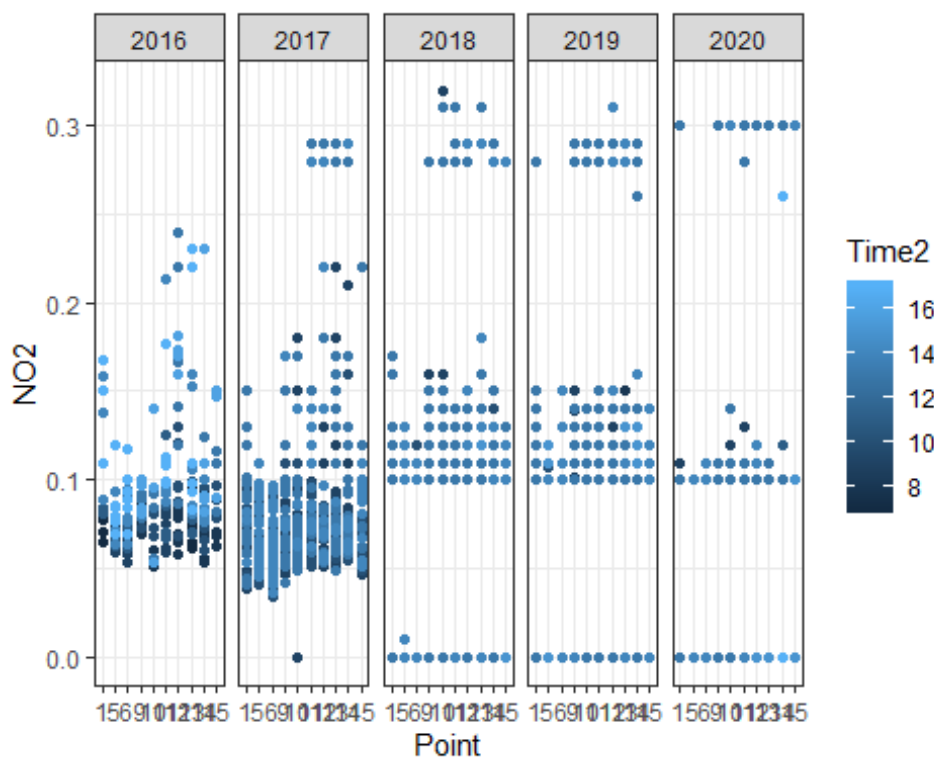


```
ggplot(data, aes(x = Point, y = Wind_V, colour = Time2)) +  
  geom_point() +  
  facet_grid( ~ Year) +  
  scale_color_continuous(breaks = c(8, 10, 12, 14, 16))
```

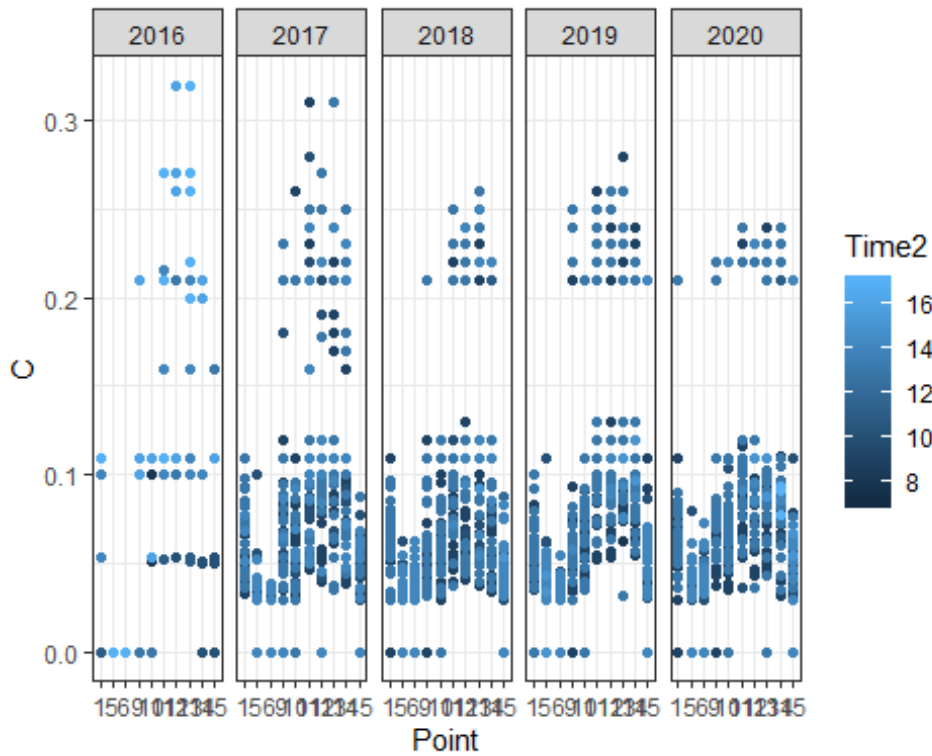




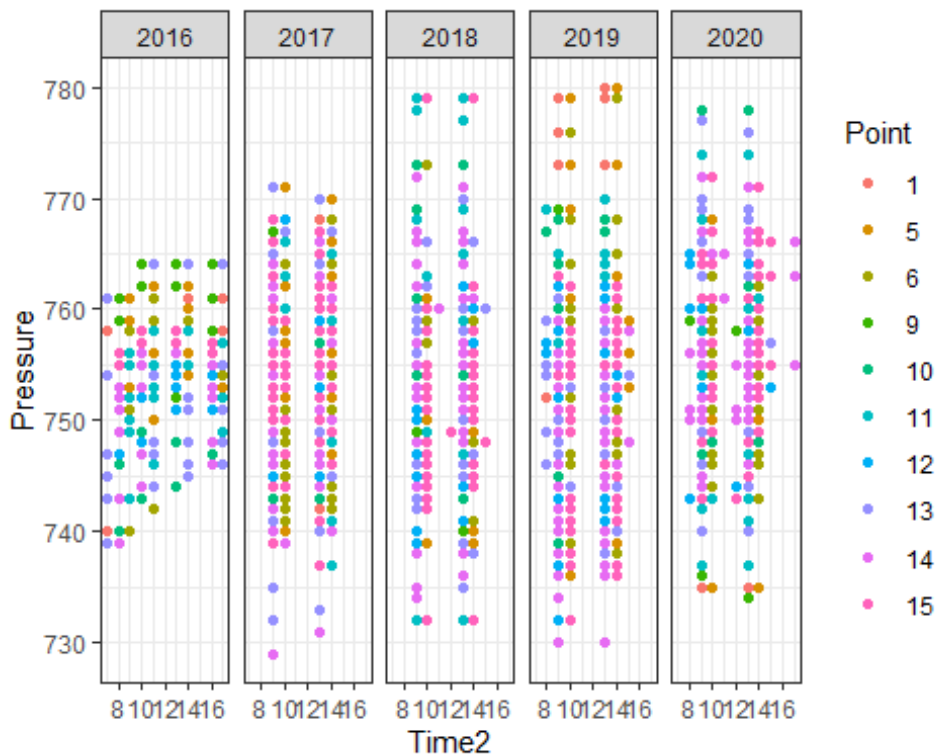
```
ggplot(data, aes(x = Point, y = NO2, colour = Time2)) +
  geom_point() +
  facet_grid( ~ Year) +
  scale_color_continuous(breaks = c(8, 10, 12, 14, 16))
```



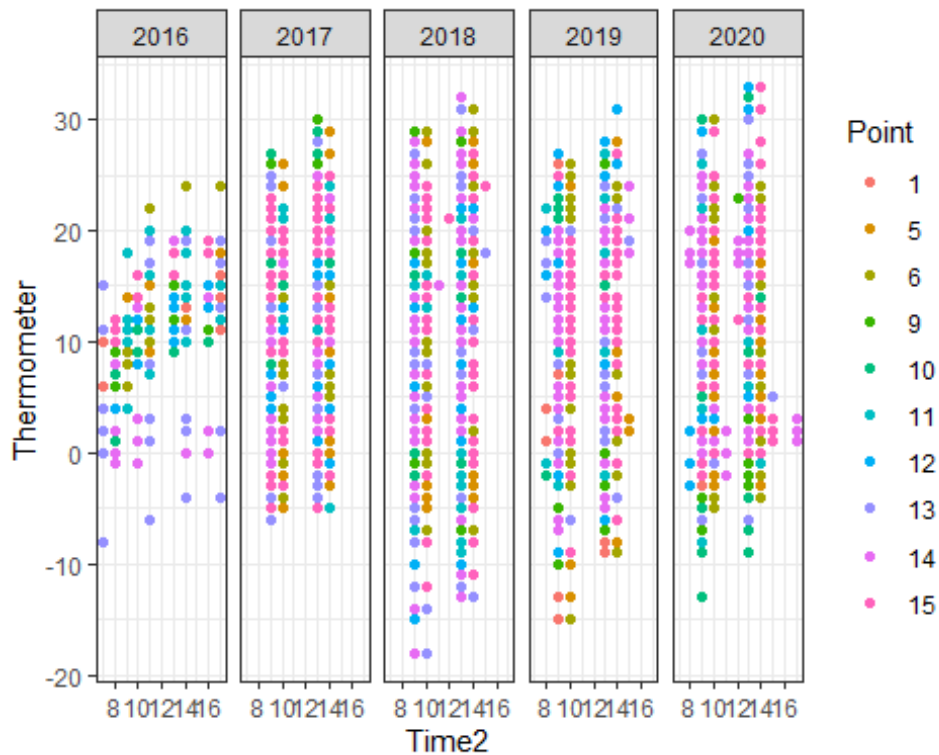
```
ggplot(data, aes(x = Point, y = C, colour = Time2)) +
  geom_point() +
  facet_grid( ~ Year) +
  scale_color_continuous(breaks = c(8, 10, 12, 14, 16))
```



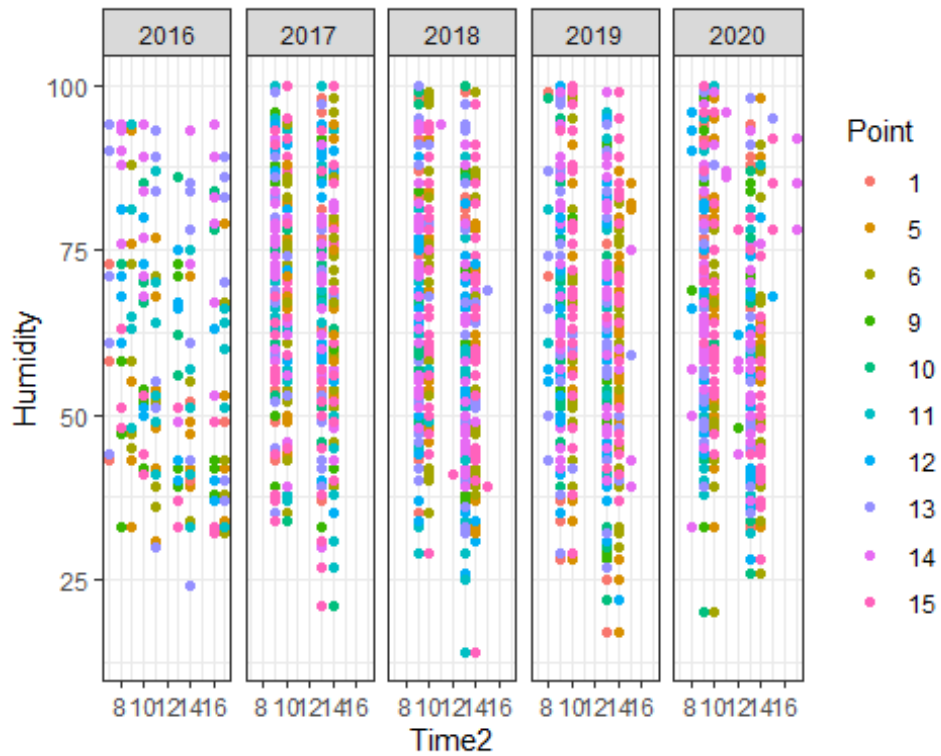
```
ggplot(data, aes(x = Time2, y = Pressure, colour = Point)) +
  geom_point() +
  scale_x_continuous(breaks = c(8, 10, 12, 14, 16)) +
  facet_grid( ~ Year)
```



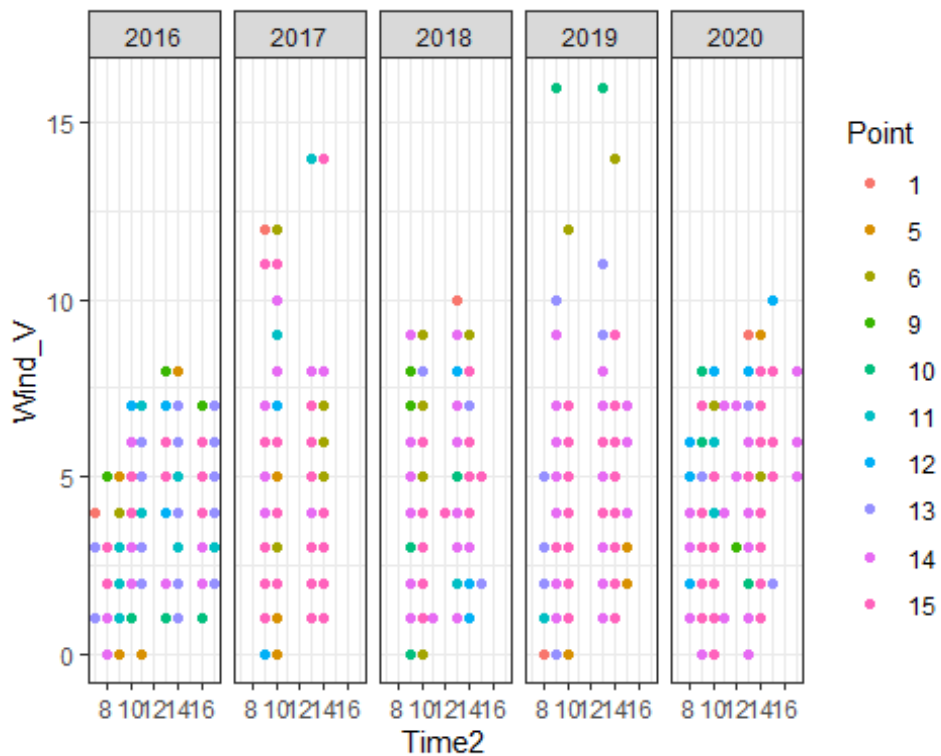
```
ggplot(data, aes(x = Time2, y = Thermometer, colour = Point)) +
  geom_point() +
  scale_x_continuous(breaks = c(8, 10, 12, 14, 16)) +
  facet_grid( ~ Year)
```



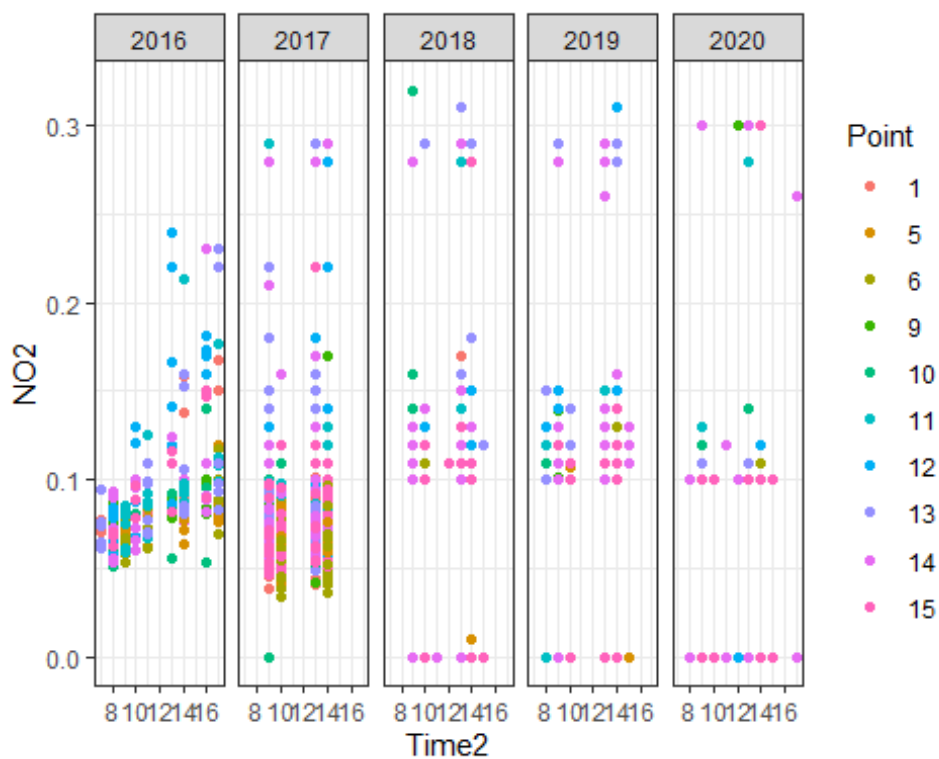
```
ggplot(data, aes(x = Time2, y = Humidity, colour = Point)) +
  geom_point() +
  scale_x_continuous(breaks = c(8, 10, 12, 14, 16)) +
  facet_grid( ~ Year)
```



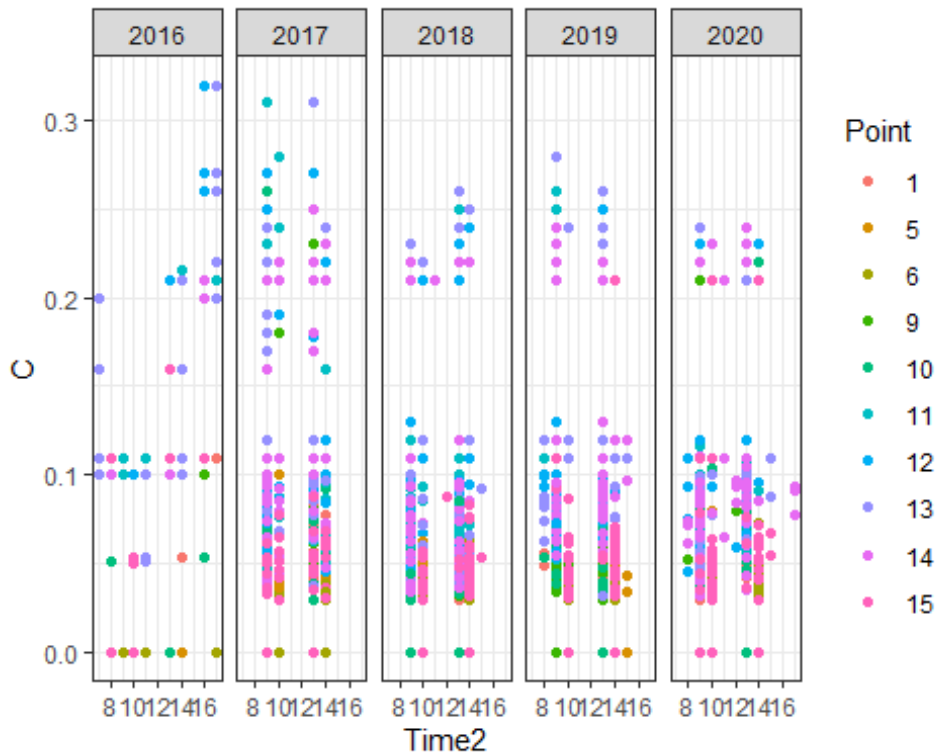
```
ggplot(data, aes(x = Time2, y = Wind_V, colour = Point)) +
  geom_point() +
  scale_x_continuous(breaks = c(8, 10, 12, 14, 16)) +
  facet_grid( ~ Year)
```



```
ggplot(data, aes(x = Time2, y = NO2, colour = Point)) +
  geom_point() +
  scale_x_continuous(breaks = c(8, 10, 12, 14, 16)) +
  facet_grid( ~ Year)
```



```
ggplot(data, aes(x = Time2, y = C, colour = Point)) +
  geom_point() +
  scale_x_continuous(breaks = c(8, 10, 12, 14, 16)) +
  facet_grid( ~ Year)
```



```
mod1 <- lmer(TSP ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 + C +
Daytime + (1 + Year|Point/Daytime), data = data)
```

```
## boundary (singular) fit: see ?isSingular
```

```
summary(mod1)
```

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: TSP ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 +
##       C + Daytime + (1 + Year | Point/Daytime)
## Data: data
##
## REML criterion at convergence: -3626.4
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.7721 -0.5974 -0.0888  0.4387  5.4186
##
## Random effects:
## Groups      Name                Variance Std.Dev. Corr
## Daytime:Point (Intercept) 3.584e-05 0.005986
##               Year2017      8.776e-05 0.009368 -1.00
##               Year2018      2.312e-04 0.015205 -1.00  1.00
##               Year2019      1.917e-06 0.001385 -0.47  0.45  0.39
##               Year2020      2.804e-04 0.016747 -1.00  1.00  1.00  0.42
## Point
##       (Intercept) 6.347e-03 0.079668
##       Year2017    4.729e-03 0.068769 -0.95
##       Year2018    3.713e-03 0.060935 -1.00  0.95
##       Year2019    7.713e-03 0.087824 -0.97  0.94  0.97
```

```

##          Year2020      4.995e-03 0.070676 -0.96  1.00  0.95  0.94
## Residual              1.164e-02 0.107888
## Number of obs: 2349, groups:  Daytime:Point, 30; Point, 10
##
## Fixed effects:
##              Estimate Std. Error t value
## (Intercept)  -2.3237361  0.2637433  -8.811
## Year2017      0.0062588  0.0240043   0.261
## Year2018     -0.0290548  0.0219339  -1.325
## Year2019     -0.0192644  0.0294874  -0.653
## Year2020     -0.0031248  0.0247231  -0.126
## Pressure      0.0034692  0.0003421  10.141
## Thermometer   0.0008824  0.0002899   3.044
## Humidity     -0.0025713  0.0001576 -16.316
## Wind_V        0.0021864  0.0012077   1.810
## NO2           0.1370195  0.0373946   3.664
## C             0.1907001  0.0500254   3.812
## Daytimeevening 0.0161693  0.0154423   1.047
## Daytimemorning -0.0003643  0.0050670  -0.072

##
## Correlation matrix not shown by default, as p = 13 > 12.
## Use print(x, correlation=TRUE) or
##      vcov(x)          if you need it

## convergence code: 0
## boundary (singular) fit: see ?isSingular

#Диагностика модели (анализ остатков)
mod1_diag <- data.frame(
  data,
  .fitted = fitted(mod1),
  .resid = resid(mod1, type = 'pearson'),
  .sresid = resid(mod1, type = 'pearson', scaled = TRUE)
)

#.fitted - предсказанные значения,
#.resid - Пирсоновские остатки,
#.sresid - стандартизованные Пирсоновские остатки

head(mod1_diag, 4)

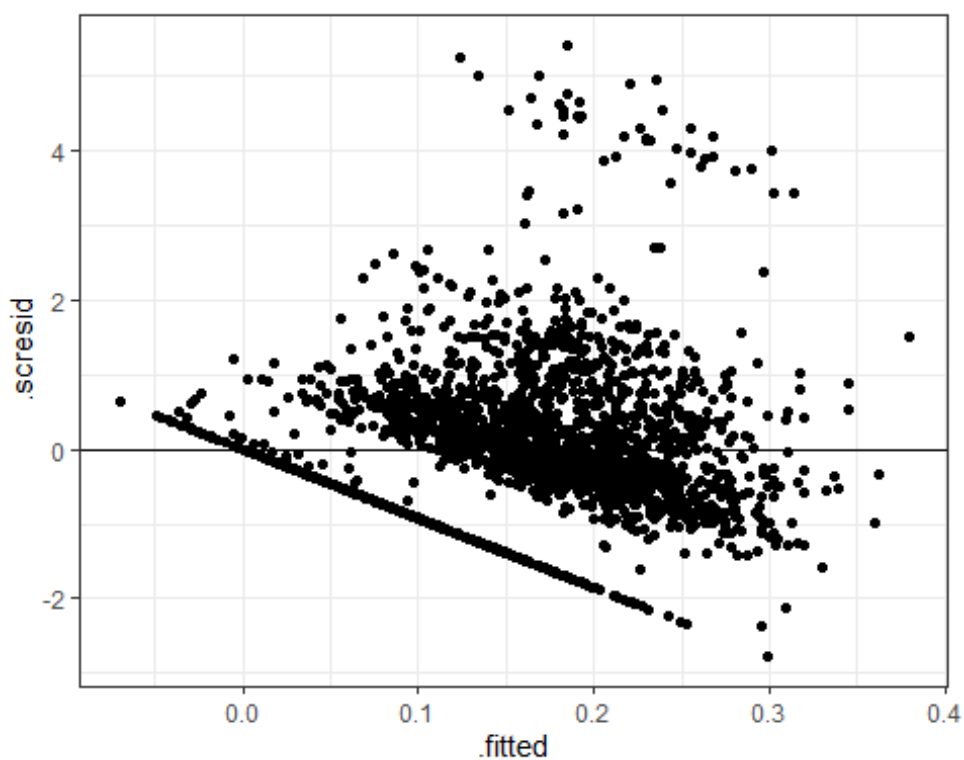
##   Year Point abs_risk_450 abs_risk_451 abs_risk_458 abs_risk      Date Time
## 1 2016     1          NA          NA          NA          NA 26.04.2016 7:00
## 2 2016     1          NA          NA          NA          NA 27.04.2016 7:00
## 3 2016     1          NA          NA          NA          NA 28.04.2016 7:00
## 4 2016    13          NA          NA          NA          NA 16.05.2016 7:00
##   Time2 Daytime Thermometer Pressure Humidity      Wind Wind_V Weather  TSP
## 1     7 morning         6       740      73 south west     4 cloudy 0.114
## 2     7 morning         6       758      58   east     3  clear 0.189
## 3     7 morning        10       758      43   east     4  clear 0.305
## 4     7 morning        15       745      61 south     1 cloudy 0.000

```

```
##   TSPn PM10 PM10n PM2.5 PM2.5n NO2 NO2n C Cn .fitted .resid
## 1 0.5 0.075 0.3 0.036 0.16 0.065 0.2 0.10 0.15 0.14355087 -0.02955087
## 2 0.5 0.124 0.3 0.059 0.16 0.071 0.2 0.10 0.15 0.24320300 -0.05420300
## 3 0.5 0.203 0.3 0.077 0.16 0.077 0.2 0.10 0.15 0.28831146 0.01668854
## 4 0.5 0.000 0.3 0.000 0.16 0.062 0.2 0.11 0.15 0.06068658 -0.06068658
##   .sresid
## 1 -0.2739028
## 2 -0.5023999
## 3 0.1546837
## 4 -0.5624953
```

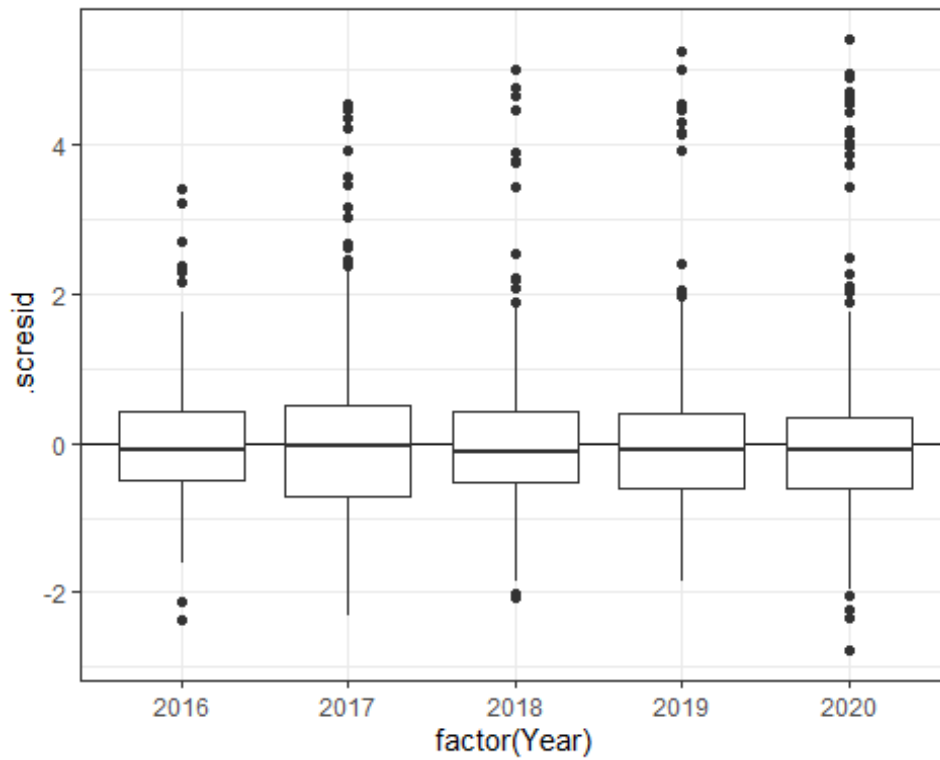
*#График остатков от предсказанных значений*

```
gg_resid <- ggplot(mod1_diag, aes(y = .sresid)) +
  geom_hline(yintercept = 0)
gg_resid + geom_point(aes(x = .fitted))
```

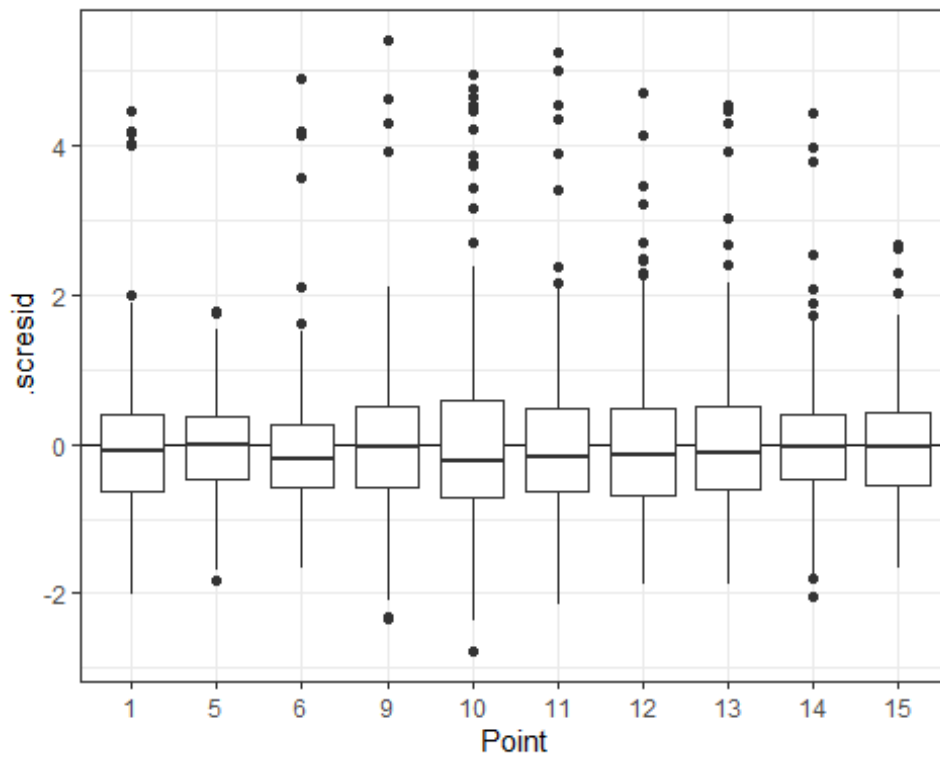


```
gg_resid + geom_boxplot(aes(x = factor(Year)))
```





```
gg_resid + geom_boxplot(aes(x = Point))
```



```
ctrl <- lmeControl(opt='optim', returnObject = TRUE)
```

```
mod1 <- lme(TSP ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 + C +
```

```

Time, random = ~1|Point, control = ctrl, data = data)
mod2 <- lme(TSP ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 + C +
Time, random = ~1 + Year|Point, control = ctrl, data = data)

AIC(mod1, mod2)

##          df          AIC
## mod1 43 -3421.418
## mod2 57 -3467.352

#Ковариата - дискретный фактор
mod2_1 <- update(mod2, weights = varIdent(form = ~ 1|Year))

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 1

mod2_2 <- update(mod2, weights = varIdent(form = ~ 1|Time))

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 2

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 3

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 2

## Warning in lme.formula(fixed = TSP ~ Year + Pressure + Thermometer + Humidity
+ : optim problem, convergence error code = 1
## message =

summary(mod2_2)

## Linear mixed-effects model fit by REML
## Data: data
##          AIC          BIC    logLik
## -3598.233 -3098.493 1886.116
##
## Random effects:
## Formula: ~1 + Year | Point
## Structure: General positive-definite, Log-Cholesky parametrization
##          StdDev      Corr
## (Intercept) 0.07302253 (Intr) Yr2017 Yr2018 Yr2019
## Year2017    0.06754283 -0.965
## Year2018    0.06241968 -0.995  0.950
## Year2019    0.08281693 -0.978  0.905  0.970
## Year2020    0.06624693 -0.959  0.999  0.942  0.895
## Residual    0.05050045
##
## Variance function:

```

```

## Structure: Different standard deviations per stratum
## Formula: ~1 | Time
## Parameter estimates:
##      7:00      8:00      9:00      10:00      11:30      13:00      14:00      14:
30
## 1.0000000 1.7210137 2.0634712 1.7545550 1.5019886 2.5771111 2.2120108 1.62307
66
##      17:30      10:30      15:30      17:00      8:30      12:30      16:00      9:
45
## 1.6266438 1.5009451 1.1996010 2.0300400 2.3183664 1.2631668 2.5400386 1.00000
00
##      13:30      13:35      13:45      9:30      14:40      15:00      15:40      11:
00
## 6.1182894 0.9999997 0.3189040 1.9952171 1.1240156 3.7794370 2.4376498 1.49863
25
##      14:10      14:45      11:50      12:00      12:55      13:10      14:55
## 1.0000001 1.0000001 1.0000000 0.9999999 1.0000000 1.0000001 1.0000001
## Fixed effects: TSP ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2
+      C + Time
##              Value Std.Error   DF    t-value p-value
## (Intercept) -2.2964316 0.24473195 2299   -9.383456 0.0000
## Year2017     -0.0079195 0.02403736 2299   -0.329468 0.7418
## Year2018     -0.0491788 0.02268574 2299   -2.167828 0.0303
## Year2019     -0.0416216 0.02842154 2299   -1.464437 0.1432
## Year2020     -0.0288938 0.02380015 2299   -1.214018 0.2249
## Pressure      0.0034133 0.00031682 2299    10.773854 0.0000
## Thermometer   0.0010671 0.00026815 2299     3.979430 0.0001
## Humidity     -0.0025056 0.00014381 2299   -17.423116 0.0000
## Wind_V        0.0022906 0.00112375 2299     2.038405 0.0416
## NO2           0.1502430 0.03573228 2299     4.204686 0.0000
## C             0.1429852 0.04473641 2299     3.196171 0.0014
## Time10:30     0.0195970 0.01104938 2299     1.773587 0.0763
## Time11:00    -0.0241370 0.04007023 2299    -0.602367 0.5470
## Time11:30    -0.0095839 0.02158930 2299    -0.443919 0.6571
## Time11:50     0.0849953 0.05192622 2299     1.636847 0.1018
## Time12:00     0.1500680 0.05233783 2299     2.867294 0.0042
## Time12:30    -0.0043774 0.03117467 2299    -0.140415 0.8883
## Time12:55     0.0302291 0.05193102 2299     0.582102 0.5606
## Time13:00     0.0440910 0.01068110 2299     4.127942 0.0000
## Time13:10     0.0079978 0.05190255 2299     0.154093 0.8775
## Time13:30     0.1366679 0.15495487 2299     0.881985 0.3779
## Time13:35    -0.0090933 0.05251705 2299    -0.173150 0.8625
## Time13:45    -0.0234144 0.01816452 2299    -1.289018 0.1975
## Time14:00    -0.0137643 0.01335895 2299    -1.030342 0.3030
## Time14:10     0.0493933 0.05197013 2299     0.950417 0.3420
## Time14:30     0.0151222 0.01104435 2299     1.369224 0.1711
## Time14:40     0.0123579 0.04222039 2299     0.292700 0.7698
## Time14:45    -0.0122918 0.05244949 2299    -0.234356 0.8147
## Time14:55    -0.1577063 0.05198666 2299    -3.033591 0.0024
## Time15:00     0.3577479 0.11101883 2299     3.222407 0.0013
## Time15:30    -0.0273327 0.02578984 2299    -1.059826 0.2893
## Time15:40     0.0136882 0.06304744 2299     0.217109 0.8281

```

```

## Time16:00    0.0222482 0.03154951 2299    0.705184 0.4808
## Time17:00    0.0235731 0.02706411 2299    0.871011 0.3838
## Time17:30    0.0288402 0.03532119 2299    0.816512 0.4143
## Time7:00     0.0145674 0.02768560 2299    0.526172 0.5988
## Time8:00     0.0039653 0.01760935 2299    0.225184 0.8219
## Time8:30     0.0561900 0.04568885 2299    1.229841 0.2189
## Time9:00     0.0410820 0.01028772 2299    3.993309 0.0001
## Time9:30    -0.0023489 0.03037762 2299   -0.077323 0.9384
## Time9:45     0.0177516 0.05198141 2299    0.341499 0.7328
## Correlation:
##              (Intr) Yr2017 Yr2018 Yr2019 Yr2020 Pressr Thrmmmt Humdty Wind_V
## Year2017      -0.090
## Year2018      -0.095 0.911
## Year2019      -0.087 0.880 0.939
## Year2020      -0.046 0.950 0.918 0.880
## Pressure      -0.993 -0.006 -0.002 -0.009 -0.048
## Thermometer   -0.418 -0.010 -0.011 -0.018 -0.043 0.397
## Humidity      -0.353 -0.040 0.002 -0.011 -0.017 0.317 0.466
## Wind_V        -0.225 0.021 0.025 0.021 0.002 0.204 0.149 0.149
## NO2           0.126 0.012 0.046 0.025 0.060 -0.145 -0.148 0.151 0.084
## C             0.028 -0.003 -0.008 -0.016 -0.023 -0.037 0.049 -0.042 0.017
## Time10:30     -0.077 0.012 -0.115 -0.094 -0.121 0.051 0.058 -0.033 0.070
## Time11:00      0.053 0.006 -0.031 -0.018 -0.040 -0.058 -0.011 -0.085 -0.010
## Time11:30     -0.029 0.190 0.154 0.119 0.139 -0.002 0.013 -0.009 0.000
## Time11:50     -0.034 0.001 -0.034 -0.016 -0.022 0.029 -0.008 0.028 -0.014
## Time12:00     -0.079 0.005 -0.019 -0.017 -0.036 0.075 0.022 -0.015 0.022
## Time12:30     -0.052 -0.001 -0.038 -0.030 -0.070 0.046 -0.008 0.007 -0.051
## Time12:55      0.031 0.004 -0.030 -0.014 -0.016 -0.039 -0.022 0.012 0.023
## Time13:00     -0.081 -0.007 -0.104 -0.086 -0.114 0.059 0.041 0.016 -0.042
## Time13:10     -0.002 0.001 -0.035 -0.017 -0.022 -0.003 -0.009 0.015 -0.040
## Time13:30      0.012 0.001 -0.007 -0.005 -0.011 -0.014 0.005 -0.003 0.007
## Time13:35     -0.014 0.000 -0.042 -0.018 -0.026 0.012 0.007 0.004 -0.052
## Time13:45      0.029 -0.006 -0.122 -0.054 -0.073 -0.043 -0.006 0.083 0.037
## Time14:00     -0.012 -0.032 -0.027 -0.022 -0.029 -0.006 -0.004 0.032 -0.051
## Time14:10      0.043 0.000 -0.039 -0.017 -0.021 -0.047 -0.047 -0.048 0.005
## Time14:30     -0.061 0.032 -0.088 -0.074 -0.093 0.033 0.034 0.015 -0.033
## Time14:40      0.018 -0.001 -0.049 -0.021 -0.027 -0.023 -0.029 -0.010 0.027
## Time14:45      0.035 -0.002 -0.039 -0.016 -0.019 -0.038 -0.045 -0.003 -0.015
## Time14:55     -0.020 0.002 -0.031 -0.015 -0.018 0.014 -0.031 0.035 -0.029
## Time15:00      0.008 0.001 -0.010 -0.008 -0.018 -0.010 0.005 -0.017 -0.024
## Time15:30      0.030 0.009 -0.050 -0.045 -0.058 -0.037 0.026 -0.100 -0.061
## Time15:40      0.021 0.001 -0.017 -0.026 -0.016 -0.024 -0.032 -0.014 -0.043
## Time16:00     -0.020 0.117 0.107 0.085 0.103 0.006 -0.013 0.006 -0.035
## Time17:00     -0.006 0.115 0.085 0.065 0.071 -0.013 0.001 -0.013 -0.055
## Time17:30     -0.016 0.140 0.116 0.093 0.109 -0.002 -0.008 -0.010 -0.051
## Time7:00      -0.076 0.183 0.153 0.121 0.139 0.048 0.043 0.001 0.084
## Time8:00      -0.055 0.134 0.095 0.059 0.081 0.032 0.026 -0.043 0.102
## Time8:30      -0.009 0.003 -0.022 -0.023 -0.038 0.003 0.006 -0.006 0.027
## Time9:00      -0.091 -0.002 -0.104 -0.085 -0.116 0.067 0.051 -0.036 0.066
## Time9:30       0.017 0.007 -0.033 -0.046 -0.038 -0.024 -0.033 -0.039 -0.002
## Time9:45       0.000 0.003 -0.037 -0.016 -0.021 -0.004 -0.010 -0.016 -0.006
##              NO2      C      T10:30 T11:00 T11:30 T11:50 T12:00 T12:30 T12:55

```

```

## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V
## NO2
## C      -0.141
## Time10:30  0.046  0.063
## Time11:00  0.017 -0.079  0.218
## Time11:30  0.007  0.036  0.376  0.095
## Time11:50 -0.027 -0.029  0.160  0.042  0.065
## Time12:00  0.016 -0.008  0.182  0.049  0.077  0.030
## Time12:30 -0.076 -0.006  0.275  0.107  0.127  0.063  0.065
## Time12:55  0.049  0.010  0.168  0.045  0.068  0.047  0.028  0.052
## Time13:00 -0.105 -0.113  0.741  0.217  0.346  0.168  0.164  0.294  0.150
## Time13:10 -0.032  0.004  0.160  0.042  0.066  0.052  0.028  0.063  0.048
## Time13:30  0.006 -0.007  0.058  0.023  0.025  0.012  0.012  0.025  0.014
## Time13:35 -0.139 -0.012  0.147  0.041  0.061  0.044  0.029  0.070  0.030
## Time13:45 -0.188 -0.259  0.460  0.148  0.232  0.131  0.088  0.188  0.108
## Time14:00 -0.032 -0.005  0.441  0.119  0.254  0.095  0.091  0.166  0.089
## Time14:10 -0.017 -0.023  0.159  0.050  0.062  0.037  0.031  0.050  0.038
## Time14:30  0.005  0.042  0.799  0.209  0.421  0.164  0.174  0.281  0.163
## Time14:40 -0.032 -0.116  0.190  0.065  0.073  0.051  0.039  0.069  0.045
## Time14:45 -0.012 -0.137  0.144  0.054  0.056  0.043  0.029  0.053  0.036
## Time14:55  0.045 -0.012  0.162  0.041  0.066  0.052  0.031  0.059  0.051
## Time15:00  0.010 -0.012  0.083  0.028  0.039  0.016  0.019  0.034  0.016
## Time15:30 -0.041  0.029  0.362  0.107  0.166  0.064  0.096  0.127  0.065
## Time15:40 -0.019 -0.026  0.130  0.029  0.062  0.031  0.027  0.044  0.027
## Time16:00 -0.020 -0.154  0.117  0.053  0.091  0.041  0.030  0.060  0.030
## Time17:00 -0.025 -0.028  0.295  0.091  0.375  0.057  0.061  0.119  0.053
## Time17:30 -0.018 -0.127  0.211  0.069  0.353  0.046  0.047  0.084  0.037
## Time7:00   0.037 -0.027  0.297  0.078  0.456  0.050  0.067  0.094  0.053
## Time8:00   0.008 -0.064  0.350  0.110  0.193  0.074  0.083  0.125  0.076
## Time8:30  -0.002  0.006  0.196  0.070  0.088  0.038  0.044  0.092  0.039
## Time9:00  -0.022 -0.078  0.801  0.233  0.383  0.166  0.180  0.294  0.162
## Time9:30  -0.001 -0.068  0.288  0.076  0.132  0.058  0.071  0.093  0.057
## Time9:45  -0.054  0.014  0.161  0.044  0.064  0.039  0.032  0.060  0.036
##          T13:00 T13:10 T13:30 T13:35 T13:45 T14:00 T14:10 T14:30 T14:40
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V
## NO2
## C
## Time10:30

```

```

## Time11:00
## Time11:30
## Time11:50
## Time12:00
## Time12:30
## Time12:55
## Time13:00
## Time13:10      0.164
## Time13:30      0.055  0.012
## Time13:35      0.177  0.045  0.010
## Time13:45      0.530  0.123  0.037  0.152
## Time14:00      0.464  0.095  0.031  0.098  0.290
## Time14:10      0.158  0.037  0.011  0.040  0.128  0.093
## Time14:30      0.748  0.165  0.056  0.159  0.481  0.454  0.155
## Time14:40      0.210  0.047  0.015  0.054  0.191  0.111  0.054  0.188
## Time14:45      0.173  0.039  0.012  0.045  0.164  0.096  0.056  0.149  0.066
## Time14:55      0.157  0.051  0.012  0.034  0.108  0.093  0.035  0.166  0.044
## Time15:00      0.083  0.016  0.007  0.015  0.047  0.045  0.016  0.082  0.019
## Time15:30      0.336  0.068  0.026  0.073  0.201  0.191  0.072  0.355  0.083
## Time15:40      0.142  0.031  0.008  0.033  0.098  0.082  0.025  0.138  0.038
## Time16:00      0.174  0.037  0.011  0.044  0.118  0.109  0.039  0.131  0.058
## Time17:00      0.289  0.058  0.022  0.059  0.216  0.211  0.052  0.329  0.068
## Time17:30      0.243  0.044  0.016  0.048  0.173  0.149  0.042  0.259  0.063
## Time7:00       0.282  0.047  0.021  0.041  0.166  0.178  0.048  0.335  0.062
## Time8:00       0.360  0.069  0.028  0.069  0.202  0.215  0.079  0.338  0.098
## Time8:30       0.189  0.038  0.017  0.035  0.113  0.107  0.036  0.190  0.046
## Time9:00       0.802  0.161  0.059  0.163  0.520  0.476  0.165  0.786  0.212
## Time9:30       0.293  0.057  0.020  0.059  0.197  0.162  0.056  0.289  0.078
## Time9:45       0.162  0.040  0.011  0.060  0.124  0.093  0.040  0.160  0.049
## T14:45 T14:55 T15:00 T15:30 T15:40 T16:00 T17:00 T17:30 Tm7:00
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V
## NO2
## C
## Time10:30
## Time11:00
## Time11:30
## Time11:50
## Time12:00
## Time12:30
## Time12:55
## Time13:00
## Time13:10
## Time13:30
## Time13:35
## Time13:45

```

```

## Time14:00
## Time14:10
## Time14:30
## Time14:40
## Time14:45
## Time14:55      0.038
## Time15:00      0.017  0.017
## Time15:30      0.065  0.062  0.041
## Time15:40      0.029  0.029  0.014  0.063
## Time16:00      0.058  0.036  0.016  0.057  0.032
## Time17:00      0.055  0.055  0.032  0.133  0.052  0.080
## Time17:30      0.057  0.042  0.028  0.105  0.046  0.086  0.174
## Time7:00       0.047  0.050  0.032  0.132  0.046  0.080  0.209  0.483
## Time8:00       0.080  0.070  0.035  0.153  0.064  0.239  0.148  0.127  0.171
## Time8:30       0.034  0.037  0.022  0.087  0.029  0.035  0.075  0.052  0.071
## Time9:00       0.168  0.160  0.088  0.355  0.140  0.157  0.309  0.246  0.316
## Time9:30       0.062  0.056  0.031  0.139  0.077  0.063  0.107  0.093  0.108
## Time9:45       0.038  0.035  0.016  0.073  0.029  0.035  0.055  0.040  0.048
##              Tm8:00 Tm8:30 Tm9:00 Tm9:30
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V
## NO2
## C
## Time10:30
## Time11:00
## Time11:30
## Time11:50
## Time12:00
## Time12:30
## Time12:55
## Time13:00
## Time13:10
## Time13:30
## Time13:35
## Time13:45
## Time14:00
## Time14:10
## Time14:30
## Time14:40
## Time14:45
## Time14:55
## Time15:00
## Time15:30
## Time15:40
## Time16:00
## Time17:00

```

```

## Time17:30
## Time7:00
## Time8:00
## Time8:30      0.093
## Time9:00      0.379  0.202
## Time9:30      0.141  0.067  0.304
## Time9:45      0.075  0.037  0.164  0.059
##
## Standardized Within-Group Residuals:
##      Min      Q1      Med      Q3      Max
## -2.2567804 -0.6178179 -0.1126822  0.4623917  6.9002731
##
## Number of Observations: 2349
## Number of Groups: 10

#Диагностика модели (анализ остатков)
mod2_2_diag <- data.frame(
  data,
  .fitted = fitted(mod2_2),
  .resid = resid(mod2_2, type = 'pearson'),
  .sresid = resid(mod2_2, type = 'pearson', scaled = TRUE)
)

#.fitted - предсказанные значения,
#.resid - Пирсоновские остатки,
#.sresid - стандартизованные Пирсоновские остатки

head(mod2_2_diag, 4)

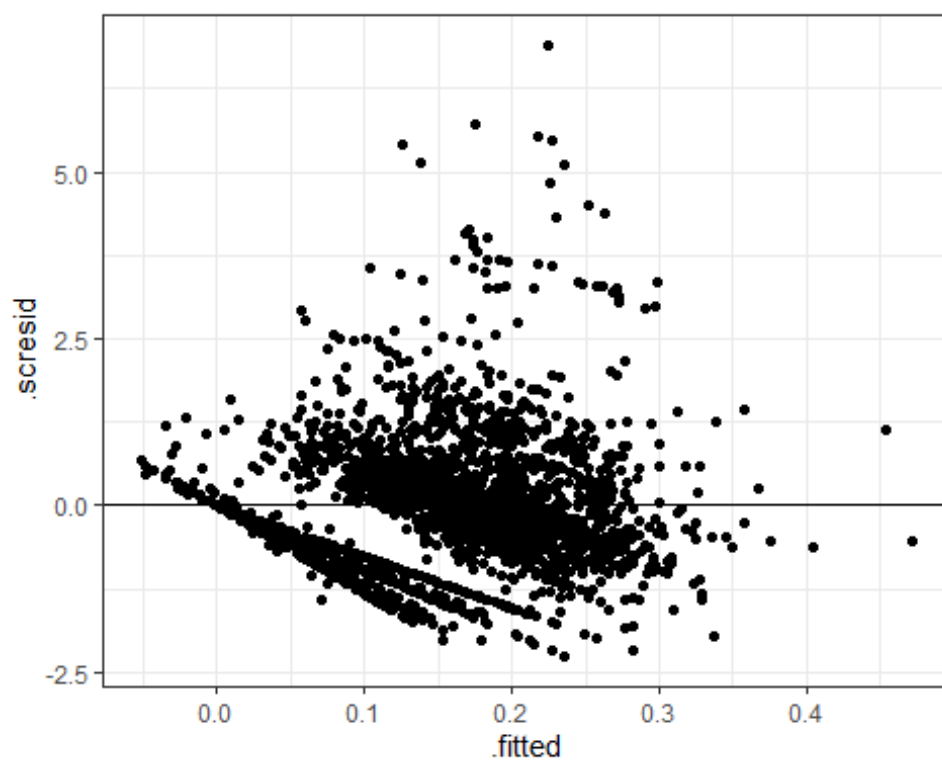
##   Year Point abs_risk_450 abs_risk_451 abs_risk_458 abs_risk      Date Time
## 1 2016     1          NA          NA          NA          NA 26.04.2016 7:00
## 2 2016     1          NA          NA          NA          NA 27.04.2016 7:00
## 3 2016     1          NA          NA          NA          NA 28.04.2016 7:00
## 4 2016    13          NA          NA          NA          NA 16.05.2016 7:00
##   Time2 Daytime Thermometer Pressure Humidity      Wind Wind_V Weather  TSP
## 1     7 morning          6       740       73 south west     4 cloudy 0.114
## 2     7 morning          6       758       58    east     3  clear 0.189
## 3     7 morning         10       758       43    east     4  clear 0.305
## 4     7 morning         15       745       61  south     1 cloudy 0.000
##   TSPn PM10 PM10n PM2.5 PM2.5n NO2 NO2n  C  Cn  .fitted  .resid
## 1  0.5 0.075  0.3 0.036  0.16 0.065  0.2 0.10 0.15 0.14168046 -0.5481230
## 2  0.5 0.124  0.3 0.059  0.16 0.071  0.2 0.10 0.15 0.23931596 -0.9963468
## 3  0.5 0.203  0.3 0.077  0.16 0.077  0.2 0.10 0.15 0.28436081  0.4086933
## 4  0.5 0.000  0.3 0.000  0.16 0.062  0.2 0.11 0.15 0.07170235 -1.4198360
##   .sresid
## 1 -0.5481230
## 2 -0.9963468
## 3  0.4086933
## 4 -1.4198360

#График остатков от предсказанных значений
gg_resid <- ggplot(mod2_2_diag, aes(y = .sresid)) +

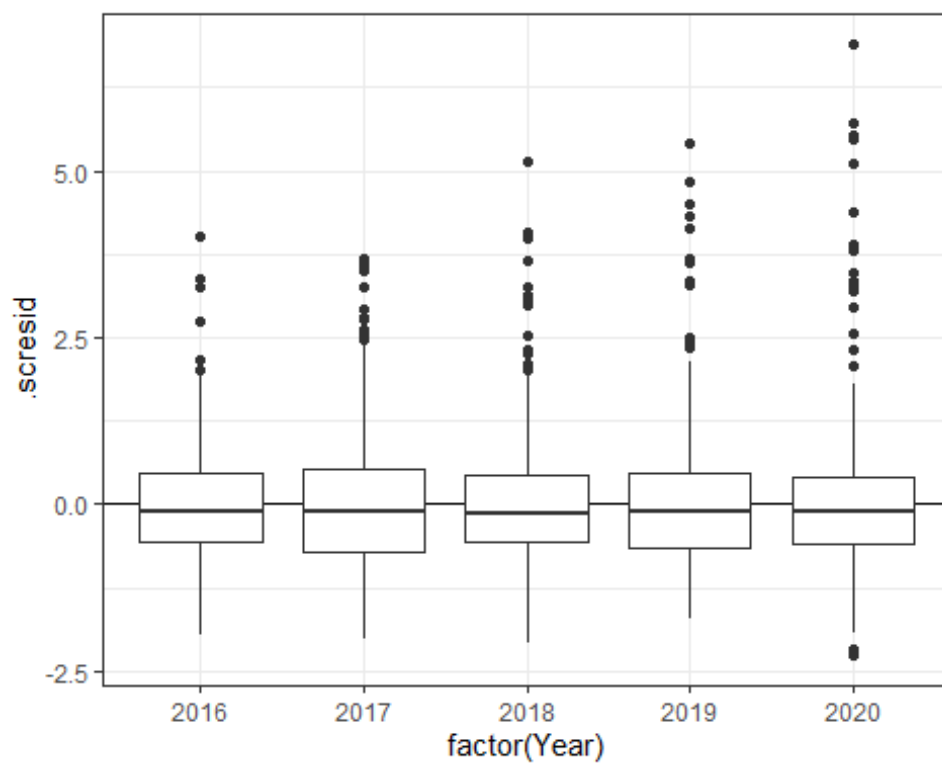
```



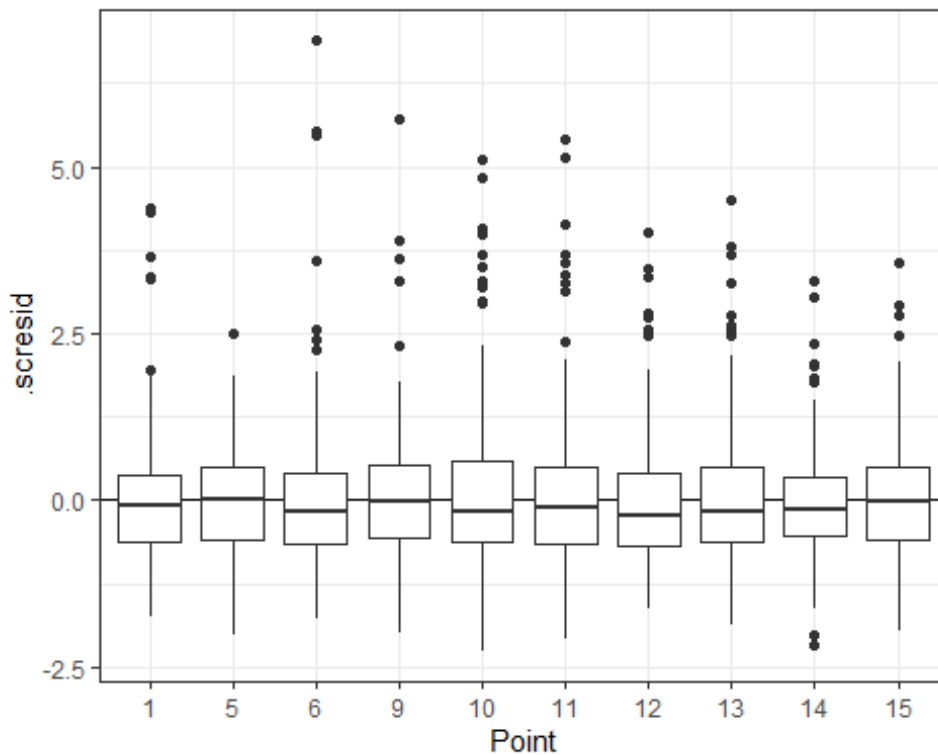
```
geom_hline(yintercept = 0)  
gg_resid + geom_point(aes(x = .fitted))
```



```
gg_resid + geom_boxplot(aes(x = factor(Year)))
```



```
gg_resid + geom_boxplot(aes(x = Point))
```



```
#Ковариата - непрерывный фактор
#mod2_3 <- update(mod2_2, weights = varPower(form = ~ Pressure))
#mod2_3 <- update(mod2_2, weights = varPower(form = ~ Thermometer))
#mod2_4 <- update(mod2, weights = varPower(form = ~ Humidity))
#mod4_5 <- update(mod4, weights = varPower(form = ~ Wind_V))
#mod2_6 <- update(mod2, weights = varPower(form = ~ NO2))
#mod4_7 <- update(mod4, weights = varPower(form = ~ C))
#При запуске этих команд появляется следующая ошибка: Error in optim(c(oldPars),
function(lmePars) -logLik(lmeSt, lmePars), : non-finite finite-difference value
[16]
```

```
AICs <- as.data.frame(AIC(mod2, mod2_1, mod2_2))
AICs[which.min(AICs$AIC), ]
```

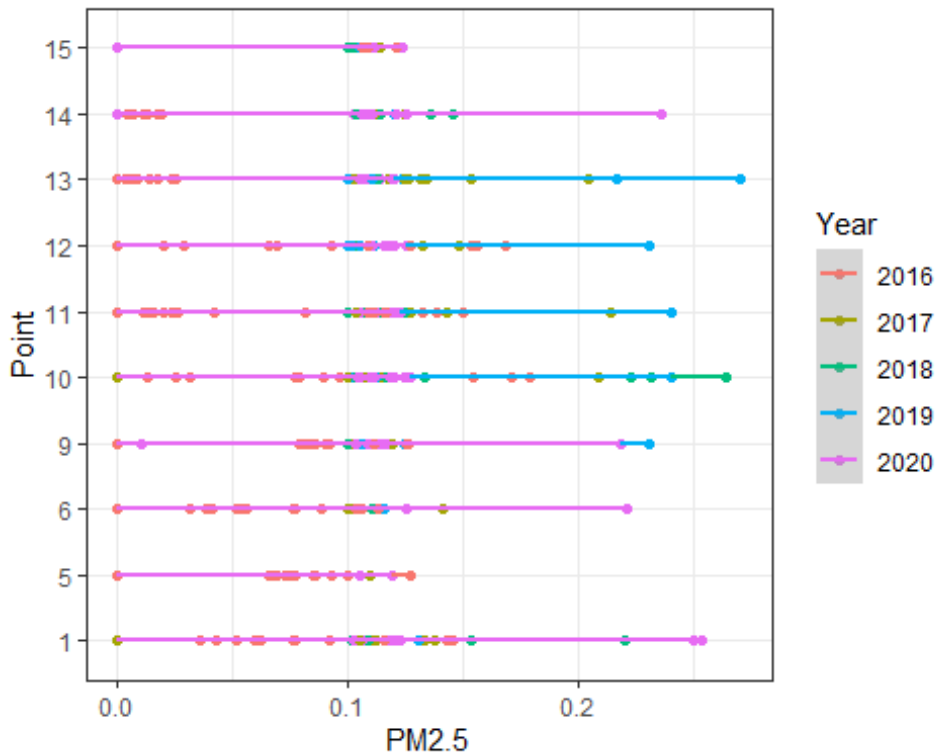
```
##          df          AIC
## mod2_2 87 -3598.233
```

```
summary(mod2_2)$call
```

```
## lme.formula(fixed = TSP ~ Year + Pressure + Thermometer + Humidity +
##           Wind_V + NO2 + C + Time, data = data, random = ~1 + Year |
##           Point, weights = varIdent(form = ~1 | Time), control = ctrl)
```

```
#PM2.5
```

```
ggplot(data, aes(x = PM2.5, y = Point, color = Year)) +
  geom_point() +
  geom_smooth(se = TRUE, method = "lm", size = 1)
```



*#Нет ли коллинеарности дискретных и непрерывных предикторов?*

```
mod1 <- lm(PM2.5 ~ Pressure * Thermometer * Humidity * Wind_V * NO2 * C, data = data)
Anova(mod1)
```

```
## Anova Table (Type II tests)
```

```
##
```

```
## Response: PM2.5
```

```
##
```

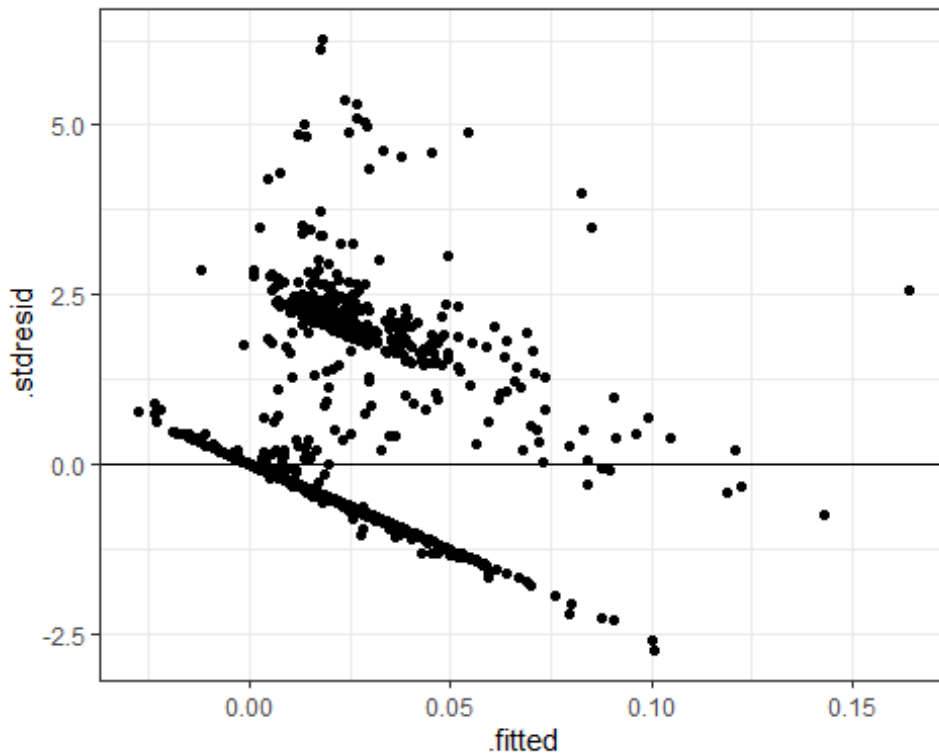
	Sum Sq	Df	F value	Pr(>F)	
## Pressure	0.0566	2	17.4249	3.088e-08	***
## Thermometer	0.0553	12	2.8363	0.0007100	***
## Humidity	0.1295	10	7.9736	9.816e-13	***
## Wind_V	0.0979	13	4.6375	6.071e-08	***
## NO2	0.0580	12	2.9773	0.0003856	***
## C	0.0563	12	2.8876	0.0005692	***
## Pressure:Thermometer	0.0003	1	0.1852	0.6669856	
## Pressure:Humidity	0.0056	1	3.4474	0.0634793	.
## Thermometer:Humidity	0.0270	5	3.3226	0.0054055	**
## Pressure:Wind_V	0.0114	1	7.0197	0.0081172	**
## Thermometer:Wind_V	0.0054	6	0.5569	0.7648963	
## Humidity:Wind_V	0.0349	5	4.2948	0.0006841	***
## Pressure:NO2	0.0009	1	0.5780	0.4471598	
## Thermometer:NO2	0.0188	6	1.9283	0.0727738	.
## Humidity:NO2	0.0082	5	1.0142	0.4075507	
## Wind_V:NO2	0.0046	6	0.4672	0.8330326	
## Pressure:C	0.0006	1	0.3487	0.5549031	
## Thermometer:C	0.0180	5	2.2150	0.0502925	.
## Humidity:C	0.0313	5	3.8534	0.0017650	**
## Wind_V:C	0.0216	6	2.2117	0.0393315	*

```

## N02:C 0.0199 5 2.4549 0.0315191 *
## Pressure:Thermometer:Humidity 0.0027 1 1.6837 0.1945633
## Pressure:Thermometer:Wind_V 0.0014 1 0.8536 0.3556247
## Pressure:Humidity:Wind_V 0.0127 1 7.8123 0.0052327 **
## Thermometer:Humidity:Wind_V 0.0116 3 2.3740 0.0684009 .
## Pressure:Thermometer:N02 0.0007 1 0.4301 0.5120291
## Pressure:Humidity:N02 0.0001 1 0.0607 0.8054116
## Thermometer:Humidity:N02 0.0034 3 0.6956 0.5547048
## Pressure:Wind_V:N02 0.0055 1 3.3844 0.0659458 .
## Thermometer:Wind_V:N02 0.0014 3 0.2873 0.8345690
## Humidity:Wind_V:N02 0.0078 3 1.5983 0.1877607
## Pressure:Thermometer:C 0.0002 1 0.1340 0.7143159
## Pressure:Humidity:C 0.0003 1 0.2141 0.6436308
## Thermometer:Humidity:C 0.0121 2 3.7407 0.0238827 *
## Pressure:Wind_V:C 0.0097 1 5.9728 0.0146037 *
## Thermometer:Wind_V:C 0.0133 3 2.7346 0.0422260 *
## Humidity:Wind_V:C 0.0042 2 1.2817 0.2777686
## Pressure:N02:C 0.0005 1 0.3289 0.5663816
## Thermometer:N02:C 0.0137 3 2.8078 0.0382622 *
## Humidity:N02:C 0.0171 2 5.2662 0.0052261 **
## Wind_V:N02:C 0.0012 3 0.2474 0.8632235
## Pressure:Thermometer:Humidity:Wind_V 0.0128 1 7.8846 0.0050280 **
## Pressure:Thermometer:Humidity:N02 0.0029 1 1.7905 0.1809941
## Pressure:Thermometer:Wind_V:N02 0.0059 1 3.6538 0.0560679 .
## Pressure:Humidity:Wind_V:N02 0.0020 1 1.2337 0.2668080
## Thermometer:Humidity:Wind_V:N02 0.0117 2 3.5897 0.0277626 *
## Pressure:Thermometer:Humidity:C 0.0001 1 0.0500 0.8230079
## Pressure:Thermometer:Wind_V:C 0.0008 1 0.5107 0.4748971
## Pressure:Humidity:Wind_V:C 0.0000 1 0.0002 0.9895576
## Thermometer:Humidity:Wind_V:C 0.0130 2 3.9923 0.0185860 *
## Pressure:Thermometer:N02:C 0.0000 1 0.0007 0.9783026
## Pressure:Humidity:N02:C 0.0047 1 2.8790 0.0898779 .
## Thermometer:Humidity:N02:C 0.0115 2 3.5373 0.0292517 *
## Pressure:Wind_V:N02:C 0.0004 1 0.2753 0.5998603
## Thermometer:Wind_V:N02:C 0.0110 2 3.3806 0.0341987 *
## Humidity:Wind_V:N02:C 0.0014 1 0.8594 0.3539987
## Pressure:Thermometer:Humidity:Wind_V:N02 0.0010 1 0.6408 0.4234997
## Pressure:Thermometer:Humidity:Wind_V:C 0.0005 1 0.2790 0.5974244
## Pressure:Thermometer:Humidity:N02:C 0.0012 1 0.7524 0.3858201
## Pressure:Thermometer:Wind_V:N02:C 0.0036 1 2.1860 0.1394040
## Pressure:Humidity:Wind_V:N02:C 0.0019 1 1.1595 0.2816785
## Thermometer:Humidity:Wind_V:N02:C 0.0091 1 5.5860 0.0181874 *
## Pressure:Thermometer:Humidity:Wind_V:N02:C 0.0014 1 0.8491 0.3568981
## Residuals 3.7108 2285
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

mod1_diag <- fortify(mod1)
ggplot(mod1_diag, aes(x = .fitted, y = .stdresid)) +
  geom_point() +
  geom_hline(yintercept = 0)

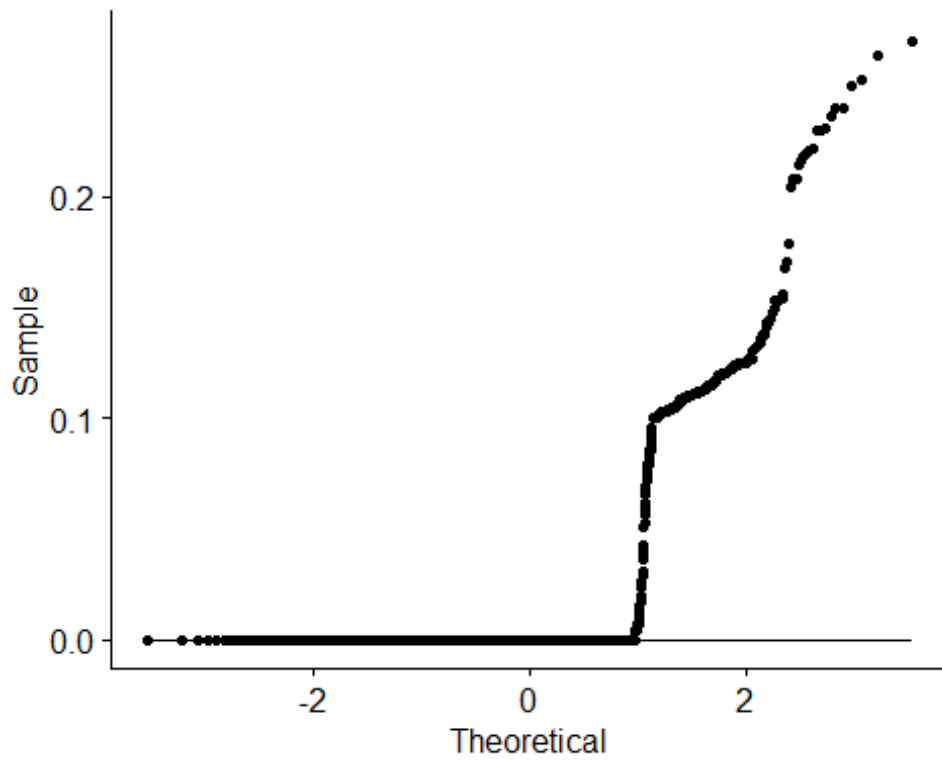
```



*#Присутствуют признаки гетероскедастичности*

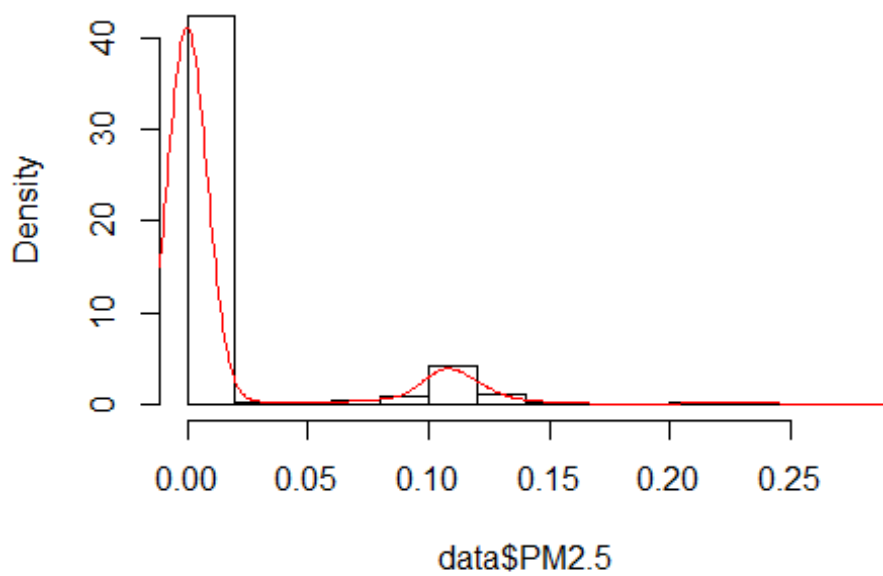
*#Наличие гетероскедастичности - нарушение условий применимости моделей, основанных на нормальном распределении отклика. Возможные пути решения: преобразовать зависимую переменную (Log), использовать более сложную модель, ввести ковариату дисперсии*

```
ggqqplot(data$PM2.5)
```

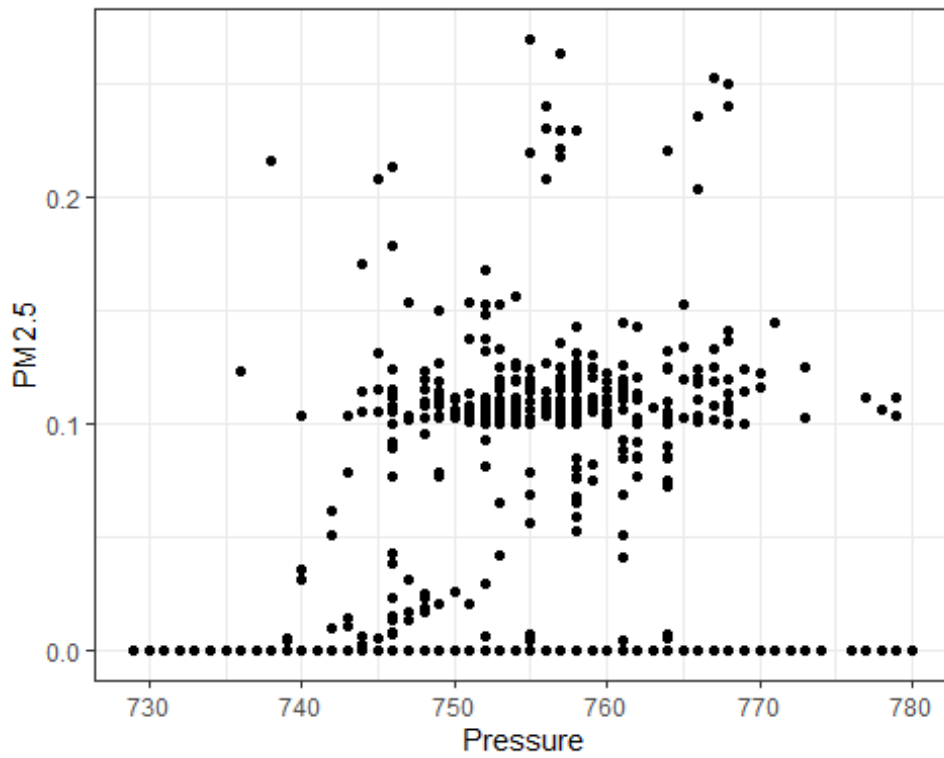


```
hist(data$PM2.5,probability=T)
lines(density(data$PM2.5),col=2)
```

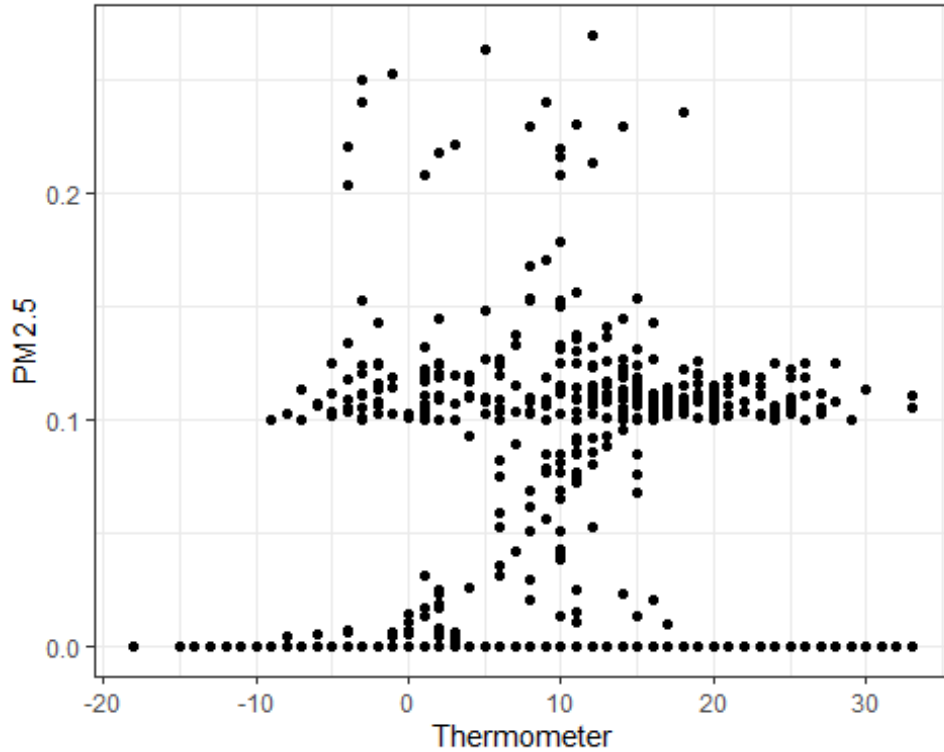
### Histogram of data\$PM2.5



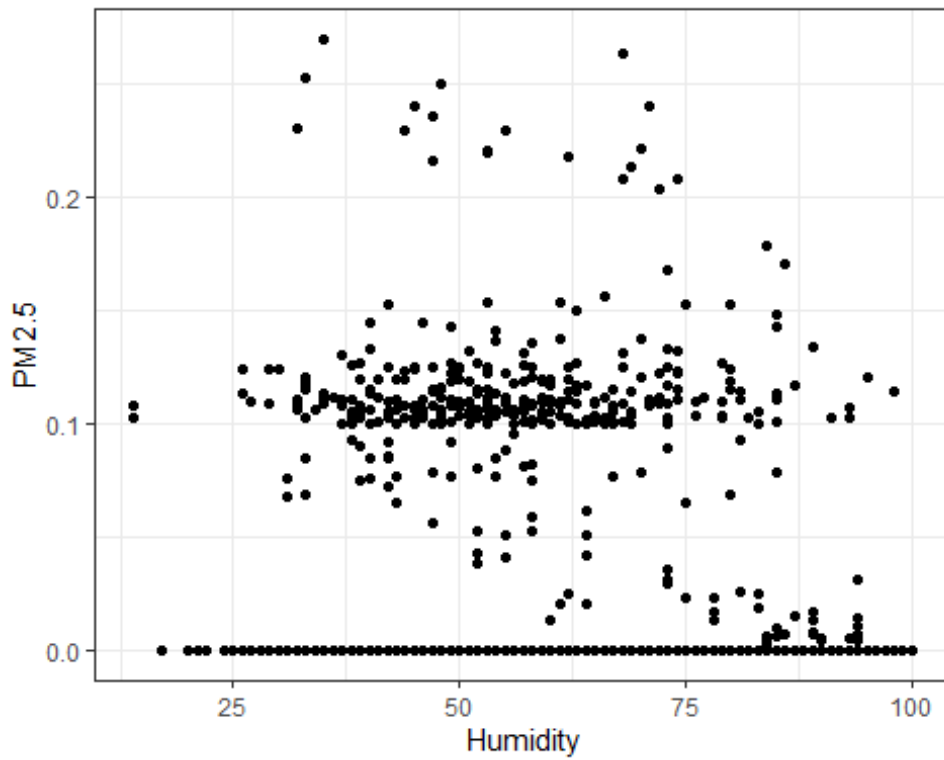
```
ggplot(data, aes(x = Pressure, y = PM2.5)) +
  geom_point()
```



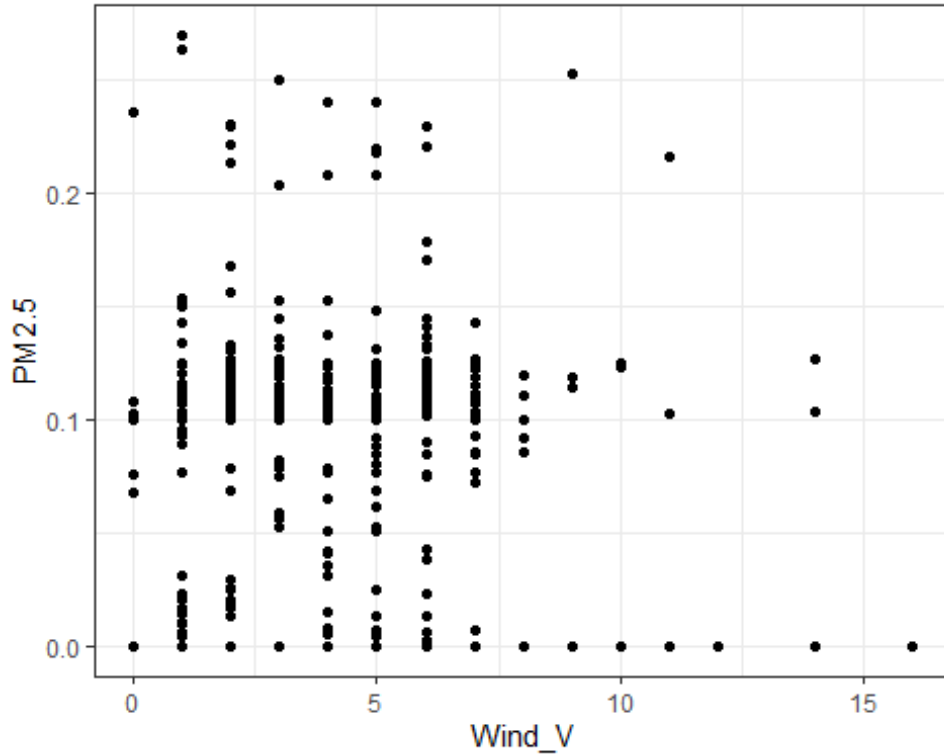
```
ggplot(data, aes(x = Thermometer, y = PM2.5)) +  
  geom_point()
```



```
ggplot(data, aes(x = Humidity, y = PM2.5)) +  
  geom_point()
```

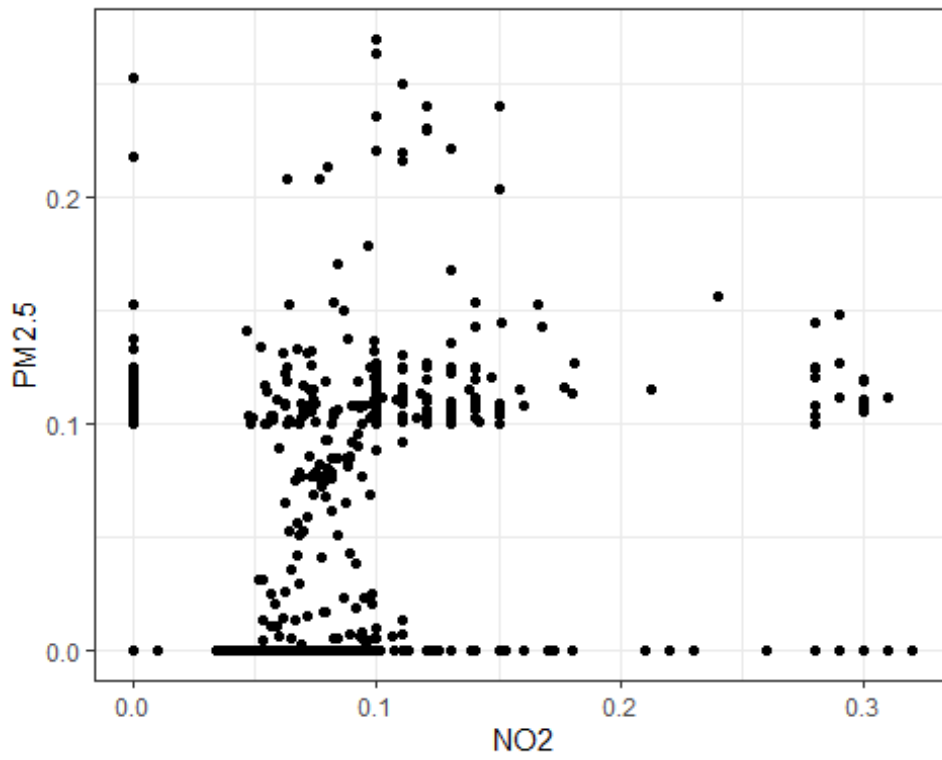


```
ggplot(data, aes(x = Wind_V, y = PM2.5)) +  
  geom_point()
```

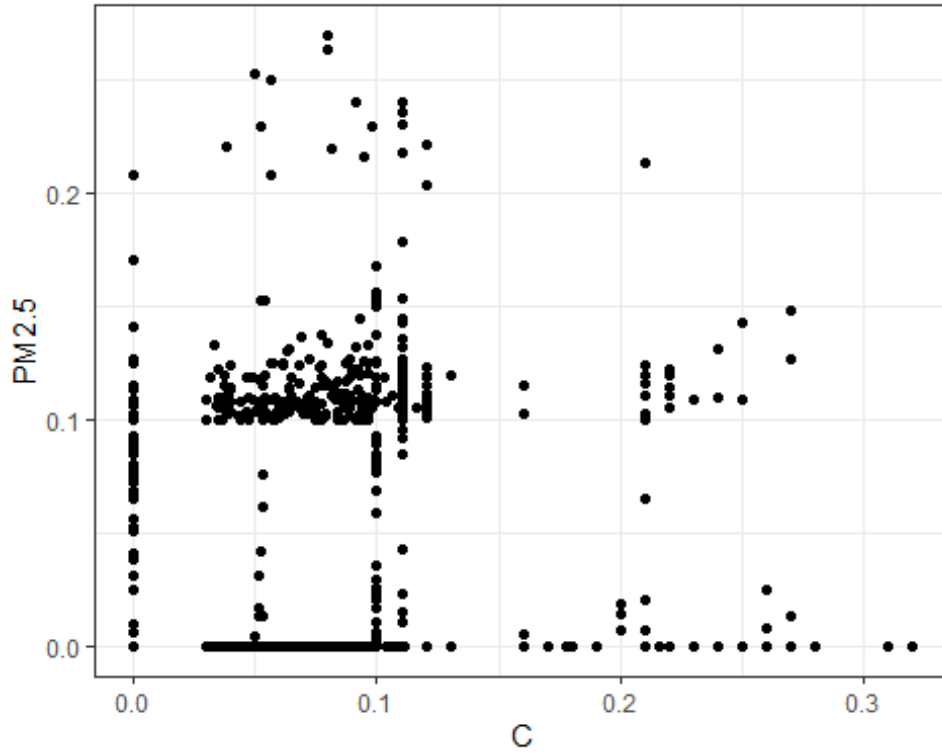


```
ggplot(data, aes(x = NO2, y = PM2.5)) +  
  geom_point()
```

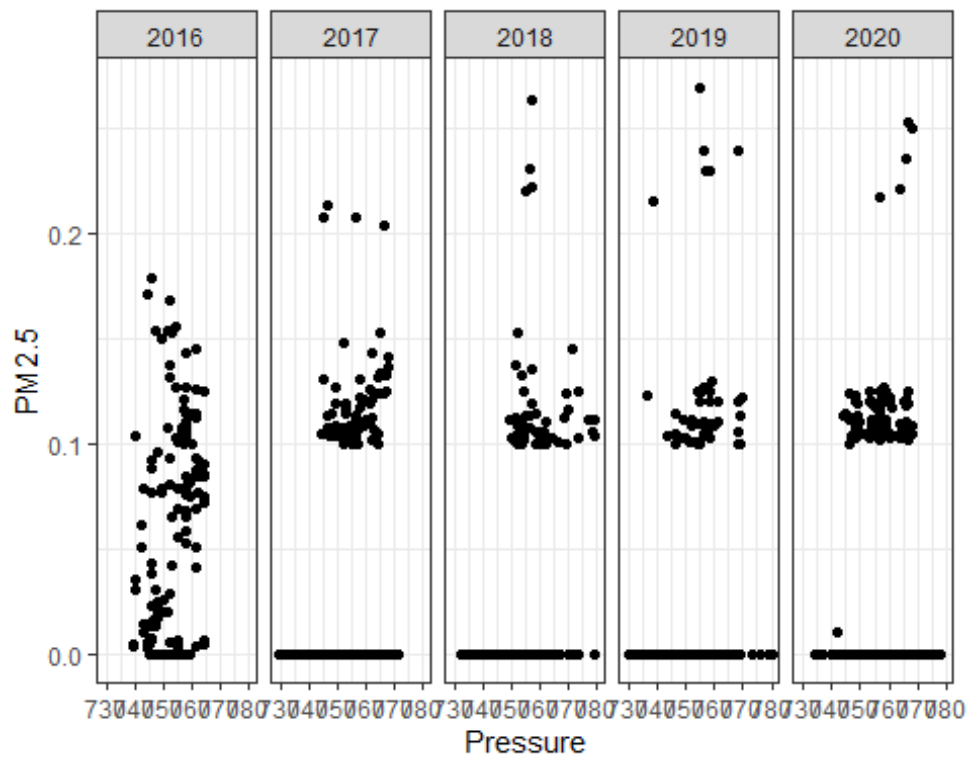




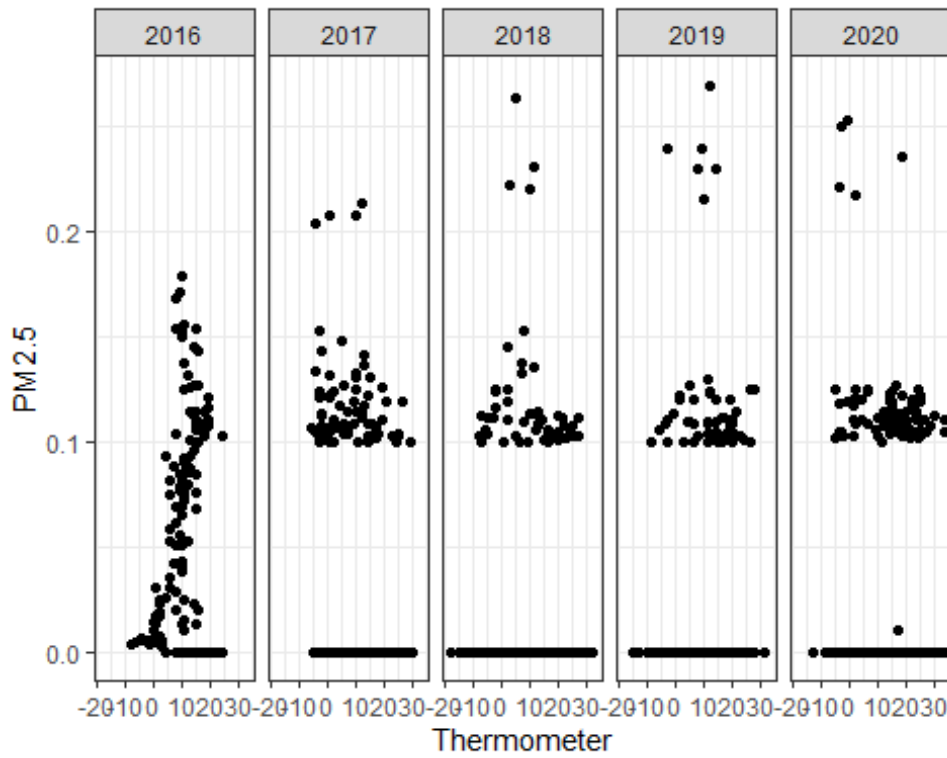
```
ggplot(data, aes(x = C, y = PM2.5)) +  
  geom_point()
```



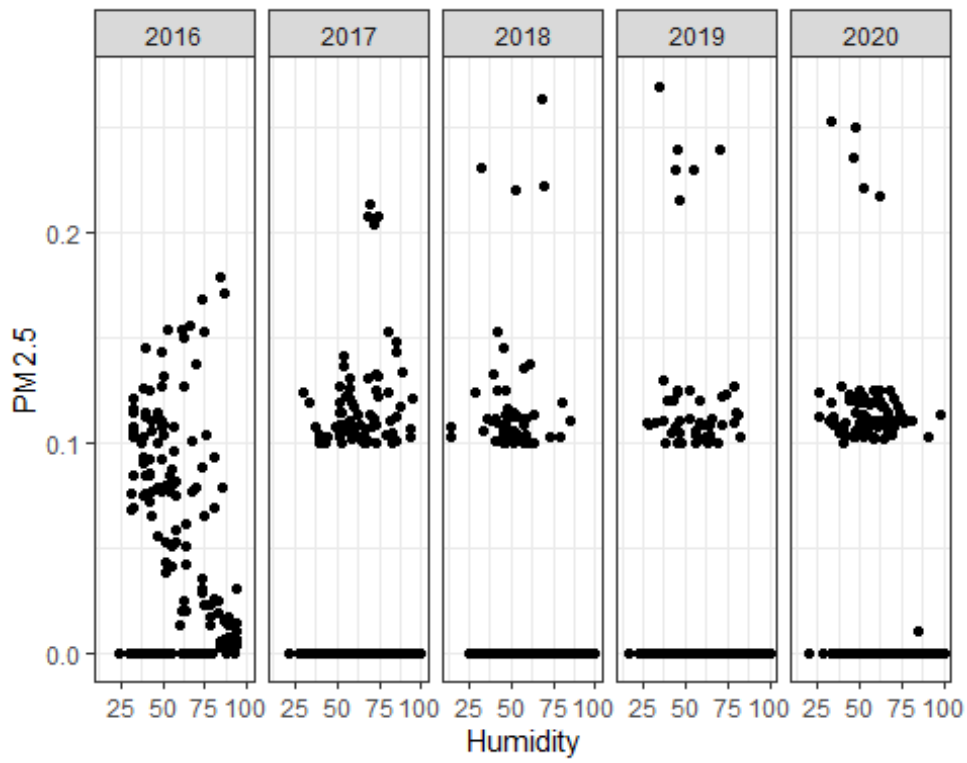
```
ggplot(data, aes(x = Pressure, y = PM2.5)) +
  geom_point() +
  facet_grid(~ Year)
```



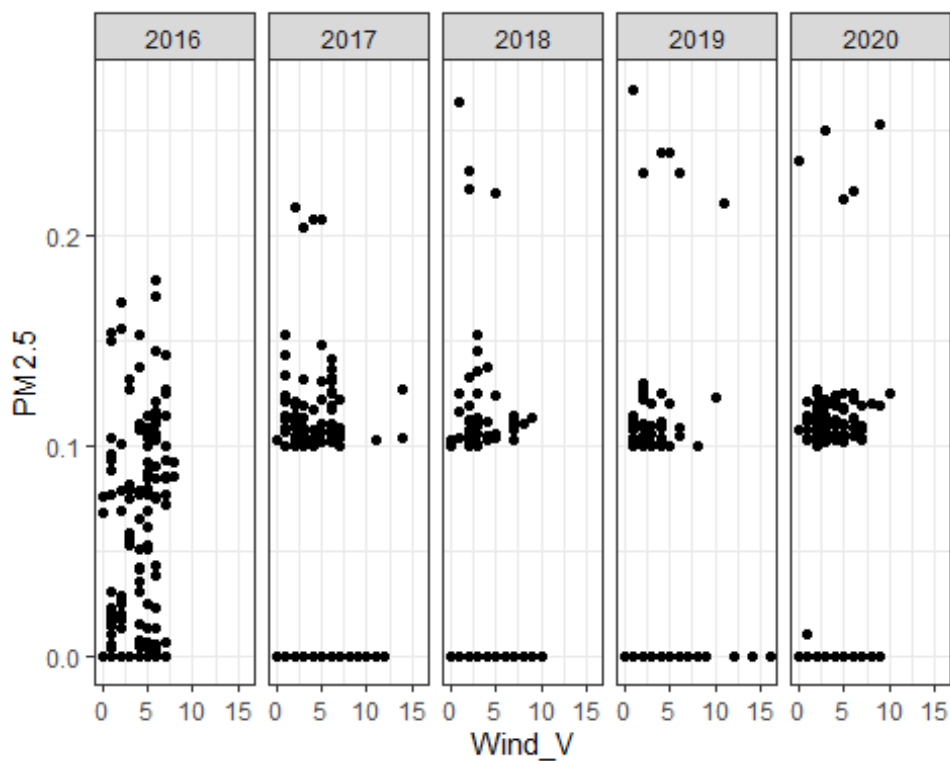
```
ggplot(data, aes(x = Thermometer, y = PM2.5)) +
  geom_point() +
  facet_grid(~ Year)
```



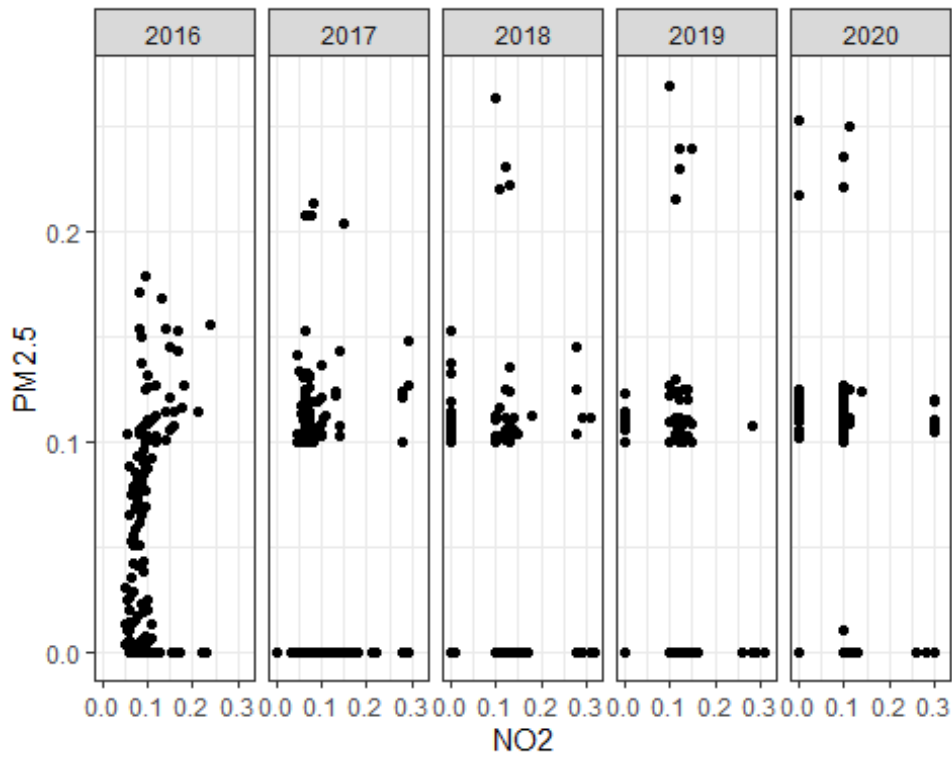
```
ggplot(data, aes(x = Humidity, y = PM2.5)) +  
  geom_point() +  
  facet_grid(~ Year)
```



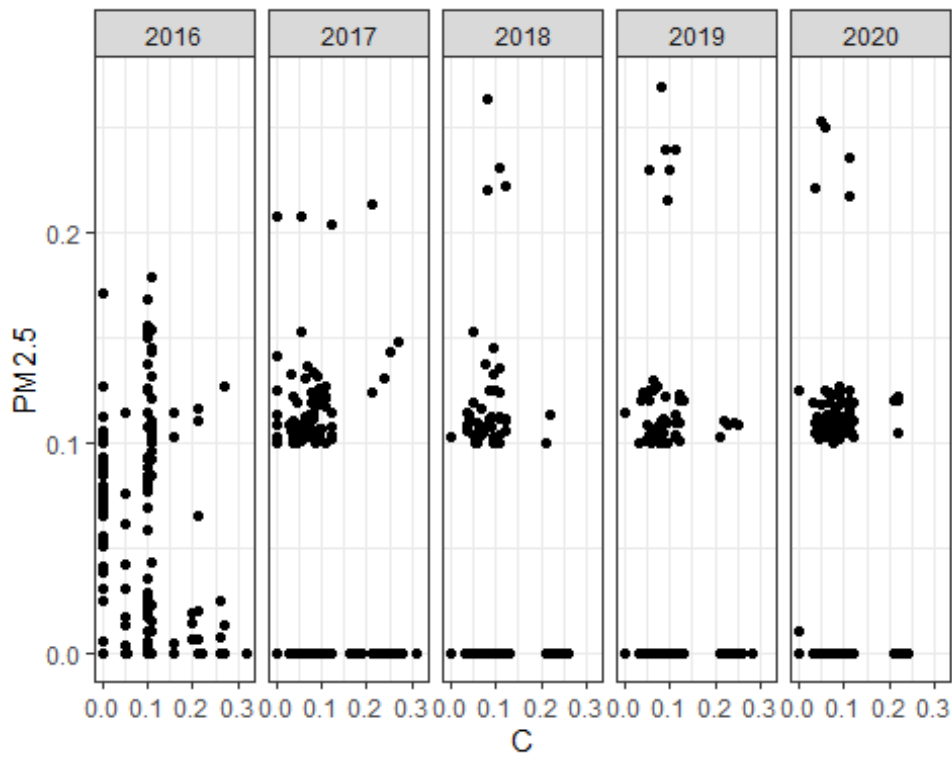
```
ggplot(data, aes(x = Wind_V, y = PM2.5)) +
  geom_point() +
  facet_grid( ~ Year)
```



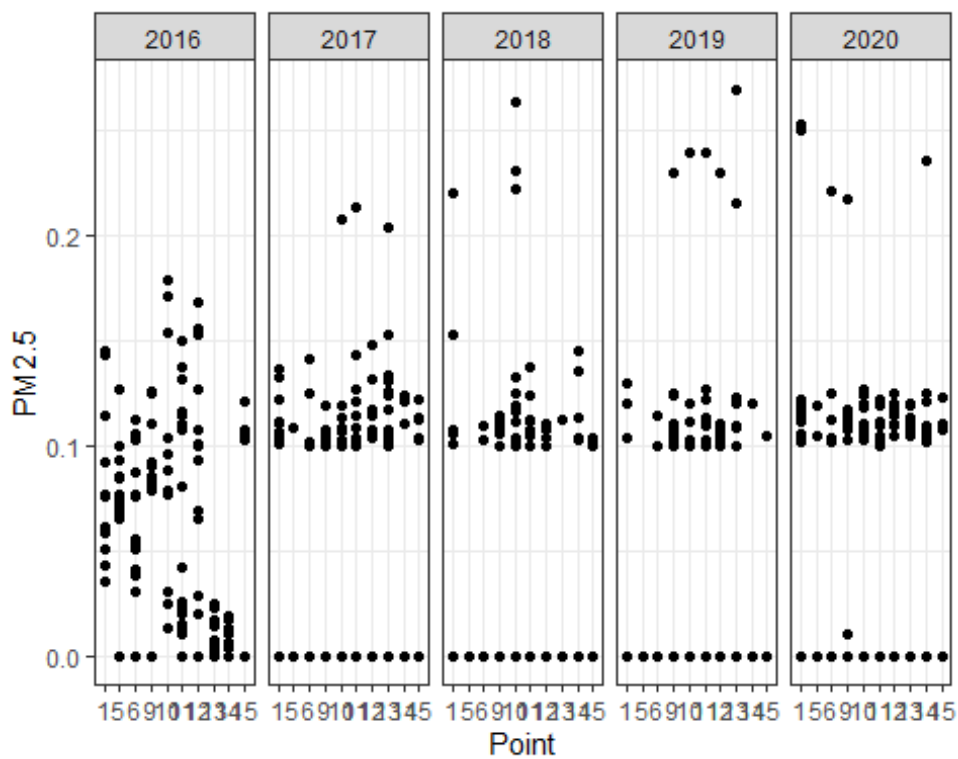
```
ggplot(data, aes(x = NO2, y = PM2.5)) +
  geom_point() +
  facet_grid( ~ Year)
```



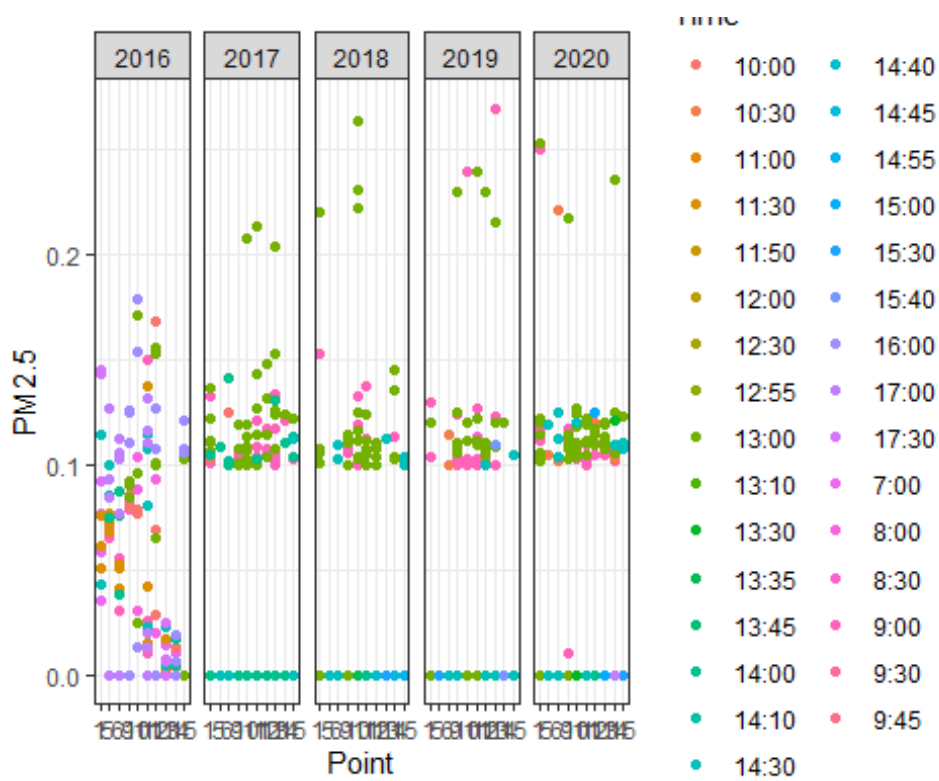
```
ggplot(data, aes(x = C, y = PM2.5)) +  
  geom_point() +  
  facet_grid(~ Year)
```



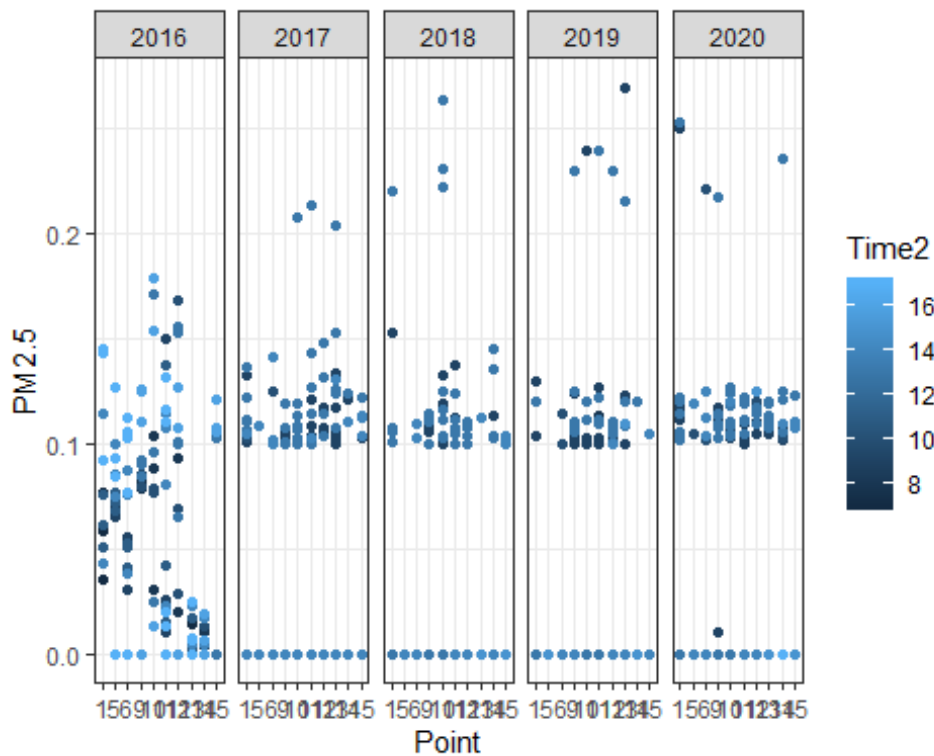
```
ggplot(data, aes(x = Point, y = PM2.5)) +  
  geom_point() +  
  facet_grid( ~ Year)
```



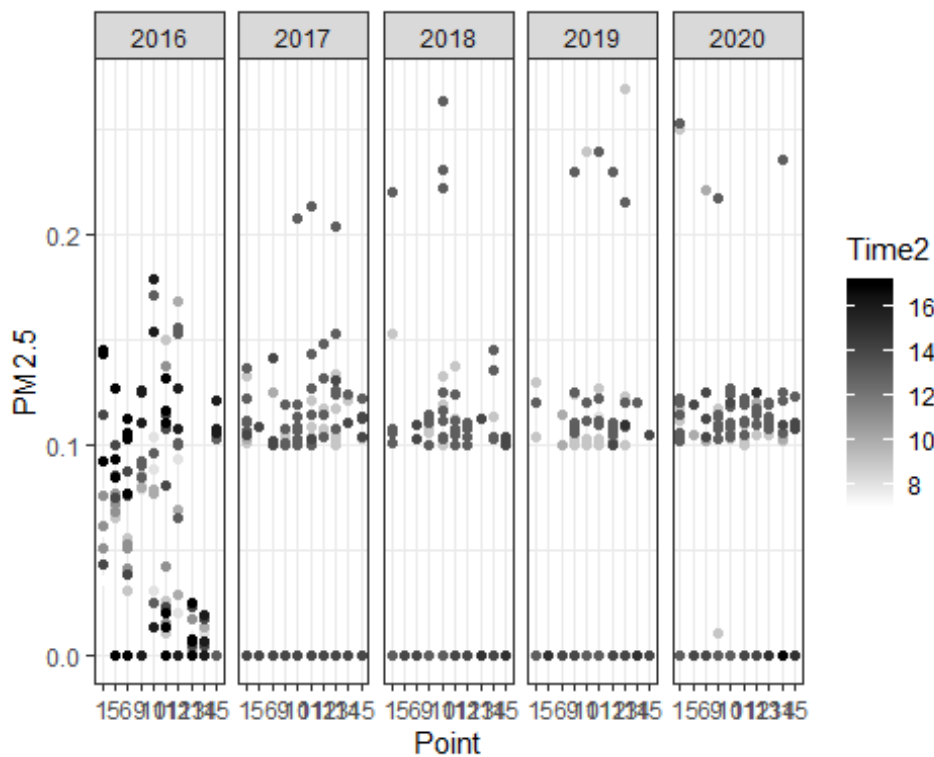
```
ggplot(data, aes(x = Point, y = PM2.5, colour = Time)) +  
  geom_point() +  
  facet_grid( ~ Year)
```



```
ggplot(data, aes(x = Point, y = PM2.5, colour = Time2)) +
  geom_point() +
  facet_grid( ~ Year) +
  scale_color_continuous(breaks = c(8, 10, 12, 14, 16))
```

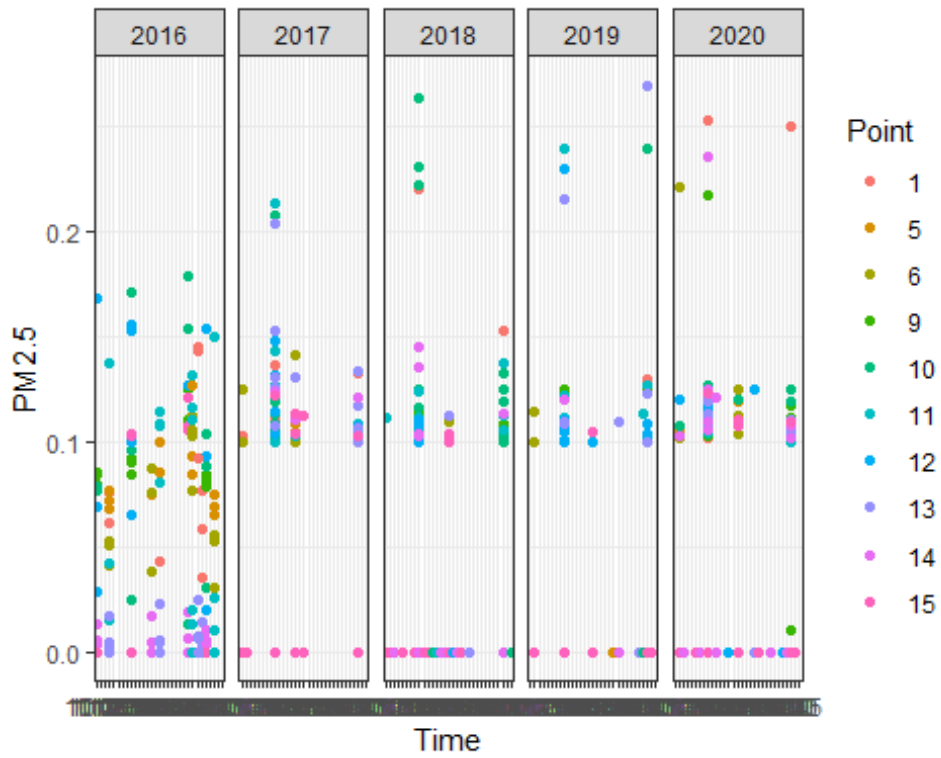


```
ggplot(data, aes(x = Point, y = PM2.5, colour = Time2)) +
  geom_point() +
  facet_grid( ~ Year) +
  scale_color_gradient(low = 'white', high = 'black', breaks = c(8, 10, 12, 14,
16))
```

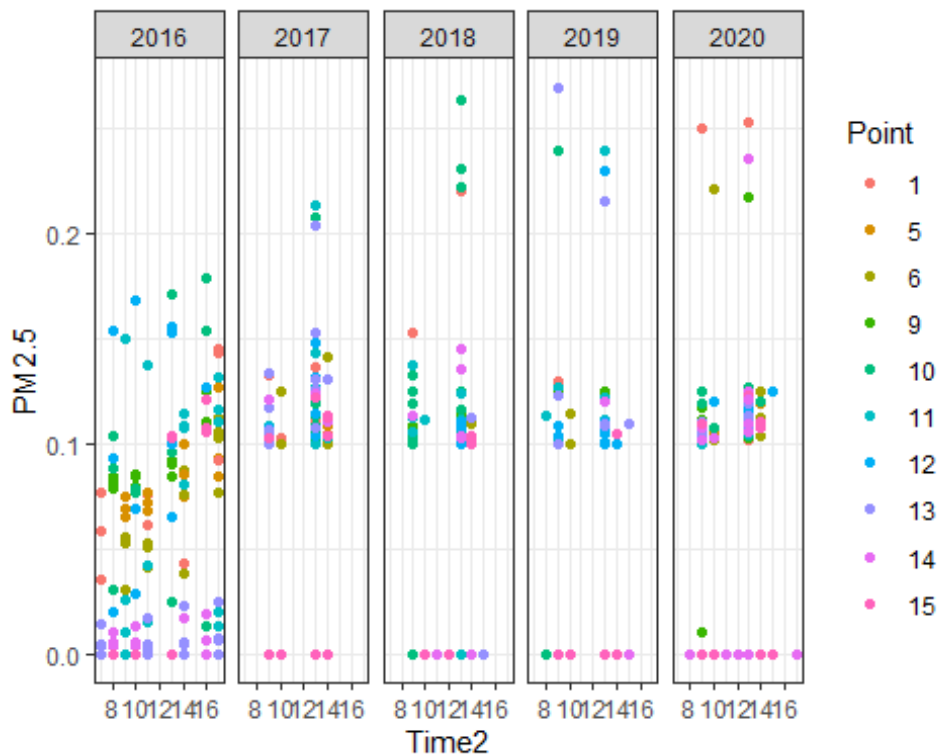


```
ggplot(data, aes(x = Time, y = PM2.5, colour = Point)) +
  geom_point() +
  facet_grid( ~ Year)
```





```
ggplot(data, aes(x = Time2, y = PM2.5, colour = Point)) +
  geom_point() +
  scale_x_continuous(breaks = c(8, 10, 12, 14, 16)) +
  facet_grid( ~ Year)
```



```

mod1 <- lmer(PM2.5 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 + C
+ Daytime + (1 + Year|Point/Daytime), data = data)

## boundary (singular) fit: see ?isSingular

summary(mod1)

## Linear mixed model fit by REML ['lmerMod']
## Formula: PM2.5 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 +
##       C + Daytime + (1 + Year | Point/Daytime)
##       Data: data
##
## REML criterion at convergence: -8351.3
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.1878 -0.5243 -0.2747  0.0406  6.1882
##
## Random effects:
##      Groups             Name             Variance  Std.Dev.  Corr
##      Daytime:Point (Intercept) 2.315e-05  0.004811
##                      Year2017  4.968e-06  0.002229  -0.99
##                      Year2018  3.752e-06  0.001937  -0.98  1.00
##                      Year2019  5.932e-05  0.007702  -1.00  0.97  0.96
##                      Year2020  2.709e-06  0.001646  -0.93  0.98  0.99  0.89
##      Point              (Intercept) 7.361e-04  0.027130
##                      Year2017  6.138e-04  0.024775  -0.97
##                      Year2018  3.626e-04  0.019041  -0.99  0.98
##                      Year2019  7.477e-04  0.027344  -0.96  1.00  0.97
##                      Year2020  4.838e-04  0.021995  -0.97  0.99  0.99  0.98
##      Residual                    1.545e-03  0.039306
## Number of obs: 2349, groups:  Daytime:Point, 30; Point, 10
##
## Fixed effects:
##              Estimate Std. Error t value
## (Intercept)  -5.026e-01  9.570e-02  -5.251
## Year2017      -2.577e-02  8.644e-03  -2.981
## Year2018      -3.025e-02  7.037e-03  -4.299
## Year2019      -3.007e-02  9.507e-03  -3.163
## Year2020      -2.428e-02  7.847e-03  -3.094
## Pressure       7.471e-04  1.242e-04   6.014
## Thermometer   -3.319e-04  1.055e-04  -3.147
## Humidity      -2.937e-04  5.736e-05  -5.119
## Wind_V        1.408e-03  4.391e-04   3.206
## NO2            3.359e-02  1.363e-02   2.465
## C              8.398e-03  1.837e-02   0.457
## Daytimeevening 8.124e-03  5.754e-03   1.412
## Daytimemorning -5.197e-03  1.874e-03  -2.773
##
## Correlation matrix not shown by default, as p = 13 > 12.
## Use print(x, correlation=TRUE) or
##       vcov(x)           if you need it

```

```
## convergence code: 0
## boundary (singular) fit: see ?isSingular

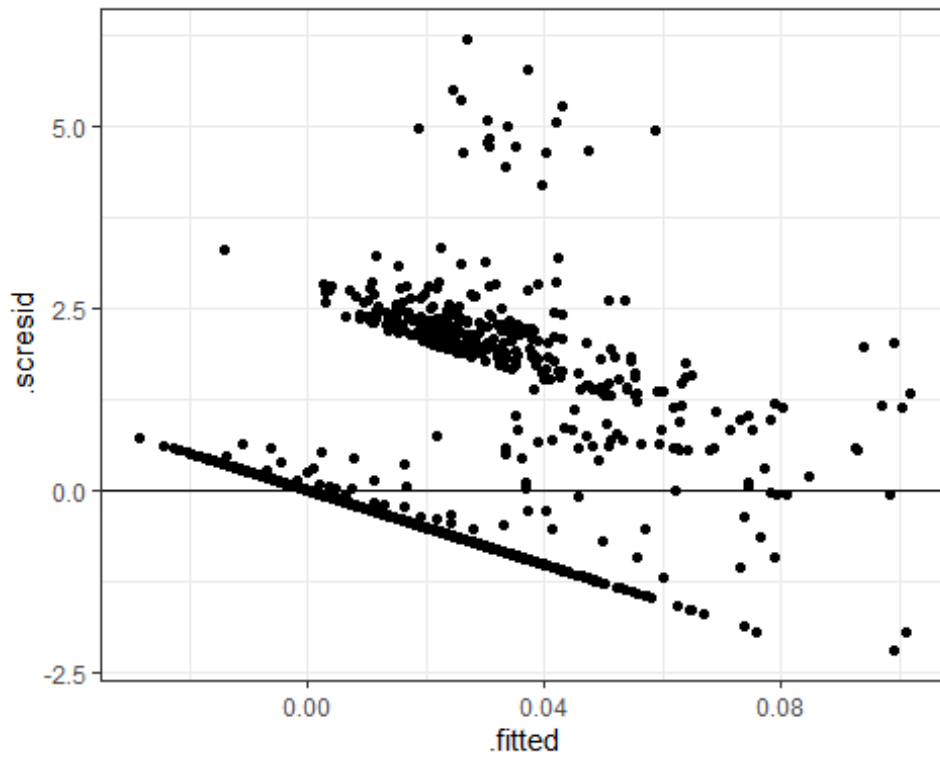
#Диагностика модели (анализ остатков)
mod1_diag <- data.frame(
  data,
  .fitted = fitted(mod1),
  .resid = resid(mod1, type = 'pearson'),
  .sresid = resid(mod1, type = 'pearson', scaled = TRUE)
)

#.fitted - предсказанные значения,
#.resid - Пирсоновские остатки,
#.sresid - стандартизованные Пирсоновские остатки

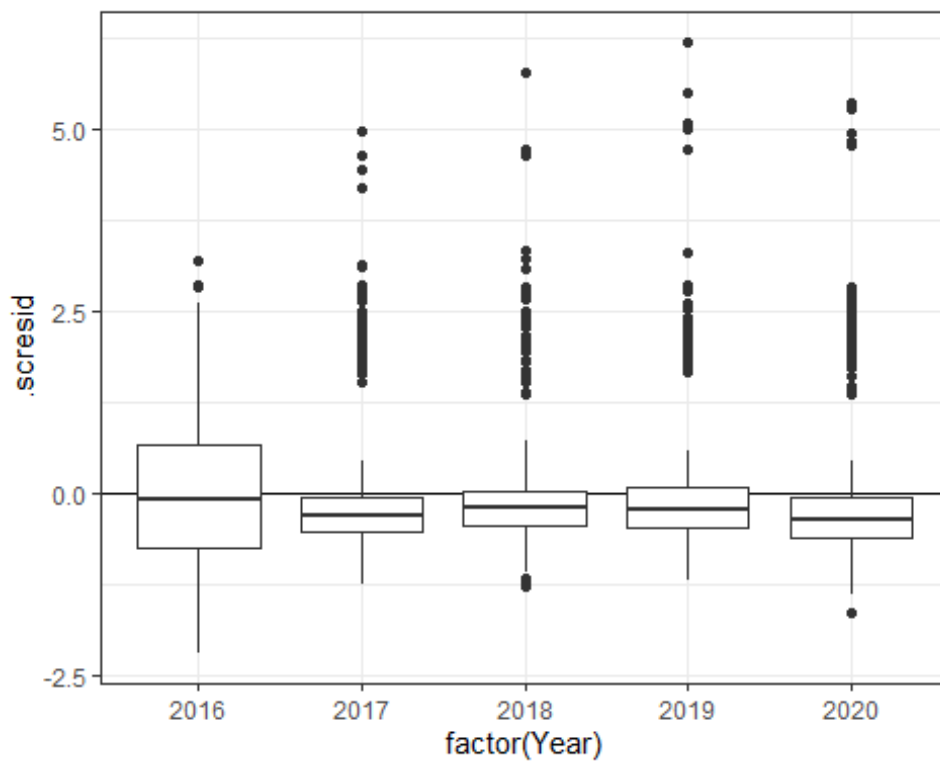
head(mod1_diag, 4)

##   Year Point abs_risk_450 abs_risk_451 abs_risk_458 abs_risk      Date Time
## 1 2016     1          NA          NA          NA          NA 26.04.2016 7:00
## 2 2016     1          NA          NA          NA          NA 27.04.2016 7:00
## 3 2016     1          NA          NA          NA          NA 28.04.2016 7:00
## 4 2016    13          NA          NA          NA          NA 16.05.2016 7:00
##   Time2 Daytime Thermometer Pressure Humidity      Wind Wind_V Weather   TSP
## 1     7 morning           6       740       73 south west     4 cloudy 0.114
## 2     7 morning           6       758       58   east     3  clear 0.189
## 3     7 morning          10       758       43   east     4  clear 0.305
## 4     7 morning          15       745       61 south     1 cloudy 0.000
##   TSPn PM10 PM10n PM2.5 PM2.5n   NO2 NO2n   C   Cn      .fitted      .resi
##   d
## 1 0.5 0.075  0.3 0.036  0.16 0.065  0.2 0.10 0.15  0.056937434 -0.02093743
## 2 0.5 0.124  0.3 0.059  0.16 0.071  0.2 0.10 0.15  0.073583167 -0.01458316
## 3 0.5 0.203  0.3 0.077  0.16 0.077  0.2 0.10 0.15  0.078269979 -0.00126997
## 4 0.5 0.000  0.3 0.000  0.16 0.062  0.2 0.11 0.15 -0.005576783  0.00557678
##   .sresid
## 1 -0.53268234
## 2 -0.37101947
## 3 -0.03231033
## 4  0.14188242

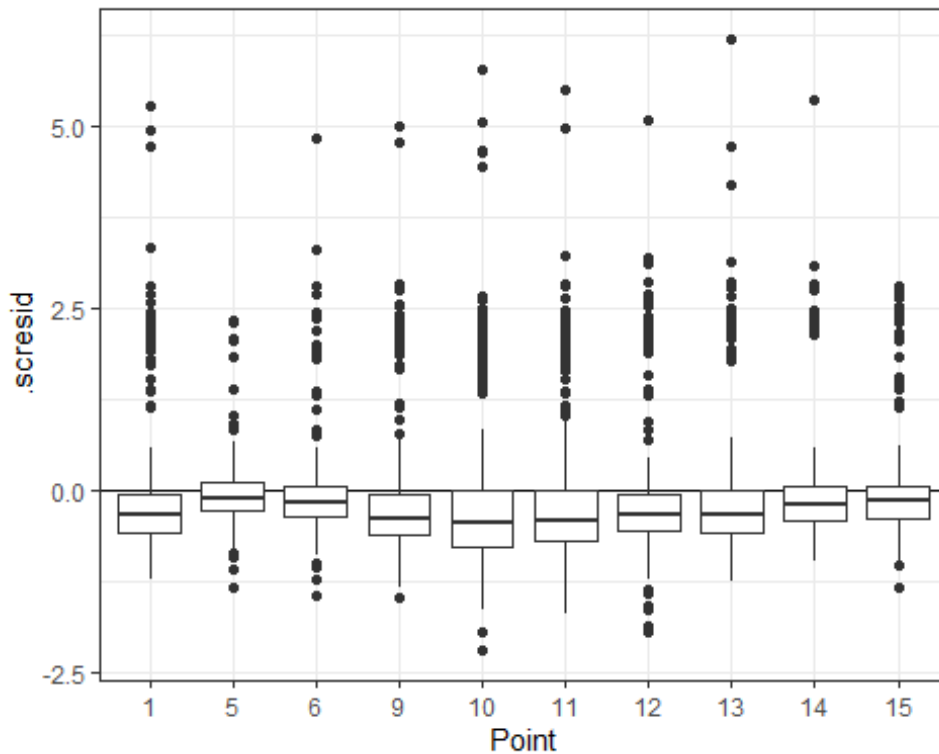
#График остатков от предсказанных значений
gg_resid <- ggplot(mod1_diag, aes(y = .sresid)) +
  geom_hline(yintercept = 0)
gg_resid + geom_point(aes(x = .fitted))
```



```
gg_resid + geom_boxplot(aes(x = factor(Year)))
```



```
gg_resid + geom_boxplot(aes(x = Point))
```



```
ctrl <- lmeControl(opt='optim', returnObject = TRUE)

mod1 <- lme(PM2.5 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 + C
+ Time, random = ~1|Point, control = ctrl, data = data)
mod2 <- lme(PM2.5 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 + C
+ Time, random = ~1 + Year|Point, control = ctrl, data = data)

AIC(mod1, mod2)

##      df      AIC
## mod1 43 -8077.575
## mod2 57 -8095.525

#Ковариата - дискретный фактор
mod2_1 <- update(mod2, weights = varIdent(form = ~ 1|Year))

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 1

mod2_2 <- update(mod2, weights = varIdent(form = ~ 1|Time))

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 2

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 3
```

```
## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 2

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 2

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 1

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 10

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 2

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 2

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 10

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 7

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 2

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 2

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 6

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 6

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 6

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
```

```

1
## -1, block 6

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
1
## -1, block 6

## Warning in lme.formula(fixed = PM2.5 ~ Year + Pressure + Thermometer + Humidi
ty + : optim problem, convergence error code = 1
## message =

summary(mod2_2)

## Linear mixed-effects model fit by REML
## Data: data
##      AIC      BIC   logLik
## -8497.234 -7997.495 4335.617
##
## Random effects:
## Formula: ~1 + Year | Point
## Structure: General positive-definite, Log-Cholesky parametrization
##           StdDev      Corr
## (Intercept) 0.02560735 (Intr) Yr2017 Yr2018 Yr2019
## Year2017    0.02438039 -0.999
## Year2018    0.02244867 -0.999  0.999
## Year2019    0.02469008 -1.000  0.999  0.999
## Year2020    0.01883417 -0.999  0.999  0.999  1.000
## Residual    0.01138647
##
## Variance function:
## Structure: Different standard deviations per stratum
## Formula: ~1 | Time
## Parameter estimates:
##           7:00      8:00      9:00      10:00      11:30      13:00
## 1.000000e+00 2.560282e+00 3.358748e+00 2.221371e+00 2.916480e+00 4.593513e+00
##           14:00      14:30      17:30      10:30      15:30      17:00
## 3.009812e+00 2.455602e+00 3.079893e+00 1.828754e+00 2.917177e-01 4.275730e+00
##           8:30      12:30      16:00      9:45      13:30      13:35
## 3.660949e+00 5.474067e-01 5.152676e+00 1.000002e+00 5.692787e+00 1.000004e+00
##           13:45      9:30      14:40      15:00      15:40      11:00
## 9.590039e-10 3.520031e-01 3.709508e-01 5.732504e+00 4.929246e+00 5.423736e-01
##           14:10      14:45      11:50      12:00      12:55      13:10
## 1.000004e+00 1.000006e+00 9.999977e-01 1.000001e+00 9.999960e-01 9.999998e-01
##           14:55
## 9.999953e-01
## Fixed effects: PM2.5 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO
2 +      C + Time
##           Value Std.Error DF t-value p-value
## (Intercept) -0.3209922 0.06783487 2299 -4.731964 0.0000
## Year2017    -0.0301979 0.00851811 2299 -3.545138 0.0004
## Year2018    -0.0338822 0.00799968 2299 -4.235444 0.0000
## Year2019    -0.0342244 0.00860193 2299 -3.978694 0.0001

```

```

## Year2020      -0.0293439 0.00700200 2299 -4.190788 0.0000
## Pressure      0.0004828 0.00008765 2299 5.508424 0.0000
## Thermometer -0.0001963 0.00007874 2299 -2.493206 0.0127
## Humidity      -0.0001524 0.00003943 2299 -3.864571 0.0001
## Wind_V        0.0007328 0.00030112 2299 2.433685 0.0150
## NO2           0.0203605 0.00761324 2299 2.674349 0.0075
## C             0.0122462 0.00744062 2299 1.645854 0.0999
## Time10:30     0.0045622 0.00333384 2299 1.368451 0.1713
## Time11:00    -0.0013783 0.00465005 2299 -0.296412 0.7669
## Time11:30    -0.0042755 0.00813435 2299 -0.525606 0.5992
## Time11:50     0.0006772 0.01191859 2299 0.056820 0.9547
## Time12:00     0.0105305 0.01195927 2299 0.880529 0.3787
## Time12:30    -0.0043096 0.00439385 2299 -0.980829 0.3268
## Time12:55    -0.0000668 0.01191684 2299 -0.005604 0.9955
## Time13:00     0.0205507 0.00341884 2299 6.011031 0.0000
## Time13:10    -0.0023131 0.01190314 2299 -0.194331 0.8459
## Time13:30     0.0205417 0.03257552 2299 0.630587 0.5284
## Time13:35    -0.0158625 0.01205034 2299 -1.316350 0.1882
## Time13:45    -0.0135390 0.00392213 2299 -3.451963 0.0006
## Time14:00     0.0056773 0.00399134 2299 1.422394 0.1550
## Time14:10     0.0004484 0.01191204 2299 0.037639 0.9700
## Time14:30     0.0068252 0.00346743 2299 1.968373 0.0491
## Time14:40    -0.0061713 0.00464982 2299 -1.327216 0.1846
## Time14:45    -0.0054775 0.01196164 2299 -0.457922 0.6471
## Time14:55     0.0033674 0.01193965 2299 0.282038 0.7779
## Time15:00     0.0372911 0.03785794 2299 0.985028 0.3247
## Time15:30    -0.0009260 0.00351563 2299 -0.263386 0.7923
## Time15:40     0.0239160 0.02826939 2299 0.846004 0.3976
## Time16:00     0.0256993 0.01347799 2299 1.906757 0.0567
## Time17:00     0.0197261 0.01164814 2299 1.693496 0.0905
## Time17:30     0.0142742 0.01377618 2299 1.036154 0.3002
## Time7:00     -0.0038704 0.00818276 2299 -0.472990 0.6363
## Time8:00      0.0003087 0.00562675 2299 0.054868 0.9562
## Time8:30      0.0134866 0.01606953 2299 0.839262 0.4014
## Time9:00      0.0103042 0.00314394 2299 3.277465 0.0011
## Time9:30     -0.0003568 0.00340794 2299 -0.104707 0.9166
## Time9:45     -0.0089868 0.01191735 2299 -0.754091 0.4509
## Correlation:
##              (Intr) Yr2017 Yr2018 Yr2019 Yr2020 Pressr Thrmmt Humdty Wind_V
## Year2017      -0.133
## Year2018      -0.127 0.954
## Year2019      -0.136 0.959 0.976
## Year2020      -0.090 0.942 0.966 0.968
## Pressure      -0.990 0.007 0.005 0.012 -0.031
## Thermometer -0.401 -0.003 -0.022 -0.013 -0.019 0.379
## Humidity      -0.302 -0.023 0.009 0.011 -0.010 0.262 0.505
## Wind_V        -0.207 0.017 0.028 0.030 -0.015 0.184 0.179 0.196
## NO2           -0.130 -0.003 0.026 0.017 0.027 0.105 -0.082 0.368 0.162
## C             0.421 0.008 0.010 -0.001 0.043 -0.432 -0.241 -0.246 0.007
## Time10:30     -0.083 0.022 -0.126 -0.124 -0.147 0.058 0.058 -0.023 0.065
## Time11:00      0.078 -0.003 -0.113 -0.097 -0.154 -0.089 -0.001 -0.151 -0.009
## Time11:30     -0.022 0.170 0.141 0.126 0.154 -0.008 0.018 -0.011 -0.013

```



```

## Time11:50 -0.048 0.005 -0.048 -0.032 -0.035 0.041 0.005 0.035 -0.012
## Time12:00 -0.116 0.010 -0.027 -0.032 -0.048 0.110 0.009 -0.003 0.055
## Time12:30 -0.056 -0.009 -0.104 -0.100 -0.180 0.046 -0.060 -0.013 -0.081
## Time12:55 0.021 0.006 -0.045 -0.031 -0.030 -0.031 -0.010 0.032 0.036
## Time13:00 -0.069 0.005 -0.103 -0.099 -0.130 0.049 0.056 0.006 -0.041
## Time13:10 -0.003 0.005 -0.049 -0.034 -0.033 -0.004 -0.002 0.019 -0.042
## Time13:30 0.012 0.001 -0.014 -0.012 -0.020 -0.015 0.009 0.004 0.012
## Time13:35 0.015 0.004 -0.052 -0.032 -0.041 -0.018 0.011 -0.022 -0.071
## Time13:45 0.056 0.006 -0.160 -0.100 -0.137 -0.078 0.078 0.108 0.029
## Time14:00 0.003 -0.027 -0.022 -0.021 -0.027 -0.020 -0.008 0.014 -0.048
## Time14:10 0.056 0.002 -0.052 -0.033 -0.041 -0.061 -0.046 -0.061 0.002
## Time14:30 -0.056 0.046 -0.090 -0.091 -0.105 0.029 0.034 0.008 -0.029
## Time14:40 0.010 0.004 -0.132 -0.082 -0.114 -0.025 0.017 0.000 0.053
## Time14:45 0.024 -0.001 -0.053 -0.033 -0.045 -0.029 -0.018 0.002 -0.019
## Time14:55 -0.044 0.005 -0.046 -0.031 -0.032 0.036 -0.024 0.049 -0.027
## Time15:00 0.001 0.002 -0.010 -0.010 -0.018 -0.003 0.004 -0.009 -0.015
## Time15:30 0.072 0.031 -0.117 -0.136 -0.136 -0.090 0.021 -0.190 -0.079
## Time15:40 0.010 0.002 -0.013 -0.019 -0.016 -0.012 -0.015 -0.013 -0.030
## Time16:00 -0.036 0.078 0.071 0.065 0.080 0.024 0.005 0.014 -0.015
## Time17:00 0.001 0.091 0.066 0.060 0.074 -0.017 0.002 -0.013 -0.038
## Time17:30 -0.042 0.119 0.103 0.091 0.104 0.024 0.027 -0.001 -0.049
## Time7:00 -0.112 0.204 0.179 0.157 0.177 0.077 0.081 0.015 0.054
## Time8:00 -0.070 0.119 0.074 0.056 0.075 0.047 0.036 -0.022 0.085
## Time8:30 -0.001 0.001 -0.026 -0.028 -0.043 -0.004 -0.001 -0.005 0.023
## Time9:00 -0.097 0.009 -0.110 -0.104 -0.140 0.074 0.070 -0.026 0.053
## Time9:30 -0.009 0.026 -0.107 -0.146 -0.144 -0.011 -0.052 -0.091 -0.004
## Time9:45 0.015 0.006 -0.049 -0.030 -0.038 -0.020 -0.007 -0.032 -0.015
## NO2 C T10:30 T11:00 T11:30 T11:50 T12:00 T12:30 T12:55
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V
## NO2
## C 0.689
## Time10:30 0.038 0.048
## Time11:00 -0.165 -0.021 0.552
## Time11:30 0.003 0.022 0.293 0.138
## Time11:50 -0.025 -0.069 0.229 0.143 0.070
## Time12:00 0.016 -0.034 0.243 0.151 0.069 0.070
## Time12:30 -0.107 -0.146 0.560 0.521 0.131 0.160 0.173
## Time12:55 0.054 0.046 0.235 0.142 0.072 0.079 0.064 0.138
## Time13:00 -0.123 -0.133 0.699 0.509 0.236 0.204 0.200 0.550 0.186
## Time13:10 -0.022 -0.034 0.228 0.147 0.072 0.085 0.064 0.156 0.080
## Time13:30 -0.006 0.003 0.080 0.069 0.021 0.022 0.022 0.067 0.023
## Time13:35 -0.143 -0.118 0.207 0.168 0.061 0.075 0.053 0.173 0.060
## Time13:45 -0.341 -0.353 0.670 0.511 0.240 0.238 0.171 0.524 0.211
## Time14:00 -0.024 -0.027 0.407 0.287 0.183 0.114 0.105 0.304 0.110
## Time14:10 -0.044 0.010 0.217 0.193 0.060 0.067 0.055 0.171 0.069

```

```

## Time14:30    0.008  0.002  0.797  0.511  0.325  0.222  0.222  0.536  0.220
## Time14:40   -0.223 -0.209  0.544  0.418  0.148  0.186  0.147  0.434  0.169
## Time14:45   -0.099 -0.095  0.207  0.188  0.057  0.075  0.054  0.187  0.065
## Time14:55    0.060  0.001  0.230  0.130  0.070  0.085  0.069  0.152  0.083
## Time15:00   -0.005  0.005  0.073  0.057  0.029  0.018  0.020  0.061  0.017
## Time15:30   -0.145  0.034  0.808  0.574  0.267  0.215  0.232  0.551  0.215
## Time15:40   -0.023 -0.014  0.094  0.069  0.031  0.028  0.026  0.075  0.025
## Time16:00   -0.058 -0.079  0.072  0.082  0.061  0.031  0.029  0.101  0.022
## Time17:00   -0.038 -0.021  0.208  0.116  0.226  0.053  0.047  0.115  0.050
## Time17:30   -0.064 -0.066  0.155  0.087  0.244  0.045  0.043  0.098  0.035
## Time7:00     0.015 -0.003  0.281  0.137  0.412  0.067  0.082  0.136  0.067
## Time8:00    -0.036 -0.032  0.318  0.253  0.150  0.088  0.104  0.265  0.087
## Time8:30    -0.003  0.002  0.163  0.136  0.042  0.041  0.048  0.142  0.043
## Time9:00    -0.064 -0.059  0.784  0.556  0.274  0.215  0.226  0.578  0.208
## Time9:30    -0.142 -0.097  0.806  0.571  0.254  0.228  0.244  0.597  0.216
## Time9:45    -0.049 -0.021  0.219  0.162  0.062  0.070  0.057  0.158  0.067
##             T13:00 T13:10 T13:30 T13:35 T13:45 T14:00 T14:10 T14:30 T14:40
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V
## NO2
## C
## Time10:30
## Time11:00
## Time11:30
## Time11:50
## Time12:00
## Time12:30
## Time12:55
## Time13:00
## Time13:10    0.201
## Time13:30    0.072  0.022
## Time13:35    0.217  0.076  0.024
## Time13:45    0.666  0.234  0.074  0.269
## Time14:00    0.391  0.115  0.040  0.114  0.361
## Time14:10    0.193  0.069  0.025  0.072  0.224  0.111
## Time14:30    0.671  0.222  0.074  0.205  0.660  0.399  0.203
## Time14:40    0.525  0.182  0.059  0.204  0.656  0.281  0.183  0.516
## Time14:45    0.206  0.074  0.024  0.084  0.265  0.116  0.083  0.202  0.203
## Time14:55    0.192  0.083  0.021  0.064  0.204  0.112  0.064  0.222  0.164
## Time15:00    0.067  0.018  0.008  0.019  0.057  0.036  0.019  0.071  0.049
## Time15:30    0.690  0.223  0.079  0.220  0.656  0.379  0.218  0.763  0.530
## Time15:40    0.088  0.028  0.009  0.029  0.086  0.049  0.027  0.093  0.067
## Time16:00    0.099  0.029  0.011  0.039  0.091  0.068  0.028  0.080  0.085
## Time17:00    0.168  0.055  0.016  0.053  0.199  0.135  0.048  0.224  0.121
## Time17:30    0.167  0.044  0.012  0.047  0.142  0.100  0.033  0.190  0.098
## Time7:00     0.262  0.064  0.021  0.053  0.189  0.158  0.052  0.320  0.140

```

```

## Time8:00      0.303  0.084  0.036  0.088  0.256  0.181  0.090  0.300  0.249
## Time8:30      0.146  0.041  0.019  0.042  0.137  0.080  0.047  0.151  0.114
## Time9:00      0.710  0.212  0.079  0.219  0.693  0.423  0.212  0.739  0.554
## Time9:30      0.716  0.226  0.079  0.223  0.697  0.392  0.220  0.766  0.564
## Time9:45      0.204  0.071  0.024  0.090  0.229  0.109  0.072  0.207  0.184
##              T14:45 T14:55 T15:00 T15:30 T15:40 T16:00 T17:00 T17:30 Tm7:00
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V
## NO2
## C
## Time10:30
## Time11:00
## Time11:30
## Time11:50
## Time12:00
## Time12:30
## Time12:55
## Time13:00
## Time13:10
## Time13:30
## Time13:35
## Time13:45
## Time14:00
## Time14:10
## Time14:30
## Time14:40
## Time14:45
## Time14:55      0.066
## Time15:00      0.018  0.018
## Time15:30      0.207  0.205  0.075
## Time15:40      0.029  0.027  0.009  0.101
## Time16:00      0.037  0.026  0.006  0.084  0.013
## Time17:00      0.051  0.051  0.016  0.189  0.024  0.043
## Time17:30      0.040  0.040  0.026  0.170  0.022  0.045  0.089
## Time7:00       0.049  0.065  0.042  0.276  0.030  0.065  0.142  0.458
## Time8:00       0.089  0.082  0.028  0.323  0.039  0.151  0.099  0.095  0.170
## Time8:30       0.046  0.041  0.016  0.158  0.019  0.022  0.032  0.025  0.045
## Time9:00       0.212  0.207  0.073  0.755  0.092  0.093  0.189  0.176  0.301
## Time9:30       0.225  0.216  0.072  0.836  0.109  0.102  0.186  0.163  0.258
## Time9:45       0.073  0.066  0.019  0.217  0.026  0.031  0.048  0.038  0.058
##              Tm8:00 Tm8:30 Tm9:00 Tm9:30
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure

```

```

## Thermometer
## Humidity
## Wind_V
## NO2
## C
## Time10:30
## Time11:00
## Time11:30
## Time11:50
## Time12:00
## Time12:30
## Time12:55
## Time13:00
## Time13:10
## Time13:30
## Time13:35
## Time13:45
## Time14:00
## Time14:10
## Time14:30
## Time14:40
## Time14:45
## Time14:55
## Time15:00
## Time15:30
## Time15:40
## Time16:00
## Time17:00
## Time17:30
## Time7:00
## Time8:00
## Time8:30      0.075
## Time9:00      0.330  0.161
## Time9:30      0.347  0.166  0.773
## Time9:45      0.091  0.043  0.219  0.214
##
## Standardized Within-Group Residuals:
##           Min           Q1           Med           Q3           Max
## -2.0933286 -0.4742701 -0.3137191 -0.0537153  9.5883189
##
## Number of Observations: 2349
## Number of Groups: 10

#Диагностика модели (анализ остатков)
mod2_2_diag <- data.frame(
  data,
  .fitted = fitted(mod2_2),
  .resid = resid(mod2_2, type = 'pearson'),
  .sresid = resid(mod2_2, type = 'pearson', scaled = TRUE)
)

#.fitted - предсказанные значения,

```

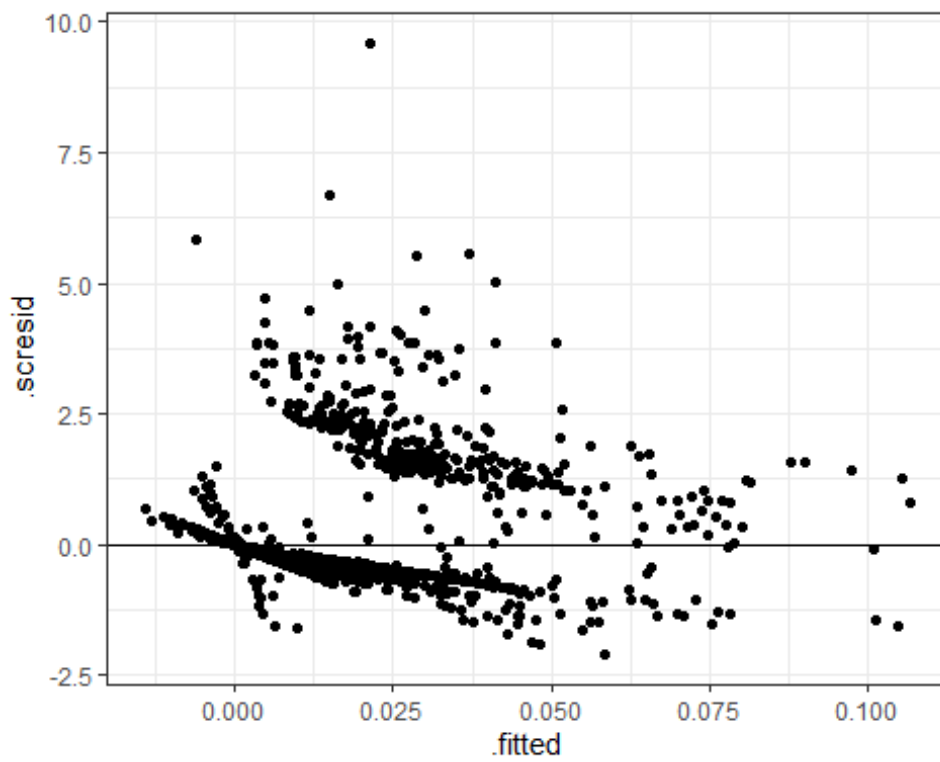
```
#.resid - Пирсоновские остатки,  
#.scredid - стандартизованные Пирсоновские остатки
```

```
head(mod2_2_diag, 4)
```

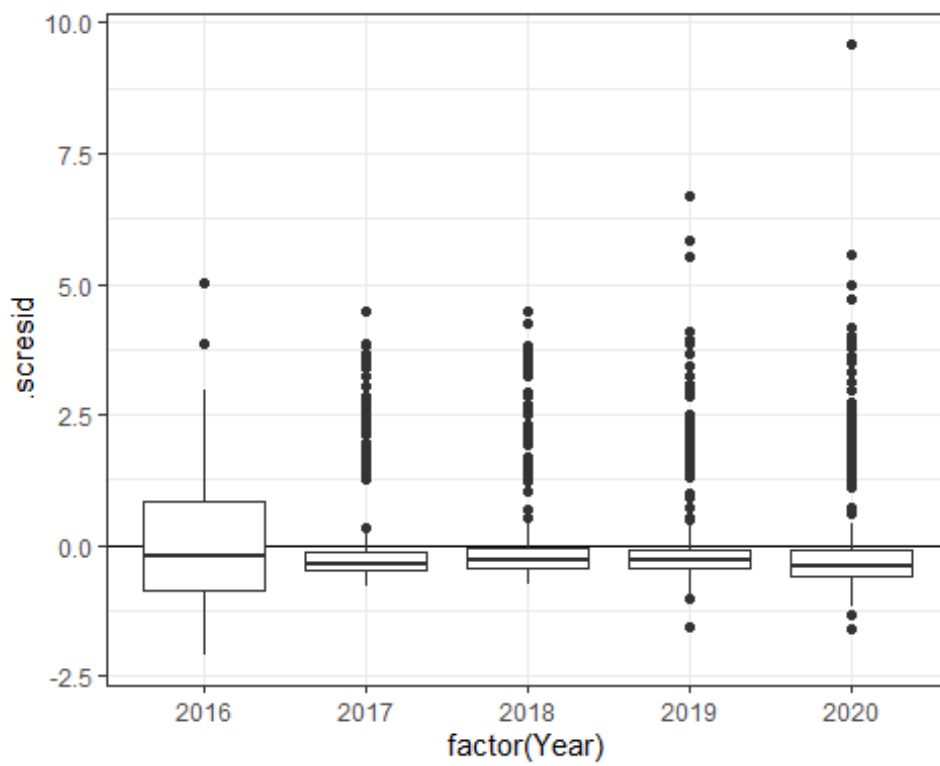
```
##   Year Point abs_risk_450 abs_risk_451 abs_risk_458 abs_risk      Date Time  
## 1 2016     1          NA          NA          NA      NA 26.04.2016 7:00  
## 2 2016     1          NA          NA          NA      NA 27.04.2016 7:00  
## 3 2016     1          NA          NA          NA      NA 28.04.2016 7:00  
## 4 2016    13          NA          NA          NA      NA 16.05.2016 7:00  
##   Time2 Daytime Thermometer Pressure Humidity      Wind Wind_V Weather   TSP  
## 1     7 morning          6       740       73 south west     4 cloudy 0.114  
## 2     7 morning          6       758       58   east     3  clear 0.189  
## 3     7 morning         10       758       43   east     4  clear 0.305  
## 4     7 morning         15       745       61 south     1 cloudy 0.000  
##   TSPn PM10 PM10n PM2.5 PM2.5n   NO2 NO2n    C   Cn      .fitted      .resi  
d  
## 1  0.5 0.075   0.3 0.036   0.16 0.065   0.2 0.10 0.15  0.0547356957 -1.6454346  
5  
## 2  0.5 0.124   0.3 0.059   0.16 0.071   0.2 0.10 0.15  0.0651016354 -0.5358670  
7  
## 3  0.5 0.203   0.3 0.077   0.16 0.077   0.2 0.10 0.15  0.0674568798  0.8381103  
6  
## 4  0.5 0.000   0.3 0.000   0.16 0.062   0.2 0.11 0.15 -0.0009467521  0.0831470  
9  
##      .scredid  
## 1 -1.64543465  
## 2 -0.53586707  
## 3  0.83811036  
## 4  0.08314709
```

```
#График остатков от предсказанных значений
```

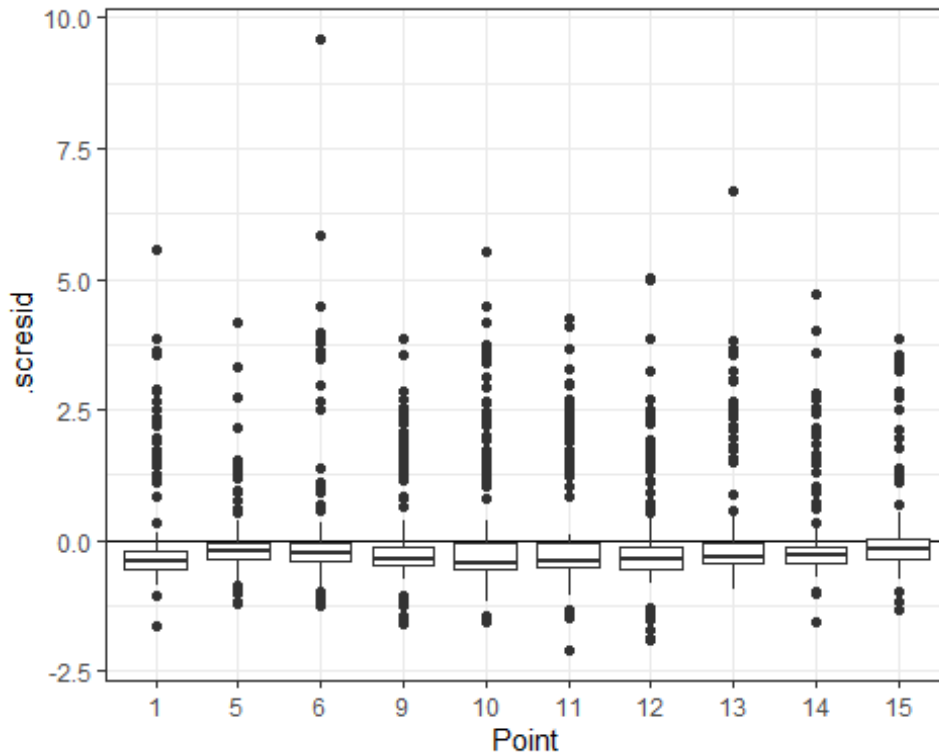
```
gg_resid <- ggplot(mod2_2_diag, aes(y = .scredid)) +  
  geom_hline(yintercept = 0)  
gg_resid + geom_point(aes(x = .fitted))
```



```
gg_resid + geom_boxplot(aes(x = factor(Year)))
```



```
gg_resid + geom_boxplot(aes(x = Point))
```



```
#Ковариата - непрерывный фактор
#mod2_3 <- update(mod2_2, weights = varPower(form = ~ Pressure))
#mod2_3 <- update(mod2_2, weights = varPower(form = ~ Thermometer))
#mod2_4 <- update(mod2, weights = varPower(form = ~ Humidity))
#mod4_5 <- update(mod4, weights = varPower(form = ~ Wind_V))
#mod2_6 <- update(mod2, weights = varPower(form = ~ NO2))
#mod4_7 <- update(mod4, weights = varPower(form = ~ C))
#При запуске этих команд появляется следующая ошибка: Error in optim(c(oldPars),
function(lmePars) -logLik(lmeSt, lmePars), : non-finite finite-difference value
[16]
```

```
AICs <- as.data.frame(AIC(mod2, mod2_1, mod2_2))
AICs[which.min(AICs$AIC), ]
```

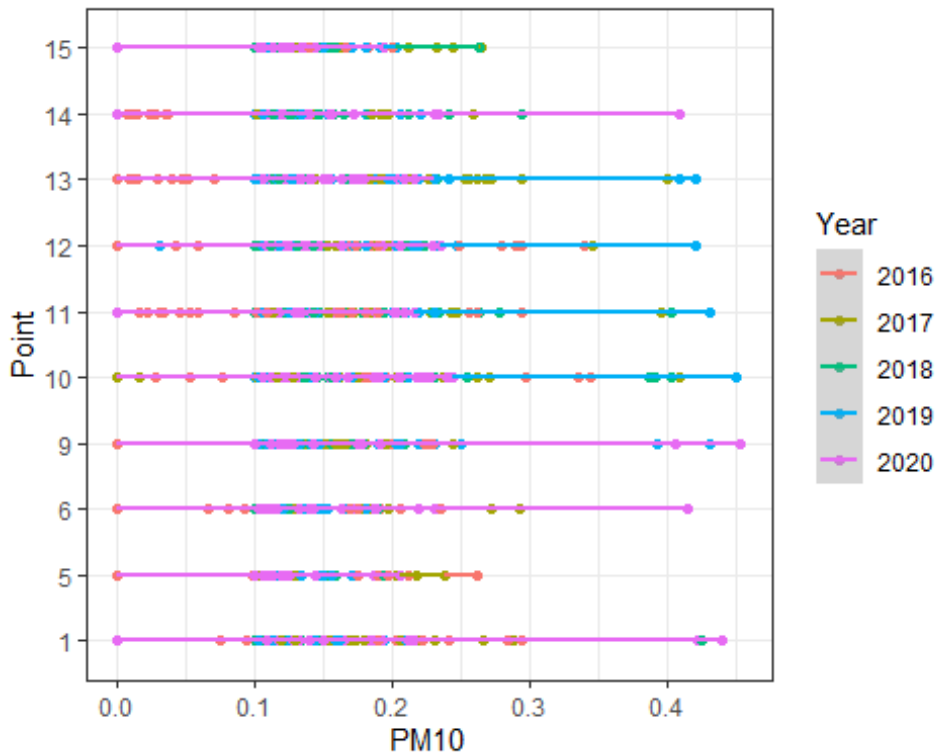
```
##          df          AIC
## mod2_2 87 -8497.234
```

```
summary(mod2_2)$call
```

```
## lme.formula(fixed = PM2.5 ~ Year + Pressure + Thermometer + Humidity +
##           Wind_V + NO2 + C + Time, data = data, random = ~1 + Year |
##           Point, weights = varIdent(form = ~1 | Time), control = ctrl)
```

```
#PM10
```

```
ggplot(data, aes(x = PM10, y = Point, color = Year)) +
  geom_point() +
  geom_smooth(se = TRUE, method = "lm", size = 1)
```



*#Нет ли коллинеарности дискретных и непрерывных предикторов?*

```
mod1 <- lm(PM10 ~ Pressure * Thermometer * Humidity * Wind_V * NO2 * C, data = data)
Anova(mod1)
```

```
## Anova Table (Type II tests)
```

```
##
```

```
## Response: PM10
```

```
##
```

	Sum Sq	Df	F value	Pr(>F)	
## Pressure	0.4777	2	44.3937	< 2.2e-16	***
## Thermometer	0.1762	12	2.7292	0.0011216	**
## Humidity	1.2511	10	23.2557	< 2.2e-16	***
## Wind_V	0.2058	13	2.9422	0.0002859	***
## NO2	0.4660	12	7.2180	4.165e-13	***
## C	0.3632	12	5.6267	1.327e-09	***
## Pressure:Thermometer	0.0137	1	2.5389	0.1112123	
## Pressure:Humidity	0.0066	1	1.2355	0.2664558	
## Thermometer:Humidity	0.0753	5	2.7995	0.0158411	*
## Pressure:Wind_V	0.0004	1	0.0713	0.7895369	
## Thermometer:Wind_V	0.0299	6	0.9255	0.4752682	
## Humidity:Wind_V	0.0796	5	2.9577	0.0114830	*
## Pressure:NO2	0.0023	1	0.4354	0.5094093	
## Thermometer:NO2	0.0749	6	2.3212	0.0308095	*
## Humidity:NO2	0.0932	5	3.4658	0.0040065	**
## Wind_V:NO2	0.0343	6	1.0625	0.3828940	
## Pressure:C	0.0031	1	0.5741	0.4487091	
## Thermometer:C	0.0547	5	2.0323	0.0712086	.
## Humidity:C	0.1554	5	5.7772	2.627e-05	***
## Wind_V:C	0.0587	6	1.8183	0.0917247	.

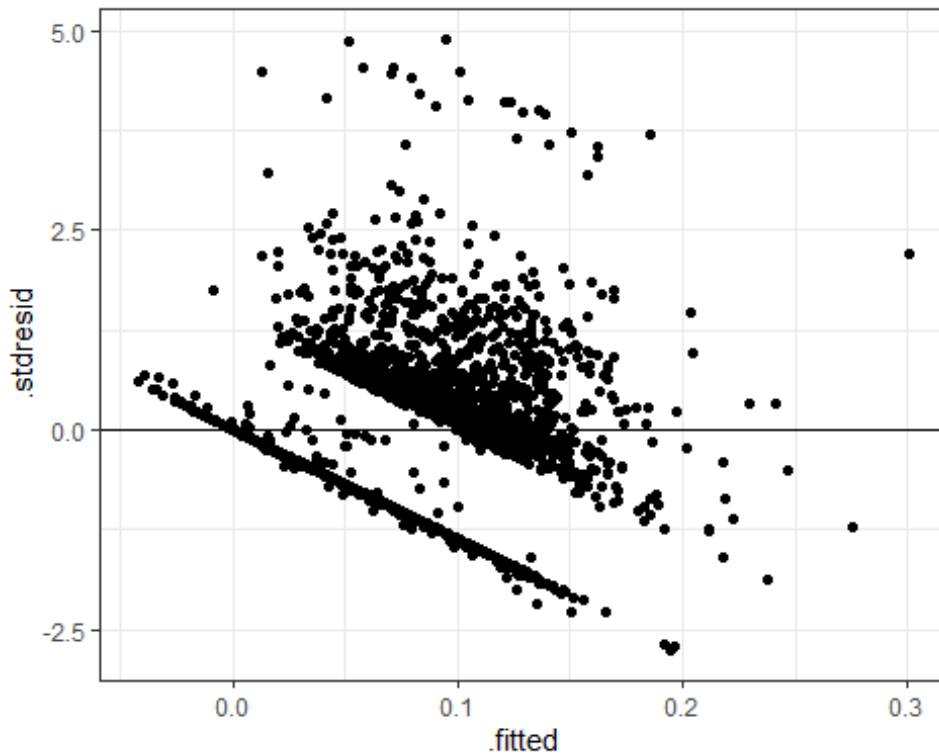


```

## N02:C 0.1704 5 6.3347 7.541e-06 ***
## Pressure:Thermometer:Humidity 0.0134 1 2.4912 0.1146219
## Pressure:Thermometer:Wind_V 0.0063 1 1.1706 0.2793939
## Pressure:Humidity:Wind_V 0.0109 1 2.0235 0.1550157
## Thermometer:Humidity:Wind_V 0.0170 3 1.0503 0.3691678
## Pressure:Thermometer:N02 0.0007 1 0.1280 0.7205426
## Pressure:Humidity:N02 0.0003 1 0.0501 0.8228811
## Thermometer:Humidity:N02 0.0087 3 0.5389 0.6556394
## Pressure:Wind_V:N02 0.0219 1 4.0620 0.0439763 *
## Thermometer:Wind_V:N02 0.0251 3 1.5571 0.1978269
## Humidity:Wind_V:N02 0.0224 3 1.3875 0.2447417
## Pressure:Thermometer:C 0.0008 1 0.1463 0.7021185
## Pressure:Humidity:C 0.0015 1 0.2876 0.5917876
## Thermometer:Humidity:C 0.0121 2 1.1264 0.3243626
## Pressure:Wind_V:C 0.0359 1 6.6792 0.0098159 **
## Thermometer:Wind_V:C 0.0220 3 1.3604 0.2531057
## Humidity:Wind_V:C 0.0033 2 0.3107 0.7329313
## Pressure:N02:C 0.0001 1 0.0238 0.8774596
## Thermometer:N02:C 0.0530 3 3.2834 0.0200564 *
## Humidity:N02:C 0.1142 2 10.6117 2.586e-05 ***
## Wind_V:N02:C 0.0189 3 1.1707 0.3194458
## Pressure:Thermometer:Humidity:Wind_V 0.0728 1 13.5315 0.0002400 ***
## Pressure:Thermometer:Humidity:N02 0.0104 1 1.9314 0.1647415
## Pressure:Thermometer:Wind_V:N02 0.0191 1 3.5593 0.0593391 .
## Pressure:Humidity:Wind_V:N02 0.0046 1 0.8629 0.3530129
## Thermometer:Humidity:Wind_V:N02 0.0140 2 1.2982 0.2732324
## Pressure:Thermometer:Humidity:C 0.0022 1 0.4026 0.5258279
## Pressure:Thermometer:Wind_V:C 0.0066 1 1.2228 0.2689276
## Pressure:Humidity:Wind_V:C 0.0001 1 0.0122 0.9121275
## Thermometer:Humidity:Wind_V:C 0.0061 2 0.5654 0.5682339
## Pressure:Thermometer:N02:C 0.0041 1 0.7675 0.3810706
## Pressure:Humidity:N02:C 0.0210 1 3.8992 0.0484285 *
## Thermometer:Humidity:N02:C 0.0084 2 0.7808 0.4581678
## Pressure:Wind_V:N02:C 0.0011 1 0.1994 0.6552734
## Thermometer:Wind_V:N02:C 0.0221 2 2.0496 0.1290289
## Humidity:Wind_V:N02:C 0.0136 1 2.5219 0.1124103
## Pressure:Thermometer:Humidity:Wind_V:N02 0.0017 1 0.3141 0.5752196
## Pressure:Thermometer:Humidity:Wind_V:C 0.0015 1 0.2840 0.5941718
## Pressure:Thermometer:Humidity:N02:C 0.0114 1 2.1114 0.1463441
## Pressure:Thermometer:Wind_V:N02:C 0.0054 1 0.9952 0.3185864
## Pressure:Humidity:Wind_V:N02:C 0.0003 1 0.0490 0.8247811
## Thermometer:Humidity:Wind_V:N02:C 0.0032 1 0.5925 0.4415191
## Pressure:Thermometer:Humidity:Wind_V:N02:C 0.0008 1 0.1476 0.7008732
## Residuals 12.2928 2285
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

mod1_diag <- fortify(mod1)
ggplot(mod1_diag, aes(x = .fitted, y = .stdresid)) +
  geom_point() +
  geom_hline(yintercept = 0)

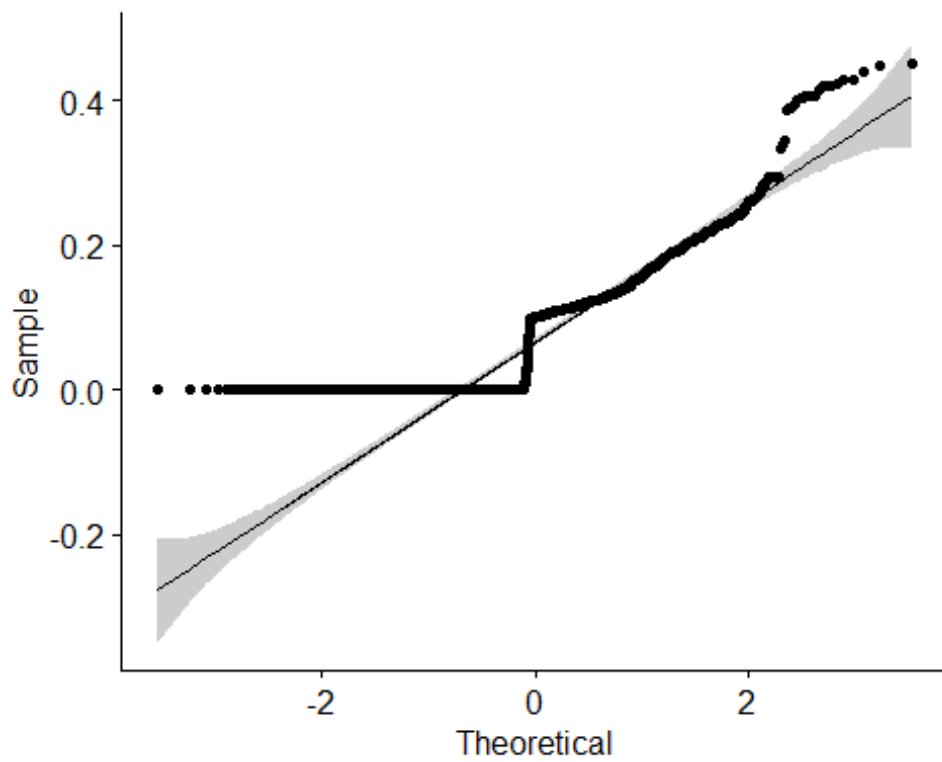
```



*#Присутствуют признаки гетероскедастичности*

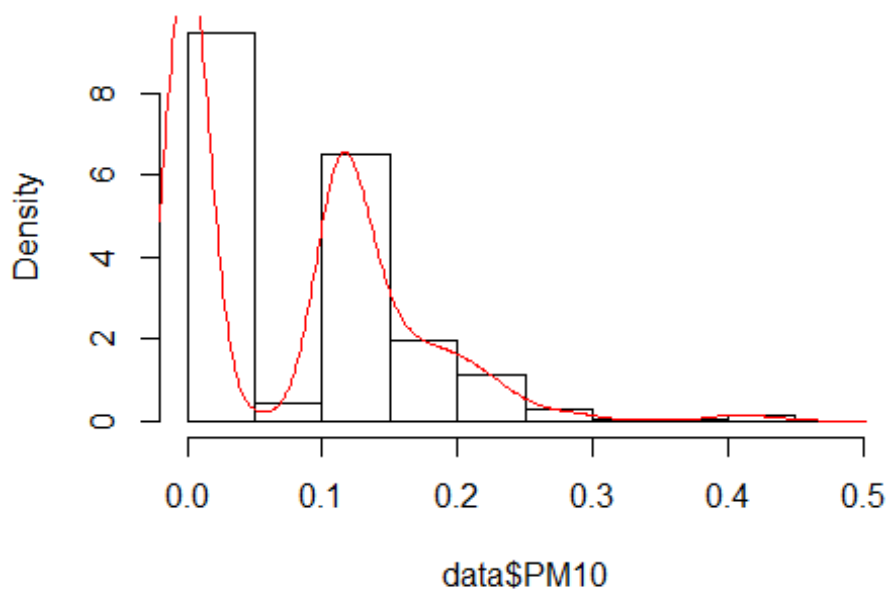
*#Наличие гетероскедастичности - нарушение условий применимости моделей, основанных на нормальном распределении отклика. Возможные пути решения: преобразовать зависимую переменную (Log), использовать более сложную модель, ввести ковариату дисперсии*

```
ggqqplot(data$PM10)
```

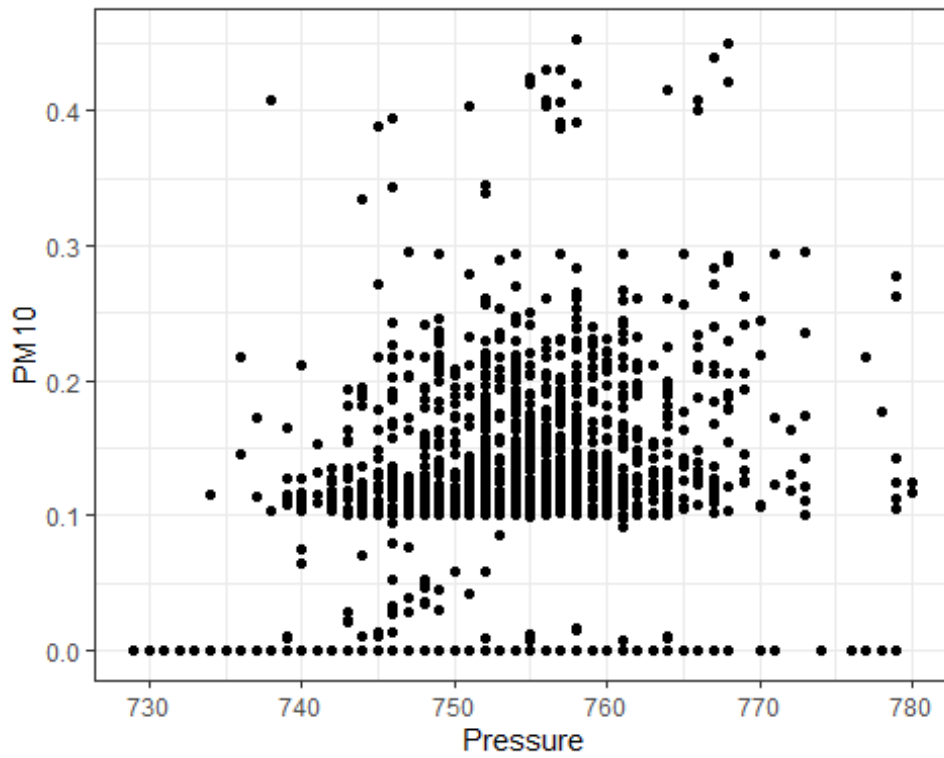


```
hist(data$PM10,probability=T)
lines(density(data$PM10),col=2)
```

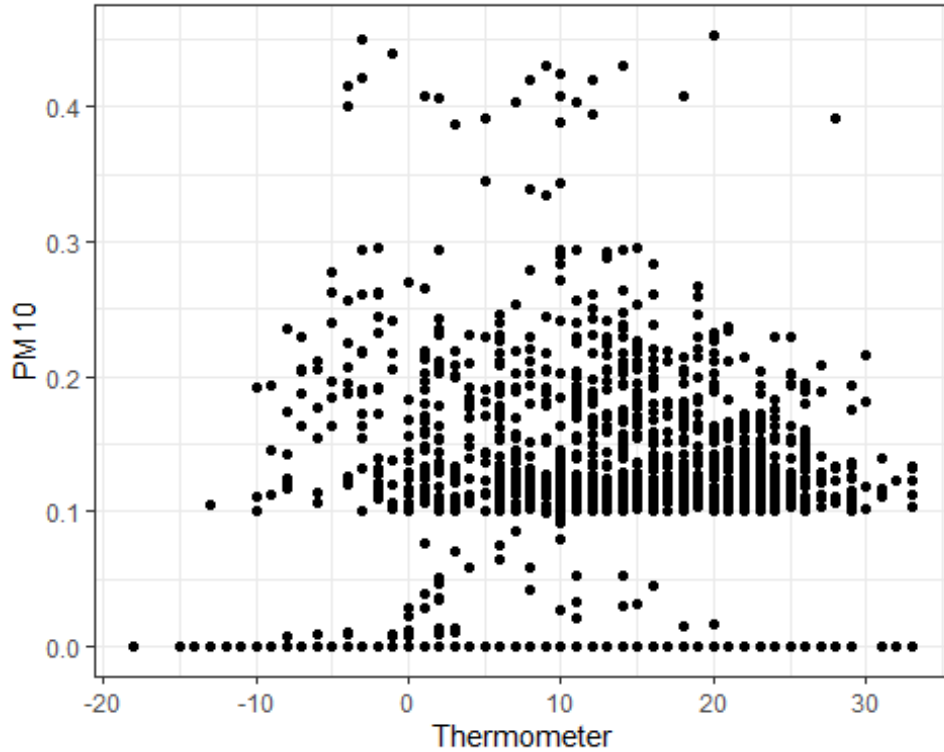
**Histogram of data\$PM10**



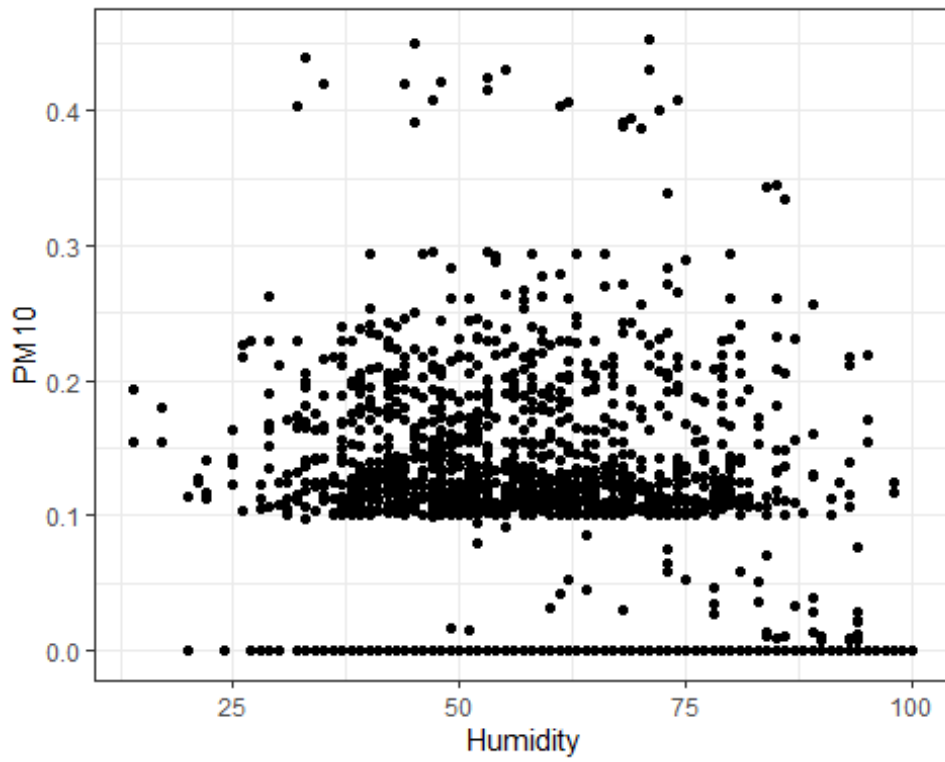
```
ggplot(data, aes(x = Pressure, y = PM10)) +
  geom_point()
```



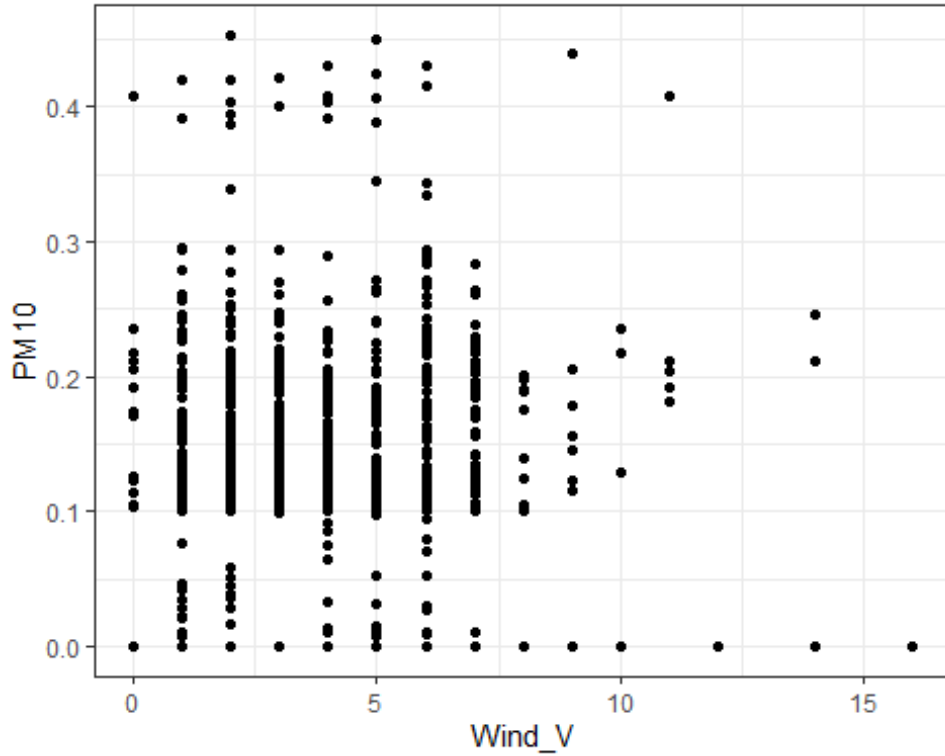
```
ggplot(data, aes(x = Thermometer, y = PM10)) +  
  geom_point()
```



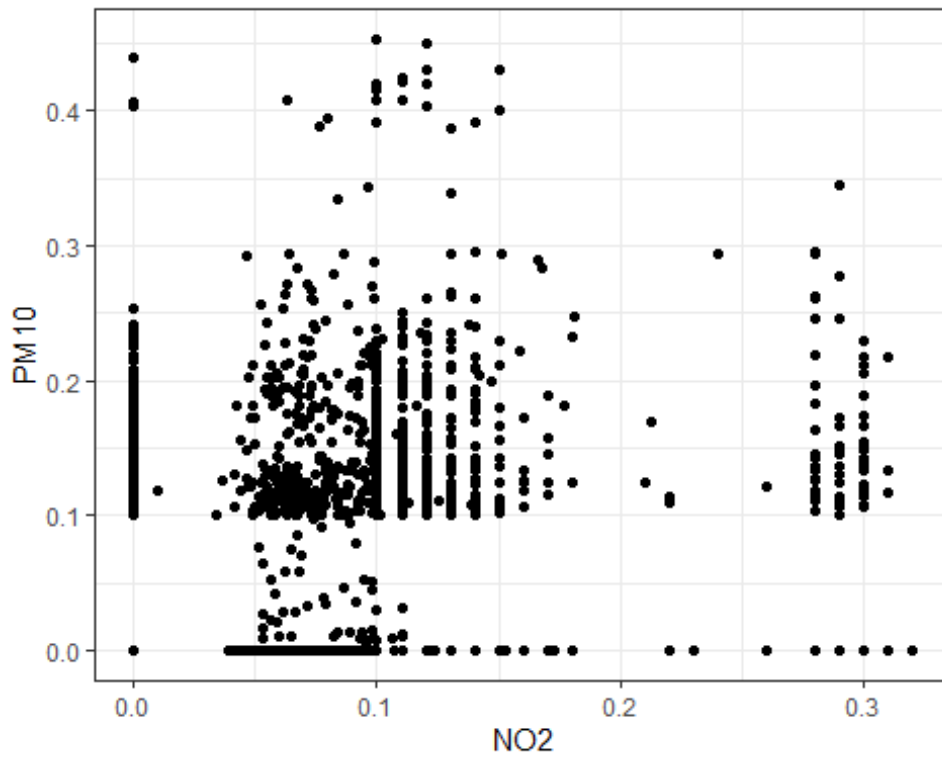
```
ggplot(data, aes(x = Humidity, y = PM10)) +  
  geom_point()
```



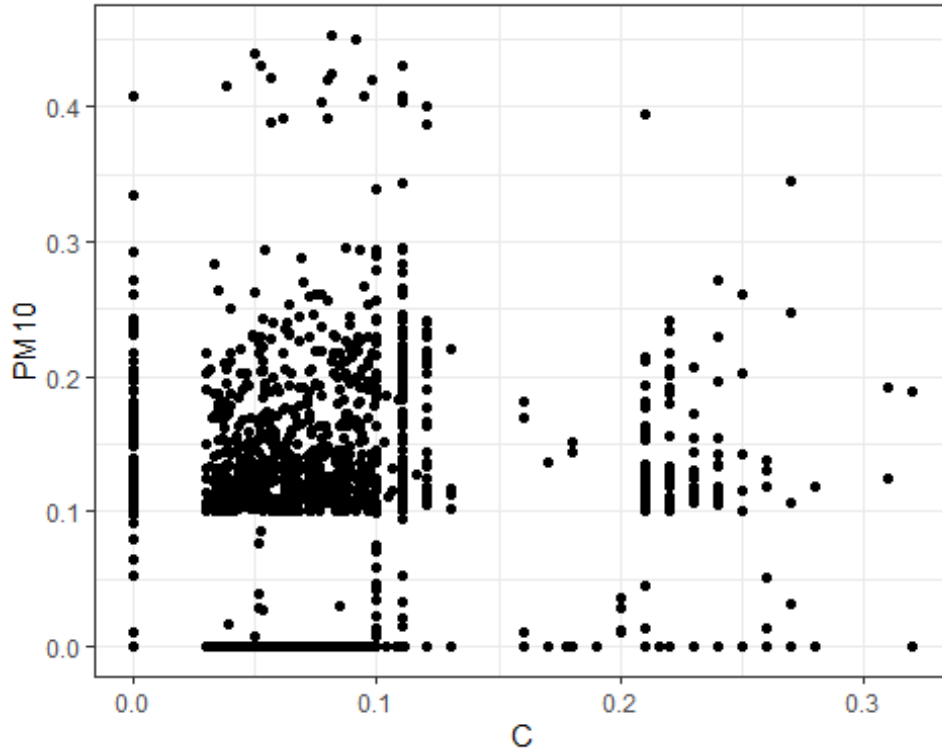
```
ggplot(data, aes(x = Wind_V, y = PM10)) +  
  geom_point()
```



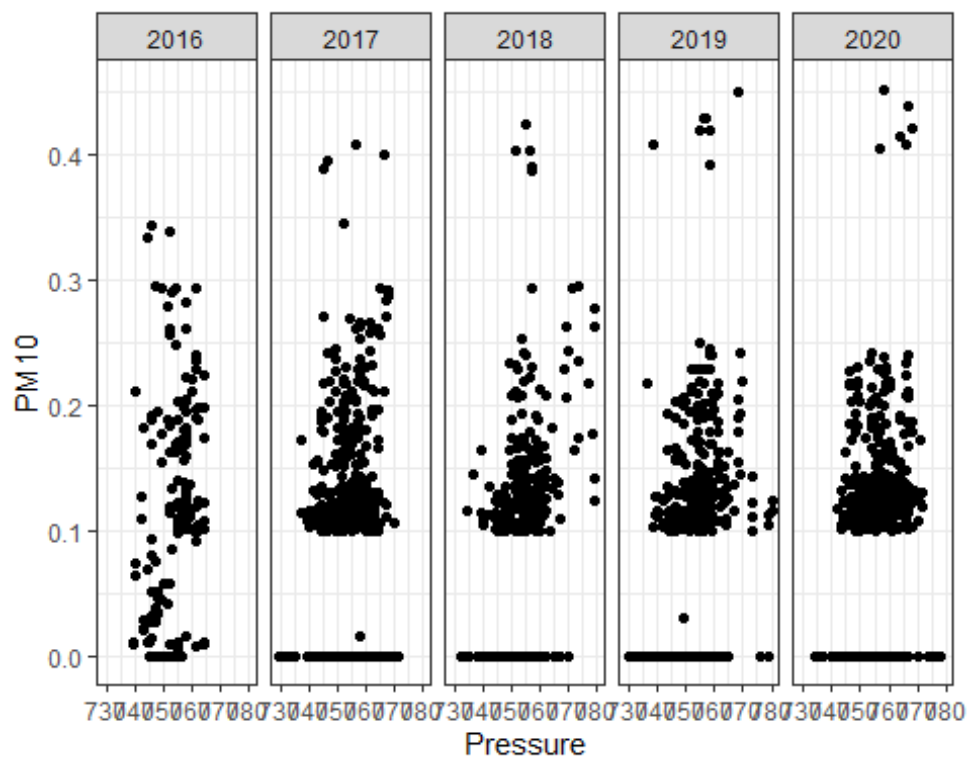
```
ggplot(data, aes(x = N02, y = PM10)) +  
  geom_point()
```



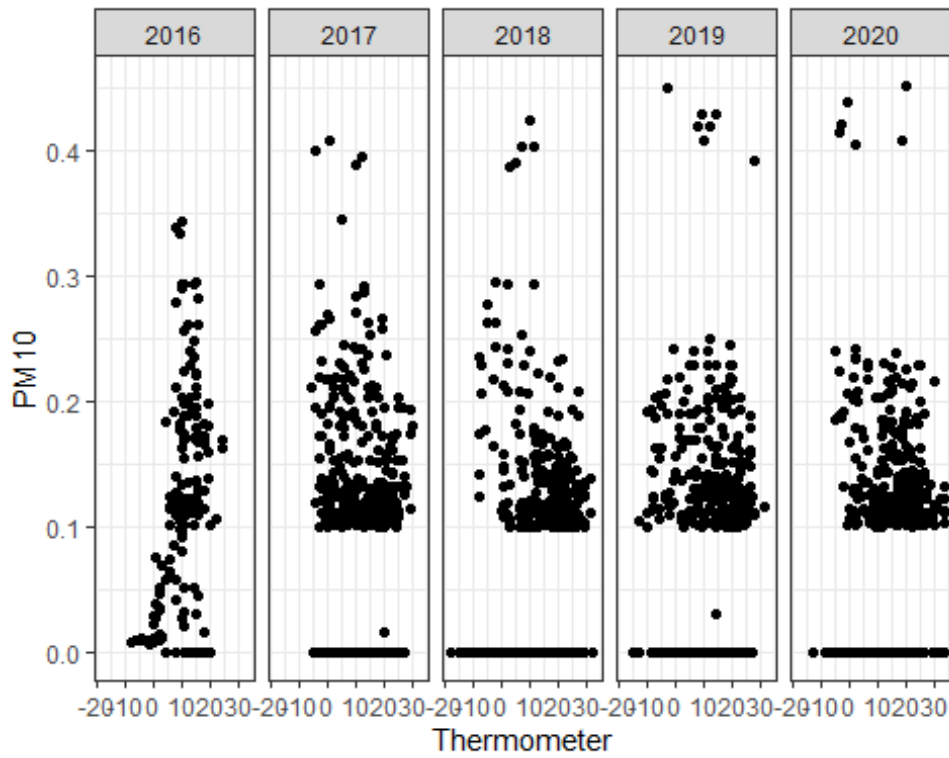
```
ggplot(data, aes(x = C, y = PM10)) +  
  geom_point()
```



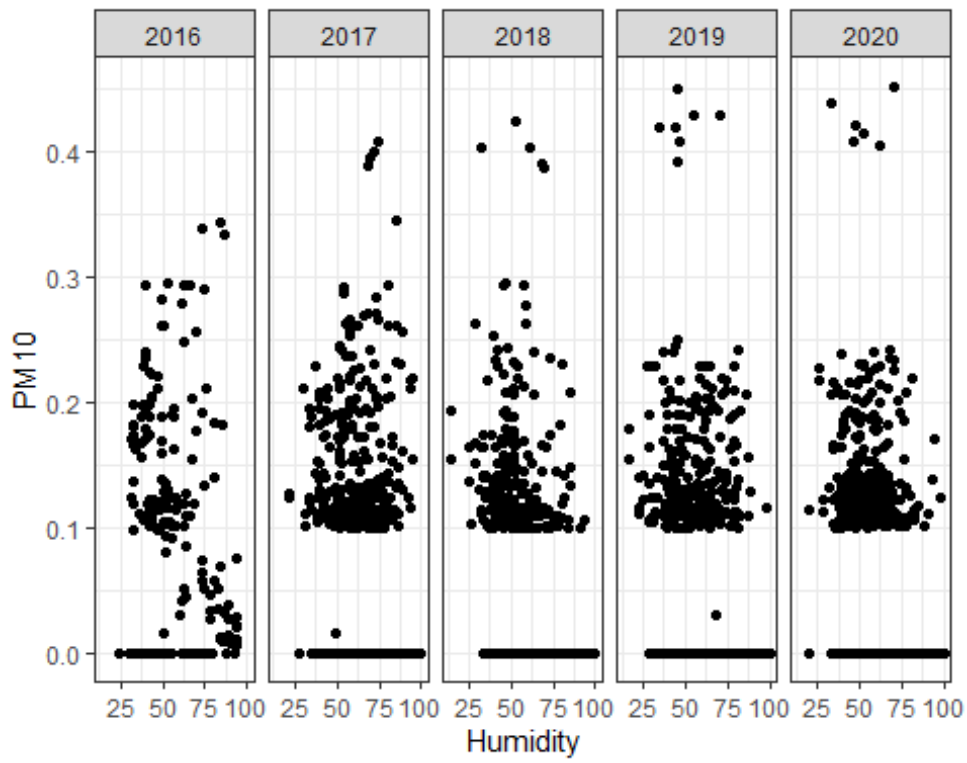
```
ggplot(data, aes(x = Pressure, y = PM10)) +  
  geom_point() +  
  facet_grid(~ Year)
```



```
ggplot(data, aes(x = Thermometer, y = PM10)) +  
  geom_point() +  
  facet_grid(~ Year)
```

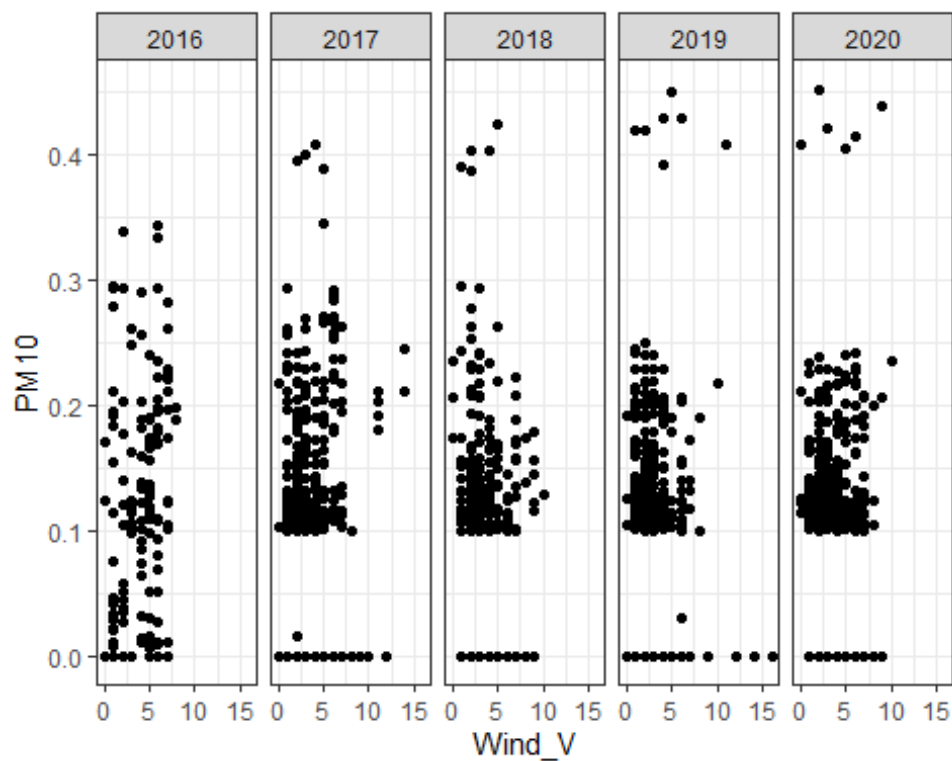


```
ggplot(data, aes(x = Humidity, y = PM10)) +  
  geom_point() +  
  facet_grid(~ Year)
```

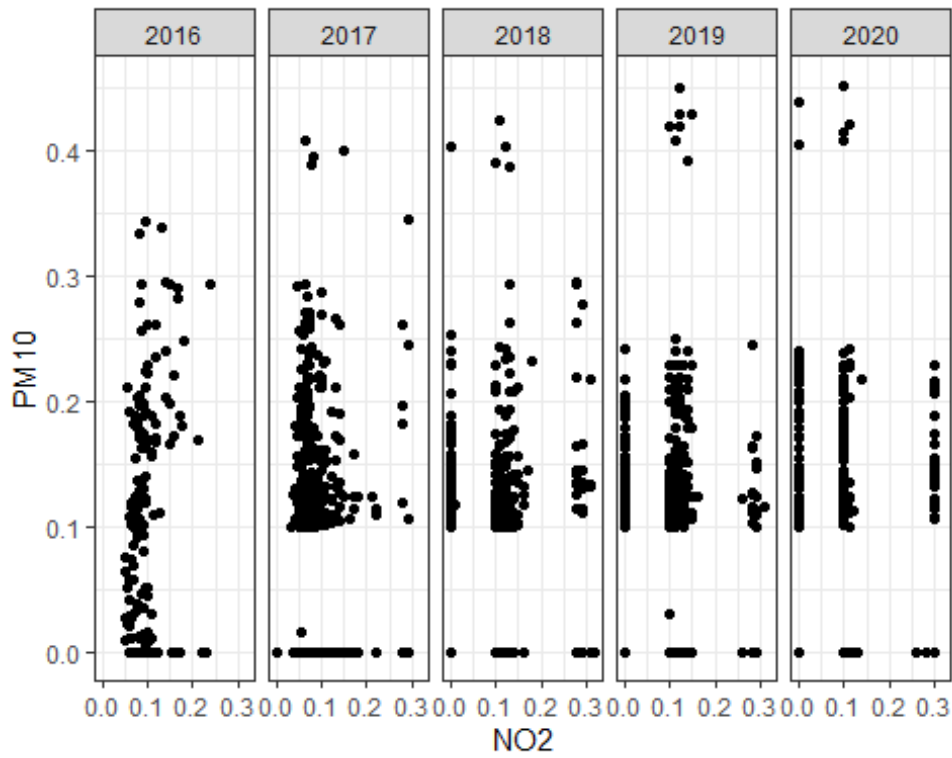




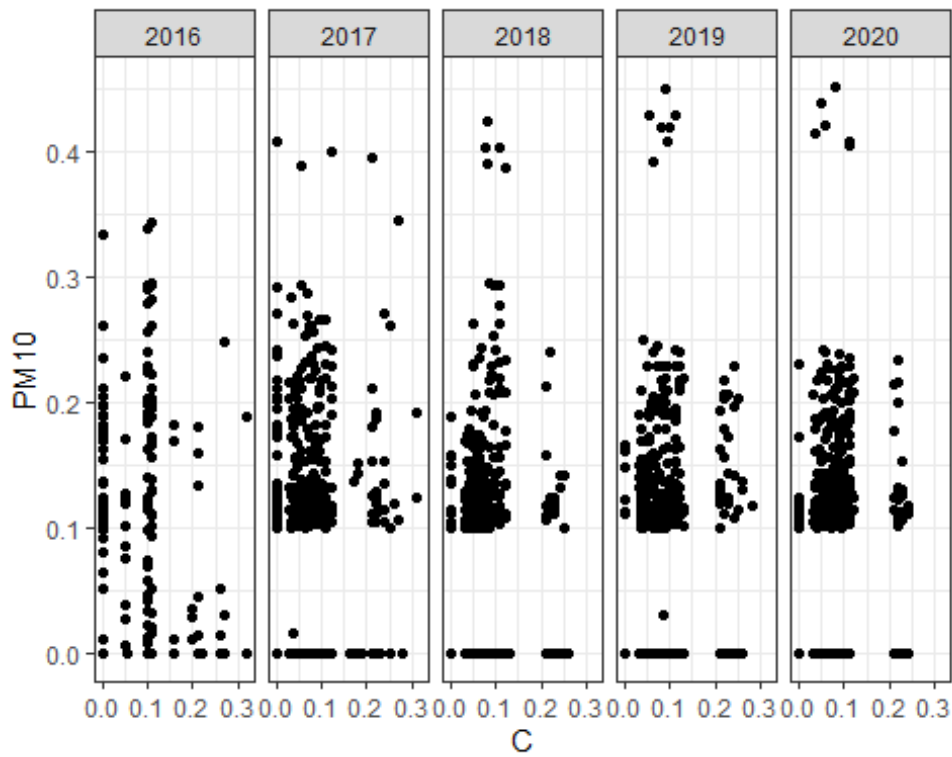
```
ggplot(data, aes(x = Wind_V, y = PM10)) +
  geom_point() +
  facet_grid( ~ Year)
```



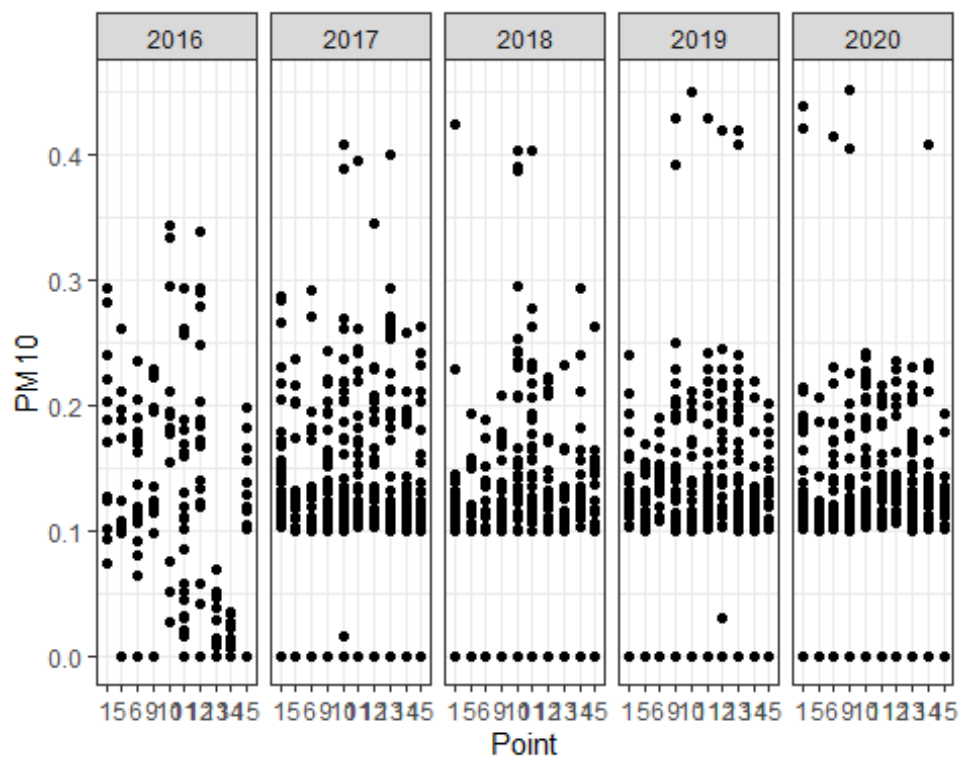
```
ggplot(data, aes(x = NO2, y = PM10)) +
  geom_point() +
  facet_grid( ~ Year)
```



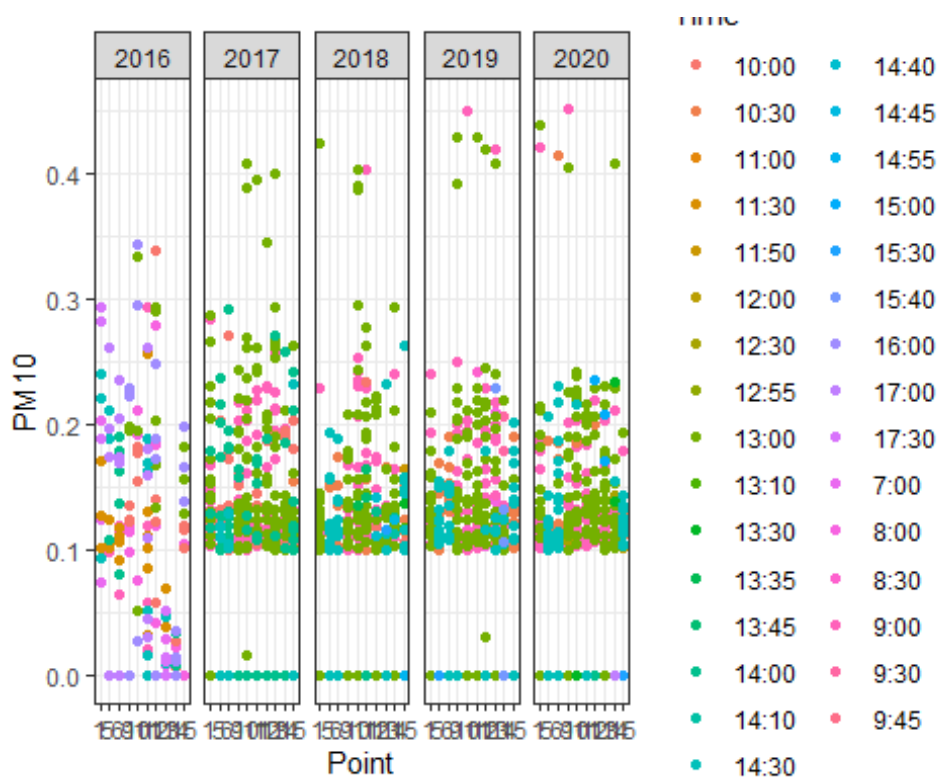
```
ggplot(data, aes(x = C, y = PM10)) +  
  geom_point() +  
  facet_grid(~ Year)
```



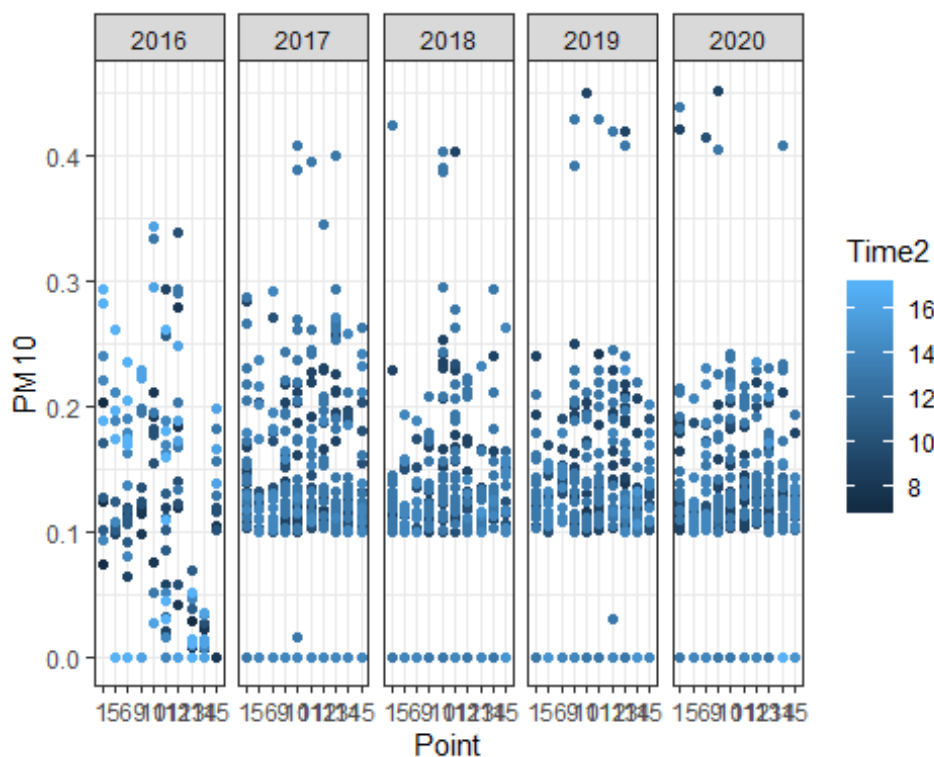
```
ggplot(data, aes(x = Point, y = PM10)) +  
  geom_point() +  
  facet_grid( ~ Year)
```



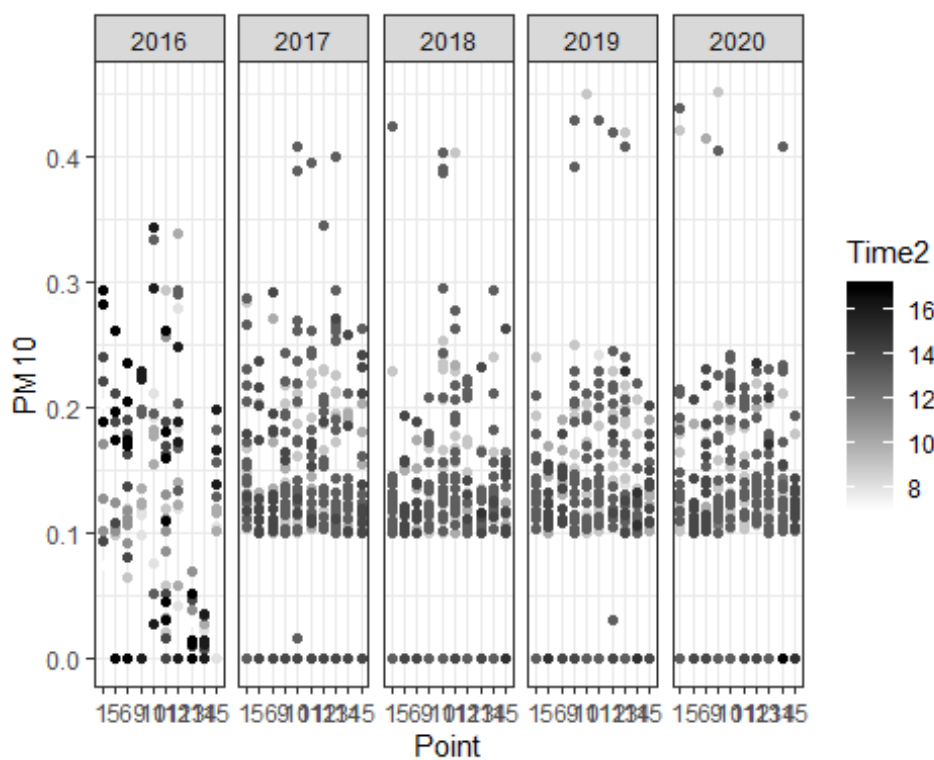
```
ggplot(data, aes(x = Point, y = PM10, colour = Time)) +  
  geom_point() +  
  facet_grid( ~ Year)
```



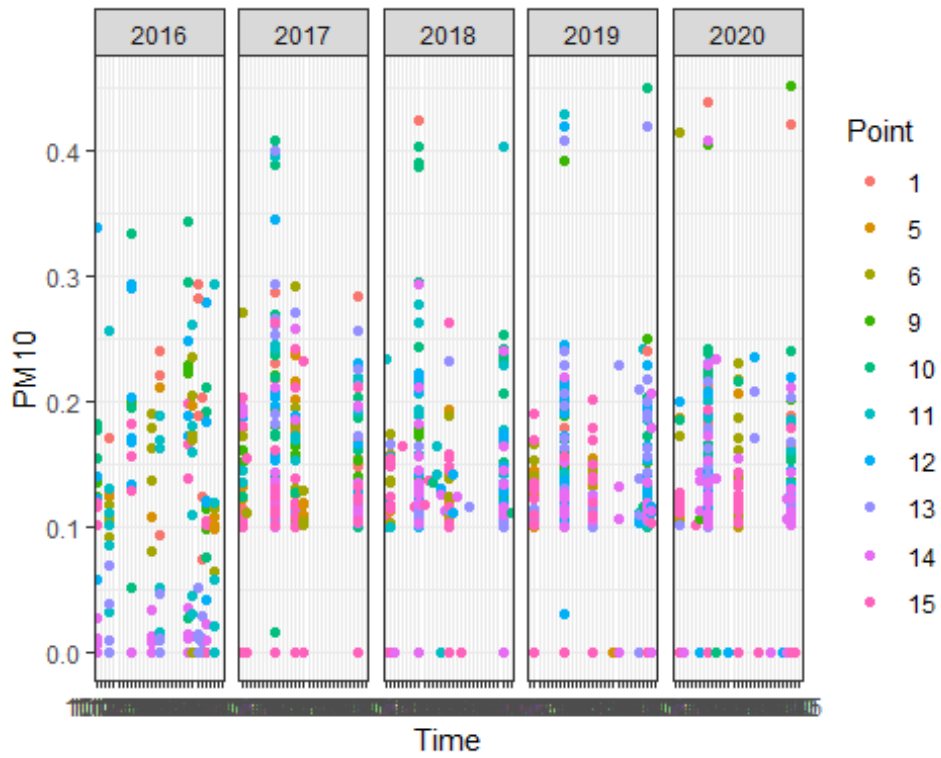
```
ggplot(data, aes(x = Point, y = PM10, colour = Time2)) +
  geom_point() +
  facet_grid(~ Year) +
  scale_color_continuous(breaks = c(8, 10, 12, 14, 16))
```



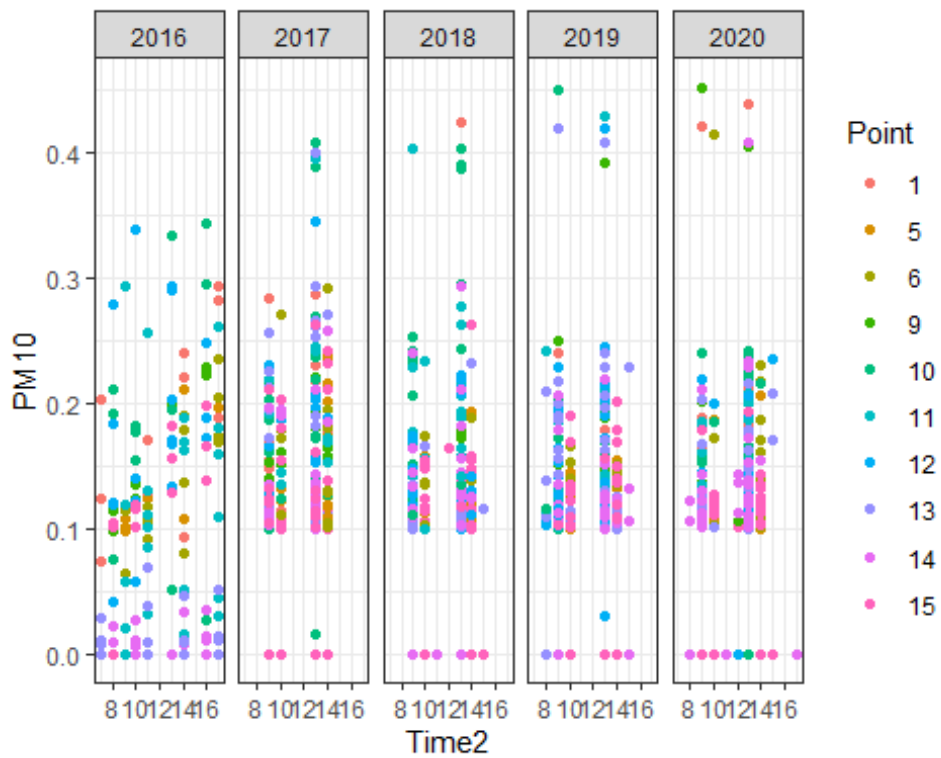
```
ggplot(data, aes(x = Point, y = PM10, colour = Time2)) +
  geom_point() +
  facet_grid( ~ Year) +
  scale_color_gradient(low = 'white', high = 'black', breaks = c(8, 10, 12, 14,
16))
```



```
ggplot(data, aes(x = Time, y = PM10, colour = Point)) +
  geom_point() +
  facet_grid( ~ Year)
```



```
ggplot(data, aes(x = Time2, y = PM10, colour = Point)) +
  geom_point() +
  scale_x_continuous(breaks = c(8, 10, 12, 14, 16)) +
  facet_grid( ~ Year)
```



```

mod1 <- lmer(PM10 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 + C
+ Daytime + (1 + Year|Point/Daytime), data = data)

## boundary (singular) fit: see ?isSingular

summary(mod1)

## Linear mixed model fit by REML ['lmerMod']
## Formula: PM10 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 +
##       C + Daytime + (1 + Year | Point/Daytime)
##       Data: data
##
## REML criterion at convergence: -5558.8
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.6080 -0.7054 -0.0655  0.5733  5.0774
##
## Random effects:
##   Groups             Name                Variance  Std.Dev.  Corr
##   Daytime:Point (Intercept) 0.000e+00 0.000000
##                   Year2017  1.366e-05 0.003697   NaN
##                   Year2018  9.976e-06 0.003159   NaN -1.00
##                   Year2019  1.096e-05 0.003310   NaN -1.00  1.00
##                   Year2020  3.259e-06 0.001805   NaN  1.00 -1.00 -1.00
##   Point              (Intercept) 3.153e-03 0.056153
##                   Year2017  2.396e-03 0.048949 -0.95
##                   Year2018  1.820e-03 0.042665 -0.99  0.99
##                   Year2019  4.010e-03 0.063324 -0.95  0.99  0.98
##                   Year2020  2.401e-03 0.048999 -0.97  0.99  1.00  0.97
##   Residual                    5.097e-03 0.071396
## Number of obs: 2349, groups:  Daytime:Point, 30; Point, 10
##
## Fixed effects:
##              Estimate Std. Error t value
## (Intercept)  -1.5317552  0.1741648  -8.795
## Year2017      -0.0057140  0.0168425  -0.339
## Year2018      -0.0289539  0.0150280  -1.927
## Year2019      -0.0203174  0.0210775  -0.964
## Year2020      -0.0117980  0.0168374  -0.701
## Pressure       0.0022531  0.0002258   9.977
## Thermometer    0.0003129  0.0001916   1.633
## Humidity       -0.0014097  0.0001041 -13.537
## Wind_V         0.0012684  0.0007980   1.589
## NO2            0.1312642  0.0247525   5.303
## C              0.0819140  0.0339904   2.410
## Daytimeevening 0.0033880  0.0101510   0.334
## Daytimemorning -0.0086480  0.0032153  -2.690
##
## Correlation matrix not shown by default, as p = 13 > 12.
## Use print(x, correlation=TRUE) or
##       vcov(x)           if you need it

```

```
## convergence code: 0
## boundary (singular) fit: see ?isSingular

#Диагностика модели (анализ остатков)
mod1_diag <- data.frame(
  data,
  .fitted = fitted(mod1),
  .resid = resid(mod1, type = 'pearson'),
  .sresid = resid(mod1, type = 'pearson', scaled = TRUE)
)

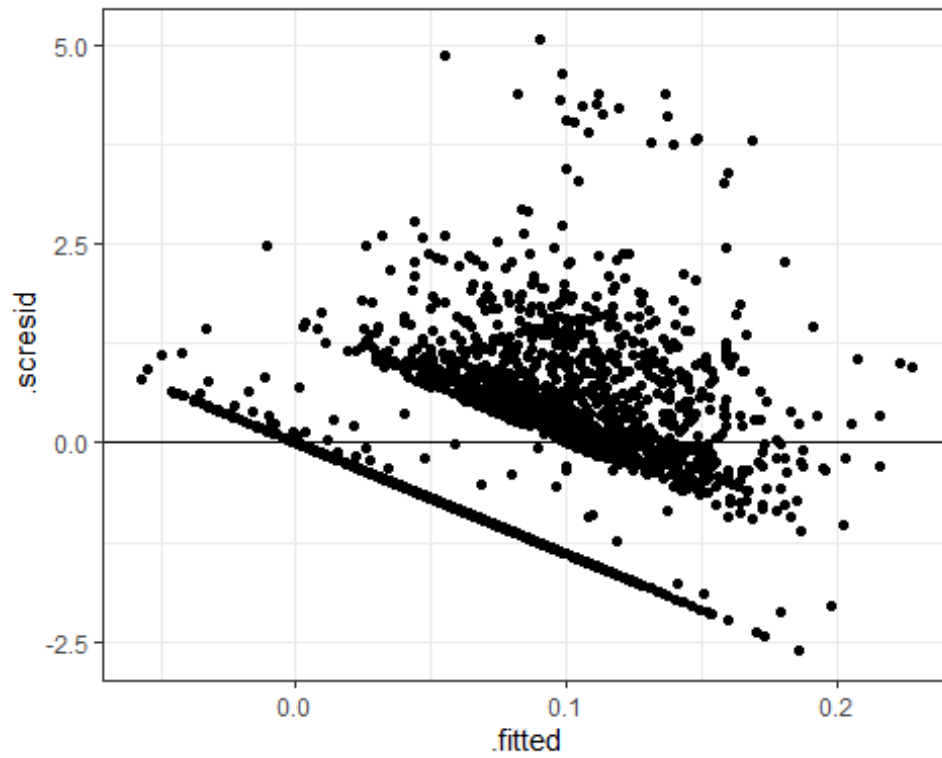
#.fitted - предсказанные значения,
#.resid - Пирсоновские остатки,
#.sresid - стандартизованные Пирсоновские остатки

head(mod1_diag, 4)

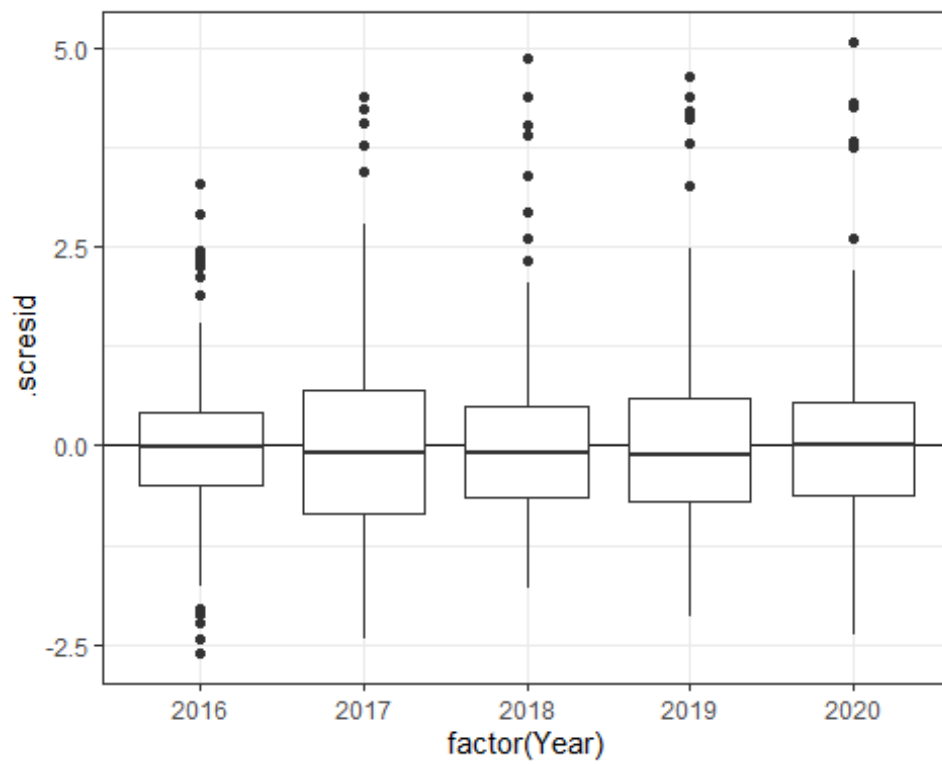
##   Year Point abs_risk_450 abs_risk_451 abs_risk_458 abs_risk      Date Time
## 1 2016     1          NA          NA          NA      NA 26.04.2016 7:00
## 2 2016     1          NA          NA          NA      NA 27.04.2016 7:00
## 3 2016     1          NA          NA          NA      NA 28.04.2016 7:00
## 4 2016    13          NA          NA          NA      NA 16.05.2016 7:00
##   Time2 Daytime Thermometer Pressure Humidity      Wind Wind_V Weather  TSP
## 1     7 morning           6       740       73 south west     4 cloudy 0.114
## 2     7 morning           6       758       58  east     3  clear 0.189
## 3     7 morning          10       758       43  east     4  clear 0.305
## 4     7 morning          15       745       61 south     1 cloudy 0.000
##   TSPn PM10 PM10n PM2.5 PM2.5n  NO2 NO2n    C  Cn      .fitted      .resi
##   d
## 1 0.5 0.075  0.3 0.036  0.16 0.065  0.2 0.10 0.15  0.100238319 -0.02523831
## 2 0.5 0.124  0.3 0.059  0.16 0.071  0.2 0.10 0.15  0.161459876 -0.03745987
## 3 0.5 0.203  0.3 0.077  0.16 0.077  0.2 0.10 0.15  0.185913185  0.01708681
## 4 0.5 0.000  0.3 0.000  0.16 0.062  0.2 0.11 0.15 -0.001092027  0.00109202
##
##      .sresid
## 1 -0.35349545
## 2 -0.52467423
## 3  0.23932305
## 4  0.01529526

#График остатков от предсказанных значений
gg_resid <- ggplot(mod1_diag, aes(y = .sresid)) +
  geom_hline(yintercept = 0)
gg_resid + geom_point(aes(x = .fitted))
```

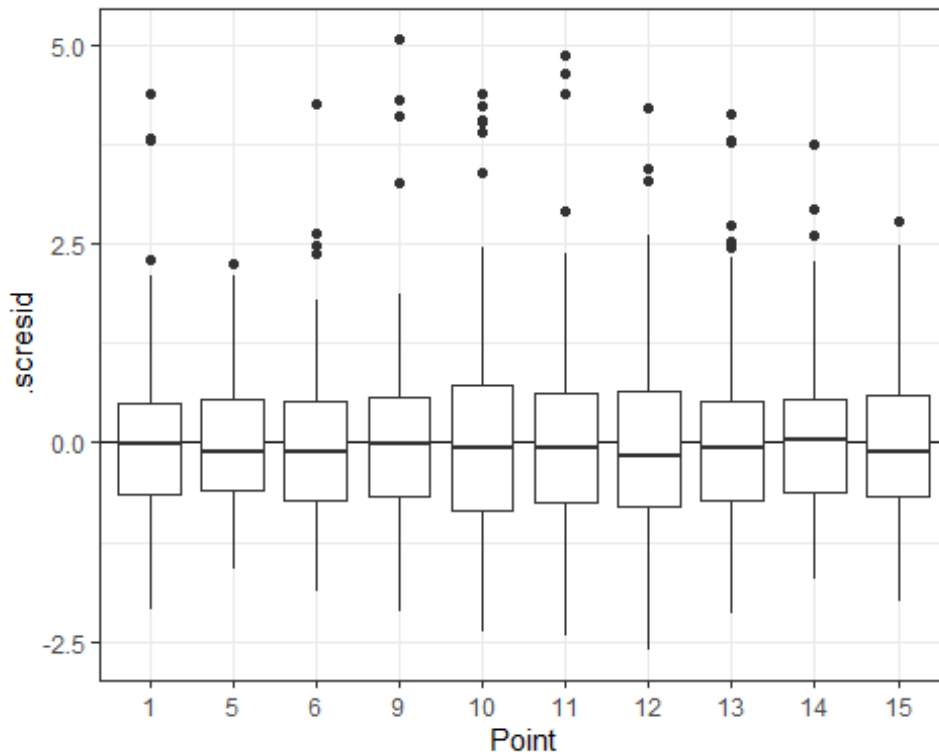




```
gg_resid + geom_boxplot(aes(x = factor(Year)))
```



```
gg_resid + geom_boxplot(aes(x = Point))
```



```
ctrl <- lmeControl(opt='optim', returnObject = TRUE)

mod1 <- lme(PM10 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 + C +
Time, random = ~1|Point, control = ctrl, data = data)
mod2 <- lme(PM10 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2 + C +
Time, random = ~1 + Year|Point, control = ctrl, data = data)

AIC(mod1, mod2)

##          df          AIC
## mod1 43 -5300.478
## mod2 57 -5350.762

#Ковариата - дискретный фактор
mod2_1 <- update(mod2, weights = varIdent(form = ~ 1|Year))

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 1

mod2_2 <- update(mod2, weights = varIdent(form = ~ 1|Time))

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 3

## Warning in logLik.reStruct(object, conLin): Singular precision matrix in leve
l
## -1, block 3
```

```
## Warning in logLik.reStruct(object, conLin): Singular precision matrix in level
1
## -1, block 2

## Warning in lme.formula(fixed = PM10 ~ Year + Pressure + Thermometer + Humidity + : optim problem, convergence error code = 1
## message =

summary(mod2_2)

## Linear mixed-effects model fit by REML
## Data: data
##      AIC      BIC    logLik
## -5382.584 -4882.844 2778.292
##
## Random effects:
## Formula: ~1 + Year | Point
## Structure: General positive-definite, Log-Cholesky parametrization
##           StdDev      Corr
## (Intercept) 0.05456655 (Intr) Yr2017 Yr2018 Yr2019
## Year2017    0.04775800 -0.988
## Year2018    0.04502516 -0.990  0.988
## Year2019    0.06282170 -0.974  0.987  0.992
## Year2020    0.04323879 -0.989  0.972  0.961  0.936
## Residual    0.03910525
##
## Variance function:
## Structure: Different standard deviations per stratum
## Formula: ~1 | Time
## Parameter estimates:
##      7:00      8:00      9:00      10:00      11:30      13:00
## 1.000000000 1.641757829 1.794825602 1.775311899 1.392704883 2.069194290
##      14:00      14:30      17:30      10:30      15:30      17:00
## 1.952776868 1.497681222 1.850576485 1.504515078 0.996784278 2.005608986
##      8:30      12:30      16:00      9:45      13:30      13:35
## 2.493654161 1.180654104 2.247499852 1.000000183 2.969257242 0.9999999702
##      13:45      9:30      14:40      15:00      15:40      11:00
## 0.000226822 1.989666117 0.598785183 0.013417451 1.781710820 0.736758722
##      14:10      14:45      11:50      12:00      12:55      13:10
## 1.000000029 1.000000168 1.000000031 1.000000157 1.000000046 0.999999913
##      14:55
## 1.000000042
## Fixed effects: PM10 ~ Year + Pressure + Thermometer + Humidity + Wind_V + NO2
+      C + Time
##           Value Std.Error  DF    t-value p-value
## (Intercept) -1.4878437 0.15898558 2299   -9.358356  0.0000
## Year2017     -0.0101531 0.01696957 2299   -0.598314  0.5497
## Year2018     -0.0359338 0.01623968 2299   -2.212713  0.0270
## Year2019     -0.0288680 0.02131417 2299   -1.354402  0.1757
## Year2020     -0.0211384 0.01574623 2299   -1.342444  0.1796
## Pressure      0.0021595 0.00020450 2299   10.559865  0.0000
## Thermometer   0.0002879 0.00017146 2299    1.679146  0.0933
```

```

## Humidity      -0.0013542 0.00007205 2299 -18.794664 0.0000
## Wind_V        0.0017976 0.00050757 2299  3.541570 0.0004
## NO2           0.1362023 0.01891230 2299  7.201786 0.0000
## C             0.0709075 0.01973657 2299  3.592696 0.0003
## Time10:30     0.0108341 0.00829189 2299  1.306590 0.1915
## Time11:00    -0.0274909 0.01669119 2299 -1.647029 0.0997
## Time11:30     0.0101818 0.01502189 2299  0.677796 0.4980
## Time11:50     0.0904250 0.04018818 2299  2.250039 0.0245
## Time12:00     0.1078273 0.04019618 2299  2.682525 0.0074
## Time12:30     0.0240110 0.02230681 2299  1.076398 0.2819
## Time12:55     0.0541378 0.04014332 2299  1.348614 0.1776
## Time13:00     0.0376888 0.00775157 2299  4.862090 0.0000
## Time13:10     0.0379549 0.04015393 2299  0.945234 0.3446
## Time13:30     0.0564468 0.05862029 2299  0.962922 0.3357
## Time13:35     0.0082197 0.04047002 2299  0.203105 0.8391
## Time13:45     0.0215917 0.00998513 2299  2.162390 0.0307
## Time14:00     0.0061477 0.00961399 2299  0.639457 0.5226
## Time14:10     0.0729277 0.04012919 2299  1.817323 0.0693
## Time14:30     0.0161808 0.00817471 2299  1.979378 0.0479
## Time14:40     0.0443911 0.01893357 2299  2.344569 0.0191
## Time14:45     0.0384348 0.04027352 2299  0.954344 0.3400
## Time14:55    -0.0593922 0.04020546 2299 -1.477218 0.1398
## Time15:00     0.1767780 0.00872342 2299 20.264759 0.0000
## Time15:30    -0.0086432 0.01693505 2299 -0.510376 0.6098
## Time15:40     0.0381845 0.03622704 2299  1.054033 0.2920
## Time16:00     0.0177264 0.02171919 2299  0.816165 0.4145
## Time17:00     0.0245953 0.02002563 2299  1.228189 0.2195
## Time17:30     0.0254766 0.02825403 2299  0.901696 0.3673
## Time7:00      0.0240837 0.01932057 2299  1.246530 0.2127
## Time8:00      0.0103801 0.01308012 2299  0.793575 0.4275
## Time8:30      0.0302043 0.03770942 2299  0.800974 0.4232
## Time9:00      0.0284443 0.00755733 2299  3.763802 0.0002
## Time9:30      0.0162857 0.02318579 2299  0.702402 0.4825
## Time9:45      0.0311047 0.04019248 2299  0.773892 0.4391
## Correlation:
##              (Intr) Yr2017 Yr2018 Yr2019 Yr2020 Pressr Thrmmmt Humdty Wind_V
## Year2017      -0.117
## Year2018      -0.123  0.946
## Year2019      -0.115  0.950  0.959
## Year2020      -0.082  0.931  0.934  0.909
## Pressure      -0.992  0.004  0.013  0.005 -0.028
## Thermometer   -0.431  0.003 -0.005 -0.009 -0.031  0.423
## Humidity      -0.489 -0.024  0.006 -0.006 -0.008  0.473  0.314
## Wind_V        -0.568  0.024  0.018  0.014 -0.010  0.581  0.038 -0.271
## NO2           -0.086 -0.002  0.030  0.005  0.033  0.065 -0.109  0.335  0.063
## C             0.454  0.009  0.018  0.002  0.038 -0.473 -0.129 -0.261 -0.059
## Time10:30     -0.086  0.005 -0.100 -0.079 -0.113  0.055  0.066 -0.001  0.062
## Time11:00      0.042 -0.001 -0.056 -0.035 -0.077 -0.055  0.029 -0.092 -0.011
## Time11:30     -0.036  0.184  0.155  0.113  0.155 -0.001  0.031  0.056 -0.057
## Time11:50     -0.032  0.003 -0.028 -0.012 -0.018  0.026 -0.009  0.033 -0.009
## Time12:00     -0.071  0.004 -0.013 -0.012 -0.031  0.065  0.029  0.011  0.056
## Time12:30     -0.028 -0.002 -0.034 -0.025 -0.064  0.019 -0.017  0.017 -0.014

```

```

## Time12:55    0.014  0.004 -0.027 -0.011 -0.015 -0.022 -0.023  0.003 -0.010
## Time13:00   -0.080 -0.009 -0.093 -0.075 -0.103  0.050  0.042  0.051 -0.037
## Time13:10    0.005  0.003 -0.029 -0.012 -0.017 -0.011 -0.011  0.020 -0.036
## Time13:30    0.011  0.001 -0.014 -0.009 -0.020 -0.015  0.010 -0.011 -0.008
## Time13:35    0.008  0.000 -0.033 -0.013 -0.019 -0.012 -0.002  0.001 -0.047
## Time13:45   -0.012 -0.016 -0.150 -0.068 -0.100 -0.006 -0.046  0.034 -0.111
## Time14:00   -0.008 -0.032 -0.026 -0.020 -0.029 -0.016 -0.008  0.040 -0.061
## Time14:10    0.040 -0.003 -0.034 -0.016 -0.020 -0.045 -0.041 -0.041 -0.012
## Time14:30   -0.056  0.026 -0.075 -0.061 -0.084  0.022  0.039  0.062 -0.039
## Time14:40   -0.016 -0.007 -0.075 -0.034 -0.048  0.007 -0.034 -0.008 -0.013
## Time14:45    0.011 -0.004 -0.035 -0.016 -0.022 -0.015 -0.035  0.005 -0.035
## Time14:55   -0.023  0.002 -0.027 -0.011 -0.015  0.015 -0.026  0.051 -0.018
## Time15:00    0.032 -0.003 -0.088 -0.070 -0.162 -0.064  0.152  0.048 -0.170
## Time15:30    0.047  0.009 -0.043 -0.040 -0.056 -0.062  0.048 -0.072 -0.029
## Time15:40    0.033  0.001 -0.019 -0.028 -0.018 -0.040 -0.039 -0.006 -0.041
## Time16:00   -0.050  0.125  0.111  0.084  0.111  0.031 -0.002  0.007  0.001
## Time17:00   -0.004  0.108  0.082  0.060  0.078 -0.019  0.008  0.022 -0.058
## Time17:30   -0.053  0.112  0.096  0.072  0.095  0.033  0.041  0.089 -0.083
## Time7:00    -0.127  0.168  0.145  0.107  0.141  0.097  0.092  0.103 -0.006
## Time8:00    -0.076  0.129  0.091  0.055  0.085  0.050  0.017 -0.085  0.127
## Time8:30    -0.010  0.000 -0.019 -0.018 -0.032  0.004  0.000 -0.013  0.016
## Time9:00    -0.110 -0.008 -0.094 -0.076 -0.107  0.079  0.064  0.002  0.058
## Time9:30     0.000  0.002 -0.029 -0.038 -0.036 -0.010 -0.014 -0.003 -0.017
## Time9:45     0.008  0.002 -0.030 -0.012 -0.017 -0.013 -0.011 -0.015 -0.011
##              NO2      C          T10:30 T11:00 T11:30 T11:50 T12:00 T12:30 T12:55
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V
## NO2
## C          0.738
## Time10:30   0.046  0.041
## Time11:00  -0.104 -0.023  0.375
## Time11:30   0.017  0.000  0.381  0.154
## Time11:50  -0.028 -0.056  0.162  0.075  0.069
## Time12:00   0.016 -0.010  0.166  0.078  0.068  0.031
## Time12:30  -0.059 -0.078  0.282  0.176  0.124  0.062  0.063
## Time12:55   0.033  0.033  0.166  0.073  0.068  0.048  0.030  0.055
## Time13:00  -0.127 -0.154  0.756  0.389  0.372  0.165  0.161  0.304  0.151
## Time13:10  -0.020 -0.027  0.162  0.076  0.070  0.051  0.029  0.060  0.049
## Time13:30  -0.010  0.005  0.111  0.066  0.046  0.024  0.023  0.047  0.024
## Time13:35  -0.111 -0.102  0.142  0.084  0.064  0.039  0.027  0.065  0.031
## Time13:45  -0.362 -0.375  0.614  0.340  0.334  0.165  0.117  0.269  0.133
## Time14:00  -0.025 -0.038  0.498  0.245  0.291  0.102  0.097  0.188  0.099
## Time14:10  -0.026  0.001  0.145  0.081  0.058  0.033  0.027  0.053  0.034
## Time14:30   0.019 -0.008  0.803  0.370  0.430  0.167  0.160  0.287  0.166
## Time14:40  -0.135 -0.140  0.303  0.166  0.119  0.079  0.061  0.127  0.067
## Time14:45  -0.076 -0.079  0.139  0.081  0.060  0.039  0.027  0.060  0.032

```

## Time14:55	0.038	-0.002	0.164	0.068	0.070	0.051	0.031	0.058	0.051
## Time15:00	-0.037	0.018	0.754	0.400	0.372	0.145	0.160	0.313	0.145
## Time15:30	-0.046	0.033	0.393	0.200	0.178	0.071	0.091	0.140	0.074
## Time15:40	-0.022	-0.013	0.169	0.072	0.090	0.035	0.033	0.056	0.034
## Time16:00	-0.099	-0.113	0.167	0.113	0.150	0.049	0.043	0.088	0.039
## Time17:00	-0.043	-0.041	0.290	0.134	0.342	0.056	0.051	0.105	0.052
## Time17:30	-0.080	-0.120	0.187	0.085	0.287	0.044	0.035	0.079	0.032
## Time7:00	0.008	-0.055	0.290	0.117	0.416	0.056	0.060	0.103	0.050
## Time8:00	-0.030	-0.005	0.378	0.209	0.237	0.077	0.091	0.149	0.077
## Time8:30	-0.005	0.000	0.170	0.098	0.074	0.033	0.038	0.075	0.033
## Time9:00	-0.057	-0.071	0.794	0.399	0.390	0.162	0.171	0.303	0.156
## Time9:30	-0.030	-0.027	0.269	0.122	0.130	0.055	0.061	0.094	0.053
## Time9:45	-0.040	-0.029	0.149	0.080	0.063	0.036	0.029	0.059	0.033
##	T13:00	T13:10	T13:30	T13:35	T13:45	T14:00	T14:10	T14:30	T14:40
## Year2017									
## Year2018									
## Year2019									
## Year2020									
## Pressure									
## Thermometer									
## Humidity									
## Wind_V									
## NO2									
## C									
## Time10:30									
## Time11:00									
## Time11:30									
## Time11:50									
## Time12:00									
## Time12:30									
## Time12:55									
## Time13:00									
## Time13:10	0.162								
## Time13:30	0.110	0.024							
## Time13:35	0.181	0.039	0.022						
## Time13:45	0.732	0.159	0.092	0.196					
## Time14:00	0.531	0.103	0.069	0.104	0.441				
## Time14:10	0.158	0.034	0.021	0.037	0.151	0.102			
## Time14:30	0.773	0.167	0.110	0.151	0.653	0.514	0.146		
## Time14:40	0.356	0.076	0.045	0.090	0.365	0.209	0.075	0.311	
## Time14:45	0.171	0.038	0.020	0.046	0.184	0.106	0.050	0.148	0.087
## Time14:55	0.156	0.051	0.023	0.033	0.142	0.101	0.032	0.168	0.070
## Time15:00	0.776	0.151	0.115	0.152	0.622	0.480	0.141	0.765	0.281
## Time15:30	0.377	0.074	0.057	0.074	0.304	0.240	0.074	0.389	0.149
## Time15:40	0.192	0.036	0.021	0.039	0.158	0.116	0.045	0.178	0.076
## Time16:00	0.226	0.046	0.030	0.057	0.176	0.148	0.046	0.183	0.107
## Time17:00	0.284	0.056	0.038	0.056	0.290	0.226	0.047	0.322	0.105
## Time17:30	0.233	0.042	0.025	0.050	0.205	0.151	0.031	0.231	0.079
## Time7:00	0.317	0.053	0.035	0.052	0.229	0.209	0.041	0.336	0.091
## Time8:00	0.412	0.074	0.058	0.078	0.281	0.259	0.081	0.375	0.179
## Time8:30	0.174	0.032	0.027	0.034	0.144	0.107	0.031	0.167	0.068
## Time9:00	0.848	0.159	0.113	0.171	0.709	0.540	0.160	0.795	0.347

```

## Time9:30      0.292  0.055  0.035  0.057  0.235  0.177  0.061  0.276  0.122
## Time9:45      0.169  0.035  0.022  0.056  0.161  0.099  0.036  0.151  0.079
##              T14:45 T14:55 T15:00 T15:30 T15:40 T16:00 T17:00 T17:30 Tm7:00
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V
## NO2
## C
## Time10:30
## Time11:00
## Time11:30
## Time11:50
## Time12:00
## Time12:30
## Time12:55
## Time13:00
## Time13:10
## Time13:30
## Time13:35
## Time13:45
## Time14:00
## Time14:10
## Time14:30
## Time14:40
## Time14:45
## Time14:55      0.034
## Time15:00      0.142  0.143
## Time15:30      0.070  0.068  0.393
## Time15:40      0.047  0.035  0.167  0.089
## Time16:00      0.055  0.042  0.171  0.092  0.045
## Time17:00      0.052  0.053  0.269  0.134  0.066  0.109
## Time17:30      0.044  0.039  0.240  0.101  0.053  0.104  0.141
## Time7:00       0.046  0.055  0.339  0.147  0.069  0.136  0.194  0.373
## Time8:00       0.077  0.073  0.346  0.196  0.089  0.253  0.168  0.131  0.205
## Time8:30       0.030  0.032  0.178  0.085  0.034  0.046  0.059  0.041  0.061
## Time9:00       0.163  0.157  0.790  0.389  0.190  0.212  0.293  0.222  0.325
## Time9:30       0.064  0.054  0.261  0.141  0.094  0.072  0.099  0.073  0.101
## Time9:45       0.038  0.033  0.147  0.074  0.036  0.049  0.051  0.038  0.049
##              Tm8:00 Tm8:30 Tm9:00 Tm9:30
## Year2017
## Year2018
## Year2019
## Year2020
## Pressure
## Thermometer
## Humidity
## Wind_V

```

```

## N02
## C
## Time10:30
## Time11:00
## Time11:30
## Time11:50
## Time12:00
## Time12:30
## Time12:55
## Time13:00
## Time13:10
## Time13:30
## Time13:35
## Time13:45
## Time14:00
## Time14:10
## Time14:30
## Time14:40
## Time14:45
## Time14:55
## Time15:00
## Time15:30
## Time15:40
## Time16:00
## Time17:00
## Time17:30
## Time7:00
## Time8:00
## Time8:30      0.092
## Time9:00      0.427  0.180
## Time9:30      0.144  0.057  0.295
## Time9:45      0.082  0.035  0.169  0.055
##
## Standardized Within-Group Residuals:
##      Min      Q1      Med      Q3      Max
## -2.5525080 -0.7157628 -0.0634282  0.5806522  5.2935560
##
## Number of Observations: 2349
## Number of Groups: 10

#Диагностика модели (анализ остатков)
mod2_2_diag <- data.frame(
  data,
  .fitted = fitted(mod2_2),
  .resid = resid(mod2_2, type = 'pearson'),
  .sresid = resid(mod2_2, type = 'pearson', scaled = TRUE)
)

#.fitted - предсказанные значения,
#.resid - Пирсоновские остатки,
#.sresid - стандартизованные Пирсоновские остатки

```

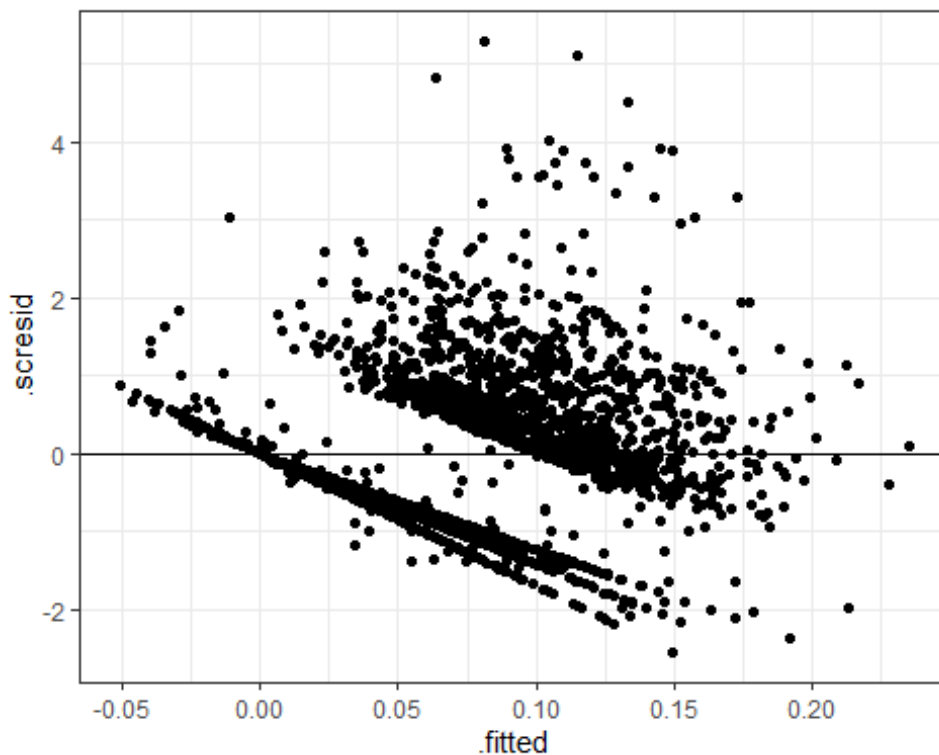


```
head(mod2_2_diag, 4)
```

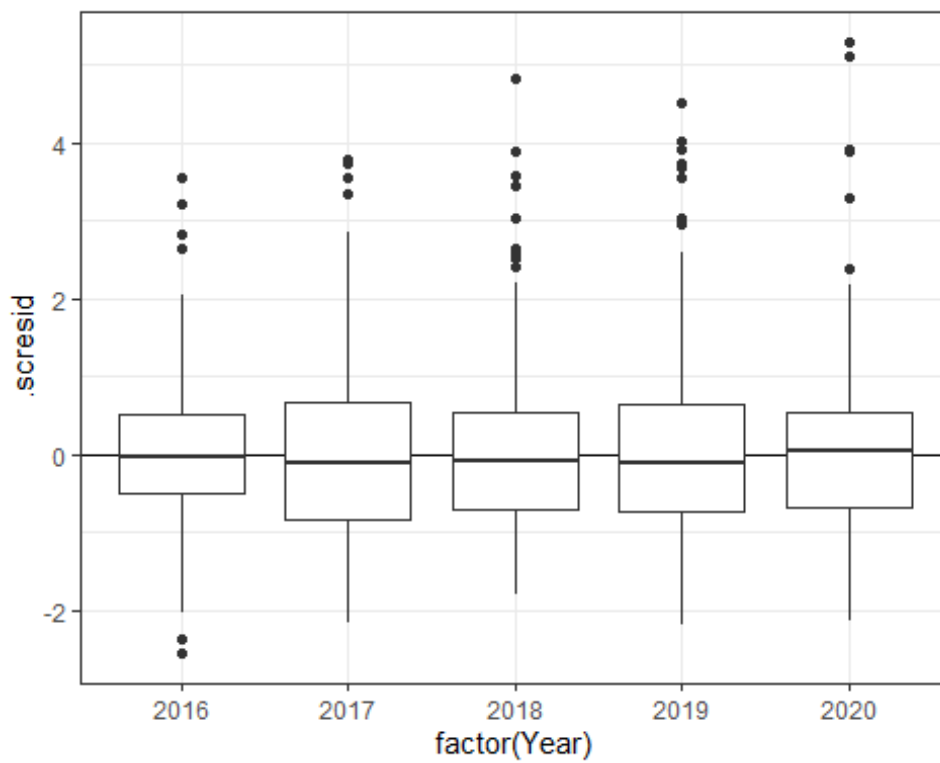
```
##   Year Point abs_risk_450 abs_risk_451 abs_risk_458 abs_risk      Date Time
## 1 2016     1          NA          NA          NA      NA 26.04.2016 7:00
## 2 2016     1          NA          NA          NA      NA 27.04.2016 7:00
## 3 2016     1          NA          NA          NA      NA 28.04.2016 7:00
## 4 2016    13          NA          NA          NA      NA 16.05.2016 7:00
##   Time2 Daytime Thermometer Pressure Humidity      Wind Wind_V Weather   TSP
## 1     7 morning           6       740       73 south west     4 cloudy 0.114
## 2     7 morning           6       758       58     east     3  clear 0.189
## 3     7 morning          10       758       43     east     4  clear 0.305
## 4     7 morning          15       745       61  south     1 cloudy 0.000
##   TSPn PM10 PM10n PM2.5 PM2.5n  NO2 NO2n    C  Cn   .fitted   .resid
## 1  0.5 0.075  0.3 0.036  0.16 0.065  0.2 0.10 0.15 0.10299909 -0.7159930
## 2  0.5 0.124  0.3 0.059  0.16 0.071  0.2 0.10 0.15 0.16120246 -0.9513418
## 3  0.5 0.203  0.3 0.077  0.16 0.077  0.2 0.10 0.15 0.18528222  0.4530793
## 4  0.5 0.000  0.3 0.000  0.16 0.062  0.2 0.11 0.15 0.01208996 -0.3091647
##   .sresid
## 1 -0.7159930
## 2 -0.9513418
## 3  0.4530793
## 4 -0.3091647
```

*#График остатков от предсказанных значений*

```
gg_resid <- ggplot(mod2_2_diag, aes(y = .sresid)) +
  geom_hline(yintercept = 0)
gg_resid + geom_point(aes(x = .fitted))
```



```
gg_resid + geom_boxplot(aes(x = factor(Year)))
```



```
gg_resid + geom_boxplot(aes(x = Point))
```

