Assignment 6 STAT 315-463: Multivariable Statistical Methods and Applications

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QUESTION 1 Generalised additive models

a) Import the data to R and fit a series of GAMs to the Value using a smoother on Date.

```
# Read in the datasets and convert the string "Date" into Date datatype variables
CCC05 <- read.table("CCC05.csv", header = TRUE, sep = ',', na.strings = "na")
CCC05$Date <- as.Date(CCC05$Date, "%d/%m/%Y")
```

```
library(gam)
library(ggplot2)

# Kept showing Error in names(dat) <- object$term :
# 'names' attribute [1] must be the same length as the vector [0]
CCC05 <- transform(CCC05, ndate = as.numeric(Date),
                   nyear  = as.numeric(format(Date, '%Y')),
                   nmonth = as.numeric(format(Date, '%m')),
                   nday = as.numeric(format(Date, '%j')))

# Start with the default model and 4 more with different spar parameters

CCC05.gam <- gam(Value ~ s(nyear) + s(nmonth) +s(nday), data = CCC05 )
pred_default <- predict(CCC05.gam)
summary(CCC05.gam)
```

```
##
## Call: gam(formula = Value ~ s(nyear) + s(nmonth) + s(nday), data = CCC05)
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -2.03005 -0.19084  0.08084  0.30188  0.86313
##
## (Dispersion Parameter for gaussian family taken to be 0.2553)
##
##     Null Deviance: 49.5862 on 122 degrees of freedom
## Residual Deviance: 28.0784 on 110.0003 degrees of freedom
## AIC: 195.3644
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##            Df  Sum Sq Mean Sq F value    Pr(>F)
```

```
## s(nyear)    1 12.0657 12.0657 47.2689 3.926e-10 ***
## s(nmonth)   1  0.2207  0.2207  0.8646    0.3545
## s(nday)     1  1.3653  1.3653  5.3487    0.0226 *
## Residuals 110 28.0784  0.2553
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
##             Npar Df Npar F     Pr(F)
## (Intercept)
## s(nyear)          3 7.8969 8.091e-05 ***
## s(nmonth)         3 1.7100    0.1691
## s(nday)           3 1.8543    0.1416
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
CCC05.gam1 <- gam(Value ~ s(nyear, sp=1.0) + s(nmonth, sp = 1.0) +
                    s(nday, sp = 1.0), data = CCC05)
pred1 <- predict(CCC05.gam1)
summary(CCC05.gam1)
```

```
##
## Call: gam(formula = Value ~ s(nyear, sp = 1) + s(nmonth, sp = 1) +
##     s(nday, sp = 1), data = CCC05)
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -2.11710 -0.28785 -0.01818  0.38619  1.04720
##
## (Dispersion Parameter for gaussian family taken to be 0.2981)
##
##     Null Deviance: 49.5862 on 122 degrees of freedom
## Residual Deviance: 35.0015 on 117.3956 degrees of freedom
## AIC: 207.6818
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##                       Df Sum Sq Mean Sq F value    Pr(>F)
## s(nyear, sp = 1)     1.0 11.932 11.9322 40.0210 4.736e-09 ***
## s(nmonth, sp = 1)    1.0  0.111  0.1113  0.3732   0.54243
## s(nday, sp = 1)      1.0  1.666  1.6661  5.5882   0.01972 *
## Residuals          117.4 35.001  0.2981
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
##                   Npar Df  Npar F    Pr(F)
## (Intercept)
## s(nyear, sp = 1)      0.0 17.4747 0.003987 **
## s(nmonth, sp = 1)     0.0  0.2069 0.015504 *
## s(nday, sp = 1)       1.6  1.7826 0.179368
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
CCC05.gam2 <- gam(Value ~ s(nyear, sp=0.01) + s(nmonth, sp = 0.01) +
                    s(nday, sp = 0.01), data = CCC05)
pred2 <- predict(CCC05.gam2)
summary(CCC05.gam2)
```

```
##
## Call: gam(formula = Value ~ s(nyear, sp = 0.01) + s(nmonth, sp = 0.01) +
##     s(nday, sp = 0.01), data = CCC05)
## Deviance Residuals:
##     Min      1Q  Median      3Q     Max
## -1.1183 -0.1609  0.0117  0.1688  0.6473
##
## (Dispersion Parameter for gaussian family taken to be 0.2468)
##
##     Null Deviance: 49.5862 on 122 degrees of freedom
## Residual Deviance: 9.5027 on 38.4959 degrees of freedom
## AIC: 205.1122
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##                         Df Sum Sq Mean Sq F value    Pr(>F)
## s(nyear, sp = 0.01)   1.000 9.5682  9.5682 38.7614 2.649e-07 ***
## s(nmonth, sp = 0.01)  1.000 0.1811  0.1811  0.7337   0.39699
## s(nday, sp = 0.01)    1.000 0.7149  0.7149  2.8960   0.09686 .
## Residuals            38.496 9.5027  0.2468
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
##                      Npar Df Npar F     Pr(F)
## (Intercept)
## s(nyear, sp = 0.01)      8.9  3.585  0.002615 **
## s(nmonth, sp = 0.01)     9.9 87.522 < 2.2e-16 ***
## s(nday, sp = 0.01)      61.7 15.955 2.887e-15 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
CCC05.gam3 <- gam(Value ~ s(nyear, sp=0.25) + s(nmonth, sp = 0.25) +
                    s(nday, sp = 0.25), data = CCC05)
pred3 <- predict(CCC05.gam3)
summary(CCC05.gam3)
```

```
##
## Call: gam(formula = Value ~ s(nyear, sp = 0.25) + s(nmonth, sp = 0.25) +
##     s(nday, sp = 0.25), data = CCC05)
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -1.36086 -0.20307  0.04743  0.20540  0.81026
##
## (Dispersion Parameter for gaussian family taken to be 0.2527)
##
```

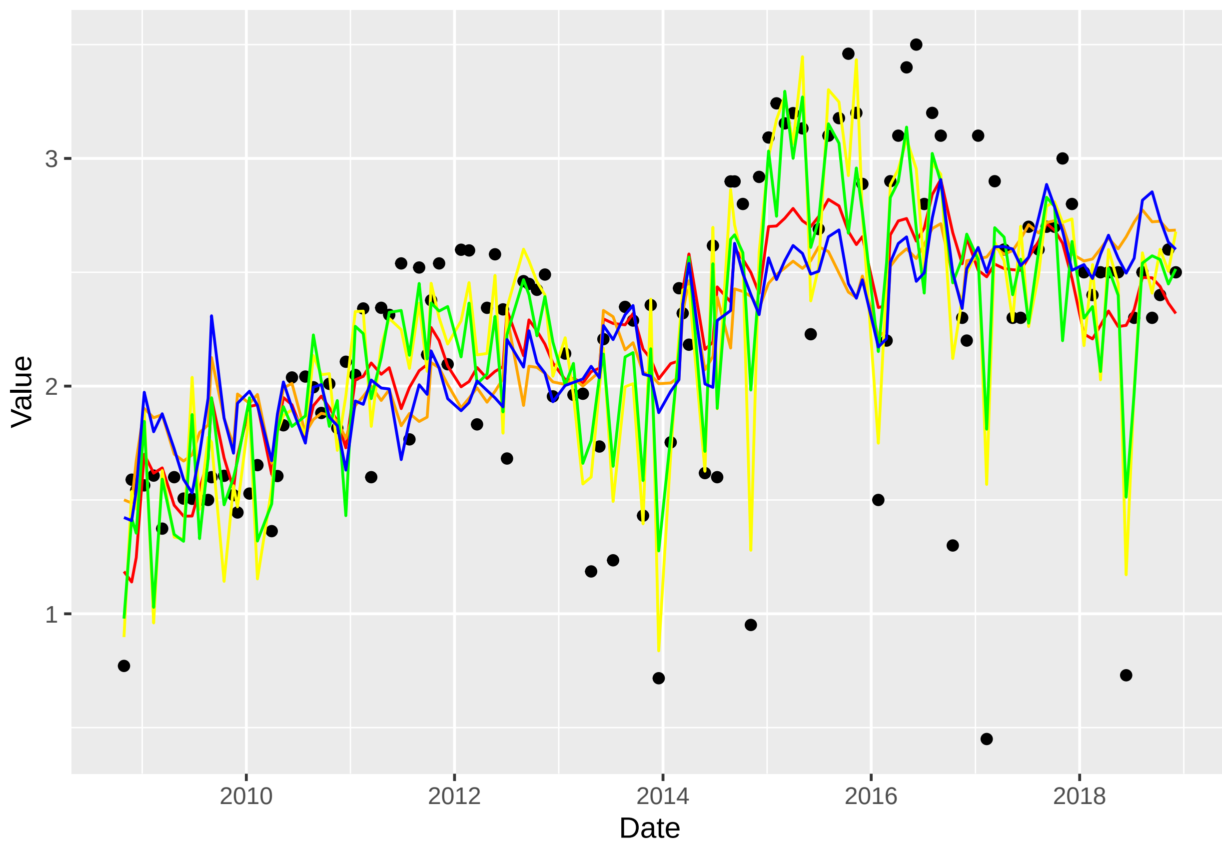
```
##     Null Deviance: 49.5862 on 122 degrees of freedom
## Residual Deviance: 15.182 on 60.0689 degrees of freedom
## AIC: 219.5961
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##                         Df  Sum Sq Mean Sq F value    Pr(>F)
## s(nyear, sp = 0.25)   1.000 11.2607 11.2607 44.5538 8.904e-09 ***
## s(nmonth, sp = 0.25)  1.000  0.2210  0.2210  0.8743   0.35351
## s(nday, sp = 0.25)    1.000  1.3014  1.3014  5.1492   0.02686 *
## Residuals            60.069 15.1820  0.2527
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
##                      Npar Df  Npar F     Pr(F)
## (Intercept)
## s(nyear, sp = 0.25)      6.5  3.7308  0.002579 **
## s(nmonth, sp = 0.25)     7.3 18.7427 3.233e-13 ***
## s(nday, sp = 0.25)      45.2  3.9190 5.668e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
CCC05.gam4 <- gam(Value ~ s(nyear, sp=0.75) + s(nmonth, sp = 0.75) +
                    s(nday, sp = 0.75), data = CCC05)
pred4 <- predict(CCC05.gam4)
summary(CCC05.gam4)
```

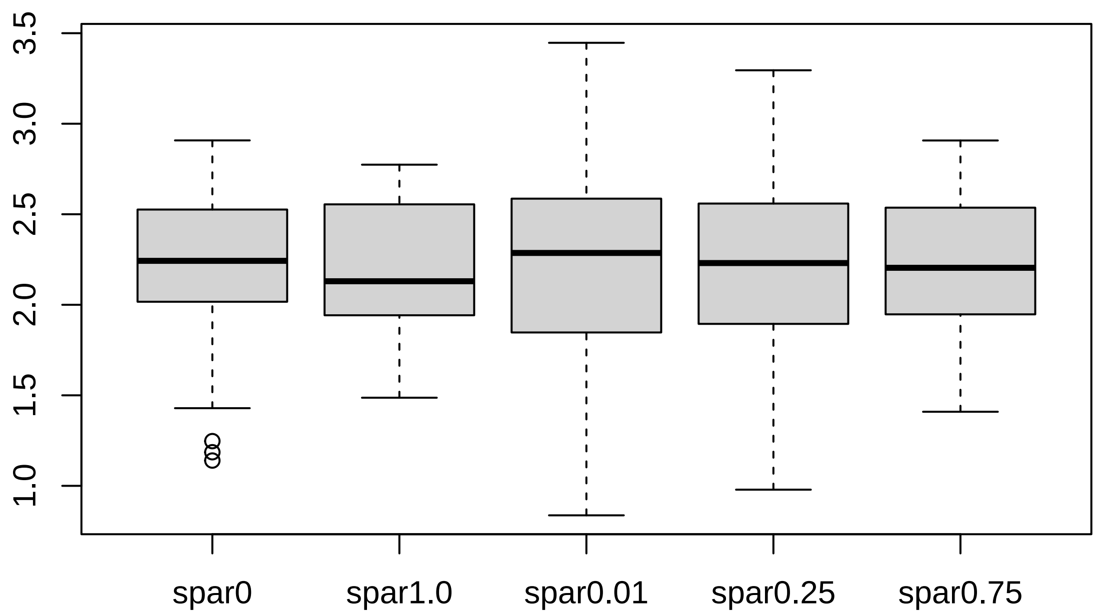
```
##
## Call: gam(formula = Value ~ s(nyear, sp = 0.75) + s(nmonth, sp = 0.75) +
##     s(nday, sp = 0.75), data = CCC05)
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -2.04990 -0.26239 -0.01294  0.35989  1.03976
##
## (Dispersion Parameter for gaussian family taken to be 0.2899)
##
##     Null Deviance: 49.5862 on 122 degrees of freedom
## Residual Deviance: 32.5685 on 112.3503 degrees of freedom
## AIC: 208.9111
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##                         Df Sum Sq Mean Sq F value    Pr(>F)
## s(nyear, sp = 0.75)     1.00 11.876 11.8764 40.9694 3.693e-09 ***
## s(nmonth, sp = 0.75)    1.00  0.126  0.1258  0.4339  0.511429
## s(nday, sp = 0.75)      1.00  2.015  2.0148  6.9502  0.009566 **
## Residuals             112.35 32.568  0.2899
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
```

```
##                          Npar Df  Npar F   Pr(F)
## (Intercept)
## s(nyear, sp = 0.75)          0.1 16.8892 0.01278 *
## s(nmonth, sp = 0.75)         0.2  0.0438 0.43071
## s(nday, sp = 0.75)           6.3  1.4286 0.20731
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

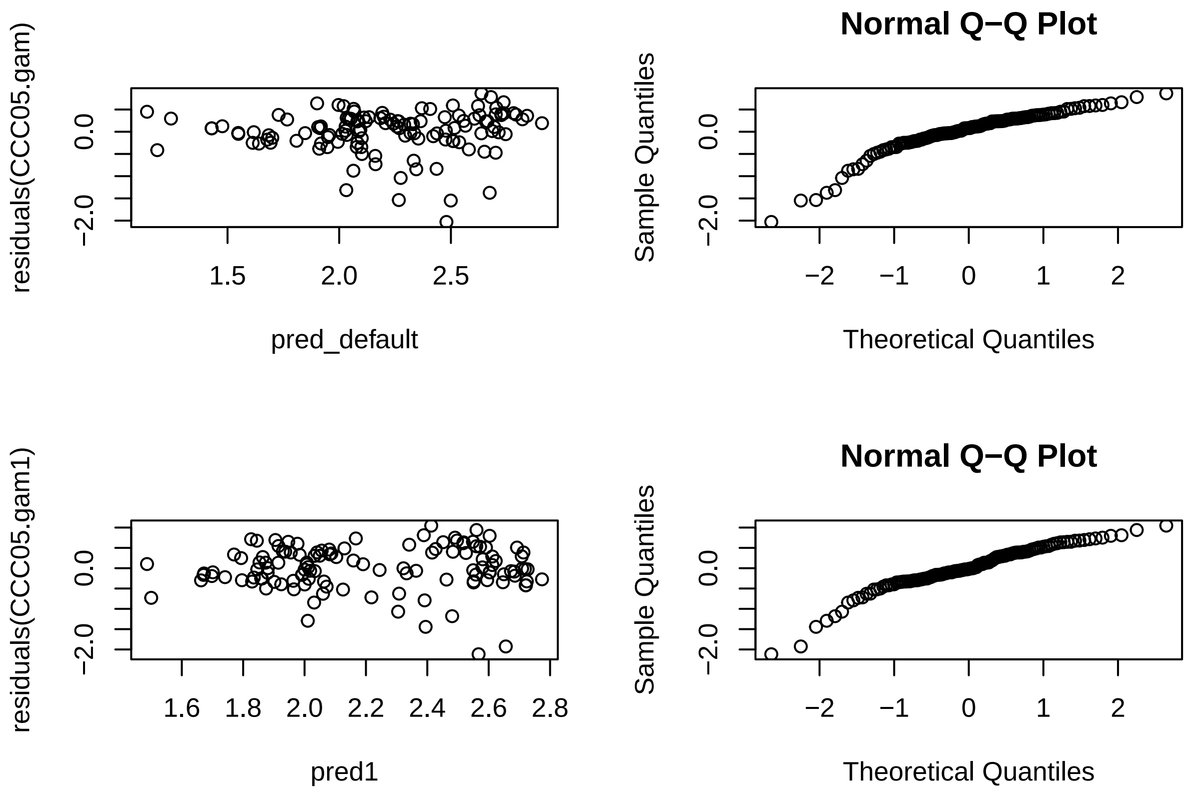
```
ggplot(data = CCC05, aes(x = Date, y = Value)) +
  geom_point() +
  geom_line(aes(x=Date, y=pred_default), colour = "red") +
  geom_line(aes(x=Date, y=pred1), colour = "orange") +
  geom_line(aes(x=Date, y=pred2), colour = "yellow") +
  geom_line(aes(x=Date, y=pred3), colour = "green") +
  geom_line(aes(x=Date, y=pred4), colour = "blue")
```



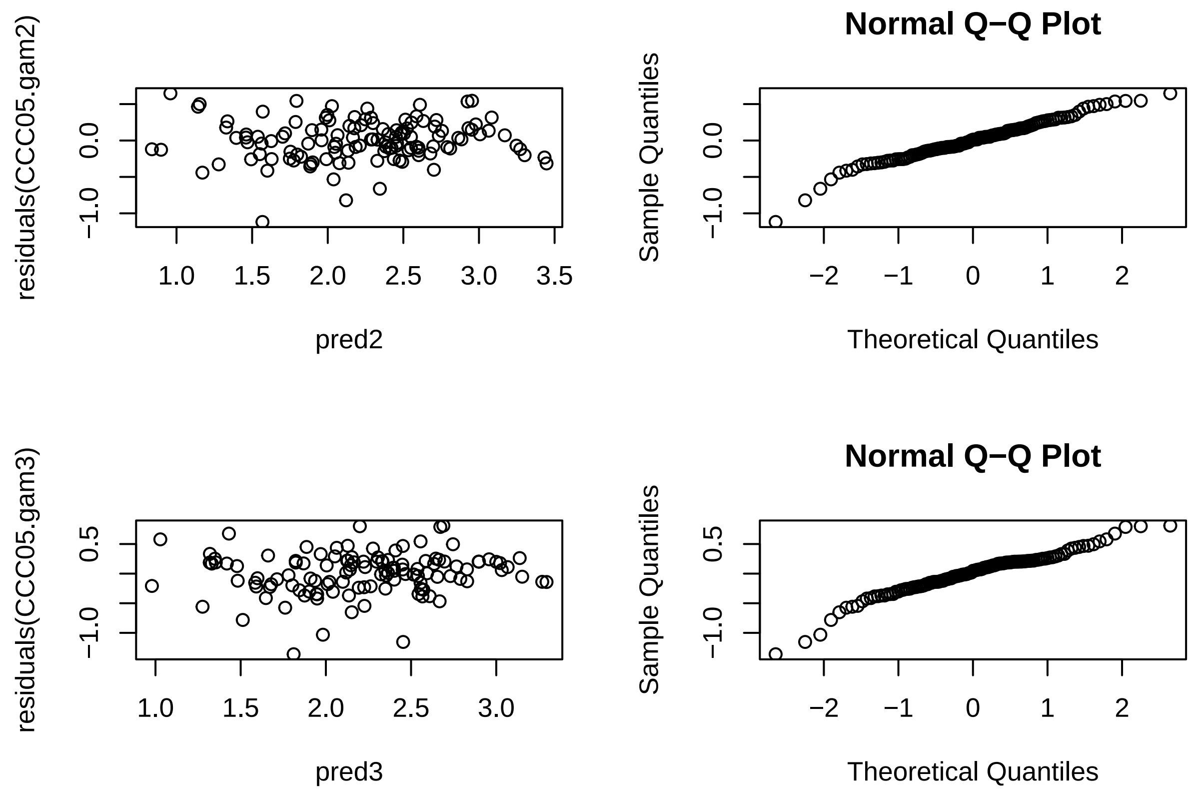

```
data <- data.frame(spar0 = fitted.values(CCC05.gam),
                   spar1.0 = fitted.values(CCC05.gam1),
                   spar0.01 = fitted.values(CCC05.gam2),
                   spar0.25 = fitted.values(CCC05.gam3),
                   spar0.75 = fitted.values(CCC05.gam4)
                   )

boxplot(data)
```



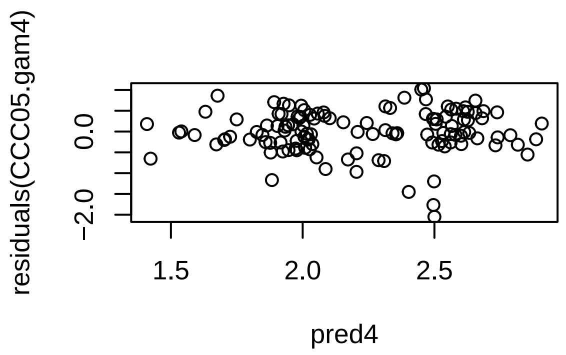

```
par(mfrow=c(2,2))
plot(pred_default, residuals(CCC05.gam),)
qqnorm(residuals(CCC05.gam))
plot(pred1, residuals(CCC05.gam1))
qqnorm(residuals(CCC05.gam1))
```

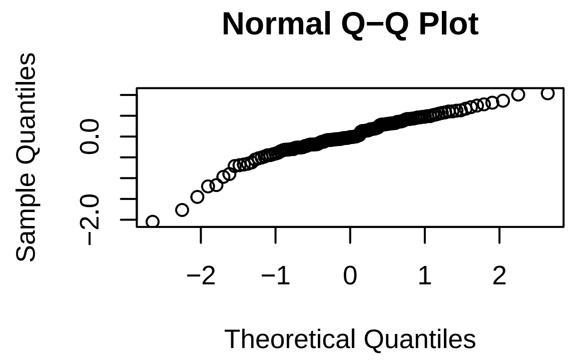



```
plot(pred2, residuals(CCC05.gam2))
qqnorm(residuals(CCC05.gam2))
plot(pred3, residuals(CCC05.gam3))
qqnorm(residuals(CCC05.gam3))
```




```
plot(pred4, residuals(CCC05.gam4))
qqnorm(residuals(CCC05.gam4))
```






```
ECAN93 <- read.table("ECAN93.csv", header = TRUE, sep = ',', na.strings = "na")
ECAN93$Date <- as.Date(ECAN93$Date, "%d/%m/%Y")

ECAN93 <- transform(ECAN93, ndate = as.numeric(Date),
                    nyear  = as.numeric(format(Date, '%Y')),
                    nmonth = as.numeric(format(Date, '%m')),
                    nday = as.numeric(format(Date, '%j')))


# Start with the default model and 4 more with different spar parameters
ECAN93.gam <- gam(Value ~ s(nyear) + s(nmonth) +s(nday), data = ECAN93 )
pred_default <- predict(ECAN93.gam)
summary(ECAN93.gam)
```

```
##
## Call: gam(formula = Value ~ s(nyear) + s(nmonth) + s(nday), data = ECAN93)
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -4.61712 -0.24791  0.05168  0.30614  1.31908
##
## (Dispersion Parameter for gaussian family taken to be 0.4072)
##
##     Null Deviance: 271.865 on 178 degrees of freedom
## Residual Deviance: 67.6002 on 165.9998 degrees of freedom
## AIC: 361.6745
```

```
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##             Df  Sum Sq Mean Sq  F value    Pr(>F)
## s(nyear)     1 187.412 187.412 460.2108 < 2.2e-16 ***
## s(nmonth)    1  12.344  12.344  30.3131 1.374e-07 ***
## s(nday)      1   0.135   0.135   0.3325     0.565
## Residuals 166  67.600   0.407
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
##             Npar Df Npar F     Pr(F)
## (Intercept)
## s(nyear)          3 1.6923   0.17064
## s(nmonth)         3 9.1194 1.274e-05 ***
## s(nday)           3 3.5343   0.01612 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
ECAN93.gam$y
```

```
##   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20
## 4.1 4.2 4.2 4.0 4.4 4.6 4.4 4.5 4.5 4.2 4.3 4.2 4.4 4.3 4.2 4.4 4.3 4.6 4.6 4.6
##  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40
## 4.4 4.4 4.3 4.5 4.1 4.0 4.3 4.1 4.4 4.4 4.9 5.2 5.8 5.8 5.3 5.5 5.9 5.2 5.1 5.1
##  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60
## 5.3 5.8 5.3 5.4 4.9 5.1 4.7 4.5 4.3 4.2 4.7 4.9 5.0 5.4 5.3 6.0 6.1 6.2 5.6 5.5
##  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  77  78  79  80
## 5.4 5.5 5.6 5.8 6.1 6.0 5.8 5.9 5.9 5.7 5.7 5.2 5.3 5.1 5.3 5.5 5.7 5.2 5.8 4.5
##  81  82  83  84  85  86  87  88  89  90  91  92  93  94  95  96  97  98  99 100
## 6.8 4.5 6.5 3.9 6.9 7.1 6.9 6.5 6.3 6.5 6.0 6.6 6.6 6.4 5.9 3.0 5.8 6.2 5.6 6.3
## 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120
## 6.4 1.7 6.3 5.9 5.8 5.5 6.6 6.1 5.6 6.0 6.1 6.4 6.6 6.7 7.4 7.9 7.8 7.2 6.8 6.4
## 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140
## 7.0 7.3 7.0 7.8 7.7 8.0 7.6 7.5 7.3 7.4 6.9 6.5 6.4 6.4 6.6 7.1 6.9 7.2 6.7 7.2
## 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160
## 6.7 6.6 6.7 6.5 6.8 6.5 7.2 6.9 7.4 7.4 7.1 7.0 7.1 6.8 6.9 7.0 7.0 7.3 6.5 7.0
## 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179
## 7.0 7.5 7.8 7.6 7.8 8.0 7.8 7.1 5.9 7.0 7.6 7.4 7.3 8.3 8.3 8.4 8.0 7.9 8.1
```

```
ECAN93.gam$X
```

```
## NULL
```

```
ECAN93.gam1 <- gam(Value ~ s(nyear, sp=1.0) + s(nmonth, sp = 1.0) +
                    s(nday, sp = 1.0), data = ECAN93)
pred1 <- predict(CCC05.gam1)
summary(ECAN93.gam1)
```

```
##
```

```
## Call: gam(formula = Value ~ s(nyear, sp = 1) + s(nmonth, sp = 1) +
##     s(nday, sp = 1), data = ECAN93)
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -4.67518 -0.28111  0.03948  0.29924  1.38015
##
## (Dispersion Parameter for gaussian family taken to be 0.4135)
##
##     Null Deviance: 271.865 on 178 degrees of freedom
## Residual Deviance: 71.5782 on 173.1225 degrees of freedom
## AIC: 357.6645
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##                      Df  Sum Sq Mean Sq  F value    Pr(>F)
## s(nyear, sp = 1)    1.00 185.391 185.391 448.3950 < 2.2e-16 ***
## s(nmonth, sp = 1)   1.00  12.375  12.375  29.9317 1.547e-07 ***
## s(nday, sp = 1)     1.00   0.129   0.129   0.3126    0.5768
## Residuals         173.12  71.578   0.413
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
##                   Npar Df  Npar F   Pr(F)
## (Intercept)
## s(nyear, sp = 1)      0.0 0.27713 0.03056 *
## s(nmonth, sp = 1)     0.0 0.50310 0.01365 *
## s(nday, sp = 1)       1.9 3.01404 0.05536 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
ECAN93.gam2 <- gam(Value ~ s(nyear, sp=0.01) + s(nmonth, sp = 0.01) +
                    s(nday, sp = 0.01), data = ECAN93)
pred2 <- predict(ECAN93.gam2)
summary(ECAN93.gam2)
```

```
##
## Call: gam(formula = Value ~ s(nyear, sp = 0.01) + s(nmonth, sp = 0.01) +
##     s(nday, sp = 0.01), data = ECAN93)
## Deviance Residuals:
##       Min        1Q    Median        3Q       Max
## -1.735764 -0.241031 -0.003287  0.187134  1.588007
##
## (Dispersion Parameter for gaussian family taken to be 0.3015)
##
##     Null Deviance: 271.865 on 178 degrees of freedom
## Residual Deviance: 25.3447 on 84.0508 degrees of freedom
## AIC: 349.9663
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##                         Df  Sum Sq Mean Sq  F value    Pr(>F)
```

```
## s(nyear, sp = 0.01)   1.000 169.259 169.259 561.3163 < 2.2e-16 ***
## s(nmonth, sp = 0.01)  1.000  12.600  12.600  41.7869 6.344e-09 ***
## s(nday, sp = 0.01)    1.000   0.029   0.029   0.0976    0.7555
## Residuals            84.051  25.345   0.302
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
##                      Npar Df Npar F     Pr(F)
## (Intercept)
## s(nyear, sp = 0.01)     12.9  2.775  0.002577 **
## s(nmonth, sp = 0.01)     9.9 74.760 < 2.2e-16 ***
## s(nday, sp = 0.01)      68.2 12.293 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
ECAN93.gam3 <- gam(Value ~ s(nyear, sp=0.25) + s(nmonth, sp = 0.25) +
                     s(nday, sp = 0.25), data = ECAN93)
pred3 <- predict(ECAN93.gam3)
summary(ECAN93.gam3)
```

```
##
## Call: gam(formula = Value ~ s(nyear, sp = 0.25) + s(nmonth, sp = 0.25) +
##     s(nday, sp = 0.25), data = ECAN93)
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -2.85861 -0.22425 -0.01348  0.24210  1.14952
##
## (Dispersion Parameter for gaussian family taken to be 0.3098)
##
##     Null Deviance: 271.865 on 178 degrees of freedom
## Residual Deviance: 34.067 on 109.9649 degrees of freedom
## AIC: 351.0789
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##                          Df  Sum Sq Mean Sq F value    Pr(>F)
## s(nyear, sp = 0.25)    1.00 137.235 137.235 442.981 < 2.2e-16 ***
## s(nmonth, sp = 0.25)   1.00  13.659  13.659  44.089 1.237e-09 ***
## s(nday, sp = 0.25)     1.00   7.043   7.043  22.735 5.738e-06 ***
## Residuals            109.96  34.067   0.310
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
##                      Npar Df  Npar F     Pr(F)
## (Intercept)
## s(nyear, sp = 0.25)      9.4  2.9618  0.002989 **
## s(nmonth, sp = 0.25)     7.3 17.1267 1.776e-15 ***
## s(nday, sp = 0.25)      48.3  3.4062 5.741e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
ECAN93.gam4 <- gam(Value ~ s(nyear, sp=0.75) + s(nmonth, sp = 0.75) +
                    s(nday, sp = 0.75), data = ECAN93)
pred4 <- predict(ECAN93.gam4)
summary(ECAN93.gam4)
```

```
##
## Call: gam(formula = Value ~ s(nyear, sp = 0.75) + s(nmonth, sp = 0.75) +
##     s(nday, sp = 0.75), data = ECAN93)
## Deviance Residuals:
##      Min       1Q   Median       3Q      Max
## -4.60281 -0.27861  0.03792  0.29949  1.26901
##
## (Dispersion Parameter for gaussian family taken to be 0.4149)
##
##     Null Deviance: 271.865 on 178 degrees of freedom
## Residual Deviance: 69.4372 on 167.3419 degrees of freedom
## AIC: 363.7898
##
## Number of Local Scoring Iterations: NA
##
## Anova for Parametric Effects
##                          Df  Sum Sq Mean Sq F value    Pr(>F)
## s(nyear, sp = 0.75)    1.00 186.155 186.155 448.630 < 2.2e-16 ***
## s(nmonth, sp = 0.75)   1.00  12.372  12.372  29.816 1.691e-07 ***
## s(nday, sp = 0.75)     1.00   0.126   0.126   0.304    0.5821
## Residuals            167.34  69.437   0.415
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Anova for Nonparametric Effects
##                      Npar Df  Npar F  Pr(F)
## (Intercept)
## s(nyear, sp = 0.75)      0.5 0.36689 0.3889
## s(nmonth, sp = 0.75)     0.2 0.29010 0.2919
## s(nday, sp = 0.75)       7.0 1.47183 0.1808
```

```r
# ggplot(data = ECAN93, aes(x = Date, y = Value)) +
  # geom_point() +
  # geom_line(aes(x=Date, y=pred_default), colour = "pink") +
  # geom_line(aes(x=Date, y=pred1), colour = "lightblue") +
  # geom_line(aes(x=Date, y=pred2), colour = "lightgreen") +
  # geom_line(aes(x=Date, y=pred3), colour = "purple") +
  # geom_line(aes(x=Date, y=pred4), colour = "black")
```

QUESTION 2 Multiple Comparisons

```r
# Read in dataset
library(xlsx)
herbicides <- read.xlsx("herbicides.xlsx", sheetIndex = 1)
```

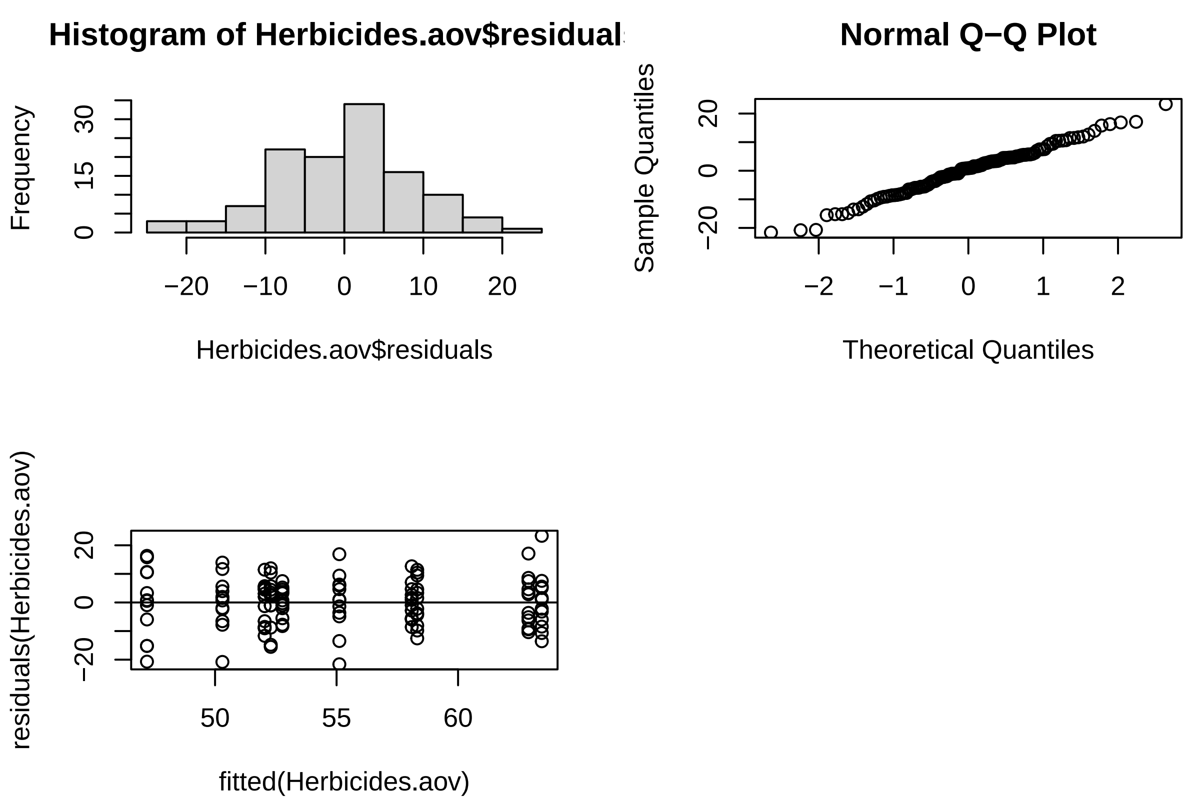
(a) Carry out an analysis of variance on the data with Herbicide as the explanatory variable and Grass_percent" as the response.

```
library(multcomp)

Herbicides.aov <- aov(Grass_percent ~ Herbicide, herbicides)
summary(Herbicides.aov)
```

```
##              Df Sum Sq Mean Sq F value   Pr(>F)
## Herbicide     9   3092   343.5   4.412 6.09e-05 ***
## Residuals   110   8564    77.9
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

(b) Discuss the residuals

```
# Residual distribution
par(mfrow = c(2, 2))
hist(Herbicides.aov$residuals)
qqnorm(Herbicides.aov$residuals)
plot(fitted(Herbicides.aov), residuals(Herbicides.aov))
abline(0,0)
```



From the histogram of residuals, we can see that it is pretty close to be normally distributed. The Q-Q plot also suggests that as there is no obvious skewness or tailed part. The points in the residual-fitted plot also are evenly distributed around 0 without any patterns.

(c) Carry out an LSD type analysis comparing all possible pairs of treatments. Note which pairs have a significant difference.

```
library(agricolae)
pairwise.t.test(herbicides$Grass_percent, herbicides$Herbicide, p.adj = "none")
```

```
##
##  Pairwise comparisons using t tests with pooled SD
##
## data:  herbicides$Grass_percent and herbicides$Herbicide
##
##                        Aminopyralid Aminopyralid+triclopyr Chlorsulfuron
## Aminopyralid+triclopyr 0.87938      -                      -
## Chlorsulfuron          0.00374      0.00585                -
## Flumetsulam            0.14035      0.18525                0.14235
## MCPA                   0.15764      0.20653                0.12639
## MCPB                   0.02262      0.03293                0.51663
## MCPB+bentazone         0.00249      0.00396                0.89442
## Nil                    0.00200      0.00321                0.83996
## Sclerotinia            1.6e-05      3.0e-05                0.12471
## Thifensulfuron-methyl  0.00041      0.00068                0.49456
##                        Flumetsulam MCPA    MCPB    MCPB+bentazone Nil
## Aminopyralid+triclopyr -           -       -       -              -
## Chlorsulfuron          -           -       -       -              -
## Flumetsulam            -           -       -       -              -
## MCPA                   0.95031     -       -       -              -
## MCPB                   0.41000     0.37567 -       -              -
## MCPB+bentazone         0.11011     0.09713 0.43492 -              -
## Nil                    0.09577     0.08420 0.39547 0.94480        -
## Sclerotinia            0.00310     0.00256 0.03006 0.16016        0.18150
## Thifensulfuron-methyl  0.03270     0.02809 0.18431 0.58184        0.63011
##                        Sclerotinia
## Aminopyralid+triclopyr -
## Chlorsulfuron          -
## Flumetsulam            -
## MCPA                   -
## MCPB                   -
## MCPB+bentazone         -
## Nil                    -
## Sclerotinia            -
## Thifensulfuron-methyl  0.39070
##
## P value adjustment method: none
```

```
mse <- sum(Herbicides.aov$residuals * Herbicides.aov$residuals)/Herbicides.aov$df.residual
LSD.test(herbicides$Grass_percent, herbicides$Herbicide, Herbicides.aov$df.residual, mse, console = TRUE
```

```
##
## Study: herbicides$Grass_percent ~ herbicides$Herbicide
##
## LSD t Test for herbicides$Grass_percent
##
## Mean Square Error:  77.8534
```

```
##
## herbicides$Herbicide,  means and individual ( 95 %) CI
##
##                         herbicides.Grass_percent       std  r      LCL      UCL
## Aminopyralid                            63.44375  9.913055 12 58.39597 68.49153
## Aminopyralid+triclopyr                  62.89583  8.645617 12 57.84805 67.94361
## Chlorsulfuron                           52.77083  5.158244 12 47.72305 57.81861
## Flumetsulam                             58.09375  6.201202 12 53.04597 63.14153
## MCPA                                    58.31875  8.093657 12 53.27097 63.36653
## MCPB                                    55.11458 10.260590 12 50.06680 60.16236
## MCPB+bentazone                          52.29167  8.893201 12 47.24389 57.33945
## Nil                                     52.04167  7.303551 12 46.99389 57.08945
## Sclerotinia                             47.19792 12.355696 12 42.15014 52.24570
## Thifensulfuron-methyl                   50.30208  9.196476 12 45.25430 55.34986
##                            Min   Max
## Aminopyralid           49.875 86.75
## Aminopyralid+triclopyr 52.500 80.00
## Chlorsulfuron          44.500 60.25
## Flumetsulam            49.500 70.75
## MCPA                   45.750 69.75
## MCPB                   33.500 72.00
## MCPB+bentazone         36.750 64.25
## Nil                    40.375 63.50
## Sclerotinia            26.500 63.50
## Thifensulfuron-methyl  29.500 64.25
##
## Alpha: 0.05 ; DF Error: 110
## Critical Value of t: 1.981765
##
## least Significant Difference: 7.138638
##
## Treatments with the same letter are not significantly different.
##
##                         herbicides$Grass_percent groups
## Aminopyralid                            63.44375      a
## Aminopyralid+triclopyr                  62.89583      a
## MCPA                                    58.31875     ab
## Flumetsulam                             58.09375     ab
## MCPB                                    55.11458     bc
## Chlorsulfuron                           52.77083    bcd
## MCPB+bentazone                          52.29167    bcd
## Nil                                     52.04167    bcd
## Thifensulfuron-methyl                   50.30208     cd
## Sclerotinia                             47.19792      d
```

The LSD value obtained here is 7.14. From the result above, we can see that there is no significant difference between Aminopyralid and Aminopyralid + triclopyr, MCPA and Flumetsulam, Chlorsulfuron, MCPB+bentazone and Nil.

(d) Carry out pairwise comparisons using Bonferroni, Tukey and Dunnett adjustments and in each case show the pairs with significant differences.

(e) How do the conclusions in (c) and (d) differ?