Proposal

Time series_spruce_sub900 Analysis

8 März 2018

Data

Dendrochronology data has been supplied by the archaeological service of the canton Berne (Kantonsarchäologie 2018) through a personal contact at the dendrology laboratory in Sutz, BE.

The chronologies have been compiled from individual measurements in the canton of Berne. Typically, the wooden structure of old buildings is sampled by boring the beams. The drilling core is then analyzed by microscoping, recording the sequence of tree ring widht. Subsequently, the sample is matched with existing chronological data, serving the double purpose of strengthening the chronology by overlaying a certain period with more evidence as well as dating the sample in an effort to date the construction year of the sampled building.

All chronologies end in 2017 and have varying lengths of at least 650 years. The supplier of the data recommended ignoring data after 1800 due to an insufficient amount of data (individual treering measurements to compute a robust annual mean) for the period after 1800.

Spruce data above 900 m

This chronology was compiled from buildings in the Bernese Oberland which are located above 900 m. Spruce was a common building material and there is a wealth of houses supplying data. It is almost sure that trees have not been transported uphill when building houses, so this data can be assumed to originate almost entirely from trees that grew above 900 m. It is known that treering width at high altitudes is mostly dependent on the average temperature during spring.

Spruce data below 900 m

Originating also mostly from sampled buildings, this chronology is not sure to only contain data from trees that grew in the lower regions on the canton of Berne. The original author of the data tried to clean the data by only including samples that are below Thun in the Bernese Oberland. It can be assumed that most of the measured samples did actually grow at low altitude. Tree growth mostly depends on the yearly precipitation as the temperature effect is less pronounced at these altitudes.

Preliminary Analysis

```
par(mfrow=c(1,2))
plot(spruce_sub900_ts,
     main="Spruce, < 900 m",
     ylab="tree ring width [1/100 mm]",
     xlab="year")

plot(spruce_sup_900_ts,
     main="Spruce, > 900 m",
     ylab="tree ring width [1/100 mm]",
     xlab="year")
```

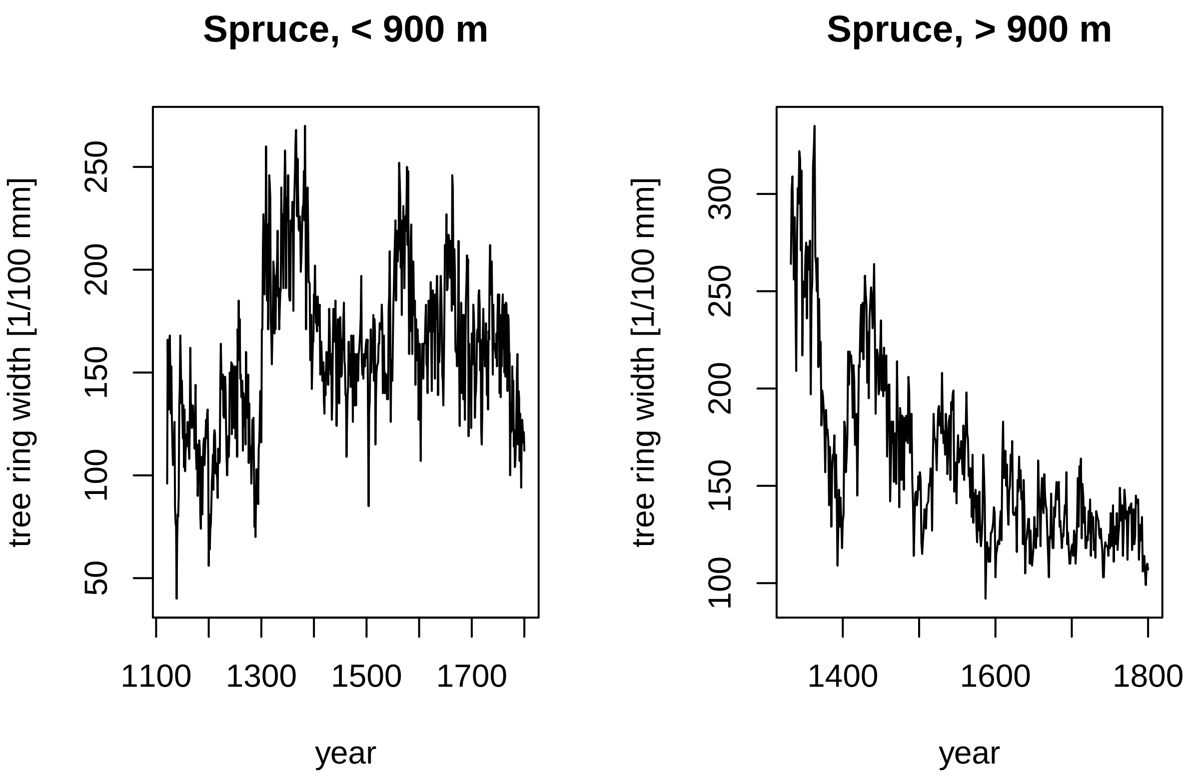


Figure 1: Timeseries for spruce below / above 900 m

Spruce below 900 m

A first analysis of the time series for spruce below 900 m

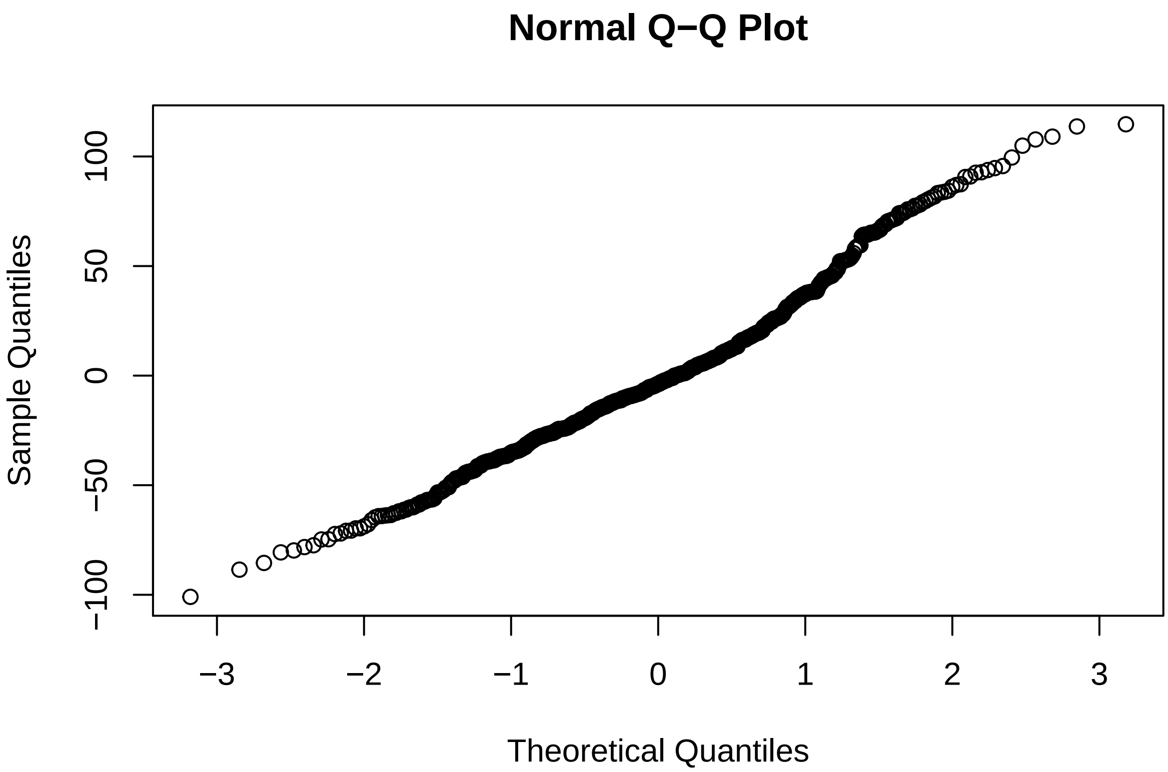
```
t <- seq(from=1,length=length(spruce_sub900_ts))
model <- lm(spruce_sub900_ts~t)
summary(model)
```

```
##
## Call:
## lm(formula = spruce_sub900_ts ~ t)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -100.951  -24.360   -3.739   19.482  114.700
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.398e+02  2.888e+00  48.415  < 2e-16 ***
## t           5.881e-02  7.349e-03   8.003 5.29e-15 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 37.62 on 678 degrees of freedom
## Multiple R-squared:  0.0863, Adjusted R-squared:  0.08496
## F-statistic: 64.04 on 1 and 678 DF,  p-value: 5.289e-15
```

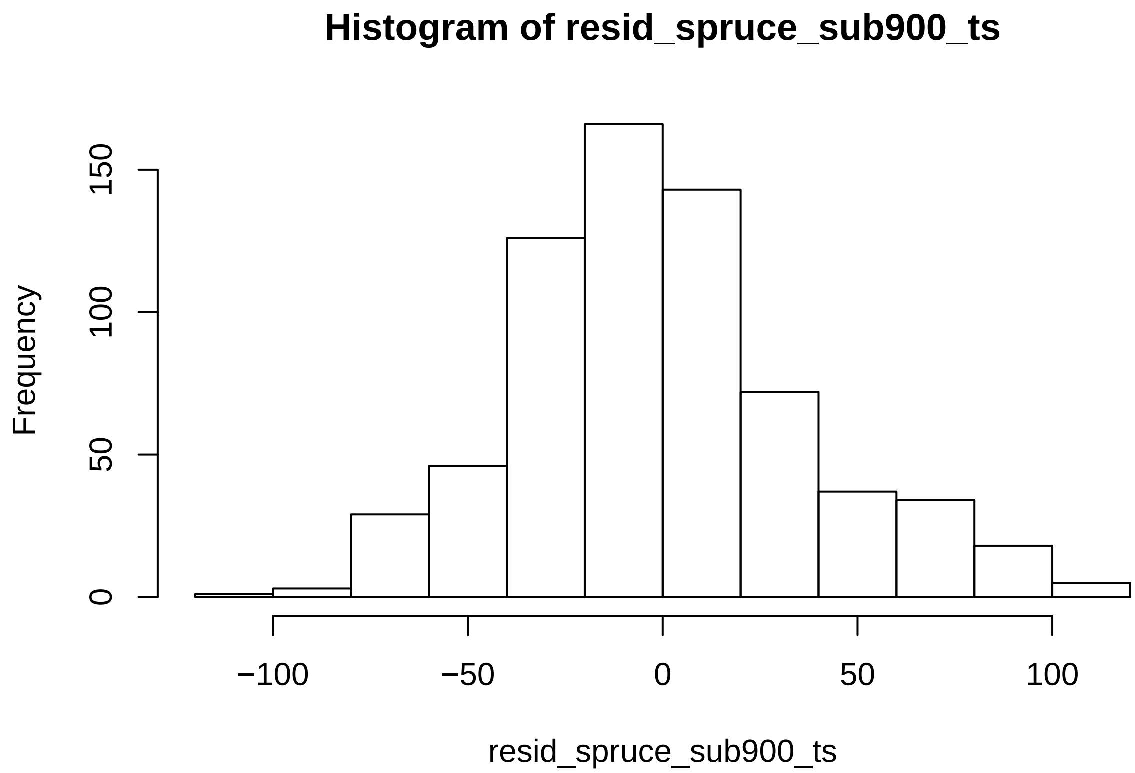
```
resid_spruce_sub900 <- residuals(model)
resid_spruce_sub900_ts <- ts(resid_spruce_sub900,end=1800)
mean(resid_spruce_sub900_ts) # ~ zero mean
```

```
## [1] 3.282576e-15
```

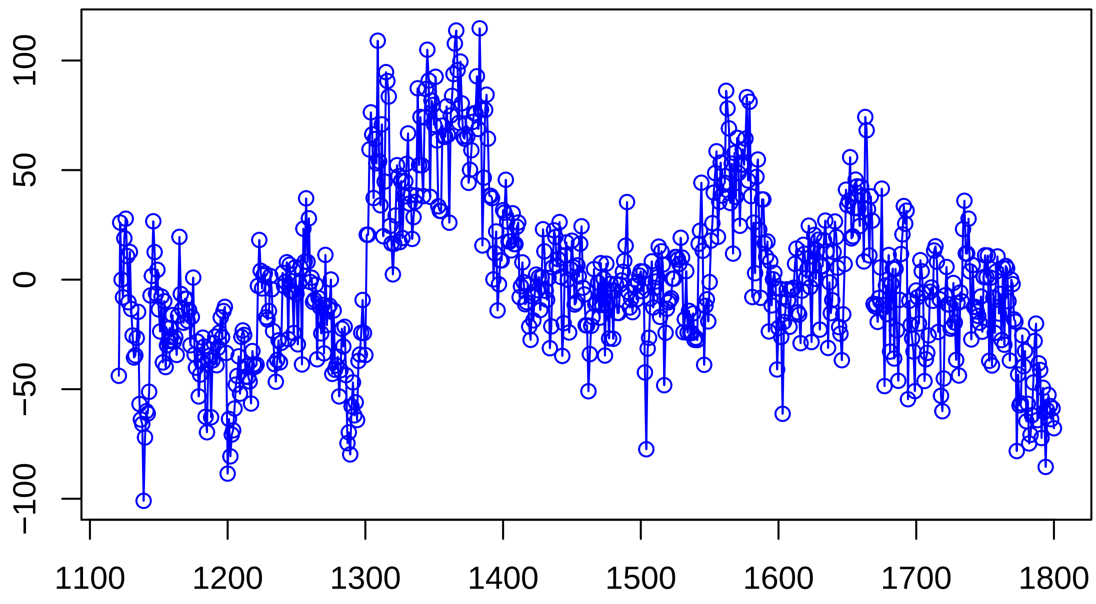
```
qqnorm(resid_spruce_sub900_ts) # close to a normal distribution
```




```
hist(resid_spruce_sub900_ts) # slightly right-skewed
```




```
plotc(resid_spruce_sub900_ts)
```

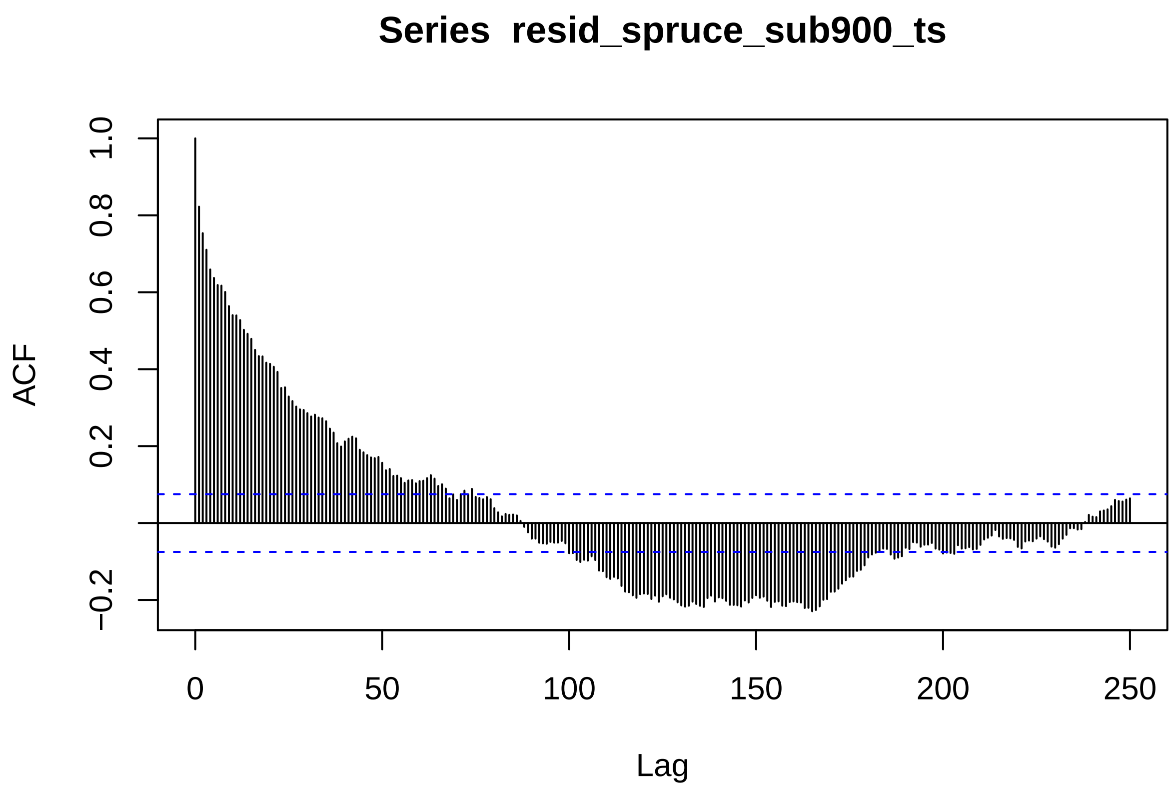


```r
Box.test(resid_spruce_sub900_ts,lag=200,type="Ljung-Box")
```

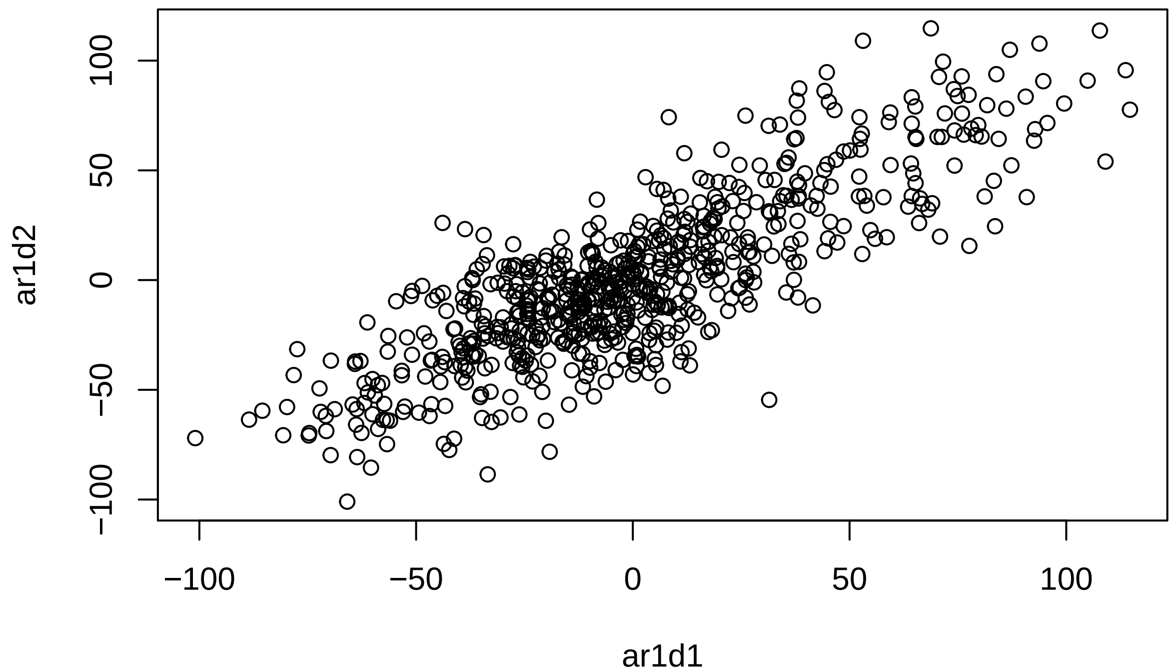
```
##
##  Box-Ljung test
##
## data:  resid_spruce_sub900_ts
## X-squared = 8685.3, df = 200, p-value < 2.2e-16
```

```r
# Reject H0: The residuals are not iid
# Which was to be expected, given the nature of the data

# Sample ACF shows non-stationarity.
acf(resid_spruce_sub900_ts,lag.max = 250)
```



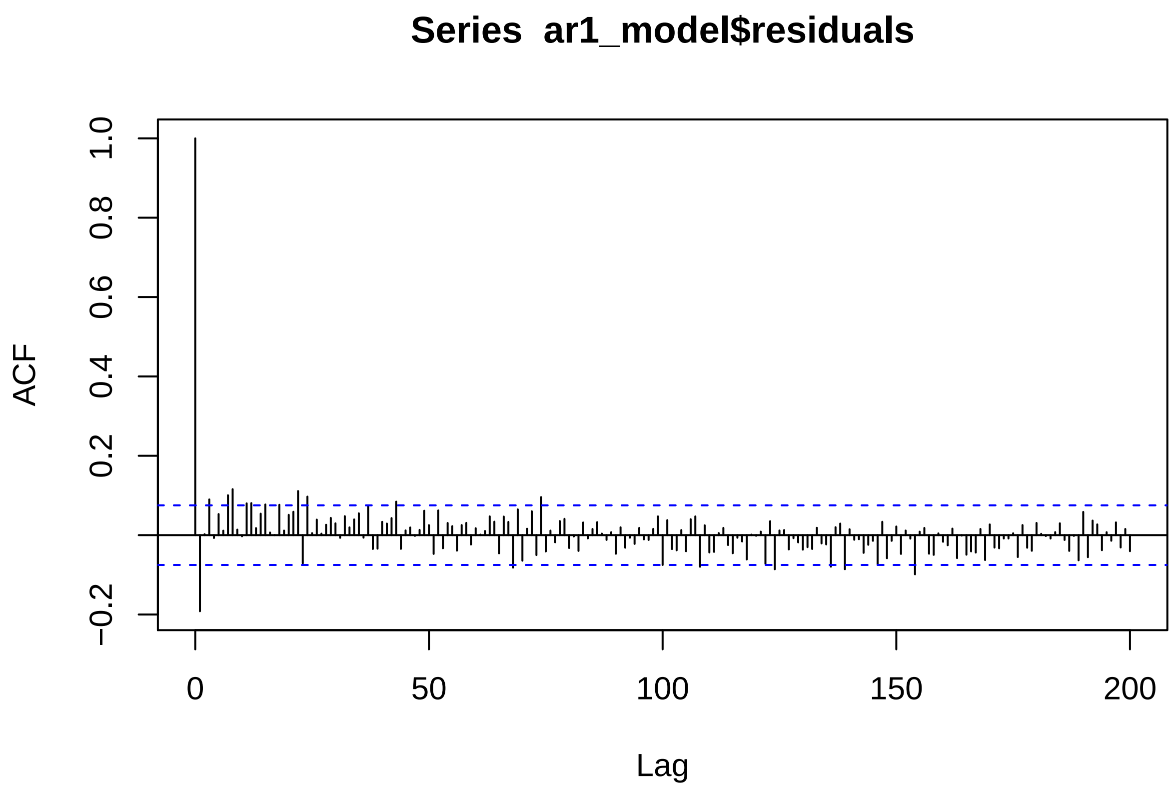

```r
# try to paramtrize an AR(1) model
ar1d1 <- resid_spruce_sub900[1:(length(resid_spruce_sub900)-1)]
ar1d2 <- resid_spruce_sub900[-1]
plot(ar1d2~ar1d1)
```




```
ar1_model <- lm(ar1d2~ar1d1)
summary(ar1_model) #
```

```
##
## Call:
## lm(formula = ar1d2 ~ ar1d1)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -80.579 -14.117   0.745  13.194  67.398
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.01791    0.81501  -0.022    0.982
## ar1d1        0.82644    0.02173  38.024   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 21.24 on 677 degrees of freedom
## Multiple R-squared:  0.6811, Adjusted R-squared:  0.6806
## F-statistic:  1446 on 1 and 677 DF,  p-value: < 2.2e-16
```

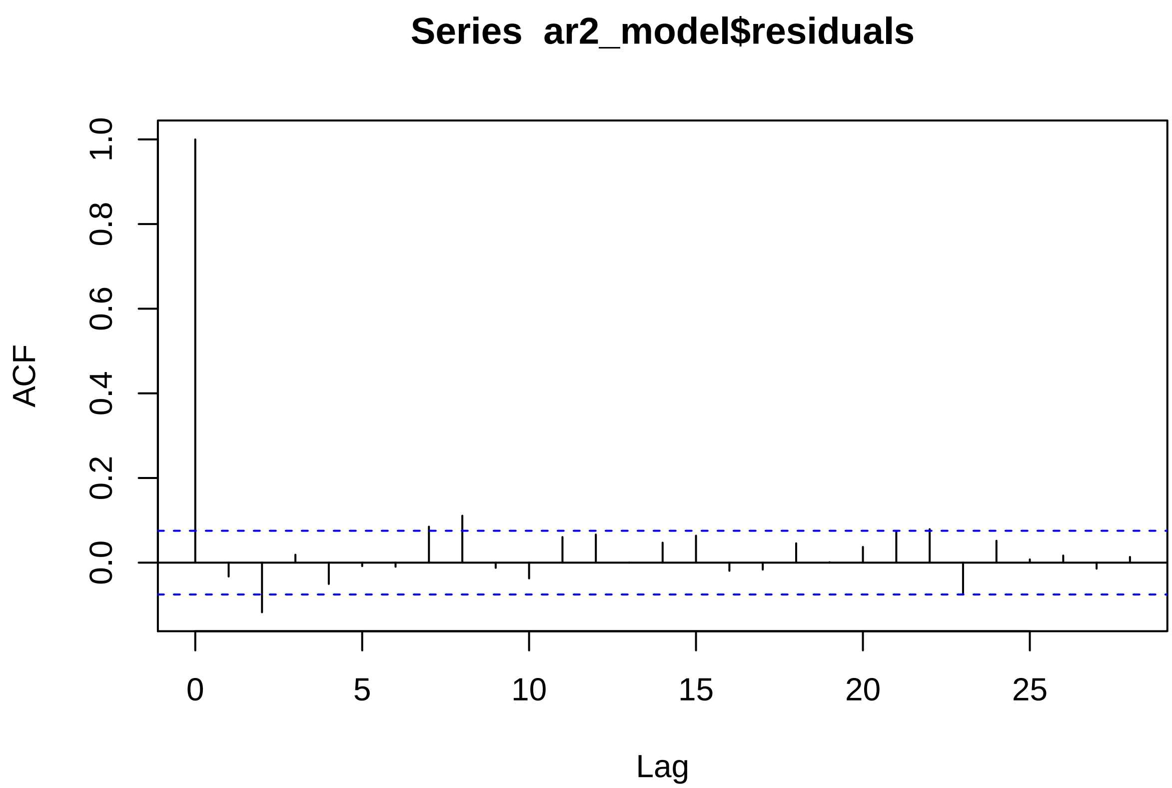
```
acf(ar1_model$residuals,lag.max = 200) # already looks a lot better, but to many gamma(h) outside of ra
```



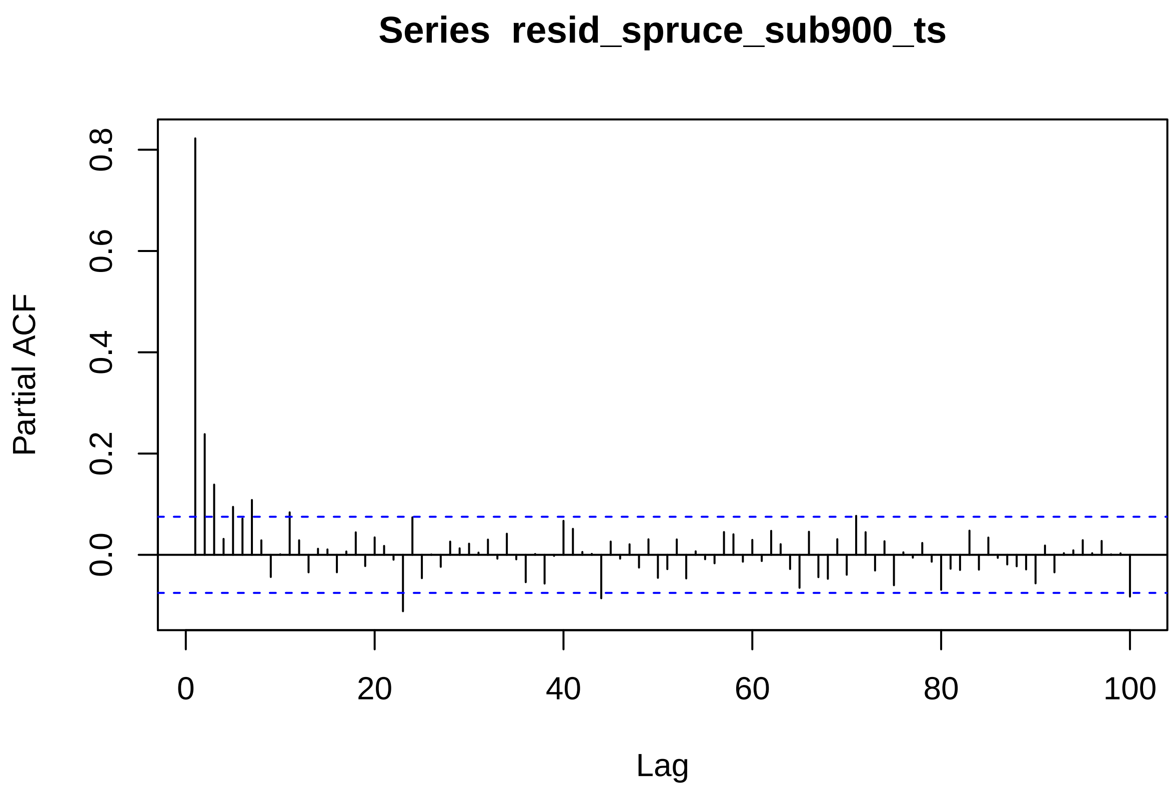

```r
# AR(2)?
ar2d1 <- resid_spruce_sub900[1:(length(resid_spruce_sub900)-2)]
ar2d2 <- resid_spruce_sub900[2:(length(resid_spruce_sub900)-1)]
ar2d3 <- resid_spruce_sub900[3:length(resid_spruce_sub900)]
ar2_model <- lm(ar2d3~ar2d1+ar2d2)
summary(ar2_model)
```

```
##
## Call:
## lm(formula = ar2d3 ~ ar2d1 + ar2d2)
##
## Residuals:
##    Min      1Q Median      3Q     Max
## -80.47 -12.49   1.49  14.36  61.73
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.12236    0.78840  -0.155    0.877
## ar2d1        0.23616    0.03720   6.348 4.01e-10 ***
## ar2d2        0.63475    0.03717  17.075  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 20.53 on 675 degrees of freedom
## Multiple R-squared:  0.7027, Adjusted R-squared:  0.7018
## F-statistic: 797.7 on 2 and 675 DF,  p-value: < 2.2e-16
```

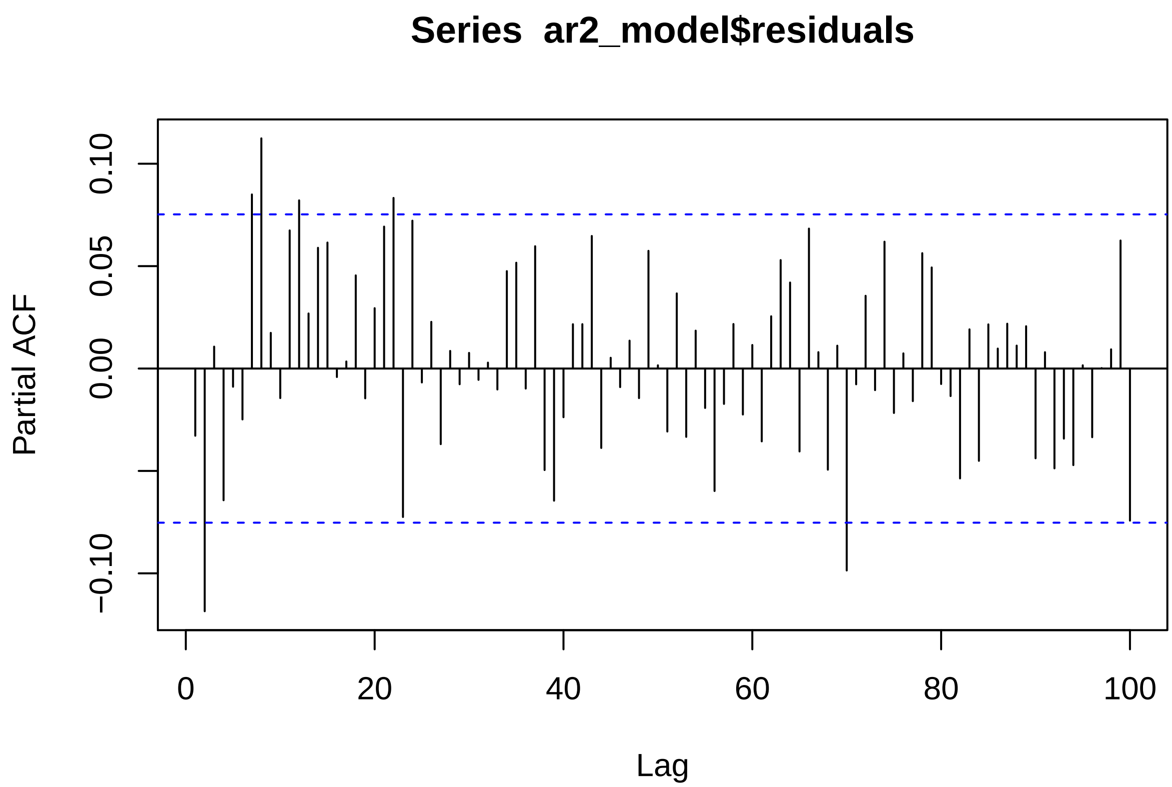
```r
acf(ar2_model$residuals) # still not...
```




```r
pacf(resid_spruce_sub900_ts,100)
```




```
pacf(ar2_model$residuals,100) #
```

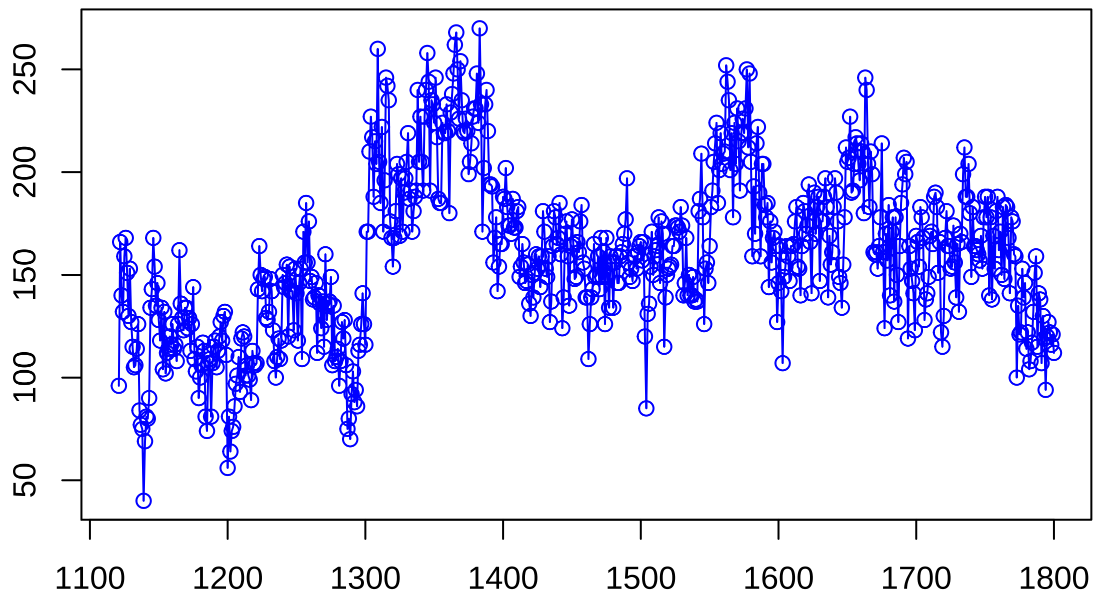



```r
# Include a longterm temperature trend as another explanatory variable

climate <- read.csv("../data/loehle_global_temp_reconstruction.csv",header=T)
climate_ts <- ts(climate$Temp..Anom.,start=16,end=1935)

climate_sub900 <- climate[climate$Year..AD.>=1121 & climate$Year..AD. <= 1800,]
climate_sup900 <- climate[climate$Year..AD.>=1332 & climate$Year..AD. <= 1800,]

climate_sub900_ts <- ts(climate_sub900$Temp..Anom.,start=1121,end=1800)
plotc(spruce_sub900_ts)
lines(climate_sub900*mean(spruce_sub900_ts))
```

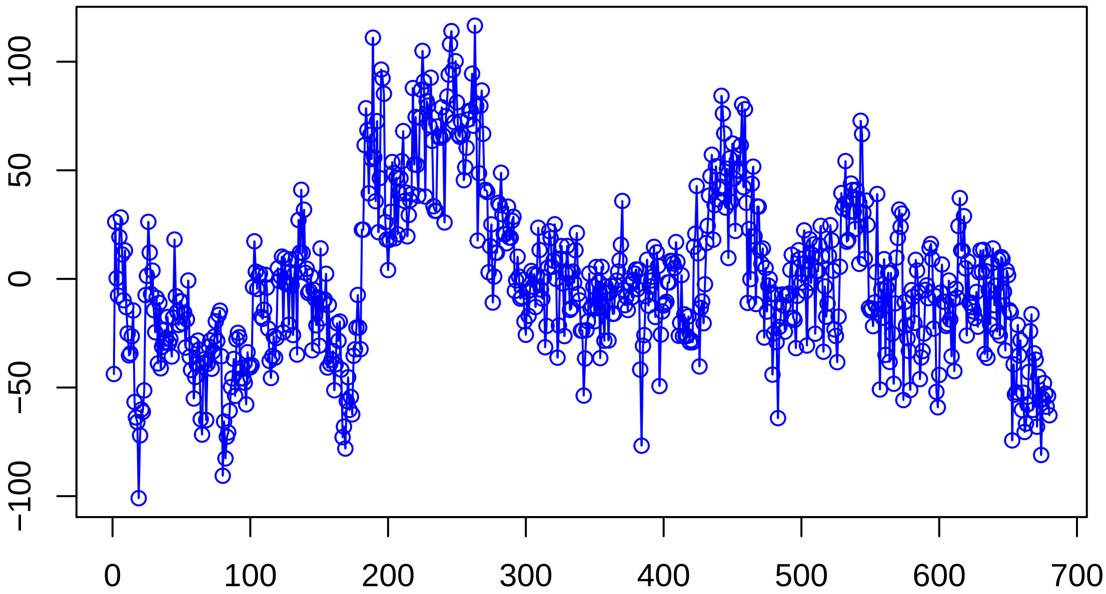



```
#plotc(climate_sub900_ts)

model2 <- lm(spruce_sub900_ts~t+climate_sub900_ts)
summary(model2)
```

```
##
## Call:
## lm(formula = spruce_sub900_ts ~ t + climate_sub900_ts)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -100.943  -25.351   -3.606   19.136  116.574
##
## Coefficients:
##                     Estimate Std. Error t value Pr(>|t|)
## (Intercept)       140.871545   2.969231  47.444  < 2e-16 ***
## t                   0.049208   0.009784   5.030  6.3e-07 ***
## climate_sub900_ts -11.409768   7.685170  -1.485    0.138
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 37.58 on 677 degrees of freedom
## Multiple R-squared:  0.08927,    Adjusted R-squared:  0.08658
## F-statistic: 33.18 on 2 and 677 DF,  p-value: 1.792e-14
```

```r
plotc(model2$residuals)
```



Spruce above 900 m

A first analysis of the time series for spruce above 900 m

```r
t <- seq(from=1,length=length(spruce_sup_900_ts))
model <- lm(spruce_sup_900_ts~t)
summary(model) # cubic trend is still significant
```

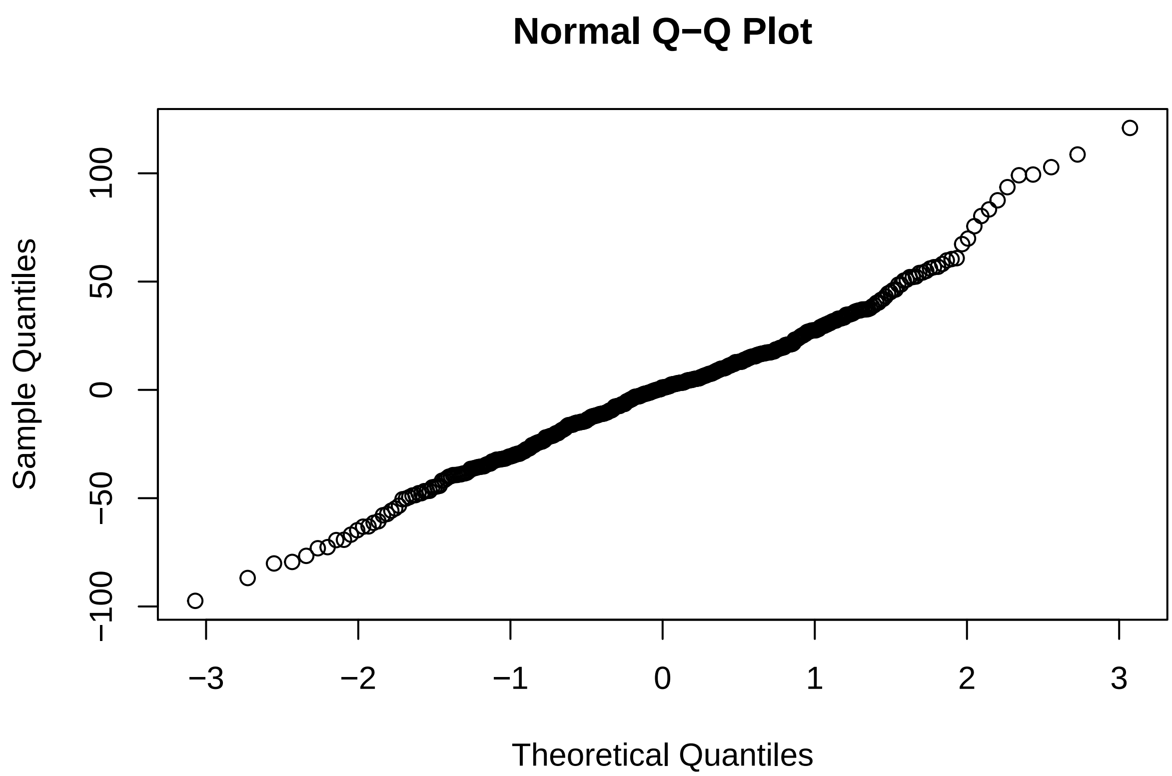
```
##
## Call:
## lm(formula = spruce_sup_900_ts ~ t)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -97.399 -19.152   1.091  16.906 120.934
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 222.2440     2.9007   76.62   <2e-16 ***
## t            -0.2556     0.0107  -23.89   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 31.36 on 467 degrees of freedom
```

```
## Multiple R-squared:  0.5501, Adjusted R-squared:  0.5491
## F-statistic:   571 on 1 and 467 DF,  p-value: < 2.2e-16
```

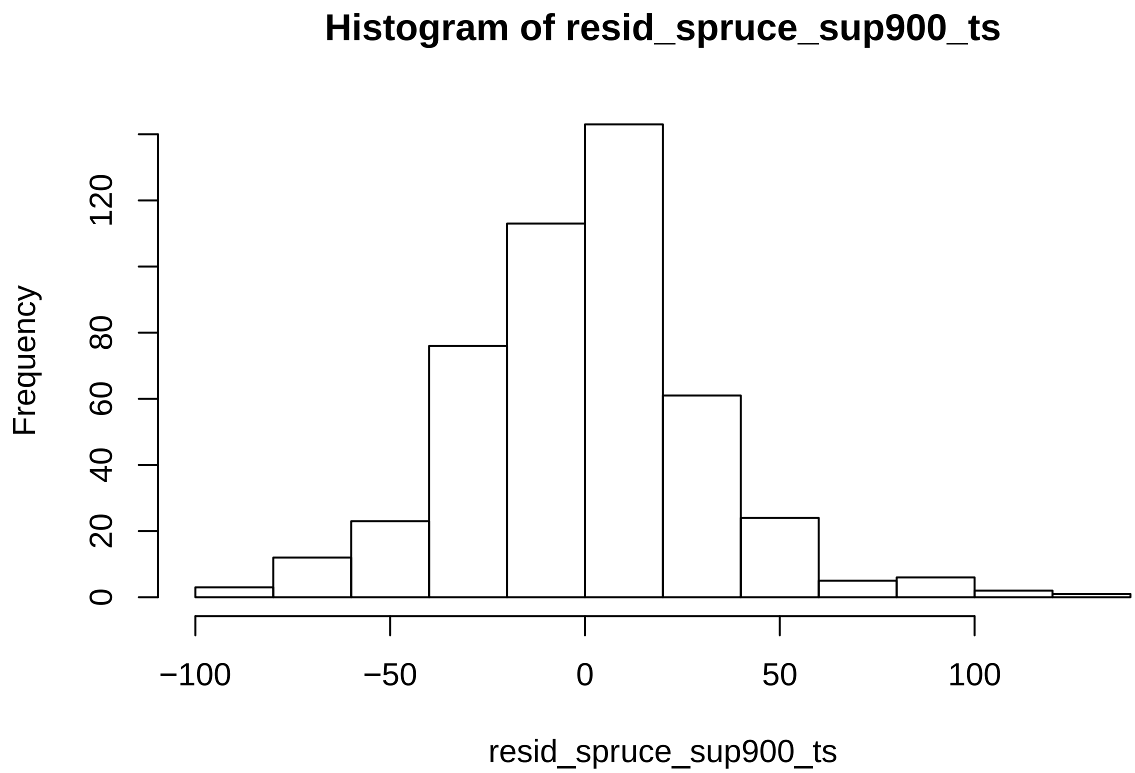
```r
resid_spruce_sup900 <- residuals(model)
resid_spruce_sup900_ts <- ts(resid_spruce_sup900,end=1800)
mean(resid_spruce_sub900_ts) # ~ zero mean
```

```
## [1] 3.282576e-15
```

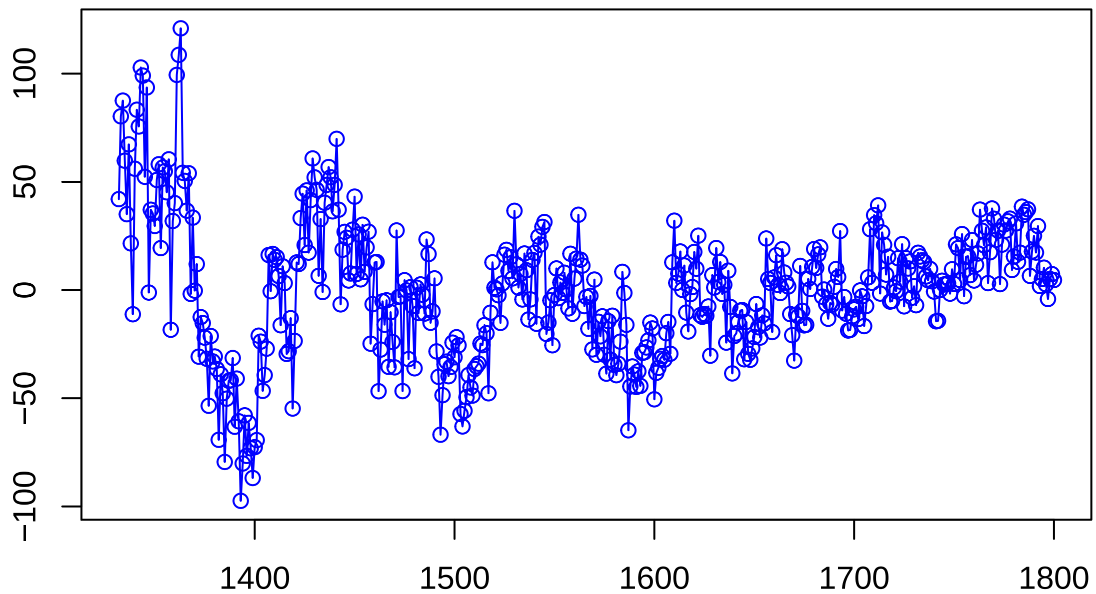
```r
qqnorm(resid_spruce_sup900_ts) # close to a normal distribution
```




```r
hist(resid_spruce_sup900_ts) # slightly right-skewed
```




```
plotc(resid_spruce_sup900_ts)
```

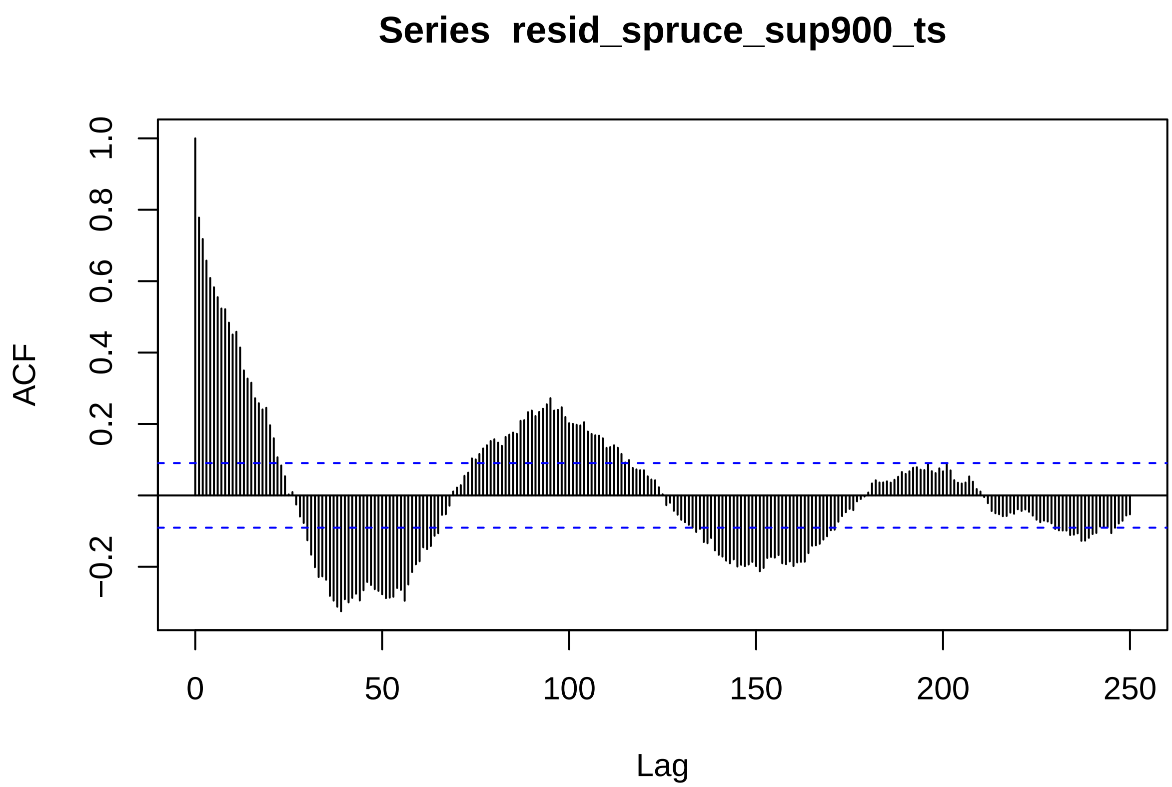



```r
Box.test(resid_spruce_sup900_ts,lag=200,type="Ljung-Box")
```

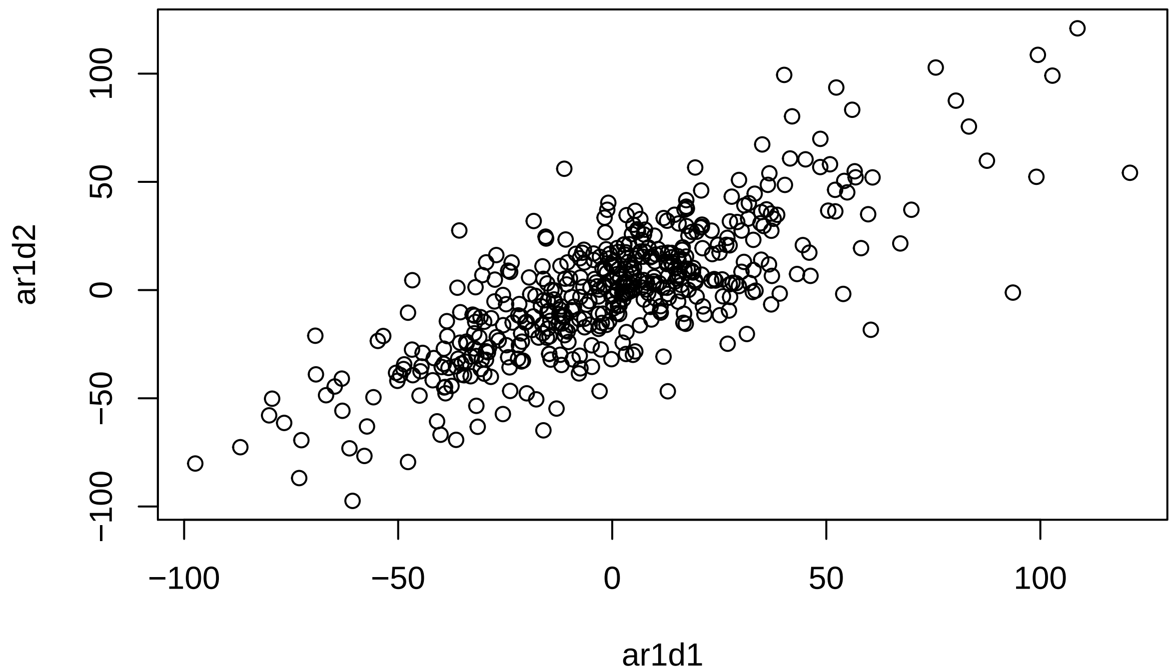
```
##
##  Box-Ljung test
##
## data:  resid_spruce_sup900_ts
## X-squared = 5064.7, df = 200, p-value < 2.2e-16
```

```r
# Reject H0: The residuals are not iid
# Which was to be expected, given the nature of the data

# Sample ACF shows non-stationarity.
acf(resid_spruce_sup900_ts,lag.max = 250)
```



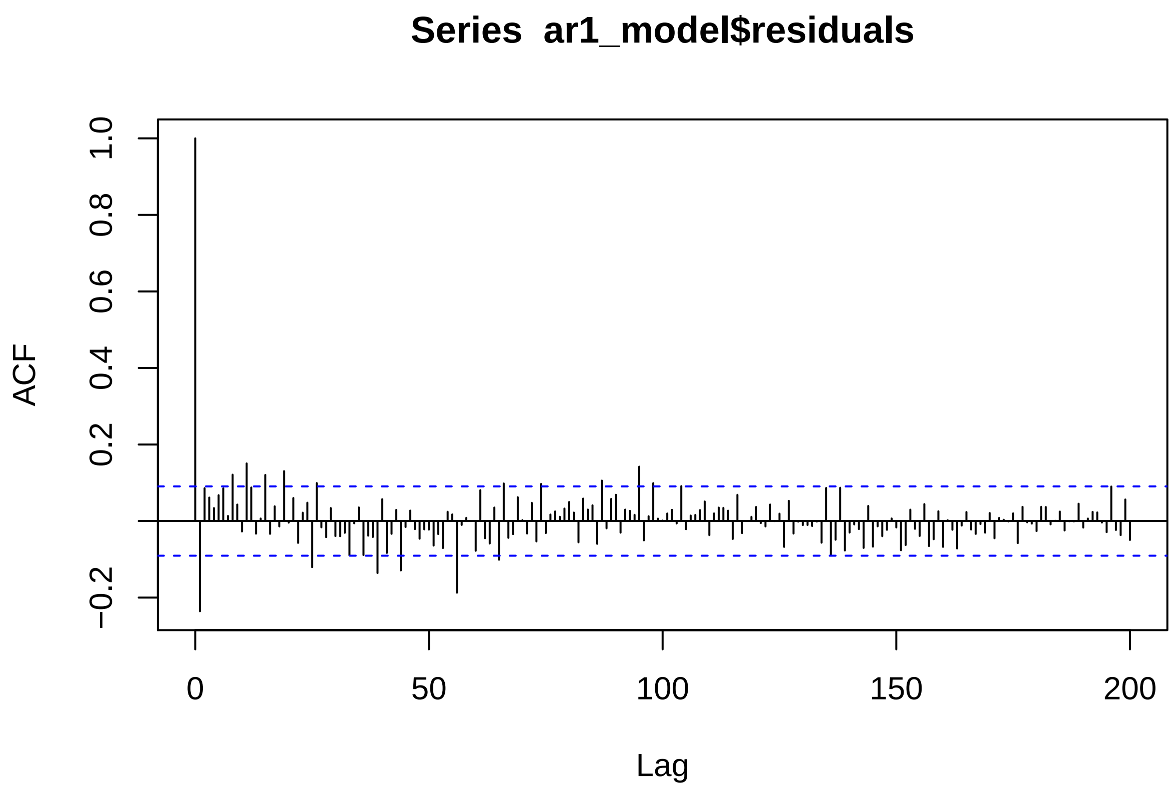

```r
# try to paramtrize an AR(1) model
ar1d1 <- resid_spruce_sup900[1:(length(resid_spruce_sup900)-1)]
ar1d2 <- resid_spruce_sup900[-1]
plot(ar1d2~ar1d1)
```




```r
ar1_model <- lm(ar1d2~ar1d1)
summary(ar1_model) #
```

```
##
## Call:
## lm(formula = ar1d2 ~ ar1d1)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -73.896 -11.570  -0.401  11.542  68.250
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.08209    0.90706  -0.091    0.928
## ar1d1        0.77812    0.02896  26.872   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 19.62 on 466 degrees of freedom
## Multiple R-squared:  0.6078, Adjusted R-squared:  0.6069
## F-statistic: 722.1 on 1 and 466 DF,  p-value: < 2.2e-16
```

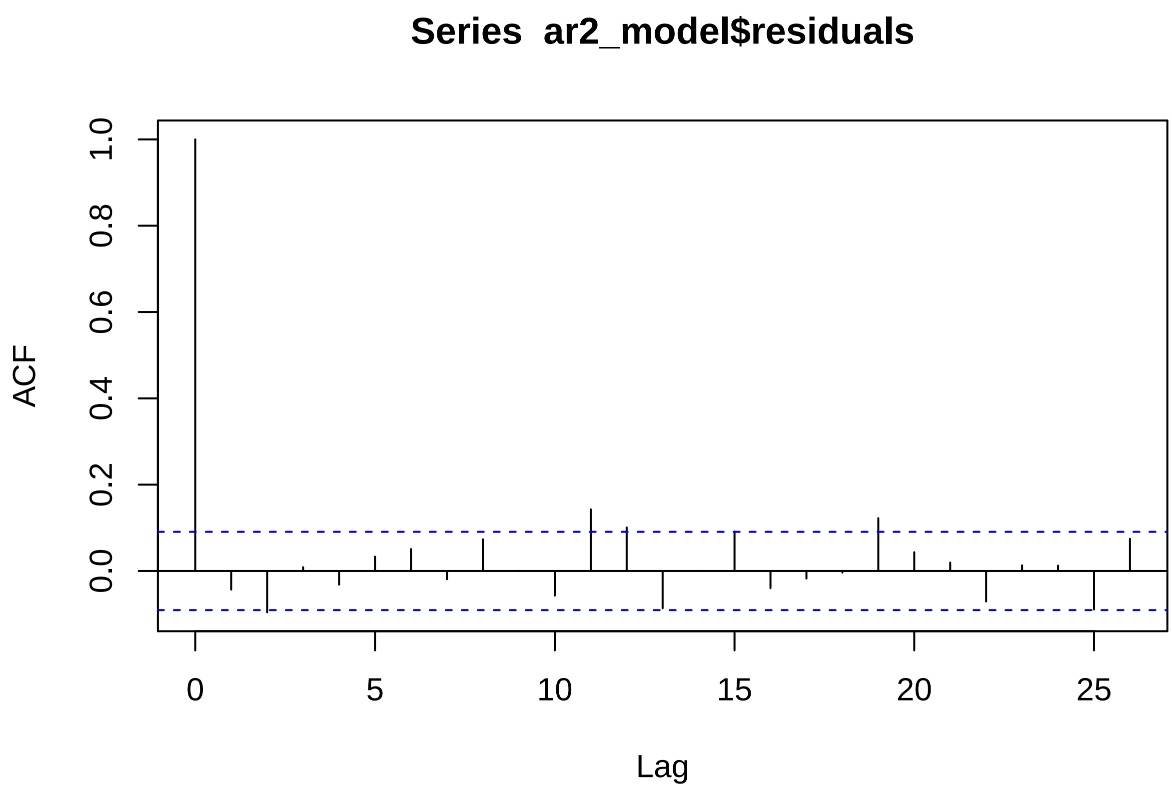
```r
acf(ar1_model$residuals,lag.max = 200) # already looks a lot better, but to many gamma(h) outside of ra
```



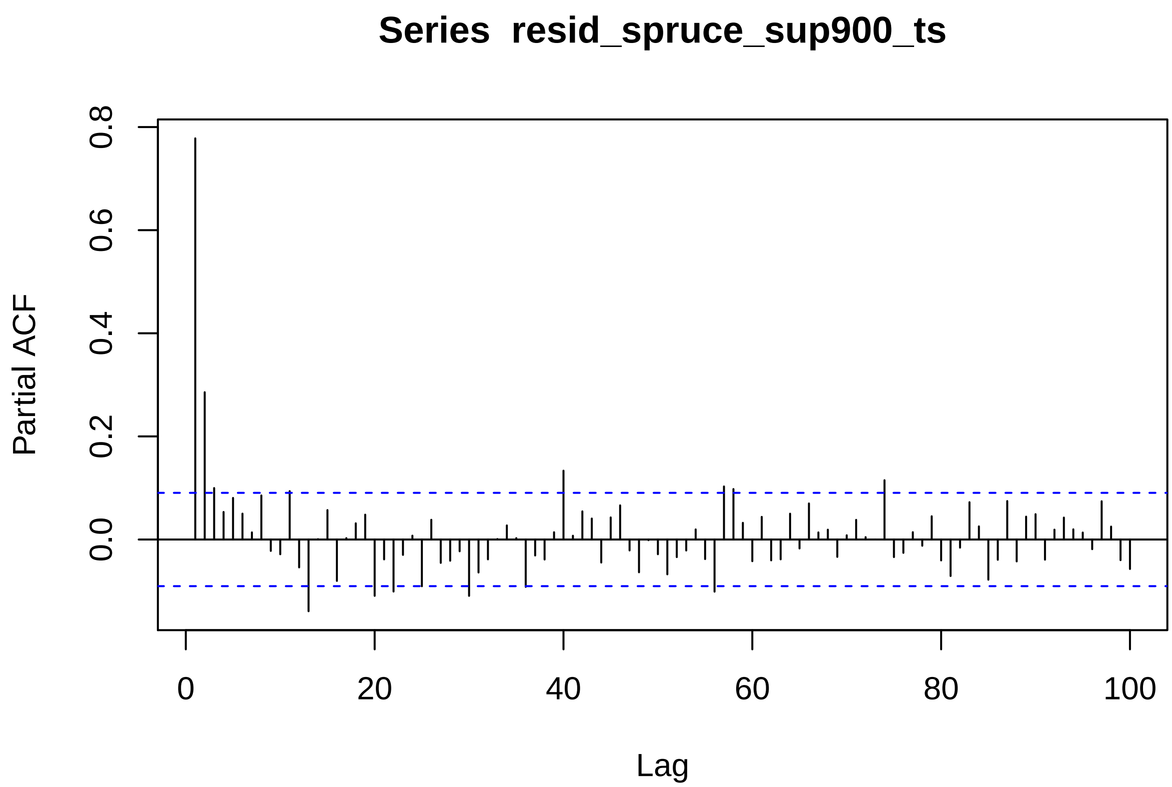

```r
# AR(2)?
ar2d1 <- resid_spruce_sup900[1:(length(resid_spruce_sup900)-2)]
ar2d2 <- resid_spruce_sup900[2:(length(resid_spruce_sup900)-1)]
ar2d3 <- resid_spruce_sup900[3:length(resid_spruce_sup900)]
ar2_model <- lm(ar2d3~ar2d1+ar2d2)
summary(ar2_model)
```

```
##
## Call:
## lm(formula = ar2d3 ~ ar2d1 + ar2d2)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -67.217  -9.827   0.411  10.918  68.385
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.20009    0.86291  -0.232    0.817
## ar2d1        0.29621    0.04394   6.741 4.68e-11 ***
## ar2d2        0.54238    0.04402  12.321  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 18.65 on 464 degrees of freedom
## Multiple R-squared:  0.6423, Adjusted R-squared:  0.6407
## F-statistic: 416.5 on 2 and 464 DF,  p-value: < 2.2e-16
```

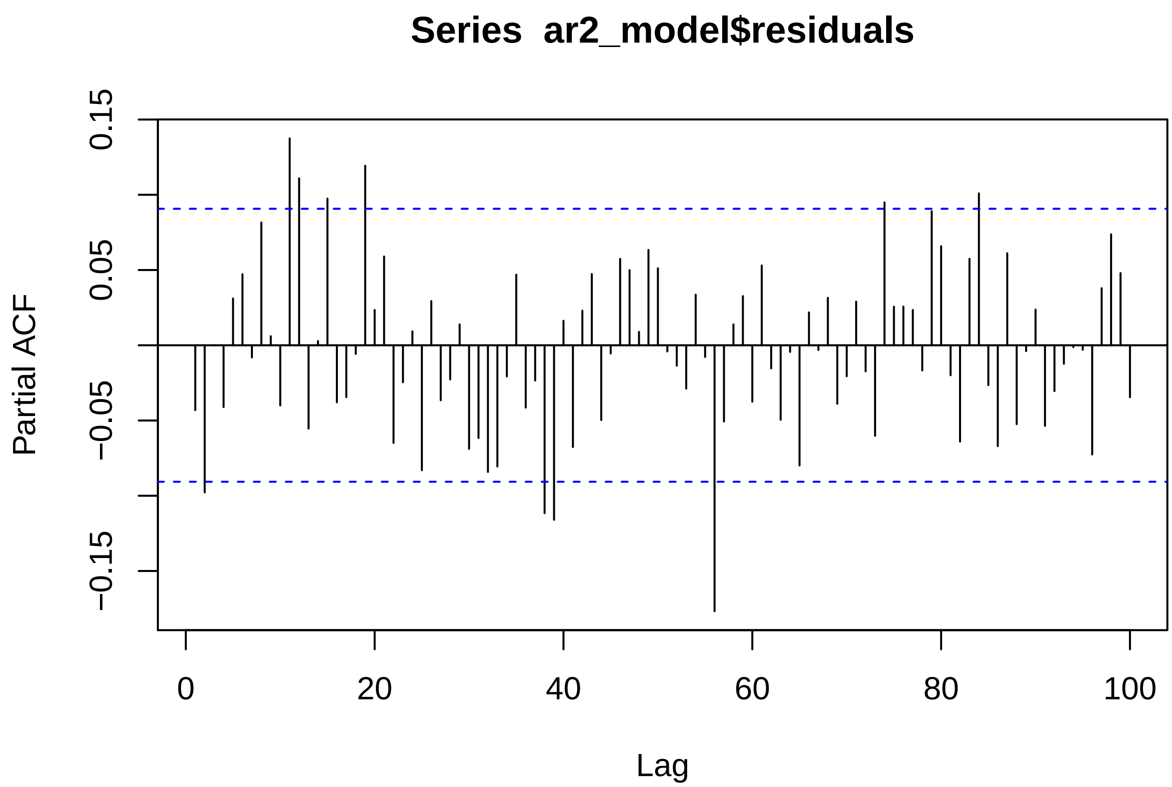
```r
acf(ar2_model$residuals) # still not...
```




```r
pacf(resid_spruce_sup900_ts,100)
```




```
pacf(ar2_model$residuals,100) #
```




```r
# Determine the AR process automatically

sup900_ar <- ar(resid_spruce_sup900_ts)
```

Questions to be answered

Climatic trends are to be identified by analyzing the correlation between 3 different chronologies.

Methods

The project team will answer the questions using the following methods:

- Method 1
- Method 2

References

Kantonsarchäologie, Bern. 2018. "Dendrochronologische Reihen Für Fichten Und Weisstannen." Biel: Departement für Bildung und Kultur Bern.