# Impact of forest management practices on stream water quality:

## First results of generalized additive mixed models (GAMMs)



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# Problem and research focus

- Forested catchments are considered to guarantee the high quality of surface and drinking water.

- Atmospheric input of acid deposition: long-term risk for stream acidification!

- Forest management practices improve water quality

We aim to
determine trends of stream acidification depending on

- management practices
- site conditions

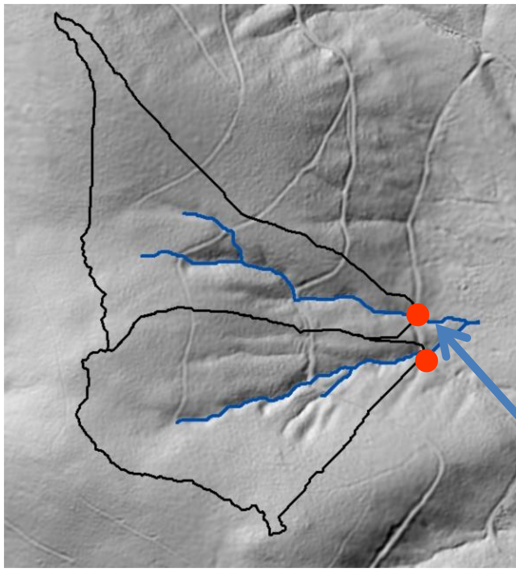
on the basis of statistical analyses.

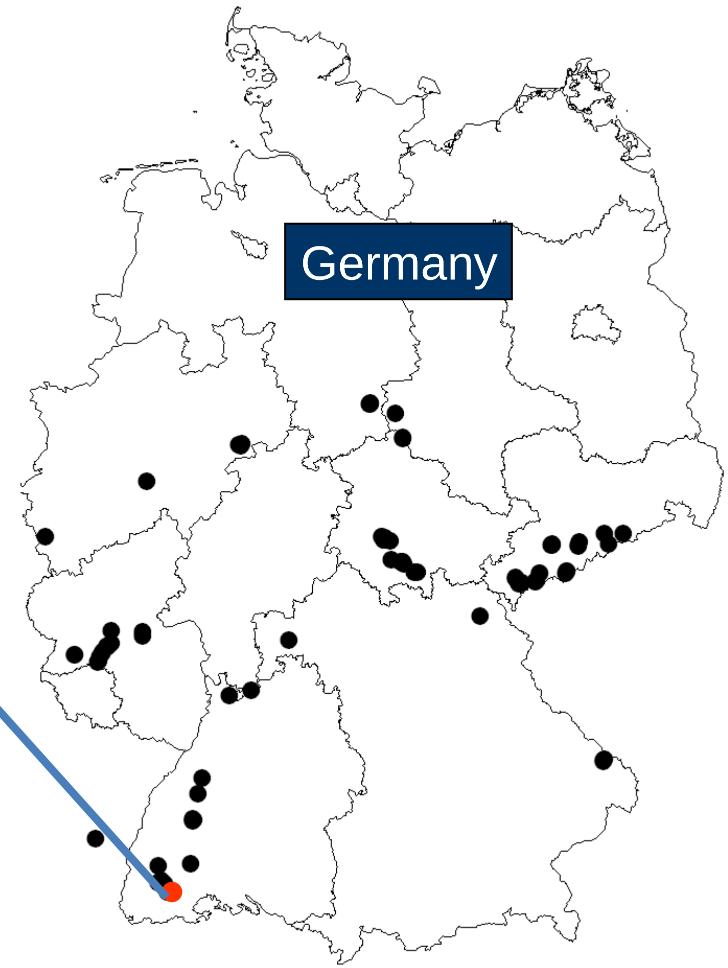
# Research questions

- Can we observe a significant impact of liming, storms and bark beetle infestation on water quality?
- What are the main influencing variables (e.g. deposition, geology,…) for water quality?

# Investigation sites

- Water quality data of 86 streams (●)
- forested mountain ranges






- Indicators of stream water quality

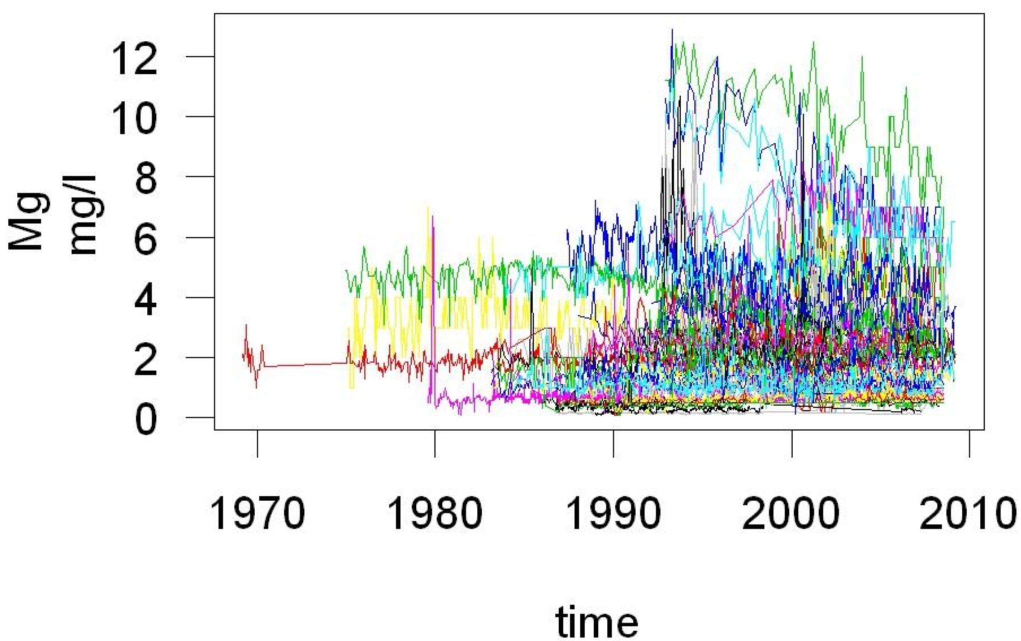
- $Ca^{2+}$, $Mg^{2+}$, $SO_4^{2-}$, $NO_3^-$, $Cl^-$
- Quotient of acidification:

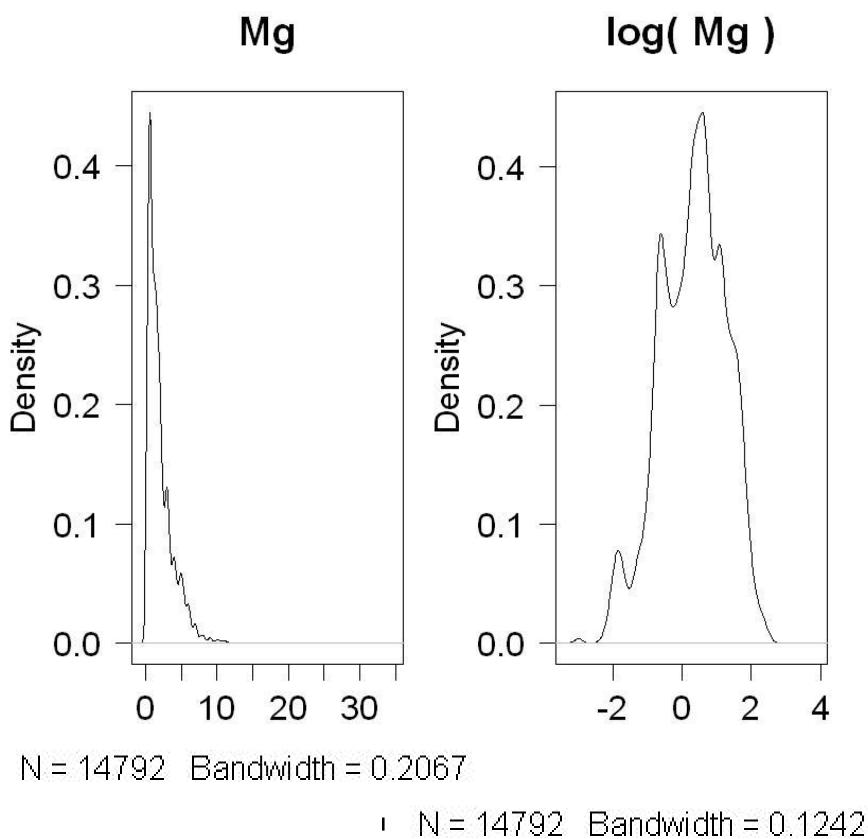
$$QA = (Ca^{2+} + Mg^{2+}) / (SO_4^{2-} + NO_3^- + Cl^-)$$

- pH value
- Acidification products ($Al^{3+}$, $Mn^{2+}$)
- Conc. of humic substances (DOC)

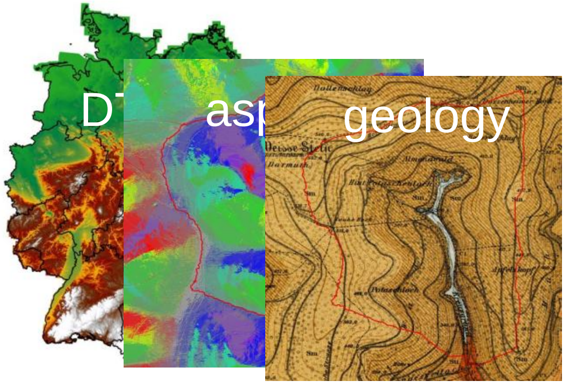
# Observed concentrations

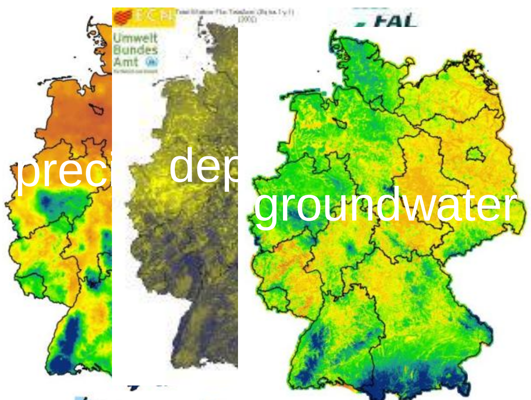
- varying reporting levels
- sampling frequencies from weekly to monthly
- individual observation period started between 1969 and 2001 and ended 1990 and 2009
- Example: Mg concentration

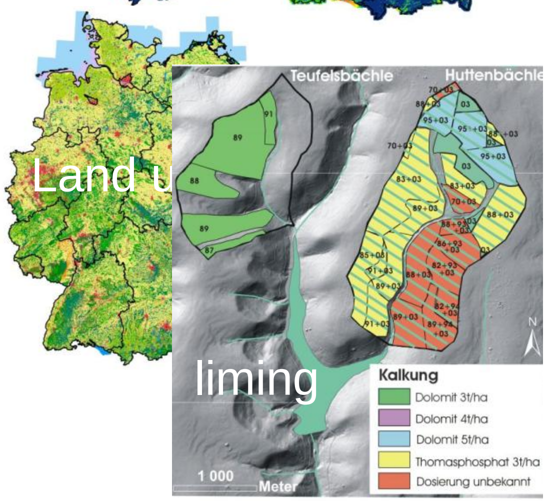


# Explanatory variables




- Descriptive factors of catchment (area, height, location, perimeter, shape, slope, aspect)
- Soil types, soil water (field capacity, available field capacity, air capacity, rate of percolation, depth of the effective root zone) and base saturation (BZE I sites)
- Geology, drainage density and silicate weathering rates
- Meteorology (precipitation, temperature, sunshine duration, pot. and act. evaporation, climatic water balance)
- Deposition and critical loads of pot. acidity
- Runoff depth, low-flow MN10q, BaseFlowIndex and groundwater recharge

<u>Potential forest management drivers for stream water quality</u>

<u>Controllable drivers</u>

- Land use (CORINE 1990, 2000 and site description from publications)
- Liming for soil protection purposes

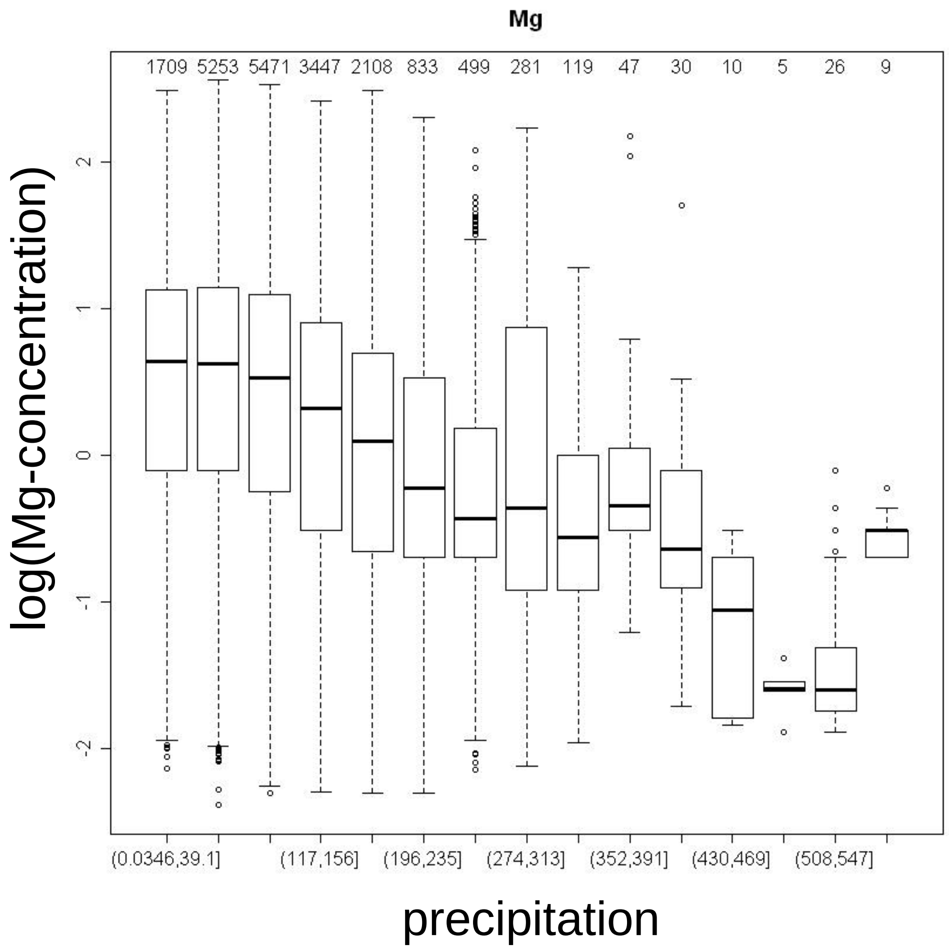
<u>Uncontrollable drivers</u>

- Natural disturbance of stand structure (Storm and bark beetle infestation)

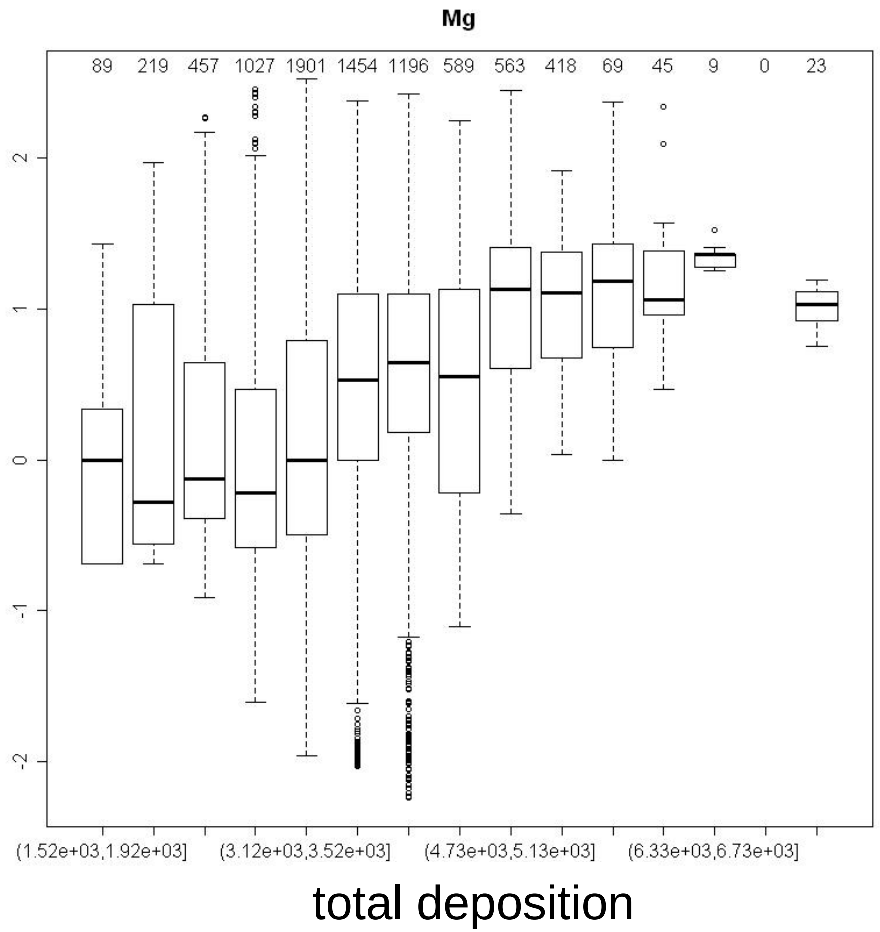

BZE = first national soil inventory (1989-1992)

# Correlation

Diluting effect:




Acidification effect:



# Method: GAMMs

$y \sim \gamma(\mu)$

$log(y) = g(y) = \eta,\ y = g^{-1}(\eta) = exp(\eta)$

**Linear predictor for location *i* and time *t*:**

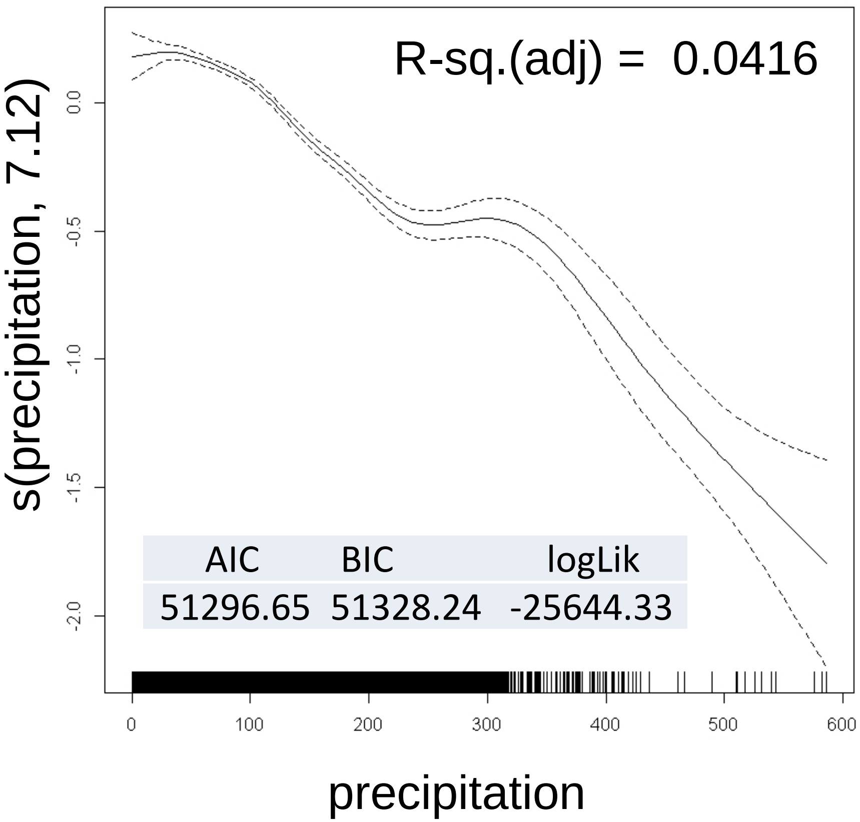
$\eta_{it} = \beta_0 + \beta_1\ x\ I(precipitation) + \beta_2\ x\ I(total\ deposition) + \ldots \beta_{p-1} x_{it}^{(p-1)} + b_{it}$

random effect on location $i$: $b_{i\,t} \sim N(0,\ \tau^2)$

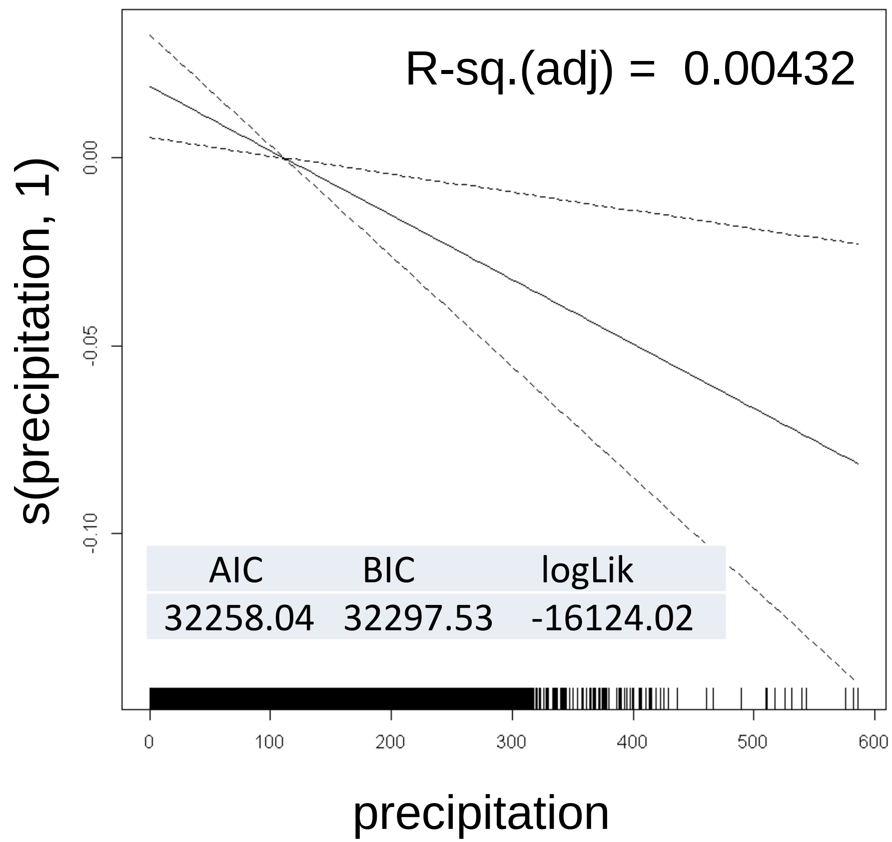
# First Models

Fit.GAMM.1 <-gamm(Mg~s(precipitation),
family = Gamma(link = “log“),
data=Daten)

Fit.GAMM.2 <- gamm(Mg~s(precipitation),
family = Gamma(link = “log“),
random=list(stream number=~1),
data=Daten)




| AIC | BIC | logLik |
|---|---|---|
| 51296.65 | 51328.24 | -25644.33 |




| AIC | BIC | logLik |
|---|---|---|
| 32258.04 | 32297.53 | -16124.02 |

Fit.GAMM.3 <--gamm(Mg~s(precipitation)+s(total deposition), family = Gamma(link = “log“), random=list(stream number=~1), data=Daten)

Family: Gamma
Link function: log

Formula:
Mg ~ s(P) + s(acid)

Parametric coefficients:

| | Estimate | Std. Error | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| (Intercept) | 0.5866 | 0.0911 | 6.439 | 1.28e-10 | *** |

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Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:

| | edf | Ref.df | F | p-value | |
|---|---|---|---|---|---|
| s(precipitation) | 2.904 | 2.904 | 13.43 | 2.16e-08 | *** |
| s(total deposition) | 7.571 | 7.571 | 12.22 | < 2e-16 | *** |

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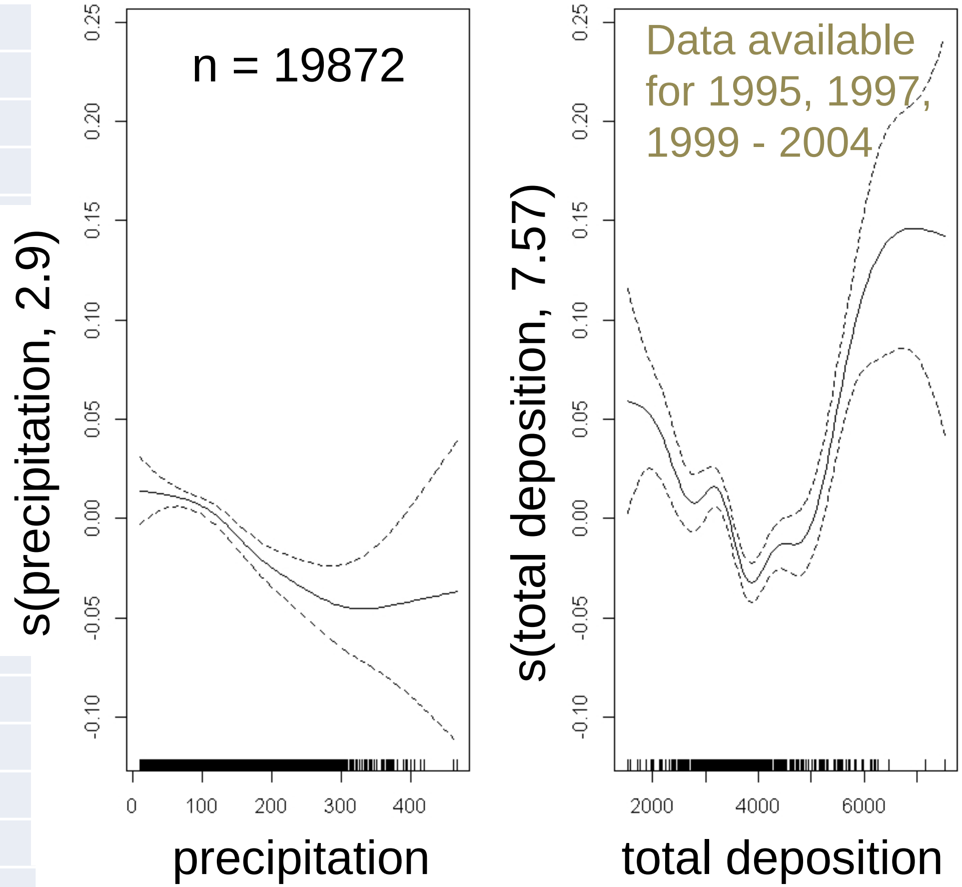
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) = 0.00508 Scale est. = 0.04152 n = 7631



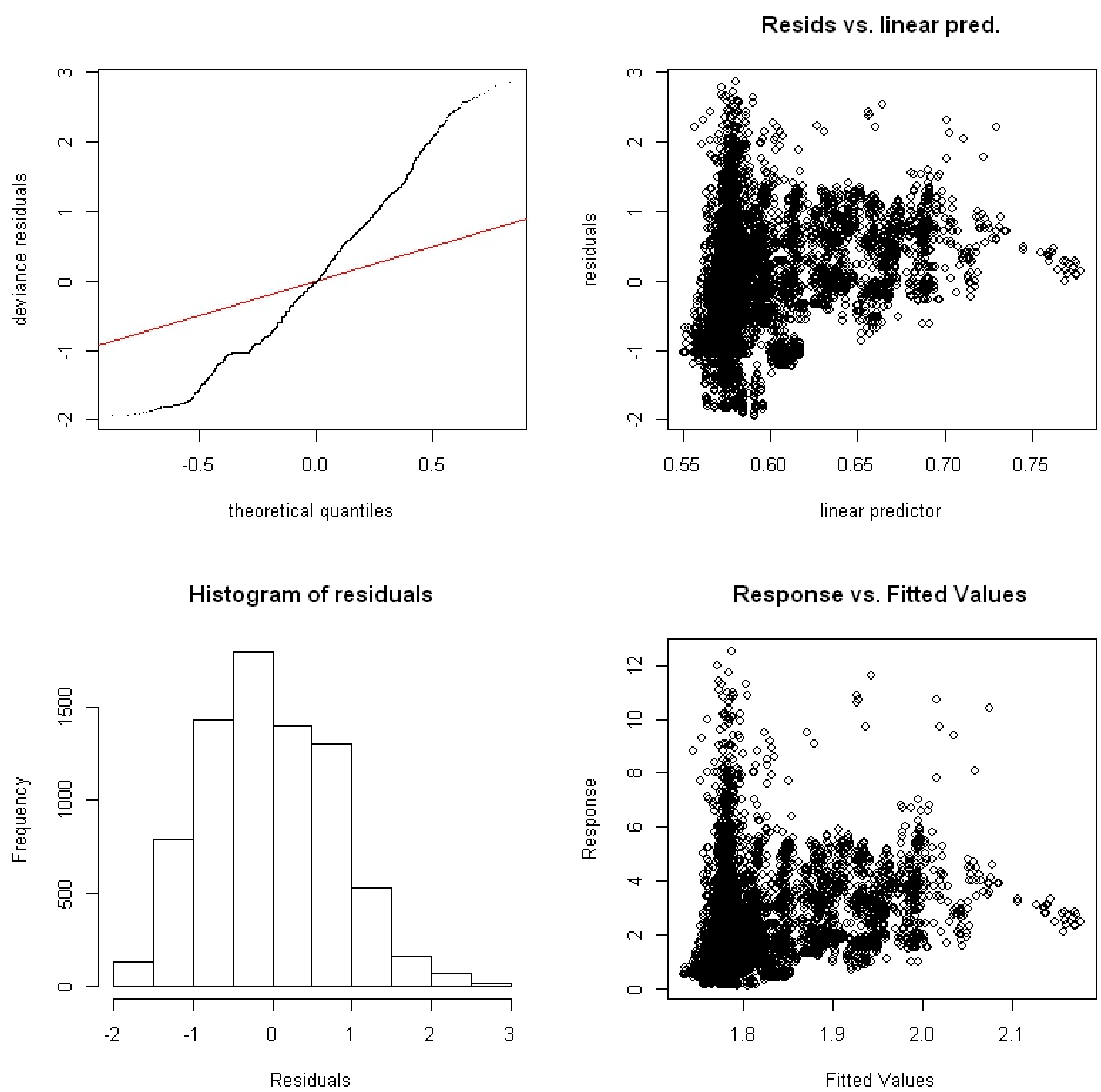

Linear mixed-effects model fit by maximum likelihood
Data: data

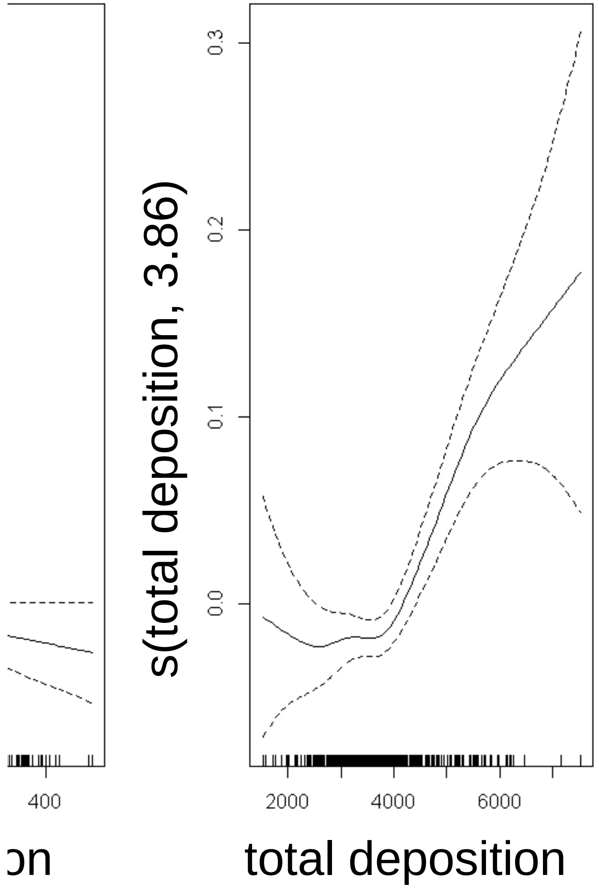
| AIC | BIC | logLik |
|---|---|---|
| -2010.046 | -1961.466 | 1012.023 |

Formula: ~1 | V %in% g.0 %in% g

| | (Intercept) | Residual |
|---|---|---|
| StdDev: | 0.8143698 | 0.2037639 |

Fit.GAMM.4 <- gamm(Mg~s(precipitation)+s(total deposition),family = Gamma(link = "log"), random=list(stream number=~1), correlation=corCAR1(form=~Date|stream number),data=Daten)




ts model fit by maximum likelihood

gLik

368 2531.194

in% g.0 %in% g

sidual

2 0.2215068

# Questions

- How can I include the aspect variable?
  → sinus transformation of aspect =0.5(1+sin(aspect)-90°C))
  → 0 = south, 1 = north
  *"Fehler in smooth.construct.tp.smooth.spec(object, dk$data, dk$knots) : A term has fewer unique covariate combinations than specified maximum degrees of freedom"*

- How to handle with percentage values (0%, …, 100%)?
  → Used it for mapped information (geology, soil type, land use, liming, storm area, bark beetle infestation)
  → as factor()?

- How to deal with error messages when including the correlation term?
  *"Fehler in Initialize.corCAR1(X[[2L]], ...) : covariate must have unique values within groups for "corCAR1" objects"*

- How to get good model?

# Thanks for provision of data !

**Bavaria:**

- Büro für Angewandte Hydrologie München
- Nationalparkverwaltung Bayerischer Wald
- Landesamt für Umwelt
- Bayerische Landesanstalt für Wald und Forstwirtschaft

**Saxony:**

- Landestalsperrenverwaltung des Freistaates Sachsen
- Staatsbetrieb Sachsenforst
- Dresden University of Technology

**Saxony-Anhalt:**

- Talsperrenbetrieb Sachsen-Anhalt (AöR)

**Thuringia:**

- Thüringer Fernwasserversorgung

**Rhineland-Palatinate:**

- Stadtwerke Idar-Oberstein
- SWT Stadtwerke Trier Versorgungs-GmbH LUWG
- Landesamt für Umwelt, Wasserwirtschaft und Gewerbeaufsicht Rheinland-Pfalz

**North-Rhine-Westfalen:**

- WSW Energie & Wasser AG
- WAG Nordeifel mbH
- Wasserverband Aabachtalsperre

**Baden-Württemberg:**

- Zweckverband Wasserversorgung Kleine Kinzig
- Limnologie-Büro Hoehn
- Forstliche Versuchs- und Forschungsanstalt BW
- LfU (Landesanstalt f. Umweltschutz Baden-Württemberg, Karlsruhe Abt 4 Wasser)
- LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg

**Lower Saxony:**

- Forest Research Institute of Lower Saxony

**Other data sources:**
DWD: German Weather Service
HAD: Hydrological Atlas of Germany
UBA: Umweltbundesamt
vTI: Johann Heinrich von Thünen-Institut, Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei