Explore Trends of WiMMed Indicators

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2016 March

Prepare Data

1. Read data of Mann-Kendal Sen-Slope for each pixels and WiMMed indicators
2. Read data of topographic variable:
    - Convert radian to deg.
    - Create categorical variable for elevation (250 m)
    - Classify aspect into 8 categories
3. Read data from hydrological basin
4. Read spatial data:
    - Select only centroides of interest
5. Create two dataframes:
    - **Full Dataframe** with all variables and all pixels (`fulldf`)
    - :red_circle: In this exploration we don't filter the data by elevation

```
# Trend analysis data
# Define name of indicators (see variables names)
# Use annual and season aggregation
indicadores <- c("pre", "pre_snow", "pre_snow_per", "temp",
                 "pnau", "pnsp", "pnsu", "pnwi",
                 "preau", "presp", "presu", "prewi",
                 "tempau", "tempsp", "tempsu", "tempwi")

# Loop to read files
for (j in indicadores){
  aux <- read.csv(file=paste(di, "/data/derived/", j, ".csv", sep= ""),
              header = TRUE,
              sep = ',')
  assign(j, aux)
}
# --

# Define pixels of interes
pixels_interes <- pre$nie_malla_modi_id

# Read Topographic data
rawtopo <- read.csv(file=paste(di, "/data/topo_nie_malla_modis.csv", sep=""),
                    header=TRUE,
                    sep = ",")

# function to convert radian to degree
rad2deg <- function(rad) {(rad * 180) / (pi)}


topo <- rawtopo %>%
```

```r
  filter(id %in% pixels_interes) %>%
  mutate(nie_malla_modi_id = id,
         slope50mean_deg = rad2deg(slope50mean),
         slope50median_deg = rad2deg(slope50median),
         aspect50mean_deg = rad2deg(aspect50mean),
         aspect50median_deg = rad2deg(aspect50median)) %>%
  dplyr::select(nie_malla_modi_id, dem50mean, dem50median, slope50mean_deg,
                slope50median_deg, aspect50mean_deg, aspect50median_deg)

## Create interval variables (250 m) for dem; and classify aspect into 8 categories
topo <- topo %>%
  mutate(dem50mean_group = cut(dem50mean,
                        breaks = seq(from=0, to=3500, by=250),
                        labels = c("0-250", "251-500","501-750","751-1000",
                                   "1001-1250","1251-1500","1501-1750","1751-2000",
                                   "2001-2250","2251-2500","2501-2750", "2751-3000",
                                   "3001-3250", "3251-3500")),
         aspect50mean_deg_group = cut(aspect50mean_deg,
                                      breaks= c(22.5, 67.5, 112.5, 157.5, 202.5, 247.5, 292.5, 337.5, 35
                                      labels = c("N", "NE", "E", "SE", "S", "SW", "W", "NW")))


# --

# Read spatial data and Get lat/long
centroides <- rgdal::readOGR(dsn=paste(di, "/data/geoinfo", sep=""),
                             layer = "centroides_selected", verbose = FALSE)
# Select only attributes of interest and rename them
centroides <- centroides[c("id")]

# Create lat/lng by id
xycentroides <- cbind(centroides@data, coordinates(centroides))
names(xycentroides) <- c("nie_malla_modi_id", "lon","lat")

xycentroides <- filter(xycentroides, nie_malla_modi_id %in% pixels_interes)
# --

# Hydrological basin
basin <- read.csv(file=paste(di, "/data/derived/pixel_region.csv", sep=""),
                  header=TRUE,
                  sep = ",")
# --


# Create un dataframe con todos los datos
fulldf <- topo %>%
  inner_join(pre,  by=c("nie_malla_modi_id")) %>%
  inner_join(pre_snow,  by=c("nie_malla_modi_id")) %>%
  inner_join(pre_snow_per,  by=c("nie_malla_modi_id")) %>%
  inner_join(temp,  by=c("nie_malla_modi_id")) %>%
  inner_join(pnau,  by=c("nie_malla_modi_id")) %>%
  inner_join(pnsp,  by=c("nie_malla_modi_id")) %>%
  inner_join(pnsu,  by=c("nie_malla_modi_id")) %>%
```

```r
  inner_join(pnwi,  by=c("nie_malla_modi_id")) %>%
  inner_join(preau,  by=c("nie_malla_modi_id")) %>%
  inner_join(presp,  by=c("nie_malla_modi_id")) %>%
  inner_join(presu,  by=c("nie_malla_modi_id")) %>%
  inner_join(prewi,  by=c("nie_malla_modi_id")) %>%
  inner_join(tempau,  by=c("nie_malla_modi_id")) %>%
  inner_join(tempsp,  by=c("nie_malla_modi_id")) %>%
  inner_join(tempsu,  by=c("nie_malla_modi_id")) %>%
  inner_join(tempwi,  by=c("nie_malla_modi_id")) %>%
  inner_join(xycentroides, by="nie_malla_modi_id") %>%
  inner_join(basin, by="nie_malla_modi_id")


# Create subset of pixels above 1250
fulldf1250 <- fulldf %>%
  filter(dem50mean > 1250)
```

Explore trends of annual variables by basin

We explore the pattern of snow-cover indicators trends by hydrological basin.

```r
## Summary statistics
misvariables<- c('tau_pre', 'sen_slope_pre', 'tau_pre_snow', 'sen_slope_pre_snow',
                 'tau_pre_snow_per', 'sen_slope_pre_snow_per', 'tau_temp', 'sen_slope_temp')

variable_agrupa <- 'basin_name'
prefijo  <- 'basin_'
df <- fulldf

stats_basin <- data.frame()

for (i in misvariables){
  vnames <- c(variable_agrupa, i)
  aux <- df %>%
    dplyr::select(one_of(vnames)) %>%
    mutate_(vinterest = i) %>%
    group_by_(.dots=variable_agrupa) %>%
    summarise(mean=mean(vinterest),
              sd = sd(vinterest),
              se = sd / sqrt (length(vinterest)))
  aux <- aux %>%
    mutate(variable = i)

  stats_basin <- rbind(stats_basin, aux)
  # assign(paste0(prefijo,i), aux)

}
```

Pre

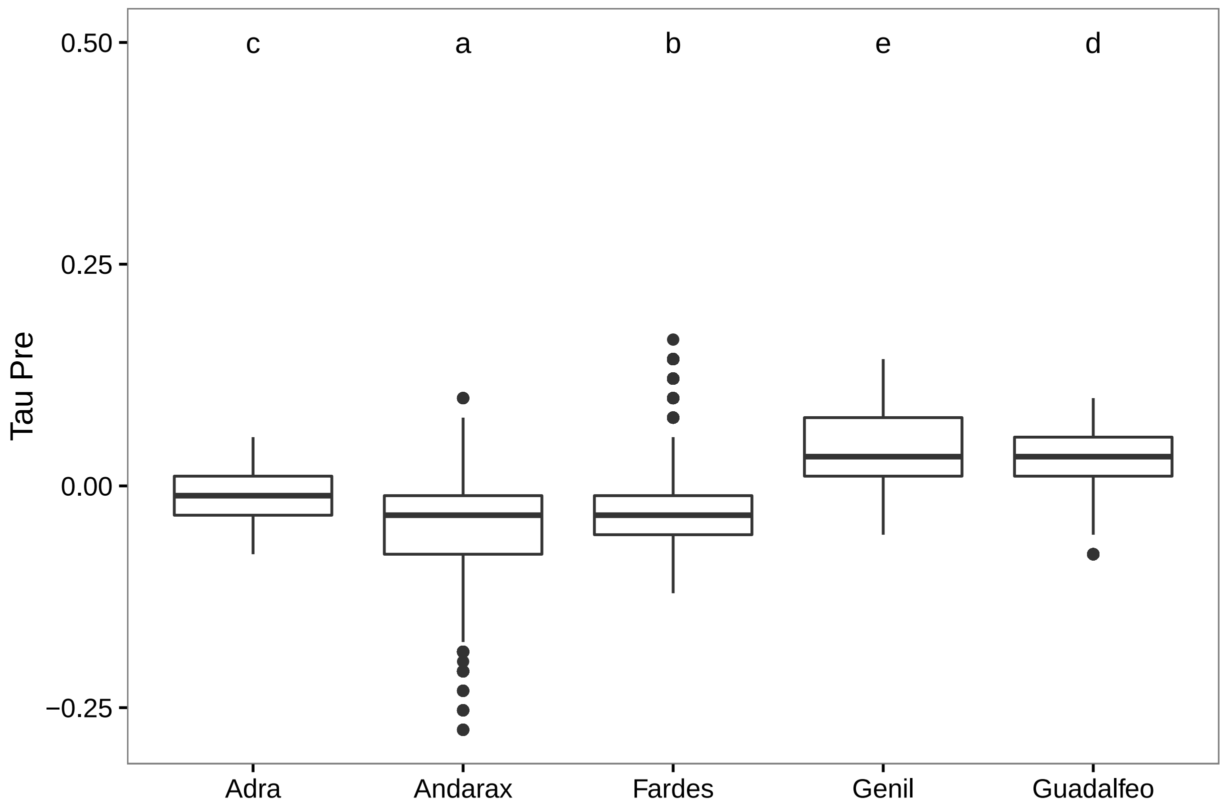
```
df_letter_aux <- data.frame()
df <- fulldf
```

```
# Tau pre
# ANOVA
variable <- 'tau_pre'
my_ylab <- 'Tau Pre'


myformula <- formula(paste(variable, '~ basin_name', sep=''))
mod <- aov(myformula, data=df)
pander(tidy(mod), caption=my_ylab)
```

Table 1: Tau Pre

term	df	sumsq	meansq	statistic	p.value
basin_name	4	9.865	2.466	947.2	0
Residuals	7989	20.8	0.002604	NA	NA

```
## Multiple comparisons
tuk <- glht(mod, linfct = mcp(basin_name = "Tukey"))
# Convert comparisons into letters
df_letter <- fortify(cld(tuk)) %>%
  transmute(basin_name = as.factor(lhs),
         tukey_basin_name = letters) %>%
  mutate(variable = variable)

df_letter_aux <- rbind(df_letter_aux, df_letter)

## ANOVA plots
ggplot(df, aes_string(x='basin_name', y=variable)) +
  geom_boxplot() +
  geom_text(data=df_letter, aes(label = tukey_basin_name, x=basin_name, y=0.5),
           position = position_dodge(width=0.9)) +
  theme_bw() + mythemeggplot +
  ylab(my_ylab) + xlab('')
```



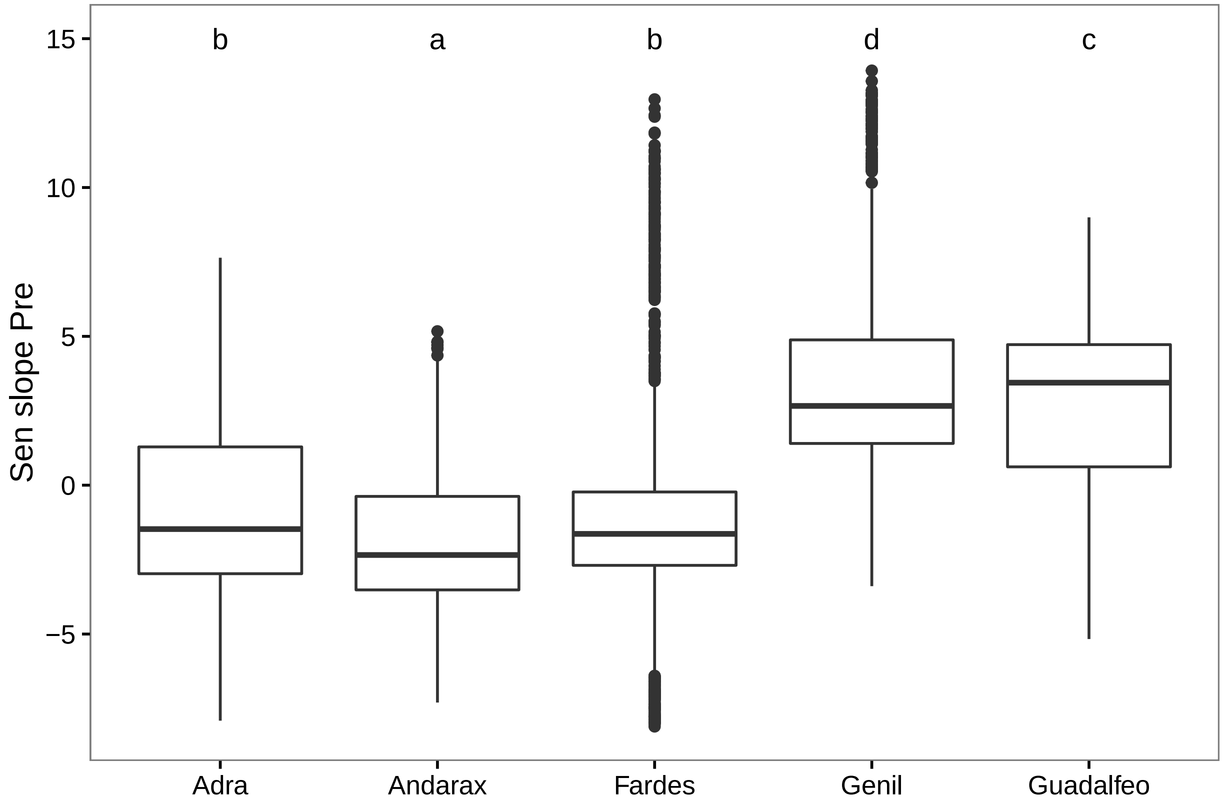

```
# Sen Pre
# ANOVA
variable <- 'sen_slope_pre'
my_ylab <- 'Sen slope Pre'

myformula <- formula(paste(variable, '~ basin_name', sep=''))
mod <- aov(myformula, data=df)
pander(tidy(mod), caption=my_ylab)
```

Table 2: Sen slope Pre

term	df	sumsq	meansq	statistic	p.value
basin_name	4	36119	9030	1028	0
Residuals	7989	70192	8.786	NA	NA

```
## Multiple comparisons
tuk <- glht(mod, linfct = mcp(basin_name = "Tukey"))
# Convert comparisons into letters
df_letter <- fortify(cld(tuk)) %>%
  transmute(basin_name = as.factor(lhs),
         tukey_basin_name = letters) %>%
  mutate(variable = variable)

df_letter_aux <- rbind(df_letter_aux, df_letter)

## ANOVA plots
```

```r
ggplot(df, aes_string(x='basin_name', y=variable)) +
  geom_boxplot() +
  geom_text(data=df_letter, aes(label = tukey_basin_name, x=basin_name, y=15),
            position = position_dodge(width=0.9)) +
  theme_bw() + mythemeggplot +
  ylab(my_ylab) + xlab('')
```



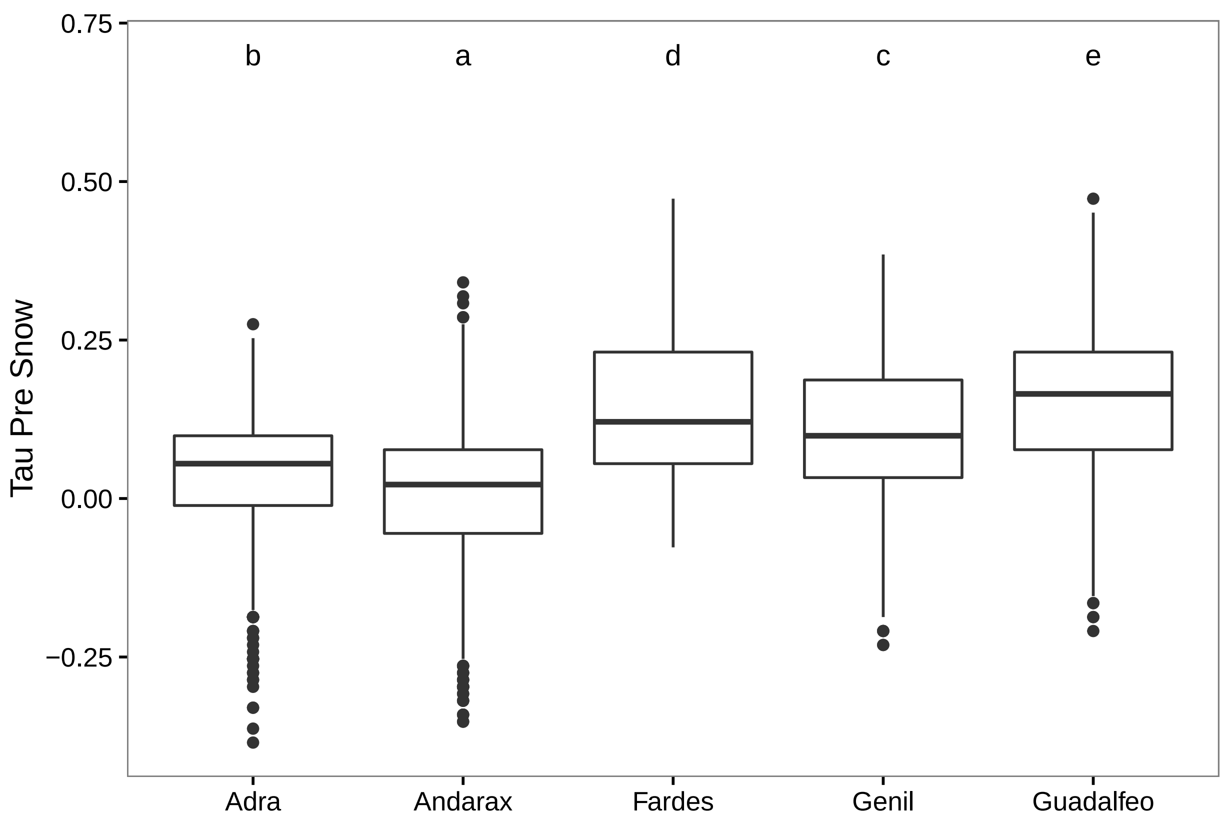
Pre Snow

```r
# Tau Pre Snow
# ANOVA
variable <- 'tau_pre_snow'
my_ylab <- 'Tau Pre Snow'

myformula <- formula(paste(variable, '~ basin_name', sep=''))
mod <- aov(myformula, data=df)
pander(tidy(mod), caption=my_ylab)
```

Table 3: Tau Pre Snow

term	df	sumsq	meansq	statistic	p.value
basin_name	4	33.34	8.335	656.9	0
Residuals	7989	101.4	0.01269	NA	NA

```r
## Multiple comparisons
tuk <- glht(mod, linfct = mcp(basin_name = "Tukey"))
# Convert comparisons into letters
df_letter <- fortify(cld(tuk)) %>%
  transmute(basin_name = as.factor(lhs),
         tukey_basin_name = letters) %>%
  mutate(variable = variable)

df_letter_aux <- rbind(df_letter_aux, df_letter)

## ANOVA plots
ggplot(df, aes_string(x='basin_name', y=variable)) +
  geom_boxplot() +
  geom_text(data=df_letter, aes(label = tukey_basin_name, x=basin_name, y=0.7),
            position = position_dodge(width=0.9)) +
  theme_bw() + mythemeggplot +
  ylab(my_ylab) + xlab('')
```

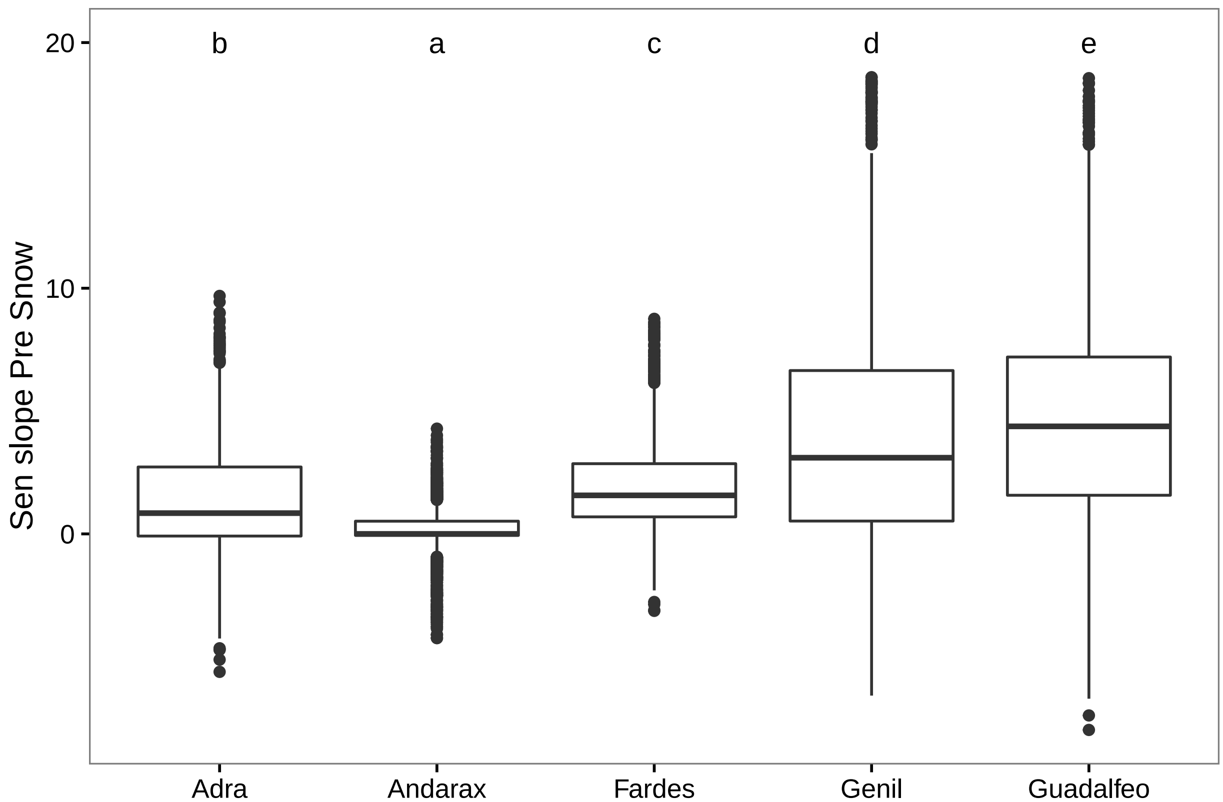



```r
# Sen Pre Snow
# ANOVA
variable <- 'sen_slope_pre_snow'
my_ylab <- 'Sen slope Pre Snow'

myformula <- formula(paste(variable, '~ basin_name', sep=''))
mod <- aov(myformula, data=df)
pander(tidy(mod), caption=my_ylab)
```

Table 4: Sen slope Pre Snow

term	df	sumsq	meansq	statistic	p.value
basin_name	4	26876	6719	660.3	0
Residuals	7989	81287	10.17	NA	NA

```
## Multiple comparisons
tuk <- glht(mod, linfct = mcp(basin_name = "Tukey"))
# Convert comparisons into letters
df_letter <- fortify(cld(tuk)) %>%
  transmute(basin_name = as.factor(lhs),
         tukey_basin_name = letters) %>%
  mutate(variable = variable)

df_letter_aux <- rbind(df_letter_aux, df_letter)

## ANOVA plots
ggplot(df, aes_string(x='basin_name', y=variable)) +
  geom_boxplot() +
  geom_text(data=df_letter, aes(label = tukey_basin_name, x=basin_name, y=20),
           position = position_dodge(width=0.9)) +
  theme_bw() + mythemeggplot +
  ylab(my_ylab) + xlab('')
```



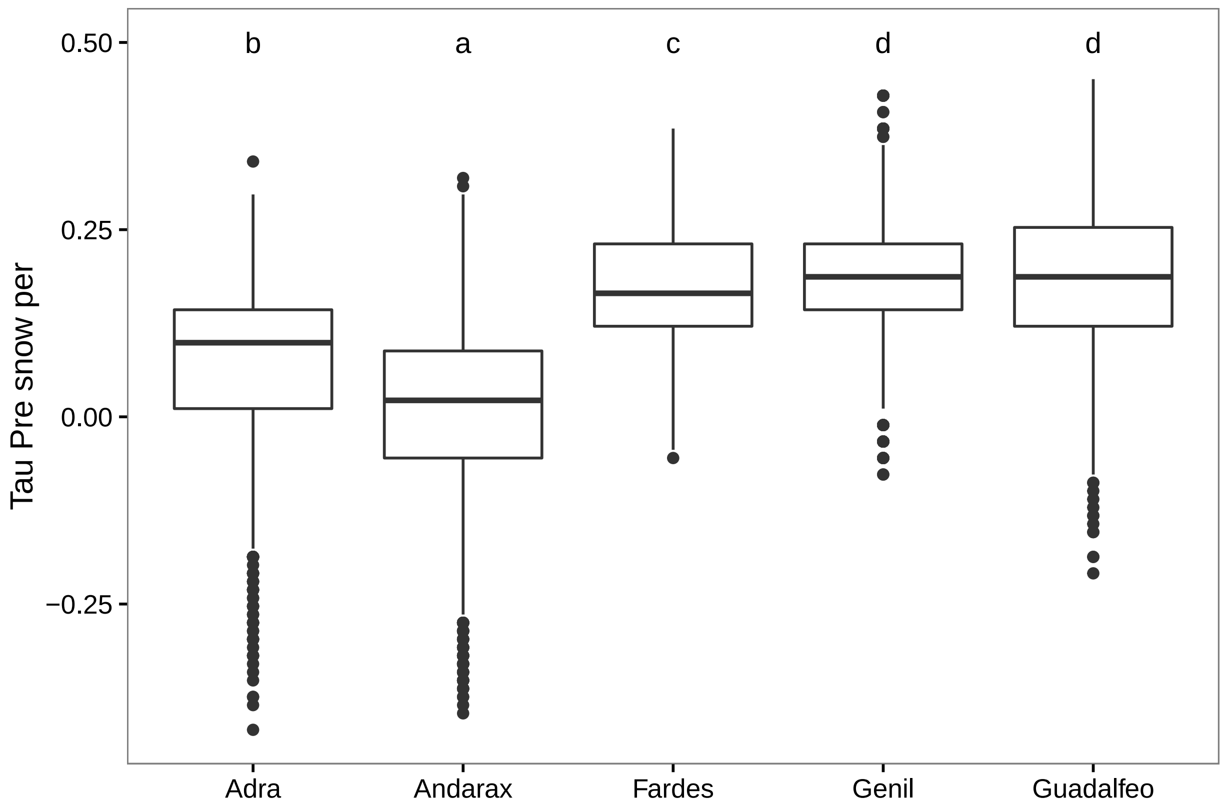
Pre Snow per

```
# Pre Snow per
# ANOVA
variable <- 'tau_pre_snow_per'
my_ylab <- 'Tau Pre snow per'

myformula <- formula(paste(variable, '~ basin_name', sep=''))
mod <- aov(myformula, data=df)
pander(tidy(mod), caption=my_ylab)
```

Table 5: Tau Pre snow per

term	df	sumsq	meansq	statistic	p.value
basin_name	4	51.26	12.82	1172	0
Residuals	7989	87.34	0.01093	NA	NA

```
## Multiple comparisons
tuk <- glht(mod, linfct = mcp(basin_name = "Tukey"))
# Convert comparisons into letters
df_letter <- fortify(cld(tuk)) %>%
  transmute(basin_name = as.factor(lhs),
         tukey_basin_name = letters) %>%
  mutate(variable = variable)

df_letter_aux <- rbind(df_letter_aux, df_letter)

## ANOVA plots
ggplot(df, aes_string(x='basin_name', y=variable)) +
  geom_boxplot() +
  geom_text(data=df_letter, aes(label = tukey_basin_name, x=basin_name, y=0.5),
           position = position_dodge(width=0.9)) +
  theme_bw() + mythemeggplot +
  ylab(my_ylab) + xlab('')
```



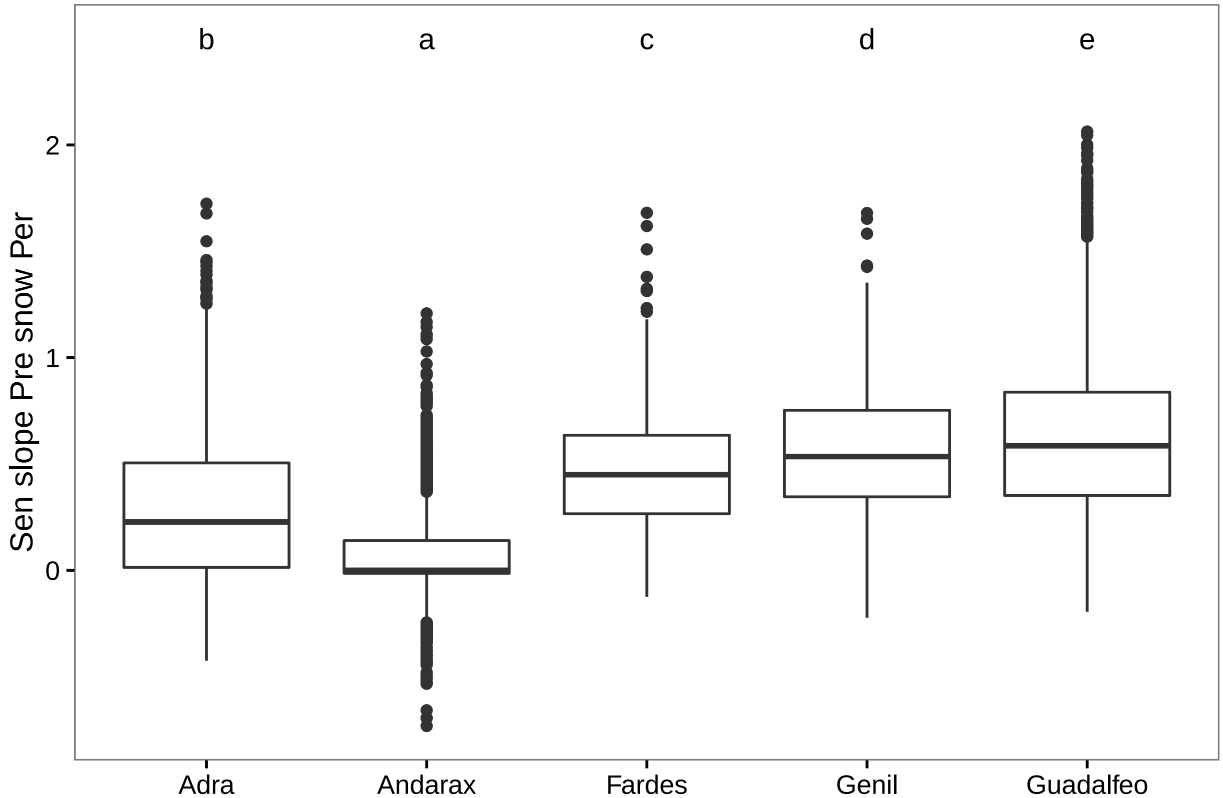

```r
# Sen Pre snow per
# ANOVA
variable <- 'sen_slope_pre_snow_per'
my_ylab <- 'Sen slope Pre snow Per'

myformula <- formula(paste(variable, '~ basin_name', sep=''))
mod <- aov(myformula, data=df)
pander(tidy(mod), caption=my_ylab)
```

Table 6: Sen slope Pre snow Per

term	df	sumsq	meansq	statistic	p.value
basin_name	4	408.9	102.2	990.7	0
Residuals	7989	824.2	0.1032	NA	NA

```r
## Multiple comparisons
tuk <- glht(mod, linfct = mcp(basin_name = "Tukey"))
# Convert comparisons into letters
df_letter <- fortify(cld(tuk)) %>%
  transmute(basin_name = as.factor(lhs),
            tukey_basin_name = letters) %>%
  mutate(variable = variable)

df_letter_aux <- rbind(df_letter_aux, df_letter)

## ANOVA plots
```

```r
ggplot(df, aes_string(x='basin_name', y=variable)) +
  geom_boxplot() +
  geom_text(data=df_letter, aes(label = tukey_basin_name, x=basin_name, y=2.5),
            position = position_dodge(width=0.9)) +
  theme_bw() + mythemeggplot +
  ylab(my_ylab) + xlab('')
```



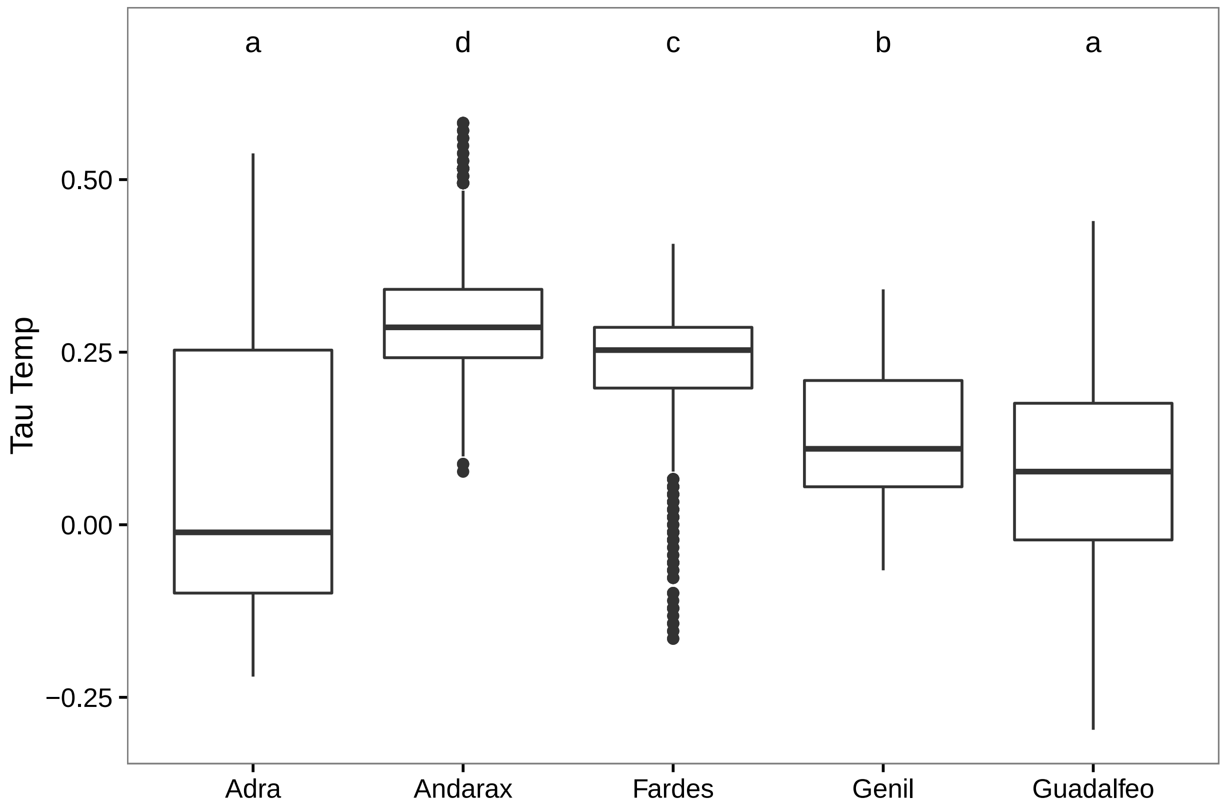
Temp

```r
# Tau temp
# ANOVA
variable <- 'tau_temp'
my_ylab <- 'Tau Temp'

myformula <- formula(paste(variable, '~ basin_name', sep=''))
mod <- aov(myformula, data=df)
pander(tidy(mod), caption=my_ylab)
```

Table 7: Tau Temp

term	df	sumsq	meansq	statistic	p.value
basin_name	4	77.58	19.39	1073	0
Residuals	7989	144.4	0.01807	NA	NA

```
## Multiple comparisons
tuk <- glht(mod, linfct = mcp(basin_name = "Tukey"))
# Convert comparisons into letters
df_letter <- fortify(cld(tuk)) %>%
  transmute(basin_name = as.factor(lhs),
         tukey_basin_name = letters) %>%
  mutate(variable = variable)

df_letter_aux <- rbind(df_letter_aux, df_letter)

## ANOVA plots
ggplot(df, aes_string(x='basin_name', y=variable)) +
  geom_boxplot() +
  geom_text(data=df_letter, aes(label = tukey_basin_name, x=basin_name, y=0.7),
           position = position_dodge(width=0.9)) +
  theme_bw() + mythemeggplot +
  ylab(my_ylab) + xlab('')
```

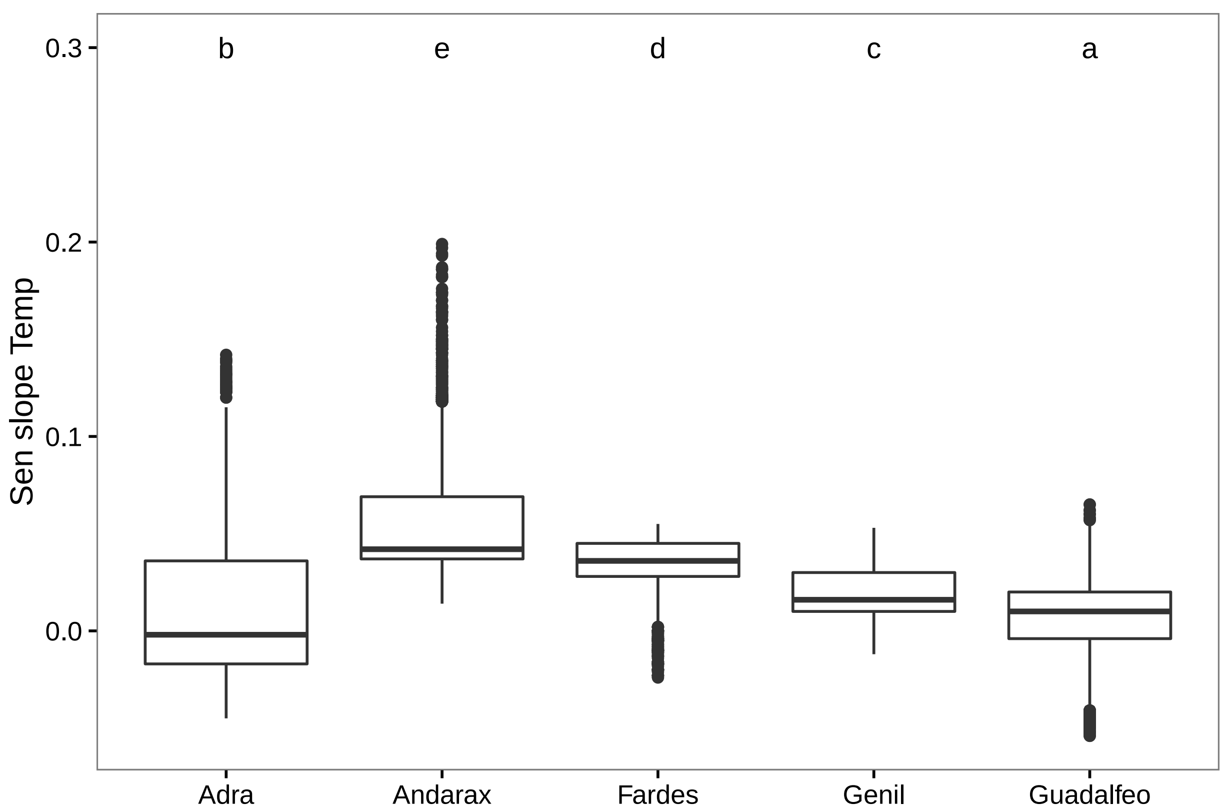



```
# Sen temp
# ANOVA
variable <- 'sen_slope_temp'
my_ylab <- 'Sen slope Temp'

myformula <- formula(paste(variable, '~ basin_name', sep=''))
mod <- aov(myformula, data=df)
pander(tidy(mod), caption=my_ylab)
```

Table 8: Sen slope Temp

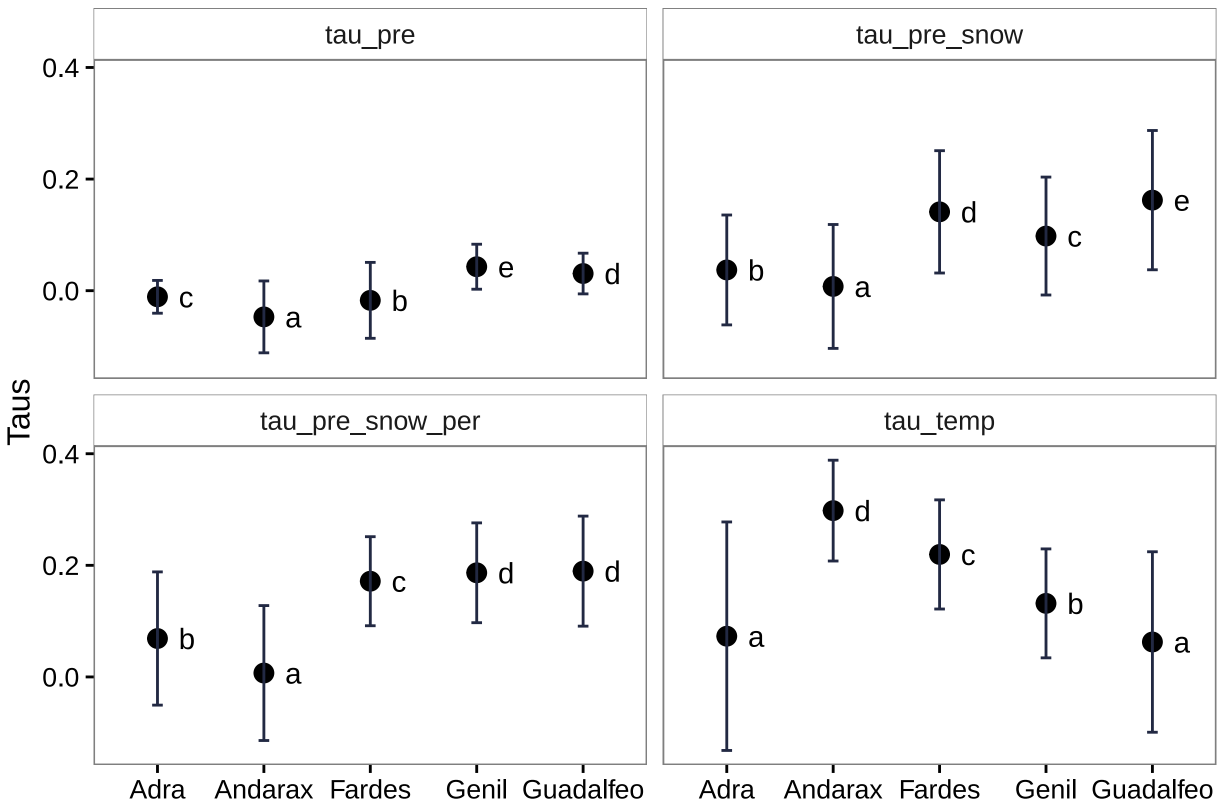
term	df	sumsq	meansq	statistic	p.value
basin_name	4	3.186	0.7965	1087	0
Residuals	7989	5.854	0.0007328	NA	NA

```
## Multiple comparisons
tuk <- glht(mod, linfct = mcp(basin_name = "Tukey"))
# Convert comparisons into letters
df_letter <- fortify(cld(tuk)) %>%
  transmute(basin_name = as.factor(lhs),
         tukey_basin_name = letters) %>%
  mutate(variable = variable)

df_letter_aux <- rbind(df_letter_aux, df_letter)

## ANOVA plots
ggplot(df, aes_string(x='basin_name', y=variable)) +
  geom_boxplot() +
  geom_text(data=df_letter, aes(label = tukey_basin_name, x=basin_name, y=.3),
           position = position_dodge(width=0.9)) +
  theme_bw() + mythemeggplot +
  ylab(my_ylab) + xlab('')
```



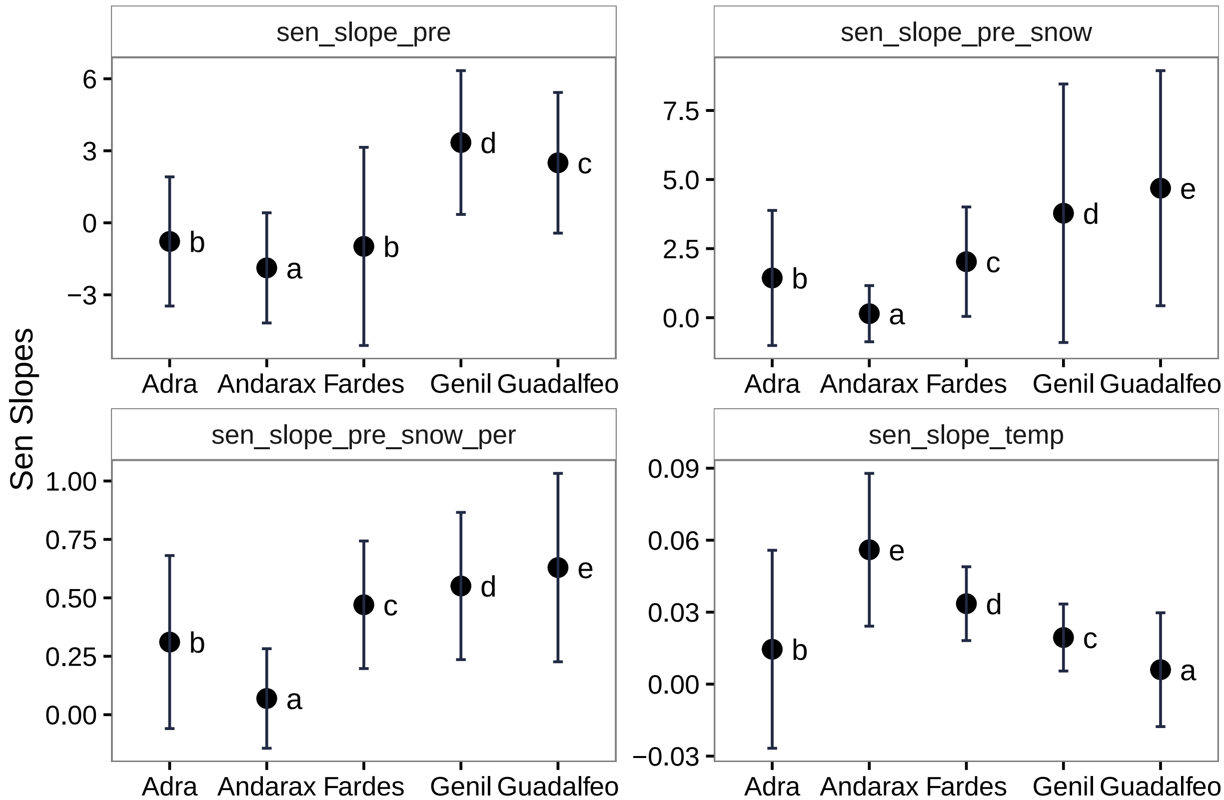

```
# Create a df with letter and variables
df_basin <- stats_basin %>%
```

```r
  dplyr::inner_join(df_letter_aux, by=c('basin_name', 'variable'))

df_basin_tau <- df_basin %>%
  dplyr::filter(grepl("tau", variable))


ggplot(df_basin_tau, aes(x=basin_name, y=mean)) +
  geom_point(stat='identity', size=3, fill='#222943') +
  geom_errorbar(aes(ymin=mean - sd, ymax= mean + sd),
                width=0.1,
                colour='#222943',
                position=position_dodge(.9)) +
  facet_wrap(~variable) +
  geom_text(aes(label = tukey_basin_name, x=basin_name, y=mean),
            hjust=0, nudge_x = 0.2) + mythemeggplot +
  xlab('') + ylab('Taus')
```




```r
# Create a df with letter and variables
df_basin_sen <- df_basin %>%
  dplyr::filter(grepl("sen", variable))


ggplot(df_basin_sen, aes(x=basin_name, y=mean)) +
  geom_point(stat='identity', size=3, fill='#222943') +
  geom_errorbar(aes(ymin=mean - sd, ymax= mean + sd),
                width=0.1,
                colour='#222943',
```

```r
                position=position_dodge(.9)) +
  facet_wrap(~variable, scales="free") +
  geom_text(aes(label = tukey_basin_name, x=basin_name, y=mean),
            hjust=0, nudge_x = 0.2) + mythemeggplot +
  xlab('') + ylab('Sen Slopes')
```



Tau Pre

```r
pander(filter(df_basin_tau, variable=="tau_pre"))
```

basin_name	mean	sd	se	variable	tukey_basin_name
Adra	-0.01098937	0.02939731	0.0009137712	tau_pre	c
Andarax	-0.04696509	0.06439582	0.0013536781	tau_pre	a
Fardes	-0.01735042	0.06803209	0.0019721519	tau_pre	b
Genil	0.04294557	0.04032604	0.0011493613	tau_pre	e
Guadalfeo	0.03074198	0.03646328	0.0007644780	tau_pre	d

Sen Slope Pre

```r
pander(filter(df_basin_sen, variable=="sen_slope_pre"))
```

basin_name	mean	sd	se	variable	tukey_basin_name
Adra	-0.7765169	2.689399	0.08359592	sen_slope_pre	b

basin_name	mean	sd	se	variable	tukey_basin_name
Andarax	-1.8775444	2.294969	0.04824303	sen_slope_pre	a
Fardes	-0.9828429	4.127396	0.11964723	sen_slope_pre	b
Genil	3.3436109	2.994633	0.08535218	sen_slope_pre	d
Guadalfeo	2.4990914	2.929432	0.06141758	sen_slope_pre	c

Tau Pre Snow

```
pander(filter(df_basin_tau, variable=="tau_pre_snow"))
```

basin_name	mean	sd	se	variable	tukey_basin_name
Adra	0.037144928	0.09847796	0.003061039	tau_pre_snow	b
Andarax	0.007602298	0.11102690	0.002333920	tau_pre_snow	a
Fardes	0.141271429	0.10960964	0.003177425	tau_pre_snow	d
Genil	0.097918765	0.10568860	0.003012306	tau_pre_snow	c
Guadalfeo	0.162268132	0.12482449	0.002617032	tau_pre_snow	e

Sen Slope Pre Snow

```
pander(filter(df_basin_sen, variable=="sen_slope_pre_snow"))
```

basin_name	mean	sd	se	variable	tukey_basin_name
Adra	1.4374705	2.444580	0.07598609	sen_slope_pre_snow	b
Andarax	0.1435996	1.016705	0.02137237	sen_slope_pre_snow	a
Fardes	2.0264252	1.981475	0.05744009	sen_slope_pre_snow	c
Genil	3.7799163	4.679172	0.13336441	sen_slope_pre_snow	d
Guadalfeo	4.6871486	4.255009	0.08920922	sen_slope_pre_snow	e

Tau Pre Snow per

```
pander(filter(df_basin_tau, variable=="tau_pre_snow_per"))
```

basin_name	mean	sd	se	variable	tukey_basin_name
Adra	0.068837681	0.11937209	0.003710501	tau_pre_snow_per	b

basin_name	mean	sd	se	variable	tukey_basin_name
Andarax	0.006970393	0.12092334	0.002541955	tau_pre_snow_per	a
Fardes	0.171544538	0.07978442	0.002312835	tau_pre_snow_per	c
Genil	0.186624695	0.08944616	0.002549369	tau_pre_snow_per	d
Guadalfeo	0.189606154	0.09862933	0.002067833	tau_pre_snow_per	d

Sen Slope Pre Snow per

```
pander(filter(df_basin_sen, variable=="sen_slope_pre_snow_per"))
```

Table 14: Table continues below

basin_name	mean	sd	se	variable
Adra	0.31071787	0.3701305	0.011504951	sen_slope_pre_snow_per
Andarax	0.06940831	0.2129421	0.004476300	sen_slope_pre_snow_per
Fardes	0.47031681	0.2729192	0.007911532	sen_slope_pre_snow_per
Genil	0.55064663	0.3149000	0.008975190	sen_slope_pre_snow_per
Guadalfeo	0.62944747	0.4030842	0.008450941	sen_slope_pre_snow_per

tukey_basin_name
b
a
c
d
e

Tau Temp

```
pander(filter(df_basin_tau, variable=="tau_temp"))
```

basin_name	mean	sd	se	variable	tukey_basin_name
Adra	0.07298647	0.20477850	0.006365231	tau_temp	a
Andarax	0.29805435	0.09032576	0.001898757	tau_temp	d
Fardes	0.21952857	0.09781271	0.002835449	tau_temp	c
Genil	0.13181235	0.09761136	0.002782091	tau_temp	b
Guadalfeo	0.06259604	0.16174236	0.003391041	tau_temp	a

Sen Slope Temp

```r
pander(filter(df_basin_sen, variable=="sen_slope_temp"))
```

basin_name	mean	sd	se	variable	tukey_basin_name
Adra	0.014535266	0.04125712	0.0012824156	sen_slope_temp	b
Andarax	0.056003977	0.03183629	0.0006692374	sen_slope_temp	e
Fardes	0.033536975	0.01538286	0.0004459268	sen_slope_temp	d
Genil	0.019424045	0.01397369	0.0003982740	sen_slope_temp	c
Guadalfeo	0.006018462	0.02372294	0.0004973680	sen_slope_temp	a

Explore trends by elevation

Taus

```r
myvariable <- 'tau_pre'
myylab <- 'Tau Pre'

# GAM
myformula <- formula(paste(myvariable, '~ s(dem50mean)', sep=''))
modgam <- mgcv::gam(formula = myformula,
                    data= df)
anova(modgam)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## tau_pre ~ s(dem50mean)
##
## Approximate significance of smooth terms:
##                 edf Ref.df     F p-value
## s(dem50mean) 8.442  8.914 421.1  <2e-16
```

```r
mygam_summ <- summary(modgam)
mygam_summ
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## tau_pre ~ s(dem50mean)
```

```
##
## Parametric coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.0019388  0.0005714  -3.393 0.000695 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                 edf Ref.df     F p-value
## s(dem50mean) 8.442  8.914 421.1  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =   0.32   Deviance explained =   32%
## GCV = 0.0026134  Scale est. = 0.0026103  n = 7994
```

```r
# Plot GAM
a <-ggplot(df, aes_string(x='dem50mean', y=myvariable)) + geom_point(col='grey') +
  geom_smooth(method="gam", formula = y ~ s(x), fill='red', col='red') +
  annotate("text", x = 3000, y=0.3,
           label= paste0("Dev. exp. = ", round((mygam_summ$dev.expl)*100, 2), " %")) +
  mythemeggplot +
  xlab('Elevation') + ylab(myylab)



myvariable <- 'tau_pre_snow'
myylab <- 'Tau Pre Snow'

# GAM
myformula <- formula(paste(myvariable, '~ s(dem50mean)', sep=''))
modgam <- mgcv::gam(formula = myformula,
                    data= df)
anova(modgam)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## tau_pre_snow ~ s(dem50mean)
##
## Approximate significance of smooth terms:
##                 edf Ref.df     F p-value
## s(dem50mean) 8.801  8.989 189.5  <2e-16
```

```r
mygam_summ <- summary(modgam)
mygam_summ
```

```
##
## Family: gaussian
## Link function: identity
##
```

```
## Formula:
## tau_pre_snow ~ s(dem50mean)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 0.089249   0.001318   67.71   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 8.801  8.989 189.5  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.176   Deviance explained = 17.7%
## GCV = 0.013908  Scale est. = 0.013891  n = 7994
```

```
# Plot GAM
b <- ggplot(df, aes_string(x='dem50mean', y=myvariable)) + geom_point(col='grey') +
  geom_smooth(method="gam", formula = y ~ s(x), fill='red', col='red') +
  annotate("text", x = 3000, y=0.6,
           label= paste0("Dev. exp. = ", round((mygam_summ$dev.expl)*100, 2), " %")) +
  mythemeggplot +
  xlab('Elevation') + ylab(myylab)


myvariable <- 'tau_pre_snow_per'
myylab <- 'Tau Pre Snow per'

# GAM
myformula <- formula(paste(myvariable, '~ s(dem50mean)', sep=''))
modgam <- mgcv::gam(formula = myformula,
                    data= df)
anova(modgam)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## tau_pre_snow_per ~ s(dem50mean)
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 8.863  8.995 241.2  <2e-16
```

```
mygam_summ <- summary(modgam)
mygam_summ
```

```
##
## Family: gaussian
## Link function: identity
```

```
##
## Formula:
## tau_pre_snow_per ~ s(dem50mean)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 0.119120   0.001306   91.19   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 8.863  8.995 241.2  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.213   Deviance explained = 21.4%
## GCV = 0.013658  Scale est. = 0.013641  n = 7994
```

```r
# Plot GAM
c <- ggplot(df, aes_string(x='dem50mean', y=myvariable)) + geom_point(col='grey') +
  geom_smooth(method="gam", formula = y ~ s(x), fill='red', col='red') +
  annotate("text", x = 3000, y=-0.25,
           label= paste0("Dev. exp. = ", round((mygam_summ$dev.expl)*100, 2), " %")) +
  mythemeggplot +
  xlab('Elevation') + ylab(myylab)


myvariable <- 'tau_temp'
myylab <- 'Tau temp'

# GAM
myformula <- formula(paste(myvariable, '~ s(dem50mean)', sep=''))
modgam <- mgcv::gam(formula = myformula,
                    data= df)
anova(modgam)
```

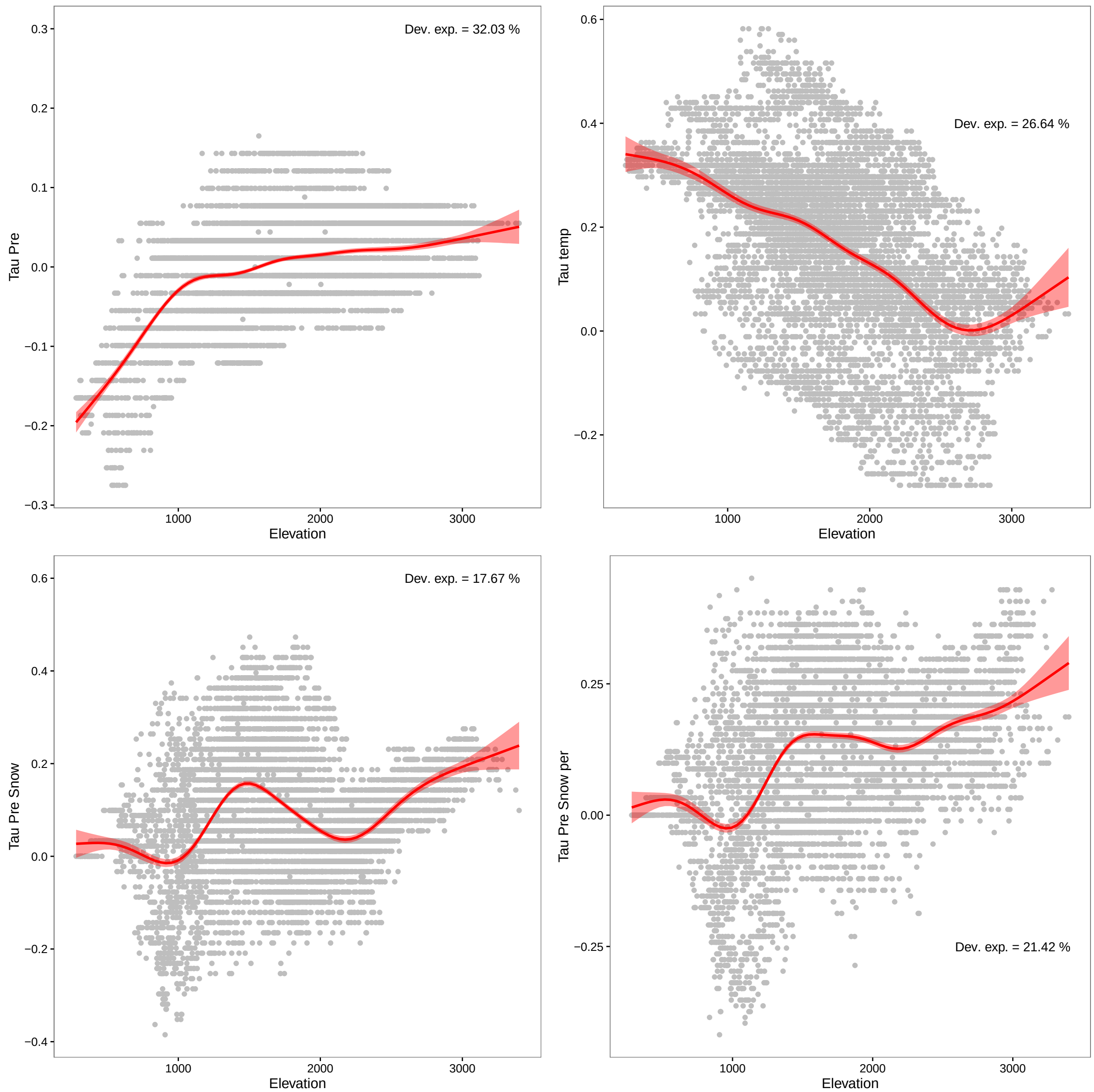
```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## tau_temp ~ s(dem50mean)
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 7.872  8.675 333.6  <2e-16
```

```r
mygam_summ <- summary(modgam)
mygam_summ
```

```
##
## Family: gaussian
```

```
## Link function: identity
##
## Formula:
## tau_temp ~ s(dem50mean)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 0.164616   0.001597   103.1   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 7.872  8.675 333.6  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.266   Deviance explained = 26.6%
## GCV = 0.020417  Scale est. = 0.020394  n = 7994
```

```r
# Plot GAM
d <- ggplot(df, aes_string(x='dem50mean', y=myvariable)) + geom_point(col='grey') +
  geom_smooth(method="gam", formula = y ~ s(x), fill='red', col='red') +
  annotate("text", x = 3000, y=0.4,
           label= paste0("Dev. exp. = ", round((mygam_summ$dev.expl)*100, 2), " %")) +
  mythemeggplot +
  xlab('Elevation') + ylab(myylab)


grid.arrange(a, d, b, c, nrow=2)
```



Sen

```r
myvariable <- 'sen_slope_pre'
myylab <- 'Sen Slope pre'

# GAM
myformula <- formula(paste(myvariable, '~ s(dem50mean)', sep=''))
modgam <- mgcv::gam(formula = myformula,
                    data= df)
anova(modgam)
```

```
##
```

```
## Family: gaussian
## Link function: identity
##
## Formula:
## sen_slope_pre ~ s(dem50mean)
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 6.991  8.081 124.4  <2e-16
```

```
mygam_summ <- summary(modgam)
mygam_summ
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## sen_slope_pre ~ s(dem50mean)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.44774    0.03845   11.64   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 6.991  8.081 124.4  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.111   Deviance explained = 11.2%
## GCV =  11.83  Scale est. = 11.818    n = 7994
```

```
# Plot GAM
a <-ggplot(df, aes_string(x='dem50mean', y=myvariable)) + geom_point(col='grey') +
  geom_smooth(method="gam", formula = y ~ s(x), fill='red', col='red') +
  annotate("text", x = 3000, y=10,
           label= paste0("Dev. exp. = ", round((mygam_summ$dev.expl)*100, 2), " %")) +
  mythemeggplot +
  xlab('Elevation') + ylab(myylab)



myvariable <- 'sen_slope_pre_snow'
myylab <- 'Sen Slope Pre snow'

# GAM
myformula <- formula(paste(myvariable, '~ s(dem50mean)', sep=''))
modgam <- mgcv::gam(formula = myformula,
                    data= df)
anova(modgam)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## sen_slope_pre_snow ~ s(dem50mean)
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 8.440  8.914 790.3  <2e-16
```

```
mygam_summ <- summary(modgam)
mygam_summ
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## sen_slope_pre_snow ~ s(dem50mean)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  2.44440    0.02999   81.51   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##               edf Ref.df     F p-value
## s(dem50mean) 8.44  8.914 790.3  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.469   Deviance explained = 46.9%
## GCV =  7.198  Scale est. = 7.1895    n = 7994
```

```
# Plot GAM
b <- ggplot(df, aes_string(x='dem50mean', y=myvariable)) + geom_point(col='grey') +
  geom_smooth(method="gam", formula = y ~ s(x), fill='red', col='red') +
  annotate("text", x = 3000, y=0,
           label= paste0("Dev. exp. = ", round((mygam_summ$dev.expl)*100, 2), " %")) +
  mythemeggplot +
  xlab('Elevation') + ylab(myylab)


myvariable <- 'sen_slope_pre_snow_per'
myylab <- 'Sen slope Pre snow per'

# GAM
myformula <- formula(paste(myvariable, '~ s(dem50mean)', sep=''))
modgam <- mgcv::gam(formula = myformula,
                    data= df)
anova(modgam)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## sen_slope_pre_snow_per ~ s(dem50mean)
##
## Approximate significance of smooth terms:
##                 edf Ref.df     F p-value
## s(dem50mean) 8.367  8.891 436.9  <2e-16
```

```
mygam_summ <- summary(modgam)
mygam_summ
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## sen_slope_pre_snow_per ~ s(dem50mean)
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 0.393818   0.003604   109.3   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                 edf Ref.df     F p-value
## s(dem50mean) 8.367  8.891 436.9  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.327   Deviance explained = 32.8%
## GCV = 0.10394  Scale est. = 0.10381   n = 7994
```

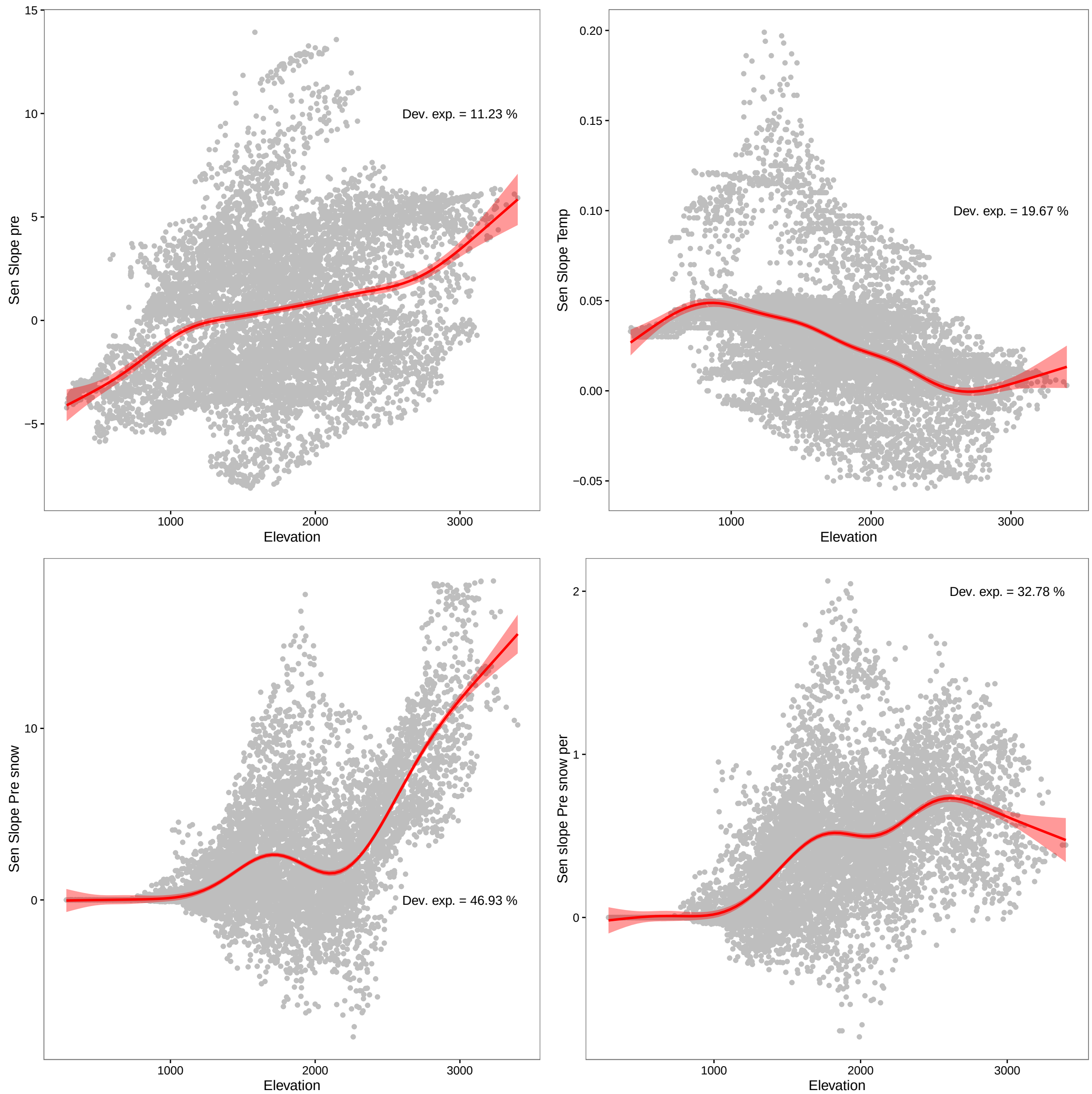
```
# Plot GAM
c <- ggplot(df, aes_string(x='dem50mean', y=myvariable)) + geom_point(col='grey') +
  geom_smooth(method="gam", formula = y ~ s(x), fill='red', col='red') +
  annotate("text", x = 3000, y=2,
           label= paste0("Dev. exp. = ", round((mygam_summ$dev.expl)*100, 2), " %")) +
  mythemeggplot +
  xlab('Elevation') + ylab(myylab)


myvariable <- 'sen_slope_temp'
myylab <- 'Sen Slope Temp'

# GAM
myformula <- formula(paste(myvariable, '~ s(dem50mean)', sep=''))
modgam <- mgcv::gam(formula = myformula,
                    data= df)
anova(modgam)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## sen_slope_temp ~ s(dem50mean)
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 7.688  8.571 227.4  <2e-16
```

```
mygam_summ <- summary(modgam)
mygam_summ
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## sen_slope_temp ~ s(dem50mean)
##
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 0.0274322  0.0003373   81.33   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                edf Ref.df     F p-value
## s(dem50mean) 7.688  8.571 227.4  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.196   Deviance explained = 19.7%
## GCV = 0.00091034  Scale est. = 0.00090935  n = 7994
```

```
# Plot GAM
d <- ggplot(df, aes_string(x='dem50mean', y=myvariable)) + geom_point(col='grey') +
  geom_smooth(method="gam", formula = y ~ s(x), fill='red', col='red') +
  annotate("text", x = 3000, y=0.1,
           label= paste0("Dev. exp. = ", round((mygam_summ$dev.expl)*100, 2), " %")) +
  mythemeggplot +
  xlab('Elevation') + ylab(myylab)


grid.arrange(a, d, b, c, nrow=2)
```


Sen Slope pre
Dev. exp. = 11.23 %
Elevation
Sen Slope Temp
Dev. exp. = 19.67 %
Elevation
Sen Slope Pre snow
Dev. exp. = 46.93 %
Elevation
Sen slope Pre snow per
Dev. exp. = 32.78 %
Elevation