Code for *Tree-Ring Evidence of Increasing Drought Risks amidst Projected Flood Intensification in the Kabul River Basin (Afghanistan and Pakistan)* by Khan et al. (2022)

Hung Nguyen

2022-05-14

Introduction and Preparations

This document details the process of producing the results presented in **Tree-Ring Evidence of Increasing Drought Risks amidst Projected Flood Intensification in the Kabul River Basin (Afghanistan and Pakistan)** by Khan et al. (2022).

To reproduce the results, please do the following:

- This code requires R 4.1.0 and above.
- Download the code repository from the GitHub repo and extract the downloaded `.zip` file to your working folder.
- Open `chitral-precip.Rproj` in RStudio (**It's important to open this first so that the file path is loaded properly**).
- Install and load the following packages if you don't already have them. For package `ldsr`, please use the development version which can be installed from GitHub with

```
remotes::install_github('ntthung/ldsr')
```

```
library(dplR)       # Tree ring data processing
library(ldsr)       # Tree ring data processing
library(data.table) # Data handling
library(missMDA)    # Imputation
library(qmap)       # Bias correction
library(modifiedmk) # Trend analysis
library(ggplot2)    # Plotting
library(cowplot)    # Plotting
library(patchwork)  # Plotting
library(ggprism)    # Plotting
library(ggnewscale) # Plotting
theme_set(theme_prism(base_size = 10, base_fontface = 'plain', base_line_size = 0.2))
```

- Open `paper-code.Rmd`, which is the source code for this document.
- Follow the written details below and run the code chunks one by one.

This R Markdown is set to render both HTML and PDF outputs. To do so, please run

```
rmarkdown::render('paper-code.Rmd', output_format = 'all', output_options = list(hightlight = 'tango'))
```

For quick access to the final results please see the .csv file in results/.

The code utilities to support the main code are stored in the folder R/. We need to load them first before running the main code.

```
source('R/init.R')
source('R/input-selection-functions.R')
source('R/correlation_functions.R')
source('R/drought_analysis_functions.R')
```

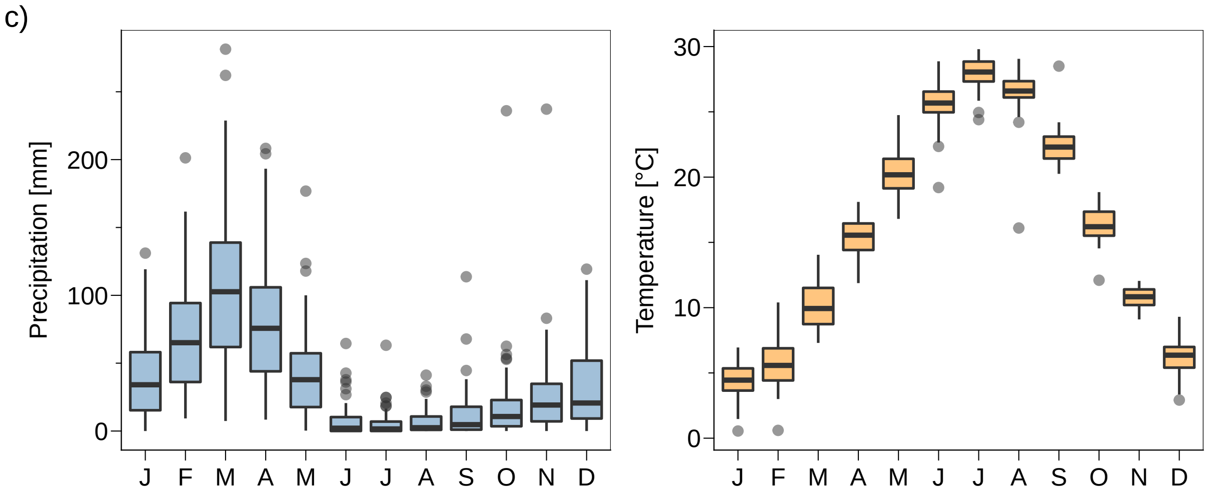
Data

Climate data

```
# Monthly temperature
TmWide <- fread('data/chitral-monthly-T.csv')
Tm <- melt(TmWide, id.var = 'year', variable.name = 'month2', variable.factor = TRUE, value.name = 'Tm'
         )[, month := as.integer(month2)
         ][order(year, month)]
# Monthly precipitation
PmWide <- fread('data/chitral-monthly-P.csv')
Pm <- melt(PmWide, id.var = 'year', variable.name = 'month2', variable.factor = TRUE, value.name = 'Pm'
         )[, month := as.integer(month2)
         ][order(year, month)]
```

Figure 1c

```
p1 <- ggplot(Pm) +
  geom_boxplot(aes(month2, Pm), fill = 'steelblue', alpha = 0.5) +
  labs(x = NULL, y = 'Precipitation [mm]', tag = 'c)') +
  scale_x_discrete(labels = \(x) substr(x, 1, 1)) +
  scale_y_continuous(guide = guide_prism_minor()) +
  panel_border('black', 0.2)

p2 <- ggplot(Tm) +
  geom_boxplot(aes(month2, Tm), fill = 'darkorange', alpha = 0.5) +
  labs(x = NULL, y = 'Temperature [\u00b0C]') +
  scale_x_discrete(labels = \(x) substr(x, 1, 1)) +
  scale_y_continuous(guide = guide_prism_minor()) +
  panel_border('black', 0.2)
p1 + p2
```

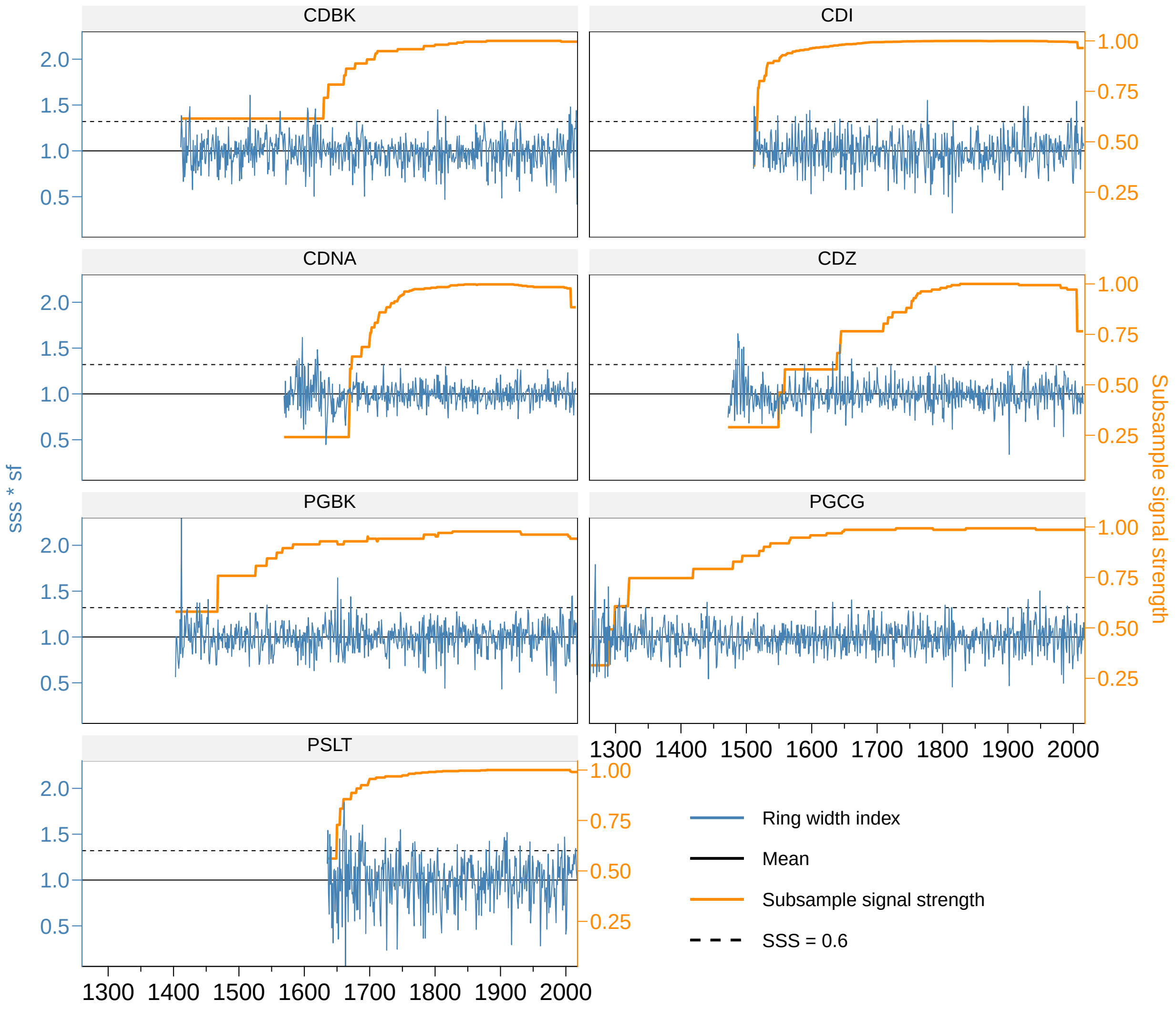


Tree ring data

```
# Read ARSTAN outputs
crnRaw <- lapplyrbind(
  list.files('data/', '.tabs', full.names = TRUE),
  function(fn) {
    dt <- fread(fn)
    dt[, site := substr(fn, 6, nchar(fn) - 5)]
  })
setkey(crnRaw, site)
sssOut <- fread('data/sss.csv', key = 'site')
crn <- merge(crnRaw, sssOut, by = c('site', 'year'))

firstYear <- crn[sss > 0.6][, .N, by = year][N >= 4, first(year)]
lastYear <- 2018
# Use the residual chronology
crnWide <- crn[year %in% firstYear:lastYear, dcast(.SD, year ~ site, value.var = c('res'))]
```

Figure S1 - Chronology and SSS plot

```
sf <- 2.2
ggplot(sssOut) +
  geom_hline(aes(yintercept = 1, linetype = 'Mean', color = 'Mean')) +
  # geom_hline(aes(yintercept = 0.85 * sf,
               # color = 'SSS = 0.85', linetype = 'SSS = 0.85')) +
  geom_hline(aes(yintercept = 0.6 * sf,
               color = 'SSS = 0.6', linetype = 'SSS = 0.6')) +
  geom_line(aes(year, sss * sf,
              col = 'Subsample signal strength',
              linetype = 'Subsample signal strength'), size = 0.5) +
  geom_line(aes(year, res,
              col = 'Ring width index',
              linetype = 'Ring width index'), crn) +
  facet_wrap(~site, ncol = 2) +
scale_x_continuous(
  name = NULL,
  breaks = seq(1300, 2000, 100),
  minor_breaks = seq(1300, 2000, 50),
  guide = guide_prism_minor(),
  expand = c(0, 0)) +
scale_y_continuous(

  sec.axis = sec_axis(~ . / sf, name = 'Subsample signal strength',
                      breaks = seq(0, 1, 0.25)),
  expand = c(0, 0)) +
scale_color_manual(
  name = NULL,
  breaks = c('Ring width index', 'Mean',
             'Subsample signal strength', 'SSS = 0.6'),
  values = c('steelblue', 'black', 'darkorange', 'black')) +
scale_linetype_manual(
  name = NULL,
  breaks = c('Ring width index', 'Mean',
             'Subsample signal strength', 'SSS = 0.6'),
  values = c(1, 1, 1, 2)) +
guides(color = guide_legend(override.aes = list(size = 0.50))) +
theme(
  strip.background = element_rect('gray95', NA),
  legend.position = c(0.75, 0.1),
  legend.key.width = unit(1, 'cm'),
  panel.border = element_rect(NA, 'black', 0.2),
  axis.ticks.y.right = element_line(color = 'darkorange'),
  axis.text.y.right = element_text(color = 'darkorange', size = 9),
  axis.title.y.right = element_text(color = 'darkorange', size = 9),
  axis.line.y.right = element_line(color = 'darkorange'),
  axis.ticks.y.left = element_line(color = 'steelblue'),
  axis.text.y.left = element_text(color = 'steelblue', size = 9),
  axis.title.y.left = element_text(color = 'steelblue', size = 9),
  axis.line.y.left = element_line(color = 'steelblue'))
```



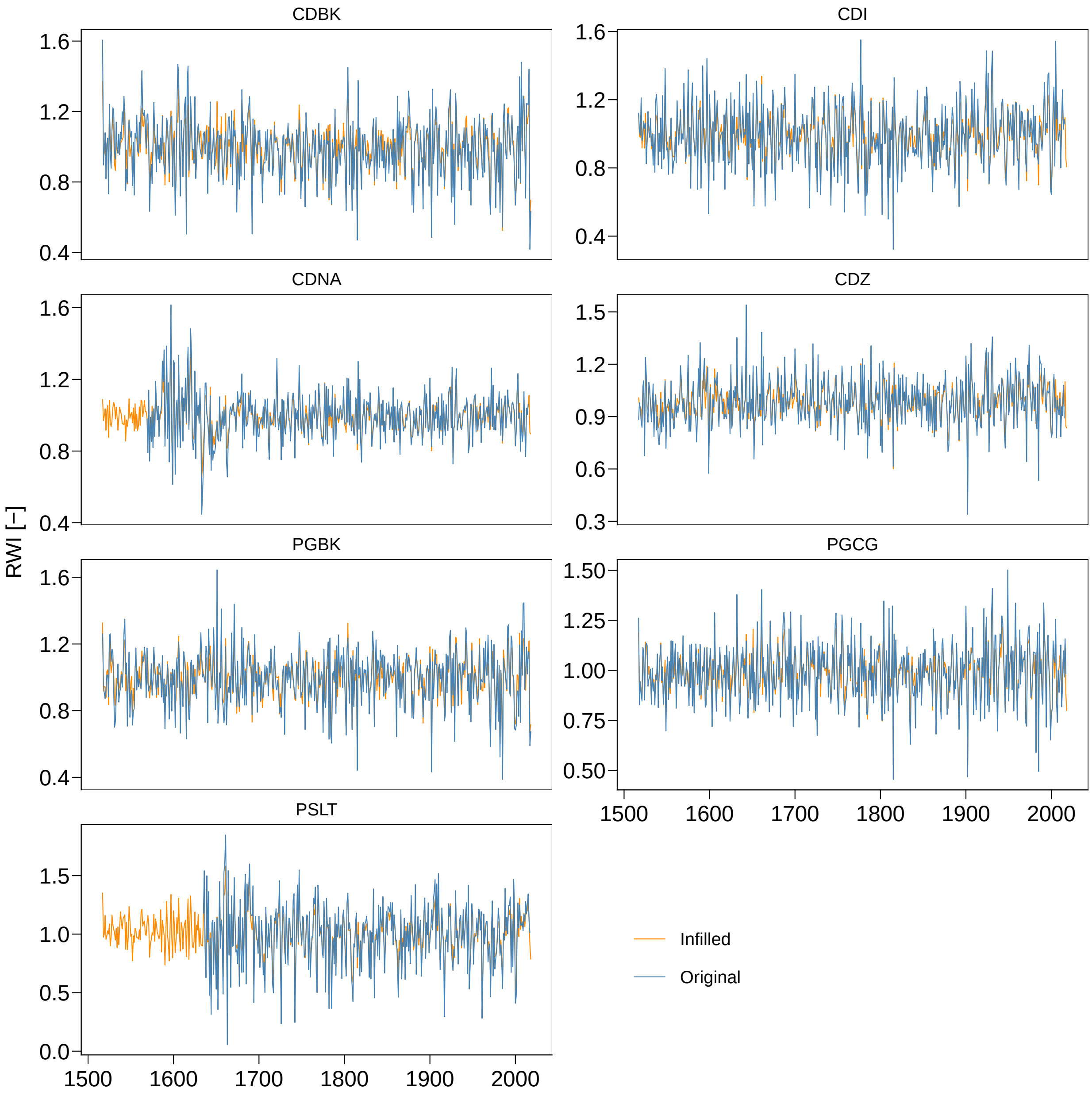
Climate-growth relationship

First we infill the tree ring data

```
X <- crnWide[, -'year'] |>
  as.matrix() |>
  imputePCA(ncp = 6) |>
  {\(x) x$completeObs}()
PC <- prcomp(X, scale. = TRUE)$x
Xraw <- as.matrix(crnWide[, -'year'])
impModel <- imputePCA(Xraw, ncp = 6)
Xfilled <- impModel$completeObs
Xfitted <- impModel$fittedX
colnames(Xfitted) <- colnames(Xfilled)

crnFitted <- as.data.table(as.data.frame(Xfitted))
crnFitted[, year := 1517:2018]
crnFittedLong <- melt(
  crnFitted, id.vars = 'year', variable.name = 'site', value.name = 'rwi')
crnMerge <- rbindlist(
  list(Infilled = crnFittedLong, Original = crn[, .(site, year, rwi = res)]),
  use.names = TRUE,
  idcol = 'type')
```

Figure S2

```
ggplot(crnMerge[year >= 1517]) +
  geom_line(aes(year, rwi, color = type)) +
  facet_wrap(vars(site), ncol = 2, scales = 'free_y') +
  scale_color_manual(values = c('darkorange', 'steelblue')) +
  scale_x_continuous(breaks = seq(1500, 2000, 100)) +
  labs(x = NULL, y = 'RWI [-]') +
  panel_border('black', 0.2) +
  theme(legend.position = c(0.6, 0.1))
```

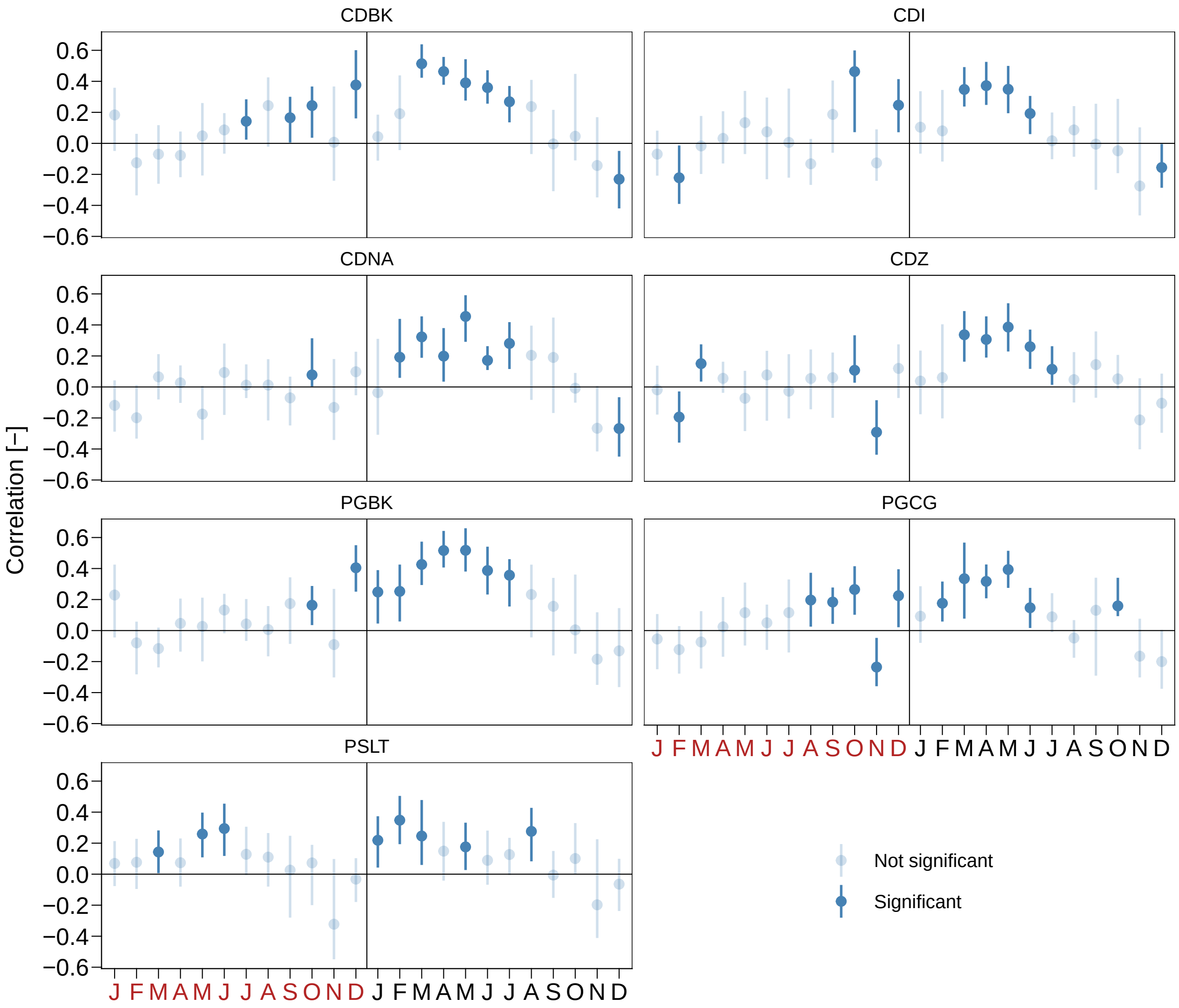


Calculate bootstrapped correlations

```r
treeYears <- crnWide$year
# Current year
# Merge TR in 1965-2018 with precipitation in 1965-2018
instIndc <- which(treeYears %in% 1965:2018)
XYc <- cbind(Xfilled[instIndc, ], as.matrix(PmWide[, -'year']))

# Tree rings and previous year precipitation
# Merge TR in 1966-2018 with precipitation in 1965-2017
instIndp <- which((treeYears - 1) %in% 1965:2017) # previous year streamflow
XYp <- cbind(Xfilled[instIndp, ], as.matrix(PmWide[-.N, -'year']))

# Tree rings and next year precipitation
# Merge TR in 1963-2016 with precipitation in 1965-2018
# instIndn <- which((treeYears + 1) %in% 1965:2018) # next year streamflow
# XYn <- cbind(Xfilled[instIndn, ], as.matrix(PmWide[, -'year']))

set.seed(2022)
corDTc <- cor_boot(XYc, 1:7, 8:19, groupNames = c('site', 'month')) # current year
corDTp <- cor_boot(XYp, 1:7, 8:19, groupNames = c('site', 'month')) # current year
# corDTn <- cor_boot(XYn, 1:7, 8:19, groupNames = c('site', 'month')) # current year

corDTc[, month := paste0(month, 'c')]
corDTp[, month := paste0(month, 'p')]
# corDTn[, month := paste0(month, 'n')]

corDTPm <- rbind(corDTp, corDTc)
corDTPm[, month := factor(month, c(paste0(month.abb, 'p'), paste0(month.abb, 'c')))]
```

Figure 2

```r
ggplot(corDTPm) +
  geom_linerange(
    aes(x = month, ymin = low, ymax = high, alpha = signif), color = 'steelblue') +
  geom_point(
    aes(x = month, y = rho0, alpha = signif), color = 'steelblue') +
  geom_hline(aes(yintercept = 0)) +
  geom_vline(xintercept = 12.5) +
  facet_wrap(vars(site), ncol = 2) +
  scale_x_discrete(name = NULL, labels = monthLab) +
  scale_y_continuous(name = 'Correlation [-]',
                     breaks = c(-0.6, -0.4, -0.2, 0, 0.2, 0.4, 0.6)) +
  scale_alpha_manual(
    values = c(0.25, 1), labels = c('Not significant', 'Significant')) +
  theme(
    legend.position = c(0.75, 0.1),
    axis.text.x = ggtext::element_markdown()) +
  panel_border('black', 0.2)
```



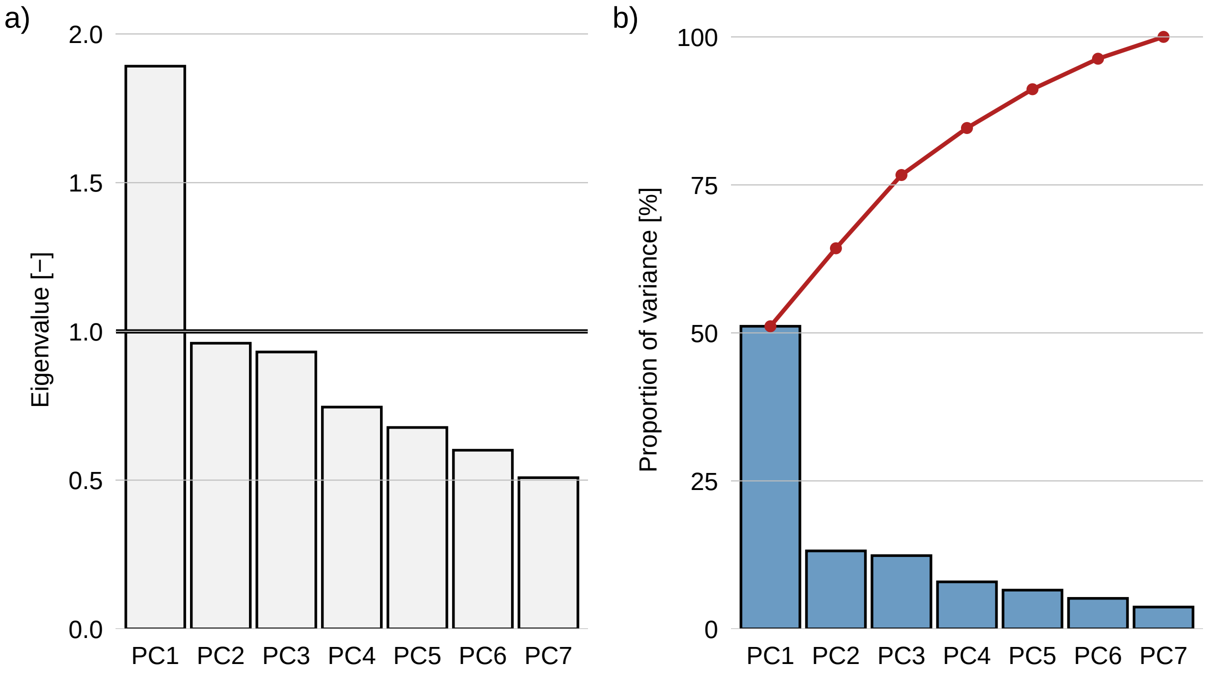
September to August precipitation reconstruction

Principal compnent analysis

```
PCfit <- prcomp(X, scale. = TRUE)
PC <- PCfit$x
pcDT <- as.data.table(as.data.frame(summary(PCfit)$importance),
                      keep.rownames = 'var') |>
  melt(id.vars = 'var', variable.name = 'PC')
```

Figure S3

```
p1 <- ggplot(pcDT[var == 'Standard deviation']) +
  geom_col(aes(PC, value), color = 'black', fill = 'gray95') +
  geom_hline(yintercept = 1, size = 0.8) +
  scale_y_continuous(expand = expansion(add = c(0, 0.01)),
                      limits = c(0, 2)) +
  labs(x = NULL, y = 'Eigenvalue [-]', tag = 'a)') +
  theme(
    panel.grid.major.y = element_line('gray'),
    panel.ontop = TRUE,
    axis.ticks = element_blank(),
    axis.line = element_blank())
p2 <- ggplot() +
  geom_col(
    aes(PC, value * 100),
    pcDT[var == 'Proportion of Variance'],
    fill = 'steelblue', color = 'black', alpha = 0.8) +
  geom_line(
    aes(PC, value * 100, group = 1),
    pcDT[var == 'Cumulative Proportion'],
    color = 'firebrick', size = 0.8) +
  geom_point(
    aes(PC, value * 100),
    pcDT[var == 'Cumulative Proportion'],
    color = 'firebrick', size = 1.6) +
  labs(x = NULL, y = 'Proportion of variance [%]', tag = 'b)') +
  scale_y_continuous(expand = expansion(add = c(0, 1))) +
  theme(
    panel.grid.major.y = element_line('gray'),
    panel.ontop = TRUE,
    axis.ticks = element_blank(),
    axis.line = element_blank())

p1 + p2
```



Reconstruction

```
Pm[, year2 := fifelse(month %in% 9:12, year + 1, year)]
PSepAug <- Pm[, .(Qa = sum(Pm)), by = .(year = year2)][year %in% 1966:lastYear]
instInd <- which(firstYear:lastYear %in% PSepAug$year)

sv <- c(1, 2)
sPC <- as.data.table(PC[, sv, drop = FALSE])
lmFit <- PCR_reconstruction(PSepAug, sPC, firstYear, transform = 'none')
set.seed(42)
cvFolds <- make_Z(PSepAug$Qa, frac = 0.25, contiguous = TRUE)
lmCV <- cvPCR(PSepAug, sPC, firstYear, transform = 'none',
              Z = cvFolds, use.robust.mean = FALSE)
```

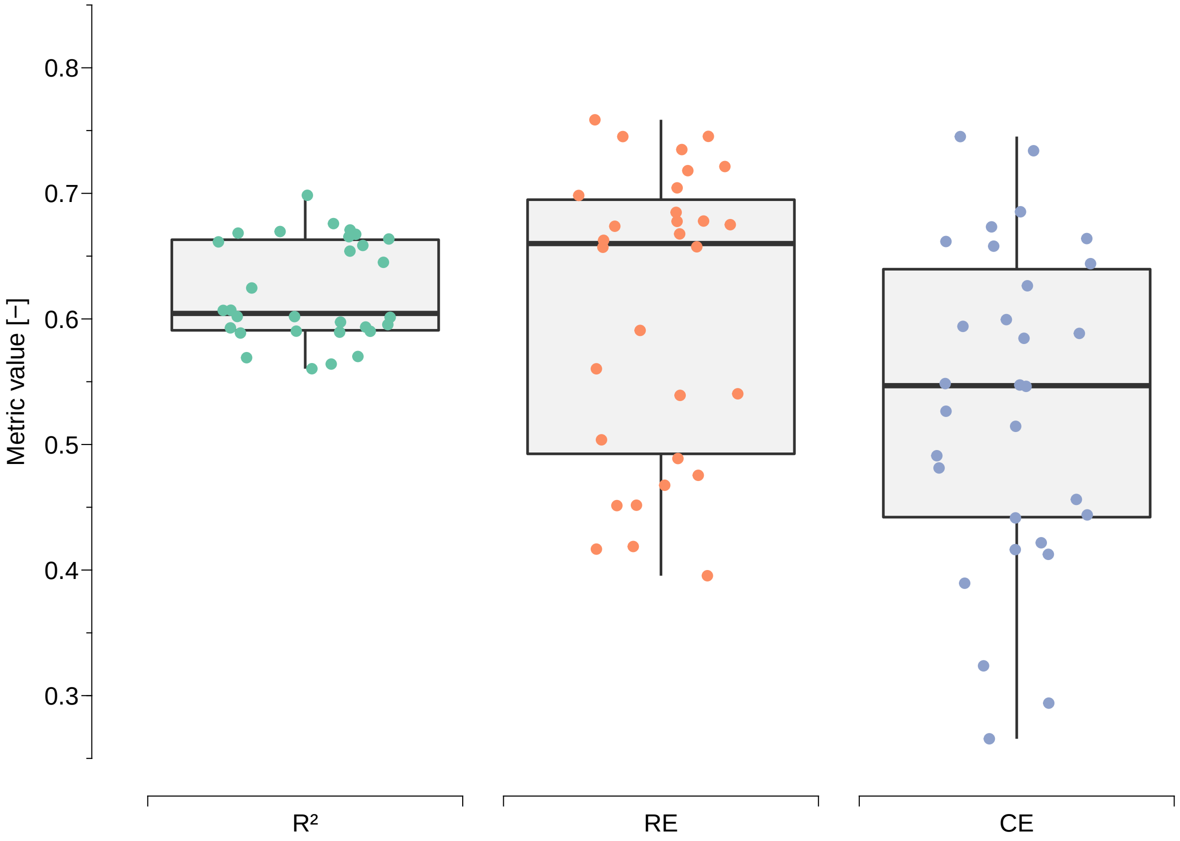
Performance scores

```
round(lmCV$metrics, 2)
```

```
##      R2   RE   CE nRMSE  KGE
## 1: 0.62 0.61 0.53   0.2 0.67
```

Figure S4 - score distribution

```
scores <- melt(lmCV$metrics.dist[, .(R2, RE, CE)],
               measure.vars = 1:3,
               variable.name = 'metric')
ggplot(scores) +
  geom_boxplot(aes(metric, value), fill = 'grey95') +
  geom_jitter(aes(metric, value, color = metric), width = 0.25) +
  scale_color_brewer(palette = 'Set2') +
  scale_x_discrete(
    name = NULL,
    guide = guide_prism_bracket(),
    labels = c('R\u00b2', 'RE', 'CE')) +
  scale_y_continuous(
    name = 'Metric value [-]',
    limits = c(0.25, 0.85),
    breaks = seq(0.2, 0.9, 0.1),
    minor_breaks = seq(0.25, 0.85, 0.05),
    guide = guide_prism_offset_minor()) +
  theme(legend.position = 'none')
```



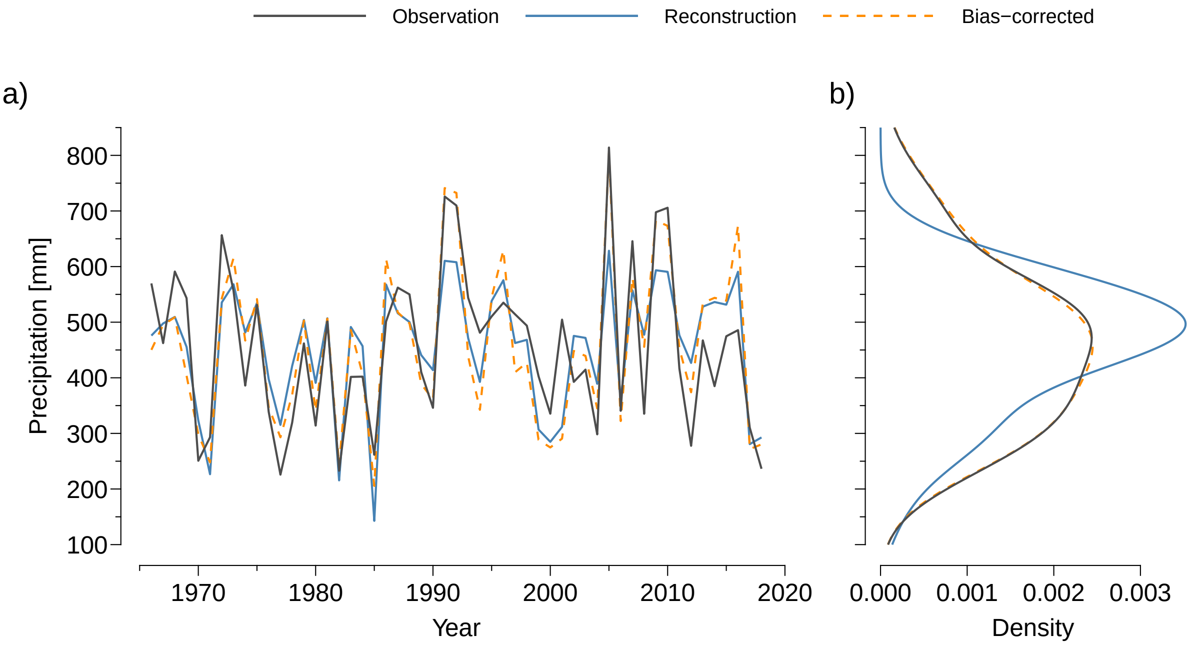
Final reconstruction with bias correction

```
recFinal <- lmFit$rec
recFinal[, lp20 := dplR::pass.filt(Q, 20, 'low')]
recFinal[, lp50 := dplR::pass.filt(Q, 50, 'low')]
bcFit <- fitQmap(
  PSepAug$Qa,
  recFinal[year %in% PSepAug$year, Q],
  'RQUANT',
  wet.day = FALSE)
recFinal[, Qbc := doQmap(Q, bcFit)]
```

Figure 3

```
p1 <- ggplot(recFinal[year %in% PSepAug$year]) +
  geom_line(aes(year, Q, colour = 'Reconstruction', linetype = 'Reconstruction'), size = 0.4) +
  geom_line(aes(year, Qbc, colour = 'Bias-corrected', linetype = 'Bias-corrected'), size = 0.4) +
  geom_line(aes(year, Qa, colour = 'Observation', linetype = 'Observation'),
            PSepAug, size = 0.4) +
  scale_colour_manual(
    name = NULL,
    values = c('Observation' = 'gray30',
               'Reconstruction' = 'steelblue',
               'Bias-corrected' = 'darkorange')) +
  scale_linetype_manual(
    name = NULL,
    values = c('Observation' = 1,
               'Reconstruction' = 1,
               'Bias-corrected' = 2)) +
  scale_x_continuous(
    minor_breaks = seq(1965, 2020, 5),
    limits = c(1966, 2018),
    guide = guide_prism_offset_minor()) +
  scale_y_continuous(
    minor_breaks = seq(100, 850, 50),
    breaks = seq(100, 850, 100),
    limits = c(100, 850),
    guide = guide_prism_offset_minor()) +
  labs(x = 'Year', y = 'Precipitation [mm]', tag = 'a)') +
  theme(
    plot.margin = margin(r = 10),
    legend.box.margin = margin(),
    legend.margin = margin(),
    legend.key.width = unit(2, 'cm'),
    legend.position = 'top')
p2 <- ggplot() +
  stat_density(aes(y = Q, colour = 'Reconstruction', linetype = 'Reconstruction'),
               recFinal[year %in% PSepAug$year], geom = 'line', bw = 60, size = 0.4) +
  stat_density(aes(y = Qbc, colour = 'Bias-corrected', linetype = 'Bias-corrected'),
               recFinal[year %in% PSepAug$year], geom = 'line', bw = 70, size = 0.4) +
  stat_density(aes(y = Qa, colour = 'Observation', linetype = 'Observation'),
               PSepAug, geom = 'line', bw = 70, size = 0.4) +
  scale_colour_manual(
    name = NULL,
    values = c('Observation' = 'gray30',
               'Reconstruction' = 'steelblue',
               'Bias-corrected' = 'darkorange')) +
  scale_linetype_manual(
    name = NULL,
    values = c('Observation' = 1,
               'Reconstruction' = 1,
               'Bias-corrected' = 2)) +
  scale_x_continuous(guide = guide_prism_offset()) +
  scale_y_continuous(
    minor_breaks = seq(100, 850, 50),
    breaks = seq(100, 850, 100),
    limits = c(100, 850),
    guide = guide_prism_offset_minor()) +
  labs(y = NULL, x = 'Density', colour = NULL, tag = 'b)') +
  theme(
    axis.text.y = element_blank(),
    legend.box.margin = margin(),
    legend.margin = margin(),
    legend.key.width = unit(2, 'cm'),
    legend.position = 'top') +
  theme(legend.position = 'top')

layout <- '
```

```
CCC
AAB
AAB
AAB
AAB
AAB
AAB
'

p1 + p2 + guide_area() +
  plot_layout(design = layout, guides = 'collect')
```



Trend and drought analyses

Calculate rolling statistics and extract drought events

```
alignType <- 'right'
recFinal[, rolMax := frollapply(Qbc, 50, max, align = alignType)]
recFinal[, rolMin := frollapply(Qbc, 50, min, align = alignType)]
recFinal[, rolMed := frollapply(Qbc, 50, median, align = alignType)]
recFinal[, period := fcase(
  year %in% 1517:1767, 1,
  default = 2)]
densCals <- recFinal[, {
  d <- density(Qbc, cut = 0, bw = 45)
  list(x = d$x, y = d$y / max(d$y) * 1.5)
}, by = period]
```

```
medians <- recFinal[, {
  d <- density(Qbc, cut = 0, bw = 45)
  m <- median(Qbc)
  y <- approx(d$x, d$y, m)$y
  list(x = m, y = y / max(d$y) * 1.5)
}, by = period]

recFinal[, dP := Qbc - mean(Qbc),
       ][, type := classify_events(dP)
       ][, dp10 := pass.filt(dP, 10)]
droughts <- get_timing(recFinal$dP, recFinal$type)[type == 'drought']
droughts[, ':='(yearStart = recFinal[start, year],
                period = recFinal[start, period],
                yearFinal = recFinal[final, year])]
worstDroughts <- droughts[order(peak)][1:3]
```

Mann-Kendall trend test with trend-free prewhitening

```
recFinal[!is.na(rolMax), tfpwmk(rolMax)] |> round(6)
```

```
##         Z-Value     Sen’s Slope Old Sen’s Slope         P-value               S
##        0.576500        0.000000        0.000000        0.564277     1844.000000
##          Var(S)             Tau
## 10220016.000000        0.018092
```

```
recFinal[!is.na(rolMin), tfpwmk(rolMin)] |> round(6)
```

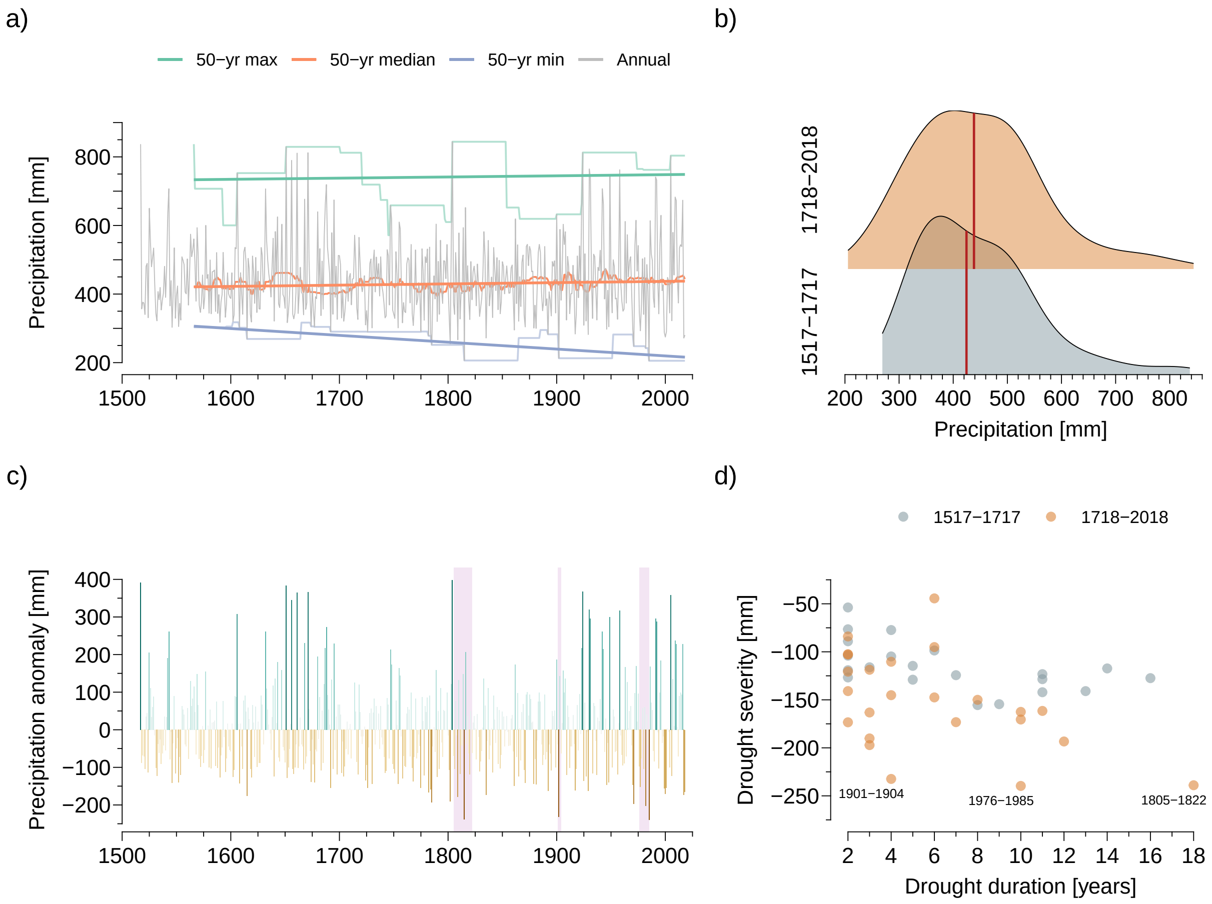
```
##         Z-Value     Sen’s Slope Old Sen’s Slope         P-value               S
##      -30.312840       -0.168350       -0.168237        0.000000   -97260.000000
##          Var(S)             Tau
## 10294526.000000       -0.954222
```

```
recFinal[!is.na(rolMed), tfpwmk(rolMed)] |> round(6)
```

```
##         Z-Value     Sen’s Slope Old Sen’s Slope         P-value               S
##       15.055906        0.040892        0.041507        0.000000    48308.000000
##          Var(S)             Tau
## 10294526.000000        0.473952
```

Figure 4

```
p1 <- ggplot(recFinal) +
  labs(x = NULL, y = 'P [mm]') +
  geom_line(aes(year, rolMax, colour = '50-yr max'), na.rm = TRUE, size = 0.4, alpha = 0.5) +
  geom_line(aes(year, rolMin, colour = '50-yr min'), na.rm = TRUE, size = 0.4, alpha = 0.5) +
  geom_line(aes(year, rolMed, colour = '50-yr median'), na.rm = TRUE, size = 0.4, alpha = 1) +
  geom_line(aes(year, Qbc, color = 'Annual')) +
  geom_smooth(aes(year, rolMax, colour = '50-yr max'), size = 0.6,
              formula = 'y ~ x', method = 'lm', na.rm = TRUE, fill = NA) +
  geom_smooth(aes(year, rolMin, colour = '50-yr min'), size = 0.6,
              formula = 'y ~ x', method = 'lm', na.rm = TRUE, fill = NA) +
  geom_smooth(aes(year, rolMed, colour = '50-yr median'), size= 0.6,
              formula = 'y ~ x', method = 'lm', na.rm = TRUE, fill = NA) +
  scale_x_continuous(
    expand = c(0, 0),
    minor_breaks = seq(1500, 2025, 25),
    limits = c(1500, 2025),
    guide = guide_prism_offset_minor()) +
  scale_y_continuous(
    minor_breaks = seq(200, 900, 50),
    breaks = seq(200, 900, 100),
    limits = c(200, 900),
    labels = skip_label(2),
    guide = guide_prism_offset_minor()) +
  labs(x = NULL, y = 'Precipitation [mm]', colour = NULL, tag = 'a)') +
  scale_color_manual(values = c(RColorBrewer::brewer.pal(3, 'Set2'), 'gray')) +
  theme(
    legend.key.width = unit(0.5, 'cm'),
    legend.position = 'top')

p2 <- ggplot(densCals) +
  geom_ribbon(aes(x, ymin = period, ymax = y + period, group = factor(period),
                  fill = factor(period)),
              alpha = 0.5) +
  geom_line(aes(x, y + period, group = factor(period))) +
  geom_linerange(aes(x, ymin = period, ymax = period + y), medians, colour = 'firebrick') +
  scale_fill_manual(
    labels = c('1517-1717', '1718-2018'),
    values = wesanderson::wes_palette('Royal1', 4)[c(1, 4)]) +
  scale_x_continuous(
    guide = guide_prism_offset_minor(),
    breaks = seq(200, 900, 100),
    minor_breaks = seq(200, 900, 20)) +
  scale_y_continuous(
    expand = c(0, 0),
    breaks = c(1.5, 2.5),
    labels = c('1517-1717', '            1718-2018')) +
  labs(x = 'Precipitation [mm]', y = NULL, tag = 'b)') +
  theme(
    legend.position = 'none',
    axis.line.y = element_blank(),
    axis.text.y.left = element_text(angle = 90, hjust = 0.5),
    axis.ticks.y = element_blank())

p3 <- ggplot(recFinal) +
  geom_rect(
    aes(xmin = yearStart, xmax = yearFinal, ymin = -Inf, ymax = Inf),
    worstDroughts,
    fill = 'magenta4', alpha = 0.1) +
  geom_col(aes(year, dP, fill = dP), recFinal[dP > 0]) +
  scale_fill_distiller(
    palette = 'BrBG',
    limits = abs_range(recFinal$dP),
    # limits = abs_range(recFinal$dP),
    guide = guide_none(),
    direction = 1) +
  ggnewscale::new_scale_fill() +
  geom_col(aes(year, dP, fill = dP), recFinal[dP < 0]) +
  scale_fill_distiller(
    palette = 'BrBG',
    # limits = abs_range(recFinal$dP),
    limits = c(min(recFinal$dP), -min(recFinal$dP)),
    guide = guide_none(),
    direction = 1) +
  scale_color_manual(values = 'black') +
  scale_x_continuous(
    expand = c(0, 0),
    minor_breaks = seq(1500, 2025, 25),
    limits = c(1500, 2025),
    guide = guide_prism_offset_minor()) +
  scale_y_continuous(
    breaks = seq(-300, 400, 100),
    minor_breaks = seq(-300, 400, 50),
    guide = guide_prism_offset_minor()) +
  labs(x = NULL, y = 'Precipitation anomaly [mm]', tag = 'c)') +
  theme(
    legend.position = 'top')

p4 <- ggplot(droughts) +
  geom_point(aes(dur, peak, color = as.character(period)), alpha = 0.6) +
  geom_text(
    aes(dur, peak, label = paste(yearStart, yearFinal, sep = '-')),
    worstDroughts,
    size = 2, hjust = 0.8, nudge_y = -15) +
  scale_x_continuous(
    breaks = seq(2, 20, 2),
    guide = guide_prism_offset_minor()) +
  scale_y_continuous(
    breaks = seq(-300, 0, 50),
    limits = c(-275, -25),
    guide = guide_prism_offset_minor()) +
  scale_color_manual(
    labels = c('1517-1717', '1718-2018'),
    values = wesanderson::wes_palette('Royal1', 4)[c(1, 4)]) +
  labs(x = 'Drought duration [years]', y = 'Drought severity [mm]', tag = 'd)') +
  theme(legend.position = 'top')

p1 + p2 + p3 + p4 +
  plot_layout(widths = c(1.5, 1))
```



Export the reconstruction

```
recFinal[, period := NULL]
fwrite(
  recFinal[, .(year, P = Q, Plower = Ql, Pupper = Qu, Pbc = Qbc)],
  'results/chitral-sep-aug-precip-reconst.csv')
```