



Supplement of

Various ways of using empirical orthogonal functions for climate model evaluation

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Common EOFs for GCM evaluation

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Introduction

This is supporting material to empirical-statistical downscaling (ESD) of temperature and precipitation over the Nordic countries. This document can also be regarded as a lab note book for the analysis underpinning this study.

One assumption behind downscaling is to utilise large-scale features that the global climate models (GCMs) can skilfully reproduce and the dependency of local scale climate upon these. Hence it's crucial to evaluate the GCM output to establish whether they skillfully reproduce real features, and in particular, it is important to evaluate how well the GCMs reproduce large-scale climate change and variability before using them as a basis for climate change adaptation. ESD can include some degree of evaluation, e.g. through the use of common empirical orthogonal functions, henceforth referred to as “common EOFs” (Benestad (2001)). This concept is explained more recently in Benestad (2021). Here, the acronym ‘EOF’ refers to ‘empirical orthogonal functions’ which are similar to principal component analysis and closely connected to the mathematical concepts known as eigenfunctions and eigenvalues.

Below is an analysis that provides an objective and deep evaluation of the predictors used to represent the large-scale conditions in downscaling as they are simulated by the GCMs, focusing on the most salient information embedded in the data. It goes beyond the framework suggested in Benestad (2001) by comparing large multi-model ensembles with a focus on the the ensemble’s ability to reproduce physical conditions such as the mean annual cycle, interannual variability and historical long-term trends, rather than emphasising individual members.

Another objective is to compare the evaluation of two generations of GCM simulations: CMIP5 and CMIP6. Here is a demonstration of how such a comparison can make use of the models’ ability to reproduce the mean annual cycle, the interannual variability and historical trends over 1959-2021 in this case. The 63-year long period 1959-2021 is chosen because monthly ERA5 data are available in a single dataset from 1950 until present time and because 2021 was the last year with complete data for all months at the time of the analysis.

More information about EOFs and common EOFs are available from <https://doi.org/10.1142/6908> and a short hands-on demonstration is available ads a YouTube <https://youtu.be/32mtHHAoq6k>.

Set-up

The evaluation of GCM results based on common EOFs is implemented with the help of the R-package `esd`. The following chunk activates it and sets the working environment

```
library(esd)
#setwd('~/.R')
```

Special functions

The following code chunk defines a number of functions used in this analysis:

```
## Function to split the CMIP file names into model, ssp and RIPF
decipher <- function(x) {
  i <- gregexpr('_',x)[[1]]
  model <- substr(x,i[2]+1,i[3]-1)
  ssp <- substr(x,i[3]+1,i[4]-1)
  ripf <- substr(x,i[4]+1,i[4]+8)
  interval <- substr(x,i[5]+1,regexpr('.nc',x)[[1]]-1)
  return(c(model,ssp,ripf,interval))
}

## Method for calculating common EOFs of large multi-model ensembles with GCMs' mean annual cycle
## Most of its operations involve preparation of the data and collecting the right data from multiple
## data files.
EOF.GCMsAC <- function(x,lon=NULL,lat=NULL,verbose=FALSE,...) {
  ## This function combines the annual cycles from different GCMs and performs a
  ## common EOF on the joint data
  #print('EOF.GCMsAC')
  runs <- names(x)
  runs <- runs[-grep('era5',runs)]
  #print(runs)
  if (length(grep('era5',names(x)))>0) X <- subset(x[['era5']],is=list(lon=lon,lat=lat))
  n <- length(runs)
  for (i in 1:n) {
    #print(runs[i])
    z <- subset(x[[runs[i]]],is=list(lon=lon,lat=lat))
    X <- combine(X,z)
  }
  if (verbose) print(str(X))
  eof <- EOF(X,anomaly=FALSE,verbose=verbose,...)
  invisible(eof)
}

## Method for calculating common EOFs of the GCMs' annually aggregated data
## Most of its operations involve preparation of the data and collecting the right data from multiple
## data files.
EOF.GCMsAM <- function(x,lon=NULL,lat=NULL,...) {
  ## This function combines the annual means from different GCMs and performs a
  ## common EOF on the joint data
  print('EOF.GCMsAM')
  runs <- names(x)
  era5 <- runs[grep('era5',runs)][1]
  runs <- runs[-grep('era5',runs)]
  #print(runs)
  if (length(grep(era5,names(x)))>0) X <- subset(x[[era5]],is=list(lon=lon,lat=lat))
  X <- regrid(X,is=list(lon=seq(min(lon(X)),max(lon(X)),by=1),lat=seq(min(lat(X)),max(lat(X)),by=1)))
  n <- length(runs); print(n)
  for (i in 1:n) {
    print(runs[i])
    z <- subset(x[[runs[i]]],is=list(lon=lon,lat=lat))
    attr(z,'source') <- runs[i]
  }
}
```

```

    X <- combine(X,z)
  }
  print('Calculate EOF for joint dataset')
  eof <- EOF(X,anomaly=FALSE,...)
  invisible(eof)
}

## Function for estimating root-mean-square-error (RMSE) of the common EOFs for the mean annual cycle
RMSE.AC.CEOF <- function(x) {
  n <- attr(x,'n.apps')
  rmse <- rep(0,n); modelid <- rep('NA',n)
  for (i in 1:n) {
    y <- attr(x,paste0('appendix.',i))
    for (j in (1:20)) rmse[i] <- rmse[i] + (RMSE(coredata(x[,j]),coredata(y[,j]))*attr(x,'eigenvalue'))
    rmse[i] <- round(sqrt(rmse[i])/sqrt(sum(attr(x,'eigenvalue')^2)),3)
    modelid[i] <- attr(y,"source")
  }
  names(rmse) <- modelid
  rmse <- rmse[order(rmse,decreasing=FALSE)]
  return(rmse)
}

## Convert the list with trend maps into a field object to speed up the analysis and to
## enable EOFs for reducing the data volume.
list2field <- function(x,it='annual',lon=NULL,lat=NULL,plot=TRUE,...) {
  #print('list2field')
  cn <- names(x)
  if (!is.null(it)) if (is.character(it)) cn <- names(x)[grep(it,names(x))]
  n <- length(cn)
  print(cn)
  Y <- subset(x[[cn[1]]],is=list(lon=lon,lat=lat)) # GCMs
  nxy <- length(Y)
  X <- matrix(rep(NA,n*nxy),n,nxy)
  for (i in 1:n) {
    z <- regrid(subset(x[[cn[i]]],is=list(lon=lon,lat=lat)),is=Y)
    X[i,] <- c(z)
    #print(c(i,cn[i],round(mean(X[i,],na.rm=TRUE),2)))
  }

  X <- as.field(zoo(X,order.by=1:n),param=param,unit=esd::unit(Y),lon=lon(Y),lat=lat(Y),
    info='trend maps: list2field (GCMsAC.R)',longname='trend coefficients')

  if (plot) map(subset(X,is=list(lon=c(0,40),lat=c(58,70))),FUN='sd',
    main='Multi-modal ensemble trend spread (CMIP6)',sub='1959-2021')
  #par(fig=c(0,0.3,0,0.3),new=TRUE)
  #hist(c(r),lwd=3,col=rgb(0,0,0,0.5))
  attr(X,'ID') <- cn
  invisible(X)
}

## The following function evaluates given PC of the ensemble by comparing the rank of the observations
## If the observations and model results belong to the same statistical population, then the rank should

```

```

## be random between 0 and 100%. We can use a Monte-Carlo approach to estimate confidence interval.
## x is the common EOF-object and ip is the PC number.
evalGCMsAM <- function(x, cmip, ip=1, N.test=300, breaks=seq(0,1,by=0.05), plot=TRUE, verbose=FALSE) {
  d <- dim(x)
  n <- attr(x, 'n.apps')
  #rank <- apply(coredata(x), 2, order)
  X <- matrix(rep(NA, d[1]*(n+1)), n+1, d[1])
  X[1,] <- coredata(x)[, ip]
  for (i in 1:n) {
    if (length(X[i+1,]) == length(coredata(attr(x, paste0('appendix.', i)))[, ip]))
      X[i+1,] <- coredata(attr(x, paste0('appendix.', i)))[, ip]
  }
  cmip[!is.finite(apply(X[-1,], 1, mean))] <- NA
  X5 <- X[c(T, is.element(cmip, 'brown')),,]; d5 <- dim(X5)
  X6 <- X[c(T, is.element(cmip, 'darkgreen')),,]; d6 <- dim(X6)
  eval5 <- apply(X5, 2, function(x) order(x)[1]/length(x))
  eval6 <- apply(X6, 2, function(x) order(x)[1]/length(x))
  ## Monte-Carlo null-distribution:
  null5 <- matrix(rep(NA, d5[1]*N.test), N.test, d5[1])
  null6 <- matrix(rep(NA, d6[1]*N.test), N.test, d6[1])
  for (i in 1:N.test) {
    X5[i,] <- rnorm(length(X5)); dim(X5) <- d5
    X6[i,] <- rnorm(length(X6)); dim(X6) <- d6
    null5[i,] <- apply(X5, 1, function(x) order(x)[1]/length(x))
    null6[i,] <- apply(X6, 1, function(x) order(x)[1]/length(x))
  }
  z5 <- apply(null5, 1, function(x) hist(x, breaks=breaks, plot=FALSE)$density)
  z6 <- apply(null6, 1, function(x) hist(x, breaks=breaks, plot=FALSE)$density)
  h5 <- hist(eval5, breaks=breaks, plot=FALSE)
  h6 <- hist(eval6, breaks=breaks, plot=FALSE)
  attr(h5, 'Monte-Carlo null.distribution') <- z5
  attr(h6, 'Monte-Carlo null.distribution') <- z6

  ## Plot the results
  if (plot) {
    plot(eval5, type='b', col='brown', lty=2, pch=19, cex=1.5, ylim=c(0,1),
         main='Rank evaluation statistics', xlab='year', ylab='rank in ensemble')
    lines(eval6, type='b', col='darkgreen', lty=3, pch=19)
    grid()
  }
  return(list(eval.CMIP5=h5, eval.CMIP6=h6, rank.CMIP5=eval5, rank.CMIP6=eval6, CMIP5=X5, CMIP6=X6))
}

# Not used...
# hatched <- function(m,s,col='grey50') {
#   polygon(c(1:12, rev(1:12)), c(m+s, m-1), col=col, border=col)
# }

```

Calculations

The following chunk of code is used for initialising the calculations. It contains some options (parameters) used for carrying out this analysis.

```
print('---<GCMSACAM.R>---')
```

```
## [1] "---<GCMSACAM.R>---"
```

```
par0 <- par()
plot <- TRUE
reprocess <- FALSE
outpath <- '~/R/'
regions <- rep('NA',5)
lon <- matrix(c(-5,45, 0,60, -15,50, -25,40, 0,35),2,5)
lat <- matrix(c(55,72, 66,85, 50,75, 45,72, 58,72),2,5)

for (i in 1:5) regions[i] <- paste0(paste(lon[,i],collapse='-'), 'E.', paste(lat[,i],collapse='-'), 'N')
#regions <- regions[i] ## Only show results for the first region if this line is uncommented.
print(regions)
```

```
## [1] "-5-45E.55-72N" "0-60E.66-85N" "-15-50E.50-75N" "-25-40E.45-72N"
## [5] "0-35E.58-72N"
```

```
paths <- c('~/.data/CMIP5.monthly/', '~/.data/CMIP6.monthly/')
run <- 'r1i1p1f1|r1i1p1'
## Some of the data downloaded from ESGF and processed locally turned out to be bad:
#[1] "/home/rasmus/b/data/CMIP6.monthly/ssp245/tas_Amon_IPSL-CM6A-LR_ssp245_r1i1p1f1_1850-2100.nc"
#[1] "Warning : Frequency found in the attribute does not match the frequency detected in data"
#[1] "tas" "degC" "-34" "999726"
#[1] "Trend statistics"
# Min. 1st Qu. Median Mean 3rd Qu. Max.
# -43583 -43583 -43583 -43583 -43583 -43582
## This data is excluded from the analysis
bad.data <- NULL
```

Post- and pre-processing

The post-processing can be a bit time-consuming and the code therefore searches for results saved previously in the specified path. It will only carry out all the pre-processing if there is no data files with the expected file name.

```
print('Post-processing:')
```

```
## [1] "Post-processing:"
```

```
print(regions); print(paths)
```

```
## [1] "-5-45E.55-72N" "0-60E.66-85N" "-15-50E.50-75N" "-25-40E.45-72N"
## [5] "0-35E.58-72N"
```

```
## [1] "~/data/CMIP5.monthly/" "~/data/CMIP6.monthly/"
```

```

for (ir in 1:length(regions)) {
  for (path in paths) {
    rcps <- list.files(path=path)
    rcps <- rcps[grepl("RCP45|ssp245",rcps)]
    for (rcp in rcps) {
      print(rcp)
      for (param in c('tas', 'pr', 'psl')) {
        if (param=='pr') {
          gcmfiles <- list.files(path=paste0(path,rcp),pattern='pr_Amon',full.names = TRUE)
          gcmfiles <- gcmfiles[grepl(run,gcmfiles)]
          gcmfiles <- gcmfiles[grepl('_1850-|_1860-|_1861-',gcmfiles)]
          reanalysis <- '~/data/ERA5/ERA5_tp_mon.nc'
        } else if (param=='tas') {
          gcmfiles <- list.files(path=paste0(path,rcp),pattern='tas_Amon',full.names = TRUE)
          gcmfiles <- gcmfiles[grepl(run,gcmfiles)]
          gcmfiles <- gcmfiles[grepl('_1850-|_1860-|_1861-',gcmfiles)]
          reanalysis <- '~/data/ERA5/ERA5_t2m_mon.nc'
        } else if (param=='psl') {
          gcmfiles <- list.files(path=paste0(path,rcp),pattern='psl_Amon',full.names = TRUE)
          gcmfiles <- gcmfiles[grepl(run,gcmfiles)]
          gcmfiles <- gcmfiles[grepl('_1850-|_1860-|_1861-',gcmfiles)]
          reanalysis <- '~/data/ERA5/ERA5_slp_mon.nc'
        }
      }

      output <- paste0('GCMsACAM.',param,'.',tolower(rcp),'',regions[ir],'.rda')
      # eof.output <- paste0('eof.',output)

      print(output)
      ##gcmfiles <- gcmfiles[1:3] ## Testing

      if (!file.exists(output) | (reprocess)) {
        print(gcmfiles); i <- 0
        Y <- list(); Z <- list(); W <- list(); AM <- list()

        print(paste('Number of CMIP6 files to read=',length(gcmfiles)))
        for (gcmfile in gcmfiles) {
          ## Estimate the mean annual cycle
          print(gcmfile)
          X <- retrieve(gcmfile,it=c(1959,2021),lon=lon[,ir],lat=lat[,ir])
          if (param=='pr') {
            X <- X * 30 ## mm/month
            attr(X,'unit') <- 'mm/month'
            FUN='sum'
          } else FUN='mean'
          print(c(varid(X),esd::unit(X),round(range(X,na.rm=TRUE))))
          #cim <- paste(attr(X,'model_id'),attr(X,'realization'),i,sep='.')
          cim <- paste(decipher(gcmfile)[1:3],collapse='.')
          ## Mean annual cycle
          acm <- aggregate(X,month)
          ## Mean annual variability
          acs <- aggregate(X,month,FUN='sd')
          ## Annual total
          act <- annual(X,FUN=FUN)
        }
      }
    }
  }
}

```

```

djf <- annual(subset(X,it='djf'),FUN=FUN,nmin=3)
mam <- annual(subset(X,it='mam'),FUN=FUN,nmin=3)
jja <- annual(subset(X,it='jja'),FUN=FUN,nmin=3)
son <- annual(subset(X,it='son'),FUN=FUN,nmin=3)
AM[[cim]] <- act
AM[[paste0('djf.',cim)]] <- djf
AM[[paste0('mam.',cim)]] <- mam
AM[[paste0('jja.',cim)]] <- jja
AM[[paste0('son.',cim)]] <- son
## Past trends
if (plot) par(par0)
act <- map(annual(X),FUN='trend',plot=plot)
print('Trend statistics'); print(summary(c(act)))
actDJF <- map(annual(subset(X,it='djf'),nmin=3),FUN='trend',plot=plot)
actMAM <- map(annual(subset(X,it='mam'),nmin=3),FUN='trend',plot=plot)
actJJA <- map(annual(subset(X,it='jja'),nmin=3),FUN='trend',plot=plot)
actSON <- map(annual(subset(X,it='son'),nmin=3),FUN='trend',plot=plot)
Y[[cim]] <- acm
Z[[cim]] <- acs
W[[paste(cim,param,'trend.annual',sep='.')]] <- act
W[[paste(cim,param,'trend.DJF',sep='.')]] <- actDJF
W[[paste(cim,param,'trend.MAM',sep='.')]] <- actMAM
W[[paste(cim,param,'trend.JJA',sep='.')]] <- actJJA
W[[paste(cim,param,'trend.SON',sep='.')]] <- actSON
#map(Y[[cim]])
i <- i + 1
}
## Also show the era5 reanalysis
print('Retrieve ERA5 reanalysis also')
X <- retrieve(reanalysis,it=c(1959,2021),lon=lon[,ir],lat=lat[,ir])
if (param=='pr') {
  X <- X * 30 * 1000 ## m/day -> mm/month
  attr(X,'unit') <- 'mm/month'
  FUN='sum'
} else FUN='mean'
acm <- aggregate(X,month)
acs <- aggregate(X,month,FUN='sd')
## Annual total
act <- annual(X,FUN=FUN)
djf <- annual(subset(X,it='djf'),FUN=FUN,nmin=3)
mam <- annual(subset(X,it='mam'),FUN=FUN,nmin=3)
jja <- annual(subset(X,it='jja'),FUN=FUN,nmin=3)
son <- annual(subset(X,it='son'),FUN=FUN,nmin=3)
Y[['era5']] <- acm
Z[['era5']] <- acs
AM[['era5']] <- act
AM[['djf.era5']] <- djf
AM[['mam.era5']] <- mam
AM[['jja.era5']] <- jja
AM[['son.era5']] <- son
act <- map(annual(X),FUN='trend',plot=plot)
actDJF <- map(annual(subset(X,it='djf'),nmin=3),FUN='trend',plot=plot)
actMAM <- map(annual(subset(X,it='mam'),nmin=3),FUN='trend',plot=plot)

```


The second annual mean TAS mode (13% of the variance) exhibits a northwest-southeast temperature gradient.

The CMIP5/6 ensembles are compared through rank statistics of the ERA5 PC within the ensemble spread for each year for the annual mean results. In this case, this rank comparison is applied to the leading PC that was associated with the majority of the variance. The rank statistics is tested against Monte-Carlo simulations with same number of years and ensemble members to provide a reference for what the results would look like for a perfect case where the observations and the model results belong to the same statistical population. The results suggest that ERA5 tends to have a low rank and lie in the lower part of the ensemble spread, rather than having an equal chance of being anywhere within it. The CMIP6 (darkgreen) seems to have a slightly better rank distribution than CMIP5 (red).

An asymptotic one-sample Kolmogorov-Smirnov test is applied to the ranks of PC1 corresponding to ERA5 within the GCM ensembles and a uniform distribution to see whether the ERA5 data belong to the same statistical population as that of the CMIP data. The tests suggest that the CMIP populations are from the same as ERA5 based on the observed interannual variability. Hence, the CMIP ensembles may suggest a realistic confidence interval for TAS.

A test for normality for last year (2021) suggest that the leading PC for both CMIP5 and CMIP6 annual TAS for a given year is approximately normally distributed. However, some of the values in the tail of the distribution do deviate from the normal distribution. This means that the ensemble spread in terms of annual TAS may roughly be represented by the ensemble mean μ_e and standard deviation σ_e .

The analysis for annual mean TAS is repeated for seasonal mean TAS. For winter (DJF), the leading mode only accounts for 57% of the variance and the second mode for 17%, and the spatio-temporal pattern of variability is more complicated than for the annual mean TAS. Again, the Kolmogorov-Smirnov test suggests that leading PC for ERA5 doesn't belong to the same statistical population as the CMIP ensembles, but the weights for 2021 representing the respective ensembles are approximately normally distributed.

The two leading common EOFs for spring (MAM) account for 57% and 15% of the variance respectively, with pronounced variability over the eastern part of the Barents Sea for the gravest mode and in the northwest towards Greenland for the second mode. These 'hotspots' may perhaps be associated with the simulation of sea-ice in some models and may indicate an aspect of model discrepancy. While the ERA5 results for spring also has different amplitude as that of the ensemble members, the results also suggest that they show a stronger deviation from the normal distribution.

For summer (JJA) the variance of the two leading common EOFs account for 54% and 14%. The rank metric of ERA5 deviates from a uniform distribution, but both CMIP ensembles indicate that the weights for summer TAS PC1 for 2021 are close to being normally distributed.

The common EOFs for autumn (SON) follow a similar story as the other seasons.

Spatial trend maps A third application of common EOFs is the application of EOF to a data matrix for which each column was made up of a spatial trend map, one for each GCM in addition to ERA5. The standard deviation (σ) of the 1959-2021 annual mean TAS linear trend estimates suggests greatest scatter in the eastern part of the domain, and an EOF analysis of the trend patterns (carried out on the absolute values) indicates that most GCMs reproduced the observed historical trend with strongest amplitude in the northeast (96% variance for the leading mode). The black circular points imposed onto the PC represents the ERA5 reanalysis. The model results exhibit a scatter around the observations. The second EOF suggests that the simulated trends also varied in terms of a northwest-southeast temperature gradient. These anomalies may possibly be connected to internal variations and the position of the jet-stream.

A scatter plot of the PCs of the two leading modes suggests that most of the GCM results for TAS are consistent with those for the leading mode based on ERA5 (black symbol in the scatter plot), albeit with most GCMs shifted towards lower values for the second mode (gradient TAS structure). The red symbols mark the CMIP5 and the darkgreen CMIP6 PC weights for the trend maps. The number shown near the symbols indicate the model associated with the data point.

Robustness with respect to choice of region The common EOF analysis is then repeated for different regions and there are slight variations of the eigenvalues (variances accounted for). In some of the smaller domains, the CMIP5 indicates a strong deviation from the normal distribution whereas the CMIP6 results appear to be more robustly approximately normally distributed for seasonal mean TAS PC1 for 2021.

One region that differs substantially from the others is the Barents region dominated by maritime climate where the leading seasonal cycle TAS account for 96% of the variance and most of the variability takes place in the north near the sea-ice edge. While the second mode only accounts for 2% of the variance, there is a distinct change in behaviour for the seasonal cycle in TAS between CMIP5 and CMIP6 where CMIP6 is visually in closer agreement with ERA5 than CMIP5. The strongest variability in mean spring TAS is seen over parts of the Barents Sea which also may coincide with the edge of the sea-ice.

```
##-----
## Diagnostics

regions <- sub('.rda','',sub('GCMsACAM.tas.ssp245.','',list.files(pattern = 'GCMsACAM.tas.ssp245.')))
seasons <- c('annual','djf','mam','jja','son')

for (region in regions) {
  print(region)
  for (param in c('tas', 'pr', 'psl')[1]) {
    GCMs.AC.all <- NULL; GCMs.trend.all <- NULL; GCMs.AM.all <- NULL
    for (rcp in c('rcp45','ssp245')) {
      output <- paste0('GCMsACAM.',param,'.',rcp,'.',region,'.rda')
      load(output)
      if (is.null(GCMs.AC.all)) {GCMs.AC.all <- GCMs.AC; GCMs.AC.all$era5 <- NULL} else
        GCMs.AC.all <- c(GCMs.AC.all,GCMs.AC)
      if (is.null(GCMs.trend.all)) {GCMs.trend.all <- GCMs.trend; GCMs.trend.all$era5 <- NULL} else
        GCMs.trend.all <- c(GCMs.trend.all,GCMs.trend)
      if (is.null(GCMs.AM.all)) {GCMs.AM.all <- GCMs.AM; GCMs.AM.all$era5 <- NULL} else
        GCMs.AM.all <- c(GCMs.AM.all,GCMs.AM)
    }
    GCMs.AC.all -> GCMs.AC; rm('GCMs.AC.all')
    GCMs.trend.all -> GCMs.trend; rm('GCMs.trend.all')
    GCMs.AM.all -> GCMs.AM

    ## Exclude known bad data
    if (length(bad.data) > 0) {
      for (bad in bad.data) {GCMs.AC[[bad]] <- NULL; GCMs.AM[[bad]] <- NULL; GCMs.trend[[bad]] <- NULL}
    }

    if (region == regions[1]) print(names(GCMs.AC))
    ## Fix problems
    n <- length(GCMs.AC)
    m <- length(GCMs.AM)
    for (i in 1:n) attr(GCMs.AC[[i]],'source') <- names(GCMs.AC)[i]
    for (i in 1:m) attr(GCMs.AM[[i]],'source') <- names(GCMs.AM)[i]

    ## CIESM_ssp245_r1i1p1f1 seems to have units of m rather than mm
    if (param=='pr') {
      for (i in 1:n) {
        if (max(GCMs.AC[[i]]) < 1) GCMs.AC[[i]] <- 1000*GCMs.AC[[i]]
      }
    }
  }
}
```

```

## Show the CMIP5 and CMIP56 with different colours
col <- names(GCMs.AC)
col <- col[grep('rcp|ssp',col)]
col[grep('rcp',col)] <- 'brown'; col[grep('ssp',col)] <- 'darkgreen'
print(table(col))
ngcms <- length(col)

## Use common EOFs of mean annual cycle to compare the GCMs' ability to reproduce the
## mean annual cycle with that seen in the ERA5 reanalysis
ceof.ac <- EOF.GCMsAC(GCMs.AC)

## Estimate ensemble mean and standard deviation for plotting
pc1.ac <- matrix(rep(NA,12*ngcms),12,ngcms); pc2.ac <- pc1.ac
for (i in 1:ngcms) {
  pc1.ac[,i] <- attr(ceof.ac,paste0('appendix.',i))[,1]
  pc2.ac[,i] <- attr(ceof.ac,paste0('appendix.',i))[,2]
}

if (plot) {
  par(par0)
  plot(ceof.ac,col=col,alpha=0.2,new=FALSE)
  par(par0)
  plot(ceof.ac,col=col,alpha=0.5,ip=2,new=FALSE)
}

## Scalar metric: Use variance-weighted (eigenvalues) sum of RMSE of the PCs wrt ERA5
w.rmse <- RMSE.AC.CEOF(ceof.ac)
## Table of ranking
## Generate table for LaTeX document:
write.table(w.rmse,sep=' & ', eol = ' \\\n', quote = FALSE)

## Mann-Witney (two-sample Wilcoxon test) U-test?
cmip5 <- grep('rcp',names(w.rmse))
cmip6 <- grep('ssp',names(w.rmse))
print(wilcox.test(w.rmse[cmip6],w.rmse[cmip5],alternative='less'))

## Use common EOFs of annually aggregated data to compare the interannual variability
## simulated by GCMs with the ERA5 reanalysis

for (is in seasons) {
  print(paste('Season',is))
  am.names <- names(GCMs.AM.all)
  if (is!='annual') keep <- am.names[grep(is,am.names)] else
    keep <- am.names[-grep('djf|mam|jja|son',am.names)]
  GCMs.AM <- GCMs.AM.all[keep]

  ceof.am <- EOF.GCMsAM(GCMs.AM)
  if (plot) {
    par(par0)
    plot(ceof.am,col=col,alpha=0.3,new=FALSE)
    par(par0)
    plot(ceof.am,col=col,alpha=0.3,ip=2,new=FALSE)
  }
}

```

```

## Evaluation of the annual mean results in terms of how observations rank within the ensemble PC
par(par0)
eval.am <- evalGCMsAM(ceof.am,col)
plot(eval.am[[1]]$mids,(eval.am[[1]]$density),type='l',lwd=1,col='brown',lty=2,main='Obs-ensemble')
lines(eval.am[[2]]$mids,(eval.am[[2]]$density),type='l',lwd=1,col='darkgreen')
grid()
for (i in 1:300) {
  lines(eval.am[[1]]$mids,attr(eval.am[[1]], 'Monte-Carlo null.distribution')[,i],type='l',lty=2,col='brown')
  lines(eval.am[[2]]$mids,attr(eval.am[[2]], 'Monte-Carlo null.distribution')[,i],type='l',lty=2,col='darkgreen')
}
lines(eval.am[[1]]$mids,(eval.am[[1]]$density),type='l',lwd=3,col='brown')
lines(eval.am[[2]]$mids,(eval.am[[2]]$density),type='l',lwd=3,col='darkgreen')

## Testing the distribution of trend statistics using Kolmogorov-Smirnov Test
rank.test.CMIP5 <- ks.test(eval.am$rank.CMIP5,'punif')
rank.test.CMIP6 <- ks.test(eval.am$rank.CMIP6,'punif')
print("rank.test.CMIP5"); print(rank.test.CMIP5)
print("rank.test.CMIP6"); print(rank.test.CMIP6)

## Check to see if the data is normally distributed
qqnorm(eval.am$CMIP5[,length(eval.am$CMIP5[,1])],main='CMIP5')
grid()
qqline(eval.am$CMIP5[,length(eval.am$CMIP5[,1])])

qqnorm(eval.am$CMIP6[,length(eval.am$CMIP6[,1])],main='CMIP6')
grid()
qqline(eval.am$CMIP6[,length(eval.am$CMIP6[,1])])
}

## Use EOFs of trend maps to assess the trends in the GCMs:
Z <- list2field(GCMs.trend,plot=plot)
attr(Z,'unit') <- 'trend'
n <- length(attr(Z,'ID'))
col <- attr(Z,'ID')
col <- col[grep('rcp|ssp|era5',attr(Z,'ID'))]
col[grep('rcp',col)] <- 'red'; col[grep('ssp',col)] <- 'blue'
col[grep('era5',col)] <- 'black'
teof <- EOF(Z,anomaly=FALSE)
n <- dim(teof)[1]
if (plot) {
  par(par0)
  plot(teof,new=FALSE)
  ## Add a point indicating the ERA5 trends
  par(fig=c(0.05,1,0.025,0.475),mar=c(3,3,2,2),new=TRUE)
  lines((1:n)[is.element(col,'red')],teof[is.element(col,'red'),1],col='red',lty=2,lwd=1)
  lines((1:n)[is.element(col,'blue')],teof[is.element(col,'blue'),1],col='blue',lwd=1)
  points((1:n)[is.element(col,'black')],teof[(1:n)[is.element(col,'black')],1],col='black',cex=1.5)
  par(par0)
  plot(teof,ip=2,new=FALSE)
  ## Add a point indicating the ERA5 trends
  par(fig=c(0.05,1,0.025,0.475),mar=c(3,3,2,2),new=TRUE)
  lines((1:n)[is.element(col,'red')],teof[is.element(col,'red'),2],col='red',lty=2,lwd=1)
}

```

```

lines((1:n)[is.element(col, 'blue')], teof[is.element(col, 'blue'), 2], col='blue', lwd=1)
points((1:n)[is.element(col, 'black')], teof[(1:n)[is.element(col, 'black')], 2], col='black', cex=1.5,
}

## Another way to evaluate is with a scatterplot of the PCs of the two leading modes:
tnms <- names(GCMs.trend); tnms <- tnms[grepl('annual', tnms)]
print(tnms)
icmip5 <- grep('rcp', tnms)
icmip6 <- grep('ssp', tnms)
if (plot) {
  par(par0)
  plot(teof[, 1], teof[, 2], xlab='Mode 1', ylab='Mode2');
  points(teof[n, 1], teof[n, 2], pch=19, col='black', cex=1.5);
  points(teof[icmip5, 1], teof[icmip5, 2], col='red', lwd=2)
  points(teof[icmip6, 1], teof[icmip6, 2], col='blue', lwd=2)
  text(teof[-n, 1], teof[-n, 2], 1:(n-1), cex=0.6, col='grey40', pos=1)
}
}
}

```

The ranking of the CMIP simulations was based on common EOF analysis of the TAS mean annual cycle. A Wilcoxon rank sum test was applied to the RMSE scored for the leading PC of the common EOFs for the mean annual cycle in TAS and the results suggested that the improvement of CMIP6 simulations over CMIP5 was statistically significant at the 5% level.

Total precipitation (PR)

```

##-----
## Diagnostics

regions <- sub('.rda', '', sub('GCMsACAM.tas.ssp245.', '', list.files(pattern = 'GCMsACAM.tas.ssp245.')))
seasons <- c('annual', 'djf', 'mam', 'jja', 'son')

for (region in regions) {
  for (param in c('tas', 'pr', 'psl')[2]) {
    GCMs.AC.all <- NULL; GCMs.trend.all <- NULL; GCMs.AM.all <- NULL
    for (rcp in c('rcp45', 'ssp245')) {
      output <- paste0('GCMsACAM.', param, '.', rcp, '.', region, '.rda')
      load(output)
      if (is.null(GCMs.AC.all)) {GCMs.AC.all <- GCMs.AC; GCMs.AC.all$era5 <- NULL} else
        GCMs.AC.all <- c(GCMs.AC.all, GCMs.AC)
      if (is.null(GCMs.trend.all)) {GCMs.trend.all <- GCMs.trend; GCMs.trend.all$era5 <- NULL} else
        GCMs.trend.all <- c(GCMs.trend.all, GCMs.trend)
      if (is.null(GCMs.AM.all)) {GCMs.AM.all <- GCMs.AM; GCMs.AM.all$era5 <- NULL} else
        GCMs.AM.all <- c(GCMs.AM.all, GCMs.AM)
    }
    GCMs.AC.all -> GCMs.AC; rm('GCMs.AC.all')
    GCMs.trend.all -> GCMs.trend; rm('GCMs.trend.all')
    GCMs.AM.all -> GCMs.AM

## Exclude known bad data
if (length(bad.data) > 0) {

```

```

for (bad in bad.data) {GCMs.AC[[bad]] <- NULL; GCMs.AM[[bad]] <- NULL; GCMs.trend[[bad]] <- NULL}
}

if (region==regions[1]) print(names(GCMs.AC))

## Fix problems
n <- length(GCMs.AC)
m <- length(GCMs.AM)
for (i in 1:n) attr(GCMs.AC[[i]], 'source') <- names(GCMs.AC)[i]
for (i in 1:m) attr(GCMs.AM[[i]], 'source') <- names(GCMs.AM)[i]

## CIESM_ssp245_r1i1p1f1 seems to have units of m rather than mm
if (param=='pr') {
  for (i in 1:n) {
    if (max(GCMs.AC[[i]]) < 1) GCMs.AC[[i]] <- 1000*GCMs.AC[[i]]
  }
}

## Show the CMIP5 and CMIP56 with different colours
col <- names(GCMs.AC)
col <- col[grep('rcp|ssp', col)]
col[grep('rcp', col)] <- 'brown'; col[grep('ssp', col)] <- 'darkgreen'
print(table(col))
ngcms <- length(col)

## Use common EOFs of mean annual cycle to compare the GCMs' ability to reproduce the
## mean annual cycle with that seen in the ERA5 reanalysis
ceof.ac <- EOF.GCMsAC(GCMs.AC)

## Estimate ensemble mean and standard deviation for plotting
pc1.ac <- matrix(rep(NA, 12*ngcms), 12, ngcms); pc2.ac <- pc1.ac
for (i in 1:ngcms) {
  pc1.ac[,i] <- attr(ceof.ac, paste0('appendix.', i))[,1]
  pc2.ac[,i] <- attr(ceof.ac, paste0('appendix.', i))[,2]
}

if (plot) {
  par(par0)
  plot(ceof.ac, col=col, alpha=0.2, new=FALSE)
  par(par0)
  plot(ceof.ac, col=col, alpha=0.5, ip=2, new=FALSE)
}

## Scalar metric: Use variance-weighted (eigenvalues) sum of RMSE of the PCs wrt ERA5
w.rmse <- RMSE.AC.CEOF(ceof.ac)
## Table of ranking
## Generate table for LaTeX document:
write.table(w.rmse, sep=' & ', eol = '\\\\ \n', quote = FALSE)

## Mann-Witney (two-sample Wilcoxon test) U-test?
cmip5 <- grep('rcp', names(w.rmse))
cmip6 <- grep('ssp', names(w.rmse))
print(wilcox.test(w.rmse[cmip6], w.rmse[cmip5], alternative='less'))

```

```

## Use common EOFs of annually aggregated data to compare the interannual variability
## simulated by GCMs with the ERA5 reanalysis

for (is in seasons) {
  print(paste('Season',is))
  am.names <- names(GCMs.AM.all)
  if (is!='annual') keep <- am.names[grepl(is,am.names)] else
    keep <- am.names[-grepl('djf|mam|jja|son',am.names)]
  GCMs.AM <- GCMs.AM.all[keep]

  ceof.am <- EOF.GCMsAM(GCMs.AM)
  if (plot) {
    par(par0)
    plot(ceof.am,col=col,alpha=0.3,new=FALSE)
    par(par0)
    plot(ceof.am,col=col,alpha=0.3,ip=2,new=FALSE)
  }

  ## Evaluation of the annual mean results in terms of how observations rank within the ensemble PC
  par(par0)
  eval.am <- evalGCMsAM(ceof.am,col)
  plot(eval.am[[1]]$mids,(eval.am[[1]]$density),type='l',lwd=1,col='brown',lty=2,main='Obs-ensemble')
  lines(eval.am[[2]]$mids,(eval.am[[2]]$density),type='l',lwd=1,col='darkgreen')
  grid()
  for (i in 1:300) {
    lines(eval.am[[1]]$mids,attr(eval.am[[1]],'Monte-Carlo null.distribution')[i],type='l',lty=2,col='brown')
    lines(eval.am[[2]]$mids,attr(eval.am[[2]],'Monte-Carlo null.distribution')[i],type='l',lty=2,col='darkgreen')
  }
  lines(eval.am[[1]]$mids,(eval.am[[1]]$density),type='l',lwd=3,lty=2,col='brown')
  lines(eval.am[[2]]$mids,(eval.am[[2]]$density),type='l',lwd=3,col='darkgreen')

  ## Testing the distribution of trend statistics using Kolmogorov-Smirnov Test
  rank.test.CMIP5 <- ks.test(eval.am$rank.CMIP5,'punif')
  rank.test.CMIP6 <- ks.test(eval.am$rank.CMIP6,'punif')
  print("rank.test.CMIP5"); print(rank.test.CMIP5)
  print("rank.test.CMIP6"); print(rank.test.CMIP6)

  ## Check to see if the data is normally distributed
  qqnorm(eval.am$CMIP5[,length(eval.am$CMIP5[,1])],main='CMIP5')
  grid()
  qqline(eval.am$CMIP5[,length(eval.am$CMIP5[,1])])

  qqnorm(eval.am$CMIP6[,length(eval.am$CMIP6[,1])],main='CMIP6')
  grid()
  qqline(eval.am$CMIP6[,length(eval.am$CMIP6[,1])])
}

## Use EOFs of trend maps to assess the trends in the GCMs:
Z <- list2field(GCMs.trend,plot=plot)
n <- length(attr(Z,'ID'))
col <- attr(Z,'ID')

```



```

col <- col[grep('rcp|ssp|era5',attr(Z,'ID'))]
col[grep('rcp',col)] <- 'brown'; col[grep('ssp',col)] <- 'darkgreen'
col[grep('era5',col)] <- 'black'
teof <- EOF(Z,anomaly=FALSE)
n <- dim(teof)[1]
if (plot) {
  par(par0)
  plot(teof,new=FALSE)
  ## Add a point indicating the ERA5 trends
  par(fig=c(0.05,1,0.025,0.475),mar=c(3,3,2,2),new=TRUE)
  lines((1:n)[is.element(col,'brown')],teof[is.element(col,'brown'),1],col='brown',lty=2,lwd=1)
  lines((1:n)[is.element(col,'darkgreen')],teof[is.element(col,'darkgreen'),1],col='darkgreen',lwd=1)
  points((1:n)[is.element(col,'black')],teof[(1:n)[is.element(col,'black')],1],col='black',cex=1.5,
  par(par0)
  plot(teof,ip=2,new=FALSE)
  ## Add a point indicating the ERA5 trends
  par(fig=c(0.05,1,0.025,0.475),mar=c(3,3,2,2),new=TRUE)
  lines((1:n)[is.element(col,'brown')],teof[is.element(col,'brown'),2],col='brown',lty=2,lwd=1)
  lines((1:n)[is.element(col,'darkgreen')],teof[is.element(col,'darkgreen'),2],col='darkgreen',lwd=1)
  points((1:n)[is.element(col,'black')],teof[(1:n)[is.element(col,'black')],2],col='black',cex=1.5,
}

## Another way to evaluate is with a scatterplot of the PCs of the two leading modes:
tnms <- names(GCMs.trend); tnms <- tnms[grep('annual',tnms)]
print(tnms)
icmip5 <- grep('rcp',tnms)
icmip6 <- grep('ssp',tnms)
if (plot) {
  par(par0)
  plot(teof[,1],teof[,2],xlab='Mode 1',ylab='Mode2');
  points(teof[n,1],teof[n,2],pch=19,col='black',cex=1.5);
  points(teof[icmip5,1],teof[icmip5,2],col='red',lwd=2)
  points(teof[icmip6,1],teof[icmip6,2],col='blue',lwd=2)
  text(teof[-n,1],teof[-n,2],1:(n-1),cex=0.6,col='grey40',pos=1)
}
}
}

```

Mean seasonal cycle in PR The leading common EOF for the mean seasonal cycle of total precipitation (PR) explains 71% of the variance and is dominated by the rainfall along the west coast of Norway. The GCMs seem to reproduce the same feature, with more pronounced rainfall in autumn and winter. The simulated amplitude varies somewhat between the GCMs, but they more or less reproduce the same covariance structure found in the ERA5 reanalysis. The blue curves clustered more tightly around the black ERA5 results, also indicating improved skill over the CMIP5 results.

The second mode for the mean annual cycle represents about 15% of the variance of a precipitation pattern that is more uniform over the Nordic region land, and is associated with a peak in July-September. The exact timing of this peak, which may be associated with convective activity, varies somewhat between the GCMs. However, they all approximately reproduce the features found in ERA5.

In general, the blue curves are closer to the black ERA5, however, there are also some that deviate with lower weights during summer. The red curves representing CMIP5 are more systematically on the lower side in summer than CMIP6. The second mode has a character that can be associated with convective activity, and these results may suggest that the CMIP6 simulations are more skillful at simulating the seasonal variations

in precipitation over the Nordic countries.

The ranking of the CMIP simulations is based on common EOF analysis of the PR mean annual cycle. A Wilcoxon rank sum test applied to the RMSE scored for the leading PC of the common EOFs for the mean annual cycle in PR and the results suggests that the improvement of CMIP6 simulations over CMIP5 was statistically significant at the 5% level.

Annually and seasonally aggregated PR The spatio-temporal covariance structure for the annual precipitation, a predictor for interannual precipitation, is well captured by all GCMs. The leading mode (27% of the variance) was dominated by the hotspot along the west coast of Norway whereas the second mode (17%) captured a region stretching from southern Norway and Sweden and extends into the Baltic Sea. This second mode may represent rainfall connected with low-pressure systems traveling into the Baltic Sea. Both red and blue curves clustered around the black curve with similar amplitudes and trend in terms of the first mode and slightly reduced amplitude for the second mode.

The leading PC weights for annual PR for 2021 is close to being normally distributed for both CMIP5 and CMIP6.

The summer mean PR differed from the annual, winter and spring-time variability with more pronounced action over the Baltic countries in mode 1 (19%), most likely associated with convective activity. However, the second mode (15%) described strongest action over the Norwegian West coast.

Spatial trend maps The spread in the trend of the 1959-2021 annual precipitation totals suggests greatest spread between the models along the west and northern coast of Norway. An EOF analysis of these trend maps reconfirms this pattern (71% of the variance), but does not suggest features of different characters in some models, as was the case for TAS. The second mode of the annual total PR trend maps explains 10% of the variance and picks up the contrasting PR statistics along the west coast of Norway and the rest of the Nordic region.

A scatter plot of the PCs of the two leading modes suggested that the GCM results for PR are slightly biased compared with those based on ERA5 (black symbol in the scatter plot), albeit with most GCMs shifted towards lower values for the leading mode. Both CMIP5 and CMIP6 are biased, and one CMIP6 is a lone outlier. The scatter of the CMIP6 second mode points is centered more around the ERA5 results than the CMIP5 results which generally are biased towards greater values.

Robustness with respect to choice of region Different regions give similar results with some variations. For instance, a larger domain reduced the difference between the first and second eigenvalues. The rank metric is generally uniformly distributed, suggesting that ERA5 and the CMIP ensembles belong to the same statistical populations. Also, the PR aggregated for 2021 also seems to be more or less normally distributed. When it comes to the common EOFs applied to trend maps, the results suggest that both CMIP ensembles tend to be a bit biased even if they are not inconsistent with the ERA5 data. For some regions, the difference in the RMSE scores for the mean seasonal cycle was not statistically significant at the 5%-level. The spatial patterns also varied with choice of region.

The results for the distinct Barents region with an emphasis on the maritime climate and the Barents Sea indicates pronounced variability over the Greenland-Iceland-Norwegian Sea where low-pressure systems (mid-latitude cyclones) are more frequent. The leading mode accounts for 66% of the variance. The spatial pattern for the second common EOF (23%) indicates stronger covariance over the surrounding land areas. The difference in RMSE scores for the mean seasonal cycle in PR is not statistically significant at the 5%-level for this region.

Mean sea-level pressure (PSL)

```
##-----  
## Diagnostics  
  
regions <- sub('.rda','',sub('GCMsACAM.tas.ssp245.','',list.files(pattern = 'GCMsACAM.tas.ssp245.')))  
seasons <- c('annual','djf','mam','jja','son')  
  
for (region in regions) {  
  for (param in c('tas', 'pr', 'psl')[3]) {  
    GCMs.AC.all <- NULL; GCMs.trend.all <- NULL; GCMs.AM.all <- NULL  
    for (rcp in c('rcp45','ssp245')) {  
      output <- paste0('GCMsACAM.',param,'.',rcp,'.',region,'.rda')  
      load(output)  
      if (is.null(GCMs.AC.all)) {GCMs.AC.all <- GCMs.AC; GCMs.AC.all$era5 <- NULL} else  
        GCMs.AC.all <- c(GCMs.AC.all,GCMs.AC)  
      if (is.null(GCMs.trend.all)) {GCMs.trend.all <- GCMs.trend; GCMs.trend.all$era5 <- NULL} else  
        GCMs.trend.all <- c(GCMs.trend.all,GCMs.trend)  
      if (is.null(GCMs.AM.all)) {GCMs.AM.all <- GCMs.AM; GCMs.AM.all$era5 <- NULL} else  
        GCMs.AM.all <- c(GCMs.AM.all,GCMs.AM)  
    }  
    GCMs.AC.all -> GCMs.AC; rm('GCMs.AC.all')  
    GCMs.trend.all -> GCMs.trend; rm('GCMs.trend.all')  
    GCMs.AM.all -> GCMs.AM  
  
    ## Exclude known bad data  
    if (length(bad.data) > 0) {  
      for (bad in bad.data) {GCMs.AC[[bad]] <- NULL; GCMs.AM[[bad]] <- NULL; GCMs.trend[[bad]] <- NULL}  
    }  
  
    if (region==regions[1]) print(names(GCMs.AC))  
  
    ## Fix problems  
    n <- length(GCMs.AC)  
    m <- length(GCMs.AM)  
    for (i in 1:n) attr(GCMs.AC[[i]],'source') <- names(GCMs.AC)[i]  
    for (i in 1:m) attr(GCMs.AM[[i]],'source') <- names(GCMs.AM)[i]  
  
    ## CIESM_ssp245_r1i1p1f1 seems to have units of m rather than mm  
    if (param=='pr') {  
      for (i in 1:n) {  
        if (max(GCMs.AC[[i]]) < 1) GCMs.AC[[i]] <- 1000*GCMs.AC[[i]]  
      }  
    }  
  
    ## Show the CMIP5 and CMIP56 with different colours  
    col <- names(GCMs.AC)  
    col <- col[grep('rcp|ssp',col)]  
    col[grep('rcp',col)] <- 'brown'; col[grep('ssp',col)] <- 'darkgreen'  
    print(table(col))  
    ngcms <- length(col)  
  
    ## Use common EOFs of mean annual cycle to compare the GCMs' ability to reproduce the
```

```

## mean annual cycle with that seen in the ERA5 reanalysis
ceof.ac <- EOF.GCMsAC(GCMs.AC)

## Estimate ensemble mean and standard deviation for plotting
pc1.ac <- matrix(rep(NA,12*ngcms),12,ngcms); pc2.ac <- pc1.ac
for (i in 1:ngcms) {
  pc1.ac[,i] <- attr(ceof.ac,paste0('appendix.',i))[,1]
  pc2.ac[,i] <- attr(ceof.ac,paste0('appendix.',i))[,2]
}

if (plot) {
  par(par0)
  plot(ceof.ac,col=col,alpha=0.2,new=FALSE)
  par(par0)
  plot(ceof.ac,col=col,alpha=0.5,ip=2,new=FALSE)
}

## Scalar metric: Use variance-weighted (eigenvalues) sum of RMSE of the PCs wrt ERA5
w.rmse <- RMSE.AC.CEOF(ceof.ac)
## Table of ranking
## Generate table for LaTeX document:
write.table(w.rmse,sep=' & ', eol = '\\\\ \n', quote = FALSE)

## Mann-Witney (two-sample Wilcoxon test) U-test?
cmip5 <- grep('rcp',names(w.rmse))
cmip6 <- grep('ssp',names(w.rmse))
print(wilcox.test(w.rmse[cmip6],w.rmse[cmip5],alternative='less'))

## Use common EOFs of annually aggregated data to compare the interannual variability
## simulated by GCMs with the ERA5 reanalysis

for (is in seasons) {
  print(paste('Season',is))
  am.names <- names(GCMs.AM.all)
  if (is!='annual') keep <- am.names[grep(is,am.names)] else
    keep <- am.names[-grep('djf|mam|jja|son',am.names)]
  GCMs.AM <- GCMs.AM.all[keep]

  ceof.am <- EOF.GCMsAM(GCMs.AM)
  if (plot) {
    par(par0)
    plot(ceof.am,col=col,alpha=0.3,new=FALSE)
    par(par0)
    plot(ceof.am,col=col,alpha=0.3,ip=2,new=FALSE)
  }

  ## Evaluation of the annual mean results in terms of how observations rank within the ensemble PC
  par(par0)
  eval.am <- evalGCMsAM(ceof.am,col)
  plot(eval.am[[1]]$mids,(eval.am[[1]]$density),type='l',lwd=1,lty=2,col='brown',main='Obs-ensemble')
  lines(eval.am[[2]]$mids,(eval.am[[2]]$density),type='l',lwd=1,col='darkgreen')
  grid()
  for (i in 1:300) {

```

```

    lines(eval.am[[1]]$mids,attr(eval.am[[1]],'Monte-Carlo null.distribution')[,i],type='l',lty=2,col='brown')
    lines(eval.am[[2]]$mids,attr(eval.am[[2]],'Monte-Carlo null.distribution')[,i],type='l',lty=2,col='darkgreen')
  }
  lines(eval.am[[1]]$mids,(eval.am[[1]]$density),type='l',lwd=3,lty=2,col='brown')
  lines(eval.am[[2]]$mids,(eval.am[[2]]$density),type='l',lwd=3,col='darkgreen')

  ## Testing the distribution of trend statistics using Kolmogorov-Smirnov Test
  rank.test.CMIP5 <- ks.test(eval.am$rank.CMIP5,'punif')
  rank.test.CMIP6 <- ks.test(eval.am$rank.CMIP6,'punif')
  print("rank.test.CMIP5"); print(rank.test.CMIP5)
  print("rank.test.CMIP6"); print(rank.test.CMIP6)

  ## Check to see if the data is normally distributed
  qqnorm(eval.am$CMIP5[,length(eval.am$CMIP5[,1])],main='CMIP5')
  grid()
  qqline(eval.am$CMIP5[,length(eval.am$CMIP5[,1])])

  qqnorm(eval.am$CMIP6[,length(eval.am$CMIP6[,1])],main='CMIP6')
  grid()
  qqline(eval.am$CMIP6[,length(eval.am$CMIP6[,1])])
}

## Use EOFs of trend maps to assess the trends in the GCMs:
Z <- list2field(GCMs.trend,plot=plot)
n <- length(attr(Z,'ID'))
col <- attr(Z,'ID')
col <- col[grep('rcp|ssp|era5',attr(Z,'ID'))]
col[grep('rcp',col)] <- 'brown'; col[grep('ssp',col)] <- 'darkgreen'
col[grep('era5',col)] <- 'black'
teof <- EOF(Z,anomaly=FALSE)
n <- dim(teof)[1]
if (plot) {
  par(par0)
  plot(teof,new=FALSE)
  ## Add a point indicating the ERA5 trends
  par(fig=c(0.05,1,0.025,0.475),mar=c(3,3,2,2),new=TRUE)
  lines((1:n)[is.element(col,'brown')],teof[is.element(col,'brown'),1],col='brown',lty=2,lwd=1)
  lines((1:n)[is.element(col,'darkgreen')],teof[is.element(col,'darkgreen'),1],col='darkgreen',lwd=1)
  points((1:n)[is.element(col,'black')],teof[(1:n)[is.element(col,'black')],1],col='black',cex=1.5)
  par(par0)
  plot(teof,ip=2,new=FALSE)
  ## Add a point indicating the ERA5 trends
  par(fig=c(0.05,1,0.025,0.475),mar=c(3,3,2,2),new=TRUE)
  lines((1:n)[is.element(col,'brown')],teof[is.element(col,'brown'),2],col='brown',lty=2,lwd=1)
  lines((1:n)[is.element(col,'darkgreen')],teof[is.element(col,'darkgreen'),2],col='darkgreen',lwd=1)
  points((1:n)[is.element(col,'black')],teof[(1:n)[is.element(col,'black')],2],col='black',cex=1.5)
}

## Another way to evaluate is with a scatterplot of the PCs of the two leading modes:
tnms <- names(GCMs.trend); tnms <- tnms[grep('annual',tnms)]
print(tnms)
icmip5 <- grep('rcp',tnms)

```

```

icmip6 <- grep('ssp',tnms)
if (plot) {
  par(par0)
  plot(teof[,1],teof[,2],xlab='Mode 1',ylab='Mode2');
  points(teof[n,1],teof[n,2],pch=19,col='black',cex=1.5);
  points(teof[icmip5,1],teof[icmip5,2],col='red',lwd=2)
  points(teof[icmip6,1],teof[icmip6,2],col='blue',lwd=2)
  text(teof[-n,1],teof[-n,2],1:(n-1),cex=0.6,col='grey40',pos=1)
}
}
}

```

Mean seasonal cycle in PSL The evaluation of the mean seasonal cycle in PSL shows a pattern of a northwest-southeast gradient accounting for 86% of the variance. As with TAS and PR, the CMIP6 simulations (darkgreen curves) follow that of ERA5 (black) more closely than the CMIP5, indicating an improvement. All the CMIP results nevertheless reproduce the observed statistics, which can be explained by seasonal dependency of the cyclonic activity over the Norwegian Sea (low-pressures systems are most pronounced in winter), with some skill.

The second mode for the annual PSL cycle describes a west-east gradient pattern associated with 8% of the variance. A Wilcoxon rank sum test on the RMSE scores based on PC1 of the mean seasonal cycle for CMIP5 and CMIP6 respectively suggests that the CMIP6 ensemble represent an improvement over CMIP5 with a p-value of 0.0006.

Annually and seasonall mean PSL The interannual variability in PSL suggests a nexus of action over northern Fennoscandia, and all CMIP simulations more or less reproduced its amplitude. There is little trend to discern in the leading mode that was associated with 62% of the variance. The second mode is associated with 16% representing an southwest-northeast gradient (probably a degenerate mode as it has similar value for its eigenvalue as the third mode). The model simulations reproduces this pattern with similar amplitude as ERA5.

Trend maps The trend analysis indicates greatest model spread in the north and least in the south. An EOF analysis of the annual PSL trend maps indicates a negative bias (85% of the variance), and the pattern bear some resemblance to the trends in TAS. The second mode (9%) represents a southwest-northeast gradient. A scatter-plot of the PCs of these EOFs suggest that ERA5 is well within the scatter of data points from the CMIP simulations.

The ranking of the CMIP simulations was based on common EOF analysis of the PSL mean annual cycle. A Wilcoxon rank sum test was applied to the RMSE scored for the leading PC of the common EOFs for the mean annual cycle in PSL and the results suggested that the improvement of CMIP6 simulations over CMIP5 was statistically significant at the 5% level.

Robustness with respect to different regions Repeating the common EOF analysis on other regions does not change the conclusions, even though there are some variations in the details.

For the distinct Barents region, the common EOF for seasonal mean cycle in the PSL exhibits the fingerprint of the mid-latitude storm-tracks. The CMIP6 ensemble represents a significant improvement over CMIP5 with a p-value of 3.8×10^{-5} . However, the main action for the whole year is south of Franz Josef Land and central Barents Sea. A similar pattern of action is seen on an annual basis and in each season, although not at exactly the same spot, indicating a distinct structure between the mean seasonal variability and interannual variability.

```
## Same type of distribution:
print(ks.test(runif(1000), 'punif'))
```

```
##
## Asymptotic one-sample Kolmogorov-Smirnov test
##
## data: runif(1000)
## D = 0.026919, p-value = 0.4634
## alternative hypothesis: two-sided
```

```
## Different types of distributions:
print(ks.test(rnorm(1000), 'punif'))
```

```
##
## Asymptotic one-sample Kolmogorov-Smirnov test
##
## data: rnorm(1000)
## D = 0.50451, p-value < 2.2e-16
## alternative hypothesis: two-sided
```

```
print(ks.test(rexp(1000), 'punif'))
```

```
##
## Asymptotic one-sample Kolmogorov-Smirnov test
##
## data: rexp(1000)
## D = 0.377, p-value < 2.2e-16
## alternative hypothesis: two-sided
```

R-script pulling CMIP data from ESGF

The following R-script was used to download and prepare netCDF files with CMIP6 data from the Earth System Grid Federation (ESGF). It was designed to get metadata about GCMs and only download GCM results which are not already stored on the local disk.

```
## CMIP6 data
## @RasmusBenestad, 2021-04-16
## This script competes incomplete CMIP6 data from Earth System Grid Federation (ESGF)
## this is used to download historical files and add them to existing scenarios
## CDO: <https://www.unidata.ucar.edu/software/netcdf/workshops/2012/third\_party/CDO.html>

library(esd)
## Get the latest metadata from ESGF

## Function to check the time period covered
getinterval <- function(file, param='tas', verbose=FALSE) {
  if (!file.exists(file)) return(NULL)
  ncid <- nc_open(file)
  time <- check.ncdf4(ncid, param=param, verbose=verbose)$time
  nc_close(ncid)
  print(range(time$vdate))
}
```

```

    return(time$vdate)
}

## Function to split the CMIP file names into model, ssp and RIPF
decipher <- function(x) {
  i <- gregexpr('_',x)[[1]]
  model <- substr(x,i[2]+1,i[3]-1)
  ssp <- substr(x,i[3]+1,i[4]-1)
  ripf <- substr(x,i[4]+1,i[4]+8)
  interval <- substr(x,i[5]+1,regexpr('.nc',x)[[1]]-1)
  return(c(model,ssp,ripf,interval))
}

## Function that makes sure that the files are organised from south to north along their latitude axis
s2n <- function(file) {
  ncid <- nc_open(file)
  lats <- ncvarget(ncid,'lat')
  nc_close(ncid)
  n <- length(lats)
  if (lats[n] < lats[1]) {
    system(paste('cdo invertlat',file,'out.nc'))
    file.remove(file)
    file.rename('out.nc',file)
  }
}

url <- "https://esgf-data.dkrz.de/esg-search/search/"

overwrite <- FALSE
expids <- c("ssp245","ssp370","ssp126","ssp585","ssp119")
params <- c("tas","psl","pr")
lon <- NULL; lat <- NULL
localpath <- '~/data/CMIP/CMIP6.monthly/'
print(paste('cmip6download-CDO.R - URF for ESGF=',url,'Local path=',localpath))

## Skip simulations that cause problems:
#skip <- c("tas_Amon_BCC-ESM1_ssp370_r2i1p1f1.nc","tas_Amon_BCC-ESM1_ssp370_r3i1p1f1.nc")
#skip <- c("tas_Amon_EC-Earth3_ssp370_r13i1p1f1.nc","tas_Amon_EC-Earth3_ssp370_r132i1p1f1.nc","tas_Amon_EC-Earth3_ssp370_r134i1p1f1.nc")
#skip <- c("tas_Amon_IPSL-CM6A-LR_ssp370_r10i1p1f1.nc")
skip <- c()
system('rm tmp.cmip6.*.nc',ignore.stdout = TRUE, ignore.stderr = TRUE)
## Loop through the SSPs
for (expid in expids) {
  ## Set the path for a file structure similar to the KNMI ClimateExplorer that works with DSensemble
  path <- paste0(localpath,expid)
  if (!dir.exists(path)) dir.create(path)
  print(paste('Downloading new CMIP files from ESGF into ',path))

  ## Loop through the parameters
  for (param in params) {
    metafname <- paste('meta',expid,param,as.Date(Sys.time()),'rda',sep='.')
    print(paste('Retrieving ESGF metadata and saving in',metafname))
  }
}

```



```

## Get the ESGF metadata on the CMIP6 runs
if (!file.exists(metafname)) {
  meta <- meta.ESGF(url=url,param=param,expid = expid)
  save(meta,file=metafname)
} else {
  print(paste('Found',metafname))
  load(metafname)
}
M <- dim(meta)[1]
print(table(meta$period))

if (!is.null(meta)) {
  print(meta$title)

  ## Extract the different simulations - there may be repeated ones in several chunks
  simulations <- rownames(table(paste(param,'Amon',meta$model,expid,meta$member.id,sep='_')))
  #MODS <- rownames(table(paste(meta$model,expid,meta$member.id,sep='_')))
  MODS <- rownames(table(paste(meta$model,expid,meta$member.id,sep='_')))
  models <- paste(meta$model,expid,meta$member.id,sep='_')
  n <- length(MODS)
  print(paste('Download',n,'model simulations for',expid,'and',param))
  downloaded <- list.files(path=path,pattern=paste0(param,'_Amon'))
  if (length(downloaded)==0) overwrite <- TRUE ## If the catalog is new, then download all
  for (i in 1:n) {
    print(MODS[i])
    imatch <- regexpr(simulations[i],c(downloaded,skip))
    ## Check if the file has already been downloaded - if it is, skip the download unless overwrite
    if ( (sum(imatch > 0)==0) | (overwrite) ) {
      #i1 <- regexpr(MODS[i],models)
      #ims <- (1:length(models))[i1 > 0]
      ims <- c(grep(sub(expid,'historical',paste0(param,'_Amon_*',MODS[i])),meta$title),
               grep(paste0(param,'_Amon_*',MODS[i]),meta$title))
      print(meta$title[ims])
      print(paste('i=',i,'of',n,'runs in',expid,'run=',simulations[i]))
      print(decipher(simulations[i]))
      print(paste(ims,c("model=","ssp=","ripf=","interval="), collapse=', '))
      ## Try to find the true timeinterval of the files
      trueinterval <- c()
      for (ii in 1:length(ims)) {
        print(meta$model[ims[ii]])
        ## Download the netCDF files for the same model and ripf from the remote ESGF repository
        tmpfile <- paste0('tmp.cmip6.',ii,'.nc')
        file.selection <- meta$http[ims[ii]]
        ## Add a layer of filter to ensure that no 'tas_ImonAnt' or 'ImonAnt' runs are included
        file.selection <- file.selection[grep(paste0(param,'_Amon_'),file.selection)]
        test <- try(download.file(file.selection,tmpfile))
        if (tolower(substr(test,1,5))=="error") system('rm tmp.cmip6.*.nc') else
          yrs <- try(year(getinterval(tmpfile,param)))
        if (!inherits(yrs,'try-error'))
          trueinterval <- try(range(year(c(trueinterval,getinterval(tmpfile,param)))))
      }
      ## Show files that have been downloaded
      file.segments <- list.files(pattern='tmp.cmip6.')
    }
  }
}

```

```

print(file.segments)
if (is.null(trueinterval)) trueinterval <- c(NA,NA)
print(paste('Time period covered:',paste(trueinterval,sollapse='-')))
##if (tolower(substr(test,1,5))=="error") print(paste('Error: Skip',file.selection)) else {
if (length(file.segments)==0) print(paste('Error: Skip',simulations[i])) else {
  ncname <- paste0(paste(param,'Amon',MODS[i],paste(trueinterval,collapse='-'),sep='_'),'.nc')
  print(paste('Last past - save results in ',file.path(path,ncname)))
  for (file.seg in file.segments) s2n(file.seg) ## Make sure the data is ordered from south
  ## Combine the chunks:
  if (length(ims)>1) system(paste('cdo -O mergetime tmp.cmip6.*.nc ',file.path(path,ncname)))
  if (length(ims)==1) file.rename(tmpfile,file.path(path,ncname))
  ## Clean up the temporary files:
  system('rm tmp.cmip6.*.nc')
  ## Fix bad time intervals
  tim <- getinterval(file.path(path,ncname),param)
  nstr <- decipher(ncname)
  datafraction <- (max(year(tim))-min(year(tim)))
  cperiod <- paste(range(year(tim)),collapse='-')
  newname <- sub(nstr[4],cperiod,ncname)
  print(paste('rename ',ncname,newname))
  file.rename(file.path(path,ncname),file.path(path,newname))
}
} else (print(paste('Skipping',i,' - already downloaded',simulations[i])))
}
} else {
  print(paste('----- Empty metadata',metafname,'-----'))
}
}
}
}

```

Test with bad data

The common EOF framework was tested with ‘bad’ data where the ERA5 data were replaced by ERA5 precipitation PR whereas the GCM data were surface air temperature TAS. This is an artificial situation where we expect a failure of the ensemble to reproduce the ‘observations’.

```

##-----
## Diagnostics of mixed PR and TAS to simulate bad match

region <- sub('.rda','',sub('GCMsACAM.tas.ssp245.','',list.files(path='~/R',pattern = 'GCMsACAM.tas.ssp'))
season <- 'annual'

GCMs.AM.bad <- NULL
rcp <- 'ssp245'
for (param in c('tas', 'pr')) {
  output <- paste0('~/R/GCMsACAM.',param, '.',rcp, '.',region, '.rda')
  load(output)
  if (param=='tas') GCMs.AM.bad <- GCMs.AM else GCMs.AM.bad$era5 <- 0.01*GCMs.AM$era
}

m <- length(GCMs.AM.bad)
for (i in 1:m) attr(GCMs.AM.bad[[i]],'source') <- names(GCMs.AM)[i]

```

```
## Show the CMIP5 and CMIP56 with different colours
```

```
col <- names(GCMs.AM.bad)
col <- col[grep('rcp|ssp',col)]
col[grep('ssp',col)] <- 'darkgreen'
print(table(col))
```

```
## col
## darkgreen
##      200
```

```
ngcms <- length(col)
```

```
ceof.am <- EOF.GCMsAM(GCMs.AM.bad)
```

```
## [1] "EOF.GCMsAM"
## [1] 200
## [1] "ACCESS-CM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.ACCESS-CM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -6 mm/month degC djf.ACCESS-CM2.ssp245.r1i1p1f1"
## [1] "mam.ACCESS-CM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.ACCESS-CM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.ACCESS-CM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "ACCESS-ESM1-5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.ACCESS-ESM1-5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -4 mm/month degC djf.ACCESS-ESM1-5.ssp245.r1i1p1f1"
## [1] "mam.ACCESS-ESM1-5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.ACCESS-ESM1-5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.ACCESS-ESM1-5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "AWI-CM-1-1-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.AWI-CM-1-1-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -3 mm/month degC djf.AWI-CM-1-1-MR.ssp245.r1i1p1f1"
## [1] "mam.AWI-CM-1-1-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.AWI-CM-1-1-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.AWI-CM-1-1-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "BCC-CSM2-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.BCC-CSM2-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
```

```

## [1] "combine.field detected scale issues - sx= 8 sy= -7 mm/month degC djf.BCC-CSM2-MR.ssp245.r1i1p1f1"
## [1] "mam.BCC-CSM2-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.BCC-CSM2-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.BCC-CSM2-MR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "CAMS-CSM1-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -1 mm/month degC CAMS-CSM1-0.ssp245.r1i1p1f1"
## [1] "djf.CAMS-CSM1-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -11 mm/month degC djf.CAMS-CSM1-0.ssp245.r1i1p1f1"
## [1] "mam.CAMS-CSM1-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -1 mm/month degC mam.CAMS-CSM1-0.ssp245.r1i1p1f1"
## [1] "jja.CAMS-CSM1-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.CAMS-CSM1-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "CanESM5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.CanESM5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -1 mm/month degC djf.CanESM5.ssp245.r1i1p1f1"
## [1] "mam.CanESM5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.CanESM5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.CanESM5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "CESM2-WACCM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.CESM2-WACCM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -3 mm/month degC djf.CESM2-WACCM.ssp245.r1i1p1f1"
## [1] "mam.CESM2-WACCM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= 0 mm/month degC mam.CESM2-WACCM.ssp245.r1i1p1f1"
## [1] "jja.CESM2-WACCM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.CESM2-WACCM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "CIESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.CIESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -2 mm/month degC djf.CIESM.ssp245.r1i1p1f1"
## [1] "mam.CIESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.CIESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.CIESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"

```

```

## [1] "CMCC-CM2-SR5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.CMCC-CM2-SR5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -1 mm/month degC djf.CMCC-CM2-SR5.ssp245.r1i1p1f1"
## [1] "mam.CMCC-CM2-SR5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.CMCC-CM2-SR5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.CMCC-CM2-SR5.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "CMCC-ESM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.CMCC-ESM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "mam.CMCC-ESM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.CMCC-ESM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.CMCC-ESM2.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "CNRM-CM6-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.CNRM-CM6-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -5 mm/month degC djf.CNRM-CM6-1.ssp245.r1i1p1f2"
## [1] "mam.CNRM-CM6-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.CNRM-CM6-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "son.CNRM-CM6-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "CNRM-CM6-1-HR.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.CNRM-CM6-1-HR.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -9 mm/month degC djf.CNRM-CM6-1-HR.ssp245.r1i1p1f2"
## [1] "mam.CNRM-CM6-1-HR.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -1 mm/month degC mam.CNRM-CM6-1-HR.ssp245.r1i1p1f2"
## [1] "jja.CNRM-CM6-1-HR.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "son.CNRM-CM6-1-HR.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "CNRM-ESM2-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.CNRM-ESM2-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -4 mm/month degC djf.CNRM-ESM2-1.ssp245.r1i1p1f2"
## [1] "mam.CNRM-ESM2-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= 0 mm/month degC mam.CNRM-ESM2-1.ssp245.r1i1p1f2"
## [1] "jja.CNRM-ESM2-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"

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## [1] "son.CNRM-ESM2-1.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "E3SM-1-1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.E3SM-1-1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -4 mm/month degC djf.E3SM-1-1.ssp245.r1i1p1f1"
## [1] "mam.E3SM-1-1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.E3SM-1-1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.E3SM-1-1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "EC-Earth3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= 0 mm/month degC EC-Earth3.ssp245.r1i1p1f1"
## [1] "djf.EC-Earth3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -9 mm/month degC djf.EC-Earth3.ssp245.r1i1p1f1"
## [1] "mam.EC-Earth3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -3 mm/month degC mam.EC-Earth3.ssp245.r1i1p1f1"
## [1] "jja.EC-Earth3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.EC-Earth3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "EC-Earth3-CC.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.EC-Earth3-CC.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -5 mm/month degC djf.EC-Earth3-CC.ssp245.r1i1p1f1"
## [1] "mam.EC-Earth3-CC.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.EC-Earth3-CC.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.EC-Earth3-CC.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "EC-Earth3-Veg.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.EC-Earth3-Veg.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -6 mm/month degC djf.EC-Earth3-Veg.ssp245.r1i1p1f1"
## [1] "mam.EC-Earth3-Veg.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -1 mm/month degC mam.EC-Earth3-Veg.ssp245.r1i1p1f1"
## [1] "jja.EC-Earth3-Veg.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.EC-Earth3-Veg.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "EC-Earth3-Veg-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.EC-Earth3-Veg-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -6 mm/month degC djf.EC-Earth3-Veg-LR.ssp245.r1i1p1f1"

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## [1] "mam.EC-Earth3-Veg-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -1 mm/month degC mam.EC-Earth3-Veg-LR.ssp245.r1i1p1f1"
## [1] "jja.EC-Earth3-Veg-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.EC-Earth3-Veg-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "FGOALS-f3-L.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.FGOALS-f3-L.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -7 mm/month degC djf.FGOALS-f3-L.ssp245.r1i1p1f1"
## [1] "mam.FGOALS-f3-L.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= 0 mm/month degC mam.FGOALS-f3-L.ssp245.r1i1p1f1"
## [1] "jja.FGOALS-f3-L.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.FGOALS-f3-L.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "FGOALS-g3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -2 mm/month degC FGOALS-g3.ssp245.r1i1p1f1"
## [1] "djf.FGOALS-g3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -14 mm/month degC djf.FGOALS-g3.ssp245.r1i1p1f1"
## [1] "mam.FGOALS-g3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -3 mm/month degC mam.FGOALS-g3.ssp245.r1i1p1f1"
## [1] "jja.FGOALS-g3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.FGOALS-g3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -2 mm/month degC son.FGOALS-g3.ssp245.r1i1p1f1"
## [1] "FIO-ESM-2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.FIO-ESM-2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -1 mm/month degC djf.FIO-ESM-2-0.ssp245.r1i1p1f1"
## [1] "mam.FIO-ESM-2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.FIO-ESM-2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.FIO-ESM-2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "GISS-E2-1-G.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= 0 mm/month degC GISS-E2-1-G.ssp245.r1i1p1f2"
## [1] "djf.GISS-E2-1-G.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -9 mm/month degC djf.GISS-E2-1-G.ssp245.r1i1p1f2"
## [1] "mam.GISS-E2-1-G.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -2 mm/month degC mam.GISS-E2-1-G.ssp245.r1i1p1f2"
## [1] "jja.GISS-E2-1-G.ssp245.r1i1p1f2"

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## [1] "Warning - different units: mm/month degC"
## [1] "son.GISS-E2-1-G.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "GISS-E2-1-H.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -2 mm/month degC GISS-E2-1-H.ssp245.r1i1p1f2"
## [1] "djf.GISS-E2-1-H.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -12 mm/month degC djf.GISS-E2-1-H.ssp245.r1i1p1f2"
## [1] "mam.GISS-E2-1-H.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -3 mm/month degC mam.GISS-E2-1-H.ssp245.r1i1p1f2"
## [1] "jja.GISS-E2-1-H.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "son.GISS-E2-1-H.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -2 mm/month degC son.GISS-E2-1-H.ssp245.r1i1p1f2"
## [1] "HadGEM3-GC31-LL.ssp245.r1i1p1f3"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.HadGEM3-GC31-LL.ssp245.r1i1p1f3"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -5 mm/month degC djf.HadGEM3-GC31-LL.ssp245.r1i1p1f3"
## [1] "mam.HadGEM3-GC31-LL.ssp245.r1i1p1f3"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.HadGEM3-GC31-LL.ssp245.r1i1p1f3"
## [1] "Warning - different units: mm/month degC"
## [1] "son.HadGEM3-GC31-LL.ssp245.r1i1p1f3"
## [1] "Warning - different units: mm/month degC"
## [1] "IITM-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.IITM-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -5 mm/month degC djf.IITM-ESM.ssp245.r1i1p1f1"
## [1] "mam.IITM-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.IITM-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.IITM-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "INM-CM4-8.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.INM-CM4-8.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -6 mm/month degC djf.INM-CM4-8.ssp245.r1i1p1f1"
## [1] "mam.INM-CM4-8.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.INM-CM4-8.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.INM-CM4-8.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "INM-CM5-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.INM-CM5-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"

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## [1] "combine.field detected scale issues - sx= 8 sy= -5 mm/month degC djf.INM-CM5-0.ssp245.r1i1p1f1"
## [1] "mam.INM-CM5-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.INM-CM5-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.INM-CM5-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "IPSL-CM6A-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.IPSL-CM6A-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -6 mm/month degC djf.IPSL-CM6A-LR.ssp245.r1i1p1f1"
## [1] "mam.IPSL-CM6A-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.IPSL-CM6A-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.IPSL-CM6A-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "KACE-1-0-G.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.KACE-1-0-G.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -7 mm/month degC djf.KACE-1-0-G.ssp245.r1i1p1f1"
## [1] "mam.KACE-1-0-G.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.KACE-1-0-G.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.KACE-1-0-G.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "KIOST-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.KIOST-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -6 mm/month degC djf.KIOST-ESM.ssp245.r1i1p1f1"
## [1] "mam.KIOST-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= 0 mm/month degC mam.KIOST-ESM.ssp245.r1i1p1f1"
## [1] "jja.KIOST-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.KIOST-ESM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "MCM-UA-1-0.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.MCM-UA-1-0.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -8 mm/month degC djf.MCM-UA-1-0.ssp245.r1i1p1f2"
## [1] "mam.MCM-UA-1-0.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= 0 mm/month degC mam.MCM-UA-1-0.ssp245.r1i1p1f2"
## [1] "jja.MCM-UA-1-0.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "son.MCM-UA-1-0.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "MIROC-ES2L.ssp245.r1i1p1f2"

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## [1] "Warning - different units: mm/month degC"
## [1] "djf.MIROC-ES2L.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -6 mm/month degC djf.MIROC-ES2L.ssp245.r1i1p1f2"
## [1] "mam.MIROC-ES2L.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.MIROC-ES2L.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "son.MIROC-ES2L.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "MIROC6.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.MIROC6.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -4 mm/month degC djf.MIROC6.ssp245.r1i1p1f1"
## [1] "mam.MIROC6.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.MIROC6.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.MIROC6.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "MPI-ESM1-2-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.MPI-ESM1-2-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -4 mm/month degC djf.MPI-ESM1-2-LR.ssp245.r1i1p1f1"
## [1] "mam.MPI-ESM1-2-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.MPI-ESM1-2-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.MPI-ESM1-2-LR.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "MRI-ESM2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.MRI-ESM2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -3 mm/month degC djf.MRI-ESM2-0.ssp245.r1i1p1f1"
## [1] "mam.MRI-ESM2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.MRI-ESM2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.MRI-ESM2-0.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "NESM3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.NESM3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -7 mm/month degC djf.NESM3.ssp245.r1i1p1f1"
## [1] "mam.NESM3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -2 mm/month degC mam.NESM3.ssp245.r1i1p1f1"
## [1] "jja.NESM3.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.NESM3.ssp245.r1i1p1f1"

```

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## [1] "Warning - different units: mm/month degC"
## [1] "NorESM2-LM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.NorESM2-LM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -3 mm/month degC djf.NorESM2-LM.ssp245.r1i1p1f1"
## [1] "mam.NorESM2-LM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.NorESM2-LM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.NorESM2-LM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "NorESM2-MM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.NorESM2-MM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -4 mm/month degC djf.NorESM2-MM.ssp245.r1i1p1f1"
## [1] "mam.NorESM2-MM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.NorESM2-MM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.NorESM2-MM.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "TaiESM1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.TaiESM1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -5 mm/month degC djf.TaiESM1.ssp245.r1i1p1f1"
## [1] "mam.TaiESM1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.TaiESM1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "son.TaiESM1.ssp245.r1i1p1f1"
## [1] "Warning - different units: mm/month degC"
## [1] "UKESM1-0-LL.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "djf.UKESM1-0-LL.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "combine.field detected scale issues - sx= 8 sy= -5 mm/month degC djf.UKESM1-0-LL.ssp245.r1i1p1f2"
## [1] "mam.UKESM1-0-LL.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "jja.UKESM1-0-LL.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "son.UKESM1-0-LL.ssp245.r1i1p1f2"
## [1] "Warning - different units: mm/month degC"
## [1] "Calculate EOF for joint dataset"

```

```

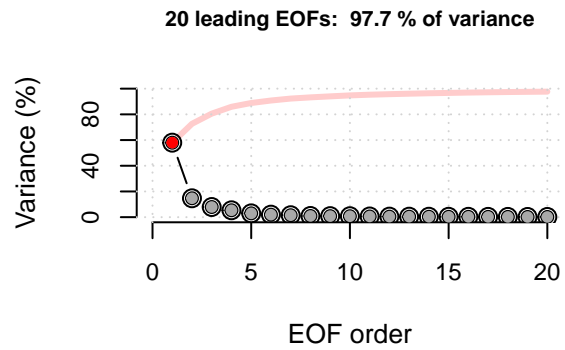
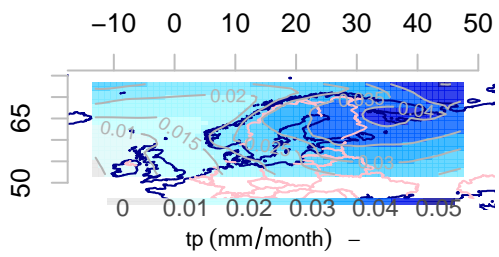
if (plot) {
  par(par0)
  plot(ceof.am,col=col,alpha=0.3,new=FALSE)
  par(par0)
  plot(ceof.am,col=col,alpha=0.3,ip=2,new=FALSE)
  par(par0)
  plot(ceof.am,col=col,alpha=0.3,ip=3,new=FALSE)
}

```

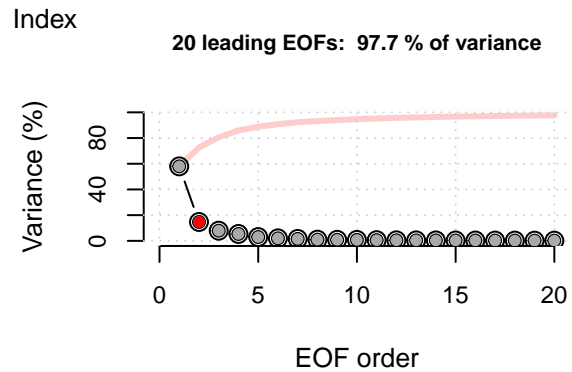
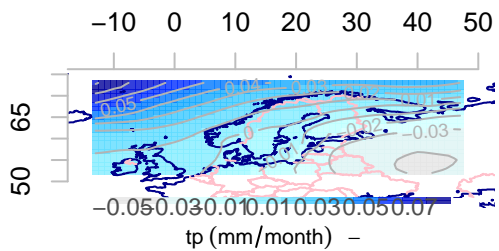
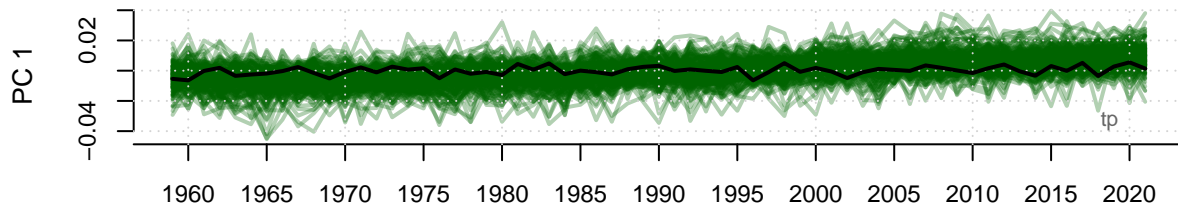
```

par(par0)
plot(ceof.am,col=col,alpha=0.3,ip=4,new=FALSE)
}

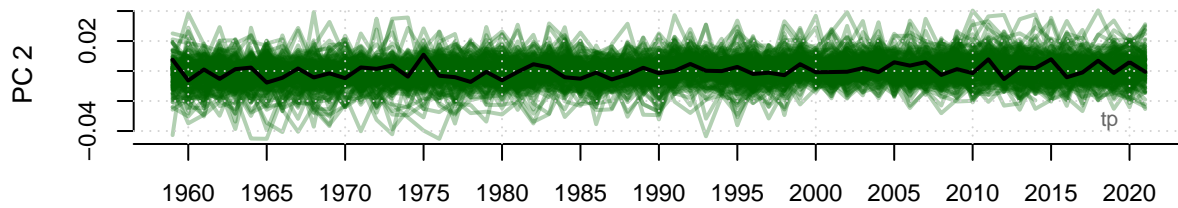
```



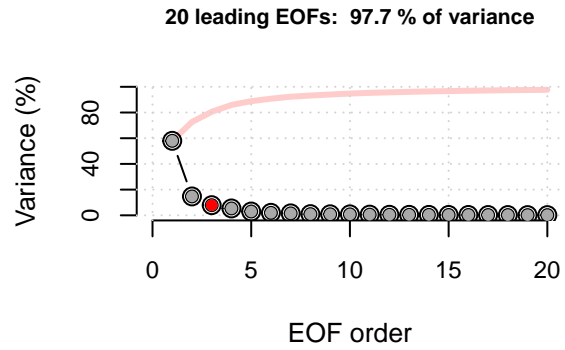
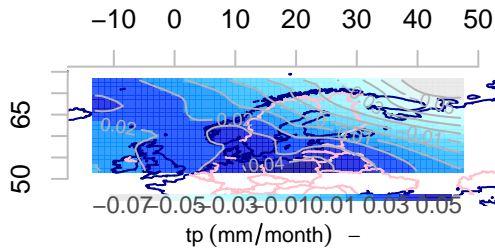
Leading PC#1 of Total precipitation – Explained variance = 57.97%



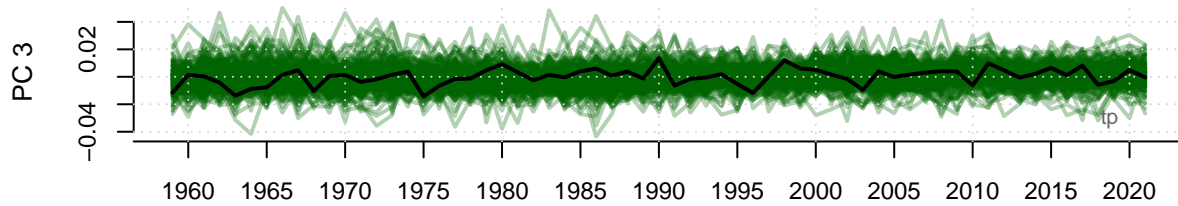
Leading PC#2 of Total precipitation – Explained variance = 14.69%



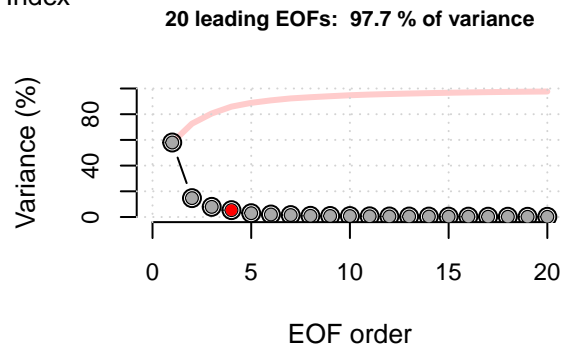
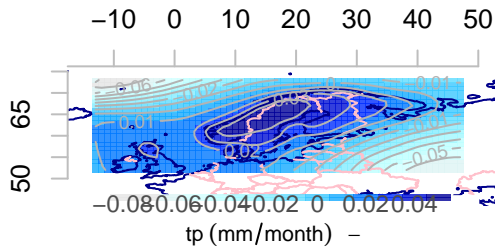
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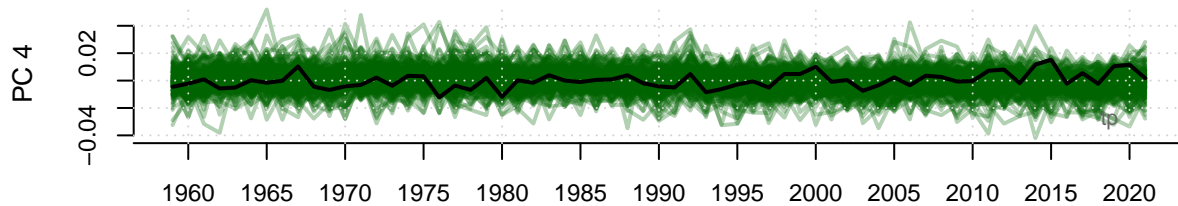
Leading PC#3 of Total precipitation – Explained variance = 7.89%



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Leading PC#4 of Total precipitation – Explained variance = 5.34%



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Benestad, R.E. 2001. "A Comparison Between Two Empirical Downscaling Strategies." *Int. J. Climatology*. RMetS. <https://doi.org/10.1002/joc.703>.

———. 2021. "A Norwegian Approach to Downscaling." *Geosci. Model Dev. Discuss.* Copernicus. <https://doi.org/10.5194/gmd-2021-176>.