Supplement of Geosci. Model Dev., 19, 10849–10862, 2026
https://doi.org/10.5194/gmd-19-10849-2026-supplement
© Author(s) 2026. CC BY 4.0 License.



Geoscientific Model Development
Open Access
EGU

Supplement of

A simple weather generator that converts statistical information from downscaled global climate models to sequences of daily precipitation and temperature

Rasmus E. Benestad

Correspondence to: Rasmus E. Benestad (rasmus.benestad@met.no)

The copyright of individual parts of the supplement might differ from the article licence.

SPRINGS-WP2

Rasmus E. Benestad

2024-04-17

Contents

1 Introduction **1**

2 A simple Weather Generator (WG) **3**

2.1 Schematic design 3

2.2 Diagnosing the output 4

3 Simulations of daily temperature **202**

3.1 Demonstrations involving a grater amount of evaluation against observations 206

References **228**

1 Introduction

This document is provides supporting material for the paper Benestad (2026) describing the weather generator in the the open-source R-package 'esd' version 1.11.30 from DOI:10.6084/m9.figshare.1160493 Benestad and Mezghani (2026).

This is an R Markdown document which is a simple formatting syntax for authoring HTML, PDF, and MS Word documents. For more details on using R Markdown see http://rmarkdown.rstudio.com.

1.0.1 Setting up the R-environment

The following chunk sets up and installs required R-packages for this

```
## This chunk installs the esd package if it's not already installed:
install.esd <- ("esd" %in% rownames(installed.packages()) == FALSE)

if (install.esd) {
  ## Install esd from GitHub:
  install.devtools <- ("devtools" %in% rownames(installed.packages()) == FALSE)

  if (install.devtools) {
    print('Need to install the devtools package')
    ## You need online access.
    install.packages('devtools', dependencies = TRUE)
```

```
  }
  library(devtools)
  ## Need the R-packages zoo and ncdf4
  install.zoo <- ("zoo" %in% rownames(installed.packages()) == FALSE)
  if (install.zoo) install.packages('devtools', dependencies = TRUE)
  install.ncdf4 <- ("ncdf4" %in% rownames(installed.packages()) == FALSE)
  if (install.ncdf4) install.packages('ncdf4', dependencies = TRUE)
  install.ggplot2 <- ("ggplot2" %in% rownames(installed.packages()) == FALSE)
  if (install.ggplot2) install.packages('ggplot2', dependencies = TRUE)
  install.RColorBrewer <- ("RColorBrewer" %in% rownames(installed.packages()) == FALSE)
  if (install.RColorBrewer) install.packages('RColorBrewer', dependencies = TRUE)

  library(devtools)
  print('Now install the esd package')
  ## You need online access.
  install_github('metno/esd')
}
## Give information about the versions of R and the R-packages used here:

library(esd)
```

```
## Loading required package: ncdf4
```

```
## Loading required package: zoo
```

```
##
## Attaching package: 'zoo'
```

```
## The following objects are masked from 'package:base':
##
##     as.Date, as.Date.numeric
```

```
## Registered S3 methods overwritten by 'esd':
##   method        from
##   subset.matrix base
##   subset.zoo    zoo
```

```
## This script requires esd-version 1.10.82 or later
print(sessionInfo())
```

```
## R version 4.6.2 (2026-10-29)
## Platform: x86_64-pc-linux-gnu
## Running under: Ubuntu 24.04.5 LTS
##
## Matrix products: default
## BLAS:   /usr/lib/x86_64-linux-gnu/blas/libblas.so.3.12.0
## LAPACK: /usr/lib/x86_64-linux-gnu/lapack/liblapack.so.3.12.0  LAPACK version 3.12.0
##
## locale:
##  [1] LC_CTYPE=en_US.UTF-8       LC_NUMERIC=C
##  [3] LC_TIME=nb_NO.UTF-8        LC_COLLATE=en_US.UTF-8
```

```
##  [5] LC_MONETARY=nb_NO.UTF-8    LC_MESSAGES=en_US.UTF-8
##  [7] LC_PAPER=nb_NO.UTF-8       LC_NAME=C
##  [9] LC_ADDRESS=C               LC_TELEPHONE=C
## [11] LC_MEASUREMENT=nb_NO.UTF-8 LC_IDENTIFICATION=C
##
## time zone: Europe/Oslo
## tzcode source: system (glibc)
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
## [1] esd_1.11.31 zoo_1.9-1   ncdf4_1.24
##
## loaded via a namespace (and not attached):
##  [1] digest_0.6.39     fastmap_1.2.0     xfun_0.62         lattice_0.23-1
##  [5] knitr_1.52        htmltools_0.5.9   rmarkdown_2.32    cli_3.6.6
##  [9] grid_4.6.2        compiler_4.6.2    rstudioapi_0.19.0 tools_4.6.2
## [13] evaluate_1.0.5    yaml_2.3.12       otel_0.2.0        rlang_1.3.0
```

```
setwd('~/SPRINGS')
```

2 A simple Weather Generator (WG)

The WG is a Monte-Carlo type simulation which was designed for daily precipitation or temperature for one single site. This particular version for daily precipitation (`esd::WG.fw.day.precip()`) has been designed to work with downscaled 24-hr precipitation statistics (annual wet-day frequency f_w and wet-day mean precipitation μ). It tries to ensure that each year have a specified number of rainy days (from f_w) and intensities (from μ), either from observations or downscaled rainfall statistics. It then tries to shuffle the rainy days so that they match the climatology in terms of rainy seasons. It can also be told to try to cluster the wet days further to try to improve the wet-day/dry-day spell duration statistics.

The precipitation `WG` then simulates the daily amount was then taken to follow an exponential distribution, but scales by α depending on probability and according to Benestad et al. (2019). The simple WG does not yet take into account the mean seasonal cycle in precipitation statistics. It differs from DGEN weather generator described in Mezghani and Hingray (2009).

The `WG` for temperature assumes that the anomalies are normally distributed and can be represented in terms of a Fourier series. It scrambles the phase of the Fourier components with random numbers but so that their spectral power is preserved and then re-scales the magnitudes of the anomalies according to given mean and standard deviations, and after that re-introduces the climatology.

2.1 Schematic design

This schematic

```
fatarrow <- function(x,y,a=0.045,col='grey70') {
  polygon(c(x, x+a,   x+a, x+2*a, x+a,x+a, x,    x),
          c(y, y,     y+a, y-a/2, y-2*a,y-a, y-a,y),col=col)
}

par(bty='n',xaxt='n',yaxt='n',mar=rep(1,4))
```

```
nf <- layout(matrix(c(0,1,1,0,2,2,2,2,2,2,2,2,0,3,3,0),4,4, byrow=FALSE),
       widths=rep(1,4),heights = rep(1,4))
data(bjornholt)
x <- seq(1,100,by=1)
y <- coredata(bjornholt)
z <- WG(bjornholt,mu=2,fw=0.1)
plot(zoo(bjornholt),xlab='',ylab='',main='')
plot(c(0,1),c(0,1),type='n',xlab='',ylab='')
rect(0.1,0.1,0.9,0.9,col='grey')
plot(zoo(z),xlab='',ylab='',main='',col='grey20')
par(new=TRUE,mfcol=c(1,1),mar=rep(0.5,4))
plot(c(0,1),c(0,1),type='n',xlab='',ylab='')
fatarrow(0.21,0.5,col="#727897")
fatarrow(0.7,0.5,col="#727897")
text(0.5,0.5,"WG",cex=6,font=2)
text(0.5,0.99,"Input:",cex=1.5,font=2,col="#727897")
text(0.5,0.93,expression(group("[",list(f[w],mu),"]")),col="#727897")
text(0.35,0.85,"Number of wet days",pos=4)
text(0.35,0.80,"Climatology",pos=4)
text(0.35,0.75,"Daily amounts",pos=4)
par(new=TRUE,fig=c(0.35,0.55,0.15,0.4))
hist(y[y>= 1],freq=FALSE,xlab='',ylab='',main='')
lines(x,dexp(x,rate=1/wetmean(y)),col='red')
par(new=TRUE,fig=c(0.45,0.65,0.20,0.40))
plot(zoo(aggregate(bjornholt,by=month,FUN='wetfreq')),lwd=3,col="#427897")
```

2.2 Diagnosing the output

2.2.1 Default test for Norway

```
## The default test uses Bjørnholt, Oslo in Norway
wg.test <- test.WG.fwmu.day.precip(cluster=TRUE,prob_shift=0.5,verbose=FALSE)
```

```
## test.WG.fwmu.day.precip for BJØRNHOLT  and  30  runs
## length= 51360 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6027  0.6832  0.7284  0.7397  0.7720  0.9302
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.466   2.919   2.985   2.976   3.144   3.295
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.360   1.748   1.806   1.772   1.849   1.972
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.855   5.082   5.753   5.677   6.416   7.586
```

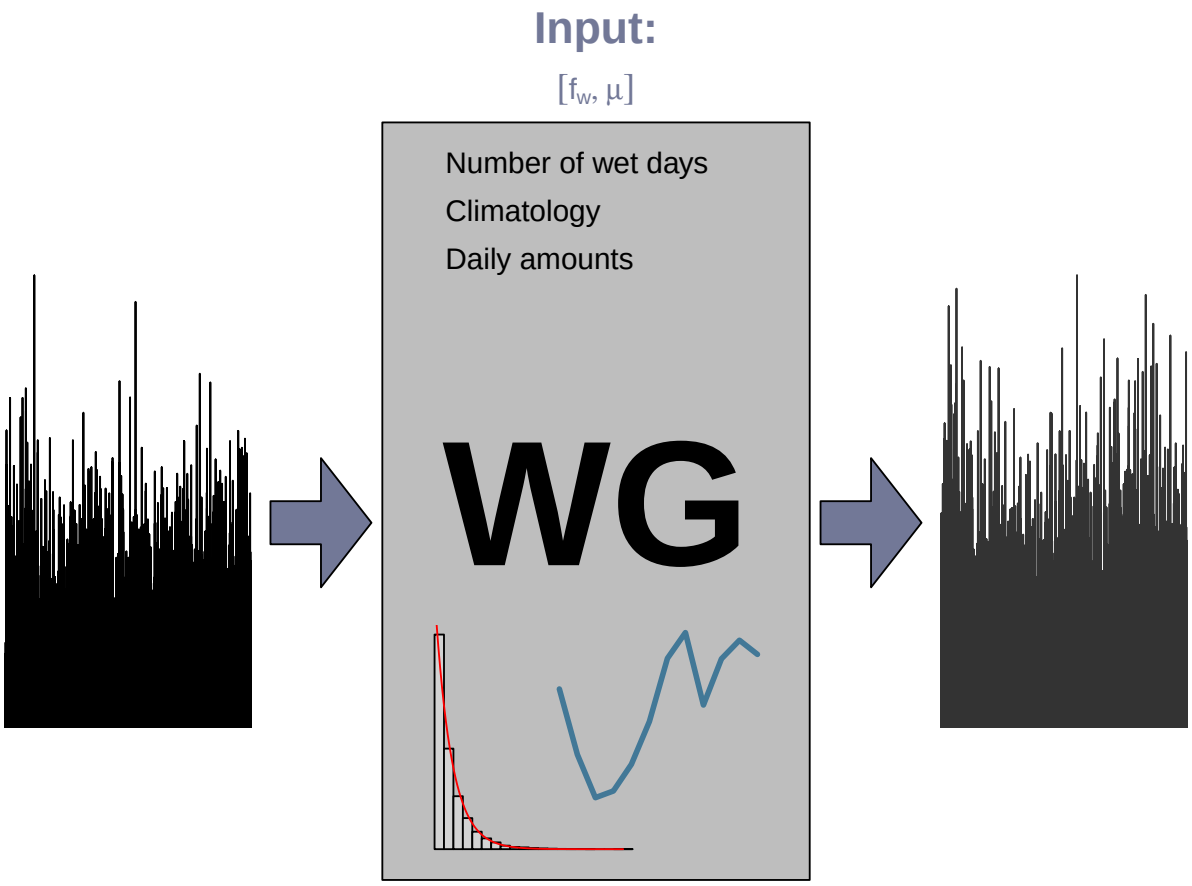


Figure 1: First supplementary figure is identical to Figure 1 in the paper.

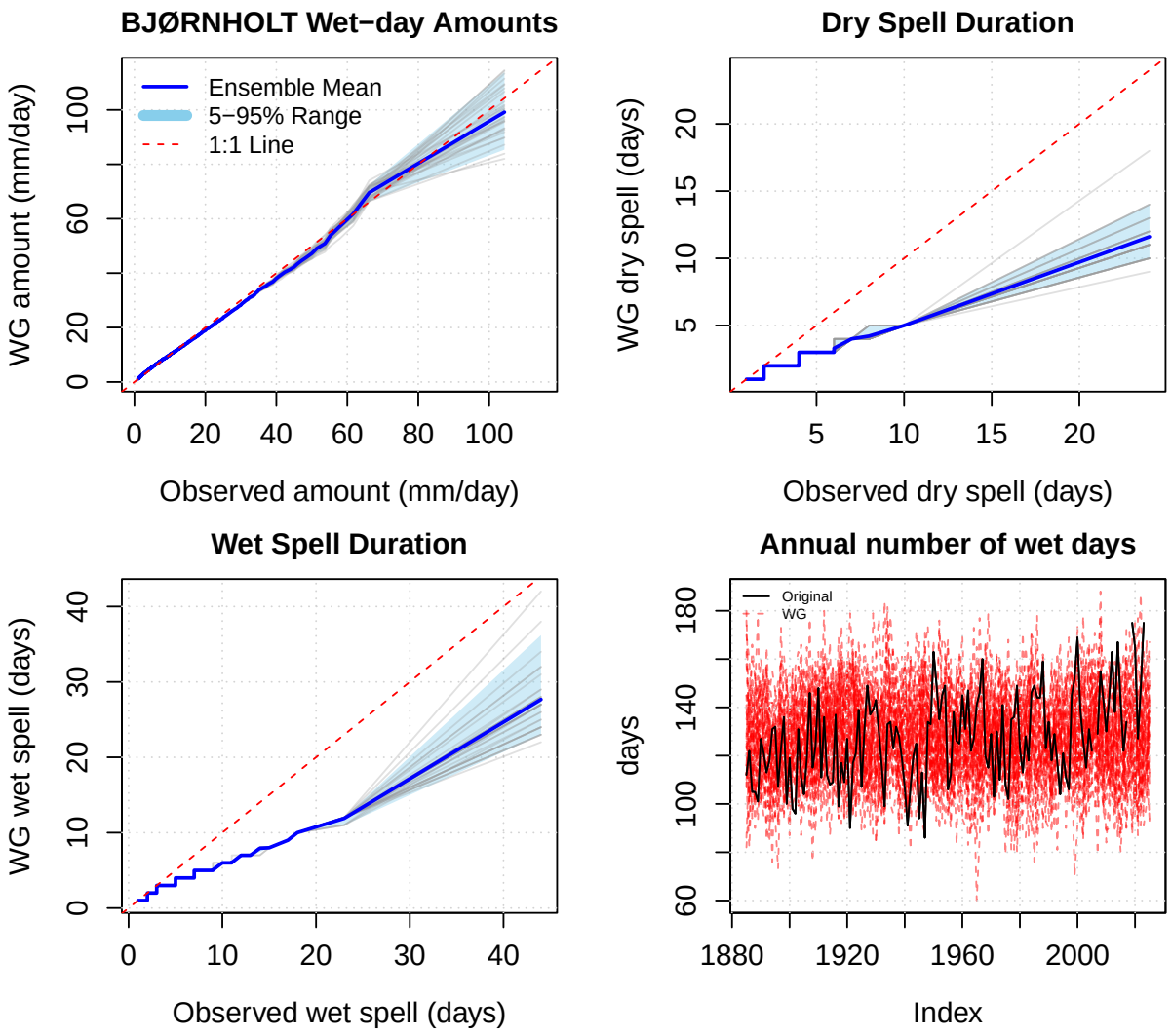


Figure 2: The R-code behind the figures shown in the paper.

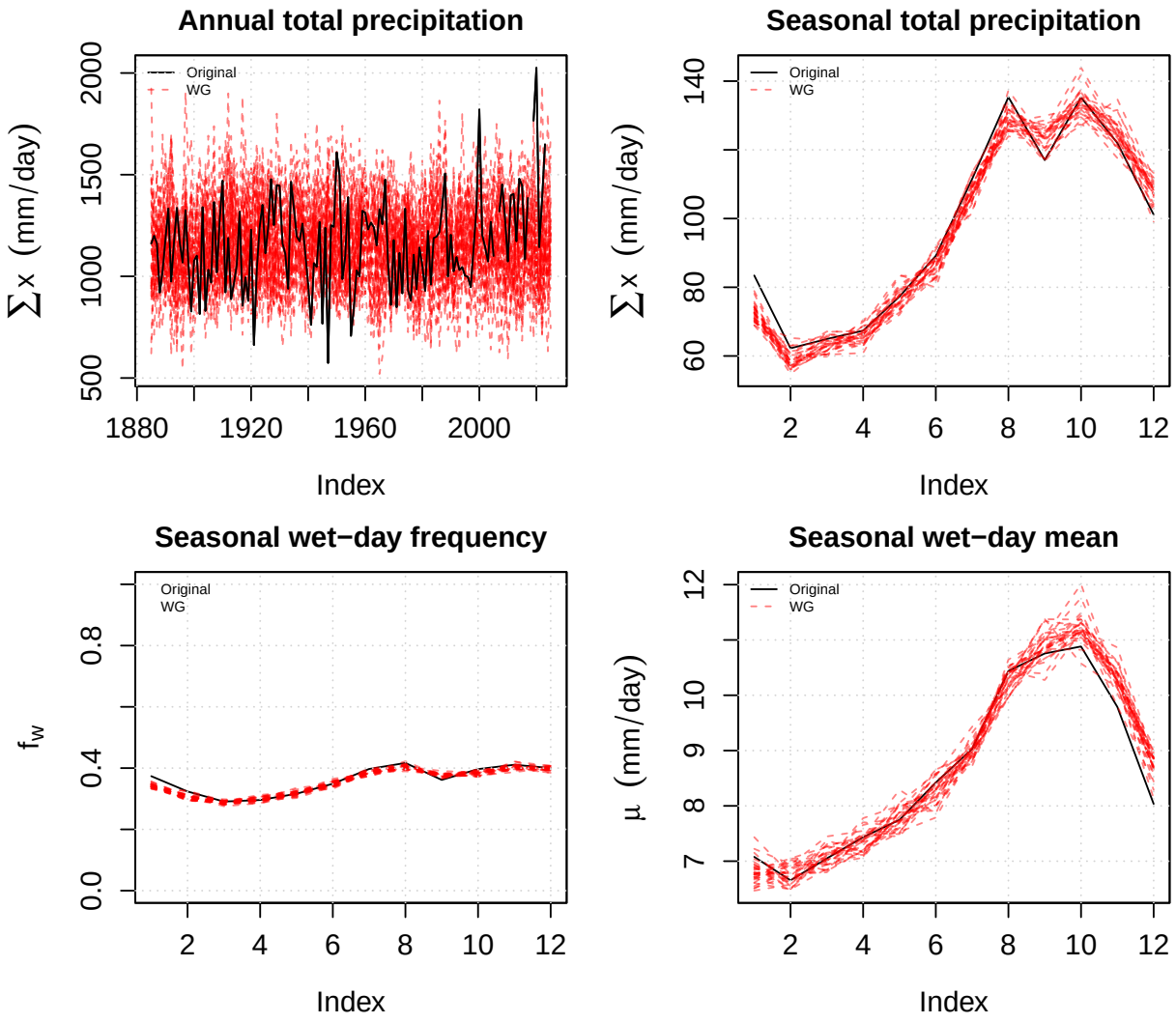


Figure 3: The R-code behind the figures shown in the paper.

```
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.2615  0.3044  0.3495  0.3540  0.3906  0.4725
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01022 0.01319 0.01448 0.01463 0.01578 0.01842
```

An attempt has been to cluster the wet and dry episodes in the above attempt. The clustering procedure can be tested

```
data(bjornholt)
z1 <- WG(bjornholt)
## Apply the clustering algorithm on a random WG simulation
z2 <- cluster_spells(z1, prob_shift = 0.4)
## Estimate the spell duration statistics
w1 <- subset(spell(z1,1),is=2)
w2 <- subset(spell(z2,1),is=2)
xylim <- c(0,max(w1,w2))
qqplot(coredata(w1),coredata(w2),xlim=xylim,ylim=xylim,
       xlab='original simulation',ylab='clustered results',
       main='Clustering of spells')
lines(c(0,50),c(0,50),lty=2,col='red')
grid()
```

We can plot histograms of the various spell statistics - first for the original data

```
s0 <- spell(bjornholt,1)
s1 <- spell(z1,1)
s2 <- spell(z2,1)
hist(s0)
```

WG simulation without clustering

```
hist(s1)
```

WG simulation with clustering

```
hist(s2)
```

We can use the Kolmogorov-Smirnov test to compare the spell duration distributions

```
# Kolmogorov-Smirnov test for dry spells with WG simulated without clustering
cat('Kolmogorov-Smirnov for spell duration statistics at Bjørnholt\n')
```

```
## Kolmogorov-Smirnov for spell duration statistics at Bjørnholt
```

```
S0 <- spell(wg.test,1)
wspells <- subset(S0,is=varid(S0)=="wet")
dspells <- subset(S0,is=varid(S0)=="dry")
cat('dry spells:\n')
```

```
## dry spells:
```

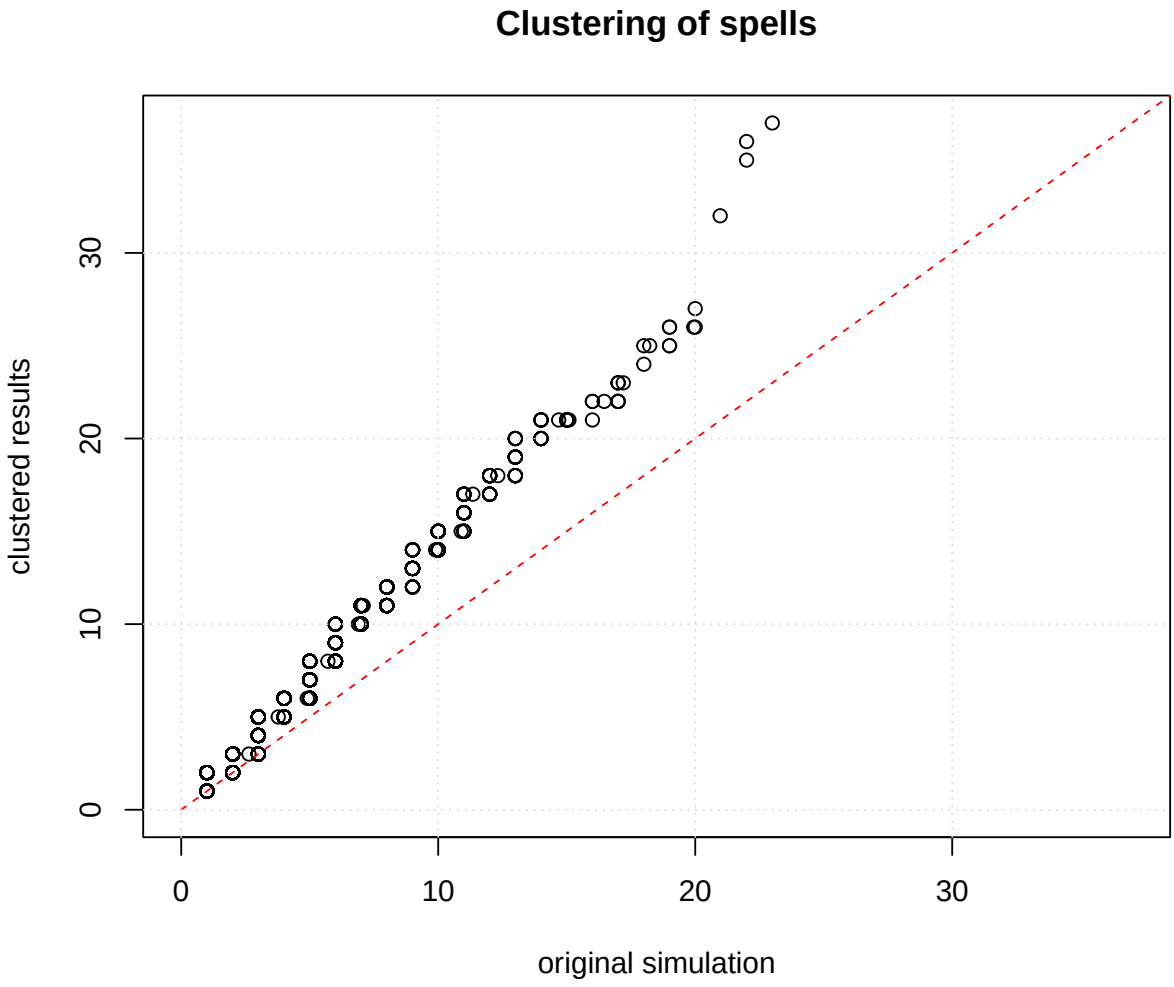


Figure 4: Clustering of spell durations.

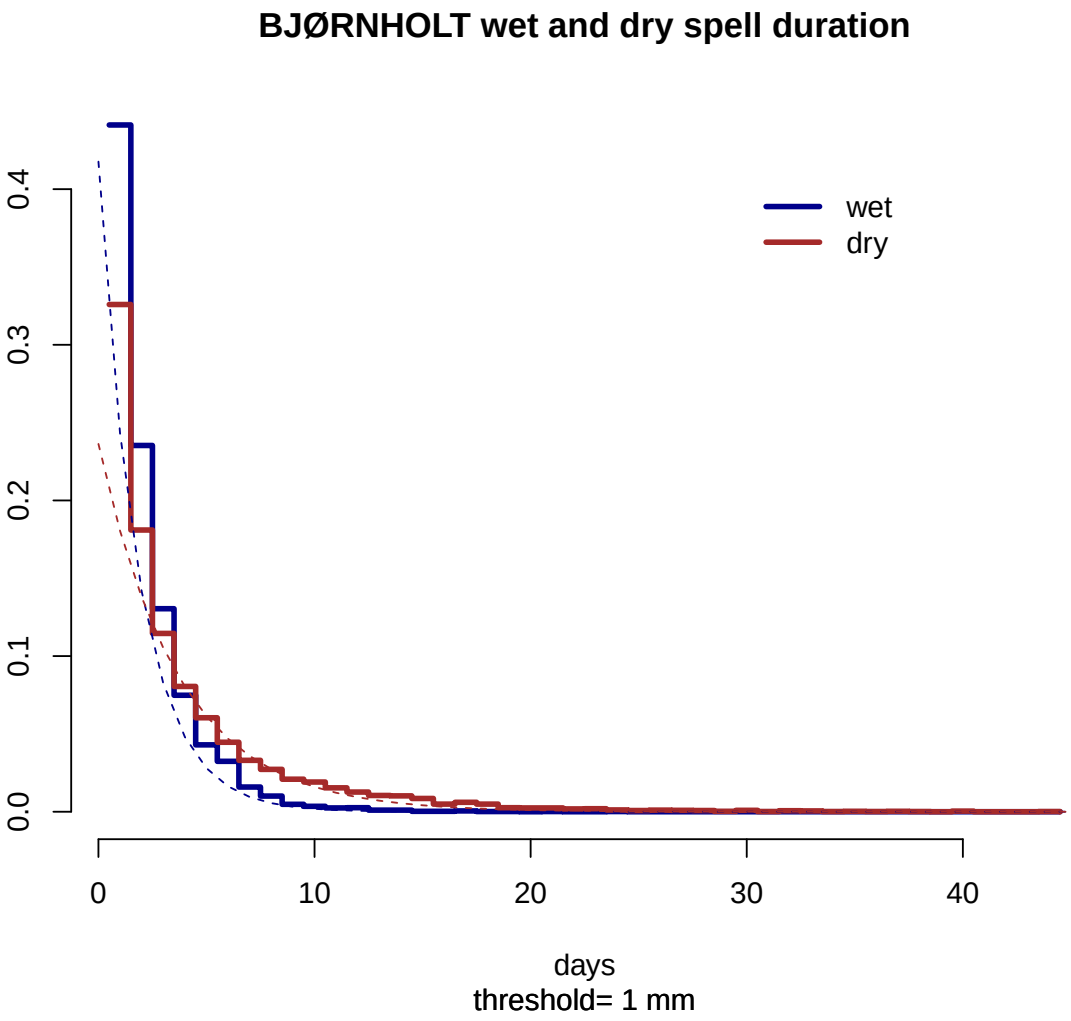


Figure 5: Statistics of spell durations.

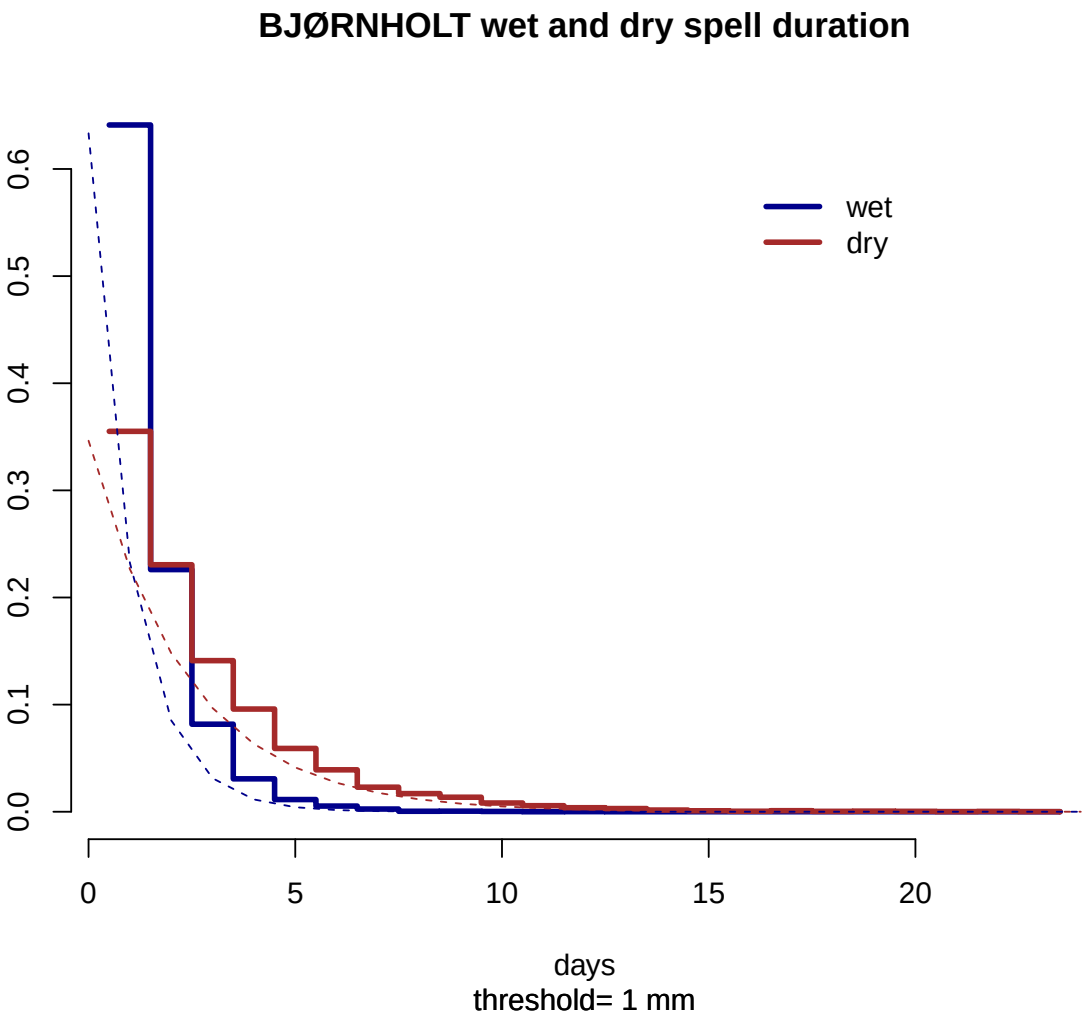


Figure 6: Clustering of spell durations for WG without cluster-adjustment.

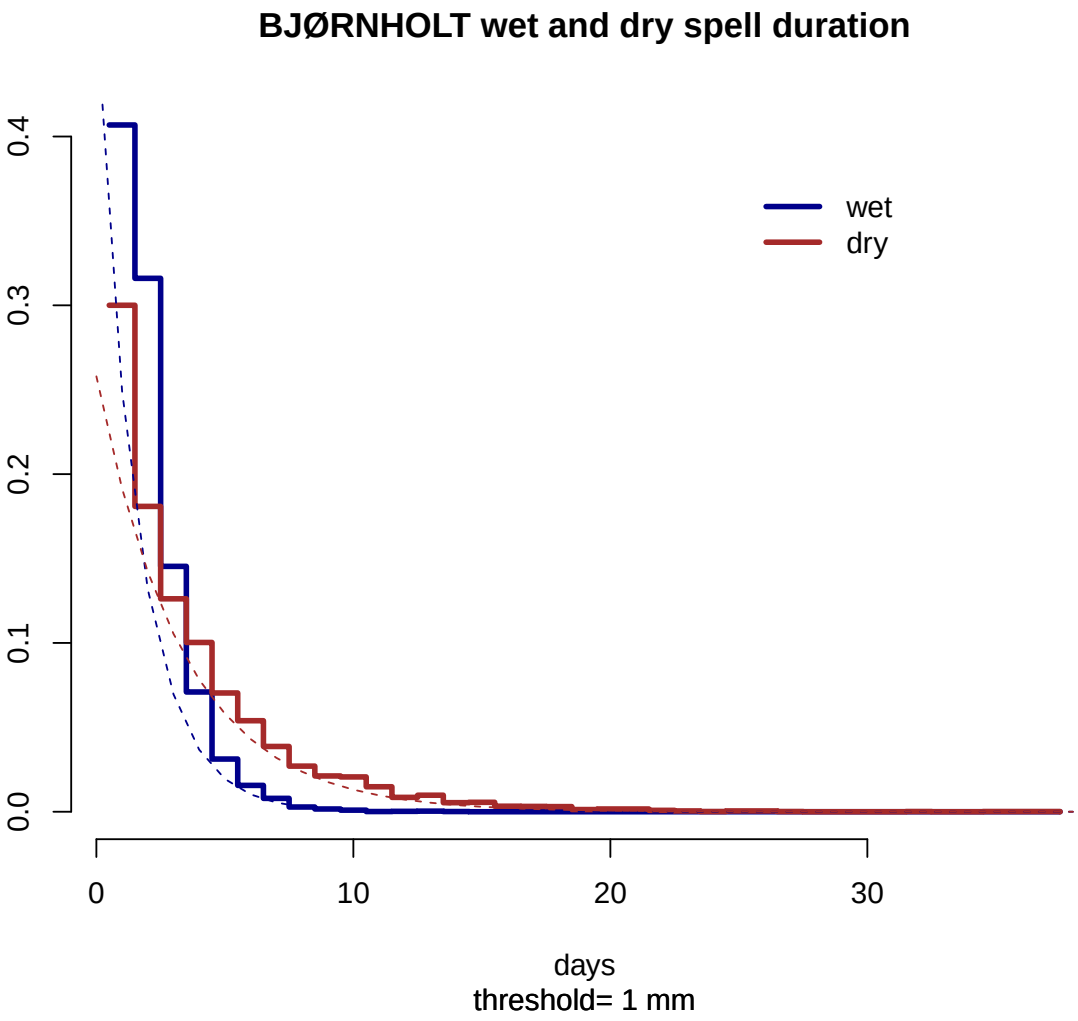


Figure 7: Clustering of spell durations for WG with cluster-adjustment.

```
test.dryspells <- ks.test(coredata(dspells[,1]),
                          coredata(dspells[,-1]))
print(test.dryspells)
```

```
##
##  Asymptotic two-sample Kolmogorov-Smirnov test
##
## data:  coredata(dspells[, 1]) and coredata(dspells[, -1])
## D = 0.12263, p-value < 2.2e-16
## alternative hypothesis: two-sided
```

```
test.wetspells <- ks.test(coredata(wspells[,1]),
                          coredata(wspells[,-1]))
cat('wet spells:\n')
```

```
## wet spells:
```

```
print(test.wetspells)
```

```
##
##  Asymptotic two-sample Kolmogorov-Smirnov test
##
## data:  coredata(wspells[, 1]) and coredata(wspells[, -1])
## D = 0.19651, p-value < 2.2e-16
## alternative hypothesis: two-sided
```

2.2.2 Ghana

```
## In-situ data shared by the Ghana Meteorological services
load('~/SPRINGS/data/ghana.data.rda')
## Find the longest series
diagnose(ghana.data$precip)
```

```
akosombo <- subset(ghana.data$precip,loc="Akosombo")
test.WG.fwmu.day.precip(akosombo,verbose=FALSE)
```

```
## test.WG.fwmu.day.precip for Akosombo  and  30  runs
## length= 12053 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.110   1.522   1.727   1.838   2.138   2.948
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   12.18   12.76   13.05   13.16   13.59   14.57
## RMSE for dry-spell duration quantiles:
```

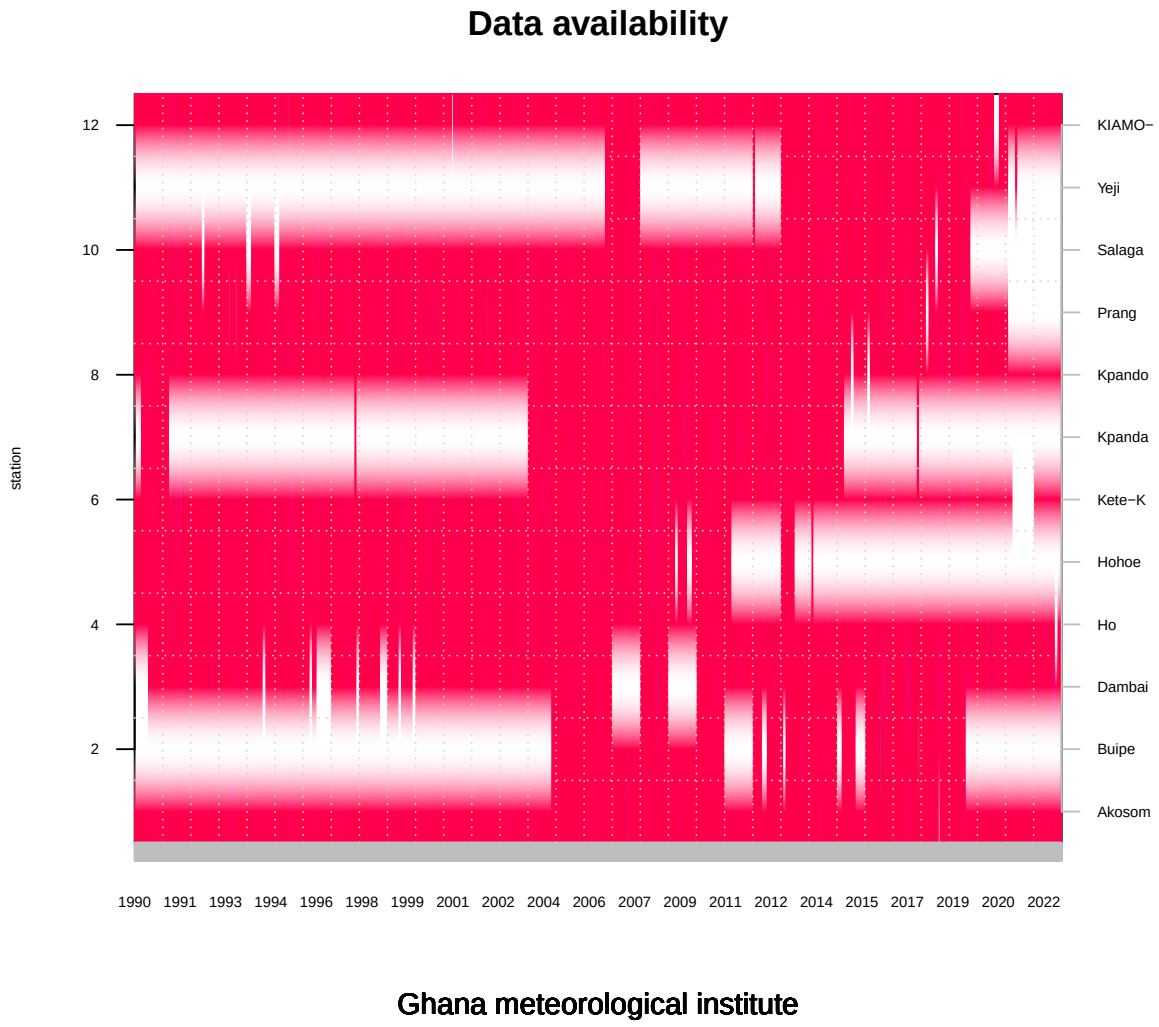


Figure 8: The R-code behind the figures shown in the paper.

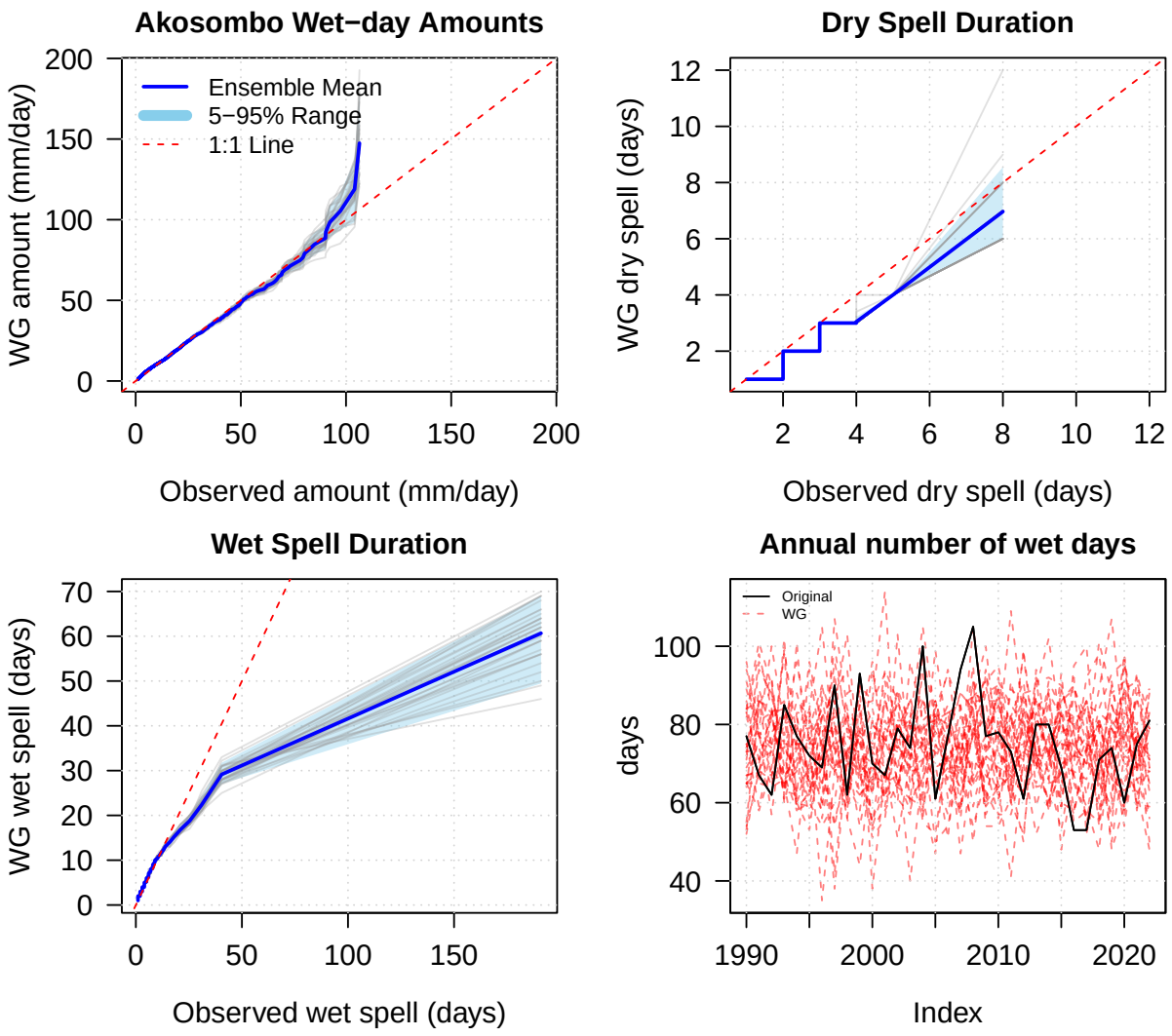


Figure 9: The R-code behind the figures shown in the paper.

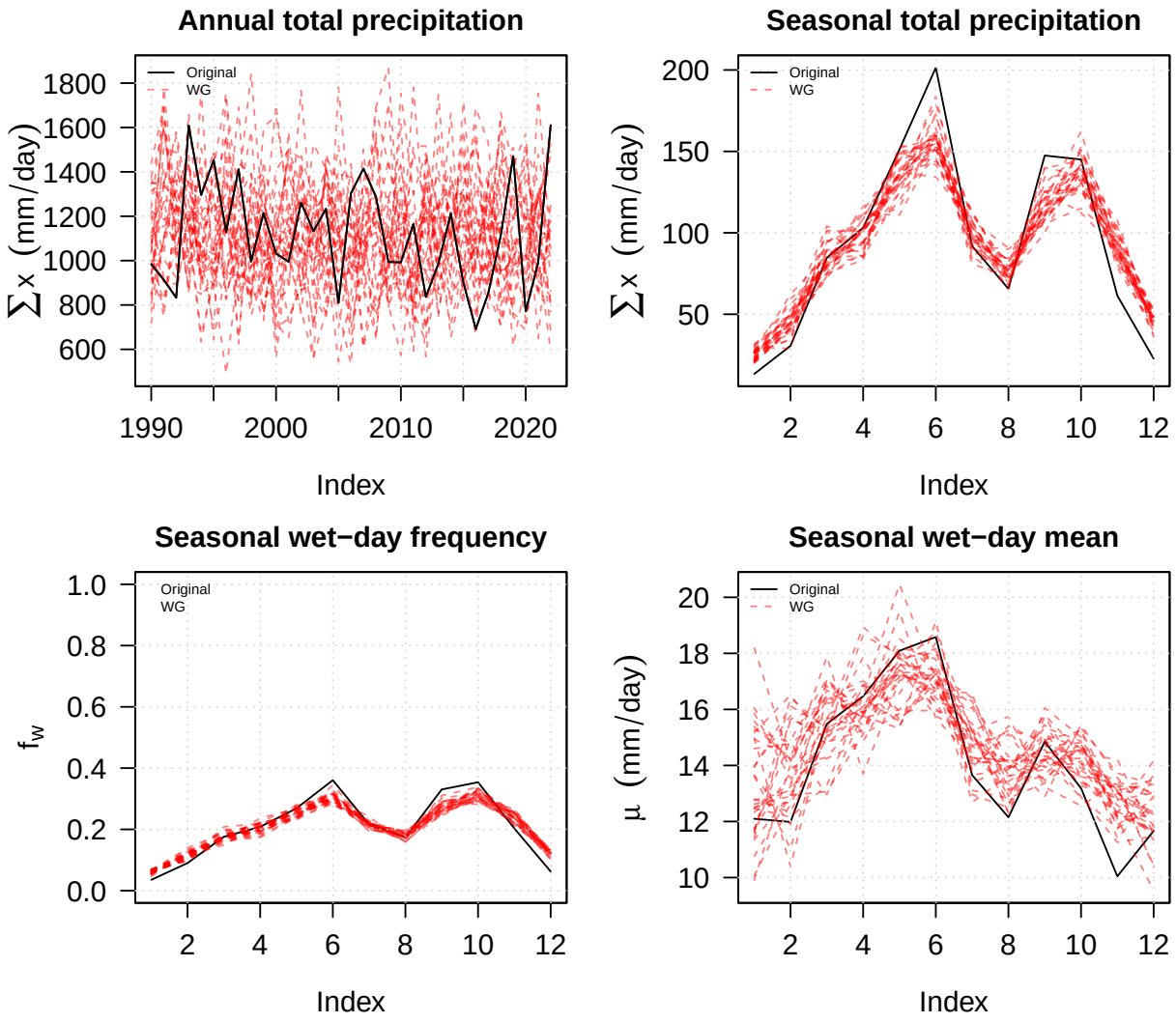


Figure 10: The R-code behind the figures shown in the paper.

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3000  0.3464  0.3742  0.3727  0.4000  0.5196
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   12.94   21.11   22.66   22.07   23.55   26.67
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.186   1.496   1.649   1.691   1.904   2.303
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.02753 0.03475 0.03759 0.03699 0.03996 0.04329
```

The detailed diagnostics below was done for CLUJ NAPOCA in Romania.

```
file.sample.stations <- '~/SPRINGS/precip.ecad.Romania+Italy.rda'
if (!file.exists(file.sample.stations)) {
  Y <- retrieve('~/data/ECAD/precip.ecad.nc',cntr=c('Romania','Italy'))
  save(Y,file=file.sample.stations)
} else load(file.sample.stations)
## Pick a random sample - one station with most valid data
Y <- subset(Y,is=list(cntr='Romania'))
nv <- apply(Y,2,'nv')
#y <- subset(Y,is=(nv == max(nv)))
y <- subset(Y,is=grep('CLUJ NAPOCA',loc(Y)))  ## Not so far from Timisoara in Romania
y <- subset(y,it=c(1950,2023))
test.WG.fwmu.day.precip(y,verbose=FALSE)
```

```
## test.WG.fwmu.day.precip for CLUJ NAPOCA  and  30  runs
## length= 25841 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9035  1.1513  1.2399  1.2518  1.3672  1.5931
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.730   2.619   3.207   3.025   3.471   3.738
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6164  0.6403  0.6633  0.6729  0.6982  0.7483
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.912   4.042   4.571   4.522   4.996   5.823
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3670  0.3920  0.4607  0.4554  0.4915  0.6136
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01371 0.01578 0.01653 0.01687 0.01831 0.02132
```

The simulated time series exhibited a less pronounced annual patter, and too few moderately heavy (30-40 mm/day) events. This underestimation of moderately heavy events is also seen in the quantile-quantile plot.

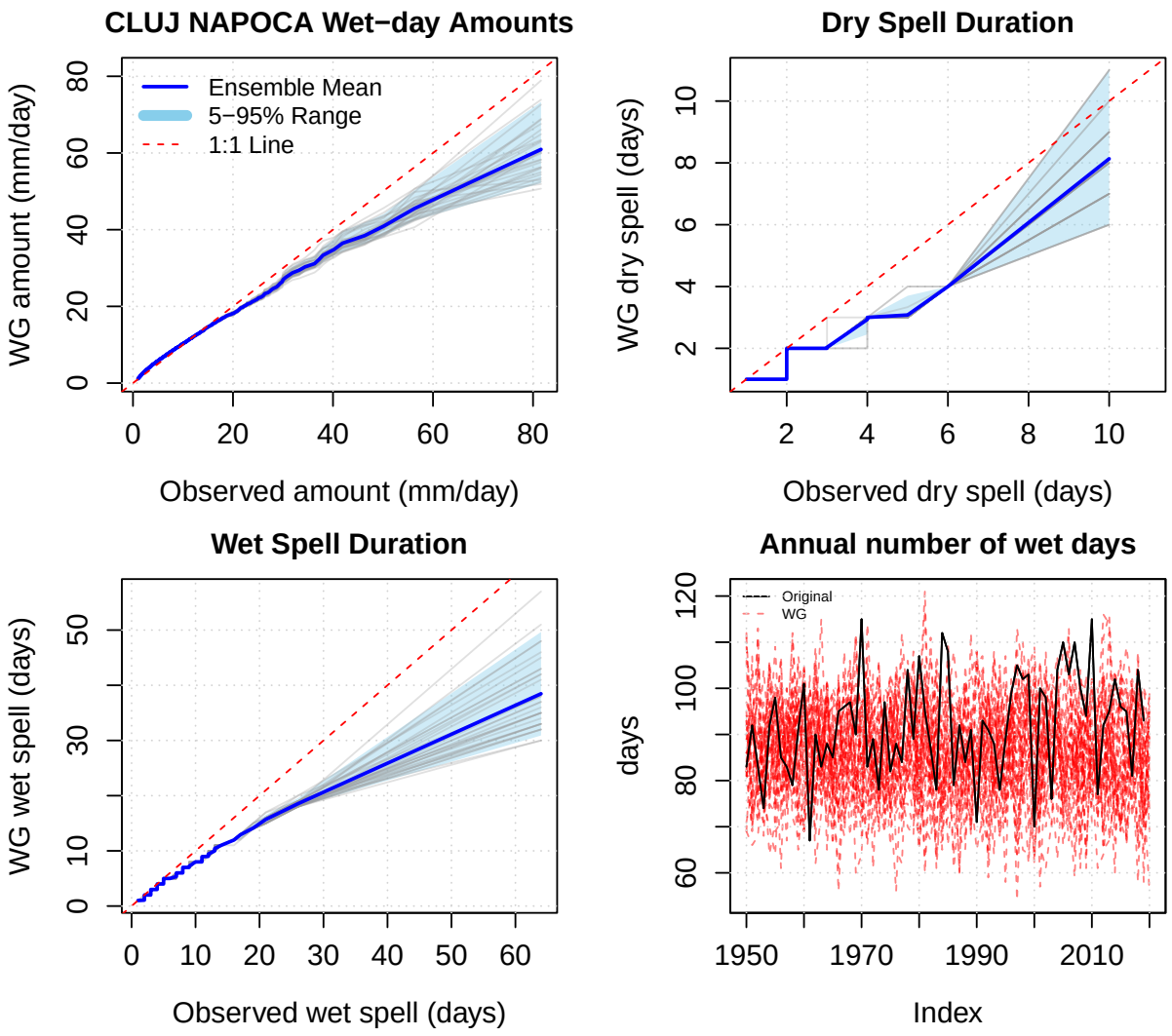


Figure 11: The R-code behind the figures shown in the paper.

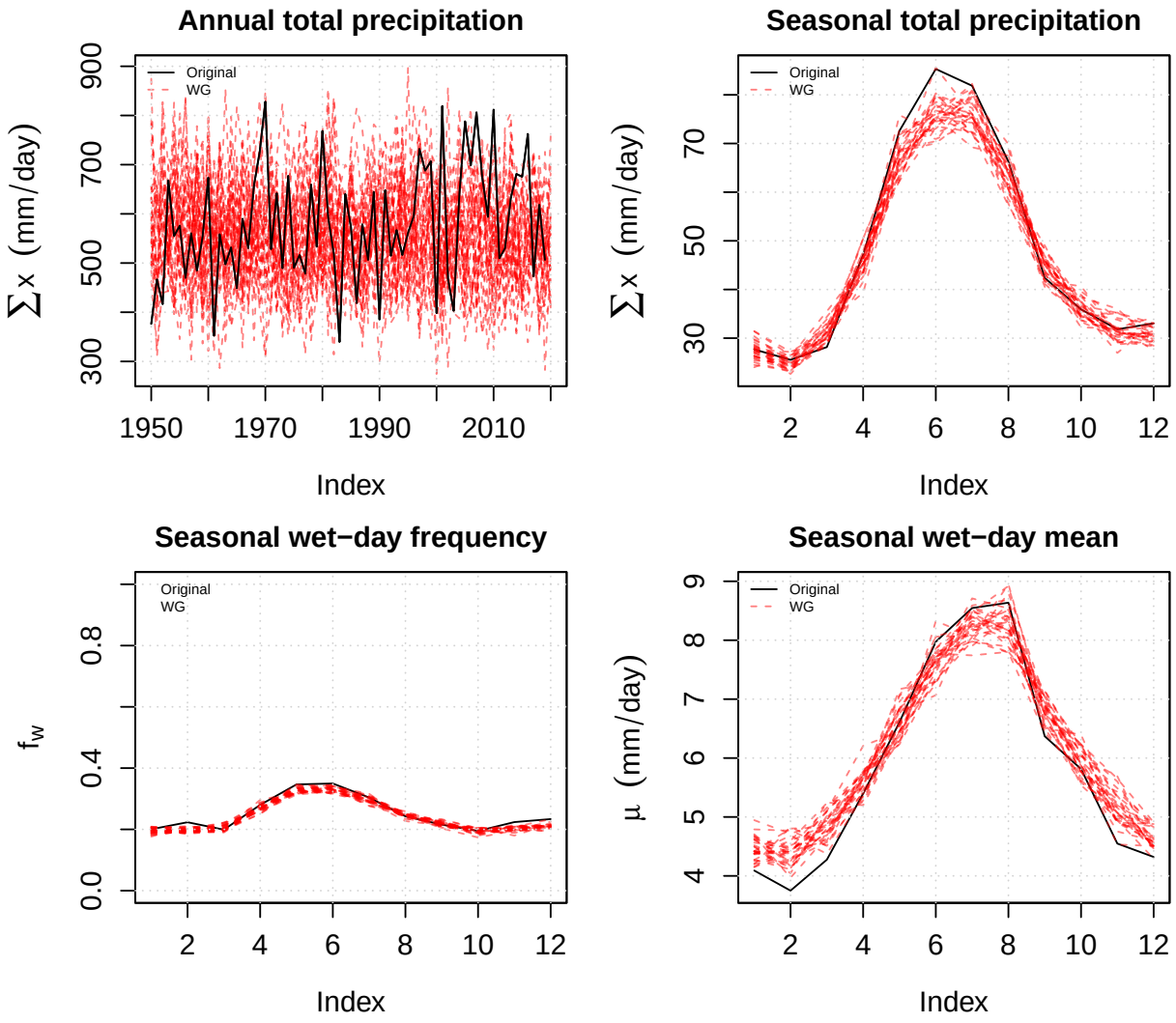


Figure 12: The R-code behind the figures shown in the paper.

The histogram and fitted exponential pdf (red) based on wet-day mean precipitation μ indicated a reasonable match for the randomly selected site of rain gauge measurements. A quantile-quantile plot suggests that the WG reproduced the magnitude of the events, but generated too many dry days.

The simulated annual total rainfall more or less matched the observed amounts. The mean annual cycle in total precipitation was similar, but the WG simulated too few wet days in winter. However, the WG exaggerates the amounts during winter, which is the reason why the simulated time series doesn't have the same repetitive seasonal pattern as observed, and still the total annual precipitation is reasonable.

The following R-chunk demonstrates how the WG can simulate a climate change where f_w is reduced by 0.1 and μ is increased by 2 mm/day.

```
z1 <- WG(y)
z2 <- WG(y,fw=-0.1, mu=2)
zz2 <- combine.stations(z2,z1)
col <- c('red','black')
plot(zoo(zz2),plot.type='single',col=col,lty=c(1,2),xlab='',ylab='mm',
     main=paste('simulated hypothetical climate change'))
grid()
```

2.2.3 Using GHCND data from the pilot regions

There is open data from https://www.ncei.noaa.gov/products/land-based-station/global-historical-climatology-network-daily with daily rainfall for the pilot regions. This data was downloaded and stored locally in case that this data source should be disabled.

```
ncfile <- '~/SPRINGS/springs.raingauges.pilot.nc'
if (!file.exists(ncfile)) {
  Y.pilot <- station.GHCND(param='precip',cntr=c('Romania','Italy','Ghana','Tanzania'))
  write2ncdf4(Y.pilot,file=ncfile)
} else Y.pilot <- retrieve(ncfile)
plot(Y.pilot,new=FALSE)
```

```
print(loc(Y.pilot))
```

```
##   [1] "NAVRONGO, GH"             "WA, GH"
##   [3] "BOLE, GH"                 "TAMALE, GH"
##   [5] "WENCHI, GH"               "KETE KRACHI, GH"
##   [7] "SUNYANI, GH"              "KUMASI, GH"
##   [9] "SEFWI BEKWAI, GH"         "HO, GH"
##  [11] "AKIM ODA, GH"             "KOFORIDUA, GH"
##  [13] "AKUSE, GH"                "AXIM, GH"
##  [15] "TAKORADI, GH"             "KOTOKA INTERNATIONAL, GH"
##  [17] "TEMA, GH"                 "ADA, GH"
##  [19] "VERONA VILLAFRANCA, IT"   "MONTE CIMONE, IT"
##  [21] "TERMOLI, IT"              "ROMA CIAMPINO, IT"
##  [23] "BRINDISI, IT"             "CAPO BELLAVISTA, IT"
##  [25] "CAGLIARI, IT"             "PAGANELLA, IT"
##  [27] "VIGNA DI VALLE, IT"       "MONTE S. ANGELO, IT"
##  [29] "BOLOGNA, IT"              "FERRARA, IT"
##  [31] "GENOA, IT"                "MANTOVA, IT"
##  [33] "MILAN, IT"                "PALERMO, IT"
```

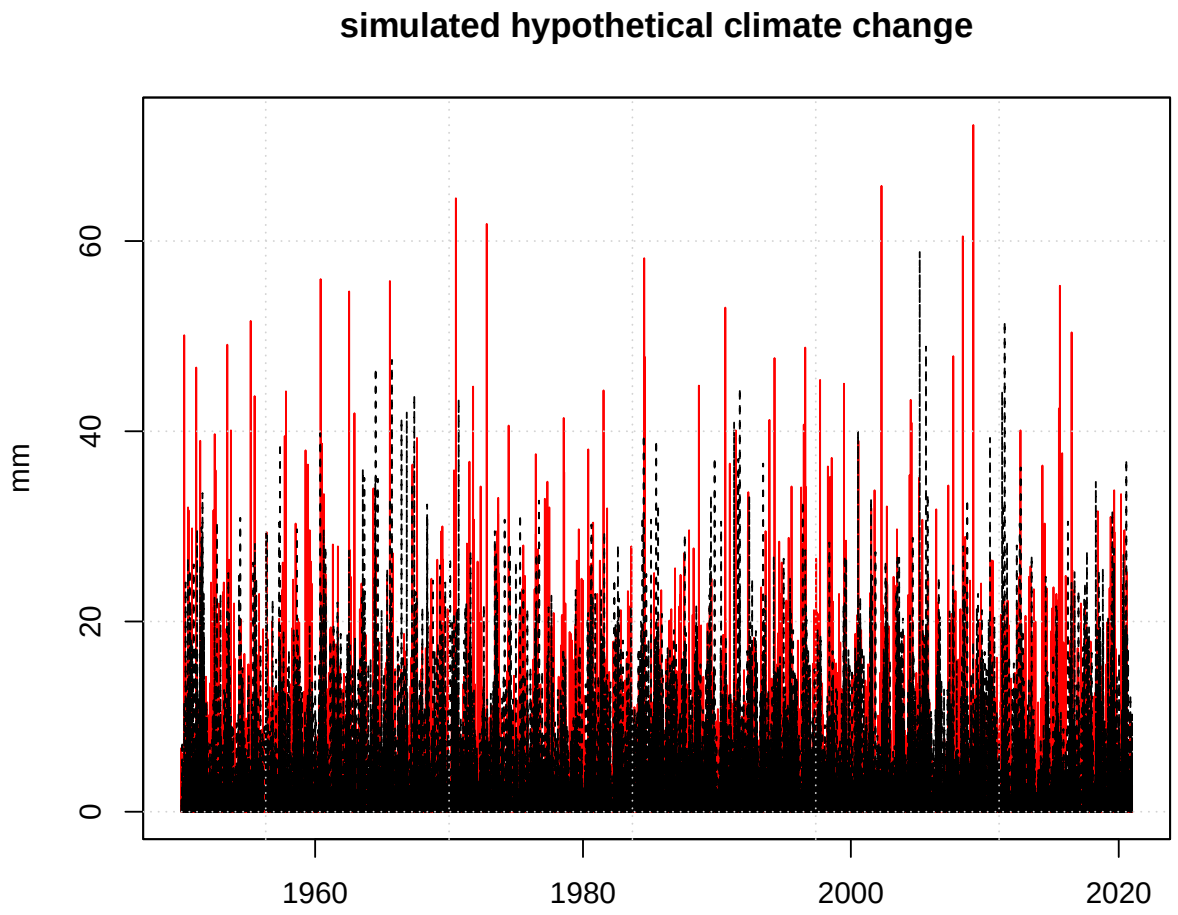


Figure 13: Demonstration of WG with reduced wet-day frequency and increased wet-day mean precipitation.

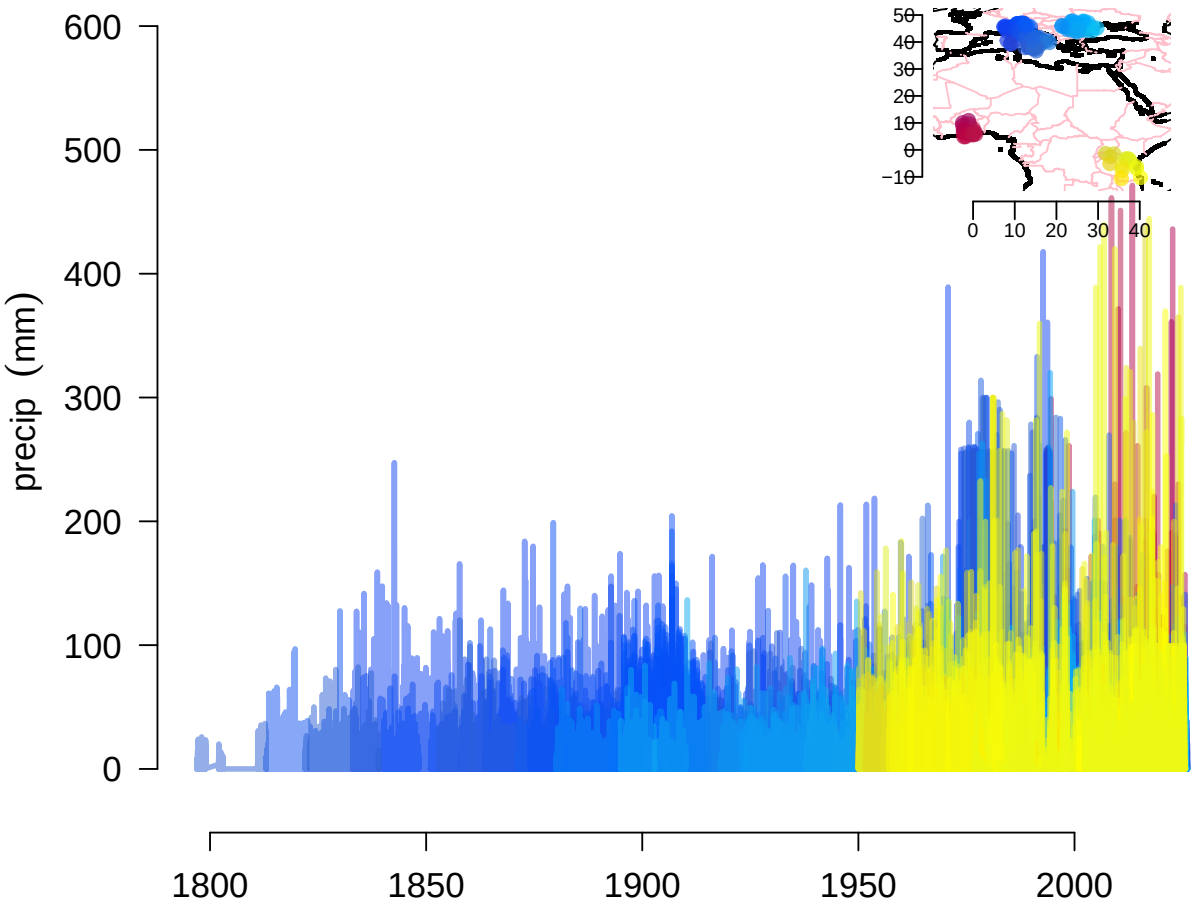


Figure 14: GHCND rain gauge data.

```
##  [35] "PESARO, IT"               "PADOVA, IT"
##  [37] "ALA, IT"                  "ALTREI, IT"
##  [39] "ANDRAZ, IT"               "ANTHOLZ, IT"
##  [41] "ARCO, IT"                 "BEZZECCA, IT"
##  [43] "BRIXEN, IT"               "CAMPITELLO, IT"
##  [45] "CASTEL TESINO, IT"        "COGNE, IT"
##  [47] "CONDINO, IT"              "CORTINA, IT"
##  [49] "FONDO, IT"                "GAND, IT"
##  [51] "GOSSENSASS, IT"           "JENESIEN, IT"
##  [53] "KASTELRUTH, IT"           "KEMATEN, IT"
##  [55] "LAVIS, IT"                "MADONNA DI CAMPIGLIO, IT"
##  [57] "MALE, IT"                 "MARIENBERG, IT"
##  [59] "MENDEL, IT"               "MEZZOLOMBARDO, IT"
##  [61] "MITTERKASER, IT"          "MITTEWALD, IT"
##  [63] "MUEHLWALD, IT"            "PANEVEGGIO, IT"
##  [65] "PEDROSS, IT"              "PEJO, IT"
##  [67] "PREDAZZO, IT"             "PROVEIS, IT"
##  [69] "RADEIN, IT"               "REIN, IT"
##  [71] "RIVA, IT"                 "ROLLE, IT"
##  [73] "ROVERETO, IT"             "SAND, IT"
##  [75] "S.BERNARDO, IT"           "SCHLANDERS, IT"
##  [77] "S.FELICE, IT"             "S.MARTINO DI CASTROZZA, "
##  [79] "ST.CASSIAN, IT"           "ST.HELENA, IT"
##  [81] "ST.MARTIN IN THURN, IT"   "ST.NIKOLAUS BEI KALTERN,"
##  [83] "ST.VEIT IN PRAGS, IT"     "TIONE, IT"
##  [85] "TOBLACH, IT"              "TRIENT, IT"
##  [87] "S. VALENTINO ALLA MUTA, " "DOBBIACO, IT"
##  [89] "RIVOLTO, IT"              "PIAN ROSA MTN TOP, IT"
##  [91] "TORINO BRIC CROCE, IT"    "CAMERI, IT"
##  [93] "GHEDI, IT"                "ISTRANA, IT"
##  [95] "TRIESTE, IT"              "CERVIA, IT"
##  [97] "RIMINI, IT"               "CAPE MELE, IT"
##  [99] "PISA, IT"                 "FRONTONE, IT"
## [101] "GROSSETO, IT"             "TERMINILLO MOUNTAIN, IT"
## [103] "PRATICA DI MARE, IT"      "CAMPOBASSO, IT"
## [105] "GRAZZANISE, IT"           "PONZA ISLAND, IT"
## [107] "CAPE PALINURO, IT"        "MARINA DI GINOSA, IT"
## [109] "MONTE SCURO, IT"          "SANTA MARIA DI LEUC, IT"
## [111] "USTICA ISLAND, IT"        "BOCCADIFALCO, IT"
## [113] "MESSINA, IT"              "TRAPANI BIRGI, IT"
## [115] "ENNA, IT"                 "COZZO SPADARO, IT"
## [117] "CAPE CACCIA, IT"          "DECIMOMANNU, IT"
## [119] "SIGONELLA, IT"            "NAPLES, IT"
## [121] "AVIANO, IT"               "ARAD, RO"
## [123] "BAIA MARE, RO"            "BUCURESTI FILARET, RO"
## [125] "BUZAU, RO"                "CALARASI, RO"
## [127] "CLUJ NAPOCA, RO"          "DROBETA TURNU SEVERIN, R"
## [129] "TG JIU, RO"               "TURNU MAGURELE, RO"
## [131] "BACAU, RO"                "BOTOSANI, RO"
## [133] "BUCURESTI BANEASA, RO"    "CARANSEBES, RO"
## [135] "CEAHLAU TOACA, RO"        "CONSTANTA, RO"
## [137] "CRAIOVA, RO"              "DEVA, RO"
## [139] "GALATI, RO"               "IASI, RO"
## [141] "MIERCUREA CIUC, RO"       "OCNA SUGATAG, RO"
```

```
## [143] "RAMNICU VALCEA, RO"       "ROSIORI DE VEDE, RO"
## [145] "SIBIU, RO"                "TULCEA, RO"
## [147] "STEFAN CEL MARE, RO"      "BISTRITA, RO"
## [149] "TRAIAN VUIA, RO"          "VARFU OMUL, RO"
## [151] "SULINA, RO"               "BUKOBA, TZ"
## [153] "MUSOMA, TZ"               "MWANZA, TZ"
## [155] "ARUSHA, TZ"               "MOSHI, TZ"
## [157] "KILIMANJARO AIRPORT, TZ"  "SAME, TZ"
## [159] "TABORA AIRPORT, TZ"       "DODOMA, TZ"
## [161] "IRINGA, TZ"               "DAR ES SALAAM AIRPORT, T"
## [163] "SONGEA, TZ"               "MTWARA, TZ"
## [165] "ZANZIBAR, TZ"
```

2.2.4 Test the weather generator (WG) with GHCDN data for the pilot regions

The next chunk tests the weather generator (WG) for three sites near the EU-SPRINGS pilot study regions. Three of these are shown below with one site selected from each: Tanzania, Nables and Romania.

```
par(cex=1.25)
## Arusha in Tanzania
y <- subset(Y.pilot,loc="ARUSHA",it=c(1961,2023))
plot(y,new=FALSE)
```

```
test.WG.fwmu.day.precip(y,verbose=FALSE)
```

```
## test.WG.fwmu.day.precip for ARUSHA, TZ  and  30  runs
## length= 23010 , n quantiles = 100  =  100

## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.632   3.099   3.285   3.285   3.524   3.830
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.732   5.927   6.470   6.394   6.771   7.461
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9487  1.0161  1.0398  1.0584  1.0989  1.1832
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   16.29   18.70   19.98   19.86   20.74   22.90
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.784   1.975   2.115   2.114   2.234   2.481
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.03194 0.03579 0.03724 0.03753 0.03907 0.04609
```

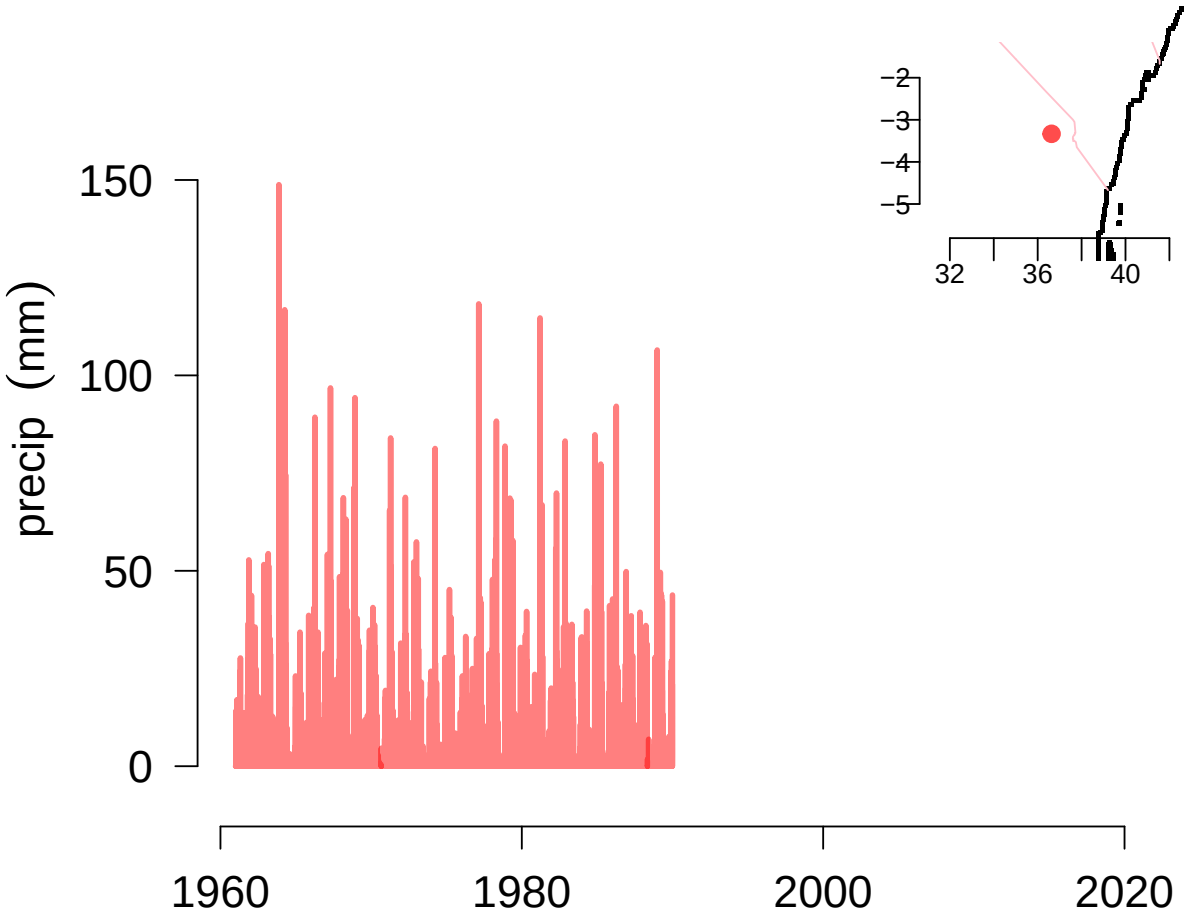


Figure 15: Test of WG performance for different countries.

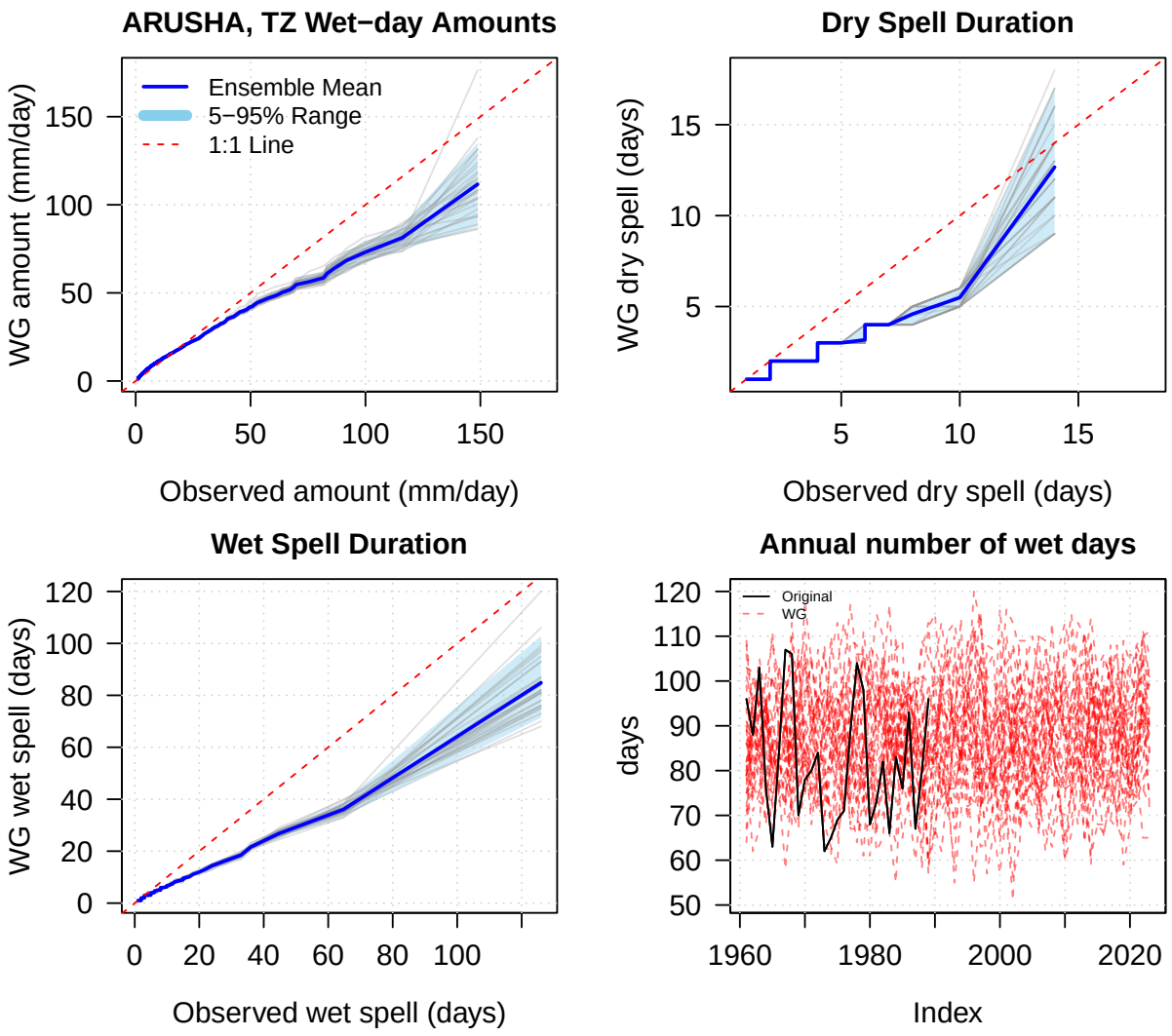


Figure 16: Test of WG performance for different countries.

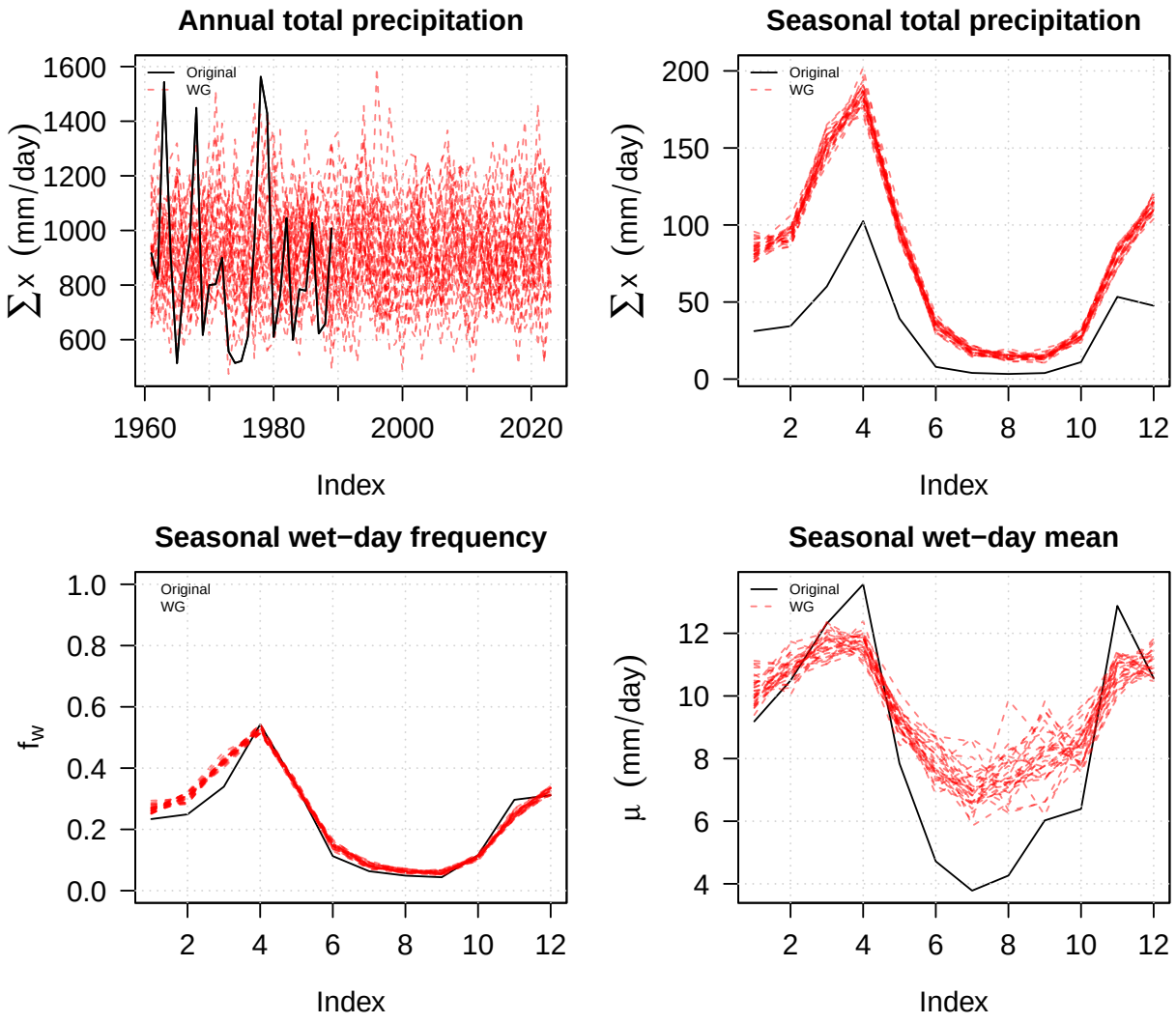


Figure 17: Test of WG performance for different countries.

```
## Naples in Italy
y <- subset(Y.pilot,loc="NAPLES",it=c(1961,2023))
plot(y,new=FALSE)
```

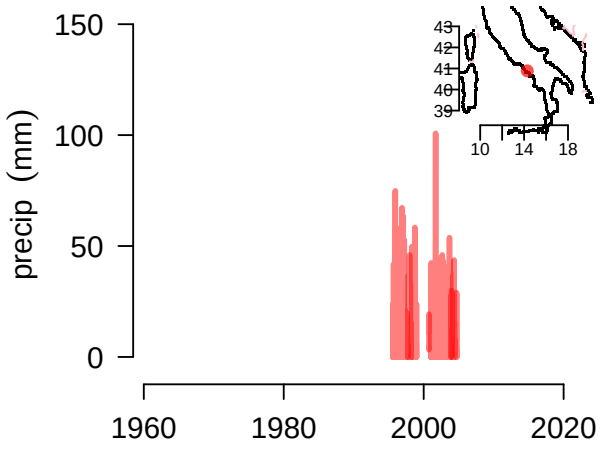


Figure 18: Test of WG performance for different countries.

```
test.WG.fwmu.day.precip(y,verbose=FALSE)
```

```
## test.WG.fwmu.day.precip for NAPLES, IT  and  30  runs
## length= 23010 , n quantiles = 100  =  100

## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.020   1.260   1.335   1.346   1.435   1.671
```

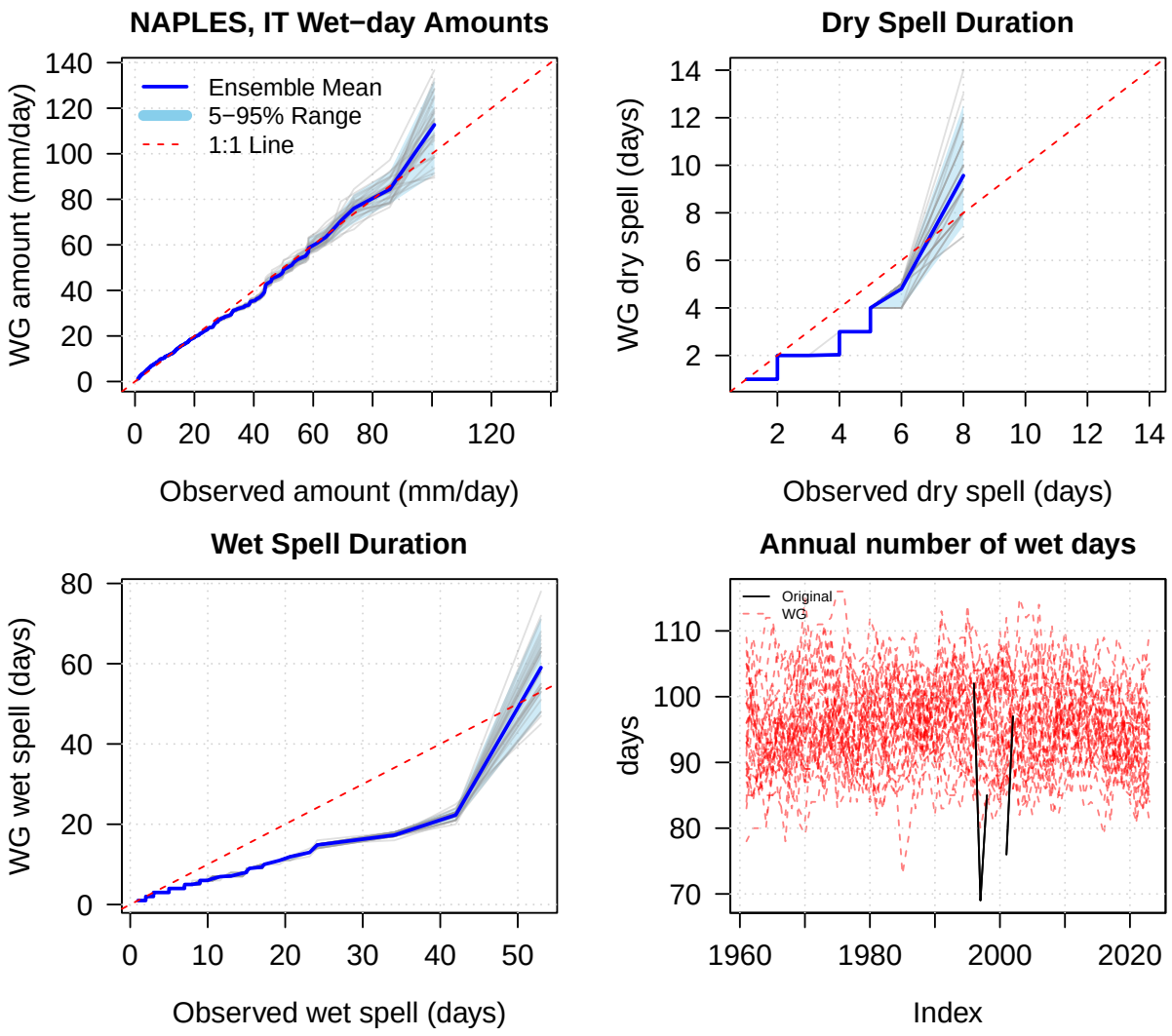


Figure 19: Test of WG performance for different countries.

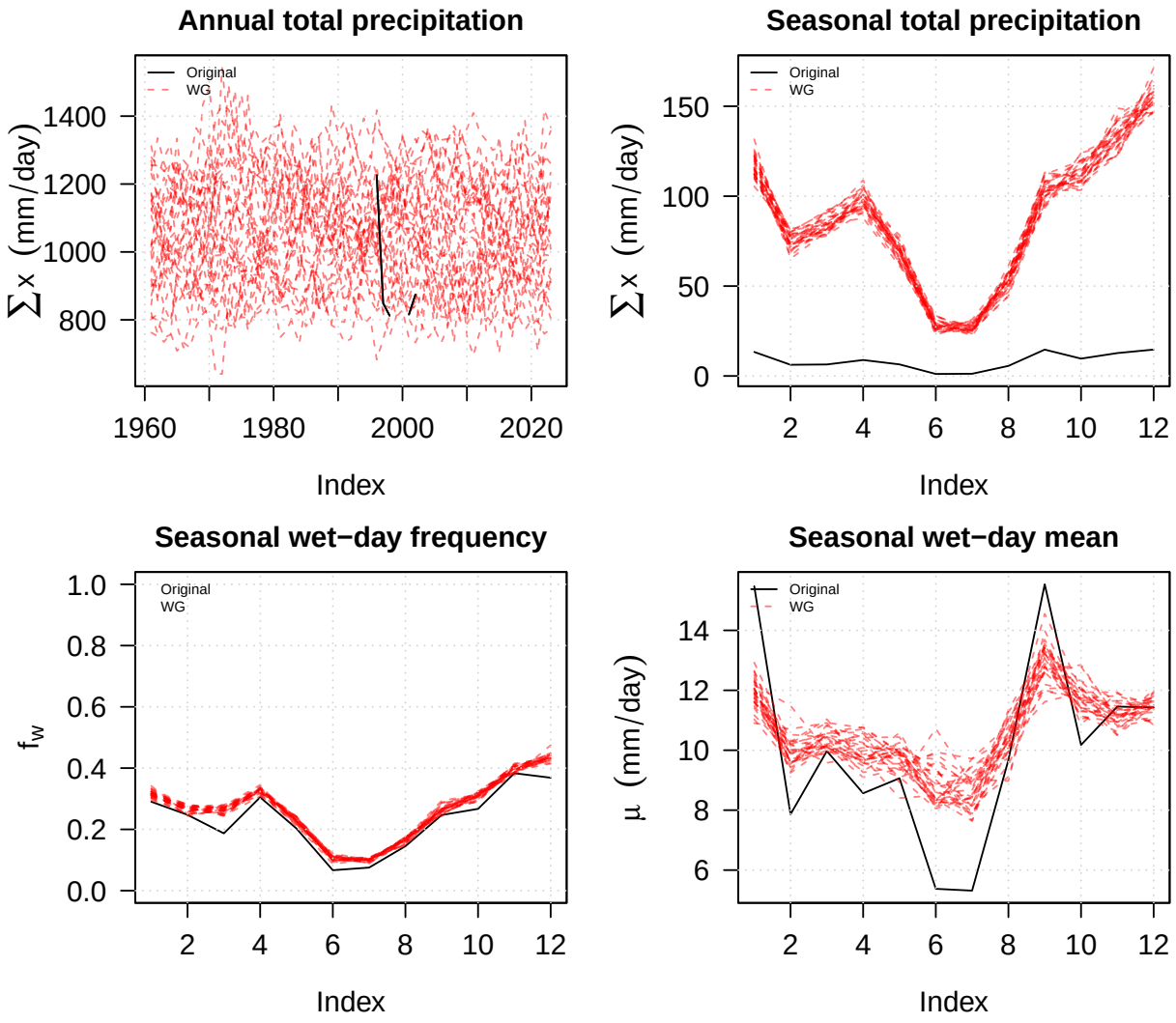


Figure 20: Test of WG performance for different countries.

```
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.870   3.969   4.052   4.086   4.117   4.667
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7141  0.7280  0.7548  0.7698  0.7906  0.9165
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   17.10   19.06   20.19   20.26   21.45   22.81
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.801   2.045   2.100   2.122   2.179   2.500
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.03634 0.03796 0.03895 0.03911 0.04004 0.04443
```

```
## Bucharest in Romania
y <- subset(Y.pilot,loc="CLUJ NAPOCA",it=c(1961,2023))
plot(y,new=FALSE)
```

```
test.WG.fwmu.day.precip(y,verbose=FALSE)
```

```
## test.WG.fwmu.day.precip for CLUJ NAPOCA, RO  and  30  runs
## length= 23010 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.096   1.163   1.282   1.282   1.361   1.529
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.947   3.023   3.254   3.238   3.407   3.978
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6708  0.7365  0.7905  0.7885  0.8352  0.9000
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.647   4.238   4.605   4.613   5.002   5.877
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3215  0.4228  0.4619  0.4697  0.5046  0.5880
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01277 0.01524 0.01659 0.01630 0.01716 0.02137
```

The performance of the WG seems to vary from place to place. The performance was poor for Naples, but the time series was also very short. For the selected site in *Tanzania* the WG did show a bias which got worse when a scaling factor was used for higher quantiles (grey). The black symbols show the results for the exponential distribution. **The statistics for dry-spell duration looks strange** The WG partly captures the rainy seasons, but short data series may preclude a good calibration of the model. The main problem with this site is data limitation and short time series. The WG is not expected to perform well with short time series.

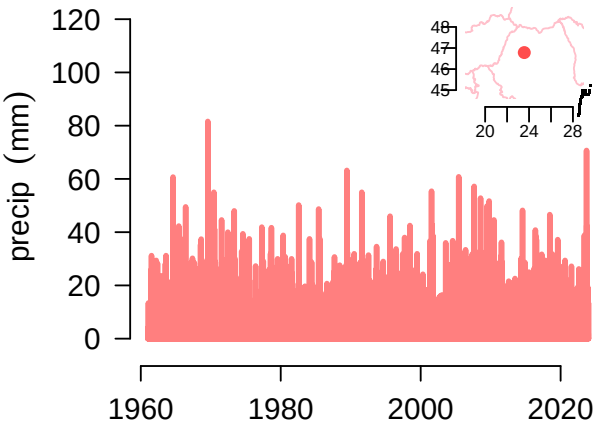


Figure 21: Test of WG performance for different countries.

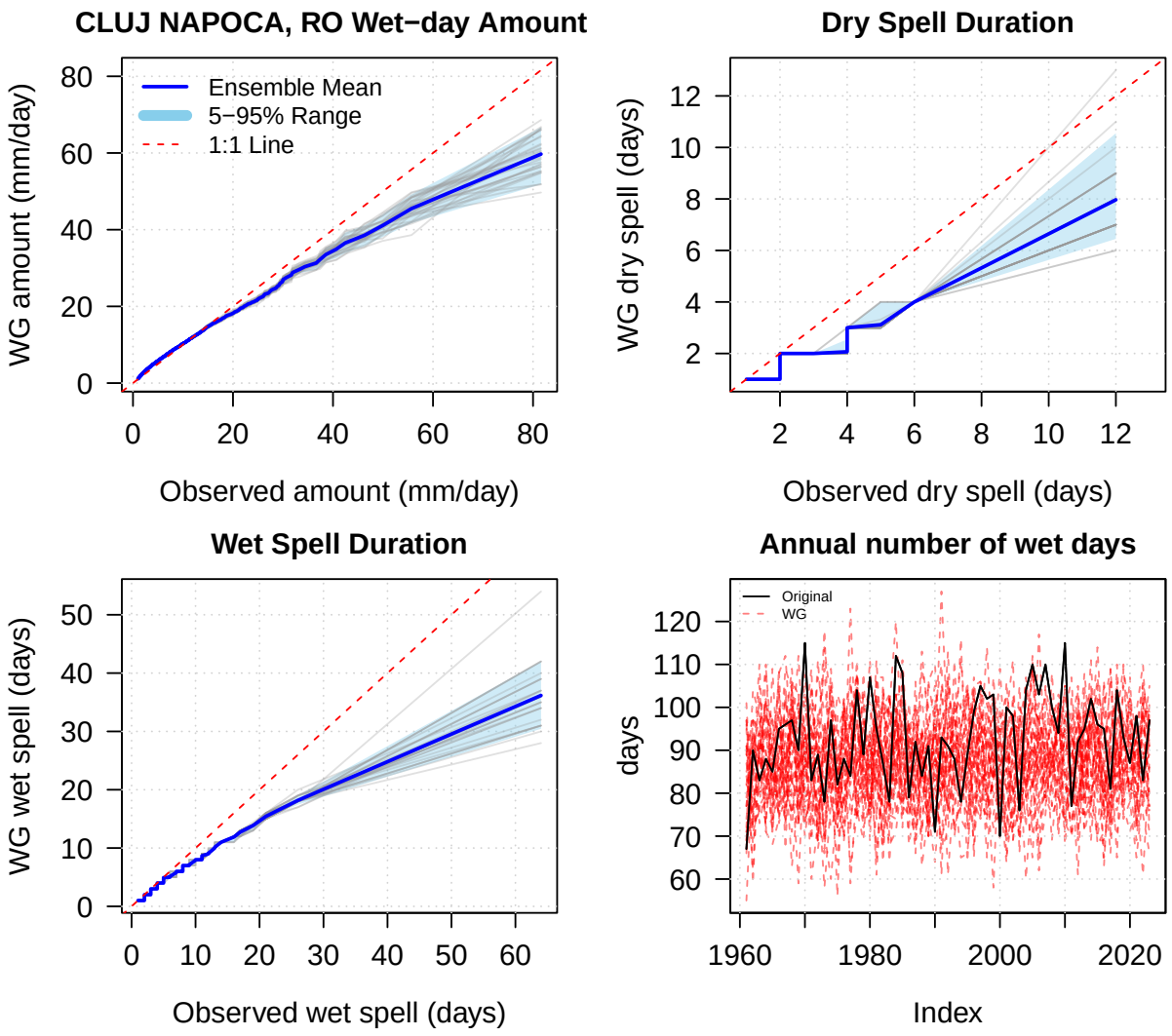


Figure 22: Test of WG performance for different countries.

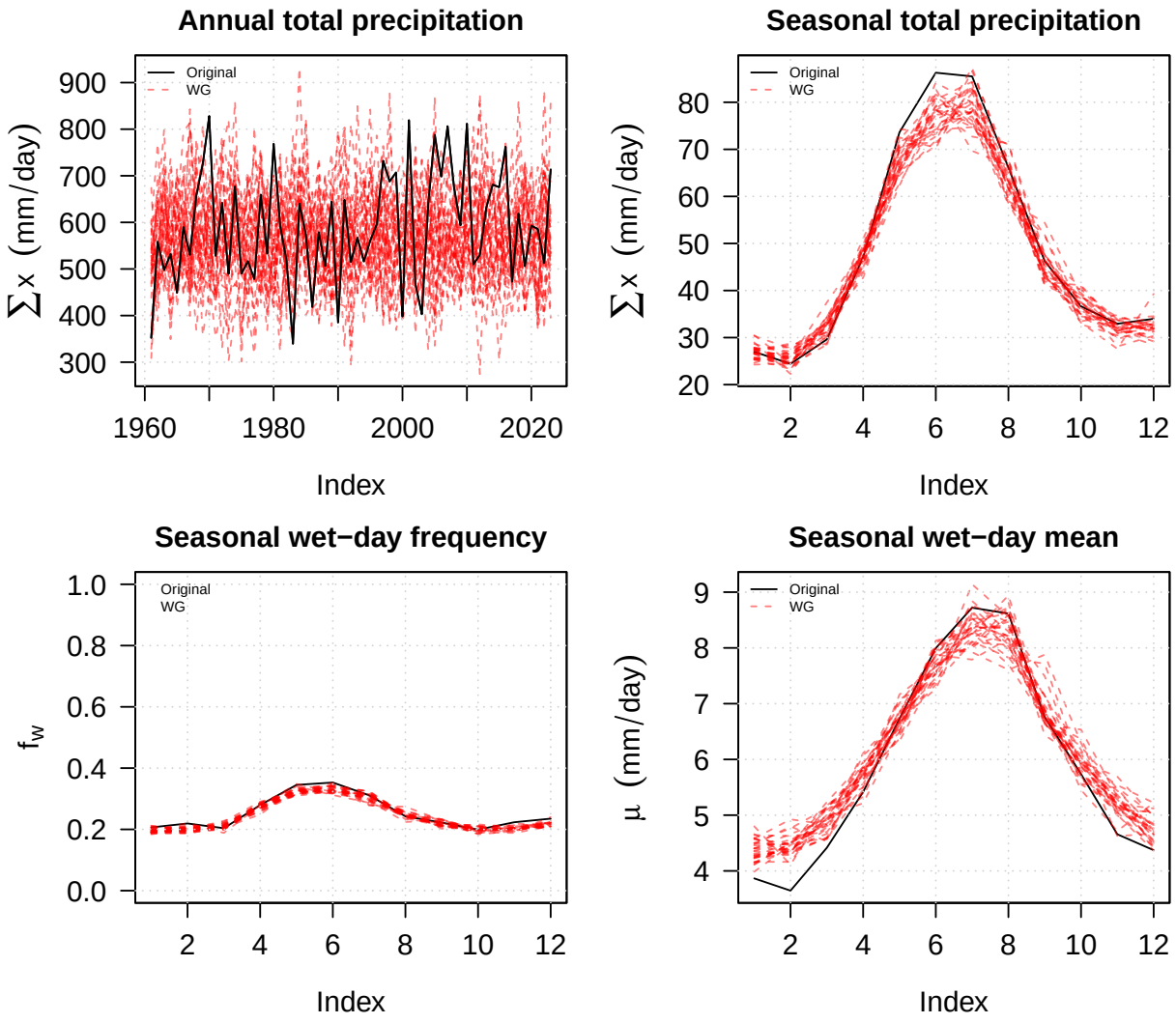


Figure 23: Test of WG performance for different countries.

The data from Naples was also too short for getting good results. The magnitudes, dry-spell and all the other statistics were off.

The test for Romania indicated a better performance, possibly due to more abundant data. The WG exhibited only a modest bias in the rain intensities for more than 20 mm/day, and the dry-spell statistics was only moderately off, although there are some strange features in pairing up of the statistics. The simulated climatology was not perfect, due to mismatches for f_w and μ.

2.2.5 Test the WG on sub-basins in Ghana with hydrological model input data

The downscaled climate scenarios provide input to the widely used Soil and Water Assessment Tool (SWAT) model Gassman et al. (2014), and SWAT is the model intended to be used for the hydrological modelling. The input data involves daily precipitation, temperature, radiation and wind averaged over 26 sub-basins in this case from CHIRPS and ERA5 gridded data sources. To bring together the downscaling work and the hydrological modelling, we try to simulate the daily precipitation used as input with the WG.

In particular, here the empirical-statistical downscaling will be used to reproduce statistical properties such as the annual wet-day frequency and wet-day mean precipitation (the threshold of 1 mm/day defines wet and dry days). The `WG` will subsequently be used to take statistical properties derived through empirical-statistical downscaling and produce daily outcomes with similar format as those used as model input for each sub-basin.

2.2.6 Sub-basin precipitation data used as input for hydrological modelling

Text files of input data were collected and they contained daily data starting from January 1st, 1984. An example_netCDF file was provided that contains data from CHIRPS, also to show an example of the required structure of the netCDF files and data files formatted for SWAT. The file contained sub-basin time-series and the mean rainfall over the sub-basin.

This section contains different data to the GHCND and in this case, the data shown are from CHIRPS. The CHIRPS data is more complete than the GHCND and does not contain missing data. In addition to testing the `WG` for these sub-basin data, we check to see if they also follow the pseudo-exponential distribution identified in Benestad et al. (2019) - the "rain equation".

```
## Read ID,NAME,LAT,LONG,ELEVATION
path <- '~/SPRINGS/data/SubBasin_time-series_data'
pcp.meta <- read.table(file.path(path,'pcp.txt'),sep=',',header=TRUE)
Y <- NULL
for (file in pcp.meta$NAME) {
  raw <- read.table(file.path(path,paste0(file,'.txt')))
  y <- zoo(raw[-1,1],order.by=as.Date(seq(1,dim(raw)[1]-1,by=1),
                                      origin=paste(substr(raw[1,1],1,4),
                                                   substr(raw[1,1],5,6),
                                                substr(raw[1,1],7,8),sep='-')))
  if (is.null(Y)) Y <- y else Y <- merge(Y,y)
}
Y.i2h <- as.station(Y,loc=sub('pcp','sub-basin ',pcp.meta$NAME),lon=pcp.meta$LONG,
                    lat=pcp.meta$LAT,alt=pcp.meta$ELEVATION,cntr='Ghana',
                    param='precip',unit='mm')
plot(Y.i2h)
```

The R-chunk below diagnoses and tests the performance of the WG for the input data used by the SWAT model Gassman et al. (2014).

```
#dev.new()
for (is in 1:length(loc(Y.i2h))) {
  y <- subset(Y.i2h,is=is)
  ## Test whether the WG can represent the time series used for input to the
  ## hydrological model
  test.WG.fwmu.day.precip(y,n=10,verbose=FALSE)
  ## Test whether the time series used for input can be described in terms of the
  ## wet-day frequency and wet-day mean precipitation
  par(mfcol=c(1,1))
  test.rainequation(y,plot=TRUE)
}
```

```
## test.WG.fwmu.day.precip for sub-basin 1  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

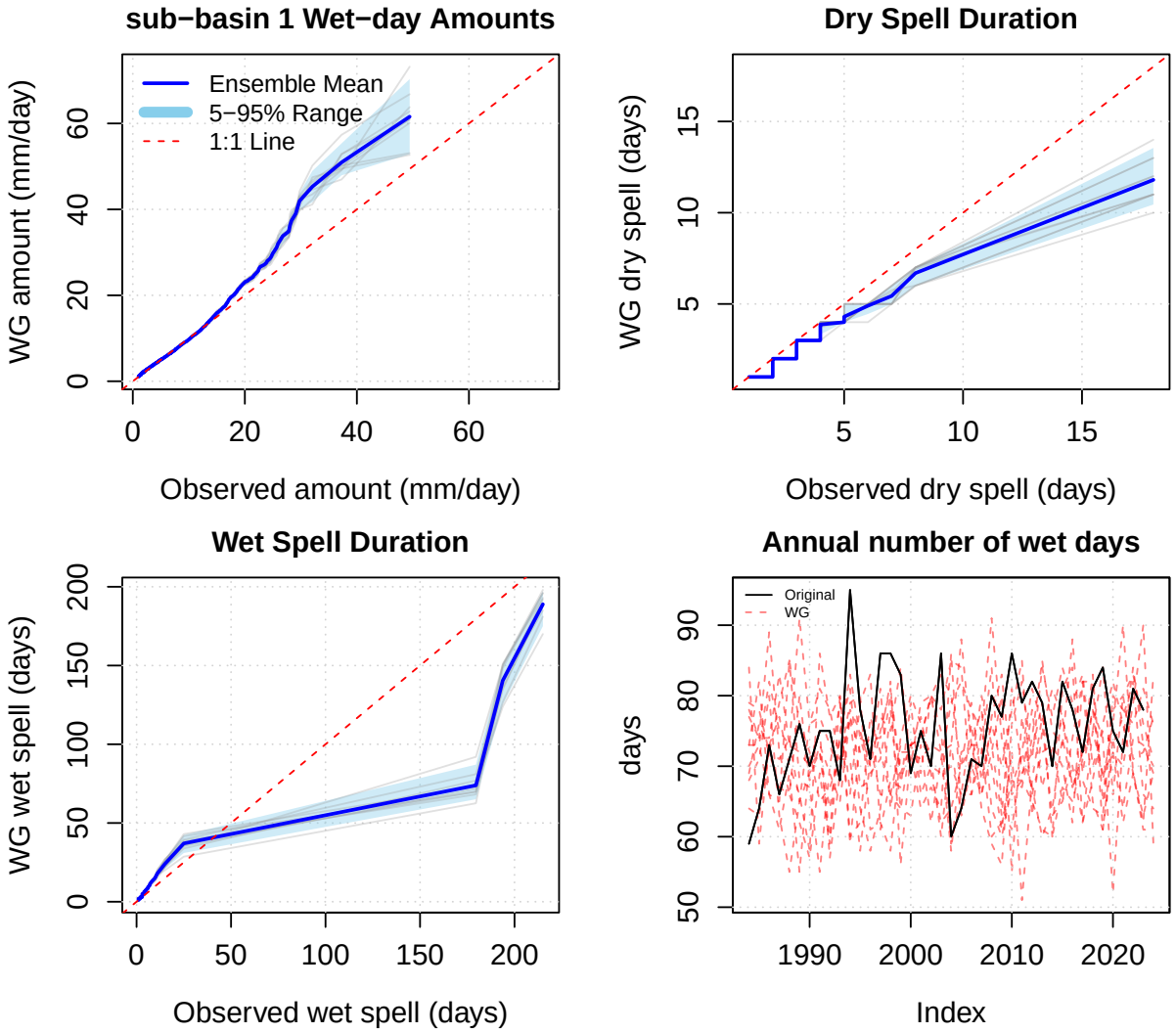


Figure 24: Tests of WG on GHCND data.

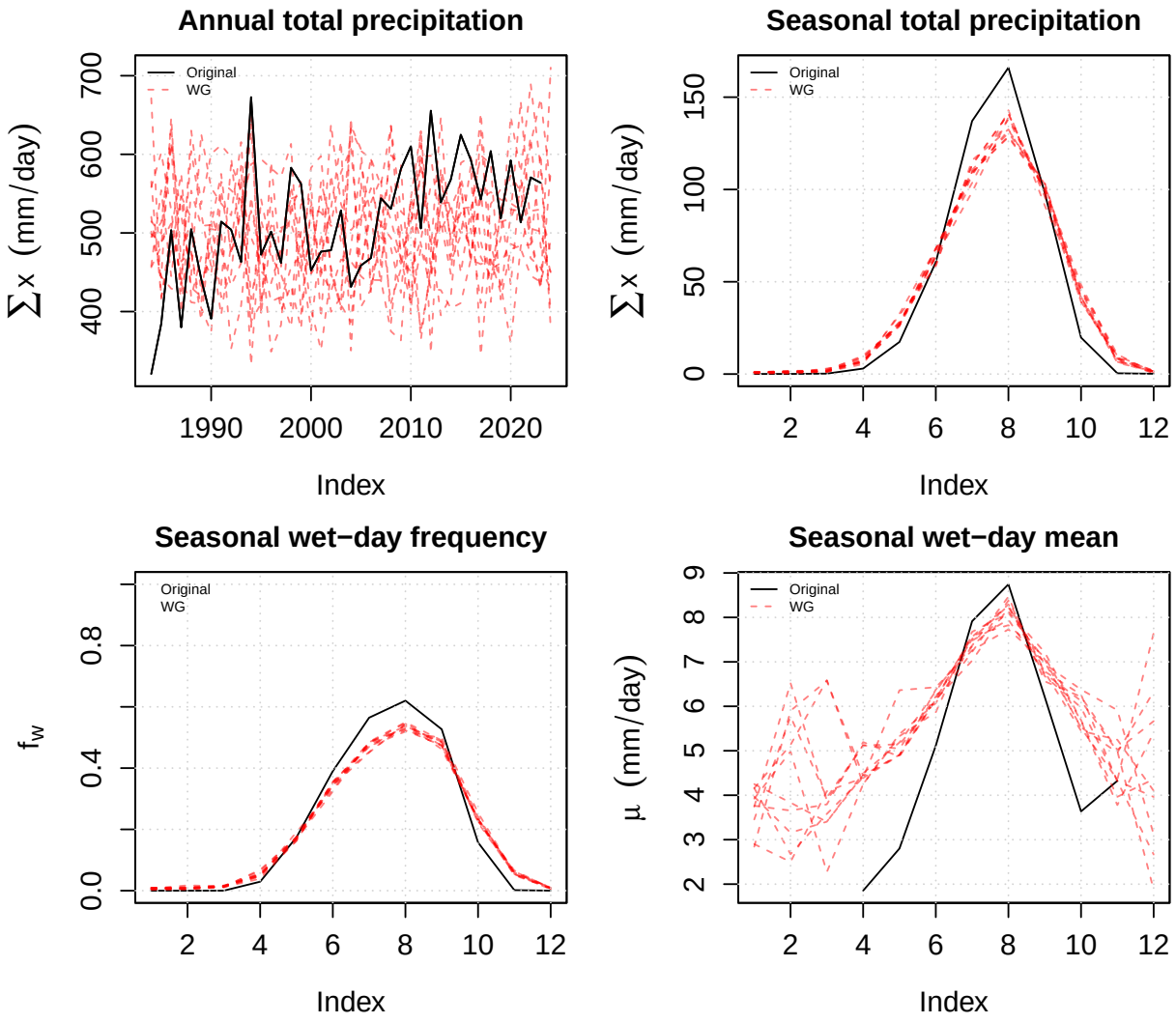


Figure 25: Tests of WG on GHCND data.

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.128   1.183   1.258   1.281   1.341   1.533
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   10.10   11.74   12.77   12.36   12.91   13.64
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6708  0.7693  0.8393  0.8376  0.9206  0.9876
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   13.37   15.08   15.96   15.74   16.78   17.53
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.462   1.562   1.670   1.644   1.717   1.835
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.04571 0.04778 0.05025 0.05009 0.05274 0.05363


## test.WG.fwmu.day.precip for sub-basin 2  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8089  0.9730  1.0354  1.1125  1.2546  1.5027
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   11.19   11.49   12.47   12.20   12.79   13.08
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6096  0.6368  0.6684  0.6964  0.7655  0.8256
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   17.79   19.73   20.58   20.38   21.48   22.51
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.719   1.791   1.872   1.920   2.019   2.267
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.04602 0.04832 0.05105 0.05119 0.05439 0.05620


## test.WG.fwmu.day.precip for sub-basin 3  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6759  0.8122  0.9037  0.9596  1.0824  1.4661
## RMSE for wet-spell duration quantiles:
```

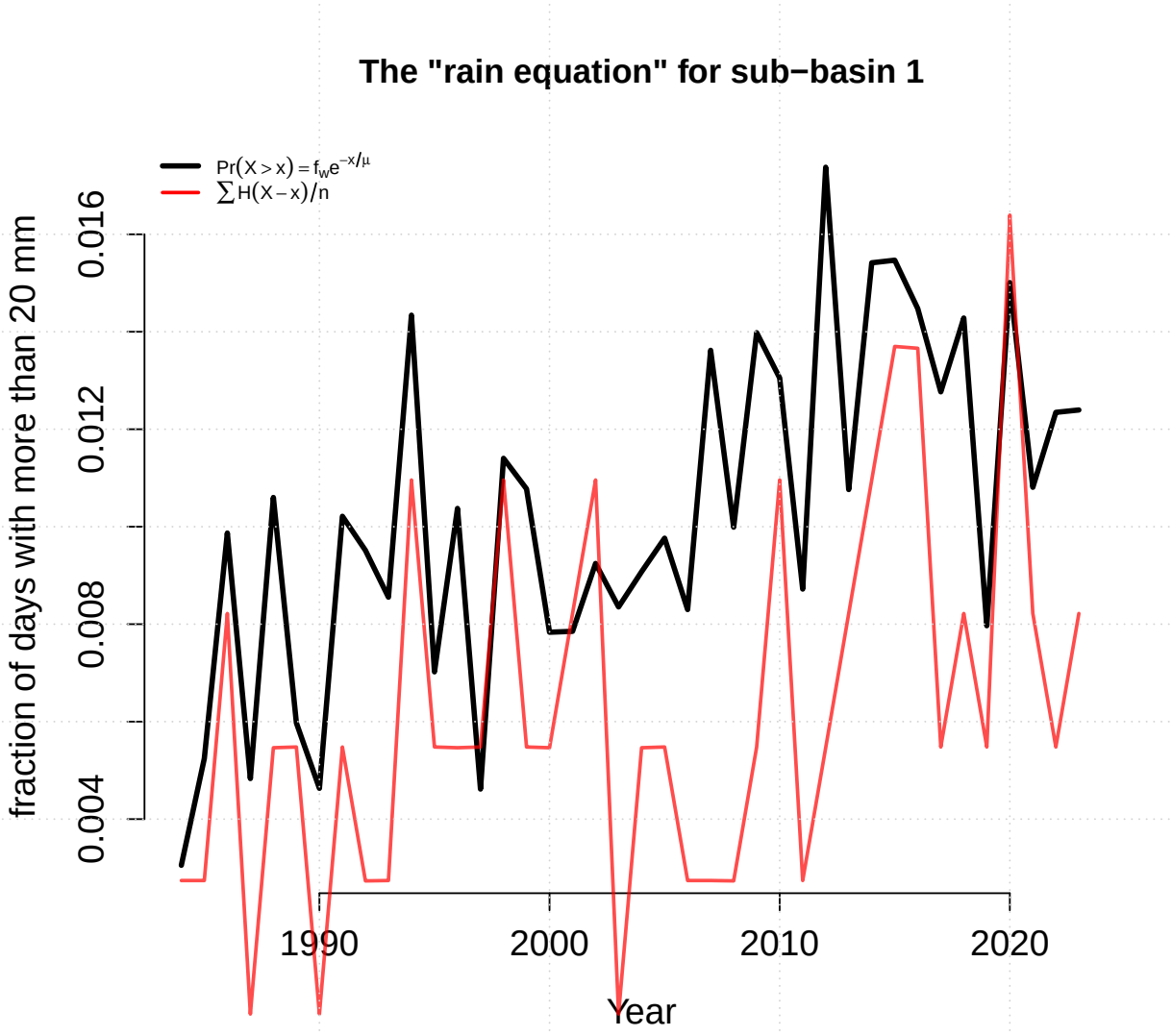


Figure 26: Tests of WG on GHCND data.

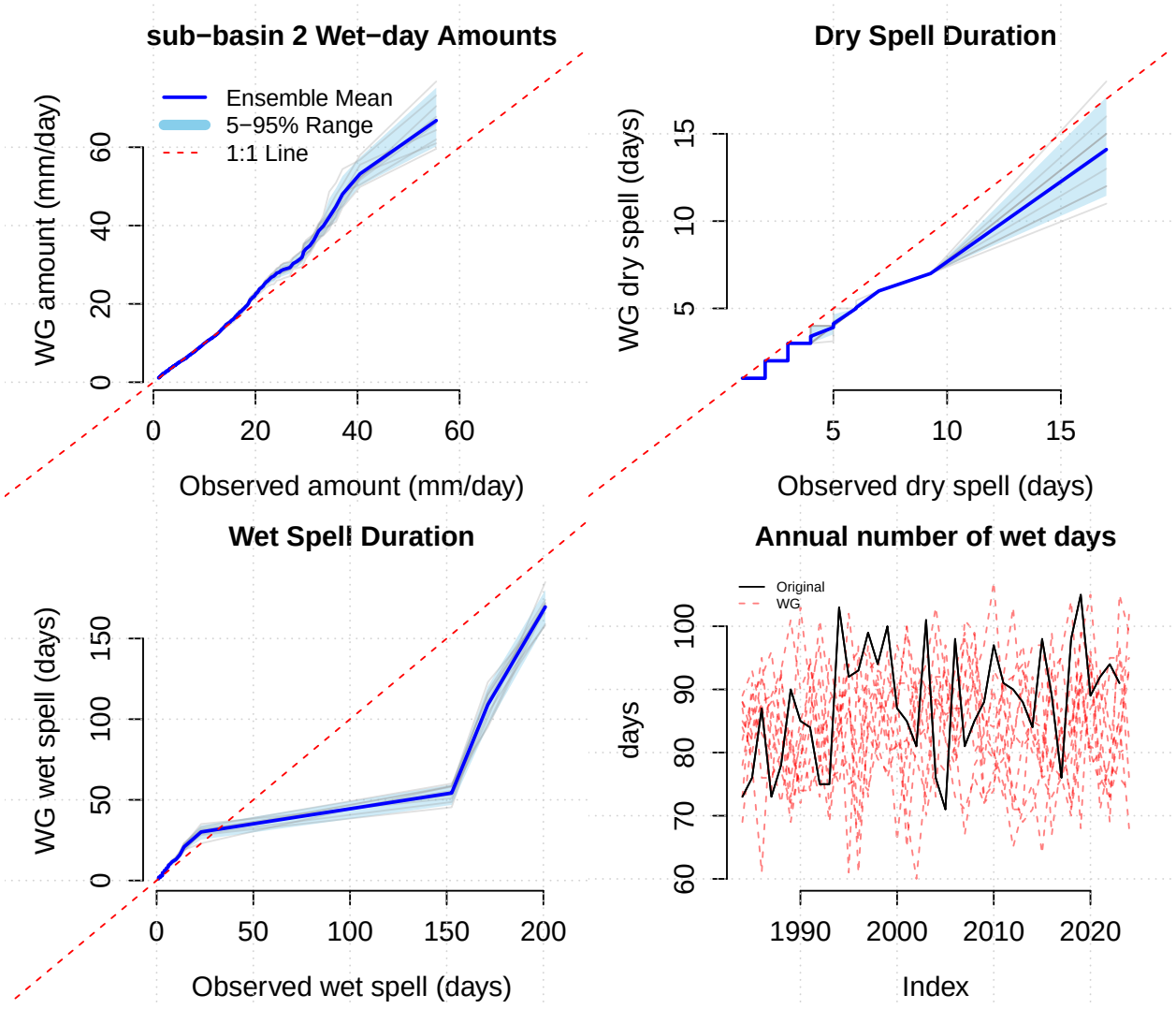


Figure 27: Tests of WG on GHCND data.

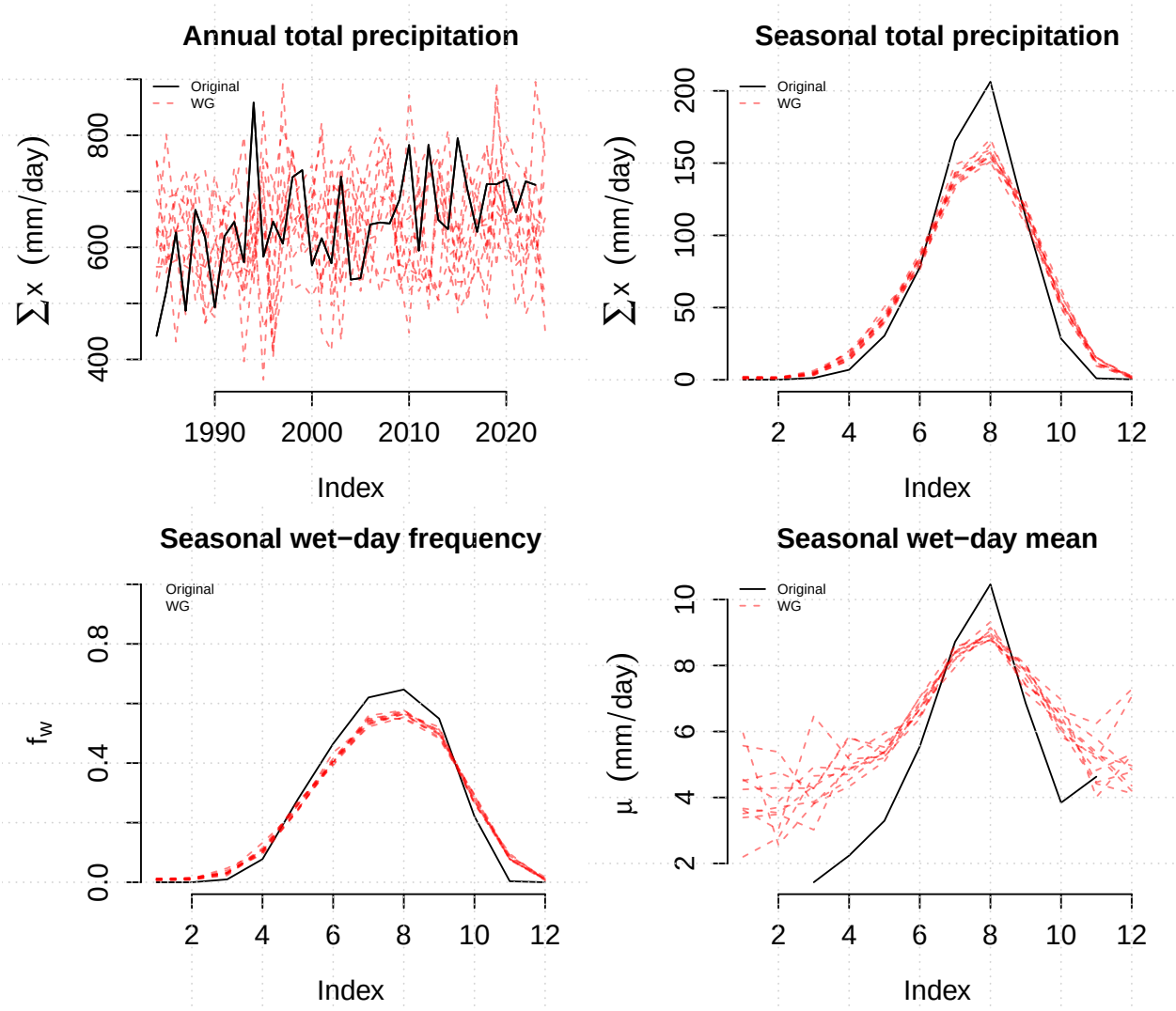


Figure 28: Tests of WG on GHCND data.

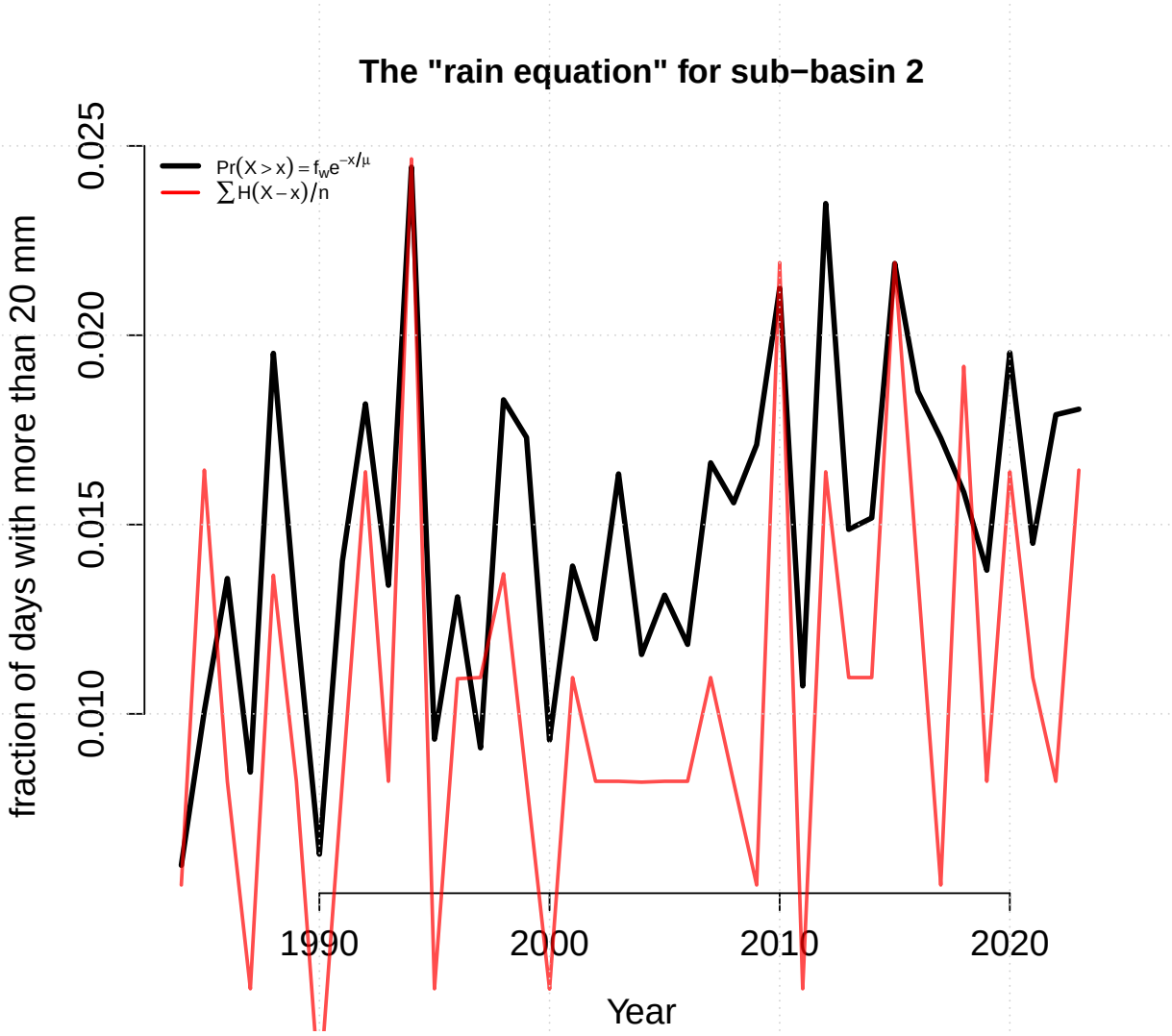


Figure 29: Tests of WG on GHCND data.

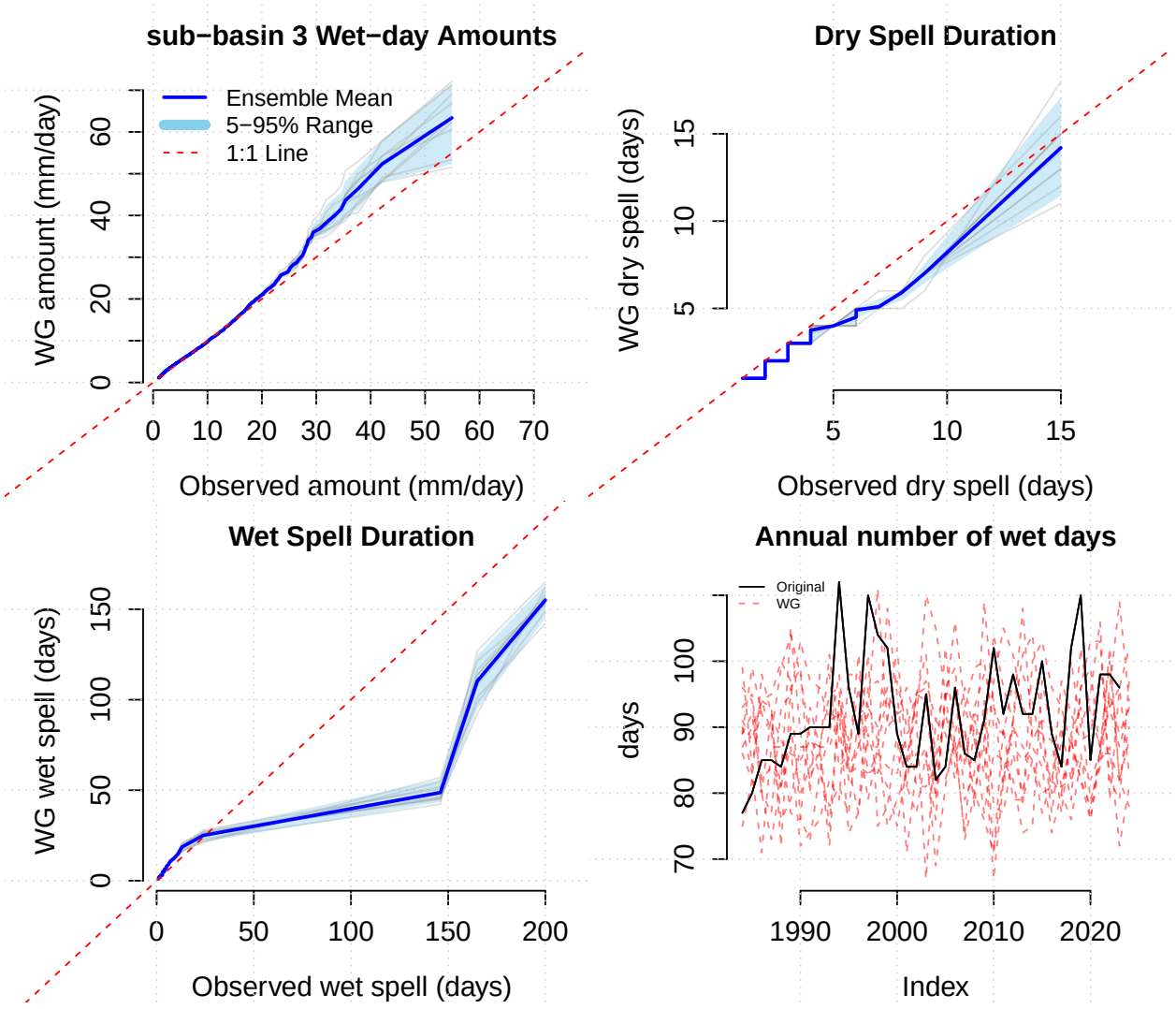


Figure 30: Tests of WG on GHCND data.

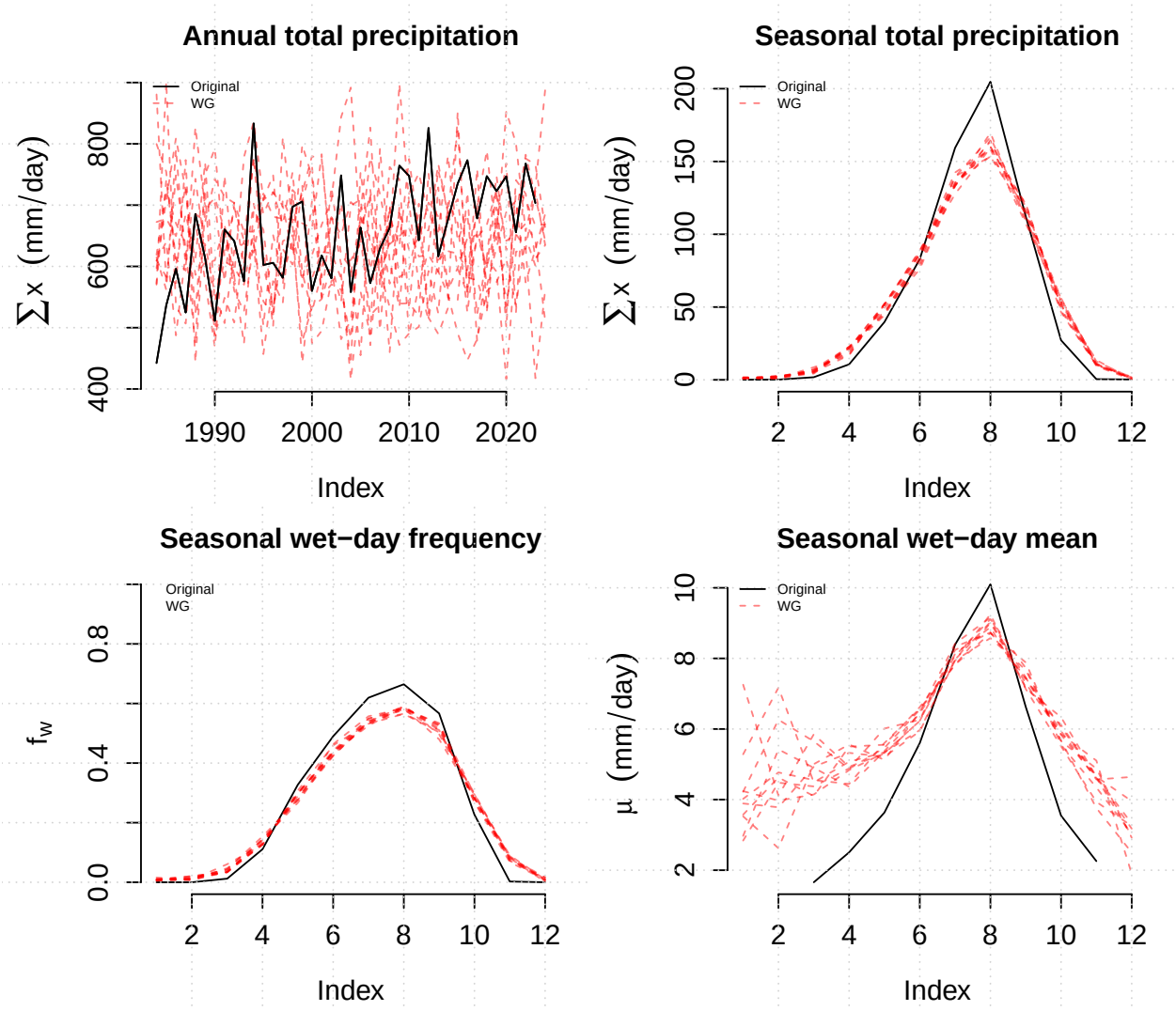


Figure 31: Tests of WG on GHCND data.

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   11.01   11.63   12.03   12.15   12.69   13.28
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6481  0.6656  0.6819  0.7007  0.6998  0.8246
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   16.00   18.00   18.69   18.57   19.50   20.14
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.725   1.813   1.887   1.917   1.990   2.139
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.04526 0.05066 0.05150 0.05163 0.05315 0.05799
```

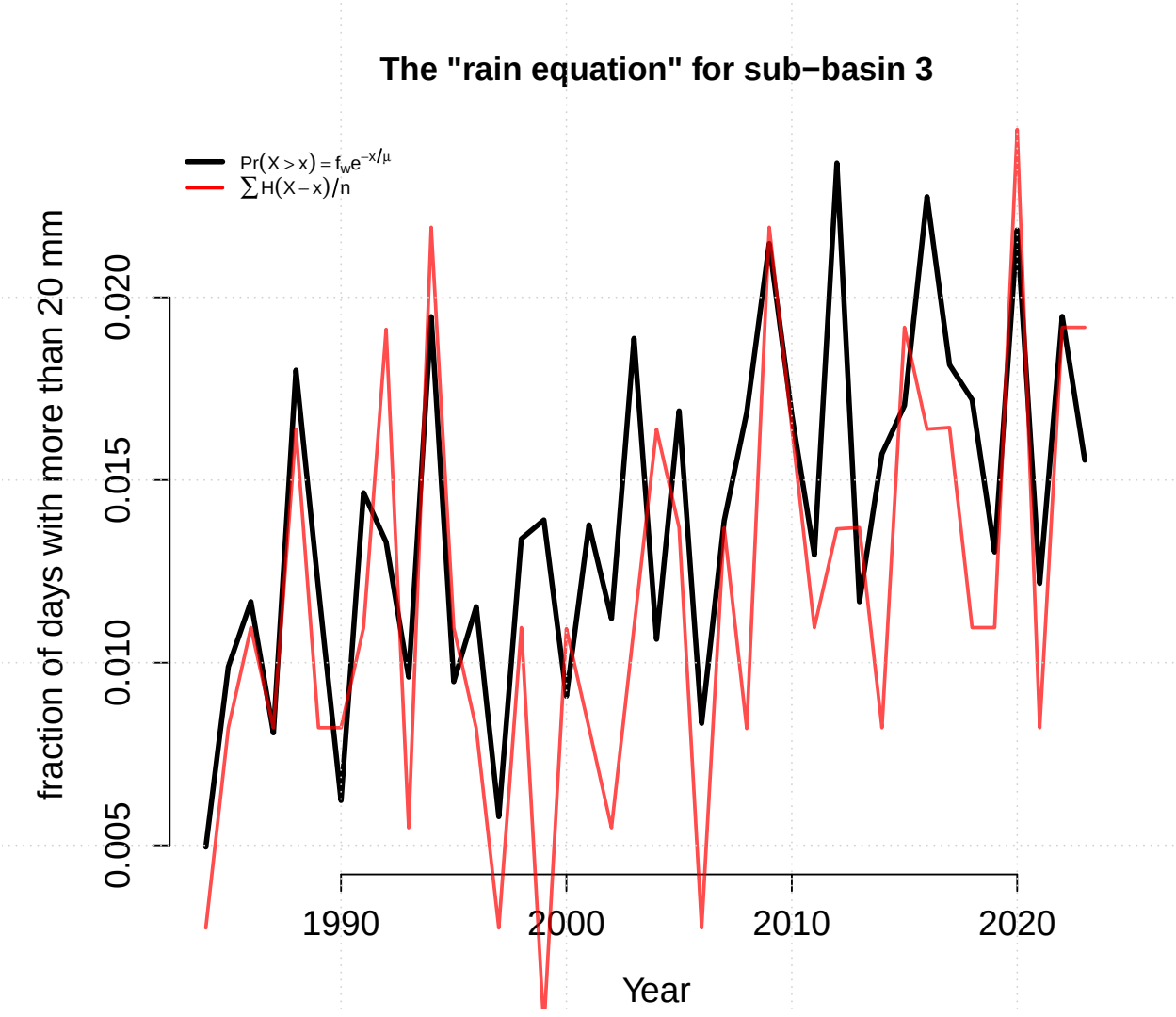


Figure 32: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 4  and  10  runs
```

```
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

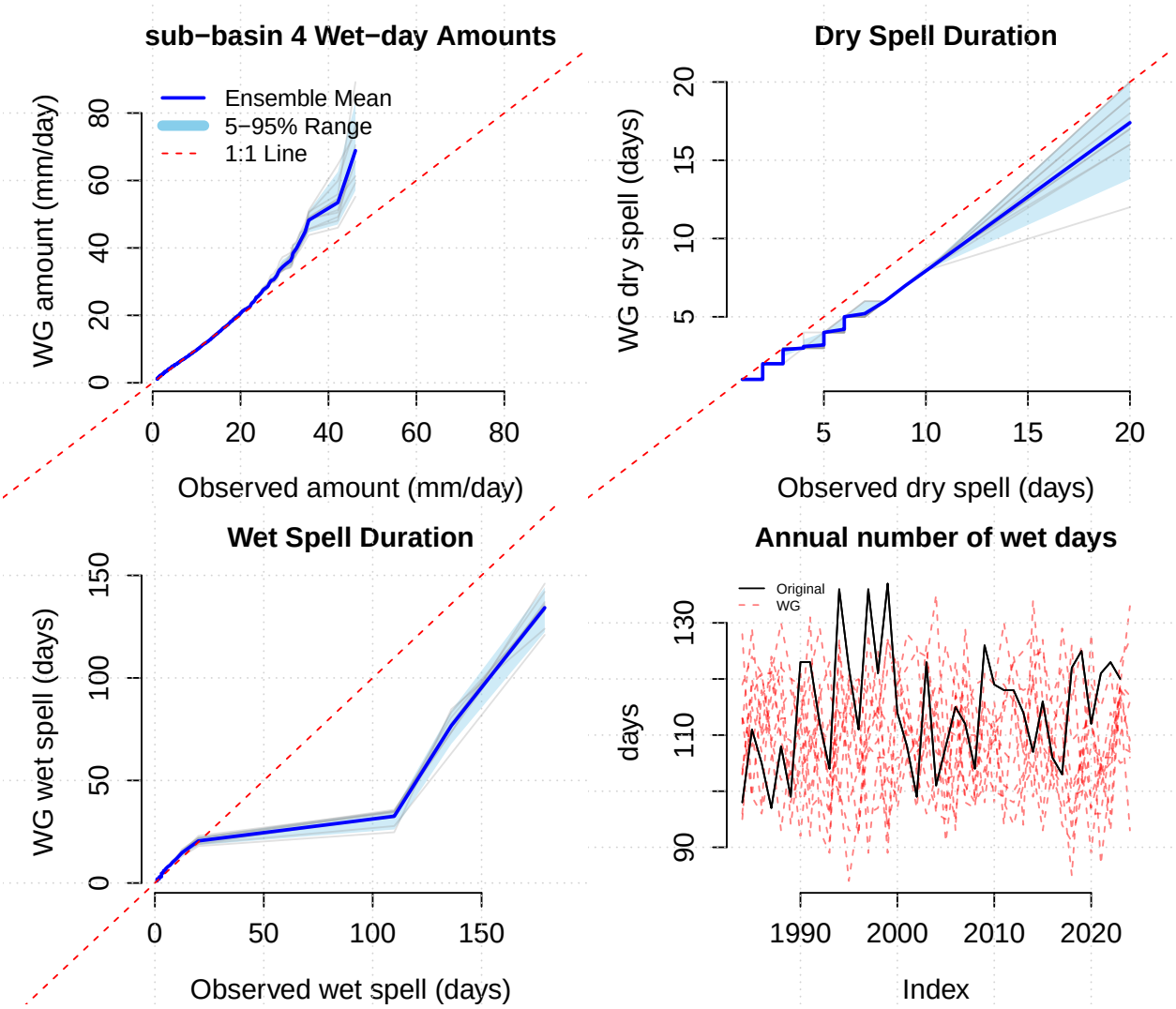


Figure 33: Tests of WG on GHCND data.

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8022  1.1139  1.1605  1.2185  1.3402  1.8393
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   10.26   10.40   10.55   10.79   10.78   12.45
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7309  0.7915  0.8391  0.8509  0.8527  1.1420
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   22.13   22.35   23.10   23.25   24.00   25.03
## RMSE for climatology in wet-day mean precipitation:
```

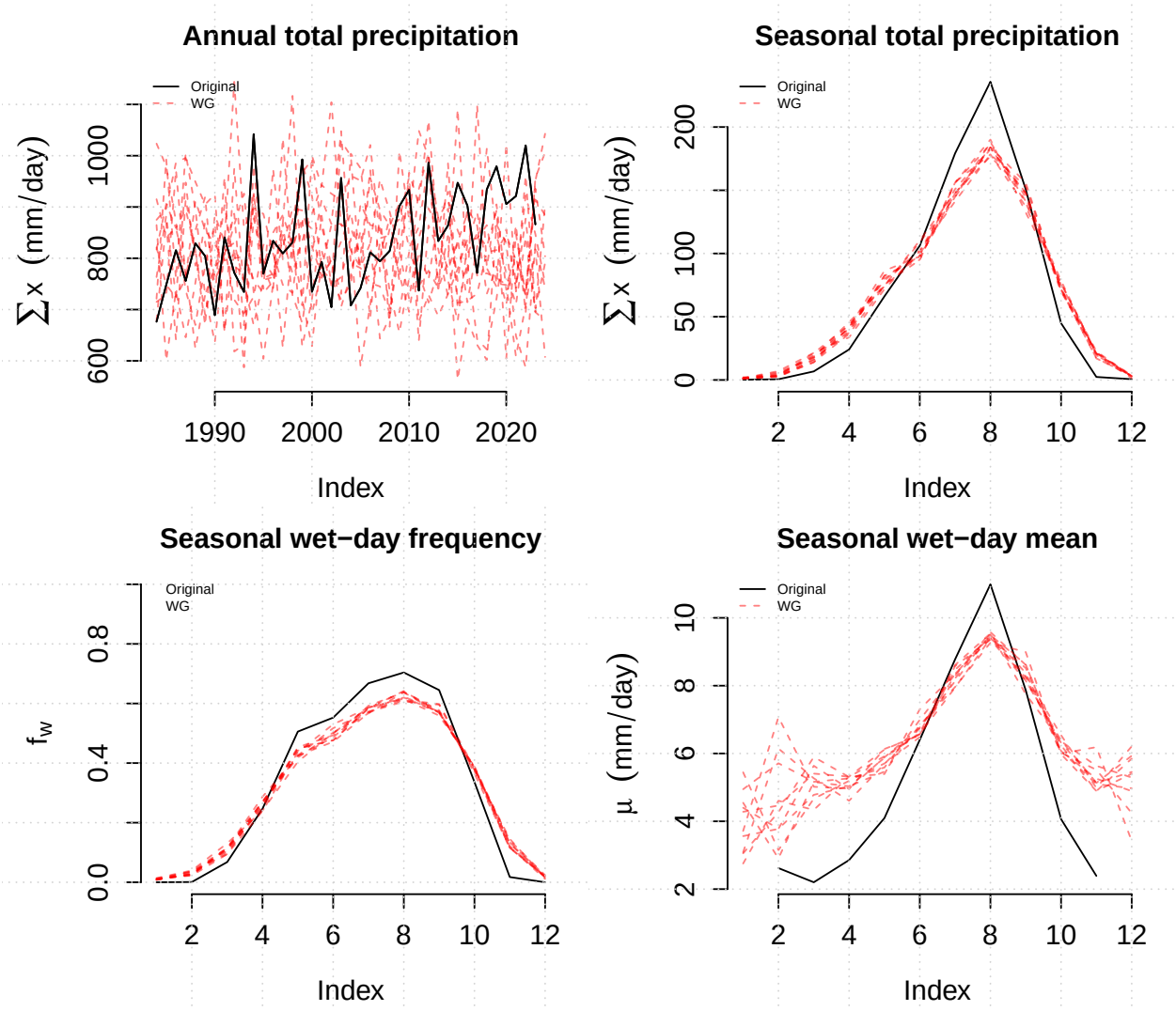


Figure 34: Tests of WG on GHCND data.

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.721   1.872   1.958   1.956   2.049   2.259
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.05345 0.05880 0.06065 0.06170 0.06510 0.06974
```

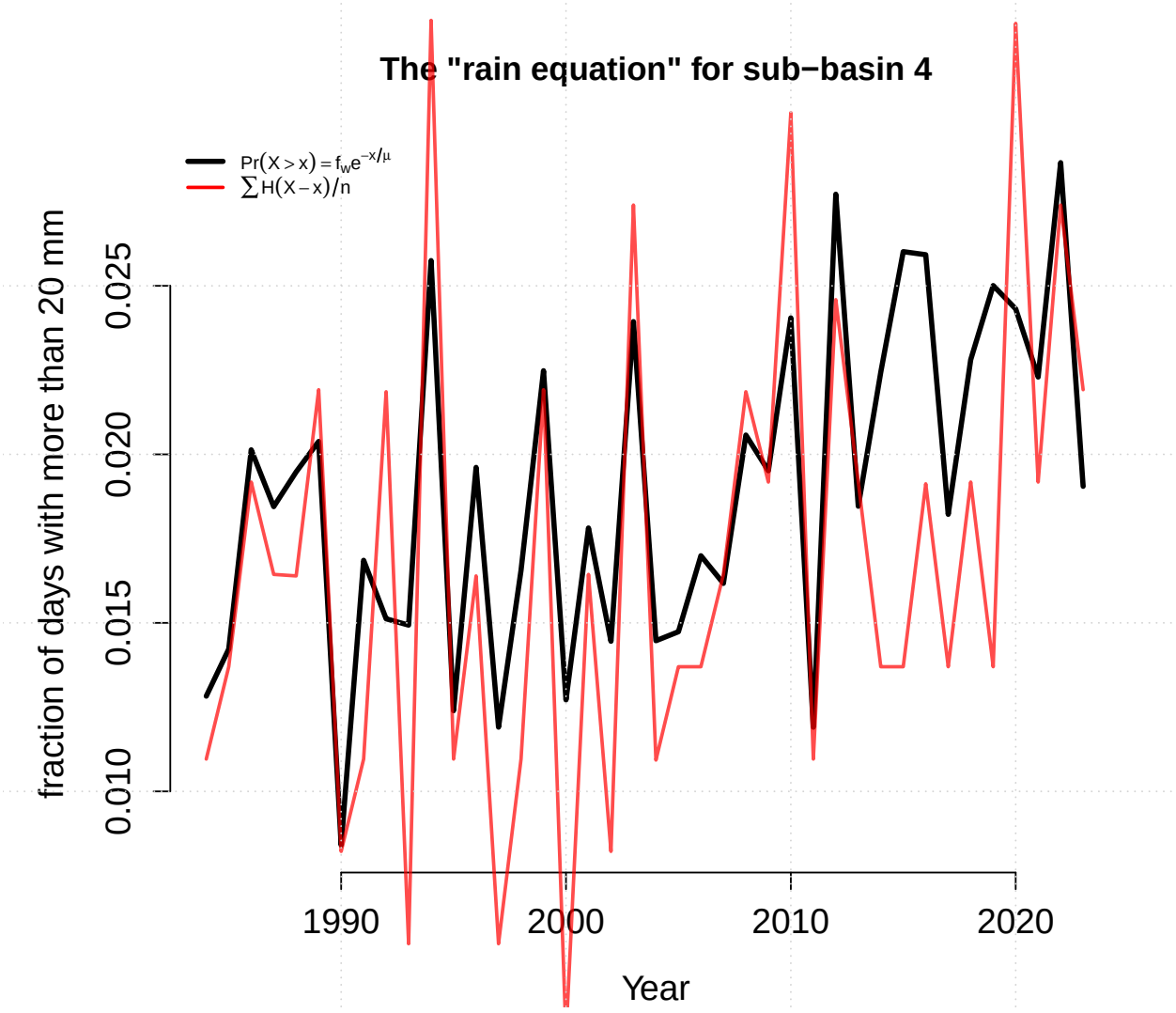


Figure 35: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 5  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.033   2.144   2.372   2.370   2.535   2.804
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

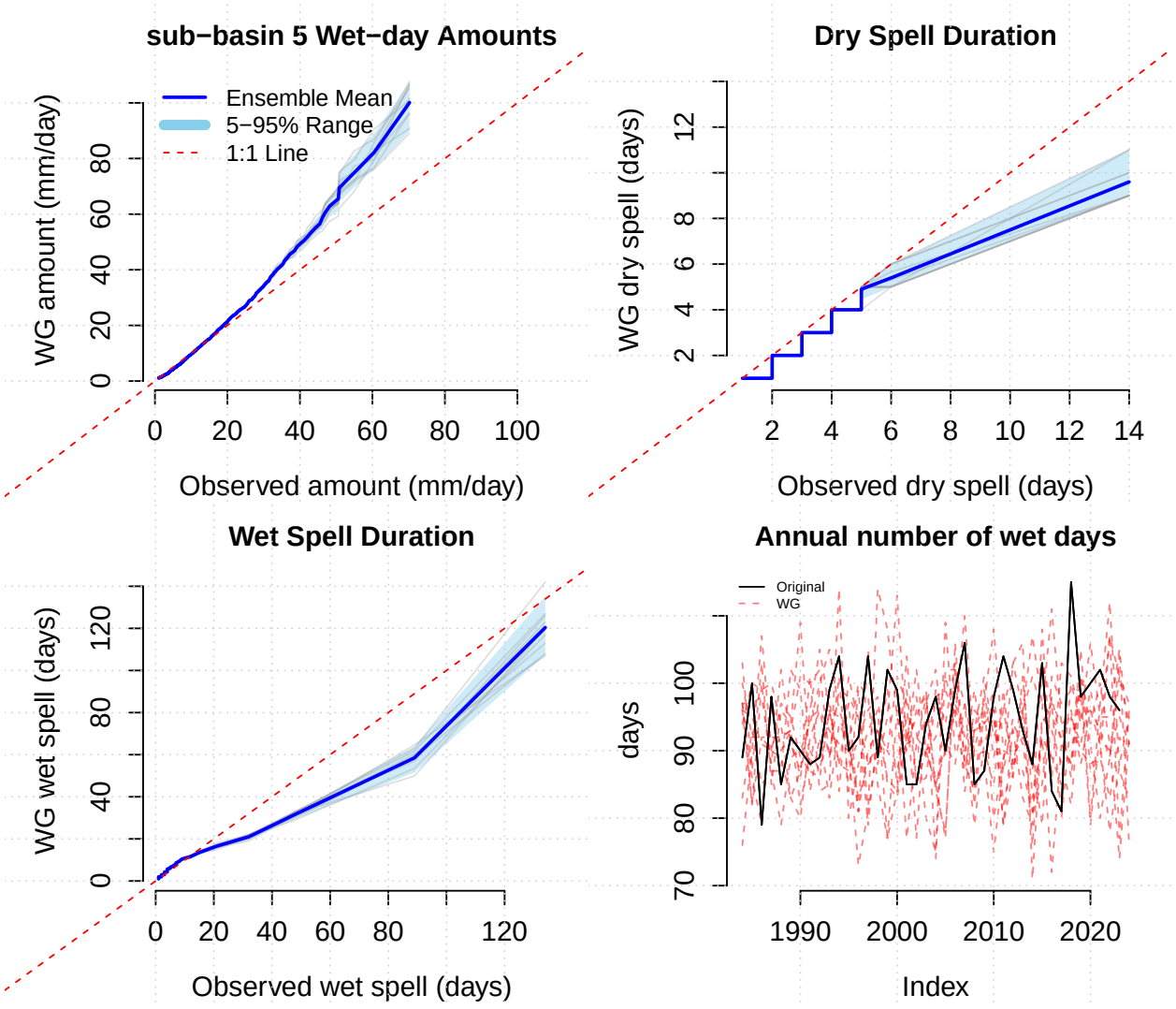


Figure 36: Tests of WG on GHCND data.

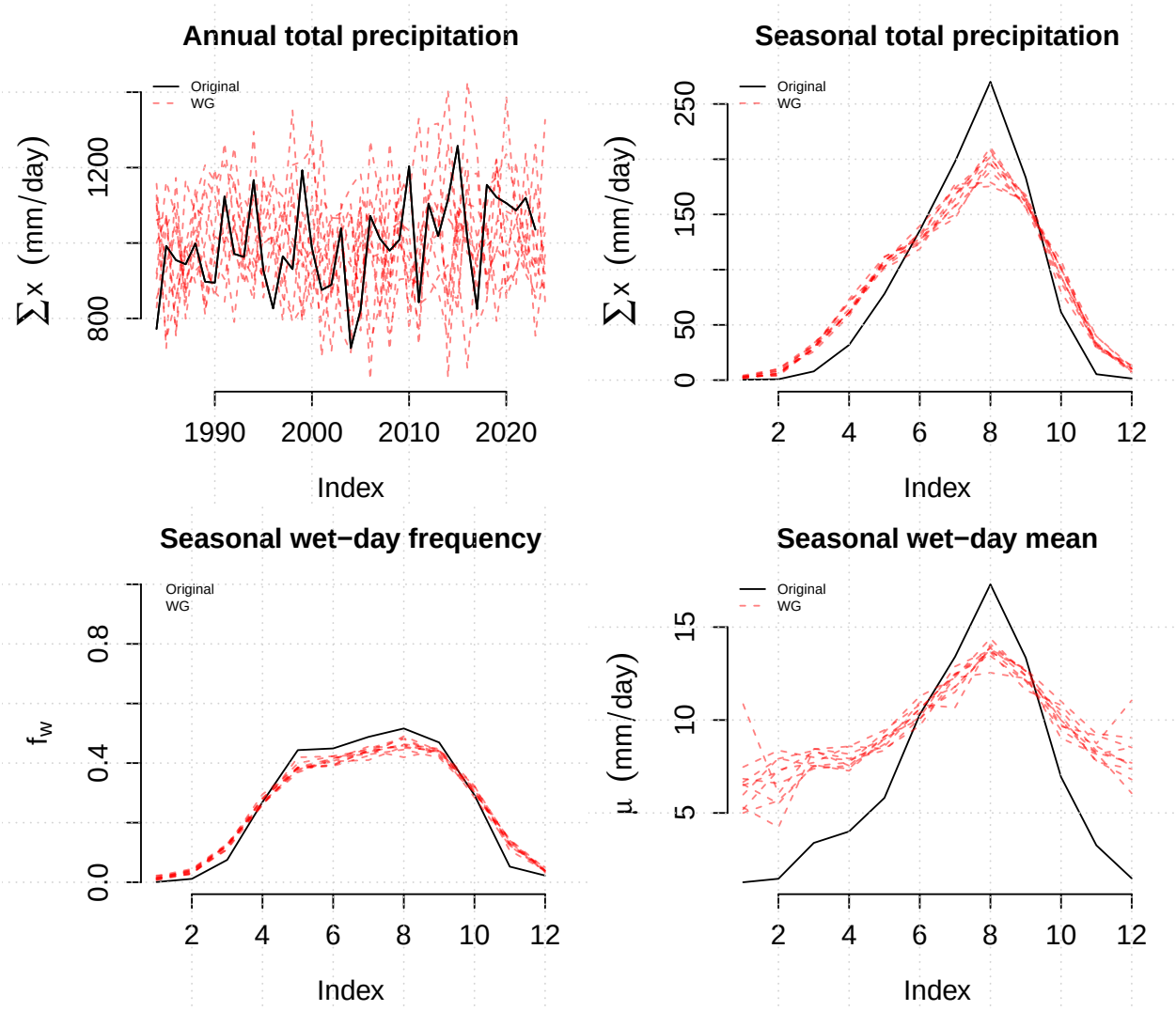


Figure 37: Tests of WG on GHCND data.

```
##   3.441   3.837   4.103   4.082   4.479   4.660
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5054  0.5590  0.6368  0.6030  0.6481  0.6671
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   29.14   30.91   33.98   33.34   35.72   36.38
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.718   3.848   4.044   4.110   4.355   4.607
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.03823 0.04135 0.04303 0.04327 0.04530 0.04923
```

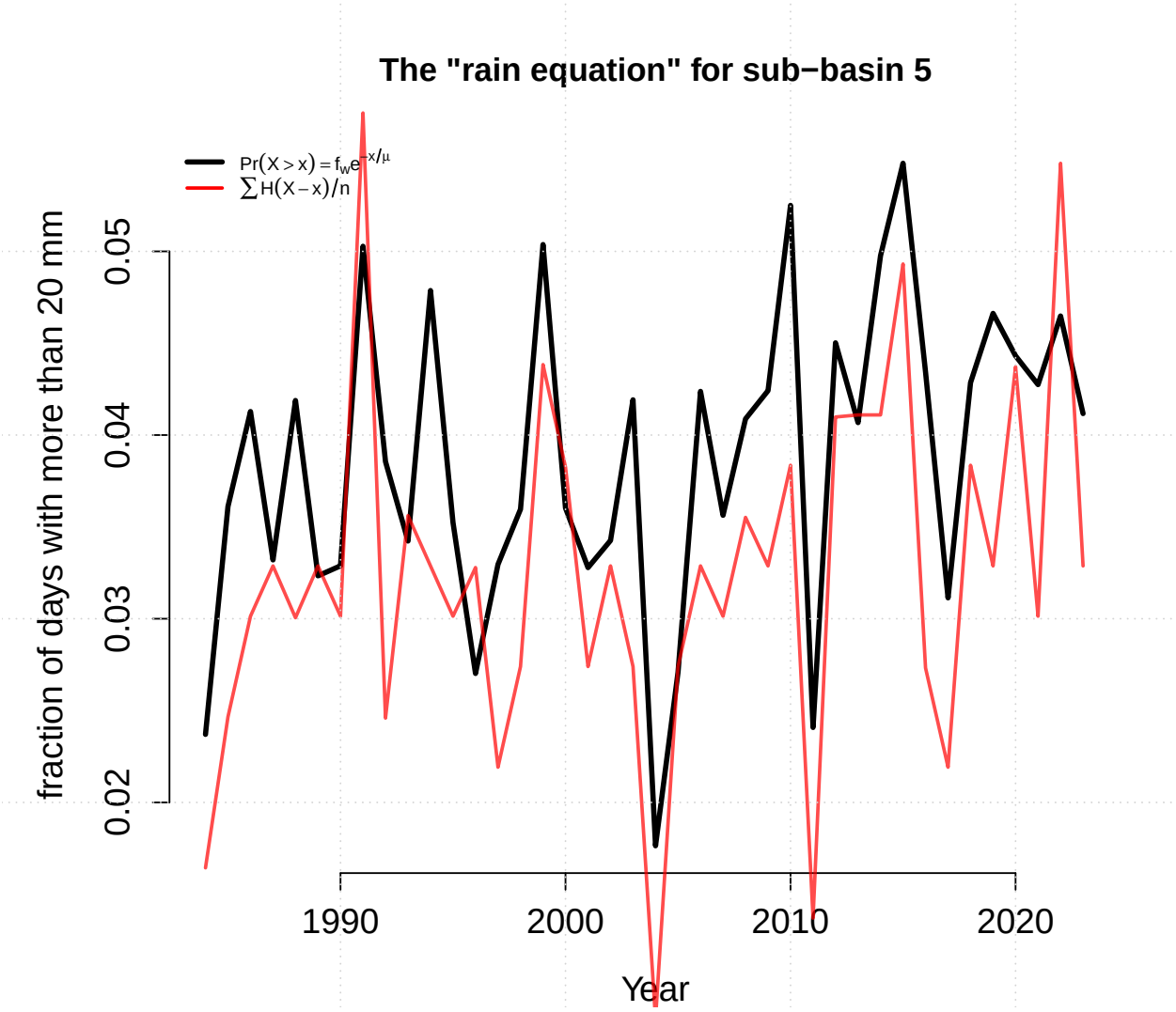


Figure 38: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 6  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

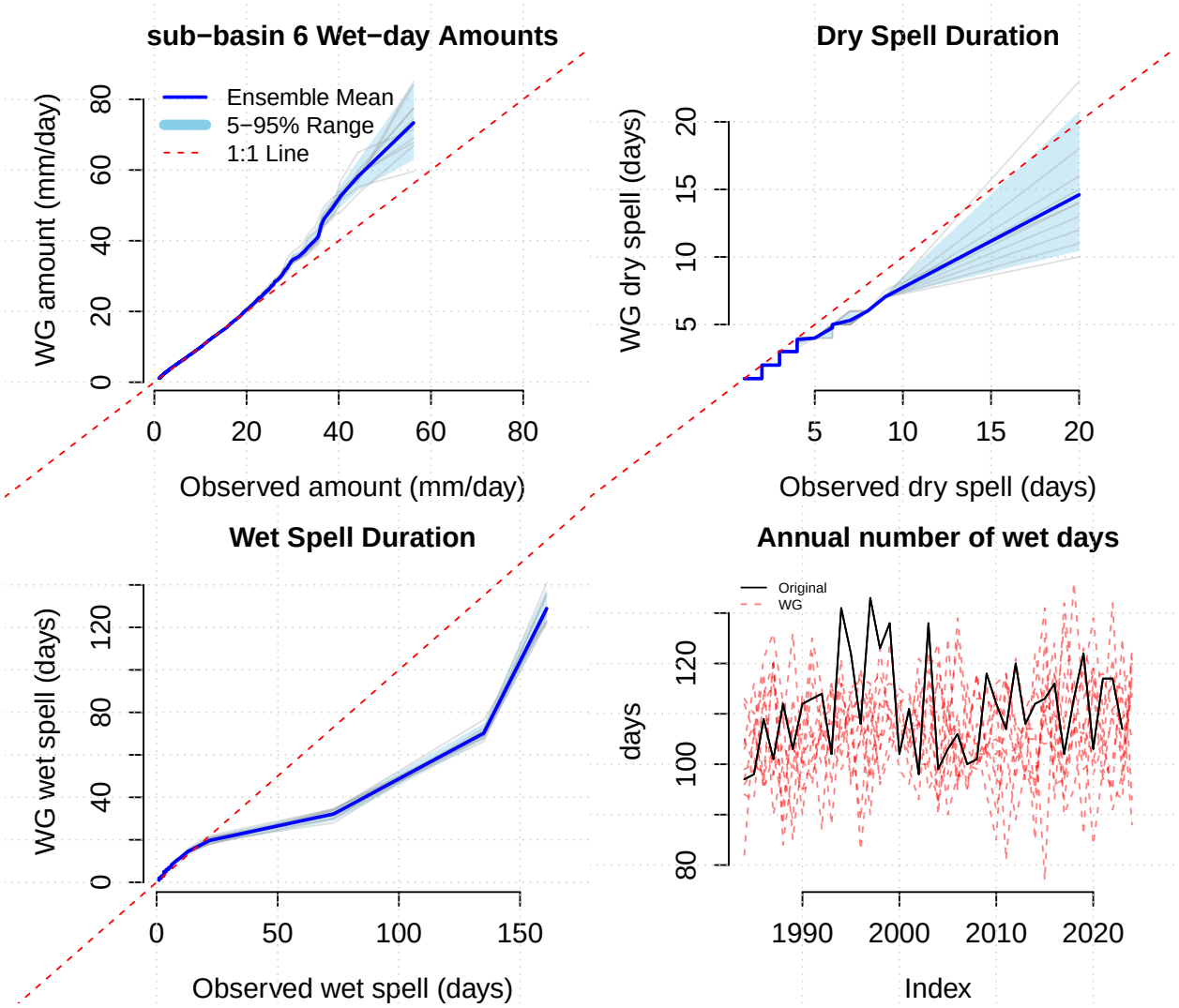


Figure 39: Tests of WG on GHCND data.

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8689  1.0856  1.1779  1.2003  1.3572  1.4704
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   8.017   8.124   8.421   8.379   8.578   8.700
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7348  0.8338  0.9165  0.9380  1.0305  1.1960
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   21.47   22.33   23.72   23.92   25.43   27.37
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.019   2.113   2.188   2.266   2.489   2.550
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

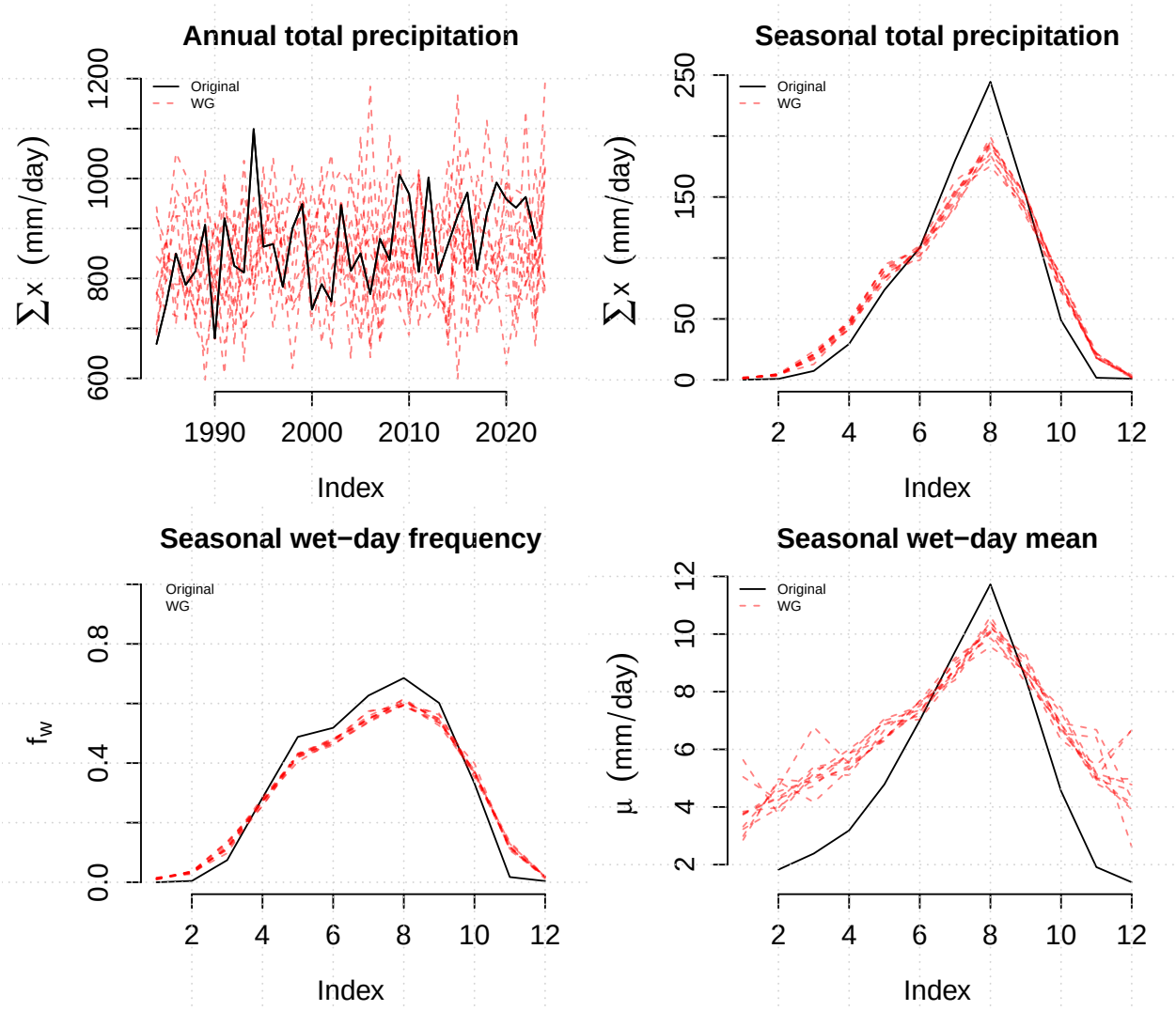


Figure 40: Tests of WG on GHCND data.

```
## 0.05249 0.05480 0.05727 0.05658 0.05789 0.06020
```

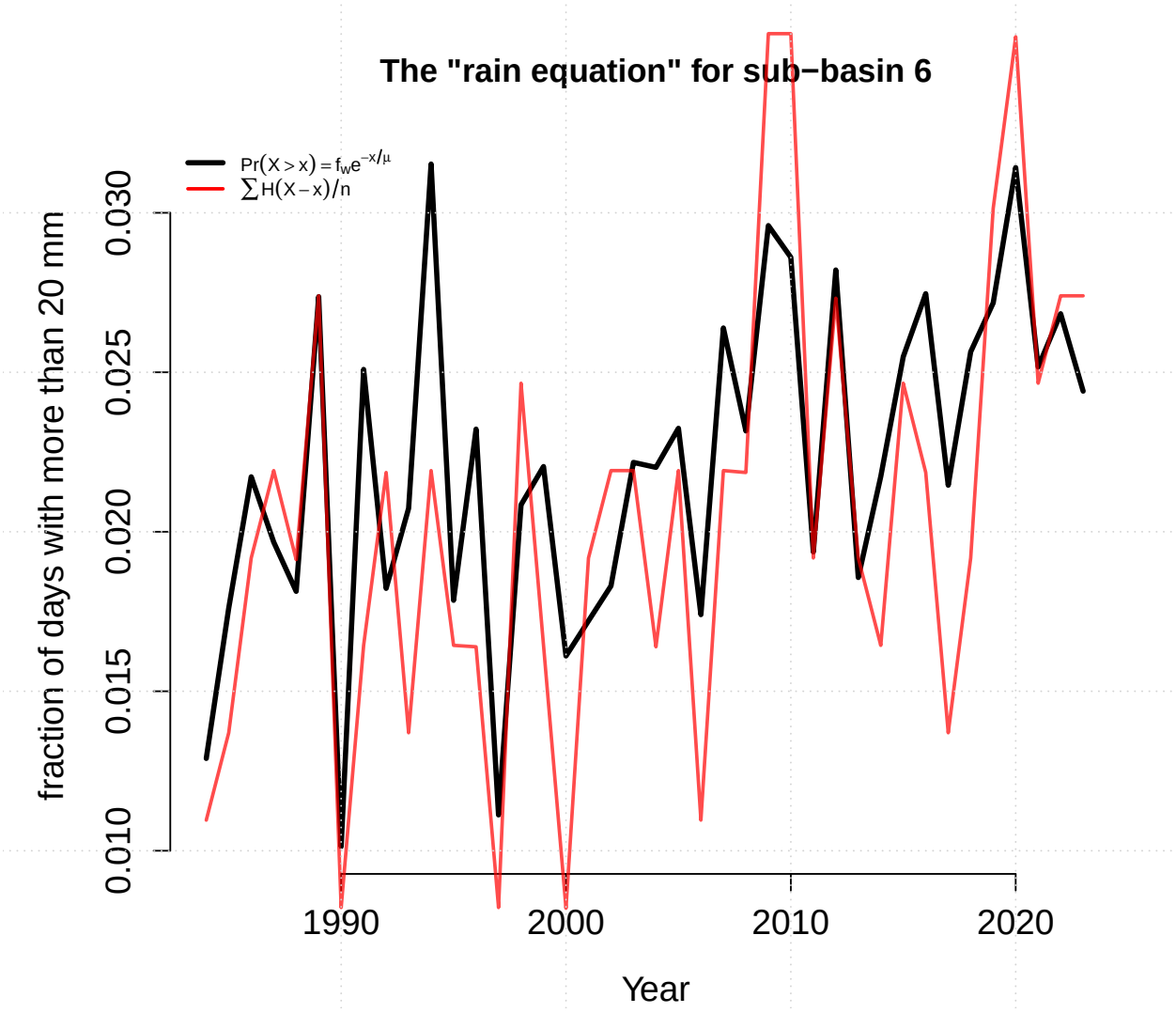


Figure 41: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 7  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5152  0.8421  0.9225  0.8882  0.9876  1.0673
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   8.198   8.414   8.799   8.910   9.020  10.244
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7685  0.8132  0.8292  0.8769  0.9747  1.0086
```

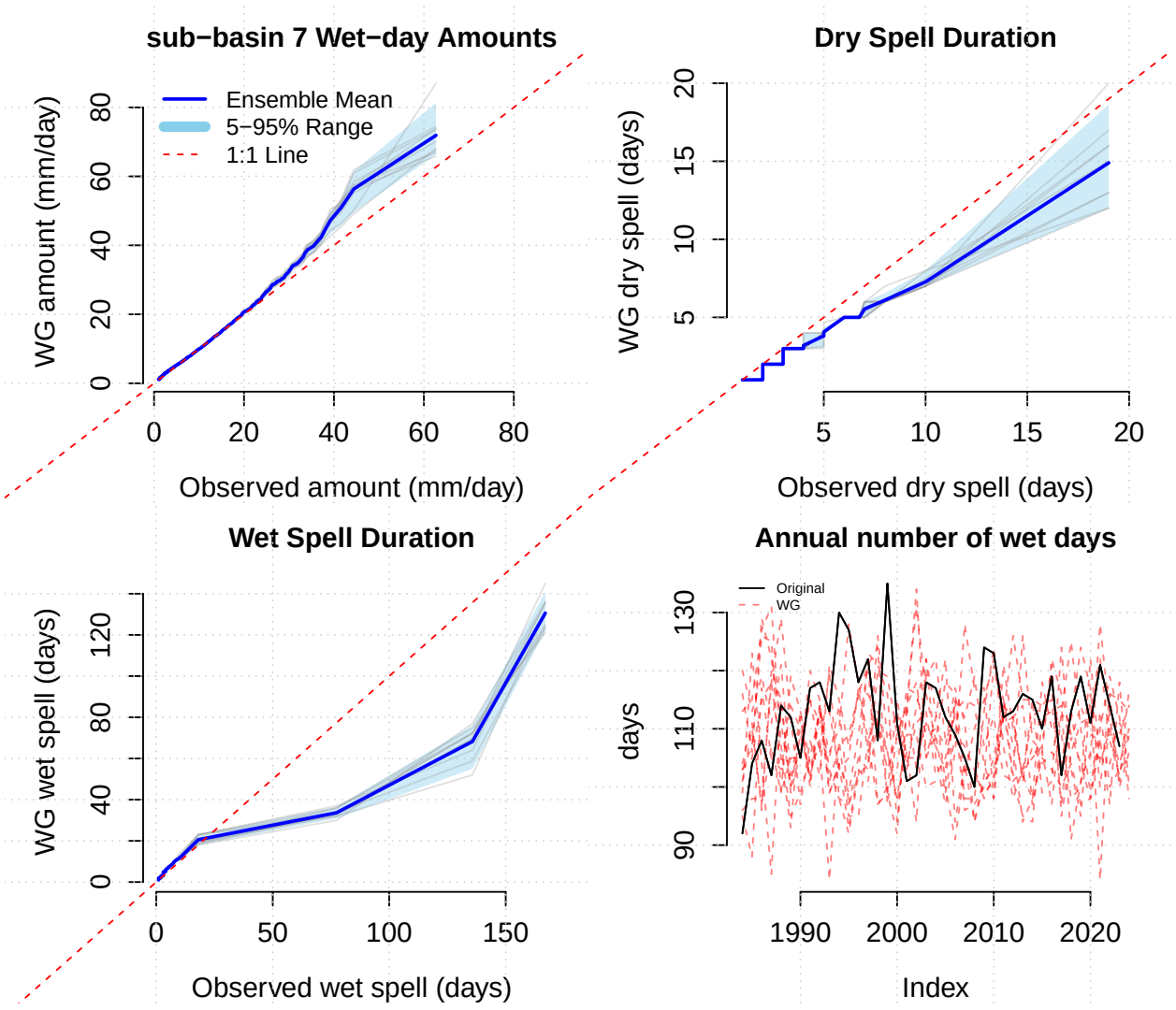


Figure 42: Tests of WG on GHCND data.

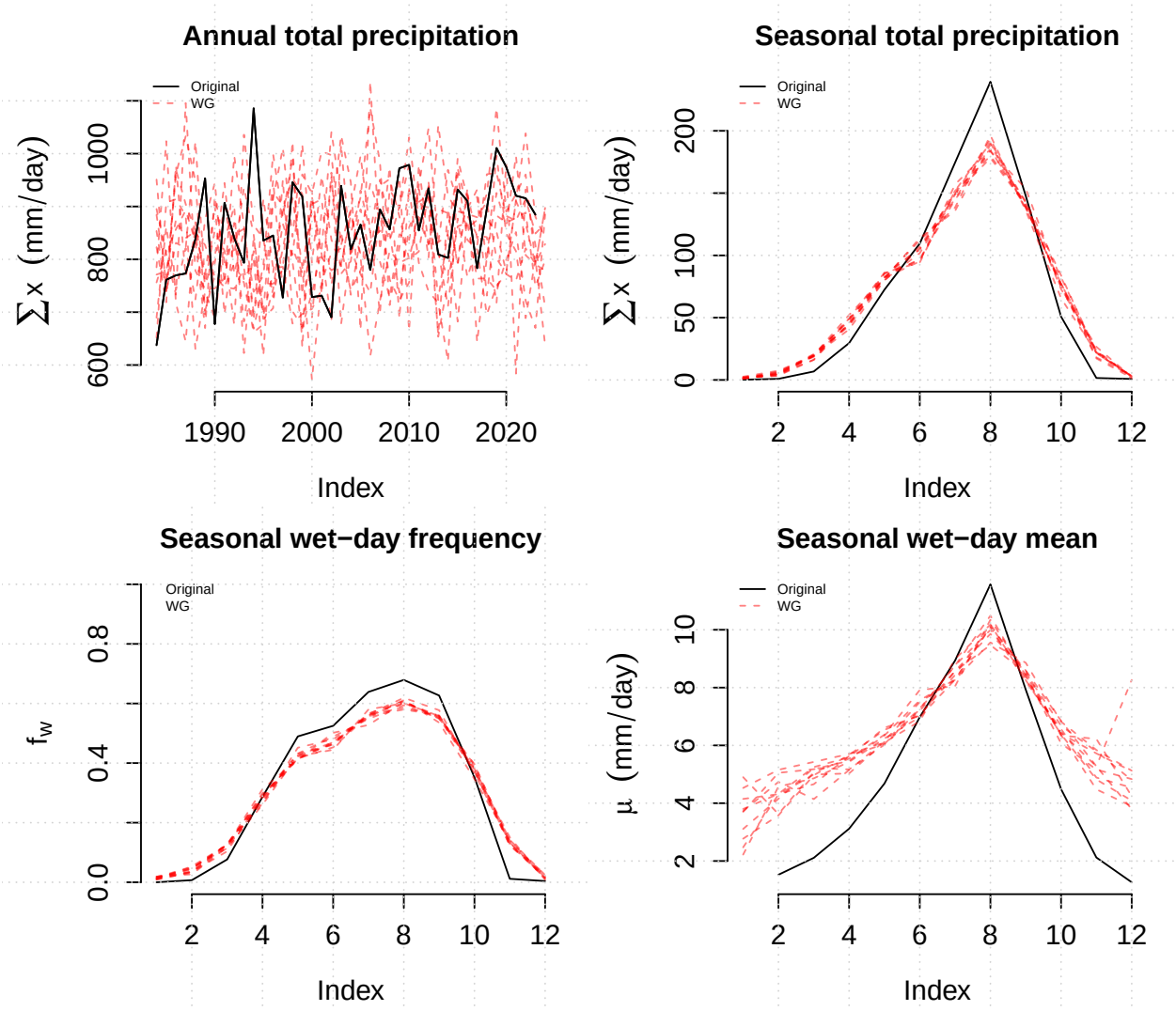


Figure 43: Tests of WG on GHCND data.

```
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   20.43   21.82   22.91   22.83   23.66   25.51
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.888   2.146   2.233   2.266   2.366   2.873
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.05711 0.06054 0.06117 0.06161 0.06329 0.06597
```

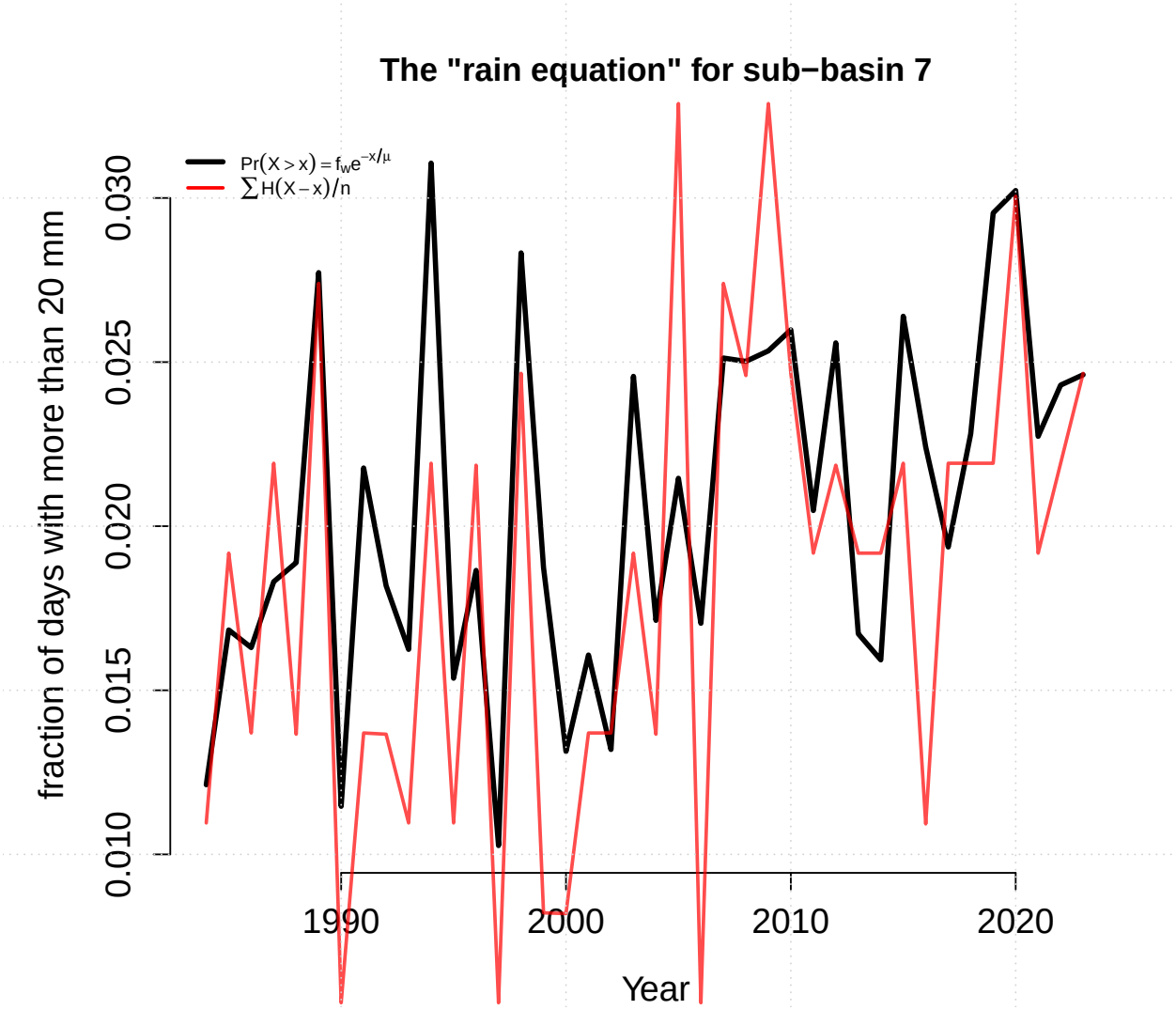


Figure 44: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 8  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
```

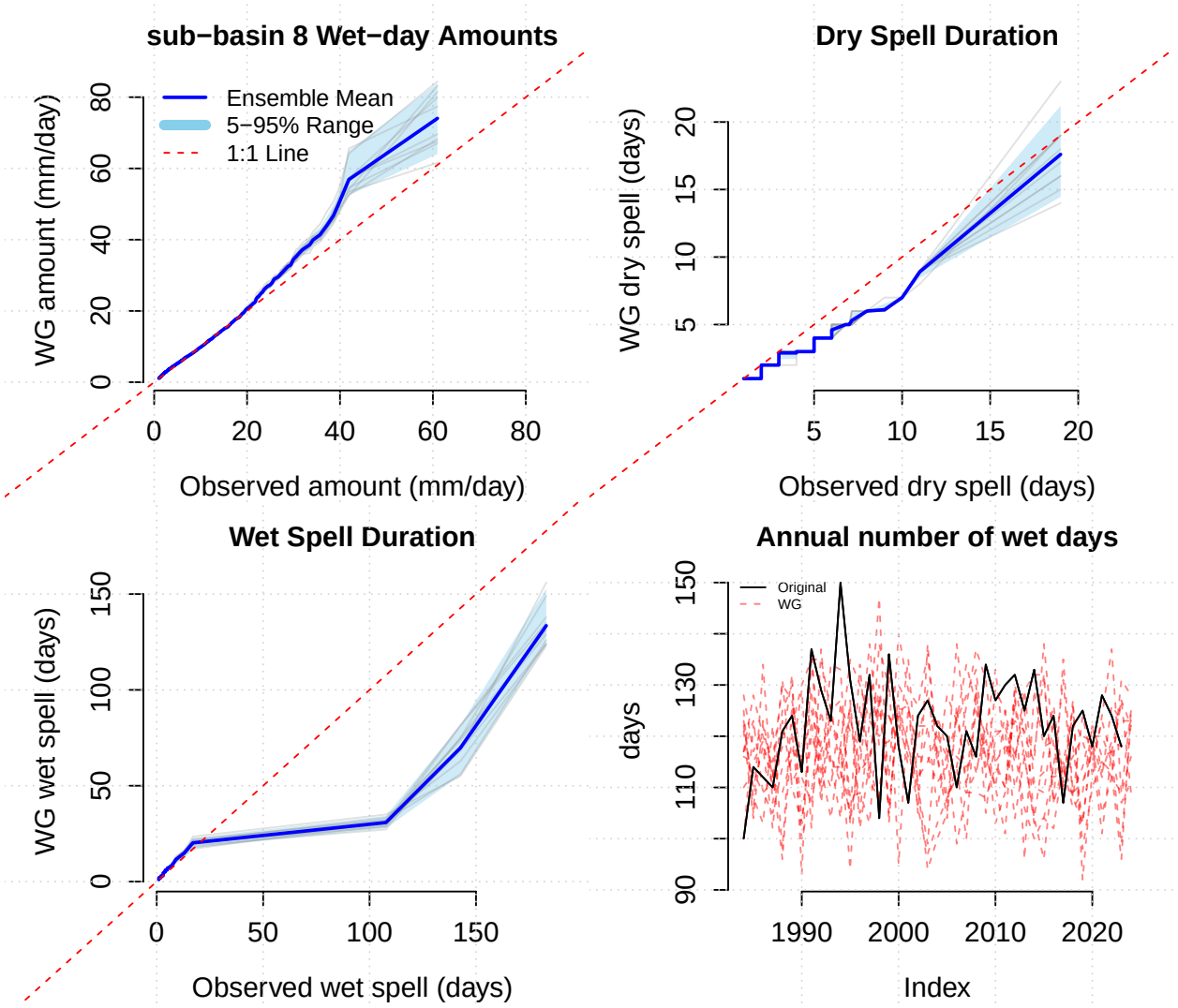


Figure 45: Tests of WG on GHCND data.

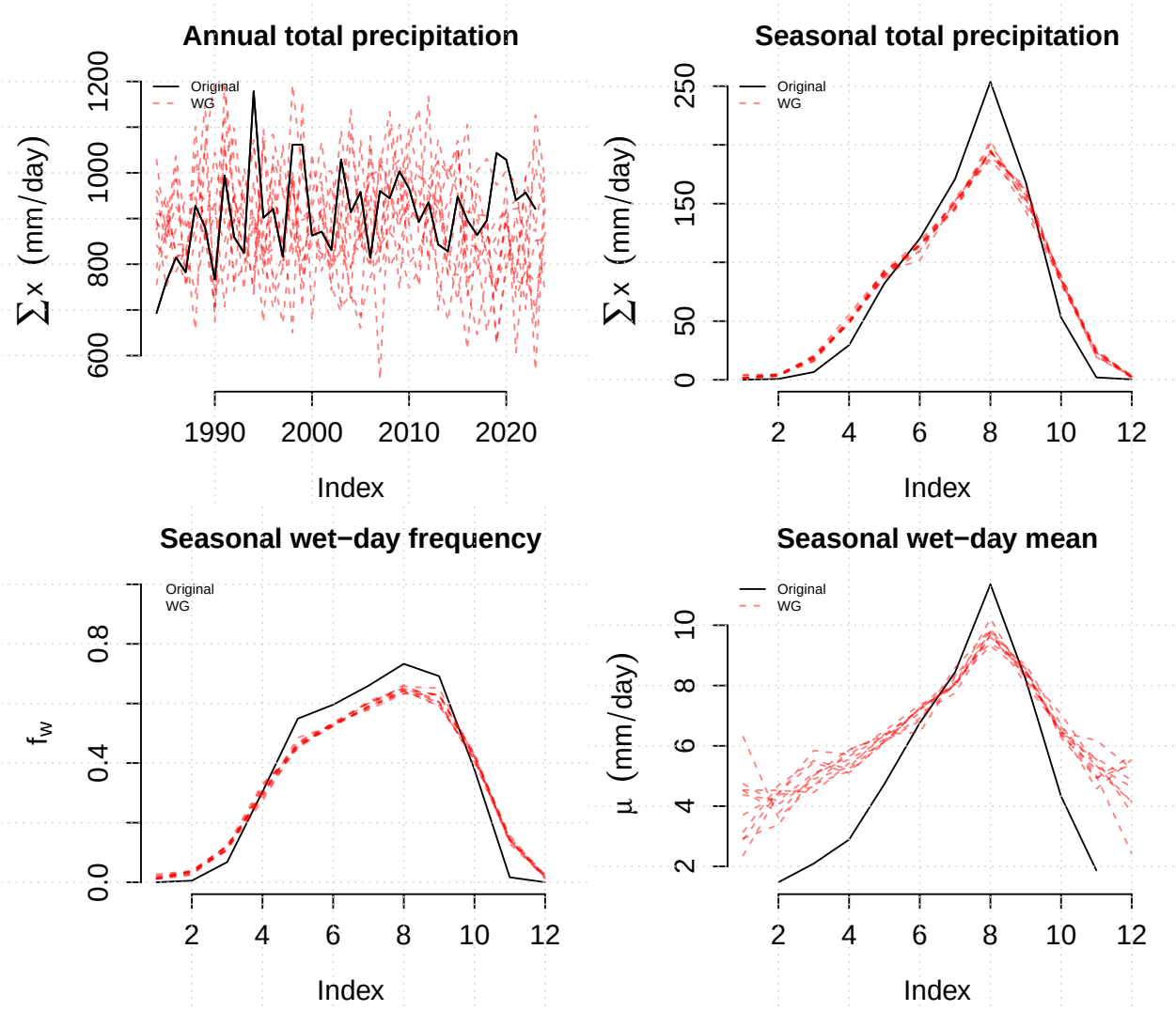


Figure 46: Tests of WG on GHCND data.

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8285  0.9880  1.0286  1.0748  1.1910  1.4596
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   10.80   11.11   11.58   11.79   12.41   12.92
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9567  0.9634  1.0040  1.0081  1.0445  1.0854
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   23.32   24.19   25.03   24.77   25.24   26.28
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.936   2.065   2.138   2.124   2.197   2.275
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.06090 0.06334 0.06654 0.06568 0.06741 0.07049


## test.WG.fwmu.day.precip for sub-basin 9  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9051  1.1415  1.2414  1.2453  1.3697  1.5169
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   7.824   7.894   8.287   8.365   8.610   9.328
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7874  0.8957  0.9921  0.9570  1.0295  1.0488
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   25.21   26.65   27.98   28.05   29.79   30.40
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.348   2.435   2.559   2.556   2.596   2.985
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.05532 0.05652 0.05904 0.05880 0.05945 0.06469


## test.WG.fwmu.day.precip for sub-basin 10  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5422  0.8926  0.9579  0.9561  1.0807  1.2810
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

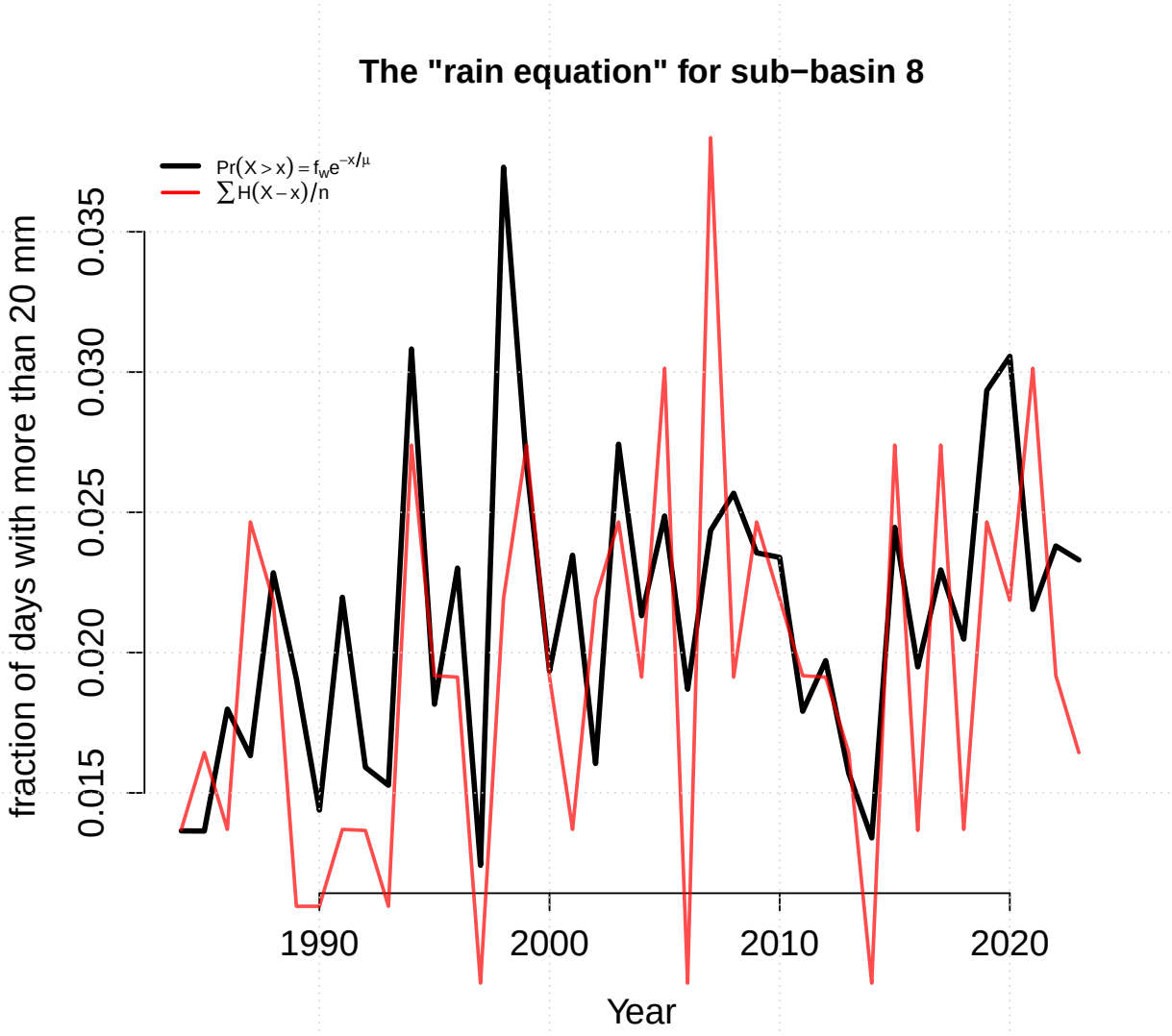


Figure 47: Tests of WG on GHCND data.

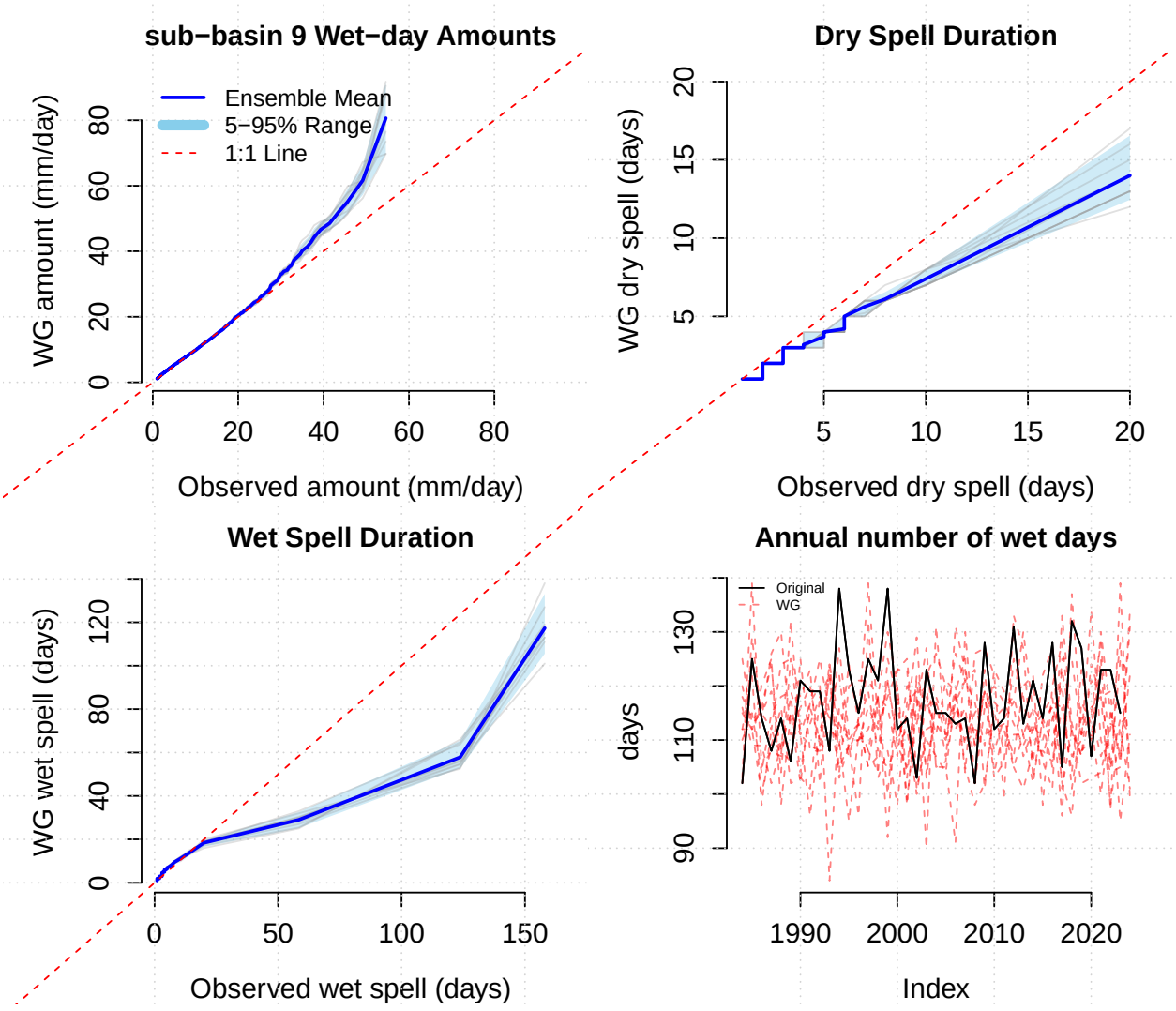


Figure 48: Tests of WG on GHCND data.

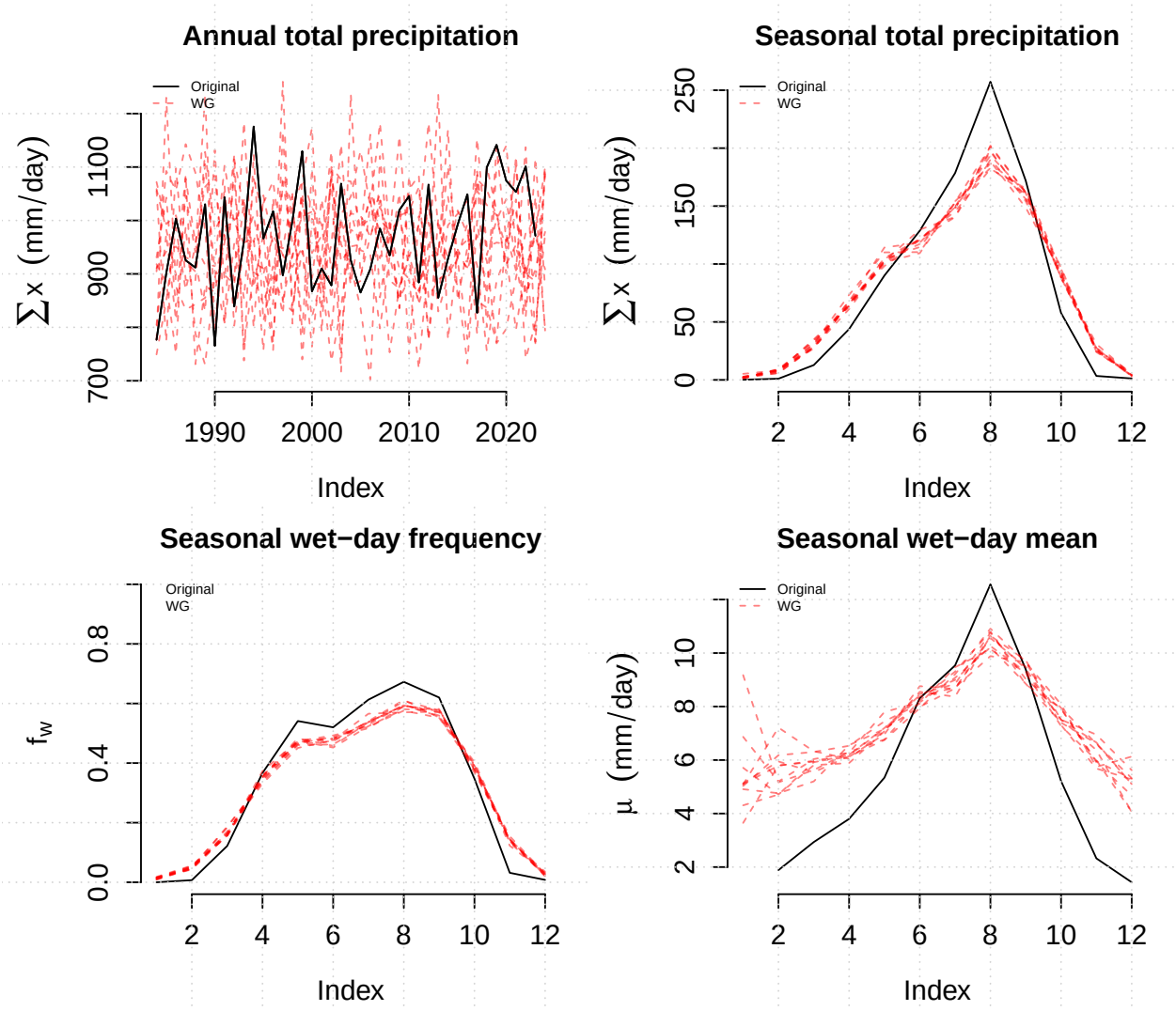


Figure 49: Tests of WG on GHCND data.

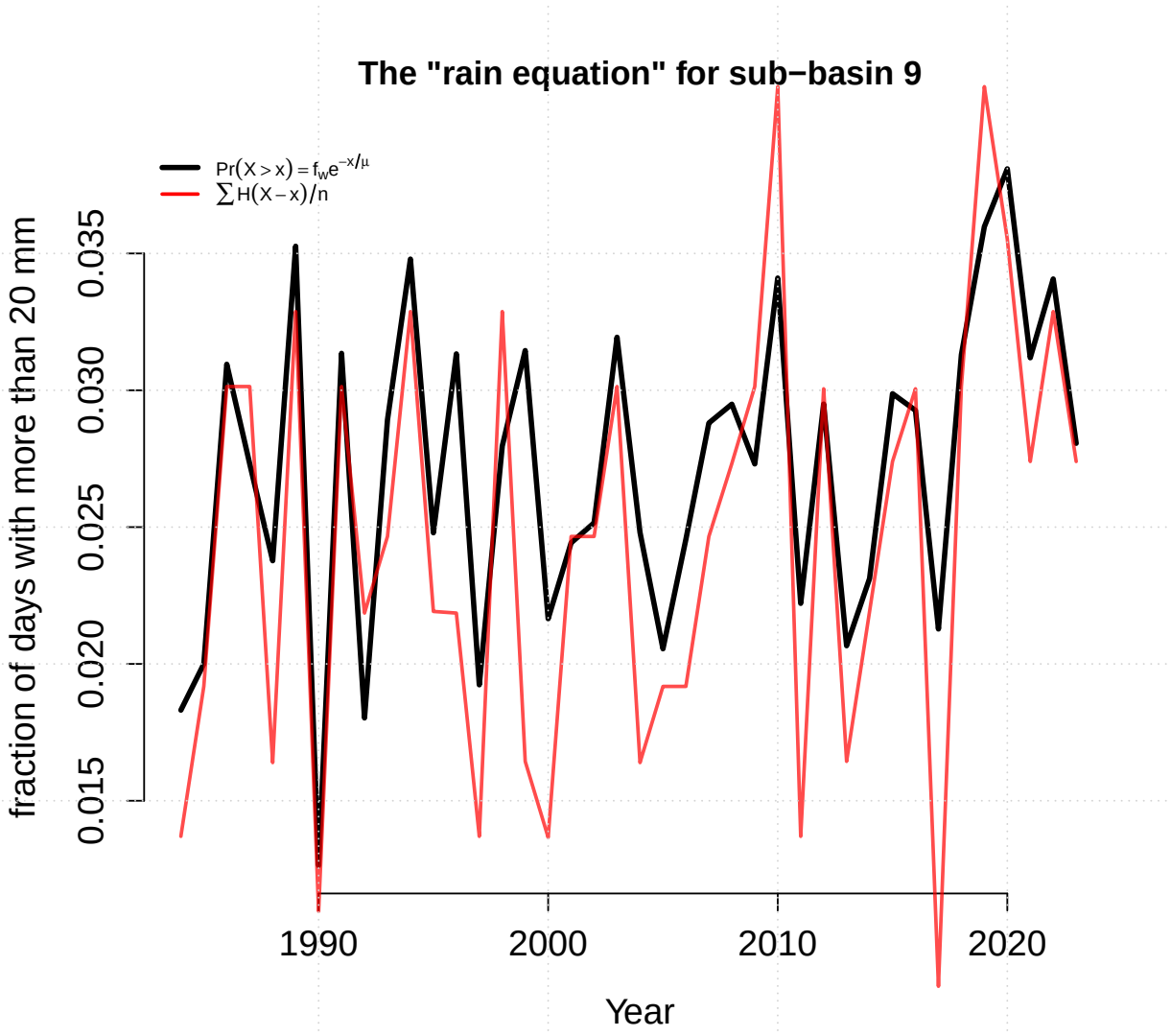


Figure 50: Tests of WG on GHCND data.

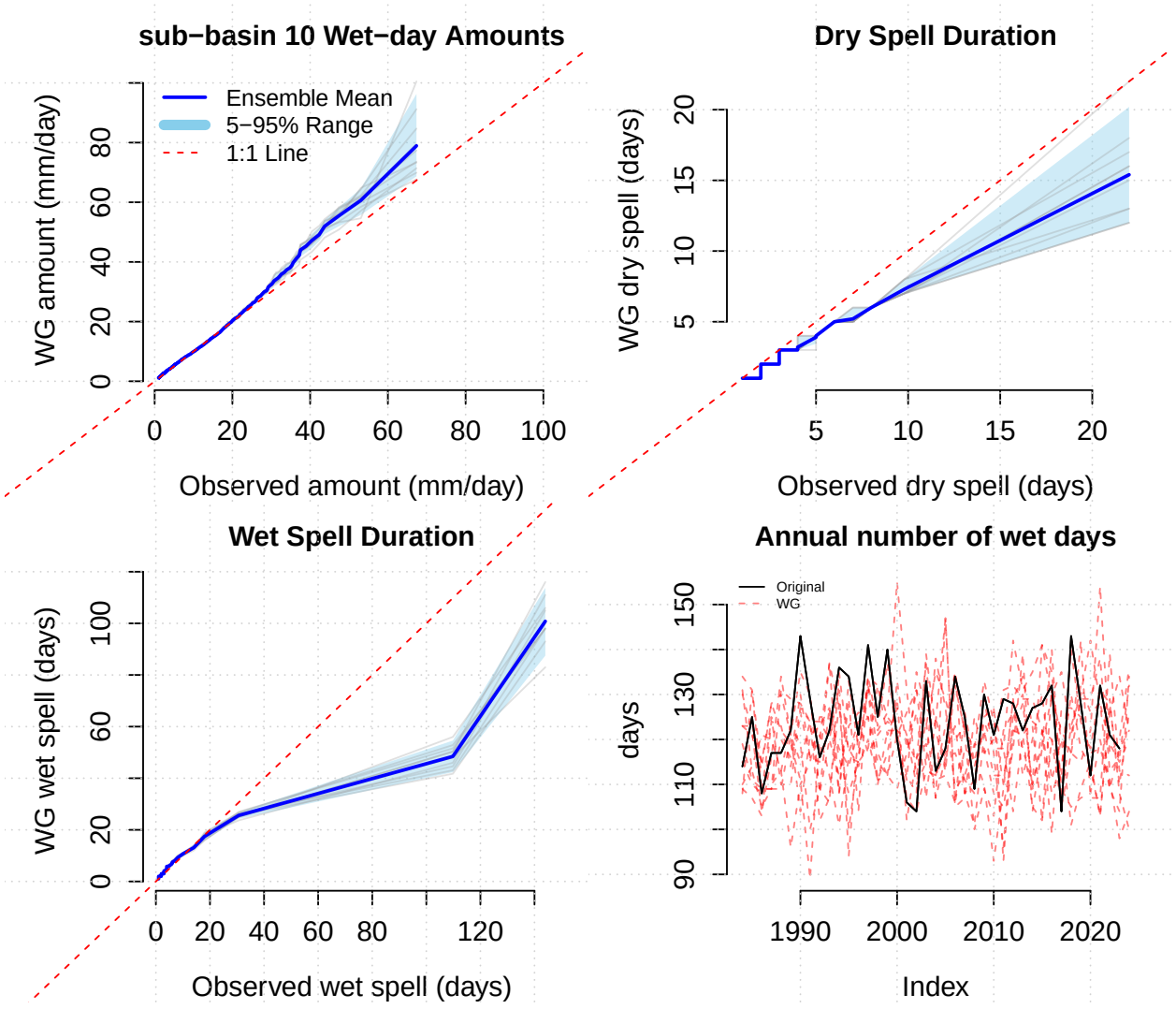


Figure 51: Tests of WG on GHCND data.

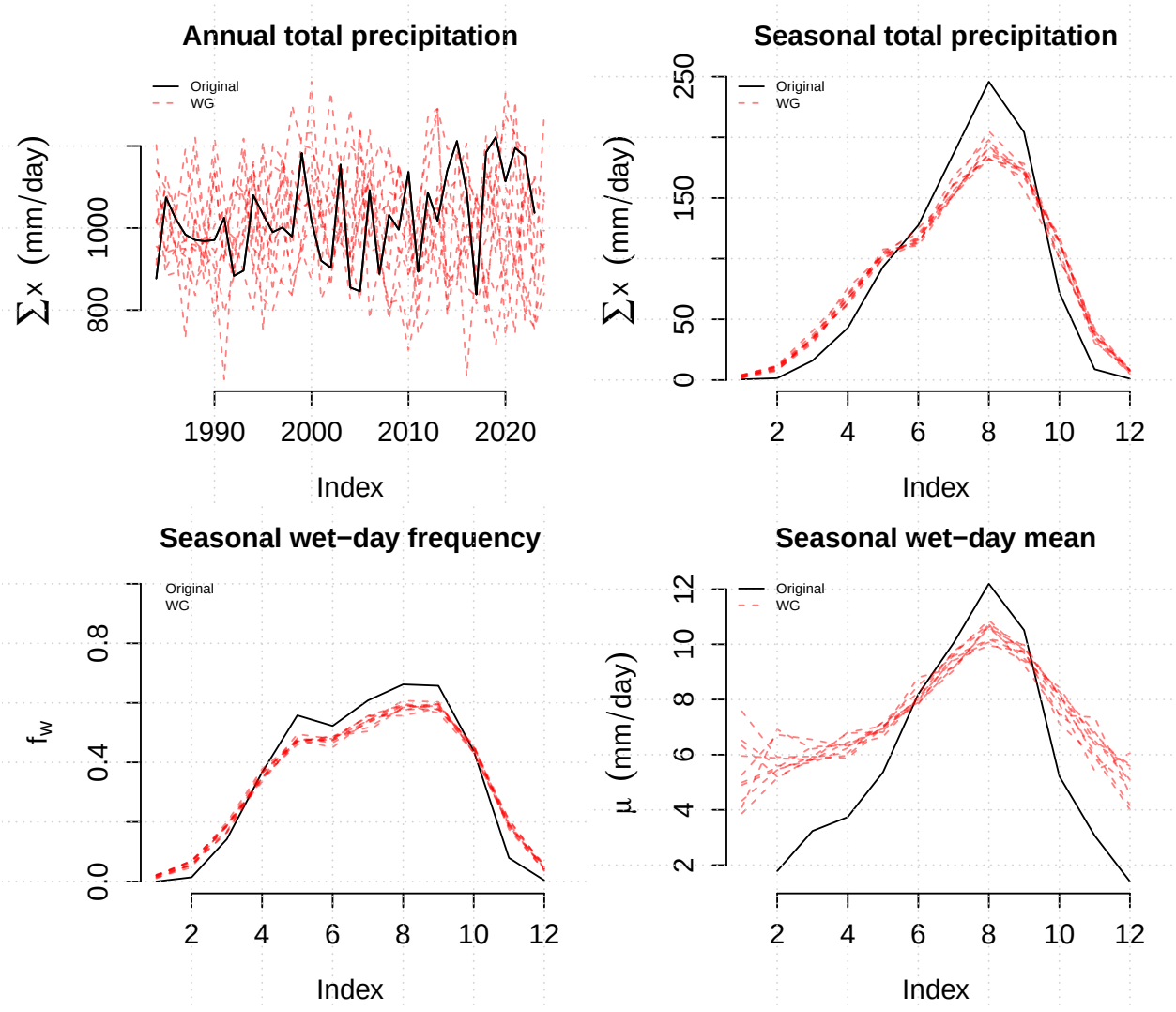


Figure 52: Tests of WG on GHCND data.

```
##   6.617   7.267   7.463   7.580   8.014   8.722
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7021  0.8931  0.9888  1.0180  1.1647  1.2642
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   23.71   27.98   29.12   28.75   29.82   32.11
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.230   2.453   2.560   2.519   2.601   2.755
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.05675 0.05985 0.06097 0.06095 0.06314 0.06418
```

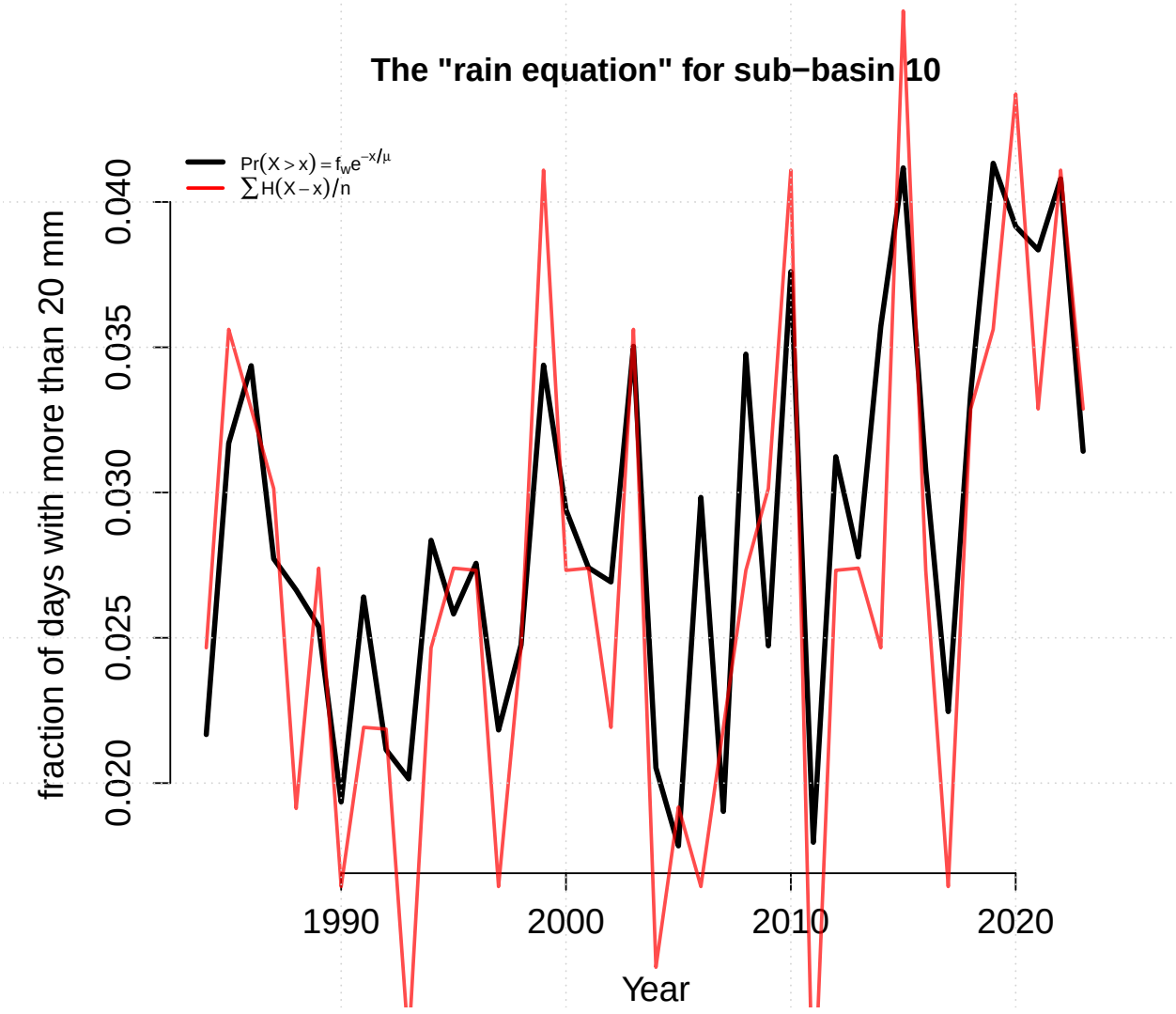


Figure 53: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 13  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

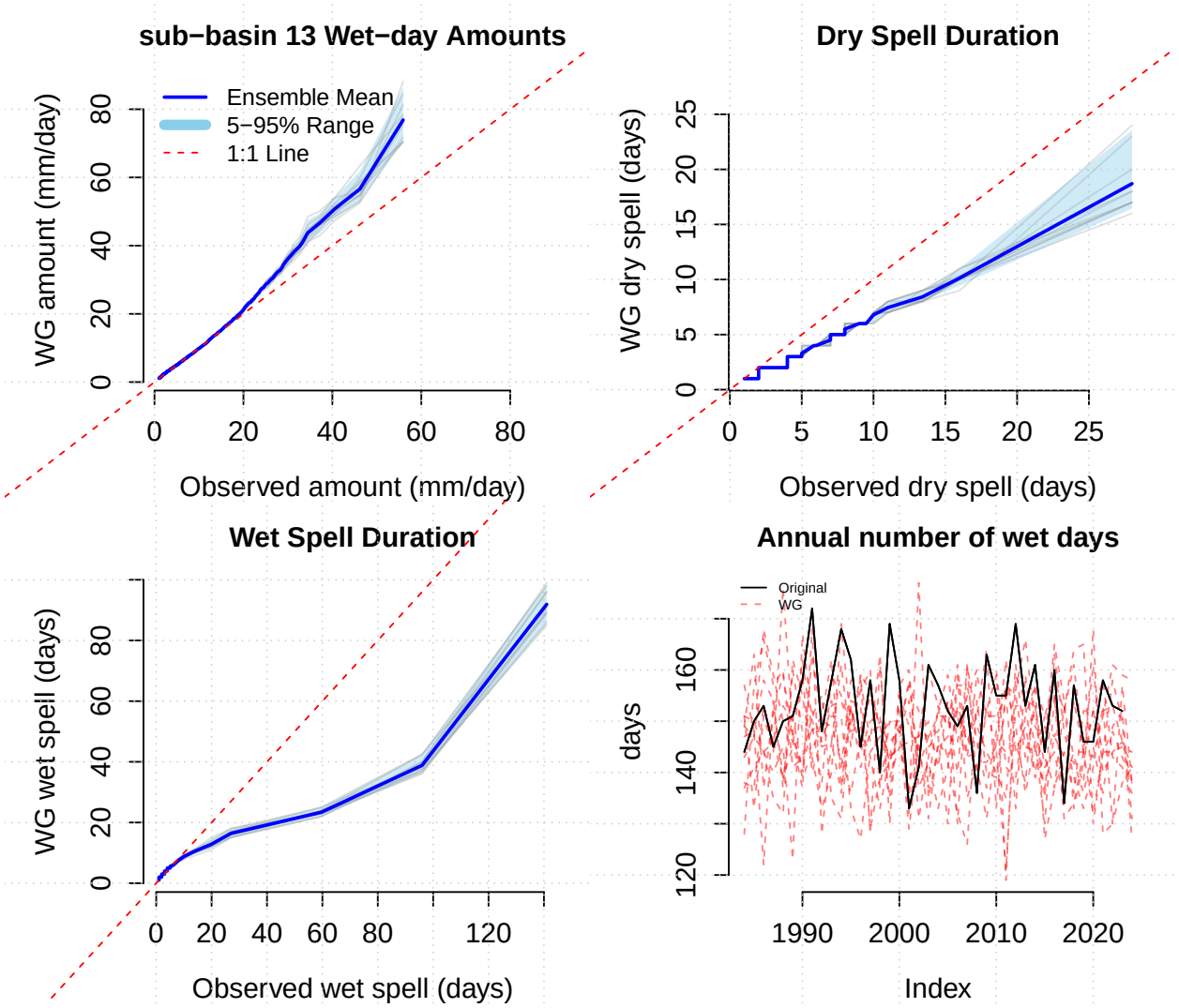


Figure 54: Tests of WG on GHCND data.

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8776  1.2166  1.2862  1.2525  1.3359  1.4293
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   7.897   8.162   8.461   8.484   8.808   9.063
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.624   1.712   1.816   1.793   1.875   1.914
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   21.24   24.86   25.62   25.43   26.09   28.81
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.909   1.944   1.952   1.995   2.027   2.223
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

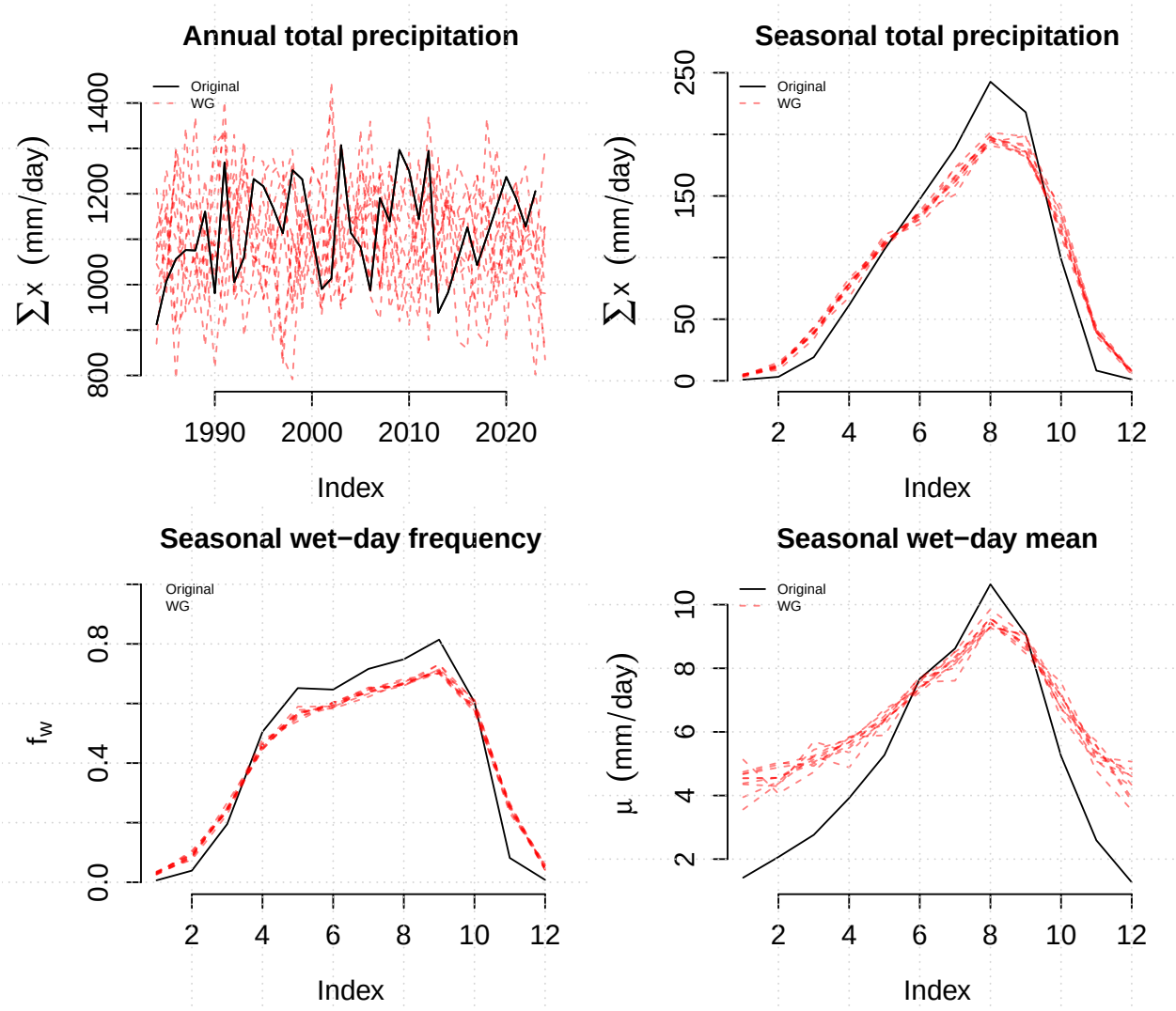


Figure 55: Tests of WG on GHCND data.

```
## 0.07393 0.07513 0.07824 0.07767 0.07957 0.08114
```

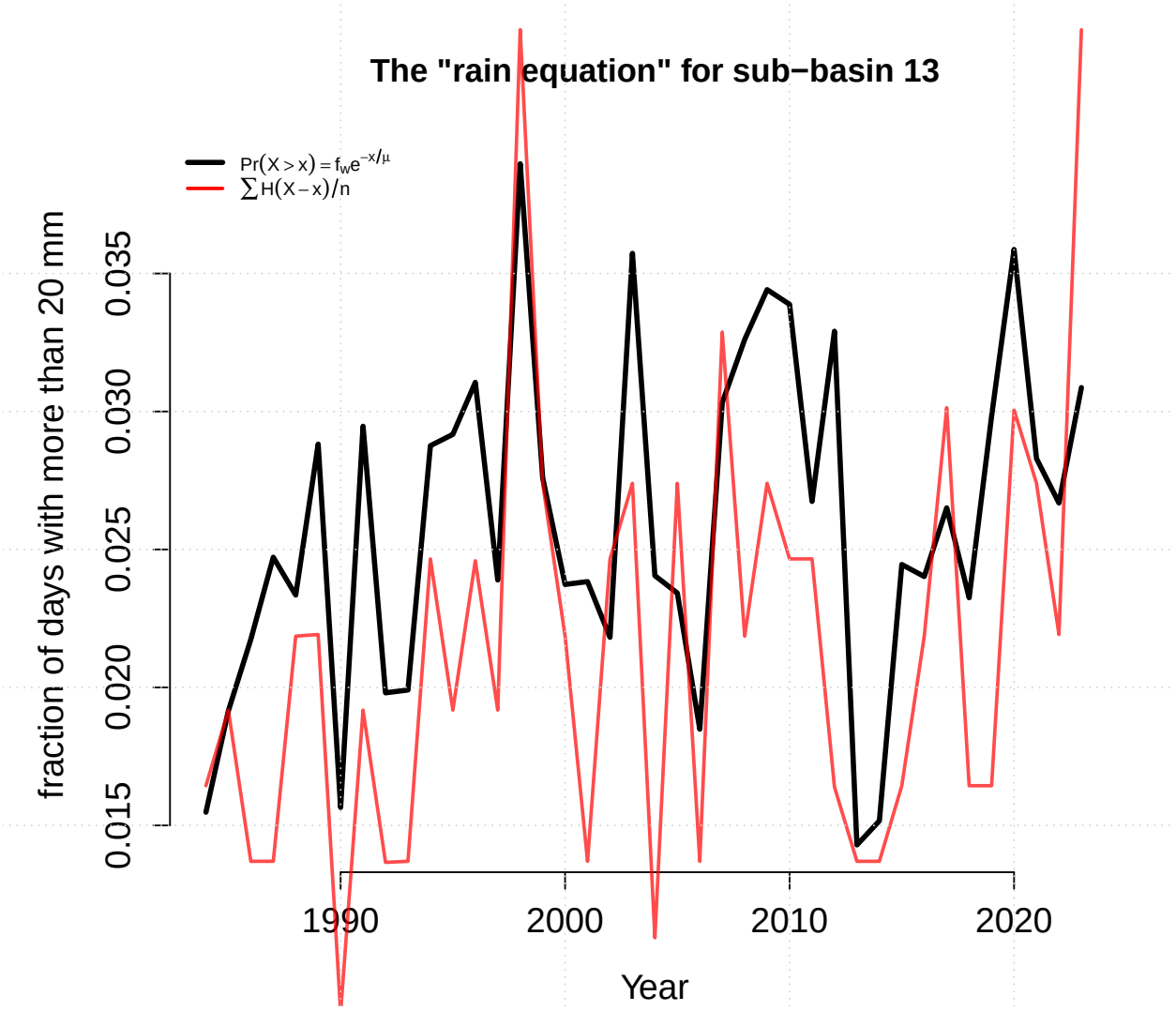


Figure 56: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 11  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8821  1.0001  1.0372  1.0549  1.0635  1.3285
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.659   6.582   7.164   7.133   7.914   8.086
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8307  0.8913  0.9347  0.9690  1.0250  1.1790
```

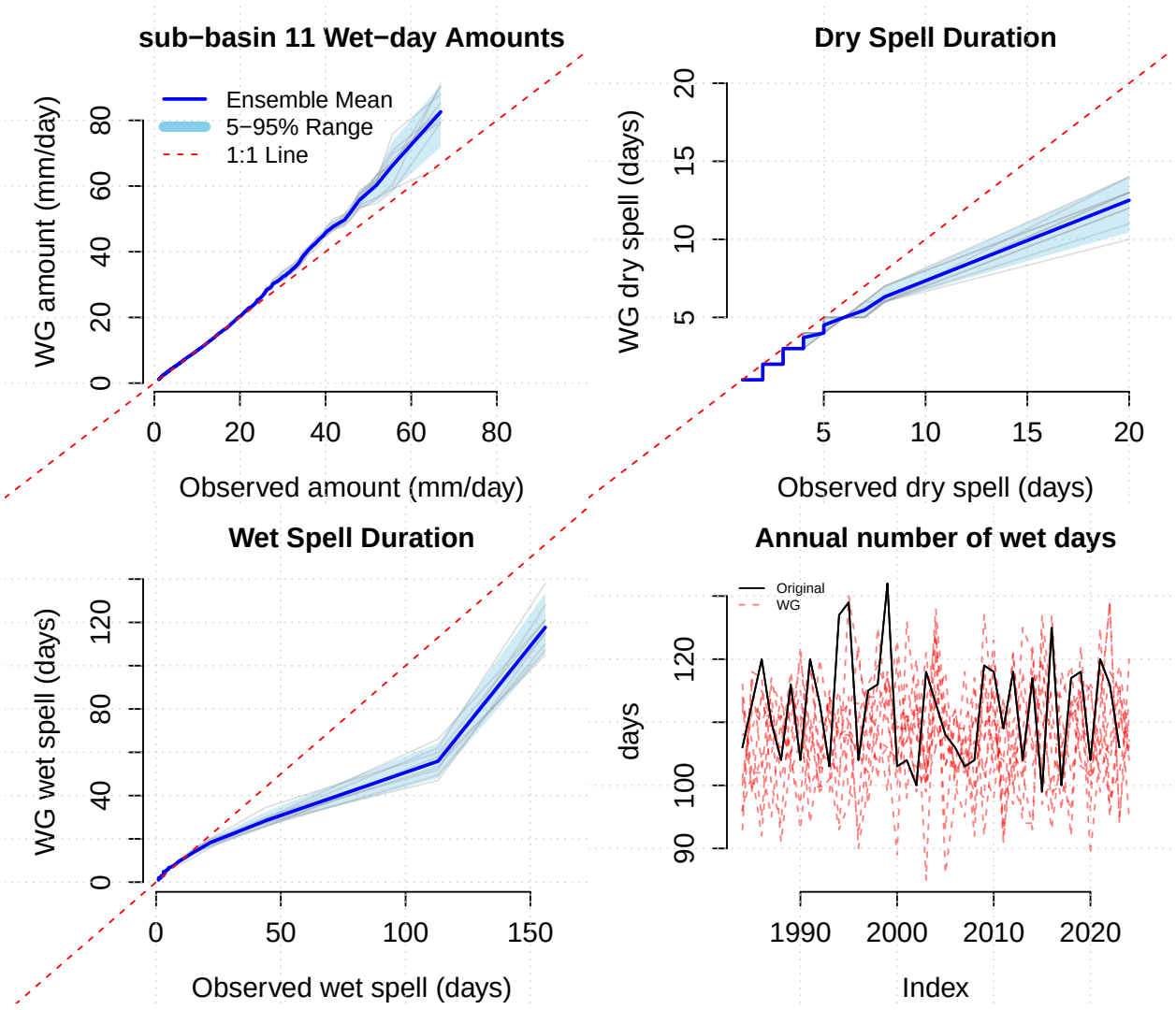


Figure 57: Tests of WG on GHCND data.

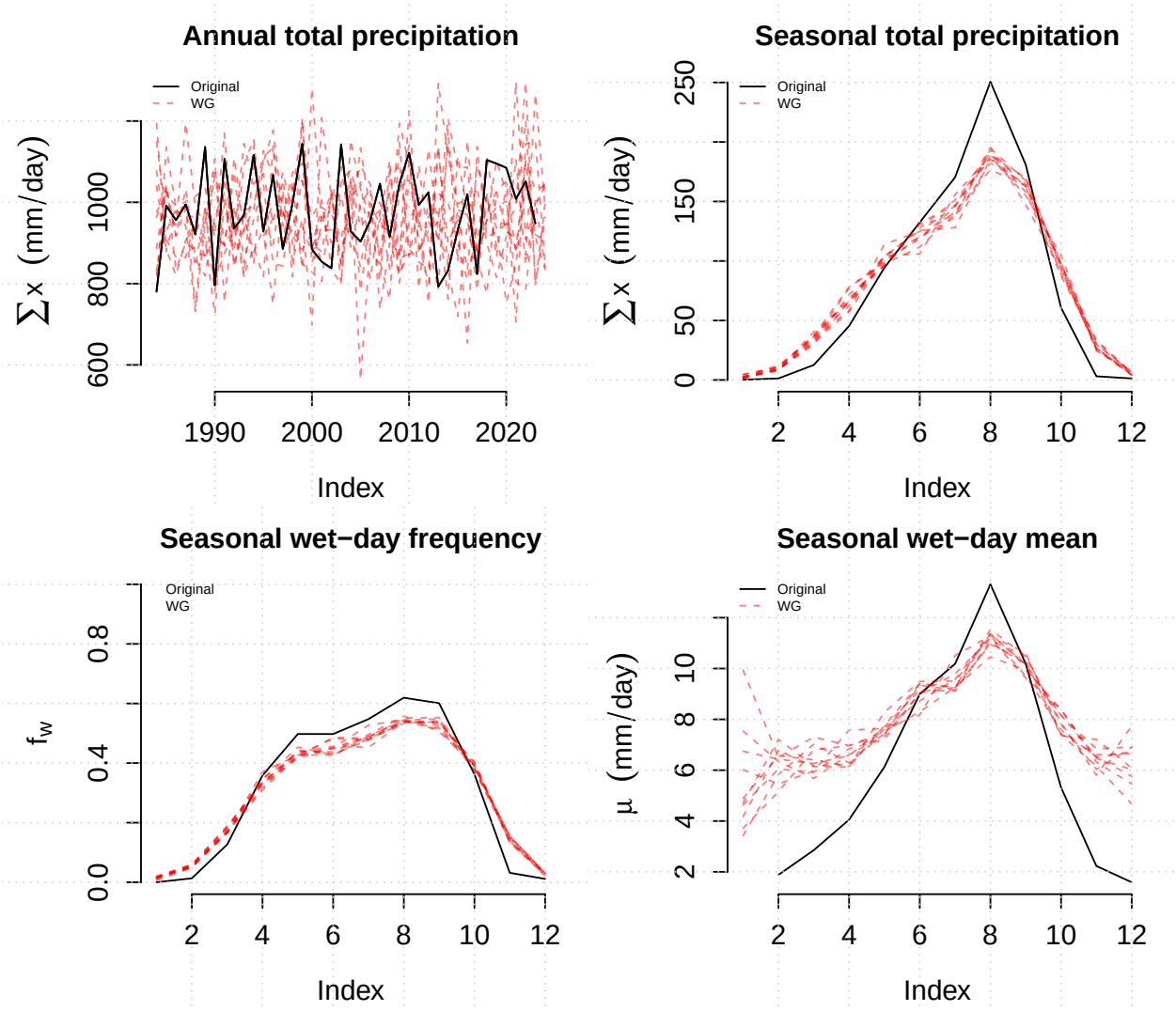


Figure 58: Tests of WG on GHCND data.

```
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   26.59   26.86   27.55   28.14   29.07   31.38
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.709   2.842   2.901   2.919   3.048   3.127
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.05513 0.05785 0.05856 0.05864 0.06055 0.06117
```

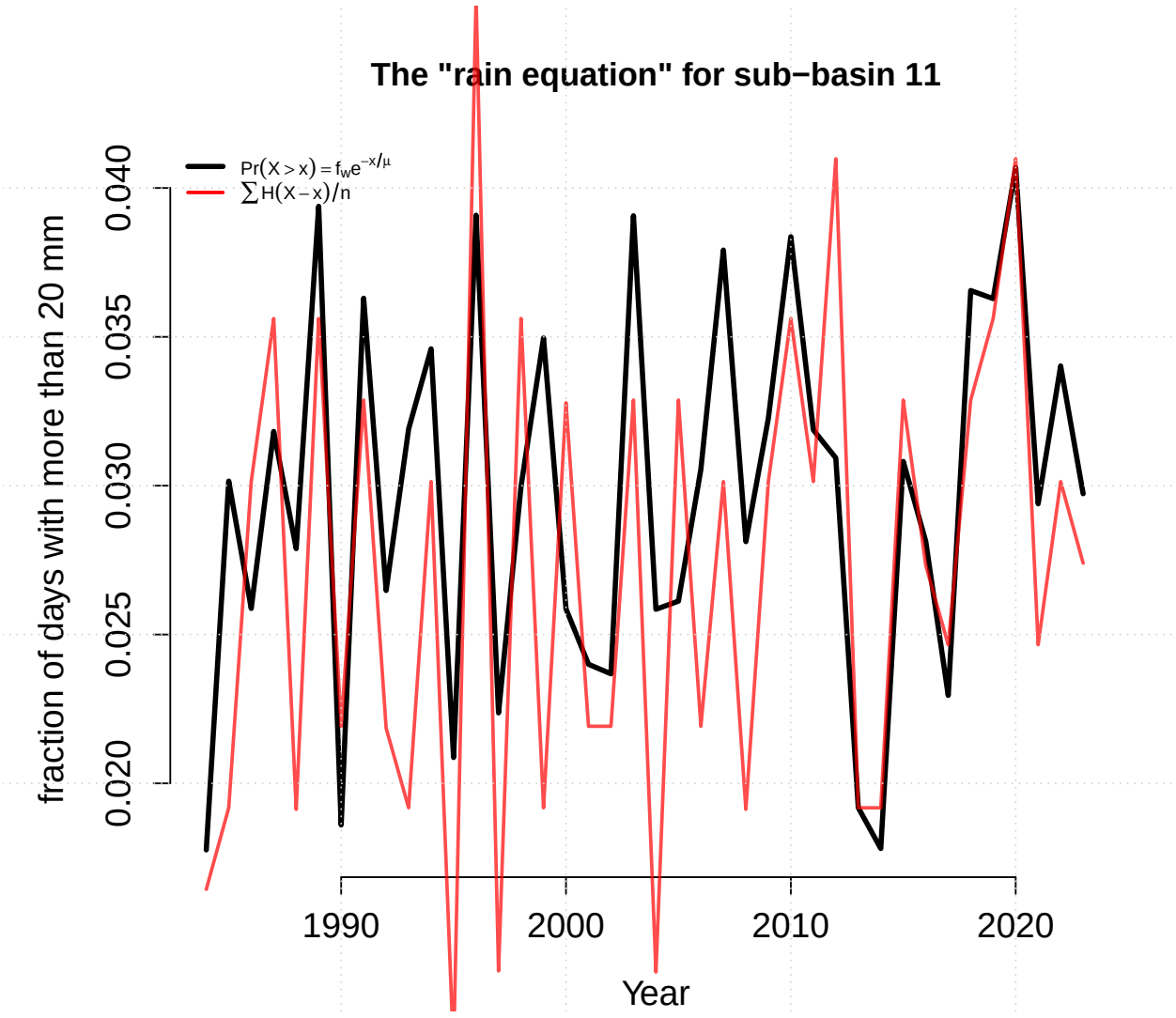


Figure 59: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 12  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
```

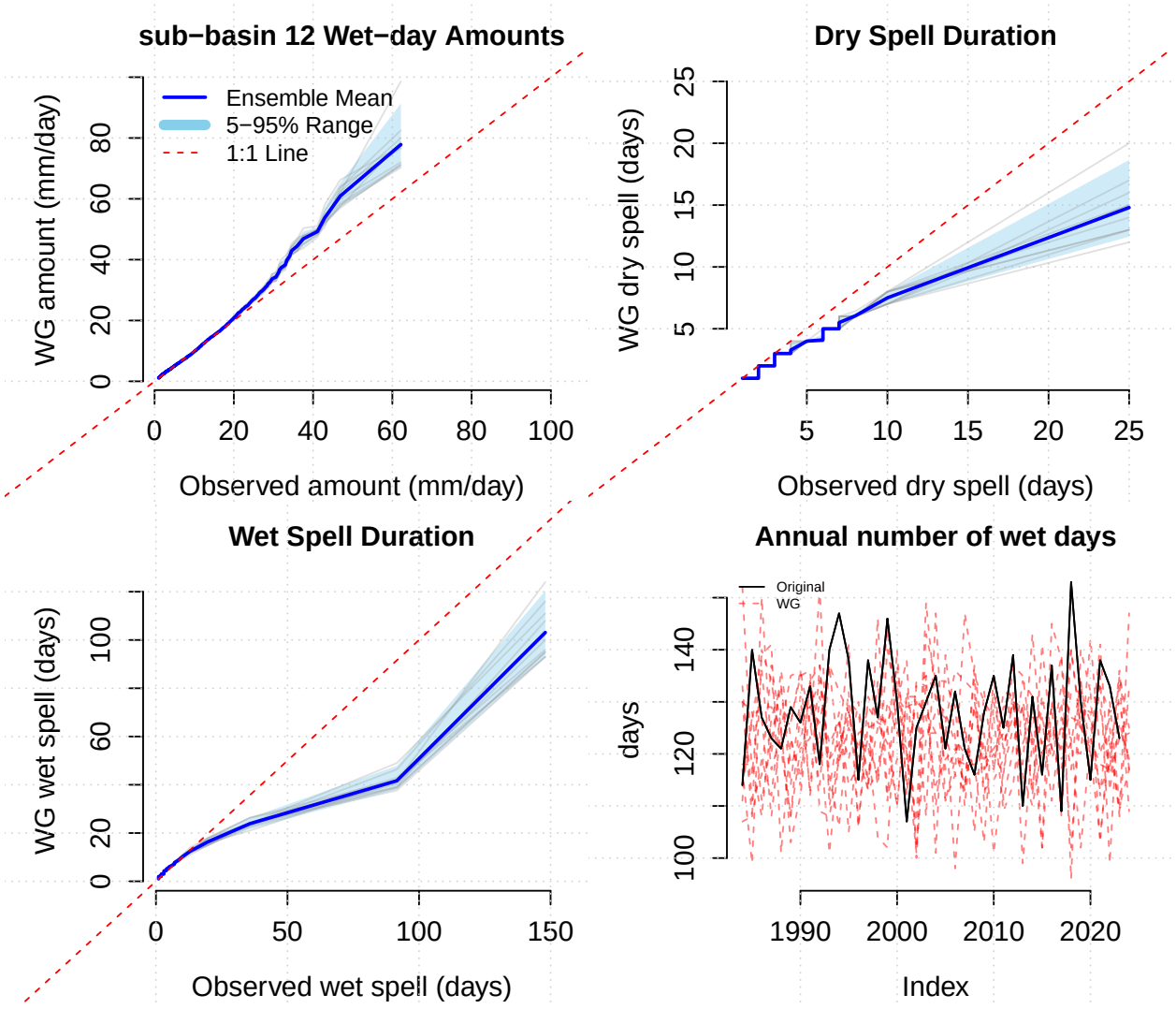


Figure 60: Tests of WG on GHCND data.

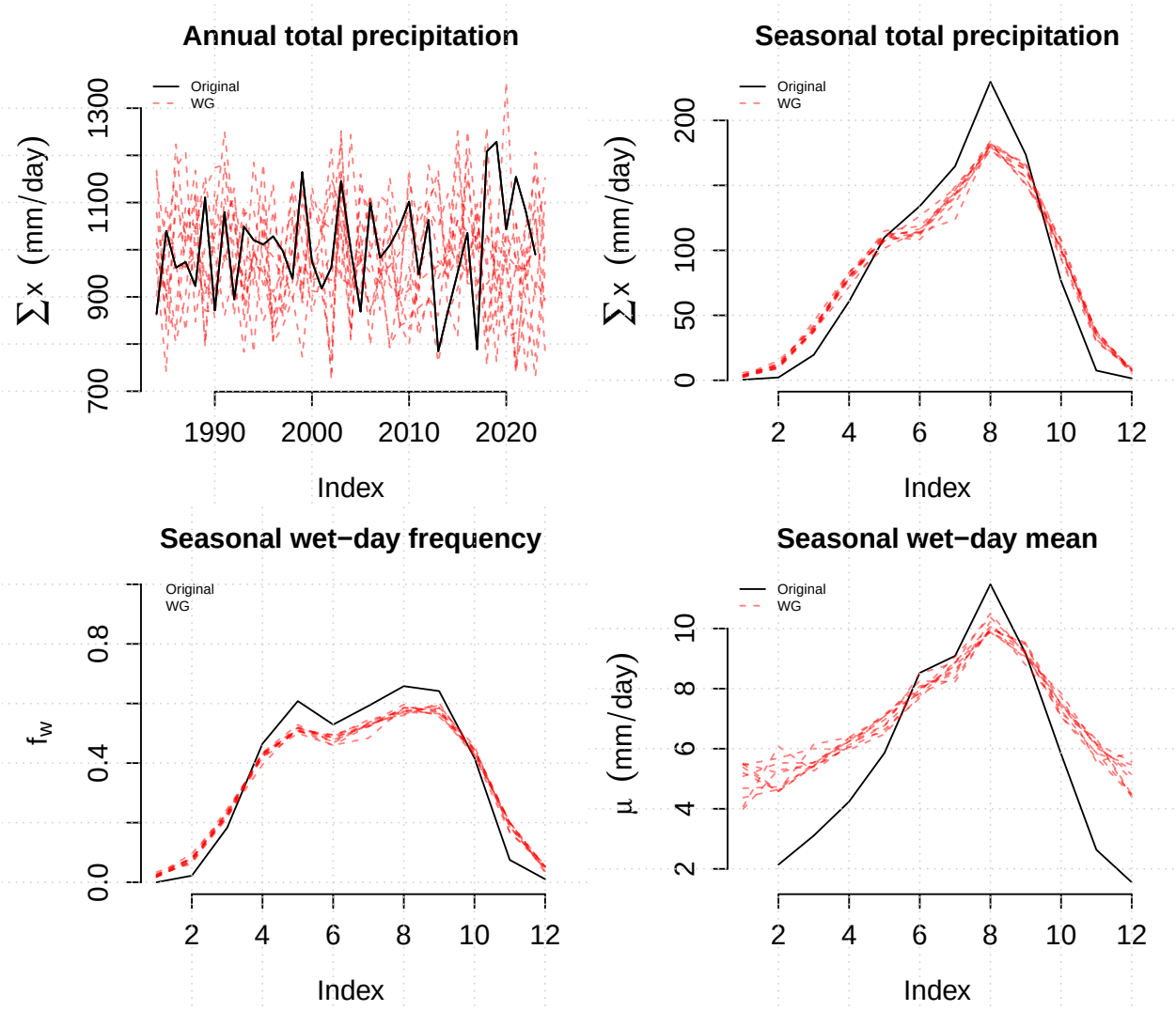


Figure 61: Tests of WG on GHCND data.

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   0.998   1.060   1.161   1.189   1.279   1.501
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.713   6.043   7.203   6.892   7.532   7.814
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8832  1.2040  1.2912  1.2777  1.4036  1.5133
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   22.01   22.80   23.82   23.78   24.61   25.70
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.905   2.082   2.135   2.104   2.163   2.175
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.06044 0.06314 0.06431 0.06457 0.06580 0.06964


## test.WG.fwmu.day.precip for sub-basin 14  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6358  0.6612  0.7264  0.7389  0.7744  0.9231
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.754   6.987   7.331   7.228   7.735   8.195
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8637  0.9158  1.0075  0.9861  1.0296  1.0845
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   19.82   21.71   22.39   22.19   22.91   24.42
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.777   1.974   1.990   1.991   2.070   2.179
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.05782 0.05969 0.06261 0.06264 0.06569 0.06694


## test.WG.fwmu.day.precip for sub-basin 15  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   0.989   1.041   1.143   1.157   1.179   1.443
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

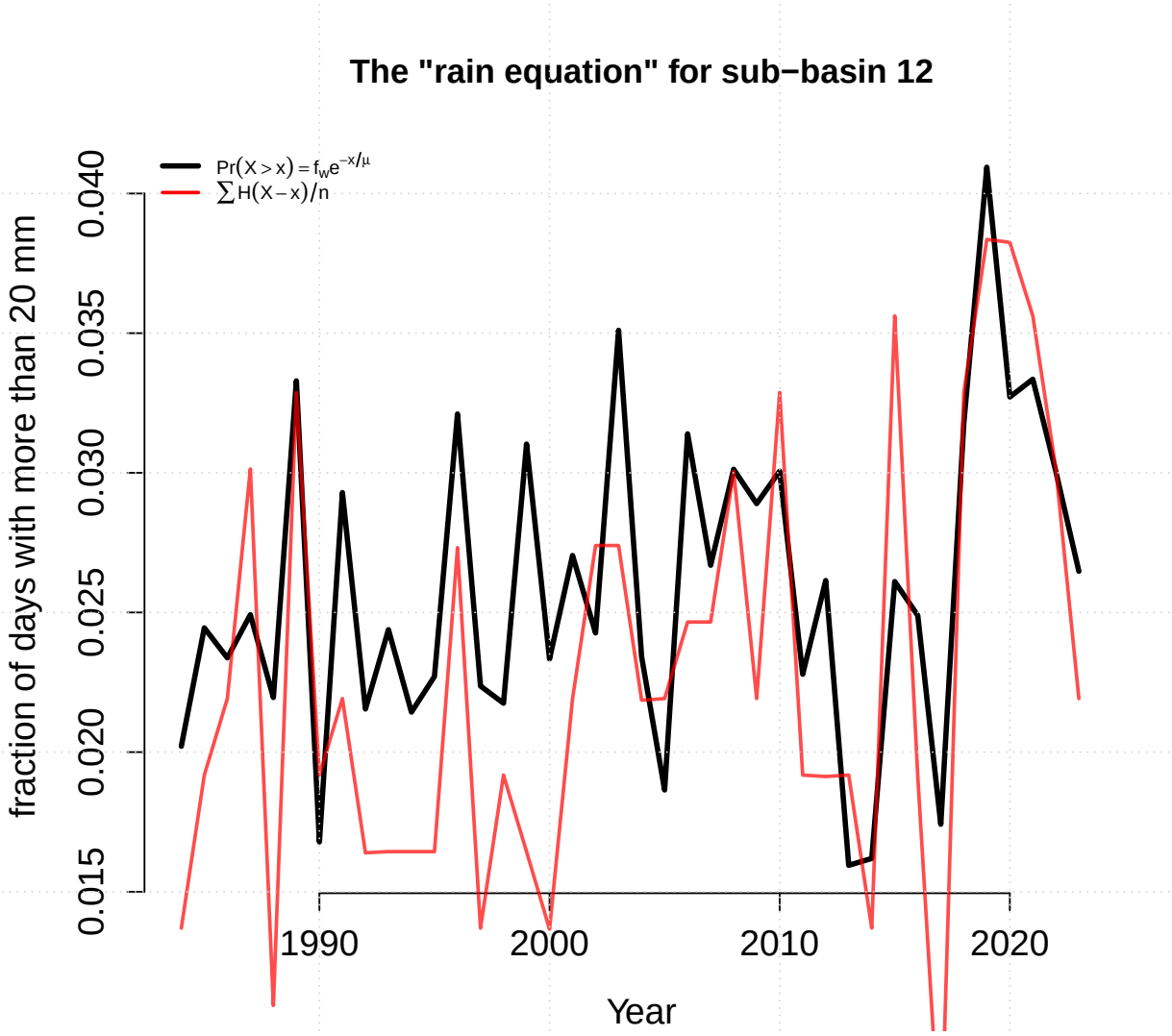


Figure 62: Tests of WG on GHCND data.

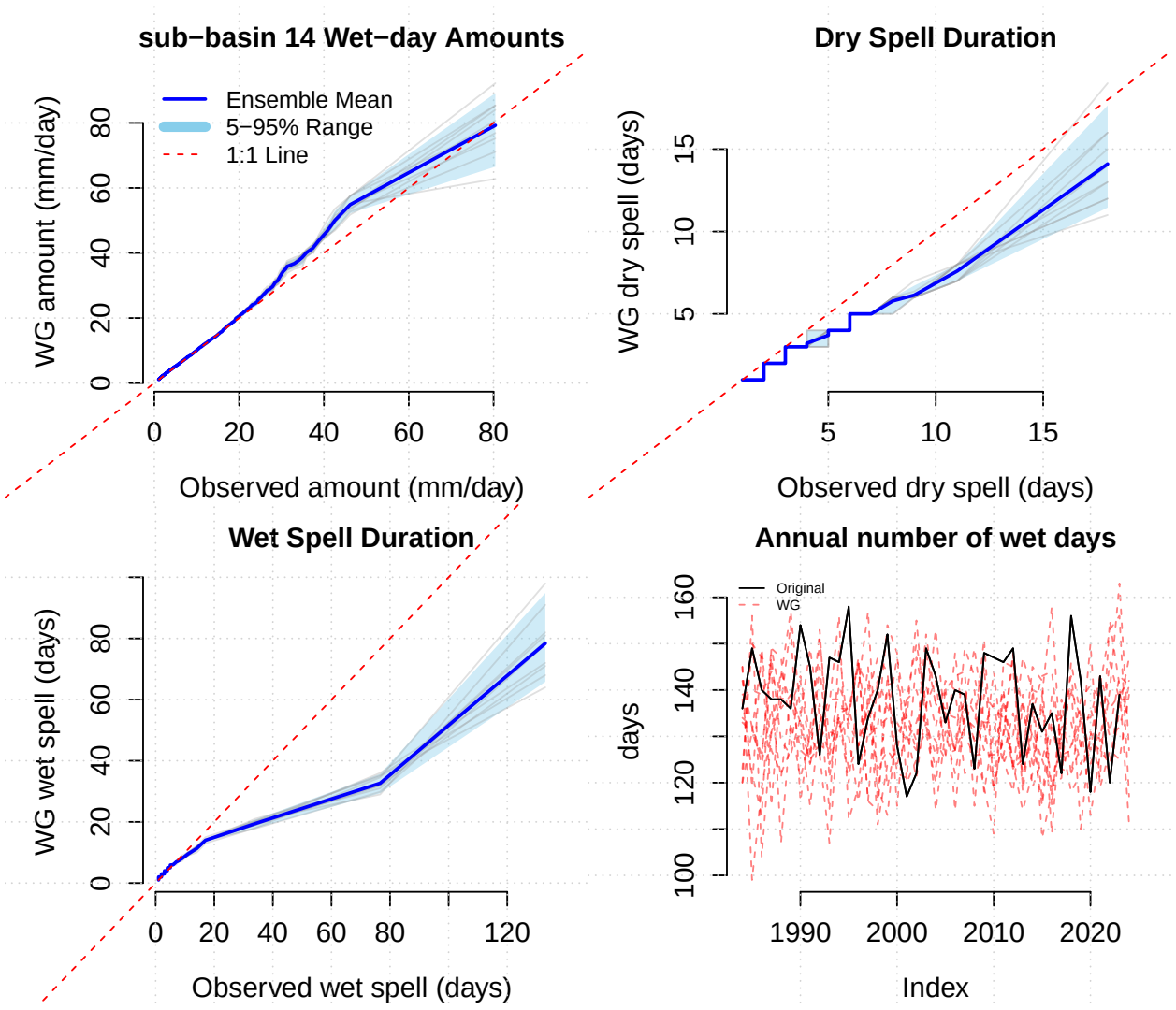


Figure 63: Tests of WG on GHCND data.

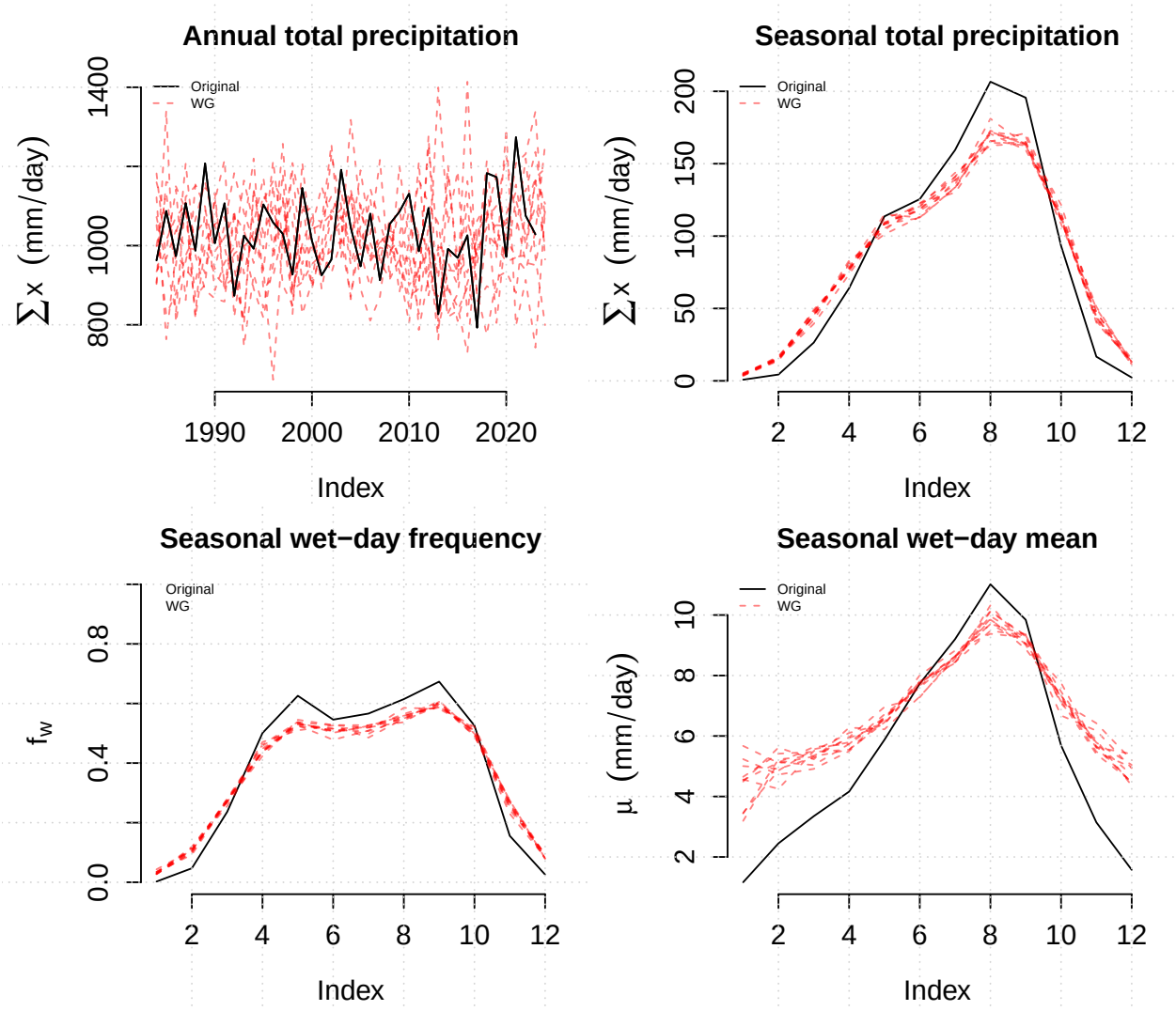


Figure 64: Tests of WG on GHCND data.

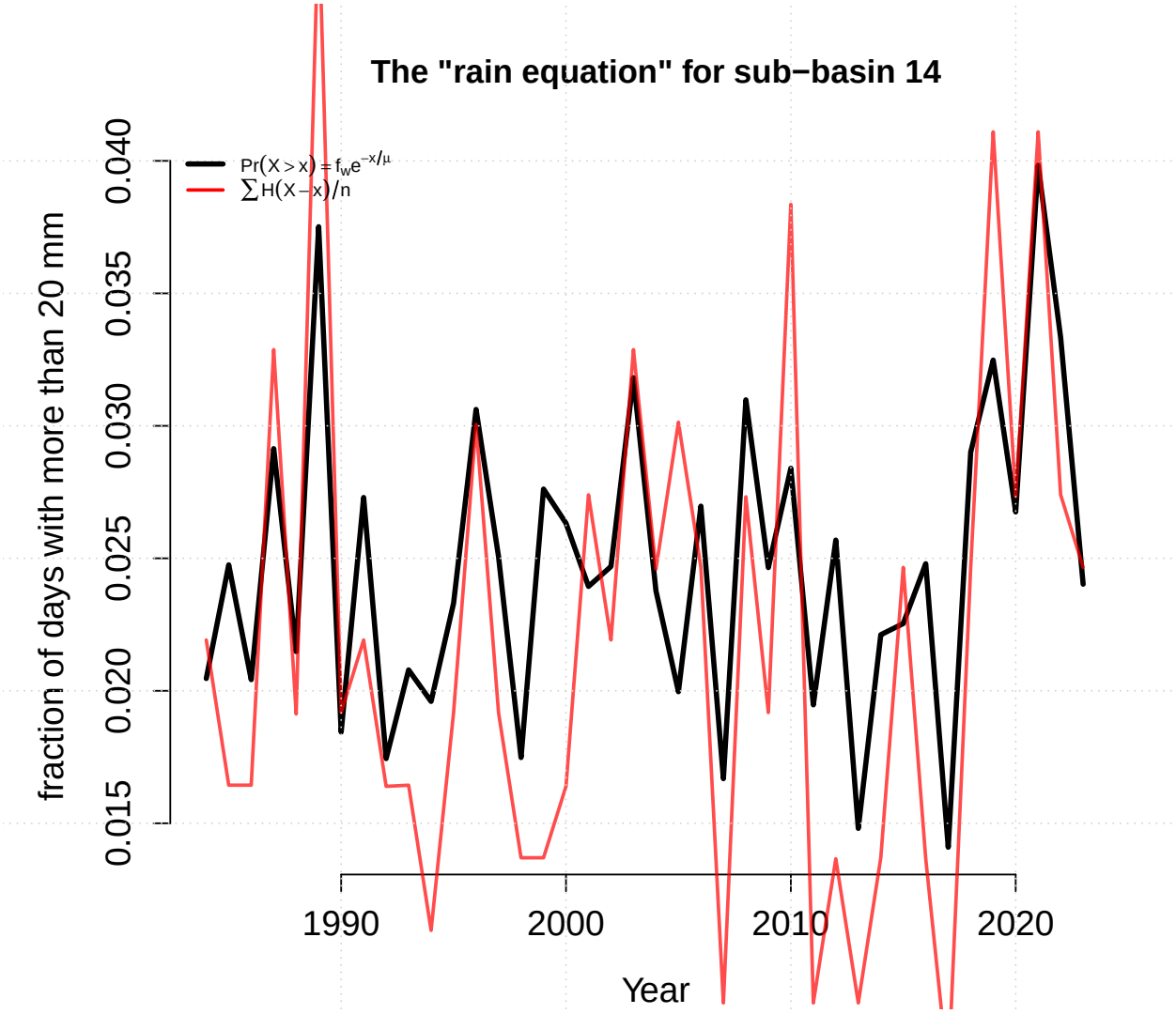


Figure 65: Tests of WG on GHCND data.

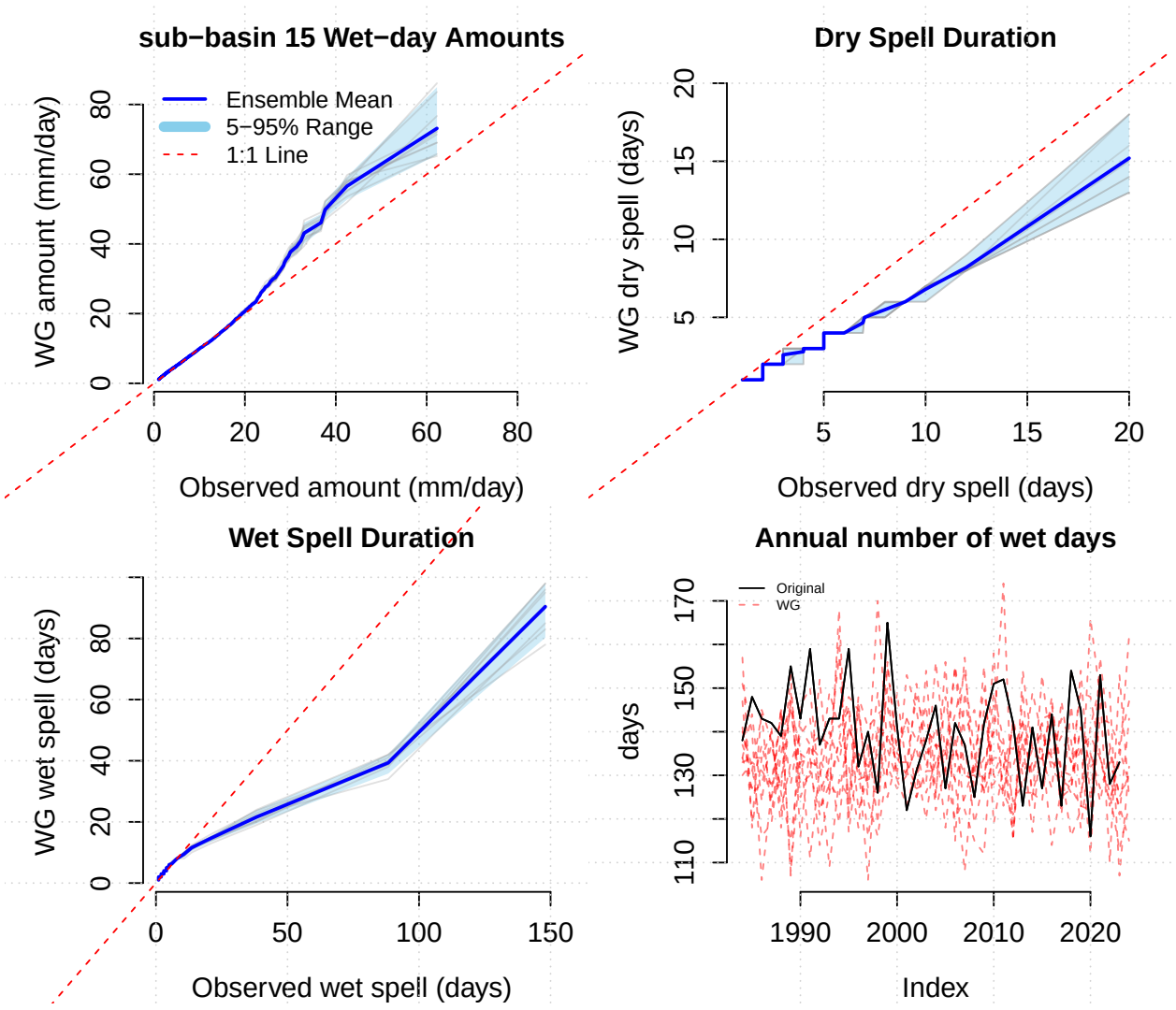


Figure 66: Tests of WG on GHCND data.

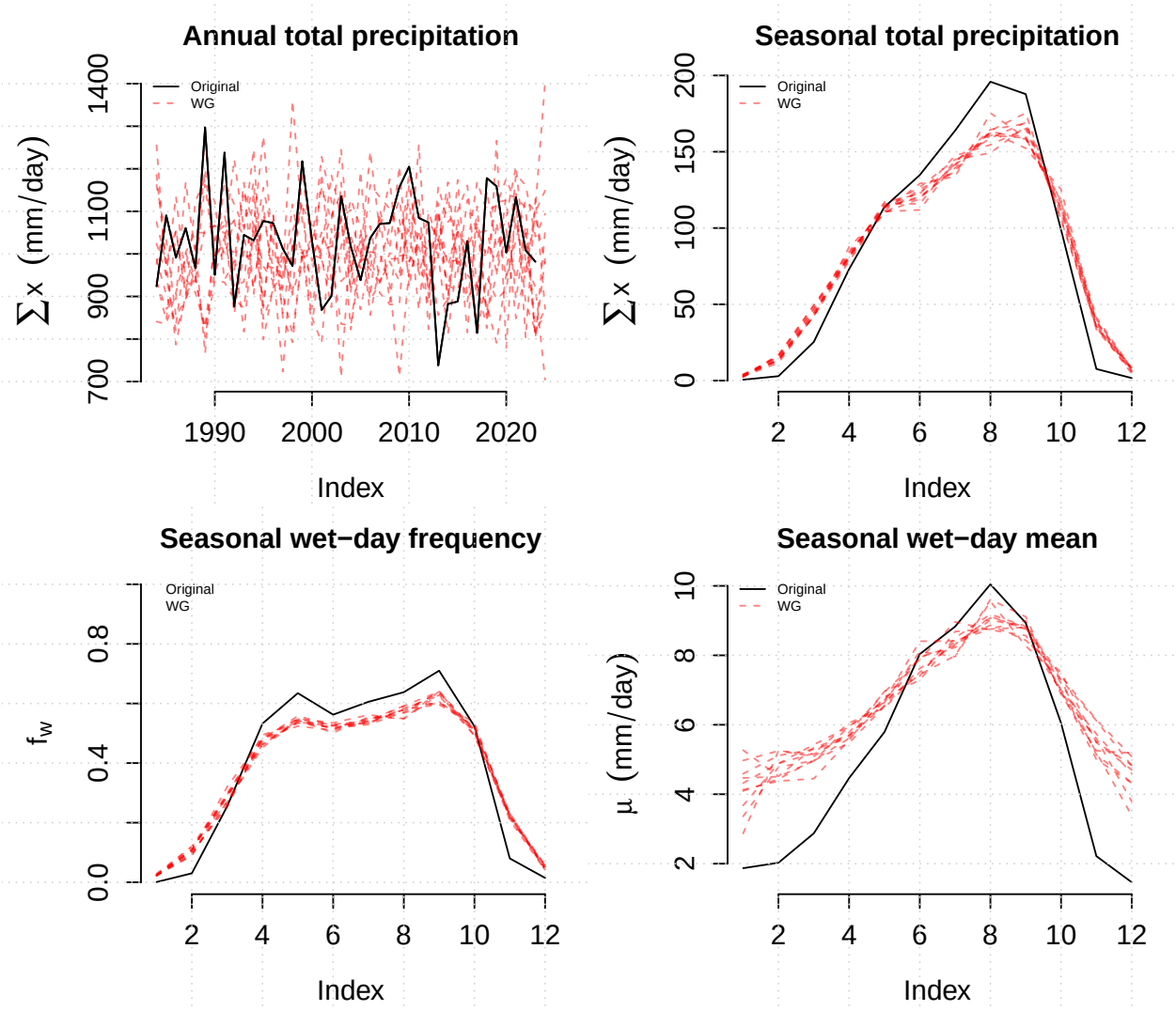


Figure 67: Tests of WG on GHCND data.

```
##   7.152   7.502   7.648   7.798   8.209   8.621
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.003   1.080   1.172   1.163   1.249   1.310
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   18.44   20.33   20.80   20.73   21.55   22.49
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.724   1.820   1.947   1.922   1.995   2.078
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.06626 0.06785 0.07095 0.07049 0.07154 0.07576
```

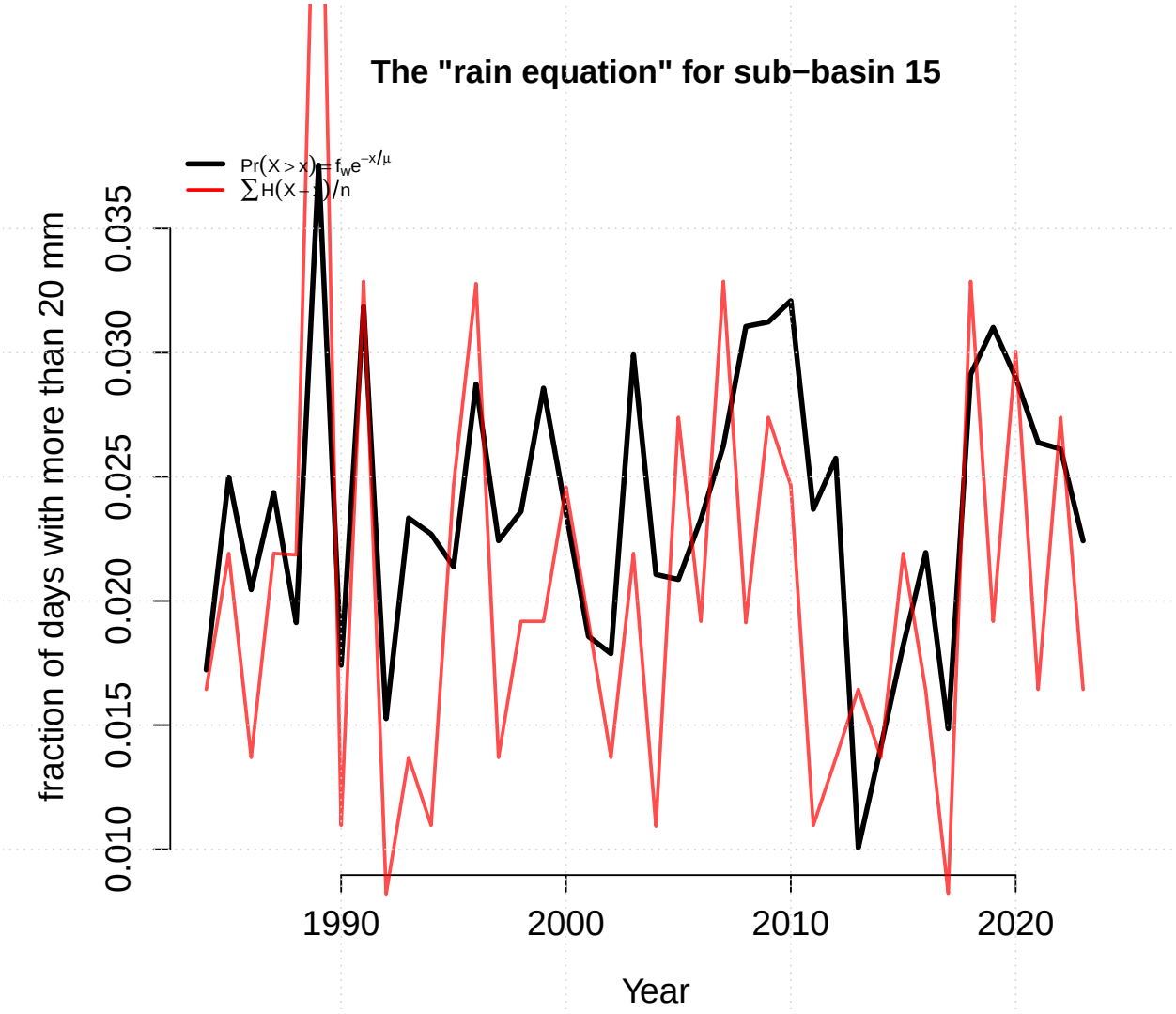


Figure 68: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 16  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

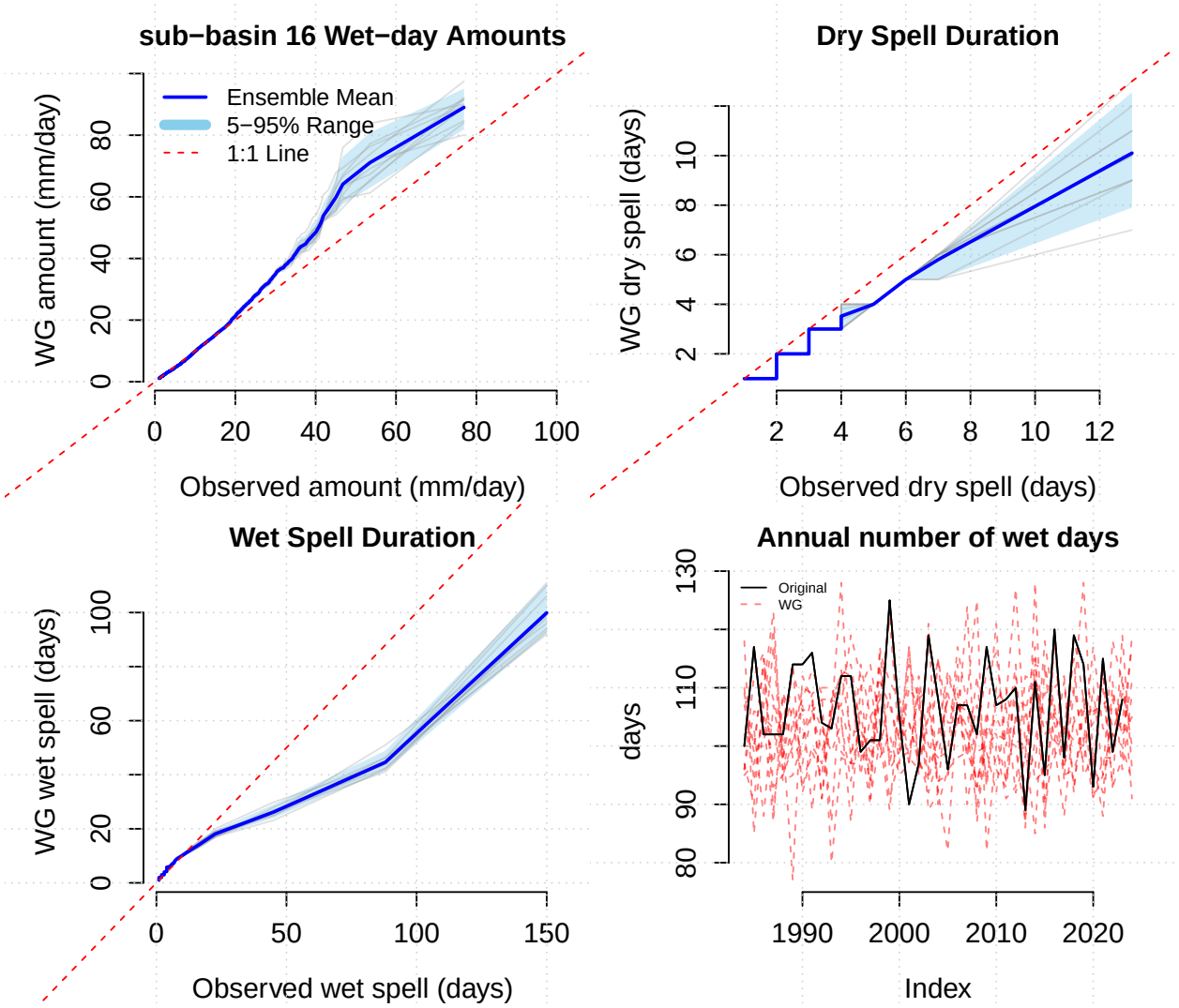


Figure 69: Tests of WG on GHCND data.

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.434   1.499   1.750   1.746   1.904   2.256
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   6.023   6.654   7.165   6.954   7.289   7.513
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5292  0.5527  0.6125  0.6241  0.6671  0.8185
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   24.25   24.81   25.25   25.87   26.85   28.83
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.797   2.945   3.097   3.137   3.233   3.535
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

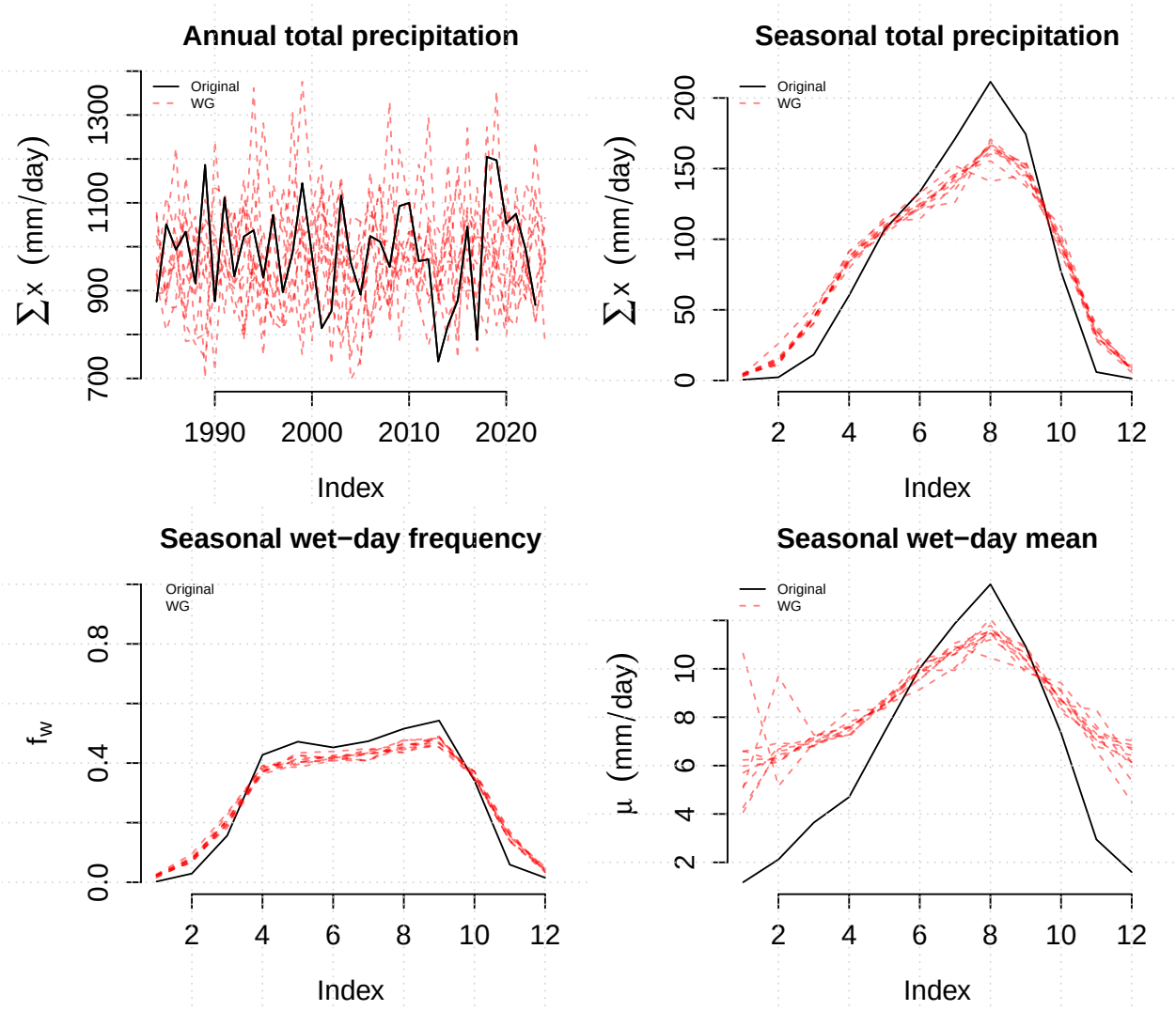


Figure 70: Tests of WG on GHCND data.

```
## 0.04688 0.05113 0.05296 0.05291 0.05546 0.05701
```

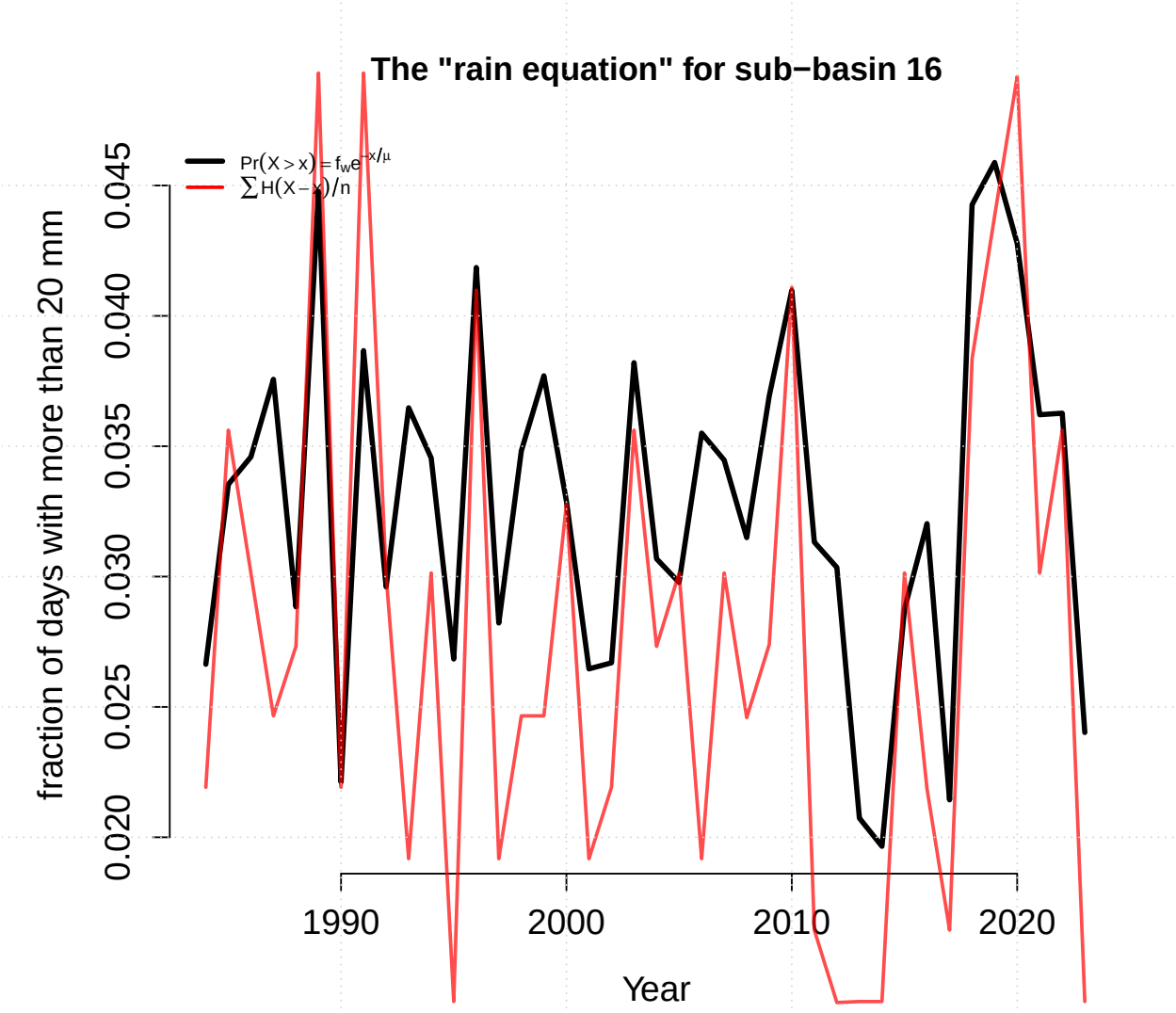


Figure 71: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 19  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.103   1.160   1.291   1.285   1.409   1.473
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   7.776   8.167   8.738   8.577   8.848   9.526
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.610   1.713   1.764   1.761   1.788   2.004
```

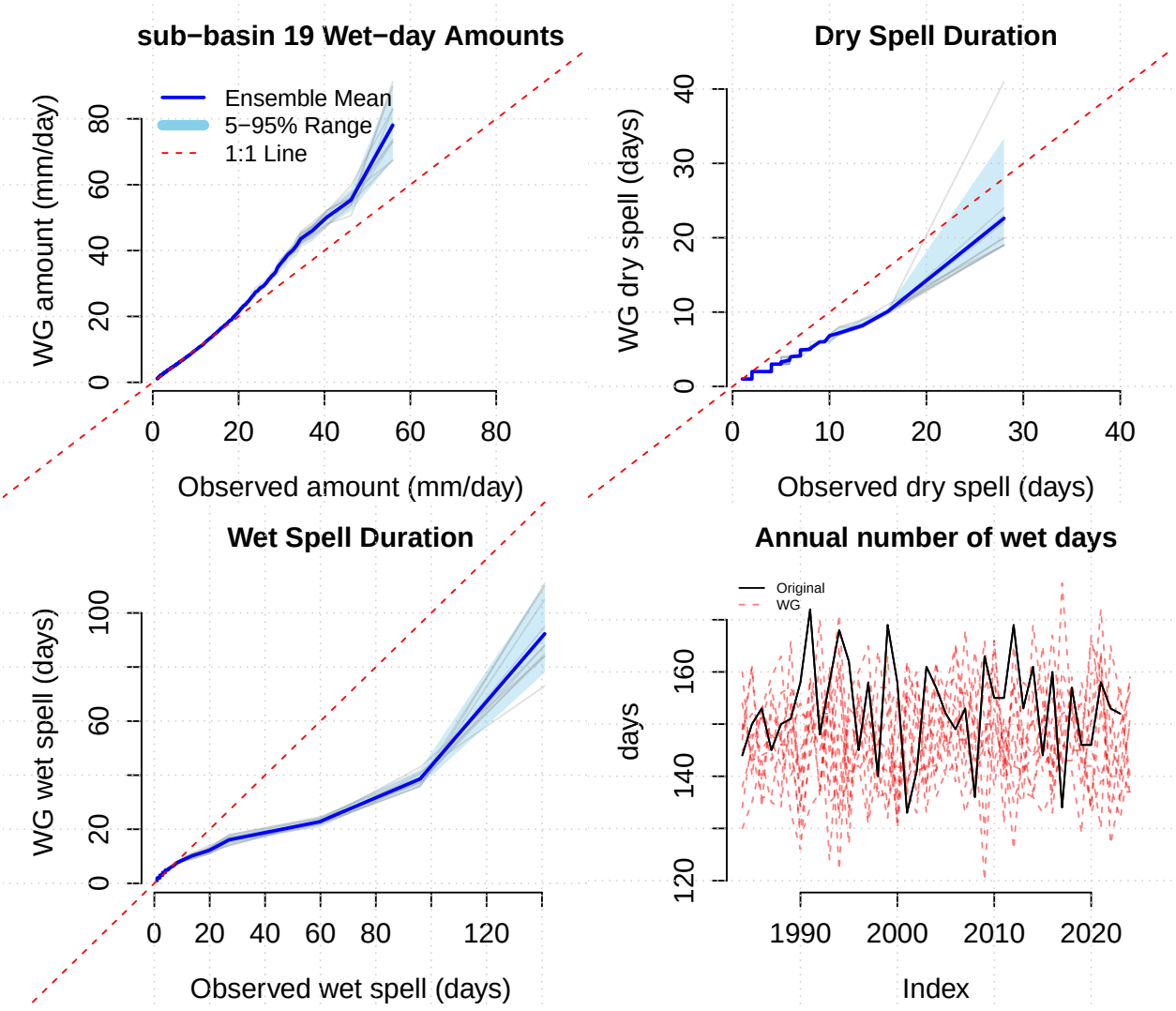


Figure 72: Tests of WG on GHCND data.

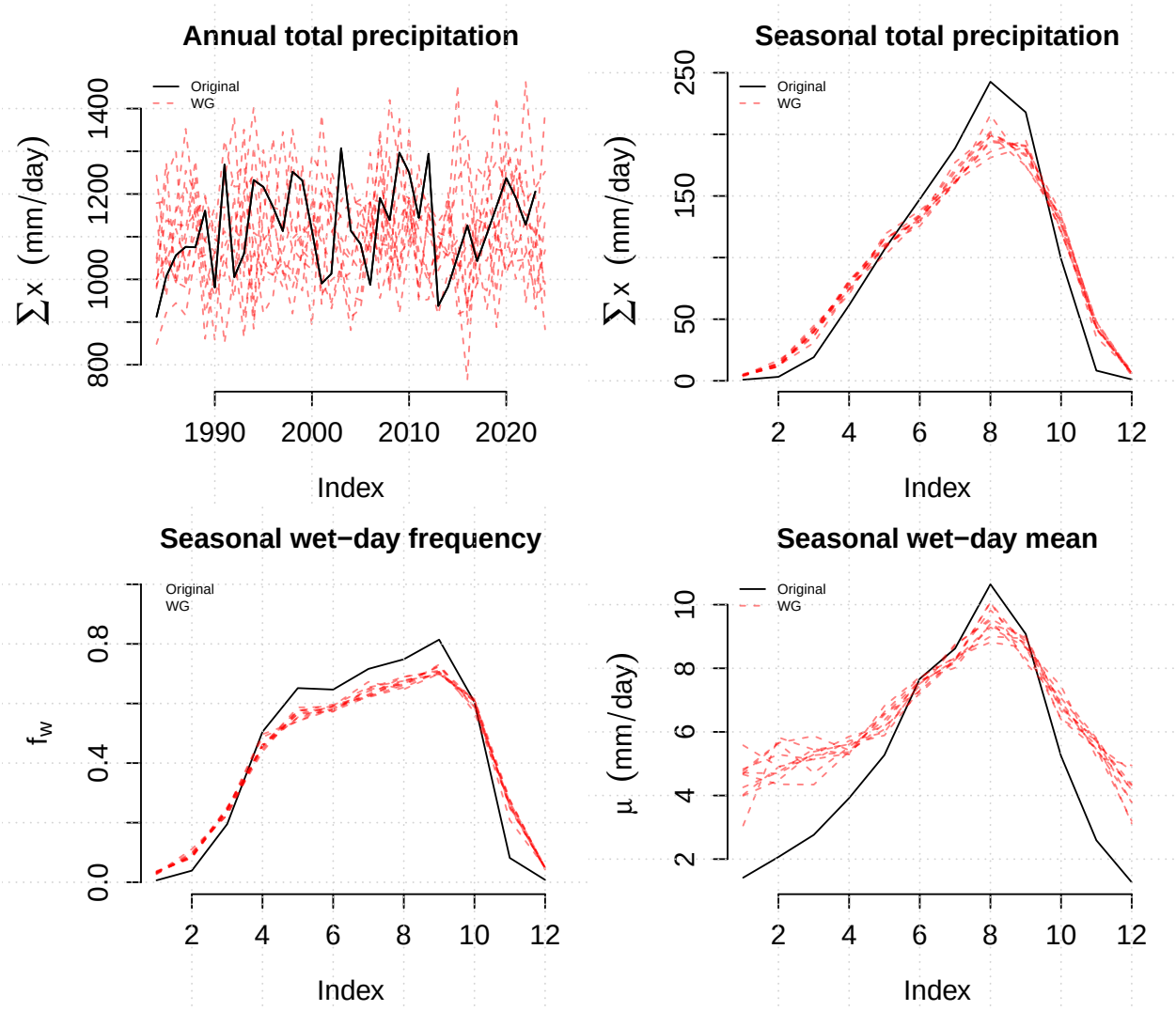


Figure 73: Tests of WG on GHCND data.

```
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   23.30   25.71   25.99   25.98   26.56   28.75
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.920   1.985   2.021   2.047   2.115   2.204
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.07191 0.07791 0.08041 0.07951 0.08128 0.08415
```

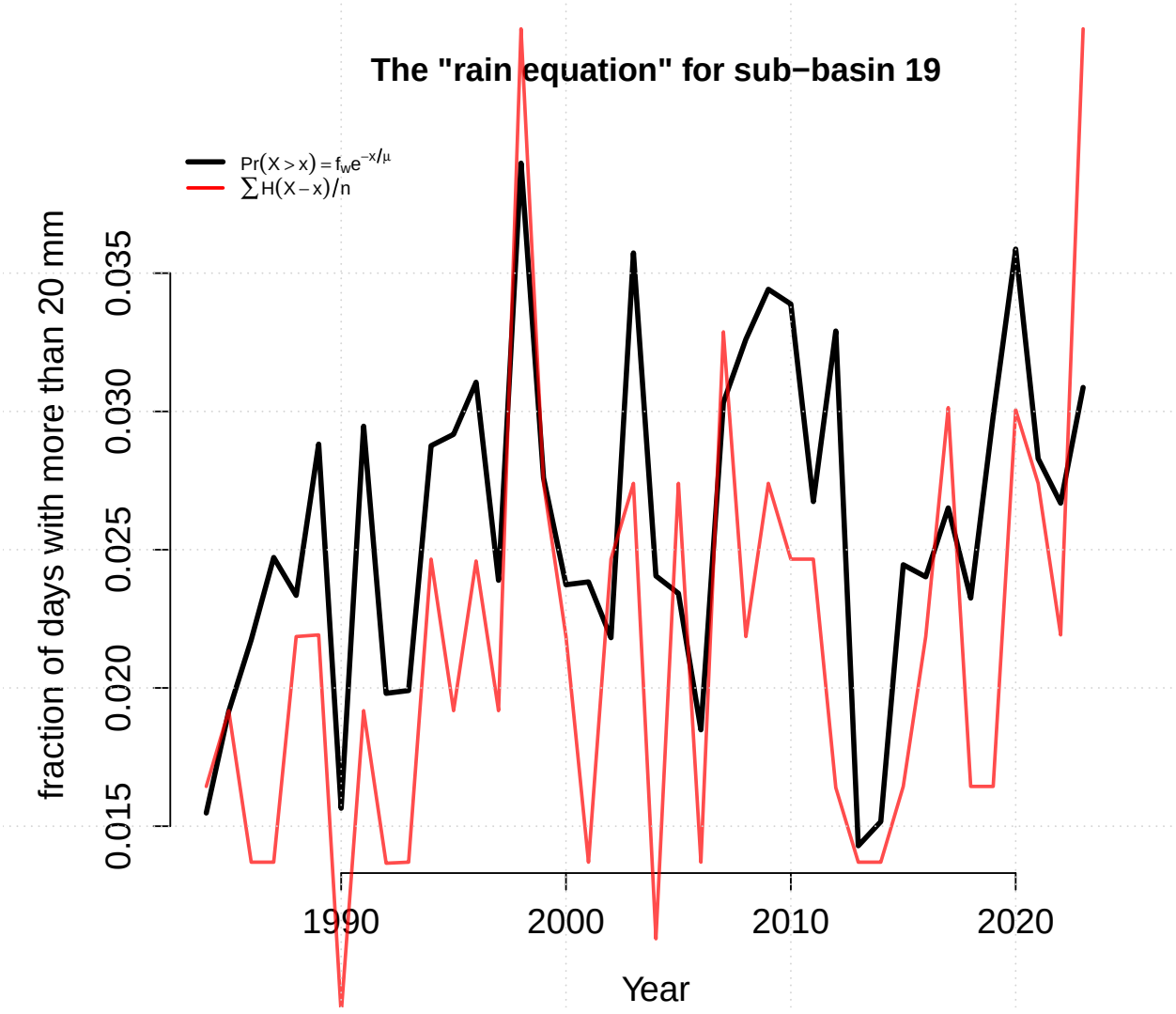


Figure 74: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 17  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
```

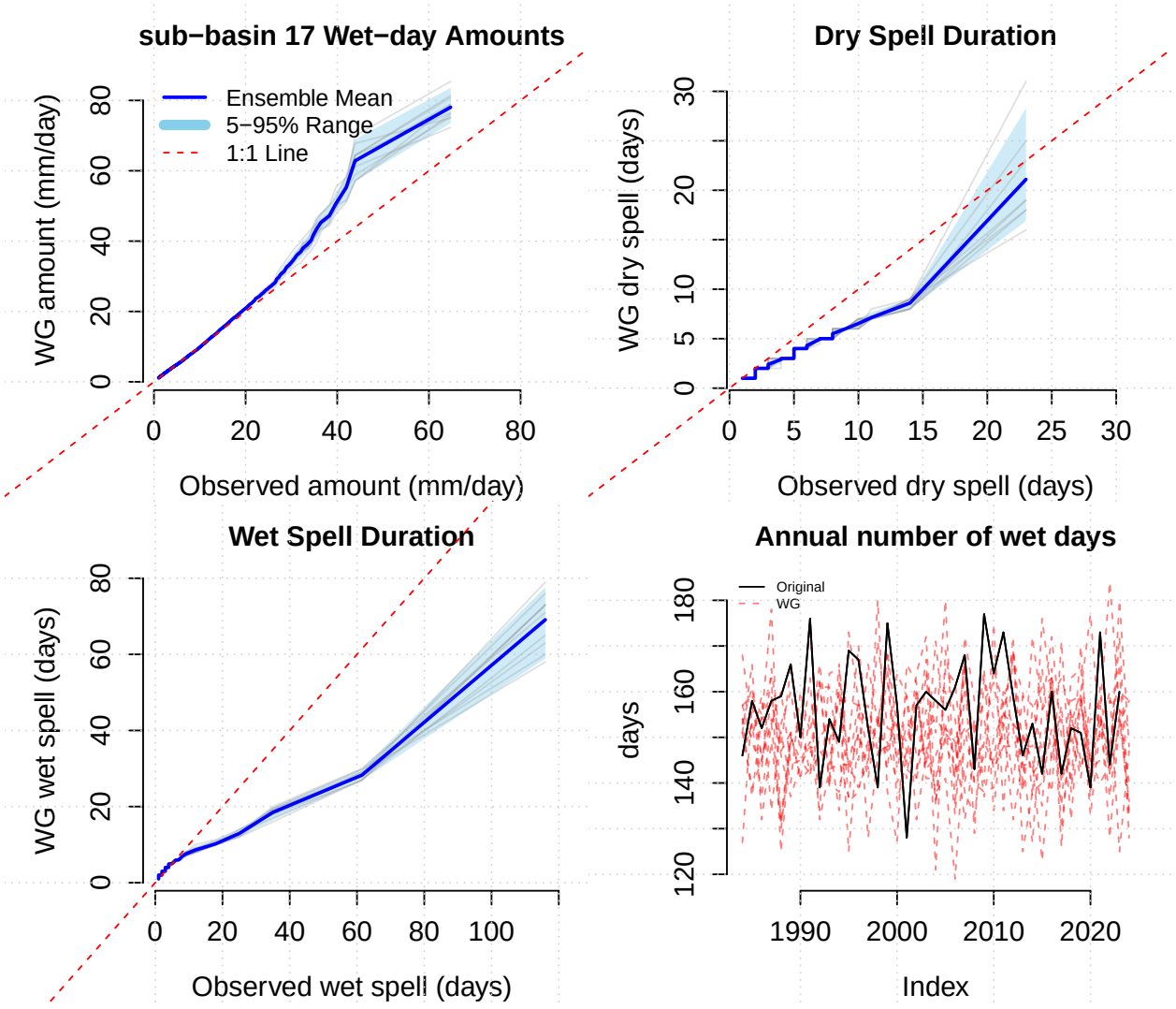


Figure 75: Tests of WG on GHCND data.

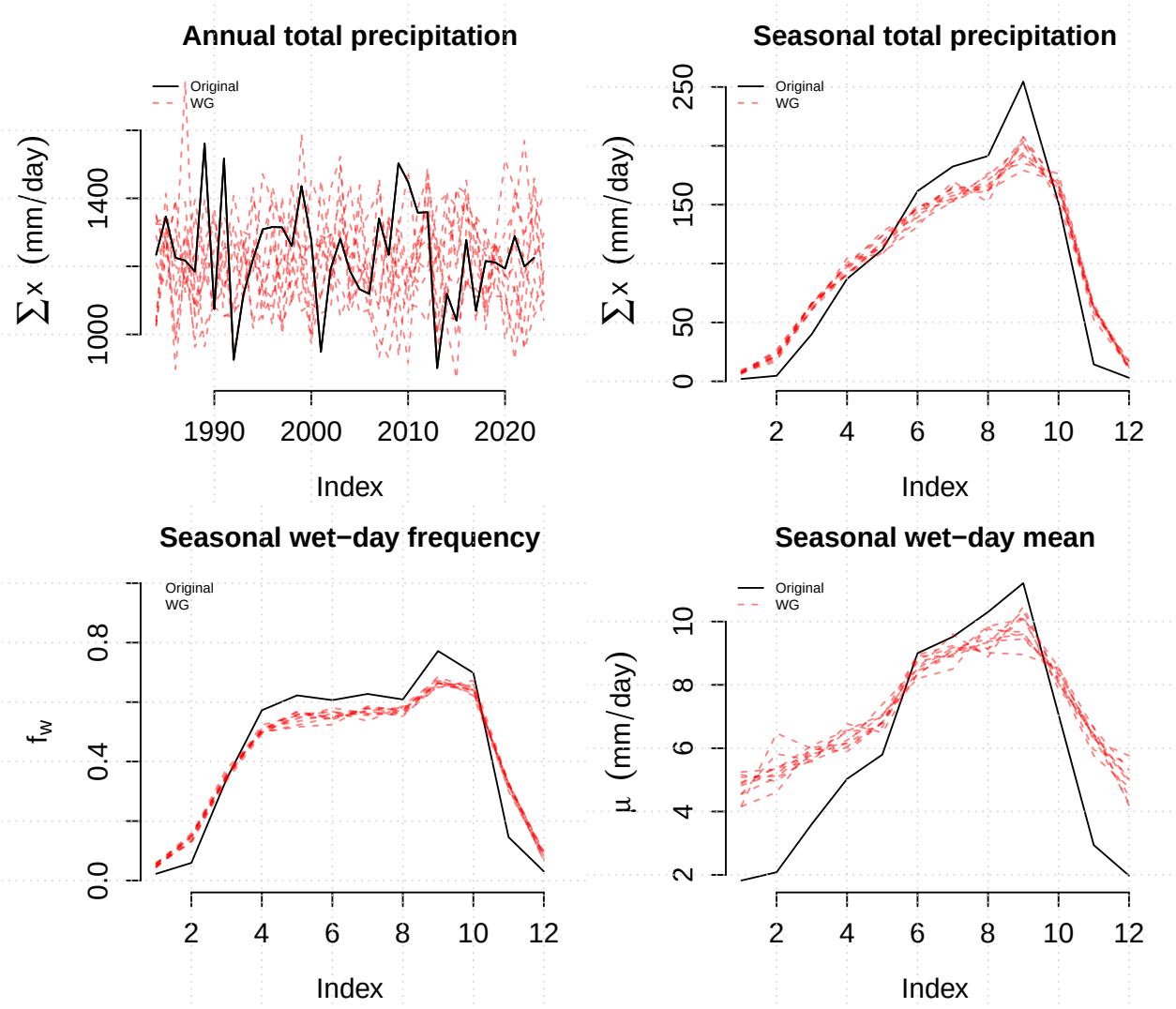


Figure 76: Tests of WG on GHCND data.

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9842  1.0878  1.2504  1.2489  1.3653  1.5932
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.426   5.902   5.999   6.189   6.638   7.030
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.225   1.255   1.333   1.321   1.351   1.442
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   26.35   27.59   28.41   28.70   28.89   32.17
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.905   2.019   2.126   2.098   2.180   2.226
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.07475 0.07616 0.07912 0.07911 0.08183 0.08514


## test.WG.fwmu.day.precip for sub-basin 20  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6849  0.8398  0.9011  0.8971  0.9834  1.0948
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.601   6.149   6.245   6.188   6.755   6.862
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.359   1.413   1.434   1.442   1.460   1.584
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   17.83   18.31   18.90   18.82   19.28   19.61
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.106   1.203   1.223   1.232   1.263   1.360
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.07368 0.07424 0.07560 0.07606 0.07752 0.07999


## test.WG.fwmu.day.precip for sub-basin 18  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.163   1.290   1.382   1.433   1.561   1.795
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

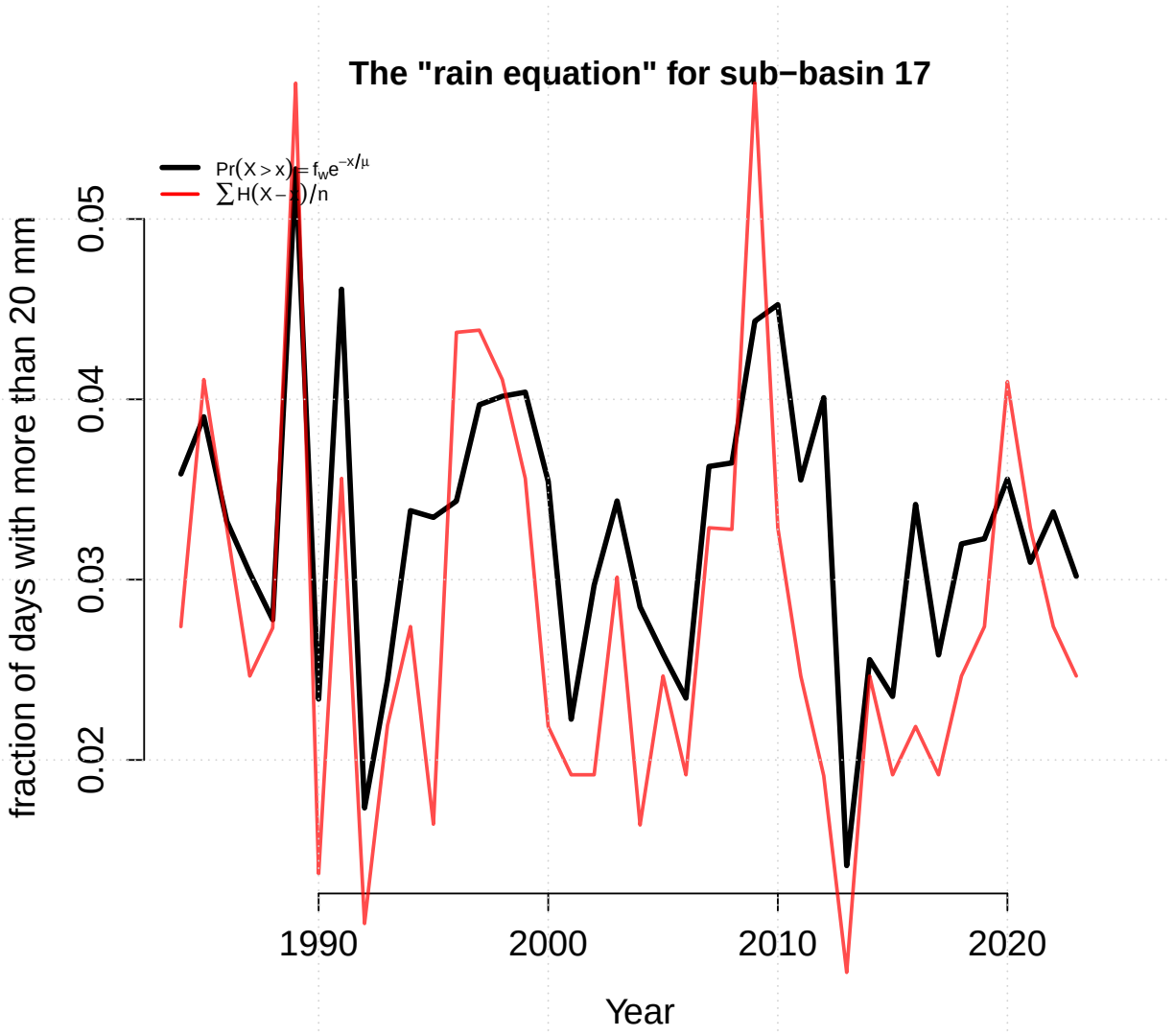


Figure 77: Tests of WG on GHCND data.

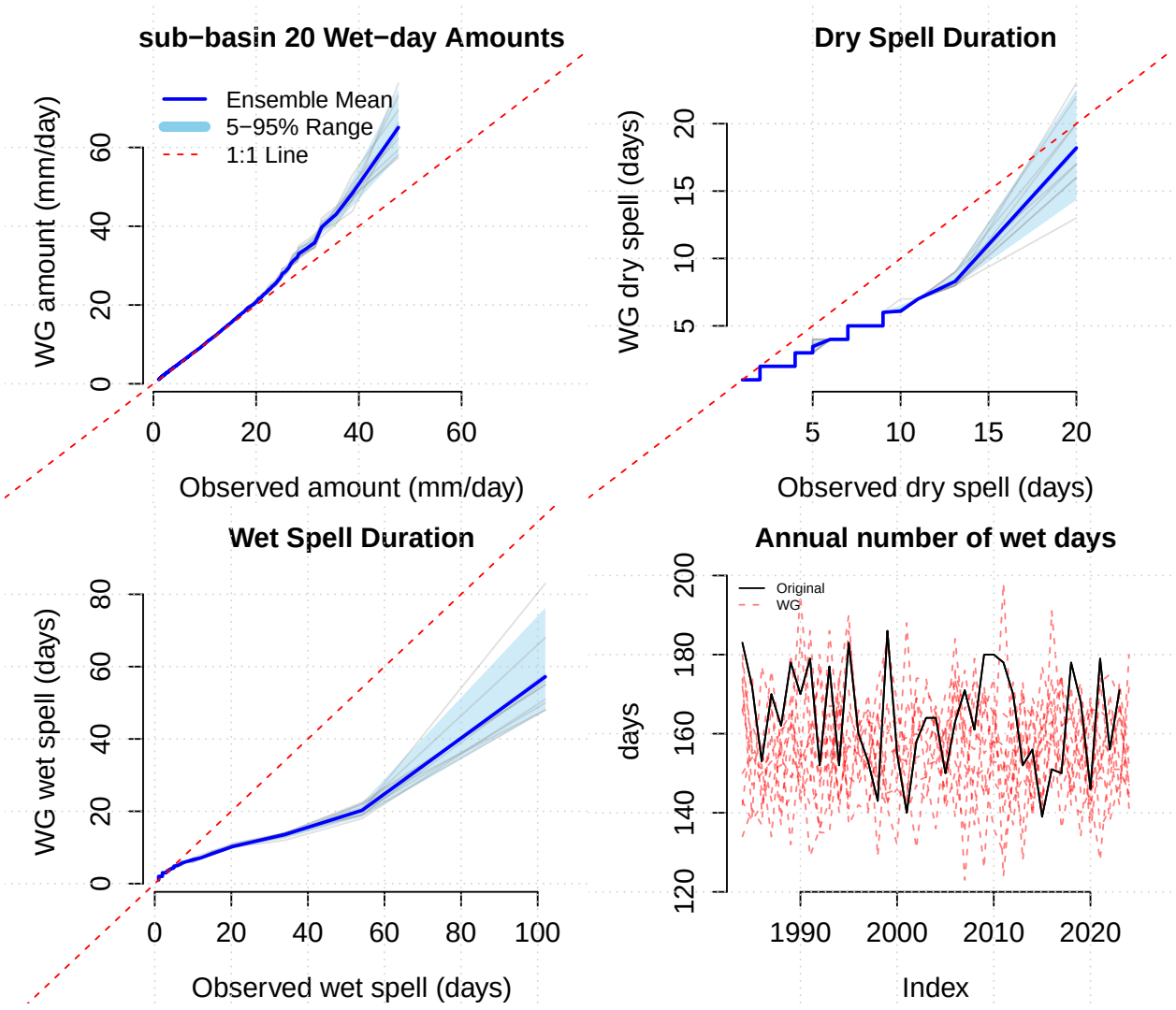


Figure 78: Tests of WG on GHCND data.

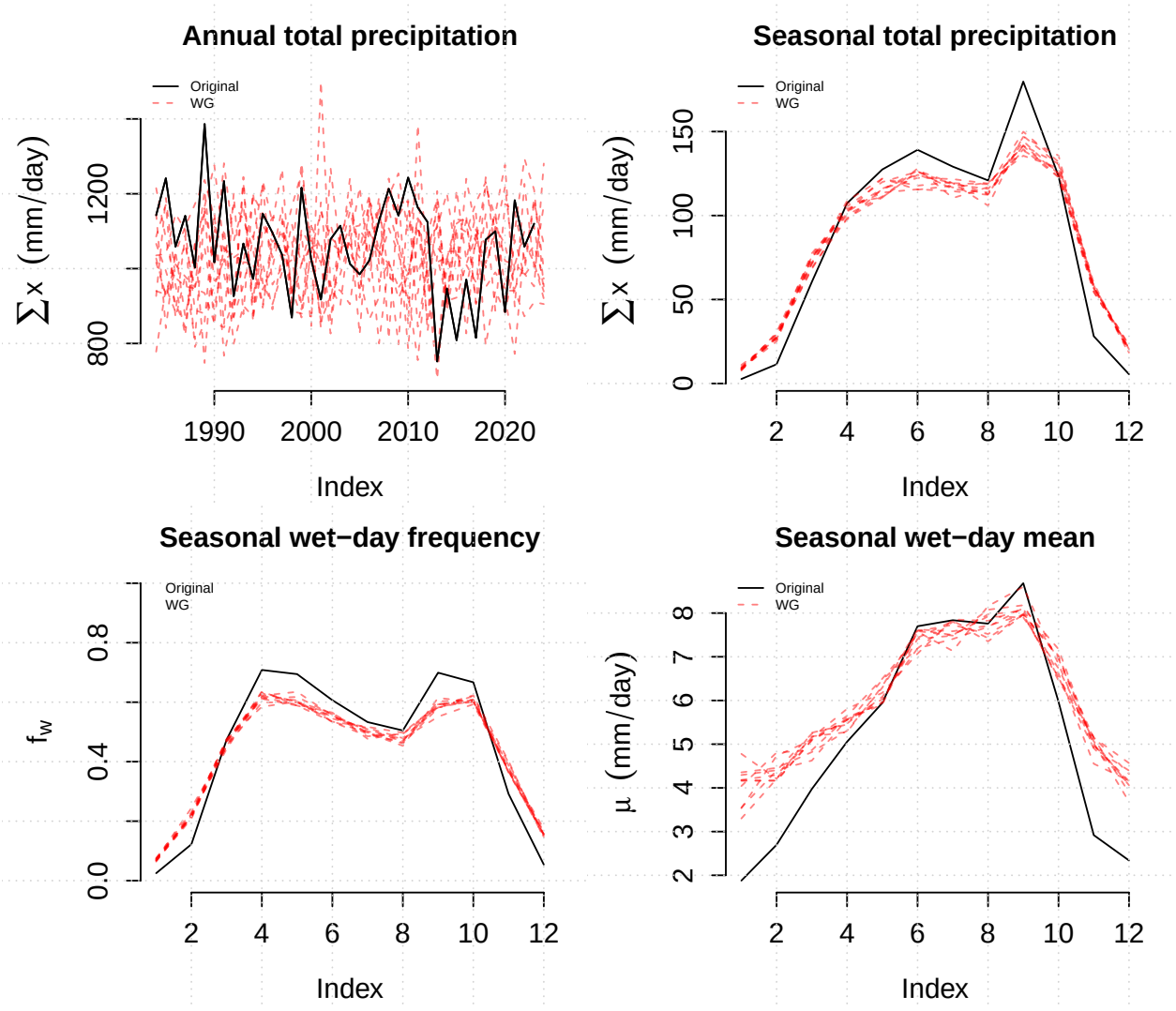


Figure 79: Tests of WG on GHCND data.

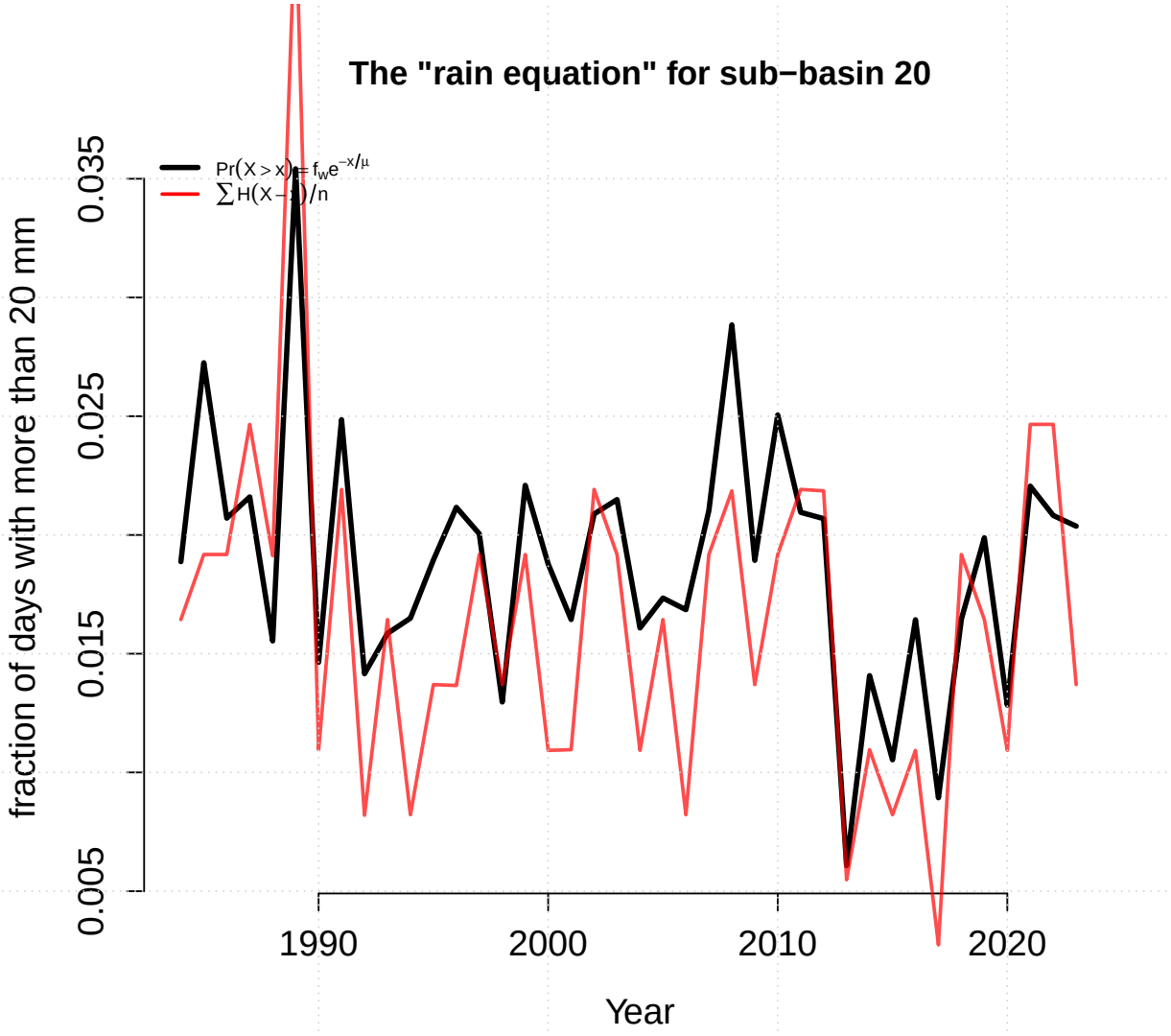


Figure 80: Tests of WG on GHCND data.

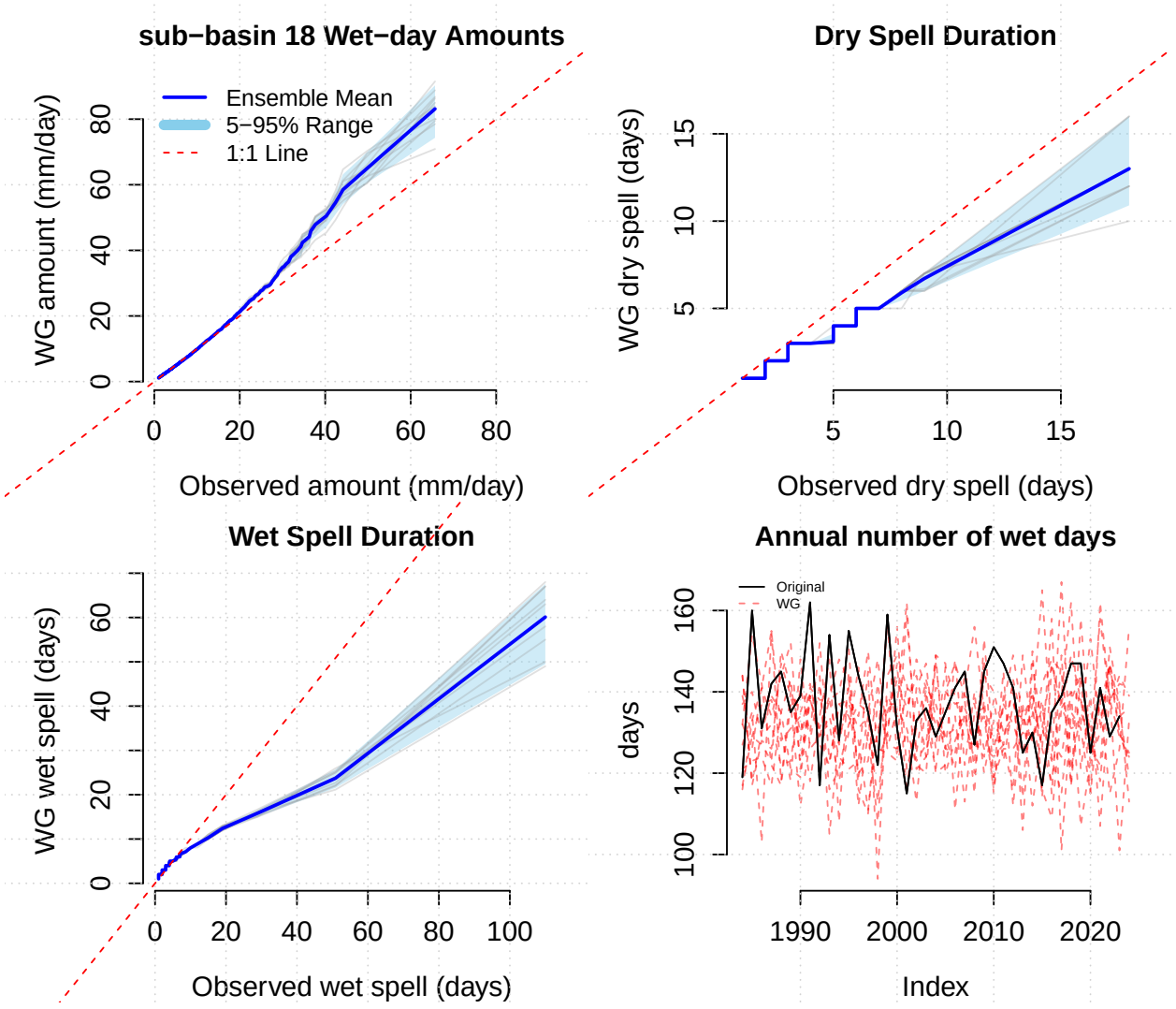


Figure 81: Tests of WG on GHCND data.

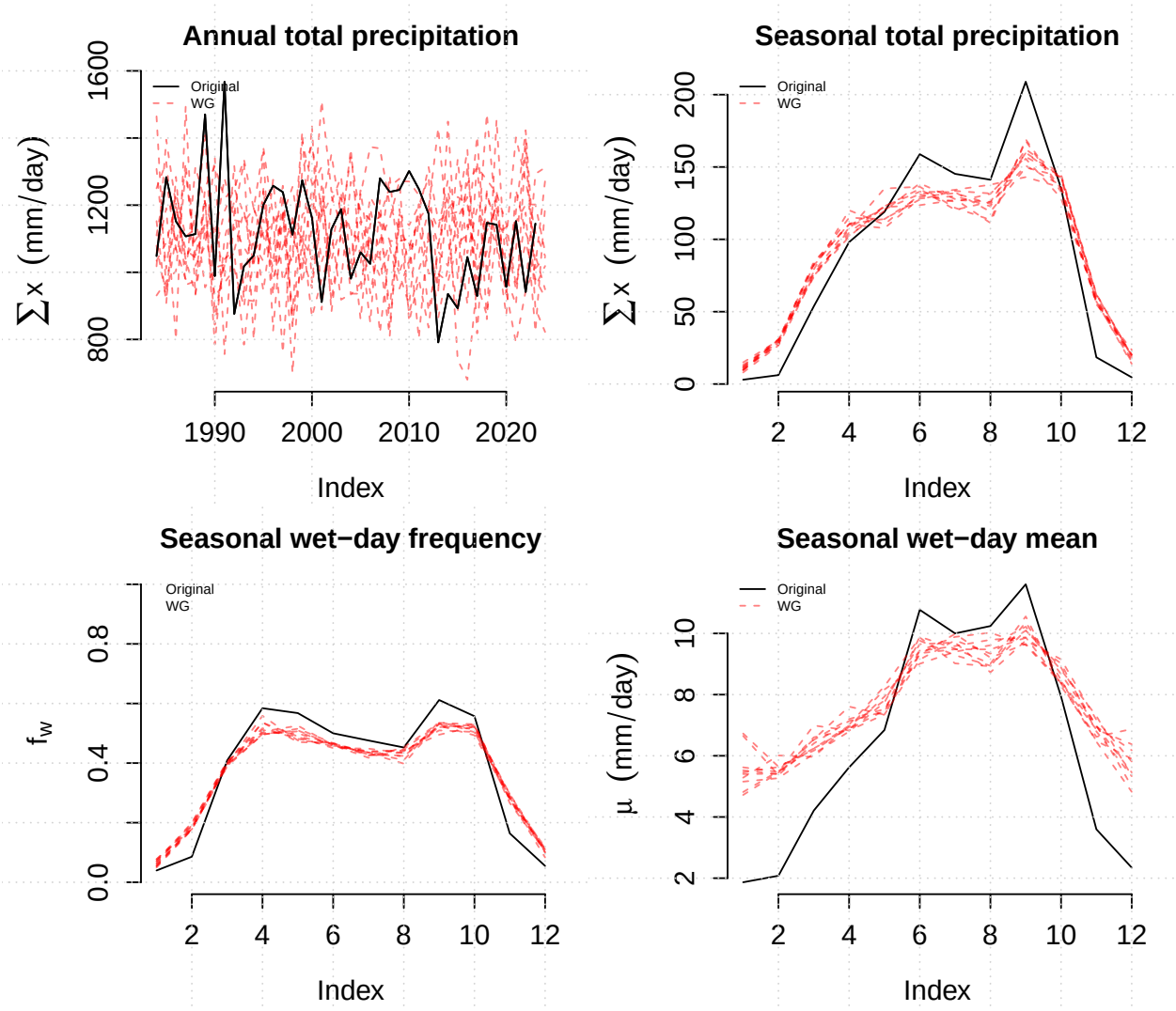


Figure 82: Tests of WG on GHCND data.

```
##   5.203   5.464   5.758   5.923   6.334   6.968
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8062  0.8958  0.9192  0.9400  0.9961  1.1314
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   24.09   25.39   26.56   26.33   27.42   27.73
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.089   2.238   2.283   2.272   2.338   2.391
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.06034 0.06469 0.06634 0.06584 0.06777 0.06848
```

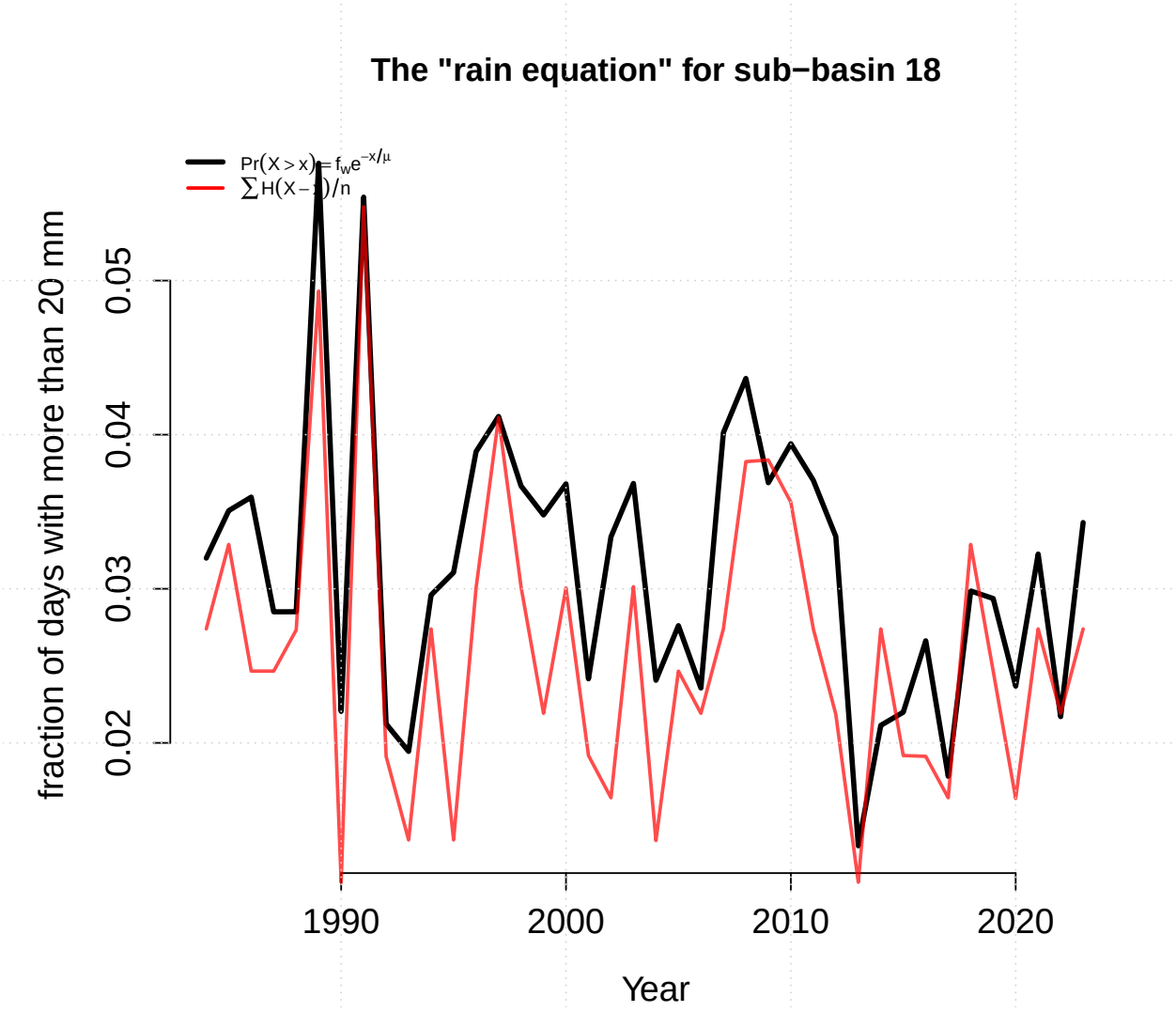


Figure 83: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 21  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

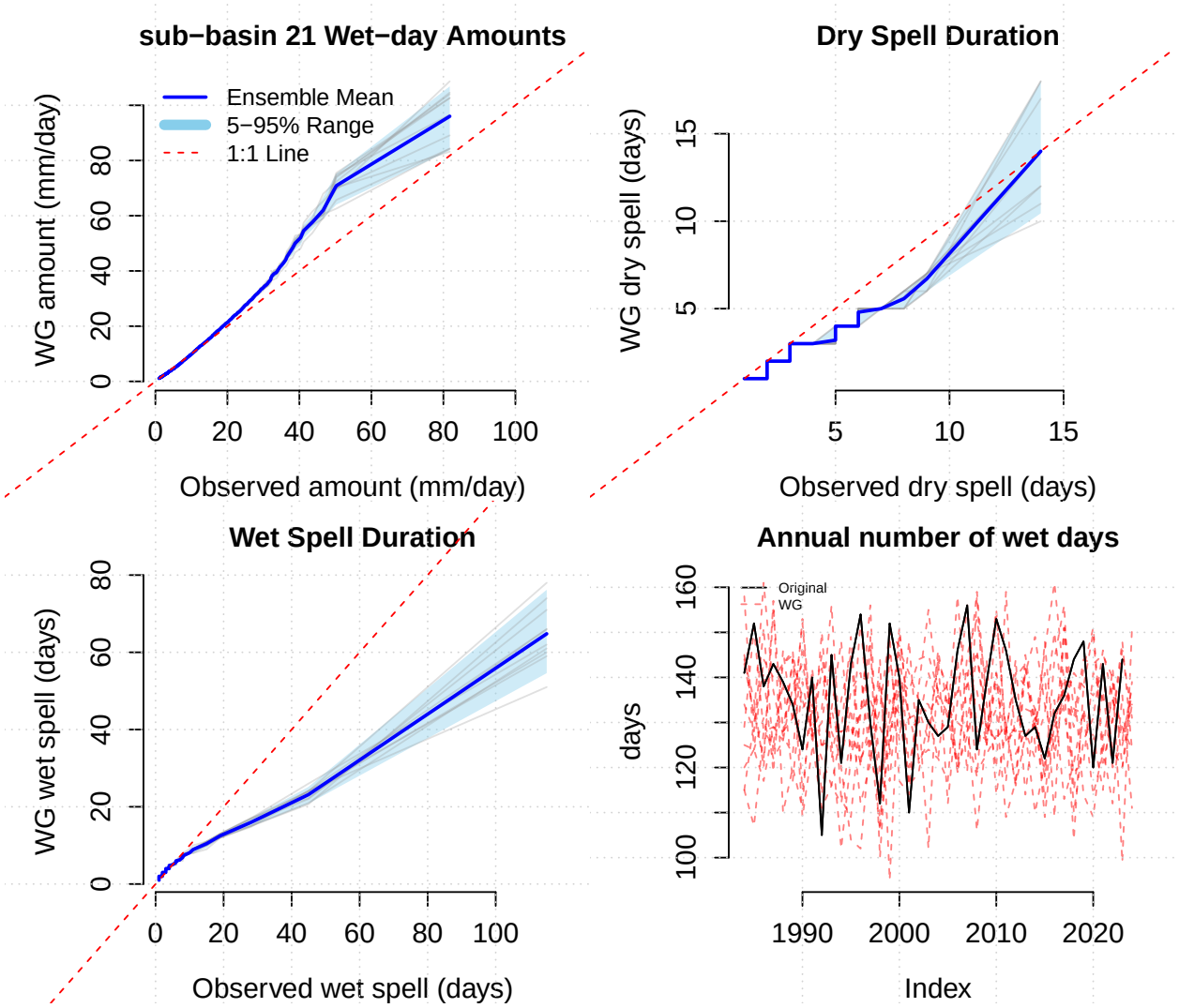


Figure 84: Tests of WG on GHCND data.

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.467   1.569   1.749   1.707   1.826   1.881
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.475   5.302   5.692   5.696   6.130   6.908
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7307  0.7576  0.7750  0.7978  0.8444  0.9132
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   28.83   30.50   31.01   31.42   32.74   34.64
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.512   2.545   2.612   2.622   2.673   2.820
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

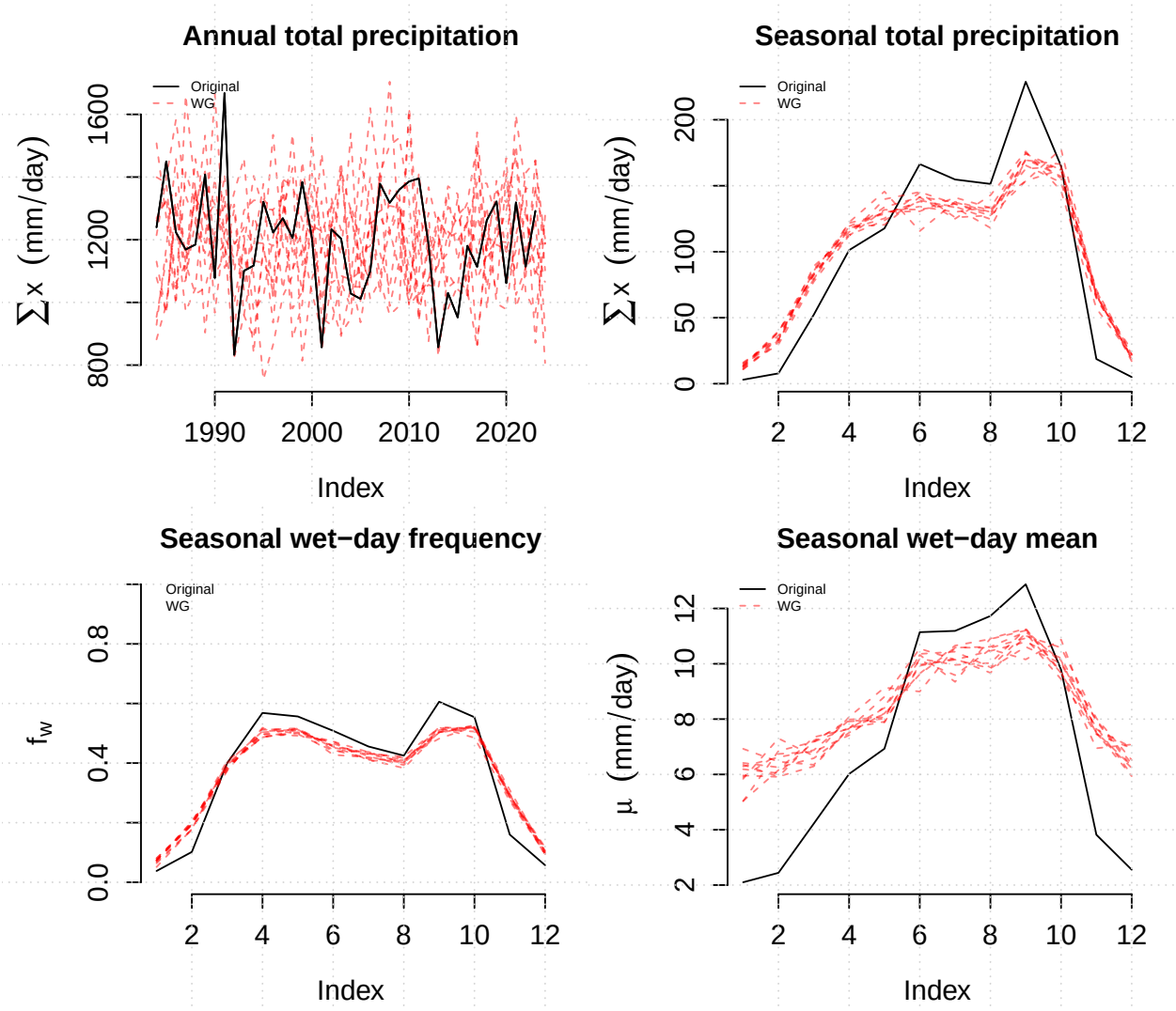


Figure 85: Tests of WG on GHCND data.

```
## 0.06044 0.06450 0.06558 0.06558 0.06681 0.07001
```

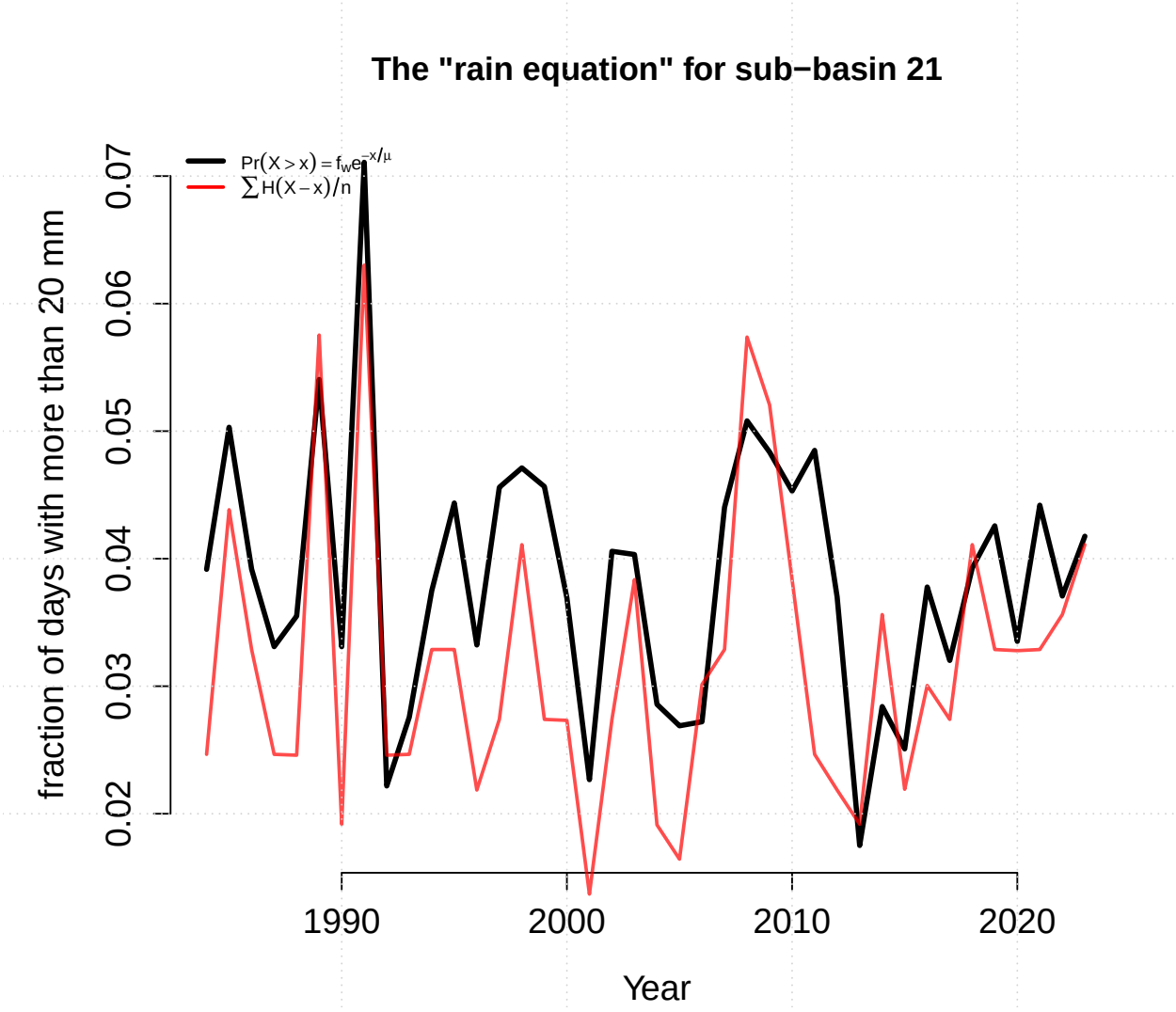


Figure 86: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 22  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9897  1.0643  1.1392  1.1420  1.2069  1.3289
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.577   4.360   4.632   4.580   4.842   5.221
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.273   1.307   1.337   1.329   1.352   1.375
```

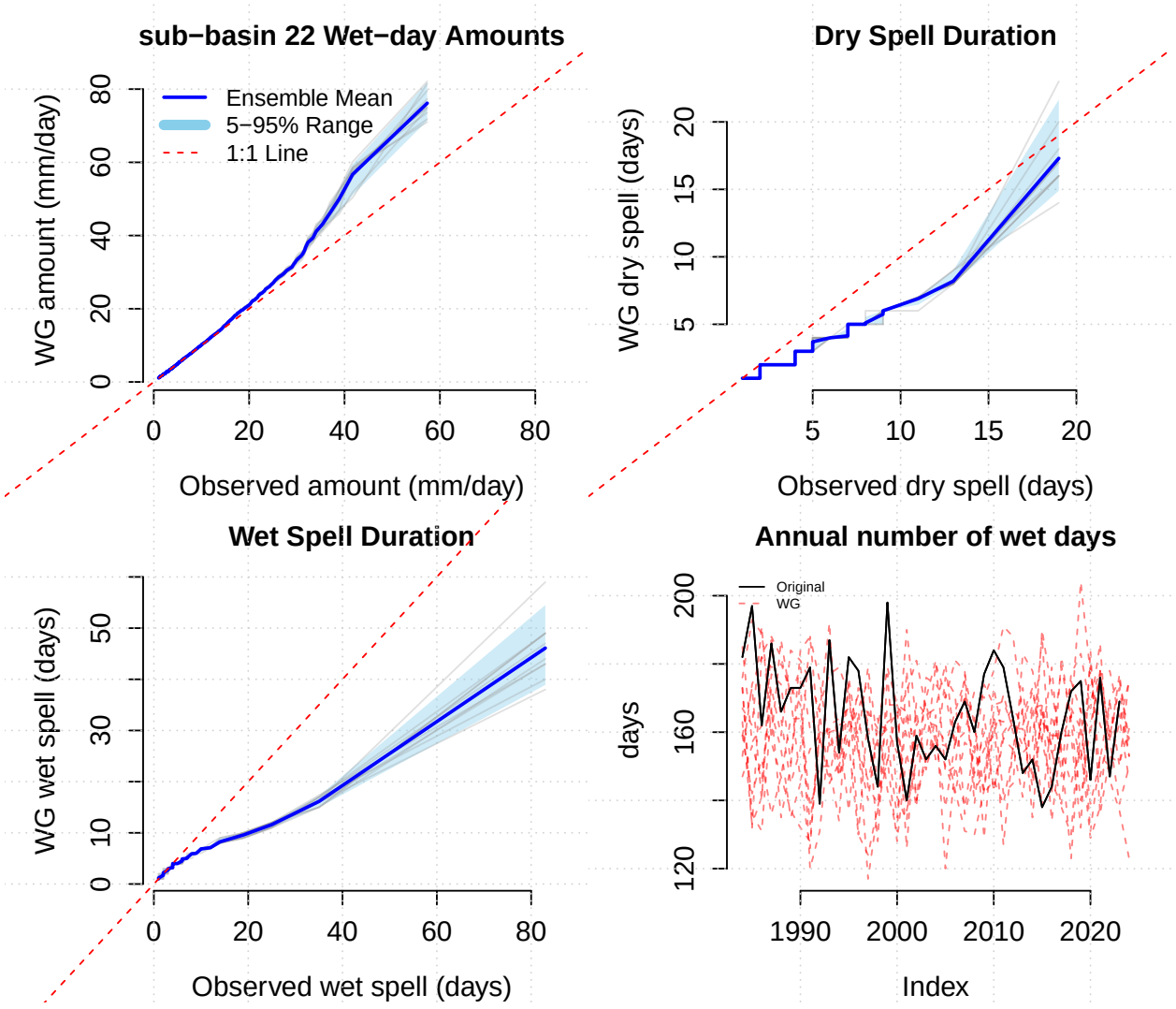


Figure 87: Tests of WG on GHCND data.

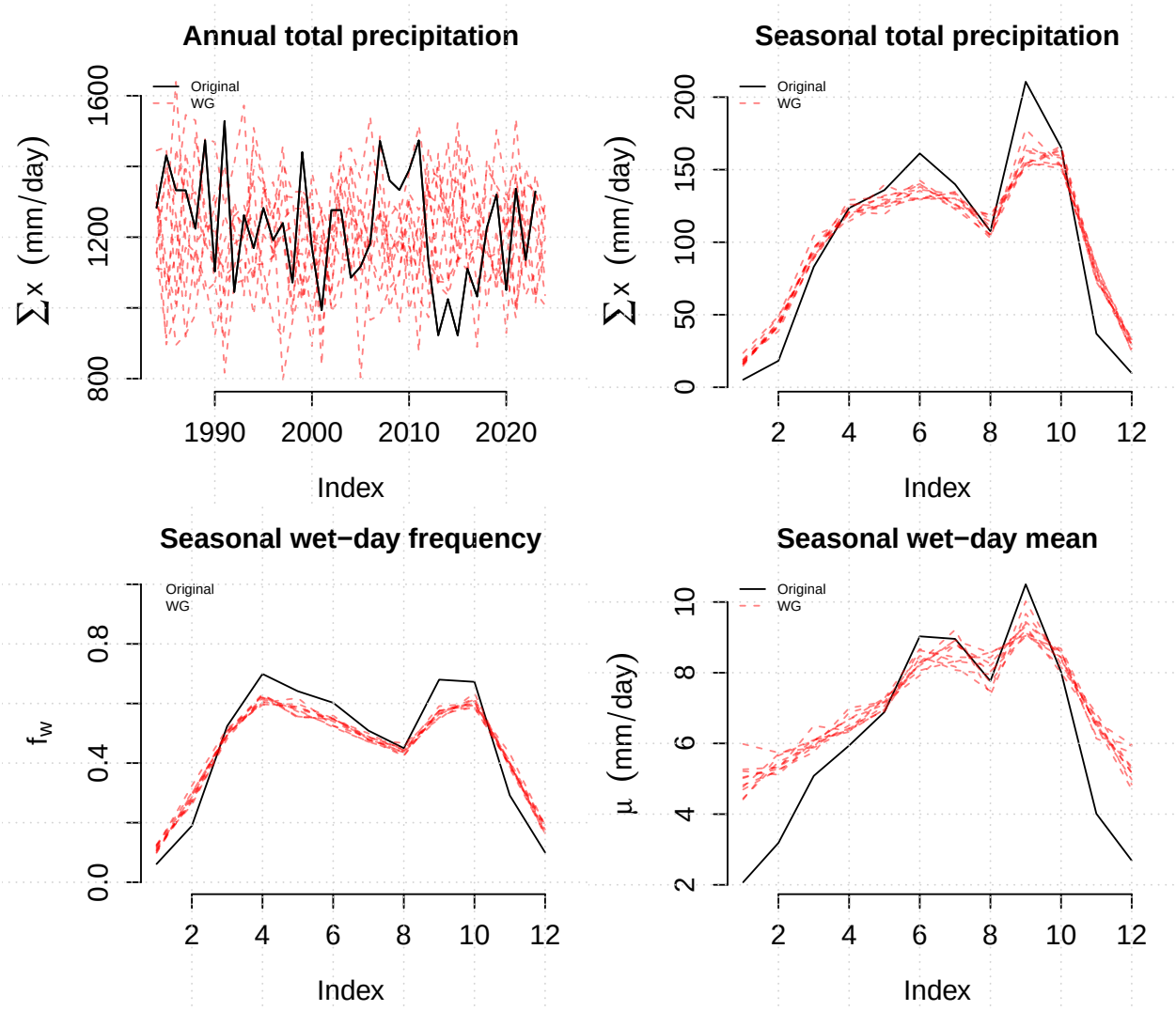


Figure 88: Tests of WG on GHCND data.

```
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   23.15   24.98   25.56   25.38   26.38   27.02
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.465   1.565   1.602   1.608   1.658   1.734
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.06951 0.07016 0.07230 0.07329 0.07642 0.07940
```

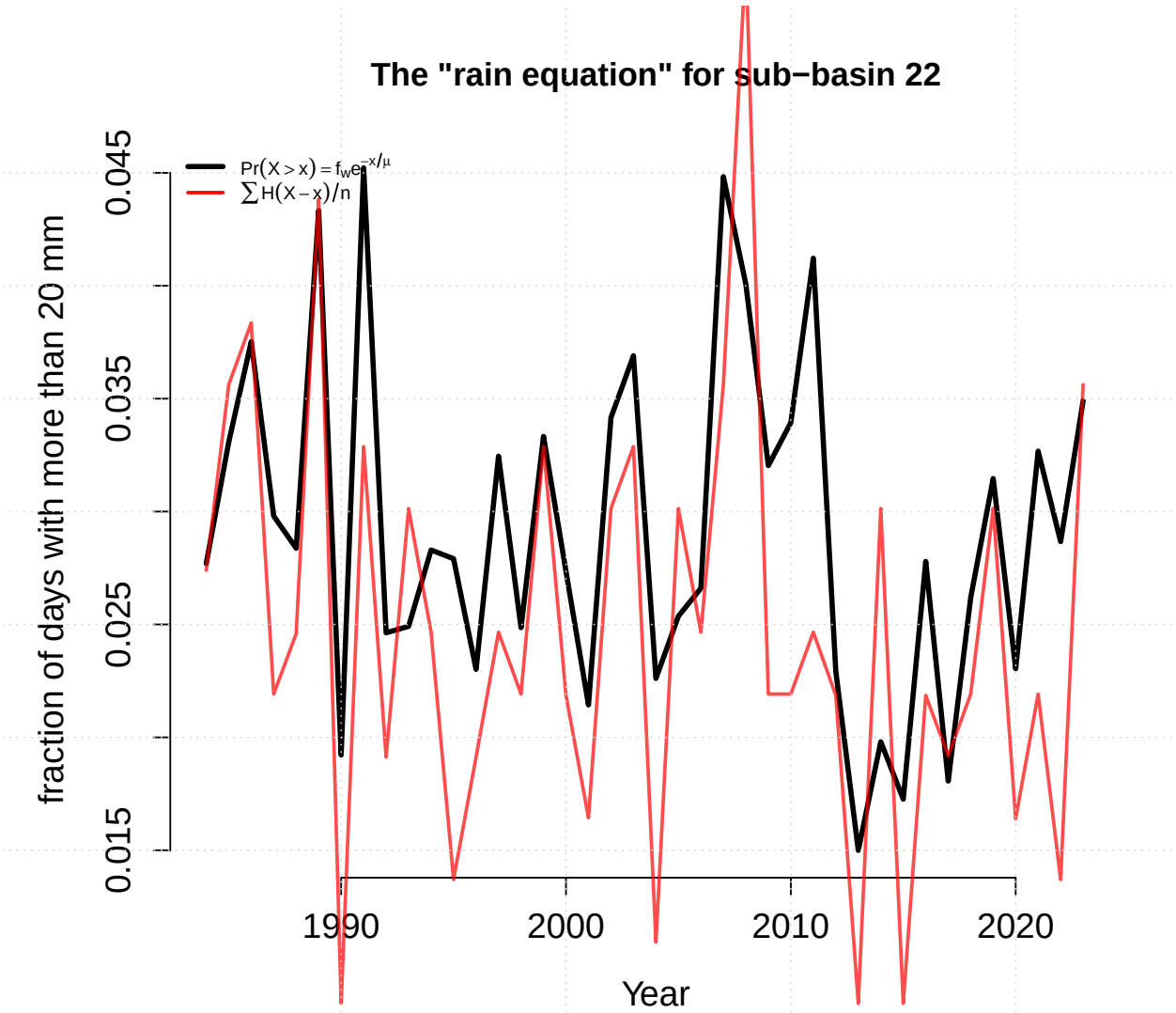


Figure 89: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 23  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
```

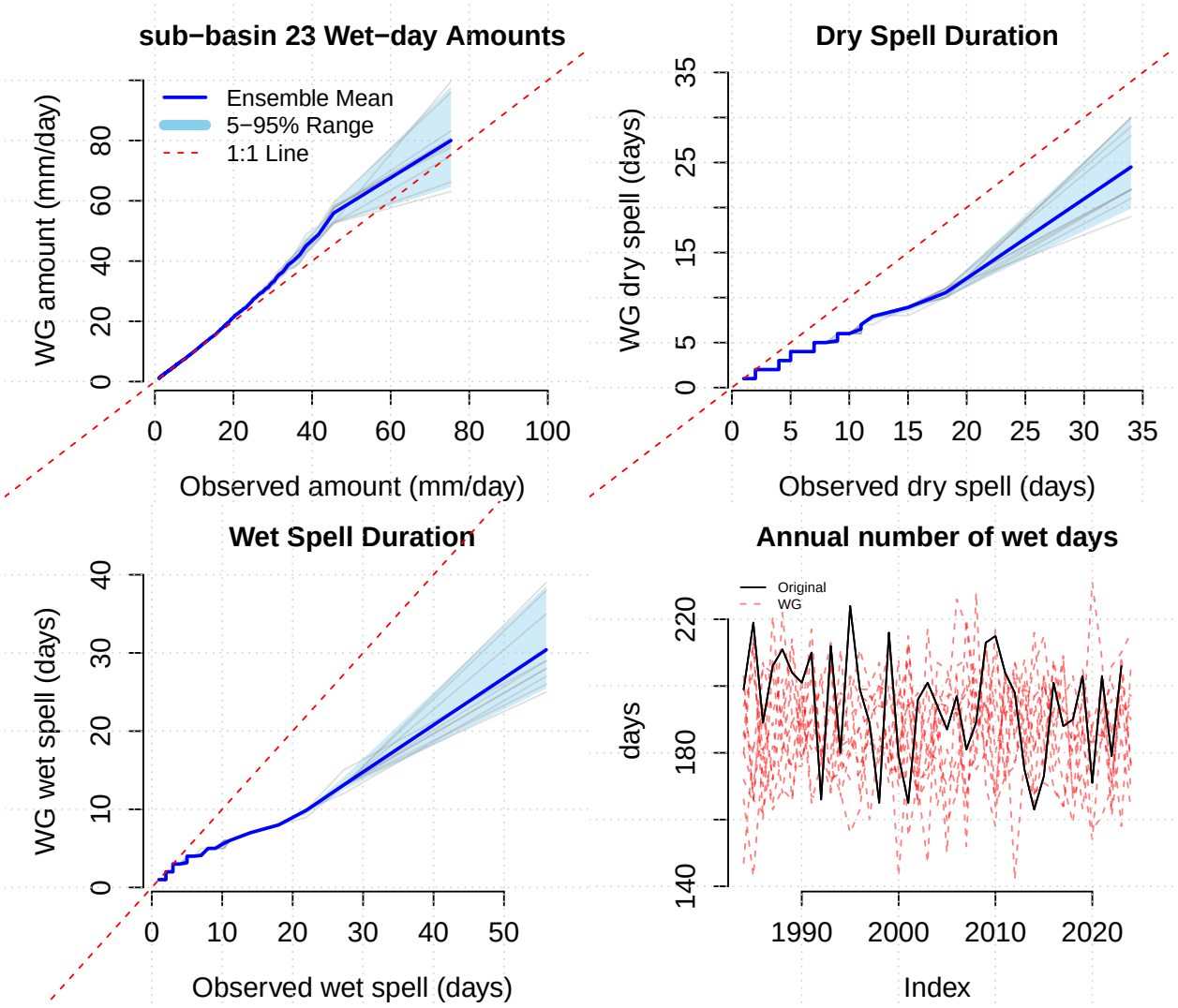


Figure 90: Tests of WG on GHCND data.

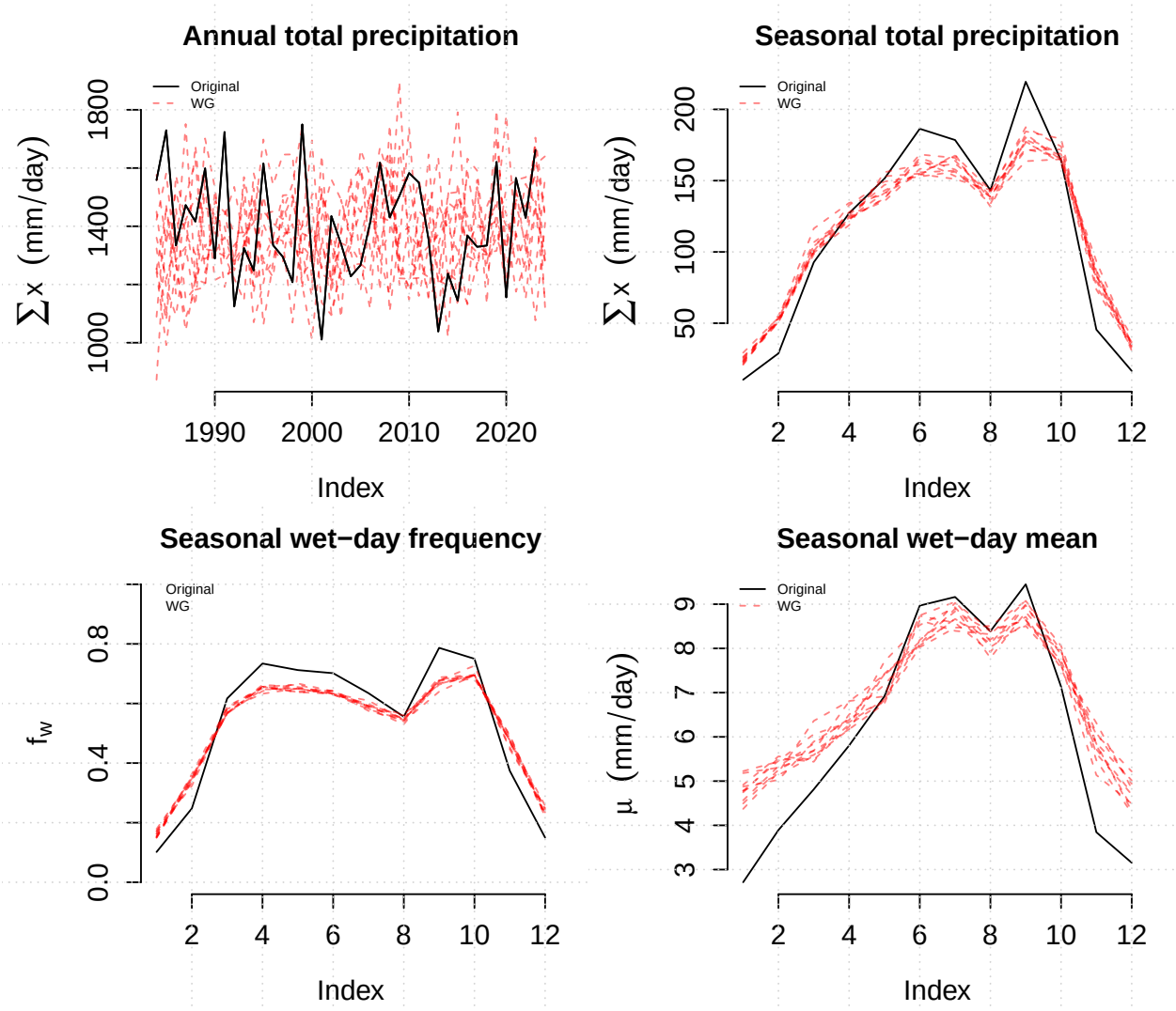


Figure 91: Tests of WG on GHCND data.

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6084  0.6836  0.8297  0.8249  0.8837  1.1346
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.966   3.324   3.686   3.558   3.809   3.946
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.792   1.833   2.076   2.025   2.176   2.315
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   21.79   23.04   23.60   23.55   24.20   24.64
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.024   1.104   1.138   1.154   1.240   1.268
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.06896 0.07255 0.07500 0.07457 0.07706 0.07867


## test.WG.fwmu.day.precip for sub-basin 24  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6879  0.8198  0.9205  0.9185  0.9639  1.2701
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.311   5.809   6.355   6.287   6.644   7.138
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.534   1.874   1.942   1.914   2.035   2.082
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   23.23   25.85   26.78   26.54   27.50   28.58
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.524   1.677   1.736   1.721   1.794   1.847
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.07200 0.07270 0.07533 0.07580 0.07728 0.08170


## test.WG.fwmu.day.precip for sub-basin 25  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   0.888   1.170   1.237   1.231   1.331   1.521
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

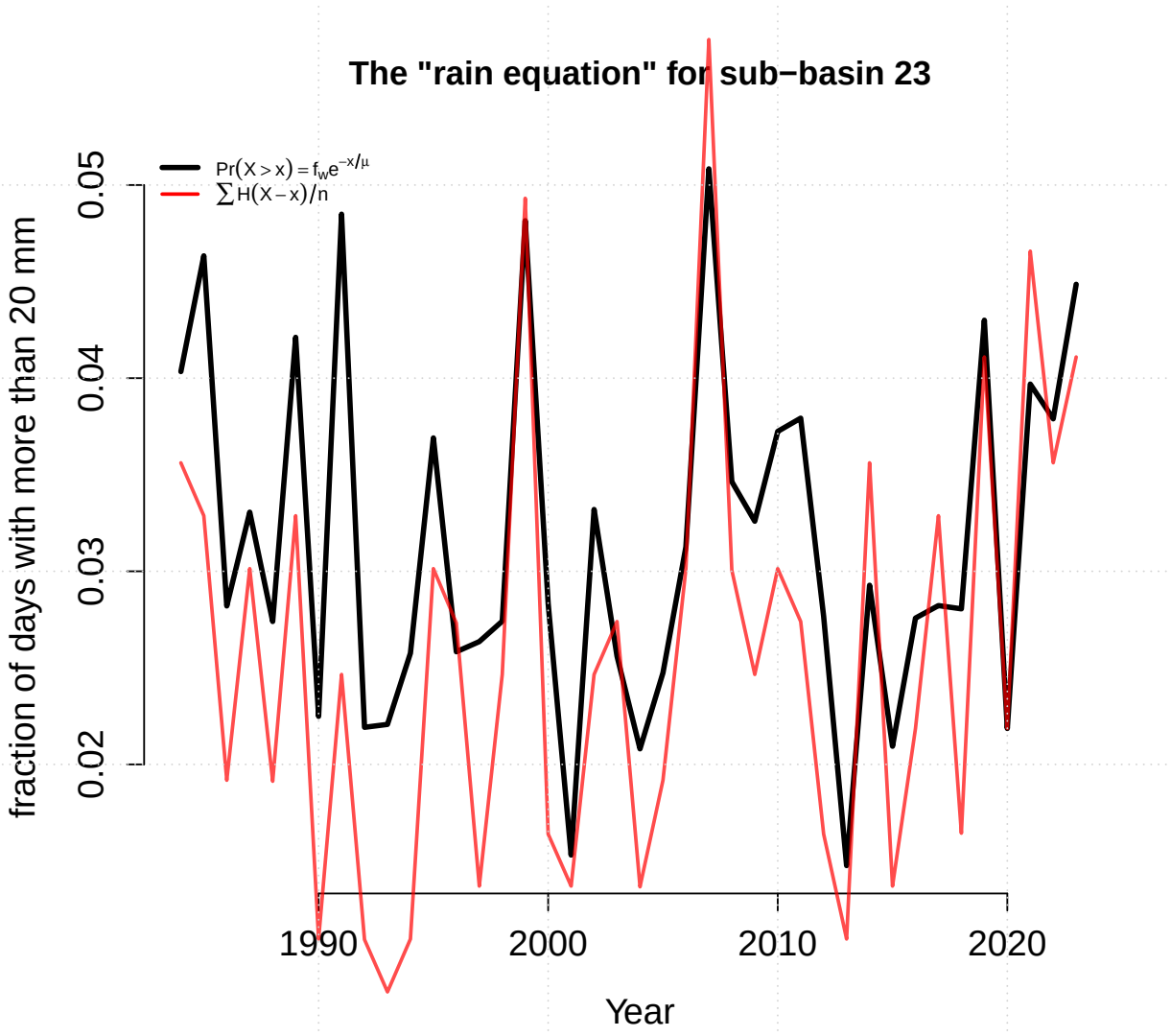


Figure 92: Tests of WG on GHCND data.

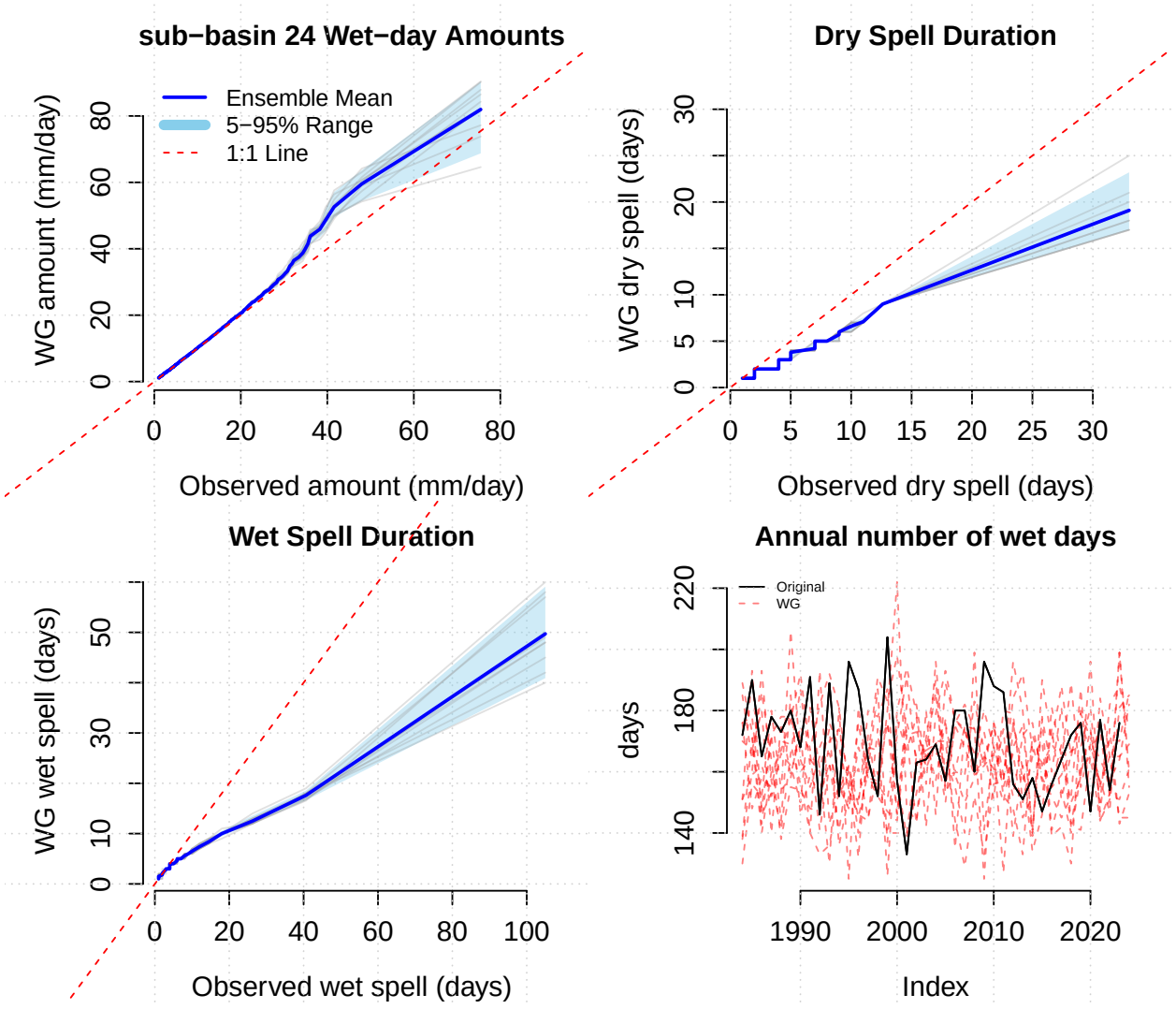


Figure 93: Tests of WG on GHCND data.

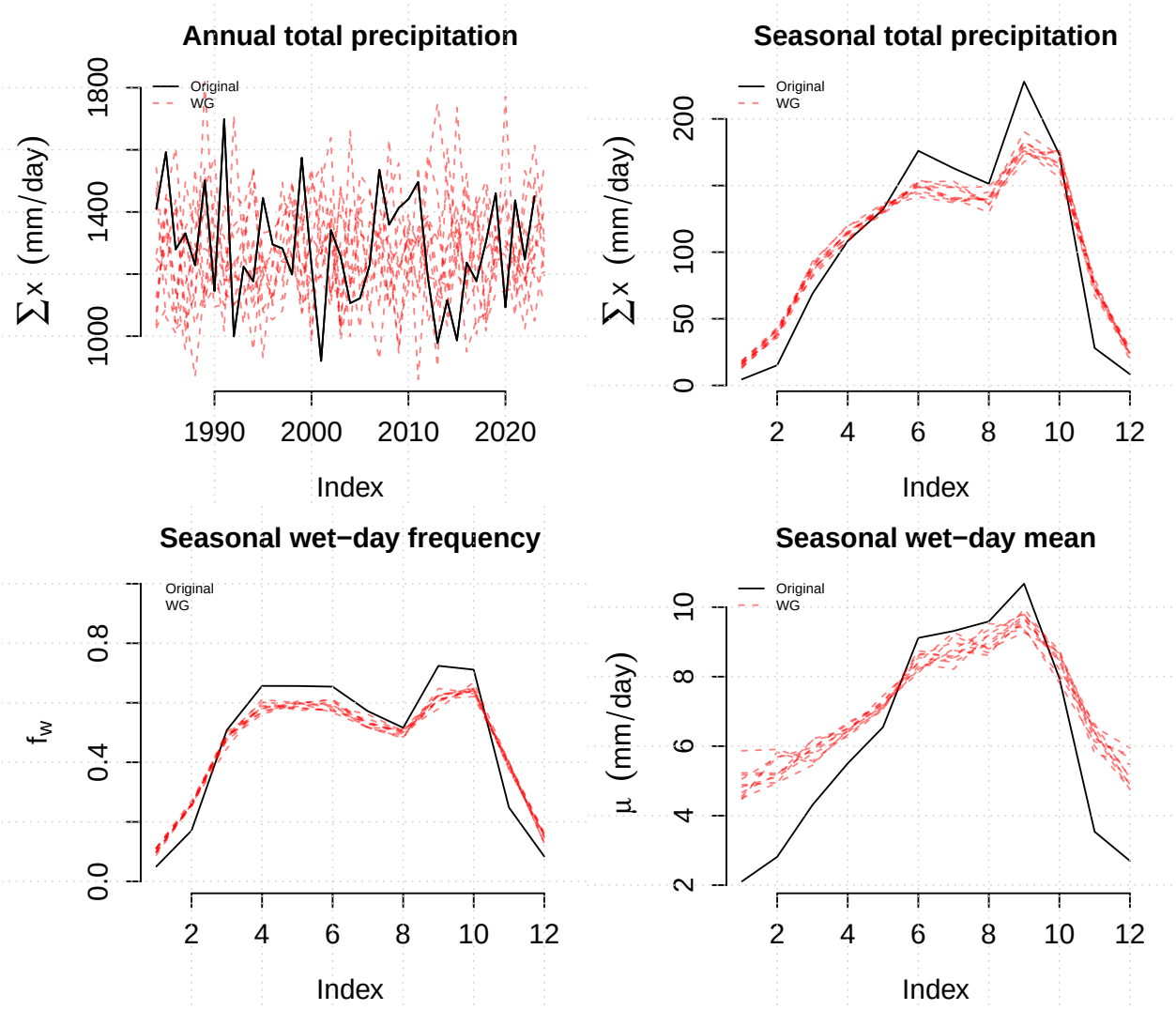


Figure 94: Tests of WG on GHCND data.

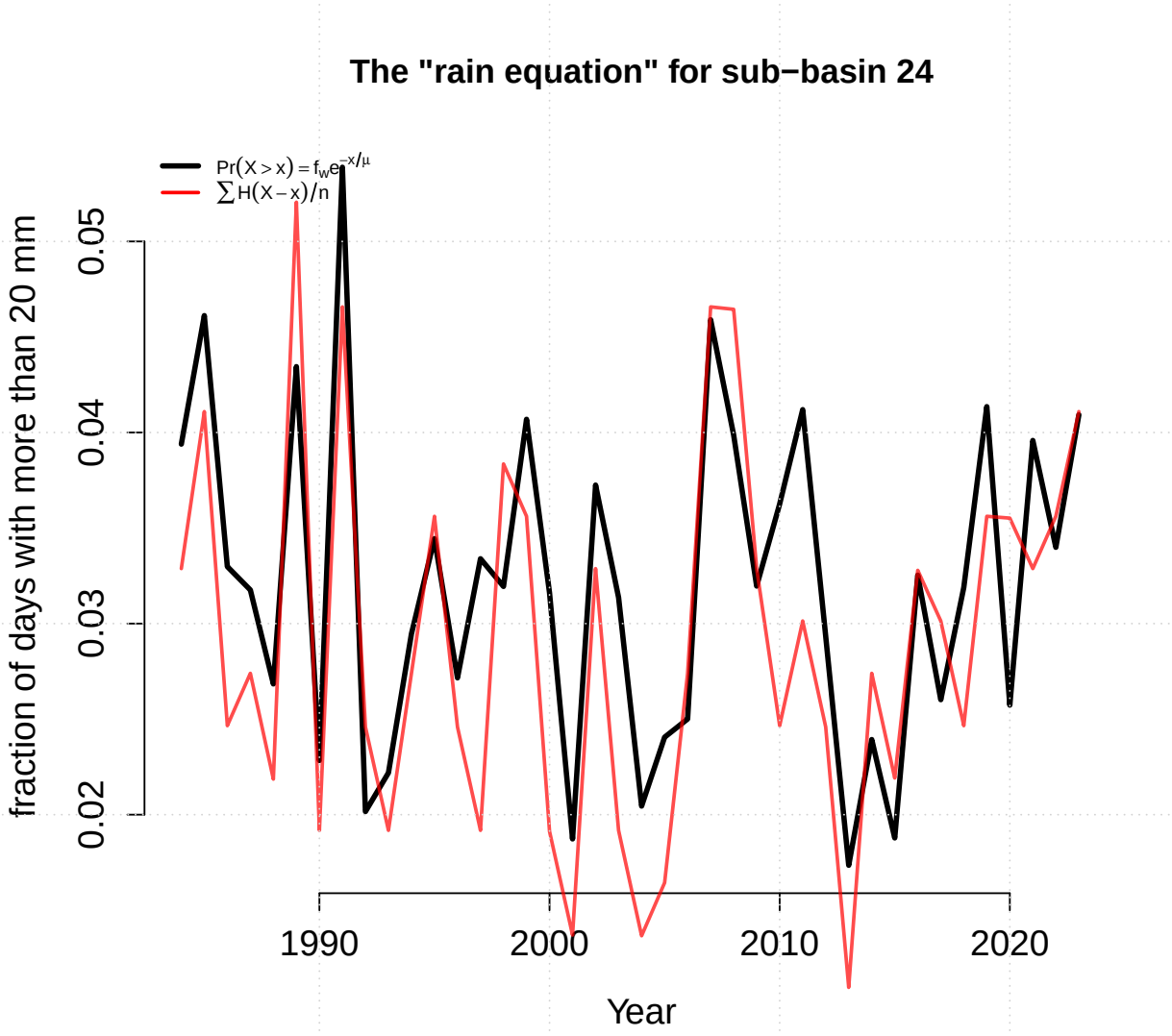


Figure 95: Tests of WG on GHCND data.

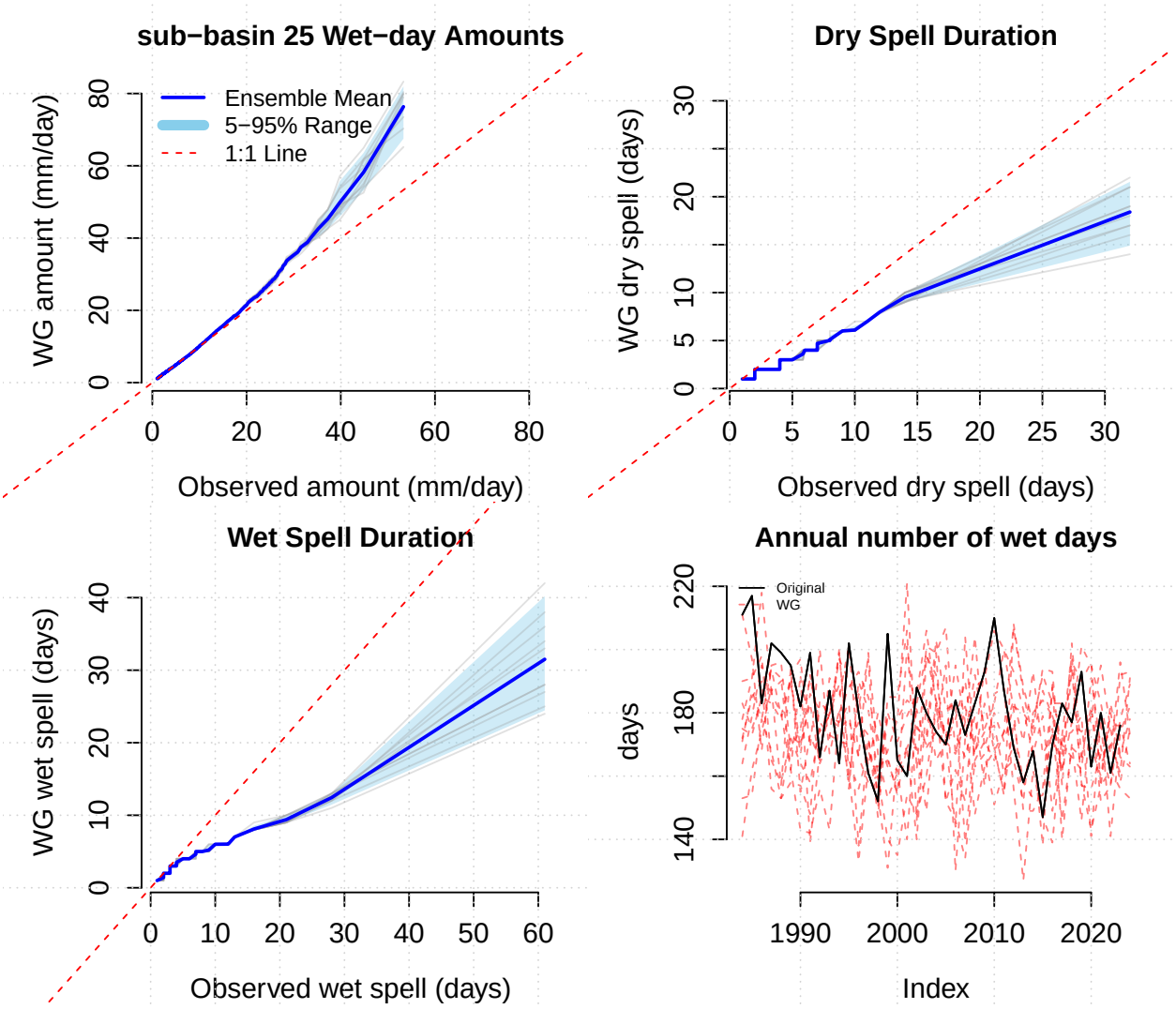


Figure 96: Tests of WG on GHCND data.

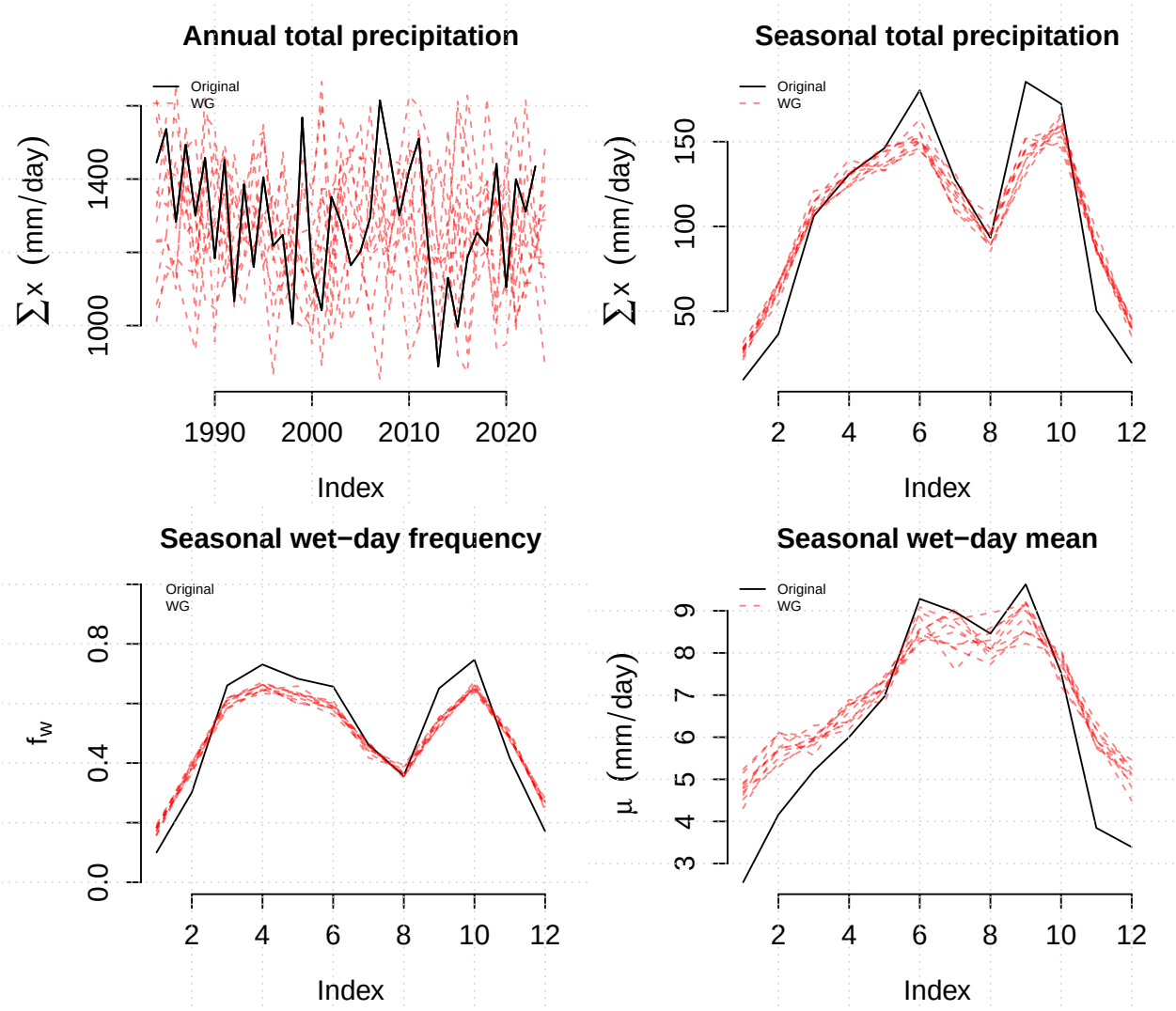


Figure 97: Tests of WG on GHCND data.

```
##   3.045   3.502   3.865   3.824   4.131   4.478
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.762   1.832   1.959   1.976   2.084   2.317
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   22.82   23.45   23.67   24.15   25.26   25.73
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.071   1.170   1.225   1.231   1.305   1.356
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.07014 0.07297 0.07396 0.07467 0.07698 0.08057
```

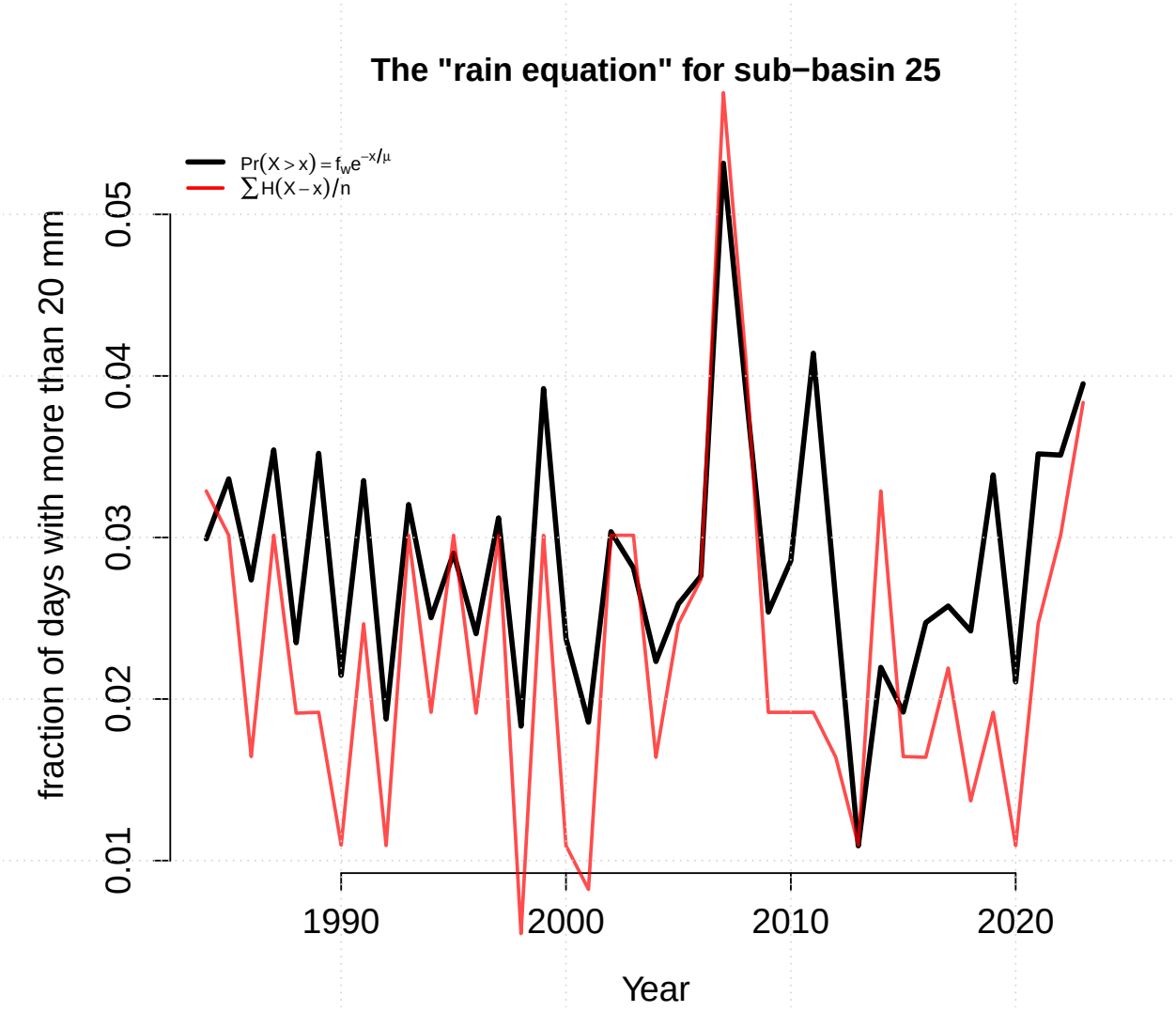


Figure 98: Tests of WG on GHCND data.

```
## test.WG.fwmu.day.precip for sub-basin 26  and  10  runs
## length= 14610 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

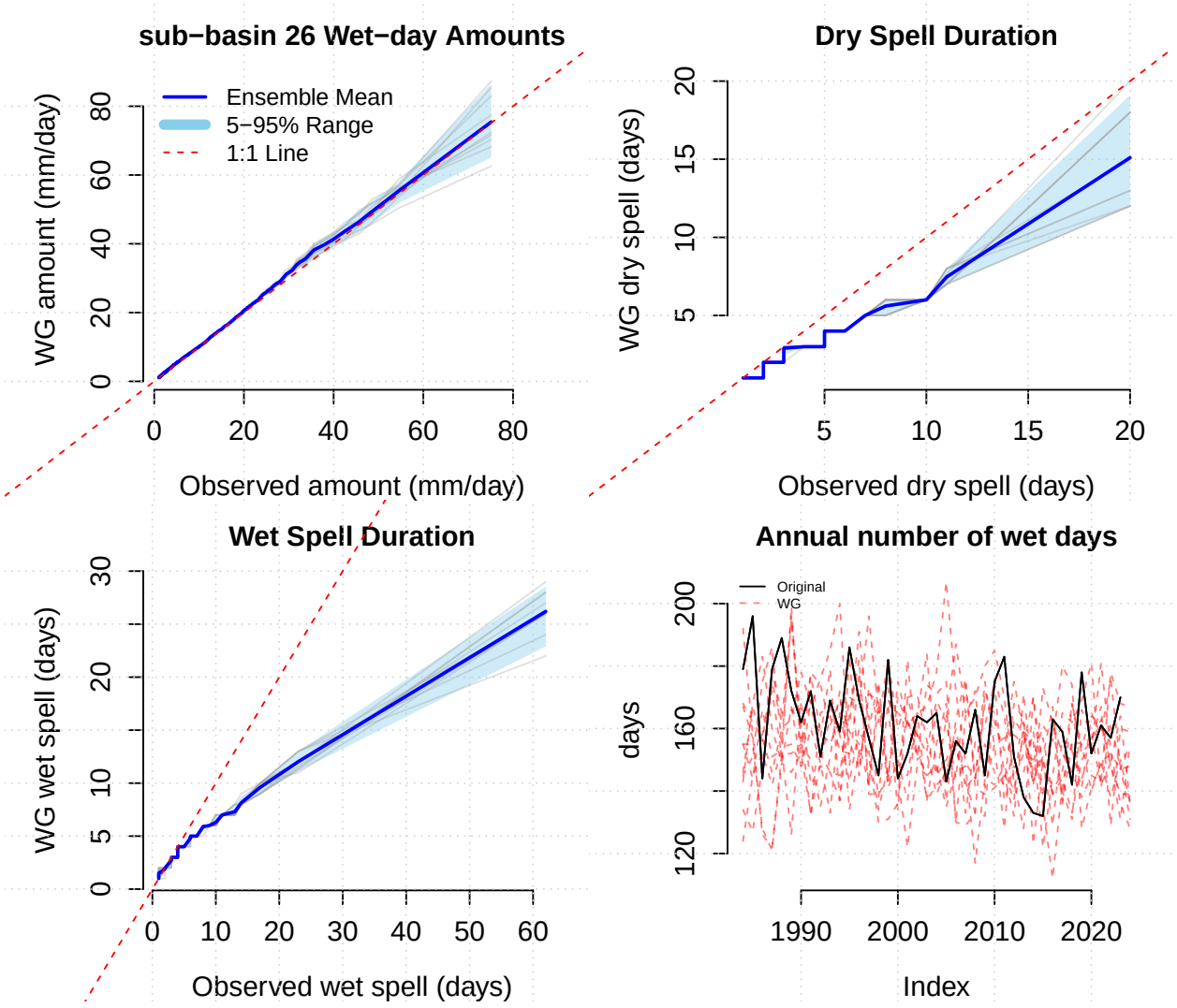


Figure 99: Tests of WG on GHCND data.

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3235  0.4261  0.4931  0.4796  0.5577  0.5706
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.716   3.881   3.958   3.982   4.026   4.329
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9447  0.9988  1.1081  1.1142  1.2245  1.2845
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   18.59   19.13   20.53   20.31   21.51   21.75
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9869  1.0606  1.0861  1.1097  1.1611  1.2354
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

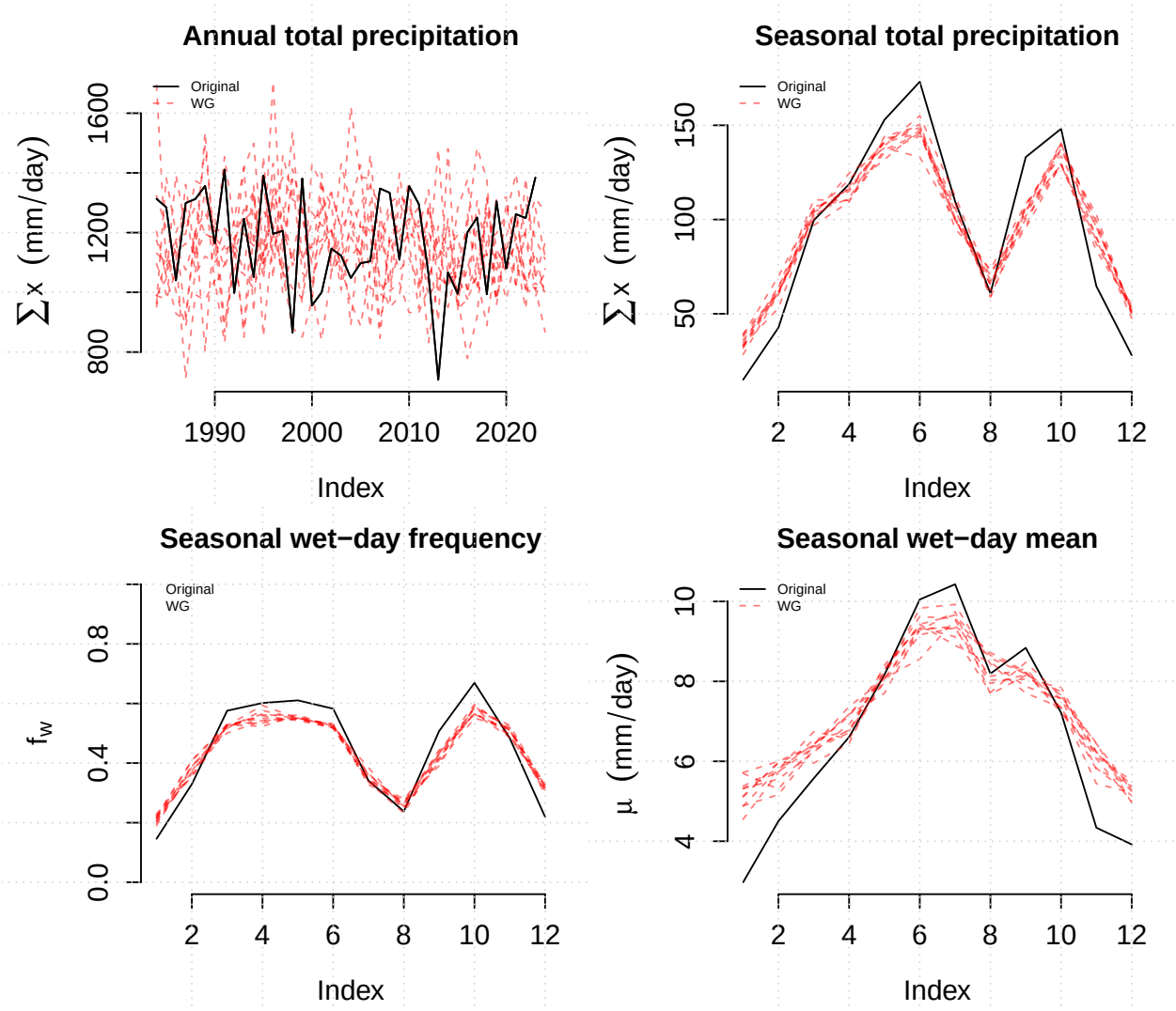


Figure 100: Tests of WG on GHCND data.

```
## 0.05773 0.06072 0.06201 0.06275 0.06381 0.06926
```

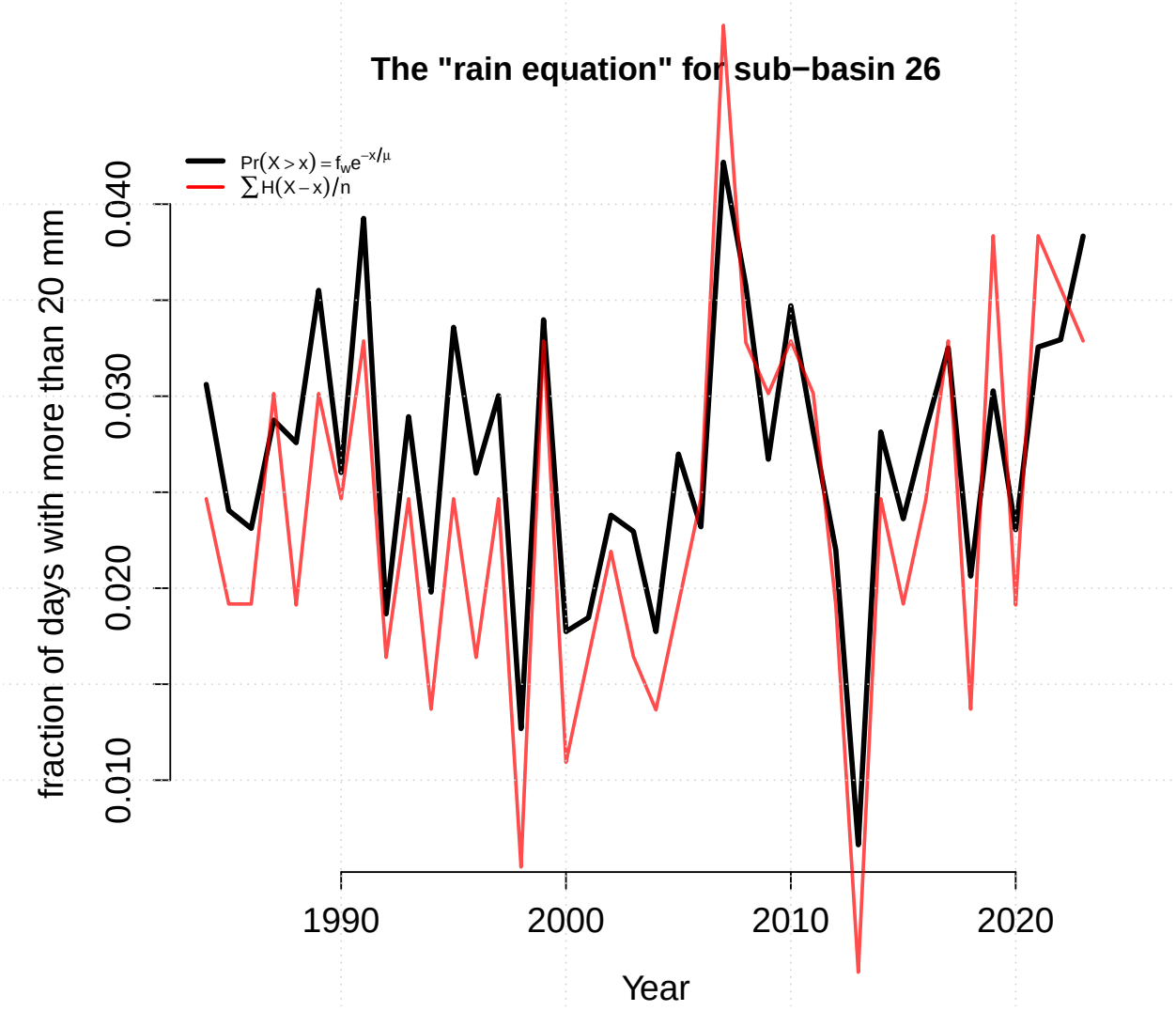


Figure 101: Tests of WG on GHCND data.

The tests reveal some differences within the sub-basins. The WG-tests suggest amplitudes up to 20 mm is generally well captured, and in some places, the dry-spell statistics is fairly well reproduced. The climatologies are reasonable, althoug there are some discrepacnies for the wet-day mean precipitation μ. For some sub-basins the number of days with heavy rainfall (more than 20 mm) is reasonably well captured with the wet-day frequency 4f_w$ and μ (the "rain equation").

The test results for WG based on CHIRPS rainfall data used as input for the hydrological modelling indicate that (1) the magnitudes are realistic for quantities up to 20-50 mm, (2) realistic climatology for $\sum_i x_i$, f_w and μ, (3) reasonable dry spell duration statistics for some sub-basins, but (4) the simulated wet-spell duration statistics often differ from that of the observations.

One observation in these tests is that the default μ-smudging factor is not appropriate for all sites and it sometimes needs to to be calibrated for the local case - which will involve testing with e.g `test.WG.fwmu.day.precip(y)`.

2.2.7 Precipitation for different local climates in Norway

The chunk below provides a further test of the `WG` made for daily precipitation based on free and available open access data from a thredds server. It selects only those stations that are plentiful of data.

```
Y <- station(param='precip',src='metnod.thredds')
## Only keep the stations number of valid (nv) data points exceeding 26000
nv <- apply(Y,2,'nv')
summary(nv)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    2904   13059   17240   17571   21420   27822
```

```
Y <- subset(Y,is=nv >= 27700)
map(Y,FUN='nv',add.text = TRUE,new=FALSE)
```

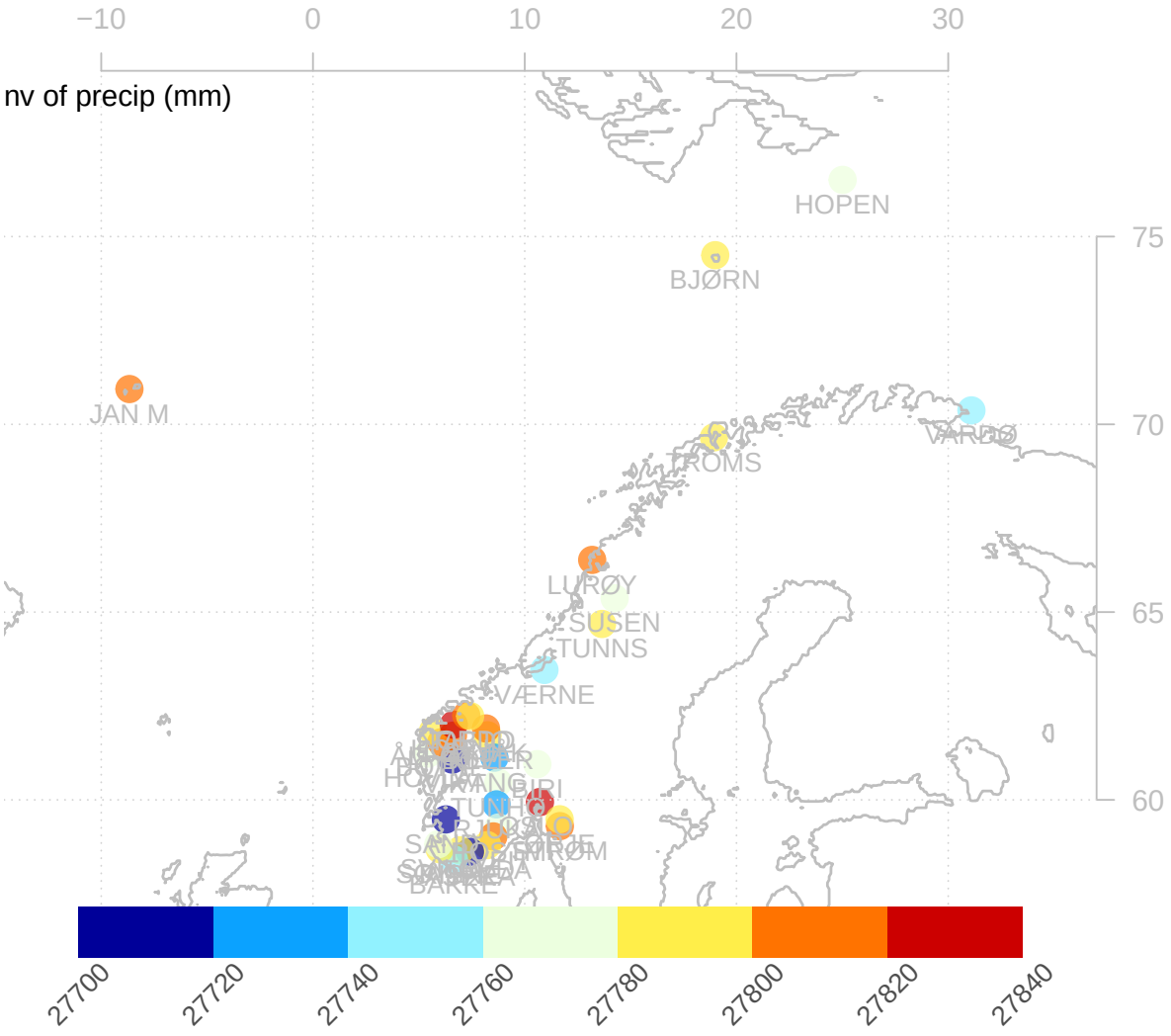


Figure 102: Norwegian rain gauge data

```
dim(Y)
```

```
## [1] 27822    35
```

These lines of R also demonstrate that it's fairly trivial to apply a test to evaluate a large number of rain gauge or daily temperature stations. In this case, a number with a good temporal coverage from open data from Norway was selected for the demonstration purpose. It is recommended to use similar lines of codes to test the WG for the specific case for which it's used - it only takes a few minutes on a laptop.

The sites are spread geographically and represent diverse local climes.

```
## Apply the test to all of the stations
par(cex=1.25,cex.axis=1.25)
ns <- dim(Y)[2] ## The number of stations
for (is in 1:ns) {
  ## Select one single station per turn
  y <- subset(Y,is=is)
  ## Apply the test to this station
  test.WG.fwmu.day.precip(y,n=10,verbose=FALSE)
}
```

```
## test.WG.fwmu.day.precip for BIRI  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.4084  0.4443  0.5260  0.5446  0.5896  0.8099
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.512   2.588   2.690   2.751   2.922   3.100
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.083   1.188   1.234   1.241   1.312   1.400
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.276   5.054   5.157   5.123   5.356   5.631
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3011  0.3227  0.3530  0.3614  0.3930  0.4547
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01613 0.01682 0.01890 0.01846 0.01938 0.02143
## test.WG.fwmu.day.precip for BØVERDAL  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3913  0.4225  0.4562  0.4693  0.4974  0.5729
## RMSE for wet-spell duration quantiles:
```

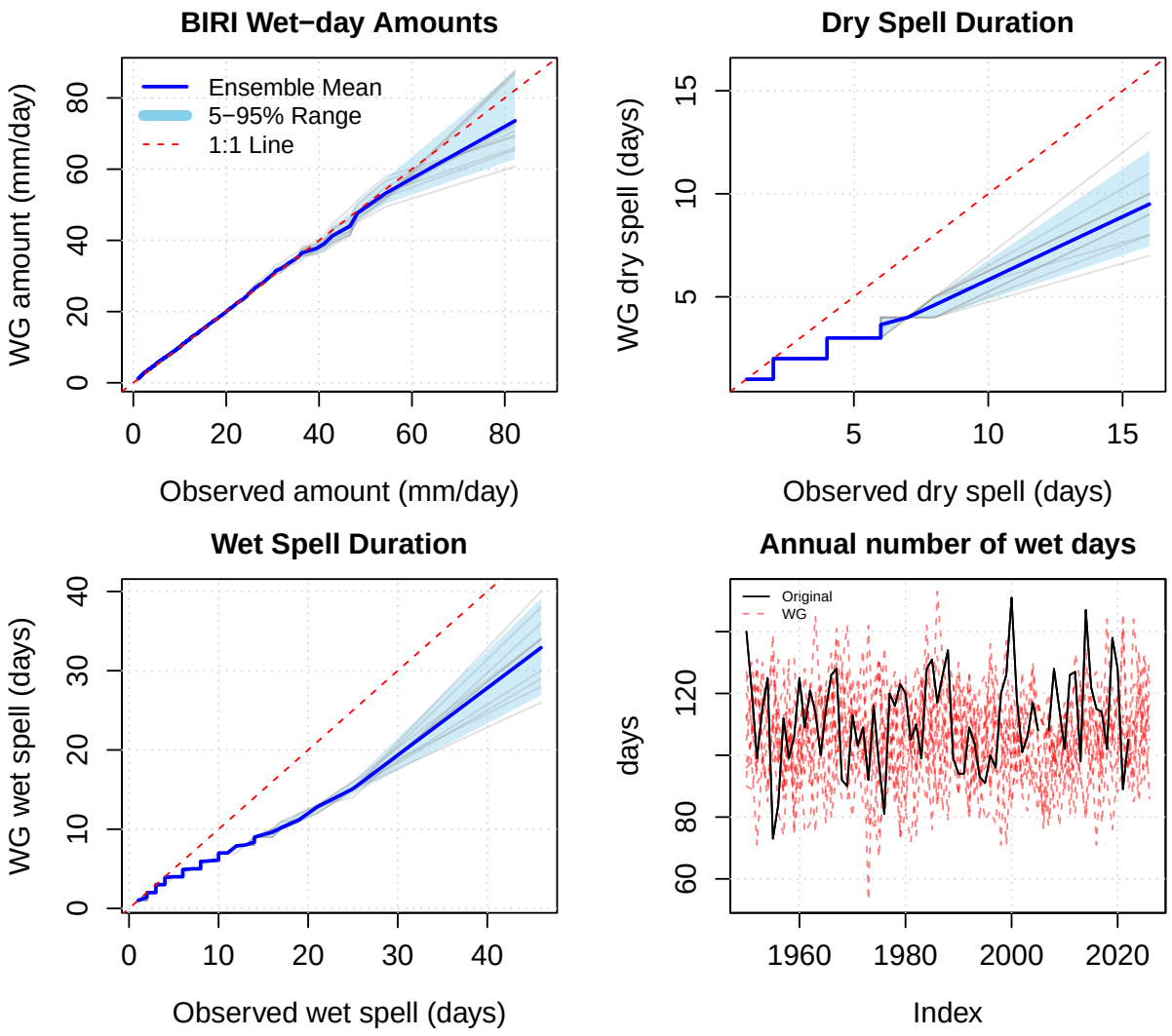


Figure 103: Tests of WG on Norwegian data

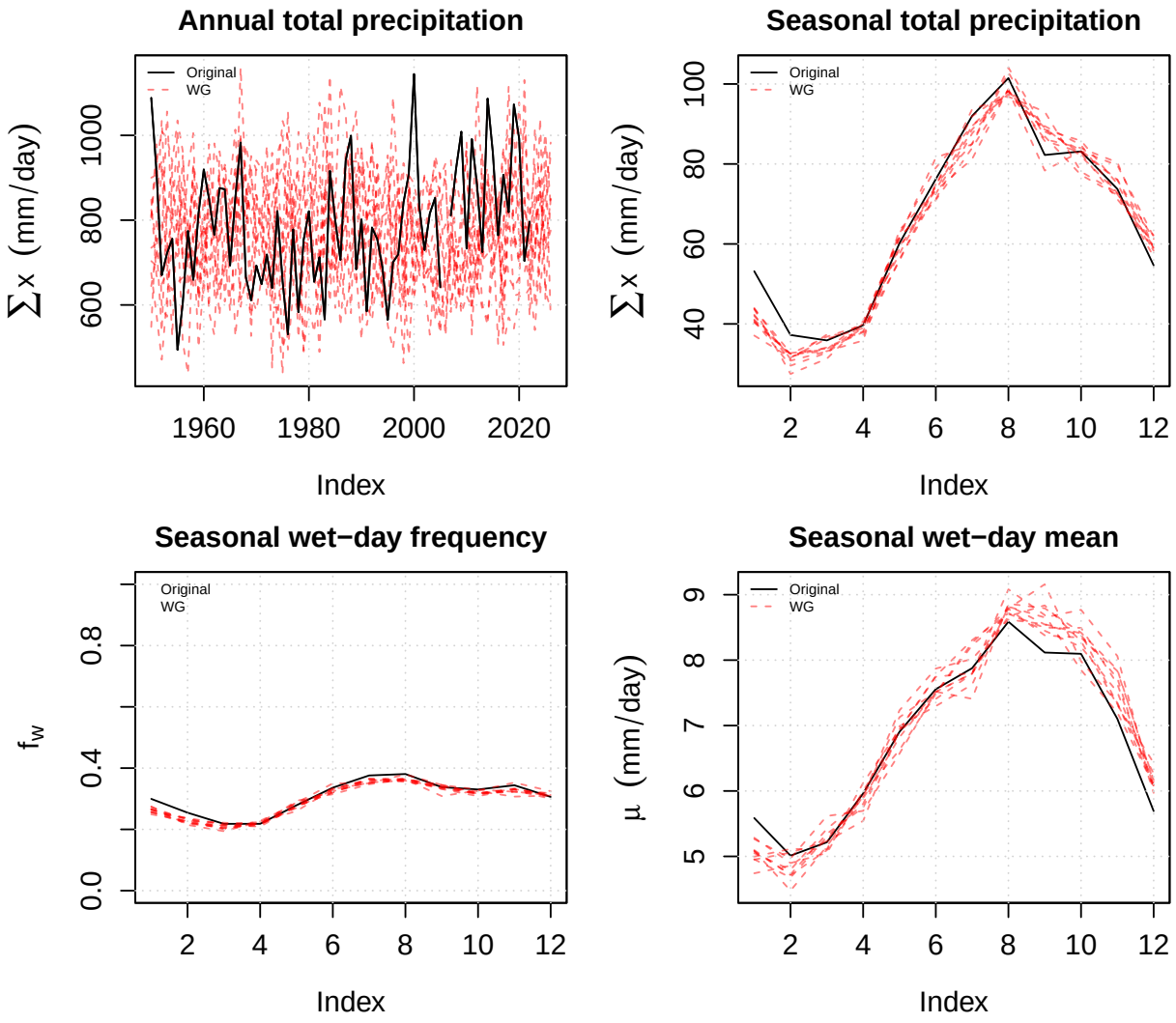


Figure 104: Tests of WG on Norwegian data

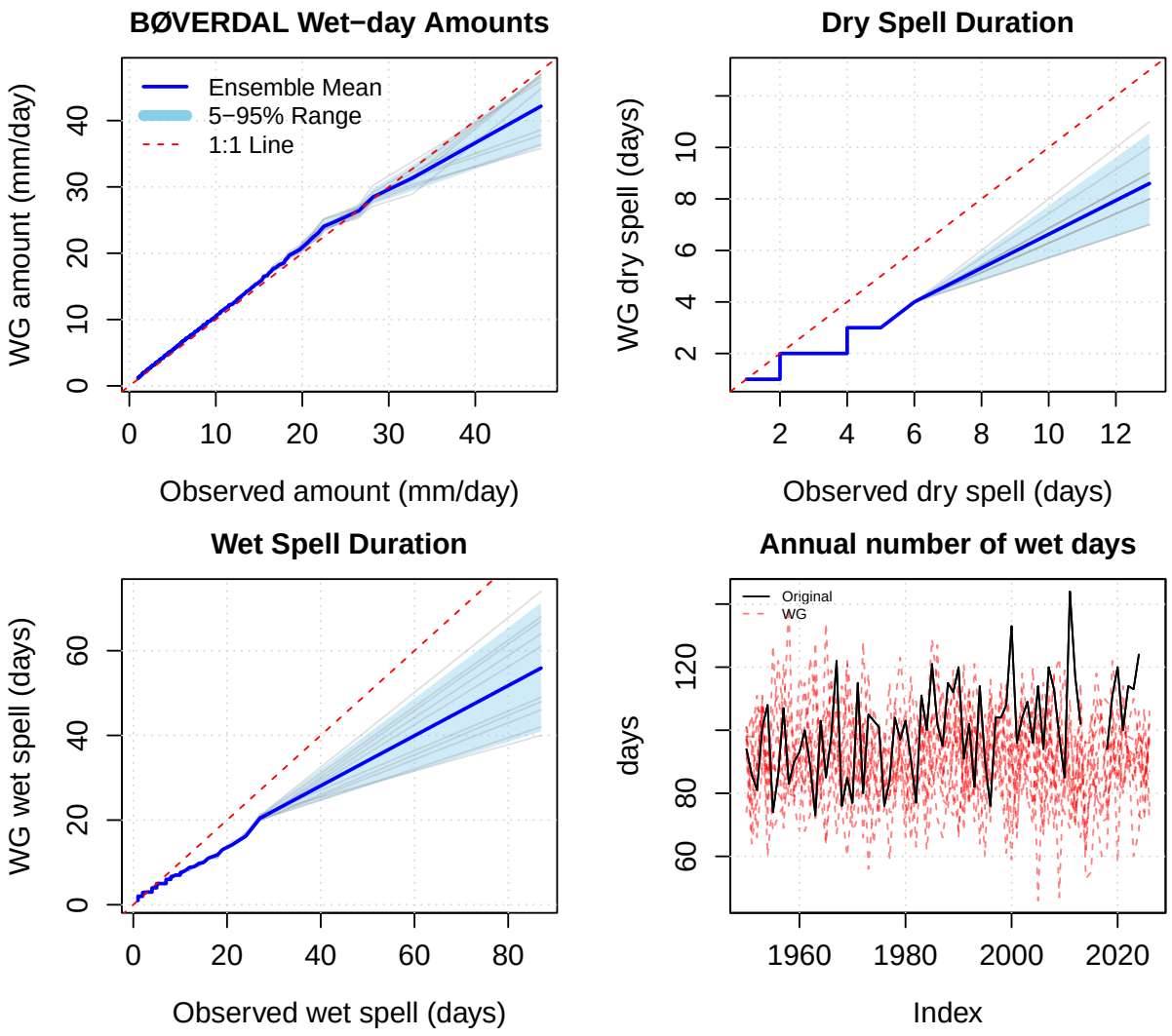


Figure 105: Tests of WG on Norwegian data

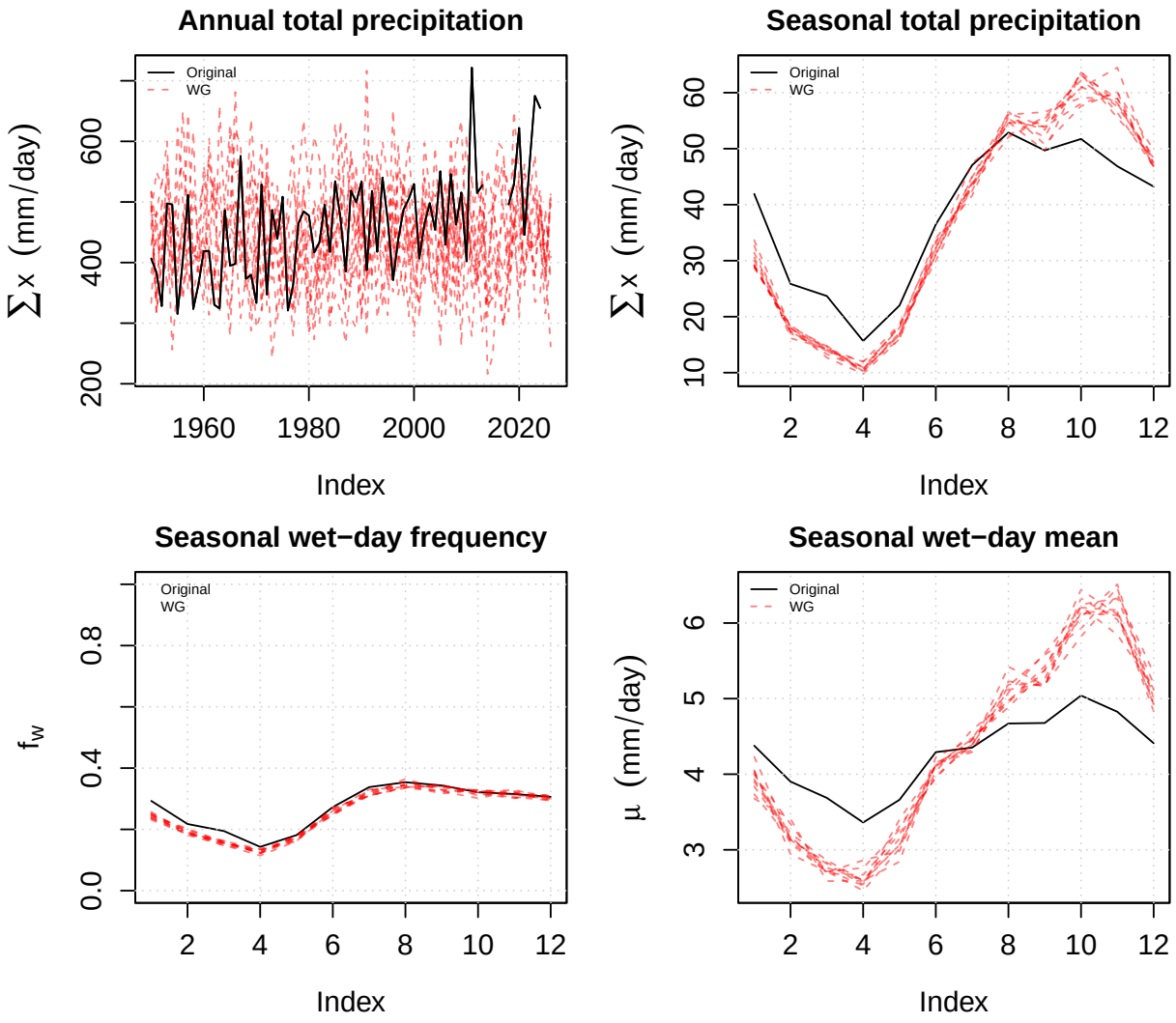


Figure 106: Tests of WG on Norwegian data

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.371   2.898   3.777   3.752   4.510   5.108
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8000  0.8544  0.8830  0.8857  0.9187  0.9747
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   6.472   7.113   7.296   7.330   7.597   8.441
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7037  0.7362  0.7654  0.7581  0.7816  0.7925
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.02012 0.02226 0.02353 0.02329 0.02427 0.02579
## test.WG.fwmu.day.precip for SKJÅK  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.4800  0.5589  0.6151  0.6062  0.6590  0.7250
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.602   3.655   4.344   4.383   5.317   6.718
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6164  0.6907  0.7457  0.7493  0.7921  0.8775
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.900   5.137   5.432   5.381   5.530   5.972
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5969  0.6123  0.6425  0.6459  0.6669  0.7404
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01973 0.02190 0.02257 0.02295 0.02361 0.02678
## test.WG.fwmu.day.precip for STRØMSFOSS SLUSE  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5595  0.6149  0.6286  0.6439  0.6600  0.7413
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.143   3.665   3.862   3.820   3.980   4.384
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.208   1.348   1.425   1.417   1.497   1.556
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.117   5.732   6.205   6.177   6.664   7.274
```

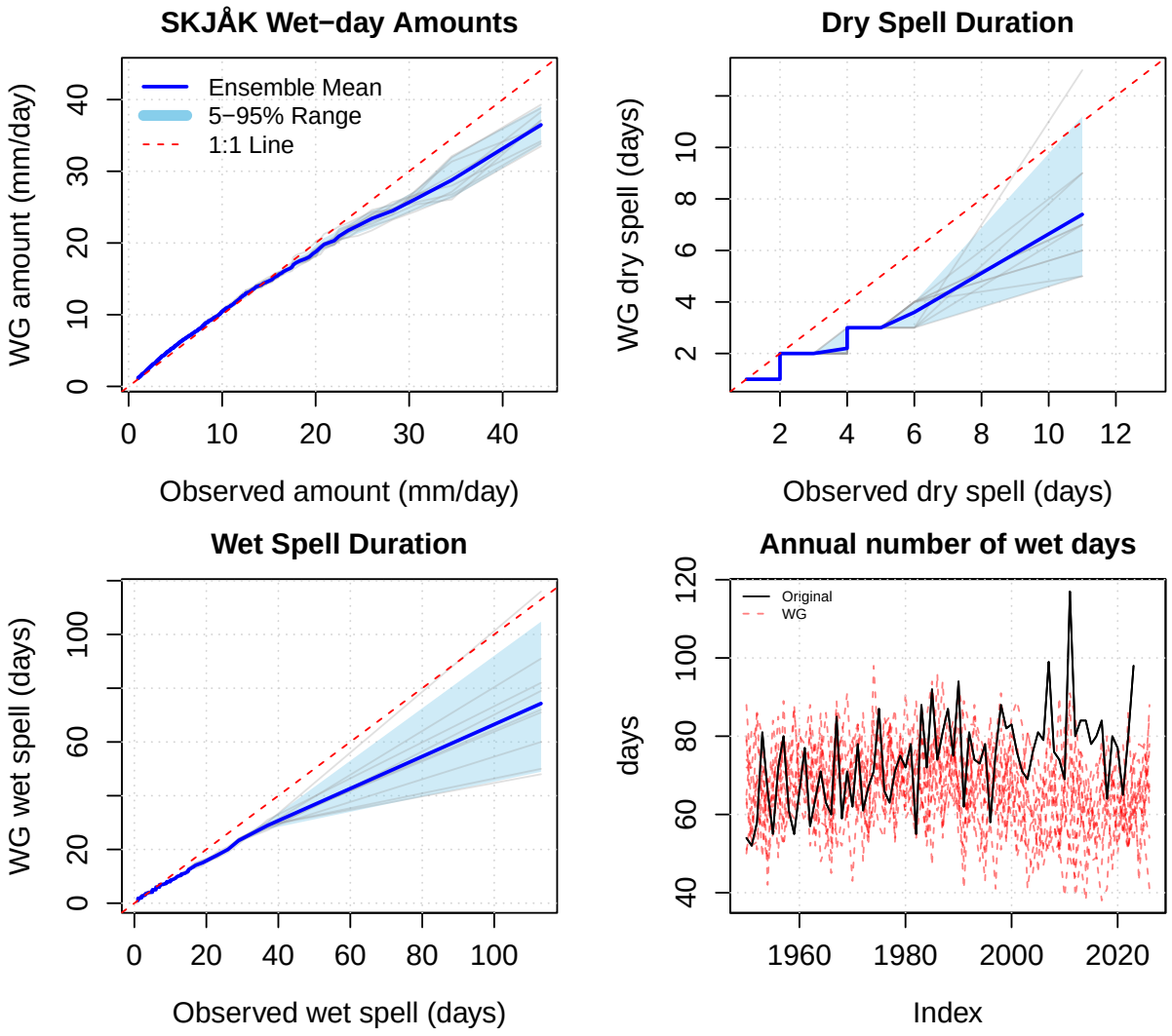


Figure 107: Tests of WG on Norwegian data

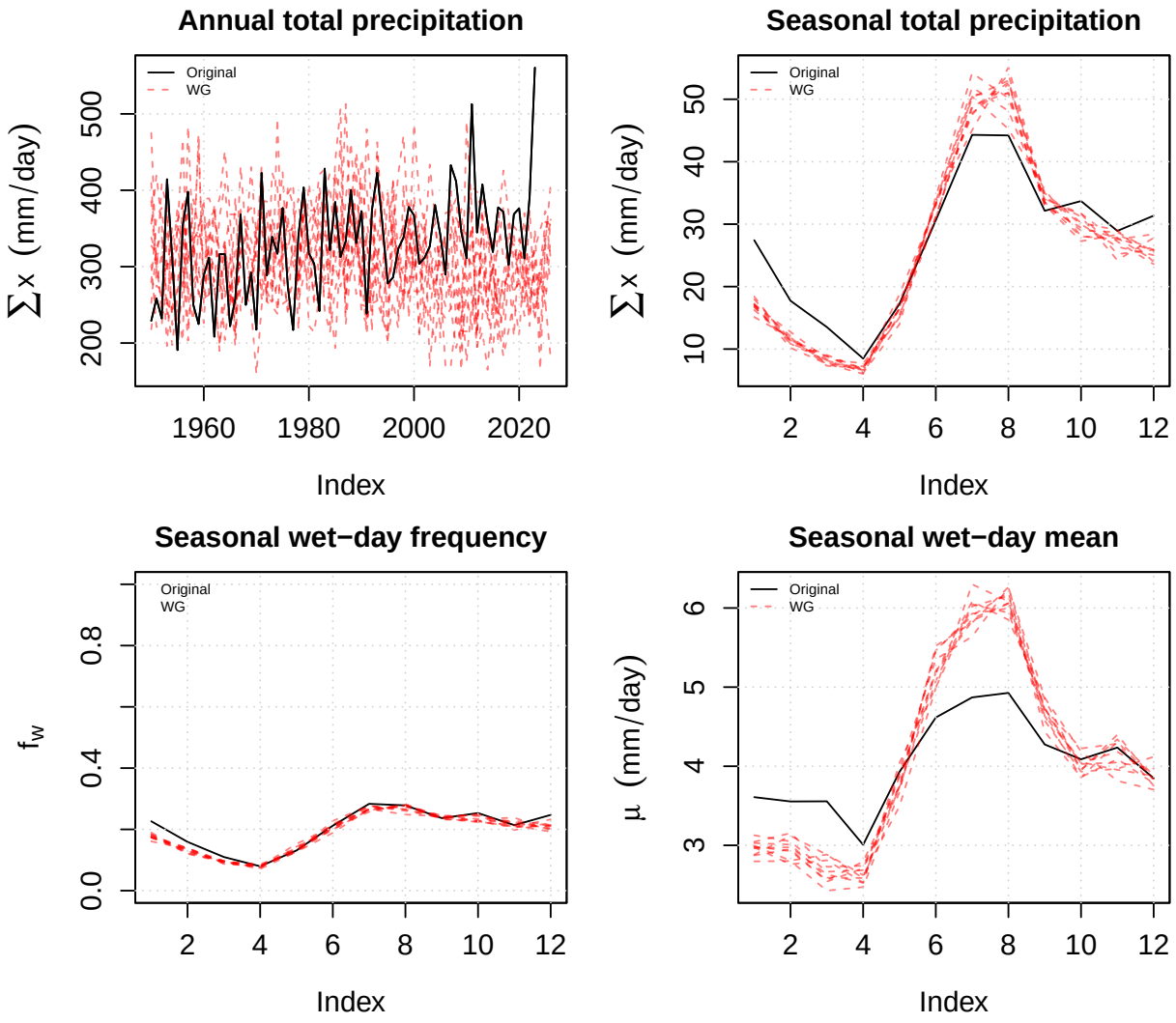


Figure 108: Tests of WG on Norwegian data

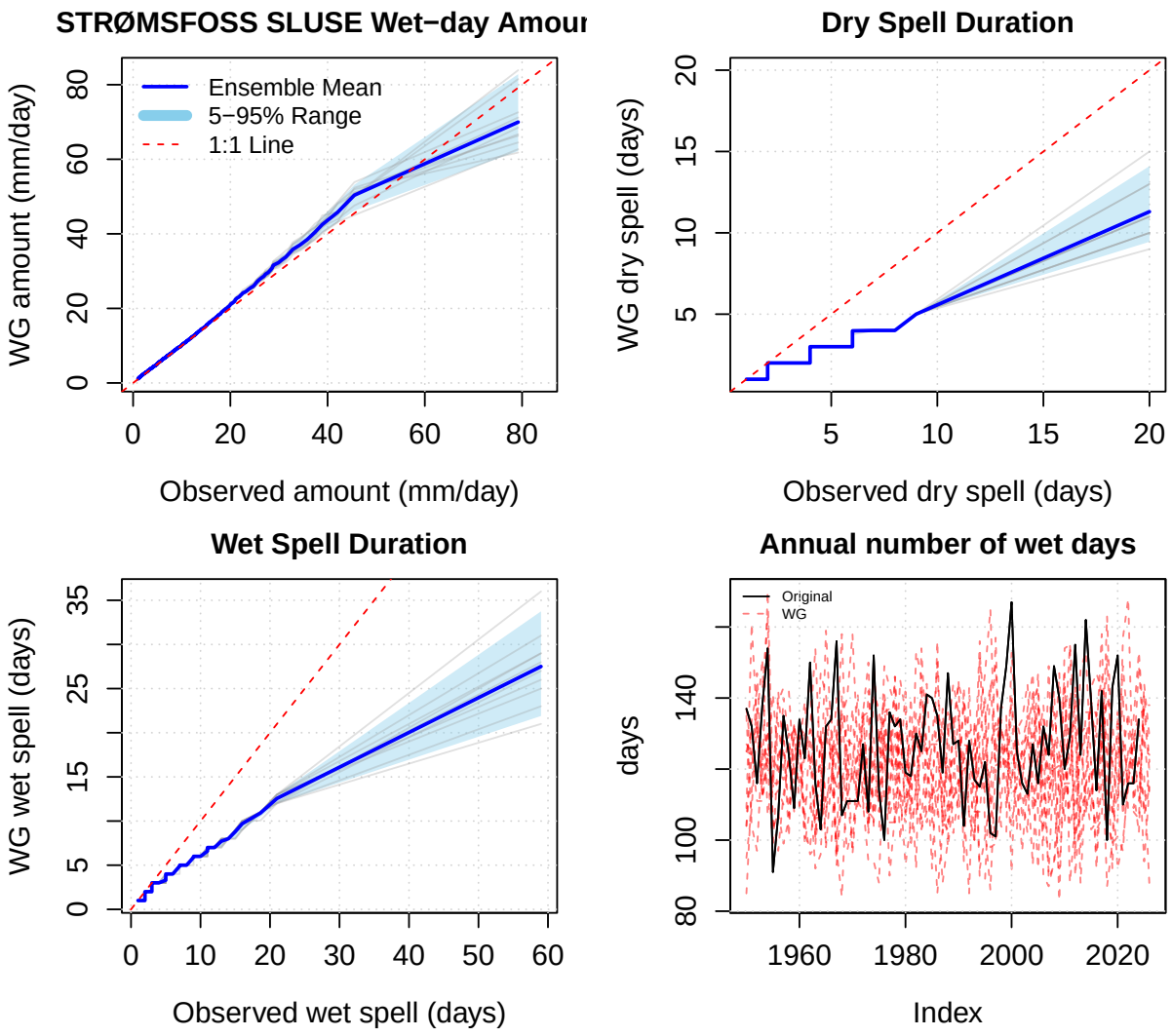


Figure 109: Tests of WG on Norwegian data

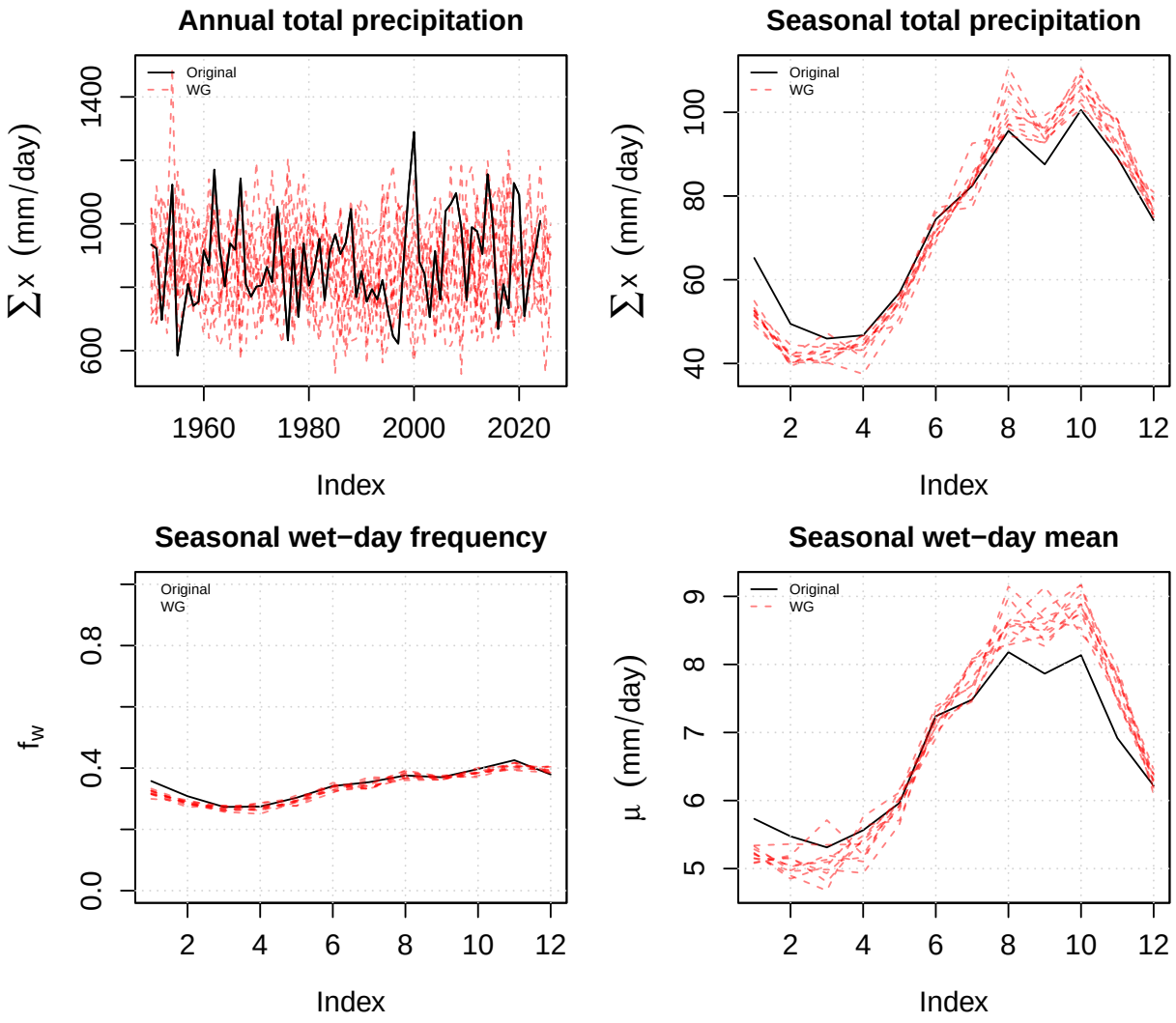


Figure 110: Tests of WG on Norwegian data

```
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3683  0.4741  0.4963  0.4937  0.5320  0.5743
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01446 0.01643 0.01809 0.01808 0.01946 0.02297
## test.WG.fwmu.day.precip for OSLO - BLINDERN  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

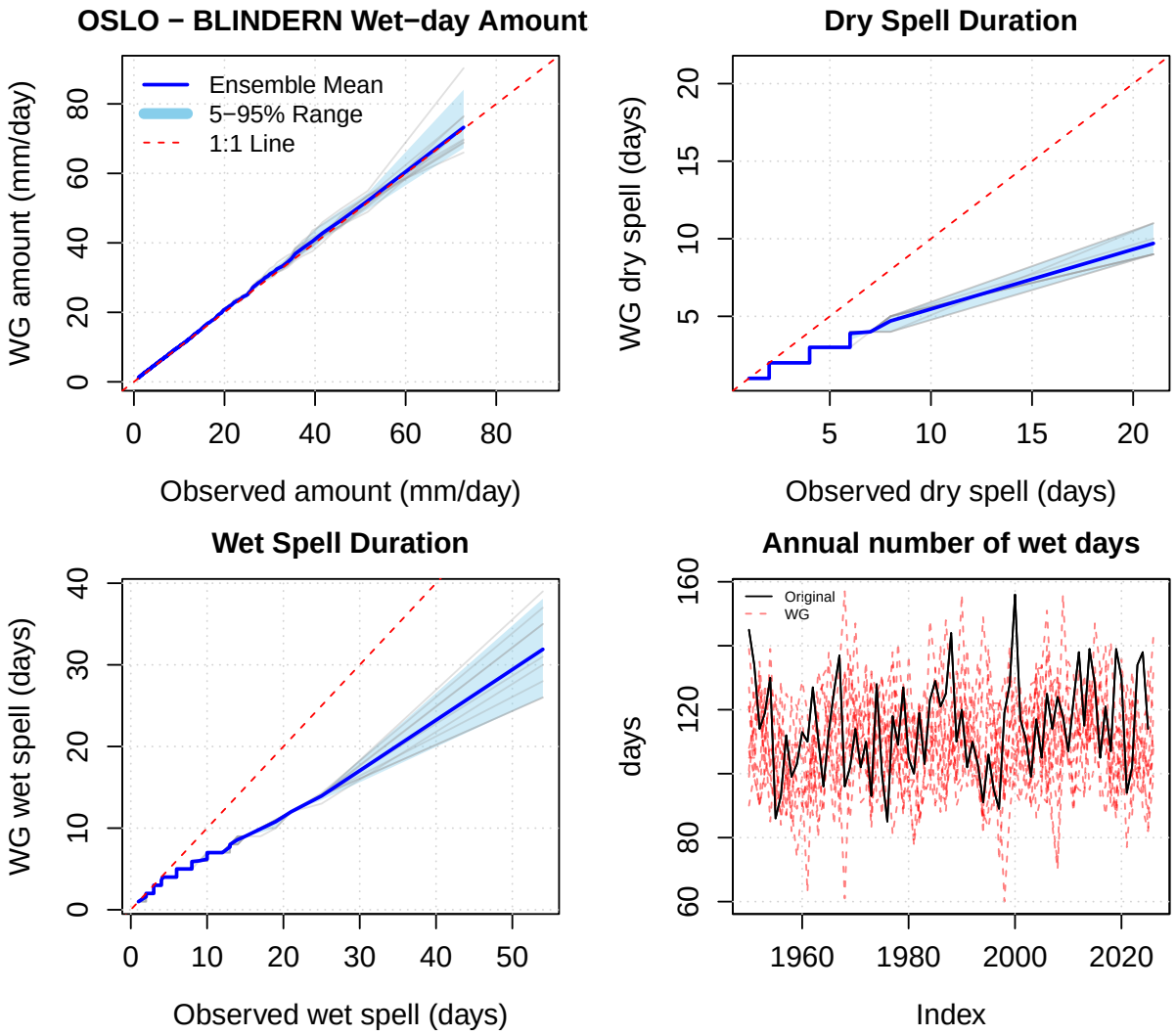


Figure 111: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.2970  0.3260  0.3596  0.3836  0.3864  0.6903
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.828   3.048   3.306   3.297   3.546   3.688
```

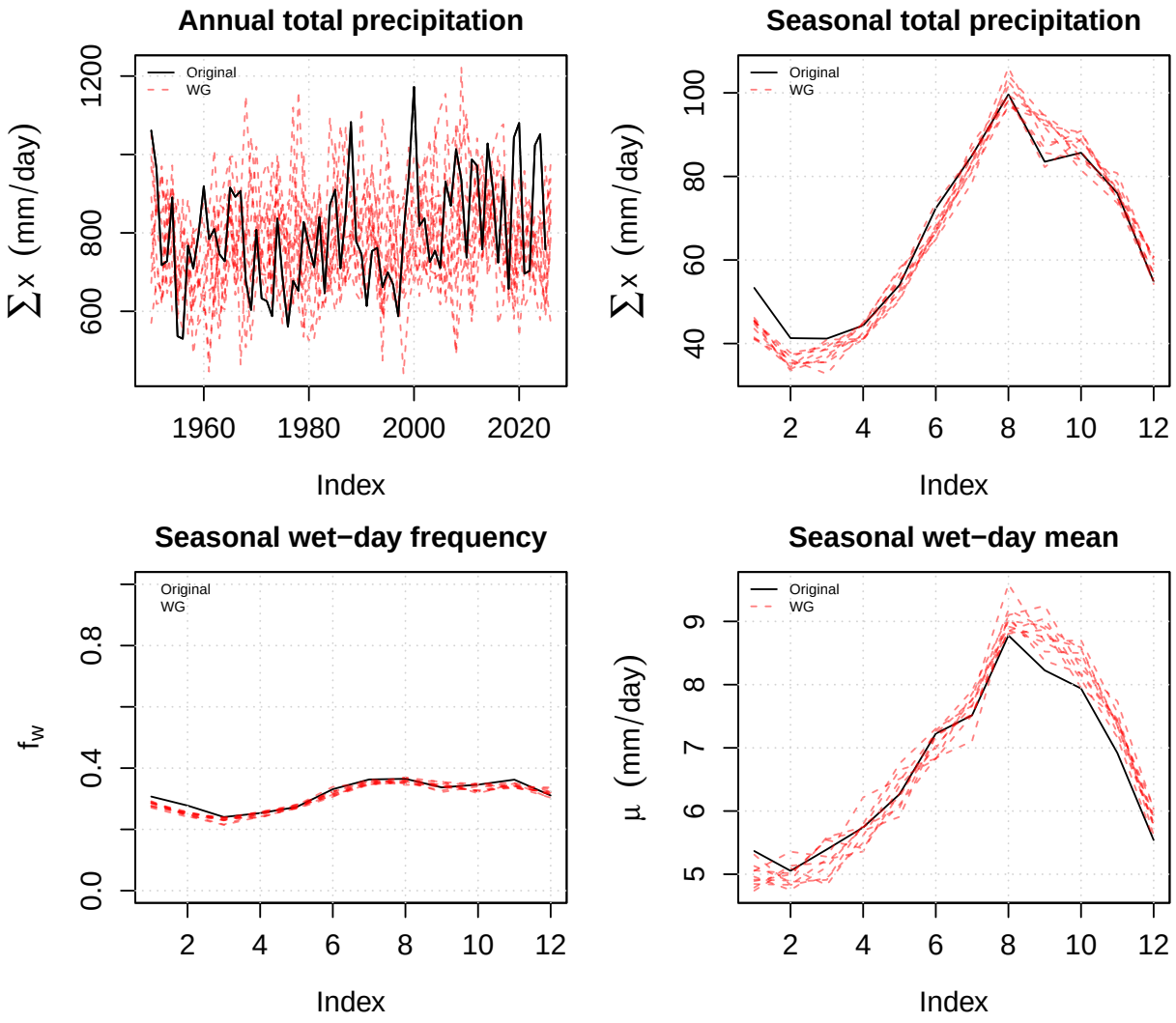


Figure 112: Tests of WG on Norwegian data

```
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.418   1.465   1.557   1.518   1.562   1.581
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.800   4.529   5.118   4.967   5.551   5.905
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.2785  0.3256  0.3521  0.3657  0.3963  0.4839
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01175 0.01495 0.01668 0.01623 0.01691 0.01971
## test.WG.fwmu.day.precip for ØRJE  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

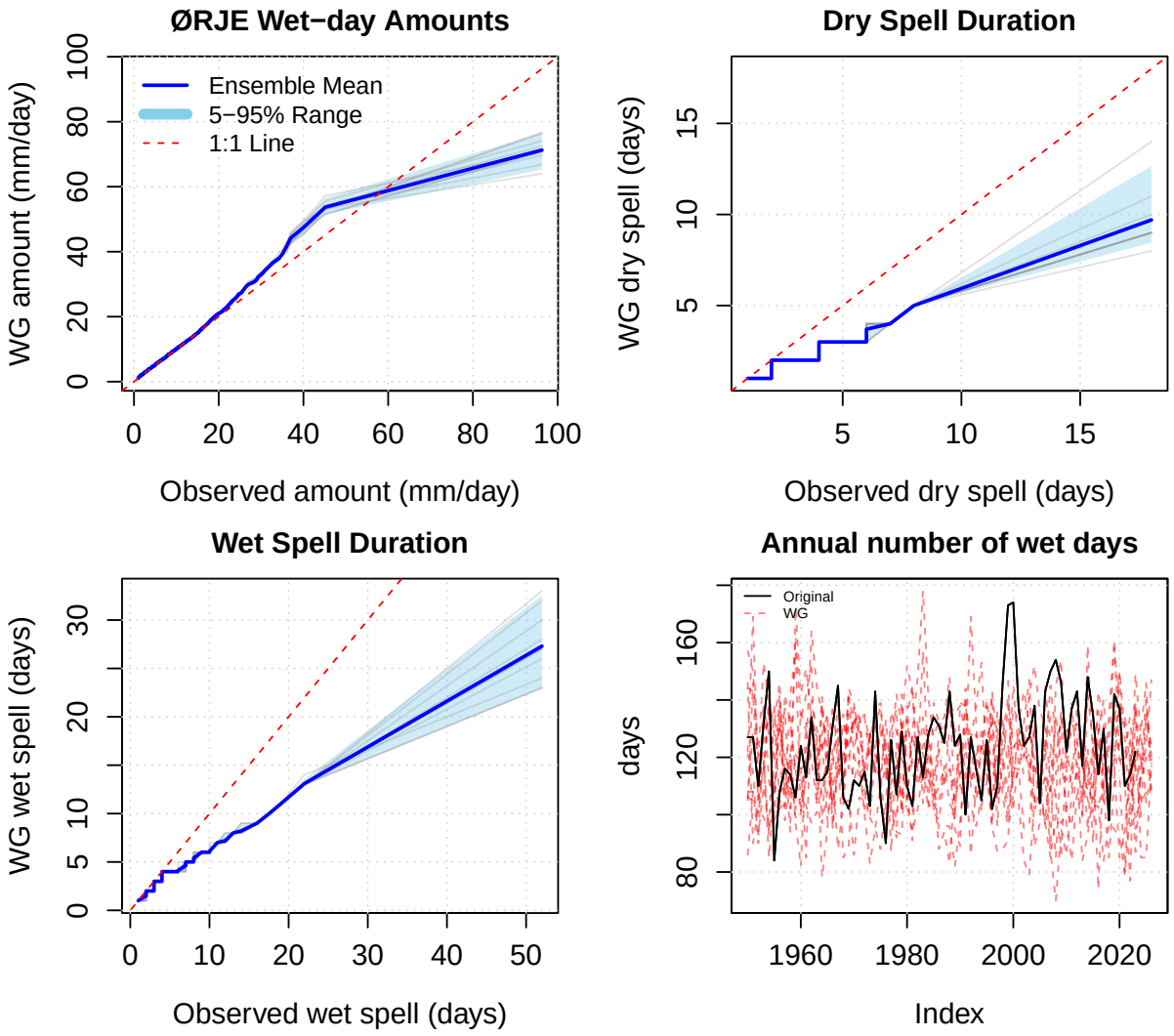


Figure 113: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
```

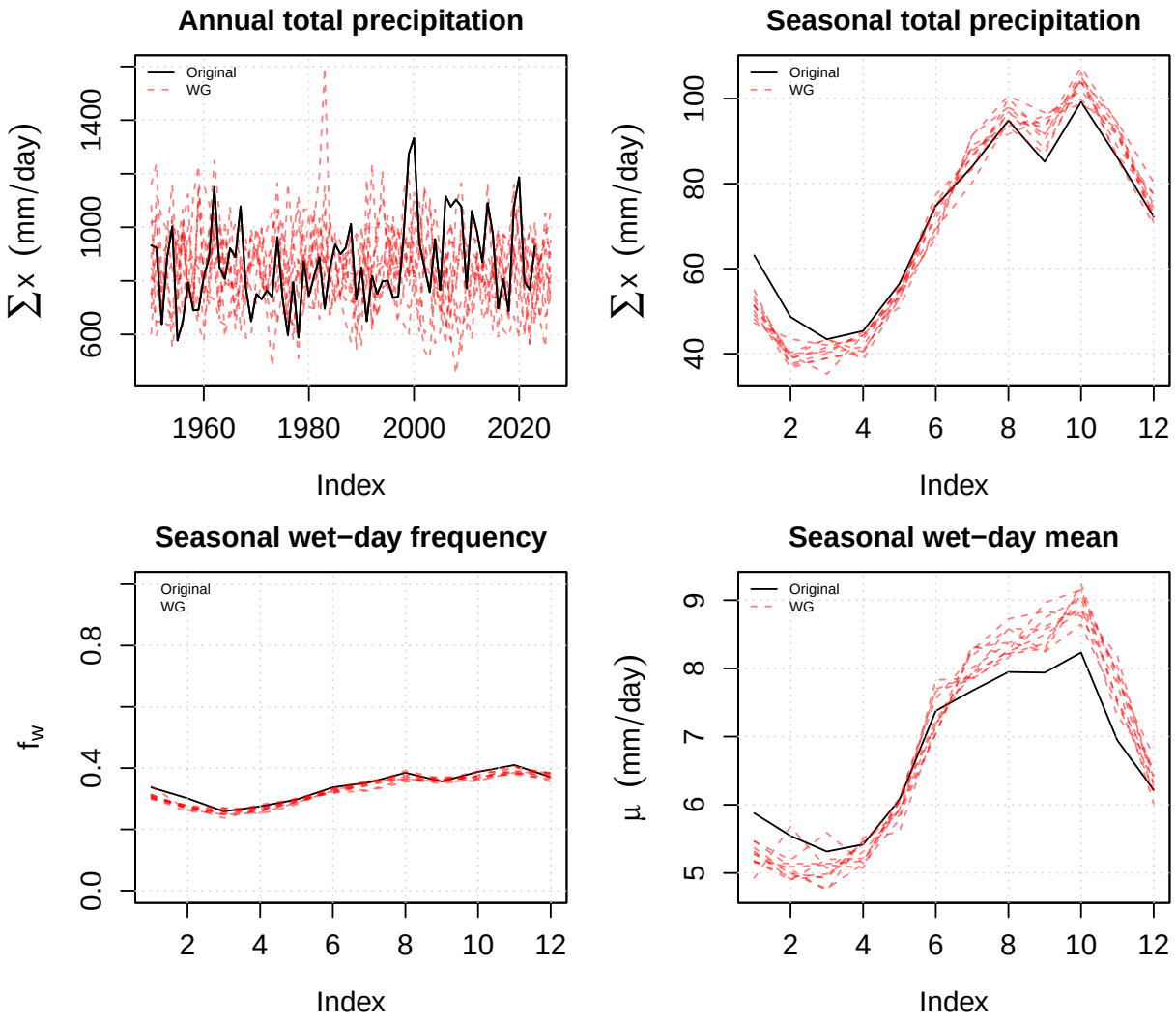


Figure 114: Tests of WG on Norwegian data

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9006  0.9924  1.0157  1.0552  1.1201  1.2497
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.917   3.153   3.319   3.315   3.506   3.656
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.105   1.334   1.369   1.339   1.390   1.439
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.327   5.697   5.871   5.874   6.344   6.858
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3784  0.4617  0.5255  0.5045  0.5555  0.5849
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01540 0.01676 0.01749 0.01788 0.01900 0.02114
## test.WG.fwmu.day.precip for VANG I VALDRES  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.555   2.609   2.695   2.811   3.052   3.264
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.952   3.567   3.831   3.756   3.903   4.312
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.334   1.419   1.576   1.546   1.580   1.800
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.075   4.903   5.216   5.178   5.563   5.752
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3336  0.3671  0.3989  0.3927  0.4185  0.4447
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.02321 0.02413 0.02507 0.02546 0.02704 0.02813
## test.WG.fwmu.day.precip for TUNHOVD  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8318  1.0719  1.1702  1.1643  1.2251  1.4582
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.001   2.185   2.221   2.232   2.314   2.371
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9487  1.0247  1.0628  1.0688  1.1235  1.1916
```

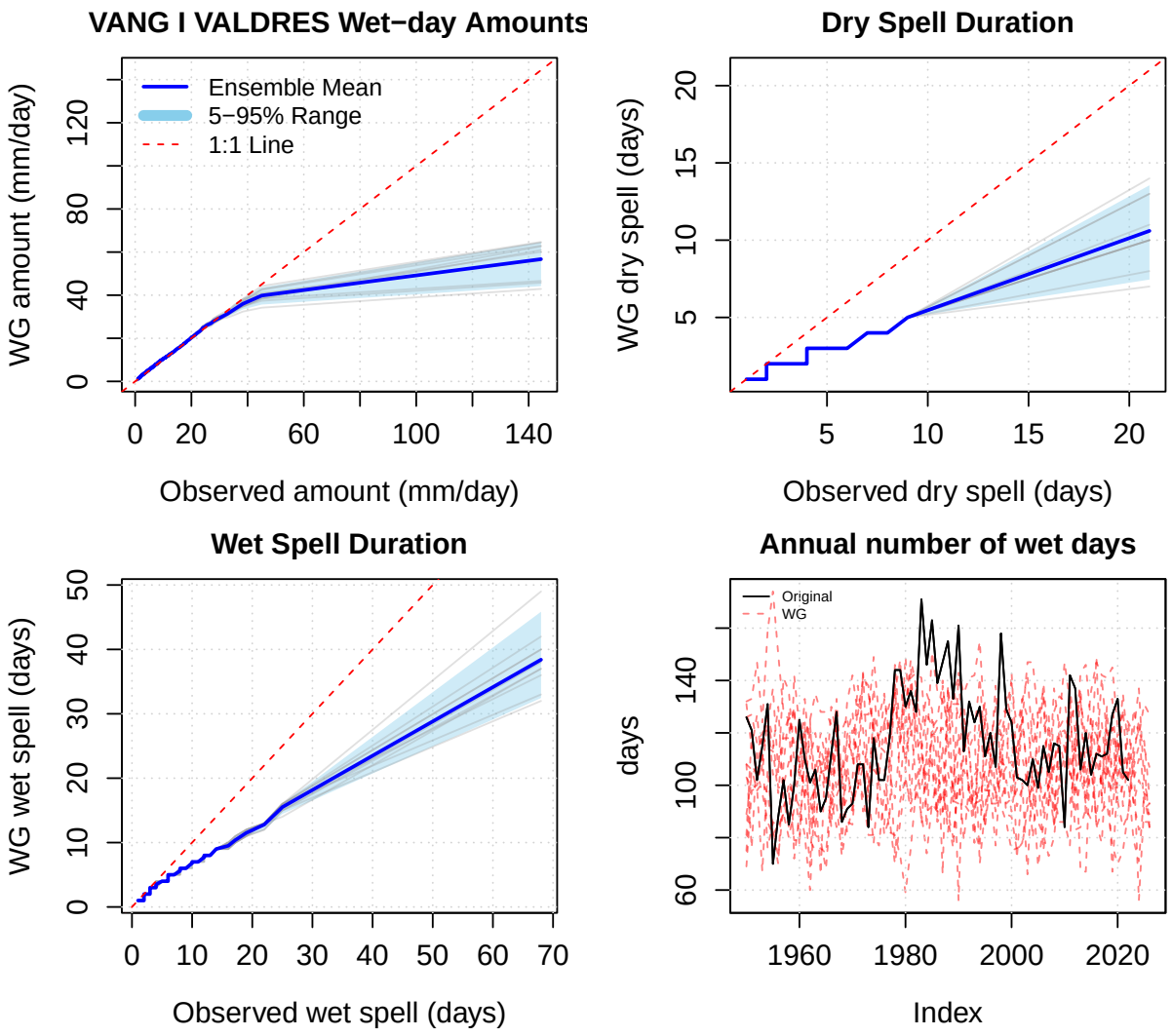


Figure 115: Tests of WG on Norwegian data

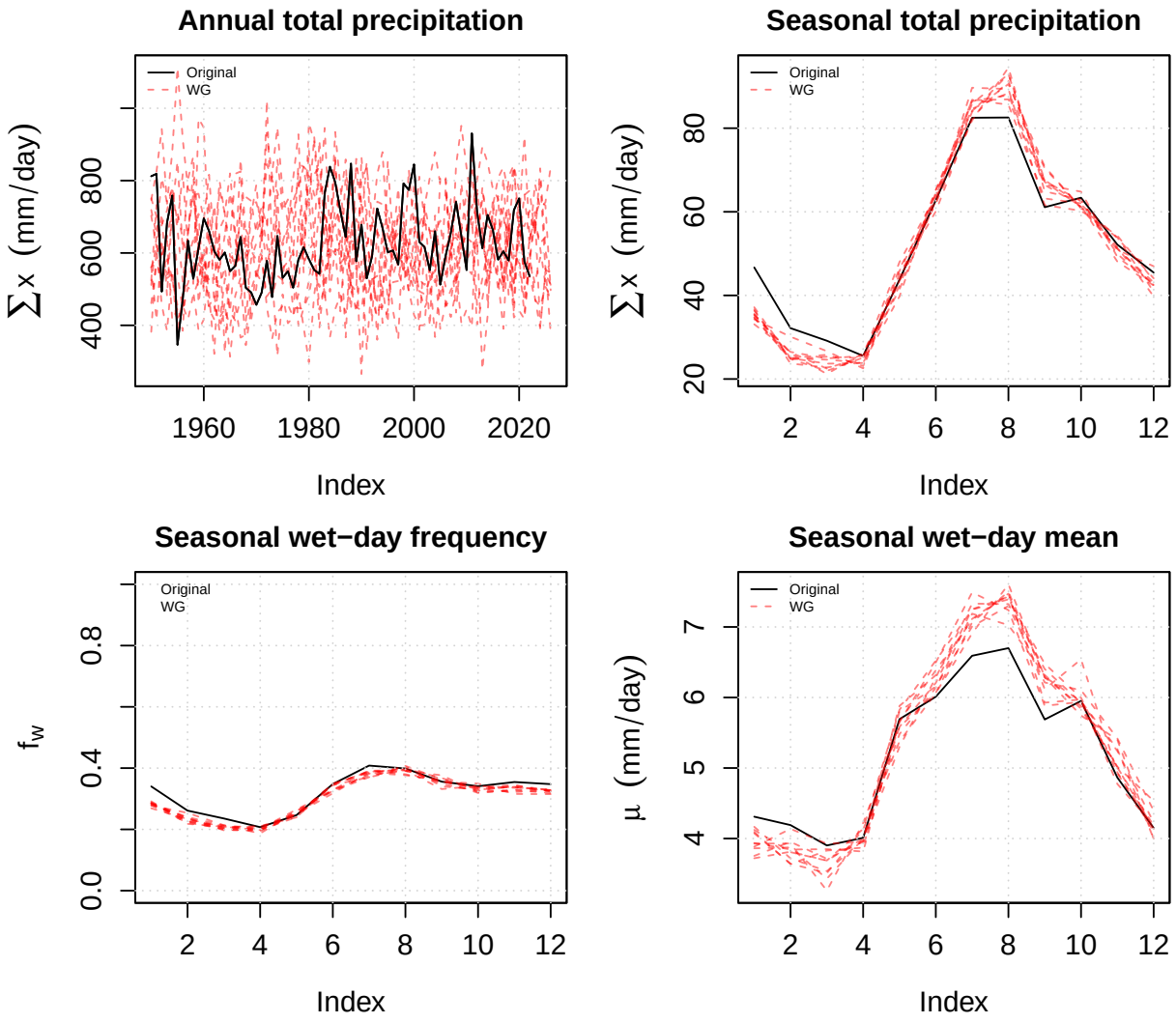


Figure 116: Tests of WG on Norwegian data

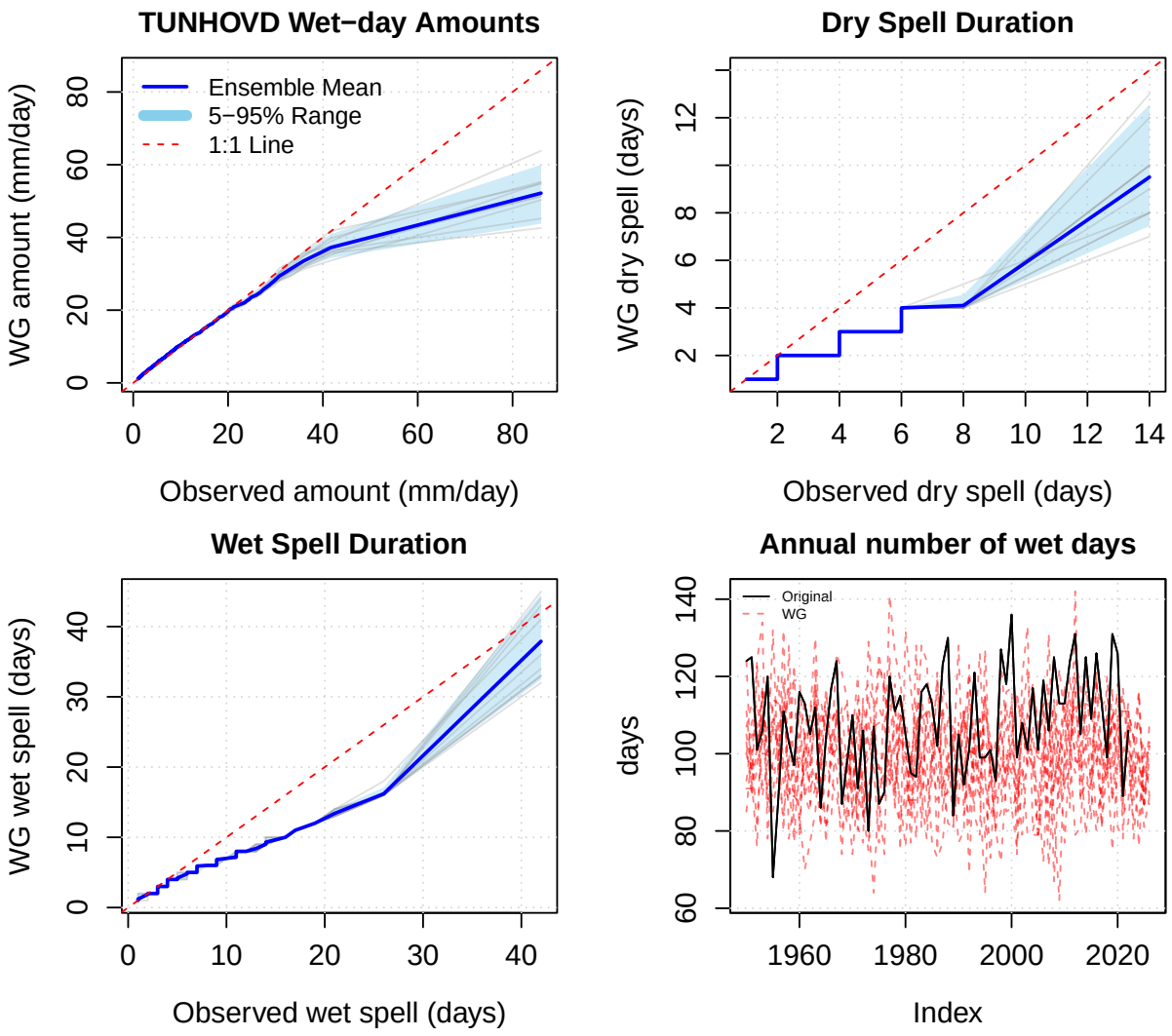


Figure 117: Tests of WG on Norwegian data

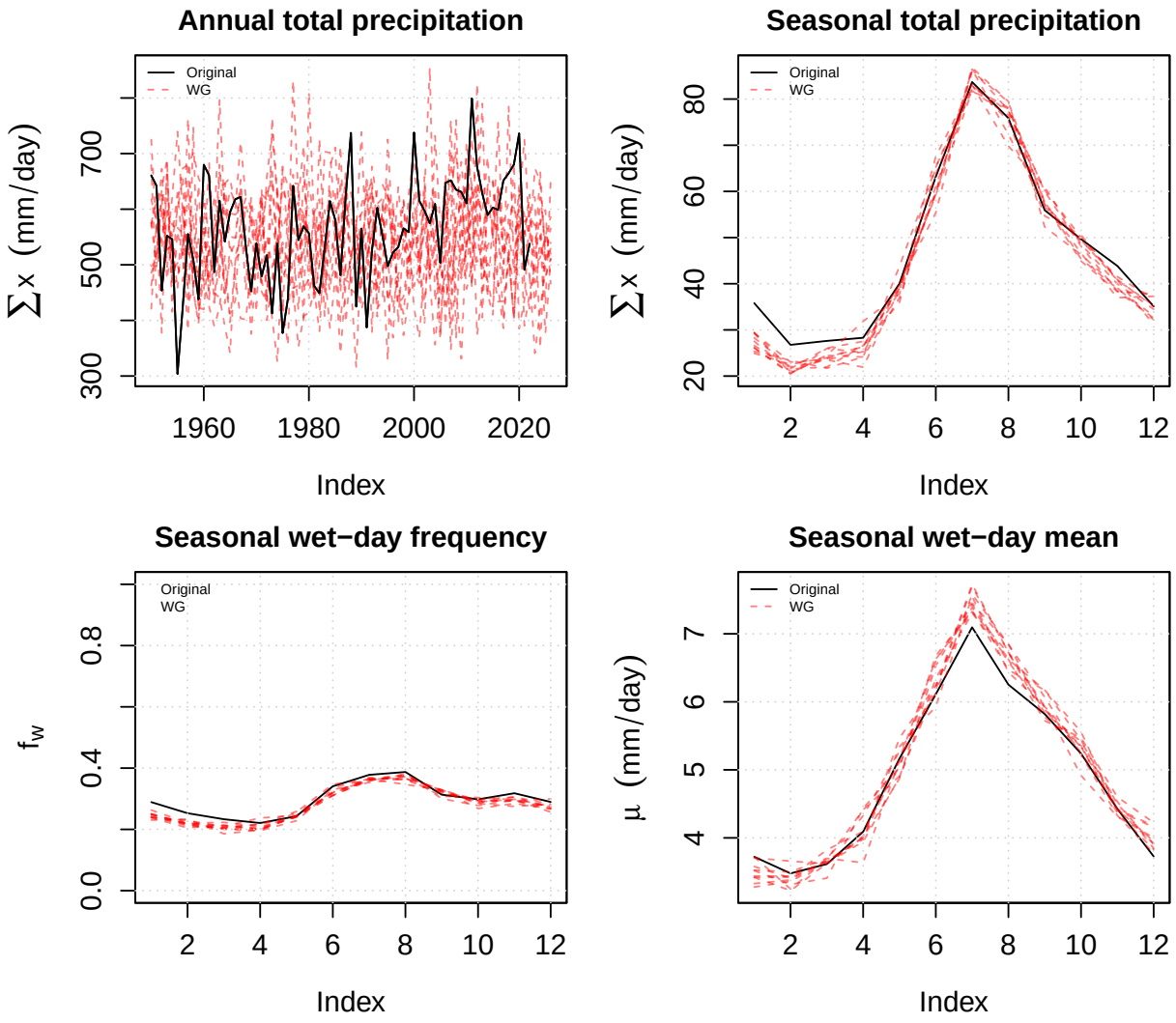


Figure 118: Tests of WG on Norwegian data

```
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.489   4.032   4.119   4.126   4.261   4.606
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.1915  0.2448  0.2695  0.2601  0.2828  0.3028
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.02200 0.02243 0.02334 0.02383 0.02437 0.02736
## test.WG.fwmu.day.precip for RJUKAN  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

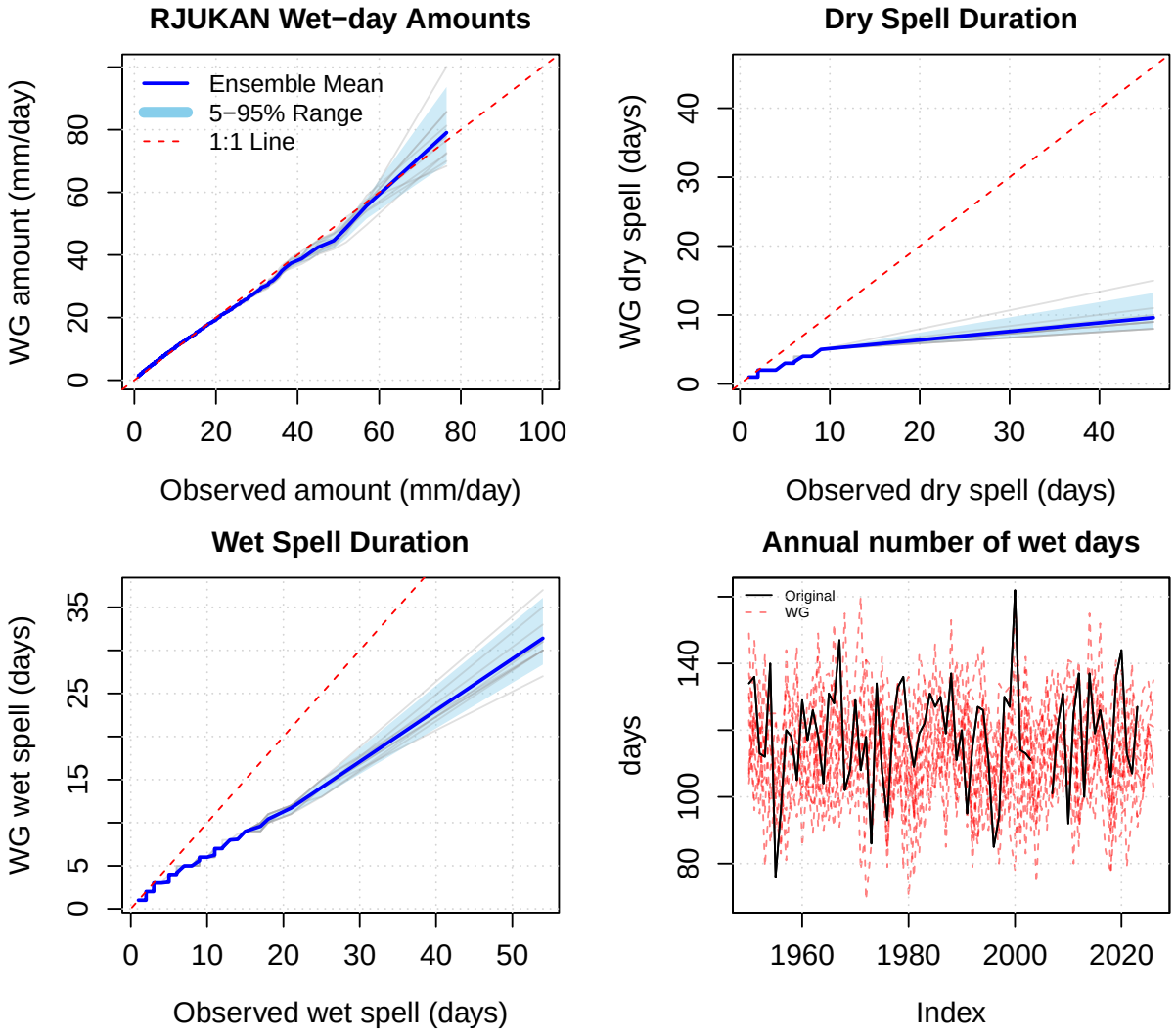


Figure 119: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5676  0.5829  0.6552  0.6739  0.7053  0.9372
```

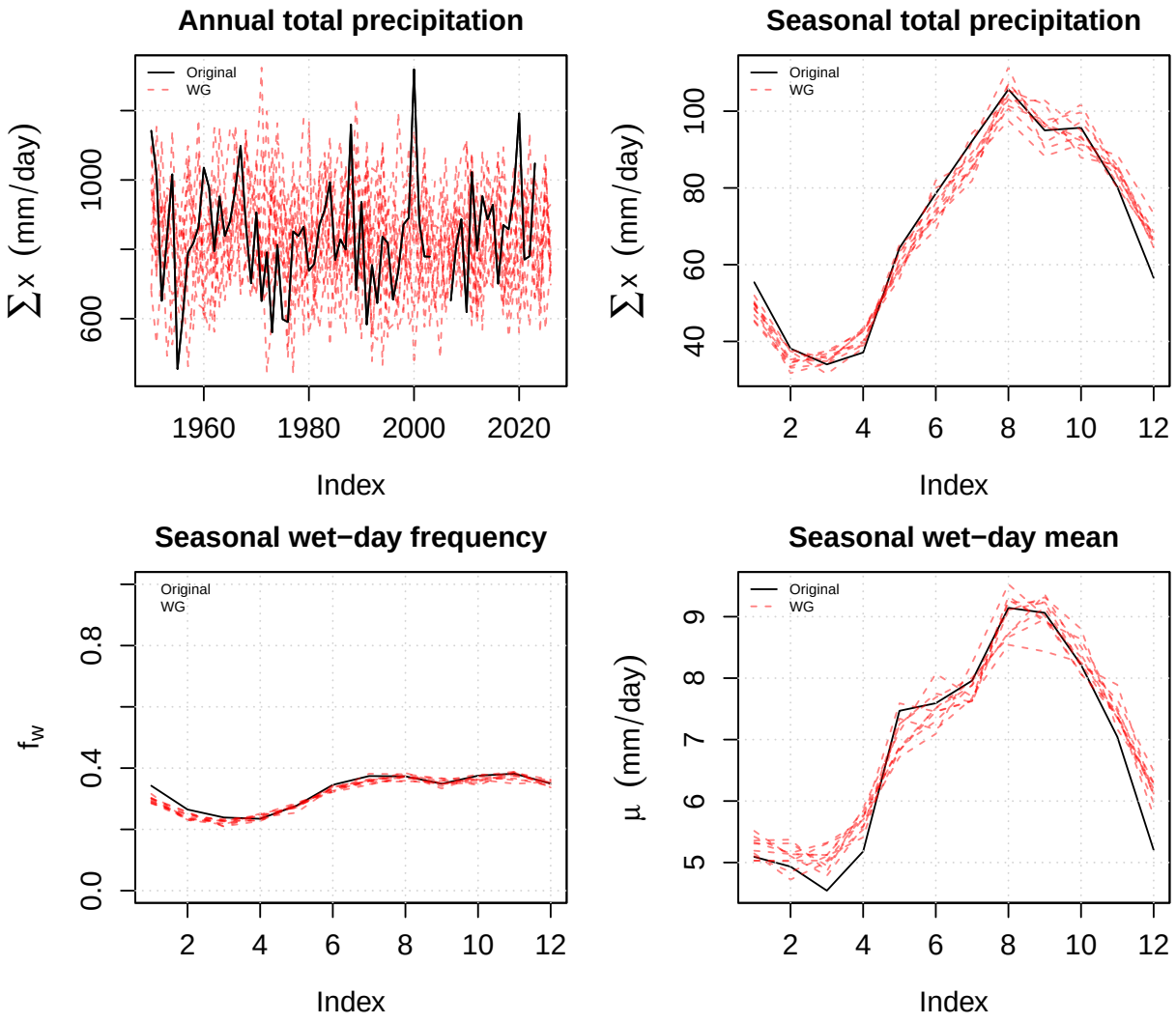


Figure 120: Tests of WG on Norwegian data

```
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.003   3.347   3.453   3.404   3.505   3.695
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.311   3.814   3.886   3.827   3.956   3.981
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.571   5.031   5.275   5.435   5.740   7.195
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3448  0.4262  0.4456  0.4463  0.4691  0.5808
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01667 0.01904 0.01963 0.01949 0.02002 0.02196
## test.WG.fwmu.day.precip for POSTMYR I DRANGEDAL  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.010   1.270   1.400   1.357   1.446   1.577
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.589   2.697   2.939   2.885   3.024   3.243
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.536   1.977   1.989   1.964   2.059   2.156
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.945   7.474   8.341   8.066   8.921   9.222
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3442  0.4482  0.4890  0.4758  0.5173  0.5312
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01287 0.01611 0.01901 0.01855 0.02100 0.02254
## test.WG.fwmu.day.precip for TVEITSUND  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3801  0.4715  0.5534  0.5467  0.6371  0.7149
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.674   2.807   2.871   2.952   3.121   3.361
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.263   2.483   2.610   2.582   2.695   2.784
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

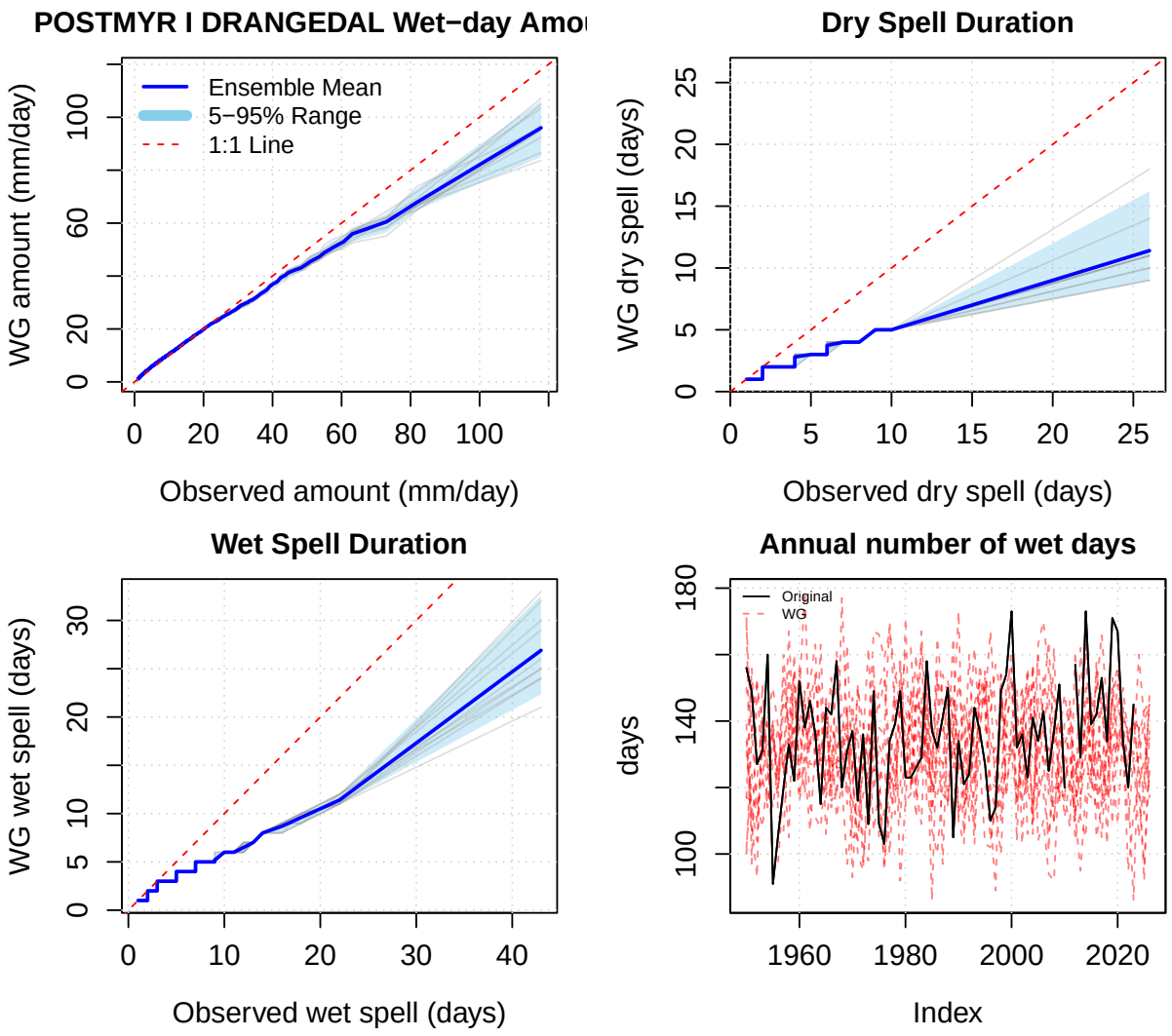


Figure 121: Tests of WG on Norwegian data

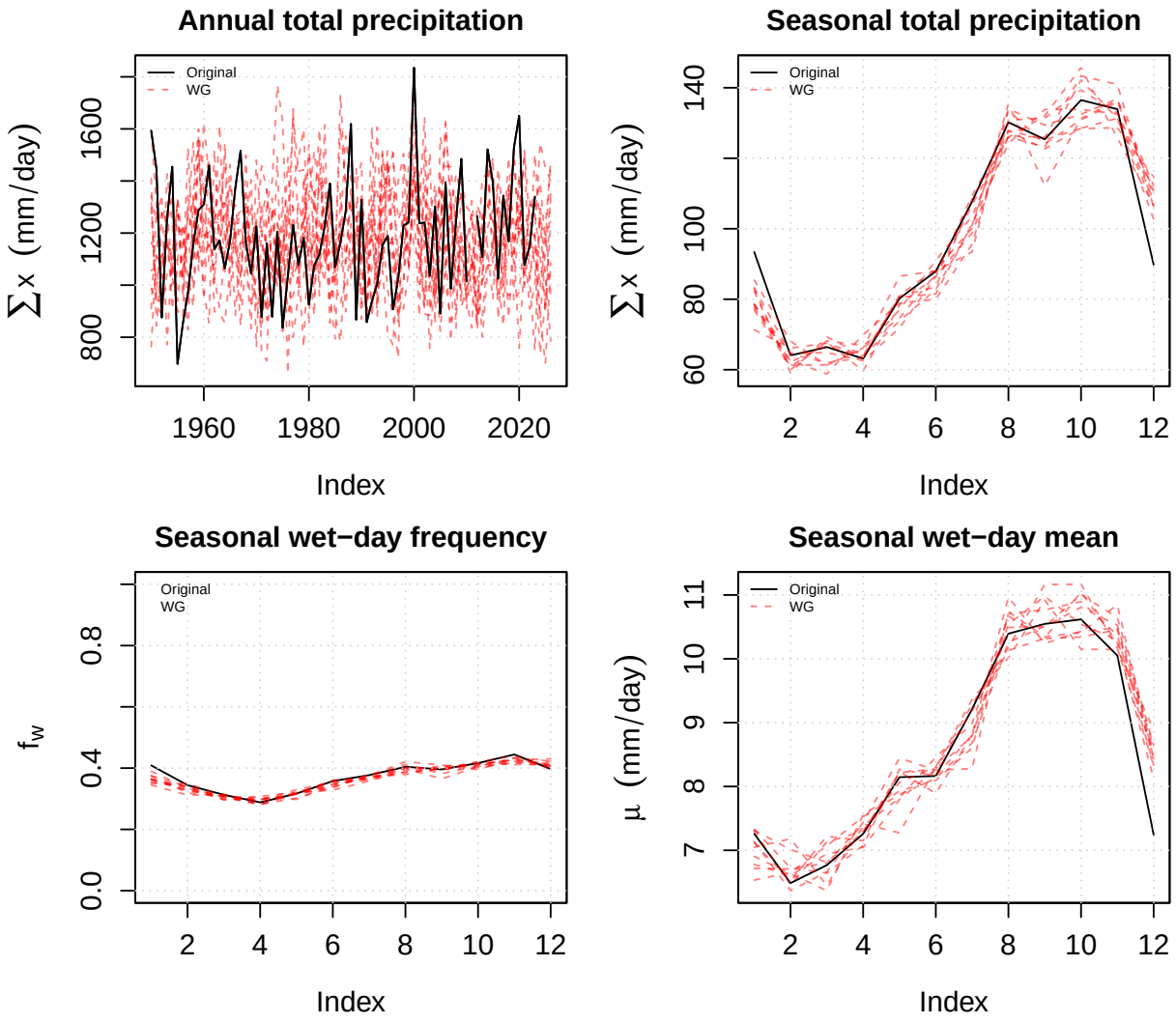


Figure 122: Tests of WG on Norwegian data

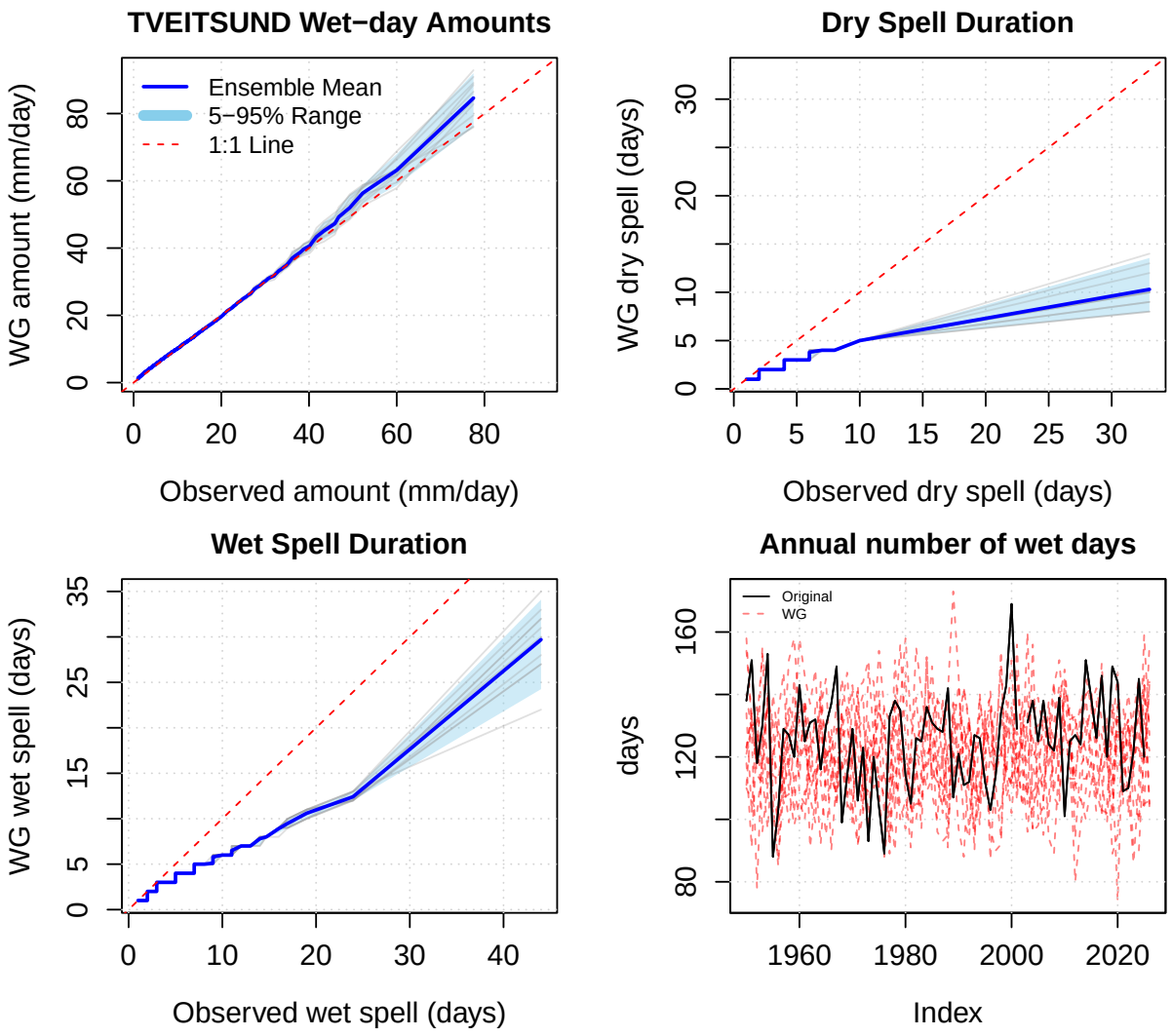


Figure 123: Tests of WG on Norwegian data

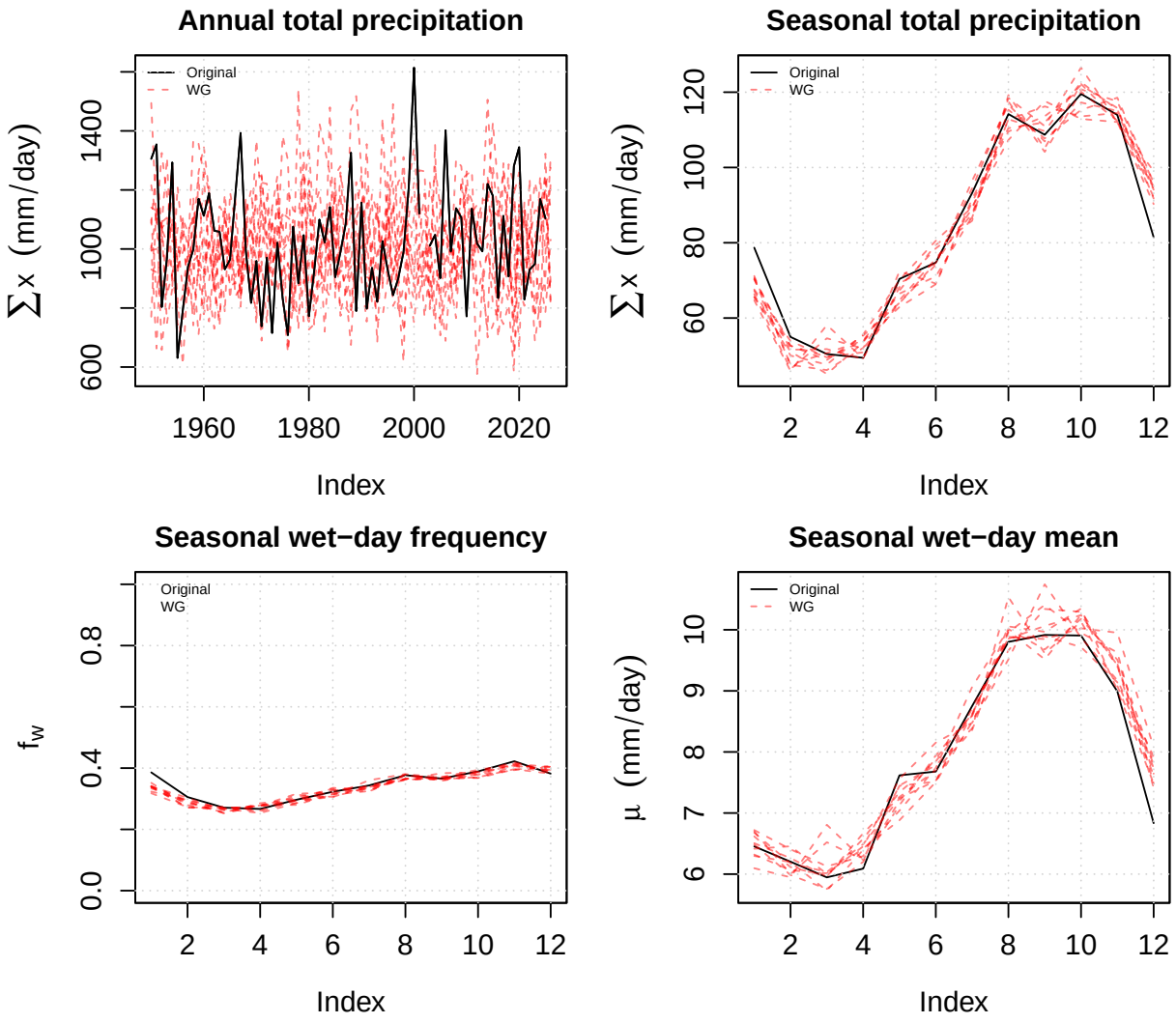


Figure 124: Tests of WG on Norwegian data

```
##   5.163   6.124   6.363   6.306   6.616   7.228
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3009  0.3731  0.3868  0.3943  0.4110  0.4934
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01721 0.01767 0.01898 0.01929 0.02051 0.02319
## test.WG.fwmu.day.precip for TOVDAL  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

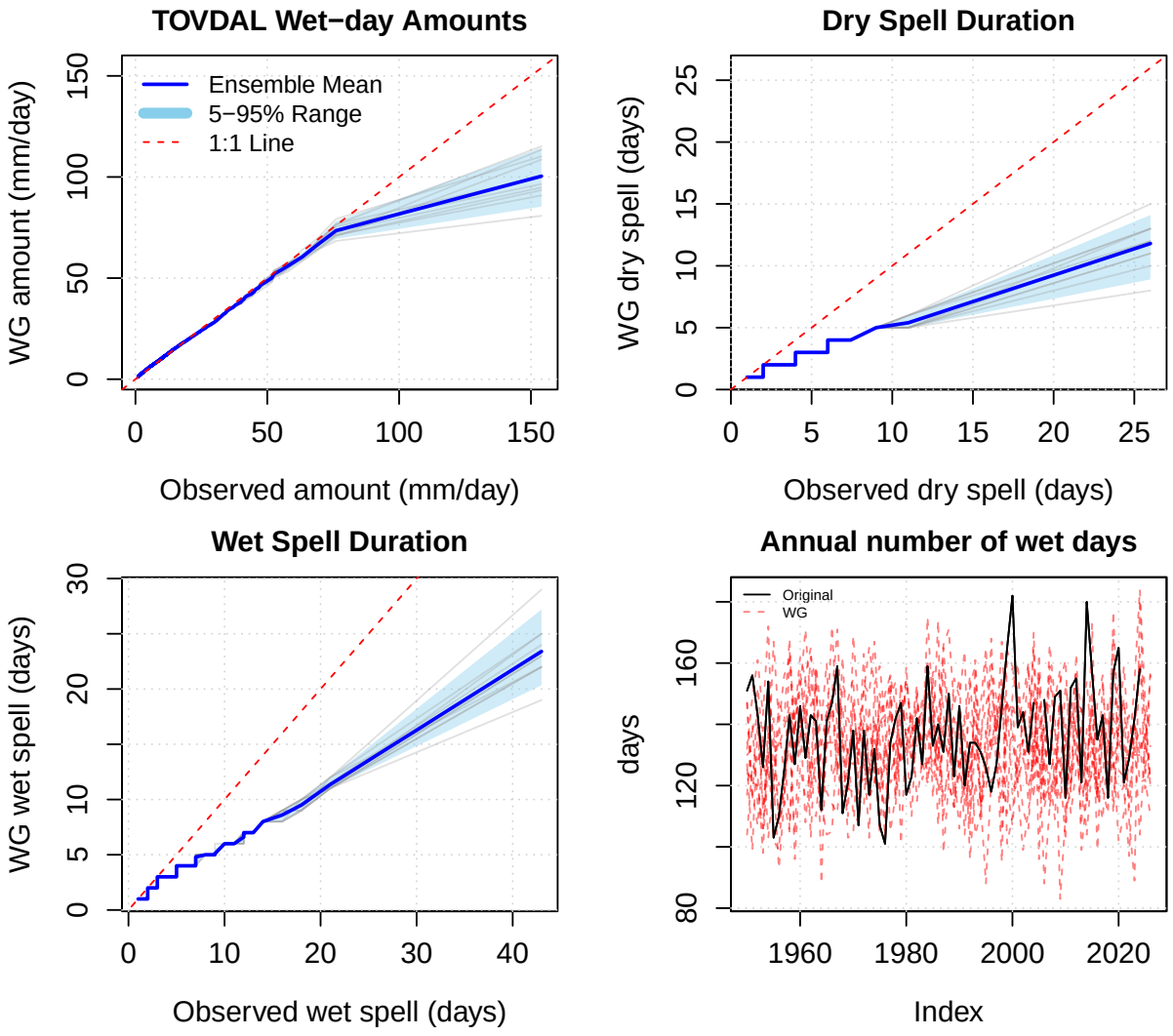


Figure 125: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.385   1.518   1.852   1.810   2.024   2.424
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

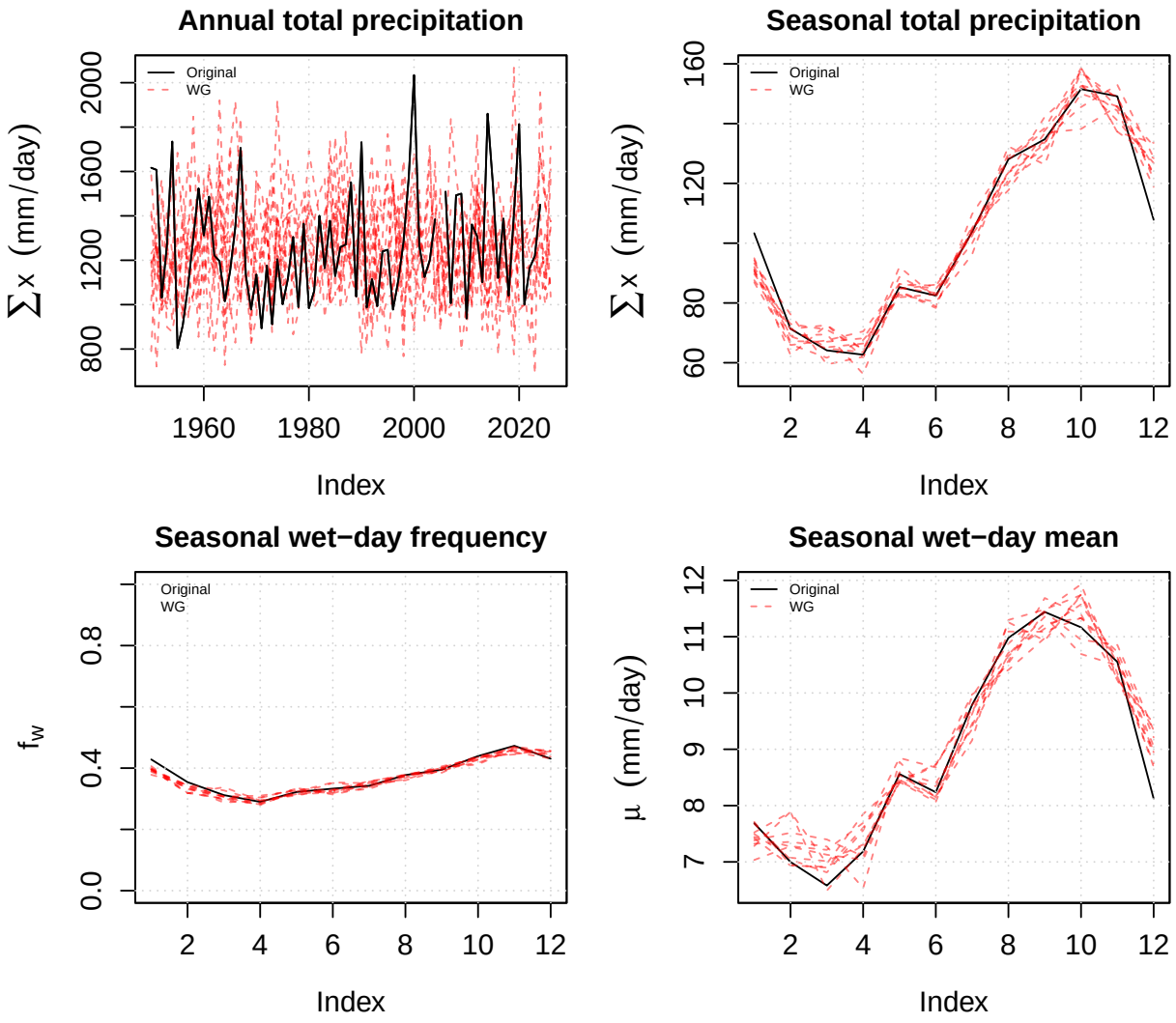


Figure 126: Tests of WG on Norwegian data

```
##   2.670   2.970   3.126   3.074   3.171   3.376
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.696   1.842   1.921   1.940   2.009   2.229
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.810   6.183   7.570   7.423   8.473  10.042
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3239  0.3855  0.4536  0.4343  0.4693  0.5411
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01416 0.01475 0.01667 0.01652 0.01800 0.01910
## test.WG.fwmu.day.precip for ÅSERAL  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

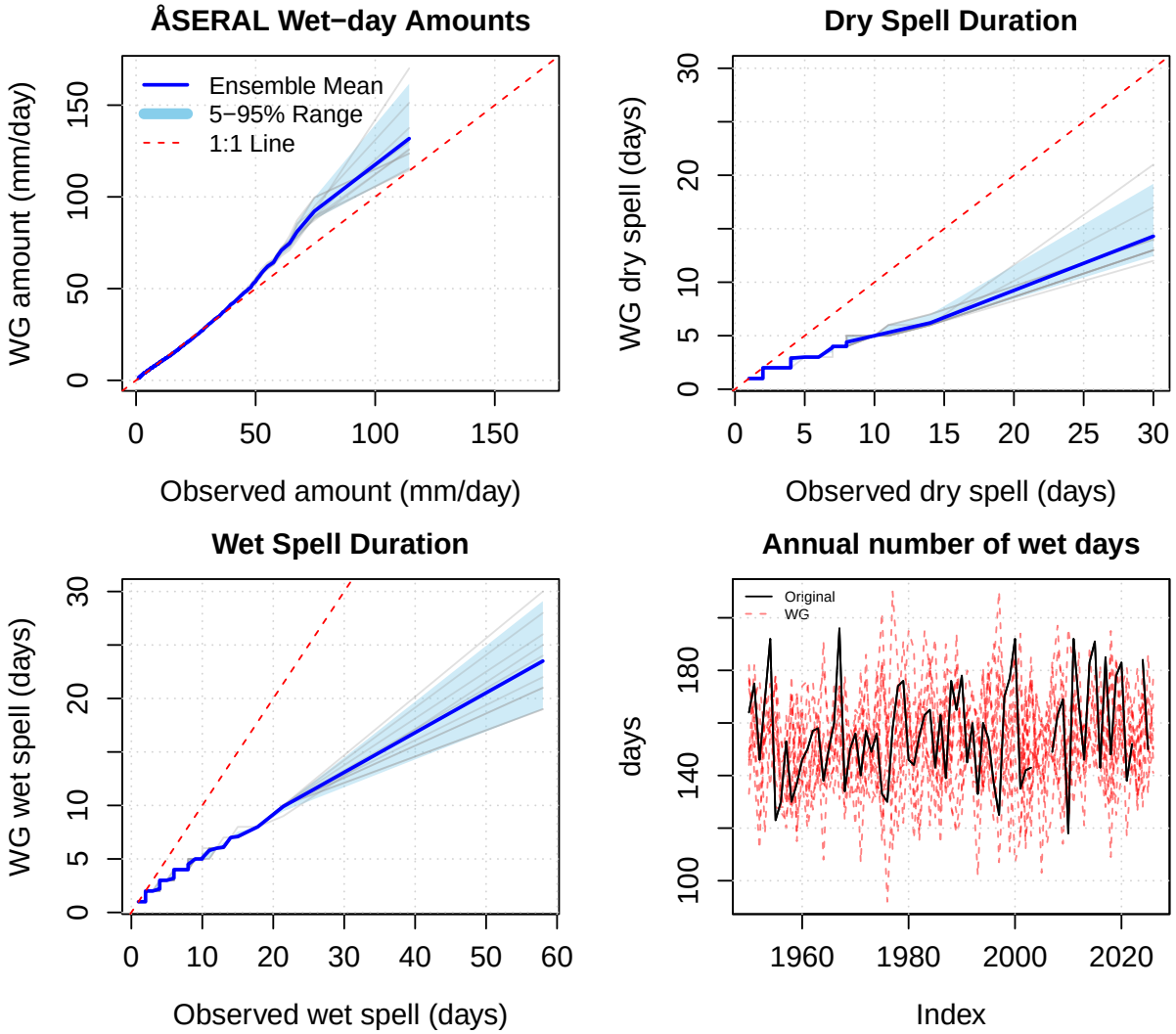


Figure 127: Tests of WG on Norwegian data

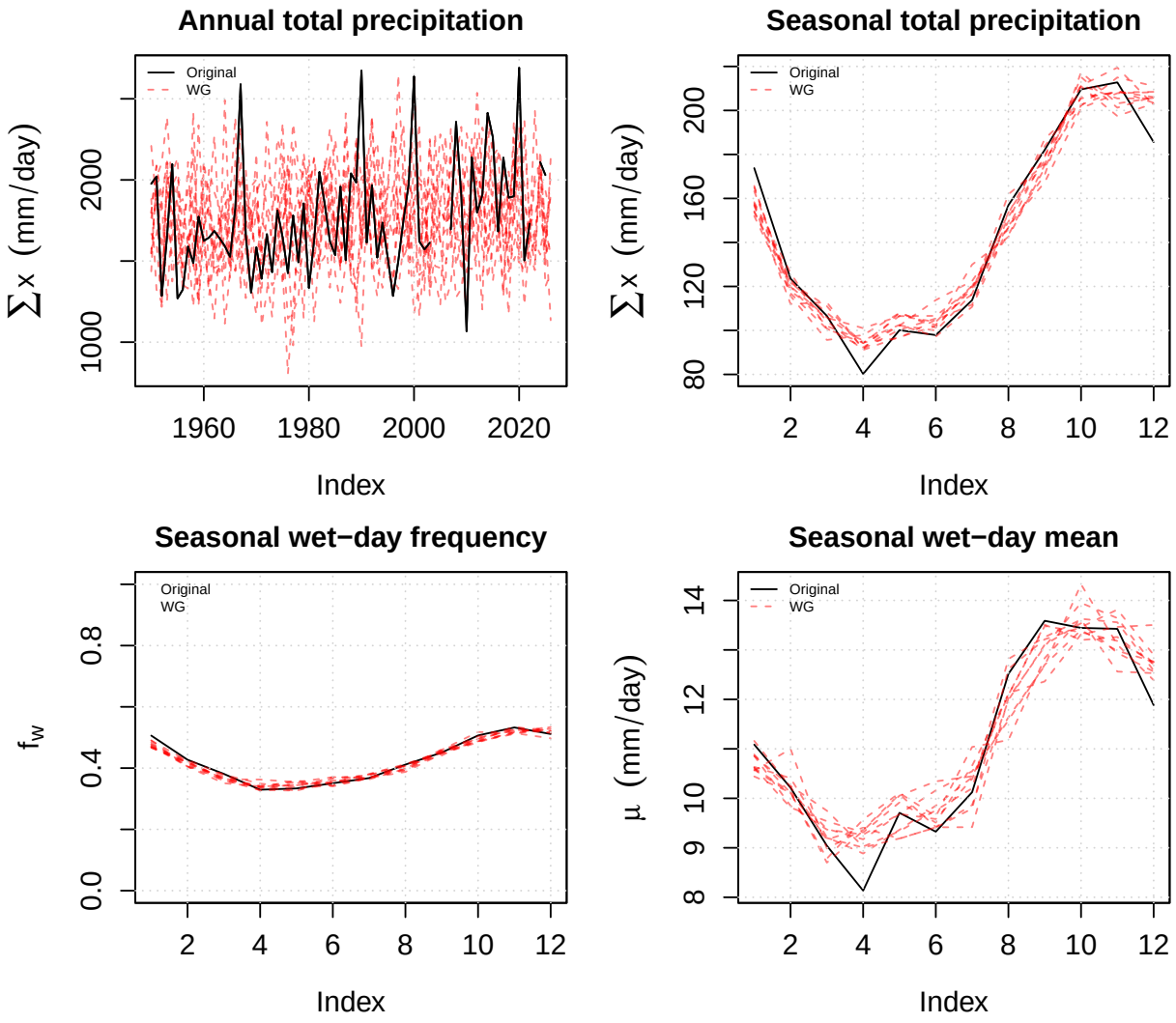


Figure 128: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.037   1.111   1.318   1.370   1.473   2.086
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.829   4.151   4.342   4.316   4.491   4.682
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.954   2.292   2.409   2.339   2.437   2.516
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   8.348   9.120  10.349  10.478  11.756  12.878
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.4401  0.5111  0.5671  0.5861  0.6905  0.7172
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01166 0.01412 0.01671 0.01557 0.01706 0.01785
## test.WG.fwmu.day.precip for RISNES I FJOTLAND  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.136   1.810   2.041   1.966   2.212   2.384
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.076   4.513   4.599   4.593   4.741   4.911
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.398   2.598   2.644   2.649   2.765   2.811
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   9.955  10.475  11.122  11.587  12.311  15.272
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.4770  0.5656  0.6148  0.6220  0.6449  0.9192
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01170 0.01399 0.01490 0.01506 0.01637 0.01837
## test.WG.fwmu.day.precip for BAKKE  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6539  0.8835  1.1820  1.1531  1.3790  1.7519
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.902   3.069   3.251   3.221   3.391   3.494
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

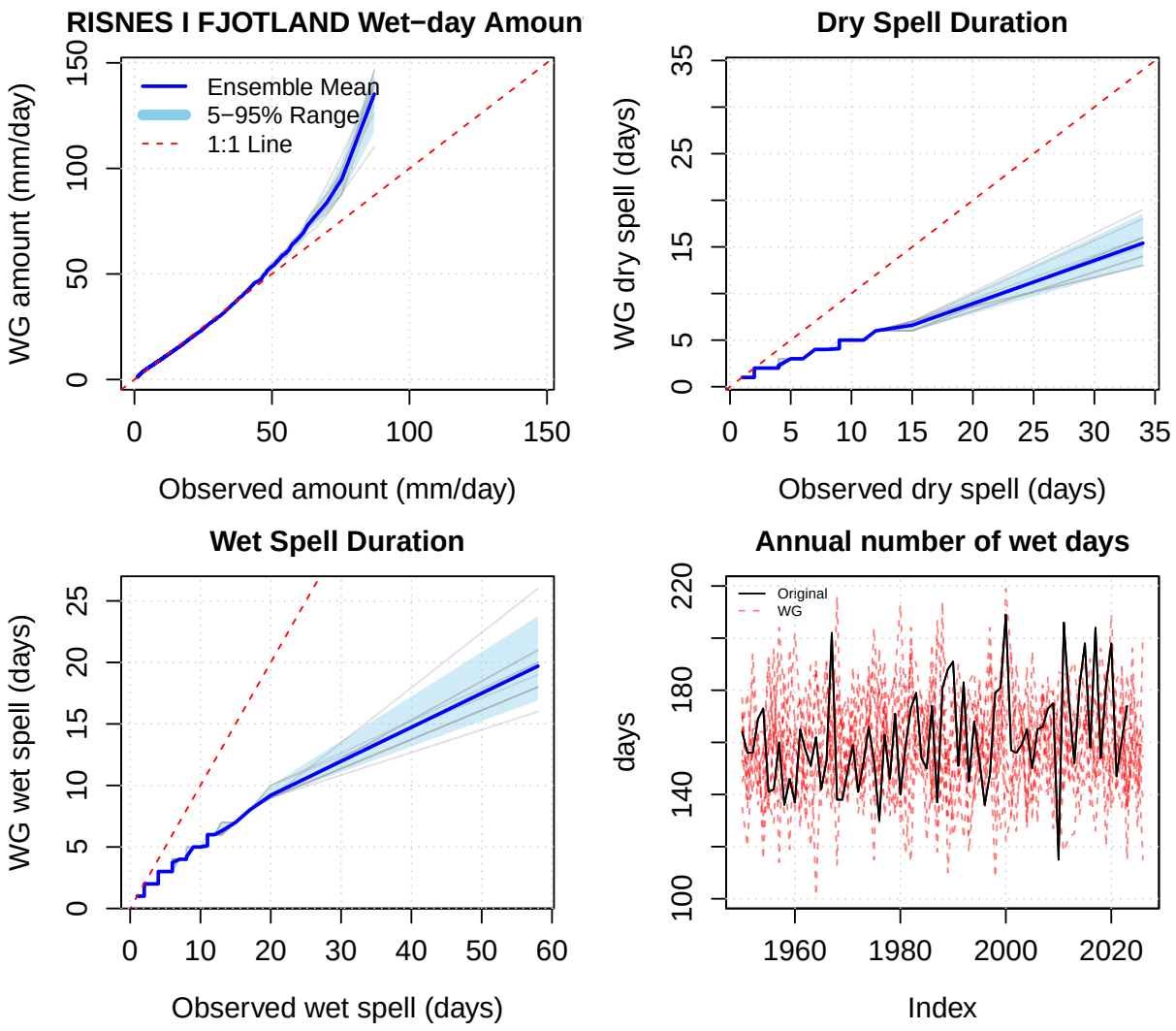


Figure 129: Tests of WG on Norwegian data

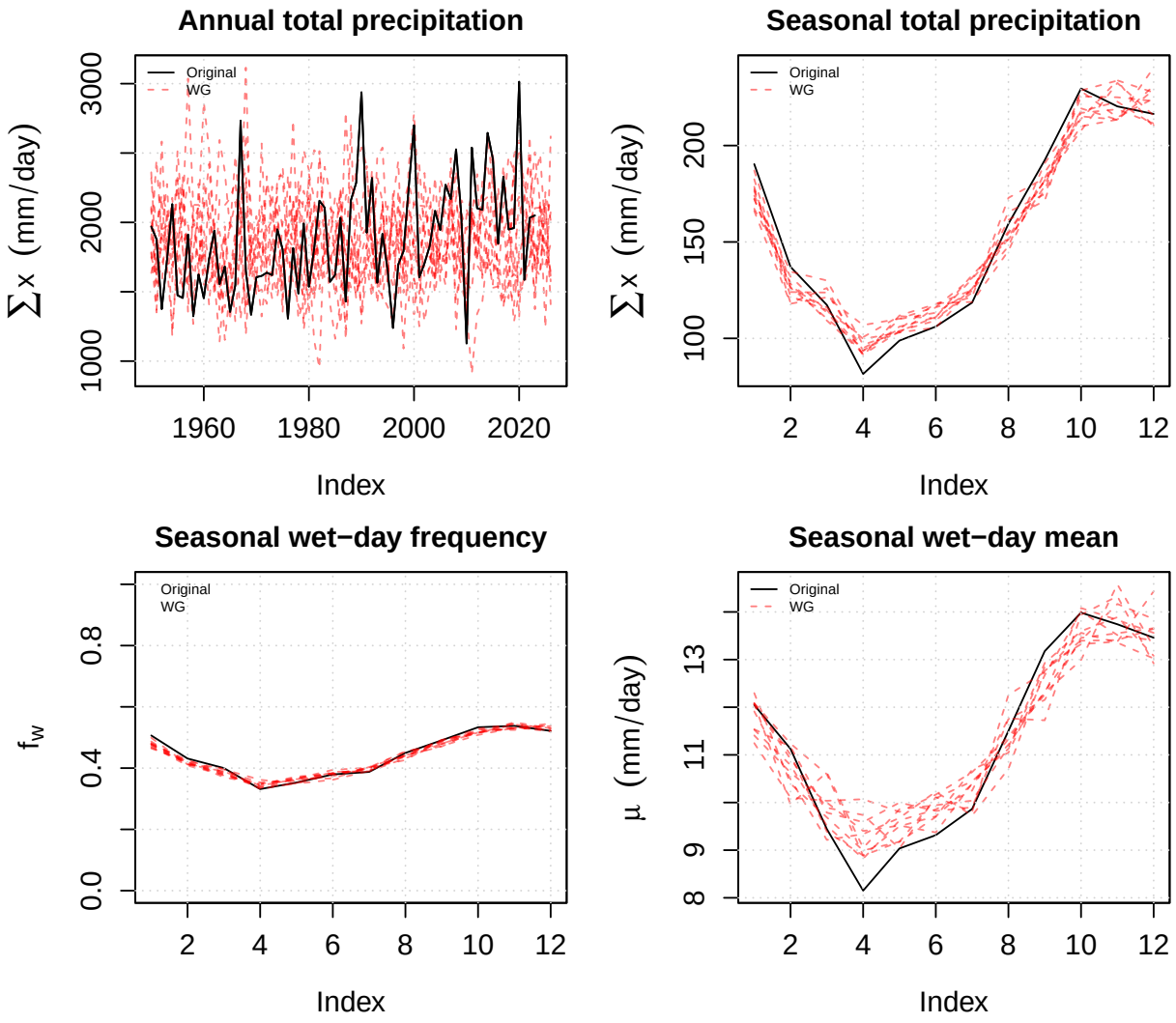


Figure 130: Tests of WG on Norwegian data

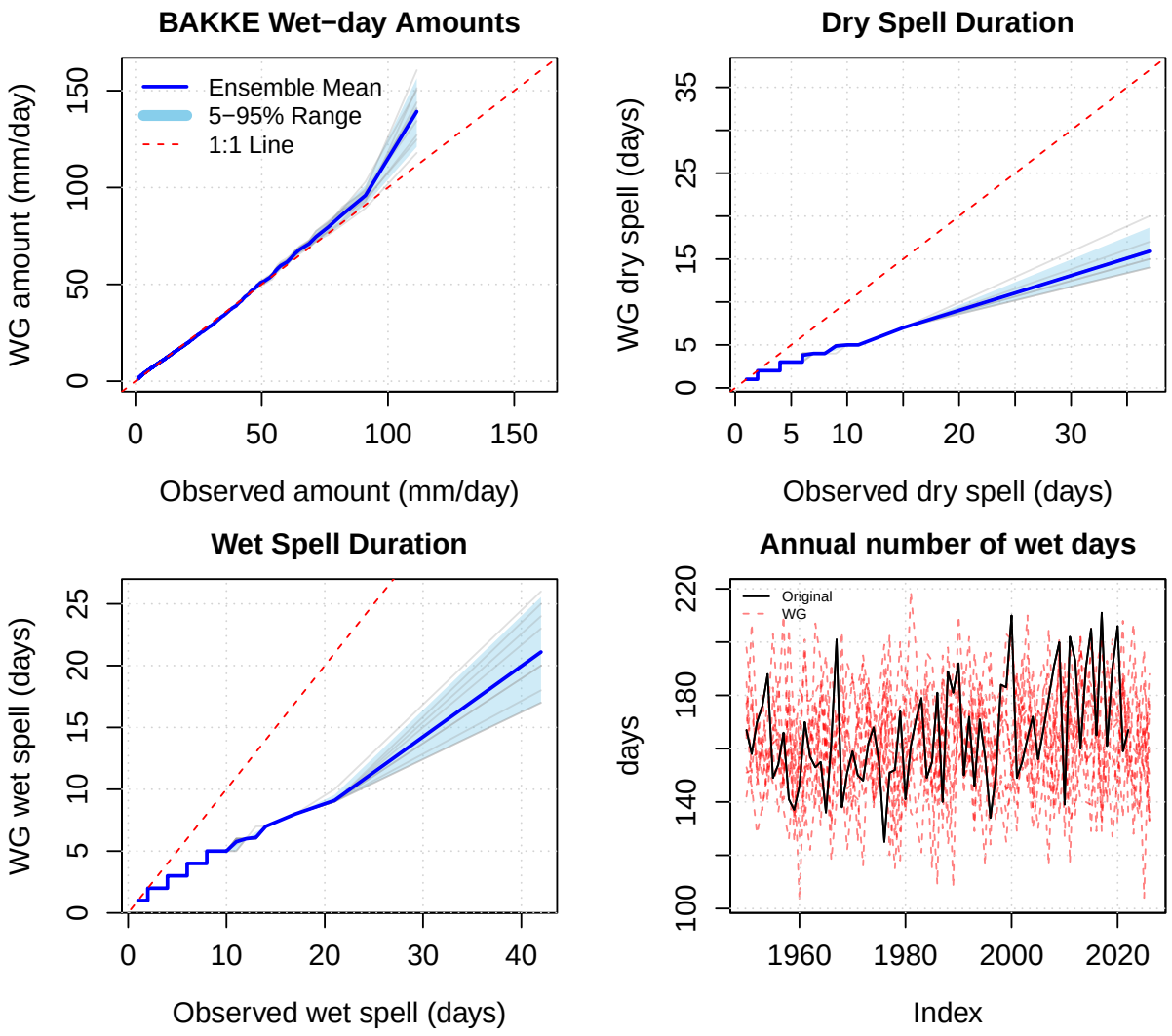


Figure 131: Tests of WG on Norwegian data

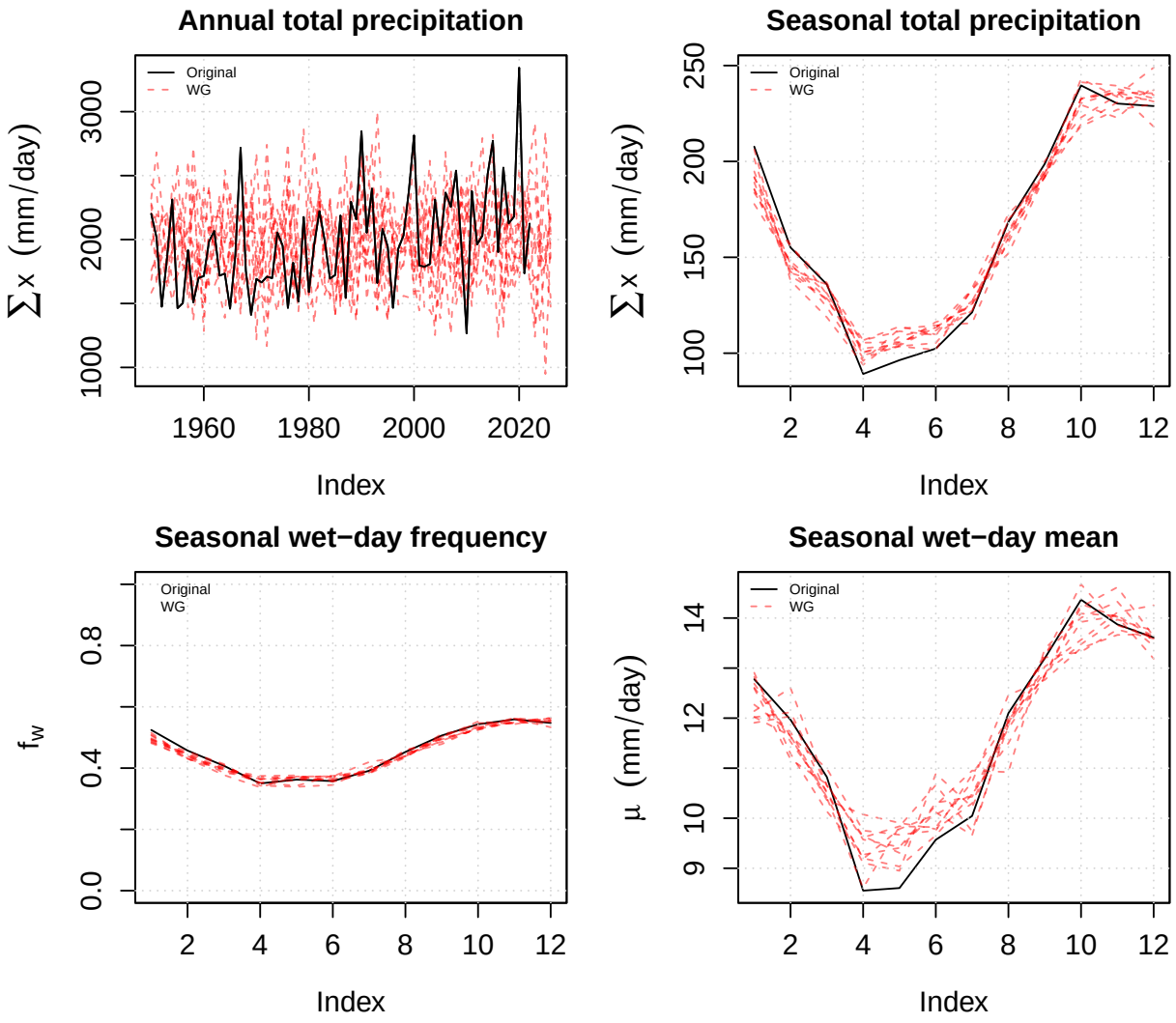


Figure 132: Tests of WG on Norwegian data

```
##   2.526   2.811   2.826   2.827   2.898   2.970
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   8.257  10.094  11.040  10.811  11.635  13.376
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.4462  0.5104  0.5819  0.5728  0.6483  0.6704
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01228 0.01420 0.01501 0.01515 0.01594 0.01842
## test.WG.fwmu.day.precip for SØYLAND I GJESDAL  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

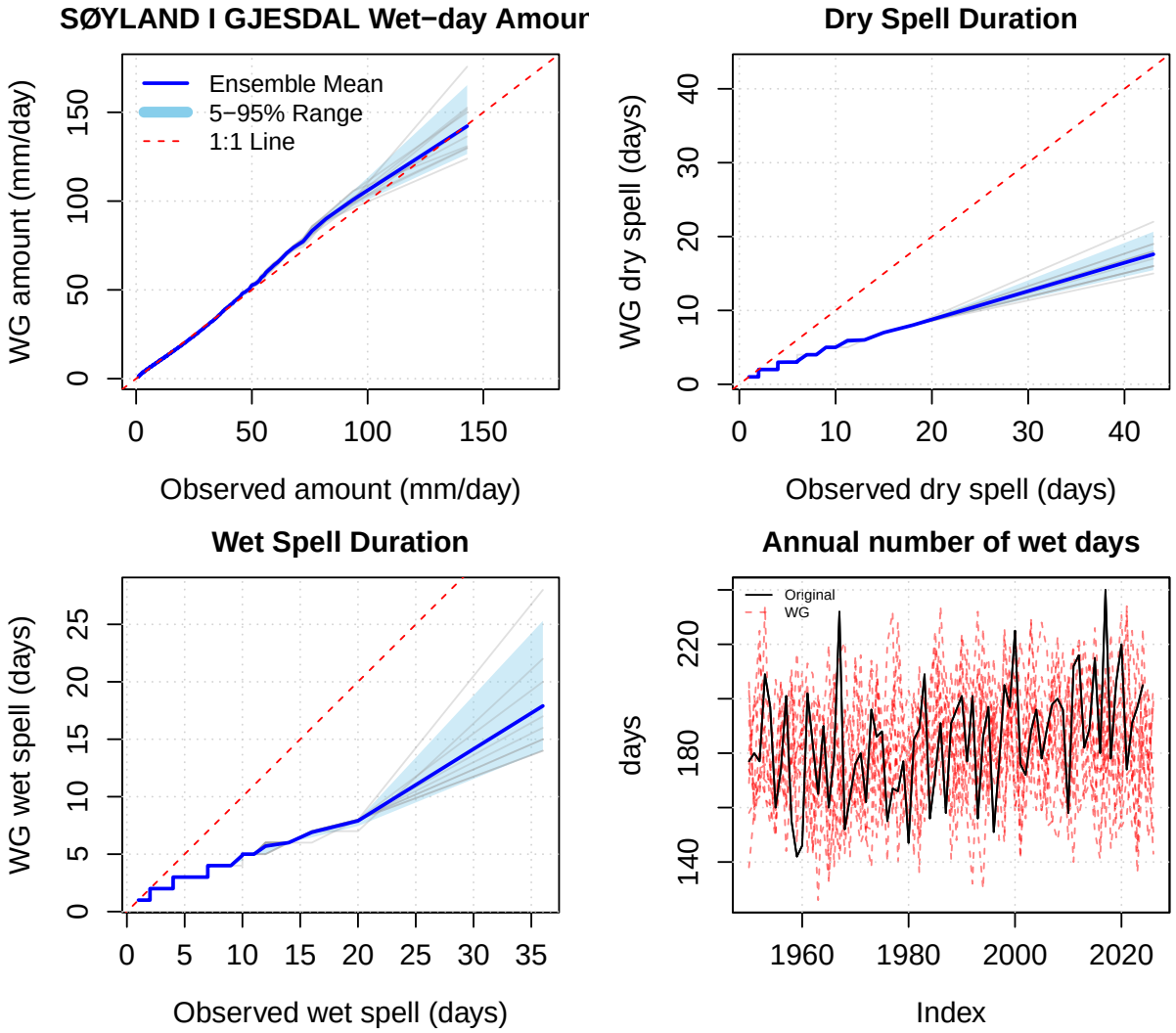


Figure 133: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

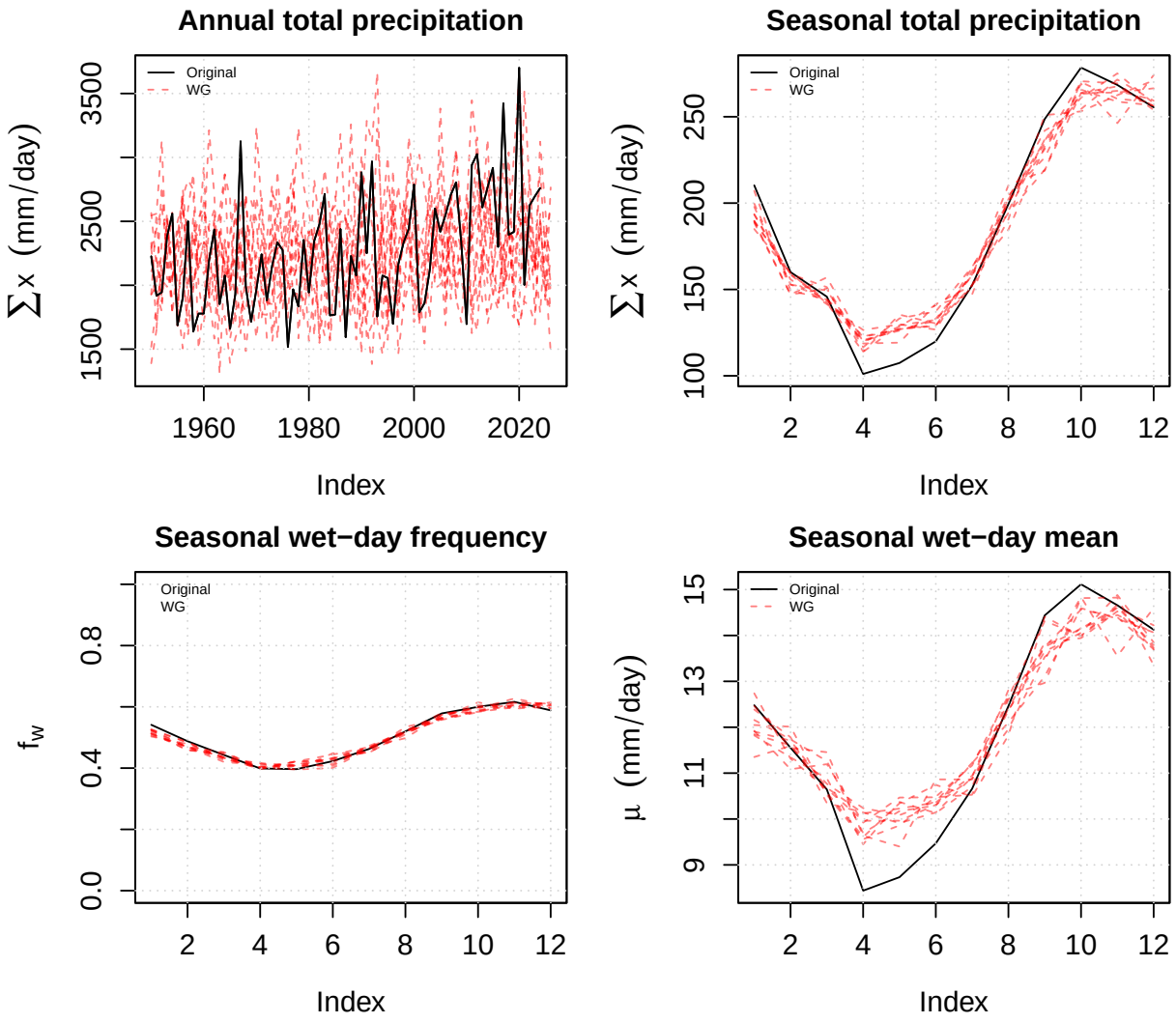


Figure 134: Tests of WG on Norwegian data

```
##  0.7745  0.8426  0.9405  0.9673  1.0089  1.3929
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.612   2.985   3.160   3.110   3.265   3.366
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.095   3.323   3.423   3.410   3.522   3.605
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   12.04   13.30   13.85   13.92   14.38   16.10
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7099  0.7550  0.7895  0.7864  0.8172  0.8844
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01013 0.01428 0.01512 0.01480 0.01579 0.01832
## test.WG.fwmu.day.precip for SVILAND  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8070  0.9149  1.0658  1.0531  1.1950  1.2721
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.994   3.197   3.275   3.232   3.280   3.389
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.387   2.674   2.778   2.749   2.860   2.917
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.192   7.051   7.737   7.890   8.898  10.758
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3098  0.3640  0.4114  0.4290  0.4746  0.5731
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01021 0.01097 0.01281 0.01316 0.01552 0.01634
## test.WG.fwmu.day.precip for SAND I RYFYLKE II  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   0.768   1.077   1.132   1.160   1.241   1.745
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.999   3.138   3.292   3.249   3.356   3.437
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.511   2.746   2.846   2.859   2.985   3.177
## RMSE for climatology in total precipitation:
```

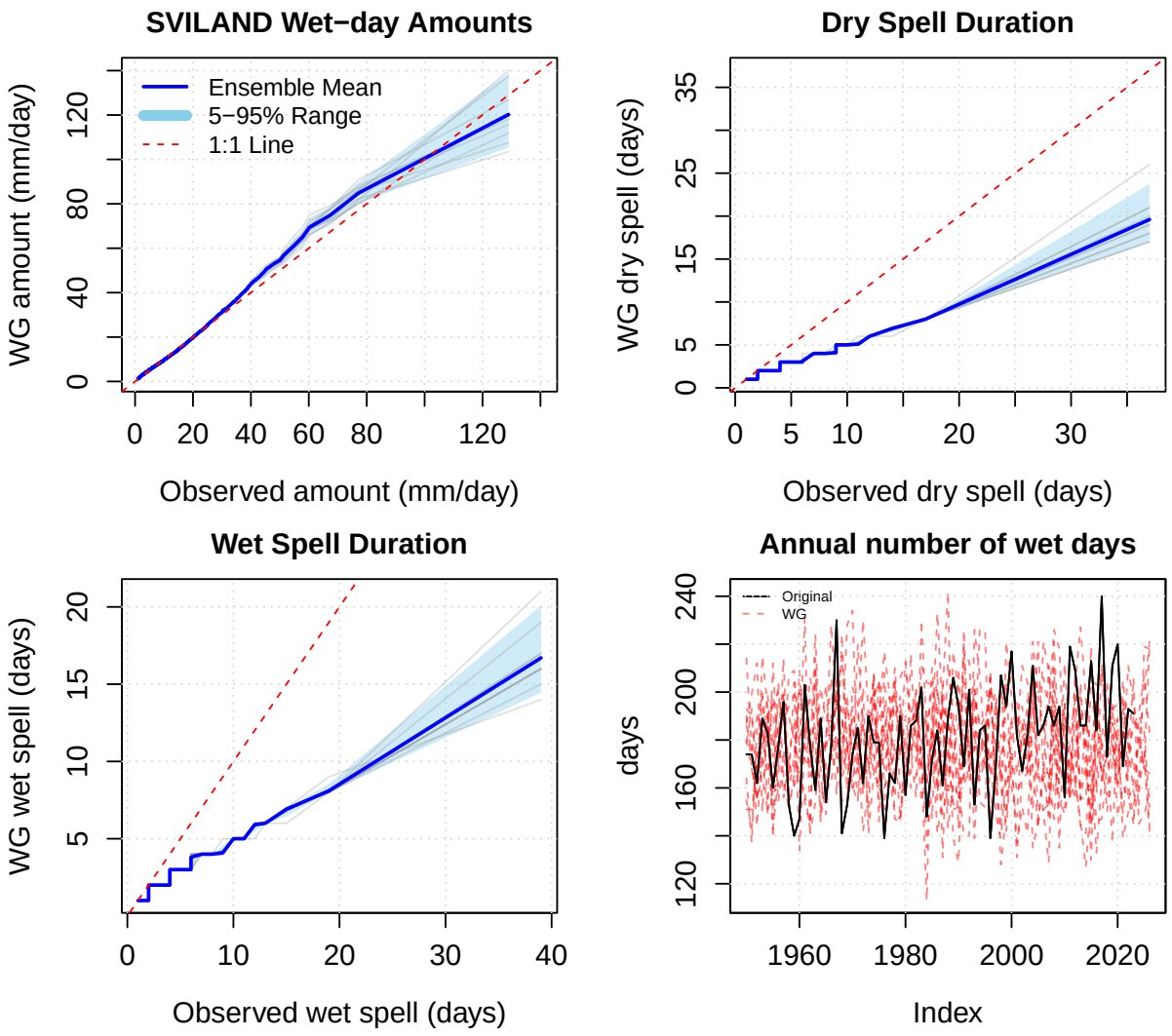


Figure 135: Tests of WG on Norwegian data

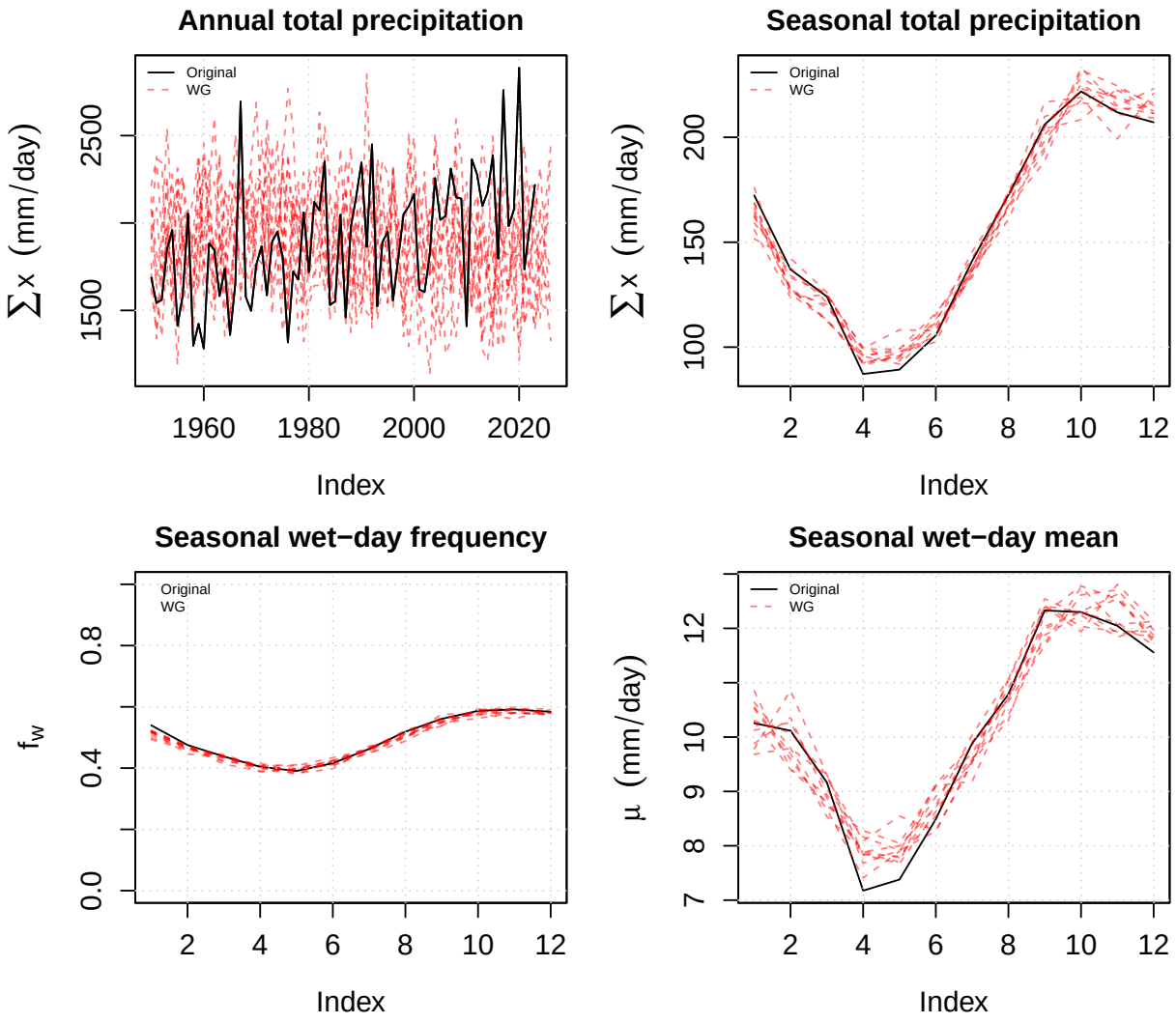


Figure 136: Tests of WG on Norwegian data

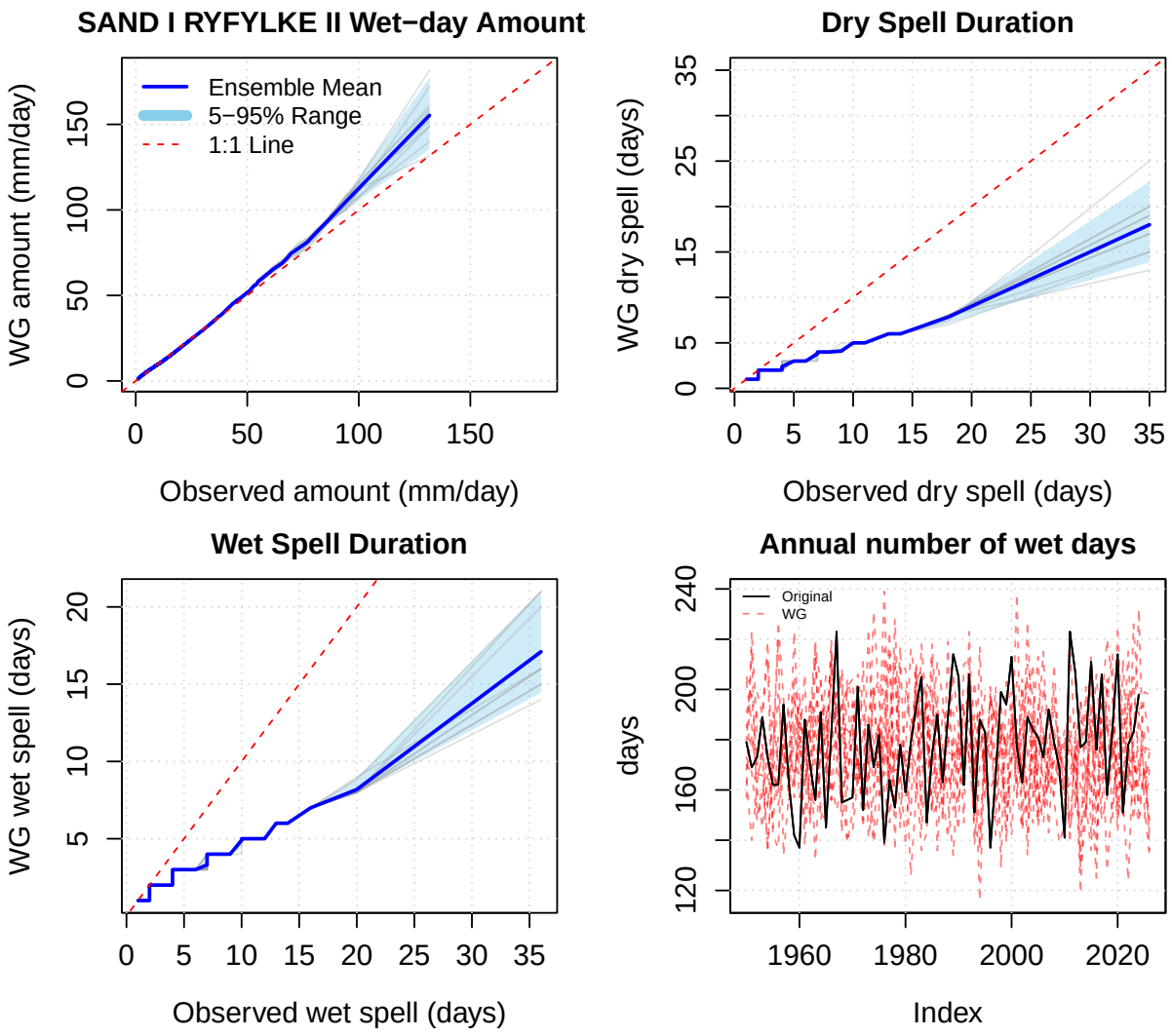


Figure 137: Tests of WG on Norwegian data

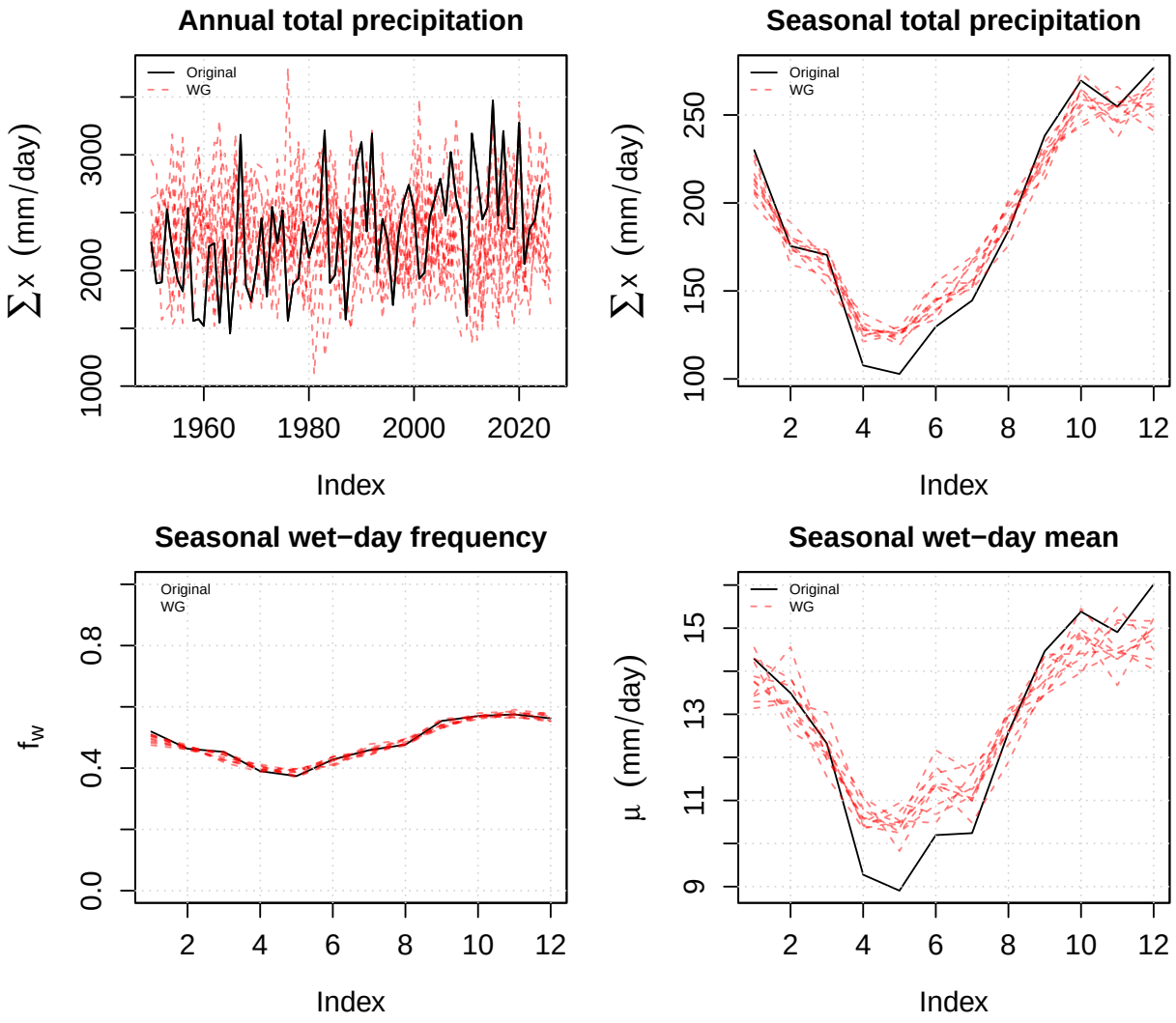


Figure 138: Tests of WG on Norwegian data

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   13.86   15.20   16.17   16.45   17.48   20.54
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8470  0.9332  0.9535  0.9685  0.9788  1.1260
## RMSE for climatology in wet-day frequency:
##     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
## 0.009311 0.011580 0.013294 0.013743 0.015795 0.018886
## test.WG.fwmu.day.precip for VIK I SOGN III  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

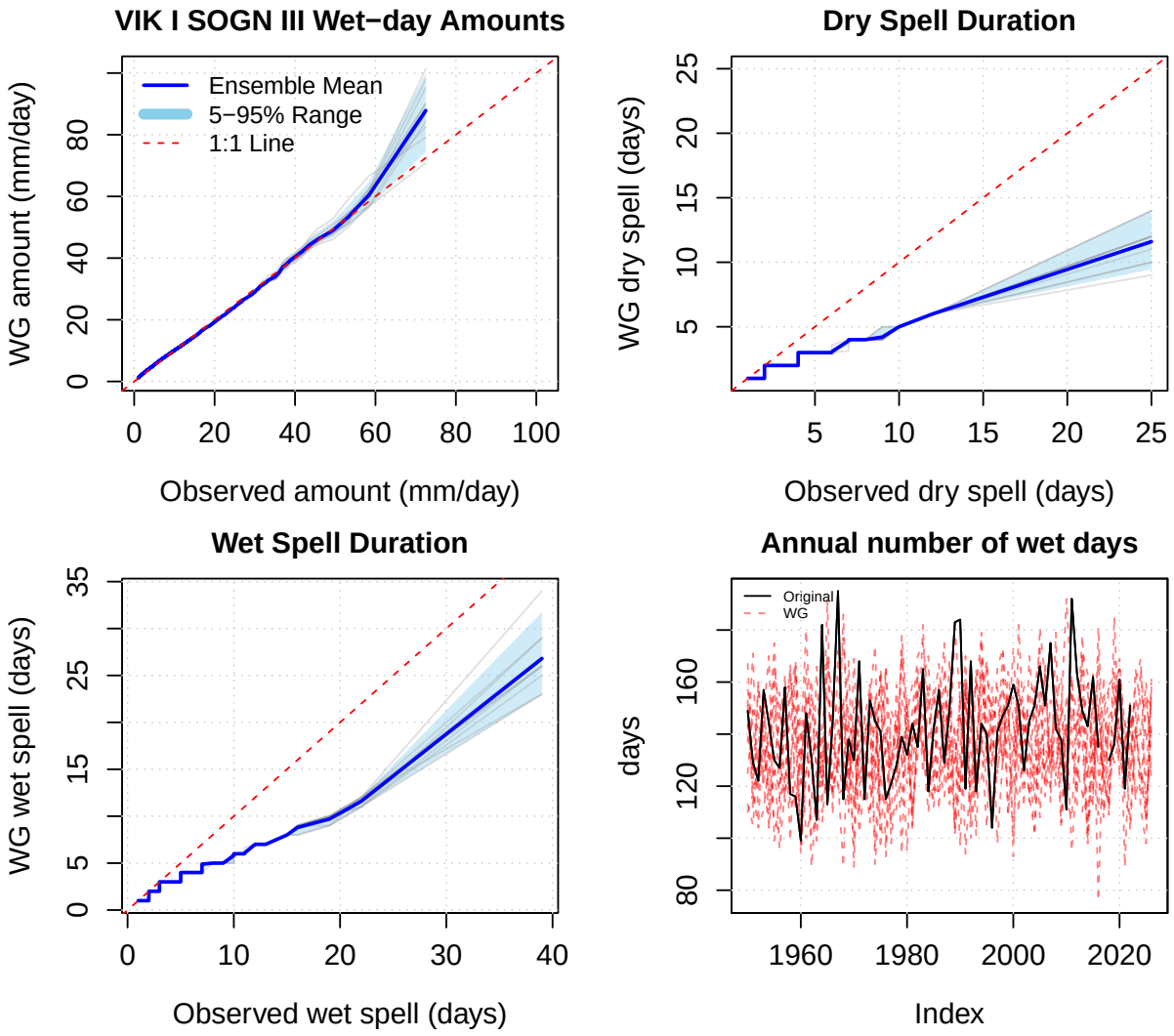


Figure 139: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.4097  0.5900  0.6762  0.6944  0.8058  1.0097
## RMSE for wet-spell duration quantiles:
```

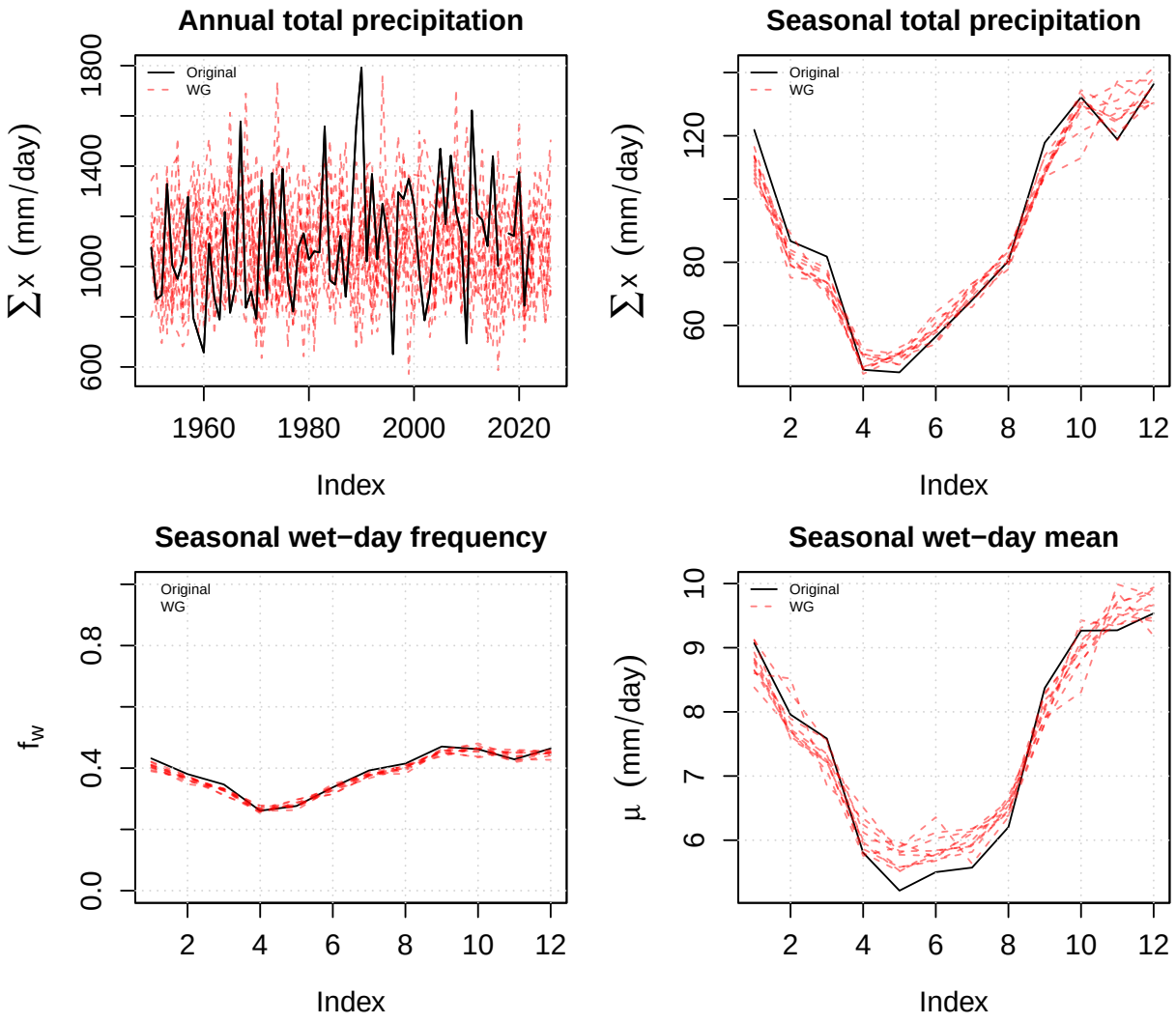


Figure 140: Tests of WG on Norwegian data

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.375   2.611   2.665   2.668   2.784   2.873
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.822   1.928   1.961   1.978   2.064   2.161
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.740   6.808   7.662   7.648   8.137   9.989
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.2632  0.3312  0.3745  0.3806  0.4323  0.5133
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01375 0.01618 0.01693 0.01729 0.01855 0.02019
## test.WG.fwmu.day.precip for HOVLANDSDAL  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.035   1.287   1.431   1.531   1.793   2.339
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.015   3.083   3.169   3.160   3.243   3.315
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.011   3.549   3.587   3.581   3.689   3.987
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   26.82   29.50   31.13   30.79   32.23   33.96
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.397   1.586   1.660   1.660   1.770   1.850
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01044 0.01257 0.01376 0.01418 0.01617 0.01839
## test.WG.fwmu.day.precip for BOTNEN I FØRDE  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.303   1.393   1.521   1.680   1.948   2.350
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.968   3.092   3.205   3.173   3.279   3.288
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.815   3.042   3.272   3.189   3.320   3.416
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   20.17   24.80   27.47   26.24   27.79   29.27
```

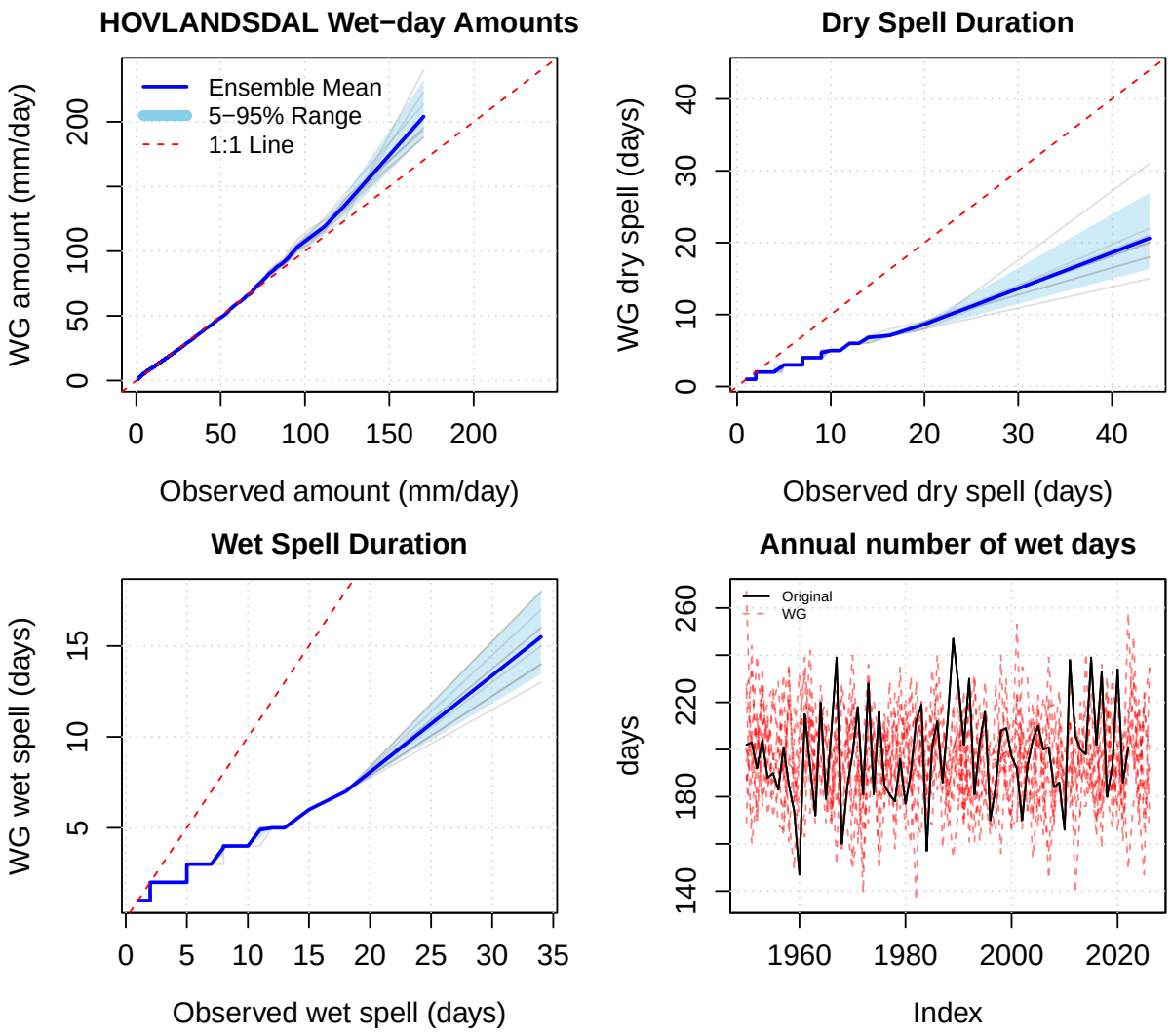


Figure 141: Tests of WG on Norwegian data

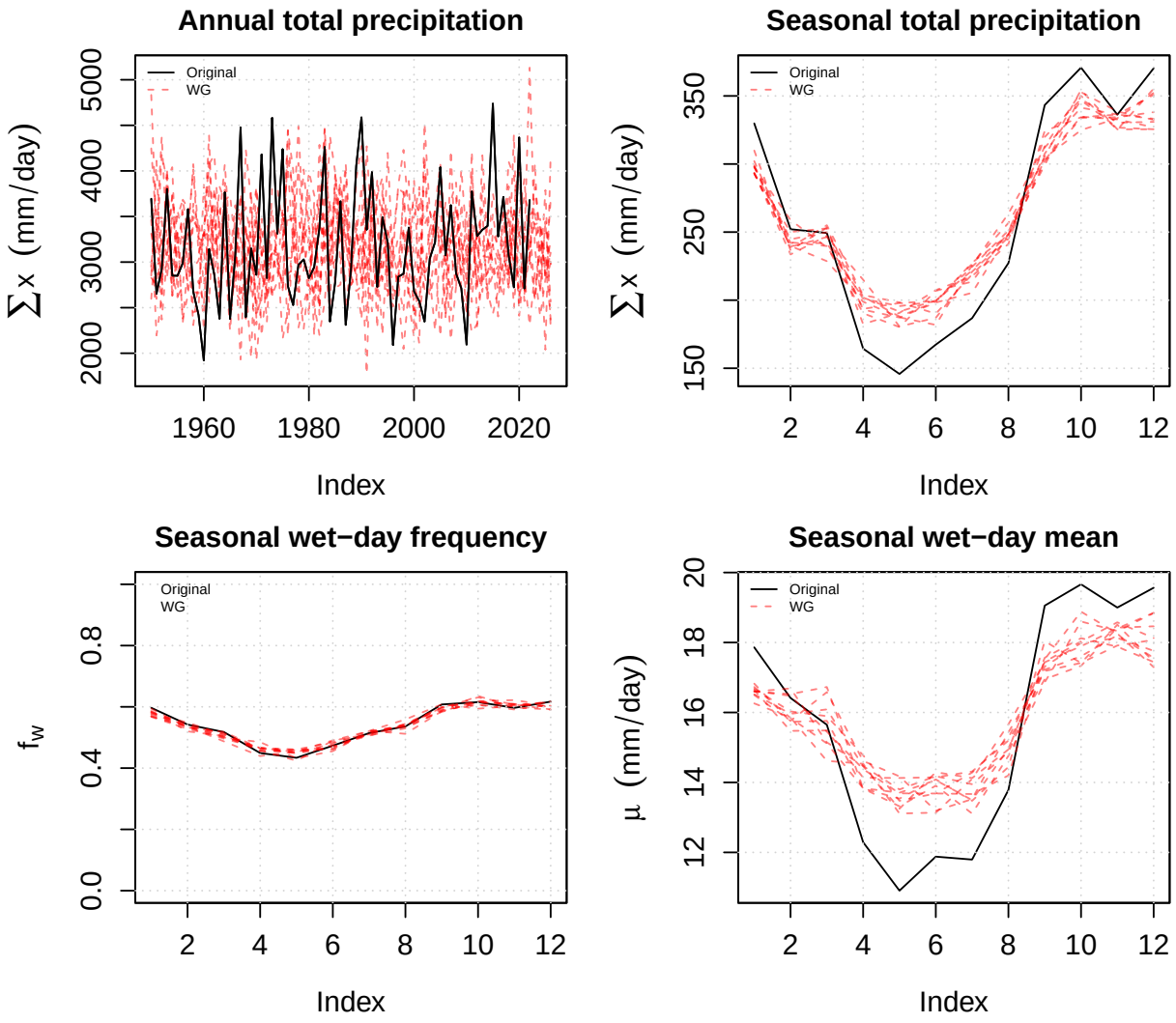


Figure 142: Tests of WG on Norwegian data

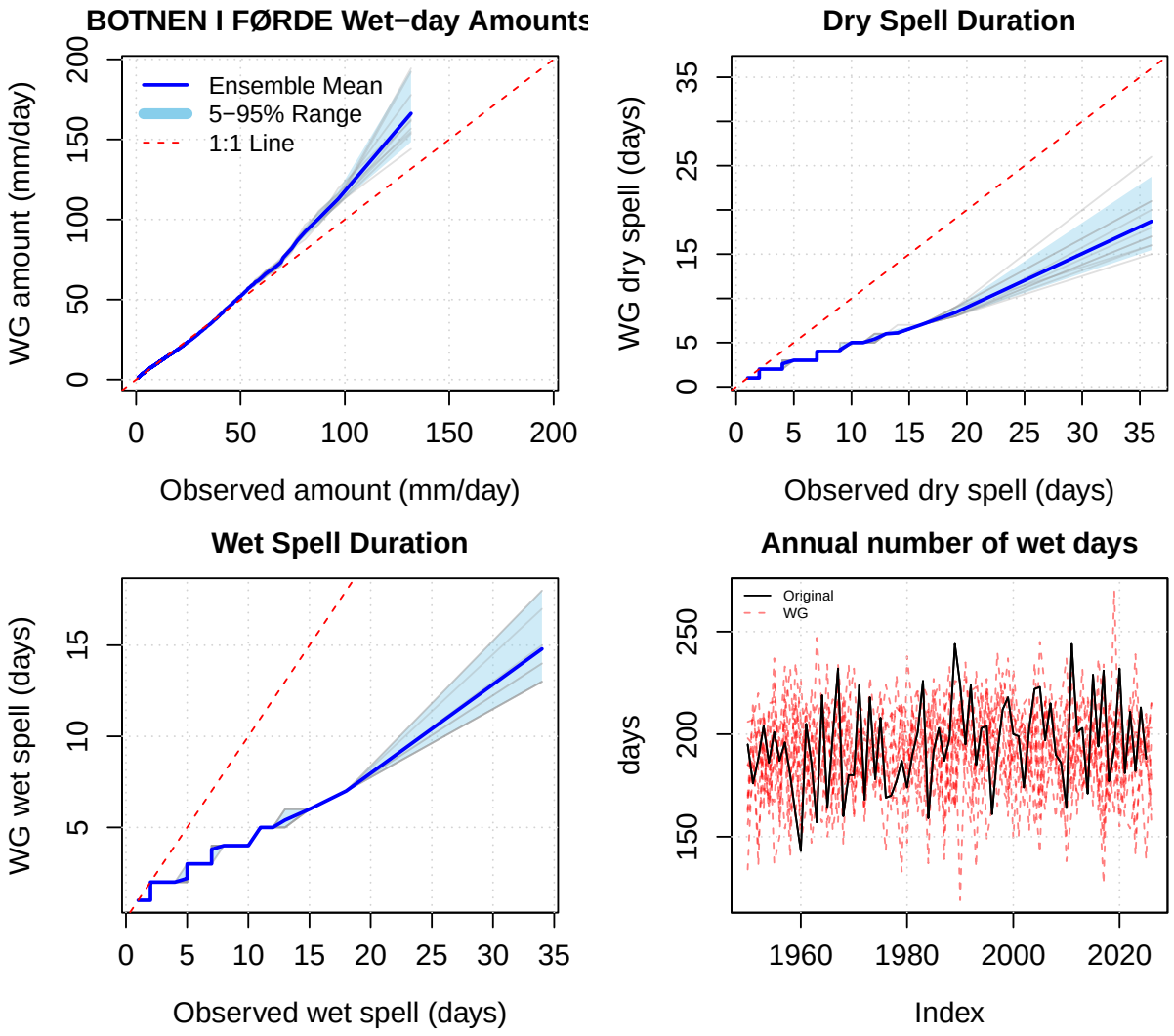


Figure 143: Tests of WG on Norwegian data

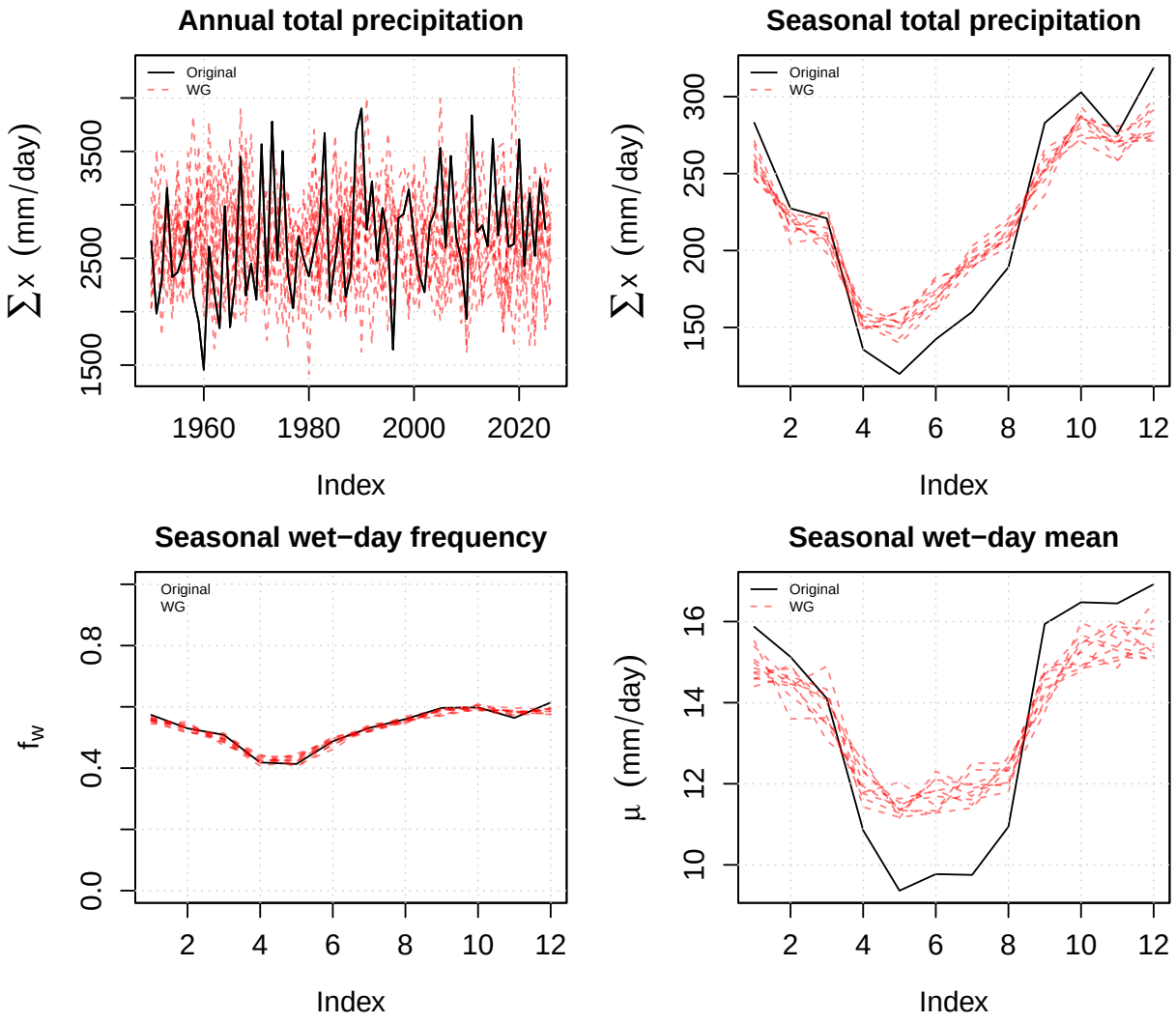


Figure 144: Tests of WG on Norwegian data

```
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.199   1.448   1.453   1.455   1.529   1.550
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01271 0.01398 0.01545 0.01564 0.01657 0.01998
## test.WG.fwmu.day.precip for ÅLFOTEN II  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

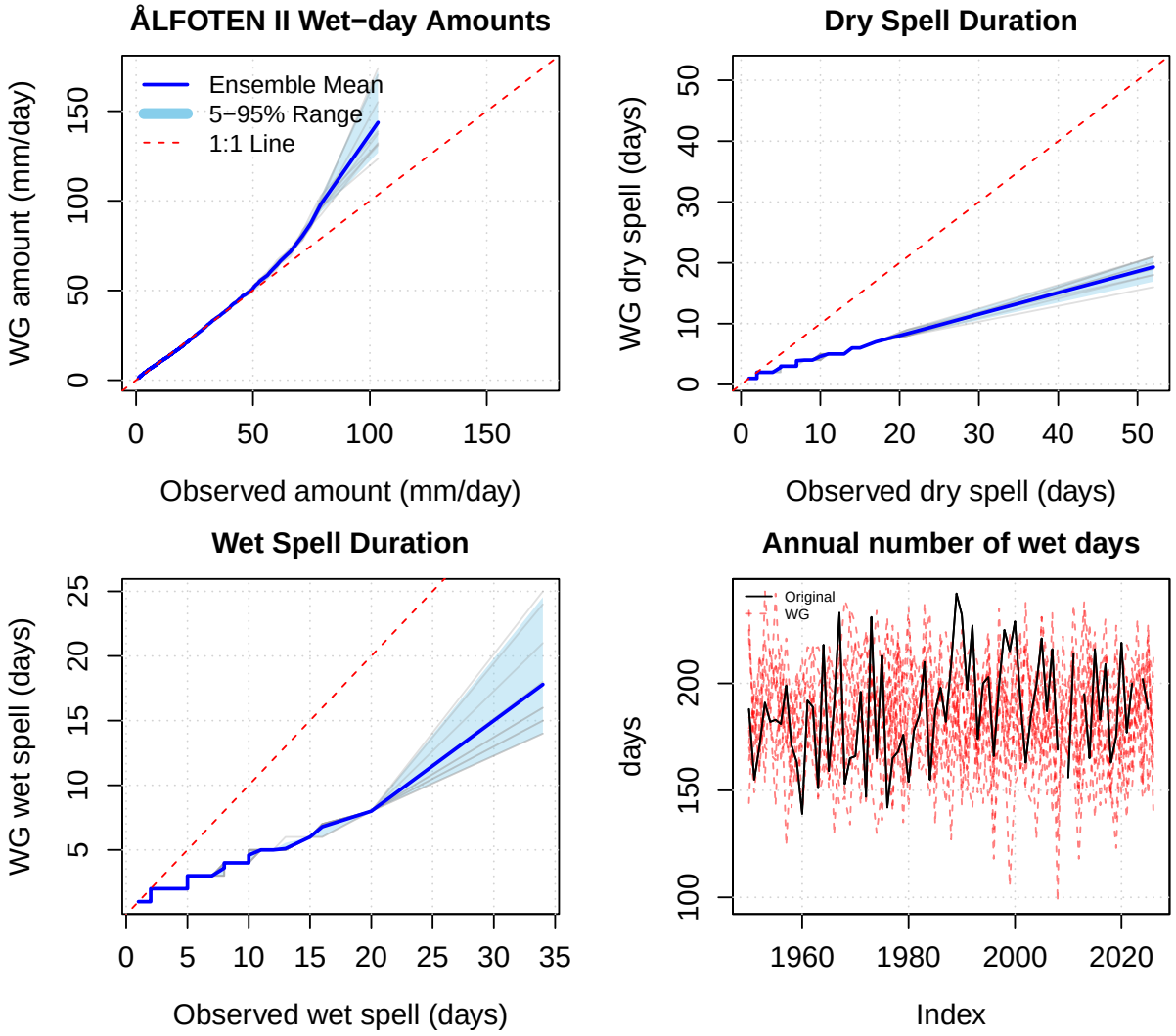


Figure 145: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.143   1.377   1.562   1.664   1.795   2.464
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.974   3.123   3.340   3.265   3.411   3.441
```

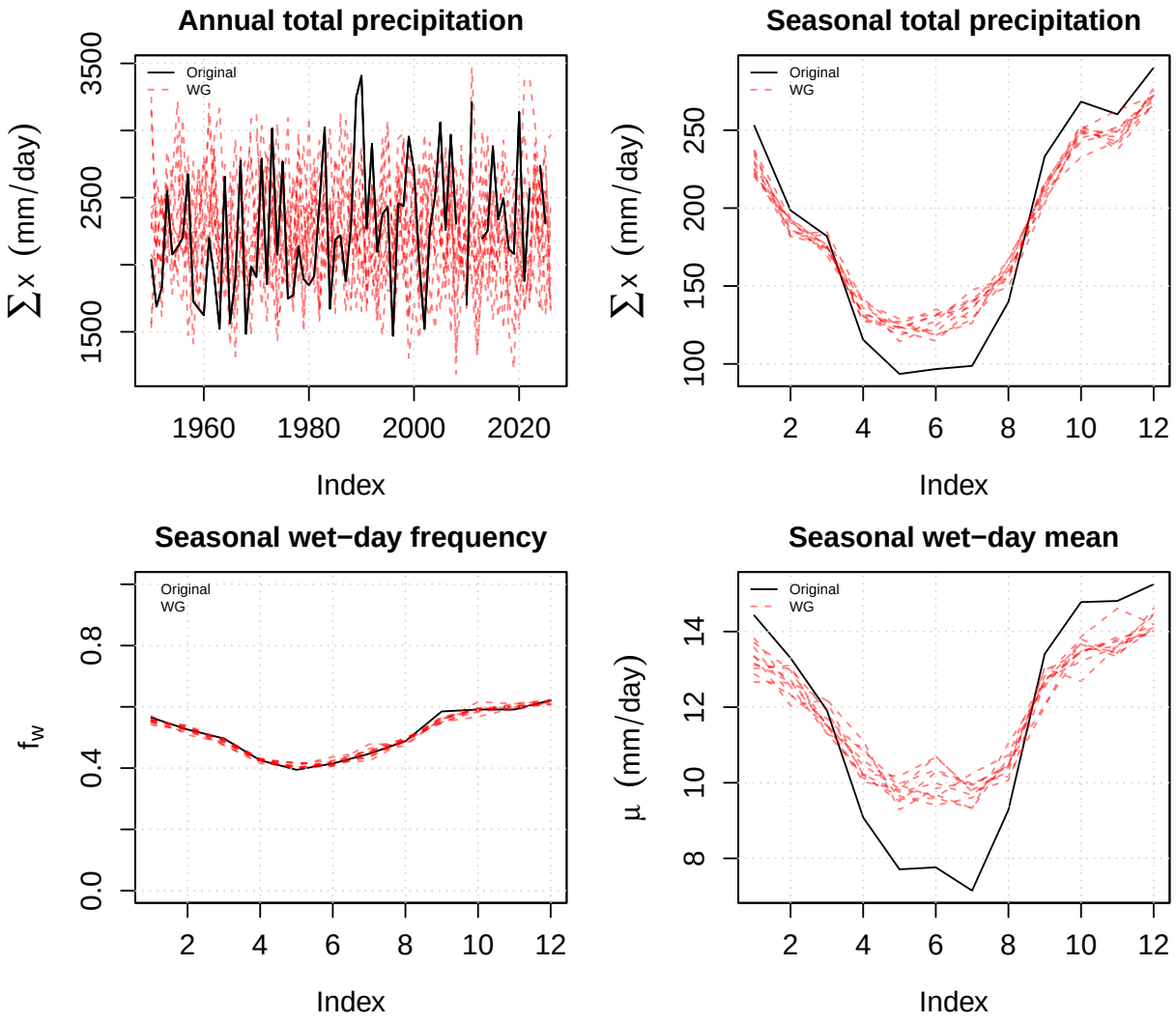


Figure 146: Tests of WG on Norwegian data

```
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.256   4.305   4.374   4.395   4.451   4.648
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   21.43   23.30   24.00   24.14   25.26   27.66
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.307   1.454   1.518   1.502   1.582   1.647
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01005 0.01097 0.01388 0.01320 0.01493 0.01579
## test.WG.fwmu.day.precip for MYKLEBUST I BREIM  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

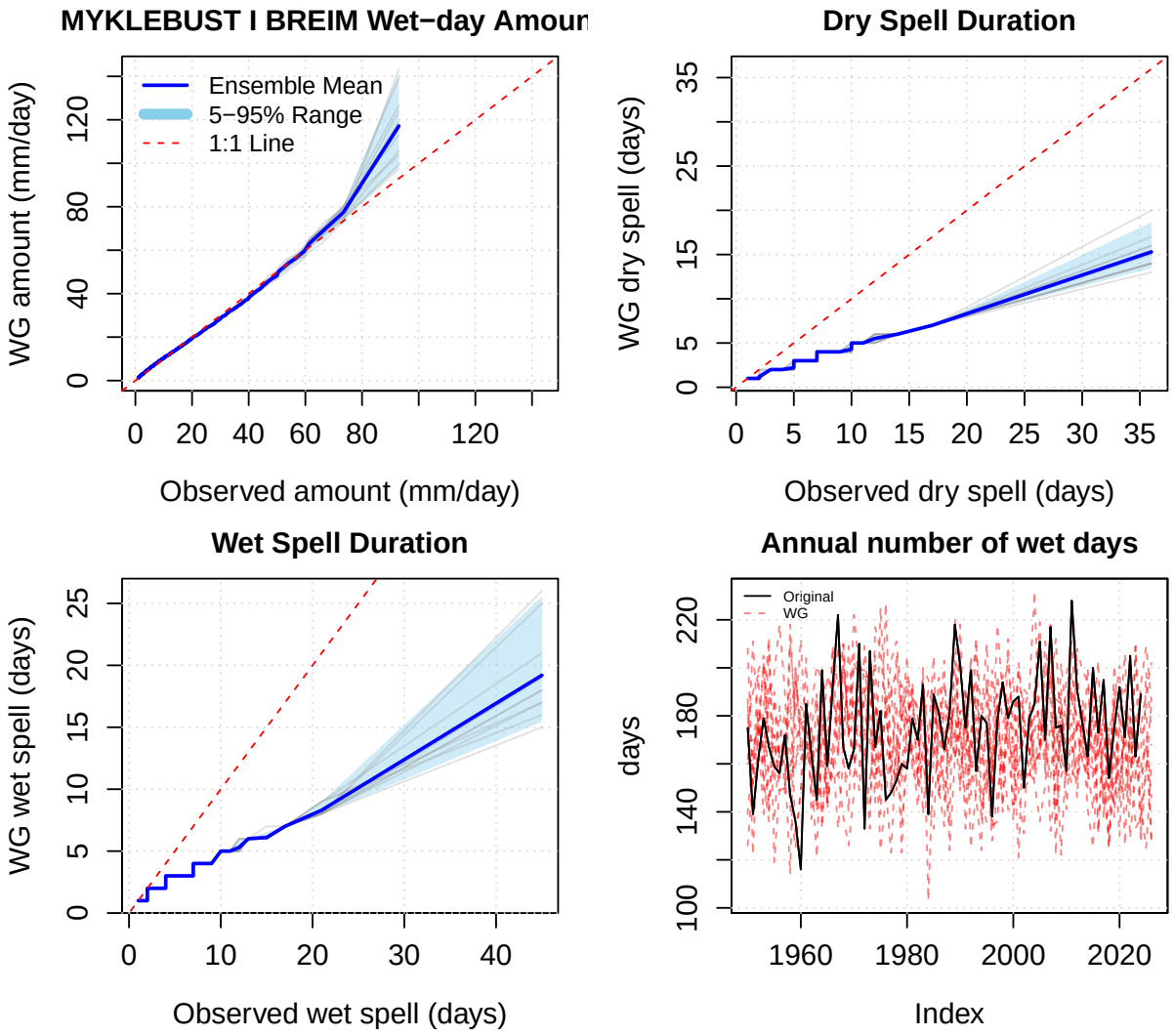


Figure 147: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
```

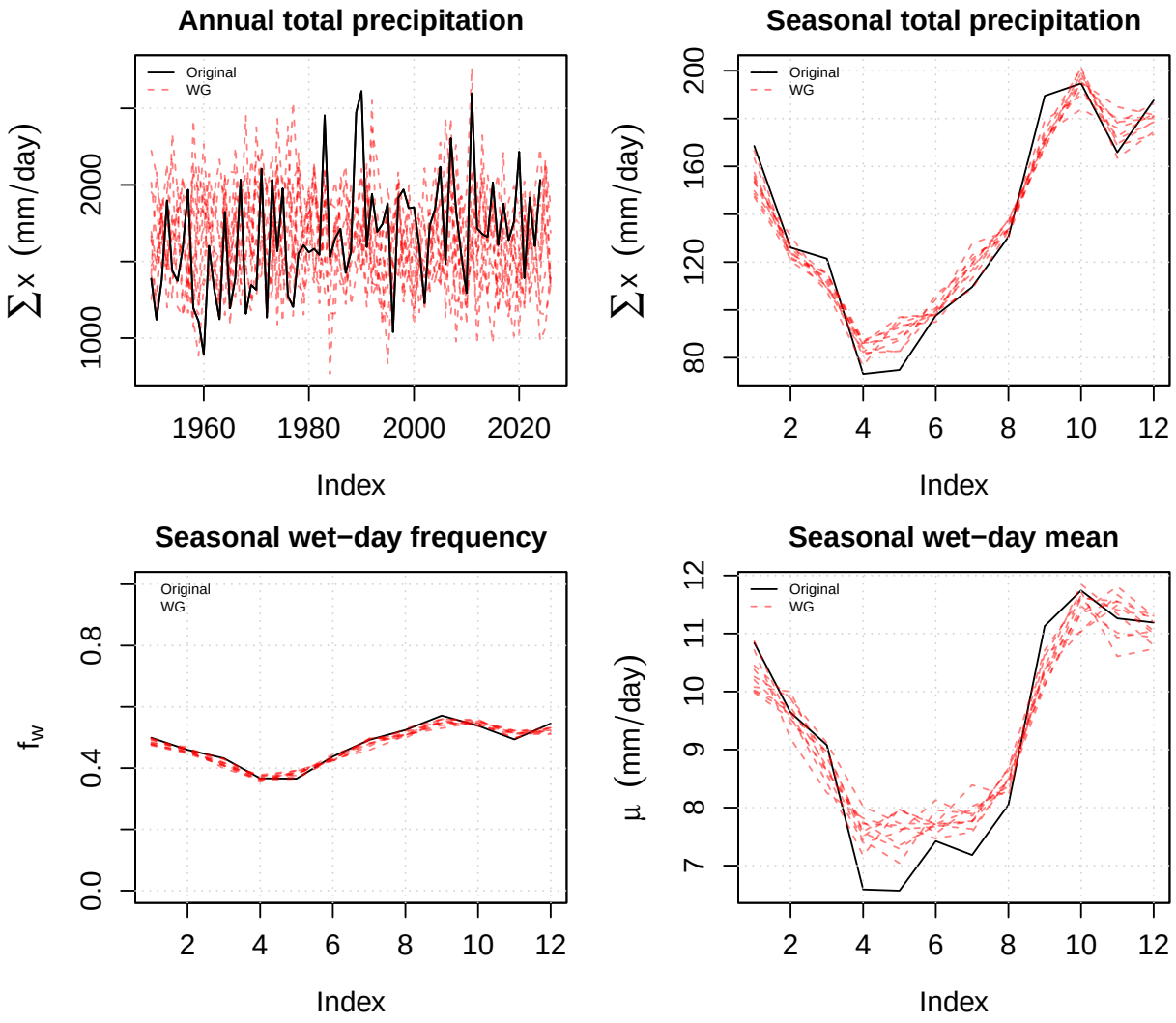


Figure 148: Tests of WG on Norwegian data

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5859  0.7567  1.0053  1.0636  1.2445  1.7504
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.347   3.670   3.877   3.785   3.934   4.091
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.850   3.063   3.175   3.133   3.228   3.302
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    9.23   10.44   10.98   10.92   11.22   12.54
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5581  0.5900  0.6253  0.6218  0.6434  0.6871
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01294 0.01387 0.01582 0.01634 0.01850 0.02224
## test.WG.fwmu.day.precip for HORNINDAL  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8756  1.1016  1.2031  1.2583  1.4267  1.6861
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.077   3.182   3.219   3.226   3.274   3.426
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.664   2.867   2.964   2.962   3.041   3.254
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   13.18   15.33   15.56   15.42   15.94   17.13
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8204  0.9341  0.9783  0.9731  1.0159  1.1033
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01175 0.01368 0.01526 0.01524 0.01672 0.01990
## test.WG.fwmu.day.precip for NORDDAL  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.4467  0.4701  0.5090  0.5146  0.5308  0.6276
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.839   5.811   5.977   5.942   6.203   6.453
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.634   1.824   1.945   1.905   2.024   2.025
```

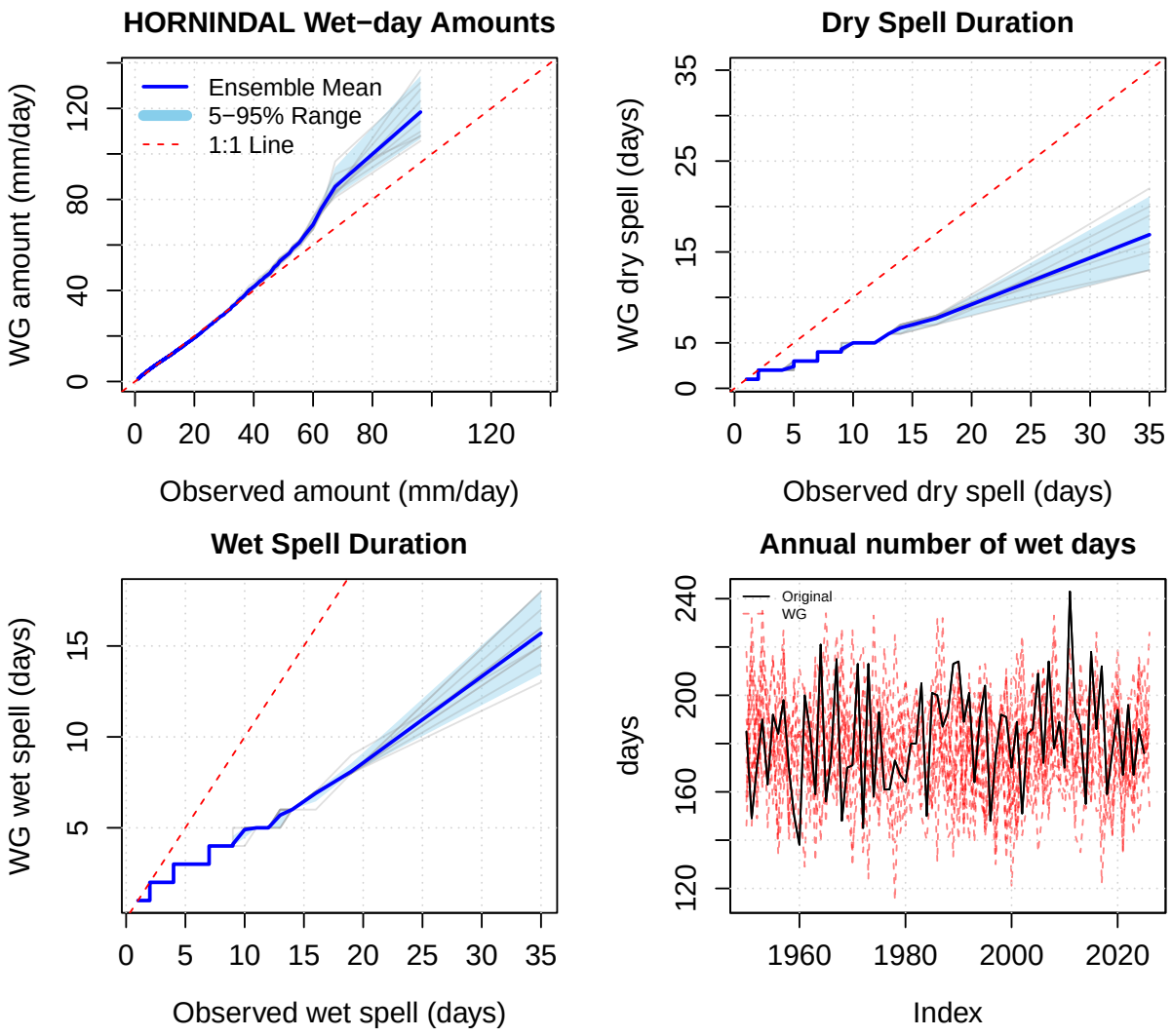


Figure 149: Tests of WG on Norwegian data

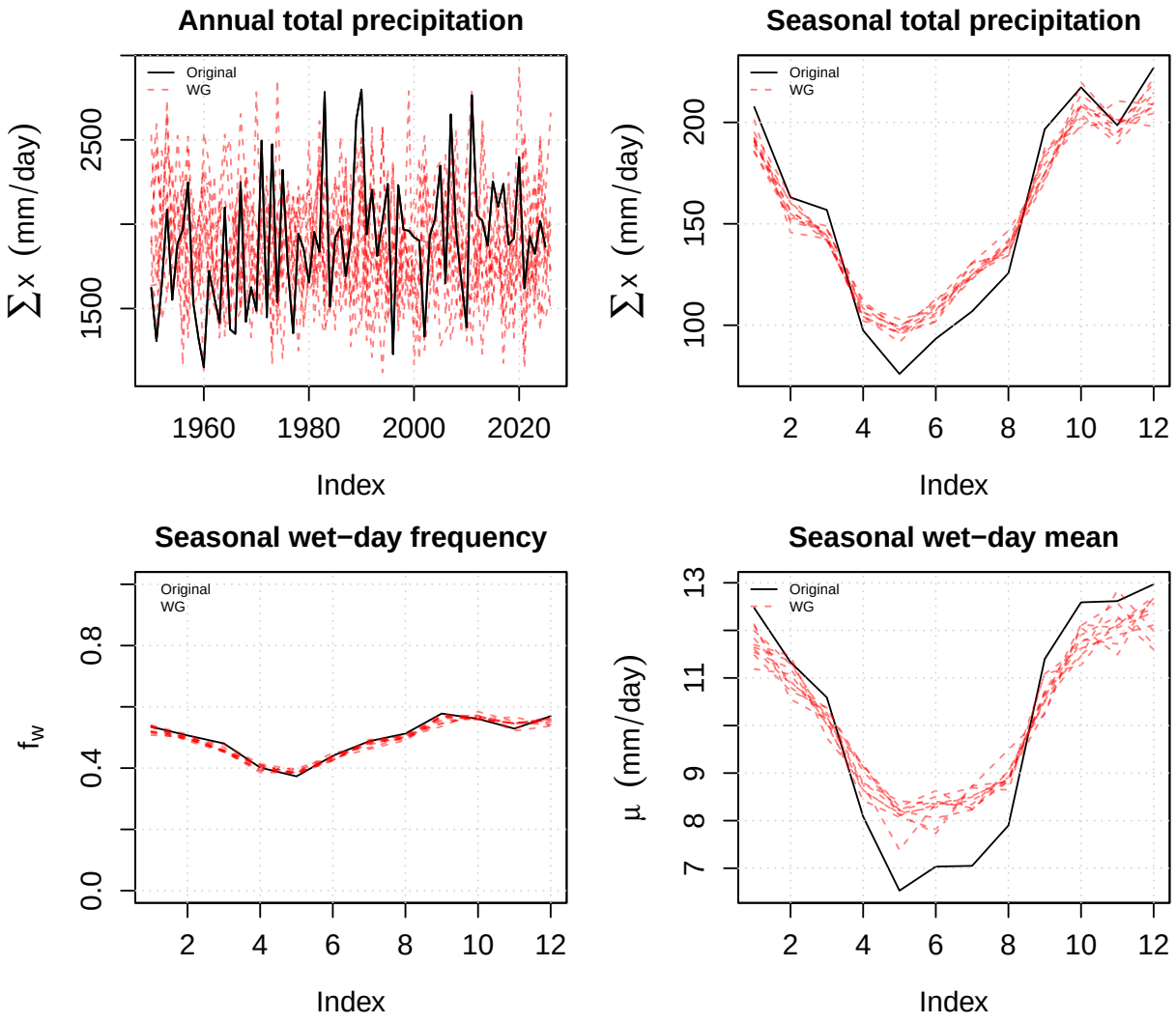


Figure 150: Tests of WG on Norwegian data

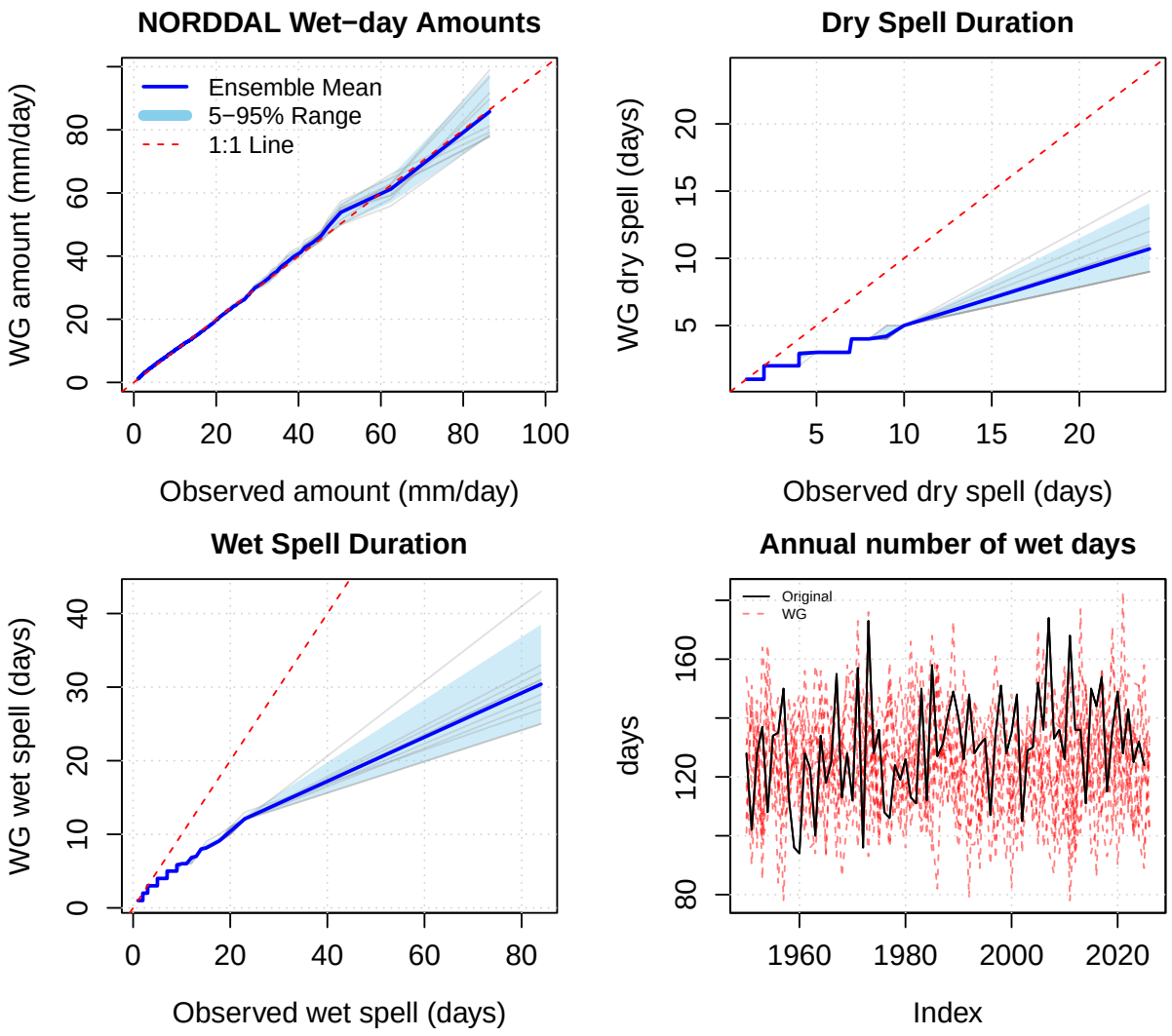


Figure 151: Tests of WG on Norwegian data

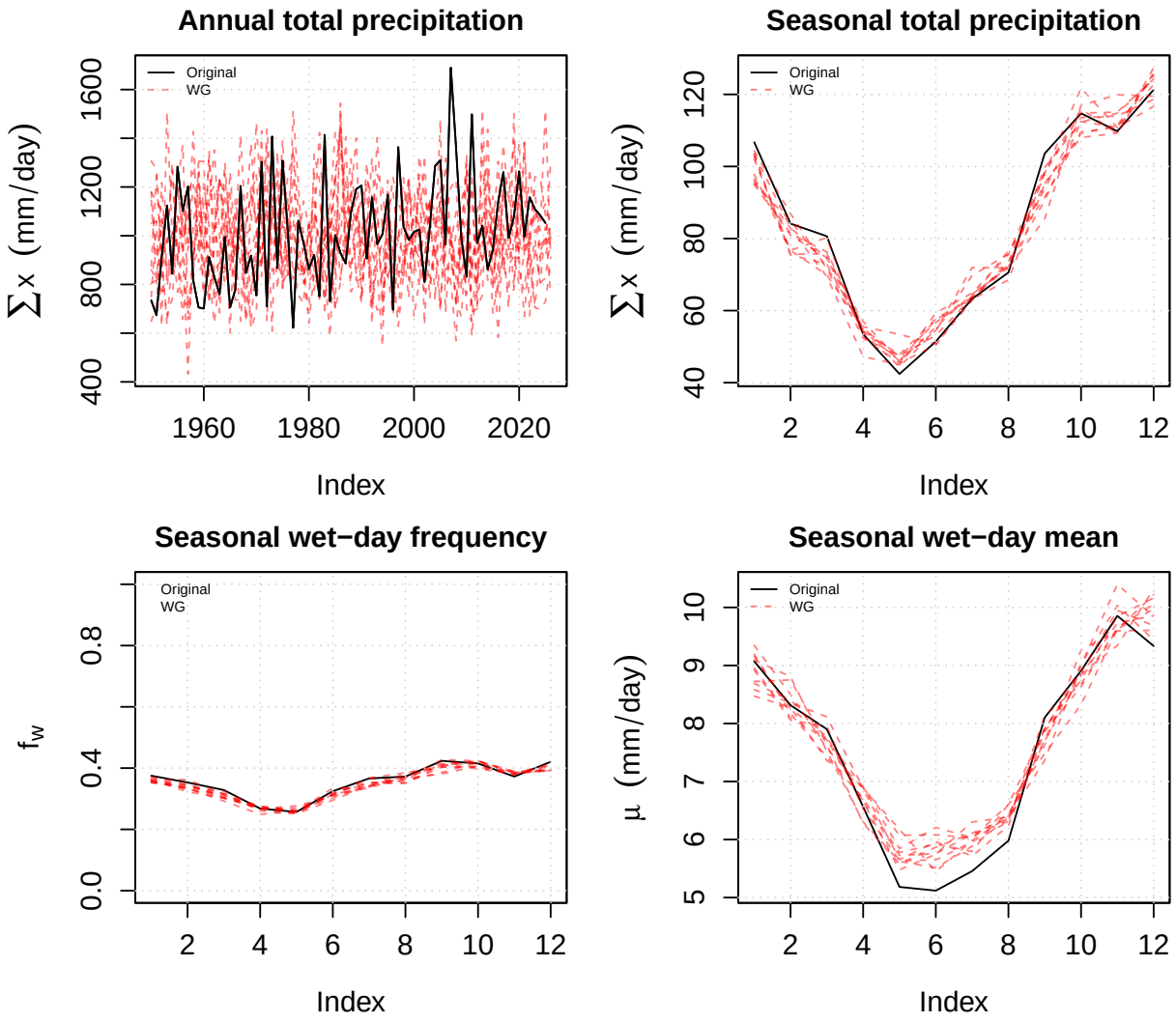


Figure 152: Tests of WG on Norwegian data

```
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.210   5.300   5.648   5.730   6.025   7.884
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3311  0.3718  0.4536  0.4452  0.4948  0.5921
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01246 0.01540 0.01629 0.01620 0.01719 0.01903
## test.WG.fwmu.day.precip for TAFJORD  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

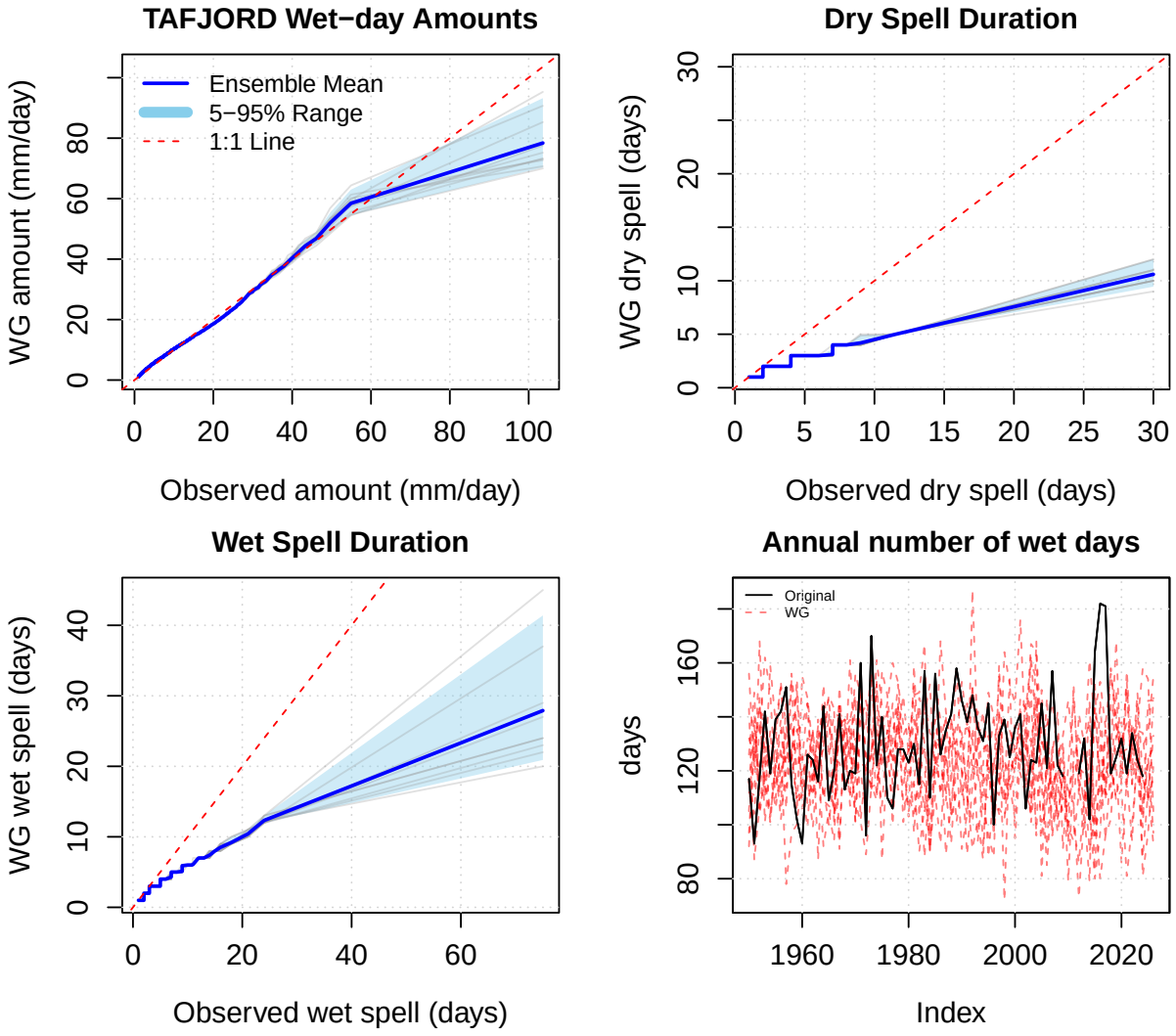


Figure 153: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7619  0.9103  1.1616  1.0694  1.1909  1.2884
```

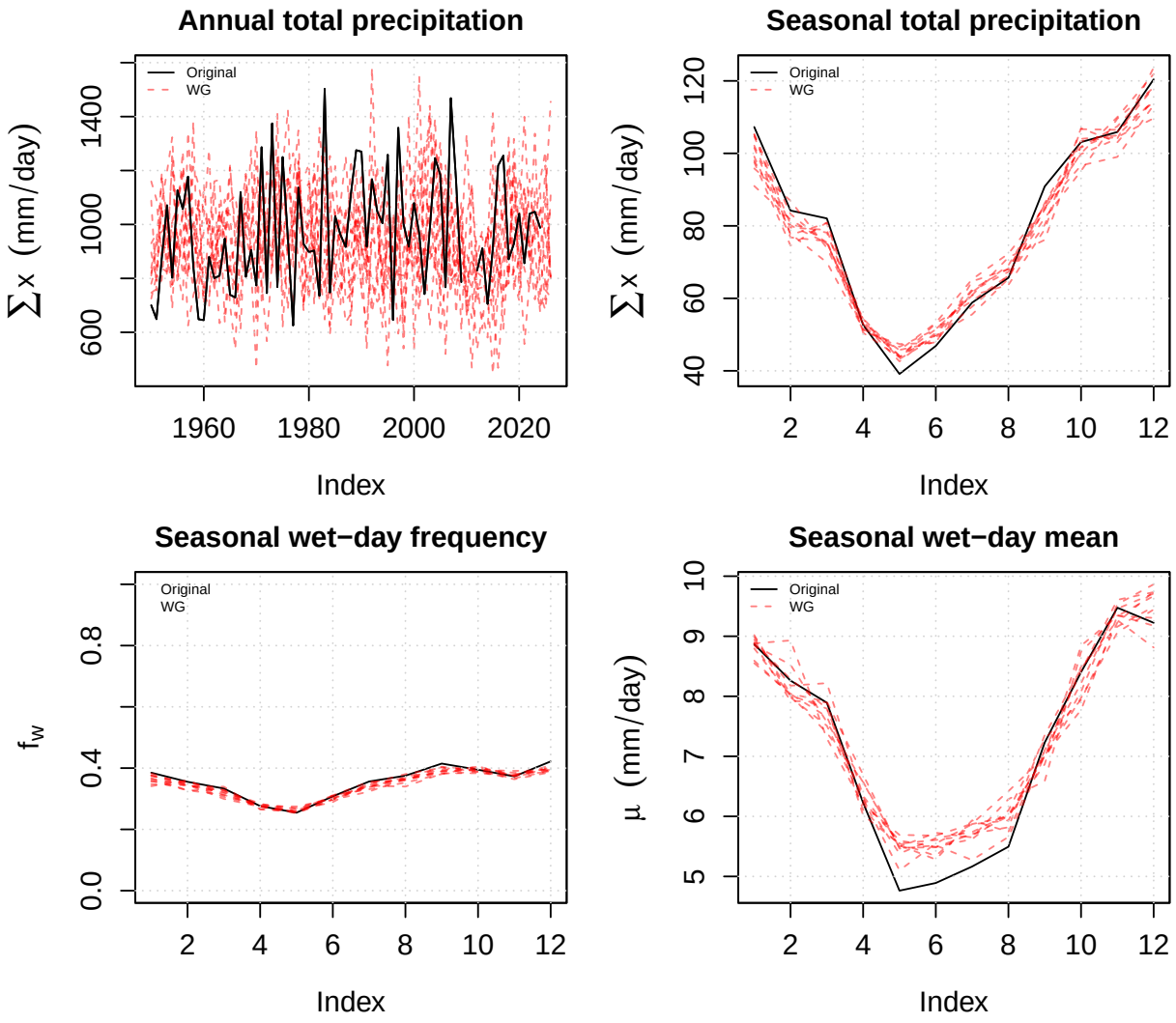


Figure 154: Tests of WG on Norwegian data

```
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.012   5.375   5.624   5.434   5.838   6.085
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.266   2.354   2.403   2.396   2.449   2.535
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   4.786   5.246   5.439   5.716   6.254   7.206
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3736  0.3876  0.4123  0.4338  0.4478  0.5851
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01291 0.01528 0.01645 0.01655 0.01796 0.01963
## test.WG.fwmu.day.precip for VÆRNES  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3991  0.4829  0.5486  0.5657  0.6101  0.8402
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.333   2.459   2.600   2.625   2.732   2.967
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.507   1.550   1.584   1.583   1.595   1.688
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   7.965   9.156   9.652   9.684  10.223  11.547
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5728  0.6806  0.7054  0.6950  0.7196  0.7638
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01744 0.01894 0.02082 0.02112 0.02308 0.02569
## test.WG.fwmu.day.precip for TUNNSJØ  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.3447  0.5708  0.6221  0.6036  0.6711  0.8358
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.047   3.308   3.536   3.448   3.603   3.658
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.480   1.612   1.815   1.750   1.860   1.944
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

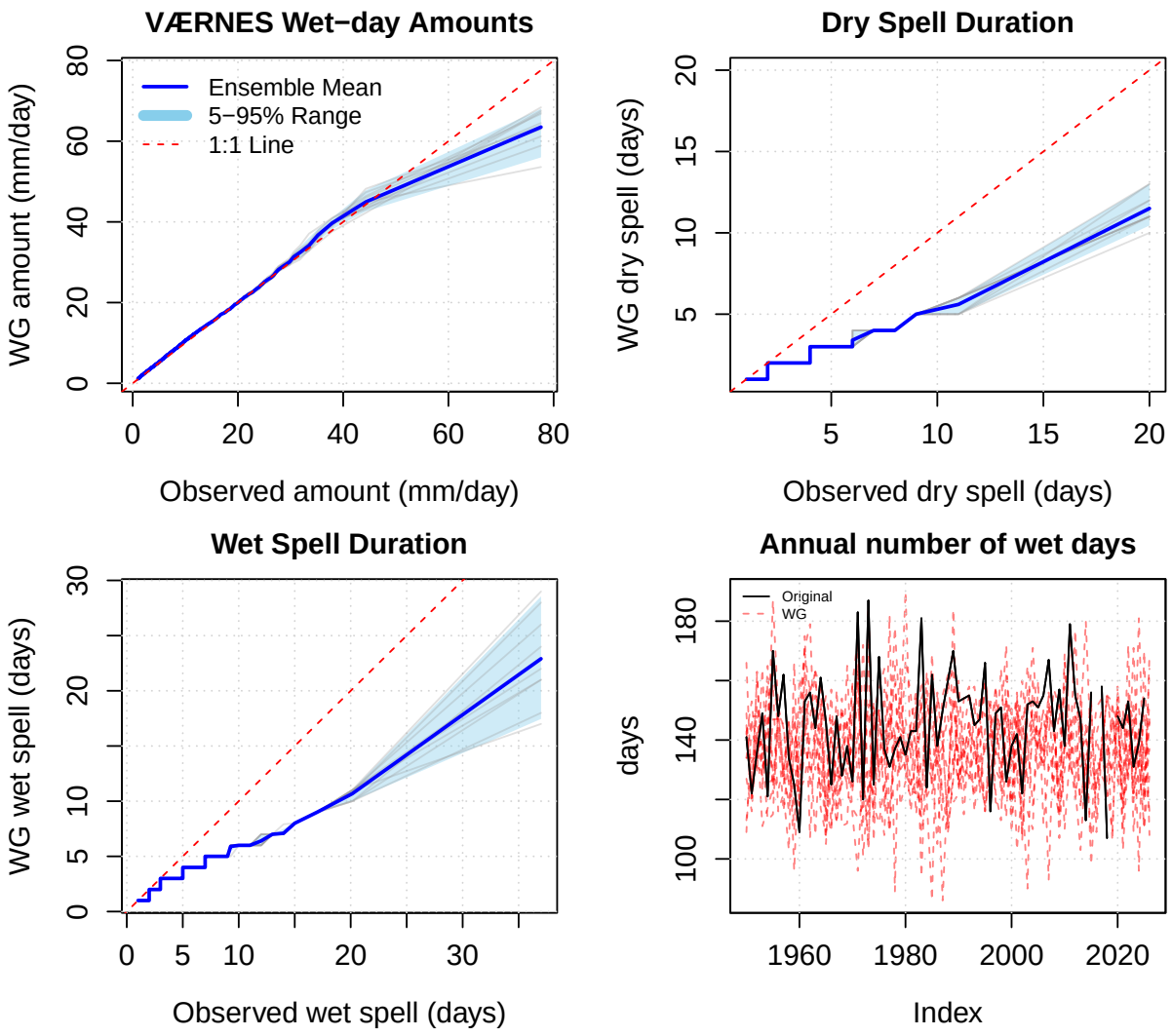


Figure 155: Tests of WG on Norwegian data

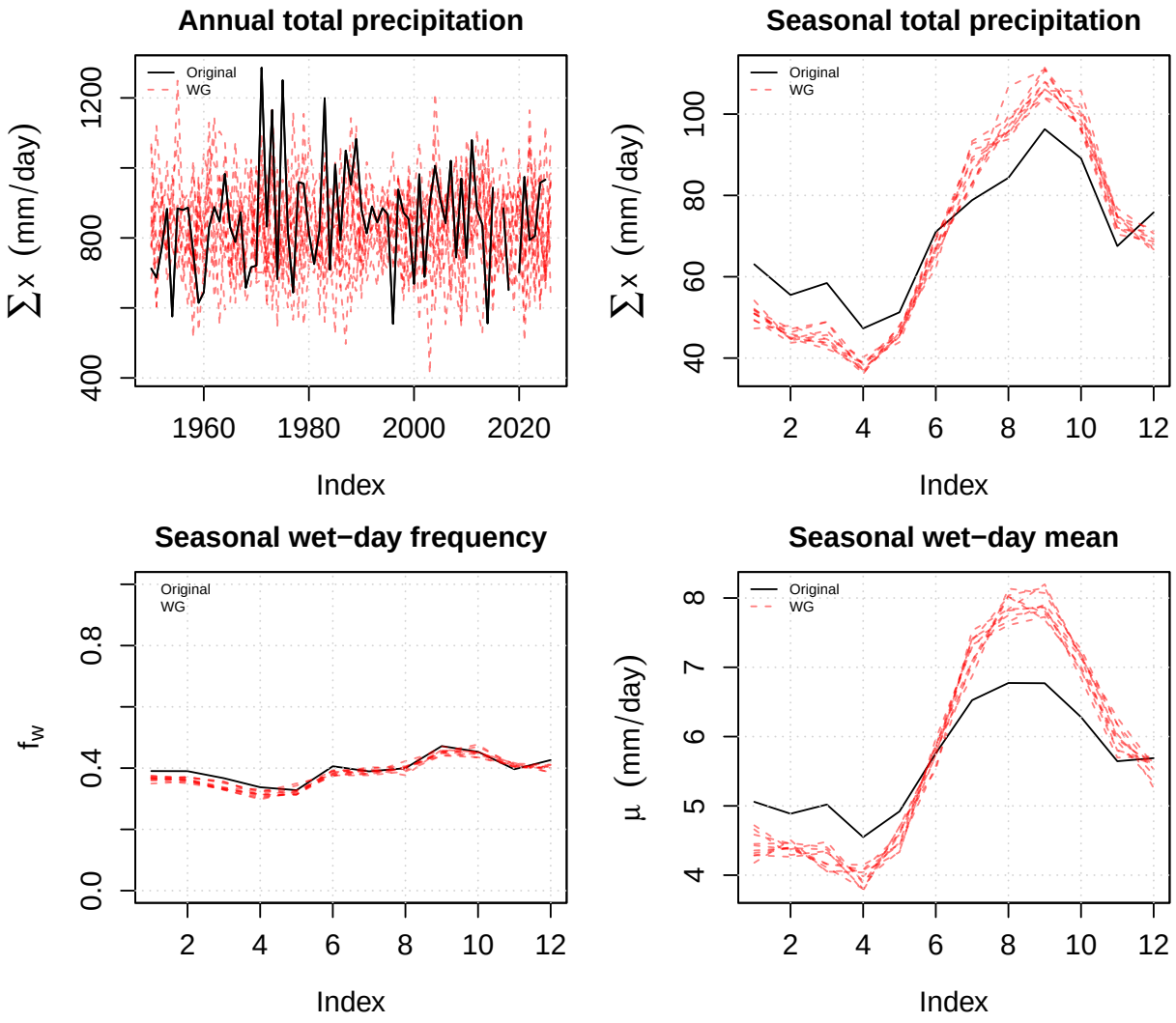


Figure 156: Tests of WG on Norwegian data

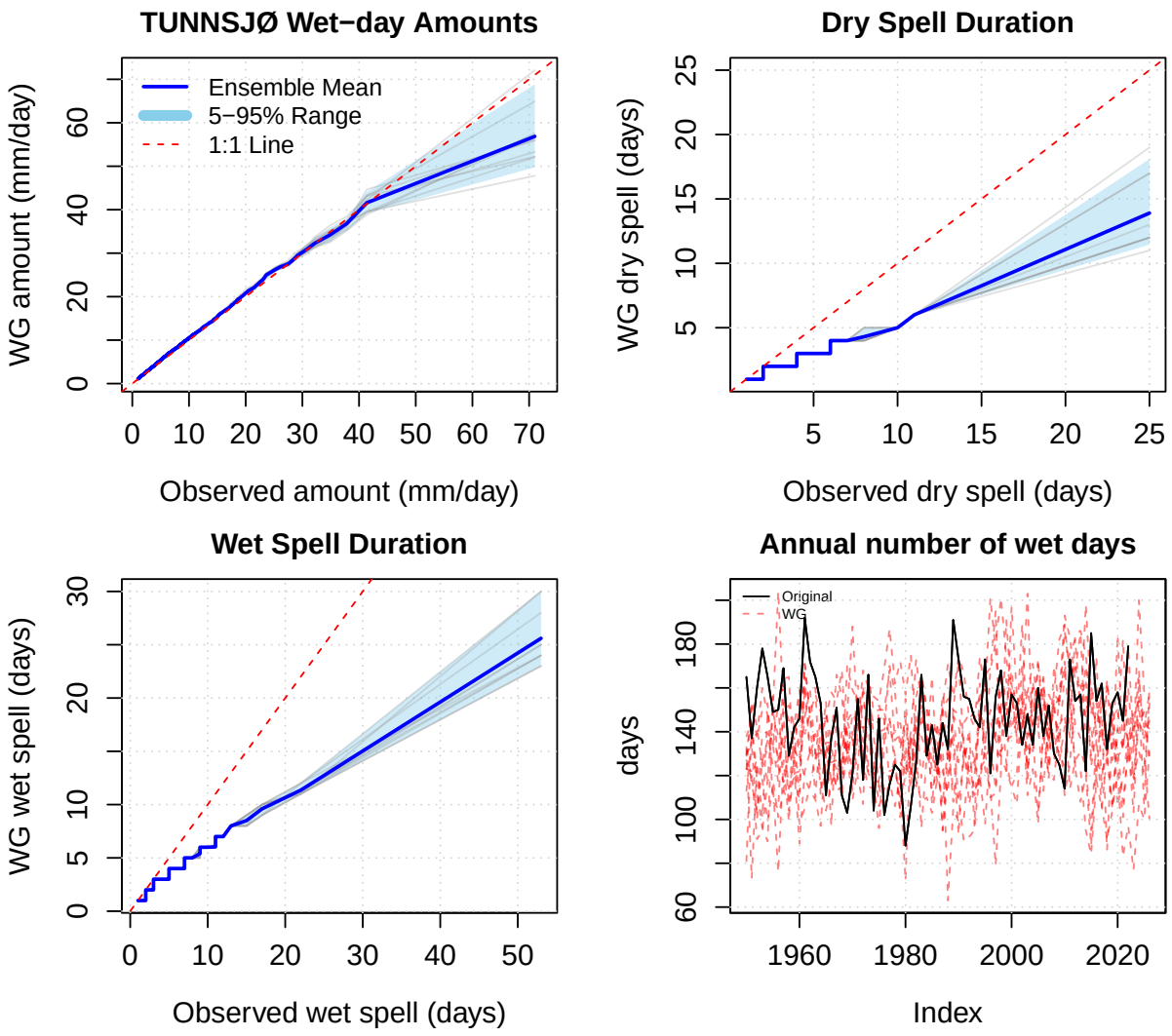


Figure 157: Tests of WG on Norwegian data

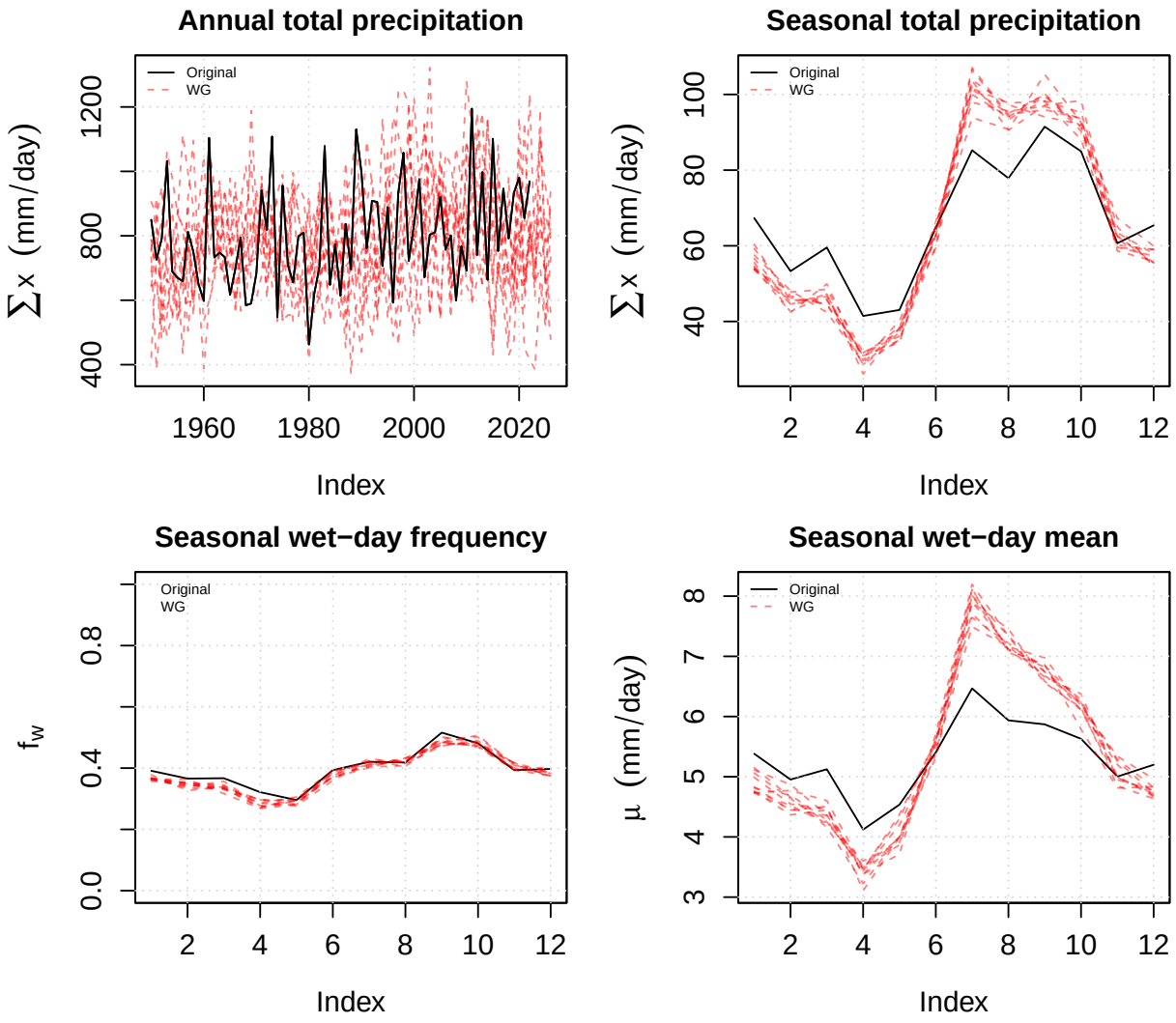


Figure 158: Tests of WG on Norwegian data

```
##   9.421   9.859  10.240  10.238  10.451  11.450
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6992  0.7171  0.7733  0.7598  0.7974  0.8165
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01675 0.02130 0.02270 0.02251 0.02475 0.02552
## test.WG.fwmu.day.precip for SUSENDAL  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

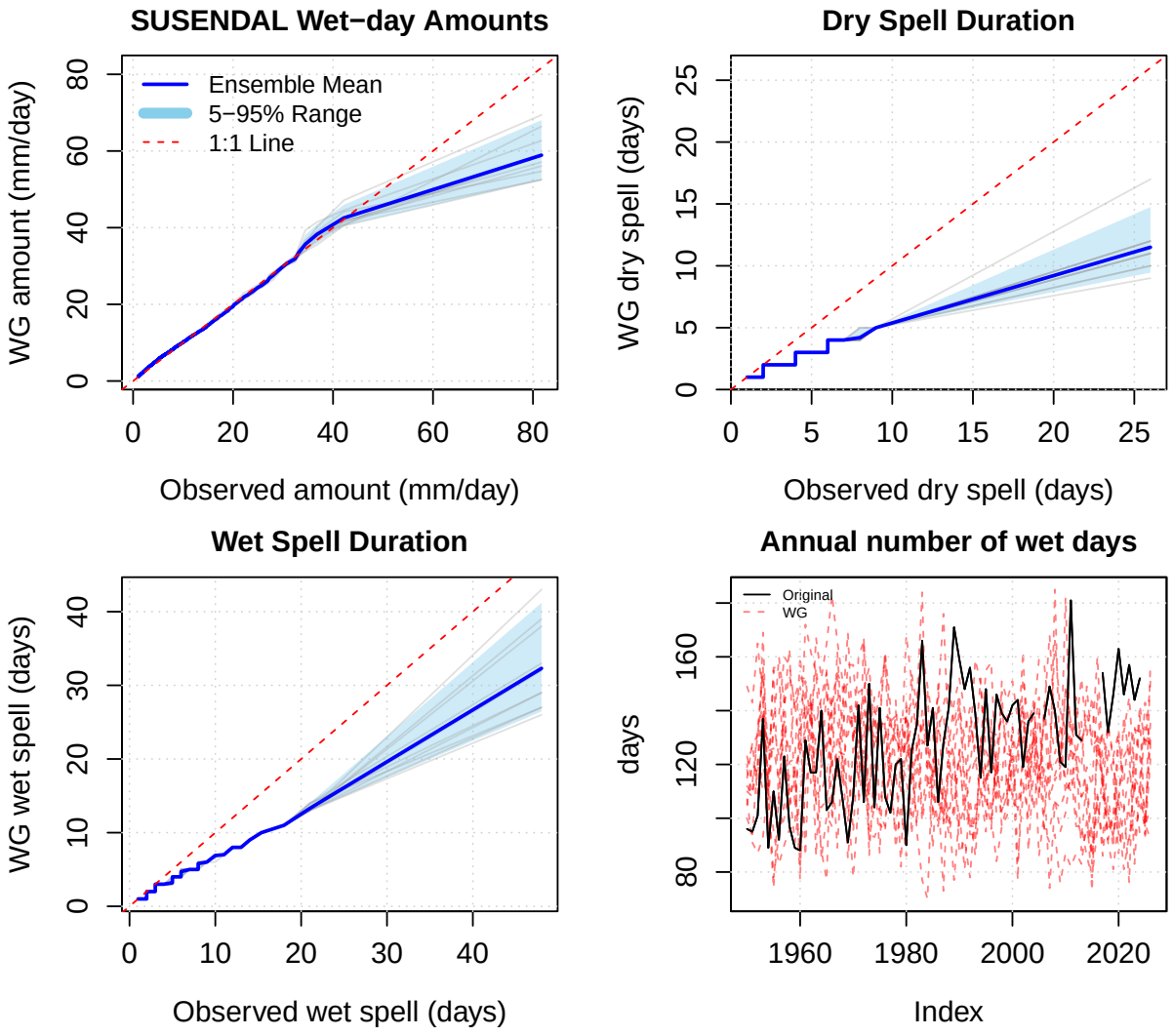


Figure 159: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.6089  0.7848  0.8733  0.8533  0.9672  1.0385
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

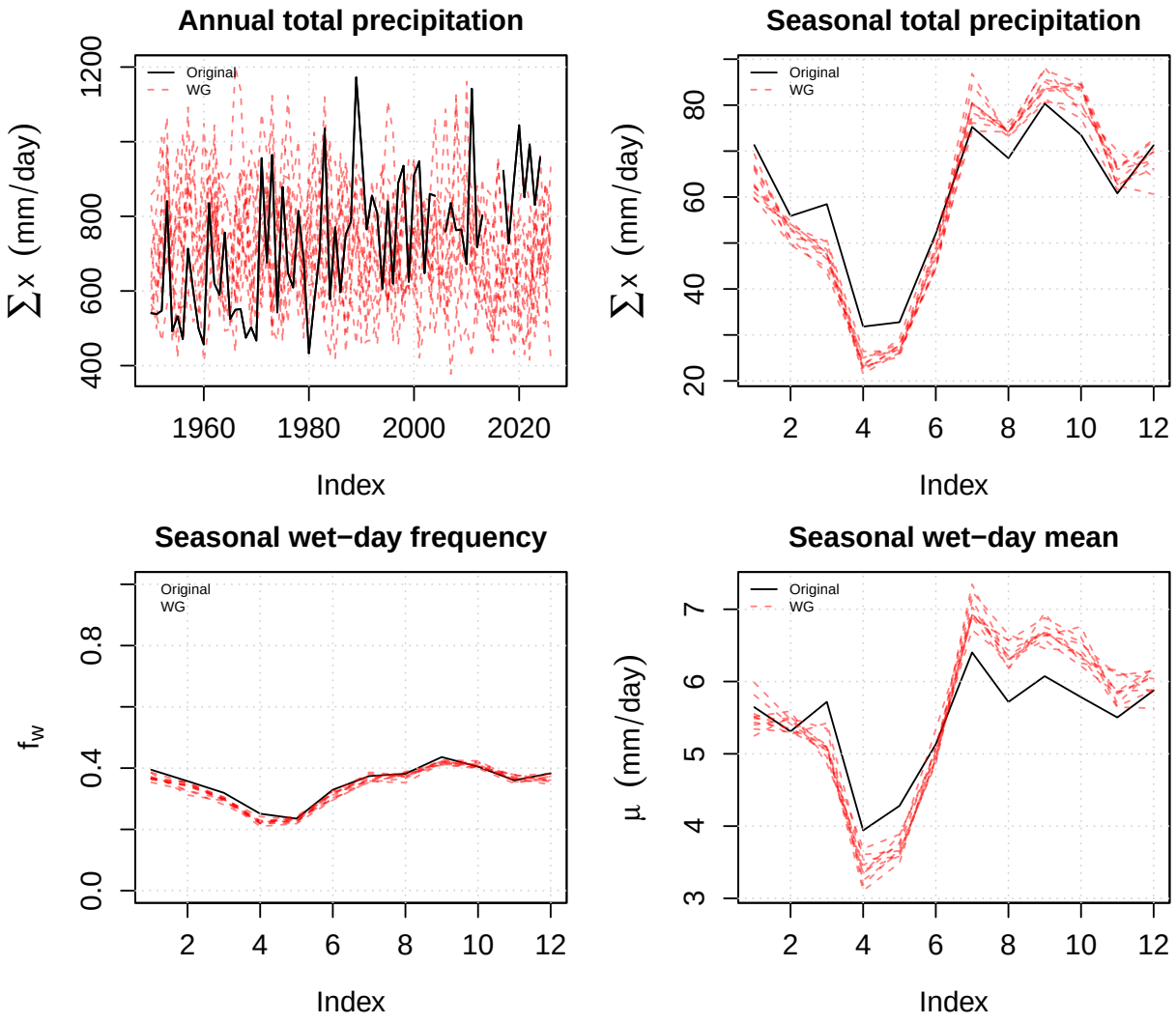


Figure 160: Tests of WG on Norwegian data

```
##   1.992   2.207   2.561   2.488   2.759   2.893
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.367   1.783   1.844   1.816   1.914   2.023
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   5.858   6.381   6.632   6.608   6.972   7.233
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.4385  0.4970  0.5164  0.5101  0.5347  0.5444
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01637 0.01766 0.01896 0.01902 0.02060 0.02202
## test.WG.fwmu.day.precip for LURØY  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

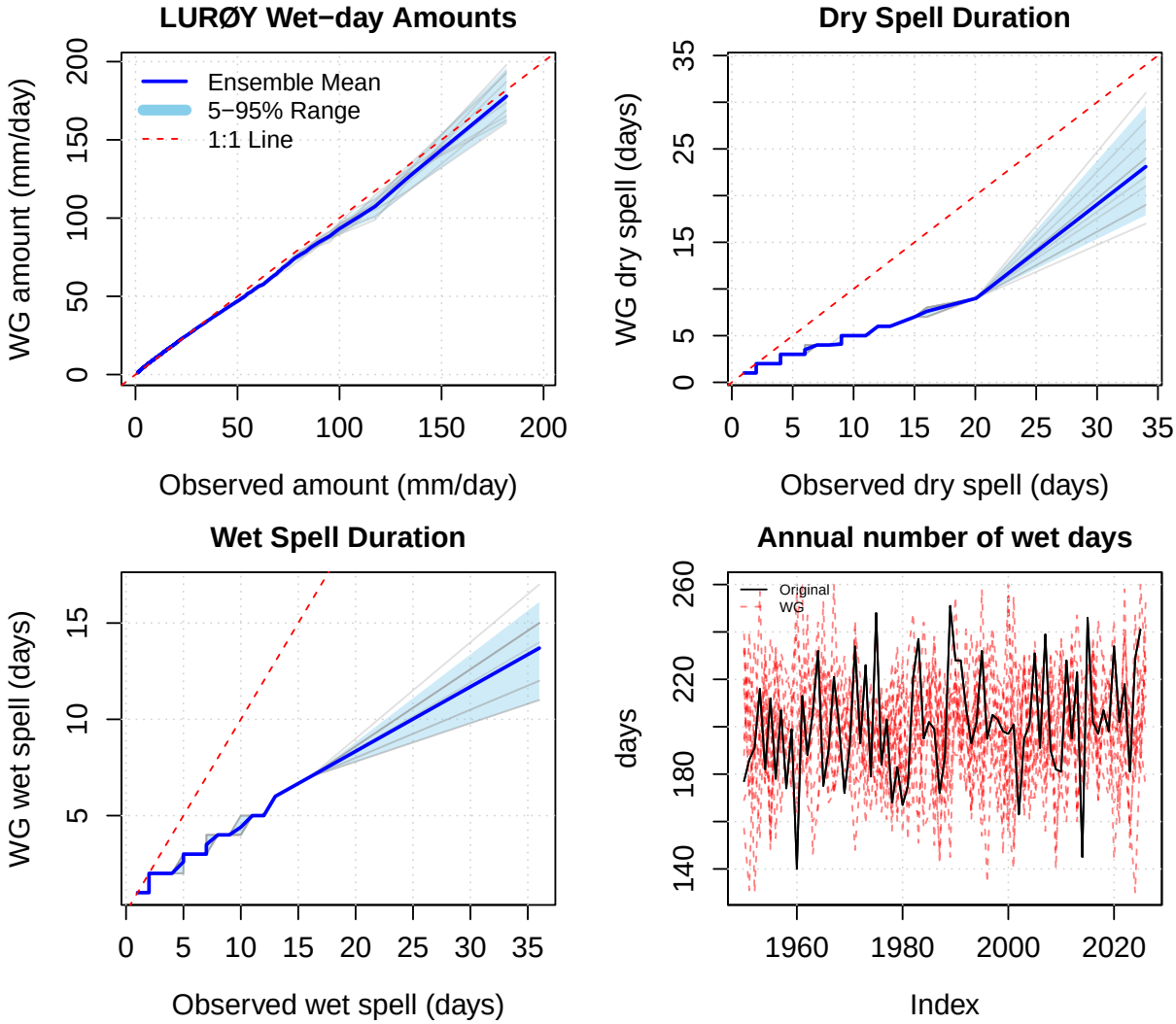


Figure 161: Tests of WG on Norwegian data

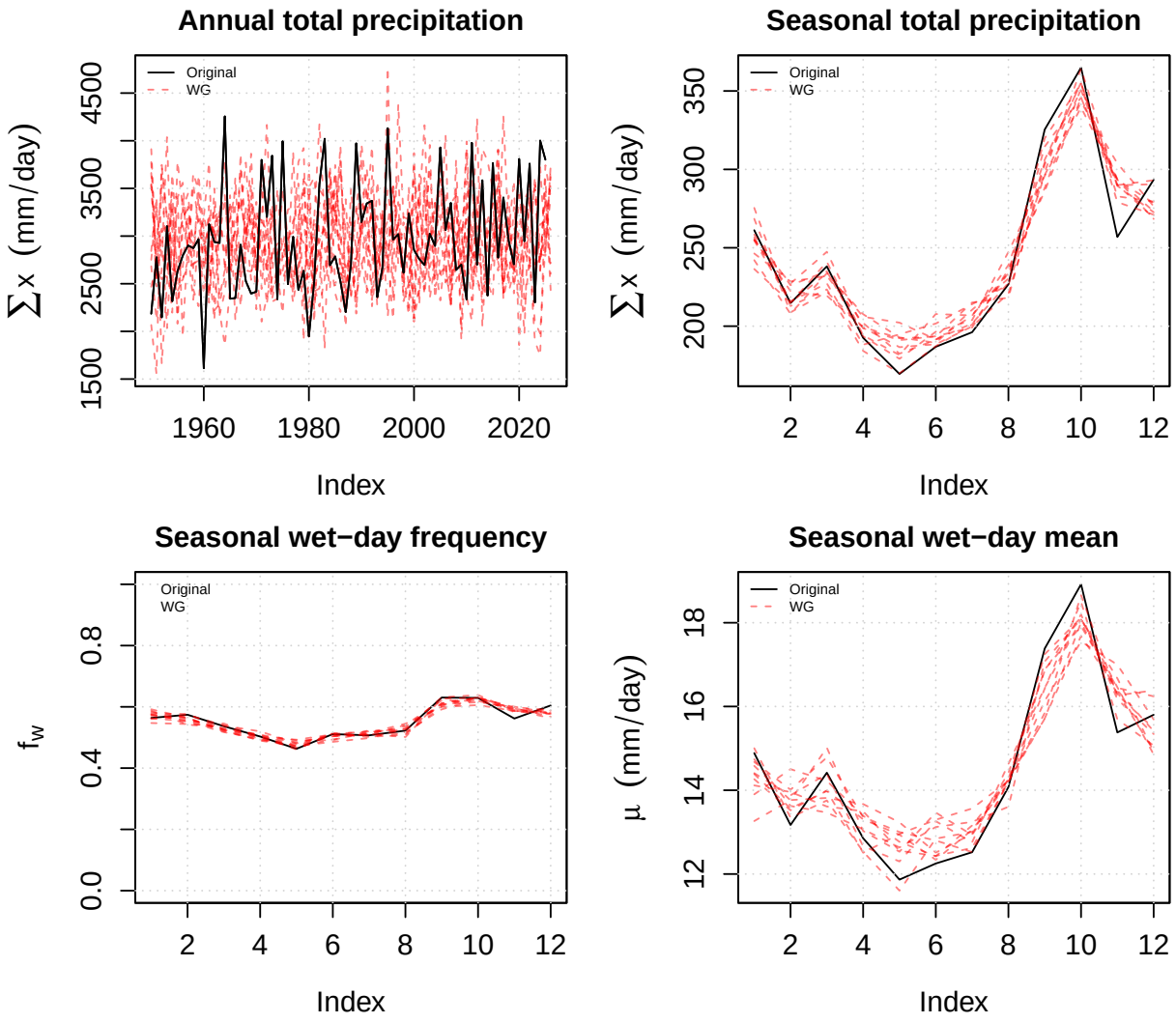


Figure 162: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.063   1.203   1.312   1.318   1.450   1.570
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.899   3.023   3.069   3.120   3.252   3.316
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.587   2.731   2.844   2.846   2.971   3.118
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   12.10   15.45   17.08   17.18   19.28   20.80
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5670  0.7126  0.7281  0.7409  0.8234  0.9203
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01449 0.01660 0.01724 0.01753 0.01812 0.02115
## test.WG.fwmu.day.precip for TROMSØ  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.9702  1.0143  1.0404  1.0599  1.1048  1.1938
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.404   2.836   2.879   2.848   2.915   3.141
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.060   2.092   2.230   2.195   2.247   2.357
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   8.394   8.622   8.825   9.070   9.393  10.221
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5045  0.5532  0.5932  0.5791  0.6073  0.6351
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.01544 0.01879 0.01913 0.01908 0.01997 0.02130
## test.WG.fwmu.day.precip for VARDØ RADIO  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.4369  0.4770  0.4960  0.5000  0.5127  0.5782
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.252   1.502   1.790   1.724   1.919   2.209
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

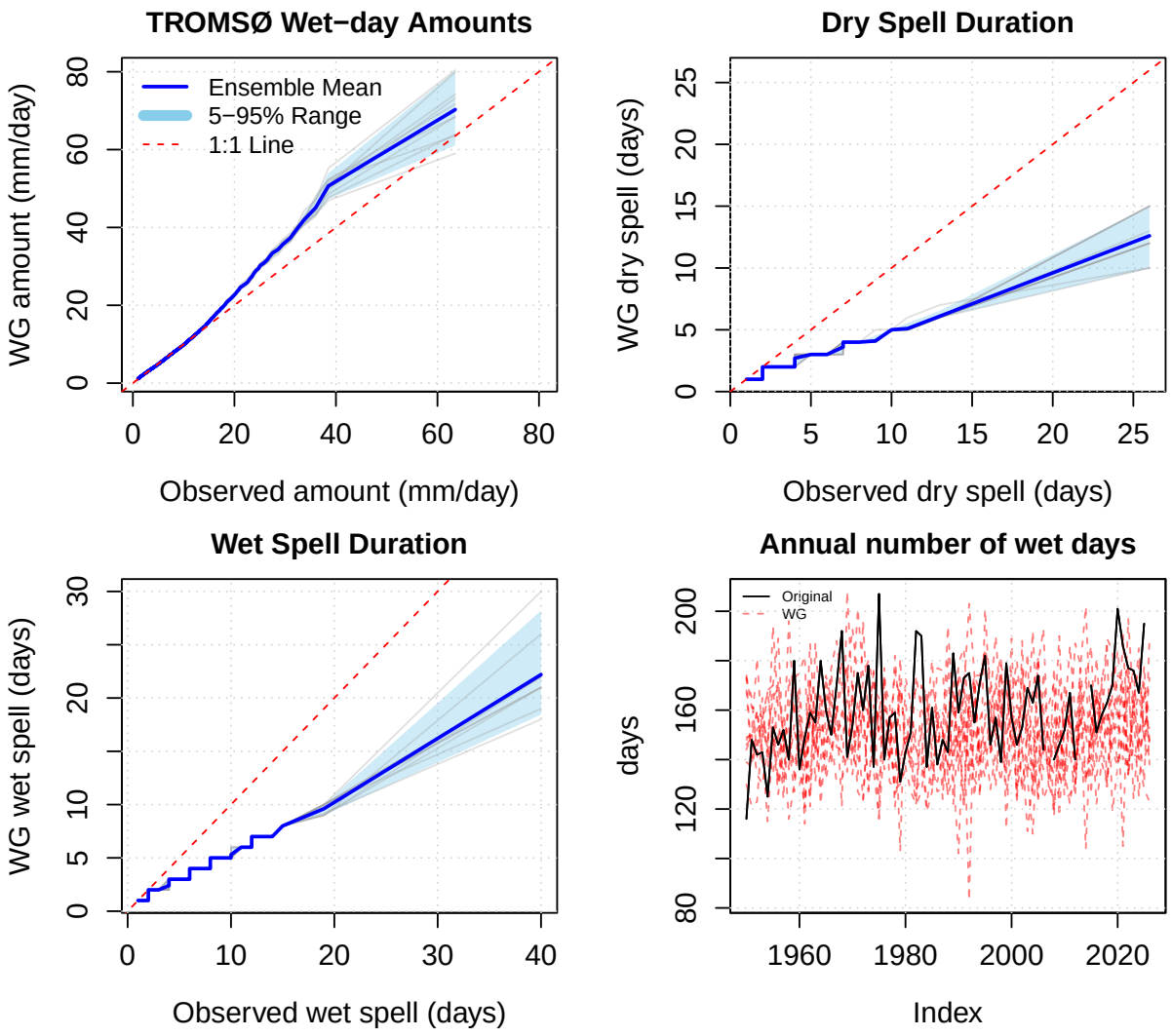


Figure 163: Tests of WG on Norwegian data

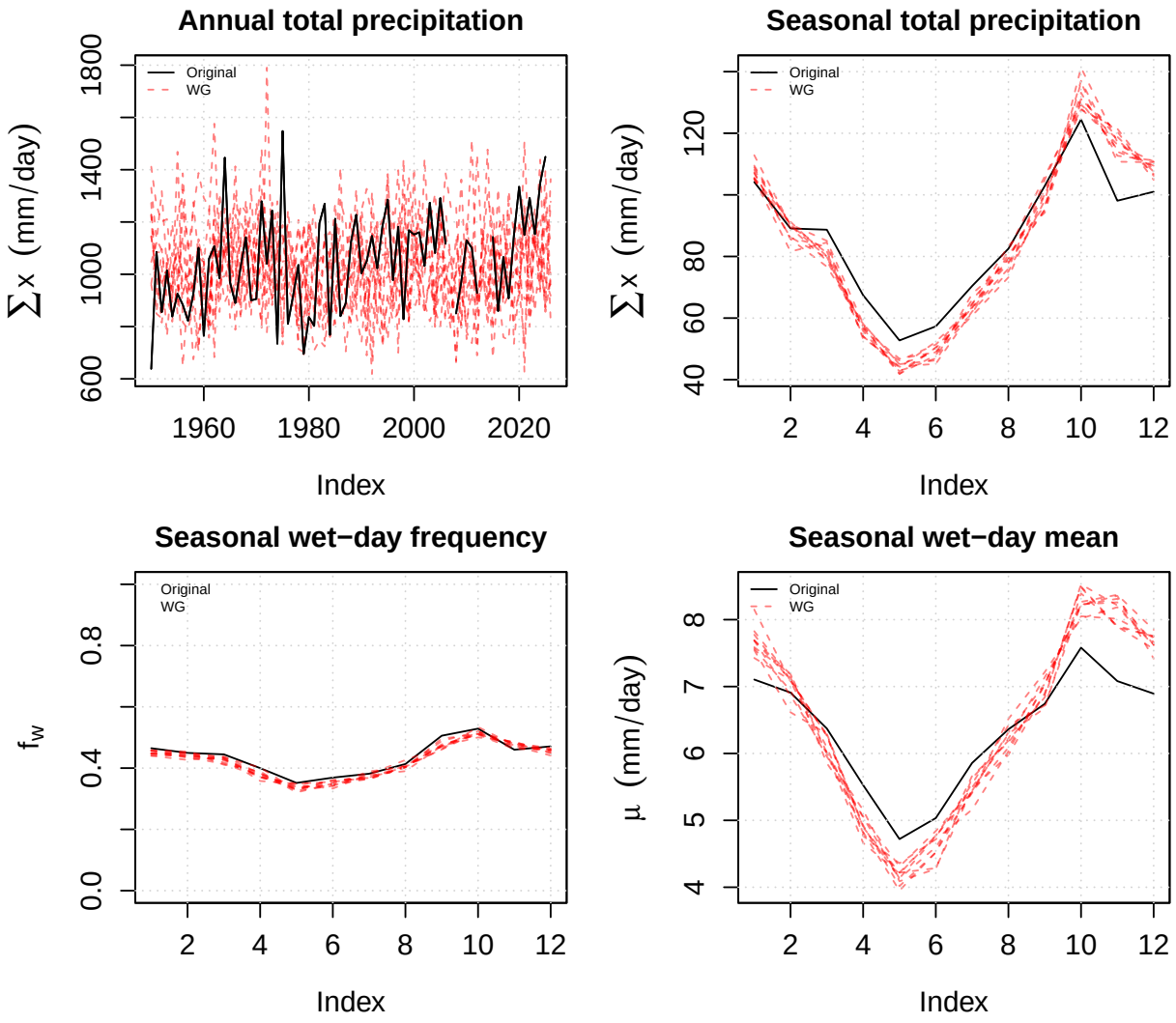


Figure 164: Tests of WG on Norwegian data

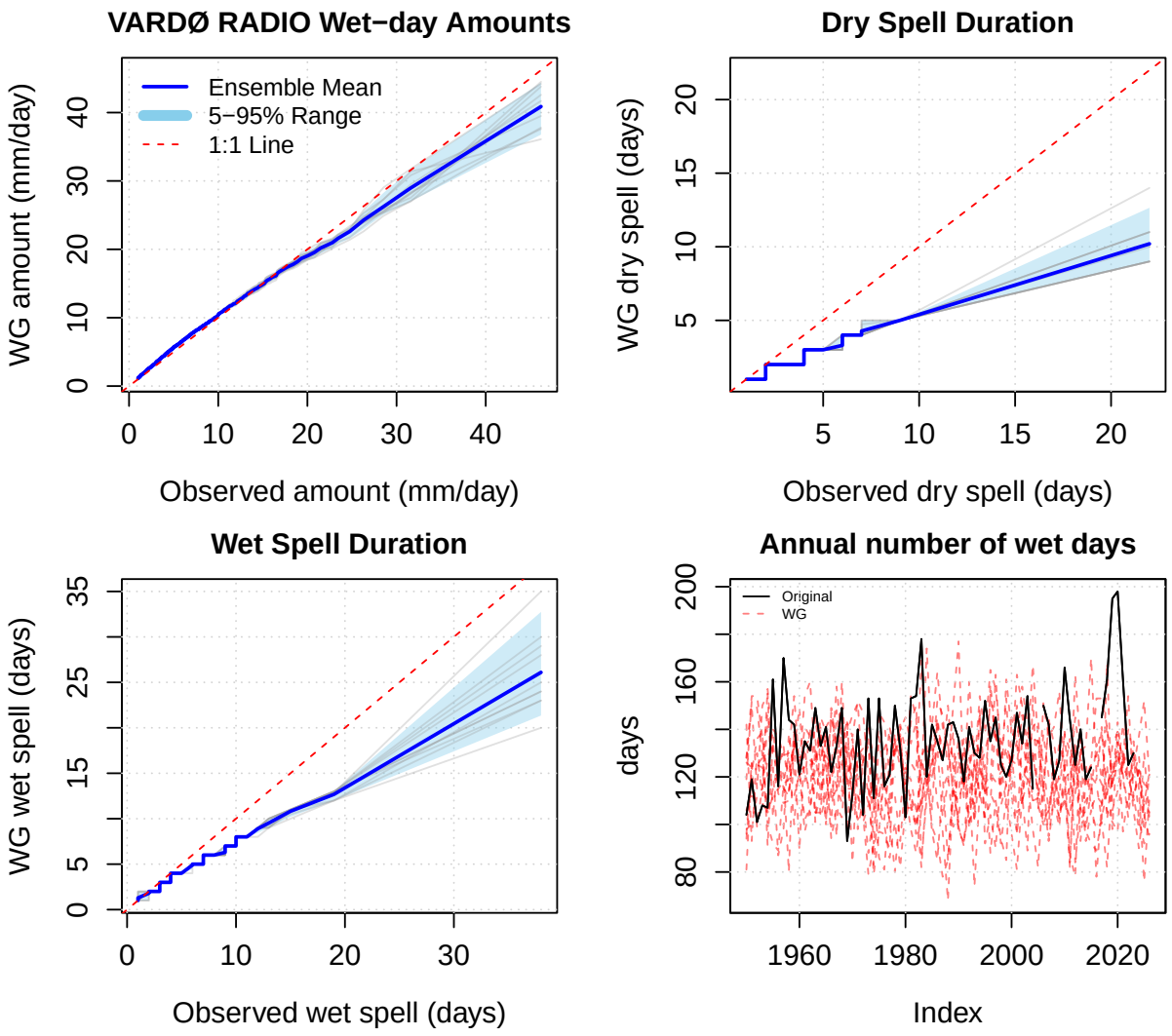


Figure 165: Tests of WG on Norwegian data

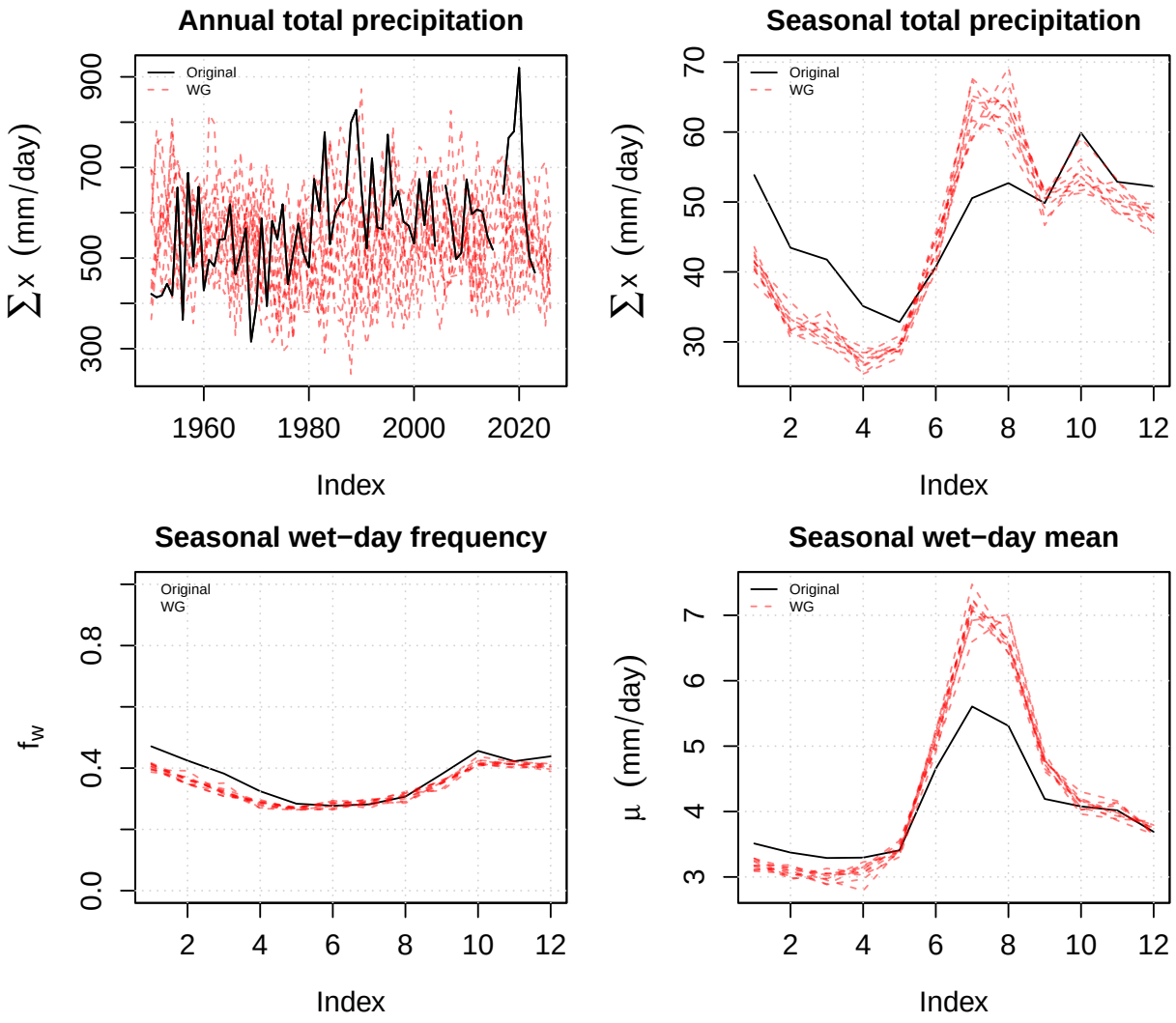


Figure 166: Tests of WG on Norwegian data

```
##   1.279   1.486   1.573   1.538   1.633   1.639
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   7.671   8.125   8.374   8.406   8.662   9.344
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5920  0.6226  0.6336  0.6441  0.6641  0.7170
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.03754 0.03836 0.03977 0.03973 0.04057 0.04296
## test.WG.fwmu.day.precip for BJØRNØYA  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot
```

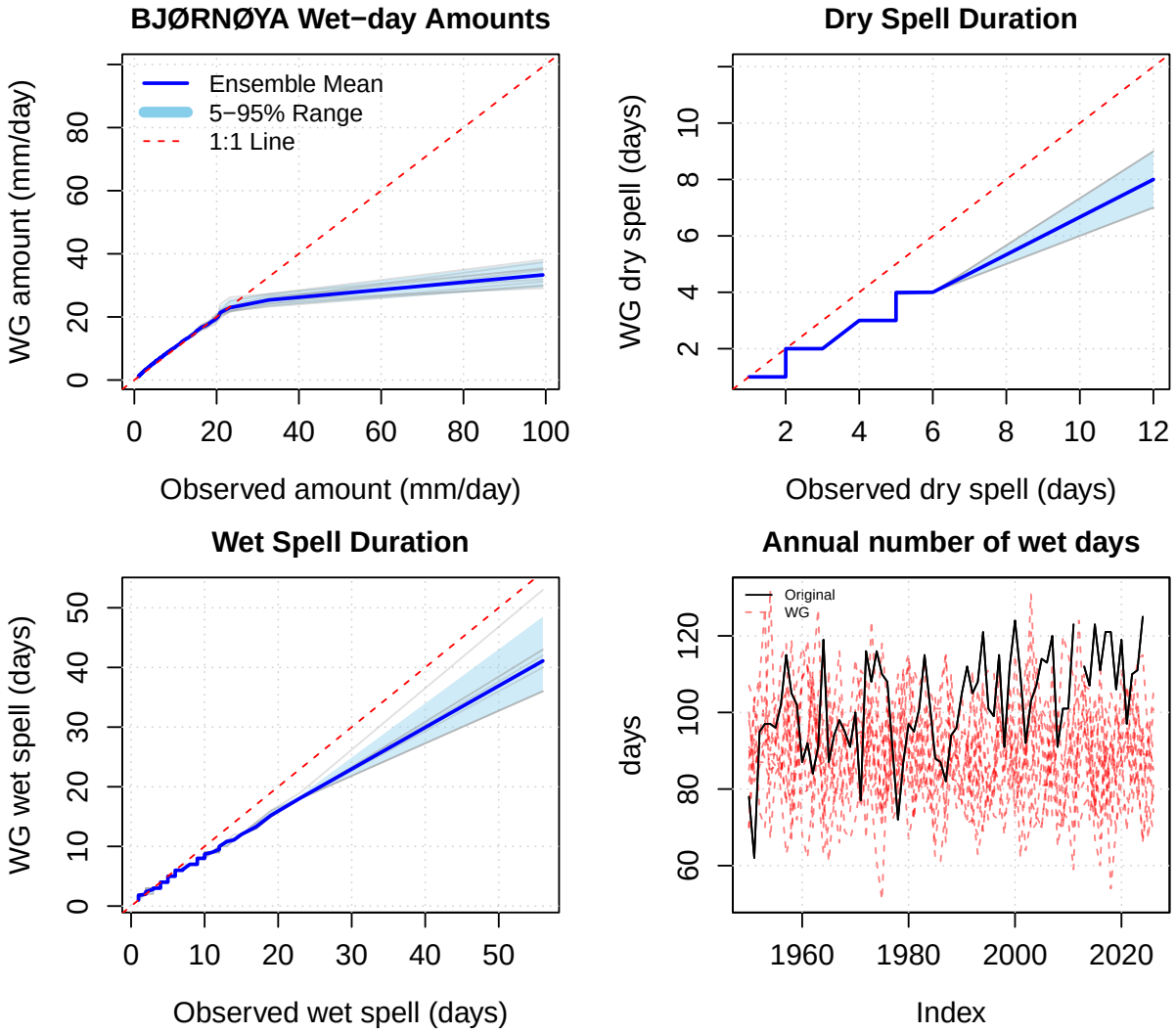


Figure 167: Tests of WG on Norwegian data

```
## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
```

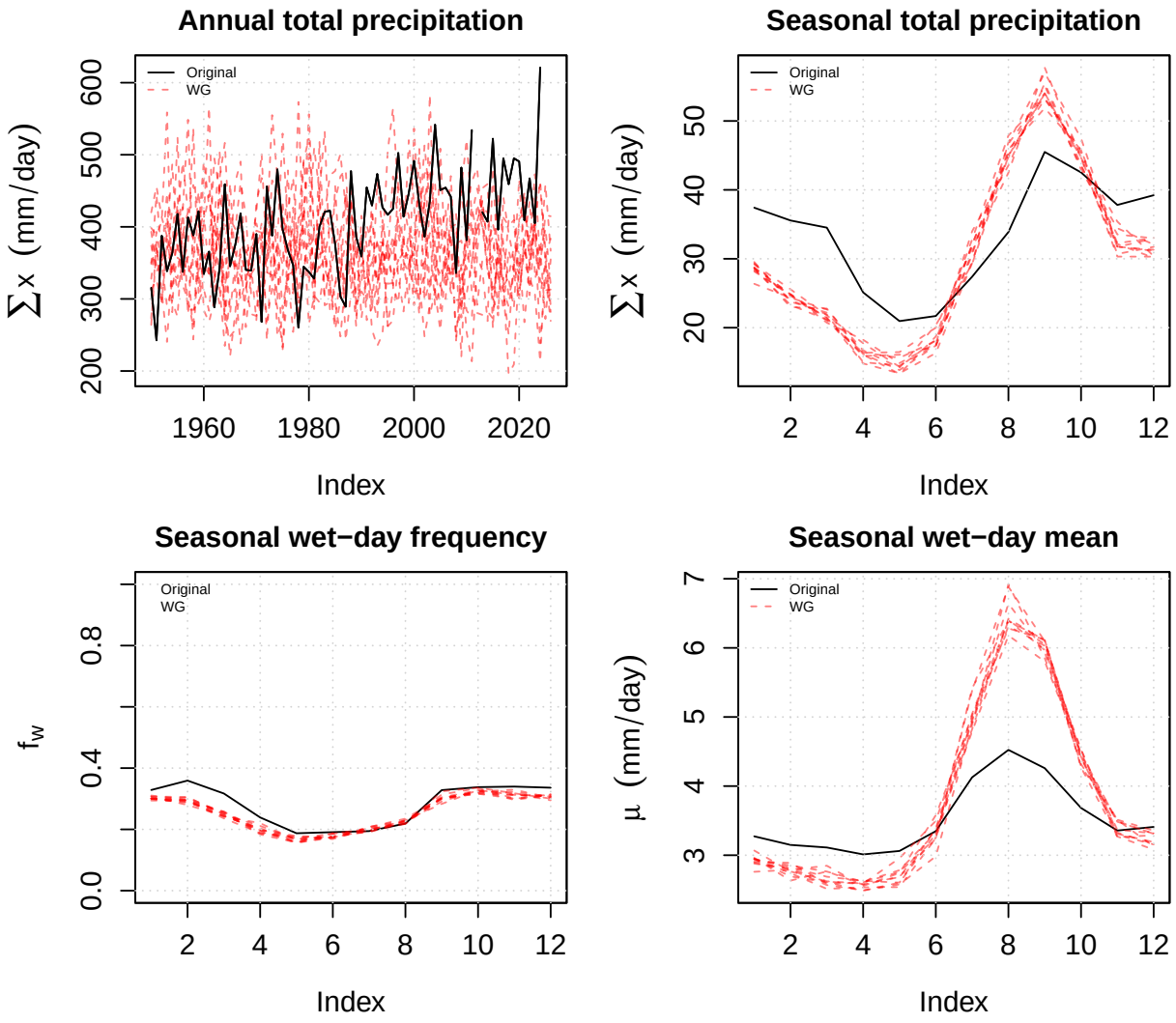


Figure 168: Tests of WG on Norwegian data

```
##   2.005   2.090   2.153   2.159   2.256   2.293
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   1.025   1.722   1.842   1.870   2.179   2.313
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7071  0.7201  0.7583  0.7593  0.7997  0.8124
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   7.677   7.864   8.109   8.133   8.312   8.886
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.7509  0.8444  0.8579  0.8755  0.9053  1.0107
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.03258 0.03462 0.03549 0.03553 0.03634 0.03913
## test.WG.fwmu.day.precip for HOPEN  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.5924  0.6376  0.6962  0.7087  0.7883  0.8329
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.100   2.437   2.756   2.769   3.111   3.308
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8307  0.8675  0.9026  0.9085  0.9434  1.0100
## RMSE for climatology in total precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   7.787   8.435   8.652   8.682   9.000   9.496
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8383  0.8815  0.9215  0.9092  0.9410  0.9724
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.02896 0.03148 0.03327 0.03259 0.03396 0.03530
## test.WG.fwmu.day.precip for JAN MAYEN  and  10  runs
## length= 27822 , n quantiles = 100  =  100
## Simulations finished - collect and inspect the results:  ensemble statistics, plot


## RMSE for daily wet-day quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8327  0.9208  0.9391  0.9633  1.0030  1.1449
## RMSE for wet-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.101   2.496   2.590   2.608   2.738   3.258
## RMSE for dry-spell duration quantiles:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8124  0.8930  0.9192  0.9317  0.9948  1.0247
## RMSE for climatology in total precipitation:
```

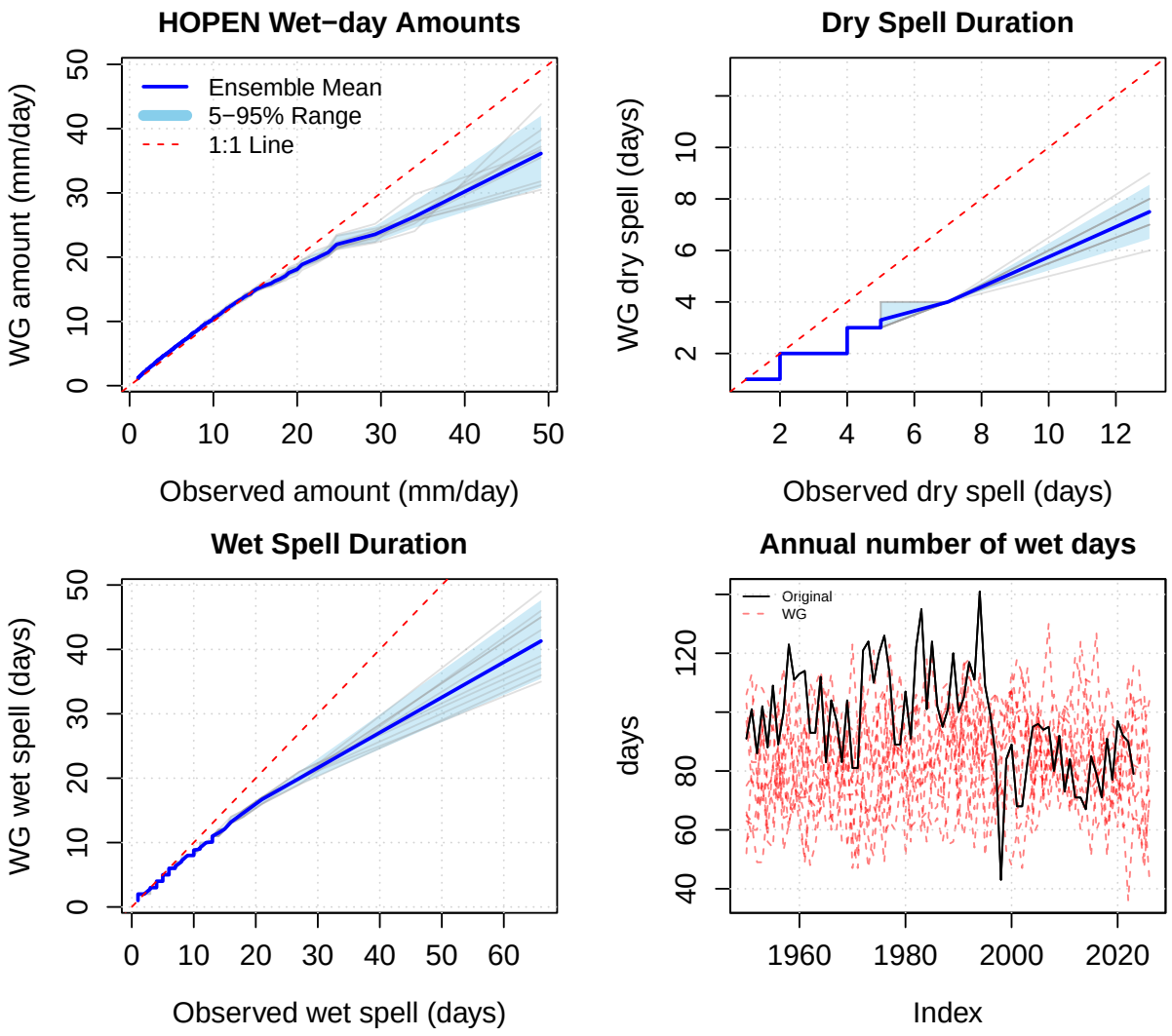


Figure 169: Tests of WG on Norwegian data

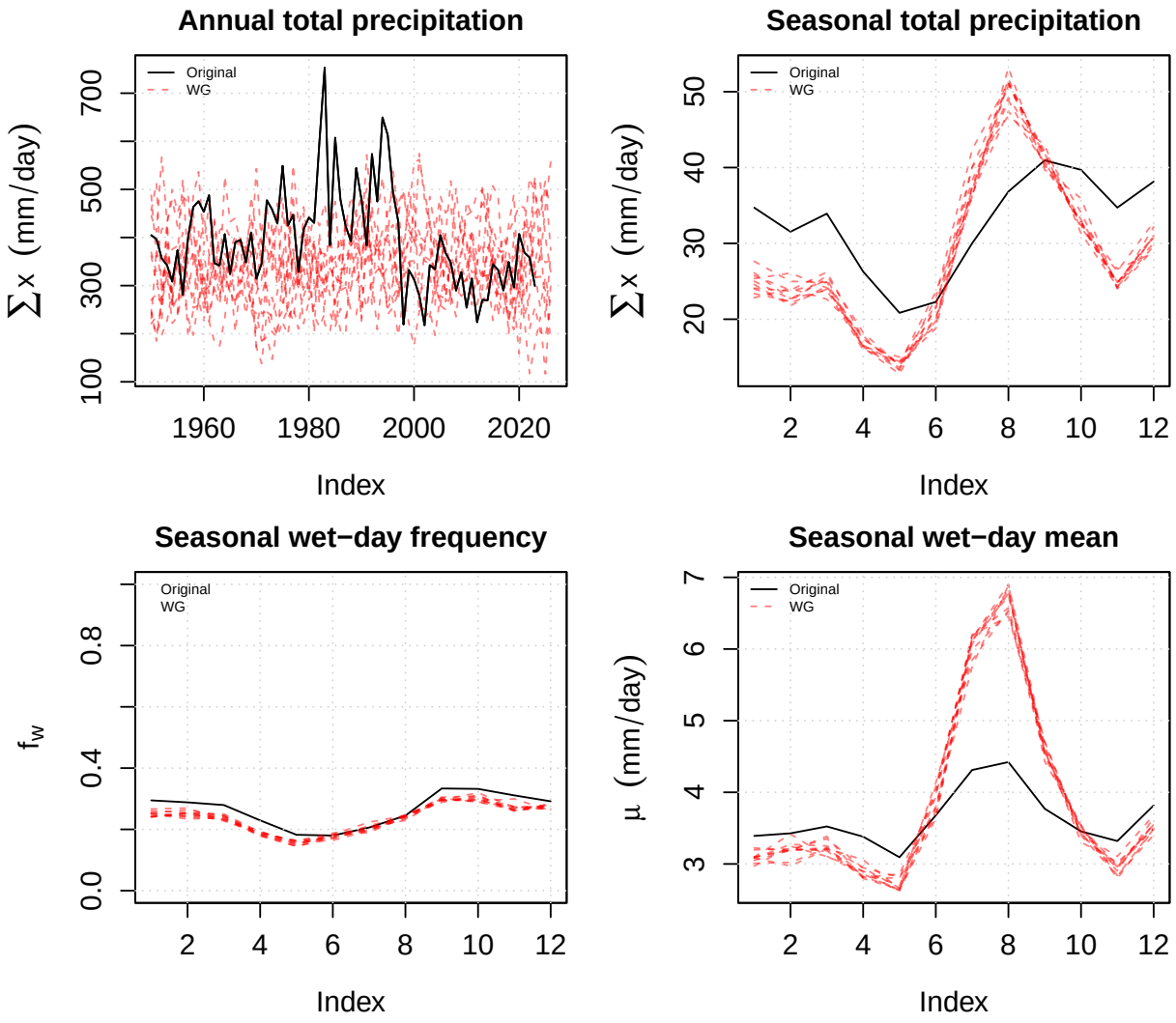


Figure 170: Tests of WG on Norwegian data

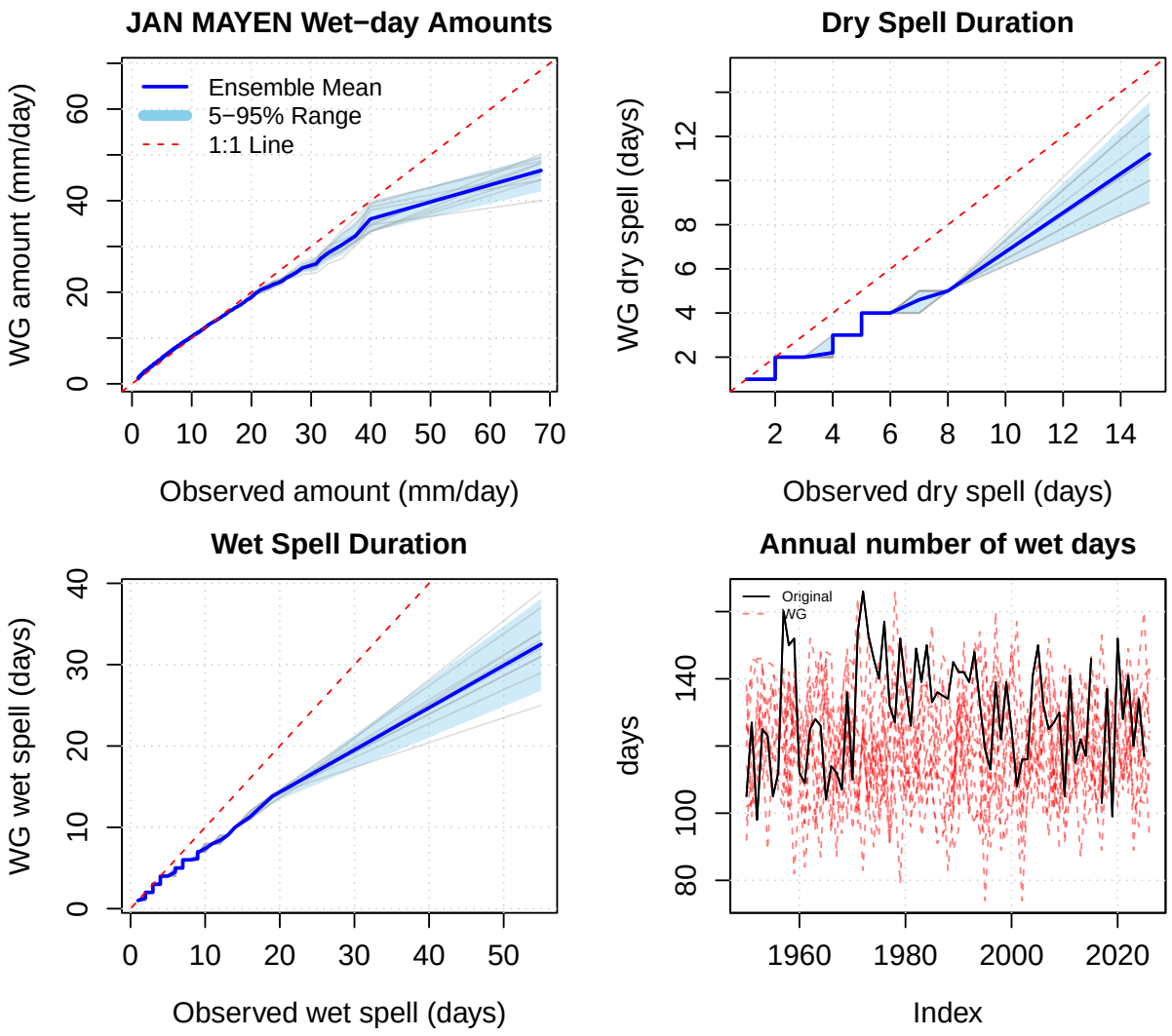


Figure 171: Tests of WG on Norwegian data

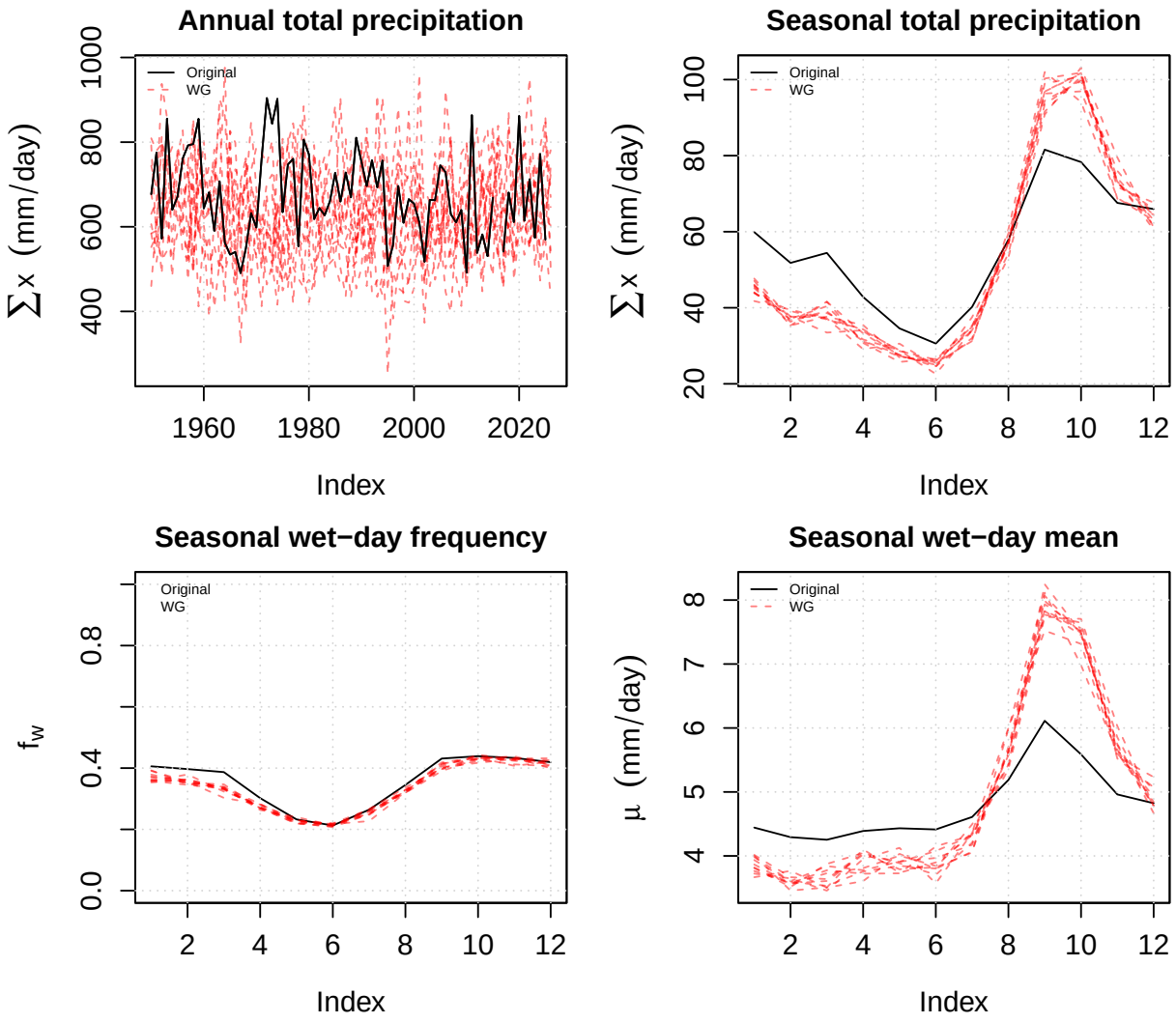


Figure 172: Tests of WG on Norwegian data

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   10.91   11.45   11.72   11.89   12.35   13.13
## RMSE for climatology in wet-day mean precipitation:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##  0.8294  0.8856  0.9060  0.9083  0.9400  0.9650
## RMSE for climatology in wet-day frequency:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## 0.02504 0.02673 0.02749 0.02743 0.02822 0.02946
```

The test results suggest that the simulations capture well amounts up to 50 mm, but there are discrepancies in the spell duration statistics without efforts into further clustering of the wet days.

2.2.8 Example of using the WG with downscaled projections

The example below involves downscaled annual key precipitation statistics from the Nordic region presented in Benestad et al. (2025). The chunk reads downscaled annual wet-day frequency f_w and wet-day mean precipitation μ from an open thredds archive and interpolates the annal data to the location of the provided station data.

```
lons <- lon(bjornholt) + c(-5,5)
lats <- lat(bjornholt) + c(-5,5)
thredds.path <- 'https://thredds.met.no/thredds/dodsC/metusers/rasmusb/'
mu.url <- 'mu_DSEns_Nordics_4seasons_1950-2100_ssp370.nc'
fw.url <- 'fw_DSEns_Nordics_4seasons_1950-2100_ssp370.nc'
param <- ncvars(paste0(thredds.path,mu.url))
## Get the ensemble mean and standard deviation
mu.m <- regrid(retrieve(paste0(thredds.path,mu.url),param=param[1],
                        lon=lons,lat=lats),bjornholt)
```

```
## [1] "Warning : Calendar attribute has not been found in the meta data and will be set automatically.
```

```
mu.s <- regrid(retrieve(paste0(thredds.path,mu.url),param=param[2],
                        lon=lons,lat=lats),bjornholt)
```

```
## [1] "Warning : Calendar attribute has not been found in the meta data and will be set automatically.
```

```
param <- ncvars(paste0(thredds.path,fw.url))
fw.m <- regrid(retrieve(paste0(thredds.path,fw.url),param=param[1],
                        lon=lons,lat=lats),bjornholt)
```

```
## [1] "Warning : Calendar attribute has not been found in the meta data and will be set automatically.
```

```
fw.s <- regrid(retrieve(paste0(thredds.path,fw.url),param=param[2],
                        lon=lons,lat=lats),bjornholt)
```

```
## [1] "Warning : Calendar attribute has not been found in the meta data and will be set automatically.
```

```
## generate a plausbile time series based on the smooth ensemble mean
## and random annual fluctuations based on the ensemble standard deviation
mu <- annual(mu.m + 0.5*rnorm(length(mu.s))*mu.s)
fw <- annual(fw.m + 0.5*rnorm(length(fw.s))*fw.s)
z.bjornholt <- WG(bjornholt,mu=mu,fw=fw)
plot(combine.stations(bjornholt,z.bjornholt))
```

The input may also be taken from individual sites represented through principal component analysis (PCA) a in Benestad et al. (2015) which provides spatially consistent annual/seasonal values for f_w and μ. This may be important for the Volta sub-basins presented above.

3 Simulations of daily temperature

The temperature has fundamentally different aspects than precipitation, as the temperature is continuously present at all times and places, and doesn't have the intermittent nature of precipitation. Hence no need to distinguish between categories such as wet and dry days. This also implies that a weather generator for temperature is very different than for precipitation. The important statistics to reproduce are the magnitudes and temporal structure (autocorrelation).

It is also useful to check the correlation between precipitation and temperature if the `WG` is to be used to simulate input for a hydrological model. If they are uncorrelated, then it may be OK to use independent simulations to represent them.

3.0.1 Ghana

```
## Bivariate statistical distribution between
akosombo.tmax <- subset(ghana.data$tmax,loc="Akosombo")
akosombo.tmin <- subset(ghana.data$tmin,loc="Akosombo")
akosombo.t2m <- 0.5*(akosombo.tmax + akosombo.tmin)
akosombo.t2m <- attrcp(akosombo.tmax,akosombo.t2m)
attr(akosombo.tmax,'variable') <- 't2m'
class(akosombo.t2m) <- class(akosombo.tmax)
par(mfcol=c(1,1))
bivariate.hist(akosombo,akosombo.t2m)
```

```
## Check whether the daily mean temperature is normally distributed
detrend <- function(x) x - trend(x)
qqnorm(anomaly(detrend(akosombo.t2m)))
grid()
qqline(anomaly(detrend(akosombo.t2m)),lty=2,col='grey')
```

```
## Carry out one WG simulation for Ferder
z.akosombo.t2m <- WG(akosombo.t2m)
xylim <- range(akosombo.t2m,z.akosombo.t2m,na.rm=TRUE)
qqplot(coredata(akosombo.t2m),coredata(z.akosombo.t2m),xlim=xylim,ylim=xylim,
       xlab='original simulation',ylab='simulated results',
       main='Temperature WG for Akosombo')
lines(xylim,xylim,lty=2,col='red')
grid()
```

The above analysis suggests that the daily temperature in Akuse is close to normally distributed and that the `WG` has a marginal low bias towards the higher temperatures.

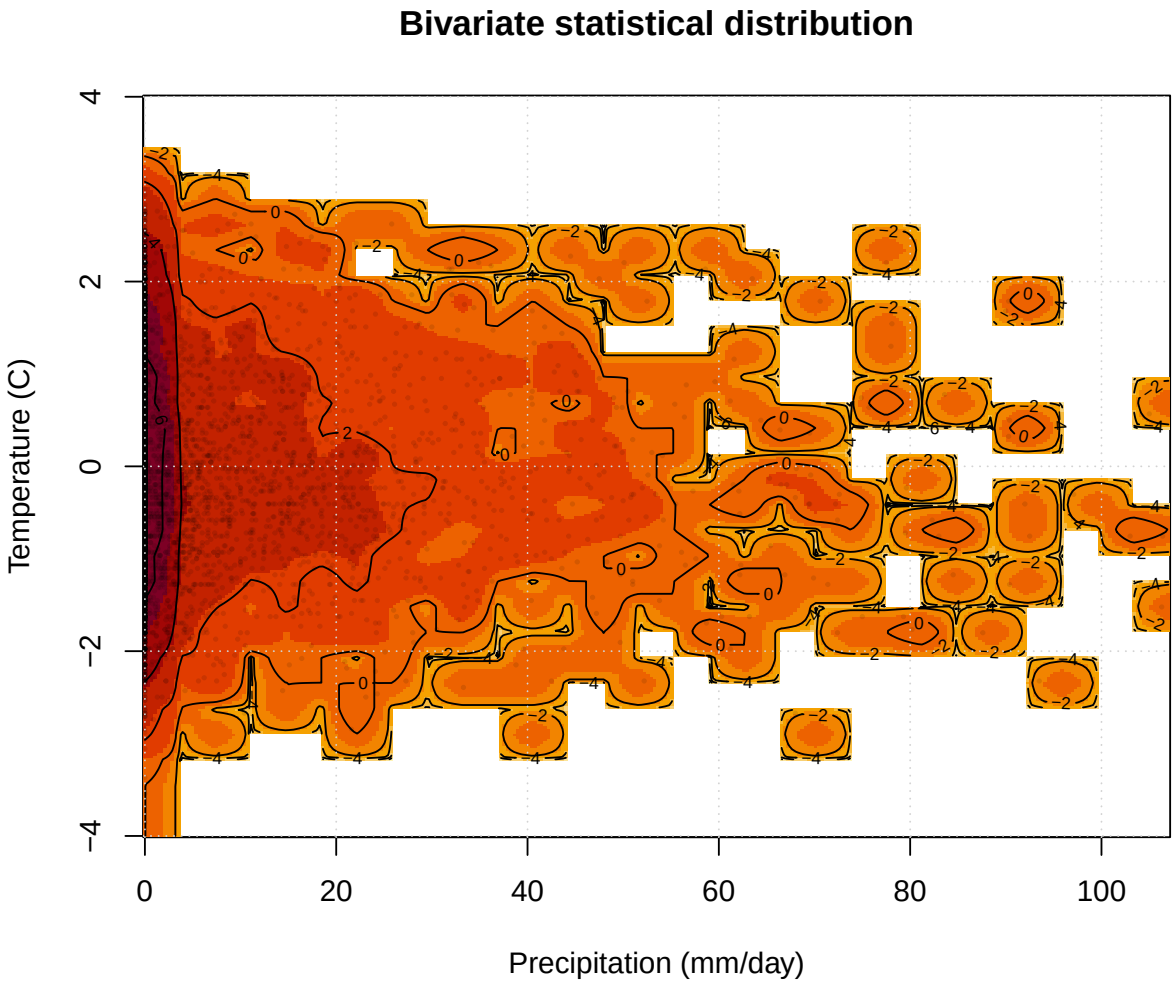


Figure 173: Rainfall correlation with temperature

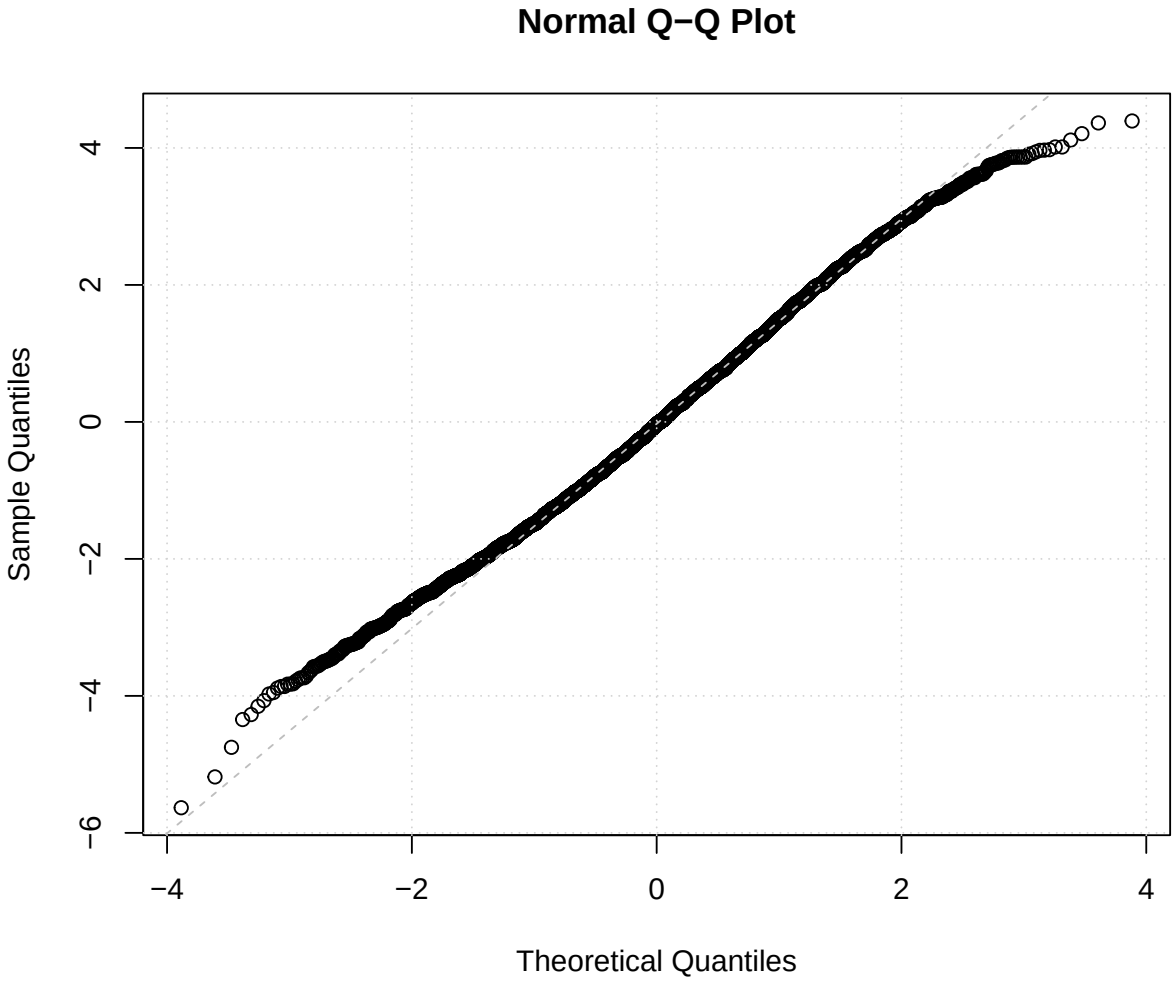


Figure 174: Rainfall correlation with temperature

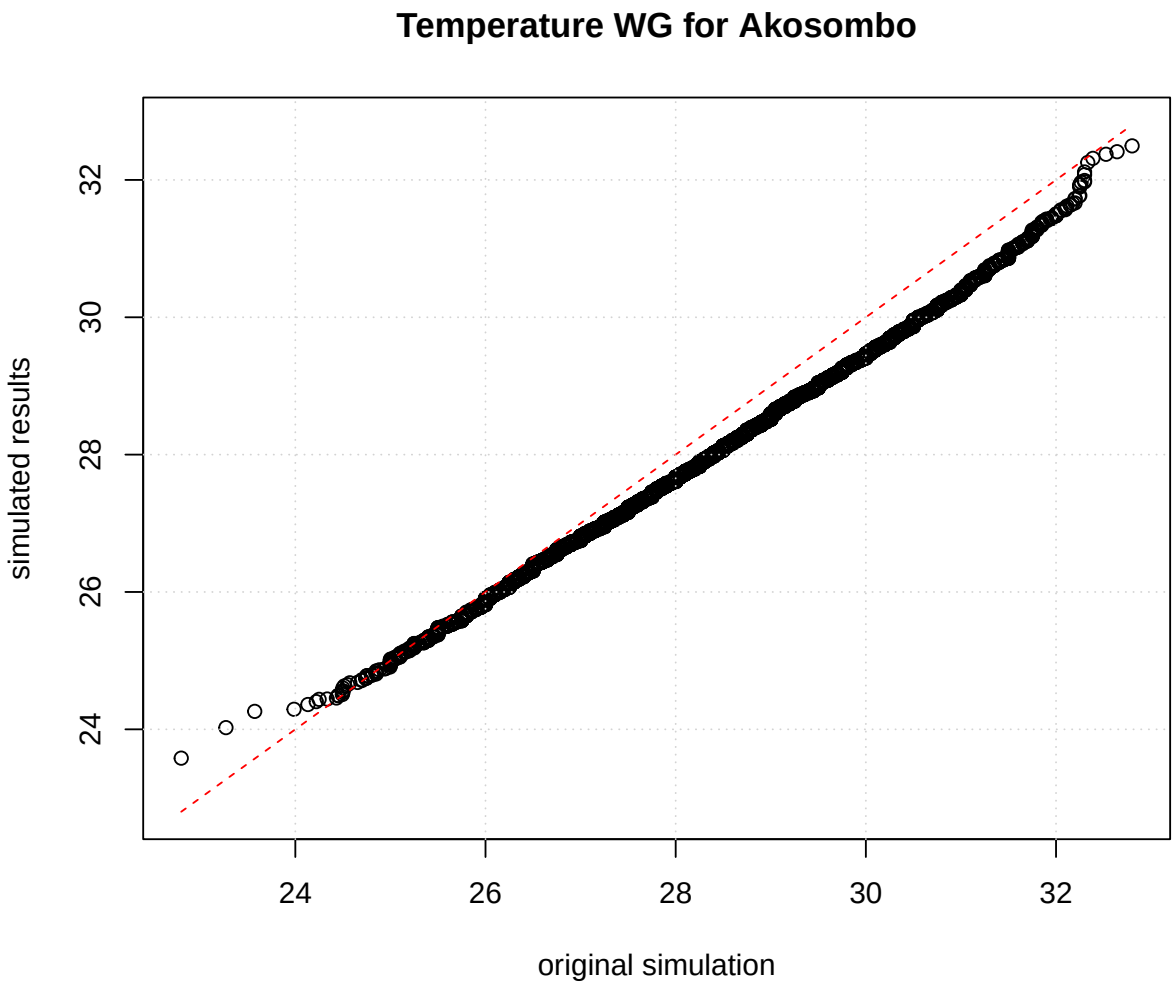


Figure 175: Rainfall correlation with temperature

3.1 Demonstrations involving a grater amount of evaluation against observations

One observation in these tests is that the default μ-smudging factor is not appropriate for all sites and it sometimes needs to to be calibrated for the local case - which will involve testing with e.g `test.WG.fwmu.day.precip(y)`.

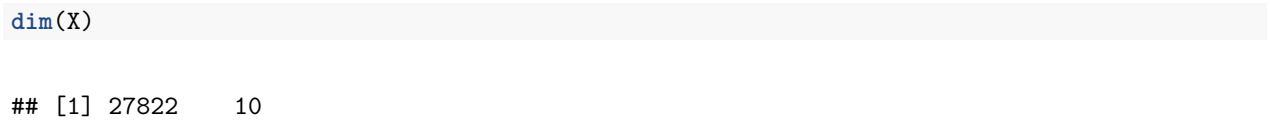
3.1.1 Temperature

The R-chunk below provides a demonstration of the WG for daily temperature for a number of Norwegian locations with free and open-access data.

```
## Fetch open Norwegian daily rain gauge data from thredds
X <- station(param='t2m',src='metnod.thredds')
## Only keep the stations number of valid (nv) data points exceeding 26000
nv <- apply(X,2,'nv')
summary(nv)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##     523   11602   15602   16805   22360   27790
```

```
X <- subset(X,is=nv >= 27700)
map(X,FUN='nv',add.text = TRUE,new=FALSE)
```



```
dim(X)
```

```
## [1] 27822    10
```

The sites are spread geographically and represent diverse local climes.

```
## Apply the test to all of the stations
par(cex=1.25,cex.axis=1.25)
ns <- dim(X)[2] ## The number of stations
for (is in 1:ns) {
  ## Select one single station per turn
  x <- subset(X,is=is)
  ## Apply the test to this station
  z <- WG(x)
  rng <- range(coredata(z),coredata(x),na.rm=TRUE)
  plot(merge(x,z),plot.type='single',col=c('black','red'),lty=c(1,2),
       main=loc(x),ylim=rng + c(0,3),ylab=expression(C*degree))
  grid()
  legend('topleft',c('Observed','simulated'),col=c('black','red'),lty=c(1,2),
         cex=0.5)
  qqplot(coredata(x),coredata(z),main=loc(x),
         xlab='Observations',ylab='WG simulation')
  grid()
  lines(rng,rng,lty=2,col='red')
}
```



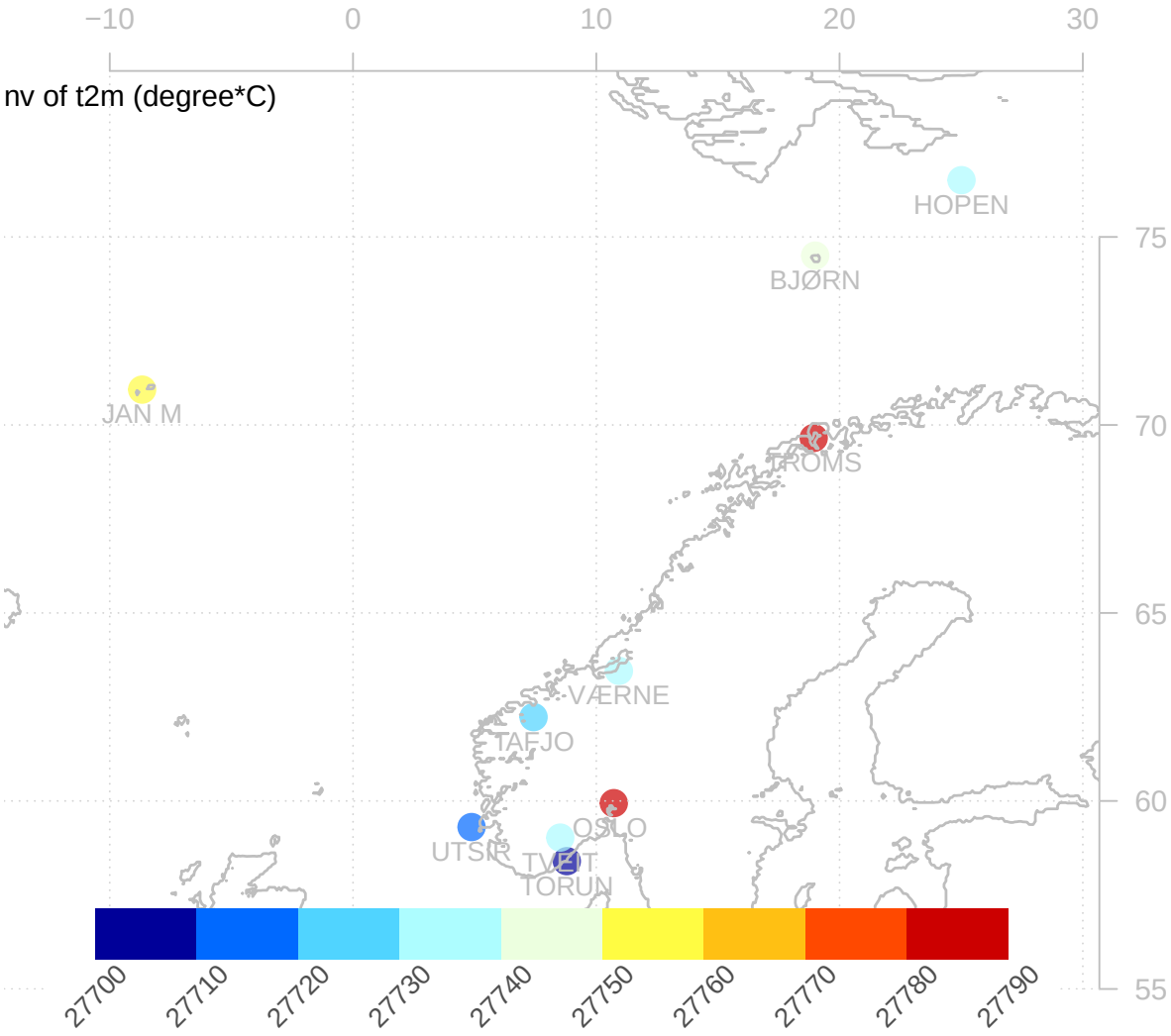


Figure 176: Norwegian temperature data

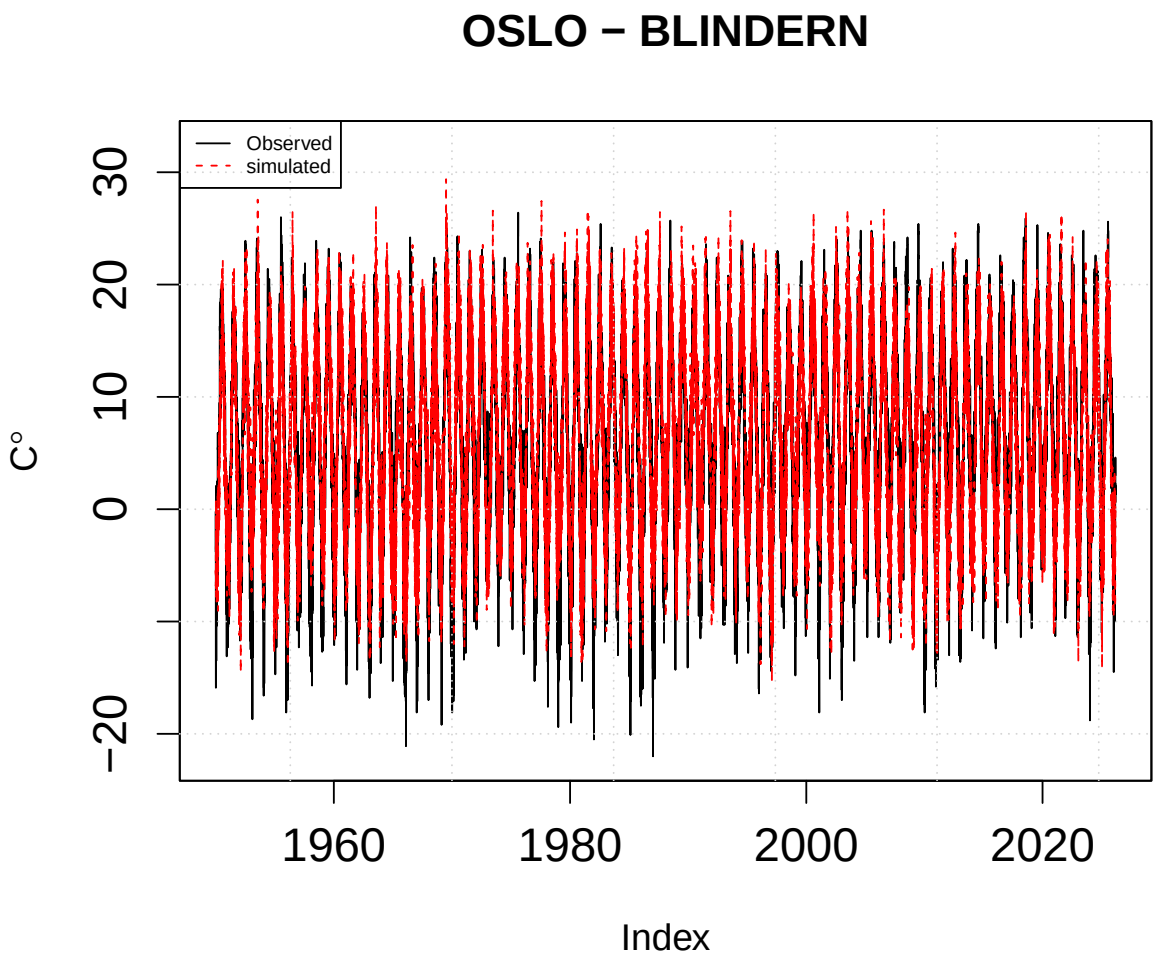


Figure 177: Evaluate WG on Norwegian temperature

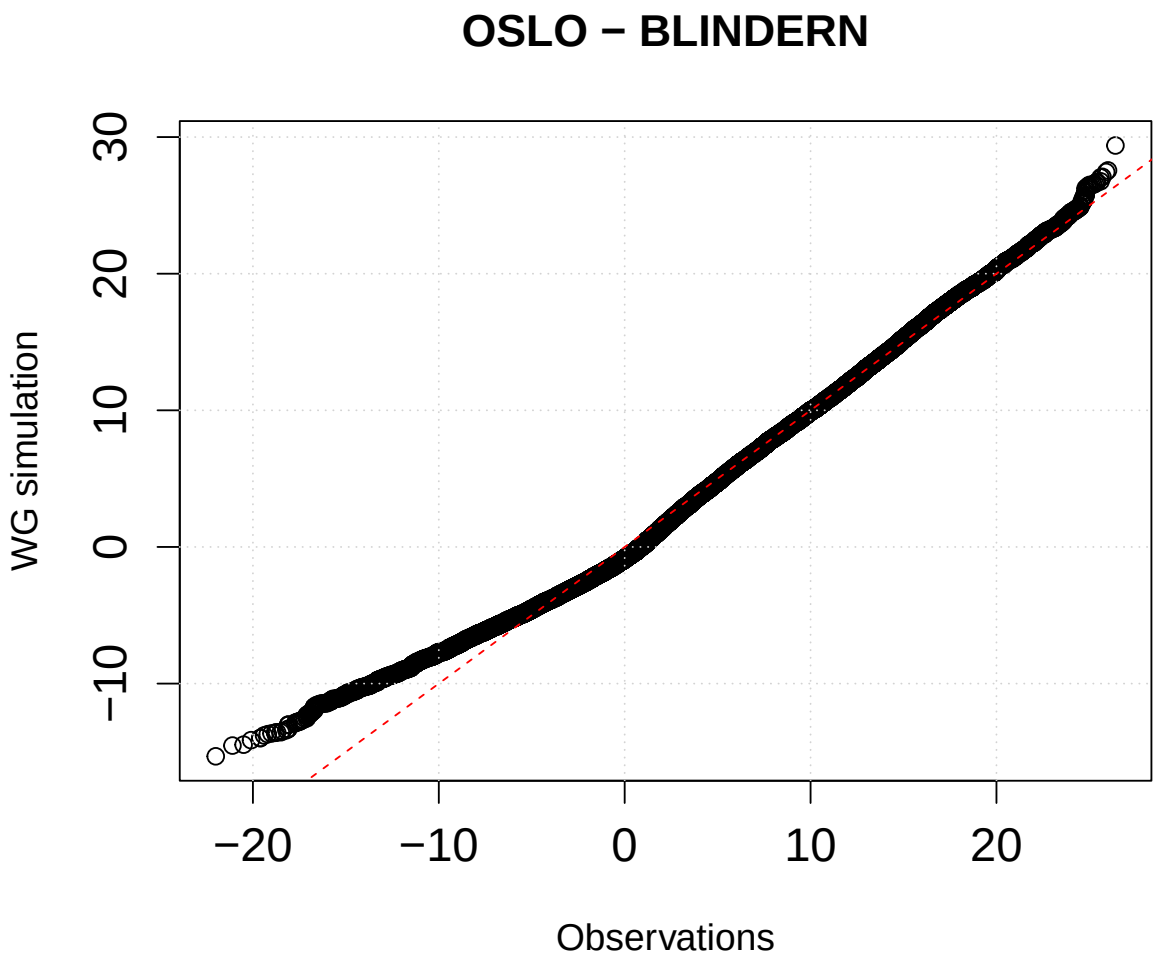


Figure 178: Evaluate WG on Norwegian temperature

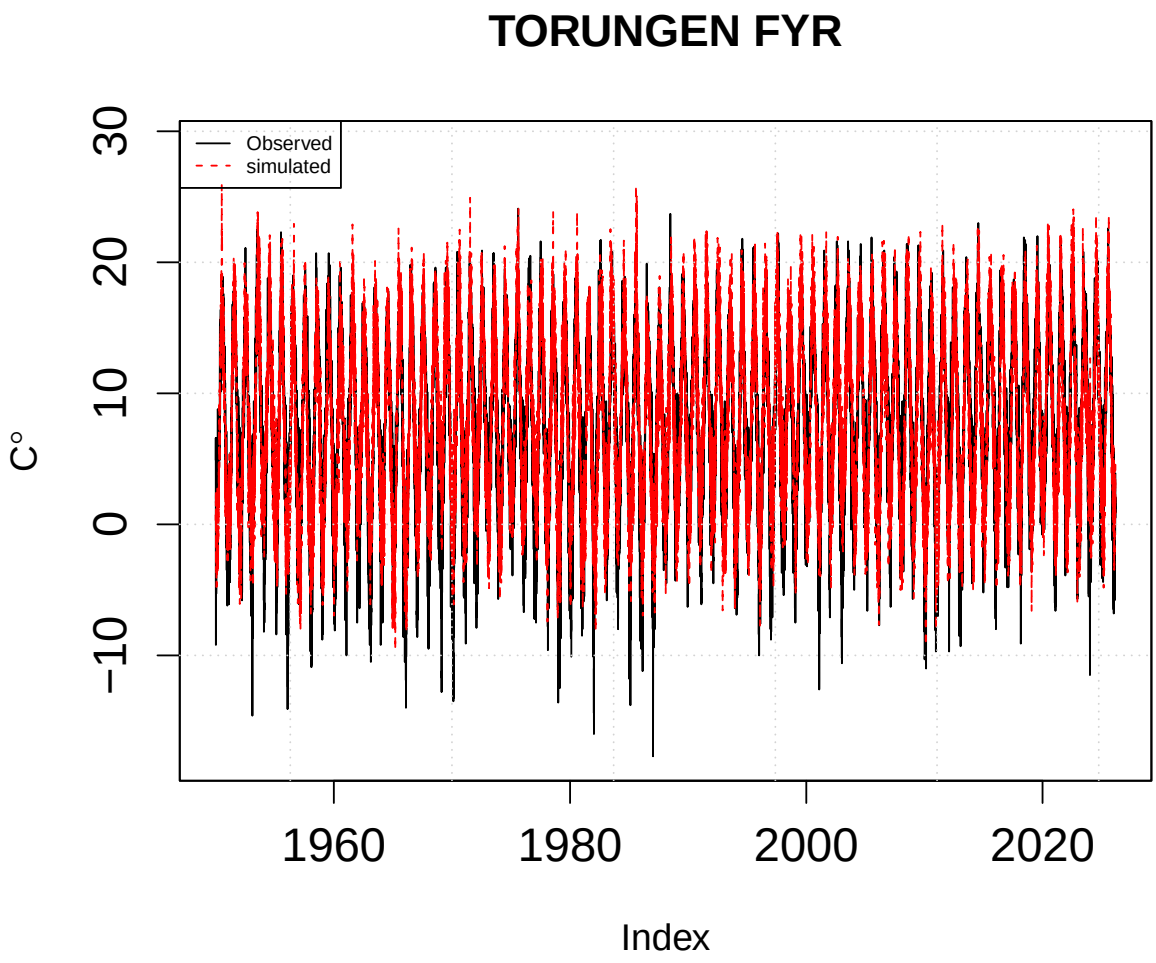


Figure 179: Evaluate WG on Norwegian temperature

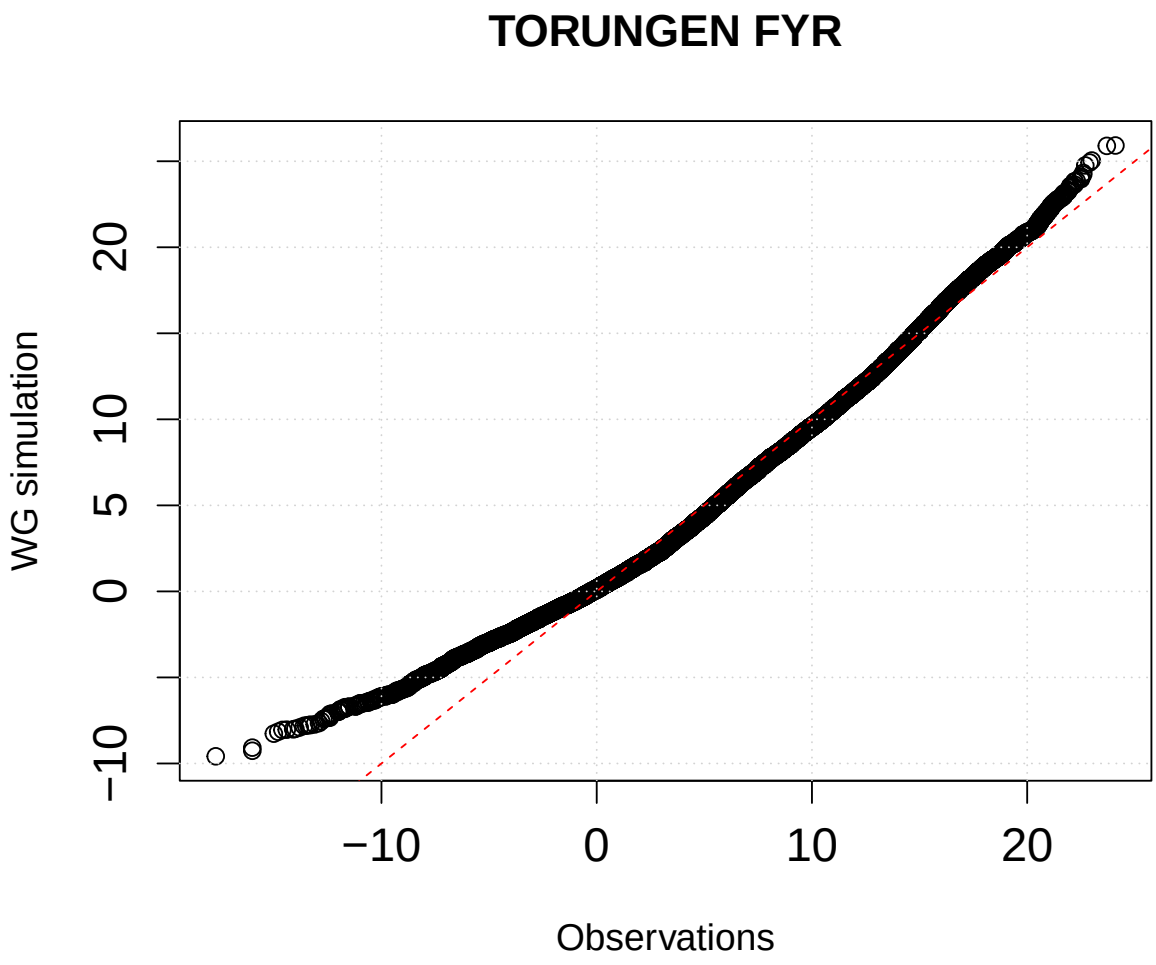


Figure 180: Evaluate WG on Norwegian temperature

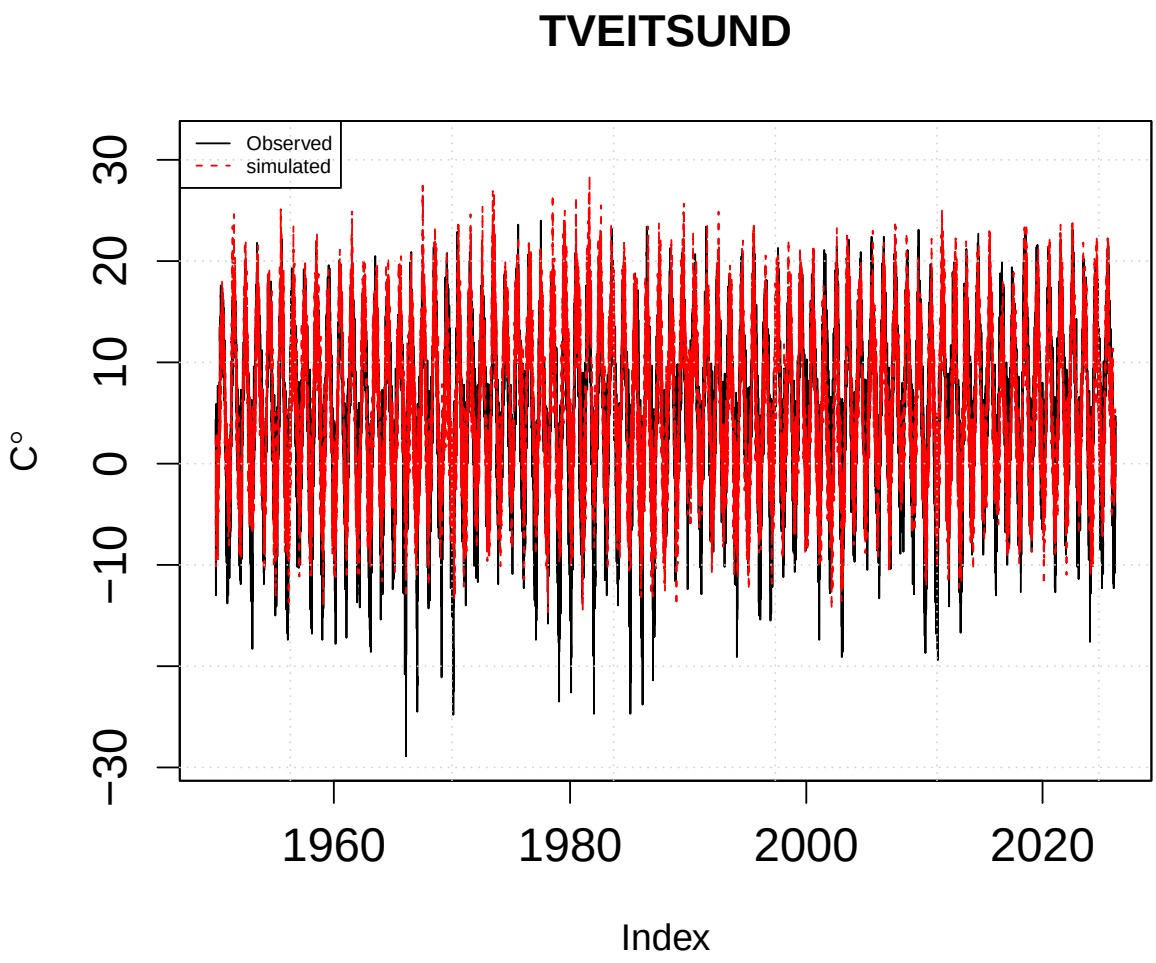


Figure 181: Evaluate WG on Norwegian temperature

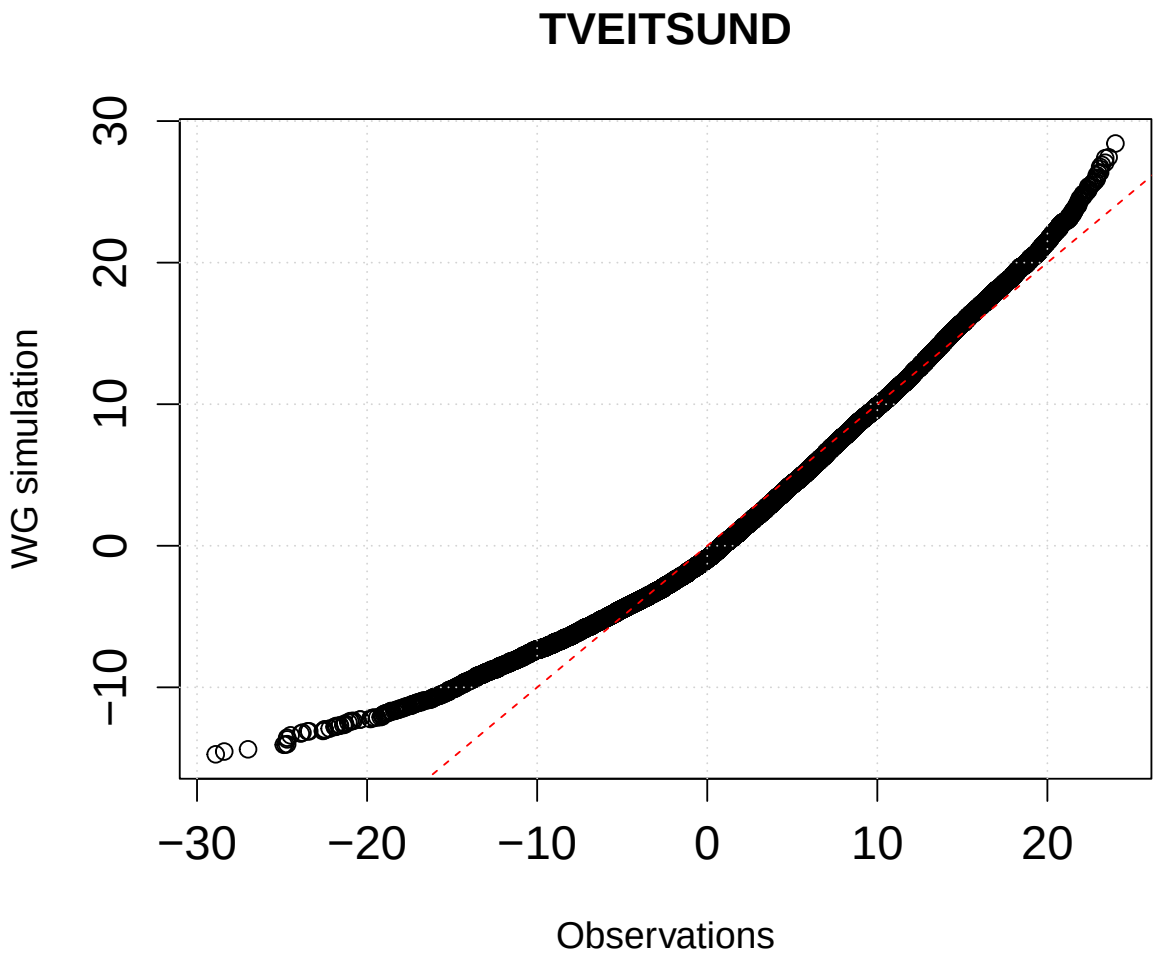


Figure 182: Evaluate WG on Norwegian temperature

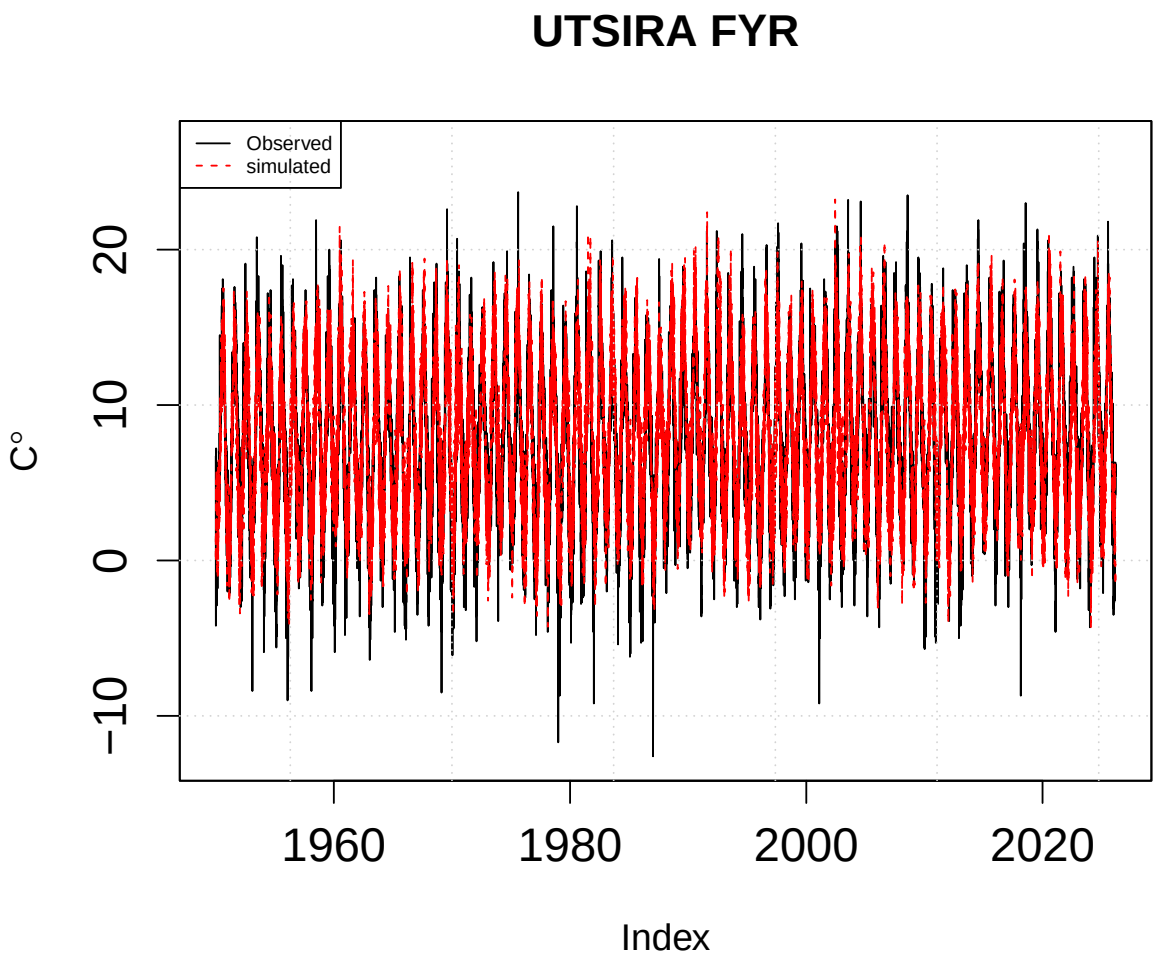


Figure 183: Evaluate WG on Norwegian temperature

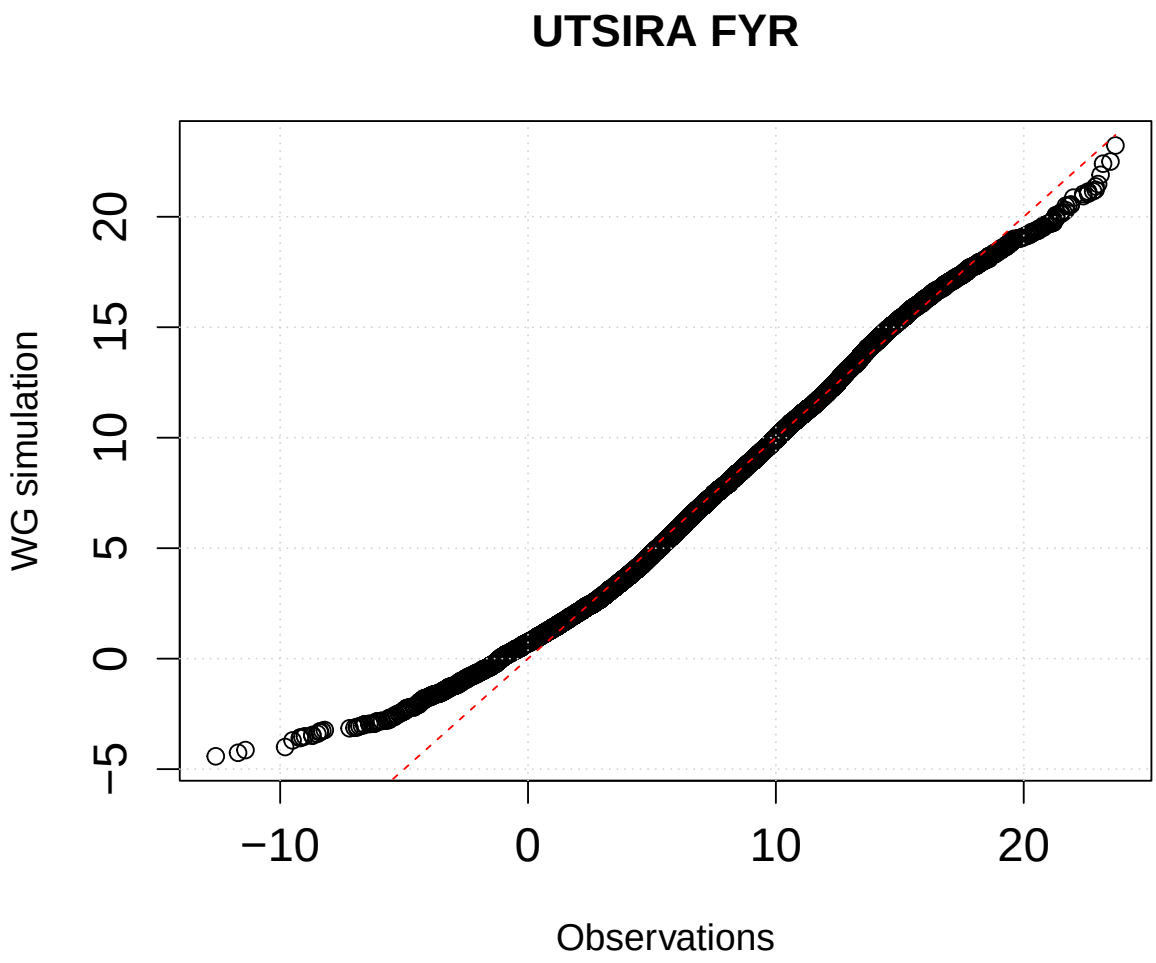


Figure 184: Evaluate WG on Norwegian temperature

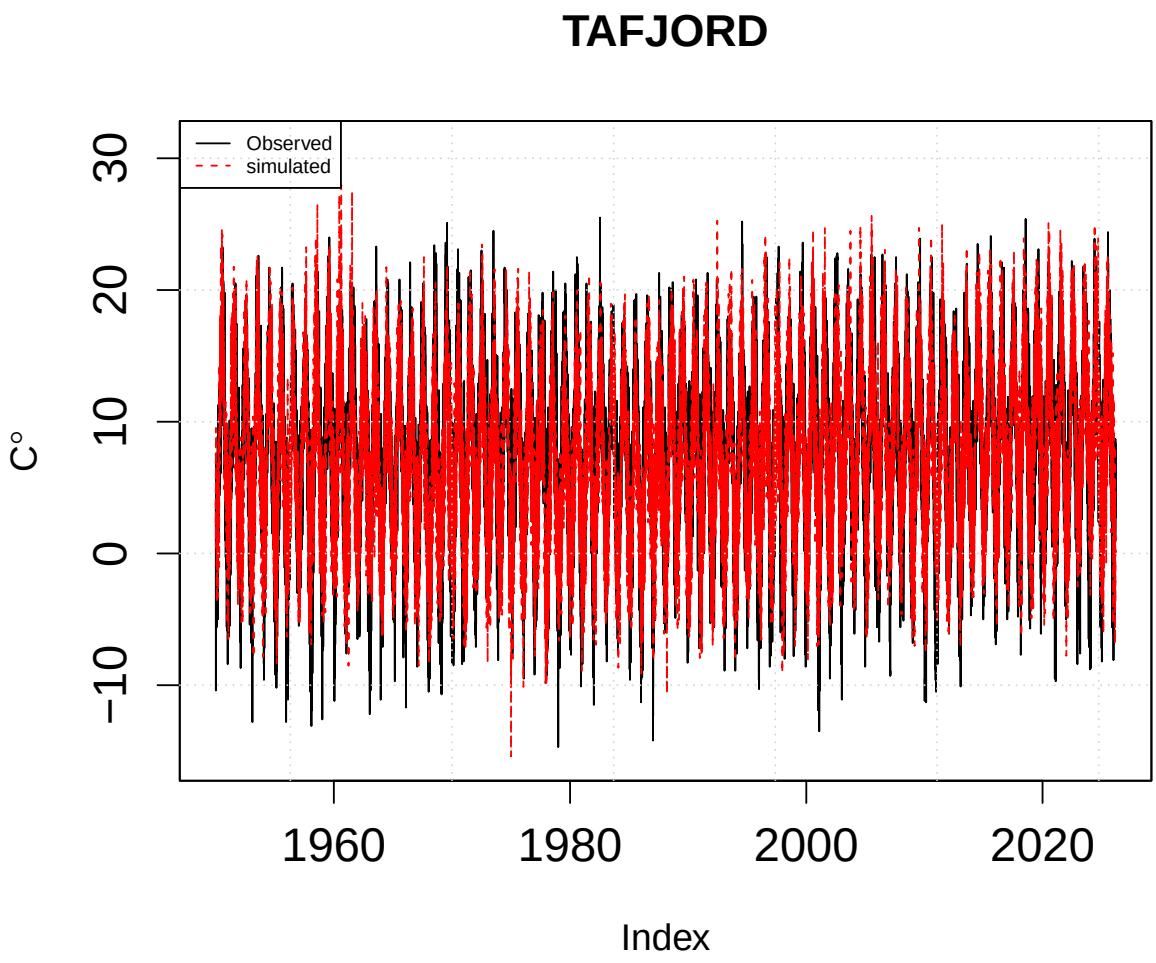


Figure 185: Evaluate WG on Norwegian temperature

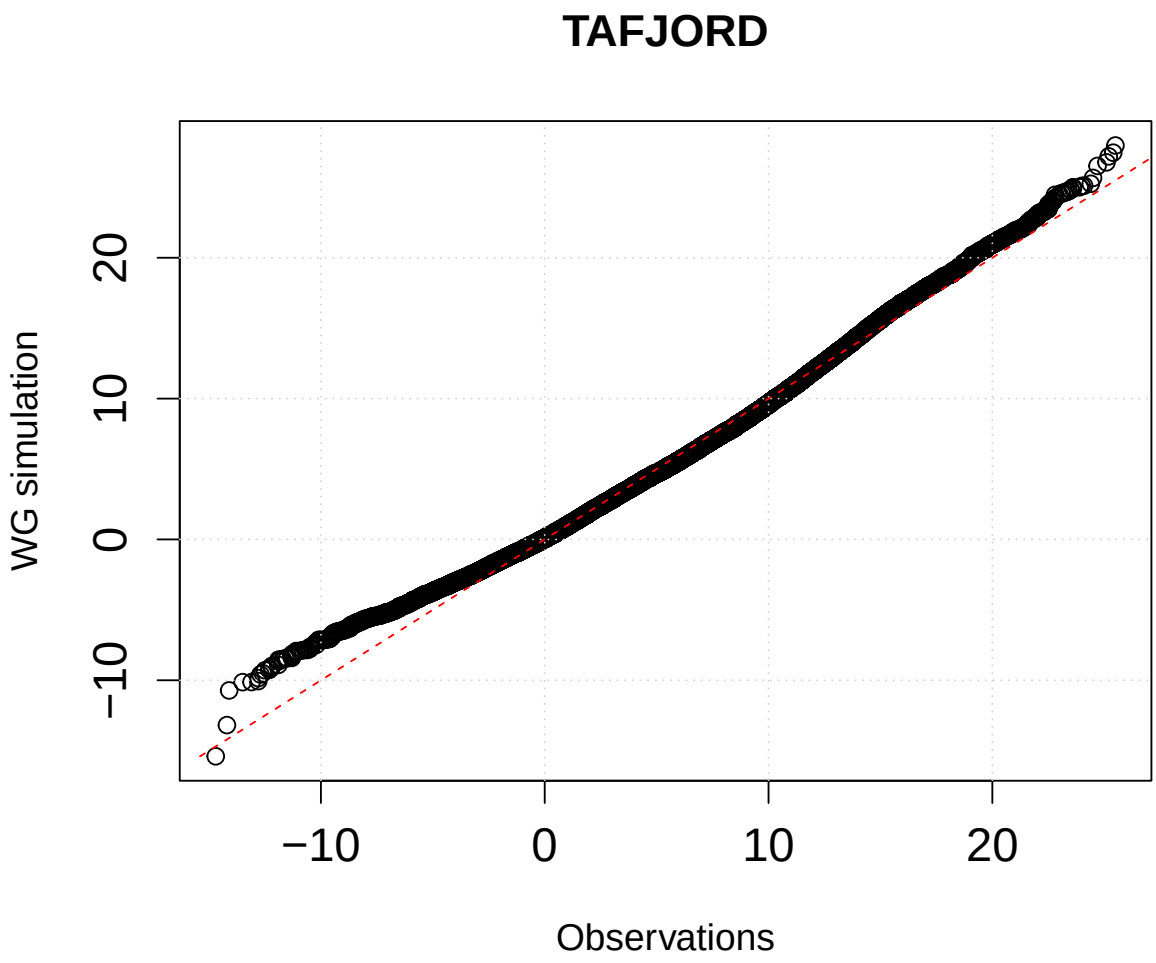


Figure 186: Evaluate WG on Norwegian temperature

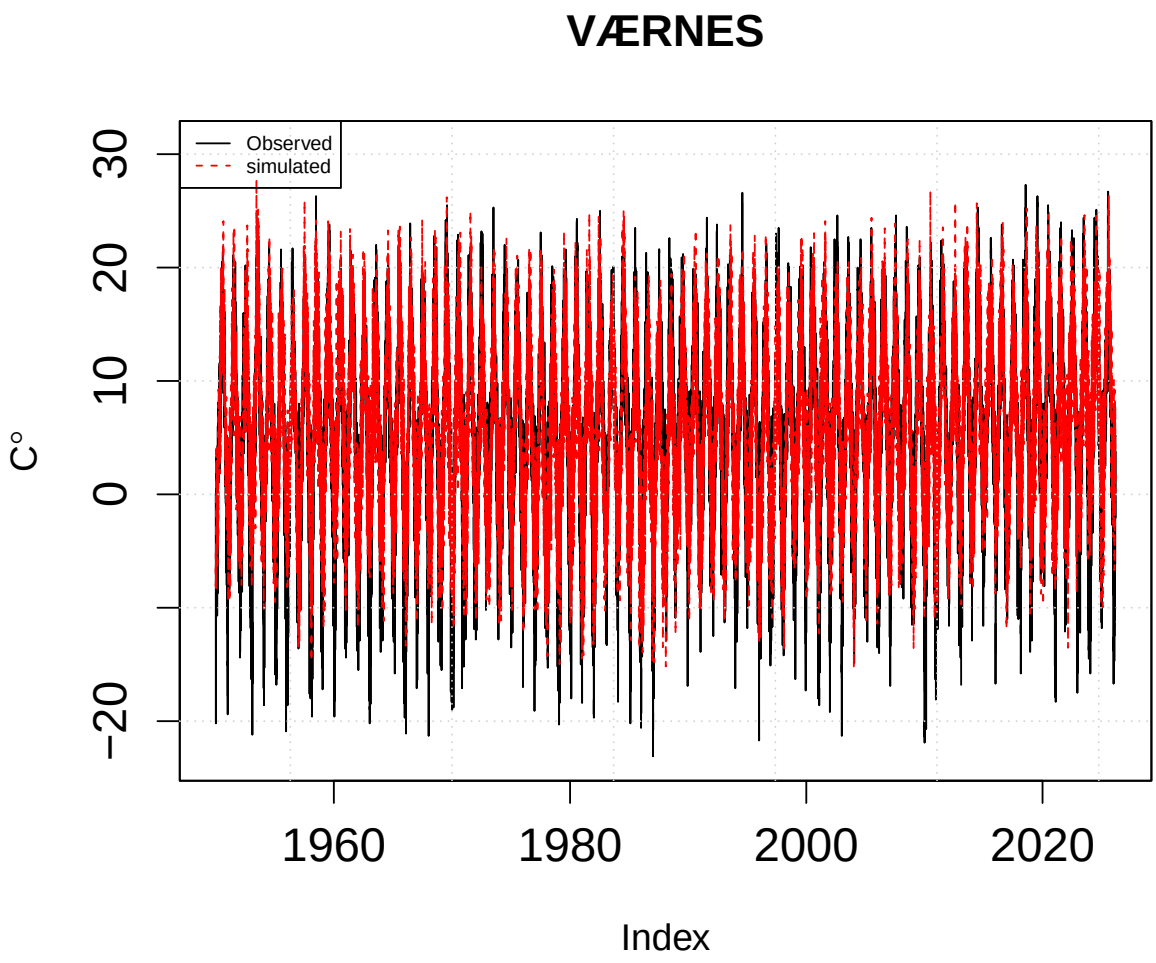


Figure 187: Evaluate WG on Norwegian temperature

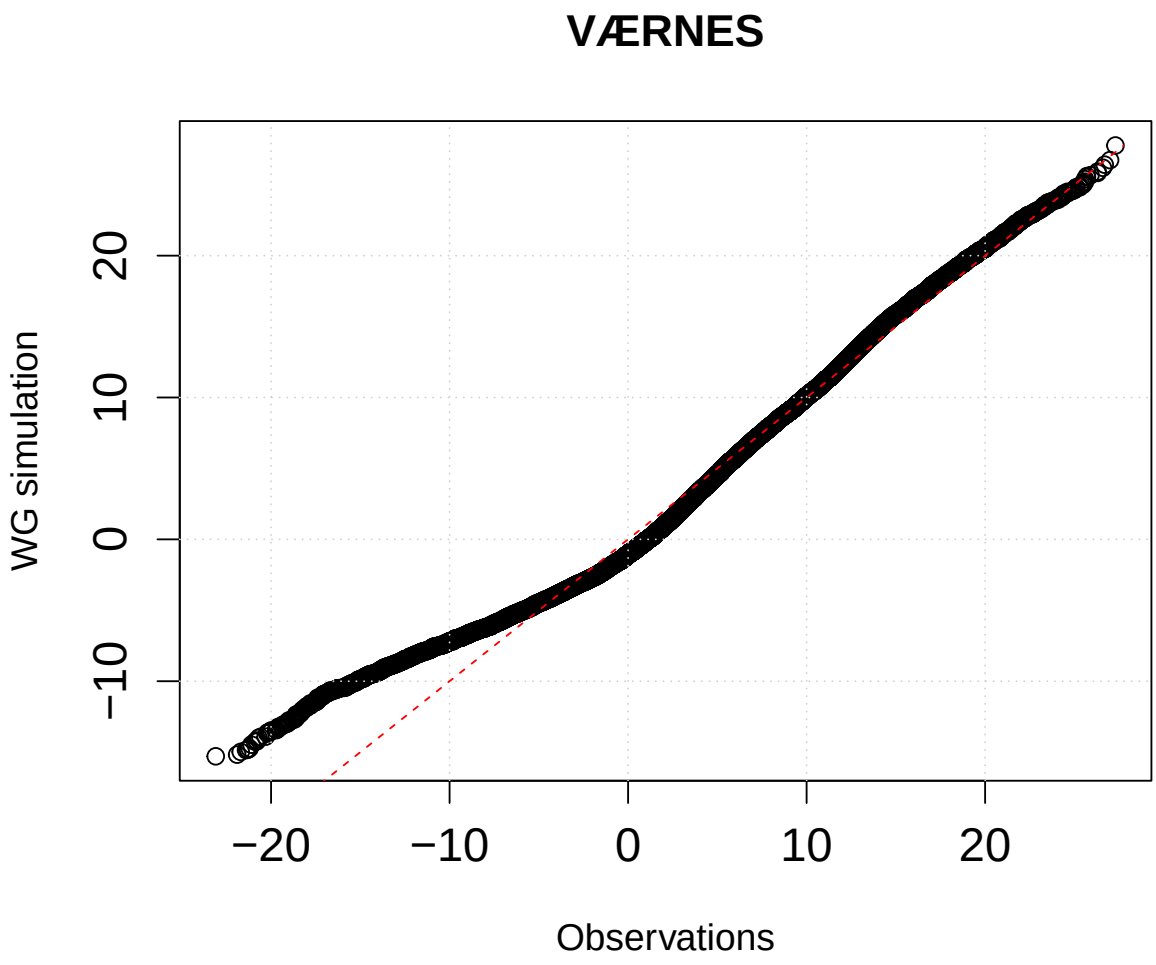


Figure 188: Evaluate WG on Norwegian temperature

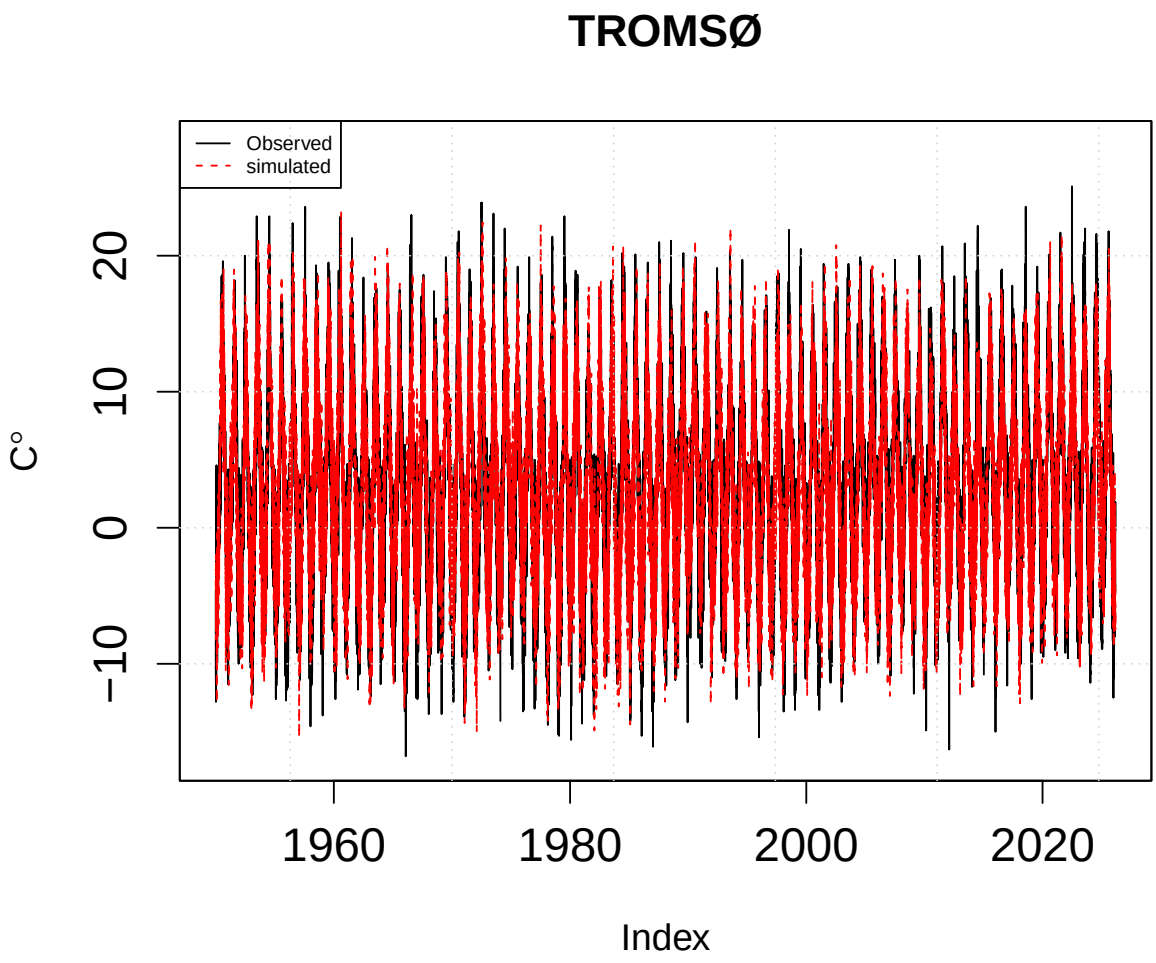


Figure 189: Evaluate WG on Norwegian temperature

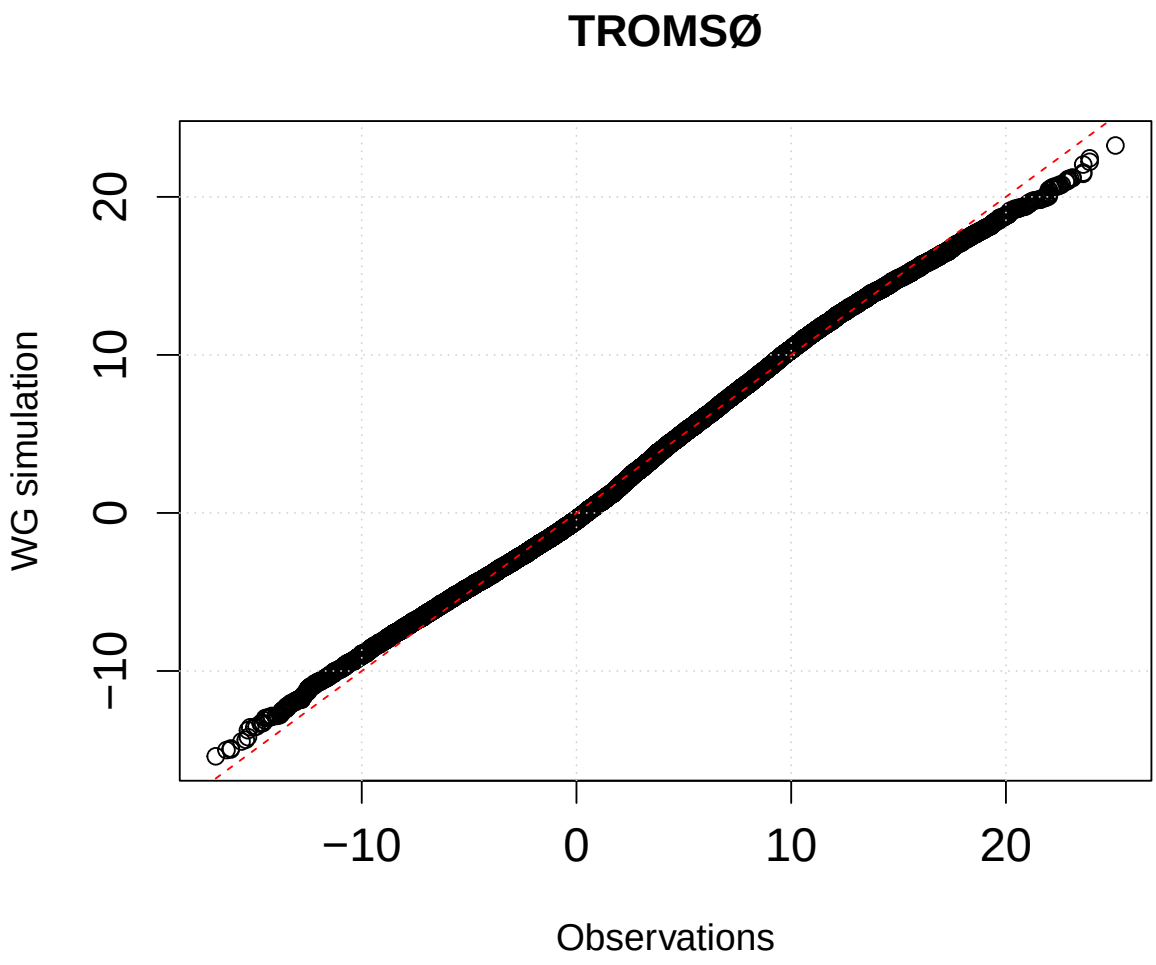


Figure 190: Evaluate WG on Norwegian temperature

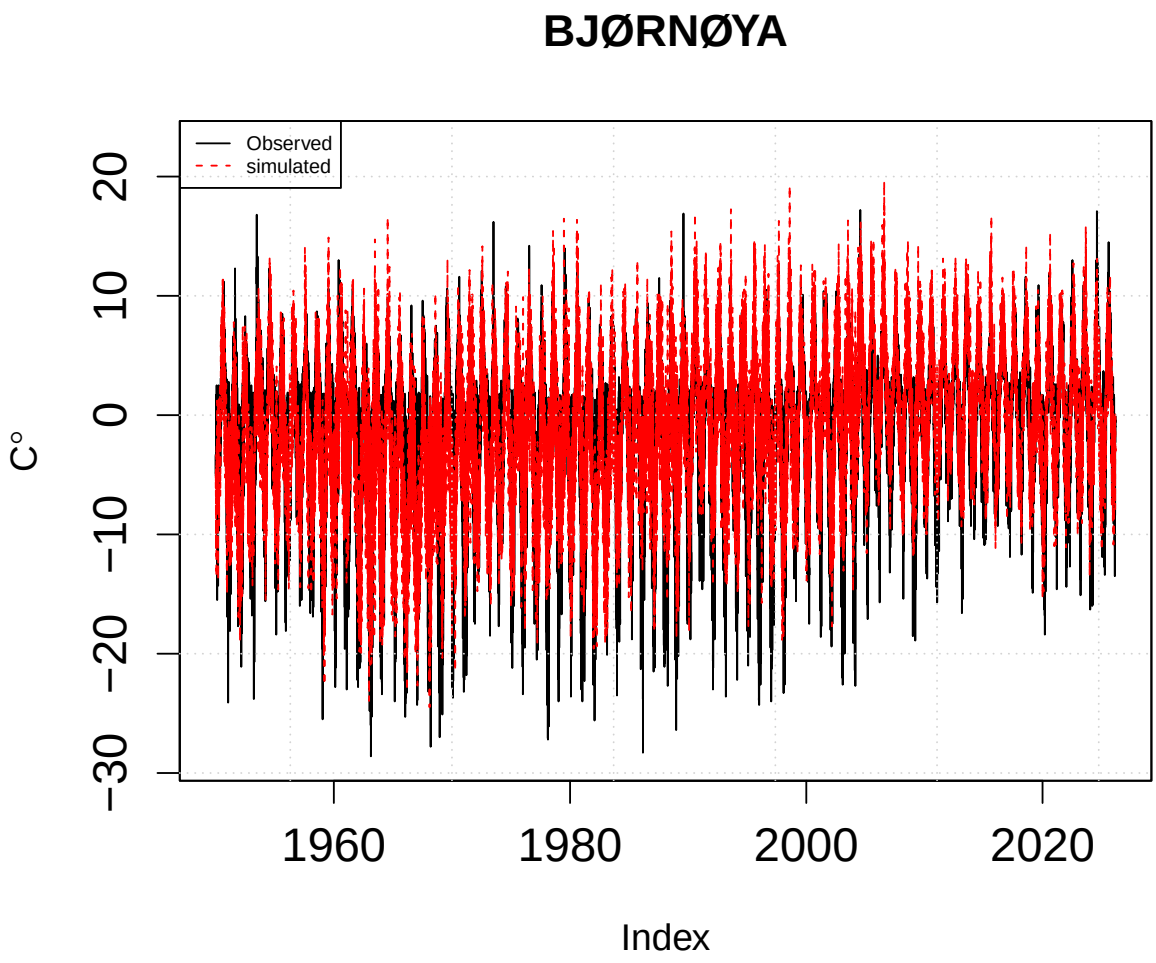


Figure 191: Evaluate WG on Norwegian temperature

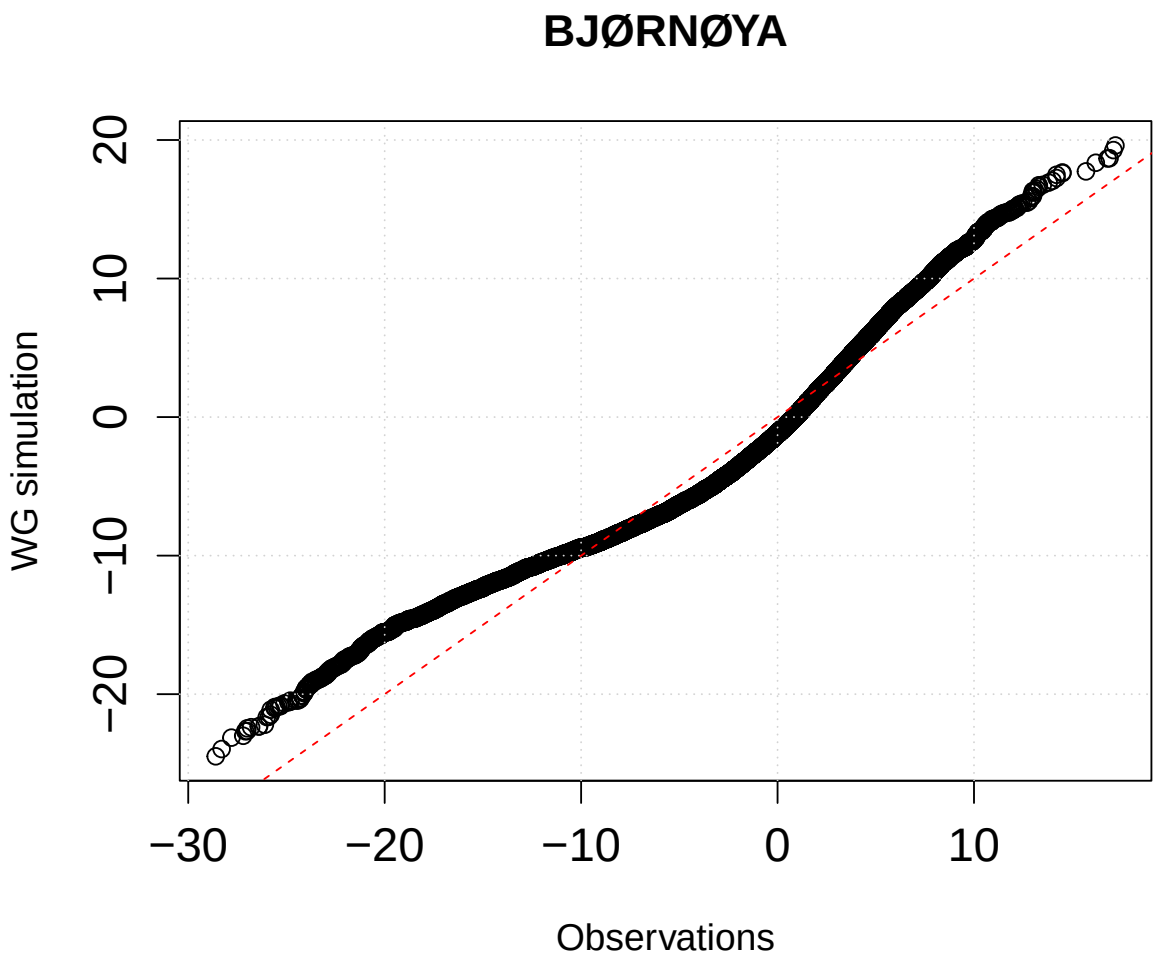


Figure 192: Evaluate WG on Norwegian temperature

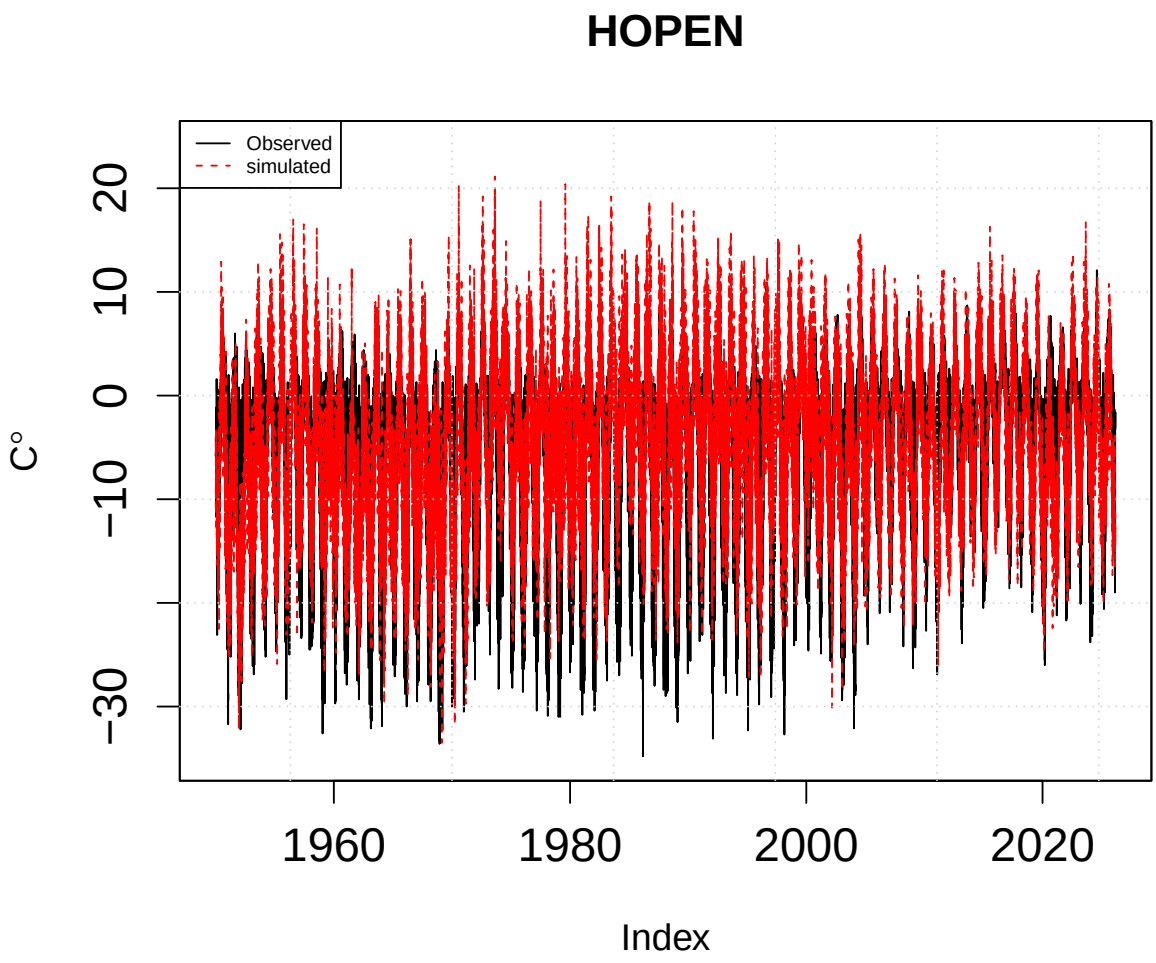


Figure 193: Evaluate WG on Norwegian temperature

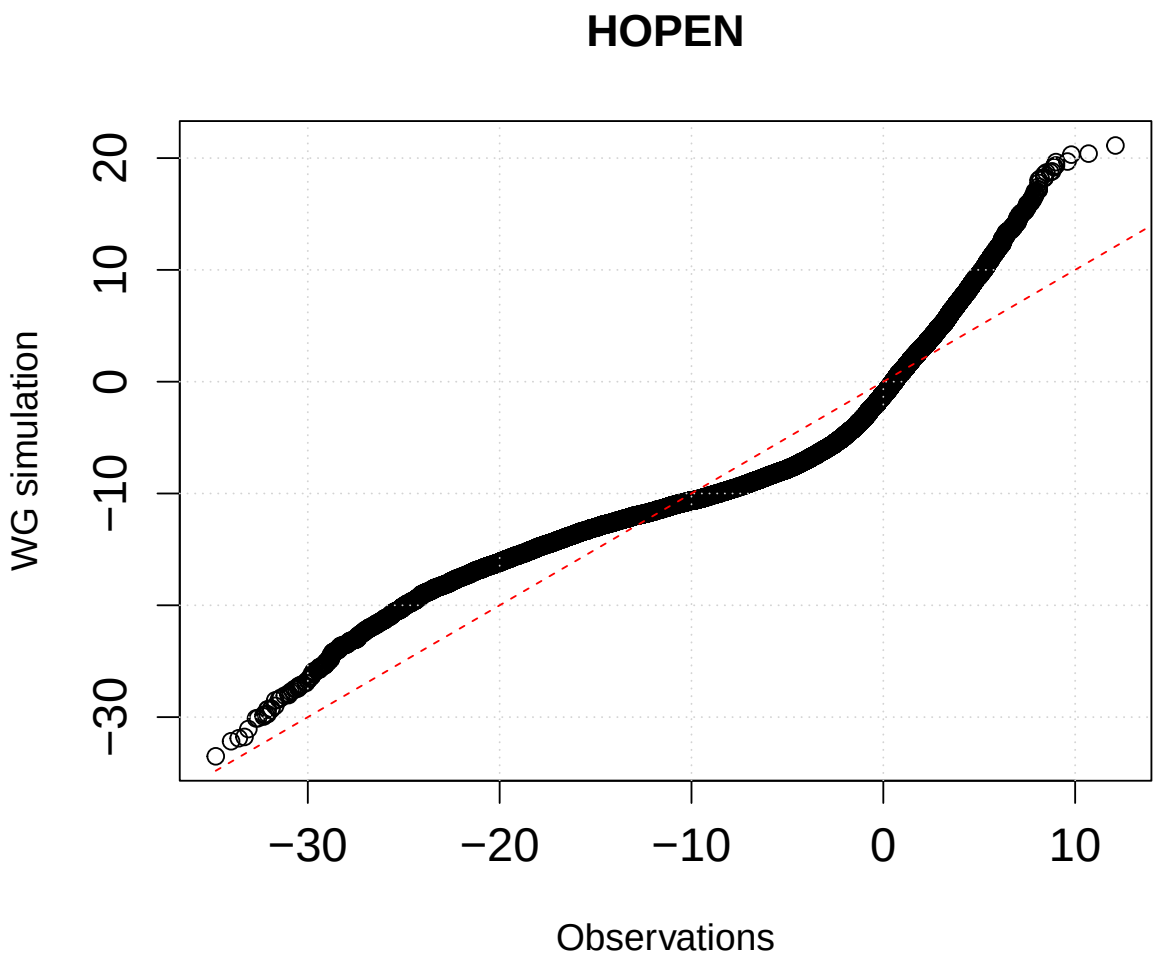


Figure 194: Evaluate WG on Norwegian temperature

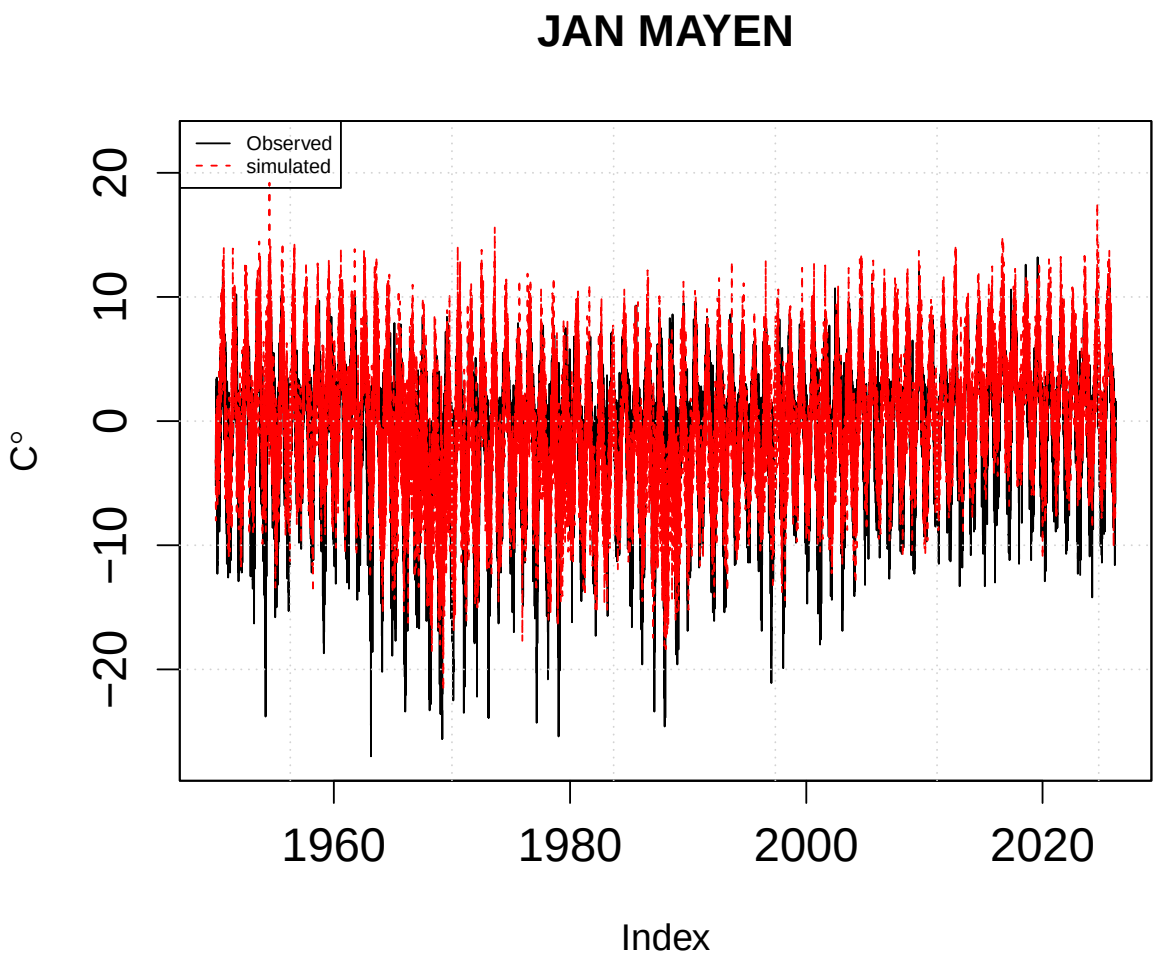


Figure 195: Evaluate WG on Norwegian temperature

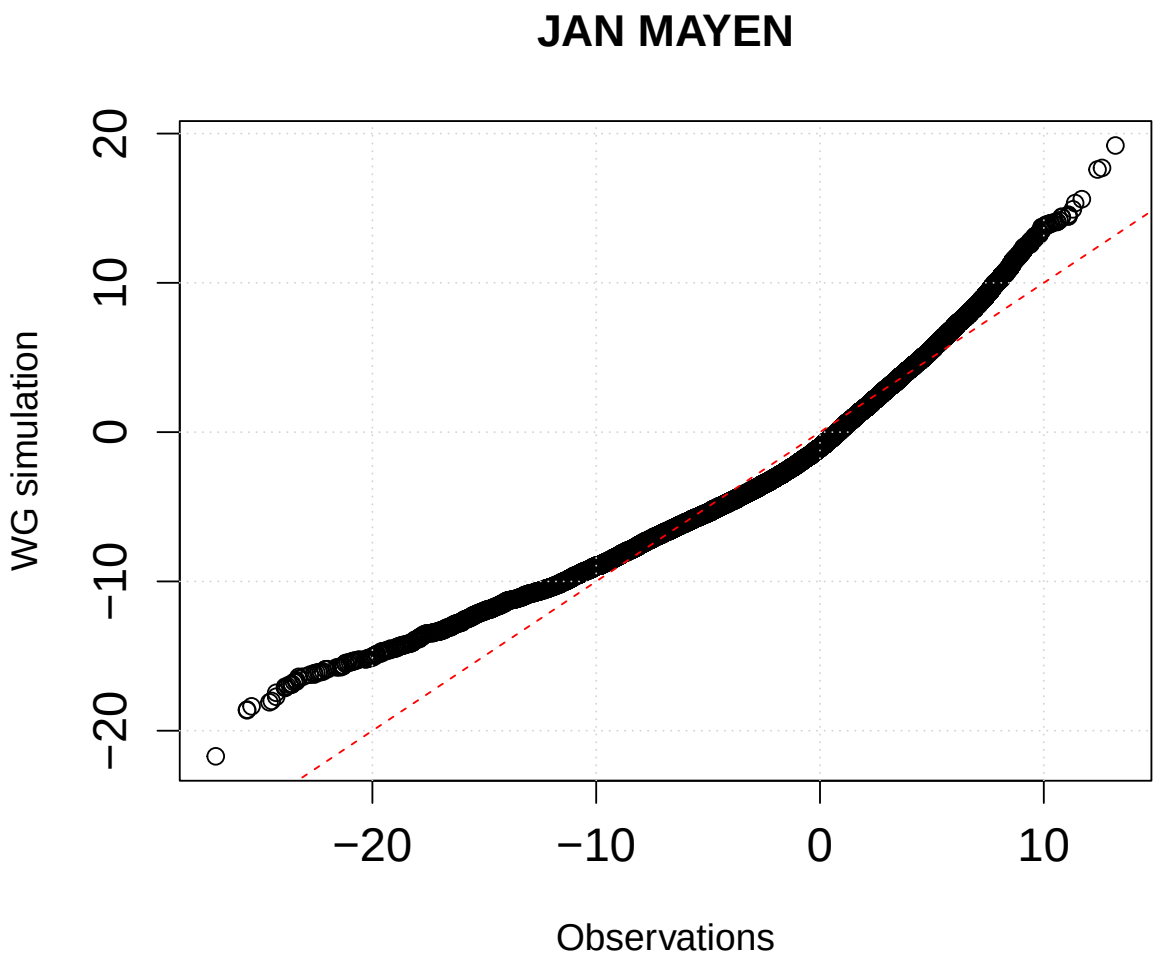


Figure 196: Evaluate WG on Norwegian temperature

The test of simple `WG` for the Norwegian daily temperatures yields variations between locations when it comes to matching the quantiles of the observations. For most sites, the anomalies are not exactly normally distributed, and this is a assumption made by this model in order to be able to simulate a climate change. One question is whether the match is sufficiently close for the need. The results for Tromsø appear to indicate a close match whereas there are deviations from the normal distributions in other locations.

References

Benestad, R., 2026. A simple weather generator that converts statistical information from downscaled global climate models to 24-hr precipitation input for hydrological models. https://doi.org/10.5194/egusphere-2026-351

Benestad, R.E., Chen, D., Mezghani, A., Fan, L., Parding, K., 2015. On using principal components to represent stations in empirical-statistical downscaling. Tellus A 67. https://doi.org/10.3402/tellusa.v67.28326

Benestad, R.E., Parding, K.M., Dobler, A., 2025. Downscaling the probability of heavy rainfall over the Nordic countries. Hydrology and Earth System Sciences 29, 45–65. https://doi.org/10.5194/hess-29-45-2025

Benestad, R.E., Parding, K.M., Erlandsen, H.B., Mezghani, A., 2019. A simple equation to study changes in rainfall statistics. Environmental Research Letters 14, 084017. https://doi.org/10.1088/1748-9326/ab2bb2

Benestad, R., Mezghani, A., 2026. Esd for Windows, Mac \& Linux. https://doi.org/10.6084/M9.FIGSHARE.1160493.V18

Gassman, P.W., Sadeghi, A.M., Srinivasan, R., 2014. Applications of the SWAT Model Special Section: Overview and Insights. Journal of Environmental Quality 43, 1–8. https://doi.org/10.2134/jeq2013.11.0466

Mezghani, A., Hingray, B., 2009. A combined downscaling-disaggregation weather generator for stochastic generation of multisite hourly weather variables over complex terrain: Development and multi-scale validation for the Upper Rhone River basin. J. Hydrol. 377, 245–260. https://doi.org/10.1016/j.jhydrol.2009.08.033