tropospheric-temperature

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Evaluation of tropospheric temperatures

This script compares tropospheric temperatures (TLT) simulated from gloal climate models (CMIP5) and data from satellites (MSU). When comparing model results to data derived from satellites, there are a number of issues to keep in mind. The satellite data provide a measure of the air teperature over a range of altitudes, and are also affected by the surface temperatures. Different vertical weights are used for data over ocean and land, respectively. To process the model results to mimic what really was observed by the sattelites, we need to apply these weights correctly.

The model results used here were only the zonal means, which makes it impossible to derive the exact results. However, it is possible to estiamte the fraction with land and fraction with ocean, and use a combined vertical weighting function with approporaite weight on land and ocean.

The global climate models (GCMs) provide results in the form of grid boxes, with latitude along one axis and pressure-level (vertical) along the other. The area of a latitude band near tthe equator is larger than a latitude band of the same width at higher latitude, due to earth's curvature (spherical shape). Hence, the global and tropical mean TLT must take into account the latitude-variable area and weight the model results accordingly.

Another issue is that different GCMs operate with different calendars, e.g. the Gregorian (which is used in the real world), 365-day calendar (no leap-year), and 360-day calendar. If this is not taken into account, the months in the future will end up in the wrong season.

R Markdown

This is an R Markdown document. Markdown 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.

```r
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

##
## Attaching package: 'esd'

## The following object is masked from 'package:base':
##
##     subset.matrix
```

CMIP5 simulations

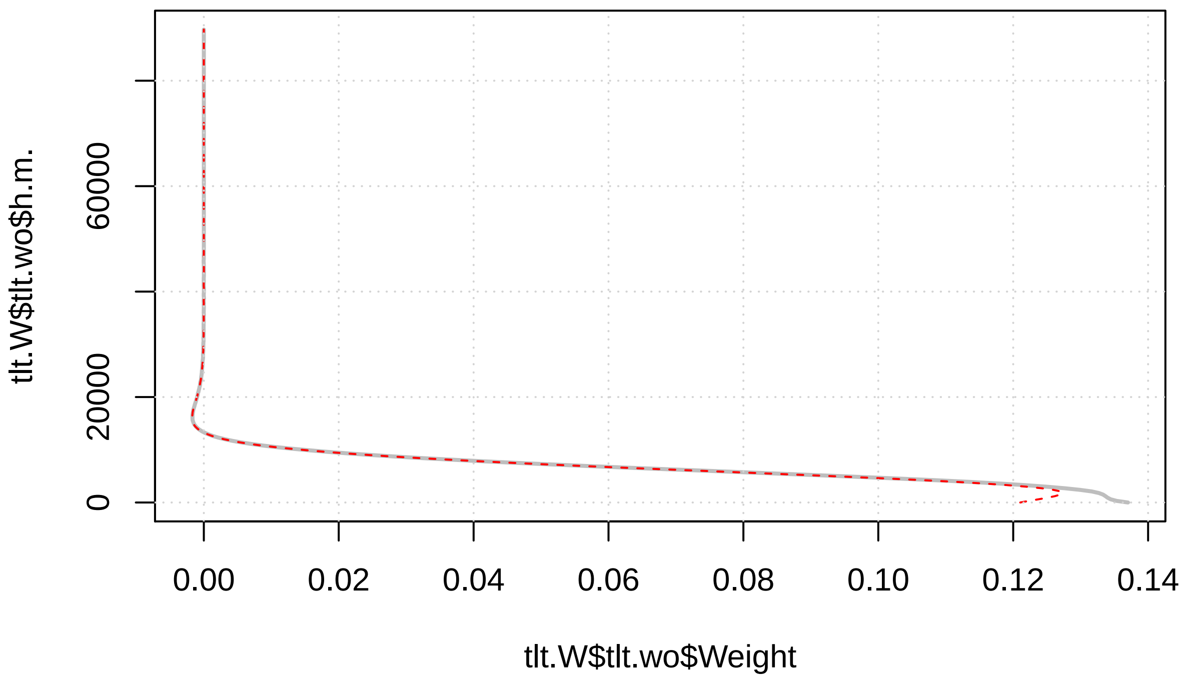
functions extracting the TLT

Vertical weigthing functions

Retrieve the weighting loads for the different heights corresponding to the TLT temperature. More on the vertical weighting function from http://www.remss.com/measurements/upper-air-temperature and http://tropic.ssec.wisc.edu/real-time/amsu/explanation.html.

```
if (!file.exists('tlt.W.rda')) {
  colnames <- c('level','h(m)','T(K)','P(pa)','PV(pa)','Weight')
  ## Weighting over land:
  ## Surface Weight                                   0.15104
  tlt.wl <- read.table('http://data.remss.com/msu/weighting_functions/std_atmosphere_wt_function_chan_tl
                 col.names = colnames)
  attr(tlt.wl,'Surface Weight') <- 0.15104
  ## Weighting over ocean
  ## Surface Weight                                   0.11863
  tlt.wo <- read.table('http://data.remss.com/msu/weighting_functions/std_atmosphere_wt_function_chan_tl
                 col.names=colnames)
  attr(tlt.wo,'Surface Weight') <- 0.11863
  tlt.W <- list(tlt.wl=tlt.wl,tlt.wo=tlt.wo)
  save(tlt.W,file='tlt.W.rda')
} else load('tlt.W.rda')
```

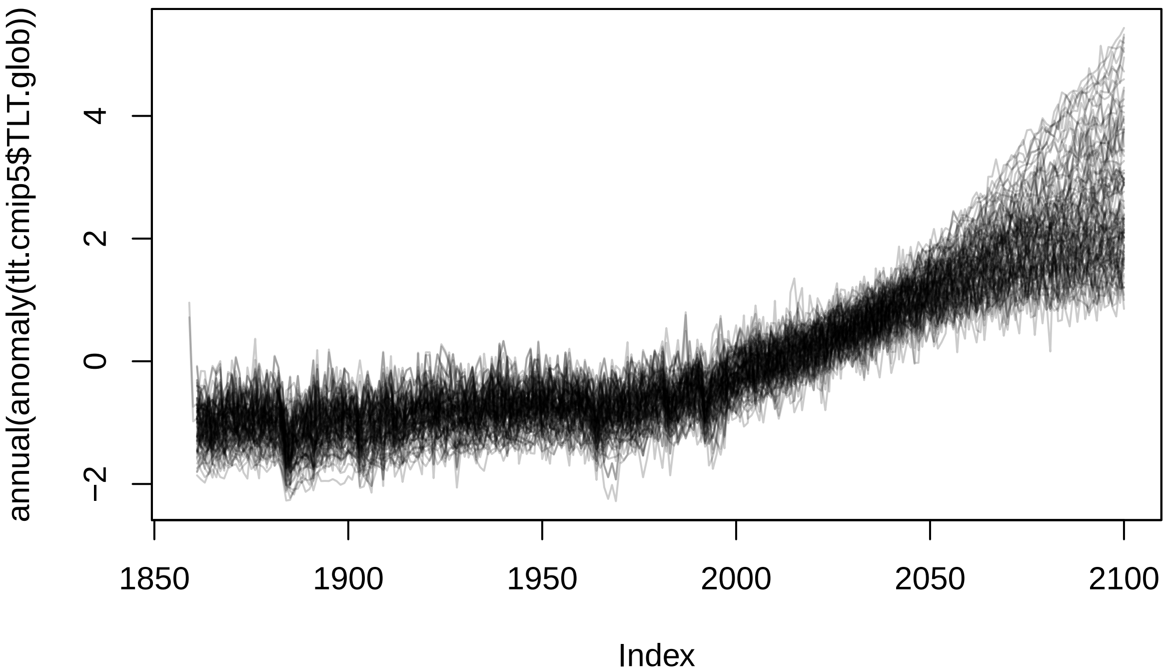
```
plot(tlt.W$tlt.wo$Weight,tlt.W$tlt.wo$h.m.,type='l',lwd=2,col='grey')
lines(tlt.W$tlt.wl$Weight,tlt.W$tlt.wl$h.m.,col='red',lty=2)
grid()
```



The air temperature needs to be weighted according to surface area (latitude) and height before it is aggregated to a product that is comparable to that of the satellite TLT.

```r
## Estimate area weighted mean temperature
areamean <- function(x,W.lat,d) {
  y <- x*c(W.lat)
  dim(y) <- c(d[1],d[2])
  z <- colSums(y,na.rm=TRUE)/sum(W.lat[,1],na.rm=TRUE)
  return(z)
}

ta2tlt <- function(fname,tlt.W,xlat=c(-90,90),varid='ta') {
  require(ncdf4)
  ncid <- nc_open(fname)
  X <- ncvar_get(ncid,varid)
  lat <- ncvar_get(ncid,'lat')
  plev <- ncvar_get(ncid,'plev')
  tim <- ncvar_get(ncid,'time')
  tunit <- ncatt_get(ncid,'time','units')
  model.id <- ncatt_get(ncid,0,'model_id')
  rcp <- ncatt_get(ncid,0,'experiment')
  ## Different GCMs use different calendars: 365-day, Gregorian, ets.
  calendar <- ncatt_get(ncid,'time','calendar')
  nc_close(ncid)
  ## Extract selected latitude band
  iy <- (lat >= min(xlat)) & (lat <= max(xlat))
  lat <- lat[iy]
  X <- X[iy,,]
  d <- dim(X)

  ## Area weights - latitude
  W.lat <- matrix(rep(cos(pi*lat/180),d[2]),d[1],d[2])
  ## Prepare for fast matrix operations
  dim(X) <- c(d[1]*d[2],d[3])
  ## Z contains the global mean temperature at different vertical levels
  Z <- apply(X,2,'areamean',W.lat,d)

  ## Estimate the TLT-temperature based on the TLT weights
  data(etopo5)
  etopo5 <- subset(etopo5,is=list(lat=xlat))
  ## Weighted average of land and ocean
  nl <- sum(etopo5 >=0)/length(etopo5); no <- sum(etopo5 <0)/length(etopo5)
  W0 <- no*tlt.W$tlt.wo$Weight + nl*tlt.W$tlt.wl$Weight
  W <- approx(tlt.W$tlt.wo$P.pa.,W0,plev,rule=2)$y

  tlt <- apply(Z,2,function(x,W) sum(x*W,na.rm=TRUE)/sum(W,na.rm=TRUE),W)

  ## Use the first time stamp and the time orgigin to set the first date, and then
  ## Assume every month since that (there are monthly mean data after all)
  t1 <- as.Date(tim[1],origin = sub('days since ','',tunit$value))
  TLT <- zoo(tlt, order.by=seq(t1,by='month',length.out=length(tim)))
  attr(TLT,'model_id') <- model.id
  attr(TLT,'rcp') <- rcp
  if (sum(is.finite(tlt))==0) browser()
  return(TLT)
}
```

Download CMIP5 data from the KNMI Climate Explorer and estimate the TLT temperature. The data is stored as zonal mean temperature with the dimensions latitude and pressure-level.



Data from satellites

Get the lower tropospheric data from the RSS:

```
if (!file.exists('RSS.glob.rda')) {
  rss.glob <- read.table('http://data.remss.com/msu/graphics/TLT/time_series/RSS_TS_channel_TLT_Global_L
  rss.trop <- read.table('http://data.remss.com/msu/graphics/TLT/time_series/RSS_TS_channel_TLT_Tropics_
  rss.glob$V3[rss.glob$V3 <= -99] <- NA
  RSS.glob <- zoo(rss.glob$V3,order.by=as.Date(paste(rss.glob$V1,rss.glob$V2,'01',sep='-')))
  rss.trop$V3[rss.trop$V3 <= -99] <- NA
  RSS.trop <- zoo(rss.trop$V3,order.by=as.Date(paste(rss.trop$V1,rss.trop$V2,'01',sep='-')))
  save(RSS.glob,file='RSS.glob.rda')
  save(RSS.trop,file='RSS.trop.rda')
} else {load('RSS.glob.rda'); load('RSS.trop.rda')}
```

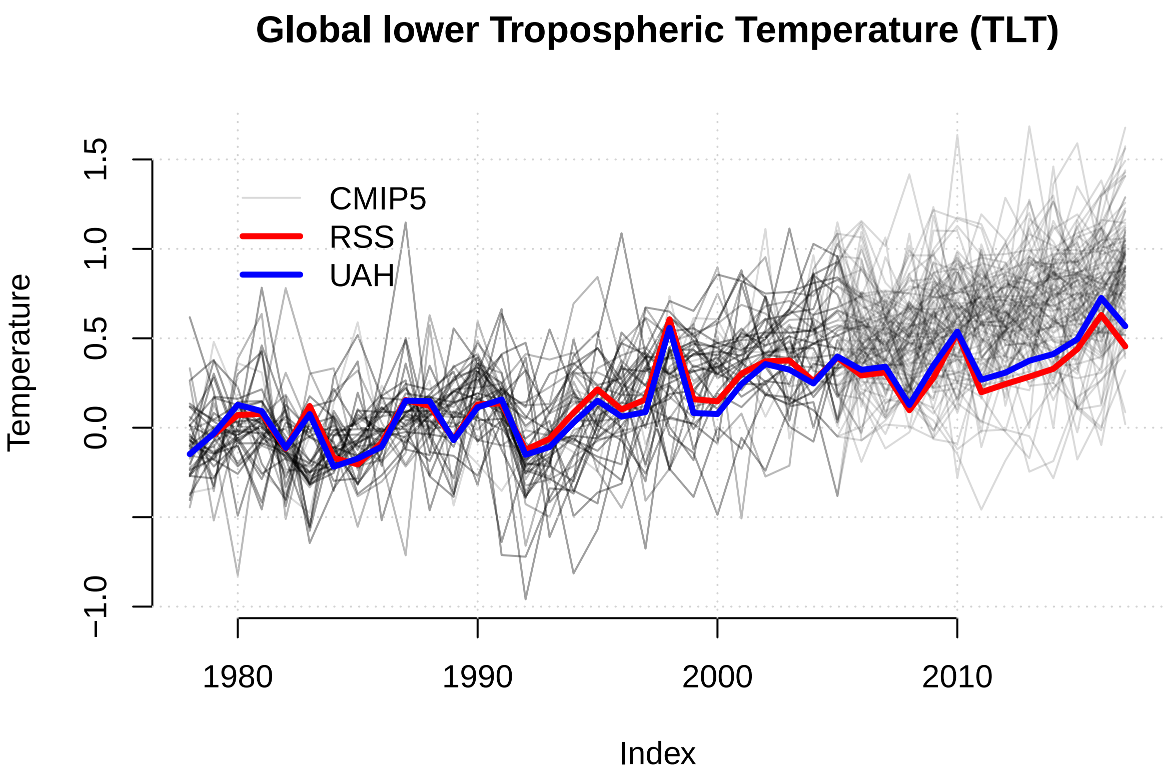
University of Alabama Huntsville

```
if (!file.exists('UAH.glob.rda')) {
  UAH <- readLines('http://www.nsstc.uah.edu/data/msu/t2lt/tltglhmam_5.6.txt')
  writeLines(UAH[-length(UAH)],con='UAHTLT.dat')
  uah <- read.table('UAHTLT.dat',skip=4,header=TRUE)
  UAH.glob <- zoo(uah$GLOBAL,order.by=as.Date(paste(uah$YEAR,uah$MON,'01',sep='-')))
  UAH.trop <- zoo(uah$TRPC,order.by=as.Date(paste(uah$YEAR,uah$MON,'01',sep='-')))
  save(UAH.glob,file='UAH.glob.rda')
  save(UAH.trop,file='UAH.trop.rda')
} else {load('UAH.glob.rda'); load('UAH.trop.rda')}
```

Comapre the data

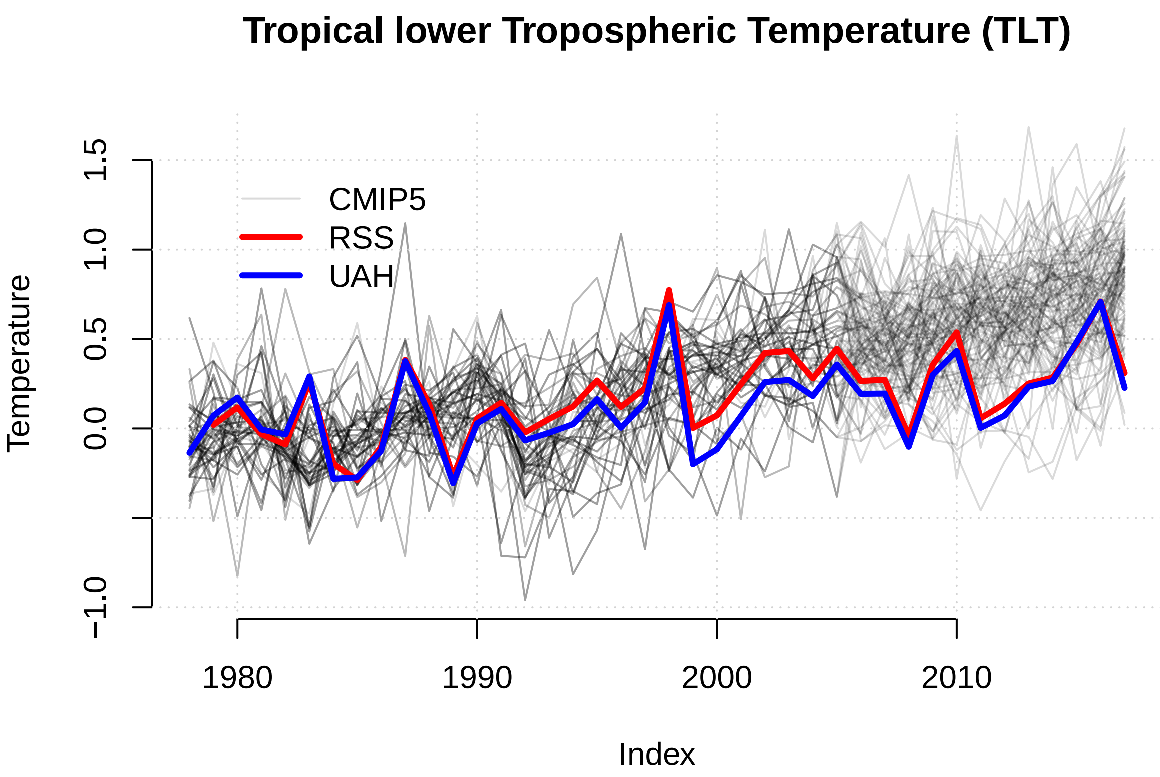
The global mean TLT temperature

```
X <- merge(annual(anomaly(RSS.glob,ref=1979:1990)),
           annual(anomaly(UAH.glob,ref=1979:1990)),
           annual(anomaly(window(tlt.cmip5$TLT.glob,start=start(RSS.glob),end=end(RSS.glob)),ref=1979:1
par(bty='n')
plot(X[,-c(1,2)],plot.type='single',col=rep(rgb(0,0,0,0.15),N),main='Global lower Tropospheric Temperat
grid()
lines(X[,1],lwd=3,col='red')
lines(X[,2],lwd=3,col='blue')
legend(1979,1.5,c('CMIP5','RSS','UAH'),col=c(rgb(0,0,0,0.15),'red','blue'),bty='n',lwd=c(1,3,3))
```



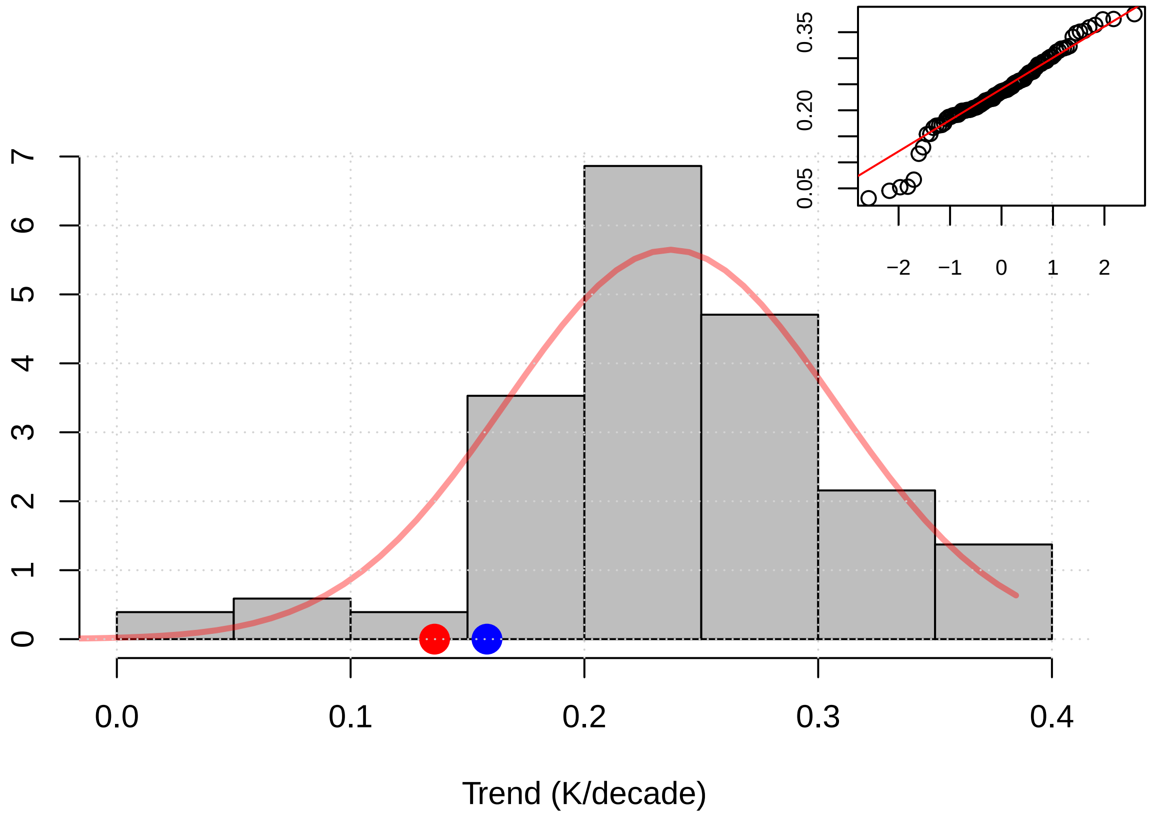
The global mean TLT temperature

```
X <- merge(annual(anomaly(RSS.trop,ref=1979:1990)),
           annual(anomaly(UAH.trop,ref=1979:1990)),
           annual(anomaly(window(tlt.cmip5$TLT.trop,start=start(RSS.trop),end=end(RSS.trop)),ref=1979:1
par(bty='n')
plot(X[,-c(1,2)],plot.type='single',col=rep(rgb(0,0,0,0.15),N),main='Tropical lower Tropospheric Tempera
grid()
lines(X[,1],lwd=3,col='red')
lines(X[,2],lwd=3,col='blue')
legend(1979,1.5,c('CMIP5','RSS','UAH'),col=c(rgb(0,0,0,0.15),'red','blue'),bty='n',lwd=c(1,3,3))
```



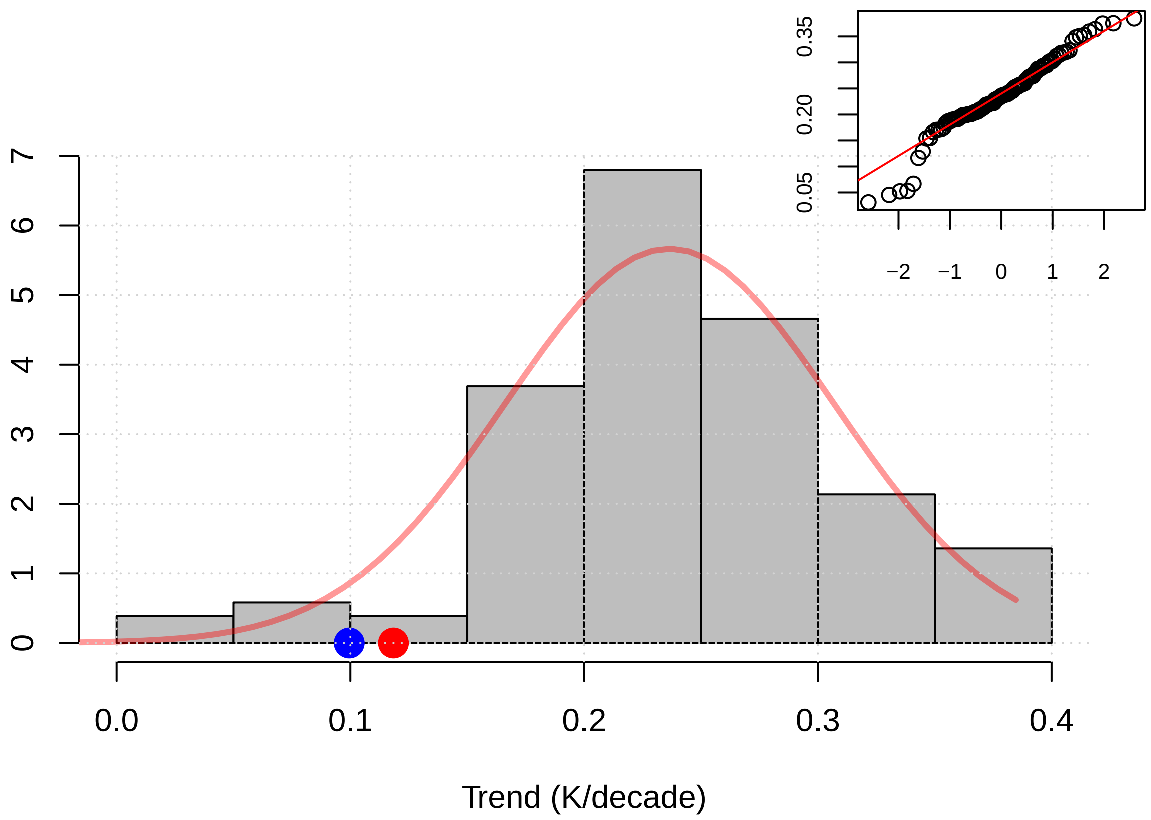
Global trend analysis

```
z <- apply(coredata(annual(anomaly(window(tlt.cmip5$TLT.glob,start=start(RSS.glob),end=end(RSS.glob)),r
h <- hist(z,col='grey',freq=FALSE,main='',ylab='',
          xlab='Trend (K/decade)')
x <- seq(-max(abs(z)),max(abs(z)),length=100)
lines(x,dnorm(x,mean=mean(z),sd=sd(z)),lwd=3,col=rgb(1,0,0,0.4))
points(trend.coef(annual(anomaly(RSS.glob,ref=1979:1990))),0,pch=19,cex=2,col='red')
points(trend.coef(annual(anomaly(UAH.glob,ref=1979:1990))),0,pch=19,cex=2,col='blue')
grid()
par(new=TRUE,fig=c(0.75,0.98,0.75,0.98),mar=rep(0,4),cex.axis=0.7)
qqnorm(z,main=''); qqline(z,col='red')
```



Tropics trend analysis

```
z <- apply(coredata(annual(anomaly(window(tlt.cmip5$TLT.trop,start=start(RSS.trop),end=end(RSS.trop)),re
h <- hist(z,col='grey',freq=FALSE,main='',ylab='',
          xlab='Trend (K/decade)')
x <- seq(-max(abs(z)),max(abs(z)),length=100)
lines(x,dnorm(x,mean=mean(z),sd=sd(z)),lwd=3,col=rgb(1,0,0,0.4))
points(trend.coef(annual(anomaly(RSS.trop,ref=1979:1990))),0,pch=19,cex=2,col='red')
points(trend.coef(annual(anomaly(UAH.trop,ref=1979:1990))),0,pch=19,cex=2,col='blue')
grid()
par(new=TRUE,fig=c(0.75,0.98,0.75,0.98),mar=rep(0,4),cex.axis=0.7)
qqnorm(z,main=''); qqline(z,col='red')
```



0.35
0.20
0.05
−2
−1
0
1
2
7
6
5
4
3
2
1
0
0.0
0.1
0.2
0.3
0.4
Trend (K/decade)