SST MHW Simulations - COCMWT

August 2023

This analysis is focused on modeling effects of trends in SST mean and variance following Oliver 2019. The site is at the former location of NOAA NDBC CHLV2, east of the mouth of Chesapeake Bay. The record extends from 1982-2021 (40 years).

This block reads in data.

```
library(lubridate)
```

```
##
## Attaching package: 'lubridate'
```

```
## The following objects are masked from 'package:base':
##
##     date, intersect, setdiff, union
```

```
XDdf=read.csv("SST_COC_CBW_Aug2023.csv") #meas WT avgd over LST
Xdf=data.frame(XDdf$COCMWT) #COCMeas WTDA
dt=mdy(XDdf$dt)
dd=decimal_date(dt)
Ddf=data.frame(dt,dd,year(dt),month(dt),day(dt))
colnames(Ddf)=c("Date","DecY","Y","M","D")
```

Check lengths

```
LD=length(Ddf$Y)
ild=which(Ddf$M==2&Ddf$D==29)
if (length(ild)>0) Ddf=Ddf[-ild,]
YV=unique(Ddf$Y)
NY=length(YV)

NR=length(Ddf$Y)
LX=dim(Xdf)[1]
print(c(NY,NR,LX,LD))
```

```
## [1]    40 14600 14610 14610
```

```
if(LX==LD & length(ild>0)) Xdf=Xdf[-ild,]
if(LX!=LD & LX!=NR) print (c("input dataframes not same length"))
```

Run marine heatwave code heatwaveR

```
library(heatwaveR)
Hdf=data.frame(Ddf$Date,Xdf)
colnames(Hdf)=c("t","temp")
YHdf=Hdf; YHdf$Y=Ddf$Y; YHdf$DecY=Ddf$DecY
Xclim=ts2clm(Hdf,climatologyPeriod = c("1987-01-01", "2016-12-31"), clmOnly=TRUE)
Xthresh=Xclim$thresh[-60]  #ignore leapday; MHW threshold
XthV=rep(Xthresh,NY)
Xseas=Xclim$seas[-60]  #ignore leapday; climatology
XsV=rep(Xseas,NY)
YHdf$tmseas=Hdf$temp-XsV
SSTAnom=YHdf$tmseas  #SST anomaly
```

Calculate statistics for time series (mean and variance)

```
#calculate annual mean SST
Xmean=aggregate(YHdf$temp ~ YHdf$Y, FUN=mean, na.action=na.pass)
colnames(Xmean)=c("Y","Tmean")
XMM=t.test(Xmean$Tmean, na.rm=TRUE)  #confint on mean SST
fitmS=lm(YHdf$tmseas ~ YHdf$DecY)  #trend on daily SST anomaly
trend=fitmS$coefficients[1]+fitmS$coefficients[2]*YHdf$DecY
YHdf$tdT=YHdf$tmseas-trend #detrend SST time series
#calculate annual variance
Xvar=aggregate(YHdf$tdT ~ YHdf$Y, FUN=var, na.action=na.pass)
colnames(Xvar)=c("Y","Tvar")
XVM=t.test(Xvar$Tvar, na.rm=TRUE)  #confint on mean variance
fitam=lm(Xmean$Tmean~Xmean$Y) #trend on annual mean SST
print(paste("ann mean SST =", format(XMM$estimate,digits=3),"+/-",format(XMM$conf.int[2]
-XMM$estimate,digits=1)))
```

```
## [1] "ann mean SST = 15.9 +/- 0.2"
```

```
print(paste("ann mean SST trend =",format(fitam$coefficients[2],  digits=3),"+/-",format
(confint(fitam)[2,2]-fitam$coefficients[2], digits=3)))
```

```
## [1] "ann mean SST trend = 0.0298 +/- 0.0161"
```

```
print(paste("p = ", format(summary(fitam)$coefficients[2,4],digits=3)))
```

```
## [1] "p =  0.000575"
```

```
fitav=lm(Xvar$Tvar~Xvar$Y)  #trend on annual variance
print(paste("ann SST var =", format(XVM$estimate,digits=3),"+/-",format(XVM$conf.int[2]-
XVM$estimate,digits=2)))
```

```
## [1] "ann SST var = 2.14 +/- 0.31"
```

```
print(paste("ann SST var trend =",format(fitav$coefficients[2],  digits=3),"+/-",format
(confint(fitav)[2,2]-fitav$coefficients[2], digits=3)))
```

```
## [1] "ann SST var trend = 0.0238 +/- 0.0257"
```

```
print(paste("p = ", format(summary(fitav)$coefficients[2,4],digits=3)))
```

```
## [1] "p =  0.0689"
```

Calculate MHW stats

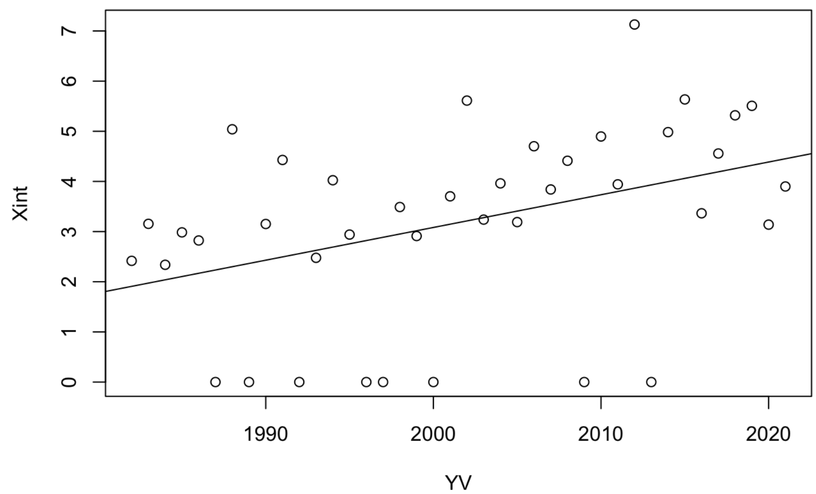
```
Xhi=rep(0,NR); N28=Xhi
Xhi[(Hdf$temp-XthV)>0]=1
N28[Hdf$temp>=28]=1
a28=aggregate(N28 ~ Ddf$Y, FUN=sum, na.action=na.pass)
colnames(a28)=c("Y","abv28")
Xa28=rep(0,length(YV))
Xa28[a28$Y-YV[1]+1]=a28$abv28
frachi=sum(Xhi)/NR
dX=diff(Xhi)
nd = which(dX==1)
np = which(dX==-1)
if (np[1]<nd[1]) np=np[-1]
if (length(np) != length(nd)) nd=nd[-length(nd)]
durXHi=np-nd
n5=which(durXHi>=5)

Dexp=aggregate(durXHi[n5] ~ Ddf$Y[nd[n5]], FUN=sum, na.action=na.pass)
Ddur=aggregate(durXHi[n5] ~ Ddf$Y[nd[n5]], FUN=mean, na.action=na.pass)
colnames(Dexp)=c("Y","expMHW")
colnames(Ddur)=c("Y","durMHW")
Xexp=rep(0,length(YV))
Xexp[Dexp$Y-YV[1]+1]=Dexp$expMHW
Xdur=rep(0,length(YV))
Xdur[Ddur$Y-YV[1]+1]=Ddur$durMHW

inten=rep(0,length(n5))
for (k in 1:length(n5)){
  inten[k]=max(SSTAnom[nd[n5[k]]:np[n5[k]]])
}
Dint=aggregate(inten ~ Ddf$Y[nd[n5]], FUN=max, na.action=na.pass)
colnames(Dint)=c("Y","intMHW")
Xint=rep(0,length(YV))
Xint[Dint$Y-YV[1]+1]=Dint$intMHW

Dmhw=aggregate(nd[n5] ~ Ddf$Y[nd[n5]], FUN=NROW, na.action=na.pass)
colnames(Dmhw)=c("Y","nMHW")
Xmhw=rep(0,length(YV))
Xmhw[Dmhw$Y-YV[1]+1]=Dmhw$nMHW
```

Print and plot MHW intensity mean and trend

```
plot(YV,Xint)
ciint=t.test(Xint, na.rm=TRUE)
print(paste("mean ann MHW intensity =", format(ciint$estimate,digits=3),"+/-",format(cii
nt$conf.int[2]-ciint$estimate,digits=3)))
```

```
## [1] "mean ann MHW intensity = 3.18 +/- 0.607"
```

```
fitint = lm(Xint ~ YV)
pint = summary(fitint)$coefficients[2,4]
if (pint<0.05) abline(fitint)
```




```
print(paste("ann MHW int trend =",format(fitint$coefficients[2],  digits=3),"+/-",format
(confint(fitint)[2,2]-fitint$coefficients[2], digits=3)))
```

```
## [1] "ann MHW int trend = 0.0652 +/- 0.0489"
```

```
print(paste("p = ", format(pint,digits=3)))
```

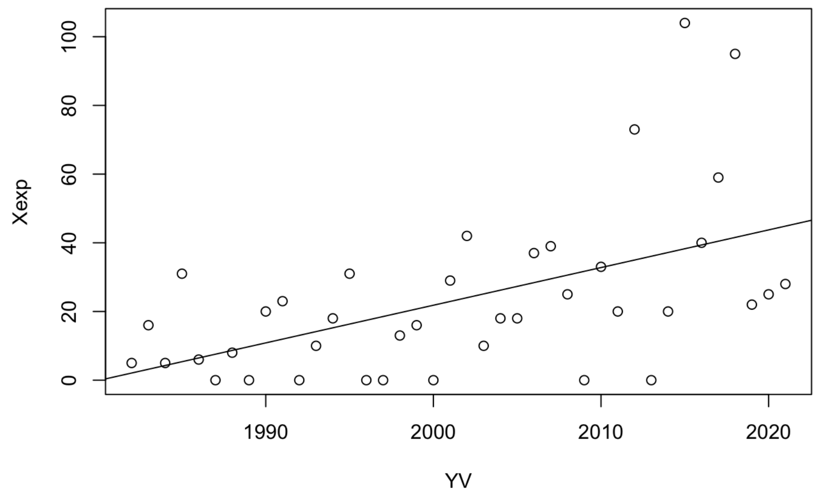
```
## [1] "p =  0.0102"
```

Print and plot MHW exposure mean and trend

```
plot(YV,Xexp)
ciexp=t.test(Xexp, na.rm=TRUE)
print(paste("mean ann MHW exposure =", format(ciexp$estimate,digits=3),"+/-",format(ciex
p$conf.int[2]-ciexp$estimate,digits=3)))
```

```
## [1] "mean ann MHW exposure = 23.5 +/- 7.76"
```

```
fitexp = lm(Xexp ~ YV)
pexp = summary(fitexp)$coefficients[2,4]
if (pexp<0.05) abline(fitexp)
```




```
print(paste("ann MHW exp trend =",format(fitexp$coefficients[2],  digits=3),"+/-",format
(confint(fitexp)[2,2]-fitexp$coefficients[2], digits=3)))
```

```
## [1] "ann MHW exp trend = 1.1 +/- 0.579"
```

```
print(paste("p = ", format(pexp,digits=3)))
```

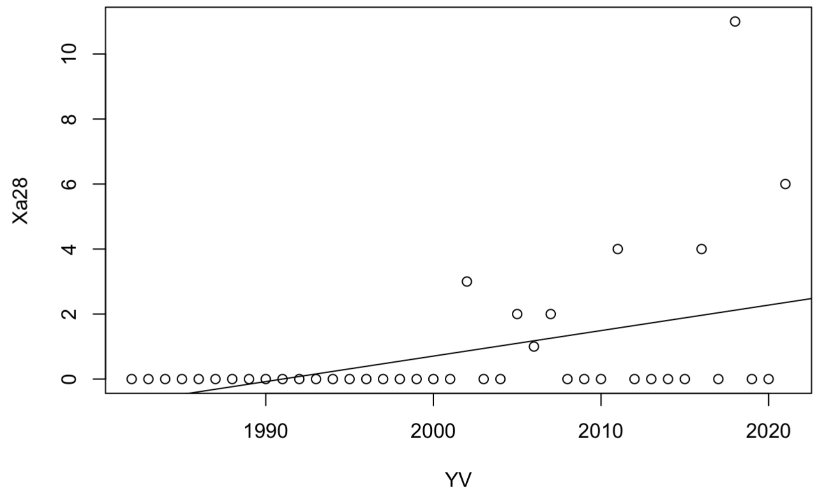
```
## [1] "p =  0.000455"
```

Print and plot SST >=28C mean and trend

```
plot(YV,Xa28)
cia28=t.test(Xa28, na.rm=TRUE)
print(paste("mean days >= 28C =", format(cia28$estimate,digits=3),"+/-",format(cia28$con
f.int[2]-cia28$estimate,digits=3)))
```

```
## [1] "mean days >= 28C = 0.825 +/- 0.687"
```

```
fita28 = lm(Xa28 ~ YV)
pa28 = summary(fita28)$coefficients[2,4]
if (pa28<0.05) abline(fita28)
```




```
print(paste("SST >= 28C trend =",format(fita28$coefficients[2],  digits=3),"+/-",format
(confint(fita28)[2,2]-fita28$coefficients[2], digits=3)))
```

```
## [1] "SST >= 28C trend = 0.0785 +/- 0.0545"
```

```
print(paste("p = ", format(pa28,digits=3)))
```

```
## [1] "p =  0.00593"
```

Print and plot MHW duration mean and trend

```
plot(YV,Xdur)
```

```r
cidur=t.test(Xdur, na.rm=TRUE)
print(paste("mean ann MHW duration =", format(cidur$estimate,digits=3),"+/-",format(cidu
r$conf.int[2]-cidur$estimate,digits=3)))
```

```
## [1] "mean ann MHW duration = 7.63 +/- 1.88"
```

```r
fitdur = lm(Xdur ~ YV)
pdur = summary(fitdur)$coefficients[2,4]
if (pdur<0.05) abline(fitdur)
print(paste("MHW duration trend =", format(fitdur$coefficients[2],  digits=3),"+/-",form
at(confint(fitdur)[2,2]-fitdur$coefficients[2], digits=3)))
```

```
## [1] "MHW duration trend = 0.121 +/- 0.16"
```

```r
print(paste("p = ", format(pdur,digits=3)))
```

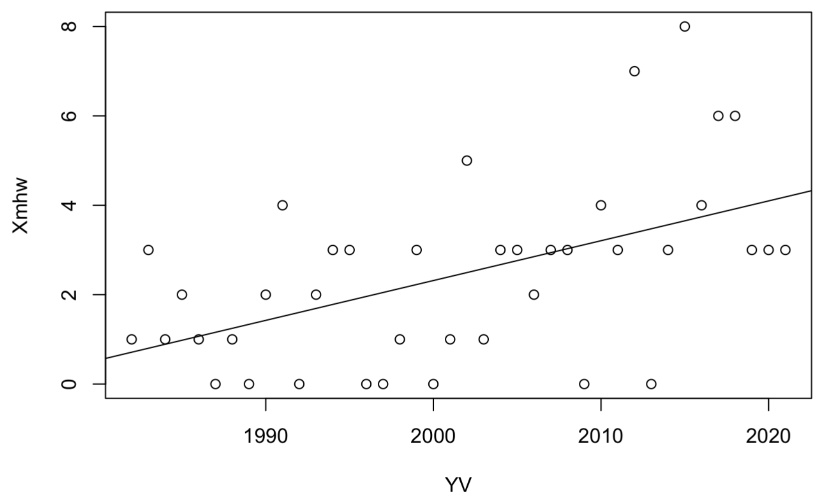
```
## [1] "p =  0.134"
```

Print and plot MHW number mean and trend

```r
plot(YV,Xmhw)
cimhw=t.test(Xmhw, na.rm=TRUE)
print(paste("mean ann # MHWs =", format(cimhw$estimate,digits=3),"+/-",format(cimhw$con
f.int[2]-cimhw$estimate,digits=3)))
```

```
## [1] "mean ann # MHWs = 2.45 +/- 0.644"
```

```r
fitmhw = lm(Xmhw ~ YV)
pmhw = summary(fitmhw)$coefficients[2,4]
if (pmhw<0.05) abline(fitmhw)
```




```
print(paste("Ann # MHWs trend =",format(fitmhw$coefficients[2],  digits=3),"+/-",format
(confint(fitmhw)[2,2]-fitmhw$coefficients[2], digits=3)))
```

```
## [1] "Ann # MHWs trend = 0.0891 +/- 0.0484"
```

```
print(paste("p = ", format(pmhw,digits=3)))
```

```
## [1] "p =  0.000622"
```

Save values for plotting

```
M = rbind(Xexp,Xint,Xdur,Xa28,Xmhw)
#write.csv(M,"MHWCV.csv")
```

Calculate parameters for autoregressive model ala Oliver 2019

```
fitL=lm(YHdf$tdT[2:NR]~YHdf$tdT[1:(NR-1)])
slope=as.numeric(fitL$coefficients[2])
sig_e=sd(fitL$residuals)
tau=-1/log(slope)

print(c(slope,sig_e,tau))
```

```
## [1]  0.9162736  0.6270785 11.4363804
```

Calculate 500 instances of SST time series using autoregressive model with parameters slope and se from above.

```
NS=500  #number of simulations
NR=length(Ddf$Y)
YV=unique(Ddf$Y)
NY=length(YV)
Q=matrix(0,nrow=NR,ncol=NS)

for (j in 1:NS){
  Er = rnorm(NR,mean=0,sd=sig_e)
  for (i in 2:NR) {Q[i,j] = slope*Q[i-1,j] + Er[i]}
}
```

Add trend and seasonal cycle back into time series.

```
Qt=Q+trend  #add trend from SST data
Qst=Qt+XsV   #add seasonal cycle to trend
Qs=Q+XsV  #add seasonal cycle w/o trend
XY=Ddf$Y
```

```
vQ=apply(Q,2,var)
summary(vQ)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   2.161   2.370   2.435   2.437   2.499   2.753
```

```
var(SSTAnom,na.rm=TRUE)
```

```
## [1] 2.56969
```

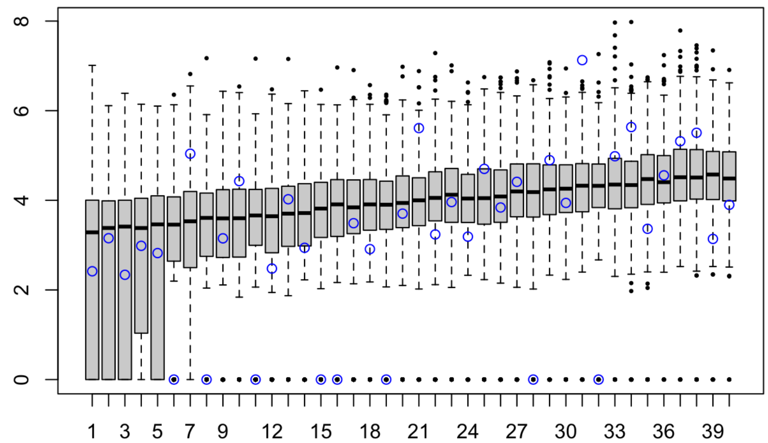
Calculate exposure and intensity for simulated SST with trend included.

```
Qexp=matrix(0,nrow=NY,ncol=NS); Qa28=Qexp; Qint=Qexp; Qdur=Qexp; Qmhw=Qexp
frachi = rep(0,NS); cnt = matrix(0, nrow=NS, ncol=50)
for (j in 1:NS) {
  Xhi=rep(0,NR); N28=Xhi
  Xhi[(Qst[,j]-XthV)>0]=1
  S1=rle(Xhi)$lengths; T1=rle(Xhi)$values
  U1=S1*T1;  E1=U1[-(which(U1==0))]
  evtab = table(factor(E1, levels=1:50))
  cnt[j,]=evtab
  frachi[j]=sum(Xhi)/NR
  dX=diff(Xhi)
  nd = which(dX==1)
  np = which(dX==-1)
  if (np[1]<nd[1]) np=np[-1]
  if (length(np) != length(nd)) nd=nd[-length(nd)]
  durXHi=np-nd
  n5=which(durXHi>=5)
  inten=rep(0,length(n5))
  for (k in 1:length(n5)){
    inten[k]=max(Qt[nd[n5[k]]:np[n5[k]],j])
  }
  Dint=aggregate(inten ~ XY[nd[n5]], FUN=max, na.action=na.pass)
  colnames(Dint)=c("Y","intMHW")
  Sint=rep(0,NY)
  Sint[Dint$Y-YV[1]+1]=Dint$intMHW
  Qint[,j]=Sint

  Dexp=aggregate(durXHi[n5] ~ XY[nd[n5]], FUN=sum, na.action=na.pass)
  colnames(Dexp)=c("Y","expMHW")
  Sexp=rep(0,NY)
  Sexp[Dexp$Y-YV[1]+1]=Dexp$expMHW
  Qexp[,j]=Sexp

  N28[Qst[,j]>=28]=1
  a28=aggregate(N28 ~ XY, FUN=sum, na.action=na.pass)
  colnames(a28)=c("Y","abv28")
  Sa28=rep(0,NY)
  Sa28[a28$Y-YV[1]+1]=a28$abv28
  Qa28[,j]=Sa28

  Ddur=aggregate(durXHi[n5] ~ XY[nd[n5]], FUN=mean, na.action=na.pass)
  colnames(Ddur)=c("Y","durMHW")
  Sdur=rep(0,NY)
  Sdur[Ddur$Y-YV[1]+1]=Ddur$durMHW
  Qdur[,j]=Sdur

  Dmhw=aggregate(nd[n5] ~ XY[nd[n5]], FUN=NROW, na.action=na.pass)
  colnames(Dmhw)=c("Y","nMHW")
  Smhw=rep(0,NY)
  Smhw[Dmhw$Y-YV[1]+1]=Dmhw$nMHW
```

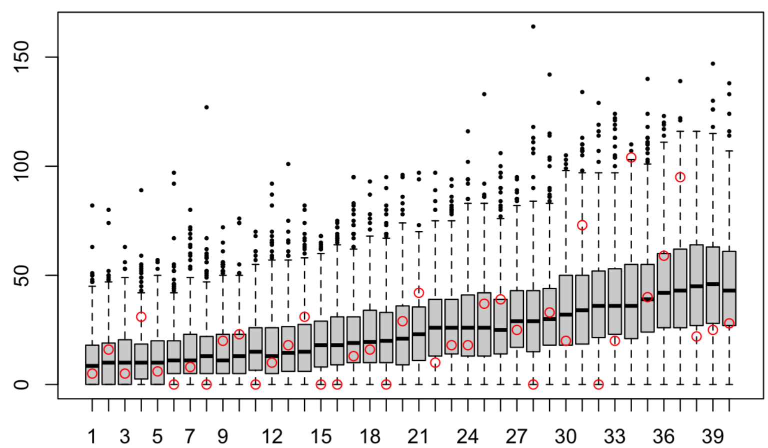
```
  Qmhw[,j]=Smhw
}
```

Plot simulation results

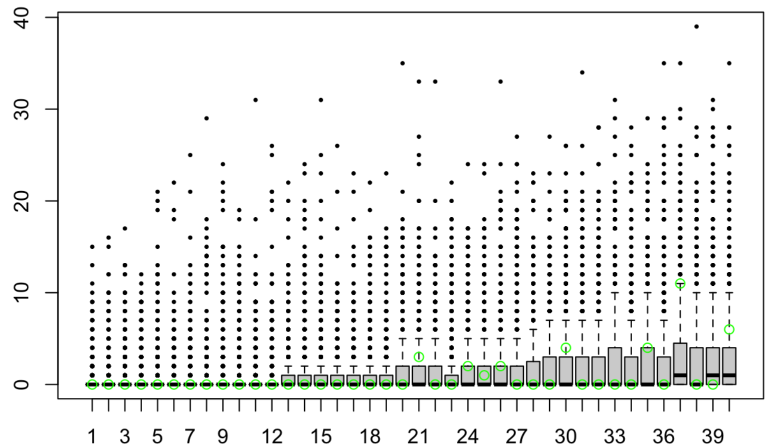
```
boxplot(t(Qint),outpch=20, outcex=0.5)
points(Xint,col="blue")  #intensity
```



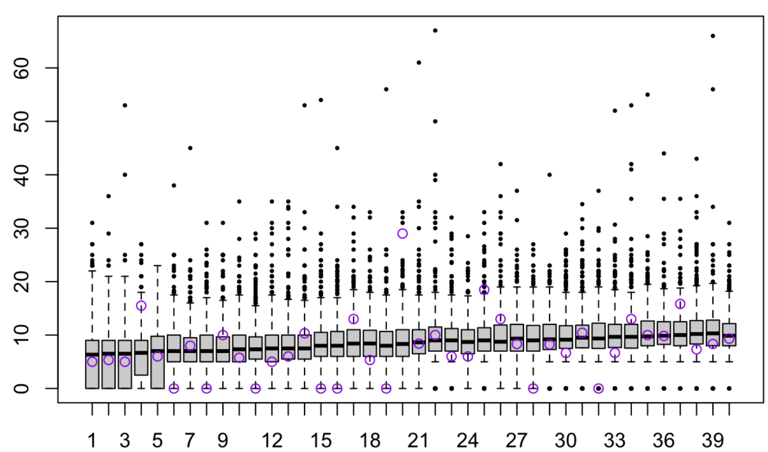

```
boxplot(t(Qexp),outpch=20, outcex=0.5)
points(Xexp,col="red")  #exposure
```



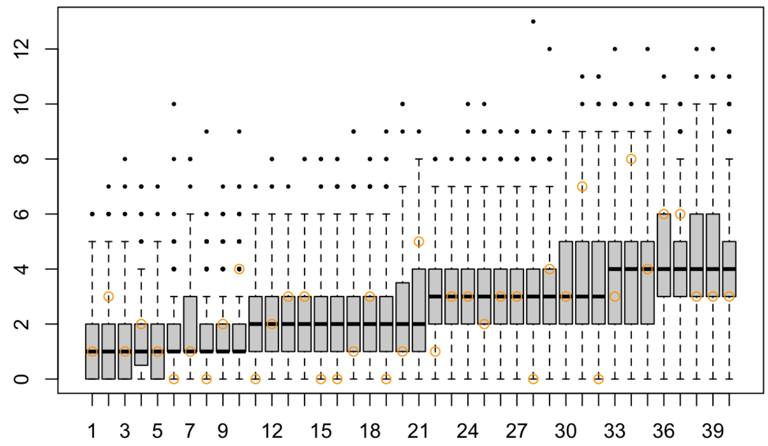

```
boxplot(t(Qa28),outpch=20, outcex=0.5)
points(Xa28,col="green")  #SST >=28C
```




```
boxplot(t(Qdur),outpch=20, outcex=0.5)
points(Xdur,col="purple")  #duration
```

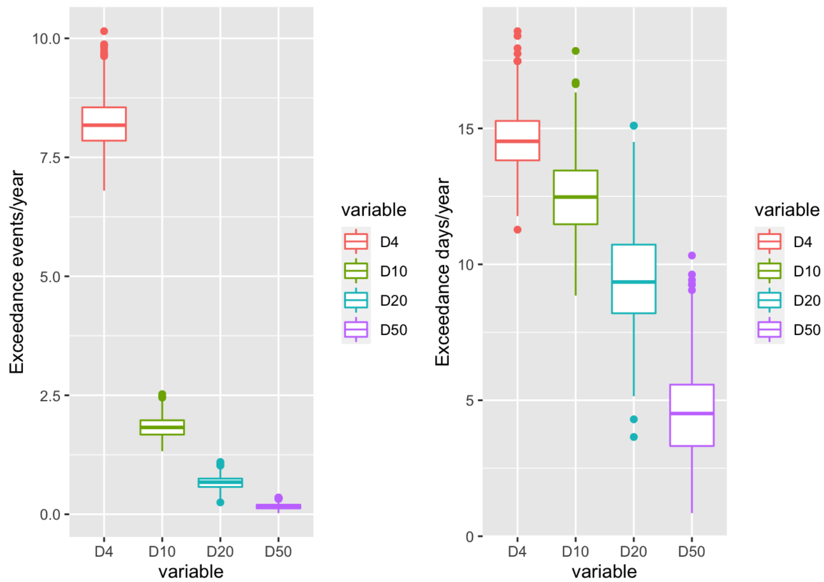



```
boxplot(t(Qmhw),outpch=20, outcex=0.5)
points(Xmhw,col="orange")  #number of MHWs
```



Calculate and plot exceedance events and durations

```
library(reshape2)
library(ggplot2)
library(patchwork)
mcnt = matrix(0, nrow=500, ncol=4); lcnt=mcnt
dcnt=cnt*matrix(rep(1:50,500), byrow=TRUE, nrow=500)
for (i in 1:500) {
  n4=sum(cnt[i,1:4])
  n10=sum(cnt[i,5:10])
  n20=sum(cnt[i,11:20])
  n50=sum(cnt[i,21:50])
  mcnt[i,]=c(n4,n10,n20,n50)
  d4=sum(dcnt[i,1:4])
  d10=sum(dcnt[i,5:10])
  d20=sum(dcnt[i,11:20])
  d50=sum(dcnt[i,21:50])
  lcnt[i,]=c(d4,d10,d20,d50)
}
cdf=data.frame(mcnt/NY)
colnames(cdf)=c("D4","D10","D20","D50")
cmdf=melt(cdf, id=NULL)
ddf=data.frame(lcnt/NY)
colnames(ddf)=c("D4","D10","D20","D50")
dmdf=melt(ddf, id=NULL)
g1=ggplot(data=cmdf, aes(x=variable, y=value, color=variable)) +
  geom_boxplot() +
  ylab("Exceedance events/year")
g2=ggplot(data=dmdf, aes(x=variable, y=value, color=variable)) +
  geom_boxplot() +
  ylab("Exceedance days/year")
print(g1+g2)
```




```
#write.csv(cbind(cdf,ddf),"EvCntCV.csv")
```

Extend simulations to 2100

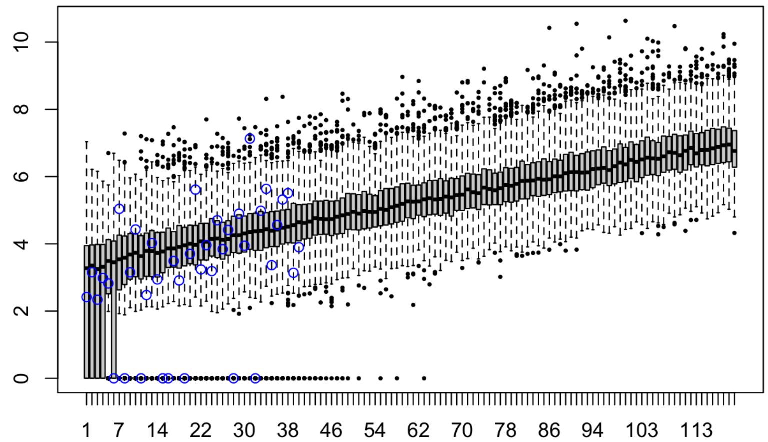
```
NS=500  #number of simulations
NY=120 #number of years
NR=NY*365 #record length in days
Z=matrix(0,nrow=NR,ncol=NS)
decY=0:(NY*365)/365+1982; decY=decY[-(length(decY))]
YMD=date_decimal(decY); YMD=as.Date(YMD); M=month(YMD);
ZY=year(YMD)
YV=unique(ZY)

for (j in 1:NS){
  Er = rnorm(NR,mean=0,sd=sig_e)
  for (i in 2:NR) {Z[i,j] = slope*Z[i-1,j] + Er[i]}
}

Ztrend=fitmS$coefficients[1]+fitmS$coefficients[2]*decY
ZsV=rep(Xseas,NY)
Zt=Z+Ztrend  #add trend from SST data
Zst=Zt+ZsV   #add seasonal cycle to trend
ZthV=rep(Xthresh,NY)
```

Calculate MHWs

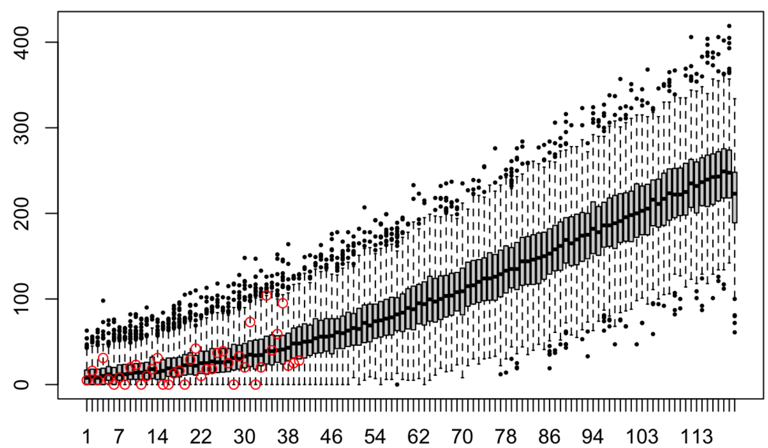
```r
Zexp=matrix(0,nrow=NY,ncol=NS); Za28=Zexp; Zint=Zexp; Zdur=Zexp; Zmhw=Zexp
frachi = rep(0,NS)
for (j in 1:NS) {
  Xhi=rep(0,NR); N28=Xhi
  Xhi[(Zst[,j]-ZthV)>0]=1
  frachi[j]=sum(Xhi)/NR
  dX=diff(Xhi)
  nd = which(dX==1)
  np = which(dX==-1)
  if (np[1]<nd[1]) np=np[-1]
  if (length(np) != length(nd)) nd=nd[-length(nd)]
  durXHi=np-nd
  n5=which(durXHi>=5)
  inten=rep(0,length(n5))
  for (k in 1:length(n5)){
    inten[k]=max(Zt[nd[n5[k]]:np[n5[k]],j])
  }
  Dint=aggregate(inten ~ ZY[nd[n5]], FUN=max, na.action=na.pass)
  colnames(Dint)=c("Y","intMHW")
  Sint=rep(0,NY)
  Sint[Dint$Y-YV[1]+1]=Dint$intMHW
  Zint[,j]=Sint

  Dexp=aggregate(durXHi[n5] ~ ZY[nd[n5]], FUN=sum, na.action=na.pass)
  colnames(Dexp)=c("Y","expMHW")
  Sexp=rep(0,NY)
  Sexp[Dexp$Y-YV[1]+1]=Dexp$expMHW
  Zexp[,j]=Sexp

  N28[Zst[,j]>=28]=1
  a28=aggregate(N28 ~ ZY, FUN=sum, na.action=na.pass)
  colnames(a28)=c("Y","abv28")
  Sa28=rep(0,NY)
  Sa28[a28$Y-YV[1]+1]=a28$abv28
  Za28[,j]=Sa28

  Ddur=aggregate(durXHi[n5] ~ ZY[nd[n5]], FUN=mean, na.action=na.pass)
  colnames(Ddur)=c("Y","durMHW")
  Sdur=rep(0,NY)
  Sdur[Ddur$Y-YV[1]+1]=Ddur$durMHW
  Zdur[,j]=Sdur

  Dmhw=aggregate(nd[n5] ~ ZY[nd[n5]], FUN=NROW, na.action=na.pass)
  colnames(Dmhw)=c("Y","nMHW")
  Smhw=rep(0,NY)
  Smhw[Dmhw$Y-YV[1]+1]=Dmhw$nMHW
  Zmhw[,j]=Smhw
}
```

Plot simulation results

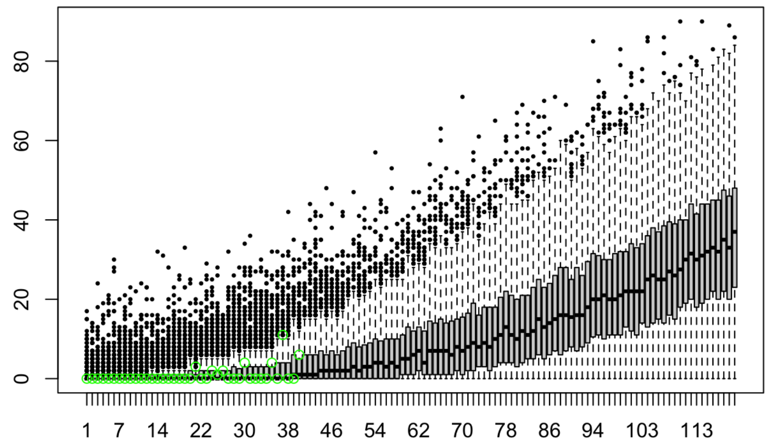
```r
boxplot(t(Zint),outpch=20, outcex=0.5)
points(Xint,col="blue")  #intensity
```



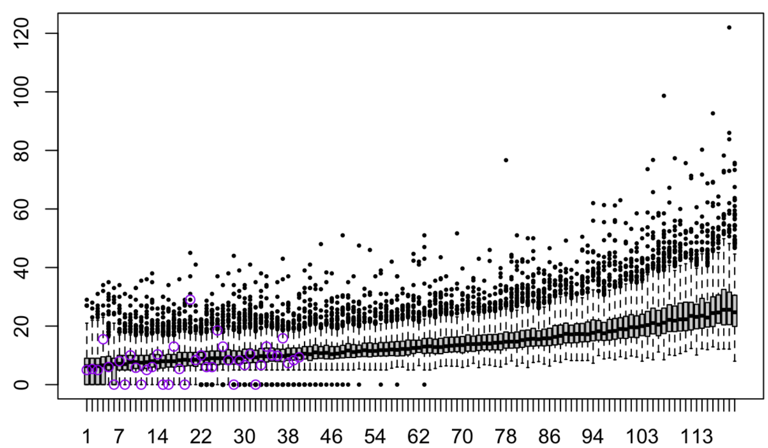

```r
boxplot(t(Zexp),outpch=20, outcex=0.5)
points(Xexp,col="red")  #exposure
```



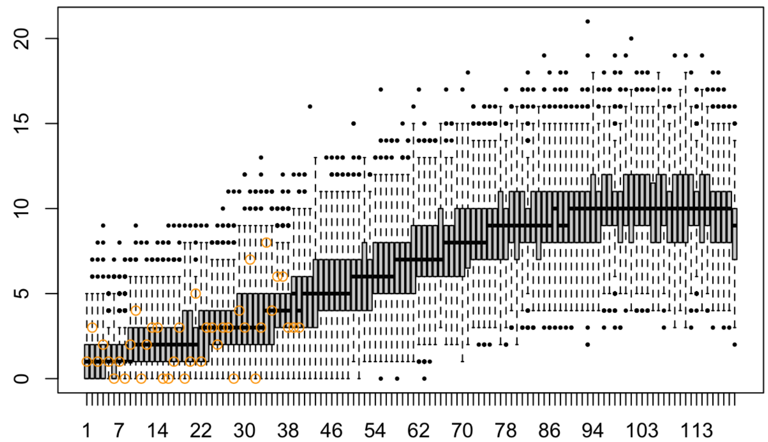

```r
boxplot(t(Za28),outpch=20, outcex=0.5)
points(Xa28,col="green")  #SST >= 28C
```




```
boxplot(t(Zdur),outpch=20, outcex=0.5)
points(Xdur,col="purple")  #duration
```




```
boxplot(t(Zmhw),outpch=20, outcex=0.5)
points(Xmhw,col="orange")  #number MHWs
```



Calculate and print trends on MHW simulation stats

```
#intensity
DIM=t.test(Zint[120,], na.rm=TRUE)
print(paste("sim mean MHW intensity 2100 =", format(DIM$estimate,digits=3),"+/-",format
(DIM$conf.int[2]-DIM$estimate,digits=1)))
```

```
## [1] "sim mean MHW intensity 2100 = 6.85 +/- 0.07"
```

```
simfitint = lm(rowMeans(Zint) ~ YV)
spint = summary(simfitint)$coefficients[2,4]
print(paste("sim MHW int trend =",format(simfitint$coefficients[2],  digits=3),"+/-",for
mat(confint(simfitint)[2,2]-simfitint$coefficients[2], digits=3)))
```

```
## [1] "sim MHW int trend = 0.0346 +/- 0.000812"
```

```
print(paste("p = ", format(spint,digits=3)))
```

```
## [1] "p =  2.31e-107"
```

```
#exposure
DEM=t.test(Zexp[120,], na.rm=TRUE)
print(paste("sim mean MHW exposure 2100 =", format(DEM$estimate,digits=3),"+/-",format(D
EM$conf.int[2]-DEM$estimate,digits=1)))
```

```
## [1] "sim mean MHW exposure 2100 = 217 +/- 4"
```

```
simfitexp = lm(rowMeans(Zexp) ~ YV)
spexp = summary(simfitexp)$coefficients[2,4]
print(paste("sim ann MHW exp trend =",format(simfitexp$coefficients[2],  digits=3),"+/-
",format(confint(simfitexp)[2,2]-simfitexp$coefficients[2], digits=3)))
```

```
## [1] "sim ann MHW exp trend = 2.11 +/- 0.0699"
```

```
print(paste("p = ", format(spexp,digits=3)))
```

```
## [1] "p =  5.11e-90"
```

```
#SST >= 28C
DAM=t.test(Za28[120,], na.rm=TRUE)
print(paste("sim mean SST>=28C 2100 =", format(DAM$estimate,digits=3),"+/-",format(DAM$c
onf.int[2]-DAM$estimate,digits=1)))
```

```
## [1] "sim mean SST>=28C 2100 = 36.7 +/- 2"
```

```
simfita28 = lm(rowMeans(Za28) ~ YV)
spa28 = summary(simfita28)$coefficients[2,4]
print(paste("sim SST >= 28C trend =",format(simfita28$coefficients[2],  digits=3),"+/-",
format(confint(simfita28)[2,2]-simfita28$coefficients[2], digits=3)))
```

```
## [1] "sim SST >= 28C trend = 0.283 +/- 0.0173"
```

```
print(paste("p = ", format(spa28,digits=3)))
```

```
## [1] "p =  1.55e-60"
```

```
#duration
DDM=t.test(Zdur[120,], na.rm=TRUE)
print(paste("sim mean MHW duration 2100 =", format(DDM$estimate,digits=3),"+/-",format(D
DM$conf.int[2]-DDM$estimate,digits=1)))
```

```
## [1] "sim mean MHW duration 2100 = 26.7 +/- 0.9"
```

```
simfitdur = lm(rowMeans(Zdur) ~ YV)
spdur = summary(simfitdur)$coefficients[2,4]
print(paste("sim MHW duration =", format(simfitdur$coefficients[2],  digits=3),"+/-",for
mat(confint(simfitdur)[2,2]-simfitdur$coefficients[2], digits=3)))
```

```
## [1] "sim MHW duration = 0.156 +/- 0.00689"
```

```r
print(paste("p = ", format(spdur,digits=3)))
```

```
## [1] "p =  5.38e-76"
```

```r
#number MHWs
DHM=t.test(Zmhw[120,], na.rm=TRUE)
print(paste("sim mean number MHWs 2100 =", format(DHM$estimate,digits=3),"+/-",format(DH
M$conf.int[2]-DHM$estimate,digits=1)))
```

```
## [1] "sim mean number MHWs 2100 = 8.84 +/- 0.2"
```

```r
simfitmhw = lm(rowMeans(Zmhw) ~ YV)
spmhw = summary(simfitmhw)$coefficients[2,4]
print(paste("Sim Ann # MHWs =",format(simfitmhw$coefficients[2],  digits=3),"+/-",format
(confint(simfitmhw)[2,2]-simfitmhw$coefficients[2], digits=3)))
```

```
## [1] "Sim Ann # MHWs = 0.087 +/- 0.00355"
```

```r
print(paste("p = ", format(spmhw,digits=3)))
```

```
## [1] "p =  6.93e-80"
```