R Scripts related to Analyzing spatio-temporal data with R: Everything you always wanted to know – but were afraid to ask

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Contents

1) Installing R packages

```
install.packages('raster')
install.packages('shiny')
install.packages('spacetime')
install.packages('leaflet')
install.packages('foreign')
install.packages('maptools')
install.packages('gstat')
install.packages('plm')
install.packages('sp')
install.packages('xts')
install.packages('rgeos')
install.packages('diveMove')
install.packages('maps')
install.packages('googleVis')
install.packages('rgdal')
install.packages('ggmap')
install.packages('data.table')
install.packages('mapdata')
install.packages('cshapes')
install.packages('rworldmap')
install.packages('dplyr')
install.packages('RColorBrewer')
install.packages('ncdf4')
install.packages('rworldmap')
install.packages('plotKML')
install.packages('tseries')
install.packages('ggfortify')
install.packages('ggplot2')
install.packages('CompRandFld')
install.packages('fields')
install.packages('spam')
install.packages('scatterplot3d')
install.packages('RandomFields')
```

2) Importing data and converting to STSDF and SDIDF spacetime formats.

2.a) Importing stations

```
### AirBase stations database (cleaned and purged) and their plot
stations <- read.csv("data/AirBase_v8_stations.csv",header=TRUE,sep="\t")
names(stations)

coord <- cbind(stations$station_longitude_deg,stations$station_latitude_deg)
stations <-stations[which(coord[,2]>20),]
coord <- cbind(stations$station_longitude_deg,stations$station_latitude_deg)
```

```r
not_duplicated <- which(!duplicated(coord))
stations <- stations[not_duplicated,]
coord <- cbind(stations$station_longitude_deg,stations$station_latitude_deg)

plot(coord)
save(stations,file='data/stations.Rdata')
```

2.b) Importing hourly data

```r
library(data.table)

file=list.files('data/OBS')
length(file)
head(file)

### Select only file containing hours data (file names with more than 15-17 characters)
filePM10 <- file[grep('PM10',file)]
filePM10 <- filePM10[nchar(filePM10)>17]
filePM25 <- file[grep('PM25',file)]
filePM25 <- filePM25[nchar(filePM25)>17]
fileO3   <- file[grep('O3',file)]
fileO3   <- fileO3[nchar(fileO3)>15]
fileNO2  <- file[grep('NO2',file)]
fileNO2  <- fileNO2[nchar(fileNO2)>16]
filePM10 <- paste('data/OBS/',filePM10,sep="")
filePM25 <- paste('data/OBS/',filePM25,sep="")
fileO3   <- paste('data/OBS/',fileO3,sep="")
fileNO2  <- paste('data/OBS/',fileNO2,sep="")

date_station <- gsub(".csv","",filePM10)
date_station <- gsub("PM10_","",date_station)

### Checking if all files have the same lenght and order
{
  length(filePM10)
  length(filePM25)
  length(fileO3)
  length(fileNO2)
  filePM10h <- gsub(".csv","",filePM10)
  filePM10h <- gsub("PM10_","",filePM10h)
  filePM25h <- gsub(".csv","",filePM25)
  filePM25h <- gsub("PM25_","",filePM25h)
  fileO3h   <- gsub(".csv","",fileO3)
  fileO3h   <- gsub("O3_","",fileO3h)
  fileNO2h  <- gsub(".csv","",fileNO2)
  fileNO2h  <- gsub("NO2_","",fileNO2h)
  all(filePM10h==filePM25h)
  all(filePM10h==fileO3h)
  all(filePM10h==fileNO2h)
}
```

```
### Preparing list for rbindList
PM10l <- vector(mode = "list", length = length(filePM10))
PM25l <- vector(mode = "list", length = length(filePM25))
O3l   <- vector(mode = "list", length = length(fileO3))
NO2l  <- vector(mode = "list", length = length(fileNO2))

for(i in 1:length(PM10l)){
  date  <- strptime(substr(date_station[i],10,19),format= "%Y%m%d%H")
  PM10t <- try(read.table(filePM10[i],header = FALSE,sep=" ",na.strings="-999",
                          col.names = c("ID","long","lat","PM10"),
                          colClasses = c("factor","numeric","numeric","numeric")))
  PM10t <- cbind(PM10t,rep(date,nrow(PM10t)))
  PM10l[[i]] <- PM10t
  PM25t <- try(read.table(filePM25[i],header = FALSE,sep=" ",na.strings="-999",
                          col.names = c("ID","long","lat","PM25"),
                          colClasses=c("factor","numeric","numeric","numeric")))
  PM25t <- cbind(PM25t,rep(date,nrow(PM25t)))
  PM25l[[i]] <- PM25t
  NO2t  <- try(read.table(fileNO2[i],header = FALSE,sep=" ",na.strings="-999",
                          col.names = c("ID","long","lat","NO2"),
                          colClasses=c("factor","numeric","numeric","numeric")))
  NO2t <- cbind(NO2t,rep(date,nrow(NO2t)))
  NO2l[[i]] <- NO2t
  O3t <- try(read.table(fileO3[i],header = FALSE,sep=" ",na.strings="-999",
                        col.names = c("ID","long","lat","O3"),
                        colClasses=c("factor","numeric","numeric","numeric")))
  O3t <- cbind(O3t,rep(date,nrow(O3t)))
  O3l[[i]] <- O3t
  cat(i,' ')
}

### Using rbindlist for faster row binding of all dataframes
PM10 <- rbindlist(PM10l)
names(PM10)[5] <- 'date'
PM10$ID2 <- paste(PM10$ID,PM10$date,sep='_')
PM25 <- rbindlist(PM25l)
names(PM25)[2:3] <- c("long1","lat1")
names(PM25)[5]   <- 'date1'
PM25$ID2 <- paste(PM25$ID,PM25$date1,sep='_')
NO2 <- rbindlist(NO2l)
names(NO2)[2:3] <- c("long2","lat2")
names(NO2)[5]   <- 'date2'
NO2$ID2 <- paste(NO2$ID,NO2$date2,sep='_')
O3 <- rbindlist(O3l)
names(O3)[2:3] <- c("long3","lat3")
names(O3)[5]   <- 'date3'
O3$ID2 <- paste(O3$ID,O3$date3,sep='_')


### Using data.table for faster merge
PM10 <- data.table(PM10)
PM25 <- data.table(PM25)
NO2  <- data.table(NO2)
```

```
O3   <- data.table(O3)
res  <- merge(PM10[,.(PM10,ID2,date,long,lat)],PM25[,.(PM25,ID2,date1,long1,lat1)],
              by="ID2",all=TRUE)
res  <- merge(res,NO2[,.(NO2,ID2,date2,long2,lat2)] ,by="ID2",all=TRUE)
res  <- merge(res, O3[,.(O3,ID2,date3,long3,lat3)] ,by="ID2",all=TRUE)
res$ID <- sapply(res$ID2, function(x) strsplit(x,"_")[[1]][1])
res$ID <- as.factor(res$ID)
res    <- data.frame(res)

### Finding locations and dates avoiding NAs
nodate <- is.na(res$date)
res$date[nodate] <- res$date1[nodate]
nodate <- is.na(res$date)
res$date[nodate] <- res$date2[nodate]
nodate <- is.na(res$date)
res$date[nodate] <- res$date3[nodate]

nolong <- is.na(res$long)
res$long[nolong] <- res$long1[nolong]
nolong <- is.na(res$long)
res$long[nolong] <- res$long2[nolong]
nolong <- is.na(res$long)
res$long[nolong] <- res$long3[nolong]

nolat <- is.na(res$lat)
res$lat[nolat] <- res$lat1[nolat]
nolat <- is.na(res$lat)
res$lat[nolat] <- res$lat2[nolat]
nolat <- is.na(res$lat)
res$lat[nolat] <- res$lat3[nolat]

### Building the final dataframe
OBS_horaire <- res[!is.na(res$date),c('ID','long','lat','date','PM10','PM25','NO2','O3')]
summary(OBS_horaire)

save(OBS_horaire,file='data/OBS_horaire.Rdata')
```

2.c) Importing daily data

```
file <- list.files('data/OBS')
length(file)
head(file)

filePM10 <- file[grep('PM10',file)]
filePM10 <- filePM10[nchar(filePM10)<=17]
filePM25 <- file[grep('PM25',file)]
filePM25 <- filePM25[nchar(filePM25)<=17]
fileO3   <- file[grep('O3',file)]
fileO3   <- fileO3[nchar(fileO3)<=15]
fileNO2  <- file[grep('NO2',file)]
fileNO2  <- fileNO2[nchar(fileNO2)<=16]
```

```
date_station <- gsub(".csv","",filePM10)
date_station <- gsub("PM10_","",date_station)

### Checking if all files have the same length and order
{
  length(filePM10)
  length(filePM25)
  length(fileO3)
  length(fileNO2)
  filePM10h <- gsub(".csv","",filePM10)
  filePM10h <- gsub("PM10_","",filePM10h)
  filePM25h <- gsub(".csv","",filePM25)
  filePM25h <- gsub("PM25_","",filePM25h)
  fileO3h   <- gsub(".csv","",fileO3)
  fileO3h   <- gsub("O3_","",fileO3h)
  fileNO2h  <- gsub(".csv","",fileNO2)
  fileNO2h  <- gsub("NO2_","",fileNO2h)
  all(filePM10h==filePM25h)
  all(filePM10h==fileO3h)
  all(filePM10h==fileNO2h)
}

PM10l <- vector(mode = "list", length = length(filePM10))
PM25l <- vector(mode = "list", length = length(filePM25))
O3l   <- vector(mode = "list", length = length(fileO3))
NO2l  <- vector(mode = "list", length = length(fileNO2))

filePM10 <- paste('data/OBS/',filePM10,sep="")
filePM25 <- paste('data/OBS/',filePM25,sep="")
fileO3   <- paste('data/OBS/',fileO3,sep="")
fileNO2  <- paste('data/OBS/',fileNO2,sep="")

for(i in 1:length(PM10l)){
      date  <- strptime(date_station[i],format= "%Y%m%d")
      PM10t <- try(read.table(filePM10[i],header = FALSE,sep=" ",na.strings="-999",
      col.names = c("ID","long","lat","PM10"),colClasses = c("factor","numeric","numeric","numeric")))
      PM10t <- cbind(PM10t,rep(date,nrow(PM10t)))
      PM10l[[i]] <- PM10t
      PM25t <- try(read.table(filePM25[i],header = FALSE,sep=" ",na.strings="-999",
      col.names = c("ID","long","lat","PM25"),colClasses = c("factor","numeric","numeric","numeric")))
      PM25t <- cbind(PM25t,rep(date,nrow(PM25t)))
      PM25l[[i]] <- PM25t
      NO2t <- try(read.table(fileNO2[i],header = FALSE,sep=" ",na.strings="-999",
      col.names = c("ID","long","lat","NO2"),colClasses = c("factor","numeric","numeric","numeric")))
      NO2t <- cbind(NO2t,rep(date,nrow(NO2t)))
      NO2l[[i]] <- NO2t
      O3t <- try(read.table(fileO3[i],header = FALSE,sep=" ",na.strings="-999",
      col.names = c("ID","long","lat","O3"),colClasses = c("factor","numeric","numeric","numeric")))
      O3t <- cbind(O3t,rep(date,nrow(O3t)))
      O3l[[i]] <- O3t
      cat(i,'')
}
```

```
### Using rbindlist for faster row binding of all loaded dataframes
PM10 <- rbindlist(PM10l)
names(PM10)[5]='date'
PM10$ID2 <- paste(PM10$ID,PM10$date,sep='_')
PM25 <- rbindlist(PM25l)
names(PM25)[2:3] <- c("long1","lat1")
names(PM25)[5]   <- 'date1'
PM25$ID2 <- paste(PM25$ID,PM25$date1,sep='_')
NO2 <- rbindlist(NO2l)
names(NO2)[2:3] <- c("long2","lat2")
names(NO2)[5]   <- 'date2'
NO2$ID2 <- paste(NO2$ID,NO2$date2,sep='_')
O3 <- rbindlist(O3l)
names(O3)[2:3] <- c("long3","lat3")
names(O3)[5]   <- 'date3'
O3$ID2 <- paste(O3$ID,O3$date3,sep='_')

### Using data.table for faster merge
PM10 <- data.table(PM10)
PM25 <- data.table(PM25)
NO2  <- data.table(NO2)
O3   <- data.table(O3)
res <- merge(PM10[,.(PM10,ID2,date,long,lat)],PM25[,.(PM25,ID2,date1,long1,lat1)],
           by="ID2",all=TRUE)
res <- merge(res,NO2[,.(NO2,ID2,date2,long2,lat2)] ,by="ID2",all=TRUE)
res <- merge(res, O3[,.(O3,ID2,date3,long3,lat3)] ,by="ID2",all=TRUE)

res$ID<-sapply(res$ID2, function(x) strsplit(x,'_')[[1]][1])
res$ID<-as.factor(res$ID)

res=data.frame(res)

### Selecting the filled dates and locations
nodate <- is.na(res$date)
res$date[nodate] <- res$date1[nodate]
nodate <- is.na(res$date)
res$date[nodate] <- res$date2[nodate]
nodate=is.na(res$date)
res$date[nodate] <- res$date3[nodate]

nolong <- is.na(res$long)
res$long[nolong] <- res$long1[nolong]
nolong <- is.na(res$long)
res$long[nolong] <- res$long2[nolong]
nolong <- is.na(res$long)
res$long[nolong] <- res$long3[nolong]

nolat <- is.na(res$lat)
res$lat[nolat] <- res$lat1[nolat]
nolat <- is.na(res$lat)
res$lat[nolat] <- res$lat2[nolat]
nolat <- is.na(res$lat)
res$lat[nolat] <- res$lat3[nolat]
```

```
OBS_jour <- res[!is.na(res$date),c('ID','long','lat','date','PM10','PM25','NO2','O3')]
summary(OBS_jour)
save(OBS_jour,file='data/OBS_jour.Rdata')
```

2.d) Importing CHIMERE grid data

```
library(ncdf4)

file <- list.files('data/CHM')
length(file)
head(file)

file <- file[grep('chim_',file,fixed=TRUE)]
file <- file[grep('.nc',file)]
file <- paste('data/CHM/',file,sep='')

a <- vector(mode = "list", length = length(file))

for(i in 1:length(file)){
  ncfile <- nc_open(file[i])
  print(file[i])
  lat  <- as.vector(ncvar_get(ncfile,"lat"))
  lon  <- as.vector(ncvar_get(ncfile,"lon"))
  PM10 <- as.vector(ncvar_get(ncfile,"PM10"))
  PM25 <- as.vector(ncvar_get(ncfile,"PM25"))
  NO2  <- as.vector(ncvar_get(ncfile,"NO2"))
  O3   <- as.vector(ncvar_get(ncfile,"O3"))
  time <- strptime(strsplit(file[i],'.',fixed = TRUE)[[1]][2],format = "%Y%m%d")
  dfr  <- data.frame(lon=lon,lat=lat,PM10=PM10,PM25=PM25,NO2=NO2,O3=O3,
                     time=rep(time,each=length(lon)))
  a[[i]]<-dfr
}
CHM <- rbindlist(a)
CHM <- data.frame(CHM)

save(CHM,file='data/CHM.Rdata')
```

2.e) Converting dataframes to spacetime objects

```
rm(list=ls())
library(spacetime)
load('data/OBS_horaire.Rdata')
load('data/OBS_jour.Rdata')
load('data/CHM.Rdata')
load('data/stations.Rdata')

### WARNING: daily data contain 2 stations with only 214 recorded days.
### This can cause problems for the construction of a ST object
```

```
STFDF_jour <- stConstruct(OBS_jour,space=c('long','lat'),time='date',
                          SpatialObj=SpatialPoints(OBS_jour[,c('long','lat')]))
STFDF_jour    <- as(STFDF_jour, "STFDF")
STFDF_30jour  <- STFDF_jour[,"2014-01-01::2014-01-31"]


### The entire dataset is too large and difficult to handle
### STIDF_obs=stConstruct(OBS_horaire,space=c('long','lat'),time='date')
### with long format and STIDF dimension s and t are wrong.
### For monitoring station data, spacetime::stplot is particularly useful if
### it knows that these are repeated measurements for fixed stations.
### Provided with an STIDF, stplot assumes they are not.
### Pebesma https://stat.ethz.ch/pipermail/r-sig-geo/2015-July/023101.html)
#STIDF_obs =as(STIDF_obs, "STFDF") ### too long

### Considering two subsamples of hourly data of 30 or 7 days

STIDF_Horaire_30j <- stConstruct(OBS_horaire[OBS_horaire$date>= "2013-12-31" &
                     OBS_horaire$date <= "2014-02-01",],space=c('long','lat'),time='date')
STIDF_Horaire_30j <- as(STIDF_Horaire_30j, "STSDF")

STIDF_Horaire_7j <- stConstruct(OBS_horaire[OBS_horaire$date>= "2013-12-31" &
                     OBS_horaire$date <= "2014-01-08",],space=c('long','lat'),time='date')
STIDF_Horaire_7j <- as(STIDF_Horaire_7j, "STSDF")

CHM_jour <- stConstruct(CHM[CHM$time>= "2013-12-31" & CHM$time <= "2014-02-01",],
                      space=c('lon','lat'),time='time')
CHM_jour <- as(CHM_jour, "STSDF")


add_ID<-function(STFDF){
  ID  <- paste('ID_',1:(dim(STFDF)[1]),sep='')
  IDs <- rep(ID,dim(STFDF)[2])
  attr(STFDF,'data') <- cbind(IDs,attr(STFDF,'data'))
  return(STFDF)
}
CHM_jour=add_ID(CHM_jour)

### Adding projections
library(sp)
proj4string(CHM_jour)   <- "+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs"
proj4string(STFDF_jour) <- "+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs"
proj4string(STIDF_Horaire_30j) <- "+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs"
proj4string(STIDF_Horaire_7j)  <- "+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs"

save(CHM_jour,file='data/CHM_jour.Rdata')
save(STFDF_jour,file='data/STFDF_jour.Rdata')
save(STIDF_Horaire_30j,file='data/STIDF_Horaire_30j.Rdata')
save(STIDF_Horaire_7j,file='data/STIDF_Horaire_7j.Rdata')
```

```
rm(list=ls())
load('data/STFDF_jour.Rdata')
```

```
### Understanding STFDF object
dim(STFDF_jour)
```

```
##     space      time variables
##       507       365         5
```

```
str(STFDF_jour)
```

```
## Formal class 'STFDF' [package "spacetime"] with 4 slots
##   ..@ data   :'data.frame':  185055 obs. of  5 variables:
##   .. ..$ ID  : Factor w/ 507 levels "FR01001","FR01005",..: 1 2 3 4 5 6 7 8 9 10 ...
##   .. ..$ PM10: num [1:185055] 6.8 9.3 8.1 9.3 12 6.9 8.3 7.7 6.2 NA ...
##   .. ..$ PM25: num [1:185055] NA NA NA NA 8.5 NA NA NA NA NA ...
##   .. ..$ NO2 : num [1:185055] 5.6 6.4 8.6 NA 10 8.3 7.8 NA 9.1 10 ...
##   .. ..$ O3  : num [1:185055] 52 NA NA NA 45 NA 55 NA NA 56 ...
##   ..@ sp     :Formal class 'SpatialPoints' [package "sp"] with 3 slots
##   .. .. ..@ coords     : num [1:507, 1:2] 5.8 6.08 6.14 6.13 6.18 ...
##   .. .. .. ..- attr(*, "dimnames")=List of 2
##   .. .. .. .. ..$ : chr [1:507] "1" "366" "731" "1096" ...
##   .. .. .. .. ..$ : chr [1:2] "long" "lat"
##   .. .. ..@ bbox       : num [1:2, 1:2] -4.49 41.92 9.48 51.05
##   .. .. .. ..- attr(*, "dimnames")=List of 2
##   .. .. .. .. ..$ : chr [1:2] "long" "lat"
##   .. .. .. .. ..$ : chr [1:2] "min" "max"
##   .. .. ..@ proj4string:Formal class 'CRS' [package "sp"] with 1 slot
##   .. .. .. .. ..@ projargs: chr "+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs +towgs84=0,0,0"
##   ..@ time   :An 'xts' object on 2014-01-01/2014-12-31 containing:
##   Data: int [1:365, 1] 1 2 3 4 5 6 7 8 9 10 ...
##  - attr(*, "dimnames")=List of 2
##   ..$ : NULL
##   ..$ : chr "timeIndex"
##   Indexed by objects of class: [POSIXct,POSIXt] TZ:
##   xts Attributes:
##  NULL
##   ..@ endTime: POSIXct[1:365], format: "2014-01-02" ...
```

```
names(STFDF_jour@data)
```

```
## [1] "ID"   "PM10" "PM25" "NO2"  "O3"
```

```
dim(STFDF_jour@data)
```

```
## [1] 185055      5
```

```
as.numeric(dim(STFDF_jour)[1]*dim(STFDF_jour)[2])
```

```
## [1] 185055
```

```
### Select and subset of STFDF object: STFDF[location_subset,time_subset,var_selection]
### Some examples:
#### 1) Select first location, first day, second variable
STFDF_jour[1,1,2]
```

```
## [1] 6.8
```

```
#### object of class numeric
class(STFDF_jour[1,1,2])
```

```
## [1] "numeric"
```

```
#### 2) Select first two locations, first day, second variable
STFDF_jour[1:2,1,2]
```

```
##            coordinates PM10
## 1   (5.804448, 49.535)  6.8
## 2 (6.076108, 49.32472)  9.3
```

```
####  object of class SpatialPointDataFrame
class(STFDF_jour[1:2,1,2])
```

```
## [1] "SpatialPointsDataFrame"
## attr(,"package")
## [1] "sp"
```

```
#### 3) Select first location, first two days, second variable
STFDF_jour[1,1:2,2]
```

```
##            PM10 timeIndex
## 2014-01-01  6.8         1
## 2014-01-02  4.0         2
```

```
####  object of class xts (time serie)
class(STFDF_jour[1,1:2,2])
```

```
## [1] "xts" "zoo"
```

```
#### 4) Select first ten locations, first two days and ID + PM10 variables
STFDF_jour[1:10,1:2,1:2]
```

```
## An object of class "STFDF"
## Slot "data":
##         ID PM10
## 1  FR01001  6.8
## 2  FR01005  9.3
## 3  FR01006  8.1
## 4  FR01009  9.3
```

```
## 5  FR01011 12.0
## 6  FR01012  6.9
## 7  FR01014  8.3
## 8  FR01015  7.7
## 9  FR01016  6.2
## 10 FR01018   NA
## 11 FR01001  4.0
## 12 FR01005  6.5
## 13 FR01006  8.6
## 14 FR01009  6.2
## 15 FR01011 11.0
## 16 FR01012 13.0
## 17 FR01014  9.6
## 18 FR01015  7.4
## 19 FR01016  4.8
## 20 FR01018   NA
##
## Slot "sp":
## SpatialPoints:
##          long      lat
## 1    5.804448 49.53500
## 366  6.076108 49.32472
## 731  6.140000 49.32083
## 1096 6.132500 49.27139
## 1461 6.180833 49.11941
## 1826 6.223336 49.11028
## 2191 6.058336 48.91500
## 2556 6.051392 48.88473
## 2921 6.093611 48.88636
## 3286 6.122772 49.10750
## Coordinate Reference System (CRS) arguments: +proj=longlat
## +ellps=WGS84 +datum=WGS84 +no_defs +towgs84=0,0,0
##
## Slot "time":
##            timeIndex
## 2014-01-01         1
## 2014-01-02         2
##
## Slot "endTime":
## [1] "2014-01-02 CET" "2014-01-03 CET"
```

```
####  object of class STFDF
class(STFDF_jour[1:10,1:2,1:2])
```

```
## [1] "STFDF"
## attr(,"package")
## [1] "spacetime"
```

```
#### 5) select 10 days time interval (using date format) and two variables (PM10 and 03)
STFDF_jour[1,"2014-01-01::2014-01-10",c('PM10','03')]
```

```
##            PM10 03 timeIndex
## 2014-01-01  6.8 52         1
```

```
## 2014-01-02  4.0 55         2
## 2014-01-03 10.0 55         3
## 2014-01-04 10.0 44         4
## 2014-01-05  7.9 57         5
## 2014-01-06  5.8 48         6
## 2014-01-07  8.7 50         7
## 2014-01-08  8.8 33         8
## 2014-01-09  6.1 49         9
## 2014-01-10  9.2 37        10
```

```
#### 6) select one station by ID (not as natural as expected), 10 days by date and 2 variables
IDs=levels(STFDF_jour$ID)
STFDF_jour[which(IDs %in% c('FR01011')),"2014-01-01::2014-01-10",c('PM10','O3')]
```

```
##            PM10 O3 timeIndex
## 2014-01-01   12 45         1
## 2014-01-02   11 43         2
## 2014-01-03   16 40         3
## 2014-01-04   16 27         4
## 2014-01-05   11 51         5
## 2014-01-06   13 33         6
## 2014-01-07   14 25         7
## 2014-01-08   16 20         8
## 2014-01-09   14 45         9
## 2014-01-10   22 23        10
```

```
#### 7) select 2 stations by ID (not as natural as expected), 10 days by date and 2 variables
temp<-STFDF_jour[which(IDs %in% c('FR01011','FR03063')),"2014-01-01::2014-01-10",c('PM10','O3')]

### Get dataframe from spacetime STFDF/STIDF
mydata<-temp@data
summary(mydata)
```

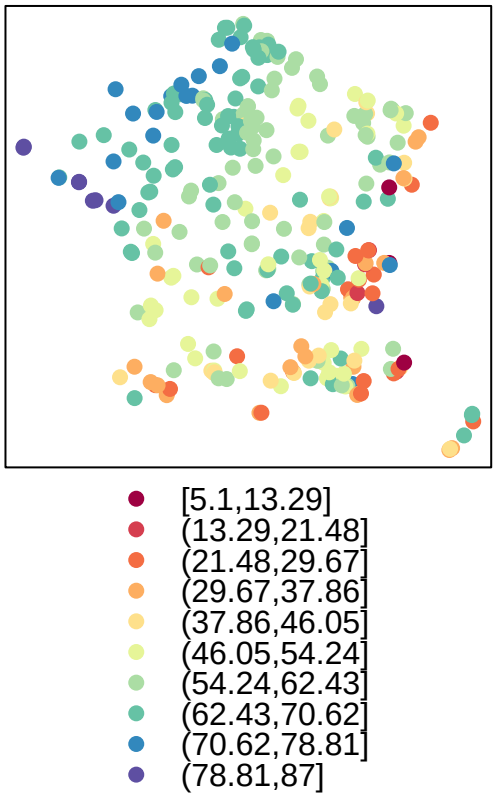
```
##       PM10             O3
##  Min.   :11.00   Min.   :16.00
##  1st Qu.:12.25   1st Qu.:27.75
##  Median :14.00   Median :39.00
##  Mean   :14.50   Mean   :37.40
##  3rd Qu.:16.00   3rd Qu.:45.00
##  Max.   :22.00   Max.   :69.00
##  NA's   :10
```

3) Plots of STFDF/STIDF

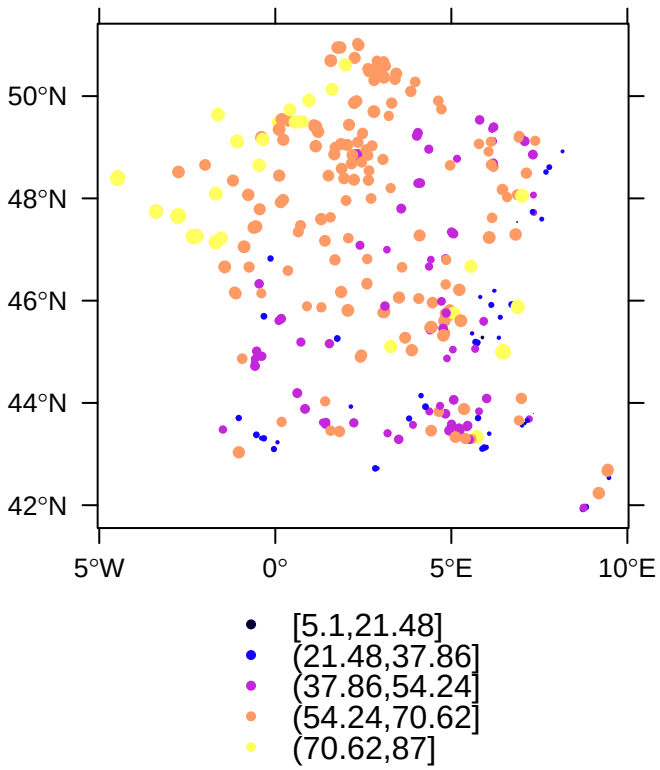
3.a) Static plots

```
#####################################
rm(list=ls())
load('data/STFDF_jour.Rdata')
library(RColorBrewer)
```

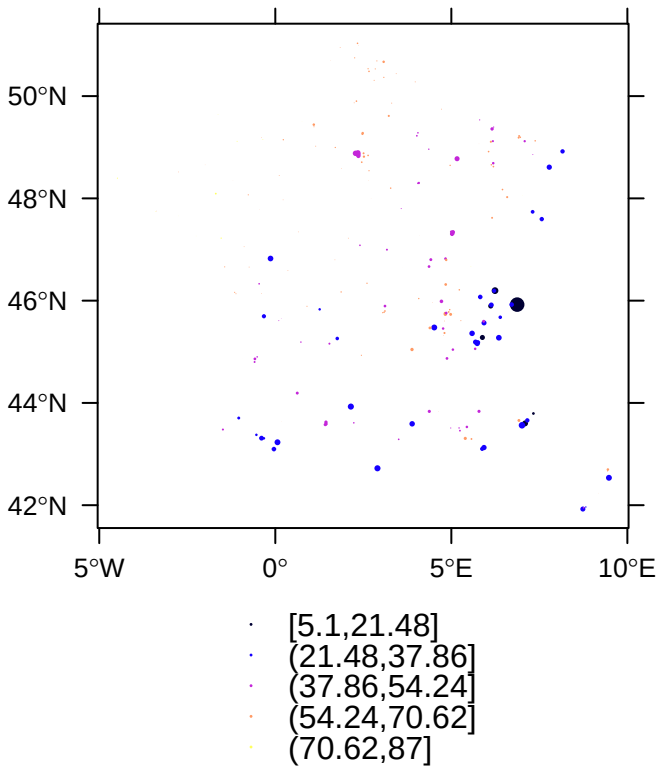
```
library(sp)

###  Some examples of spplot
#### 1) Plot all locations, 1 day (by date), 1 variable (O3)
spplot(STFDF_jour[,"2014-01-01",'O3'],col.regions=brewer.pal(10,"Spectral"),cuts=10)
```




```
#### 2) The same, but point size is proportional to O3 value for that station
cx03 = attr(STFDF_jour[,"2014-01-01",'O3'],'data')/max(attr(STFDF_jour[,"2014-01-01",'O3'],
            'data'),na.rm=T) * 5
spplot(STFDF_jour[,"2014-01-01",'O3'],cex= 0.2*as.numeric(cx03$O3),scales=list(draw=TRUE))
```




```
#### 3) Plot all locations, 1 day (by date), 2 variables (O3 and NO2)
#### point size is proportional to NO2 value, color to O3 value
cxNO2 = attr(STFDF_jour[,"2014-01-01",'NO2'],'data')/max(attr(STFDF_jour[,"2014-01-01",'NO2']
            ,'data'),na.rm=T) * 5
spplot(STFDF_jour[,"2014-01-01",'O3'],cex= 0.2*as.numeric(cxNO2$NO2),scales=list(draw=TRUE))
```



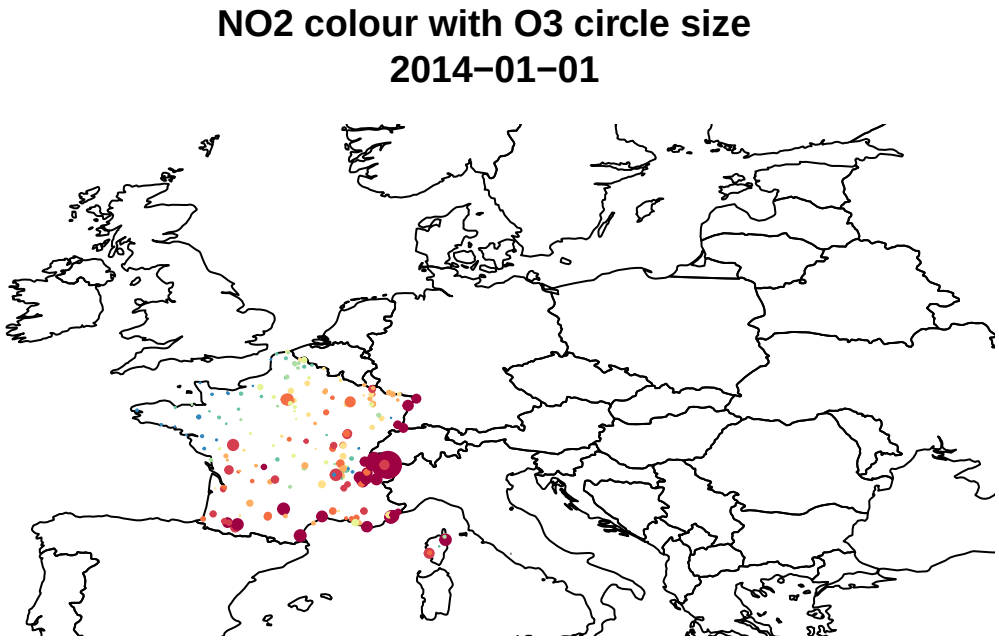

```
### Download and add map of countries
par(mfrow=c(1,1))
library(rworldmap)
library(maptools)
library(ggmap)
world <- getMap(resolution="low")
proj4string(world)
```

```
## [1] "+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs"
```

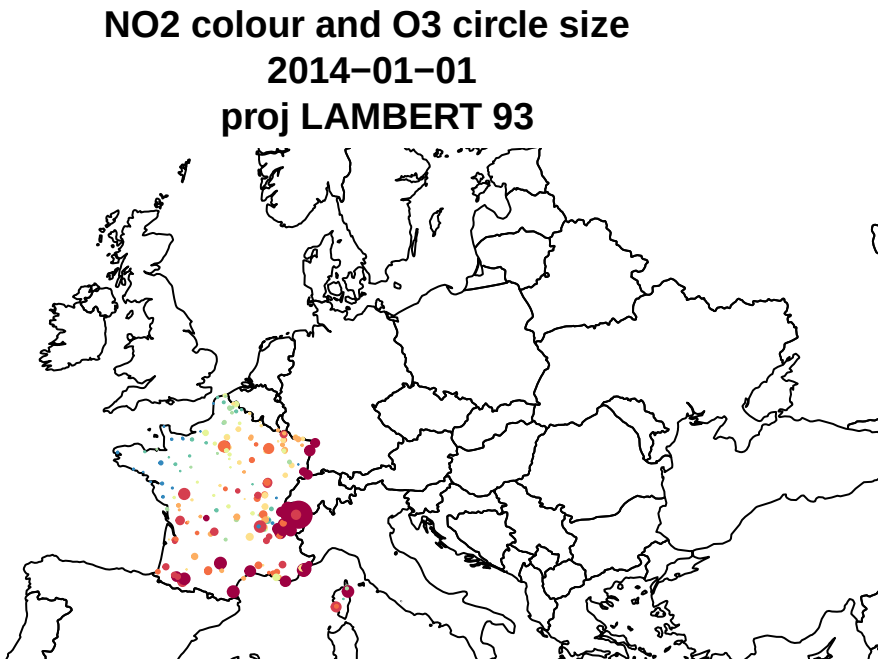
```
europe.limits <- geocode(c("Spain","Greece","Ireland","Norway","Ukraine"))
```

```
## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Spain&sensor=false

## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Greece&sensor=false

## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Ireland&sensor=false

## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Norway&sensor=false

## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Ukraine&sensor=false
```

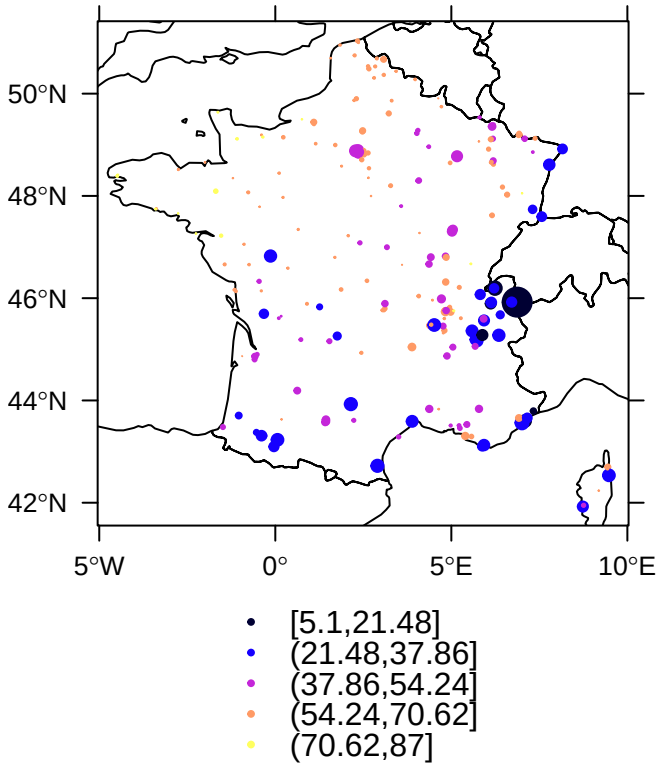
```
plot(world,xlim=range(europe.limits$lon),ylim=range(europe.limits$lat),asp=1,
     main='NO2 colour with O3 circle size \n 2014-01-01')
colours <- brewer.pal(10,"Spectral")
O3      <- attr(STFDF_jour[,"2014-01-01",'O3'],'data')
plot(STFDF_jour[,"2014-01-01",'O3'],col=colours[findInterval(O3$O3,
     quantile(O3$O3,seq(0,1,length.out =10),na.rm=T), all.inside=TRUE)],
     cex= 0.4*as.numeric(cxNO2$NO2),scales=list(draw=TRUE),add=TRUE,pch=19)
```



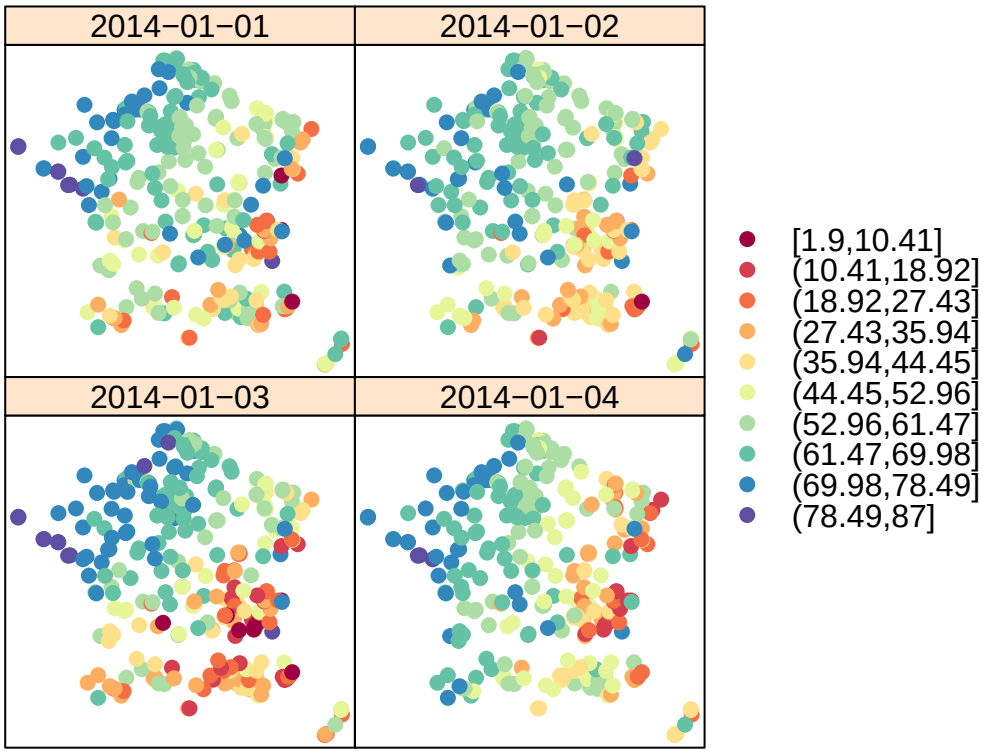

```
### Same as before but using Lambert 93 (L93) projection
splimit <- SpatialPoints(europe.limits)
proj4string(splimit) <- proj4string(world)
splimit_l93 <- spTransform(splimit,CRSobj=CRS("+init=epsg:2154"))
worldL93    <- spTransform(world,CRSobj=CRS("+init=epsg:2154"))
plot(worldL93,xlim=range(splimit_l93$lon),ylim=range(splimit_l93$lat),asp=1,
     main='NO2 colour and O3 circle size \n 2014-01-01 \n proj LAMBERT 93')
STFDF_jourL93 <- STFDF_jour
STFDF_jourL93 <- spTransform(STFDF_jourL93,CRSobj=CRS("+init=epsg:2154"))
plot(STFDF_jourL93[,"2014-01-01",'O3'],col=colours[findInterval(O3$O3,
    quantile(O3$O3,seq(0,1,length.out =10),na.rm=T), all.inside=TRUE)],
    cex= 0.4*as.numeric(cxNO2$NO2),scales=list(draw=TRUE),add=TRUE,pch=19)
```



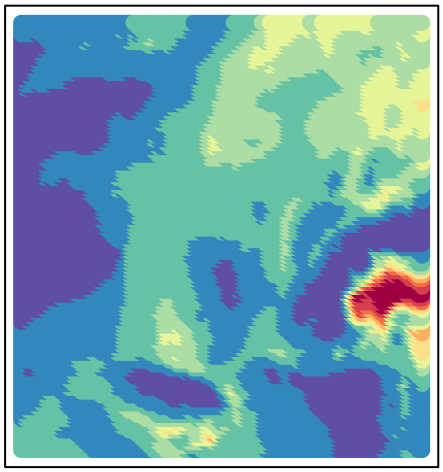
```
### The same, using spplot (easier and centered around our data)
spplot(STFDF_jour[,"2014-01-01",'O3'],cex=0.4*as.numeric(cxNO2$NO2),
       scales=list(draw=TRUE),pch=19,sp.layout =list(world,first=TRUE))
```




```
###################################

### Some examples of stplot
#### 1) Plot all locations, 4 day (by date), 1 variable (O3)
stplot(STFDF_jour[,"2014-01-01::2014-01-04",'O3'],col.regions=
       brewer.pal(10,"Spectral"),cuts=10)
```

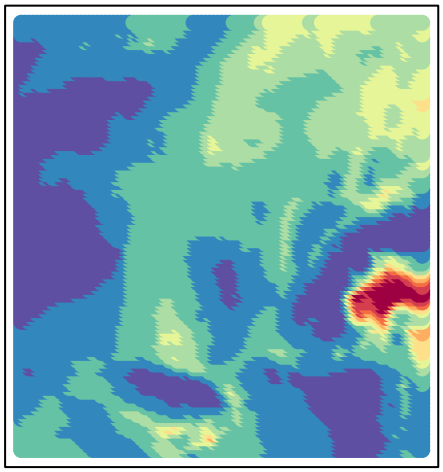



```
#### 2) Plot GRID data, 1 day (by date), 1 variable (O3)
load('data/CHM_jour.Rdata')
chim_O3_1j<-CHM_jour[,"2014-01-01",'O3']
spplot(chim_O3_1j,col.regions=brewer.pal(10,"Spectral"),cuts=10)
```



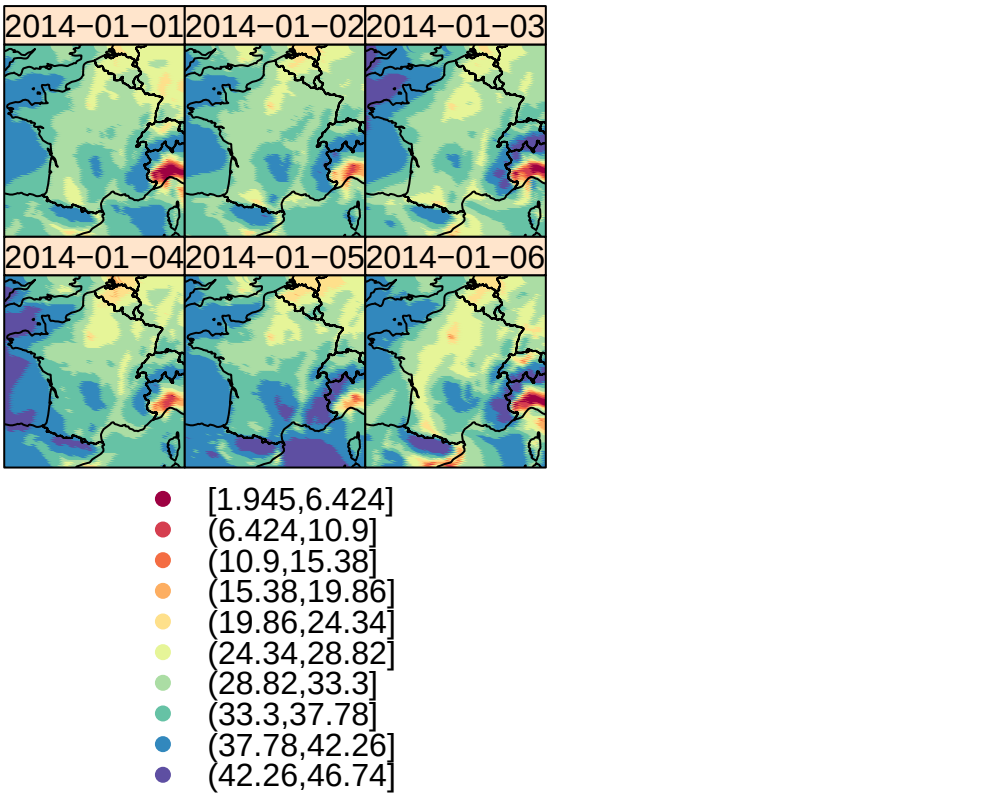
- [1.945,5.932]
- (5.932,9.919]
- (9.919,13.91]
- (13.91,17.89]
- (17.89,21.88]
- (21.88,25.87]
- (25.87,29.86]
- (29.86,33.84]
- (33.84,37.83]
- (37.83,41.82]

```
#### 3) with grid data as real gridded object
spplot(chim_03_1j,col.regions=brewer.pal(10,"Spectral"),cuts=10)
```

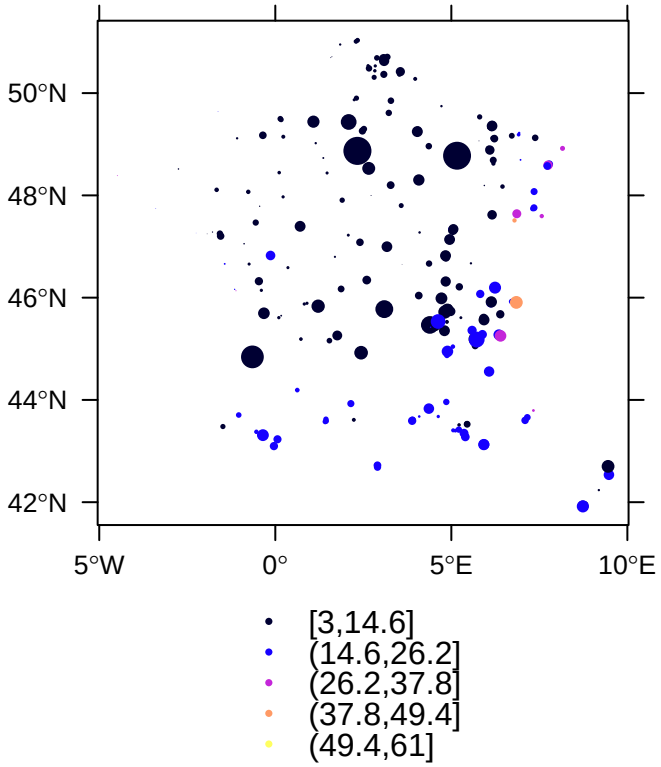


- [1.945,5.932]
- (5.932,9.919]
- (9.919,13.91]
- (13.91,17.89]
- (17.89,21.88]
- (21.88,25.87]
- (25.87,29.86]
- (29.86,33.84]
- (33.84,37.83]
- (37.83,41.82]

```
#### 4) with a STFDF we use gridded(STFDF@sp), 7 days
chim_O3_10j <- CHM_jour[,"2014-01-01::2014-01-7",'O3']
stplot(chim_O3_10j,col.regions=brewer.pal(10,"Spectral"),cuts=10,
       sp.layout=list(world,first=FALSE))
```




```
#### 5) add and plot new variable (ratio between NO2 and PM10)
NO2   <- attr(STFDF_jour[,"2014-01-01",'NO2'],'data')
PM10  <- attr(STFDF_jour[,"2014-01-01",'PM10'],'data')
ratio <- NO2$NO2/PM10$PM10
spplot(STFDF_jour[,"2014-01-01",'PM10'],cex=0.4*as.numeric(ratio),
       scales=list(draw=TRUE))
```



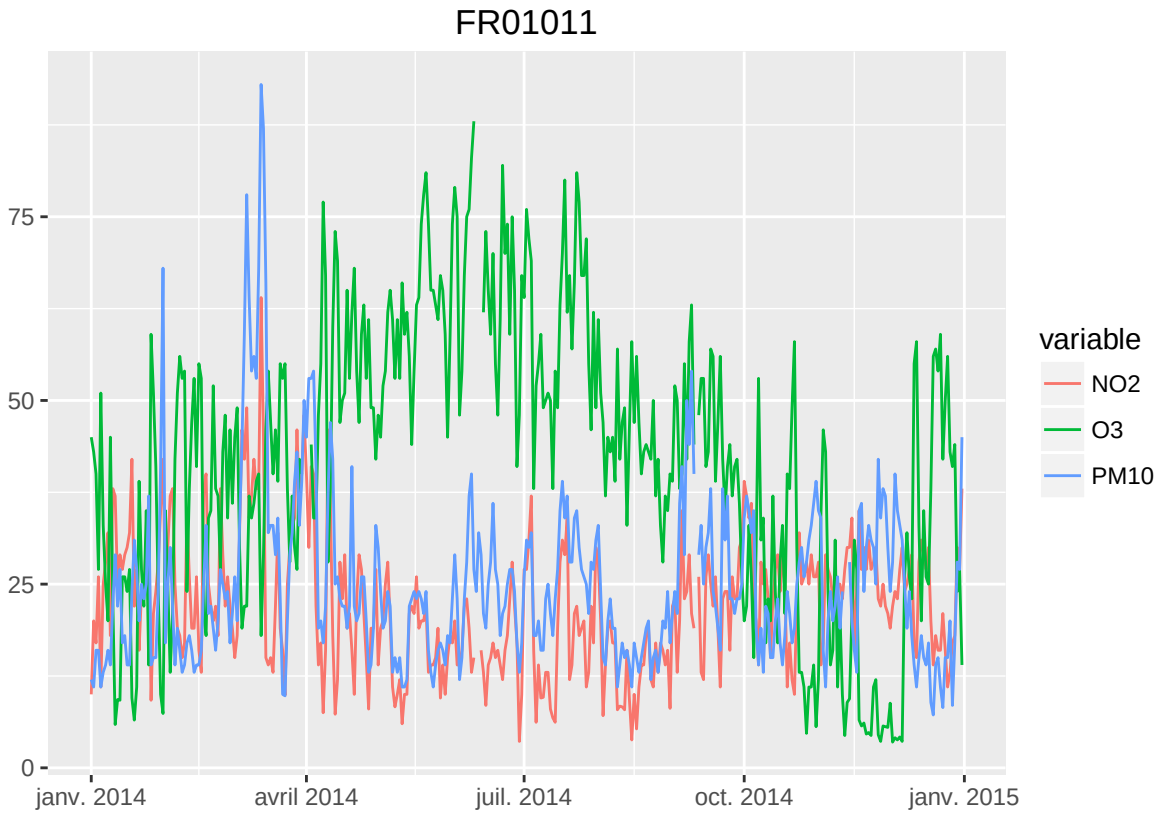
3.b) Static plots using klm (plotklm)

```
### May require an update of Google Earth
library(plotKML)
O3df    <- attr(STFDF_jour[,"2014-01-01","O3"],'data')
NO2df   <- attr(STFDF_jour[,"2014-01-01","NO2"],'data')
PM10df  <- attr(STFDF_jour[,"2014-01-01","PM10"],'data')
colours <- SAGA_pal[[1]]

### plotKML with colours for O3
plotKML(STFDF_jour[,"2014-01-01",'O3'],colours=colours[findInterval(O3df$O3,
        quantile(O3df$O3,seq(0,1,length.out =10),na.rm=T), all.inside=TRUE)])

### same for NO2 with colour_scale
plotKML(STFDF_jour[,"2014-01-01",'NO2'])
```

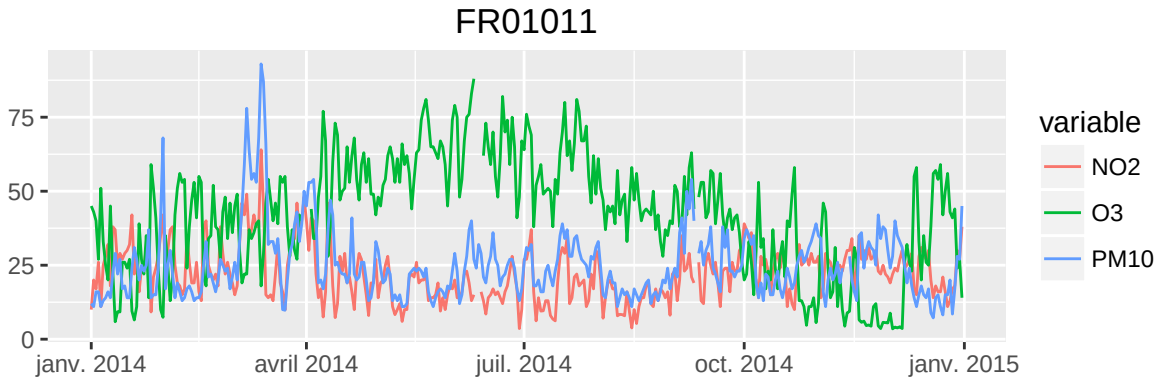
3.c) Time series plots

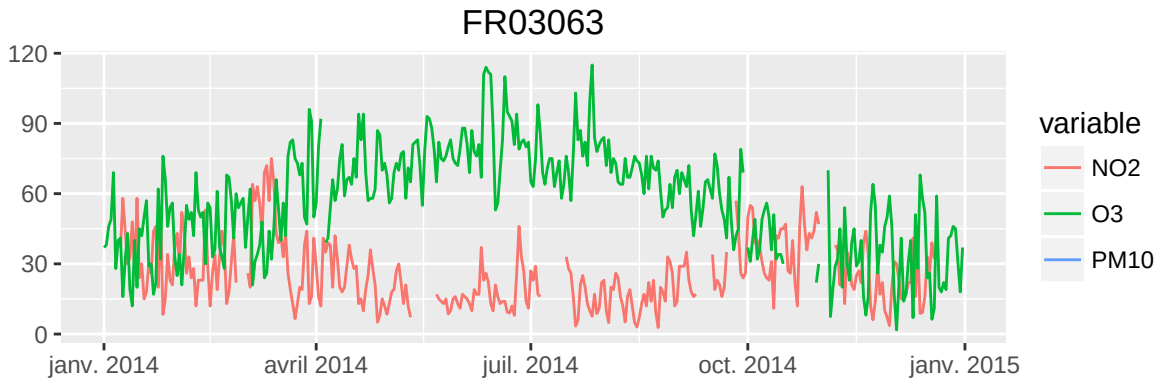
```
rm(list=ls())
library(tseries)
library(ggfortify)
library(ggplot2)
load('data/STFDF_jour.Rdata')
load('data/OBS_jour.Rdata')
```

```
### One time serie plot can represent the data corresponding to one or
### multiple locations as well as one or multiple variables.

#### 1) single location, multiple variables
IDs <- levels(OBS_jour$ID)
ts  <- STFDF_jour[which(IDs %in% c('FR01011')),,c("PM10","NO2","O3")]
colours <- brewer.pal(3,"Set1")
irr     <- irts(index(ts),as.matrix(ts[,1:3]))

p1 <- autoplot(irr, facets = FALSE)
p1 <- p1+ggtitle('FR01011')
p1
```

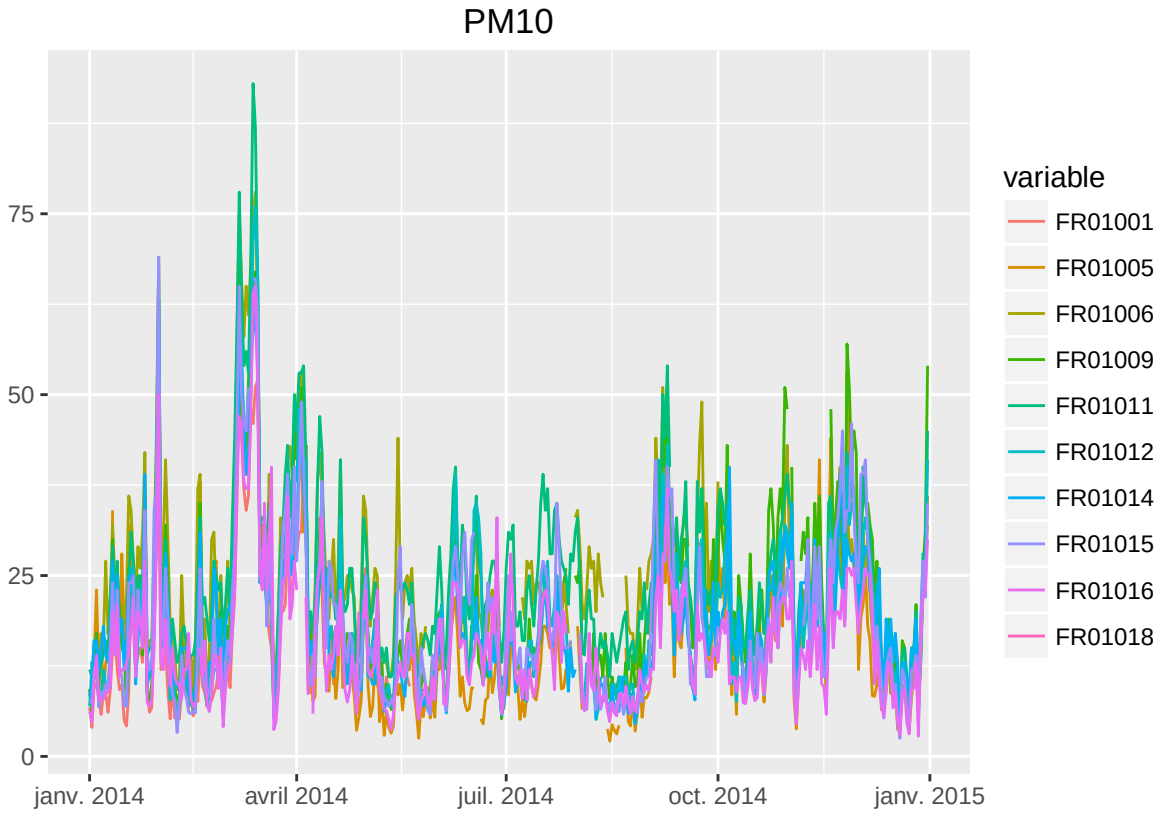



```
#### 2) Two locations, multiple variables
ts2  <- STFDF_jour[which(IDs %in% c('FR03063')),,c("PM10","NO2","O3")]
irr2 <- irts(index(ts2),as.matrix(ts2[,1:3]))
p2   <- autoplot(irr2, facets = FALSE)
p2   <- p2+ggtitle('FR03063')
new("ggmultiplot",plots=list(p1,p2),ncol=1)
```

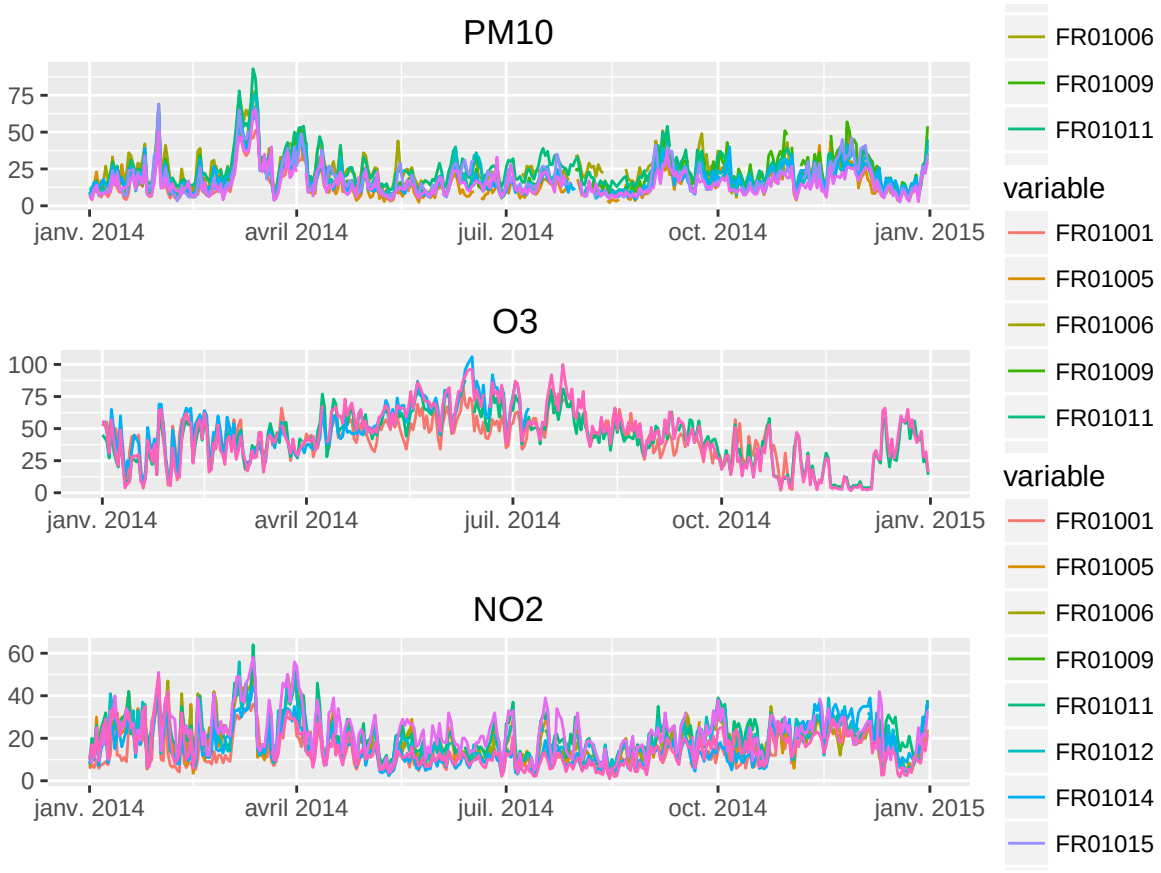




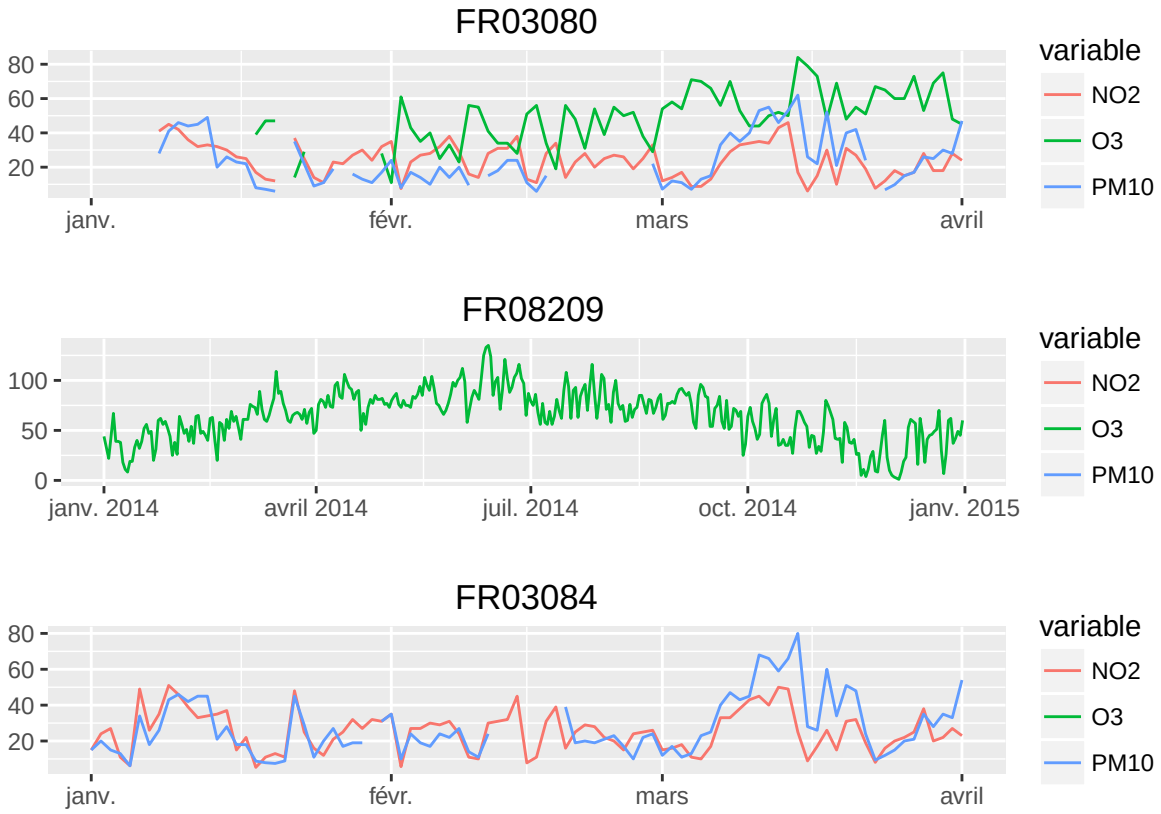

```
#### 3)  Multiple locations >3, single variable
##### PM10
init <- STFDF_jour[which(IDs==IDs[1]),,c("PM10")]
   a <- matrix(0,ncol=10,nrow=length(init[,1]))
for(i in 1:10 ){
  ID    <- IDs[i]
  a[,i] <- STFDF_jour[which(IDs==ID),,c("PM10")][,1]
}
colnames(a) <- IDs[1:10]
irr <- irts(index(init),a)
p3  <- autoplot(irr, facets = FALSE)+ggtitle('PM10')
p3
```




```
####  4) Multiple locations >3, multiples variables (grouped by variable)

#####  O3
init <- STFDF_jour[which(IDs==IDs[1]),,c("O3")]
a    <- matrix(0,ncol=10,nrow=length(init[,1]))
for(i in 1:10 ){
  ID    <- IDs[i]
  a[,i] <- STFDF_jour[which(IDs==ID),,c("O3")][,1]
}
colnames(a) <- IDs[1:10]
irr <- irts(index(init),a)
p4  <- autoplot(irr, facets = FALSE)+ggtitle('O3')

##### NO2
init <- STFDF_jour[which(IDs==IDs[1]),,c("NO2")]
a    <- matrix(0,ncol=10,nrow=length(init[,1]))
for(i in 1:10 ){
  ID    <- IDs[i]
  a[,i] <- STFDF_jour[which(IDs==ID),,c("NO2")][,1]
}
colnames(a) <- IDs[1:10]
irr <- irts(index(init),a)
p5  <- autoplot(irr, facets = FALSE)+ggtitle('NO2')

new("ggmultiplot",plots=list(p3,p4,p5),ncol=1)
```




```
####  5) As before, but grouping by location
IDs <- levels(OBS_jour$ID)
ts  <- STFDF_jour[which(IDs %in% c('FR03080')),"2014-01-01::2014-04-01",c("PM10","NO2","O3")]
colours <- brewer.pal(3,"Set1")
irr <- irts(index(ts),as.matrix(ts[,1:3]))
p1  <- autoplot(irr, facets = FALSE)
p1  <- p1+ggtitle('FR03080')

ts2  <- STFDF_jour[which(IDs %in% c('FR08209')),"2014-01-01::2015-04-01",c("PM10","NO2","O3")]
irr2 <- irts(index(ts2),as.matrix(ts2[,1:3]))
p2   <- autoplot(irr2, facets = FALSE)
p2   <- p2+ggtitle('FR08209')

ts2  <- STFDF_jour[which(IDs %in% c('FR03084')),"2014-01-01::2014-04-01",c("PM10","NO2","O3")]
irr2 <- irts(index(ts2),as.matrix(ts2[,1:3]))
p3   <- autoplot(irr2, facets = FALSE)
p3   <- p3+ggtitle('FR03084')

new("ggmultiplot",plots=list(p1,p2,p3),ncol=1)
```



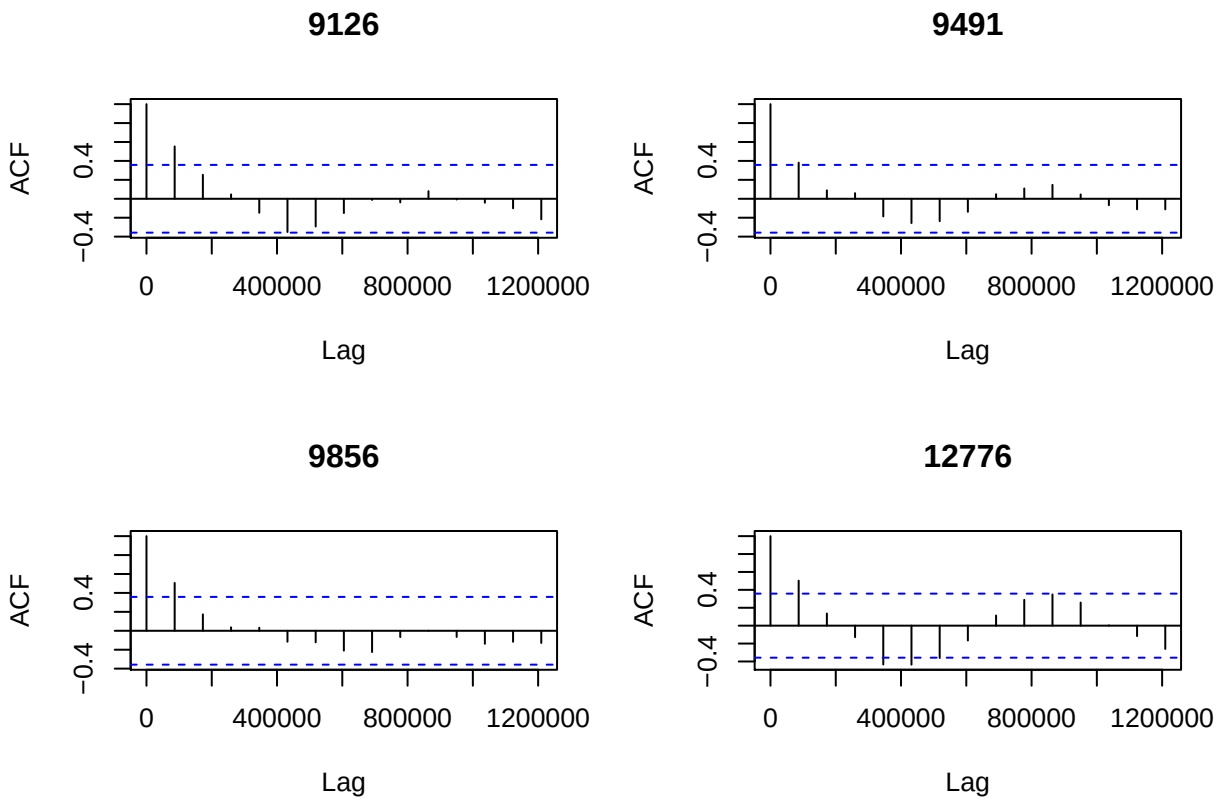
3.d) Animated plot using stplot() – RESULTS NOT DISPLAYED –

```
###  Animated plot -- NOT DISPLAYED --
### 10 days, two variables, with sp.layout, but refresh too slow
cxNO2_10j <- attr(STFDF_jour[,"2014-01-01::2014-01-10",'NO2'],'data')/
                  max(attr(STFDF_jour[,"2014-01-01::2014-01-10",'NO2'],'data'),na.rm=T) * 5
stplot(STFDF_jour[,"2014-01-01::2014-01-10",'O3'],cex=0.4* as.numeric(cxNO2_10j$NO2),
       col.regions=brewer.pal(10,"Spectral"),cuts=10,
       animate=0.2,do.repeat=F,sp.layout =list(world,first=TRUE))

### 10 days, two columns, without sp.layout: better refresh
cxNO2_4j <- attr(STFDF_jour[,"2014-01-01::2014-01-04",'NO2'],'data')
                /max(attr(STFDF_jour[,"2014-01-01::2014-01-04",'NO2'],'data'),na.rm=T) * 5
stplot(STFDF_jour[,"2014-01-01::2014-01-04",'O3'],cex=0.4* as.numeric(cxNO2_4j$NO2),
       col.regions=brewer.pal(10,"Spectral"),cuts=10, animate=0.2,do.repeat=F)

### 10 days, one variable for color one for size, with HTML output
### The animation is saved in mpeg format with high quality
### (requires installation of command line tool imagemagick)
stplot(STFDF_jour[,"2014-01-01::2014-01-10",'O3'],cex=0.4* as.numeric(cxNO2_10j$NO2),
       col.regions=brewer.pal(10,"Spectral"),cuts=10,sp.layout =world, animate=0.2,do.repeat=F)

for(i in c('01','02','03','04','05','06','07','08','09','10')){
 par(mar = c(3, 3, 2, 0.5), mgp = c(2, 0.5, 0), tcl = -0.3, cex.axis = 0.8
     ,cex.lab = 0.8, cex.main = 1)
 cxNO2_1j <- attr(STFDF_jour[,paste("2014-01-",i,sep=''),'NO2'],'data')
```

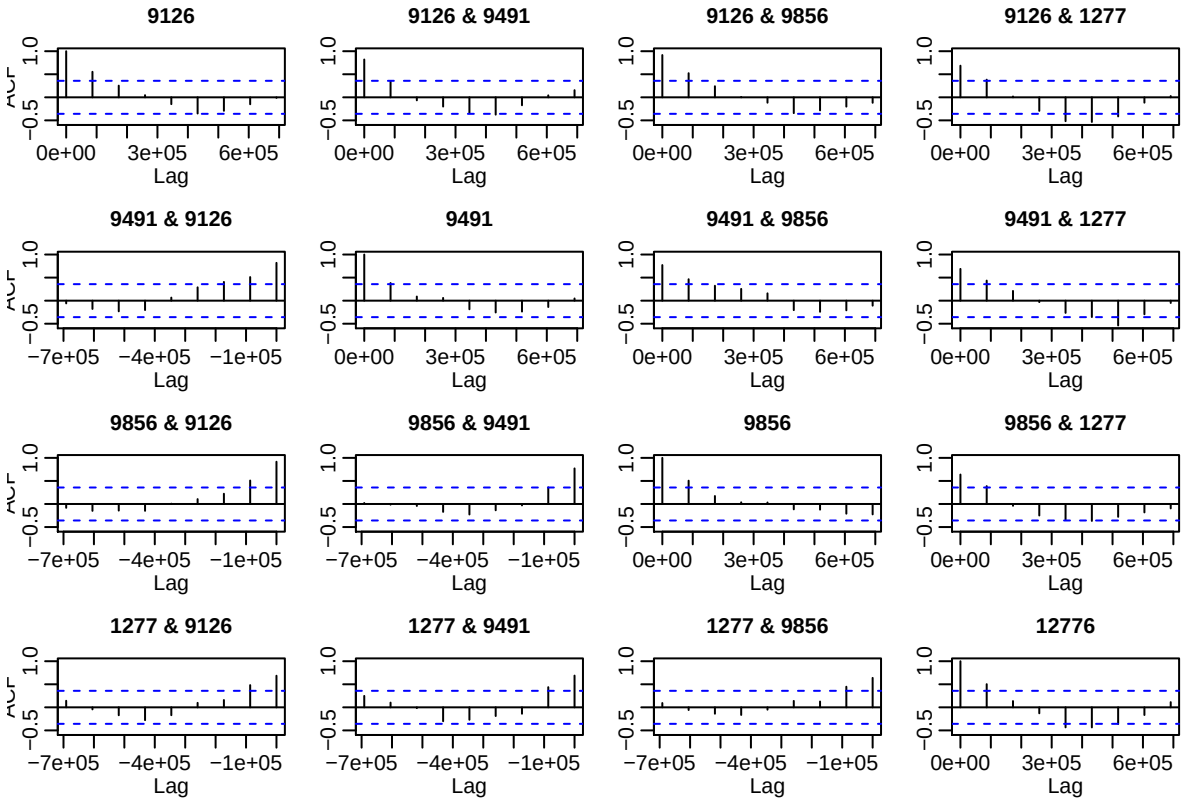
```
                /max(attr(STFDF_jour[,paste("2014-01-",i,sep=''),'NO2'],'data'),na.rm=T) * 5
 jpeg(paste('images/se',i,'.jpg',sep=''),width=5, height=5, units="in",res=600)
 cat(paste('se',i,'.jpg',sep=''),'\n')
 print(spplot(STFDF_jour[,paste("2014-01-",i,sep=''),'O3'],cex=0.4*as.numeric(cxNO2_1j$NO2),
            col.regions=brewer.pal(10,"Spectral"),cuts=10,sp.layout =world))
dev.off()
}
system('convert  -delay 25 -quality 100  images/*.jpg  animation10jours.mpeg')
system('open animation10jours.mpeg')


### Animated plotKML with colours NO2
library(plotKML)
ID <- STFDF_jour[,"2014-01-01",'ID']
plotKML(STFDF_jour[,"2014-01-01",'ID'],colour_scale=SAGA_pal[[1]],
labels='')
```

3.e) Plot of spatio-temporal dependencies

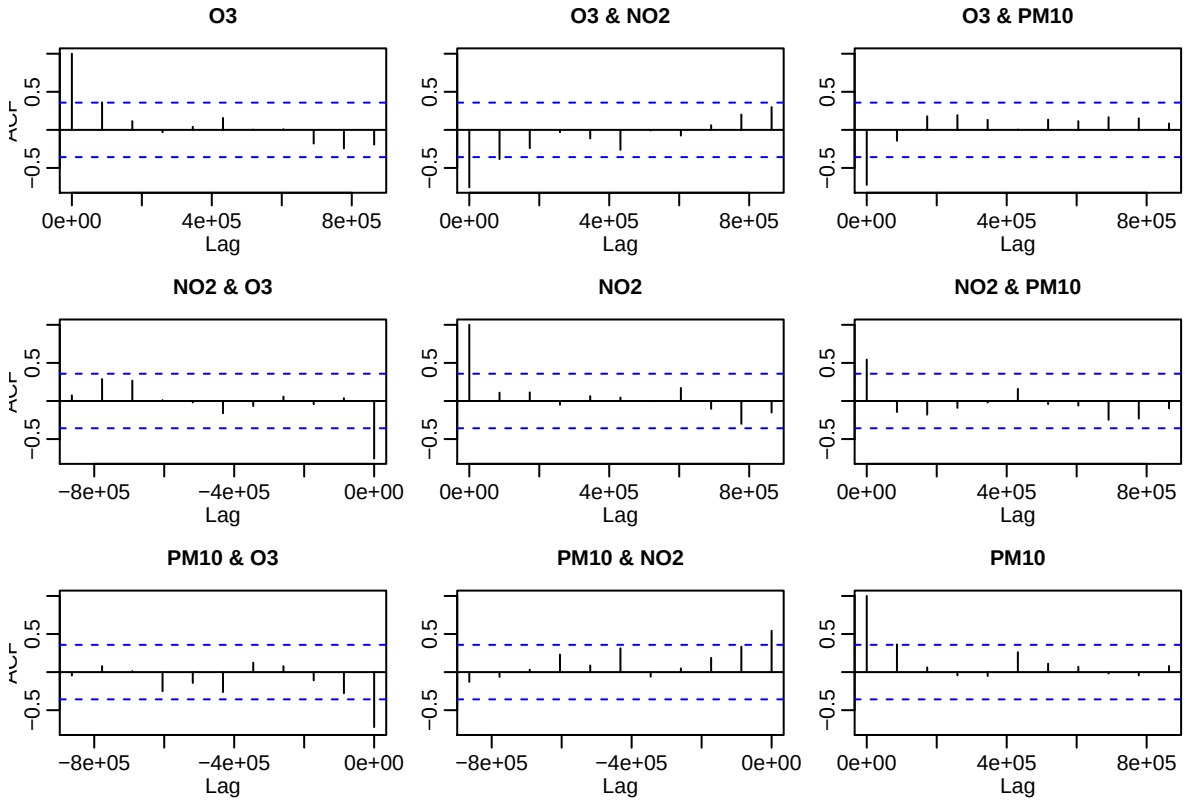
```
rm(list=ls())
library(gstat)
load('data/STFDF_jour.Rdata')


### Temporal auto-correlation
### choose station with no NA for O3 for the period 2014-01-01::2014-01-30
rn <- row.names(STFDF_jour@sp)[c(26:28,36)]

## Multiple stations, one variable
## lags are expressed in secondes, not days
par(mfrow=c(2,2))
for(i in rn) acf(STFDF_jour[i,"2014-01-01::2014-01-30","O3"]$O3,main=i)
```



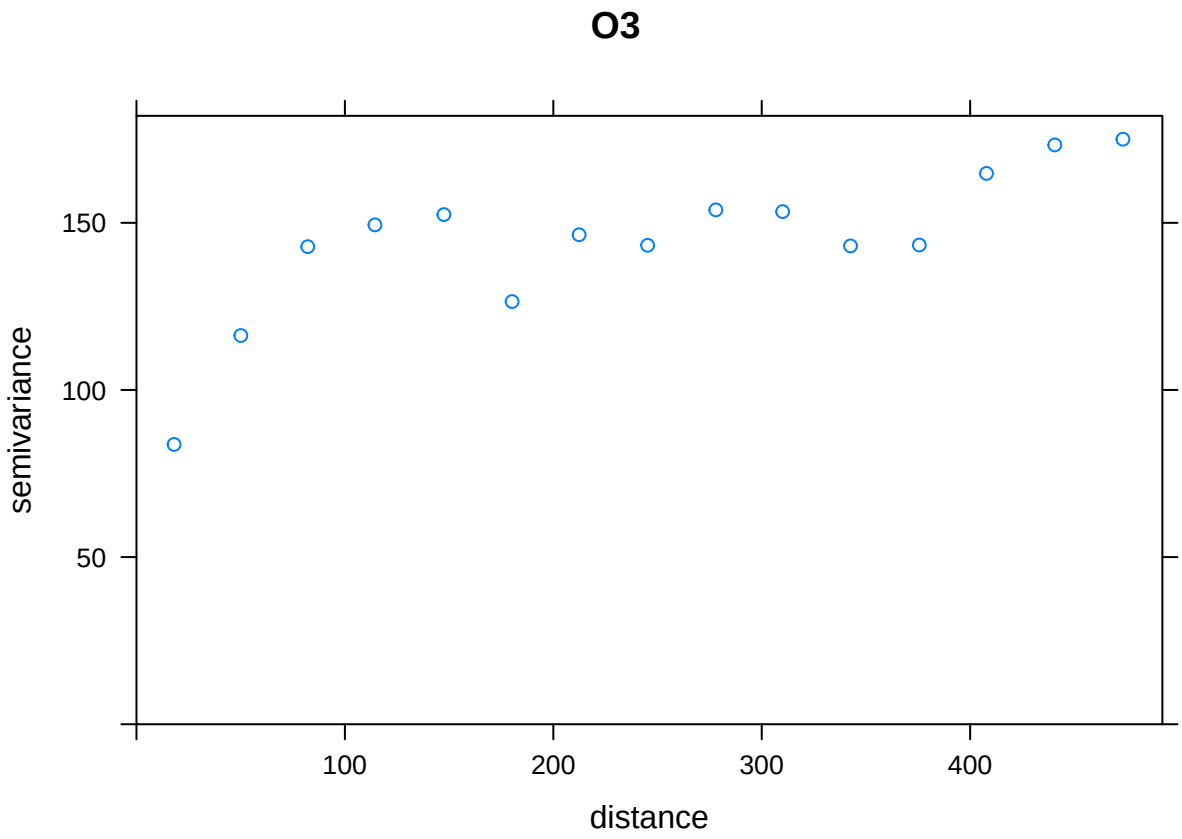

```
### Cross correlation

## Cross correlation between multiple stations and one variable
par(mfrow=c(1,1))

acf(as(STFDF_jour[rn,"2014-01-01::2014-01-30","O3"],"xts"))
```



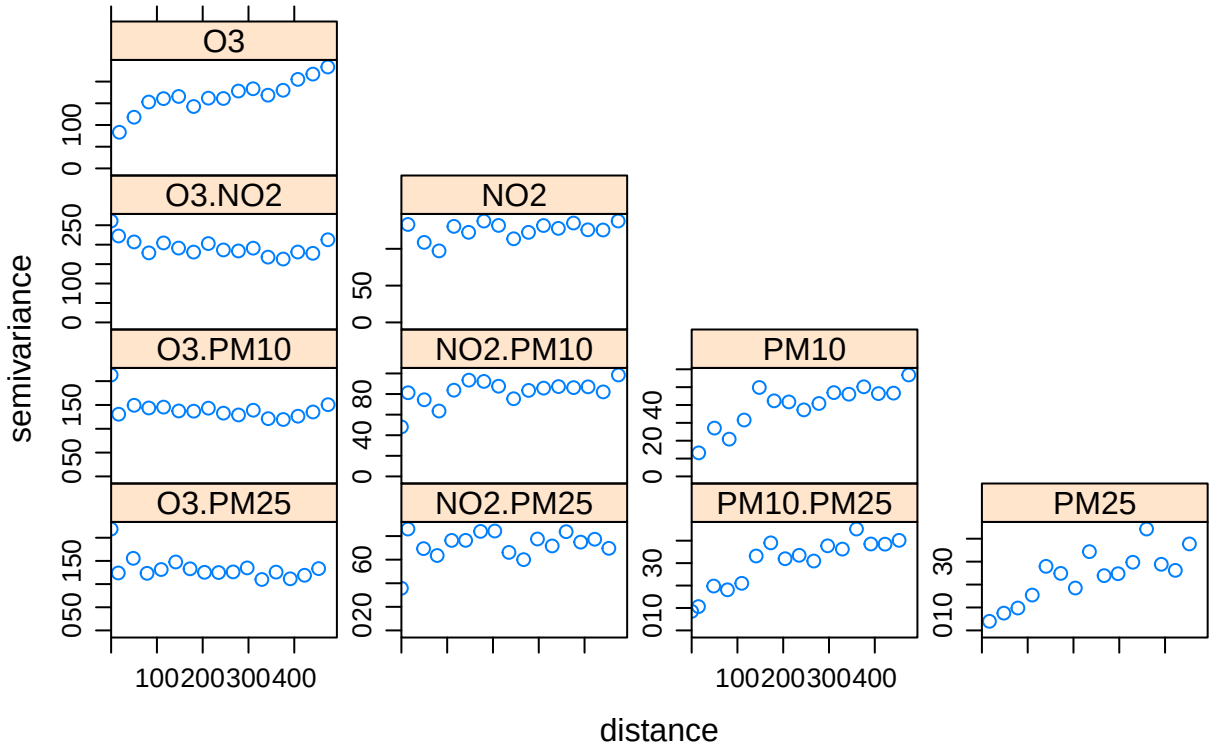

```
## Cross correlation between multiple stations and three variables

acf(STFDF_jour[5,"2014-01-01:::2014-01-30",c("O3","NO2","PM10")][,1:3])
```



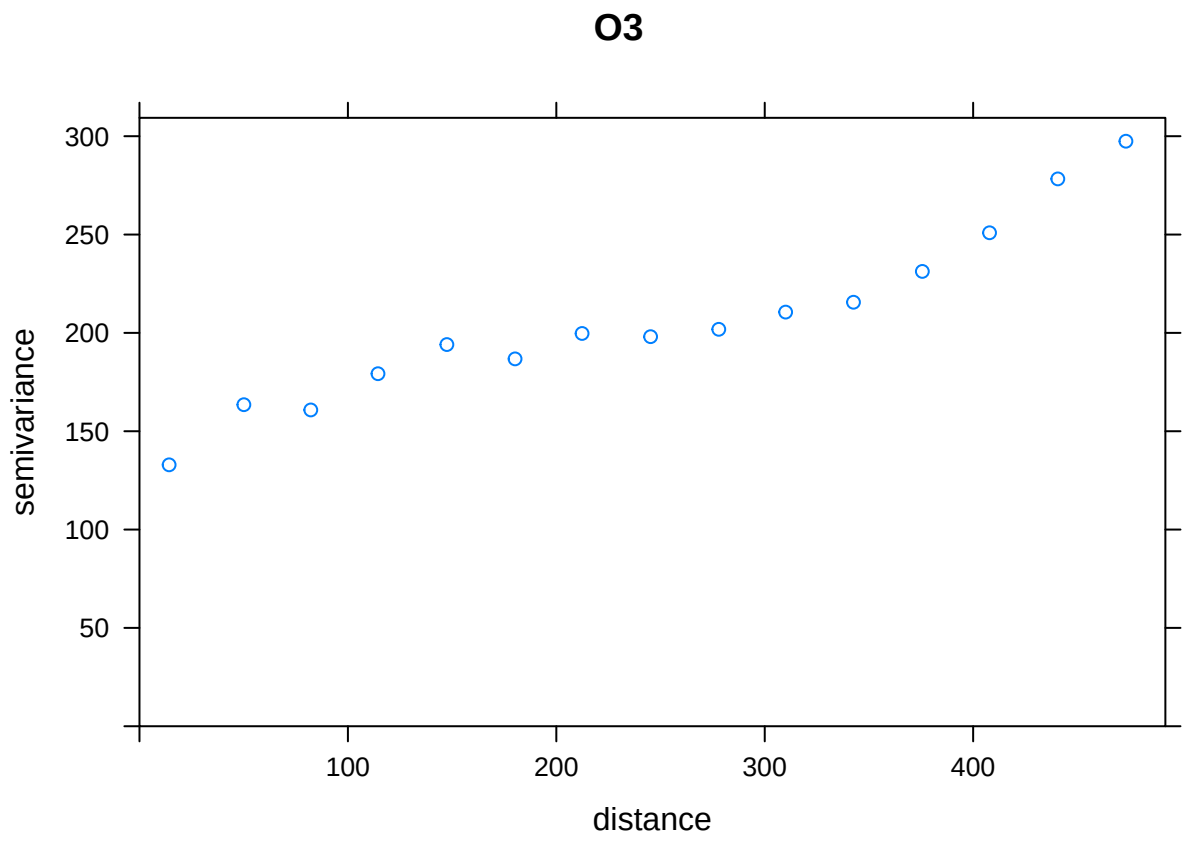

```
### Spatial auto-correlation

## Spatial auto-correlation for fixed date and one variable

library(gstat)
v <- variogram(O3~lat+long,STFDF_jour[!is.na(STFDF_jour[,"2014-01-01","O3"]$O3),"2014-01-01","O3"])
plot(v,main="O3")
```



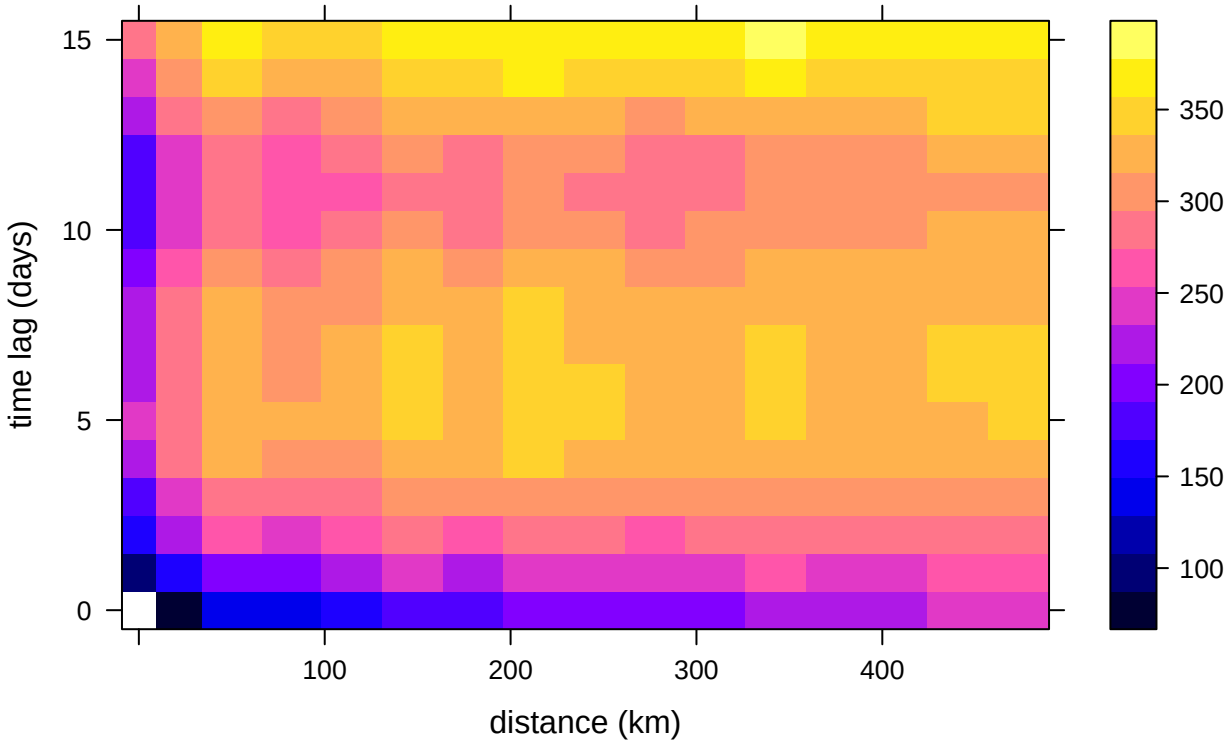

```
## Spatial auto-correlation for fixed date and multiple variables
g <- gstat(NULL, "O3", O3 ~ 1, data = STFDF_jour[!is.na(STFDF_jour[,"2014-01-01","O3"]$O3)
           ,"2014-01-01","O3"])
g <- gstat(g, "NO2", NO2 ~ 1, data = STFDF_jour[!is.na(STFDF_jour[,"2014-01-01","NO2"]$NO2)
            ,"2014-01-01","NO2"])
g <- gstat(g, "PM10", PM10 ~ 1, data = STFDF_jour[!is.na(STFDF_jour[,"2014-01-01","PM10"]$PM10)
            ,"2014-01-01","PM10"])
g <- gstat(g, "PM25", PM25 ~ 1, data = STFDF_jour[!is.na(STFDF_jour[,"2014-01-01","PM25"]$PM25)
            ,"2014-01-01","PM25"])

vm <- variogram(g)
plot(vm)
```



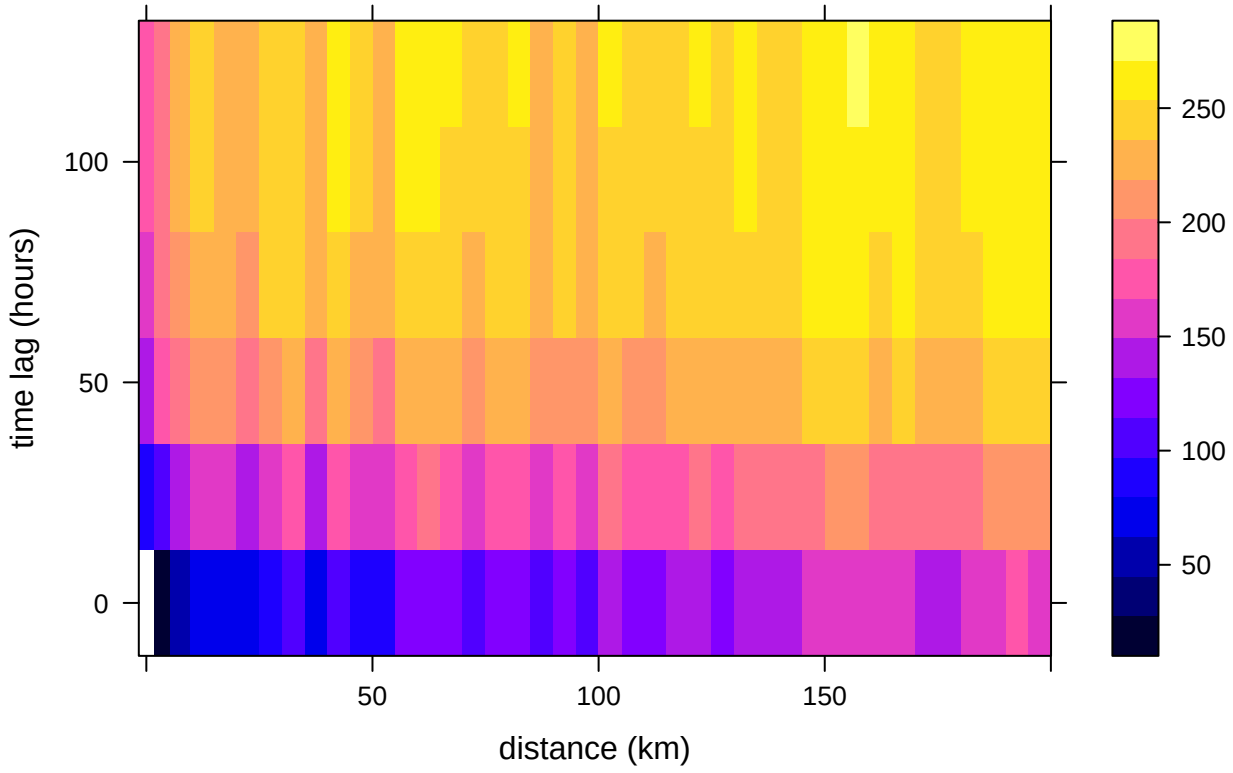

```
## mean variogram on multiple dates

lst <- lapply(1:5,function(i){x=STFDF_jour[,i,"O3"]; x$ti=i ; rownames(x@coords)=NULL;x})
pts <- do.call(rbind,lst)

vv <- variogram(O3~ti,pts[!is.na(pts$O3),])
plot(vv, main="O3")
```



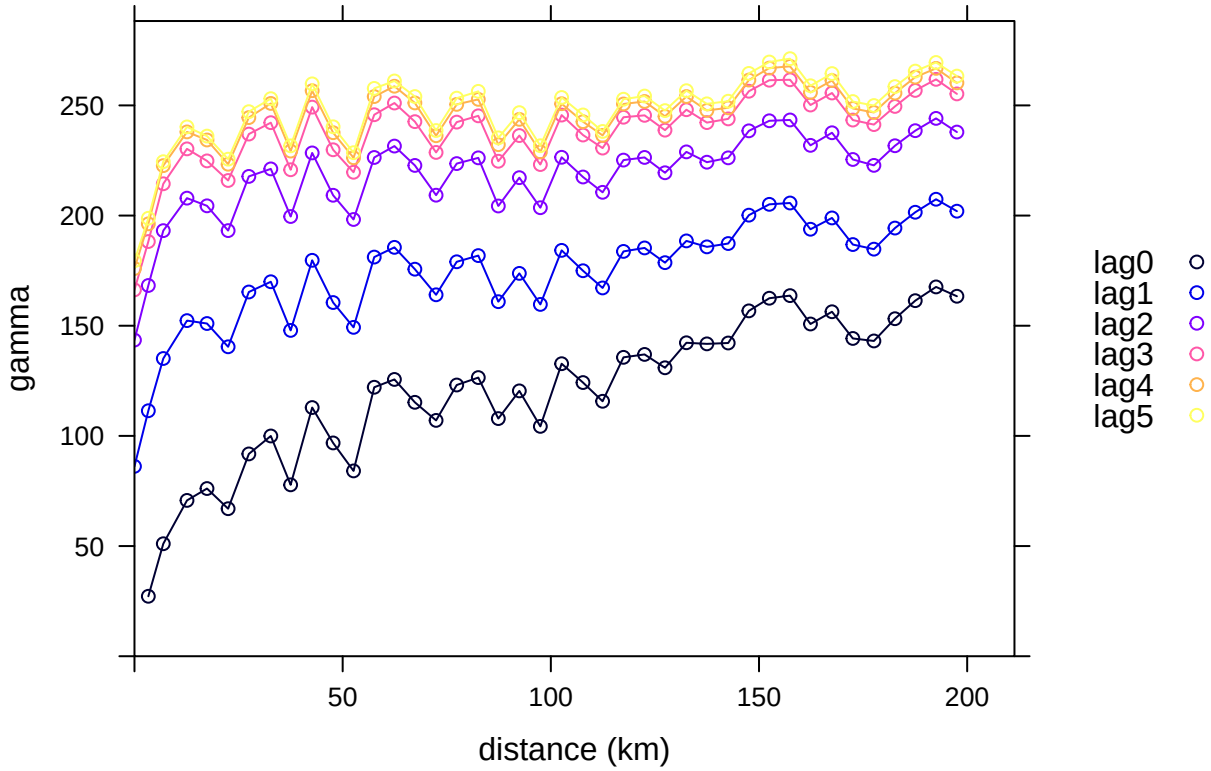

```
## Spatio-temporal auto-correlation

vst <- variogram(O3~lat+long,STFDF_jour[!is.na(STFDF_jour[,"2014-01-01::2014-01-31","O3"]$O3),
                                        "2014-01-01::2014-01-31","O3"])
plot(vst,main="O3")
```



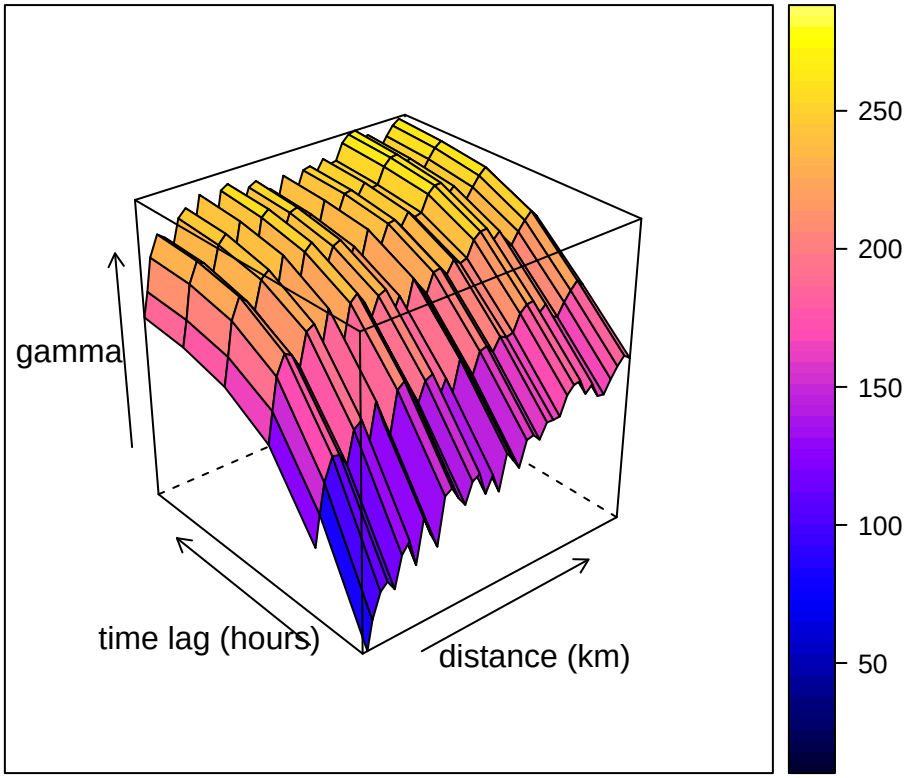

```
vvst <- variogram(O3~1,STFDF_jour[!is.na(STFDF_jour["2014-01-01::2014-12-31","O3"]$O3),
                                   "2014-01-01::2014-12-31","O3"],
                  width=5,cutoff=200,tlags=0:5)
plot(vvst)
```




```
plot(vvst,map=FALSE)
```



```
plot(vvst,wireframe=T)
```



3.f) Interactive plots with Shiny

```
setwd(paste(rep_base,'/data',sep=""))
library(raster)
library(tseries)
library(ggfortify)
library(gstat)
library(ggplot2)
library(shiny)
library(spacetime)
library(leaflet)
library(RColorBrewer)
library(sp)
library(rgeos)
library(rworldmap)
library(maptools)
library(ggmap)

load('STFDF_jour.Rdata')
ST2 <- STFDF_jour[,"2014-01-01::2014-01-30",c("ID","NO2","O3","PM10")]

### This Shiny application creates an interface that the user can navigate and that
### contains different objects,such as, maps, plots, summaries, etc, used to explore our data set.
```

```
### The user has the possibility to interact with the inteface by choosing, e.g.,
### the station to consider, the time interval or the variables to explore, and the
### resulting outputs reacts according to the choice

### The basic ingredients to construct a Shiny application are:
### 1) the UI, where the layout of the interface is defined,
### 2) the SERVER, which contains the "instructions" on how the UI should work.

### In the UI (user interface) we control:
### 1) the VISUAL ASPECT of the application (color, disposition of panels, etc.)
### 2) the INPUT variables: the objects that the user can handle and modify (db, dates, etc.)
### 3) the OUTPUT: what the app will show to the user (plots, maps, graphs, etc.)

### In the SERVER we:
### 1) explain what to do with input variables and how to generate the output
### 2) control the reactivity of the app (more complicated, but highly efficient)


runApp(list(
 ui = fluidPage(
### ui will contain the UI of the app.
### UI is of type "FluidPage": layout consisting of rows which in turn include columns.
   sidebarLayout(
### Create a layout with a sidebar and main area.
     sidebarPanel(
### Create a sidebar panel containing input controls that can in turn be passed to sidebarLayout
### sidebarPanel() contains the objects that the user can interact with, i.e. the inputs.
### To each input correspond a unique name, that can be called in the SERVER part by input$name
### Every time that an input is modified by the user, all functions in SERVER that make use of
### that input will react to the change (unless differently specified).
### Objects of different class can become inputs, such as numerical values, dataframes, files, etc.
### Different control widgets, listed below, are used to interact with the user:
###actionButton -> Action Button
###checkboxGroupInput   -> A group of check boxes
###checkboxInput    -> A single check box
###dateInput    -> A calendar to aid date selection
###dateRangeInput   -> A pair of calendars for selecting a date range
###fileInput    -> A file upload control wizard
###numericInput -> A field to enter numbers
###radioButtons -> A set of radio buttons
###selectInput  -> A box with choices to select from
###sliderInput  -> A slider bar
###submitButton -> A submit button
###textInput    -> A field to enter text

         selectInput('dataset', 'Choose Dataset', ls()[sapply(mget(ls(), .GlobalEnv),
                         function(x) 'STFDF' %in% is(x))]),
### Create a select list with all active STFDF objects. Choose one to start working.
         selectInput('vars', 'Variables', "",multiple=TRUE),
### Choose the variables of the chosen STFDF.
         dateRangeInput(inputId="tim_int",label="Choose date interval"),
### Set the time interval using two calendars.
         radioButtons("choiceID","Choice of locations using...",c(IDs = "byIDS",map = "bymap"),
```

```
                    selected=NULL),conditionalPanel(condition = "input.choiceID == 'byIDS'",
                        selectInput('IDs', 'Which station', "",multiple=TRUE)),
        conditionalPanel(condition = "input.choiceID == 'bymap'", leafletOutput("mymap")),
### Create a radio button to select the type of choice for the station:
### If Ids, it will visualize the list of all IDs amongst which the user can choose
### If map, it will show a leaflet map with marked dots in correspondence of the stations
### radioButtons() works in combination with conditionalPanel(), for the conditional choices
        actionButton("buttonUpdate","Update")
### creates a button that updates the choices made by the user and start the computations
### for generating the output. This functionality can be avoided in case that output generation
### is very fast, allowing hence an interactive and immediate control of the user on the outputs.
### We prefered to add it because our outputs are sometimes slow to compute.
### It is a way of controlling the reactivity of the application.
        ),
     mainPanel(tabsetPanel(
       tabPanel("Summary",textOutput("choices")),
       tabPanel("Cartography",plotOutput("plot_carto"),plotOutput("plot_carto2")),
       tabPanel("Plots",plotOutput("plot1")),
       tabPanel("Dependence Structure",plotOutput("dep1"),plotOutput("dep2"))
### mainPanel is the place where the outputs will be visualized. We divided in 4 tabs (tabPanel())
### Outputs are generated by the functions in the SERVER part.
### To each output correspond a unique name, that can be called in the SERVER part by output$name
### Outputs can take different forms, such as text, images, plots, maps, etc.
### htmlOutput
### imageOutput
### plotOutput
### tableOutput
### textOutput
### uiOutput
### verbatimTextOutput
        )
      ))),
 server = function(session,input, output){
### the SERVER function contains all the instruction on what to do once the inputs have been chosen

   triggerd.by <<- NULL
   data1=reactive({get(input$dataset)})
### The chosen dataset "input$dataset" is set as data1 (class STFDF)
   observeEvent(input$dataset,{
     df1<-attr(data1(),'data')
     dt1<-attr(data1(),'time')
     updateSelectInput(session, "vars",choices = names(df1))
     updateDateRangeInput(session,"tim_int",start =min(index(dt1)),end=max(index(dt1)),
                          min=min(index(dt1)),max=max(index(dt1)))
     updateSelectInput(session, "IDs",choices = levels(df1$ID))
### Once the dataset has been chosen, the widgets of "Which variable","time interval" and " available
### stations" are automatically updated to reflect the choice of the database
   })

   observeEvent({"input.choiceID == 'bymap'"},{
     ds1=as(data1(),"Spatial")
     output$mymap <- renderLeaflet({leaflet(ds1) %>%
         addTiles(urlTemplate = "http://{s}.tile.opentopomap.org/{z}/{x}/{y}.png") %>%
```

```
        setView(lng =mean(coordinates(ds1)[,1]),
                lat = mean(coordinates(ds1)[,2]), zoom = 8)%>%
        addCircles(color="red")})
### If the choice of the stations is made "by map", a leaflet map will appear in the sidebar
   })

   observeEvent(input$buttonUpdate,{
### All function contained in observeEvent(input$buttonUpdate{}) will execute only after the
### "Update" button has been clicked. It is an easy way of controlling the reactivity.
### Obviously, the outputs depends on the chosen inputs:
     nvars <- length(input$vars)
     time_interval <- input$tim_int
     int_in <- input$tim_int[1]
     int_en <- input$tim_int[2]
     int_date<-paste(int_in,int_en,sep="::")
     ndays <- as.numeric(int_en-int_in)

     if(input$choiceID == 'bymap'){
       ds1=as(data1()[,1:2],"Spatial")
       a<-matrix(unlist(input$mymap_bounds)[c(4,3,2,1)],2,2)
       b_poly <- as(extent(a), "SpatialPolygons")
       proj4string(b_poly)<-proj4string(ds1)
       inters_sp<-!is.na(over(ds1,b_poly))
       npoints <- sum((inters_sp==1)*1)
       d<-data1()[inters_sp,int_date,input$vars]
       d2<-data1()[inters_sp,int_date,c("ID",input$vars)]
     }
     if(input$choiceID == 'byIDS'){
       d<-data1()[attr(data1(),"data")$ID %in% input$IDs,int_date,input$vars]
       d2<-data1()[attr(data1(),"data")$ID %in% input$IDs,int_date,c("ID",input$vars)]
       npoints <- length(input$IDs)
       chosenID <- attr(data1(),"data")$ID %in% input$IDs
     }

     output$choices = renderText({
       paste("You have chosen ",nvars," variable(s).\n",
             "The time interval is of ",as.numeric(int_en-int_in)," days.\n",
             "You are considering ",npoints," points/stations\n",sep="")
     })
### The summary of the chosen subset is print using "renderText()".

     world<-getMap(resolution="low")

### output$plot_carto and output$plot_carto2 are cartographies plotted using
### the functions presented in Sections 3.a and 3.d. They are plotted using "renderPlot()".
### output$plot1 is a static plot as presented in Section 3.c for time series.
### output$dep1 and output$dep2 are dependency plots as explained in Section 3.e.

###Map: n stations, 1 day, 1 variable
     if (npoints>1 && ndays==0 && nvars==1 ){
       output$plot_carto <- renderPlot({spplot(d,col.regions=brewer.pal(10,"Spectral"),
                                               cuts=10,sp.layout=world)})
     }
```

```
###Map: n stations, 1 day, 2 variables
     if (npoints>1 && ndays==0 && nvars==2 ){
       output$plot_carto <- renderPlot({
         cx = attr(d,"data")[,input$vars[2]]/max(attr(d,"data")[,input$vars[2]],na.rm=T) * 5
         spplot(d[,input$vars[1]],cex=0.4*as.numeric(cx),scales=list(draw=TRUE),
                pch=19,sp.layout=world)
       })
       output$plot_carto2 <- renderPlot({
         cx = attr(d,"data")[,input$vars[1]]/max(attr(d,"data")[,input$vars[1]],na.rm=T) * 5
         spplot(d[,input$vars[2]],cex=0.4*as.numeric(cx),scales=list(draw=TRUE),
                pch=19,sp.layout=world)
       })
     }

###Animated Map: n stations, n days, 1 variable
###Time seriesPlot: n stations, n days, 1 variable
     if (npoints>1 && ndays>0 && nvars==1 ){
       output$plot_carto <- renderPlot({stplot(d,col.regions=brewer.pal(10,"Spectral"),
                                               cuts=10,sp.layout=world) })
       output$plot_carto2 <- renderPlot({stplot(d,col.regions=brewer.pal(10,"Spectral"),
                                      cuts=10,sp.layout=world, animate=0.2,do.repeat=F)})
       output$plot1 <- renderPlot({
         tim<-attr(d2,"time")
         dt<-attr(d2,"data")
         n<-dim(dt)[1]/length(tim)
         a<-split(dt,dt$ID)
         m<-matrix(0,ncol=n,nrow=length(tim))
         for (i in 1:n){
           if (!all(is.na(a[[i]][,2]))) m[,i]<-as.numeric(a[[i]][,2])
         }
         colnames(m)<-levels(d2$ID)
         ir<-irts(index(tim),m)
         p=autoplot(ir, facets = FALSE)+ggtitle(as.character(input$vars))
         p
       })

     }

###Animated Map: n stations, 1 day, 2 vars
###Time series Plot: n stations, 1 day, 2 vars
     if (npoints>1 && ndays>0 && nvars==2 ){
       output$plot_carto <- renderPlot({
         cx = attr(d,'data')[,input$vars[2]]/max(attr(d,'data')[,input$vars[2]],na.rm=T) * 5
         stplot(d[,,input$vars[1]],cex=0.4* as.numeric(cx),col.regions=brewer.pal(10,"Spectral"),
                cuts=10,sp.layout=world, animate=0.2,do.repeat=F)
       })

       output$plot_carto2 <- renderPlot({
         cx = attr(d,'data')[,input$vars[1]]/max(attr(d,'data')[,input$vars[1]],na.rm=T) * 5
         stplot(d[,,input$vars[2]],cex=0.4* as.numeric(cx),col.regions=brewer.pal(10,"Spectral"),
                cuts=10,sp.layout=world, animate=0.2,do.repeat=F)
       })
```

```
    }

### 1 station, multiple variables
    if(npoints==1 && ndays>0 && nvars>=2 ){
      output$plot1 <- renderPlot({
        colours=brewer.pal(3,"Set1")
        irr<-irts(index(d),as.matrix(d[,1:nvars]))
        p1<-autoplot(irr, facets = FALSE)
        p1})
    }

    if(npoints>1 && ndays>0 && nvars>=2 ){
      output$plot1 <- renderPlot({
        tim<-attr(d2,"time")
        dt<-attr(d2,"data")
        n<-dim(dt)[1]/length(tim)
        k<-length(input$vars)
        a<-split(dt,dt$ID)
        p=vector(mode="list",length = k)
        for (j in 1:k){
          m<-matrix(0,ncol=n,nrow=length(tim))
          for (i in 1:n){
            if (!all(is.na(a[[i]][,j+1]))) m[,i]<-as.numeric(a[[i]][,j+1])}
          colnames(m)<-levels(dt$ID)
          ir<-irts(index(tim),m)
          p[[j]]=autoplot(ir, facets = FALSE)+ggtitle(as.character(input$vars[j]))
        }
        new("ggmultiplot",plots=p,ncol=1)})
    }

    if (npoints>1 && ndays>3 && nvars==1){
      output$dep1 <- renderPlot({
        acf(as(d,"xts"),na.action = na.pass)
      })
    }

    if (npoints==1 && ndays>3 && nvars==1){
      output$dep1 <- renderPlot({
        acf(d[,input$vars],na.action = na.pass)
      })
    }

    if (ndays>3 && nvars>1 && npoints==1){
      output$dep1 <- renderPlot({
        acf(as(d,"xts"),na.action = na.pass)
      })
    }

  })
 }))
```

4.) Estimating a space-time covariance function

4.1) Data preparation

```
rm(list=ls())
DATA = 'data/'
OUT = DATA
library(rgdal)
library(sp)
library(spacetime)
######### reload saved data objects (if necessary)
load(paste0(DATA, 'OBS_jour.Rdata'))
load(paste0(DATA, 'CHM.Rdata'))
load(paste0(DATA, 'stations.Rdata'))
######### extract French background stations
IDs.bg   <- stations$station_european_code[stations$type_of_station=="Background"]
IDs.fr   <- stations$station_european_code[stations$country_name=="France"]
IDs.bgfr <- intersect(IDs.bg,IDs.fr)
idx.stations <- which(stations$station_european_code %in% IDs.bgfr)
coord    <- cbind(stations$station_longitude_deg,stations$station_latitude_deg)[idx.stations,]
######### define time window for data used for fitting
tstart   <- "2014-01-01"
tend     <- "2014-03-31"
OBS_jour <- OBS_jour[OBS_jour$ID %in% IDs.bgfr,]
OBS_sel  <- stConstruct(OBS_jour,space=c('long','lat'),time='date',
                        SpatialObj=SpatialPoints(OBS_jour[,c('long','lat')]))
OBS_sel  <- as(OBS_sel,"STFDF")
proj4string(OBS_sel)="+init=epsg:4326"
OBS_sel  <- OBS_sel[,paste0(tstart,"::",tend)]
######### transform to Lambert 93 coordinates system
OBS_sel@sp <- spTransform(OBS_sel@sp, CRS("+init=epsg:2154"))

######### interpolate gridded CHIMERE values to space-time observation points
library(fields)
CHM_sel  <- CHM[as.character(CHM$time)>=tstart&as.character(CHM$time)<=tend,]
grid.CHM <- unique(cbind(CHM_sel$lon,CHM_sel$lat))
CHM_mat  <- matrix(CHM_sel$PM10, nrow=nrow(grid.CHM))
dim(CHM_mat)
```

```
## [1] 11211    90
```

```
lon.grid <- sort(unique(CHM_sel$lon))
lat.grid <- sort(unique(CHM_sel$lat))
ind.sites.obs <- match(unique(OBS_sel@data$ID),IDs.bgfr)
fun <- function(i){
  tmp <- list(x=lon.grid,y=lat.grid,
              z=matrix(CHM_mat[,i],length(lon.grid),length(lat.grid)))
  interp.surface(tmp, coord[ind.sites.obs,])
}
CHM_sites <- sapply(1:ncol(CHM_mat),fun)
######### save as variable CHM
OBS_sel@data$CHM <- as.numeric(CHM_sites)
```

```
######### save PM10 residuals with respect to CHM as variable PM10res
OBS_sel@data$PM10res <- OBS_sel@data$PM10-as.numeric(CHM_sites)
```

4.2) Estimation with *CompRandFld*

```
library(CompRandFld)
library(spam)
######### data must follow the format t x d (with t observation times and d sites)
######### to obtain a set of stations and time points without missing data, we
######### proceed through an iterative removal of stations and time points with many
######### missing data
names(OBS_sel@data)
```

```
## [1] "ID"      "PM10"    "PM25"    "NO2"     "O3"      "CHM"     "PM10res"
```

```
data <- matrix(OBS_sel@data$PM10res, ncol = dim(OBS_sel)[1], nrow = dim(OBS_sel)[2],
    byrow = T)
dim(data)
```

```
## [1]  90 378
```

```
mean(is.na(data))
```

```
## [1] 0.4398001
```

```
space.keep <- 1:ncol(data)
time.keep <- 1:nrow(data)
propNA <- 0.9
toKeep <- apply(is.na(data), 1, mean) < propNA
time.keep <- time.keep[toKeep]
data.keep <- data[toKeep, ]
toKeep <- apply(is.na(data), 2, mean) < propNA
space.keep <- space.keep[toKeep]
data.keep <- data.keep[, toKeep]
dim(data.keep)
```

```
## [1]  90 224
```

```
propNA <- 0.2
toKeep <- apply(is.na(data.keep), 1, mean) < propNA
time.keep <- time.keep[toKeep]
data.keep <- data.keep[toKeep, ]
toKeep <- apply(is.na(data.keep), 2, mean) < propNA
space.keep <- space.keep[toKeep]
data.keep <- data.keep[, toKeep]
dim(data.keep)
```

```
## [1]  90 209
```

```
propNA <- 0.1
toKeep <- apply(is.na(data.keep), 1, mean) < propNA
time.keep <- time.keep[toKeep]
data.keep <- data.keep[toKeep, ]
toKeep <- apply(is.na(data.keep), 2, mean) < propNA
space.keep <- space.keep[toKeep]
data.keep <- data.keep[, toKeep]
dim(data.keep)
```

```
## [1]  90 190
```

```
propNA <- 0.05
toKeep <- apply(is.na(data.keep), 1, mean) < propNA
time.keep <- time.keep[toKeep]
data.keep <- data.keep[toKeep, ]
toKeep <- apply(is.na(data.keep), 2, mean) < propNA
space.keep <- space.keep[toKeep]
data.keep <- data.keep[, toKeep]
dim(data.keep)
```

```
## [1]  87 164
```

```
propNA <- 0.025
toKeep <- apply(is.na(data.keep), 1, mean) < propNA
time.keep <- time.keep[toKeep]
data.keep <- data.keep[toKeep, ]
toKeep <- apply(is.na(data.keep), 2, mean) < propNA
space.keep <- space.keep[toKeep]
data.keep <- data.keep[, toKeep]
dim(data.keep)
```

```
## [1]  78 113
```

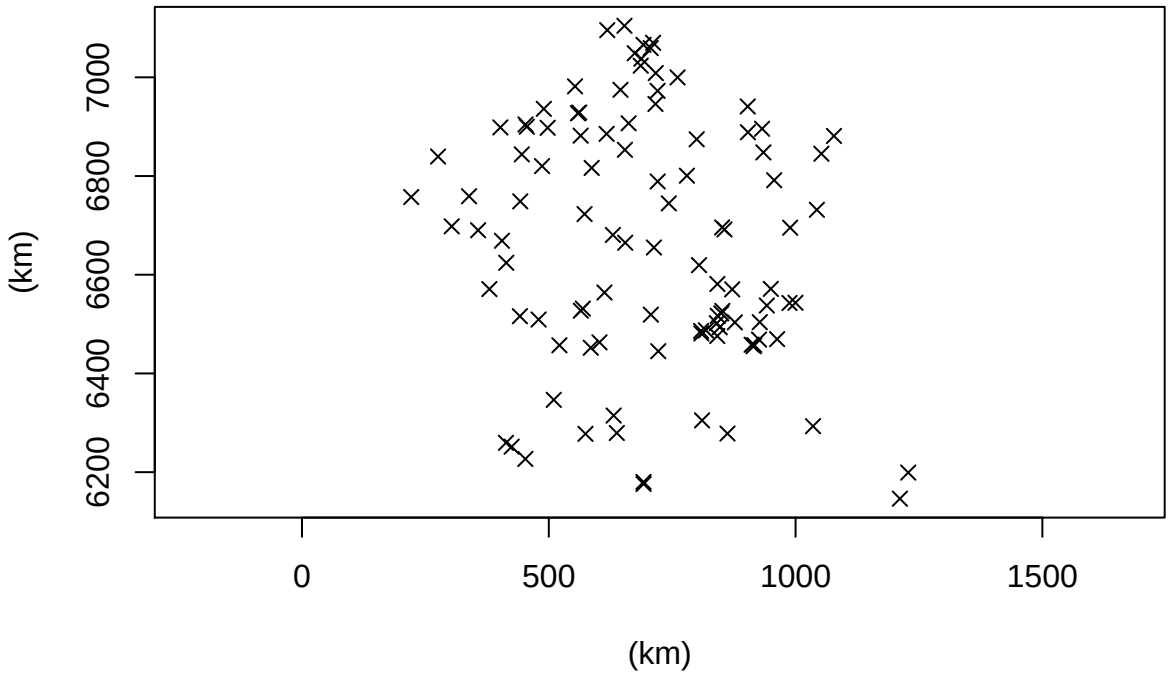
```
propNA <- 0.01
toKeep <- apply(is.na(data.keep), 1, mean) < propNA
time.keep <- time.keep[toKeep]
data.keep <- data.keep[toKeep, ]
toKeep <- apply(is.na(data.keep), 2, mean) < propNA
space.keep <- space.keep[toKeep]
data.keep <- data.keep[, toKeep]
dim(data.keep)
```

```
## [1]  70 103
```

```
propNA <- 10^(-10)
toKeep <- apply(is.na(data.keep), 1, mean) < propNA
time.keep <- time.keep[toKeep]
data.keep <- data.keep[toKeep, ]
toKeep <- apply(is.na(data.keep), 2, mean) < propNA
space.keep <- space.keep[toKeep]
data.keep <- data.keep[, toKeep]
dim(data.keep)
```

```
## [1]  70 103
```

```
coord.sel <- (OBS_sel@sp@coords/1000)[space.keep, ]  #Lambert 93 coordinates in  km
stations.fit <- stations[idx.stations[space.keep], ]
plot(coord.sel, asp = 1, xlab = "(km)", ylab = "(km)", pch = 4)
```




```
times <- (1:dim(OBS_sel)[2])[time.keep]
data <- data.keep
######### save selected data for later use
save(stations.fit, file = paste0(DATA, "stationsforfitting.Rdata"))
save(times, file = paste0(DATA, "timesforfits.Rdata"))
save(data, file = paste0(DATA, "data.Rdata"))

######### we assume that the PM10res data are stationary over space and time we
######### start by estimating the empirical mean and the empirical variance from
######### data
mean.est <- mean(data)
mean.est
```

```
## [1] 8.024326
```

```
var.est <- var(as.numeric(data))
var.est
```

```
## [1] 116.0013
```

```
######### now calculate an empirical space-time variogram
vgm.emp <- EVariogram(data = data, coordx = coord.sel, coordt = times, cloud = F,
    maxdist = 1000, maxtime = 12)
######### full likelihood estimation would be really hard and slow:
prod(dim(data))
```

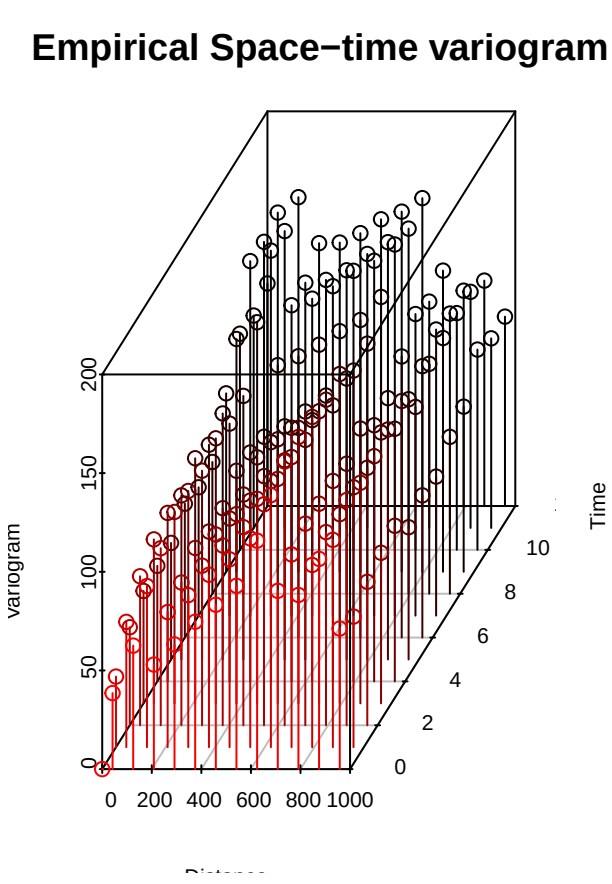
```
## [1] 7210
```

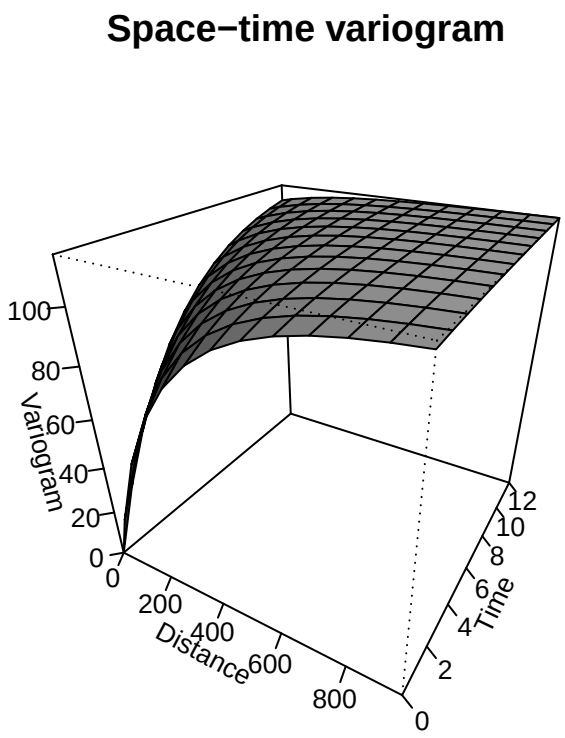
```
######### now we define some parametric models to estimate (with initial values and
######### some of the parameters fixed) space-time separable exponential model
######### without nugget
cormod1 <- "exp_exp"
fixed1 <- list(mean = mean.est, nugget = 0, sill = var.est)
start1 <- list(scale_s = 200, scale_t = 2)
# space-time separable exponential model with nugget
cormod2 <- "exp_exp"
fixed2 <- list(mean = mean.est, sill = var.est)
start2 <- list(scale_s = 200, scale_t = 2, nugget = 0)
# Gneiting model with powers fixed to 1, without nugget
cormod3 <- "gneiting"
fixed3 <- list(sill = var.est, mean = mean.est, nugget = 0, power_s = 1, power_t = 1)
start3 <- list(scale_s = 200, scale_t = 2, sep = 0.5)
# Gneiting model with powers fixed to 1, with nugget
cormod4 <- "gneiting"
fixed4 <- list(sill = var.est, mean = mean.est, power_s = 1, power_t = 1)
start4 <- list(scale_s = 200, scale_t = 2, sep = 0.5)
# Gneiting model with powers fixed to .5, without nugget
cormod5 <- "gneiting"
fixed5 <- list(sill = var.est, mean = mean.est, nugget = 0, power_s = 0.5, power_t = 0.5)
start5 <- list(scale_s = 200, scale_t = 2, sep = 0.5)
# Gneiting model with powers fixed to .5, with nugget
cormod6 <- "gneiting"
fixed6 <- list(sill = var.est, mean = mean.est, power_s = 0.5, power_t = 0.5)
start6 <- list(scale_s = 200, scale_t = 2, sep = 0.5)
# Gneiting model where powers are estimated, without nugget
cormod7 <- "gneiting"
fixed7 <- list(sill = var.est, mean = mean.est, nugget = 0)
start7 <- list(scale_s = 200, scale_t = 2, sep = 0.5, power_s = 0.5, power_t = 0.5)
# Gneiting model where powers are estimated, with nugget
cormod8 <- "gneiting"
fixed8 <- list(sill = var.est, mean = mean.est)
start8 <- list(scale_s = 200, scale_t = 2, sep = 0.5, power_s = 0.5, power_t = 0.5,
    nugget = 0)

######### pairwise likelihood fitting of the first model with space and time cut-off
######### distances
fit1PL <- FitComposite(data = data, coordx = coord.sel, coordt = times, maxdist = 300,
    maxtime = 4, corrmodel = cormod1, likelihood = "Marginal", type = "Pairwise",
    fixed = fixed1, start = start1)
fit1PL
```

```
##
## ###################################################################
## Maximum Composite-Likelihood Fitting of Gaussian Random Fields
##
## Setting: Marginal Composite-Likelihood
##
## Model associated to the likelihood objects: Gaussian
##
## Type of the likelihood objects: Pairwise
```

```
##
## Covariance model: exp_exp
## Number of spatial coordinates: 103
## Number of dependent temporal realisations: 70
## Number of replicates of the random field: 1
## Number of estimated parameters: 2
##
## Maximum log-Composite-Likelihood value: -6577607.64
##
## Estimated parameters:
## scale_s  scale_t
## 238.015    4.141
##
## ###########################################################################
```

```
######### visual comparison of empirical and fitted variogram
library(scatterplot3d)
Covariogram(fit1PL, vario = vgm.emp, show.vario = T, pch = 20)
```






```
######### weighted least squares fitting
fit1WLS <- WLeastSquare(data = data, coordx = coord.sel, coordt = times, maxdist = 300,
    maxtime = 4, corrmodel = cormod1, fixed = fixed1, start = start1, weighted = T)
fit1WLS
```

```
##
```

```
## ################################################################
## Results: Weighted Least Squares Fitting of Gaussian Random Fields.
##
## Model used from the Weighted Least Squares : Gaussian
##
## Covariance model: exp_exp
## Number of spatial coordinates: 103
## Number of dependent temporal realisations: 70
## Number of replicates of the random field: 1
## Number of estimated parameters: 2
## The value of the Weighted Least Squares at the minimum: 35788.26
## Number of spatial bins 14
## Number of temporal bins 5
## Min and max spatial distances: 2.690935 300
## Min and max temporal interval: 1 4
##
## Estimated parameters:
## scale_s  scale_t
## 306.903    3.131
##
## ################################################################
```

```
######### now we fit all models with weighted least squares or pairwise likelihood
fitsWLS <- fitsPL <- vector("list", 8)
for (i in 1:8) {
    fitsWLS[[i]] <- WLeastSquare(data = data, coordx = coord.sel, coordt = times,
        maxdist = 300, maxtime = 4, corrmodel = get(paste0("cormod", i)), fixed = get(paste0("fixed",
            i)), start = get(paste0("start", i)), weighted = T)
    fitsPL[[i]] <- FitComposite(data = data, coordx = coord.sel, coordt = times,
        maxdist = 300, maxtime = 4, corrmodel = get(paste0("cormod", i)), likelihood = "Marginal",
        type = "Pairwise", fixed = get(paste0("fixed", i)), start = get(paste0("start",
            i)), varest = T)
}
######### save lists of fit objects
save(fitsWLS, file = paste0(DATA, "fitsWLS.Rdata"))
save(fitsPL, file = paste0(DATA, "fitsPL.Rdata"))

######### which pairwise likelihood model is best in terms of the CLIC?
which.min(sapply(fitsPL, getElement, "clic"))
```

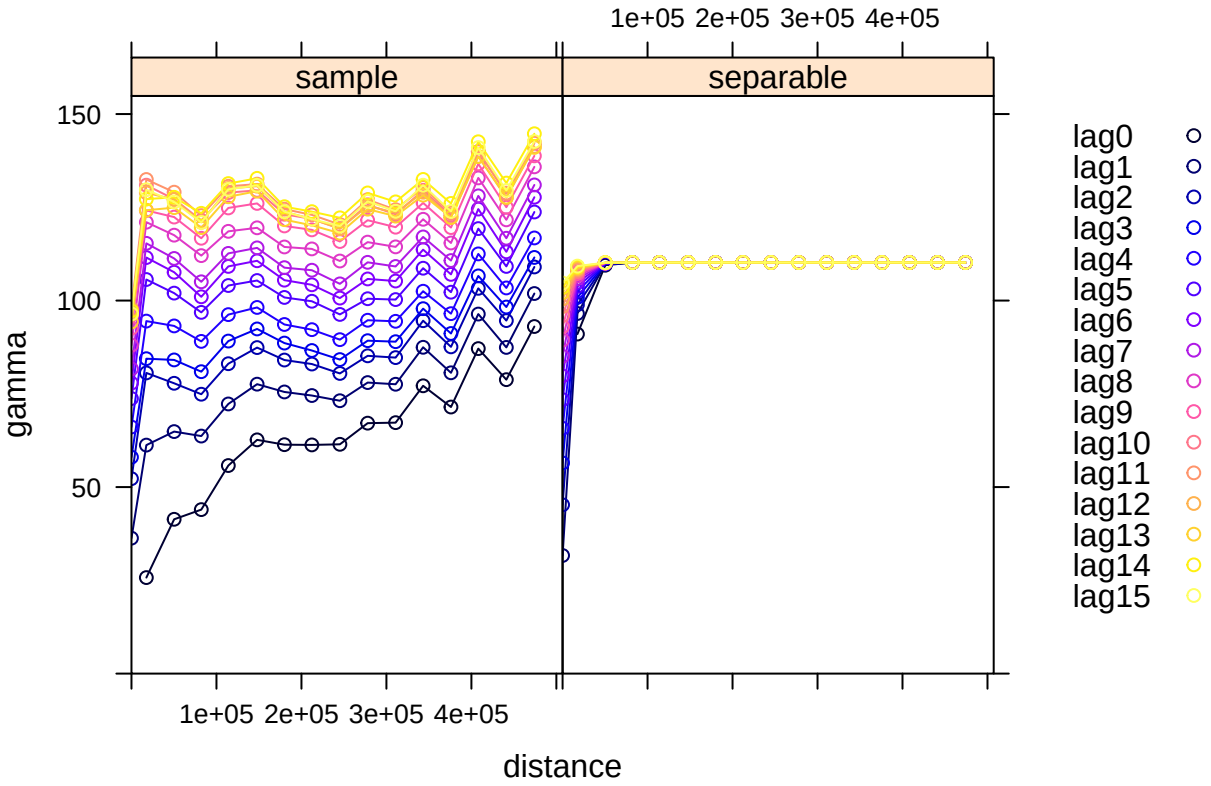
```
## [1] 2
```

```
######### test some hypotheses for embedded models
fit8 <- fitsPL[[8]]
fit7 = fitsPL[[7]]
fit5 = fitsPL[[5]]
HypoTest(fit8, fit7, fit5, statistic = "Wald")
```

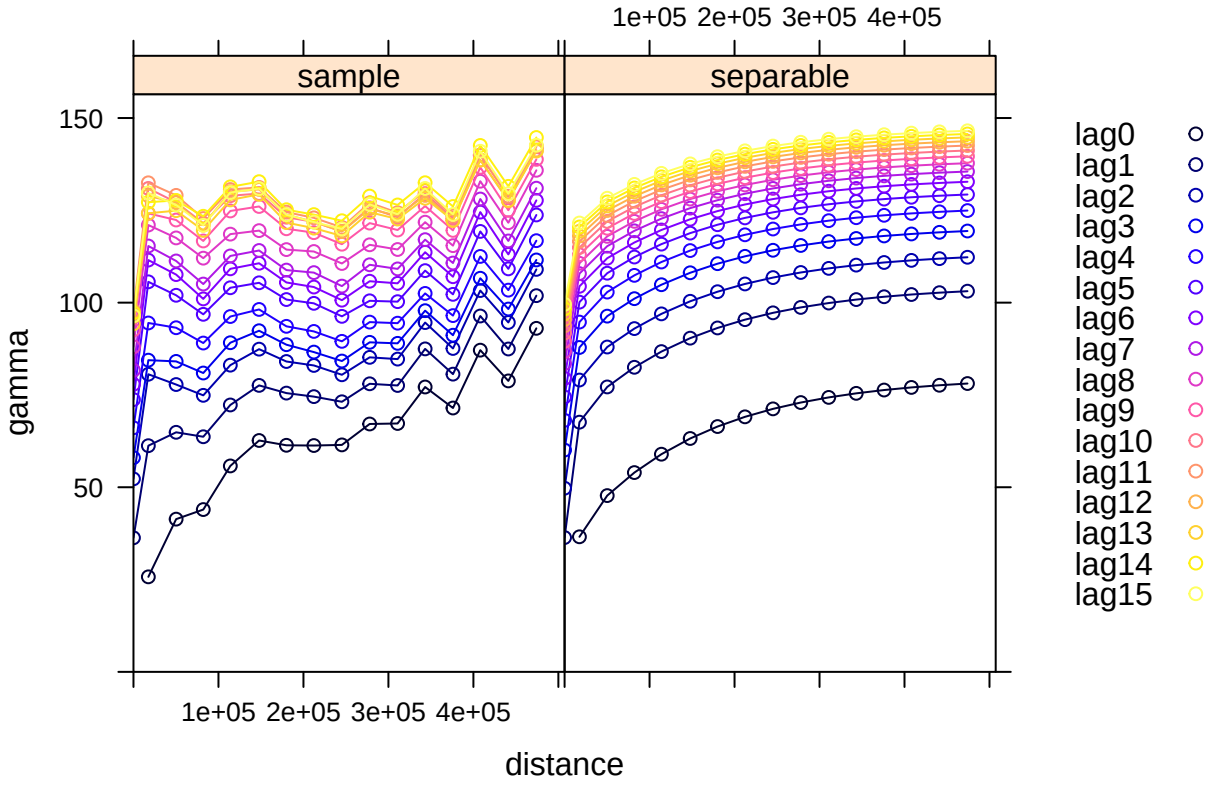
```
##      Num.Par Diff.Par Df      Chisq   Pr(>chisq)
## fit8       6       NA NA         NA           NA
## fit7       5        1  1  0.1769632 6.739961e-01
## fit5       3        2  2 27.7078933 9.622932e-07
```

4.3) Estimation with *gstat*

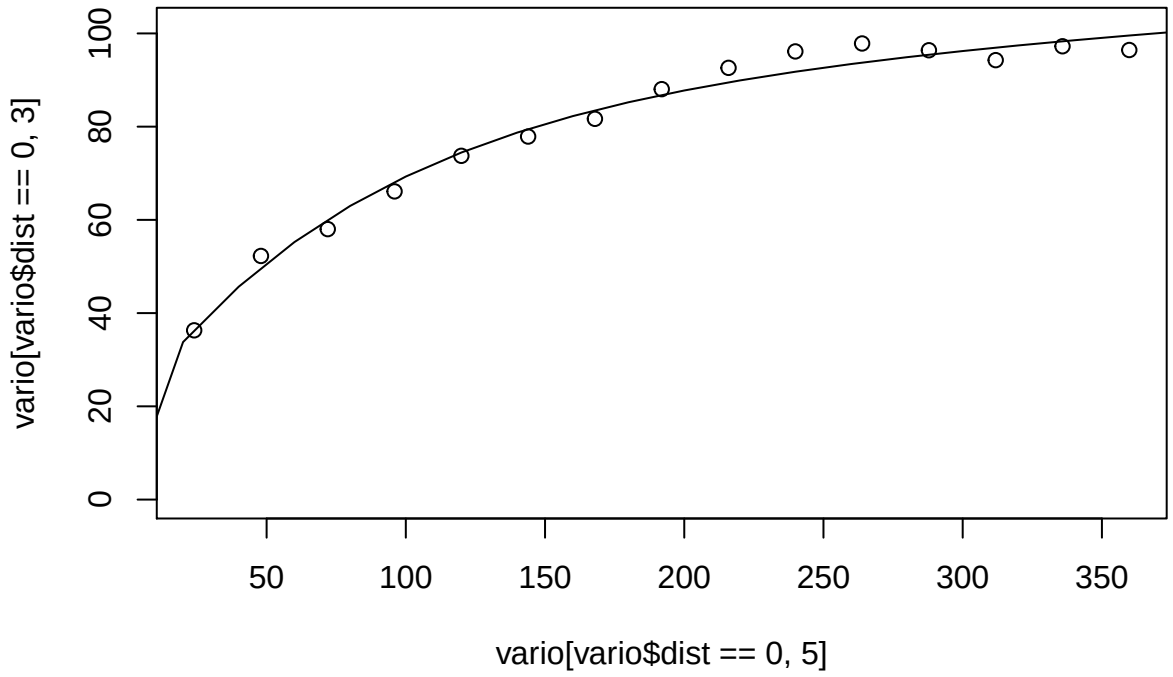
```
library(gstat)
######### We first define a function variot for plotting the marginal temporal
######### variogram at distance 0
variot <- function(model,vario=vario){
  tseq <- seq(0,400,20)
  grid <- expand.grid(seq(0,50000,10),tseq)
  dg   <- data.frame(spacelag=grid[,1],timelag=grid[,2])
  table<- variogramSurface(model,dg)
  nx   <- length(seq(0,50000,10))
  ny   <- length(seq(0,15,1))
  plot(vario[vario$dist==0,5],vario[vario$dist==0,3],ylim=range(c(0,vario[vario$dist==0,3],
       table[table[,1]==0,3]),na.rm=T))
  lines(tseq,table[table[,1]==0,3])
}

######### we calculate the empirical space-time variogram
vario <- variogramST(PM10res~1,data=OBS_sel)

######### separable model, least squares fit
separableModel <- vgmST("separable",space=vgm(0.9,"Exp",10000,0.1),
                        time=vgm(0.9,"Exp",3.5,0.1),sill=40)
separable_fit  <- fit.StVariogram(model=separableModel,object=vario)
plot(vario,separable_fit,all=T,map=F)
```



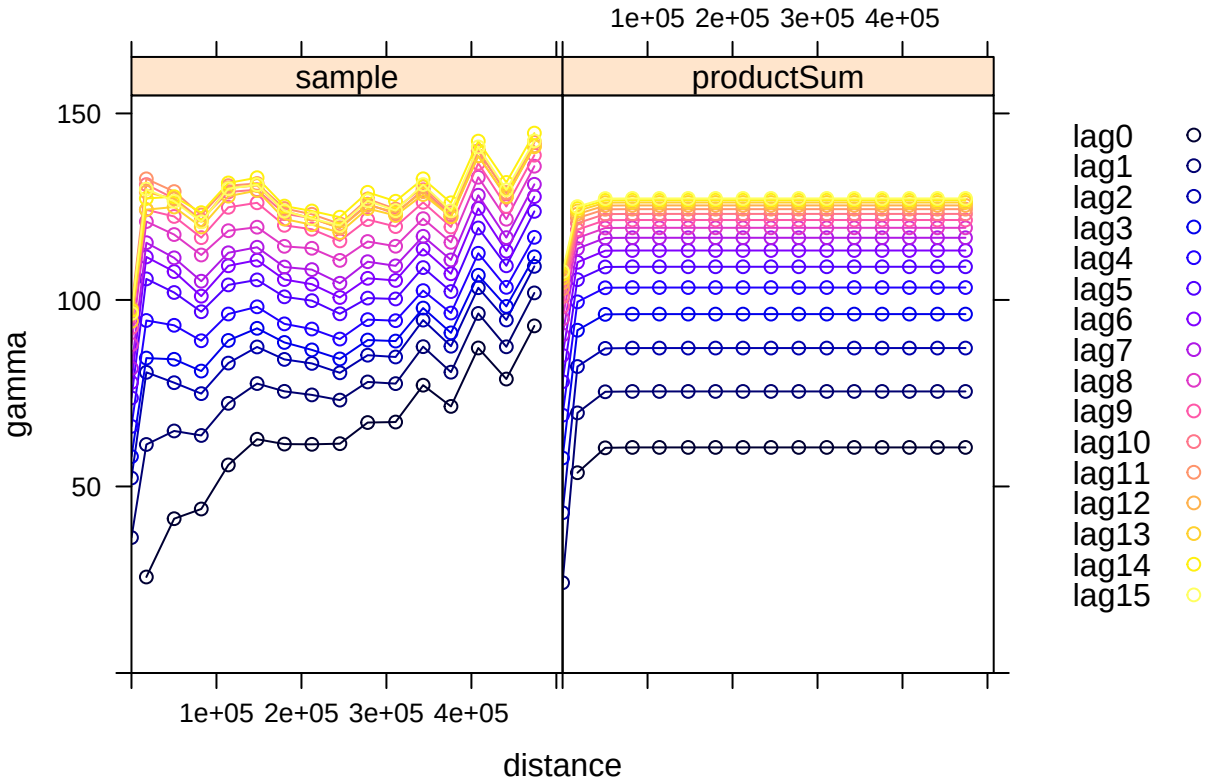
```
######### separable model, manual fit
sill <- 250
separable_man <- vgmST("separable",space=vgm(.18,"Exp",1.5e5,0.01,
                        add.to=vgm(.12,"Exp",8e3,.01)),time=vgm(80/sill,"Exp",1670,19/sill,
                        add.to=vgm(66/sill,"Exp",85,0)),sill=sill)
plot(vario,separable_man,all=T,map=F)
```



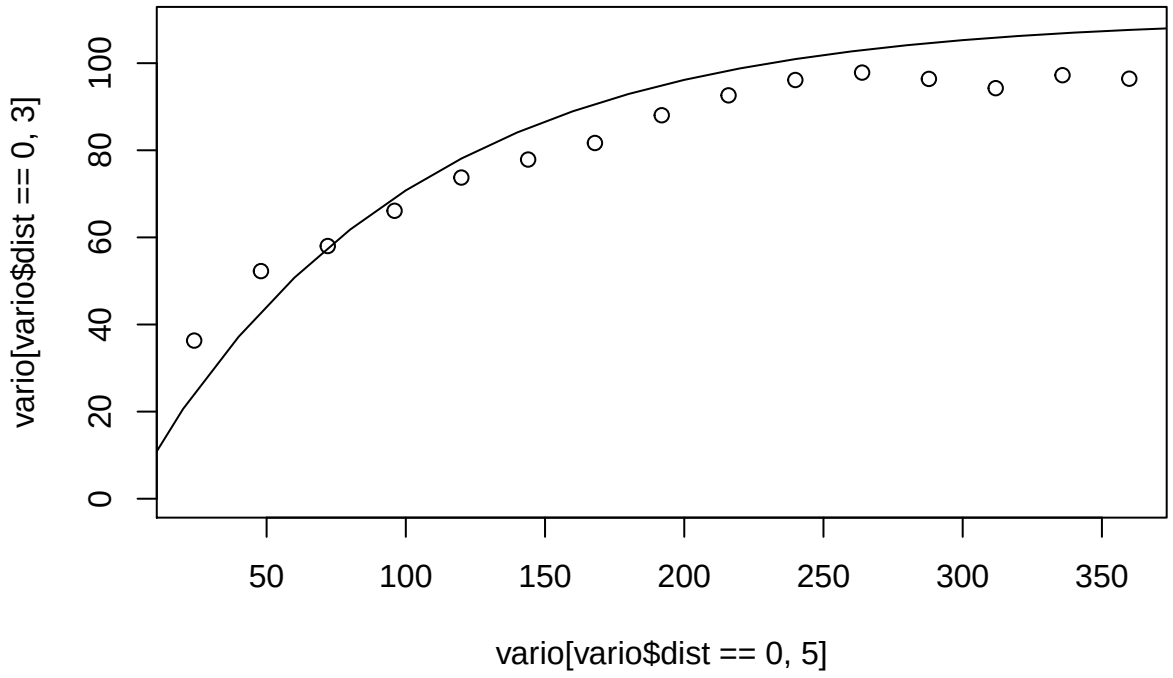

```
variot(separable_man,vario)
```



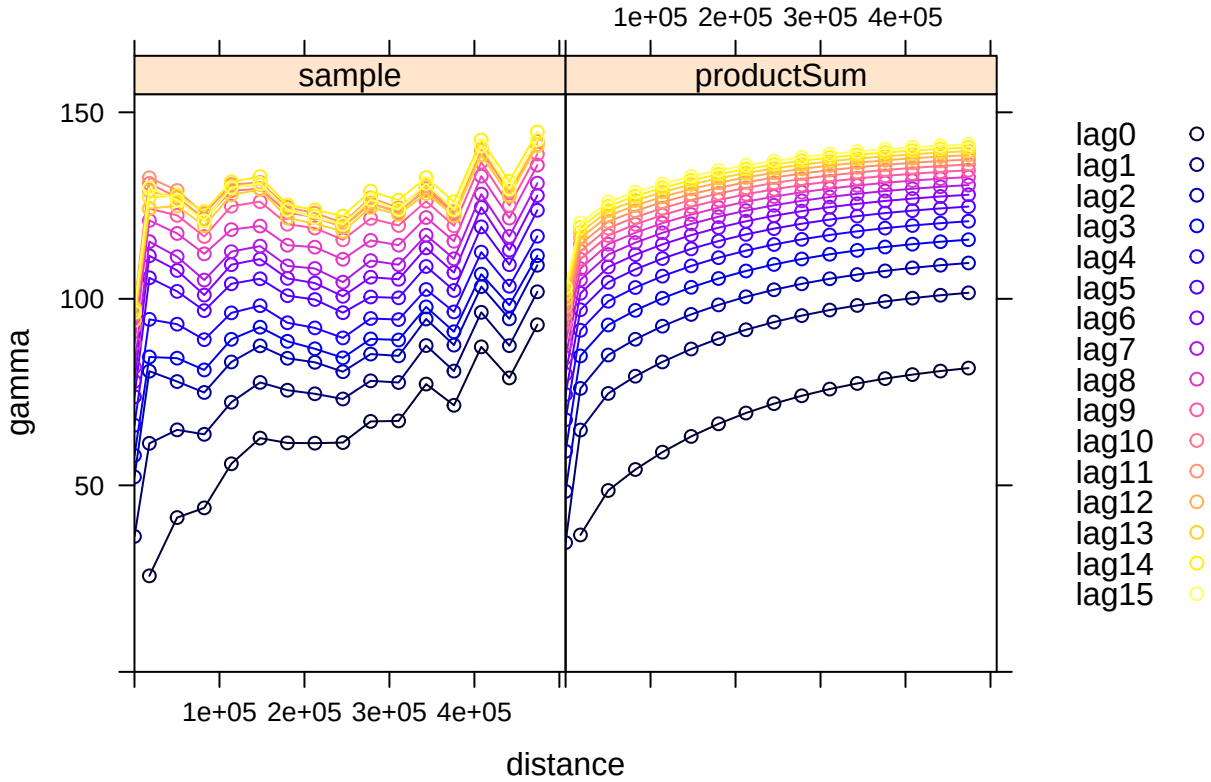

```
######### product sum model, least squares fit
ProductSum     <- vgmST("productSum",space =vgm(9,"Exp",8e3,1),time=vgm(8,"Exp",106,2),k=2)
ProductSum_fit <- fit.StVariogram(model=ProductSum,object=vario)
plot(vario,ProductSum_fit,all=T,map=F)
```



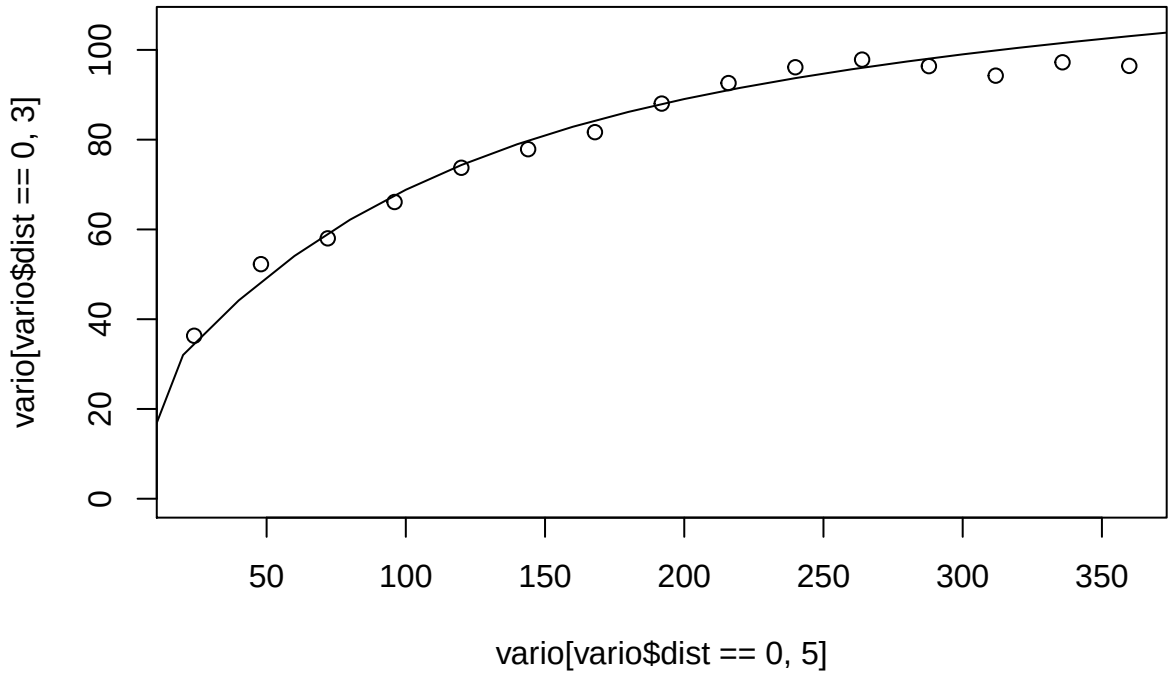
```
variot(ProductSum_fit,vario)
```



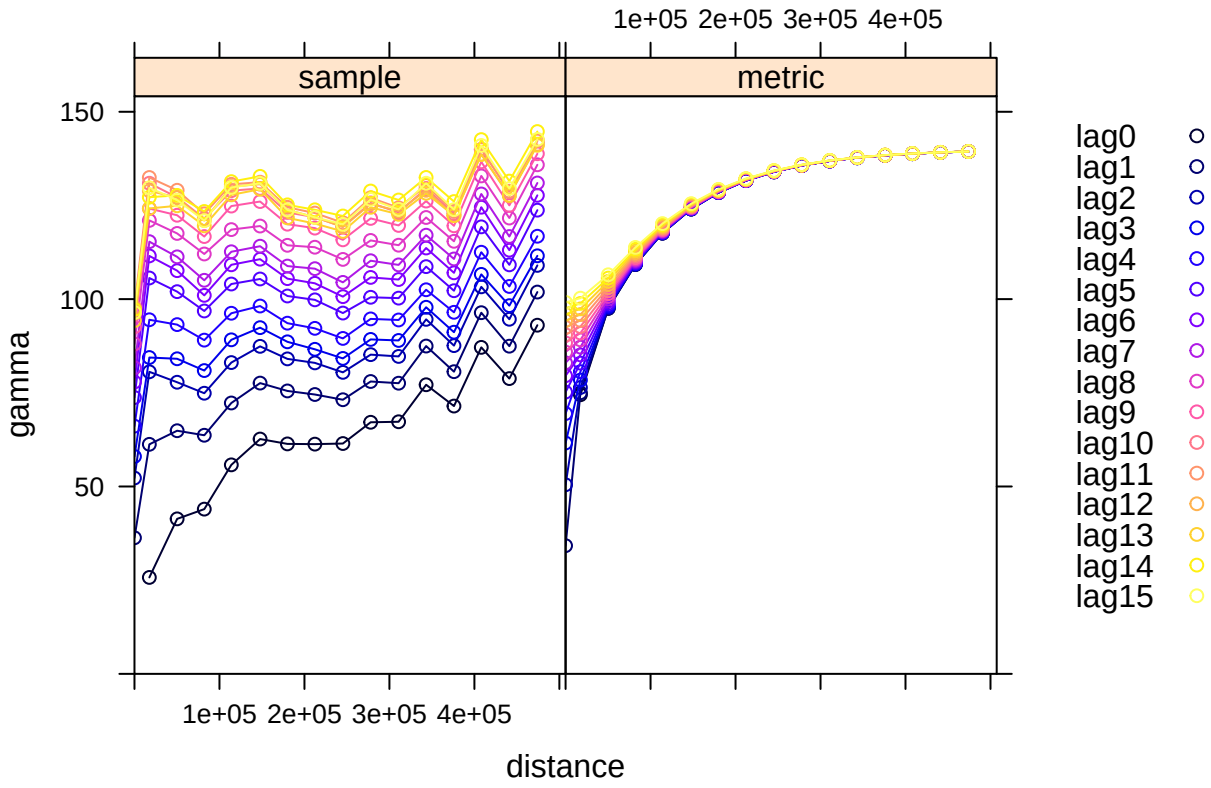

```
######### product sum model, manual fit
ProductSum_man <- vgmST("productSum",space=vgm(12.5,"Exp",2e5,0,add.to=vgm(10,"Exp",9e3,0)),
                        time=vgm(35,"Exp",800,9.5,add.to=vgm(36,"Exp",85,0)),k=0.035)
plot(vario,ProductSum_man,all=T,map=F)
```



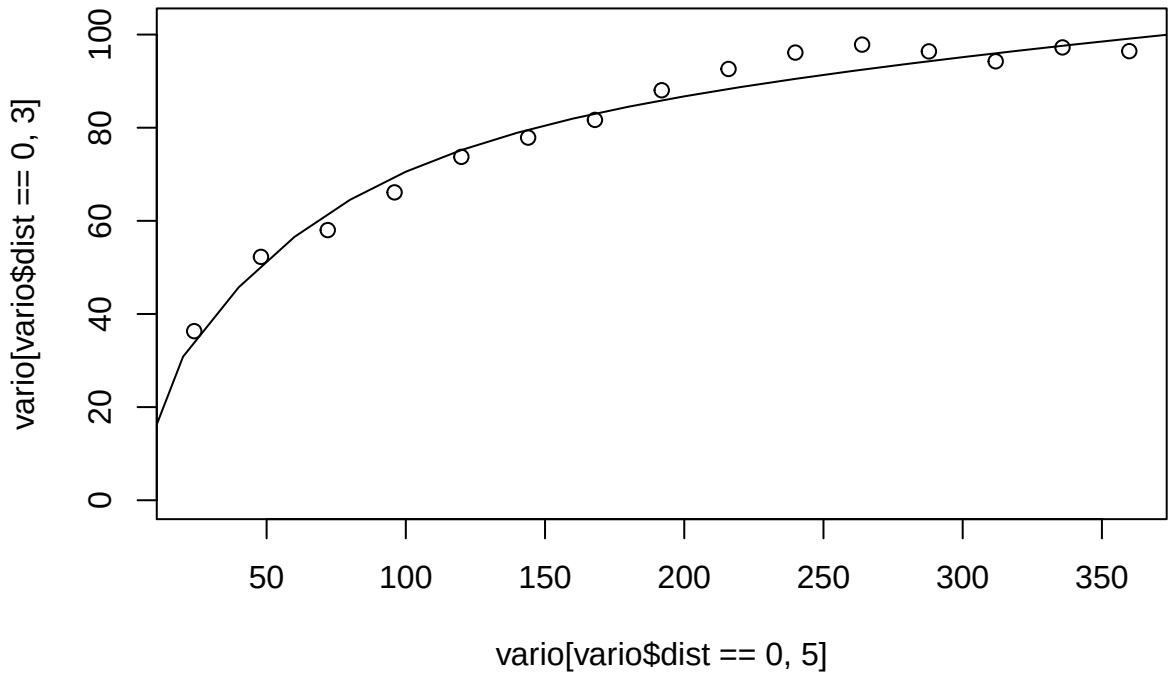
```
variot(ProductSum_man,vario)
```



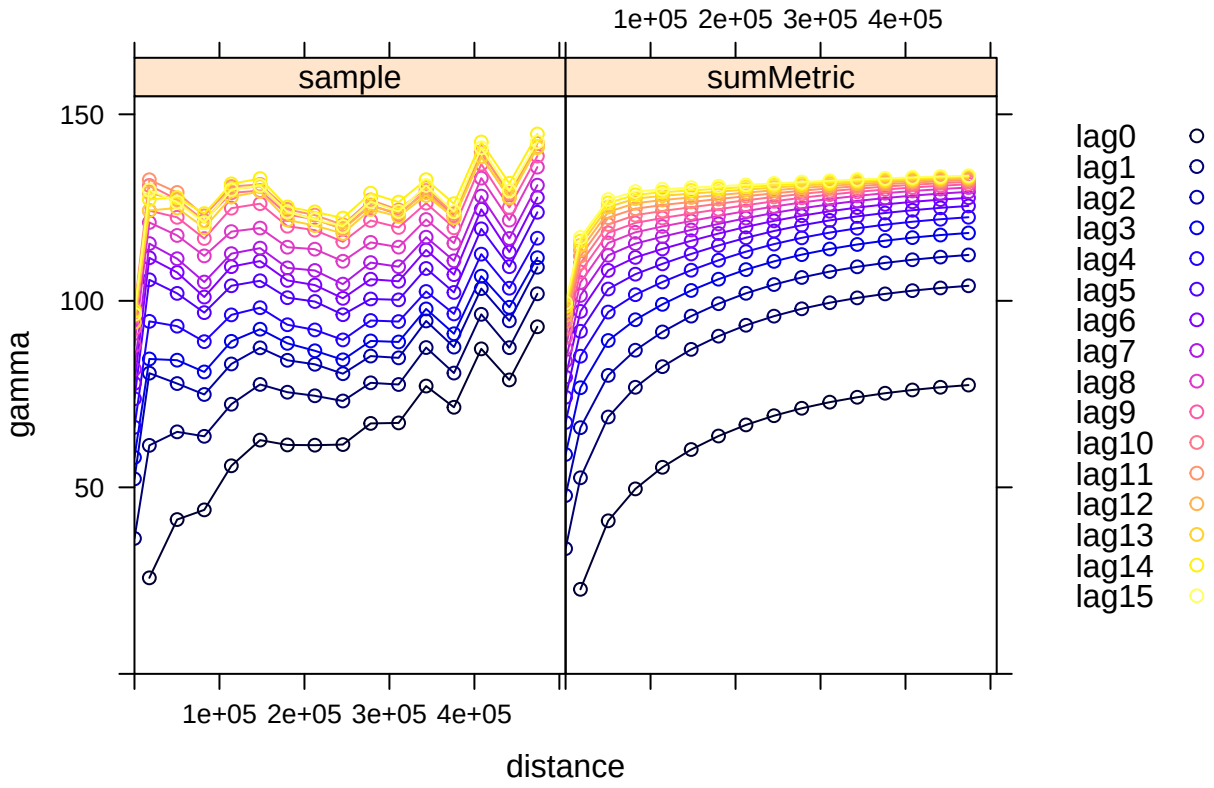

```
######### metric model, manual fit
Metric <- vgmST("metric",joint=vgm(60,"Exp",8e3,10,add.to=vgm(70,"Exp",1e5,0,stAni=1000)),
                stAni=150);model=Metric
plot(vario,Metric,map=F,all=T)
```



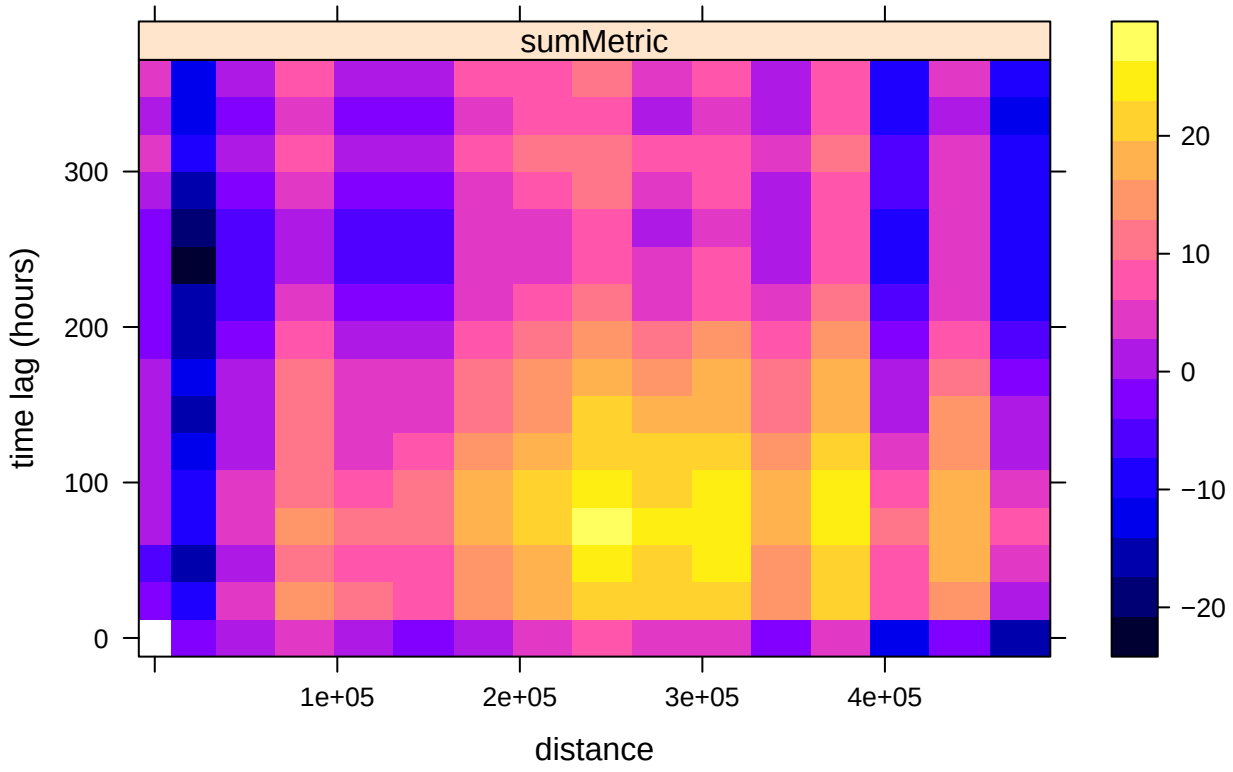
```
variot(Metric,vario)
```



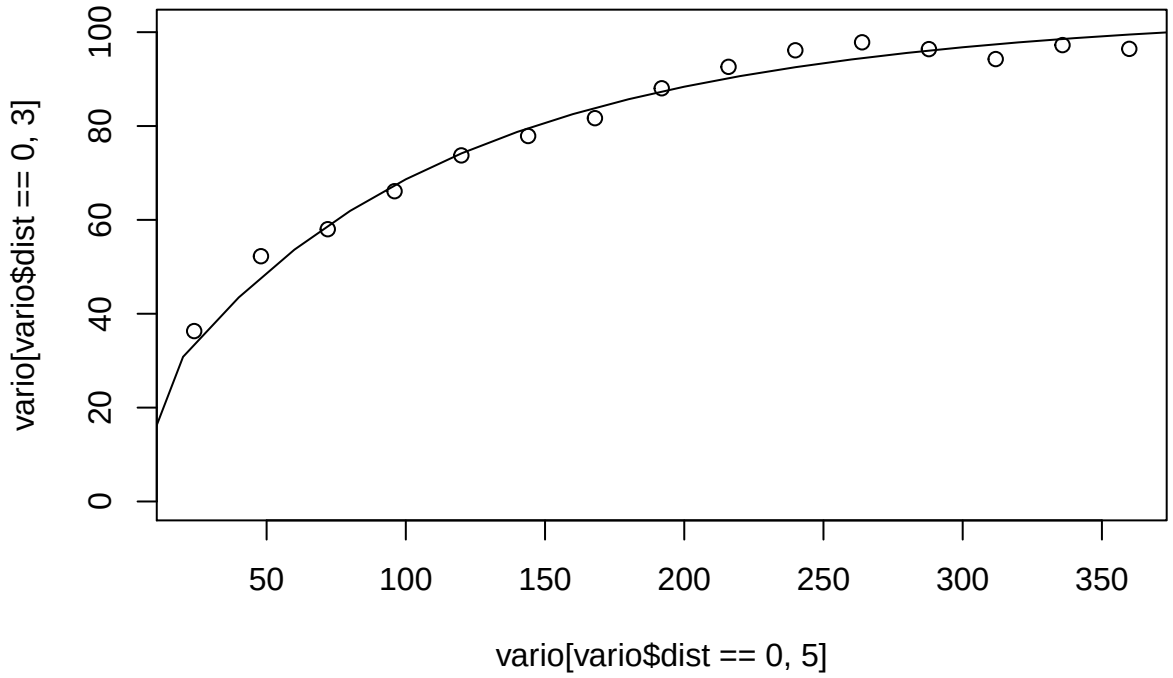

```
######### sum-metric model, manual fit
SumMetric <- vgmST("sumMetric",space=vgm(30,"Exp",20000),time=vgm(40,"Exp",70,15),
                   joint=vgm(50,"Exp",1.6e5,0),stAni=1000)
plot(vario,SumMetric,map=F,all=T)
```



```
plot(vario,SumMetric,map=T,diff=T)
```




```
variot(SumMetric,vario)
```



```
######### create list of all models fitted with gstat
models <- list(separable_fit,separable_man,ProductSum_fit,ProductSum_man,Metric,SumMetric)
######### save list of all models
save(models,file=paste0(DATA,"fits_gstat.Rdata"))
```

5) Prediction

5.1) Data Preparation

```
library(CompRandFld)
library(fields)
library(gstat)
library(rgdal)
library(sp)
library(spam)
library(spacetime)
library(RColorBrewer)
library(raster)


DATA = "data/"
load(paste0(DATA, "data.Rdata"))
load(paste0(DATA, "stationsforfitting.Rdata"))
load(paste0(DATA, "timesforfits.Rdata"))
load(paste0(DATA, "CHM.Rdata"))


### Getting the CHIMERE grid coordinates
coord <- cbind(CHM$lon, CHM$lat)
coordchm <- expand.grid(unique(CHM$lon), unique(CHM$lat))
coord.spchm <- SpatialPoints(coordchm, proj4string = CRS("+init=epsg:4326"))
# transform to Lambert 93 coordinate projection for approximately correct
# spatial geodesic distances
coord.spchm <- spTransform(coord.spchm, CRSobj = CRS("+init=epsg:2154"))

loc <- coord.spchm@coords/1000
loc_to_pred <- loc  # prediction
ns <- ncol(data)  # number of stations
nT <- nrow(data)
lT <- 2  # depth of the past used for prediction
mean.est <- mean(data)
mean.est
```

```
## [1] 8.024326
```

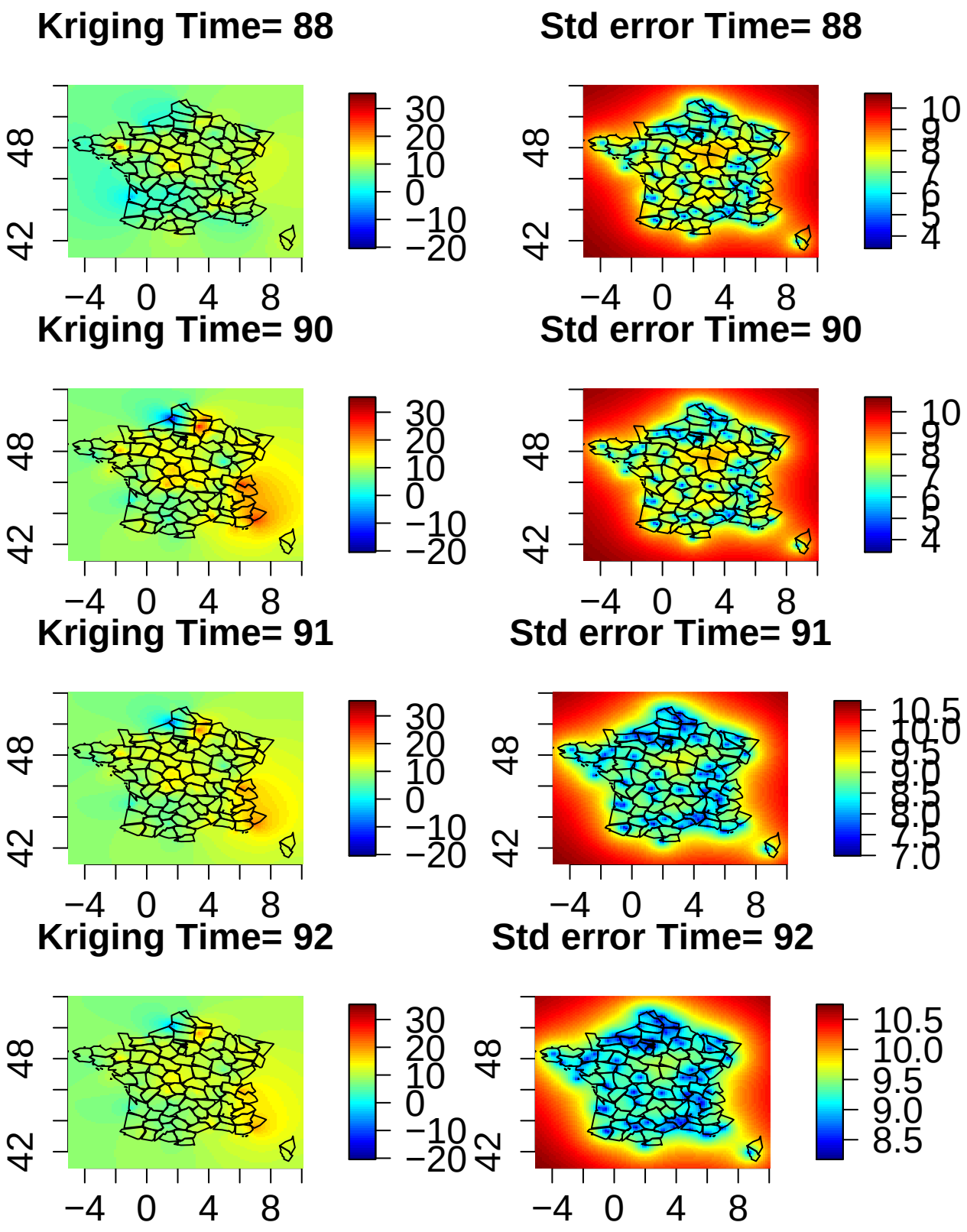
```
var.est <- var(as.numeric(data))
var.est
```

```
## [1] 116.0013
```

```
### Getting the stations coordinates
coord.sel <- cbind(stations.fit$station_longitude_deg, stations.fit$station_latitude_deg)
coord.sp <- SpatialPoints(coord.sel, proj4string = CRS("+init=epsg:4326"))
# transform to Lambert 93 coordinate projection for approximately correct
# spatial geodesic distances
coord.spt <- spTransform(coord.sp, CRSobj = CRS("+init=epsg:2154"))

coords <- coord.spt@coords/1000  # coordinates of the selected stations
coord.sel <- coords
times <- c(88:90)  # three last observation dates

dobs <- data[(nT - lT):nT, ]  # observed data locations
tt <- c(88, 90:92)
times_to_pred <- tt  # prediction times
```

5.2) A) Kriging with *CompRandFld*

```
load(paste0(DATA, "fitsPL.Rdata"))  # load the fitted models
nummod <- 8
corrmodel <- fitsPL[[nummod]]$corrmodel
param <- as.vector(fitsPL[[nummod]]$param)
param <- list(nugget = param[1], power_s = param[2], power_t = param[3], scale_s = param[4],
    scale_t = param[5], sep = param[6], sill = var.est, mean = mean.est)
pr <- Kri(loc = loc_to_pred, time = times_to_pred, coordx = coords, coordt = times,
    corrmodel = corrmodel, param = param, data = dobs)

### Plots of the predicted residuals with *image.plot*

grx <- unique(CHM$lon)
gry <- unique(CHM$lat)
rat <- diff(range(grx))/diff(range(gry))
for (i in 1:4) {
    par(pin = c(1.6, 1.6/rat))
    image.plot(grx, gry, matrix(pr$pred[i, ], nrow = length(grx)), col = tim.colors(64),
        zlim = c(-20, 35), main = paste("Kriging Time=", tt[i]), ylab = "",
        xlab = "", cex.axis = 1.5, axis.args = list(cex.axis = 1.5), asp = 1,
        cex.main = 1.5, bty = "n")
    map("france", add = TRUE)
    # namefig <- paste0('krisres',i,'.pdf') dev.copy2pdf(file=namefig)
    # system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only
    par(pin = c(1.6, 1.6/rat))
    image.plot(grx, gry, matrix(sqrt(pr$varpred[i, ]), nrow = length(grx)),
        col = tim.colors(64), main = paste("Std error Time=", tt[i]), ylab = "",
        xlab = "", cex.axis = 1.5, axis.args = list(cex.axis = 1.5), asp = 1,
        cex.main = 1.5, bty = "n")
    map("france", add = TRUE)
    # namefig <- paste0('kristdres',i,'.pdf') dev.copy2pdf(file=namefig)
    # system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only

}
```

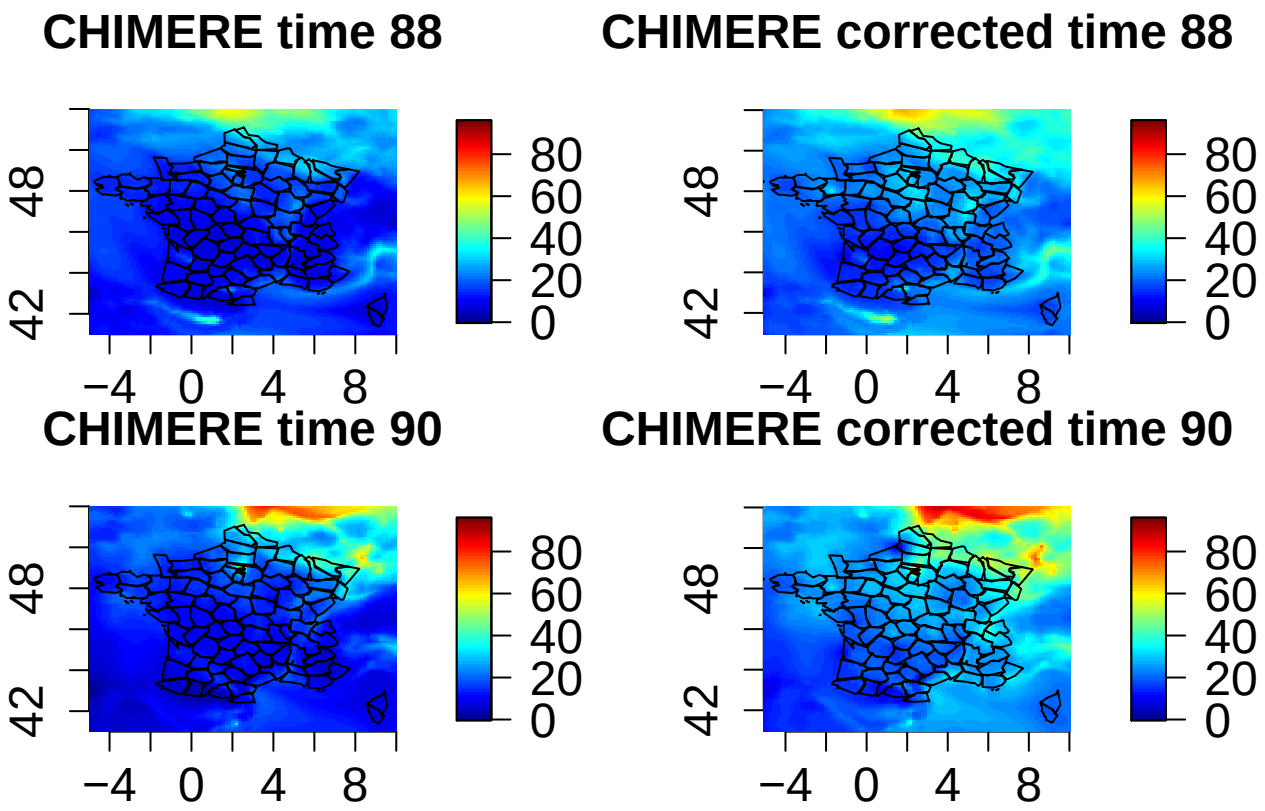


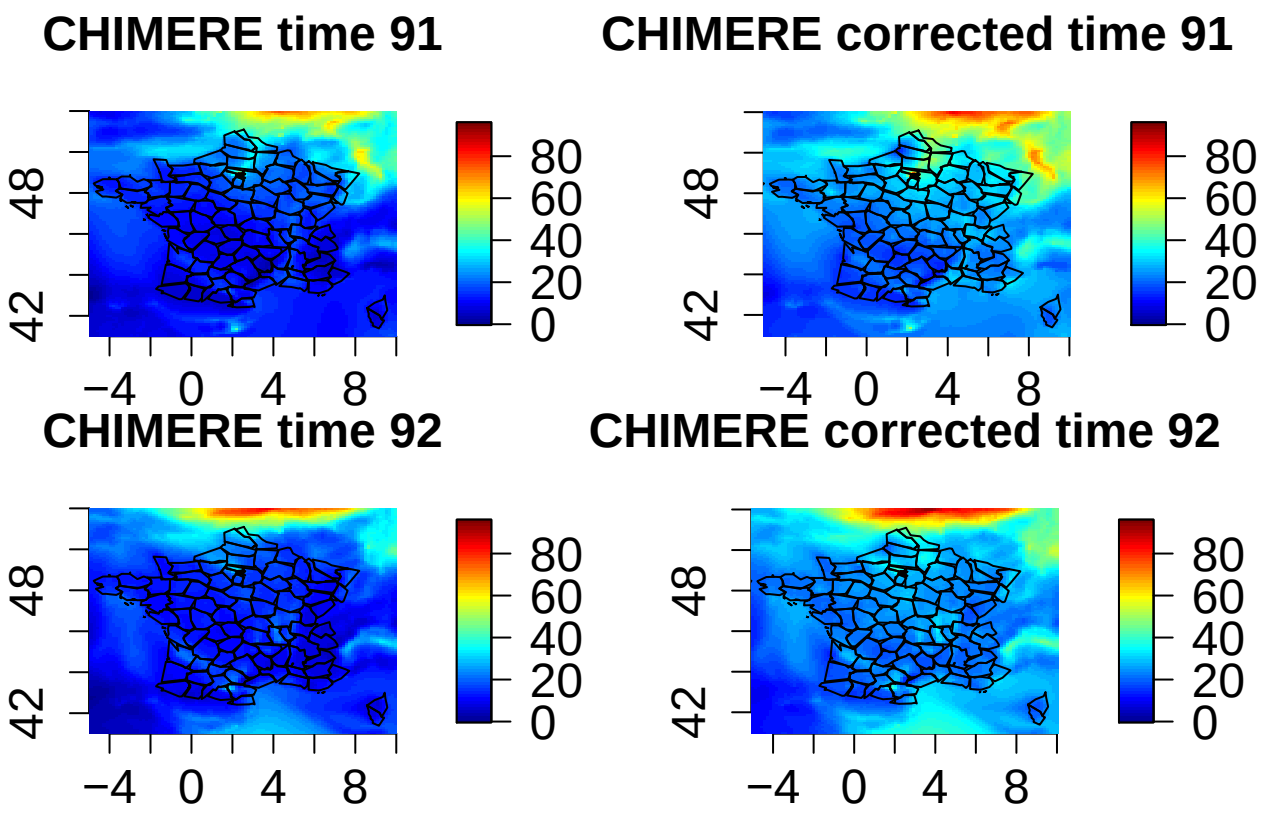

```
par(mfrow = c(1, 1))
```

```
### Plots of CHIMERE and corrected CHIMERE predictions
CHM_mat <- matrix(CHM$PM10, nrow = nrow(loc))
dim(CHM_mat)
```

```
## [1] 11211   365
```

```
zlim <- range(c(CHM_mat[, tt], pr$pred[, ] + t(CHM_mat[, tt])))
for (i in 1:4) {
    par(pin = c(1.6, 1.6/rat))
    image.plot(grx, gry, matrix(CHM_mat[, tt[i]], nrow = length(grx)), col = tim.colors(64),
        zlim = zlim, xlab = "", main = paste0("CHIMERE time ", tt[i]), ylab = "",
        xlim = range(grx), ylim = range(gry), cex.axis = 1.5, axis.args = list(cex.axis = 1.5),
        asp = 1, cex.main = 1.5, bty = "n")
    map("france", add = TRUE)
    # namefig <- paste0('predpm10',tt[i],'chm.pdf') dev.copy2pdf(file=namefig)
    # system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only

    par(pin = c(1.6, 1.6/rat))
    image.plot(grx, gry, matrix(pr$pred[i, ] + CHM_mat[, tt[i]], nrow = length(grx)),
        col = tim.colors(64), zlim = zlim, main = paste0("CHIMERE corrected time ",
            tt[i]), ylab = "", xlab = "", cex.axis = 1.5, axis.args = list(cex.axis = 1.5),
        asp = 1, cex.main = 1.5, bty = "n")
    map("france", add = TRUE)
    # namefig <- paste0('predpm10',tt[i],'.pdf') dev.copy2pdf(file=namefig)
    # system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only
    # title(main = paste('Kriging Time='
    # ,tt[i]),outer=TRUE,line=-1,cex.main=1.5)
}
```






```
par(mfrow = c(1, 1))

### Plots with the gstat tools
load(paste0(DATA, "STFDF_jour.Rdata"))
pts <- expand.grid(grx, gry)
pts <- SpatialPoints(pts)
temps <- STFDF_jour@time[tt]
mydata2 <- as.data.frame(cbind(as.double(CHM_mat[, tt]), as.double(CHM_mat[,
    tt] + t(pr$pred))))
names(mydata2) <- c("CHIMERE", "CHIMERE corrected")
CHMcor = STFDF(sp = pts, time = temps, data = mydata2)
library(rworldmap)
library(maptools)
library(ggmap)
world <- getMap(resolution = "low")
proj4string(world)
```

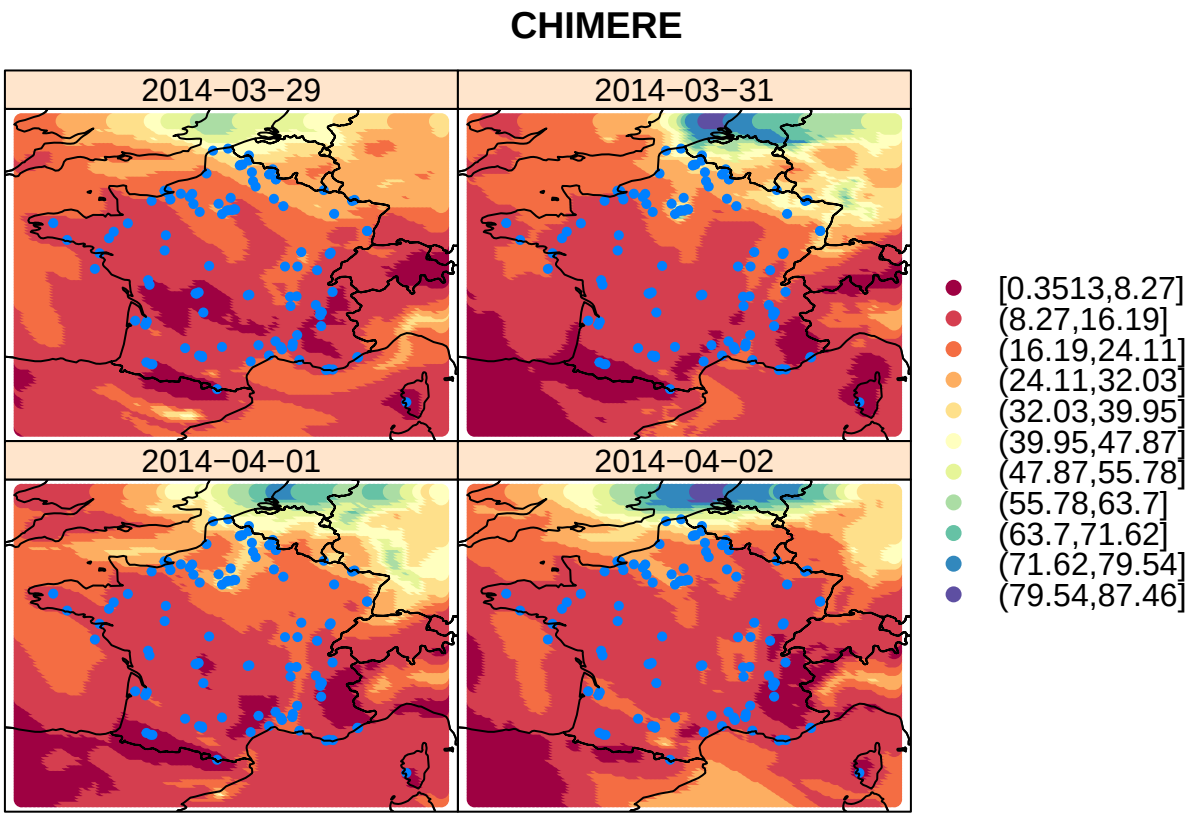
```
## [1] "+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs"
```

```
europe.limits <- geocode(c("Spain", "Greece", "Ireland", "Norway", "Ukraine"))
```

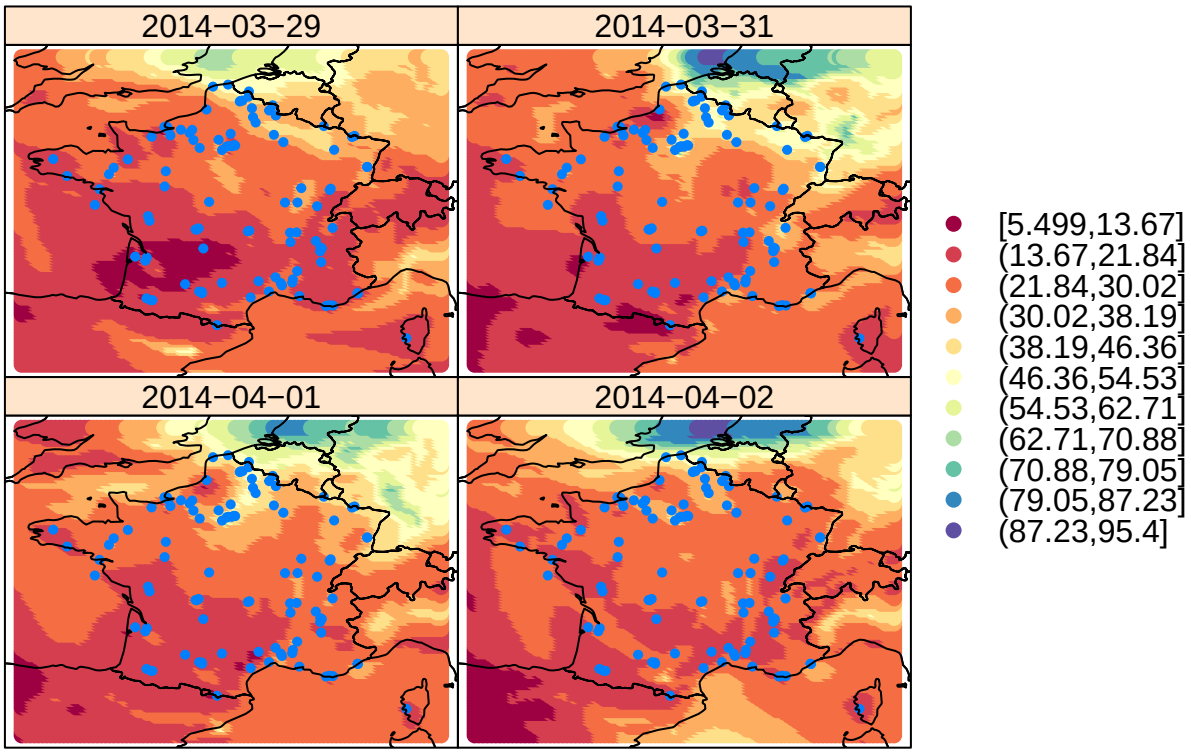
```
## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Spain&sensor=false

## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Greece&sensor=false

## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Ireland&sensor=false
```

```
## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Norway&sensor=false

## Information from URL : http://maps.googleapis.com/maps/api/geocode/json?address=Ukraine&sensor=false
```

```
lvls <- seq(0, 100, 10)


stplot(CHMcor[, 1:4, 1], col.regions = brewer.pal(11, "Spectral"), at = lvls,
    cuts = 11, sp.layout = list(coord.sp, world, cex = 0.5, pch = 19, first = FALSE),
    aspect = "iso", lattice.options = list(key = list(cex.title = 1.5)))
```



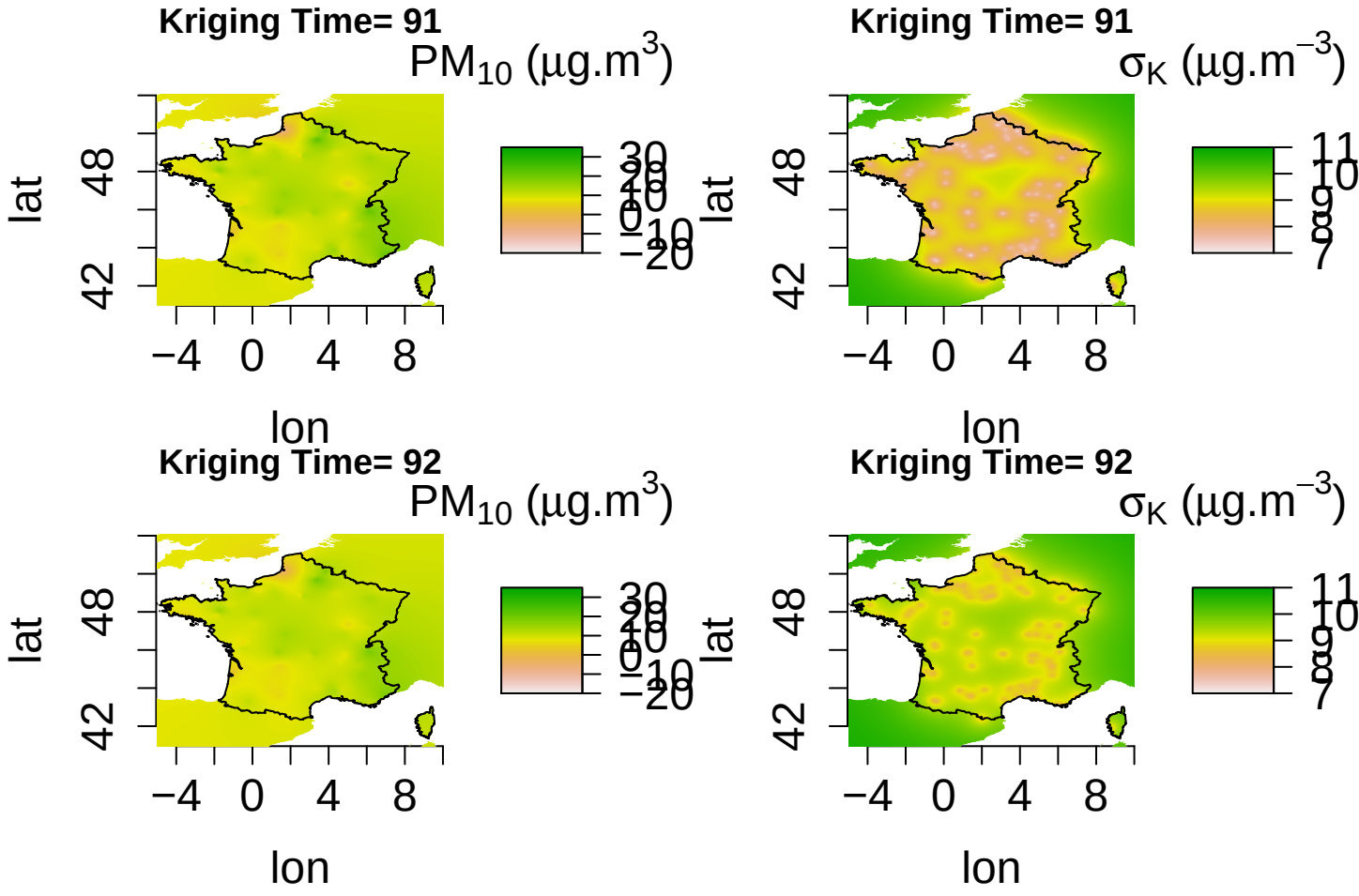

```
# namefig <- 'chimstplot2.pdf' dev.copy2pdf(file=namefig)
# system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only

stplot(CHMcor[, 1:4, 2], col.regions = brewer.pal(11, "Spectral"), at = lvls,
    cuts = 11, sp.layout = list(coord.sp, world, cex = 0.5, pch = 19, first = FALSE))
```




```
# namefig <- 'chimcorrstplot2.pdf' dev.copy2pdf(file=namefig)
# system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only

### Plots with raster tools

europe = readOGR("maps", p4s = NULL, layer = "carto_eur")


## OGR data source with driver: ESRI Shapefile
## Source: "maps", layer: "carto_eur"
## with 75 features
## It has 32 fields
```

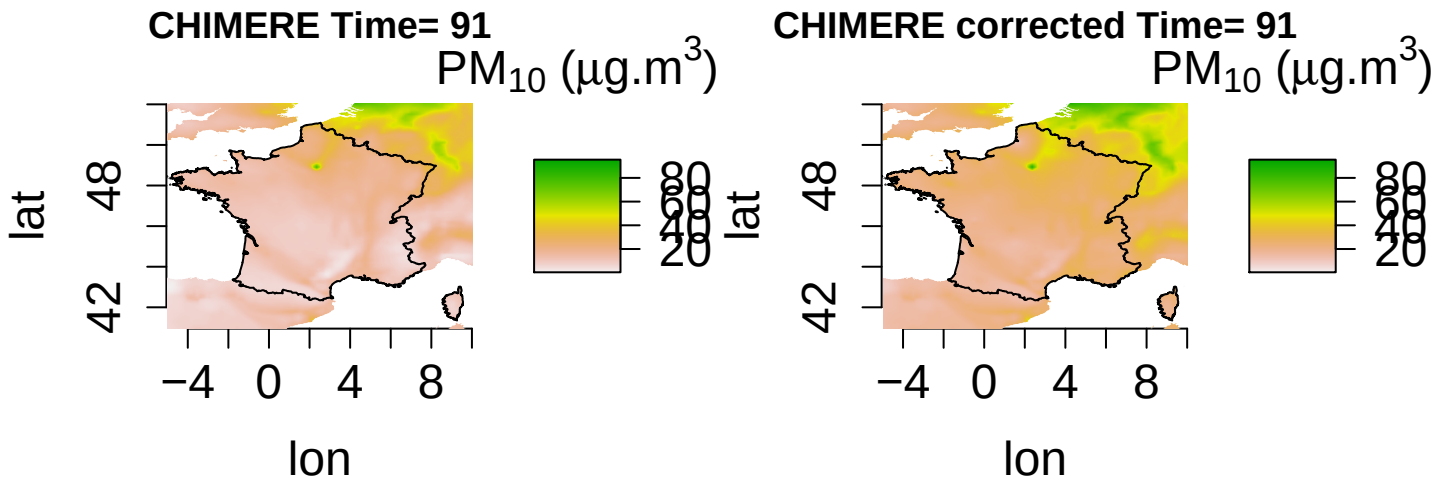
```
grx <- unique(CHM$lon)
gry <- unique(CHM$lat)

for (i in 3:4) {
    ras <- raster(list(x = grx, y = gry, z = matrix(pr$pred[i, ], nrow = length(grx)),
        col = tim.colors(64)))
    ras <- disaggregate(ras, fact = c(5, 5), method = "bilinear")
    ras <- rasterize(europe, ras, mask = T)
    plot(ras, xlab = "lon", ylab = "lat", xlim = c(-5, 10), zlim = c(-20, 35),
        legend.width = 3, cex.axis = 1.5, axis.args = list(cex.axis = 1.5),
        cex.lab = 1.5, asp = 1, main = paste("Kriging Time=", tt[i]), legend.args = list(text = expressi
            paste(PM[10], " (", mu, "g.", m^3, ")", sep = "")), line = 1.5,
            cex = 1.5), bty = "n", box = F)
    plot(europe[europe$COUNTRY == "France", ], xlim = range(grx), ylim = range(gry),
        add = T)
```

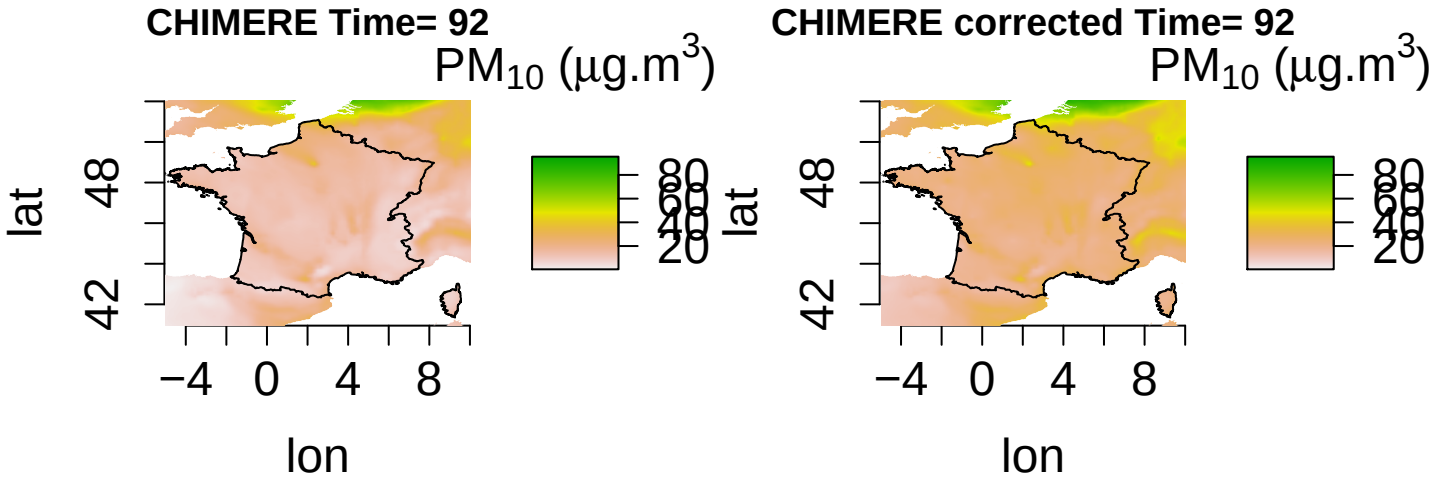
```
    # namefig <- paste0('krires',i,'ras.pdf') dev.copy2pdf(file=namefig)
    # system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only

    ras_sd <- raster(list(x = grx, y = gry, z = matrix(sqrt(pr$varpred[i, ]),
        nrow = length(grx)), col = tim.colors(64)))
    ras_sd <- disaggregate(ras_sd, fact = c(5, 5), method = "bilinear")
    ras_sd <- rasterize(europe, ras_sd, mask = T)
    plot(ras_sd, xlab = "lon", ylab = "lat", xlim = c(-5, 10), zlim = c(7, 11),
        legend.width = 3, cex.axis = 1.5, axis.args = list(cex.axis = 1.5),
        cex.lab = 1.5, asp = 1, main = paste("Kriging Time=", tt[i]), legend.args = list(text = expressi
            paste(sigma[K], " (", mu, "g.", m^-3, ")", sep = ""), line = 1.5,
            cex = 1.5), bty = "n", box = F)
    plot(europe[europe$COUNTRY == "France", ], xlim = range(grx), ylim = range(gry),
        add = T)
    # namefig <- paste0('kristdres',i,'ras.pdf') dev.copy2pdf(file=namefig)
    # system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only
}
```




```
# Comparing CHIMERE and corrected CHIMERE
zlim <- range(c(CHM_mat[, tt], pr$pred[, ] + t(CHM_mat[, tt])))
for (i in 3:4) {
    ras <- raster(list(x = grx, y = gry, z = matrix(CHM_mat[, tt[i]], nrow = length(grx)),
        col = tim.colors(64)))
```

```
    ras <- disaggregate(ras, fact = c(5, 5), method = "bilinear")
    ras <- rasterize(europe, ras, mask = T)
    plot(ras, xlab = "lon", ylab = "lat", xlim = c(-5, 10), zlim = zlim, legend.width = 3,
        cex.axis = 1.5, axis.args = list(cex.axis = 1.5), cex.lab = 1.5, asp = 1,
        main = paste("CHIMERE Time=", tt[i]), legend.args = list(text = expression("     ",
            paste(PM[10], " (", mu, "g.", m^3, ")", sep = "")), line = 1.5,
            cex = 1.5), bty = "n", box = F)
    plot(europe[europe$COUNTRY == "France", ], xlim = range(grx), ylim = range(gry),
        add = T)
    # namefig <- paste0('predpm10',tt[i],'chmras.pdf')
    # dev.copy2pdf(file=namefig) system(paste0('pdfcrop ',namefig,' ',namefig))
    # # linux with pdfcrop only

    ras_sd <- raster(list(x = grx, y = gry, z = matrix(pr$pred[i, ] + CHM_mat[,
        tt[i]], nrow = length(grx)), col = tim.colors(64)))
    ras_sd <- disaggregate(ras_sd, fact = c(5, 5), method = "bilinear")
    ras_sd <- rasterize(europe, ras_sd, mask = T)
    plot(ras_sd, xlab = "lon", ylab = "lat", xlim = c(-5, 10), zlim = zlim,
        legend.width = 3, cex.axis = 1.5, axis.args = list(cex.axis = 1.5),
        cex.lab = 1.5, asp = 1, main = paste("CHIMERE corrected Time=", tt[i]),
        legend.args = list(text = expression("     ", paste(PM[10], " (", mu,
            "g.", m^3, ")", sep = "")), line = 1.5, cex = 1.5), bty = "n", box = F)
    plot(europe[europe$COUNTRY == "France", ], xlim = range(grx), ylim = range(gry),
        add = T)
    # namefig <- paste0('predpm10',tt[i],'ras.pdf') dev.copy2pdf(file=namefig)
    # system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only
}
```





5.2) B) Cross-validation with *CompRandFld*

```
tt <- 91
times_to_pred <- tt
times <- c(89, 90)
err <- matrix(NA, ns, 8)
for (nummod in 1:8) {
    corrmodel <- fitsPL[[nummod]]$corrmodel
    if (nummod == 1) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(scale_s = param[1], scale_t = param[2], sill = var.est,
            mean = mean.est)
    } else if (nummod == 2) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(nugget = param[1], scale_s = param[2], scale_t = param[3],
            sill = var.est, mean = mean.est)
    } else if (nummod == 3) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(scale_s = param[1], power_s = 1, power_t = 1, scale_t = param[2],
            sep = param[3], sill = var.est, mean = mean.est)
    } else if (nummod == 4) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(nugget = param[1], scale_s = param[2], power_s = 1, power_t = 1,
            scale_t = param[3], sep = param[4], sill = var.est, mean = mean.est)
    } else if (nummod == 5) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(nugget = 0, scale_s = param[1], power_s = 0.5, power_t = 0.5,
            scale_t = param[2], sep = param[3], sill = var.est, mean = mean.est)
    } else if (nummod == 6) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(nugget = param[1], scale_s = param[2], power_s = 0.5,
            power_t = 0.5, scale_t = param[3], sep = param[4], sill = var.est,
            mean = mean.est)
    } else if (nummod == 7) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(power_s = param[1], power_t = param[2], scale_s = param[3],
            scale_t = param[4], sep = param[5], sill = var.est, mean = mean.est)
    } else if (nummod == 8) {
        param <- as.vector(fitsPL[[nummod]]$param)
```

```
        param <- list(nugget = param[1], power_s = param[2], power_t = param[3],
            scale_s = param[4], scale_t = param[5], sep = param[6], sill = var.est,
            mean = mean.est)
    }
    for (ista in 1:ns) {
        loc_to_pred <- coord.sel[ista, ]
        coords <- coord.sel[-ista, ]
        dobs <- data[(nT - 2):(nT - 1), -ista]

        prvc <- Kri(loc = loc_to_pred, time = times_to_pred, coordx = coords,
            coordt = times, corrmodel = corrmodel, param = param, data = dobs)
        err[ista, nummod] = data[nT, ista] - prvc$pred
    }
}
RMSE <- sqrt(apply(err^2, 2, mean))
RMSE
```

```
## [1] 9.701158 9.132365 9.319150 9.025487 9.211886 9.215222 9.222762 9.169025
```

5.2) C) External validation with *CompRandFld*

```
######### reloading saved data objects (if necessary)
load(paste0(DATA, "OBS_jour.Rdata"))
load(paste0(DATA, "CHM.Rdata"))
load(paste0(DATA, "stations.Rdata"))
######### extract French background stations
IDs.bg <- stations$station_european_code[stations$type_of_station == "Background"]
IDs.fr <- stations$station_european_code[stations$country_name == "France"]
IDs.bgfr <- intersect(IDs.bg, IDs.fr)
idx.stations <- which(stations$station_european_code %in% IDs.bgfr)
coord <- cbind(stations$station_longitude_deg, stations$station_latitude_deg)[idx.stations,
    ]
######### defining time window for data used for validation
tstart <- "2014-04-01"
tend <- "2014-04-02"  # at least two dates !
OBS_jour <- OBS_jour[OBS_jour$ID %in% IDs.bgfr, ]
OBS_sel2 <- stConstruct(OBS_jour, space = c("long", "lat"), time = "date", SpatialObj = SpatialPoints(O
    c("long", "lat")]))
OBS_sel2 <- as(OBS_sel2, "STFDF")
proj4string(OBS_sel2) <- "+init=epsg:4326"
OBS_sel2 <- OBS_sel2[, paste0(tstart, "::", tend)]
######### transforming to Lambert 93 coordinates system
OBS_sel2@sp <- spTransform(OBS_sel2@sp, CRS("+init=epsg:2154"))

######### interpolating gridded CHIMERE values to space-time observation points
library(fields)
CHM_sel <- CHM[as.character(CHM$time) >= tstart & as.character(CHM$time) <=
    tend, ]
grid.CHM <- unique(cbind(CHM_sel$lon, CHM_sel$lat))
CHM_mat2 <- matrix(CHM_sel$PM10, nrow = nrow(grid.CHM))
dim(CHM_mat2)
```

```
## [1] 11211     2
```

```
lon.grid <- sort(unique(CHM_sel$lon))
lat.grid <- sort(unique(CHM_sel$lat))
ind.sites.obs <- match(unique(OBS_sel2@data$ID), IDs.bgfr)
fun <- function(i) {
    tmp <- list(x = lon.grid, y = lat.grid, z = matrix(CHM_mat2[, i], length(lon.grid),
        length(lat.grid)))
    interp.surface(tmp, coord[ind.sites.obs, ])
}
CHM_sites <- sapply(1:ncol(CHM_mat2), fun)
######### saving as variable CHM
OBS_sel2@data$CHM <- as.numeric(CHM_sites)


tt <- 91
times_to_pred <- tt
times <- c(89, 90)
RMSE_ext <- NULL
val <- (OBS_sel2[, 1, "PM10"])$PM10
indexnona <- which(!is.na(val))
CHMval <- (OBS_sel2[, 1, "CHM"])$CHM[indexnona]
val <- val[indexnona]
for (nummod in 1:8) {
    corrmodel <- fitsPL[[nummod]]$corrmodel
    if (nummod == 1) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(scale_s = param[1], scale_t = param[2], sill = var.est,
            mean = mean.est)
    } else if (nummod == 2) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(nugget = param[1], scale_s = param[2], scale_t = param[3],
            sill = var.est, mean = mean.est)
    } else if (nummod == 3) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(scale_s = param[1], power_s = 1, power_t = 1, scale_t = param[2],
            sep = param[3], sill = var.est, mean = mean.est)
    } else if (nummod == 4) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(nugget = param[1], scale_s = param[2], power_s = 1, power_t = 1,
            scale_t = param[3], sep = param[4], sill = var.est, mean = mean.est)
    } else if (nummod == 5) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(nugget = 0, scale_s = param[1], power_s = 0.5, power_t = 0.5,
            scale_t = param[2], sep = param[3], sill = var.est, mean = mean.est)
    } else if (nummod == 6) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(nugget = param[1], scale_s = param[2], power_s = 0.5,
            power_t = 0.5, scale_t = param[3], sep = param[4], sill = var.est,
            mean = mean.est)
    } else if (nummod == 7) {
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(power_s = param[1], power_t = param[2], scale_s = param[3],
            scale_t = param[4], sep = param[5], sill = var.est, mean = mean.est)
    } else if (nummod == 8) {
```

```
        param <- as.vector(fitsPL[[nummod]]$param)
        param <- list(nugget = param[1], power_s = param[2], power_t = param[3],
            scale_s = param[4], scale_t = param[5], sep = param[6], sill = var.est,
            mean = mean.est)
    }
    loc_to_pred <- OBS_sel2@sp@coords/1000
    coords <- coord.sel
    dobs <- data[(nT - 1):(nT), ]

    prvc <- Kri(loc = loc_to_pred, time = times_to_pred, coordx = coords, coordt = times,
        corrmodel = corrmodel, param = param, data = dobs)
    RMSE_ext <- c(RMSE_ext, sqrt(mean((val - prvc$pred[indexnona] - CHMval)^2)))
}
RMSE_ext
```

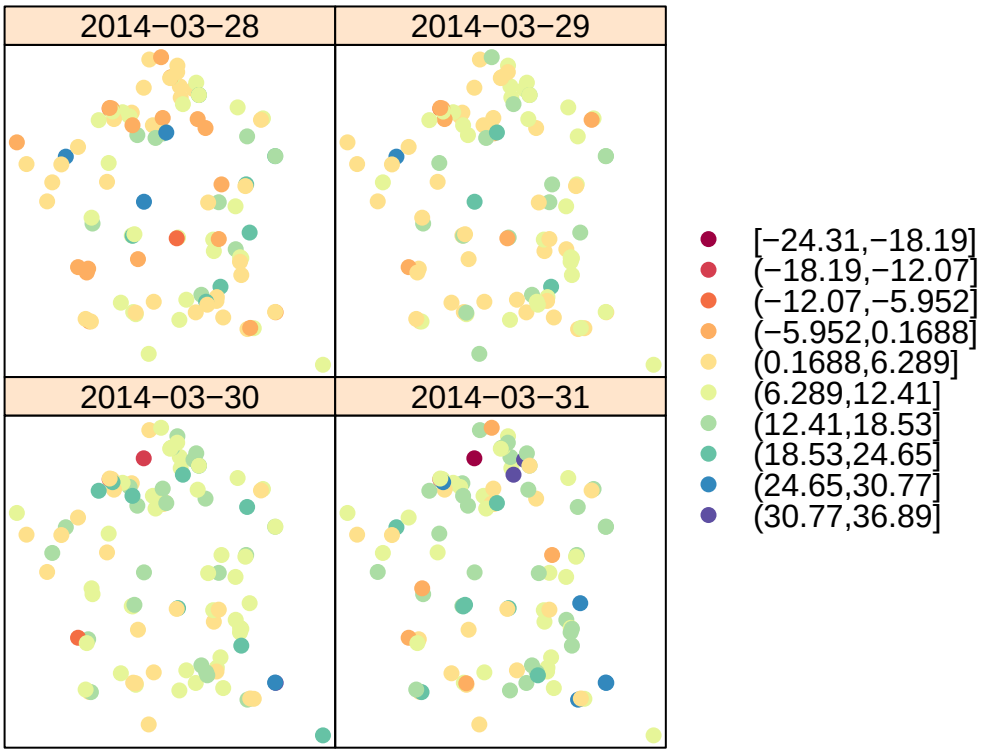
```
## [1] 12.62653 12.13389 12.14231 12.00067 12.51909 12.45865 12.41649 12.28487
```

```
### error made by CHIMERE
sqrt(mean((val - CHMval)^2))
```

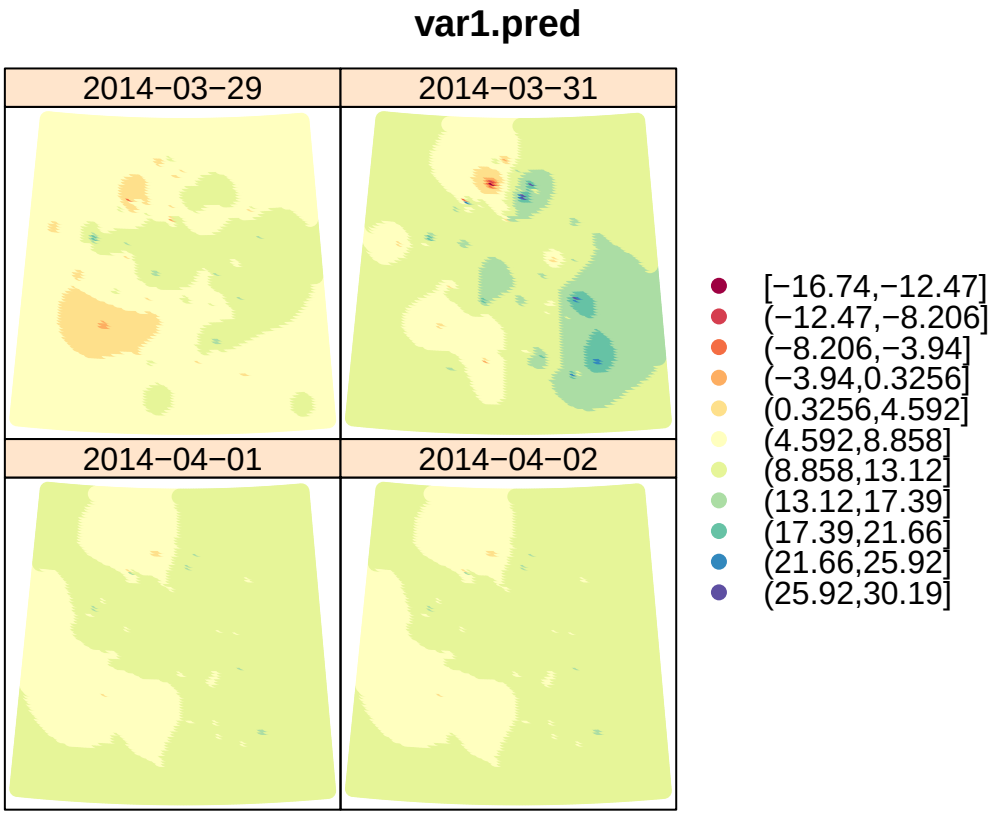
```
## [1] 19.3351
```

5.3) A) Kriging with *gstat*

```
### Kriging on selected data, no NA allowed
load(paste0(DATA, "data.Rdata"))
load(paste0(DATA, "stationsforfitting.Rdata"))
load(paste0(DATA, "timesforfits.Rdata"))
load(paste0(DATA, "STFDF_jour.Rdata"))
load(paste0(DATA, "fits_gstat.Rdata"))

### We use times from STDF_jour to ensure the correct time format
temps <- STFDF_jour@time[times]
data2 <- as.data.frame(as.vector(t(data)))
names(data2) <- "PM10res"
REScor <- STFDF(sp = coord.spt, time = temps, data = data2)
stplot(REScor[, "2014-03-28::2014-03-31", "PM10res"], col.regions = brewer.pal(10,
    "Spectral"), cuts = 10)
```

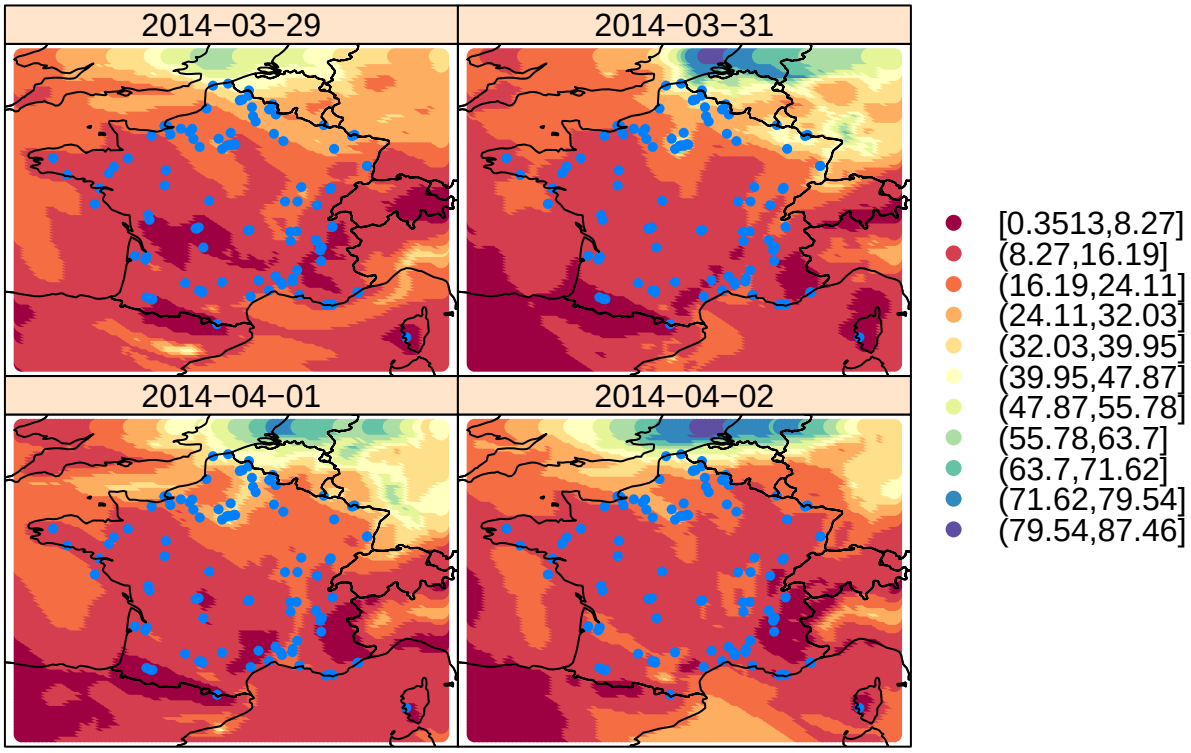



```
# Prediction dates
tt <- c(88, 90:92)
nummod <- 4  # Product sum manual
dates <- STFDF_jour@time[tt]
predGrid <- STF(coord.spchm, dates)
krig <- krigeST(PM10res ~ 1, data = REScor[, seq(as.Date("2014-03-29"), as.Date("2014-03-31"),
    by = "day")], newdata = predGrid, modelList = models[[nummod]])

stplot(krig, col.regions = brewer.pal(11, "Spectral"), cuts = 11)
```

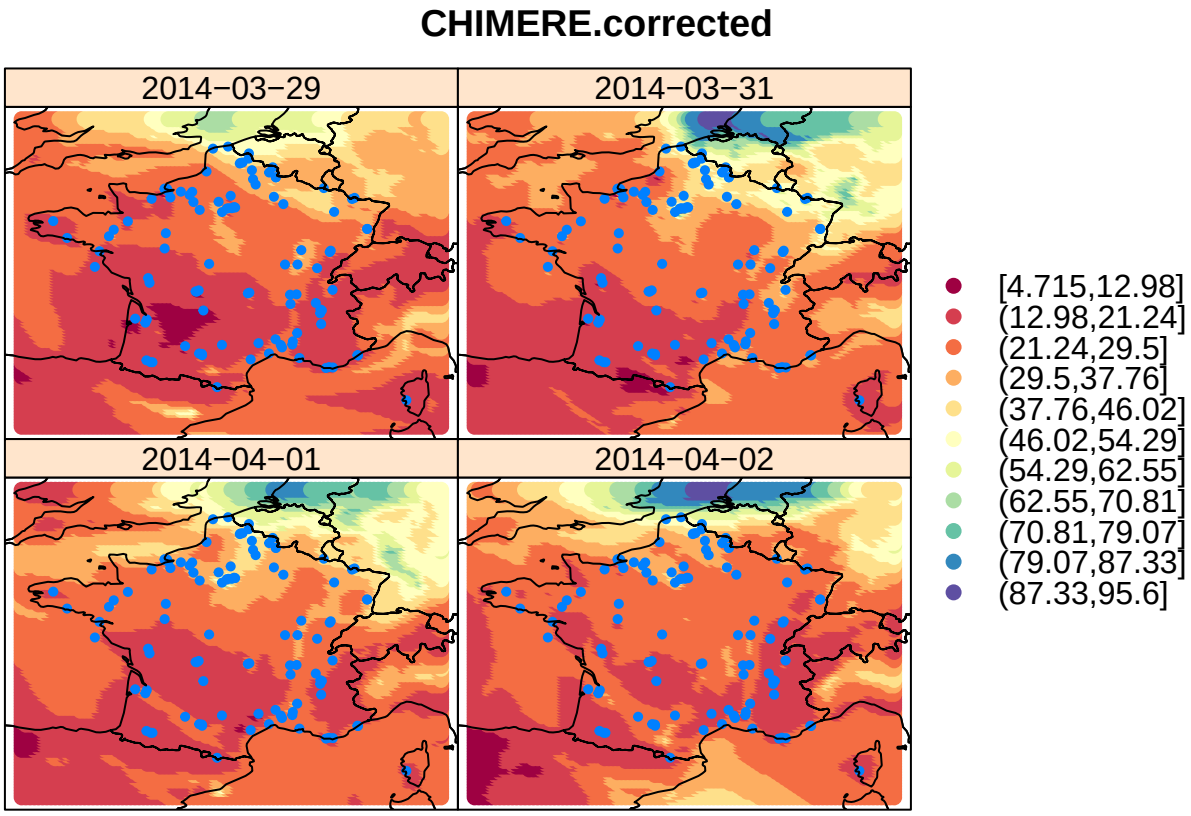



```
temps <- STFDF_jour@time[tt]
mydata2 <- as.data.frame(cbind(as.double(CHM_mat[, tt]), as.double(CHM_mat[,
    tt] + krig@data[[1]])))
names(mydata2) <- c("CHIMERE", "CHIMERE corrected")
CHMcorgs <- STFDF(sp = pts, time = temps, data = mydata2)

stplot(CHMcorgs[, 1:4, 1], col.regions = brewer.pal(11, "Spectral"), at = lvls,
    cuts = 11, sp.layout = list(coord.sp, world, cex = 0.5, pch = 19, first = FALSE))
```

CHIMERE



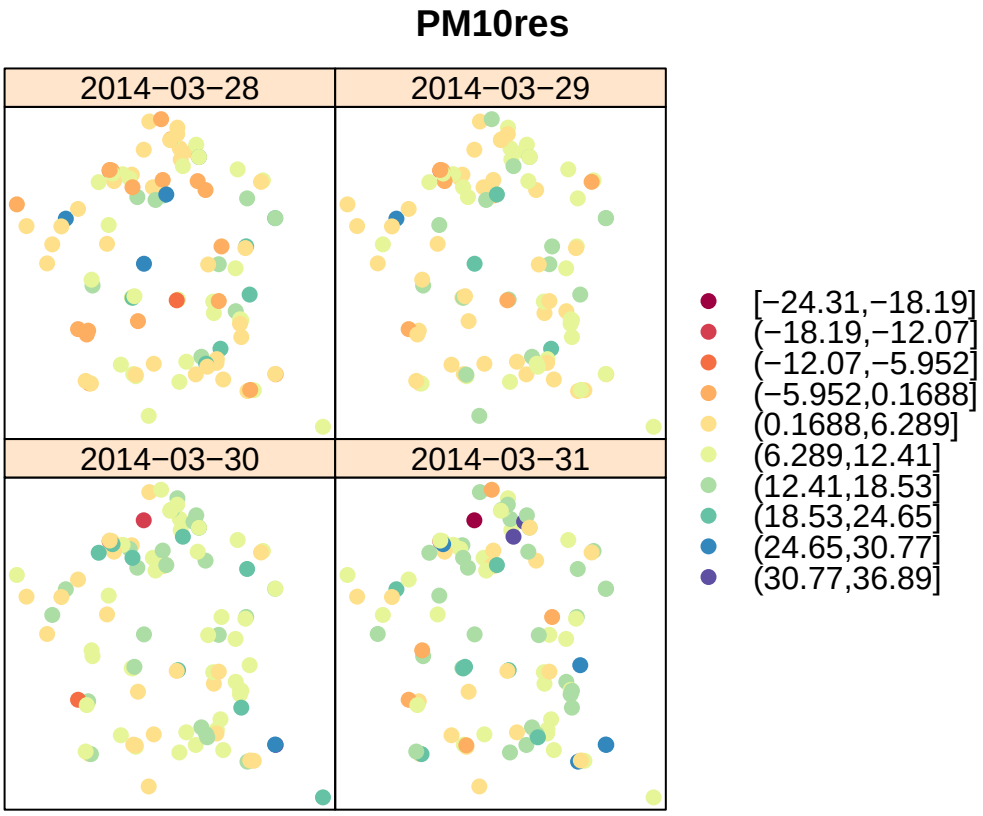

```
# namefig = 'chimgsstplot.pdf' dev.copy2pdf(file=namefig)
# system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only

stplot(CHMcorgs[, 1:4, 2], col.regions = brewer.pal(11, "Spectral"), at = lvls,
    cuts = 11, sp.layout = list(coord.sp, world, cex = 0.5, pch = 19, first = FALSE))
```




```
# namefig = 'chimcorrgsstplotpsman.pdf' dev.copy2pdf(file=namefig)
# system(paste0('pdfcrop ',namefig,' ',namefig)) # linux with pdfcrop only
```

5.3) B) Cross Validation with *gstat*

```
temps <- STFDF_jour@time[times]
data2 <- as.data.frame(as.vector(t(data)))
names(data2) <- "PM10res"
REScor <- STFDF(sp = coord.spt, time = temps, data = data2)
stplot(REScor[, "2014-03-28::2014-03-31", "PM10res"], col.regions = brewer.pal(10,
    "Spectral"), cuts = 10)
```




```
tt <- 89:90
dates <- STFDF_jour@time[tt]
times <- c(69, 70)
err <- matrix(NA, ns, 6)
for (nummod in 1:6) {
    corrmodel <- models[[nummod]]
    for (ista in 1:ns) {
        krig = krigeST(PM10res ~ 1, data = REScor[-ista, times], newdata = STF(coord.spt[ista],
            dates), modelList = corrmodel)
        err[ista, nummod] = data[nT, ista] - krig@data[2, ]
    }
}
RMSE <- sqrt(apply(err^2, 2, mean))
RMSE
```

```
## [1]  9.175435  9.429810  9.076592  9.535824  9.389305 10.135178
```

5.3) C) External validation with *gstat*

```
tt <- 91:92
dates <- STFDF_jour@time[tt]
times <- c(69, 70)
RMSE_extgs <- NULL
val <- (OBS_sel2[, 1, "PM10"])$PM10
indexnona <- which(!is.na(val))
CHMval <- (OBS_sel2[, 1, "CHM"])$CHM[indexnona]
val <- val[indexnona]
```

```
for (nummod in 1:6) {
    corrmodel <- models[[nummod]]
    krig <- krigeST(PM10res ~ 1, data = REScor[, times], newdata <- STF(OBS_sel2@sp,
        dates), modelList = corrmodel)
    RMSE_extgs <- c(RMSE_extgs, sqrt(mean((val - (krig[, 1, 1])$var1.pred[indexnona] -
        CHMval)^2)))
}
RMSE_extgs
```

```
## [1] 12.50706 13.87683 12.44715 13.42448 14.12144 13.34911
```

```
# error made by CHIMERE
sqrt(mean((val - CHMval)^2))
```

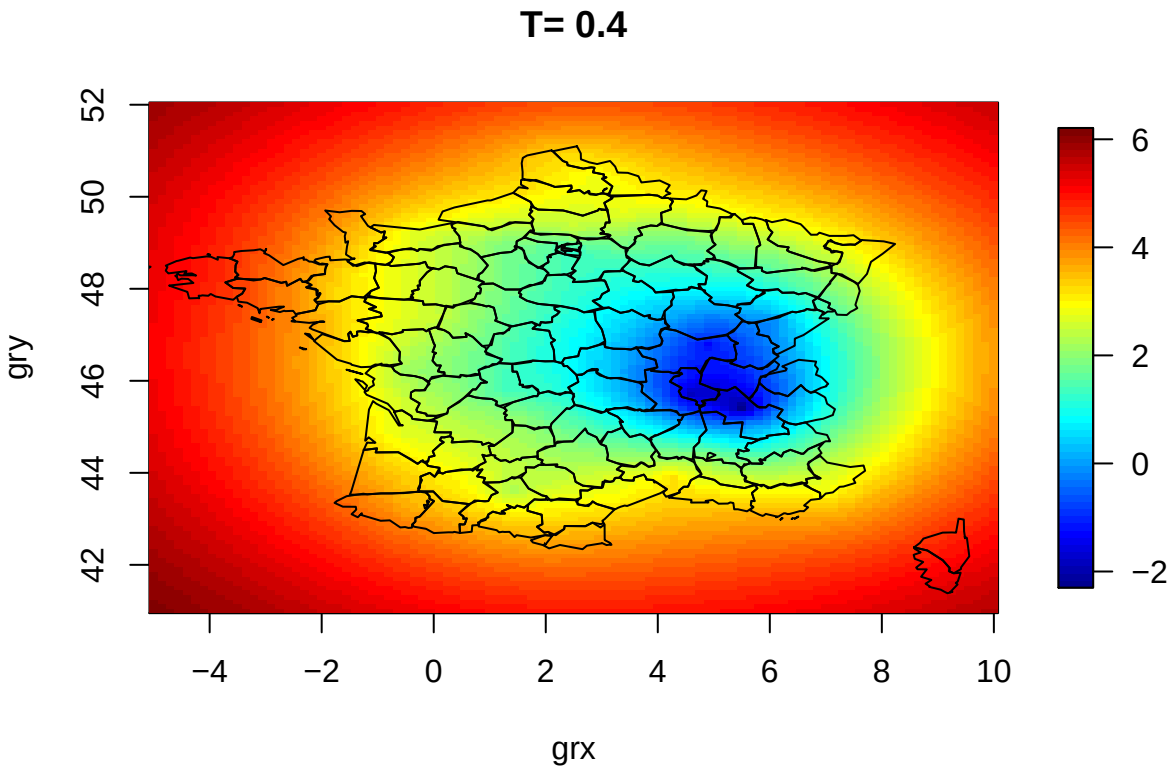
```
## [1] 19.3351
```

5.4) Miscellaneous: kriging with RandomFields

```
library(RandomFields)
load(paste0(DATA, "timesforfits.Rdata"))

times <- seq(0.1, 0.3, 0.1)  # last three observation dates
nTp <- length(times)
# Put the data as (x_i,y_i,T_i,z_i)
donnees <- cbind(rep(coord.sel[, 1], nTp), rep(coord.sel[, 2], nTp), as.vector(sapply(times,
    rep, ns)), as.vector(t(data[(nT - nTp + 1):nT, ])))
colnames(donnees) <- c("x", "y", "T", "z")

# Define the Gneiting covariance model Note : no 'sep' parameter, value 1
model <- RMnsst(phi = RMstable(scale = param$scale_s, alpha = param$power_s),
    psi = RMstable(scale = param$scale_t, alpha = param$power_t), delta = 2,
    var = param$sill) + RMnugget(param$nugget) + RMtrend(mean = mean.est)

# Define the target
loc <- coord.spchm@coords/1000
loc_to_pred <- loc

tt <- 0.4  # consecutive times only

zint <- RFinterpolate(model, x = loc, T = tt, data = donnees)
zint
```

```
## Object of class 'RFspatialPointsDataFrame'
## 'data.frame':    11211 obs. of  1 variable:
##  $ T: num  6.14 6.11 6.09 6.06 6.03 ...
```

```
zlim <- range(zint$T)
Z <- matrix(zint$T, nrow = length(grx))
image.plot(grx, gry, Z, main = paste("T=", tt), zlim = zlim)
map("france", add = TRUE)
```




```
# Strange results ...
image.plot(grx, gry, matrix(zint$T + CHM_mat[, 91], nrow = length(grx)), main = paste("T=",
    tt))
map("france", add = TRUE)
```