

US Ozone and PM2.5 Maps and Trends

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2015-07-04

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Summary

From Annual US Airdata reports available between 2008 and 2015 on [US EPA download site and data repositories](#), 2 pollutants of interest, Ozone and Particulate Material up to 2.5 micro-meters, were selected for comparative and evolutive analysis. The tool was derived from the basic example covered by Dr. Roger D. Peng in the [Coursera ‘Developing Data Products, Week 4 - yhat module](#). The core data filtering process is contained in the screener function, where the minimum data is retrieved using an adaptive radius. The screening algorithm is based on the nearest 5 reporting sites, instead of straight averaging within a fixed radius provided. The module also retrieves all data available to date, aggregated on a yearly basis. A [yhat](#) module function was also developed to verify functionality, and could be used in a multi-user distributed environment. Multiple methods including averaging a single value per county or mapping the average of the 5 nearest neighbors are performed. Pollutant levels (Ozone and PM2.5) and Radii of Reports are analyzed, indicating the absence of data from HI and very little reporting in AK. The use of radar chart is also quickly

demonstrated. However, the evolution of levels and Radii show clear trends over the period 2008 thru 2015 as well as progress in monitoring density overall. A number of interesting differences, distributions and radar charts explain clearly the evolution observed in US. Finally, the [choroplethr](#) animation summarizes well the trends in a dynamic web player, and extend mapping to all 50 states.

System and Platform Documentation

Before any analysis is performed, let's start with system and platform documentation in a fresh directory to insure reproducibility.

```
Sys.info() [1:5] # system info but exclude login and user info
```

```
##      sysname      release     version    nodename      machine
##      "Windows"    "7 x64"    "build 9200" "LEARNING-PC"    "x86-64"
```

```
userdir<-getwd() # user-defined startup directory
library(plyr)
library(dplyr)
library(tidyr)
library(data.table) # for liner
library(pbapply) # for progressbar
library(magrittr)
library(ggplot2)
library(maps)
library(mapproj)
library(RColorBrewer) # for brewer.pal(...)
library(fields) # for rdist() in screener
library(choroplethr)
library(choroplethrMaps)
library(animation)
sessionInfo() # to document platform
```

```
## R version 3.2.1 (2015-06-18)
## Platform: x86_64-w64-mingw32/x64 (64-bit)
## Running under: Windows 8 x64 (build 9200)
##
## locale:
## [1] LC_COLLATE=English_United States.1252
## [2] LC_CTYPE=English_United States.1252
## [3] LC_MONETARY=English_United States.1252
## [4] LC_NUMERIC=C
## [5] LC_TIME=English_United States.1252
##
## attached base packages:
## [1] grid      stats     graphics   grDevices utils     datasets   methods
## [8] base
##
## other attached packages:
## [1] animation_2.3      yhatr_0.13.6       choroplethrMaps_1.0
## [4] choroplethr_3.1.0   fields_8.2-1       spam_1.0-1
## [7] RColorBrewer_1.1-2  mapproj_1.2-2       maps_2.3-9
```

```

## [10] ggplot2_1.0.1      magrittr_1.5      pbapply_1.1-1
## [13] data.table_1.9.4    tidyverse_0.2.0   dplyr_0.4.2
## [16] plyr_1.8.3
##
## loaded via a namespace (and not attached):
## [1] Rcpp_0.11.6        formatR_1.2       tools_3.2.1
## [4] rpart_4.1-9        digest_0.6.8      evaluate_0.7
## [7] gtable_0.1.2       lattice_0.20-31  WDI_2.4
## [10] DBI_0.3.1         yaml_2.1.13      parallel_3.2.1
## [13] proto_0.3-10     gridExtra_0.9.1   cluster_2.0.1
## [16] stringr_1.0.0     knitr_1.10.5     nnet_7.3-9
## [19] R6_2.0.1          XML_3.98-1.3    survival_2.38-1
## [22] foreign_0.8-63   rmarkdown_0.7     latticeExtra_0.6-26
## [25] Formula_1.2-1    reshape2_1.4.1   acs_1.2
## [28] scales_0.2.5     Hmisc_3.16-0     htmltools_0.2.6
## [31] MASS_7.3-40       splines_3.2.1   assertthat_0.1
## [34] colorspace_1.2-6  stringi_0.5-5   acepack_1.3-3.3
## [37] munsell_0.4.2    chron_2.3-47

datadir <- "./data"
figdir <- "./Pollution_files/figure-html"
anidir <- "./Animations"
if (!file.exists("data")) { dir.create("data") } # data will reside in subdir ./data
if (!file.exists("figures")) { dir.create("figures") } # figures in subdir ./figures
if (!file.exists("Animations")) { dir.create("Animations") } # for animated gif

```

Reproducible Data Gathering and Transformation

All data is obtained reproducibly from documented US airdata source, aggregating the 2 pollutants Ozone and PM2.5 - Local Conditions. Monitoring sites and pollutant averages are populating the two corresponding data frames, as introduced in the Coursera Module.

```

y_monitors<-NULL
y_pollavg<-NULL
for (i in 2008:2015)
{
  url<-paste0("http://aqsdr1.epa.gov/aqsweb/aqstmp/airdata/annual_all_",
              as.character(i), ".zip", sep=' ')
  filename <- paste(datadir,strsplit(url,"/")[[1]][length(strsplit(url,"/")[[1]])],
                     sep="/")
  download.file(url, dest=filename, mode="wb")
  unzip (filename, exdir = datadir) # unzip creates and populates the data structure
  unlink(filename) # remove the zip file
  filename <-gsub(".zip",".csv",filename)
  d <- read.csv(filename,stringsAsFactors=FALSE) # populate data frame
  sub<-subset(d, Parameter.Name %in% c("PM2.5 - Local Conditions", "Ozone")
              & Pollutant.Standard %in% c("Ozone 8-Hour 2008", "PM25 Annual 2006"),
              c(Year,Longitude,Latitude,Parameter.Name, Arithmetic.Mean))
  y_poll<-aggregate(sub[, "Arithmetic.Mean"],
                   sub[,c("Year", "Longitude", "Latitude", "Parameter.Name")],
                   mean,na.rm=TRUE)
  names(y_poll)[5]<-"level"

```

```

y_poll$Parameter.Name[y_poll$Parameter.Name=="PM2.5 - Local Conditions"]<- "PM2p5"
y_poll<-transform(y_poll, Parameter.Name=factor(Parameter.Name))

if(is.null(nrow(y_monitors))) {
    y_pollavg<-y_poll
    y_monitors<-data.matrix(y_pollavg[,c("Year", "Longitude", "Latitude")])
}
else {
    y_pollavg<-rbind(y_pollavg,y_poll)
    y_monitors<-rbind(y_monitors,
                        data.matrix(y_pollavg[,c("Year", "Longitude", "Latitude")]))
}
}

names(y_pollavg)[1]<-"yr"
rm(d,sub,datadir,filename,url,i,y_poll)
y_monitors<-as.data.frame(y_monitors)
y_monitors$Year<-as.integer(y_monitors$Year)
y<-spread(y_pollavg,Parameter.Name,level)
# eliminate missing values records
y<-y[!is.na(y$Ozone),]
y<-y[!is.na(y$PM2p5),]
y_pollavg<-gather(y, "Parameter.Name", "level", 4:5)
rm(y)

```

Functional Core

Screener, Liner and Normalize Helper Functions

The core data filtering processes a positional data frame containing longitude and latitude. It returns the same information in 8 records, one for each year in 2008:2015 range:

- yr : 2008:2015
- radius: 5 closest neighbors reporting both
- Ozone : in ppm and
- PM2p5 : in ppm

```

screener <- function(df)
{
  #
  # input is a data.frame df
  #           lon      lat
  #       1 -86.70649 32.4302
  #       ...
  #
  # output the complete data.frame df
  #           lon      lat   yr   radius      Ozone      PM2p5
  #       1 -86.70649 32.4302 2008 77.67187 0.04523967 12.698744
  #       2 -86.70649 32.4302 2009 66.45152 0.03956100 10.457460
  #       3 -86.70649 32.4302 2010 66.45152 0.04697900 11.594312
  #       4 -86.70649 32.4302 2011 66.45152 0.04703300 11.413982
  #       5 -86.70649 32.4302 2012 77.67187 0.04431500 10.488044

```

```

#      6 -86.70649 32.4302 2013 77.67187 0.03956567 9.688020
#      7 -86.70649 32.4302 2014 77.67187 0.04164267 9.960654
#      8 -86.70649 32.4302 2015 77.67187 0.03565967 9.902436
#
#      ...
n<-nrow(df)
df.in<-df
df.out<-data.frame()
#
pb <- txtProgressBar(min = 0, max = n, style = 3, char="+")
for (k in 1:n) {
  df<-data.frame(df.in[k,])
  dlevel1<-data.frame()
  for (j in 2008:2015) {
    use<-vector()
    d<-rdist.earth(subset(y_pollavg, yr==j, select=-yr), data.matrix(df[,c("lon", "lat")]))
    use<-lapply(seq_len(ncol(d)), function(i) {
      head(data.frame(sort(d[,i], decreasing=FALSE, index.return=TRUE)), 5)$ix })
    r<-max(sapply(seq_len(ncol(d)), function(i) {
      head(data.frame(sort(d[,i], decreasing=FALSE, index.return=TRUE)), 5)$x }))
    l.Ozone<-sapply (use, function(idx) {
      with(subset(y_pollavg, yr==j & Parameter.Name=="Ozone", select=-yr)[idx,],
            tapply(level, Parameter.Name=="Ozone", mean)))})
    l.PM2p5<-sapply (use, function(idx) {
      with(subset(y_pollavg, yr==j & Parameter.Name=="PM2p5", select=-yr)[idx,],
            tapply(level, Parameter.Name=="PM2p5", mean)))})
    dlevel1 <- rbind(dlevel1, c(j, r, l.Ozone, l.PM2p5))
    # cleanup time
    rm(d, r, l.Ozone, l.PM2p5, use)
  }
  names(dlevel1)<-c("yr", "radius", "Ozone", "PM2p5")
  df<-data.frame(df, dlevel1, row.names = NULL)
  df.out<-rbind(df.out, df)
}
# setTxtProgressBar(pb, k)
}
# close(pb)
df<-df.out
rm(df.in, df.out, dlevel1, k, j)
df
}

```

liner() is a helper function wrapper which may be used on systems where available memory is low. It invokes screener() in a listwise fashion, and presents the advantage of a text progressbar. The returned list is bound quickly using the rbindlist data.table function.

```

liner <- function(v)
{
  p <- pblapply(seq_len(nrow(v)), function(i)
  {
    screener(v[i, ])
  })
  v <- data.frame(rbindlist(p))
  v
}

```

normalize() is a convenience reformatter function capable of addressing vectors and data frames and is used for radar charting.

```
normalize <- function(df)
{
  if (is.vector(df) == TRUE)
  {
    m <- max(df)
    n <- min(df)
    df <- (df - n)/(m - n)
  } else
  {
    df <- data.frame(sapply(seq_len(ncol(df)), function(i)
    {
      m <- max(df[, i])
      n <- min(df[, i])
      df[, i] <- (df[, i] - n)/(m - n)
      df[, i]
    }))
  }
  df
}
```

Screener ‘yhat’ Module

```
library(yhattr)

model.require <- function() {
  library(fields)
  library(pbapply)
}

model.transform <- function(df) {
  df
}

model.predict <- function(df) {
  screener(df)
}
```

yhat.config follows but is not rendered to keep the apikey private... and function is not redeployed
Only invoke yhat.deploy when changing the model, so we will not re-deploy now.

```
yhat.deploy("screener")
```

However, since the function has been deployed previously, we can call yhat.predict. It returns the expected output illustrated in the screener function.

```
data <-c("lon"=-86.70649,"lat"= 32.4302)
yhat.predict("screener",data)
```

```

##          lon      lat    yr   radius     Ozone     PM2p5
## 1 -86.70649 32.4302 2008 77.67187 0.04523967 12.698744
## 2 -86.70649 32.4302 2009 66.45152 0.03956100 10.457460
## 3 -86.70649 32.4302 2010 66.45152 0.04697900 11.594312
## 4 -86.70649 32.4302 2011 66.45152 0.04703300 11.413982
## 5 -86.70649 32.4302 2012 77.67187 0.04431500 10.488044
## 6 -86.70649 32.4302 2013 77.67187 0.03956567 9.688020
## 7 -86.70649 32.4302 2014 77.67187 0.04164267 9.960654
## 8 -86.70649 32.4302 2015 77.67187 0.03565967 9.902436

```

Analysis

Averaging Pollutants

As a first step in the analysis, the average values obtained by counties are computed.

```

pollutant<-data.frame()
set.seed(1)      # for reproducible example
# this creates an example formatted as a pollutant.map
df<-data.frame(map_data('county'))
names(df)[1]<- 'lon'
df[,c("lon","lat")] %>%
  screener %>%
  merge(df,.,by=c("lon","lat"),all=TRUE) %>%
  group_by(region,subregion,yr) %>%
  select(-group,-order) %>%
  summarise_each(funs(mean)) %>%
  as.data.frame %>%
  gather("type","level",7:8) -> pollutavg
names(pollutavg)[1:2]<-c("id","region")
#
df %>%
  group_by(region,subregion) %>%
  select(lon,lat) %>%
  summarise_each (fun_mean) %>%
  as.data.frame-> df
df[,c("lon","lat")] %>%
  screener %>%
  merge(df,.,by=c("lon","lat"),all=TRUE) %>%
  as.data.frame -> pollutant
pollutant$yr<-as.factor(pollutant$yr)

```

Histograms

It is important to observe pollutant levels, but also essential to realize at which distance the radius monitoring is occurring. Since the screener routing adapts itself to the 5 nearest neighbors mean, we need to see how these radii are distributed.

```

m1<-ggplot(pollutant,aes(x=radius)) +
  geom_histogram(binwidth=20,color="grey50",fill='blue') +
  labs(title="2008 ~ 2015 Radius (Miles) reporting Pollutants",

```

```

      x="Radius (Miles)",y="Count")+
      theme_bw()
m1

```

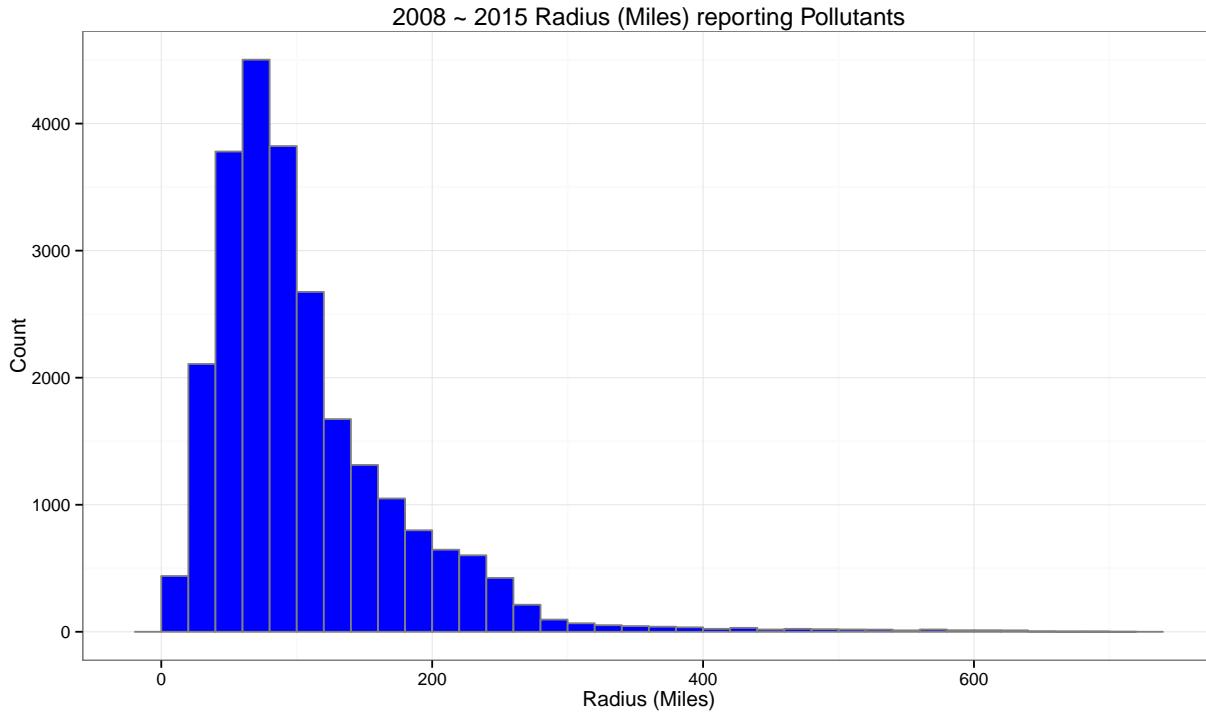


Figure 1:

```

m2<-ggplot(pollutant,aes(x=radius,fill=yr)) +
  geom_histogram(binwidth=20,color="grey50") +
  facet_wrap(~yr) +
  labs(title="Radius (Miles) reporting Pollutants by Year",
       x="Radius (Miles)",y="Count") +
  theme_bw()
m2

```

ggplot Maps

With a little re-arranging we can chart the levels and radii trends for Ozone and PM2.5 using first ggplot(). We tidy the data and merge counties information from the map_data("county"). Observing that reporting for 2015 is not complete, we will base comparisons and trends up to 2014 at this time.

```

# time to tidy the data
pollutant %>% gather("type","level",7:8) -> pollutant
names(pollutant)[3:4]<-c("id","region")
#
m.usa <- map_data("county")
m.usa <- m.usa[ , -5]
names(m.usa)[5] <- 'region'

```

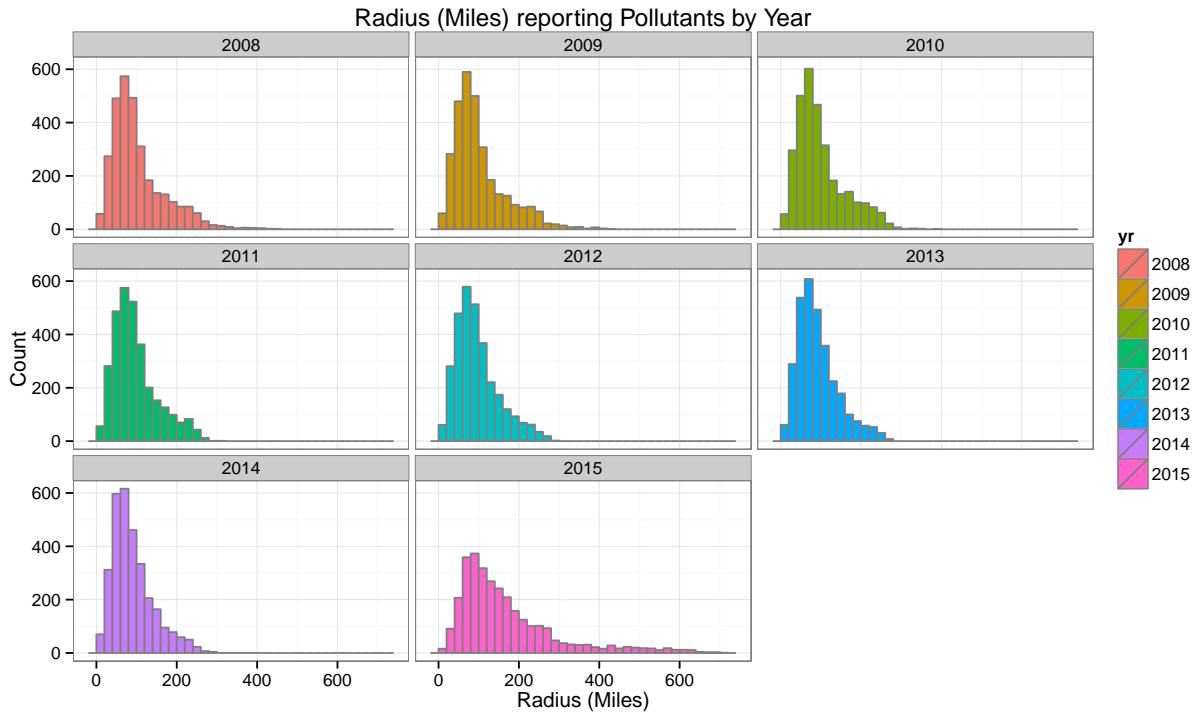


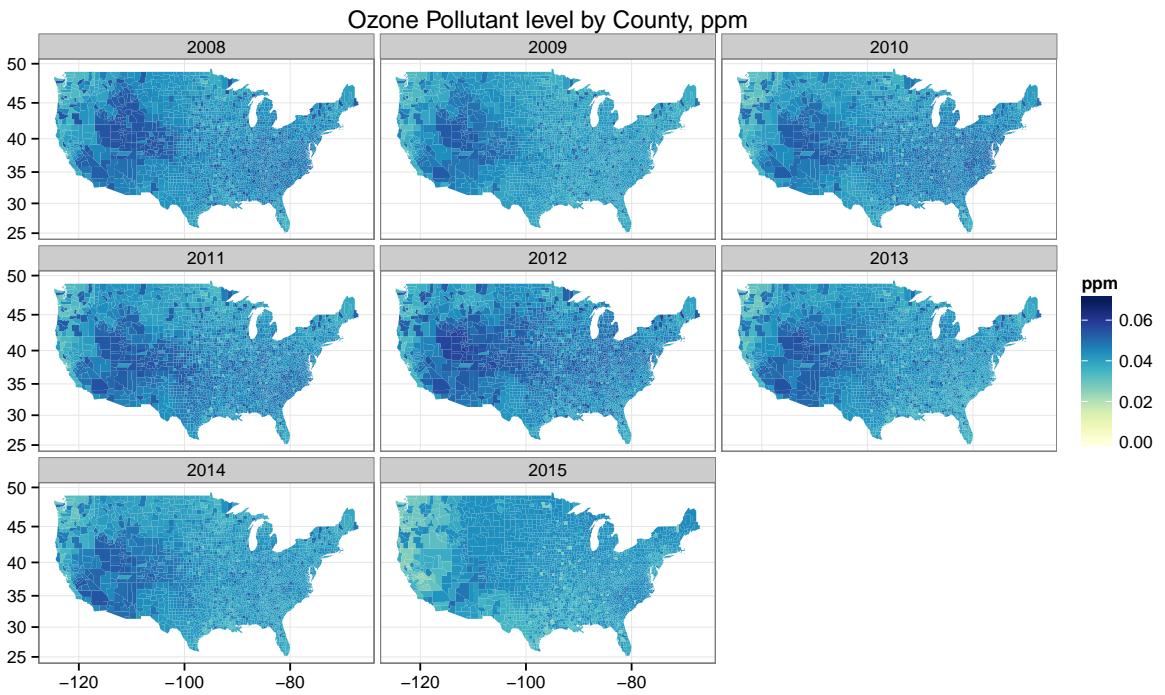
Figure 2:

We are now ready to chart these county ggplots... We will slightly adapt the scales as indicated to produce meaningful ranges of Ozone and PM2.5 (in ppm) and radii (in miles).

```

g1 <- ggplot(subset(pollutant,type=="Ozone"), aes(map_id = region)) +
  geom_map(aes(fill = level), map = m.usa) +
  expand_limits(x = m.usa$long, y = m.usa$lat) +
  scale_fill_gradient("ppm", colours=brewer.pal(9,"YlGnBu"))
g1 <- last_plot() + coord_map() + facet_wrap(~ yr,nrow=3) +
  labs(title="Ozone Pollutant level by County, ppm",x="",y "")+ theme_bw()
g1$scales$scales[[1]]$limits<-c(0,0.07)
g1

```

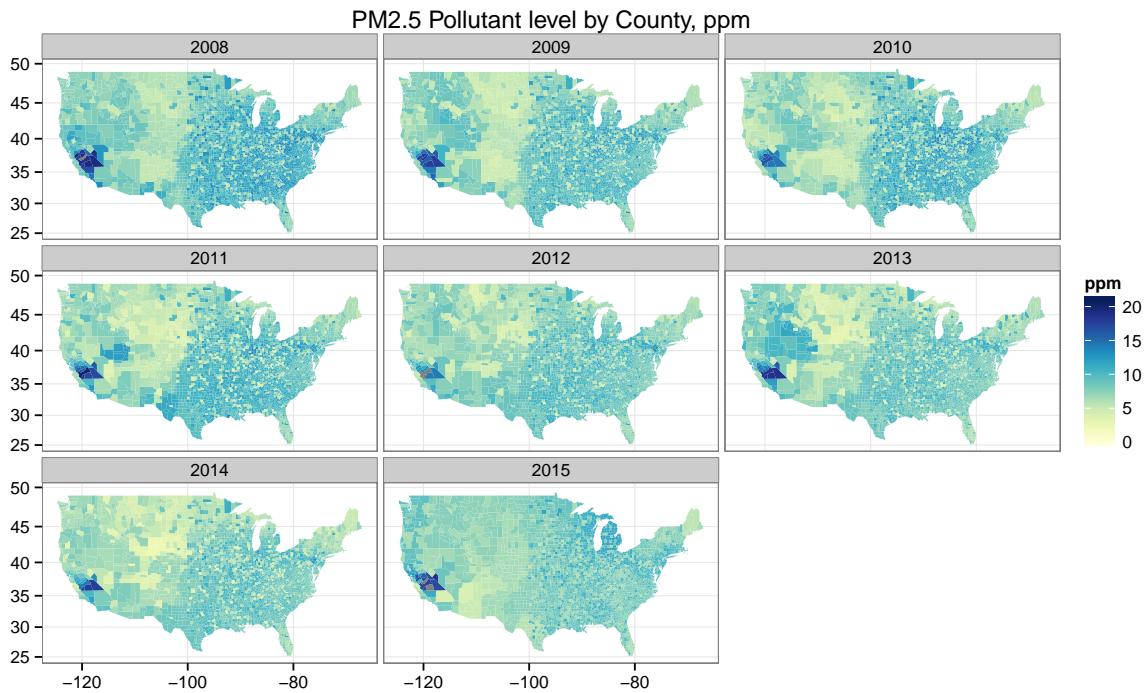


We observe: West/Southwest highest but decreasing Ozone levels over the 2008-2014 period.

```

g2 <- ggplot(subset(pollutant,type=="PM2p5"), aes(map_id = region)) +
  geom_map(aes(fill = level), map = m.usa) +
  expand_limits(x = m.usa$long, y = m.usa$lat) +
  scale_fill_gradientn("ppm", colours=brewer.pal(9, "YlGnBu"))
g2 <- last_plot() + coord_map() + facet_wrap(~ yr,nrow = 3) +
  labs(title="PM2.5 Pollutant level by County, ppm",x="",y "")+ theme_bw()
g2$scales$scales[[1]]$limits<-c(0,21)
g2

```

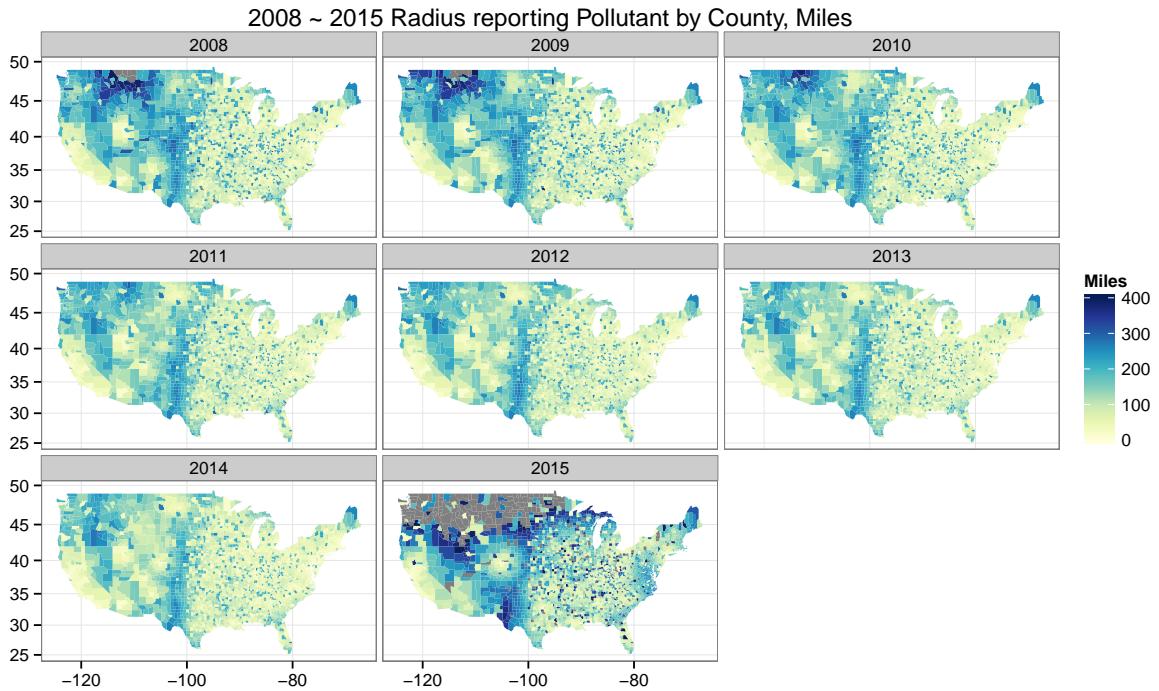


We observe: California highest levels, Western US shows low levels of PM2.5.

```

g3 <- ggplot(subset(pollutant,type=="Ozone"), aes(map_id = region)) +
  geom_map(aes(fill = radius), map = m.usa) +
  expand_limits(x = m.usa$long, y = m.usa$lat) +
  scale_fill_gradientn("Miles", colours=brewer.pal(9,"YlGnBu"))
g3 <- last_plot() + coord_map() + facet_wrap(~ yr,nrow = 3) +
  labs(title="2008 ~ 2015 Radius reporting Pollutant by County, Miles",x="",y="") + theme_bw()
g3$scales$scales[[1]]$limits<-c(0,400)
g3

```



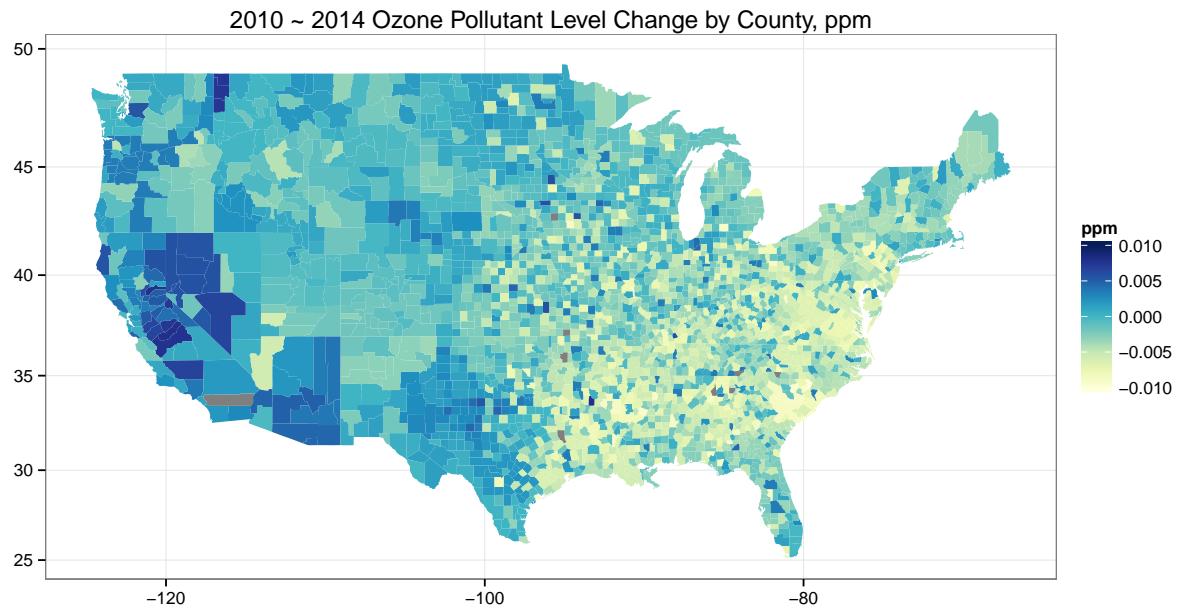
We observe generally decreasing radius, indicating data collection density increases. Grey color represents radius in excess of 400 miles.

```

subset(pollutant,type=="Ozone" & yr %in% c(2010,2014)) %>%
  group_by(id,region,yr) %>%
  select(-type,-radius) %>%
  as.data.frame -> t
t$yr<-as.character(t$yr)
t$yr<-paste0("Y",t$yr)
t %>% spread(yr,level) %>% mutate(level.change=Y2014-Y2010) -> t

g4 <- ggplot(t, aes(map_id = region)) +
  geom_map(aes(fill = level.change), map = m.usa) +
  expand_limits(x = m.usa$long, y = m.usa$lat) +
  scale_fill_gradientn("ppm", colours=brewer.pal(9,"YlGnBu"))
g4 <- last_plot() + coord_map() +
  labs(title="2010 ~ 2014 Ozone Pollutant Level Change by County, ppm",x="",y="") +
  theme_bw()
g4$scales$scales[[1]]$limits<-c(-0.010,0.01)
g4

```



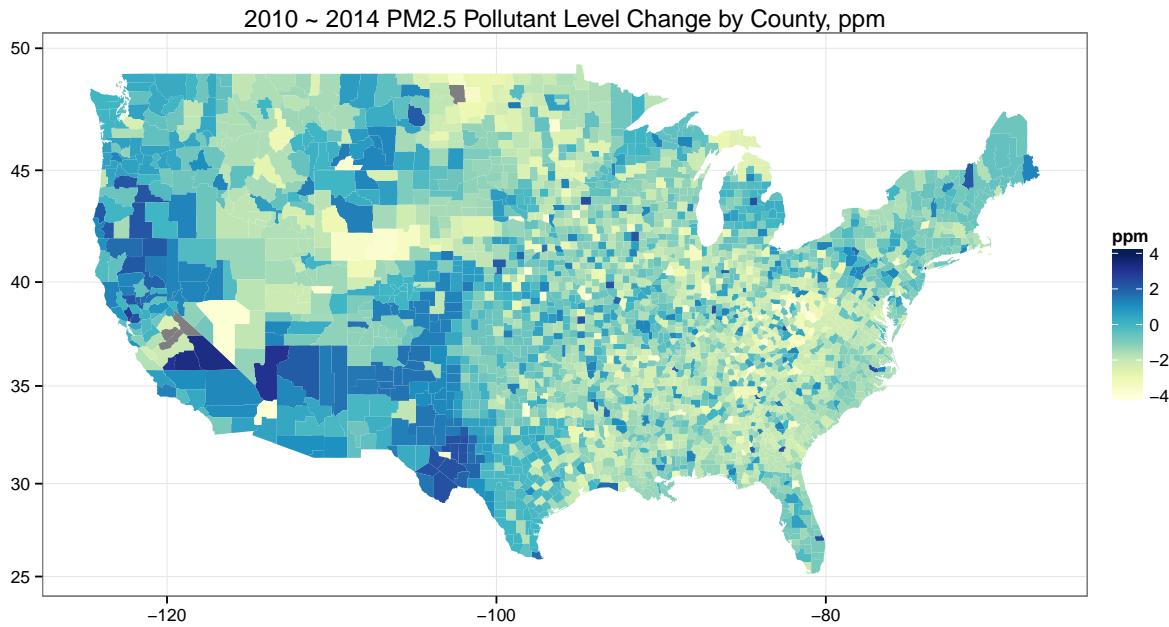
We note, over 2010-2014, Western US shows worsening while Eastern US shows improving Ozone levels.

```

subset(pollutant,type=="PM2p5" & yr %in% c(2010,2014)) %>%
  group_by(id,region,yr) %>%
  select(-type,-radius) %>%
  as.data.frame -> t
t$yr<-as.character(t$yr)
t$yr<-paste0("Y",t$yr)
t %>% spread(yr,level) %>% mutate(level.change=Y2014-Y2010) -> t

g5 <- ggplot(t, aes(map_id = region)) +
  geom_map(aes(fill = level.change), map = m.usa) +
  expand_limits(x = m.usa$long, y = m.usa$lat) +
  scale_fill_gradientn("ppm", colours=brewer.pal(9,"YlGnBu"))
g5 <- last_plot() + coord_map() +
  labs(title="2010 ~ 2014 PM2.5 Pollutant Level Change by County, ppm",x="",y="") +
  theme_bw()
g5$scales$scales[[1]]$limits<-c(-4,4)
g5

```



We note, over 2010-2014, Southwest shows worsening while North-Central US and Midwest show improving PM2.5 levels.

```

subset(pollutant, yr %in% c(2010,2014)) %>%
  group_by(id,region,yr) %>%
  select(-type,-level) %>%
  unique %>%
  as.data.frame -> t
t$yr<-as.character(t$yr)
t$yr<-paste0("Y",t$yr)
t %>% spread(yr,radius) %>% mutate(radius.change=Y2014-Y2010) -> t

g6 <- ggplot(t, aes(map_id = region)) + geom_map(aes(fill = radius.change),map = m.usa) +
  expand_limits(x = m.usa$long, y = m.usa$lat) +
  scale_fill_gradient("Miles",colours=brewer.pal(9,"YlGnBu"))
g6 <- last_plot() + coord_map() +
  labs(title="2010 ~ 2014 Radius reporting Pollutant Change by County, Miles",x="",y="") +
  theme_bw()
g6$scales$scales[[1]]$limits<-c(-200,200)
g6

rm(m.usa) # cleanup

```

We observe some significant improvements in CO (arapahoe, denver, adams...) and MT (glacier, pondera, teton...)

```
head(t[order(t$radius.change), ], 10, addrownums = FALSE)
```

##	lon	lat	id	region	Y2010	Y2014	radius.change
----	-----	-----	----	--------	-------	-------	---------------

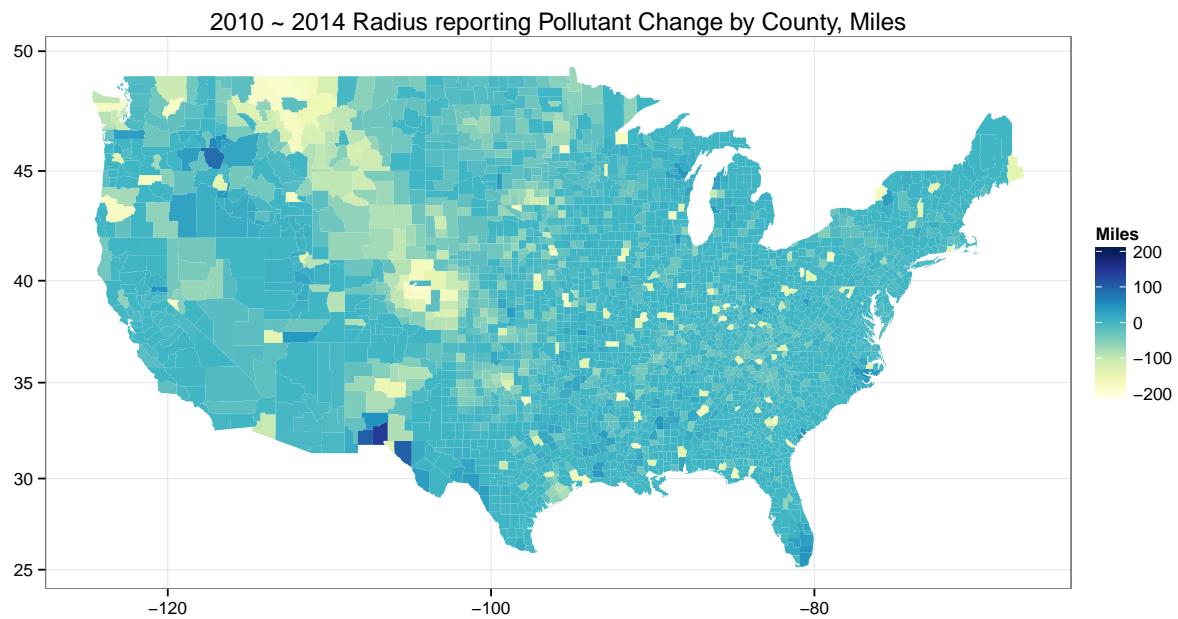


Figure 3:

```
## 227 -104.6889 39.64247 colorado arapahoe 218.3803 21.66127 -196.7190
## 233 -104.8871 39.73921 colorado denver 206.9454 17.20032 -189.7451
## 221 -104.6211 39.87180 colorado adams 219.9444 33.40823 -186.5362
## 414 -113.3766 48.70294 montana glacier 380.4980 197.22506 -183.2730
## 398 -112.3553 48.24798 montana pondera 341.6905 158.56092 -183.1295
## 400 -112.4039 47.78712 montana teton 327.1586 147.15065 -180.0079
## 207 -103.9712 39.24188 colorado elbert 246.4280 66.54129 -179.8867
## 419 -113.8835 48.28113 montana flathead 344.7318 166.60135 -178.1304
## 382 -111.7695 48.59521 montana toole 334.4835 160.26002 -174.2235
## 240 -105.0952 39.35511 colorado douglas 201.5075 29.74580 -171.7617
```

and degradations in AK (washington, crawford,...), WA (asotin), ID (washington) ...

```
tail(t[order(t$radius.change), ], 10, addrownums = FALSE)
```

```
##          lon      lat      id    region    Y2010    Y2014
## 2509 -94.12189 35.95943 arkansas washington 47.58529 105.0617
## 2513 -94.15673 35.54100 arkansas   crawford 44.23743 102.0372
## 466 -117.18300 46.29809 washington   asotin 191.01143 249.9547
## 462 -116.78746 44.42201      idaho washington 226.54678 286.4877
## 261 -105.77400 32.68776 new mexico     otero 76.86264 154.3267
## 467 -117.21664 45.56511      oregon    wallowa 176.62175 260.9981
## 246 -105.46255 31.12611      texas   hudspeth 79.49913 176.4136
## 305 -107.83193 32.20850 new mexico     luna 86.38429 184.3894
## 284 -106.77553 32.33223 new mexico   dona ana 43.45635 185.8445
## 271 -106.29431 31.69889      texas    el paso 16.87159 198.7468
```

```

##      radius.change
## 2509      57.47642
## 2513      57.79976
## 466       58.94323
## 462       59.94095
## 261       77.46404
## 467       84.37639
## 246       96.91446
## 305       98.00507
## 284      142.38816
## 271      181.87518

```

Retrieving county Data for 50 US States

Finally, we attempt another approach with choroplethr, although there is little data for AK and HI... we want to undertake the challenge to visualize not only the lower 48 but also the 49th and 50th US states... This requires a download of the complete county list for all states, a dataset available from the [US Census and data repository](#).

```

pollutant<-data.frame()
set.seed(1)      # for reproducible example
# this creates an example formatted as a pollutant.map
datadir<-"./data" ; if (!file.exists("data")) { dir.create("data") }
url<-"http://www2.census.gov/geo/docs/maps-data/data/gazetteer/Gaz_counties_national.zip"
filename <- paste(datadir,strsplit(url,"/")[1][length(strsplit(url,"/")[1])],sep="/")
download.file(url, dest=filename, mode="wb")
unzip (filename, exdir = datadir) # unzip creates and populates the data structure
unlink(filename) # remove the zip file
filename <-gsub(".zip",".txt",filename)
d <- read.delim(filename,header=TRUE,sep="\t",stringsAsFactors=FALSE) # populate
# cleanup
rm(datadir,filename,url)
names(d)<-tolower(names(d))
subset(d,select=-c(ansicode:awater_sqmi)) %>%
  rename(state.abb=usps,region=geoid,lat=intptlat,lon=intptlong) -> d
d$region<-as.numeric(d$region)
data(county.regions)
df <- data.frame(county.regions)
subset(df,select=-c(county.fips.character,state.fips.character)) %>%
  merge(d,.,by=c("region","state.abb"),all=FALSE) -> df
# cleanup
rm(d,county.regions)
df[,c("lon","lat")] %>%
  screener %>%
  merge(df,.,by=c("lon","lat"),all=TRUE) %>%
  rename(state=state.name) %>%
  as.data.frame -> t -> pollutant
rm(df) # cleanup

```

We now have a pollutant data frame that can contain all 50 states counties, and are ready to checkout AK and HI...

Checking Out AK and HI

```
m1<-ggplot(subset(t,state %in% c("alaska","hawaii")),aes(x=Ozone)) +
  geom_histogram(binwidth=0.001,color="grey50",fill="blue") +
  xlim(c(0,0.07)) + facet_grid(state ~ yr) +
  labs(title="2008 ~ 2015 Ozone Pollutant Level Distribution",
       x="pollutant level (ppm)", y="Count") +
  theme_bw()
m1
```

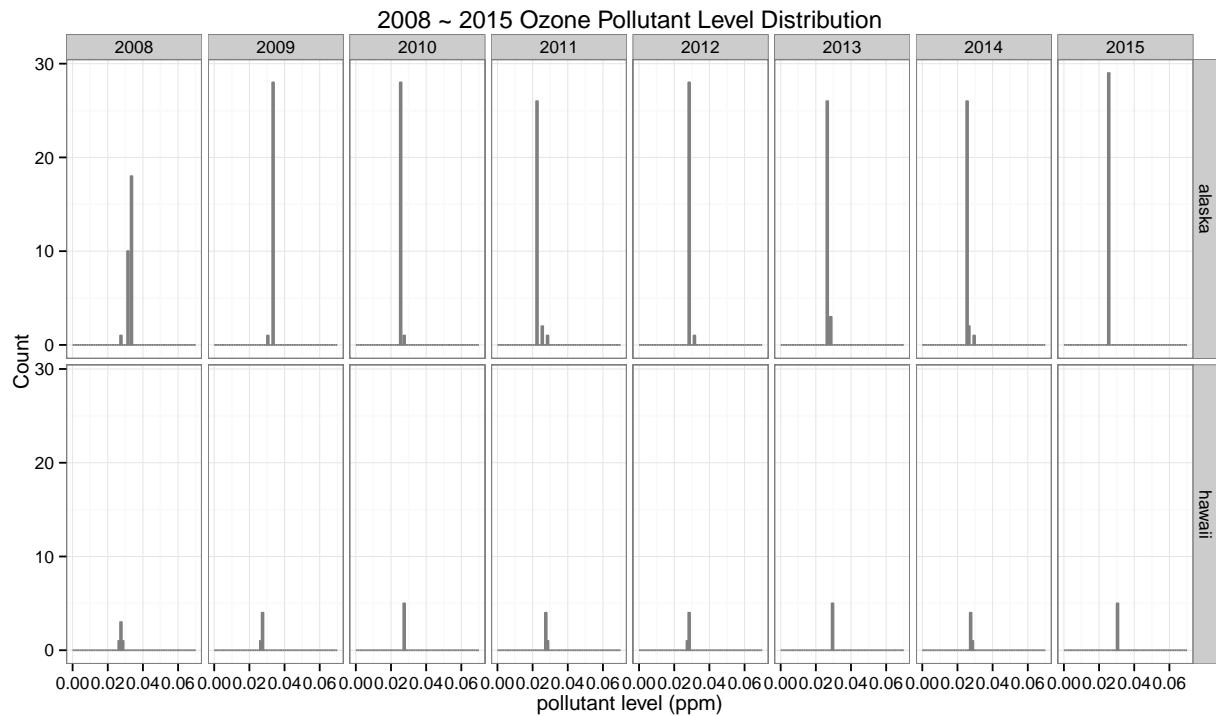


Figure 4:

```
m2<-ggplot(subset(t,state %in% c("alaska","hawaii")),aes(x=PM2p5)) +
  geom_histogram(binwidth=1,color="grey50",fill="blue") +
  xlim(c(0,20)) + facet_grid(state ~ yr) +
  labs(title="2008 ~ 2015 PM2.5 Pollutant Level Distribution",
       x="pollutant level (ppm)",y="Count") +
  theme_bw()
m2
```

```
m3<-ggplot(subset(t,state %in% c("alaska","hawaii")),aes(x=radius)) +
  geom_histogram(binwidth=30,color="grey50",fill="blue") +
  xlim(c(0,3000)) + facet_grid(state ~ yr) +
  labs(title="2008 ~ 2015 Radius (Miles) reporting Pollutants",
       x="Radius (Miles)",y="Count") +
  theme_bw()
m3
```

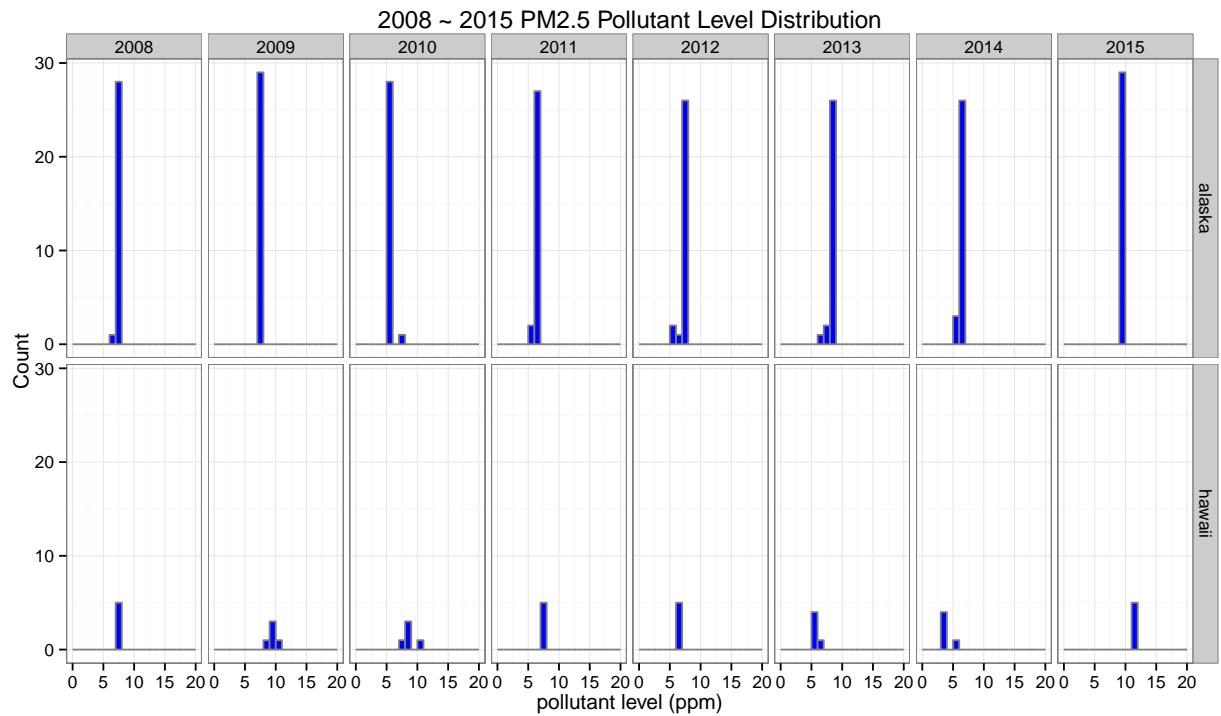
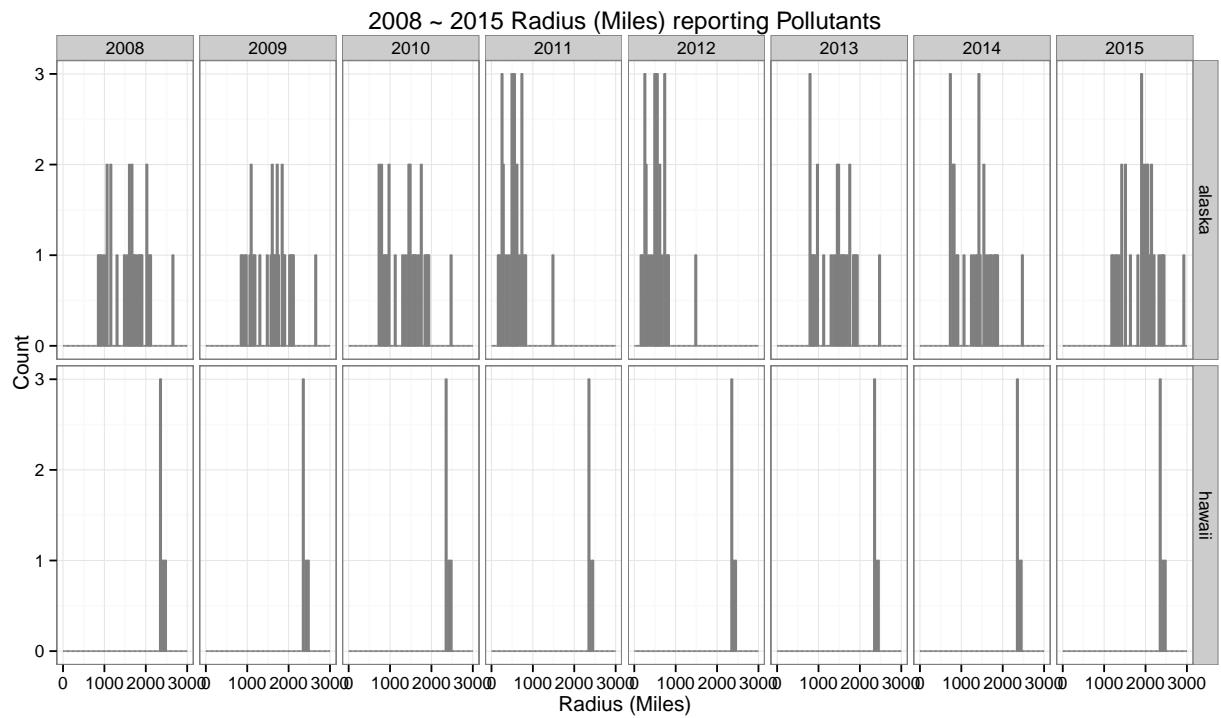


Figure 5:



We observe HI has no data reported, and radius values in excess of 2000 miles indicate most likely CA levels are reported. We also note AK has some reports below 500 miles which we retain for now in 2011 and 2012...

```

m4<-ggplot(subset(t,state %in% c("alaska","hawaii") & radius <500),aes(x=radius)) +
  geom_histogram(binwidth=20,color="grey50",fill="blue") +
  facet_wrap(state ~ yr) +
  labs(title="Radius (Miles) reporting Pollutants by Year",
       x="Radius (Miles)",y="Count") +
  theme_bw()
m4

```

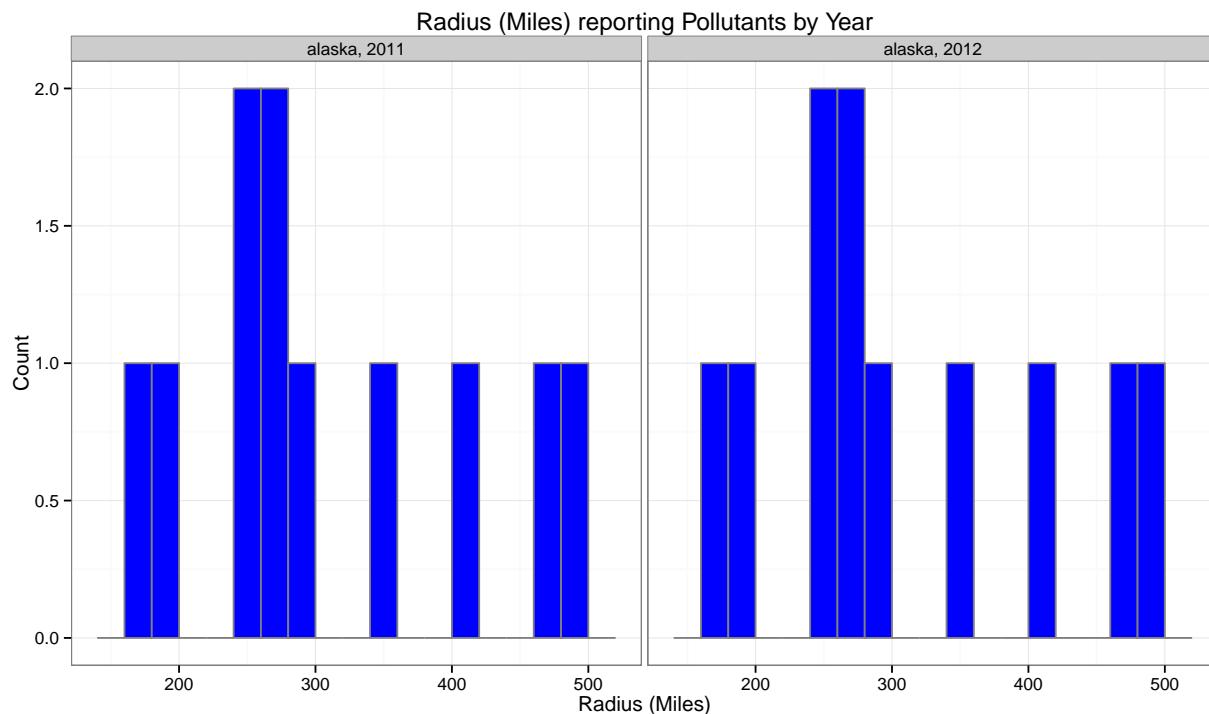


Figure 6:

Radar Charts to the Rescue

To investigate an alternate screening method, we will now use a radar chart approach to capture min and max radii corresponding to the 5 nearest neighbors reporting the pollutants. We treat Ozone and PM2.5 as type variables.

```

t$yr <- as.factor(t$yr)
t$state.abb <- as.factor(t$state.abb)
t %>%
  select(state.abb, yr, radius, Ozone) %>%
  rename(level = Ozone) %>%
  group_by(yr, state.abb) %>%
  summarise_each_(c("n_distinct", "mean", "min", "max"), c("radius", "level")) %>%
  mutate(type = "Ozone") -> temp
t %>%
  select(state.abb, yr, radius, PM2p5) %>%
  rename(level = PM2p5) %>%

```

```

group_by(yr, state.abb) %>%
  summarise_each_(c("n_distinct", "mean", "min", "max"), c("radius", "level")) %>%
  mutate(type = "PM2p5") %>%
  rbind(., temp) %>% as.data.frame -> t
t$type <- as.factor(t$type)
t %>%
  gather("radius.funs", "radius", c(3, 5, 7, 9)) %>%
  gather("level.funs", "level", 3:6) %>%
  as.data.frame-> t
levels(t$radius.funs) <- levels(t$level.funs) <- c("n", "mean", "min", "max")
subset(t, select = -c(level.funs:level)) %>%
  rename(funs = radius.funs, value = radius) %>%
  mutate(metric="radius") -> temp
subset(t, select = -c(radius.funs:radius)) %>%
  rename(funs = level.funs, value = level) %>%
  mutate(metric="level") %>%
  rbind(., temp) %>%
  as.data.frame %>%
  unique -> t
t$metric <- as.factor(t$metric)
rm(temp) # cleanup

```

We observe there is absolutely no data reported from Hawaii and most data from Alaska is extremely distant, at about 800 miles... We now chart this information side by side in ggplots.

```

data.frame(subset(t, type == "Ozone" & !fun=="n")) %>%
  rename(id=state.abb) %>% as.data.frame -> df
gg1 <- ggplot(df, aes(x=id, y=value)) + geom_point(aes(shape = funs, color = yr)) +
  labs(title = "US 50 States Ozone Level and Radius Statistics by State and Year") +
  theme(axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5)) +
  facet_wrap(~ metric, nrow=4, scales="free_y")
gg1

data.frame(subset(t, type == "PM2p5" & !fun=="n")) %>%
  rename(id=state.abb) %>% as.data.frame -> df
gg2 <- ggplot(df, aes(x=id, y=value)) + geom_point(aes(shape = funs, color = yr)) +
  labs(title = "US 50 States PM2.5 Level and Radius Statistics by State and Year") +
  theme(axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5)) +
  facet_wrap(~ metric, nrow=4, scales="free_y")
gg2

data.frame(subset(t, type == "Ozone" & !fun=="n" & !(state.abb %in% c("AK", "HI")))) %>%
  rename(id=state.abb) %>% as.data.frame -> df
gg3 <- ggplot(df, aes(x=id, y=value)) + geom_point(aes(shape = funs, color = yr)) +
  labs(title = "US Lower 48 Ozone Level and Radius Statistics by State and Year") +
  theme(axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5)) +
  facet_wrap(~ metric, nrow=4, scales="free_y")
gg3

```

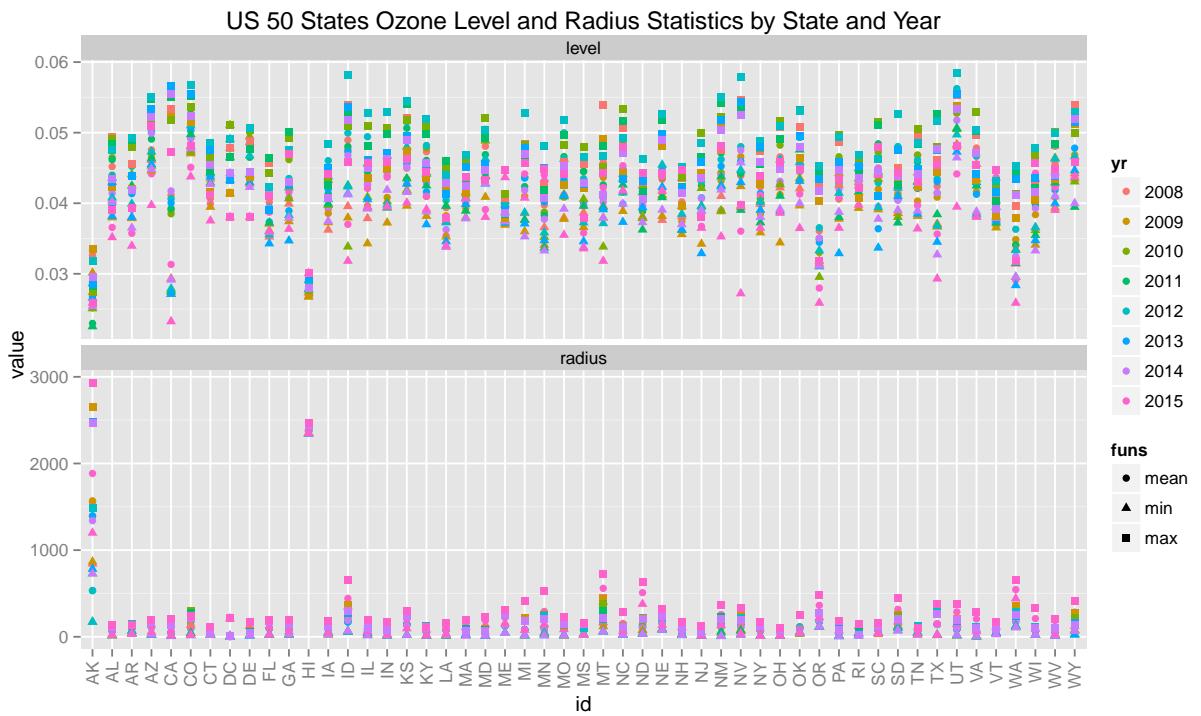


Figure 7:

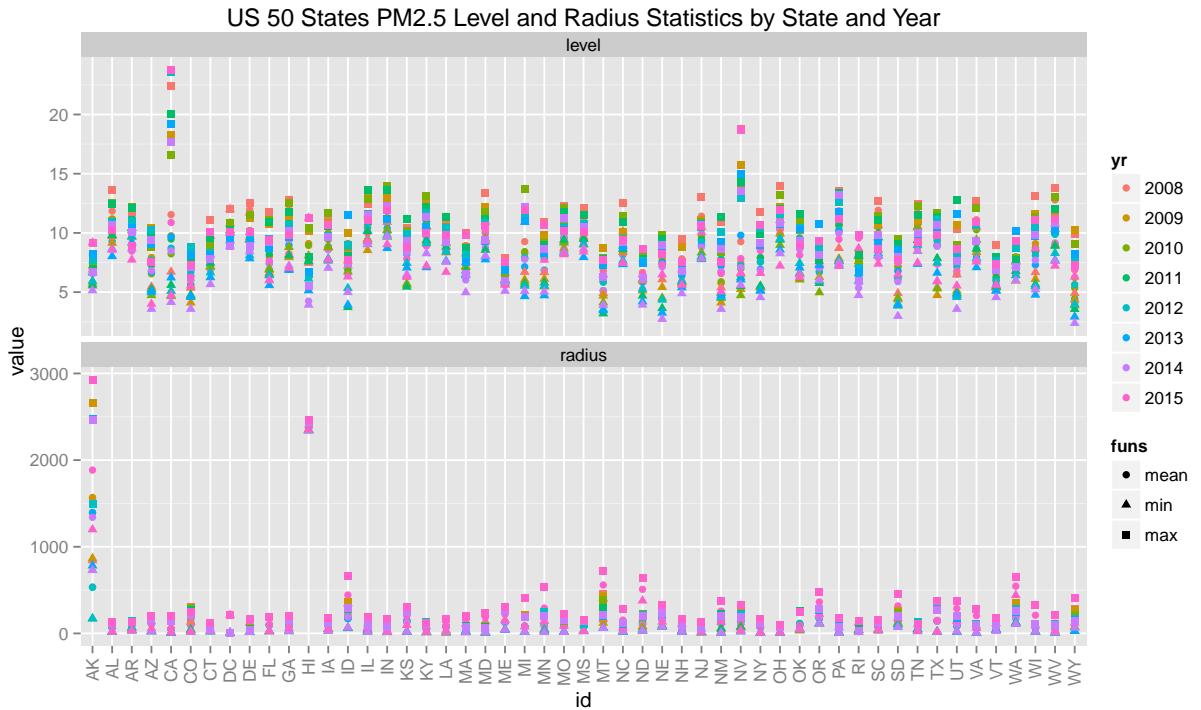
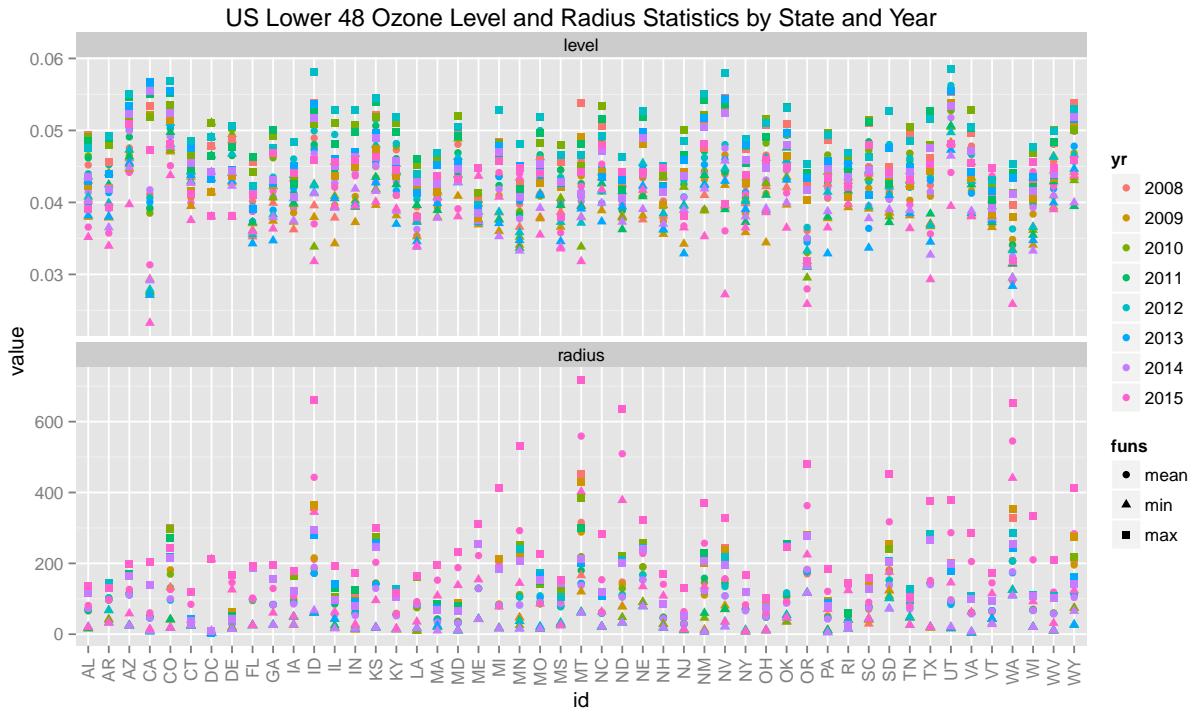


Figure 8:



We observe Radius reporting minimum is usually below 50 miles, with notable exceptions...

```
data.frame(subset(t, type == "PM2p5" & !fun=="n" & !(state.abb %in% c("AK", "HI")))) %>%
  rename(id=state.abb) %>% as.data.frame -> df
gg4 <- ggplot(df, aes(x=id, y=value)) + geom_point(aes(shape = funs, color = yr)) +
  labs(title = "US Lower 48 PM2.5 Level and Radius Statistics by State and Year") +
  theme(axis.text.x = element_text(angle = 90, hjust = 1, vjust = 0.5))+
  facet_wrap(~ metric, nrow=4,scales="free_y")
gg4
```

```
rm(df) # cleanup
```

It is important to note the high level of PM2.5 reported in CA and NV, in excess of 20ppm, while The Ozone ppm level remained overall below 7 ppm overall.

To generate the radar charts, we will use again the ggplot function, and perform charts on the normalized data. We produce faceted charts by Year and superimpose on the chart Ozone and PM2.5

```
# Define a new coordinate system
coord_radar <- function(...) {
  structure(coord_polar(...), class = c("radar", "polar", "coord"))
}
is.linear.radar <- function(coord) TRUE

subset(t,fun!="n" & metric=="radius") %>%
  unique %>% rename(id=state.abb) -> y
y$value <- normalize(y$value)
rownames(y)<-NULL
ggplot(y,aes(x=id,y=value)) +
```

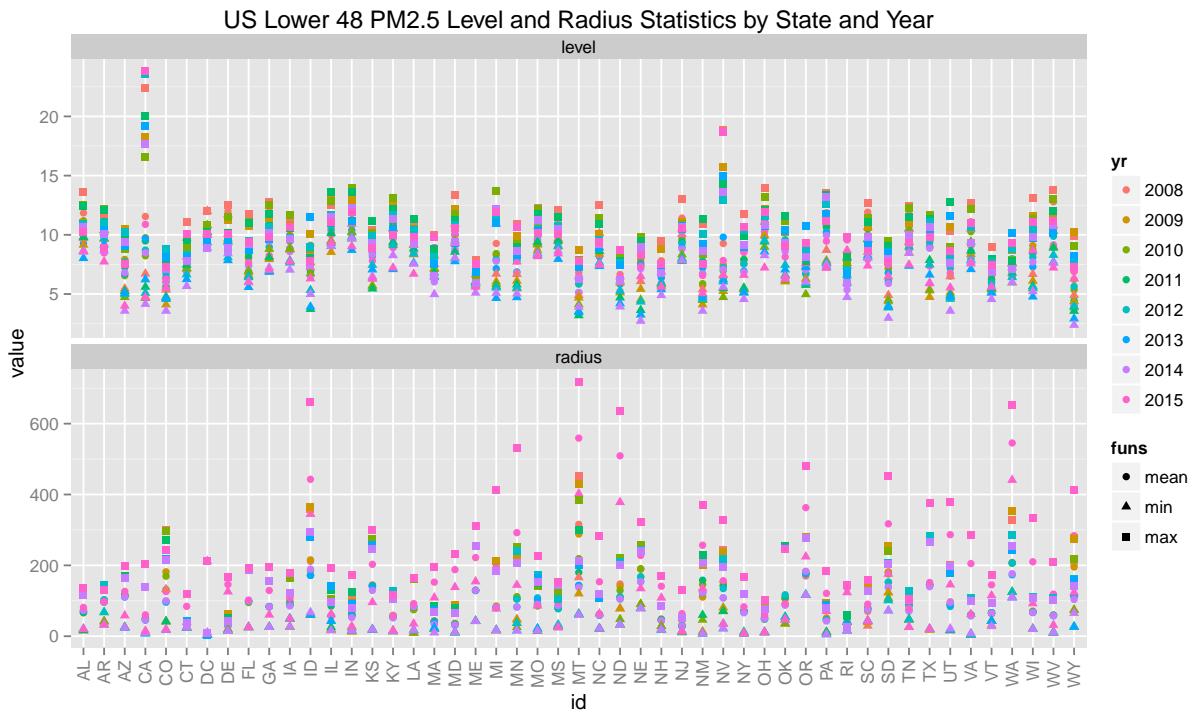
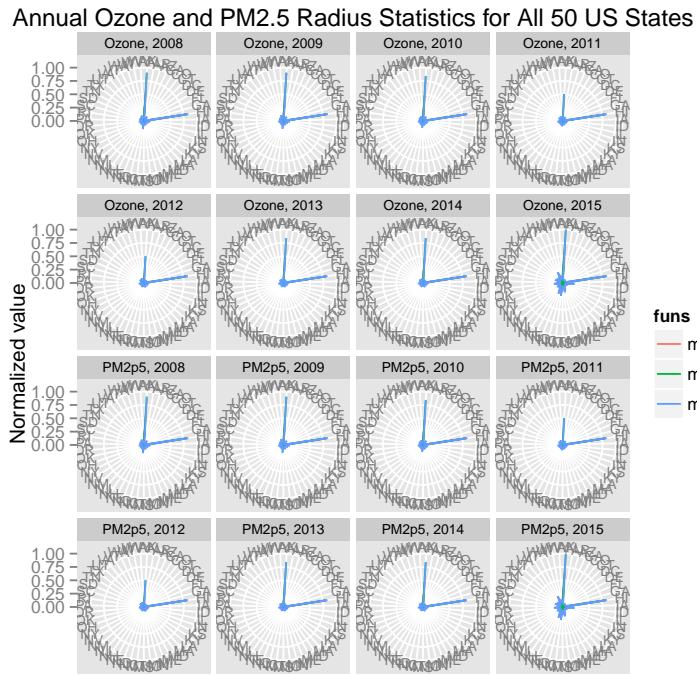


Figure 9:

```

geom_path(aes(group=type, color=funs)) +
coord_radar() + facet_wrap(type ~ yr, nrow=4) +
labs(title = "Annual Ozone and PM2.5 Radius Statistics for All 50 US States",
x="", y="Normalized value") +
theme(strip.text.x = element_text(size = rel(0.8)),
axis.text.x = element_text(size = rel(0.8)))

```



We observe that both AK and HI exhibit very large radii, so let's exclude these...

```
subset(t,funs!="n" & metric=="radius" & !state.abb %in% c("AK","HI")) %>%
  unique %>% rename(id=state.abb)-> y
y$value <- normalize(y$value)
rownames(y)<-NULL
ggplot(y,aes(x=id,y=value)) +
  geom_path(aes(group=type, color=funs)) +
  coord_radar()+facet_wrap(type ~ yr,nrow=4) +
  labs(title = "Annual Ozone and PM2.5 Radius Statistics for Lower 48 US States",
       x="",y="Normalized value") +
  theme(strip.text.x = element_text(size = rel(0.8)),
        axis.text.x = element_text(size = rel(0.8)))
```

```
rm(y,t) # cleanup
```

Choroplethr Approach with Animation

To perform this last step, we limit our observation to a radius less than 250 miles. This will provide visual support for the progress achieved between 2008 and 2015. Recognizing that such radius is quite large, we also map the current progress in collecting denser information. Levels of Ozone and PM2.5 and Radii evolutions are captured in a series of 8 annual charts, one for each variable, and animated with the choroplethr player implemented with an html file.

```
subset(pollutant,radius<250) %>% gather("type","value",9:10) -> t
# the animated story...
choropleths<-list()
setwd(figdir) # point to ./figures sub directory
```

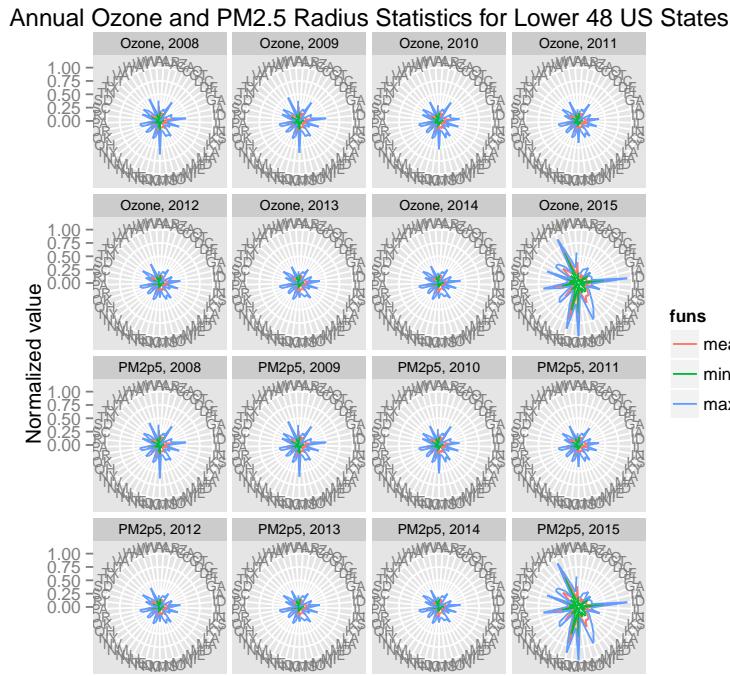


Figure 10:

```

for (j in 2008:2015) {
  i<-j-2007
  df<-subset(t,type=="Ozone" & yr==as.character(j),select=c(region,value))
  choropleths[[i]] = county_choropleth(df,
    title = paste(as.character(j),"Ozone level (ppm) Reporting Radius < 250 Miles"),
    legend = "ppm level", num_colors = 1, state_zoom = NULL, county_zoom = NULL)
  choropleths[[i]]$scales$scales[[1]]$limits<-c(0,0.07)
}
for (j in 2008:2015) {
  i<-j-1999
  df<-subset(t,type=="PM2p5" & yr==as.character(j),select=c(region,value))
  choropleths[[i]] = county_choropleth(df,
    title = paste(as.character(j),"PM2.5 level (ppm) Reporting Radius < 250 Miles"),
    legend = "ppm level", num_colors = 1, state_zoom = NULL, county_zoom = NULL)
  choropleths[[i]]$scales$scales[[1]]$limits<-c(0,21)
}
for (j in 2008:2015) {
  i<-j-1991
  df<-subset(t,type=="Ozone" & yr==as.character(j),select=c(region,radius))
  df %>% rename(value=radius) -> df
  choropleths[[i]] = county_choropleth(df,
    title = paste(as.character(j),"Pollutant Reporting Radius (Miles)"),
    legend = "Miles", num_colors = 1, state_zoom = NULL, county_zoom = NULL)
  choropleths[[i]]$scales$scales[[1]]$limits<-c(0,250)
}
choroplethr_animate(choropleths)

```

```

for (j in 1:9) {
  orig<-paste0("choropleth_",j,".png")
  dest<-paste0("choropleth_",formatC(j,width=2,flag="0"),".png")
  file.rename(from=orig,to=dest)
  file.remove(orig)
}
for(j in 1:24) {
  orig<-paste0("choropleth_",formatC(j,width=2,flag="0"),".png")
  dest<-paste0("choroplethz_",formatC(j,width=2,flag="0"),".png")
  shell(paste("convert -depth 3 -background white -quality 70",orig,dest))
}
setwd(userdir) # return to working directory
rm(t,df,orig,dest) # cleanup

```

The [choroplethr animation](#) is provided with its own player. All figures have been written to the ./figure-html sub directory and can be viewed individually as well. Alternatively, we can render as an animated gif directly provided we convert the png files into an animated gif with the [ImageMagick converter](#) and execute a shell command. We will also use the animation library to illustrate animation in a pdf document.

```

setwd(figdir)
filestocopy<-as.vector(list.files(pattern="choropleth_"))
anidir<-paste(userdir,strsplit(anidir,"/")[[1]][length(strsplit(anidir,"/")[[1]])],sep="/")
file.copy(from=filestocopy, to=anidir, copy.mode=TRUE)
setwd(anidir)
# now convert in anidir these sequentially numbered files to one gif using ImageMagick
shell("convert -delay 100 -loop 0 -depth 3 -background white -quality 70 *.png choroplethr.gif")
# for html, use animated gif via
#
# for pdf, use animate package in LaTex

```

```
# now remove all the *.png files
file.remove(list.files(pattern=".png"))
setwd(userdir)
```

Conclusions

This analysis shows definite trends and explores techniques to screen data content. ggmap and choroplethr visualization are complementing more common histograms, point charts and less frequently used, but powerful radar charts. Both external players and animated gif allow for versatile animation display in an HTML environment. The next target will be to port this type of visualization to a shiny app and extend to other pollutants as selected dynamically in the application from the US EPA records.

References

The following sources are referenced as they provided significant help and information to develop this analysis:

1. [Coursera Developing Data Product - Week 4 yhat\(Part1\) by Roger D. Peng, PhD](#)
2. [US EPA download site and data repositories](#)
3. [US Census and data repository](#)
4. [yhat](#)
5. [choroplethr Package](#)
6. [stackoverflow ggplot/mapping US counties thread](#)
7. [pbapply Package](#)
8. [ImageMagick converter](#)