

# Multilevel Urban Tree Allometric equations

erker

October 16, 2018

## Data

The urban tree database (UTD) consists of measurements on 14487 trees of 170 species in 17 cities. However, largely because of the difficulty is measuring tree age, there are only 12687 trees with complete age and diameter data (161 species, 17 cities, 309 species by city combinations 1).

Some species were measured in multiple cities, but not most. The number of trees of each city by species combination sampled ranged from 1 (both Liquidambar styraciflu and Prunus serrulata in Queens, NY) to 79 (Quercus laurifolia in Charleston, SC). The median number of trees in each species-city combination was 37.

Age is defined in this dataset as time since planting, since this is the record kept by cities. Actual age of the trees may be several years more. Diameter (cm) of the trees is measured at breast height (1.37m above ground).

In the UTD, trees are classified taxonomically down to cultivar for some individuals, but here we aggregate cultivars up to the species level. Species are then nested within Genera.

The 17 cities in the UTD cover much of the US geographically, 2, and much of the variation in climate, 3.

Rather than using the aggregated sunset zones as done in UTD, we used growing degree days (GDD) and precipitation data from climate NOAA's climate normals. Figure 3 shows



Figure 1: Number of trees sampled of each species and city combination in the urban tree database.

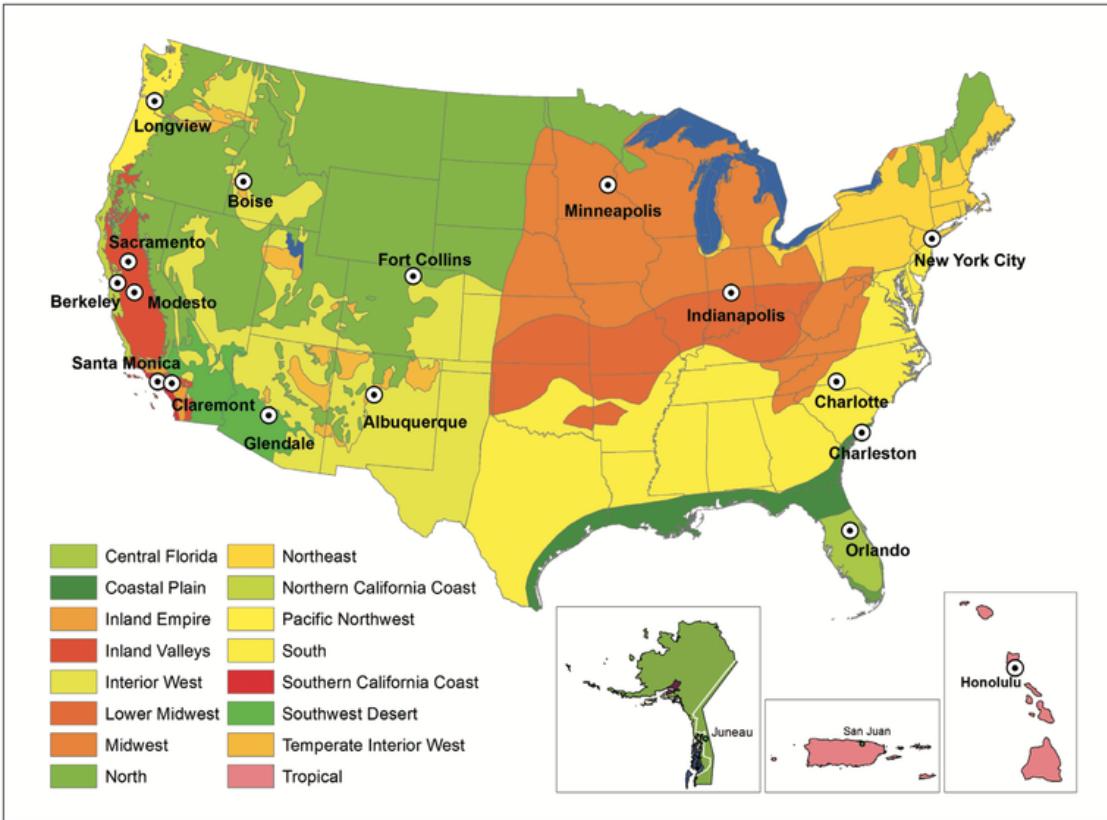


Figure 9—Climate zones were aggregated from 45 Sunset climate zones into 16 zones. Each zone has a reference city where tree growth data were collected. Sacramento, California, was added as a second reference city (with Modesto) to the Inland Valleys zone.

Figure 2: 16 climate regions and 17 representative cities in the UTD (?).

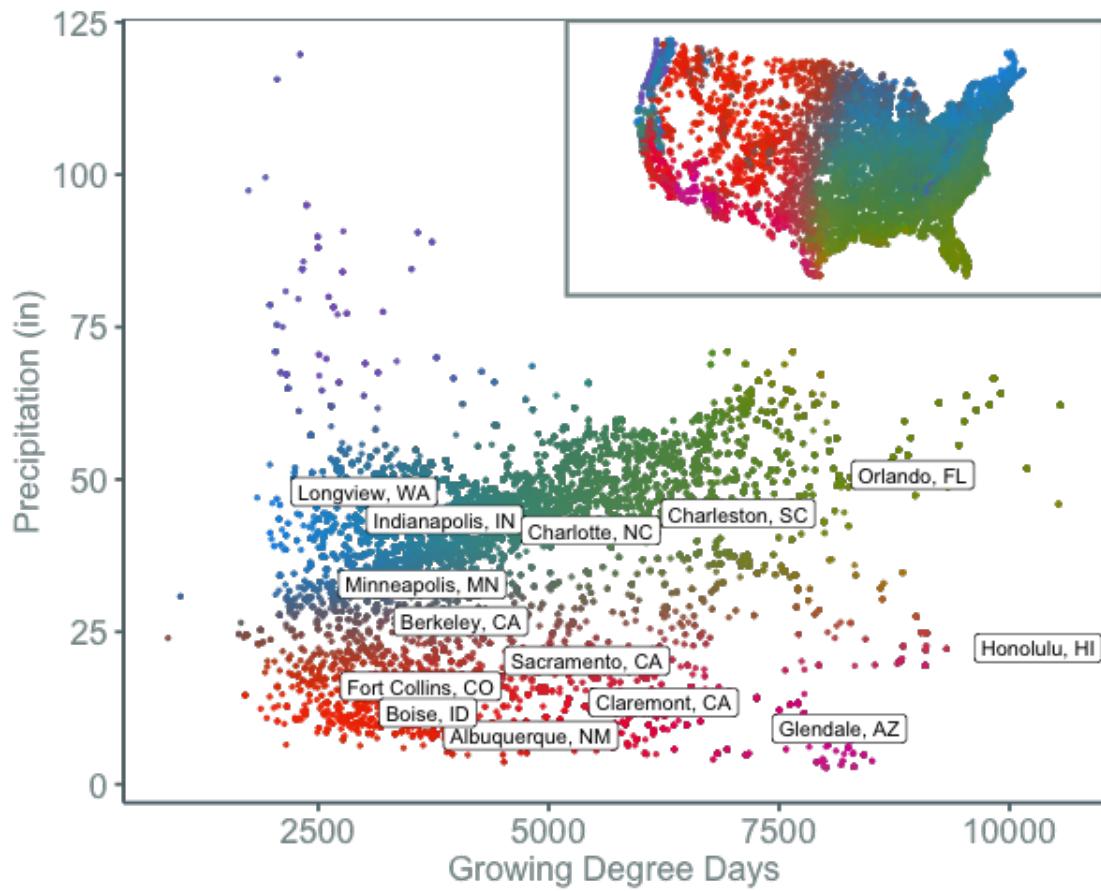


Figure 3: US census tract centroids with UTD reference cities overlaid in growing degree day (GDD) and precipitation climate space and matching color gradient in geographic space. The reference cities cover climate space well, and variation in precipitation and growing degree days is continuous.

each census tract centroid in the conterminous US plotted in GDD and precipitation space. We approximated the GDD and precipitation for each tract by assigning the values of the weather station closest to the centroid. This allows us to vary our model continuously across geographic space in a way that better captures the natural gradients of climate.

## Tidy data for this analysis

load libraries

functions

```
options(asciiType = "org")
ascii.nowarn.print <- function(x,...) {
  #op <- options(warn = -1)
  #      on.exit(options(op))

  suppressWarnings(print(ascii(x,...)))
}

}
```

read in data

```
data pdf: https://www.fs.fed.us/psw/publications/documents/psw\_gtr253/psw\_gtr\_253.pdf data webpage: https://www.fs.usda.gov/rds/archive/Product/RDS-2016-0005
d <- read_csv("../data/RDS-2016-0005/Data/TS3_Raw_tree_data.csv")
```

```
str(d)
```

```
Classes 'tbl_df', 'tbl' and 'data.frame': 14487 obs. of  41 variables:
 $ DbaseID      : int  1 2 3 4 5 6 7 8 9 10 ...
 $ Region       : chr  "InlVal" "InlVal" "InlVal" "InlVal" ...
```

```

$ City          : chr  "Modesto, CA" "Modesto, CA" "Modesto, CA" "Modesto, CA" ...
$ Source        : chr  "Motown2.xls: Completed Data" "Motown2.xls: Completed Data" "Mot...
$ TreeID        : int   1 2 3 4 5 6 7 8 9 10 ...
$ Zone          : chr  "Nursery" "Nursery" "Nursery" "Nursery" ...
$ Park/Street   : chr  "Nursery" "Nursery" "Nursery" "Nursery" ...
$ SpCode         : chr  "ACSA1" "BEPE" "CESI4" "CICA" ...
$ ScientificName: chr  "Acer saccharinum" "Betula pendula" "Celtis sinensis" "Cinnamomu...
$ CommonName    : chr  "Silver maple" "European white birch" "Chinese hackberry" "Camph...
$ TreeType       : chr  "BDL" "BDM" "BDL" "BEM" ...
$ address        : int   -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ street         : chr  "Nursery" "Nursery" "Nursery" "Nursery" ...
$ side           : int   -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ cell            : int   -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ OnStreet       : int   -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ FromStreet     : int   -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ ToStreet       : int   -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ Age            : int   0 0 0 0 0 0 0 0 0 0 ...
$ DBH (cm)       : num   2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 ...
$ TreeHt (m)     : num   2 1.5 1.8 2 2 2 2 2 2 1.6 ...
$ CrnBase        : num   -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ CrnHt (m)      : num   0.5 0.8 0.6 0.9 0.9 0.8 0.8 0.8 0.8 0.8 ...
$ CdiaPar (m)    : num   1 0.6 0.7 1 1 0.8 0.8 0.8 1 0.7 ...
$ CDiaPerp (m)   : num   1 0.6 0.7 1 1 0.8 0.8 0.8 1 0.7 ...
$ AvgCdia (m)    : num   1 0.6 0.7 1 1 0.8 0.8 0.8 1 0.7 ...
$ Leaf (m2)       : num   2.5 1.9 2.2 2 2.2 2.2 2.2 2.2 2.1 1.3 ...
$ Setback        : int   -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ TreeOr         : int   -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...

```

```

$ CarShade      : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ LandUse       : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ Shape         : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ WireConf      : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ dbh1          : num 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 ...
$ dbh2          : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ dbh3          : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ dbh4          : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ dbh5          : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ dbh6          : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ dbh7          : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
$ dbh8          : int -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 ...
- attr(*, "problems")=Classes 'tbl_df', 'tbl' and 'data.frame': 24255 obs. of 5 variables
..$ row          : int 1262 1263 1264 1265 1266 1267 1268 1269 1270 1271 ...
..$ col          : chr "side" "side" "side" "side" ...
..$ expected     : chr "an integer" "an integer" "an integer" "an integer" ...
..$ actual       : chr "C" "C" "C" "C" ...
..$ file         : chr "'../data/RDS-2016-0005/Data/TS3_Raw_tree_data.csv'" "'../data/RDS-"
- attr(*, "spec")=List of 2
..$ cols         :List of 41
... . . $ DbaseID      : list()
... . . . . - attr(*, "class")= chr "collector_integer" "collector"
... . . . $ Region      : list()
... . . . . - attr(*, "class")= chr "collector_character" "collector"
... . . . $ City        : list()
... . . . . - attr(*, "class")= chr "collector_character" "collector"
... . . . $ Source      : list()

```

```
... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ TreeID          : list()
... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ Zone            : list()
... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ Park/Street     : list()
... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ SpCode           : list()
... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ ScientificName: list()
... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ CommonName      : list()
... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ TreeType         : list()
... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ address          : list()
... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ street           : list()
... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ side             : list()
... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ cell             : list()
... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ OnStreet         : list()
... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ FromStreet       : list()
... . . . - attr(*, "class")= chr  "collector_integer" "collector"
```

```

... .$. ToStreet      : list()
... . .-. attr(*, "class")= chr  "collector_integer" "collector"
... .$. Age          : list()
... . .-. attr(*, "class")= chr  "collector_integer" "collector"
... .$. DBH (cm)     : list()
... . .-. attr(*, "class")= chr  "collector_double" "collector"
... .$. TreeHt (m)   : list()
... . .-. attr(*, "class")= chr  "collector_double" "collector"
... .$. CrnBase      : list()
... . .-. attr(*, "class")= chr  "collector_double" "collector"
... .$. CrnHt (m)    : list()
... . .-. attr(*, "class")= chr  "collector_double" "collector"
... .$. CdiaPar (m)  : list()
... . .-. attr(*, "class")= chr  "collector_double" "collector"
... .$. CDiaPerp (m) : list()
... . .-. attr(*, "class")= chr  "collector_double" "collector"
... .$. AvgCdia (m)  : list()
... . .-. attr(*, "class")= chr  "collector_double" "collector"
... .$. Leaf (m2)    : list()
... . .-. attr(*, "class")= chr  "collector_double" "collector"
... .$. Setback      : list()
... . .-. attr(*, "class")= chr  "collector_integer" "collector"
... .$. TreeOr       : list()
... . .-. attr(*, "class")= chr  "collector_integer" "collector"
... .$. CarShade     : list()
... . .-. attr(*, "class")= chr  "collector_integer" "collector"
... .$. LandUse      : list()

```

```

... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . $ Shape           : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . $ WireConf        : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . $ dbh1            : list()
... . . . .- attr(*, "class")= chr  "collector_double" "collector"
... . $ dbh2            : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . $ dbh3            : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . $ dbh4            : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . $ dbh5            : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . $ dbh6            : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . $ dbh7            : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . $ dbh8            : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
..$ default: list()
... . - attr(*, "class")= chr  "collector_guess" "collector"
... - attr(*, "class")= chr  "col_spec"

```

### explanation of variables from metadata

DbaseID = Unique id number for each tree.

Region = 16 U.S. climate regions, abbreviations are used (see 1<sub>Regionalinformation.csv</sub>).

City = City/state names where data collected.

Source = Original \*.xls filename (not available in this data publication).

TreeID = Number assigned to each tree in inventory by city.

Zone = Number/ID/name of the management area or zone that the tree is located in within a city; or nursery if young tree data collected there.

Park/Street = Data listed as Park, Street, Regional Big Tree, or Nursery (for young tree measurements).

SpCode = 4 to 6 letter code consisting of the first two letters of the genus name and the first two letters of the species name followed by two optional letters to distinguish two species with the same four-letter code (See 2<sub>Regionalspeciesandcounts.csv</sub> for a list of the SpCodes and corresponding scientific names.)

ScientificName = Botanical name of species.

CommonName = Common name of species.

Tree Type = 3 letter code where first two letters refer to life form (BD=broadleaf deciduous, BE=broadleaf evergreen, CE=coniferous evergreen, PE=palm evergreen) and the third letter is mature height (S=small which is < 8 meters, M=medium which is 8-15 meters, and L=large which is > 15 meters).

Address = From inventory, street number of building where tree is located.

Street = From inventory, the name of the street the tree is located on. (NOTE: zero values denote data were not recorded in that city. These values were left unchanged because they originated from city inventories.)

Side = From inventory, side of building or lot tree is located on (F=front, M=median, S=side, P=park). (NOTE: zero values denote data were not recorded in that city. These values were left unchanged because they originated from city inventories.)

Cell = From inventory, the cell number (i.e., 1, 2, 3, . . . ), where protocol determines the order trees at same address are numbered (e.g., driving direction or as street number

increases).

OnStreet = From inventory (omitted if not a field in city's inventory), for trees at corner addresses when tree is on cross street rather than addressed street.

FromStreet = From inventory, the name of the first cross street that forms a boundary for trees lining un-addressed boulevards. Trees are typically numbered in order (1, 2, 3 ...) on boulevards that have no development adjacent to them, no obvious parcel addresses.

ToStreet = From inventory, the name of the last cross street that forms a boundary for trees lining un-addressed boulevards.

Age = Number of years since planted. (NOTE: zero values represent newly planted trees, < 1 year old.)

DBH (cm) = Diameter at breast height (1.37 meters [m]) measured to nearest 0.1 centimeters (tape). For multi-stemmed trees forking below 1.37 m measured above the butt flare and below the point where the stem begins forking, as per protocol.

TreeHt (m) = From ground level to tree top to nearest 0.5 m (omitting erratic leader).

CrnBase (m) = Average distance between ground and lowest foliage layer to nearest 0.5 m (omitting erratic branch).

CrnHt (m) = Calculated as TreeHT minus Crnbase to nearest 0.5 m. (NOTE: zero values indicate no live crown was present, hence no other tree dimension data were available.)

CdiaPar (m) = Crown diameter measurement taken to the nearest 0.5 m parallel to the street (omitting erratic branch).

CDiaPerp (m) = Crown diameter measurement taken to the nearest 0.5 m perpendicular to the street (omitting erratic branch).

AvgCdia (m) = The average of crown diameter measured parallel and perpendicular to the street.

Leaf (m<sup>2</sup>) = Estimated using digital imaging method to nearest 0.1 squared meter (m<sup>2</sup>).

Setback = Distance from tree to nearest air-conditioned/heated space (may not be same address as tree location): 1=0-8 m, 2=8.1-12 m, 3=12.1-18 m, 4=> 18 m.

TreeOr = Taken with compass, the coordinate of tree taken from imaginary lines extending from walls of the nearest conditioned space (may not be same address as tree location).

CarShade = Number of parked automotive vehicles with some part under the tree's drip line. Car must be present (0=no autos, 1=1 auto, etc.).

LandUse = Predominant land use type where tree is growing (1=single family residential, 2=multi-family residential [duplex, apartments, condos], 3=industrial/institutional/large commercial [schools, gov't, hospitals], 4=park/vacant/other [agric., unmanaged riparian areas of greenbelts], 5=small commercial [minimart, retail boutiques, etc.], 6=transportation corridor).

Shape = Visual estimate of crown shape verified from each side with actual measured dimensions of crown height and average crown diameter (1=cylinder [maintains same crown diameter in top and bottom thirds of tree], 2=ellipsoid, the tree's center [whether vertical or horizontal is the widest, includes spherical], 3=paraboloid [widest in bottom third of crown], 4=upside down paraboloid [widest in top third of crown]).

WireConf = Utility lines that interfere with or appear above tree (0=no lines, 1=present and no potential conflict, 2=present and conflicting, 3=present and potential for conflicting).  
(NOTE: -1 denotes data were not collected.)

dbh1 = Dbh (centimeters [cm]) for multi-stemmed trees; for non-multi-stemmed trees, dbh1 is same as Dbh (cm).

dbh2 = Dbh (cm) for second stem of multi-stemmed trees.

dbh3 = Dbh (cm) for third stem of multi-stemmed trees.

dbh4 = Dbh (cm) for fourth stem of multi-stemmed trees.

dbh5 = Dbh (cm) for fifth stem of multi-stemmed trees.

dbh6 = Dbh (cm) for sixth stem of multi-stemmed trees.

dbh7 = Dbh (cm) for seventh stem of multi-stemmed trees.

dbh8 = Dbh (cm) for eighth stem of multi-stemmed trees.

## fix some species things

- change lower case species codes

```
d$SpCode <- toupper(d$SpCode)
```

- change QUAG1 to be QUAG

```
d$SpCode[d$SpCode == "QUAG1"] <- "QUAG"
```

- fix common names

There may be other common names I need to fix.

```
d$CommonName[d$CommonName == "Kurrajong"] <- "Kurrajong/Bottle tree"
```

```
d$CommonName[d$CommonName == "Bottle tree"] <- "Kurrajong/Bottle tree"
```

```
d$CommonName[d$CommonName == "Apple"] <- "Apple/Crabapple"
```

```
d$CommonName[d$CommonName == "Crabapple"] <- "Apple/Crabapple"
```

```
d$CommonName[d$CommonName == "silver maple"] <- "Silver maple"
```

```
d$CommonName[d$CommonName == "camphor tree"] <- "Camphor tree"
```

```
d$CommonName[d$CommonName == "ginkgo"] <- "Ginkgo"
```

```
d$CommonName[d$CommonName == "honeylocust"] <- "Honeylocust"
```

```
d$CommonName[d$CommonName == "ginkgo"] <- "Ginkgo"
```

```
d$CommonName[d$CommonName == "common crapemyrtle"] <- "Common crapemyrtle"
```

```
d$CommonName[d$CommonName == "sweetgum"] <- "Sweetgum"
```

```
d$CommonName[d$CommonName == "southern magnolia"] <- "Southern magnolia"
```

- change scientific names (remove cultivated variety)

```
d$ScientificName[d$ScientificName == "Prunus cerasifera cvs."] <- "Prunus cerasifera"
d$ScientificName[d$ScientificName == "Pyrus calleryana cvs."] <- "Pyrus calleryana"
```

**tidy a few names and select variables of interest here**

```
d <- d %>%
  rename(DBH = 'DBH (cm)', Leaf = 'Leaf (m2)', Species = SpCode) %>% select(Region, Ci
```

**Remove missing data (either DBH or Age)**

```
d <- filter(d, DBH != -1, Age != -1) %>%
  rename(AGE = Age)
```

**save data**

```
saveRDS(d, "../data/tidy_age_dbh.rds")
```

**str of data now**

```
d <- readRDS("../data/tidy_age_dbh.rds")
```

```
str(d)
```

```
Classes 'tbl_df', 'tbl' and 'data.frame': 12687 obs. of 8 variables:
```

```
$ Region      : chr  "InlVal" "InlVal" "InlVal" "InlVal" ...
$ City        : chr  "Modesto, CA" "Modesto, CA" "Modesto, CA" "Modesto, CA" ...
$ TreeID      : int  1 2 3 4 5 6 7 8 9 10 ...
$ Species     : chr  "ACSA1" "BEPE" "CESI4" "CICA" ...
$ DBH         : num  2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 2.5 ...
$ Leaf         : num  2.5 1.9 2.2 2 2.2 2.2 2.2 2.2 2.1 1.3 ...
```

```

$ AGE : int 0 0 0 0 0 0 0 0 0 0 ...
$ ScientificName: chr "Acer saccharinum" "Betula pendula" "Celtis sinensis" "Cinnamomum ...
- attr(*, "problems")=Classes 'tbl_df', 'tbl' and 'data.frame': 24255 obs. of 5 variables ...
..$ row : int 1262 1263 1264 1265 1266 1267 1268 1269 1270 1271 ...
..$ col : chr "side" "side" "side" "side" ...
..$ expected: chr "an integer" "an integer" "an integer" "an integer" ...
..$ actual : chr "C" "C" "C" "C" ...
..$ file : chr "'../data/RDS-2016-0005/Data/TS3_Raw_tree_data.csv'" "'../data/RDS-...
- attr(*, "spec")=List of 2
..$ cols :List of 41
... . . $ DbaseID : list()
... . . . - attr(*, "class")= chr "collector_integer" "collector"
... . . $ Region : list()
... . . . - attr(*, "class")= chr "collector_character" "collector"
... . . $ City : list()
... . . . - attr(*, "class")= chr "collector_character" "collector"
... . . $ Source : list()
... . . . - attr(*, "class")= chr "collector_character" "collector"
... . . $ TreeID : list()
... . . . - attr(*, "class")= chr "collector_integer" "collector"
... . . $ Zone : list()
... . . . - attr(*, "class")= chr "collector_character" "collector"
... . . $ Park/Street : list()
... . . . - attr(*, "class")= chr "collector_character" "collector"
... . . $ SpCode : list()
... . . . - attr(*, "class")= chr "collector_character" "collector"
... . . $ ScientificName: list()

```

```

... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ CommonName      : list()

... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ TreeType       : list()

... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ address        : list()

... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ street         : list()

... . . . - attr(*, "class")= chr  "collector_character" "collector"
... . $ side           : list()

... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ cell           : list()

... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ OnStreet        : list()

... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ FromStreet      : list()

... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ ToStreet        : list()

... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ Age            : list()

... . . . - attr(*, "class")= chr  "collector_integer" "collector"
... . $ DBH (cm)       : list()

... . . . - attr(*, "class")= chr  "collector_double" "collector"
... . $ TreeHt (m)     : list()

... . . . - attr(*, "class")= chr  "collector_double" "collector"
... . $ CrnBase        : list()

... . . . - attr(*, "class")= chr  "collector_double" "collector"

```

```

... .$. CrnHt (m)      : list()
... .$. - attr(*, "class")= chr  "collector_double" "collector"
... .$. CdiaPar (m)     : list()
... .$. - attr(*, "class")= chr  "collector_double" "collector"
... .$. CDiaPerp (m)   : list()
... .$. - attr(*, "class")= chr  "collector_double" "collector"
... .$. AvgCdia (m)    : list()
... .$. - attr(*, "class")= chr  "collector_double" "collector"
... .$. Leaf (m2)       : list()
... .$. - attr(*, "class")= chr  "collector_double" "collector"
... .$. Setback        : list()
... .$. - attr(*, "class")= chr  "collector_integer" "collector"
... .$. TreeOr         : list()
... .$. - attr(*, "class")= chr  "collector_integer" "collector"
... .$. CarShade       : list()
... .$. - attr(*, "class")= chr  "collector_integer" "collector"
... .$. LandUse        : list()
... .$. - attr(*, "class")= chr  "collector_integer" "collector"
... .$. Shape          : list()
... .$. - attr(*, "class")= chr  "collector_integer" "collector"
... .$. WireConf       : list()
... .$. - attr(*, "class")= chr  "collector_integer" "collector"
... .$. dbh1           : list()
... .$. - attr(*, "class")= chr  "collector_double" "collector"
... .$. dbh2           : list()
... .$. - attr(*, "class")= chr  "collector_integer" "collector"
... .$. dbh3           : list()

```

```

... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . . $ dbh4           : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . . $ dbh5           : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . . $ dbh6           : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . . $ dbh7           : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
... . . $ dbh8           : list()
... . . . .- attr(*, "class")= chr  "collector_integer" "collector"
..$ default: list()
... . .- attr(*, "class")= chr  "collector_guess" "collector"
...- attr(*, "class")= chr  "col_spec"

```

### save subset of data for testing

```

d <- readRDS("../data/tidy_age_dbh.rds")
clim <- read.csv("../data/cities_gdd.csv", stringsAsFactors = F) %>%
  select(-X)

species.to.filter <- c("LIST", "MAGR", "PYCA", "CICA", "GLTR", "PICH", "PLAC", "ACPL",

d2 <- d %>%
  mutate(Genus = stringr::str_extract(ScientificName, '\w*)) %>%
  select(-Leaf,-TreeID) %>%
  left_join(.,clim) %>%
  mutate(Precip = round((Precip - mean(Precip))/ 1000, 4),

```

```

GDD = round((GDD - mean(GDD))/ 1000, 4))

saveRDS(d2, "../data/age_dbh_full.rds")

d3 <- d2 %>%
  filter(Species %in% species.to.filter)

saveRDS(d3, "../data/age_dbh_testing.rds")

Joining, by = c("Region", "City", "Species", "DBH", "AGE", "ScientificName")
Error in mutate_impl(.data, dots) :
  Evaluation error: object 'Precip' not found.

Error in saveRDS(d2, "../data/age_dbh_full.rds") : object 'd2' not found
Error in eval(lhs, parent, parent) : object 'd2' not found
Error in saveRDS(d3, "../data/age_dbh_testing.rds") :
  object 'd3' not found

```

**send to krusty**

```

rsync -avz ../data/age_dbh_full.rds erker@krusty:~/allo/data/
rsync -avz ../data/age_dbh_testing.rds erker@krusty:~/allo/data/

```

**The Species for which we have age and dbh:**

```

sampled_species <- readRDS("../data/tidy_age_dbh.rds") %>%
  pull(ScientificName) %>%
  unique %>%
  as.character() %>%
  sort %>%

```

```
data.frame()  
nrow(sampled_species)  
sampled_species %>% ascii.nowarn.print
```

[1] 161

	.	
-----+-----+-----		
1   Acacia farnesiana		
2   Acacia melanoxylon		
3   Acacia salicina		
4   Acer macrophyllum		
5   Acer negundo		
6   Acer palmatum		
7   Acer platanoides		
8   Acer rubrum		
9   Acer saccharinum		
10   Acer saccharum		
11   Bauhinia x blakeana		
12   Betula nigra		
13   Betula pendula		
14   Brachychiton populneum		
15   Butia capitata		
16   Callistemon citrinus		
17   Calocedrus decurrens		
18   Calophyllum inophyllum		
19   Carpinus betulus 'Fastigiata'		
20   Carya illinoiensis		
21   Cassia x nealiae		

22	Casuarina equisetifolia	
23	Catalpa speciosa	
24	Cedrus deodara	
25	Celtis laevigata	
26	Celtis occidentalis	
27	Celtis sinensis	
28	Ceratonia siliqua	
29	Chilopsis linearis	
30	Cinnamomum camphora	
31	Citharexylum spinosum	
32	Cocos nucifera	
33	Conocarpus erectus var. argenteus	
34	Cordia subcordata	
35	Cornus florida	
36	Crataegus sp.	
37	Crataegus x lavallei	
38	Cupaniopsis anacardioides	
39	Delonix regia	
40	Elaeagnus angustifolia	
41	Elaeodendron orientale	
42	Eriobotrya japonica	
43	Eucalyptus ficifolia	
44	Eucalyptus globulus	
45	Eucalyptus microtheca	
46	Eucalyptus sideroxylon	
47	Fagus sylvatica	
48	Ficus benjamina	

49	<i>Ficus thonningii</i>	
50	<i>Filicium decipiens</i>	
51	<i>Fraxinus americana</i>	
52	<i>Fraxinus angustifolia</i>	
53	<i>Fraxinus angustifolia</i> 'Raywood'	
54	<i>Fraxinus excelsior</i> 'Hessei'	
55	<i>Fraxinus holotricha</i>	
56	<i>Fraxinus latifolia</i>	
57	<i>Fraxinus pennsylvanica</i>	
58	<i>Fraxinus pennsylvanica</i> 'Marshall'	
59	<i>Fraxinus uhdei</i>	
60	<i>Fraxinus velutina</i>	
61	<i>Fraxinus velutina</i> 'Modesto'	
62	<i>Ginkgo biloba</i>	
63	<i>Gleditsia triacanthos</i>	
64	<i>Gymnocladus dioicus</i>	
65	<i>Ilex opaca</i>	
66	<i>Ilex paraguariensis</i>	
67	<i>Jacaranda mimosifolia</i>	
68	<i>Juglans nigra</i>	
69	<i>Juniperus virginiana</i>	
70	<i>Juniperus virginiana</i> var. <i>silicicola</i>	
71	<i>Koelreuteria elegans</i>	
72	<i>Koelreuteria paniculata</i>	
73	<i>Lagerstroemia indica</i>	
74	<i>Lagerstroemia</i> sp.	
75	<i>Lagerstroemia speciosa</i>	

76	Liquidambar styraciflua	
77	Liriodendron tulipifera	
78	Magnolia grandiflora	
79	Malus angustifolia	
80	Malus sp.	
81	Melaleuca quinquenervia	
82	Metrosideros excelsa	
83	Morus alba	
84	Olea europaea	
85	Parkinsonia aculeata	
86	Parkinsonia florida	
87	Phoenix canariensis	
88	Phoenix dactylifera	
89	Picea pungens	
90	Pinus brutia	
91	Pinus canariensis	
92	Pinus contorta	
93	Pinus echinata	
94	Pinus edulis	
95	Pinus eldarica	
96	Pinus elliottii	
97	Pinus halepensis	
98	Pinus nigra	
99	Pinus ponderosa	
100	Pinus radiata	
101	Pinus sylvestris	
102	Pinus taeda	

103	Pinus thunbergiana	
104	Pistacia chinensis	
105	Pittosporum undulatum	
106	Platanus occidentalis	
107	Platanus racemosa	
108	Platanus x acerifolia	
109	Platycladus orientalis	
110	Podocarpus macrophyllus	
111	Populus angustifolia	
112	Populus balsamifera subsp. trichocarpa	
113	Populus fremontii	
114	Populus sargentii	
115	Prosopis chilensis	
116	Prunus caroliniana	
117	Prunus cerasifera	
118	Prunus serrulata	
119	Prunus sp.	
120	Prunus yedoensis	
121	Pseudotsuga menziesii	
122	Pyrus calleryana	
123	Pyrus calleryana 'Bradford'	
124	Pyrus kawakamii	
125	Pyrus sp.	
126	Quercus agrifolia	
127	Quercus alba	
128	Quercus ilex	
129	Quercus laurifolia	

130   <i>Quercus lobata</i>	
131   <i>Quercus macrocarpa</i>	
132   <i>Quercus nigra</i>	
133   <i>Quercus palustris</i>	
134   <i>Quercus phellos</i>	
135   <i>Quercus rubra</i>	
136   <i>Quercus shumardii</i>	
137   <i>Quercus virginiana</i>	
138   <i>Rhus lancea</i>	
139   <i>Robinia pseudoacacia</i>	
140   <i>Sabal palmetto</i>	
141   <i>Samanea saman</i>	
142   <i>Schinus molle</i>	
143   <i>Schinus terebinthifolius</i>	
144   <i>Sequoia sempervirens</i>	
145   <i>Swietenia mahagoni</i>	
146   <i>Syagrus romanzoffiana</i>	
147   <i>Tabebuia aurea</i>	
148   <i>Tabebuia heterophylla</i>	
149   <i>Tabebuia ochracea</i> subsp. <i>neochrysantha</i>	
150   <i>Tilia americana</i>	
151   <i>Tilia cordata</i>	
152   <i>Triadica sebifera</i>	
153   <i>Tristaniopsis conferta</i>	
154   <i>Ulmus alata</i>	
155   <i>Ulmus americana</i>	
156   <i>Ulmus parvifolia</i>	

157	<i>Ulmus pumila</i>	
158	<i>Veitchia merrillii</i>	
159	<i>Washingtonia filifera</i>	
160	<i>Washingtonia robusta</i>	
161	<i>Zelkova serrata</i>	

161 Species

## Cities and Climate

Region	City	CDD	HDD	Precip	Longitude	Latitude
CenFla	Orlando, FL	1806	289	1367	-81.37924	28.53834
GulfCo	Charleston, SC	1124	1221	1555	-79.9311	32.7765
InlEmp	Claremont, CA	134	872	523	-117.7198	34.0967
InlVal	Modesto, CA	1052	1439	315	-120.99688	37.63910
SacVal	Sacramento, CA	773	1718	470	-121.49440	38.58157
InterW	Albuquerque, NM	677	2416	250	-106.60555	35.08533
LoMidW	Indianapolis, IN	510	3153	392	-86.15807	39.76840
MidWst	Minneapolis, MN	355	4436	622	-93.26501	44.97775
NMtnPr	Fort Collins, CO	349	3332	452	-105.08442	40.58526
NoCalC	Berkeley, CA	39	1786	564	-122.27275	37.87159
NoEast	Queens, NY	560	2819	1041	-73.7949	40.7282
PacfNW	Longview, WA	157	2468	1059	-122.9382	46.1382
Piedmt	Charlotte, NC	847	1891	1426	-80.84313	35.22709
SoCalC	Santa Monica, CA	266	710	570	-118.49119	34.01945
SWDsrt	Glendale, AZ	2128	637	174	-112.1860	33.5387
TpIntW	Boise, ID	387	3325	417	-116.2023	43.6150
Tropic	Honolulu, HI	2416	0	2206	-157.85833	21.30694

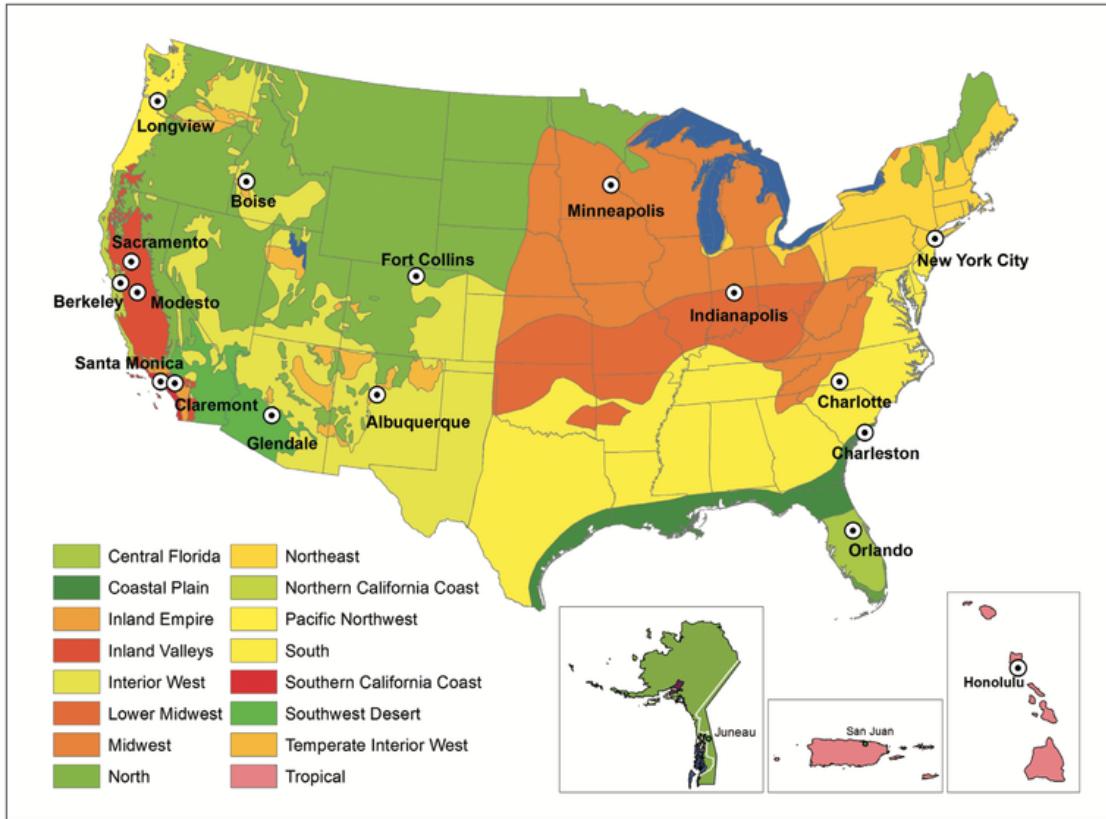


Figure 9—Climate zones were aggregated from 45 Sunset climate zones into 16 zones. Each zone has a reference city where tree growth data were collected. Sacramento, California, was added as a second reference city (with Modesto) to the Inland Valleys zone.

The ironic thing about this figure is that Fort Collins is the "North". This includes a great variety of areas including Cheyenne, WY, which according to figure 5 (McPherson and Peper 2012) in the same document have green ash trees that have 55% of the leaf area of Fort Collins green ash at age 60. This incredible variability within regions, hence the need for more continuous approach. Fort Collins equations are meant to apply to the northern parts of maine... definitely space for improvement here (though very few live there so maybe doesn't matter so much). Notice how often the reference city is on the border of the climate zone.

Get a figure showing the climate of census tracts. Basically remake the above figure to be more continuous

Make a figure showing the reference cities in GDD and Precip space to reveal where there are significant holes that could be filled. What future cities to sample.

When I make the marginal effects plot of GDD versus Precip, I should make the plot

cover the values seen in the US.

We also have unequal observations across cities. NY has very few.

## Get new climate data. Growing degree days and Precip. Make plots

Plot, census tracts in GDD and Precip Space. An inset of the US continental with the color scheme.

overlay the reference cities on this plot

units of precip are 100ths of inches

```
wget -O ../data/gdd.txt https://www1.ncdc.noaa.gov/pub/data/normals/1981-2010/supplemental/gdd.txt
```

```
wget -O ../data/precip.txt https://www1.ncdc.noaa.gov/pub/data/normals/1981-2010/product/precip.txt
```

```
wget -O ../data/temp-station-info.txt https://www1.ncdc.noaa.gov/pub/data/normals/1981-2010/temperature-station-info.txt
```

```
library(ggplot2)
library(plyr)
library(dplyr)
library(tidyr)
library(stringr)

d <- read.table("../data/gdd.txt", stringsAsFactors = F)

colnames(d) <- c("station", "grdd")

d <- d %>%
  mutate(grdd = as.numeric(str_match(grdd, "-*[0-9]+") [,1]),
        qual = str_match(grdd, "[A-Z]") [,1])
head(d)
dim(d)
```

```

d <- d %>%
  filter(qual %in% c("C","S","R"),
         gdd >= 0)
dim(d)

ll <- read.table("../data/temp-station-info.txt", fill = T, stringsAsFactors = F)
ll <- ll[,1:3] # get station, lat, and long
colnames(ll) <- c("station","lat","long")

ll <- ll %>%
  mutate(station = as.character(station),
         lat = as.numeric(lat)) %>%
  filter(complete.cases(.))

dl <- left_join(d, ll)

write.csv(dl, "../data/gdd_qt_ll.csv")

p <- read.table("../data/precip.txt", stringsAsFactors = F)
colnames(p) <- c("station", "precip_qual")

p <- p %>%
  mutate(precip = as.numeric(str_match(precip_qual, "[0-9]+") [,1]),
         qual = str_match(precip_qual, "[A-Z]") [,1])
head(p)

```

```

dim(p)

p <- p %>%
  filter(qual %in% c("C", "S", "R"),
         precip >= 0)

dim(p)

pl <- left_join(p, ll) %>%
  filter(complete.cases(.))

write.csv(pl, "../data/precip_qt_ll.csv")

```

	station	grdd	gdd	qual
1	AQW00061705	12073C	12073	C
2	CAW00064757	2636Q	2636	Q
3	CQC00914080	11168P	11168	P
4	CQC00914801	11656R	11656	R
5	FMC00914395	11423P	11423	P
6	FMC00914419	11860P	11860	P

[1] 7501 4

[1] 6340 4

Warning message:

In evalq(as.numeric(lat), <environment>) : NAs introduced by coercion  
 Joining, by = "station"

	station	precip_qual	precip	qual
1	AQC00914000	21392R	21392	R
2	AQW00061705	12263C	12263	C

```

3 CAW00064757      3172Q   3172    Q
4 CQC00914080      8339P   8339    P
5 CQC00914801      9124R   9124    R
6 CQC00914855      6976P   6976    P

[1] 9307    4
[1] 7440    4

Joining, by = "station"

:var cityclimate=cityclimate

library(sp)
library(jsonlite)
library(dplyr)

city_climate <- read.csv("../data/city_climate.csv")

cities <- city_climate %>%
  dplyr::select(City, Latitude, Longitude)

coordinates(cities) <- ~ Longitude + Latitude
proj4string(cities) <- CRS("+init=epsg:4326")

gdd <- read.csv("../data/gdd_qt_ll.csv", stringsAsFactors =F)
coordinates(gdd) <- ~long + lat
proj4string(gdd) <- CRS("+init=epsg:4326")

gdd.dists <- spDists(cities, gdd, longlat = T)
gdd.dists.min <- apply(gdd.dists, 1, function(x) which(x == min(x))[1])

```

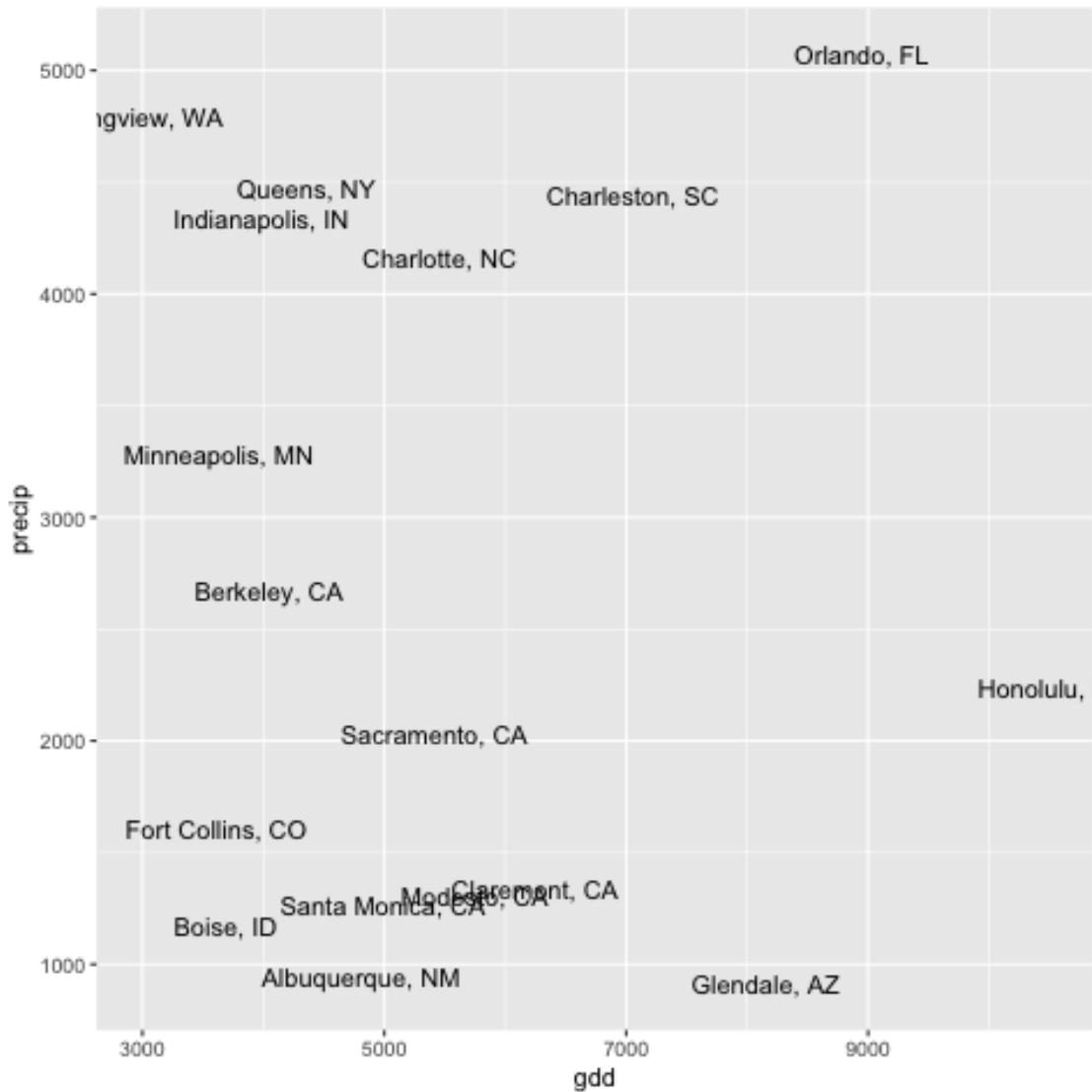
```
gdd <- gdd[gdd.dists.min,]

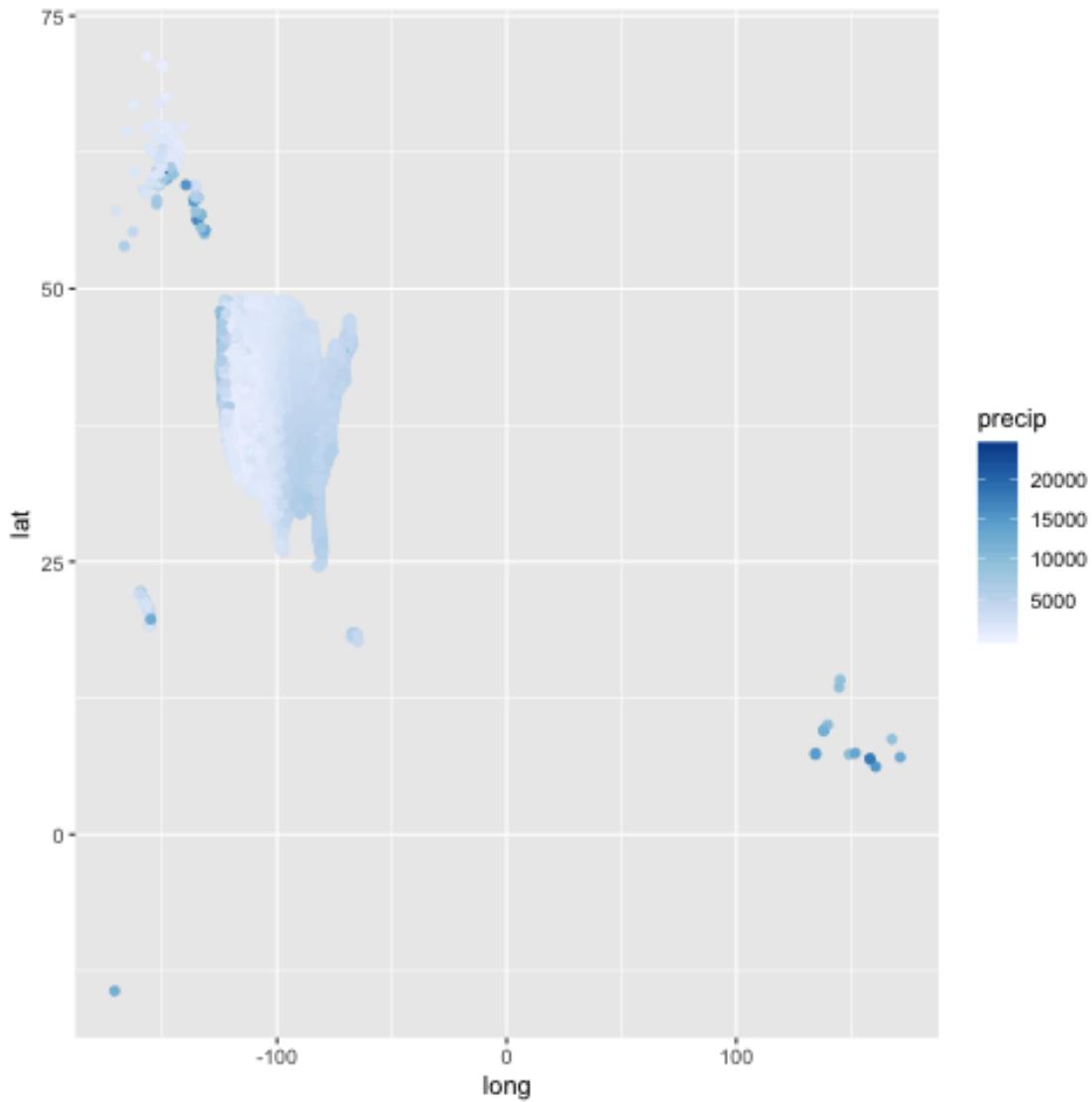
precip <- read.csv("../data/precip_qt_ll.csv", stringsAsFactors =F)
coordinates(precip) <- ~long + lat
proj4string(precip) <- CRS("+init=epsg:4326")

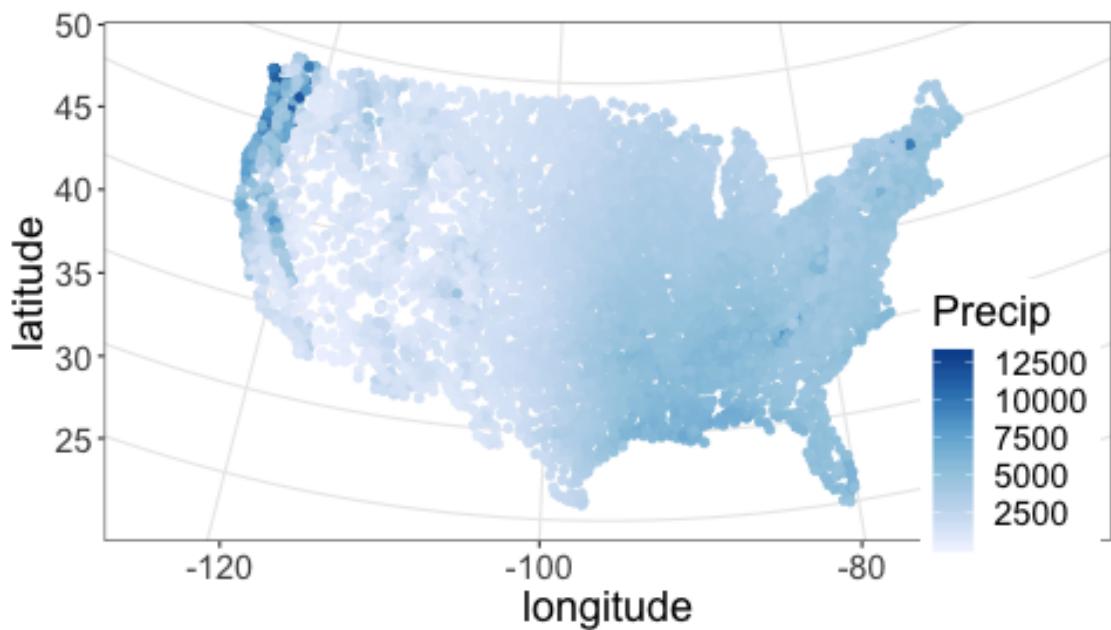
precip.dists <- spDists(cities, precip, longlat = T)
precip.dists.min <- apply(precip.dists, 1, function(x) which(x == min(x))[1])
precip <- precip[precip.dists.min,]

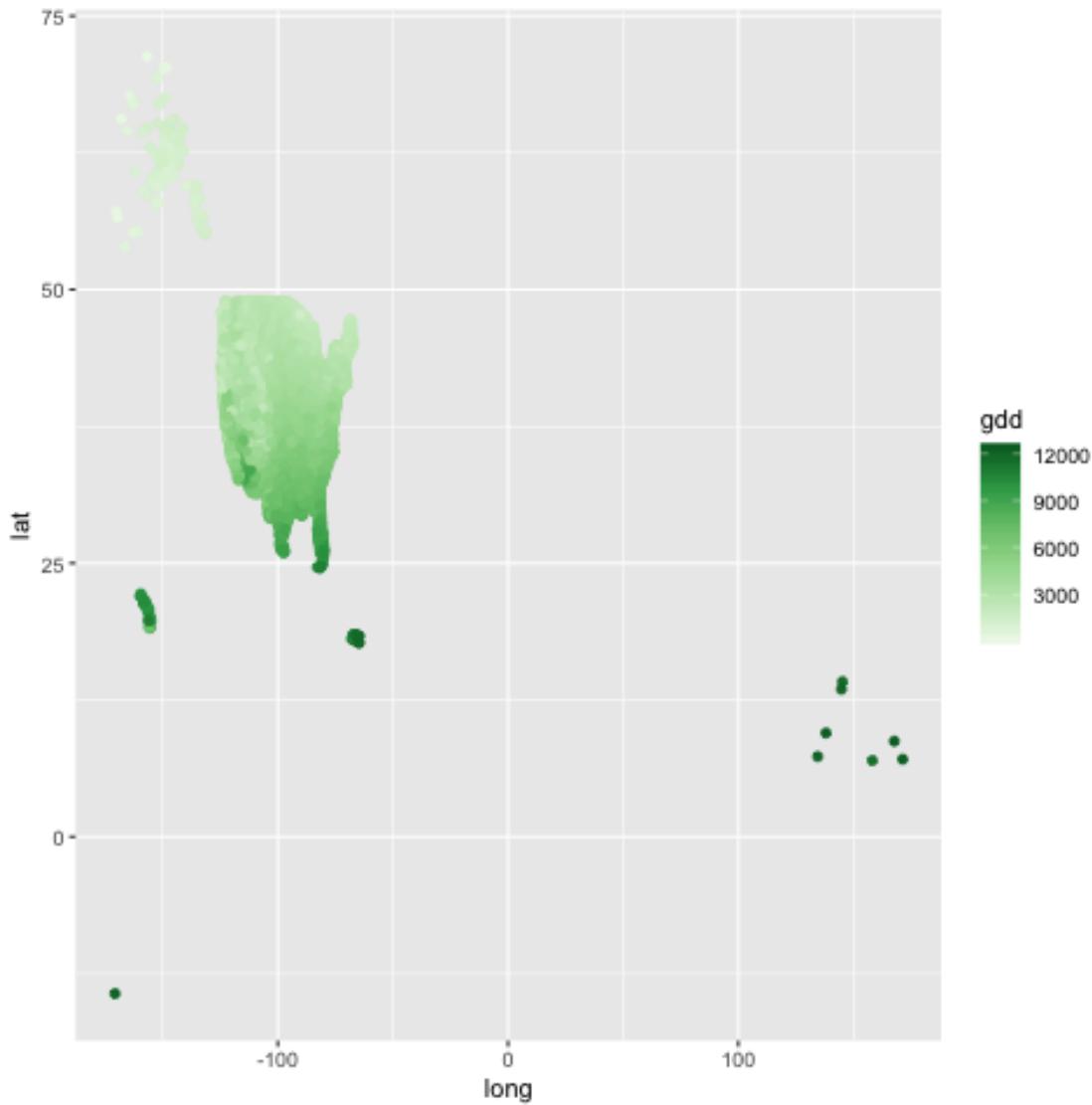
d <- bind_cols(precip@data, gdd@data,cities@data, data.frame(coordinates(cities))) %
  dplyr::select(gdd, precip, City, Longitude, Latitude)

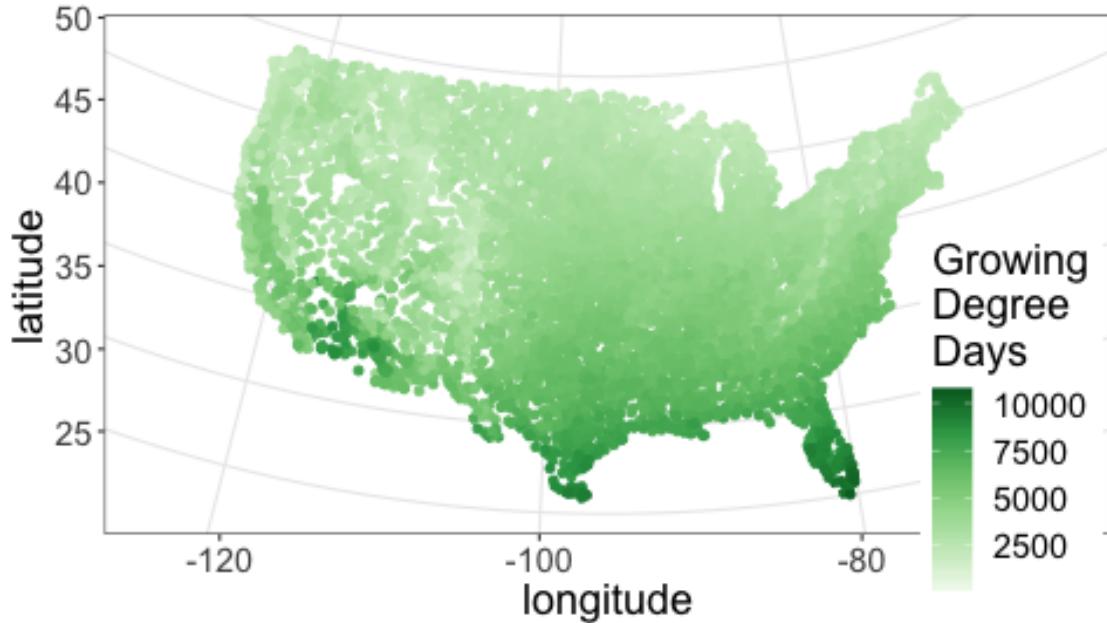
write.csv(d, "../data/cities_gdd_precip.csv")
```











Get census tract centroids and join

```
mkdir ../data/census_centroid_pop
```

```
wget -O census_centroid_pop.zip http://faculty.baruch.cuny.edu/geoportal/data/us_popctr/
```

```
unzip census_centroid_pop.zip -d ../data/census_centroid_pop/
```

```
wget -O ../data/census_centroid_pop/metadata.xml http://faculty.baruch.cuny.edu/geoporta
```

```
rm census_centroid_pop.zip
```

```
library(sp)
```

```
library(raster)
```

```

library(dplyr)
library(tidyr)
library(ggplot2)
library(reshape2)

trks <- shapefile("../data/census_centroid_pop/popctr_tracts2010.shp")

trks <- trks[trks@data$POPULATION != 0,]

trks <- spTransform(trks, CRS("+init=epsg:4326"))

d <- left_join(dl, pl) %>%
  dplyr::select(station, gdd, lat, long, precip)

dsp <- d
coordinates(dsp) <- ~long + lat
proj4string(dsp) <- CRS("+init=epsg:4326")

# find closest gdd and precip

out <- lapply(1:length(trks), function(i) {
  dists <- spDists(trks[i,], dsp, longlat = T)
  dists.min <- apply(dists, 1, function(x) which(x == min(x))[1])
  out <- dsp[dists.min,]
})


```

```

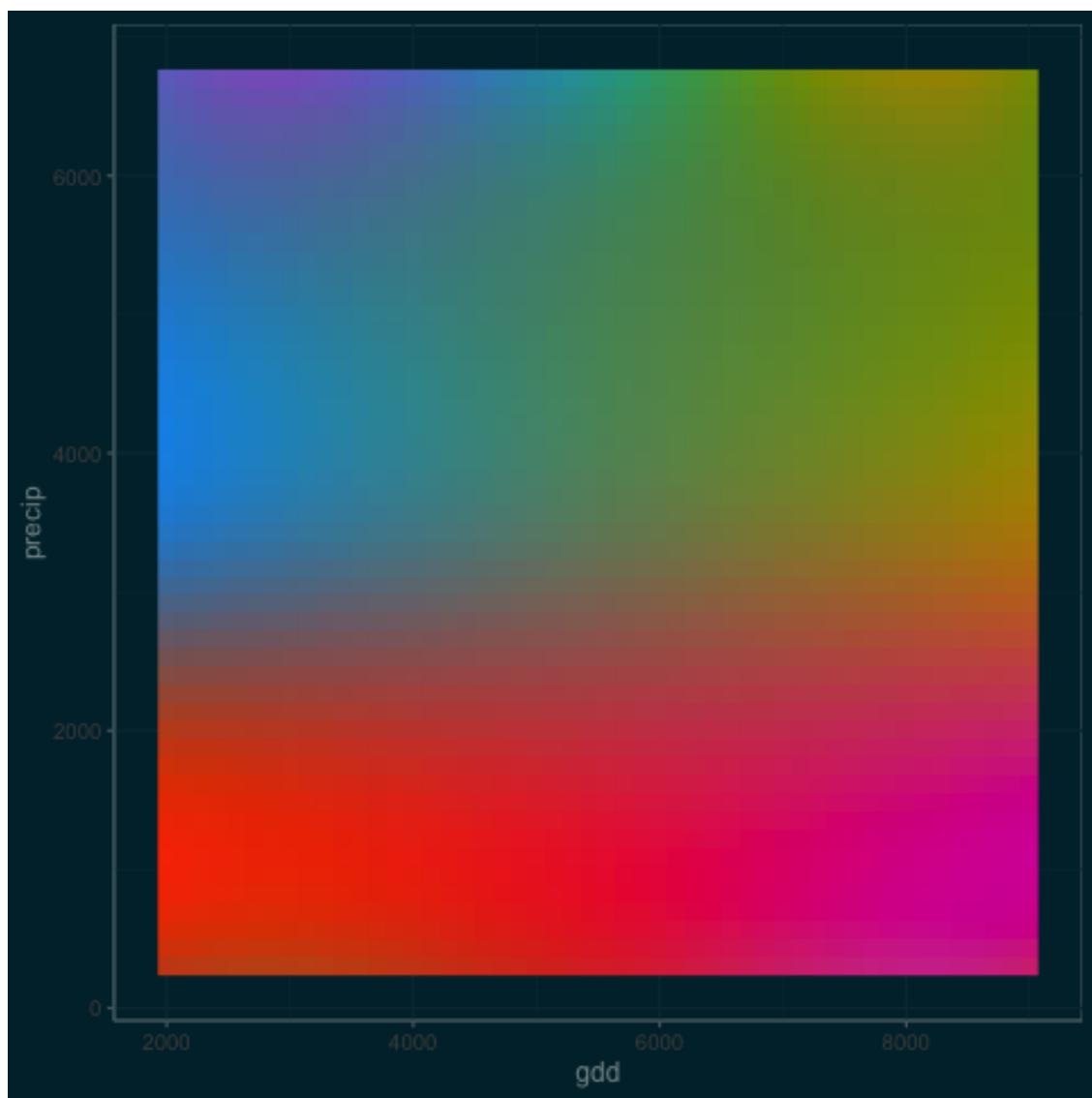
dsp.trks <- do.call("rbind", out)

Joining, by = c("station", "qual", "lat", "long")

d <- bind_cols(dsp.trks@data, trks@data) %>%
  dplyr::select(LATITUDE, LONGITUDE, POPULATION, gdd, precip, TRACT)

write.csv(d, "../data/censustractcentroids_gdd_precip_lat_long.csv")

```



```
library(sp)
```

```

library(reshape2)
library(dplyr)
library(tidyr)
library(ggplot2)

d <- read.csv("../data/censustractcentroids_gdd_precip_lat_long.csv")
dn <- d %>%
  rename(lat = LATITUDE, long = LONGITUDE, pop = POPULATION) %>%
  filter(complete.cases(.)) %>%
  filter( lat < 50, lat > 25, long < 0)

m <- as.matrix(dplyr::select(dn, gdd, precip))
cm <- as.matrix(dplyr::select(cols, gdd_col, precip_col))

whichmin <- apply(m, 1, function(mm) {
  cm[which.min(colSums((t(cm) - mm)^2)),]
})

precip_gdd_closest <- t(whichmin) %>%
  data.frame()

precip_gdd_closest_value <- left_join(precip_gdd_closest, cols) %>%
  rename(gdd = gdd_col, precip = precip_col) %>%
  dplyr::select(value)

dim(dn)

```

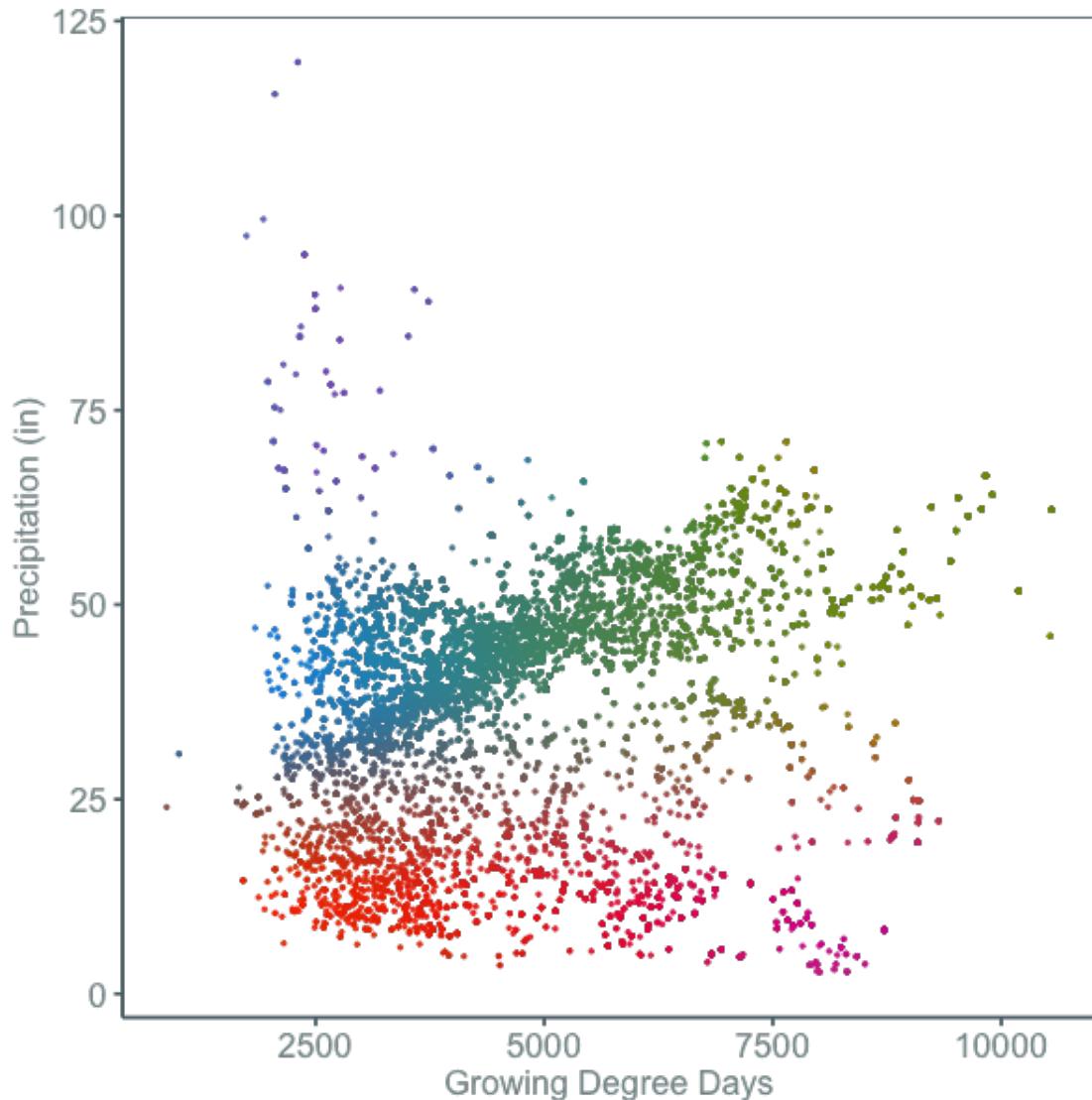
```
dim(precip_gdd_closest)
```

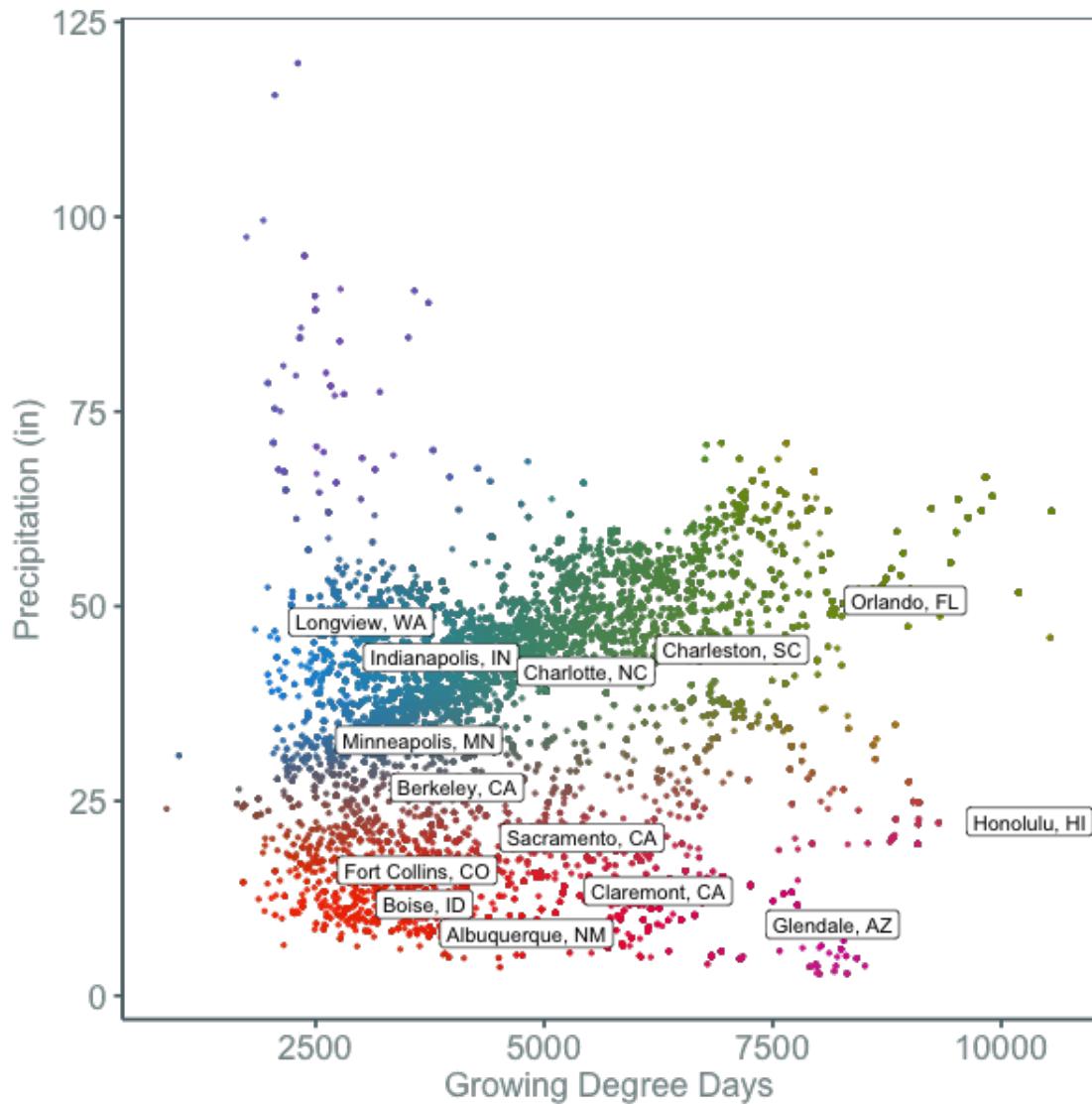
```
ddn <- cbind(dn, precip_gdd_closest_value)
```

```
Joining, by = c("gdd_col", "precip_col")
```

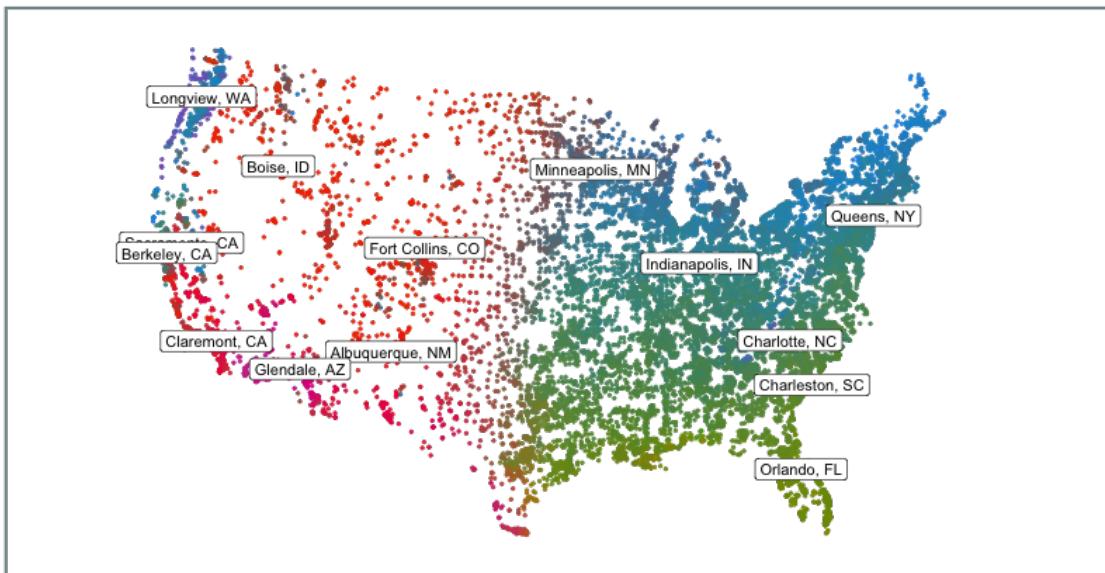
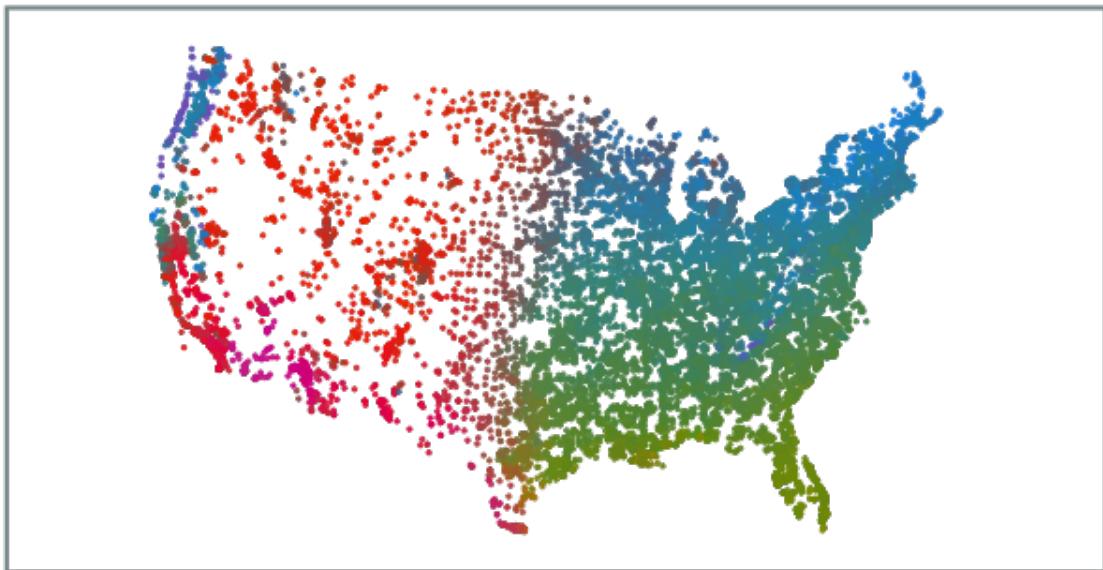
```
[1] 38487    7
```

```
[1] 38487    2
```





```
## ddn <- ddn %>%
##   mutate(value = ifelse(gdd > 9000, "gray", value),
##         value = ifelse(gdd < 2000, "gray", value),
##         value = ifelse(precip > 6700, "gray", value),
##         value = ifelse(precip < 300, "gray", value))
```



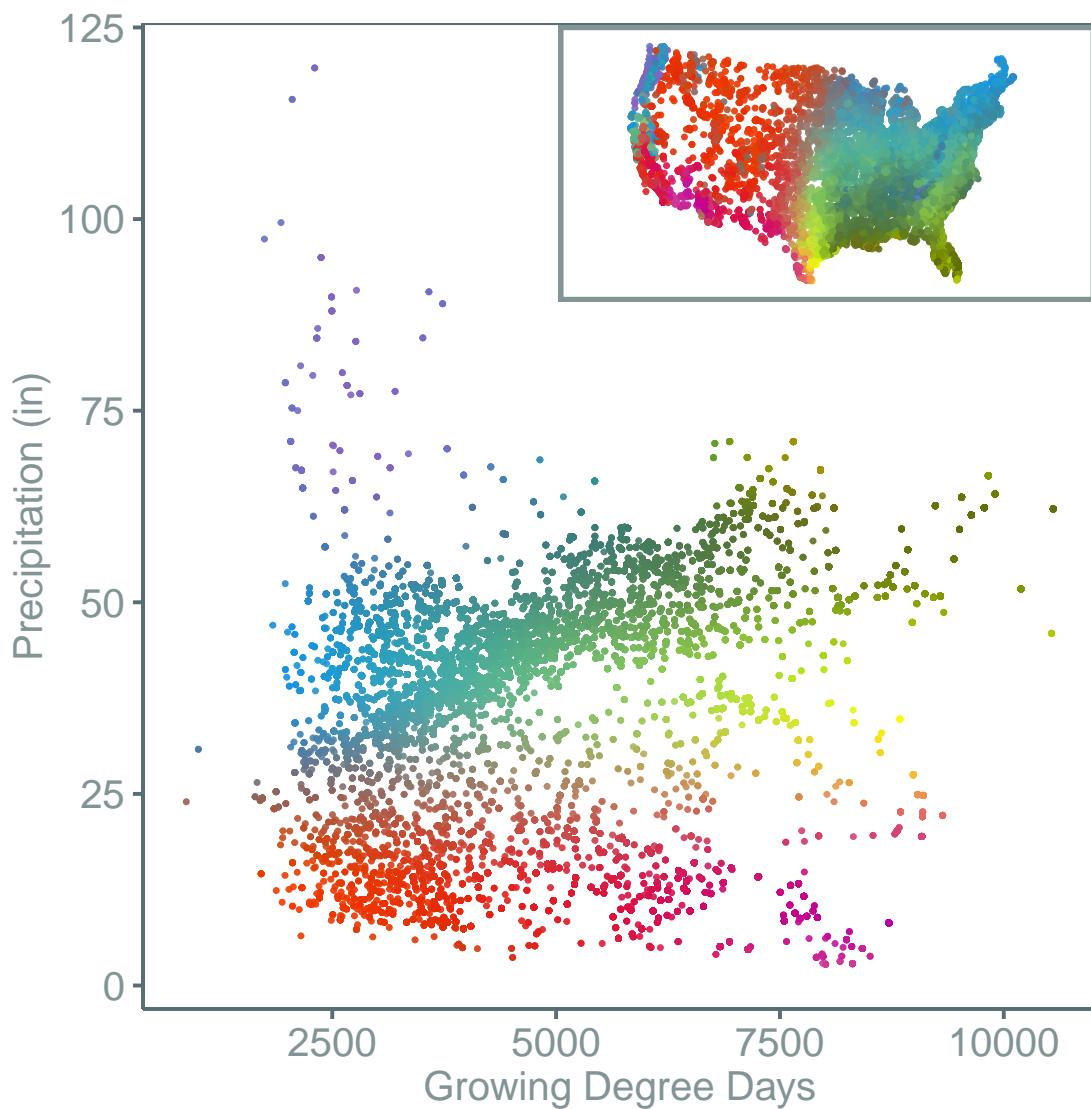
```
library(grid)
vp1 <- viewport(width = 0.5, height = 0.35, x = 0.74, y = 0.855)

#Just draw the plot twice
```

```
png("../figs/climate_space_wMap.png")
print(p)
print(mp, vp = vp1)
dev.off()
```

quartz

2



```
library(grid)
```

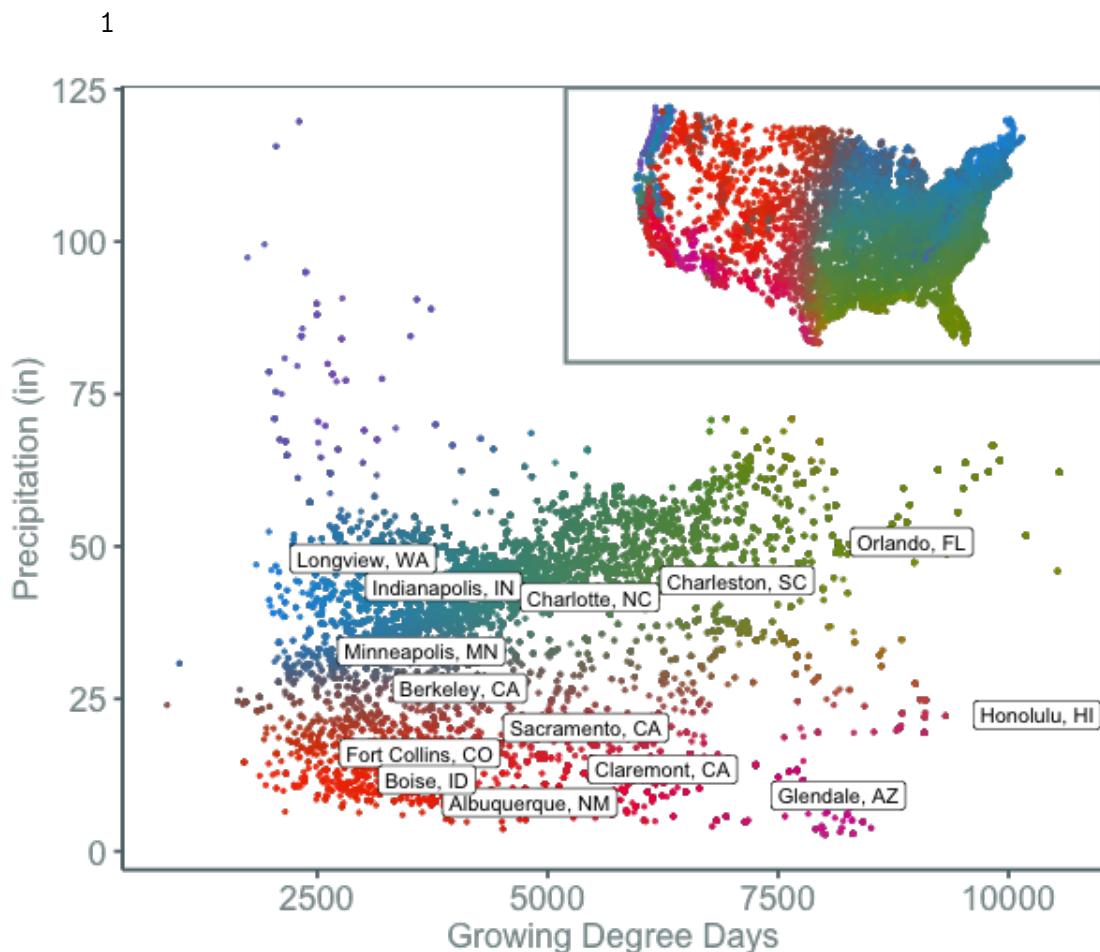
```

vp1 <- viewport(width = 0.5, height = 0.35, x = 0.743, y = 0.824)

#Just draw the plot twice
png("../figs/climate_space_wMap_labels.png", bg = "transparent", width = 600)
print(pc)
print(mp, vp = vp1)
dev.off()

```

null device



TODO: overlay the reference cities.

```
dn <- d %>%
  rename(lat = LATITUDE, long = LONGITUDE, pop = POPULATION) %>%
  filter(complete.cases(.)) %>%
  filter( lat < 50, lat > 25, long < 0)

col_gdd <- sapply(dn$gdd, function(x) cols$gdd_col[which.min(abs(x - cols$gdd_col))])
col_precip <- sapply(dn$precip, function(x) cols$precip_col[which.min(abs(x - cols$precip_col))])
```

```

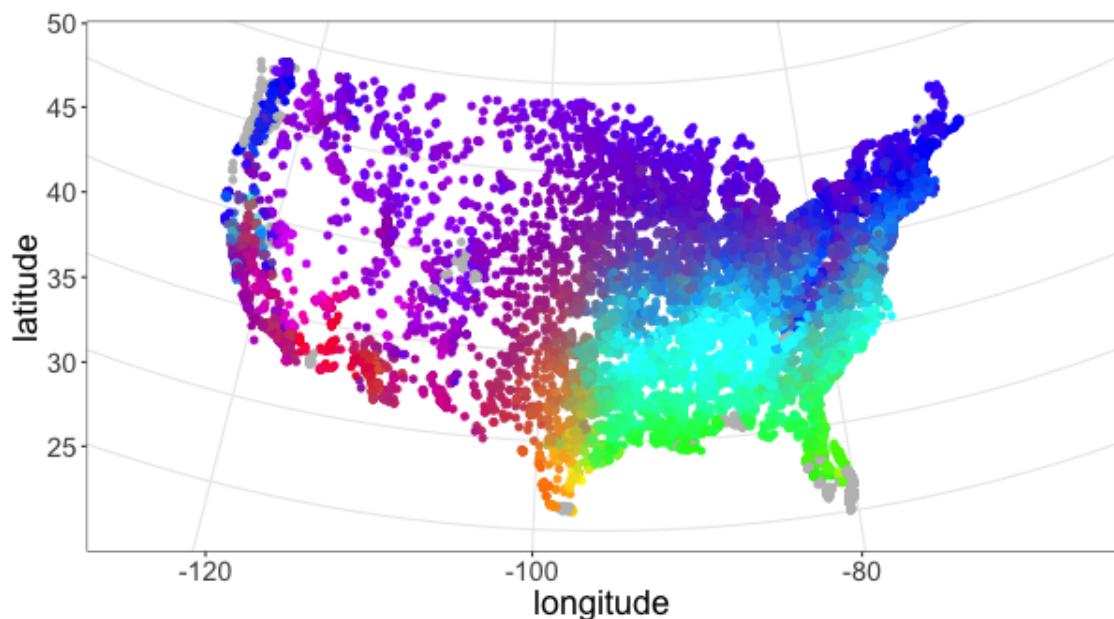
dn <- dn %>%
  mutate(gdd_col = col_gdd,
        precip_col = col_precip)

ddn <- left_join(dn, cols)

ddn <- ddn %>%
  mutate(value = ifelse(gdd > 9000, "gray", value),
        value = ifelse(gdd < 2000, "gray", value),
        value = ifelse(precip > 6700, "gray", value),
        value = ifelse(precip < 300, "gray", value))

Joining, by = c("gdd_col", "precip_col")

```

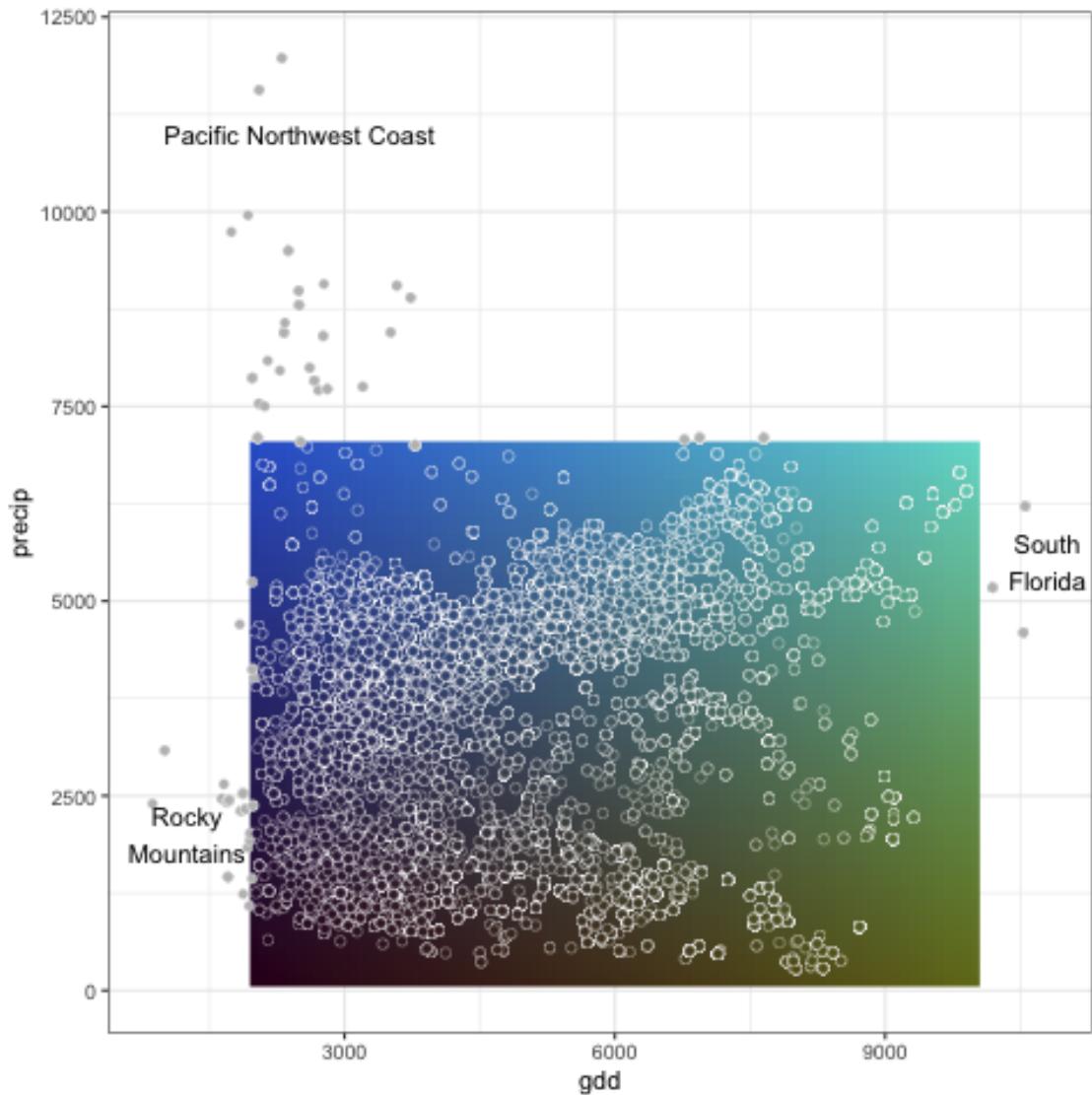


```

d <- d %>%
  rename(lat = LATITUDE, long = LONGITUDE, pop = POPULATION) %>%
  filter(complete.cases(.)) %>%
  filter( lat < 50, lat > 25, long < 0) %>%
  mutate(gdd_col = ifelse(gdd > 10000, NA, gdd),
         gdd_col = ifelse(gdd < 2000, NA, gdd_col),
         precip_col = ifelse(precip > 7000, NA, precip),
         precip_col = ifelse(precip < 100, NA, precip_col),
         red = f(gdd_col, m = 80) + 50,
         green = f(precip_col,100) + f(gdd_col,150),
         blue = f(precip_col, m = 180) + 30) %>%
  rowwise() %>%
  mutate(col = ifelse(!is.na(red) & !is.na(blue) & !is.na(green), rgb(red, green, blue)

```





The dots should instead be a contour plot of the US population.

```
library(hdrcde)

pal <- expand.grid(gdd = seq(2000,10000,100), precip = seq(100,7000,100)) %>%
  mutate(red = f(gdd, m = 80) + 50,
        green = f(precip,100) + f(gdd,150),
        blue = f(precip, m = 180) + 30,
        col = rgb(red, green, blue, maxColorValue = 255))
```

```
#  con <-  ggtern::kde2d.weighted(x = d$gdd, y = d$precip, n = 1000, lims = c(range(d$gdd), range(d$precip)))

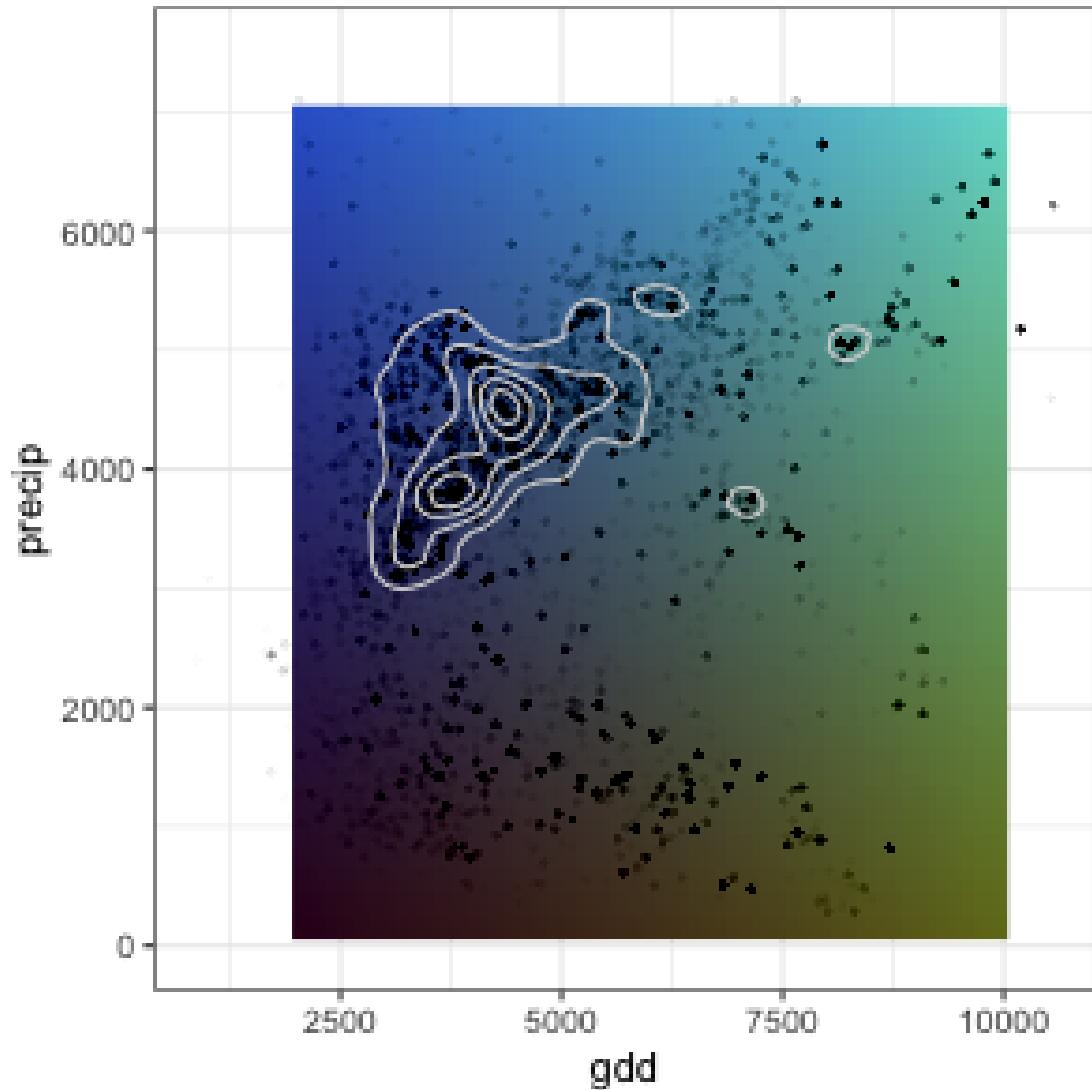
con <-  MASS::kde2d(x = d$gdd, y = d$precip, n = 100, lims = c(range(d$gdd), range(d$precip)))

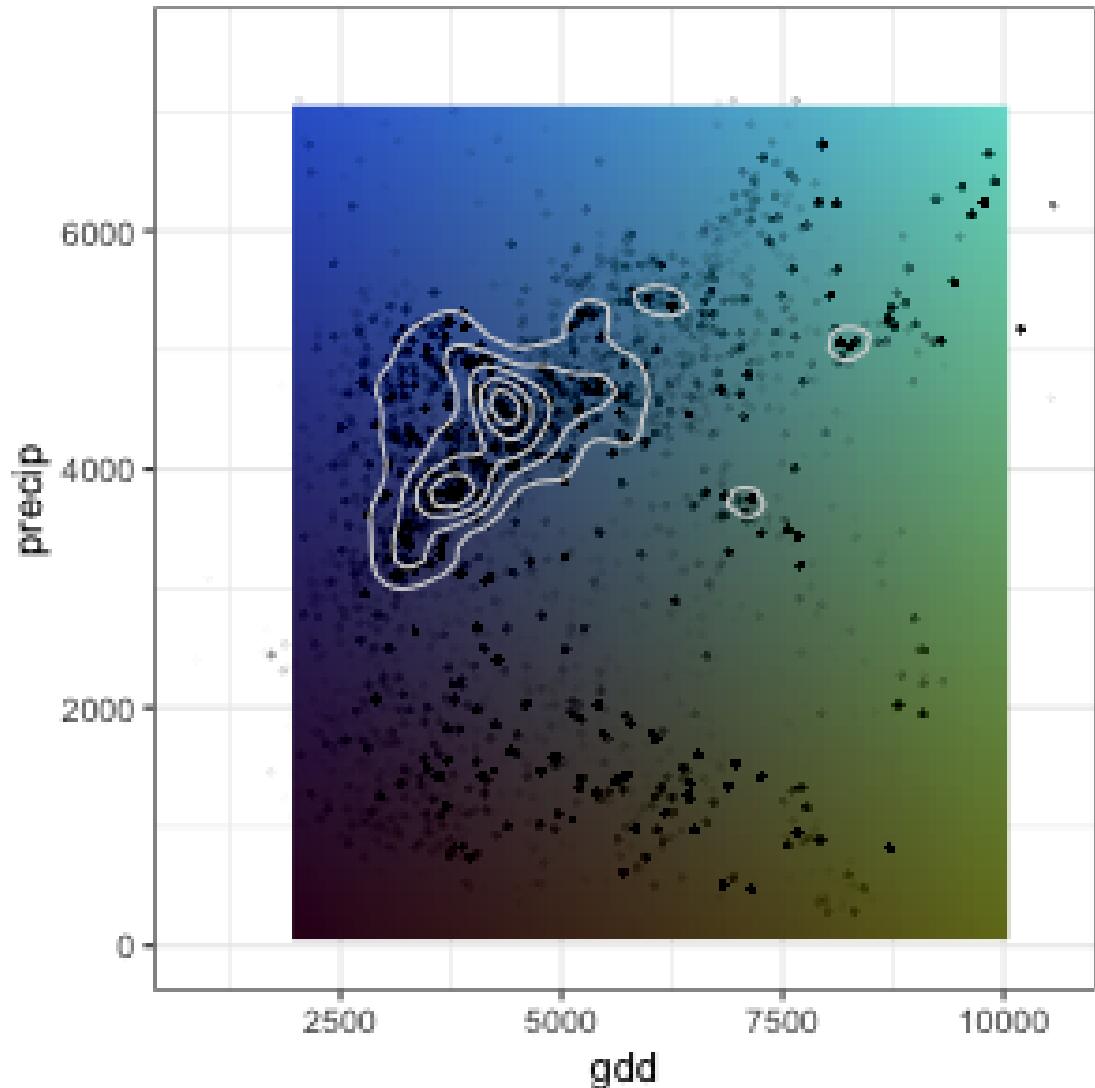
#  con2 <-  hdr.2d(x = con$x, y = con$y, den = con, prob = c(50,90))
#  con2 <-  hdr.2d(x = d$gdd, y = d$precip, prob = c(20,40,60,80))

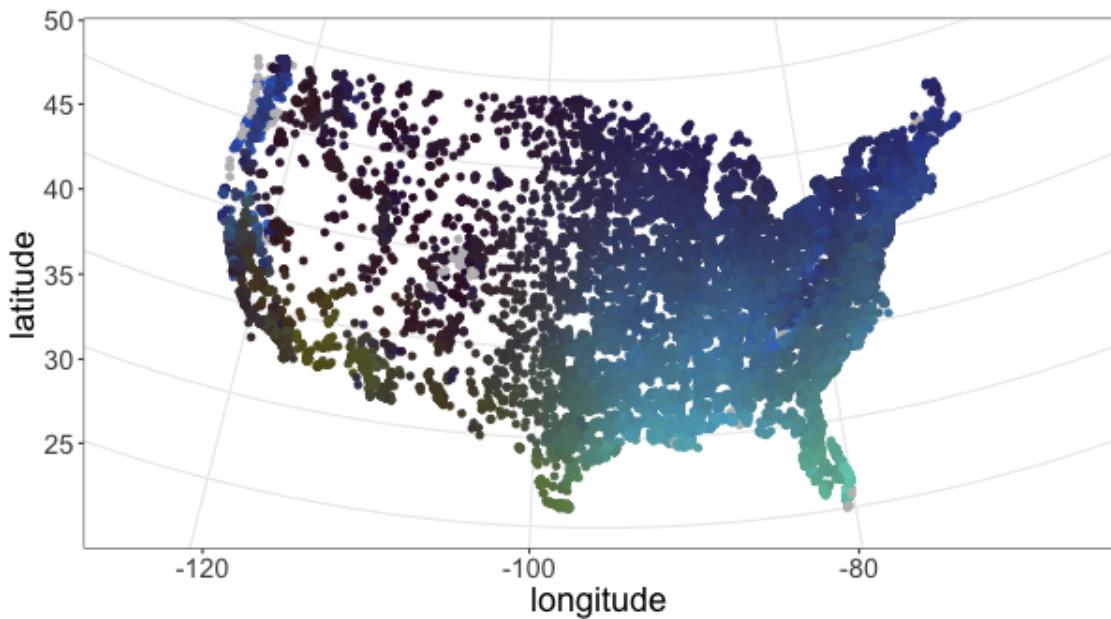
con3 <- expand.grid(gdd = con2$den$x, precip = con2$den$y)
con3 <- expand.grid(gdd = con$x, precip = con$y)

con3$z <- as.vector(con$z)

Error in expand.grid(gdd = con2$den$x, precip = con2$den$y) :
object 'con2' not found
```







Trying to do log scale

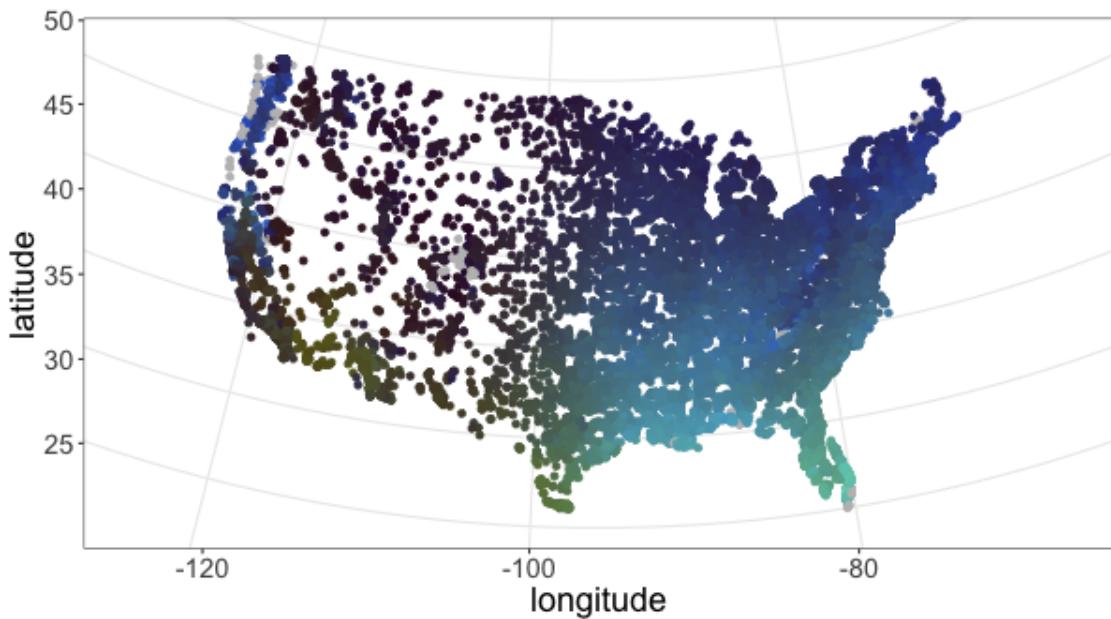
```
d <- bind_cols(dsp.trks@data, trks@data) %>%
  dplyr::select(LATITUDE, LONGITUDE, POPULATION, gdd, precip, TRACT)

f <- function(x,m = 255) {round(m * (x - min(x, na.rm = T)) / max(x, na.rm = T), 0) }

d <- d %>%
  rename(lat = LATITUDE, long = LONGITUDE, pop = POPULATION) %>%
  filter(complete.cases(.)) %>%
  filter( lat < 50, lat > 25, long < 0) %>%
  mutate(gdd_col = log(gdd),
        precip_col = log(precip),
        red = f(gdd_col, m = 80) + 50,
        green = f(precip_col,100) + f(gdd_col,150),
```

```
blue = f(precip_col, m = 180) + 30) %>%  
rowwise() %>%  
mutate(col = ifelse(!is.na(red) & !is.na(blue) & !is.na(green), rgb(red, green, bl
```

The dots should instead be a contour plot of the US population.



## Making figures for this data section

species by city raster, black if the combination exists

```

library(dplyr)
library(ggplot2)

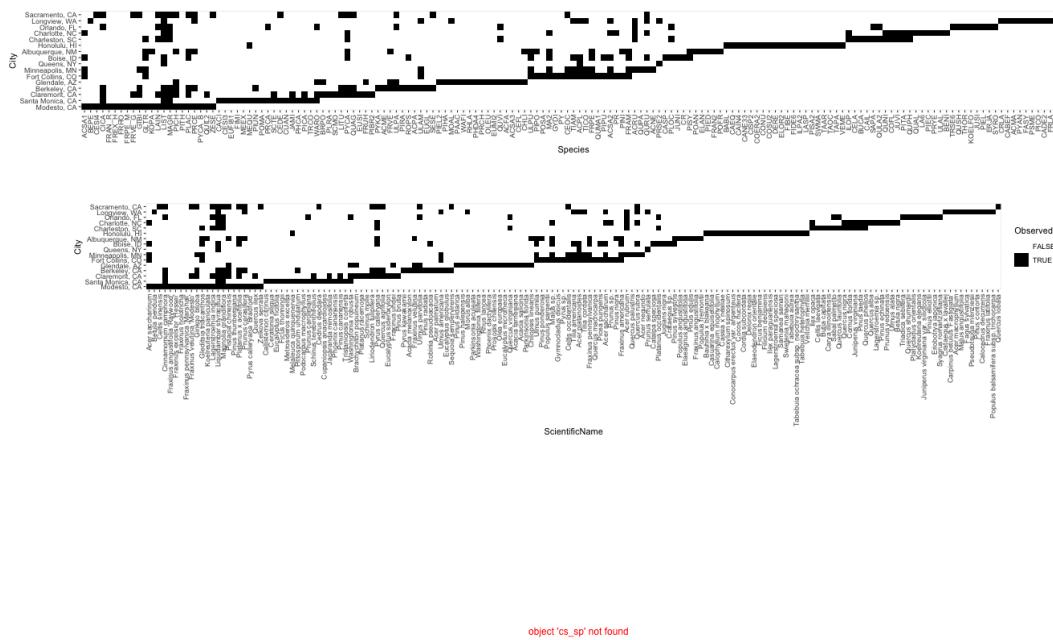
d <- readRDS("../data/tidy_age_dbh.rds")

cs <- expand.grid(City = unique(d$City), Species = unique(d$Species)) %>%
  mutate(join = paste0(City, Species))

dj <- d %>% mutate(join = paste0(City, Species)) %>% pull(join)

cs <- cs %>% mutate(Observed = join %in% dj)

```

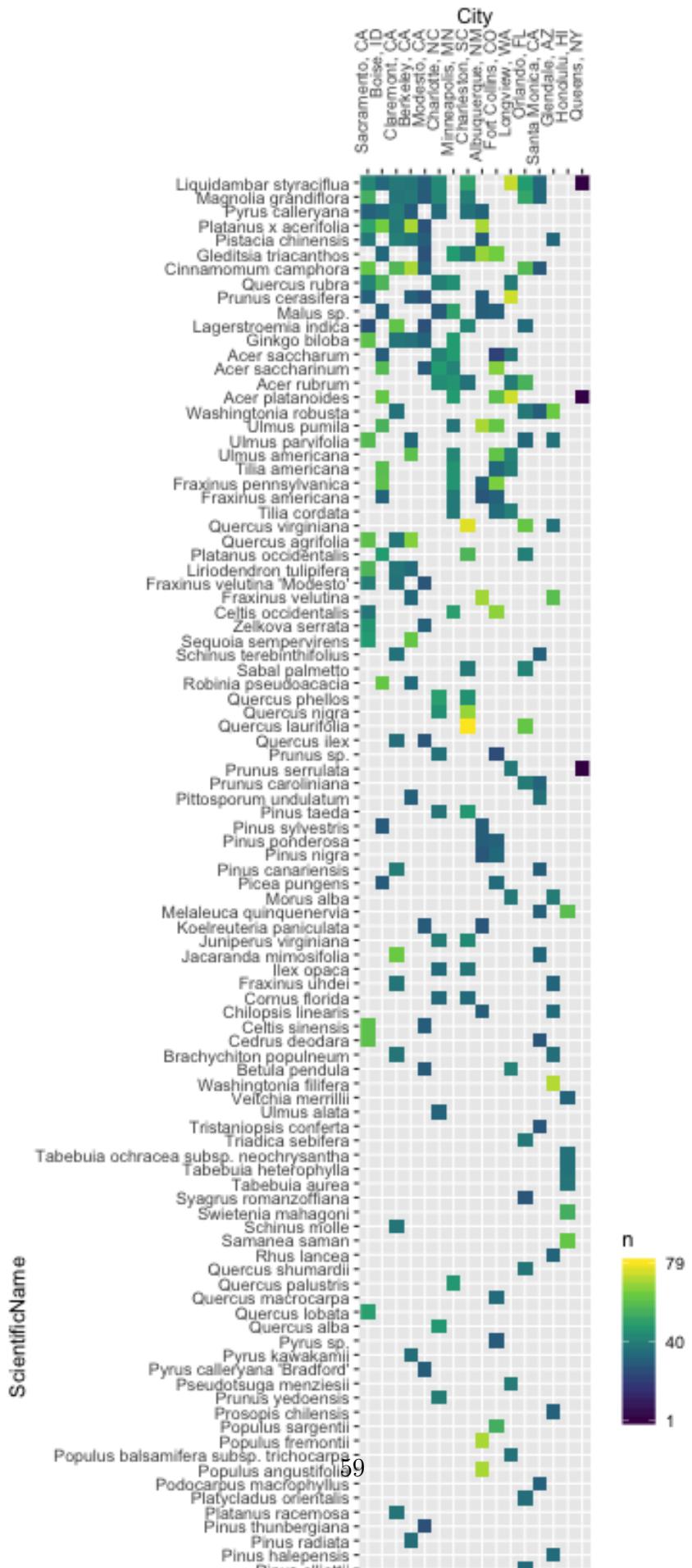


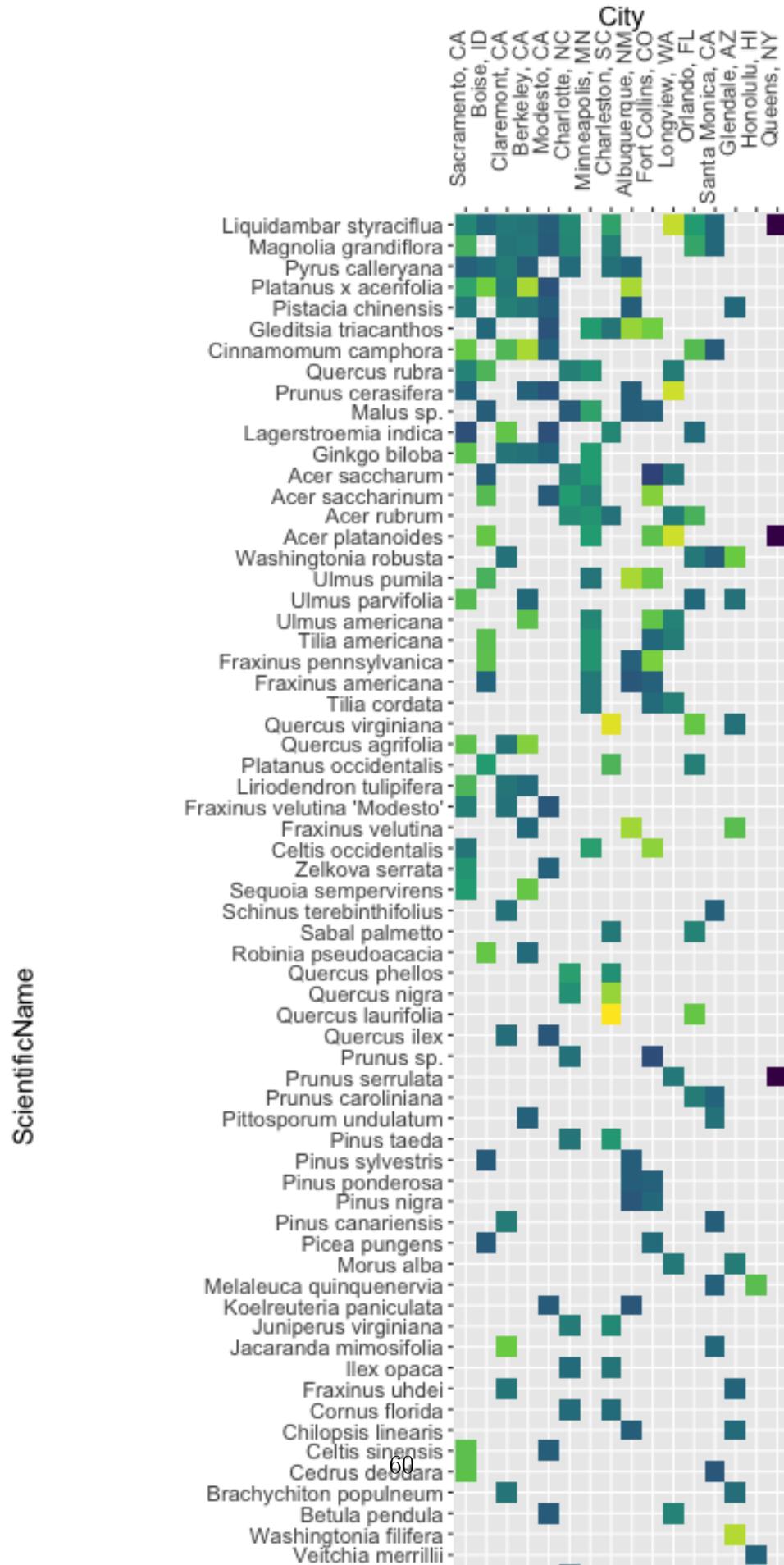
object 'cs\_sp' not found

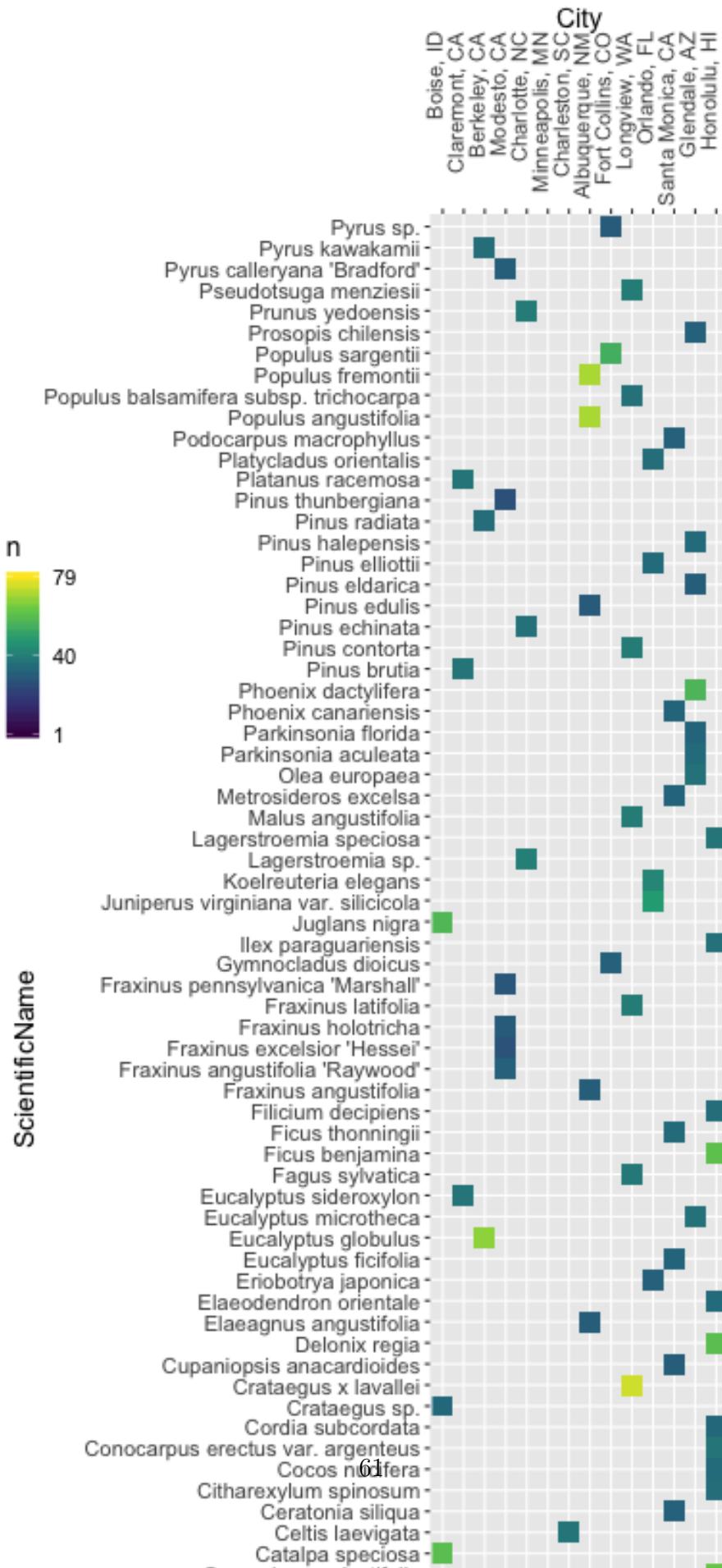
trees as fill. That is richer information.

Also along the top I could have a N cities row, and along the right I could have a N species column. But that's a lot of work for what is readily apparent when looking.

I should order left to right by n cities that a species is observed in and then by city (alphabetical)



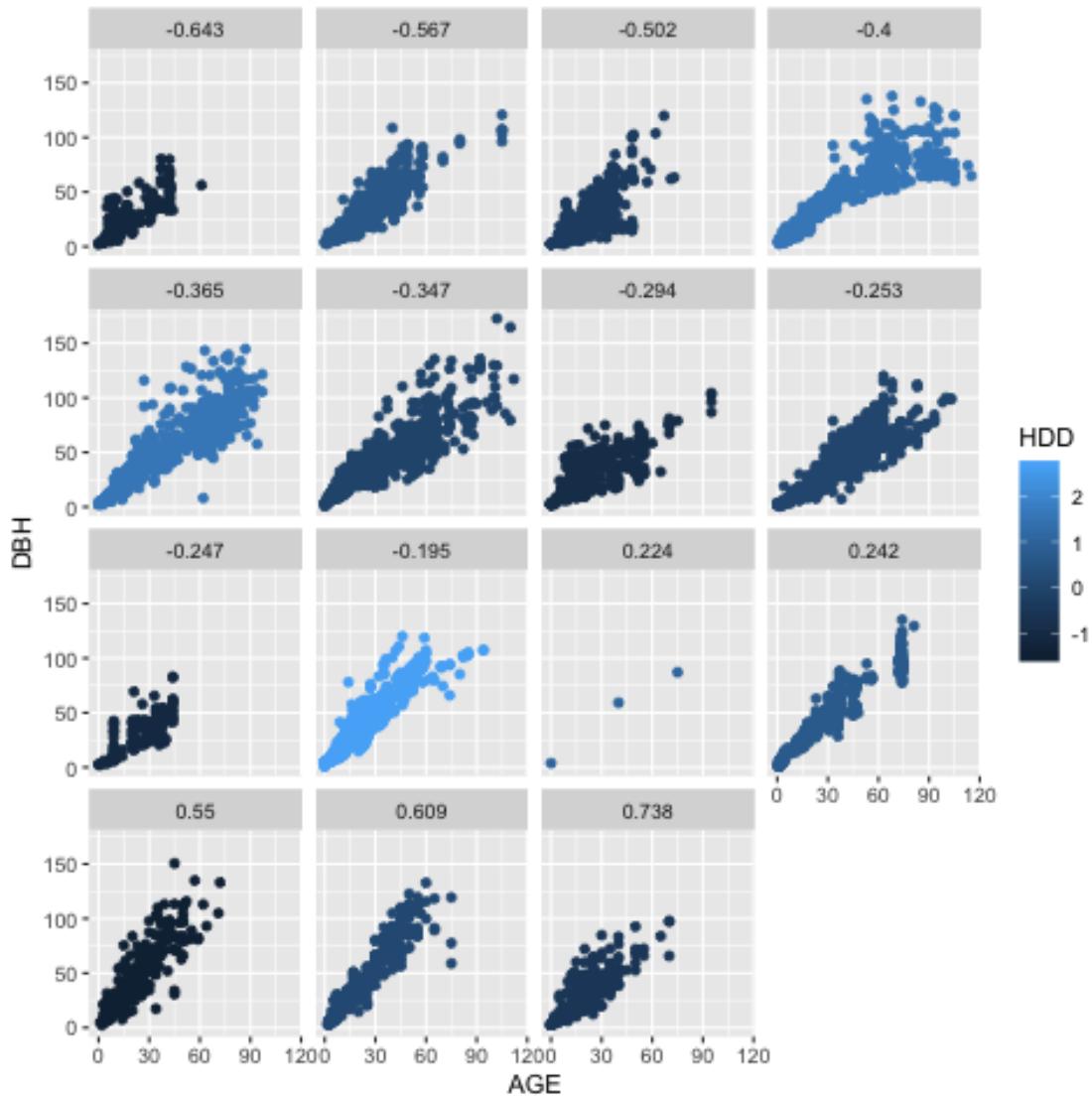


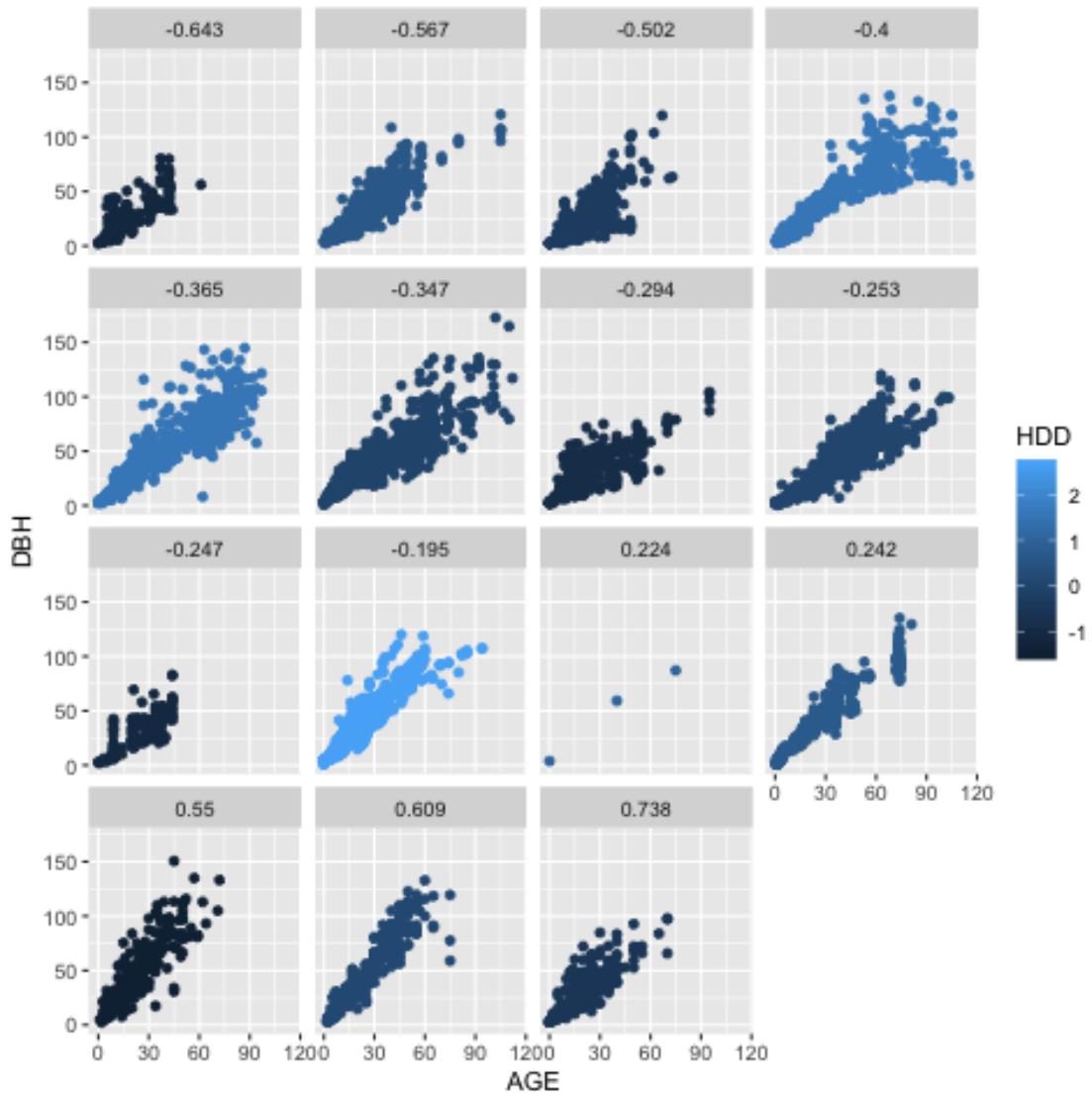




look at climate variables

```
d <- readRDS("../data/age_dbh_testing.rds")
```





Is minneapolis an influential point?