Spatial data & GIS tools

Lecture 21

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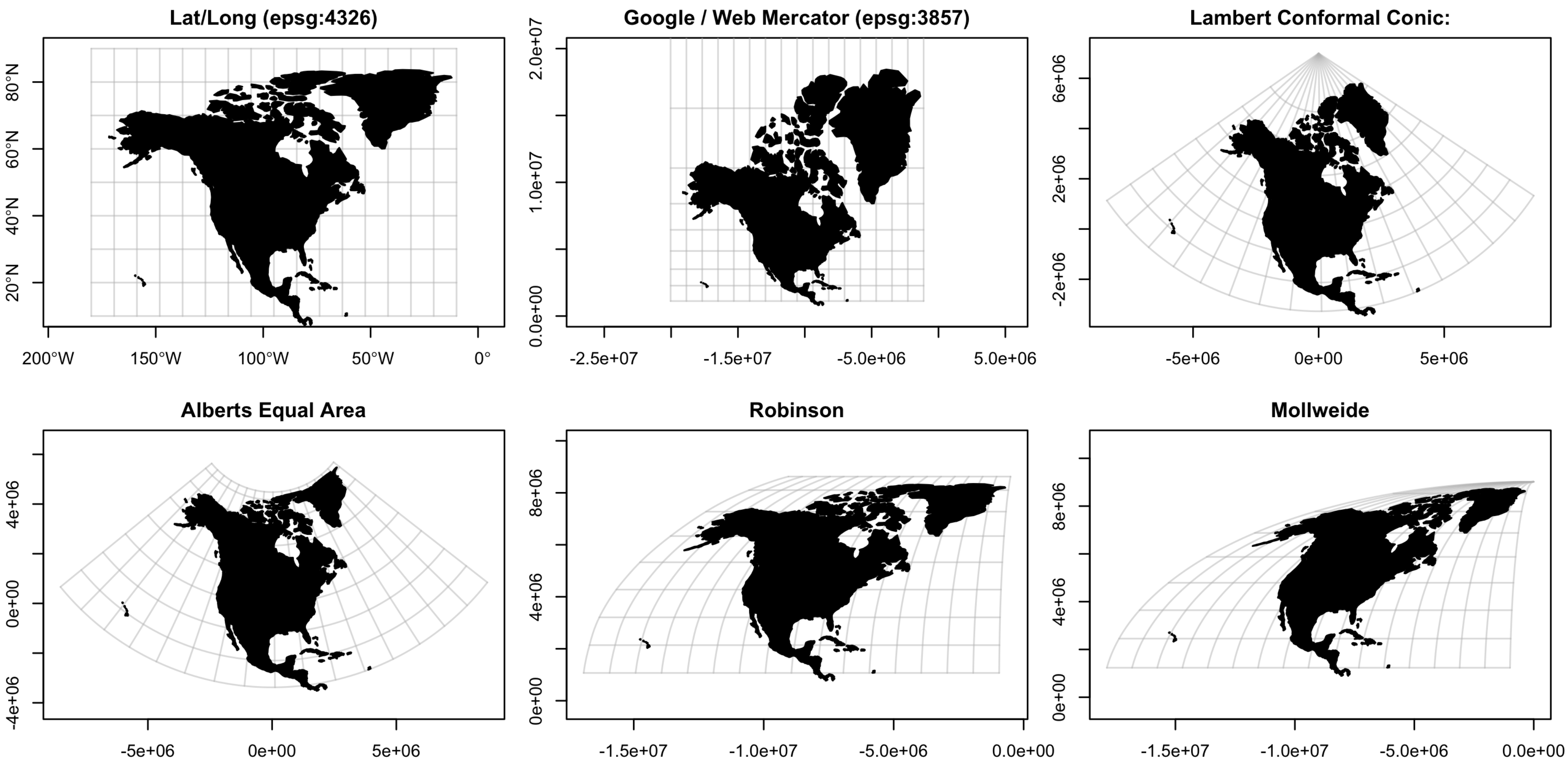
Geospatial stuff is hard

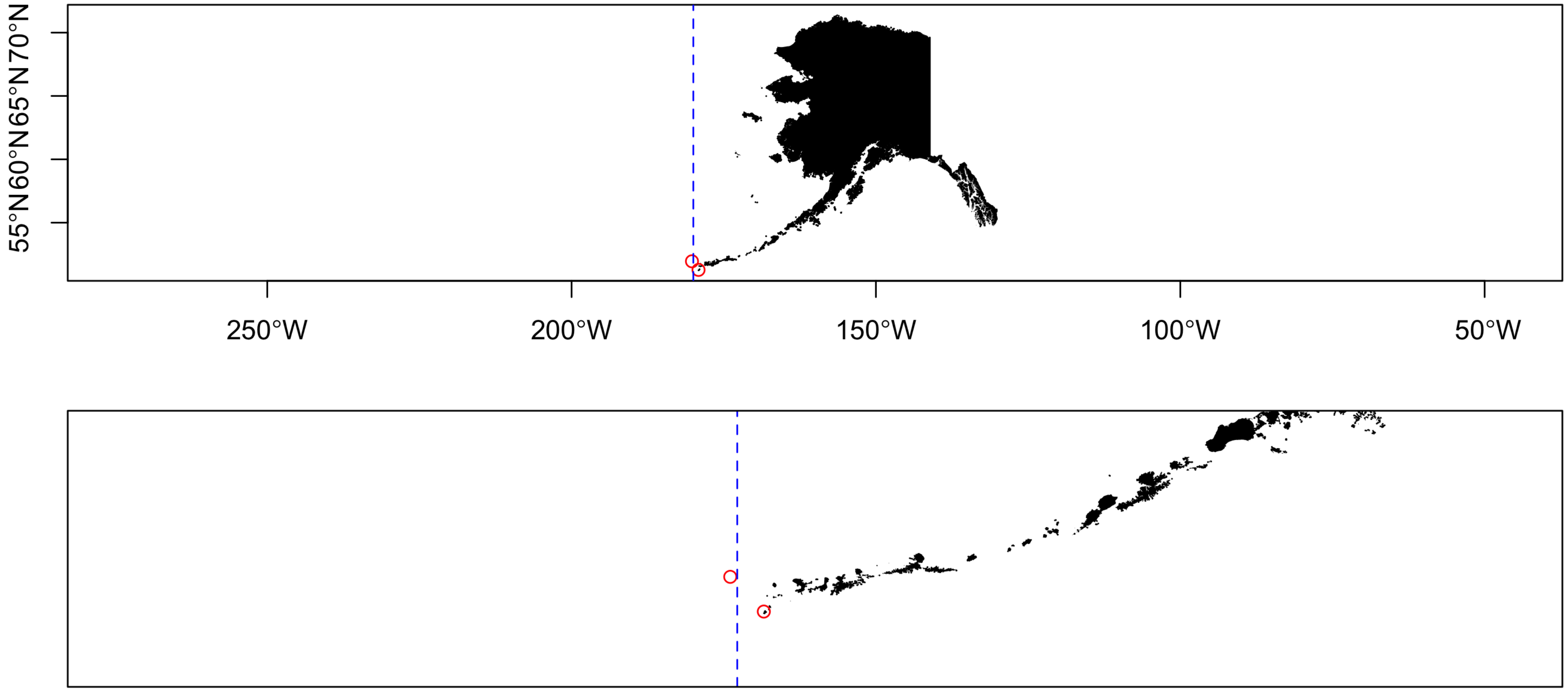
Projections



EPSG is a public registry of coordinate reference systems and related data (name comes from the European

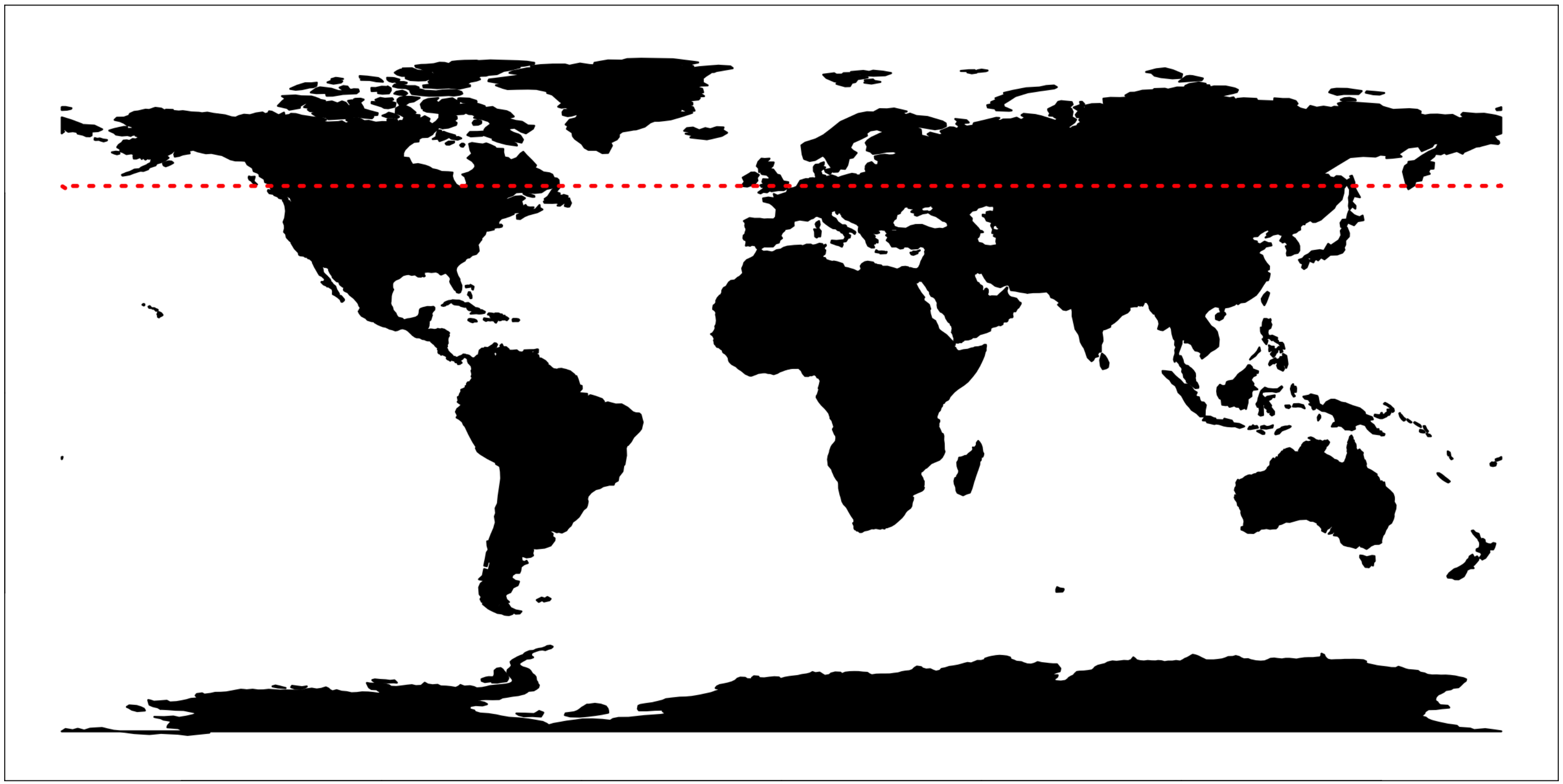
Dateline

How long is the flight between the Western most and the Eastern most points in the US?



Great circle distance

```
par(mar=c(0,0,0,0))
ak1 = c(179.776, 51.952)
ak2 = c(-179.146, 51.273)
inter = geosphere::gcIntermediate(ak1, ak2, n=50, addStartEnd=TRUE)
plot(st_geometry(world), col="black", ylim=c(-90,90), axes=TRUE)
lines(inter,col='red',lwd=2,lty=3)
```



Relationships

Source

Geospatial Data and R

Packages for geospatial data in R

R has a rich package ecosystem for read/writing, manipulating, and analyzing geospatial data. Some core packages:

- `sp` - ~~core classes for handling spatial data, additional utility functions~~ - **Deprecated**
- `rgdal` - ~~R interface to `gdal` (Geospatial Data Abstraction Library) for reading and writing spatial data~~ - **Deprecated**
- `rgeos` - ~~R interface to `geos` (Geometry Engine Open Source) library for querying and manipulating spatial data. Reading and writing WKT.~~ - **Deprecated**
- `raster` - classes and tools for handling spatial raster data.
- `sf` - Combines the functionality of `sp`, `rgdal`, and `rgeos` into a single package based on tidy simple features.
- `stars` - Reading, manipulating, writing and plotting spatiotemporal arrays (rasters)
- `terra` - Methods for spatial data analysis with vector (points, lines, polygons) and raster (grid) data. Replaces `raster`.

See more - Spatial task view

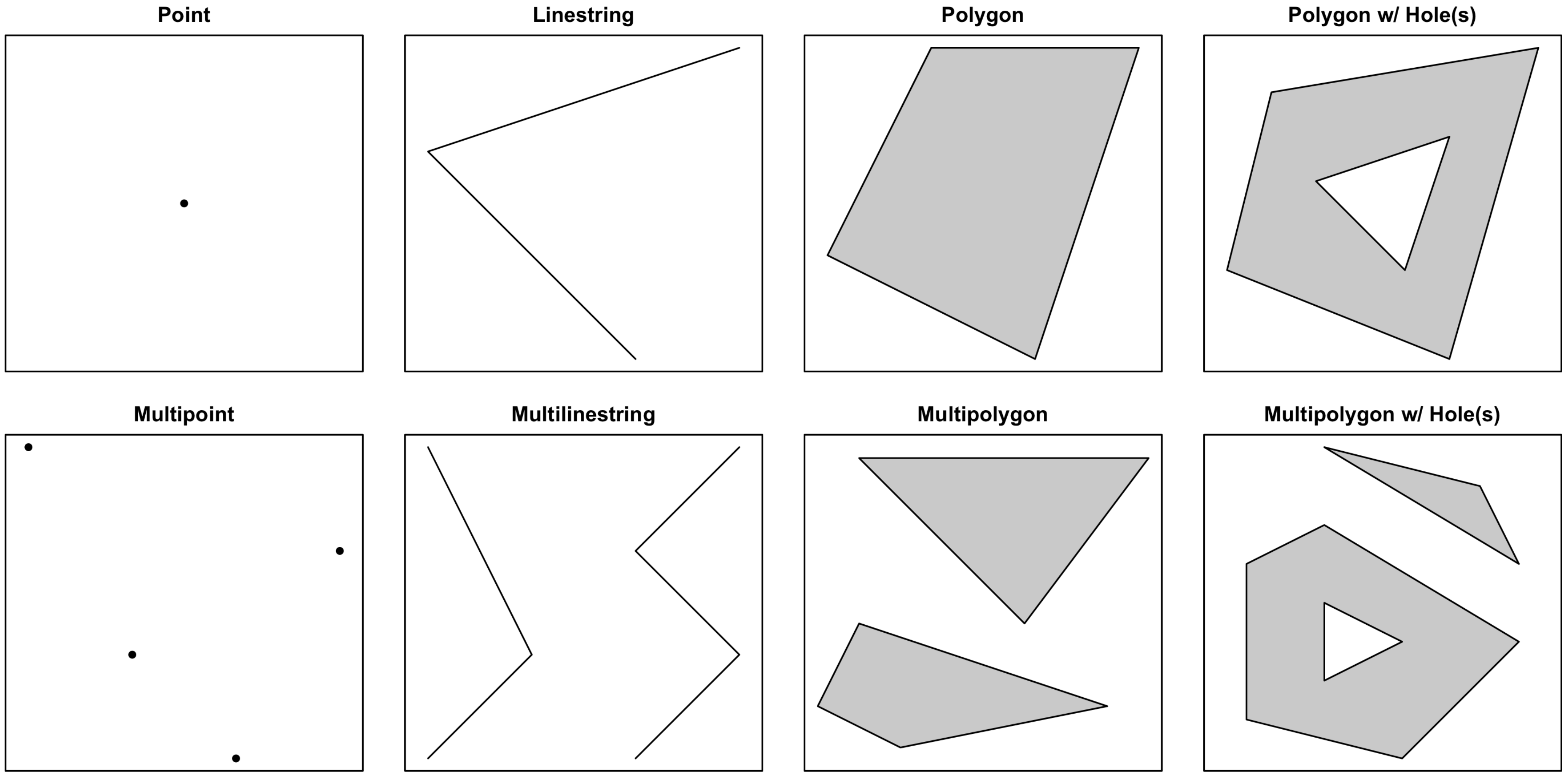
Installing `sf`

This is the hardest part of using the `sf` package, difficulty comes from is dependence on several external libraries (`geos`, `gdal`, and `proj`).

- *Windows* - installing from source works when Rtools is installed (system requirements are downloaded from rwinlib)
- *MacOS* - install dependencies via homebrew: `gdal`, `geos`, `proj`, `udunits`.
- *Linux* - Install development pacakages for GDAL (>= 2.0.0), GEOS (>= 3.3.0), Proj4 (>= 4.8.0), udunits2 from your package manager of choice.

More specific details are included in the repo README on github.

Simple Features



Reading, writing, and converting simple features

- `st_read` / `st_write` - Shapefile, GeoJSON, KML, …
- `read_sf` / `write_sf` - Same, suports tibbles …
- `st_as_sfc` / `st_as_wkt` - WKT
- `st_as_sfc` / `st_as_binary` - WKB
- `st_as_sfc` / `as(x, "Spatial")` - sp

See sf vignette #2 - Reading, Writing and Converting Simple Features.

Shapefiles

```r
fs::dir_info("data/gis/nc_counties/") |> select(path:size)
```

```
# A tibble: 4 × 3
  path                                     type     size
  <fs::path>                               <fct> <fs::b>
1 …a/gis/nc_counties/nc_counties.dbf file         41K
2 …a/gis/nc_counties/nc_counties.prj file         165
3 …a/gis/nc_counties/nc_counties.shp file       1.41M
4 …a/gis/nc_counties/nc_counties.shx file         900
```

NC Counties - `sf` + `data.frame`

```r
(st_read("data/gis/nc_counties/", quiet=TRUE))
```

```
Simple feature collection with 100 features and 8 fields
Geometry type: MULTIPOLYGON
Dimension:     XY
Bounding box:  xmin: -84.32186 ymin: 33.84175 xmax: -75.46003 ymax: 36.58815
Geodetic CRS:  NAD83
First 10 features:
         AREA PERIMETER COUNTYP010 STATE             COUNTY  FIPS STATE_FIPS
1  0.11175964  1.610396       1994    NC        Ashe County 37009         37
2  0.06159483  1.354829       1996    NC   Alleghany County 37005         37
3  0.14023009  1.769388       1998    NC       Surry County 37171         37
4  0.08912401  1.425249       1999    NC       Gates County 37073         37
5  0.06865730  4.428217       2000    NC   Currituck County 37053         37
6  0.11859434  1.404309       2001    NC      Stokes County 37169         37
7  0.06259671  2.106357       2002    NC      Camden County 37029         37
8  0.11542955  1.462524       2003    NC      Warren County 37185         37
9  0.14328609  2.397293       2004    NC Northampton County 37131         37
10 0.09245561  1.810778       2005    NC    Hertford County 37091         37
```

NC Counties - `sf` + `tbl_df`

```r
(nc = read_sf("data/gis/nc_counties/"))
```

```
Simple feature collection with 100 features and 8 fields
Geometry type: MULTIPOLYGON
Dimension:     XY
Bounding box:  xmin: -84.32186 ymin: 33.84175 xmax: -75.46003 ymax: 36.58815
Geodetic CRS:  NAD83
# A tibble: 100 × 9
     AREA PERIMETER COUNTYP010 STATE COUNTY             FIPS  STATE_FIPS SQUARE_MIL
    <dbl>     <dbl>      <dbl> <chr> <chr>              <chr> <chr>           <dbl>
 1 0.112       1.61       1994 NC    Ashe County        37009 37               429.
 2 0.0616      1.35       1996 NC    Alleghany County   37005 37               236.
 3 0.140       1.77       1998 NC    Surry County       37171 37               539.
 4 0.0891      1.43       1999 NC    Gates County       37073 37               342.
 5 0.0687      4.43       2000 NC    Currituck County   37053 37               264.
 6 0.119       1.40       2001 NC    Stokes County      37169 37               456.
 7 0.0626      2.11       2002 NC    Camden County      37029 37               241.
 8 0.115       1.46       2003 NC    Warren County      37185 37               444.
 9 0.143       2.40       2004 NC    Northampton County 37131 37               551.
```

sf classes

```r
str(nc, max.level=1)
```

```
sf [100 × 9] (S3: sf/tbl_df/tbl/data.frame)
 - attr(*, "sf_column")= chr "geometry"
 - attr(*, "agr")= Factor w/ 3 levels "constant","aggregate",..: NA NA NA NA NA
NA NA NA
  ..- attr(*, "names")= chr [1:8] "AREA" "PERIMETER" "COUNTYP010" "STATE" ...
```

```r
class(nc)
```

```
[1] "sf"         "tbl_df"     "tbl"        "data.frame"
```

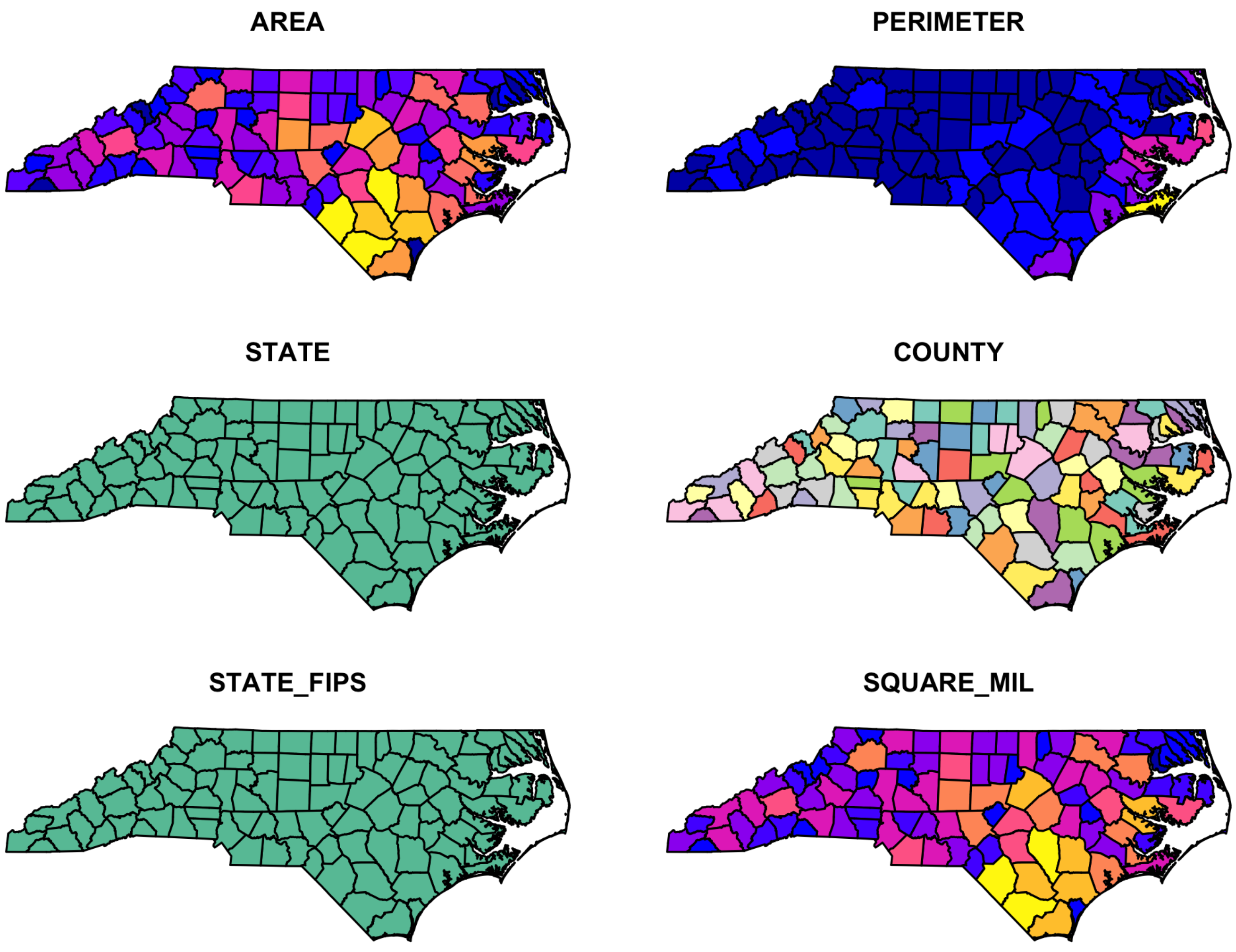
```r
class(nc$geometry)
```

```r
class(nc$geometry[[1]])
```

```
[1] "XY"           "MULTIPOLYGON" "sfg"
```

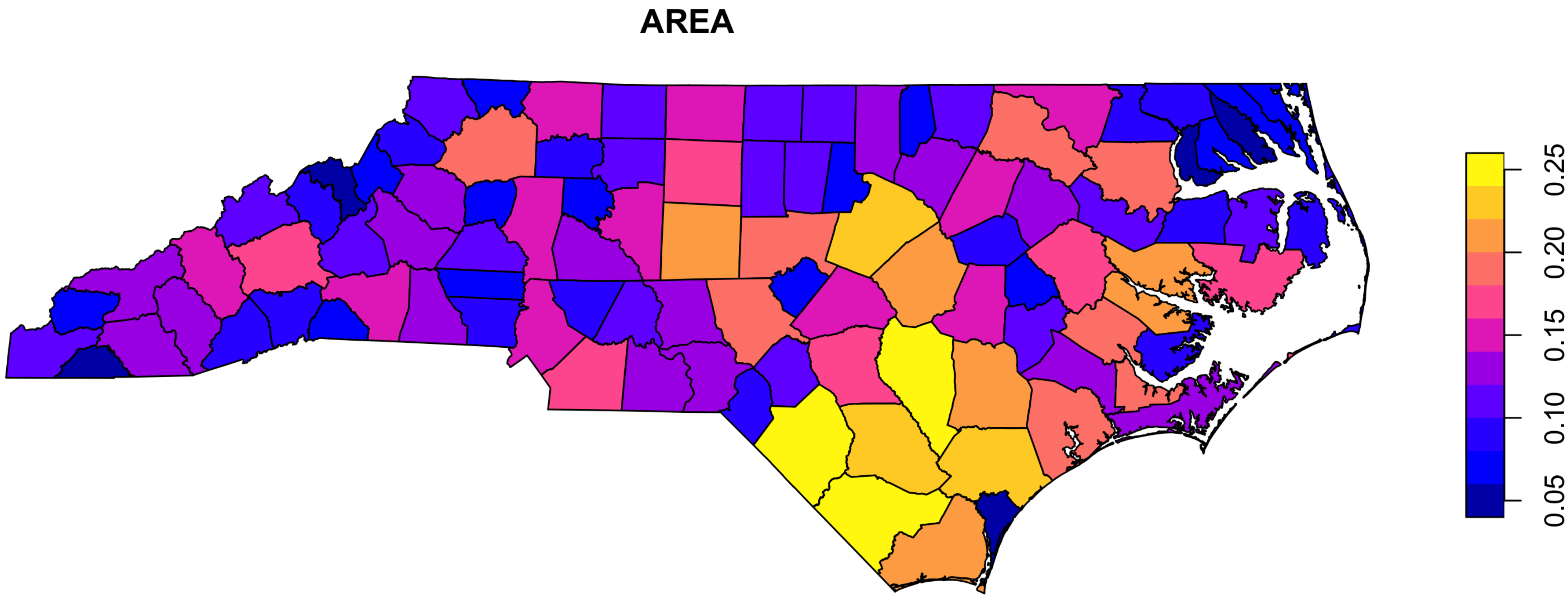
Plotting

```
plot(nc)
```



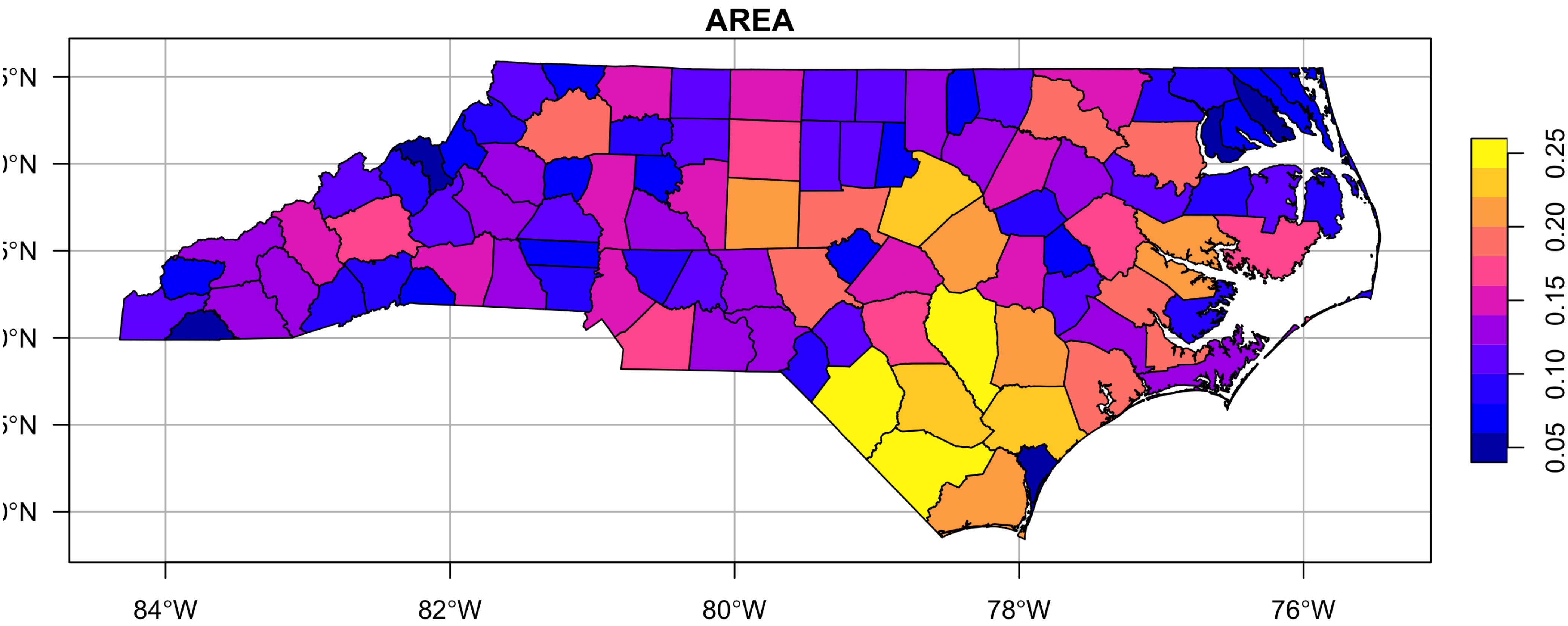
More Plotting

```r
plot(nc["AREA"])
```



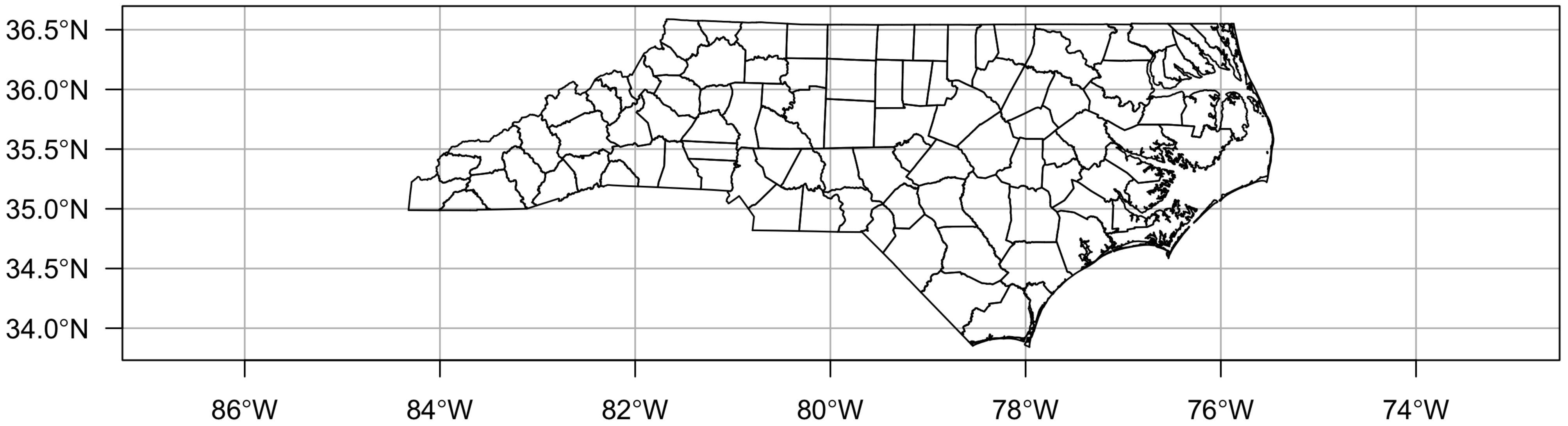
Graticules

```r
plot(nc["AREA"], graticule=TRUE, axes=TRUE, las=1)
```



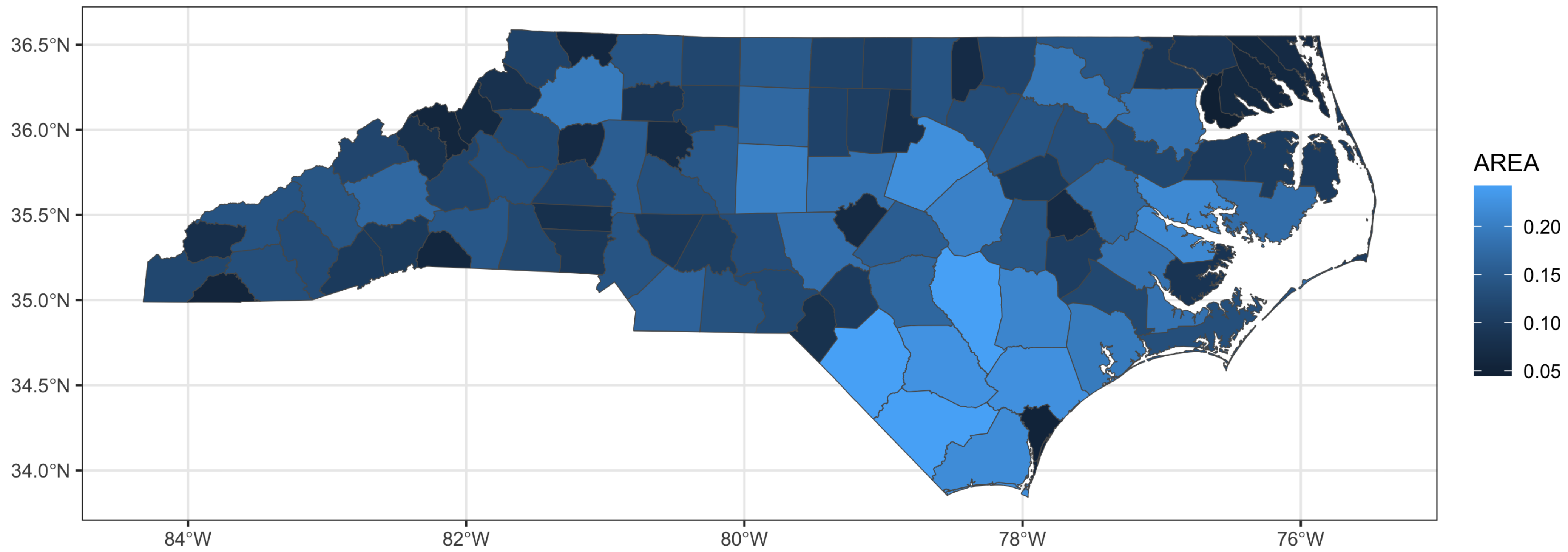
Geometries

```
plot(st_geometry(nc), graticule=TRUE, axes=TRUE, las=1)
```



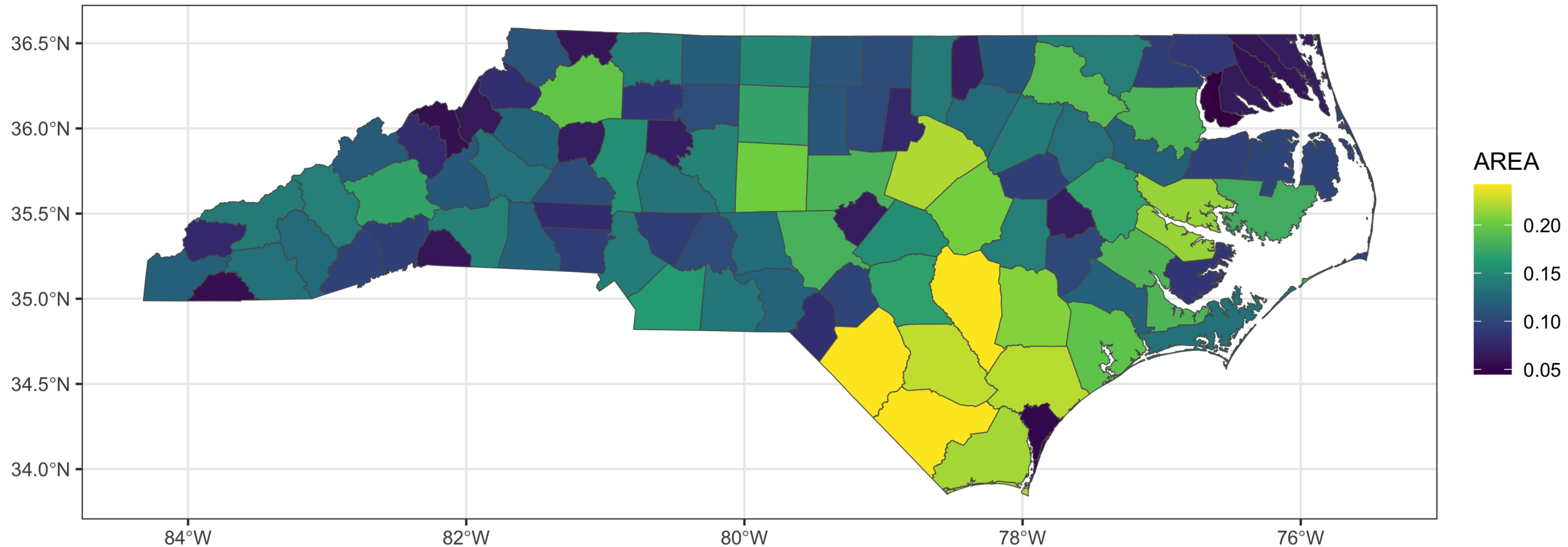
ggplot2

```r
ggplot(nc, aes(fill=AREA)) +
  geom_sf()
```



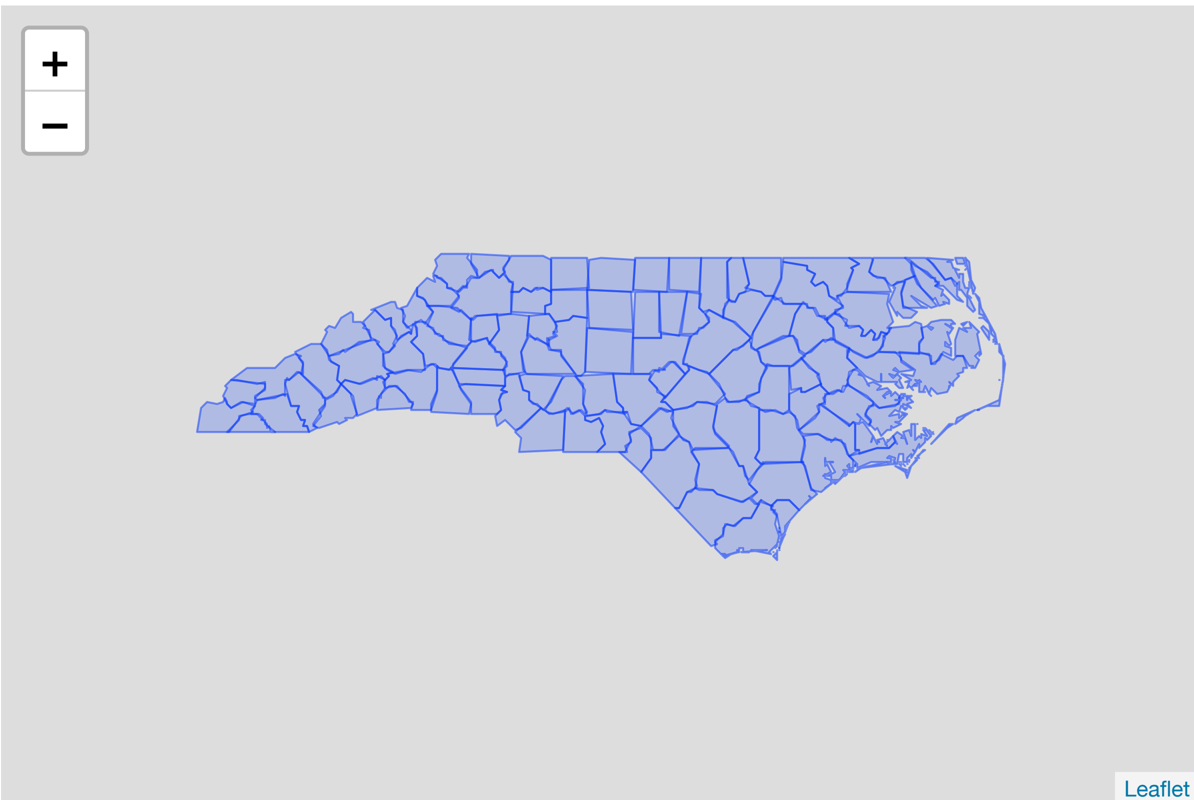
ggplot2 + palettes

```
ggplot(nc, aes(fill=AREA)) +
  geom_sf() +
  scale_fill_viridis_c()
```



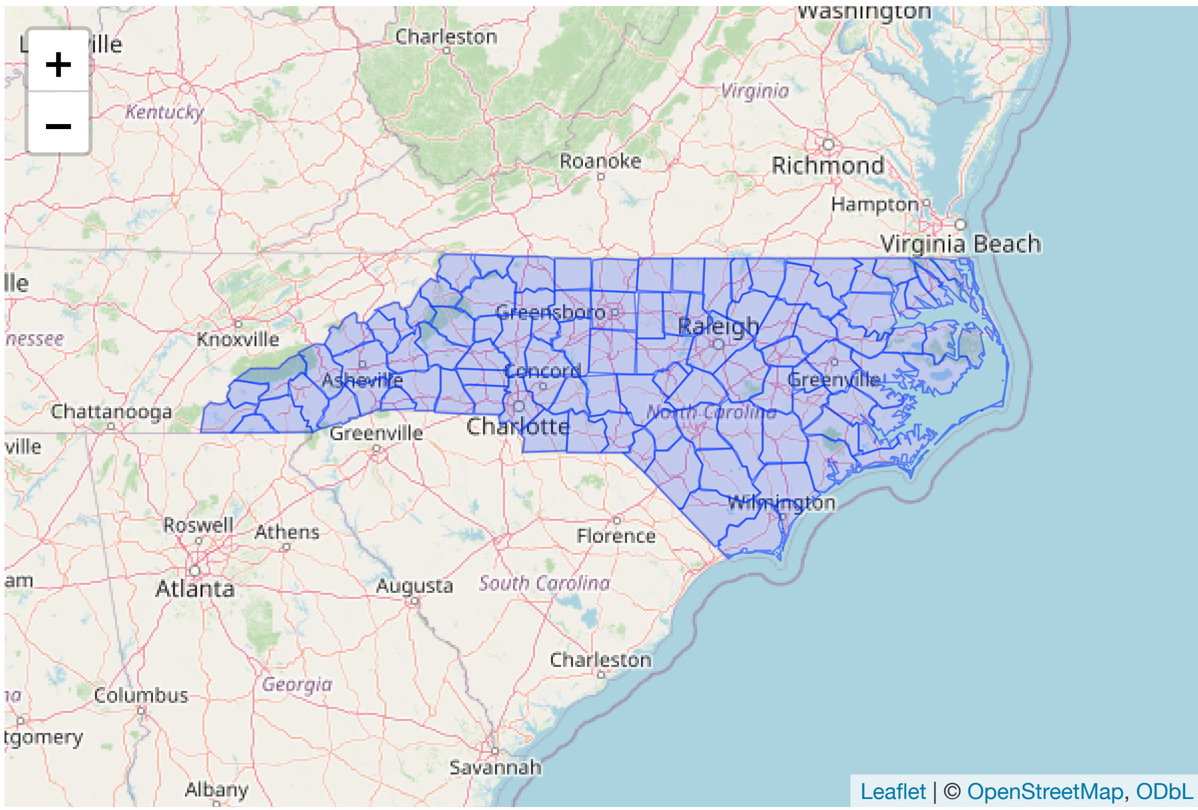
leaflet

```r
st_transform(nc, "+proj=longlat +datum=WGS84") |>
leaflet::leaflet(width = 600, height = 400) |>
  leaflet::addPolygons(
    weight = 1, popup = ~COUNTY,
    highlightOptions = leaflet::highlightOptions(color = "red", weight = 2, bringToFront = TRUE)
  )
```



leaflet + tiles

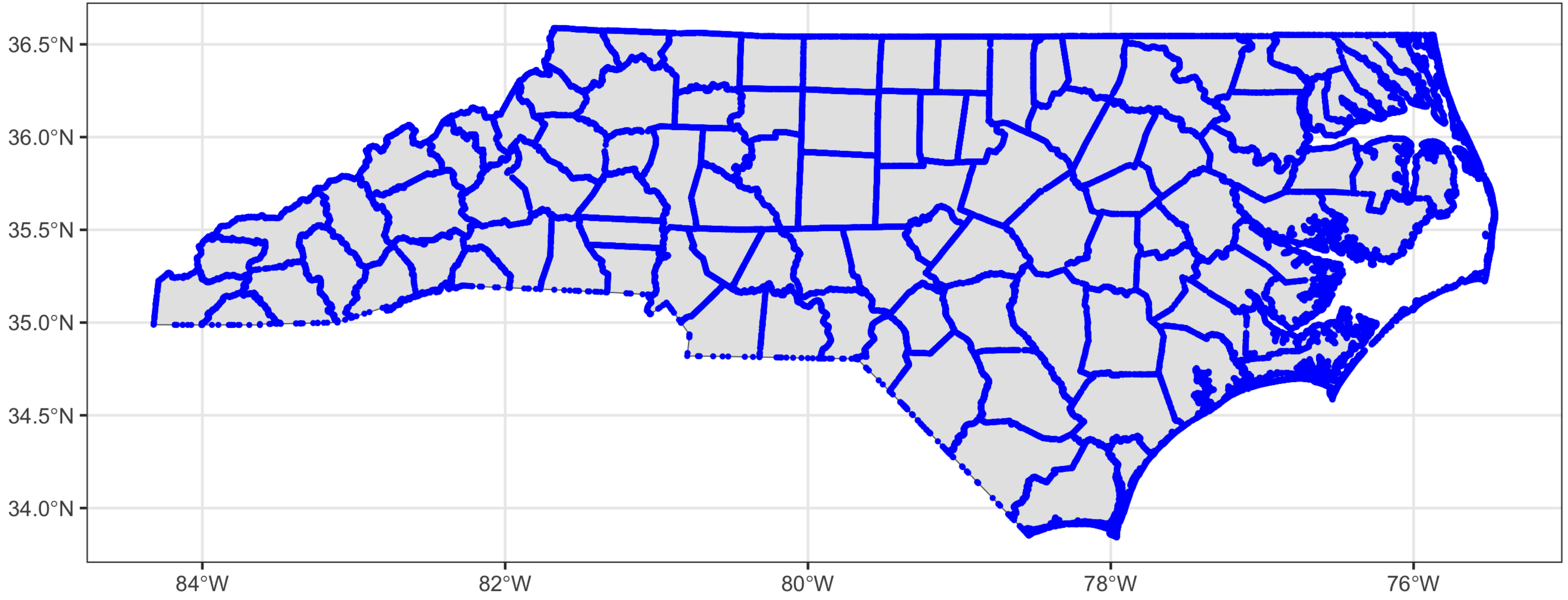
```r
st_transform(nc, "+proj=longlat +datum=WGS84") |>
leaflet::leaflet(width = 600, height = 400) |>
  leaflet::addPolygons(
    weight = 1,
    popup = ~COUNTY,
    highlightOptions = leaflet::highlightOptions(color = "red", weight = 2, bringToFront = TRUE)
  ) |>
  leaflet::addTiles()
```



GIS in R

Geometry casting

```
nc_pts = st_cast(nc, "MULTIPOINT")
ggplot() +
  geom_sf(data=nc) +
  geom_sf(data=nc_pts, size=0.5, color="blue")
```

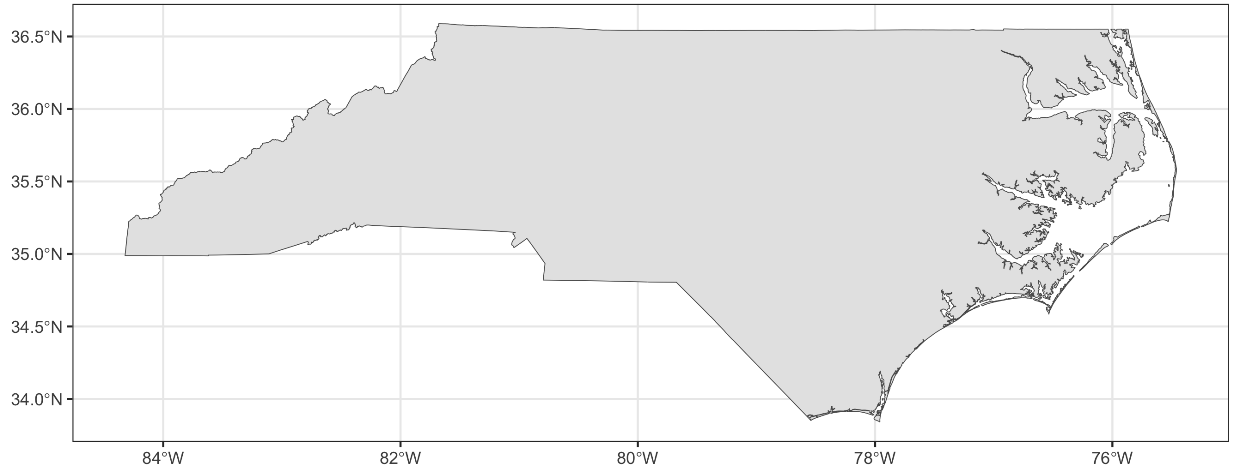


Joining

```r
(nc_state = st_union(nc))
```

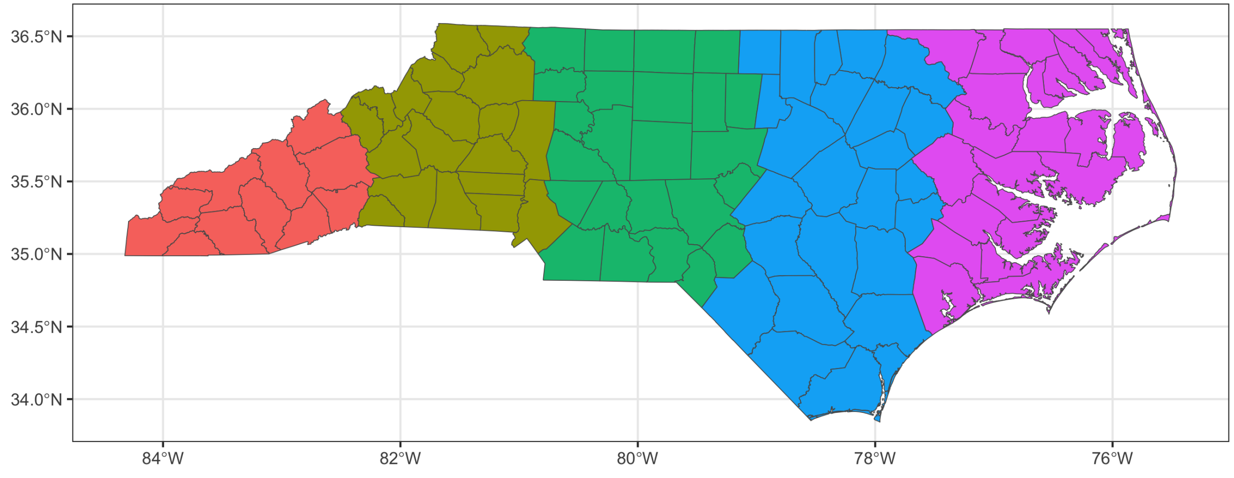
```
Geometry set for 1 feature
Geometry type: MULTIPOLYGON
Dimension:     XY
Bounding box:  xmin: -84.32186 ymin: 33.84175 xmax: -75.46003 ymax: 36.58815
Geodetic CRS:  NAD83
```

```r
ggplot() + geom_sf(data=nc_state)
```



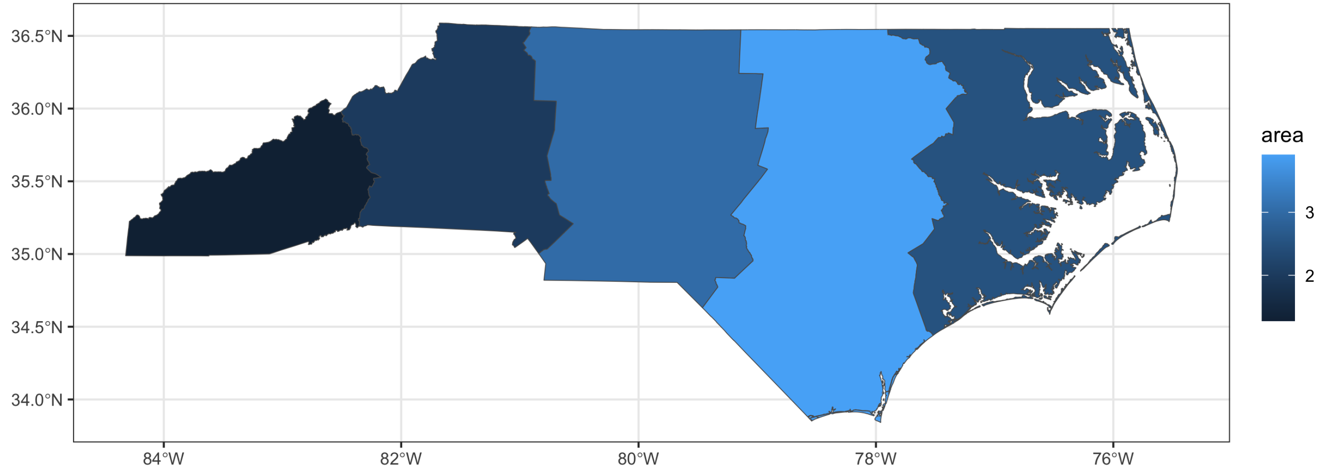
sf & dplyr

```
nc_cut = nc |>
  mutate(
    ctr_x = st_centroid(nc) |> st_coordinates() |> (\(x) x[,1])(),
    region = cut(ctr_x, breaks = 5)
  )

ggplot(nc_cut) +
  geom_sf(aes(fill=region)) +
  guides(fill = "none")
```



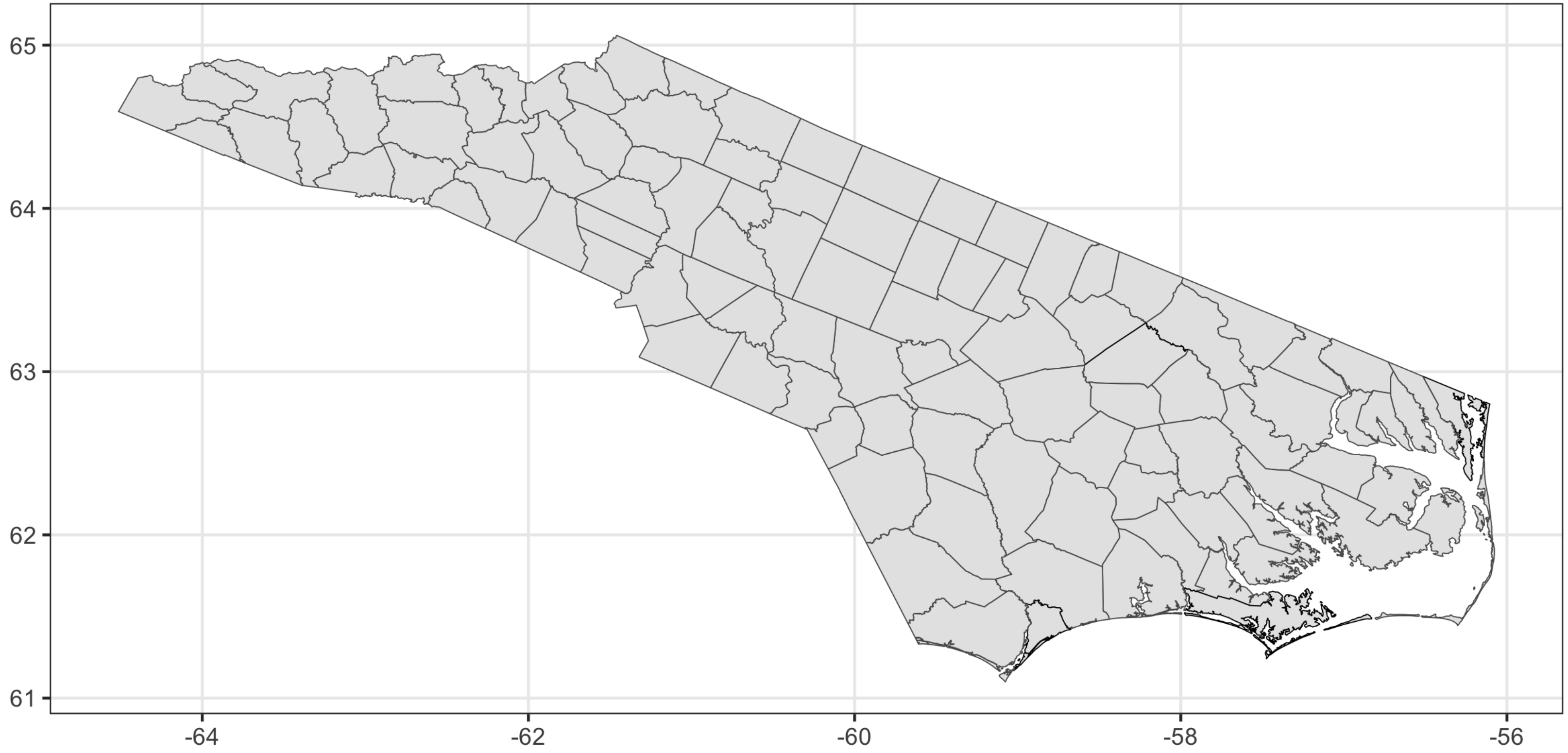
sf & dplyr (cont.)

```
nc_cut2 = nc_cut |>
  group_by(region) |>
  summarize(
    area = sum(AREA)
  )

ggplot() + geom_sf(data=nc_cut2, aes(fill=area))
```



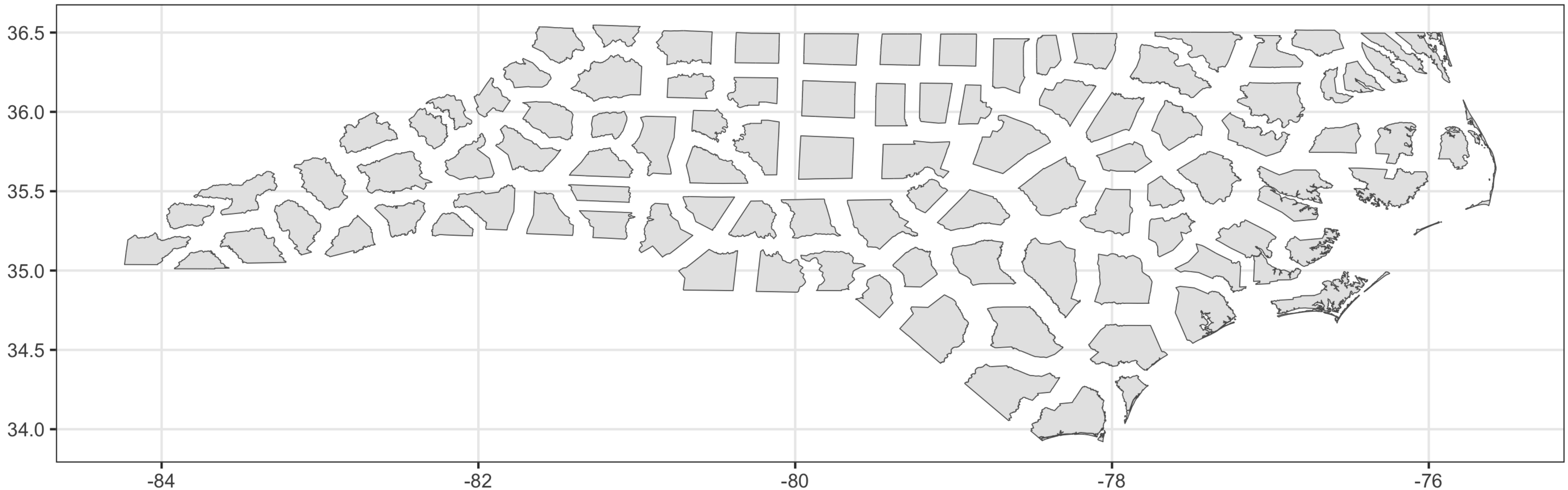
Affine Transformations

```
rotate = function(a) matrix(c(cos(a), sin(a), -sin(a), cos(a)), 2, 2)

state_rotate = (st_geometry(nc) * rotate(pi/8)) |> lwgeom::lwgeom_make_valid()
ggplot() + geom_sf(data=state_rotate)
```



Scaling + Translations

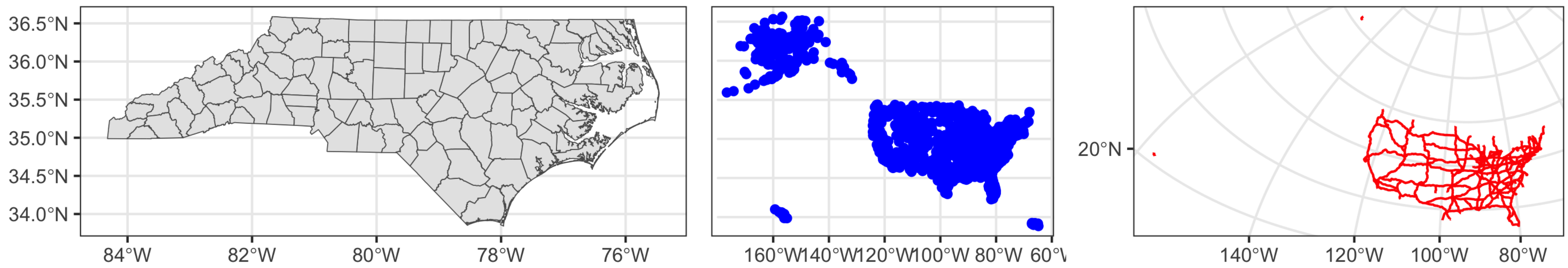
```
ctrd = st_centroid(st_geometry(nc))
nc_scaled = (st_geometry(nc) - ctrd) * 0.66 + ctrd

ggplot() + geom_sf(data=nc_scaled)
```



Some other data

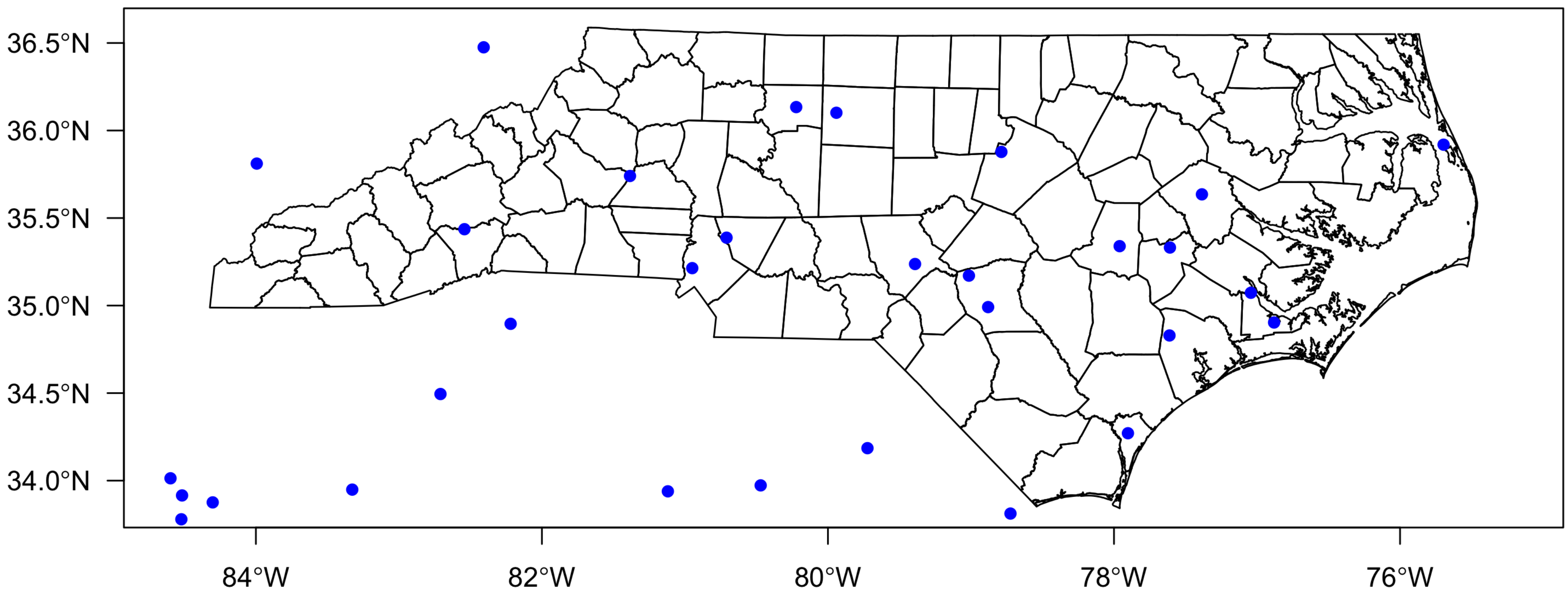
```r
air = read_sf("data/gis/airports/", quiet=TRUE)
hwy = read_sf("data/gis/us_interstates/", quiet=TRUE)
```

```r
(ggplot(nc) + geom_sf()) +
(ggplot(air) + geom_sf(color = "blue")) +
(ggplot(hwy) + geom_sf(color = "red"))
```



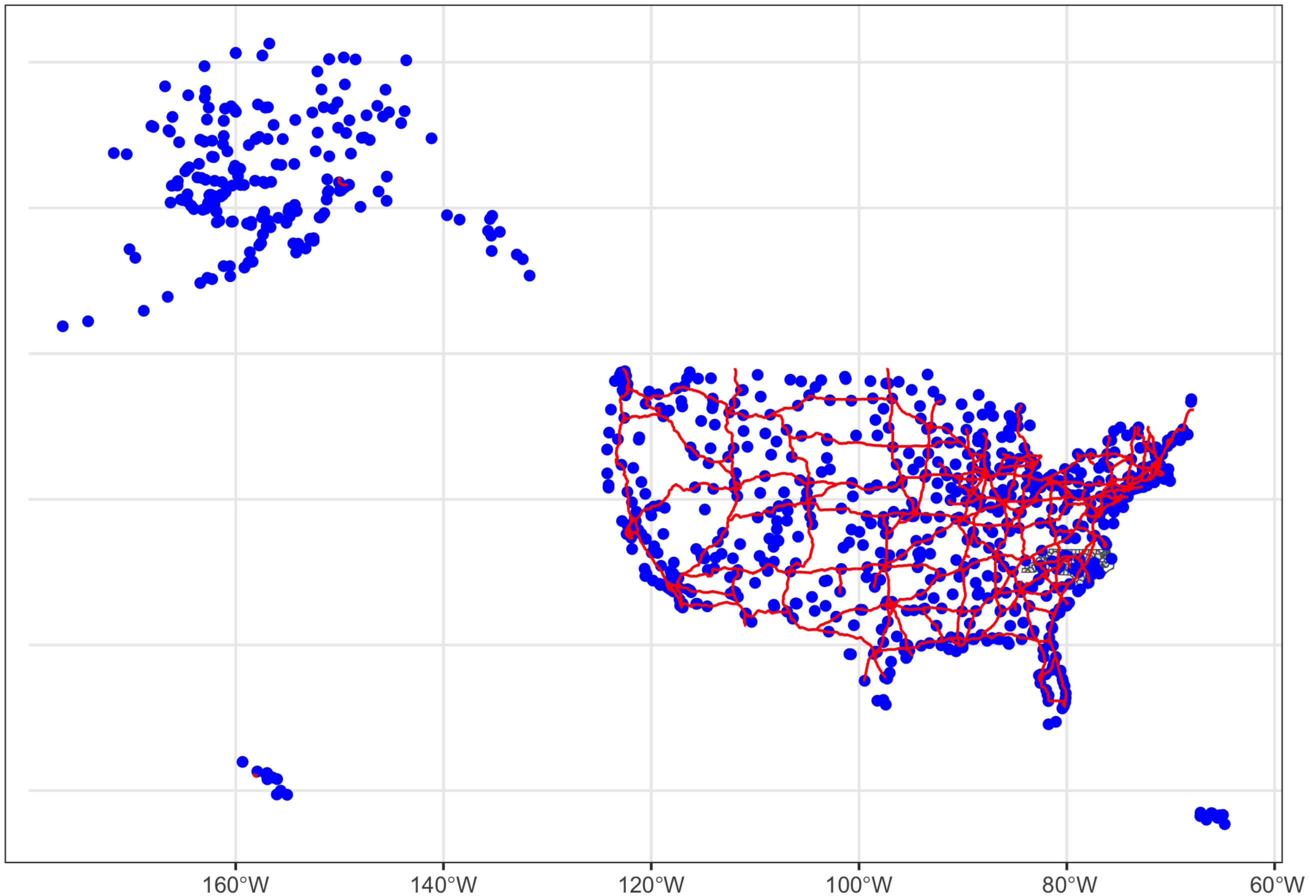
Overlays w/ base plots

```r
plot(st_geometry(nc),  axes=TRUE, las=1)
plot(st_geometry(air), axes=TRUE, pch=16, col="blue", main="air", add=TRUE)
plot(st_geometry(hwy), axes=TRUE, col="red", add=TRUE)
```



Overlays w/ ggplot

```
ggplot() +
  geom_sf(data=nc) +
  geom_sf(data=air, color="blue") +
  geom_sf(data=hwy, color="red")
```



Projections

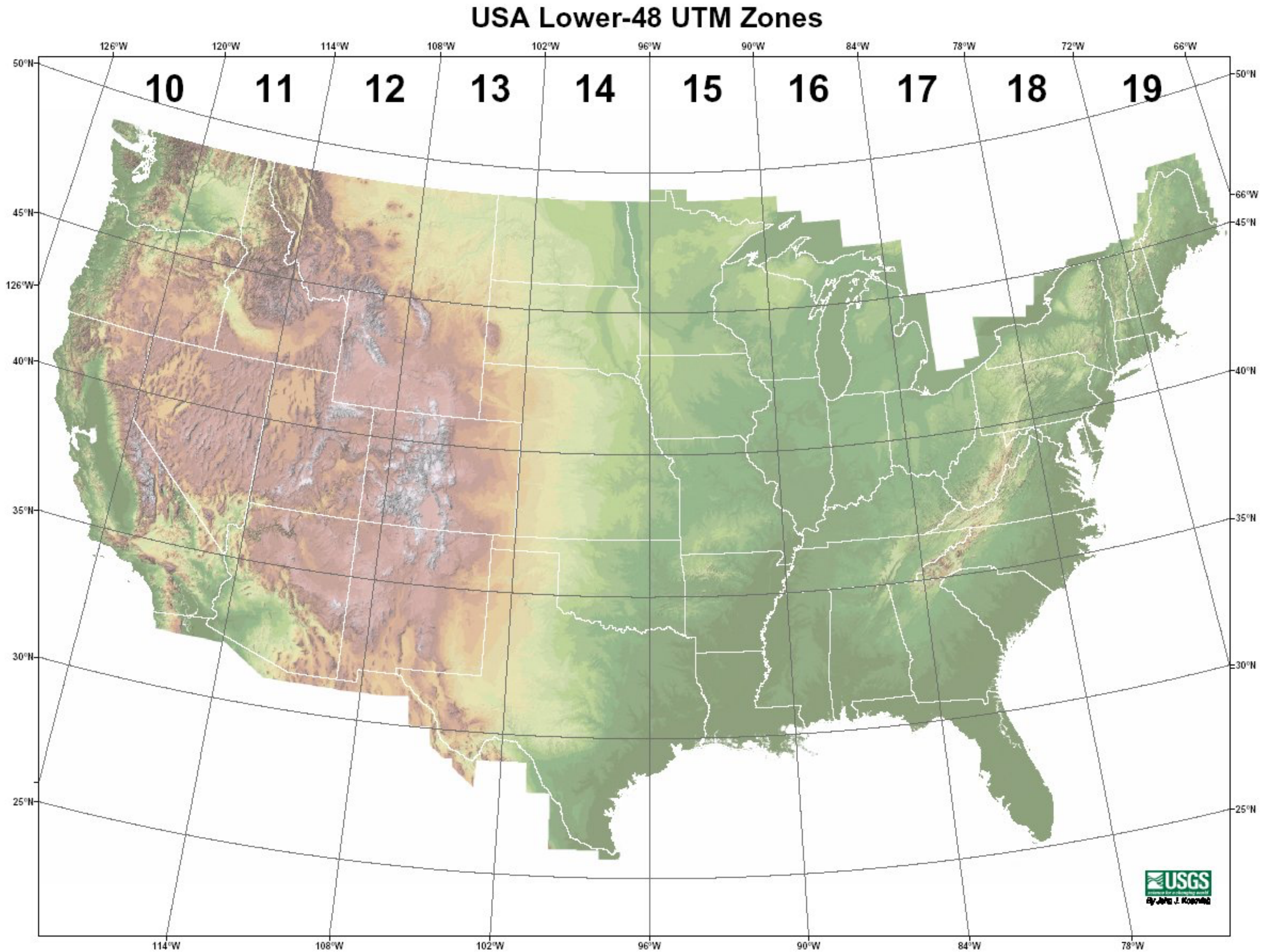
```r
st_crs(nc)
```

```
Coordinate Reference System:
  User input: NAD83
  wkt:
GEOGCRS["NAD83",
    DATUM["North American Datum 1983",
        ELLIPSOID["GRS 1980",6378137,298.257222101,
            LENGTHUNIT["metre",1]]],
    PRIMEM["Greenwich",0,
        ANGLEUNIT["degree",0.0174532925199433]],
    CS[ellipsoidal,2],
        AXIS["latitude",north,
            ORDER[1],

ANGLEUNIT["degree",0.0174532925199433]],
        AXIS["longitude",east,
            ORDER[2],
```

```r
st_crs(hwy)
```

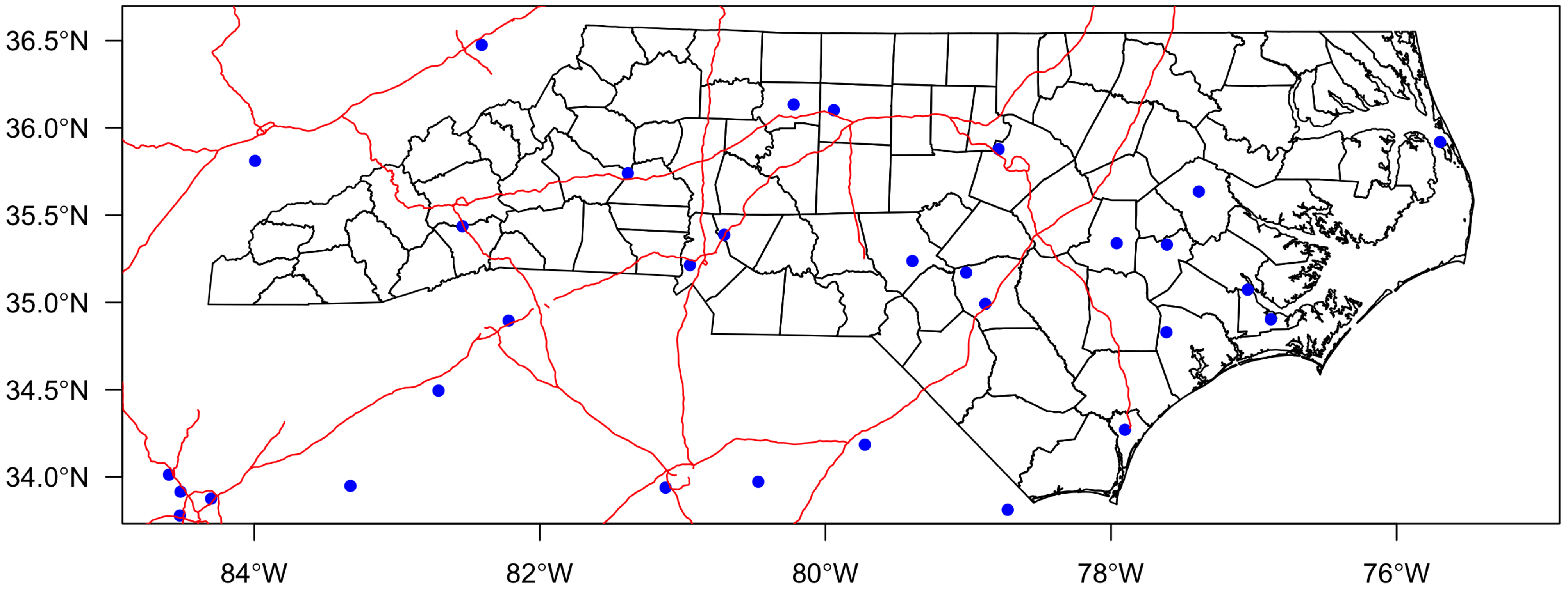
```
Coordinate Reference System:
  User input: NAD83 / UTM zone 15N
  wkt:
PROJCRS["NAD83 / UTM zone 15N",
    BASEGEOGCRS["NAD83",
        DATUM["North American Datum 1983",
            ELLIPSOID["GRS
1980",6378137,298.257222101,
                LENGTHUNIT["metre",1]]],
        PRIMEM["Greenwich",0,

ANGLEUNIT["degree",0.0174532925199433]],
        ID["EPSG",4269]],
    CONVERSION["UTM zone 15N",
        METHOD["Transverse Mercator",
            ID["EPSG",9807]],
        PARAMETER["Latitude of natural origin",0,
```

Aside - UTM Zones



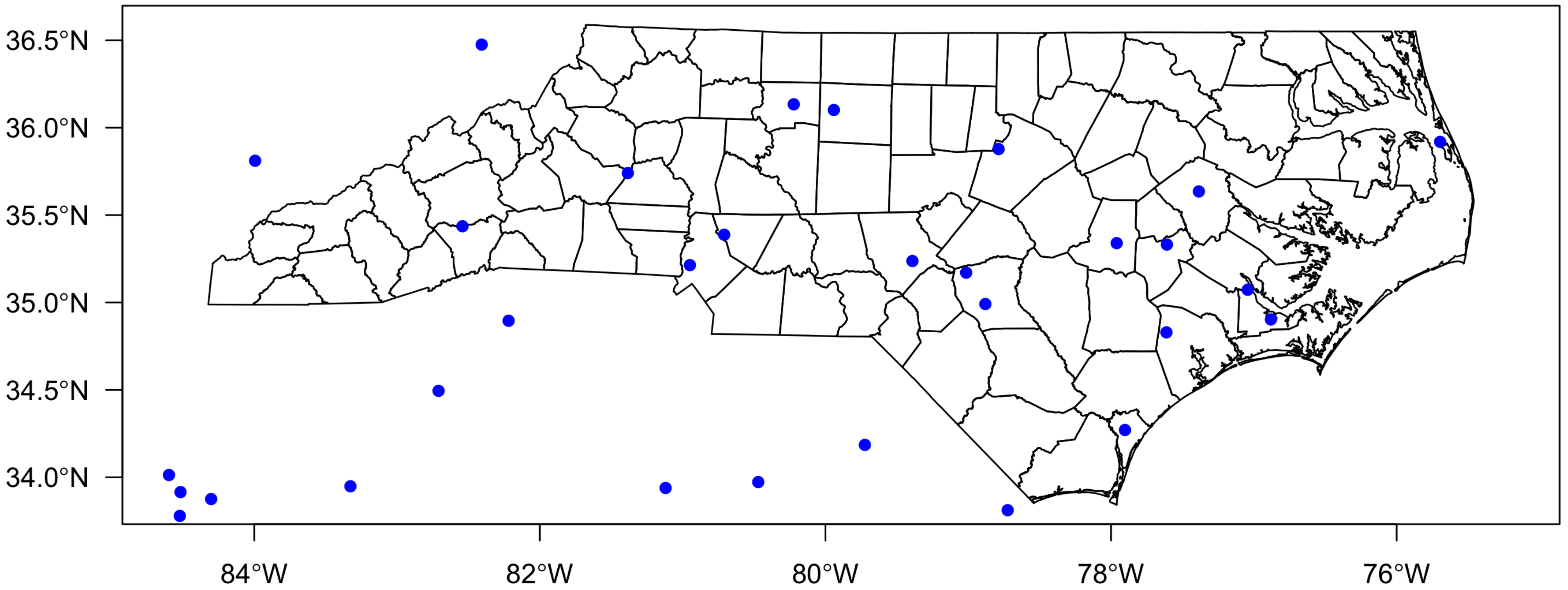
hwy -> Lat/Long

```r
hwy = st_transform(hwy, st_crs(nc))
```



Airport Example

NC Airports



Sparse Insections

```
st_intersects(nc[20:30,], air) |> str()
```

```
List of 11
 $ : int(0) 
 $ : int(0) 
 $ : int(0) 
 $ : int(0) 
 $ : int(0) 
 $ : int 268
 $ : int 717
 $ : int(0) 
 $ : int(0) 
 $ : int(0) 
 $ : int(0) 
 - attr(*, "predicate")= chr "intersects"
 - attr(*, "region.id")= chr [1:11] "1" "2" "3" "4" ...
 - attr(*, "remove_self")= logi FALSE
 - attr(*, "retain_unique")= logi FALSE
 - attr(*, "ncol")= int 940
```

Dense Insections

```
st_intersects(nc, air, sparse=FALSE) |> str()
```

```
logi [1:100, 1:940] FALSE FALSE FALSE FALSE FALSE FALSE ...
```

```
st_intersects(nc, air, sparse=FALSE) |> (\(x) x[20:30, 260:270])()
```

```
       [,1]  [,2]  [,3]  [,4]  [,5]  [,6]  [,7]  [,8]  [,9] [,10] [,11]
 [1,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
 [2,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
 [3,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
 [4,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
 [5,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
 [6,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE  TRUE FALSE FALSE
 [7,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
 [8,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
 [9,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[10,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
[11,] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
```

Which counties have airports?

```
nc_air = nc |>
  mutate(
    n_air = map_int(
      st_intersects(nc, air),
      length
    )
  ) |>
  filter(n_air > 0)

nc_air |> pull(COUNTY)
```

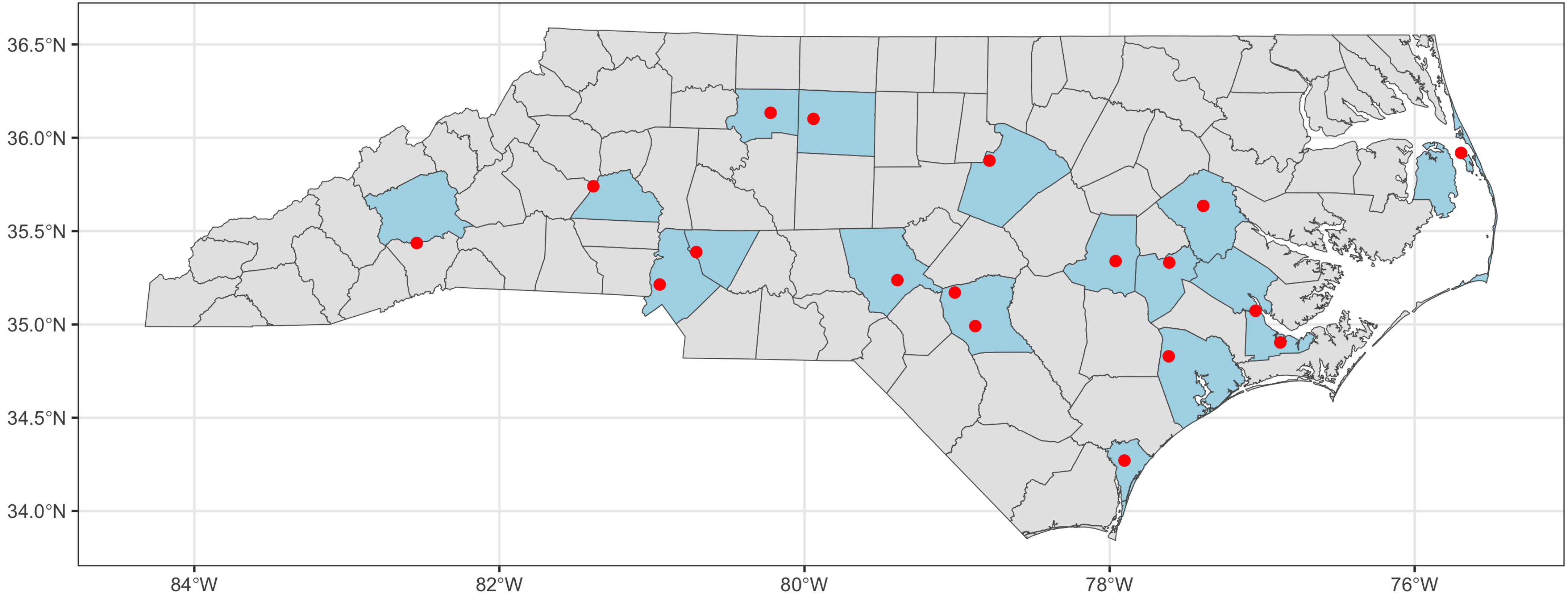
```
 [1] "Forsyth County"     "Guilford County"
"Dare County"
 [4] "Wake County"        "Pitt County"
"Catawba County"
 [7] "Buncombe County"    "Wayne County"
"Mecklenburg County"
[10] "Moore County"       "Cabarrus County"
"Lenoir County"
[13] "Craven County"      "Cumberland County"
"Onslow County"
[16] "New Hanover County"
```

```
air_nc = air |>
  slice(
    st_intersects(nc, air) |>
      unlist() |>
      unique()
  )
air_nc |> pull(AIRPT_NAME)
```

```
 [1] "SMITH REYNOLDS AIRPORT"
 [2] "PIEDMONT TRIAD INTERNATIONAL AIRPORT"
 [3] "DARE COUNTY REGIONAL AIRPORT"
 [4] "RALEIGH-DURHAM INTERNATIONAL AIRPORT"
 [5] "PITT-GREENVILLE AIRPORT"
 [6] "HICKORY REGIONAL AIRPORT"
 [7] "ASHEVILLE REGIONAL AIRPORT"
 [8] "SEYMOUR JOHNSON AIR FORCE BASE"
 [9] "CHARLOTTE/DOUGLAS INTERNATIONAL AIRPORT"
[10] "MOORE COUNTY AIRPORT"
[11] "CONCORD REGIONAL AIRPORT"
[12] "KINSTON REGIONAL JETPORT AT STALLINGS FIELD"
[13] "CHERRY POINT MARINE CORPS AIR STATION
/CUNNINGHAM FIELD/"
[14] "COASTAL CAROLINA REGIONAL AIRPORT"
[15] "POPE AIR FORCE BASE"
[16] "FAYETTEVILLE REGIONAL/GRANNIS FIELD"
```

Results

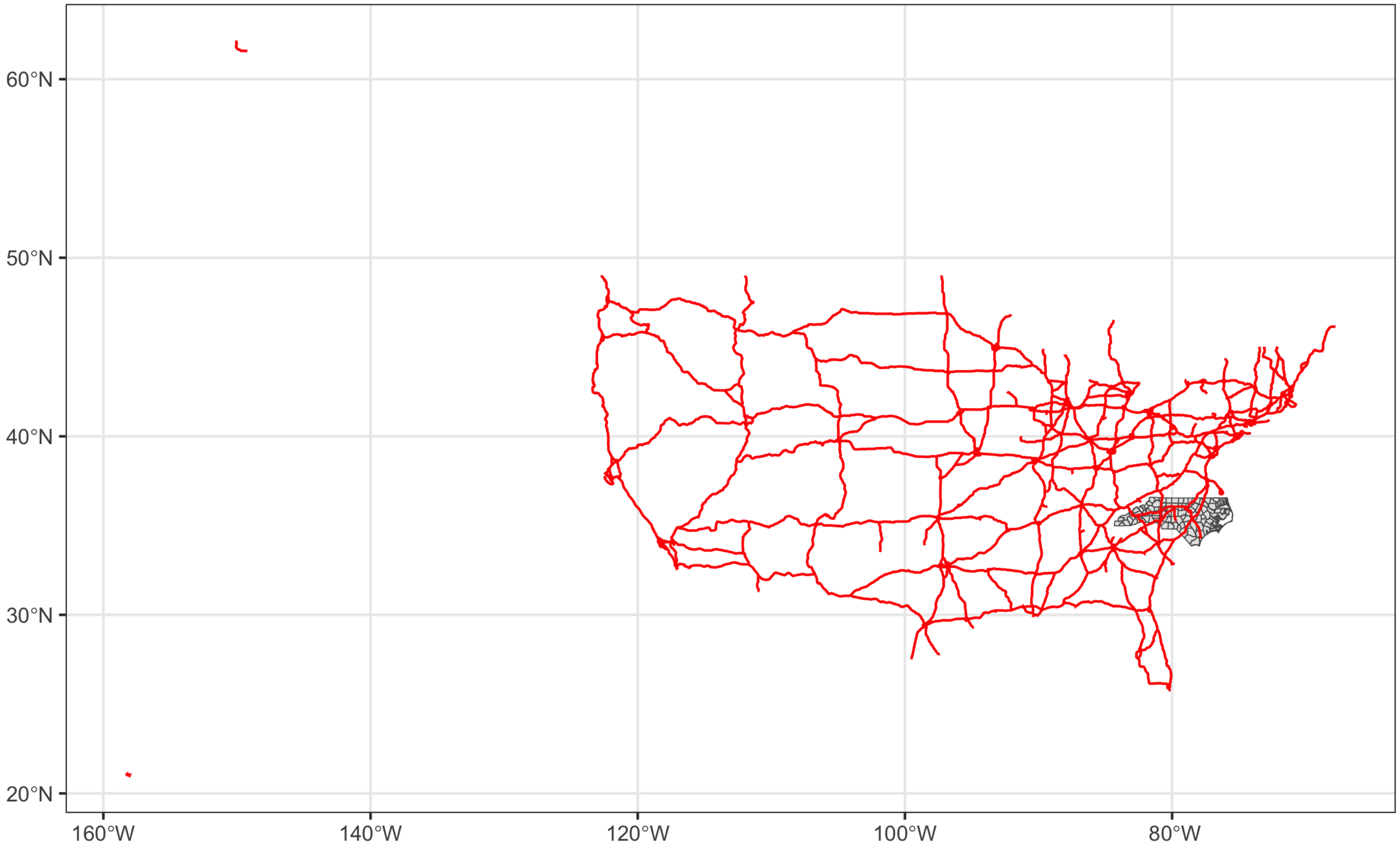
```r
ggplot() +
  geom_sf(data=nc) +
  geom_sf(data = nc_air, fill = "lightblue") +
  geom_sf(data = air_nc, color = "red", size=2)
```



Highway Example

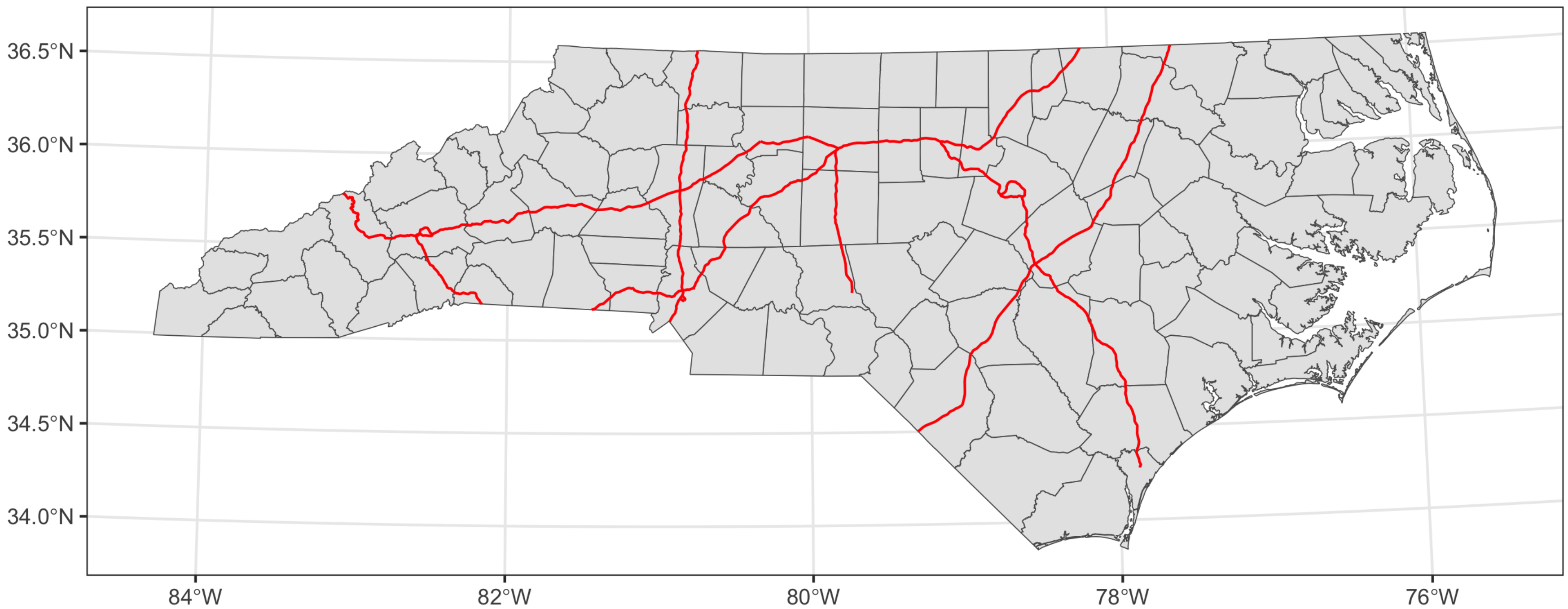
Highways

```r
ggplot() +
  geom_sf(data=nc) +
  geom_sf(data=hwy, col='red')
```



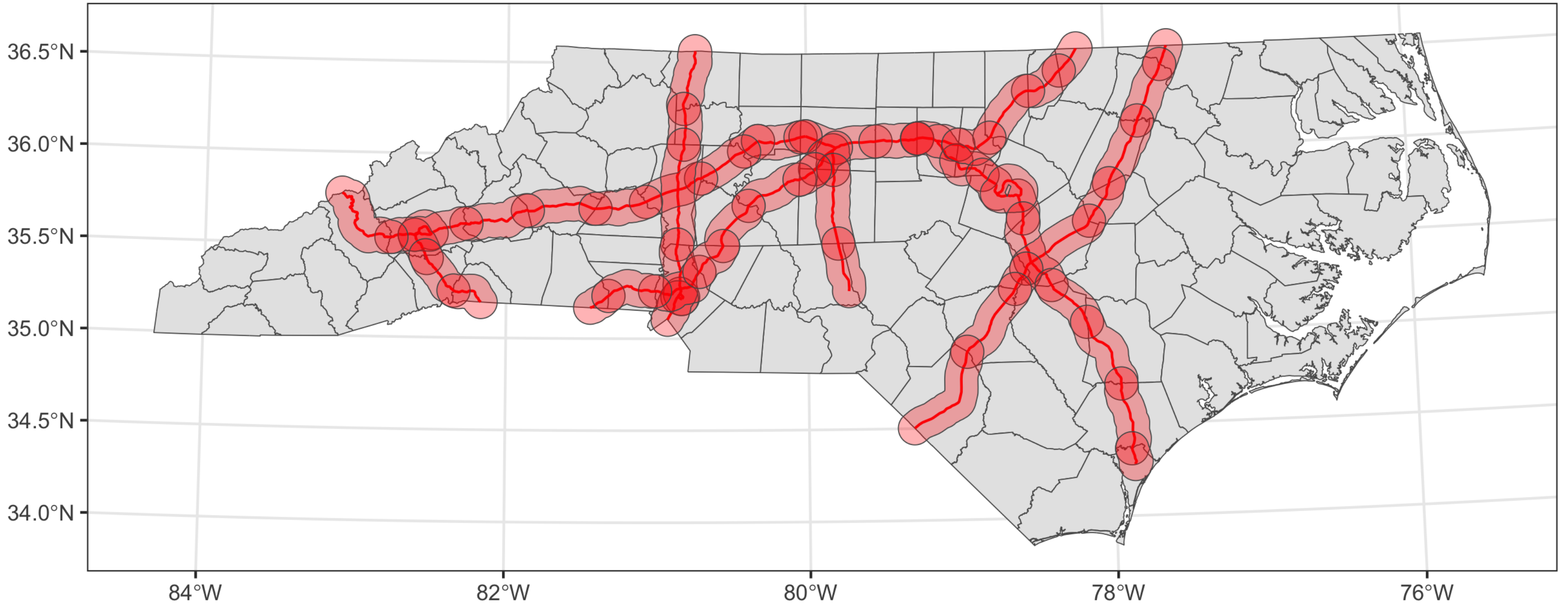
Intersection

```r
nc_utm  = st_transform(nc, "+proj=utm +zone=17 +datum=NAD83 +units=m +no_defs")
hwy_utm  = st_transform(hwy, "+proj=utm +zone=17 +datum=NAD83 +units=m +no_defs")

hwy_nc = st_intersection(hwy_utm, nc_utm)

ggplot() +
  geom_sf(data=nc_utm) +
  geom_sf(data=hwy_nc, col='red')
```



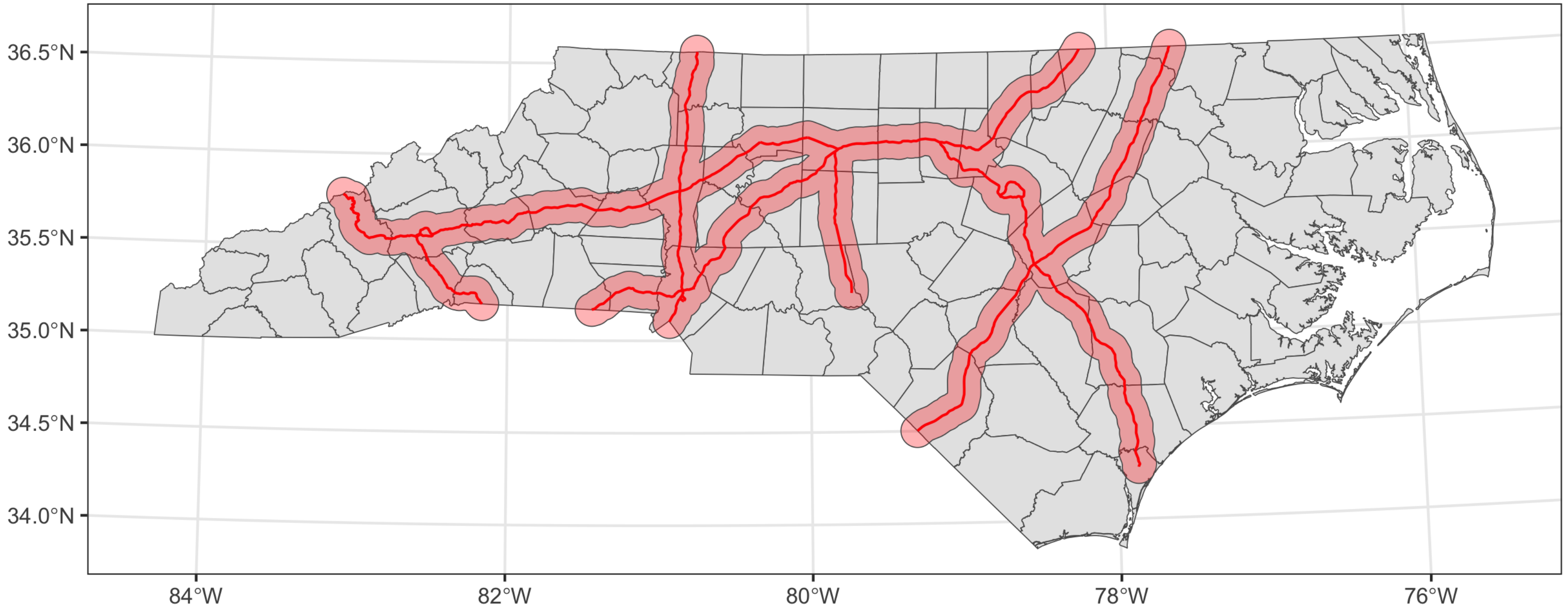
Buffering

```r
hwy_nc_buffer = hwy_nc |>
  st_buffer(10000)

ggplot() +
  geom_sf(data=nc_utm) +
  geom_sf(data=hwy_nc, color='red') +
  geom_sf(data=hwy_nc_buffer, fill='red', alpha=0.3)
```



Buffering + Union

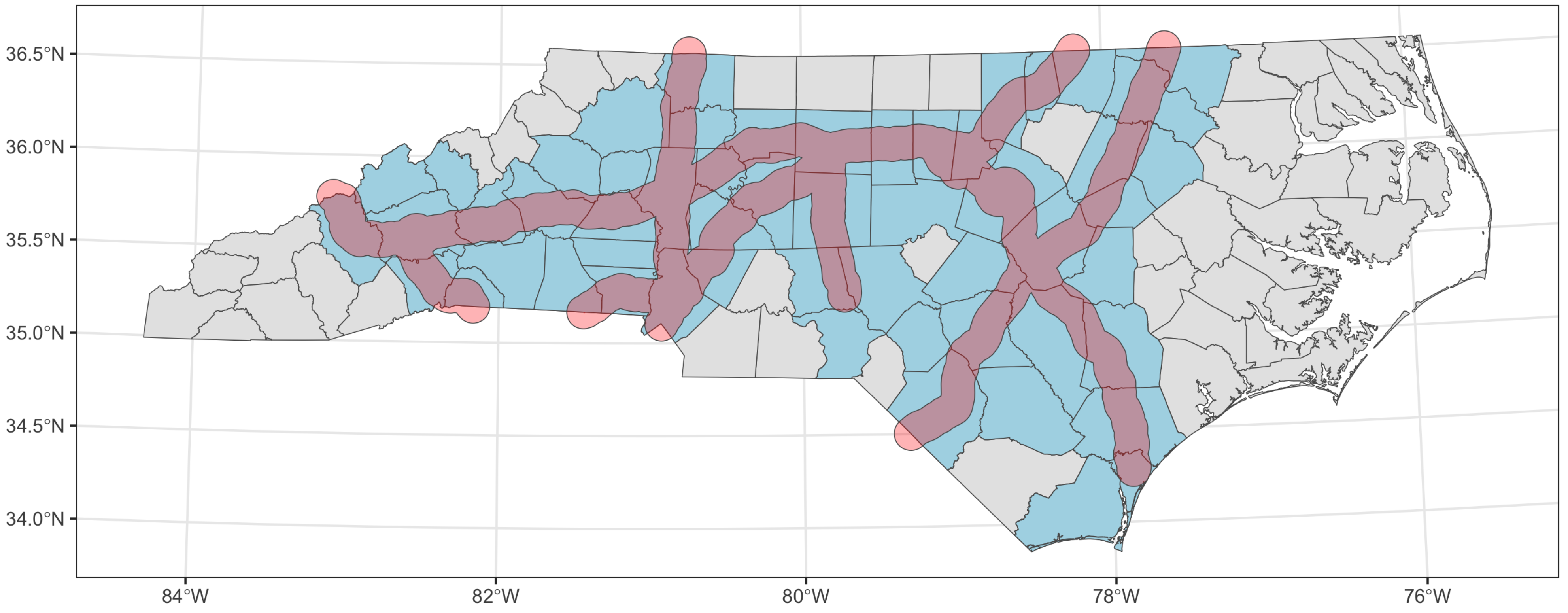
```
hwy_nc_buffer = hwy_nc |>
  st_buffer(10000) |>
  st_union() |>
  st_sf()

ggplot() +
  geom_sf(data=nc_utm) +
  geom_sf(data=hwy_nc, color='red') +
  geom_sf(data=hwy_nc_buffer, fill='red', alpha=0.3)
```



Counties near the interstate (Buffering + Union)

```
hwy_nc_buffer = hwy_nc |>
  st_buffer(10000) |>
  st_union() |>
  st_sf()

hwy_cty = nc_utm |>
  slice(
    st_intersects(hwy_nc_buffer, nc_utm) |>
      unlist() |>
      unique()
  )

ggplot() +
  geom_sf(data=nc_utm) +
  geom_sf(data=hwy_nc, color='red') +
  geom_sf(data=hwy_cty, fill='lightblue') +
  geom_sf(data=hwy_nc_buffer, fill='red', alpha=0.3)
```

Counties near the interstate (Buffering + Union)



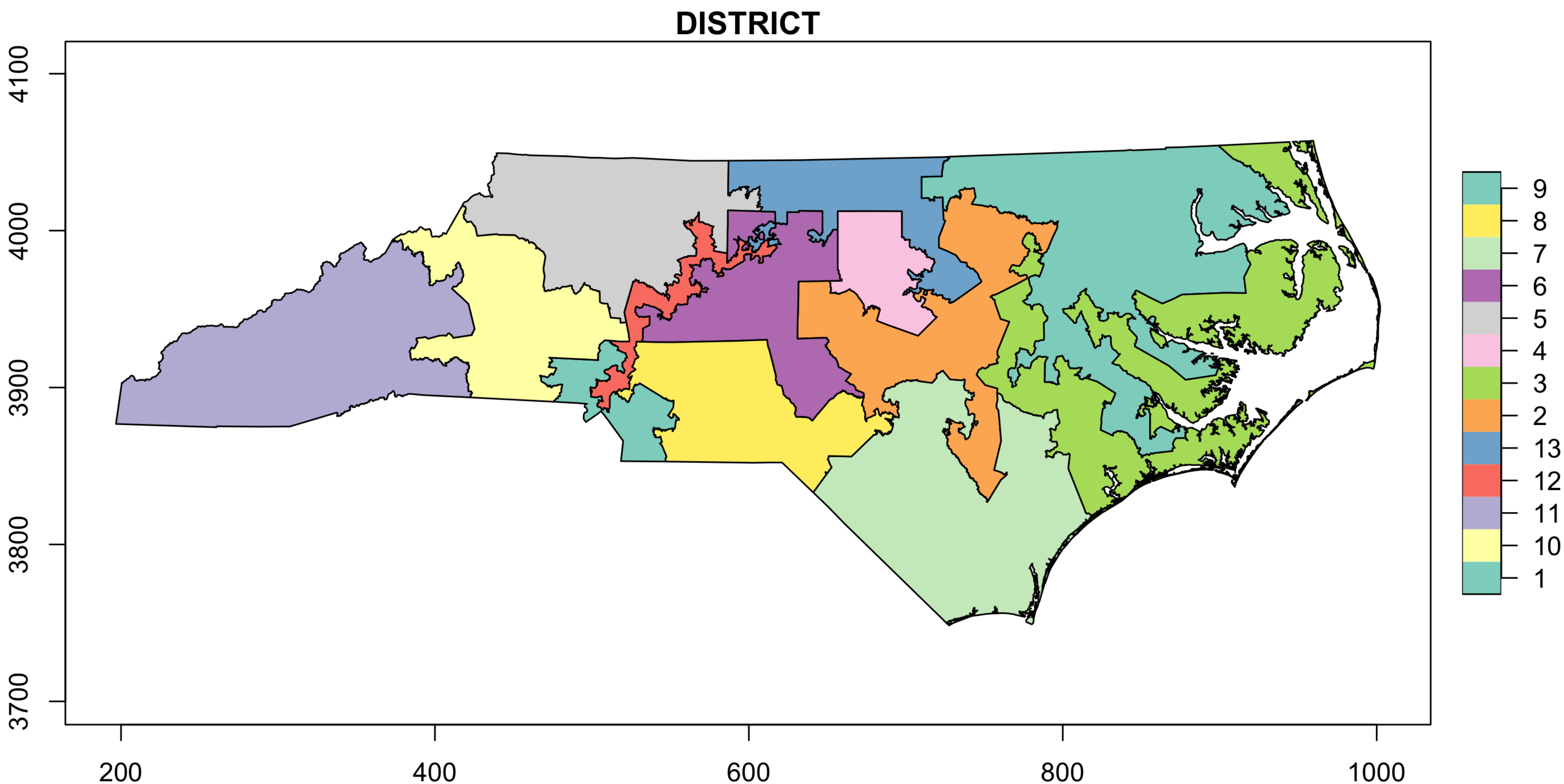
Gerrymandering Example

NC House Districts - 112th Congress

```r
( nc_house = read_sf("data/gis/nc_districts112.gpkg", quiet = TRUE) |>
    select(ID, DISTRICT) )
```

```
Simple feature collection with 13 features and 2 fields
Geometry type: MULTIPOLYGON
Dimension:     XY
Bounding box:  xmin: -84.32187 ymin: 33.84452 xmax: -75.45998 ymax: 36.58812
Geodetic CRS:  WGS 84
# A tibble: 13 × 3
   ID           DISTRICT                                                      geom
   <chr>        <chr>                                            <MULTIPOLYGON [°]>
 1 037108112001 1        (((-77.32845 35.35031, -77.35398 35.32799, -77.33696 35.322…
 2 037108112002 2        (((-78.89928 35.12619, -78.89763 35.12859, -78.89257 35.129…
 3 037108112003 3        (((-75.68266 35.23291, -75.68113 35.23237, -75.68205 35.231…
 4 037108112004 4        (((-78.77926 35.78568, -78.77947 35.77568, -78.79458 35.775…
 5 037108112005 5        (((-79.8968 36.38075, -79.89213 36.37108, -79.89287 36.3682…
 6 037108112006 6        (((-80.4201 35.68953, -80.41483 35.68918, -80.41111 35.6825…
```

```r
nc_house = nc_house |>
  st_transform("+proj=utm +zone=17 +datum=NAD83 +units=km +no_defs")
plot(nc_house[,"DISTRICT"], axes=TRUE)
```

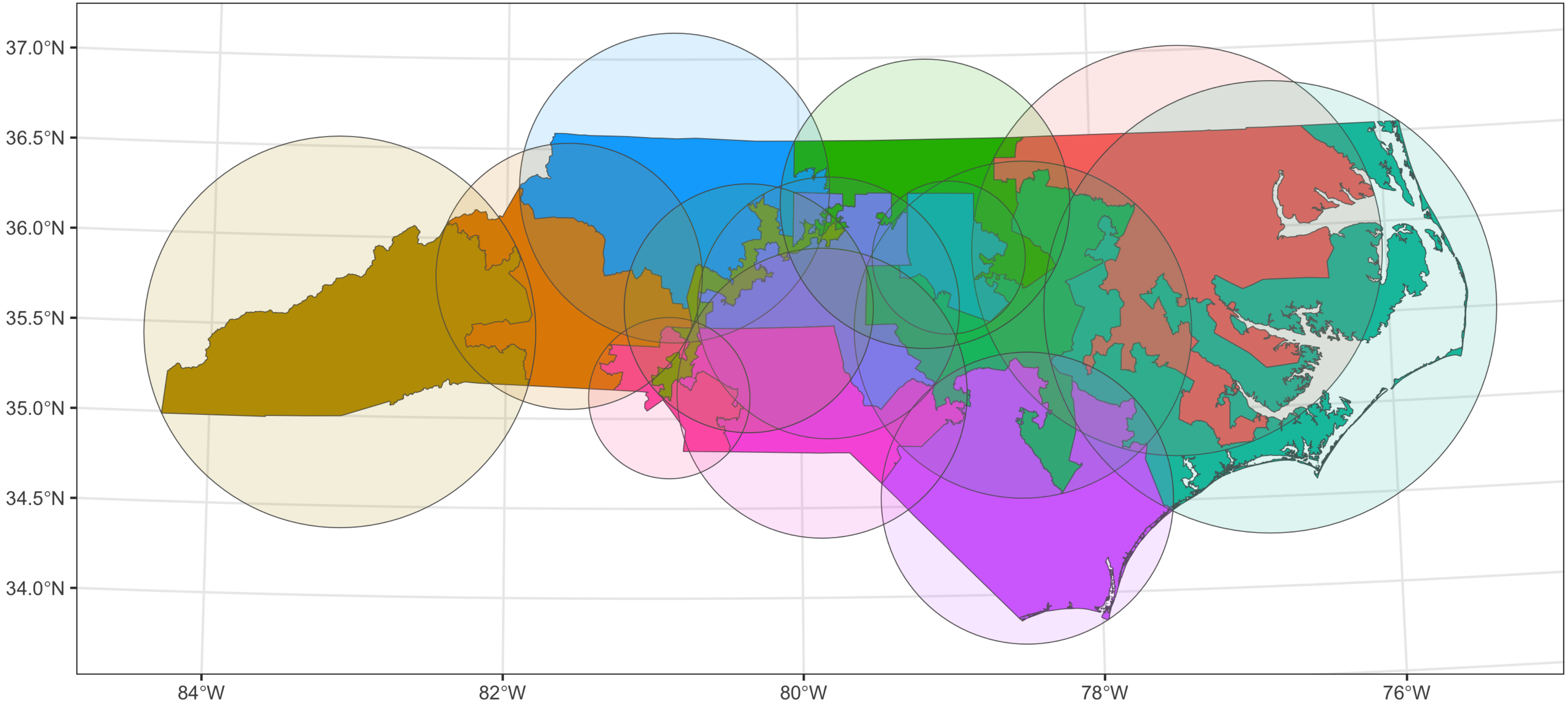


Measuring Compactness - Reock Score

The Reock score is a measure of compactness that is calculated as the ratio of a shape's area to the area of its minimum bounding circle.

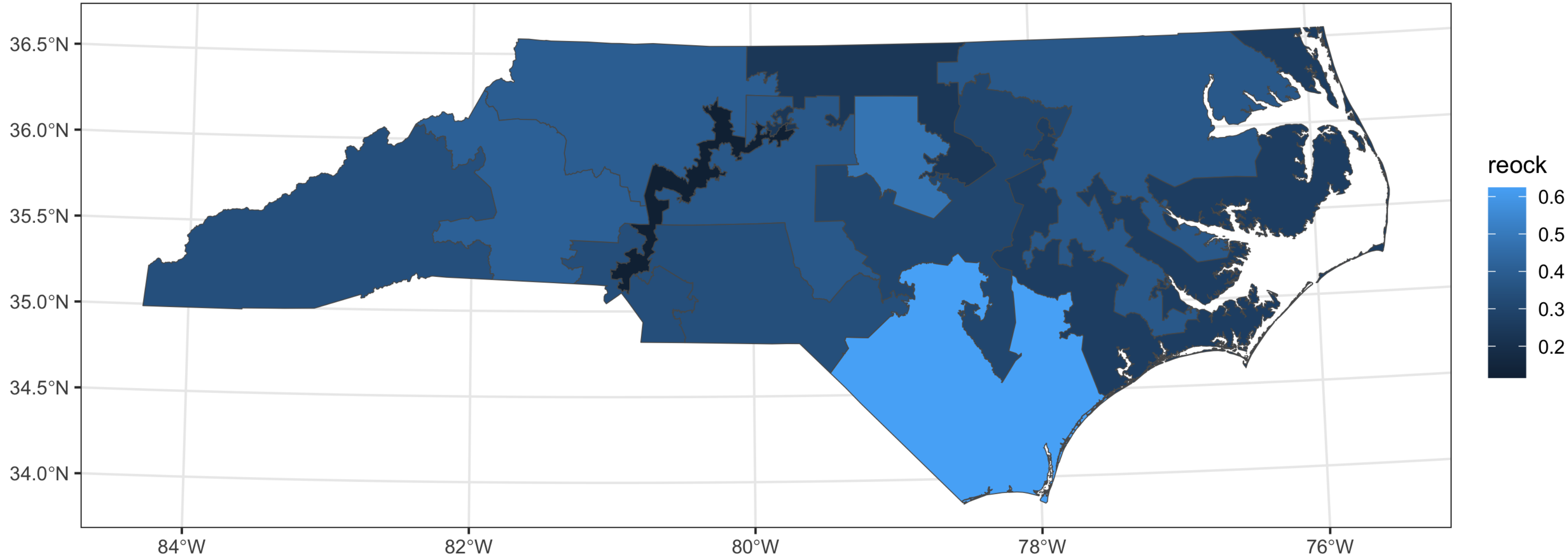
```r
circs = nc_house |>
  lwgeom::st_minimum_bounding_circle()
plot(circs |> filter(DISTRICT == 1) |> st_geometry())
plot(nc_house |> select(DISTRICT) |> filter(DISTRICT == 1), add=TRUE)
```

```r
ggplot(mapping = aes(fill=DISTRICT)) +
  geom_sf(data=nc_house) +
  geom_sf(data=circs, alpha=0.15) +
  guides(color="none", fill="none")
```



Calculating Reock

```r
nc_house |>
  mutate(reock = (st_area(nc_house) / st_area(circs)) |> as.numeric()) |>
  ggplot(aes(fill = reock)) +
    geom_sf()
```



```r
nc_house |>
  mutate(reock = st_area(nc_house) / st_area(circs)) |>
  arrange(reock) |>
  as_tibble() |>
  select(-geom) |>
  print(n=Inf)
```

```
# A tibble: 13 × 3
   ID           DISTRICT reock
   <chr>        <chr>      [1]
 1 037108112012 12       0.116
 2 037108112013 13       0.237
 3 037108112003 3        0.266
 4 037108112002 2        0.303
 5 037108112009 9        0.339
 6 037108112008 8        0.342
 7 037108112011 11       0.344
 8 037108112006 6        0.378
 9 037108112001 1        0.378
10 037108112005 5        0.399
11 037108112010 10       0.411
12 037108112004 4        0.480
13 037108112007 7        0.624
```