Spatial data & GIS tools

Lecture 22

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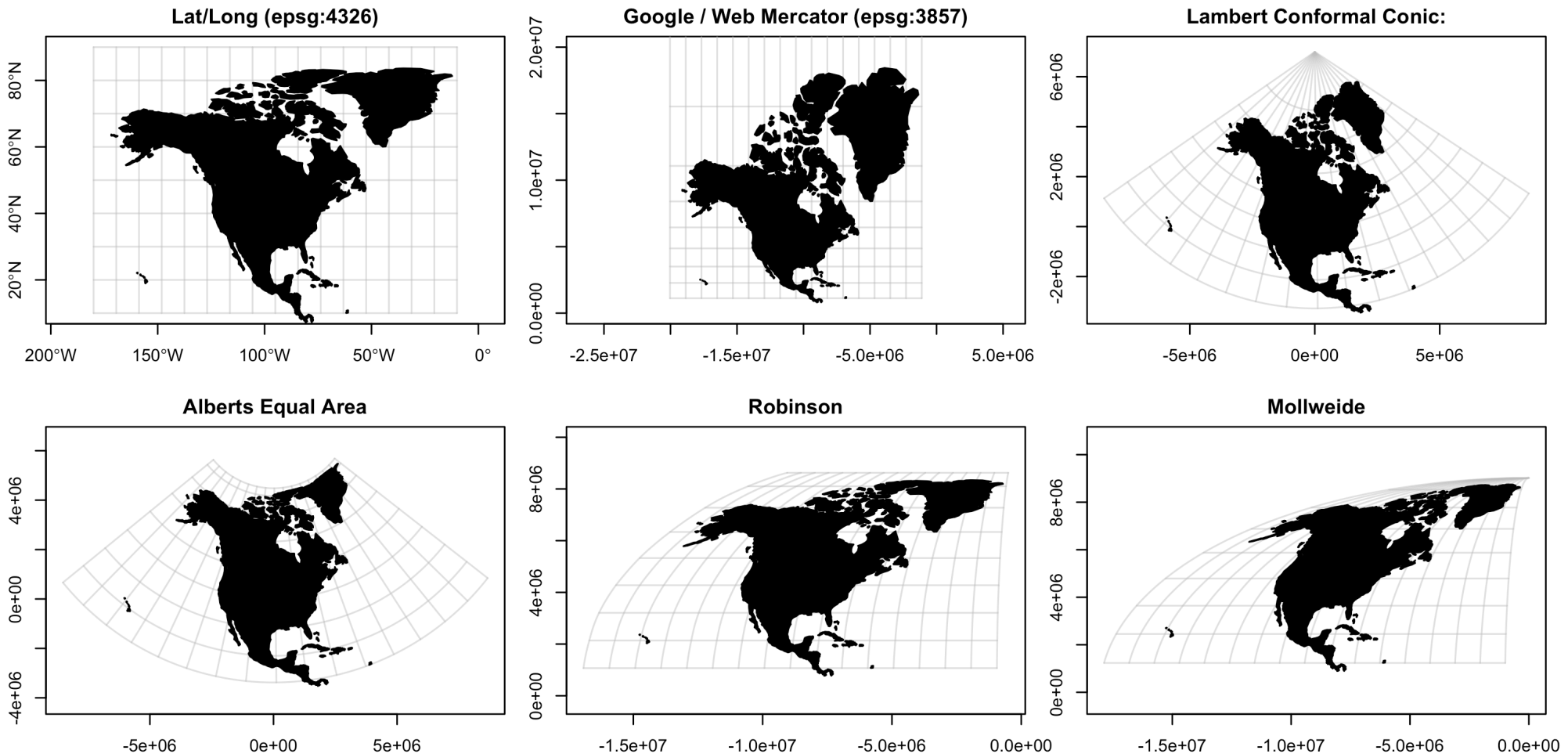
Geospatial stuff is hard

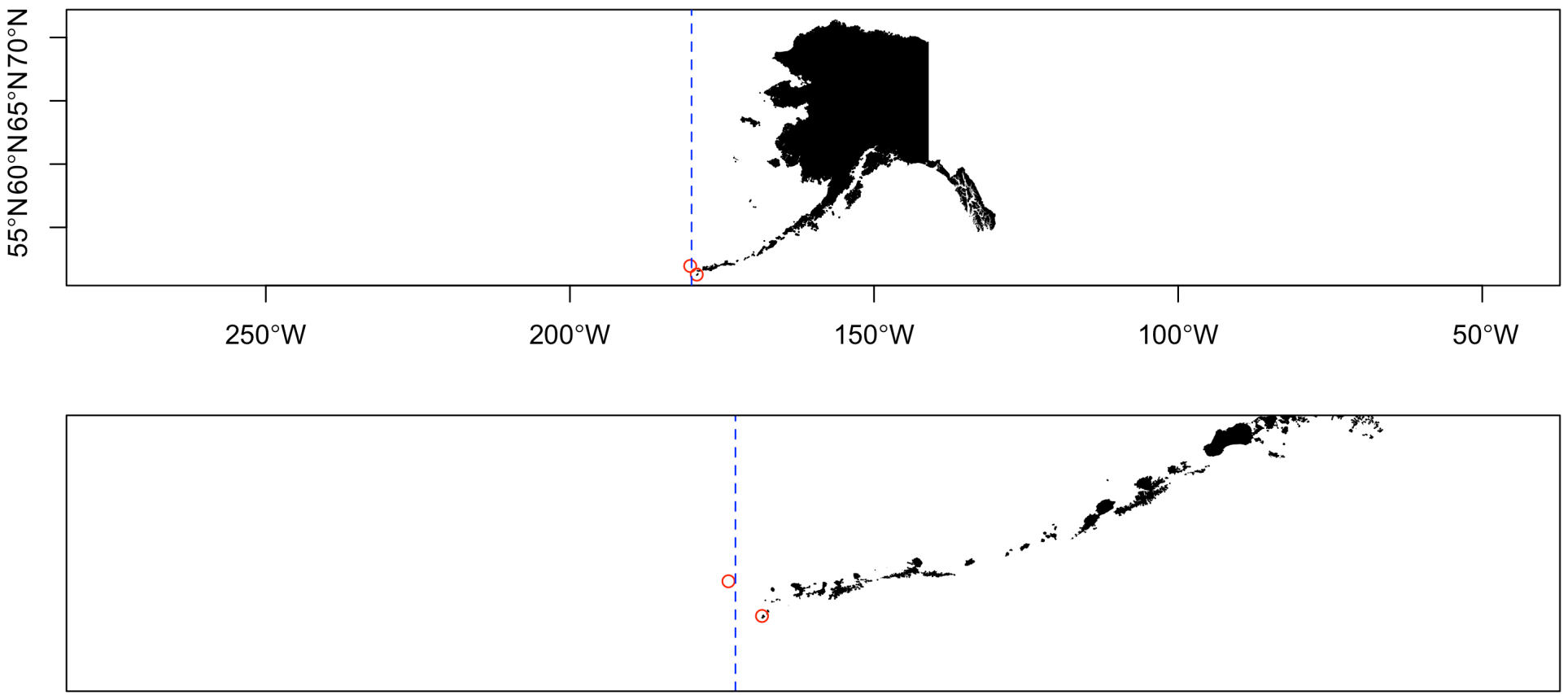
Projections



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

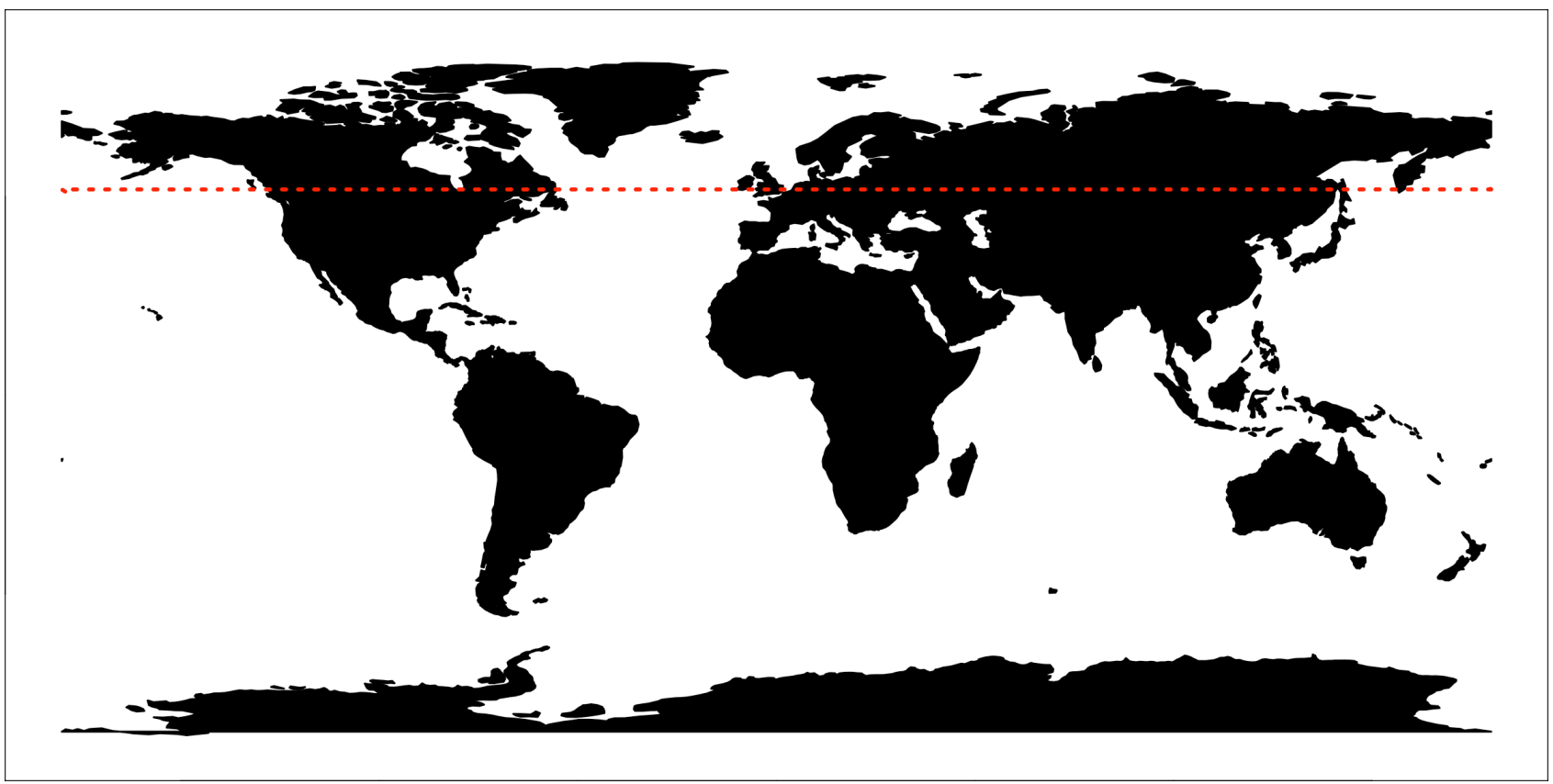
Dateline

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

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

See more - Spatial task view

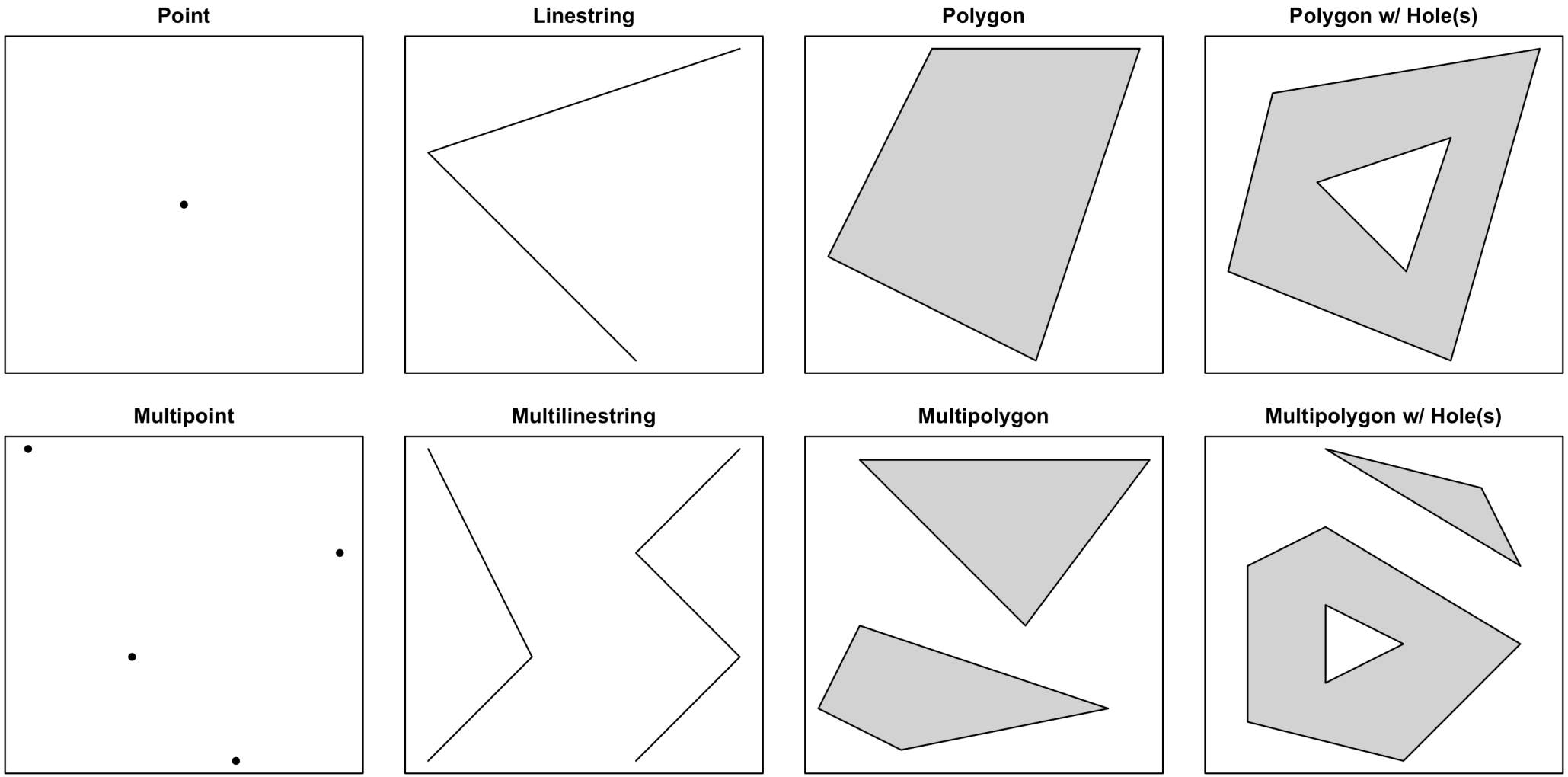
Installing `sf`

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 but returns tibbles
- `st_as_sfc` / `st_as_wkt` - WKT
- `st_as_sfc` / `st_as_binary` - WKB
- `st_as_sfc` / `as(x, "Spatial")` - sp

Shapefiles

```
1 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`

```
1 (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  0.14228609  2.207202       2004    NC Northampton County 37131         37
```

NC Counties - `sf` + `tbl`

```
1 (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.
```

`sf` classes

```
1 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" ...
```

```
1 class(nc)
```

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

```
1 class(nc)
```

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

```
1 class(nc$geometry)
```

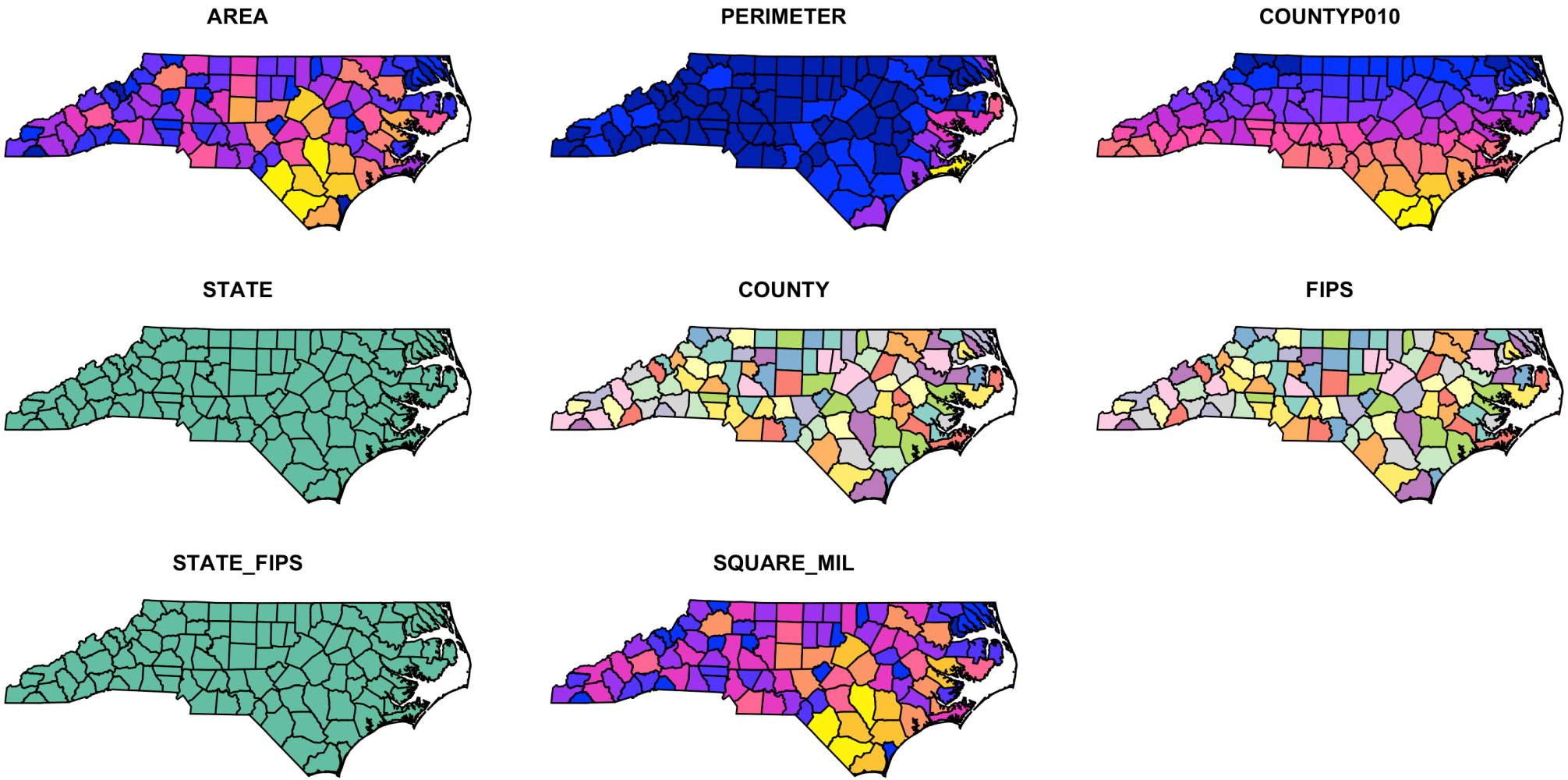
```
[1] "sfc_MULTIPOLYGON" "sfc"
```

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

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

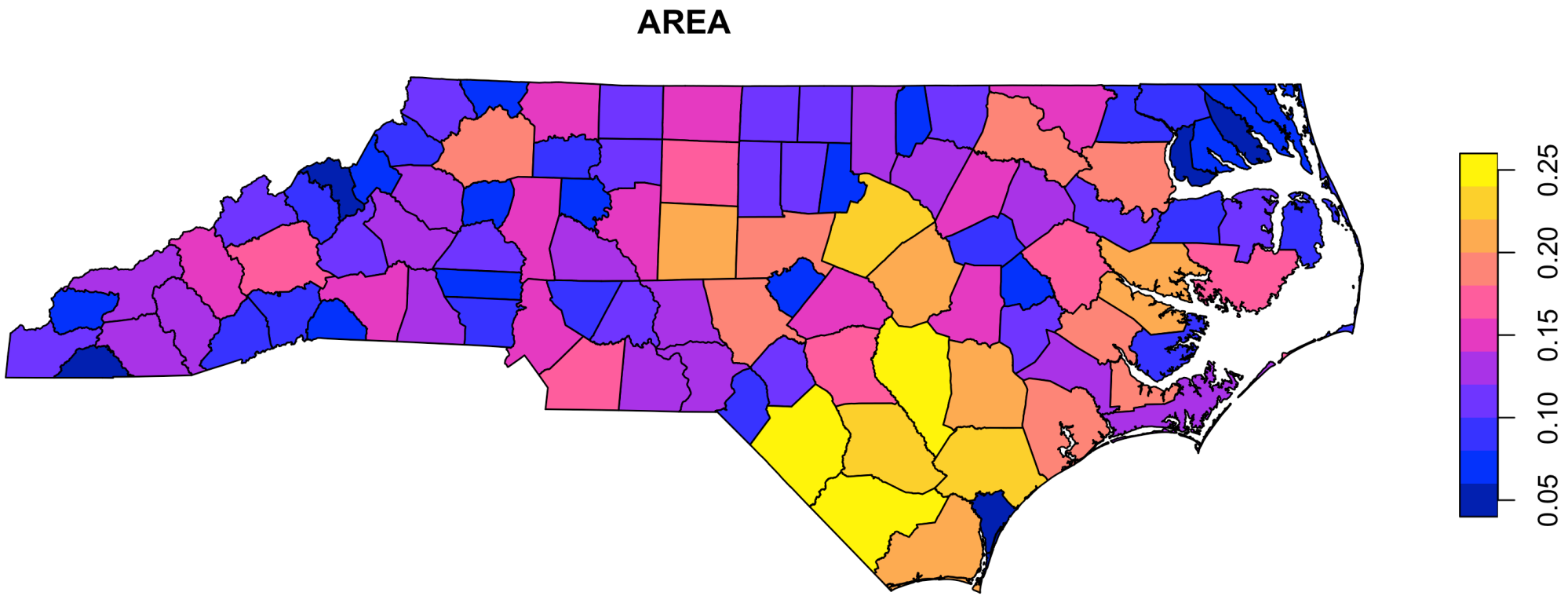
Plotting

```
1 plot(nc)
```



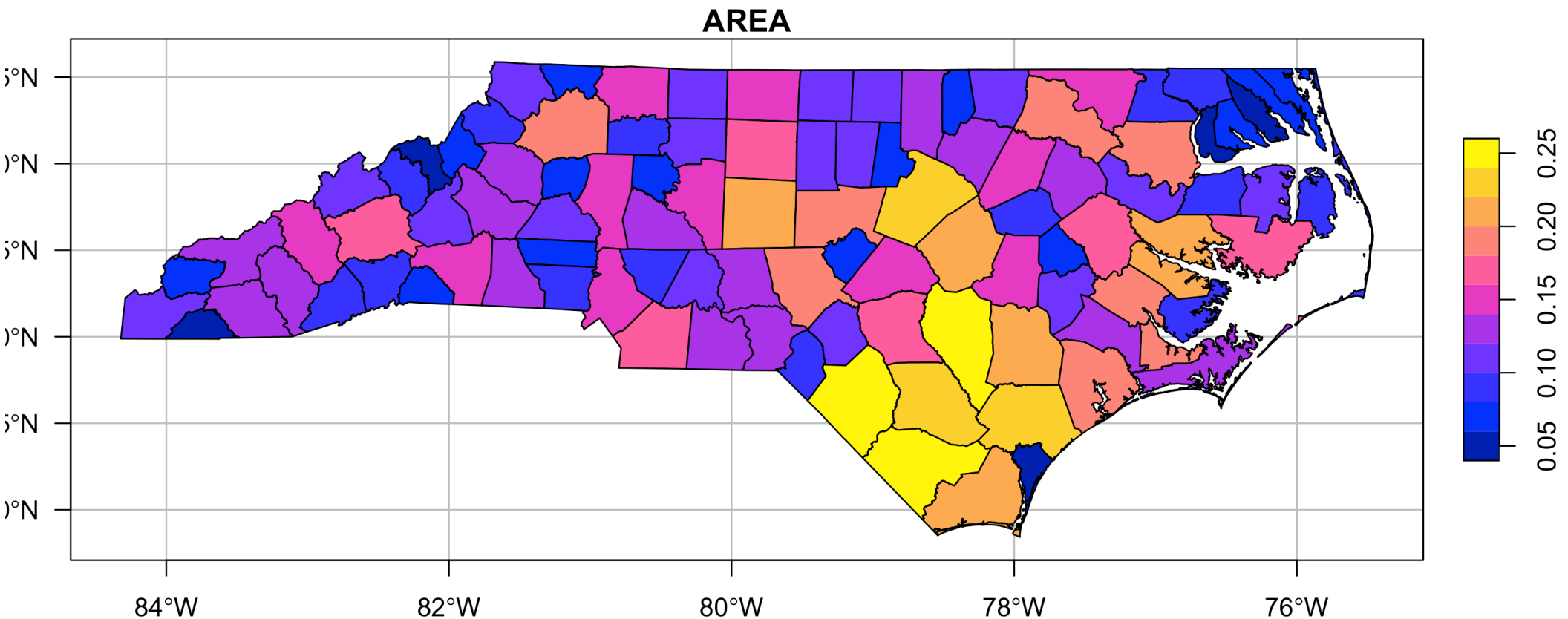
More Plotting

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



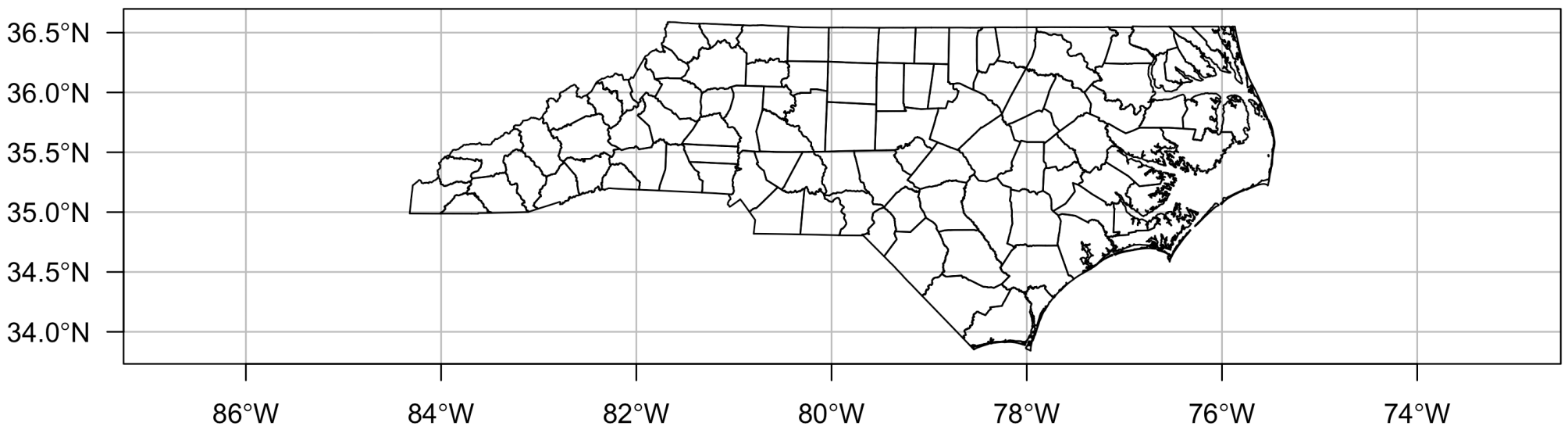
Graticules

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



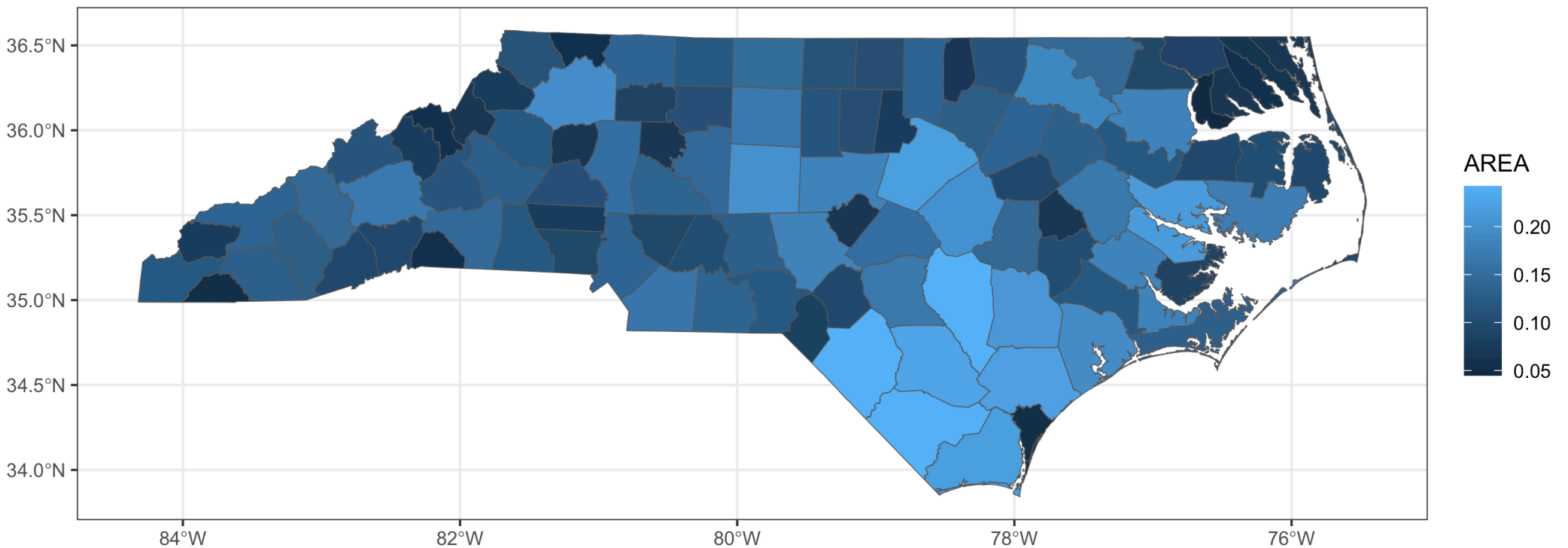
Geometries

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



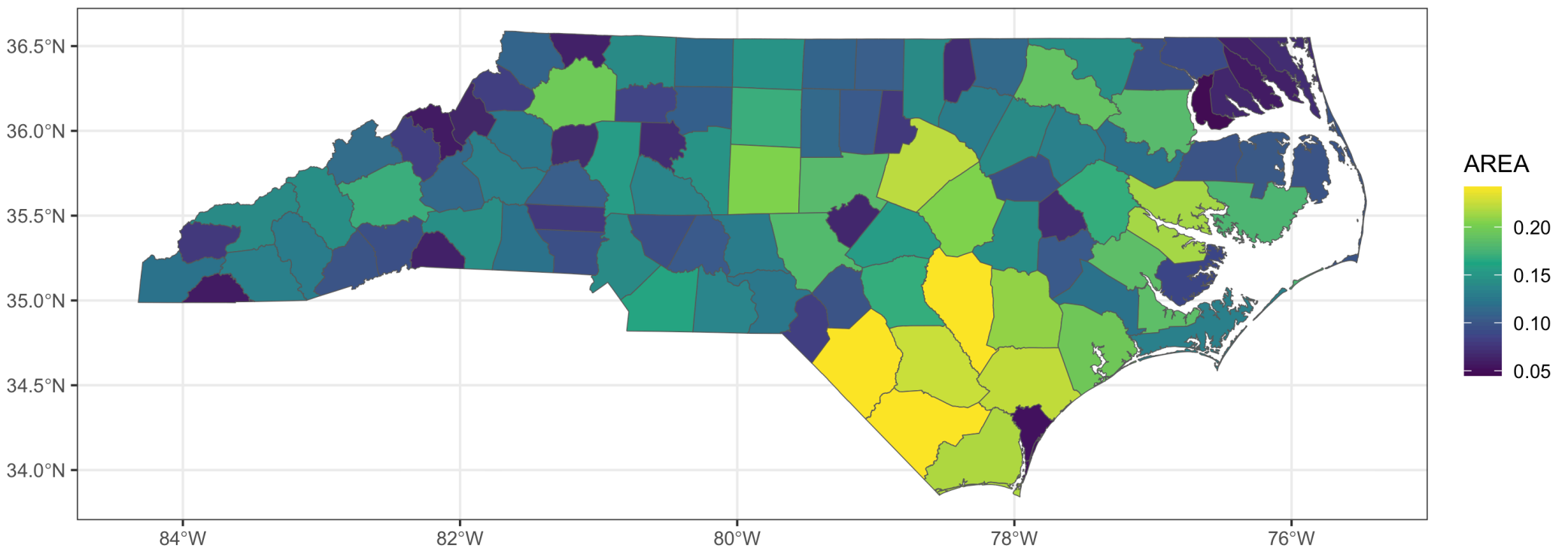
ggplot2

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



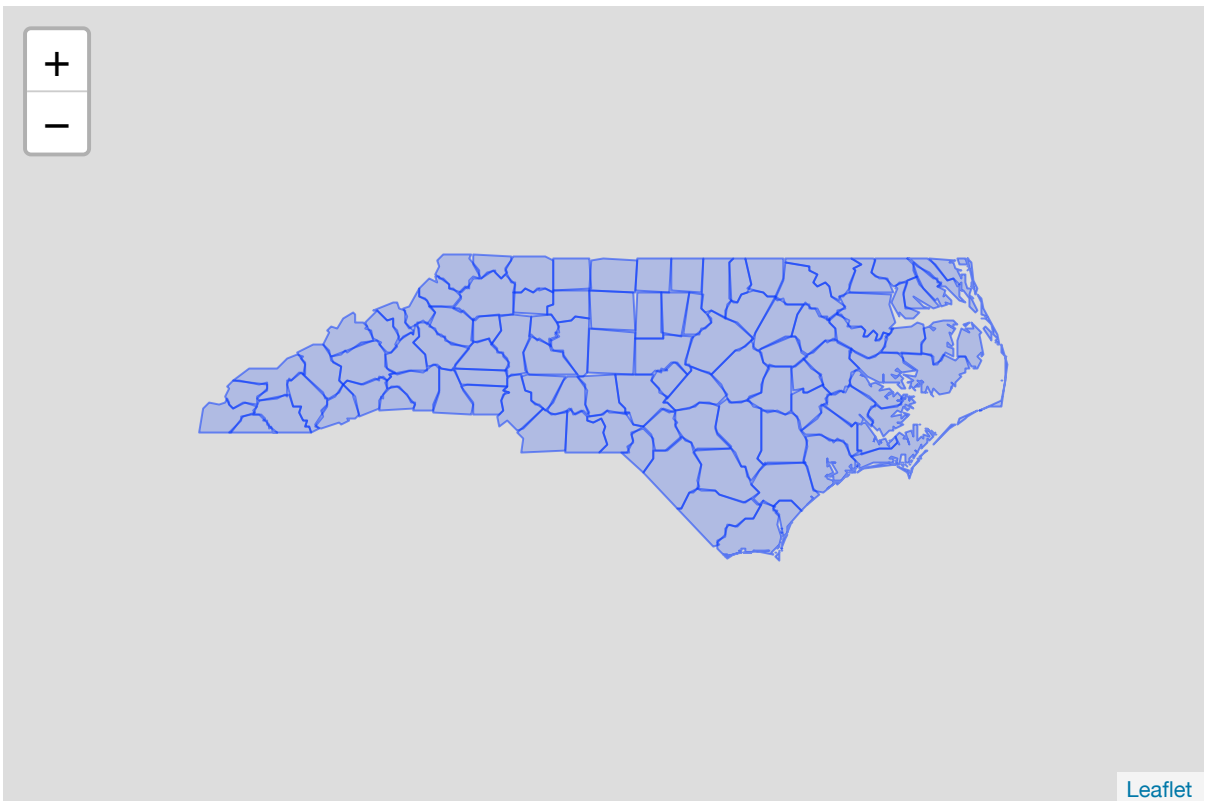
ggplot2 + palettes

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



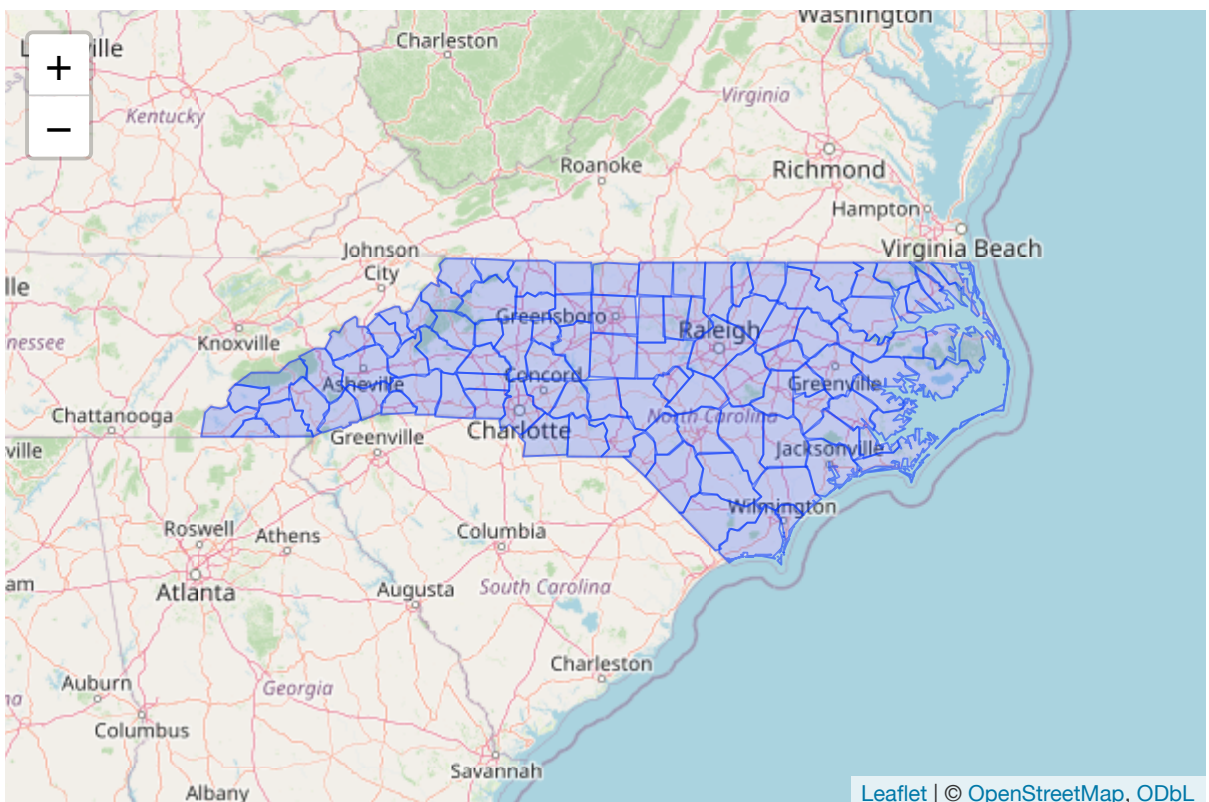
leaflet

```
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, bringT
  )
```



leaflet + tiles

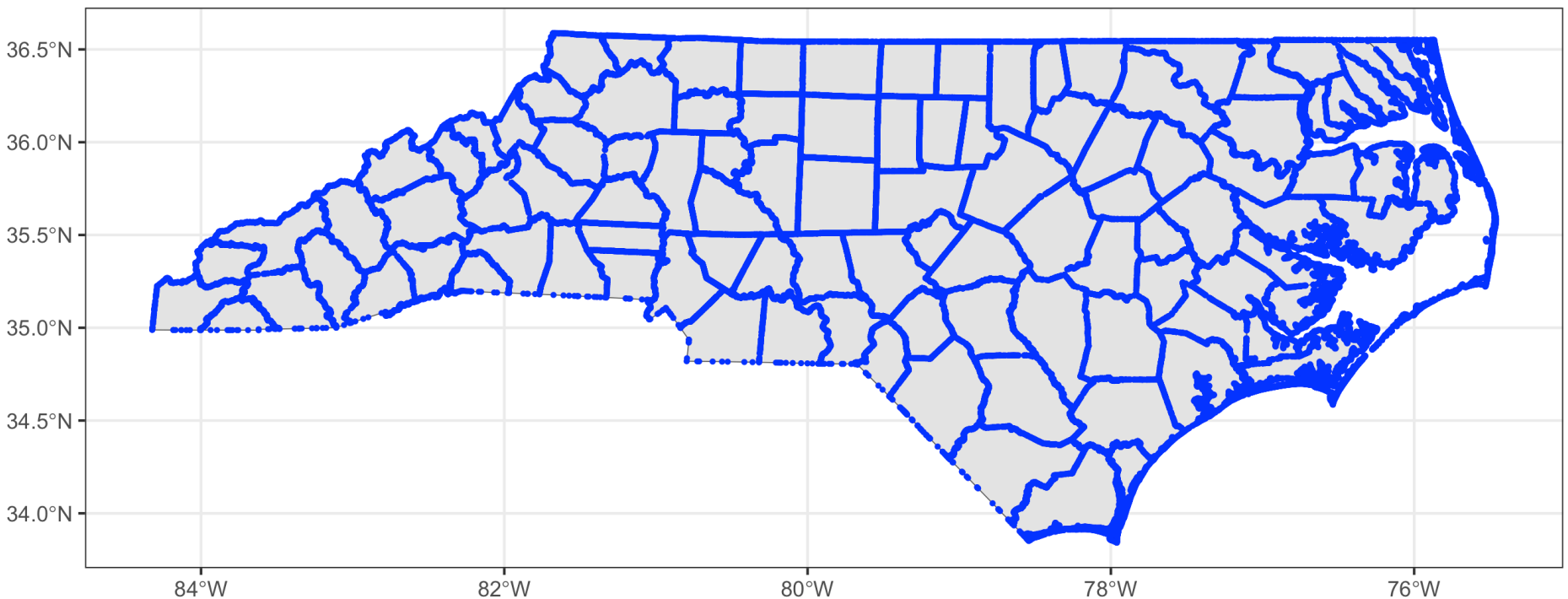
```
st_transform(nc, "+proj=longlat +datum=WGS84") |>
leaflet::leaflet(width = 600, height = 400) |>
  leaflet::addPolygons(
    weight = 1,
    popup = ~COUNTY,
    highlightOptions = leaflet::highlightOptions(color = "red", weight = 2, bringT
  ) |>
  leaflet::addTiles()
```



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")
```



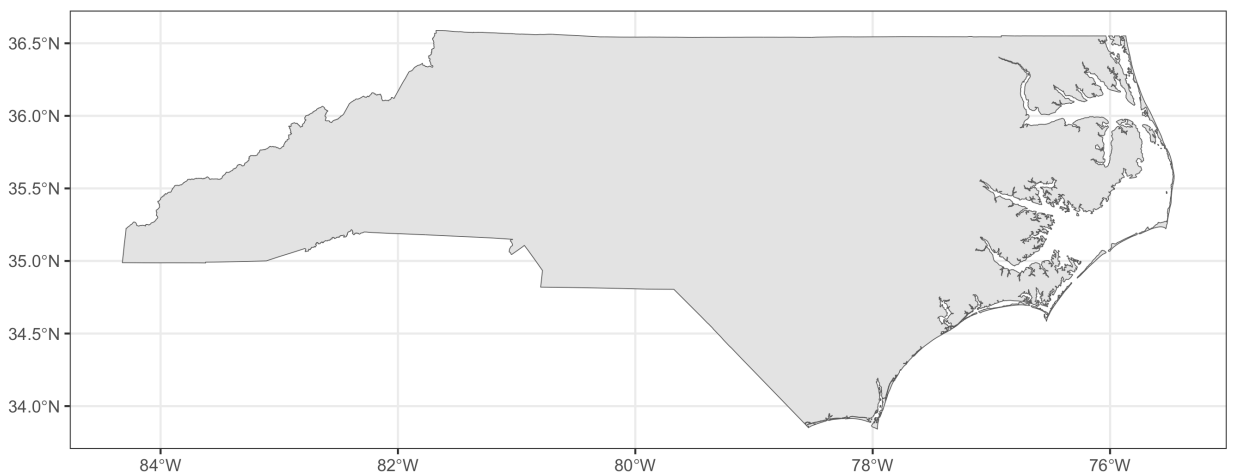
Joining

```
1 (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
```

```
MULTIPOLYGON (((-75.82791 36.19327, -75.82931 3...
```

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

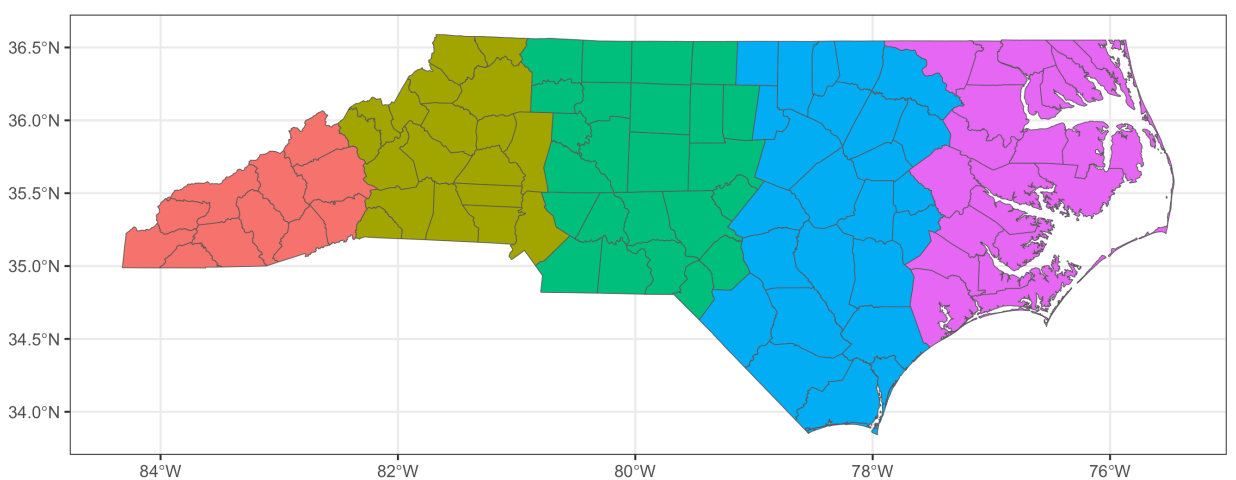


sf & dplyr

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

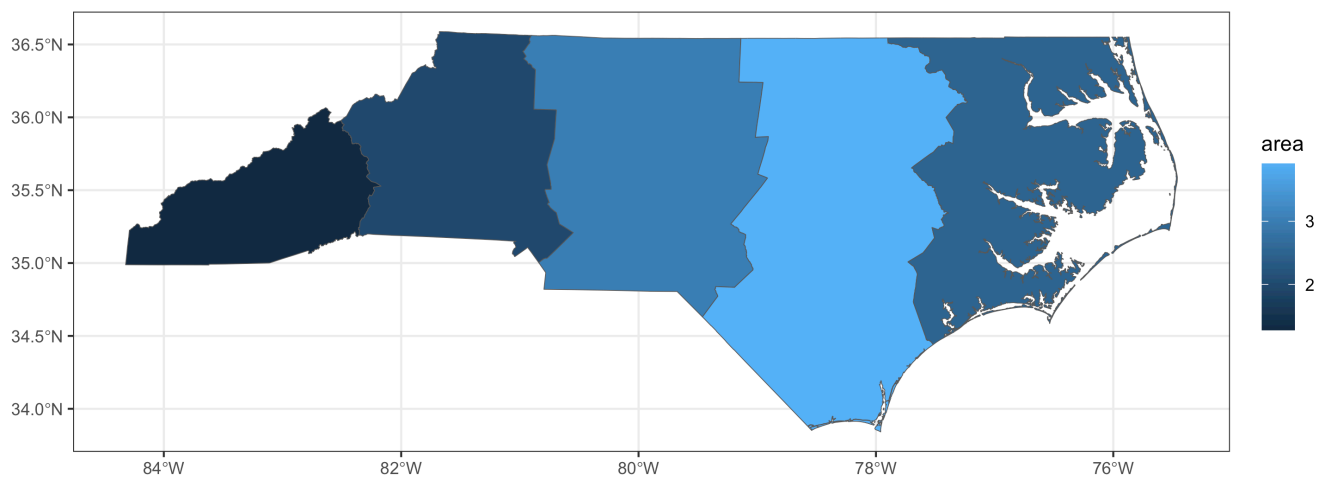
```
Warning: There was 1 warning in `stopifnot()`.
ℹ In argument: `ctr_x = (function(x) x[, 1])(st_coordinates(st_centroid(nc)))`.
Caused by warning:
! st_centroid assumes attributes are constant over geometries
```

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



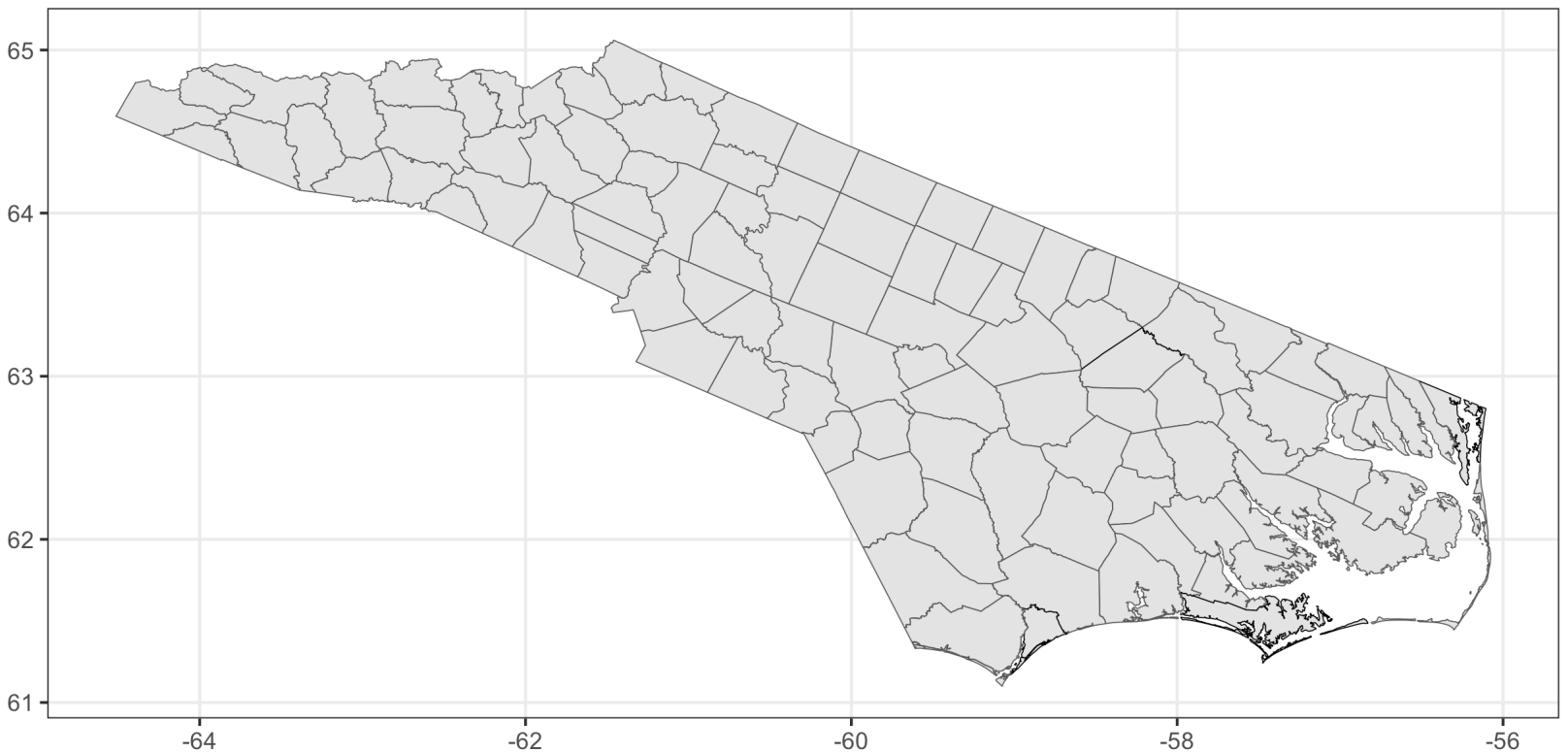
sf & dplyr (cont.)

```
1 nc_cut2 = nc_cut |>
2   group_by(region) |>
3   summarize(
4     area = sum(AREA)
5   )
6
7 ggplot() + geom_sf(data=nc_cut2, aes(fill=area))
```



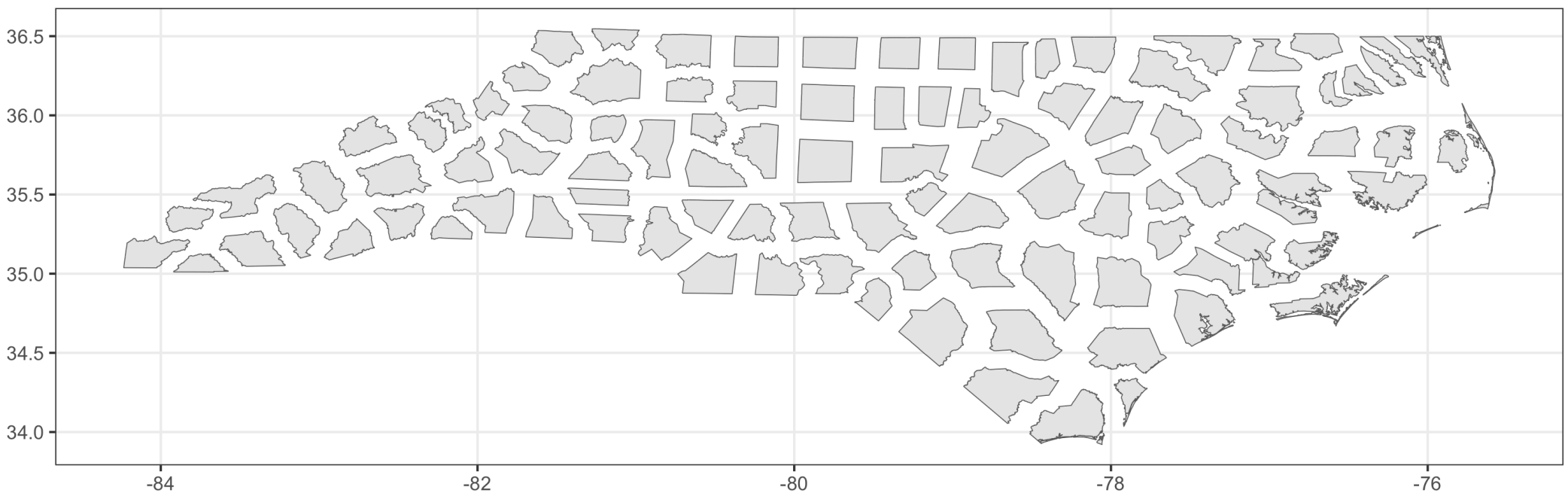
Affine Transformations

```
1 rotate = function(a) matrix(c(cos(a), sin(a), -sin(a), cos(a)), 2, 2)
2
3 state_rotate = (st_geometry(nc) * rotate(pi/8)) |> lwgeom::lwgeom_make_valid()
4 ggplot() + geom_sf(data=state_rotate)
```



Scaling + Translations

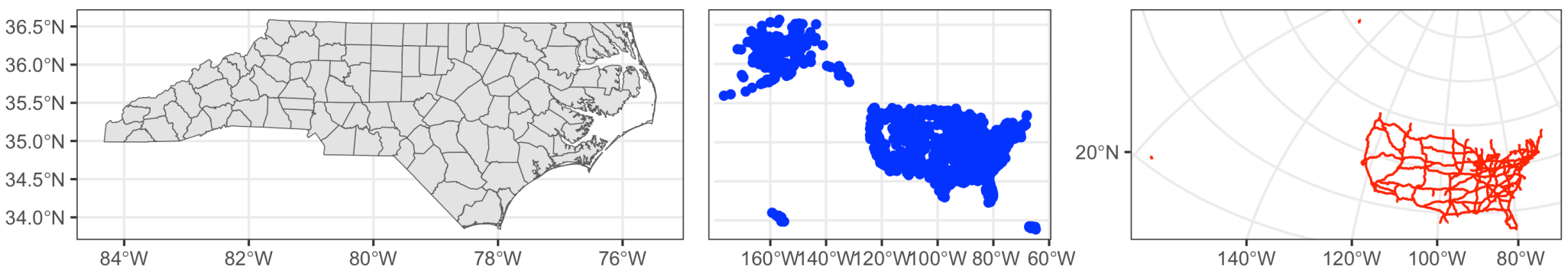
```
1 ctrd = st_centroid(st_geometry(nc))
2 nc_scaled = (st_geometry(nc) - ctrd) * 0.66 + ctrd
3
4 ggplot() + geom_sf(data=nc_scaled)
```



Some other data

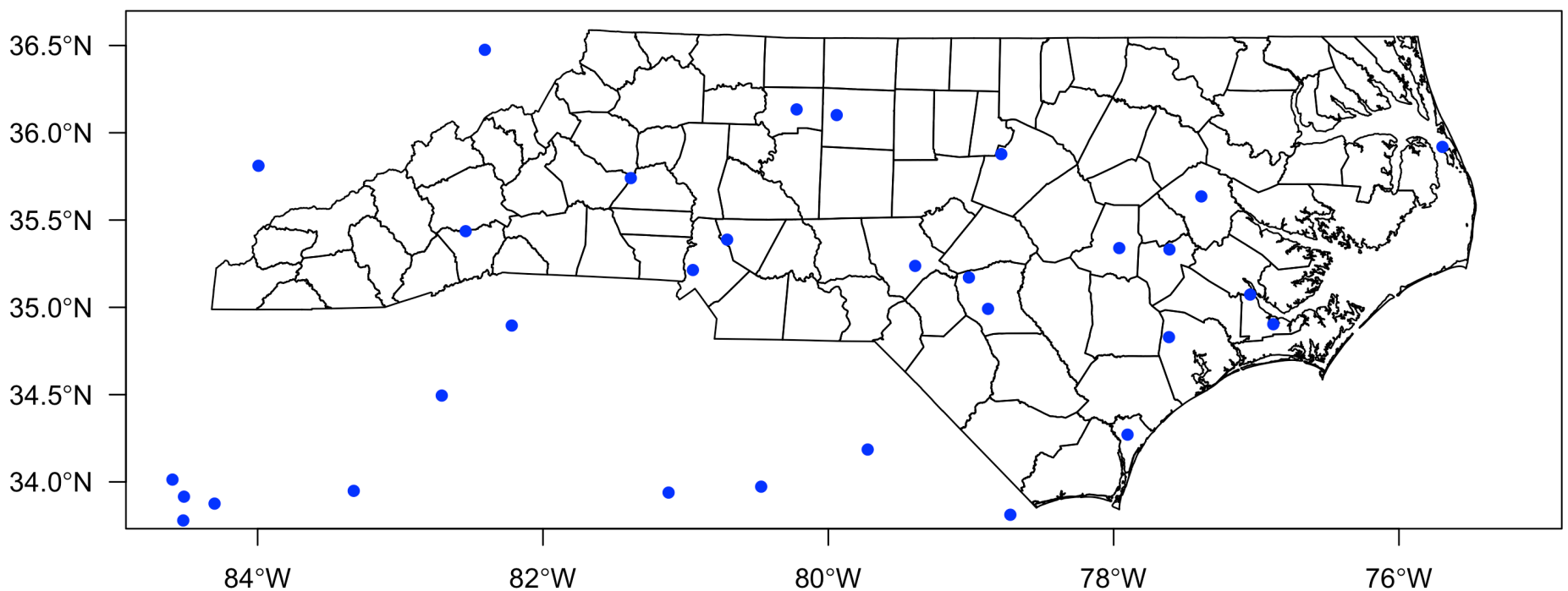
```
air = read_sf("data/gis/airports/", quiet=TRUE)
hwy = read_sf("data/gis/us_interstates/", quiet=TRUE)
```

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



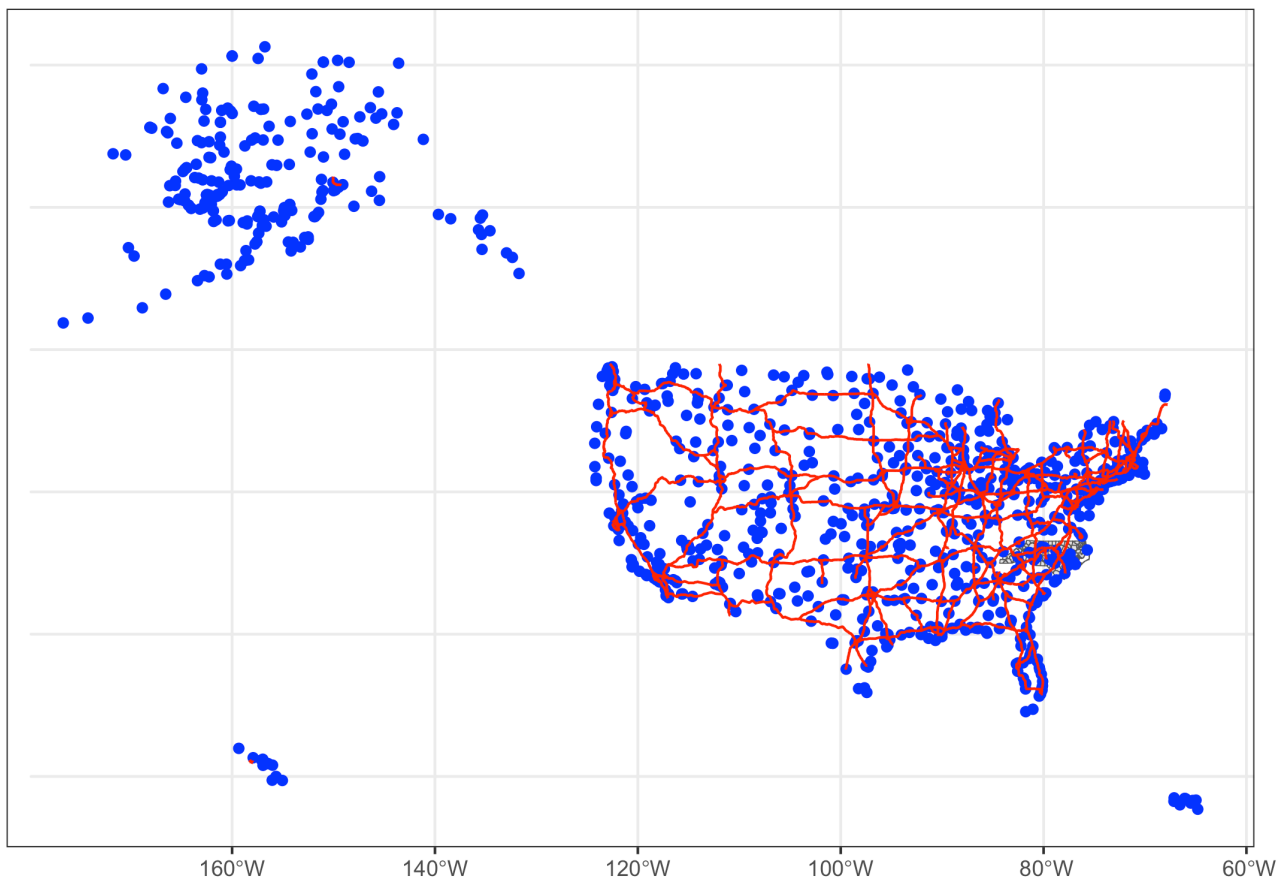
Overlays w/ base plots

```
1 plot(st_geometry(nc),  axes=TRUE, las=1)
2 plot(st_geometry(air), axes=TRUE, pch=16, col="blue", main="a
3 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

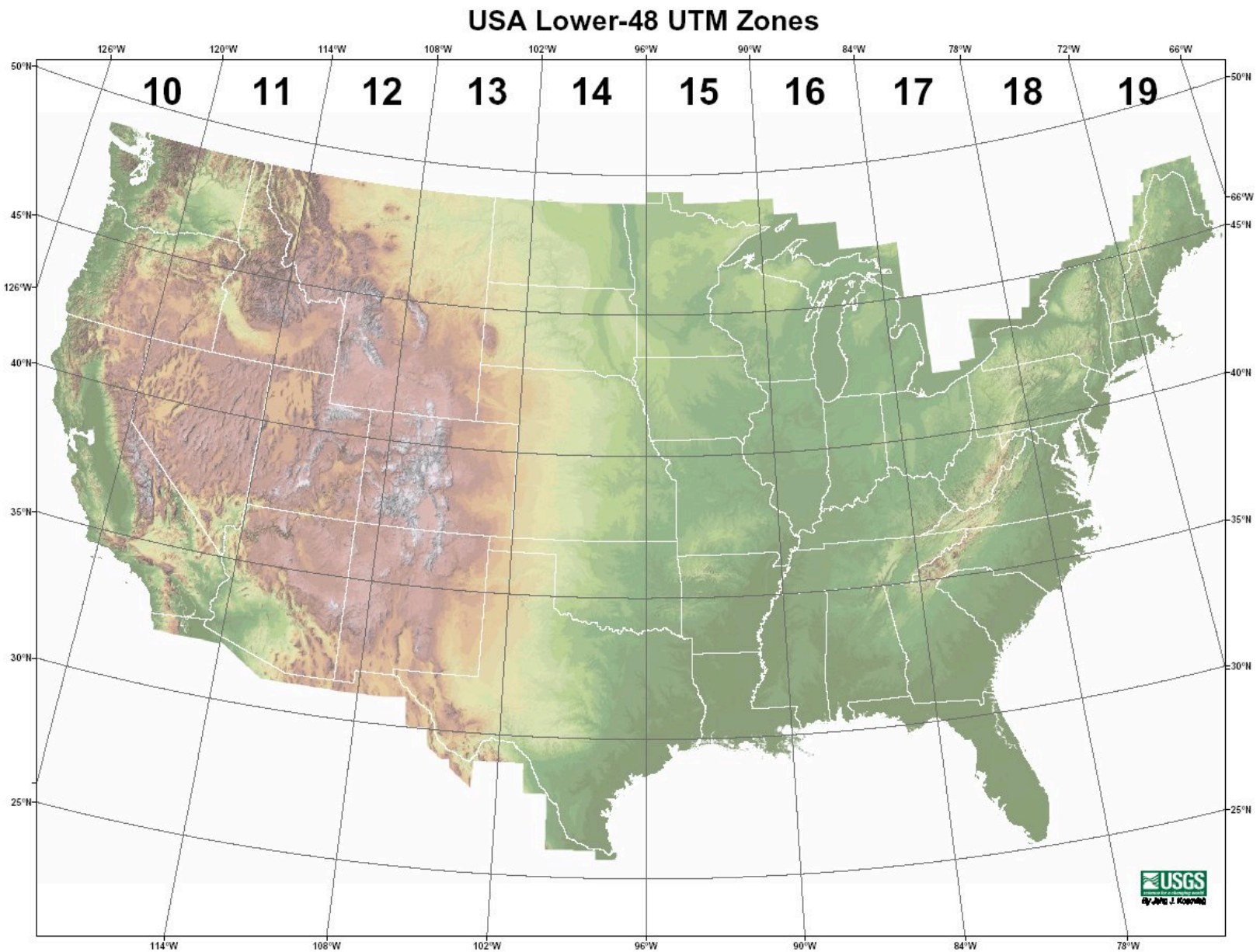
```
1 st_crs(nc)
```

```
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]],
```

```
1 st_crs(hwy)
```

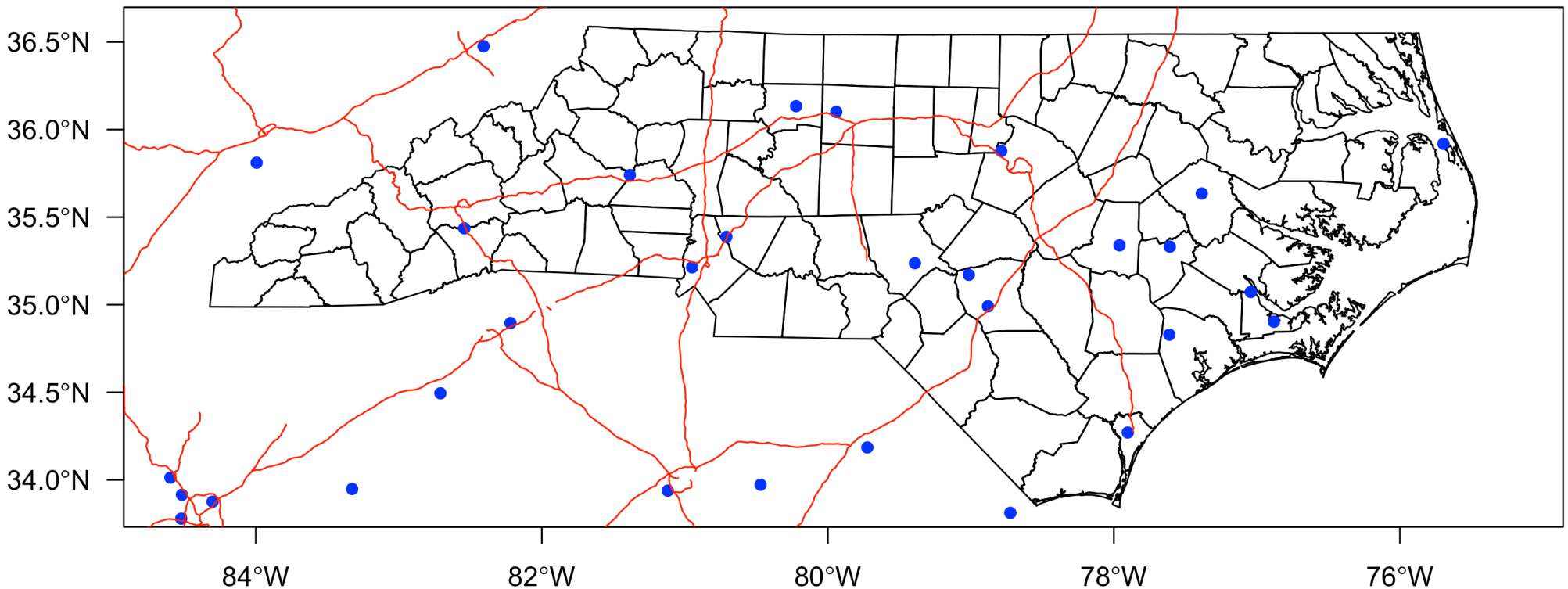
```
Coordinate Reference System:
  User input: NAD83 / UTM zone 15N
  wkt:
PROJCRS["NAD83 / UTM zone 15N",
    BASEGEOGCRS["NAD83",
        DATUM["North American Datum
1983",
            ELLIPSOID["GRS
1980",6378137,298.257222101,
                LENGTHUNIT["metre",1]]],
        PRIMEM["Greenwich",0,

ANGLEUNIT["degree",0.0174532925199433]],
        ID["EPSG",4269]],
    CONVERSION["UTM zone 15N",
        METHOD["Transverse Mercator"
```

Aside - UTM Zones



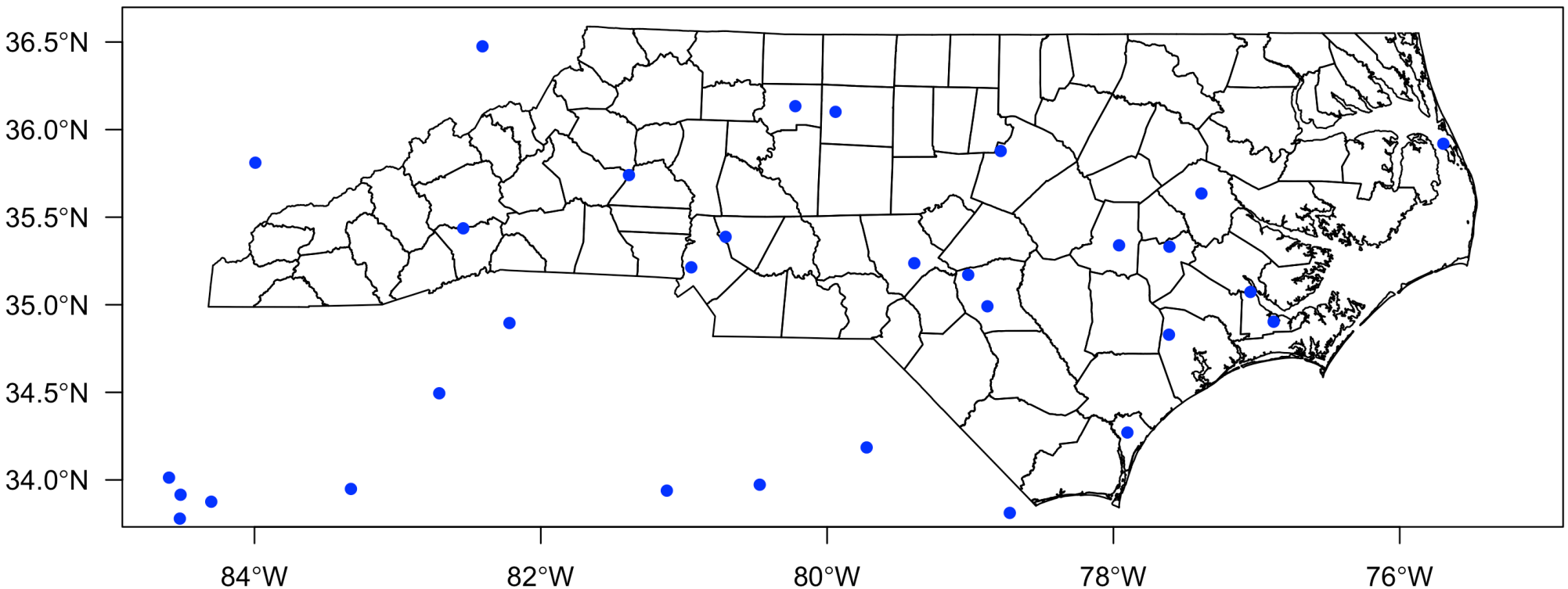
hwy -> Lat/Long

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



Airport Example

NC Airports



Sparse Insections

```
1 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
```

Dense Insections

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

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

```
1 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)
```

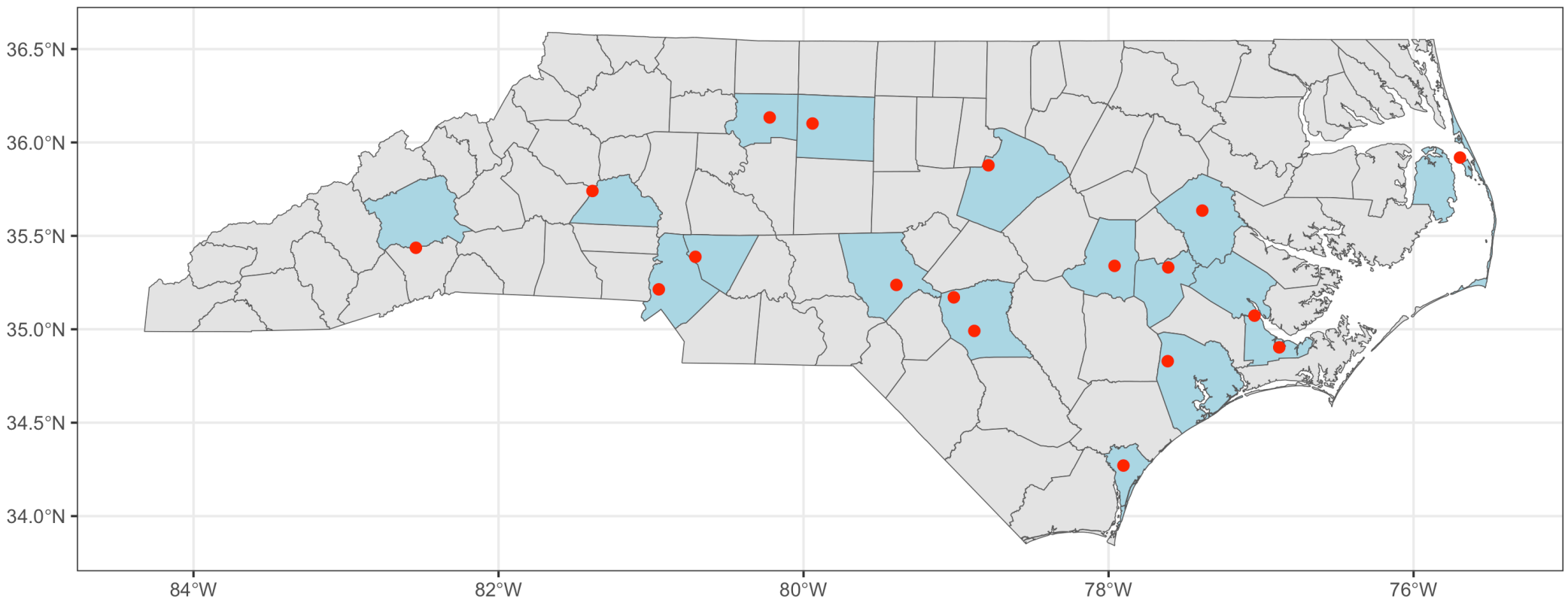
```
 [1] "Forsyth County"     "Guilford
County"
 [3] "Dare County"        "Wake County"
 [5] "Pitt County"        "Catawba
County"
 [7] "Buncombe County"    "Wayne County"
 [9] "Mecklenburg County" "Moore County"
[11] "Cabarrus County"    "Lenoir County"
[13] "Craven County"      "Cumberland
County"
[15] "Onslow County"      "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"
```

Results

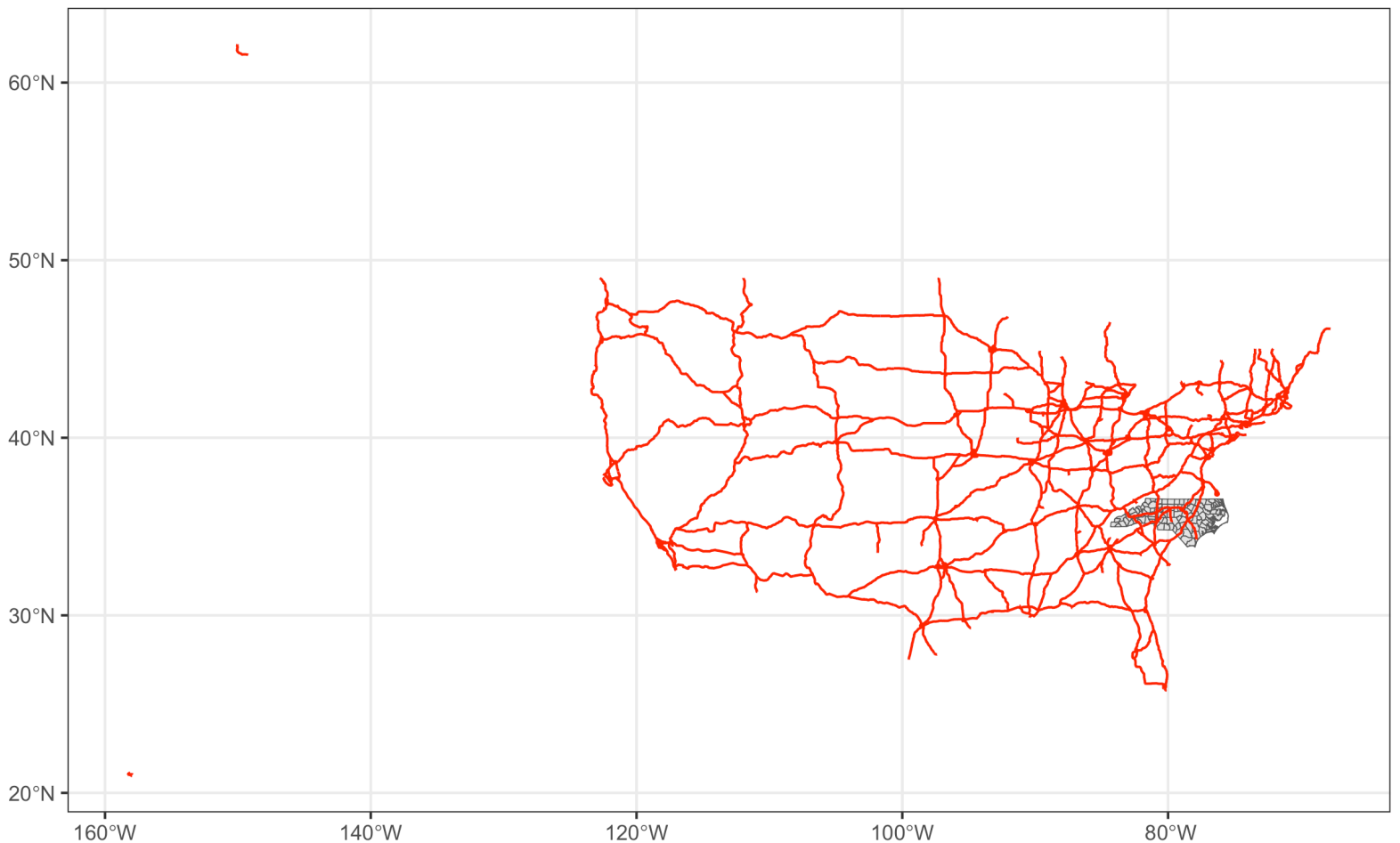
```
ggplot() +
  geom_sf(data=nc) +
  geom_sf(data = nc_air, fill = "lightblue") +
  geom_sf(data = air_nc, color = "red", size=2)
```



Highway Example

Highways

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

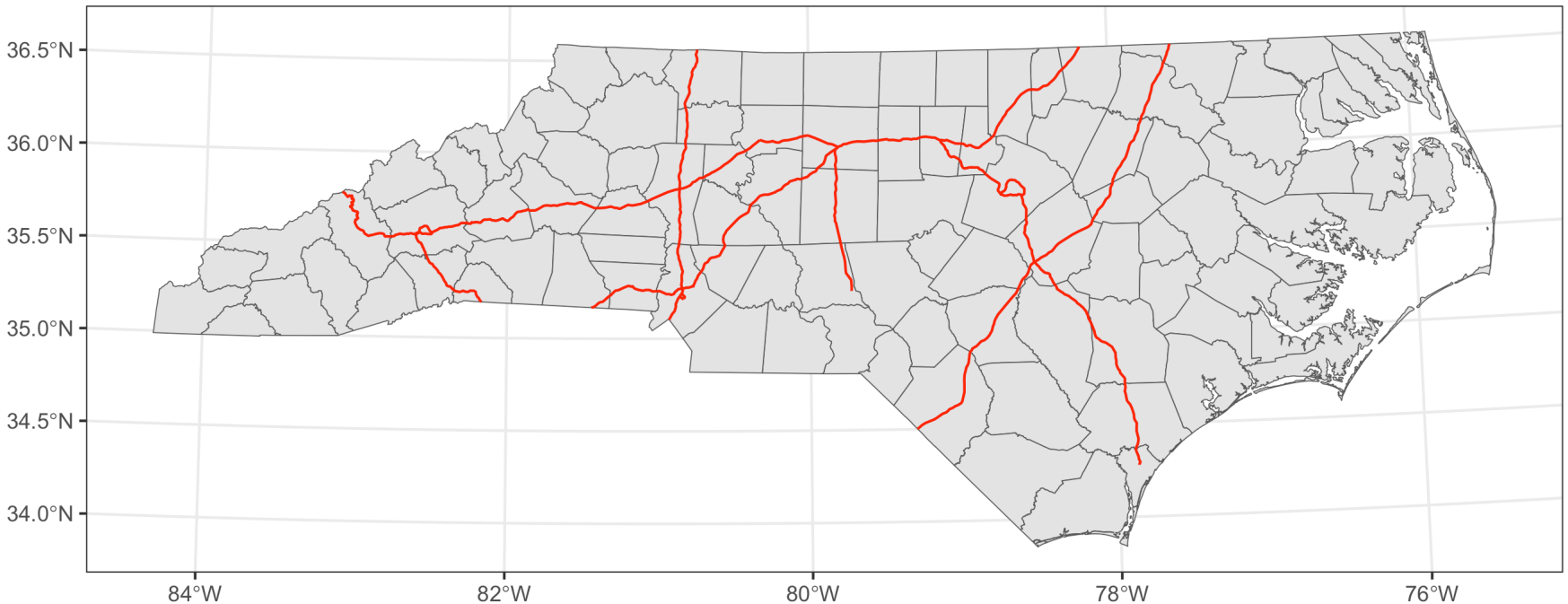


Intersection

```
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)
```

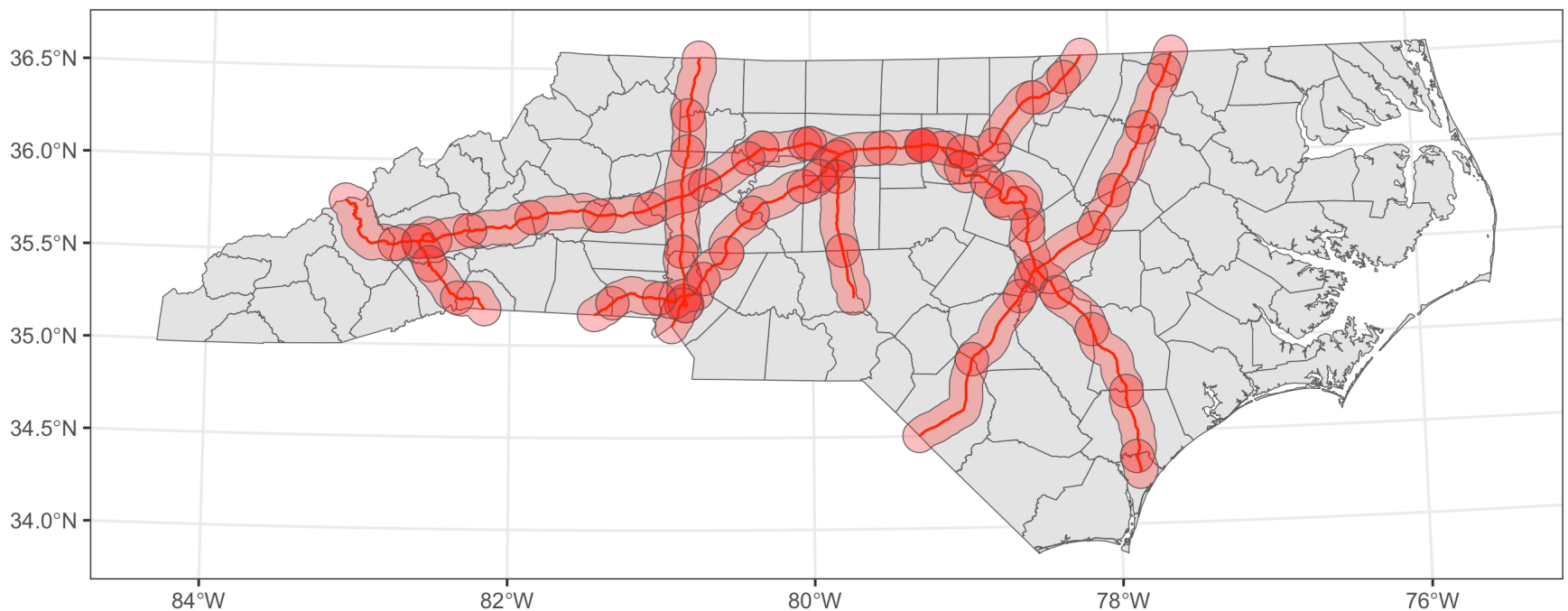
```
Warning: attribute variables are assumed to be spatially constant
throughout all geometries
```

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


36.5°N
36.0°N
35.5°N
35.0°N
34.5°N
34.0°N
84°W
82°W
80°W
78°W
76°W

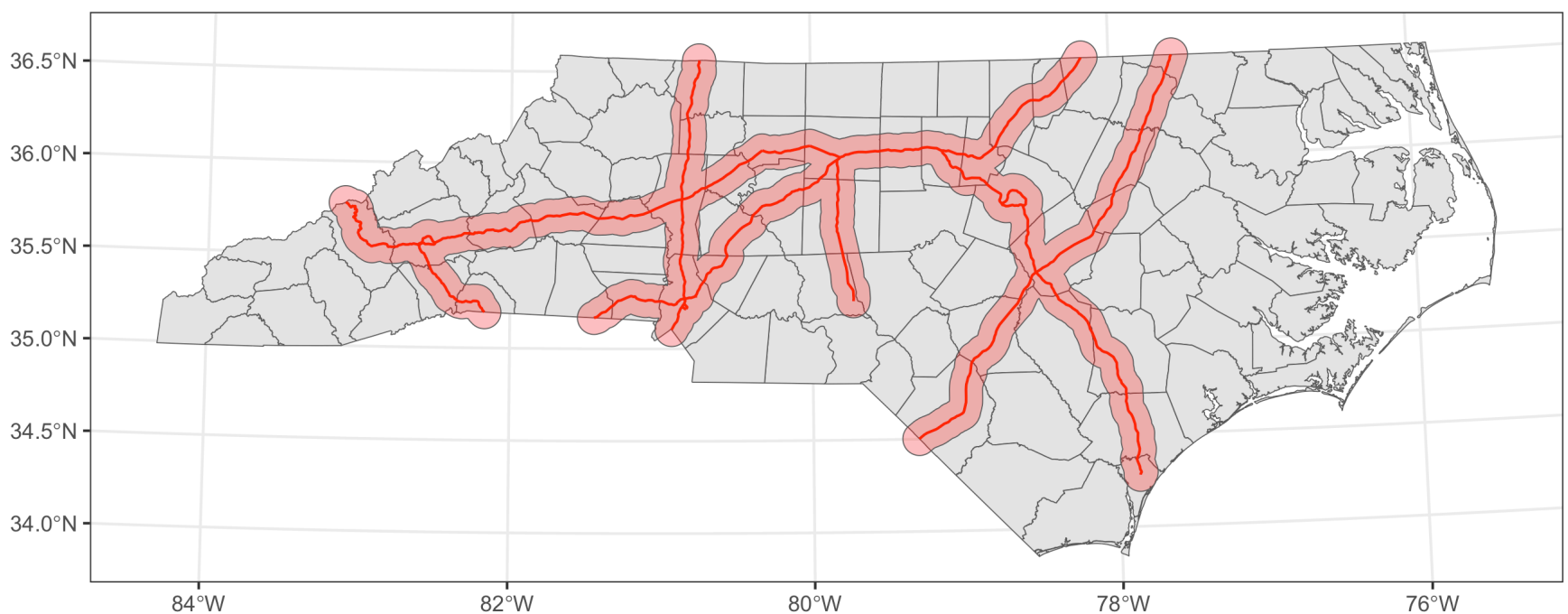
Buffering

```
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)