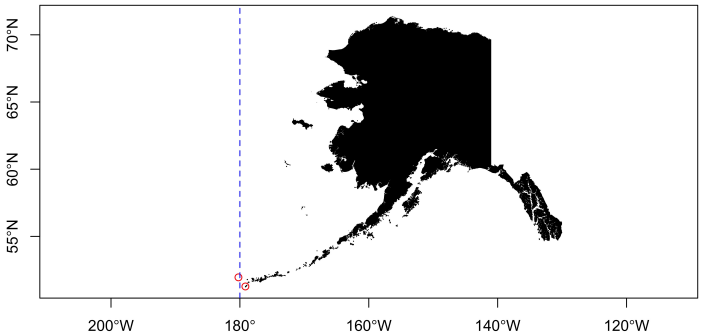
Geospatial stuff is hard

Projections

Dateline

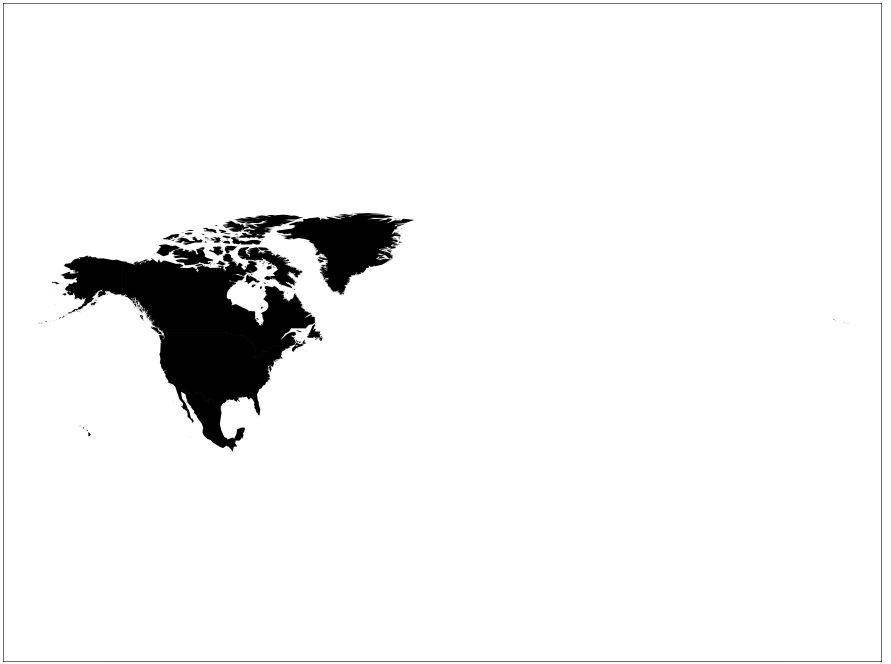
How long is the flight between the Western most and the Eastern most points in the US?



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)
```

Plotting is hard



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**
- `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.
- `stars` - Reading, manipulating, writing and plotting spatiotemporal arrays (rasters)

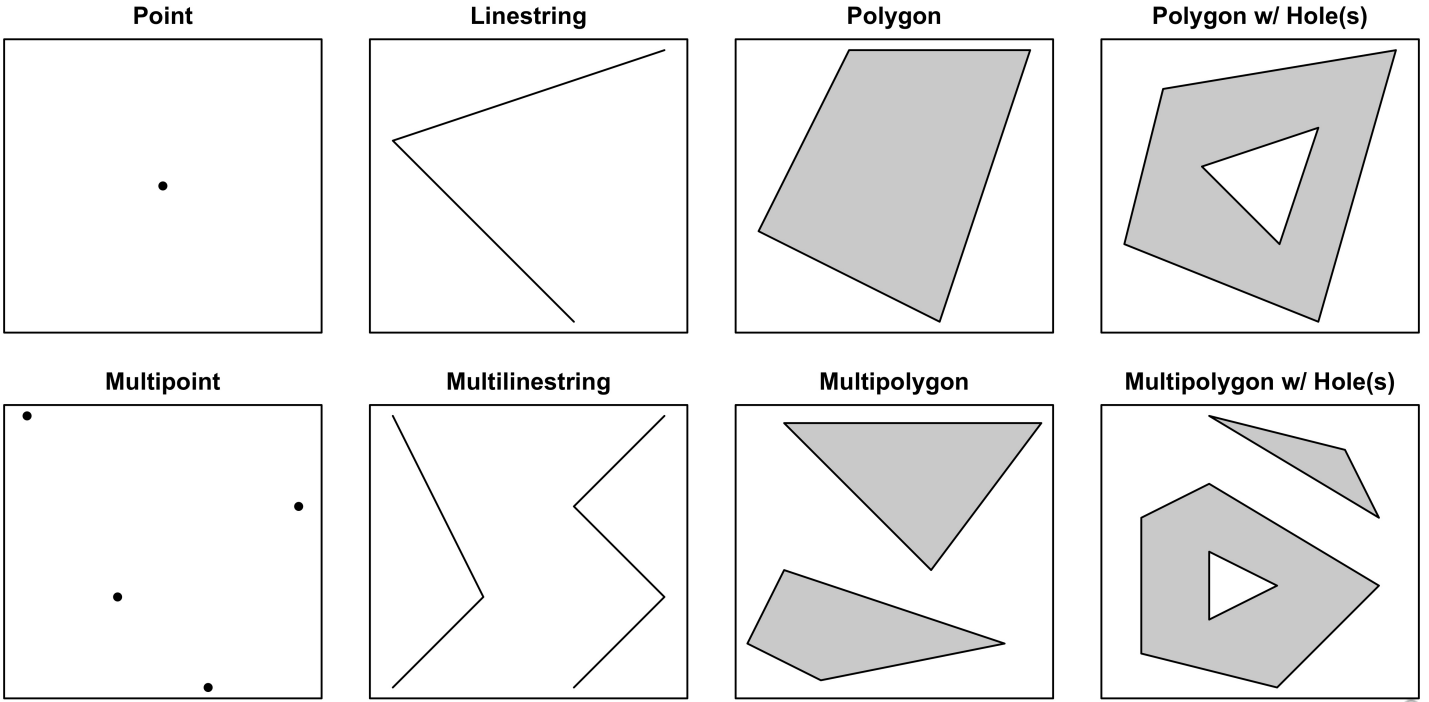
Installing `sf`

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

- `sf`
  - `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

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

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

NC Counties

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

```
## Reading layer `nc_counties' from data source
##   `/Users/rundel/Desktop/Sta523-Fa21/website/static/slides/data/gis/nc_counties' using driver `ESRI Shapefil
## 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
```

```
## 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 SQUARE_MIL
## 1  0.11175964  1.610396       1994    NC        Ashe County 37009         37    429.350
## 2  0.06159483  1.354829       1996    NC   Alleghany County 37005         37    236.459
## 3  0.14023009  1.769388       1998    NC       Surry County 37171         37    538.863
## 4  0.08912401  1.425249       1999    NC       Gates County 37073         37    342.340
## 5  0.06865730  4.428217       2000    NC   Currituck County 37053         37    263.871
## 6  0.11859434  1.404309       2001    NC      Stokes County 37169         37    455.793
## 7  0.06259671  2.106357       2002    NC      Camden County 37029         37    240.615
```

sf tibbles

```
(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 Coun… 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 Coun… 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 Co… 37131 37               551.
## 10 0.0925      1.81       2005 NC    Hertford County 37091 37               356.
## # … with 90 more rows, and 1 more variable: geometry <MULTIPOLYGON [°]>
```

sf classes

```
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" ...
```

```
class(nc)
```

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

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

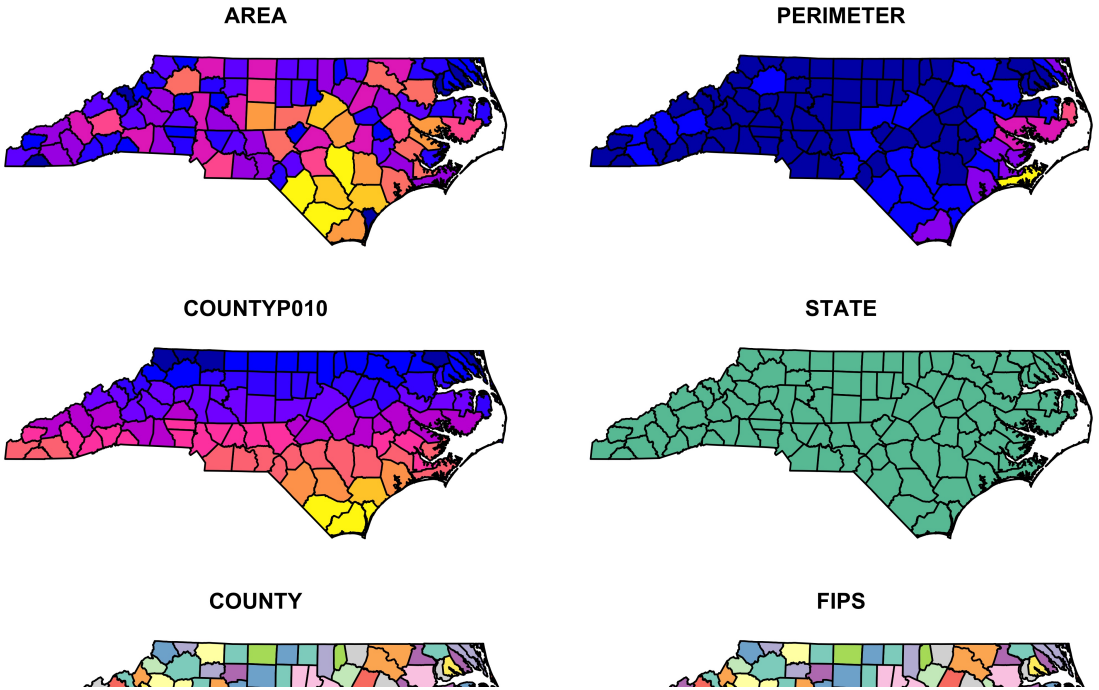
```
## [1] "sfc_MULTIPOLYGON" "sfc"
```

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

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

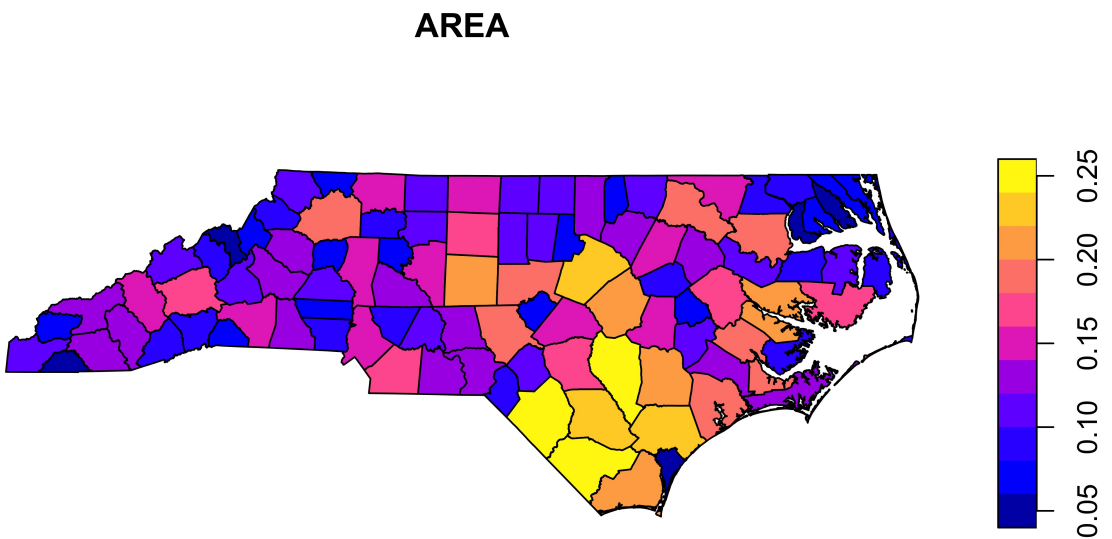
Plotting

```
plot(nc)
```



More Plotting

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



Graticules

```
par(oma=c(0,2,0,0))
plot(nc["AREA"], graticule=TRUE, axes=TRUE, las=1)
```

Geometries

```
par(oma=c(0,2,0,0))
plot(st_geometry(nc), graticule=TRUE, axes=TRUE, las=1)
```

ggplot2

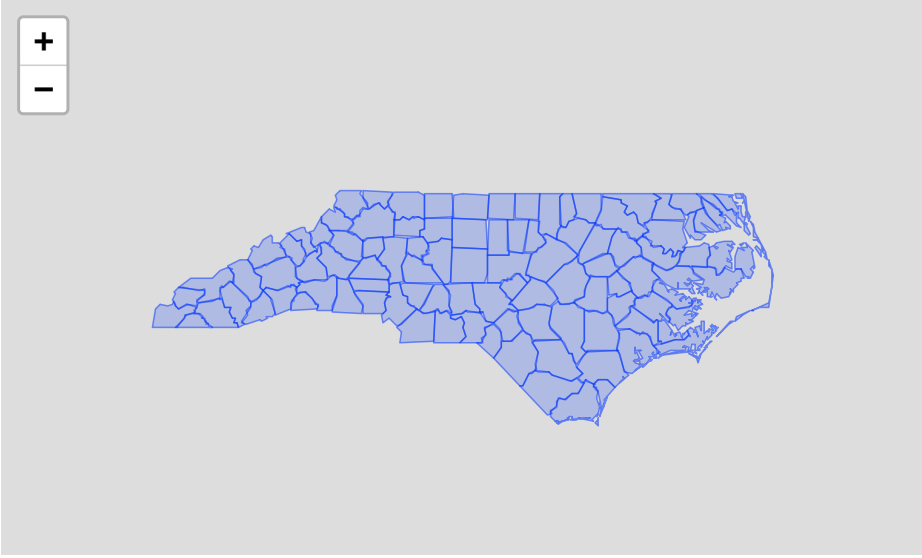
```
ggplot(nc, aes(fill=AREA)) +
  geom_sf()
```

ggplot2 + palettes

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

leaflet

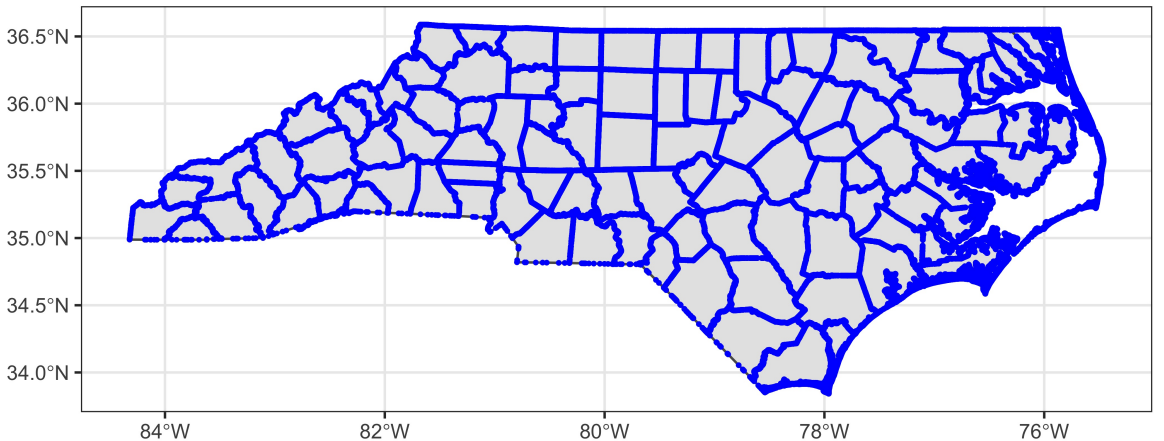
```
st_transform(nc, "+proj=longlat +datum=WGS84") %>%
leaflet::leaflet(width = 600, height = 400) %>%
  leaflet::addPolygons(
    weight = 1,
    popup = ~COUNTY,
    highlightOptions = leaflet::highlightOptions(color = "red", weight = 2, bringToFront = TRUE)
  )
```



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")
```



Grouping

```
(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...
```

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

sf & dplyr

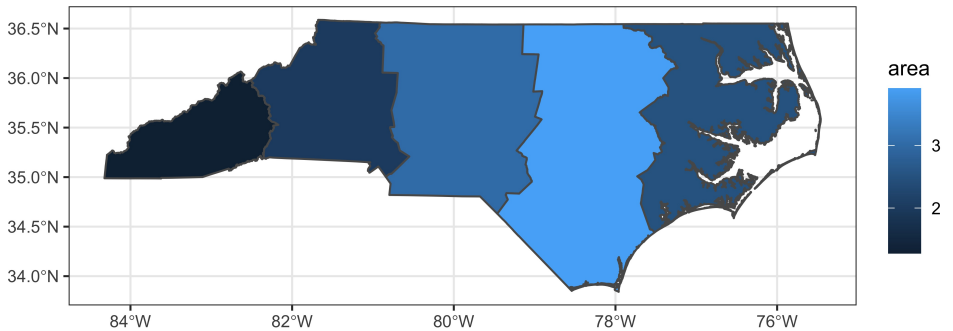
```
nc_cut = nc %>%
  mutate(
    ctr_x = st_centroid(nc) %>% st_coordinates() %>% .[,1],
    region = cut(ctr_x, breaks = 5)
  )
```

```
## Warning in st_centroid.sf(nc): st_centroid assumes attributes are constant over geometries of x
```

```
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))
```

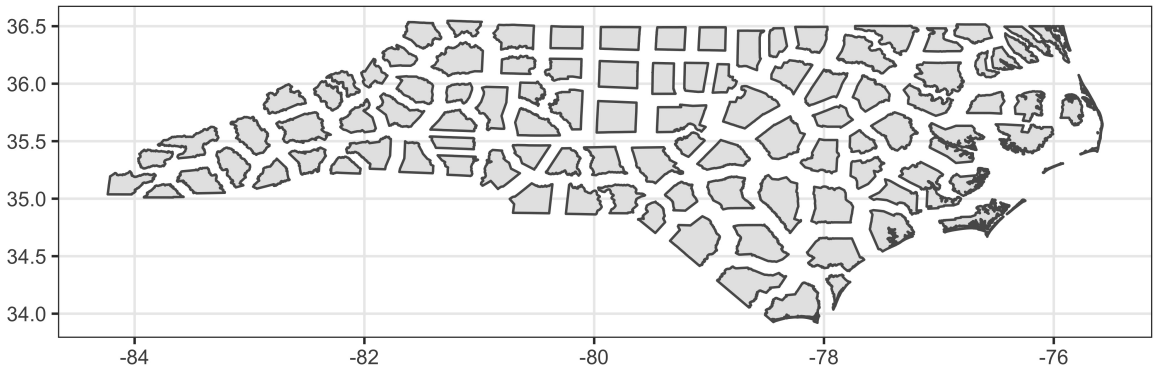


Affine Transformations

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

(ggplot() + geom_sf(data=(nc_state) * rotate(-pi/4))) +
(ggplot() + geom_sf(data=(nc_state) * rotate(pi/6)))
```

Scaling + Translations

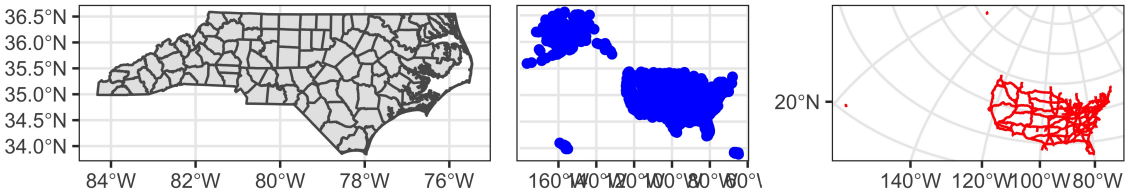
```
ctrd = st_centroid(st_geometry(nc))
nc_scaled = (st_geometry(nc) - ctrd) * 0.66 + ctrd

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



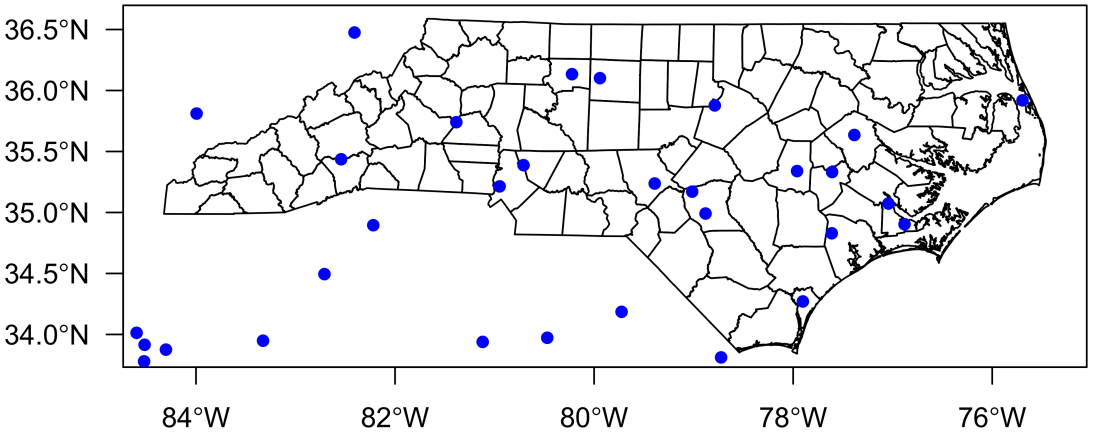
Some other data

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

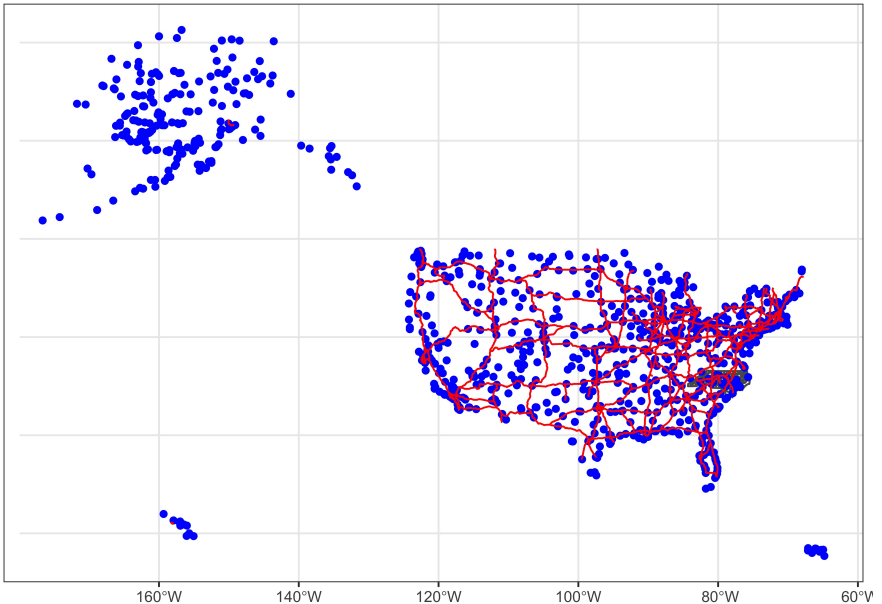
```
(ggplot(nc) + geom_sf()) +
(ggplot(air) + geom_sf(color = "blue")) +
(ggplot(hwy) + geom_sf(color = "red"))
```



Overlays?



Overlays? (ggplot)



Projections

```
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],
##             ANGLEUNIT["degree",0.0174532925199433]],
##     ID["EPSG",4269]]
```

```
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]]],
```

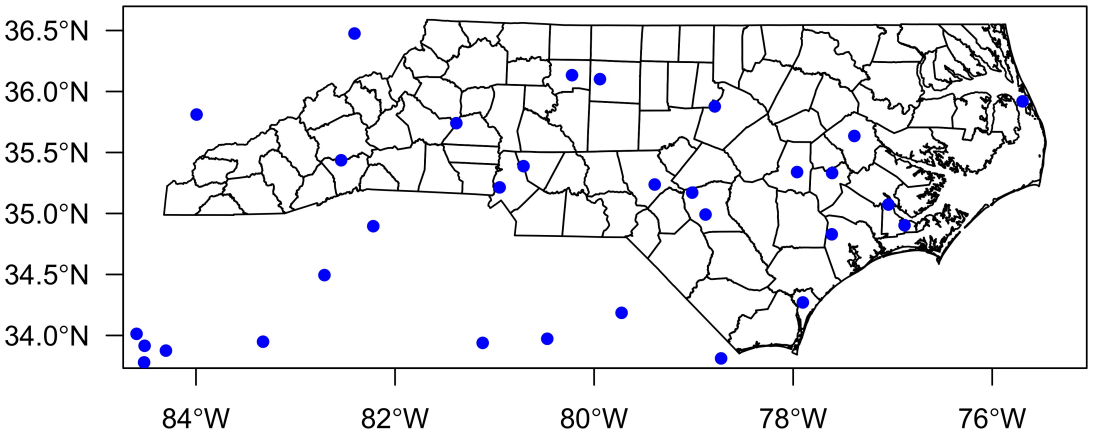
```
st_crs(air)
```

```
## 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],
##             ANGLEUNIT["degree",0.0174532925199433]],
##     ID["EPSG",4269]]
```

Aside - UTM Zones

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(*, "ncol")= int 940
##  - attr(*, "class")= chr [1:2] "sgbp" "list"
```

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) %>% .[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), lengt
  ) %>%
  filter(n_air > 0)

nc_air %>% pull(COUNTY)
```

```
##  [1] "Forsyth County"     "Guilford County"
##  [5] "Pitt County"        "Catawba County"
##  [9] "Mecklenburg County" "Moore County"
## [13] "Craven County"      "Cumberland County"
```

```
air_nc = air %>%
  slice(
    st_intersects(nc, air) %>% unlist() %>% uniqu
  )
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 /CUNNING
## [14] "COASTAL CAROLINA REGIONAL AIRPORT"
## [15] "POPE AIR FORCE BASE"
## [16] "FAYETTEVILLE REGIONAL/GRANNIS FIELD"
```

Highway Example

Highways

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

NC Interstate Highways

```
hwy_nc = st_intersection(hwy, nc)
```

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

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

Counties near the interstate (Projection)

```
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')
```

Counties near the interstate (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)
```

Counties near the interstate (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)
```

Example

How many counties in North Carolina are within 5, 10, 20, or 50 km of an interstate highway?