

Lec 22 - Spatial data

Statistical Programming

Sta 323 | Spring 2022

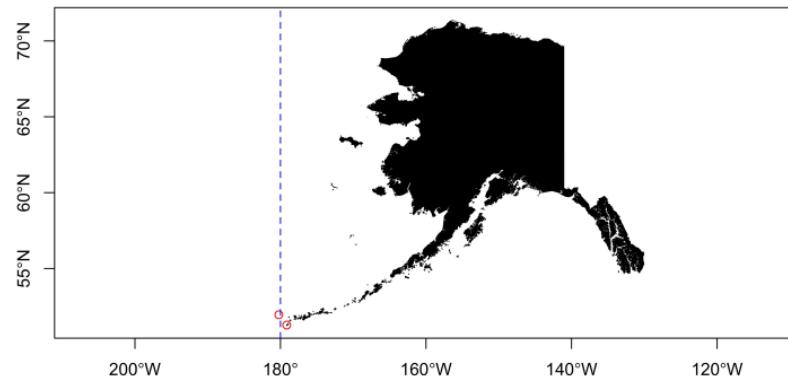
Dr. Colin Rundel

Geospatial stuff is hard

Projections

Dateline

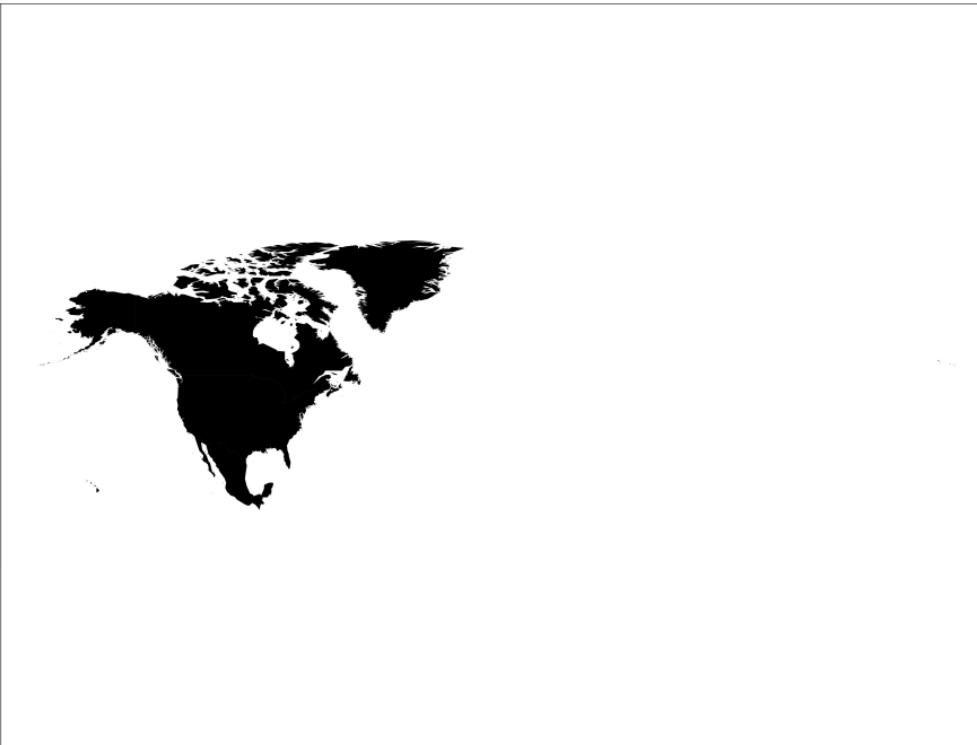
How long is the flight between the Western most and the Eastern most points in the US?



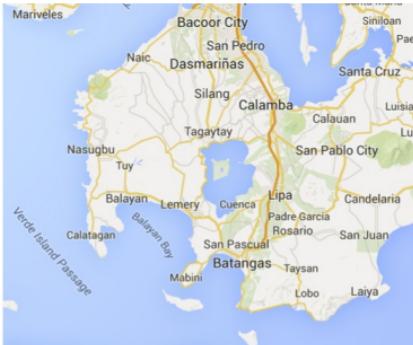
Great circle distance

```
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



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` - 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

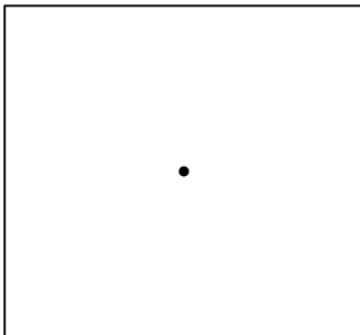
This is the hardest part of using the `sf` package, difficulty comes from its dependence on several external libraries (`geos`, `gdal`, and `proj`).

- 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 packages for GDAL ($\geq 2.0.0$), GEOS ($\geq 3.3.0$), Proj4 ($\geq 4.8.0$), `udunits2` from your package manager of choice.

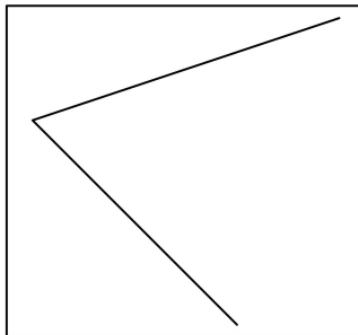
More specific details are included in the repo `README` on [github](#).

Simple Features

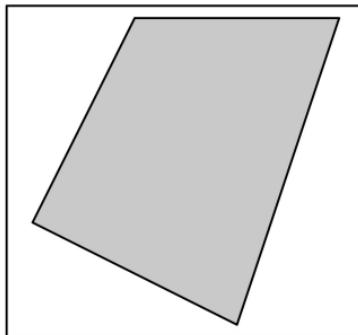
Point



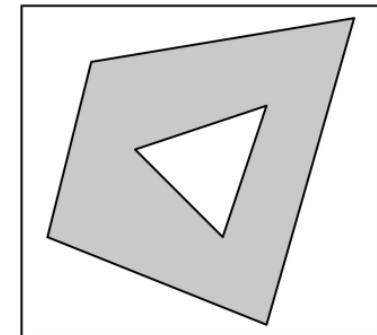
Linestring



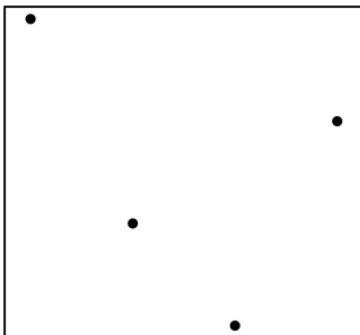
Polygon



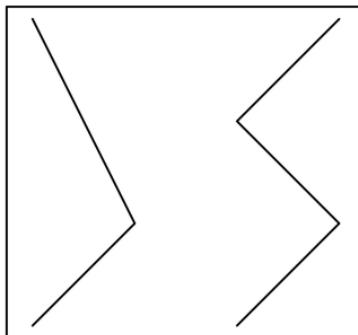
Polygon w/ Hole(s)



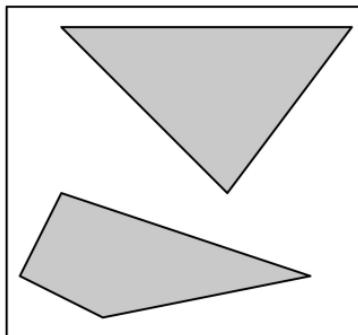
Multipoint



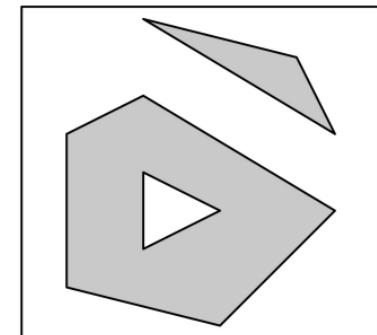
Multilinestring



Multipolygon



Multipolygon w/ Hole(s)



Reading, writing, and converting simple features

- sf
 - st_read / st_write - Shapefile, GeoJSON, KML, ...
 - read_sf / write_sf - Same, supports tibbles ...
 - st_as_sf / st_as_wkt - WKT
 - st_as_sf / st_as_binary - WKB
 - st_as_sf / 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/dbf file      41K
## 2 data/gis/nc_counties/prj file     165
## 3 data/gis/nc_counties/shp file    1.41M
## 4 data/gis/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/Sta323-Sp22/website/static/slides/data/gis/nc_counties'
##   using driver 'ESRI Shapefile'
## 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
## 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
```

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 x 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"

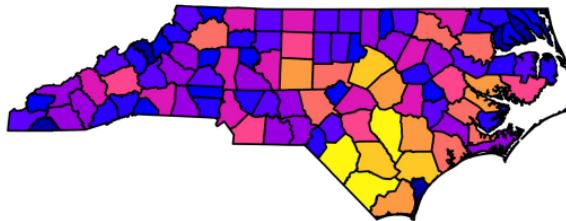
class(nc$geometry[[1]])

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

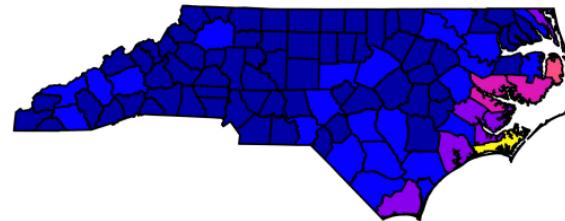
Plotting

```
plot(nc)
```

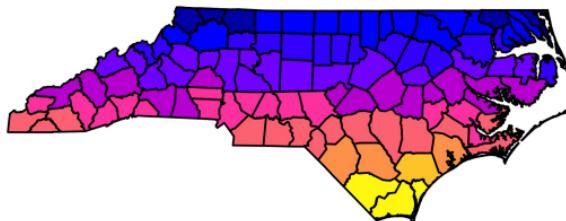
AREA



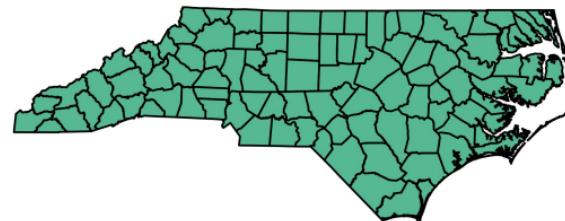
PERIMETER



COUNTYP010



STATE



COUNTY



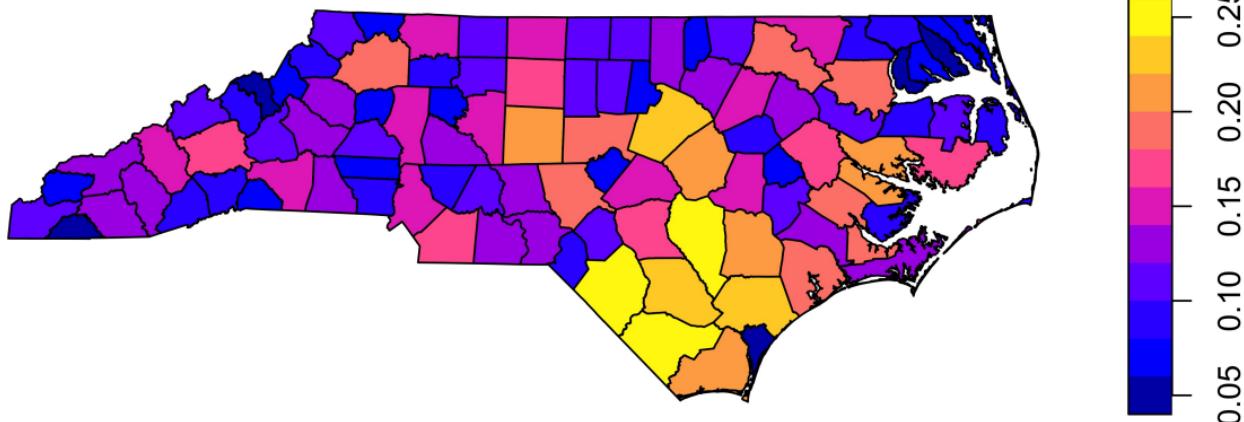
FIPS



More Plotting

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

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

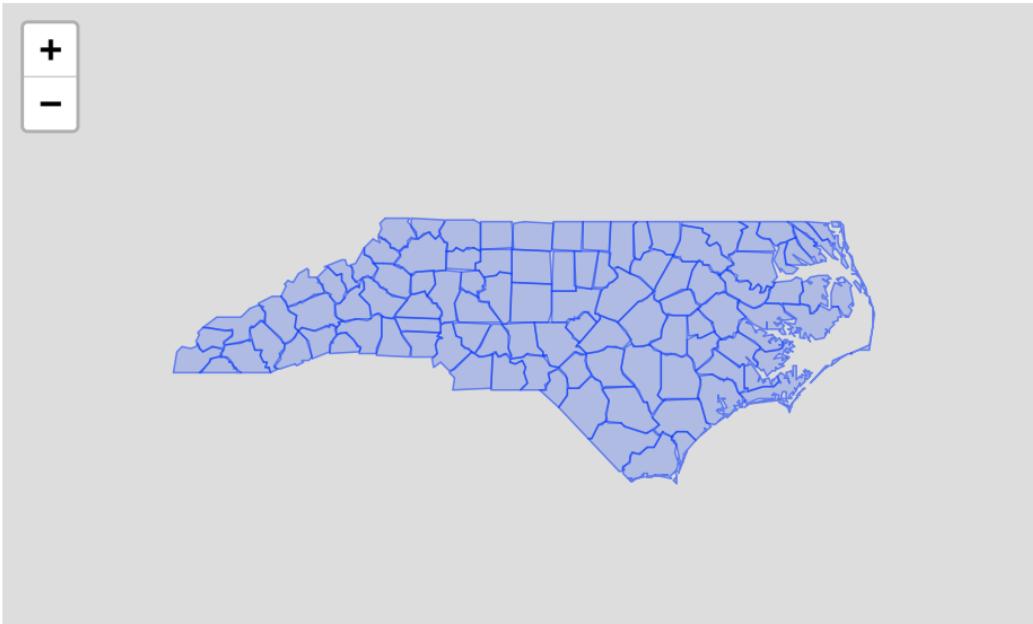
```
ggplot(nc, aes(fill=AREA)) +  
  geom_sf()
```

ggplot2 + palettes

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

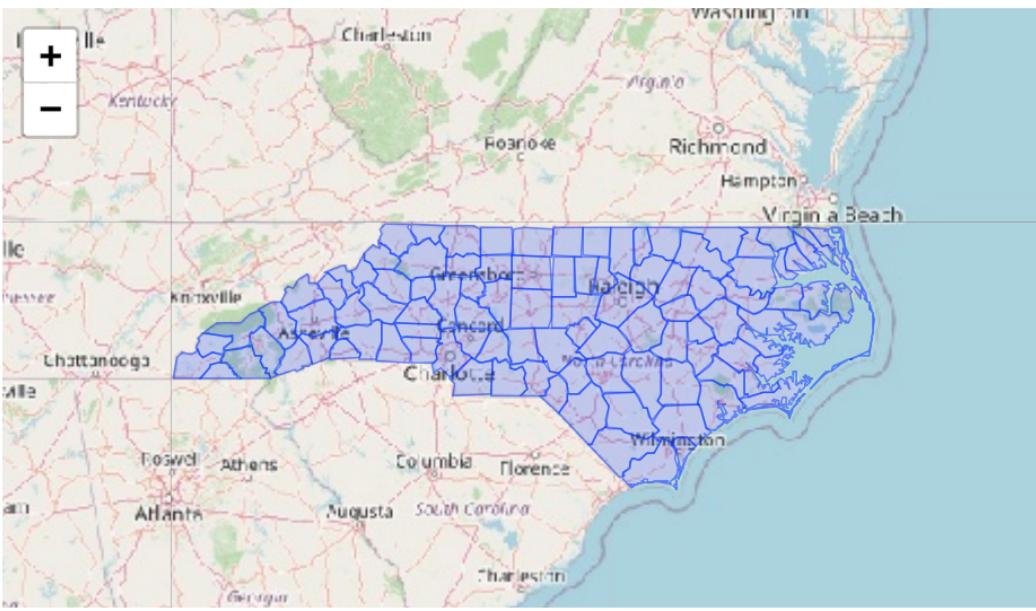
leaflet

```
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)  
    )
```



leaflet + tiles

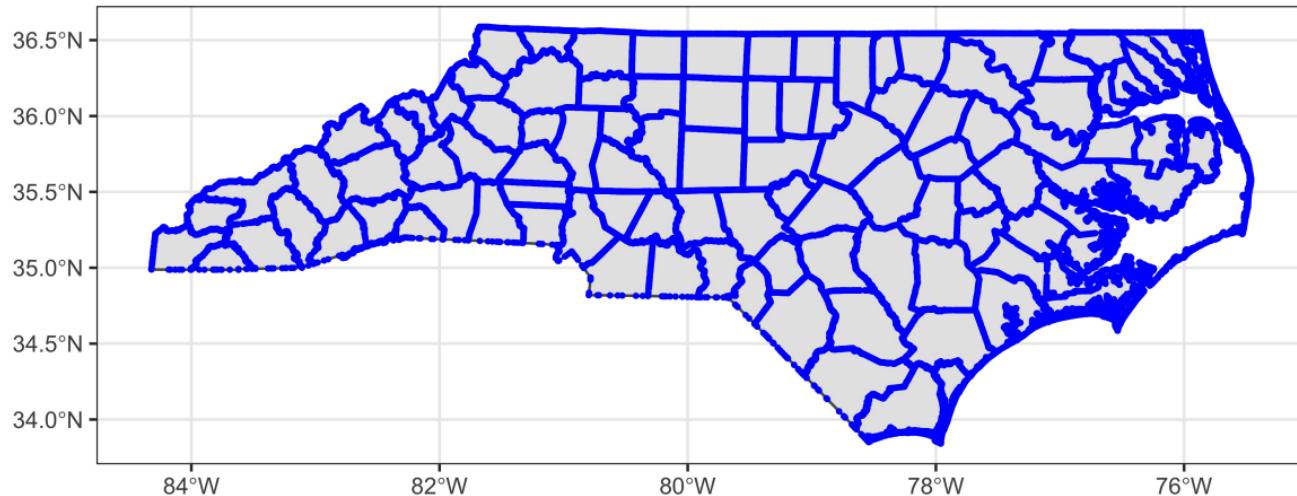
```
st_transform(nc, "+proj=longlat +datum=WGS84") %>%  
  leaflet::leaflet(width = 600, height = 400) %>%  
    leaflet::addPolygons(  
      weight = 1,  
      popup = ~COUNTY,  
      highlightOptions = leaflet::highlightOptions(color = "red", weight = 2, bringToFront = TRUE)  
    ) %>%  
  leaflet::addTiles()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



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")
```



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)
```

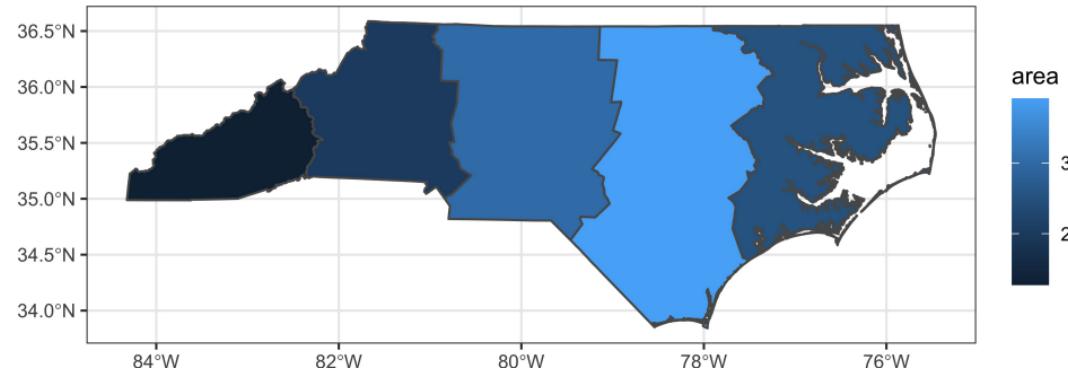
sf & dplyr

```
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))
```

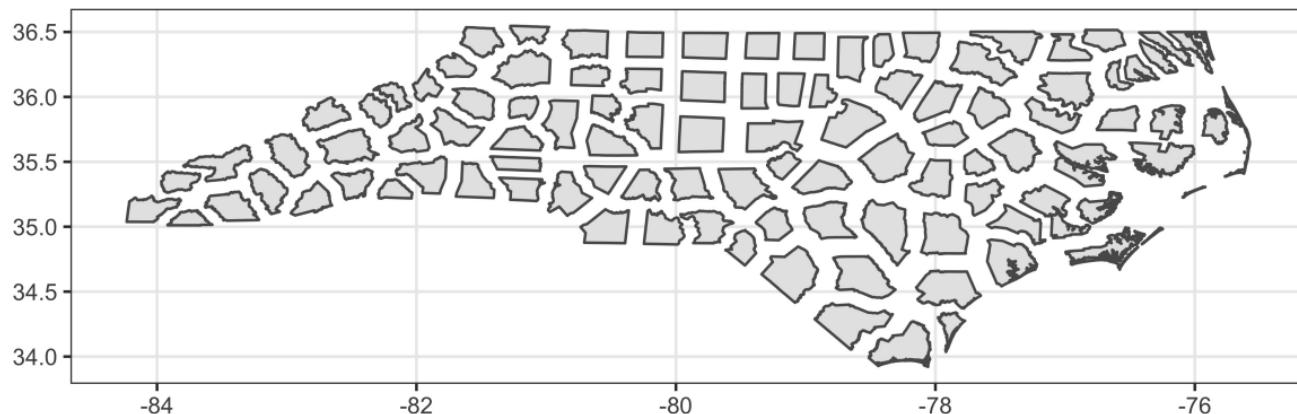


Affine Transformations

```
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

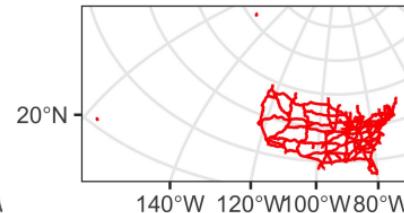
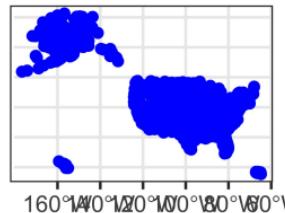
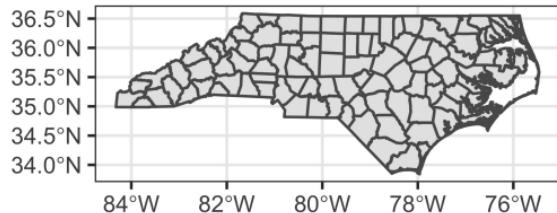
```
ctrd = st_centroid(st_geometry(nc))
nc_scaled = (st_geometry(nc) - ctrd) * 0.66 + ctrd
ggplot() + geom_sf(data=nc_scaled)
```



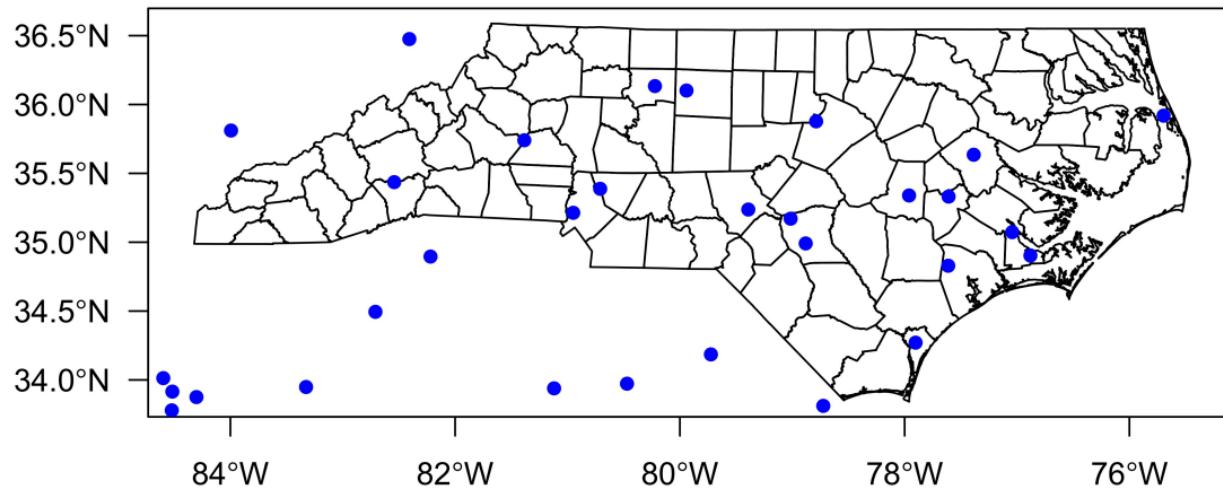
Some other data

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

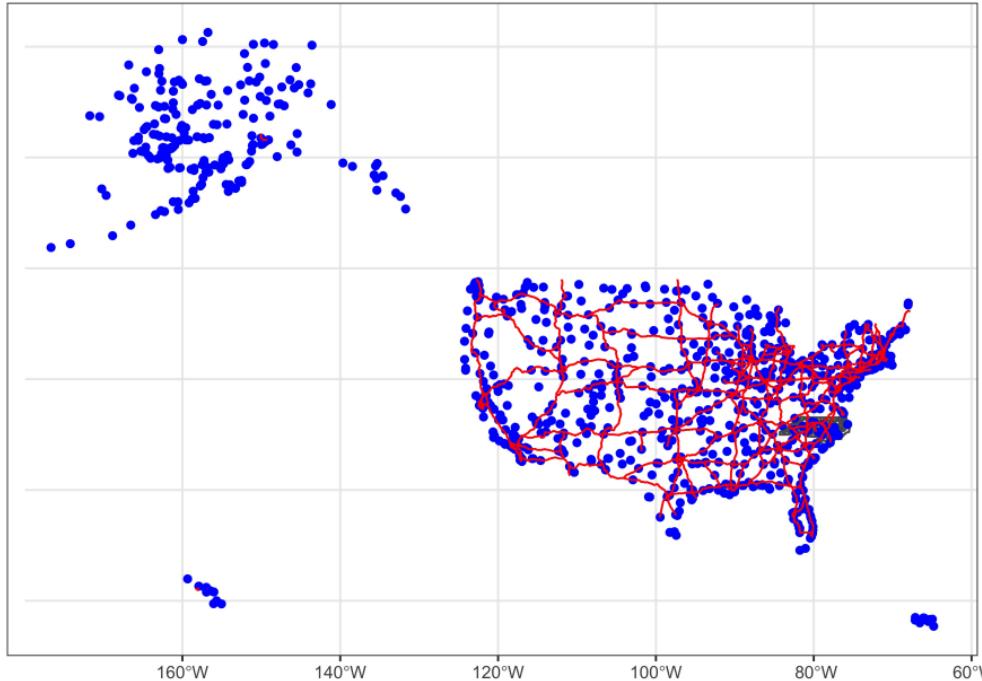
```
(ggplot(nc) + geom_sf() +
(ggplot(air) + geom_sf(color = "blue")) +
(ggplot(hwy) + geom_sf(color = "red"))
```



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]]],
```

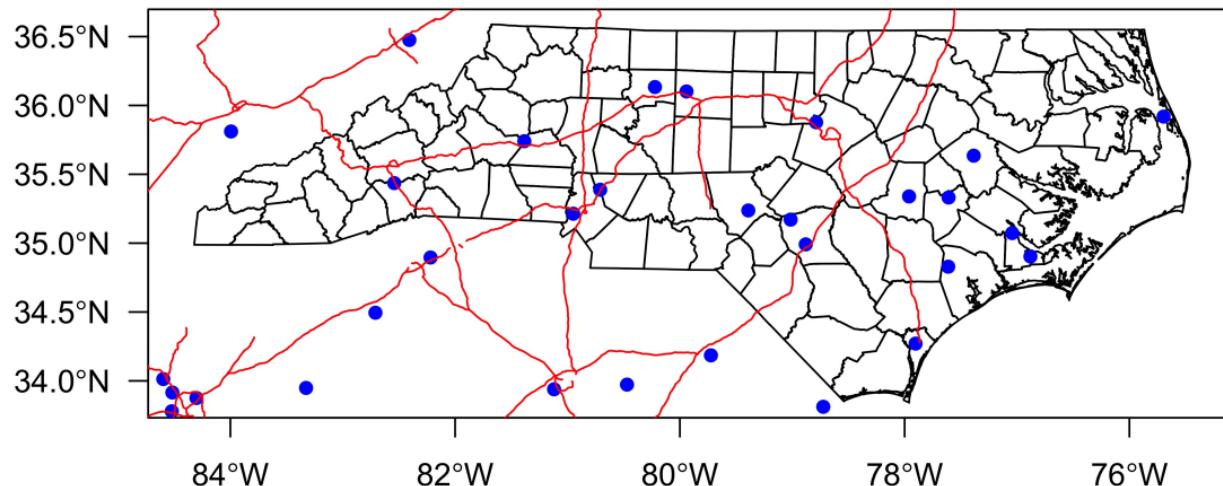
```
st_crs(air)
```

```
## 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

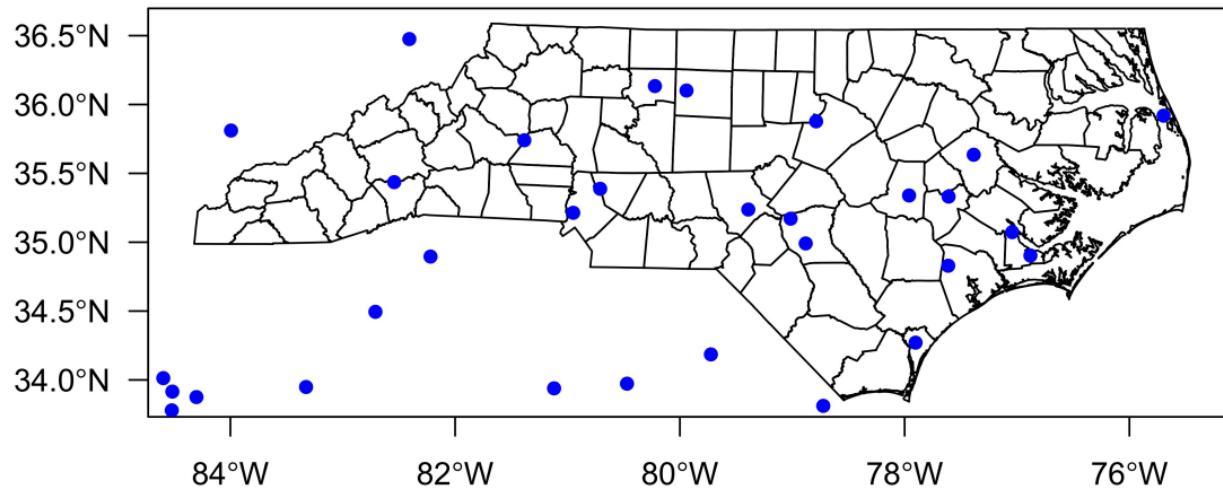
Lat/Long

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

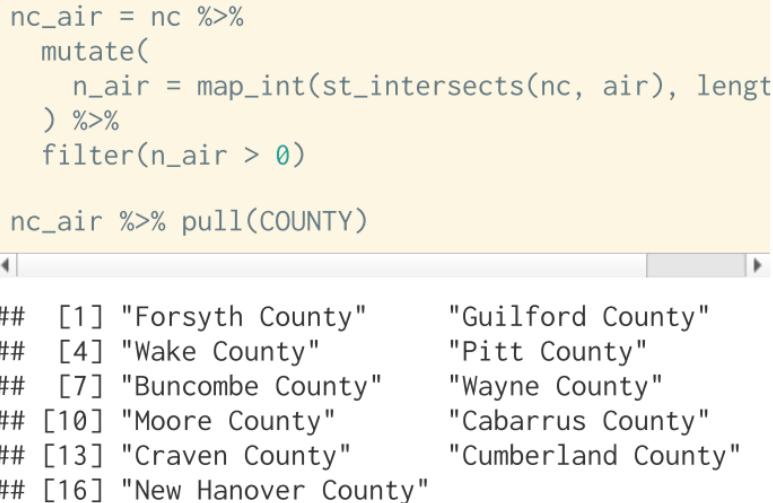
Dense Injections

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

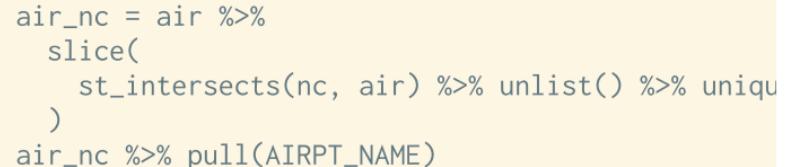
Which counties have airports?

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

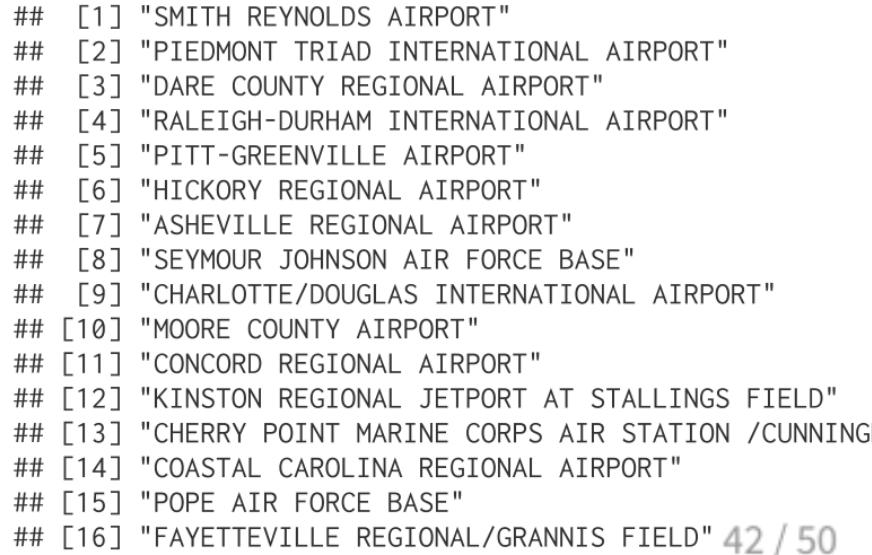
nc_air %>% pull(COUNTY)
```



```
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 /CUNNING"
## [14] "COASTAL CAROLINA REGIONAL AIRPORT"
## [15] "POPE AIR FORCE BASE"
## [16] "FAYETTEVILLE REGIONAL/GRANNIS 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')
```

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?