Lecture 16

Spatial Data and Cartography

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03/20/2017

Background

Analysis of 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.
- `rgdal` - R interface to `gdal` (Geospatial Data Abstraction Library) for reading and writing spatial data.
- `rgeos` - R interface to `geos` (Geometry Engine Open Source) library for querying and manipulating spatial data. Reading and writing WKT.
- `raster` - classes and tools for handling spatial raster data.

See more - Spatial task view

Analysis of geospatial data in R

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- ~~`sp` - core classes for handling spatial data, additional utility functions.~~
- ~~`rgdal` - R interface to `gdal` (Geospatial Data Abstraction Library) for reading and writing spatial data.~~
- ~~`rgeos` - 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 priciples.
- `raster` - classes and tools for handling spatial raster data.

See more - Spatial task view

Installing `sf`

The `sf` package is currently under active development and is evolving rapidly. The version on CRAN should be reasonably up to date, but the most current version is always available from github.

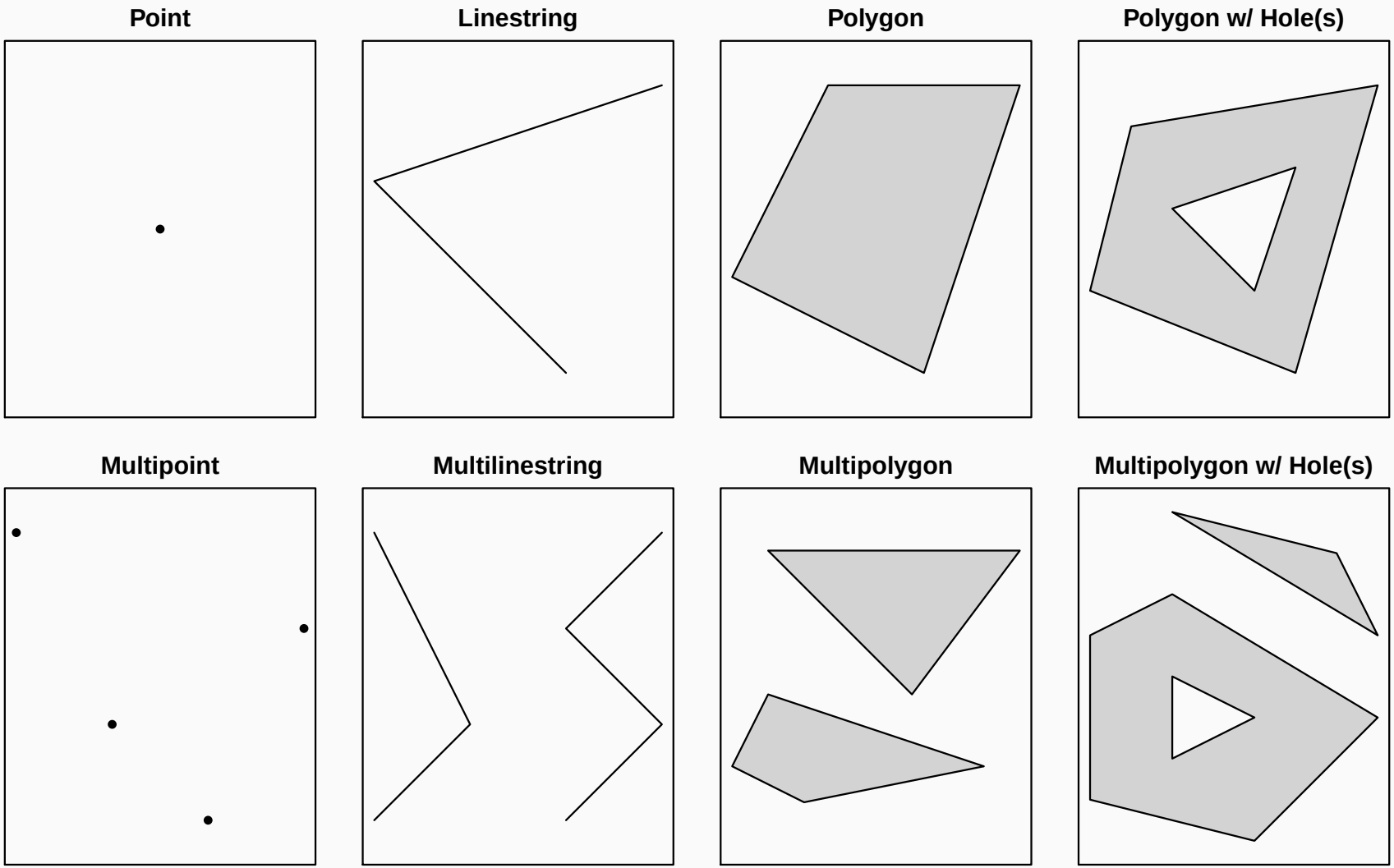
Difficulty comes from requirements for external libraries (`geos`, `gdal`, and `proj4`).

- *Windows* - installing from source works when Rtools is installed (system requirements are downloaded from rwinlib)
- *MacOS* - install dependencies via homebrew:

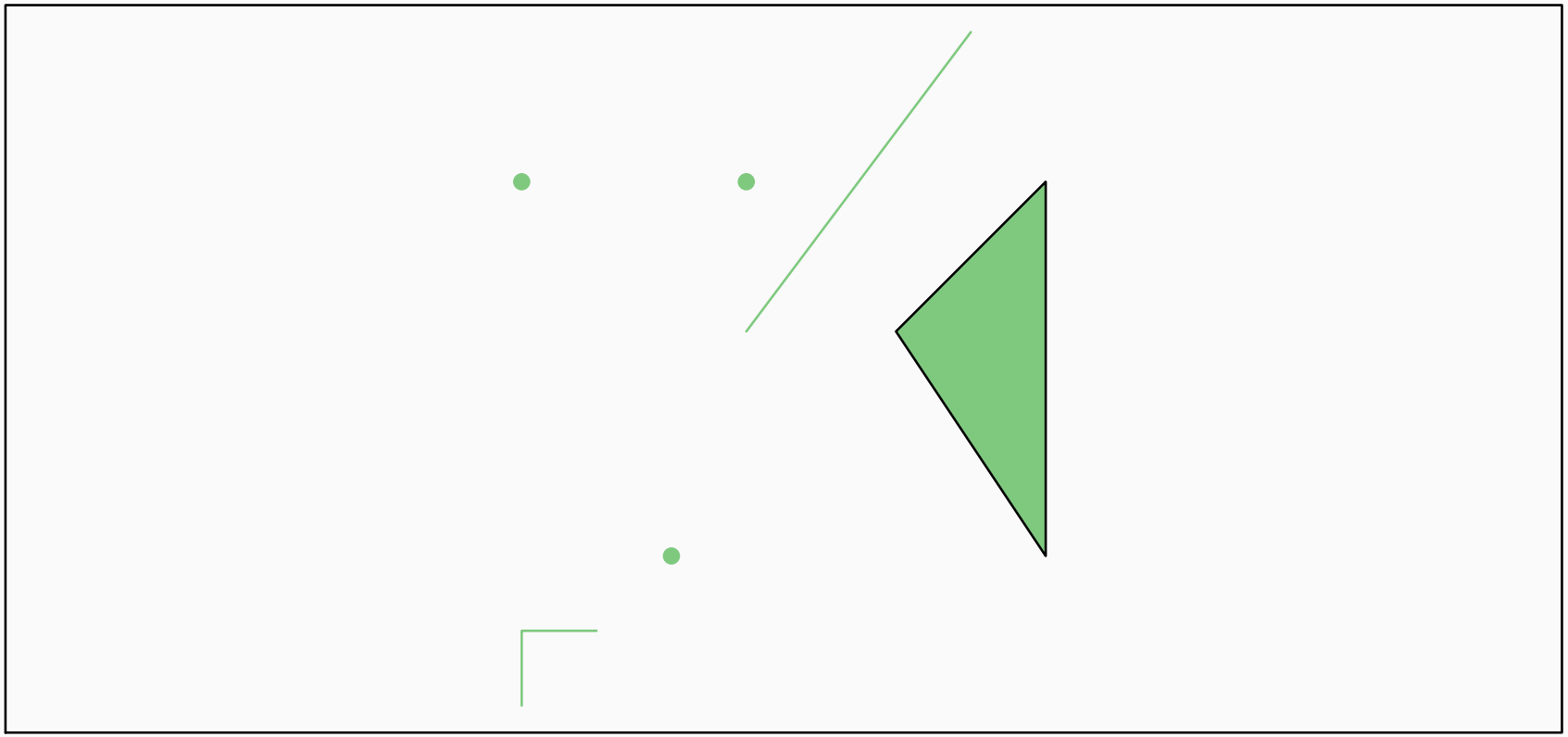
```
brew tap osgeo/osgeo4mac && brew tap --repair
brew install proj
brew install geos
brew install udunits
brew unlink gdal
brew install gdal2
```

- *Linux* - Install development pacakages for GDAL (>= 2.0.0), GEOS (>= 3.3.0) and Proj.4 (>= 4.8.0) from your package manager of choice.

Simple Features



Geometry Collection



Point, Multipoint, Multilinestring, Polygon

Reading and writing geospatial data via sp

- maptools
  - readShapePoints / writeShapePoints - Shapefile w/ points
  - readShapeLines / writeShapeLines - Shapefile w/ lines
  - readShapePoly / writeShapePoly - Shapefile w/ polygons
  - readShapeSpatial / writeShapeSpatial - Shapefile
- rgdal
  - readOGR / writeOGR - Shapefile, GeoJSON, KML, ...
- rgeos
  - readWKT / writeWKT - Well Known Text
- sf
  - st_read / st_write - Shapefile, GeoJSON, KML, ...

Reading and writing geospatial data via sp

- ~~maptools~~
  - ~~readShapePoints / writeShapePoints - Shapefile w/ points~~
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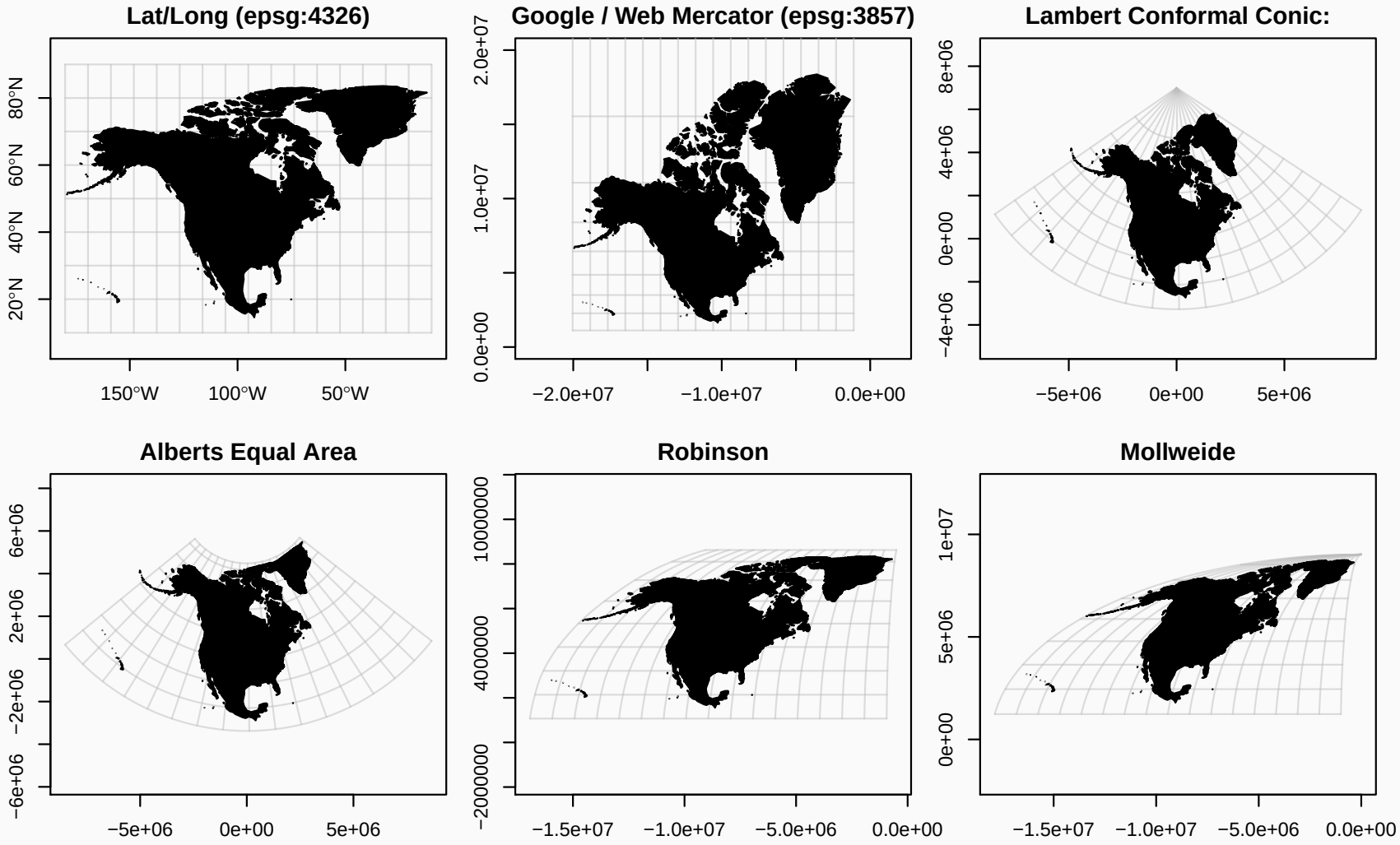
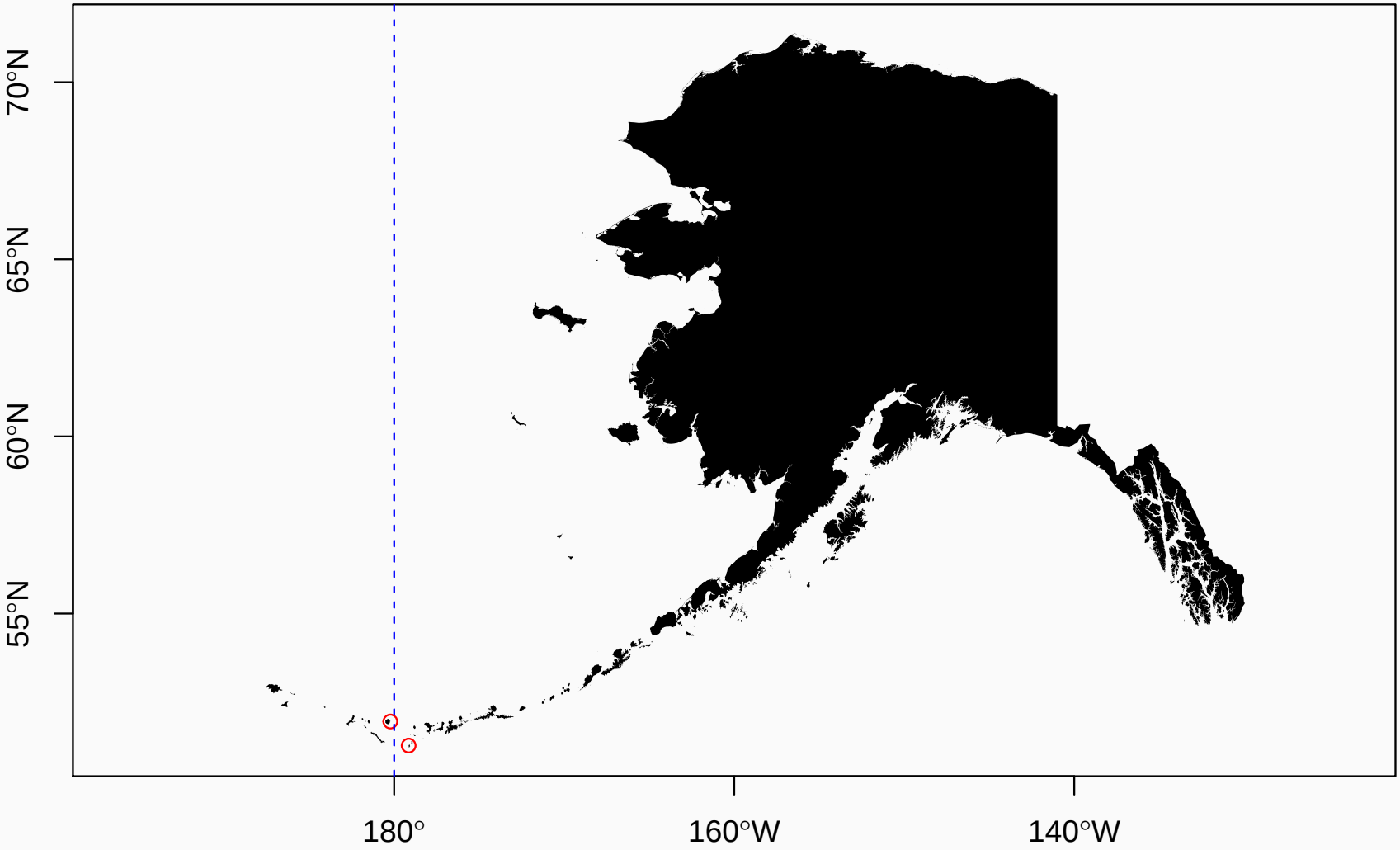
Geospatial stuff is complicated

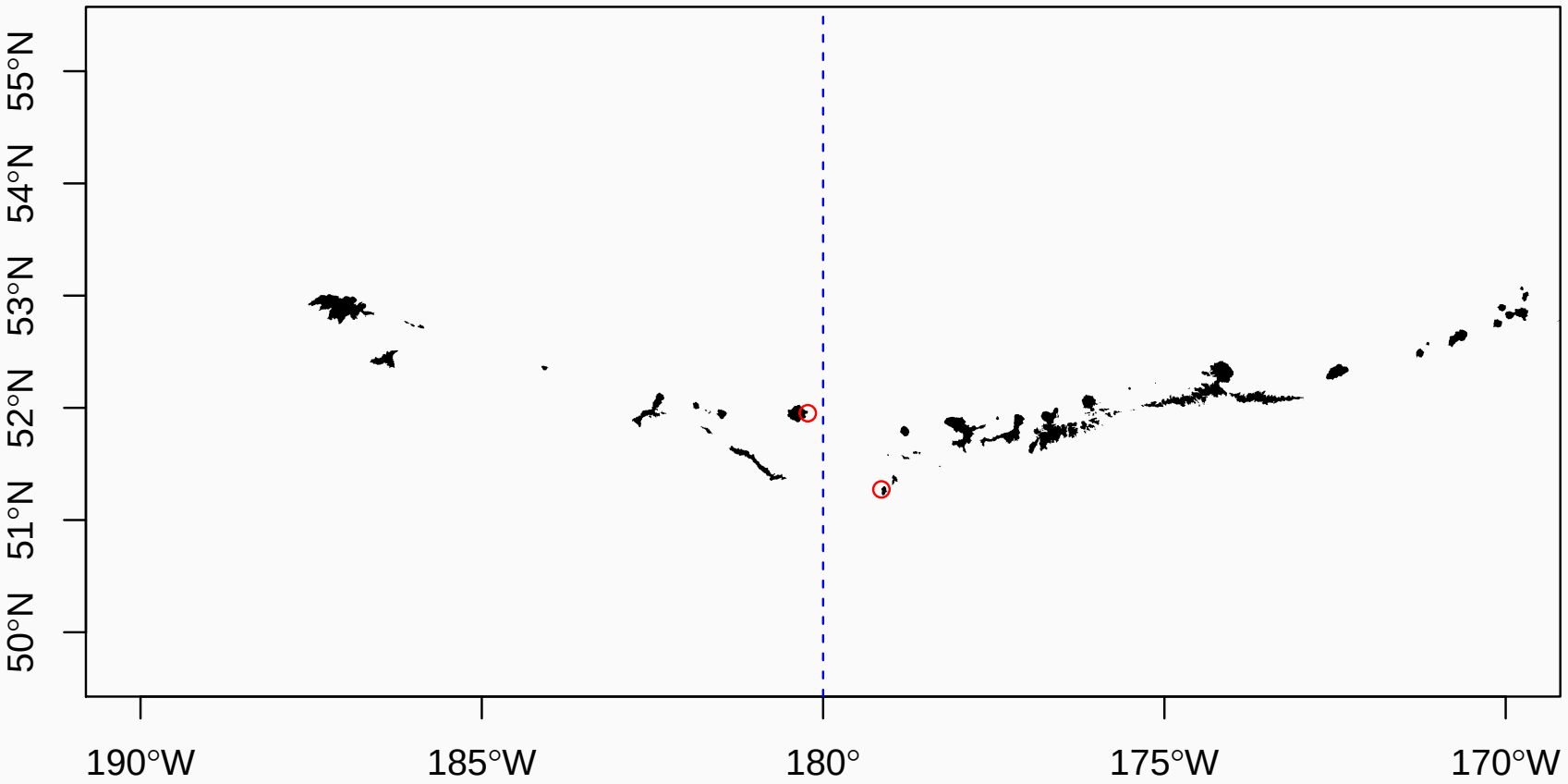
Projections

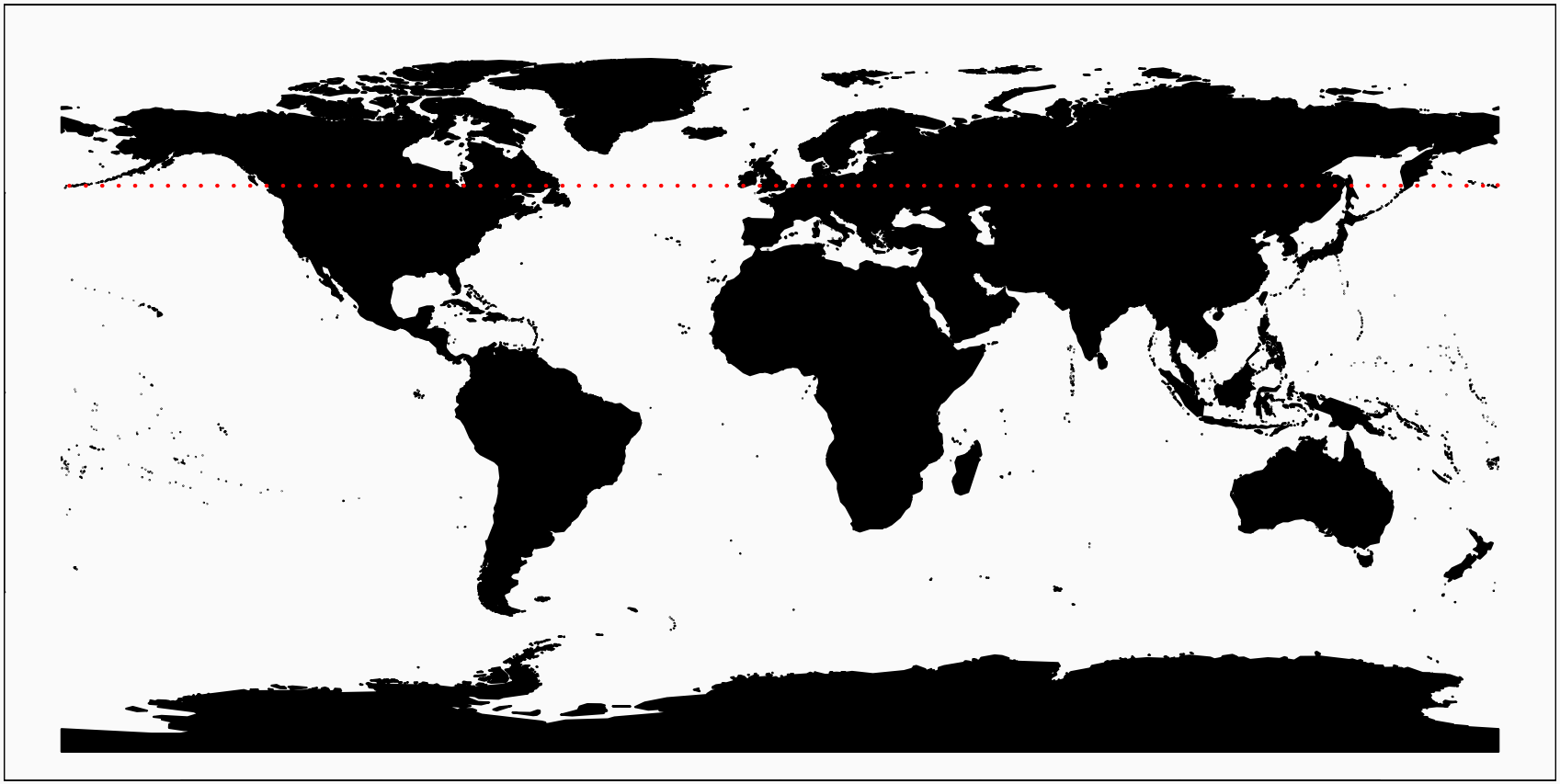


Dateline

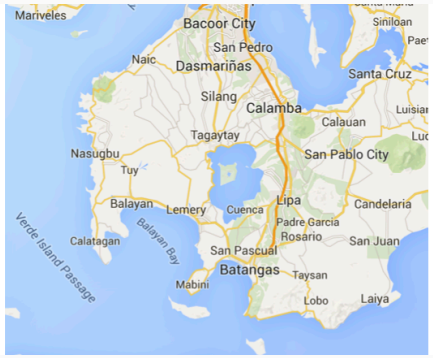
Want to fly from the Western most point in the US to the Eastern most point?



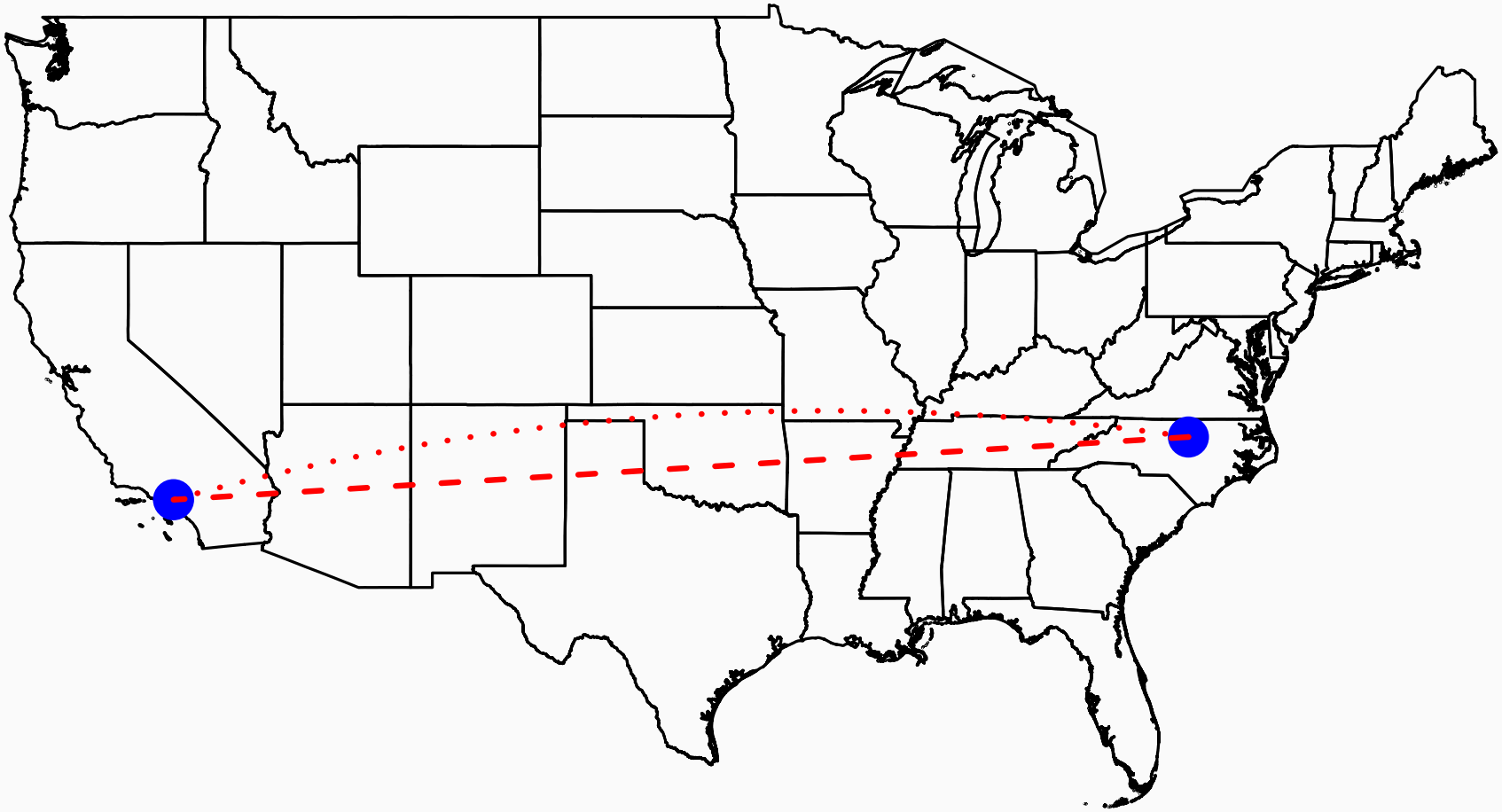

50°N
51°N
52°N
53°N
54°N
55°N
190°W
185°W
180°
175°W
170°W



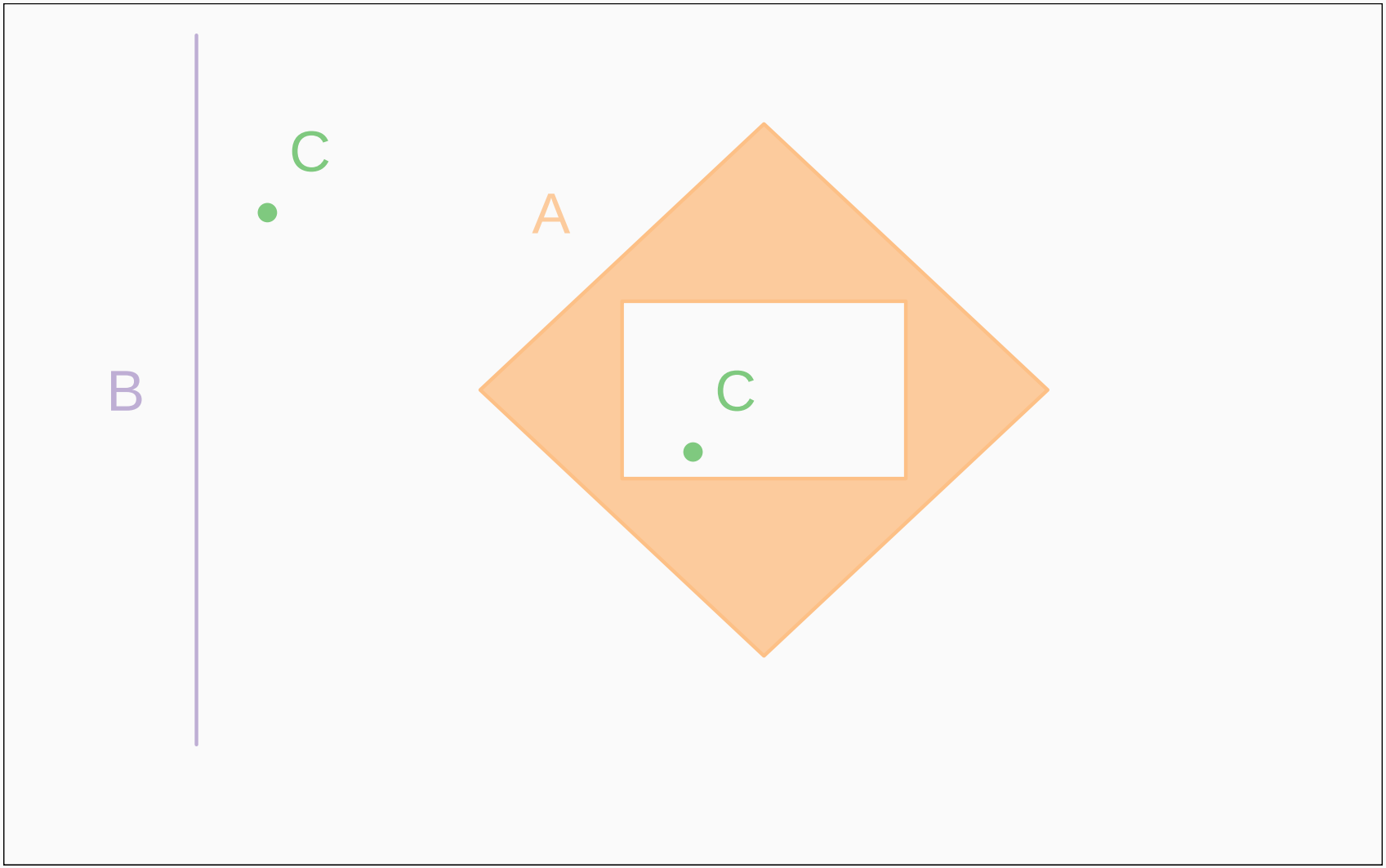
Relationships



Distance on a Sphere



Distance for Simple Features



How do we define the distance between A and B, A and C, or B and C?

Using `sf`

Example data

```
nc  = st_read("data/gis/nc_counties/", quiet=TRUE, stringsAsFactors=FALSE)
air = st_read("data/gis/airports/", quiet=TRUE, stringsAsFactors=FALSE)
hwy = st_read("data/gis/us_interstates/", quiet=TRUE, stringsAsFactors=FALSE)

head(nc)
## Simple feature collection with 6 features and 8 fields
## geometry type:  MULTIPOLYGON
## dimension:      XY
## bbox:           xmin: -81.74178 ymin: 36.07215 xmax: -75.77323 ymax: 36.58815
## epsg (SRID):    4269
## proj4string:    +proj=longlat +datum=NAD83 +no_defs
##         AREA PERIMETER COUNTYP010 STATE           COUNTY  FIPS
## 1 0.11175964  1.610396       1994    NC      Ashe County 37009
## 2 0.06159483  1.354829       1996    NC Alleghany County 37005
## 3 0.14023009  1.769388       1998    NC     Surry County 37171
## 4 0.08912401  1.425249       1999    NC     Gates County 37073
## 5 0.06865730  4.428217       2000    NC Currituck County 37053
## 6 0.11859434  1.404309       2001    NC    Stokes County 37169
##   STATE_FIPS SQUARE_MIL                          geometry
## 1         37    429.350 MULTIPOLYGON(((-81.65648656...
## 2         37    236.459 MULTIPOLYGON(((-81.30999399...
## 3         37    538.863 MULTIPOLYGON(((-80.71416384...
## 4         37    342.340 MULTIPOLYGON(((-76.91183250...
## 5         37    263.871 MULTIPOLYGON(((-75.82777792...
## 6         37    455.793 MULTIPOLYGON(((-80.43314893...
```

```
head(air)
## Simple feature collection with 6 features and 16 fields
## geometry type:  POINT
## dimension:      XY
## bbox:           xmin: -118.1506 ymin: 27.49748 xmax: -72.04514 ymax: 46.25149
## epsg (SRID):    4269
## proj4string:    +proj=longlat +datum=NAD83 +no_defs
##   AIRPRTX010 FEATURE ICAO IATA                            AIRPT_NAME
## 1          0 AIRPORT KGON  GON             GROTON-NEW LONDON AIRPORT
## 2          3 AIRPORT K6S5  6S5                RAVALLI COUNTY AIRPORT
## 3          4 AIRPORT KMHV  MHV                        MOJAVE AIRPORT
## 4          6 AIRPORT KSEE  SEE               GILLESPIE FIELD AIRPORT
## 5          7 AIRPORT KFPR  FPR ST LUCIE COUNTY INTERNATIONAL AIRPORT
## 6          8 AIRPORT KRYY  RYY           COBB COUNTY-MC COLLUM FIELD
##                  CITY STATE STATE_FIPS     COUNTY  FIPS TOT_ENP
## 1 GROTON (NEW LONDON)    CT         09 NEW LONDON 09011      75
## 2            HAMILTON    MT         30    RAVALLI 30081     112
## 3              MOJAVE    CA         06       KERN 06029     135
## 4  SAN DIEGO/EL CAJON    CA         06  SAN DIEGO 06073      30
## 5         FORT PIERCE    FL         12   ST LUCIE 12111      33
## 6             ATLANTA    GA         13       COBB 13067     110
##   LATITUDE  LONGITUDE ELEV ACT_DATE CNTL_TWR
## 1 41.33006  -72.04514    9  04/1940        Y
## 2 46.25149 -114.12554 3642  04/1940        N
## 3 35.05864 -118.15056 2801  04/1940        Y
## 4 32.82622 -116.97244  388  12/1942        Y
## 5 27.49748  -80.37263   24     <NA>        Y
## 6 34.01316  -84.59706 1041  12/1942        Y
##                       geometry
## 1  POINT(-72.045139 41.330056)
## 2  POINT(-114.12554 46.251494)
## 3 POINT(-118.150556 35.058639)
## 4 POINT(-116.972444 32.826222)
## 5  POINT(-80.372632 27.497479)
## 6  POINT(-84.597056 34.013157)
```

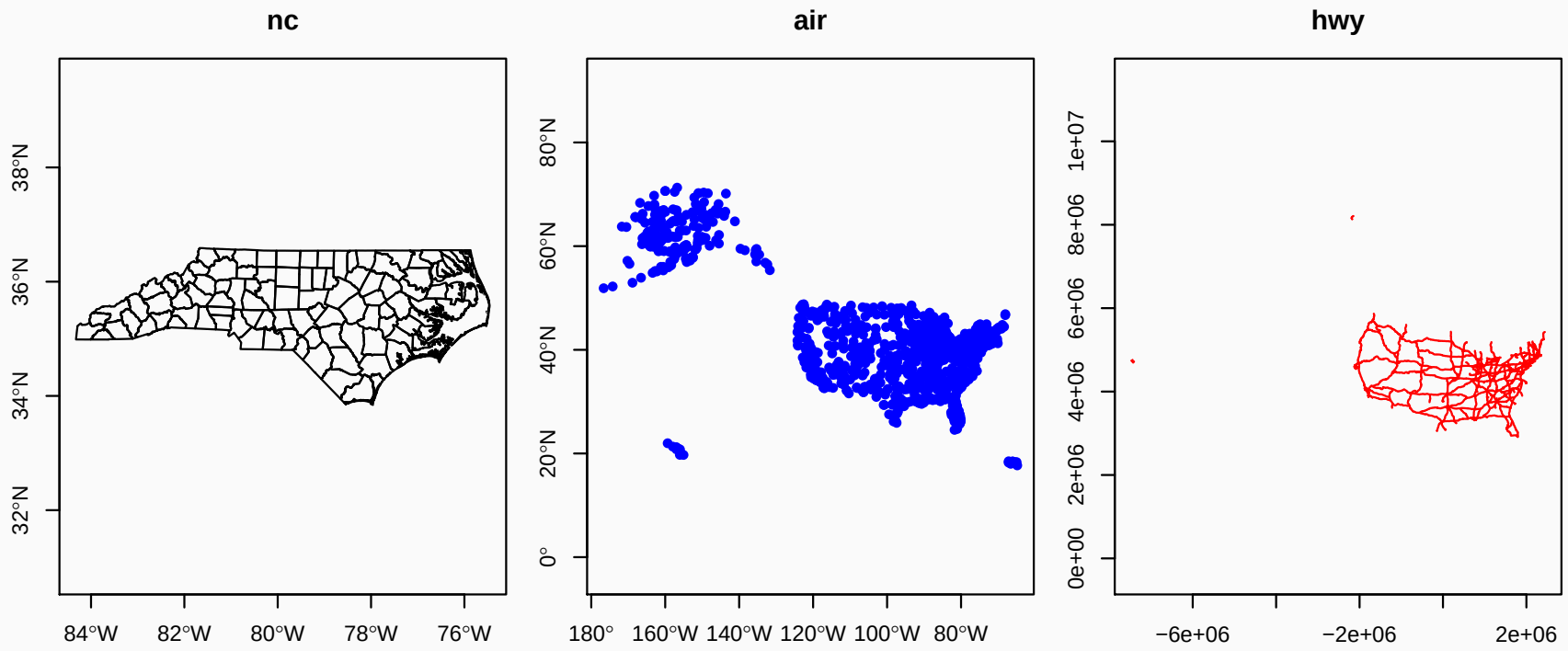
```
head(hwy)
## Simple feature collection with 6 features and 3 fields
## geometry type:  MULTILINESTRING
## dimension:      XY
## bbox:           xmin: -1910156 ymin: 3264168 xmax: 1591535 ymax: 5340953
## epsg (SRID):    26915
## proj4string:    +proj=utm +zone=15 +datum=NAD83 +units=m +no_defs
##   ROUTE_NUM DIST_MILES DIST_KM                       geometry
## 1       I10    2449.12 3941.48 MULTILINESTRING((-1881199.8...
## 2      I105      20.75   33.39 MULTILINESTRING((-1910155.9...
## 3      I110      41.42   66.65 MULTILINESTRING((1054138.60...
## 4      I115       1.58    2.55 MULTILINESTRING((-1013795.8...
## 5       I12      85.32  137.31 MULTILINESTRING((680741.744...
## 6      I124       1.73    2.79 MULTILINESTRING((1201467.26...
```

sf classes

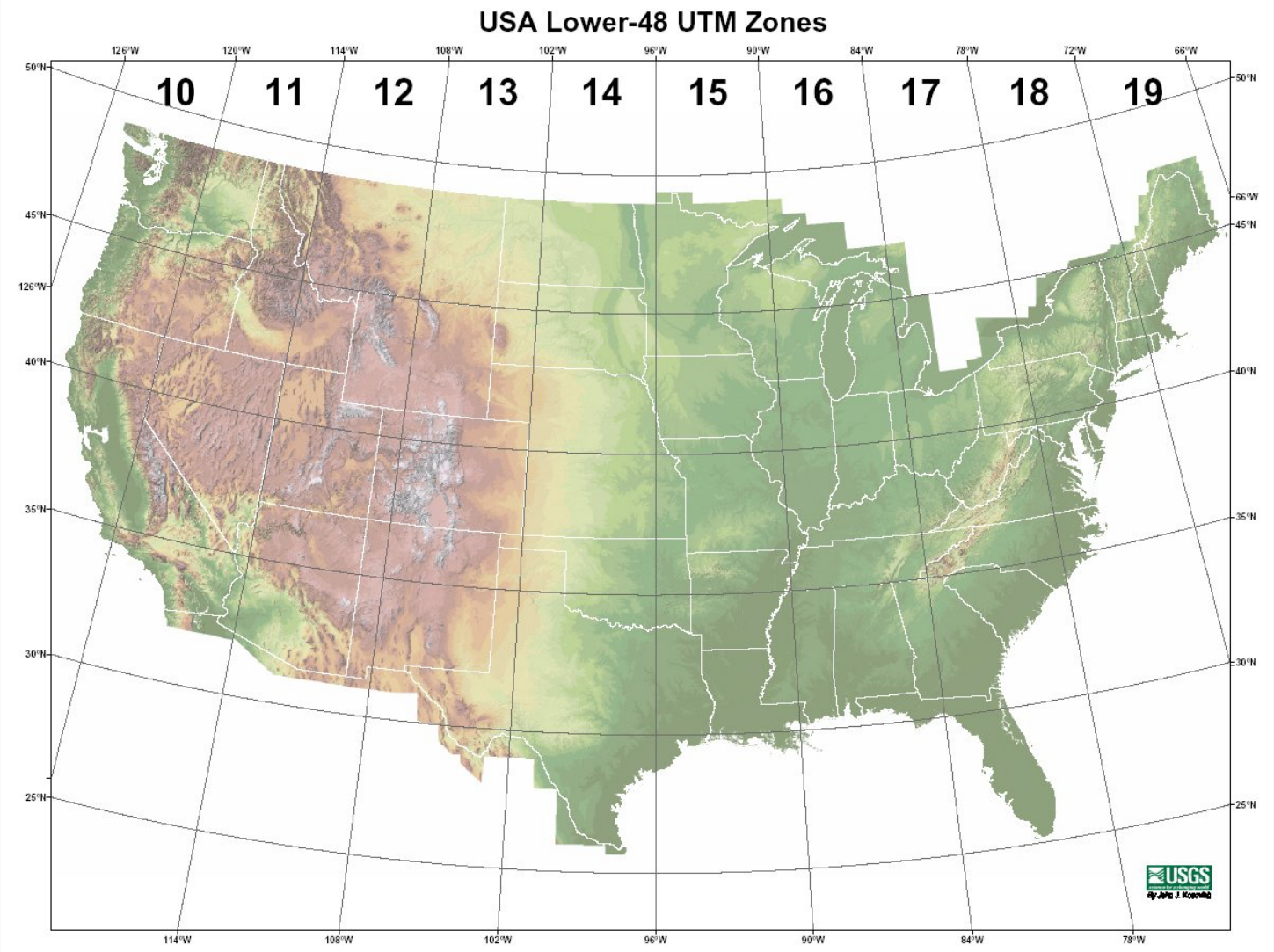
```
str(nc)
## Classes 'sf' and 'data.frame':   100 obs. of  9 variables:
##  $ AREA      : num  0.1118 0.0616 0.1402 0.0891 0.0687 ...
##  $ PERIMETER : num  1.61 1.35 1.77 1.43 4.43 ...
##  $ COUNTYP010: num  1994 1996 1998 1999 2000 ...
##  $ STATE     : chr  "NC" "NC" "NC" "NC" ...
##  $ COUNTY    : chr  "Ashe County" "Alleghany County" "Surry County" "Gates County"
##  $ FIPS      : chr  "37009" "37005" "37171" "37073" ...
##  $ STATE_FIPS: chr  "37" "37" "37" "37" ...
##  $ SQUARE_MIL: num  429 236 539 342 264 ...
##  $ geometry  : List of  100 , printing List of 1
##   ..$ :List of 1
##   .. ..$ : num [1:1030, 1:2] -81.7 -81.7 -81.7 -81.6 -81.6 ...
##   ..- attr(*, "class")= chr  "XY" "MULTIPOLYGON" "sfg"
##  - attr(*, "sf_column")= chr "geometry"
##  - attr(*, "agr")= Factor w/ 3 levels "constant","aggregate",..: NA NA NA NA NA NA
##   ..- attr(*, "names")= chr  "AREA" "PERIMETER" "COUNTYP010" "STATE" ...

class(nc)
## [1] "sf"         "data.frame"

class(nc$geometry)
## [1] "sfc_MULTIPOLYGON" "sfc"

class(nc$geometry[[1]])
## [1] "XY"           "MULTIPOLYGON" "sfg"
```

Projections

```
st_crs(nc)$proj4string
## [1] "+proj=longlat +datum=NAD83 +no_defs"
st_crs(air)$proj4string
## [1] "+proj=longlat +datum=NAD83 +no_defs"
st_crs(hwy)$proj4string
## [1] "+proj=utm +zone=15 +datum=NAD83 +units=m +no_defs"
```

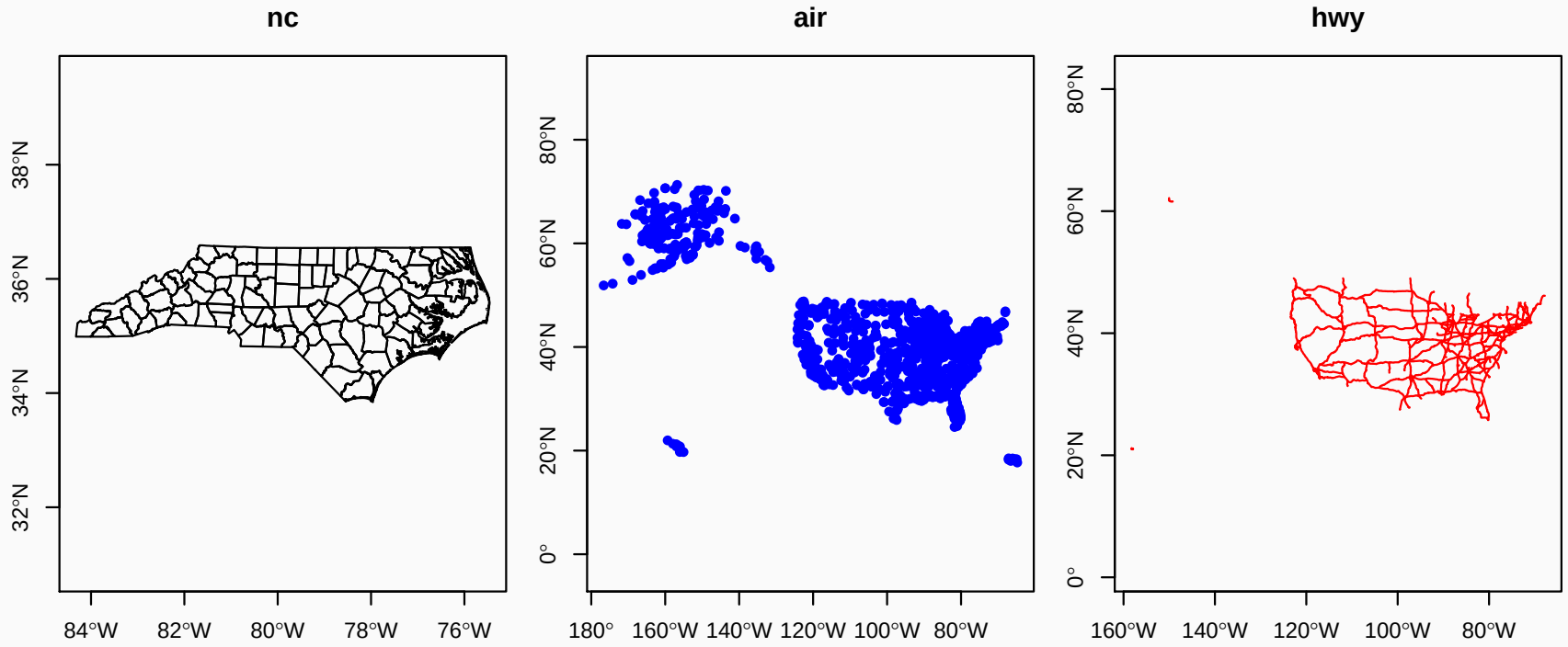


UTM Zones


USA Lower-48 UTM Zones
10
11
12
13
14
15
16
17
18
19
126°W
120°W
114°W
108°W
102°W
96°W
90°W
84°W
78°W
72°W
66°W
50°N
45°N
40°N
35°N
30°N
25°N
USGS

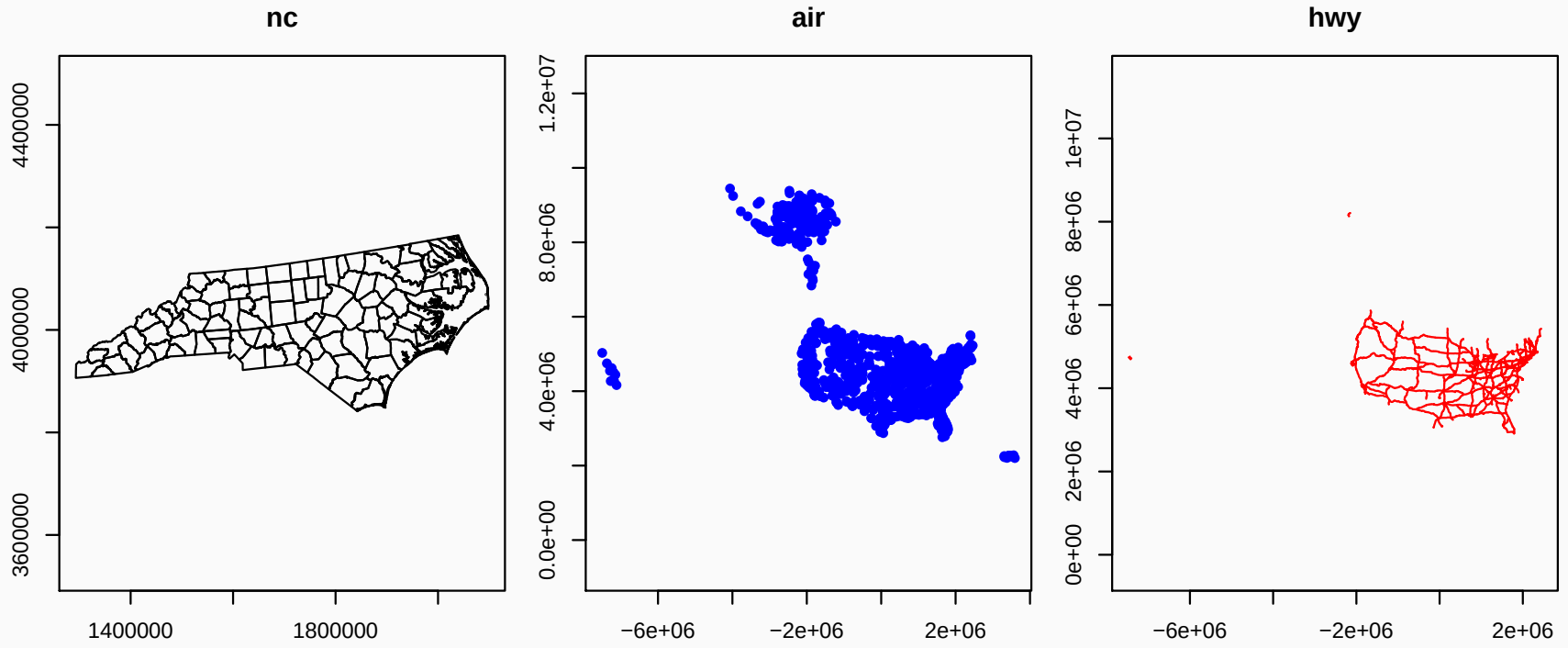
Lat/Long

```
nc_ll = nc
air_ll = air
hwy_ll = st_transform(hwy, st_crs(nc)$proj4string)
```

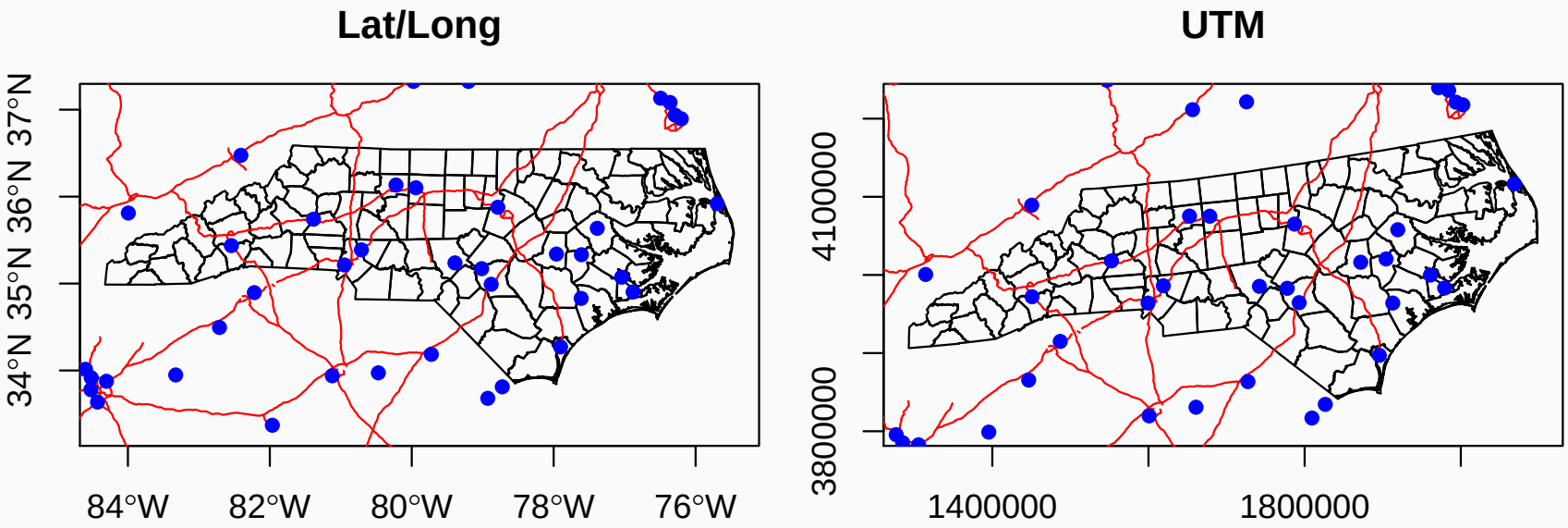


UTM

```
nc_utm = st_transform(nc, st_crs(hwy)$proj4string)
air_utm = st_transform(air, st_crs(hwy)$proj4string)
hwy_utm = hwy
```



Comparison


Lat/Long
34°N 35°N 36°N 37°N
84°W
82°W
80°W
78°W
76°W
UTM
4100000
3800000
1400000
1800000

Subsetting vs. dplyr

```
sub = nc$COUNTY %in% c("Durham County","Wake County","Orange County")
nc[sub,]
## Simple feature collection with 3 features and 8 fields
## geometry type:  MULTIPOLYGON
## dimension:      XY
## bbox:           xmin: -79.26453 ymin: 35.51905 xmax: -78.25503 ymax: 36.24385
## epsg (SRID):    4269
## proj4string:    +proj=longlat +datum=NAD83 +no_defs
##          AREA PERIMETER COUNTYP010 STATE        COUNTY  FIPS
## 29 0.10401267  1.297813       2074    NC Orange County 37135
## 30 0.07714111  1.287529       2075    NC Durham County 37063
## 37 0.22144442  2.140667       2106    NC   Wake County 37183
##    STATE_FIPS SQUARE_MIL                       geometry
## 29         37    401.465 MULTIPOLYGON(((-79.25563180...
## 30         37    297.841 MULTIPOLYGON(((-78.94843190...
## 37         37    857.610 MULTIPOLYGON(((-78.71263198...
```

```
filter(nc, COUNTY %in% c("Durham County","Wake County","Orange County"))
## Simple feature collection with 3 features and 8 fields
## geometry type:  MULTIPOLYGON
## dimension:      XY
## bbox:           xmin: -84.32186 ymin: 33.84175 xmax: -75.46003 ymax: 36.58815
## epsg (SRID):    4269
## proj4string:    +proj=longlat +datum=NAD83 +no_defs
##         AREA PERIMETER COUNTYP010 STATE        COUNTY  FIPS
## 1 0.10401267  1.297813       2074    NC Orange County 37135
## 2 0.07714111  1.287529       2075    NC Durham County 37063
## 3 0.22144442  2.140667       2106    NC   Wake County 37183
##   STATE_FIPS SQUARE_MIL                       geometry
## 1         37    401.465 MULTIPOLYGON(((-79.25563180...
## 2         37    297.841 MULTIPOLYGON(((-78.94843190...
## 3         37    857.610 MULTIPOLYGON(((-78.71263198...
```

Distance between NC counties

```
counties = c("Durham County","Wake County","Orange County")
sub = nc$COUNTY %in% counties

st_distance(nc_ll[sub, ])
## Error in st_distance(nc_ll[sub, ]): st_distance for longitude/latitude da
st_distance(nc_utm[sub, ])
## Units: m
##          [,1] [,2]     [,3]
## [1,]    0.000    0 9906.327
## [2,]    0.000    0    0.000
## [3,] 9906.327    0    0.000
```

Distance between NC counties (centroids)

```
nc_ll[sub, ] %>% st_centroid() %>% st_distance()
## Units: m
##          [,1]     [,2]     [,3]
## [1,]     0.00 22185.58 52031.22
## [2,] 22185.58     0.00 34076.78
## [3,] 52031.22 34076.78     0.00

nc_utm[sub, ] %>% st_centroid() %>% st_distance()
## Units: m
##          [,1]     [,2]     [,3]
## [1,]     0.00 22616.18 53050.15
## [2,] 22616.18     0.00 34751.60
## [3,] 53050.15 34751.60     0.00
```

Distance to the closest airport from each county?

```
d = st_distance(air_utm, nc_utm[sub,])
d[1:5,]
## Units: m
##           [,1]      [,2]      [,3]
## [1,]  846916.0  837771.1  836234.3
## [2,] 3122697.5 3146840.3 3172522.0
## [3,] 3556664.1 3584394.6 3592972.9
## [4,] 3514296.0 3540264.5 3545184.1
## [5,]  952881.7  954495.9  921201.2
```

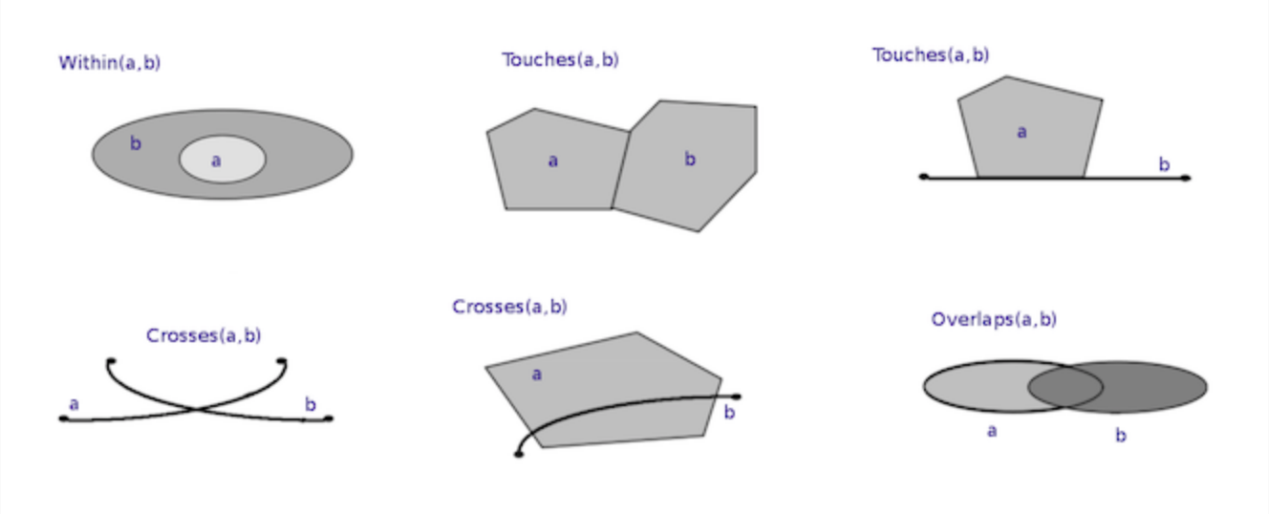
```
nearest_airport = apply(d, 2, which.min)
air %>% slice(nearest_airport) %>% .$AIRPT_NAME
## [1] "RALEIGH-DURHAM INTERNATIONAL AIRPORT"
## [2] "RALEIGH-DURHAM INTERNATIONAL AIRPORT"
## [3] "RALEIGH-DURHAM INTERNATIONAL AIRPORT"
```

Geometry Predicates

DE-9IM

	Interior	Boundary	Exterior
Interior	 $\dim[I(a) \cap I(b)] = 2$	 $\dim[I(a) \cap B(b)] = 1$	 $\dim[I(a) \cap E(b)] = 2$
Boundary	 $\dim[B(a) \cap I(b)] = 1$	 $\dim[B(a) \cap B(b)] = 0$	 $\dim[B(a) \cap E(b)] = 1$
Exterior	 $\dim[E(a) \cap I(b)] = 2$	 $\dim[E(a) \cap B(b)] = 1$	 $\dim[E(a) \cap E(b)] = 2$

Spatial predicates



st_within(a,b)

$$\begin{bmatrix} T & * & F \\ * & * & F \\ * & * & * \end{bmatrix}$$

st_touches(a,b)

$$\begin{bmatrix} F & T & * \\ * & * & * \\ * & * & * \end{bmatrix} \cup \begin{bmatrix} F & * & * \\ T & * & * \\ * & * & * \end{bmatrix} \cup \begin{bmatrix} F & * & * \\ * & T & * \\ * & * & * \end{bmatrix}$$

st_crosses(a,b)

If $\dim(a) < \dim(b)$

$$\begin{bmatrix} T & * & T \\ * & * & * \\ * & * & * \end{bmatrix}$$

If $\dim(a) > \dim(b)$

$$\begin{bmatrix} T & * & * \\ * & * & * \\ T & * & * \end{bmatrix}$$

If $\dim(any) = 1$

$$\begin{bmatrix} 0 & * & * \\ * & * & * \\ * & * & * \end{bmatrix}$$

st_overlaps(a,b) $(\dim(a) = \dim(b))$

If $\dim \in \{0,2\}$

$$\begin{bmatrix} T & * & T \\ * & * & * \\ T & * & * \end{bmatrix},$$

If $\dim = 1$

$$\begin{bmatrix} 1 & * & T \\ * & * & * \\ T & * & * \end{bmatrix}$$

Sparse vs Full Results

```
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)
```

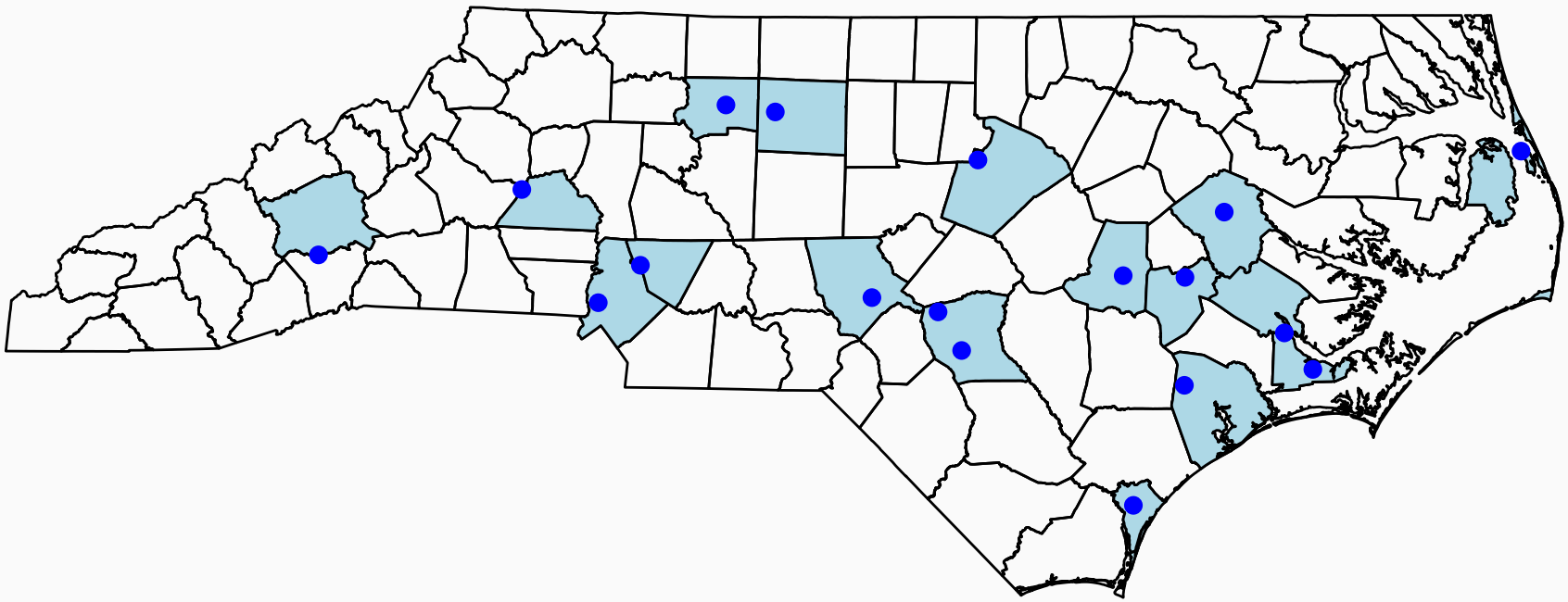
```
st_intersects(nc, air, sparse=FALSE) %>% str()
##  logi [1:100, 1:940] FALSE FALSE FALSE FALSE FALSE FALSE ...
```

Which counties have airports?

```
nc_air = st_intersects(nc, air)
has_air = map_lgl(nc_air, ~ length(.) > 0)
nc %>% slice(which(has_air)) %>% .$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_in_nc = nc_air %>% unlist() %>% unique()
air %>% slice(air_in_nc) %>% .$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"
```

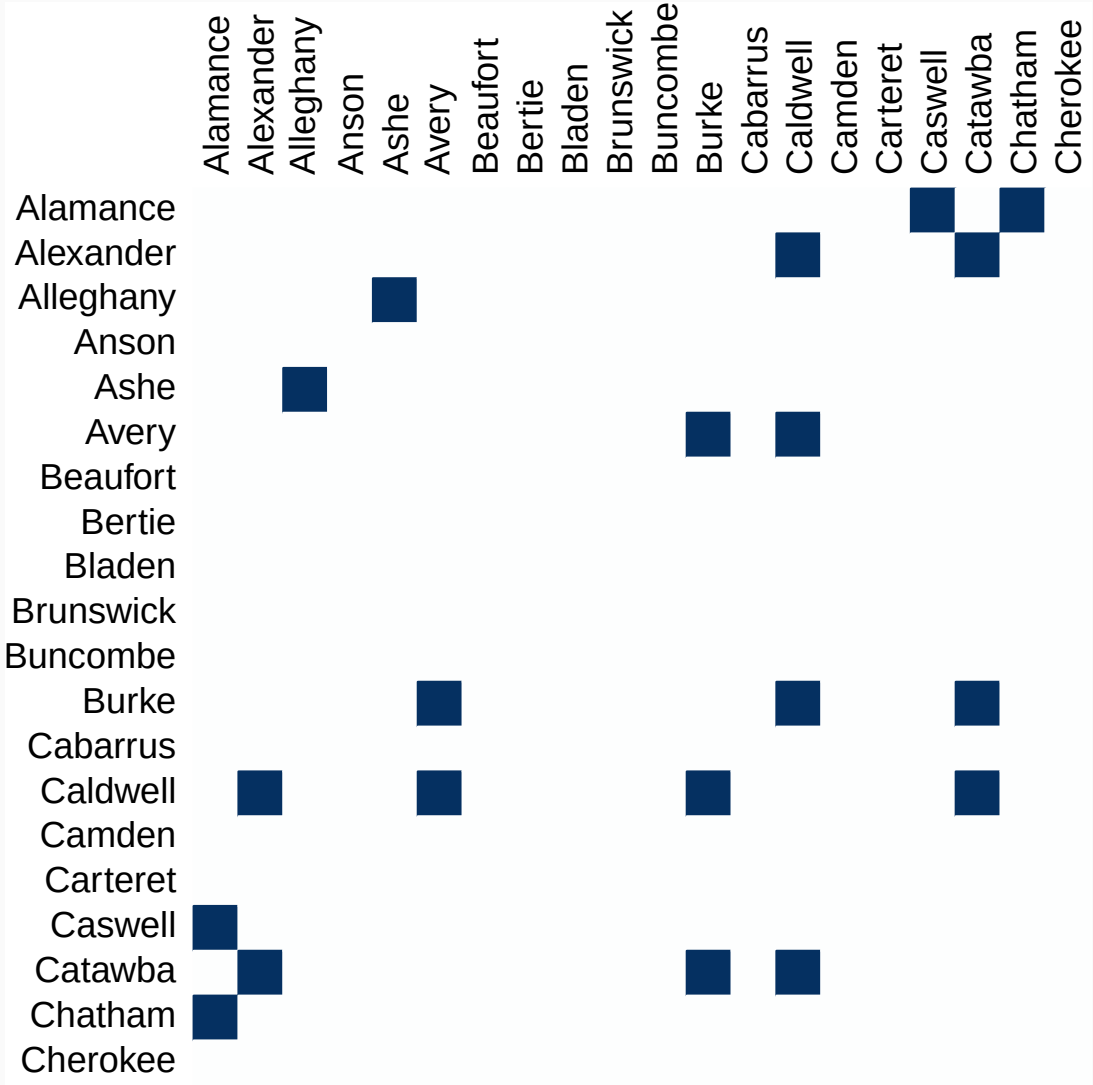
```
plot(st_geometry(nc))
plot(st_geometry(nc[has_air,]), add=TRUE, col="lightblue")
plot(st_geometry(air[air_in_nc,]), add=TRUE, pch=16, col="blue")
```



Adjacency matrix of counties

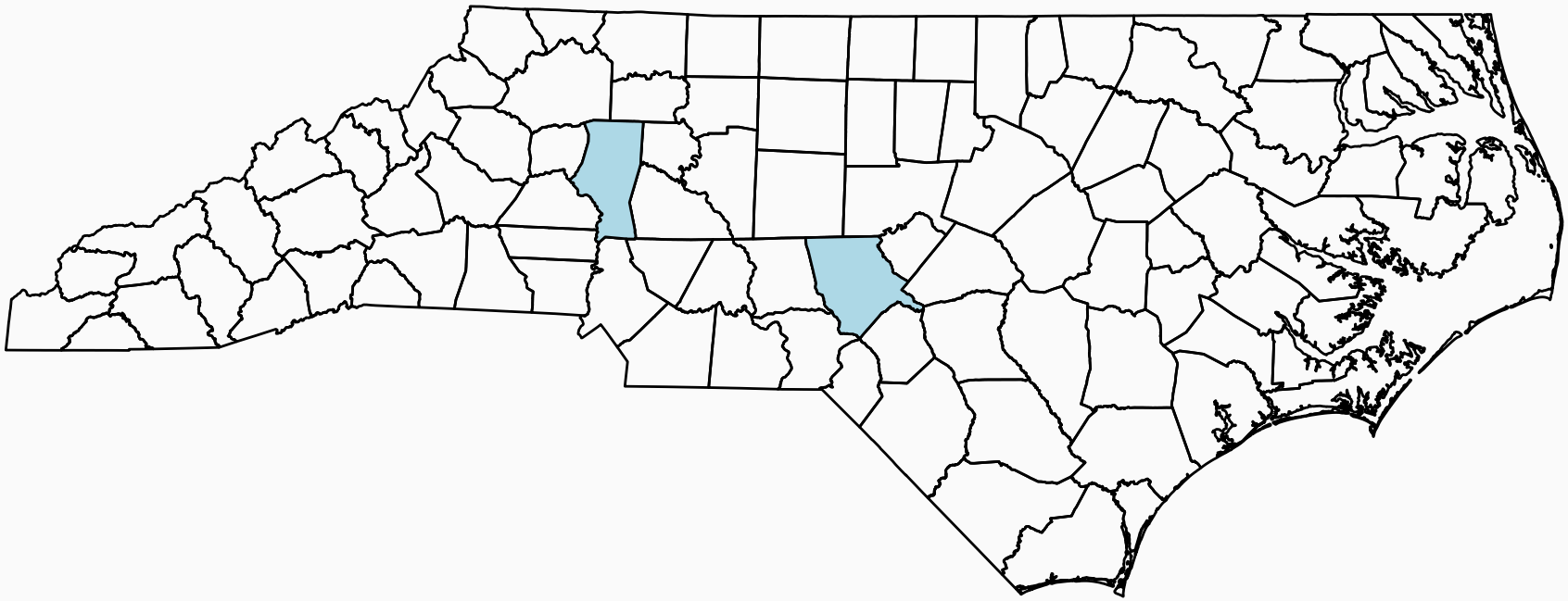
```
nc = nc[order(nc$COUNTY),]
adj = st_touches(nc, sparse=FALSE)

str(adj)
##  logi [1:100, 1:100] FALSE FALSE FALSE FALSE FALSE FALSE ...

durham = which(nc$COUNTY == "Durham County")
nc %>% slice(which(adj[durham,])) %>% .$COUNTY
## [1] "Chatham County"   "Granville County" "Orange County"
## [4] "Person County"    "Wake County"
```

```
library(corrplot)
rownames(adj) = str_replace(nc$COUNTY, " County", "")
colnames(adj) = str_replace(nc$COUNTY, " County", "")
corrplot(adj[1:20,1:20],method="color",type="full",tl.col="black",cl.pos = "
```



Which counties have the most neighbors?

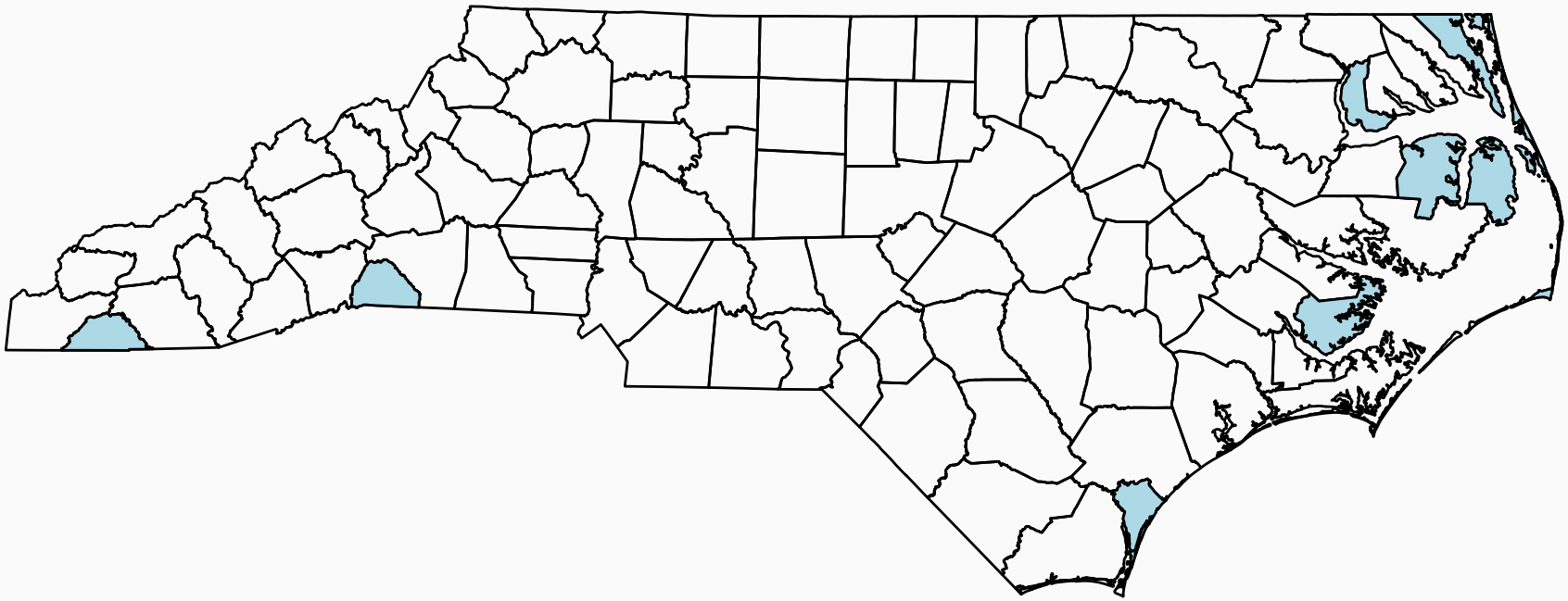
```
most_neighbors = rowSums(adj)==max(rowSums(adj))
plot(st_geometry(nc))
plot(st_geometry(nc[most_neighbors,]),add=TRUE,col="lightblue")
```



```
nc$COUNTY[most_neighbors]
## [1] "Iredell County" "Moore County"
```

Which counties have the least neighbors?

```
least_neighbors = rowSums(adj)==min(rowSums(adj))
plot(st_geometry(nc))
plot(st_geometry(nc[least_neighbors,]),add=TRUE,col="lightblue")
```



```
nc$COUNTY[least_neighbors]
## [1] "Chowan County"      "Clay County"        "Currituck County"
## [4] "Dare County"        "New Hanover County" "Pamlico County"
## [7] "Polk County"        "Tyrrell County"
```