

SEST-6577
Geographic Information Systems for Security Studies
Lecture 02 (Map Projections and Overlays)

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September 12, 2024

Outline

1. Measuring the Earth
2. Cartography and Map Overlays

Measuring the Earth

Where are we?

- latitude: 38.90894,
- longitude: -77.07458

but what does that mean?

1. *Latitude* (vertical coordinate)

- ϕ ("phi"): angle between equator & straight line from center of Earth to location
- positive in Northern hemisphere
- negative in Southern hemisphere

2. *Longitude* (horizontal coordinate)

- λ ("lambda"): angle between Prime Meridian & straight line from center of Earth to location
- positive east of Prime Meridian
- negative west of Prime Meridian

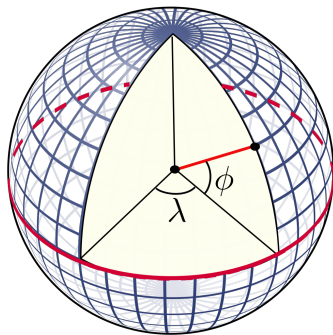


Figure 1: $\phi = \text{lat}$, $\lambda = \text{lon}$

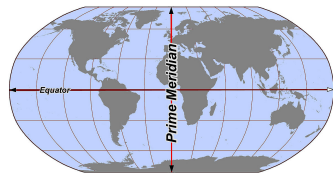


Figure 2: Prime Meridian

The Shape of Earth

What is the shape of the earth?

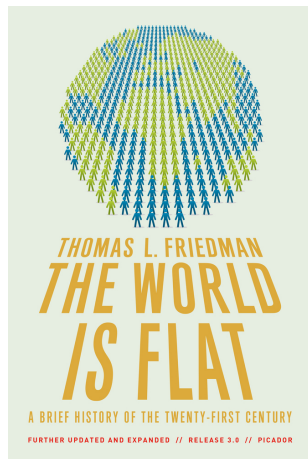


Figure 3: Wrong!



It's Turtles
All The Way Down.

Figure 4: Wrong!

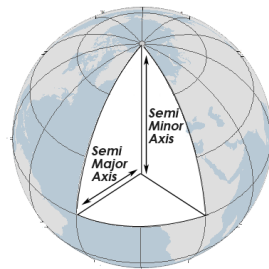
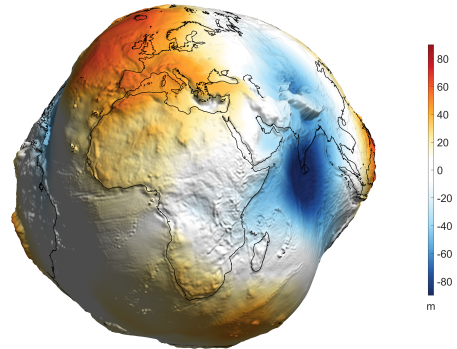


Figure 5: Also wrong?

1. *Geoid*

- a) surface of equal gravitational potential ($\sim$ mean sea level)
- b) measured, interpolated surface



Geoid height (EGM2008, nmax=1000)

Figure 6: Geoid

2. *Ellipsoid*

- a) ellipsoidal model that is best fit to Earth's shape
- b) ellipsoid = ellipse rotated around its short axis

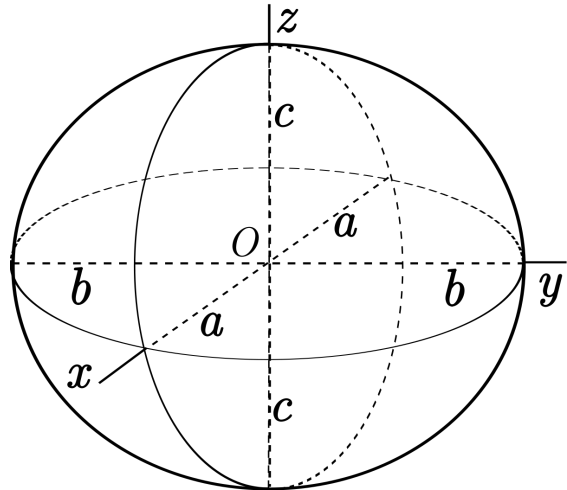


Figure 7: Ellipsoid

3. *Topography*

- a) Earth's height, relative to mean sea level
- b) measured with satellite or aerial photography

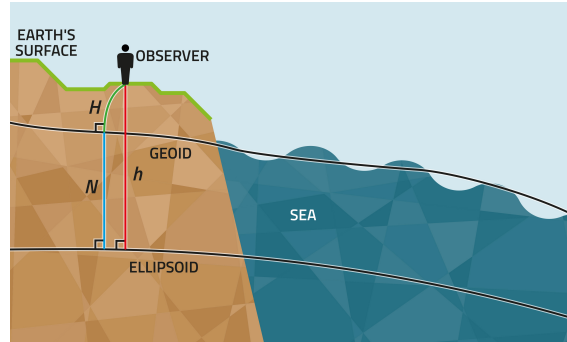


Figure 8: Topography vs. Geoid vs. Ellipsoid

Geodetic datum

- coordinate system that references ellipsoid to geoid
- examples:

ellipsoid	datum
WGS 1984	NAD 1983
Clarke 1866	NAD 1927

- translates positions on maps to real positions on Earth



Figure 9: Geodetic survey marker

World Geodetic System 1984

- international standard for GPS, satellite navigation systems
- developed by DoD, international network of scientists
- refinement of GRS 80 reference ellipsoid
- associated with North American Datum 1983 (NAD 1983)
- radius at Equator = 6378.14 km
- default in most GIS

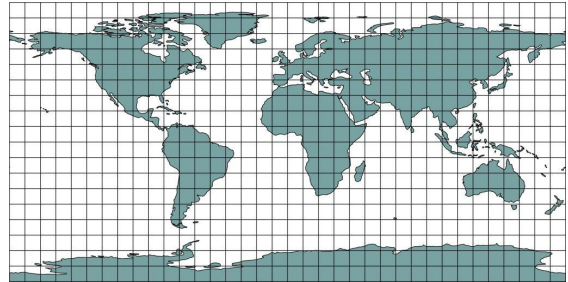


Figure 10: WGS 84

Projections and Coordinate Systems

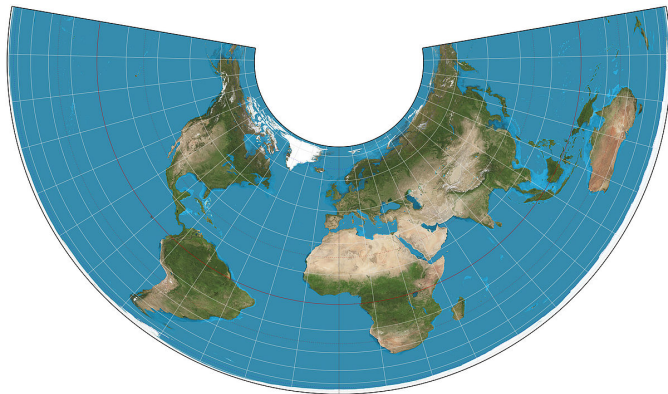


Figure 11: How to squeeze 3 dimensions into 2?

What are projections?

- transformations from Earth's 3D surface to 2D plane
1. *Cylindrical projection*
 - “wrap cylinder around Equator”
 - more distortion near poles
 2. *Conic projection*
 - “put cone on top of Earth”
 - latitudes as arcs, longitude as straight lines
 3. *Azimuthal projection*
 - “put flat plane on top of Earth”
 - projection outward from single central point

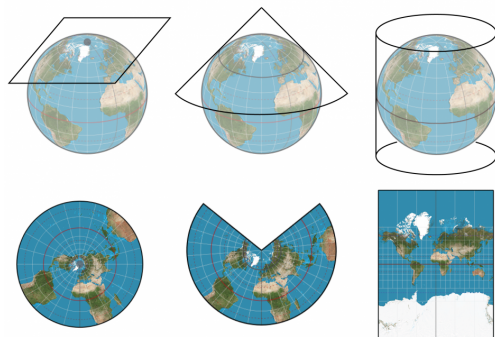


Figure 12: Azimuth, cone, cylinder

4. “Unprojected” projection

- raw geographic coordinates
- latitude → vertical axis
- longitude → horizontal axis
- effectively a cylindrical projection
- less distortion near Equator
- more distortion near poles

Map 1: Projected and Unprojected Maps of the World

Rachel Ruthven, Feb. 2, 2016

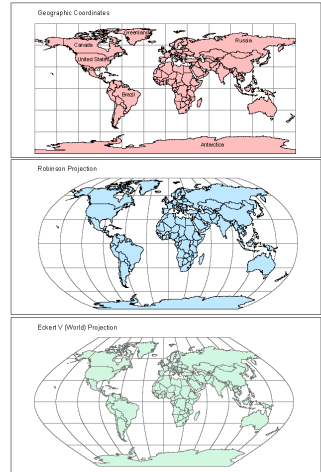


Figure 13: No free lunch

Distortion

- all projections distort Earth
- area, distance, direction, shape

1. Conformal/conic projections
(e.g. Lambert Conformal Conic)
 - preserves angles, shapes
 - distorts area
2. Equal area projections
(e.g. Albers Conic Equal Area)
 - preserves area
 - distorts angles, shapes
3. Azimuthal projections
(e.g. Azimuthal Equidistant)
 - preserves direction, distance
 - distorts shapes

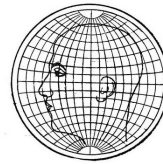


FIG. 42.—Man's head drawn on globular projection.

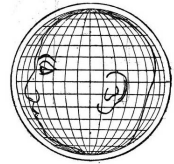


FIG. 43.—Man's head plotted on orthographic projection.

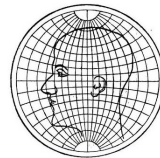


FIG. 44.—Man's head plotted on stereographic projection.

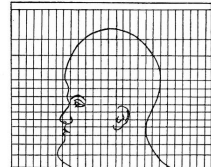


FIG. 45.—Man's head plotted on Mercator projection.

Figure 14: Funhouse mirrors

Common coordinate systems

1. *Universal Transverse Mercator (UTM)*
 - global system of 60 zones
 - cylindrical projection

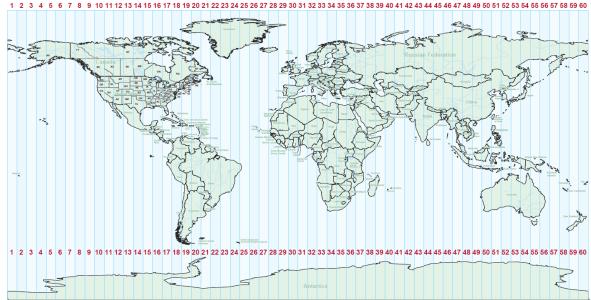


Figure 15: UTM

2. *Military Grid Reference System (MGRS)*

- derived from UTM, with different labeling convention
- NATO military standard

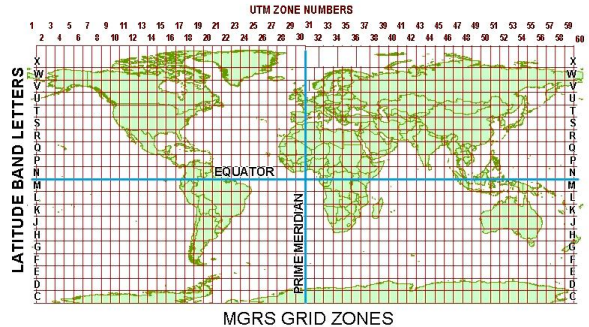


Figure 16: MGRS

3. *State Plane Coordinate Systems*

- defined separately for each U.S. state
- high local accuracy

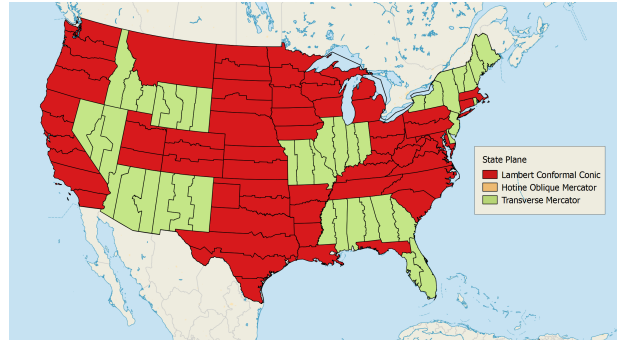
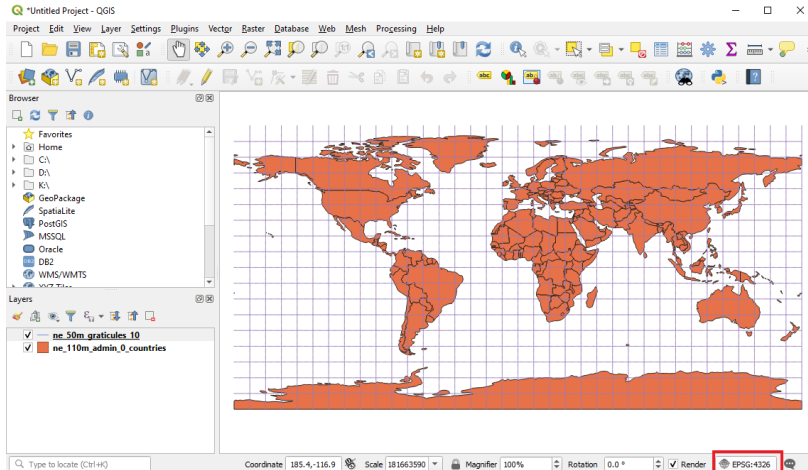


Figure 17: SPRS

In **QGIS**, your map's projection information is found in the lower-right corner (EPSG = European Petroleum Survey Group code)

- EPSG:4326 is the code for World Geodetic System (WGS84)
- this is the default in QGIS, and a standard for satellite navigation systems



Click on the EPSG code to open CRS Properties (Coordinate Reference System)

Project Properties | CRS

Project Coordinate Reference System (CRS)

☐ No projection (or unknown/non-Earth projection)

Filter

Recently used coordinate reference systems

Coordinate Reference System	Authority ID
Africa_Lambert_Conformal_Conic	EPSG:102024
Asia_Lambert_Conformal_Conic	EPSG:102012
WGS 84 / PDC Mercator	EPSG:3832
WGS 84	EPSG:4326
Google Maps Global Mercator	EPSG:900913
World_Cylindrical_Equal_Area	EPSG:54034
World_Azimuthal_Equidistant	EPSG:54032

Coordinate reference systems of the world ☐ Hide deprecated CRSs

Coordinate Reference System	Authority ID
Geographic Coordinate Systems	
Projected Coordinate Systems	
User Defined Coordinate Systems	

World_Azimuthal_Equidistant

Extent
Extent not known

Proj4
+proj=aeqd +lat_0=0 +lon_0=0 +x_0=0 +y_0=0
+ellps=WGS84 +units=m +no_defs

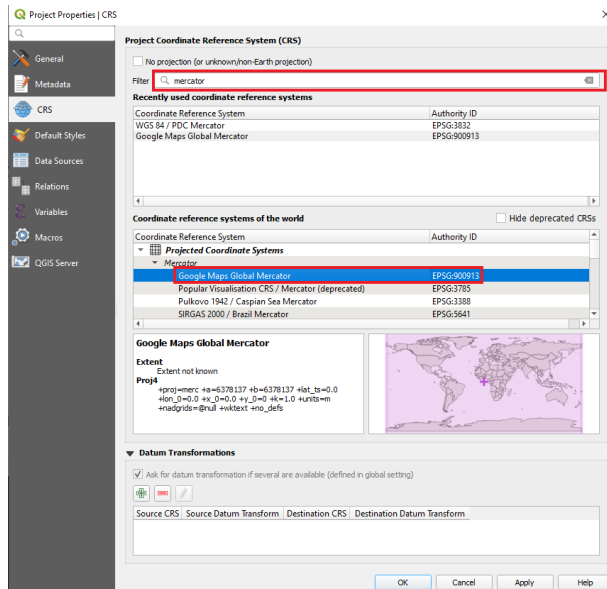
Datum Transformations

☒ Ask for datum transformation if several are available (defined in global setting)

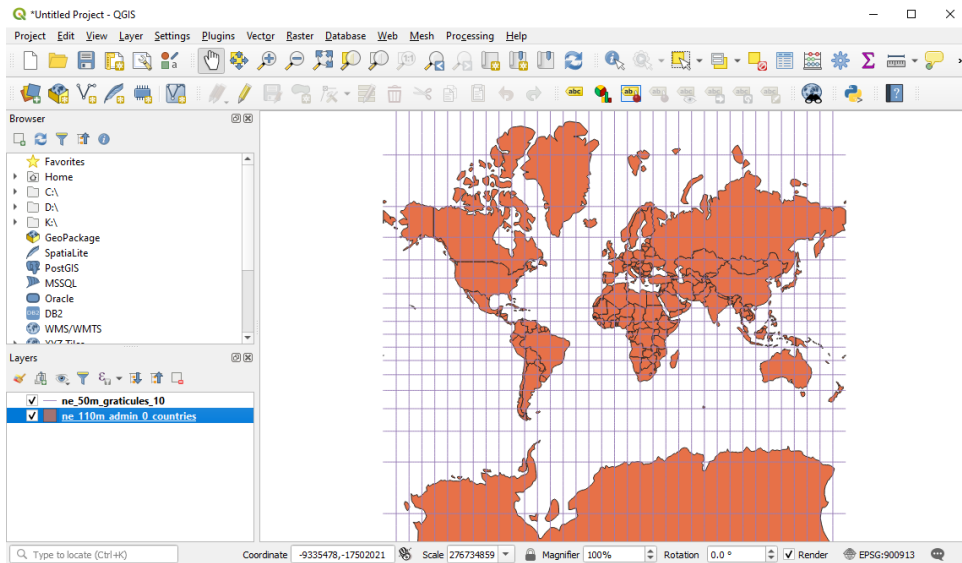
Source CRS	Source Datum Transform	Destination CRS	Destination Datum Transform

OK Cancel Apply Help

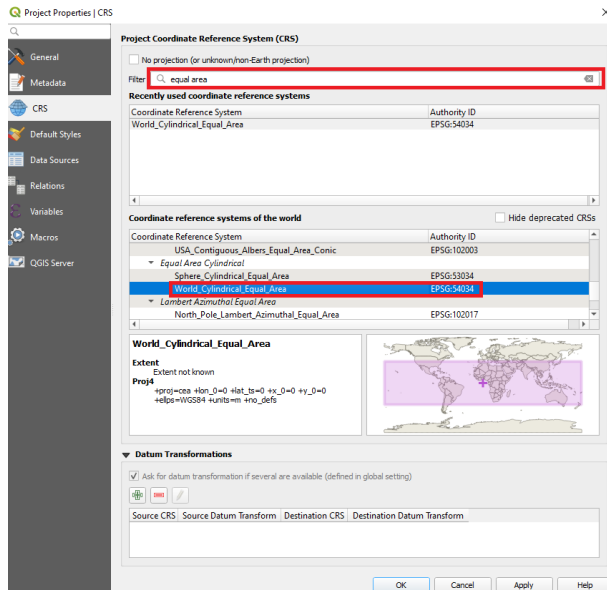
Let's change the CRS to *Mercator* (e.g. EPSG:900913, EPSG:3785). Click OK.



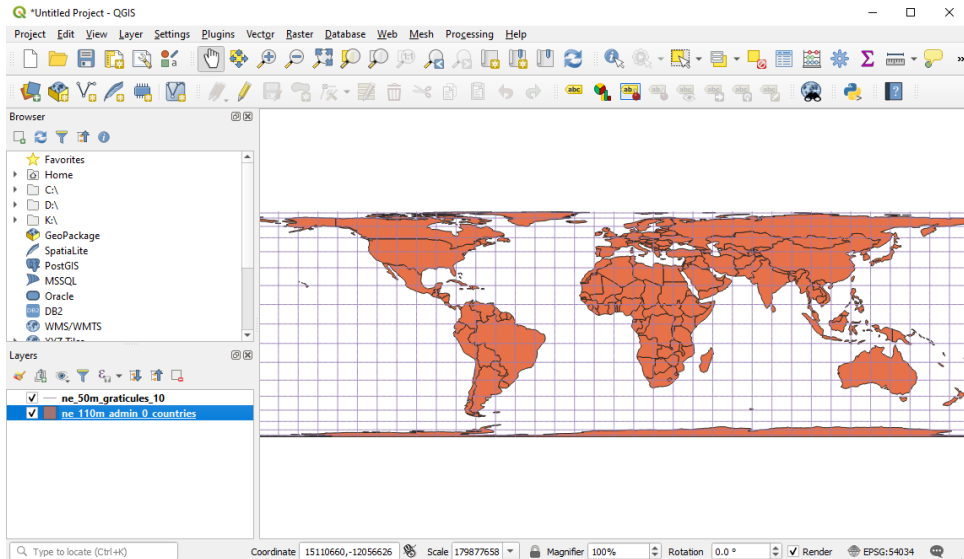
Greenland should now appear larger than the entire continent of Africa...



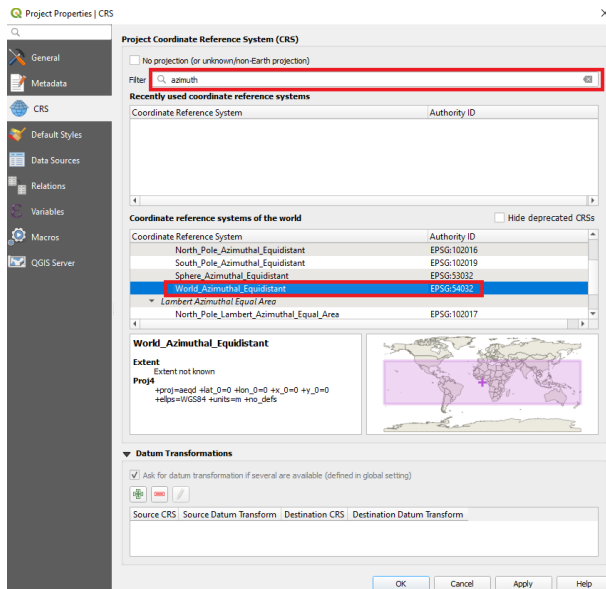
Let's change the CRS to *Equal Area* (EPSG:54034, EPSG:5070).



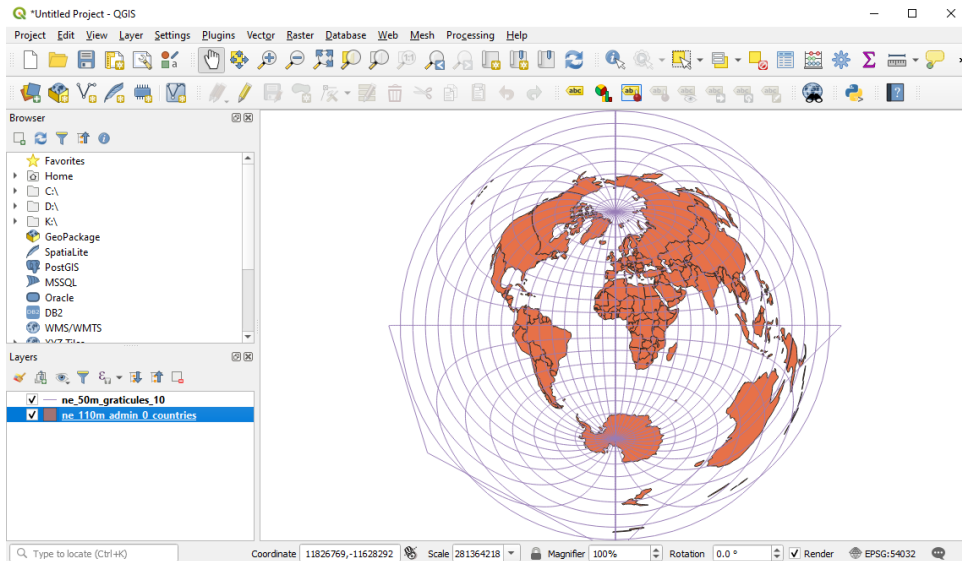
Greenland shrinks. Overcorrection or no?



Let's change the CRS to *World Azimuthal Equidistant* (EPSG:54032).



Now it looks more like a globe than a map... but better for studying the Arctic.



Here's how to check and change projections in R.

Suppose we have 2 sf objects: world (world map) and grat (graticules).

```
world = sf::read_sf("Data/World/ne_110m_admin_0_countries.geojson")  
grat = sf::read_sf("Data/World/ne_50m_graticules_10.geojson")
```

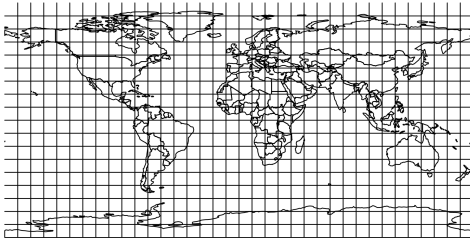
We can check their CRS with `st_crs()` from the sf library.

```
sf::st_crs(world)
```

```
## Coordinate Reference System:  
##   User input: WGS 84  
##   wkt:  
##   GEOGCRS["WGS 84",  
##     DATUM["World Geodetic System 1984",  
##       ELLIPSOID["WGS 84",6378137,298.257223563,  
##         LENGTHUNIT["metre",1]],  
##     PRIMEM["Greenwich",0,  
##       ANGLEUNIT["degree",0.0174532925199433]],  
##     CS[ellipsoidal,2],  
##       AXIS["geodetic latitude (Lat)",north,  
##         ORDER[1],  
##         ANGLEUNIT["degree",0.0174532925199433]],  
##       AXIS["geodetic longitude (Lon)",east,  
##         ORDER[2],  
##         ANGLEUNIT["degree",0.0174532925199433]],  
##     ID["EPSG",4326]]
```


Here's how these datasets look unprojected (WGS 84).

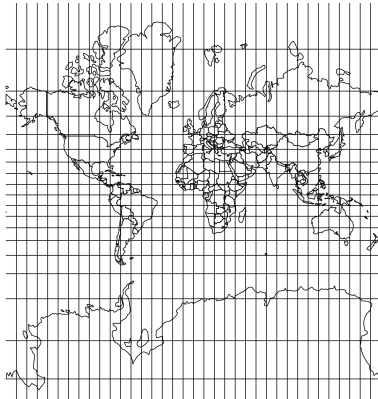
```
plot(world["geometry"],reset=FALSE)  
plot(grat["geometry"],add=TRUE)
```



We can change projections with the `st_transform()` function (sf library).

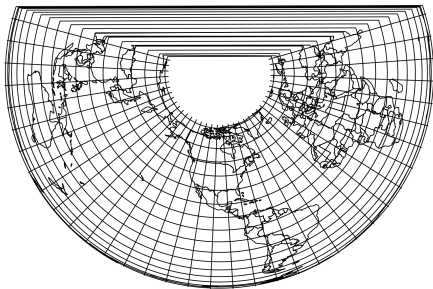
Let's transform to *Mercator* projection (e.g. EPSG:3785), and plot the result.

```
world_ = sf::st_transform(world, crs="EPSG:3785")  
grat_ = sf::st_transform(grat, crs="EPSG:3785")  
plot(world_["geometry"], reset=FALSE)  
plot(grat_["geometry"], add=TRUE)
```



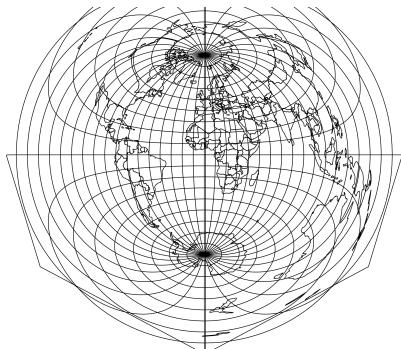
Let's transform to *Equal Area* projection (e.g. EPSG:5070).

```
world_ = sf::st_transform(world, crs="EPSG:5070")  
grat_ = sf::st_transform(grat, crs="EPSG:5070")  
plot(world_["geometry"],reset=FALSE)  
plot(grat_["geometry"],add=TRUE)
```



Let's transform to *Azimuthal Equidistant* projection (e.g. ESRI:54032).

```
world_ = sf::st_transform(world, crs="ESRI:54032")  
grat_ = sf::st_transform(grat, crs="ESRI:54032")  
plot(world_["geometry"],reset=FALSE)  
plot(grat_["geometry"],add=TRUE)
```



You can **look up a projection's EPSG code** here: spatialreference.org

Cartography and Map Overlays

Overlays

What is an overlay?

- combination of multiple layers of spatial data
- each layer represent some set of features of the real world
(e.g. elevation, roads, violence)
- when superimposed on top of each other, layers can reveal patterns and relationships between variables
(e.g. are mountainous areas more violent?)
- all layers must be on a common projection!

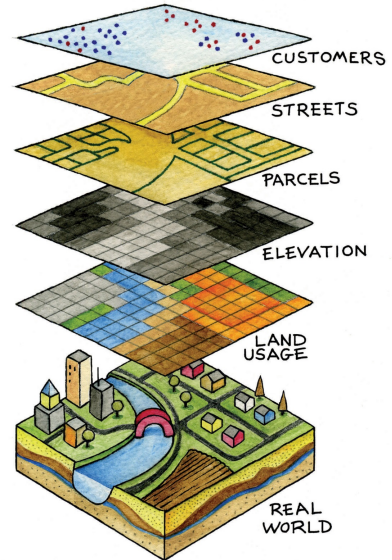


Figure 18: Multiple layers

This week's lab will be focused on map overlays

Michigan 2020 Presidential Election Results

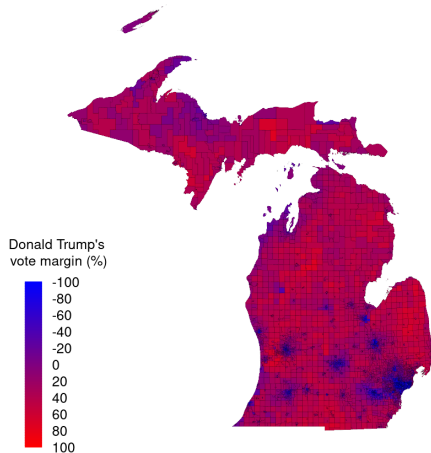


Figure 19: Last week: Single-layer map

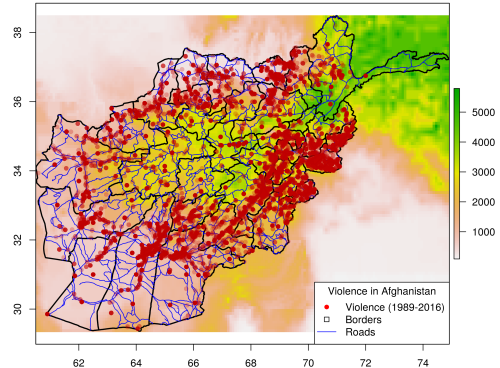


Figure 20: This week: Multi-layer map

What Makes a Good Map?

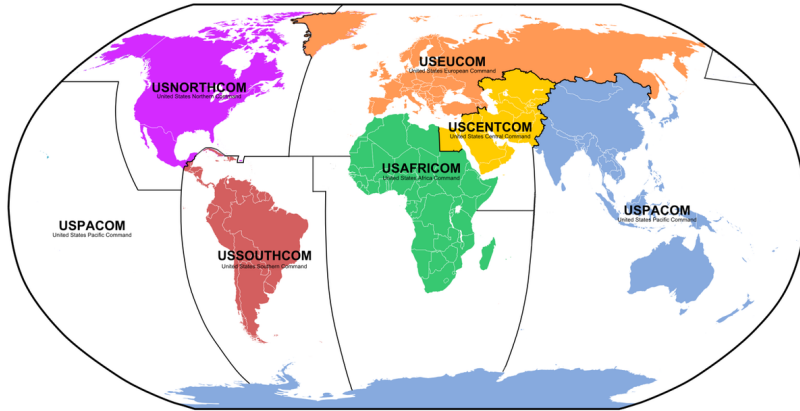


Figure 21: AOR's of U.S. Combatant Commands

A good map should **clearly communicate information**.

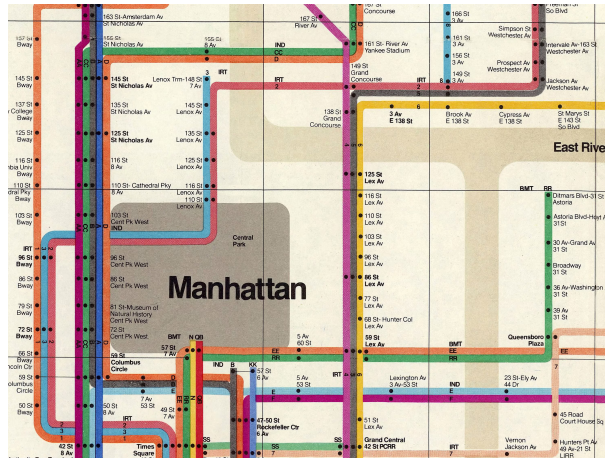


Figure 22: Vignelli's 1972 NYC Subway Map

A good map should **direct attention toward information of primary interest.**

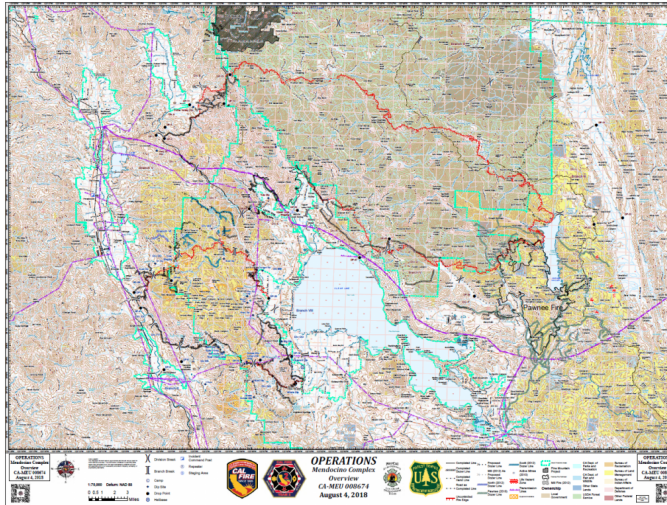


Figure 23: (Bad) Map of Mendocino Complex Fire

A good map should be **not too complex** (especially if audience is general public).

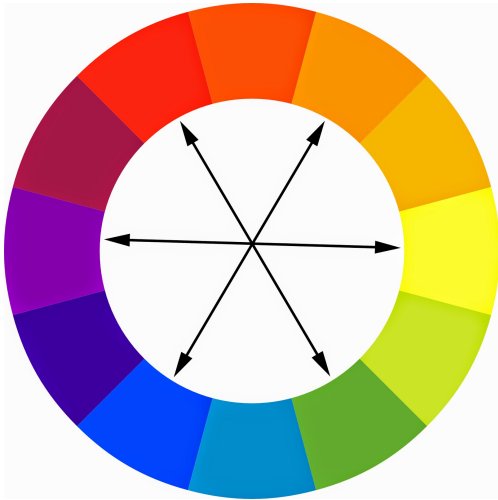


Figure 24: Complementary colors

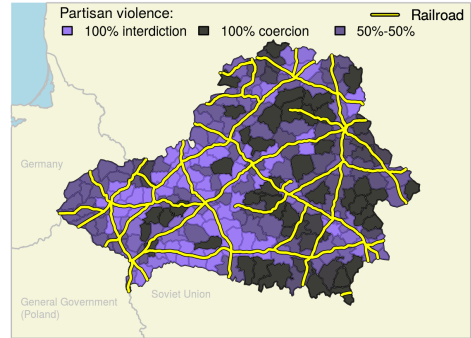


Figure 25: Map with complementary colors

A good map should **use contrasting colors/shades** (e.g. complementary colors).

Primary uses of maps

1. *Reference map*
(general information)

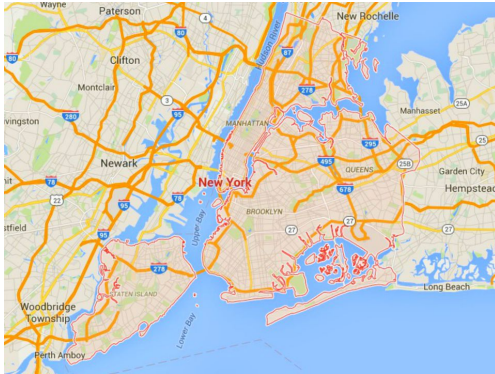


Figure 26: Interstate highways around NYC

2. *Thematic map*
(focuses on specific theme/subject)

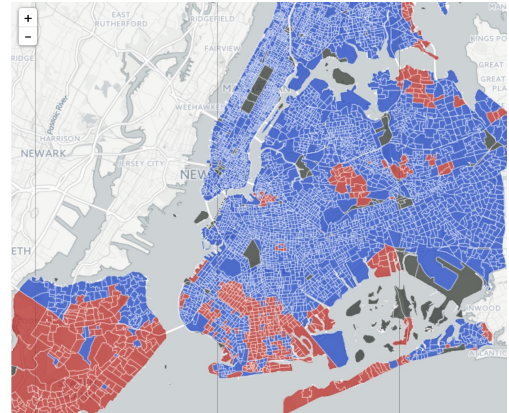


Figure 27: 2016 presidential elections in NYC