API-231 / GIS-PubPol
Meeting 02 (Map Projections and Overlays)

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Outline

Measuring the Earth

Where are we?

- latitude: 42.371389,
- longitude: -71.121944

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

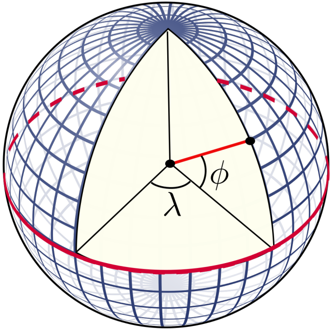


Figure 1: $\phi =$ lat, $\lambda =$ lon

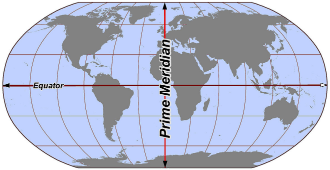


Figure 2: Prime Meridian

The Shape of Earth

What is the shape of the earth?

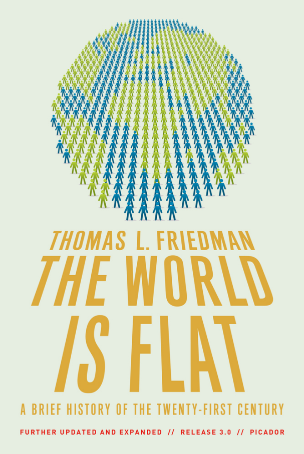


Figure 3: Wrong!

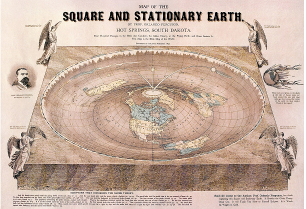


Figure 4: Wrong!

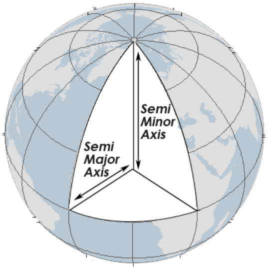


Figure 5: Also wrong?

1. *Geoid*
   a) surface of equal gravitational potential (∼ mean sea level)
   b) measured, interpolated surface

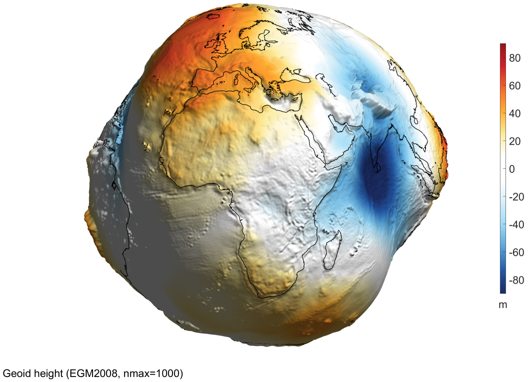


Figure 6: Geoid

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

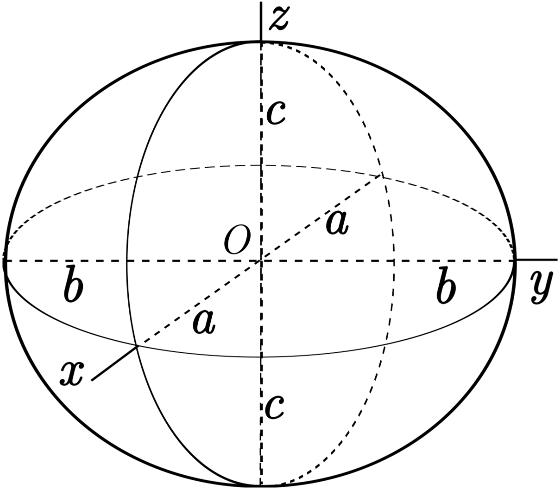


Figure 7: Ellipsoid

3. *Topography*
   a) Earth's height, relative to mean sea level
   b) measured with satellite or aerial photography

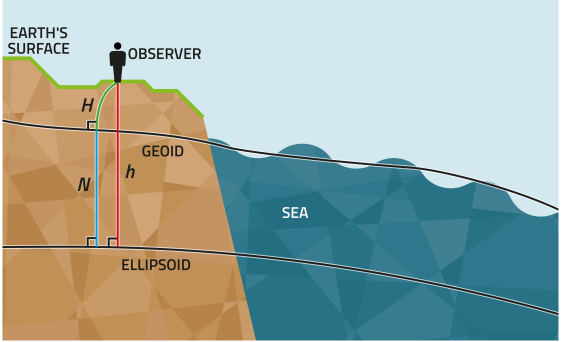


Figure 8: Topography vs. Geoid vs. Ellipsoid

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

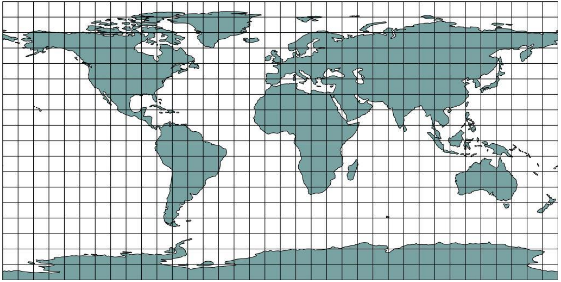


Figure 10: WGS 84

Projections and Coordinate Systems

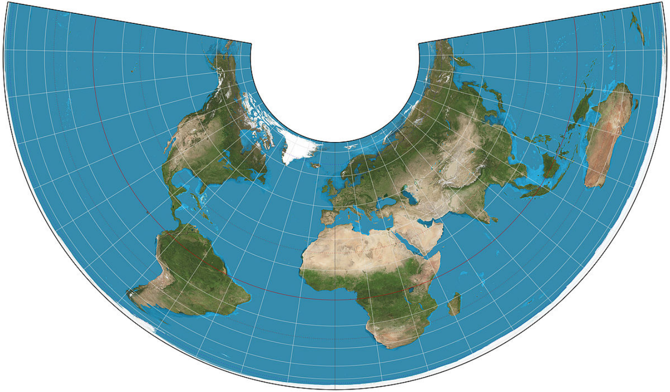


Figure 11: How to squeeze 3 dimensions into 2?

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

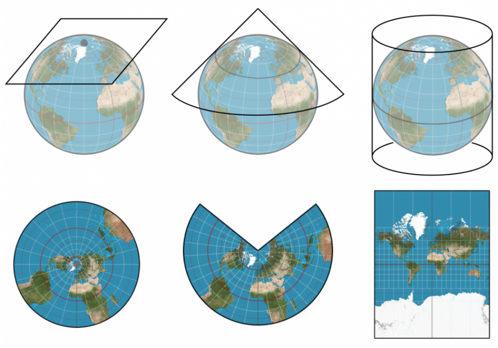


Figure 12: Azimuth, cone, cylinder

4. *"Unprojected" projection*
   - raw geographic coordinates
   - latitude $\rightarrow$ vertical axis
   - longitude $\rightarrow$ horizontal axis
   - effectively a cylindrical projection
   - less distortion near Equator
   - more distortion near poles

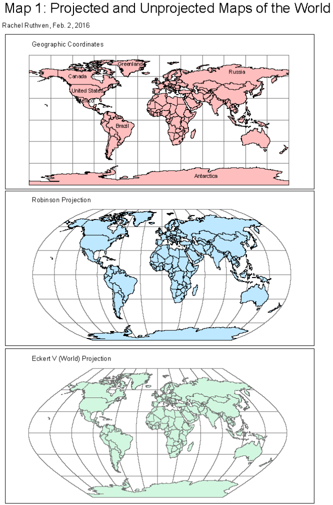


Figure 13: No free lunch

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

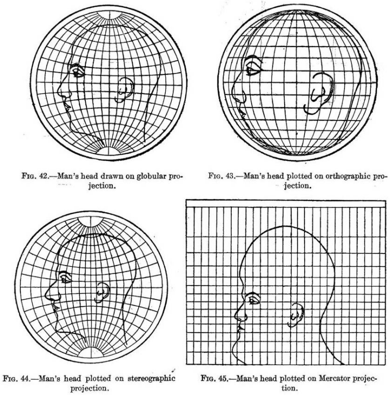


Figure 14: Funhouse mirrors

Common coordinate systems

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

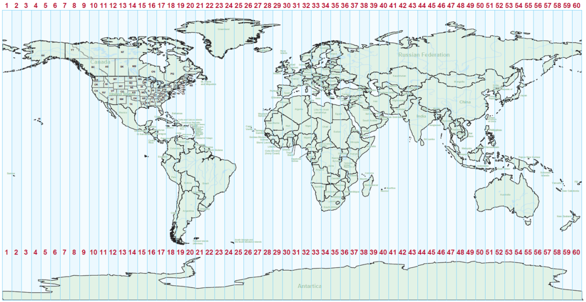


Figure 15: UTM

2. *Military Grid Reference System (MGRS)*
    - derived from UTM, with different labeling convention
    - NATO military standard

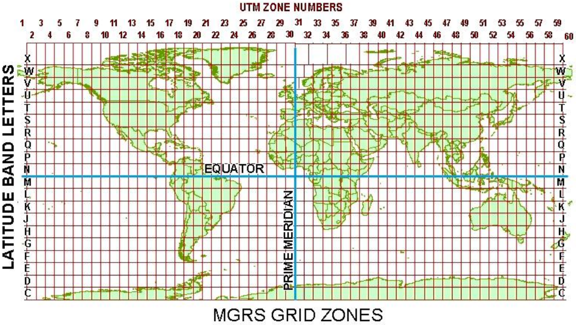


Figure 16: MGRS

3. *State Plane Coordinate Systems*
   - defined separately for each U.S. state
   - high local accuracy

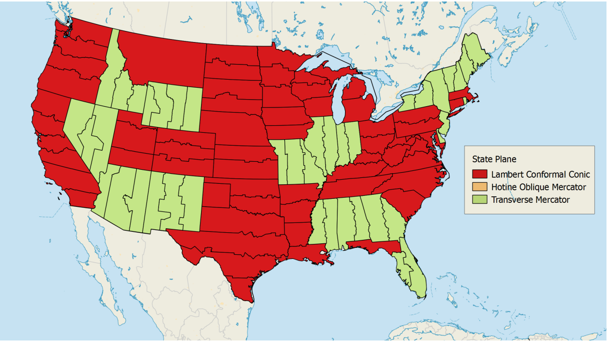
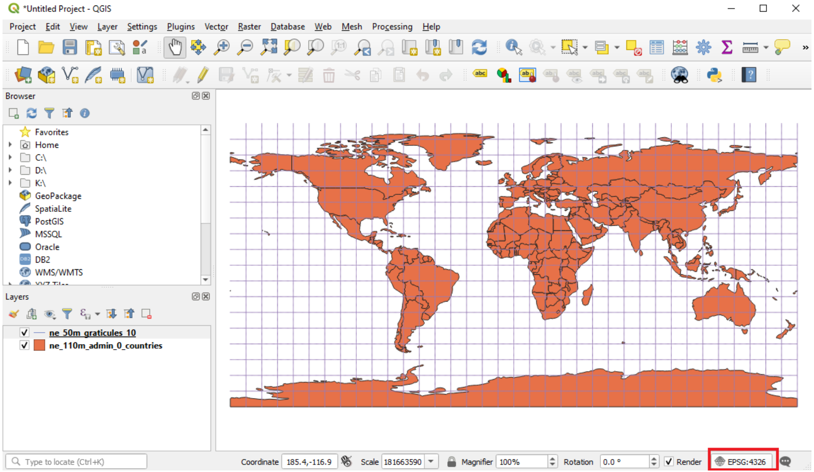
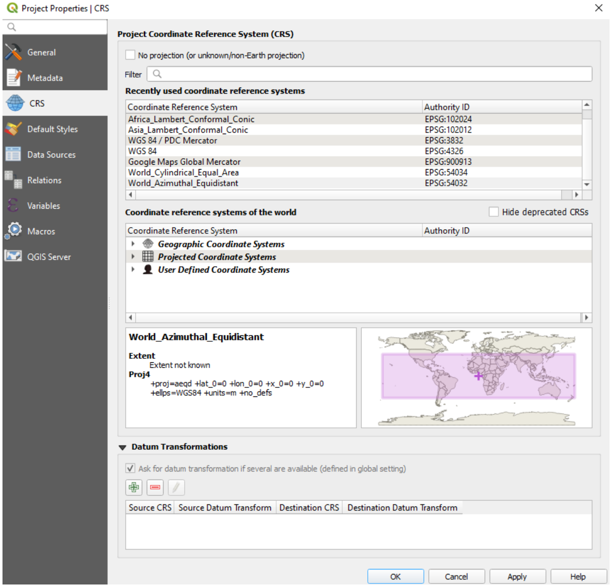


Figure 17: SPRS

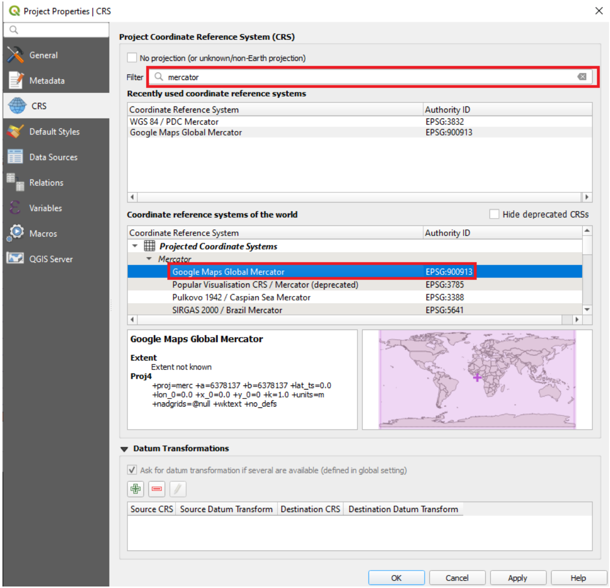


In **QGIS**, your map's projection information is found in the lower-right corner (EPSG = European Petroleum Survey Group code)

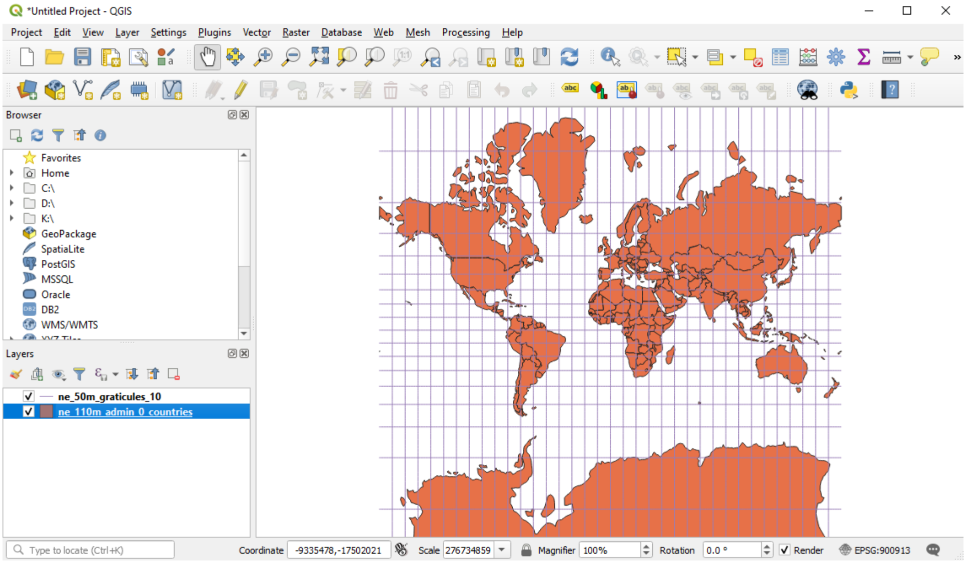
- EPSG:4326 is the code for World Geodetic System (WGS84)
- this is the default in QGIS, and a standard for satellite navigation systems



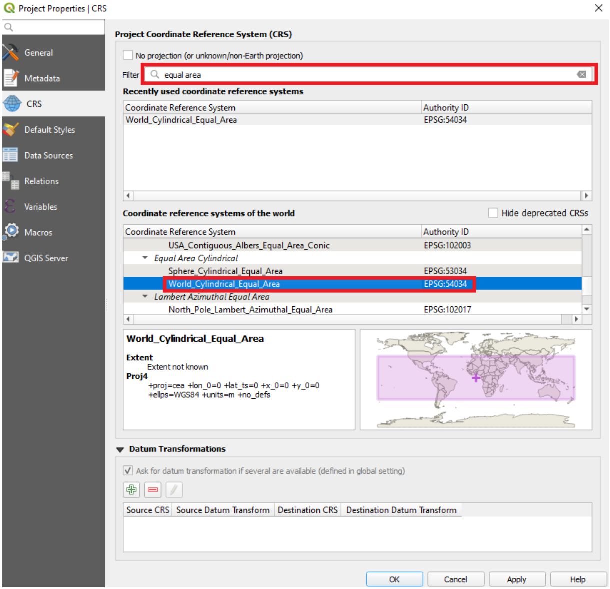
Click on the EPSG code to open `CRS Properties` (Coordinate Reference System)



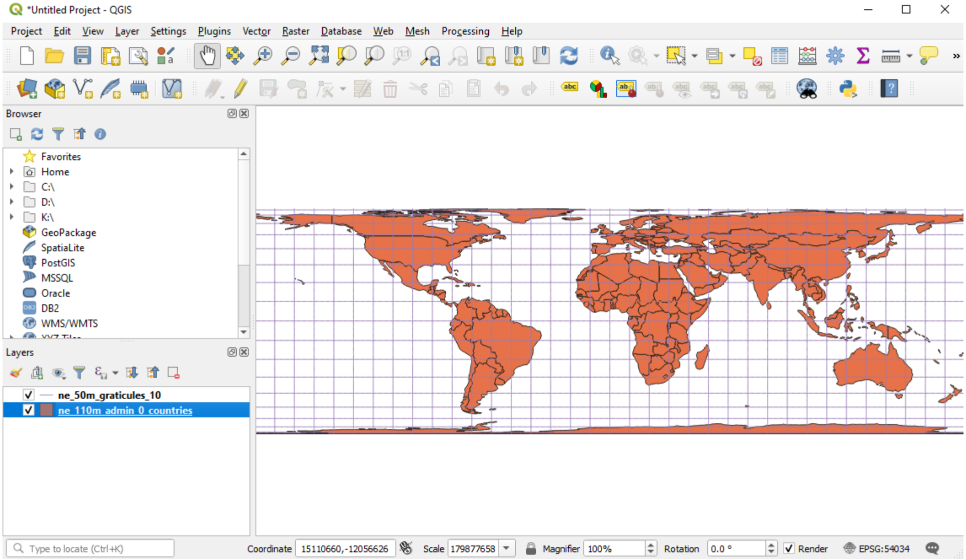
Let's change the CRS to *Mercator* (e.g. `EPSG:900913`, `EPSG:3785`). Click `OK`.



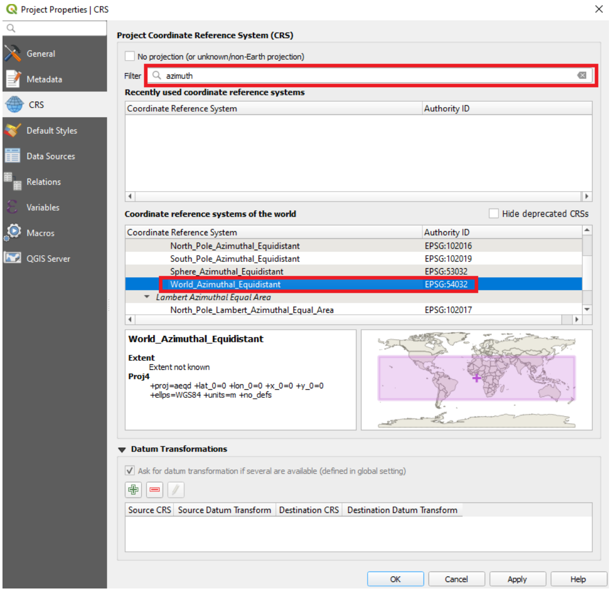
Greenland should now appear larger than the entire continent of Africa. . .



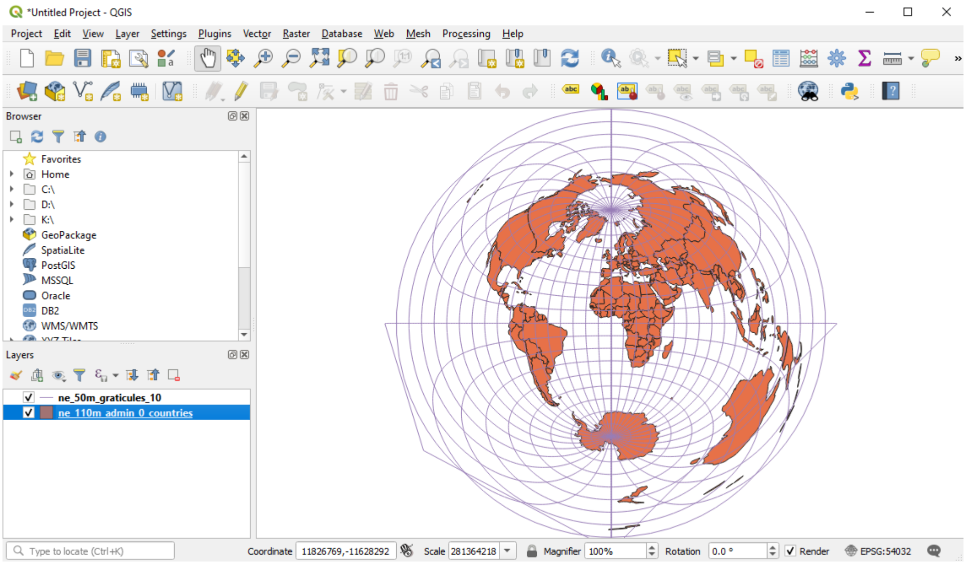
Let's change the CRS to *Equal Area* (`EPSG:54034`, `EPSG:5070`).



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")
```

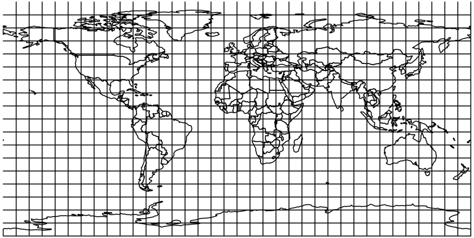
We can check their CRS with `st_crs()` from the `sf` library.

```
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).

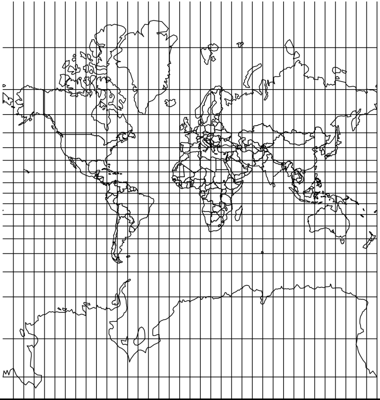
```
plot(world["geometry"])
plot(grat["geometry"],add=TRUE)
```



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

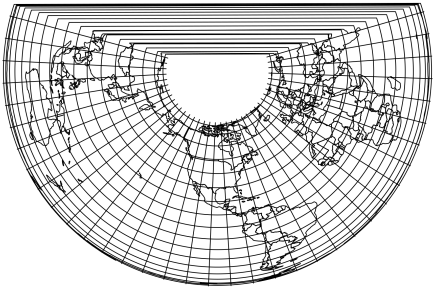
Let's transform to *Mercator* projection (e.g. EPSG:3785), and plot the result.

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



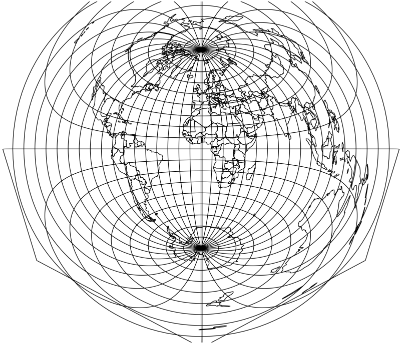
Let's transform to *Equal Area* projection (e.g. EPSG:5070).

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

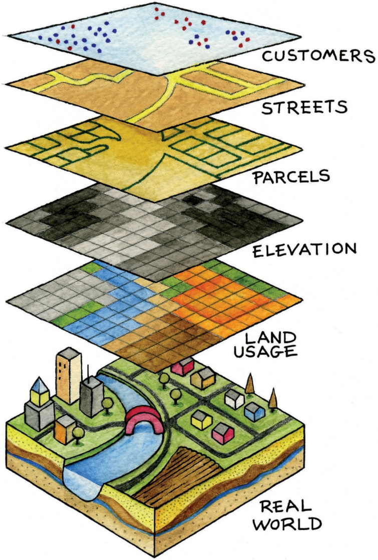


Figure 18: Multiple layers

This week's lab will be focused on map overlays

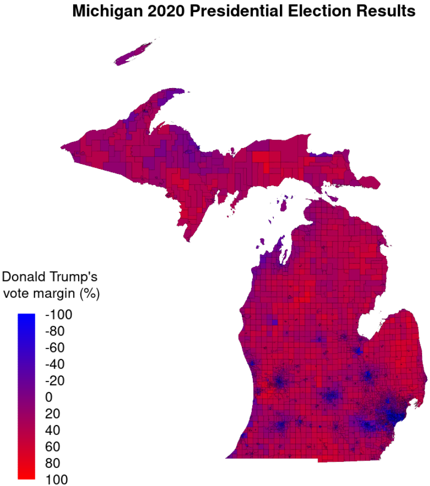


Figure 19: Last week: Single-layer map

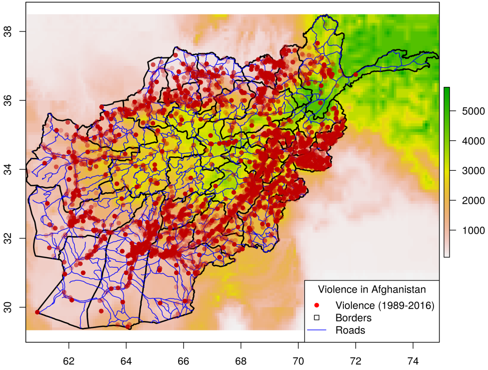


Figure 20: This week: Multi-layer map

What Makes a Good Map?

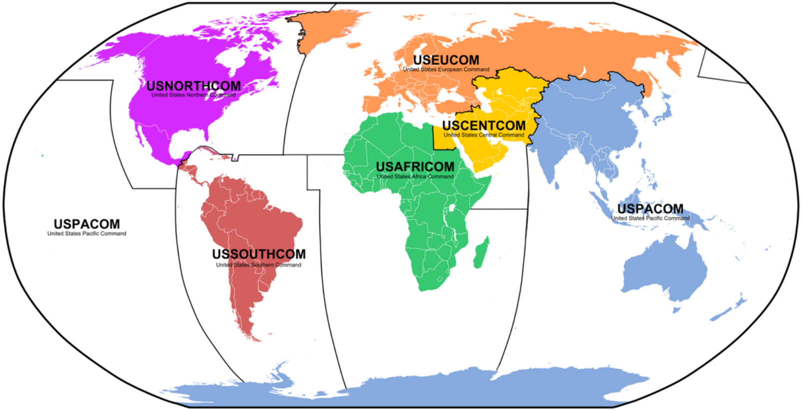


Figure 21: AOR's of U.S. Combatant Commands

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

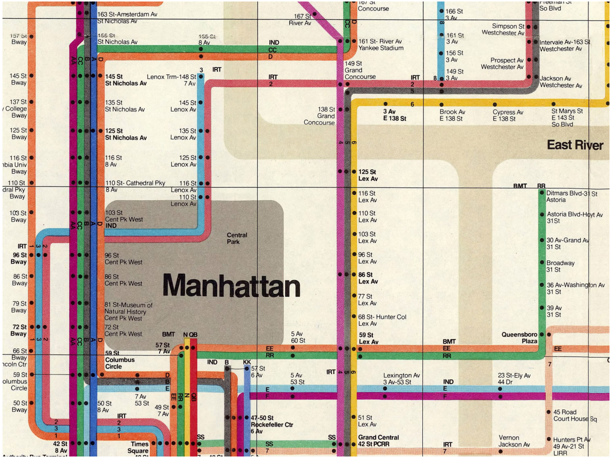


Figure 22: Vignelli's 1972 NYC Subway Map

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

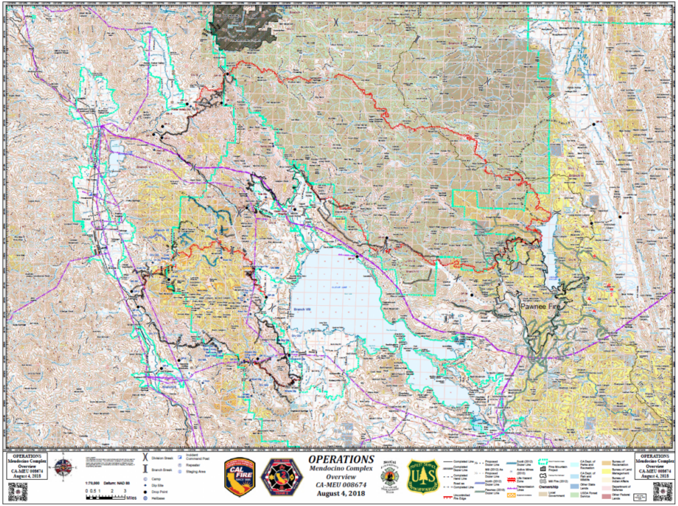


Figure 23: (Bad) Map of Mendocino Complex Fire

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

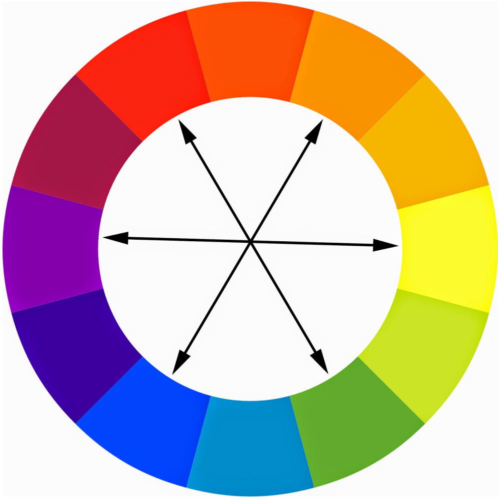


Figure 24: Complementary colors

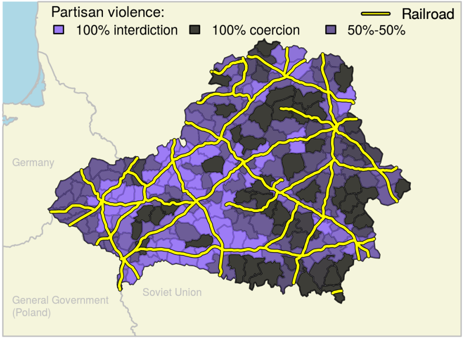


Figure 25: Map with complementary colors

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

Primary uses of maps

1. *Reference map*
   (general information)

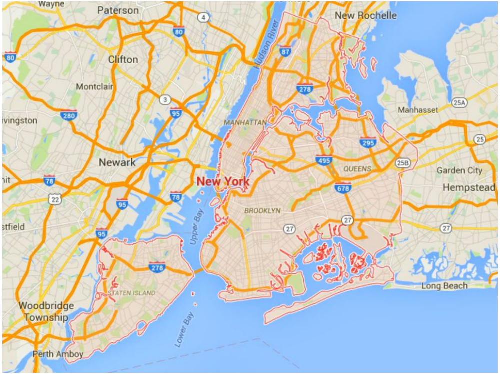


Figure 26: Interstate highways around NYC

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

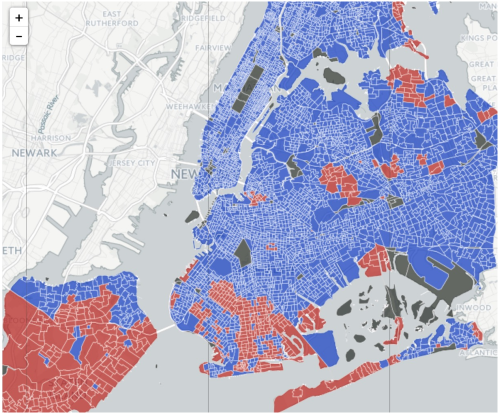


Figure 27: 2016 presidential elections in NYC