Image from NASA:
https://commons.wikimedia.org/wiki/File:Earth_Western_Hemisphere_transparent_background.png#filelinks

GIScience

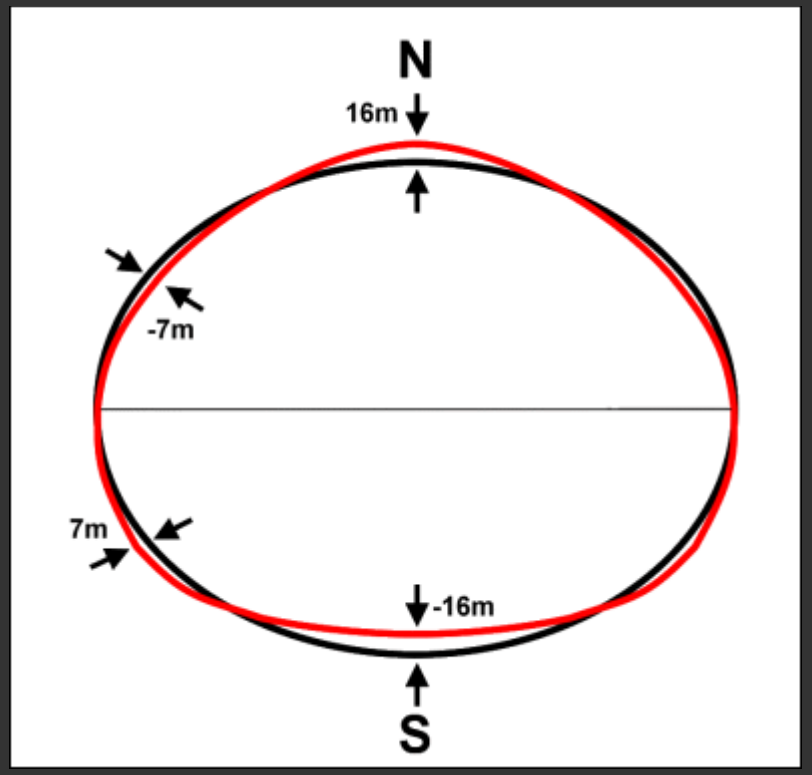
Datums and Projections

WV VIEW

AmericaView℠
Empowering Earth Observation Education
AmericaView.org - Est. 2003

Shape of the Earth

Geodesy

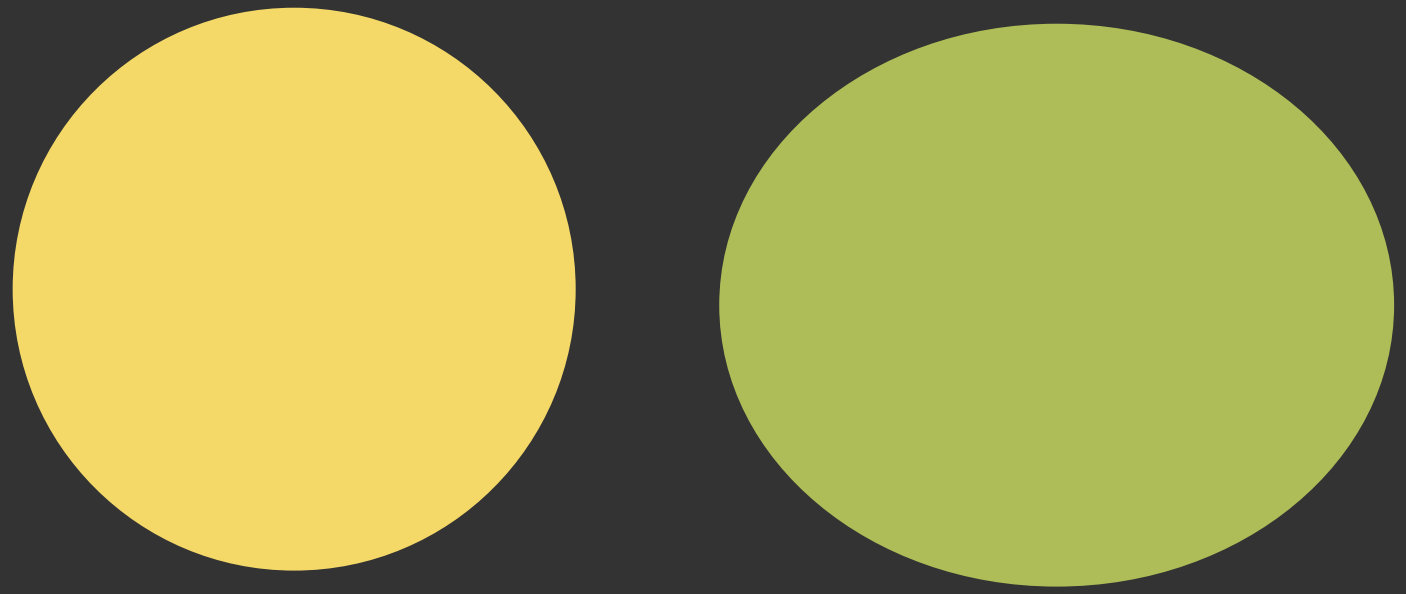


https://commons.wikimedia.org/wiki/File:Geoundnsrp.png

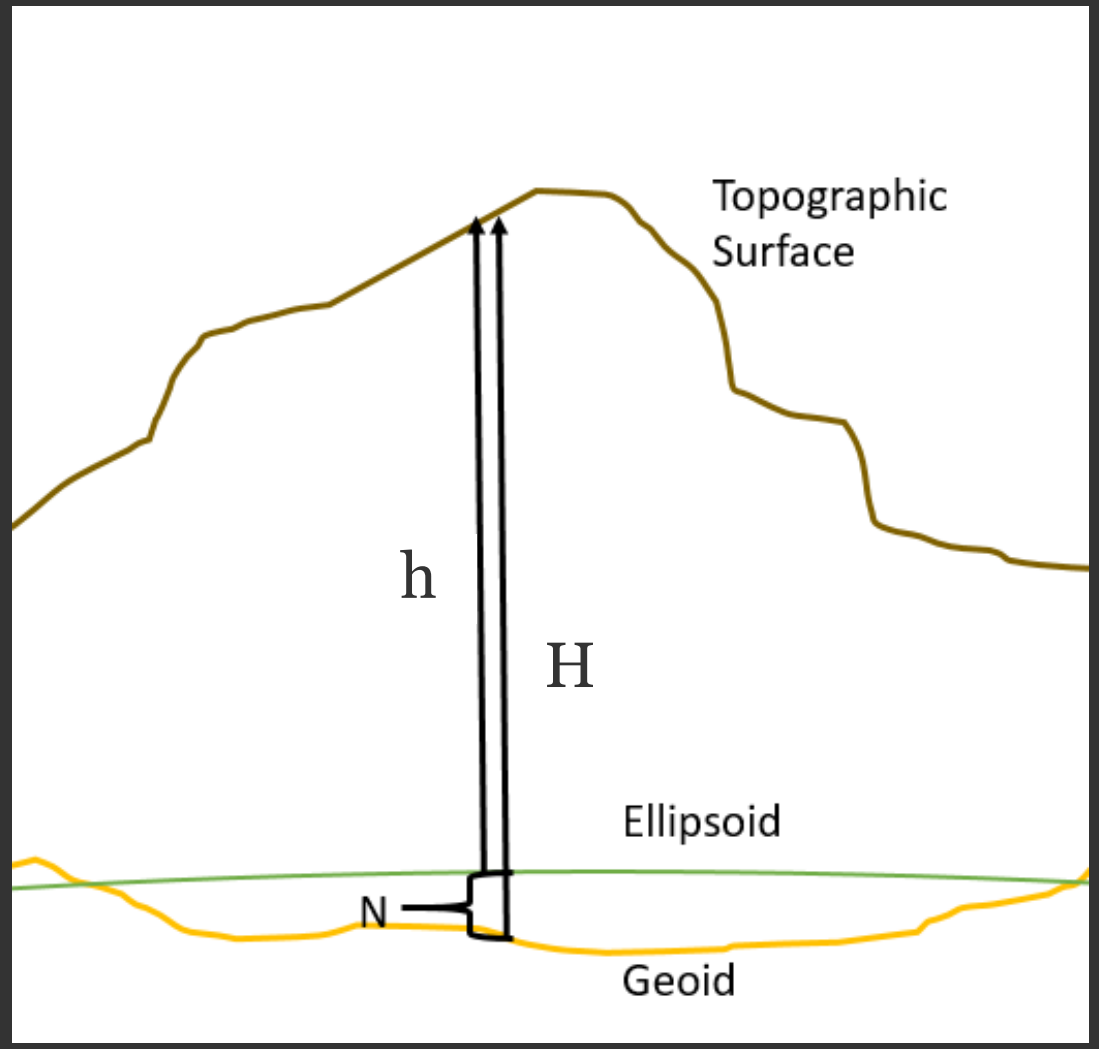
Science of measuring Earth's shape

Shape of Earth

- Oblate spheroid
- Equator has larger circumference than meridians
- Mass not evenly distributed



Modeling the Earth



True Earth surface

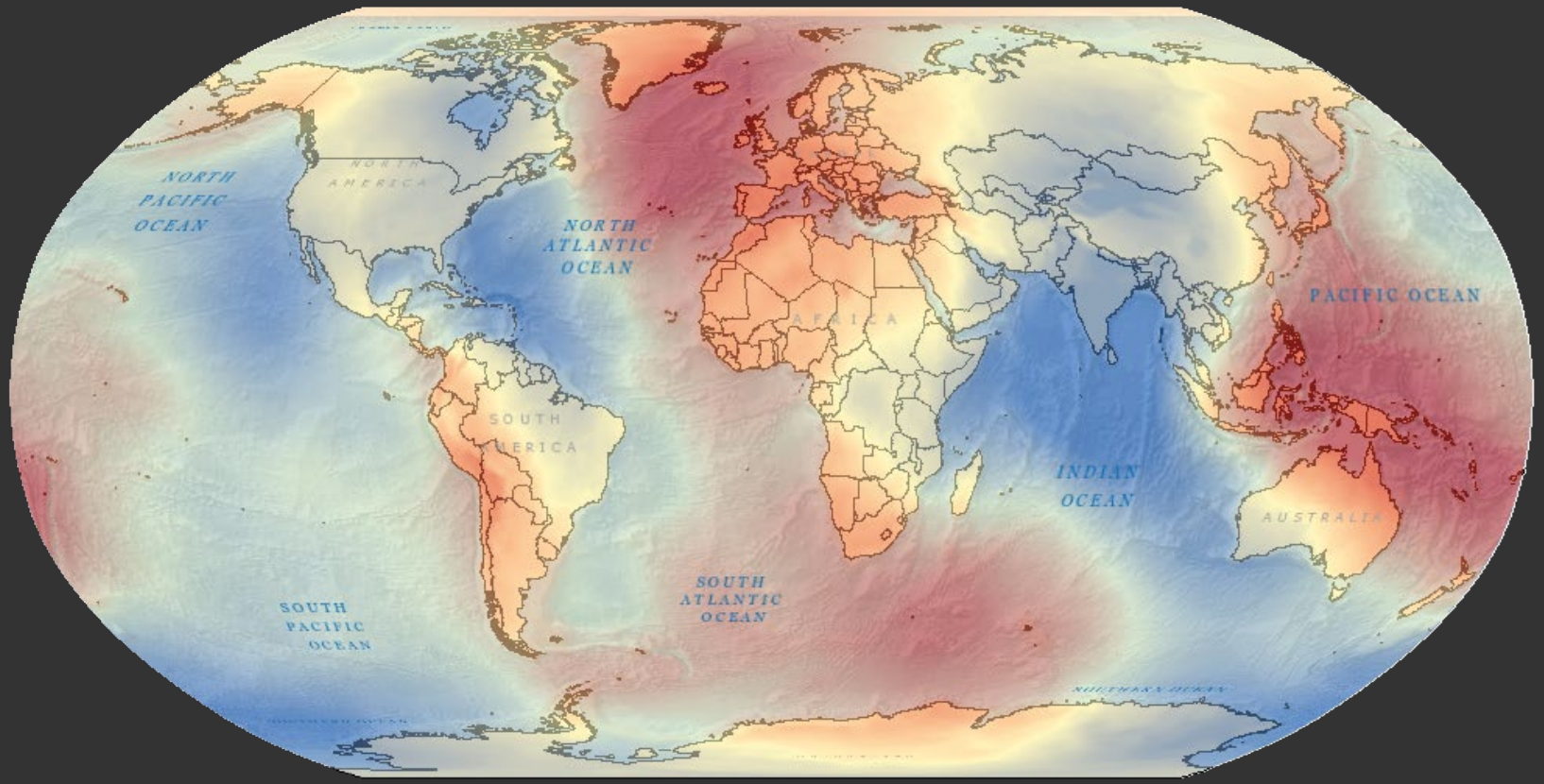
↓

Geoid

↓

Ellipsoid

The Geoid



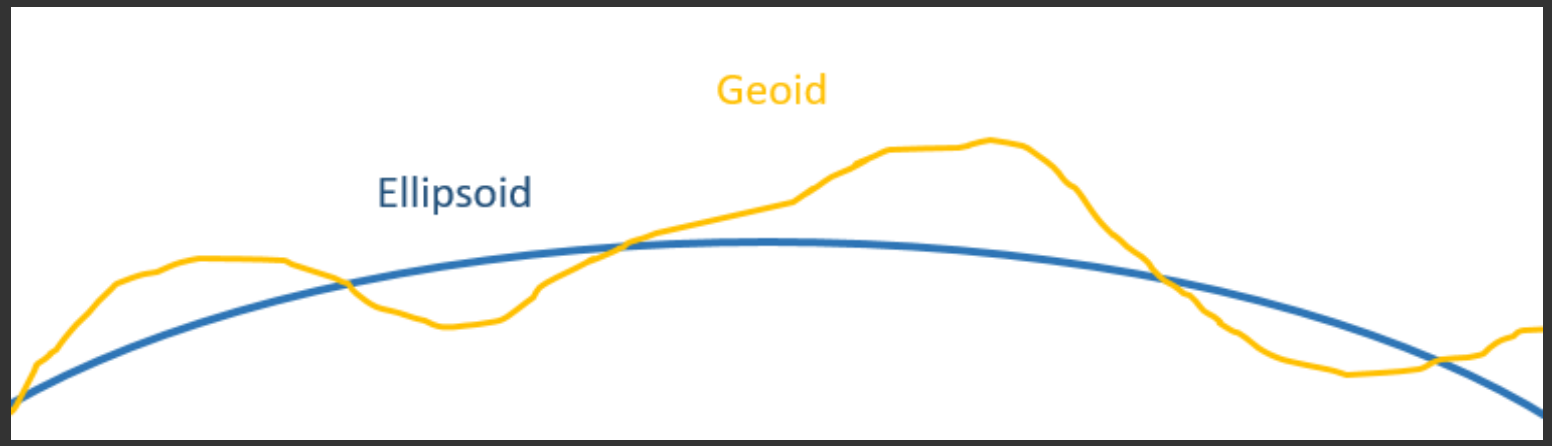
Gravitational model from the US National Geospatial-Intelligence Agency (NGA) EGM Development Team

We need a mathematically simple model of the Earth's surface

- We use an ellipsoid/spheroid
- There are different ellipsoids/spheroids used
- We call these datums

Datums

- The Earth is not perfectly round! It is an oblate spheroid
- Geoid = Accounts for the fact that the gravitational force differs over the Earth. Models Earth as a bumpy surface
- Ellipsoid (Spheroid) = Earth surface modelled as an oblate spheroid



Datums

A fully defined datum requires:

1. A reference surface = spheroid/ellipsoid
2. A terrestrial reference frame = realization of a datum using a network of precise positional measurements

Datums

There are different models

NAD27 = North American Datum of 1927

NAD83 = North American Datum of 1983

WGS84 = World Geodetic System of 1984

Think of these as different mathematical representations of the Earth

Vertical Datums

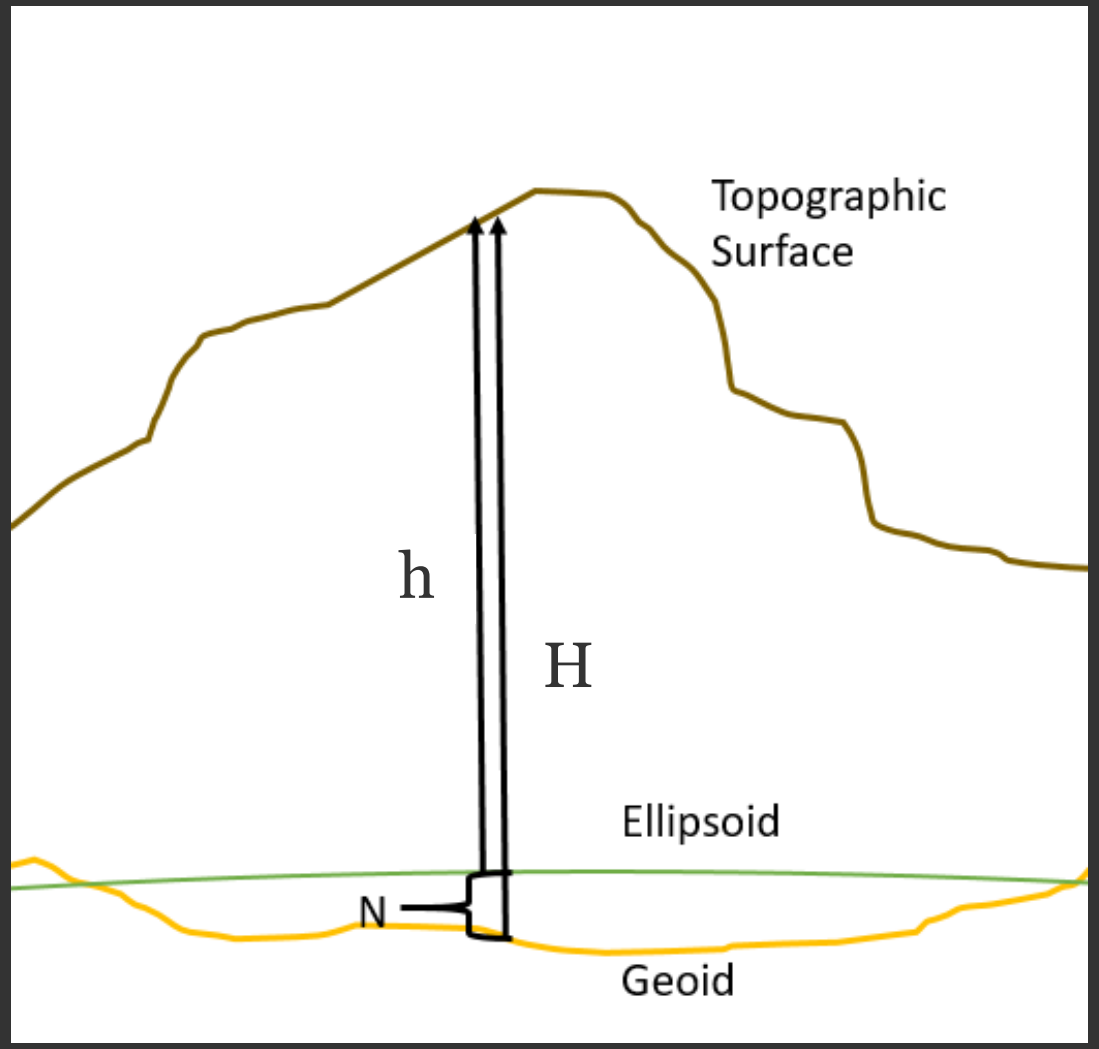
Orthometric Height (H) = height above geoid

Ellipsoidal Height (h) = height above ellipsoid

N: difference between ellipsoidal and orthometric heights

$$h = H + N$$

$$H = h - N$$

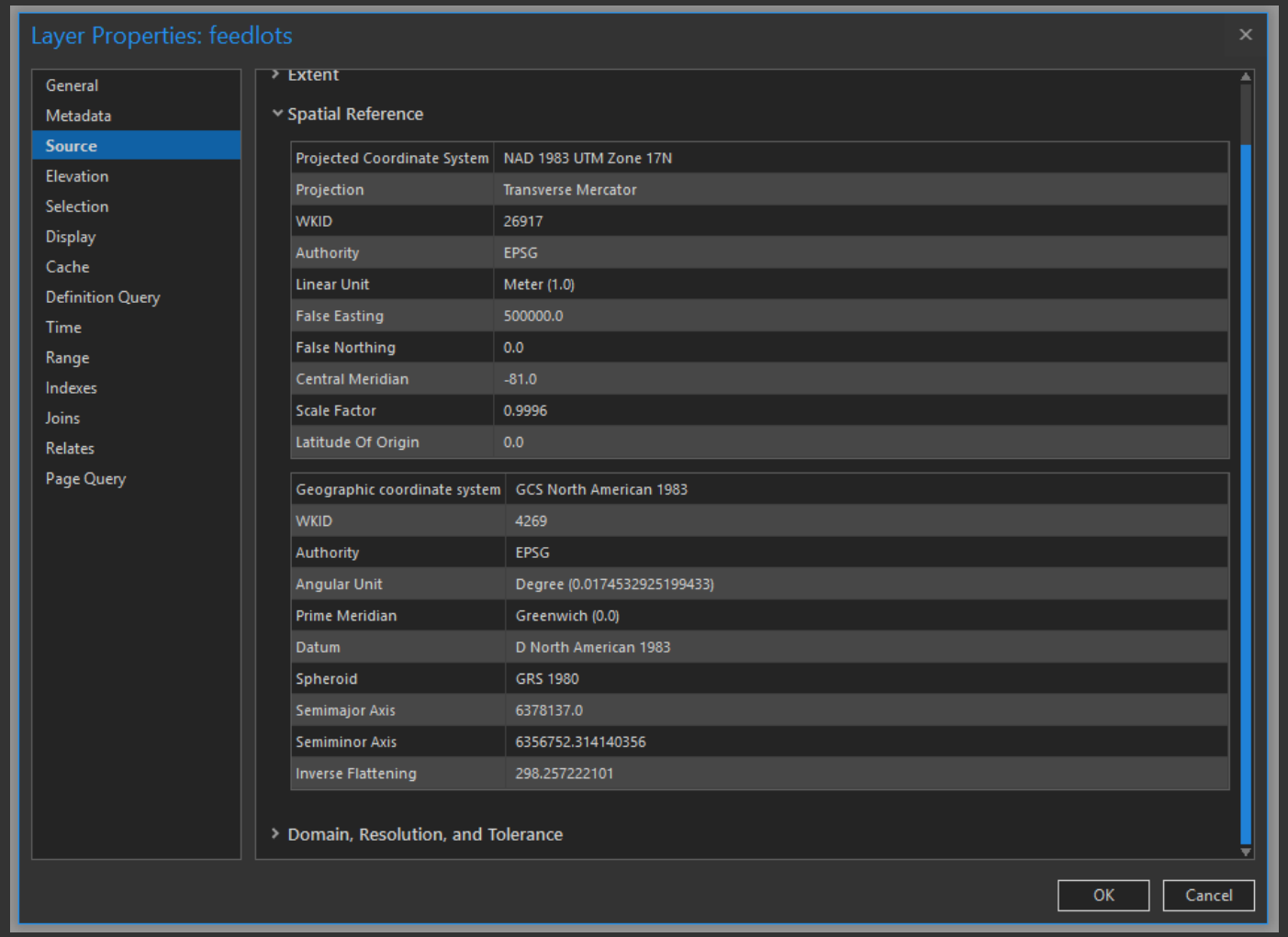


Common Vertical Datums

National Geodetic Vertical Datum of 1929 (NGVD29)

North American Vertical Datum of 1988 (NAVD88)

Datum/Projection Info in ArcGIS



Datum Transformations

- Differences between legacy datums (NAD27) and more modern datums (NAD83) can be substantial (10s to 100s of meters)
- Differences between modern datums are less substantial (meters)

Datum Transformations

Steps:

1. Convert from lat/long to X,Y,Z
2. Apply origin shift
3. Apply scale correction
4. Apply rotation correction
5. Convert from X,Y,Z back to lat/long

This can induce some errors!

$$(F - 32) \times 5/9 = C$$

$$(C \times 9/5) + 32 = F$$

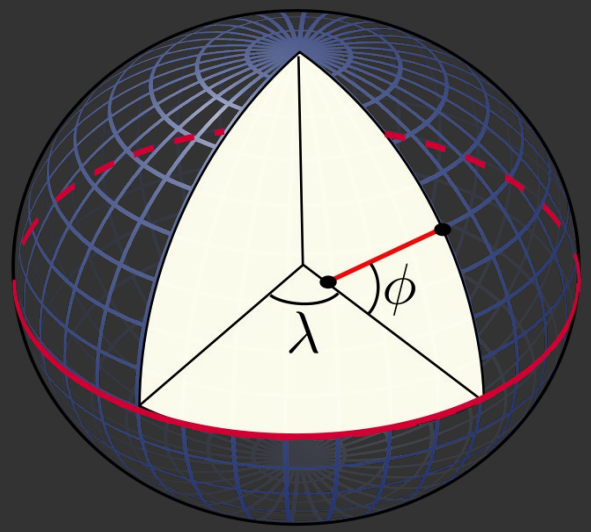
Best Practices

- Assume data transformation will cause positional errors/inaccuracies
- You should not mix datums
- If necessary, convert all datasets to same coordinate system/datum

Geographic Coordinate Systems

Coordinates on a Sphere

- Latitude and Longitude
- Specified as angles or degrees



https://commons.wikimedia.org/wiki/File:Latitude_and_longitude_graticule_on_an_ellipsoid.svg

Image from ArcGIS API for JavaScript

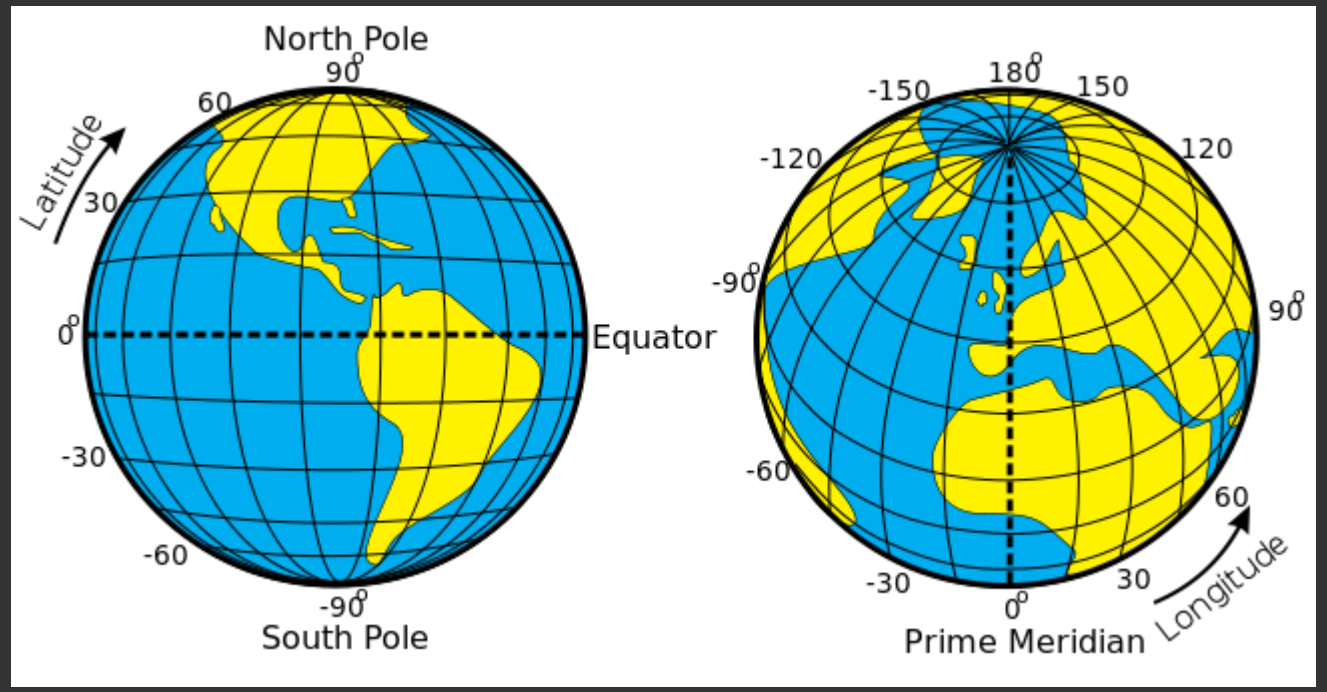
Geographic Coordinate Systems (GCS)

Latitude (Parallels)

- Measures north to south
- 90° in each hemisphere
- Increases as you go north in the northern hemisphere
- Increases as you go south in the southern hemisphere
- Zero is Equator

Longitude (Meridians)

- Measures east to west
- 180° in each hemisphere
- Increases as you go east in the eastern hemisphere
- Increases as you go west in the western hemisphere
- Zero is Prime Meridian



https://commons.wikimedia.org/wiki/File:Latitude_and_Longitude_of_the_Earth.svg

Geographic Coordinate Systems (GCS)

1 Degree = 60 Minutes = 3,600 Seconds

° = Degrees

‘ = Minutes

“ = Seconds

The Globe

Advantages

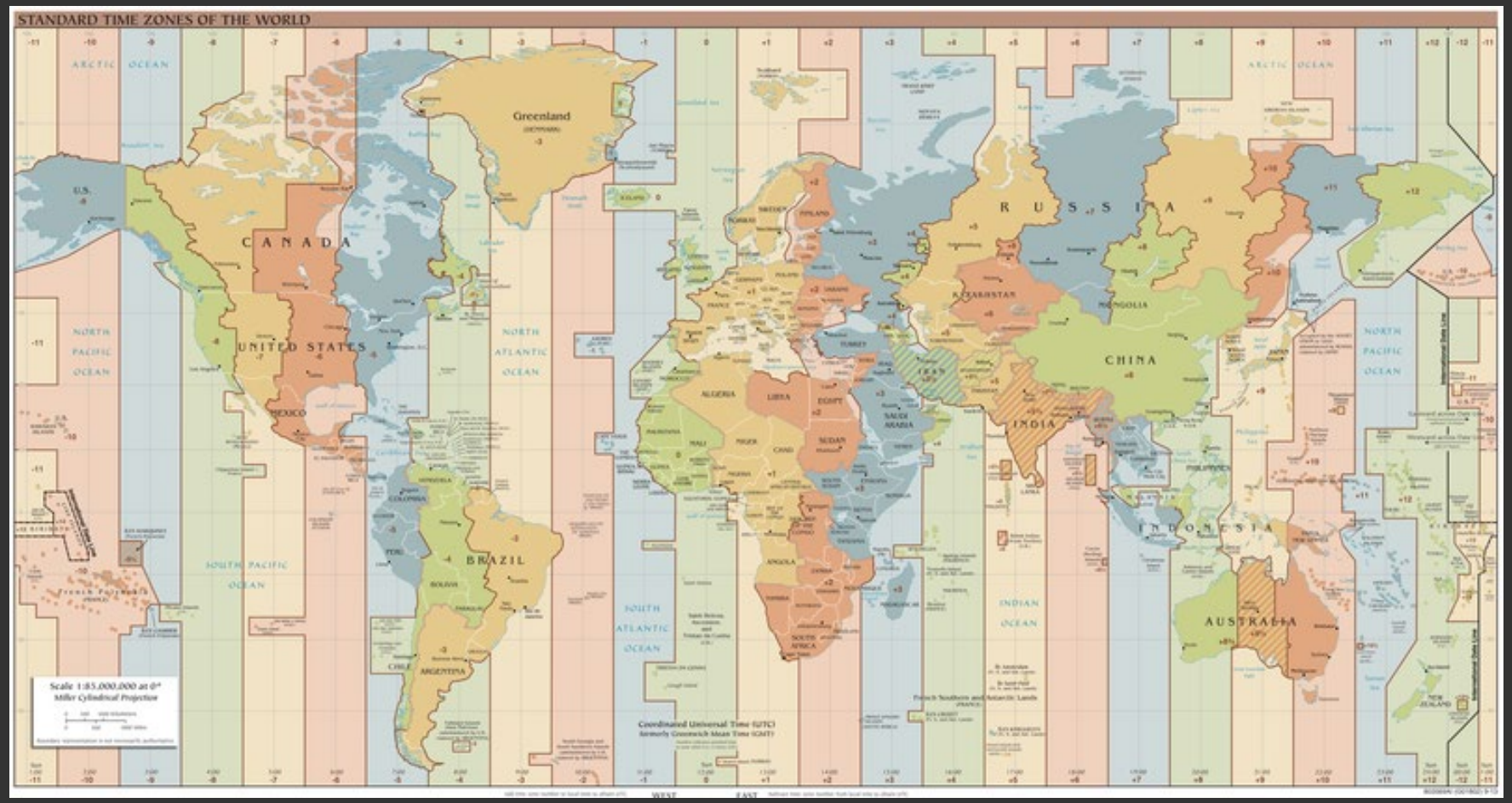
- Accurate representation
- Latitude and longitude lines

Disadvantages

- Expensive to make
- Cumbersome to handle and store
- Difficult to measure
- Not fully visible at one view

Image from ArcGIS API for JavaScript

Time Zones

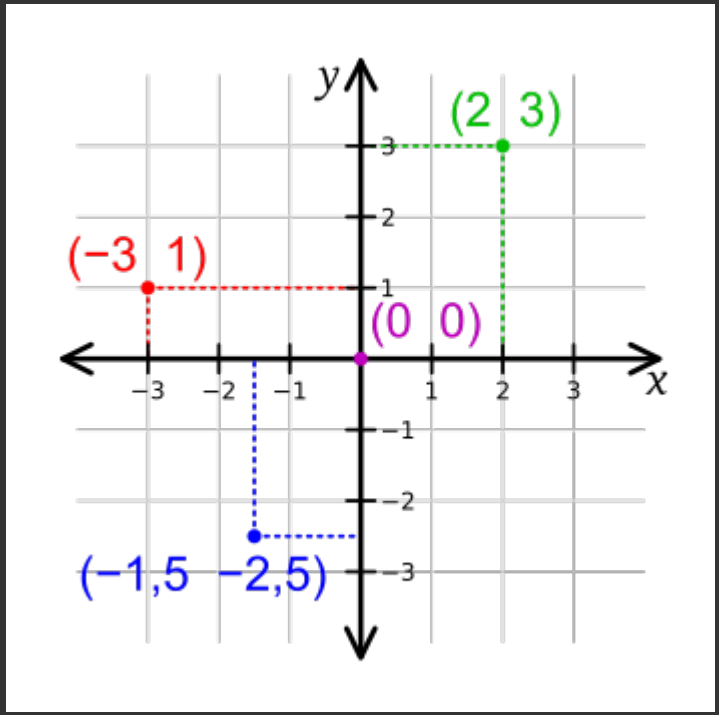


https://commons.wikimedia.org/wiki/File:World_Time_Zones_Map.png

Projected Coordinate Systems

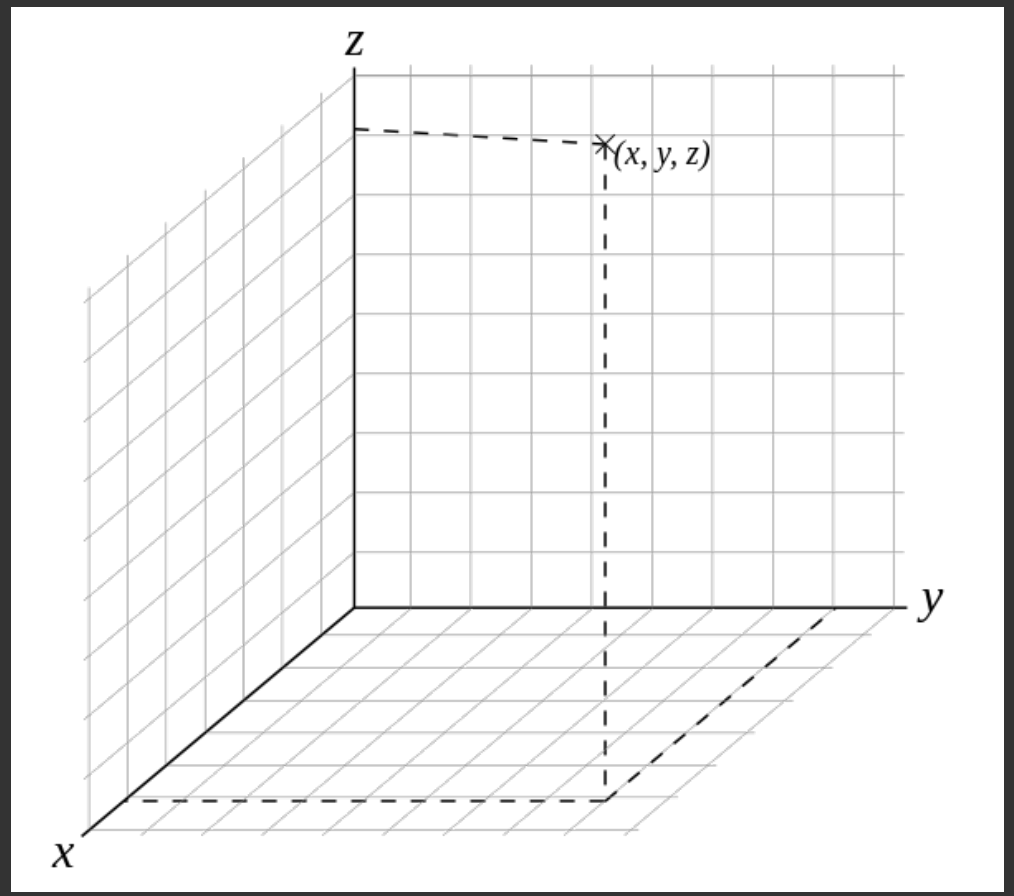
Viewing the 3D Earth on a 2D surface

- Map projections allow us to view the 3D Earth on a 2D surface
- Earth is mathematically projected to a surface that can be made flat
- We now make measurements in distance or length units as opposed to degrees
- A Cartesian coordinate system
- We call these surfaces Map Projections



https://commons.wikimedia.org/wiki/File:Cartesian_coordinate_system_(comma).svg

Coordinates in 3-D space



X, Y, Z

https://commons.wikimedia.org/wiki/File:Cartesian_with_grid.svg

Geographic vs. Projected Coordinate Systems

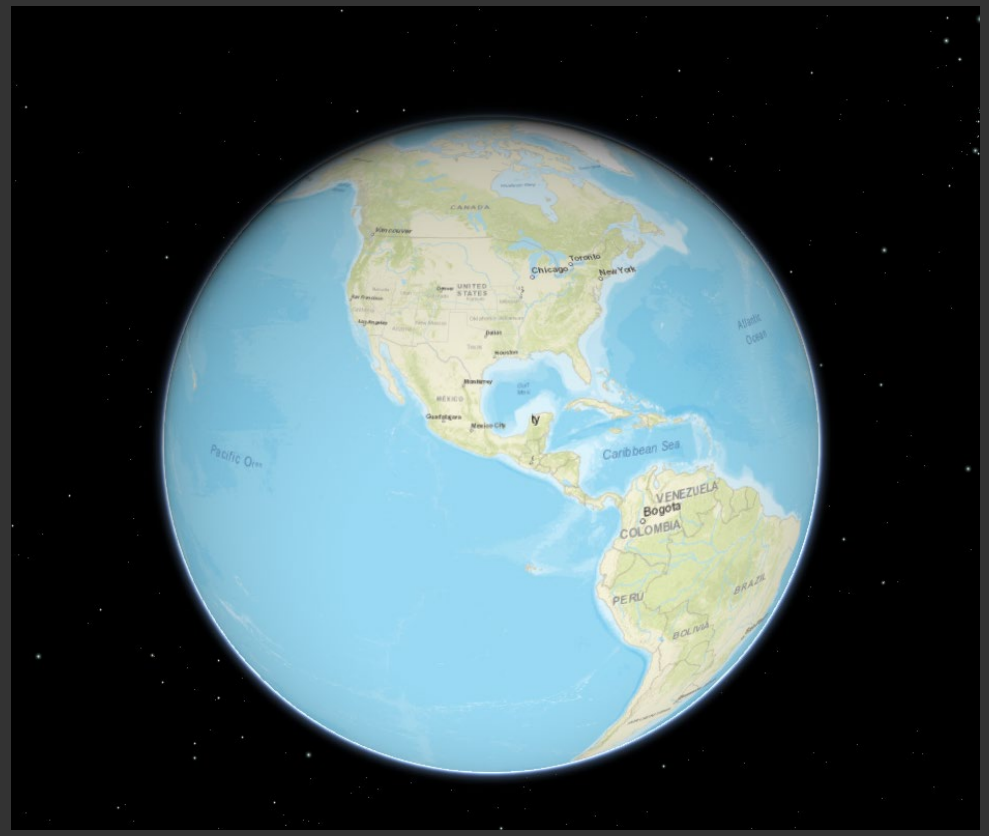


Image from ArcGIS API for JavaScript

Image from ArcGIS API for JavaScript

Why do we use map projections?

- Allow us to represent the Earth of a flat surface
- Allow us to make measurements on flat maps (Distance, Area, X/Y Coordinates)
- Measures of length and angle are uniform

Geographic coordinate system (Degrees)

Latitude and longitude are not uniform across the Earth's surface

Image from ArcGIS API for JavaScript

Projected coordinate system (Cartesian)

Measures of length and angle are uniform

Image from ArcGIS API for JavaScript

Map Projections Distortions

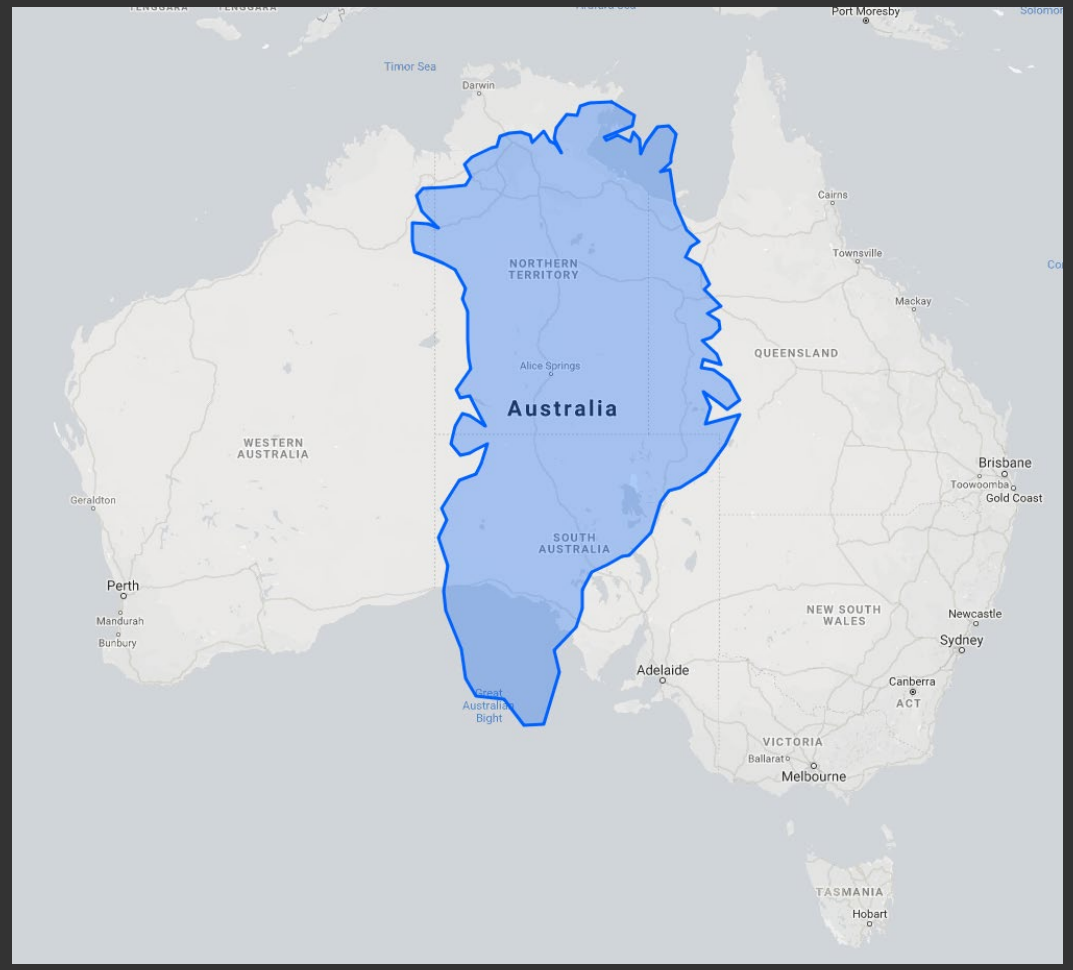
All map projections produce distortions of at least one of the following

1. Shape
2. Area
3. Distance
4. Direction

Map Projections

- All map projections produce distortions of at least one of the following:

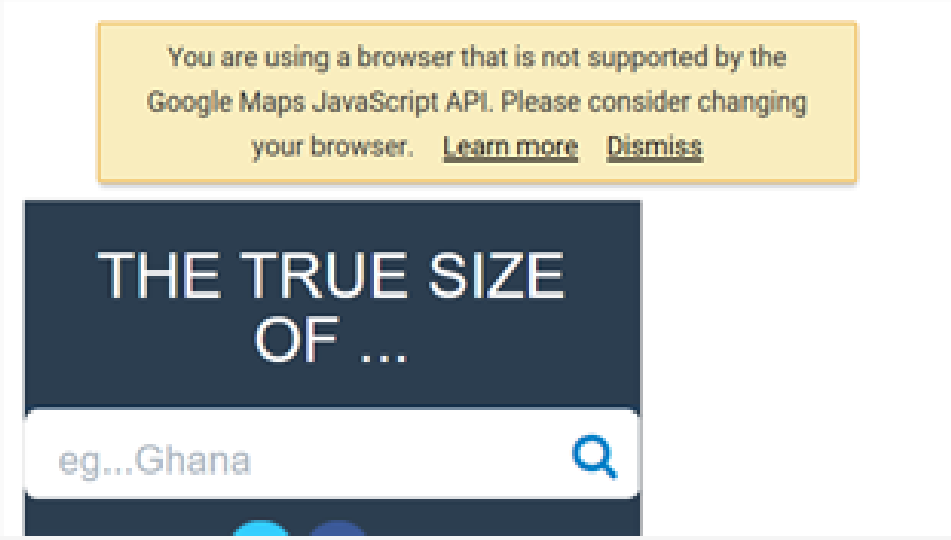
1. Shape
2. Area
3. Distance
4. Direction



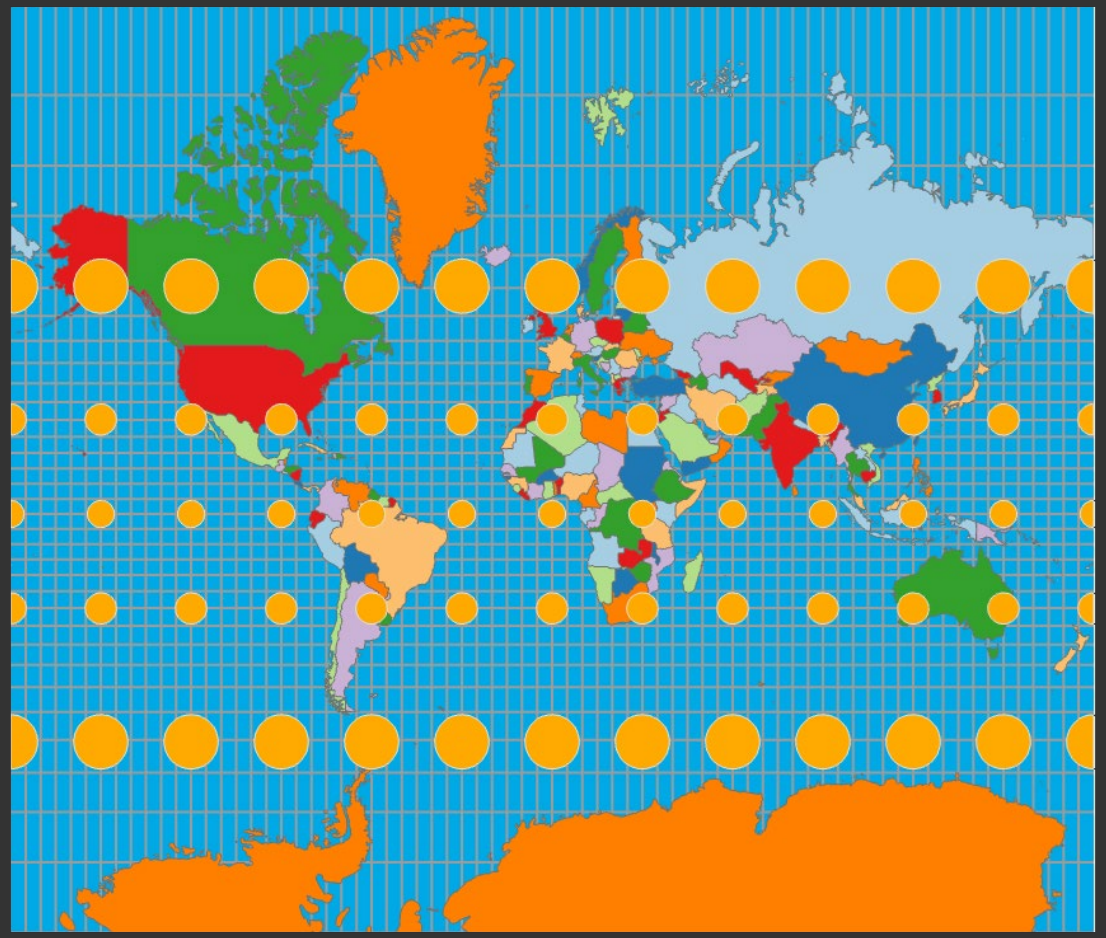
https://thetruesize.com

Web Object

Select this object and click the **Web Object** button to edit



The Tissot Indicatrix



Tissot Indicatrix

Web Object

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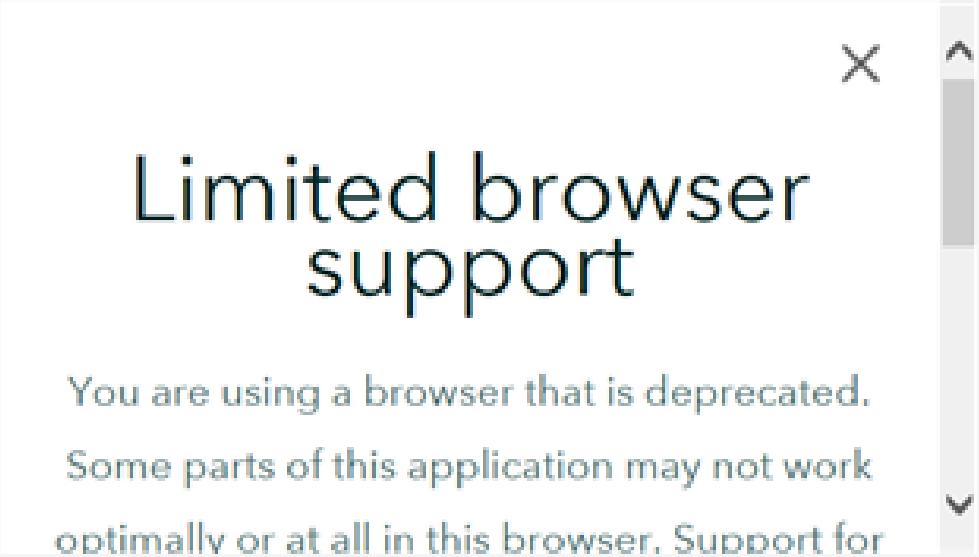


Types of Map Projections

Conformal Projections = preserves local angles and shape

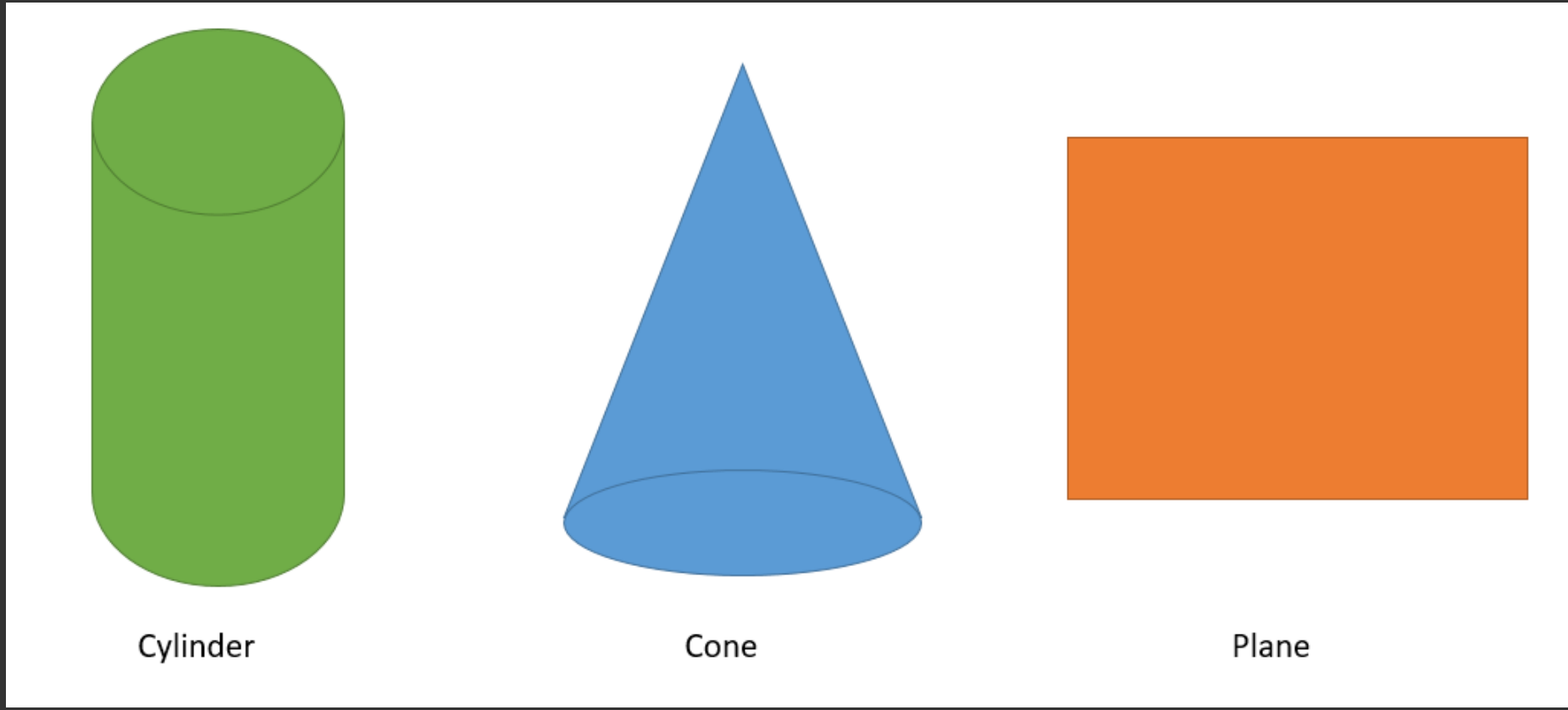
Equivalent Projections = represents areas in correct relative size

Equidistant Projections = maintains consistent scale along certain lines

Azimuthal Projections = maintains certain accurate directions

- Conformal and equivalent properties are mutually exclusive
- Conformal and equivalent properties are global properties
- Equidistant and azimuthal properties are local properties and may be true only from or to the center of the map projection

Map Projections: Developable Surfaces



Cylindrical Projections = Cylinder

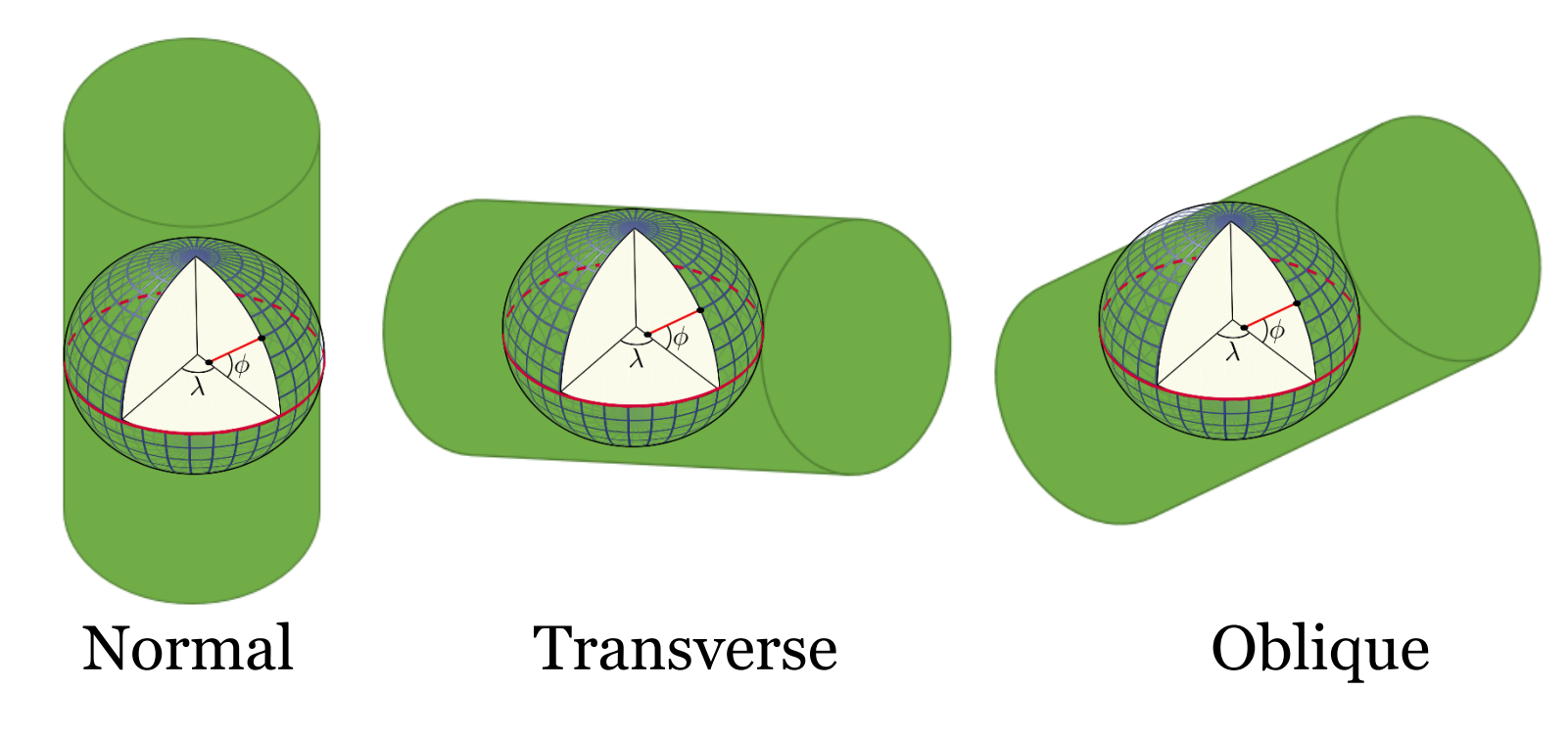
Conic Projections = Cone

Azimuthal Projections = Plane

The developable surfaces: Orientations

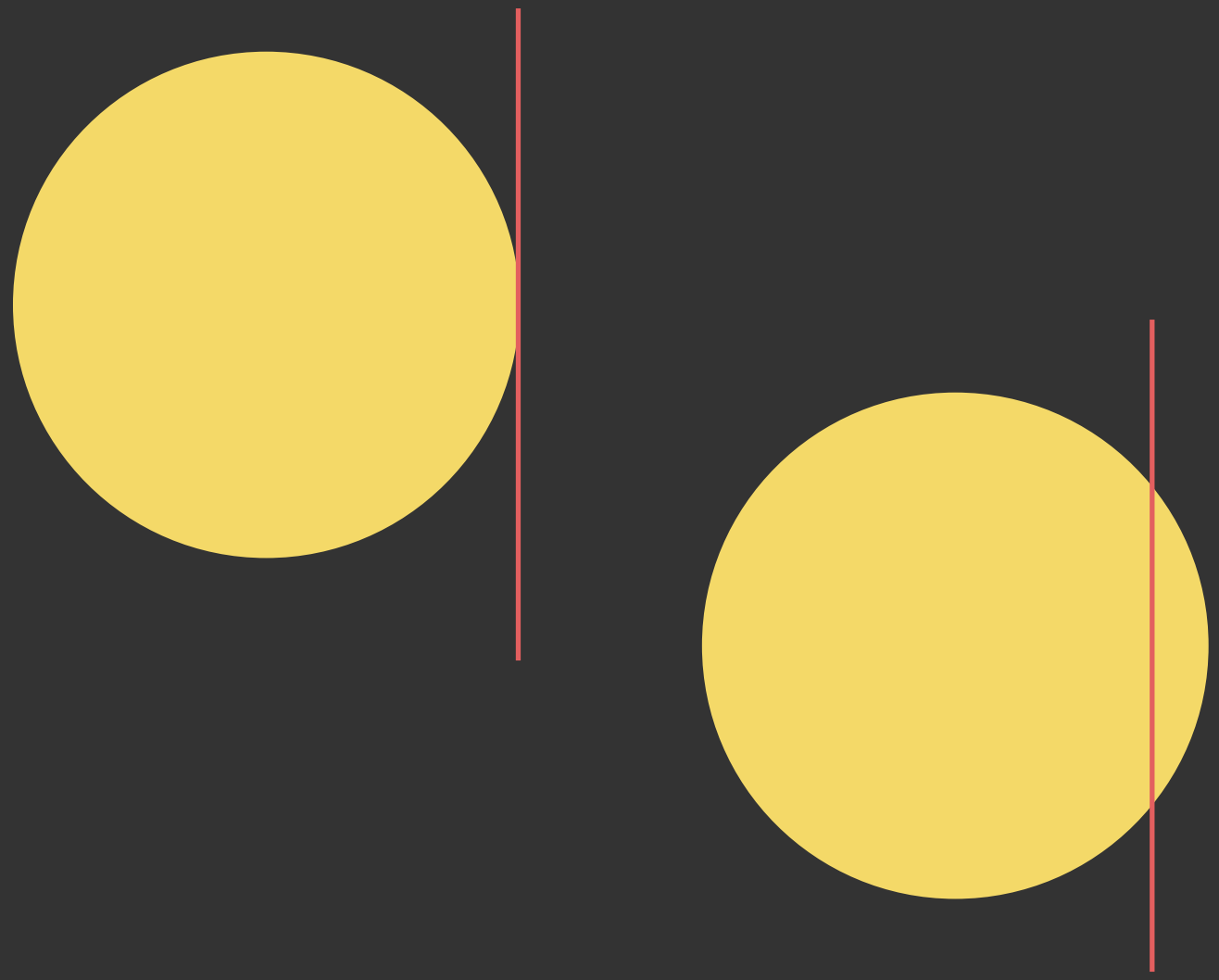
- Planes, cones, and cylinders

https://commons.wikimedia.org/wiki/File:Latitude_and_longitude_graticule_on_an_ellipsoid.svg



Tangency and Secancy

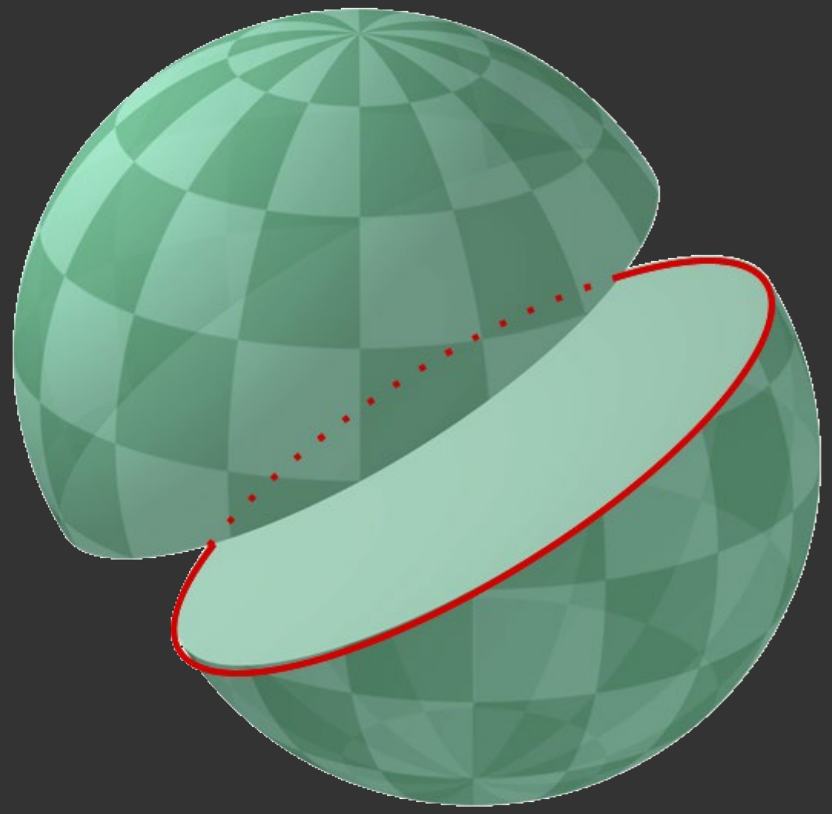
- Standard Line = where projection touches the globe
- Standard Parallel = standard line on a parallel
- Standard Meridian = standard line on a meridian



No distortions at these locations

Great Circles

- Distance measured on the ellipsoid and in a plane through the Earth's center
- Shortest path between two points
- Straight lines in a map projection are generally not straight lines and not the shortest path
- Can be used to approximate distance distortions



https://commons.wikimedia.org/wiki/File:Great_circle_hemispheres.png

Projection Examples

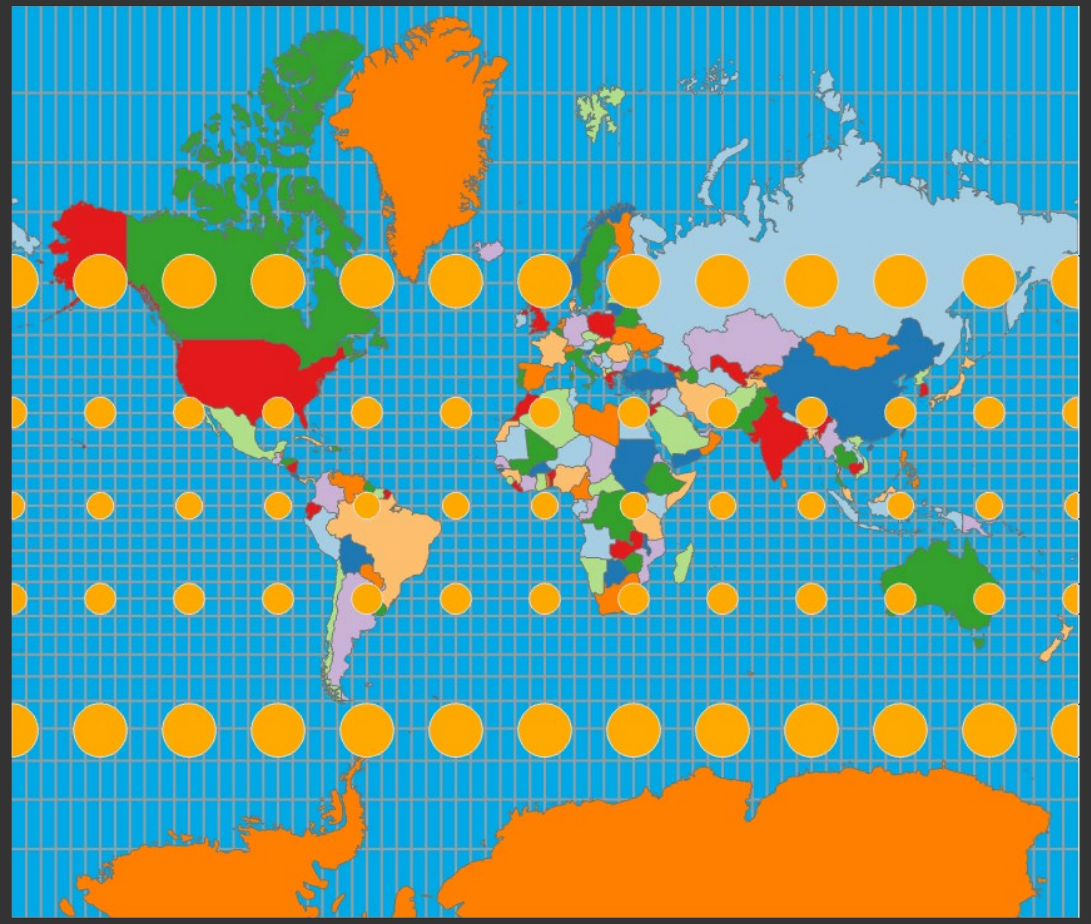
- Projection used is related to type of map and area covered by map (extent)
- Continental-scale data (North America)
  - Geographic projection (decimal degrees)
  - Lambert Conformal Conic
  - Albers Equal Area
- State-scale data (West Virginia)
  - UTM Projection, Zone 17
  - State Plane

Projected coordinate systems do not use longitude and latitude to measure locations

Instead, they use map units of the projection itself:

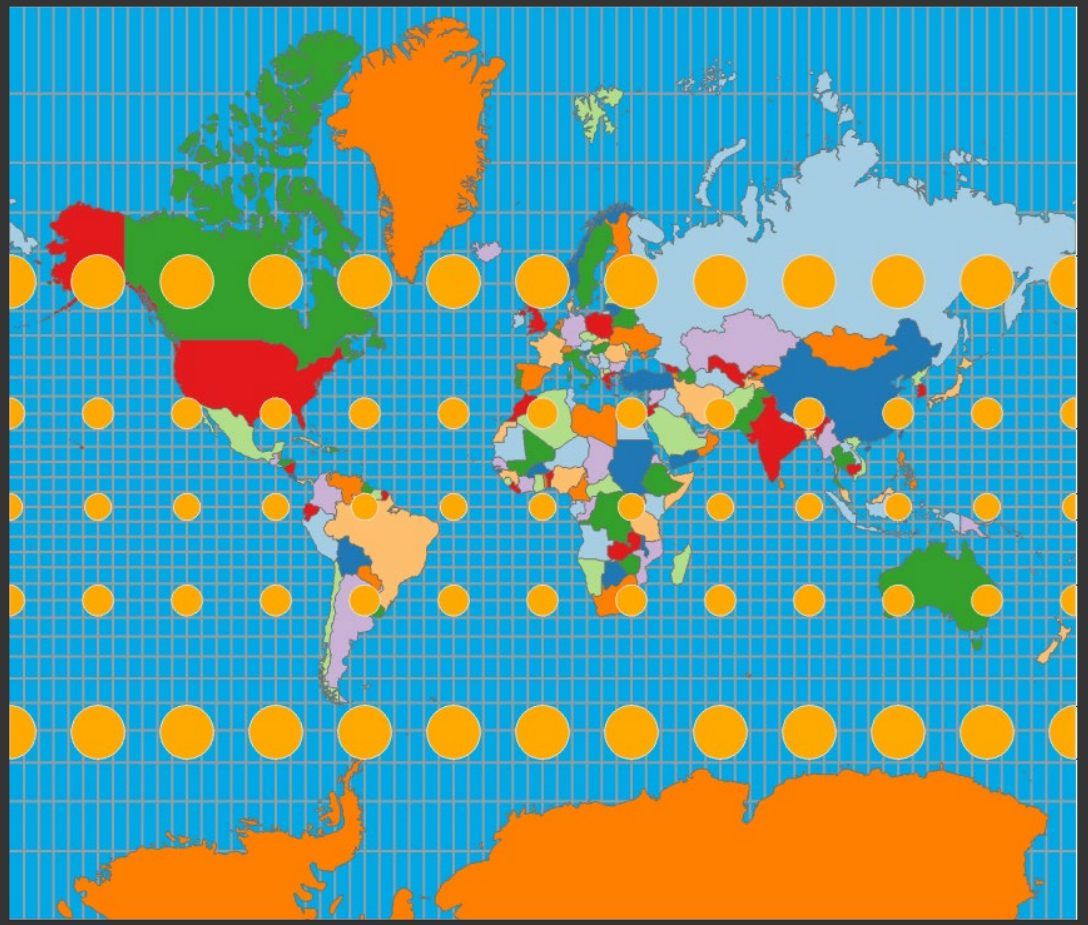
Meters (UTM, Albers, most others)
Feet (State Plane, few others)

World Projections: Mercator



- Cylindrical projection
- Maintains shape
- Distorts size
- Parallels and meridians cross at right-angles

World Projections: Web Mercator

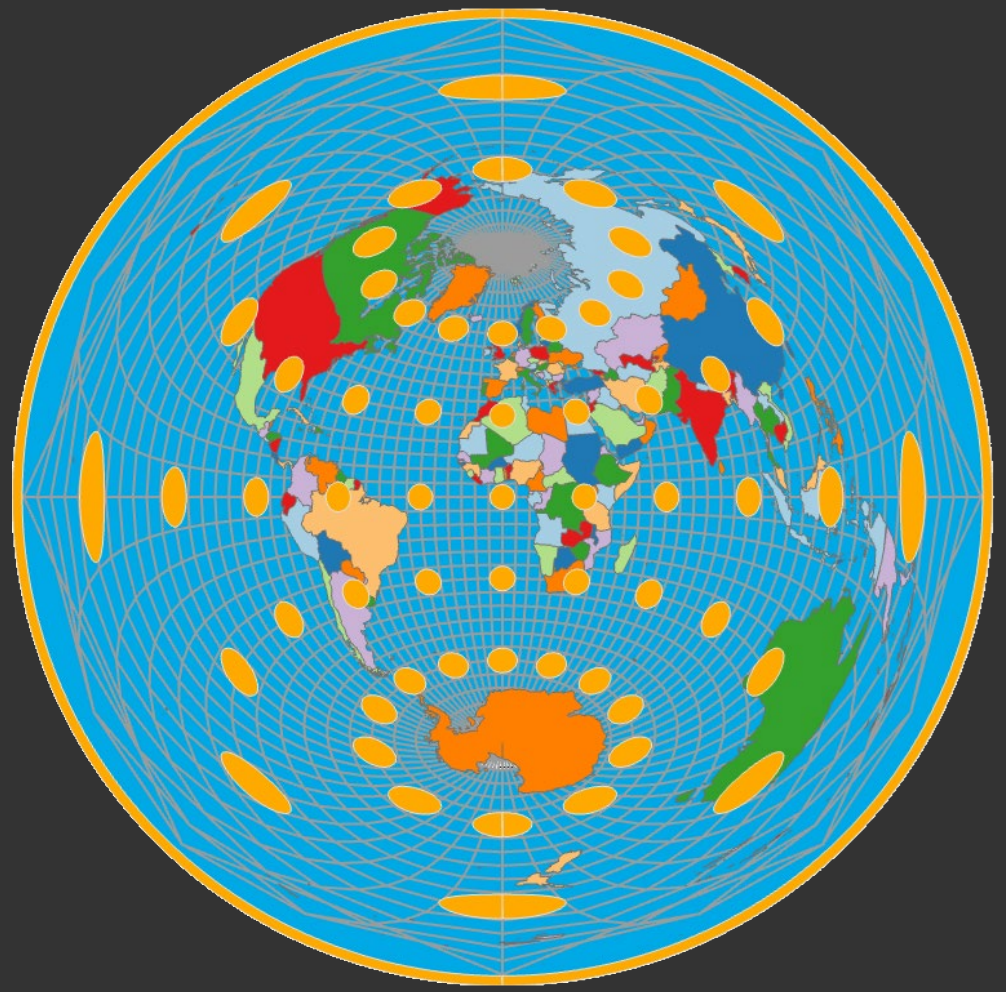


- Modification of Mercator projection that is commonly used for web maps
- Bing Maps, OpenStreetMap, Google Maps, MapQuest, ArcGIS Online
- Uses a sphere as opposed to a spheroid

World Projections: Mollweide

- Equivalent projection
- Maintains area
- Distorts shape and angle
- Pseudocylindrical

World Projections: Azimuthal Equidistant



- Azimuthal and equidistant
- Correct distance from center of map
- Correct angle from center of map

World Projections: Patterson

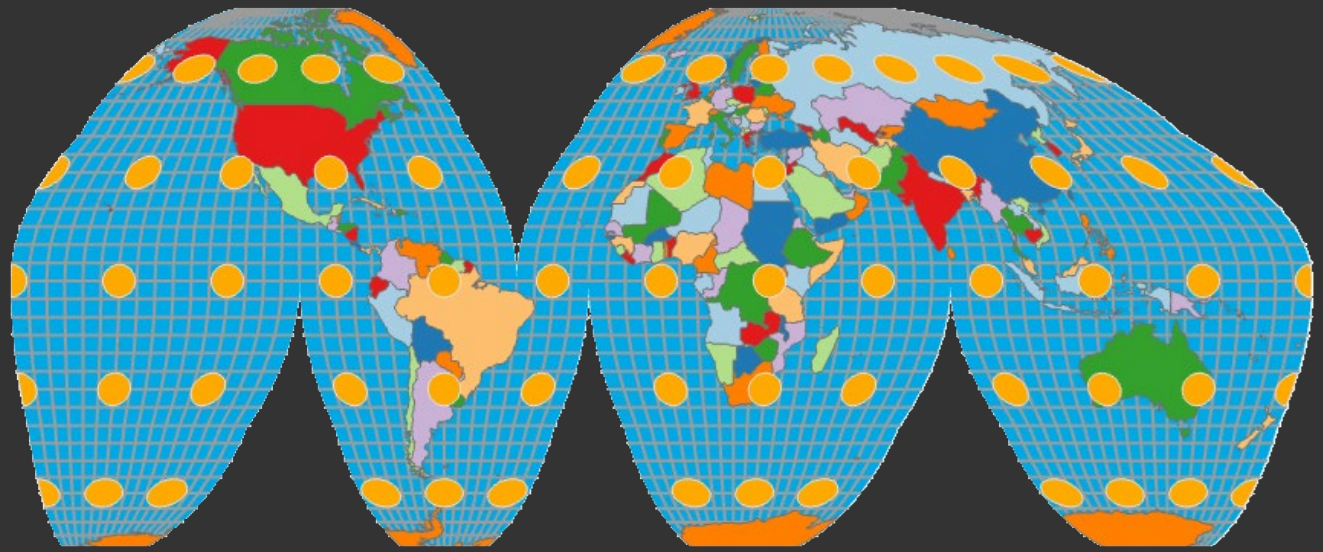
- Neither equivalent or conformal
- Strikes a balance between shape and scale distortion
- Meridians curve gently

World Projections: Eckert IV

- Equivalent
- Maintains area
- Distorts shape and angle
- Pseudocylindrical

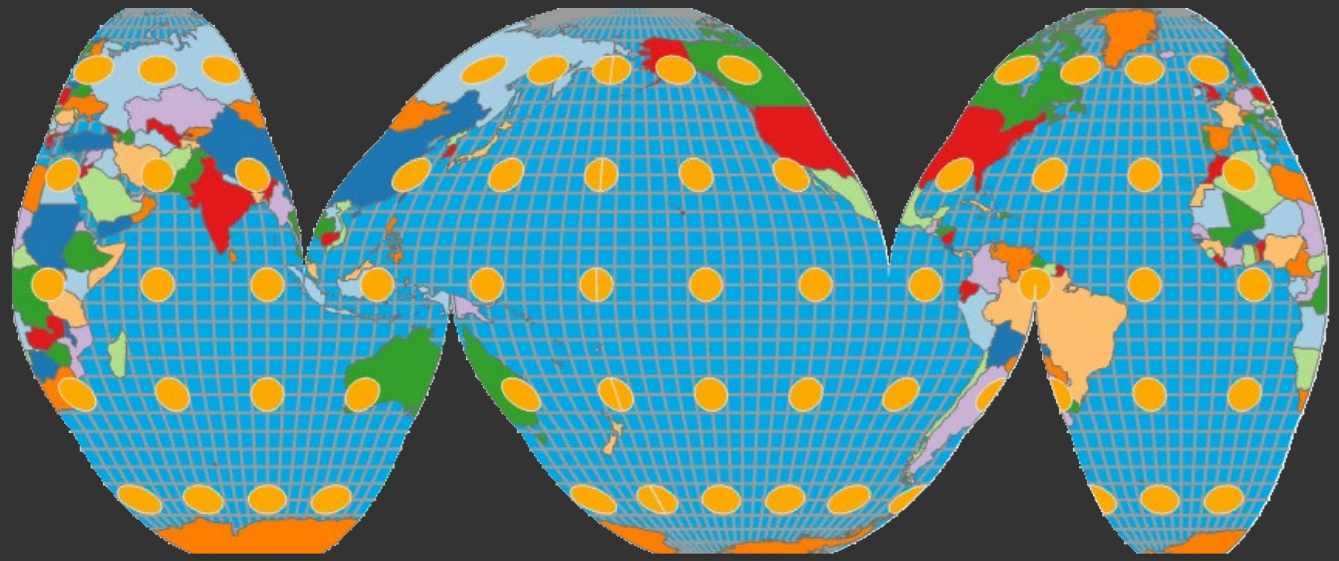
World Projections: Goode Homolosine (Land)

- Equivalent
- Maintains area
- Distorts shape and angle
- Pseudocylindrical
- Does not split contents



World Projections: Goode Homolosine (Ocean)

- Equivalent
- Maintains area
- Distorts shape and angle
- Pseudocylindrical
- Does not split oceans



World Projections: Other Examples

Berghaus Star

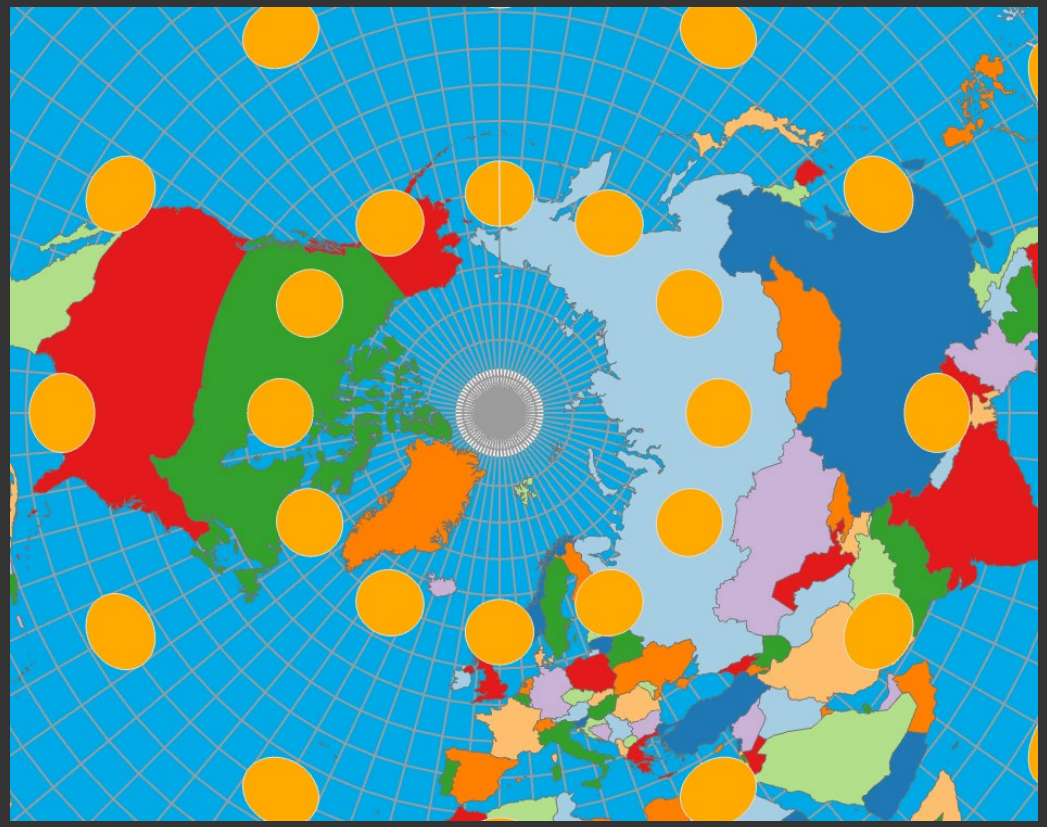
Miller Cylindrical

World Projections: Other Examples

Robinson

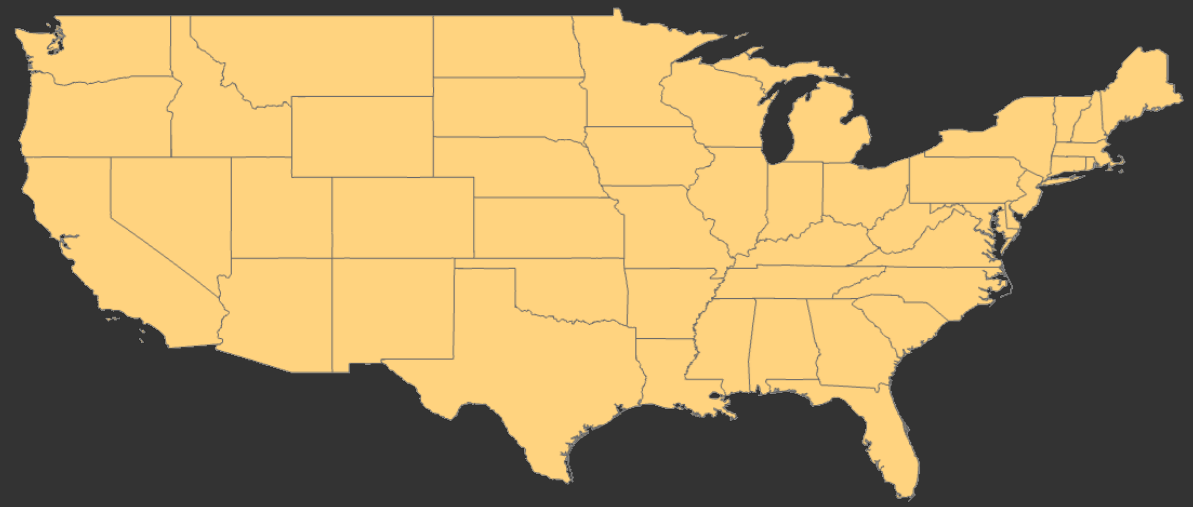
Winkel II

Polar Projections: North Pole Azimuthal Equidistant

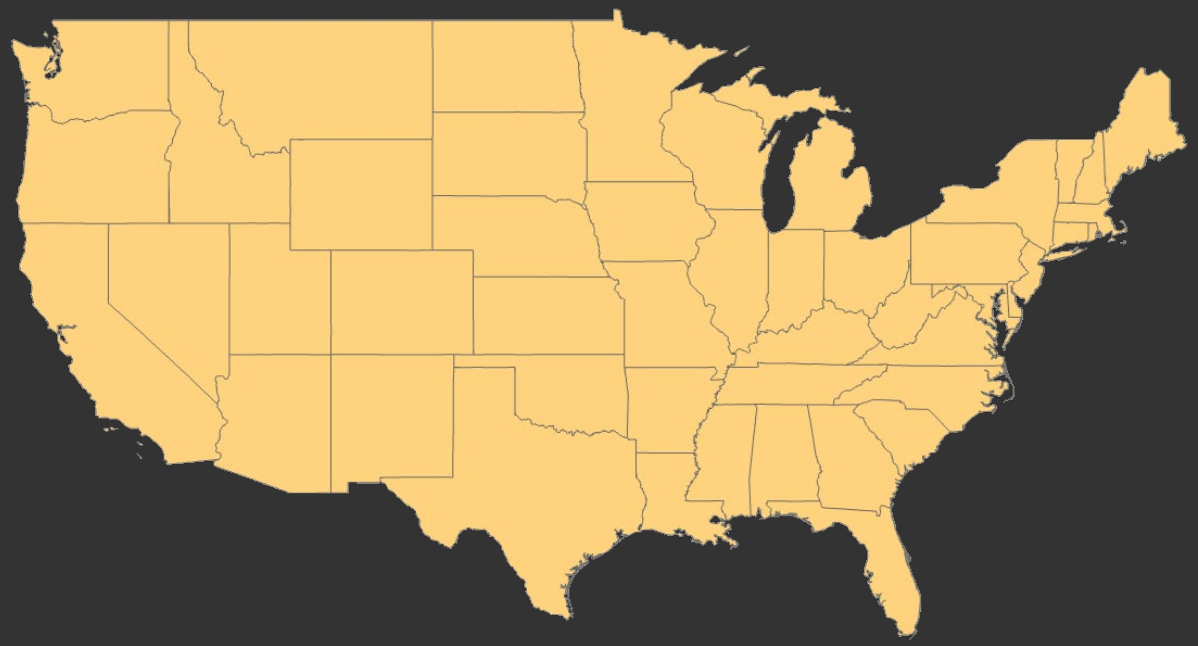


- Maintains distance and direction from the North Pole

US Projections

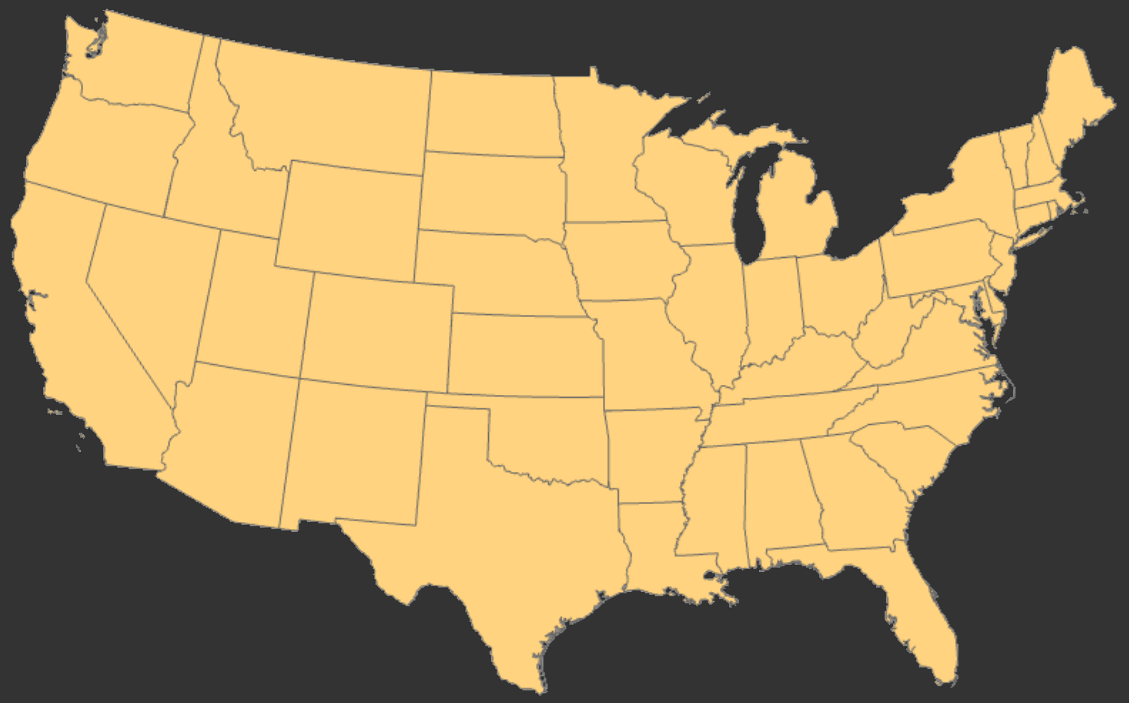


Not Projected

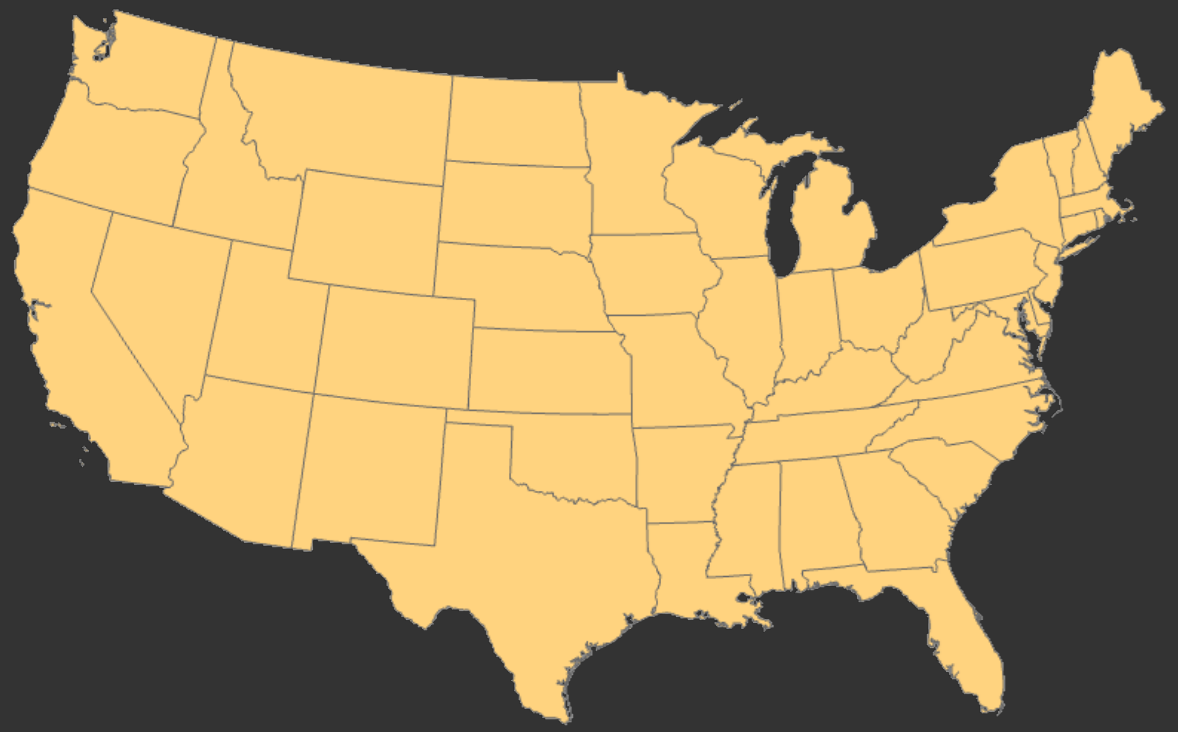


Mercator

US Projections



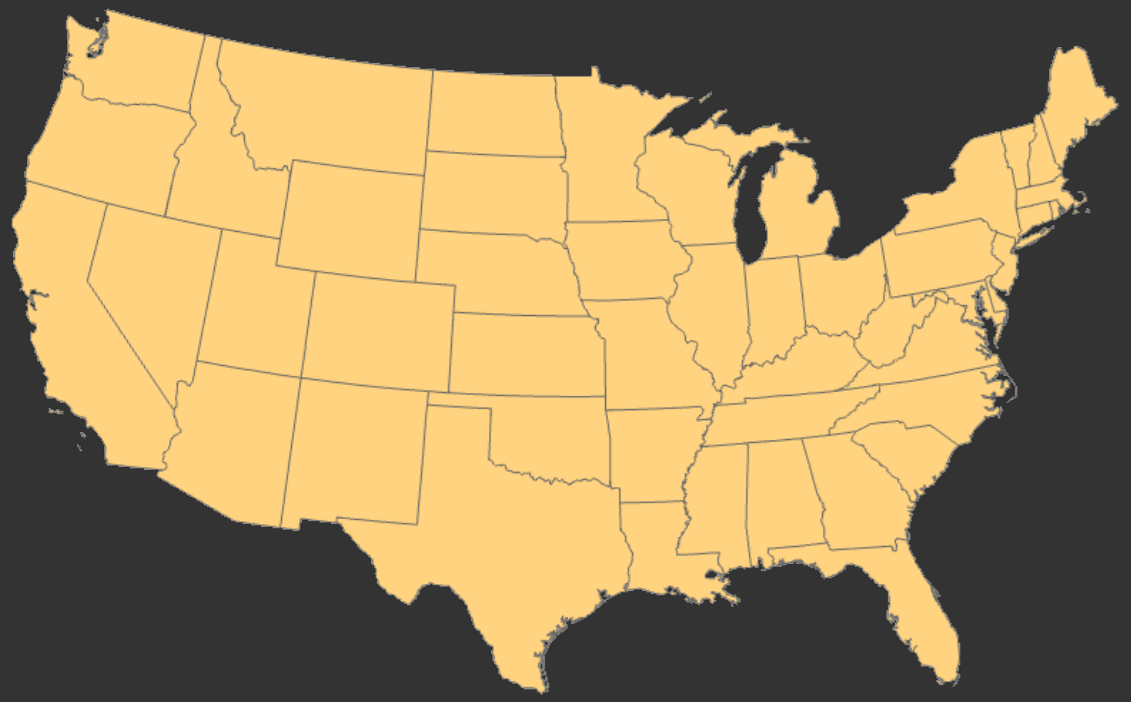
Albers Equal Area



Lambert Conformal Conic

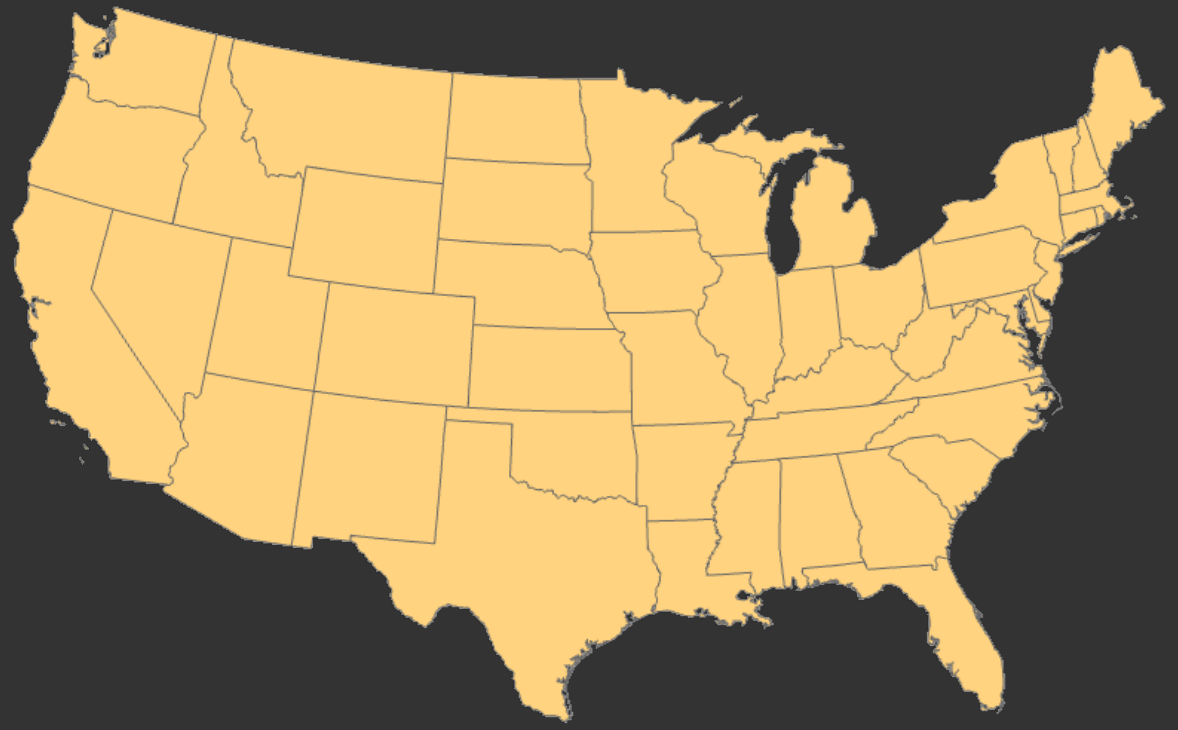
US Projections: Albers Equal Area

- Conic
- Equivalent
- Maintains area
- Two standard parallels

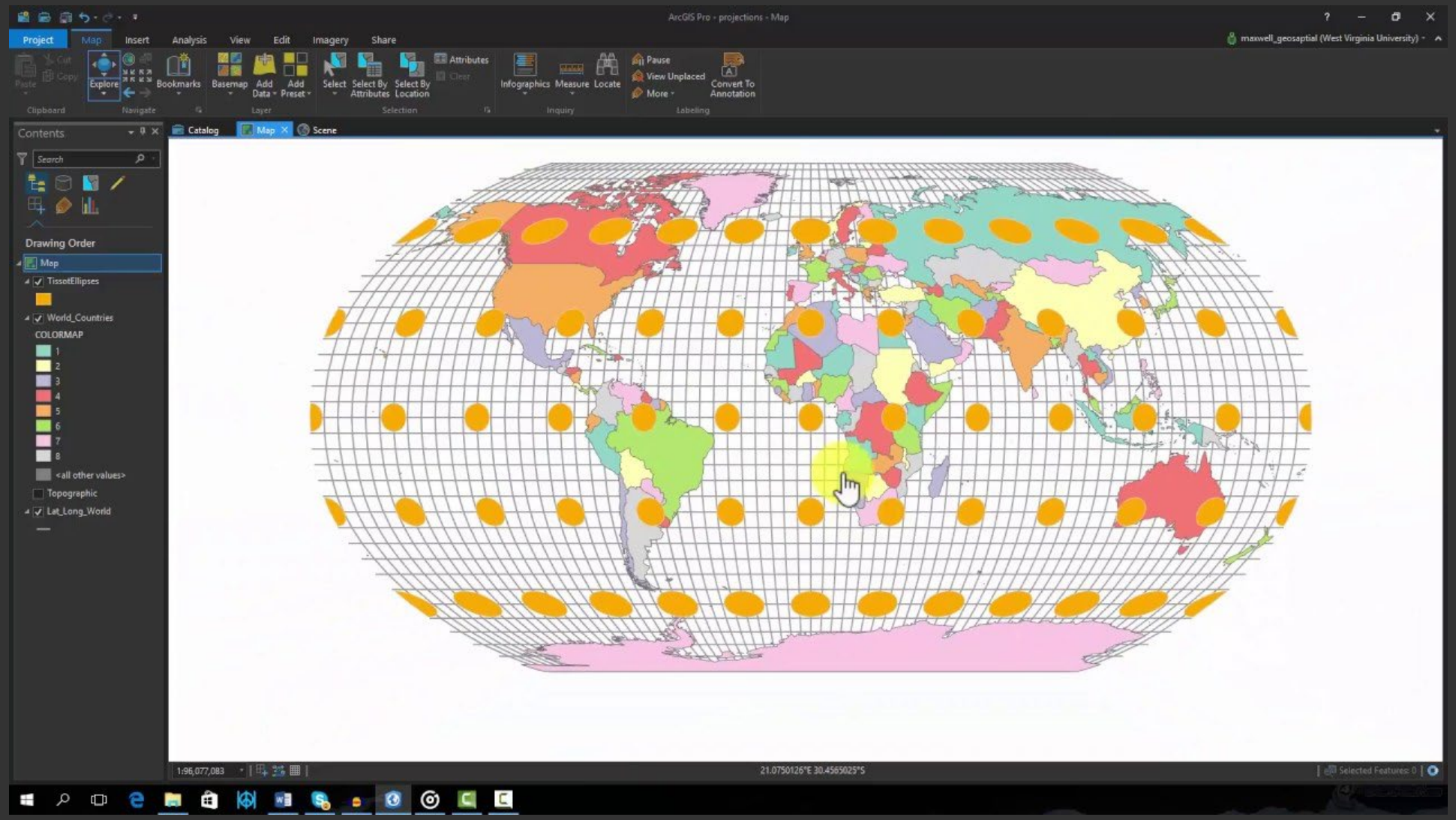


US Projections: Lambert Conformal Conic

- Conic
- Conformal
- Maintains shape
- Two standard parallels



Video: Projections in ArcGIS Pro



Universal Transverse Mercator (UTM)

Location provided in meters as Easting and Northing

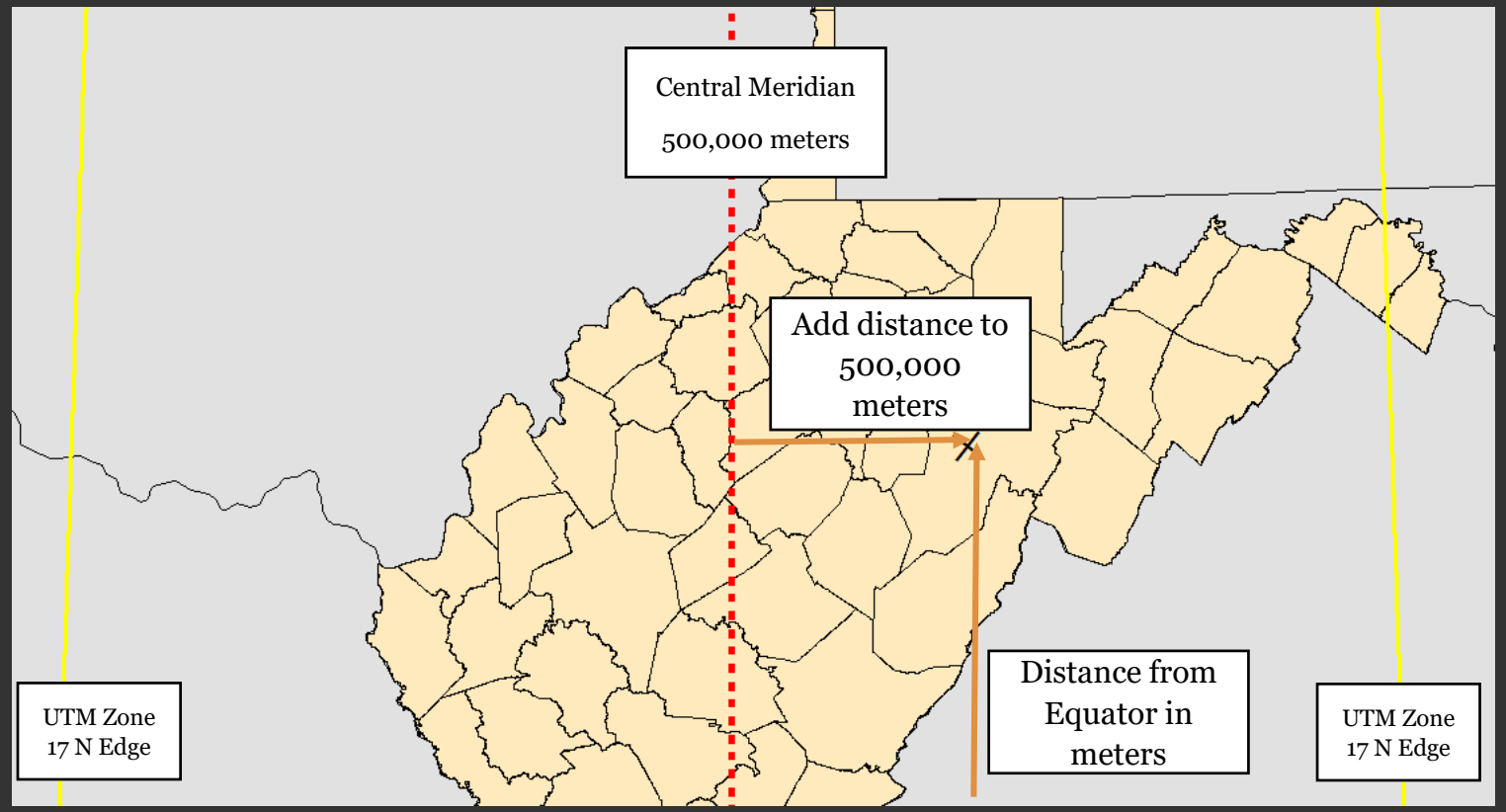
Northing = meters north of equator

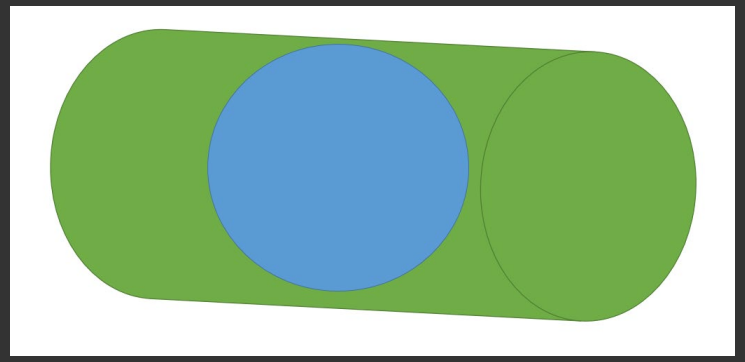
- In northern hemisphere, equator is assigned a value of 0 meters, add as you go up
- In southern hemisphere, equator is assigned a value of 10,000,000 meters, subtract as you go down

Easting = distance from central meridian in UTM zone

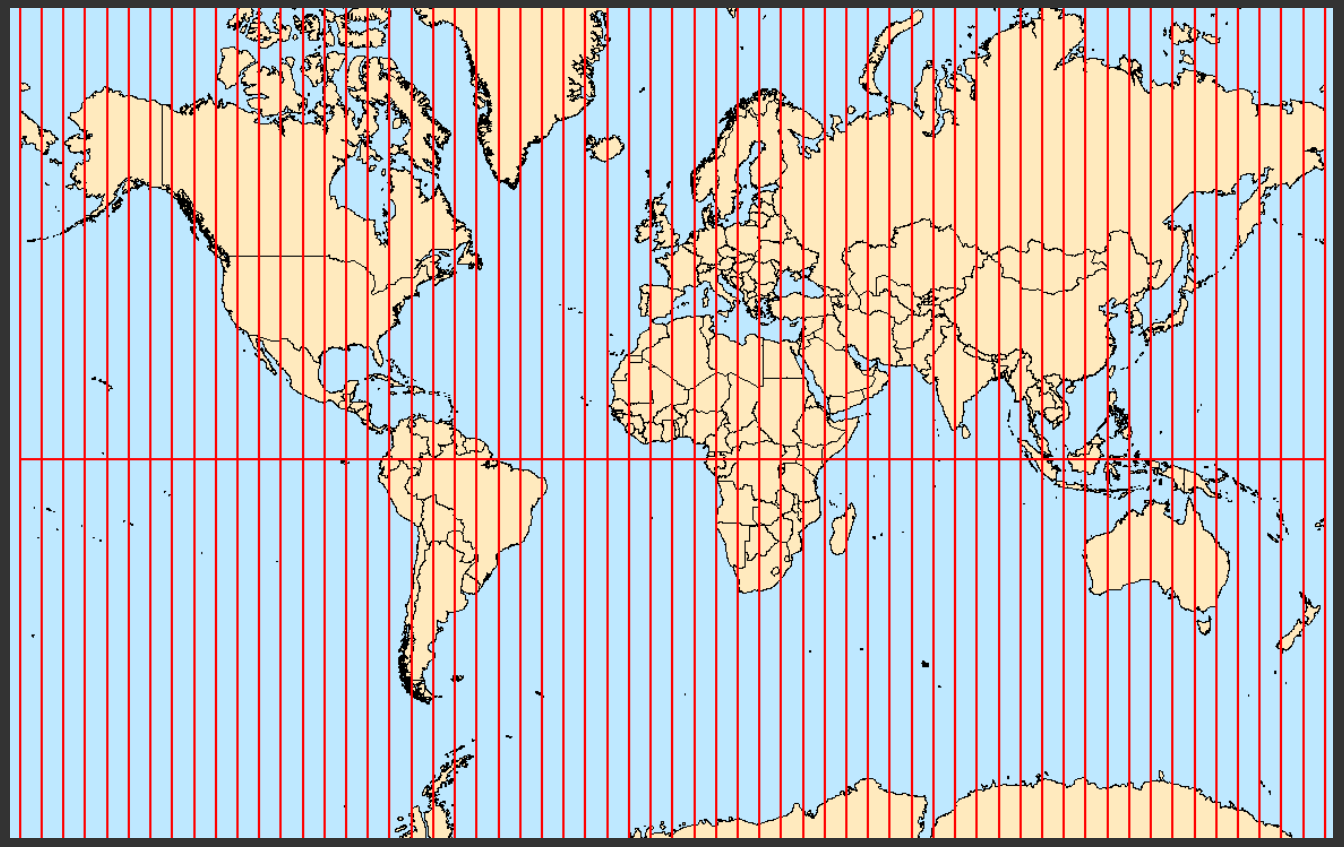
- Central meridian is assigned a value of 500,000 meters
- Add as you go east
- Subtract as you go west

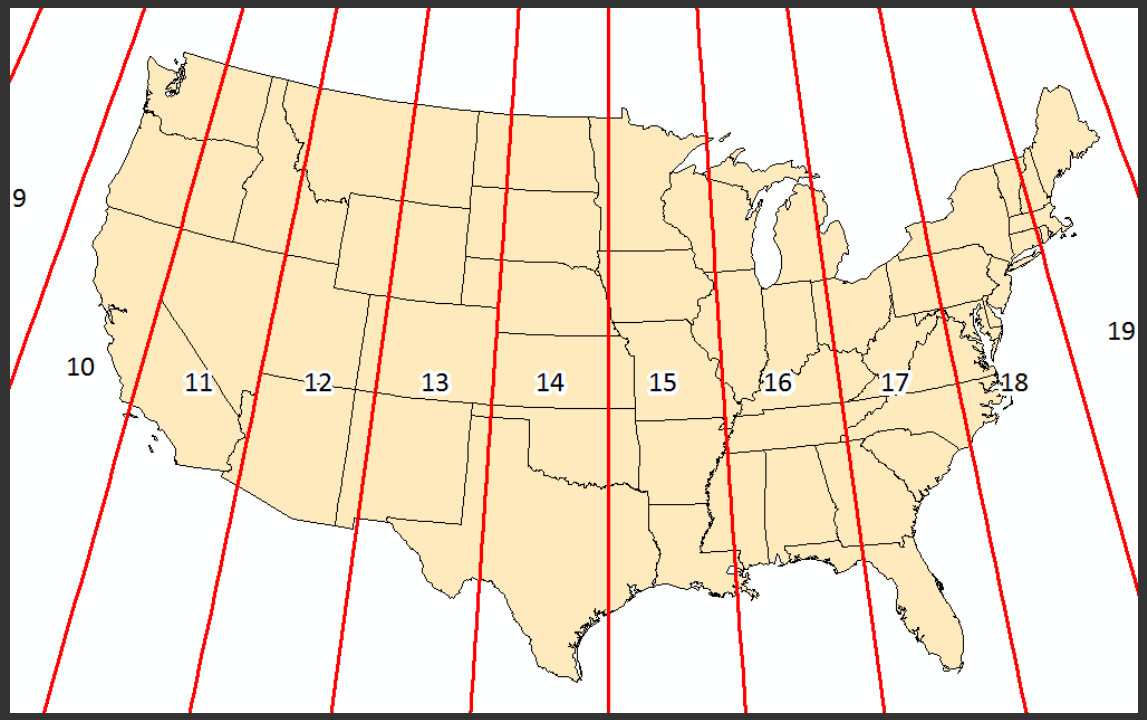
Universal Transverse Mercator (UTM)





UTM Zones

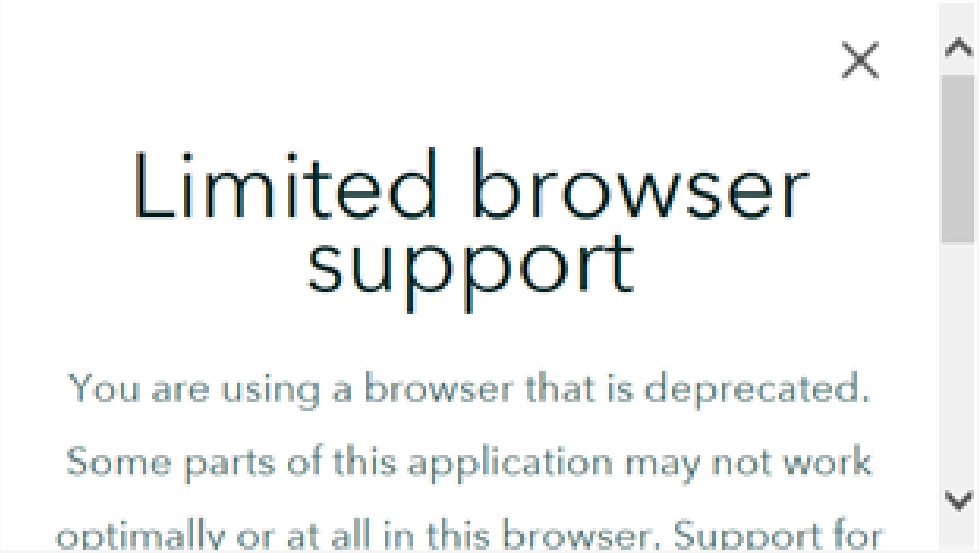




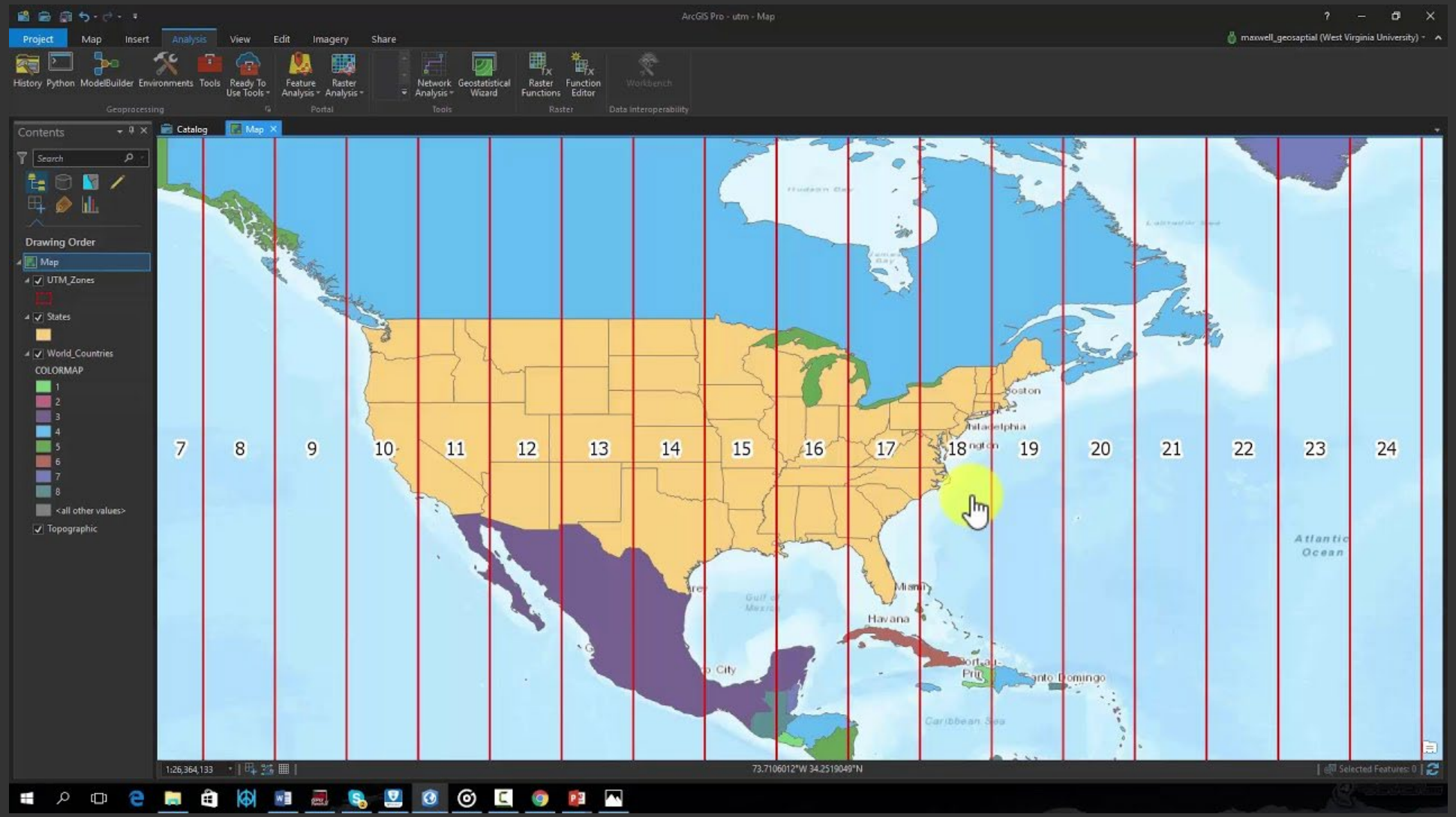
UTM Zones

Web Object

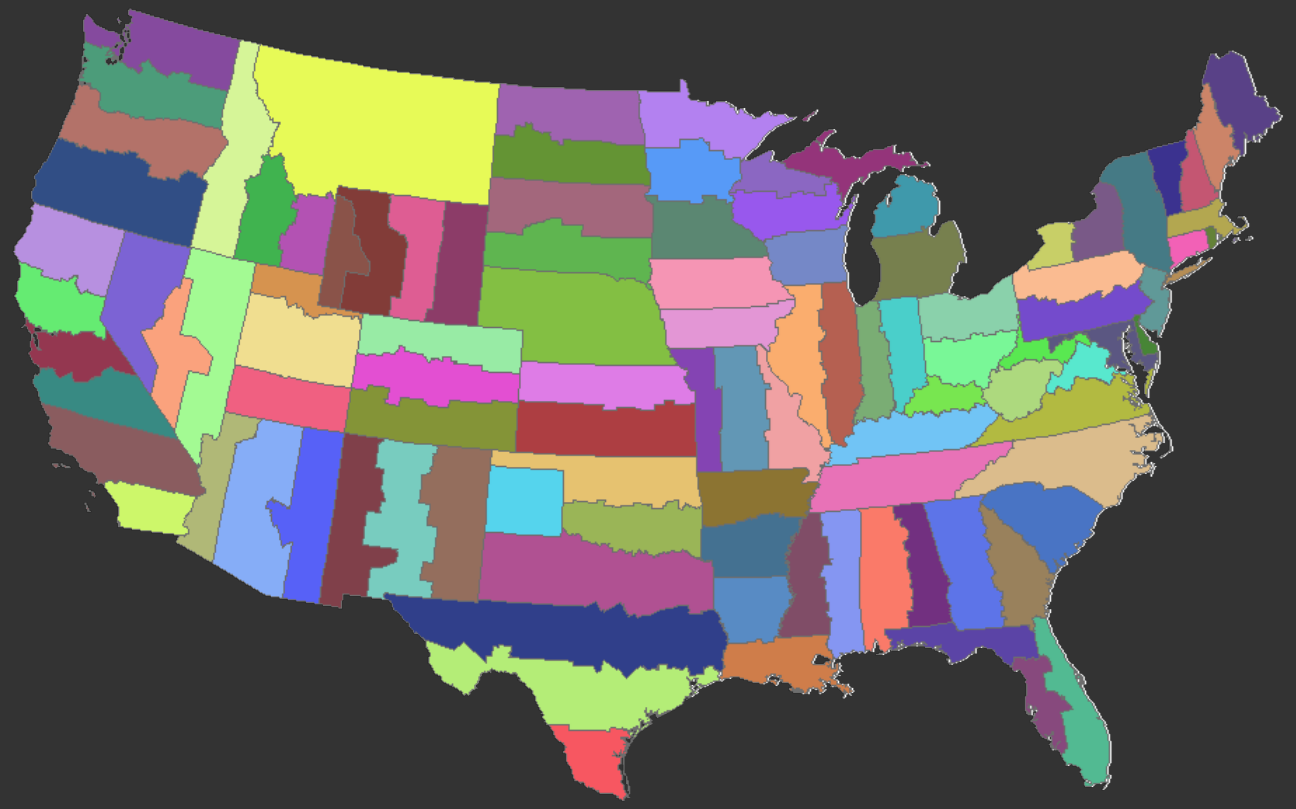
Select this object and click the **Web Object** button to edit



Video: UTM Projections



State Plane Coordinate System



- Used by surveyors
- Measurements in feet or meters
- Each zone has defined baseline (like northing) and false meridian
- Very good for accurate measurements
- Commonly used for mapping at the city- to county-scale

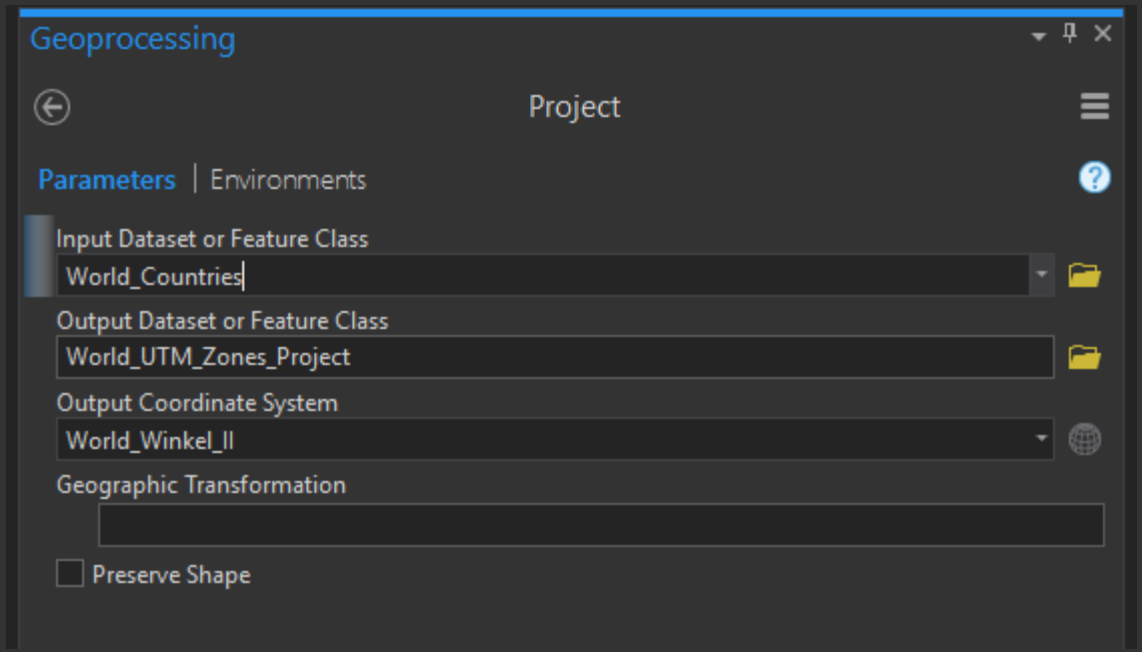
Best Practices

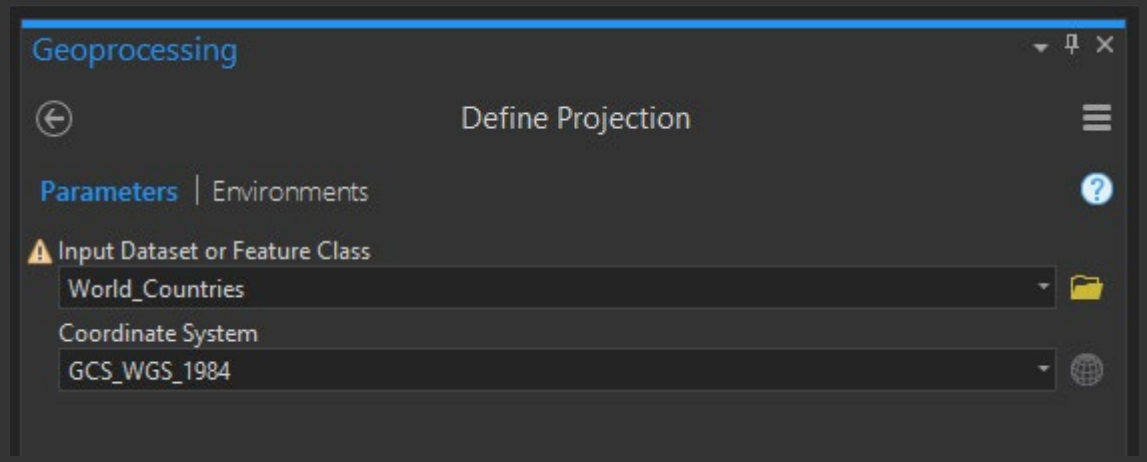
1. Should use same projection for all data
2. Use projection appropriate for scale and extent
3. Think about what map properties are maintained or distorted

Projection-on-the-Fly (ArcGIS)

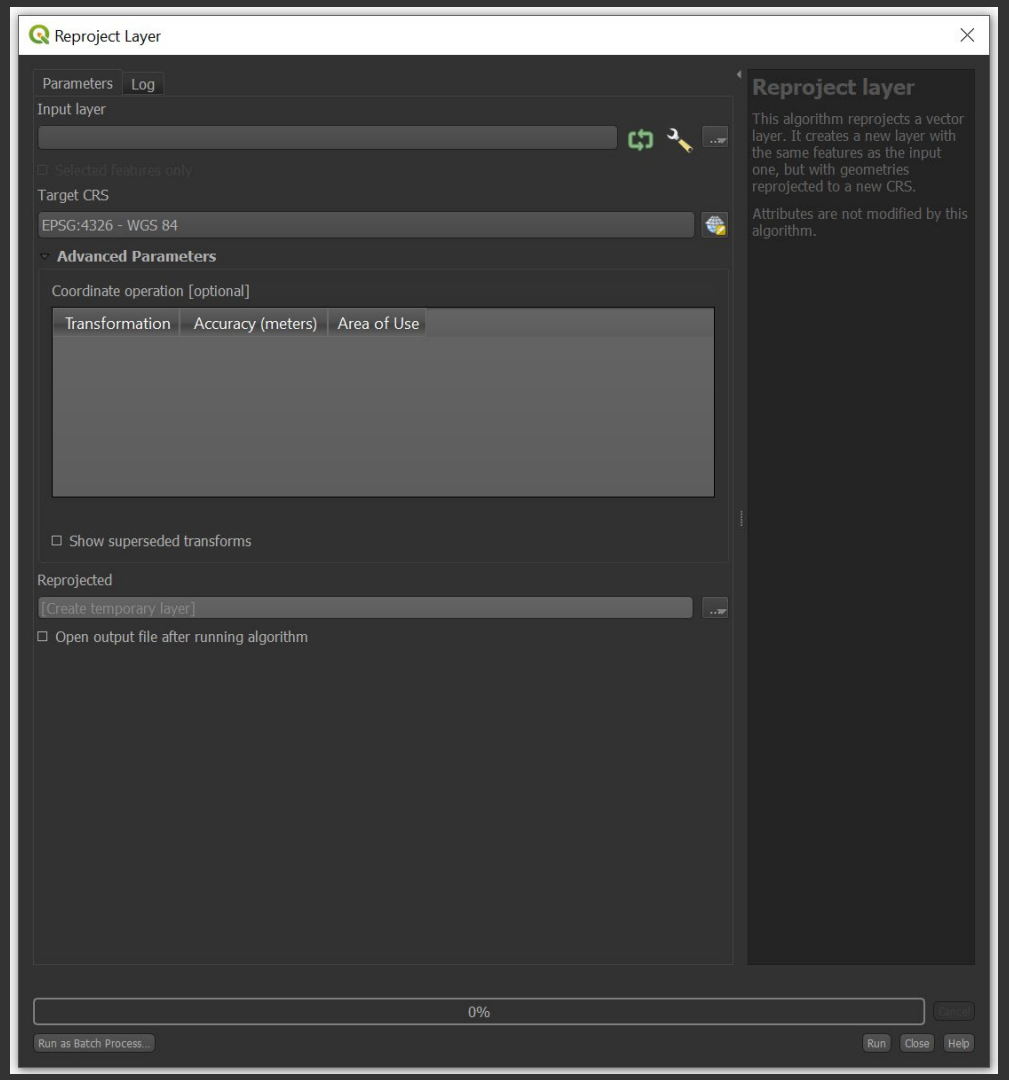
- ArcGIS Pro can apply a projection transformation on-the-fly
- So, it is not always necessary to reproject data
- Okay if you are visualizing the data
- May need to reproject if you plan to perform an analysis

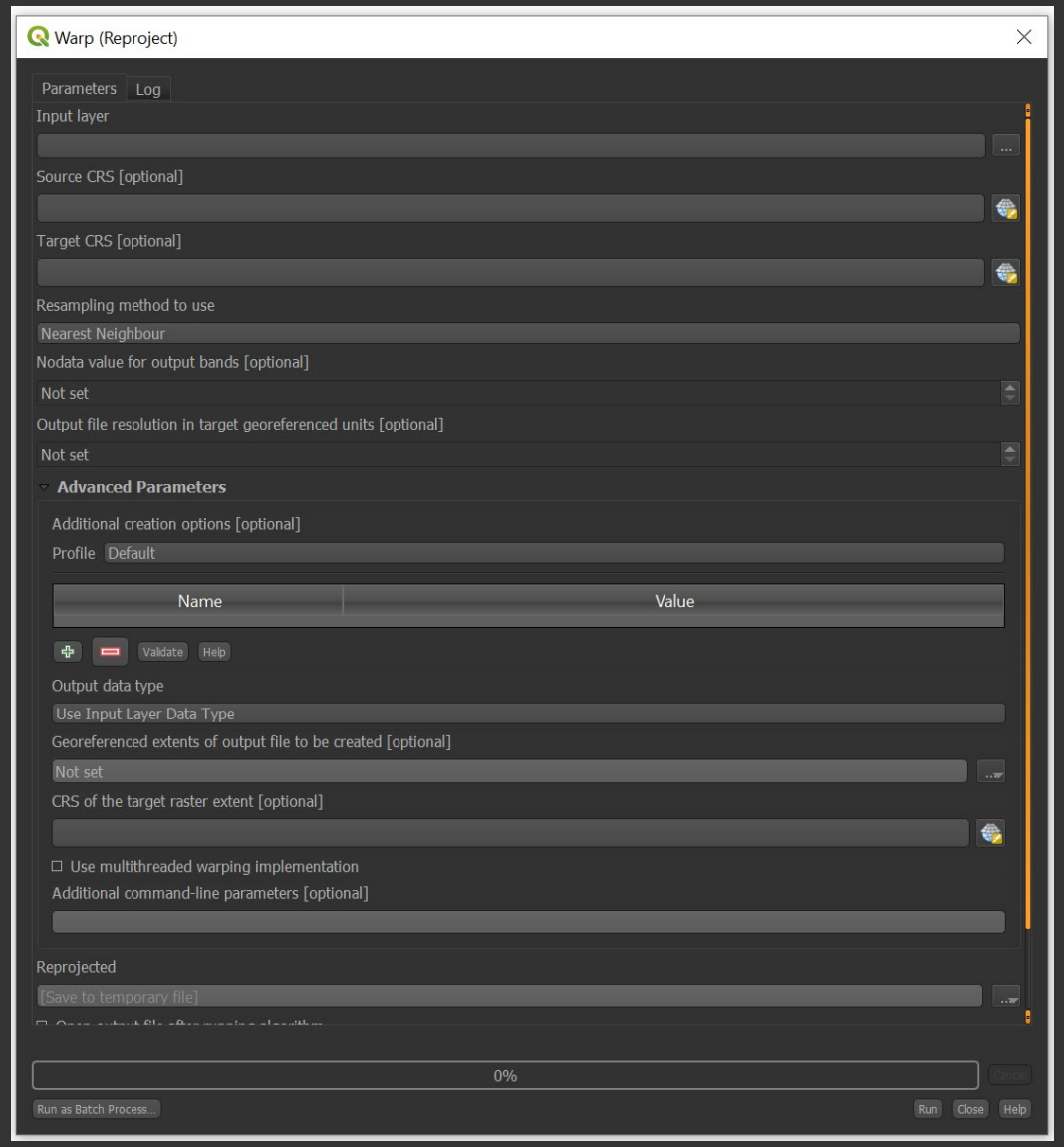
Transforming Projections and Datums in ArcGIS



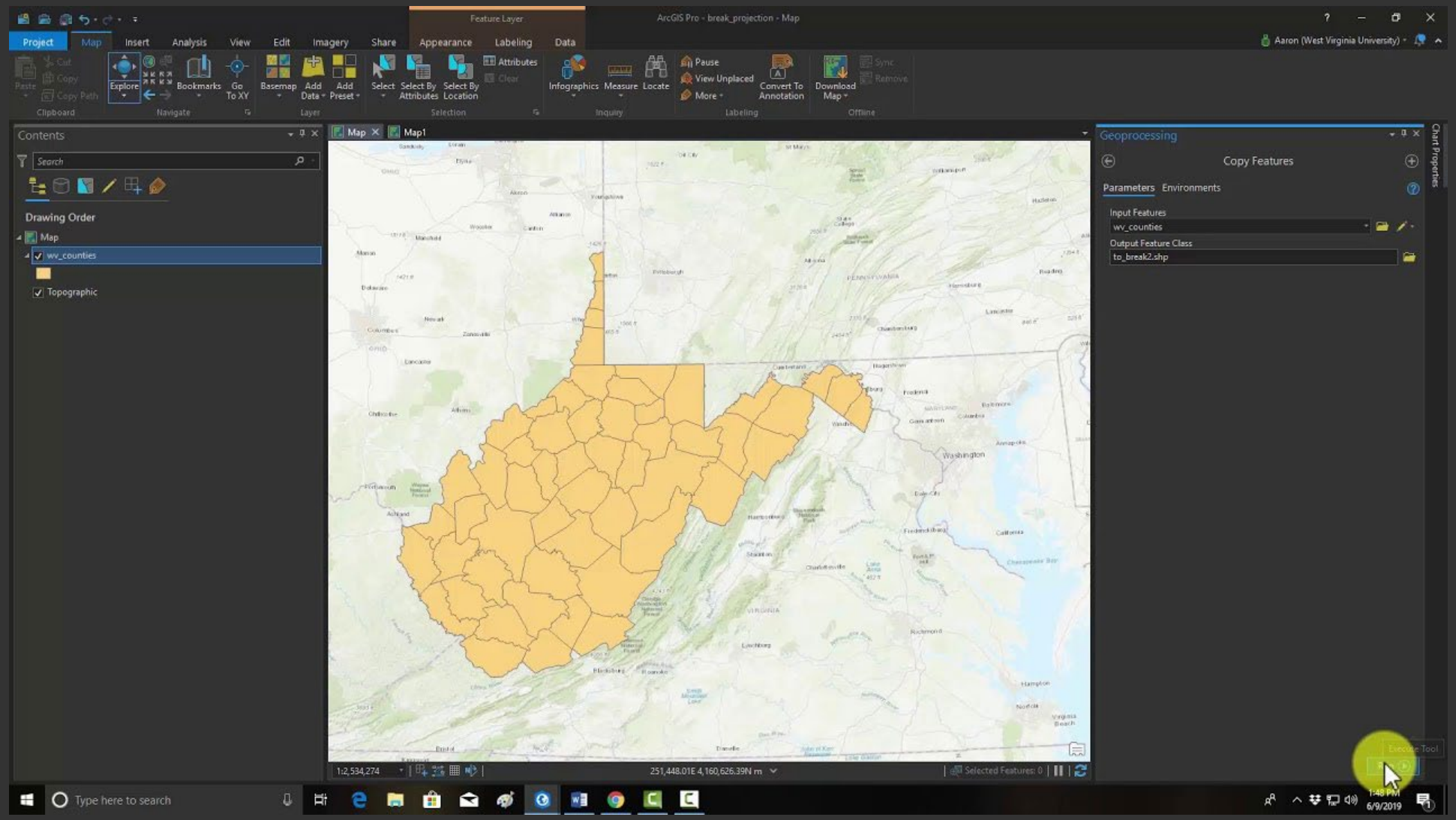


QGIS

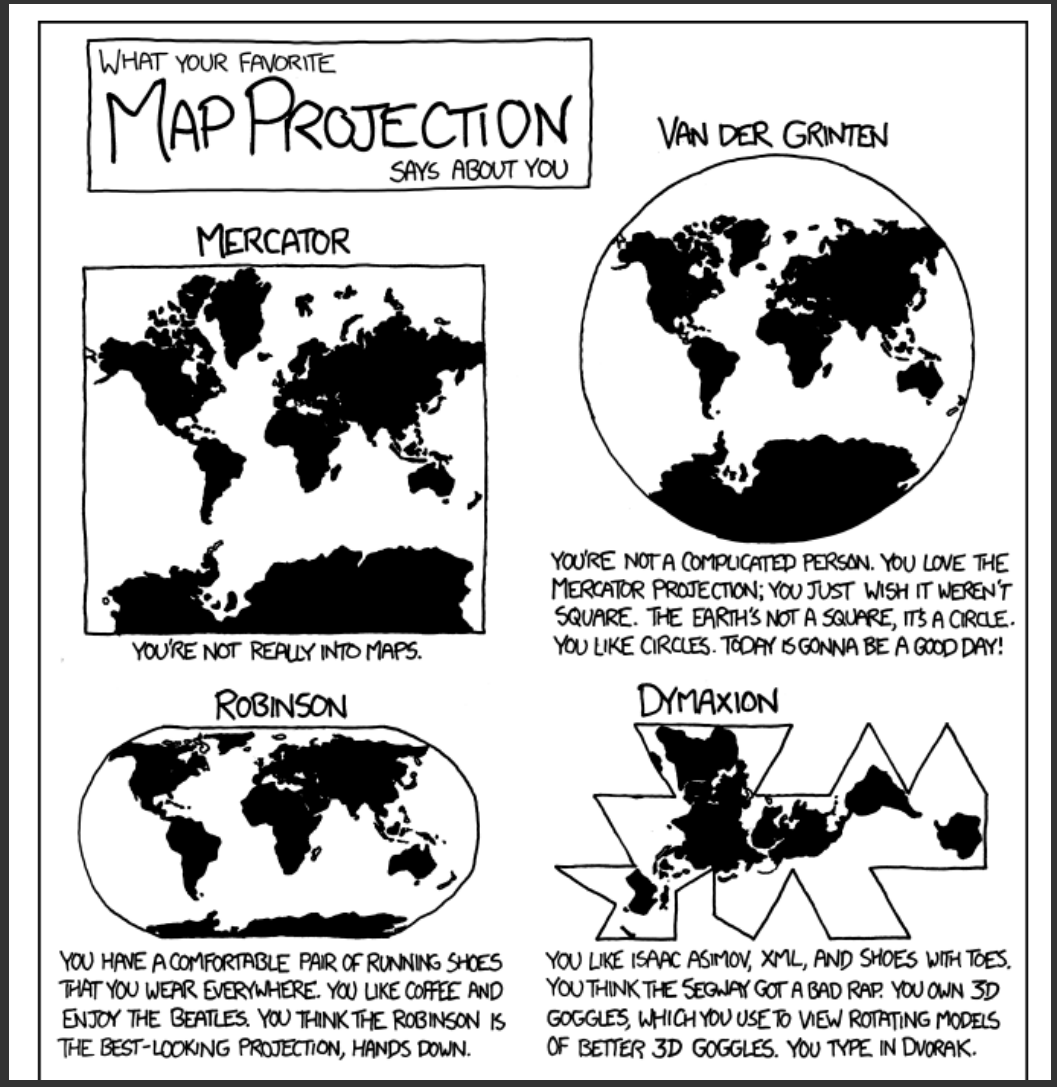

Reproject Layer
Parameters
Log
Input layer
Selected features only
Target CRS
EPSG:4326 - WGS 84
Advanced Parameters
Coordinate operation [optional]
Transformation
Accuracy (meters)
Area of Use
Show superseded transforms
Reprojected
[Create temporary layer]
Open output file after running algorithm
Reproject layer
This algorithm reprojects a vector layer. It creates a new layer with the same features as the input one, but with geometries reprojected to a new CRS.
Attributes are not modified by this algorithm.
0%
Run as Batch Process...
Run
Close
Help

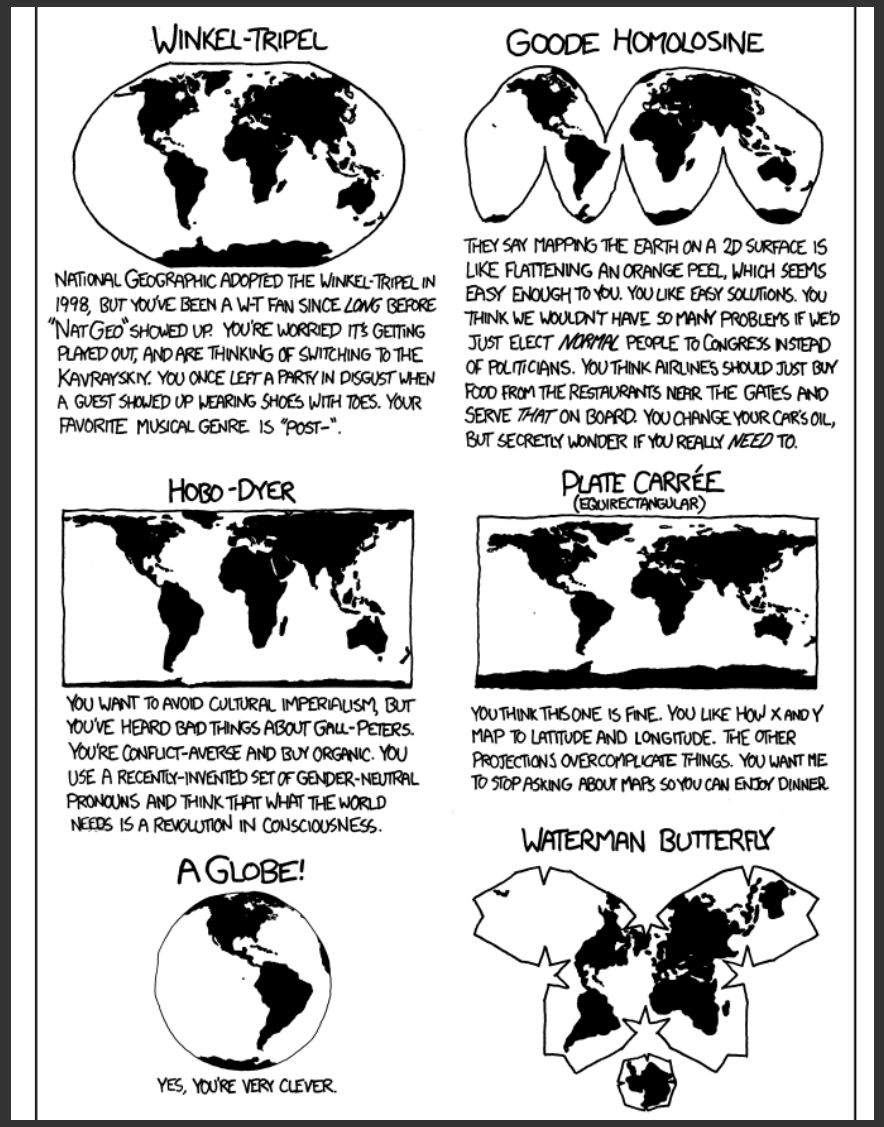

Warp (Reproject)
Parameters
Log
Input layer
Source CRS [optional]
Target CRS [optional]
Resampling method to use
Nearest Neighbour
Nodata value for output bands [optional]
Not set
Output file resolution in target georeferenced units [optional]
Not set
Advanced Parameters
Additional creation options [optional]
Profile
Default
Name
Value
Validate
Help
Output data type
Use Input Layer Data Type
Georeferenced extents of output file to be created [optional]
Not set
CRS of the target raster extent [optional]
Use multithreaded warping implementation
Additional command-line parameters [optional]
Reprojected
[Save to temporary file]
0%
Run as Batch Process...
Run
Close
Help

Video: Break a Projection



xkcd





https://xkcd.com/977/

This is the end of this lecture module.

Please return to the West Virginia View Webpage for additional content.