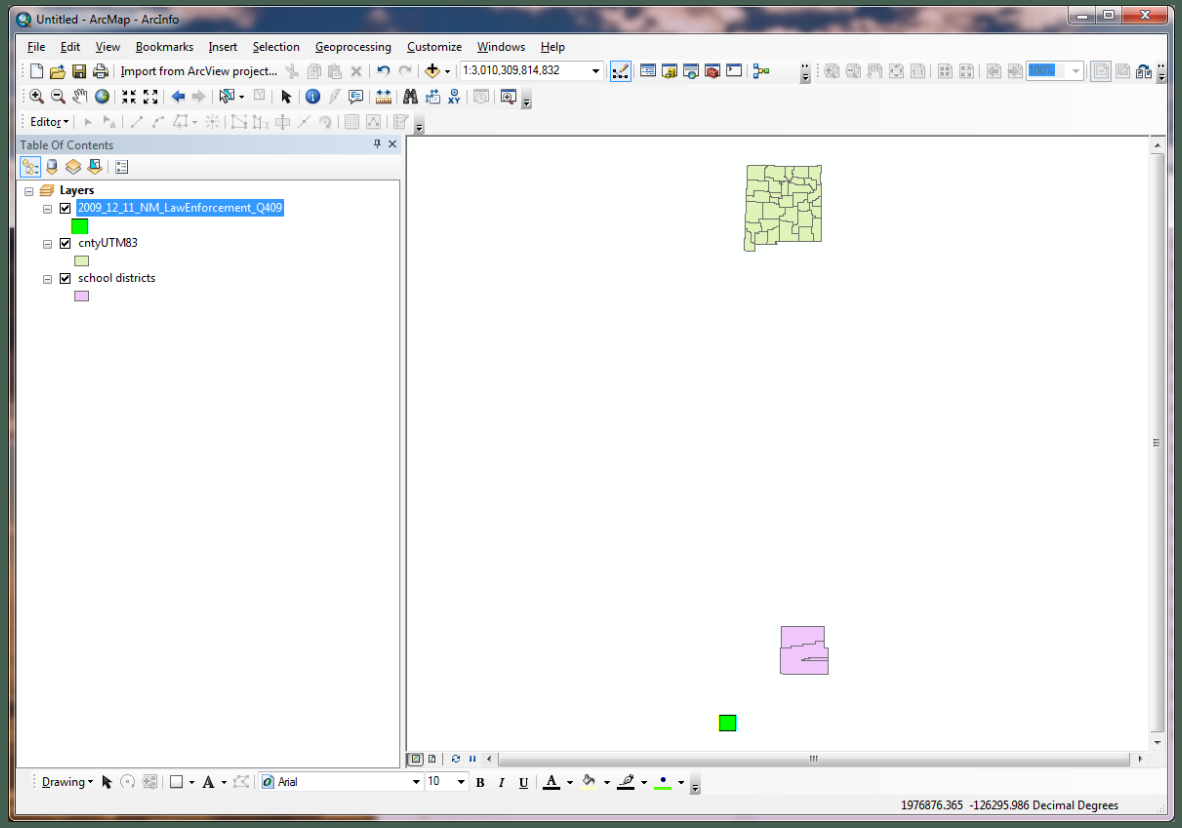
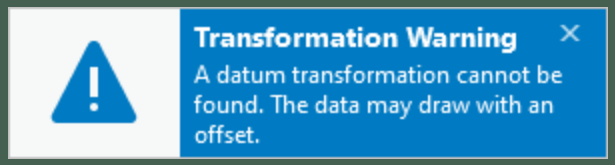
COORDINATE SYSTEMS & MAP PROJECTIONS

Sandeep Talasila, GISP

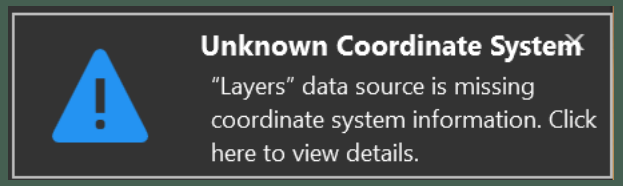
DATA OVERLAY ISSUES



DATA OVERLAY WARNINGS



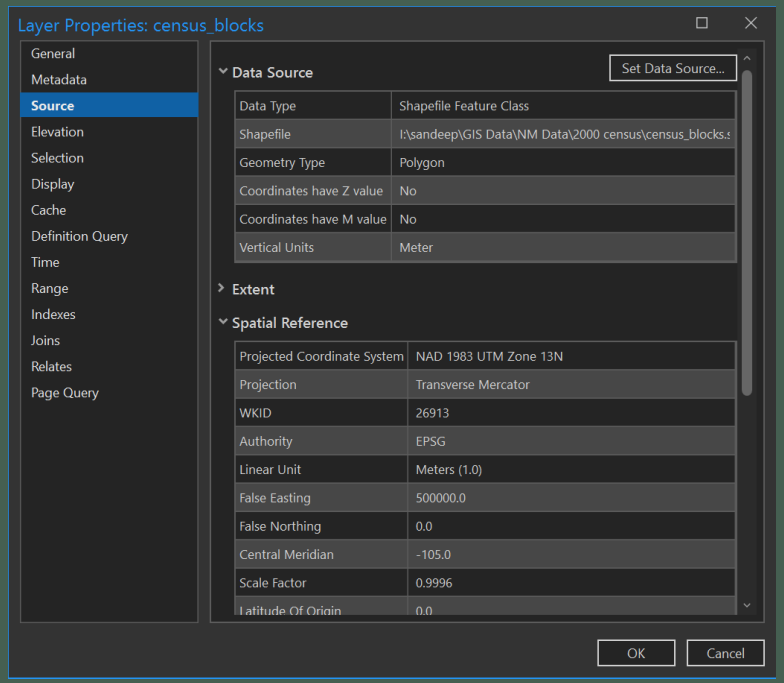
One of more of the data layers use a geographic coordinate system that is different from the one used by the map.



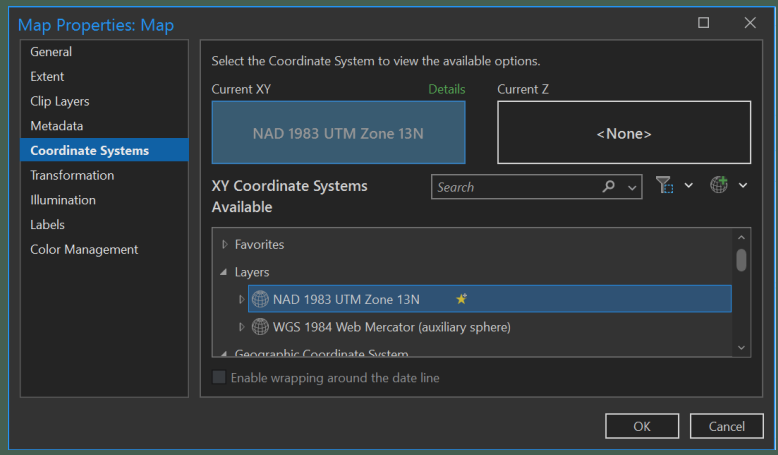
A layer is missing the spatial reference/coordinate system information

HOW TO FIND COORDINATE SYSTEM?

Coordinate system of data



Map Frame coordinate system



CHALLENGE

Curved Earth
Geographic coordinates:
(Latitude & Longitude)

Flat Map
Cartesian coordinates:
(Easting & Northing)

WHY IS THIS IMPORTANT?

- Without a coordinate system a map is just a drawing.
- There are many different coordinate systems – each one is better for certain purposes.
- The "best" systems depends on your area of interest and what you want to do.
- Data from different sources may have different coordinate systems.
- Always make sure you know the system you are working with.

PROJECTIONS VS. COORDINATE SYSTEMS

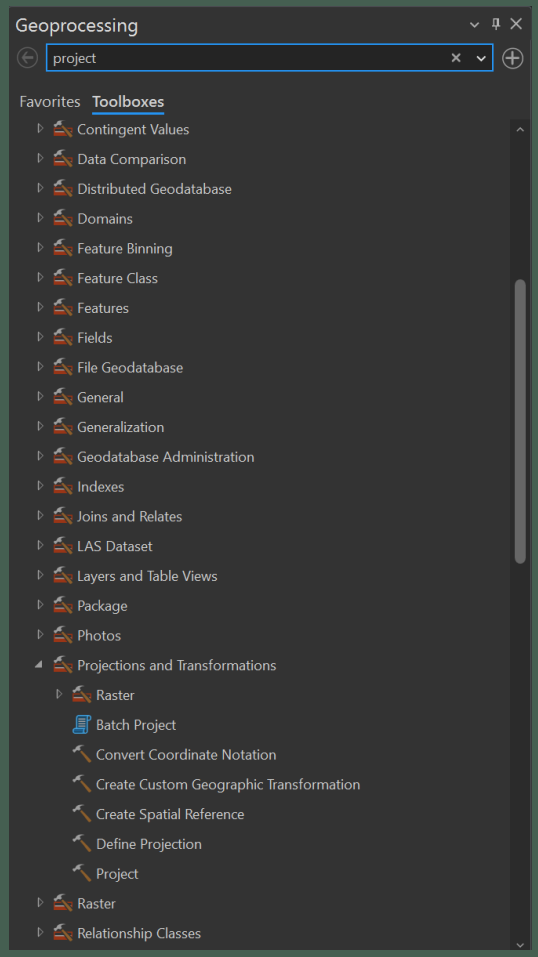
- A projection is a method for reducing the distortion when objects on the globe are displayed on a flat surface (a map).
- A coordinate system is a set of parameters that tells you how to interpret the locational coordinates for an object.
- A projection is one part of a coordinate system.

ARCGIS & PROJECTIONS

- ArcPro reprojects data on the fly so datasets in different projections appear in same place on the Map
  - Not a permanent reprojection. If you need the data set in a different projection permanently you need to use Projection Tool in Toolbox.

- Note: Problems can arise when a dataset is defined in an incorrect projection and it shows up on map in South America!

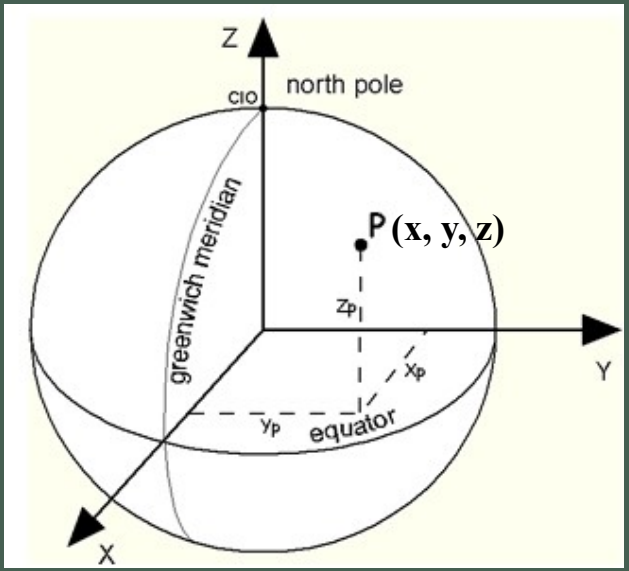
GEOPROCESSING TOOLS

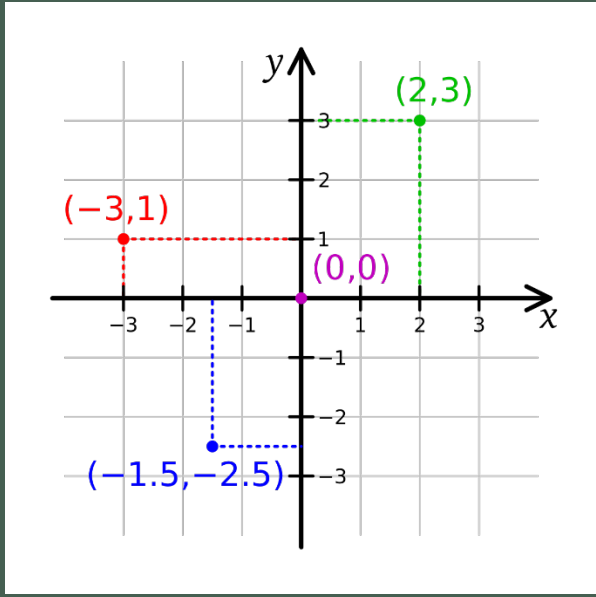


- Define Projection
  - To enter the description of the coordinate system the data is in
  - Does not modify the data
  - Not necessary if coordinate system is already correctly defined
- Project
  - To convert a dataset from one coordinate system to another
  - Makes a copy of the data, and in the process changes the coordinate system

WHAT IS A COORDINATE SYSTEM?

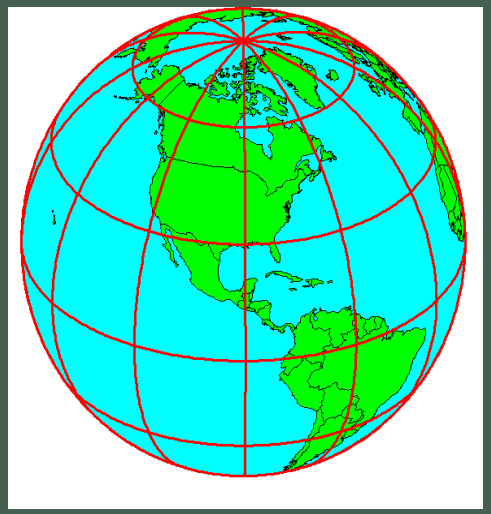
- A system that uses coordinates to represent features in a space from a point of origin.



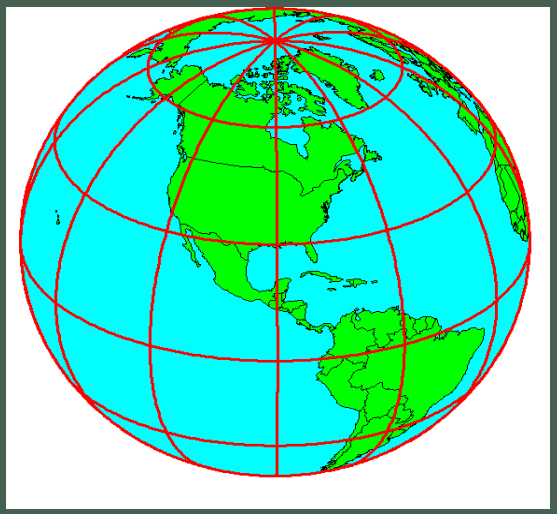


SHAPE OF THE EARTH

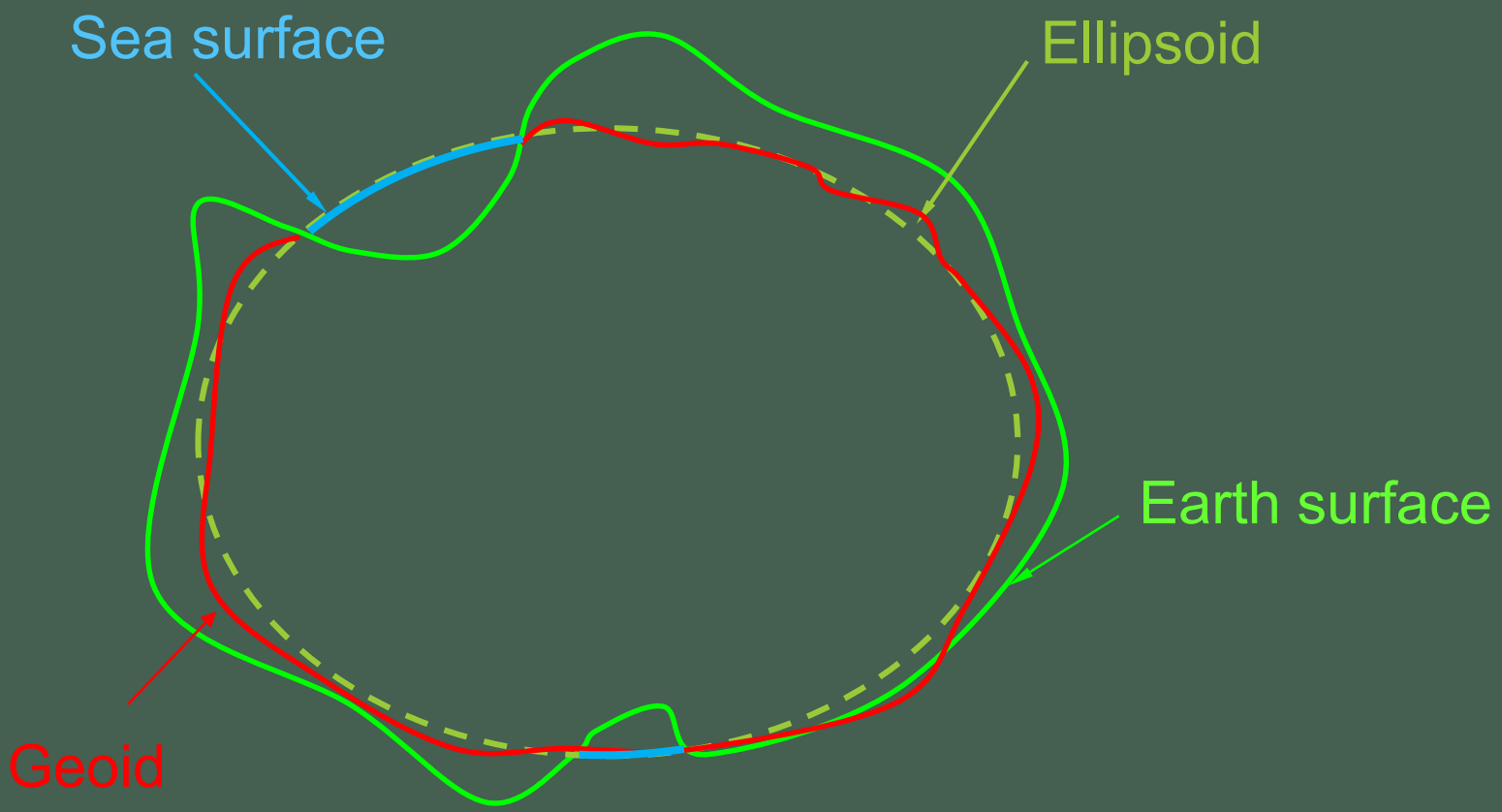
We think of the earth as a sphere



Earth bulges at the Equator and it's more like an ellipsoid



REPRESENTATIONS OF THE EARTH



DATUM

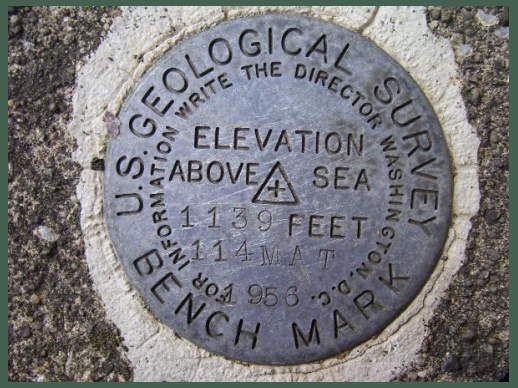
- A datum is a set of constants specifying the coordinate system used for calculating coordinates of points on earth.

  – *National Geodetic Survey*

- Datum = ellipsoid + point of origin
- Different areas of the world use different datums that fit their local area.

HORIZONTAL DATUM

- Geoids, ellipsoids, and coordinate systems are abstractions.
- Control points are collected to create a datum
- Coordinates of the control points varies for different ellipsoids as they have different coordinate grids.

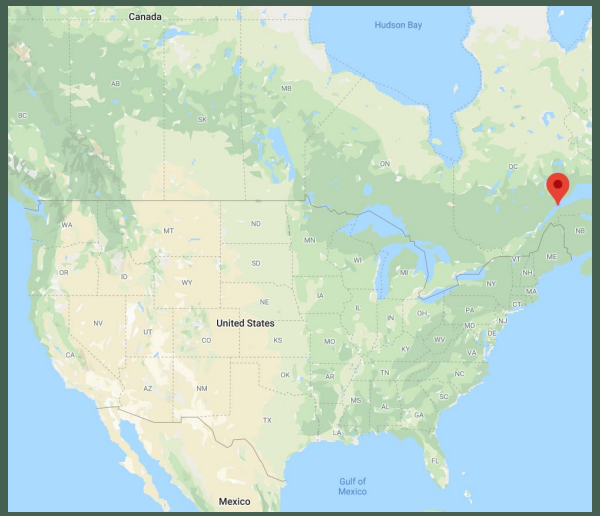


U.S. Geological Survey 1956 Benchmark, Jamestown, PA

VERTICAL DATUM

- Mean Sea Level is used as the reference point to calculate elevation data
- NAVD 88 established in 1991
- Different datums use different reference points to calculate MSL

Datum Information	
Tide Station	Pointe-au-Pere, Rimouski
Tide Station Location	Quebec, Canada
PID	TY5255
Geodetic Survey of Canada Designation	54L071
Bench Mark	1250 G
Ht above LMSL (meters)	6.271



https://www.ngs.noaa.gov/datums/vertical/north-american-vertical-datum-1988.shtml

COMMON DATUMS IN THE U.S.

- North American datum of 1927 (NAD 27)
  - Clarke 1866 ellipsoid.
  - Holds a fixed latitude and longitude in Meade's Ranch, Kansas

http://www.penryfamily.com/geographicalcenters/meadesranch.html

COMMON DATUMS IN THE U.S.

- North American datum of 1983 (NAD 83)
  - Advances in surveying and geodesy revealed weaknesses in the existing network of control points: a new datum was required to cover North America consistently
  - NAD 83 is based on both earth and satellite observations using the GRS 1980 spheroid, which is an earth-centered datum
  - NAD83 250,000 stations and 2,000,000 distance measurements.
  - Substantial shift with NAD27!

COMMON PROJECTIONS & COORDINATE SYSTEMS

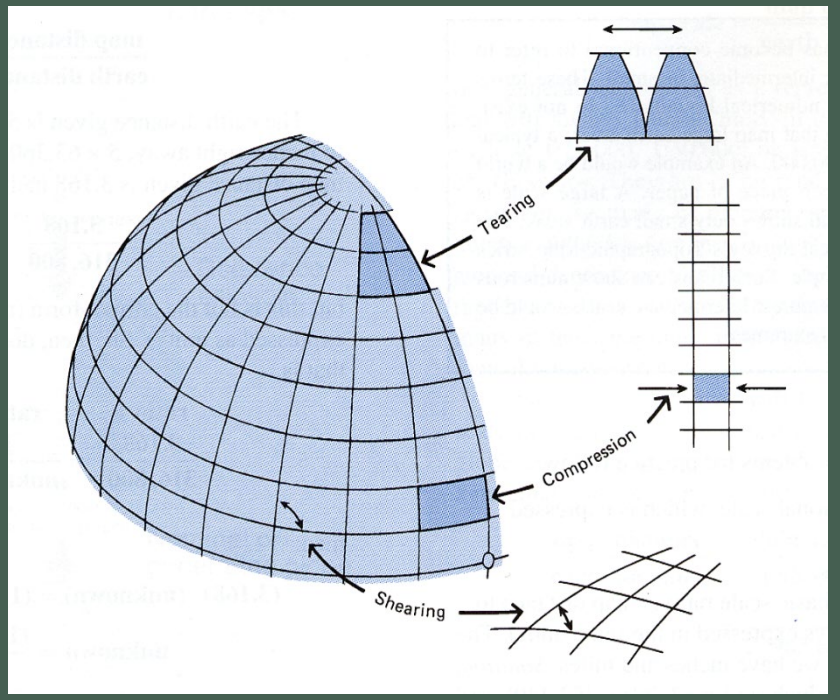
- Geographic coordinate system - 3D Coordinate Systems
  - The geographic coordinate system is not a map projection, but data is often in this format. The earth is modeled as a sphere or spheroid.
  - Ex: WGS 1984, NAD 1983
- Projected coordinate system - 2D Coordinate Systems
  - UTM (Universal Transverse Mercator)
    - The Universal Transverse Mercator coordinate system is a specialized application of the Transverse Mercator projection. The globe is divided into 60 zones, each spanning six degrees of longitude.
  - State Plane Coordinate System
    - The State Plane Coordinate System divides the 50 states of the United States, Puerto Rico, and the U.S. Virgin Islands into more than 120 numbered sections, referred to as zones.

MAP PROJECTIONS

3D to 2D Representation

MAP PROJECTION FAMILIES

- Azimuthal (Planar)
- Cylindrical
- Conic
- Mathematical



Map Distortions

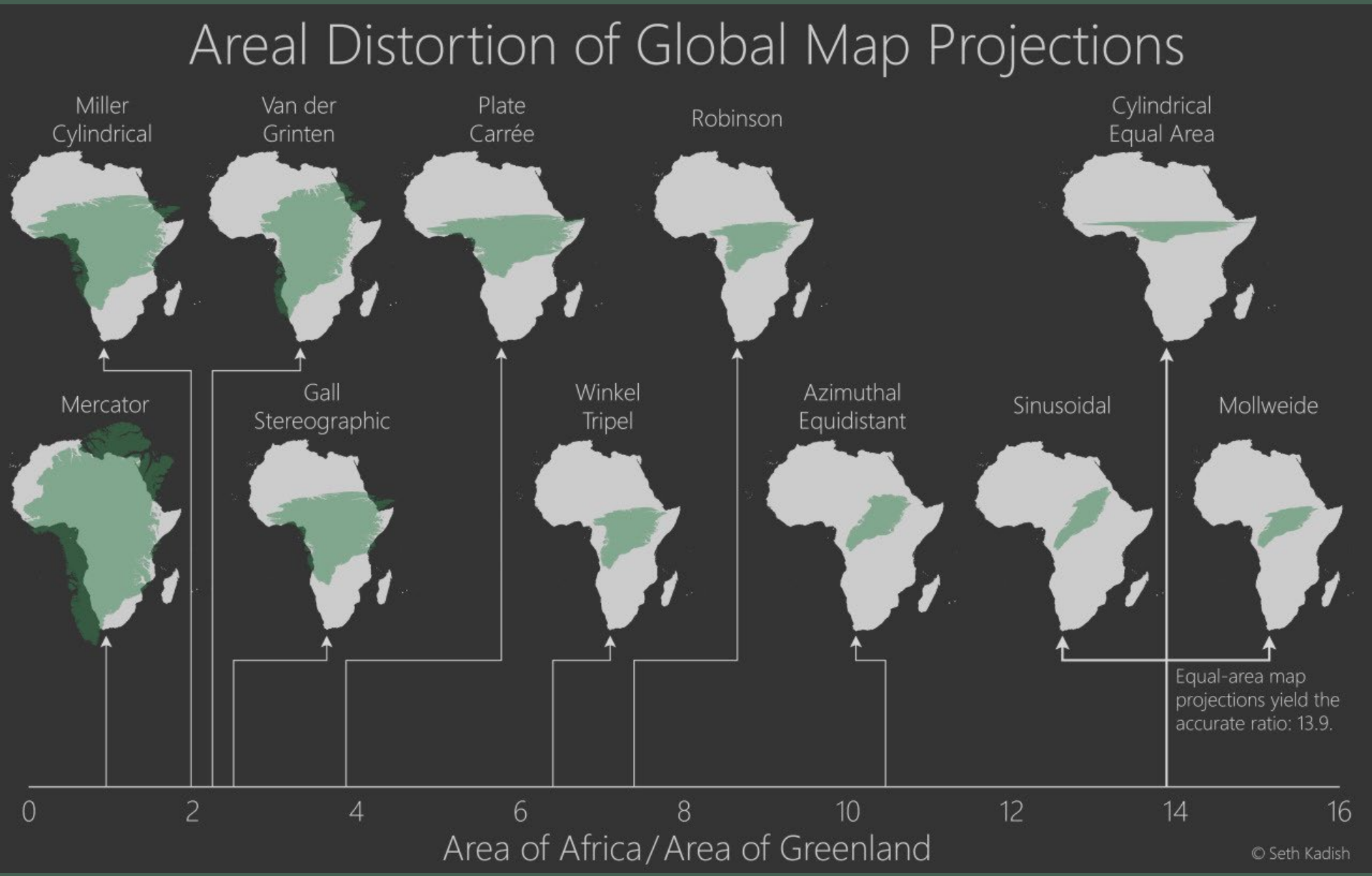
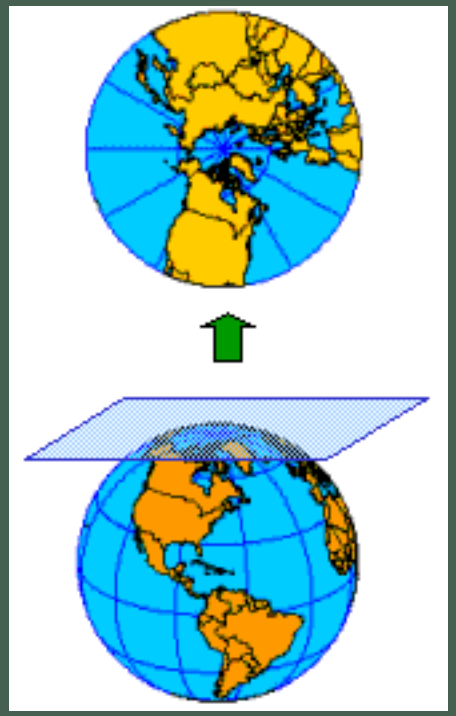
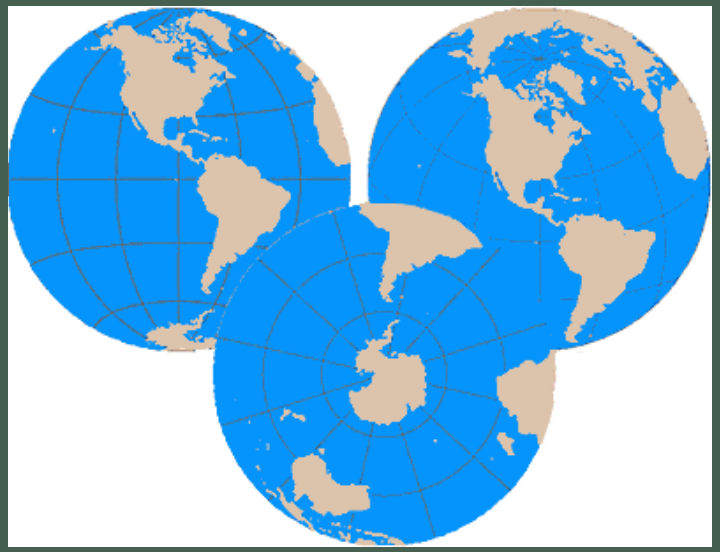


Image by Seth Kadish. For more information read the original blog post at Vizual Statistix

PLANAR PROJECTIONS



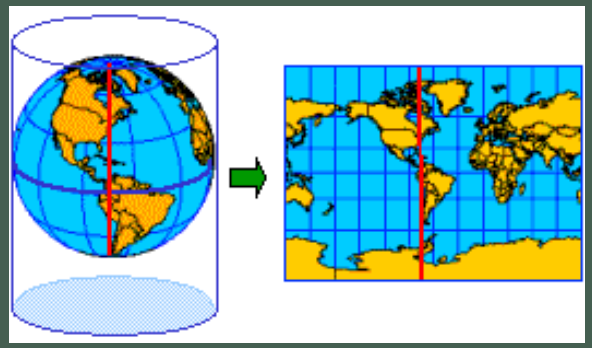
Lambert Azimuthal Equal Area

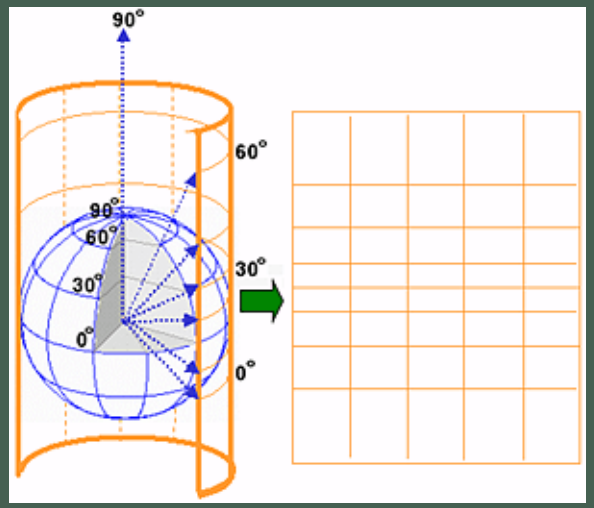


maintains direction and area

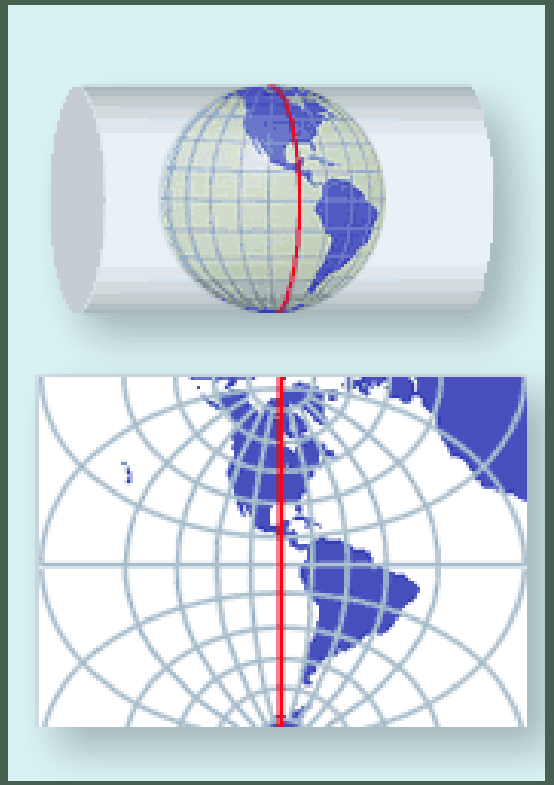
CYLINDRICAL PROJECTIONS

Standard Mercator

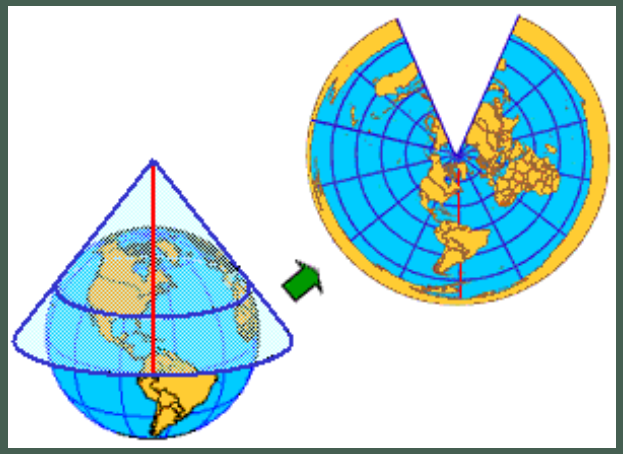


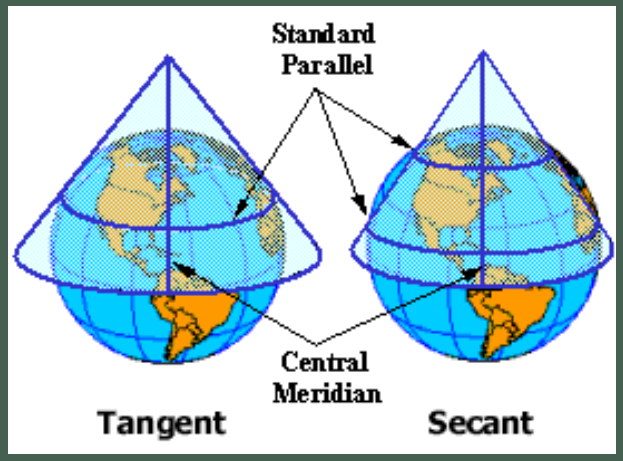


Transverse Mercator

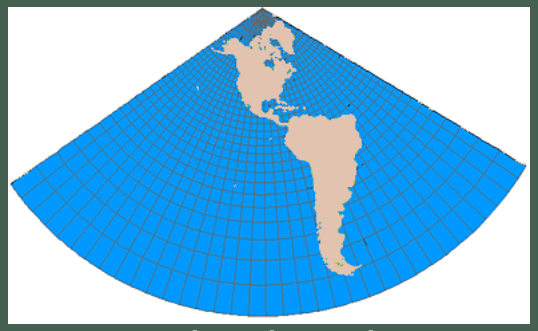


CONIC PROJECTIONS



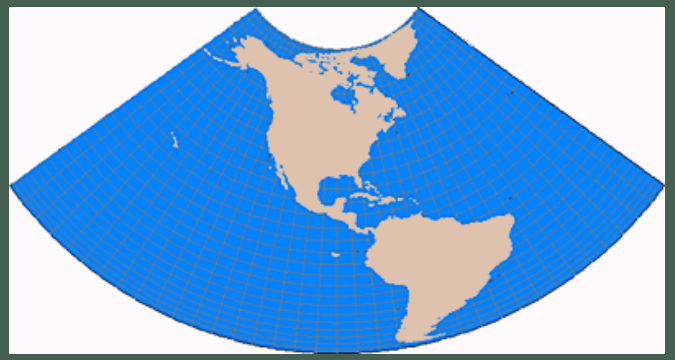


Lambert Conformal Conic



maintains shape

Albers Equal Area Conic

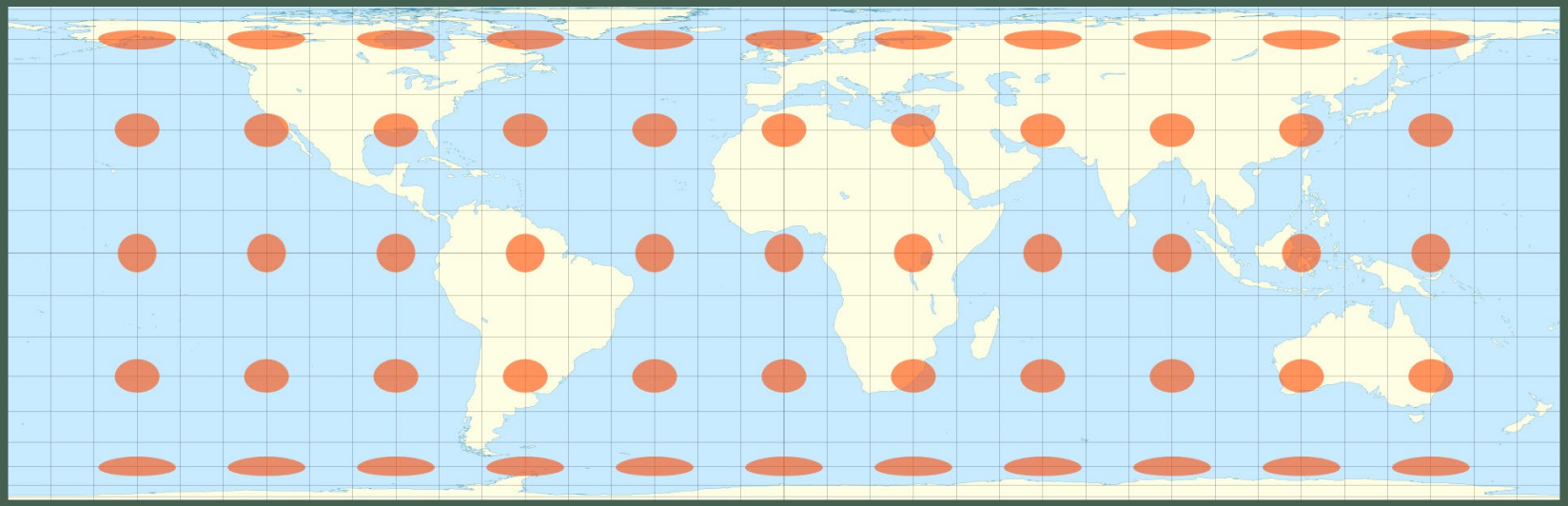


maintains area

MAP PROJECTION PROPERTIES

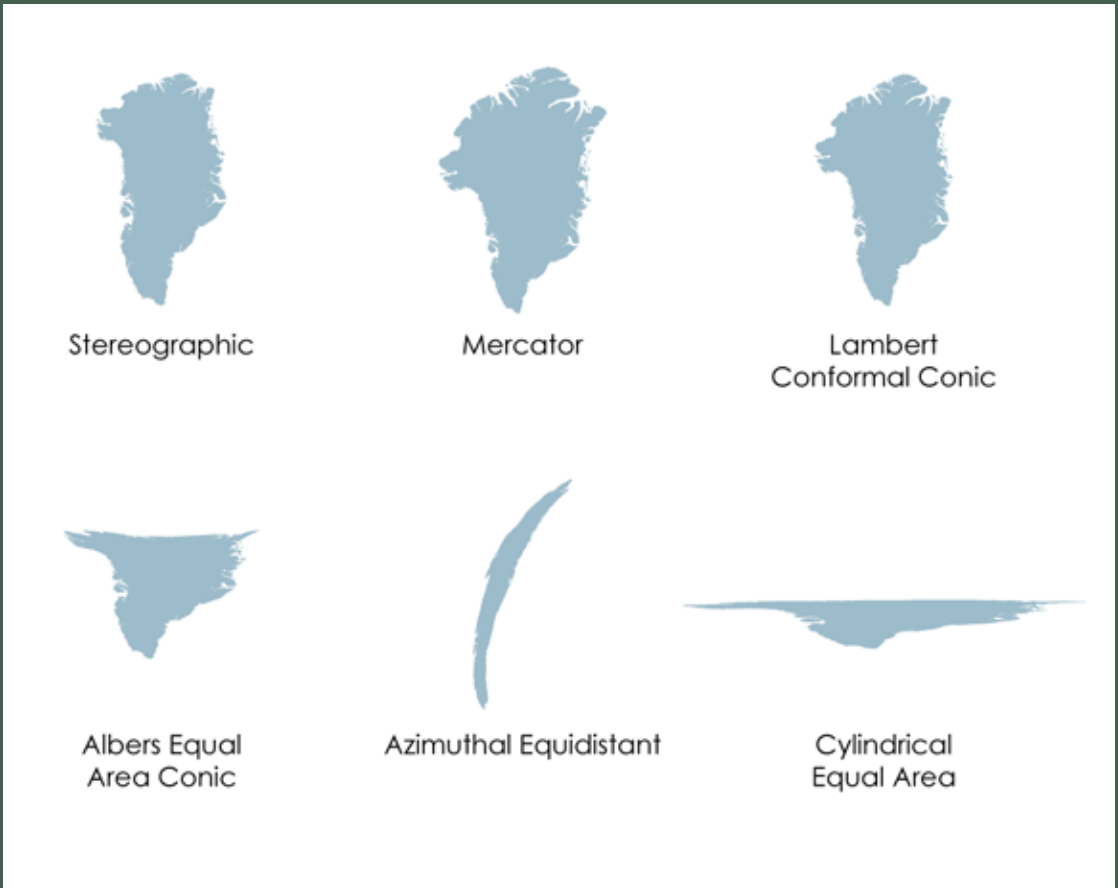
- Major Properties
  - Area and Shape
  - Mutually exclusive
- Minor Properties
  - Distance and Direction
  - can coexist but cannot be true everywhere

AREA



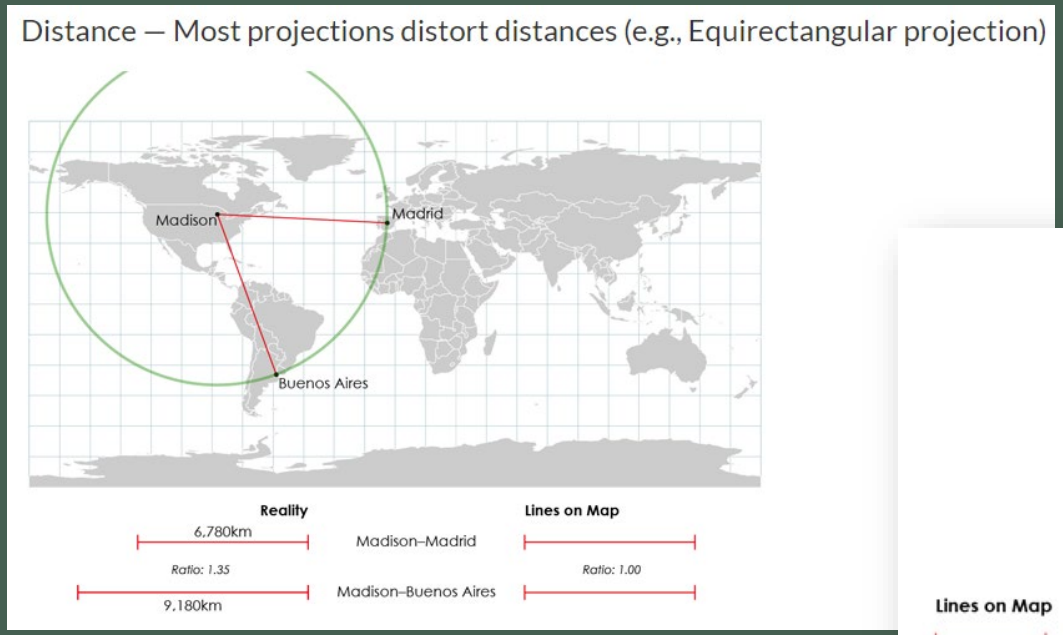
Lambert cylindrical equal-area projection

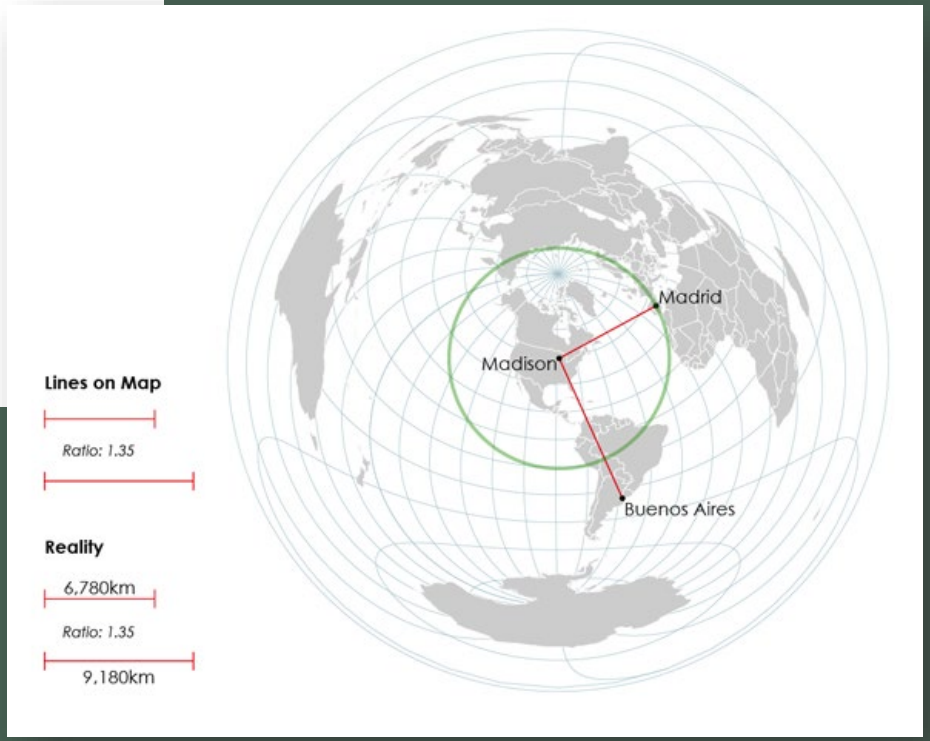
SHAPE



https://www.axismaps.com/guide/general/map-projections/

DISTANCE





https://www.axismaps.com/guide/general/map-projections/

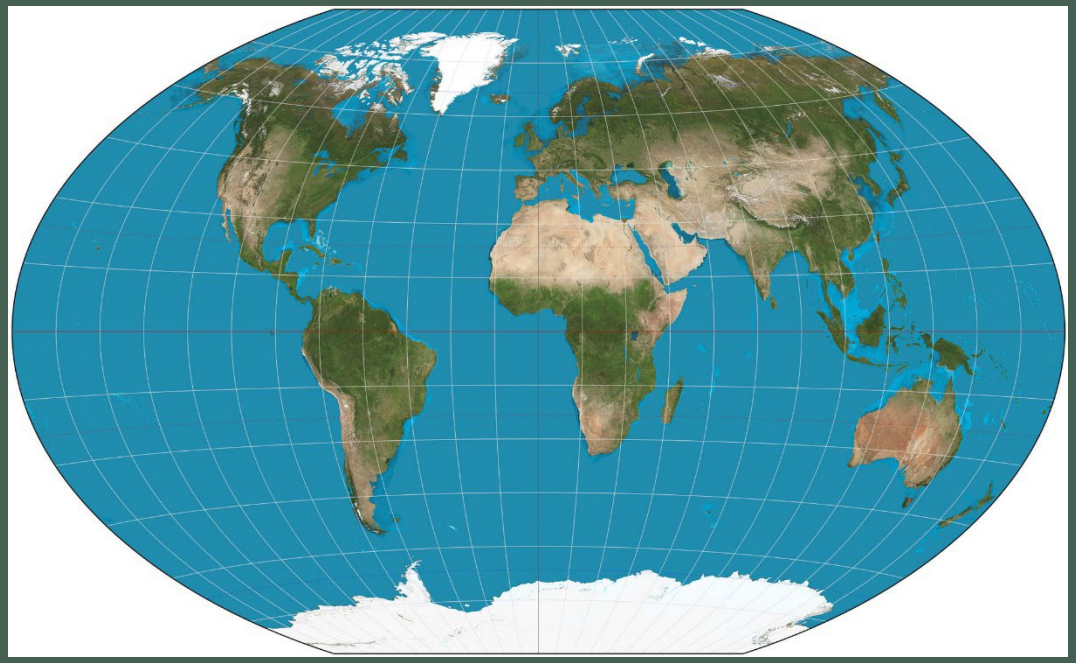
DIRECTION

- Directions – sometimes a straight line isn't the shortest path!

https://www.axismaps.com/guide/general/map-projections/

COMPROMISE MAP PROJECTIONS

- None of the map projection properties are correct, but with minimal errors



Winkel Tripel Projection

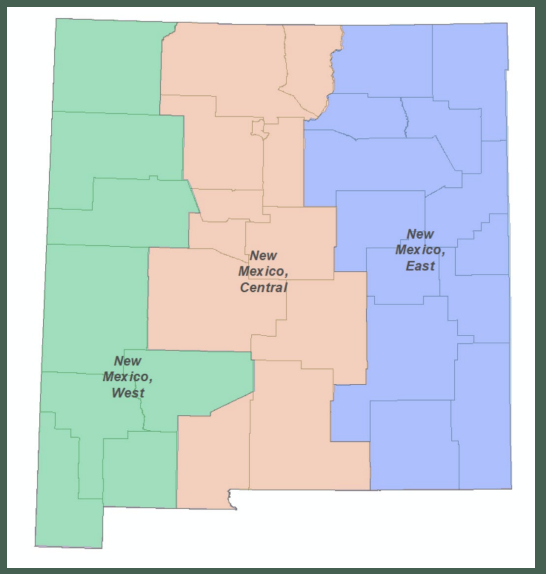
REVIEW

What does the below projections preserve?

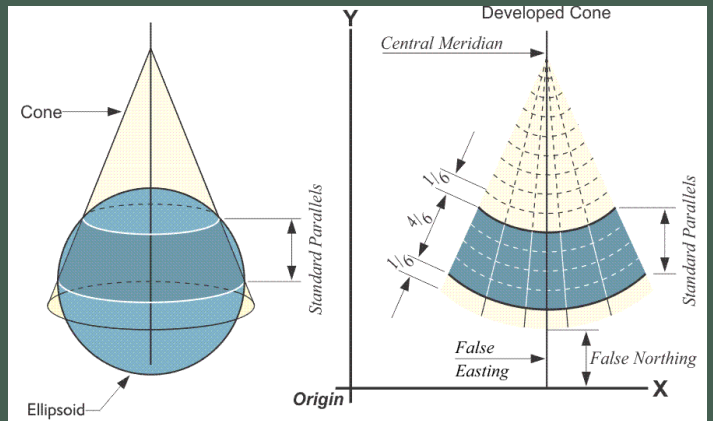
- Equal Area Map Projections: preserves ____ , distorts ____
- Conformal Map Projections: preserves ____ , distorts ____
- Equidistant Map Projections: ____
- Azimuthal Map Projection: ____
- Aphylactic Map Projection: _____

STATE PLANE COORDINATE SYSTEM

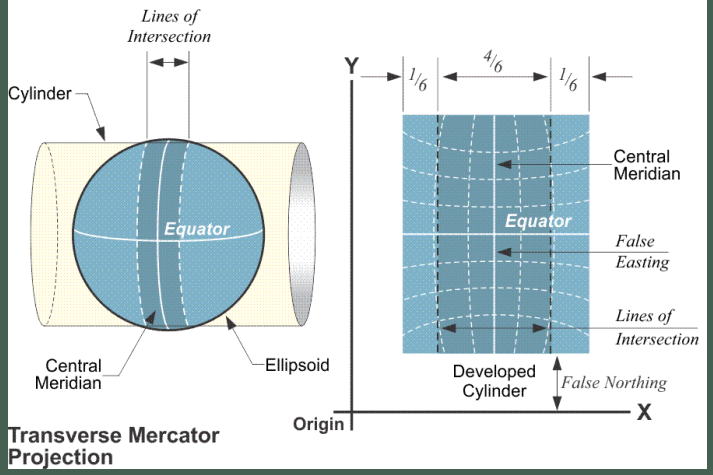
- 124 geographic zones
- High accuracy within each zone
- Not useful for regional or national mapping (small scale)
- SPCS 1983 is used currently and SPCS 2022 is coming soon



STATE PLANE COORDINATE SYSTEM



Lambert Conformal Conic Projection

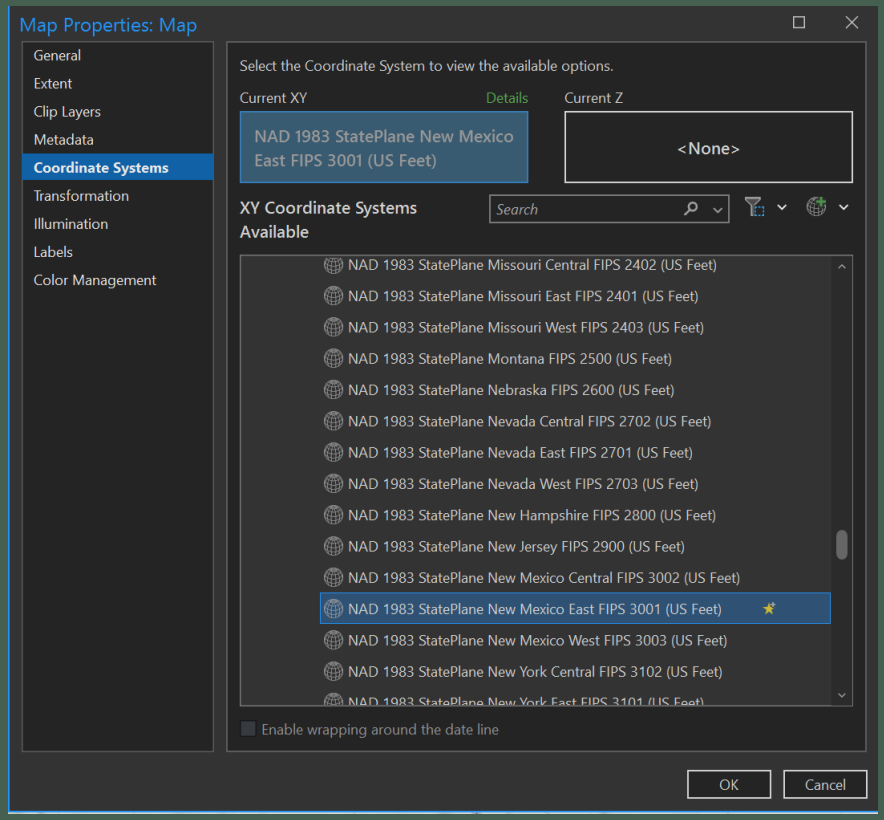


Transverse Mercator Projection

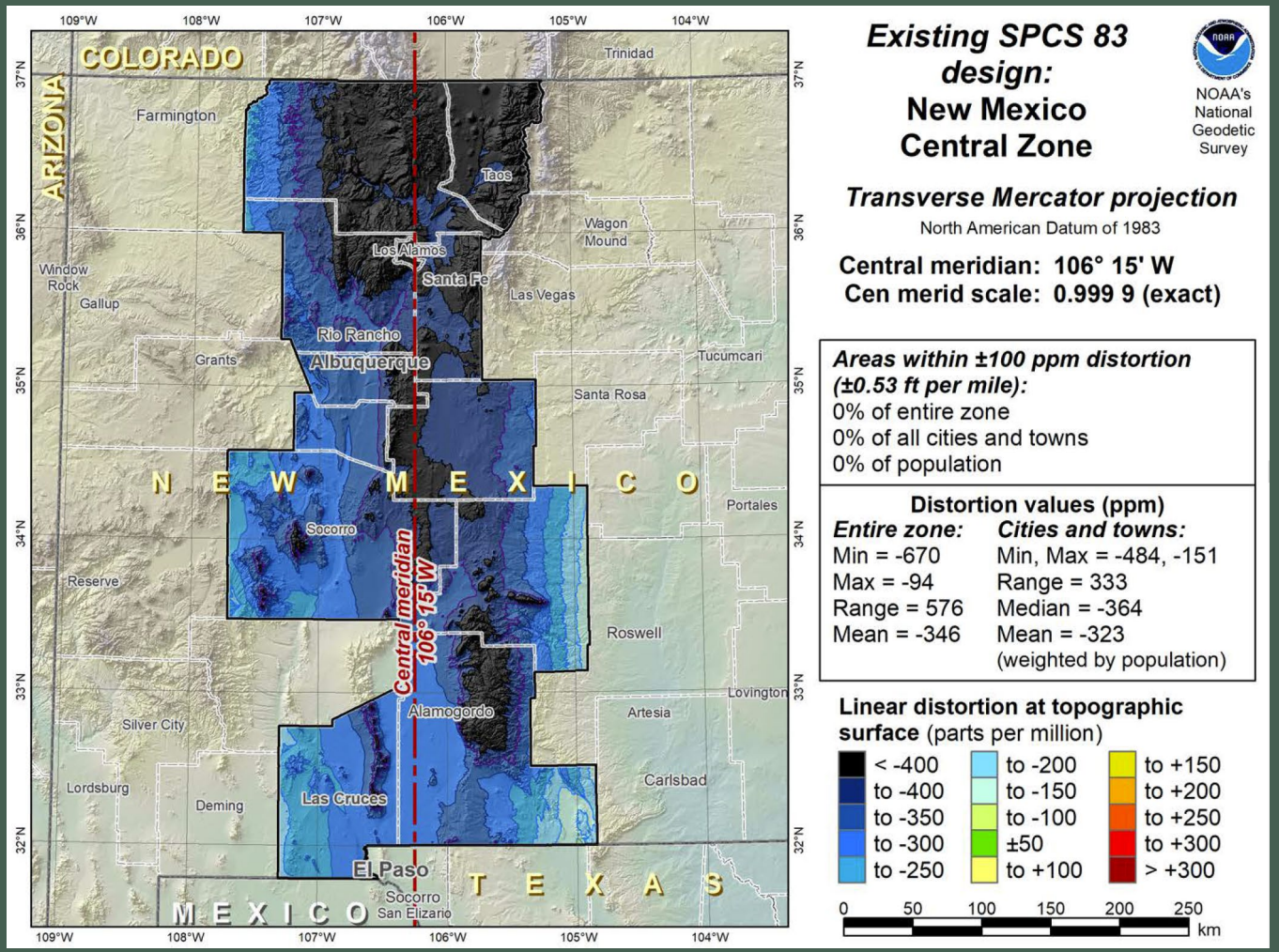
Source: GPS for Land Surveyors

STATE PLANE COORDINATE SYSTEM

- Projected Coordinate Systems > State Plane > NAD 1983 (US Feet)

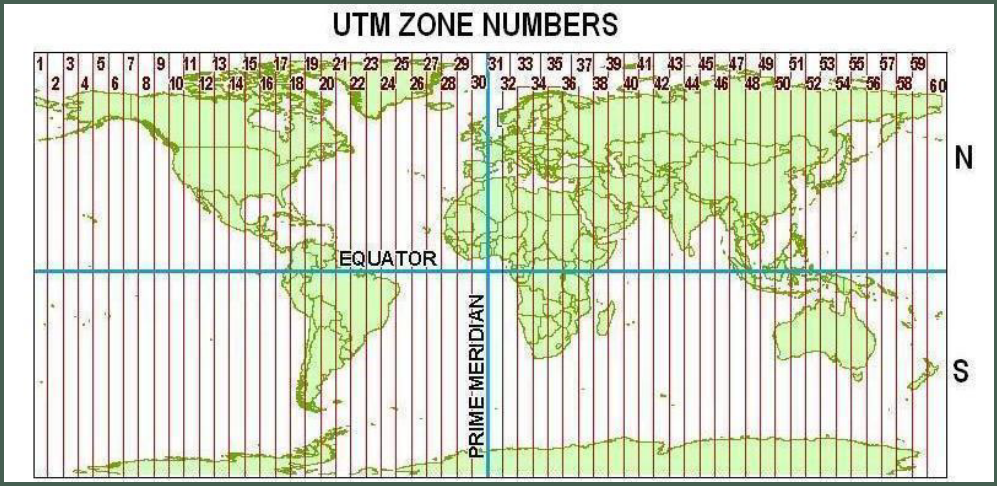


STATE PLANE COORDINATE SYSTEM

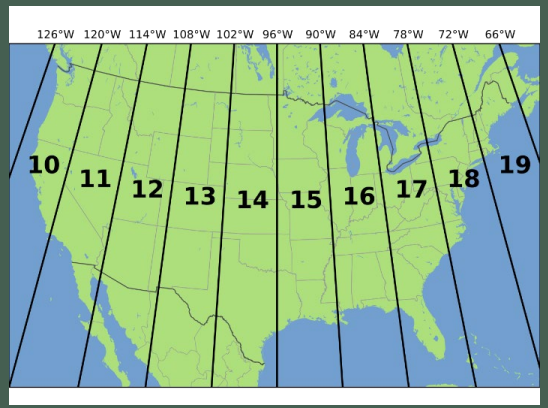


UNIVERSAL TRANSVERSE MERCATOR COORDINATE SYSTEM

- Divides earth into 60 zones, each of 6° of longitude
- Uses transverse Mercator projection
- Distortion is minimal within each zone and near central meridian of each zone

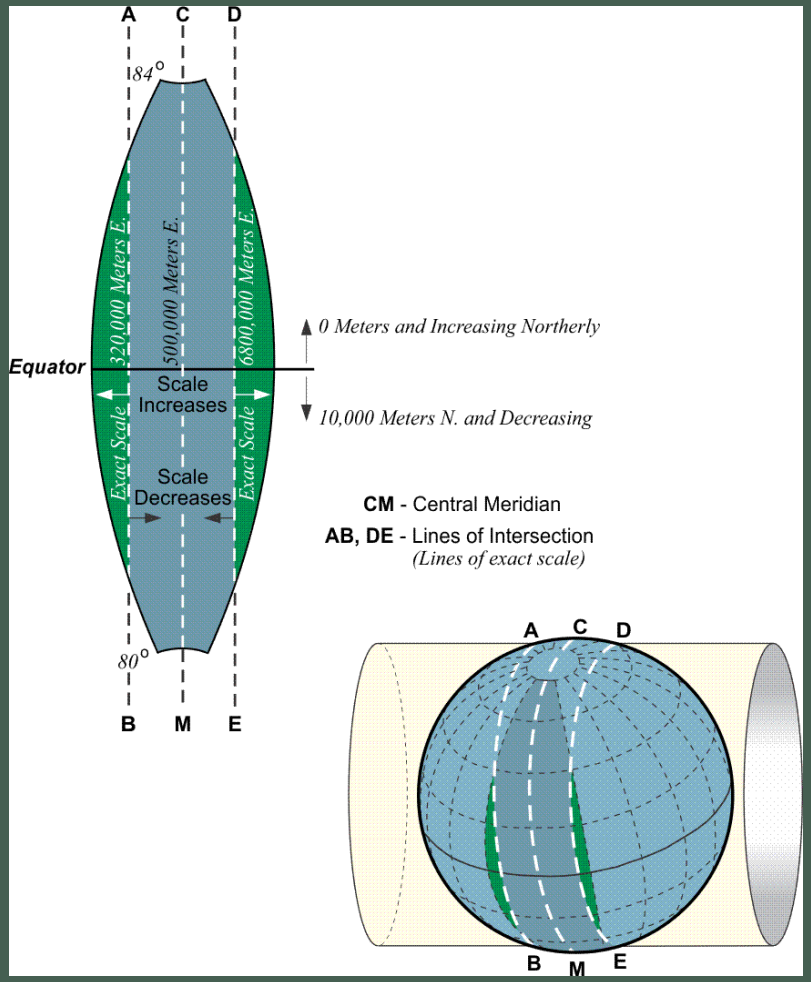


earth-info.nga.mil



Chrismurf, wikimedia.org

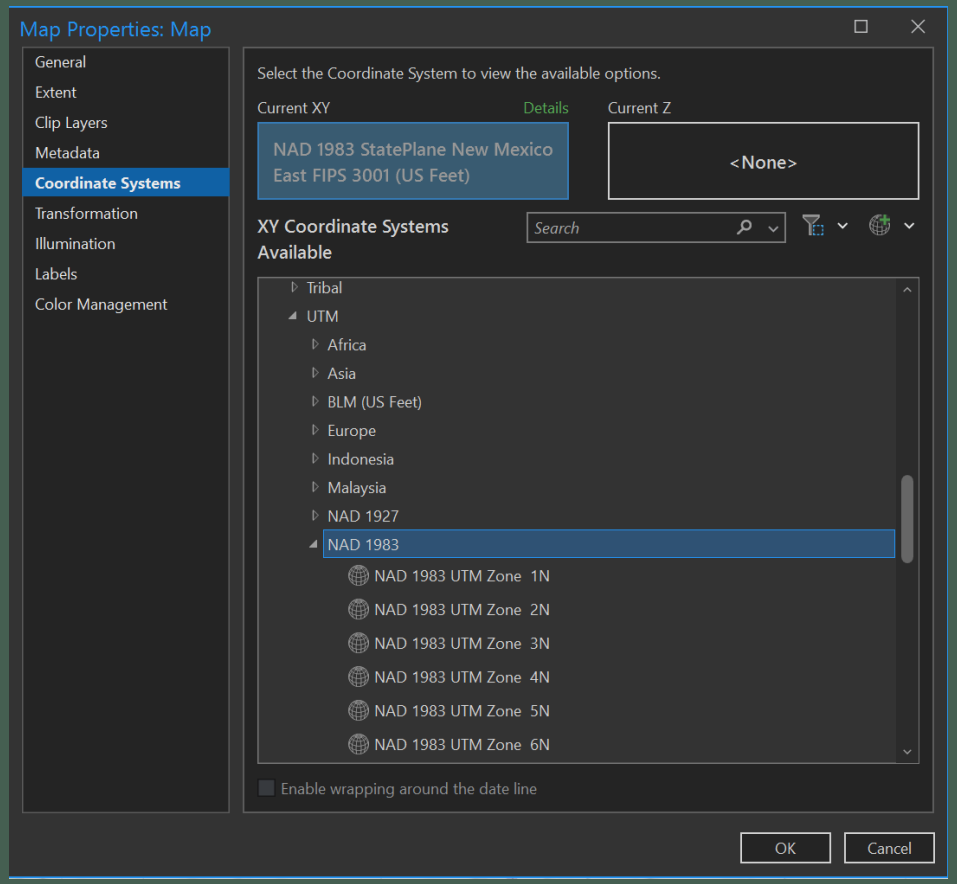
UNIVERSAL TRANSVERSE MERCATOR COORDINATE SYSTEM



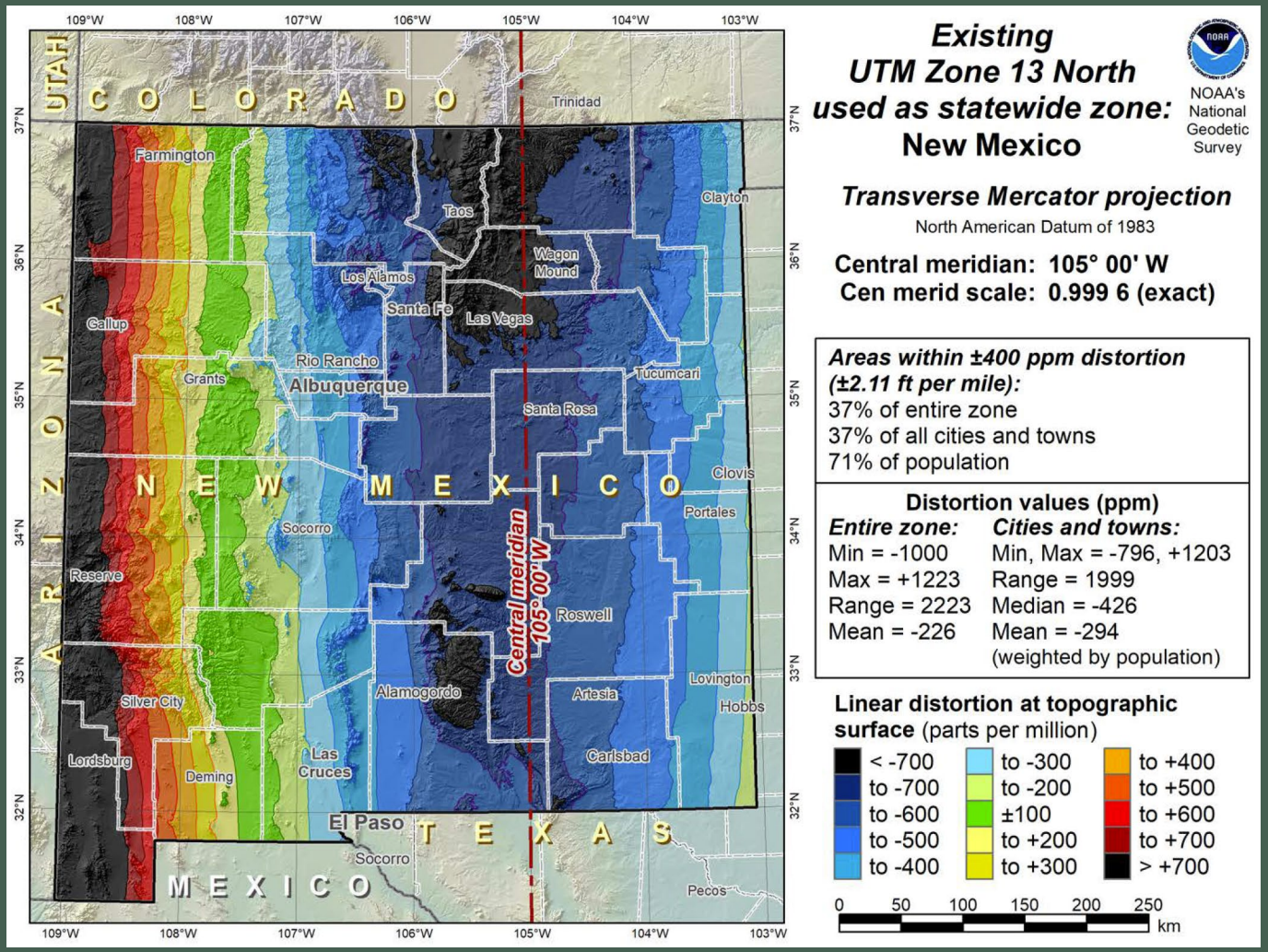
Source: GPS for Land Surveyors

UNIVERSAL TRANSVERSE MERCATOR COORDINATE SYSTEM

- Projected Coordinate Systems > UTM > NAD 1983

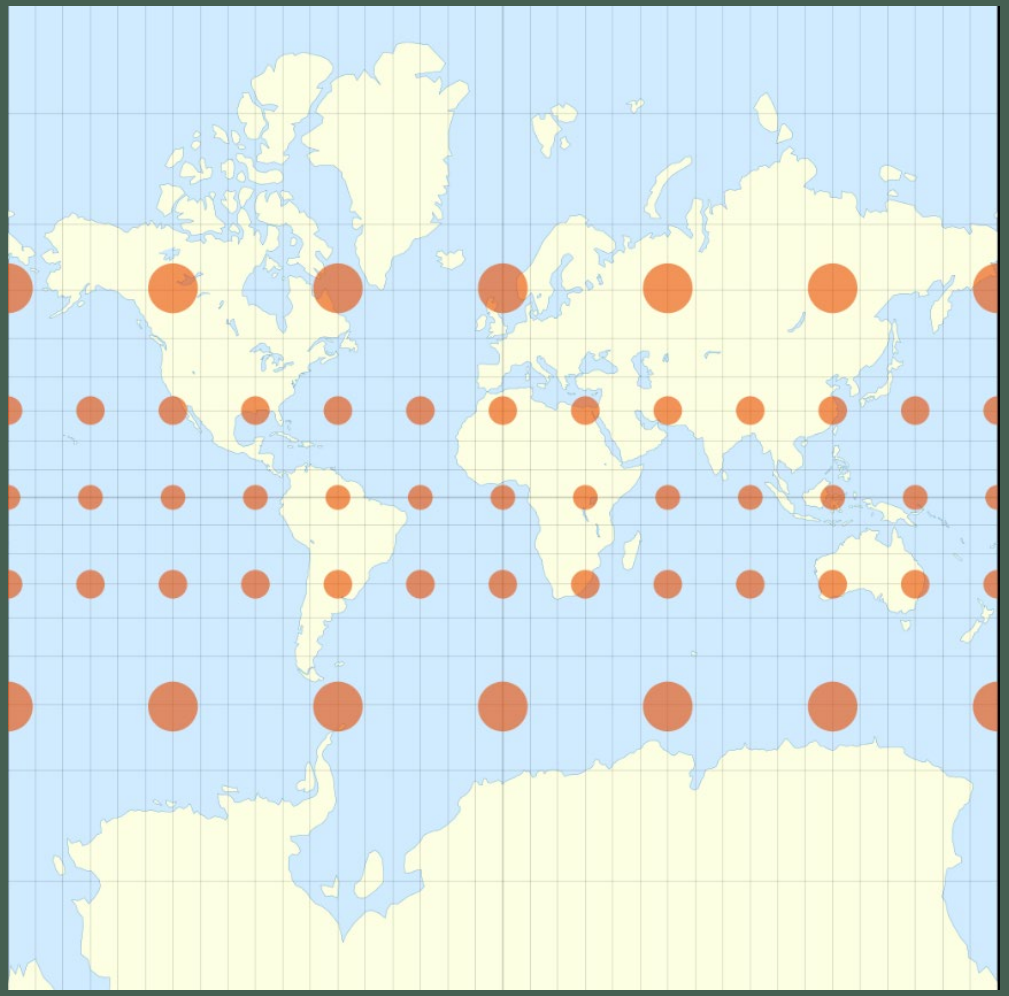


UNIVERSAL TRANSVERSE MERCATOR COORDINATE SYSTEM



PROJECTION IN WEB MAPS

- Mercator
- Gerardus Mercator in 16th Century
- Suits well for Navigation purposes
- Cylindrical Conformal



REPRESENTATION VS REALITY

https://en.wikipedia.org/wiki/Mercator_projection#/media/File:Worlds_animate.gif

WHICH PROJECTION TO USE?

Things to consider

- Projection Properties
- Deformational Patterns
- Projection Center
- Familiarity
- Software Support

CHOOSING COORDINATE SYSTEM

Guidelines for selecting a coordinate system for your spatial reference

	Datasets spanning the world or large regions	Datasets spanning countries and regions	Datasets spanning local areas
Geographic coordinates	*Geographic coordinates are the best choice of a coordinate system for data covering the world or large regions. Although maps of continents commonly use conic or other projections, geographic coordinates are preferred because of their widespread usage.*	*Use geographic coordinates if your datasets are built from GPS data or when the area covered by a dataset is larger than a UTM zone. UTM zones are 6 degrees wide and can be extended up to 12 degrees.*	*Use geographic coordinates if your data is built from data collected by GPS receivers. Despite the fact that geographic coordinates span the world, your dataset can maintain very high precision, as explained below.*
UTM zones	*Use a UTM zone if the area covered by your dataset is too large for your national map coordinate system and is within a span of 12 degrees of longitude. The Universal Transverse Mercator coordinate system preserves local angles and shapes, although there is some distortion of distance and direction.*	*Use a UTM zone if the area covered by your dataset is larger than the zone specified by your national mapping system, if you exchange data with organizations using this UTM zone, or if no national map coordinate system exists in the area. UTM is widely used throughout the world.*
National map system	*Many countries in the world have a national map coordinate system, usually with multiple zones. Use your national map coordinate zones for compliance with government agencies and data exchange with local organizations.*		

ArcMap performs on-the-fly projection of all map layers from any geographic dataset onto the projected coordinate system of your map. Any coordinate system that is reasonable for a dataset's extent will work. One factor that will influence your choice of coordinate system is whether you edit datasets together. If you do, then they will need to share the same spatial reference.

Coordinate precision in a spatial reference

GIS professionals want to know that coordinates in any coordinate system are stored with sufficient precision. The geodatabase uses high-precision storage of coordinates and any spatial reference can map the entire world with a precision of up to 10 nanometers. This extremely high resolution is seldom applied in practice; usually you can use the default setting which also has very high resolution.

as small as 10^{-9} meters

When a spatial reference is created with a geographic coordinate system using degrees as units, the default resolution is 10^{-9} degrees, or approximately 0.11 millimeters. When a spatial reference is created with any projected coordinate system using meters as units, the default resolution is 0.0001 meters, or 0.1 millimeters.

Source: Modeling Our World, second edition. Zeiler & Murphy, p. 33

CHOOSING MAP PROJECTION

World and hemispheric maps

Map projections for global maps are challenging because severe distortion is unavoidable. These are a few common choices.

General-purpose world maps

The Winkel-Tripel projection is often considered to be the best overall projection for world maps. This is the standard projection for National Geographic Society world maps.

Thematic maps

For thematic maps that display attributes based on areas of countries, it's important to use an equal area projection. The Mollweide projection is a common choice.

Hemispheric views

For hemispheric views, the orthographic projection simulates the view from space. It's a popular choice for locator maps that show the geographic extent for a detail map.

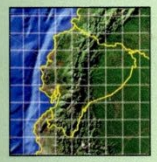
Continental and regional maps

Map projections for continents and regions are based on several factors: latitude range, map use, and orientation of map.

Consider the latitude range

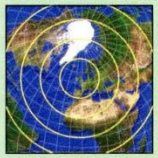
Polar regions should be mapped with an azimuthal (planar) map projection.

A country or region in the mid-latitudes could be mapped with a conic map projection.

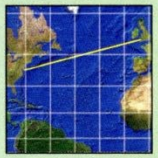


A country or region near the equator could be mapped with a cylindrical map projection.

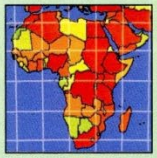
Consider the map use



The azimuthal equi-distant projection is used to show accurate airline travel distances from a center point.



The Mercator projection is used for navigational charts because straight lines represent lines of constant bearing.



The Albers equal area conic projection is widely used for thematic maps that require equal-area distribution.

Consider the map orientation

Maps of countries with greater east–west orientation such as Ukraine are best mapped with conic projections.

Maps of countries with greater north–south orientation such as Madagascar are best mapped with transverse cylindrical projections.

Large scale maps

Map projections for large scale maps of small regions and cities have low distortion of area and distance. Maps for these areas usually follow projected coordinate systems defined by regional or national mapping agencies.

This map of Munich, Germany, uses Germany zone 4, based on the Gauss-Krüger projection.

This map of Kyoto, Japan, uses zone 6 of the Japanese Geodetic Datum 2000.

This map of Sydney, Australia, is projected using Map Grid of Australian Zone 56.

Source: Modeling Our World, second edition. Zeiler & Murphy, p. 39

WHAT YOUR FAVORITE MAP PROJECTION SAYS ABOUT YOU

MERCATOR

YOU'RE NOT REALLY INTO MAPS.

VAN DER GRINTEN

YOU'RE NOT A COMPLICATED PERSON. YOU LOVE THE MERCATOR PROJECTION; YOU JUST WISH IT WEREN'T SQUARE. THE EARTH'S NOT A SQUARE, IT'S A CIRCLE. YOU LIKE CIRCLES. TODAY IS GONNA BE A GOOD DAY!

ROBINSON

YOU HAVE A COMFORTABLE PAIR OF RUNNING SHOES THAT YOU WEAR EVERYWHERE. YOU LIKE COFFEE AND ENJOY THE BEATLES. YOU THINK THE ROBINSON IS THE BEST-LOOKING PROJECTION, HANDS DOWN.

DYMAXION

YOU LIKE ISAAC ASIMOV, XML, AND SHOES WITH TOES. YOU THINK THE SEGWAY GOT A BAD RAP. YOU OWN 3D GOGGLES, WHICH YOU USE TO VIEW ROTATING MODELS OF BETTER 3D GOGGLES. YOU TYPE IN DVORAK.

WINKEL-TRIPEL

NATIONAL GEOGRAPHIC ADOPTED THE WINKEL-TRIPEL IN 1998, BUT YOU'VE BEEN A W-T FAN SINCE *LONG* BEFORE "NATGEO" SHOWED UP. YOU'RE WORRIED IT'S GETTING PLAYED OUT, AND ARE THINKING OF SWITCHING TO THE KAVRAYSKIY. YOU ONCE LEFT A PARTY IN DISGUST WHEN A GUEST SHOWED UP WEARING SHOES WITH TOES. YOUR FAVORITE MUSICAL GENRE IS "POST-".

GOODE HOMOLOSINE

THEY SAY MAPPING THE EARTH ON A 2D SURFACE IS LIKE FLATTENING AN ORANGE PEEL, WHICH SEEMS EASY ENOUGH TO YOU. YOU LIKE EASY SOLUTIONS. YOU THINK WE WOULDN'T HAVE SO MANY PROBLEMS IF WE'D JUST ELECT *NORMAL* PEOPLE TO CONGRESS INSTEAD OF POLITICIANS. YOU THINK AIRLINES SHOULD JUST BUY FOOD FROM THE RESTAURANTS NEAR THE GATES AND SERVE *THAT* ON BOARD. YOU CHANGE YOUR CAR'S OIL, BUT SECRETLY WONDER IF YOU REALLY *NEED* TO.

HOBO-DYER

YOU WANT TO AVOID CULTURAL IMPERIALISM, BUT YOU'VE HEARD BAD THINGS ABOUT GALL-PETERS. YOU'RE CONFLICT-AVERSE AND BUY ORGANIC. YOU USE A RECENTLY-INVENTED SET OF GENDER-NEUTRAL PRONOUNS AND THINK THAT WHAT THE WORLD NEEDS IS A REVOLUTION IN CONSCIOUSNESS.

A GLOBE!

YES, YOU'RE VERY CLEVER.

PEIRCE QUINCUNCIAL

YOU THINK THAT WHEN WE LOOK AT A MAP, WHAT WE REALLY SEE IS OURSELVES. AFTER YOU FIRST SAW *INCEPTION*, YOU SAT SILENT IN THE THEATER FOR SIX HOURS. IT FREAKS YOU OUT TO REALIZE THAT EVERYONE AROUND YOU HAS A SKELETON INSIDE THEM. YOU *HAVE* REALLY LOOKED AT YOUR HANDS.

PLATE CARRÉE (EQUIRECTANGULAR)

YOU THINK THIS ONE IS FINE. YOU LIKE HOW X AND Y MAP TO LATITUDE AND LONGITUDE. THE OTHER PROJECTIONS OVERCOMPLICATE THINGS. YOU WANT ME TO STOP ASKING ABOUT MAPS SO YOU CAN ENJOY DINNER.

WATERMAN BUTTERFLY

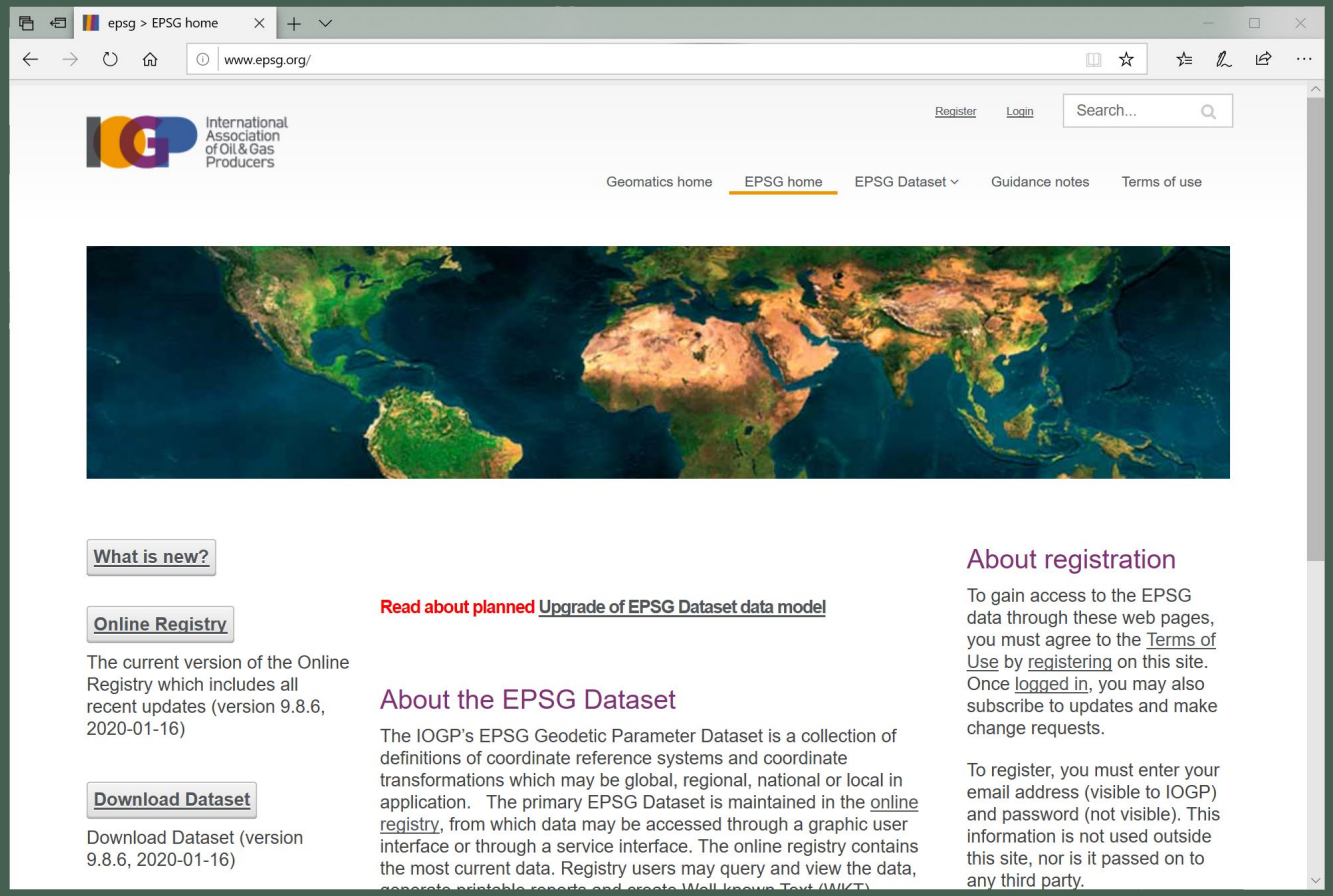
REALLY? YOU KNOW THE WATERMAN? HAVE YOU SEEN THE 1909 CAHILL MAP IT'S BASED— ...YOU HAVE A FRAMED REPRODUCTION AT HOME?! WHOA. ...LISTEN, FORGET THESE QUESTIONS. ARE YOU DOING ANYTHING TONIGHT?

GALL-PETERS

I *HATE* YOU.

https://xkcd.com/977/

EPSG GEODETIC PARAMETER DATASET



READINGS

- http://www.radicalcartography.net/index.html?projectionref
- https://www.usgs.gov/faqs/how-are-different-map-projections-used?qt-news_science_products=0#qt-news_science_products
- http://www.flexprojector.com/

MAP SCALE

Small Scale vs Large Scale

You only understand information relative to what you already understand.

You only understand the size of a building if there is a car or a person in front of it.

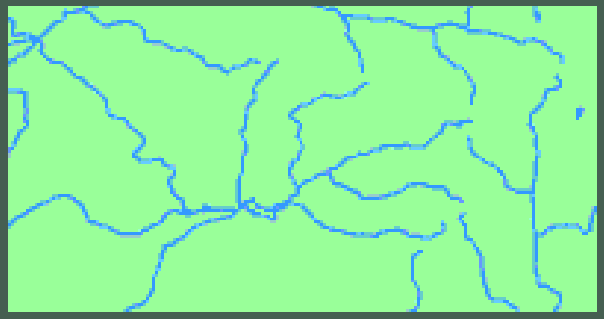
You only understand facts and figures when they can be related to tangle, comprehensible elements.

- Richard Saul Wurman, Information Anxiety, 1989

MAP SCALE

- Scale is a tool that relates subject and representation, governs content selection and detail, indicates levels of measurement, knowledge, and access. – *Jill Desimini & Charles Waldheim, Cartographic Grounds*
- Map scale is based on the representative fraction, or the ratio of a distance on the map to the same distance on the ground.
- Ex: 1:100,000 means that 1 cm on a printed map is 100,000 cm (or 1 km) in reality
- "Large is small"
  - the larger the second number, the smaller the scale of the map
  - e.g. 1:2,000 is a large scale map, while 1:1,000,000 is a small scale map
- In GIS, maps can be enlarged and reduced and plotted at many scales other than that of the original data

ABSTRACTING REAL-WORLD ENTITIES



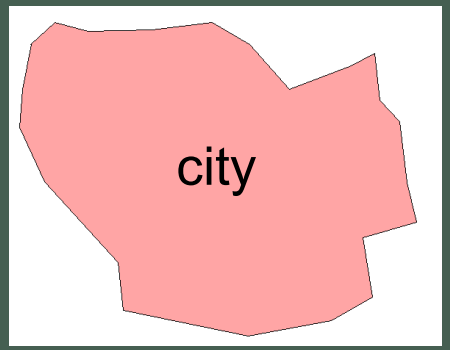
Rivers represented as lines.

A river has area.

MAP SCALE

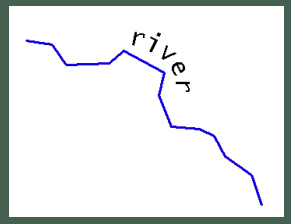
- Map scale determines the size and shape of features
- Large scale

1:500



1:24,000

- Small scale



1:24,000

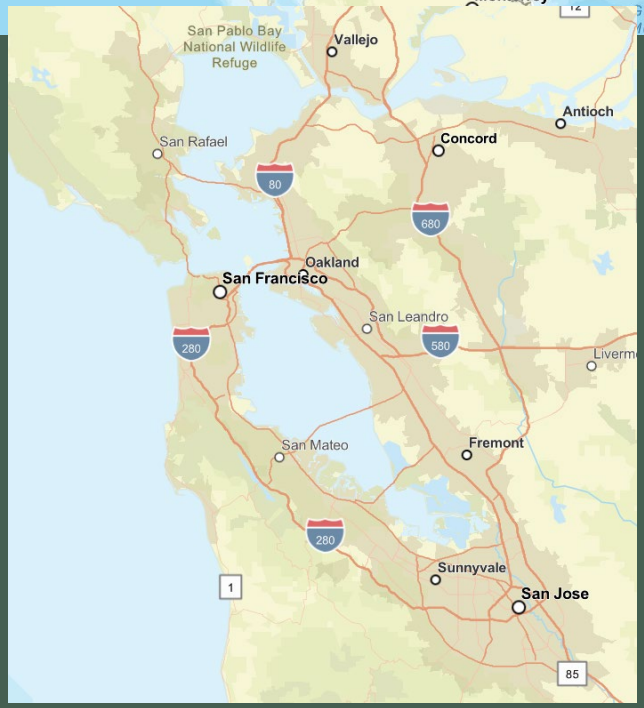
city

1:250,000

Representing geographic features at different scales

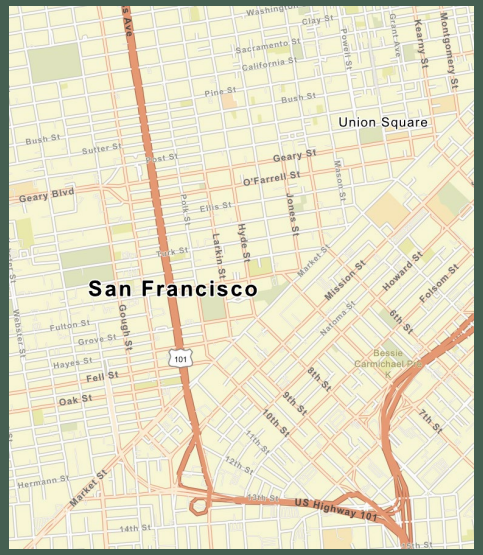
Images from Streets Basemap - ESRI

1:30,181,285



1:1,000,000

1:100,000



1:24,000

CHOOSING A MAP SCALE

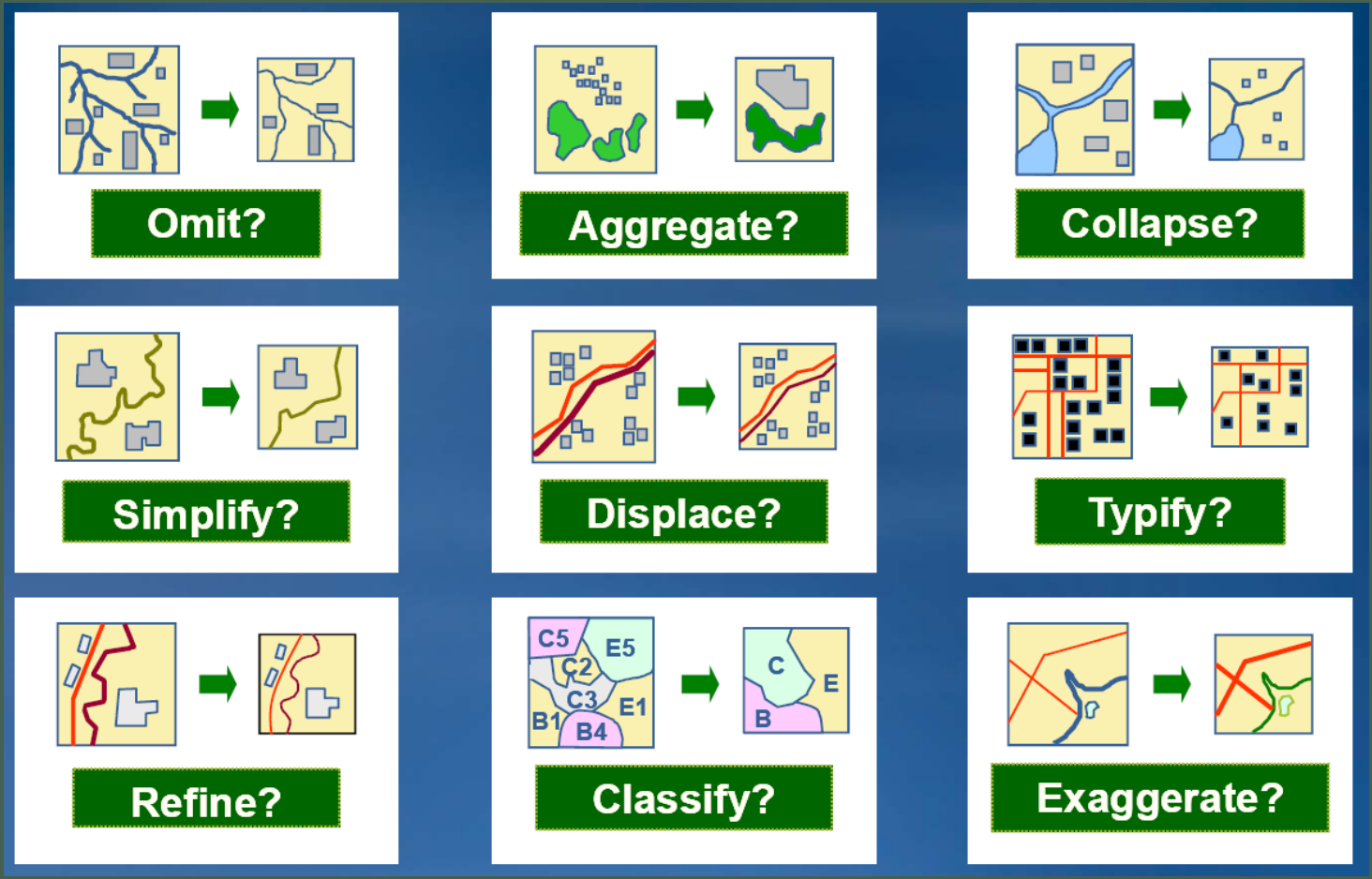
the aims of a project determine the required scale of mapping and type of ground survey or imagery required

Scale	Applications / areas
1:1,000	cadastral surveys
1:5,000	municipal planning
1:24,000	municipal/regional planning
1:50,000	resource inventories
1:100,000	regional surveys
1:250,000	reconnaissance & exploration
1:1,000,000	global surveys

MAP GENERALIZATION

How much detail on a map?

HOW MUCH DETAIL?

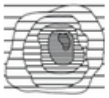
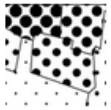
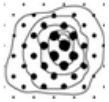
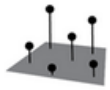


Credit: Dr. Shawn Penman, University of New Mexico

SYMBOLOGY

- Visual distinctions for symbolization
  - Location, Size, Shape, Orientation, Focus, Arrangement, Texture, Height, Saturation, Hue, and Value
- Qualitative Visual Variables
  - Hue, Orientation, Shape, Arrangement, Texture, and Focus
- Quantitative Visual Variables
  - Size, Value, Saturation, and Focus

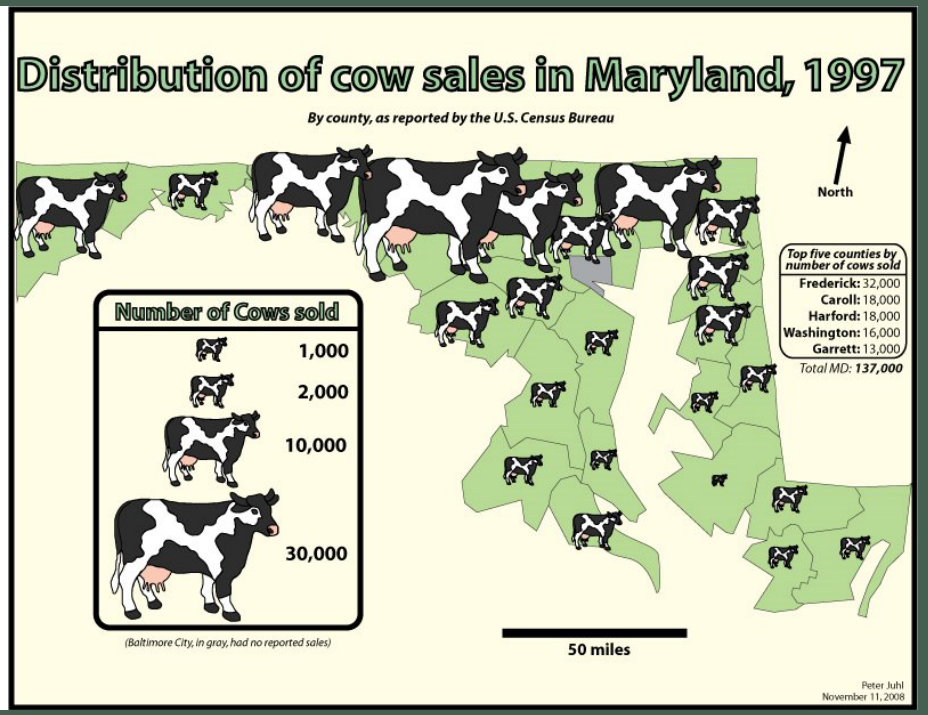
How map elements are perceived by the human eye?

Visual variable	Point	Linear	Areal	2.5D	True 3D
Spacing					
Size					
Perspective height					Not possible
Orientation				Not recommended	
Shape				Not recommended	

Arrangement				Not recommended	
Value					
Hue					
Lightness					
Saturation					

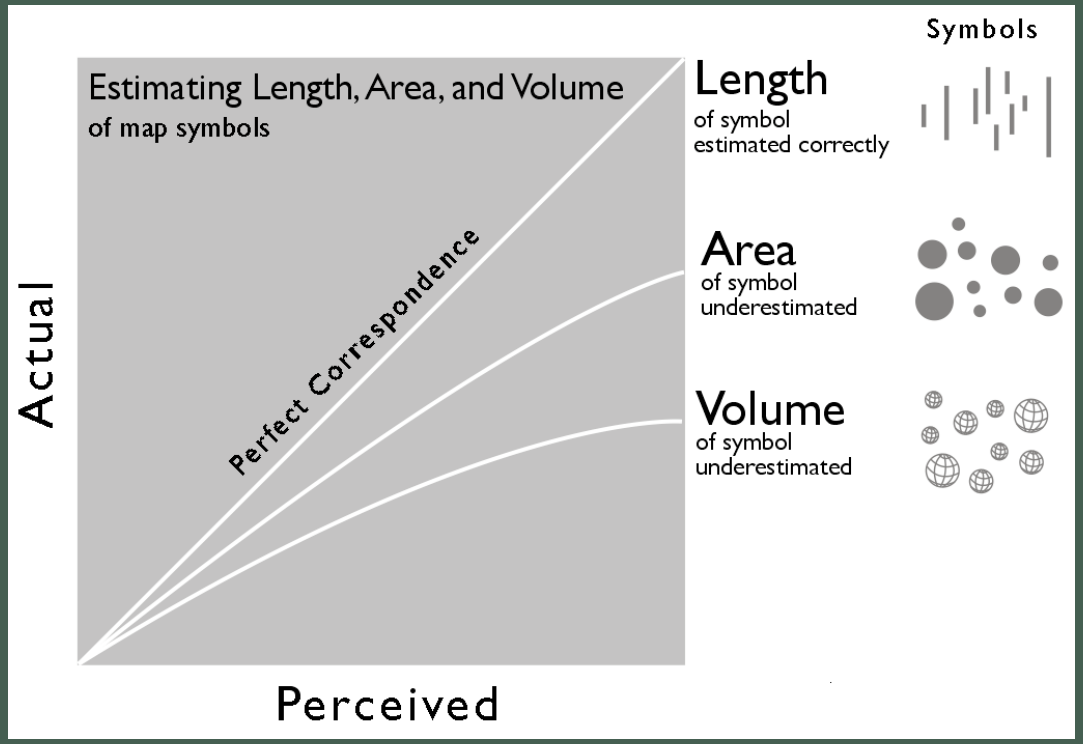
https://pro.arcgis.com/en/pro-app/help/mapping/layer-properties/symbolization.htm

INTERPRETING PROPORTIONAL SYMBOLS



SCALING

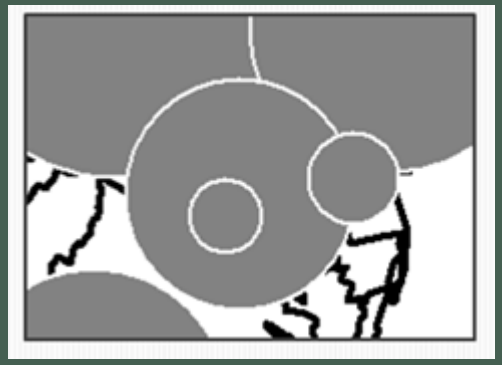
- Methods of scaling proportional symbols
  - Absolute Scaling
  - Apparent Magnitude/ Perceptual Scaling
  - Range Grading Scale



https://makingmaps.net/2007/08/28/perceptual-scaling-of-map-symbols/

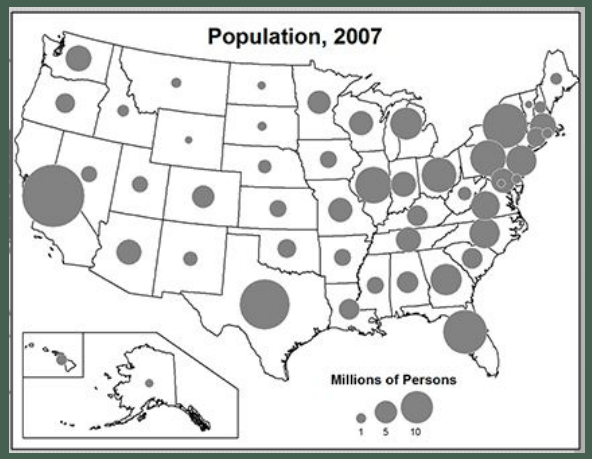
OVERLAPPING

- Expresses a sense of visual cohesiveness
- Smaller symbols should cover larger symbols
- Consider making symbols transparent when needed
- Difficult to estimate individual symbol sizes

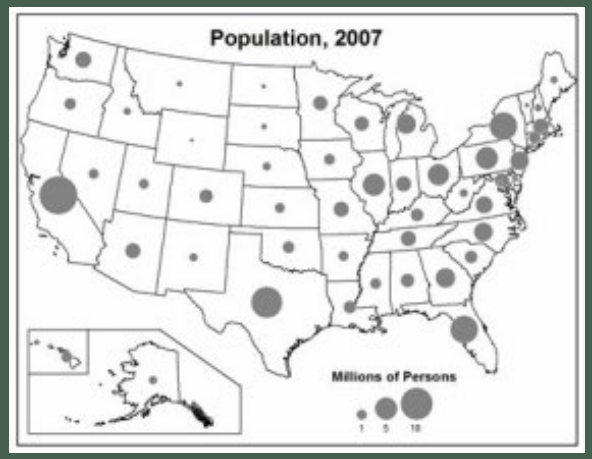


OVERLAPPING

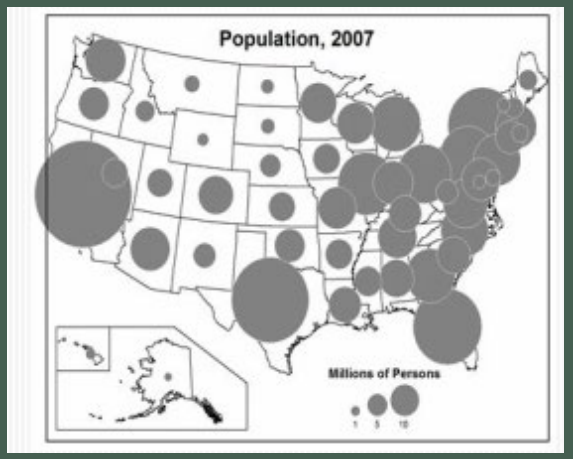
- Appropriate Overlap vs Inappropriate Overlap



Appropriate



Too little, boring



Too much overlap