Civil & Environmental ENGINEERING

Lecture 3: Map Projections and Coordinate Systems

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CEE 5190/6190

Geographic Information Systems for Civil Engineers

Spring 2020

COLLEGE of ENGINEERING
UtahStateUniversity

Reminders

- Lab starts today
- Assignment 1 live in Canvas – Introduction to ArcGIS and Coordinate Systems
  - Due: Wednesday January 15th – before class starts
- Software – Does anyone still need a license?

Objectives

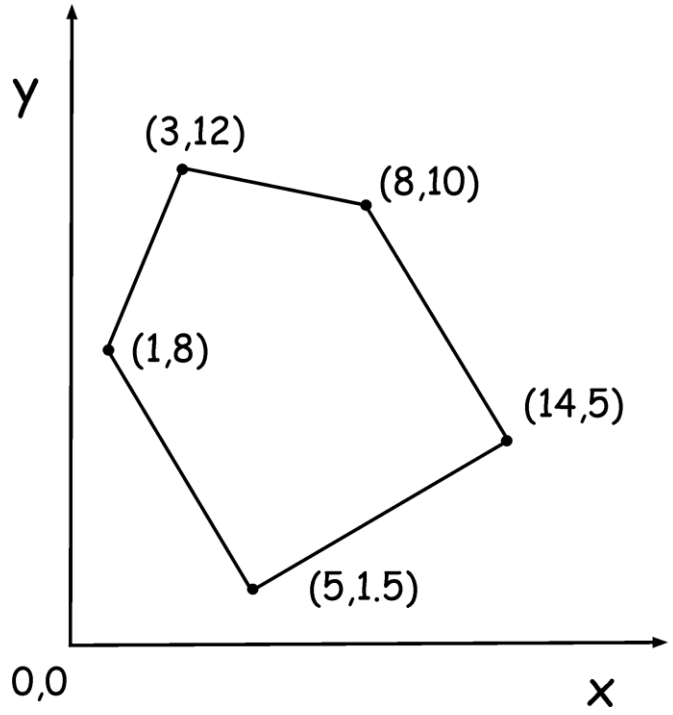
- Correctly convert data into a common coordinate system appropriate for a study site and objectives
- Become proficient in the use of GIS tools to conduct spatial analyses
- Work with data in formats common to GIS, including shapefiles, rasters, and geodatabases

Why are we covering this?

- Examples of Civil Engineering GIS Applications:
  - Planning and site location
  - Environmental analysis
  - Infrastructure design
  - Construction management
  - Data collection and as-built surveying
  - Operations and maintenance (e.g., roads, pipe networks, etc.)
- To do these well, we need to accurately represent:
  - Distances
  - Directions
  - Areas
  - Shapes

Coordinate System

- A pair or triplet of numbers that specify location with reference to some origin



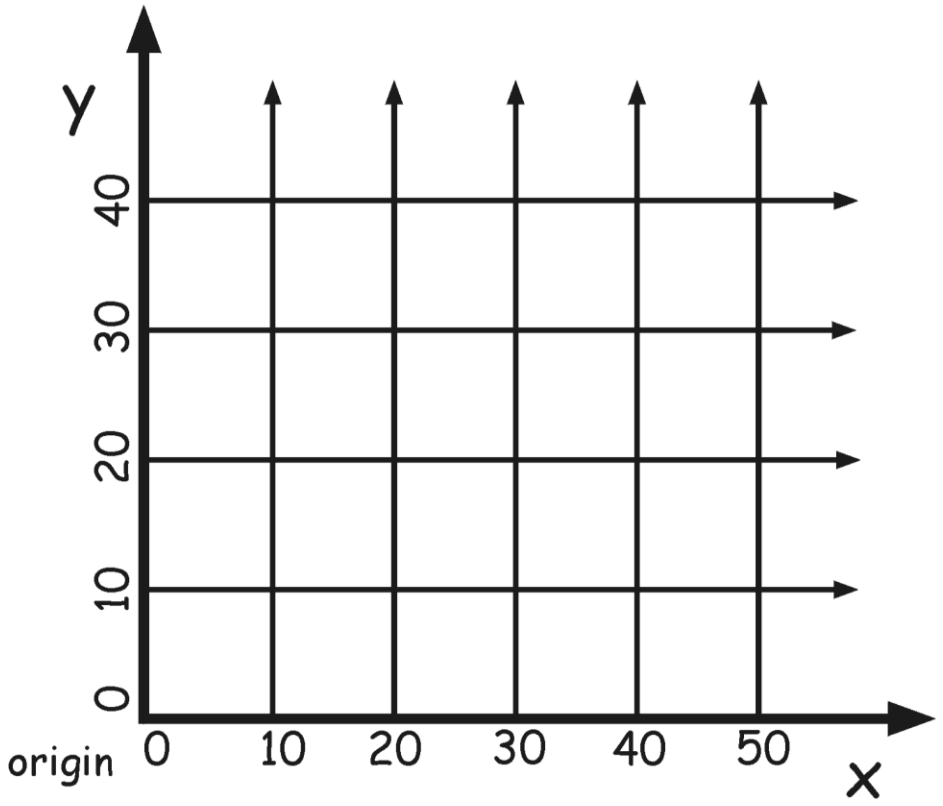
Coordinates:
1,8
3,12
8,10
14,5
5,1.5
1,8

Attributes:
Lot # :1347
Street: Willow Lane
Town: Hopkins

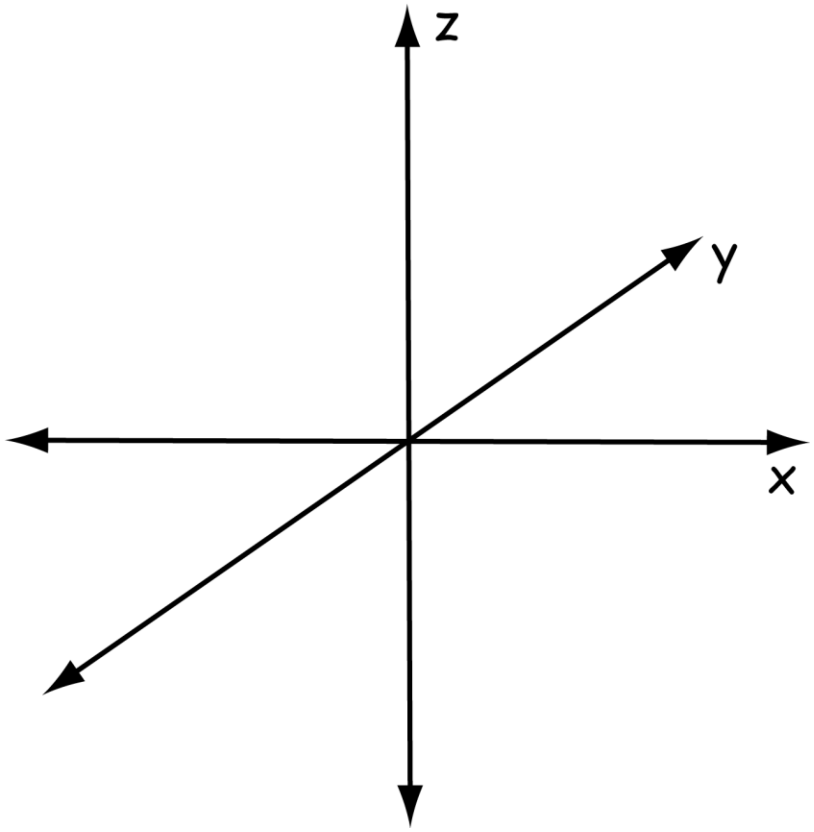
Source: Bolstad (2012)

2D vs. 3D Cartesian Coordinates

2 - Dimensional



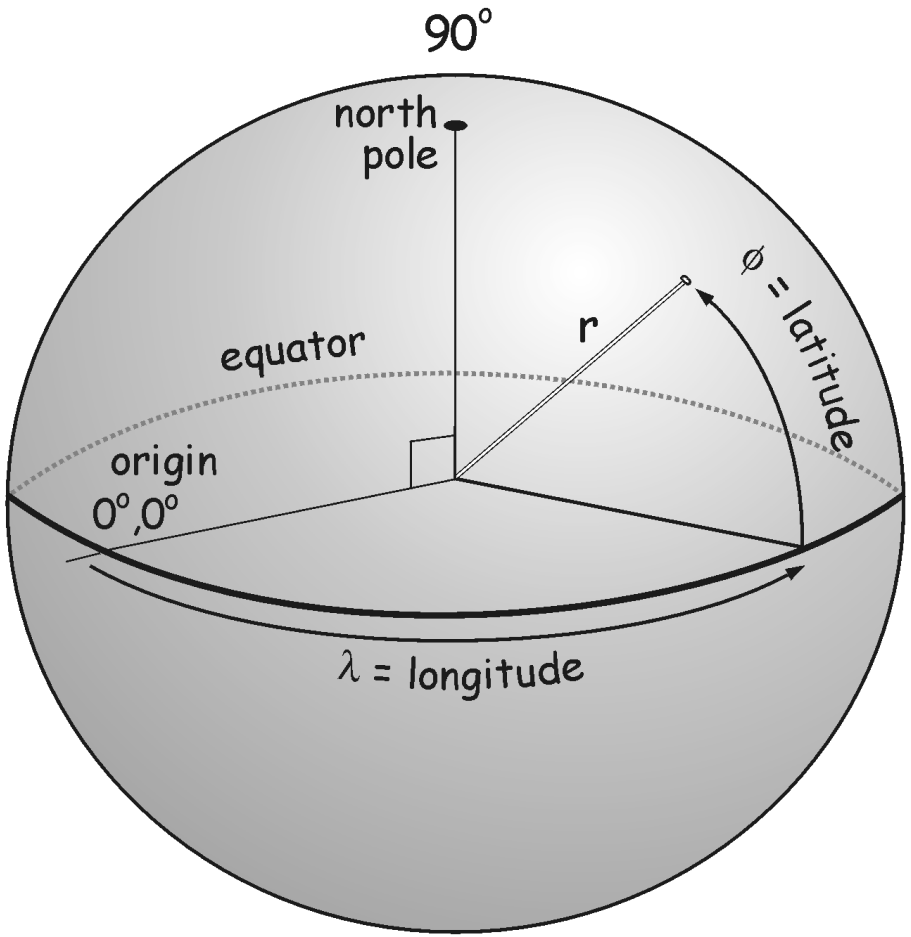
3 - Dimensional



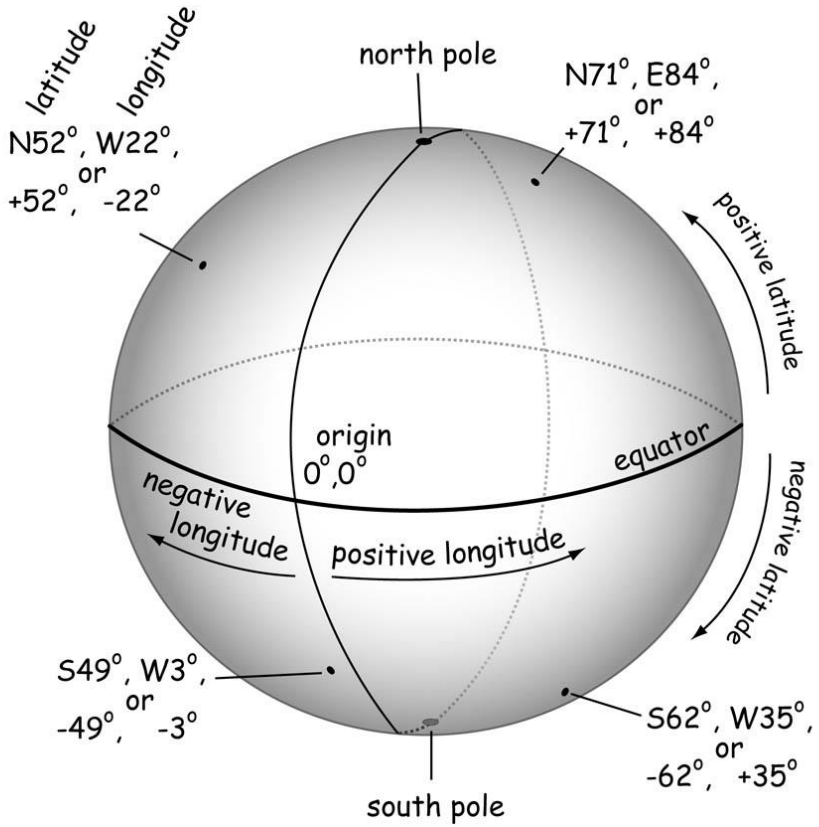
Source: Bolstad (2012)

What is the shape of the world?

Spherical coordinates



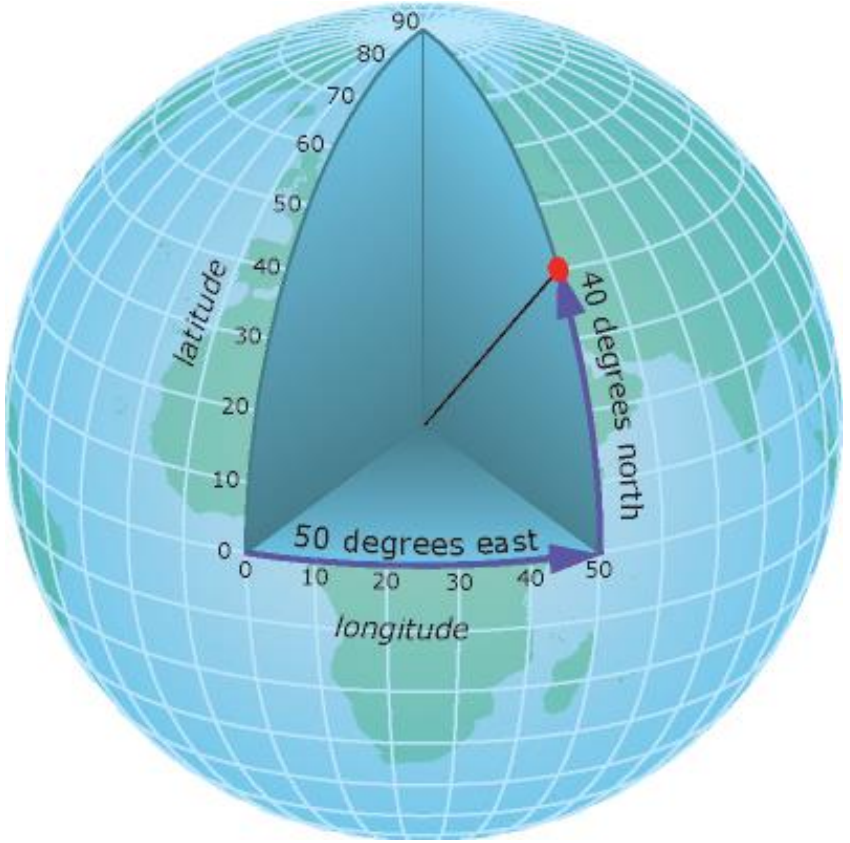
Source: Bolstad (2012)



- Two angular measurements (i.e., latitude and longitude)
- A radius

Geographic Coordinate System

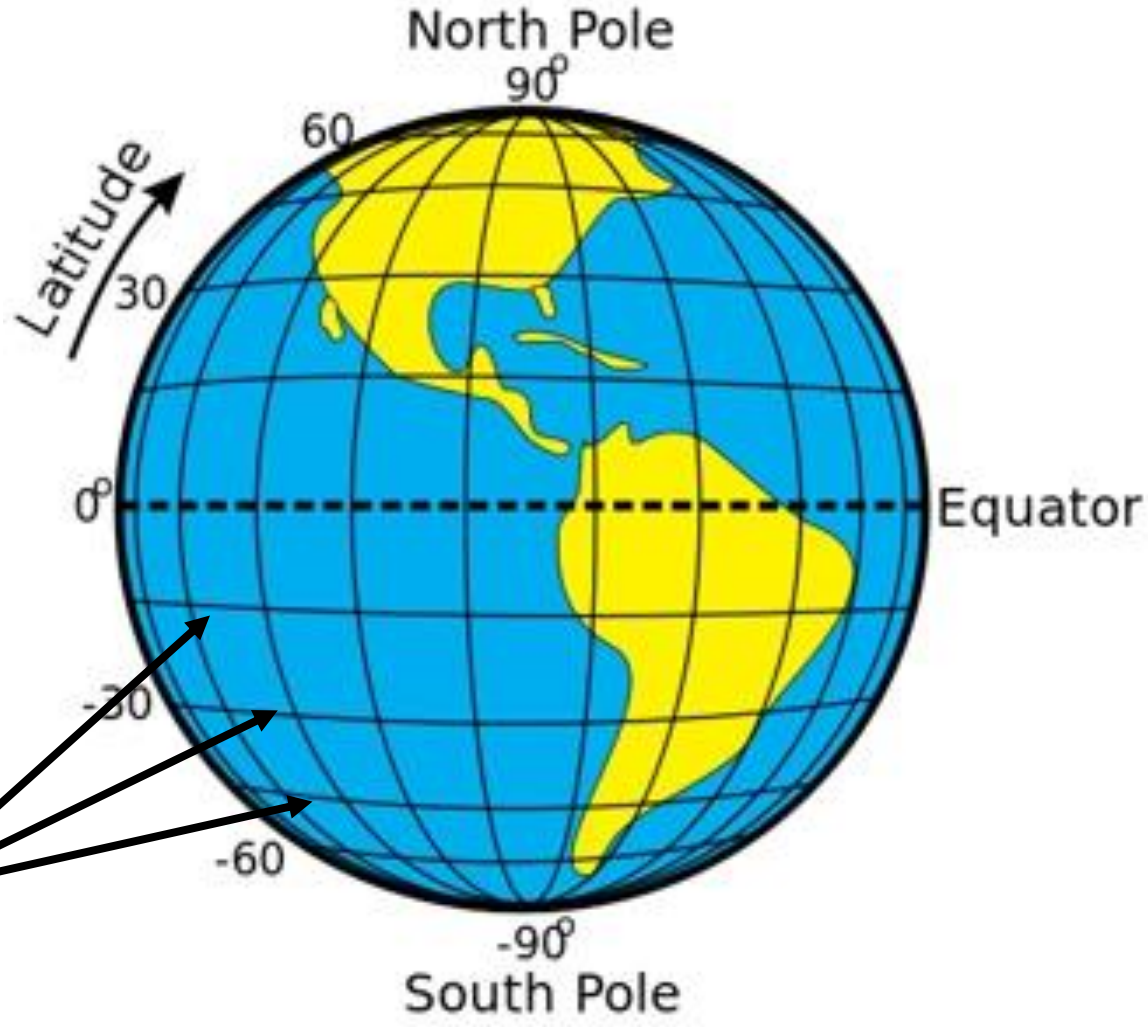
- Based on a spheroidal (either truly spherical or elliptical) surface that approximates the surface of the earth
  - A **datum** defines the surface
    - Radius for the sphere
    - Major axis and minor axis
    - Position of the surface relative to the center of the earth
  - All **coordinates** (e.g., Latitude and Longitude) are referenced to a datum



https://desktop.arcgis.com/en/arcmap/latest/map/projections/geographic-coordinate-system.htm

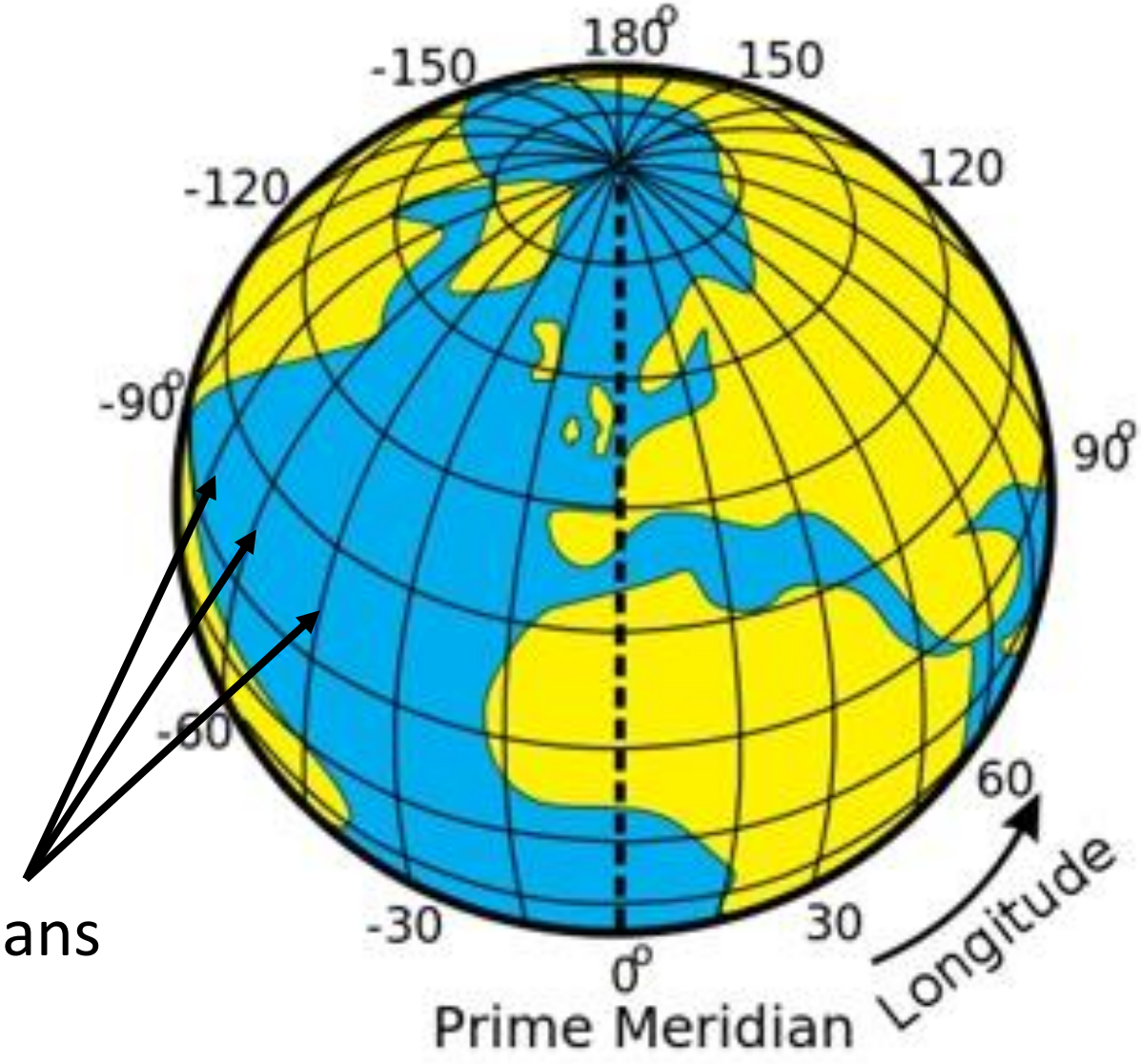
Latitude

- Lines of latitude = parallels
- Equator = 0° latitude (plane oriented perpendicular to the spin axis of the earth)
- Circumference of parallels varies
- 1° latitude = 111 km



Longitude

- Lines of longitude = meridians
- Meridians defined by planes that pass through earth's spin axis
- Prime meridian = 0° longitude
- 1° longitude:
  - 111 km at equator
  - 0 km at poles
  - Equal circumference

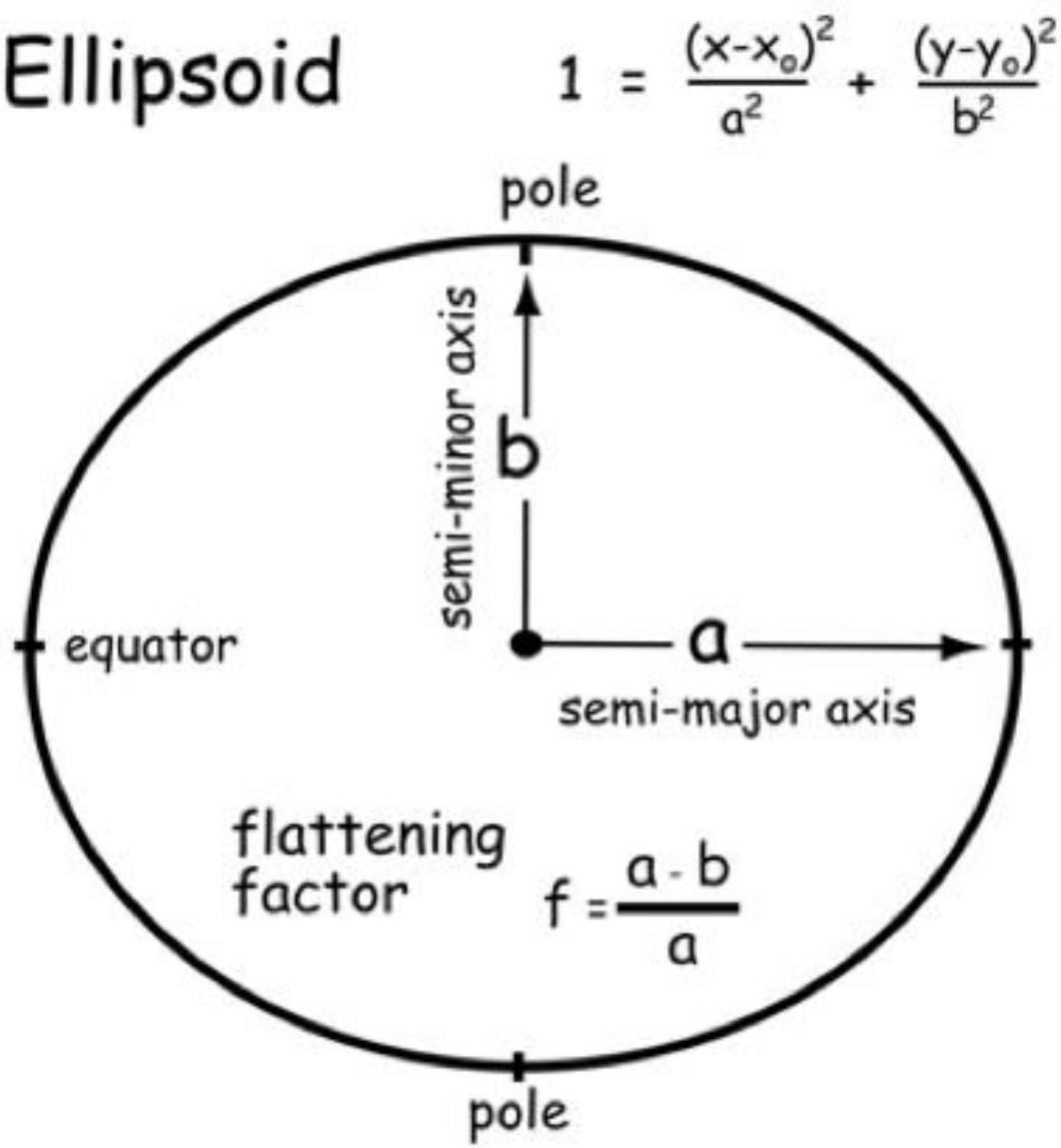


Datum and Vertical Coordinates

- A datum is a reference system or an approximation of the Earth's surface against which positional measurements are made for computing locations
  - A surface that wraps around the globe
  - Mathematically defined to represent the “average” earth radius
- **Horizontal datums** are used for describing a point on the Earth's surface, in latitude and longitude or another coordinate system
  - Commonly used: World Geodetic System (WGS) 84, North American Datum (NAD) 83
- **Vertical datums** are used to measure elevations or underwater depths

Ellipsoid

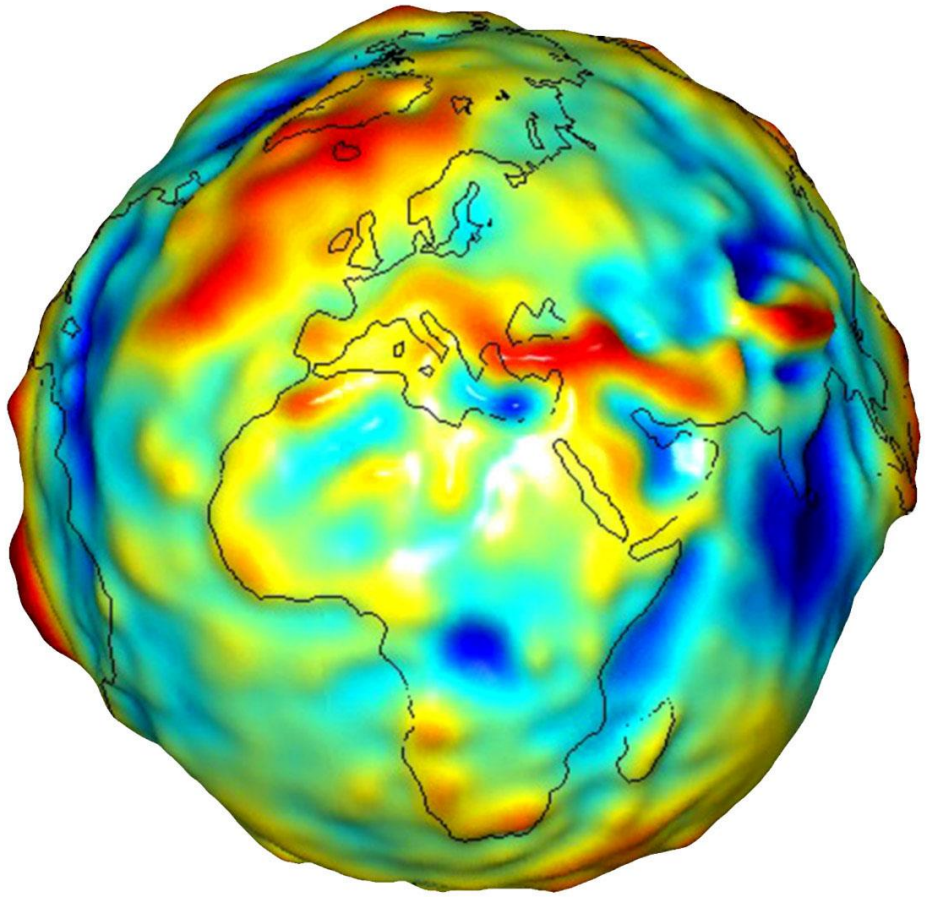
- The Earth is not a perfect sphere – it rotates around its shortest (minor) axis
- An ellipsoid is used as an approximation of its shape
- Oblate Ellipsoid = a sphere that has been flattened slightly at the poles



Source: Bolstad (2012)

Earth's Geoid

- The shape that the surface of the oceans would take under the influence of Earth's gravitation and rotation alone (no wind and tides)
- Effectively a model of global mean sea level (zero elevation)
- Used to measure precise surface elevations



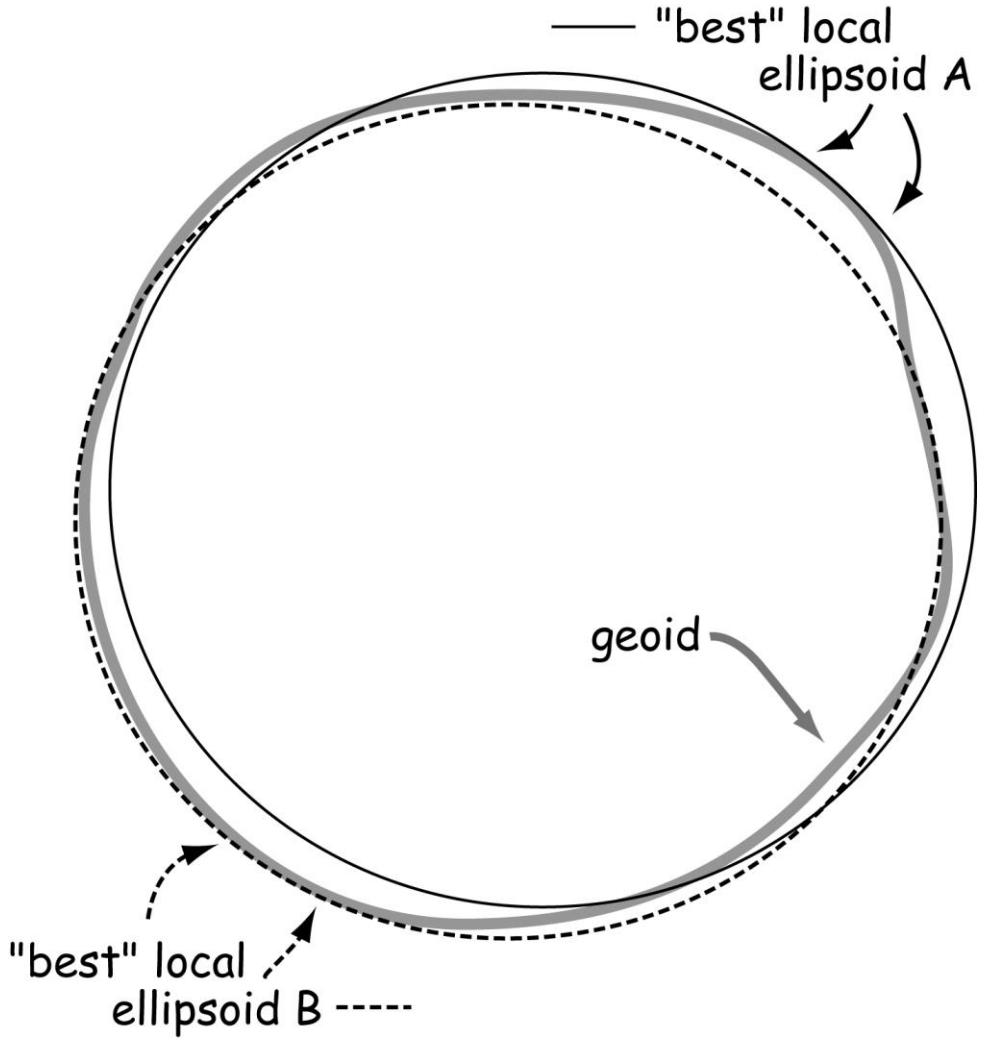
Red and orange areas have a slightly stronger gravity field as a result of uneven mass distribution

Source: Bolstad (2012)

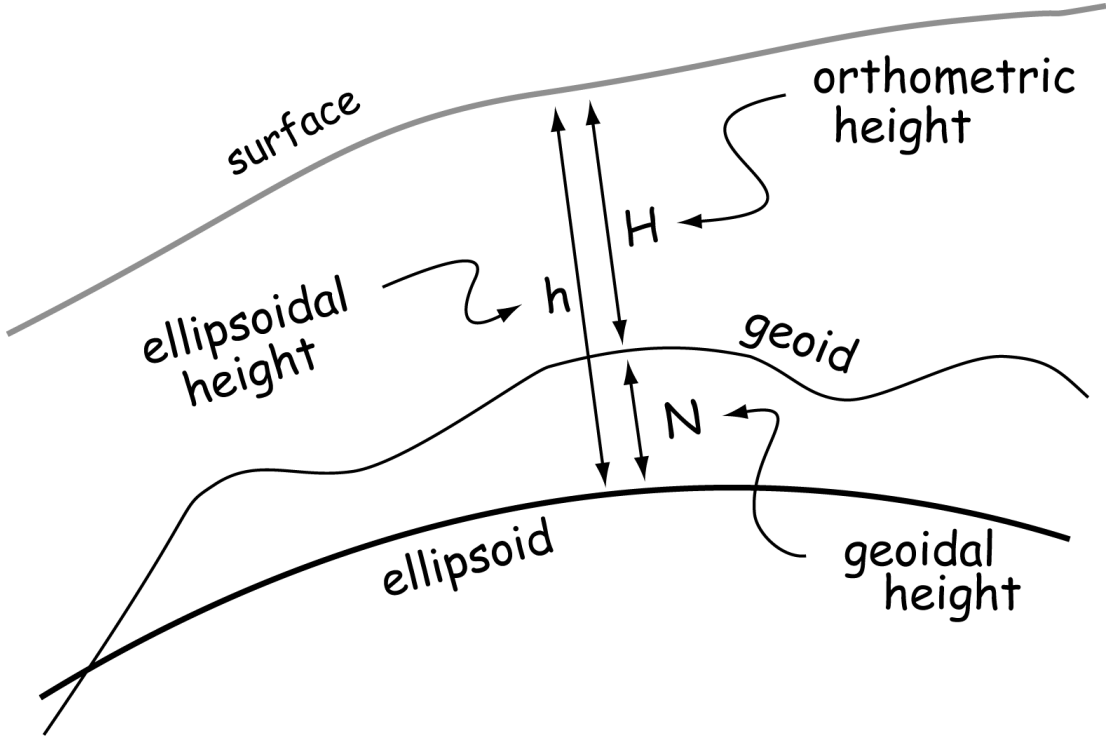
Geographic Coordinates

- Latitude and Longitude defined using an ellipsoid
- Elevation defined using the geoid
- Earth datums define standard values of the ellipsoid and geoid

Ellipsoid versus Geoid



Earth surface elevation is measured from the geoid



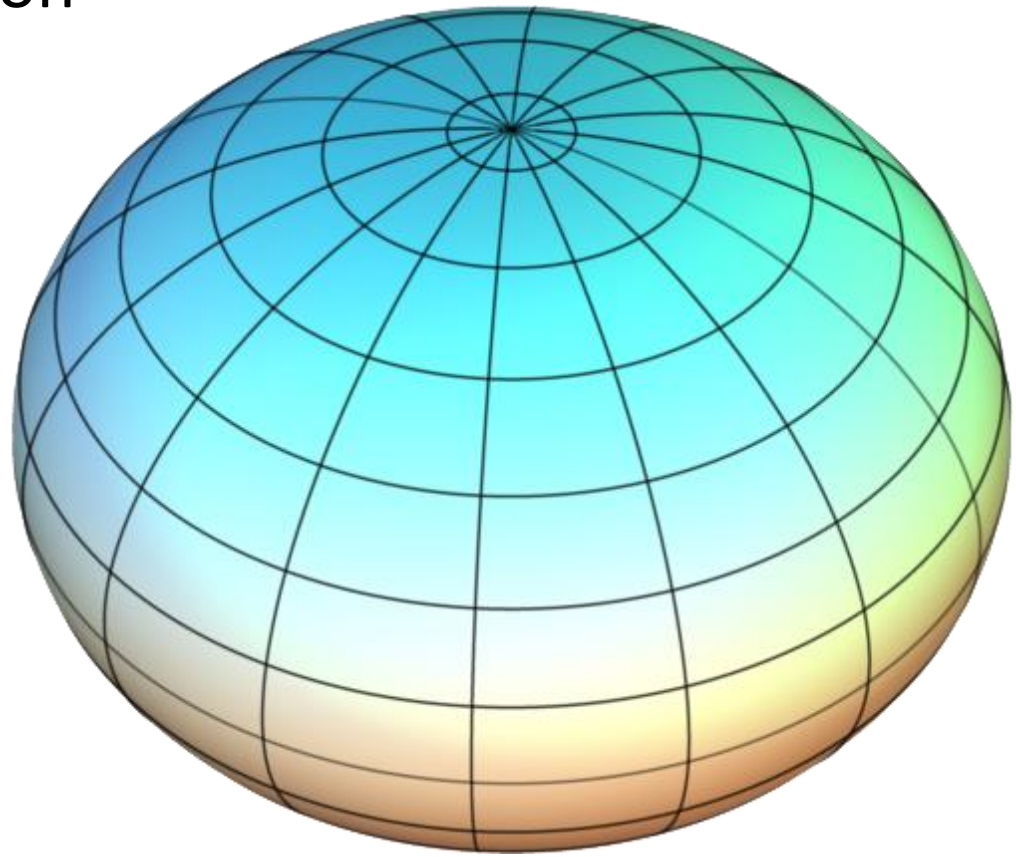
$$h = H + N$$

ellipsoidal height = orthometric height + geoidal height

Source: Bolstad (2012)

Take Home Points

- Accurate depiction of location depends on the shape of the earth
- GIS is all about location, location, location
- Elevations are relative to the Earth's shape
- We generally model the shape of the earth as an oblate ellipsoid



The challenge:

From this…



to this…



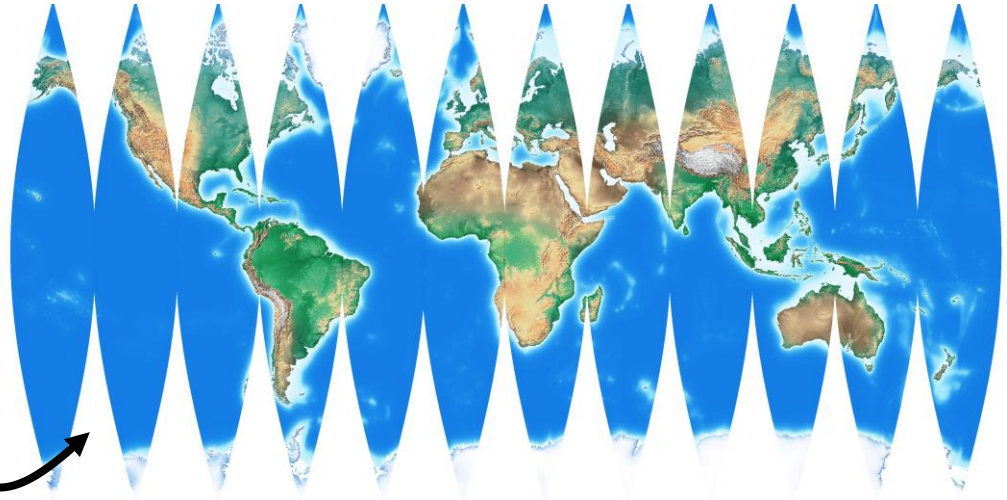
While maintaining accuracy in distance, direction, area, and shape

Projected Coordinate System

- A method for representing a spherical or curved surface on a flat plane
- A series of mathematical transformations that convert location of points on a curved surface to locations on a flat plane
  - Also requires a datum because projected coordinate systems are based on geographic coordinates

WARNING: ALL projected coordinate systems cause distortion in the shape, area, distance or direction of data

Why distortion?



Filling in spaces adds distortion

Reduce scale

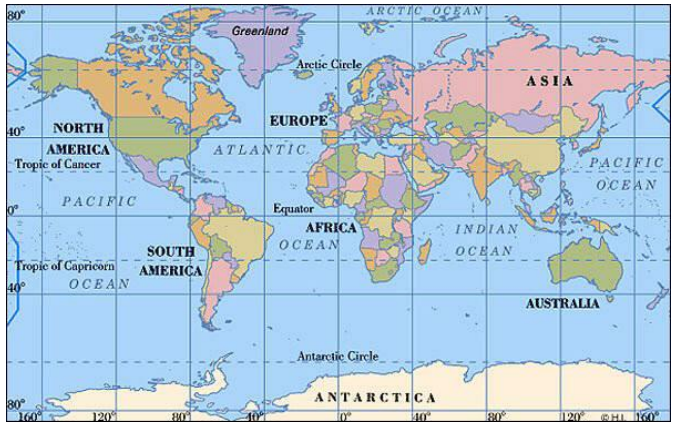
Flatten





Globe

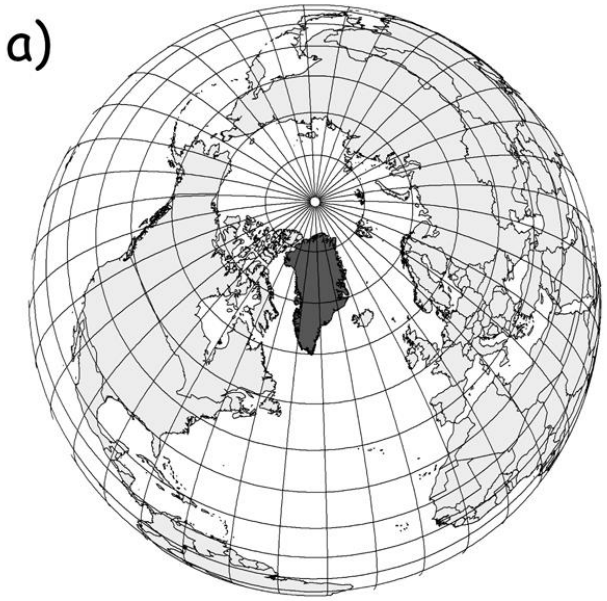
Map



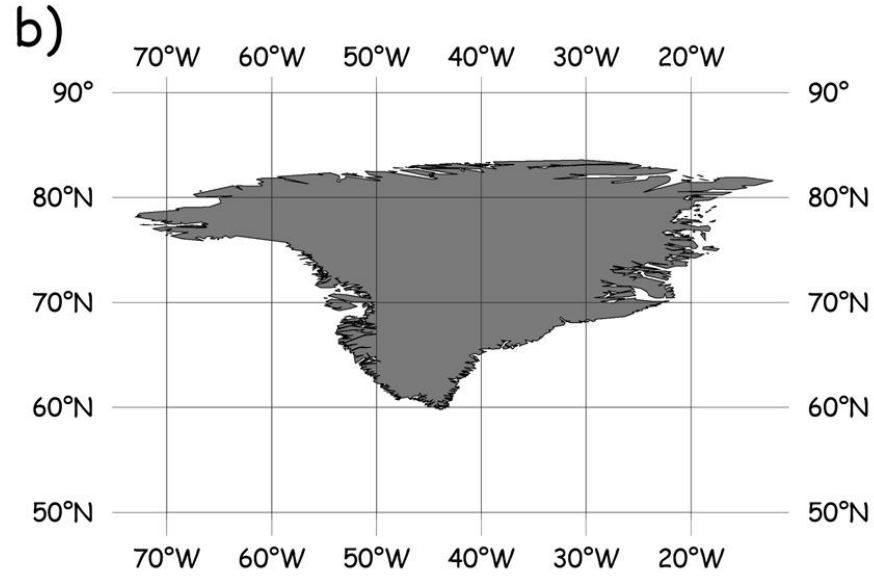
Map Scale = Globe distance / Earth Distance (e.g., 1:24,000)

Scale Factor = Map distance / Globe Distance (e.g., 0.9996)

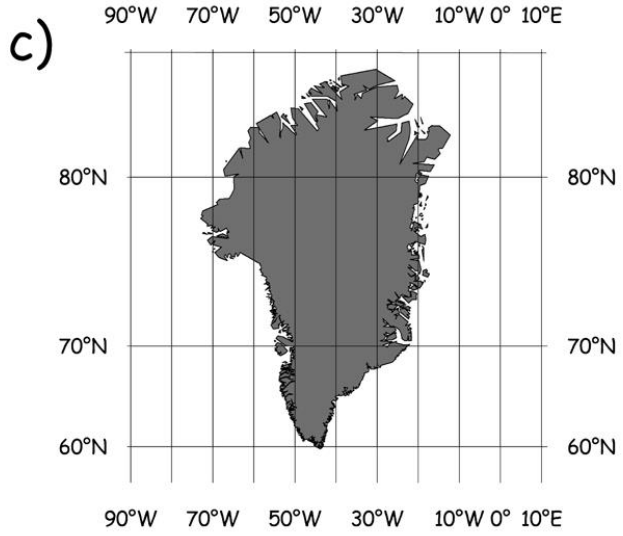
Greenland as an Example



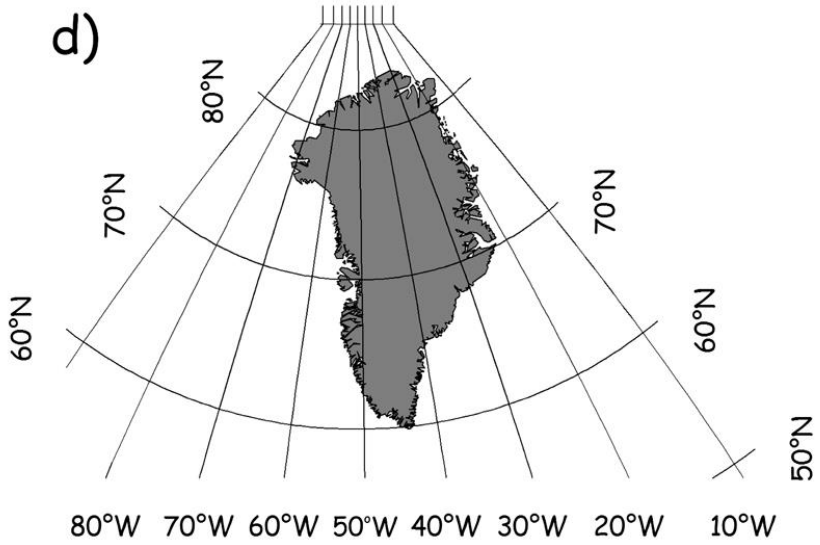
Unprojected



Geographic coordinates on a plane



Mercator projection

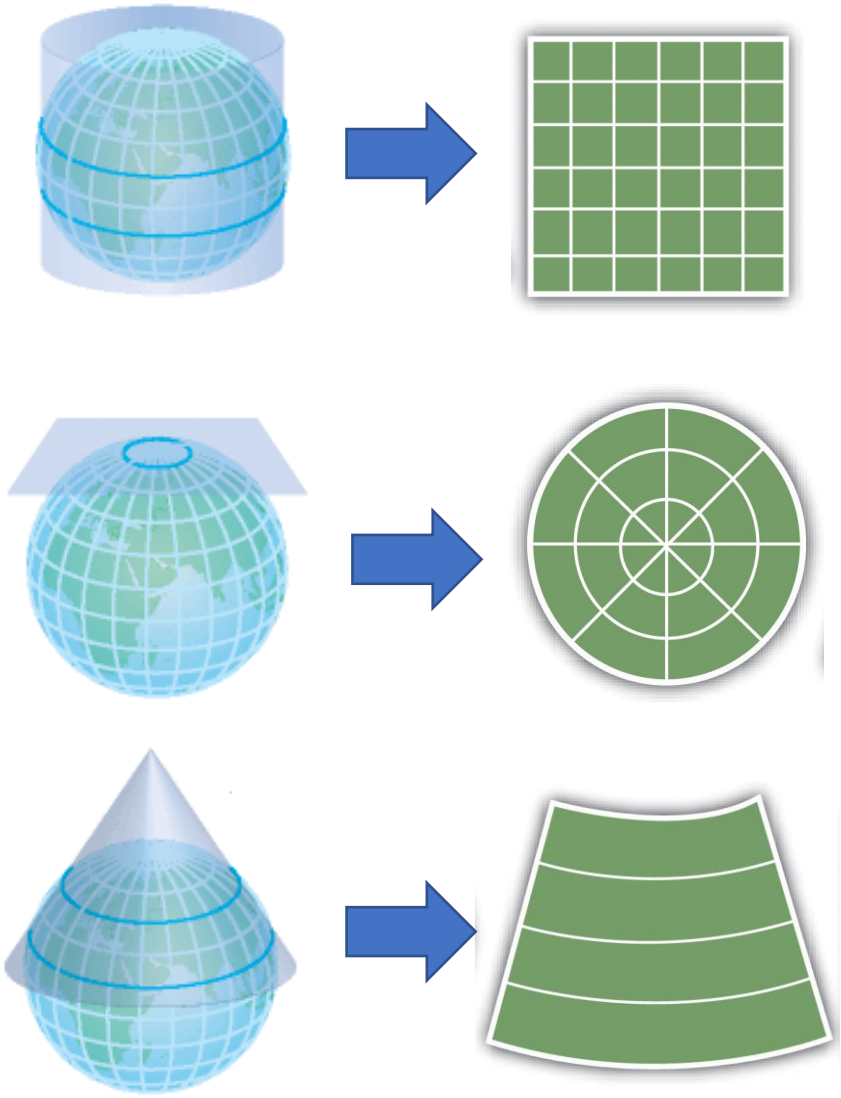


Transverse Mercator projection

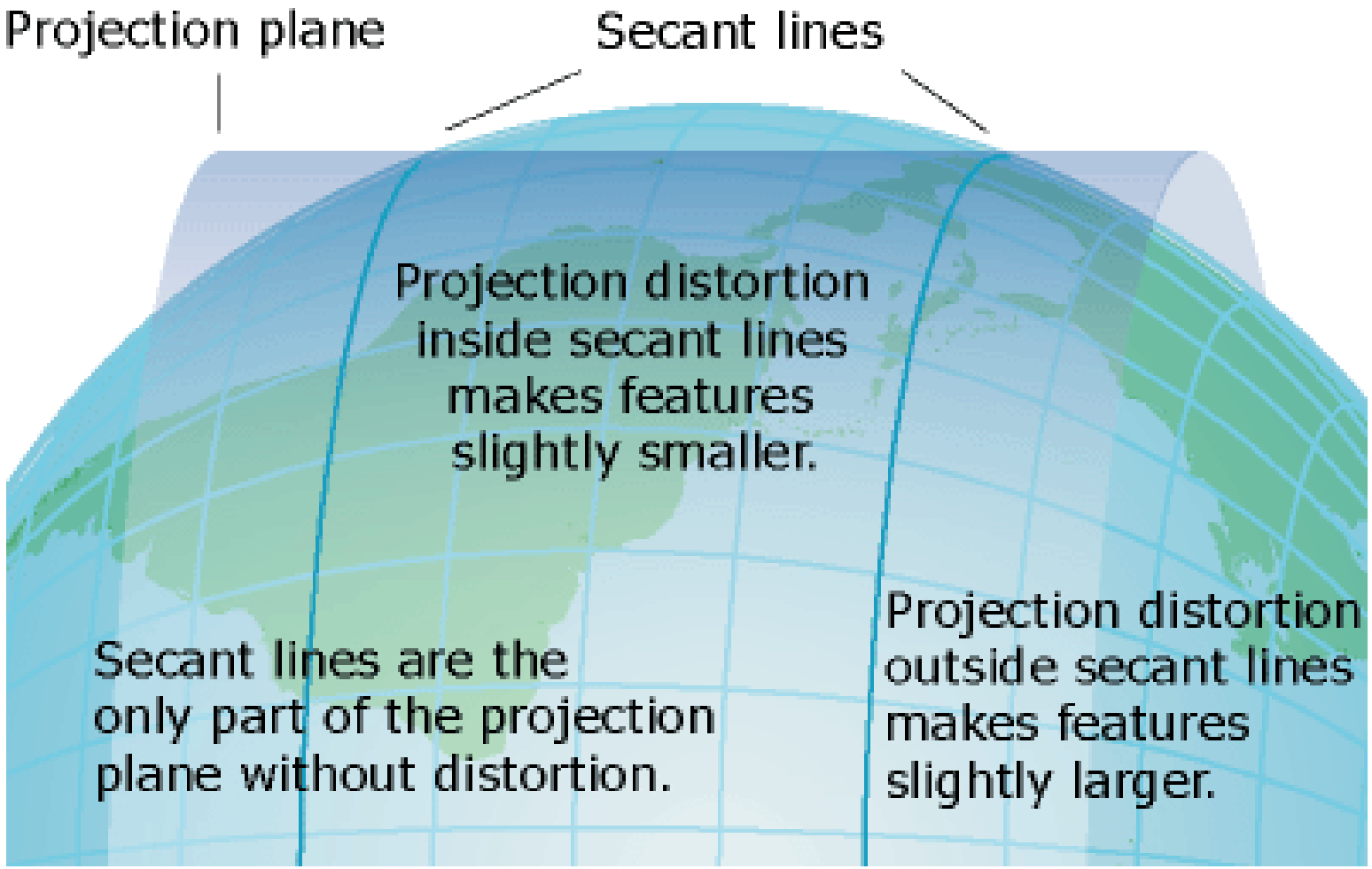
Source: Bolstad (2012)

Types of Projections

- Cylindrical
  - Easy to use
  - Latitude and longitude are at right angles
  - Shows true direction
  - Distorts high latitudes
- Azimuthal/Planar
  - Useful for polar regions
  - Distorts direction and distance
- Conical
  - Useful for showing small areas accurately
- Others…



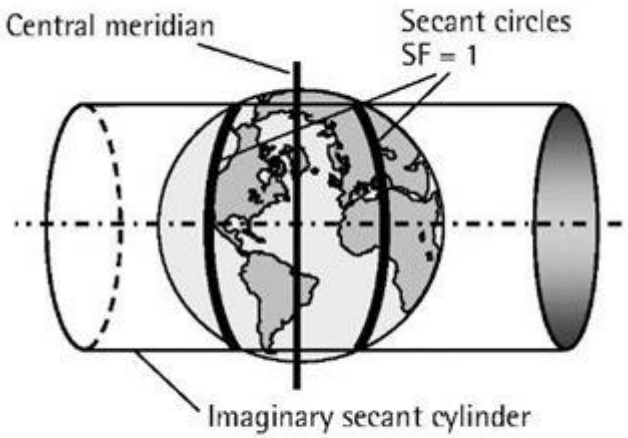
More about distortion

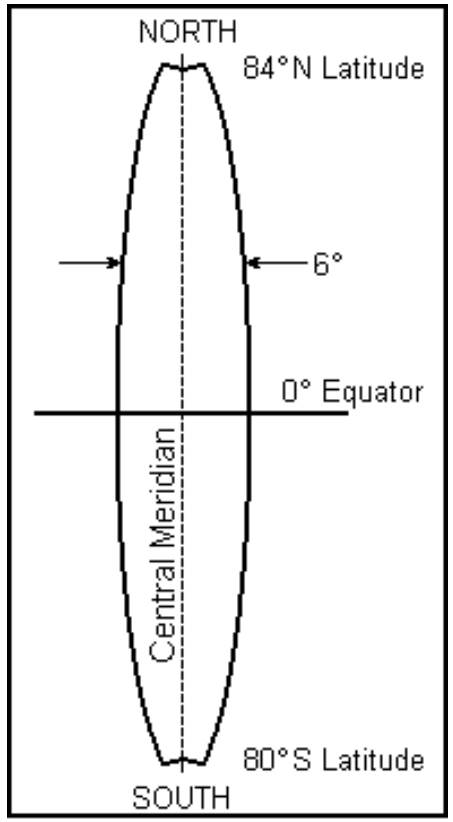


http://webhelp.esri.com/arcgisdesktop/9.2/printBooks_topics.cfm?pid=22

Example: Universal Transverse Mercator

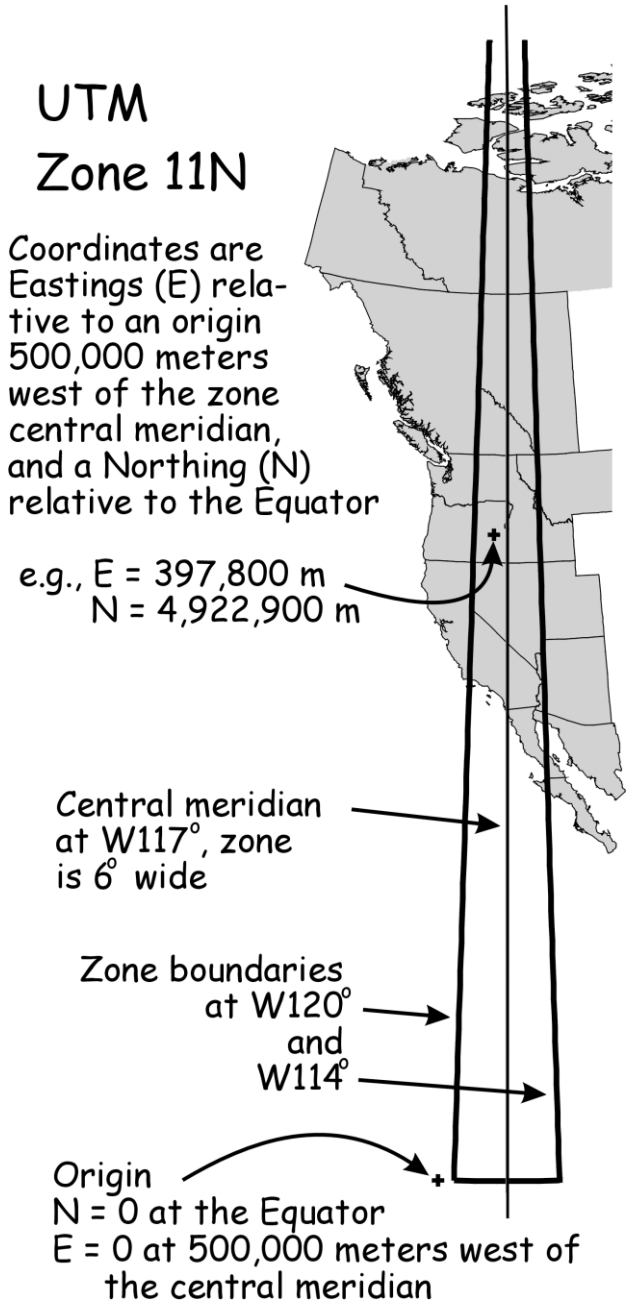
- Multiple map projections - each zone represents a 6° band of longitude (roughly 660,000 m at the equator)
- Horizontal cylinder touches globe at two secant lines for each zone
- Minimal distortion and accurate directions
- Used extensively in Utah





Universal Transverse Mercator

- Each zone has a central meridian located at exactly the middle of the zone
- Point of origin in each zone is the intersection of the zone's central meridian and the equator
- To avoid negative coordinates, the central meridian of each zone is set at 500,000 m East
- Equator is set as 0 m northing for locations north of the equator

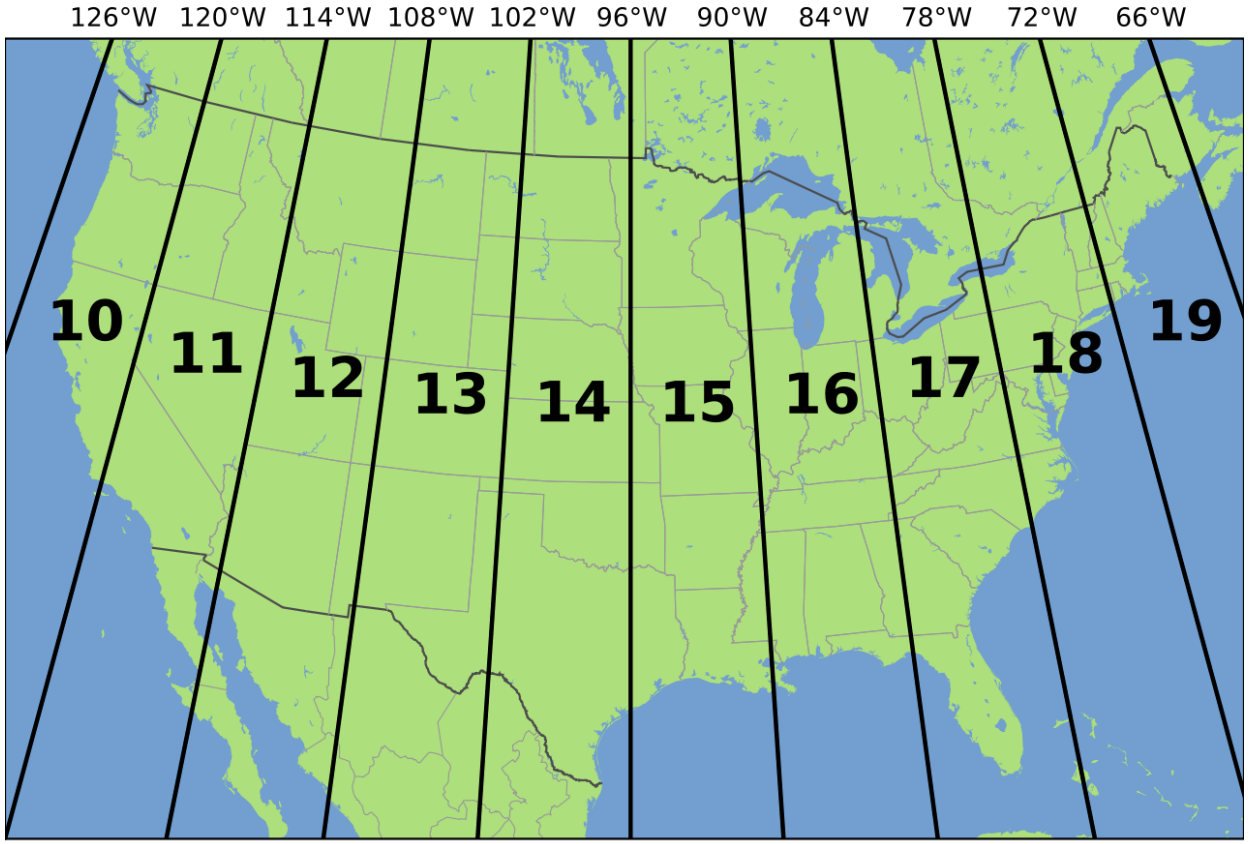


Source: Bolstad (2012)

UTM Zones in the U.S.

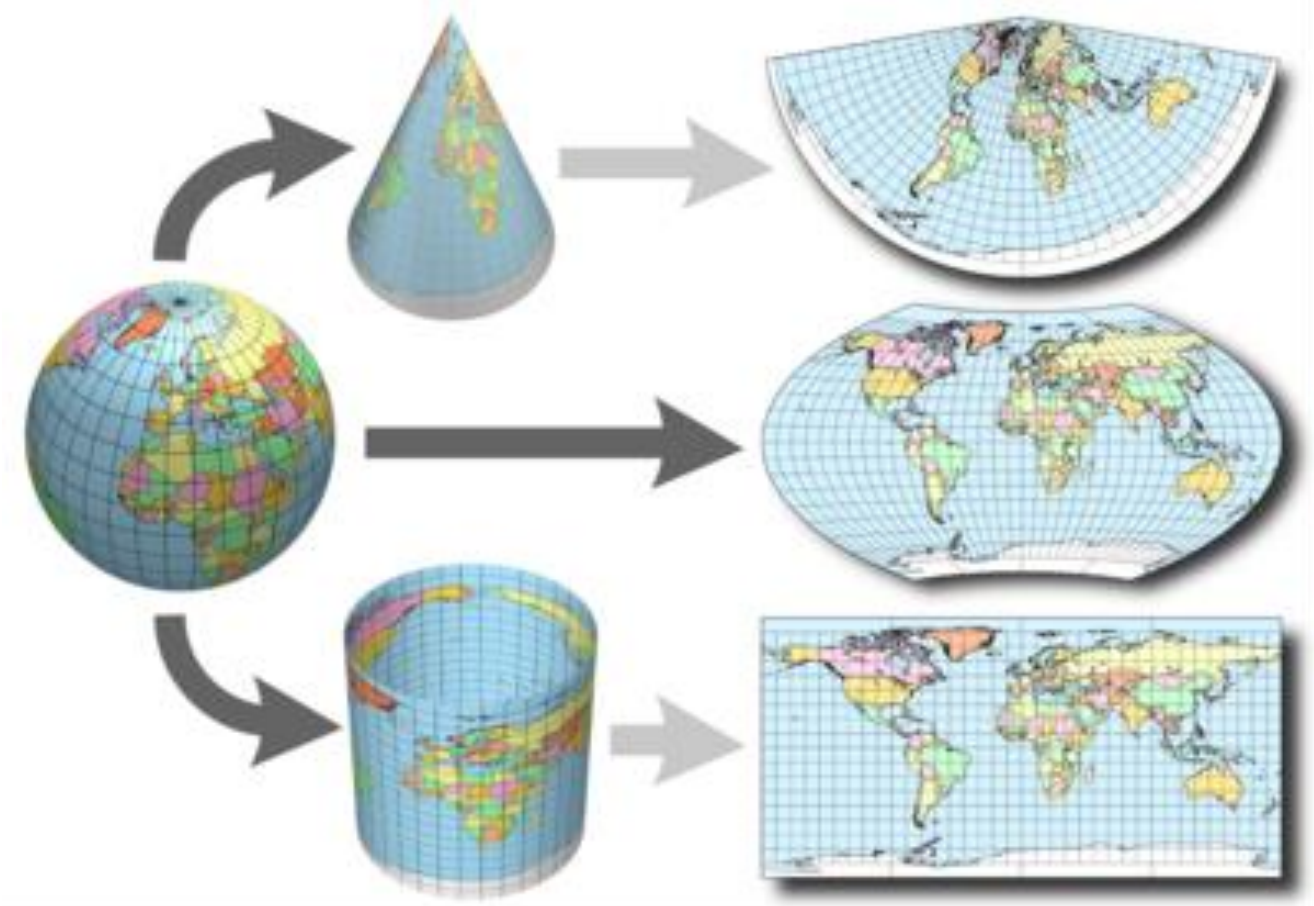
- UTM is designed to cover the whole Earth
  - Excluding Arctic and Antarctic regions
- For Utah
  - UTM Zone 12 North
  - (108° W – 114° W)

Coordinates are measured in meters



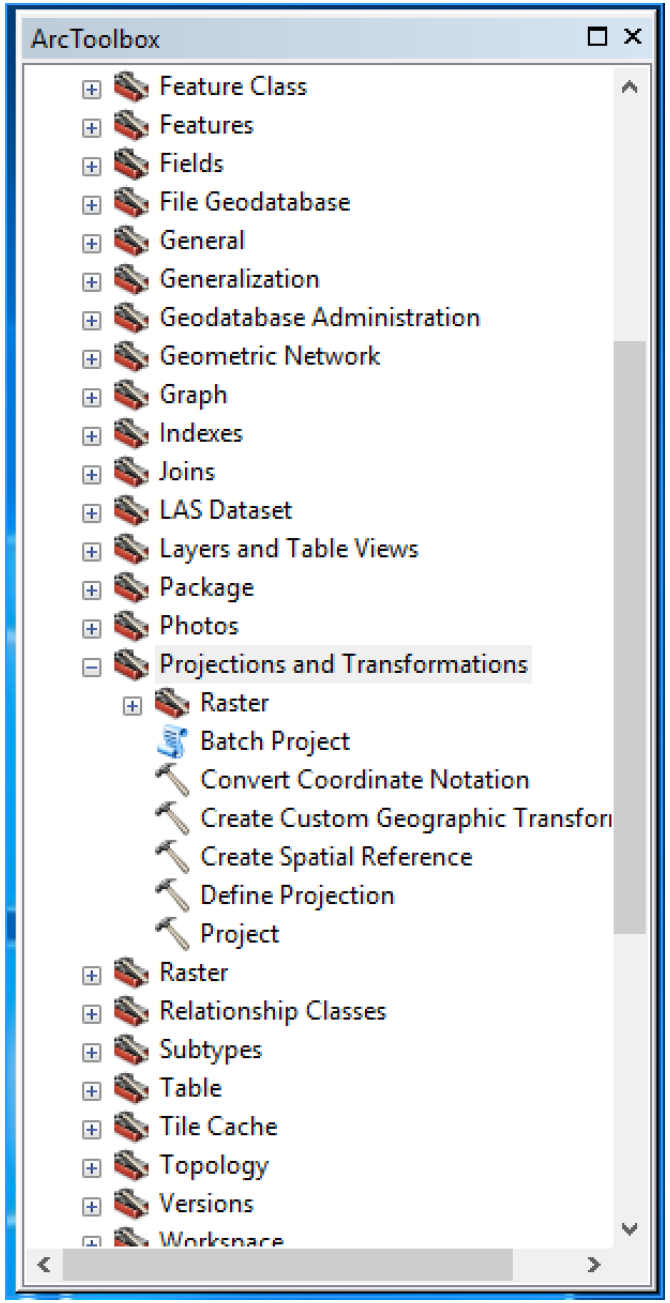
How to choose?

- Extent of the map
  - Global?
  - Hemisphere?
  - Near the poles?
  - A single state?
  - A city?
- Location of the map
  - High versus low latitude
  - Longitude
- Objective of analysis
  - What do you want to preserve?
    - Shape
    - Area
    - Distance
    - Direction



In Practice

- ArcGIS provides tools for:
  - Defining the coordinate system
  - Converting from one coordinate system to another
  - Creating custom transformations
- Spatial Reference = Datum + Coordinate System + Projection
- For consistent analysis, the spatial reference of all datasets should be the same

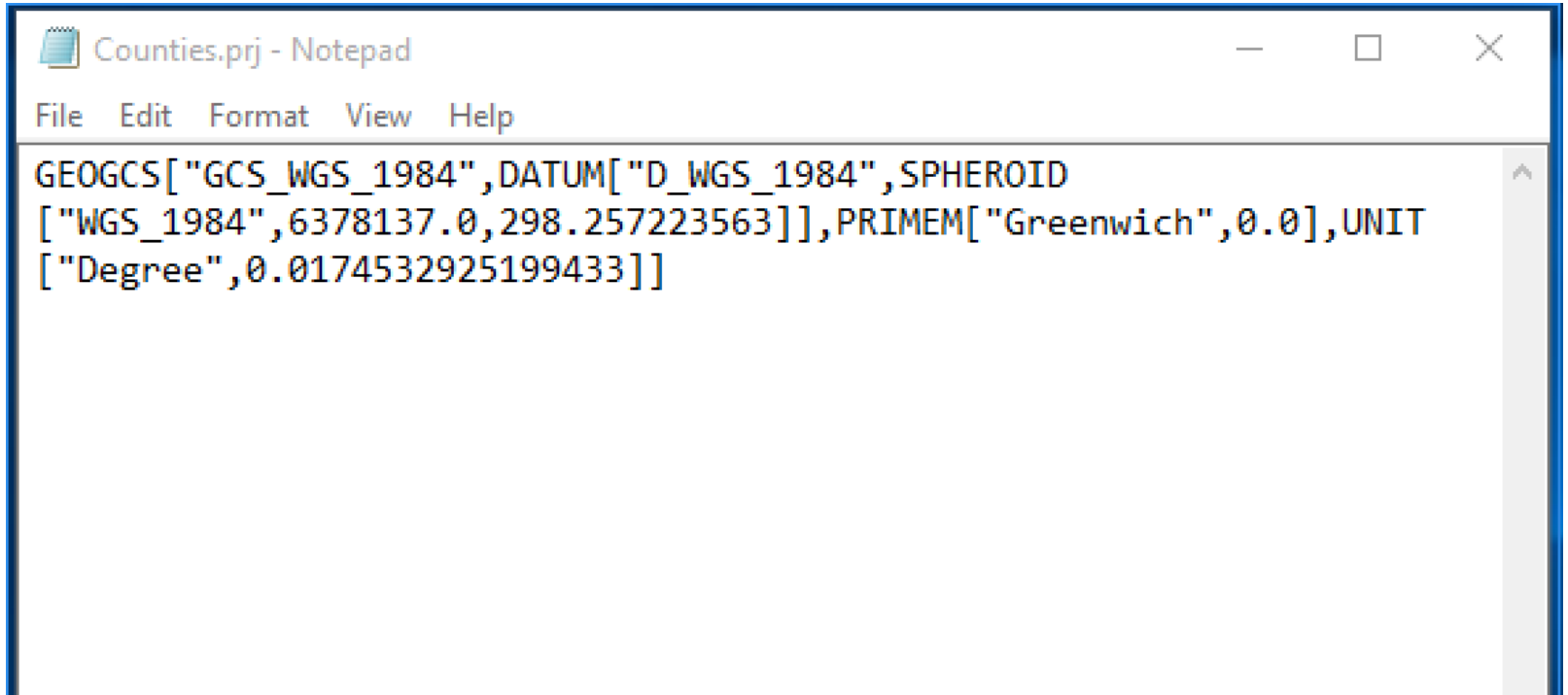


Some helpful concepts

- Geographic coordinate systems
  - Use a spheroid/datum
  - Latitude and longitude coordinates in angular degrees
- Projected coordinate systems
  - Based on a flat plane (the spheroid projected onto a 2D surface)
  - Use linear units (feet, meters, etc.)
  - Allows distances and areas to be sensibly calculated (but with potential distortion)

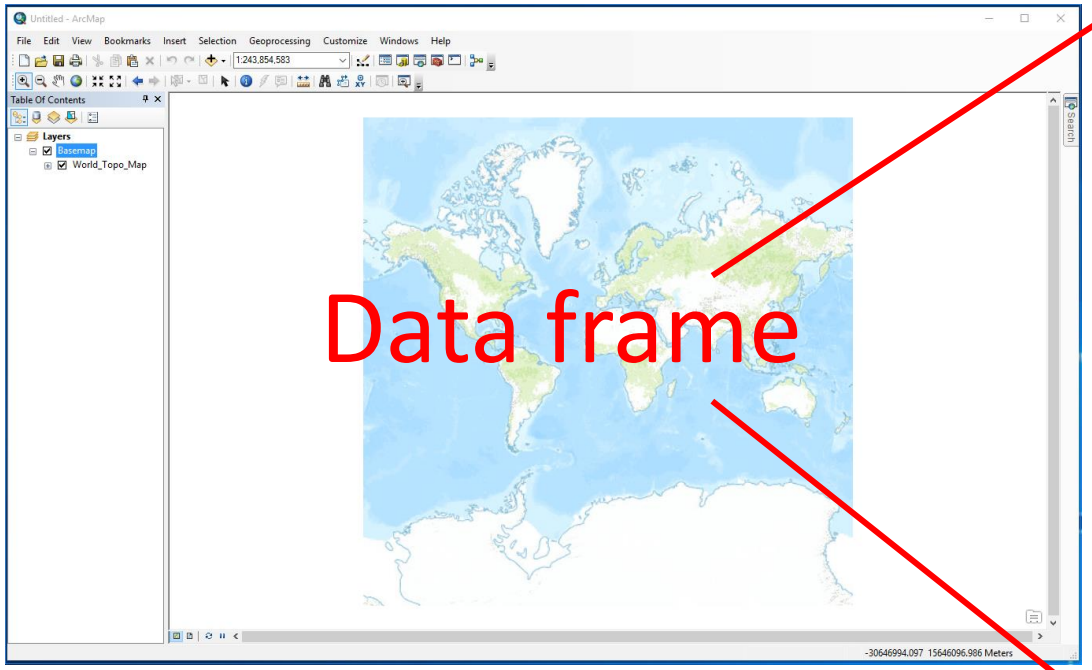
ArcGIS .prj Files

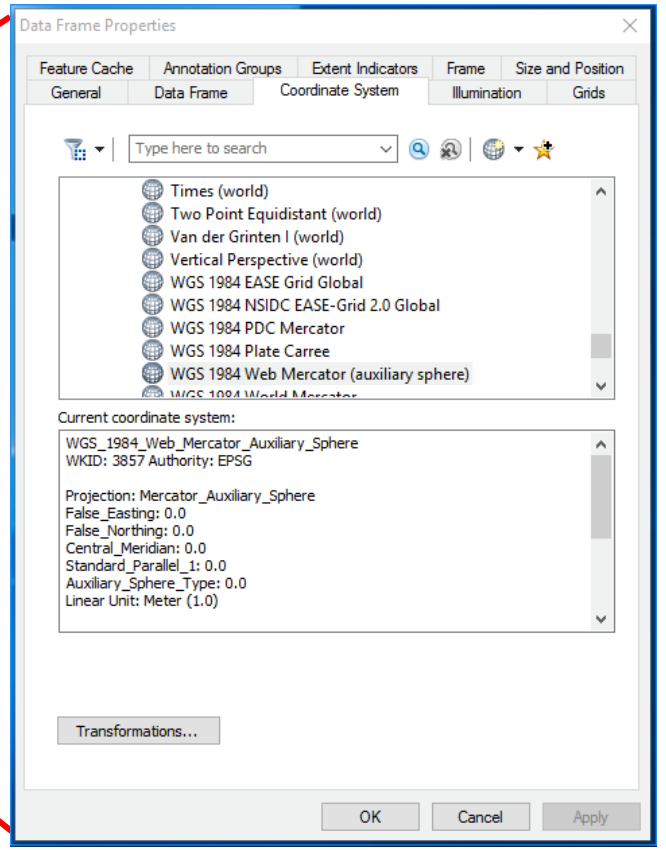
- Stored with a shapefile dataset
- Defines the coordinate system and projection information



Important to understand…

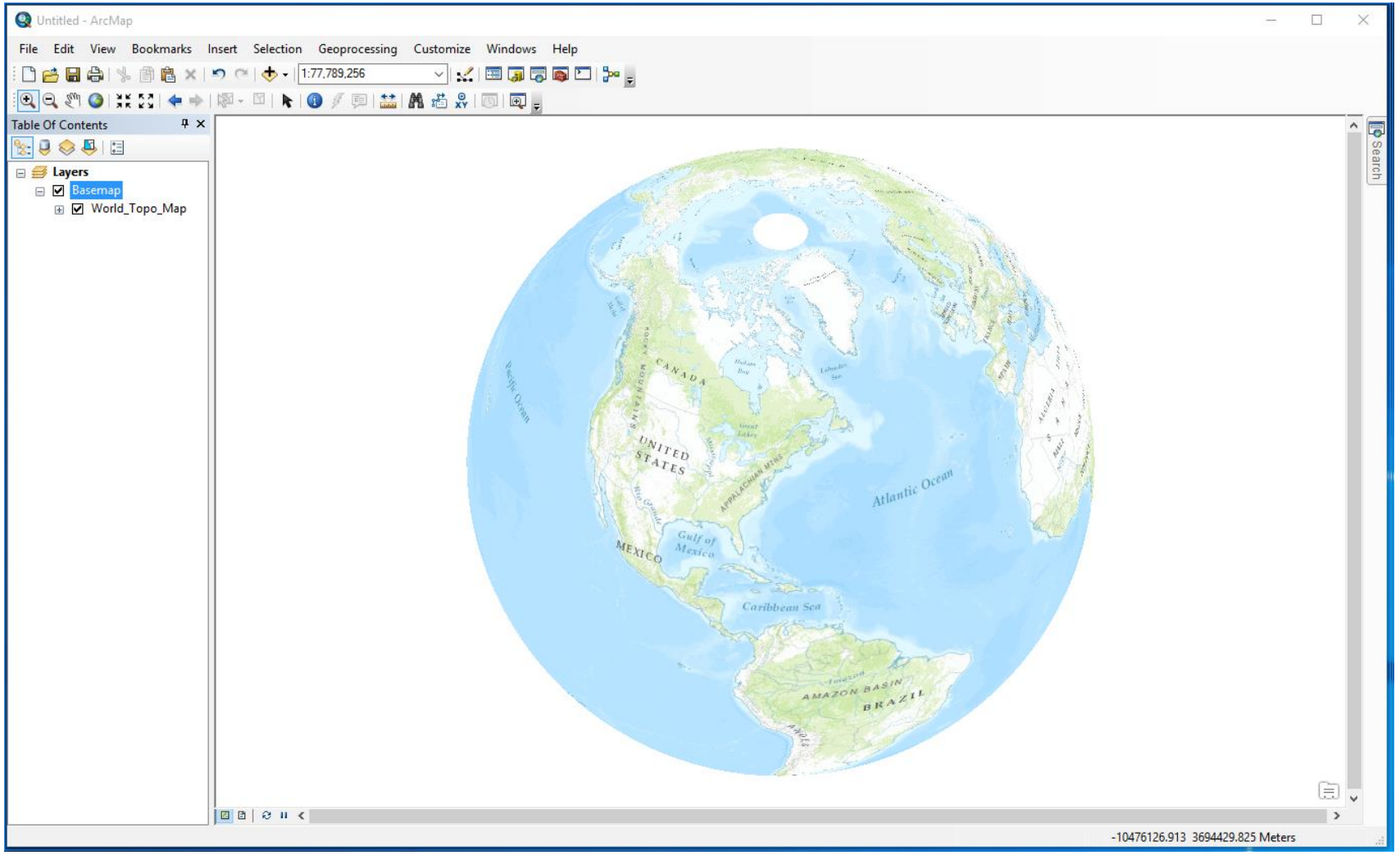
- **Data frames** have a defined coordinate system
- **Datasets** have a defined coordinate system
- They are not always the same!!!!





ArcGIS always assigns the data frame the coordinate system of the first layer you load

You can change the projection of the data frame



Important to understand…

- Your data are stored in one coordinate system (geographic or projected)
  - This should not be changed without transforming the data!
- The data frame can be changed to many coordinate systems
  - This re-projects the data on the fly
  - This does NOT transform the way your data are stored!
- The ability of on-the-fly visualization/ re-projection eliminates the need to transform data for many applications

Coordinate System Transformations

- **Transformation** = Converting from one datum to another
- **Project** = Convert from a geographic coordinate system to a projected coordinate system

- Remember: Each time you do a conversion, you introduce some error – e.g., rounding error from calculations

Summary (1)

- Accurate depiction of location depends on the shape of the earth
- GIS is all about location, location, location
- Projected coordinate systems are required for engineering analyses (e.g., calculations of lengths, areas, etc.)
- The projection system matters because all projected coordinate systems have distortion (error)

Summary (2)

- For consistent analysis, the spatial reference of datasets should be the same
- Choosing an appropriate projection depends on extent, location, and study objectives
- ArcGIS provides tools for projecting a data frame and for managing the projection of datasets

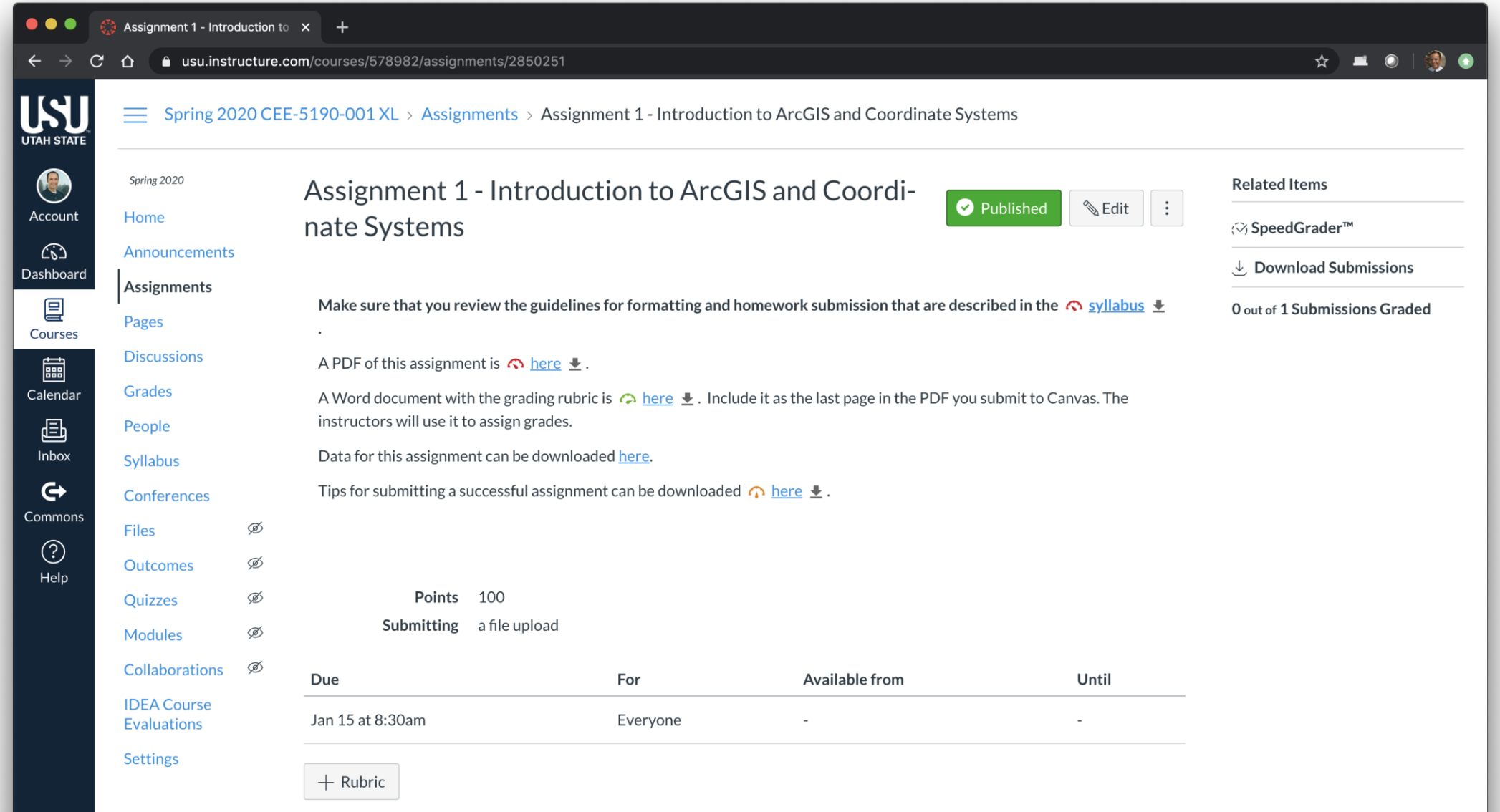
Where can I go to learn more?

- Chapter 3 in Bolstad – GIS Fundamentals Book
- ArcGIS Help Topic: http://desktop.arcgis.com/en/arcmap/latest/map/projections/what-are-map-projections.htm
- ArcGIS Projections and Transformations Toolset: http://desktop.arcgis.com/en/arcmap/latest/tools/data-management-toolbox/an-overview-of-projections-and-transformations-toolset.htm

Assignment 1 – Introduction to ArcGIS and Coordinate Systems

- Objective: Evaluate potential sites for the construction of a warehouse in Logan, UT
- Given a shapefile depicting available land parcels, you will learn how to:
  - Investigate the coordinate system of a dataset and other metadata
  - Project the shapefile to the required coordinate system
  - Perform simple queries on the attribute table to identify potential building sites

Assignment 1 in Canvas

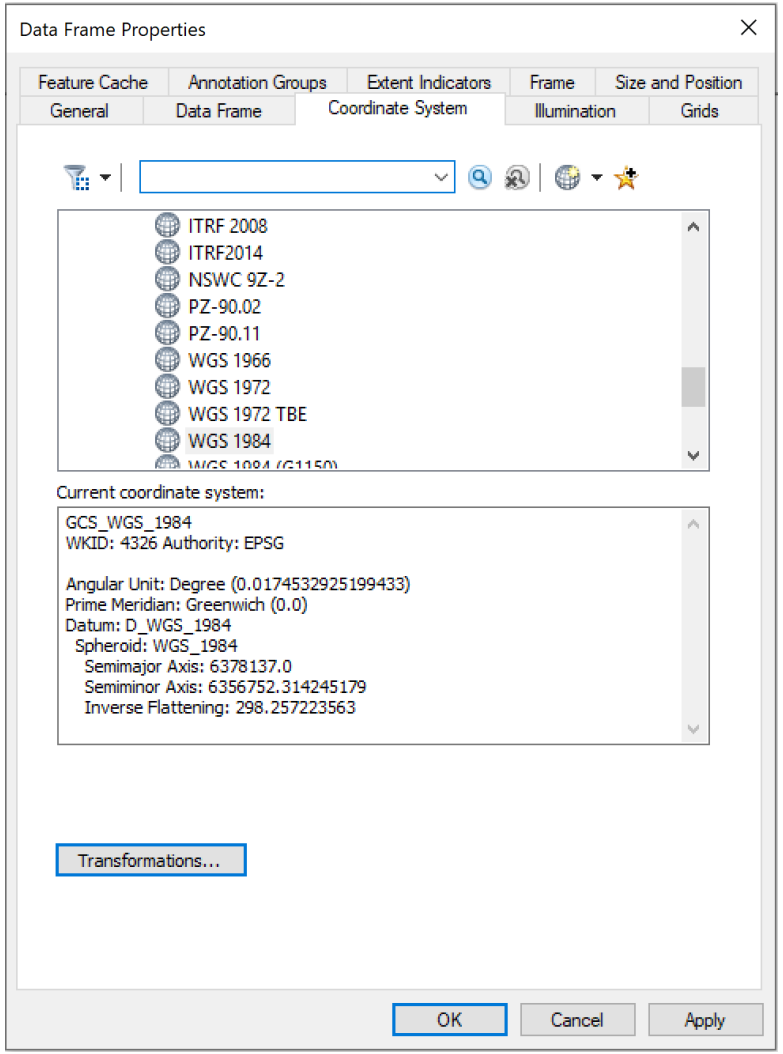


Viewing Dataset Coordinate System

- Using ArcMap
  - Right click on a dataset in the ArcMap table of contents and select “Properties” – view the “Source” tab
  - Right click on a dataset in the ArcMap table of contents and select Data → View Item Description
- Using ArcCatalog inside ArcMap
  - Open the ArcCatalog panel in ArcMap
  - Right click on a dataset and select “Item Description”
- In ArcCatalog
  - Select a dataset in the catalog tree on the left
  - Select the “Description” tab on the right
- Right click on data frame in ArcMap to get DataFrame properties

Viewing Data Frame Coordinate System

- To view the coordinate system of a data frame:
  - Right click anywhere in the data frame (map)
  - Select “Data Frame Properties”
  - Choose the “Coordinate System” tab



Credits

- Several figures adapted from:

  Bolstad, P. (2012). GIS Fundamentals, Fourth Edition, Eider Press, White Bear Lake, MN, 674 p.