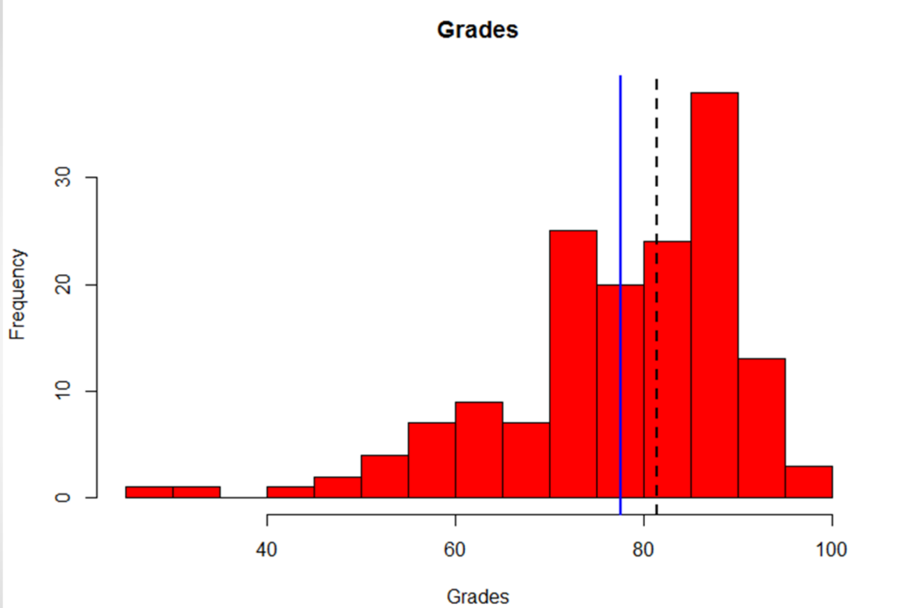
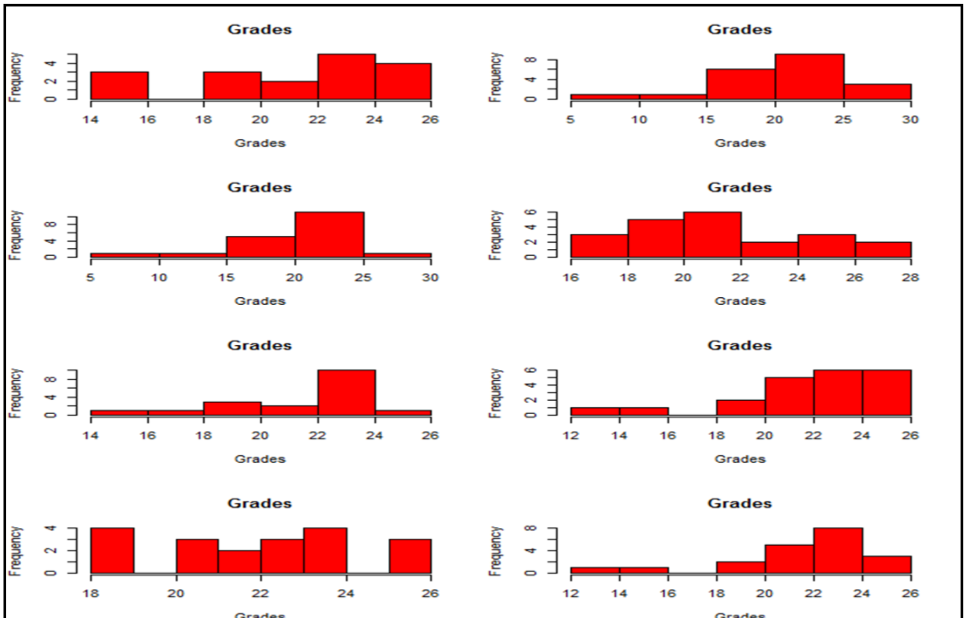


- **Min = 25**
- **Max = 96.43**

- **Mean = 77.55**
- **Max = 81.48**



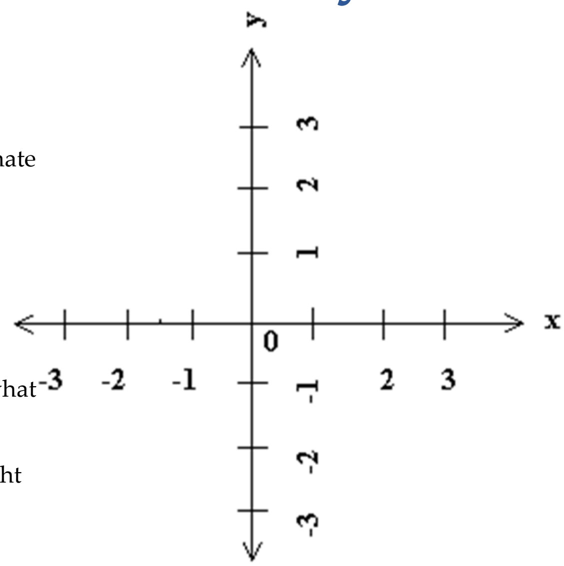
Coordinate Systems and Projections

GIS and the Need for a Reference System

- Both data models:
  - Rasters
  - Vectors
- Require a projection (coordinate system) defined ahead of time
- Why is it so important?
  - Draw things
  - Overlay things
  - Measure how far things are
  - Calculate area

Basic Coordinate System

If your data is not overlaying properly, its most likely due to data stored in different coordinate systems



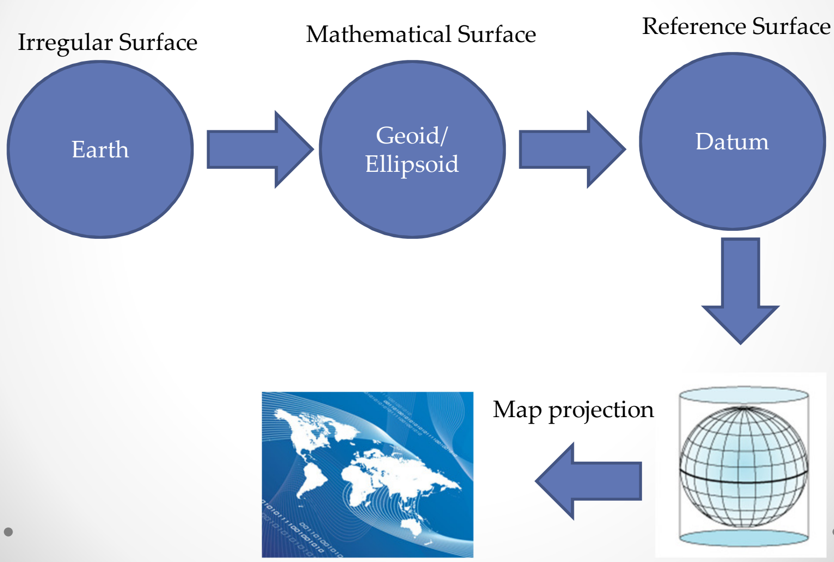
So back to our first question, what is a coordinate system? If you have had a class in Algebra or Geometry, this figure to the right will look familiar.

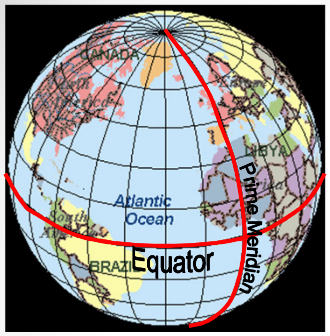
Coordinate Systems

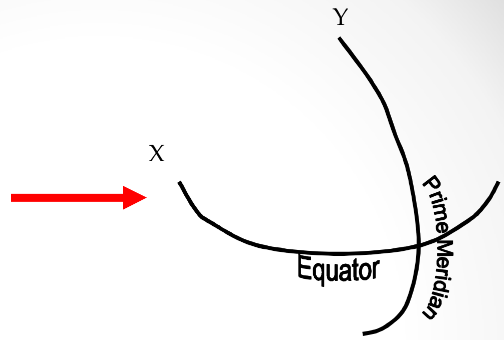
- There are 2 types of coordinate systems:
  - **Geographic Coordinate Systems**
  - **Projected Coordinate Systems**

What is the most faithful map representation of the earth?

- A globe!



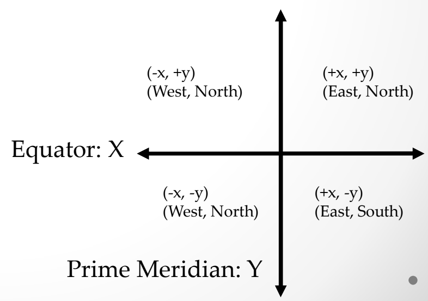




The intersection of the Prime Meridian and the Equator form the axes of the geographic coordinate system

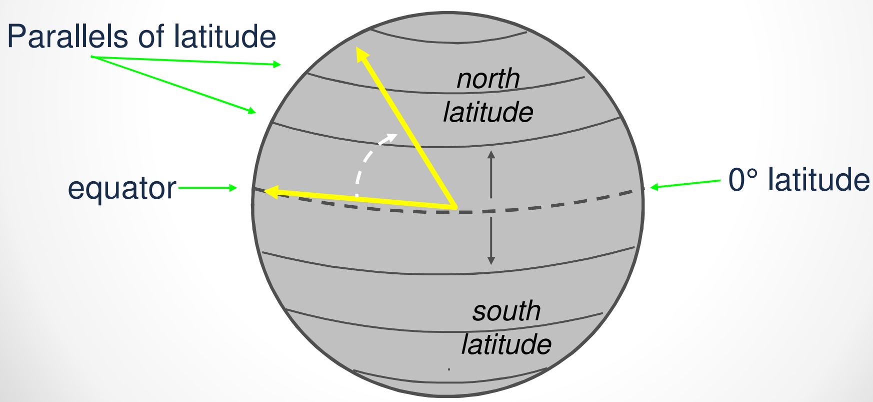
"Flatten out" the axes and the coordinate plane is like the one to the right

Longitude is the X coordinate
Latitude is the Y coordinate



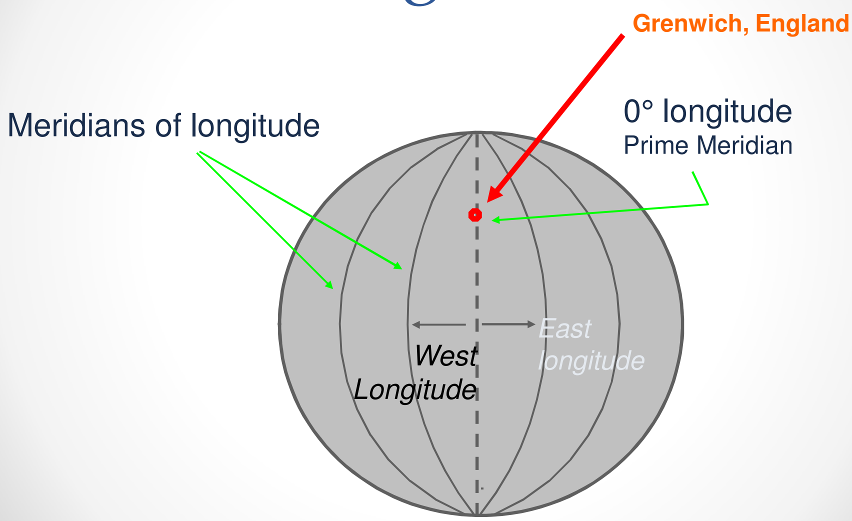
Lat / Long Coordinate System

Latitude



Lat / Long Coordinate System

Longitude



Geographic Coordinate System

- The latitude and longitude define the location of points on the surface of a sphere or spheroid ➔ Units are in:
  - Decimal Degrees (**DD**) -92.5
  - Degrees/Minutes/Seconds (**DMS**) 92° 30′ 00″ W

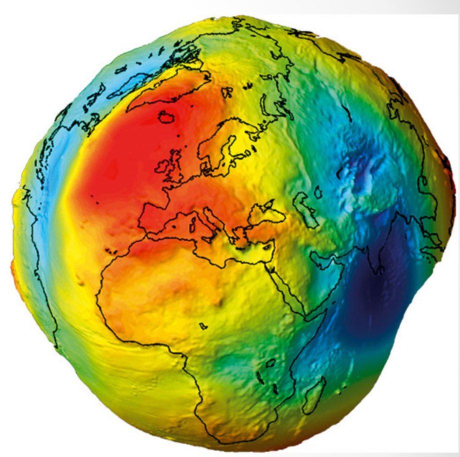
Geographic Coordinates (ϕ, λ, z)

- Latitude (ϕ) and Longitude (λ) defined using an **ellipsoid** ➔ an ellipse rotated about an axis
- It is a model of the earth
- Elevation (z) defined using **geoid**, a surface of constant gravitational potential
  - Better than MSL

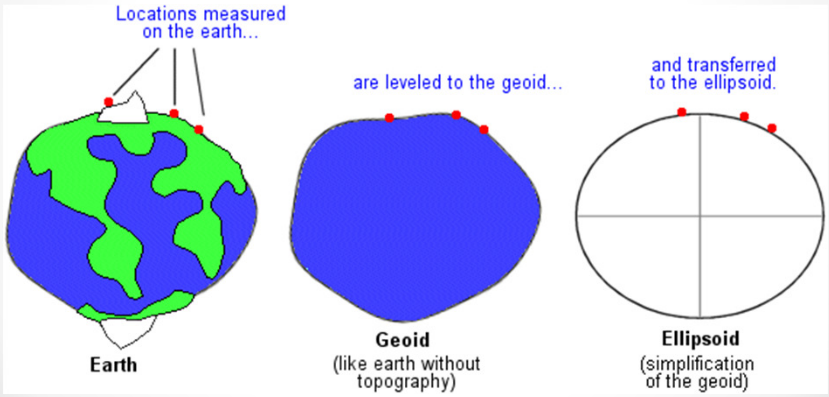
Geographic Coordinate System

- Earth is not a sphere
- Poles are flattened
- Bulges at equator

- Earth is a spheroid or **ellipsoid**

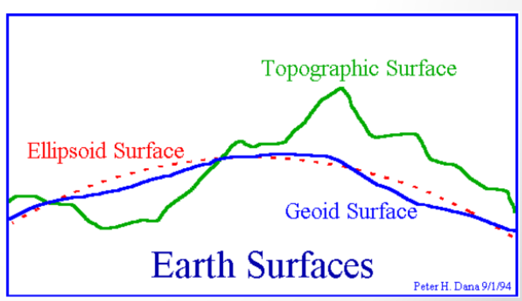


The Earth's Shape



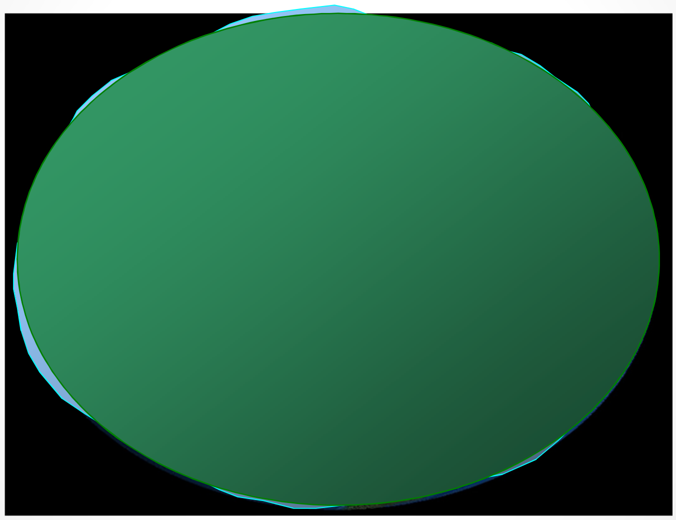
Geographic Coordinate System

- Spheroid **approximates** the shape of the earth
  - It is a model of how the earth looks



"Figure" of the Earth

Best-fit ellipsoid
(e.g., GRS-80, WGS-84)

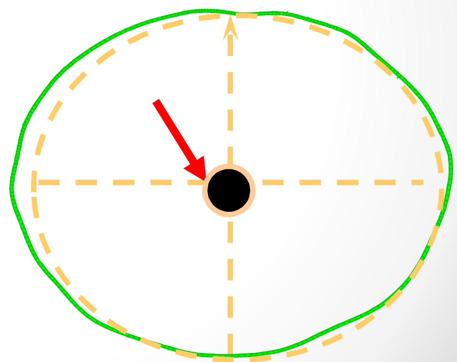


Geographic Coordinate System

- All models require a center ➔ **Datum**
- A **datum** defines the position of the spheroid relative to the center of the earth
  - Origin and orientation of latitude and longitude lines are determined by the datum
  - Hundreds of datums
  - WGS84 is a worldwide datum that we will be using

WGS84: WGS84 ellipsoid origin center of earth

- The origin of the spheroid is at the center of the earth's mass ➔ ideal for a GPS datum
- Used by all GPS locations



Datums vs. Spheroids

- A datum is essentially the model that is used to translate a spheroid into locations on the earth
- A different datum is generally used for each spheroid
- Prior to satellites, datums were realized by referenced survey monuments (250,000+) with known position
- These monuments were connected by a network of measurements enabling the computation of a position

Satellite Based Datums

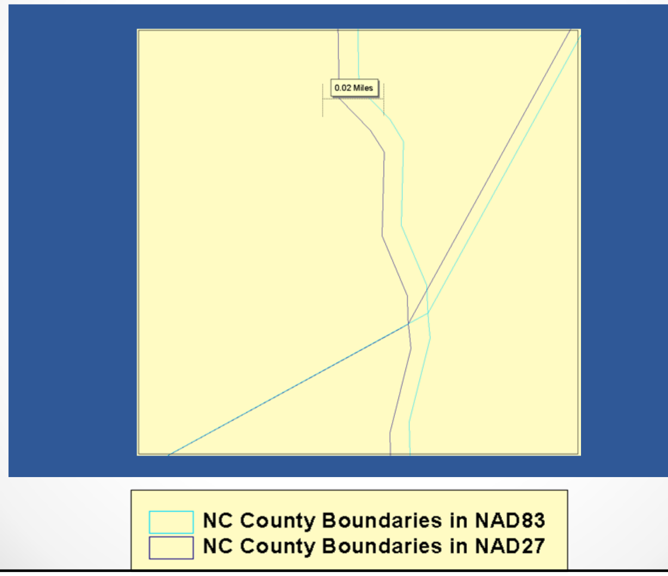
- The errors of the old datums stem from fact they used the surface of the earth as the reference point
- With satellite measurements the **center of the spheroid** can be matched with the center of the earth
- This allows a spheroid to correctly map the earth such that all Latitude/Longitude measurements from all maps created with that datum agree

Datums-things to remember

- Lat/long coordinates calculated with one datum are valid only with reference to that datum.
- This means those coordinates calculated with NAD 27 are in reference to a NAD 27 earth surface, not a NAD 83 earth surface.
- To be viewed in NAD 83, their position must be recalculated and they will be given new coordinates.

Datum Differences May Be Difficult to See

Errors up to 1 km can result from confusing one datum for another



Geographic Coordinate System

- Lat/lon good for locating positions on surface of a globe
- **Lat/lon is not efficient for measuring distances and areas!**
  - Latitude and longitude **are not uniform units of measure**
  - One degree of longitude at equator = 111.321 km (Clarke 1866 spheroid)
  - One degree of longitude at 60° latitude = 55.802 km (Clarke 1866 spheroid)

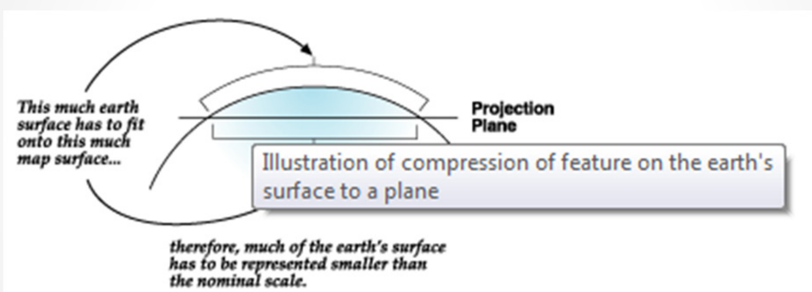
Flattening the Earth

Projections and Coordinates

- There are many reasons for wanting to project the Earth's surface onto a **plane**, rather than deal with the curved surface
  - The paper used to output GIS maps is flat
  - Flat maps are scanned and digitized to create GIS databases
  - Square and rectangular rasters are flat
  - The Earth has to be projected to see all of it at once
  - It's much easier to measure distance on a plane

Projected Coordinate Systems

- Projected Coordinate Systems **mathematically transform** the 3 dimensional earth so that it can be modeled in 2 dimensions.
- This results in distortion
- Different projections are used for different areas and purposes



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Projected Coordinate Systems

- A map projection is the systematic transformation of locations on the earth (latitude/longitude) to **planar coordinates**
- It is the method which translate your position on the globe or geoid into an position on a **two-dimensional map**
- The basis for this transformation is the geographic coordinate system (which references a datum)
- **All projections have errors**
- Map projections are designed for specific purposes that minimize a particular kind of error

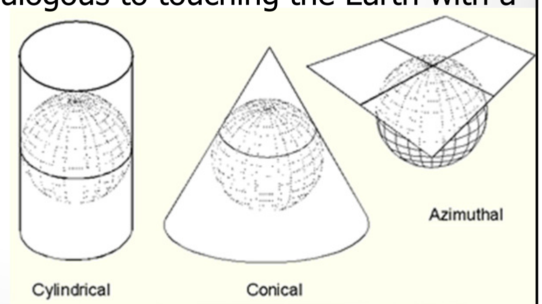
Projecting the World

- This process of flattening the earth will cause distortions in one or more of the following spatial properties:
- **Shape**
  - **Conformal** map projections preserve shape
- **Area**
  - Equal area map projections preserve area
- **Distance/Scale**
  - Equidistant map projections preserve distance
- **Direction/Angle**
  - Azimuthal map projections preserve true direction

Map Projections

Different projection systems have been developed:

- **Cylindrical** - analogous to wrapping a cylinder of paper around the Earth, projecting the Earth's features onto it, and then unwrapping the cylinder
- **Conical** – analogous to wrapping a sheet of paper around the Earth in a cone
- **Azimuthal or planar** - analogous to touching the Earth with a sheet of flat paper

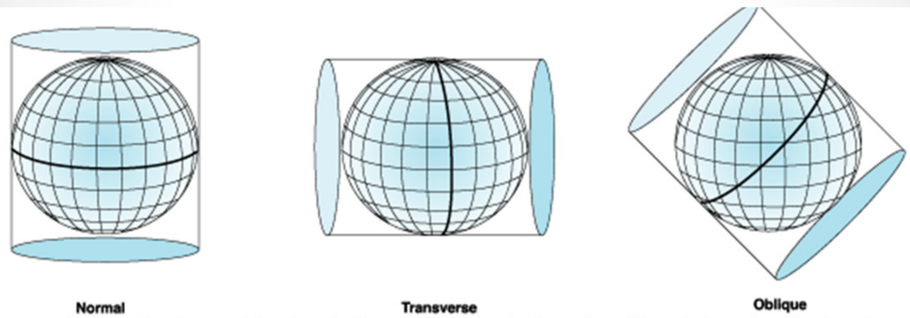


Cylindrical Projections

- The Mercator projection is the best-known cylindrical projection

- The cylinder is wrapped around the Equator
- The projection is **conformal**
  - Shape of small features is preserved
  - Features in high latitudes are significantly enlarged but retain their shape

Cylindrical Projections



A cylinder is placed over a globe. The cylinder can touch the globe along a line of latitude (normal case), a line of longitude (transverse case), or another line (oblique case).

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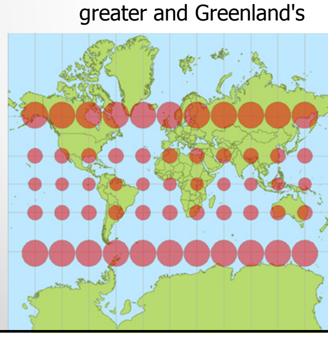
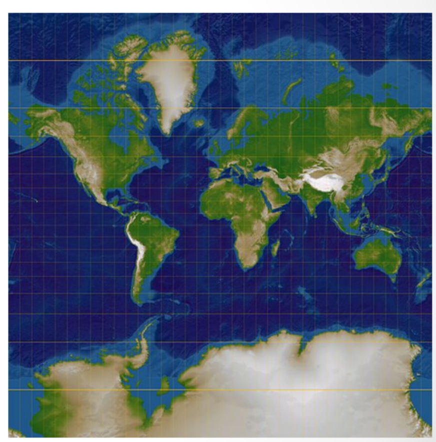
Mercator Projection

- The Mercator projection exaggerates areas far from the equator
- For example:
  - Greenland takes as much space on the map as Africa
  - In reality Africa's area is 14 times greater and Greenland's





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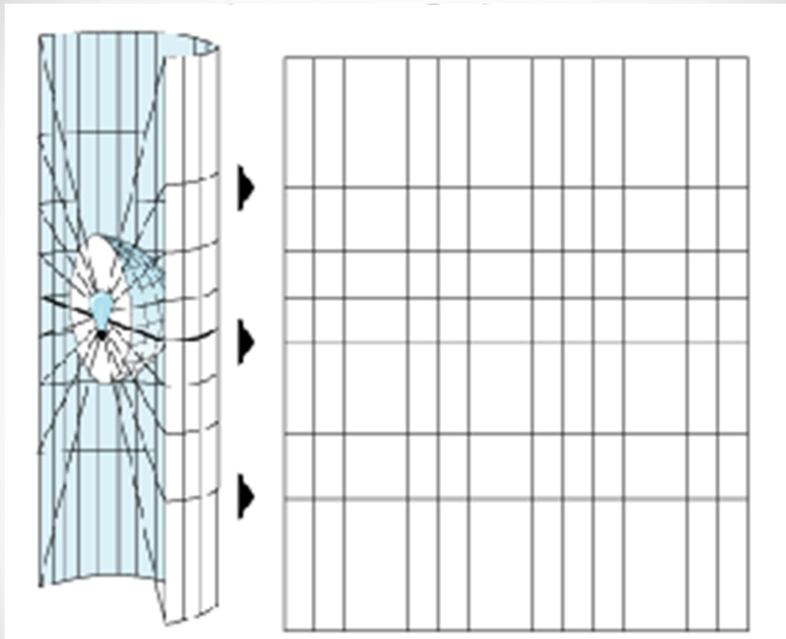
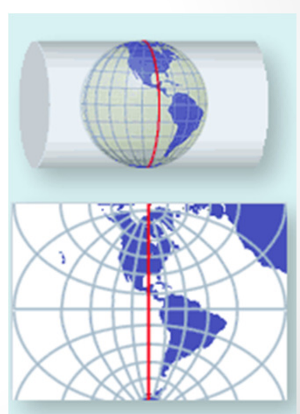
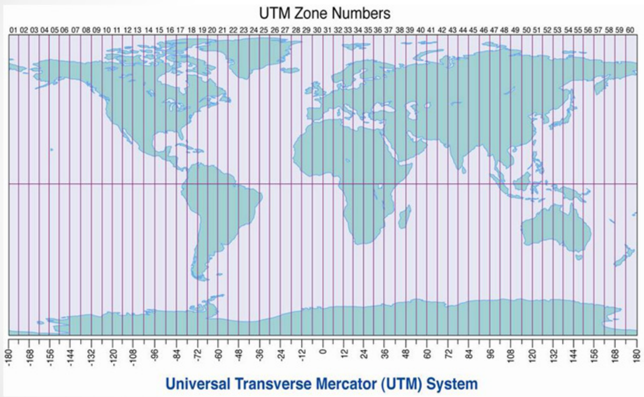


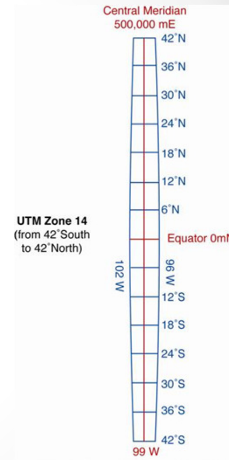
The Universal Transverse Mercator (UTM) Projection

- A type of cylindrical projection
- Implemented as an internationally standard coordinate system
  - Initially devised as a military standard
  - Uses a system of 60 zones
  - Maximum distortion is 0.04%
- *Transverse* Mercator because the cylinder is wrapped around the Poles, not the Equator



The Universal Transverse Mercator (UTM) Projection





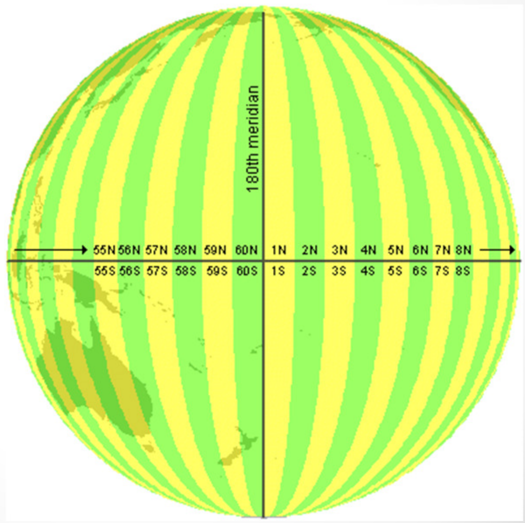
- **The UTM system is not a single map projection**
- **Zones are each six degrees of longitude, numbered as shown at the top, from W to E**

Implications of the UTM Zone System

- UTM coordinates are in **meters**
- Because each zone defines a different projection (60 different projections!) maps will not fit together across a zone boundary
- Zones become a problem at high latitudes (especially for cities that cross boundaries!)
- Jurisdictions that span two zones must make special arrangements
  - Use only one of the two projections, and accept the greater-than-normal distortions in the other zone
  - Use a different projection spanning the jurisdiction

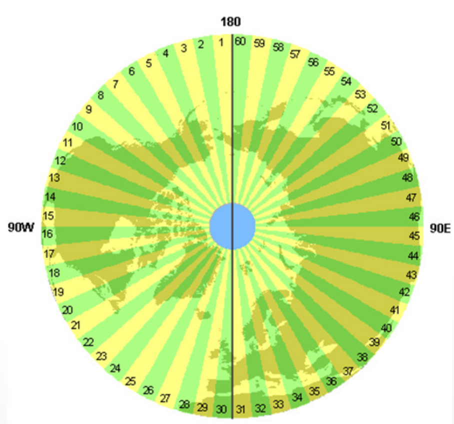
Universal Transverse Mercator

- UTM zones



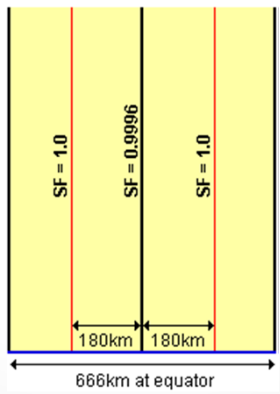
UTM Zones

- .. as seen from the North Pole



UTM Projections

- Each zone uses a custom Transverse Mercator projection with its own central meridian

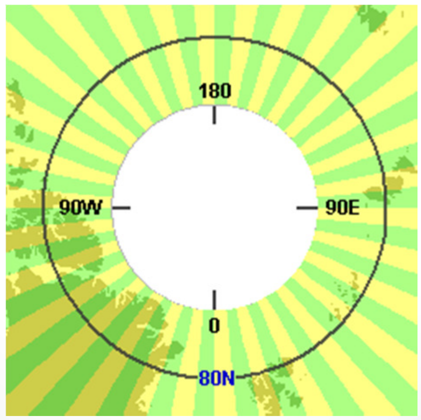


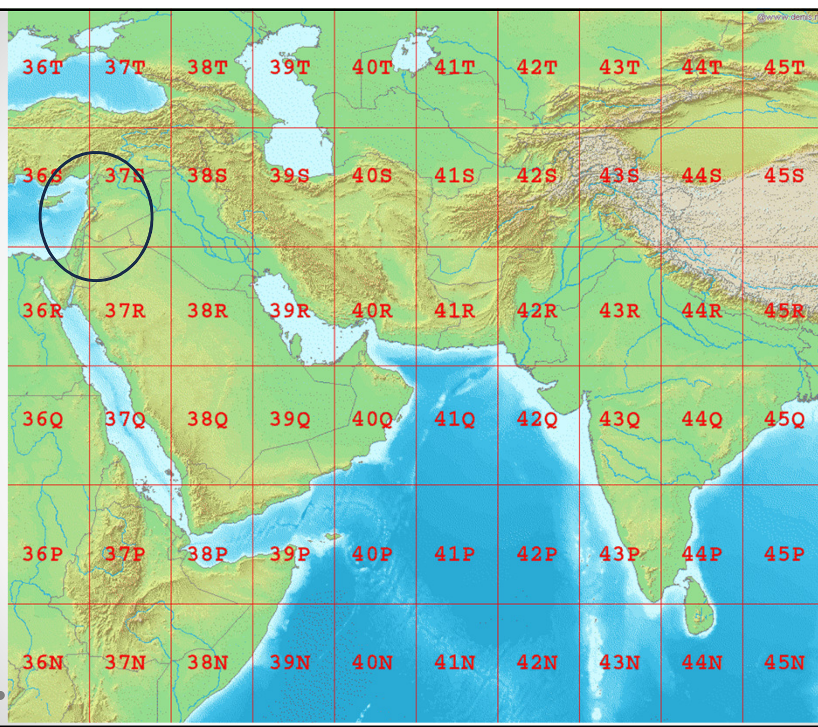
UTM projection

- Scale distortion is 0.9996 along the central meridian of a zone
- There is no scale distortion along the standard meridians
- Scale is no more than 0.1% in the zone
- Scale distortion gets to unacceptable levels beyond the edges of the zones
- Shapes of small shapes preserved; shapes of large shapes minimally distorted within the zone
- Local angles are true ➔ Direction preserved
- Distance is constant along the central meridian

Universal Polar Stereographic

- Fills the holes of UTM in polar regions





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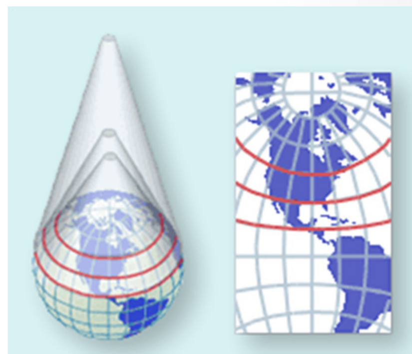
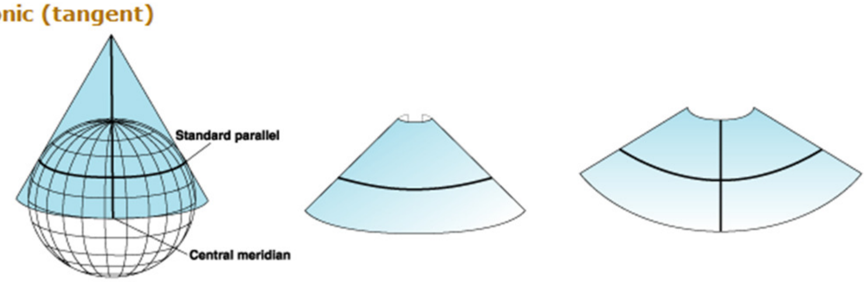
Conic Projections

Conceptualized as the result of wrapping a cone of paper around the Earth

- The most simple Conic projection is **tangent** to the globe along a line of latitude ➔ known as the standard parallel
- The Lambert Conformal Conic projection is commonly used to map North America
  - Preserves what?
- On this projection lines of latitude appear as arcs of circles, and lines of longitude are straight lines radiating from the North Pole

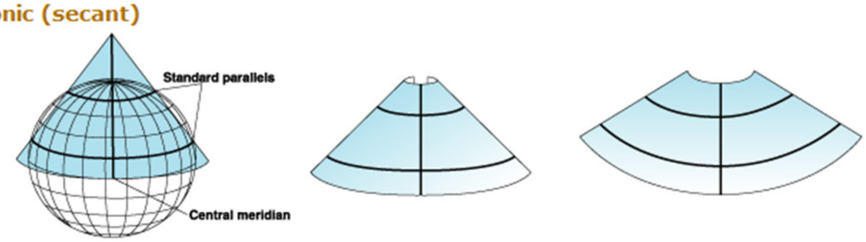


Conic (tangent)



A cone is placed over a globe. The cone and globe meet along a latitude line. This is the standard parallel. The cone is cut along the line of longitude that is opposite the central meridian and flattened into a plane.

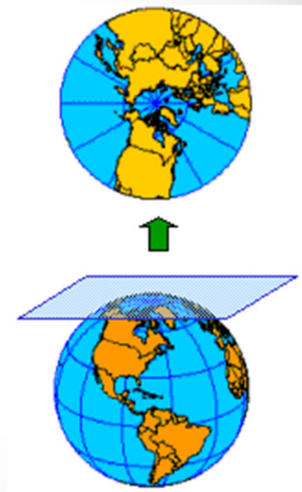
Conic (secant)

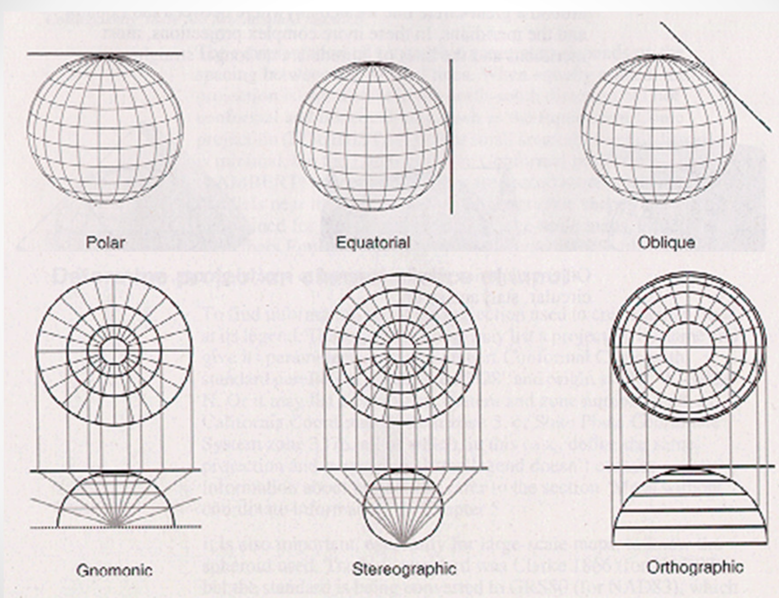


A cone is placed over a globe but cuts through the surface. The cone and globe meet along two latitude lines. These are the standard parallels. The cone is cut along the line of longitude that is opposite the central meridian and flattened into a plane.

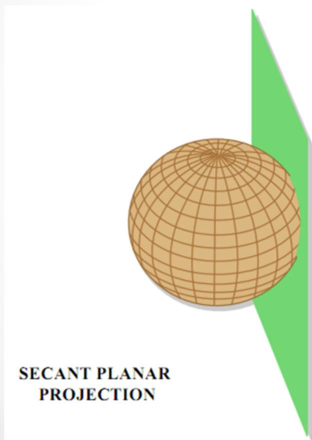
Planar Projections

- Planar projections project map data onto a flat surface touching the globe
- A planar projection is also known as an azimuthal projection or a zenithal projection
- Usually tangent to the globe at one point but may be secant also





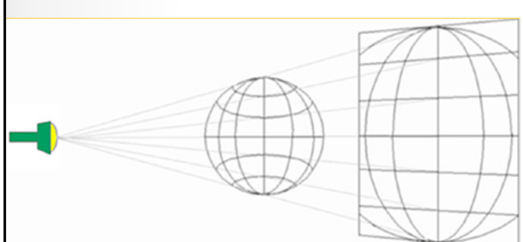
Planar Secant Projection

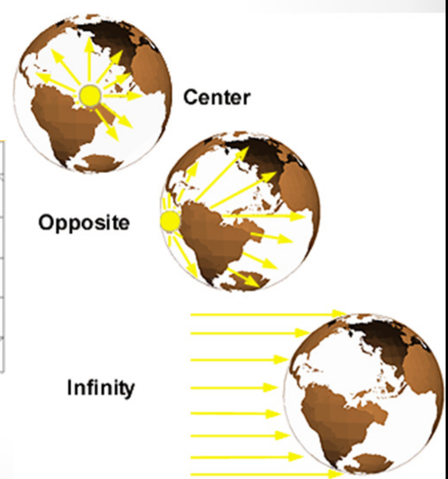


- Earth intersects the plane on a small circle
- All points on circle have no scale distortion

Perspective

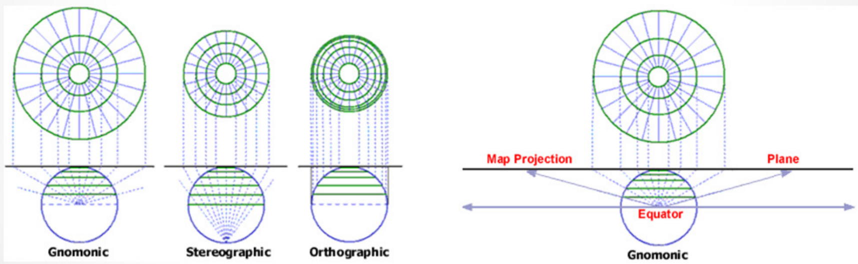
- In addition to the type of projection there are many perspectives
- **Perspectives** → Position of the light source





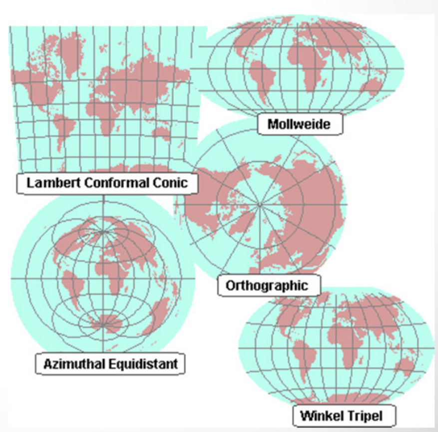
Perspectives

- 3 perspectives for polar planar



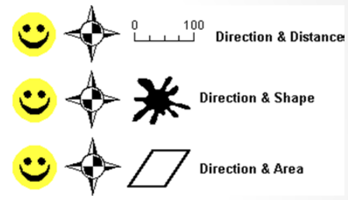
Understanding Distortion

- Distortion cannot be avoided ➔ Geometry ➔ Orange peel
- We have to choose the from distortion we can live with
  - **Shape**
  - **Area**
  - **Distance**
  - **Direction**

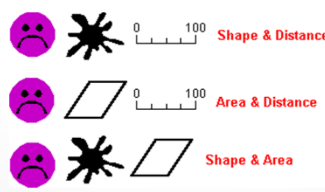


Preserving Properties

- If two properties are to be preserved then one is always direction



- These properties are incompatible:



No flat map can be both equivalent and conformal

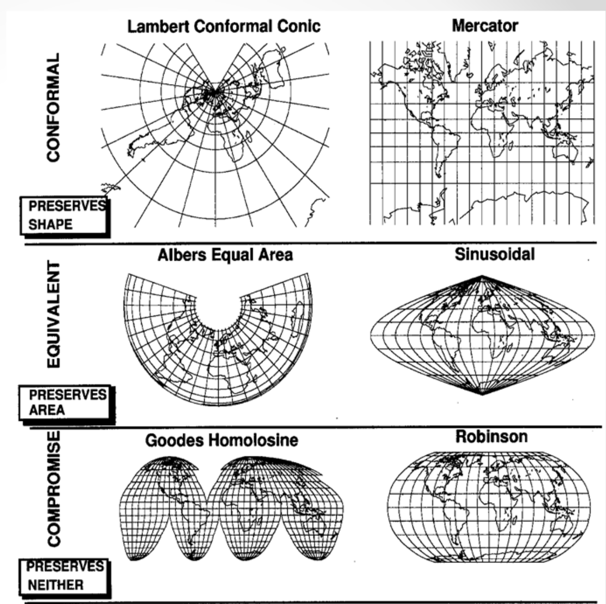
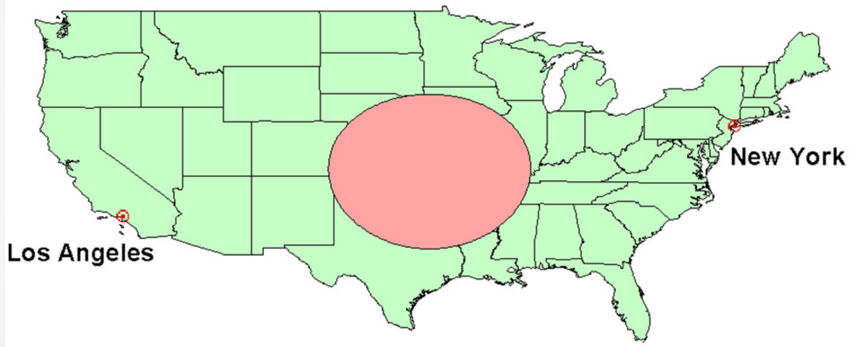
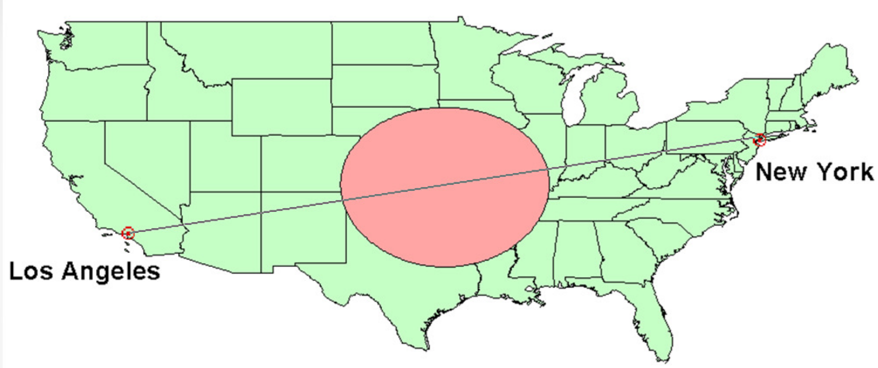


Figure 2.9 Examples of projections classified by their distortions. Conformal projections preserve local shape, equivalent projections preserve area, while compromise projections lie between the two. No projection can be equivalent and conformal.



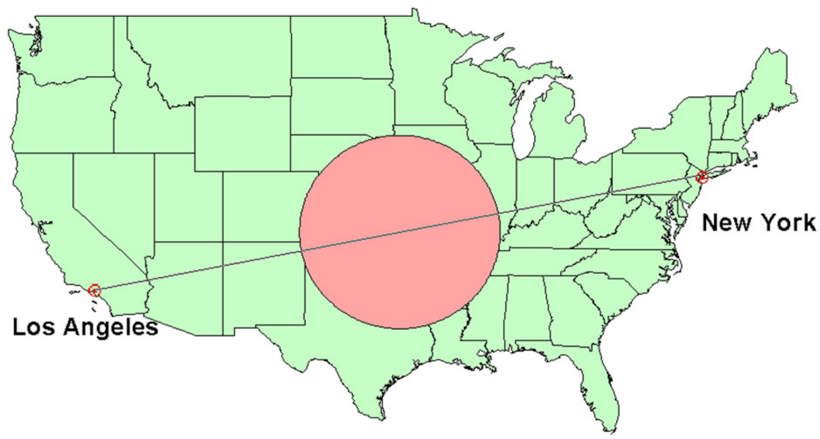
Distance Units: Decimal Degrees
Projection: None

No projection



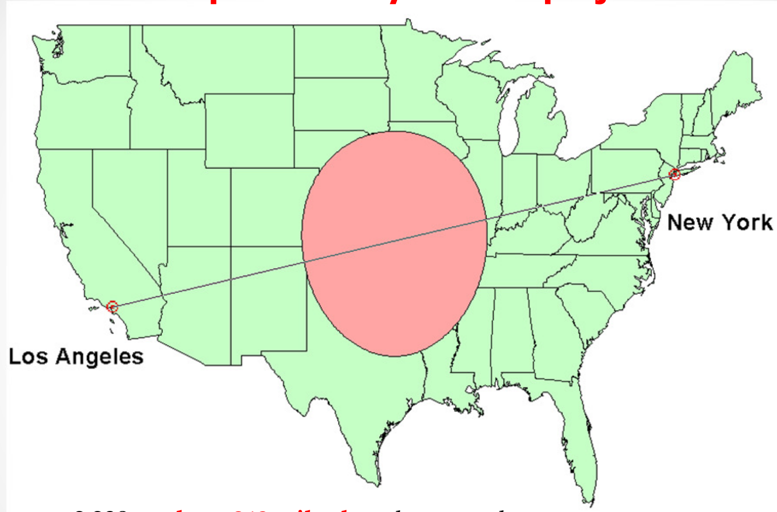
Undistorted distance measurement is **2451 miles**

Mercator projection



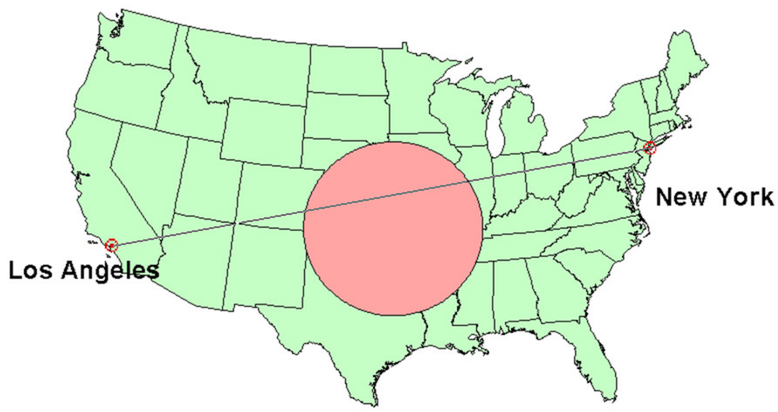
Distance = 3,142 miles…**691 miles further**
Changing to the Mercator projection shows shapes and direction accurately, but sacrifices distance and area

Peters Equal-Area Cylindrical projection



Distance = 2,238 … **about 213 miles less** than actual
Peters Equal-Area Cylindrical projection preserves area but sacrifices shape, distance, and direction.

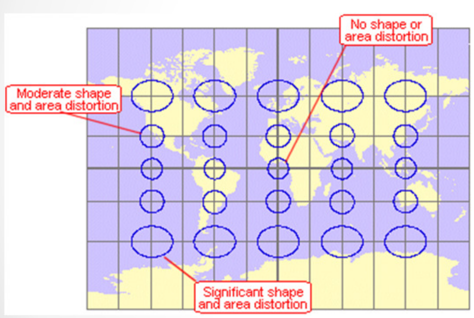
Equidistant Conic (Coterminous U.S.)

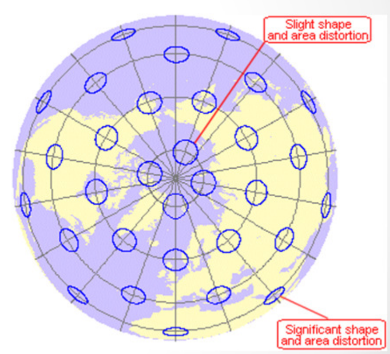


Distance = 2,452 (**almost the same as original**)

Projection preserves shape and accurate east-west distances, but sacrifices direction and area

Tissot Indicatrices





Choosing a Map Projection

Characteristics of Map Projections

Projection Category	Properties	Common Uses
Conformal	Preserves local shapes and angles	Topographic maps, navigation charts, weather maps
Equal Area	Preserves areas	Dot density maps, thematic maps
Equidistant	Preserves distance from one or two specified points to all other points on the map	Maps of airline distances, seismic maps showing distances from an earthquake epicenter
Azimuthal	All directions are true from a single specified point (usually the center) to all other points on the map	Navigation and route planning maps
Compromise	No point is completely distortion free; distortion is minimized near the center and along the equator	World maps

Readings:

http://resources.arcgis.com/

In ArcGIS Desktop 10 Help library/ Professional library/ Guide books/ Map projections

- Map projections
  - What are map projections?
  - Projection basics for GIS professionals
  - The geoid, ellipsoid, spheroid and datum
  - Identifying an unknown coordinate system
  - Converting Degrees Minutes Seconds values to Decimal Degree values
  - Geographic coordinate systems
  - Projected coordinate systems
  - Geographic transformations
  - Vertical coordinate systems
    - What are vertical coordinate systems?
    - Vertical datums
    - Geoid
  - Supported map projections

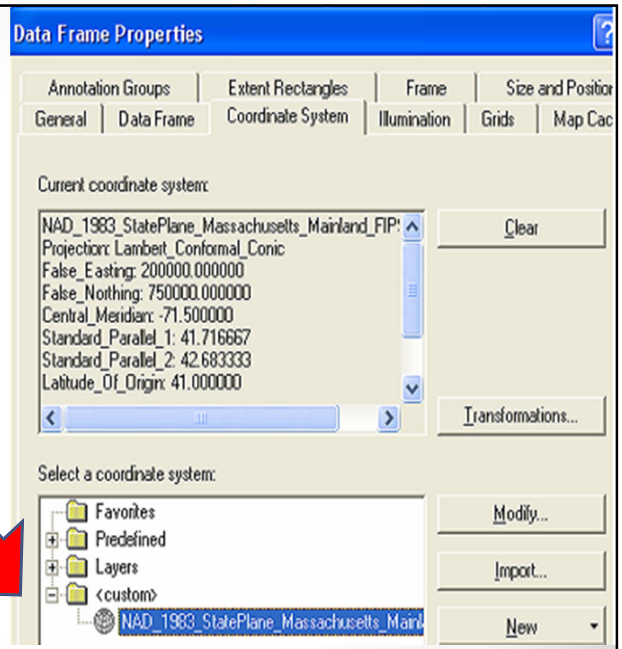
ArcGIS Projections

- By default, ArcGIS will display your map using the coordinate system (map projection) of the first layer you added
- ArcGIS can handle data in different coordinate systems as long as the projection/coordinate system of each data set is defined in a way that the software can understand
- Typically this means a shape file has a .prj file in addition to all the other files that make up the data set (e.g., parks.prj)
- When you pull up data in different coordinate systems, ArcGIS tries to use the information in the various.prj files to project all the layers into one projection so that they all correctly overlay each other
- Other layers are transformed on the fly (visually)
- A common problem in using GIS data arises when different data sets are in different map projections/coordinate systems

Projections in ArcGIS

- When you first add data to an ArcMap data frame, the dataframe sets itself to the coordinate system of the first data set to load
- If the first data set has a .prj file, the data frame takes on the coordinate system specified in that .prj file
- If the first data set has no defined coordinate system, the dataframe coordinate system remains unknown
- You can tell what coordinate system your data frame is in by right-clicking on the data frame in the ArcMap table of contents and choosing Properties
- Go to the Coordinate System tab ➔ You will either see coordinate system parameters or you will see that it says unknown

- You can change the projection from there
- It has all the projection systems supported by Arc



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Projections in ArcGIS

- Every data set is in some coordinate system
- But in ArcGIS and its predecessors, it was and is possible to create data without explicitly documenting the map projection or coordinate system
- There is lots of GIS data out there with no defined coordinate system, especially in Lebannon

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Spatial Reference = Datum + Projection + Coordinate system

- For consistent analysis the spatial reference of data sets should be the same
- ArcGIS does projection on the fly so can display data with different spatial references properly ***if they are properly specified***
- ArcGIS terminology
  - **Define projection:** Specify the projection for some data without changing the data
  - **Project:** Change the data from one projection to another

In ArcGIS …

- Arctoolbox contains the projection tools:
  - **DEFINE**
  - **PROJECT**
- These are two different tools:
  - Use **DEFINE** to define the projection of a data layer for which the projection is undefined
  - Use **PROJECT** when you want to project the data into a new or desired projection
  - DO NOT EVER USE DEFINE to put a data set into the desired projection – that will really mess things up
- In ArcToolbox, the DEFINE and PROJECT tools are found under **Data Management Tools** – Projections and Transformations
  - The DEFINE PROJECTION tool is there
  - The PROJECT tool for vector data is found under **FEATURES**
  - The PROJECT tool for Raster data is found under **RASTER**

Define versus **Project**: a critical distinction!

Define

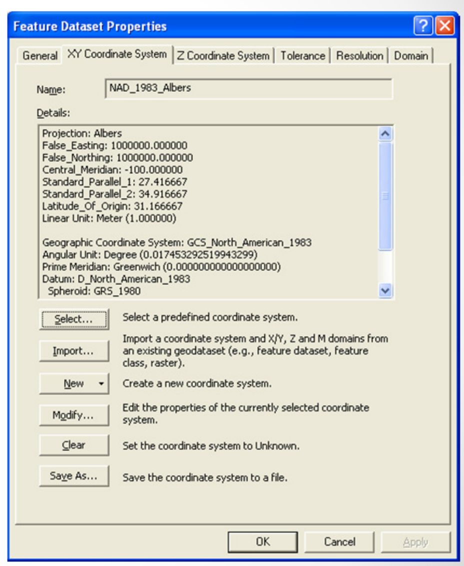
- Informs the ArcGIS system of the data's actual, current projection
- Is essentially metadata ➔ For shapefiles and coverages, saved in a *.prj* file
- Does <u>not</u> change the actual data ➔ No new file created
- Define it wrong, and all subsequent analyses or projections of that data are likely to be wrong!

Project

- Actually projects the data. Think of this as "*<u>re</u>*project"
- The data *does* change ➔ New file!!!
- The current projection (input) <u>must already be known</u> by the ArcGIS system,
  - That is, you have to do a **Define** first, if somebody has not already done it
- The <u>desired</u> projection (output) is specified on the **Project** command

ArcGIS Spatial Reference Frames

- Defined for a feature dataset in ArcCatalog
- XY Coordinate System
  - Projected
  - Geographic
- Z Coordinate system
- Tolerance
- Resolution
- M Domain



Summary Concepts

- The spatial reference of a dataset comprises datum, projection and coordinate system.
- For consistent analysis the spatial reference of data sets should be the same.
- ArcGIS does projection on the fly so can display data with different spatial references properly ***if they are properly specified.***
- ArcGIS terminology
  - **Define projection.** Specify the projection for some data without changing the data.
  - **Project.** Change the data from one projection to another.

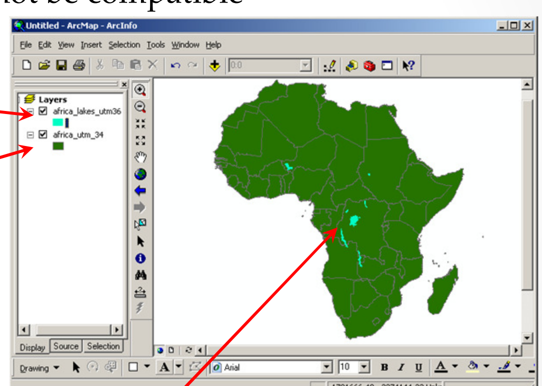
Projecting Spatial Data Sets

Used for going **between** projections

Source data may not be compatible

UTM 36

UTM 34

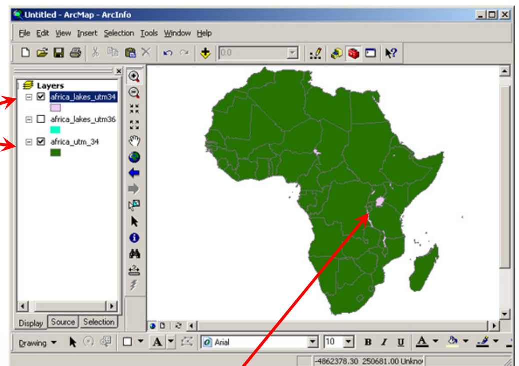


Lake Victoria is **not** in central Africa

Projecting spatial data sets

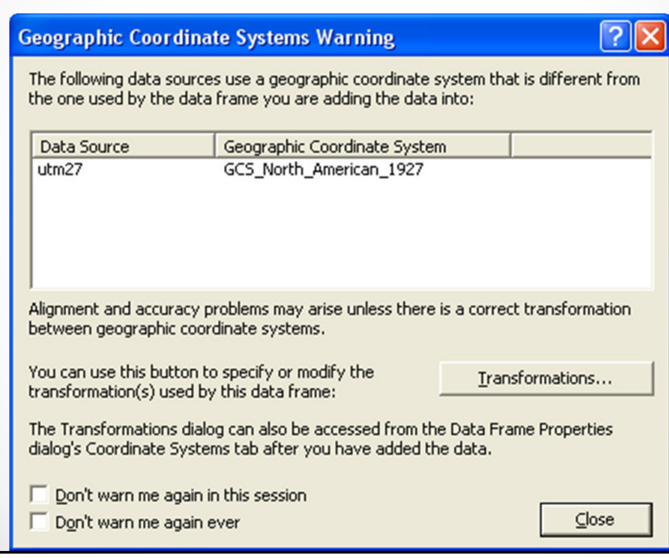
- Used for going between projections
- Data sets are now compatible

both are now UTM 34



Lake Victoria really **is** in east Africa

Warning: different geographic coordinate system…



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