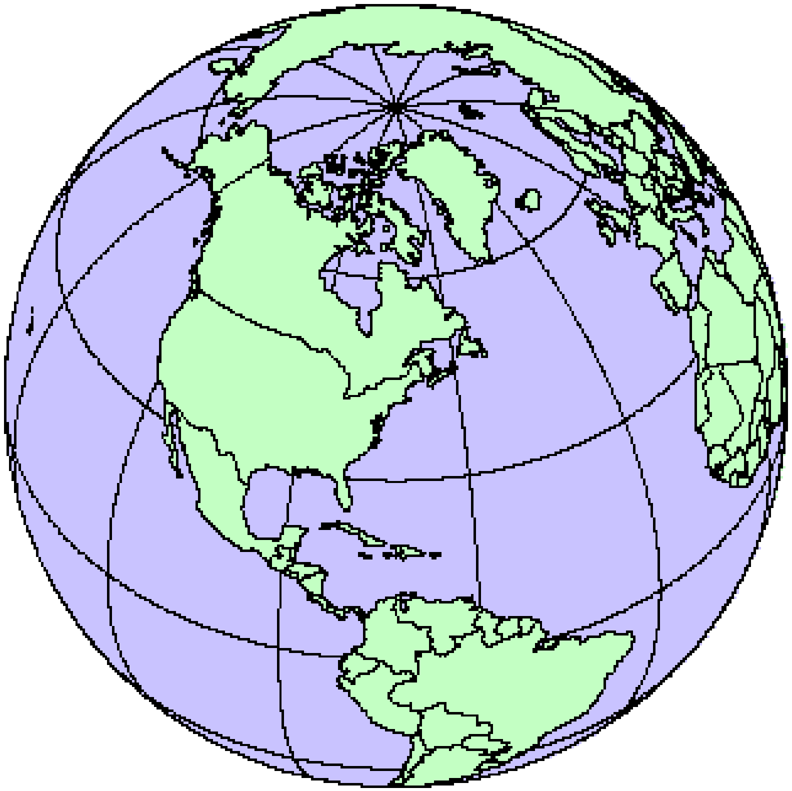
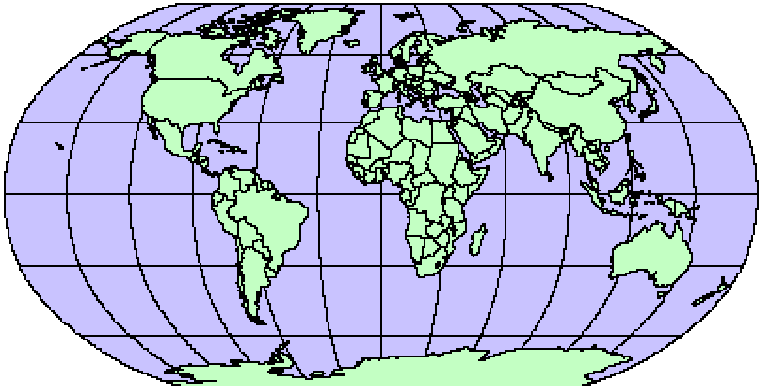
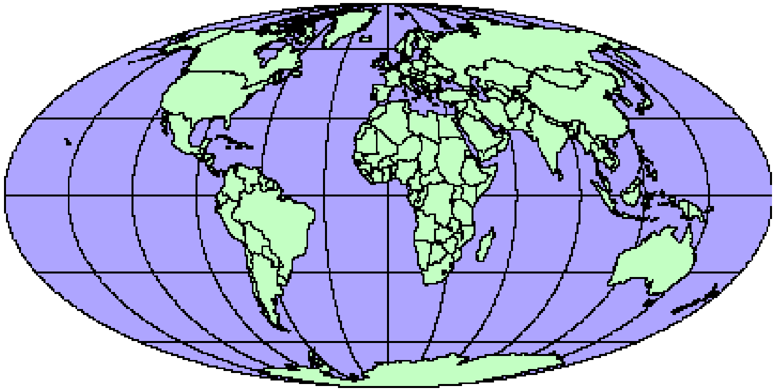
Map Projections & Coordinate Systems







From Last Time – Earth Datums

Datum = Reference surface

- **Horizontal Datum** – a reference ellipsoid, of a specific size and placement, for deriving and recording Lat. & Long.
  - Smaller ellipsoids will give different Lat. & Long. than larger; geocentric give different result than nongeocentric
- **Vertical Datum** – a reference surface of zero elevation
  - an equipotential surface of gravity, the **Geoid** (Orthometric Heights); e.g. NAVD88, EGM08, NVVD1929
  - a reference ellipsoid (ellipsoid heights or Heights above Ellipsoid, H.A.E.); e.g. WGS84, NAD83
- **Datum Shifts** – Differences in horizontal datums result in **differences in Lat. & Long. for the same point**, therefore we must know the datum before plotting the point or it can be “shifted” from its actual location.

Laying the Earth Flat

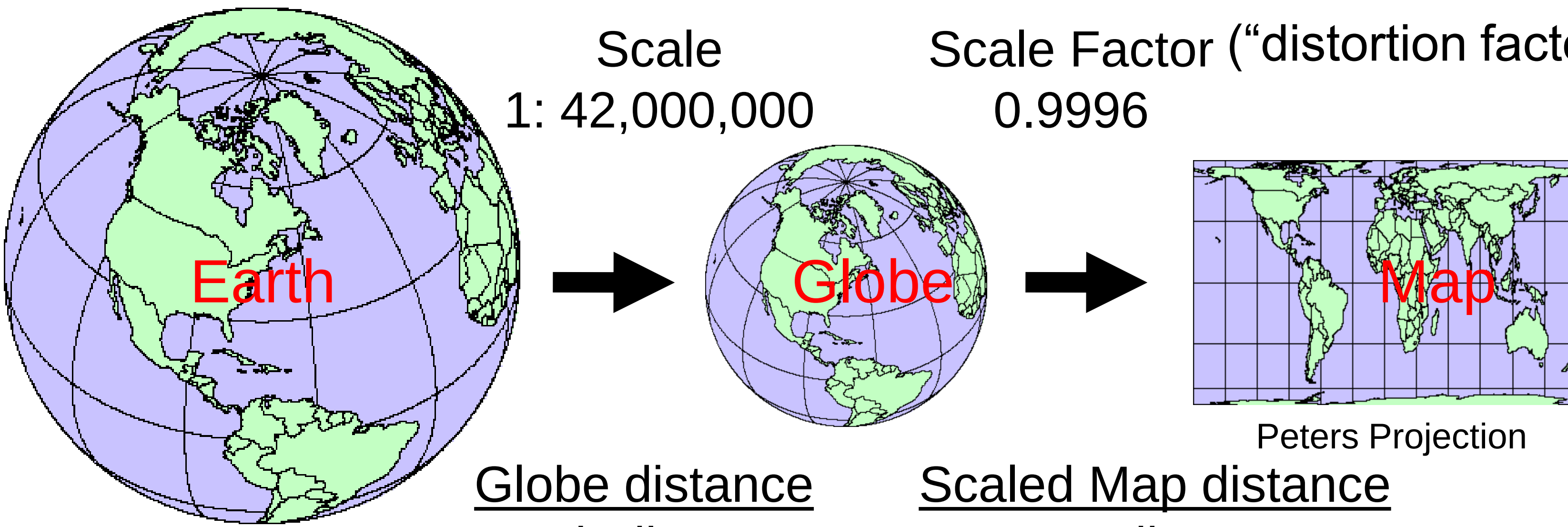
- Why?
  - Need convenient means of measuring and comparing distances, directions, areas, shapes in Cartesian coordinates
  - Traditional surveying instruments measure in meters or feet, not degrees of lat. & lon.
  - Globes are bulky and can't show detail.
    - 1:24,000 globe would have diameter of ~ 13 m
    - Typical globe has scale of ~ 1:42,000,000
  - Distance & area computations more complex on a sphere.

Laying the Earth Flat

- How?
  - Projections – transformation of curved earth to a flat map; systematic rendering of the lat. & lon. graticule to rectangular coordinate system.

Scale
1: 42,000,000

Scale Factor ("distortion factor")
0.9996

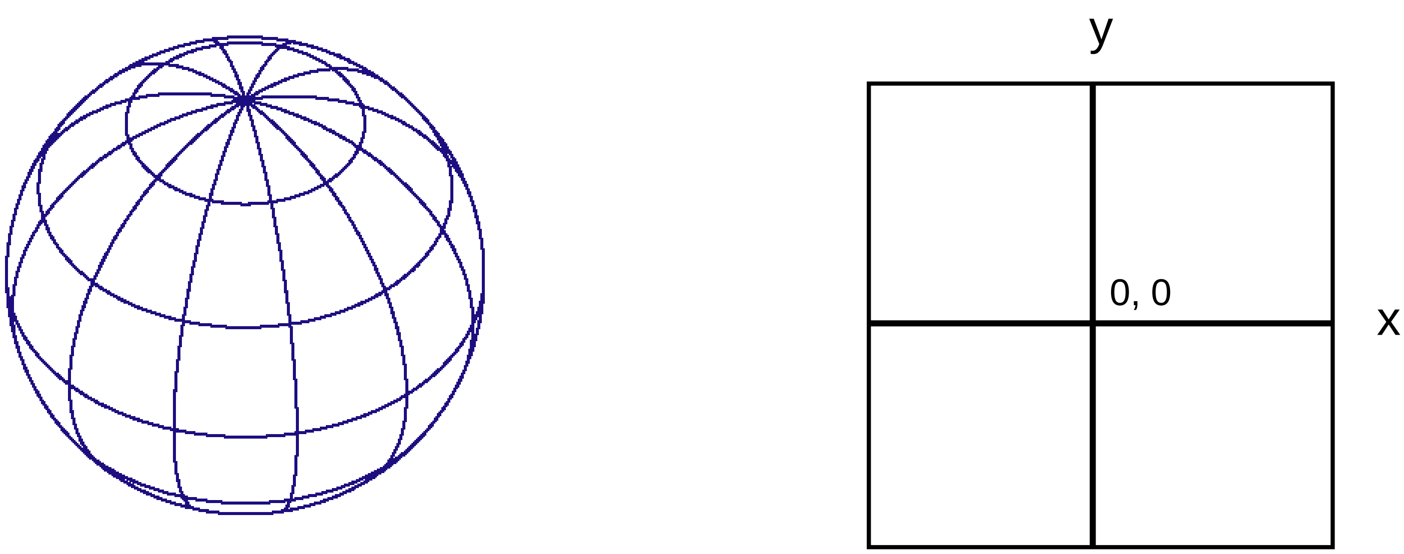


Peters Projection

$$\text{Scale} = \frac{\text{Globe distance}}{\text{Earth distance}} \qquad \text{Scale Factor} = \frac{\text{Scaled Map distance}}{\text{True distance}}$$

Laying the Earth Flat

- Systematic rendering of Lat. (ϕ) & Lon. (λ) to Cartesian (x, y) coordinates:

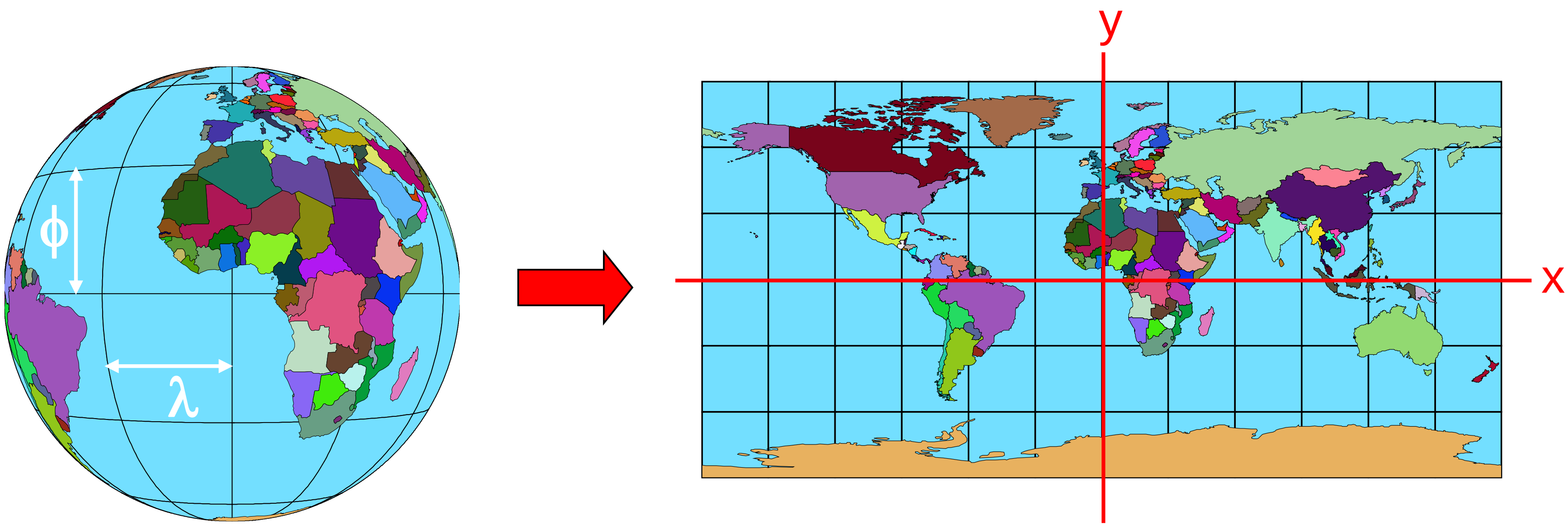


Geographic Coordinates (ϕ, λ) ⟷ Projected Coordinates (x, y)

Map Projection

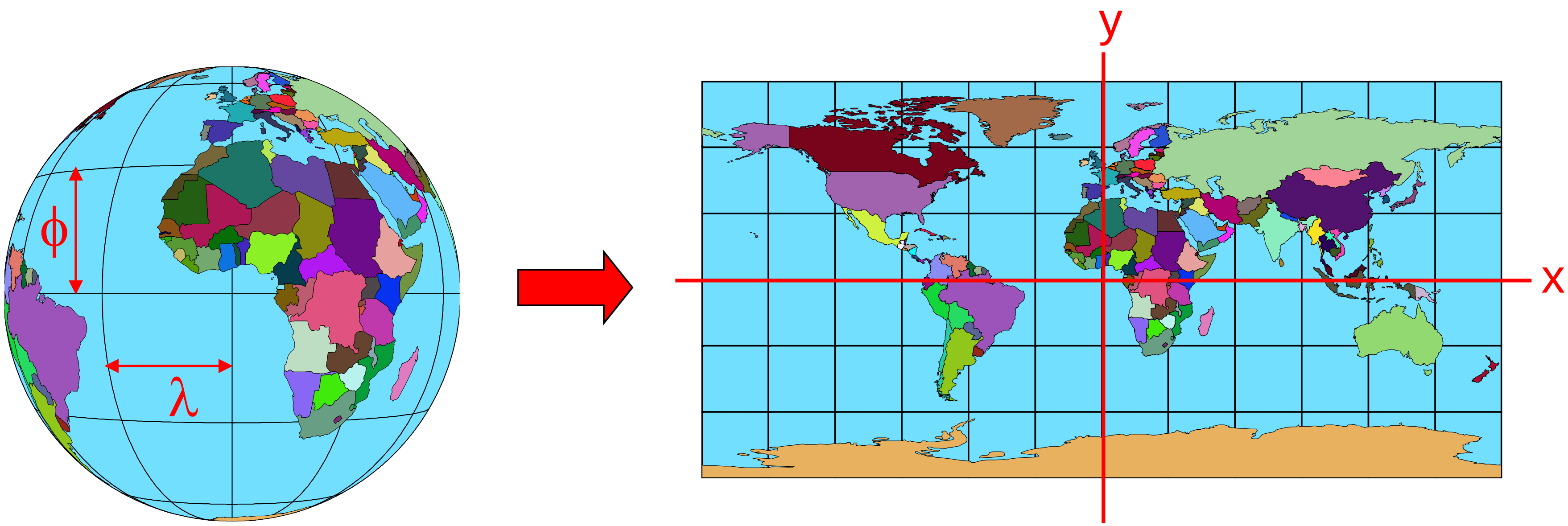
Laying the Earth Flat

- "Geographic" display – no projection
  - x = λ, y = ϕ
  - Grid lines have same scale and spacing



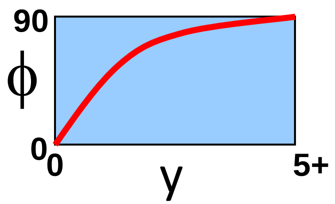
“Geographic” Display

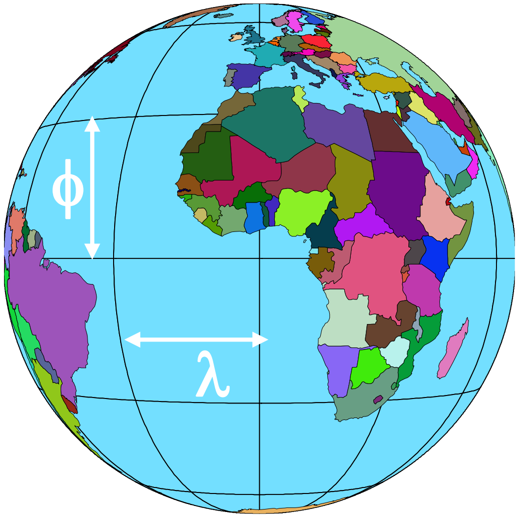
- Distance and areas distorted by varying amounts (**scale not “true”**); e.g. high latitudes

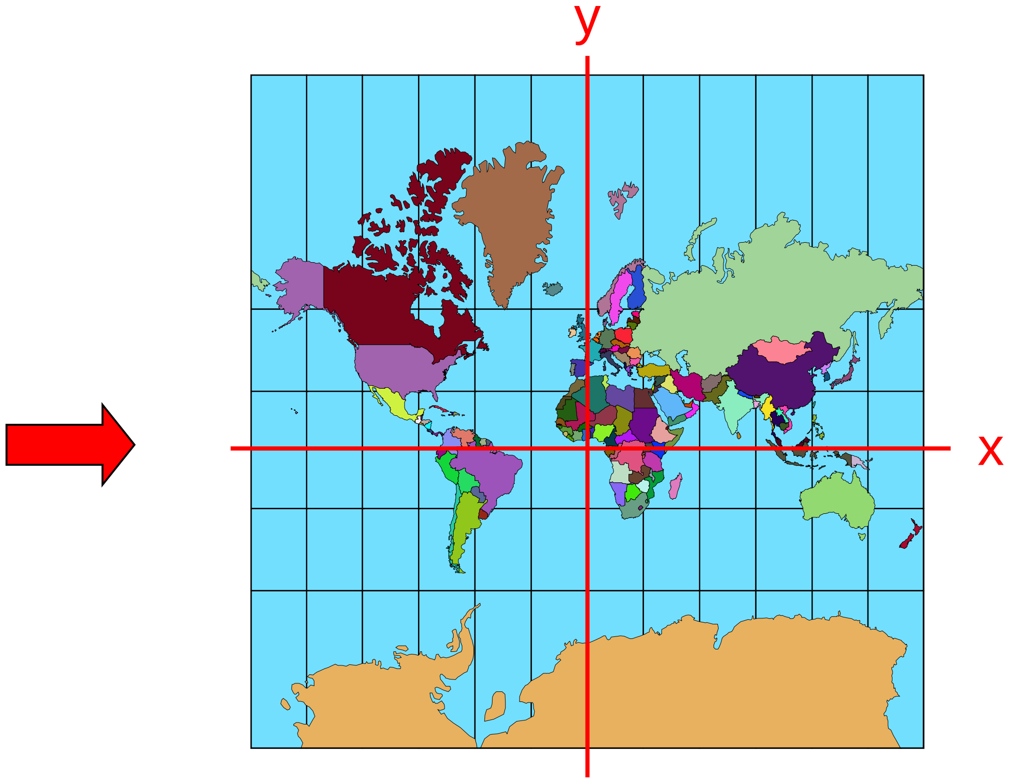


Projected Display: Parametric Equations

- E.g. Mercator projection:
  - $x = \lambda$
  - $y = \ln [\tan \phi + \sec \phi]$





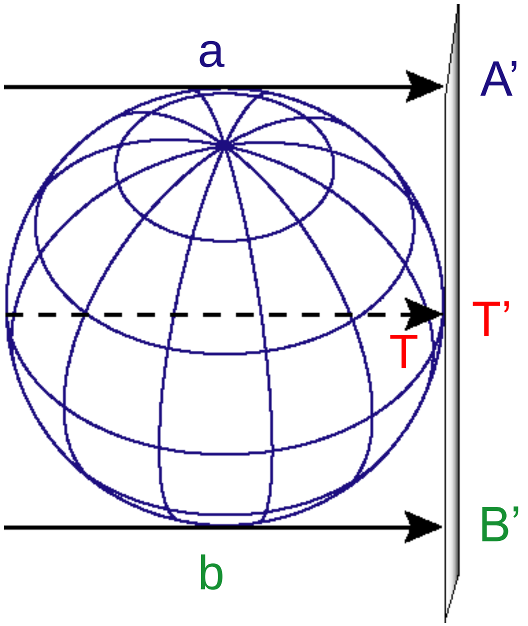


Laying the Earth Flat

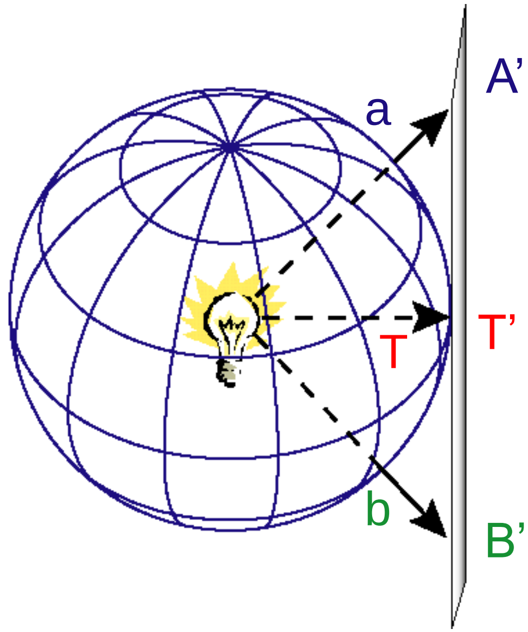
- How?

Projection types ("*perspective*" *classes*):

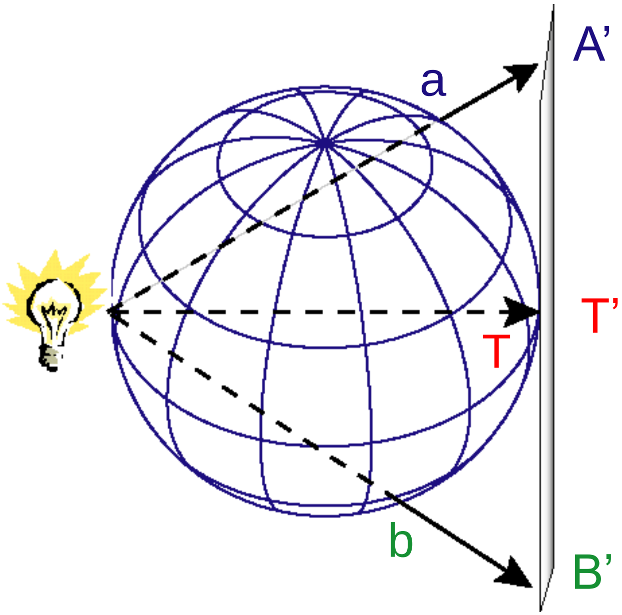
Orthographic



Gnomonic

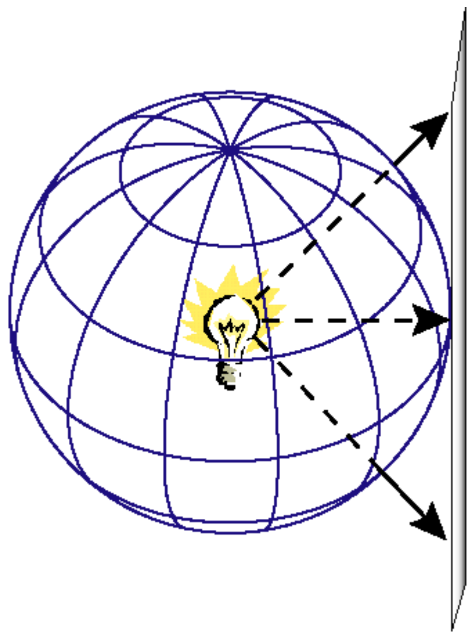


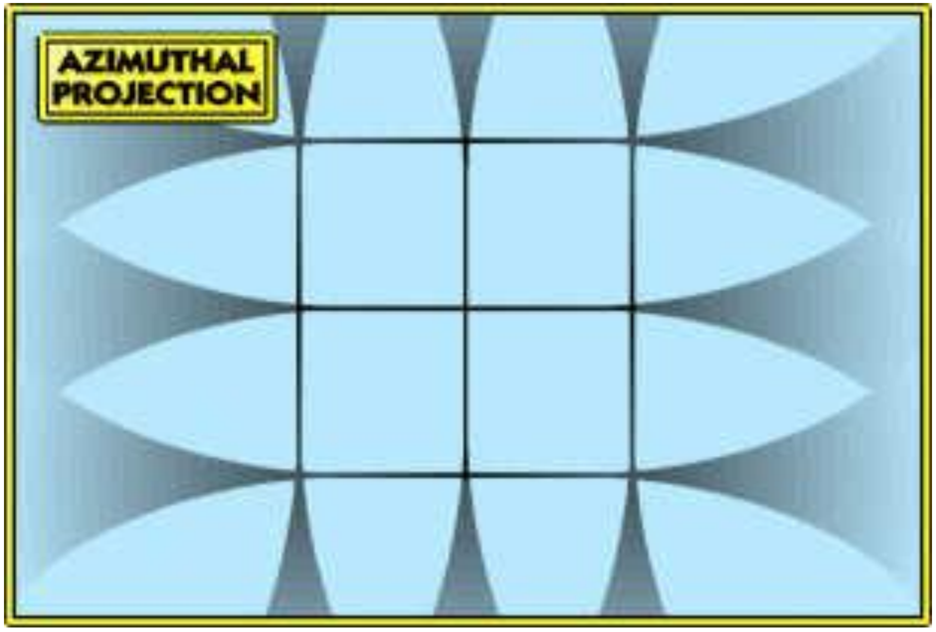
Stereographic



Light Bulb at Center (Gnomic)

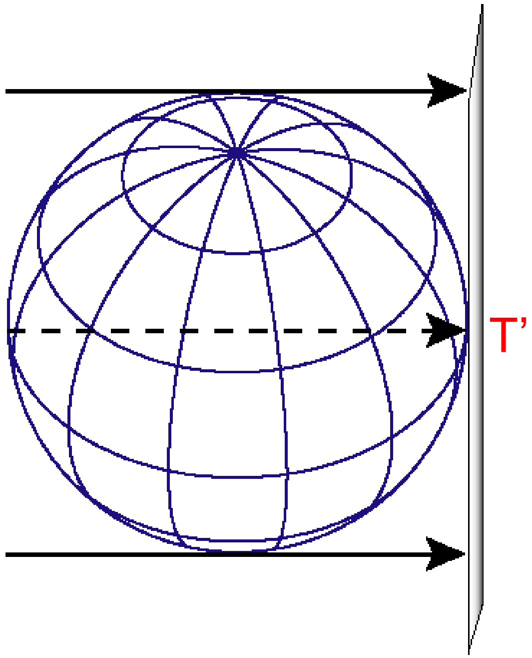
- Grid Lines “out of focus” away from point of tangency

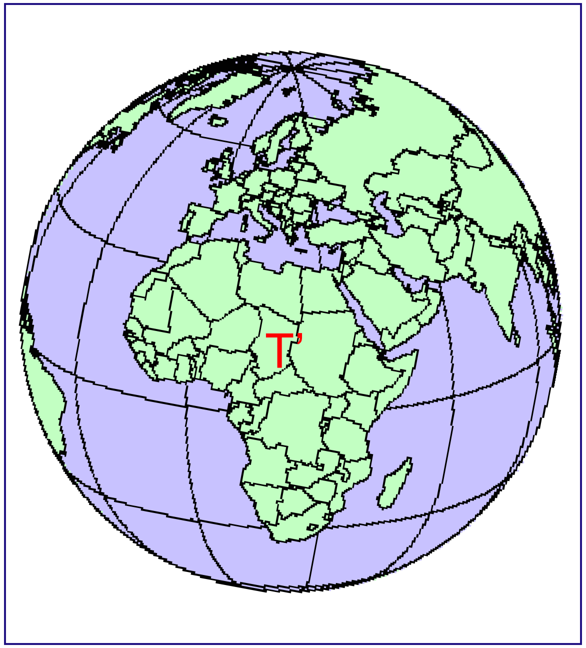




Orthographic

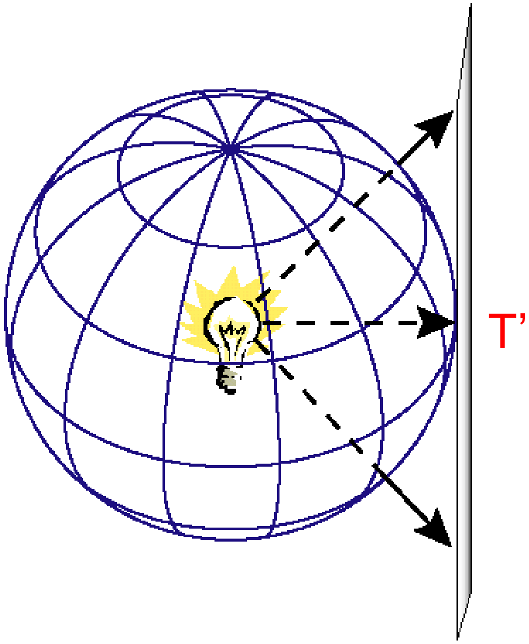
- Light source at infinity; neither area or angles are preserved, except locally

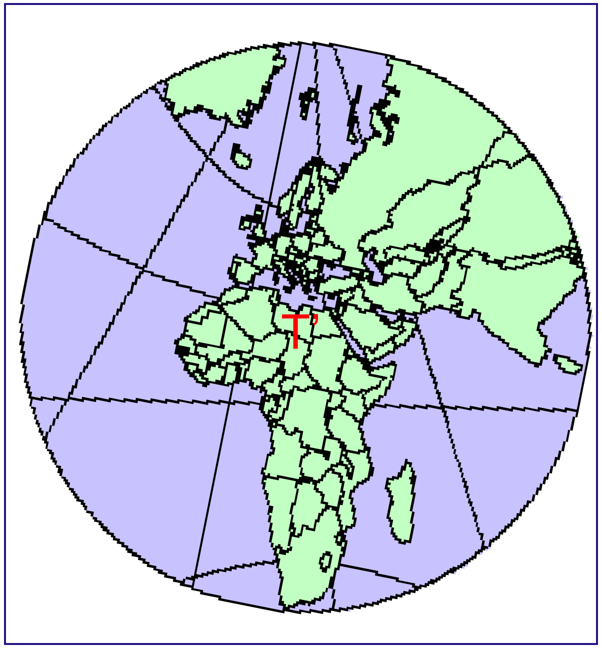




Gnomonic

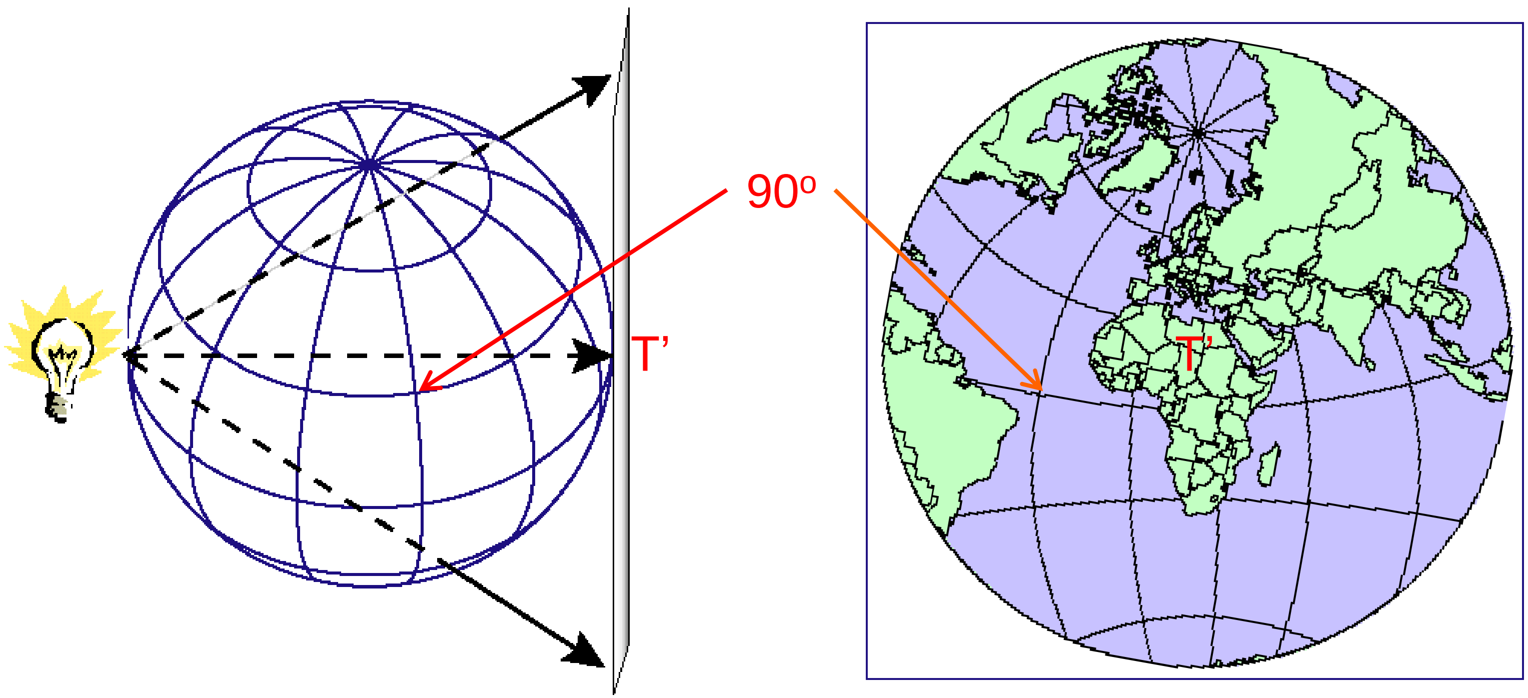
- All great circles are straight lines
- Same as image produced by spherical lens





Stereographic

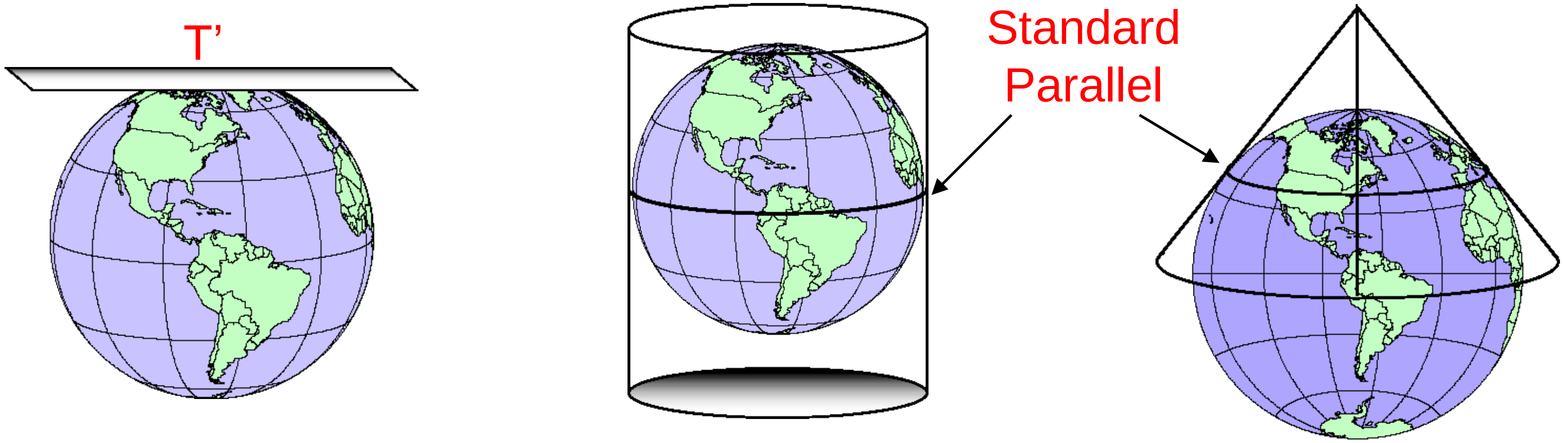
- Projection is conformal, preserves angles and shapes for small areas near point of tangency, larger areas away from point are distorted. Great circles are circles.



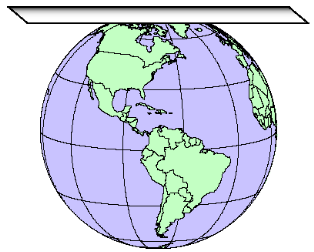
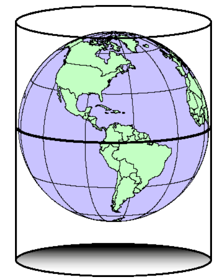
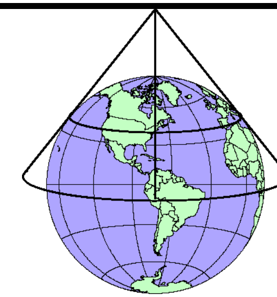
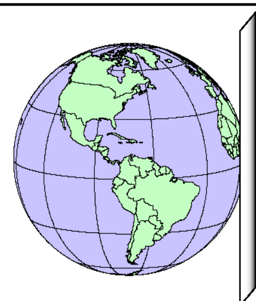
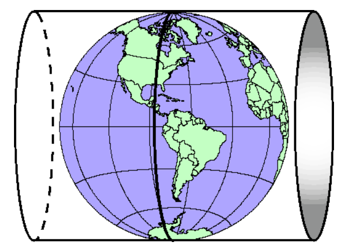
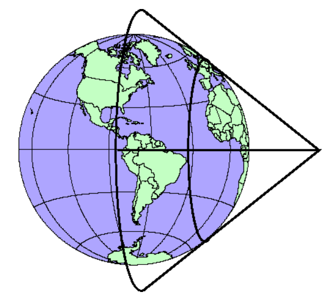
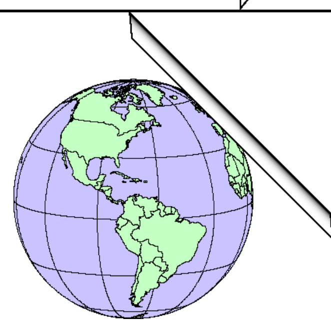
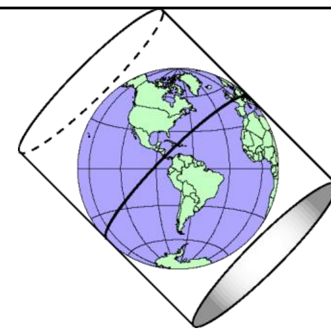
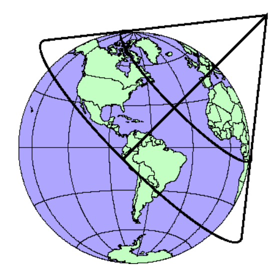
Developable Surfaces

- Surface for projection:
  - Plane (azimuthal projections)
  - Cylinder (cylindrical projections)
  - Cone (conical projections)

Cylinder and cone produce a line of intersection (standard parallel) rather than at a point

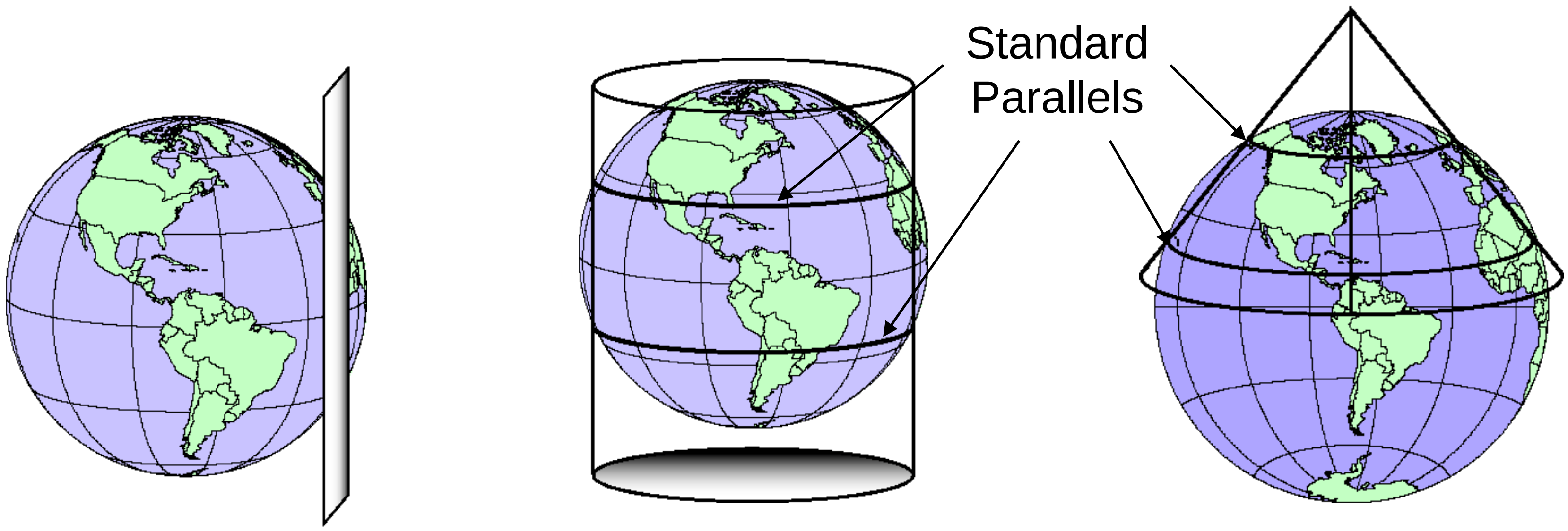


3 orientations for developable surfaces

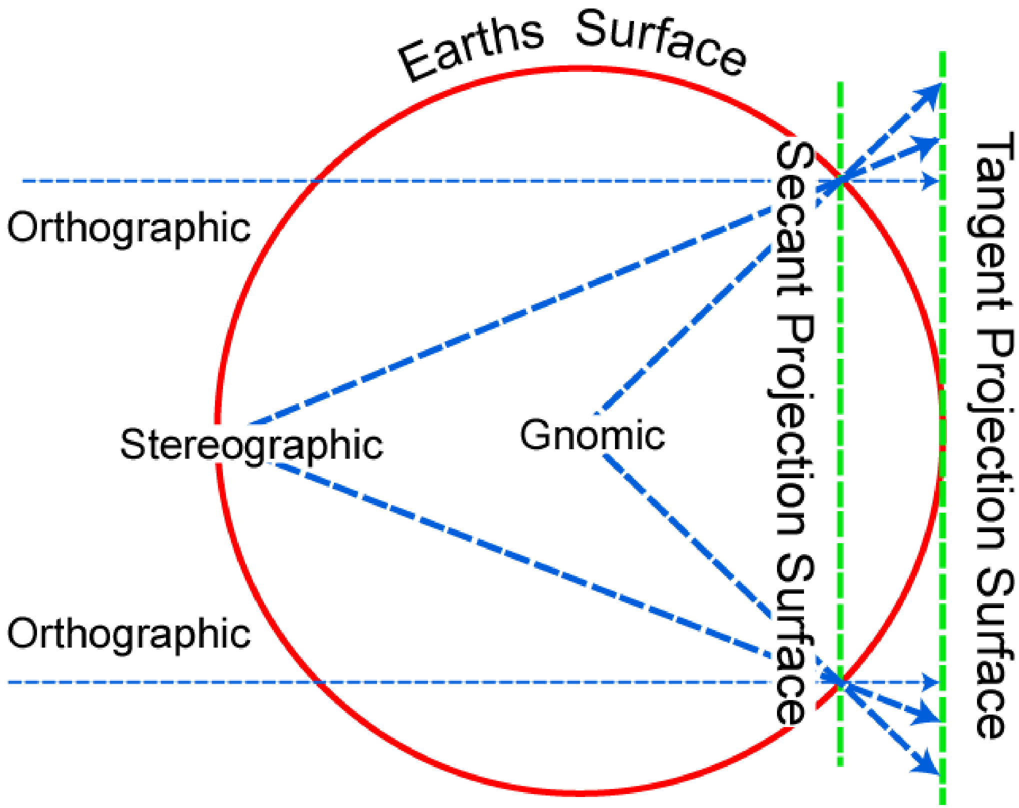
Normal			
Transverse			
Oblique			

Tangent or Secant?

- Developable surfaces can be tangent at a point or line, or secant if they penetrate globe
  - Secant balances distortion over wider region
  - Secant cone & cylinder produce two standard parallels



Tangent or Secant?



Projection produces distortion of:

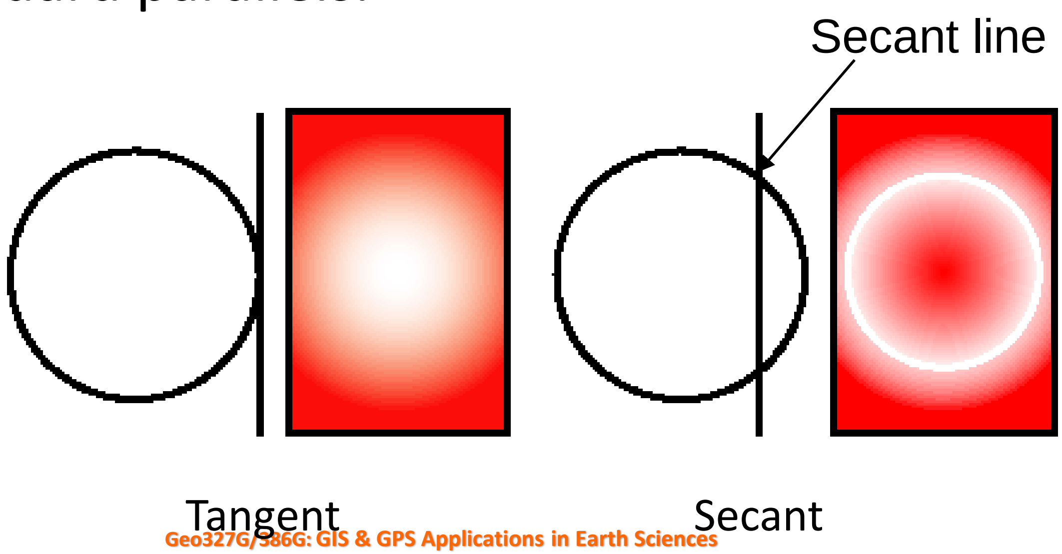
- Distance
- Area
- Angle – bearing, direction
- Shape

Distortions vary with scale; minute for large-scale maps (e.g. 1:24,000), gross for small-scale maps (e.g. 1: 5,000,000)

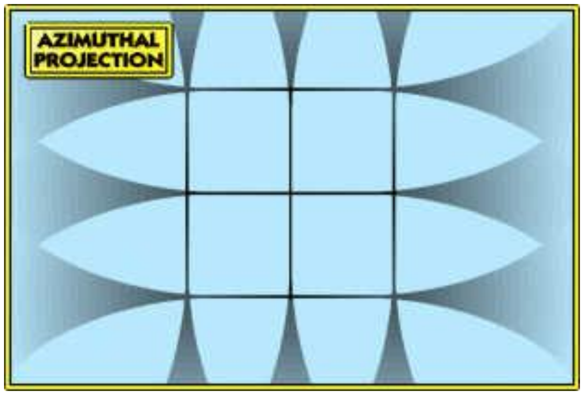
Goal: find a projection that minimizes distortion of *property of interest*

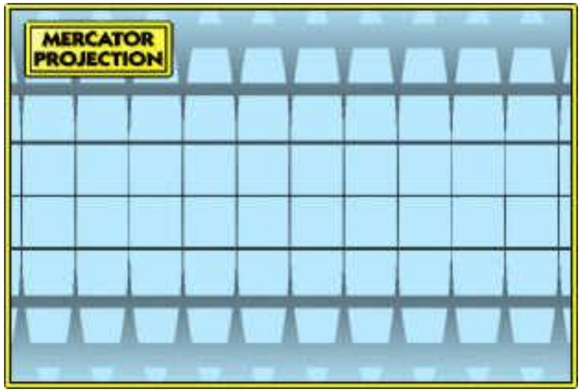
Where’s the distortion?

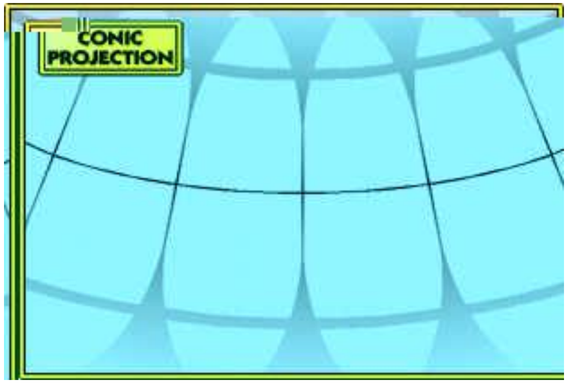
- **No distortion along standard parallels, secants or point of tangency.**
- For tangent projections, distortion increases away from point or line of tangency.
- For secant projections, distortion increases toward and away from standard parallels.



Distortions







Azimuthal

Cylindrical

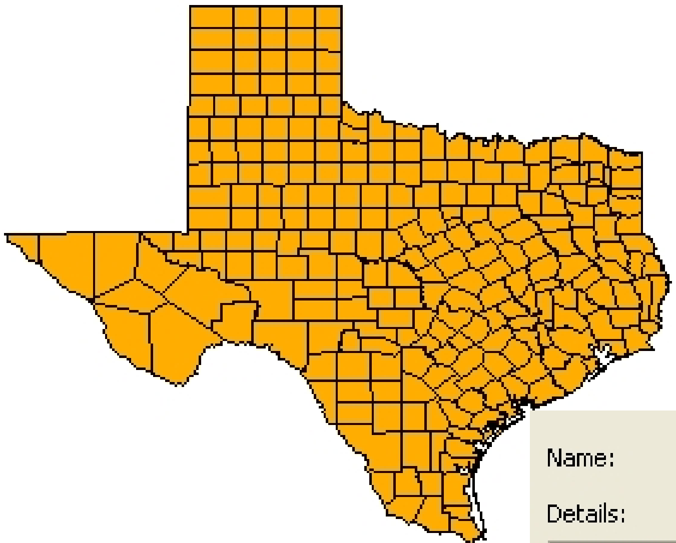
Conic

How do I select a projection?

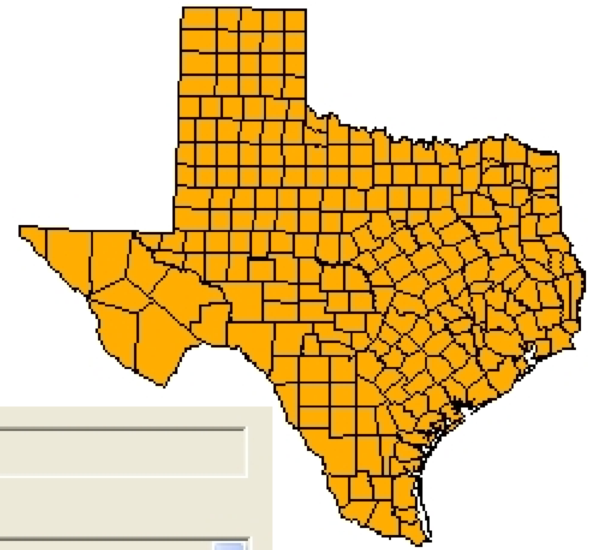
- Scale is critical – projection type makes very little difference at large scales
- For large regions or continents consider:
  - Latitude of area
    - Low latitudes – normal cylindrical
    - Middle latitudes – conical projection
    - High latitudes – normal azimuthal
  - Extent
    - Broad E-W area (e.g. US) – conical
    - Broad N-S area (e.g. S. America) – transverse cylindrical
  - Theme
    - e.g. Equal area vs. conformal (scale same in all directions)

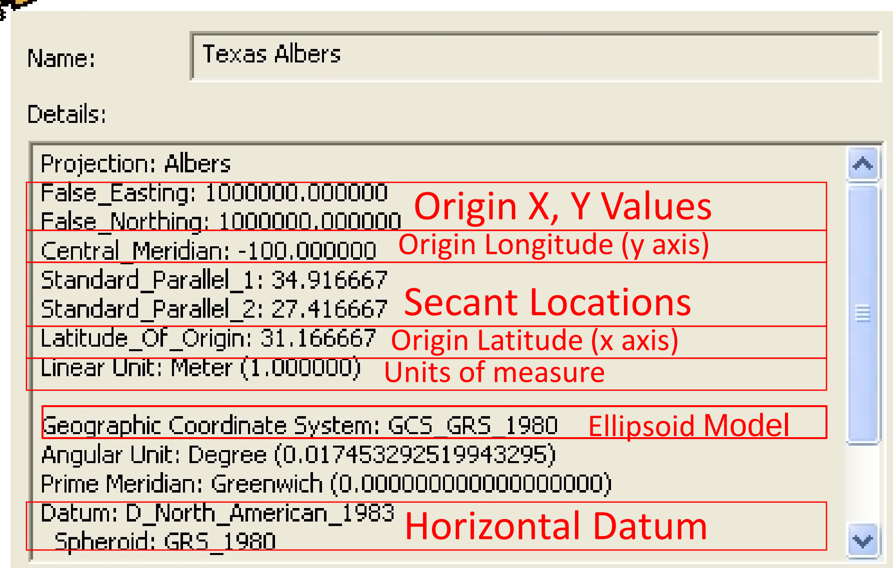
What needs to be specified?

Geographic (unprojected)



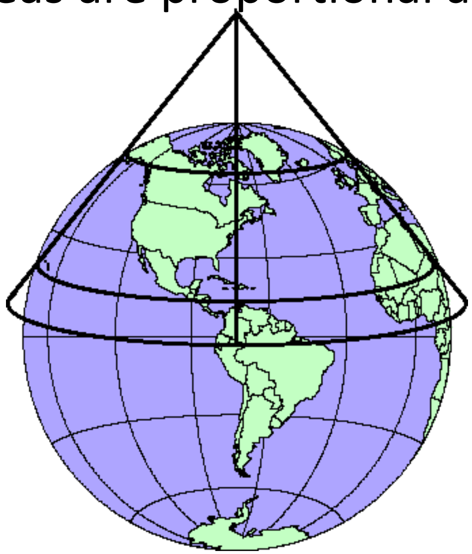
Texas Albers (Equal Area Conic)

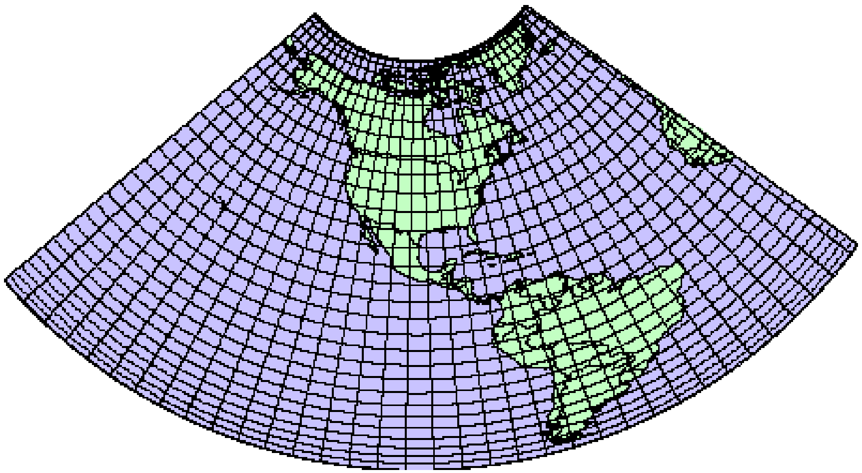




Projections in common use, US

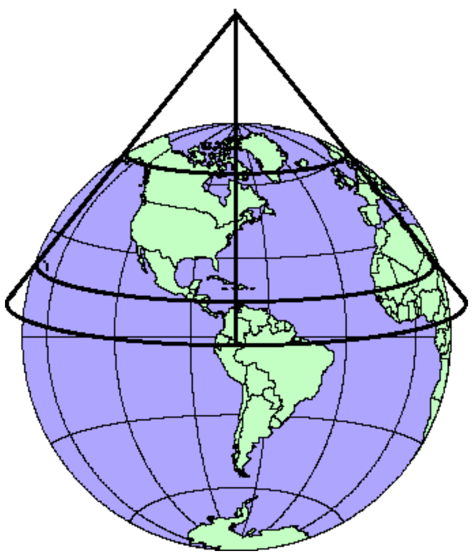
- Albers Equal Area Conic
  - Standard parallels at 29°30’ and 45°30’ for conterminous US. Latitude <u>range</u> should not exceed 30-35°
  - Preserves area, distorts scale and distance (except on standard parallels!)
  - Areas are proportional and directions true in limited areas

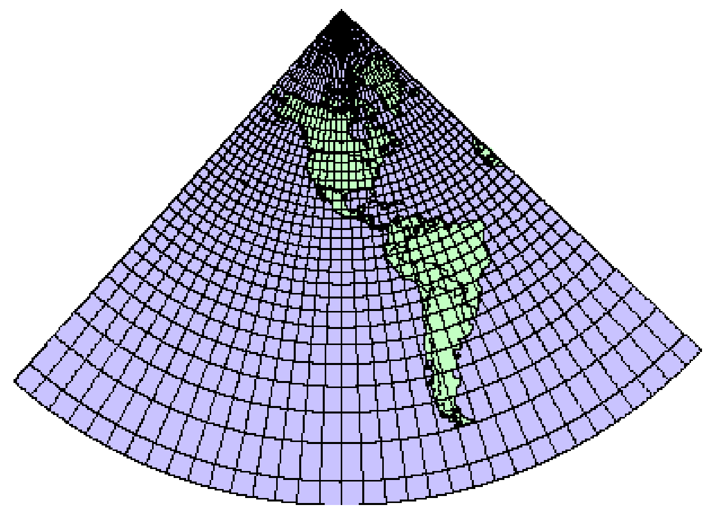




Projections in common use, US

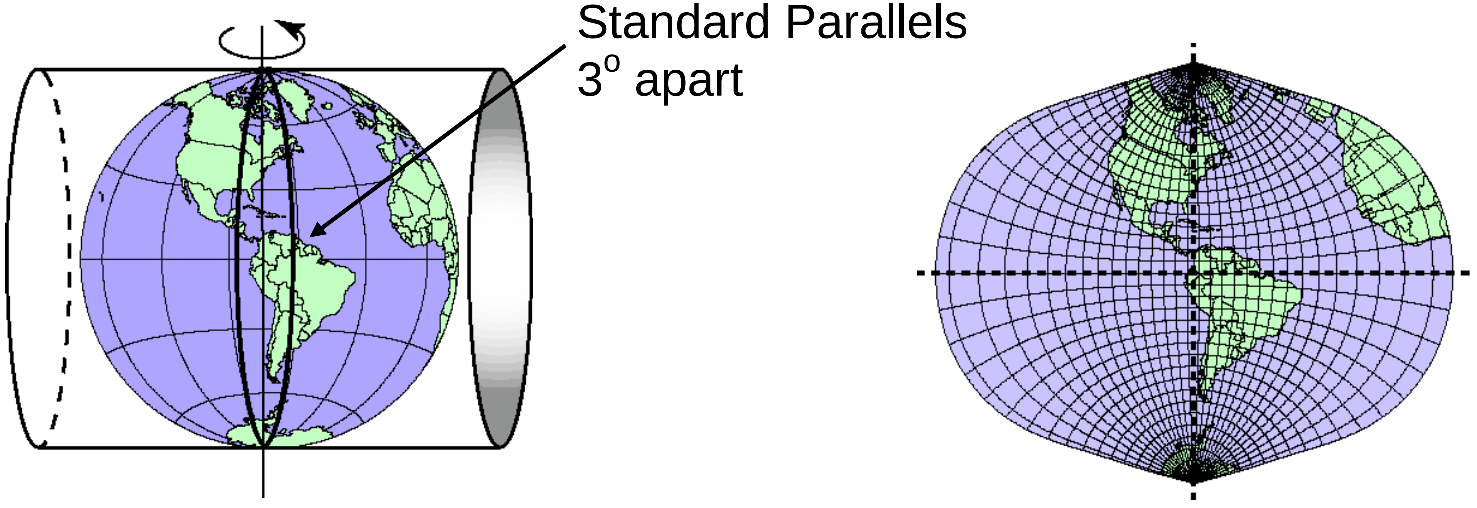
- Lambert Conformal Conic
  - Projection used by USGS for most maps of conterminous US (E-W extent is large)
  - Used by SPCS for state zones that spread E-W (Texas)
  - Conformal





Projections in common use, US

- Cylindrical
  - Transverse Mercator – basis for UTM coordinate system and State Plane Coordinate Systems that spread N-S

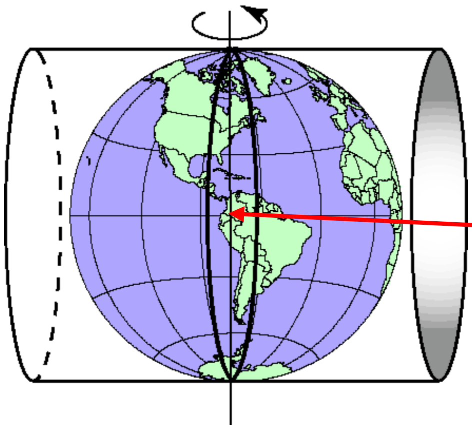


Rectangular Coordinate Systems

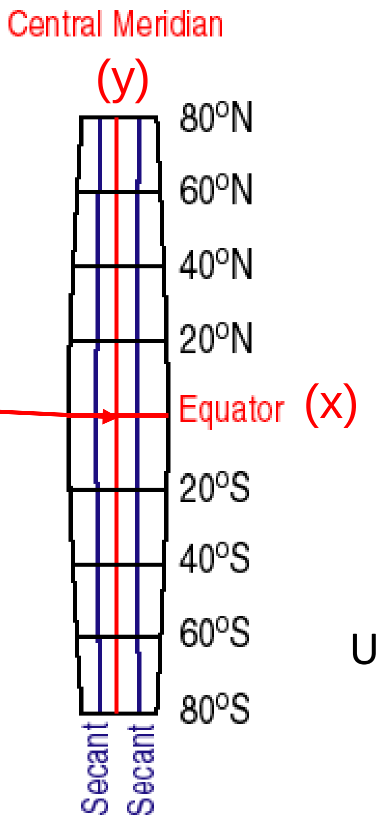
- Universal Transverse Mercator (UTM)
  - US military developed for global cartesian reference frame.
- State Plane Coordinate System (SPCS)
  - Coordinates specific to states; used for property definitions.
- Public Land Survey System (PLS)
  - National system once used for property description
  - no common datum or axes, units in miles or fractional miles.

UTM Coordinate System

- T. M. secant projection is rotated about vertical axis in 6^o increments to produce 60 UTM zones.



Rotate in 6^o increments



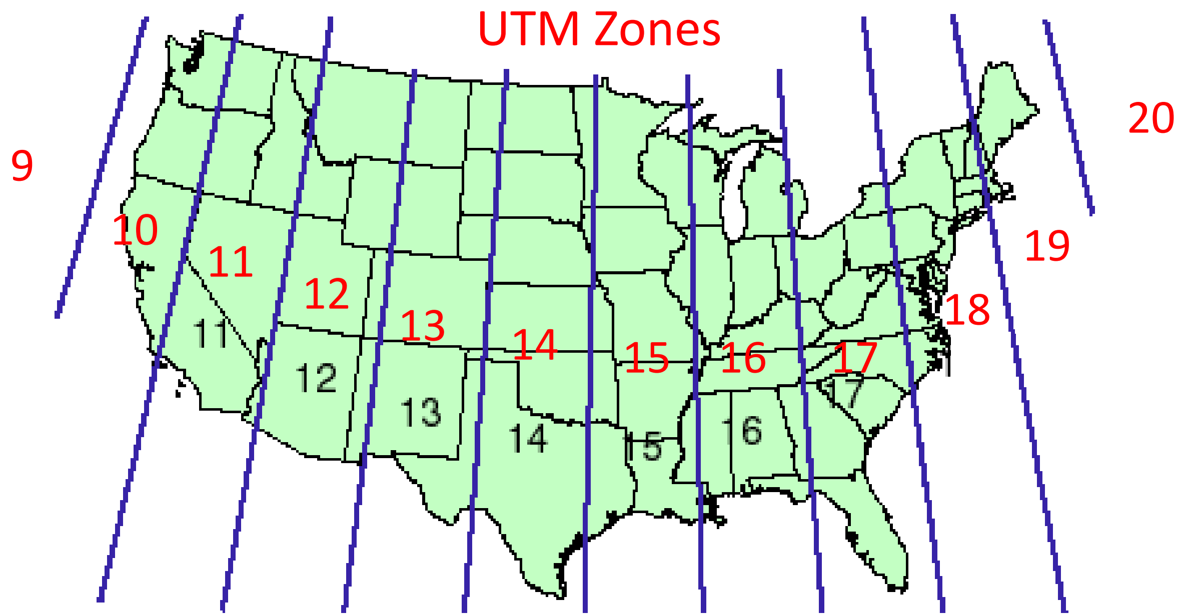
UTM Zone is 6^o wide

UTM Coordinate System

- T. M. secant projection is rotated about vertical axis in 6^o increments to produce 60 UTM zones.
- Zone boundaries are parallel to meridians.
- Zones numbered from 180^o (begins zone 1) eastward and extend from 80^o S to 84^o N.
- Each zone has a central meridian with a scale factor in US of 0.9996 (central meridian is farthest from secants, meaning scale distortion is greatest here).
- Secants are 1.5^o on either side of the central meridian.

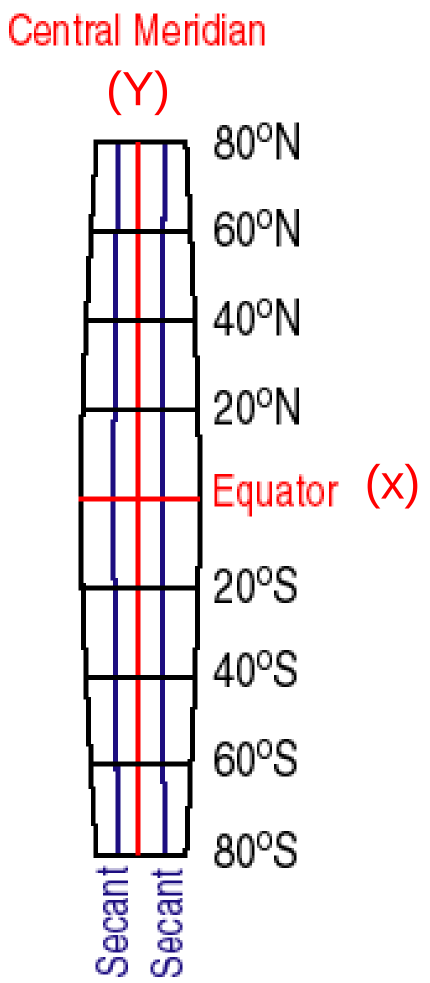
UTM Coordinate System

- Zone boundaries are parallel to meridians.
- Zones numbered from 180^o (begins zone 1) eastward and extend from 80^o S to 84^o N.



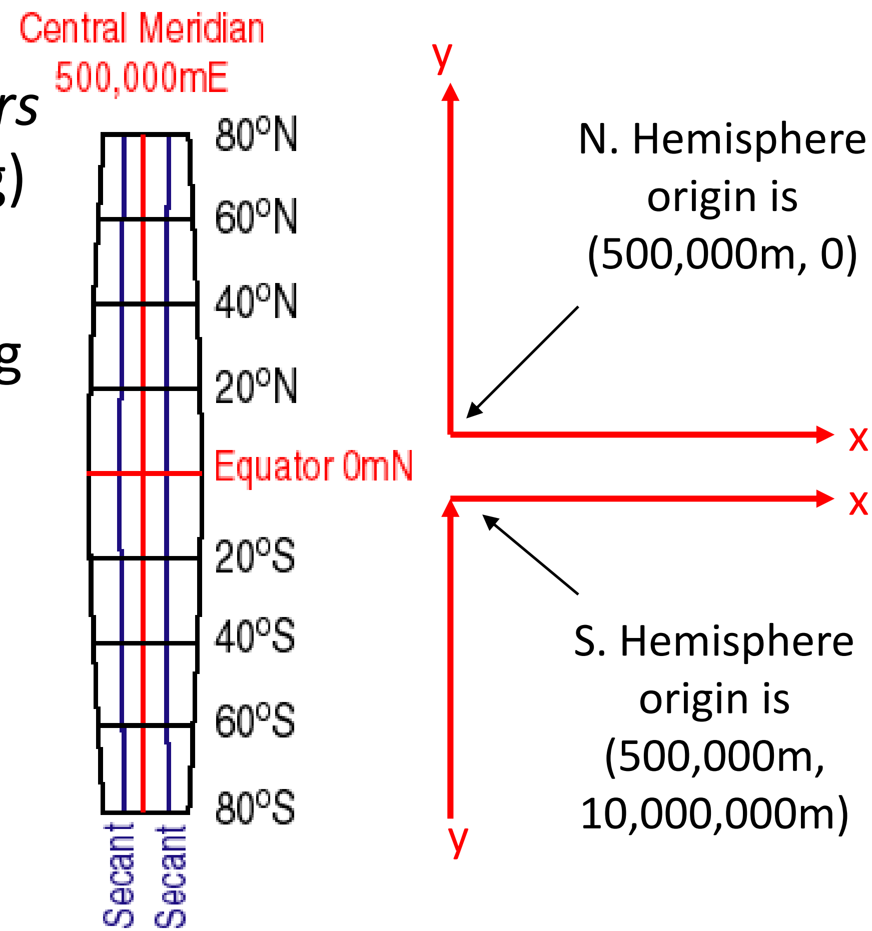
UTM Coordinate System

- Central meridian of each zone in US has a scale factor of 0.9996 (max. distortion).
- Secants are 1.5° on either side of the central meridian.

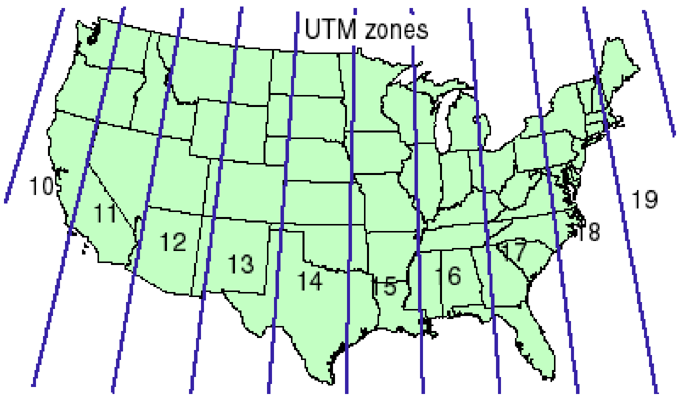


UTM Coordinate System

- Locations are given in *meters* from central meridian (Easting) and equator (Northing).
- (-) Eastings avoided by giving X value of 500,000 m (“false easting”) to the Central Meridian
- In S. hemisphere, equator is given “false northing” of 10,000,000 m to avoid (-) Northings.

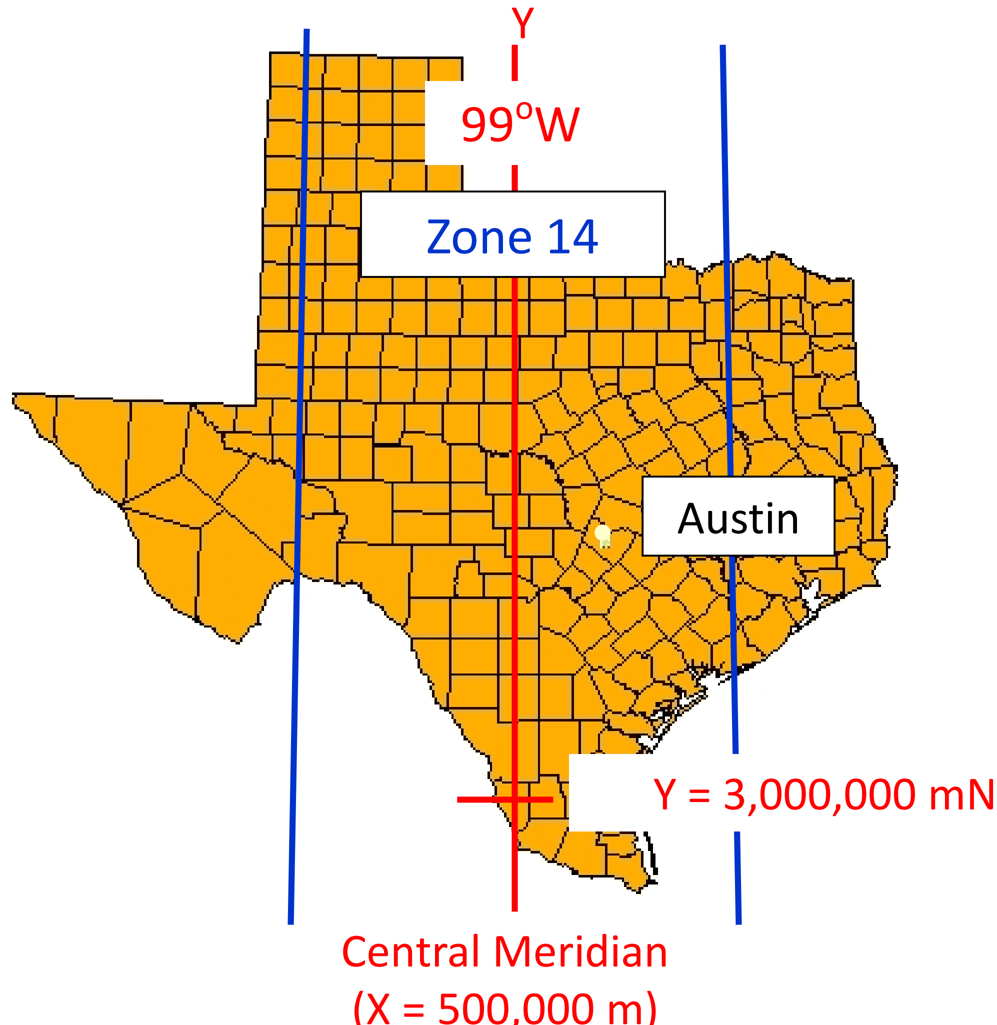


UTM Coordinate System



UTM Coordinates for central Austin:

Zone 14
621,000 mE, 3,350,000 mN



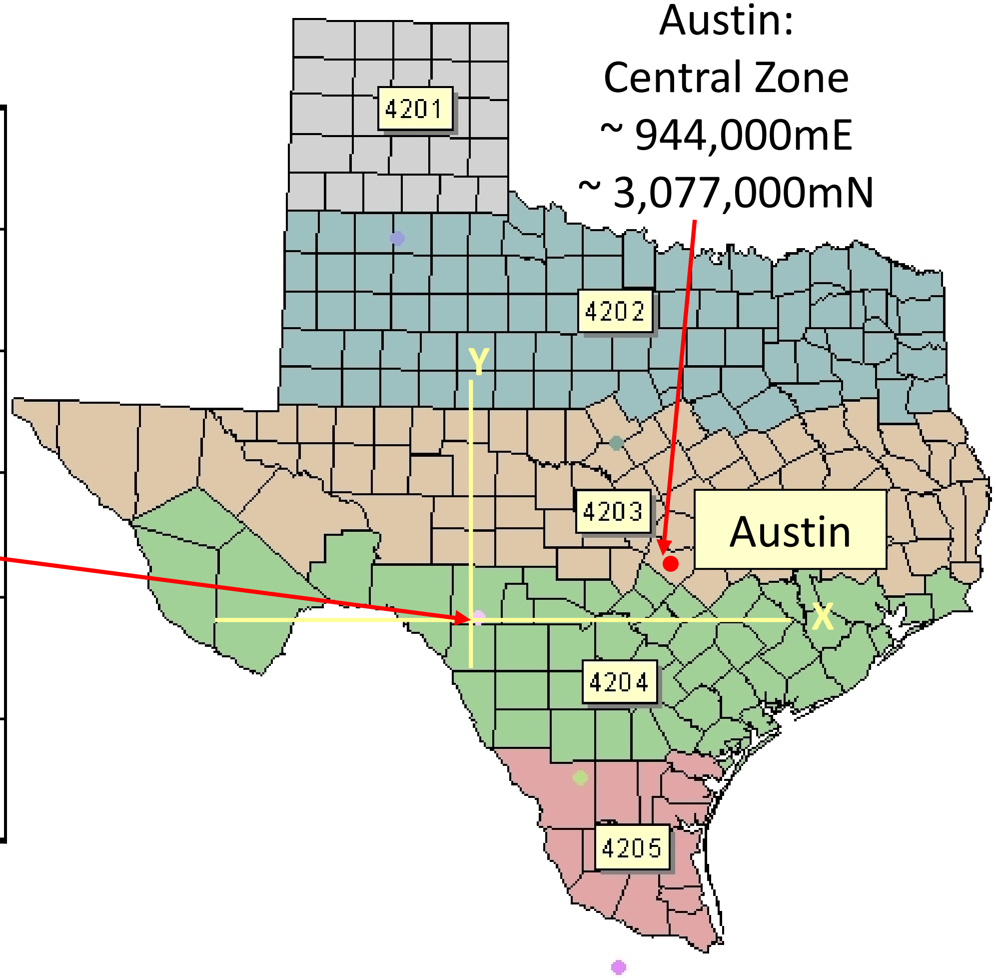
State Plane Coordinate System (SPCS)

- Developed in 1930's to provide states a reference system that was tied to national datum (NAD27); *units in feet*.
- Updated to NAD83, *units in meters*; some maps still show SPCS NAD27 coordinates.
- Some larger states are divided into "zones".
- X, Y coordinates are given relative to origin outside of zone; false eastings and northings different for each zone.

Texas NAD83 SPCS (meters)

Zone Code	Stand. Parallels	Origin	F. Easting F. Northing
4201 North	34.650 36.183	-101.50 34.00	200,000 1,000,000
4202 N. Cent.	32.133 33.967	-98.50 31.67	600,000 2,000,000
4203 Central	30.117 31.883	-100.33 29.67	700,000 3,000,000
4204 S. Cent.	28.383 30.283	-99.00 27.83	600,000 4,000,000
4205 South	26.167 27.833	-98.50 25.67	500,000 5,000,000

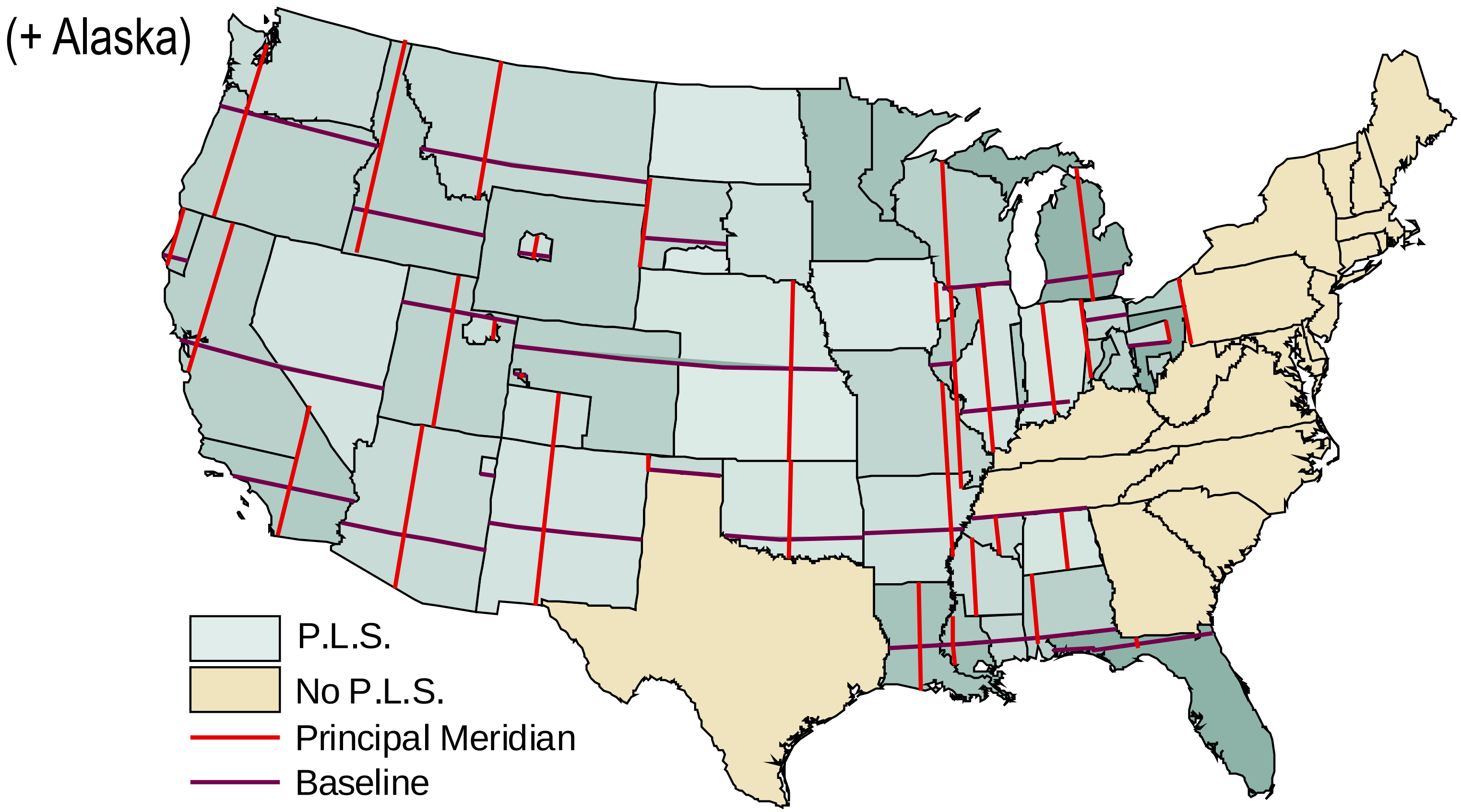
Austin:
Central Zone
~ 944,000mE
~ 3,077,000mN



Public Land Survey System (PLSS)

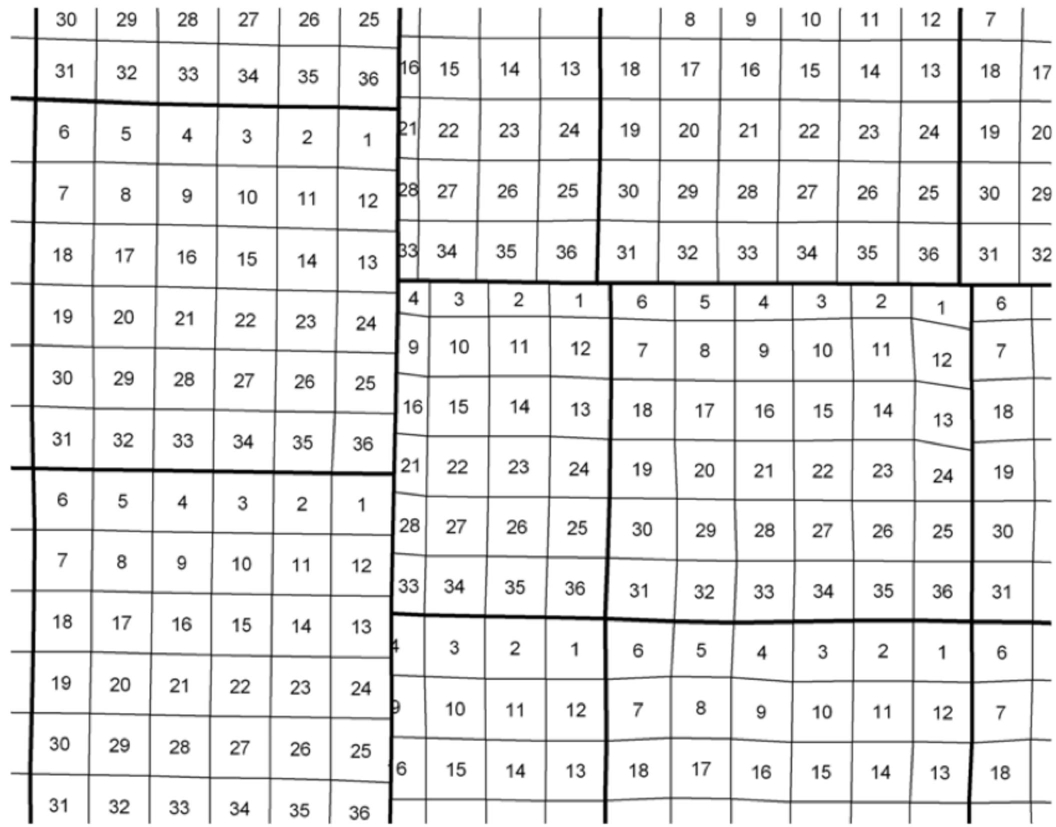
- System developed to survey and apportion public lands in the US, c. 1785
- Coordinate axes are *principal baselines* and *meridians*, which are distributed among the states.
- Grid system based on miles and fractional miles from baseline and meridian origin.
- Not in Texas, nor 19 other states
- Units are miles and fractional miles; feet and yards are also in use.

Principal Baselines & Meridians



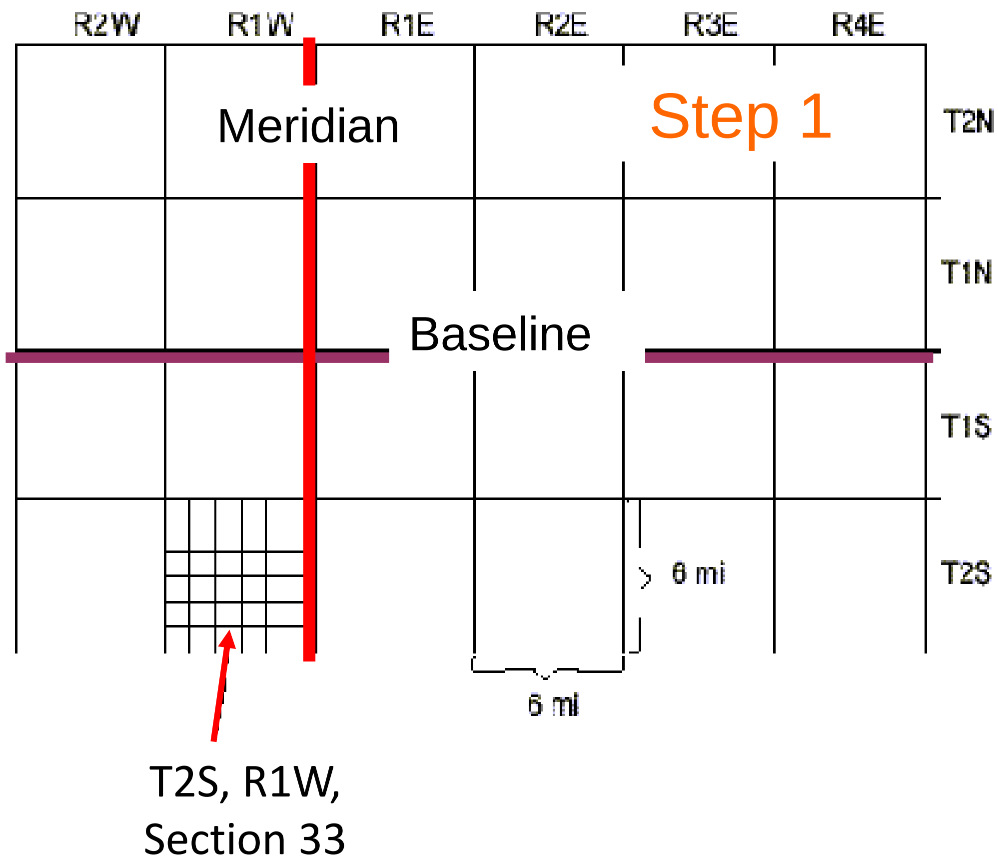
PLSS Nominal Townships and Sections

- **Township**:
Nominally 36 mi^2
Section:
Nominally 1 mi^2 (640 acres)
    - Once surveyed, Section and Township corners, by law, were accepted as "True"
    - Adjustments for different Principle Meridians, survey errors & graft resulted in irregularities

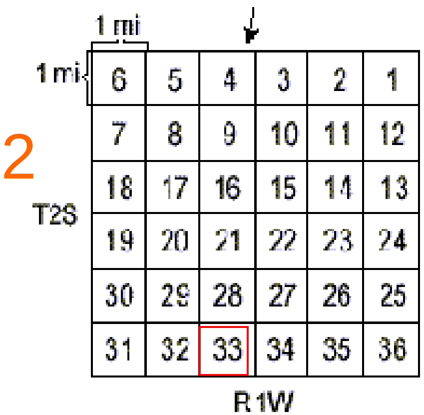


From Bolstad, Fig. 3-50

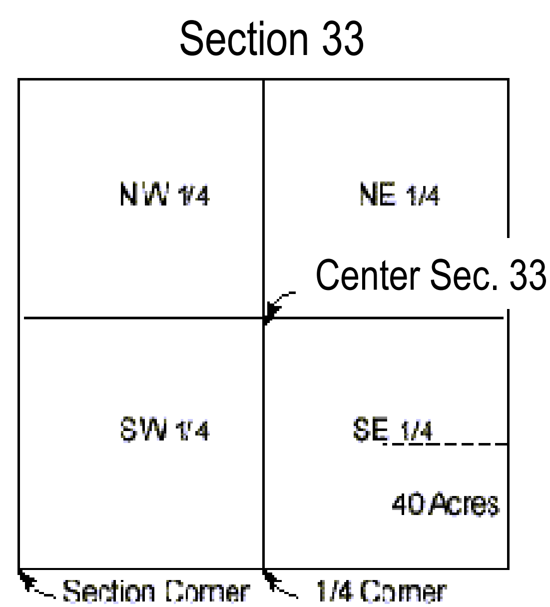
Public Land Survey System (PLS)



Step 2



Step 3



Summary

- Projections transform geographic coordinates (ϕ, λ) to cartesian (x, y).
- Projections distort distance, area, direction and shape to greater or lesser degrees; choose projection that minimizes the distortion of the map theme.
- Points of tangency, standard parallels and secants are points or lines of no distortion.
- A conformal map has the same scale in all directions.

Summary (cont.)

- Projection characteristics are classified by:
  - Light source location
    - Gnomonic
    - Stereographic
    - Orthographic
  - Developable surface
    - Plane (azimuthal)
    - Cylinder (cylindrical)
    - Cone (conic)
  - Orientation
    - Normal
    - Transverse
    - Oblique

Summary (cont.)

- Modern coordinate systems are based on projections that minimize distortion within narrow, conformal zones.
- UTM is a global system using WGS84/NAD83; others are local with varying datums.