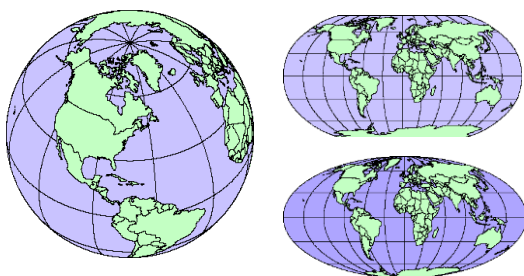


Map Projections & Coordinate Systems



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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.

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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.

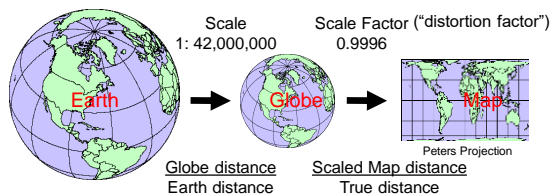
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Laying the Earth Flat

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



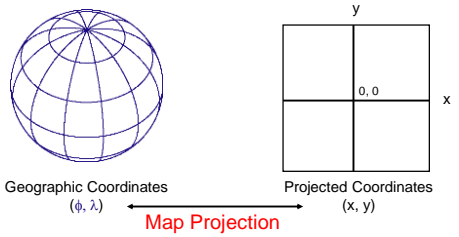
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### Laying the Earth Flat

Systematic rendering of Lat. ( $\phi$ ) & Lon. ( $\lambda$ ) to Cartesian ( $x, y$ ) coordinates:



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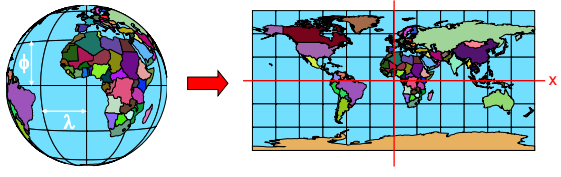
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### Laying the Earth Flat

"Geographic" display – no projection

- $x = \lambda, y = \phi$
- Grid lines have same scale and spacing



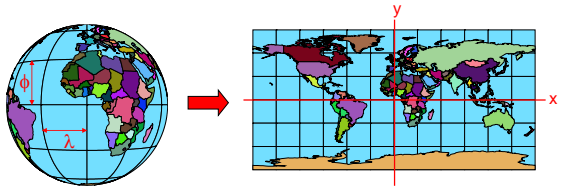
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### "Geographic" Display

Distance and areas distorted by varying amounts (scale not "true"); e.g. high latitudes



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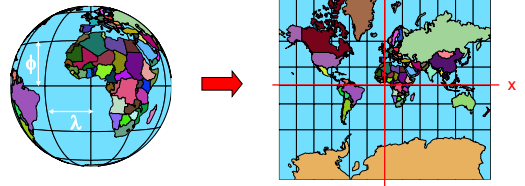
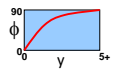
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### Projected Display: Parametric Equations

E.g. Mercator projection:

- $x = \lambda$
- $y = \ln [\tan \phi + \sec \phi]$



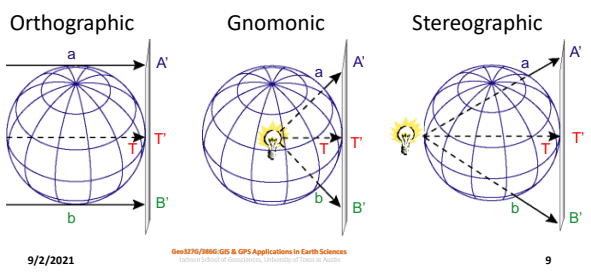
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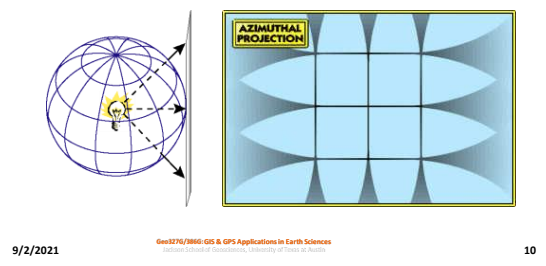
Laying the Earth Flat

How? Projection types ("perspective" classes):



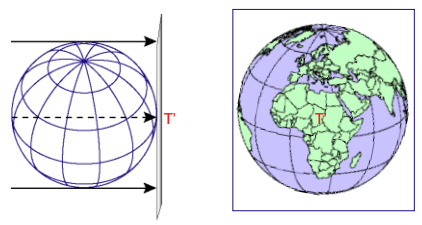
Light Bulb at Center (Gnomonic)

Grid Lines "out of focus" away from point of tangency



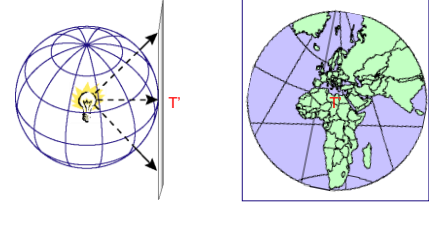
Orthographic

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



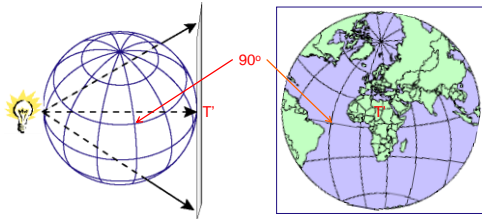
Gnomonic

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.



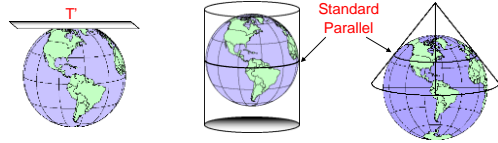
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### Developable Surfaces

- 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



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### 3 orientations for developable surfaces

Normal			
Transverse			
Oblique			

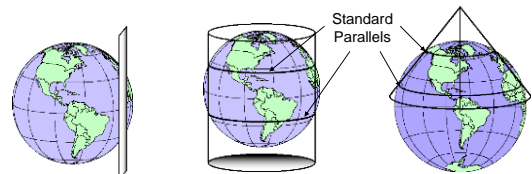
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### Tangent or Secant?

- 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

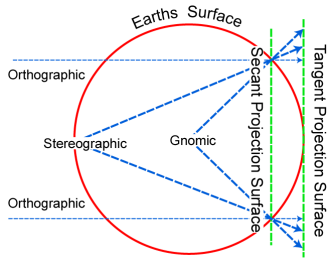


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Tangent or Secant?



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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*

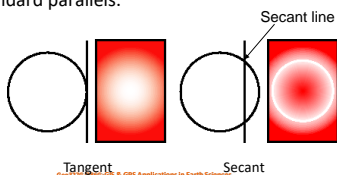
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Where's the distortion?

- 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.

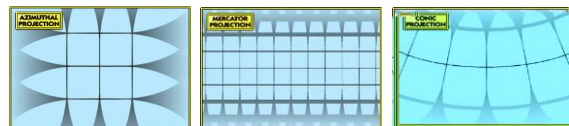


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Distortions



Azimuthal

Cylindrical

Conic

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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)

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What needs to be specified?

Geographic (unprojected) → Texas Albers (Equal Area Conic)

Name: Texas Albers

Details:

- Projection: Albers
- False Easting: 1000000.000000 Origin X, Y Values
- False Northing: 1000000.000000
- Central Meridian: 100.000000 Origin Longitude (y axis)
- Standard Parallel 1: 34.916667
- Standard Parallel 2: 27.416667 Secant Locations
- Latitude\_Of\_Origin: 31.166667 Origin Latitude (x axis)
- Linear Unit: Meter (1.000000) Units of measure
- Geographic Coordinate System: GCS: GRS 1980 Ellipsoid Model
- Angular Unit: Degree (0.017453292519943295)
- Prime Meridian: Greenwich (0.0000000000000000)
- Datum: D: North American\_1983 Horizontal Datum
- Spheroid: GRS\_1980

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Projections in common use, US

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



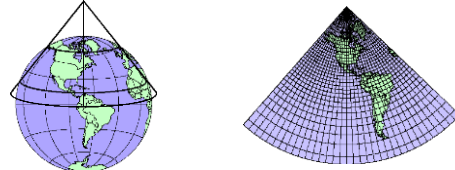
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Projections in common use, US

- ❑ 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



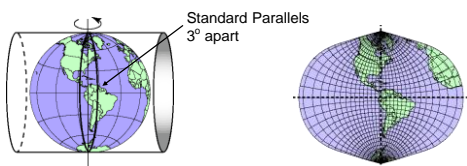
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Projections in common use, US

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



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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.

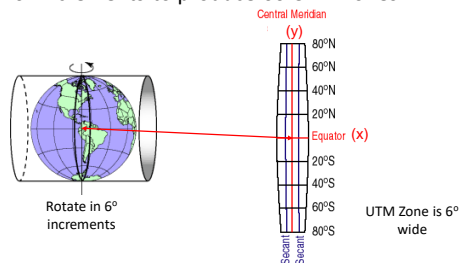
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UTM Coordinate System

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



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UTM Coordinate System

- T. M. secant projection is rotated about vertical axis in 6° increments to produce 60 UTM zones.
- Zone boundaries are parallel to meridians.
- Zones numbered from 180° (begins zone 1) eastward and extend from 80° S to 84° 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° on either side of the central meridian.

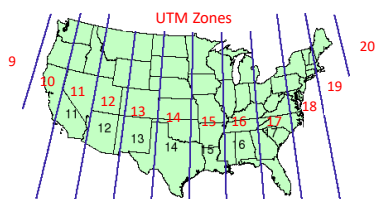
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UTM Coordinate System

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



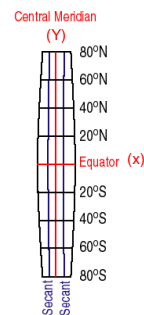
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UTM Coordinate System

- 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.



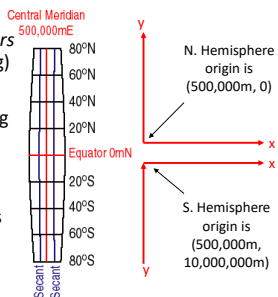
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UTM Coordinate System

- 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.

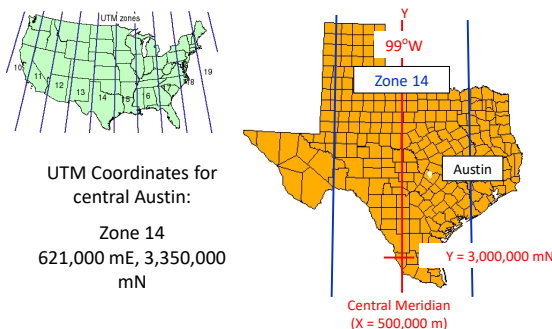


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UTM Coordinate System



UTM Coordinates for central Austin:  
 Zone 14  
 621,000 mE, 3,350,000 mN

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### State Plane Coordinate System (SPCS)

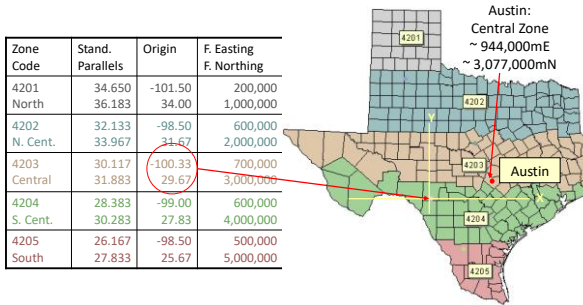
- ❑ Developed in 1930's to provide states a reference system that was tied to national datum (NAD27); *units in feet*.
- ❑ Updated to NAD83, *units in meters*; some maps still show SPCS NAD27 coordinates.
- ❑ Some larger states are divided into "zones".
- ❑ X, Y coordinates are given relative to origin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

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### Texas NAD83 SPCS (meters)



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### Public Land Survey System (PLSS)

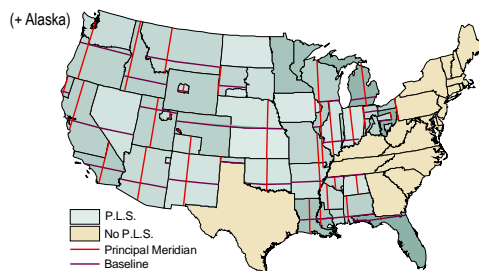
- ❑ System developed to survey and apportion public lands in the US, c. 1785
- ❑ Coordinate axes are *principal baselines* and *meridians*, which are distributed among the states.
- ❑ Grid system based on miles and fractional miles from baseline and meridian origin.
- ❑ Not in Texas, nor 19 other states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

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### Principal Baselines & Meridians



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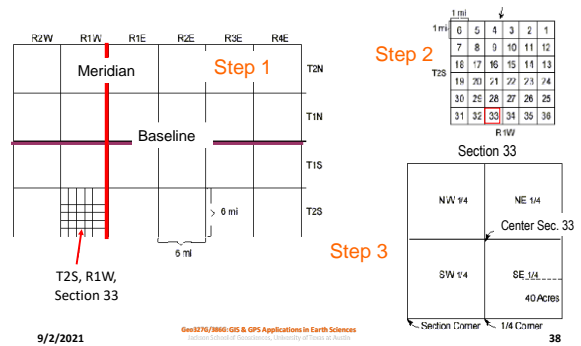
PLSS Nominal Townships and Sections

- **Township:**  
Nominally 36 mi<sup>2</sup>
- **Section:**  
Nominally 1 mi<sup>2</sup> (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

30	29	28	27	26	25	15	14	13	12	11	10	9	8	7
31	32	33	34	35	36	16	15	14	13	12	11	10	9	8
5	4	3	2	1		22	23	24	25	26	27	28	29	30
6	5	4	3	2	1	23	24	25	26	27	28	29	30	31
7	6	5	4	3	2	1	24	25	26	27	28	29	30	31
18	17	16	15	14	13	4	3	2	1	6	5	4	3	2
19	18	17	16	15	14	5	4	3	2	1	6	5	4	3
20	19	18	17	16	15	6	5	4	3	2	1	6	5	4
21	20	19	18	17	16	7	6	5	4	3	2	1	6	5
22	21	20	19	18	17	8	7	6	5	4	3	2	1	6
23	22	21	20	19	18	9	8	7	6	5	4	3	2	1
24	23	22	21	20	19	10	9	8	7	6	5	4	3	2
25	24	23	22	21	20	11	10	9	8	7	6	5	4	3
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56	55	54	53	52	51	42	41	40	39	38	37	36	35	34
57	56	55	54	53	52	43	42	41	40	39	38	37	36	35
58	57	56	55	54	53	44	43	42	41	40	39	38	37	36
59	58	57	56	55	54	45	44	43	42	41	40	39	38	37
60	59	58	57	56	55	46	45	44	43	42	41	40	39	38

From Bolstad, Fig. 3-50

Public Land Survey System (PLS)



Summary

- Projections transform geographic coordinates ( $\phi$ ,  $\lambda$ ) 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.