Map Projections & Coordinate Systems

Laying the Earth Flat

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

- "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

- E.g., Mercator projection:
  - \( x = \lambda \)
  - \( y = \ln(\tan\phi + \sec\phi) \)

Laying the Earth Flat

- How?
  - Projection types (“perspective” classes):

Light Bulb at Center (Gnomonic)

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

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

**Orthographic**

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

**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

<table>
<thead>
<tr>
<th>Normal</th>
<th>Transverse</th>
<th>Oblique</th>
</tr>
</thead>
</table>

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

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 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.

- **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° 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.

UTM Zones

- 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.

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)

<table>
<thead>
<tr>
<th>Zone Code</th>
<th>Stand. Parallels</th>
<th>Origin</th>
<th>F. Easting</th>
<th>F. Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>4201</td>
<td>34.650</td>
<td>-101.50</td>
<td>200,000</td>
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<tr>
<td>North</td>
<td>36.383</td>
<td>34.00</td>
<td>1,000,000</td>
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<tr>
<td>4202 N. Cent.</td>
<td>31.333</td>
<td>-98.50</td>
<td>600,000</td>
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<tr>
<td>33.967</td>
<td>31.42</td>
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<tr>
<td>4203</td>
<td>30.117</td>
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<tr>
<td>Central</td>
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<td>29.65</td>
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<tr>
<td>4204</td>
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<tr>
<td>S. Cent.</td>
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<td>27.85</td>
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<tr>
<td>South</td>
<td>27.833</td>
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<td>5,000,000</td>
<td></td>
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Austin: Central Zone ~ 944,000mE ~ 3,077,000mN

- Y = 3,000,000 mN
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 mi²
- **Section:**
  - Nominally 1 mi² (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

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.

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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.

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