Laying the earth flat

Why?
- Need convenient means of measuring and comparing distances, directions, areas, shapes.
- 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.

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

Laying the earth flat

Systematic rendering of Lat. (φ) & Lon. (λ) to cartesian (x, y) coordinates:
Laying the earth flat

- "Geographic" display – no projection
  - $x = \lambda$, $y = \phi$
  - 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:
  - $x = \lambda$
  - $y = \ln \left[ \tan \left( \frac{\phi}{2} + \sec \phi \right) \right]$

How?

Projection types ("perspective" classes):

Orthographic

Gnomonic

Stereographic
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

- 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.
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)

What needs to be specified?

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Texas Albers (Equal Area Conic)
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 $6^\circ$ increments to produce 60 UTM zones.

- Zone boundaries are parallel to meridians.

- Zones numbered from $180^\circ$ (begins zone 1) eastward and extend from $80^\circ$ S to $84^\circ$ 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 $1.5^\circ$ on either side of the central meridian.
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 Coordinates for central Austin:
Zone 14
621,000 mE, 3,350,000 mN

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>North</td>
<td>34.650</td>
<td>34.00</td>
<td>200,000</td>
</tr>
<tr>
<td>4202</td>
<td>N. Cent.</td>
<td>33.904</td>
<td>34.50</td>
<td>600,000</td>
</tr>
<tr>
<td>4203</td>
<td>Central</td>
<td>31.883</td>
<td>39.50</td>
<td>2,000,000</td>
</tr>
<tr>
<td>4204</td>
<td>S. Cent.</td>
<td>30.281</td>
<td>38.86</td>
<td>4,000,000</td>
</tr>
<tr>
<td>4205</td>
<td>South</td>
<td>27.833</td>
<td>25.67</td>
<td>5,000,000</td>
</tr>
</tbody>
</table>

Public Land Survey System (PLS)

- 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

Step 1: T2S, R1W, Section 33

Step 2: Center Sec. 33

Step 3: T25, R1W, Section 33
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.)

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.