Map Projections & Coordinates

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. grid to rectangular coordinate system.

```
<table>
<thead>
<tr>
<th>Geographic Coordinates</th>
<th>Projected Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>((\phi), (\lambda))</td>
<td>(x, y)</td>
</tr>
</tbody>
</table>
```

Laying the earth flat

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

![Map Projection Diagram]

Scale 1: 42,000,000
Scale Factor (for areas) 0.9996

Map distance
Globe distance
Earth distance

M. Helper
08-30-16
GEO327G/386G, UT Austin

1

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2

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3

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4
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:

- \( x = \lambda \)
- \( y = \ln(\tan \phi + \sec \phi) \)

Laying the earth flat

How?

Projection types (“perspective” classes):

- Orthographic
- Gnomic
- Stereographic
Light Bulb at Center (Gnomic)

- 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.

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 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

**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.
Map Projections & Coordinate Systems

**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 Diagram](image)

**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 Diagram](image)

**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.

![State Plane Coordinate System Diagram](image)
### 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>34.860</td>
<td>34.00</td>
<td>200,000</td>
</tr>
<tr>
<td>4202</td>
<td>N. Cent.</td>
<td>31.967</td>
<td>31.55</td>
<td>600,000</td>
</tr>
<tr>
<td>4203</td>
<td>Central</td>
<td>31.883</td>
<td>30.75</td>
<td>1,000,000</td>
</tr>
<tr>
<td>4204</td>
<td>S. Cent.</td>
<td>28.883</td>
<td>27.55</td>
<td>0,000,000</td>
</tr>
<tr>
<td>4205</td>
<td>South</td>
<td>27.883</td>
<td>25.55</td>
<td>5,000,000</td>
</tr>
</tbody>
</table>

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### 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.**

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### Principal Baselines & Meridians

- **Public Land Survey System (PLS)**
  - Step 1
  - Step 2
  - Step 3

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

Projection characteristics are classified by:

- Light source location
  - Gnomonic
  - Stereographic
  - Orthographic
- Developable surface
  - Plane (azimuthal)
  - Cylinder (cylindrical)
  - Cone (conic)
- Orientation
  - Normal
  - Transverse
  - Oblique