Map Projections & Coordinate Systems
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.
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.

![Diagram showing the process of laying the Earth flat]

- Globe distance
- Earth distance
- Globe distance
- Map distance

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

Peters Projection
Laying the Earth Flat

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

Geographic Coordinates ($\phi, \lambda$) \[\mapsto\] Map Projection \[\leftrightarrow\] Projected Coordinates ($x, y$)

9/7/2017
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

Gnomonic

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
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>
<tbody>
<tr>
<td><img src="image1" alt="Normal" /></td>
<td><img src="image2" alt="Transverse" /></td>
<td><img src="image3" alt="Oblique" /></td>
</tr>
<tr>
<td><img src="image4" alt="Normal" /></td>
<td><img src="image5" alt="Transverse" /></td>
<td><img src="image6" alt="Oblique" /></td>
</tr>
<tr>
<td><img src="image7" alt="Normal" /></td>
<td><img src="image8" alt="Transverse" /></td>
<td><img src="image9" alt="Oblique" /></td>
</tr>
</tbody>
</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
Tangent or Secant?

Earth's Surface

Orthographic

Secant Projection Surface

Stereographic

Gnomonic

Orthographic

Tangent Projection Surface
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)

<table>
<thead>
<tr>
<th>Origin X, Y Values</th>
<th>Origin Longitude (y axis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin Latitude (x axis)</td>
<td>Units of measure</td>
</tr>
<tr>
<td>Secant Locations</td>
<td>Horizontal Datum</td>
</tr>
</tbody>
</table>

- Origin Latitude (x axis)
- Origin Longitude (y axis)
- Units of measure
- Origin X, Y Values
- Secant Locations
- Horizontal Datum

Geographic Coordinate System: GCS GRS 1980
Angular Unit: Degree (0.017453292519943295)
Prime Meridian: Greenwich (0.000000000000000000)
Datum: D North American 1983
Spheroid: GRS 1980
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.
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

![Diagram of Standard Parallels 3° apart]
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.

UTM Zone is 6° wide
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

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

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

Central Meridian (X = 500,000 m)

Y = 3,000,000 mN

UTM Coordinate System
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 northing 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>North</td>
<td>34.650 36.183</td>
<td>-101.50 34.00</td>
<td>200,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>N. Cent.</td>
<td>32.133 33.967</td>
<td>-98.50 31.67</td>
<td>600,000</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Central</td>
<td>30.117 31.883</td>
<td>-100.33 29.67</td>
<td>700,000</td>
<td>3,000,000</td>
</tr>
<tr>
<td>S. Cent.</td>
<td>28.383 30.283</td>
<td>-99.00 27.83</td>
<td>600,000</td>
<td>4,000,000</td>
</tr>
<tr>
<td>South</td>
<td>26.167 27.833</td>
<td>-98.50 25.67</td>
<td>500,000</td>
<td>5,000,000</td>
</tr>
</tbody>
</table>

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

- P.L.S.
- No P.L.S.
- Principal Meridian
- Baseline
Public Land Survey System (PLS)

Step 1: T2S, R1W, Section 33

Step 2: Meridian, Baseline

Step 3: Section 33, Center Sec. 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.
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.