Map Projections & Coordinate Systems

From Last Time - 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
  - e.g. an equipotential surface of gravity, the Geoid (Orthometric Heights)
  - e.g. a reference ellipsoid (ellipsoid heights or Heights above Ellipsoid, H.A.E.)
- 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.

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.

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.

Scaled Map
distance
True distance

Globe distance
Earth distance

Scale
1: 42,000,000
Scale Factor ("distortion factor")
0.9996
Laying the Earth Flat

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

Geographic Coordinates ($\phi, \lambda$) → Projected Coordinates ($x, y$)

“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

Projection types ("perspective" classes):

- Orthographic
- Gnomonic
- Stereographic

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.

• 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.
Map Projections & Coordinate Systems

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

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

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.

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 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

Locations are given in meters from central meridian (Eastings) and equator (Notings).
- (-) 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 (-) Notings.

UTM Coordinate System

Central Meridian

Equator

N. Hemisphere origin is (500,000m, 0)

S. Hemisphere origin is (500,000m, 10,000,000m)

UTM Coordinates for central Austin:

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

Central Meridian

Austin

Y = 3,000,000 mN

X = 500,000 m
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 F. Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>4201 North</td>
<td>34.650 34.658</td>
<td>36.183 34.06</td>
<td>200,000 1,000,000</td>
</tr>
<tr>
<td>4202 N. Cent</td>
<td>32.133 31.967</td>
<td>31.883 29.67</td>
<td>600,000 1,000,000</td>
</tr>
<tr>
<td>4203 Central</td>
<td>30.337 30.008</td>
<td>30.000 28.00</td>
<td>700,000 1,000,000</td>
</tr>
<tr>
<td>4204 S. Cent</td>
<td>28.383 27.833</td>
<td>28.000 26.00</td>
<td>400,000 5,000,000</td>
</tr>
<tr>
<td>4205 South</td>
<td>26.167 25.000</td>
<td>25.000 23.00</td>
<td>500,000 5,000,000</td>
</tr>
</tbody>
</table>

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.
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

From Bolstad, Fig. 3-50

Public Land Survey System (PLS)

Step 1

Step 2

Step 3

T2S, R1W, Section 33

Section 33

Center Sec. 33

Summary

- Projections transform geographic coordinates (ϕ, λ) 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.