Geodesy and Datums

Ellipsoid and Geoid

Geographic Coordinate system
Defining the Ellipsoid

• The Earth is not perfectly round
  – “Fatter” around the waist (equator)
  – Flattened at the Poles

• To define this unique shape we use an ellipsoid

• Each ellipsoid has the following dimensions
  – Semi-major axis (equatorial)
    • The semi-major axis is always larger than the semi-minor axis
  – Semi-minor axis (polar)
Ellipsoid

\[ f = \frac{r_e - r_i}{r_e} \]

- Equator
- Pole
- Semi-major axis
- Semi-minor axis

Bolstad 2002
# Official Ellipsoids

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Equatorial Radius, ( r_1 ) meters</th>
<th>Polar Radius, ( r_2 ) meters</th>
<th>Flattening Factor, ( f )</th>
<th>Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airy</td>
<td>1830</td>
<td>6,377,563.4</td>
<td>6,356,256.9</td>
<td>1/299.32</td>
<td>Great Britain</td>
</tr>
<tr>
<td>Bessel</td>
<td>1841</td>
<td>6,377,397.2</td>
<td>6,356,079.0</td>
<td>1/299.15</td>
<td>Central Europe, Chile, Indonesia</td>
</tr>
<tr>
<td>Clarke</td>
<td>1866</td>
<td>6,378,206.4</td>
<td>6,356,583.8</td>
<td>1/294.98</td>
<td>North America: Philippines</td>
</tr>
<tr>
<td>Clarke</td>
<td>1880</td>
<td>6,378,249.1</td>
<td>6,356,514.9</td>
<td>1/293.46</td>
<td>Most of Africa: France</td>
</tr>
<tr>
<td>International</td>
<td>1924</td>
<td>6,378,388.0</td>
<td>6,356,911.9</td>
<td>1/297.00</td>
<td>Much of the World</td>
</tr>
<tr>
<td>Australian</td>
<td>1965</td>
<td>6,378,160.0</td>
<td>6,356,774.7</td>
<td>1/298.25</td>
<td>Australia</td>
</tr>
<tr>
<td>WGS72</td>
<td>1972</td>
<td>6,378,135.0</td>
<td>6,356,750.5</td>
<td>1/298.26</td>
<td>NASA, US Defense Dept.</td>
</tr>
<tr>
<td>GRS80</td>
<td>1980</td>
<td>6,378,137.0</td>
<td>6,356,752.3</td>
<td>1/298.26</td>
<td>Worldwide</td>
</tr>
<tr>
<td>WGS84</td>
<td>1984</td>
<td>6,378,137.0</td>
<td>6,356,752.3</td>
<td>1/298.26</td>
<td>Worldwide</td>
</tr>
</tbody>
</table>
Datums

• *A datum* provides the coordinates of an *initial point* that can be precisely located in the field.

• A datum requires two components:
  – Specification of an ellipsoid
  – Points and lines which have been meticulously surveyed.
Datums

• Different geographic coordinate systems may be defined and used
  – Defined based on the shape of the earth with adjustments for best accuracy
  • Differ in accuracy (older versus newer)
  • Differ in purpose (for small or large areas)
  • Customized for smallest error in specific locales
Datum definition

• A datum definition includes
  – The particular spheroid used based on a determination of the earth’s major and minor axis
    • Clarke 1866 vs GRS80
    • Estimate has varied in accuracy
    • New satellite determinations are most accurate
  – The adjustment or fit (translation of center)

• Together these define the GCS
Note for GPS Users

- GPS units may be set to collect points in more than one datum and projection
  - Often UTM or long-lat units may be specified
    - UTM NAD 1983
    - UTM NAD 1927
    - Lat-Lon NAD 1983… etc

- You MUST know and record the datum in order to use the data correctly later!!!!!!
  - Be careful—the default datum setting might not be the one you want
Datum transformations

- Projections are exact mathematical formulas
  - Projection conversions can be accomplished very accurately

- Converting one datum to another requires specialized fitting
  - Not exact; errors may accumulate with repeated transformations
  - Several methods available
    - Some better than others for particular changes
    - Not all methods work for all transformations

Converting datums should be done only when necessary, and care should be taken in choosing the best method.
<table>
<thead>
<tr>
<th>Datum Name</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>North American Datum of 1927 (NAD27)</td>
<td>Until the creation of NAD83, this was the datum of choice for use in North America. It is now being replaced by NAD83, but a huge amount of historical spatial data remains in NAD27.</td>
</tr>
<tr>
<td>North American Datum of 1983 (NAD83)</td>
<td>The currently preferred datum for use in both North and South America. This datum has been slowly replacing NAD27; most new spatial data generated in the Americas are being produced based on this datum.</td>
</tr>
</tbody>
</table>
### World Geodetic System of 1972 (WGS72)

Originally developed by the U.S. Department of Defense with cooperation from many of the U.S.'s NATO allies, this datum's principle purpose was to assist in the targeting of nuclear-armed intercontinental ballistic missiles (ICBMs) and submarine launched ballistic missiles (SLBMs). At the time, the accuracy of these weapons was not particularly good (at least by today's standards), so this datum was not particularly accurate.

### World Geodetic System of 1984 (WGS84)

Developed by the U.S. Department of Defense with cooperation with the U.S.'s NATO allies, the WGS84 datum was again designed primarily for weapons targeting purposes. However, WGS84 was much more accurate than WGS72, and thus has caught on for purposes outside the military.
### Datum Variation

An example of different coordinates for identical points, based on differing datums.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Longitude</td>
<td>Latitude</td>
<td>Longitude</td>
</tr>
<tr>
<td>Miami</td>
<td>-80° 16' 12.0&quot;</td>
<td>25° 49' 55.2&quot;</td>
<td>-80° 16' 12.0&quot;</td>
</tr>
<tr>
<td>Denver</td>
<td>-105° 4' 12.0&quot;</td>
<td>39° 45' 0.0&quot;</td>
<td>-105° 4' 15.6&quot;</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>-118° 15' 0.0&quot;</td>
<td>34° 0' 0.0&quot;</td>
<td>-118° 15' 3.6&quot;</td>
</tr>
<tr>
<td>New York</td>
<td>-74° 6' 0.0&quot;</td>
<td>40° 45' 0.0&quot;</td>
<td>-74° 6' 0.0&quot;</td>
</tr>
<tr>
<td>Seattle</td>
<td>-122° 19' 1.2&quot;</td>
<td>47° 35' 20.4&quot;</td>
<td>-122° 19' 4.8&quot;</td>
</tr>
</tbody>
</table>
Datum Variation

Position Shifts from Datum Differences
Texas Capitol Dome Horizontal Benchmark

Peter H. Dana 9/1/94
Topo maps show three different coordinate systems:

- An unprojected system **GCS (degrees)**
- Two projected systems
  - **State Plane (feet)**
  - **UTM (meters)**

Same point has different x-y values depending on the coordinate system used.
UTM Zone 13

Same point—different x-y’s

GCS

State Plane
• Every feature class stores x-y values based on a specific CS
• The CS may be projected or unprojected
• The feature class also has a label documenting the CS parameters
On the fly projection in ArcMap

**Source Layers**

World in GCS_WGS84

Latlon in GCS_WGS84

**Data frame coordinate system**

Robinson_WGS_84

Input layers have any CS

Set data frame to desired CS
Projections and datums

• Every map projection is based on a GCS
• Every GCS has a datum
• Therefore: Every projection has a datum

  – Projections based on different datums will be offset from one another
  • Amount of offset depends on region
  • Typically 0 – 300 meters

UTM Zone 13 NAD 1983 ≠ UTM Zone 13 NAD 1297!
Review

- In GIS we must uniquely define the location of all coordinates to a frame of reference
  - First, we define the Earth’s shape with an Ellipsoid
  - The Geoid is a gravitationally defined surface and the reason for locally applicable ellipsoids
  - Datums are used to specify exact coordinate locations relative to an ellipsoid