Coordinate Systems, Datum and Map Projection

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“Every map user and maker should have a basic understanding of projections no matter how much computers seem to have automated the process.”

- John P. Snyder
Why is this important?

- Creating spatial data (collecting GPS data)
- Import into GIS and overlay with other layers
- Acquiring spatial data from other sources
- Display your GPS data using maps
Coordinate Systems

There are 2 types of coordinate systems:

– Geographic Coordinate Systems

– Projected Coordinate Systems
Geographic Coordinate System

- Earth is not a sphere
- Poles are flattened
- Bulges at equator

Earth is ellipsoid ......or a spheroid
Geographic Coordinate System

- Ellipsoid **approximates** the shape of the earth
  - Model of the earth
  - Also called an “spheroid”
### Geographic Coordinate System

<table>
<thead>
<tr>
<th>Reference Ellipsoid</th>
<th>Equatorial Radius $a$ (m)</th>
<th>Reciprocal Flattening $1/f$</th>
<th>$\Delta a$ (m) with WGS84</th>
<th>$\Delta f \times 10^4$ with WGS84</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airy 1830</td>
<td>6377563.396</td>
<td>299.3249646</td>
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<td>860.655</td>
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</table>
Geographic Coordinate System

- A **datum** defines the position of the ellipsoid relative to the center of the earth
  - Origin and orientation of latitude and longitude lines are determined by the datum
  - Hundreds of datums customized for different parts of the world
Geographic Coordinate System

- A reference system using latitude and longitude to define the location of points on the surface of an Ellipsoid (φ, λ, h)
  - decimal degrees (DD) -92.5
  - degrees/minutes/seconds (DMS) 31° 25’ 10” E

Example:
A location of a point in Khan Younis:
φ = 31° 20’ N
λ = 34° 20’ E
h = 78.454 m
# Common Datums

<table>
<thead>
<tr>
<th>Datum</th>
<th>Ref. Ellipsoid</th>
<th>$\Delta X$ (m)</th>
<th>$\Delta Y$ (m)</th>
<th>$\Delta Z$ (m)</th>
<th>$S$ (ppm)</th>
<th>$\varepsilon_x$</th>
<th>$\varepsilon_y$</th>
<th>$\varepsilon_z$</th>
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<td>-2</td>
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<td>Old Egyptian</td>
<td>Helmert 1906</td>
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<td>685</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Transforming between datums

- GPS
- GIS
- Special software
- Develop your tool

\[
X = \frac{(v + h) \cos \phi \cos \lambda}{\sqrt{1 - e^2 \sin^2 \phi}}
\]
\[
Y = \frac{(v + h) \cos \phi \sin \lambda}{\sqrt{1 - e^2 \sin^2 \phi}}
\]
\[
Z = \frac{[v(1 - e^2) + h] \sin \phi}{\sqrt{1 - e^2 \sin^2 \phi}}
\]

\[
1 = \frac{\Delta X}{s_Z} - s_Y
\]

\[
\tan \lambda = \frac{Y}{X}
\]

\[
\tan \phi = \frac{Z(1 - f) + e^2 \sin^2 \mu}{(1 - f)(p - e^2 \cos^2 \mu)}
\]

\[
\tan \mu = \frac{Z}{p} \left[ \frac{(1 - f) + e^2 \alpha}{r} \right]
\]

\[
h = p \cos \phi + Z \sin \phi - \alpha \sqrt{1 - e^2 \sin^2 \phi}
\]
Geographic Coordinate System

• Universal Coordinate System (lat/lon)

• Lat/lon good for locating positions on surface of a globe

• Lat/lon is not efficient for measuring distances and areas!

  – Latitude and longitude are not uniform units of measure

  – One degree of longitude at equator = 111.321 km (Clarke 1866 ellipsoid)

  – One degree of longitude at 60° latitude = 55.802 km (Clarke 1866 ellipsoid)
Projected Coordinate Systems

- A map projection is the systematic transformation of locations on the earth (latitude/longitude) to planar coordinates.

- The basis for this transformation is the geographic coordinate system (which references a datum).

- Map projections are designed for specific purposes.
Map Projection

\[(x, y) = f(\phi, \lambda)\]
Map Projection

(a) Imaginary cone

(b) Imaginary cylinder

(c) Scale greater than true

(d) Scale less than true

Scales exact

N

Scale greater than true

Scale less than true

Scales exact

Scale greater than true
This process of flattening the earth will cause distortions in one or more of the following spatial properties:

- **Shape**
  - Conformal map projections preserve shape
- **Area**
  - Equal area map projections preserve area
- **Distance/Scale**
  - Equidistant map projections preserve distance
- **Direction/Angle**
  - Azimuthal map projections preserve true direction
Map Projection

عناصر إسقاط خمسة:

- Latitude of Origin
- Central Meridian
- False Easting
- False Northing
- Scale Factor
### Projected Coordinate Systems

<table>
<thead>
<tr>
<th>Datum name</th>
<th>Old Palestine Grid (OPG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellipsoid</td>
<td>Clarke 1880 modified</td>
</tr>
<tr>
<td></td>
<td>( a = 6378300.789 \text{ m} )</td>
</tr>
<tr>
<td></td>
<td>( 1/f = 293.466 )</td>
</tr>
<tr>
<td></td>
<td>( b = 6356566.412 \text{ m} )</td>
</tr>
<tr>
<td>Projection</td>
<td>Type: Cassini Soldner</td>
</tr>
<tr>
<td></td>
<td>Latitude of Origin: 31 44 02.749 N</td>
</tr>
<tr>
<td></td>
<td>Central Meridian: 35 12 43.490 E</td>
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<tr>
<td></td>
<td>False Northing: 1126867.909 m</td>
</tr>
<tr>
<td></td>
<td>False Easting: 170251.555 m</td>
</tr>
<tr>
<td></td>
<td>Scale: 1.0</td>
</tr>
</tbody>
</table>
\[ \begin{align*}
\chi &= R (\lambda - \lambda_0) \\
y &= R \ln[\tan(\pi/4 + \phi/2)]
\end{align*} \]

Mercator Projection
Universal Transverse Mercator (UTM)

- Developed by military
- Grid system
- Earth divided into 60 zones
- Great for small areas
  - minimal map distortion
  - distortion greater at edge of zones
- Most common map projection used
Universal Transverse Mercator- UTM Grid
Universal Transverse Mercator - UTM Grid

\[ x = FE + k_0 v \left[ A + (1 - T + C) \frac{A^3}{6} + \left(5 - 18T + T^2 + 72C - 58e^2\right) \frac{A^5}{120} \right] \]

\[ y = FN + k_\alpha \left[ M - M_\alpha + v \tan \phi \left( \frac{A^2}{2} + (5 - T + 9C + 4C^2) \frac{A^4}{24} + \left(61 - 58T + T^2 + 600C - 330e^2\right) \frac{A^6}{720} \right) \right] \]
Projection Transformation

a) From one projection to another - same datum

- Projected Coordinates: e.g. Palestine 1923 Cassini
- Geographic Coordinates: Palestine 1923

b) From one projection to another - different datums

- Projected Coordinates: e.g. Palestine 1923 Cassini
- Geographic Coordinates: Palestine 1923
- Datum transformation, an empirical model
- Projected Coordinates: e.g. WGS84 UTM-Zone 36
- Geographic Coordinates: WGS84

Back projection, an exact conversion
Projection, an exact conversion
Transforming between Coordinates

- GPS
- GIS
- Special software
- Develop your tool
When GPS points don’t align with GIS Data

Most likely a projection issue if:

• There are huge errors…data points do not overlay
• Features could be displayed in wrong state or hemisphere!
When GPS points don’t align with GIS Data

Possibly a datum issue if:

- GPS data overlays with GIS data, but off by several hundred feet
- Differences between NAD27 and NAD83 can be as much as 500 feet
- This creates problems when doing analysis
 Thank You !!!