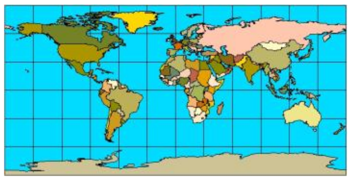
Geographic Datums & Coordinates

- What is the shape of the earth?
  - Why is it relevant for GIS?



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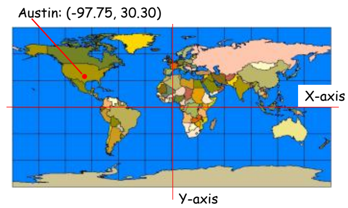
Make a Map, Graph the World

- What determines spacing of 30° increments of Lat. & Lon. ?
- *Dimensions and shape of earth (= DATUM)*
  - Map Projection
  - Map Scale



- Graph shows 30° increments of Lat. & Lon.

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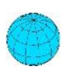
The Figure of the Earth

- Models
  - Sphere with radius of ~6378 km
  - Ellipsoid (or Spheroid) with equatorial radius (semimajor axis) of ~6378 km and polar radius (semiminor axis) of ~6357 km
    - Difference of ~21 km usually expressed as "flattening" (f) ratio of the ellipsoid:
      - f = difference/major axis = ~1/300 for earth



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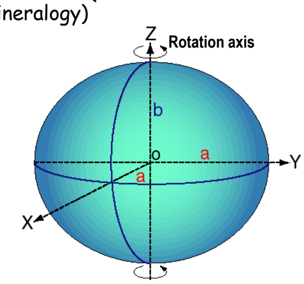
Ellipsoid / Spheroid

- Rotate an ellipse around an axis (c.f. Oblate indicatrix of optical mineralogy)

a = Semimajor axis

b = Semiminor axis

X, Y, Z = Reference frame



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Standard Earth Ellipsoids

Ellipsoid	Major Axis a (km)	Minor Axis b (km)	Flattening (1/*f*)
Clark (1886)	6,378.206	6,356.584	294.98
GRS 80	6,378.137	6,356.752	298.257

- At least 40 other ellipsoids in use globally

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Earth Ellipsoids Distances

Ellipsoid	1^0 of Latitude
Clark (1886)	~110,591 meters
GRS 80	~110,598 meters

~ 7 meter difference is significant with modern software, but the real difference is the Datums with which they are typically associated.

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Horizontal Control Datums

Datum = shape of ellipsoid and location of origin for axis of rotation relative to center of mass of earth.

Common North American datums:

- NAD27 (1927 North American Datum)
  - Clarke (1866) ellipsoid, non-geocentric (local) origin for axis of rotation*
- NAD83 (1983 North American Datum)
  - GRS80 ellipsoid, geocentric origin for axis of rotation
- WGS84 (1984 World Geodetic System)
  - WGS84 ellipsoid; geocentric, nearly identical to NAD83
- Other datums in use globally

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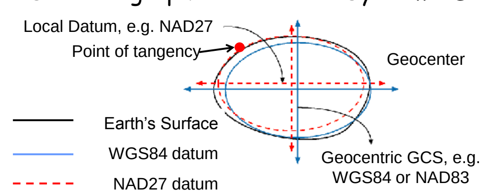
Datum Rotation Axes and the Geocenter

- Geocenter = center of mass of earth
- Local Datum vs. Geocentric Datum
- "GCS" = Geographic Coordinate System = Datum



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NGS "Geodetic Datum"

- A set of constants specifying the coordinate system used for geodetic control
- Used for calculating the coordinates of points on Earth
- NAD83 is the modern (legal) horizontal control datum for US, Canada, Mexico and Central America

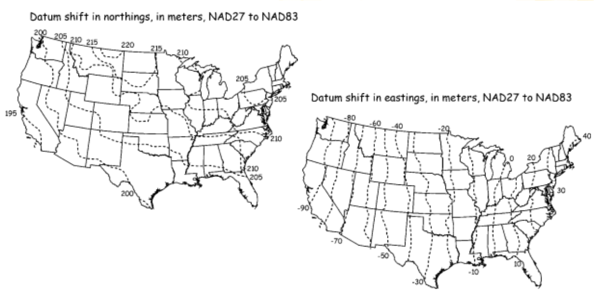
Adjustments to NAD83

- HARN (or HPGN) – High Accuracy Reference Network = *Empirical corrections to NAD83*
- Cooperative initiative between N.G.S. and states using GPS to refine NAD83 network of control points
- Network of 16,000 stations surveyed from 1986-1997, allowing network accuracy of 5mm

Datum "shifts"

- Coordinate shift by application of wrong datum can result in horizontal positioning errors as great as 800 m
- An example compares the WGS84 location of the Texas state capitol dome to 13 other datums.

Datum "shifts"



NAD27, NAD83 & WGS 84 Coordinates

Datum	Latitude	Longitude
NAD 1927	48.7440490722656	122.466903686523
NAD 1983	48.7438798543649	-122.46818353793
WGS 1984	48.7438798534299	-122.46818353793

Datum Transformations - Theoretical

- Equations relating Lat. & Lon. in one datum to the same in another:

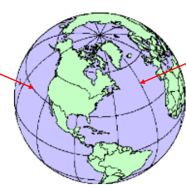
1) Convert Lat., Lon. and elevation to X, Y, Z
   - Using known X, Y, Z offsets of datums, transform from X, Y, Z of old to X, Y, Z of new
   - Convert new X, Y, Z to Lat., Lon. and elevation of new datum
   - E.g. Molodensky, Geocentric Translation, Coordinate Frame Methods

Datum Transformations - Emperical

2) Use Grid of differences to convert values directly from one datum to another
   - E.g. NADCON (US), NTv2 (Canada)
   - Emperical; potentially most accurate (NAD27 to NAD83 accurate to ~0.15 m for Cont. US)
   - HARN and HPGS values used for grid to update NAD83
     - Stand-alone programs are available to do conversions by most methods; also done within ArcGIS ArcMap &Toolbox
     - See Digital Book on Map Projections for more info.

Latitude and Longitude

- Historical Development
- Coordinates on an ellipsoidal earth



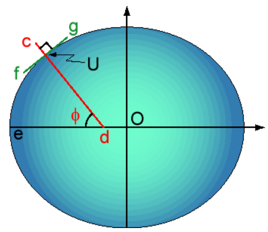
Coordinates have roots in marine navigation

- **Latitude:** measured by vertical angle to polaris (N. Hemisphere) or to other stars and constellations (S. Hemisphere)
- **Longitude:** determined by local time of day vs. standard time (e.g. GMT)
  - requires accurate clocks; 1 hour difference = 15° of Longitude*

Latitude(ϕ) on Ellipsoidal Earth

Latitude of point U calculated by:

1) Defining the tangent plane ($\overline{fg}$) to the ellipsoid at U.
2) Defining the line perpendicular to the tangent plane ($\overline{cd}$) passing through U.
3) Latitude (ϕ) is the angle that the perpendicular in 2) makes with the equatorial plane (angle cde).

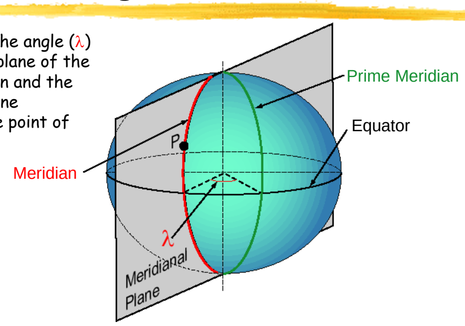


Latitude facts:

- Lines of latitude (parallels) are evenly spaced (small circles) from 0° at equator (a great circle) to 90° at poles.
- 60 nautical miles (~ 110 km)/1°, ~1.8 km/minute and ~ 30 m/second of latitude.
- N. latitudes are positive (+ϕ), S. latitudes are negative (-ϕ).

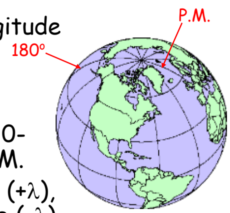
Longitude (λ)

Longitude is the angle (λ) between the plane of the prime meridian and the meridianal plane containing the point of interest (P).



Longitude facts:

- Lines of longitude (meridians) converge at the poles; the distance of a degree of longitude varies with latitude.
- Zero longitude is the Prime (Greenwich) Meridian (PM); longitude is measured from 0-180° east and west of the PM.
- East longitudes are positive (+λ), west longitudes are negative (-λ).



Units of Measure

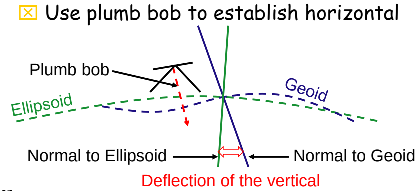
- Decimal degrees (DD), e.g. - 90.50°, 35.40°
  - order by long., then lat.
  - Format used by ArcGIS software
- Degrees, Minutes, Seconds (DMS), e.g. – 90° 30′ 00″, 35° 24′, 00″
- Degrees, Decimal Minutes (DDM) e.g. – 90° 30.0′, 35° 24.0′

Vertical Datums

- Sea Level (MSL), Geoid
  - Geoid = surface of constant gravitational potential that best fits MSL
    - governed by mass distribution of earth
- Ellipsoid (HAE = Height above ellipsoid)
  - Geometric surface
  - Datum used by most GPS receivers

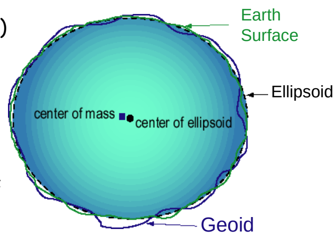
Vertical Datums

- Can't directly observe Geoid or Ellipsoid
  - So traditionally MSL heights found by level line surveys away from coasts.
    - Use plumb bob to establish horizontal



Sea Level (MSL), Geoid

- Measure ht. of sea surface (via satellites) and connect with costal surveys on land to get geoid.
- Sea "Level" (geoid) not level; as much as 85 to -105 m of relief globally.



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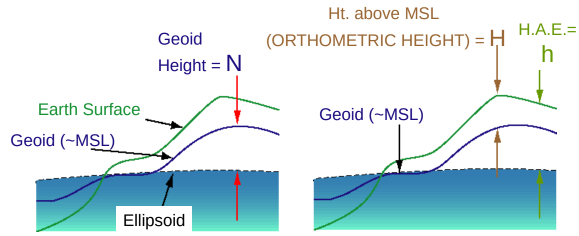
Geoid, Ellipsoid and Elevation (H)

h = H + N or H = h - N



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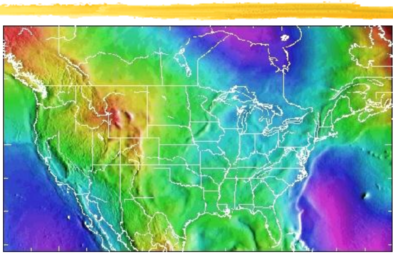
Geoid of the conterminous US



GEOID99 heights (= Geoid – Ellipsoid) range from a low of -50.97 m (magenta) in the Atlantic Ocean to a high of 3.23 m (red) in the Labrador Strait.

Source: NGS at http://www.ngs.noaa.gov/GEOID/GEOID99/geoid99.html

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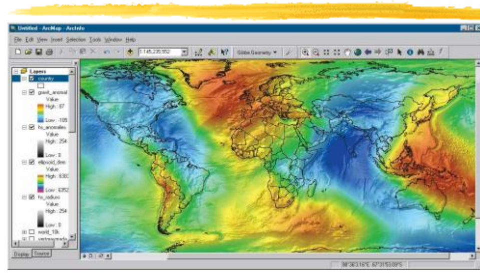
Geoid of the World (EGM96)



Source: http://www.esri.com/news/arcuser/0703/geoid1of3.html

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To convert HAE to orthometric (elev. above MSL) height:

- Need accurate model of geoid height (e.g. N.G.S. GEOID99)
  - GEOID99 has 1 x 1 minute grid spacing
- Compute difference between HAE and Geoid height (online here for US)
- Current model allows conversions accurate to ~ 5 cm
- More precise orthometric heights require local gravity survey

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N. American Vertical Datums

- National Geodetic Vertical Datum 1929 (NGVD29)
  - ~mean sea level height based on 26 tide gauges and 1000's of bench marks. Not MSL, *not Geoid, not an equipotential surface*
  - Failed to account for sea surface topography (unknown at the time)

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N. American Vertical Datums

- North American Vertical Datum 1988 (NAVD88)
  - Established 1991
  - Fixed to 1 tidal benchmark in Quebec
  - Based on best fit to vertical obs. of US, Canada and Mexico benchmarks

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Next time: How do we get from 3D earth models to 2D maps?

- Map Projections – transforming a curved surface to a flat graph
- Rectangular coordinate systems for smaller regions – UTM, SPCS, PLS

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