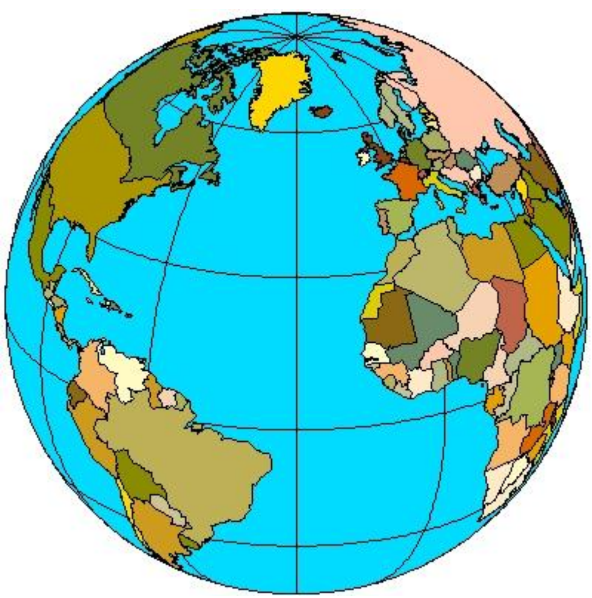
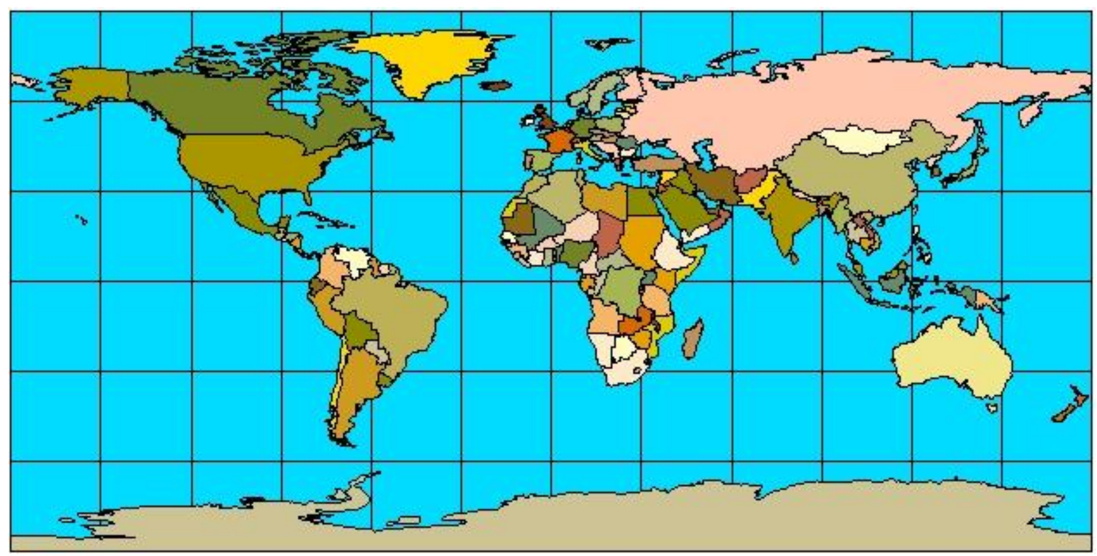
Geographic Datums & Coordinates

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

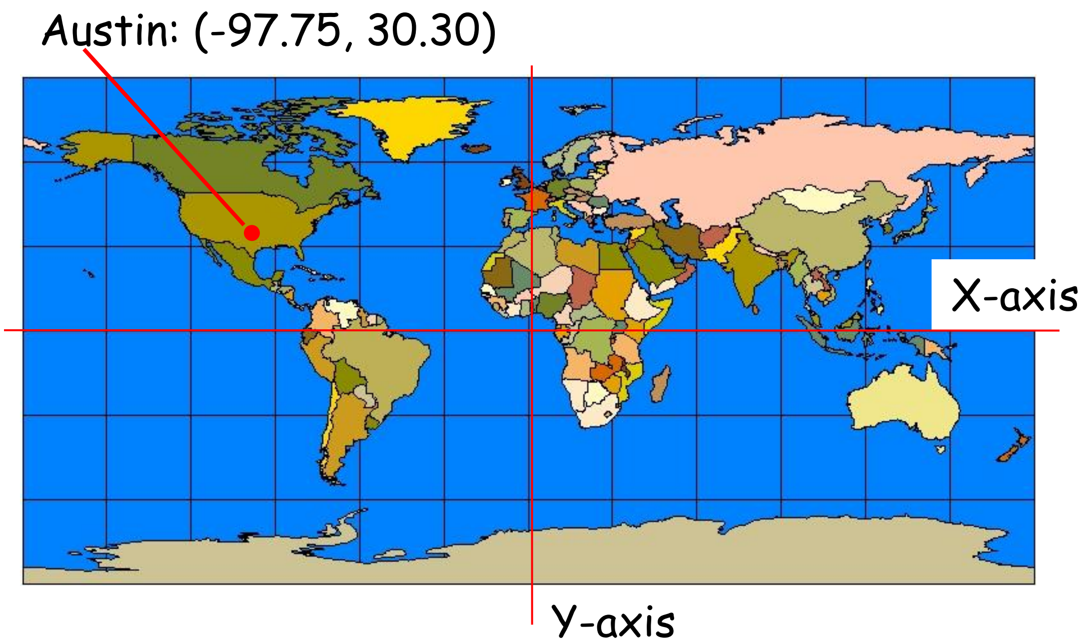




M. Helper

Make a Map, Graph the World

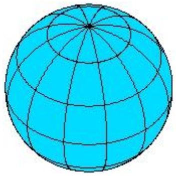
- What determines spacing of 30º increments of Lat. & Lon. ?
- *Dimensions and shape of earth* *(= DATUM)*
  - Map Projection
  - Map Scale



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

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

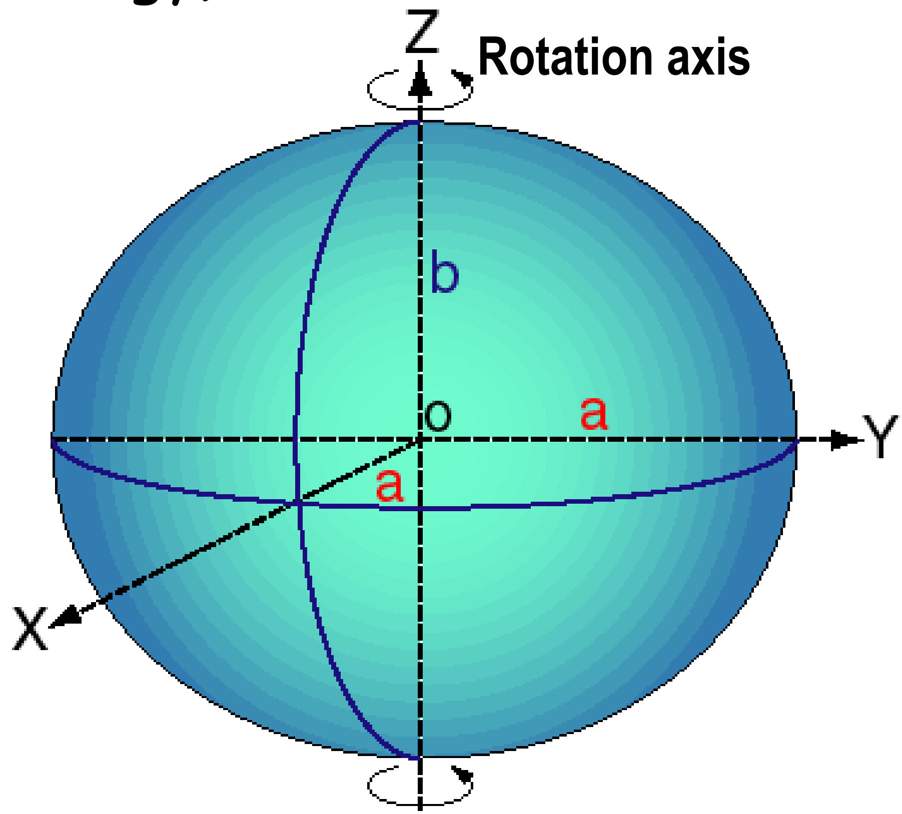
Ellipsoid / Spheroid

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

a = Semimajor axis

b = Seminimor axis

X, Y, Z = Reference frame



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

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.

Horizontal Control Datums

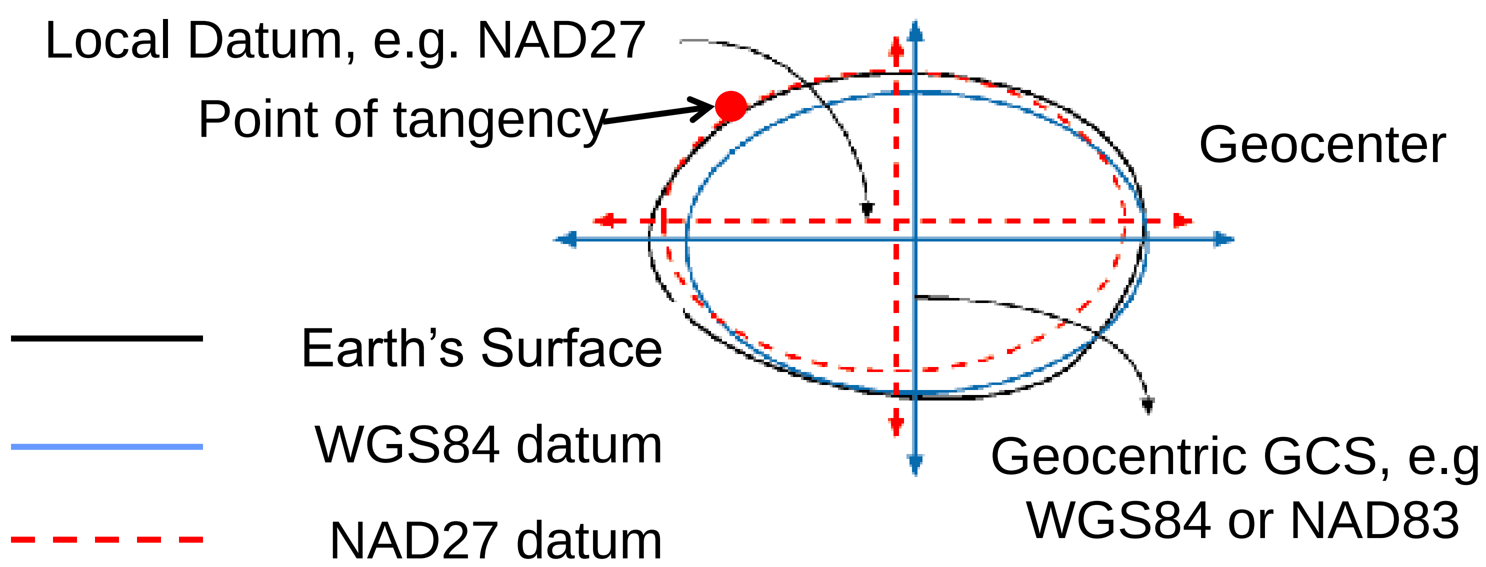
Datum = shape of ellipsoid and location of origin for axis of rotation relative to center of mass of earth.

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

Datum Rotation Axes and the Geocenter

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



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

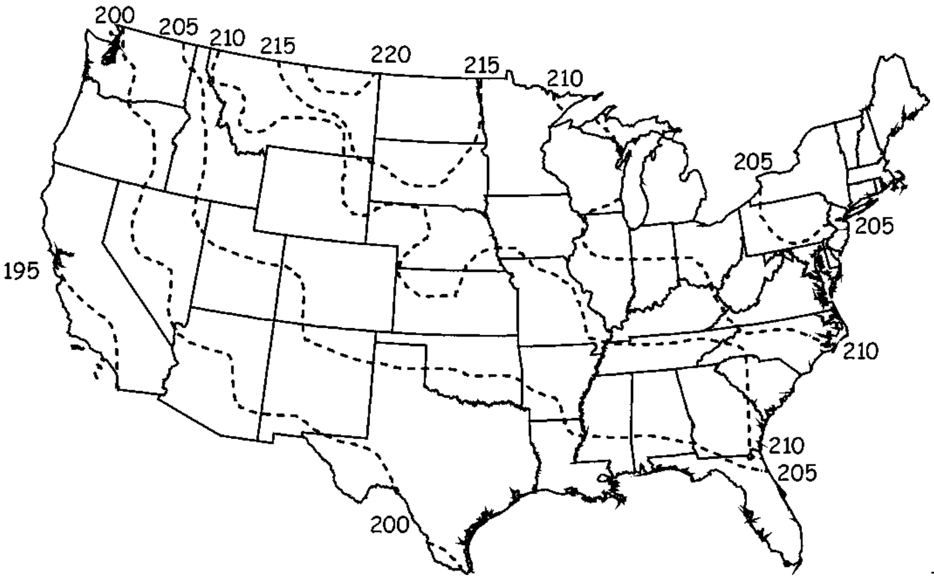
- HARN (or HPGN) – High Accuracy Reference Network = *Empirical corrections to NAD83*
- Cooperative initiative between N.G.S. and states using GPS to refine NAD83 network of control points
- Network of 16,000 stations surveyed from 1986-1997, allowing network accuracy of 5mm

Datum "shifts"

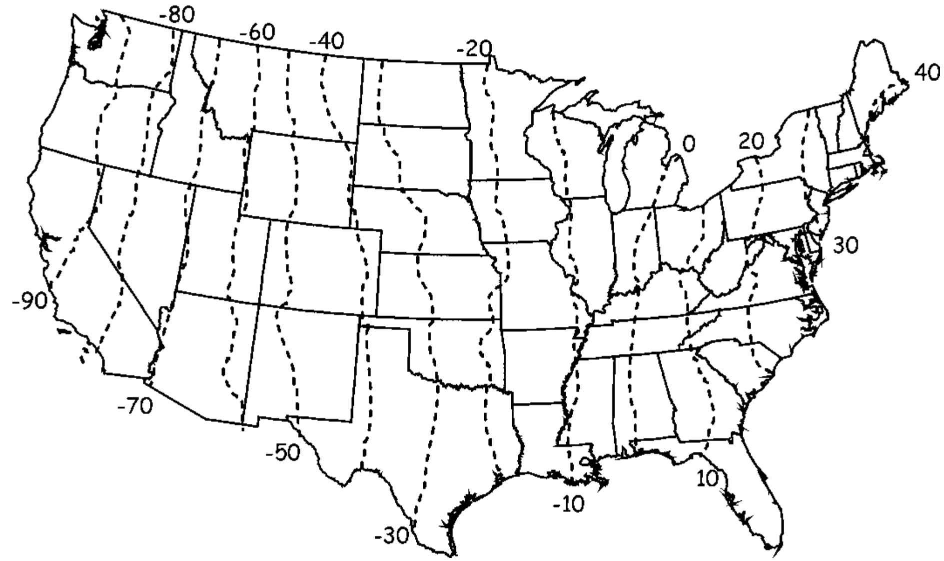
- Coordinate shift by application of wrong datum can result in horizontal positioning errors as great as 800 m
- An example compares the WGS84 location of the Texas state capitol dome to 13 other datums.

Datum "shifts"

Datum shift in northings, in meters, NAD27 to NAD83



Datum shift in eastings, in meters, NAD27 to NAD83



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

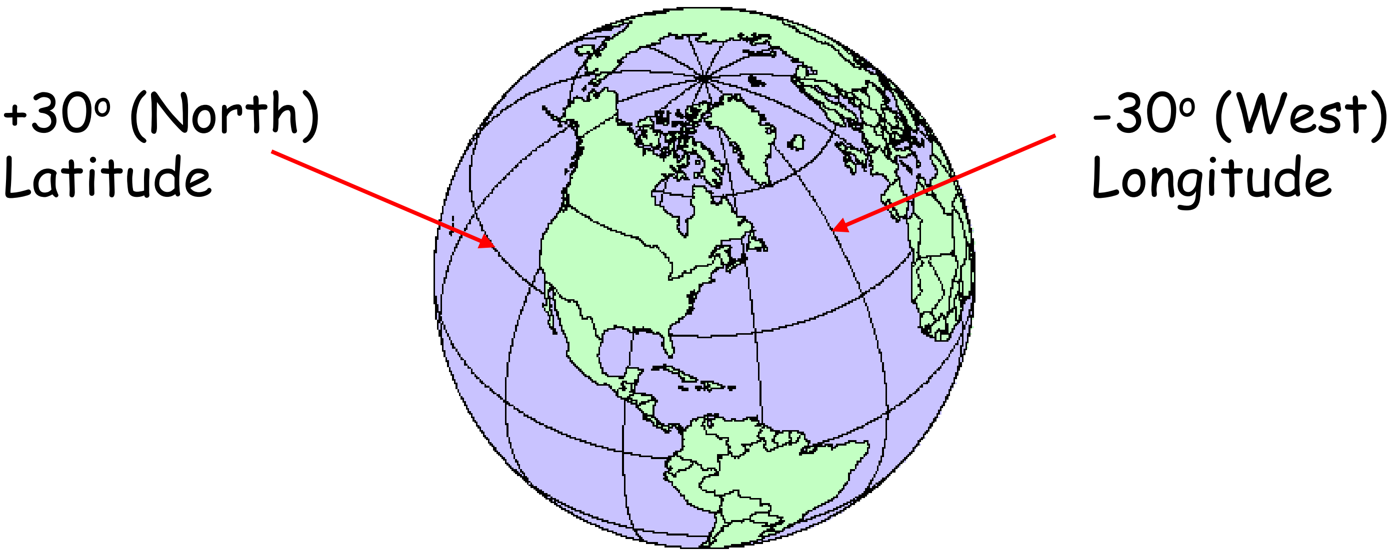
Datum Transformations - Emperical

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



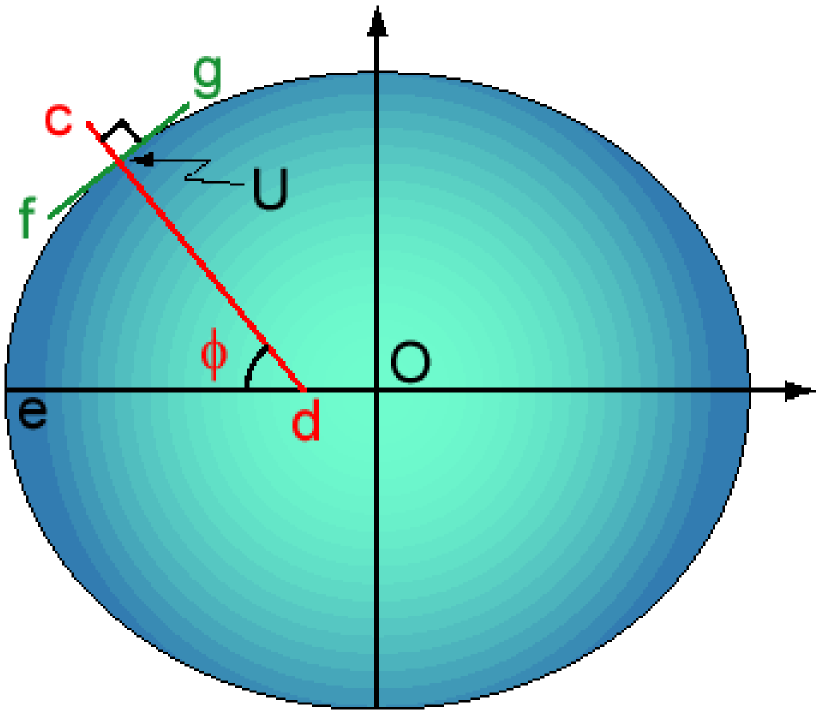
Coordinates have roots in marine navigation

- 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

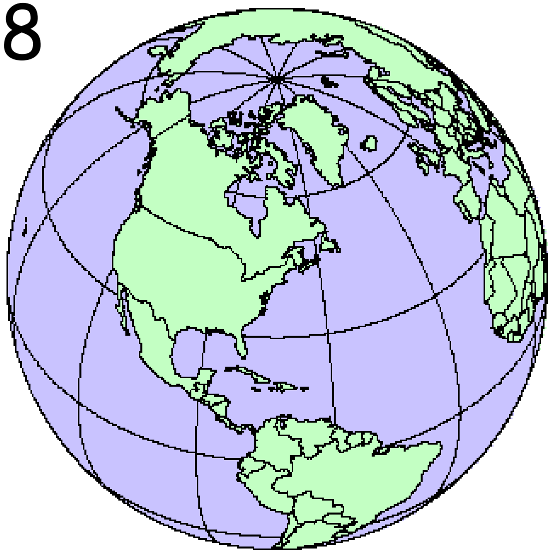
Latitude of point U calculated by:

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).



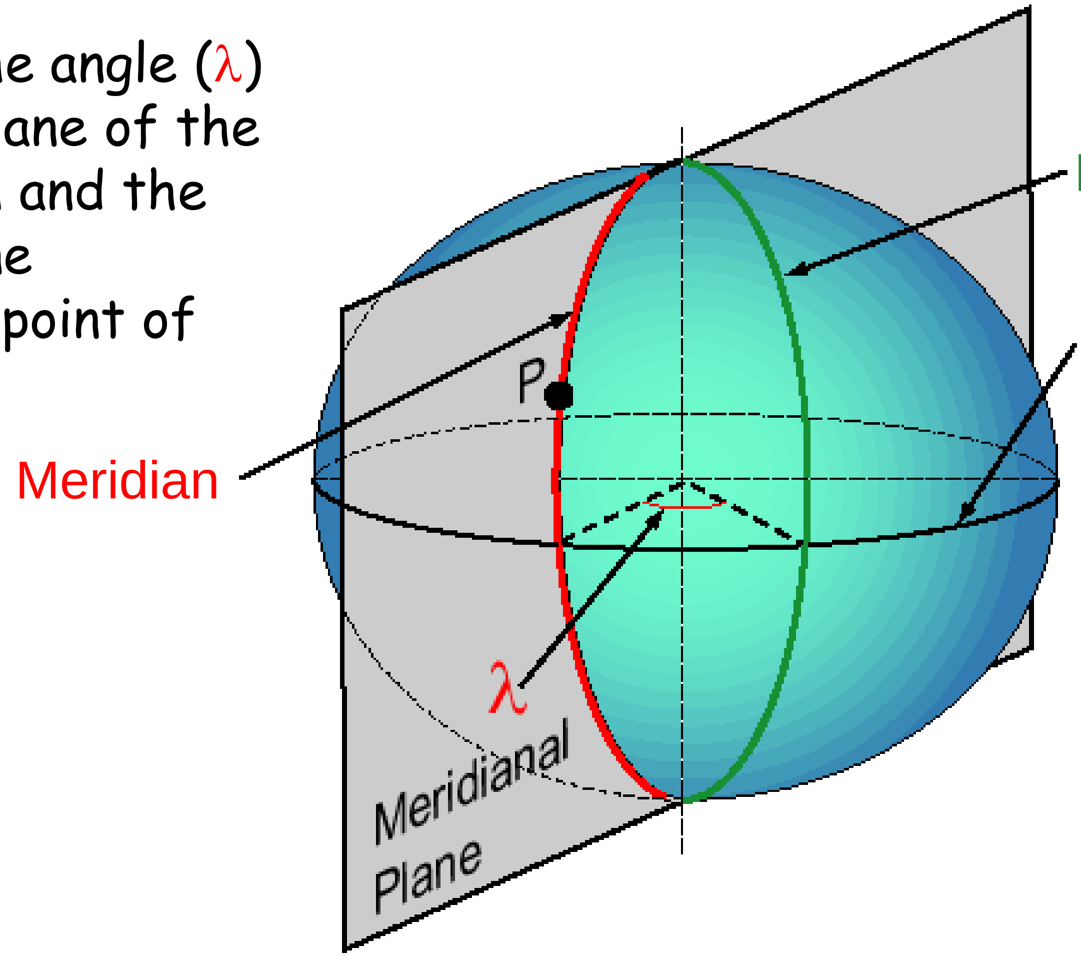
Latitude facts:

- 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 ($+\phi$), S. latitudes are negative ($-\phi$).



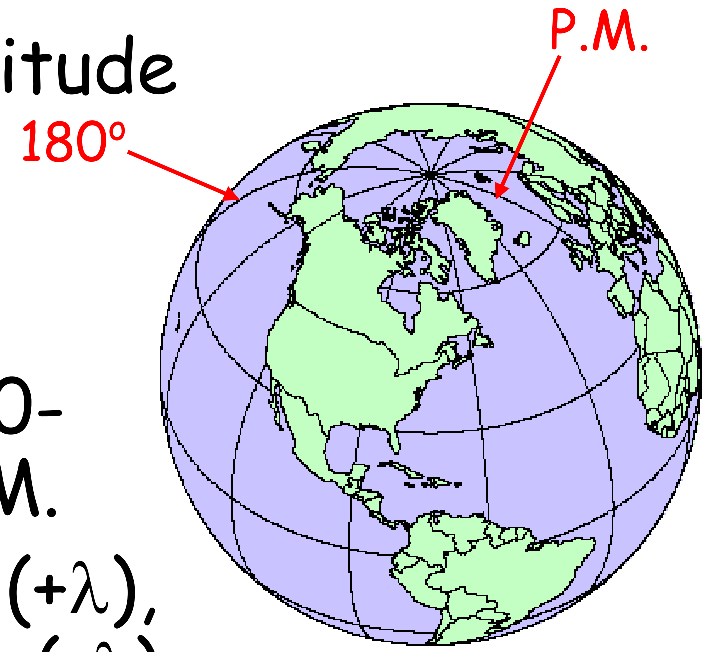
Longitude (λ)

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 ($+\lambda$), west longitudes are negative ($-\lambda$).



Units of Measure

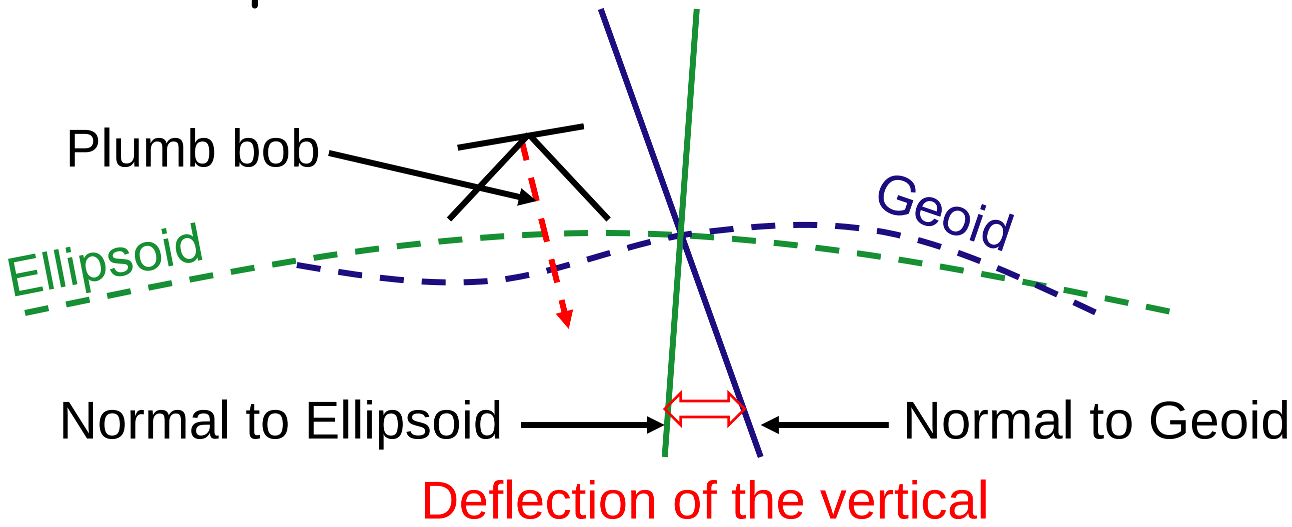
- Decimal degrees (DD), e.g. - 90.50°, 35.40°
  - order by long., then lat.
  - Format used by ArcGIS software
- Degrees, Minutes, Seconds (DMS), e.g. – 90° 30′ 00″, 35° 24′, 00″
- Degrees, Decimal Minutes (DDM) e.g.
  – 90° 30.0′, 35° 24.0′

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

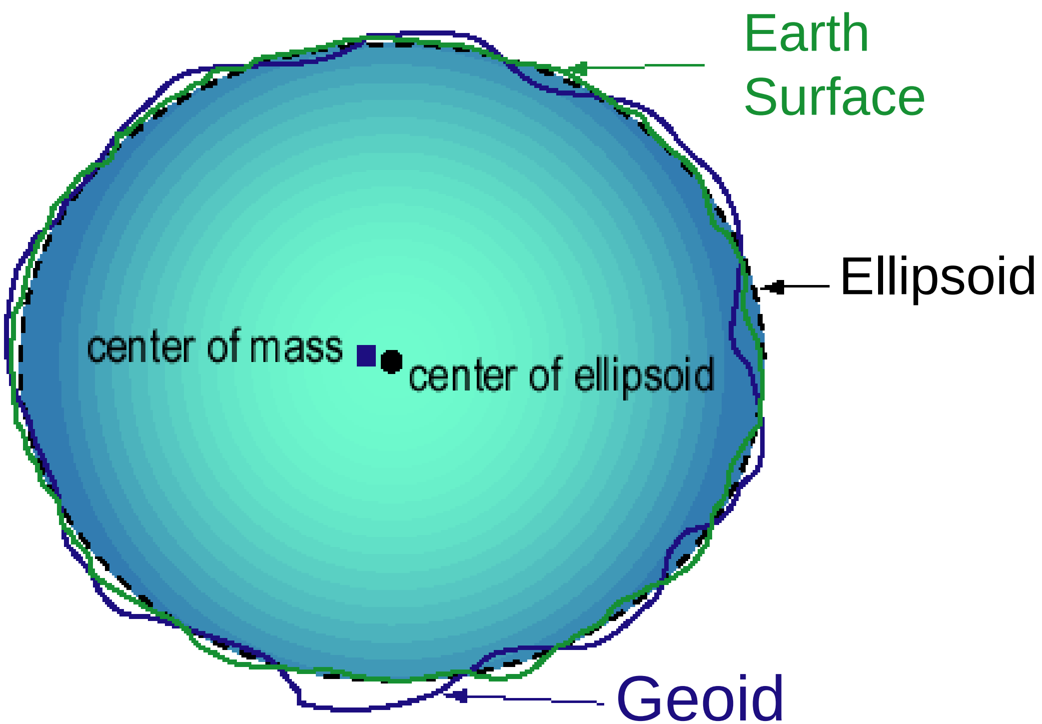
Vertical Datums

- 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



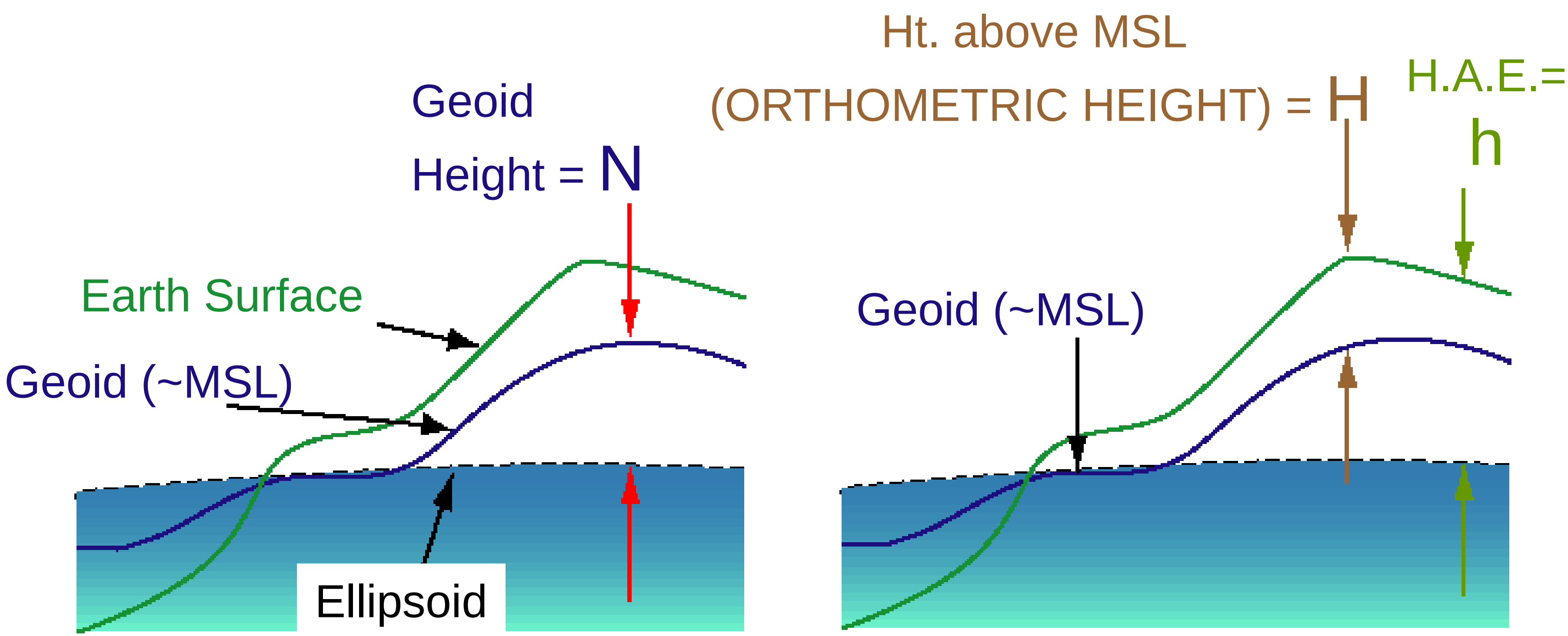
Sea Level (MSL), Geoid

- 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.

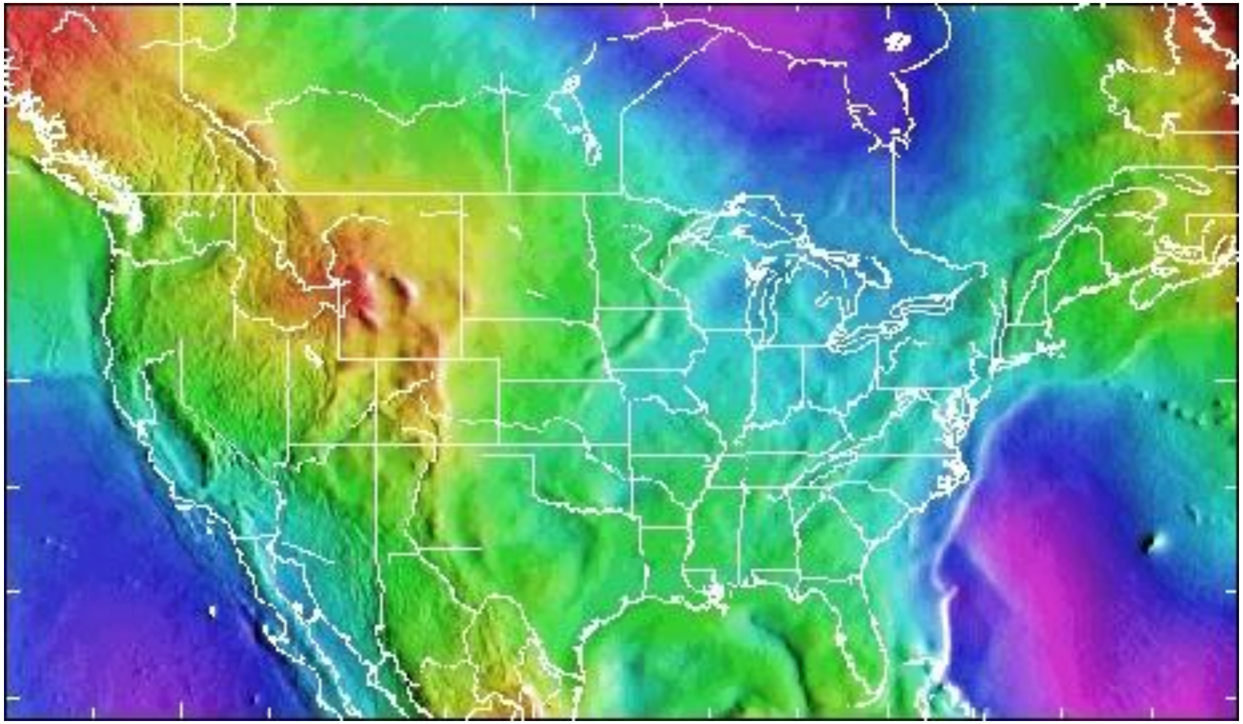


Geoid, Ellipsoid and Elevation (H)

h = H + N   or   H = h - N



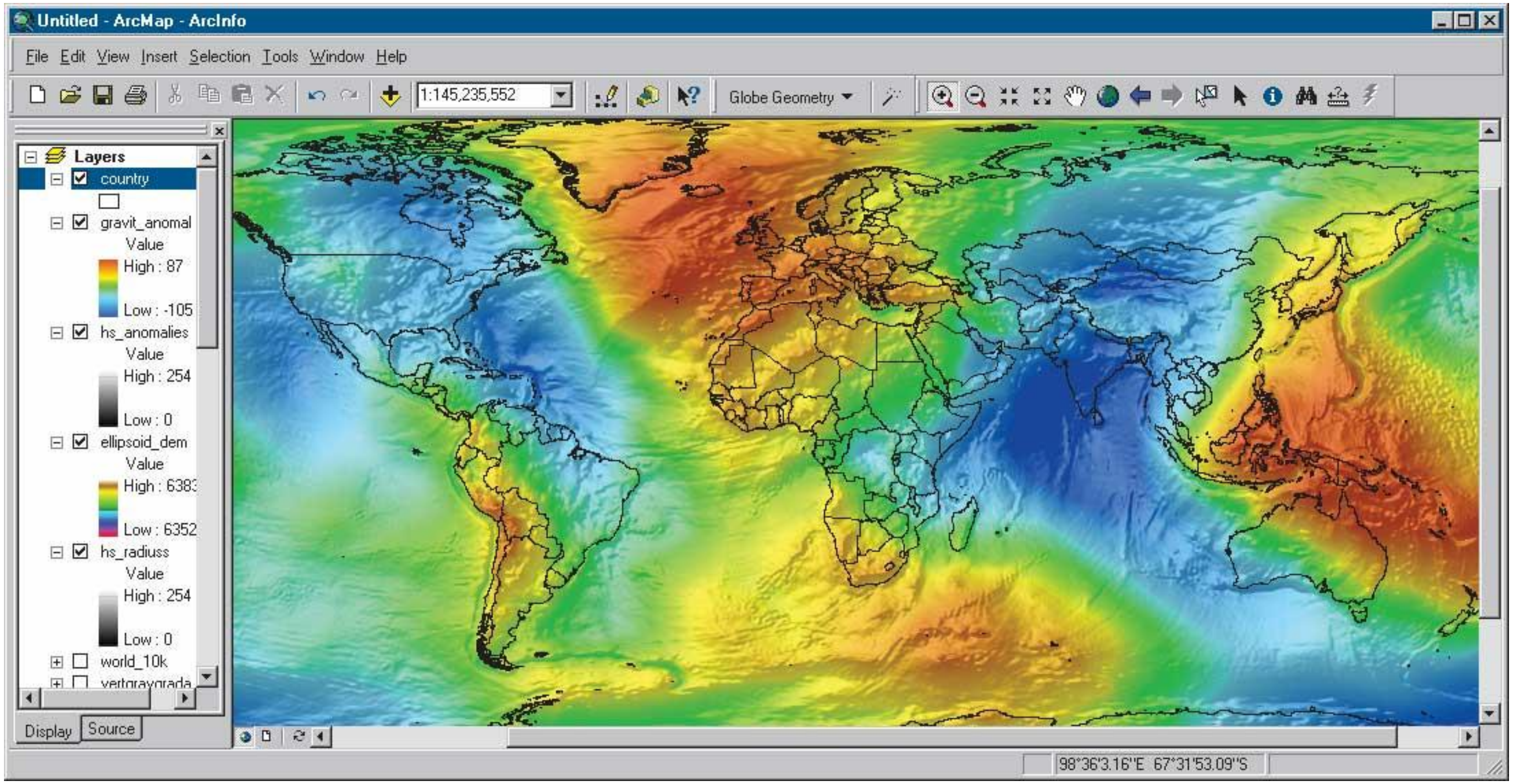
Geoid of the conterminous US



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

Geoid of the World (EGM96)



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

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

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)

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

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