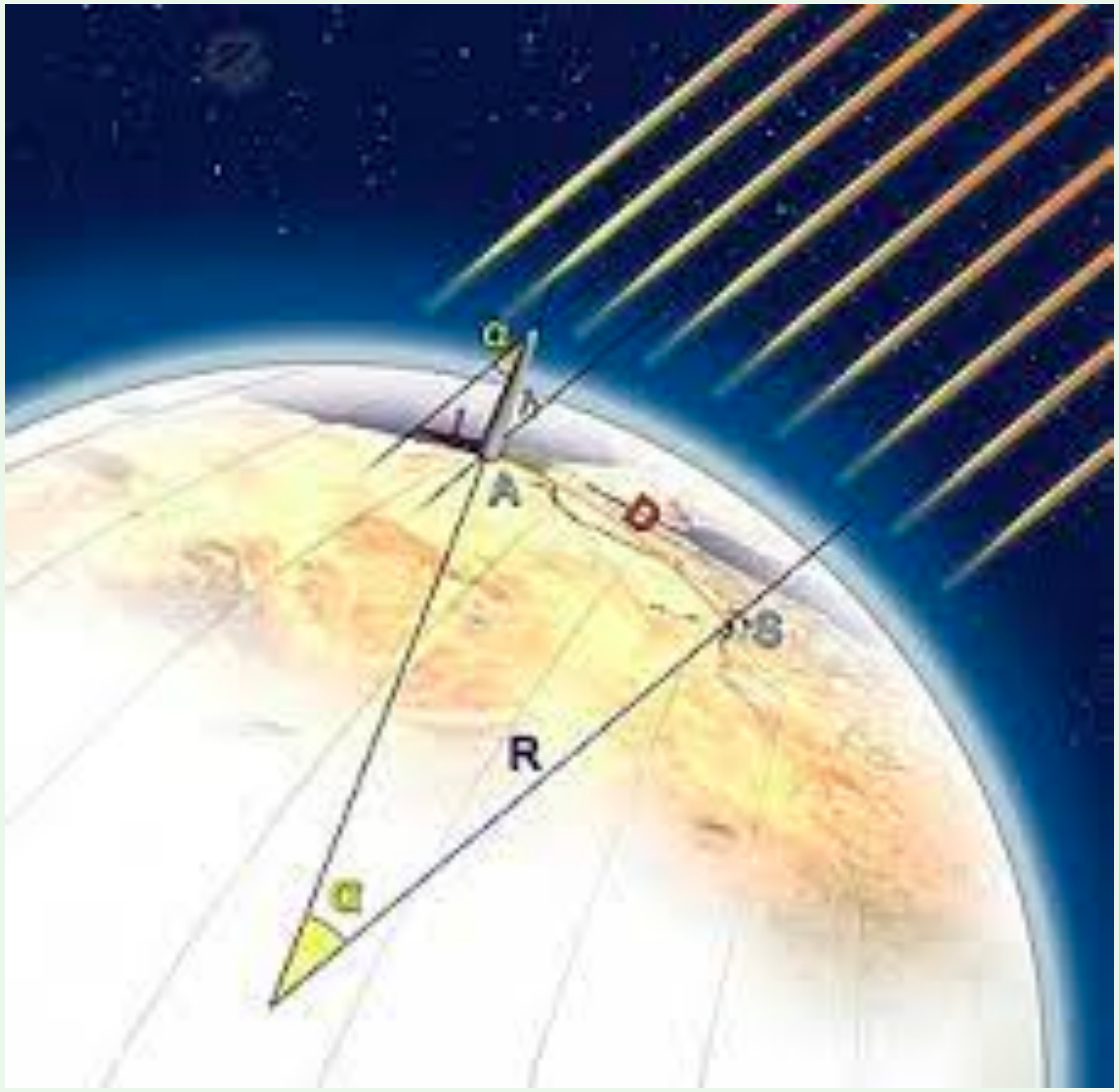
GEOG 358: Introduction to Geographic Information Systems

Measuring location on Earth's surface



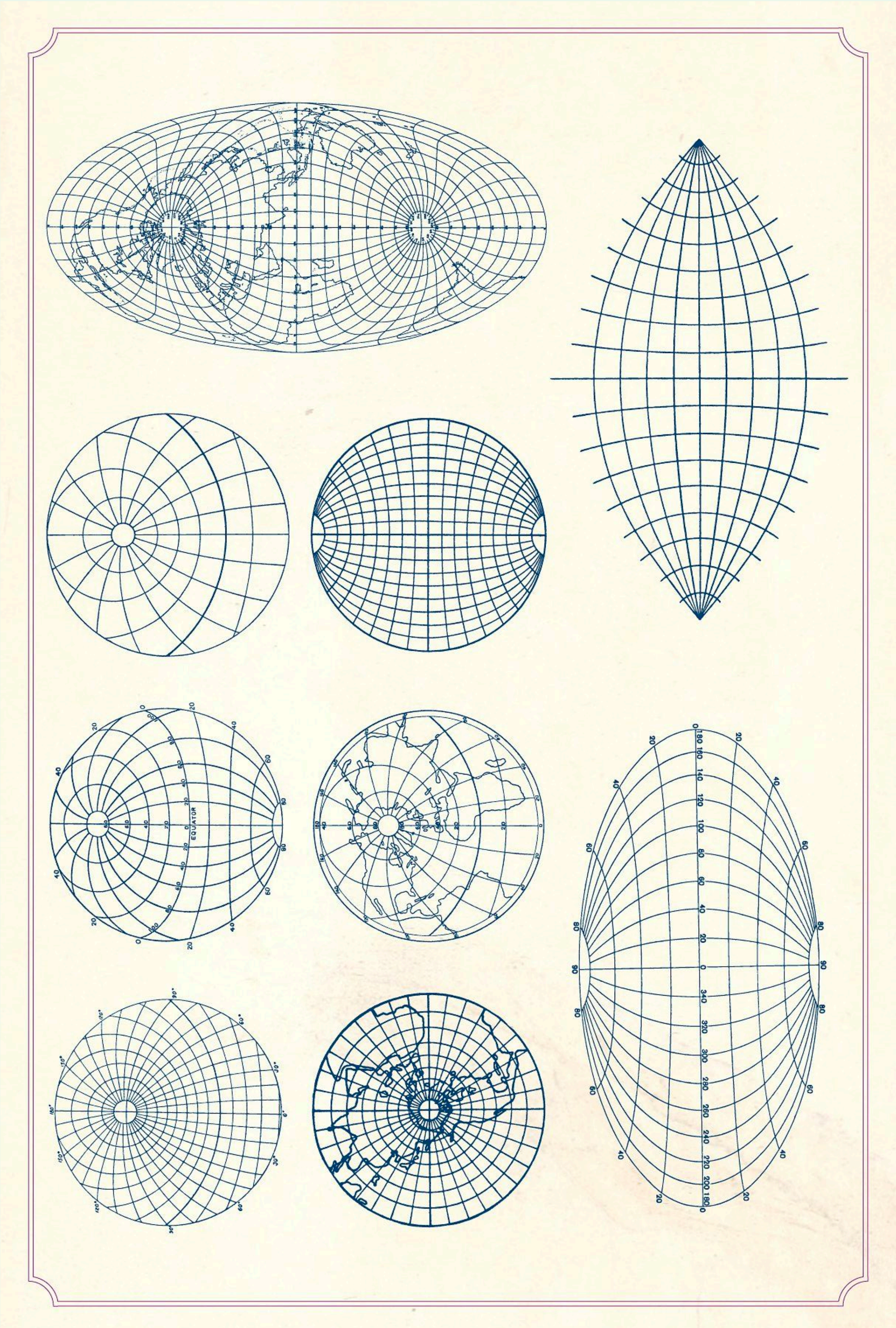
Measuring location on Earth's surface

Topics

- Measurement
- Latitude and longitude
- Ellipsoids, datums, & geoids oh my!
- Geographic coordinate systems
- Map projections

Basic Coordinate Systems

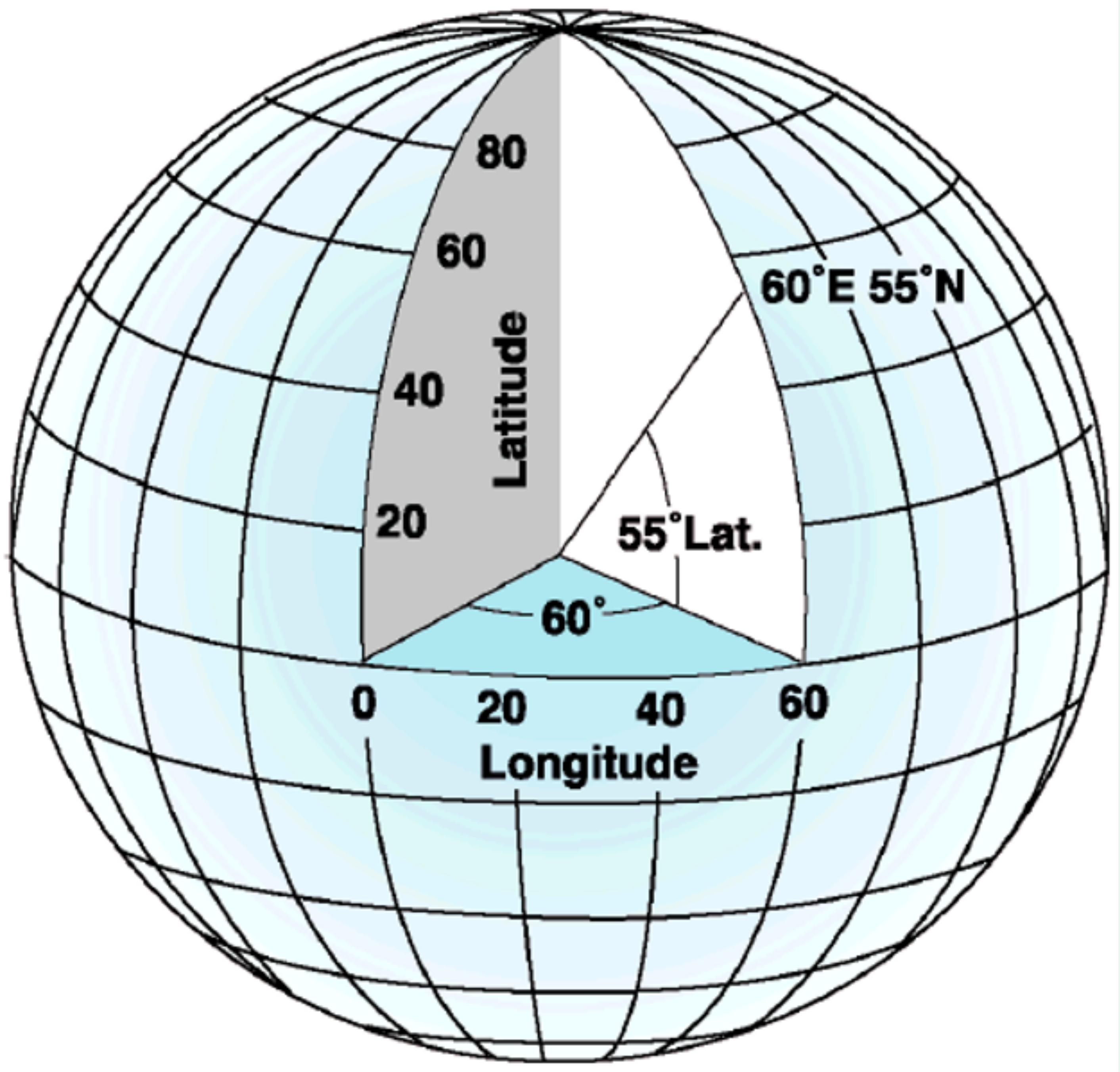
- unambiguously specify location in space
- relationships between locations can be calculated
    - distance
    - direction



Latitude & longitude

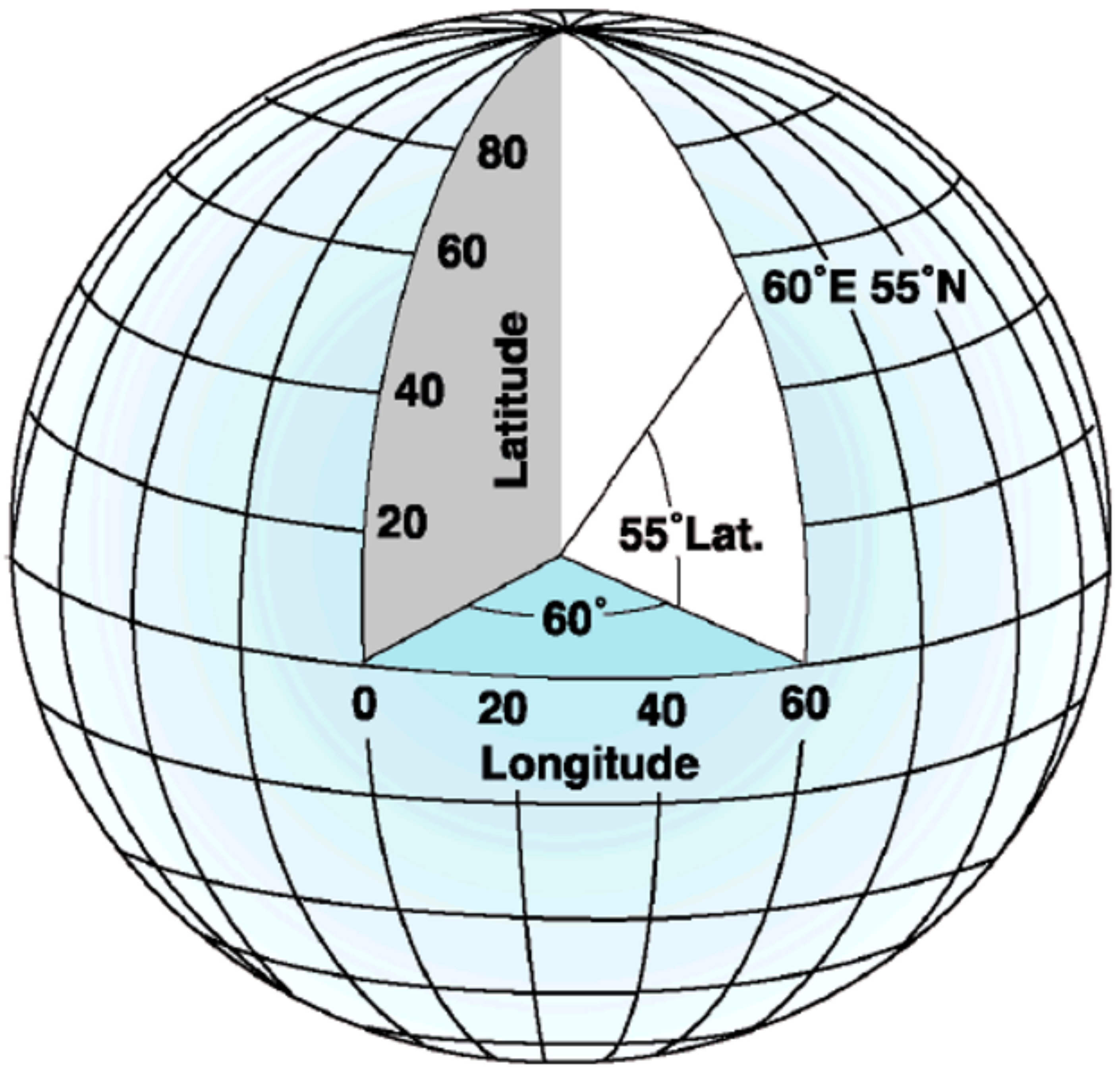
- Latitude (ϕ) is the angular measurement between the equatorial plane and the radius to a point on Earth's surface

- Longitude (λ) is the angular measurement between the prime meridian and the radius to a point on Earth's surface



Latitude & longitude

- The surface length of a degree of latitude is essentially constant
- The surface length of a degree of longitude depends on latitude
    - 0 at the poles
    - greatest at the equator (~111 km)

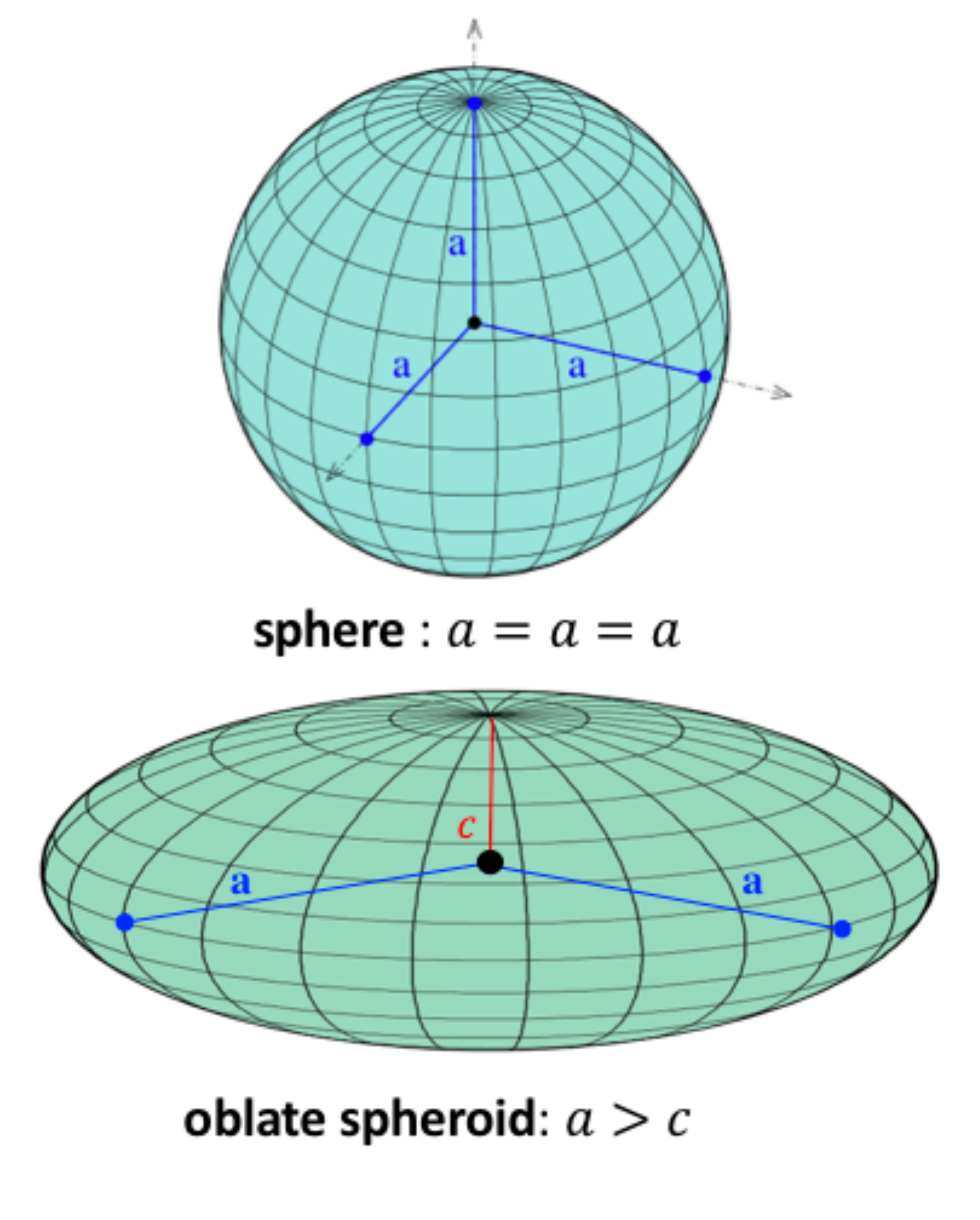


Ellipsoids

From Wikipedia:

In geodesy, a reference ellipsoid is a mathematically defined surface that approximates the geoid—which is the truer, imperfect figure of Earth as opposed to a perfect, smooth, and unaltered sphere—which factors in the undulations of Earth's gravity due to variations in the composition and density of the interior, as well as the subsequent flattening caused by the centrifugal force from the rotation of Earth on its axis. Because of their relative simplicity, reference ellipsoids are used as a preferred surface on which geodetic network computations are performed and point coordinates such as latitude, longitude, and elevation are defined.

In the context of standardization and geographic applications, a geodesic reference ellipsoid is the mathematical model used as foundation by spatial reference system or geodetic datum definitions.



Ellipsoids

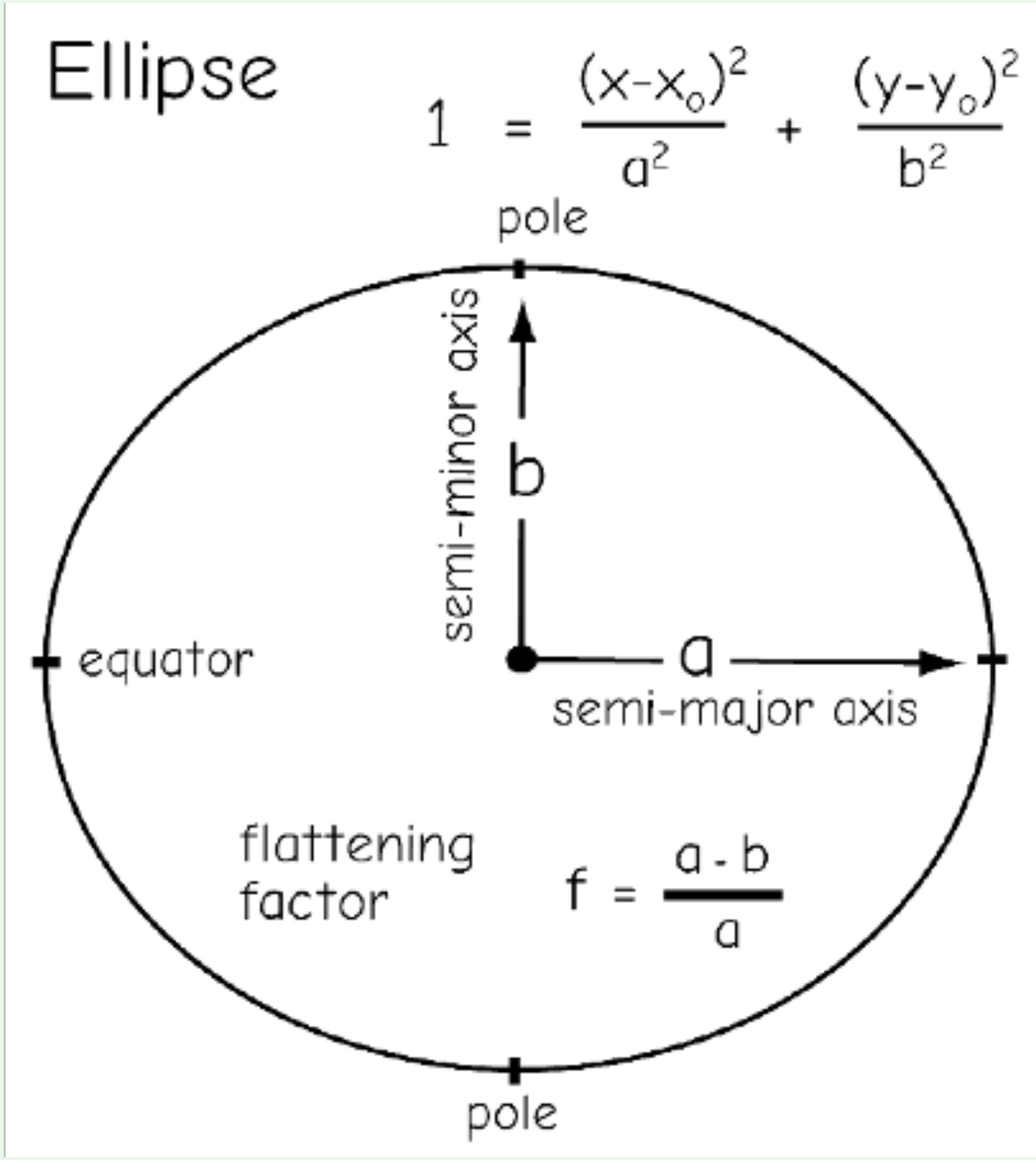
- Newton (1670) suggested an ellipsoidal earth (due to centrifugal force)

- Parameters to define an ellipsoid

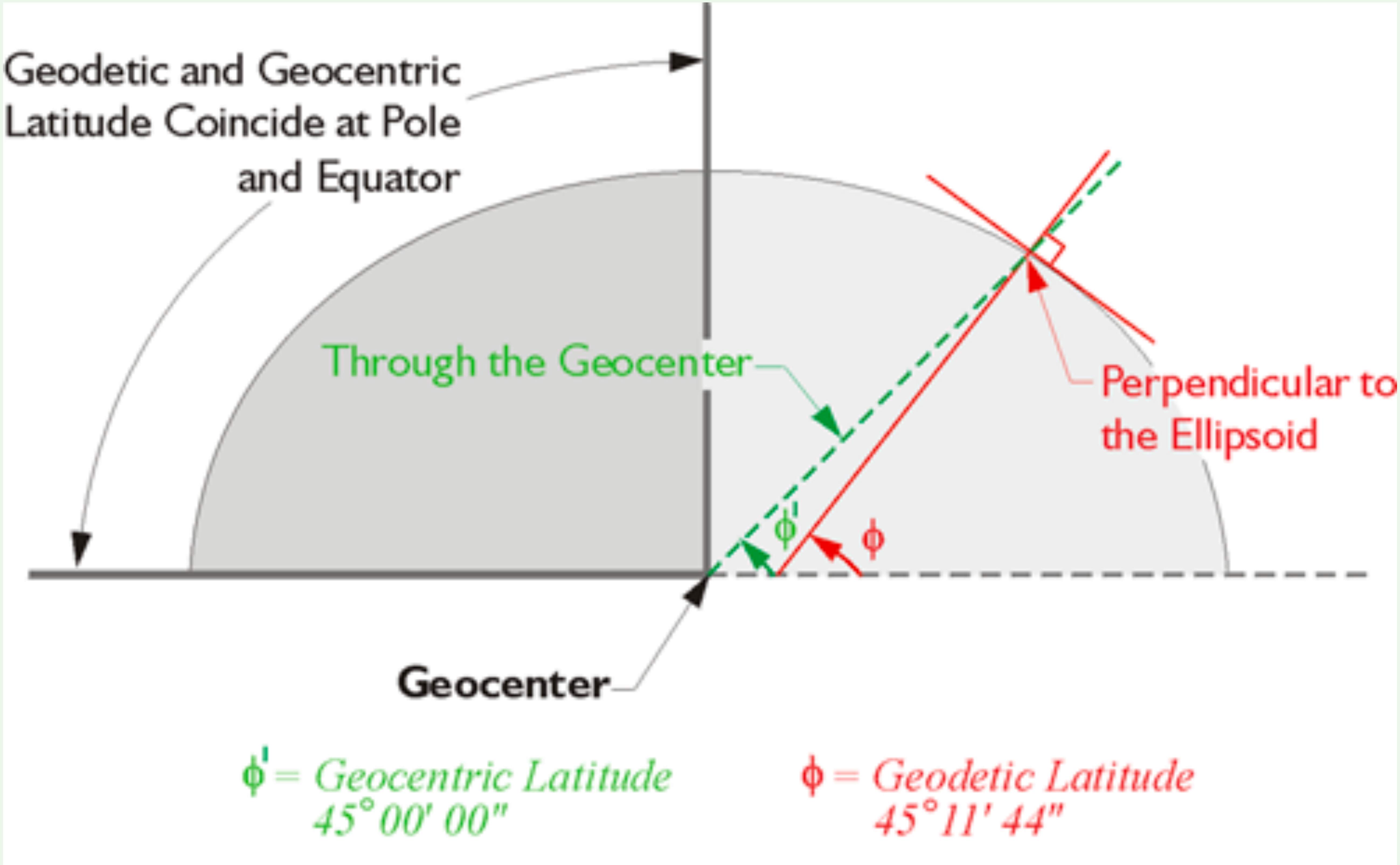
  - a: semi-major axis

  - b: semi-minor axis

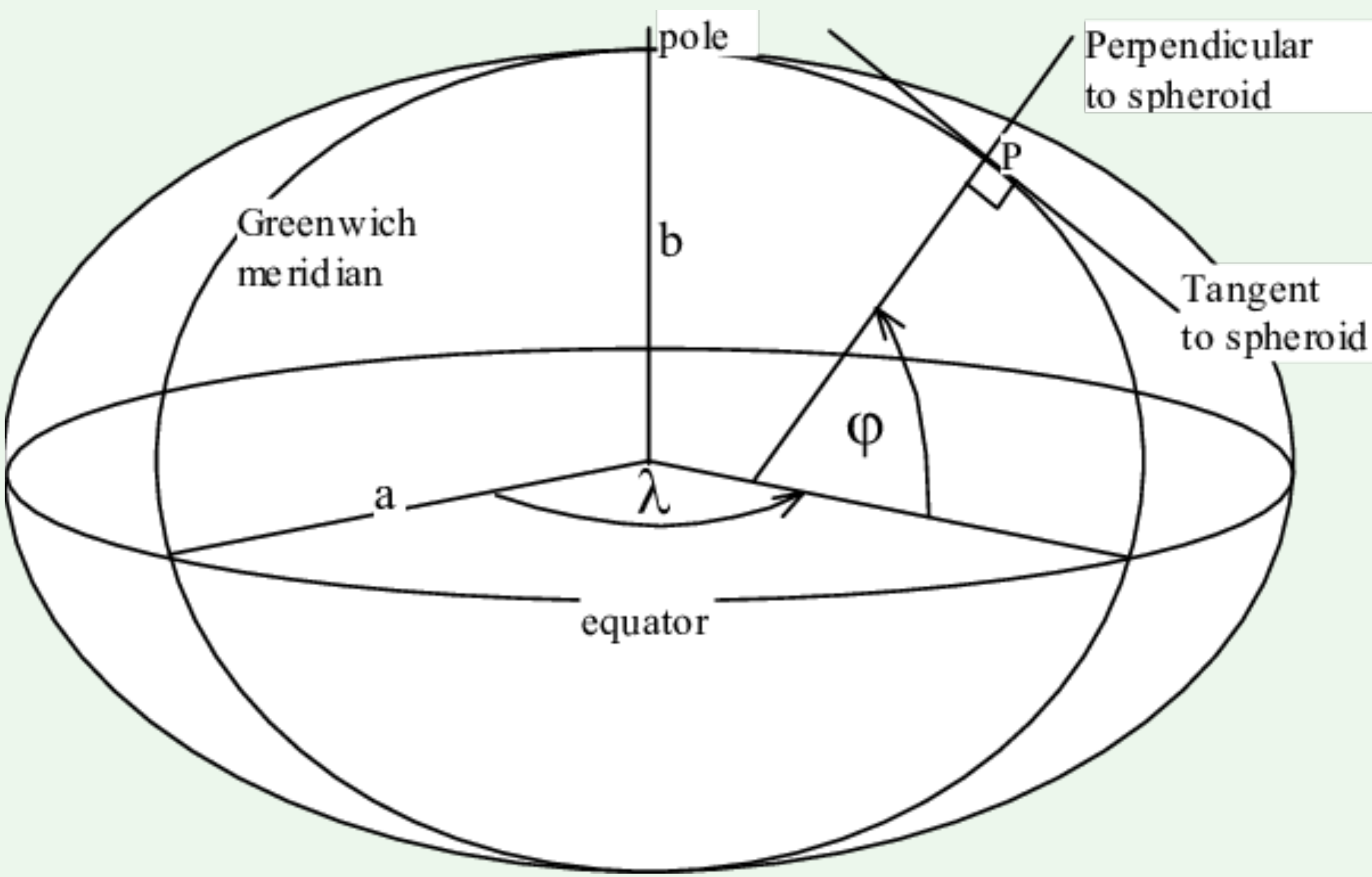
  - f: flattening factor

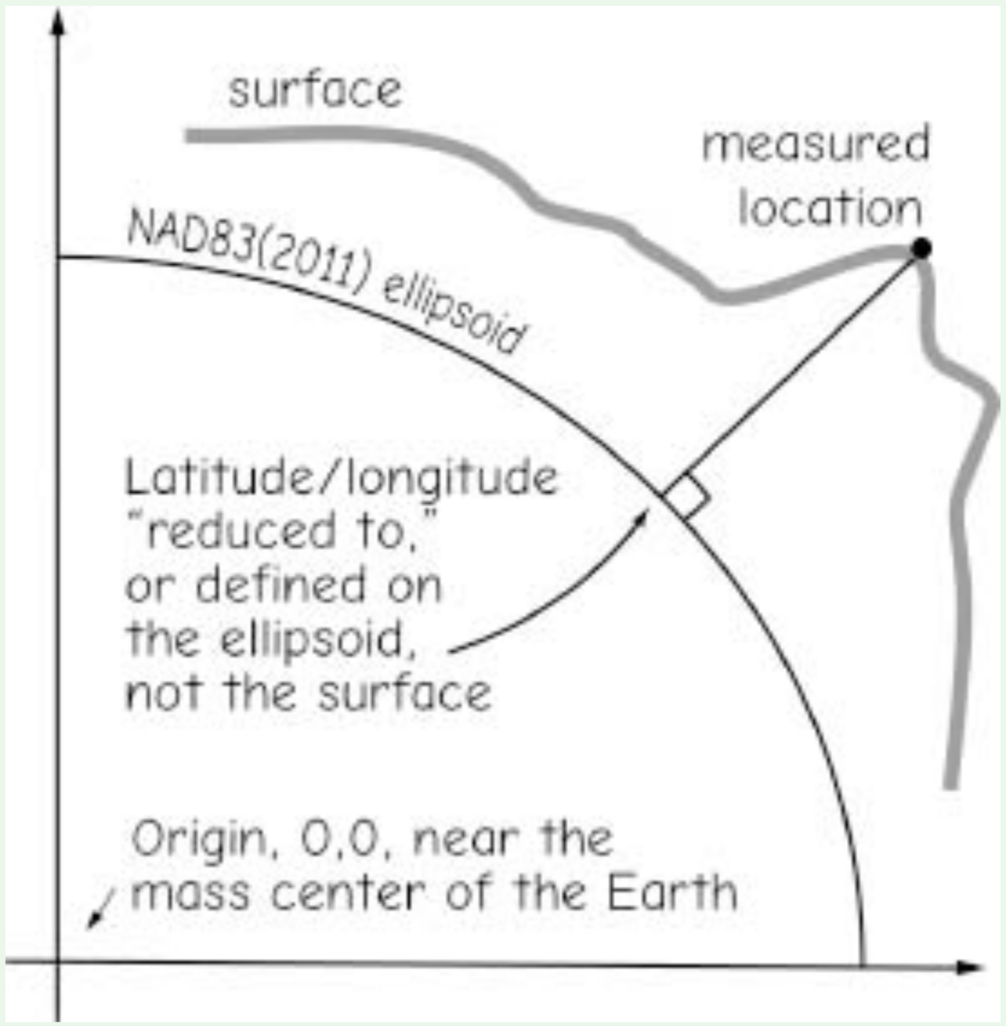


Geodetic latitude & longitude

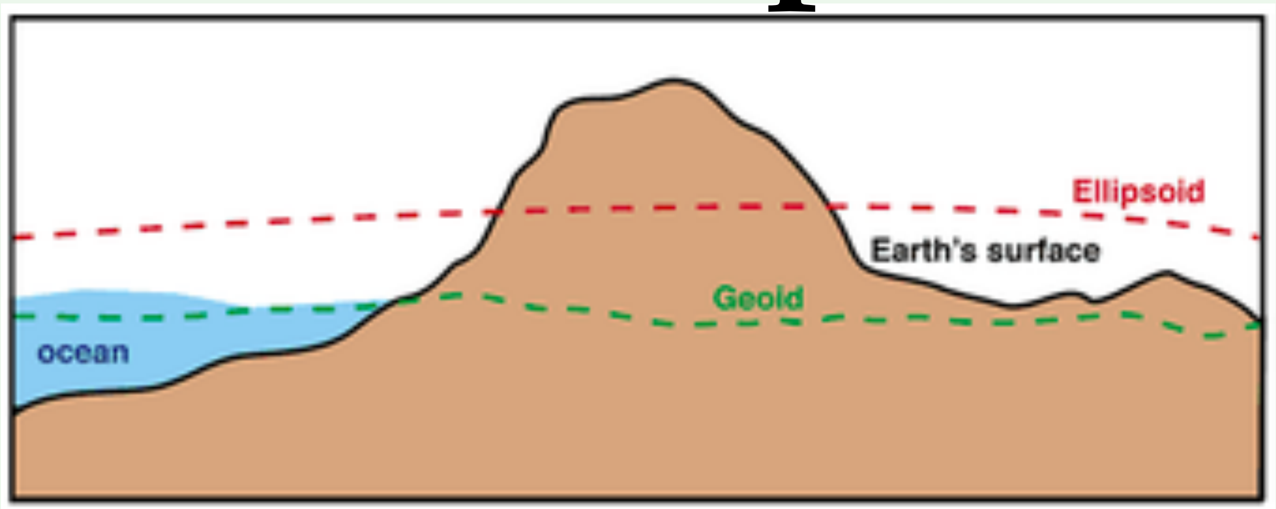


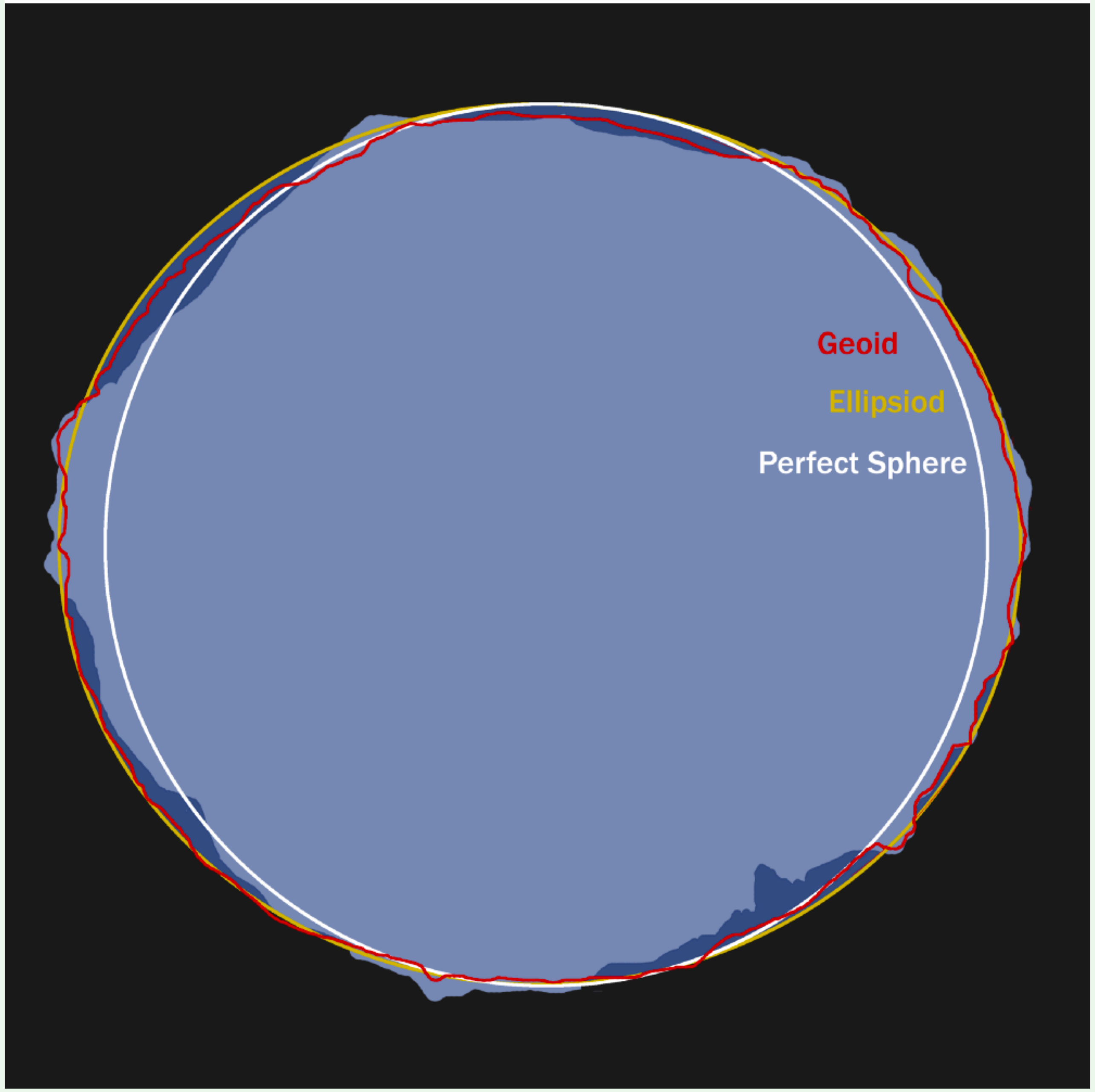
Geodetic latitude & longitude





Which ellipsoid?





Ellipsoidal models of Earth

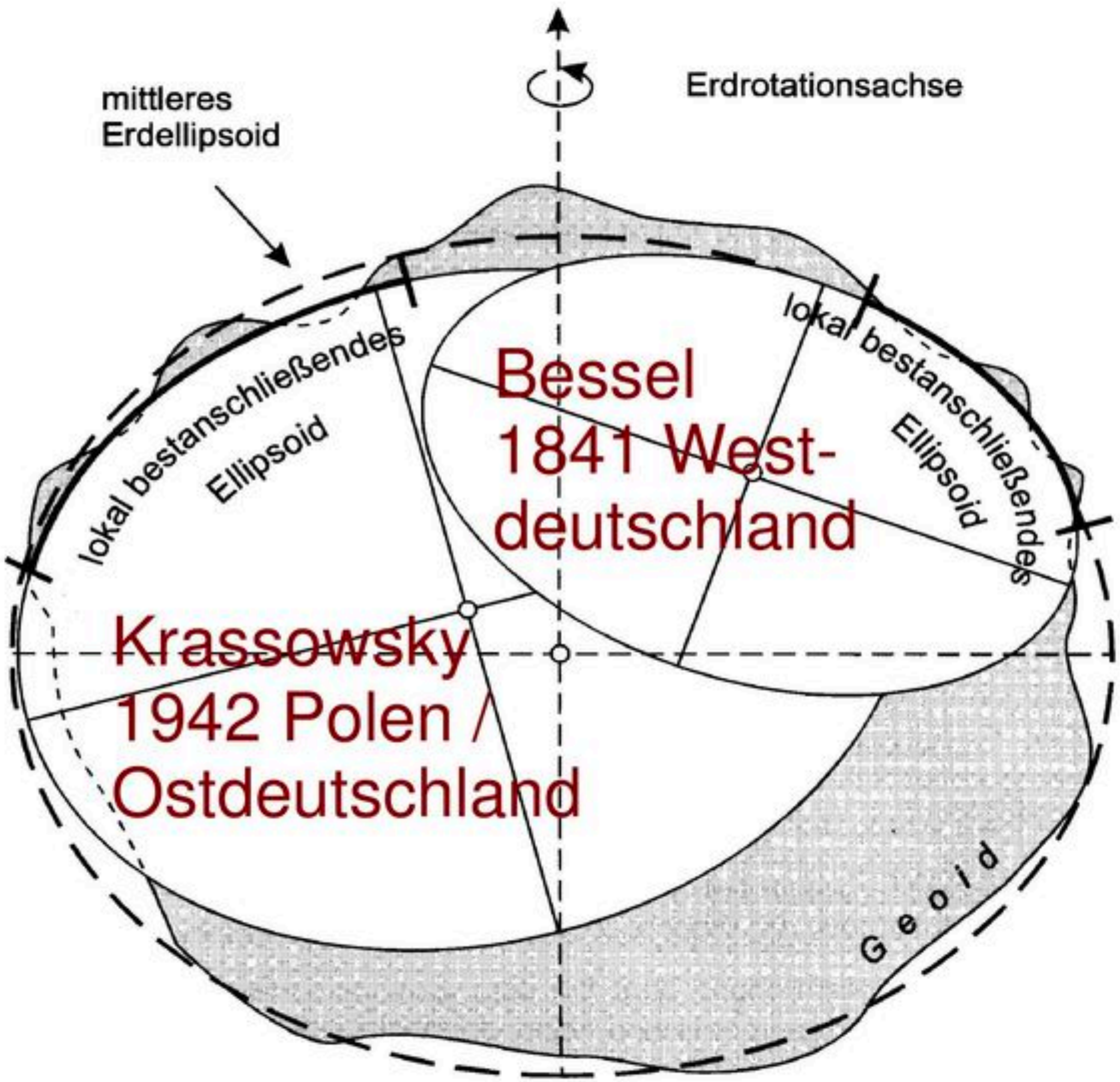
- Reference ellipsoids are used by different nations for different regions
- Different ellipsoids though time as technology has improved

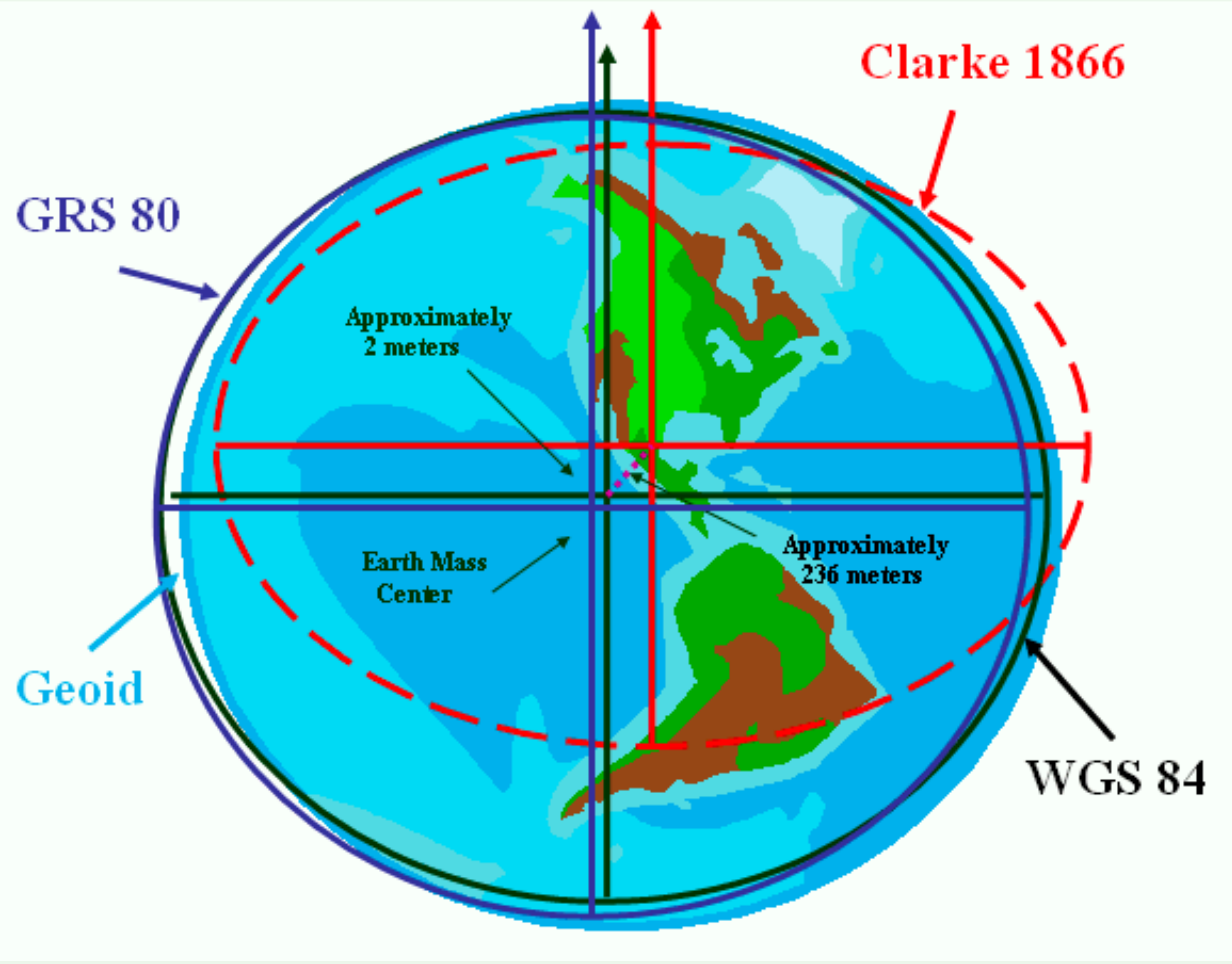
Selected Reference Ellipsoids

Ellipse	Semi-Major Axis (meters)	1/Flattening
Airy 1830	6377563.396	299.3249646
Bessel 1841	6377397.155	299.1528128
Clarke 1866	6378206.4	294.9786982
Clarke 1880	6378249.145	293.465
Everest 1830	6377276.345	300.8017
Fischer 1960 (Mercury)	6378166.0	298.3
Fischer 1968	6378150.0	298.3
G R S 1967	6378160.0	298.247167427
G R S 1975	6378140.0	298.257
G R S 1980	6378137.0	298.257222101
Hough 1956	6378270.0	297.0
International	6378388.0	297.0
Krassovsky 1940	6378245.0	298.3
South American 1969	6378160.0	298.25
WGS 60	6378165.0	298.3
WGS 66	6378145.0	298.25
WGS 72	6378135.0	298.26
WGS 84	6378137.0	298.257223563

Peter H. Dana 9/1/94

Ellipsoide


mittleres
Erdellipsoid
Erdrotationsachse
lokal bestanschließendes
Ellipsoid
lokal bestanschließendes
Ellipsoid
Bessel
1841 West-
deutschland
Krassowsky
1942 Polen /
Ostdeutschland
Geoid

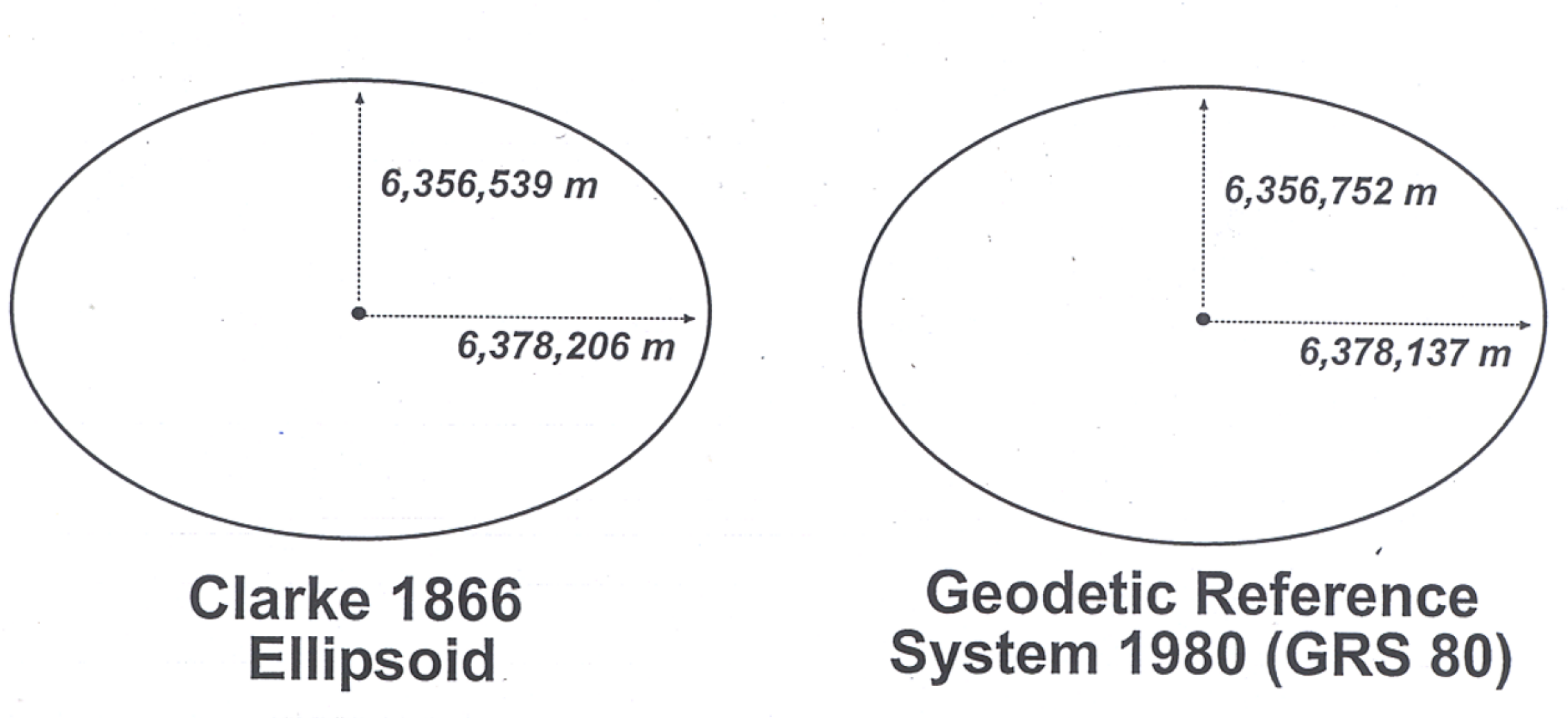


Clarke 1866
GRS 80
Approximately
2 meters
Earth Mass
Center
Approximately
236 meters
Geoid
WGS 84

Which ellipsoid is best?

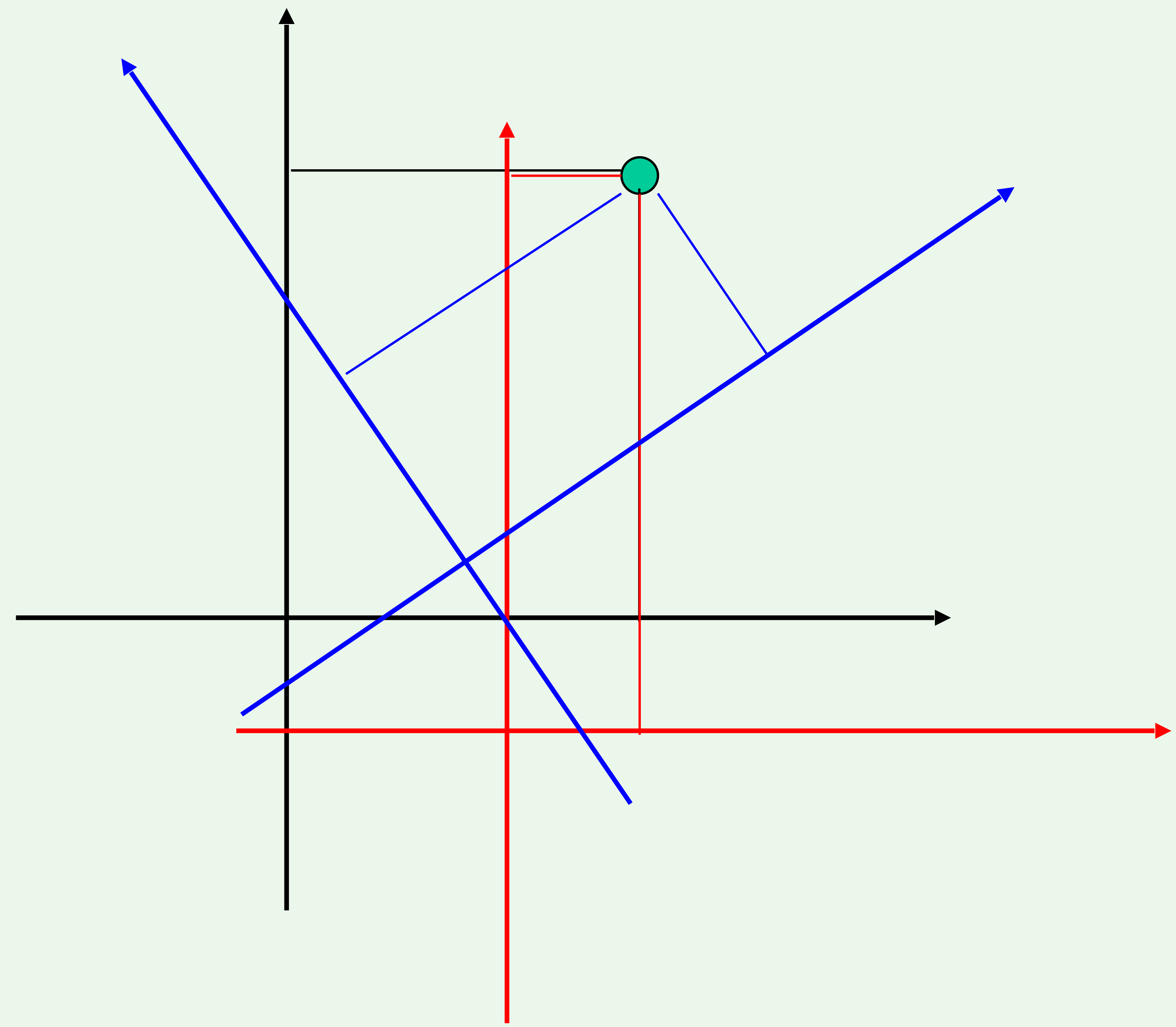
- Choice is based on the area of Earth being mapped
  - Different countries have adopted different ellipsoids
  - Different ellipsoids have been used for the same area at different times
- Different surveys generated different estimates
  - Size of the ellipsoid and the alignment to Earth's surface vary
  - Generally more recent models are more accurate than earlier ones

The Clarke 1866 and GRS80 ellipsoids



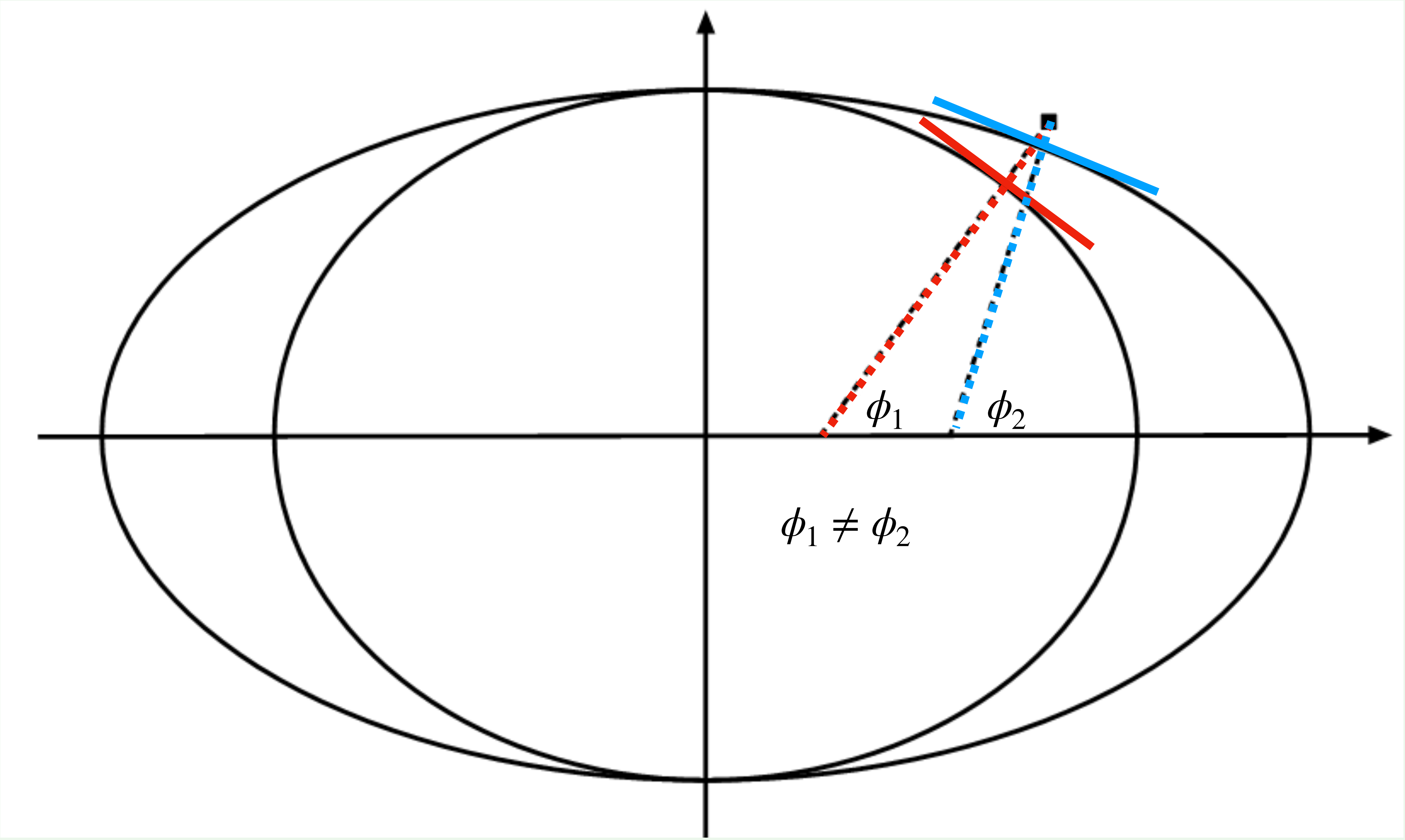
Coordinates Are Not Enough!

- Latitude and longitude are defined on ellipsoids or spheroids
- Ellipsoid model must be given in order to accurately specify a location

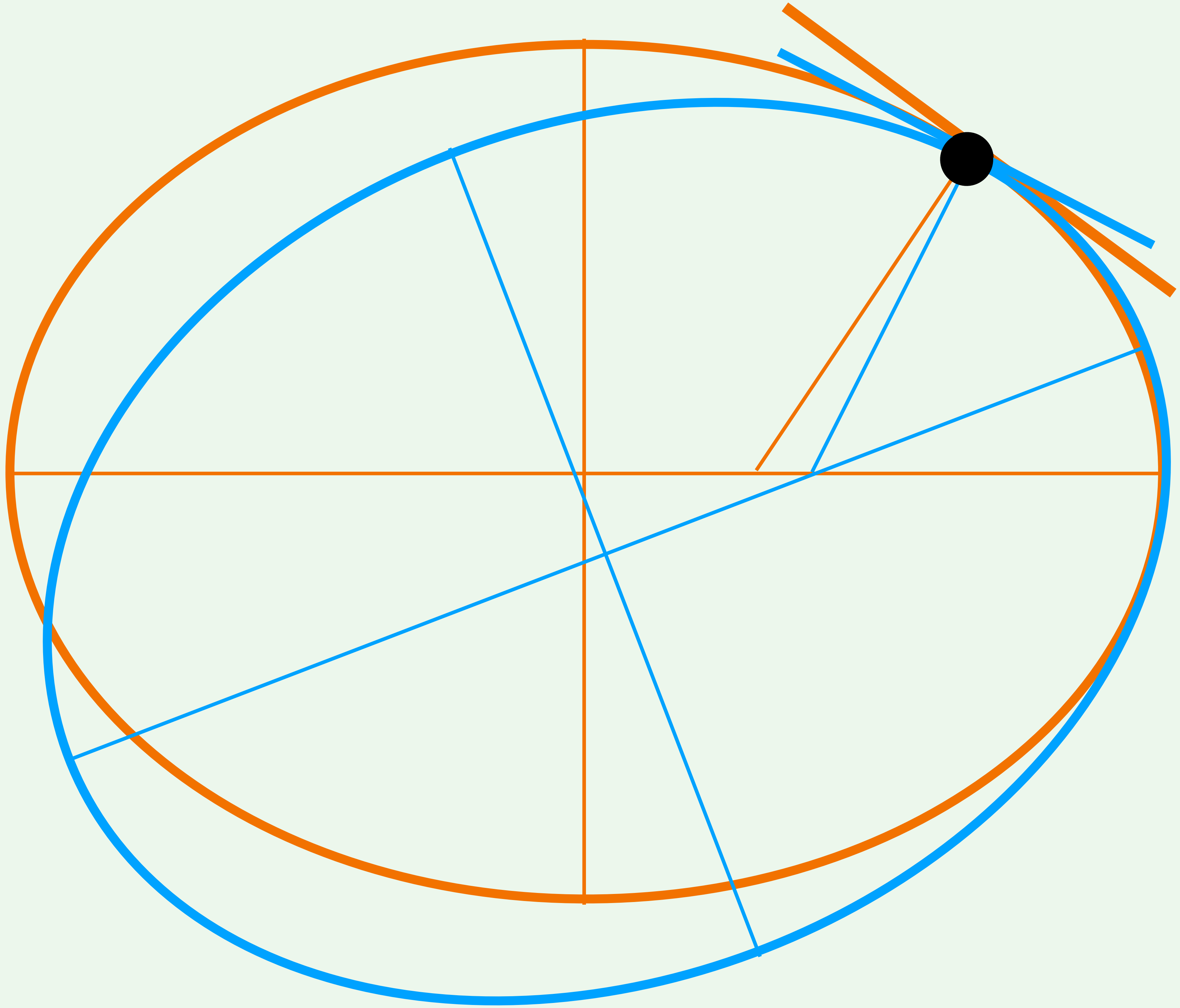


$$(x, y) \neq (x, y) \neq (x, y)$$
$$(3, 4) \neq (1, 5) \neq (3, 2)$$

Different ellipsoids, different coordinates



Same ellipsoid, different coordinates



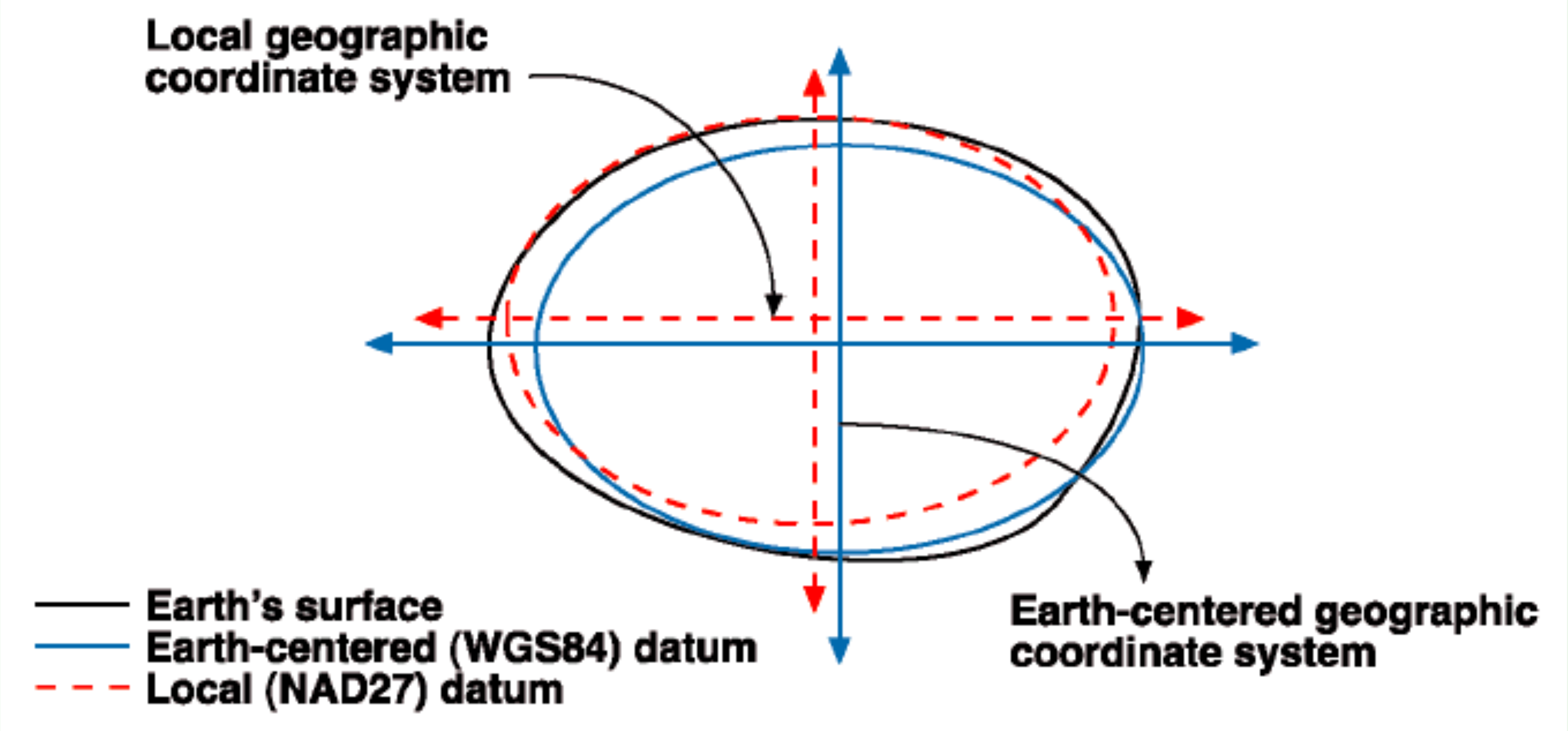
Datum

- Horizontal datum
  - specifies an ellipsoid to approximate the shape and size of the Earth
  - defines how the spheroid is **aligned** to Earth
- Geodetic network is a datum realized/ materialized by survey marks

https://geodesy.noaa.gov/datums/horizontal/north-american-datum-1983.shtml

Datums control ellipsoid alignment

- Local datum--fitted to a certain region on earth (NAD27)
- Global datum--overall fitted to earth (NAD83 and WGS84)



Realization of a datum

- Imaginary sphere or ellipsoid model is aligned to the Earth through celestial observation
- A network of precisely-measured control points based on the selected sphere or ellipsoid
- Control points are measured relative to other control points and provided as monuments
- The National Geodetic Survey (NGS) maintains approximately 270,000 first-order horizontal control points
- Control networks can then be extended from first-order control points

Survey benchmarks


```
National Geodetic Survey,   Retrieval Date = SEPTEMBER 26, 2011
OB0554  DESIGNATION -  CAPE SMALL  OB0554  PID         -  OB0554
OB0554  STATE/COUNTY-  ME/SAGADAHOC   USGS QUAD   -  PHIPPSBURG (1957)
OB0554
OB0554                        *CURRENT SURVEY CONTROL
OB0554  ___________________________________________________________________
OB0554* NAD 83(1996)    -   43 46 42.87649(N) 069 50 42.26065(W)    ADJUSTED
OB0554* NAVD 88         -         73.     (meters)  240.    (feet)   SCALED
OB0554  ___________________________________________________________________
OB0554  LAPLACE CORR-            2.33  (seconds)                     DEFLEC99
OB0554  GEOID HEIGHT-          -25.73  (meters)                      GEOID03
OB0554  HORZ ORDER  -  FIRST
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Figure 3-15: A portion of a National Geodetic Survey control point data sheet.

Triangulation to build networks

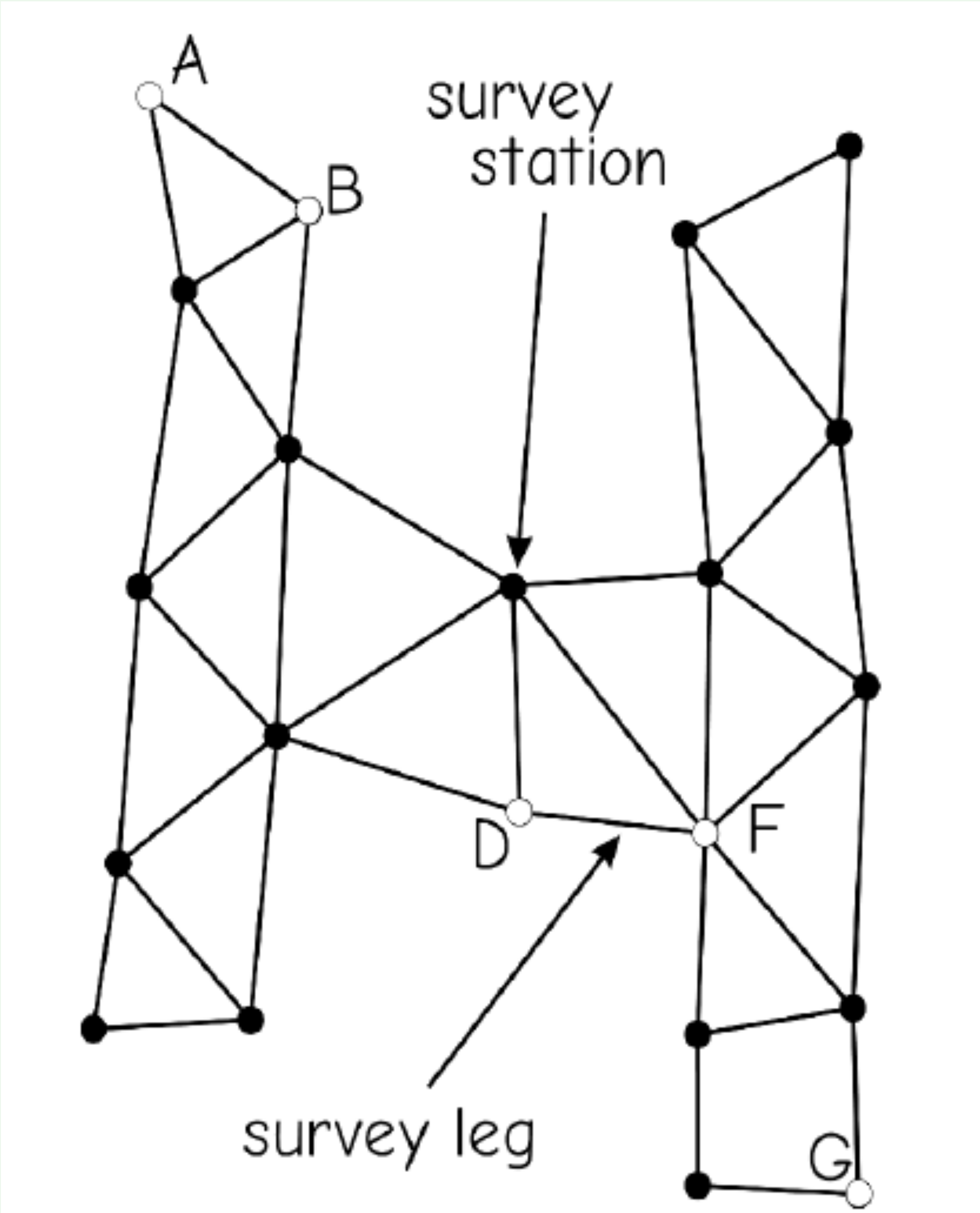


Figure 3-16: A triangulation survey network. Stations may be measured using astronomical (open circles) or surface surveys (filled circles).

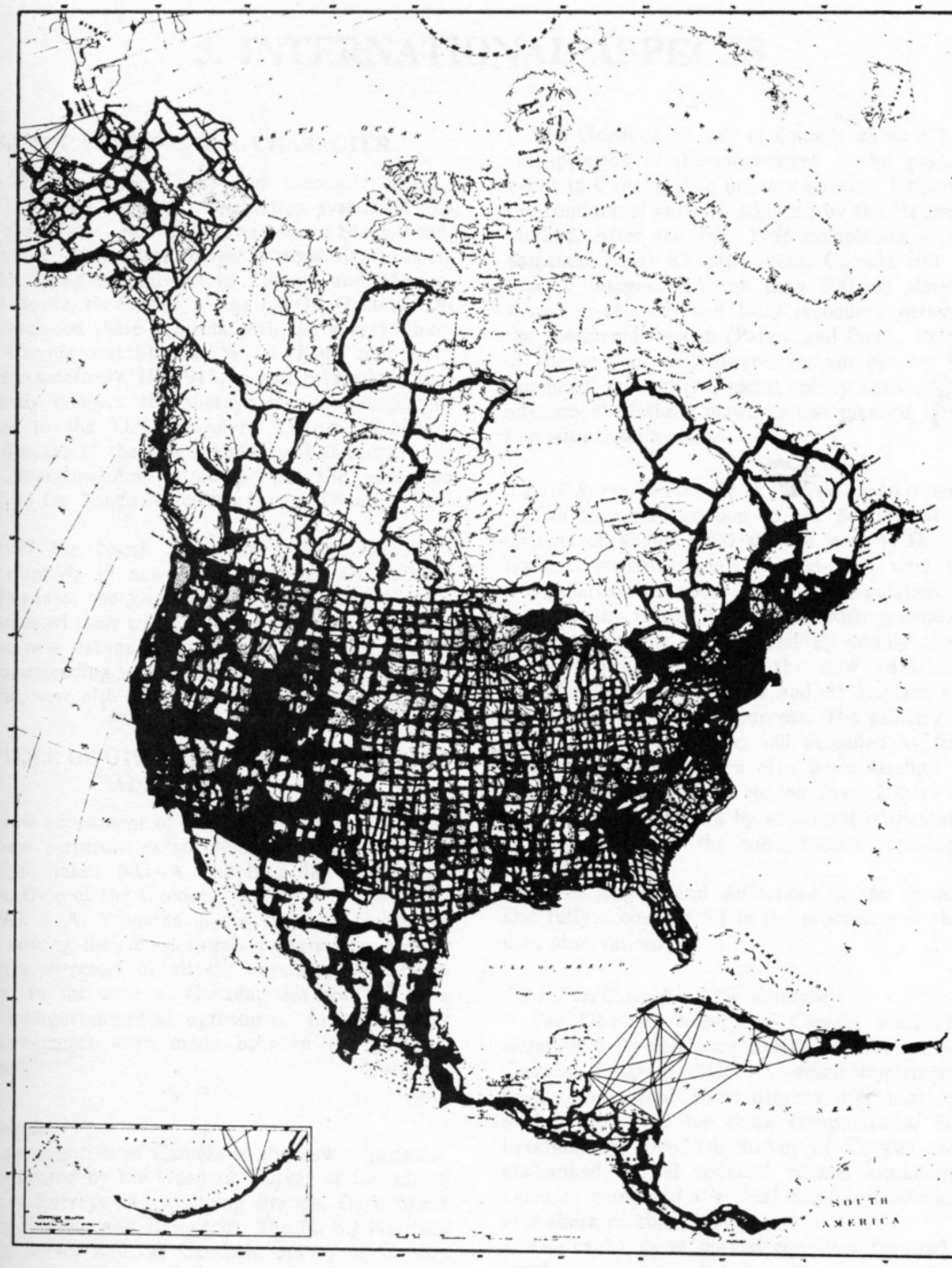
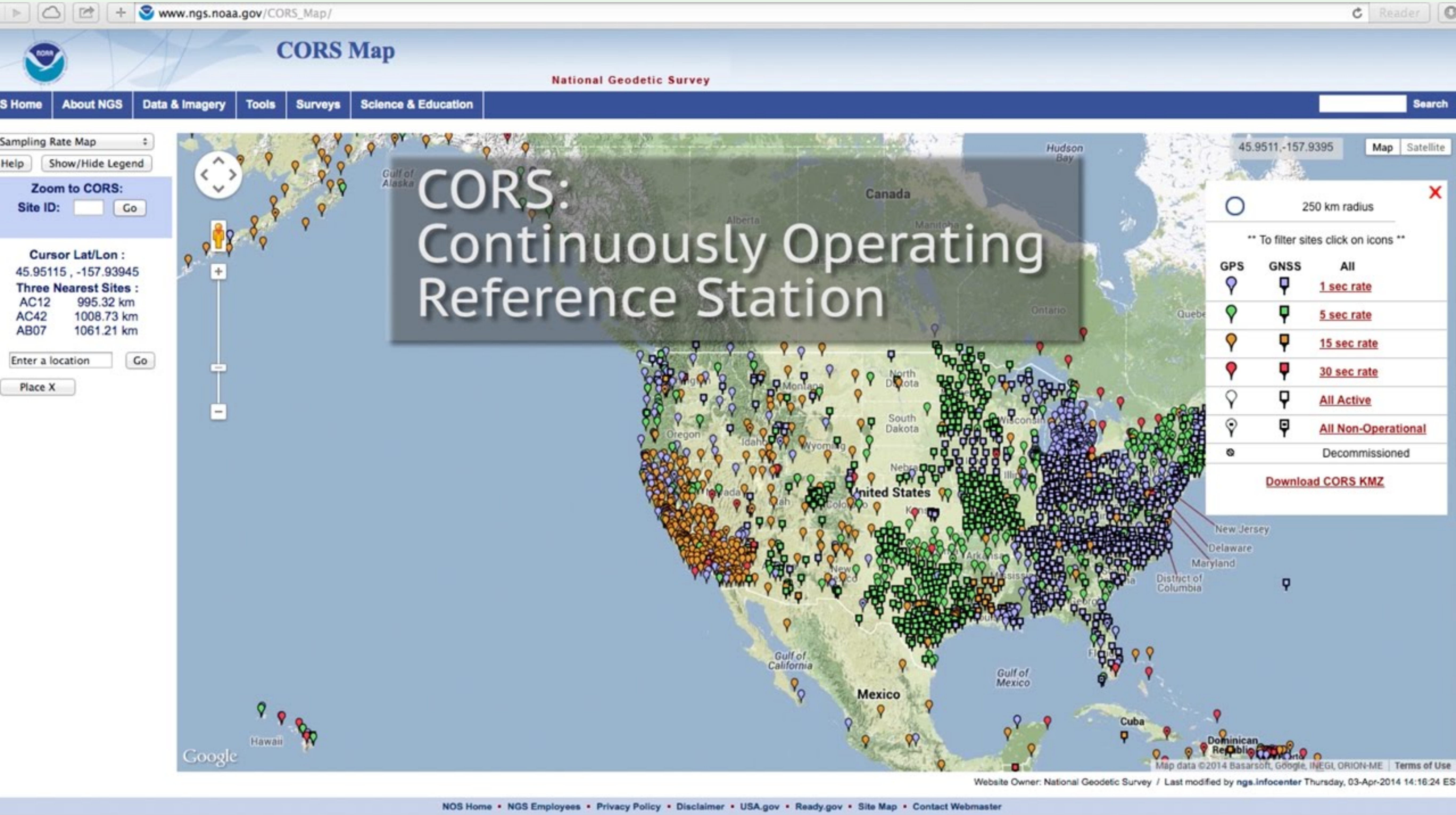


Figure 4.3. Status of geodetic control in North American in 1981.

CORS: Continuously Operating Reference Station



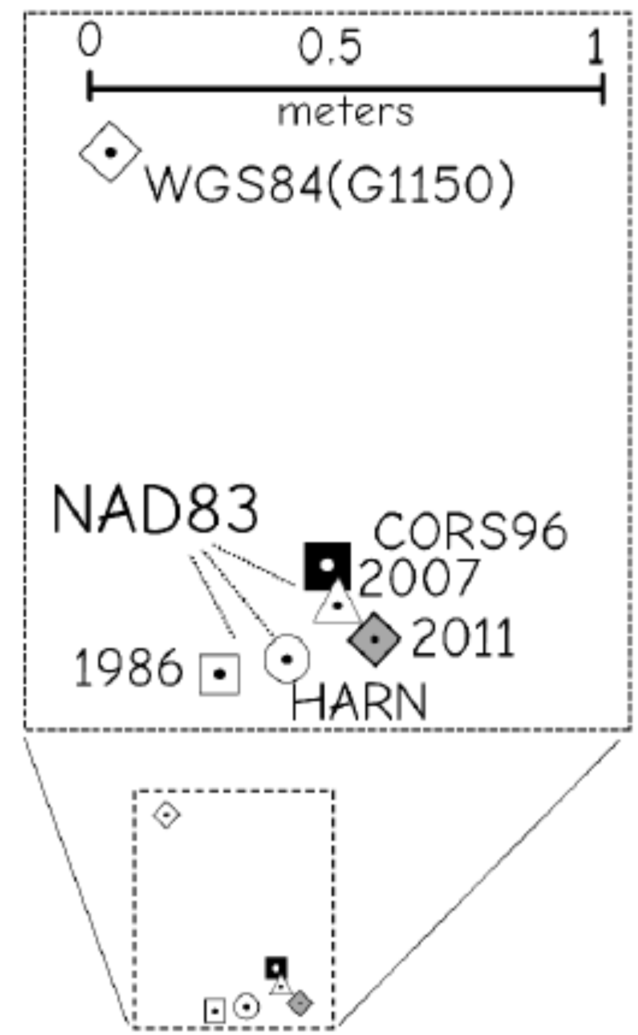
Datum adjustments

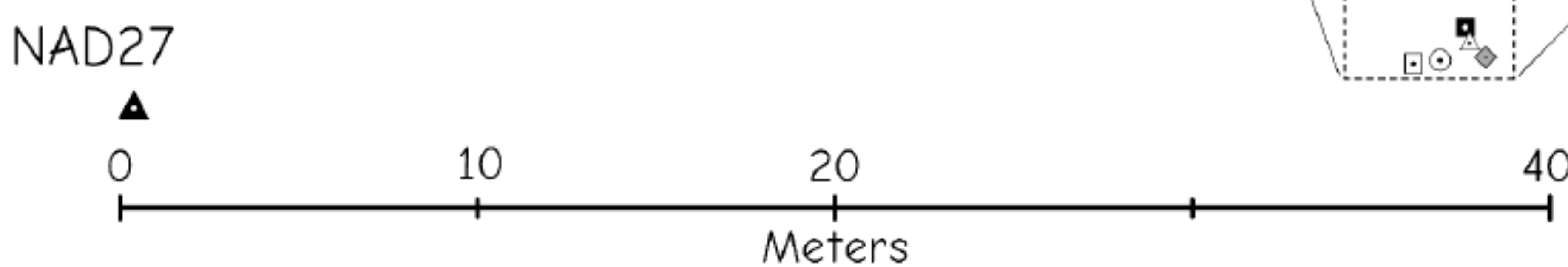
- Small changes on ellipsoid alignment to the Earth
  - More control points are added
  - Better measurements on existing control points
- Lead to coordinate changes in control points
- NAD83, NAD83(1986), 2007, 2011, HARN, CORS93, …

Horizontal position shifts with datum version

Successive datum transformations for New Jersey control point, Bloom 1

Datum	Longitude (W)	Latitude(N)	Shift(m)
NAD27	74° 12' 3.86927"	40° 47' 0.76531"	
NAD83(1986)	74° 12' 2.39240"	40° 47' 1.12726"	36.3
NAD83(HARN)	74° 12' 2.39069"	40° 47' 1.12762"	0.04
NAD83(CORS96)	74° 12' 2.39009"	40° 47' 1.12936"	0.05
NAD83(2007)	74° 12' 2.38977"	40° 47' 1.12912"	0.01
NAD83(2011)	74° 12' 2.38891"	40° 47' 1.12839	0.03
WGS84(G1150)	74° 12' 2.39720"	40° 47' 1.15946"	0.98





Commonly Used Datums

- Datums used in USA
  - North American Datum of 1927 (NAD27)
    - Clark 1866 ellipsoid
  - North American Datum of 1983 (NAD83)
    - GRS80 ellipsoid
    - Various adjustments NAD83(1986), 2007, 2011, HARN, CORS96
- World Geodetic System of 1984 (WGS84)
  - USA DoD, civilian GPS software
  - GRS80 ellipsoid
  - Various adjustments G730, G873, G1150, G1674, G1762, …
- International terrestrial reference framework (ITRF)
  - Various adjustments ITRF89, 90, 91, …

Geographic Coordinate Systems (GCS)

- Based on a spheroid model of the Earth
- Using two angular measurements (latitude and longitude) to specify a location on the model

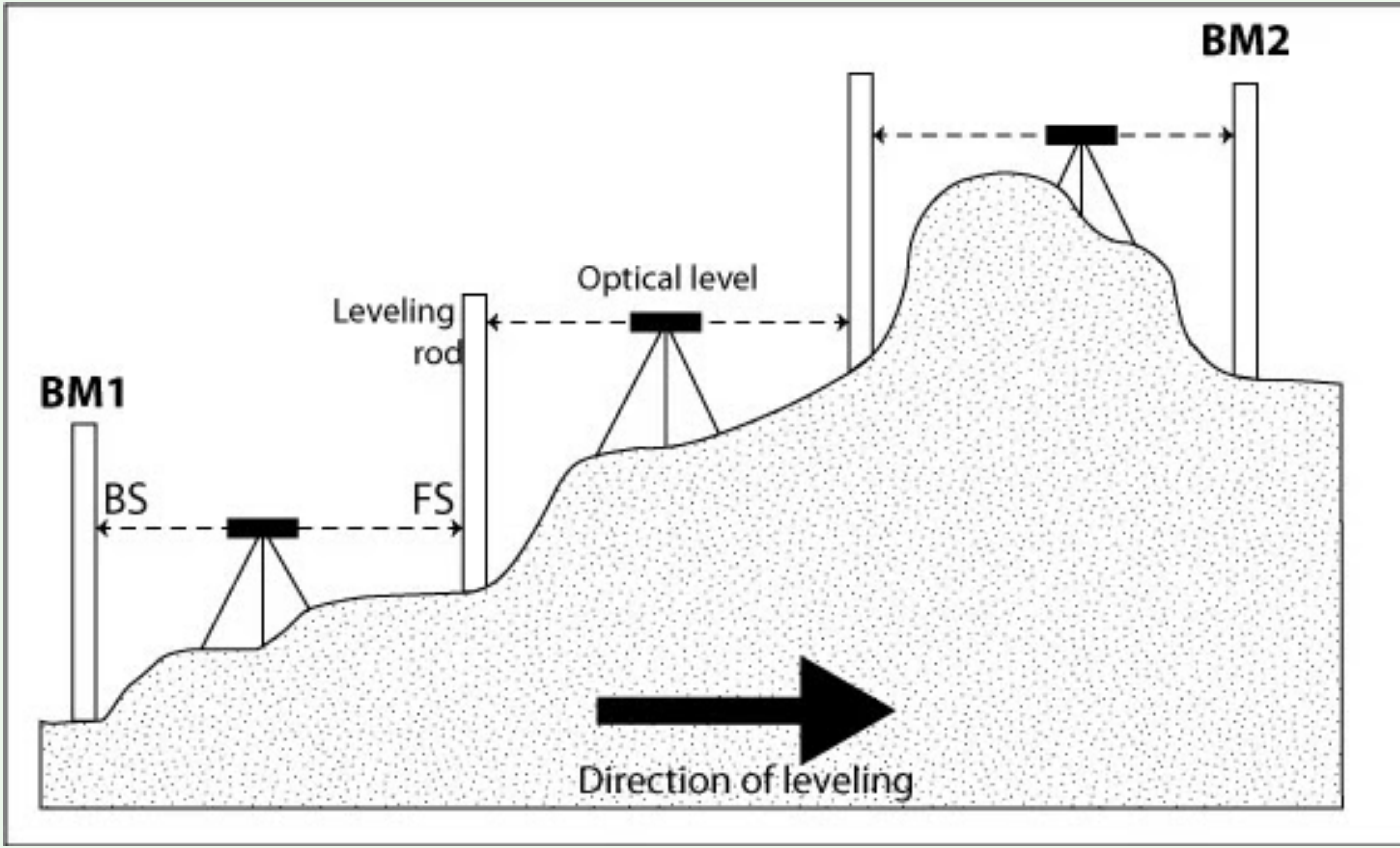
Geographic Coordinate System		
Datum	Unit of Measure	Prime Meridian

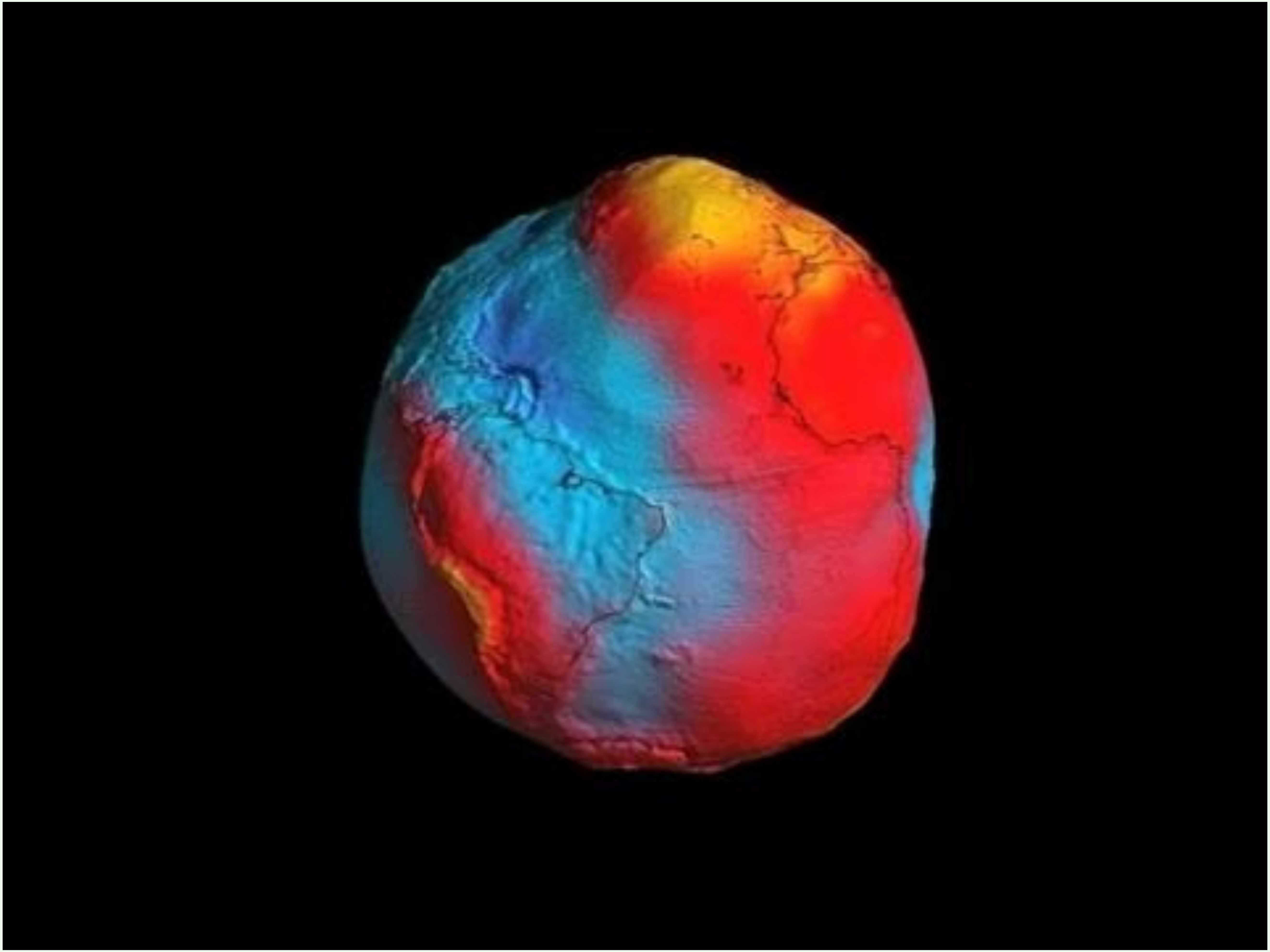
Vertical datum

- The highest peak in Colorado (Mt. Elbert) has a height of 14,433 feet
- Where is the zero elevation?
  - The center of the Earth
  - Sphere or ellipsoid surface
  - Mean sea level
- The *zero surface to which elevations are referred* is called a **vertical datum**
- Mean sea level was usually used as the zero surface
  - Flat and follows the curvature of Earth
  - Measurable (vs ellipsoid which is not)
  - Available worldwide

Local Vertical Datum

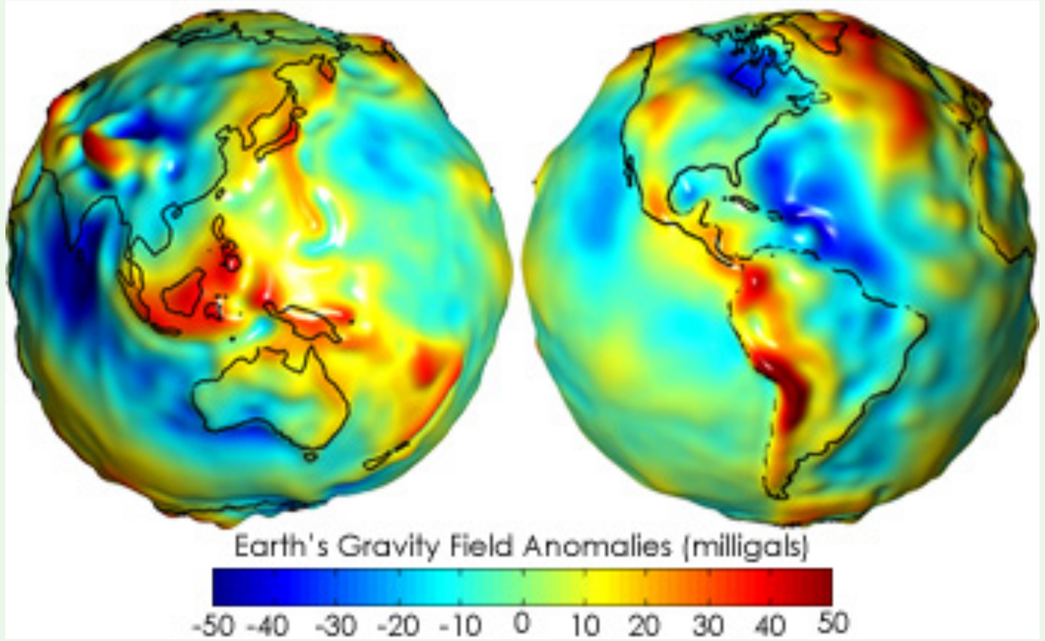
- Local vertical datum
  - Start from tide stations (long term observations)
  - Extended to inland using leveling survey
- National Geodetic Vertical Datum of 1929 (NGVD29)
- North American Vertical Datum of 1988 (NAVD88)
- Both NGVD29 and NAVD88 are realized as networks of vertical control points


BM2
Optical level
Leveling
rod
BM1
BS
FS
Direction of leveling



Geoid and Global Vertical Datum

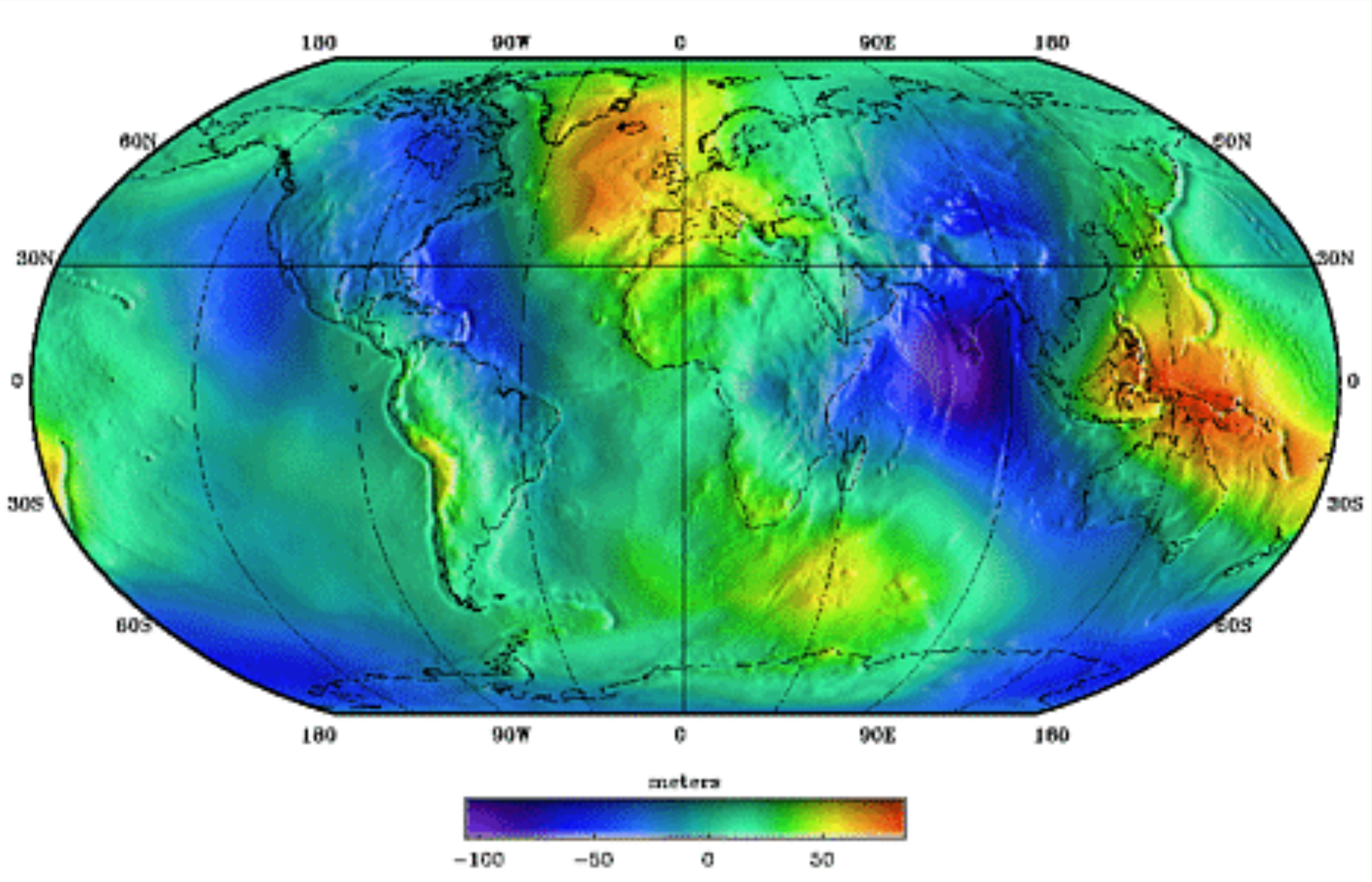
- A equipotential surface extended through land with effects of gravity
  - Calm and uniform water cover the earth surface
  - irregularities in the density of the Earth's crust and mantle
- A measured surface (not mathematically defined) using surface and satellite instruments
- A **global** vertical datum



Earth Geopotential Model (EGM96)

WGS84 ellipsoid is the reference surface

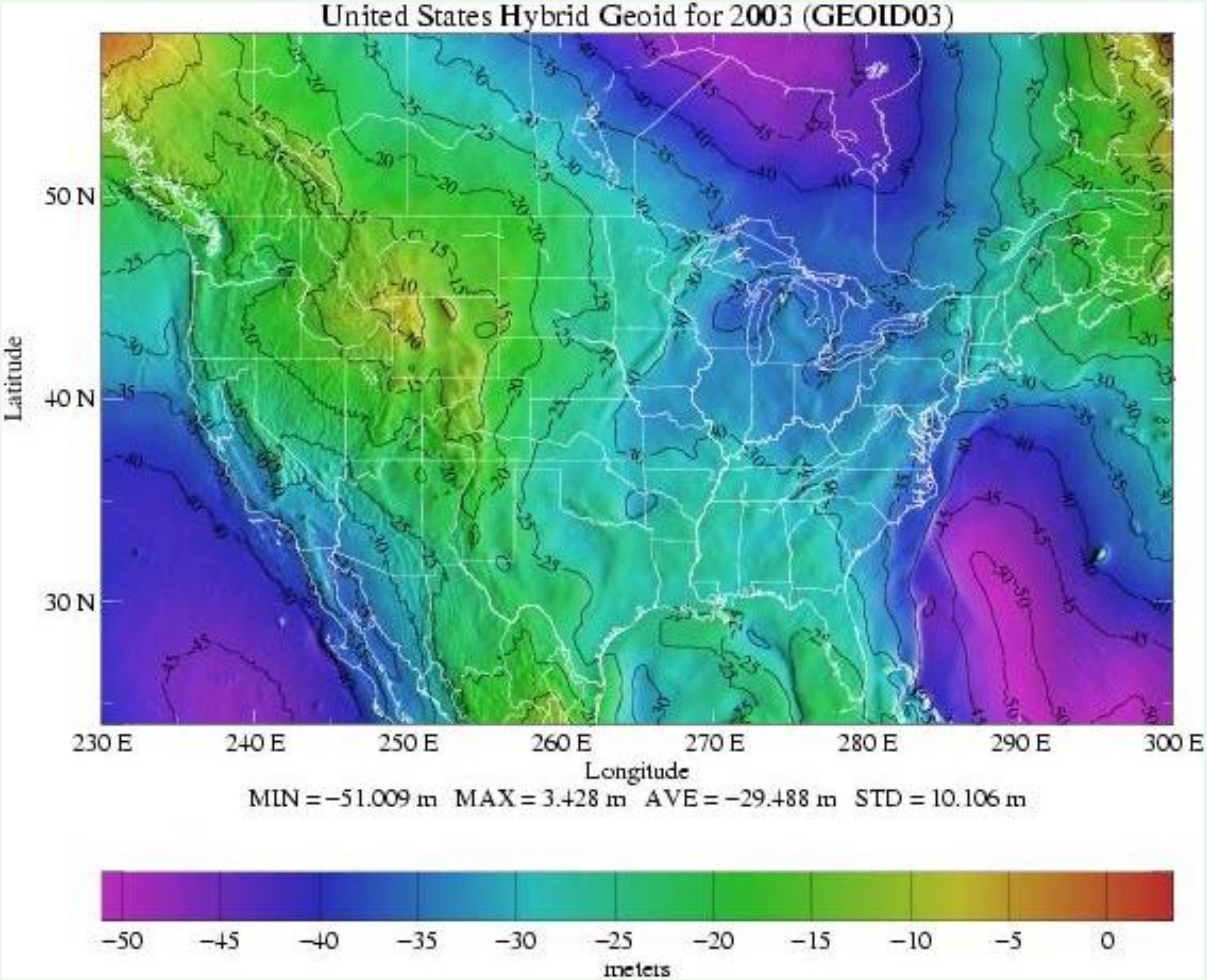
Max=86.4m, min=-107m



Height is from the ellipsoid to geoid (geoid-ellipsoid)

- The SRTM (Shuttle Radar Topography Mission) global elevation data uses EGM96 as its vertical datum
- Problem occurs when comparing SRTM elevation data with local elevation data

National Geodetic Survey Geoid03 (US)



Different heights

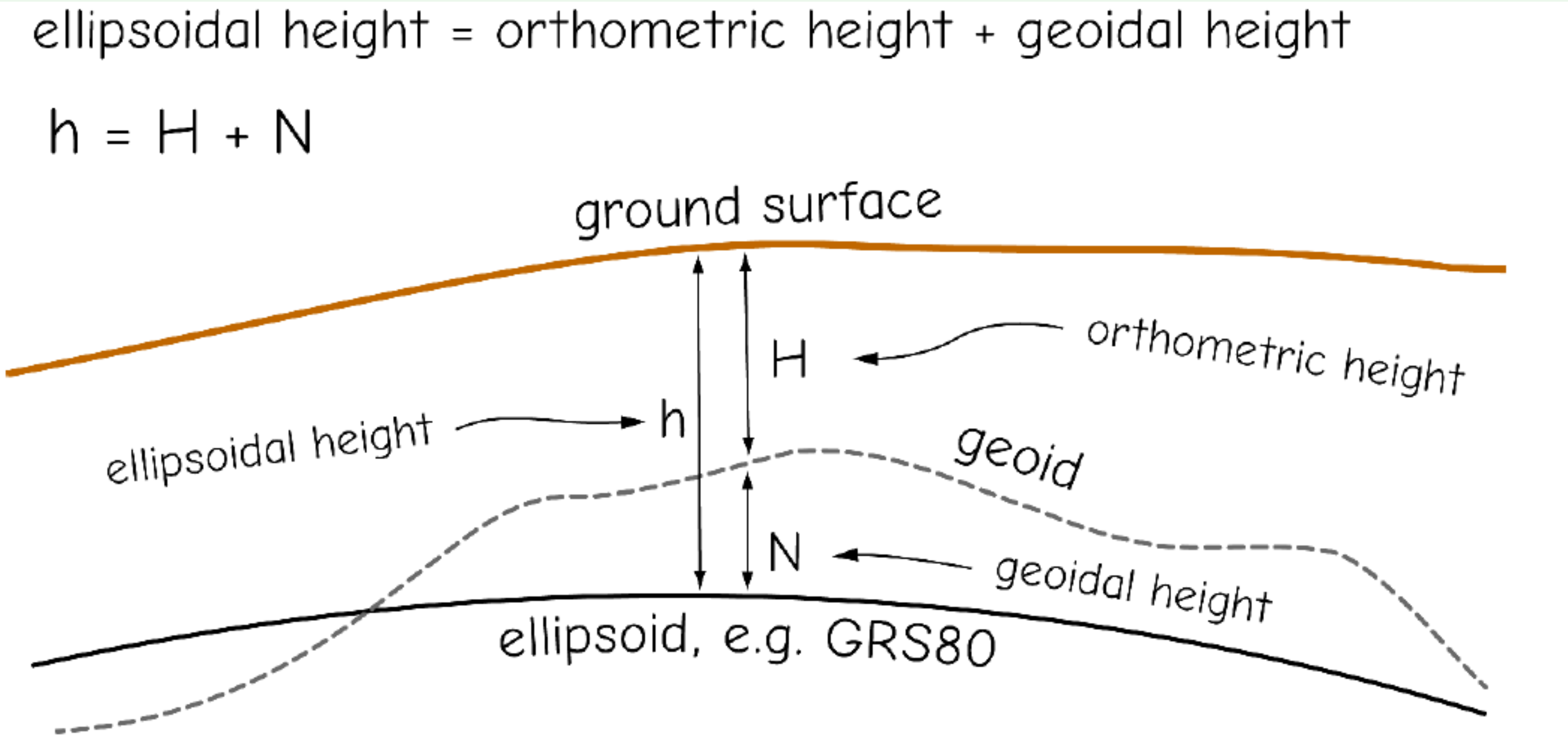


Figure 3-8: Ellipsoidal, orthometric, and geoidal height are interrelated. Note that values for N are highly exaggerated in this figure – values for N are typically much less than H. We often use this formula, e.g., to calculate orthometric height (elevation) when we know the ellipsoidal height (commonly from GPS), and geoidal height (from national models).

Different Geoids

- GEOID96, 03, 09, 12B
- Better measurements
- Many equipotential surfaces