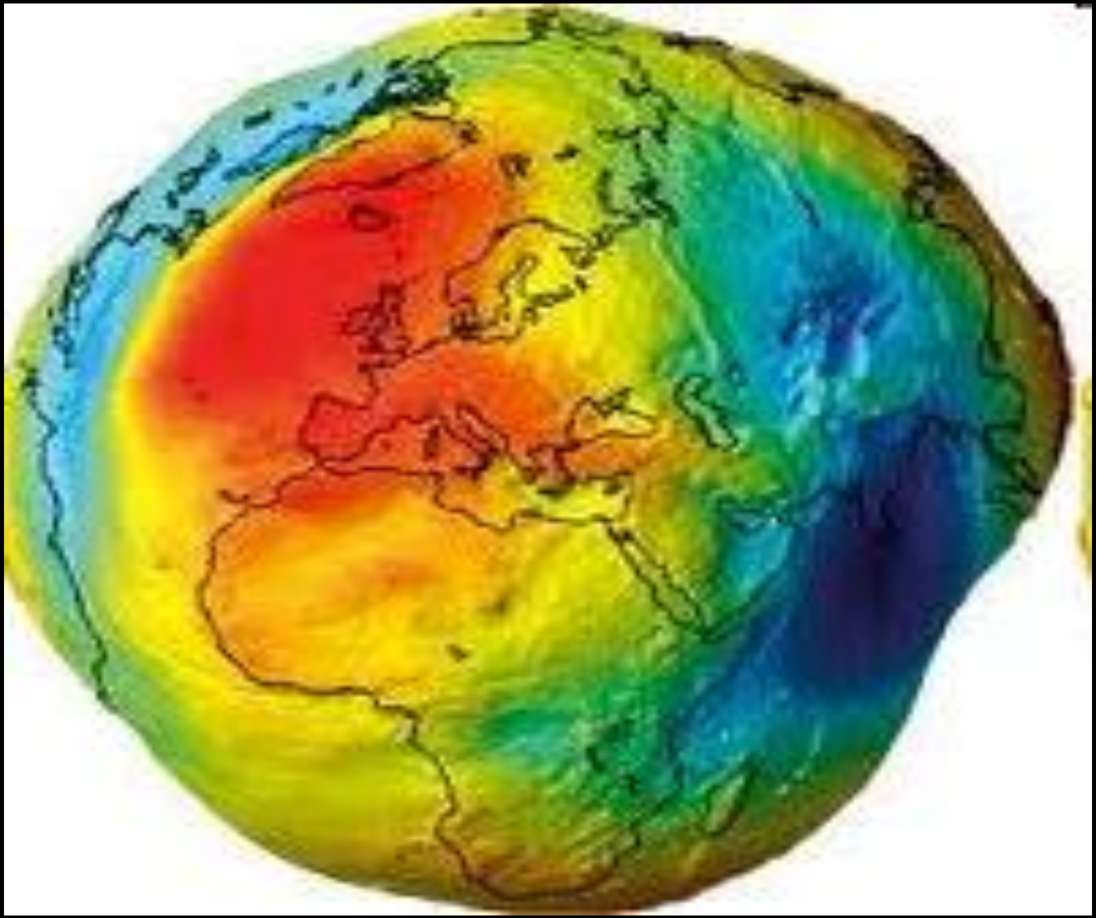
Physical figure of the earth



Earth has a highly irregular and constantly changing surface

How can we make measurements on such a irregular figure?

- Approximation of the above figure using mathematically smooth surfaces.

- There are many models available such as

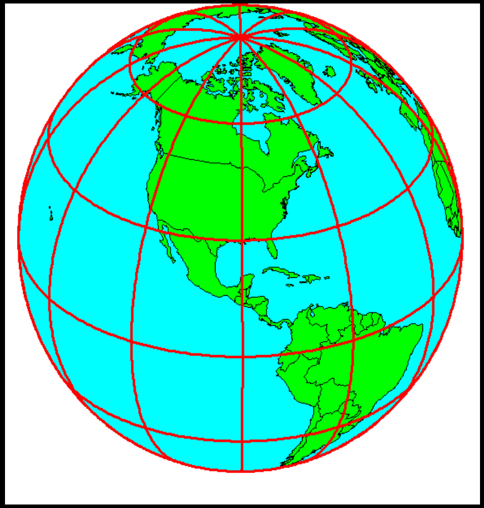
    Flat earth model

    Spherical model- Eratosthenes

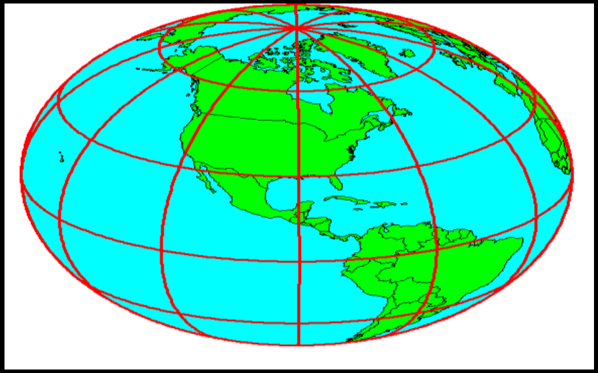
    Ellipsoidal model- Sir Isaac Newton

Shape of the Earth

We think of the earth as a sphere ...
Ex: Globe



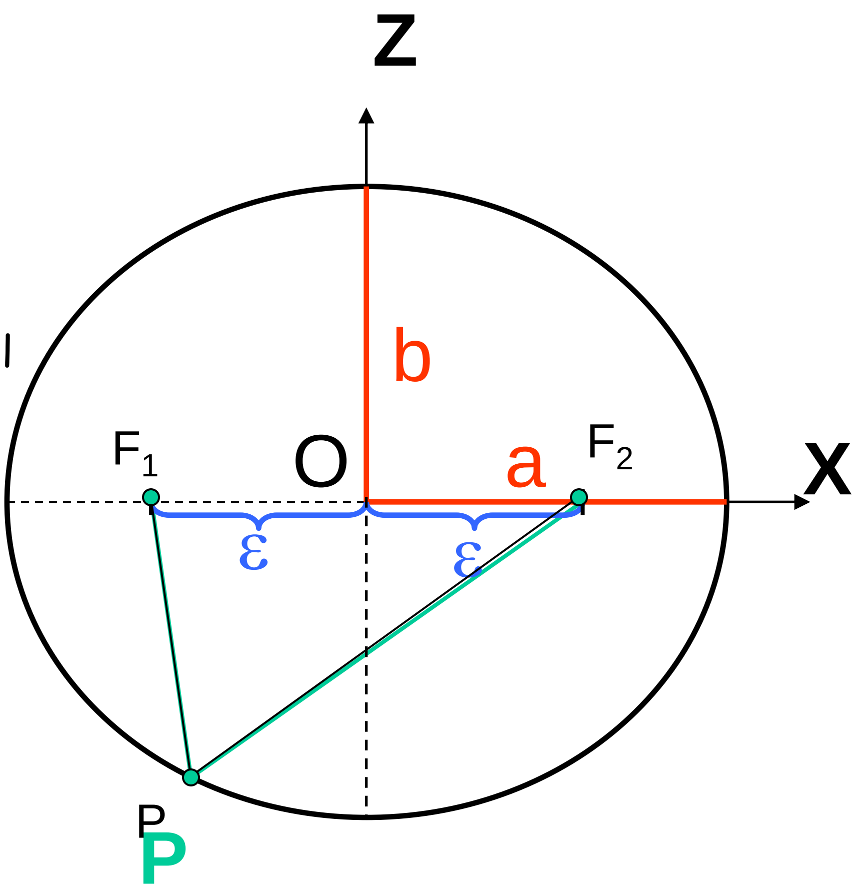
when it is actually an oblate spheroid (ellipsoid), slightly larger in radius at the equator than at the poles.



Ellipse

An ellipse is defined by:

- Focal length = ε
- Flattening ratio: $f = (a-b)/a$
- Distance F_1-P-F_2 is constant for all points P on ellipse
- When $\varepsilon = 0$ then ellipse = circle

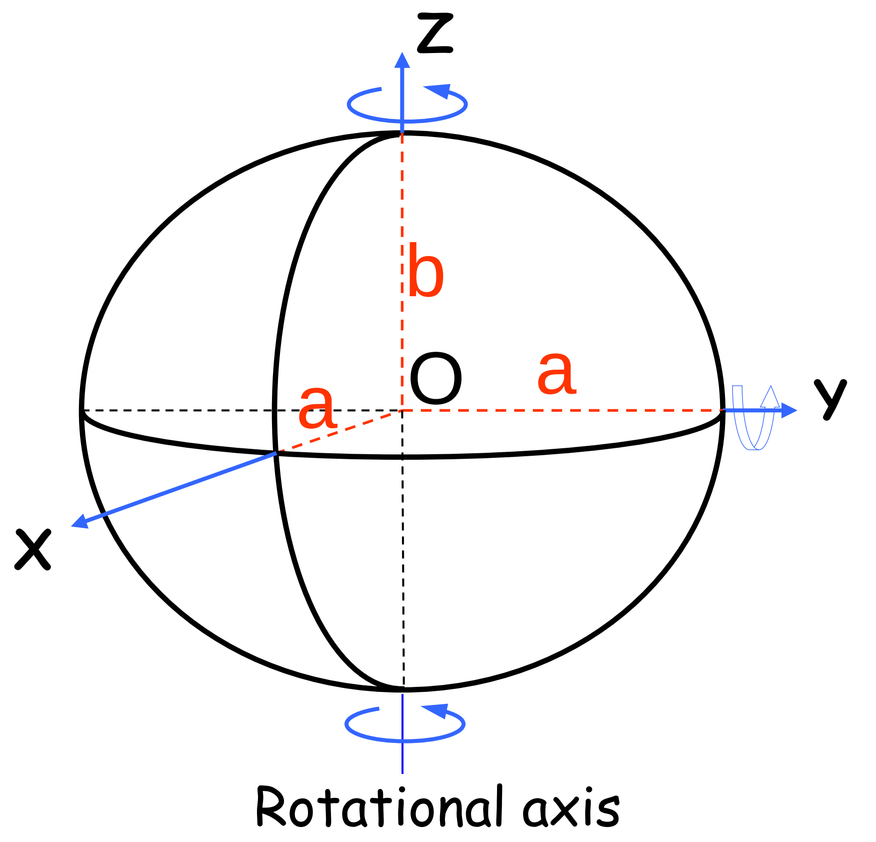


For the earth:

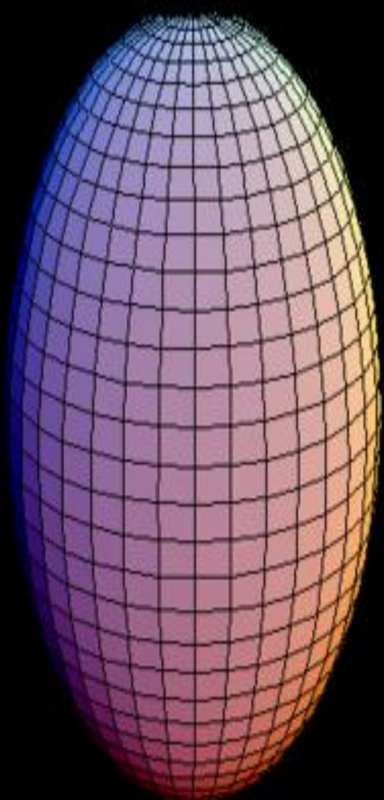
- Major axis: $a = 6378$ km
- Minor axis: $b = 6357$ km
- Flattening ratio: $f = 1/300$

How to obtain Spheroids

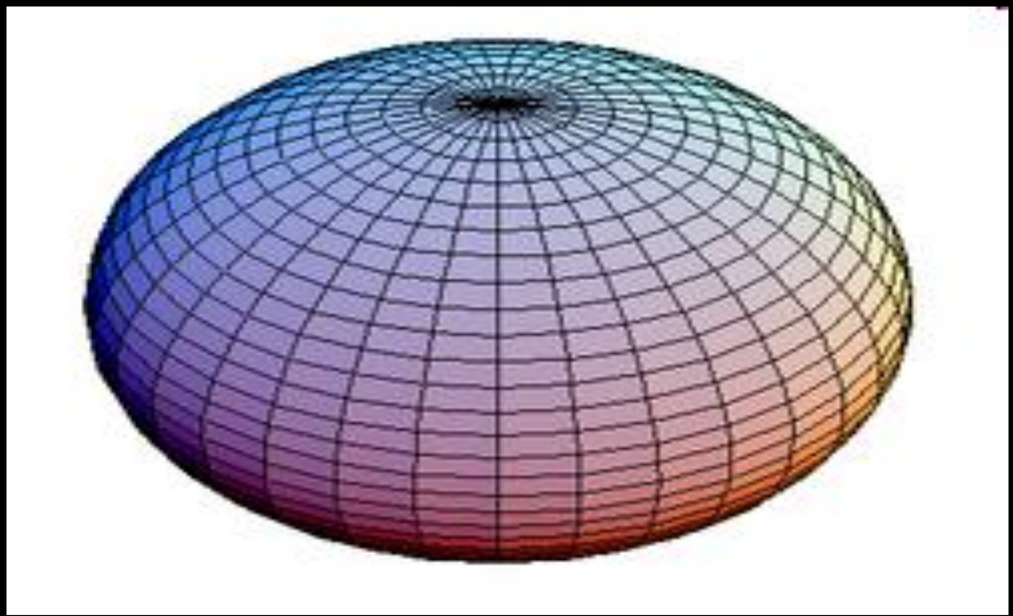
Rotate an ellipse around one of its axis.



Spheroid



Prolate spheroid



Oblate spheroid
(commonly referred as ellipsoid)

So what is reference ellipsoid?

- is a theoretical mathematical model that shows a smooth, simplistic representation of the Earth's surface. It is used to measure distances on the surface without having to account for things like elevation changes and landforms.

Selected Reference Ellipsoids

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

Datum

- **A datum defines the size and shape of the earth, and the origin and orientation of the axis used to define the location of points.**

- **Datum serves as a reference frame for measurements (both horizontal and vertical) on the earth surface.**

- **Datum comprises both horizontal and vertical reference frame.**

  Horizontal datum : Any reference ellipsoids

  Vertical datum: Geoid , Mean Sea Level (MSL)

Types of Datum

- **Local datum**

  A local datum aligns its spheroid to closely fit the earth's surface in a particular area.

  A point on the surface of the spheroid is matched to a particular position on the surface of the earth. This point is known as the origin point of the datum. The coordinates of the origin point are fixed, and all other points are calculated from it.

Example: Indian Datum

Reference Spheroid : Everest 1930

Origin: kalyanpur, Madhya Pradesh

- **Global or Geocentric datum**

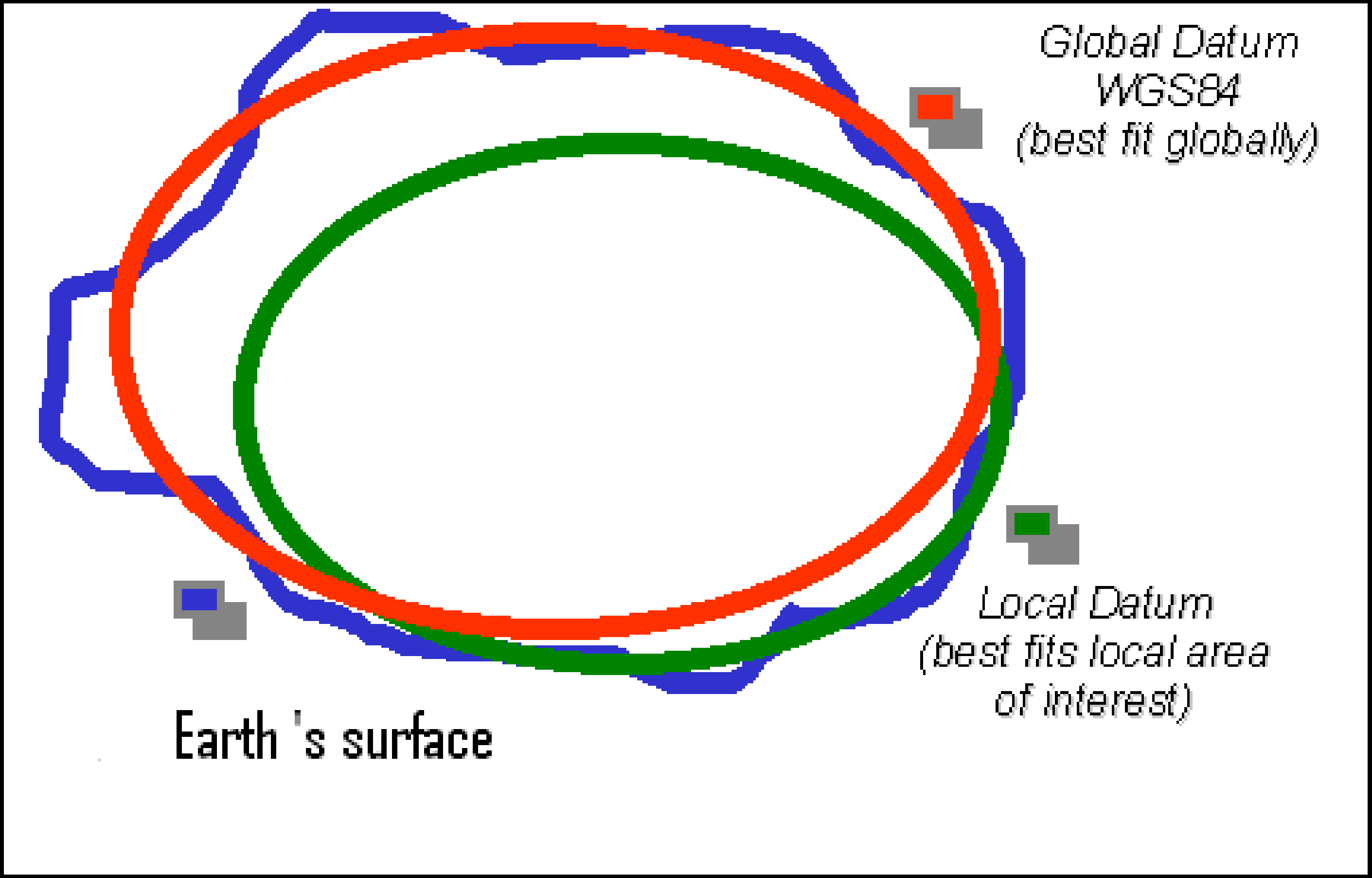
An earth-centered, or geocentric, datum uses the earth's center of mass as the origin. It serves as the framework for locational measurement worldwide.

Example: WGS 84 datum

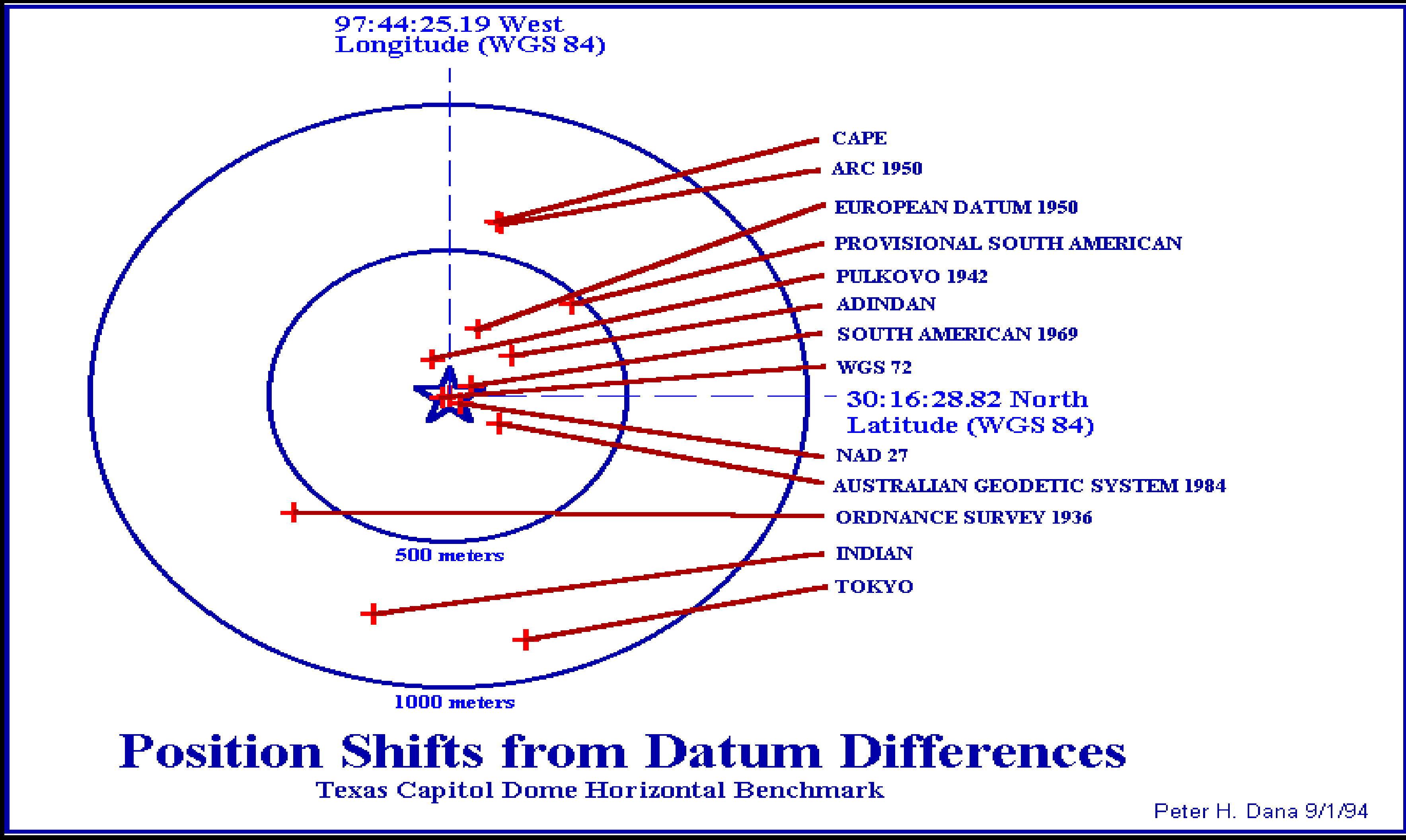
Reference Spheroid: WGS 84

Origin : Earth’s center of the Mass

Pictorial representation of Datums



Position accuracy due to datum shift



Vertical Datum

- Used for measuring elevations of a point on the earth’s surface.

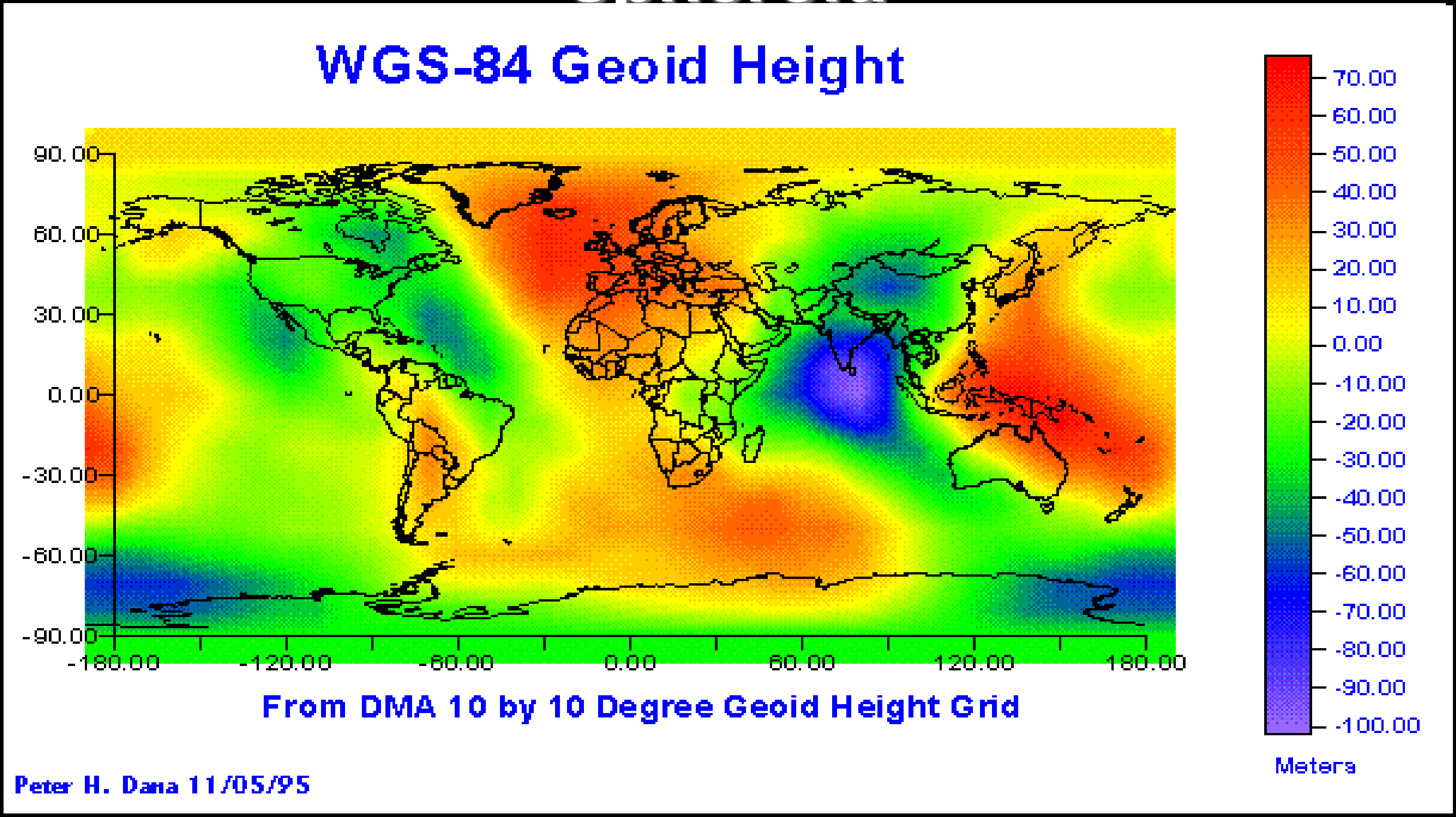
- Example:
- Mean sea level-based on tidal
- Geoid- based on gravimetric measurements
- WGS 84 datum –(both horizontal and vertical)- based on Ellipsoid

What is Geoid?

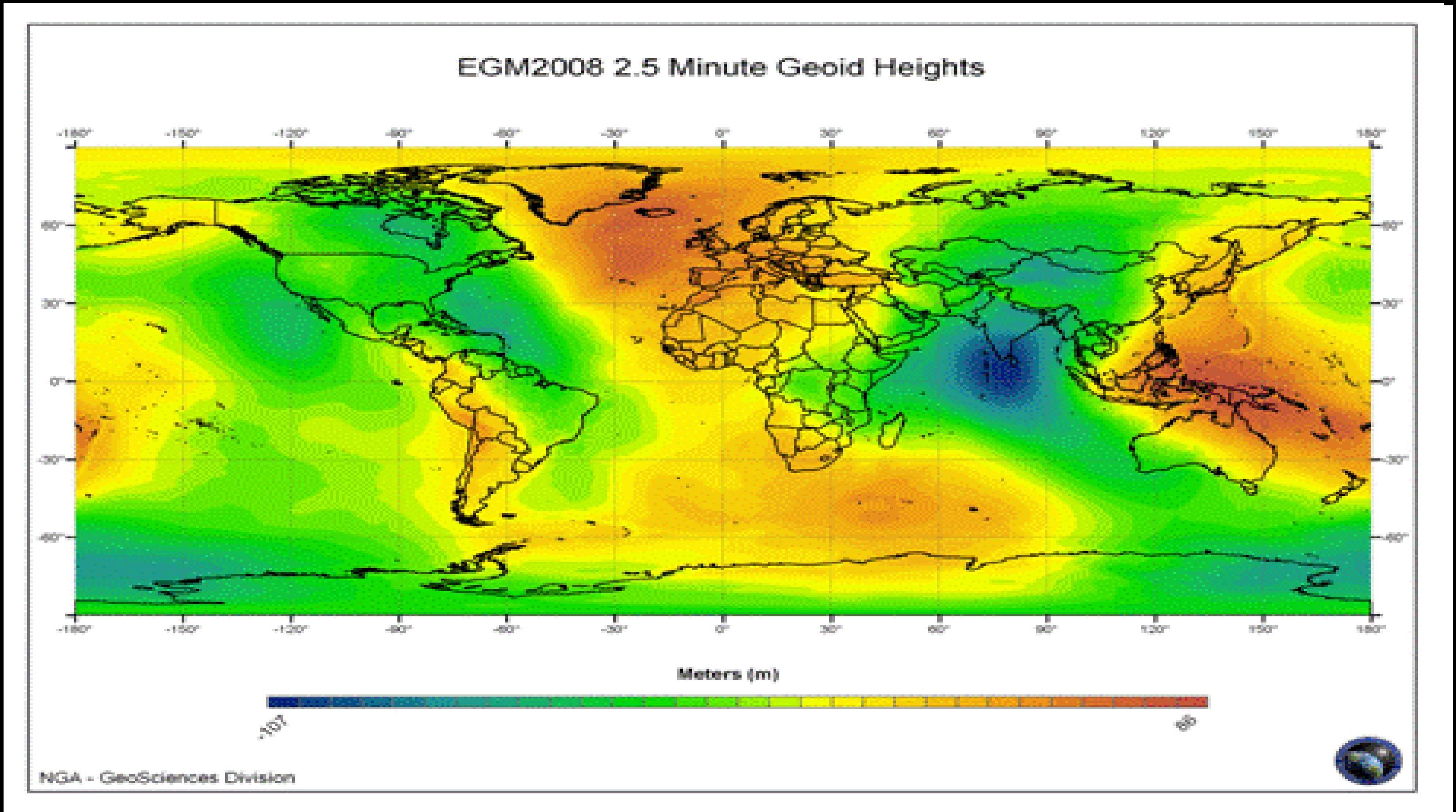
- is a "mathematical figure of the Earth," a smooth but highly irregular surface that corresponds not to the actual surface of the Earth's crust, but to a surface which can only be known through extensive gravitational measurements and calculations – C.F.Gauss.

- is a equipotential surface, which is perpendicular to the direction of gravity pull.

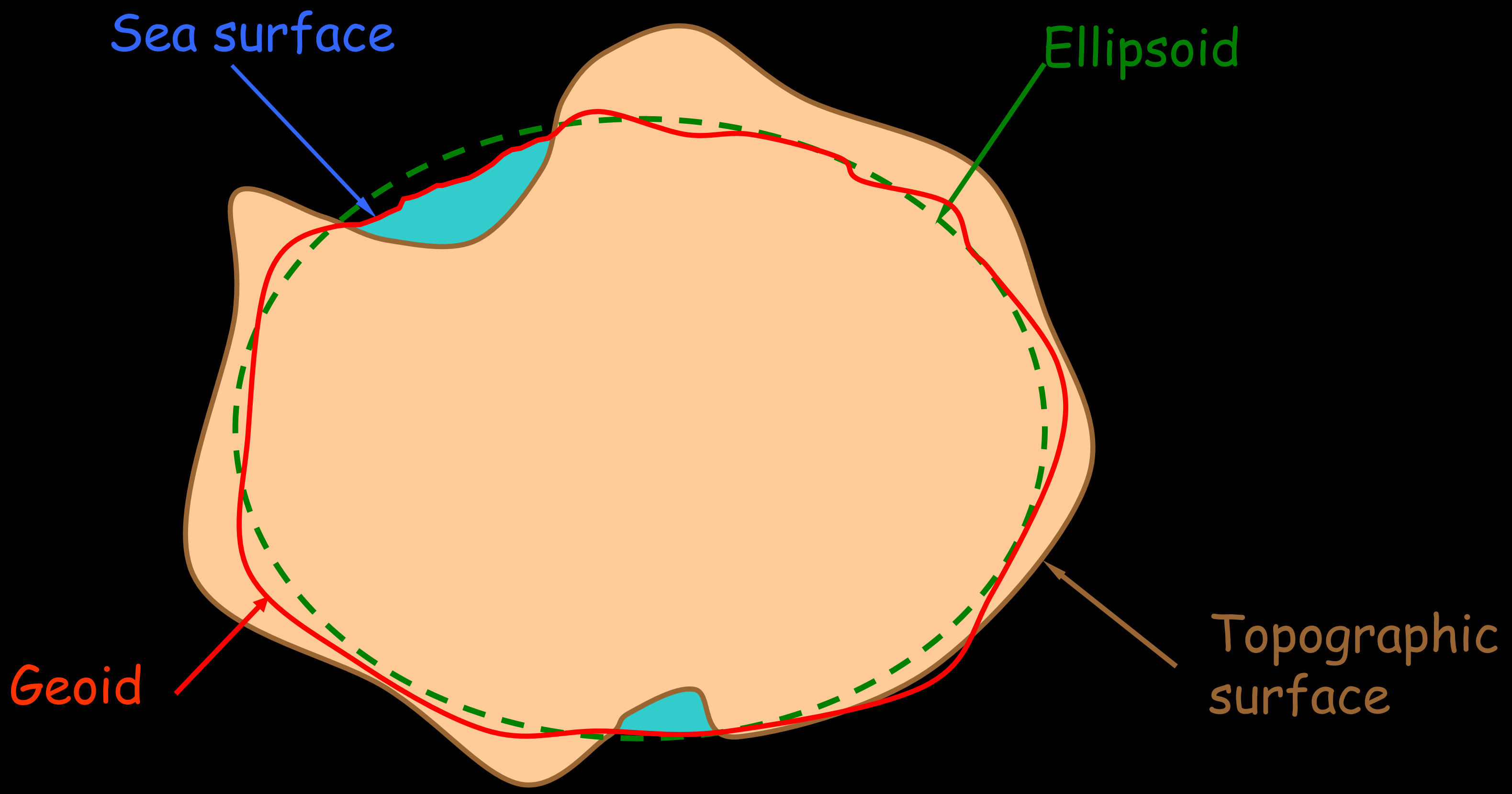
Earth Gravitational Model (EGM) 1996 heights based on WGS 84 reference spheroid



EGM 2008 Geoid heights on WGS 84 Ellipsoid

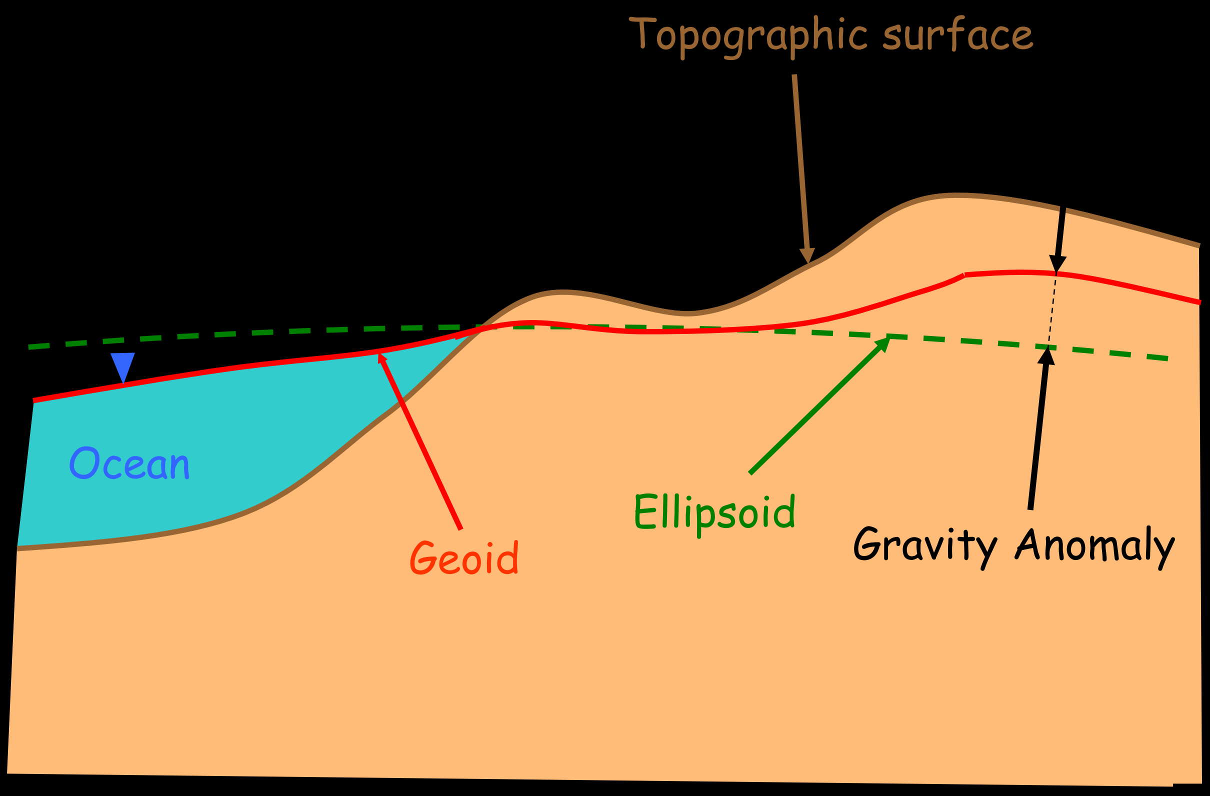


Earth Surfaces

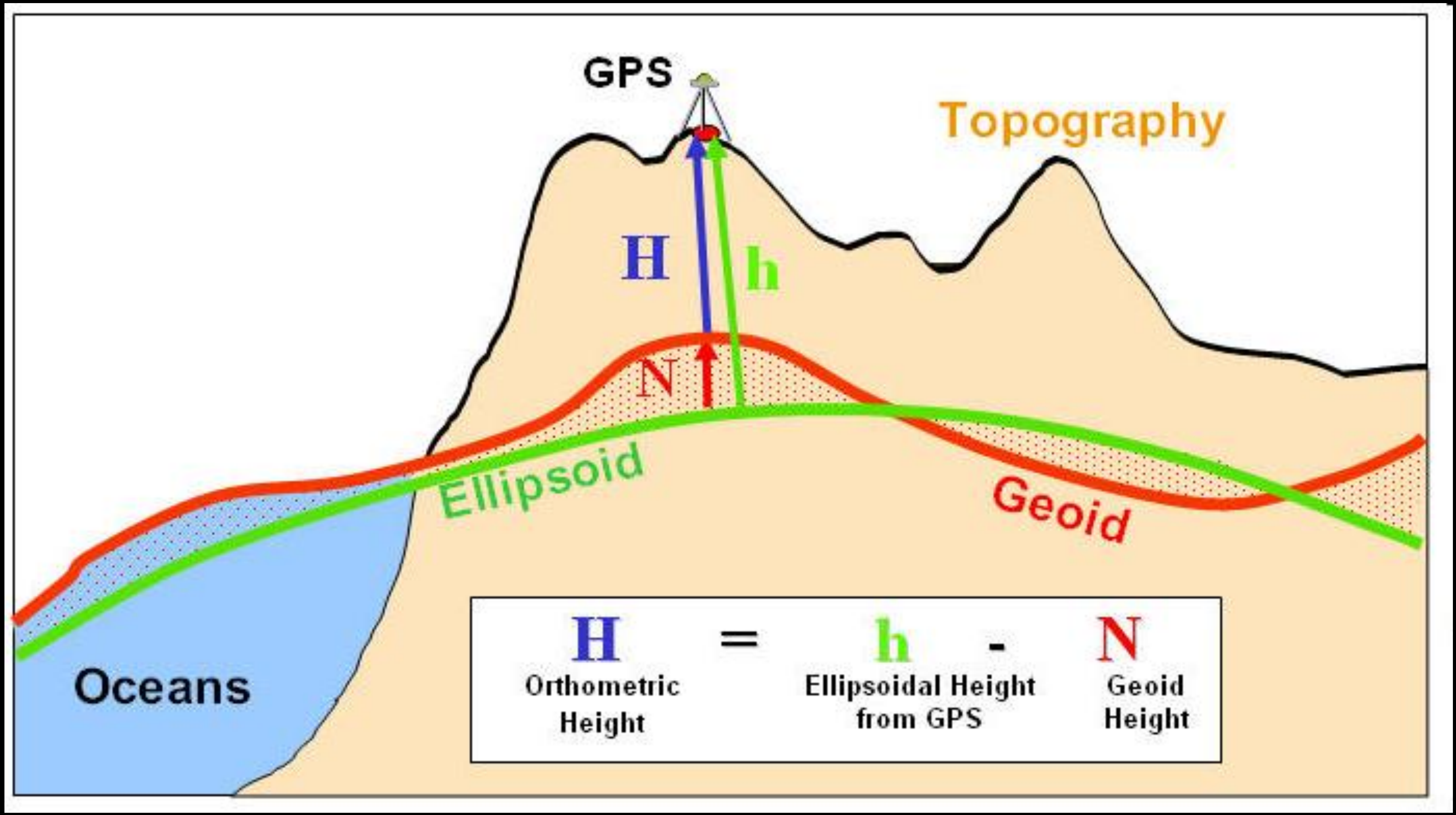


Geoid is a surface of constant gravity.

Earth Surfaces



Elevation Measurements



Coordinate Systems

- A grid (coordinate) system allows the location of a point on a map (or on the surface of the earth) to be described in a way that is meaningful and universally understood.

- Essential for both the process of map making and spatial search and analysis.

Common examples:

- Cartesian coordinate system
- Geodetic coordinate system

Types of grid systems

- Cartesian coordinate Systems
  - positions are defined by their perpendicular distances from a set of fixed axes.

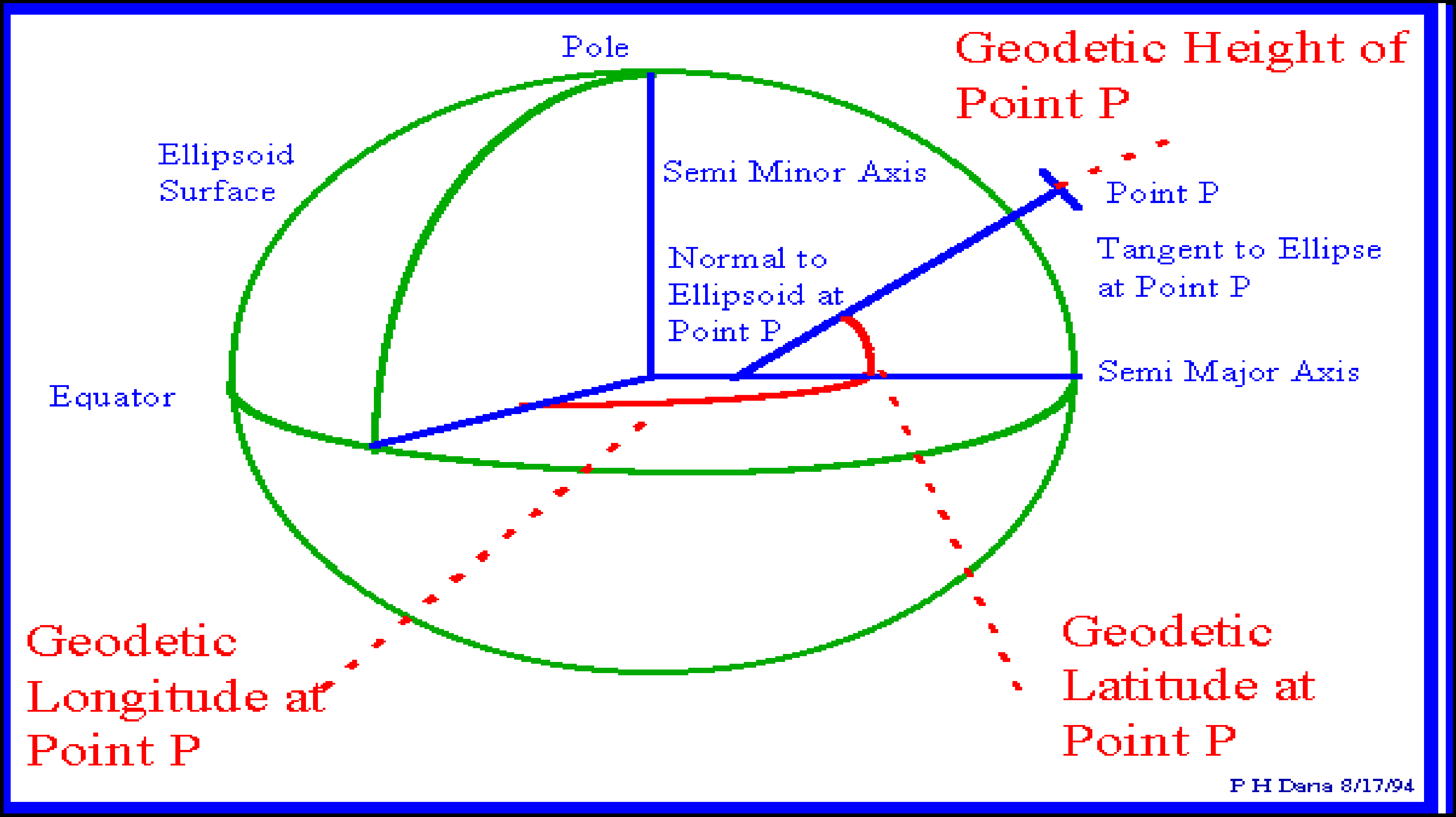
- Polar coordinate System
  - positions are defined by their distance from a point of origin and an angle, or angles, which give direction relative to an axis or a plane passing through the origin

Geodetic Co-ordinate Systems

A system to define the Position on the earth's surface in the form of degrees of latitude and longitude. This is a form of spherical polar coordinate system.

It uses a three-dimensional spherical / ellipsoidal surface to define locations on the earth.

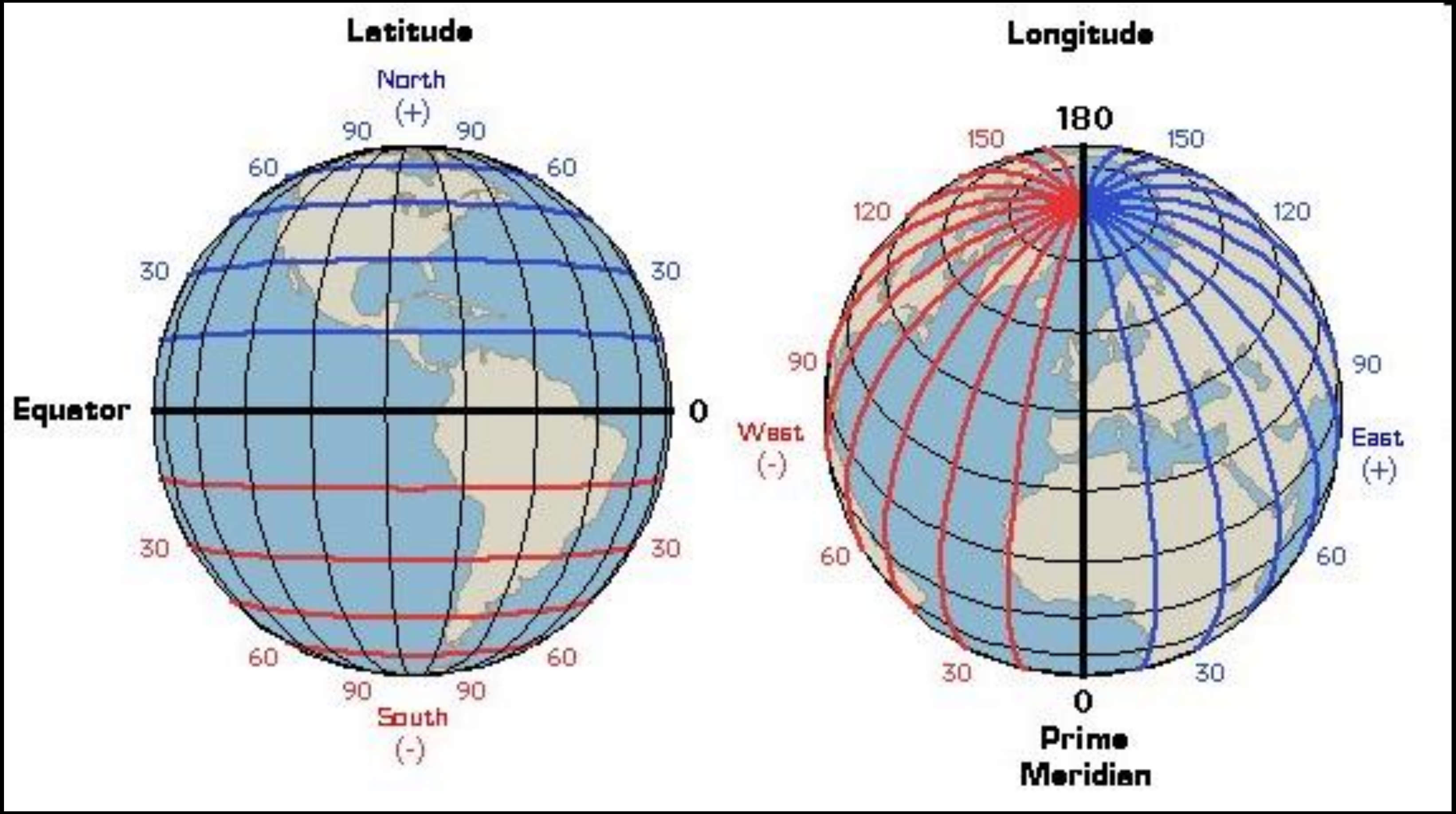
Geodetic Coordinate System



Geodetic Coordinate System

- Latitude, Longitude, Height
- The most commonly used coordinate system
- The Prime Meridian and the Equator are the reference planes used to define latitude and longitude.
- The geodetic latitude (there are many other defined latitudes) of a point is the angle from the equatorial plane to the vertical direction of a line normal to the reference ellipsoid.
- The geodetic longitude of a point is the angle between a reference plane and a plane passing through the point, both planes being perpendicular to the equatorial plane.
- The geodetic height at a point is the distance from the reference ellipsoid to the point in a direction normal to the ellipsoid.

Pictorial representation of Equator, North & South Poles with Latitudes and Longitudes



Terms associated with coordinate system

Parallels

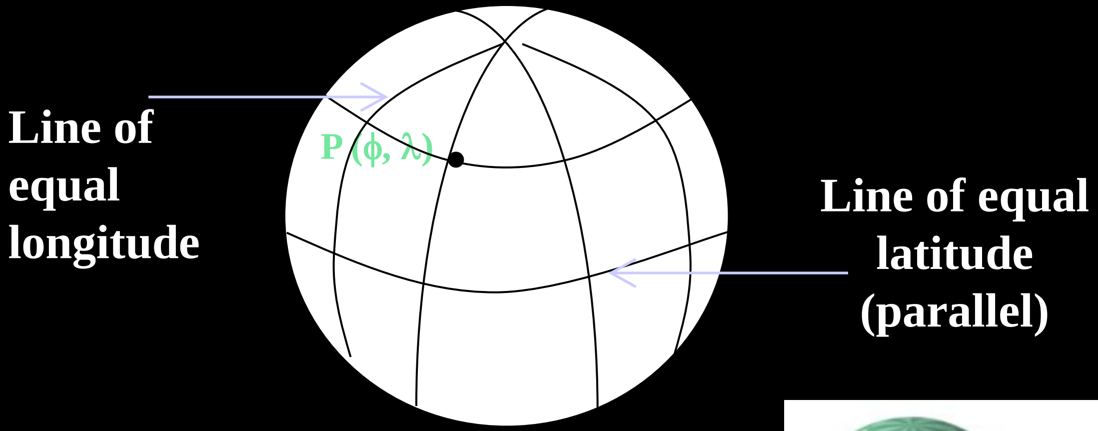
-Lines of equal latitude

Meridian

-Lines of equal longitude

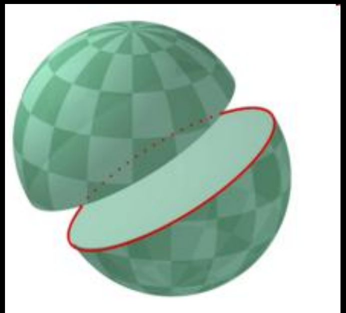
Graticule

-set of parallels and meridians seen on a map



Great Circle:

is a circle that runs along the surface of that sphere so as to cut it into two equal halves



Geodetic latitudes and Longitudes

- Latitude and longitude values are traditionally measured either in decimal degrees or in degrees, minutes, and seconds (DMS).
- Latitude values are measured relative to the equator and range from -90° at the South Pole to +90° at the North Pole.
- Longitude values are measured relative to the prime meridian. They range from -180° when traveling west to 180° when traveling east.
- Although longitude and latitude can locate exact positions on the surface of the globe, they are not uniform units of measure.

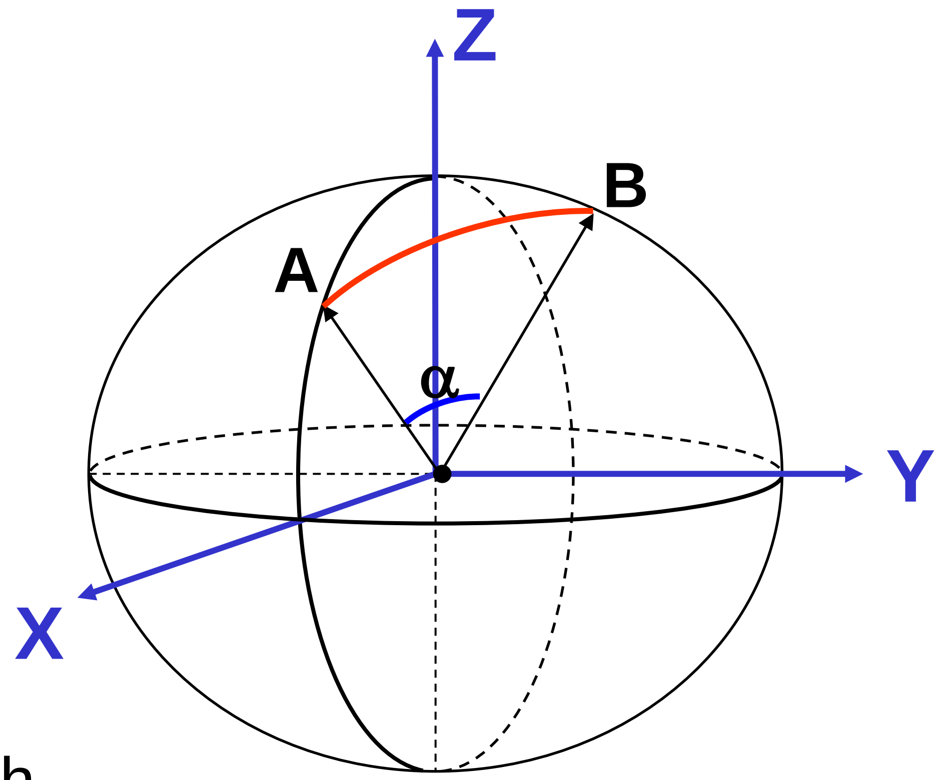
Calculating shortest distance on the surface of Spherical Earth

- The great-circle distance or orthodromic distance is the shortest distance between any two points A (ϕ_1, λ_1) and B (ϕ_2, λ_2) on the surface of a sphere measured along a path on the surface of the sphere.

where

- Φ_1, λ_1 – geodetic or geographical latitude and longitude of the points

Great circle distance between A & B = Rα



where

R =6370 km- radius of the earth

α = angle in radians

$$\text{Distance} = R\cos^{-1}(\sin\phi_1 \sin\phi_2 + \cos\phi_1 \cos\phi_2 \cos(\lambda_1 - \lambda_2))$$

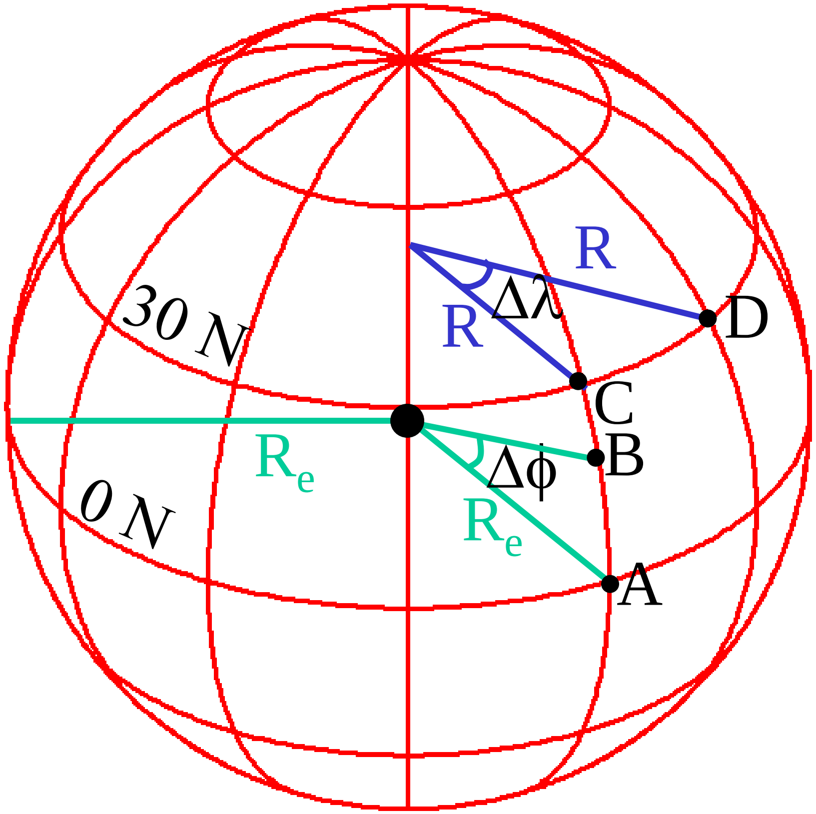
Note: latitudes and longitudes are in decimal degrees

Length on Meridians and Parallels

(Lat, Long) = (ϕ, λ)

Length on a Meridian:
AB = $R_e \, \Delta\phi$
(same for all latitudes)

Length on a Parallel:
CD = $R \, \Delta\lambda = R_e \, \Delta\lambda \, \mathrm{Cos} \, \phi$
(varies with latitude)



Note: latitudes and longitudes are in decimal degrees

R_e-radius of the earth

Other Types of Coordinate Systems

Projected Coordinate Systems (PCS):

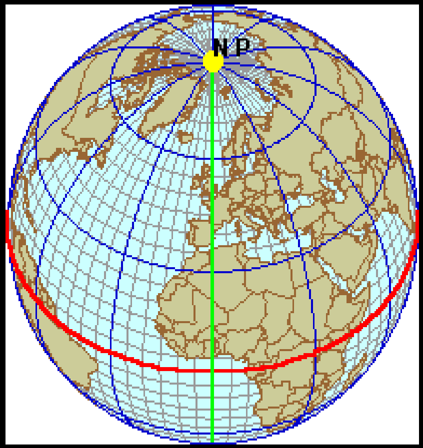
A PCS is defined on a flat, 2D surface.

Has constant lengths, angles, and areas across the two dimensions.

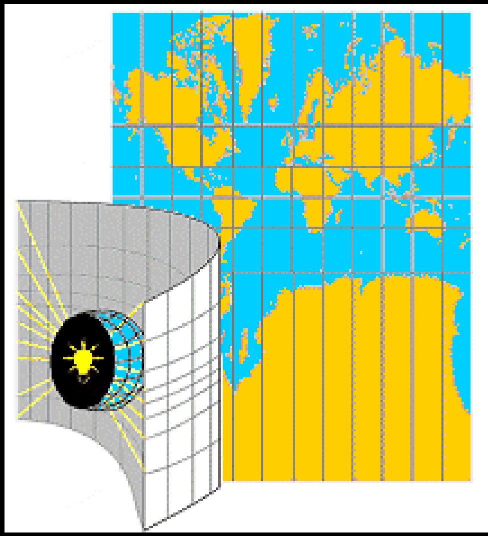
A PCS is always based on a geographic coordinate system that is based on a sphere or spheroid.

Locations are identified by x,y coordinates on a grid

Coordinate Systems
Geographic vs. Projected



- Geographic Coordinate Systems (GCS)
  - Location measured from curved surface of the earth
  - Measurement units latitude and longitude
    - Degrees-minutes-seconds (DMS)
    - Decimal degrees (DD) or radians (rad)



- Projected Coordinate Systems (PCS)
  - Flat surface
  - Units can be in meters, feet, inches
  - Distortions will occur, except for very fine scale maps

  Example: UTM, State Plane Coordinate (SPC) System

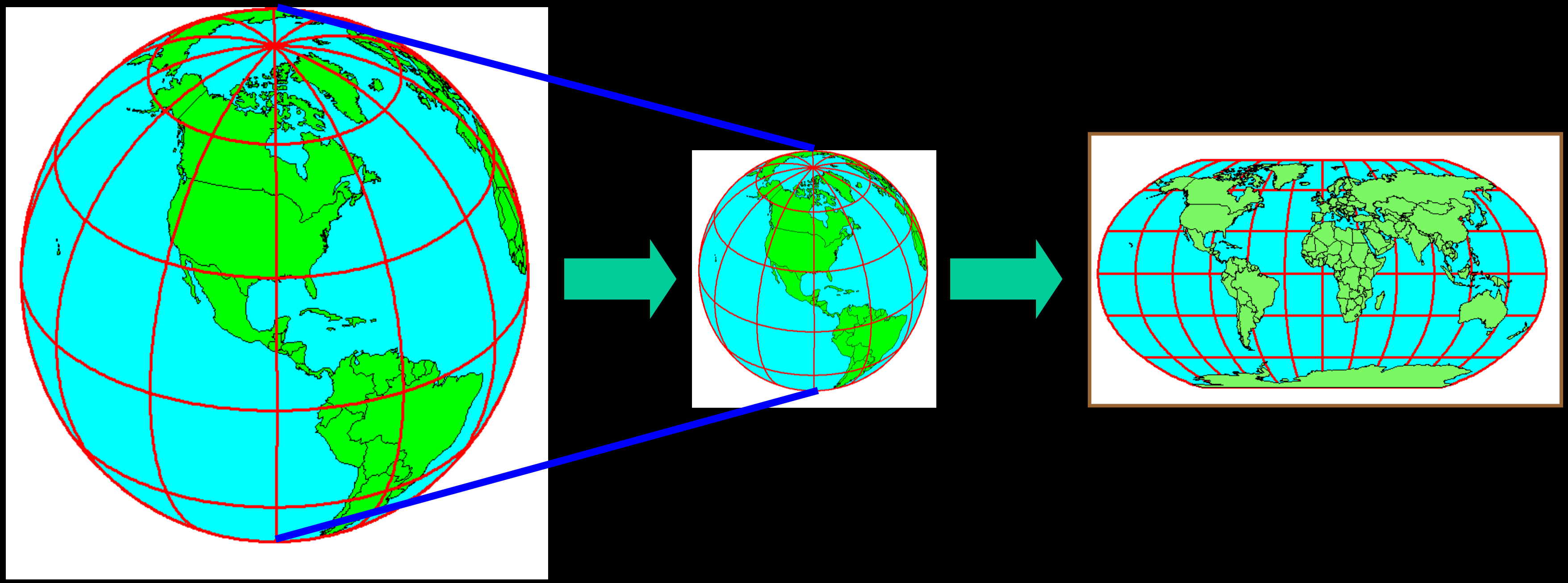
Why we need Map projections?

The problem is
Earth is 3D
But the paper is flat (2D)

Map Projections

- **Map projections refer to the techniques cartographers and mathematicians have created to** depict **all or part of a three-dimensional, roughly** spherical **surface on** two-dimensional**, flat surfaces with** minimal distortion**.**

Earth to Globe to Map



Basics of Map Projection

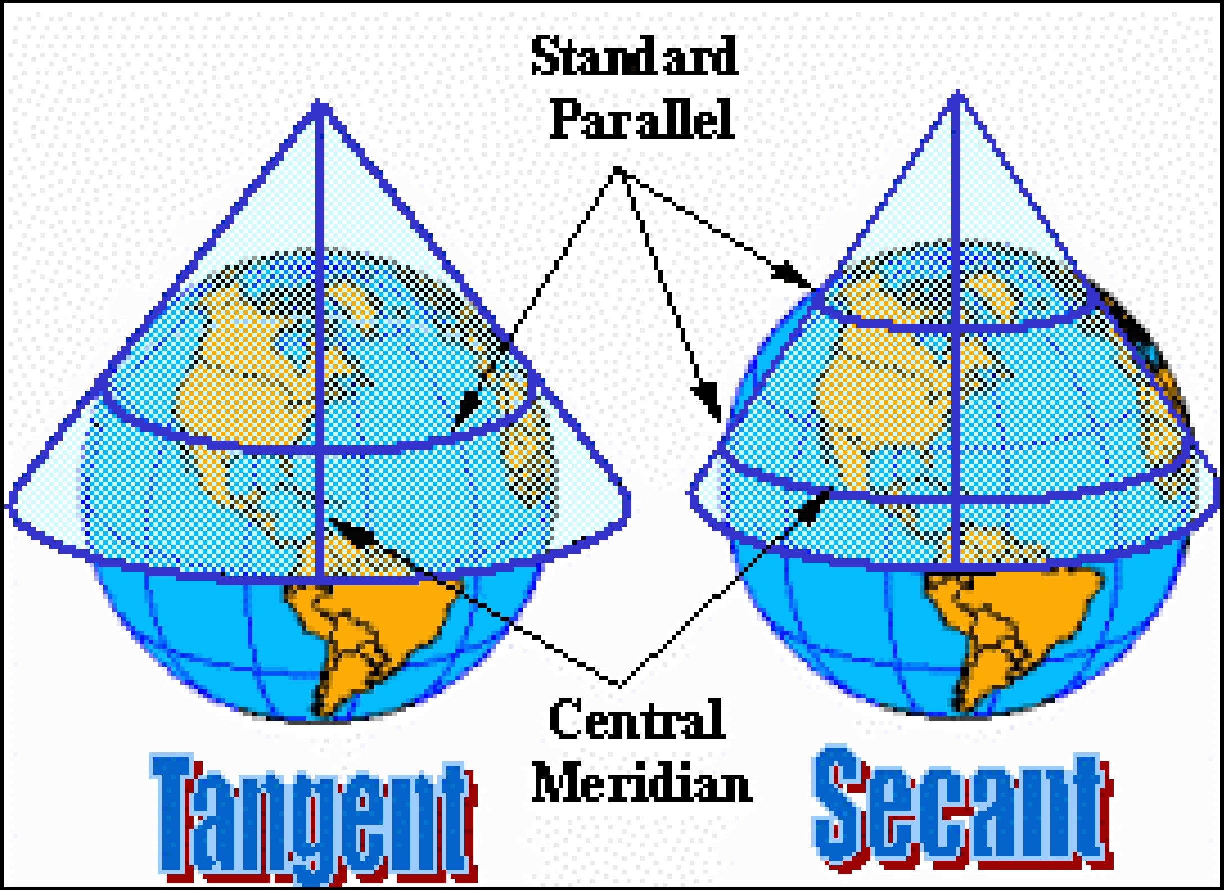
- A map projection is a set of mathematical principles for conversion of locations from a 3D earth surface to a 2D map representation.
- This conversion necessarily distorts some aspect of the earth's surface, such as area, shape, distance, or direction.
- No projection is best overall.

Basic Types of Map projections

The three basic types of map projections are

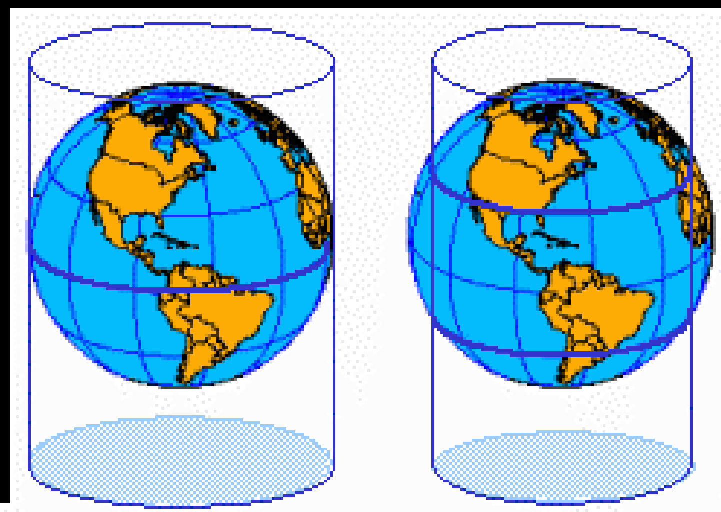
- **Cylindrical (Transverse Mercator) - good for North-South land areas**
- **Conic (Albers Equal Area, Lambert Conformal Conic) - good for East-West land areas**
- **Azimuthal (Lambert Azimuthal Equal Area) - good for global views**

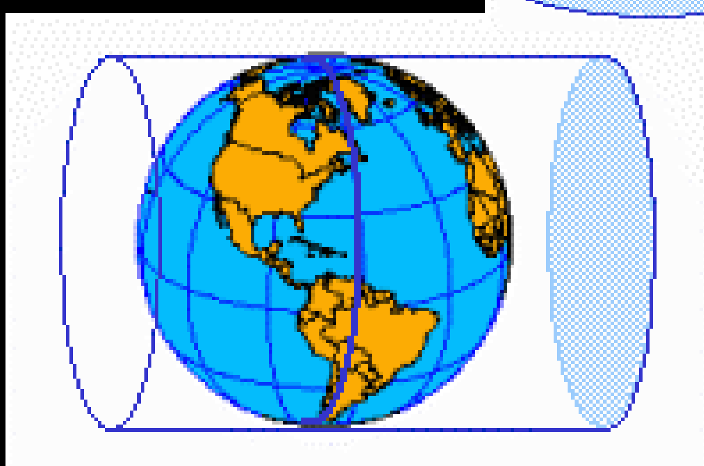
Conic Projections
(Albers, Lambert)



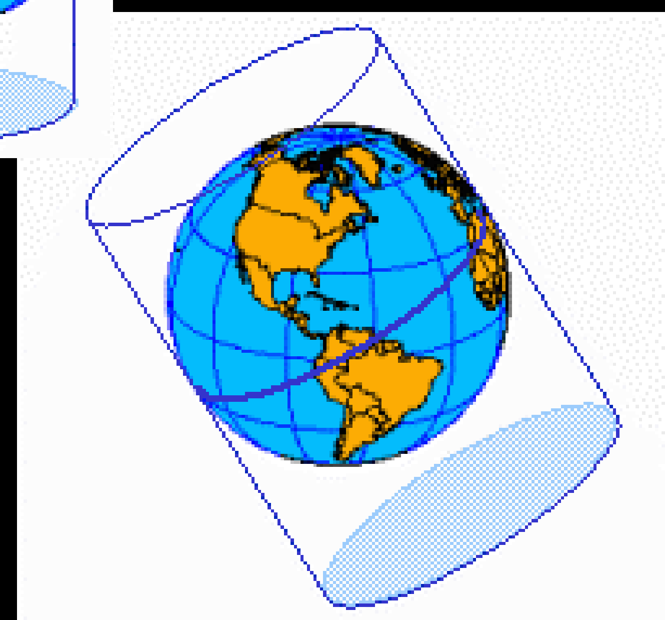
Cylindrical Projections

(Mercator)

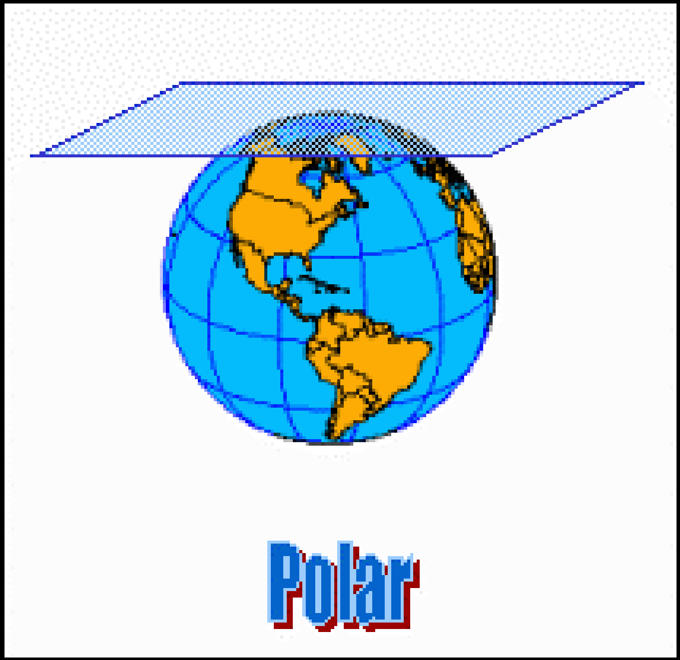


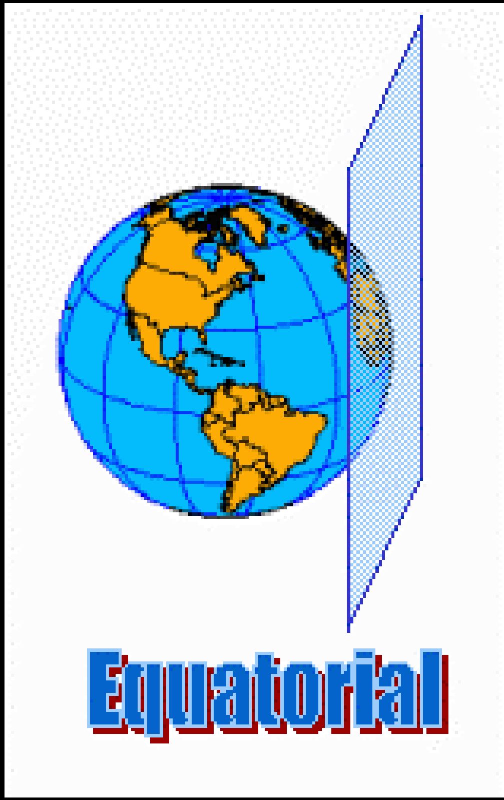


Oblique



Azimuthal
(Lambert)





Choosing a map projection

- Use equal area projections for thematic or distribution maps.
- Presentation maps are usually conformal projections, although compromise and equal area projections can also be used.
- Navigational maps are usually Mercator, true direction, and/or equidistant.

Other factors to be considered while choosing a map projection

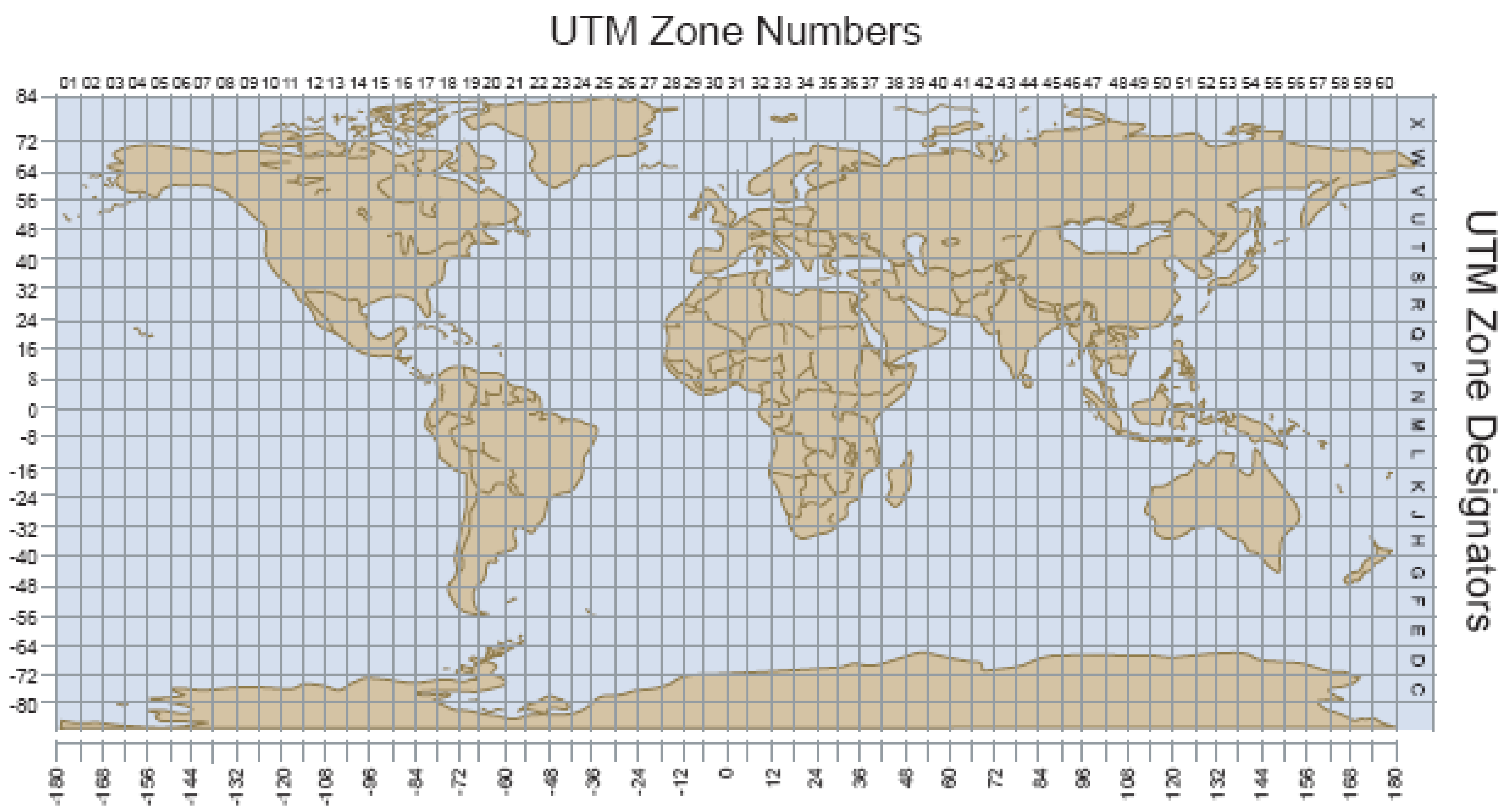
- The extent of the area to be mapped. Is it a database of the world, a continent, or a state?
- Location of the area to be mapped. Is it a polar, midlatitude, or equatorial region?
- Predominant extent of the area to be mapped. Is the area roughly circular or longer in the east–west, north–south, or some oblique direction?

Example of Projected Coordinate system

Universal Transverse Mercator

- Uses the Transverse Mercator projection
- 60 zones cover the earth from East to West
- Each zone has a Central Meridian (λ_o)
- zones are 6° wide, and go from pole to pole.
- Reference Latitude (ϕ_o), is the equator
- Preserves direction and small shapes (conformal projection).
- units are in meters

UTM Transverse Mercator (UTM) System



Summary on map projections

- To prepare a map, the earth is first reduced to a globe and then projected onto a flat surface.

- Three basic types of map projections: conic, cylindrical and azimuthal.

- A particular projected coordinate system is defined by a datum, a projection type and a set of projection parameters

Topic to be covered in next session

<u>Basics of GIS</u>

- Spatial Data Analysis