CRP 4080: Introduction to Geographic Information Systems for planners

Lecture 3: Coordinate System & Projection

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City and Regional Planning
Fall 2024

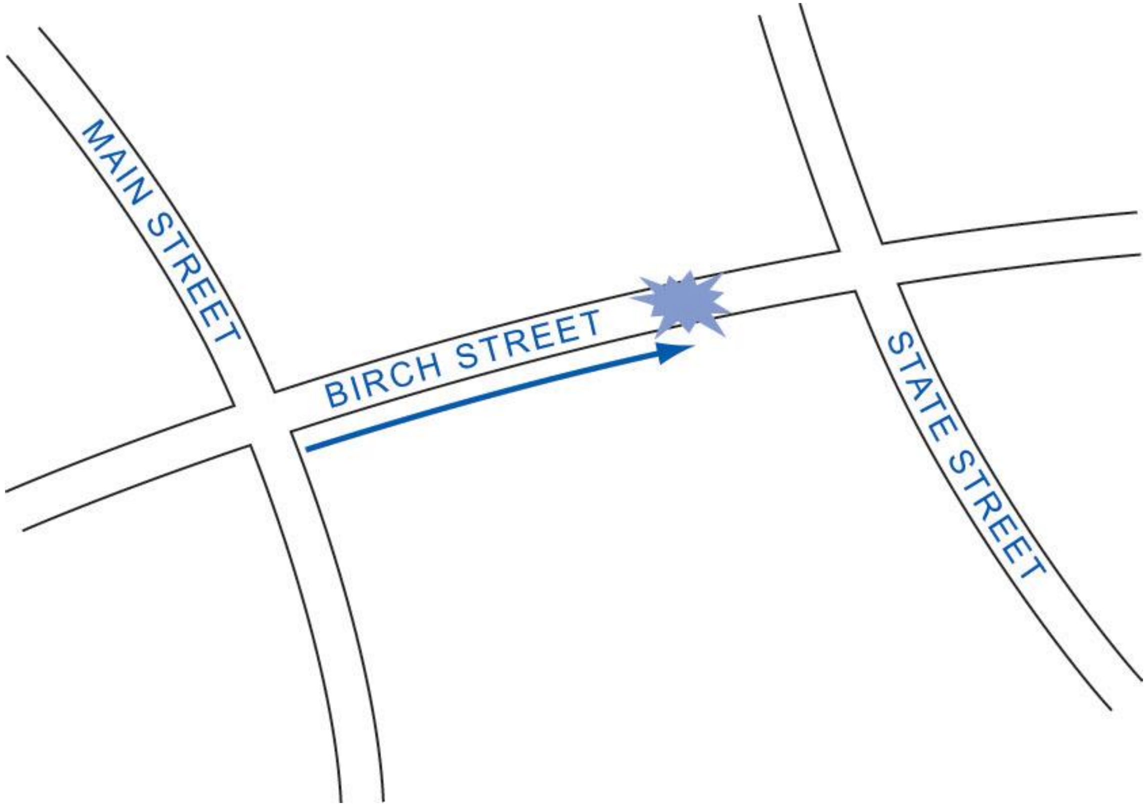
Announcement

- We will begin tracking attendance starting this week (seriously)!
- Lab 1 is due today
- Lab 2 is due on Friday (Sep 13^{th})
- Canvas Discussion Section
- TA office hours: Wednesday 4:30 pm to 6:30 pm.
- Instructor OH: Tuesday, 3-6pm by appointment

Georeferencing

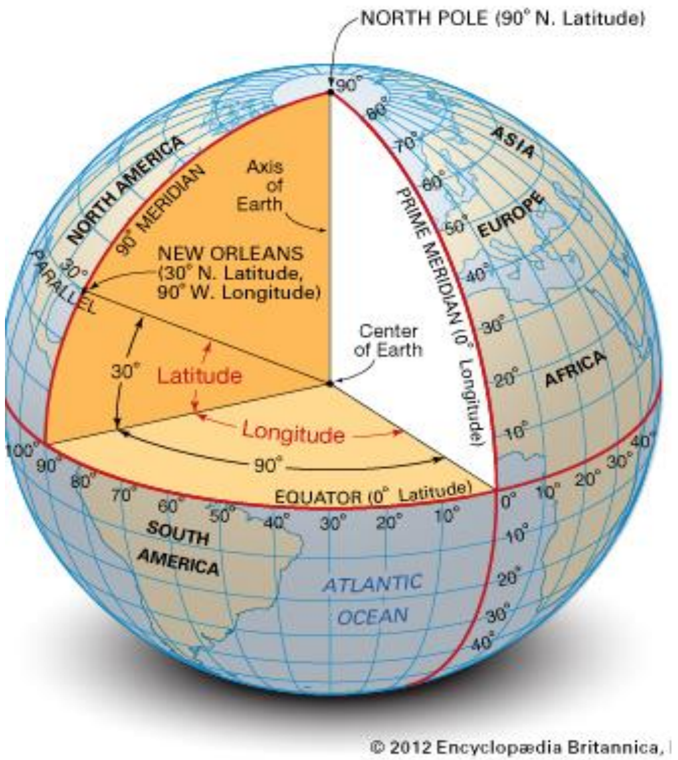
- In GIS, all information must be linked to the Earth's surface or "georeferenced".
- The method of georeferencing must be: *Unique, Shared, Persistent through time*

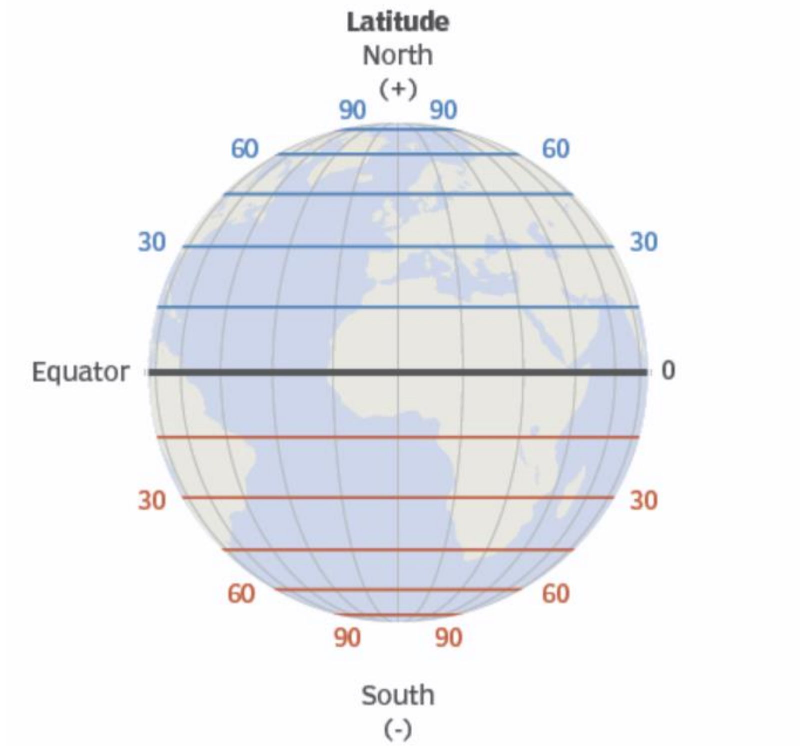
An incident's position is determined by measuring its distance (87 m) along one road (Birch Street) from a well-defined point (its intersection with Main Street)

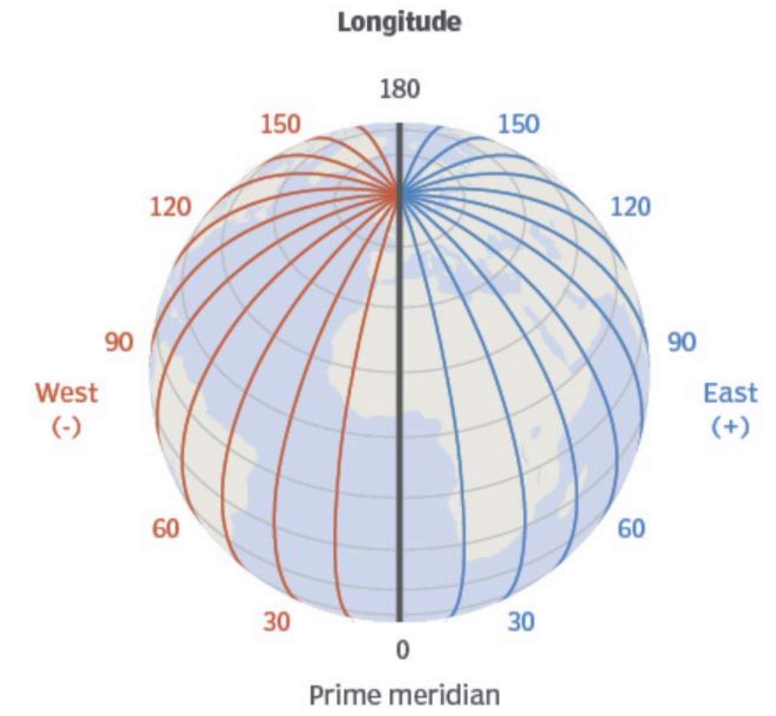


Latitude (parallels) and Longitude (Meridians)

The most common georeferencing method/system is using Latitude and Longitude —the basis of any *geographic coordinate system*.







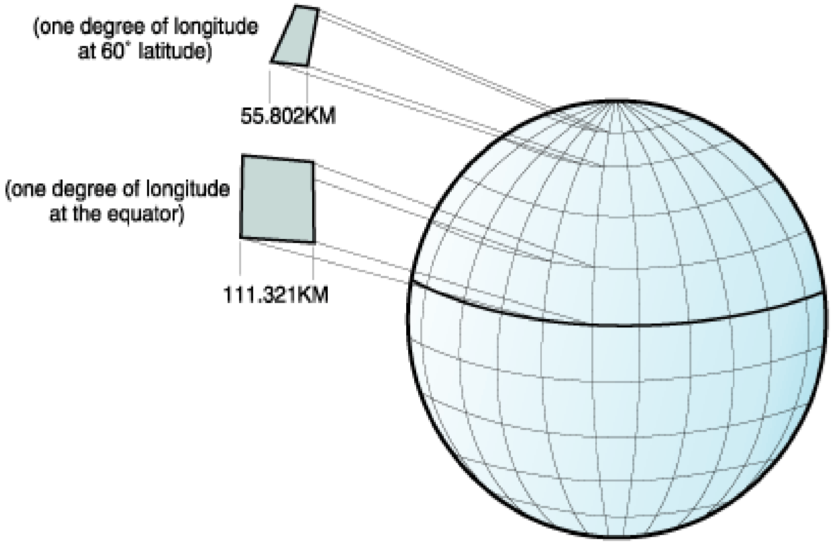
Latitude and Longitude

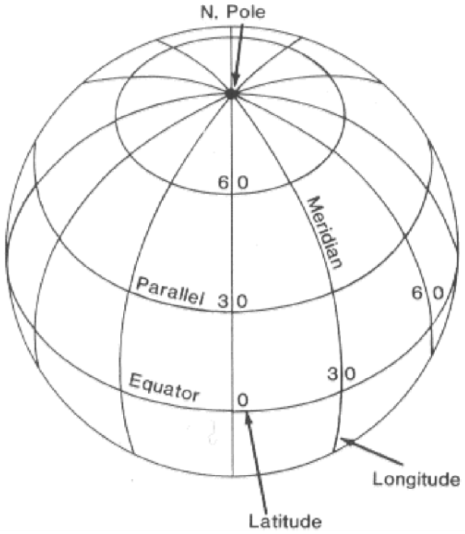
Uses a well-defined and fixed reference frame based on two axes: **Equator, center of mass**, and the **Prime Meridian (Greenwich)**

Metric, standard, stable, unique

The US has negatively numbered longitudes & positively numbered latitudes

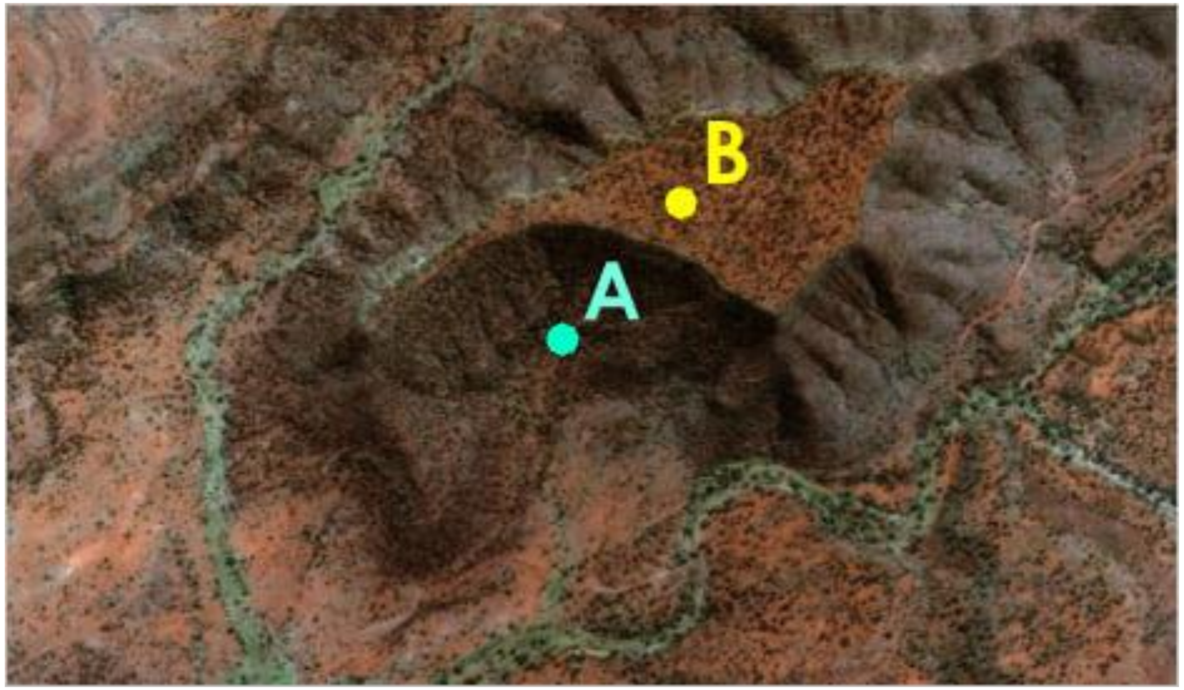
The Royal Observatory
Greenwich, England



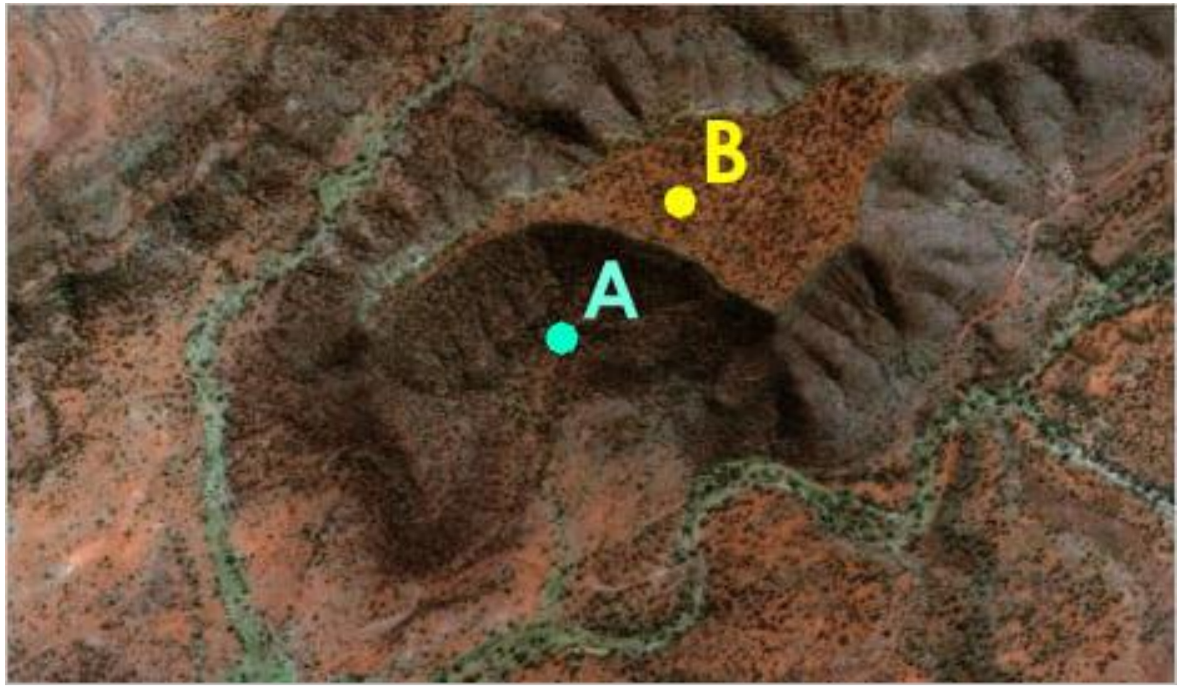


Let's imagine

You are part of an international search and rescue team looking for a group of injured hikers in the Australian outback. The point location you have from their satellite phone is **134.577°E, 24.006°S**. You locate them at point B using your machine, but your teammates from Australian locate them at point A. So, what happens?



Let’s imagine



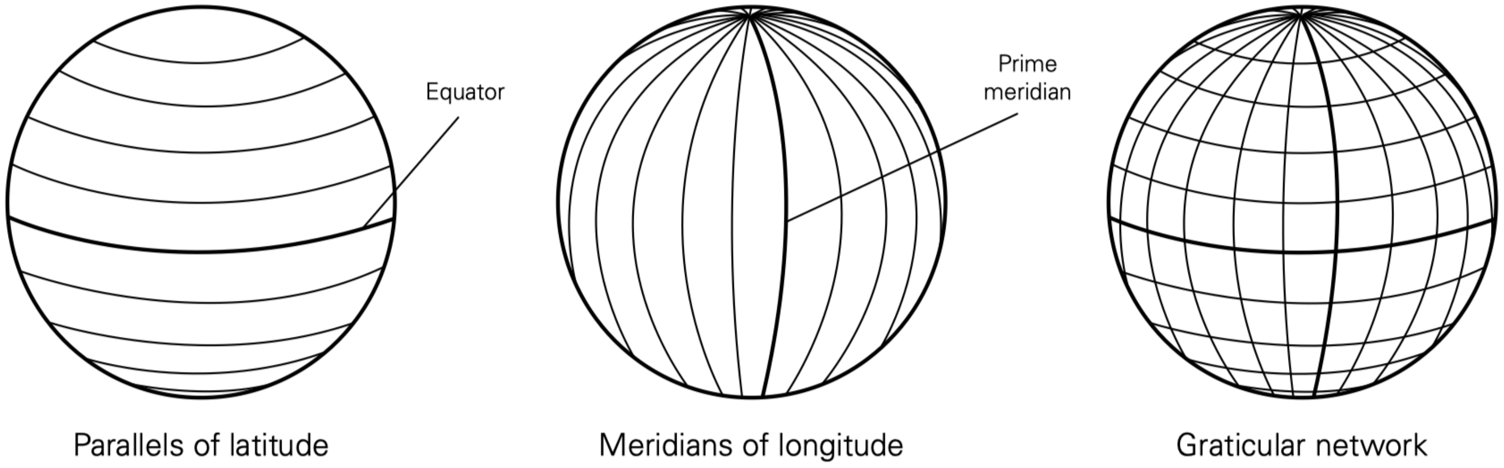
Both location A and B in the above image are correct.

- A is 134.577°E, 24.006°S in one geographic coordinate system **GCS (Australian Geodetic Datum 1984)**
- B is the same coordinate location in another **GCS (World Geodetic System 1984)**.

Why the rescue could go wrong?

What is GCS (geographic coordinate system)?

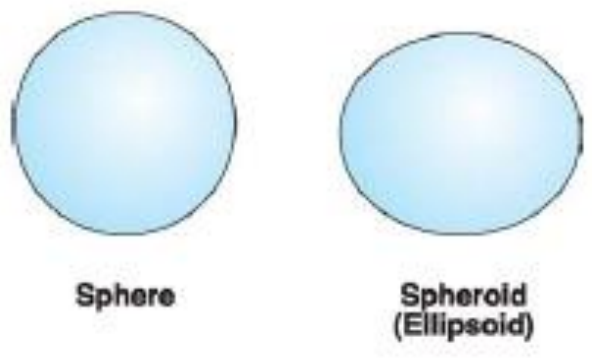
- **A geographic coordinate system (GCS)** is a reference framework that defines the locations of features on a **spherical model** of the earth.
- uses latitude-longitude, Decimal Degrees or degrees, minutes, seconds (DMS)



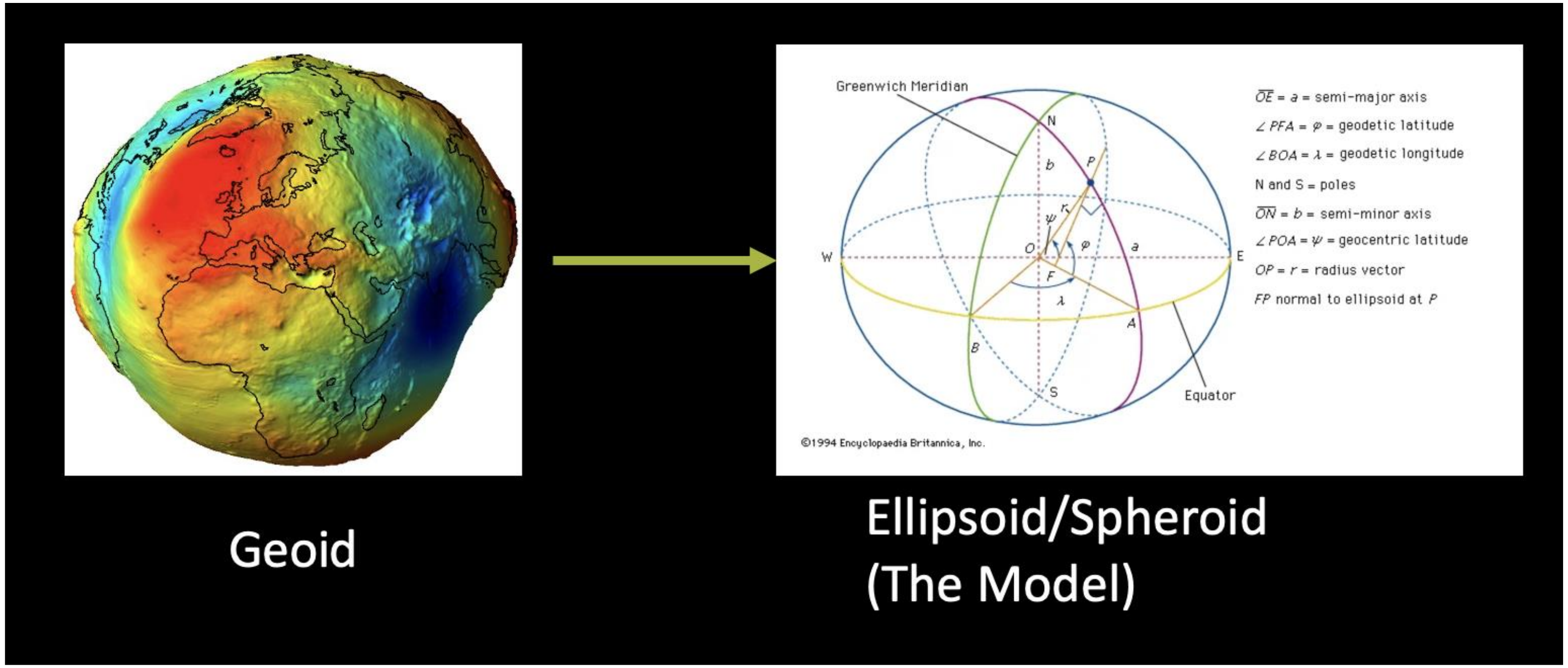
Then, what is a **spherical model?**

Creating a model of the Earth: spheroids and ellipsoids

From the lumpy earth to the model

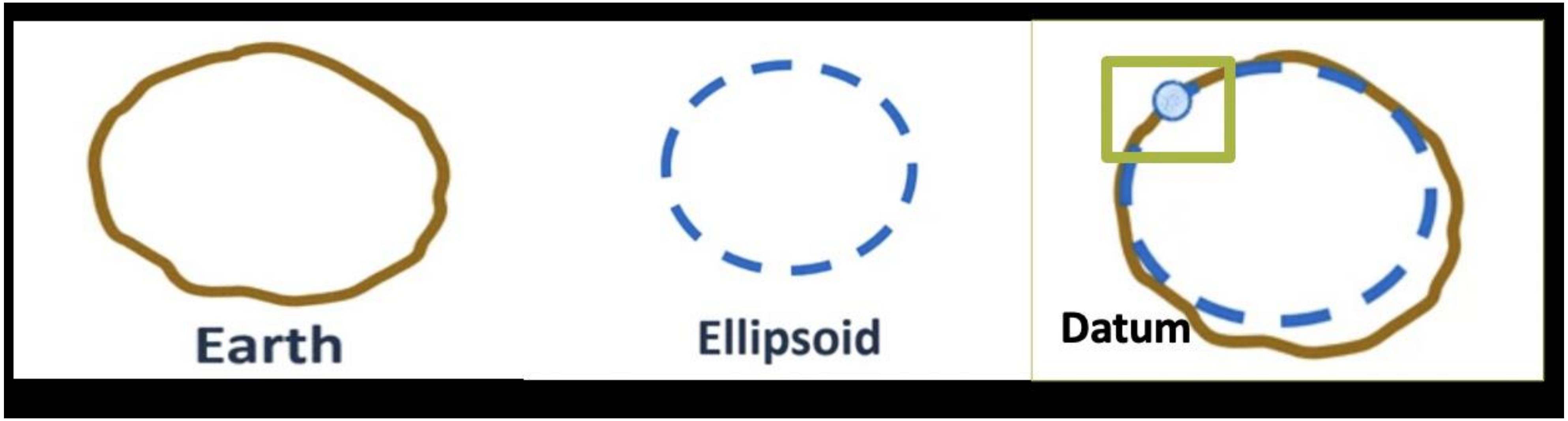


- Our earth isn't FLAT, it isn't a perfect sphere as well!
- In order to create a simplified model of the earth, we use an oblate spheroid or ellipsoid (a mathematical model of the earth's surface)

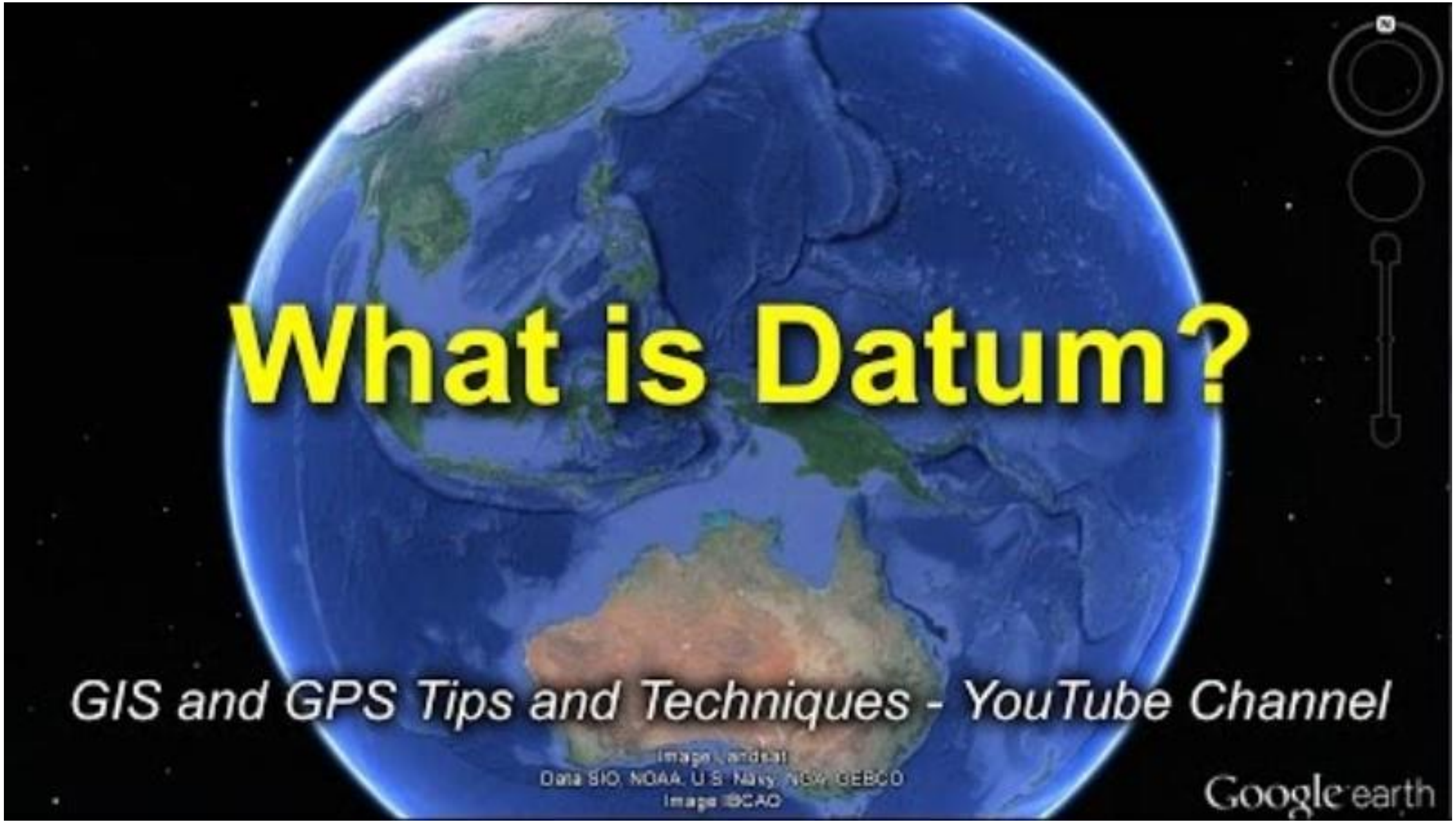


Datum

- Ellipsoid can be tailored for specific regions – match actual shape of that area.
- Datum defines the point on ellipsoid linked to point on earth (the reference point, from which all other points are calculated) and the orientation of the spheroid.
- Datum provides a frame of reference for measuring locations on the earth surface.

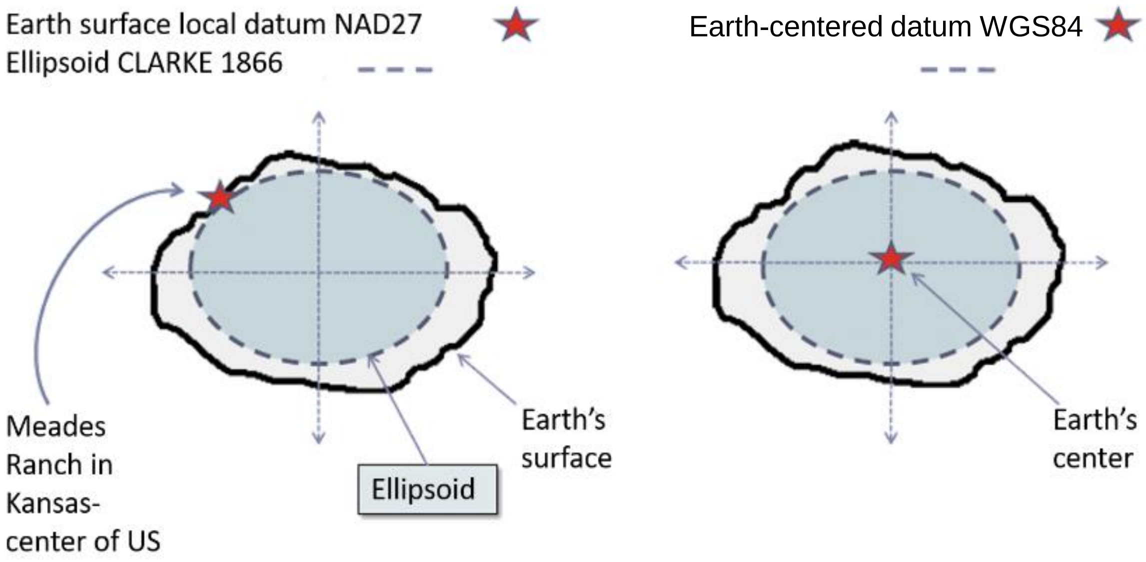


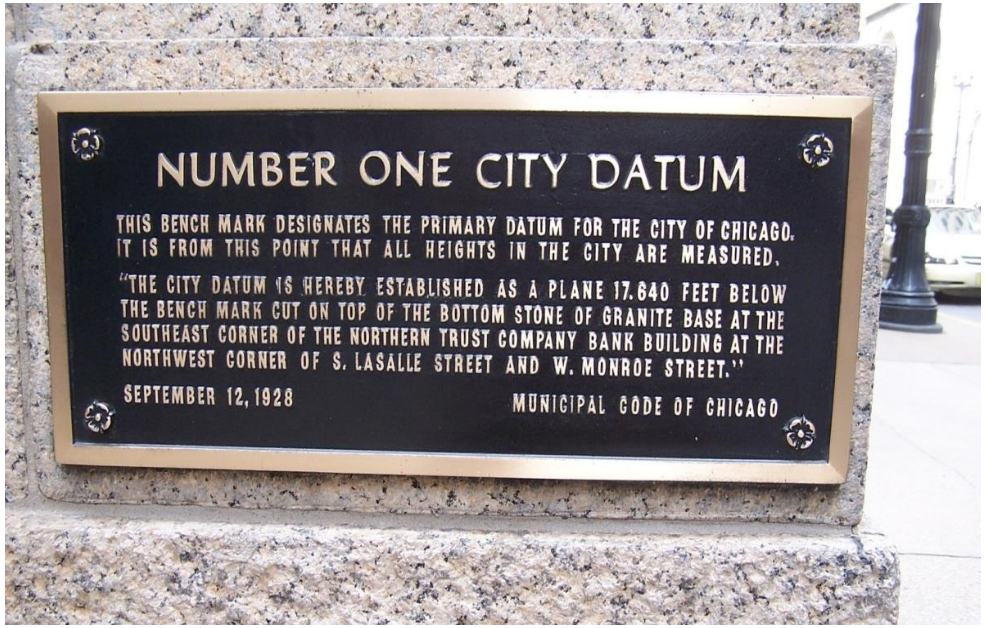
Datum


What is Datum?
GIS and GPS Tips and Techniques - YouTube Channel
Google earth

Datum

- Datum can be either a global datum (e.g., WGS84) or a local datum (e.g., NAD 83)
- Global datum usually uses the Earth's center of mass as its reference point.
- Hundreds of locally-developed reference datums around the world, usually referenced to some convenient local point





Local reference point

Some Datums to recognize:

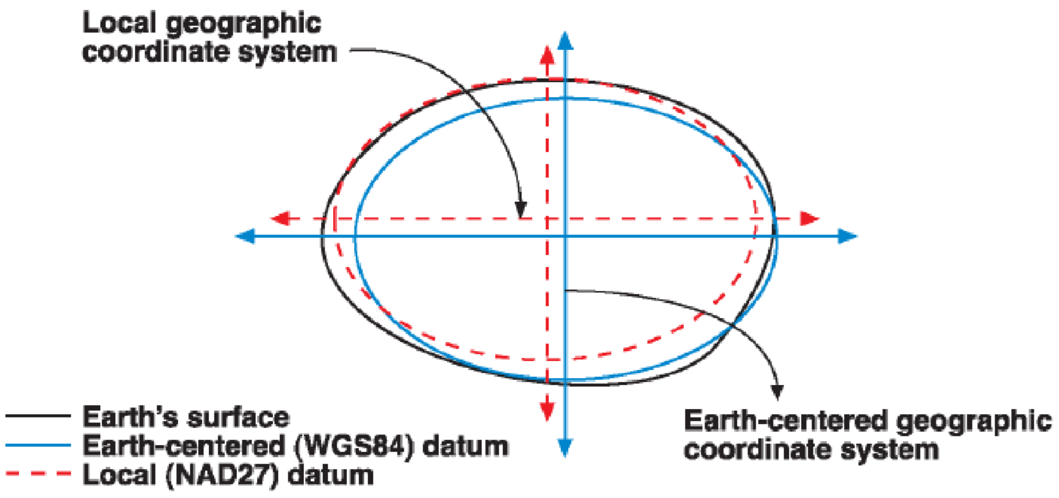
- North American Datum of 1927 (**NAD 27**): based on the Clarke spheroid of 1866 with origin at Meades Ranch in Kansas

- North American Datum of 1983 (**NAD 83**): based on the Geodetic Reference System (GRS) 1980 spheroid. Improved satellite and remote sensing technology
  - Differences with NAD27 can be as much as 200 m

- World Geodetic System of 1984 (**WGS 84**):
  - Universal datum based on center of Earth's mass; using Doppler satellite surveying techniques.
  - Almost identical to NAD83 (Compatible)
  - Only world referencing system in place today.
  - Default standard datum for coordinates stored in GPS units.

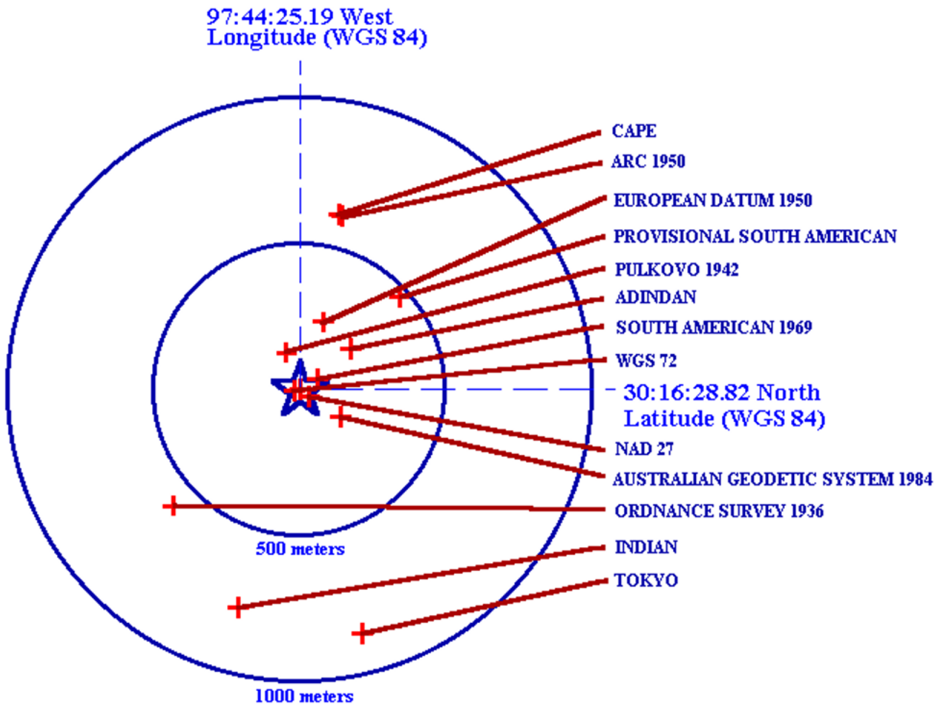
Datums

Since reference datums have different center points, a specific point on the earth can have substantially different coordinates depending on the datum used to make the measurement.



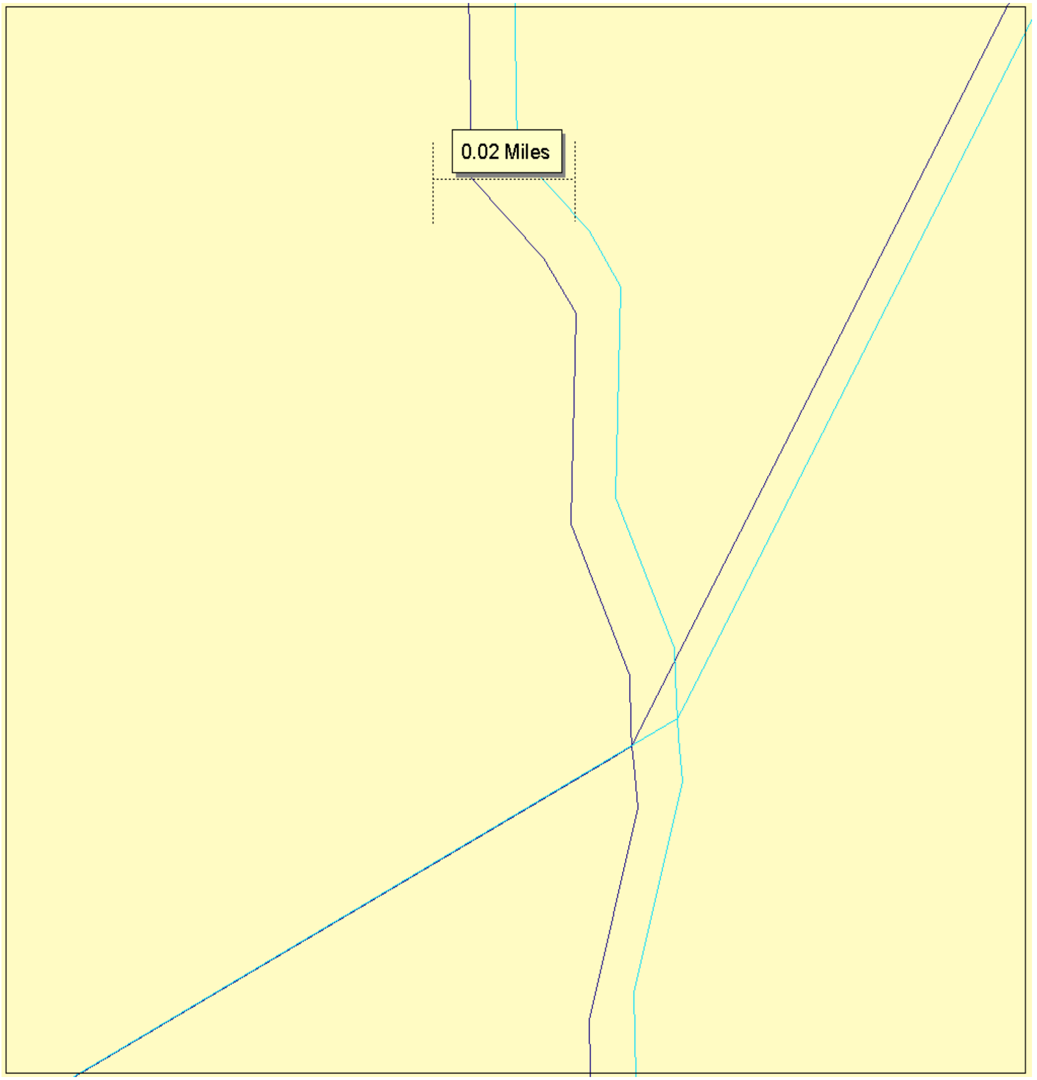
Example 1: coordinates for the city of Bellingham, Washington (the same point), using 3 different spheroids/datum

Spheroid	Datum	Longitude	Latitude
Clarke 1866	NAD 27	-122.46690368652	48.7440490722656
GRS 1980	NAD 83	-122.46818353793	48.7438798543649
WGS 1984	WGS 1984	-122.46818353793	48.7438798534299



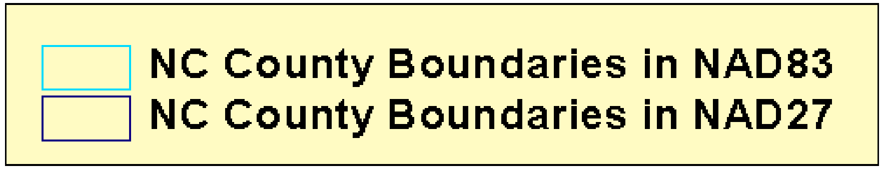
Example 2: Position shifts from Datum differences (Texas Capital Dome Horizontal Benchmark.

Datum Errors May Be Difficult to See



In this case, the boundaries are roughly 32 meters off: datum shifts are not uniform

Errors up to 1 km can result from confusing one datum for another



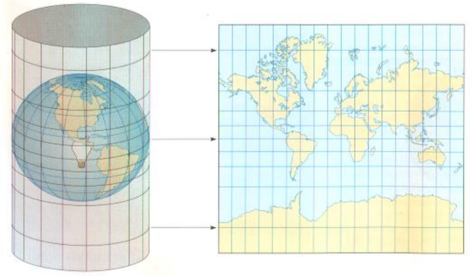
What do we need to know today? – 3 Elements

Datum (Surfaces)

- Uses a model of the Earth to define the size and shape of the planet for a Geographic locating system
- Based on a Spheroid (or Elipsoid) (to take into account Earth's true shape)

Projection (Method)

– An orderly method used to represent all or part of a 3D globe on a 2D map

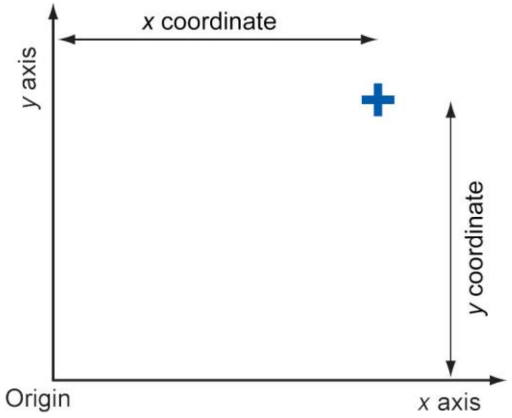


Coordinate System (Location System)

– Referencing framework superimposed on top of the projection surface so that position can be measured and estimated

– Define the origin and orientation of the coordinate systems

– **GCS and PCS**

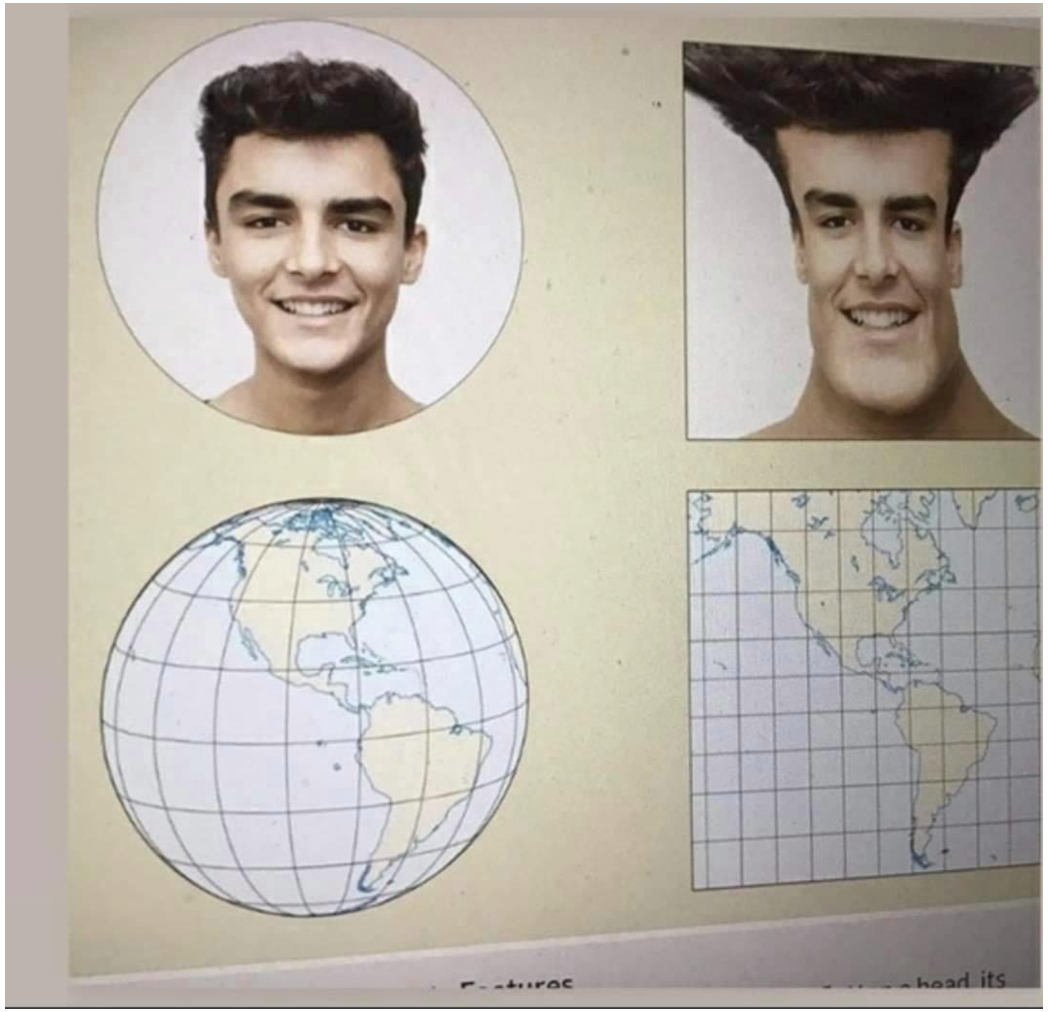


Map Projection?

a mathematical method used to represent the 3D curved surface of the Earth on a 2D flat surface.

- angular coordinates (e.g., degrees of latitude and longitude) into planar coordinates (e.g., meters, feet).

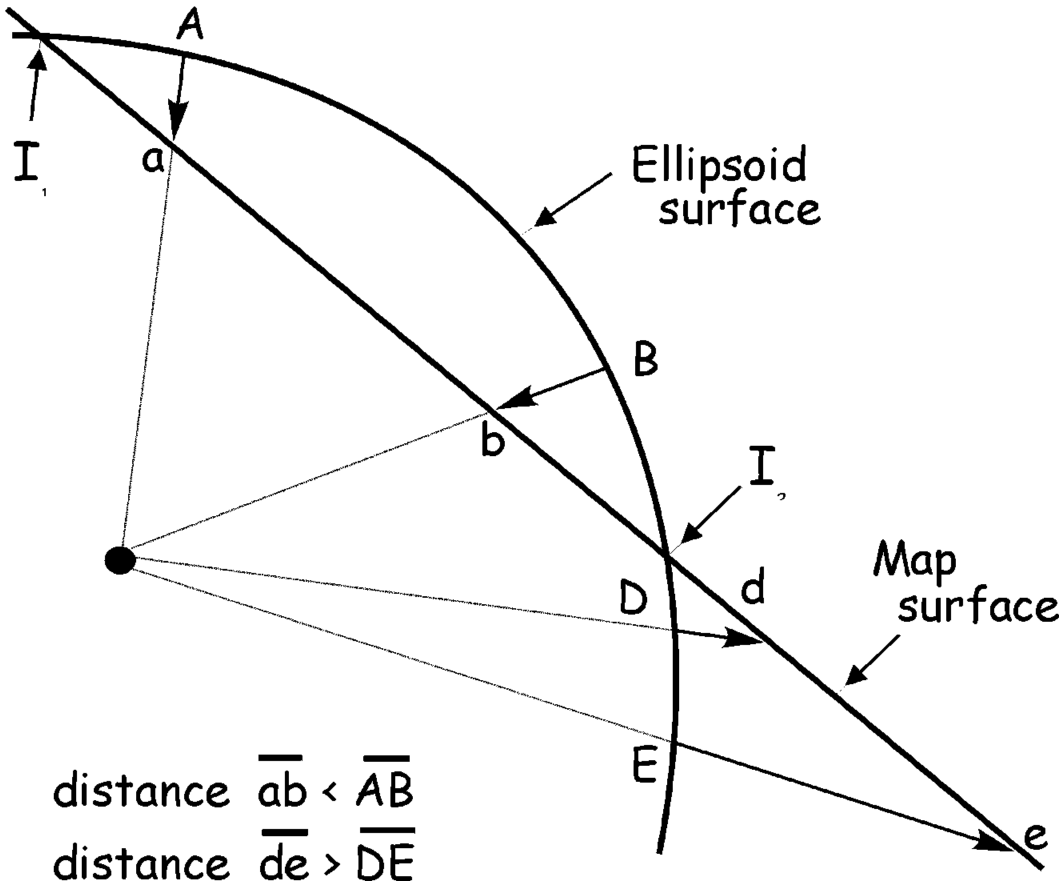
- All projections distort some combination of either the **shape, size, distance or direction** of land masses.



Map Projection – distortion

"All maps lie flat, therefore all maps lie."

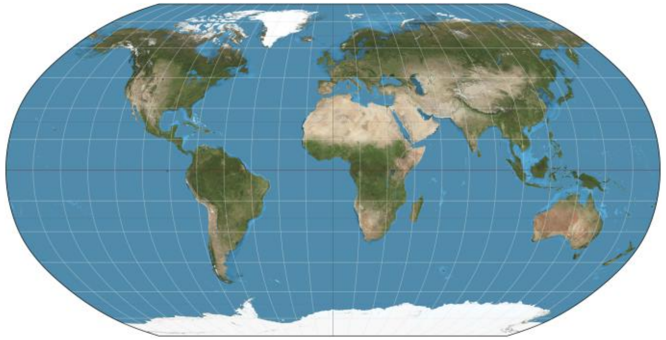
All projections distort some combination of either the **shape, size, distance or direction** of land masses.



Map Projection – distortion

- ***Shape (Conformal projections):*** attempt to represent shapes correctly, but relative sizes are off (e.g., Mercator projection)
- ***Area (Equivalent/Equal Area Projections):*** distort shapes but show areas proportional to their actual areas (e.g., Albers Equal-Area projection).
- ***Distance (Equidistant Projections):*** preserve distances and are good for length and perimeter measurements (e.g., Equidistant Conic projection).
- ***Direction* (Azimuthal projections): p**reserve directions from a central point, but distorting distance and shape elsewhere.

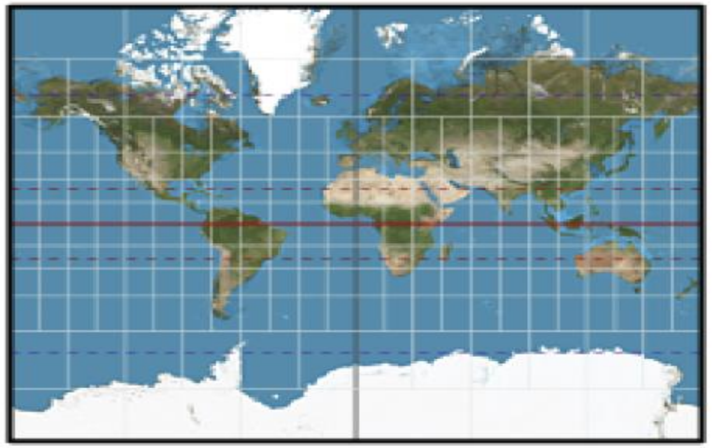
Compromise: does not preserve either areas or angles, but finds a compromise between the two, typically to present a more aesthetically pleasing map while reducing excessive distortion (e.g., Robinson projection).

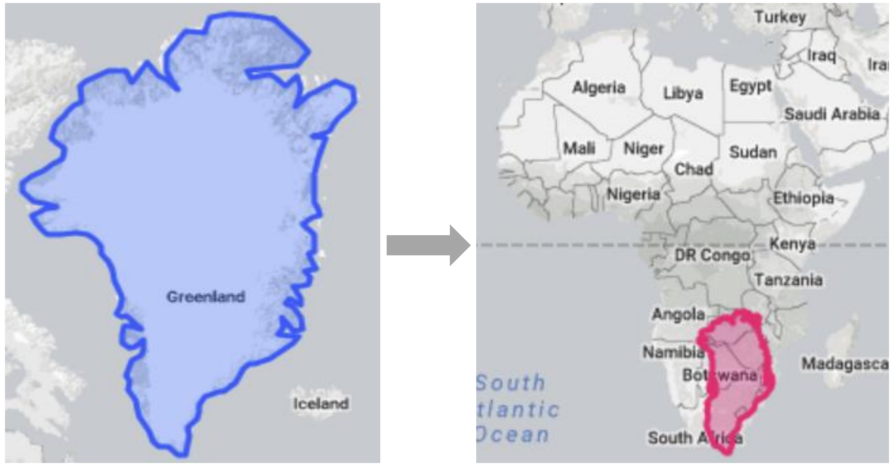


Robinson projection

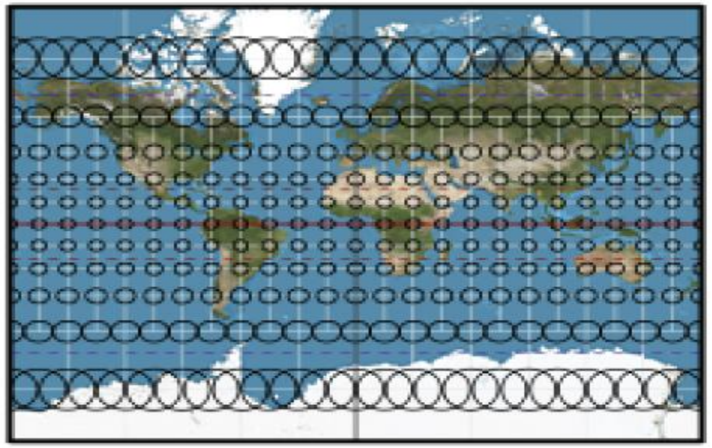
Map Projection – distortion

Shape (Conformal projections) - e.g., Mercator projection (Preserves true shape - exaggerates areas)

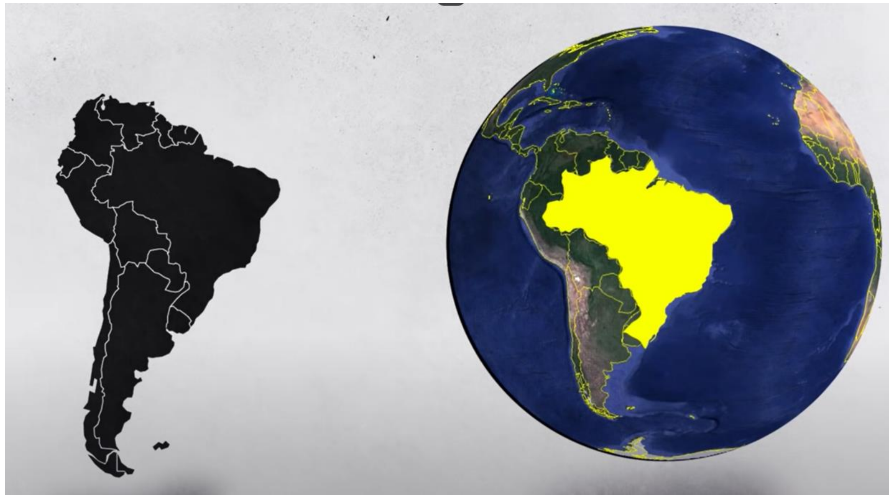




Greenland is portrayed as being larger than Africa, or Australia.



The Mercator projection with Tissot's indicatrix of deformation.



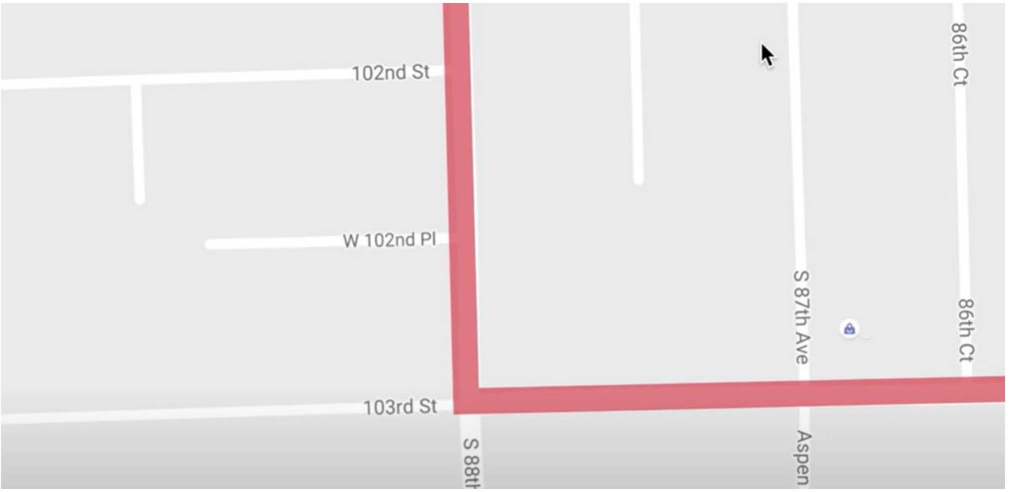
the shape is right!

Map Projection – distortion

Shape (Conformal projections) - e.g., Mercator projection

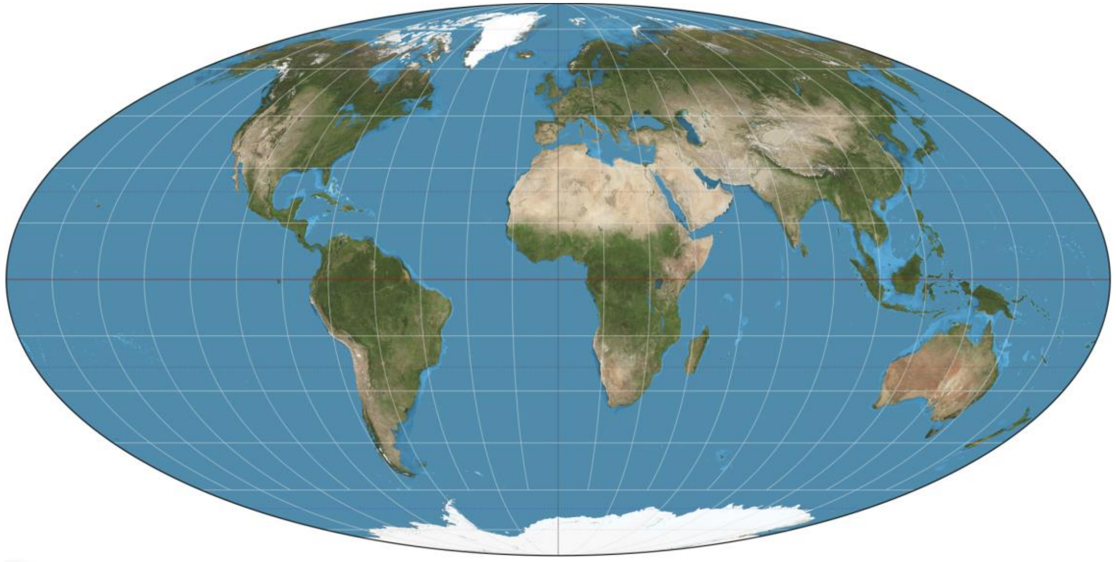
special purpose projection, intended as a navigational tool.

- Any straight line drawn on this projection represents an actual compass bearing,
- and generally do not describe the shortest distance between points.
- many navigation Apps use Mercator projection because Mercator's ability to preserve shape and angles - a 90 degree left turn on the map is a 90 degree

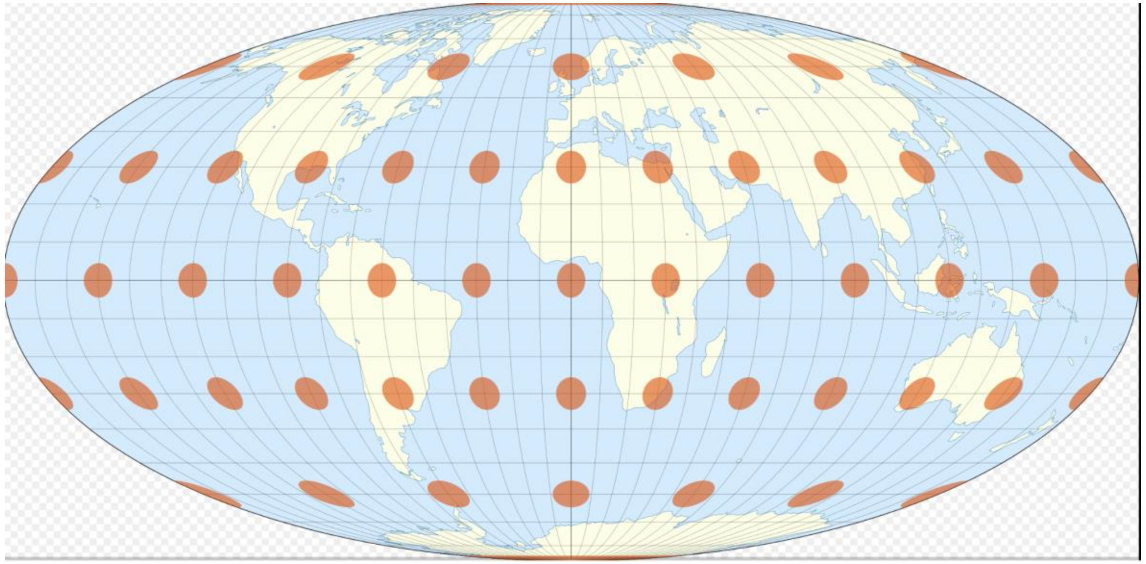


Map Projection – distortion

Area (Equal Area Projections) - Shows true size - squishes or stretches shapes



Mollweide projection of the world

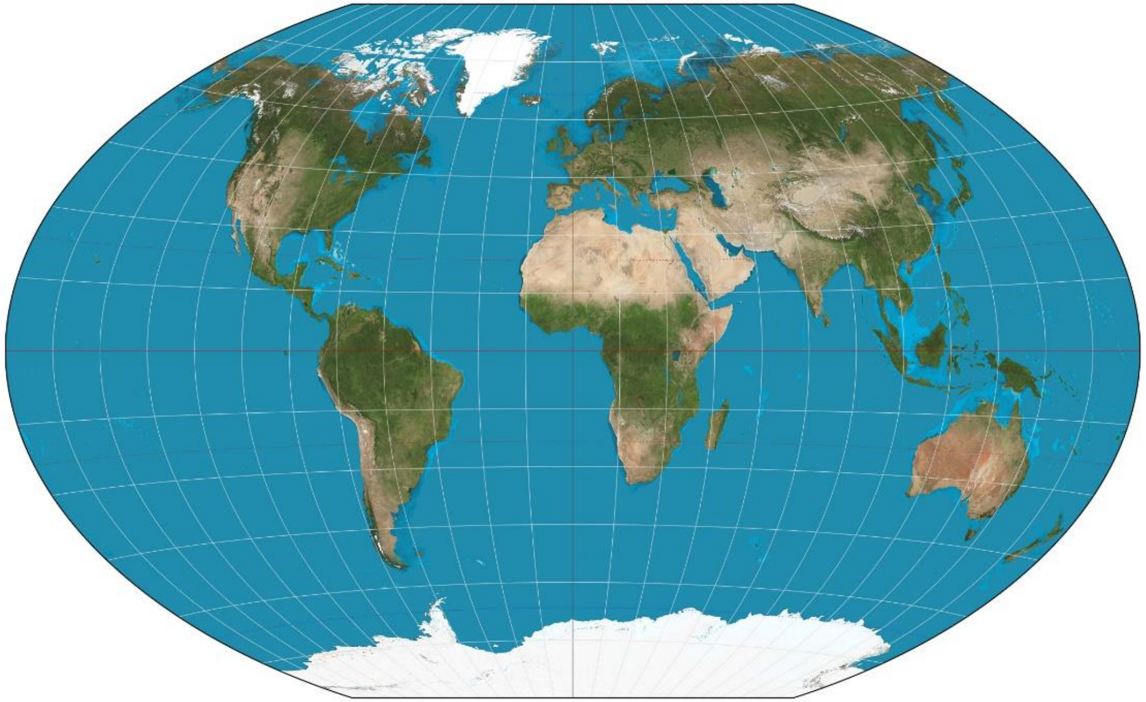


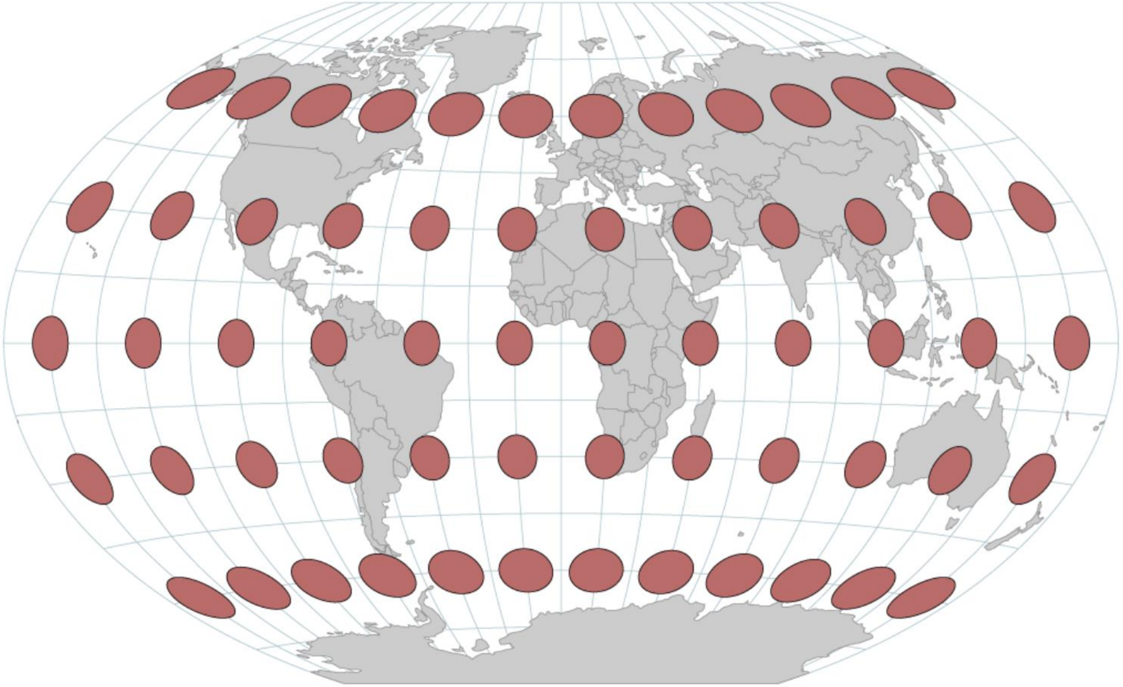
The Mollweide projection with Tissot's indicatrix of deformation

Source: Daniel Huffman, 2010

Map Projection – distortion

compromise projection



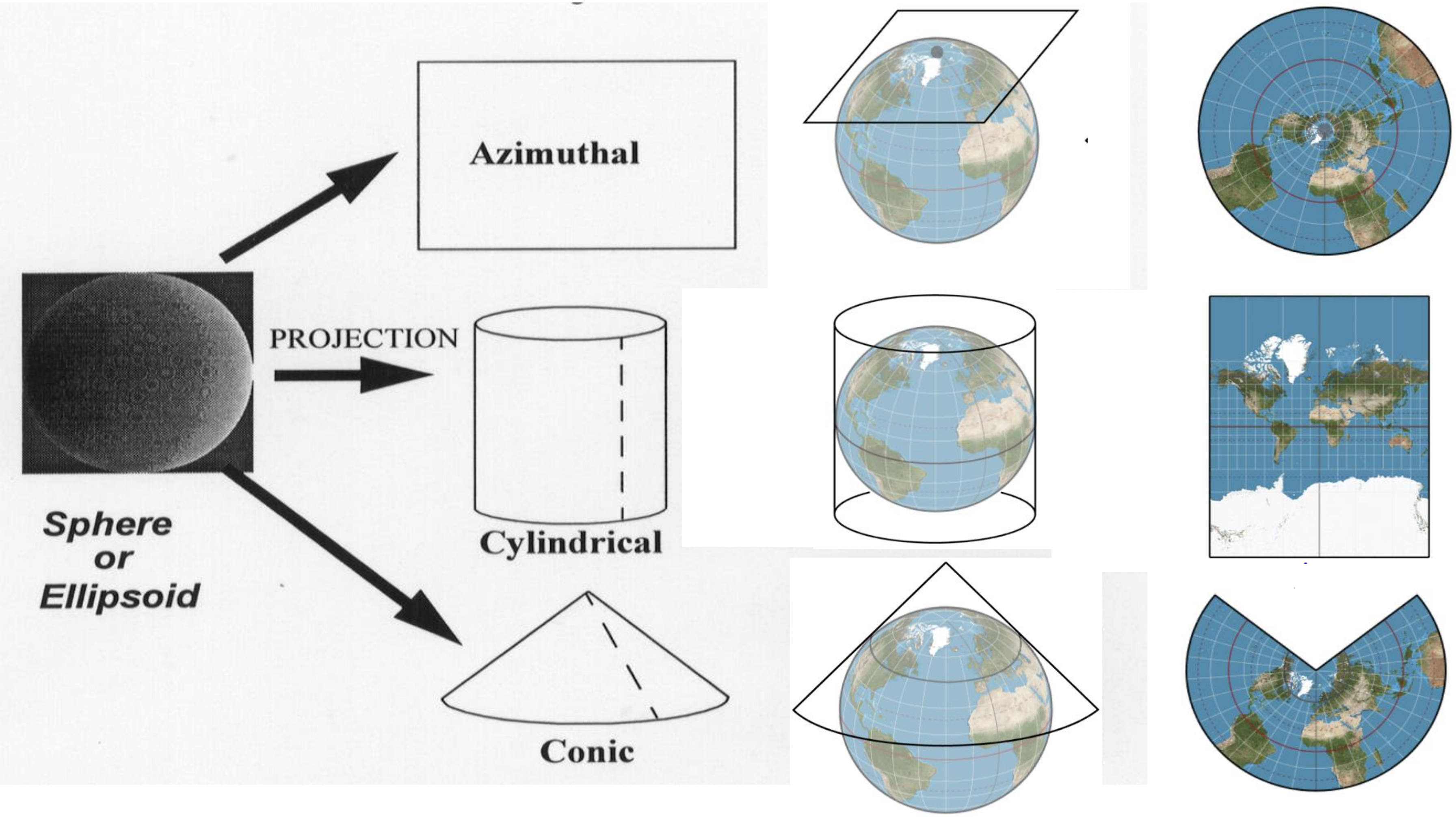


The Winkel Triple projection, which is so-called because it aims to minimize three kinds of distortion: area, direction and distance

Source: Daniel Huffman, 2010

Common Types of Projections

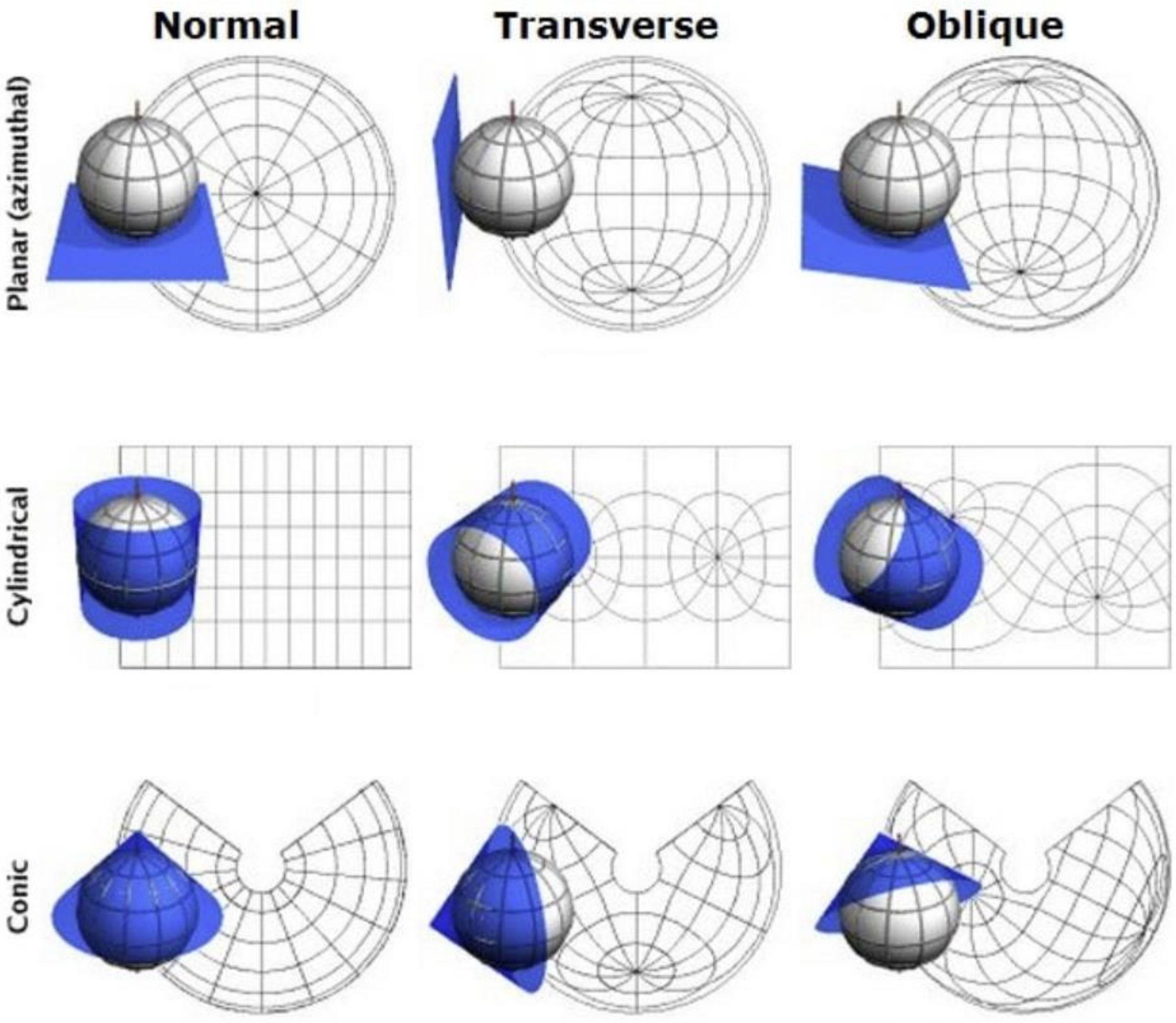
- **Azimuthal (Planar):** uses a flat plane
- **Conic**: uses a cone
- **Cylindrical:** uses a cylinder



Projection orientation/Aspect

- Aspect refers to the orientation of the projection surface (i.e., a cylinder, cone, or plane) to the reference globe.
    - Aspect also impacts where distortion is on the map.

- Three major types:
    - **Normal:** Aligned with the equator (e.g., Mercator).
    - **Transverse:** Rotated 90 degrees to align with a meridian (e.g., Transverse Mercator).
    - **Oblique:** Tilted at an angle between the equator and meridians.



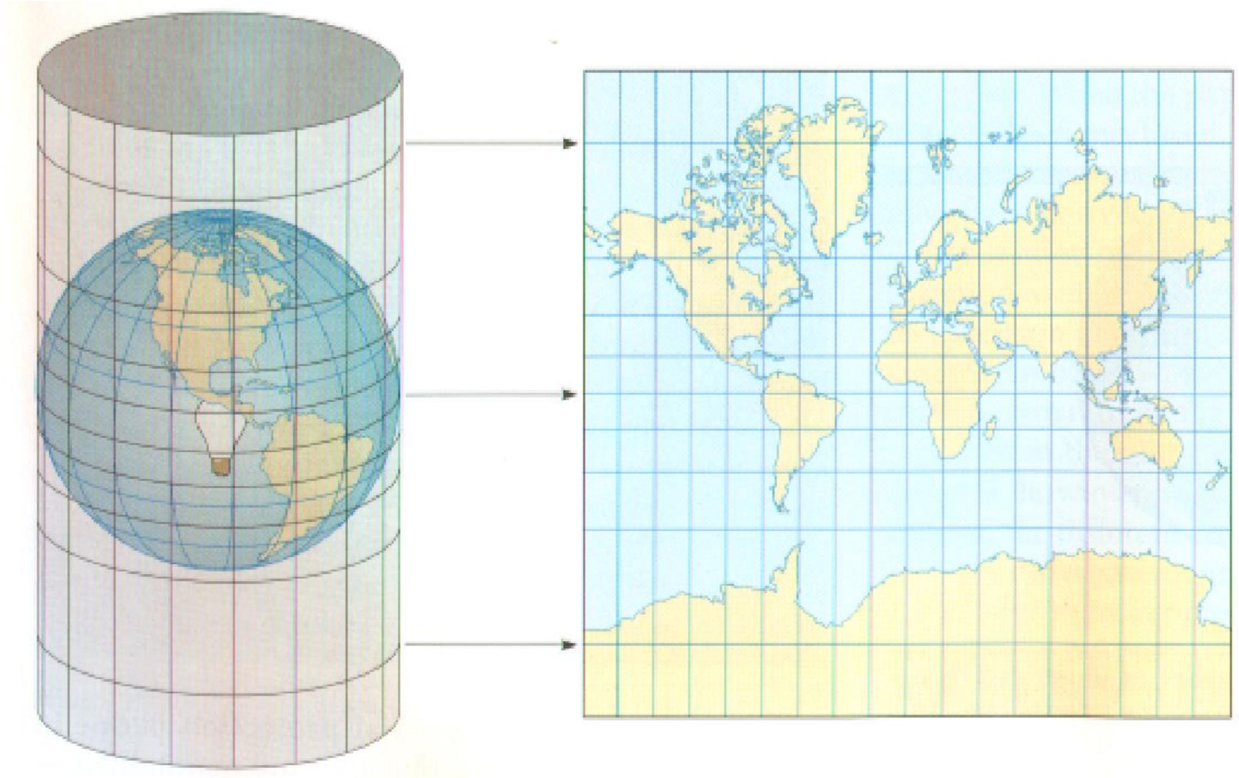
Projection aspects for all the developable surfaces. Source: Furuti, 2002

Cylindrical Projections - if in Normal aspect

-Globe is projected onto a cylinder tangent at equator. Low distortion at equator – more approaching poles

- Conformal, displays true direction along straight lines – good for navigation. Web mapping service uses it.

A good choice for use in equatorial and tropical regions



Conic Projections

- Surface of globe projected onto cone tangent at standard parallel (typically for normal aspect)
- Many conical projections are conformal (preserves local angles and shapes, e.g., Lambert Conformal Conic); non-conformal: Albers Equal-Area Conic.
- Normally shows just one semi-hemisphere in middle latitudes; very popular for maps of E-W oriented land masses (i.e., the conterminous United States, a.k.a., “the lower 48”

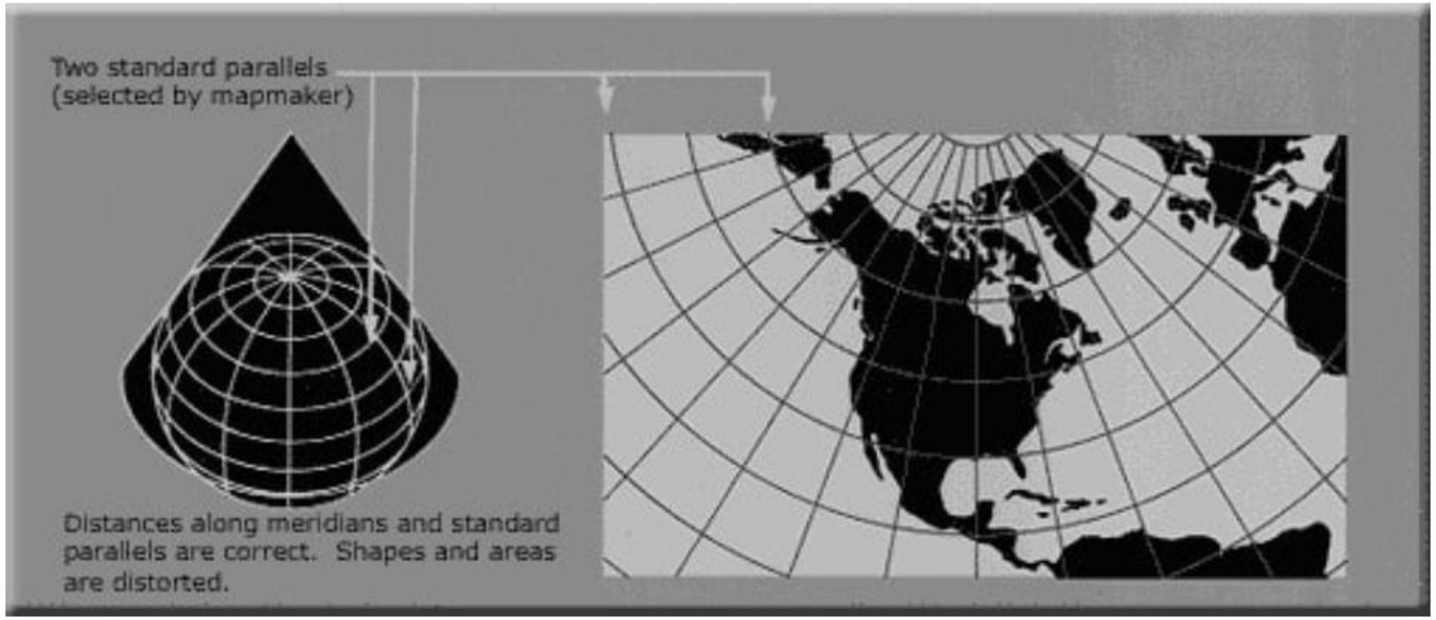
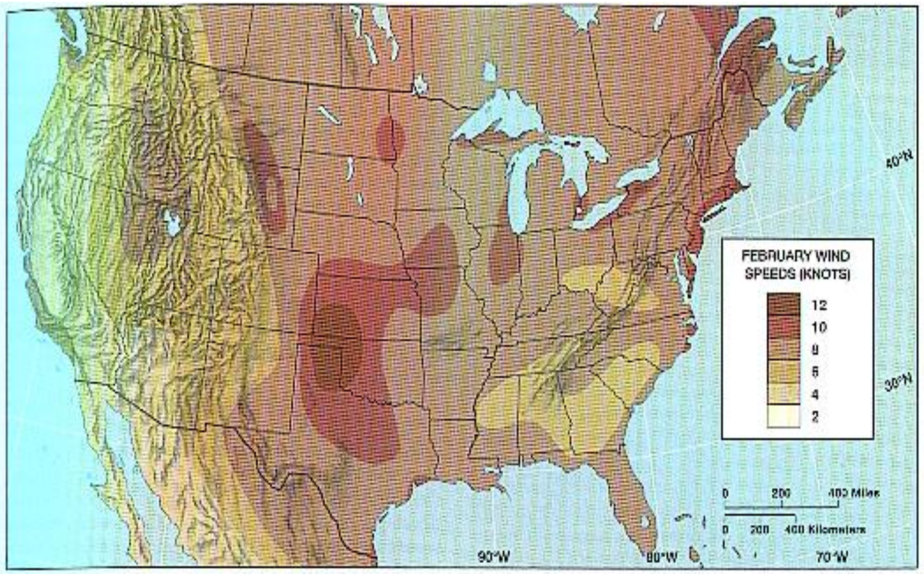


Figure 32. Source: USGS



Azimuthal (Planar or Polar) Projections

- Surface of globe is projected onto a plane tangent at only one point (usually N or S pole - Usually only one hemisphere shown).
- Preserve the direction from a single point.
- Works well to highlight specific area (i.e. airport) - Shows true bearing (direction) and distance to other points from center - the shortest distance from the center to any other point on the map is a straight line

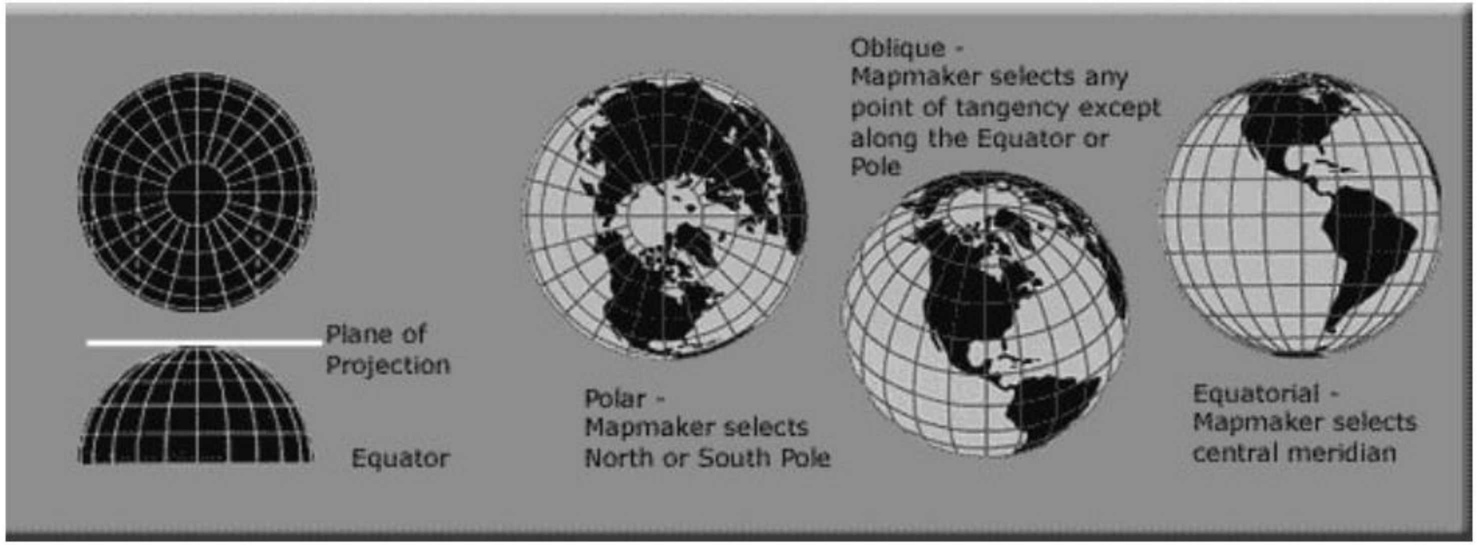


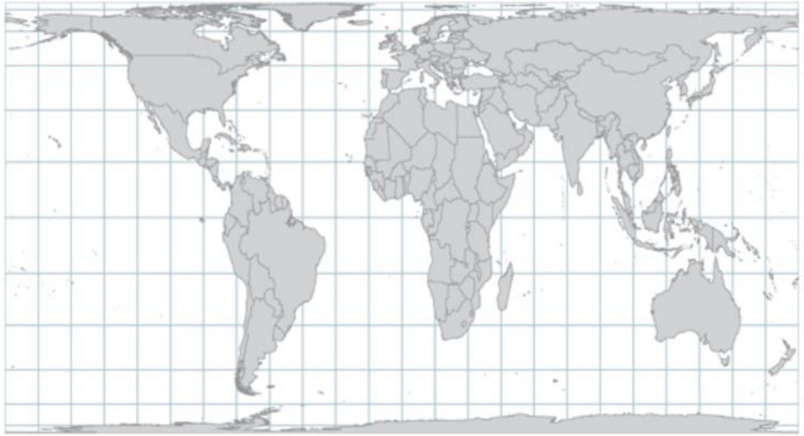
Figure 11. Planar projections explained. Source: USGS

Map Projection – which one to choose?

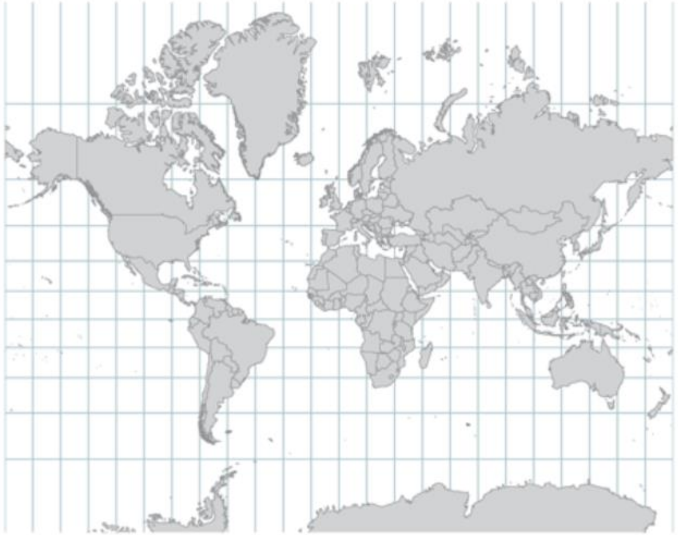
- a debate for decades about the need to only use equivalent/equal area to reduce the biased view - mid-latitude countries are more important than equatorial ones…

- different projections serve different purposes…no right or wring, no better or worse…

- what properties are critical to preserve (e.g., area equivalence) at the expense of others (e.g., conformality), while still considering the overall aesthetics.



Cylindrical Equal-Area



Mercator