GE2215 Lecture 5
Spatial Reference and Coordinate Systems

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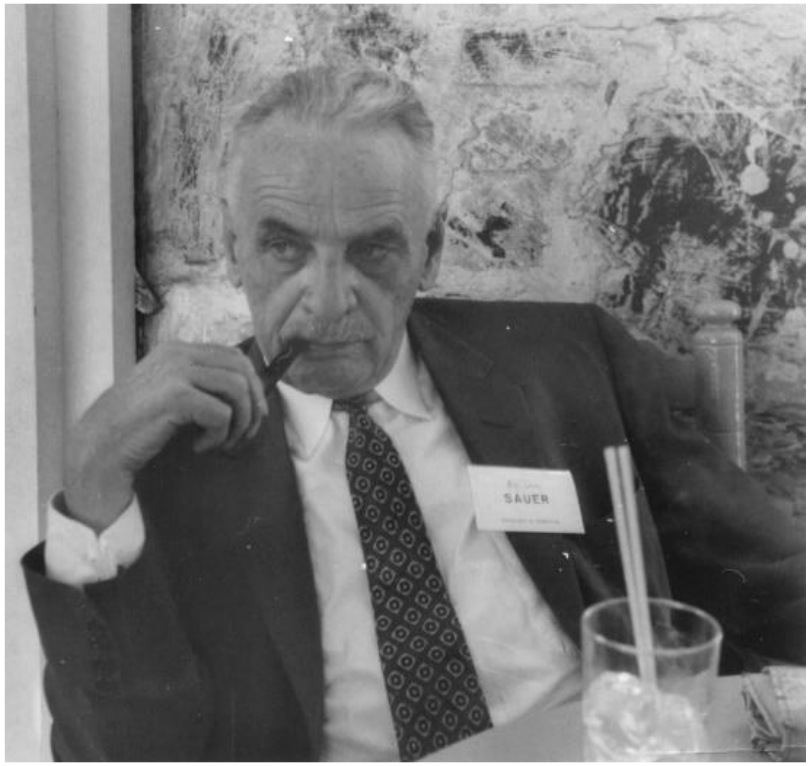
Recap: What is map?

- “The map speaks across the barriers of language. it is sometimes claimed as the language of geography.”

Sauer, 1956



- A visual tool, geography language, effective in communicating geospatial data

Recap: Types of maps

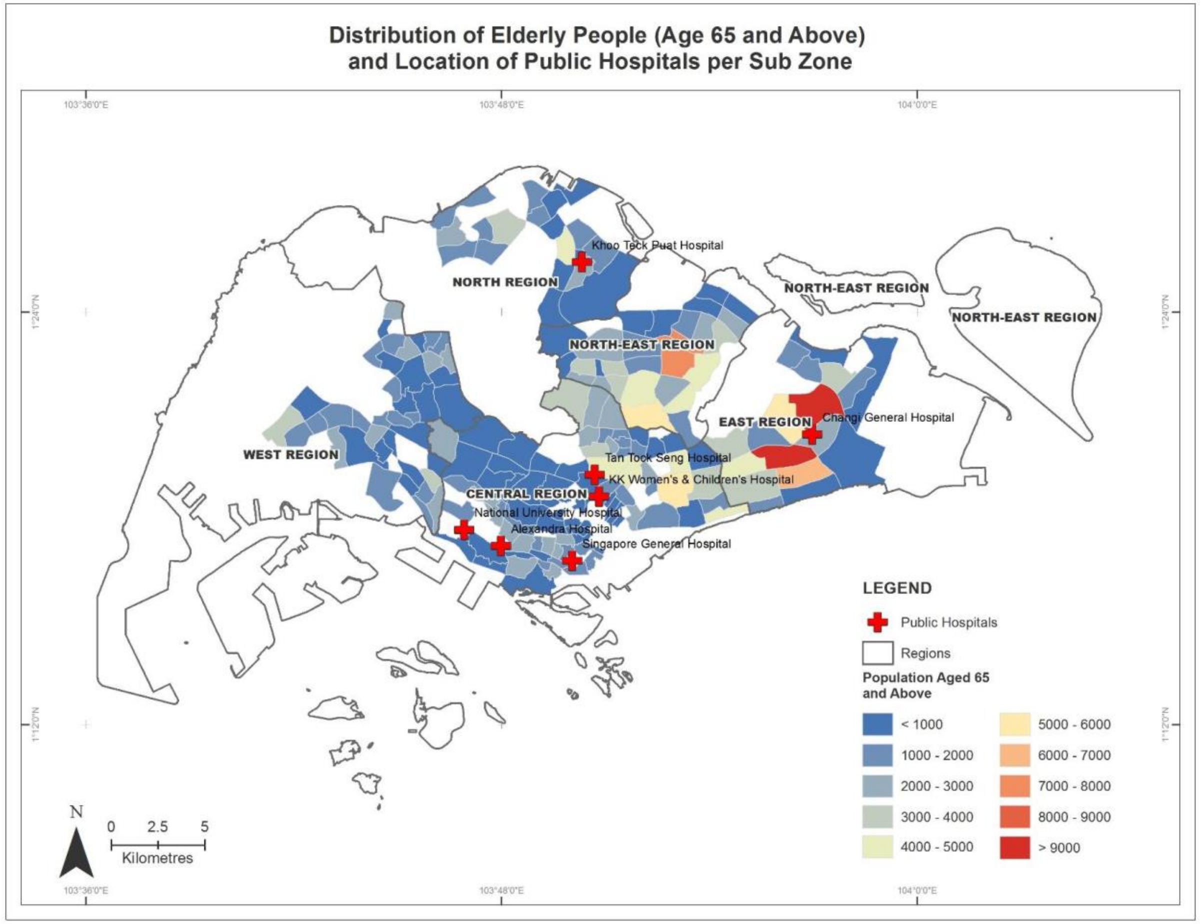
- Based on different classification strategies, cartographers classify maps into:
  - **General reference** or **thematic**
  - **Qualitative** or **quantitative**
- Common types of quantitative maps
  - Dot map
  - Choropleth map
  - Graduated symbol map
  - Pie chart map
  - Flow map
  - Isarithmic map

Recap: Classifying features

- The derived data are often required to be classified prior to mapping, e.g., the choropleth map, the graduated symbol map
- Two parameters for classifying features
  - Number of classes
  - Value ranges of those classes
- Six common methods for classification
  - Equal intervals
  - Natural breaks
  - Quantile
  - Mean standard deviation
  - Maximum breaks
  - Optimal
    - Jenks-Caspall
    - Fisher-Jenks

Recap: Map elements

- Title and subtitle
- Legend
- Mapped area
- Frame line and neat line
- Scale
- Orientation
- Graticule (grid)
- Inset
- Data source



(**Source**: ERICKSON CASILES LANUZA

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Recap: Principles of map design

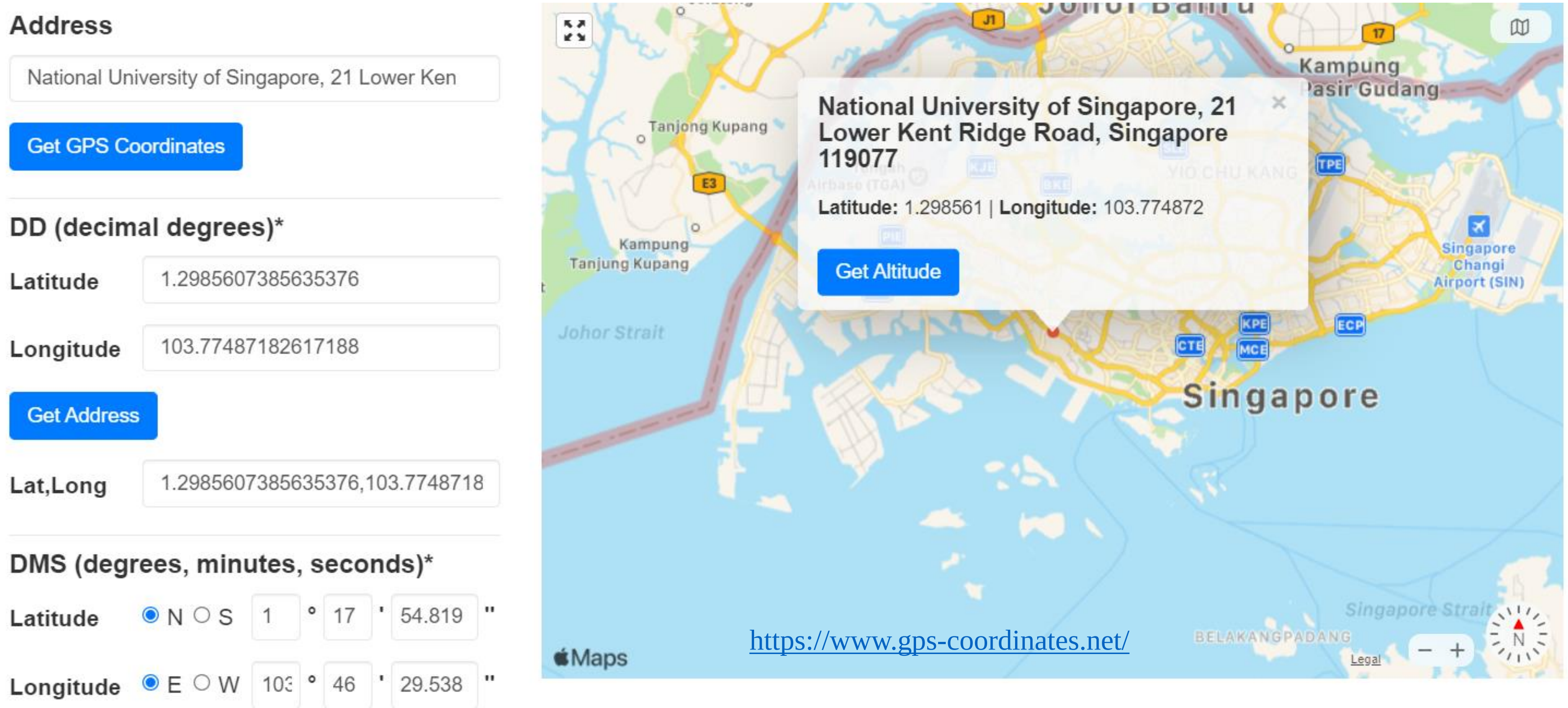
- There are no right or wrong design, but there are better or worse maps.
- A good design makes map more **effective**, **interpretable** and **understandable**, and communicates the correct message.
- Characteristics of a good map:
  - Simplicity
  - Balance
  - Contrast

Outlines of this lecture

- **Why coordinate systems matter?**
- Geographic coordinate systems
- Map projections
- Projected coordinate systems
- Spatial coordinate transformation

Why does coordinate systems matter?

- An example: what is the location of NUS?
  - The location of NUS is (103°46’30”, 1°17’55”)
  - The location of NUS is (21094 m, 30930 m)



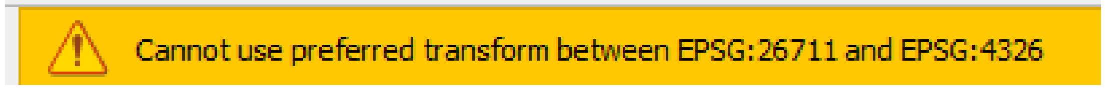
https://www.gps-coordinates.net/

Why does coordinate systems matter?

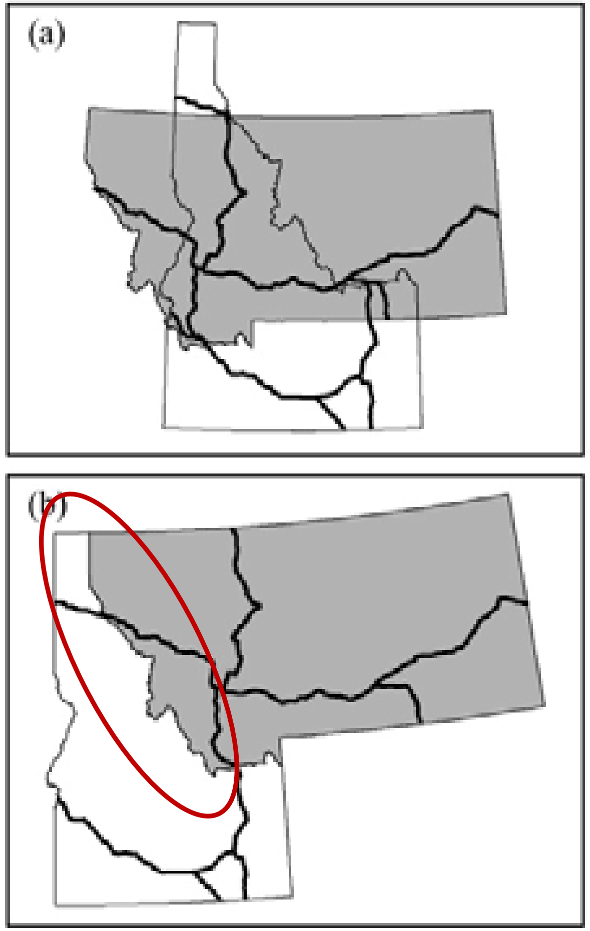
- Why a location is sometimes measured in longitude and latitude values, while sometimes it is measured in meters?
  - Different coordinate systems are used
- What is the coordinate system that uses longitude and latitude?
- What is the coordinate system that uses coordinates in meters?

Why does coordinate systems matter?

- It is used for:
  - Talking about locations and spatial measurements
  - Creating a new set of spatial data (e.g., point layers from GPS data)
  - Acquiring spatial data from other data sources (e.g., an existing geodatabase)
  - Overlaying/Displaying two or more map layers. They are not going to register spatially unless they are based on the same coordinate system



Why does coordinate systems matter?

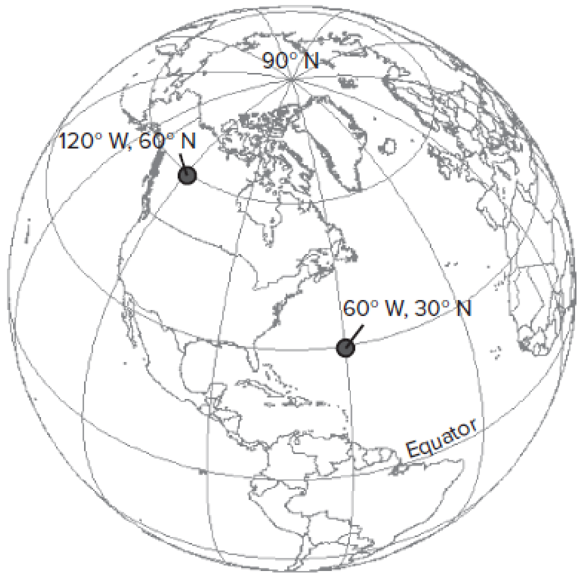


- Interstate highways in Idaho and Montana based on different coordinate systems

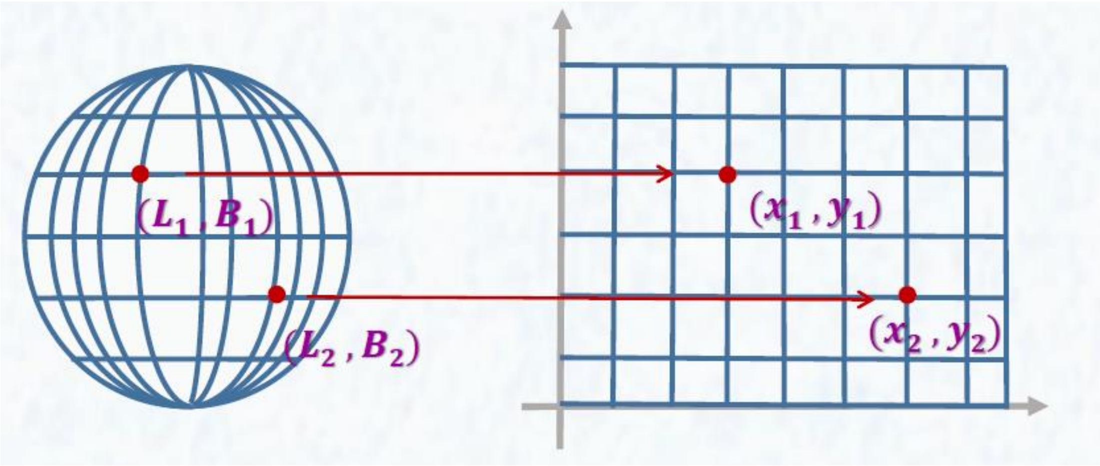
- Interstate highways in Idaho and Montana based on the same coordinate systems

Coordinate systems

- What is the location of NUS?
  - The location of NUS is (103°46’30”, 1°17’55”)
  - The location of NUS is (21094 m, 30930 m)
- There are two type of coordinate systems
  - Geographic Coordinate Systems (GCS)
  - Projected Coordinate Systems (PCS)



GCS is a **spherical** coordinate system



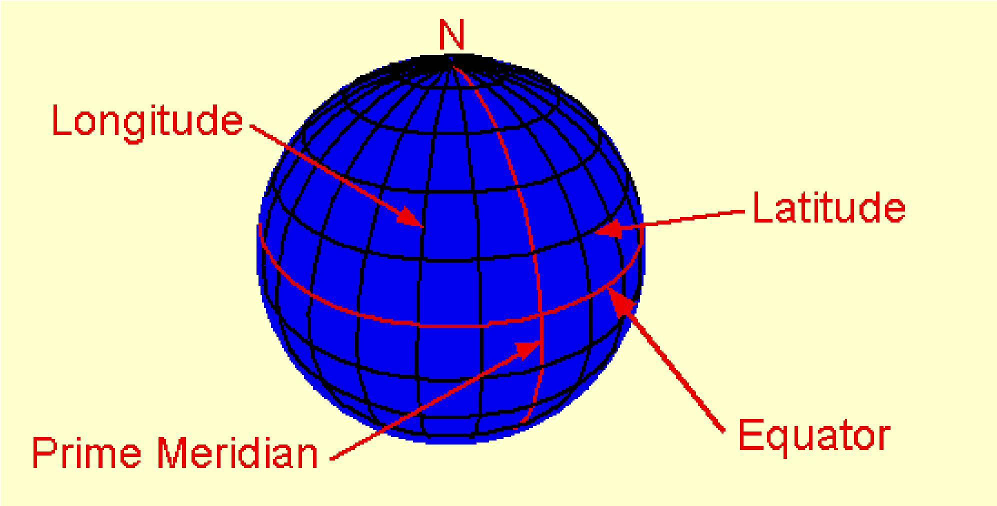
- PCS is a **plane** coordinate system. We have to transform the earth surface onto a plane first
- Projection is needed

Outlines of this lecture

- Why coordinate systems matter?
- **Geographic coordinate systems**
- Map projections
- Projected coordinate systems
- Spatial coordinate transformation

Geographic Coordinate Systems

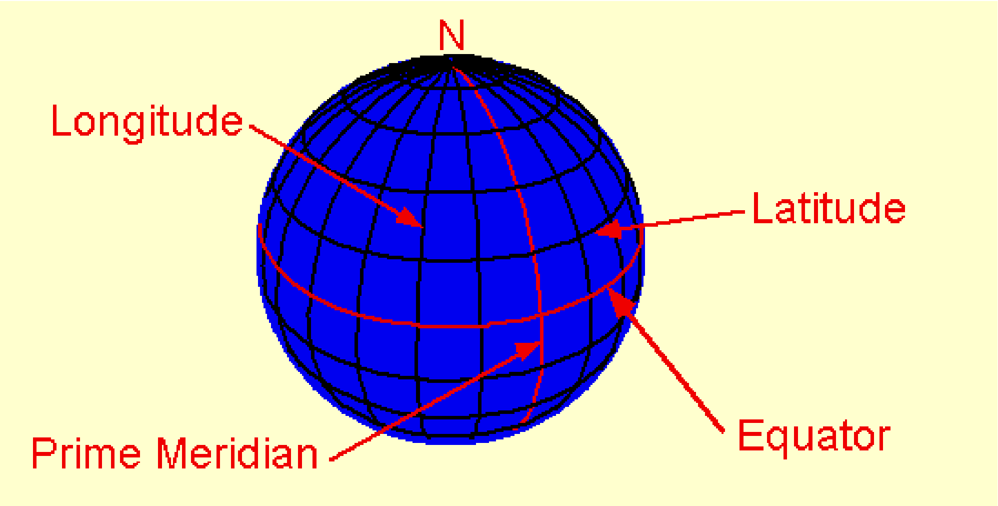
- The geographic coordinate system is defined by longitude and latitude, both of which are angular measures.
- Latitude measures the angular distance north or south of the Equator



- The Equator is 0 degree
- The latitude range is [-90, 90], where a negative value means the measured point is in the south of the Equator
- **Parallels** are lines of equal latitude

Geographic Coordinate Systems

- Longitude is the angular distance measured west and east of the Prime Meridian (which has been set arbitrarily at Greenwich, England)
- The Prime Meridian is 0-degree longitude
- **Meridians** are lines of equal longitude



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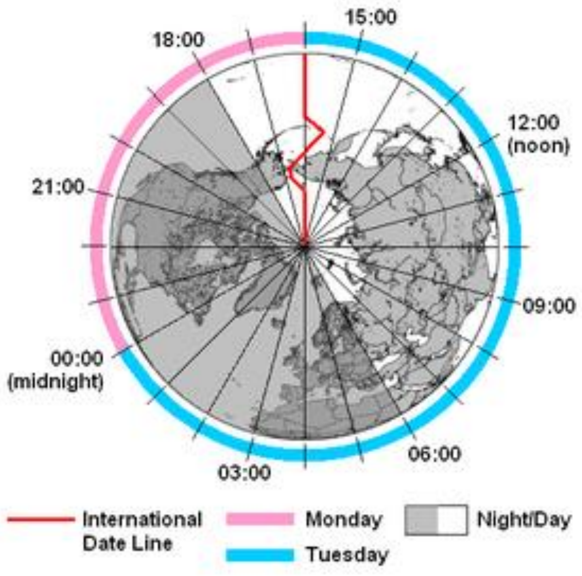
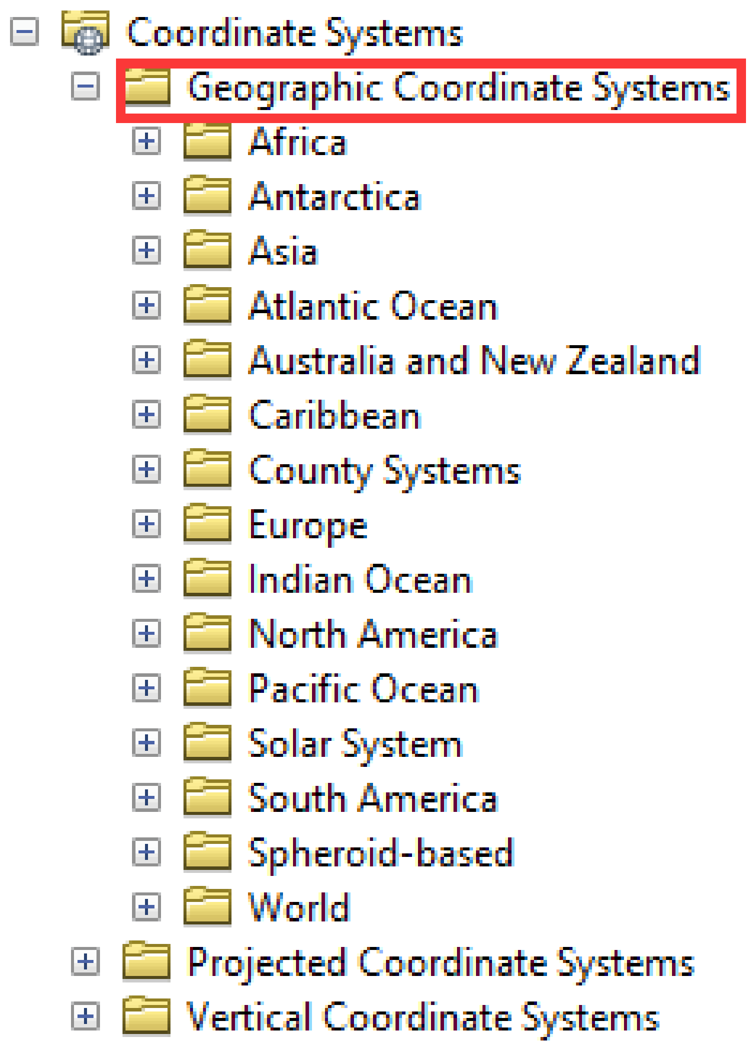
Geographic Coordinate Systems

- The longitude range is [-180, 180], where a negative value means the measured point is in the west of the Prime Meridian
- The international date line roughly follows the 180-degree meridian



Why are there different GCSs?

- In a GIS software, for example ArcGIS, there are usually a large number of Geographic Coordinate Systems for us to choose from, why?
  - To answer this question, we need to figure out the shape of earth first.
  - So, what is the real shape of the earth??
    - A sphere?
    - An ellipsoid?

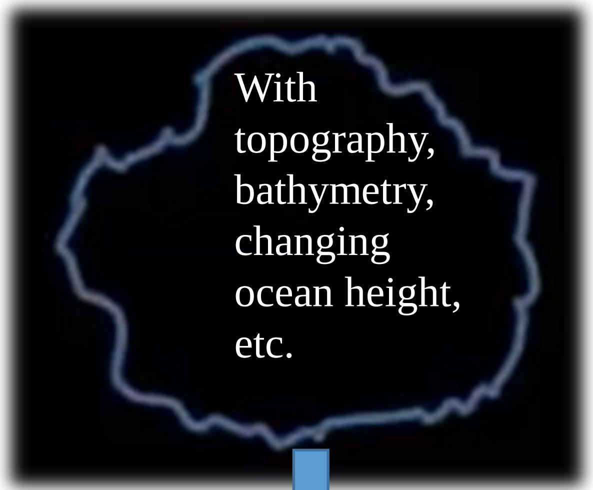


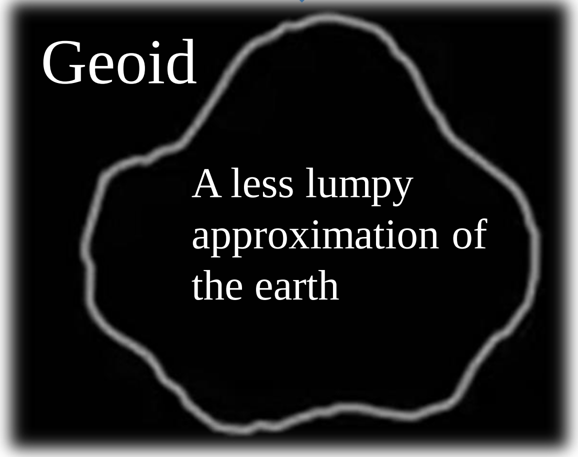

What is the real shape of the earth?
1
2
3

What shape is the earth?

A sphere

The real shape

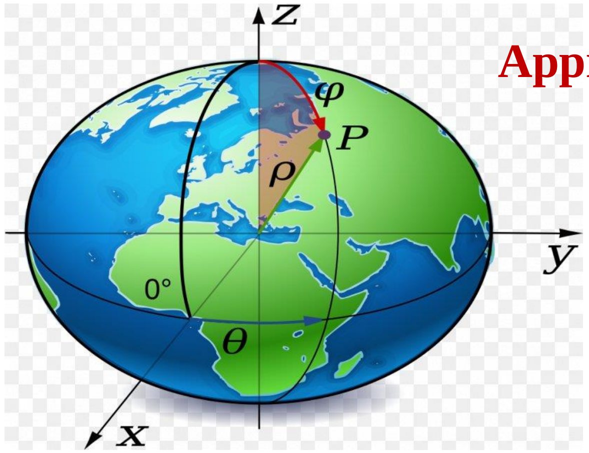




Approximated by

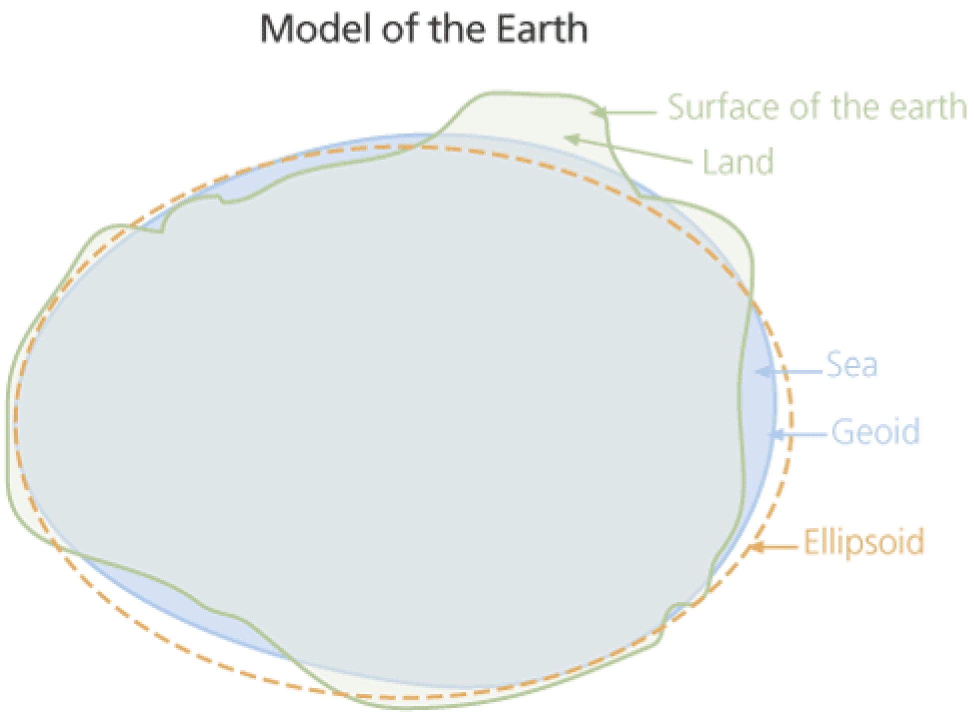
An ellipsoid: a clean mathematical object

A way of assigning a set of coordinates to locations



 https://www.youtube.com/watch?v=Z41Dt7_R180&t=98s

Model of the earth



(Source: ESRI)

- **Surface of the earth**: is very rough with mountains, basins and canyons. (**Irregular** and difficult to be represented by mathematical models)

Simplification ⬇

- **Geoid**: extends the **mean sea surface** to the land and form a continuous, closed and curved surface (**irregular** but **unique**)

Approximation ⬇

- **Earth ellipsoid**: approximates the geoid, and represent the shape and size of the real earth (**regular** and can be represented by mathematical models, **not unique**)

Model of the earth

- A large number of earth ellipsoids have been estimated

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

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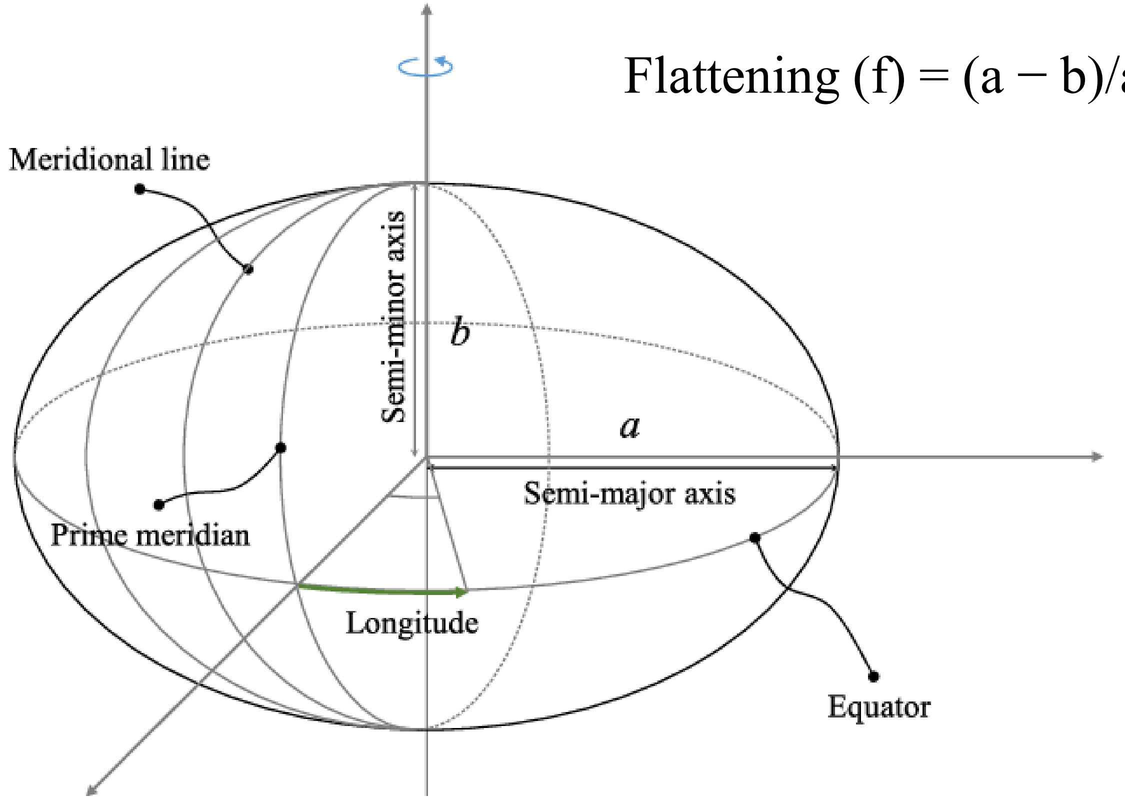
- Length of the major and minor axis
  - –Determines the shape of the earth model
- Orientation of the ellipsoid
  - –Determines the orientation of the earth model

Flattening (f) = (a − b)/a



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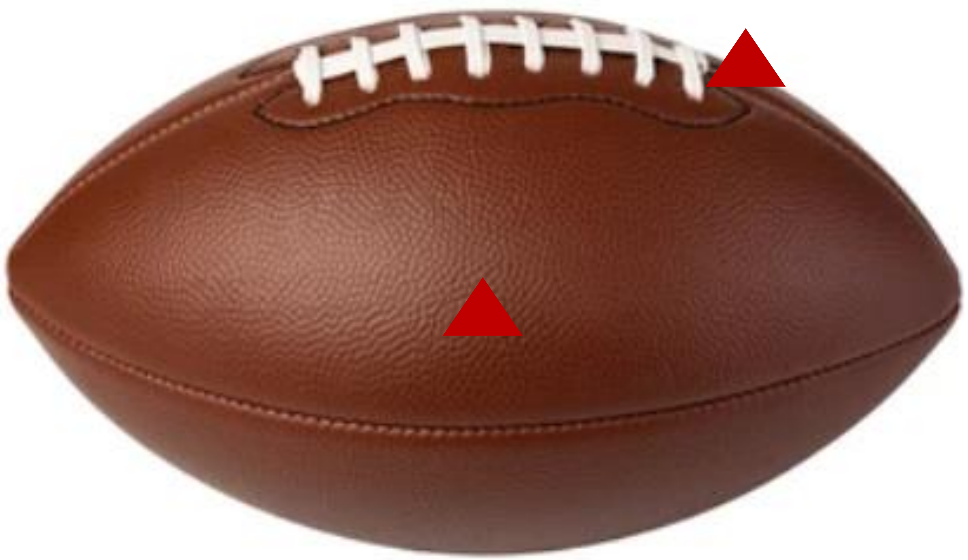
Datum

- With **parameters** of the ellipsoid, the **shape** of the earth is identified. But the **location** of the earth is not confirmed yet. An origin point is needed:
  - Origin point is on the **surface** of the local area (Local datum)
  - Origin point is at the **center** of earth (Geocentric datum)



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Datum

- The ellipsoid with the earth parameters and the origin is often called the **reference ellipsoid** or **datum**
- A **datum** is a mathematical model of the Earth, that is the reference for calculating geographic coordinates.

A datum = an ellipsoid + an origin

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Datum

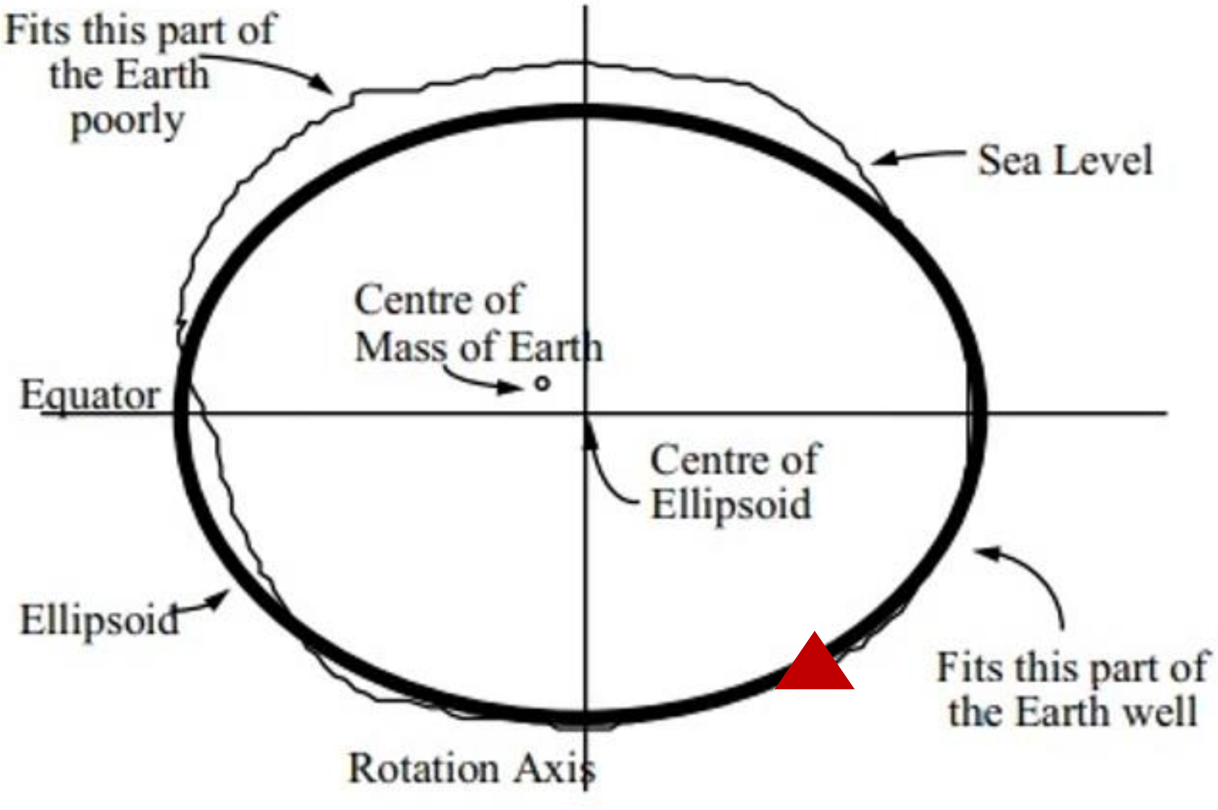

Figure 2: *Local datum with best fit ellipsoid.*

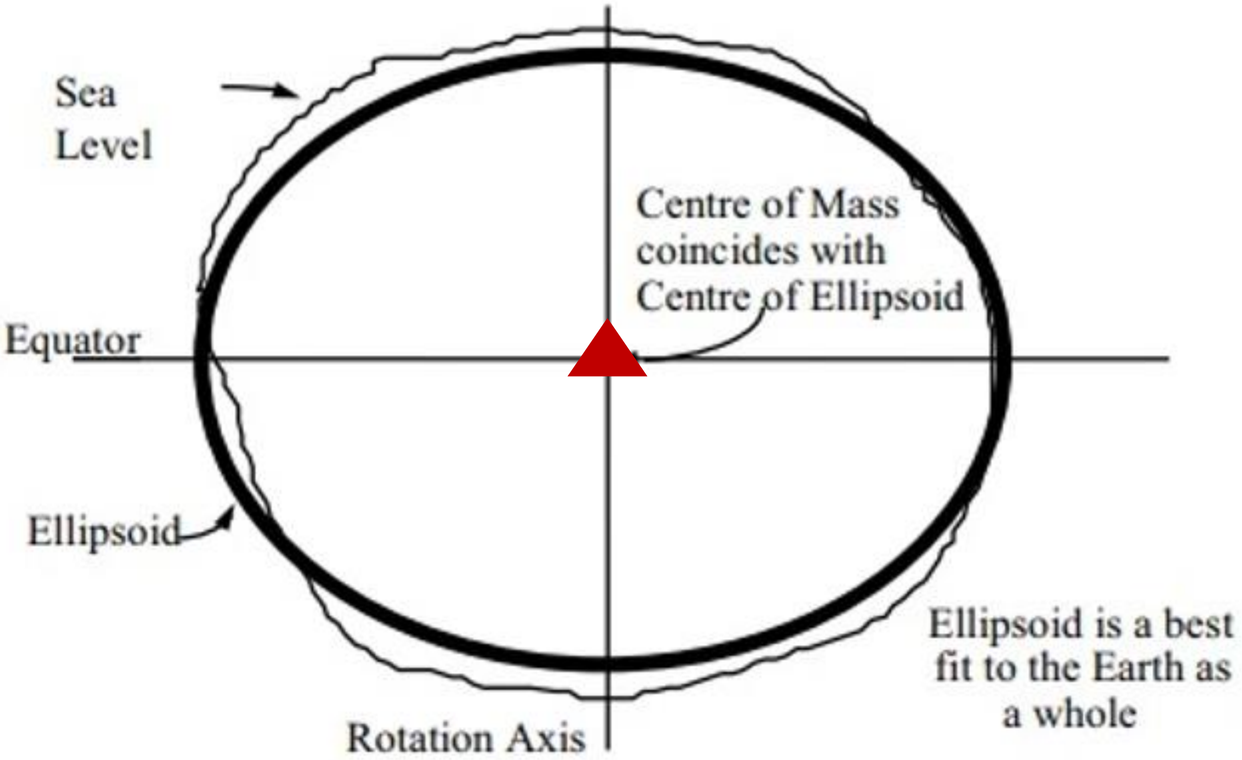

Figure 3: *Geocentric datum with ellipsoid that is a best fit to the world.*

Why are there different GCSs?

- Because only one datum will cause varying errors at different parts of the world
- To reduce and minimize errors in the local area, different countries customize their own datums. Hundreds of datums are customized for different parts of the world.
- Each datum determines one GCS, thus one datum corresponds to one GCS.

A datum = an ellipsoid + an origin

Common datums

- North American Datum 1927 (**NAD27**)
  - Uses the Clarke 1866 spheroid/ellipsoid.
  - Reference point is located at Kansas
  - Origin = local
- North American Datum 1983 (**NAD83**)
  - Uses GRS80 spheroid/ellipsoid
  - Origin = geocententered (center of the earth)
- **WGS 1984** (used by GPS)
  - Developed by US. Department of Defense
  - Used by all GPS satellites
  - Nearly identical to NAD83

Selected Reference Ellipsoids

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Singapore datum – **SVY21 datum**

- References WGS84 ellipsoid
- Origin
  - Latitude: 1° 22' 02.915414"
  - Longitude: 103° 49' 31.975227"

Why do we need a local datum for Singapore?

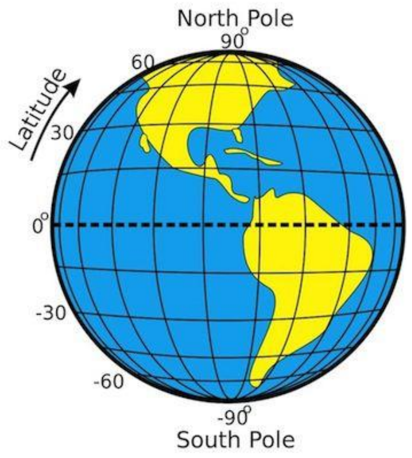
Degrees, minutes, seconds to decimal degrees conversion:
https://www.rapidtables.com/convert/number/degrees-minutes-seconds-to-degrees.html

Outlines of this lecture

- Why coordinate systems matter?
- Geographic coordinate systems
- **Map projections**
- Projected coordinate systems
- Spatial coordinate transformation

Why map projection?

- Geographic coordinates are spherical coordinates represented by longitudes and latitudes. It is not easy to calculate the **distance**, **direction** and **area** on a curve surface.
- The commonly used maps are **plane-based**, which accord with people's visual and psychological perceptions, and are convenient for the above measurements.
- Map projection is needed to turn a curve surface to a plane surface



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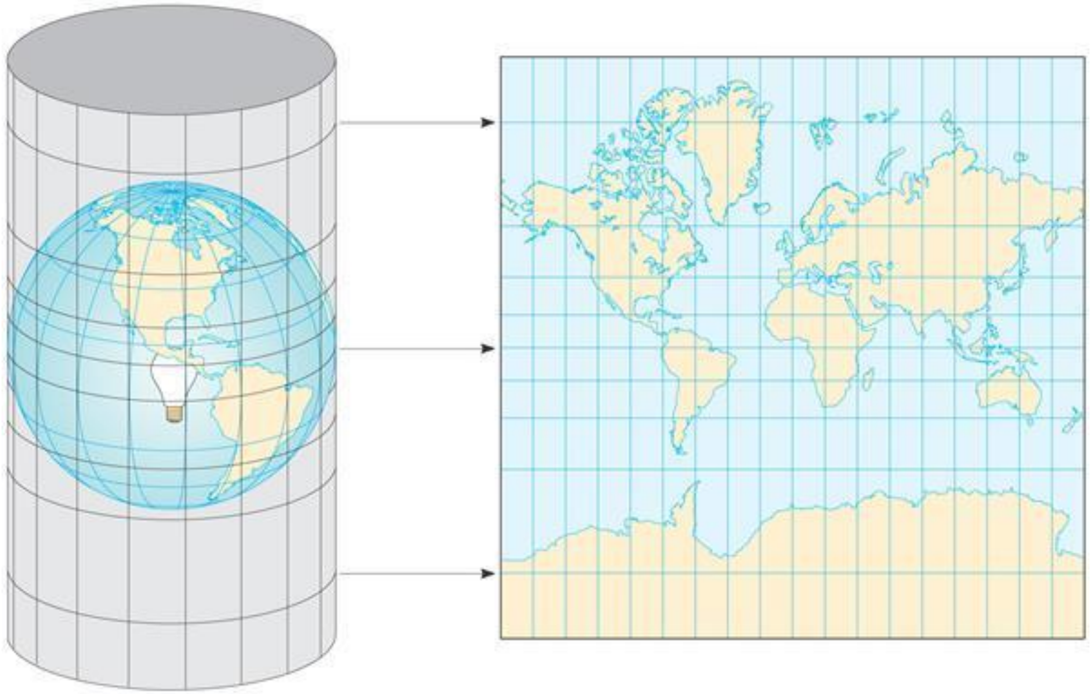
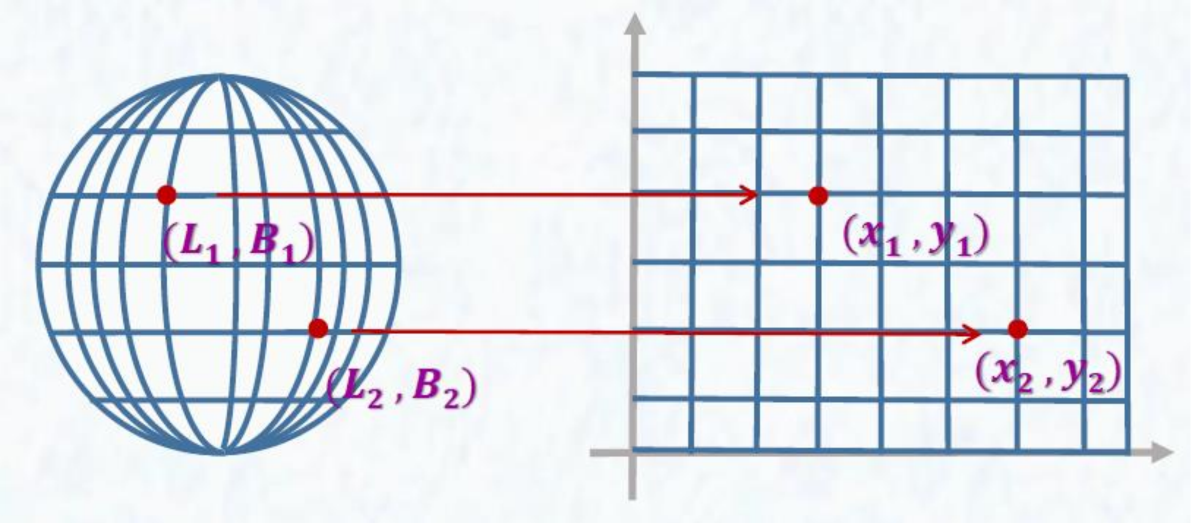
An example of map projection



Essence of map projection

- Essence of map projection
  - Building the **mapping relationships** between a **spherical** coordinate (L, B) and a corresponding **planar** coordinate (x, y)



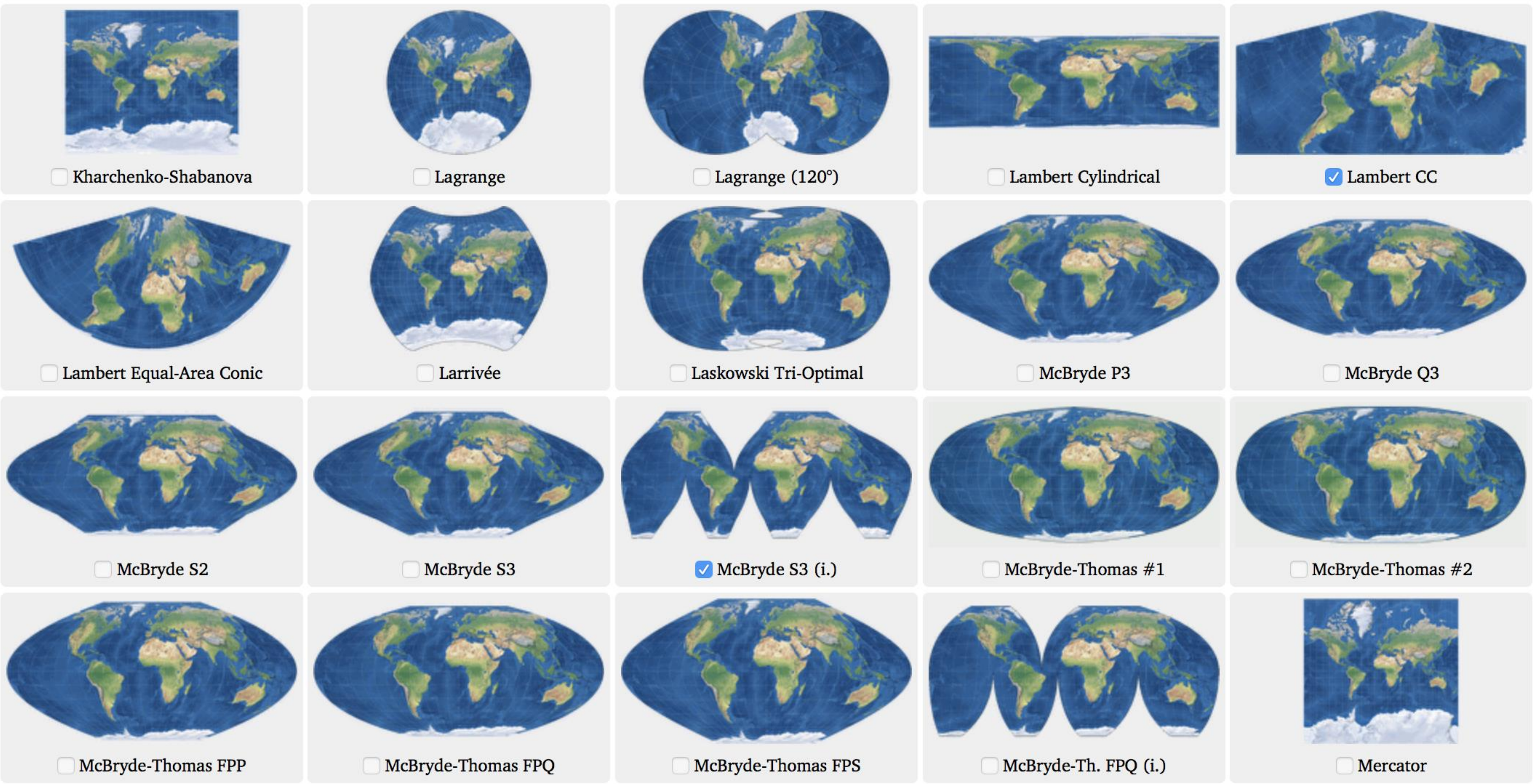
$x = f_1(L, B)$ $y = f_2(L, B)$

(L, B) – Spherical coordinates
(x, y) – Planar coordinates

Different kinds of map projections determine functions of f_1 and f_2 based on certain conditions

Projection types

There are more than 250 map projections



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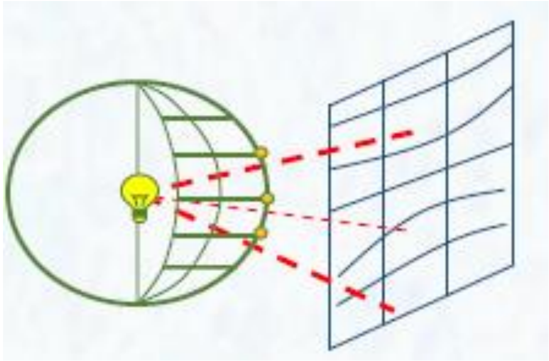
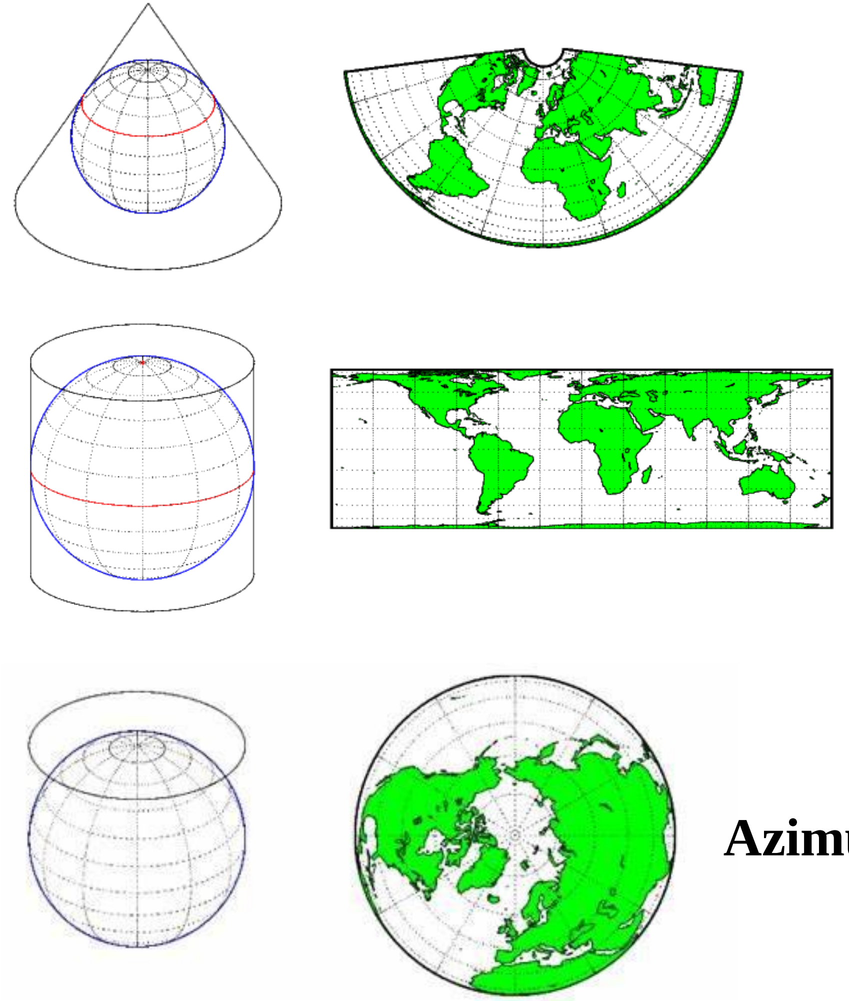
Geometric projection



Earth

Projection surface



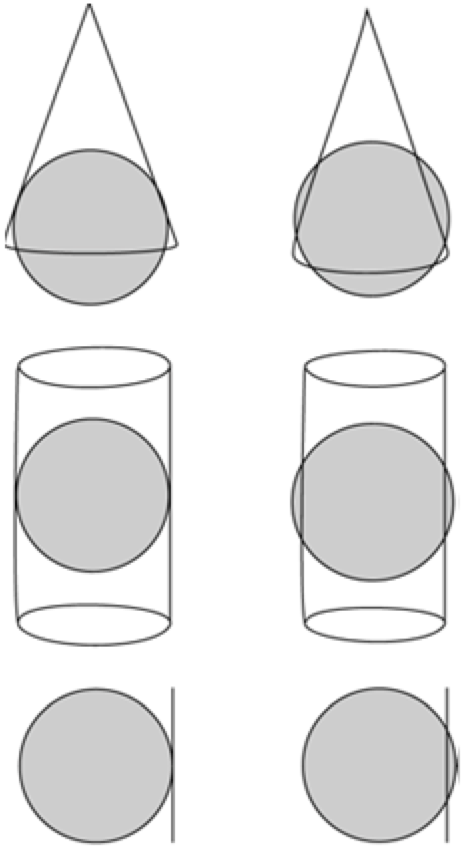
Conic

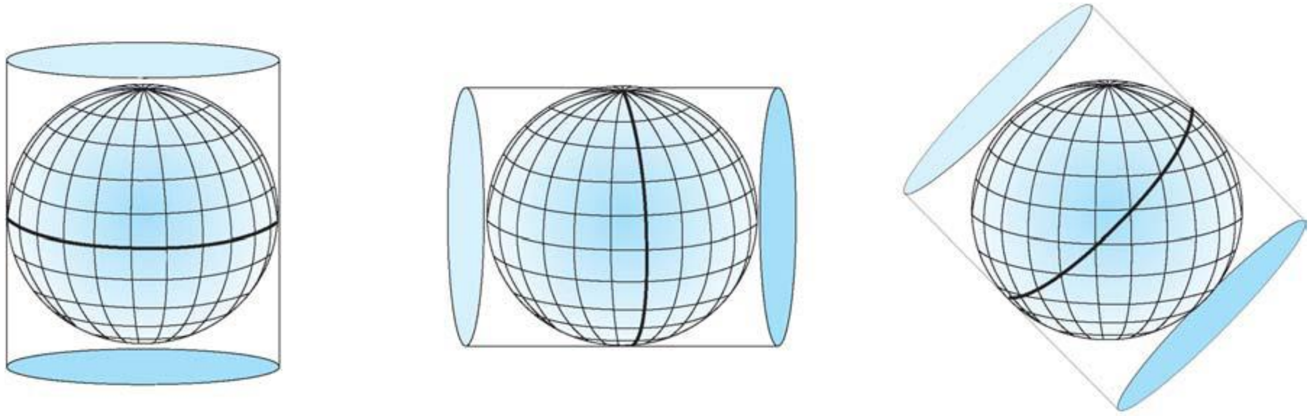
Cylindrical

Azimuthal

Geometric projection

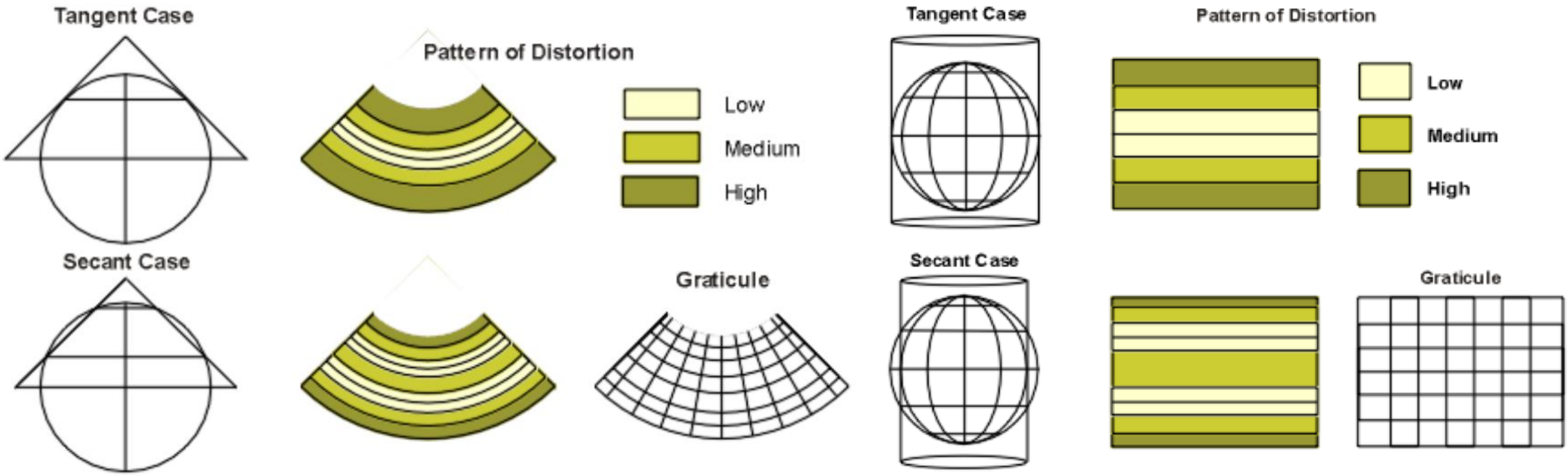
Tangential/simple (just touching) | Secant (intersecting)





Normal | Transverse | Oblique

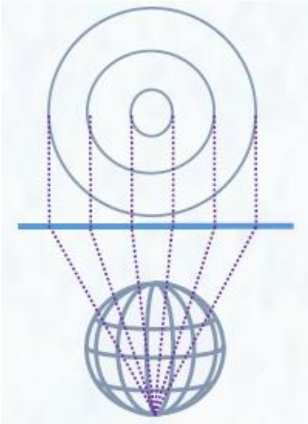
Geometric projection



Secant projections, compared to tangent projections, result in increased low and decreased high distortion.

Deformation rule-based projection

- **Equal-angle projection**: the **angle** (and the shape) between two lines will not change after projection



The area is enlarged, but the angle remains unchanged

- **Equal-area projection**: the **area** of polygons will not change after projection

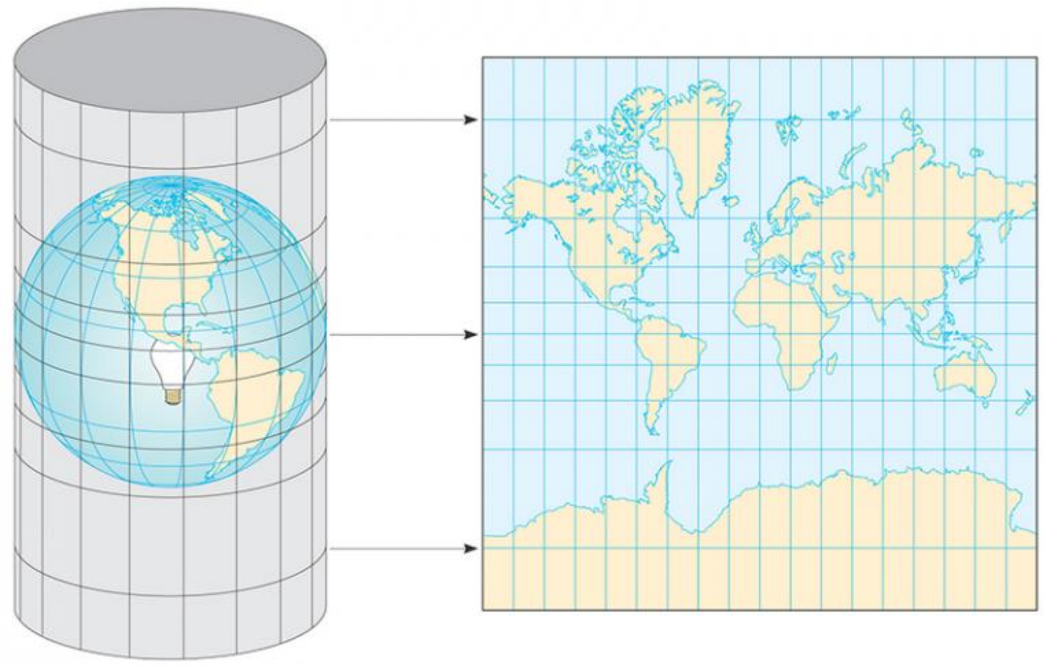
- **Equal-distance projection**: it is a type of **arbitrary** projection. The distance along a certain direction won't occur deformation. However, in other directions, small deformations occur in angle, shape, area, and distance.

Commonly used map projections

- Mercator
- Transverse Mercator
- Lambert Conformal Conic
- Albers Equal-Area Conic

Mercator projection

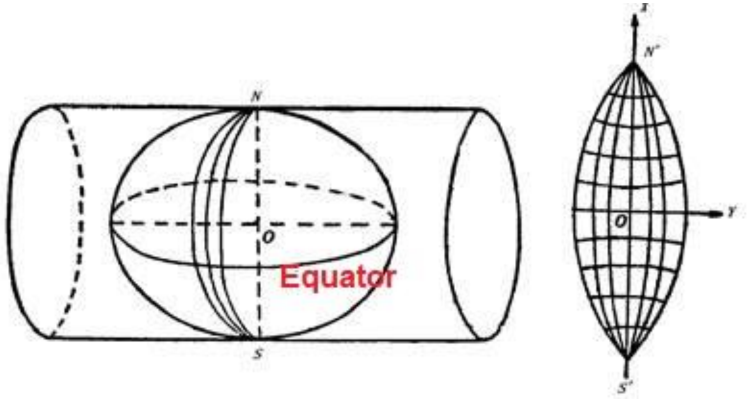
- Mercator is a cylindrical projection.
- Mercator is a conformal map projection.
- Directions, angles, and shapes are maintained at infinitesimal scale.
- Area is increasingly distorted toward the polar regions.

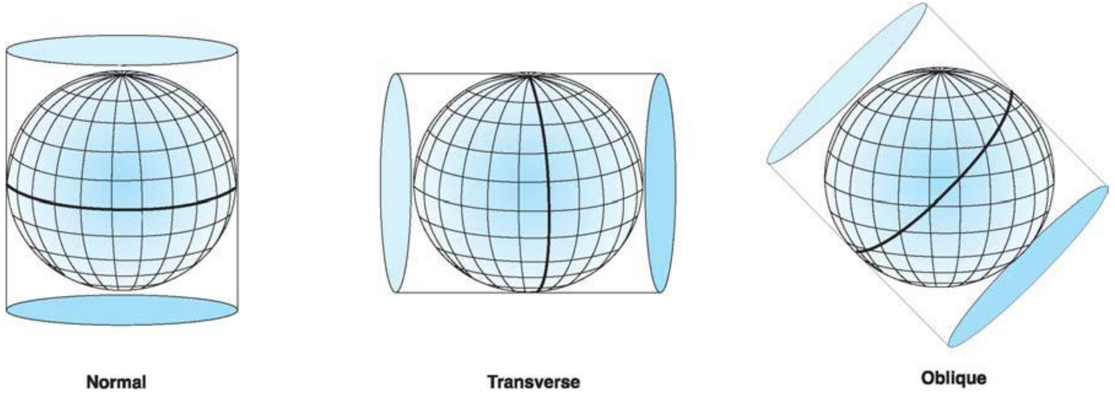


Started by Google in 2005 and has become the standard Web map projection, used in Esri Basemap, OpenStreetMap, Web map services.

Transverse Mercator Projection

- It is a variation of **Mercator** projection
- It is a **transverse, cylindrical, and secant** projection
- It was proposed by Gauss and then supplemented by Kruger in 1912
- Therefore it has another name: **Gauss-Kruger projection**
- It is an **equal-angle (conformal)** projection





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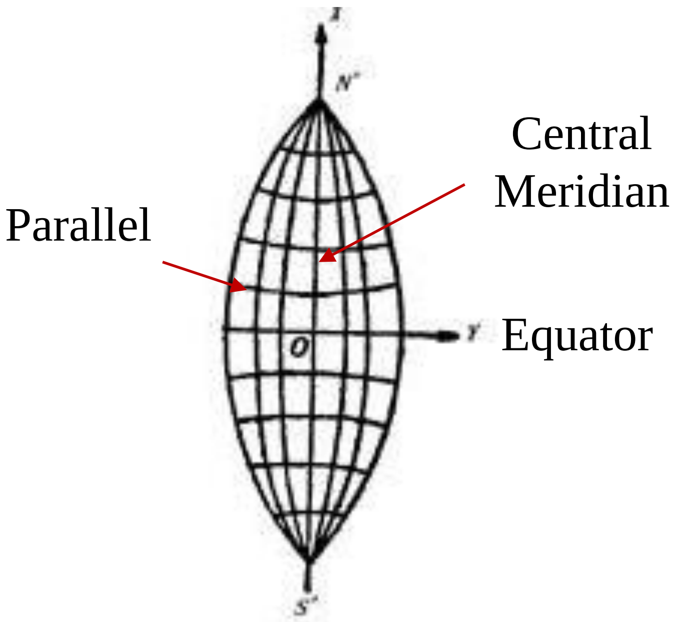
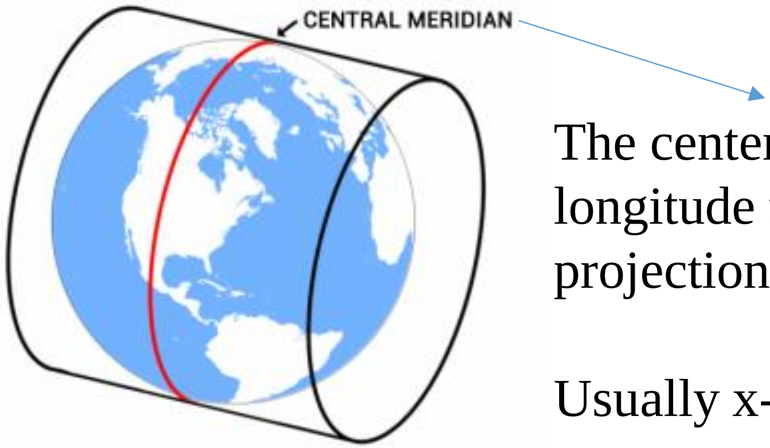
Transverse Mercator Projection

Shapes of Meridians and Parallels

- **Meridian**: The **central meridian** is a straight line, and the other meridians are curve lines convergent to the two poles
- **Parallel**: The **equator** is a straight line, and the other parallels are curve lines that are convex to the equator
- **Meridians** and **parallels** are still **perpendicular** to each other after projection

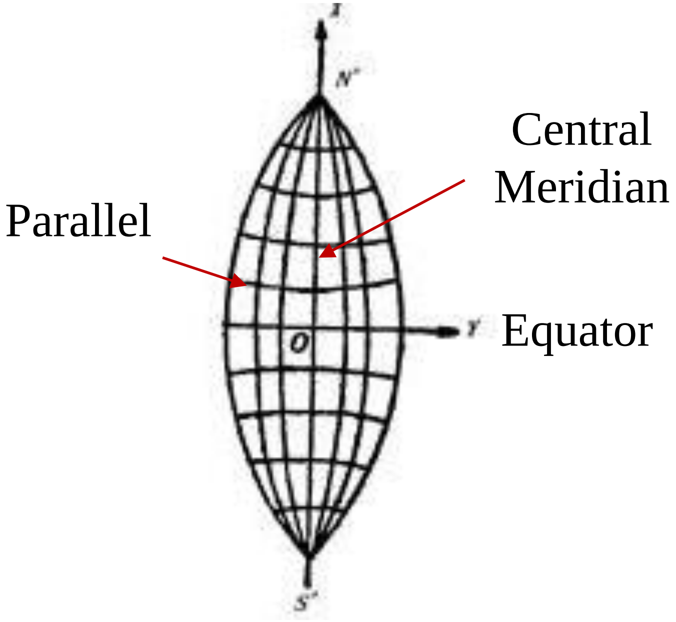




The centerline of longitude for projection systems

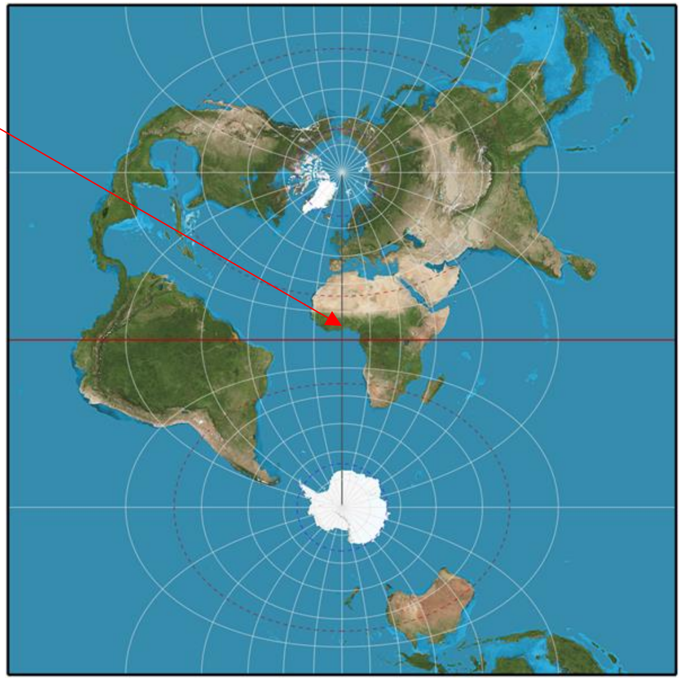
Usually x-origin

Transverse Mercator Projection



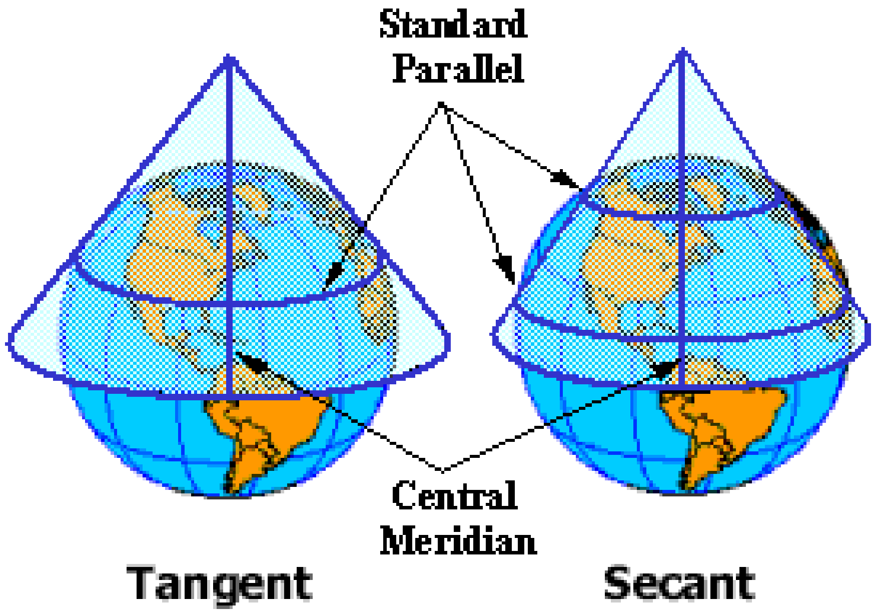
Deformation characteristics

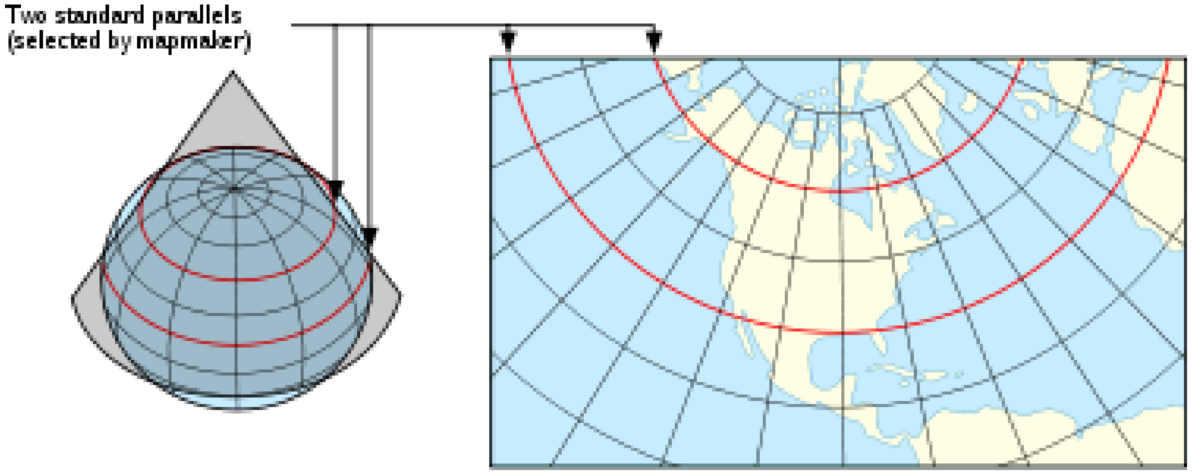
- No deformation on the **central meridian**
- On the **same parallel**, a point **further** from the central meridian will have **larger** deformation
- On the **same meridian**, a point with **lower** latitude will have **larger** deformation



Lambert Conformal Conic Projection

- It is a **secant**, **conic** projection
- It is an **equal-angle (conformal)** projection
- The **Lambert conformal conic** projection is a standard choice for mapping a mid-latitude area





Lambert Conformal Conic Projection

Shapes of Meridians and Parallels

- All the meridians are equally spaced straight lines converging to a common point
- The parallels are represented as circular arcs centered on the pole

Lambert Conformal Conic Projection

Deformation characteristics

- Lambert conformal conic is an equal-angle (conformal) map projection
- Directions, angles, and shapes are maintained at infinitesimal scale
- Distances are accurate only along the standard parallels. Scale, area, and distances are increasingly distorted away from the standard parallels, but they are the same along any given parallel and symmetric across the central meridian

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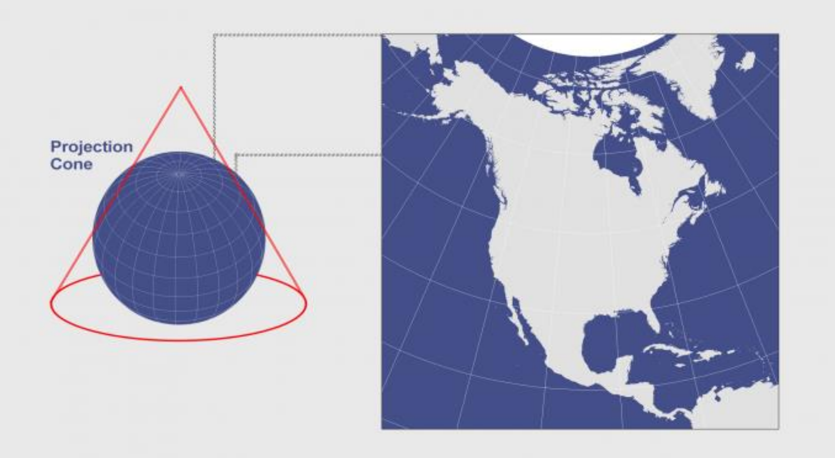
Albers Equal-Area Conic Projection



- It is a **conic**, **equal-area** projection
- Neither shape nor linear scale is truly correct
- The distortion of shape, and scale properties is minimized in the region between the two standard parallels
- This projection is best suited for land masses extending in an east-to-west orientation rather than those lying north to south

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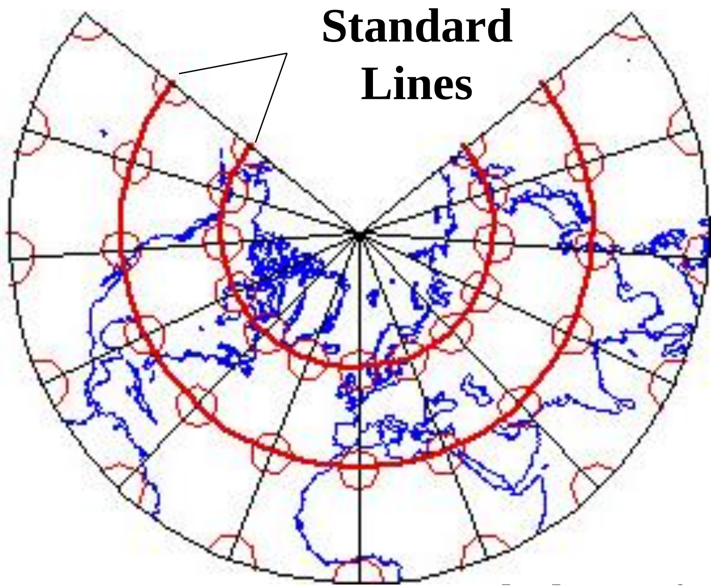
Scale factor

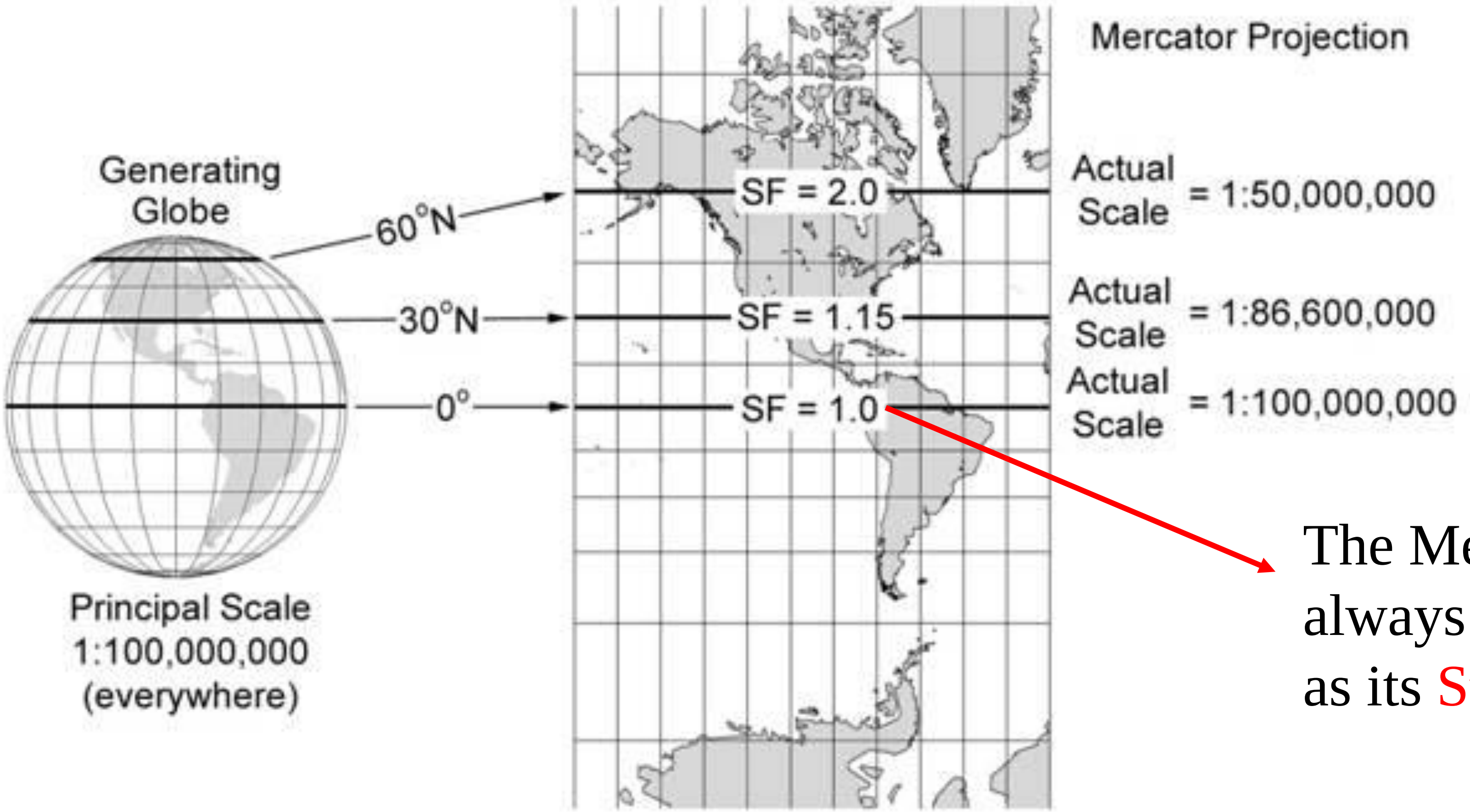
Verbal Scale
1 in. = 1,485 mi
1 cm = 940 km

- Scale: the ratio of map distance to ground distance
- The scale of a projected map may be thought of as having two components:
  - **Principal Scale**: the scale on the generating globe (Generating globe is the globe that is reduced to the scale of the map)
  - **Actual Scale (Local Scale)**: the scale at a local area on the map (plane)
- Local Scale equals to Principal Scale in the following cases
  - On the central Meridians (TM)
  - On the standard lines (conic projection)
- **Scale factor** (SF)
  - Actual Scale (Local Scale)/Principal Scale



Scale factor

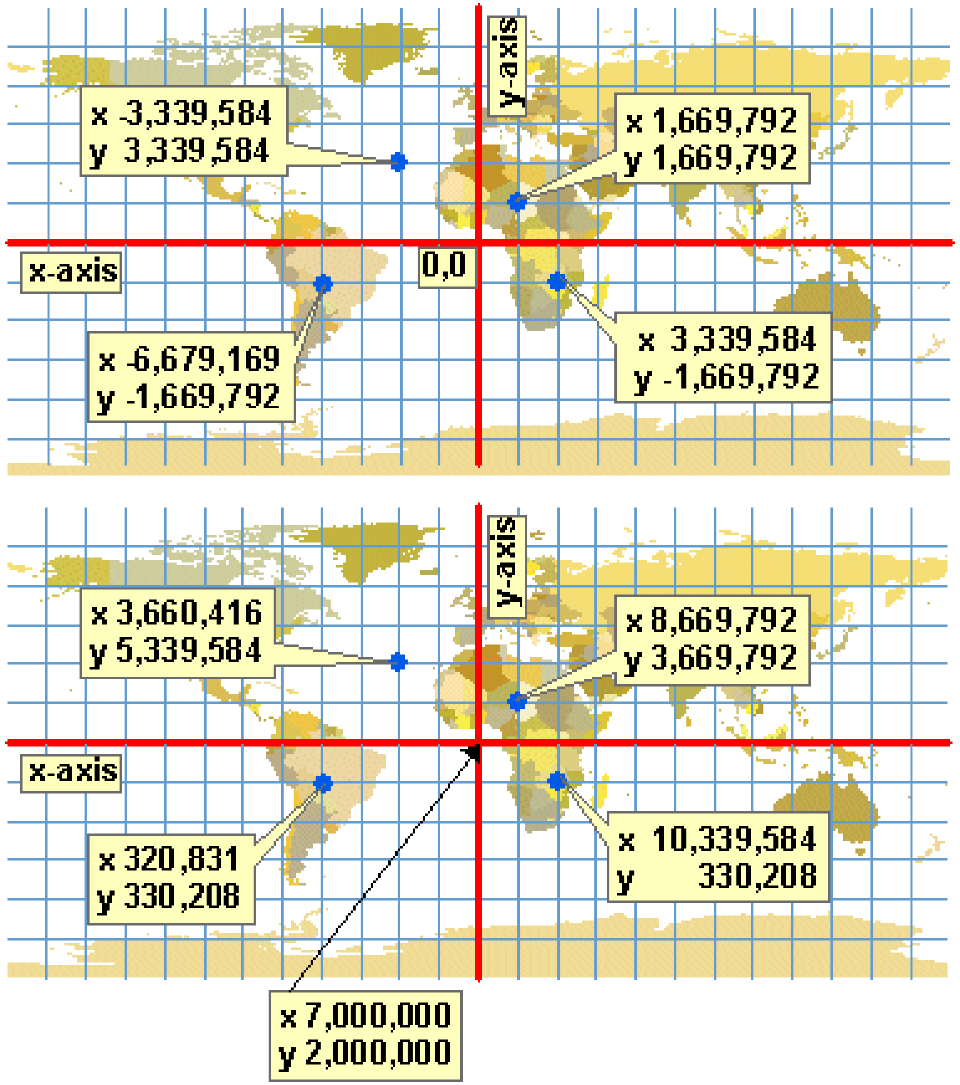
- SF can change across a map



The Mercator Projection always has the Equator as its Standard Parallel

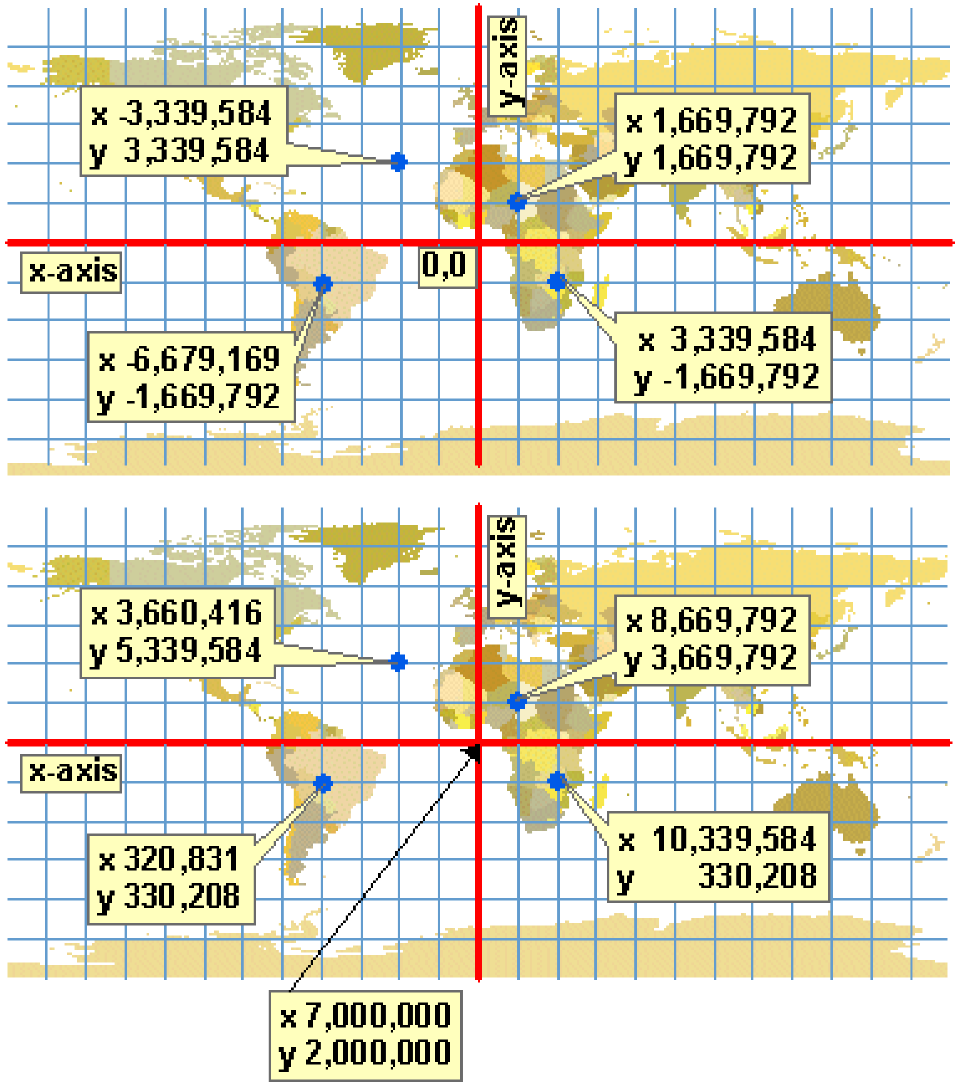
False easting and northing

- Two big numbers that are added to each x- and y-coordinate, respectively.
  - The numbers are big enough to ensure that all coordinate values—or at least all those in your area of interest—come out positive.



False easting and northing

- The definition of the Transverse Mercator Projection requires the following parameters: scale factor at central meridian, longitude of central meridian, latitude of origin, false easting, and false northing.
- The Lambert conformal conic projection is defined by following parameters: first and second standard parallels, central meridian, latitude of projection's origin, false easting and false northing.

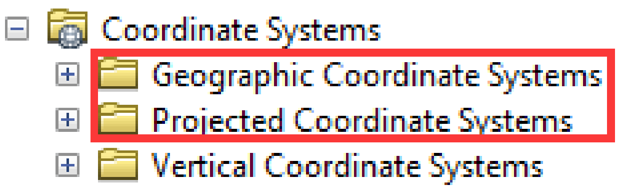


Outlines of this lecture

- Why coordinate systems matter?
- Geographic coordinate systems
- Map projections
- **Projected coordinate systems**
- Spatial coordinate transformation

Projected Coordinate Systems (PCS)

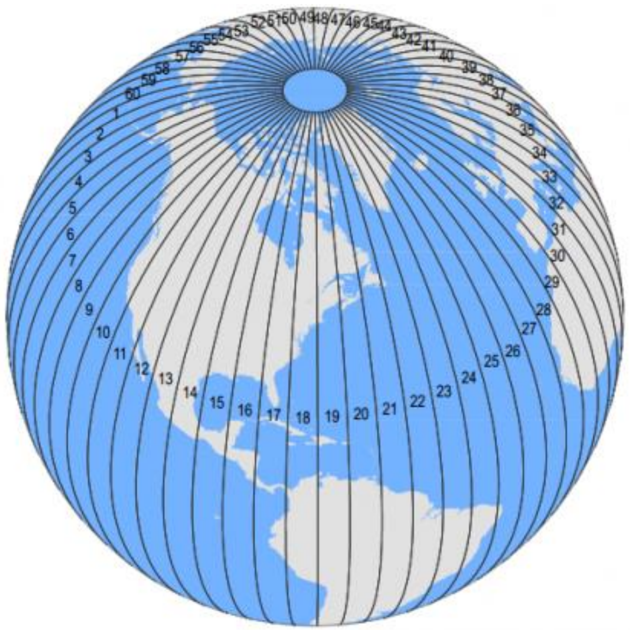
- A **projected coordinate system** = a **map projection** + a **datum**

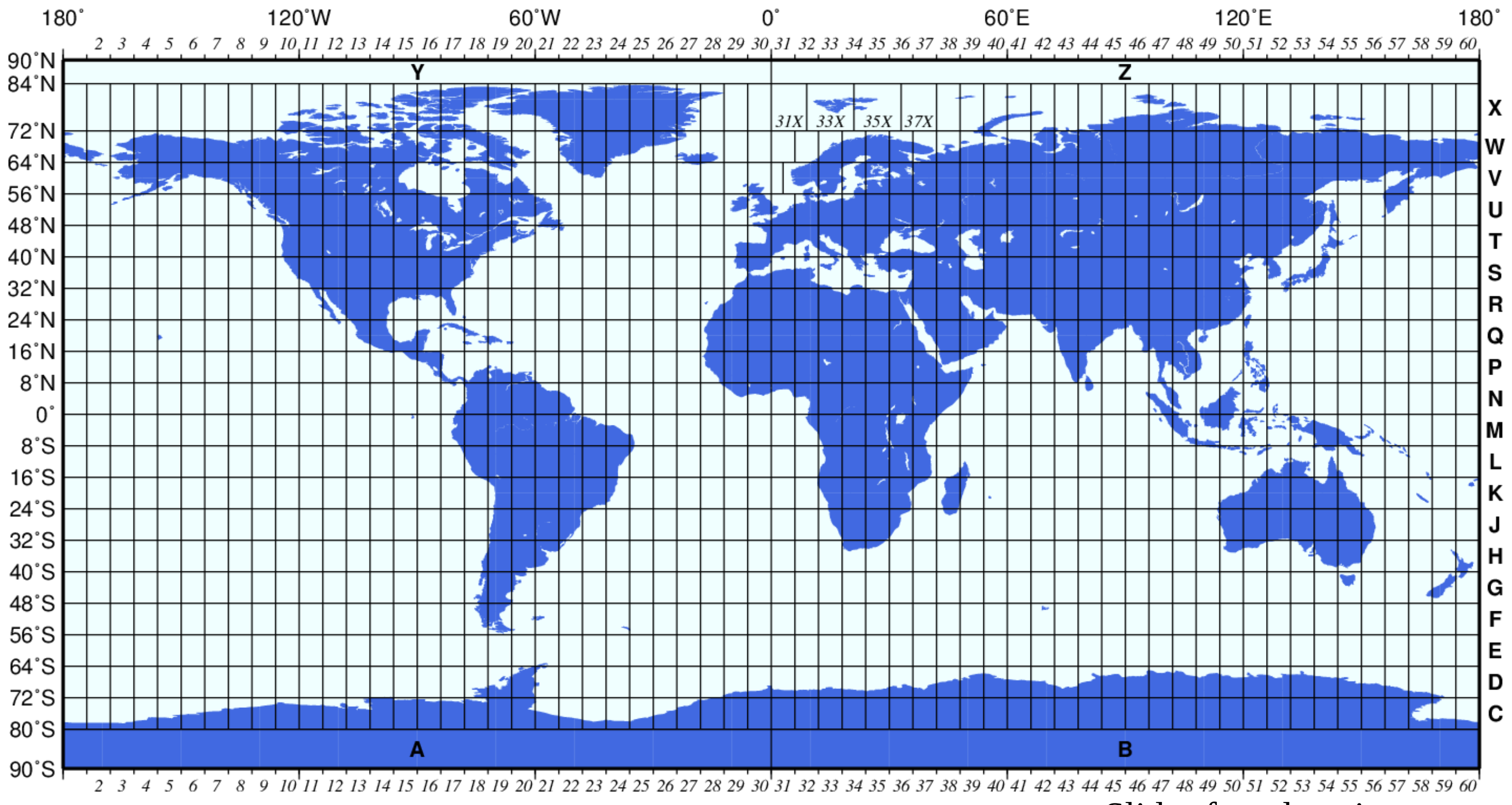


- When creating a new spatial data file, either a **GCS** or a **PCS** should be assigned
  - If you expect the map unit to be **degree**, then a **GCS** should be assigned as no map projection is required
  - If you expect the map unit to be **meter** (or km, mile…), then a **PCS** should be assigned as a map projection is required

Universal Transverse Mercator (UTM)

- The **UTM gird system** is the most commonly used **PCS**
- It uses **Transverse Mercator** projection





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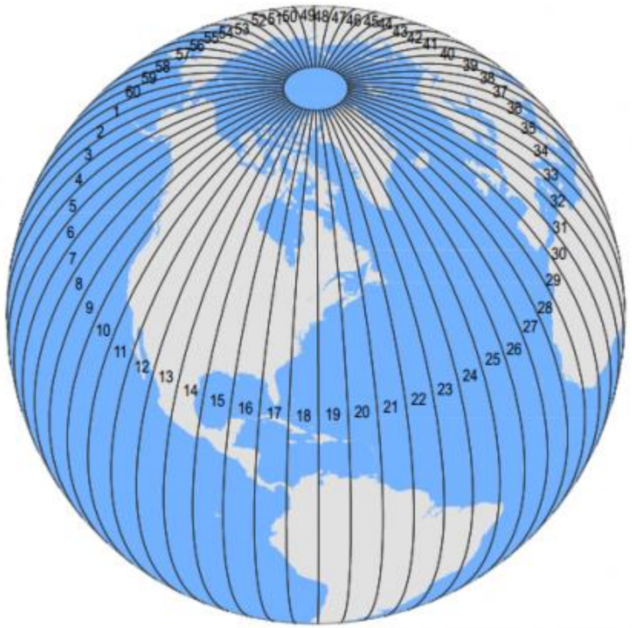
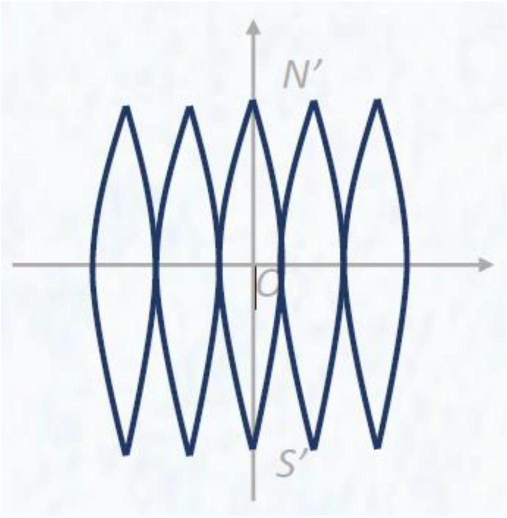
Universal Transverse Mercator (UTM)



- For any projection, the further a location is from the tangent line (just touching) or secant line (intersecting), the larger the deformation will be
- To maintain the level of accuracy, the UTM system is divided into many zones, with each zone defined by a different projection center (i.e., different parameters of map projection).
  - Each zone covers **3 degrees** or **6 degrees** of longitude
  - Each zone is further divided into the northern and southern hemispheres



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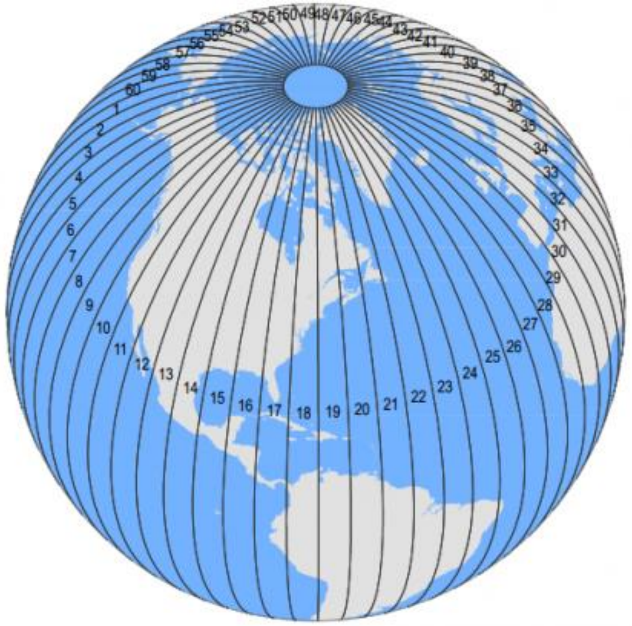
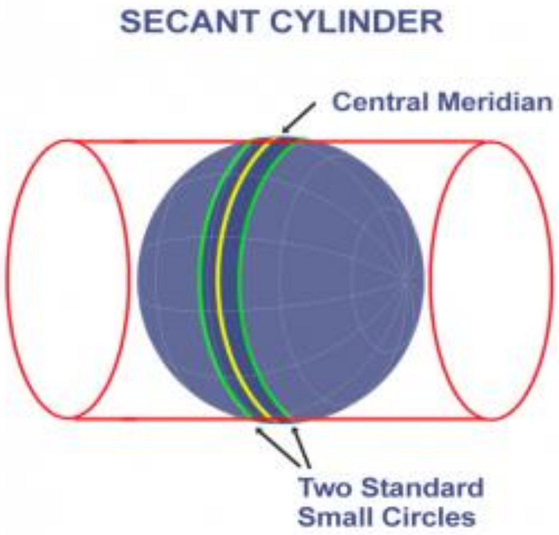
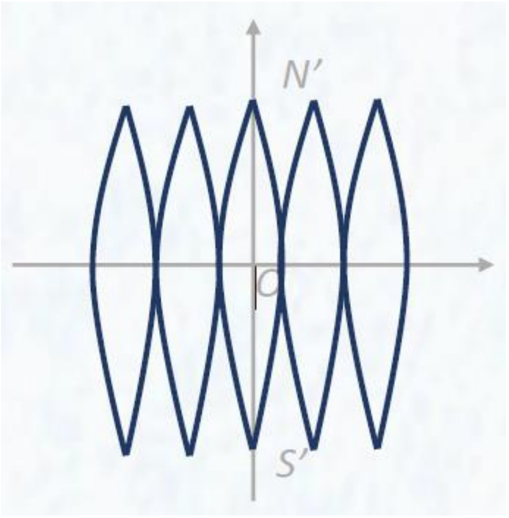
Universal Transverse Mercator (UTM)



- In other words, the Universal Transverse Mercator places the cylinder 60 times or 120 times for each UTM zone.
- This means that all 60 or 120 wedges are flattened out with a transverse cylinder. Each time it's slightly rotated using a different meridian as a central line.

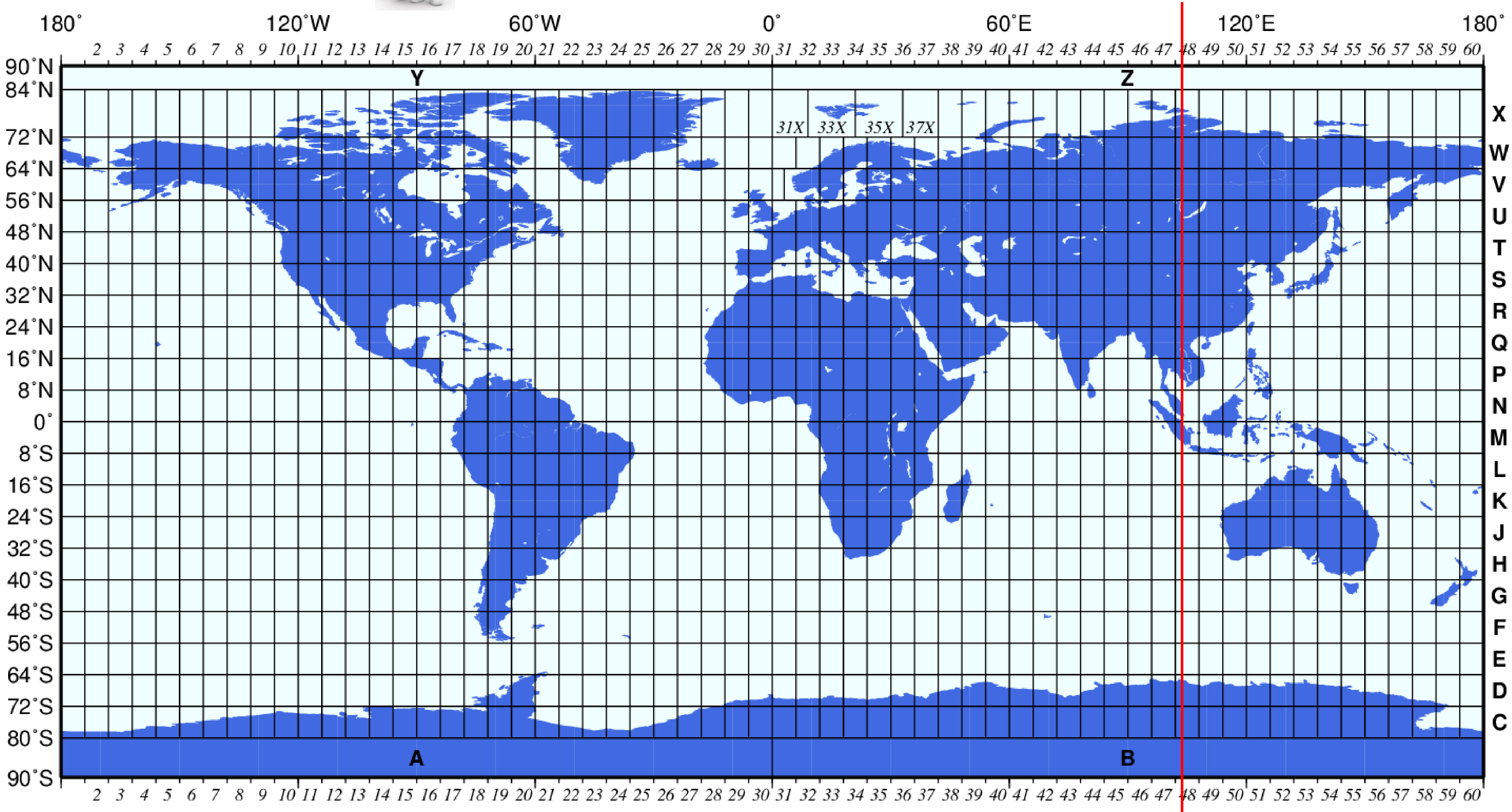




Universal Transverse Mercator (UTM)

Map scale		
1/25,000 – 1/50,000	→	**Six-degree** division is adopted. The whole earth is divided into **60** zones
>1/10,000	→	**Three-degree** division is used. The whole earth is divided into **120** zones

Which projection zone does Singapore fall into?



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Singapore PCS – SVY21

- Projection: Transverse Mercator
- Datum: SVY21

A projected coordinate system = a map projection + a datum

- Ellipsoid: WGS84

A datum = an ellipsoid + an origin

- Origin
  - Latitude: 1° 22' 02.915414"
  - Longitude: 103° 49' 31.975227"

Outlines of this lecture

- Why coordinate systems matter?
- Geographic coordinate systems
- Map projections
- Projected coordinate systems
- **Spatial coordinate transformation**

Spatial coordinate transformation

- Often, the data sets we have are in different coordinate systems
- It is a good idea to transform them to the same coordinate system

Projection

Geographic coordinate → **Projected coordinate**

Reprojection

Projected coordinate system 1 → **Projected coordinate system 2**

The algorithms and mathematical methods of **projections** and **reprojections** are not required to master. This can easily be done in most of GIS software

Summary

- Why coordinate systems matter?
  - Talking about locations and spatial measurements
  - Creating a new set of spatial data
  - Acquiring spatial data from other data sources
  - Overlaying/Displaying two or more map layers
- Geographic coordinate systems
  - Defined by longitude and latitude (Meridian and Parallel)
  - A datum = an ellipsoid + an origin (Local and Geocentric datum)
  - Common datums and Singapore datum – **SVY21** datum

Summary

- Map projections
  - Transform spherical coordinates to planar coordinates
  - **Categories** of map projection
    - Conic, cylindrical, azimuthal projections
    - Equal angle, equal-area, and arbitrary projections
- Projected coordinate system
  - A PCS = a map projection + a datum
  - Common used PCSs: **UTM** and **SVY21** projection
- Spatial coordinate transformation
  - **Projection** and **reprojection**

THANK YOU