

Map Projection

Projections

- Goal: translate places on the Earth (3D) to Cartesian coordinates (2D)

Similarities and differences among globe and maps

Similarities	Differences
Physical features are the same (bodies of water, countries)	Maps are spatially distorted; a globe is more accurate
Globes and maps can both be expensive	Maps are more portable
Both are universally recognized	Maps are flat; globes are round
Both express longitude and latitude	A map has a legend; a globe doesn't
Both are representations of the world	A map allows you to see the earth all at once. You only see a section of the earth on a globe
Both are subject to change	A map is discreet; a globe is continuous
	Maps are less expensive, easier to find
	Maps take up more space
	Maps are more for personal use; globes are more often used for educational purposes

Map Projections

- The systematic transformation of points on the Earth's surface to corresponding points on a plane surface.
 - Map projections always introduce some type of distortion
 - selection of a projection is done to minimize distortion for the particular application

- A **map projection** is any method of representing the **surface** of a sphere or other three-dimensional body on a plane.
- Map projections are necessary for creating **maps**.
- All map projections distort the surface in some fashion.
- Depending on the purpose of the map, some distortions are acceptable and others are not;
- therefore different map projections exist in order to preserve some properties of the sphere-like body at the expense of other properties.
- There is no limit to the number of possible map projections.

- A [map](#) of all or part of Earth's surface is a flat representation of a curved surface.
- Therefore a map projection must have been used to create the map, and, conversely, maps could not exist without map projections.
- **Maps can be more useful than [globes](#) in many situations:**
 - they are more compact and easier to store;
 - they readily accommodate an enormous range of scales;
 - they are viewed easily on computer displays;
 - they can facilitate measuring properties of the terrain being mapped;
 - they can show larger portions of the Earth's surface at once; and
 - they are cheaper to produce and transport.

Metric properties of maps

- **Many properties can be measured on the Earth's surface independently of its geography.** Some of these properties are:
 - Area
 - Shape
 - Direction
 - Bearing
 - Distance
 - Scale
- Map projections can be constructed to preserve one or more of these properties,
- Each projection preserves or compromises or approximates basic metric properties in different ways.

Why do we need a projection?

Creating maps

- we must choose an appropriate projection for the map to communicate effectively
- part of good cartographic design

Sharing/receiving geographic data

- along with **datum**, coordinate system, we must know the map projection in which the data are stored
- Then we're able to overlay maps from originally different projections

Best projection

- The mathematics of projection **do not permit** any particular map projection to be "**best**" for everything.
- Something will always get distorted.
- Therefore a diversity of projections exists to service the many uses of maps and their vast range of scales.
- Modern national mapping systems typically employ a **transverse Mercator** or close variant for large-scale maps in order to preserve conformality and low variation in scale over small areas.
- For smaller-scale maps, such as those spanning continents or the entire world, many projections are in common use according to their fitness for the purpose.

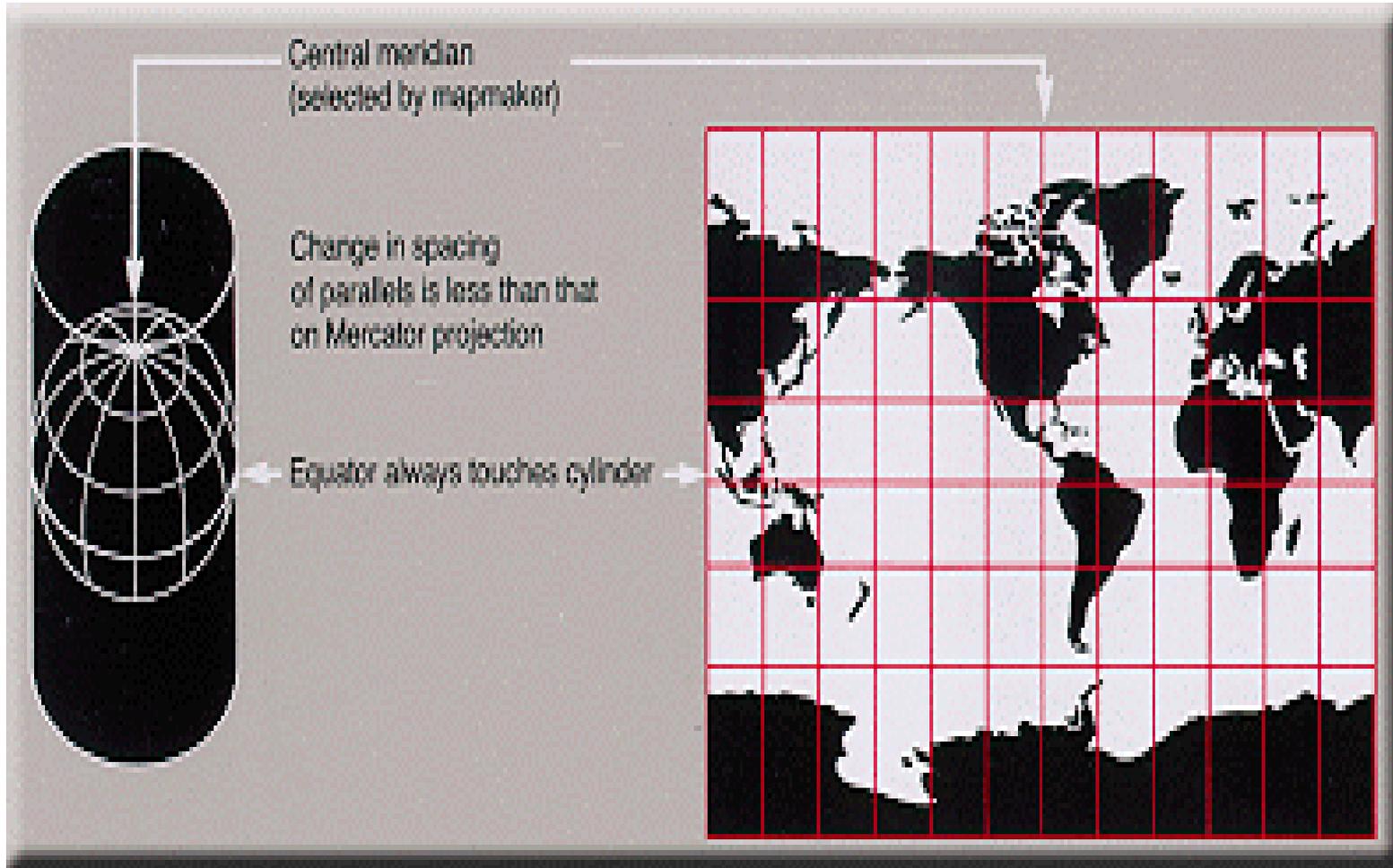
- Thematic maps normally require an **equal area projection** so that phenomena per unit area are shown in correct proportion.
- However, **representing area ratios correctly necessarily distorts shapes more than many maps that are not equal-area.**
- Hence reference maps of the world often appear on **compromise projections** instead.

Construction of a map projection

- The creation of a map projection involves two steps:
 - Selection of a model for the shape of the Earth or planetary body (usually choosing between a sphere or ellipsoid). Because the Earth's actual shape is irregular.
 - Transformation of geographic coordinates (longitude and latitude) to Cartesian (x,y) or polar plane coordinates.

Choosing a projection surface

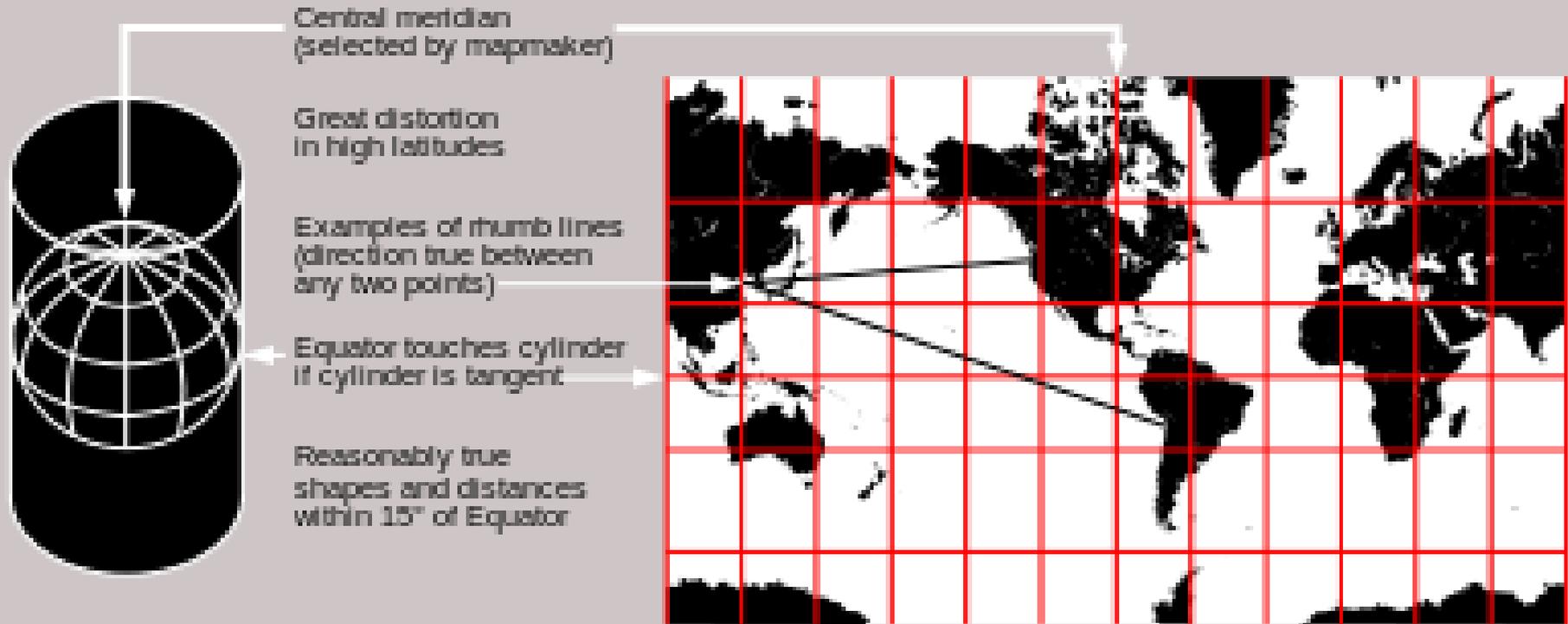
- A surface that can be **unfolded or unrolled into a plane or sheet without stretching, tearing or shrinking** is called a *developable surface*.
- The
 - **cylinder,**
 - **cone** and
 - of course the **plane** are all developable surfaces.
- The **sphere and ellipsoid** are **not developable surfaces**.
- As noted in the introduction, any projection of a sphere or an ellipsoid onto a plane will have to distort the image. **(To compare, one cannot flatten an orange peel without tearing and warping it.)**
- One way of describing a projection is first to project from the Earth's surface to a developable surface such as a cylinder or cone, and then to unroll the surface into a plane.
- While the **first step inevitably distorts some properties of the globe**, the developable surface can then be unfolded without further distortion.



- A [Miller cylindrical projection](#) maps the globe onto a cylinder.

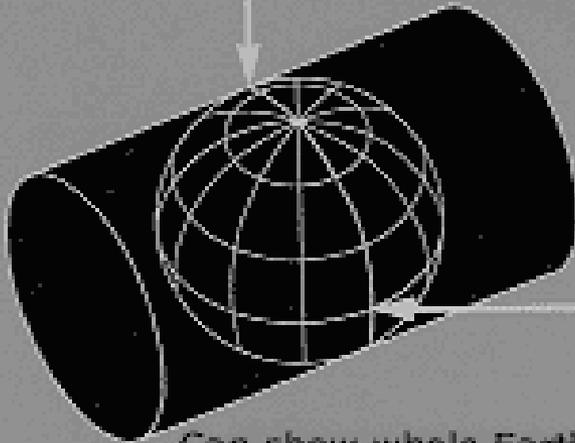
Aspects of the projection

- Once a choice is made between projecting onto a cylinder, cone, or plane, the **aspect** of the shape must be specified.
- The aspect describes how the developable surface is placed relative to the globe:
 - it may be **normal** (such that the surface's axis of symmetry coincides with the Earth's axis),
 - **transverse** (at right angles to the Earth's axis) or
 - **oblique** (any angle in between).
- The developable surface may also be either tangent or secant to the sphere or ellipsoid.
- Tangent means the surface touches but does not slice through the globe;
- Secant means the surface does slice through the globe.



- The Mercator projection shows courses of constant bearing as straight lines.

Central meridian selected by mapmaker touches cylinder if the cylinder is tangent.



Equator



Can show whole Earth, but the directions, distances, and areas are reasonably accurate only within 15 degrees of the central meridian.

No straight rhumb lines.

- This [transverse Mercator projection](#) is mathematically the same as a standard Mercator, but oriented around a different axis.

Scale

- A [globe](#) is the only way to represent the earth with **constant scale** throughout the entire map in all directions.
- A map cannot achieve that property for any area, **no matter how small**. It can, however, **achieve constant scale along specific lines**.
- Some possible properties are:
 - The **scale depends on location, but not on direction**. This is equivalent to preservation of angles, the defining characteristic of a **Conformal map**.
 - **Scale is constant along any parallel in the direction of the parallel**. This applies for any **Cylindrical or pseudocylindrical projection in normal aspect**.
- Combination of the above: the **scale depends on latitude only, not on longitude or direction**. This applies for the **Mercator projection in normal aspect**.
- Scale is constant along all straight lines radiating from a particular geographic location. This is the defining characteristic of an equidistant projection such as the [Azimuthal equidistant projection](#).
- There are also projections (Maurer, Close) where true distances from *two* points are preserved.

Choosing a model for the shape of the Earth

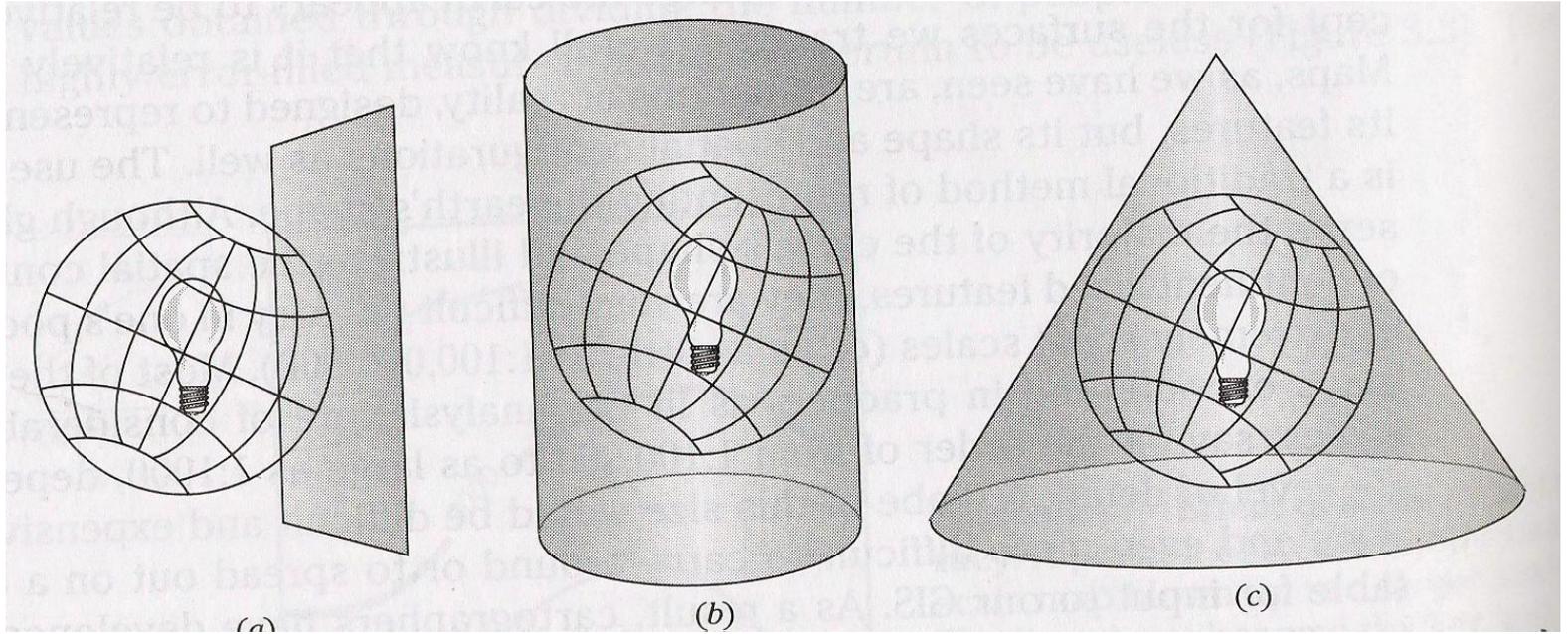
- Projection construction is also affected by how the shape of the Earth is approximated.
- In the following section on projection categories, the earth is taken as a [sphere](#) in order to simplify the discussion. However, the Earth's actual shape is closer to an oblate [ellipsoid](#). Whether spherical or ellipsoidal, the principles discussed hold without loss of generality.
- Selecting a model for a shape of the Earth involves choosing between the advantages and disadvantages of a sphere versus an ellipsoid.
- Spherical models are useful for small-scale maps such as world atlases and globes, since the error at that scale is not usually noticeable or important enough to justify using the more complicated ellipsoid.
- The ellipsoidal model is commonly used to construct [topographic maps](#) and for other large- and medium-scale maps that need to accurately depict the land surface.

- A third model of the shape of the Earth is the [geoid](#), a complex and more accurate representation of the global mean sea level surface that is obtained through a combination of terrestrial and satellite gravity measurements. This model is not used for mapping because of its complexity, but rather is used for control purposes in the construction of [geographic datums](#).
- A geoid is used to construct a datum by adding irregularities to the ellipsoid in order to better match the Earth's actual shape.
- It takes into account the large-scale features in the Earth's gravity field associated with [mantle convection](#) patterns, and the gravity signatures of very large geomorphic features such as mountain ranges, plateaus and plains.
- A few modern datums, such as [WGS84](#) which is used in the [Global Positioning System](#), are optimized to represent the entire earth as well as possible with a single ellipsoid, at the expense of accuracy in smaller regions.

Classification

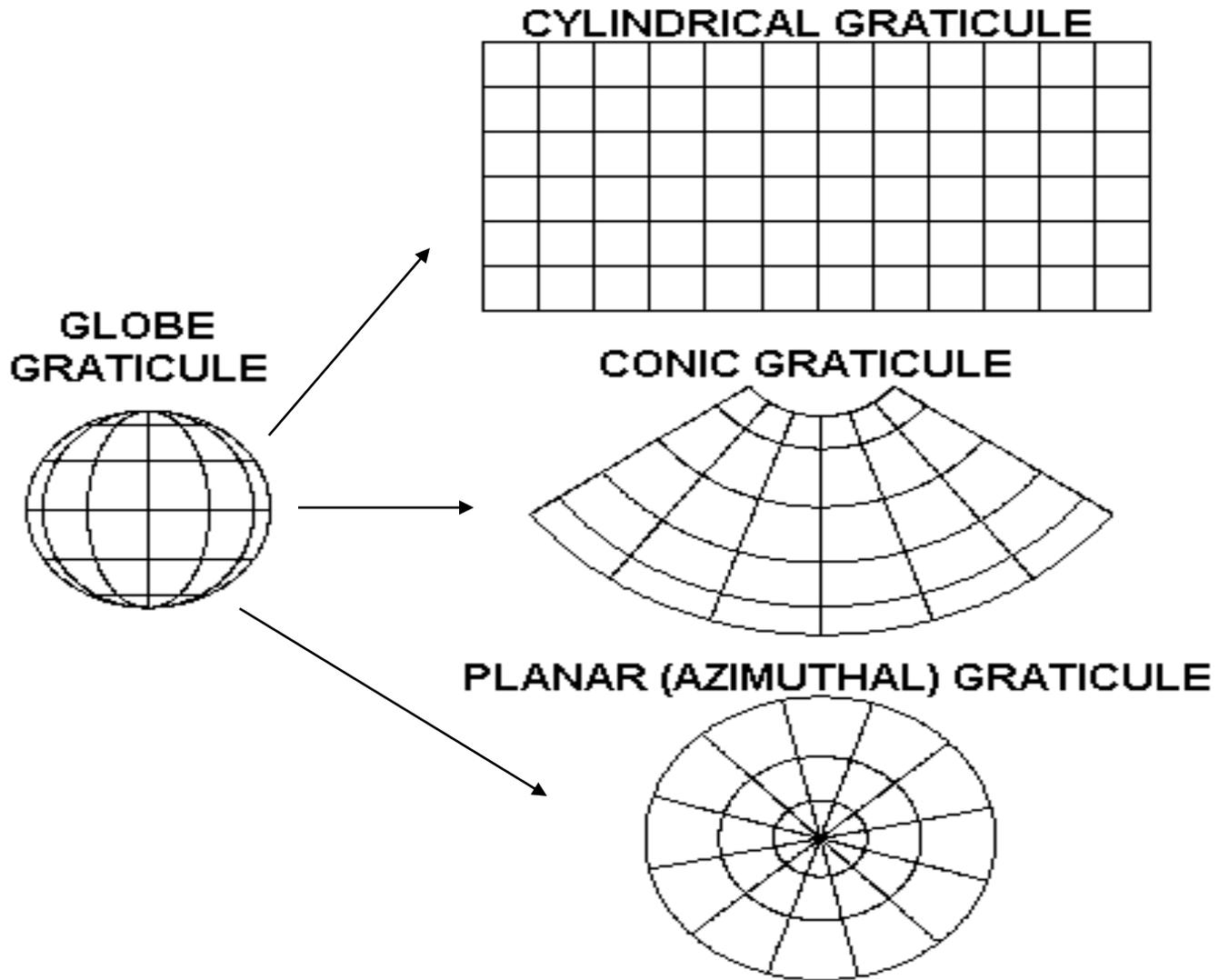
- A fundamental projection classification is based on the type of projection surface onto which the globe is conceptually projected.
- The projections are described in terms of placing a gigantic surface in contact with the earth, followed by an implied scaling operation.
- These surfaces are:
 - cylindrical (e.g. [Mercator](#)),
 - conic (e.g., [Albers](#)), or
 - azimuthal or plane (e.g. [stereographic](#)).
- Many mathematical projections, however, do not neatly fit into any of these three conceptual projection methods. Hence other peer categories have been described in the literature, such as:
 - pseudoconic,
 - pseudocylindrical,
 - pseudoazimuthal,
 - retroazimuthal, and
 - [polyconic](#).

Types of projections



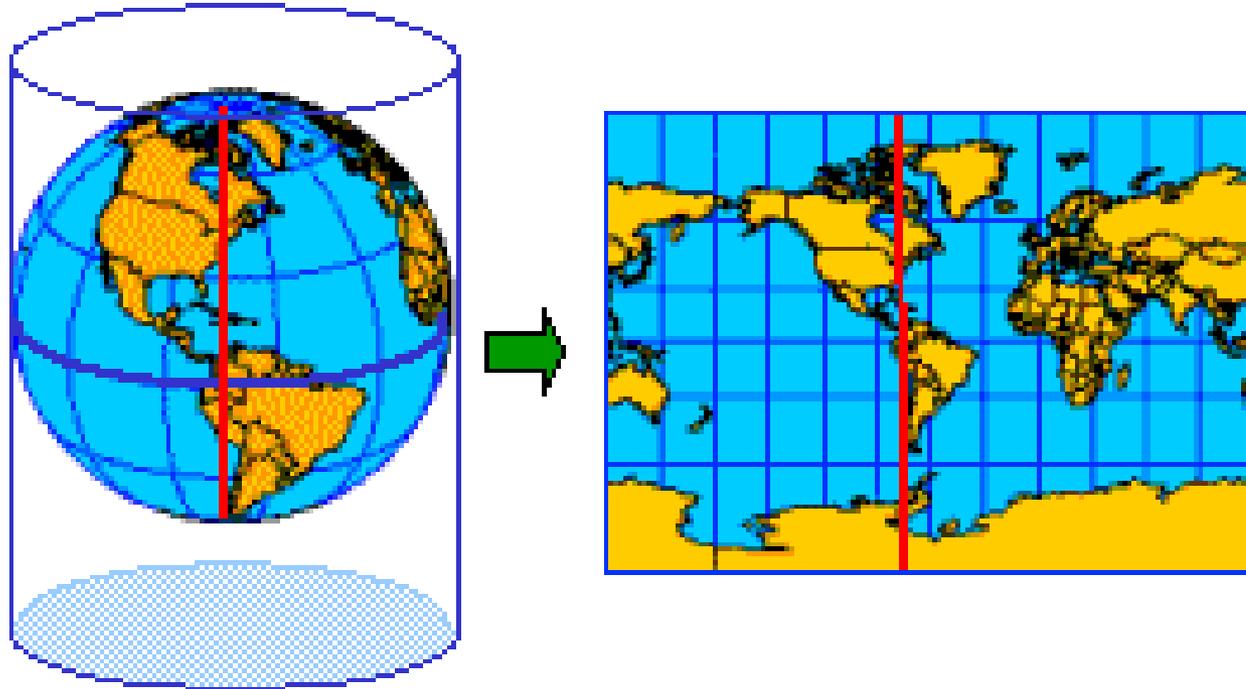
(a) Azimuthal (b) Cylindrical (c) Conic

Views of projected surfaces



- Another way to classify projections is according to properties of the model they preserve. Some of the more common categories are:
 - Preserving direction (*azimuthal*), a trait possible only from one or two points to every other point
 - Preserving shape locally (conformal or *orthomorphic*)
 - Preserving area (*equal-area* or *equiareal* or *equivalent* or *authalic*)
 - Preserving distance (*equidistant*), a trait possible only between one or two points and every other point
 - Preserving shortest route, a trait preserved only by the gnomonic projection
- Because the sphere is not a developable surface, it is impossible to construct a map projection that is both equal-area and conformal.

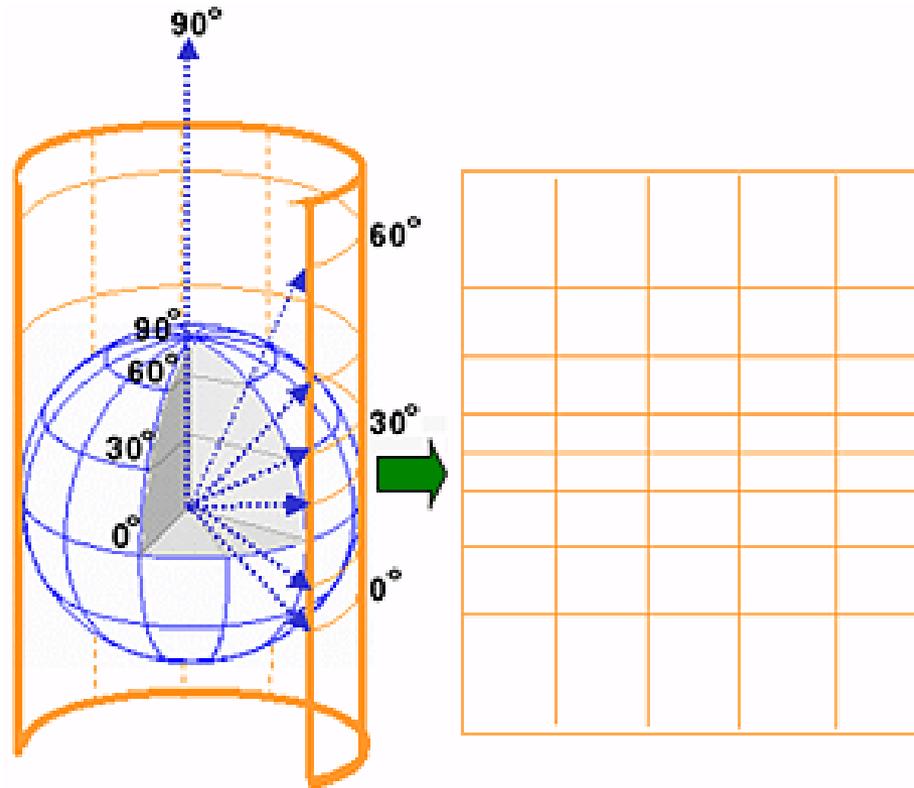
Cylindrical projections



You cut the cylinder along any meridian and unroll it to produce your base map.

Note: the meridian running down the center of the map is called the central meridian (the red line).

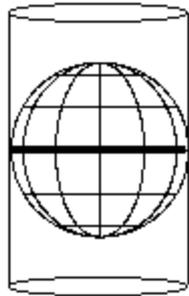
Cylindrical projections (Cont.)



The light source's origin for the map projection is also the origin of the spherical coordinate system, so simply extending the degree lines until they reach the cylinder creates the map projection. The poles cannot be displayed on the map projection because the projected 90 degree latitude will never contact the cylinder. (ESRI Press)

Tangent vs. Secant Projections

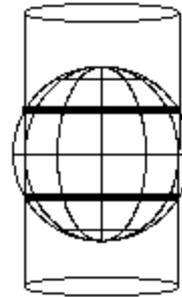
TANGENT



Surface
tangent
to globe

= one *standard line*

SECANT



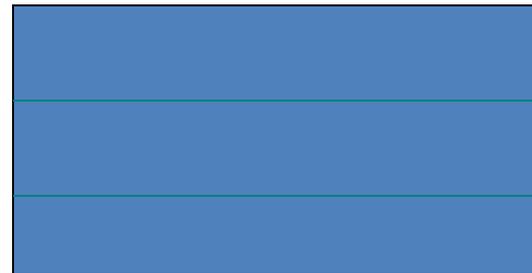
Surface
intersects
globe

= two *standard lines*

Standard line

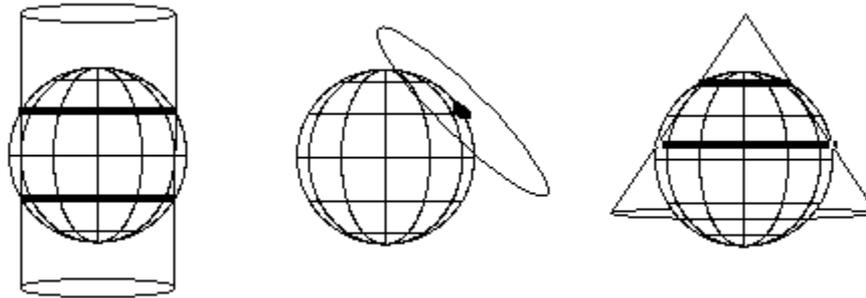


Standard line



Standard line

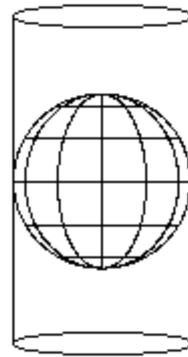
Standard Lines or Point



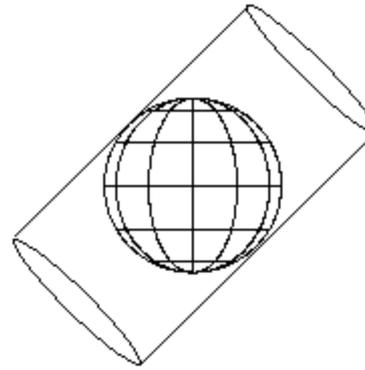
standard point/lines: on a projected map, the location(s) free of all distortion at the exact point or lines where the surface (cylinder, cone, plane) touches the globe.

Projection Aspects

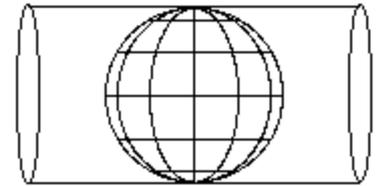
cylindrical



REGULAR

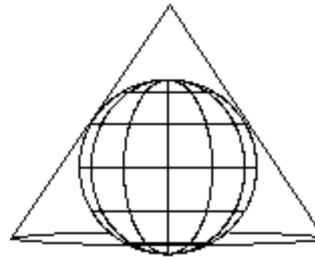


OBLIQUE

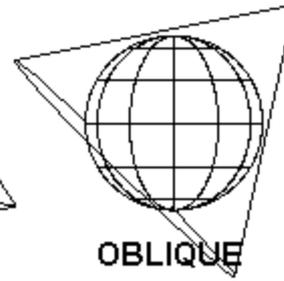


TRANSVERSE

conical

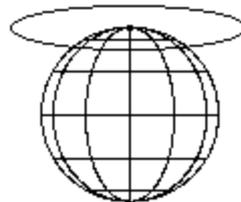


REGULAR

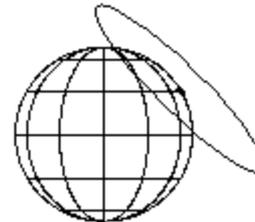


OBLIQUE

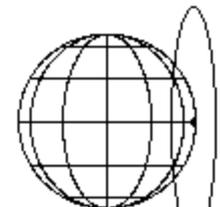
planar



POLAR



OBLIQUE



EQUATORIAL

Preservation of Properties

- Map projections always introduce some sort of distortion. How to deal with it?
 - Choose a map projection that *preserves the globe properties* appropriate for the application
- Note: The preservation of properties offers an alternative -- perhaps more meaningful -- way to categorize projections

Map projections distortion

Projections cause distortion. The projection process will distort one or more of the four spatial properties listed below. Distortion of these spatial properties is inherent in any map.

Shape

Area

Distance

Direction

Preservation of properties

Conformal projections

- -preserve *shape*
- shape preserved for local (small) areas
(angular relationships are preserved at each point)
- sacrifices preservation of area away from standard point/lines

Equivalent/Equal-Area projections

- -preserve *area*
- all areas are correctly sized relative to one another
- sacrifices preservation of shape away from standard point/lines

Equidistant projections

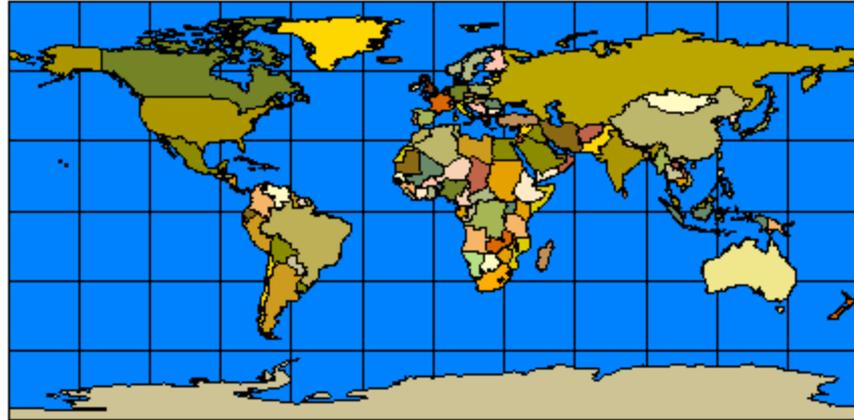
- -preserve *distance*
- scale is correct from one to all other points on the map, or along all meridians
- however, between other points on map, scale is incorrect

Azimuthal projections

- -preserve *direction*
- azimuths (lines of true direction) from the center point of the projection to all other points are correct

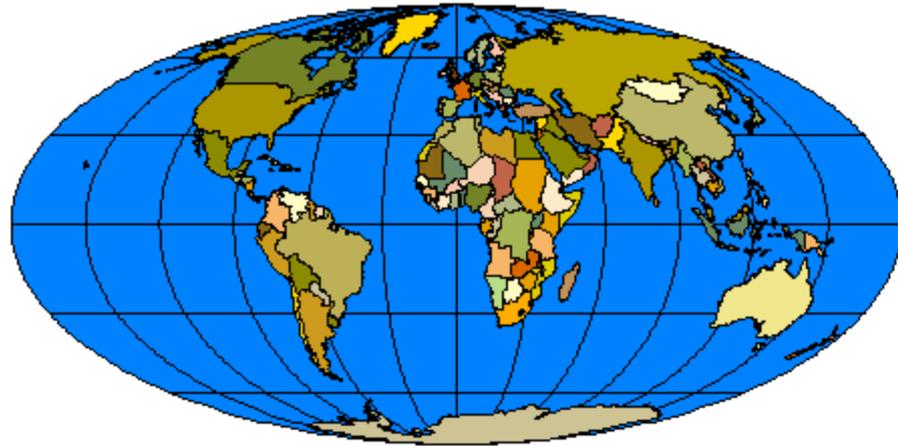
Famous (and frequent) projection issue...

Mercator
(conformal)

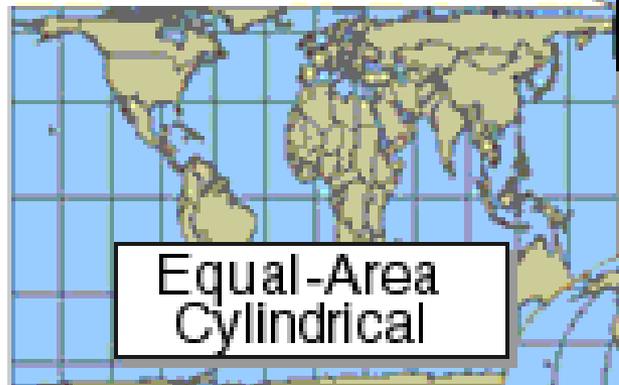
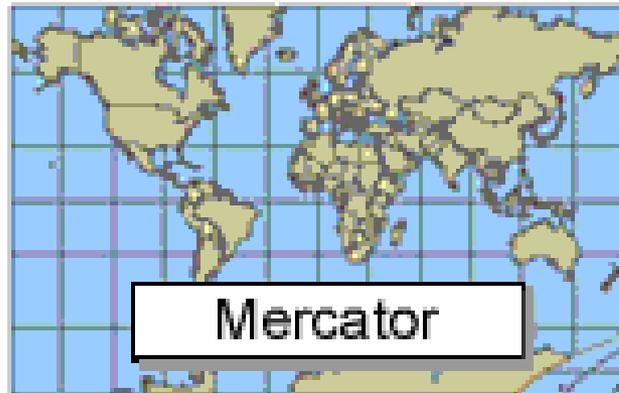


**why not use other (many)
more appropriate
projections?**

e.g., Mollweide
(equal area)



3-11 Map projections distortion (Cont.)



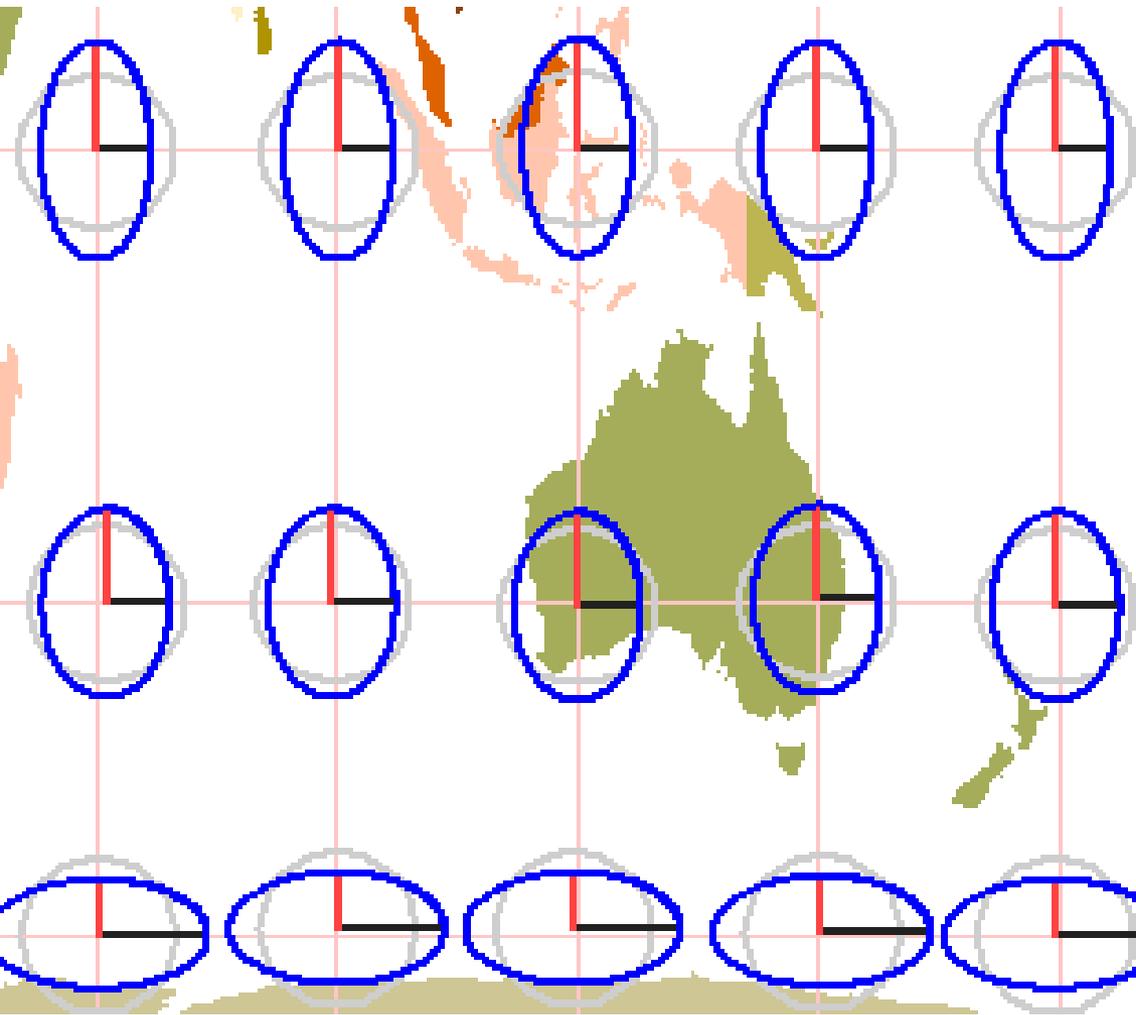
The Mercator projection maintains shape and direction.

The Sinusoidal and Equal-Area Cylindrical projections both maintain area, but look quite different from each other.

The Robinson projection **does not enforce any specific properties** but is widely used because it makes the earth's surface and its features "look right."

Tissot's Indicatrix

The Tissot indicatrix is a figure that shows how a projection changes the geometry. It does so in a simple manner: by showing what a circle would look like on the map.



This is an *equal area* projection.

Blue circles are the projected circles (here, ellipses).

Grey circles are reference circles.

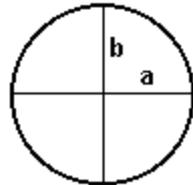
Radii are for reference regarding distance distortion.

Area scale

An indicator of distortion on projected maps.

s = "area scale" = product of semi-axes of circle/ellipse.

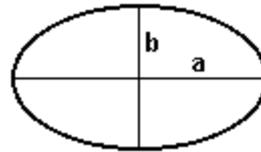
UNPROJECTED



$$\begin{aligned} a &= b = 1 \\ \text{(unprojected)} \\ s &= a * b \\ &= 1 \end{aligned}$$

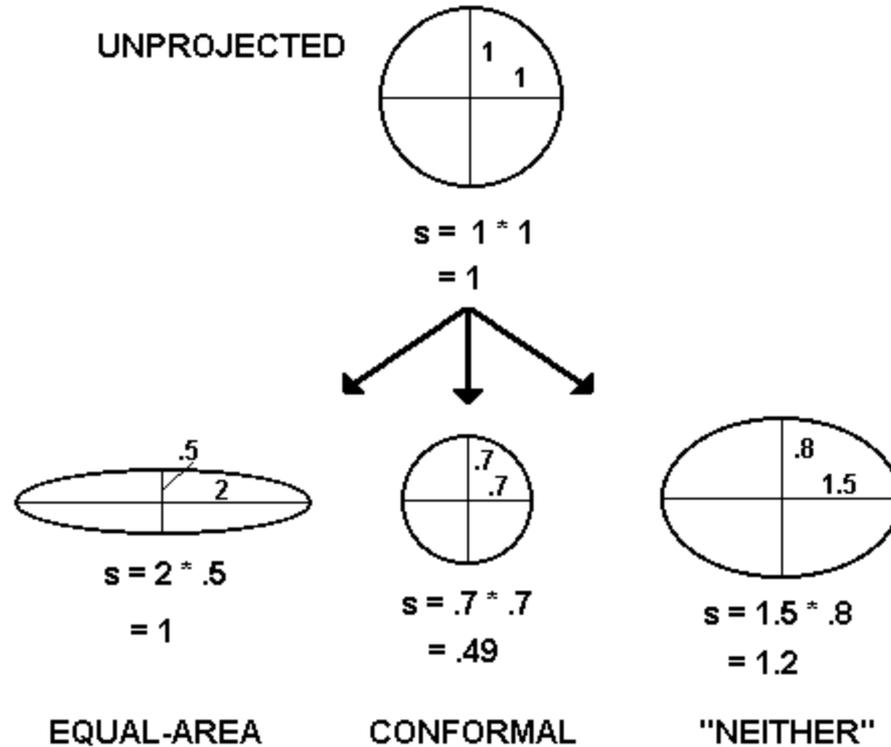
distortion
introduced

PROJECTED



$$\begin{aligned} s &= a * b \\ &= ?? \\ \text{depends on projection} \\ &\text{and location} \end{aligned}$$

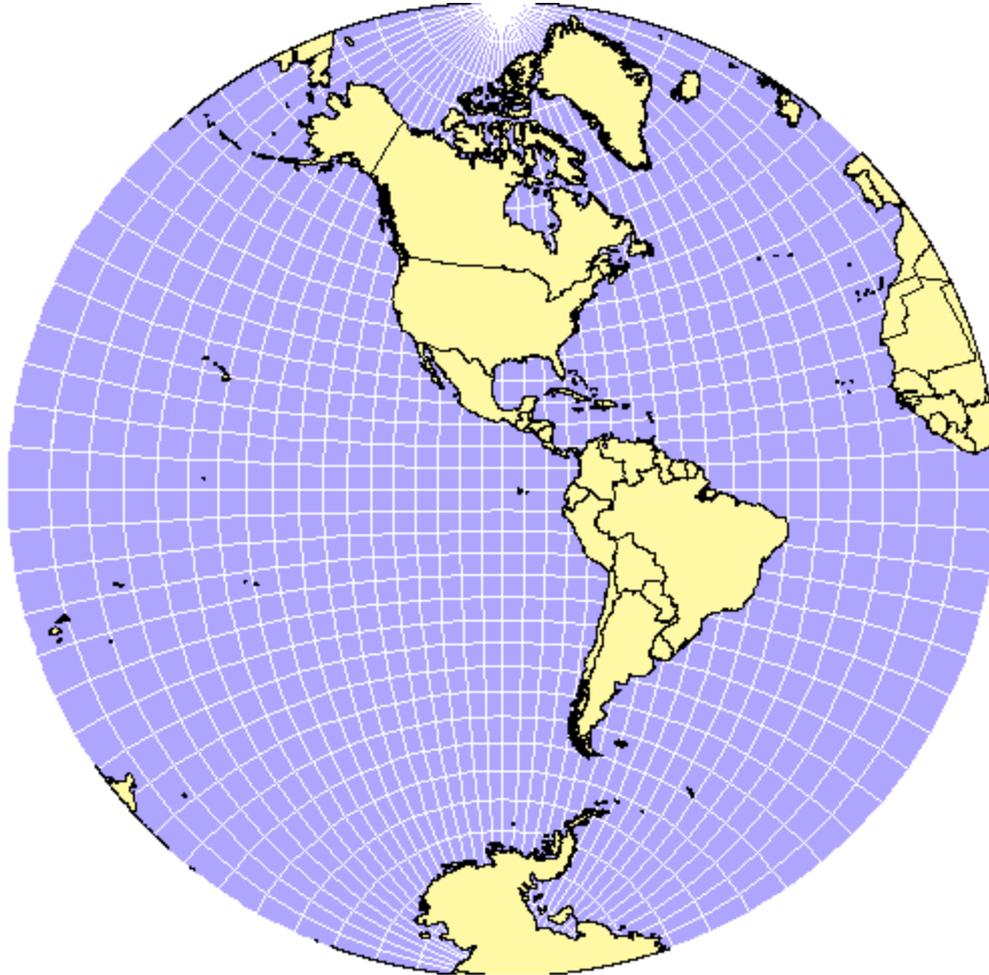
Conformal vs. Equal-area projections



Examples of projections

- Do the following examples clear up some myths we have grown to believe?

Conformal example

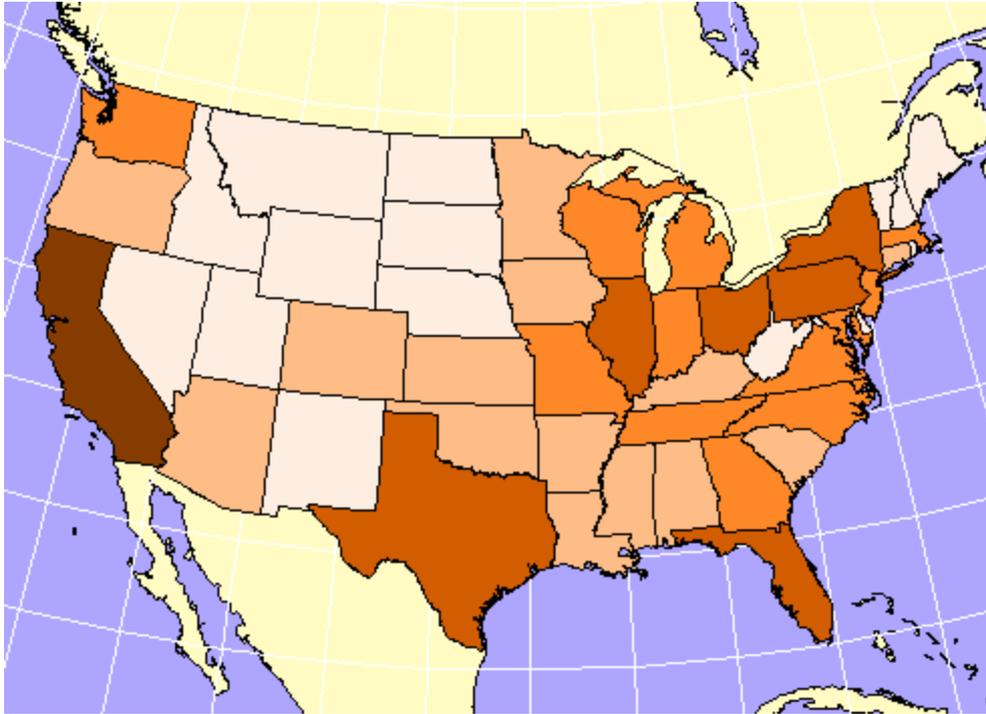


Stereographic
projection

- planar with equatorial
aspect

Myth:
Antarctica's shape

Equal-area example

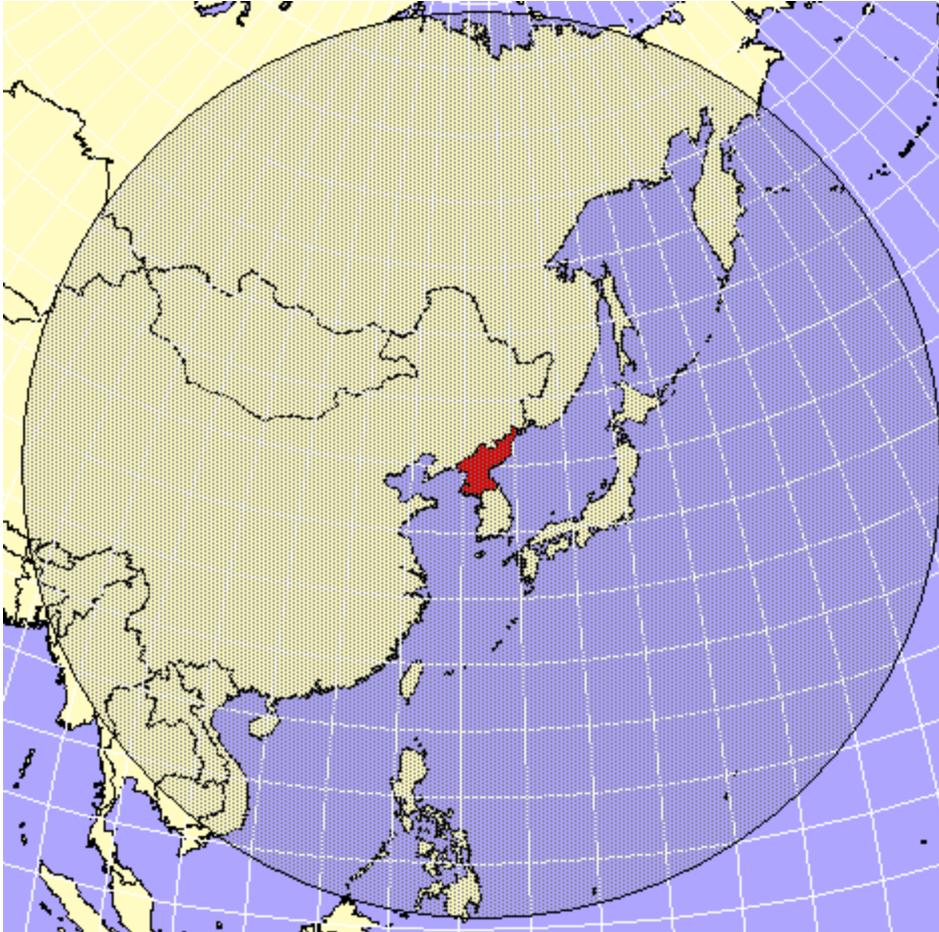


Albers Equal Area
projection

- conic with two standard
lines

Population density map

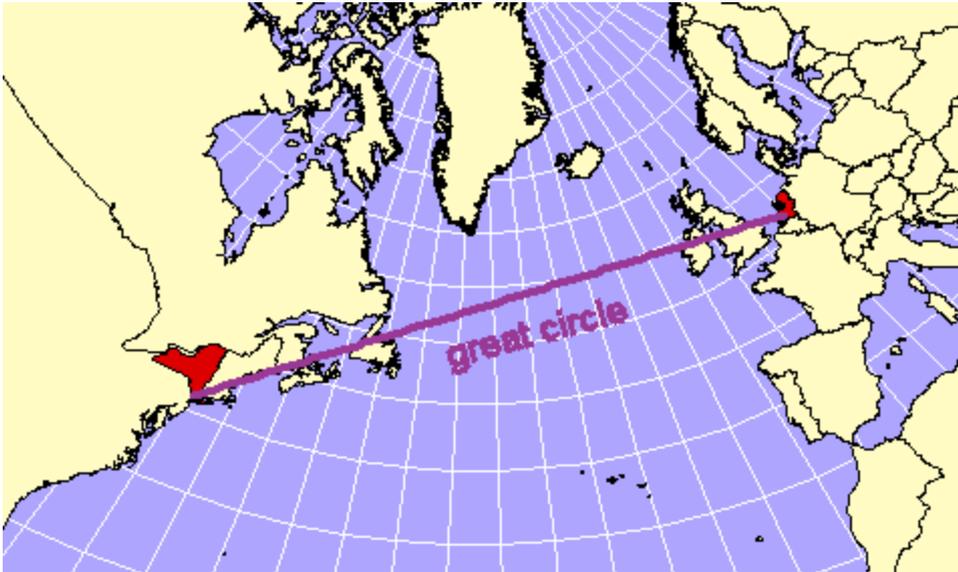
Equidistant example



Azimuthal Equidistant
projection

- planar with standard
point centered on North
Korea

True direction



Gnomonic

- planar with standard point

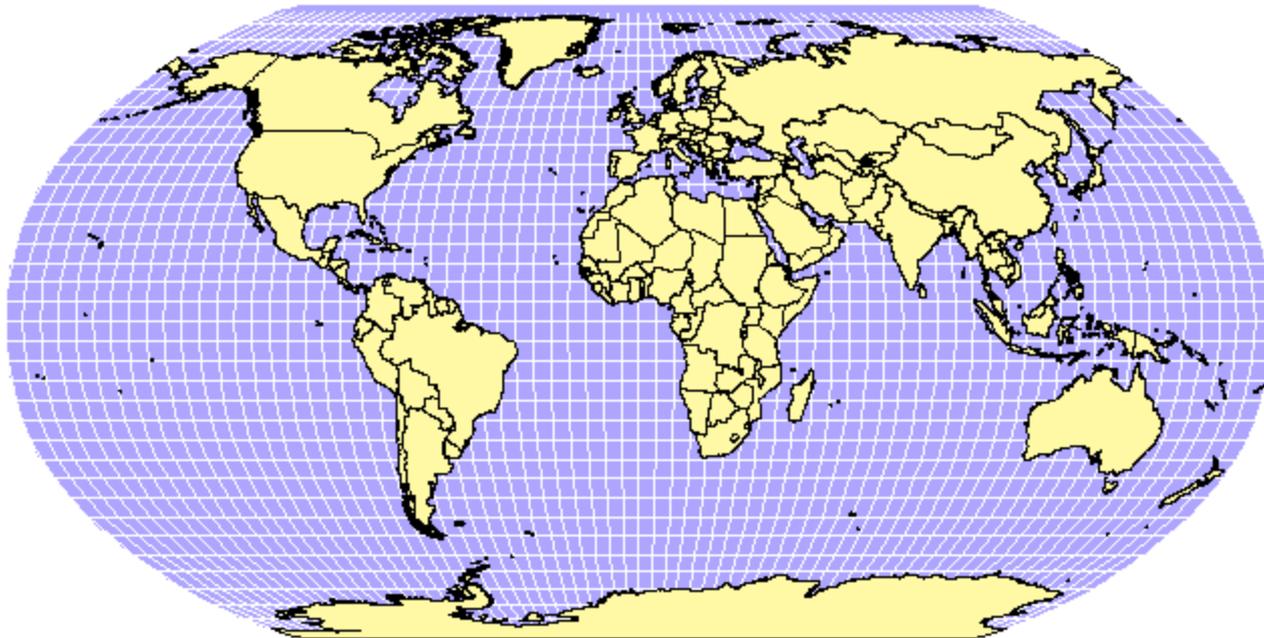
...compare with Mercator projection:



Compromise projections

- ...don't preserve any properties completely, but achieve compromise between them

Example: Robinson projection - designed for world maps

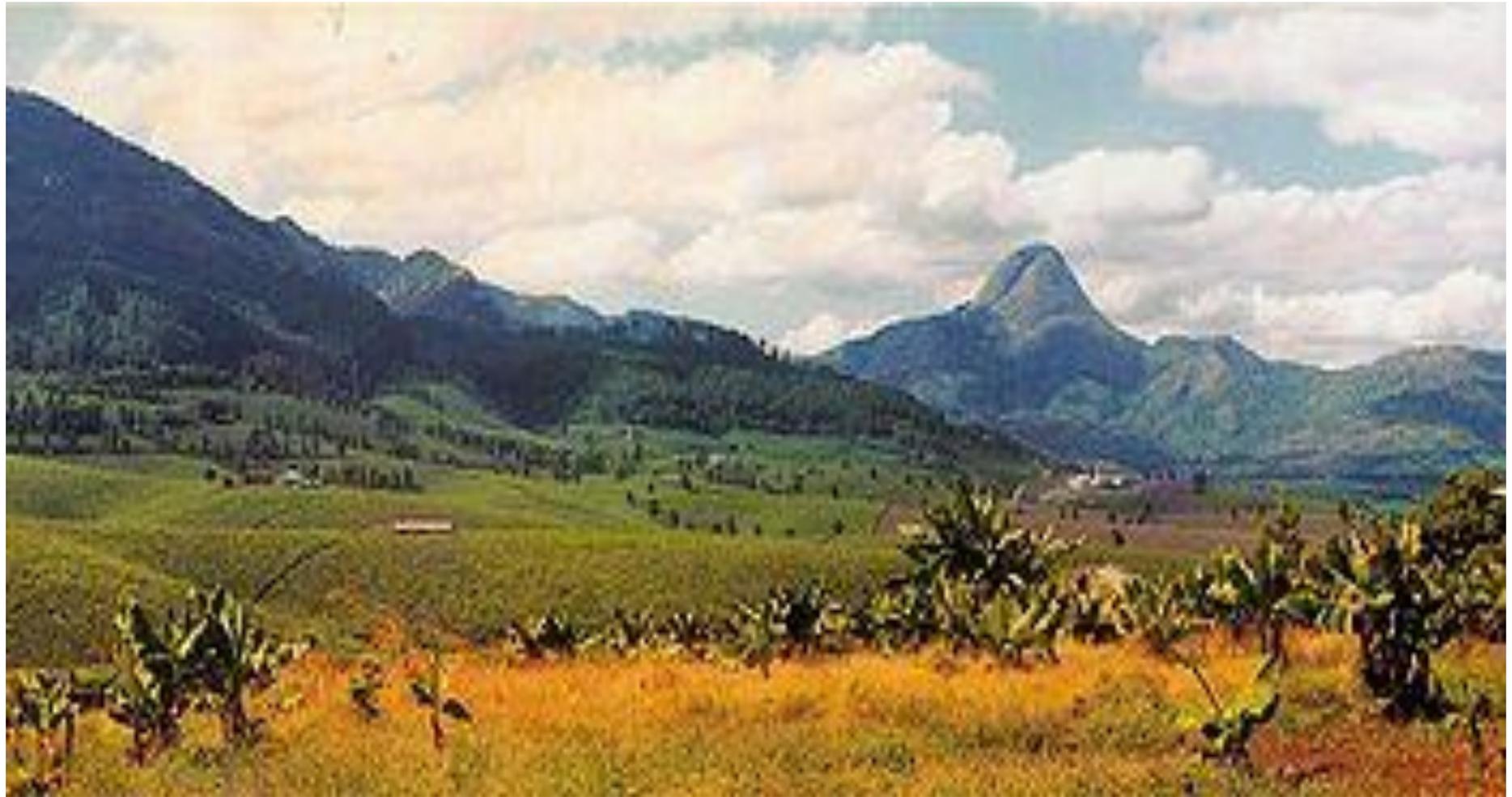


Landscape

- **Landscape** comprises the visible features of an area of land, including the physical elements of landforms such as:
 - (ice-capped) mountains,
 - hills,
 - water bodies such as rivers, lakes, ponds and the sea,
 - living elements of land cover including indigenous vegetation, human elements including different forms of land use, buildings and structures, and
 - transitory elements such as lighting and weather conditions.

- Combining both their physical origins and the cultural overlay of human presence, often created over millennia, landscapes reflect the living synthesis of people and place **vital to local and national identity.**
- Landscapes, **their character and quality**, help **define the self-image of a region**, its sense of place that differentiates it from other regions. It is the dynamic backdrop to people's lives.

- The Earth has a vast range of landscapes including the:
 - icy landscapes of polar regions,
 - mountainous landscapes,
 - vast arid desert landscapes,
 - islands and coastal landscapes,
 - densely forested or wooded landscapes including past boreal forests and tropical rainforests, and
 - agricultural landscapes of temperate and tropical regions.
- Landscape may be further reviewed under the following specific categories:
 - cultural landscape,
 - landscape ecology,
 - landscape planning,
 - landscape assessment and
 - landscape design.



- Diversified and partly man-shaped landscape



- The mountains and forests are an example of landscapes that can be perceived and valued as natural and pristine.

