TEMPLE UNIVERSITY®

Geovisualization

Principles of Cartography and GIS in a Nutshell

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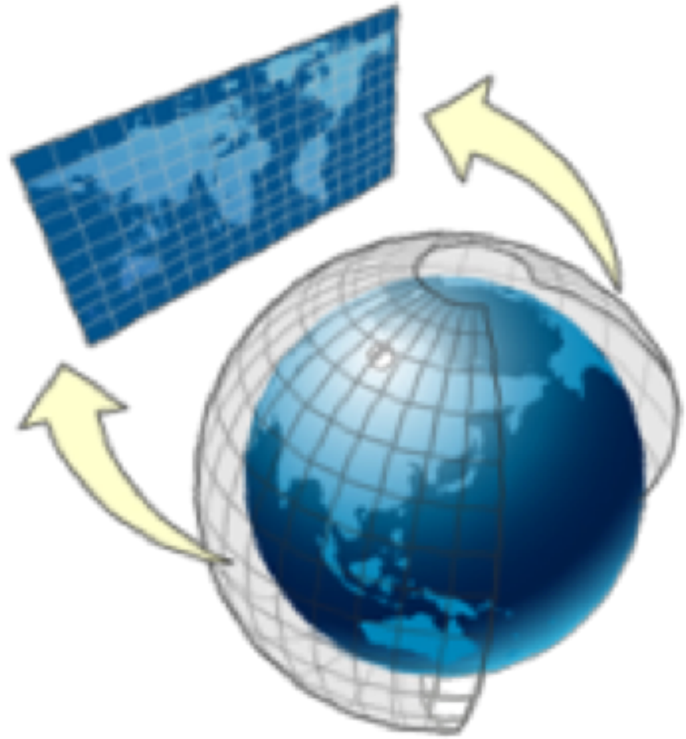
Today's agenda

- Mapping principle
- Scale
- Generalization
- Coordinate system
- Projections



In class exercises

Configure Python programing environment and Python basics

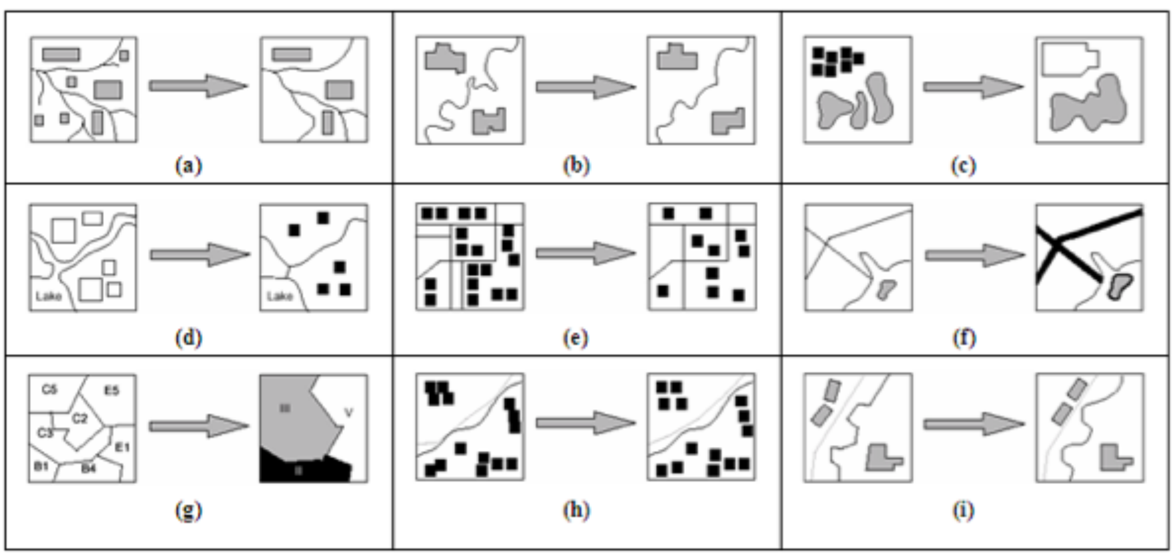
Learning objectives

1. Maps as Models

- Understand the reason for abstraction inherent in map making

2. Generalization and Scale

- Understand how scale is expressed on a map
- Understand why generalization is necessary and ubiquitous in cartography, GIS, and geovisualization
- Differentiate between model generalization and cartographic generalization



Learning objectives

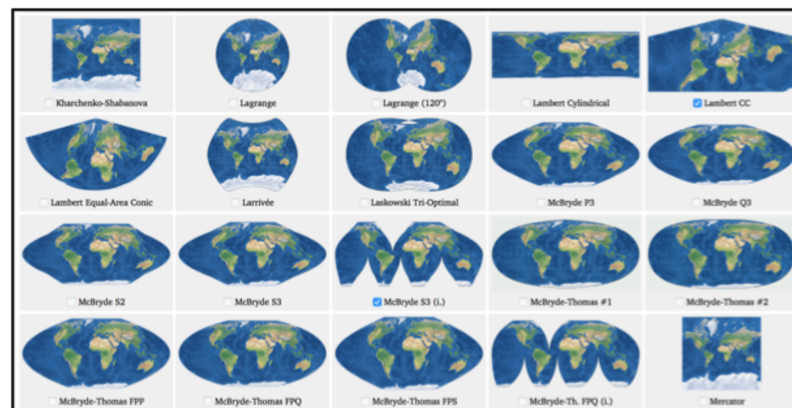
3. Coordinate System

- Describe models used to represent the shape of the Earth
- Distinguish between spherical and planar coordinate systems

4. Projections

- Describe the geometric properties of the globe that may be distorted in the map projection process

- Understand how to visualize distortion using Tissot's indicatrices



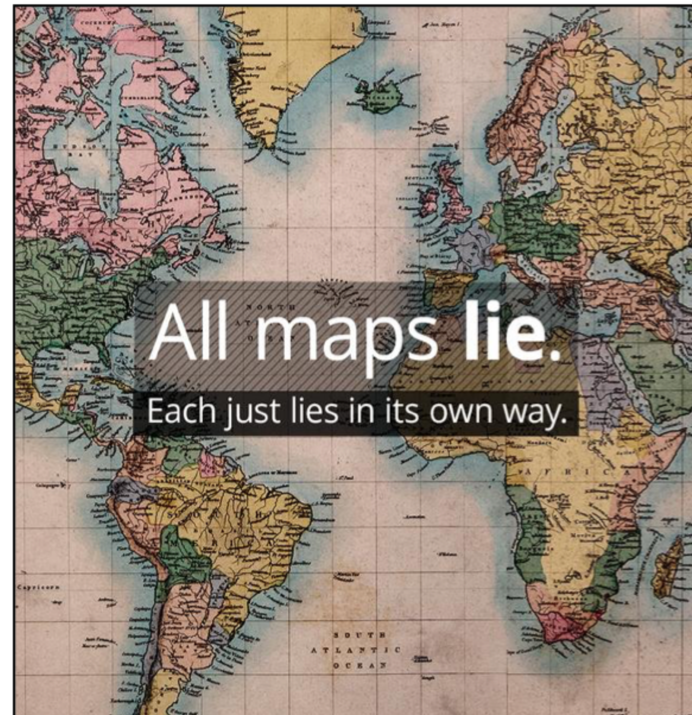
Why Care about Mapping Principles?

All maps lie – to some extent

- Projections introduce shape, area, distance, and directional distortion
- Maps simplify the world and lie by omission
- Map symbols exaggerate and minimize the extent of features

Not only is it easy to lie with maps, it's essential!

- "A good map tells a multitude of white lies; it suppresses the truth to help the user see what needs to be seen" (Mark Monmonier, How to Lie with Maps, 1996, p. 25)

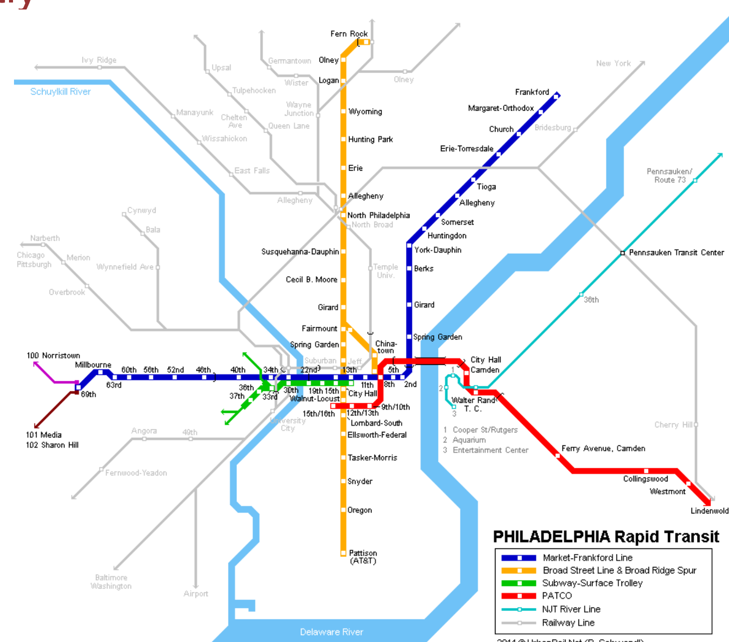


Maps as Models

Maps are models of reality

- Emphasize some aspects of reality in a cartographic representation while ignoring or greatly simplifying other aspects of reality
- Abstraction leads to greater communication and understanding

Strava heat map



Rapid transit map

Maps as Models

A map is a reduced, selective, and symbolized graphical representation of the environment.

❑ Reduction

Scale refers to the amount of reduction that has taken place on a given map

❑ Selection

- It is impossible to show every feature or phenomenon
- It is the cartographer's job to decide what to show, and what to omit, based on the purpose of the map

❑ Symbolization

- Everything on a map is a symbol that represents a feature or phenomenon
- All symbols are abstract, but some more than others

Scales

Small scale (coarse) **Large Scale (fine)**

Three definitions of Scales

Geographic scale

- Extent of the study area (neighborhood, city, region, etc.)
- Large scale = large area

Cartographic scale

- Representative fraction (RF)
- Large scale = small area with lots of details

Data resolution

- Denotes granularity of the data (Census tracts, block groups, etc.)
- Low resolution = coarse
- High resolution = finer grains

Cartographic Scale

Relationship between distance on the map and distance on the ground

1 : 24,000	numeric scale/representative fraction
1 inch = 24,000 inch = 2000 ft	verbal scale
1 2000 ft	graphic scale: bar scale

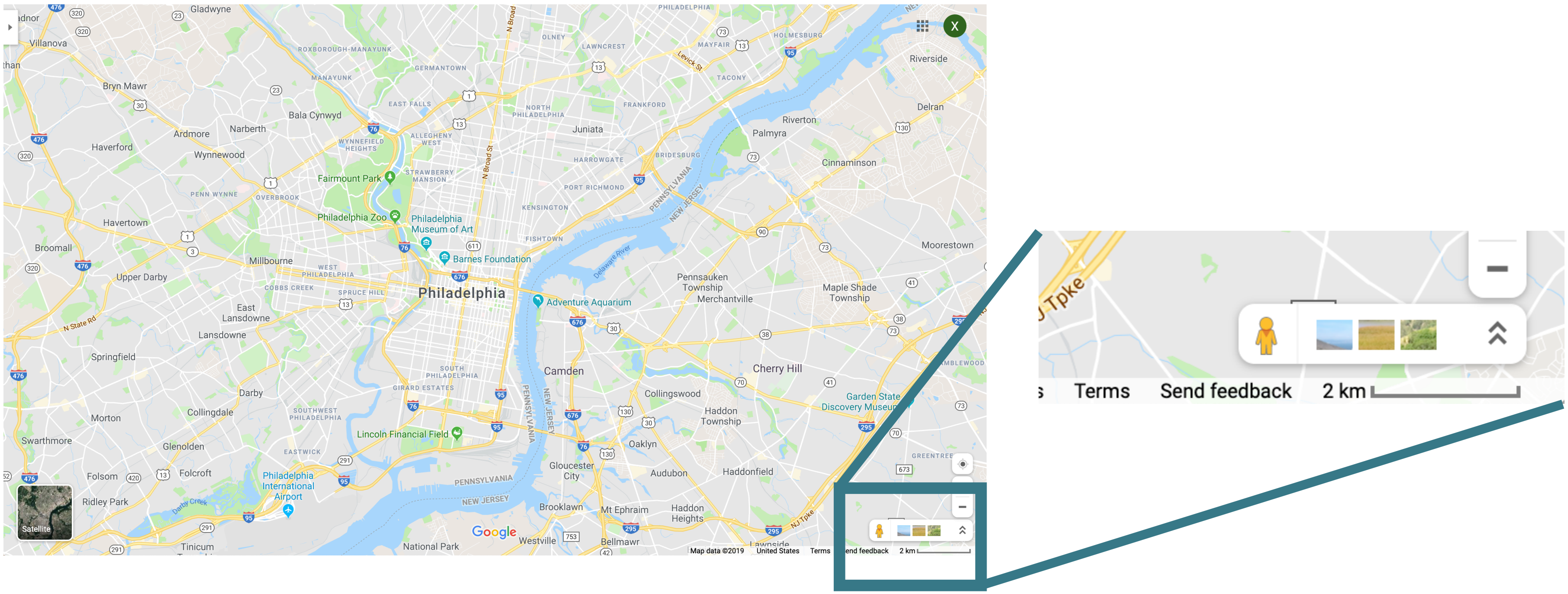
Large Scale (fine) 1:20,000

Large scale = zoomed in
think LARGE and detailed features

Small Scale (coarse) 1:200,000,000

Small scale = zoomed out
think SMALL and generalized features

Cartographic Scale



Cartographic Convention for Expressing Scale

Scale Class	Representative Fraction	Verbal scale	Examples
Large Scale	1:24,000	1 inch to 2,000 ft	USGS Topographic Map
	1:63,360	1 inch to 1 mile	USGS Topographic Map
Medium Scale	1:500,000	1 cm to 5 km	Aeronautical Chart
Small Scale	1:10,000,000	1 cm to 100 km	Continental Maps
	1:100,000,000	1 inch to 1,000 km	World Maps

Scale implications

Selection and Generalization

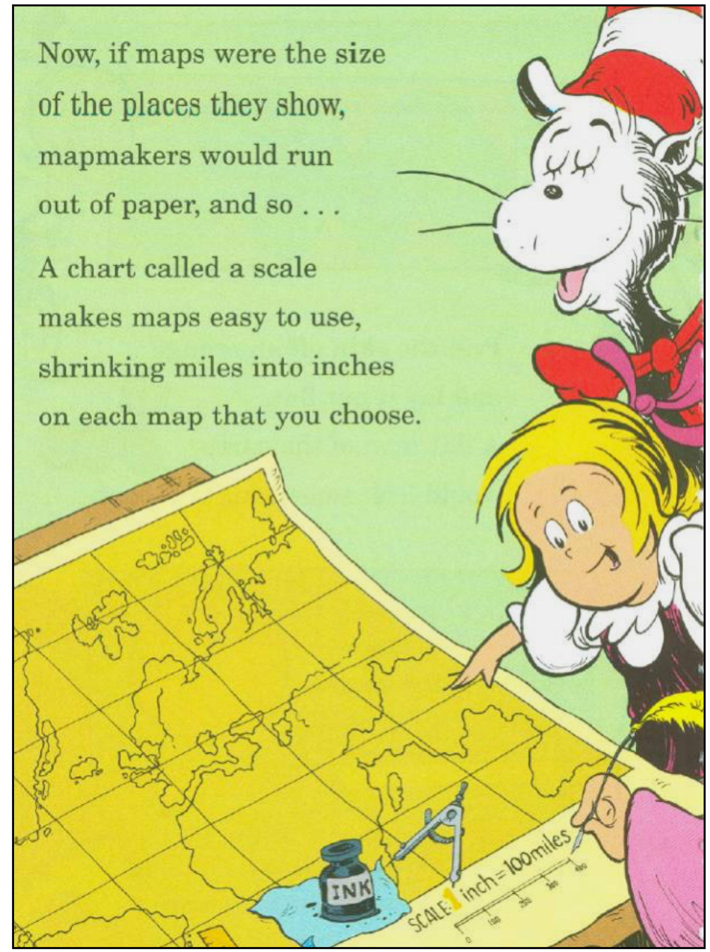
- Scale changes often drive the need to perform generalization

Cartographic generalization

Process by which geospatial data undergo abstraction

Reducing the information content of maps

- scale change
- map purpose
- intended audience
- technical constraints



Cartographic generalization

When is generalization required?

Congestion

- Too many objects are compressed into a small space

Coalescence

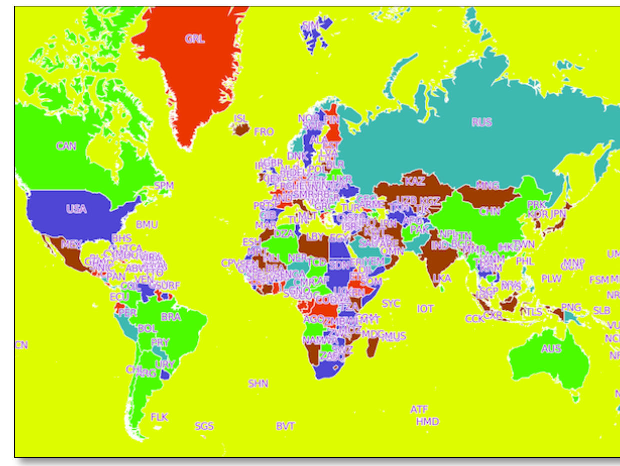
- Features graphically collide or self-intersect

Conflict/Complication

- Inconsistency between or among features
- Problems that occur due to a specific spatial configuration

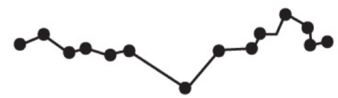
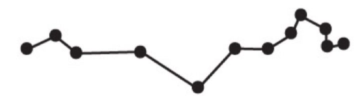
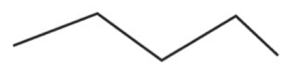
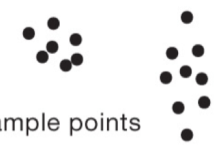
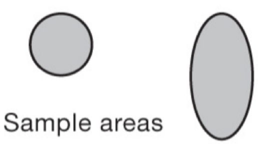
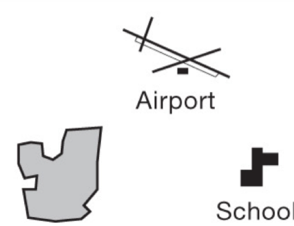
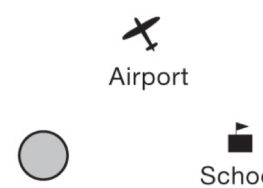
e.g, river that flows hill up after generalization of contour lines

Aesthetics



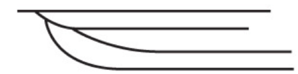
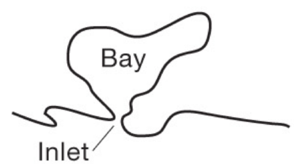
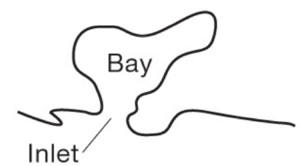
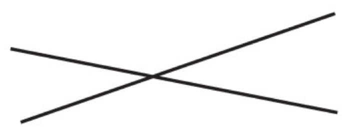
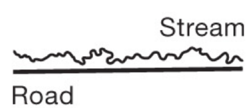
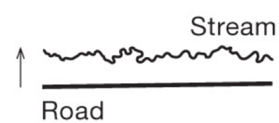
Slocum 6.3

Generalization Tasks (I)

Spatial Operator	Original Map	Generalized Map
Simplification Selectively reducing the number of points required to represent an object	 15 points to represent line	 13 points to represent line
Smoothing Reducing angularity of angles between lines		
Aggregation Grouping point locations and representing them as areal objects	 Sample points	 Sample areas
Amalgamation Grouping of individual areal features into a larger element	 Individual small lakes	 Small lakes clustered
Collapse Replacing an object's physical details with a symbol representing the object	 Airport School City boundary	 Airport School Presence of city

Slocum 6.3

Generalization Tasks (II)

Spatial Operator	Original Map	Generalized Map
Merging Grouping of line features	 All railroad yard rail lines	 Representation of railroad yard
Refinement Selecting specific portions of an object to represent the entire object	 All streams in watershed	 Only major streams in watershed
Exaggeration To amplify a specific portion of an object		
Enhancement To elevate the message imparted by the object	 Roads cross	 Roads cross; one bridges the other
Displacement Separating objects		

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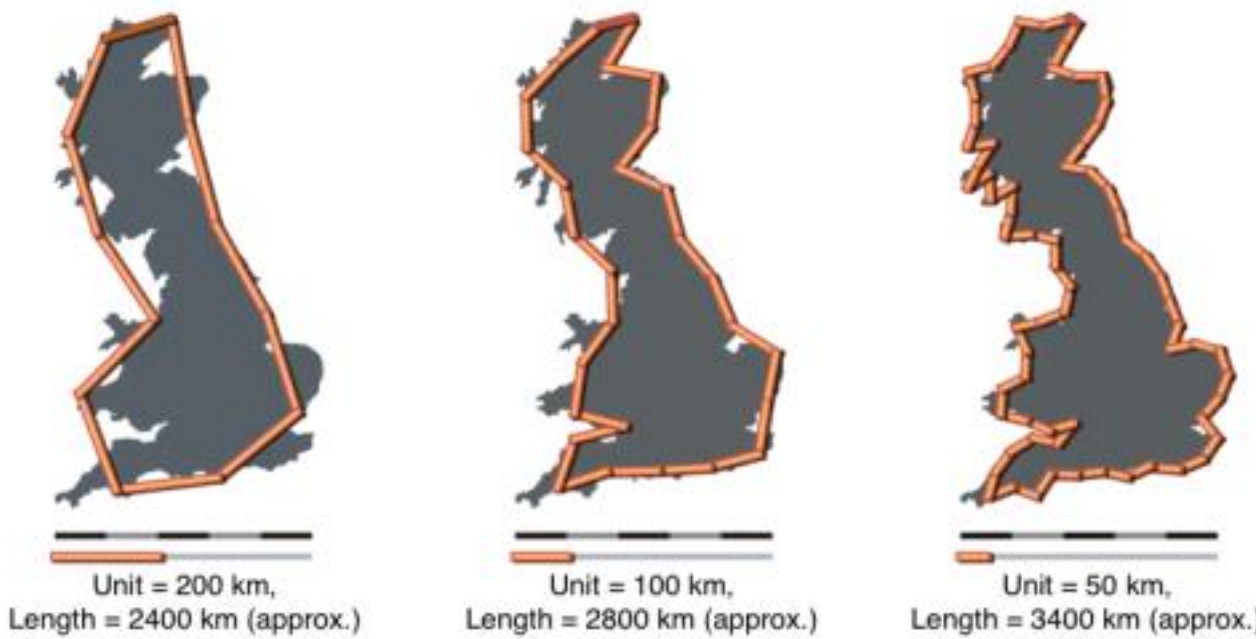
Model generalization

- Typically for data-reducing
- Motivated by desire for economy in storage space or computational complexity
- Implications on analysis: generalization can reduce accuracy and precision



Additional Resources

Free web-based generalization tool

- http://mapshaper.org

The International Cartographic Association (ICA) Commission on Generalization and Multiple Representation

- http://generalisation.icaci.org

ScaleMaster interactive demonstration

- http://ScaleMaster.org

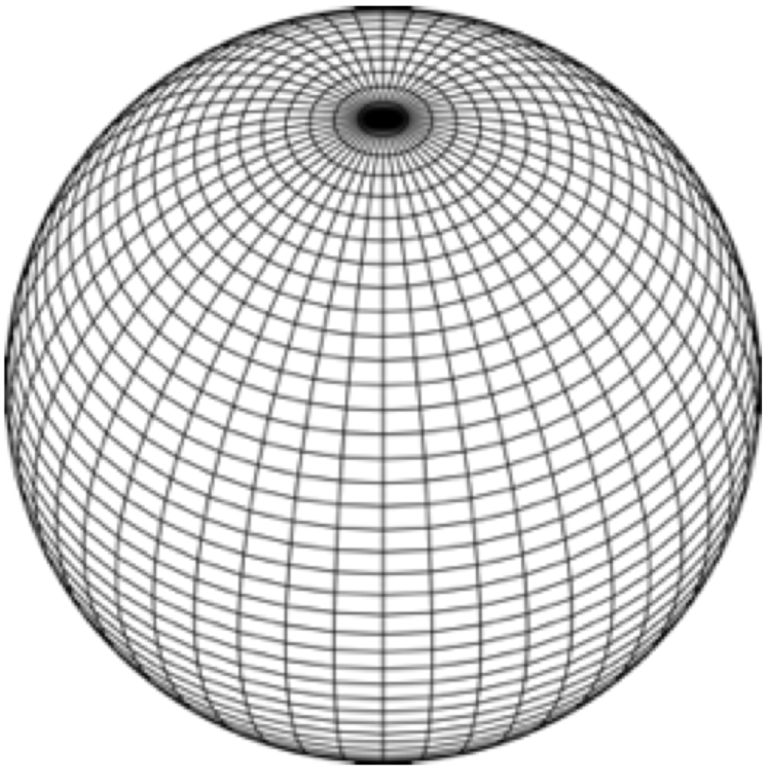
Geographic Information Technology Training Alliance (GITTA). 2006. Generalization of Map Data

- http://www.gitta.info/Generalisati/en/html/index.html


ANY
QUESTIONS
?

Earth is not flat

Earth is a sphere



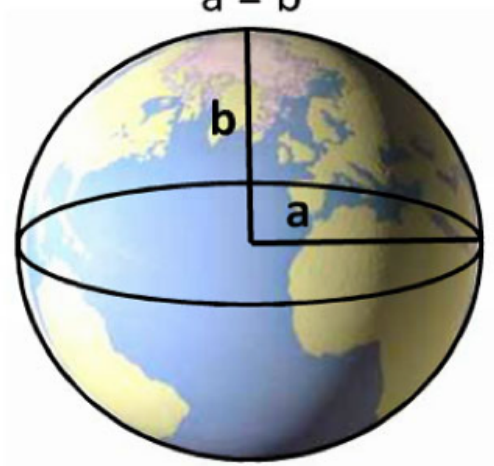
Coordinate Systems

Earth is a rotating ellipsoid

- Slightly flattened sphere (compressed from north to south)
- Slightly bulging round the equator

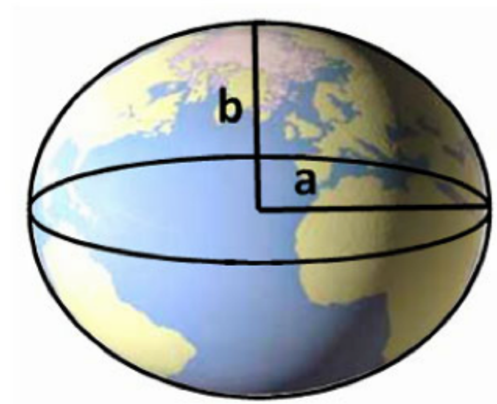
Sphere

$a = b$



Ellipsoid

$a > b$

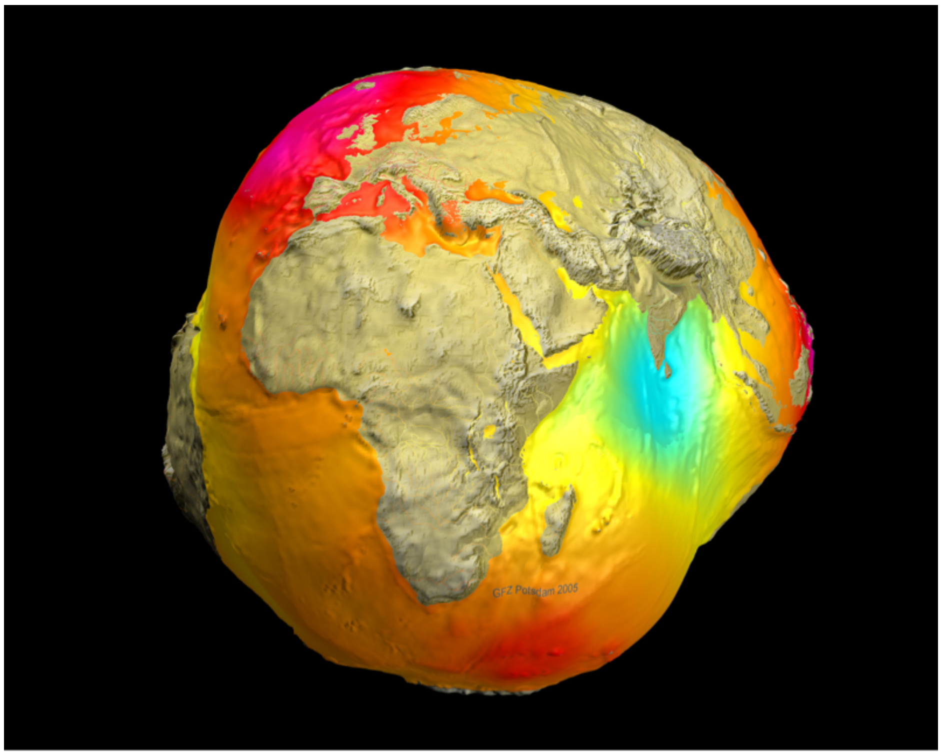


a = Semi major axis

b = Semi minor axis

$\frac{a-b}{a}$ = flattening

Earth is shaped like a lumpy Potato



https://apod.nasa.gov/apod/ap141215.html

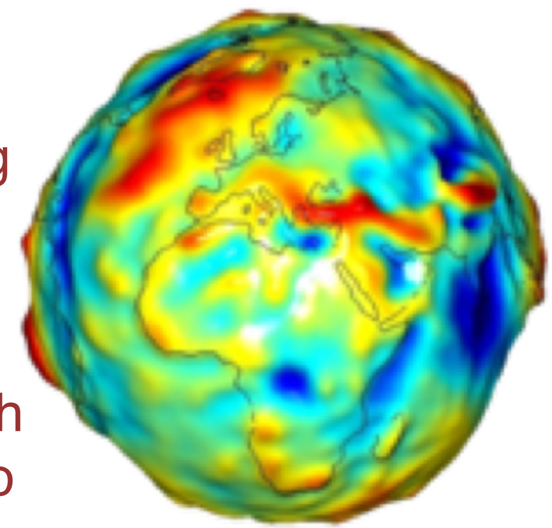
Potsdam Gravity Potato

Red areas indicate slightly stronger than usual gravity, while blue indicates slightly weaker gravity

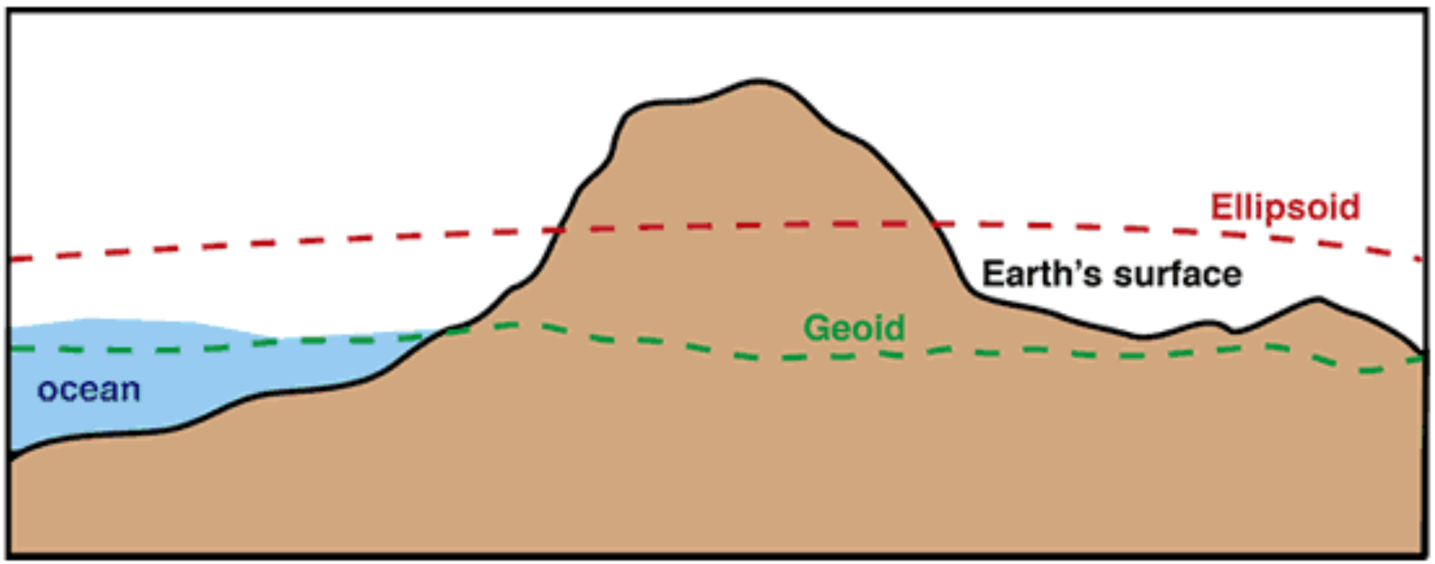
Earth is a Geoid

Geoid

- A standard surface of equal gravitational pull (equipotential surface)
- Shape of an idealized sea-level surface extending around the entire globe
- Results from the uneven distribution of mass
- within and on the Earth’s surface
- Does not correspond to actual surface of the Earth
- “true physical figure of the Earth” that defines zero elevation



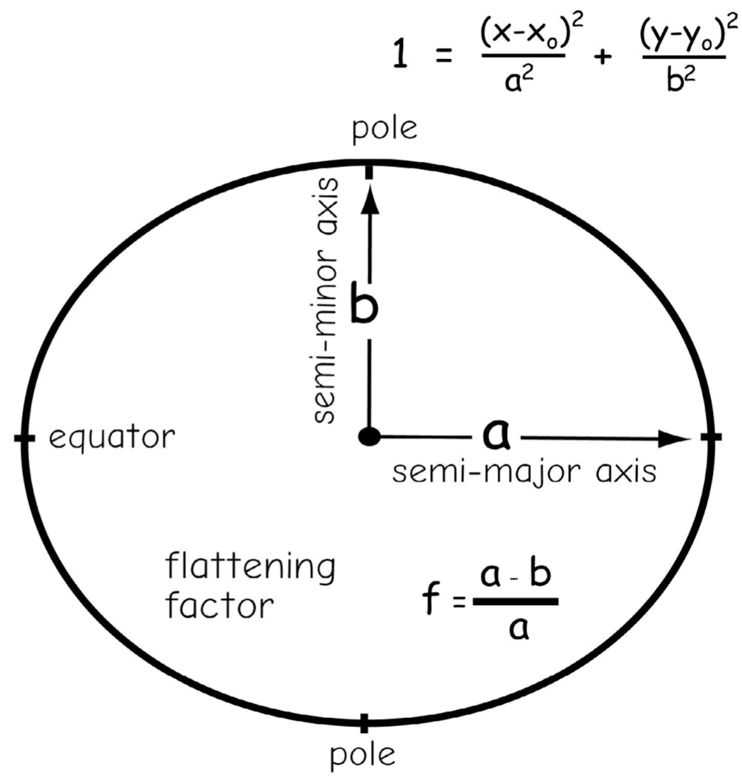
Geoid and Ellipsoid



Ellipsoid as reference Earth surface

Reference Ellipsoids

- Often used instead of geoids
- Idealized surfaces (perfectly smooth)
- Designed to approximate the actual geoid as close as possible
- Used to relating any geographic location to a standard reference system

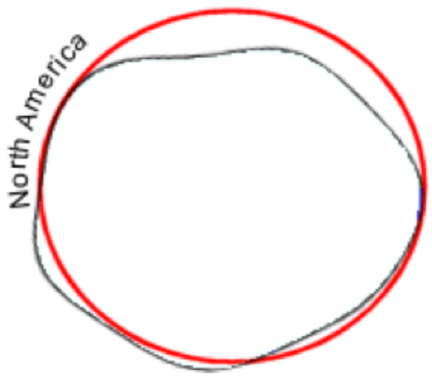


Ellipsoid as reference Earth surface

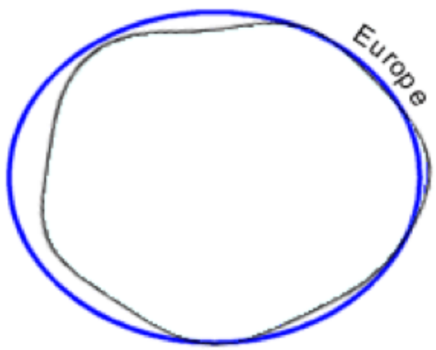
The *ellipsoid* (also called spheroid) provides a relatively simple mathematical figure of the Earth. t is used to measure locations, the latitude and longitude, of points of interest. These locations on the ellipsoid are then projected onto a mapping plane. There are many different ellipsoids defined in the world, some well-known are the WGS84, GRS80, International 1924 (also known as Hayford), Krasovsky, Bessel, or the Clarke 1880 ellipsoid.

Ellipsoid as reference Earth surface

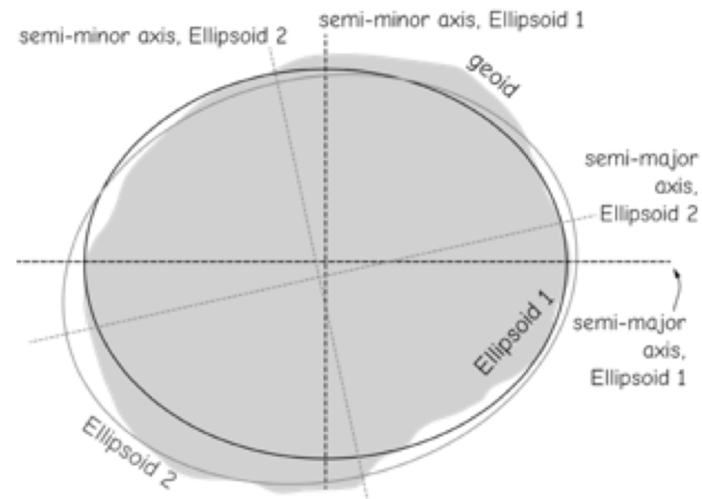
- Because of geoidal variation in the Earth's shape, different ellipsoids are used in different parts of the world.
- It is important to select the ellipsoid that best fits the geoid at the region of interest



The red ellipsoid fits the geoid well in North America.



The blue ellipsoid fits the geoid well in Europe.



Many Ellipsoids are used!

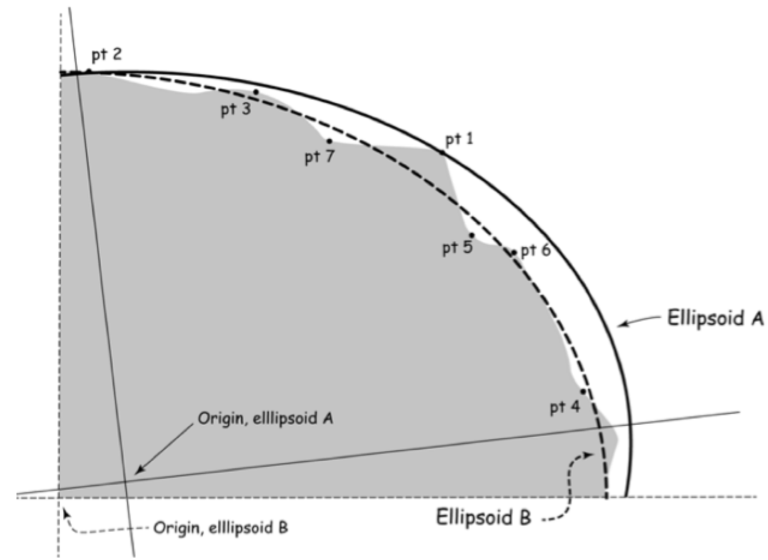
Ellipsoid	Semi-major axis (a)	1/flattening (f)
Airy 1830,	6377563.396	299.3249646
Australian National	6378160	298.25
Bessel 1841 (Namibia)	6377483.865	299.1528128
Bessel 1841	6377397.155	299.1528128
Clarke 1866,	6378206.4	294.9786982
Clarke 1880,	6378249.145	293.465
Everest (India 1830)"	6377276.345	300.8017
Modified Fischer 1960	6378155	298.3
Helmert 1906	6378200	298.3
Hough 1960	6378270	297
International 1924	6378388	297
Krassovsky 1940	6378245	298.3
GRS 80	6378137	298.2572221
South American 1969	6378160	298.25
WGS 72	6378135	298.26
WGS 84	6378137	298.2572236

Sample of ellipsoids from Peter Dana's website: http://www.colorado.edu/geography/gcraft/notes/datum/edlist.html

Geodetic Datum (I)

Geodetic Datum describes the shape of the Earth in mathematical terms. A datum defines the radius, inverse flattening, semi-major axis and semi-minor axis for an ellipsoid.

- Reference surface
- Standard representation of shape and size of the Earth, as well as a reference point and orientation for a coordinate system
- Establishes a common basis for mapping a region



Necessary components

- Abstract coordinate system (spherical, cartesian, etc.) with origin
- Set of precisely measured points to specify a reference frame
- Points uniquely fix (locate and orient) the coordinate system

Geodetic Datum (II)

The National Geodetic Survey (NGS) establishes geodetic latitudes and longitudes of known points

- Precisely surveyed points are commonly
- known as benchmarks
- Starting points for subsequent, detailed, local surveys
- Control survey points are often identified with a number
- of nearby signs to aid in recovery

Examples of Geodetic Datums

North American Datum 1927 (NAD1927)

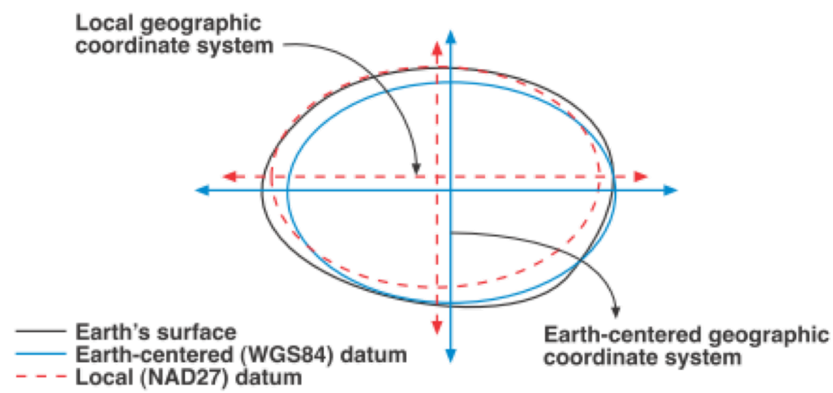
- Datum based on the Clarke Ellipsoid of 1866
- Was created by way of manual surveying of the entire continent
- Legacy datum

North American Datum 1983 (NAD1983)

- Datum based on a newer ellipsoid, GRS80
- Earth-centered reference

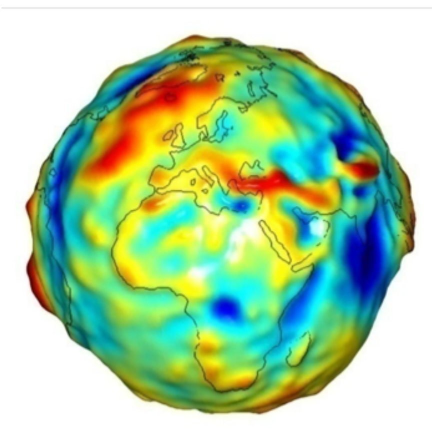
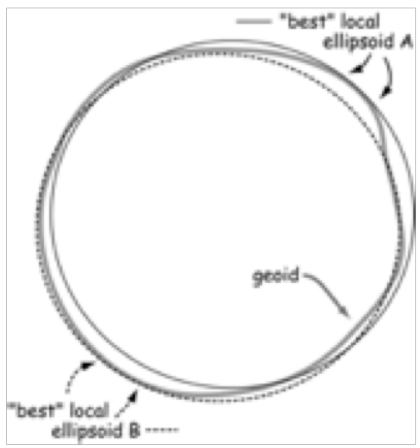
World Geodetic System 1984 (WGS1984)

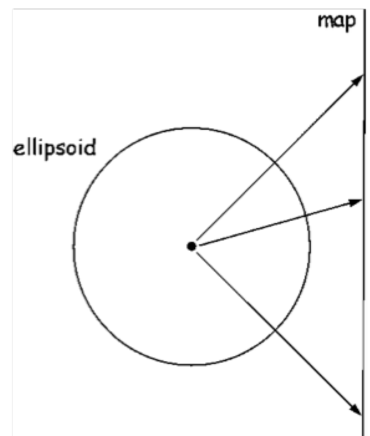
- Global datum, Designed to fit the geoid to be used anywhere on Earth
- WGS84 is standard for Global Positioning System(GPS)



From Earth to Map

Geoid is the "true" representation, but it is a measured and interpolated surface, and not a mathematically defined surface.



Geoid

Ellipsoid/Datum

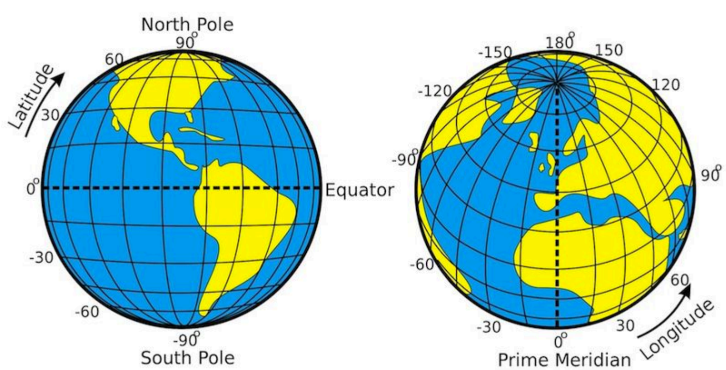
Map

Coordinate Systems

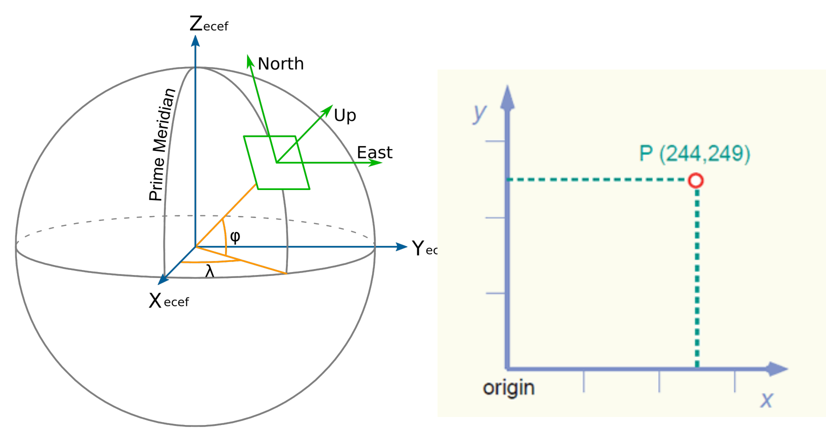
Provide a spatial referencing system to locate points on Earth's surface

- **Spherical coordinate system**
  Coordinates describe locations on sphere: Latitude and Longitude

- **Cartesian coordinate system**
  Coordinates describe locations within a Cartesian space: Easting (X) and Northing (Y)



Spherical coordinate



Cartesian coordinate

Spherical coordinate system

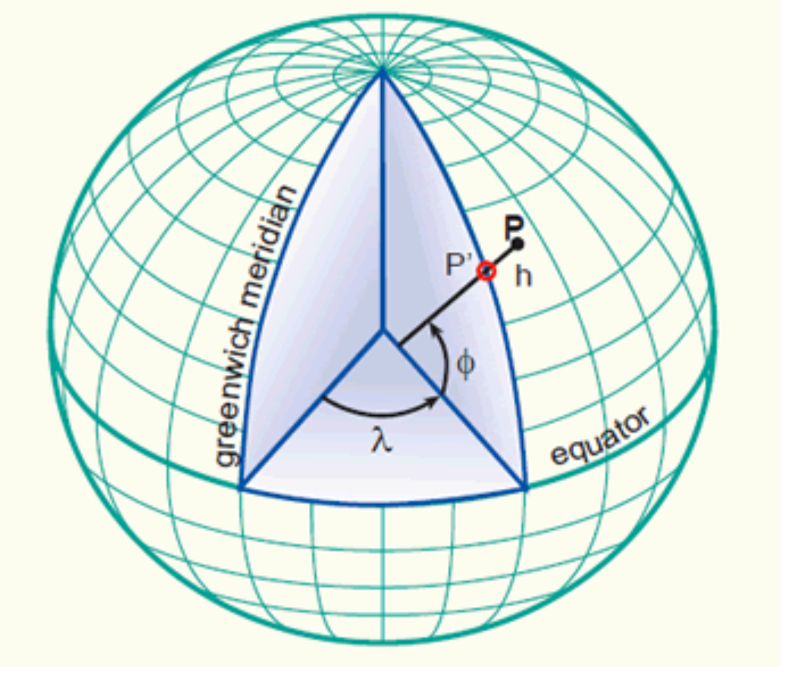
Spherical grid system showing parallels and meridians

❑ Parallels

- Lines parallel to equator
- Allow us to measure angular distance north and south (latitude)
- Up to a maximum of 90° north (North Pole) and 90° south (South Pole)

❑ Meridians

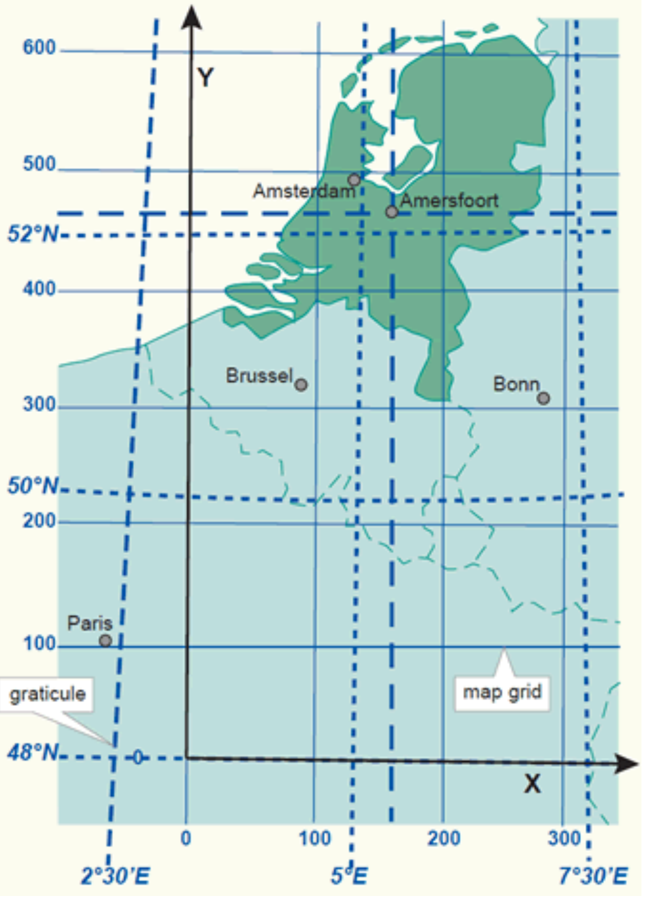
- Lines going from pole to pole
- Start at the prime meridian
- Allow us to measure angular distance east and west (longitude) up to a maximum of 180° where they would meet at the international date line



Cartesian coordinate system

A map usually be presented as flat, screen or paper

- A flat map has only two dimensions: width (left to right) and length (bottom to top).
- Two-dimensional Cartesian coordinates(x, y), also known as planar rectangular coordinates, are used to describe the location of any point in a map plane, unambigiously.




ANY
QUESTIONS
?

Flat map and Earth sphere

Previous version of Google Maps

Current Google Maps

Map projection

Earth is a big blue marble that's the shape of a sphere (or close to it). This is why a globe is the best way to represent the Earth.

A map usually be presented as flat, screen or paper

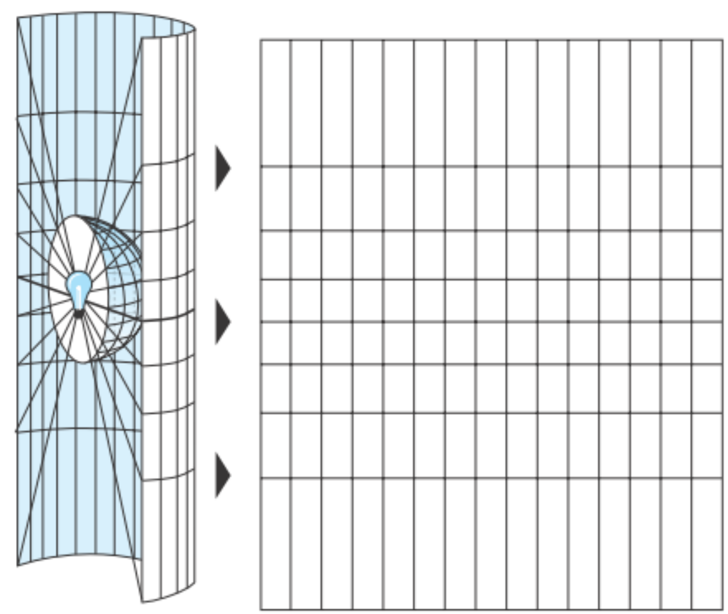
This is why we use map projections on globes and flatten it out in two-dimensions. But as you're about to find out, **you can't represent Earth's surface in two dimensions without distortion**.

Peel an Orange and Flatten the Peels !

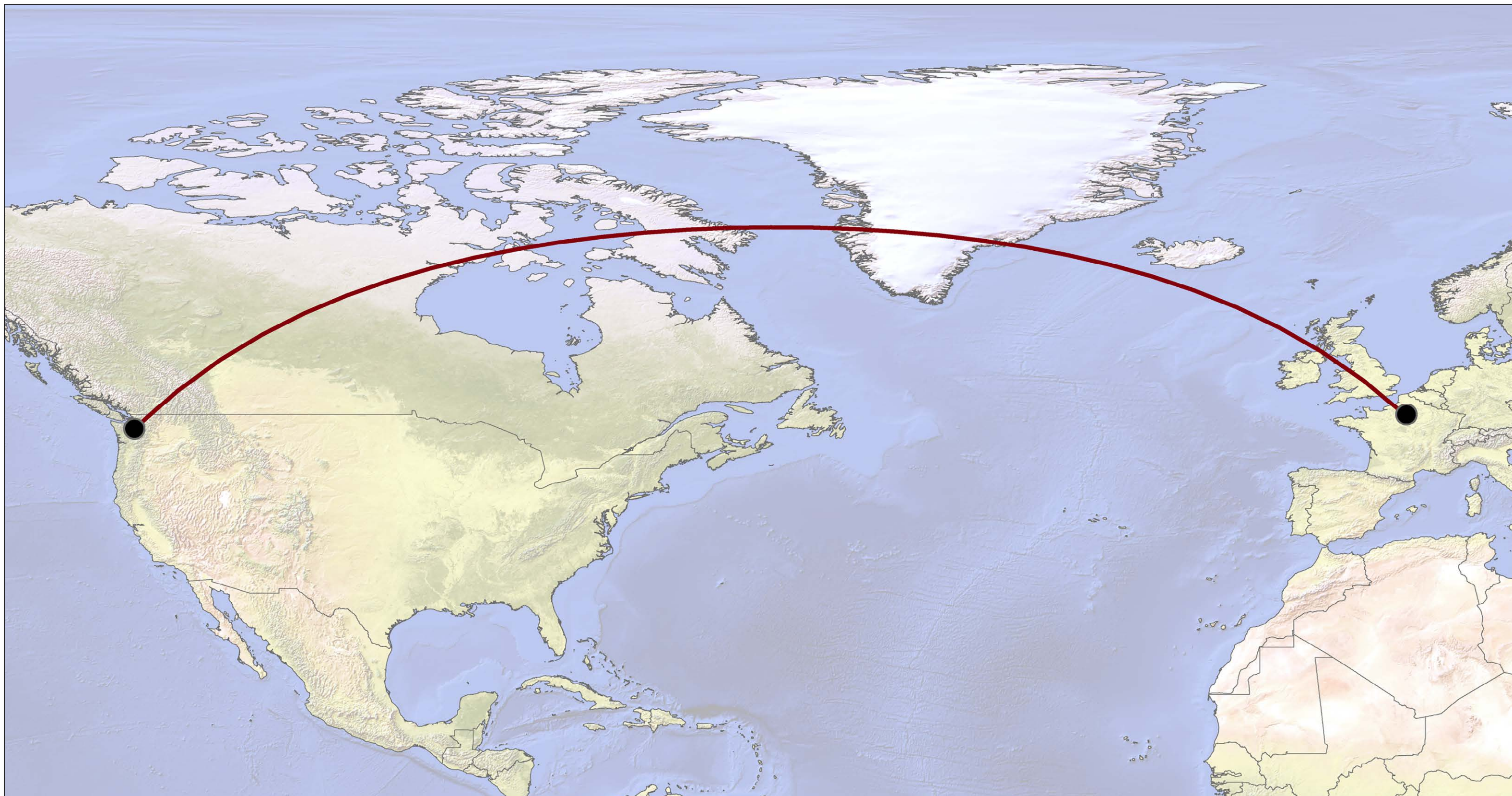
Map projection

Map Projections

- Defined by mathematical formulas
- Transformation between spherical coordinate system and planar coordinate system
- Most projections may be viewed as sending rays of light from a projection source through the sphere/ellipsoid onto a map
- Distortions are unavoidable because of the transition from a curved surface to a flat or simply curved map
- Distortions vary across the map



Distortion Example

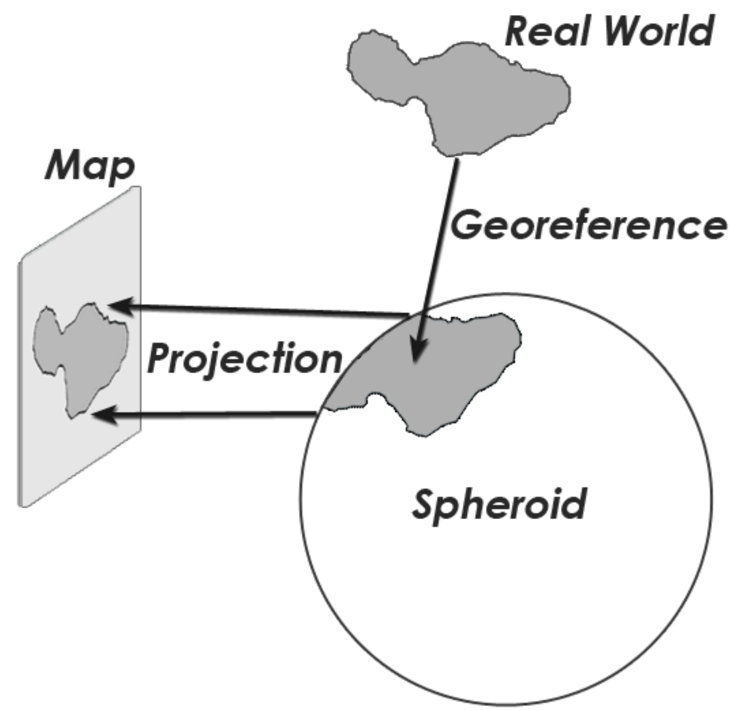


Map projection

Because you can’t display 3D surfaces perfectly in two dimensions, distortions always occur.

- map projections distort **distance**, **direction**, **scale** and **area**.

- Every projection has strengths and weaknesses. All in all, it is up to the cartographer to determine what projection is most favorable for its purpose.



Map projections with different distortions

Area

- An equal-area map portrays areas over the entire map so that all mapped areas have the same proportional relationship to the areas on the Earth

Shape

- A conformal map preserves shape when local angles are preserved and the scale of any point on a map is the same in any direction

Distance

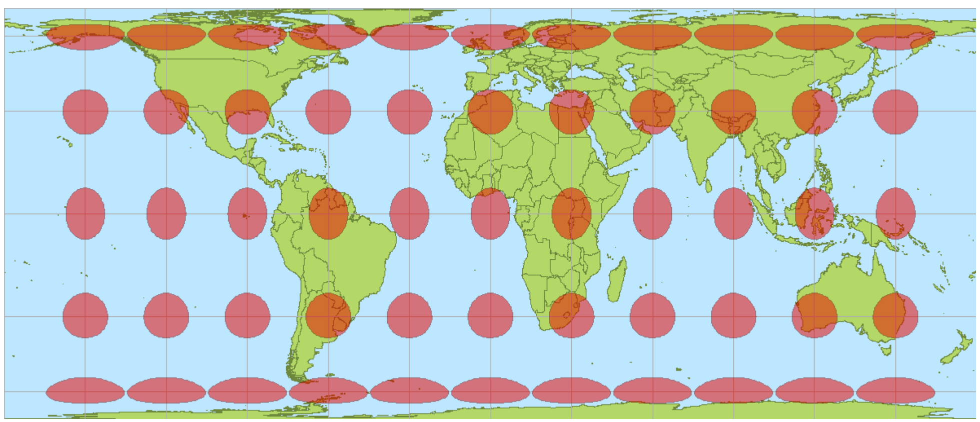
- A map is equidistant when it preserves distance from a point or line, achieved when scale remains constant

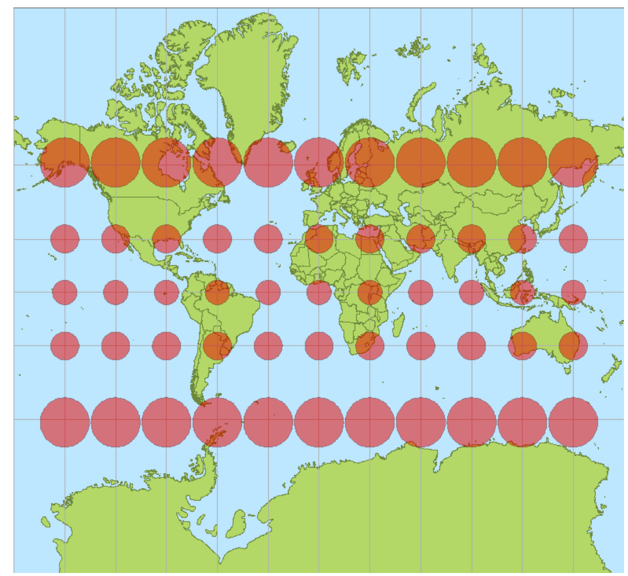
Direction

- A true direction projection map preserves direction when azimuths (angles from a point on a line to another point) are portrayed correctly in all directions

Tissot's Indicatrix

Graphical representation of distortion at various points across a projection

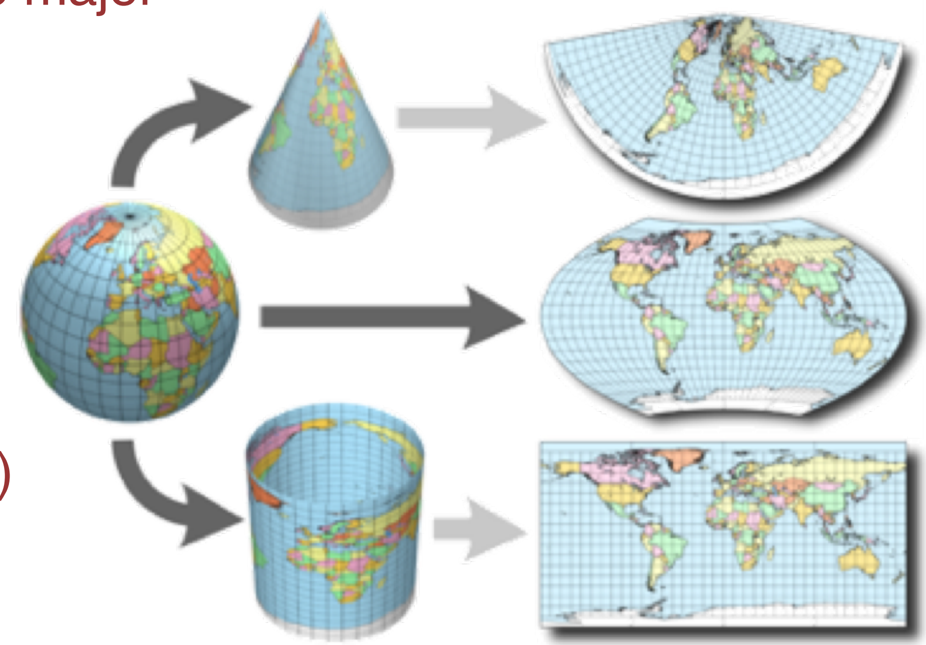




Map Surfaces

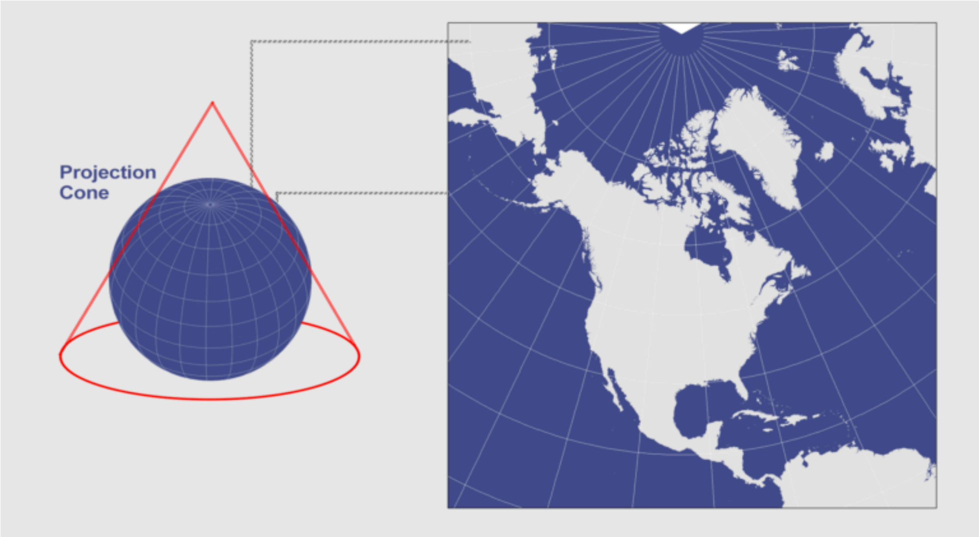
Most map projections are based on a developable surface. There are 3 major types of Map Projections.

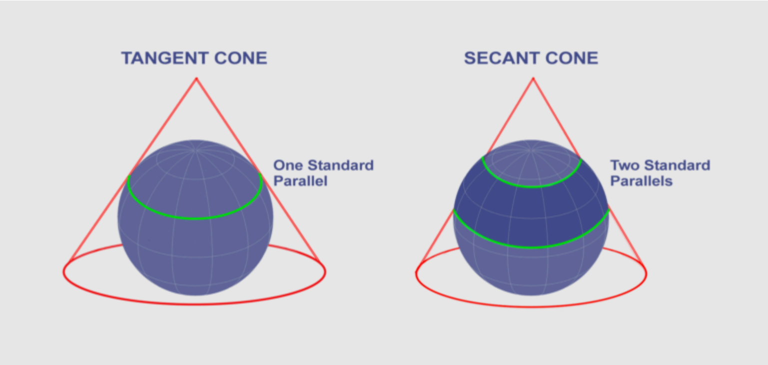
- Cone (conic projection)
- Plane (planar projection)
- Cylinder (cylindrical projection)



Conic Projections

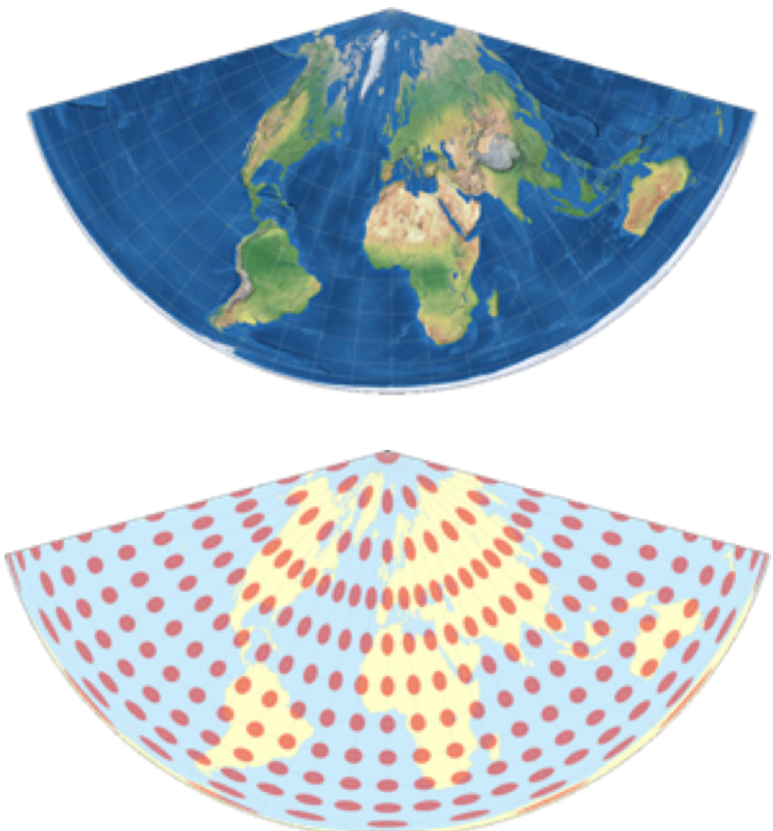
When you place a cone on the Earth and unwrap it, this results in a conic projection. For example, Albers Equal Area Conic and the Lambert Conformal Conic projections are conic projections.



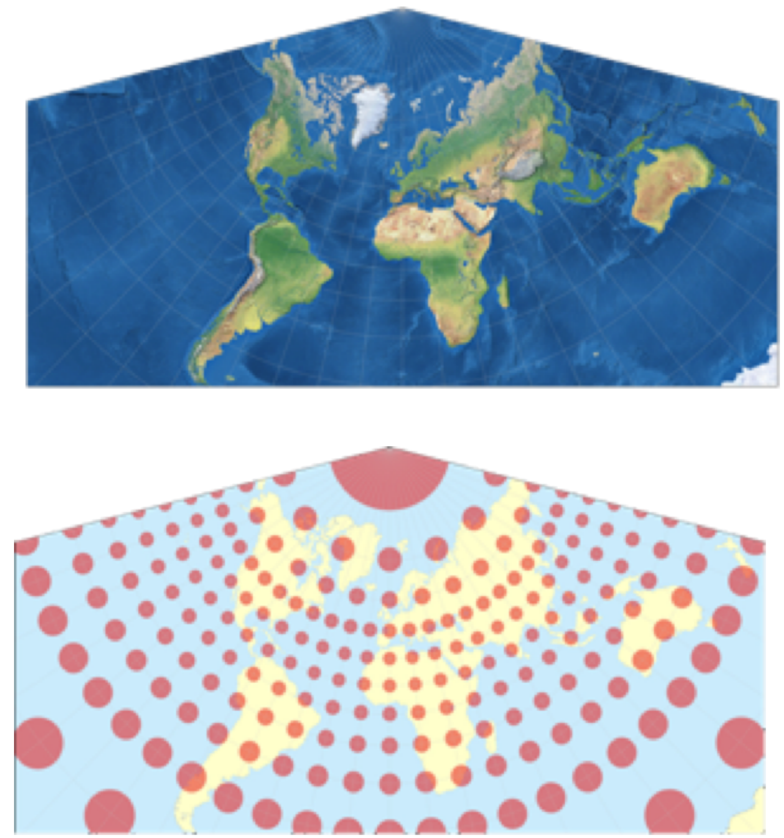


Tangent vs. Secant

Conic Projections

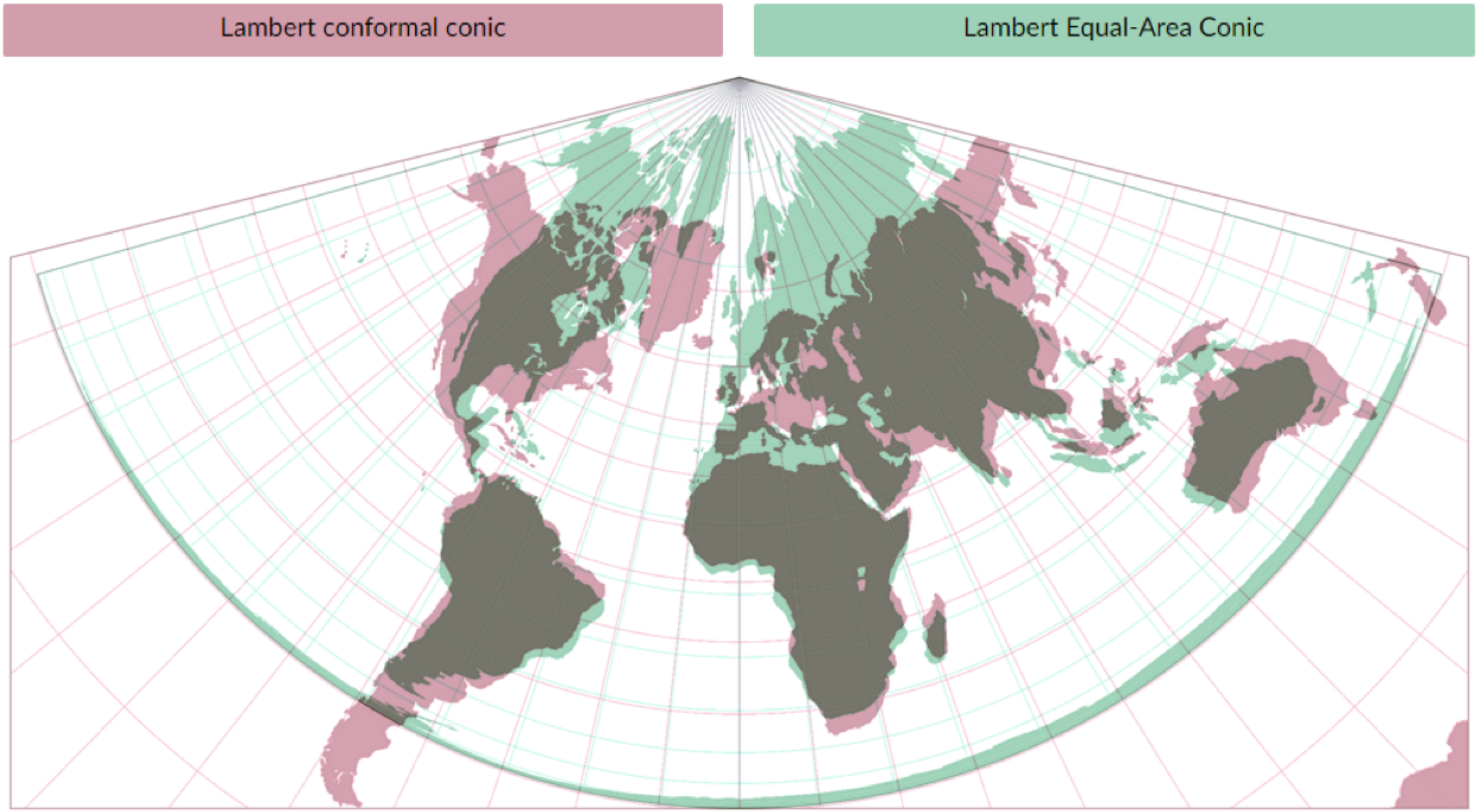


Lambert Equal-Area Conic



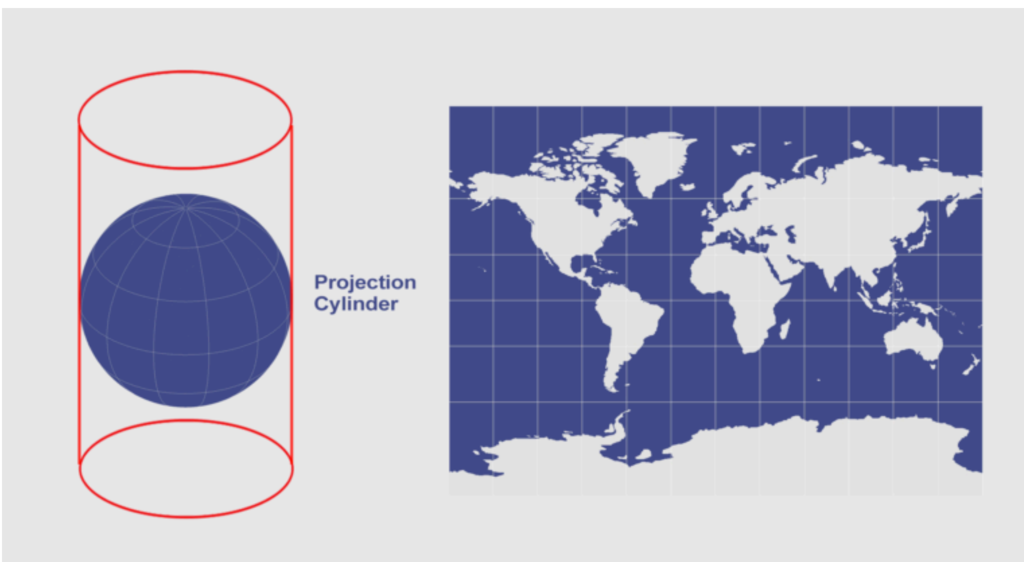
Lambert Conformal Conic (LCC)

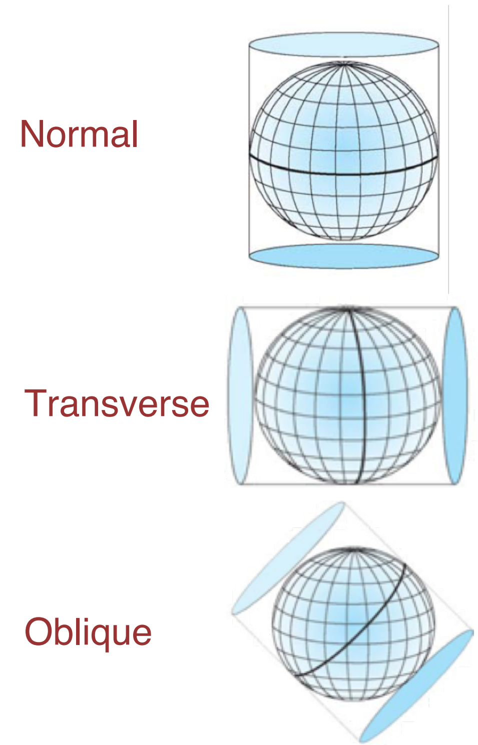
Conformal vs. Equal-Area



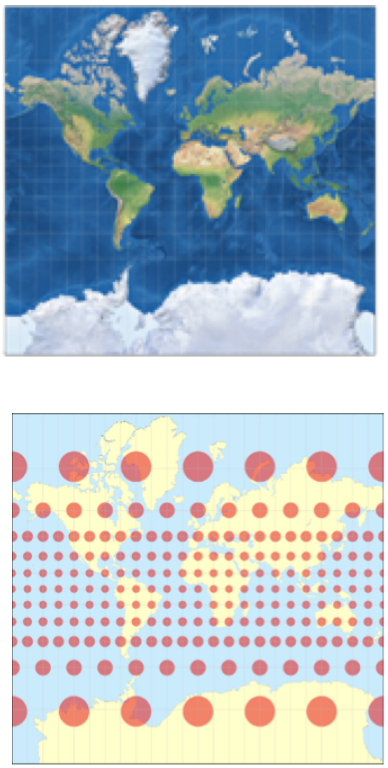
Cylindrical Projections

When you place a cylinder around a globe and unravel it, you get the cylindrical projection. Strangely enough, you see **cylindrical map projections** like the Mercator and Miller for wall maps even though it inflates the Arctic.

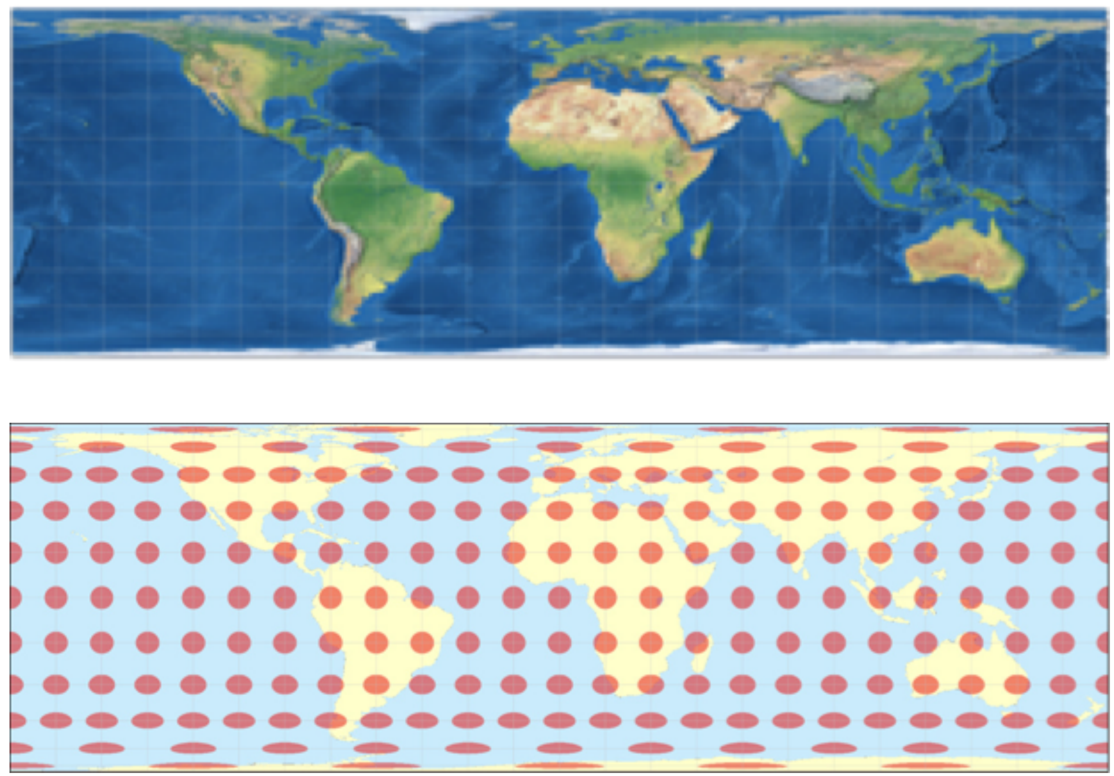




Cylindrical Projections

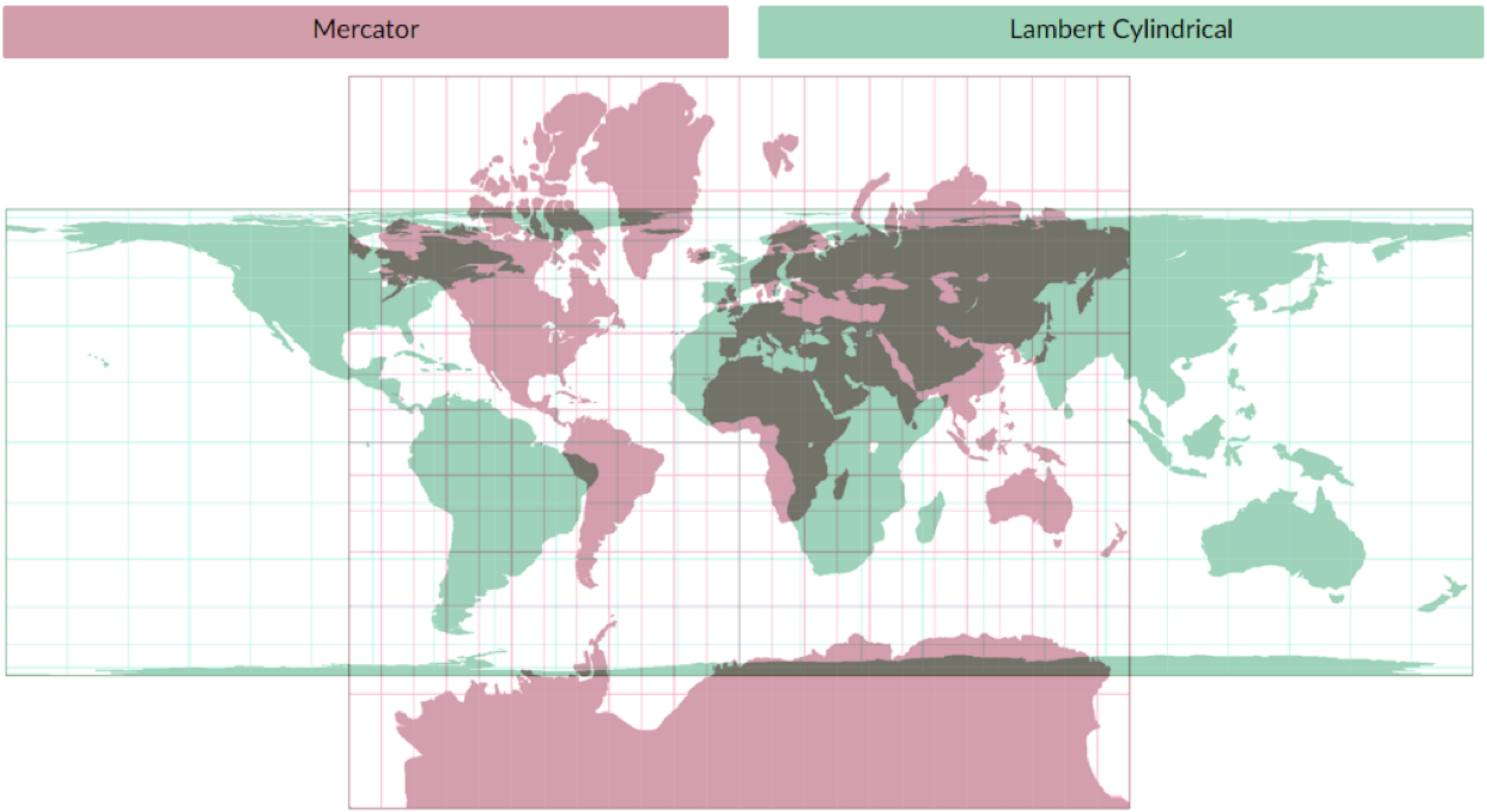


Mercator



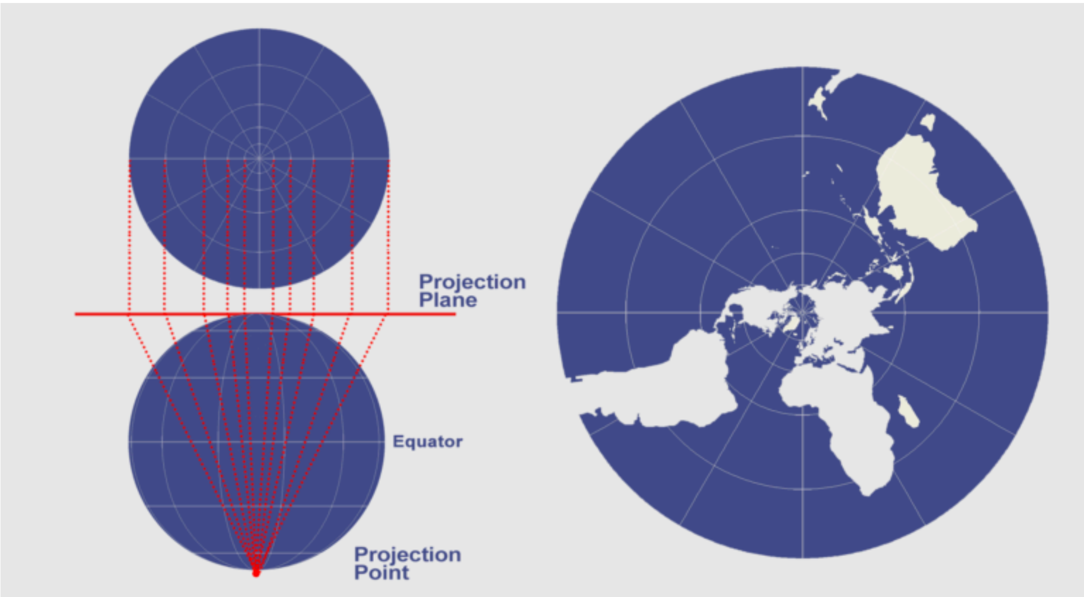
Lambert Cylindrical

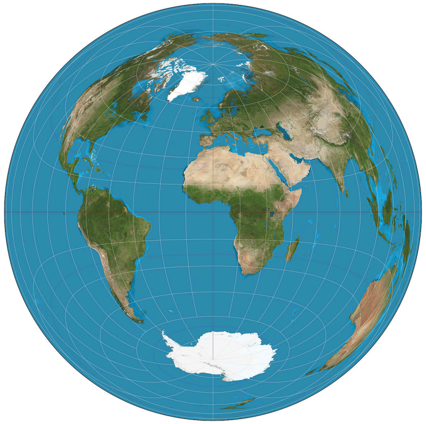
Conformal vs. Equal-Area



Azimuthal Projections

Plot the surface of Earth using a flat plane. Similar to light rays radiating from a source following straight lines, those light rays intercept the globe onto a plane at various angles.





Summary of projections

Different projections preserve different properties and have strengths and weakness.

Based on the developable surface
- Cylindrical projection
- Conic projection
- Azimutal Projection

Preserve
- Area
- Shape
- Distance
- Direction

Why do we change projections

“The earth is round. The challenge of any world map is to represent a round earth on a flat surface. There are literally thousands of map projections. Each has certain strengths and corresponding weaknesses. Choosing among them is an exercise in values clarification: you have to decide what's important to you. That is generally determined by the way you intend to use the map. The Peters Projection is an area accurate map.”

cite: http://www.petersmap.com/

https://www.youtube.com/watch?v=eLqC3FNNOaI

Selecting a Projection that preserves…

- Area **Albers Equal Area Conic, Cylindrical Equal Area**
  - An equal-area map portrays areas over the entire map so that all mapped areas have the same proportional relationship to the areas on the Earth
- Shape **Mercator, Lambert Conformal**
  - A conformal map preserves shape when local angles are preserved and the scale of any point on a map is the same in any direction
- Distance **Lambert Conformal Conic (LCC)**
  - A map is equidistant when it preserves distance from a point or line, achieved when scale remains constant

- Direction **Mercator, Orthographic**
  - A true direction projection map preserves direction when azimuths (angles from a point on a line to another point) are portrayed correctly in all directions

Slocum 8.6

Useful Links

Interactive Map Album of Projections

- http://projections.mgis.psu.edu

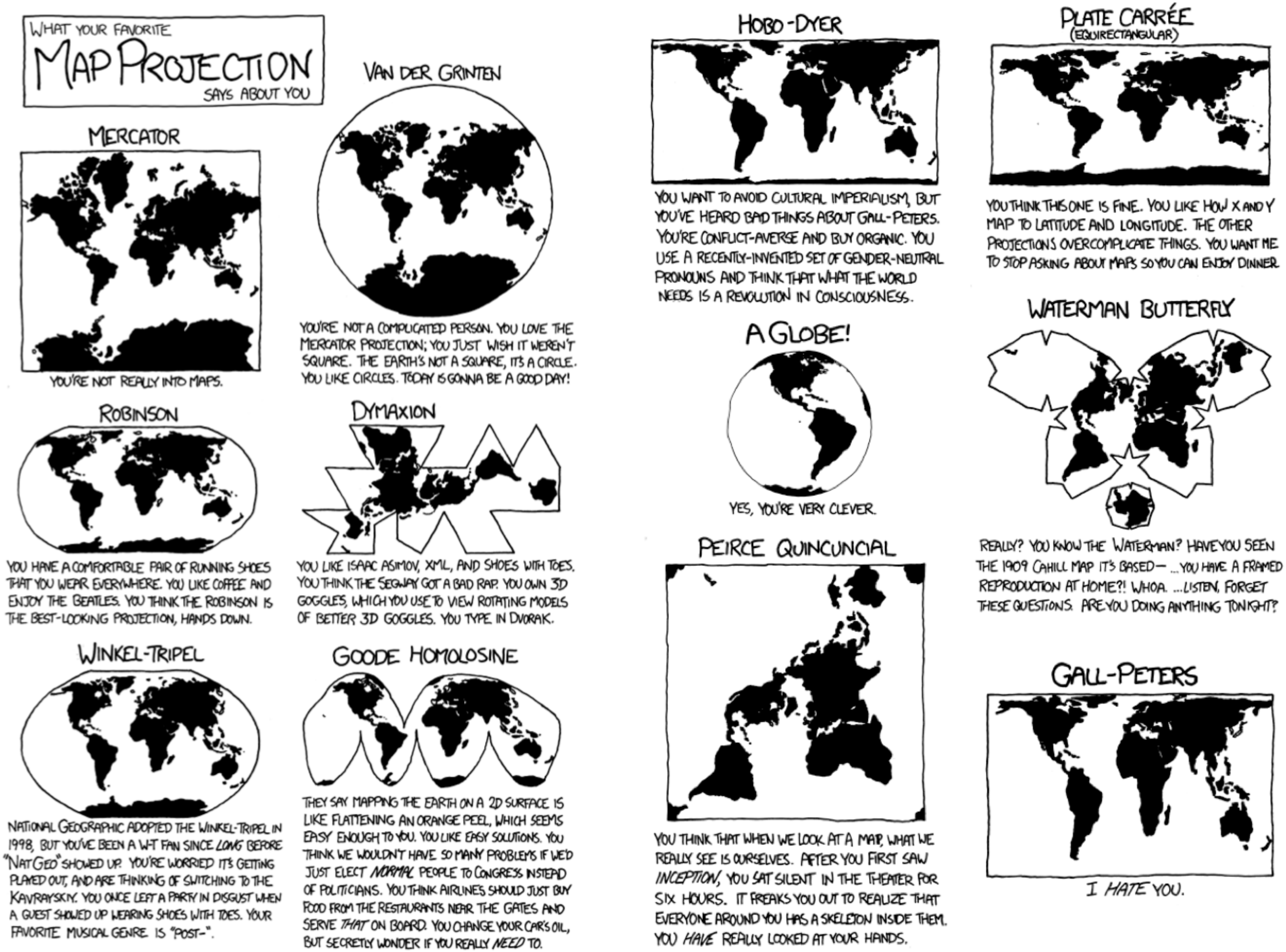
Flex Projector: a freeware, cross-platform application for creating custom world map projections

- http://www.flexprojector.com/

More Information on projections

- http://map-projections.net/index.php
- https://www.mapthematics.com/ProjectionsList.php


ANY
QUESTIONS
?


WHAT YOUR FAVORITE
MAP PROJECTION
SAYS ABOUT YOU
MERCATOR
YOU'RE NOT REALLY INTO MAPS.
VAN DER GRINTEN
YOU'RE NOT A COMPLICATED PERSON. YOU LOVE THE MERCATOR PROJECTION; YOU JUST WISH IT WEREN'T SQUARE. THE EARTH'S NOT A SQUARE, IT'S A CIRCLE. YOU LIKE CIRCLES. TODAY IS GONNA BE A GOOD DAY!
ROBINSON
YOU HAVE A COMFORTABLE PAIR OF RUNNING SHOES THAT YOU WEAR EVERYWHERE. YOU LIKE COFFEE AND ENJOY THE BEATLES. YOU THINK THE ROBINSON IS THE BEST-LOOKING PROJECTION, HANDS DOWN.
DYMAXION
YOU LIKE ISAAC ASIMOV, XML, AND SHOES WITH TOES. YOU THINK THE SEGWAY GOT A BAD RAP. YOU OWN 3D GOGGLES, WHICH YOU USE TO VIEW ROTATING MODELS OF BETTER 3D GOGGLES. YOU TYPE IN DVORAK.
WINKEL-TRIPEL
NATIONAL GEOGRAPHIC ADOPTED THE WINKEL-TRIPEL IN 1998, BUT YOU'VE BEEN A W-T FAN SINCE *LONG* BEFORE "NAT GEO" SHOWED UP. YOU'RE WORRIED IT'S GETTING PLAYED OUT, AND ARE THINKING OF SWITCHING TO THE KAVRAYSKIY. YOU ONCE LEFT A PARTY IN DISGUST WHEN A GUEST SHOWED UP WEARING SHOES WITH TOES. YOUR FAVORITE MUSICAL GENRE IS "POST-".
GOODE HOMOLOSINE
THEY SAY MAPPING THE EARTH ON A 2D SURFACE IS LIKE FLATTENING AN ORANGE PEEL, WHICH SEEMS EASY ENOUGH TO YOU. YOU LIKE EASY SOLUTIONS. YOU THINK WE WOULDN'T HAVE SO MANY PROBLEMS IF WE'D JUST ELECT *NORMAL* PEOPLE TO CONGRESS INSTEAD OF POLITICIANS. YOU THINK AIRLINES SHOULD JUST BUY FOOD FROM THE RESTAURANTS NEAR THE GATES AND SERVE *THAT* ON BOARD. YOU CHANGE YOUR CAR'S OIL, BUT SECRETLY WONDER IF YOU REALLY *NEED* TO.
HOBO-DYER
YOU WANT TO AVOID CULTURAL IMPERIALISM, BUT YOU'VE HEARD BAD THINGS ABOUT GALL-PETERS. YOU'RE CONFLICT-AVERSE AND BUY ORGANIC. YOU USE A RECENTLY-INVENTED SET OF GENDER-NEUTRAL PRONOUNS AND THINK THAT WHAT THE WORLD NEEDS IS A REVOLUTION IN CONSCIOUSNESS.
A GLOBE!
YES, YOU'RE VERY CLEVER.
PEIRCE QUINCUNCIAL
YOU THINK THAT WHEN WE LOOK AT A MAP, WHAT WE REALLY SEE IS OURSELVES. AFTER YOU FIRST SAW *INCEPTION*, YOU SAT SILENT IN THE THEATER FOR SIX HOURS. IT FREAKS YOU OUT TO REALIZE THAT EVERYONE AROUND YOU HAS A SKELETON INSIDE THEM. YOU *HAVE* REALLY LOOKED AT YOUR HANDS.
PLATE CARRÉE
(EQUIRECTANGULAR)
YOU THINK THIS ONE IS FINE. YOU LIKE HOW X AND Y MAP TO LATITUDE AND LONGITUDE. THE OTHER PROJECTIONS OVERCOMPLICATE THINGS. YOU WANT ME TO STOP ASKING ABOUT MAPS SO YOU CAN ENJOY DINNER.
WATERMAN BUTTERFLY
REALLY? YOU KNOW THE WATERMAN? HAVE YOU SEEN THE 1909 CAHILL MAP IT'S BASED— ...YOU HAVE A FRAMED REPRODUCTION AT HOME?! WHOA. ...LISTEN, FORGET THESE QUESTIONS. ARE YOU DOING ANYTHING TONIGHT?
GALL-PETERS
I *HATE* YOU.