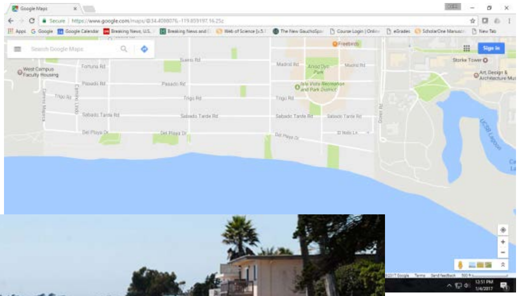
Analytical and Computer Cartography

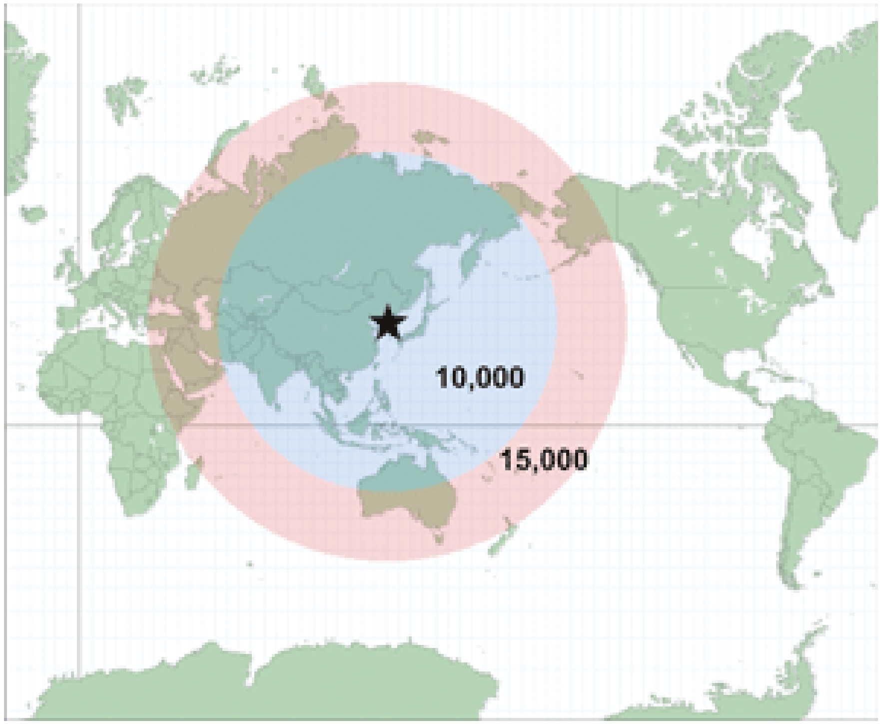
Lecture 2:
Review: Map Projections

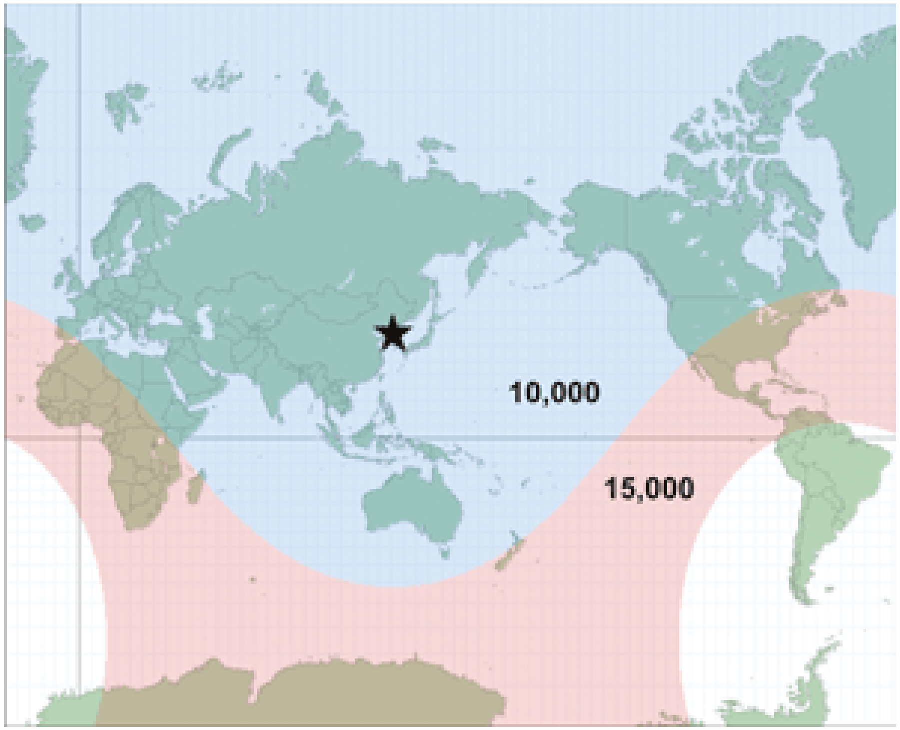
Transformations in Mapping

- T1: True earth to globe
  - Lengths scaled by the Representative Fraction e.g. 1:1M
  - Real world objects become symbols (representations) e.g. coast to a blue line
  - Need to choose earth model (Datum)
- T2: 3D earth to flat map
  - Map projection transformation
  - Inherent distortion!



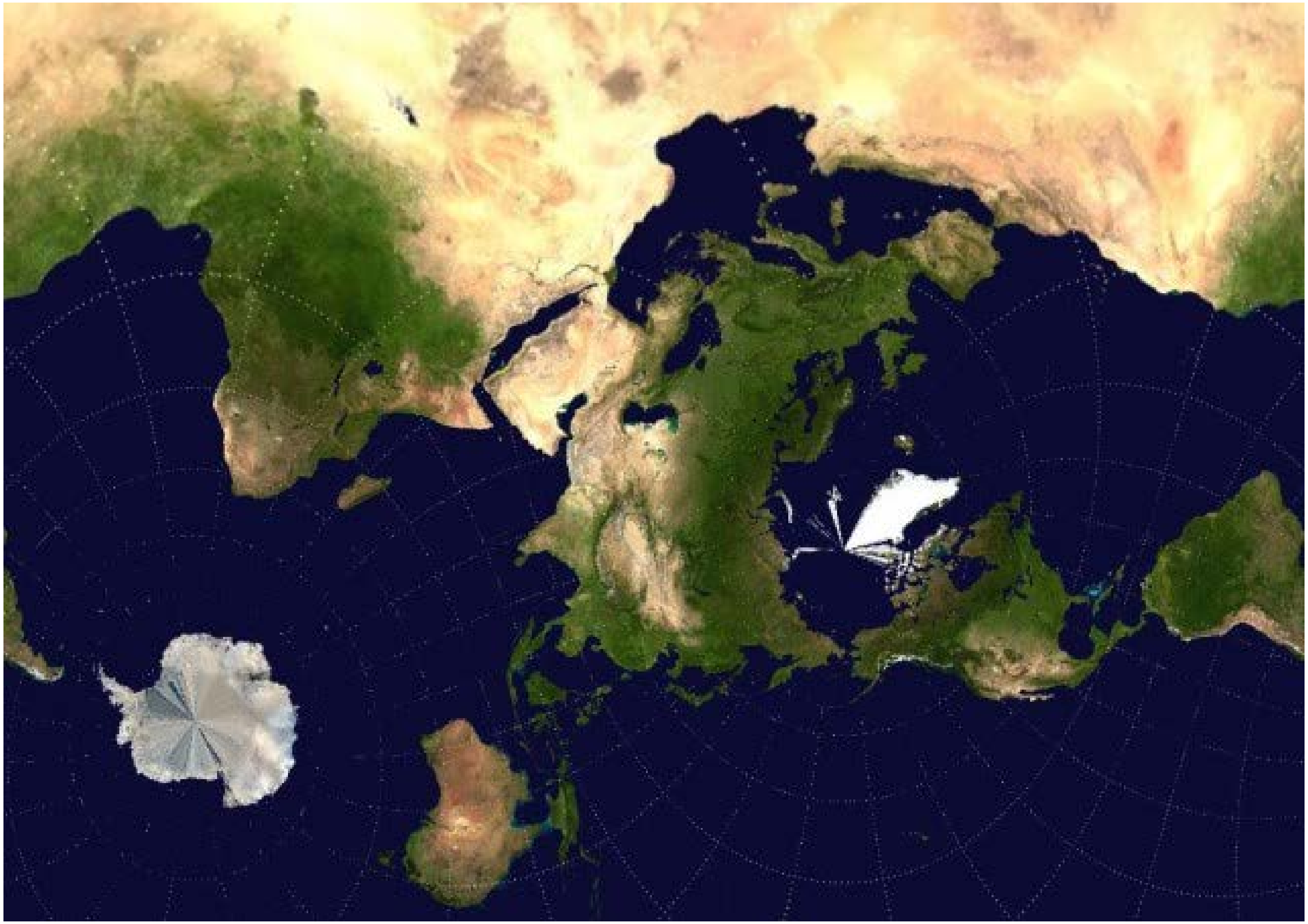
The North Korean Missile Threat





Source: http://www.esri.com/news/arcuser/0111/geodesic.html

Extrema

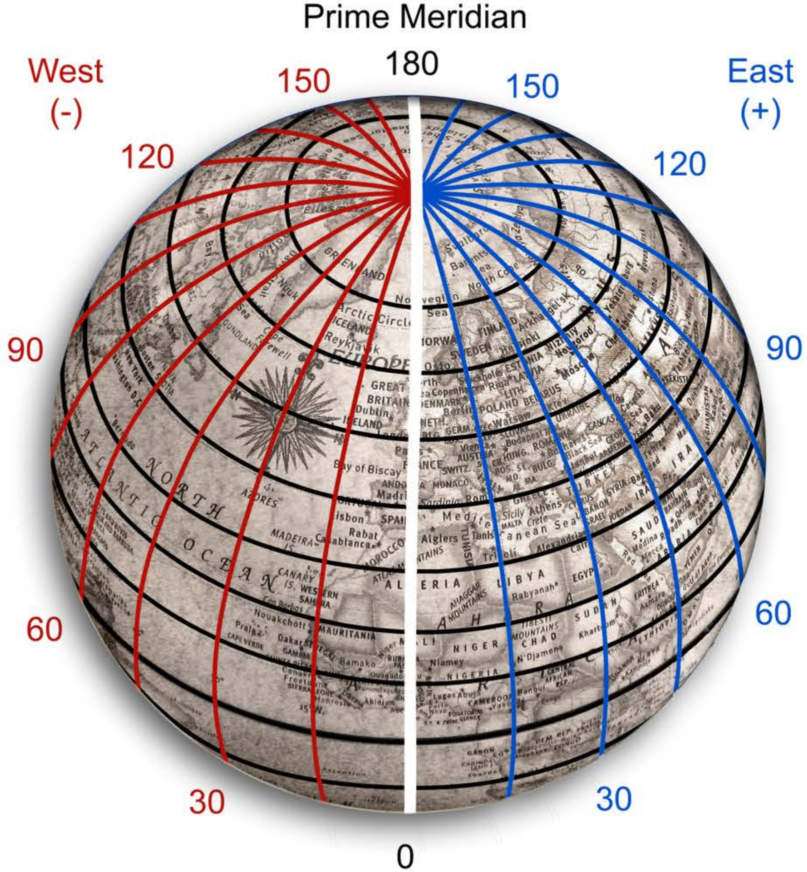


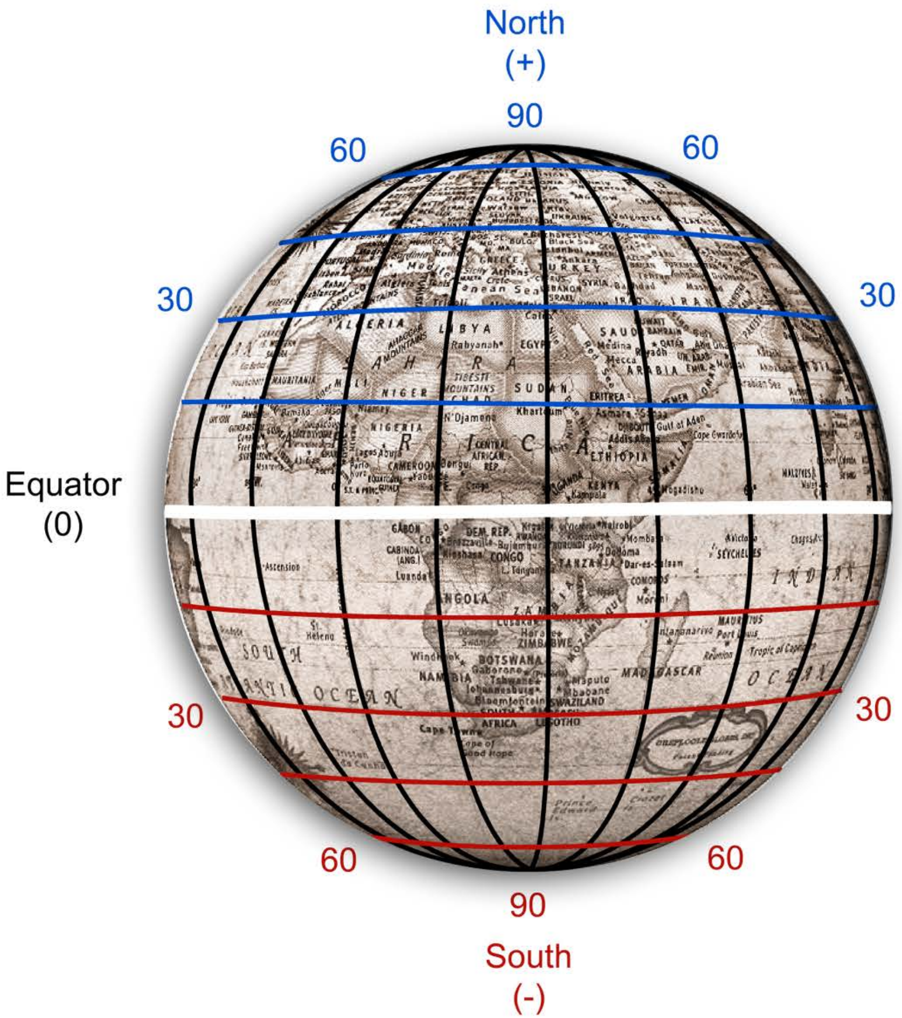
Source: http://www.andrewt.net/blog/posts/fun-with-the-mercator-projection/

The graticule

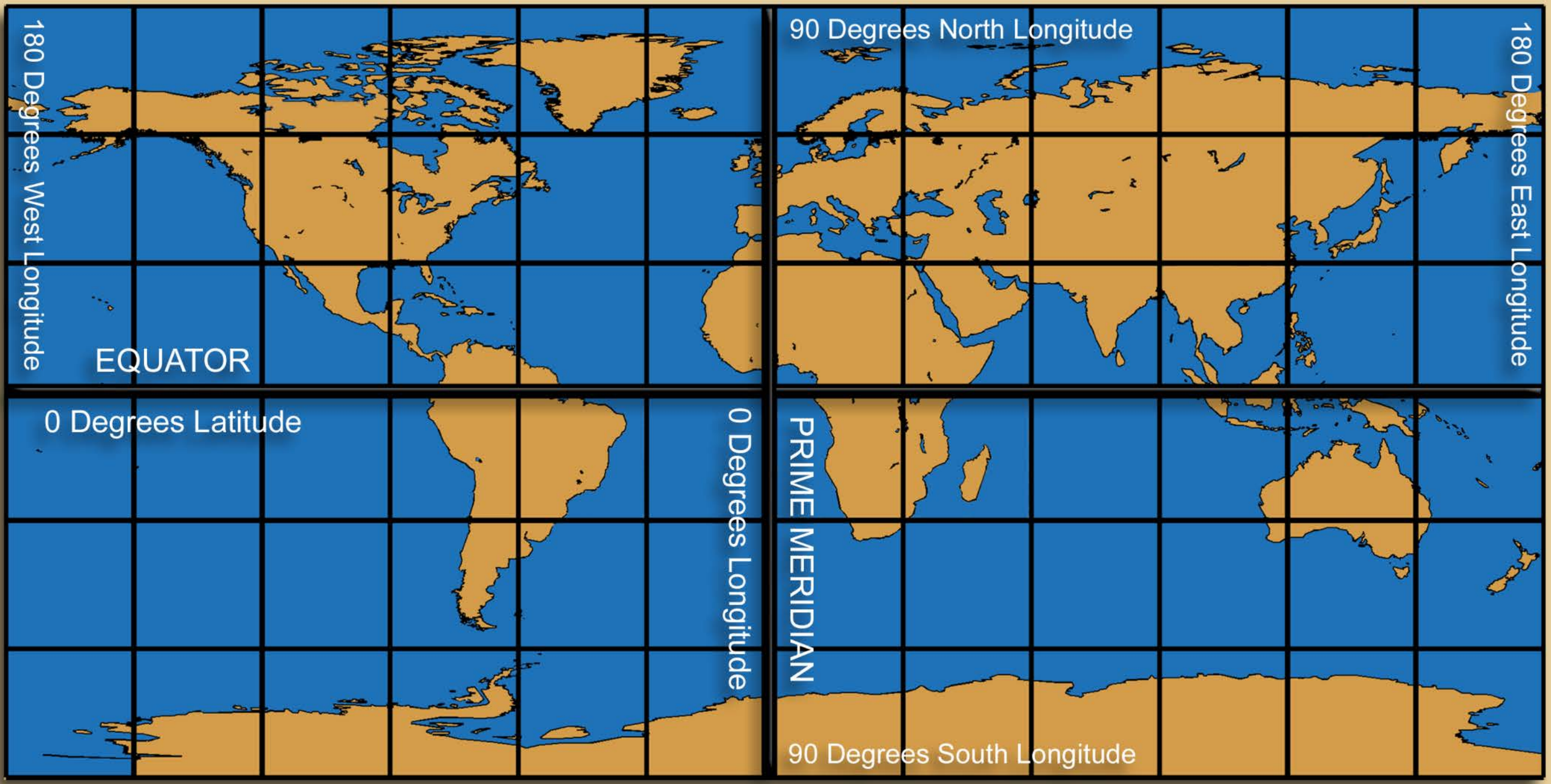
- **Graticule:** The latitude and longitude grid drawn on a map or globe. The angle at which the graticule meets is the best first indicator of what projection has been used for the map.

The graticule shows increments of latitude and longitude





Geographic Coordinates



For example: ArcGIS PRJ file

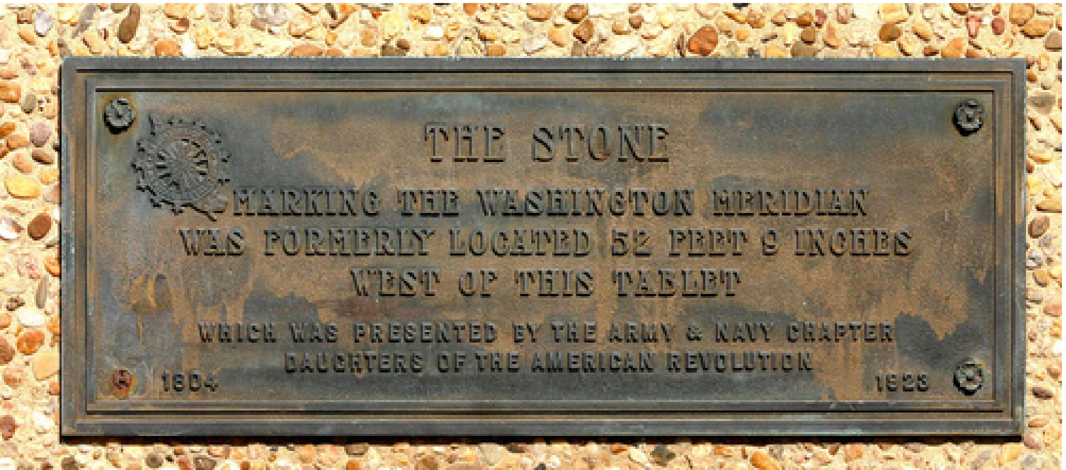
GEOGCS["Geographic Coordinate System",
DATUM["WGS84",
SPHEROID
["GRS1980",6378137,298.257222096042]],
PRIMEM["Greenwich",0],
UNIT["degree",0.0174532925199433]]

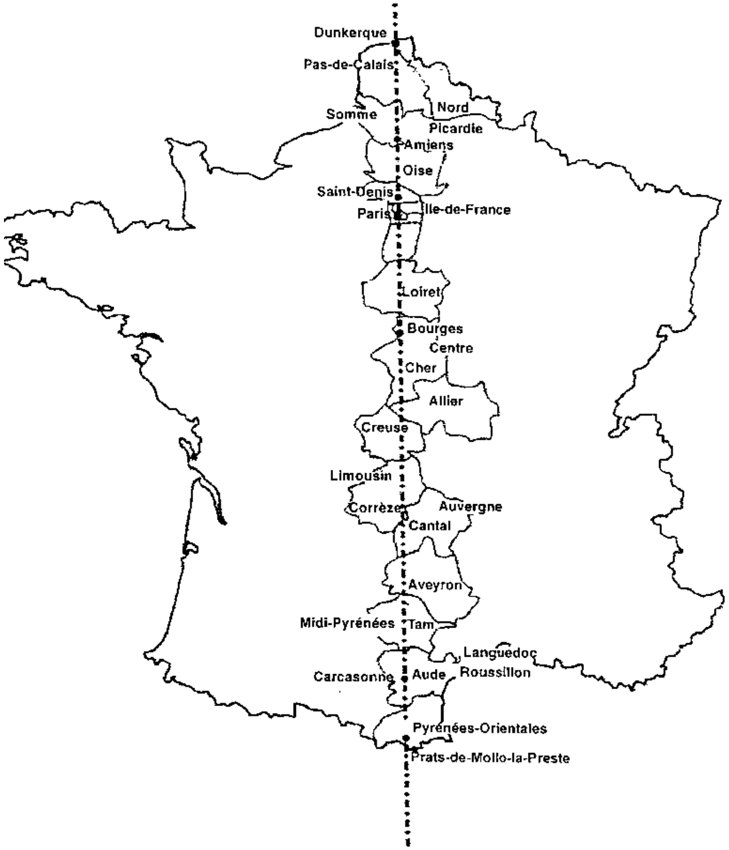
The longitude problem

- Latitude has as a point of origin (the equator) and ends at the poles: distinct locations
- It can be measured directly by observing the sun or the stars
- Can also measure the tropics

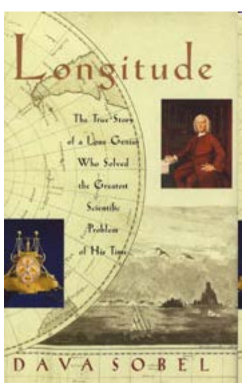
  of Cancer and Capricorn
- Not so for longitude
- Hard to measure

At first, each country had its own prime meridian

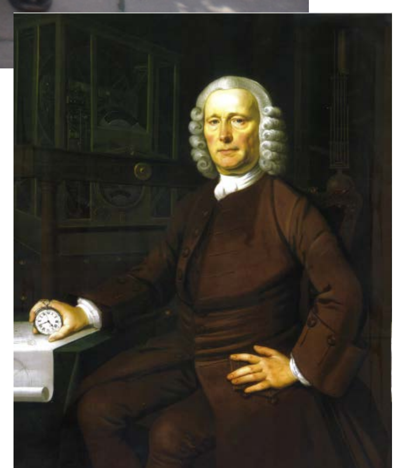




The longitude solution



John Harrison's
Chronometer
Won longitude
Prize 1773



The International Meridian Conference (1884: Washington DC)

"That it is the opinion of this Congress that it is desirable to adopt a single prime meridian for all nations, in place of the multiplicity of initial meridians which now exist."

"That the Conference proposes to the Governments here represented the adoption of the meridian passing through the center of the transit instrument at the Observatory of Greenwich as the initial meridian for longitude."

"That from this meridian longitude shall be counted in two directions up to 180 degrees, east longitude being plus and west longitude minus."

The Prime Meridian (1884)

Now, on to projections

Round

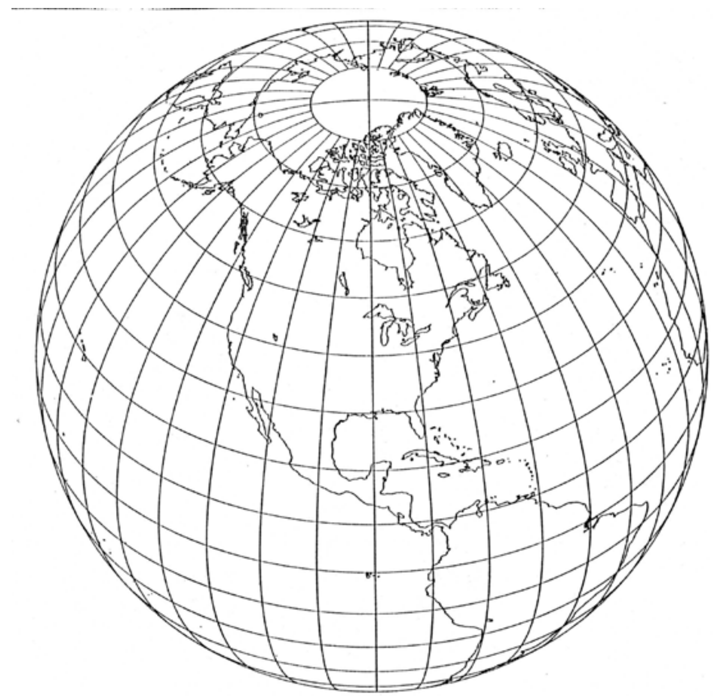


Figure 50D.—Oblique Orthographic projection, with shorelines, 10° graticule, central latitude 40° N. Central meridian 90° W.

Flat

Advantages of projections

- Globes are hard to store and use
- Globes cannot show the whole world at once, at equal visual range
- Projection can be optimized to minimize distortion by region
- Computer screens are flat
- Projected map can be used for thematic mapping

Projection properties

- Form: cylindrical, planar, conic
- Aspect: Equatorial, polar, oblique
- Tangency: Tangent vs. Secant
- Distortion: Conformal vs. Equivalent
- Interrupted vs. Continuous
- Analog vs. mathematical
- Shape: Ellipse with flat poles preferred
- Purpose
- Extent: World vs. Country
- Mash-ups

Classes of Projections

A CLASSIFICATION OF MAP PROJECTIONS[1]

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University of Michigan

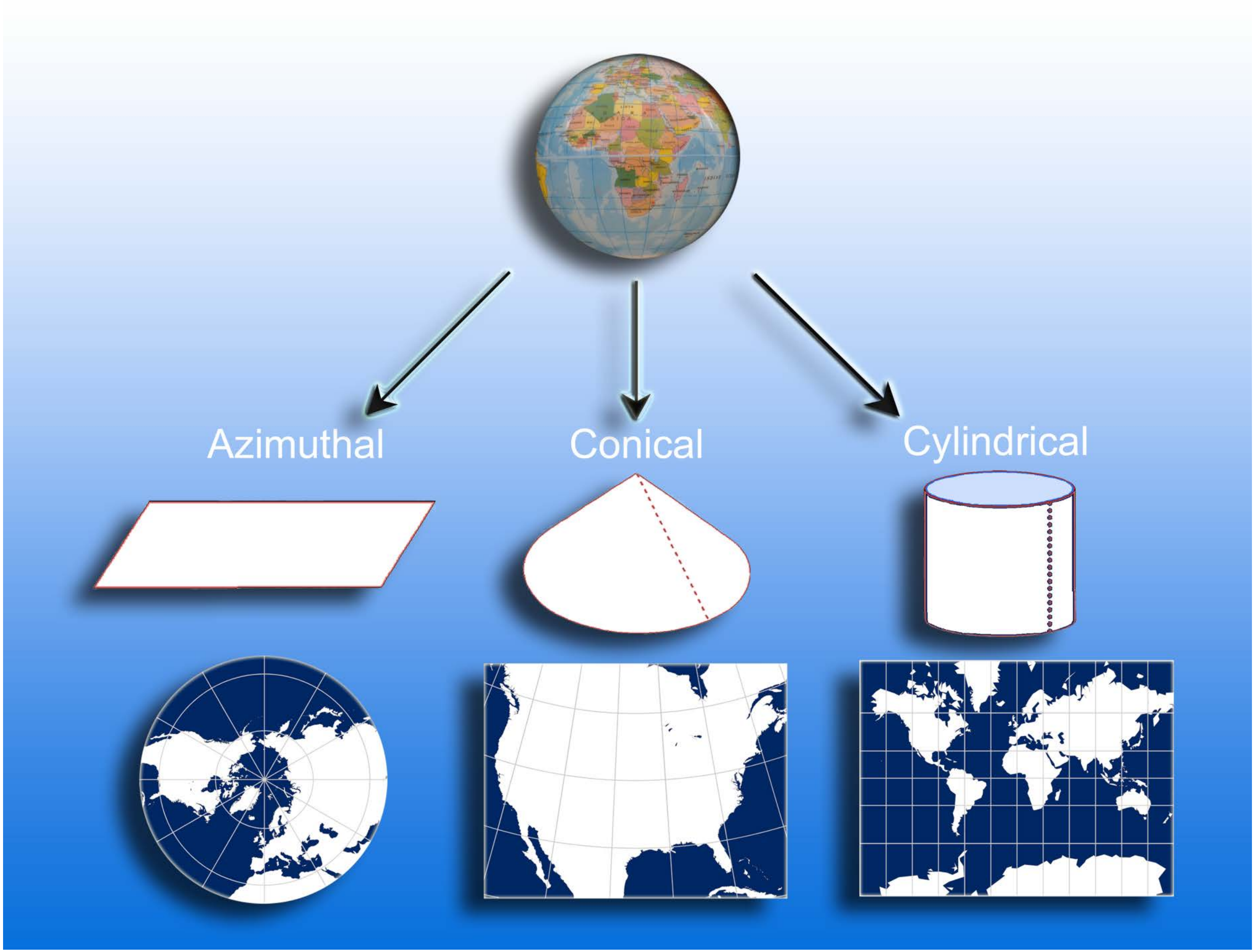
THE desire for a classification of map projections stems from the fact that an infinite number of distinct projections are possible. Hence, the fundamental problem in classifying map projections is the partitioning of this infinite set into a comprehensible and useful finite number of all-inclusive and preferably non-overlapping classes.

Several classifications of map projections are to be found in the cartographic literature. The advantages and disadvantages of each, of course, depend on the purpose, just as the properties by which classes are to be distinguished depend on the purpose. The classification based on geometric models (perspectivities) separating projections into conic, cylindric, planar, polyconic, polycylindric, etc., is convenient and is often used. The major shortcoming of this system is that it is not all-inclusive. Another most important method of transformations and Euclidean geometry, continuous transformations and topology, etc.

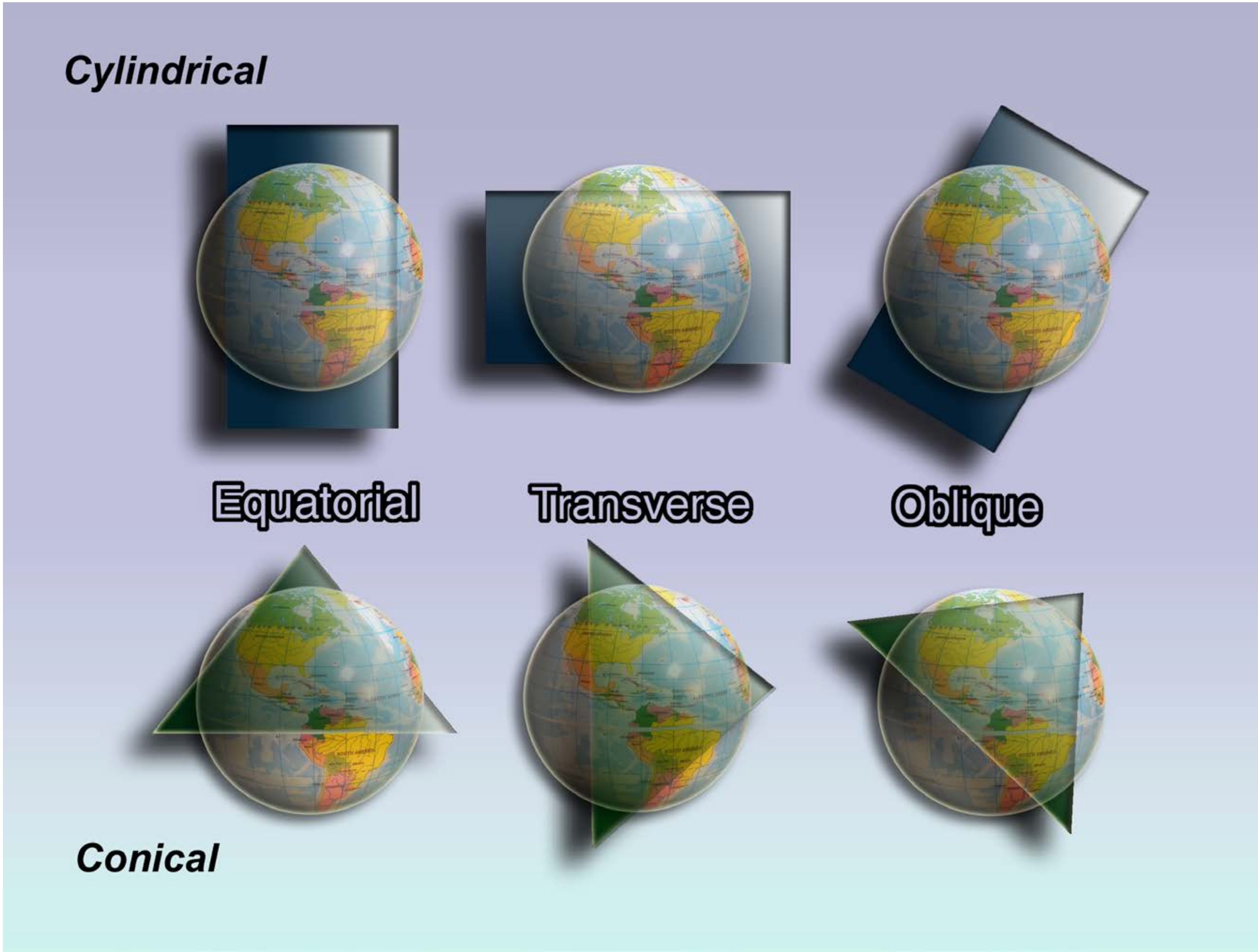
Still other classifications are based on the appearance of the meridians and parallels on the map, i.e., whether these consist of circles, ellipses, quartics, etc.[2] Projections can also be classified according to the form of the equations; whether these are linear, algebraic, transcendental, and so forth. Maurer, in his study of map projections,[3] attempts to partition 237 projections into classes and subclasses based on combinations of these systems. Several of the problems of projection classification are discussed by Maurer, and a most interesting but very involved Venn diagram is presented showing the overlap and interrelations of the various classes. Tissot is another who recognized fine distinctions and obtained an elaborate classification of map projections.[4] More recently, classifications have been pre-

Thinking about projections

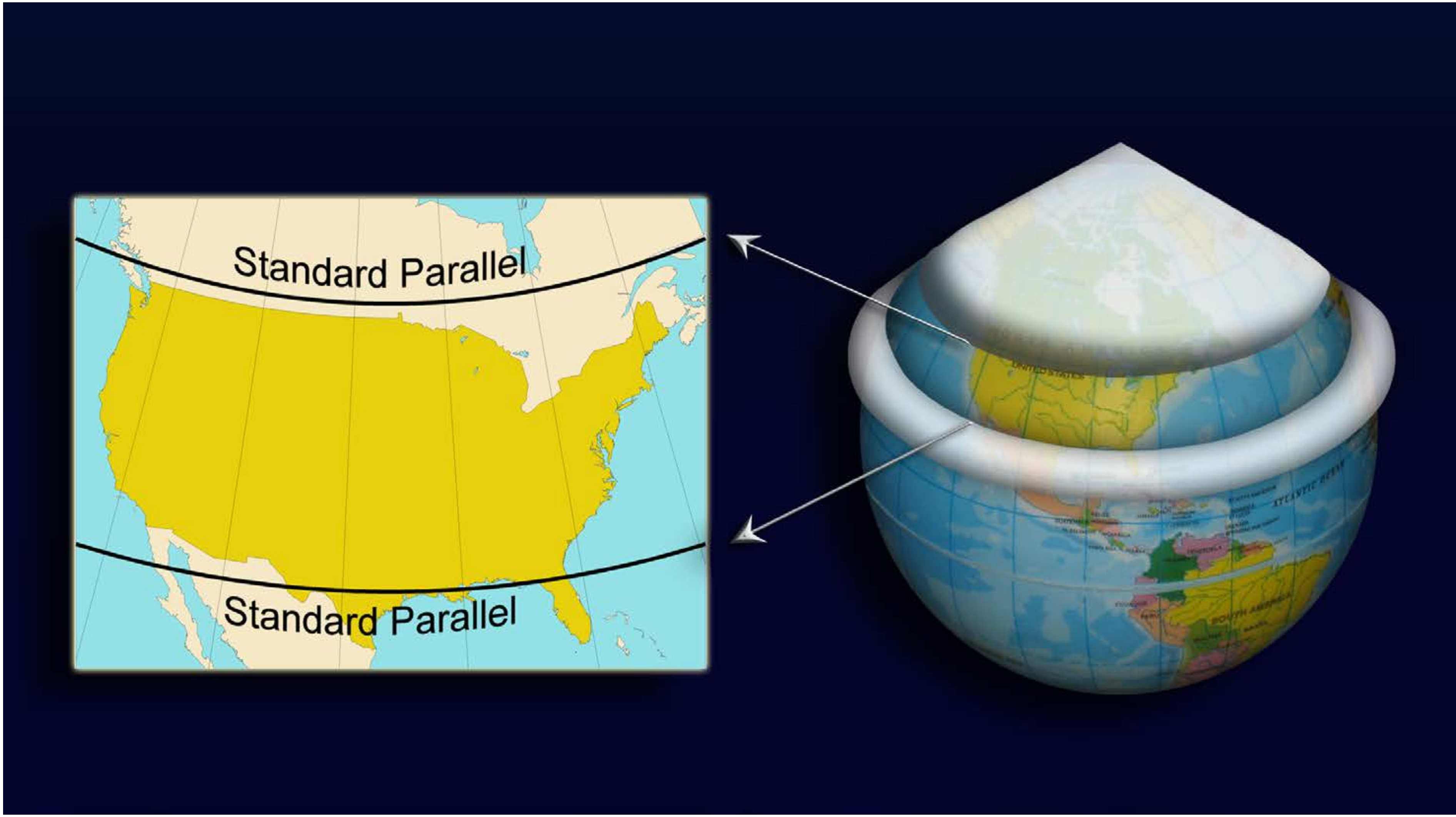
Map projections: Form



Map projections: Aspect

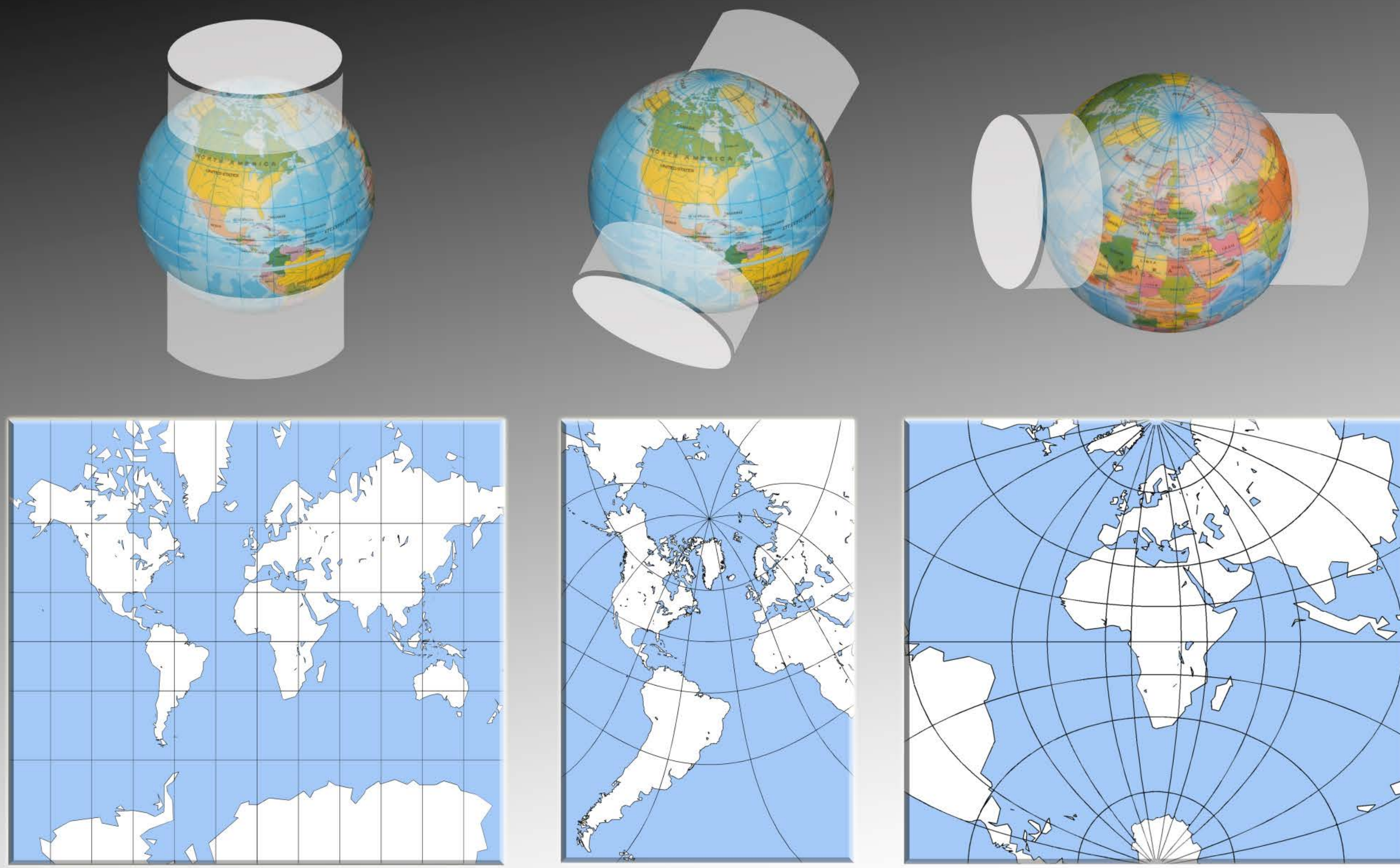


Secant vs. Tangent



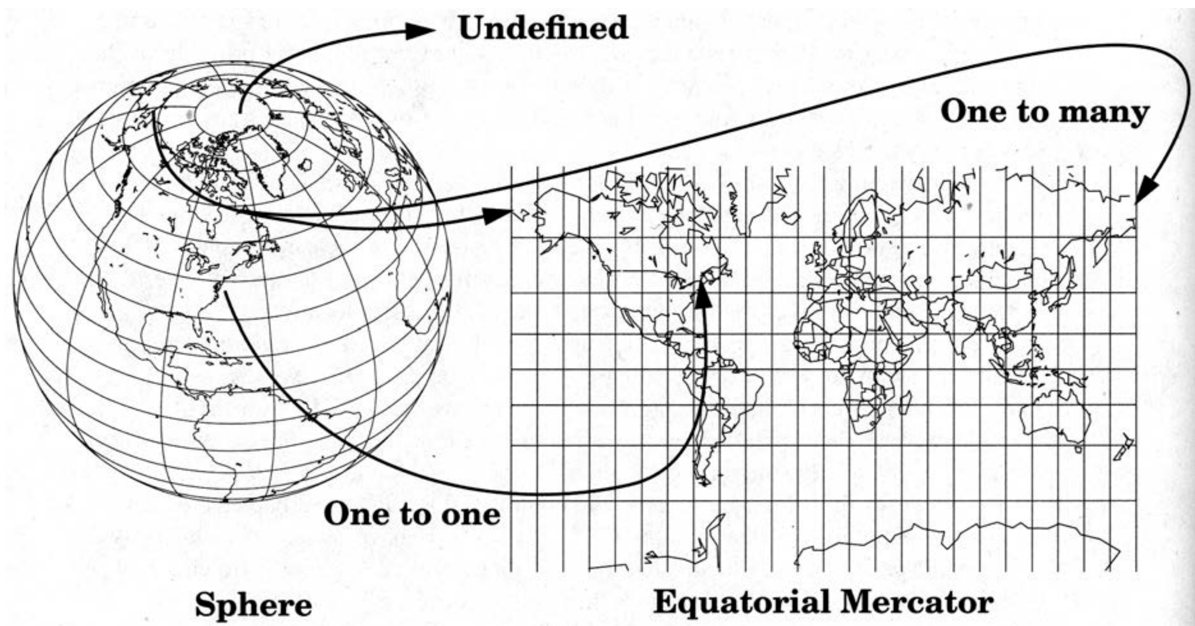
Secant Cylindrical Projections

Equatorial | Oblique | Transverse



Thinking about projections

- Mathematical (and digital)
- Input is long/lat pair (λ, ϕ) (lambda, phi)
- Output is (x, y) coordinates on paper



Again, mathematically

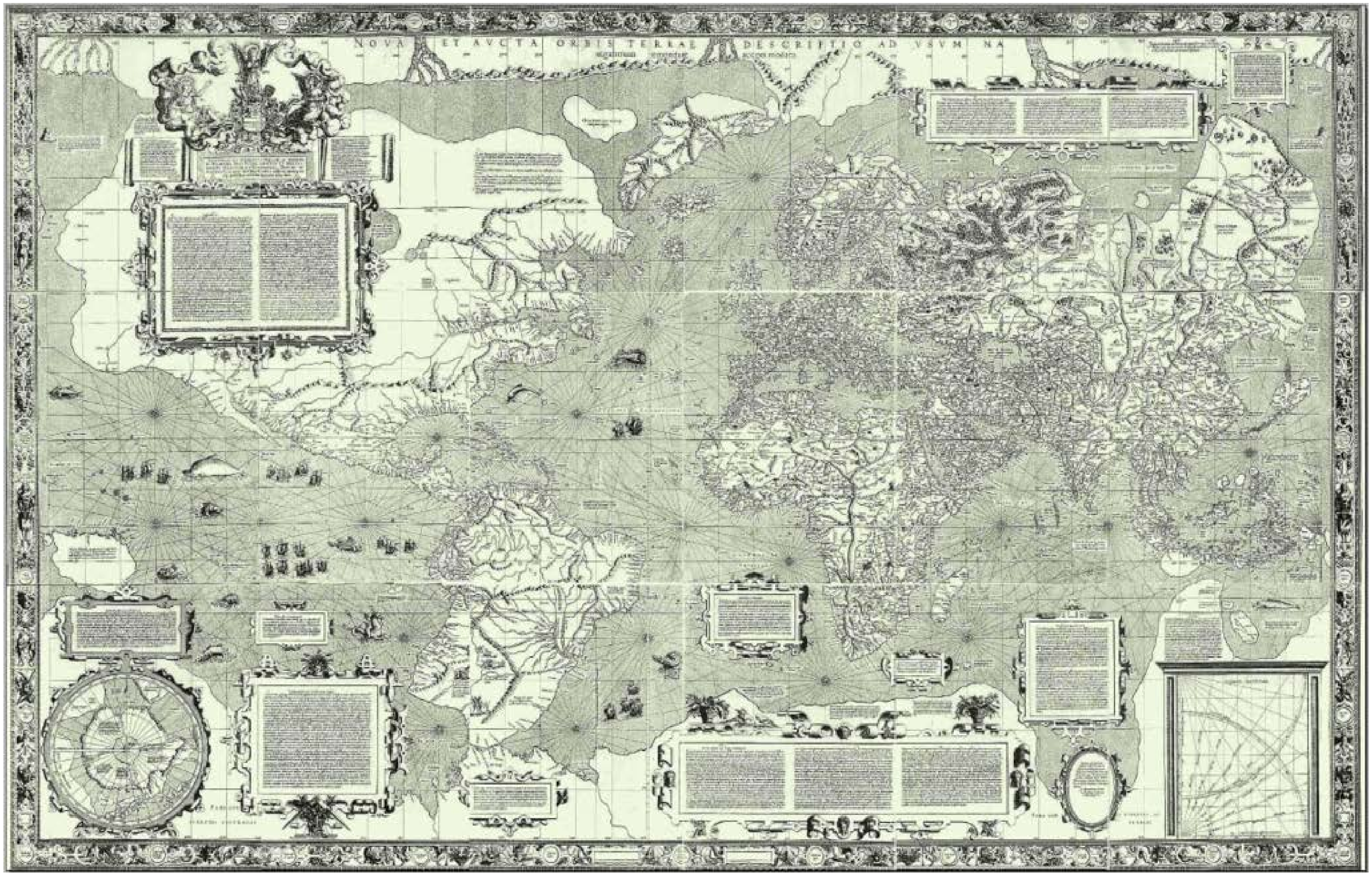
$$x' = Rs(\lambda - \lambda_0)$$

$$y' = Rs\log\left(\tan\left[\frac{\pi}{4} + \frac{\phi}{2}\right]\right)$$

We already know R and s

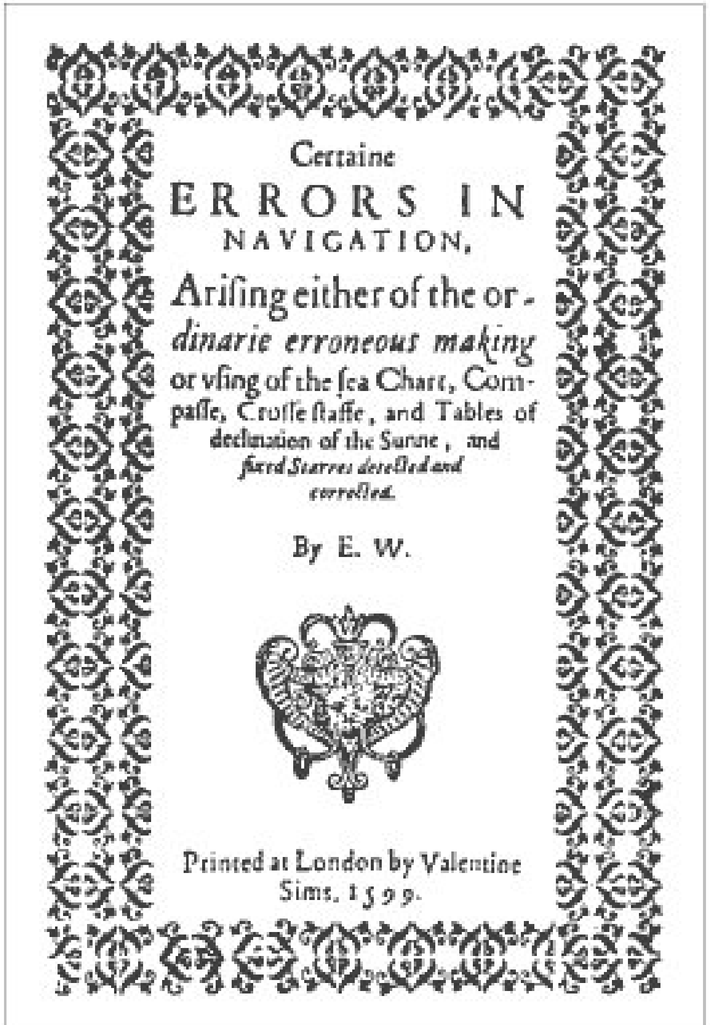
Equatorial Mercator

Mercator world map of 1569 *Nova et Aucta Orbis Terrae Descriptio ad Usum Navigantium Emendate Accommodata* ("New and more complete representation of the terrestrial globe properly adapted for use in navigation")



Mercator formula: Edward Wright 1599

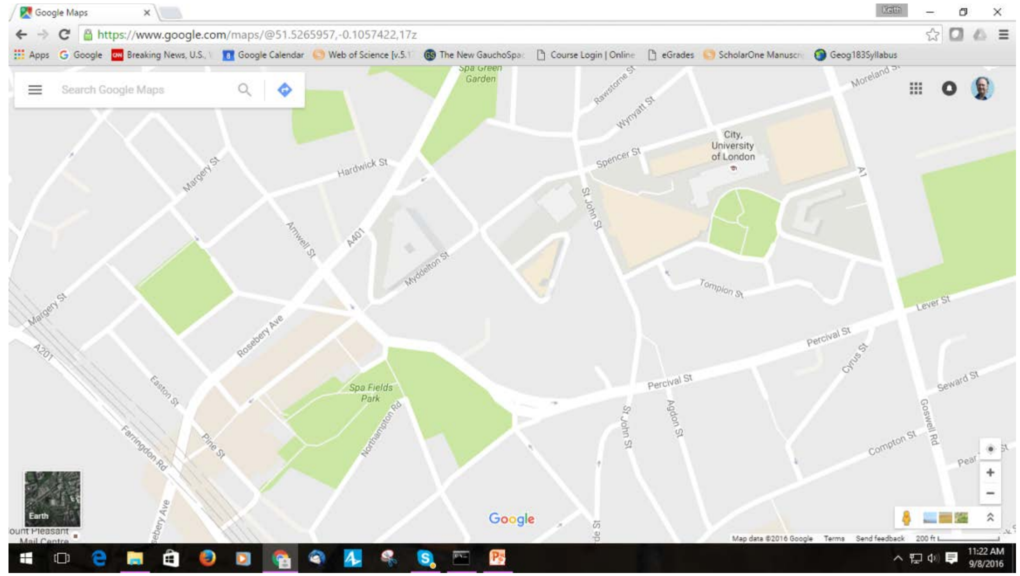
"the only Fellow of Caius ever to be granted sabbatical leave in order to engage in piracy"

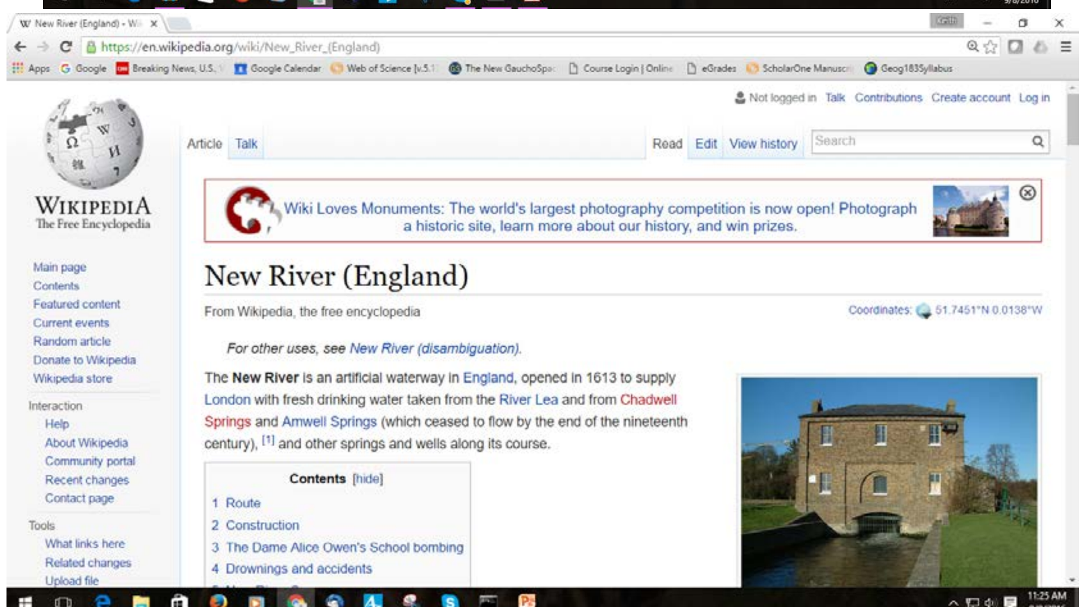


Certaine
ERRORS IN
NAVIGATION,
Arising either of the ordinarie erroneous making or vsing of the sea Chart, Compasse, Crosse staffe, and Tables of declination of the Sunne, and fixed Starres detected and corrected.

By E. W.

Printed at London by Valentine Sims, 1599.





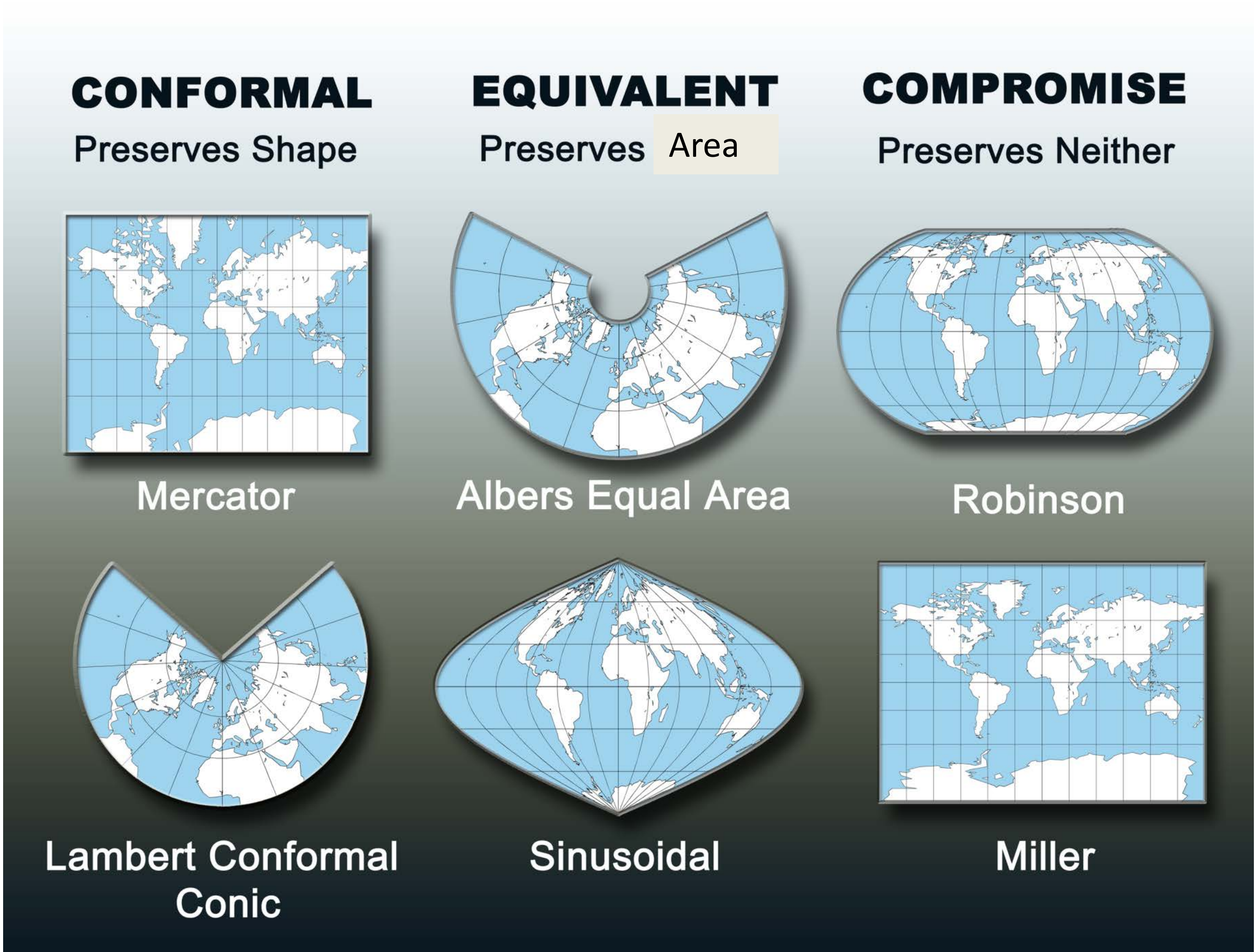
The West Wing map projections episode Season 2 Episode 16

- https://www.youtube.com/watch?v=vVX-PrBRtTY
- 892,048 views

During the projection transformation

- We have to distort the 3D earth
- We may reduce scale (generalize)
- We make break lines (interruptions)
- We distort scale
- We distort area
- We distort directions

No flat map can be both equivalent and conformal

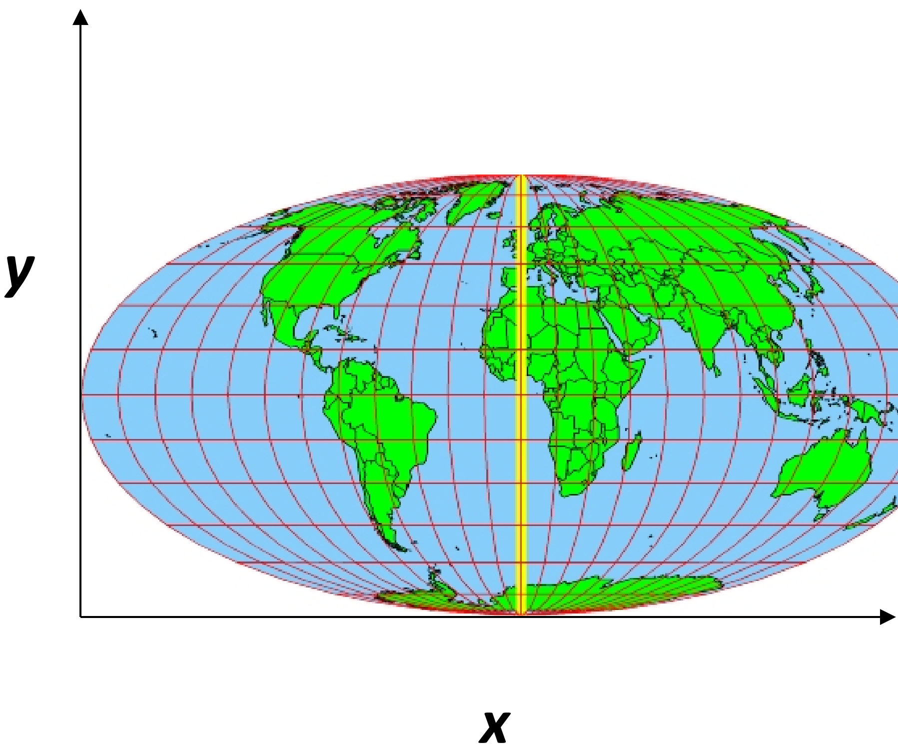


Classification by Independence

- $x = f(\lambda)$ and $y = f(\phi)$
- $x = f(\lambda, \phi)$ and $y = f(\phi)$
- $x = f(\lambda, \phi)$ and $y = f(\lambda, \phi)$
- Partitioning into gores
- Invertible exactly or numerically
- Works for both sphere and ellipsoid

Mollweide: An equal area pseudocylindrical projection

x and *y* are not independent



$$x = \frac{2\sqrt{2}}{\pi}\lambda\cos\left(\frac{\theta}{2}\right)$$

$$y = \sqrt{2}\sin\left(\frac{\theta}{2}\right)$$

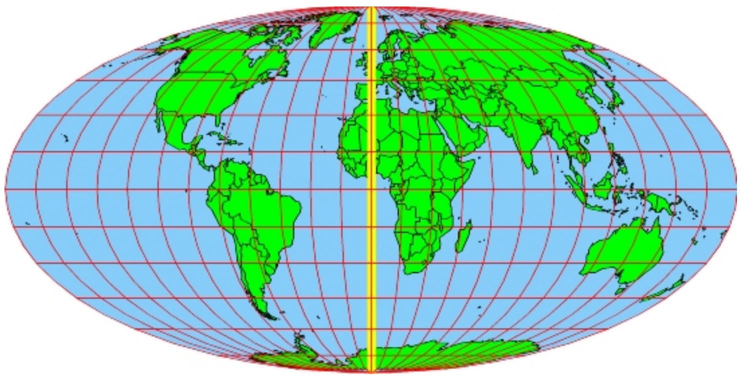
$$2\theta + \sin(2\theta) = \pi\sin(\phi)$$

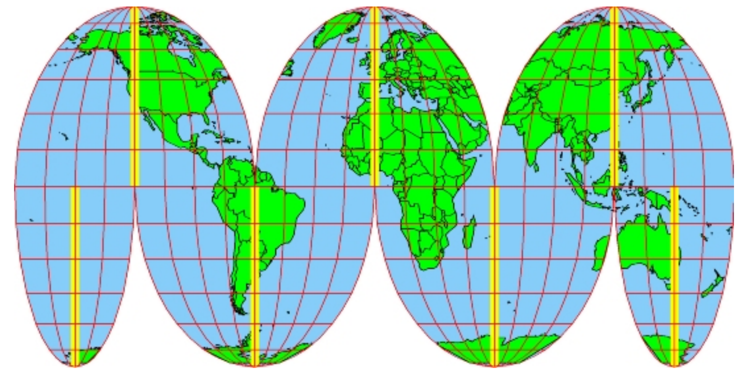
The central meridian

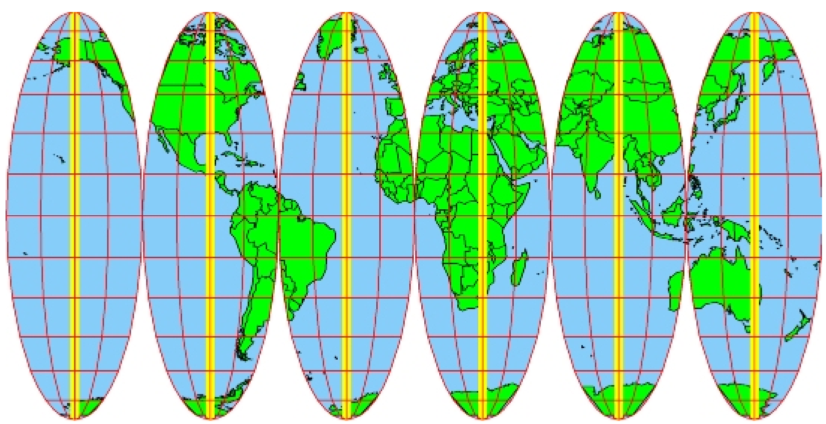
- In the mathematical derivation, x can map onto any meridian, by default we get 0^o
- $x' = f(\lambda - \lambda_0)$
- We can change the center of the map
- Can even change the direction of the axis (by rotation)

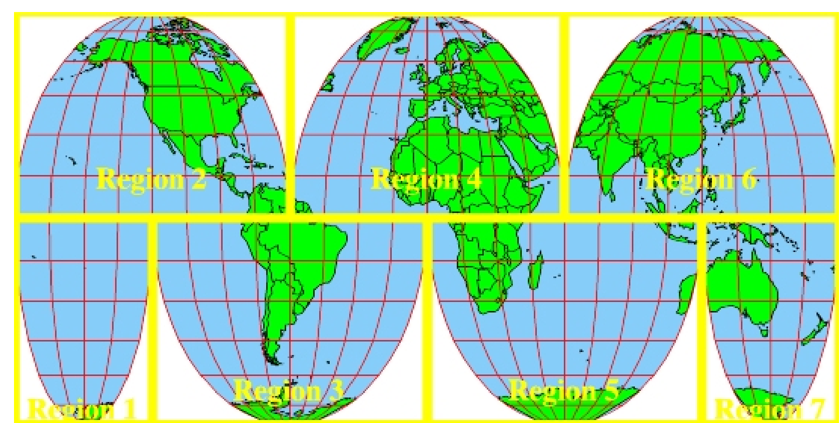
Changing the central meridian

We can also choose the interruptions





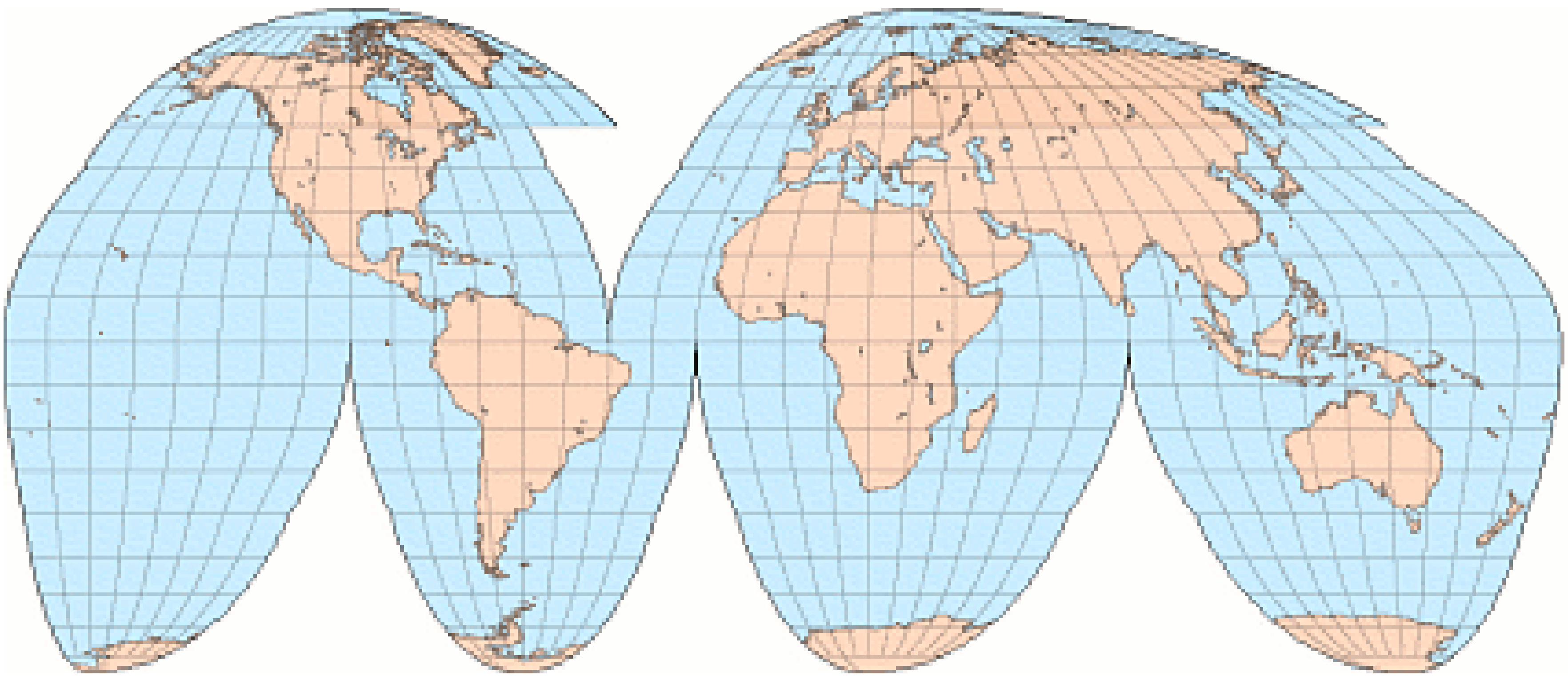




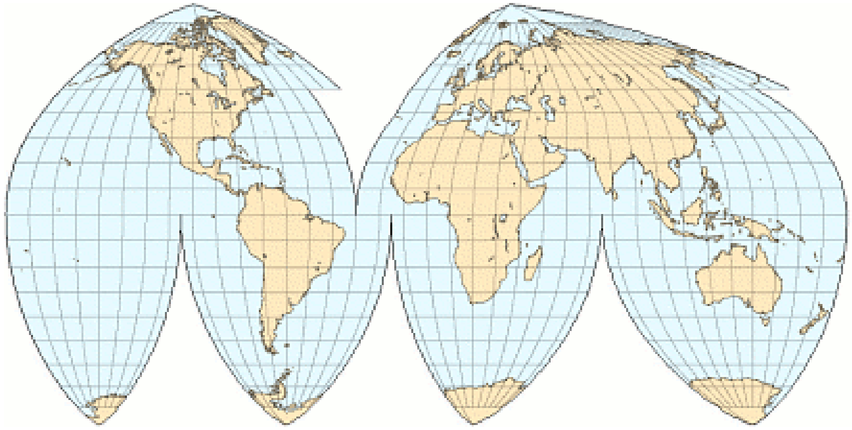
Interrupted Mollweide

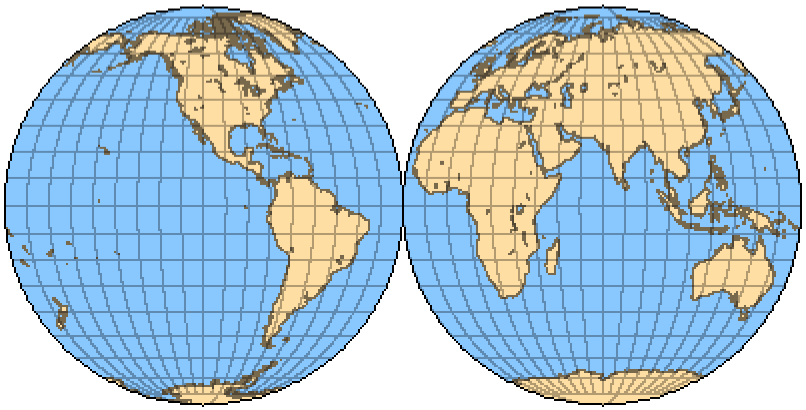
And mix projections together

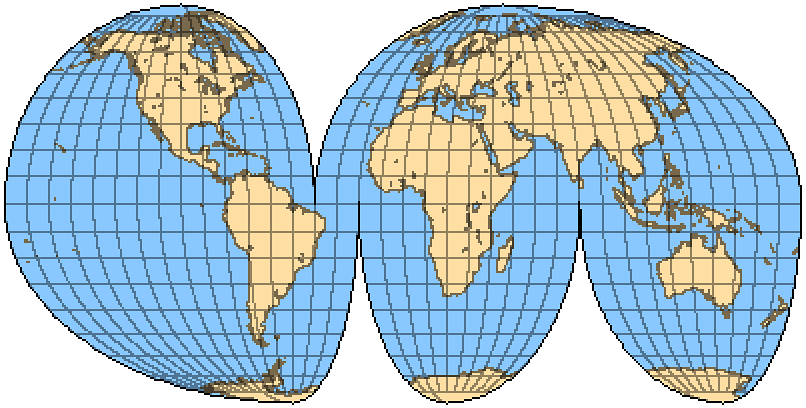
Goode's Homolosine=Mollweide (lobes) plus sinusoidal near the equator (J.P. Goode, 1923)

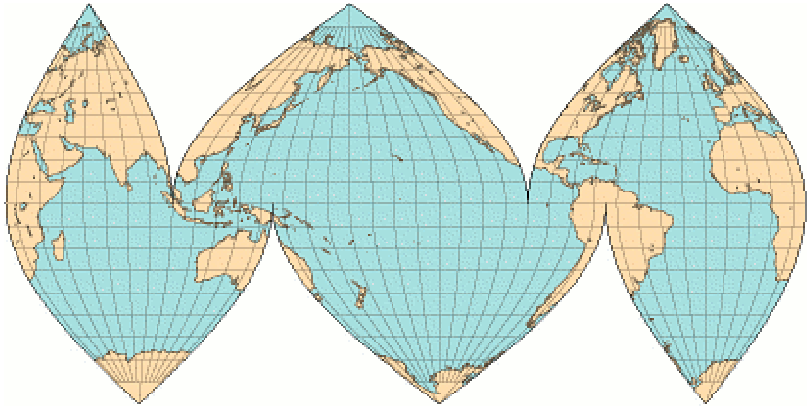


Many possible interruptions

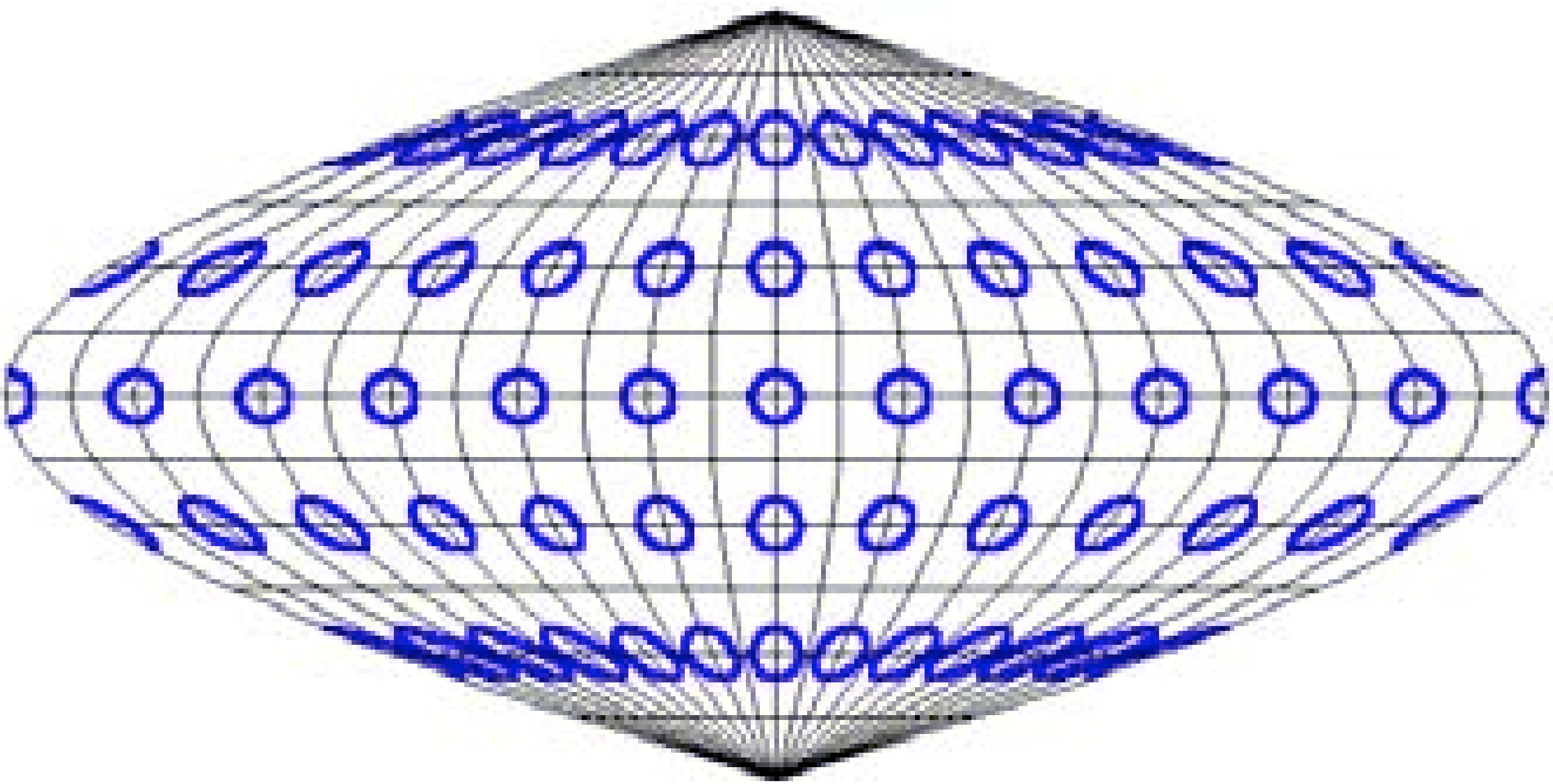






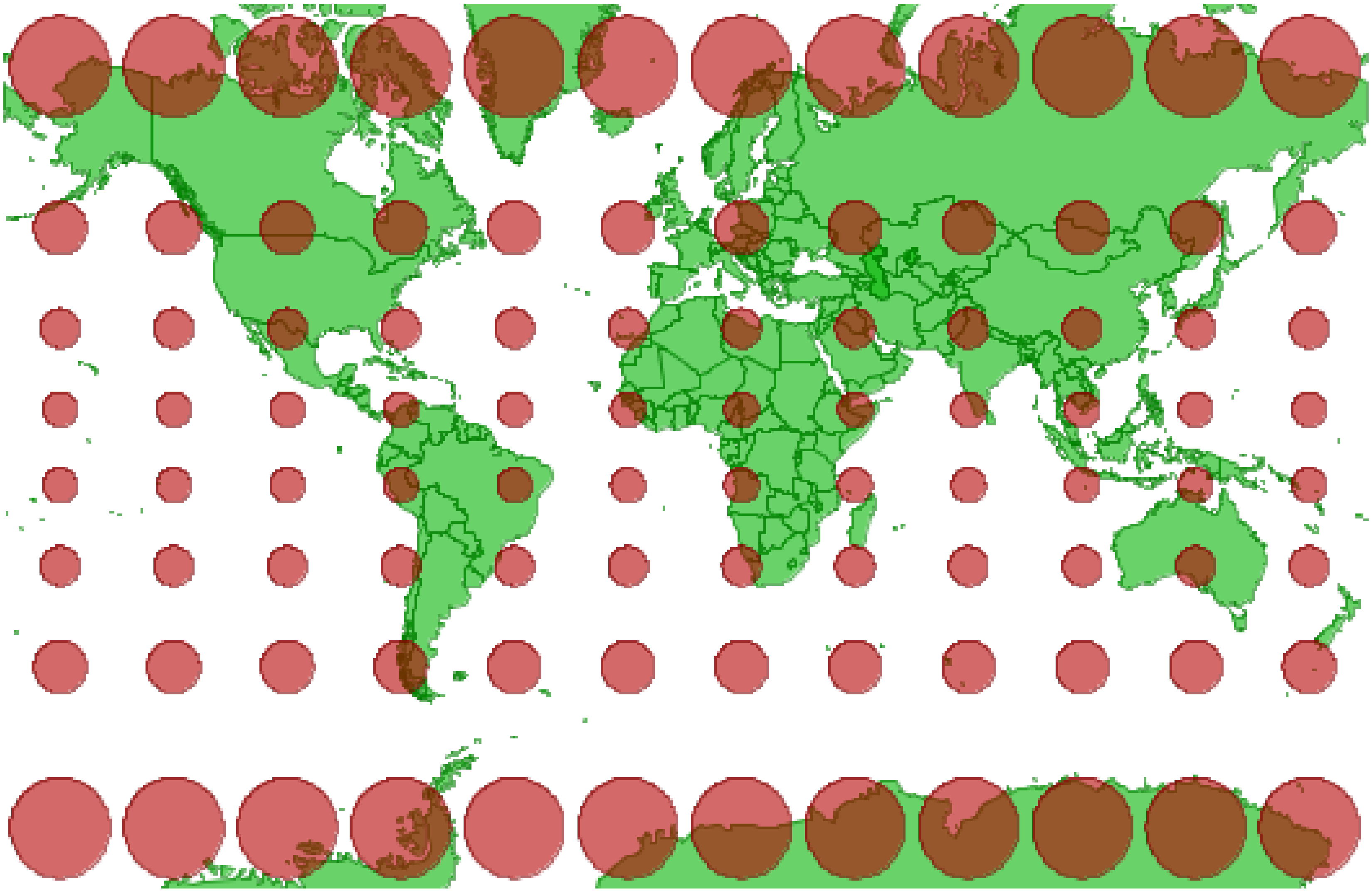


Projection distortion: Tissot's Indicatrix

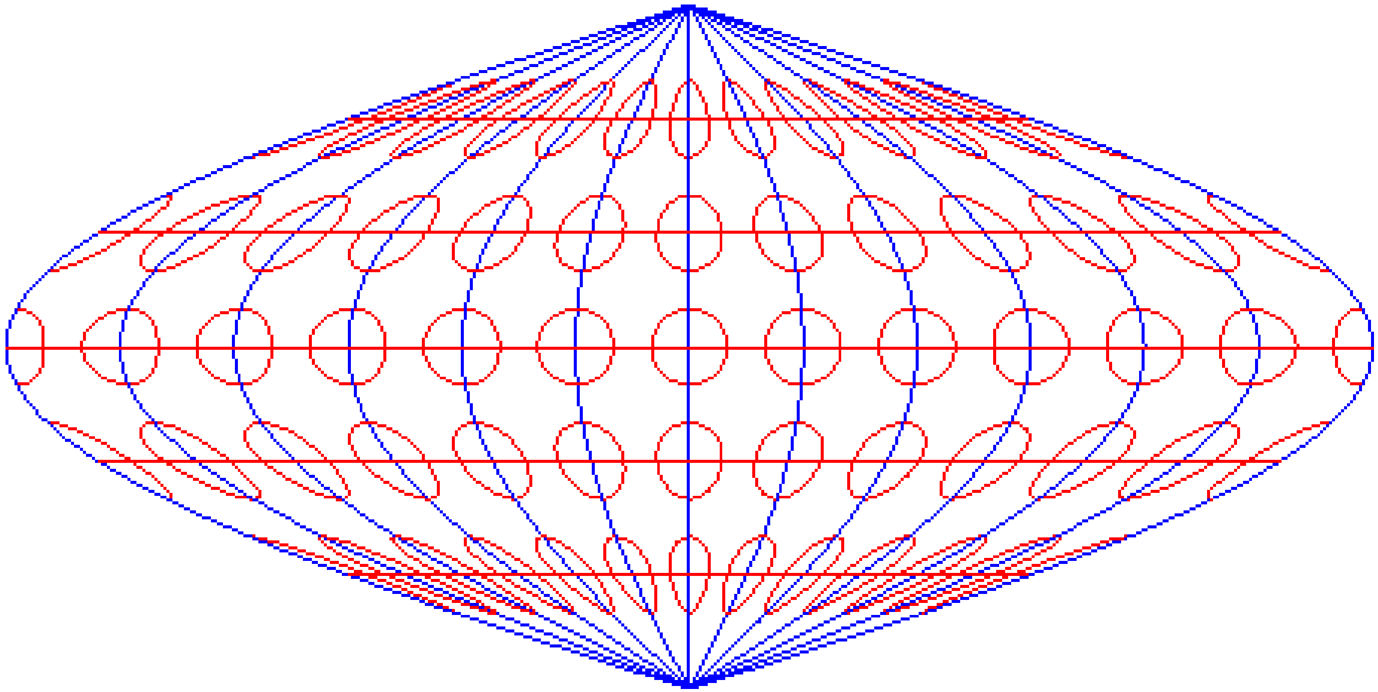


Werner projection

Mercator plus Tissot

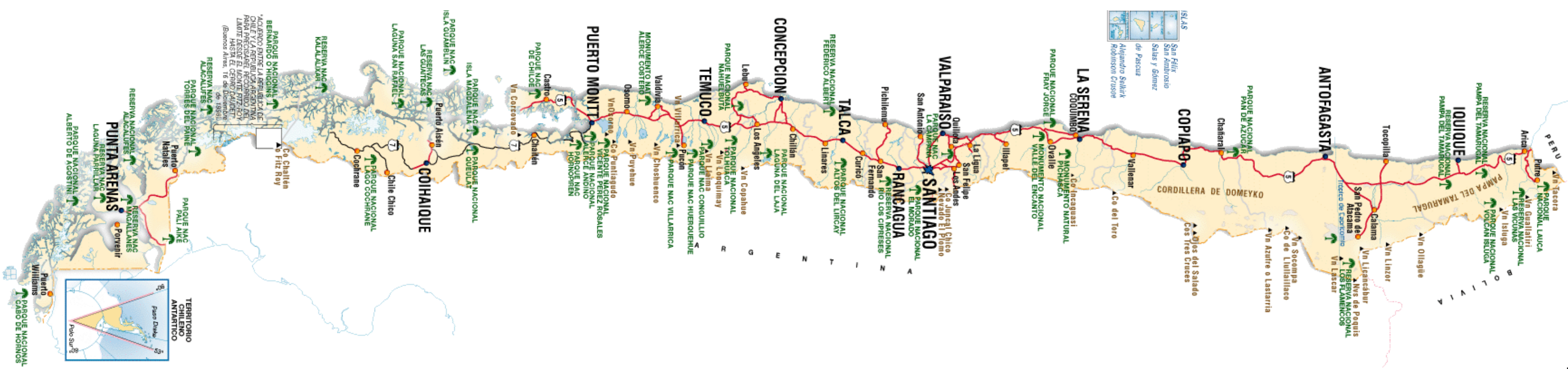


Sinusoidal plus Tissot

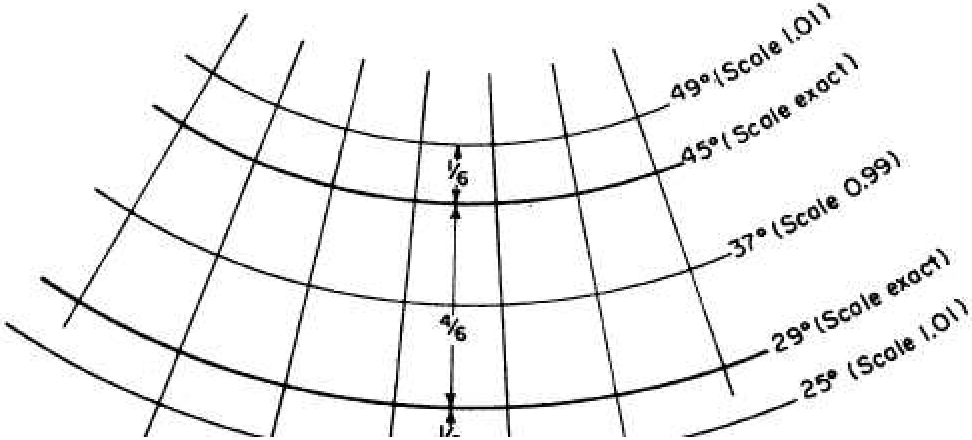


Minimizing projection error

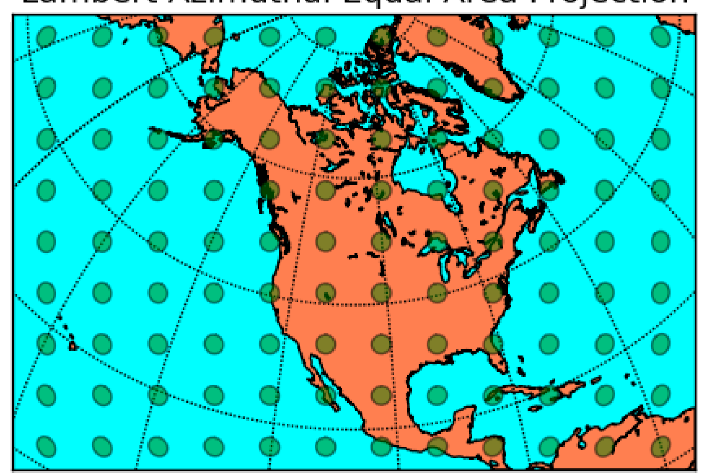
- Use a small area
- Choose a projection to limit error
- Compute expected error amount and location
- Use secant projection
- Customize: e.g. Chile



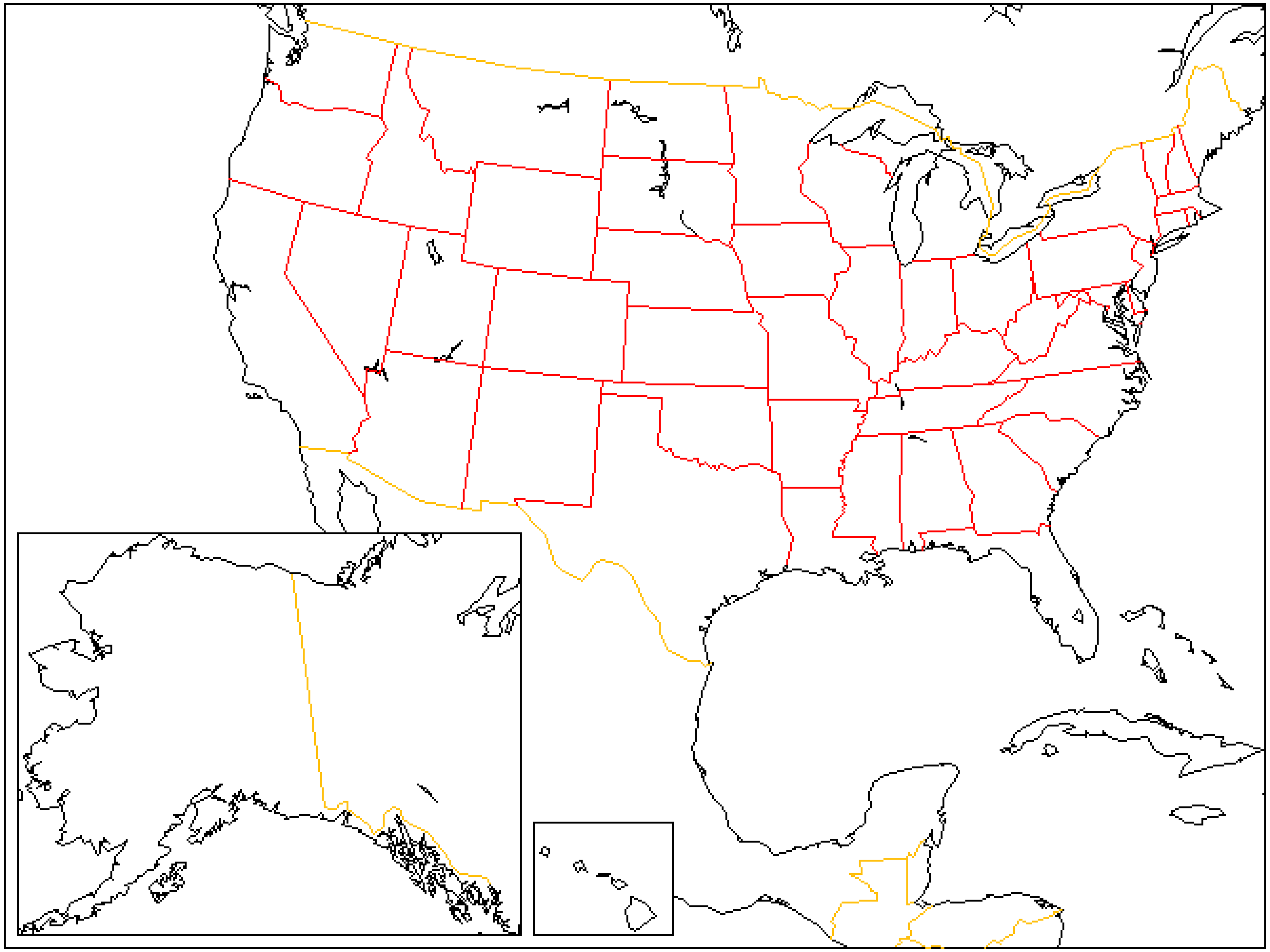
Distortion on the Secant Conic
Lambert conformal conic projection



Lambert Azimuthal Equal Area Projection

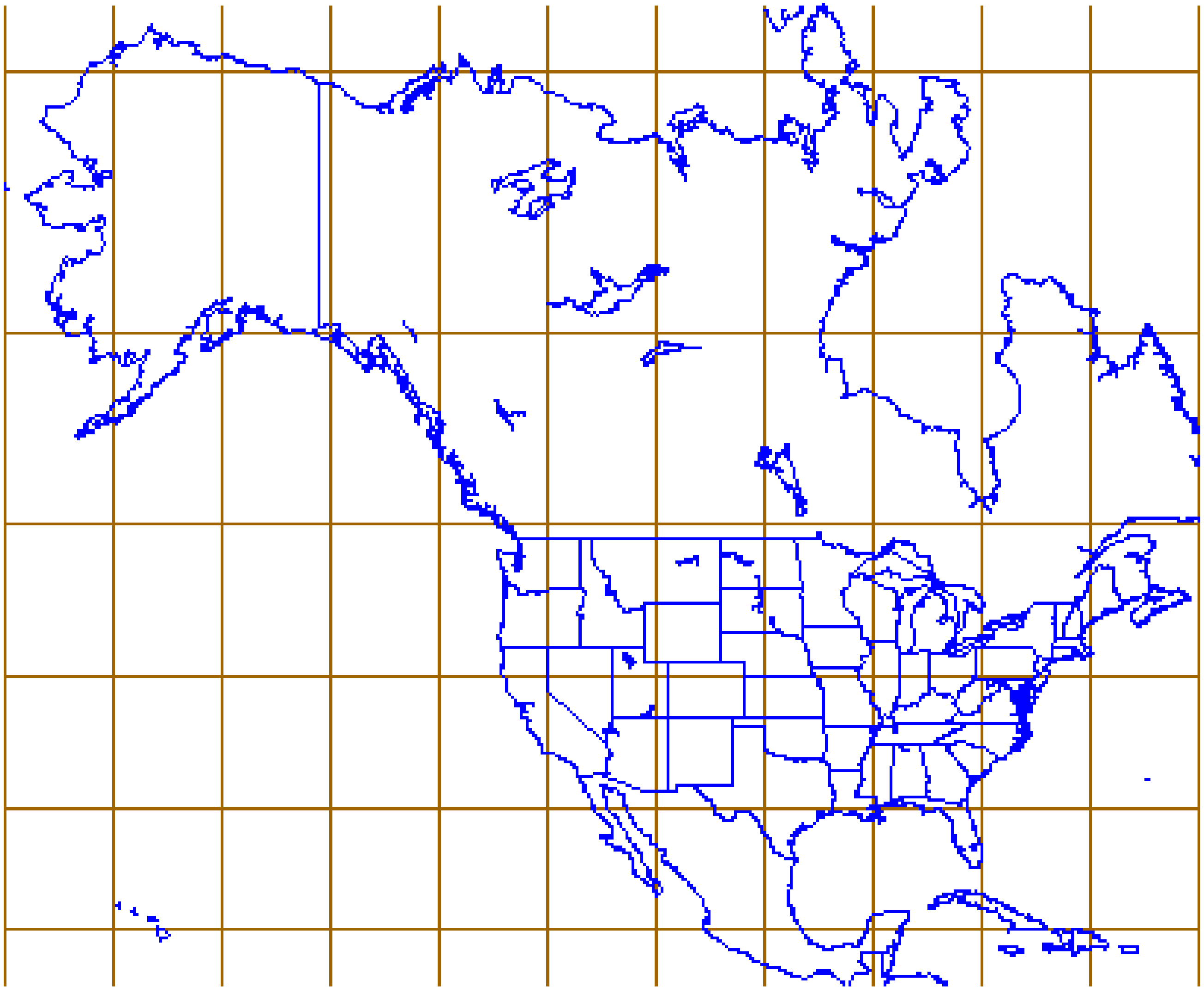


Projections for the USA



Lambert conformal conic

USA on Mercator



Blended projections

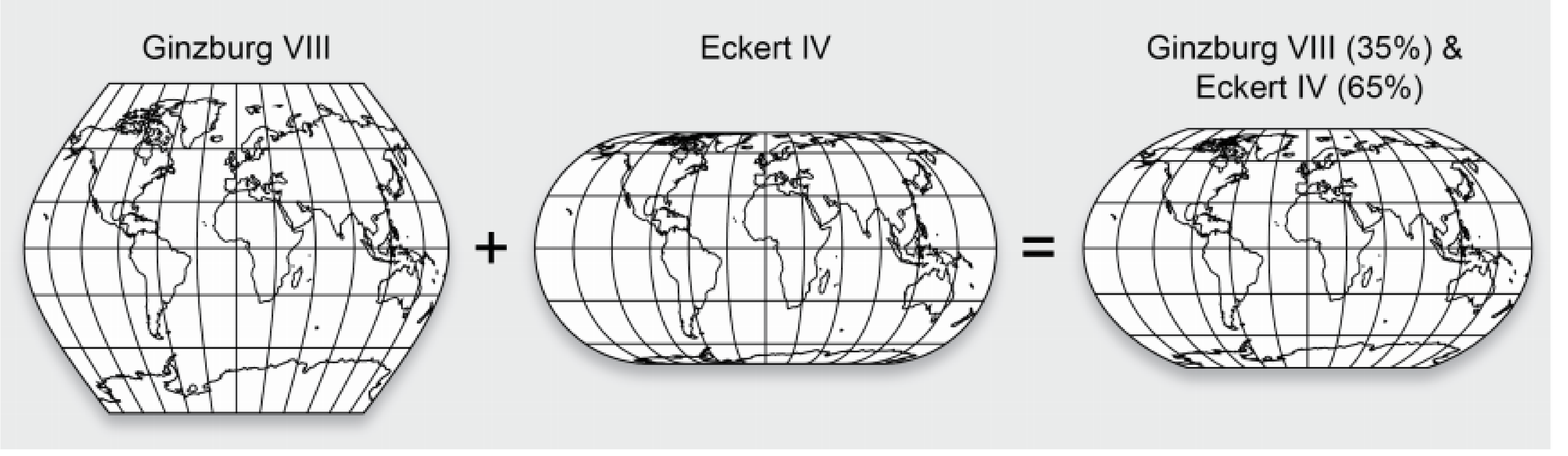
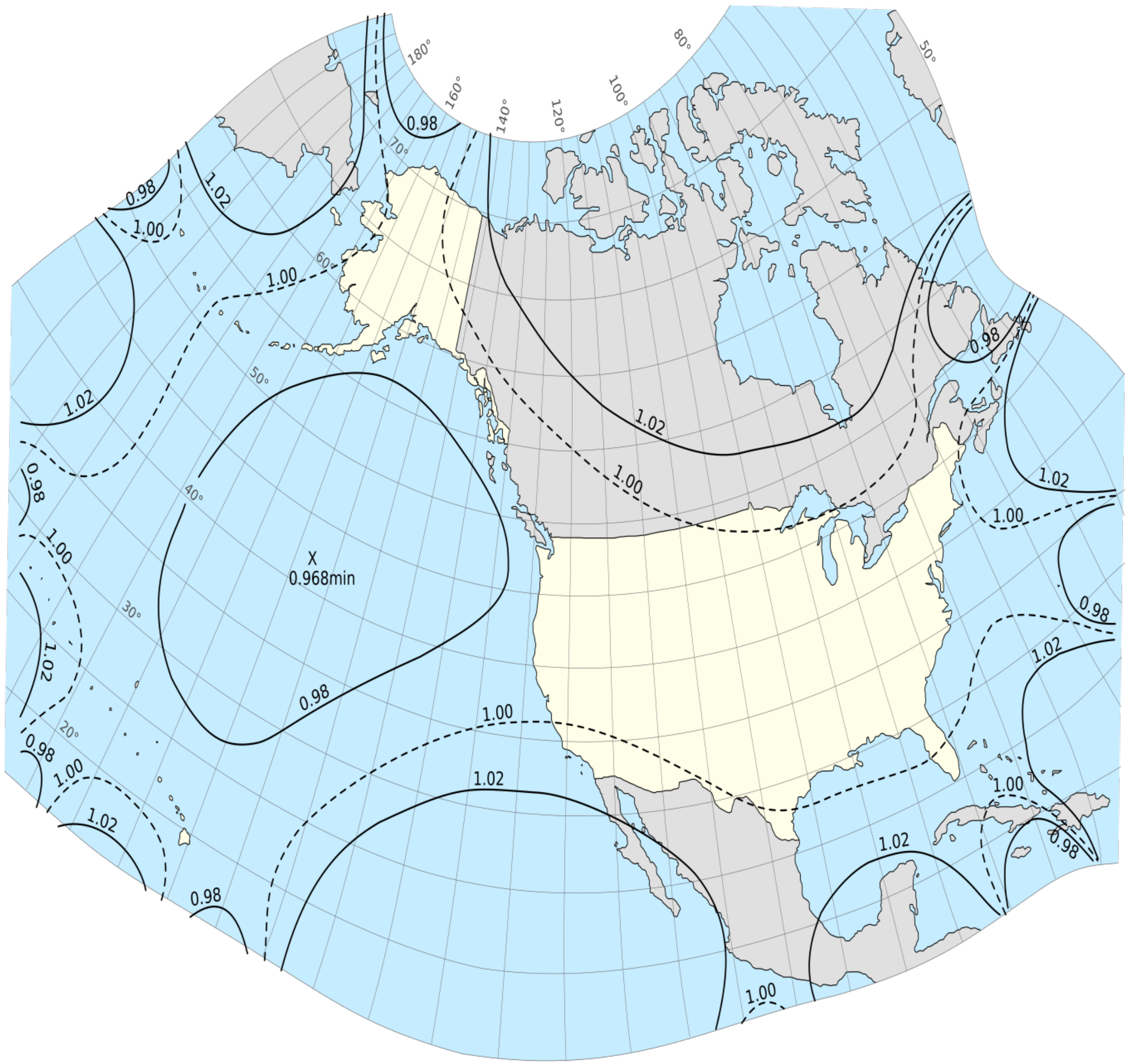
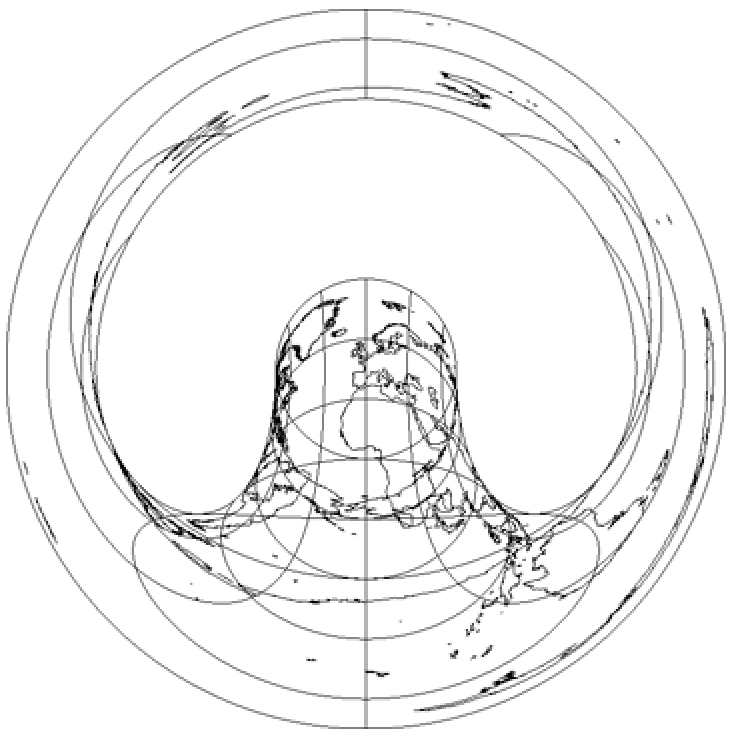


Figure 3: A projection created by computing the weighted means of the Ginzburg VIII (35%) and the Eckert IV (65%) projections and scaling vertical coordinates by the factor 0.9.

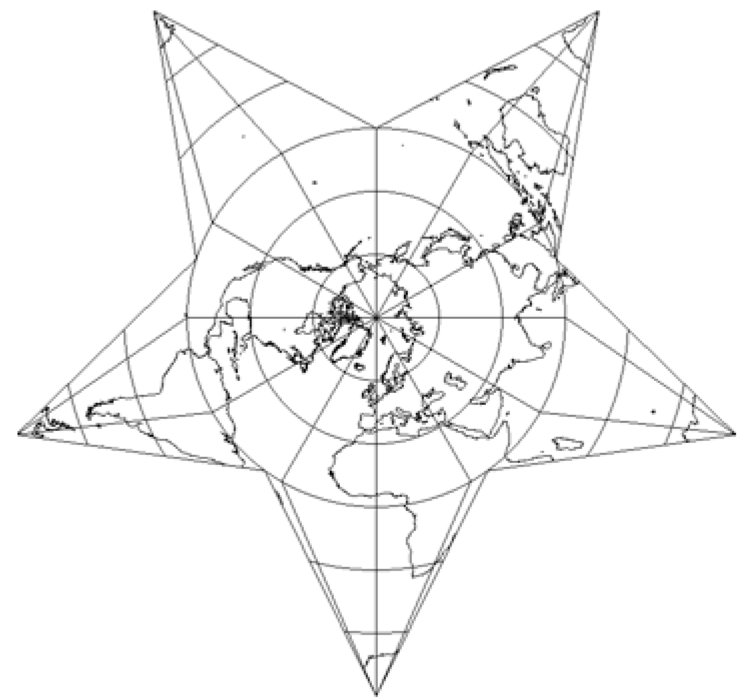
GS-50 Snyder



Fun projections

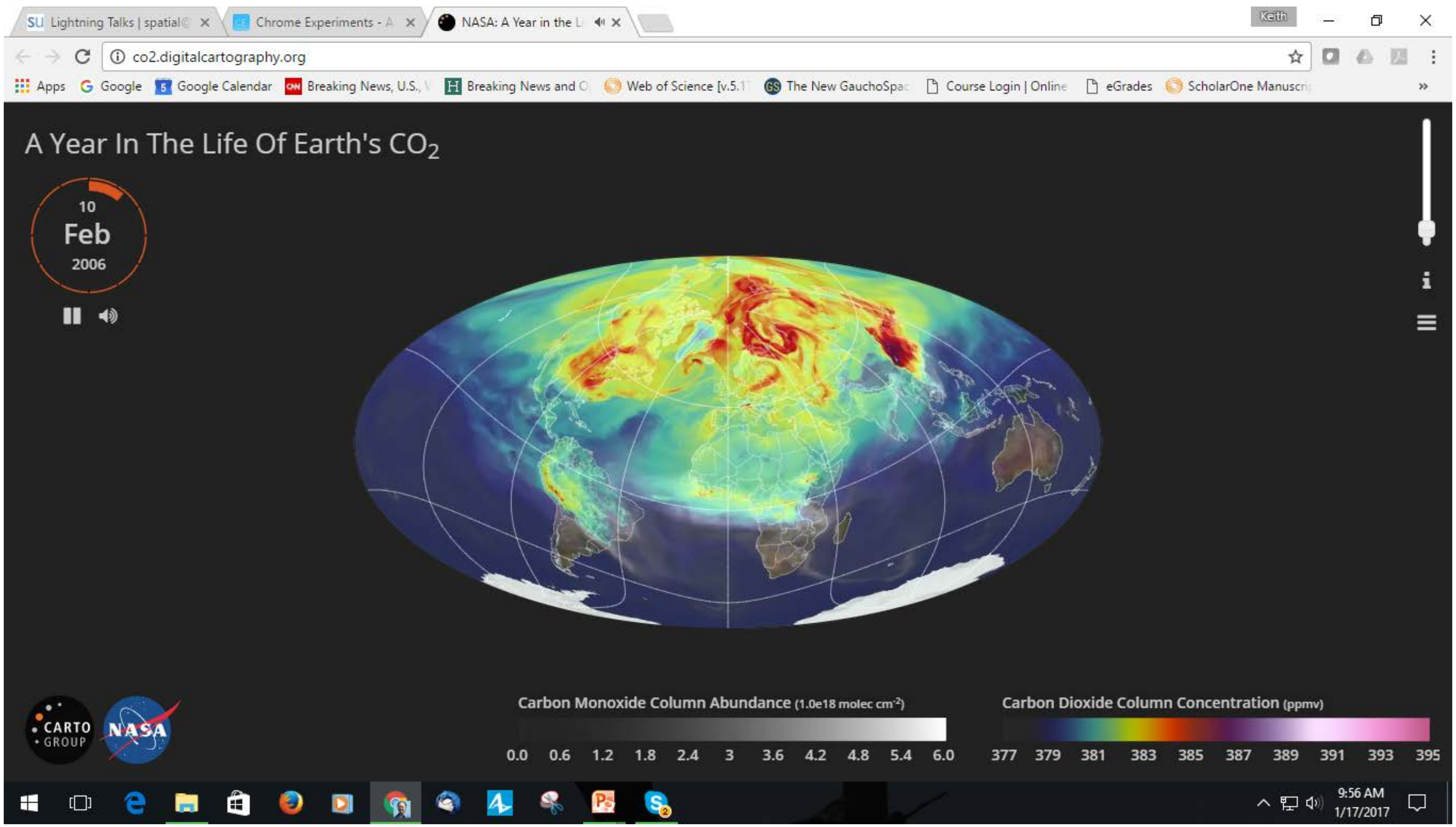


Hammer retroazimuthal



Berghaus star

Bernhard Jenny: Adaptive Projections
goo.gl/ig4he6



http://www.progonos.com/furuti/MapProj/Normal/ProjPoly/Foldout/foldout.html

Projection websites

- Geographers Craft: http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj_f.html
- Wikipedia:
- http://en.wikipedia.org/wiki/Map_projection
- Gallery of Map Projections:
- http://www.csiss.org/map-projections/index.html
- Daan Strebe's Map Projection Essentials
- https://www.mapthematics.com/Essentials.php
- Carlos Furuti: http://www.progonos.com/furuti/MapProj/Normal/TOC/cartTOC.html
- Hunter College: http://www.geography.hunter.cuny.edu/mp/

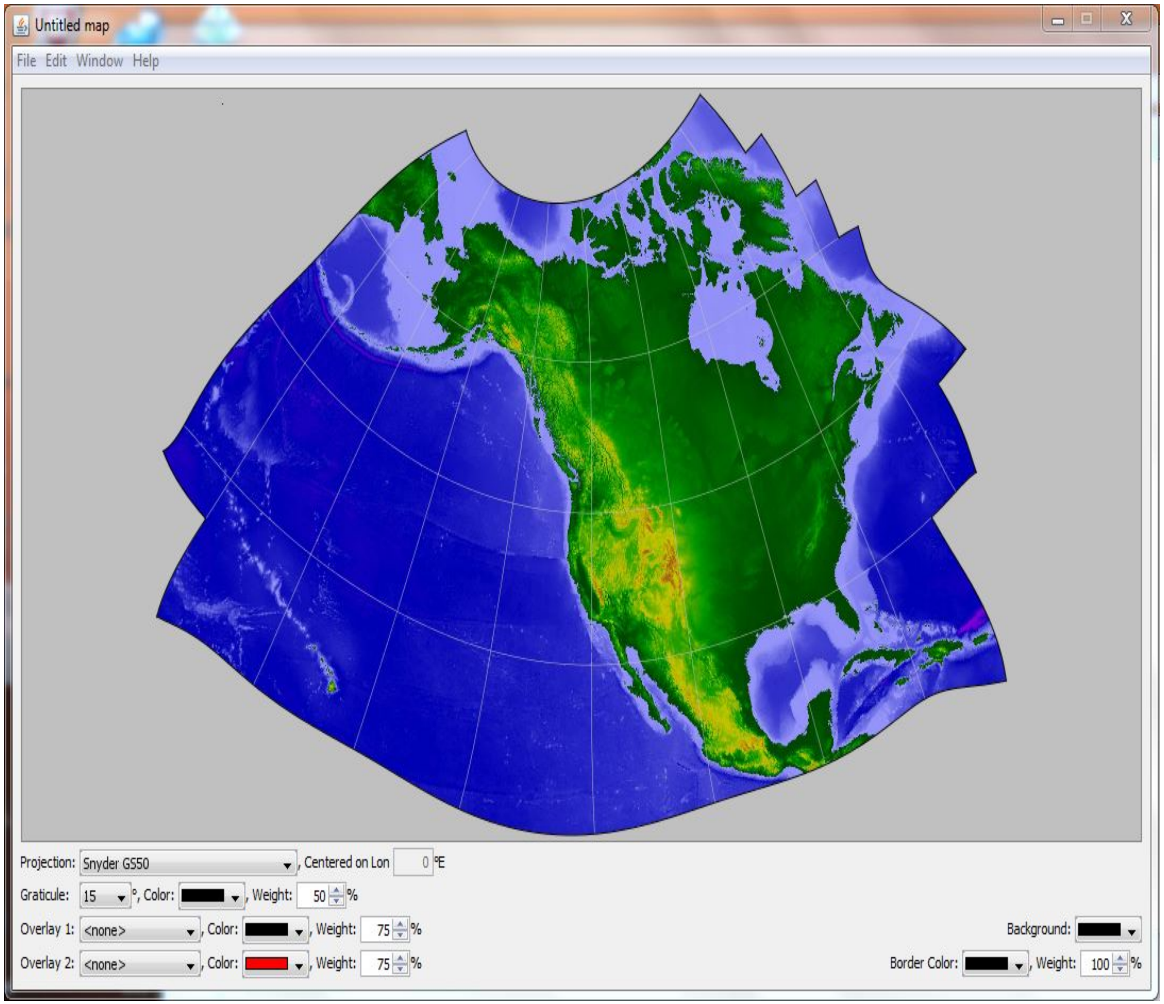
Miscellaneous

- Floating Ring https://slvg.soe.ucsc.edu/map.html
- National Geographic Kids Module http://nationalgeographic.org/activity/investigating-map-projections/
- MATLAB http://www.mathworks.com/discovery/map-projection.html
- IDL http://www.idlcoyote.com/documents/cg_maps.php
- Mathematica https://www.wolfram.com/mathematica/new-in-10/geographic-visualization/use-any-map-projection.html
- NOBLEED http://noobeed.com/nb_ex_map_projection.htm
- R https://cran.r-project.org/web/packages/mapproj/index.html

Software and Directories

- Projection selection tool http://projectionwizard.org/
- NASA Gprojector http://www.giss.nasa.gov/tools/gprojector/
- Hunter College page http://www.geo.hunter.cuny.edu/mp/software.html
- Map Projection gallery http://www.csiss.org/map-projections/
- Natural Earth http://www.shadedrelief.com/NE_proj/
- Mapthematics and Geocart3 https://www.mapthematics.com/
- Flex Projector http://www.flexprojector.com/

NASA: G.Projector—Global Map Projector (Raster only)



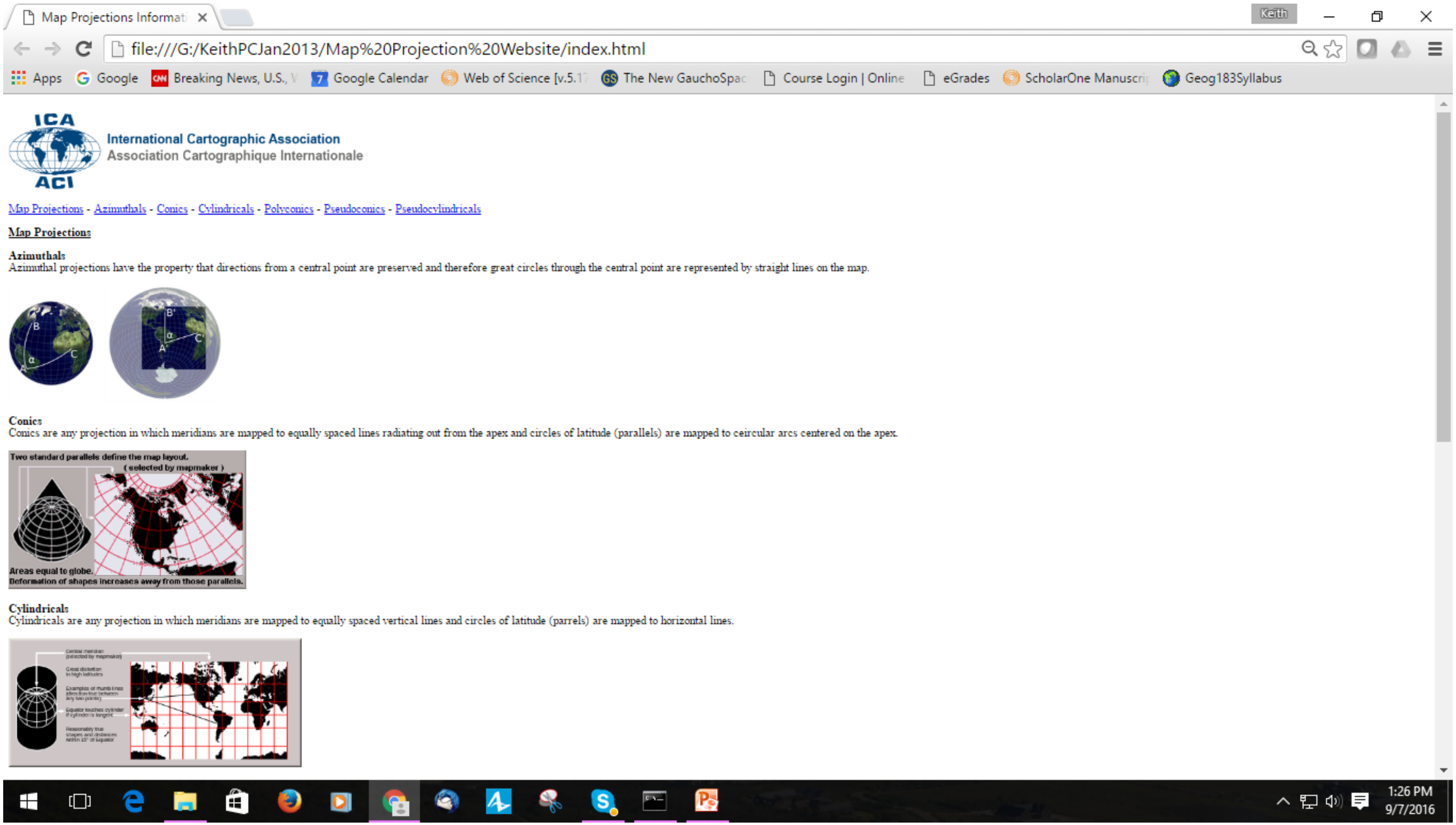
Code Libraries

- Matthew's Map Projection Software http://www.users.globalnet.co.uk/~arcus/mmps/
- PROJ.4 https://trac.osgeo.org/proj/
- GEOTRANS http://earth-info.nga.mil/GandG/geotrans/
- Java Map projection Library http://javamapprojlib.sourceforge.net/

Other Resources

- Geographers Craft http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj.html
- Gall-Peters https://sites.google.com/site/thepowerofcartography/gall-peters-map-projection
- MicroCAM: http://www.csiss.org/map-projections/microcam/

A Map Projections Information Clearinghouse?



Map Projections : Summary (1)

- Cartographic transformations: scale, projection, symbolization
- Projections convert the surface of a 3D sphere (oid) into a plane
- There are 180 degrees of latitude and 360 of longitude
- It is easy to measure latitude, harder for longitude
- The prime meridian was standardized in 1884 at Greenwich
- Map projections can be created mechanically or mathematically

Map Projections : Summary (2)

- We can project onto a plane, a cylinder or a cone
- We can orient the projection as equatorial, oblique or transverse
- We can make the projection tangent or secant
- No flat map can be both equivalent and conformal
- Projection matters