Week 3: Geodesy, Datums, Map Projections, and Coordinate Systems

GEOG 011

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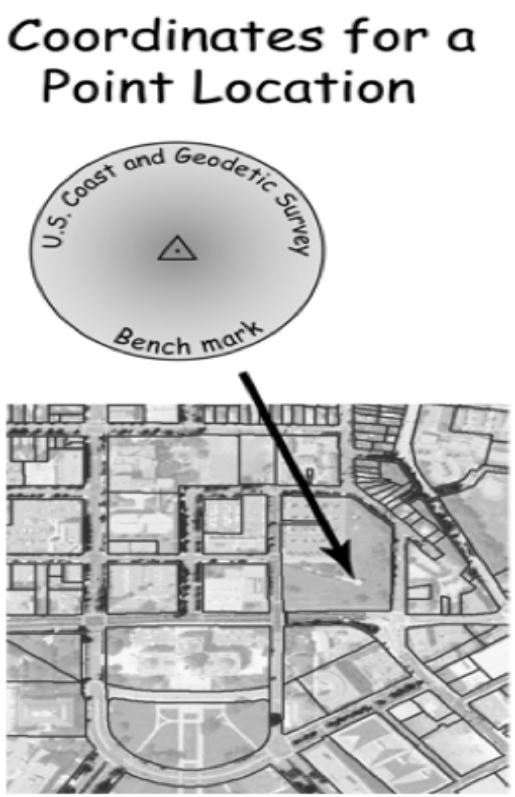
Geodesy

Keywords

- The science of measuring the shape of the earth
- Complex, technical, and confusing
- Geodesy is full of technical terms widely and incorrectly used interchangeably, e.g. datum and ellipsoid and geographic coordinate system
- GIS professionals need to know the basics

Coordinates for the Same Place



From Surveyor Data:

	Latitude (N)	Longitude (W)
NAD83(2007)	44 57 23.23074	093 05 58.28007
NAD83(1986)	44 57 23.22405	093 05 58.27471
NAD83(1996)	44 57 23.23047	093 05 58.27944

	X	Y	
SPC MNS	317,778.887	871,048.844	MT
SPC MNS	1,042,579.57	2,857,766.08	sFT
UTM15	4,978,117.714	492,150.186	MT

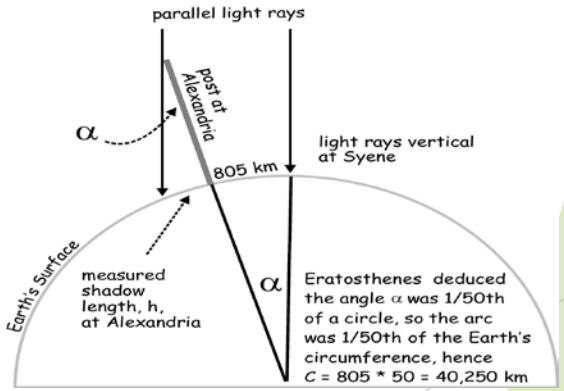
From Data Layers:

	X	Y	
MN-Ramsey	573,475.592	160,414.122	sFT
MN-Ramsey	174,195.315	48,893.966	MT
SPC MNC	890,795.838	95,819.779	MT
SPC MNC	2,922,552.206	314,365.207	sFT
LCC	542,153.586	18,266.334	MT

Bolstad 2012, Fig 3-1

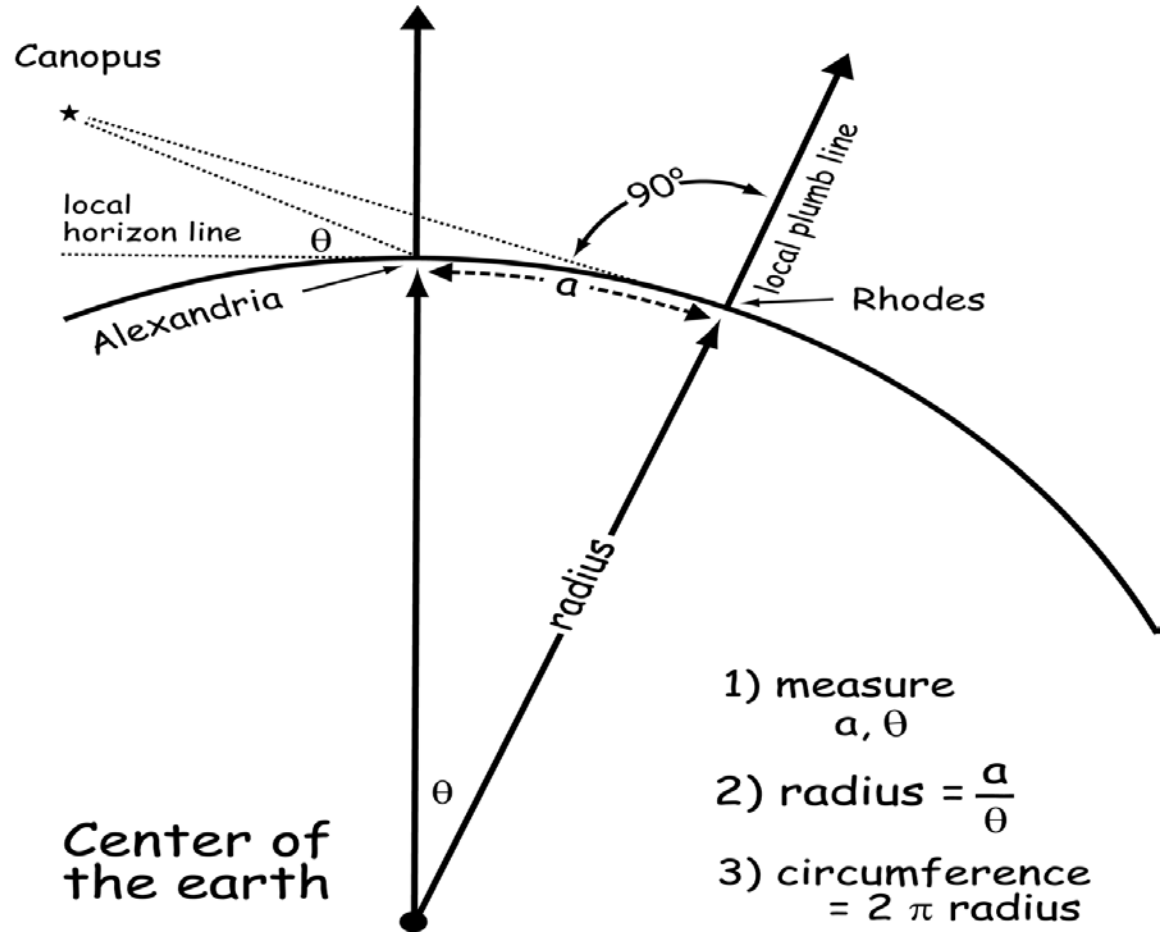
Earth Estimated by Eratosthenes

https://www.youtube.com/watch?v=G8cbIWMv0rI



Bolstad 2012, Fig 3-2

Earth Estimated by Posidonius



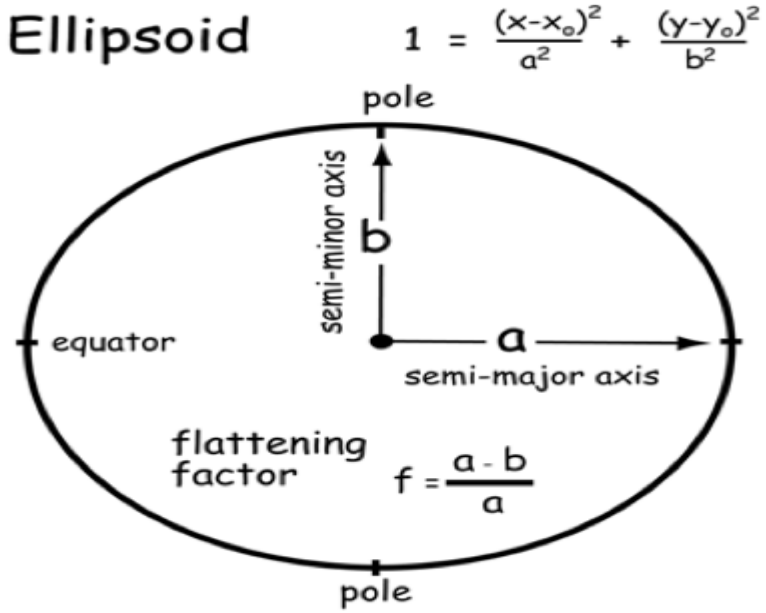
Bolstad 2012, Fig 3-3

Ellipsoid

Keywords

Spheroid – a sphere, or approximately a sphere

Ellipsoid – a sphere slightly flattened at the poles, sometimes called an oblate spheroid; an approximation of the Earth's shape



Bolstad 2012, Fig 3-4

Table 3-1: Official ellipsoids. Radii may be specified more precisely than the 0.1 meter shown here (from Snyder, 1987 and other sources).

Name	Year	Equatorial Radius, r_1 meters	Polar Radius, r_2 meters	Flattening Factor, f	Users
Airy	1830	6,377,563.4	6,356,256.9	1/ 299.32	Great Britain
Bessel	1841	6,377,397.2	6,356,079.0	1/ 299.15	Central Europe, Chile, Indonesia
Clarke	1866	6,378,206.4	6,356,583.8	1/ 294.98	North America; Philippines
Clarke	1880	6,378,249.1	6,356,514.9	1/ 293.46	Most of Africa; France
Inter-national	1924	6,378,388.0	6,356,911.9	1/ 297.00	Much of the world
Austra-lian	1965	6,378,160.0	6,356,774.7	1/ 298.25	Australia
WGS72	1972	6,378,135.0	6,356,750.5	1/ 298.26	NASA, US Defense Dept.
GRS80	1980	6,378,137.0	6,356,752.3	1/ 298.26	Worldwide
WGS84	1984 - cur-rent	6,378,137.0	6,356,752.3	1/ 298.26	Worldwide

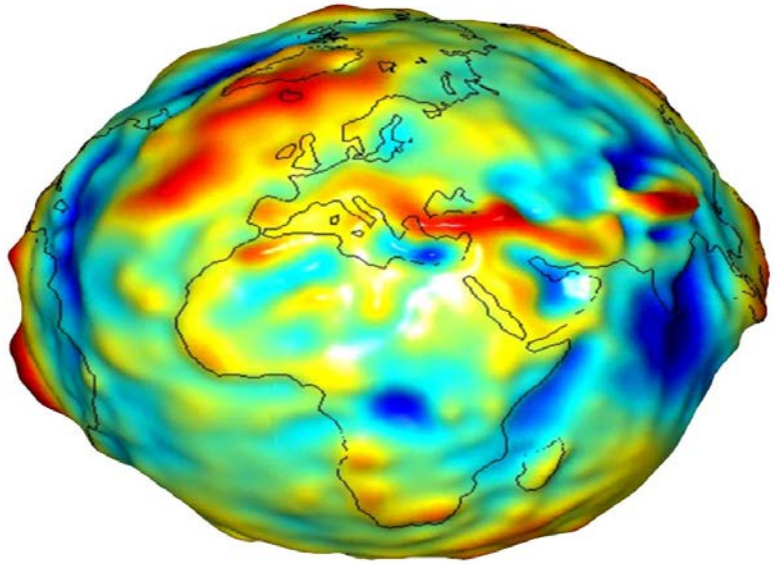
Bolstad 2012, Table 3-1

Geoid

Keywords

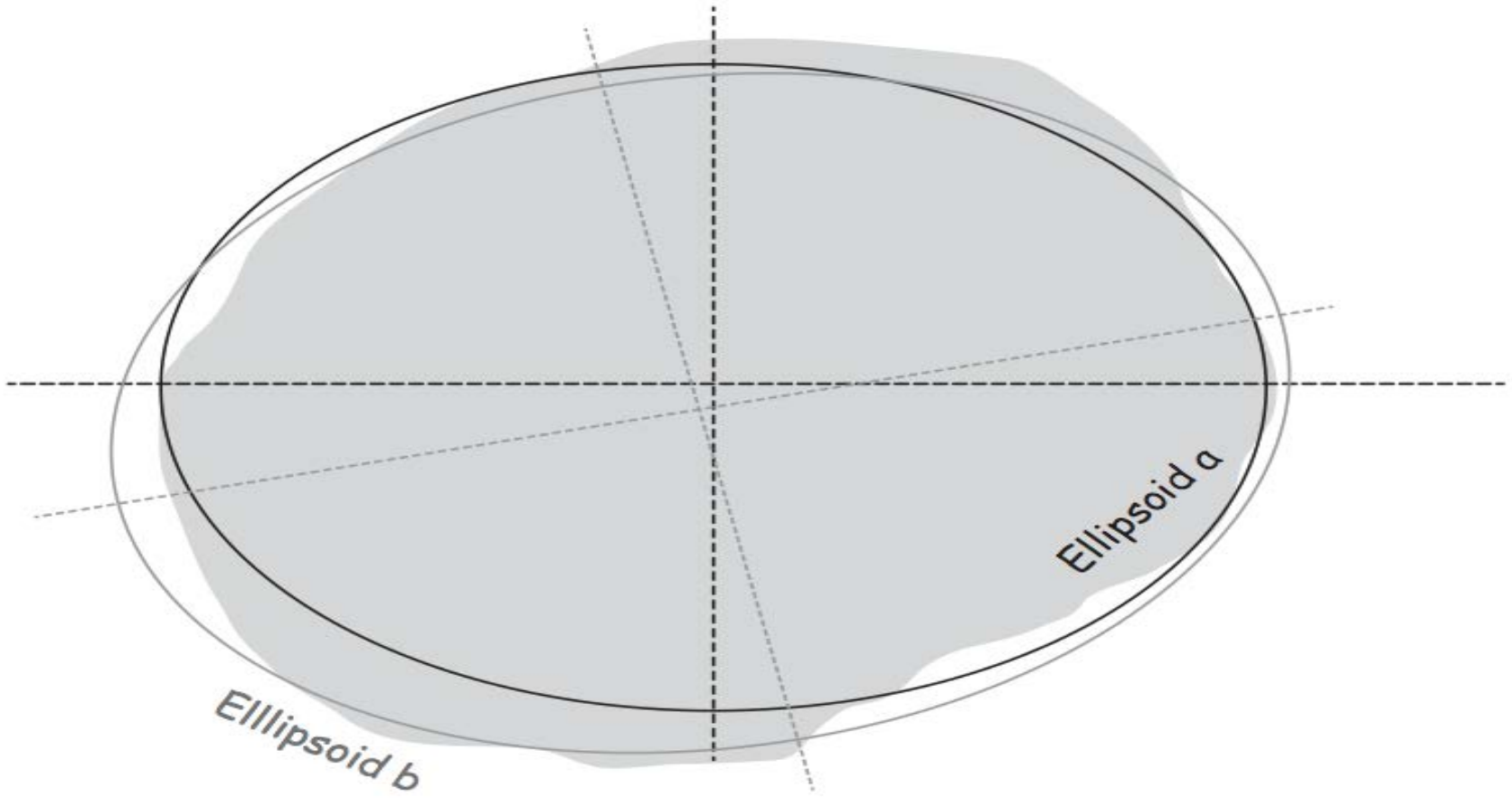
Geoid – the 3D surface along which gravitational pull is constant

Note: These are not mountains and valleys!



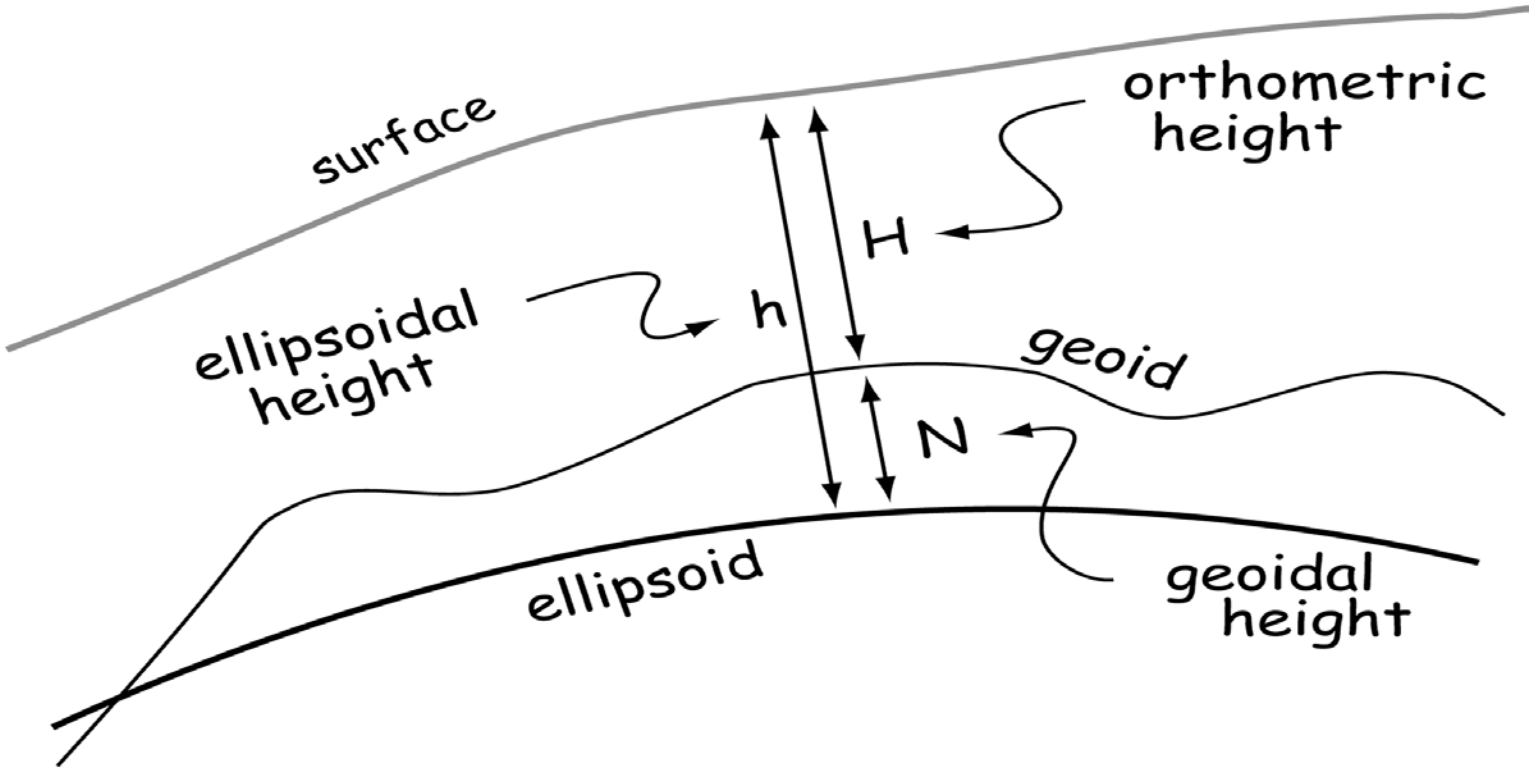
Bolstad 2012, Fig 3-7

How Geoids Affect Ellipsoid Creation



Bolstad 2012, Fig 3-8

Geoid as Reference for Heights

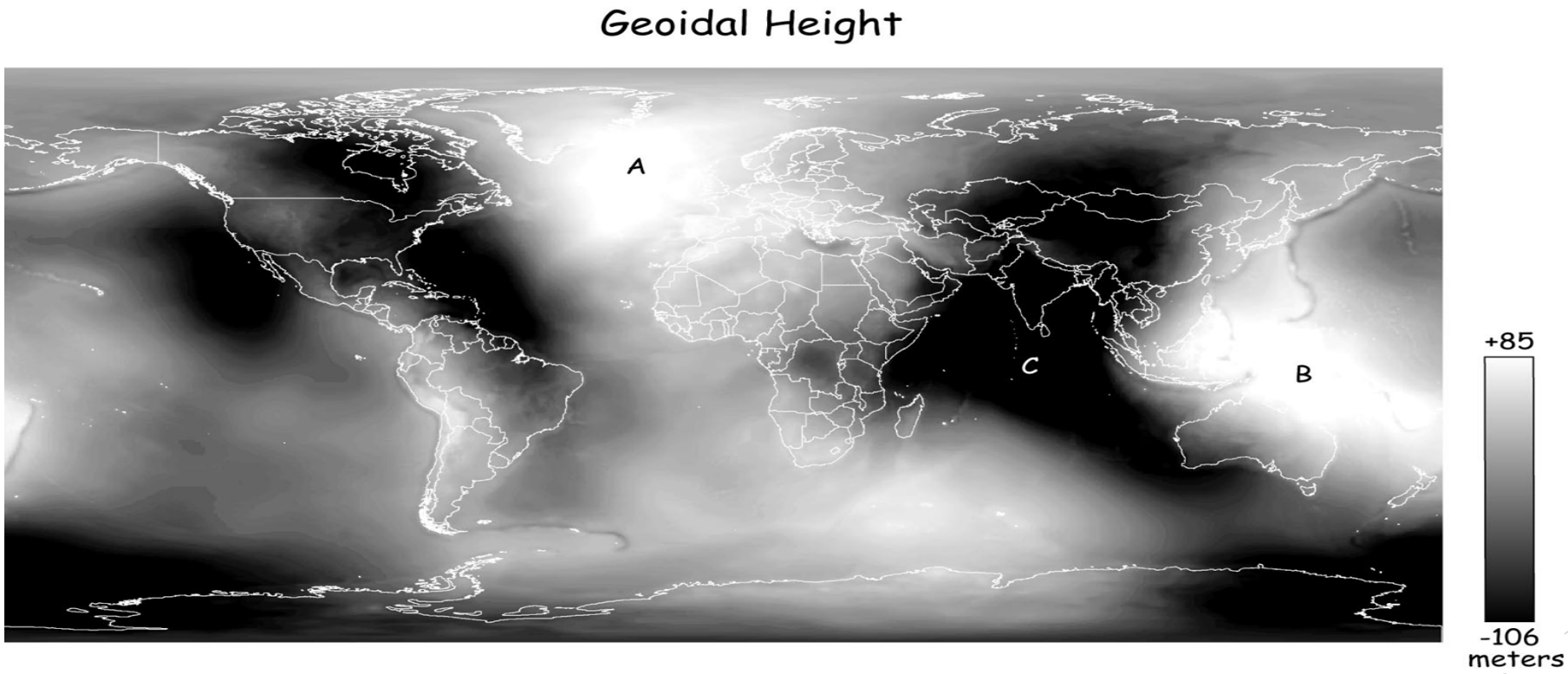


$$h = H + N$$

ellipsoidal height = orthometric height + geoidal height

Bolstad 2012, Fig 3-9

Map of Geoidal Heights



Bolstad 2012, Fig 3-10

Revisiting Latitude and Longitude

Poles – the points that the axis of revolution passes through

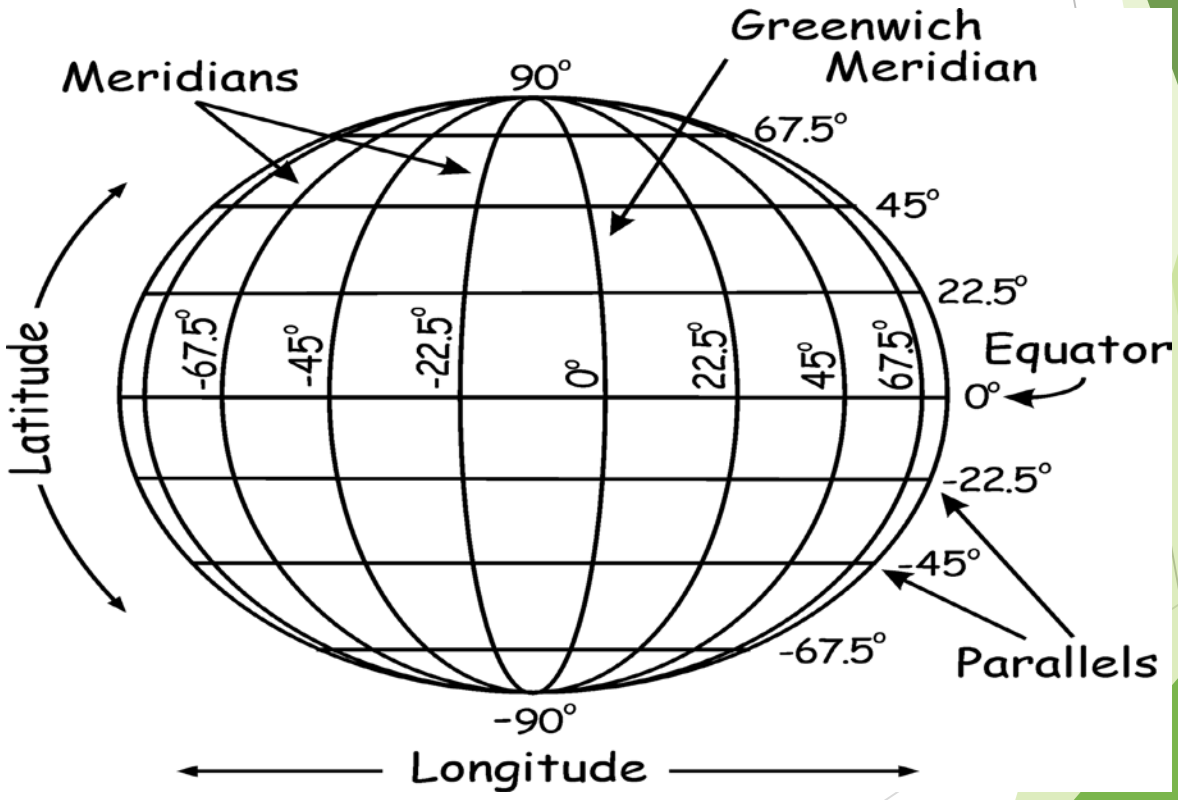
Meridians – lines of constant longitude; these converge at the poles

Keywords

Prime Meridian – a relatively arbitrary origin for longitude

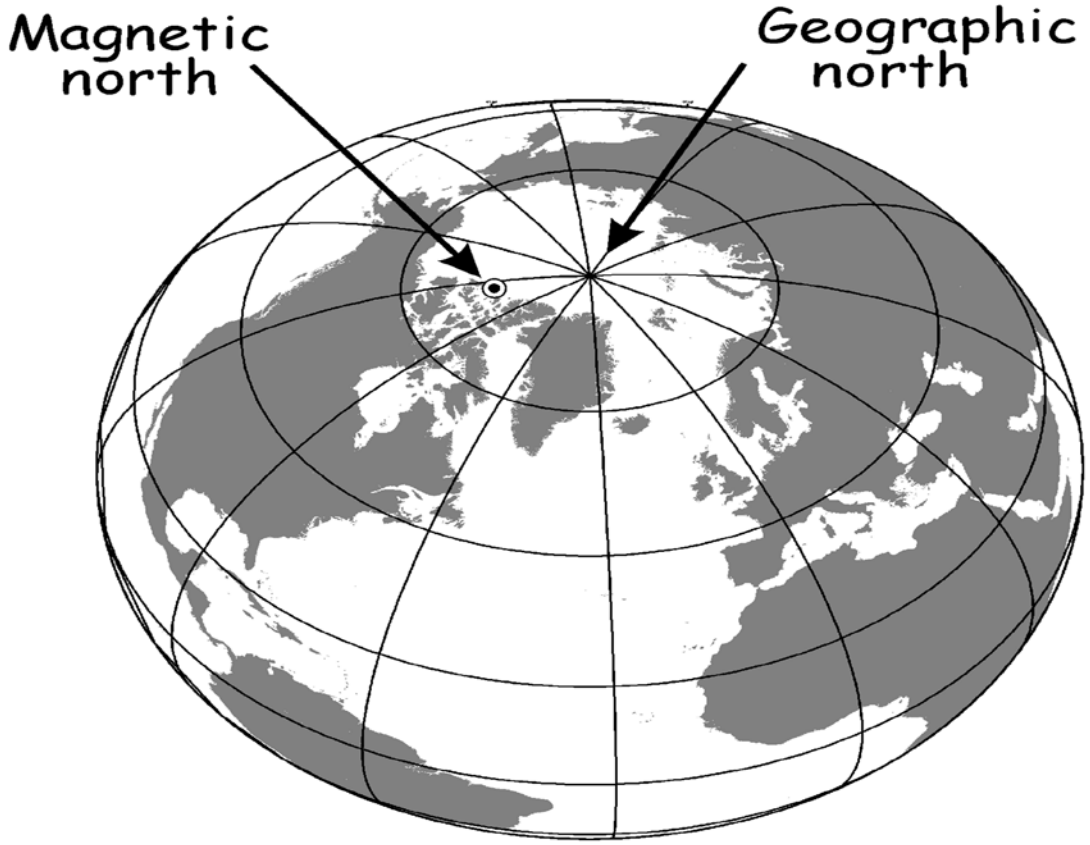
Parallels - lines of constant latitude; these run parallel to each other, and cover increasingly less distance toward the poles

Equator – the widest parallel



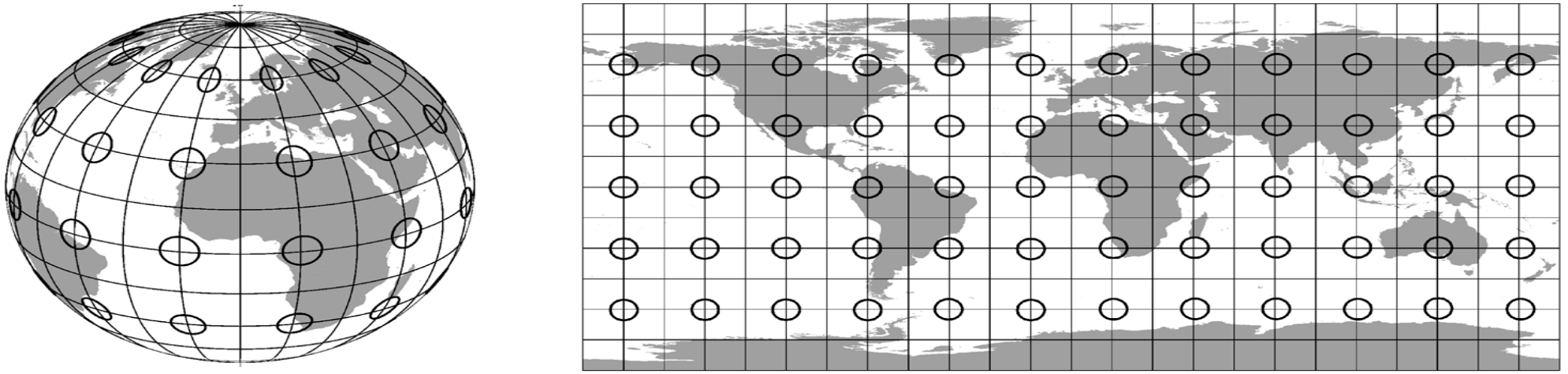
Bolstad 2012, Fig 3-11

Difference Between Norths



Bolstad 2012, Fig 3-12

Influence of Convergence at Poles on Flat Maps



Bolstad 2012, Fig 3-13

Datums (Horizontal)

Keywords

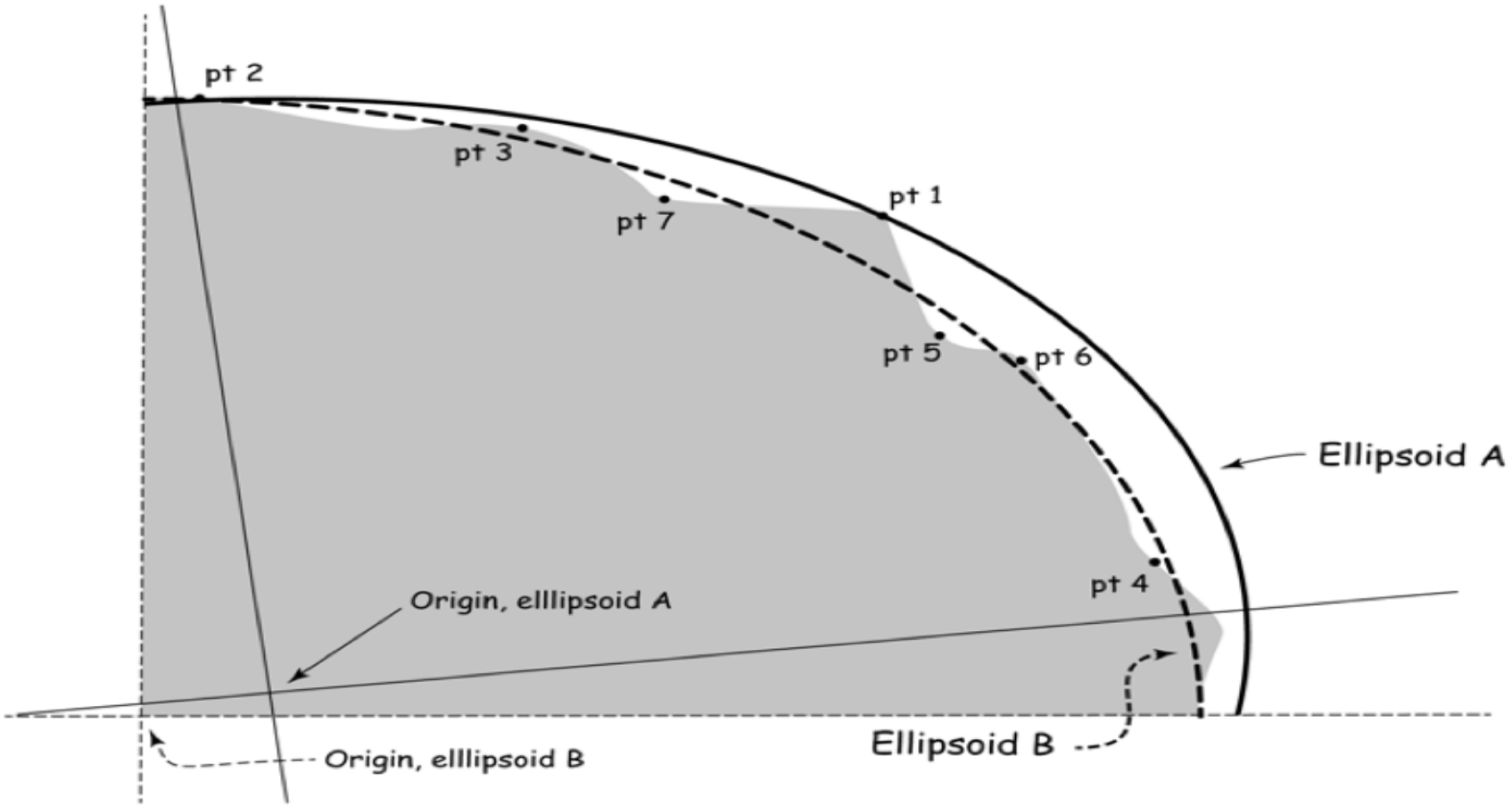
- A datum is a reference surface
- Often used interchangeably with ellipsoid or geographic coordinate system (technically, this is not right, but practically for non-geodesists, this is fine)
- An adequate oversimplification: a datum is an ellipsoid plus a set of measurements taken to fit the ellipsoid to the geoid.
- Example of measurements taken are locations of and distances to survey marker (aka benchmarks)

Survey Markers

Bolstad 2012, Fig 3-15

Bolstad 2012, Fig 3-16

How Datums Change Ellipsoids



Bolstad 2012, Fig 3-19

Commonly Used Datums

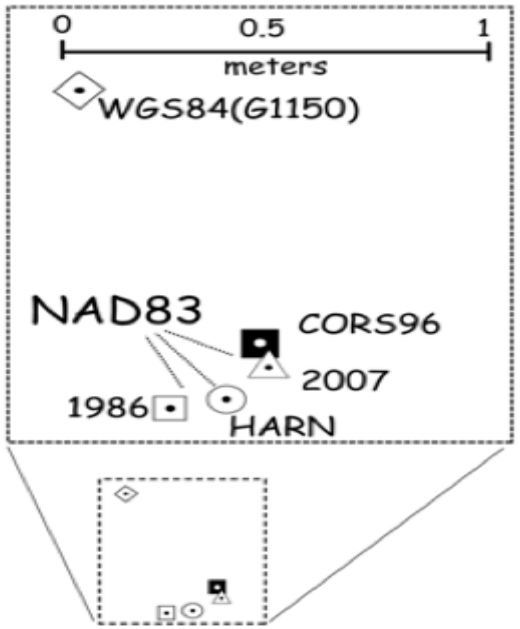
- North American Datum
  - NAD27
  - NAD83
    - NAD83(HARN)
    - NAD83(CORS)
- World Geodetic System of 1984 (WGS84)
- International Terrestrial Reference Frames (ITRF)
- To learn more, start with Bolstad 2012, pp. 88-95

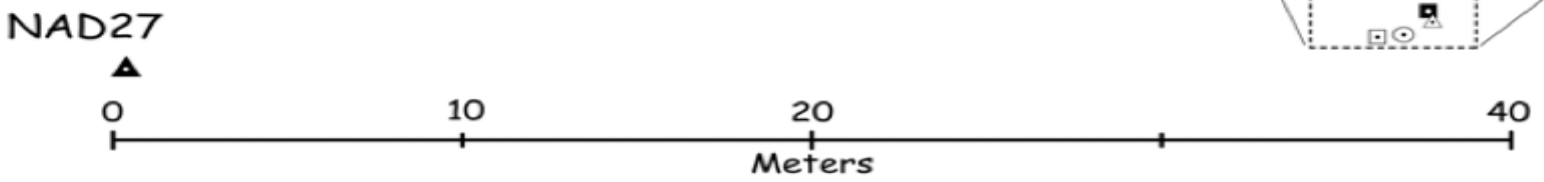
Datum Shifts

Examples of Datum Shifts

Successive datum transformations for New Jersey control point, Bloom 1

Datum	Longitude (W)	Latitude(N)	Shift(m)
NAD27	74° 12' 3.86927"	40° 47' 0.76531"	36.3
NAD83(1986)	74° 12' 2.39240"	40° 47' 1.12726"	0.04
NAD83(HARN)	74° 12' 2.39069"	40° 47' 1.12762"	0.05
NAD83(CORS96)	74° 12' 2.39009"	40° 47' 1.12936"	0.01
NAD83(2007)	74° 12' 2.38977"	40° 47' 1.12912"	0.95
WGS84(G1150)	74° 12' 2.39720"	40° 47' 1.15946"	

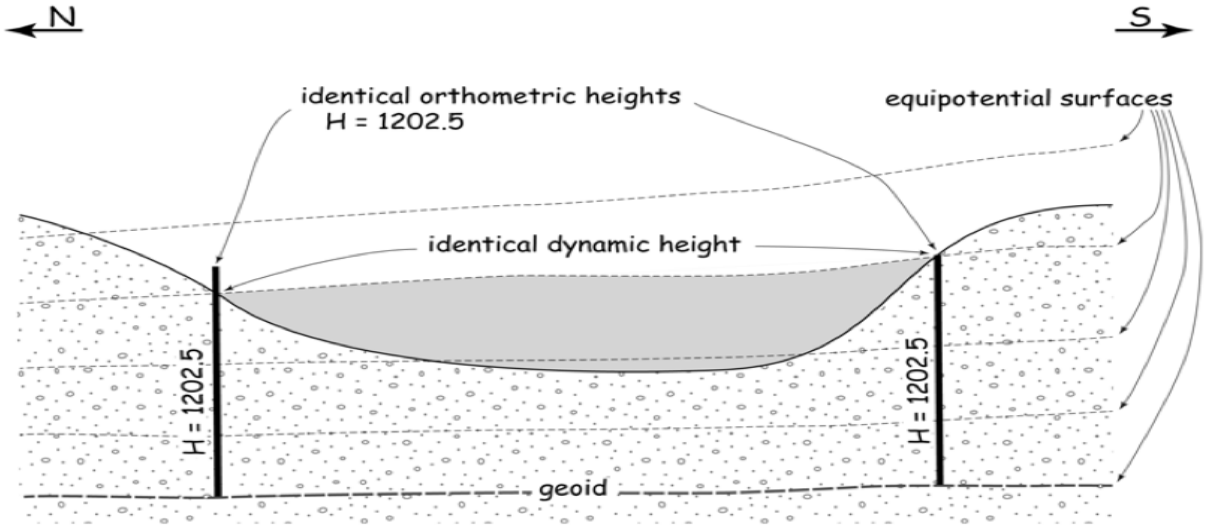




Bolstad 2012, Fig 3-21

Vertical Datums

- Similar in concept to horizontal datums, but used for measuring heights
- Orthometric height is relative to geoid; dynamic heights are relative to equipotential surfaces such as the geoid



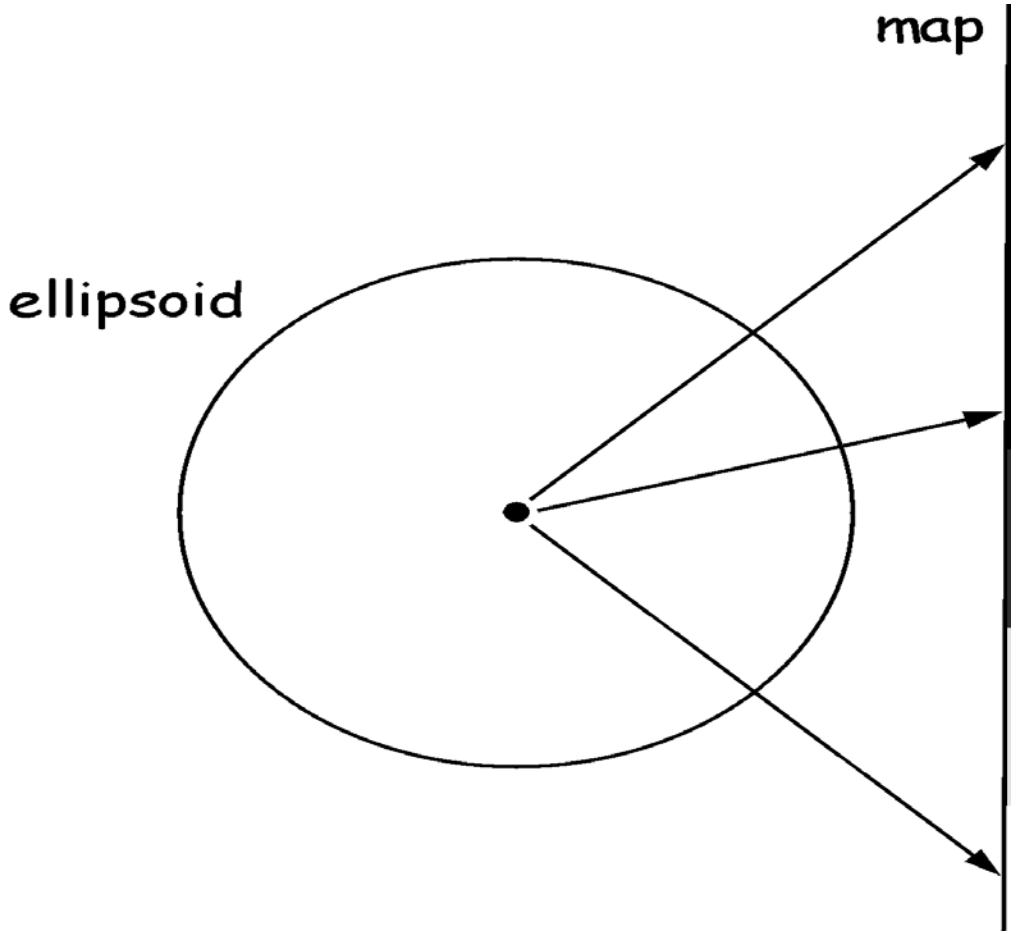
Bolstad 2012, Fig 3-28

That was geodesy, which is 3D.
Map Projections, which are 2D, is next.

Let's take a 10 minute break.

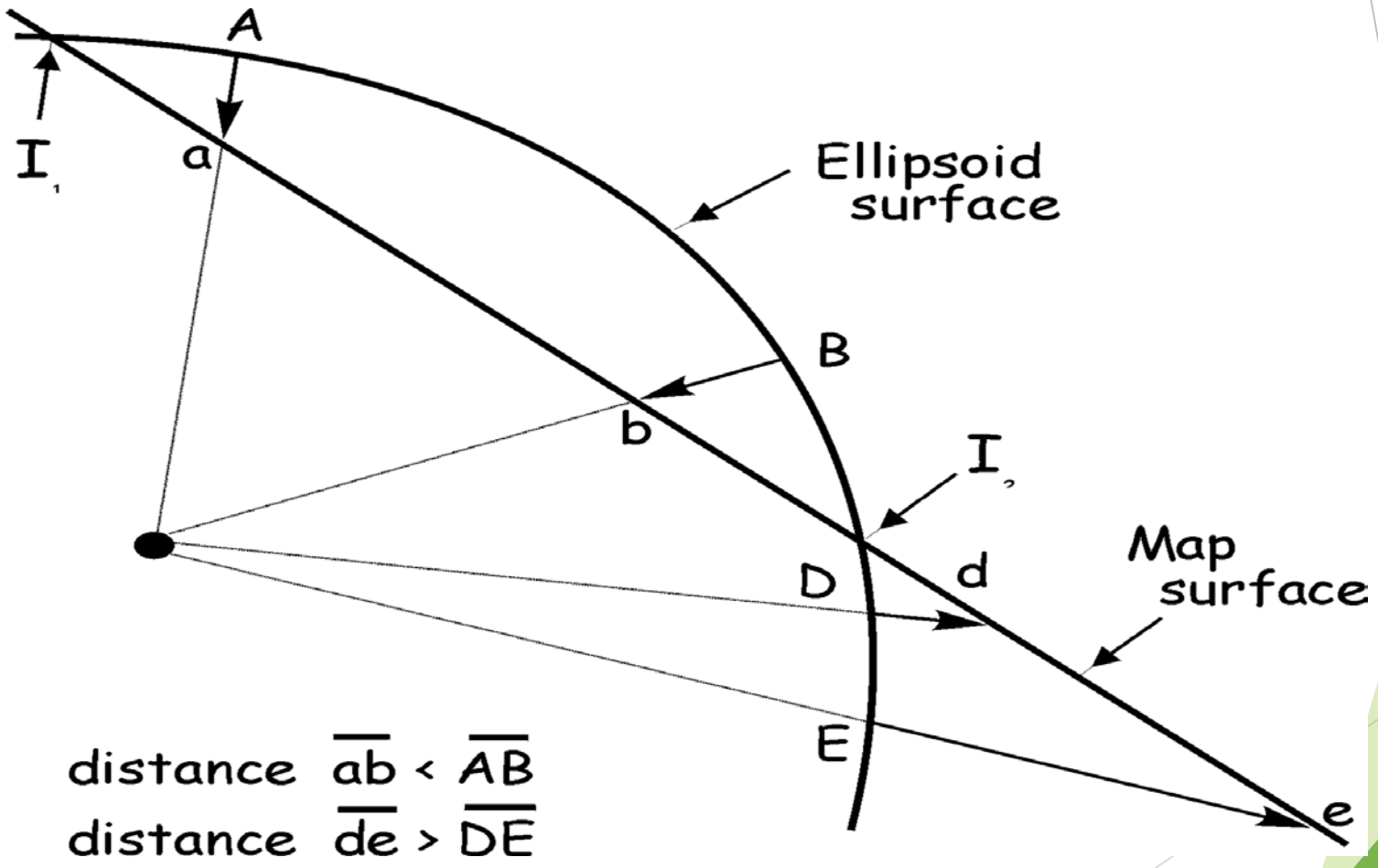
Think of it as Projecting an Image with a Light Source

Note: Map projections need to know the shape of the earth, so they are based on datums



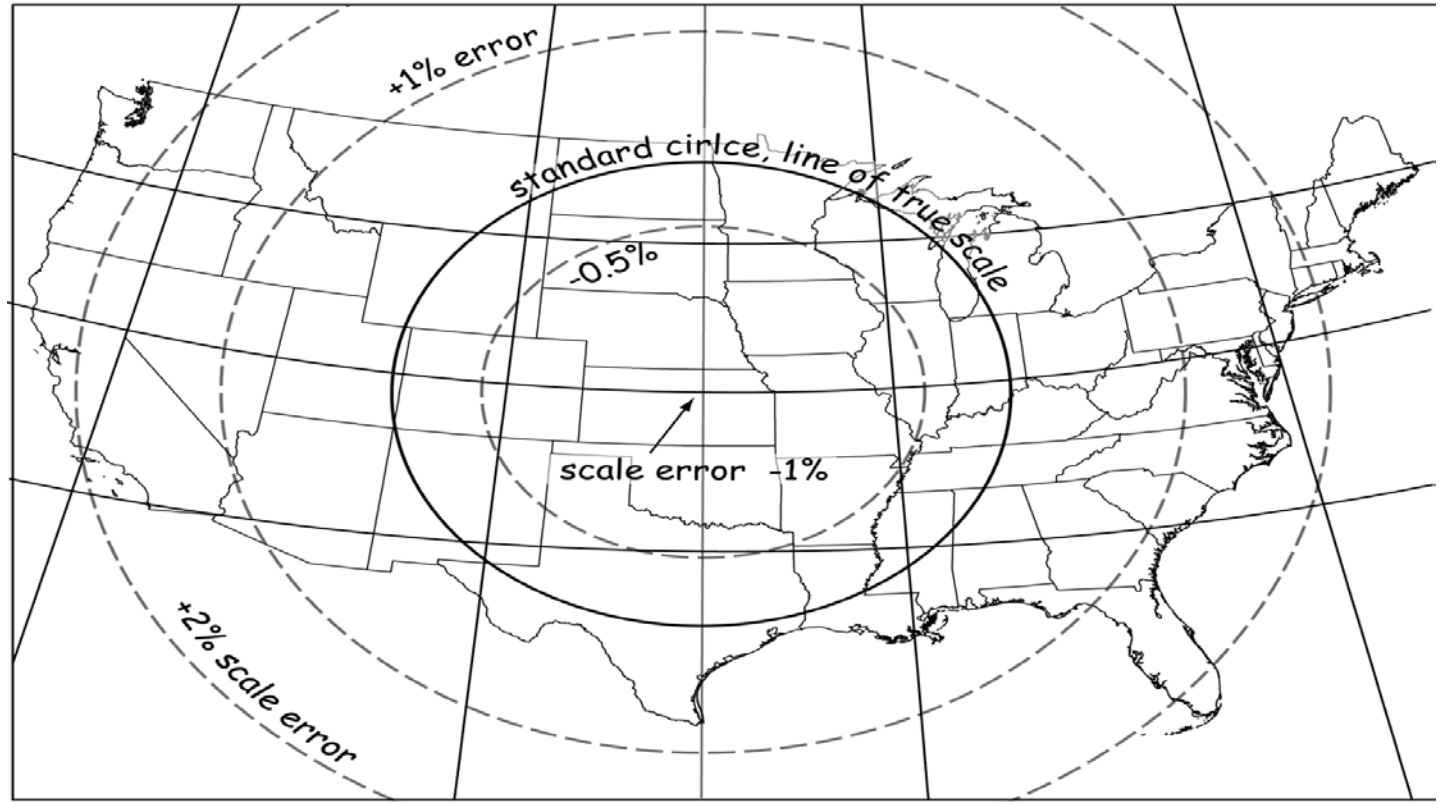
Bolstad 2012, Fig 3-29

Distortions



Bolstad 2012, Fig 3-30

True Scale at Standard Circles (and Standard Parallels)



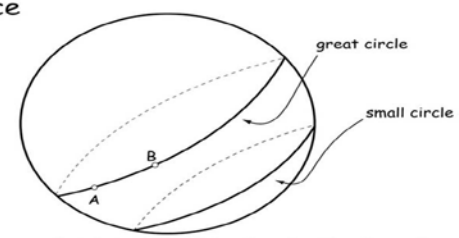
Bolstad 2012, Fig 3-31

Great Circles and Small Circles

Great Circle Distance

Consder two points on the Earth's surface, A with geographic coordinates (lat.,lon.) (ϕ_A, λ_A), and

B, with geographic coordinates (ϕ_B, λ_B)



The great circle distance from point A to point B is given by the formula:

$$d = r \cdot \cos^{-1}[(\cos(\phi_A)\cos(\phi_B)\cos(\lambda_A-\lambda_B)\} + \sin(\phi_A)\sin(\phi_B)],$$

where d is the shortest distance on the surface of the Earth from A to B, and r is the Earth's radius, approximately 6378 km.

This formula may be used to find the distance distortion caused by a projection between two points, for example, between Ursine and Moab, Utah, when using UTM Zone 12N coordinates, NAD83?

Great circle distance:

Latitude, longitude of Ursine, Utah = 37.98481°, -114.216944°
Latitude, longitude of Moab, Utah = 38.57361°, -109.551111°

$$d = 6378 \cdot \cos^{-1}[(\cos(37.98481)\cos(38.57361)\cos(-114.216944 - 109.551111\} + \sin(37.98481)\sin(38.57361)\ ]$$

$$= 412.906 \text{ km}$$

Grid distance (UTM Zone 12N coordinates):

Grid coordinates of Ursine, Utah = 217,529.8, 4,208,972.8
Grid coordinates of Moab, Utah = 626,239.2, 4,270,405.9

$$dg = [(X_A - X_B)^2 + (Y_A - Y_B)^2]^{0.5}$$

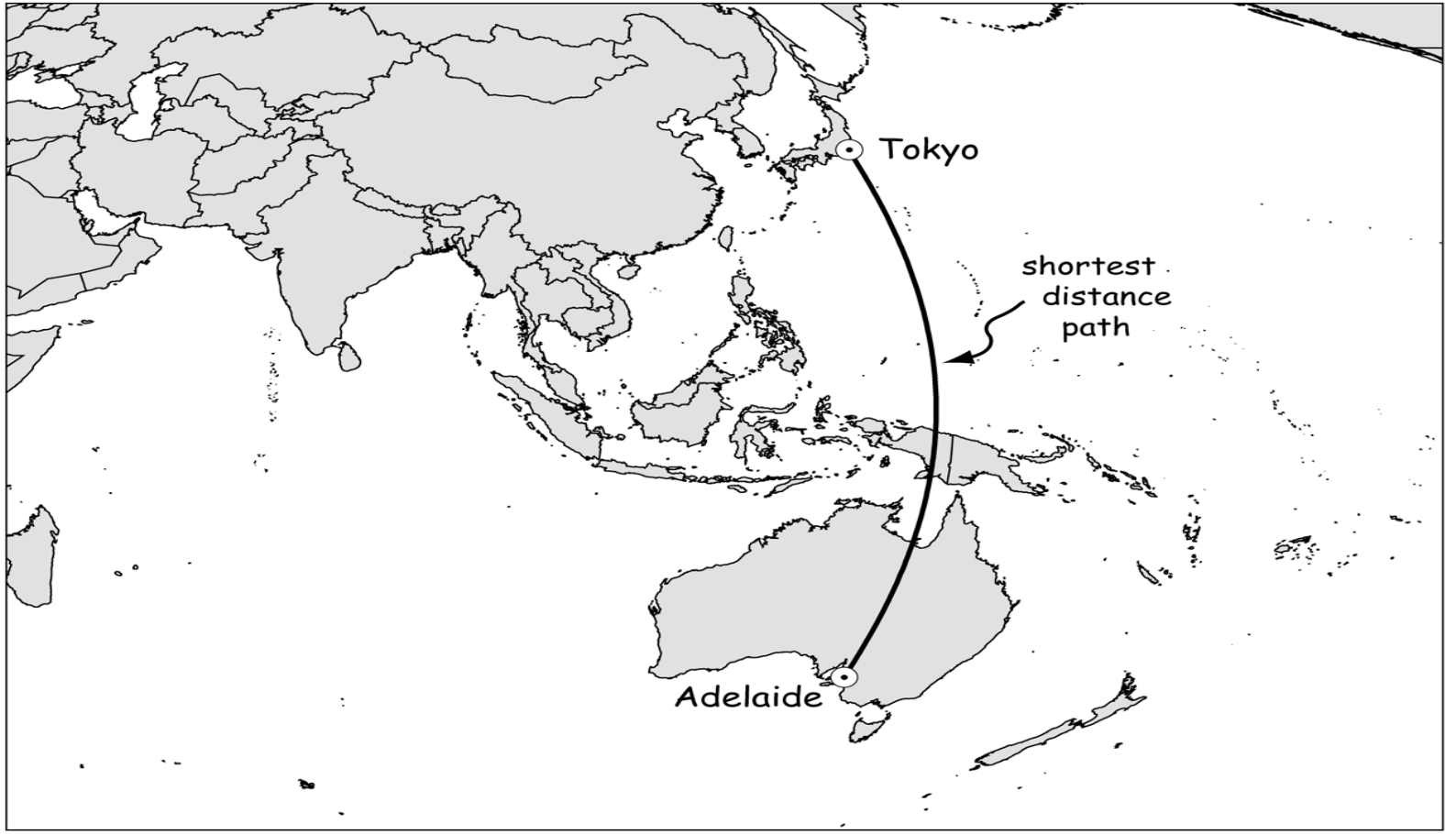
$$= [(217,529.8 - 626,239.2)^2 + (4,208,972.8 - 4,270,405.9)^2]^{0.5}$$

$$= 413.300 \text{ km}$$

distortion is 412.906 - 413.300 = -0.394 km, or a 394 meter lengthening

Bolstad 2012, Fig 3-32

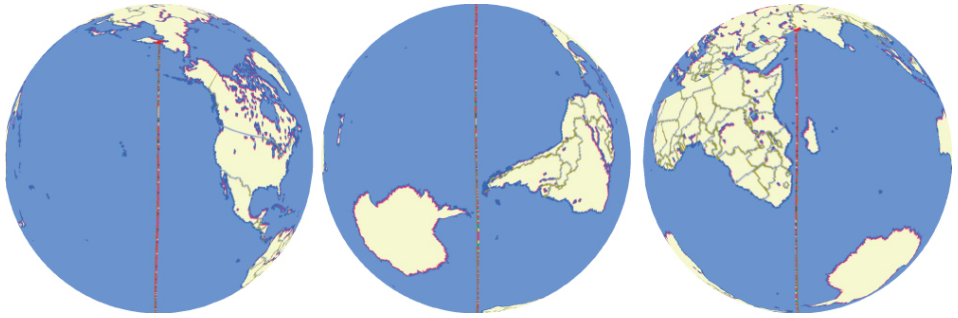
Distortion in a 2D Map



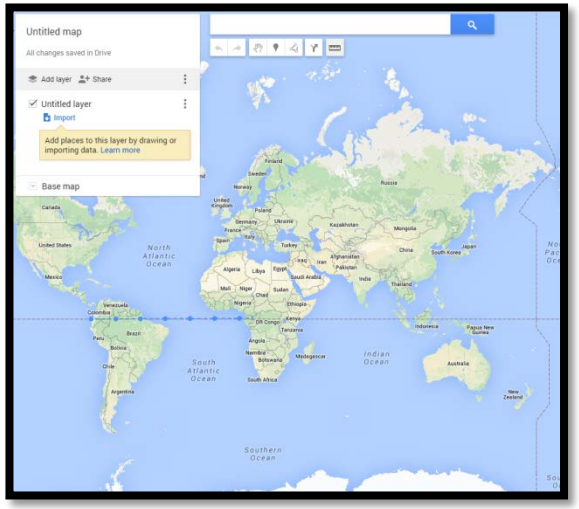
Bolstad 2012, Fig 3-33

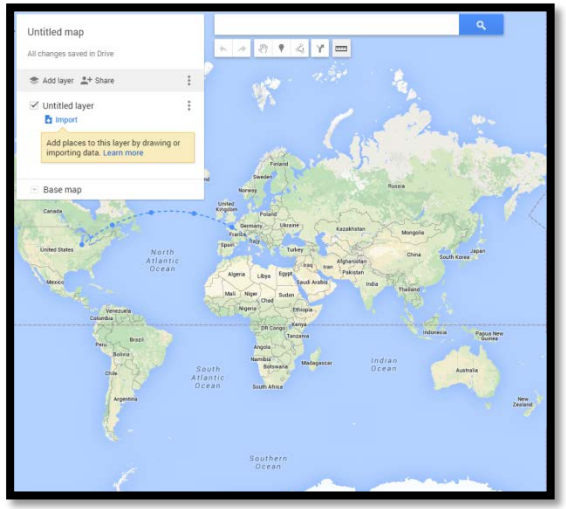
Longest Straight Line You Can Sail

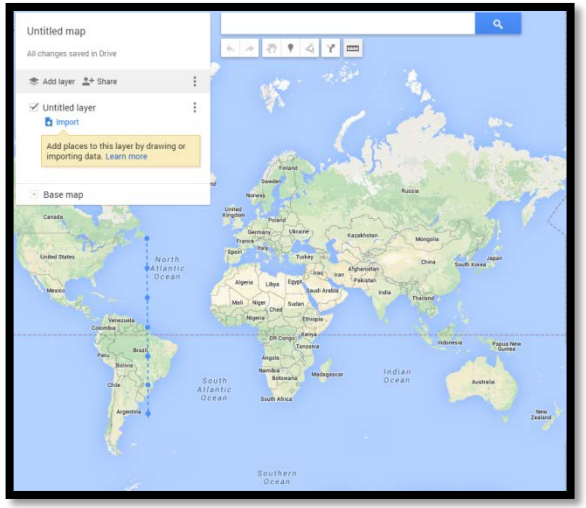
https://www.youtube.com/watch?v=VpQwuGueeoA

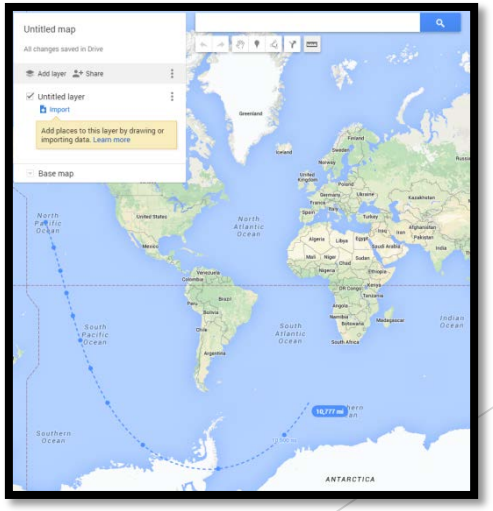


Geodesic Distances in Google My Maps



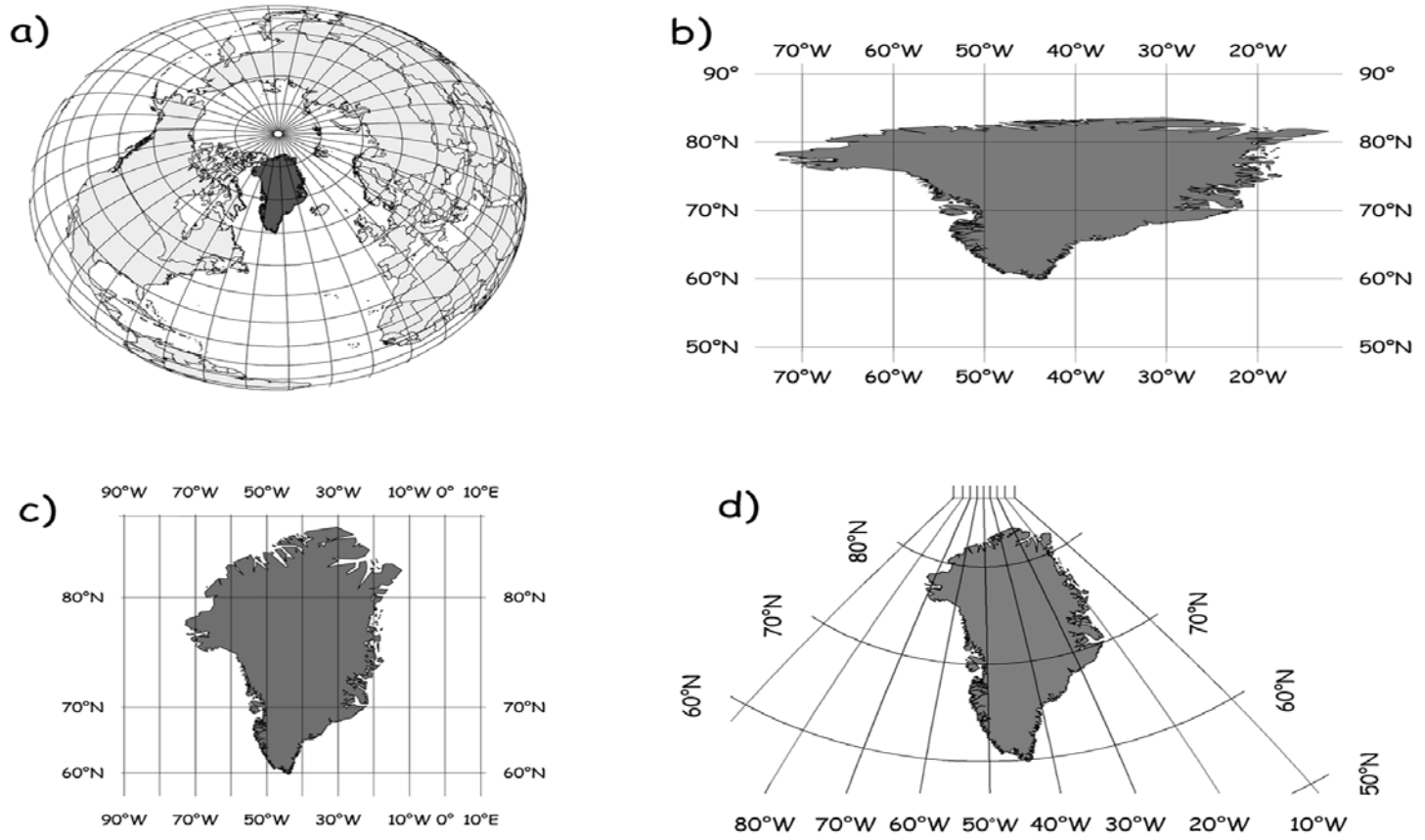






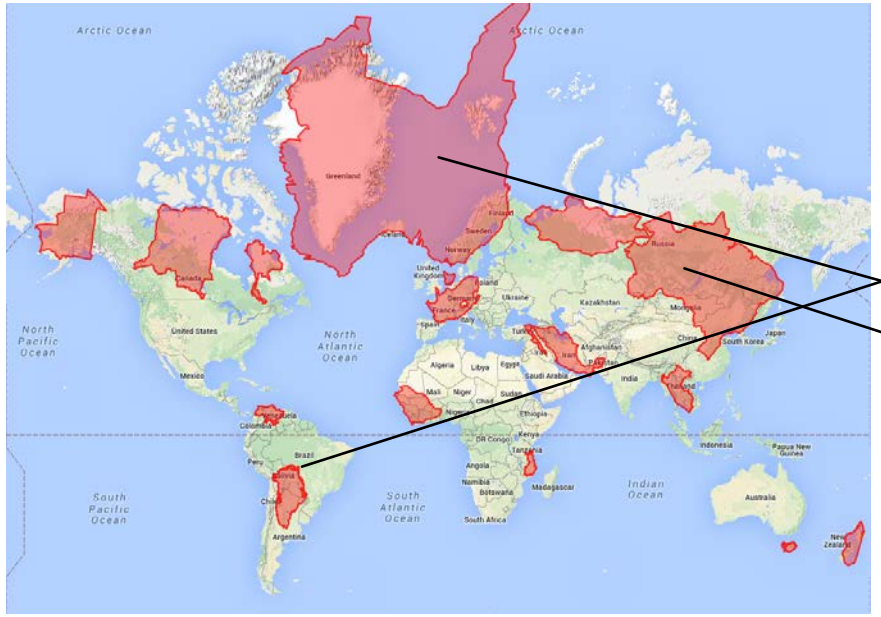
https://www.google.com/mymaps

Different Views of Greenland



Bolstad 2012, Fig 3-34

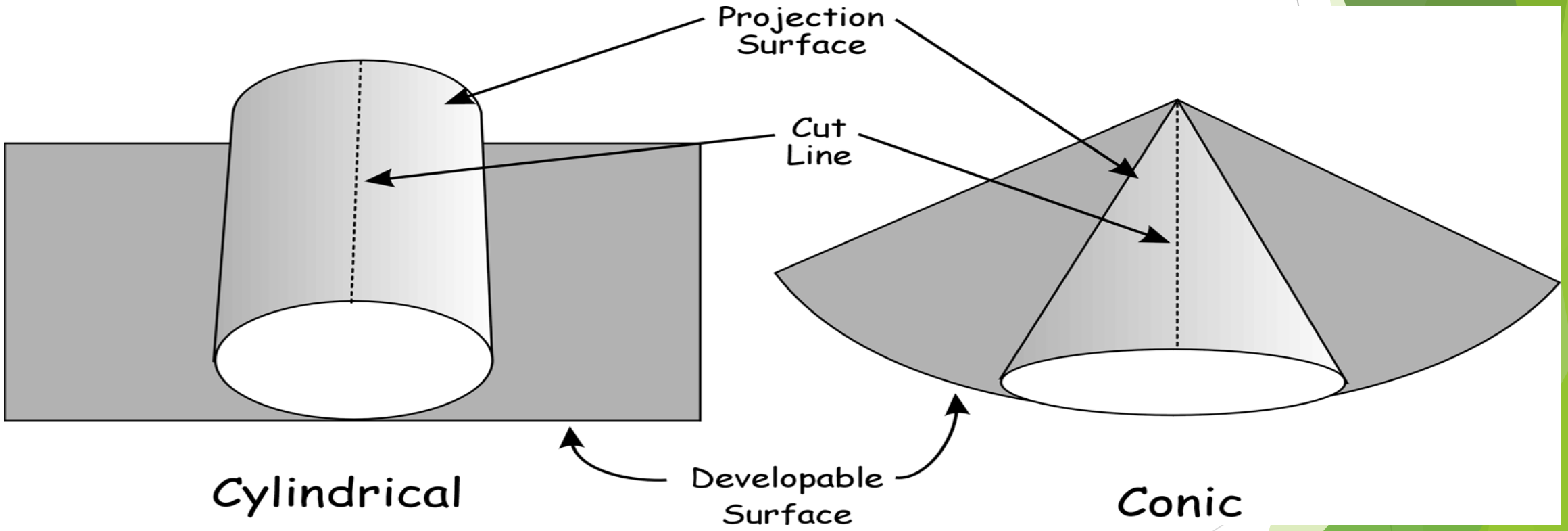
Mercator Puzzle



Spoiler Alert:
Solution beneath this box

https://gmaps-samples.googlecode.com/svn/trunk/poly/puzzledrag.html

Developable Surfaces

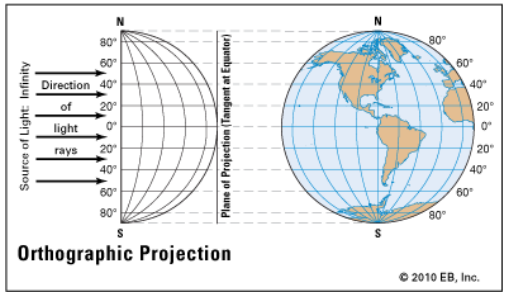


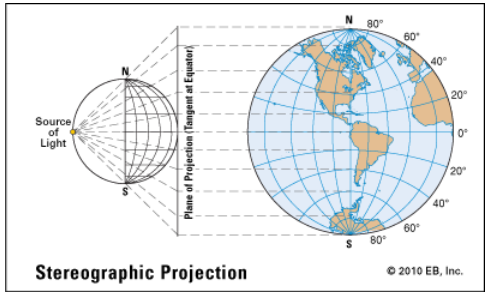
Bolstad 2012, Fig 3-35

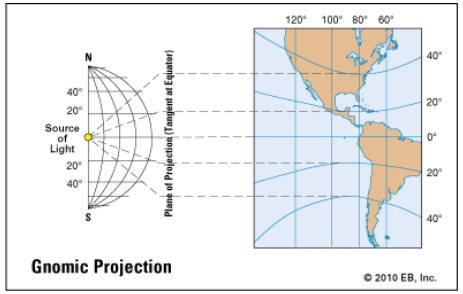
Azimuthal Projections

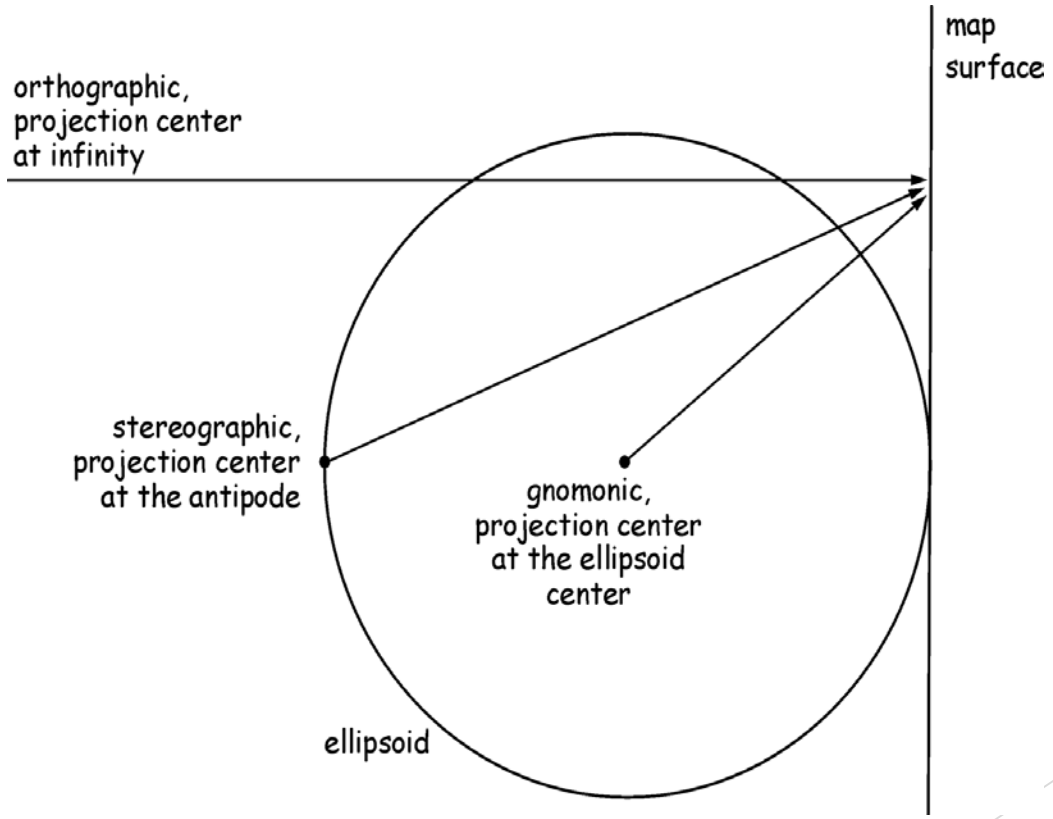
Keywords

Azimuth – direction of an object from the perspective of the observer



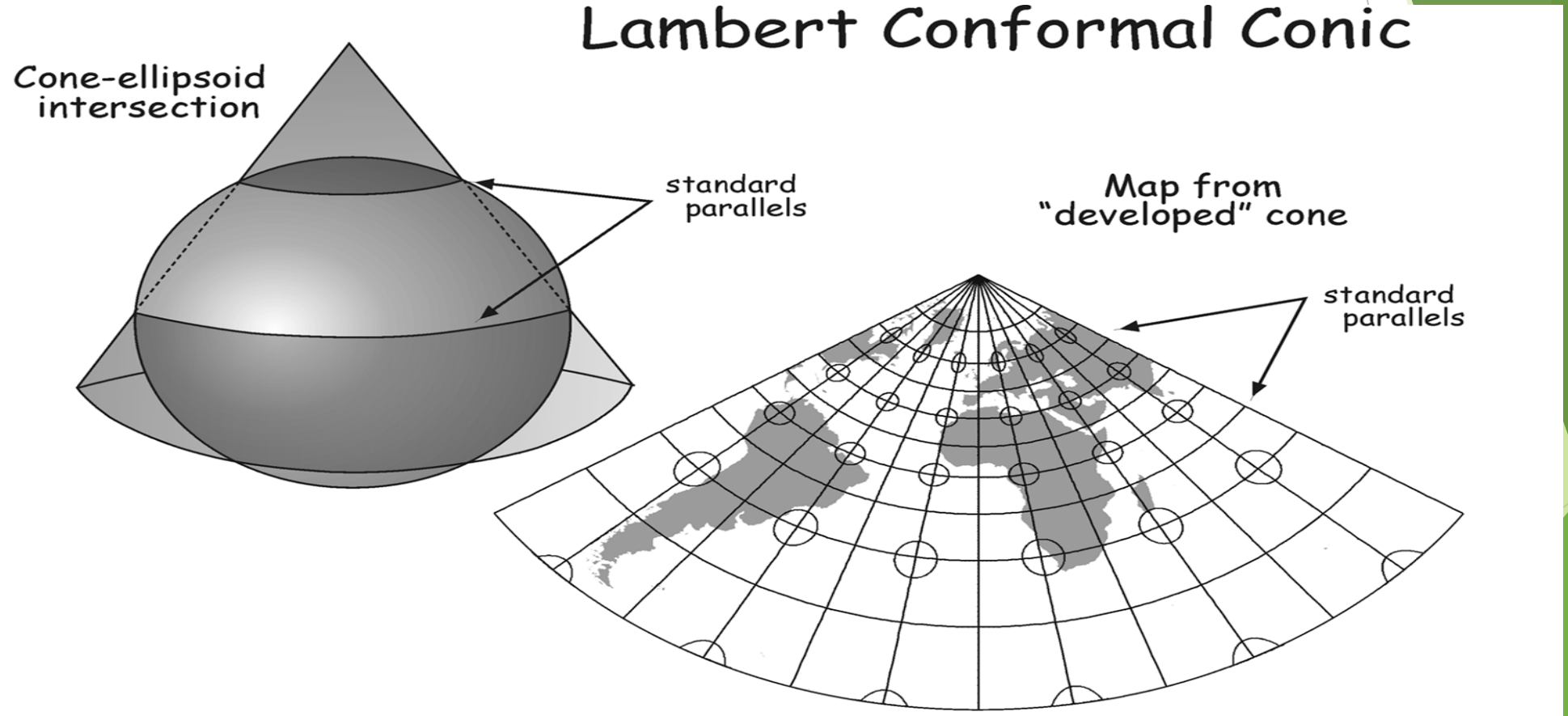






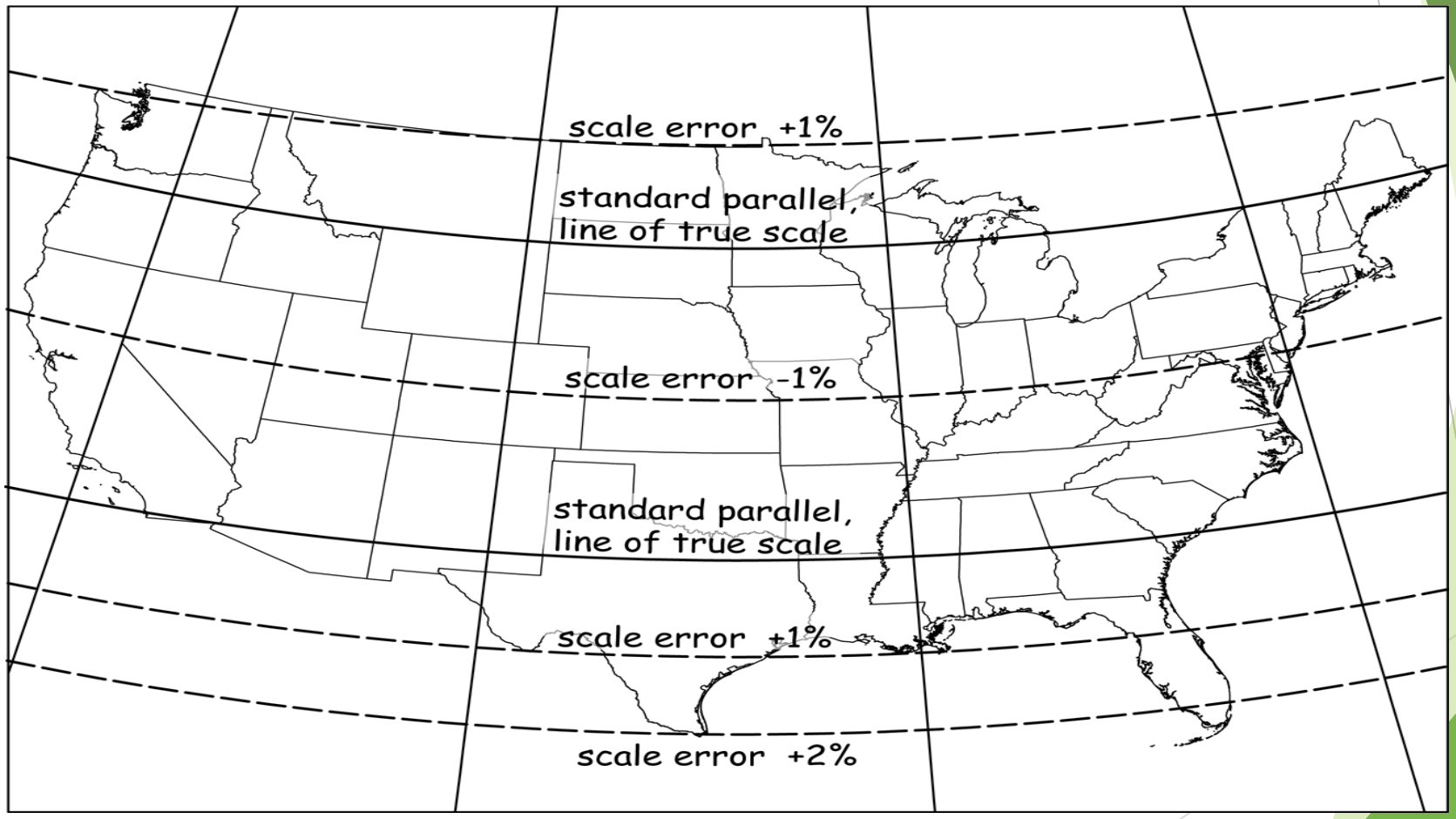
Bolstad 2012, Fig 3-36

Lambert Conformal Conic



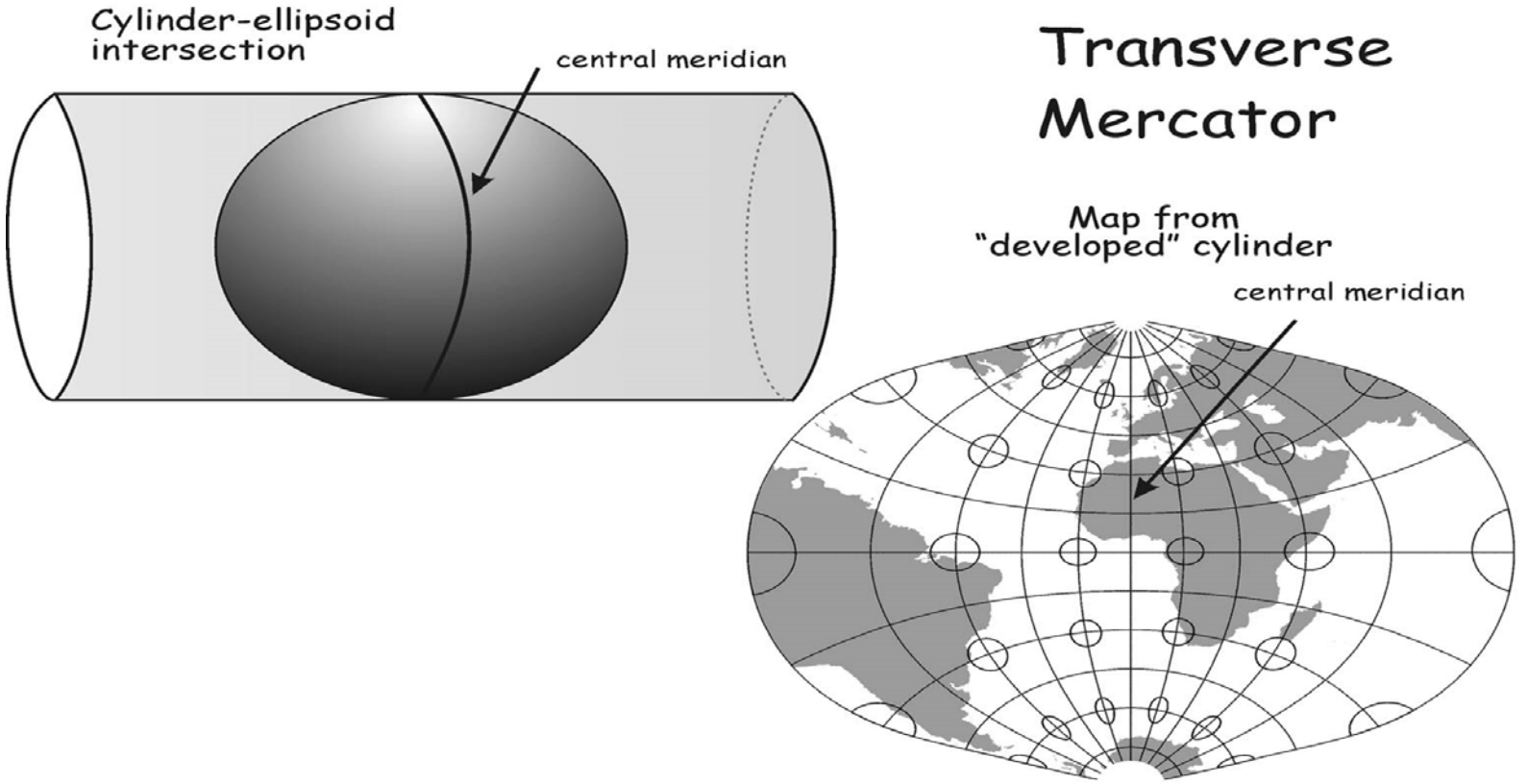
Bolstad 2012, Fig 3-37t

Lambert Conformal Conic, continued



Bolstad 2012, Fig 3-37b

Transverse Mercator



Bolstad 2012, Fig 3-38t

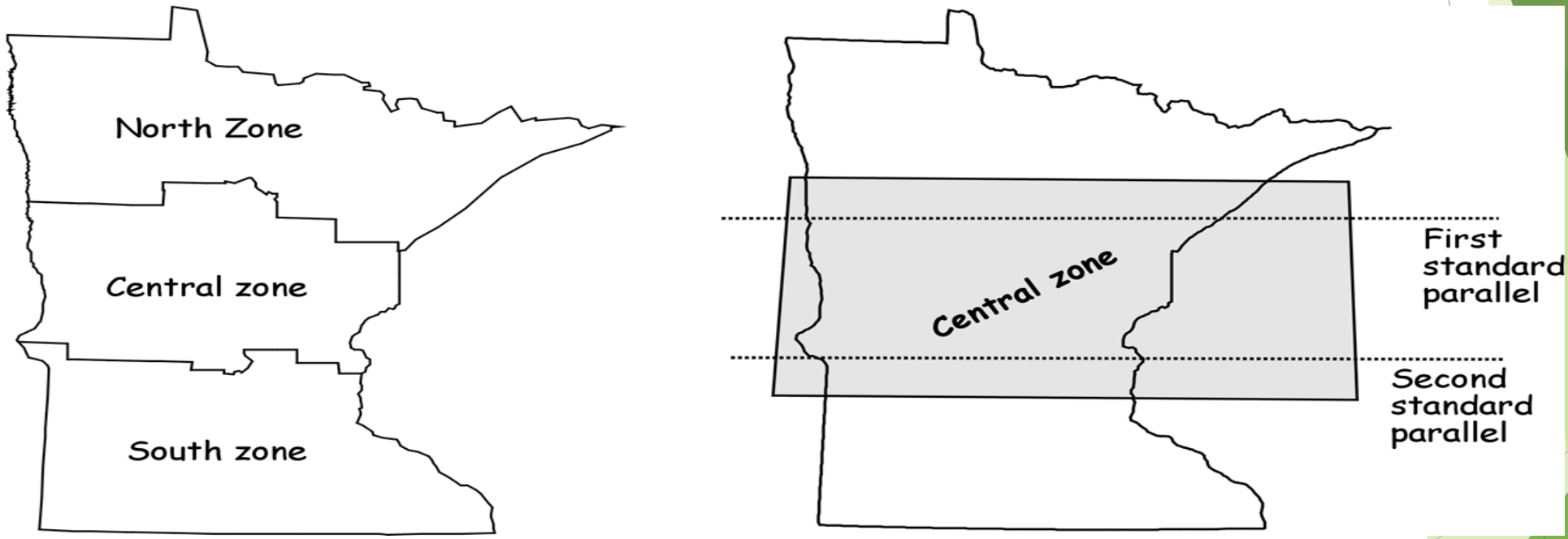
Transverse Mercator, continued

Bolstad 2012, Fig 3-38b

State Plane Coordinate System

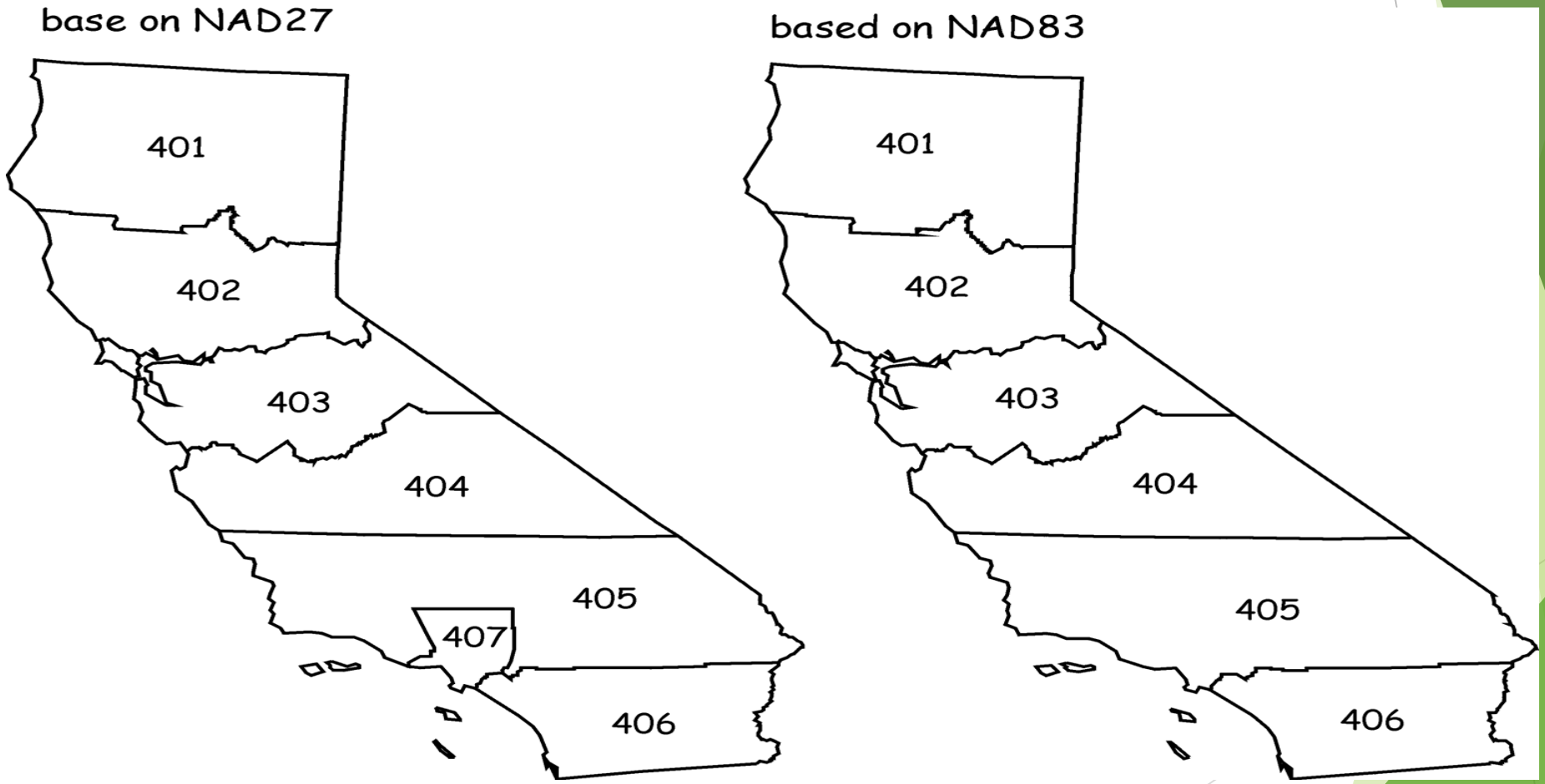
Bolstad 2012, Fig 3-39

State Plane Coordinate System, continued



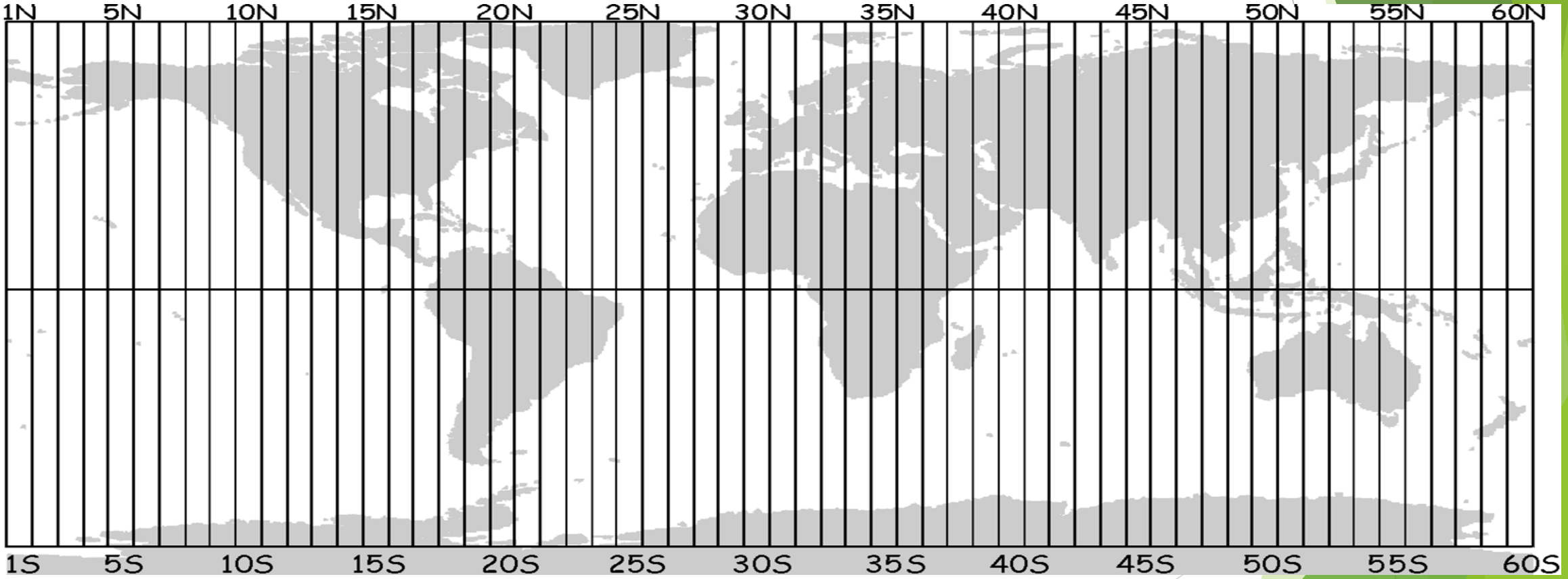
Bolstad 2012, Fig 3-40

Changes to State Plane



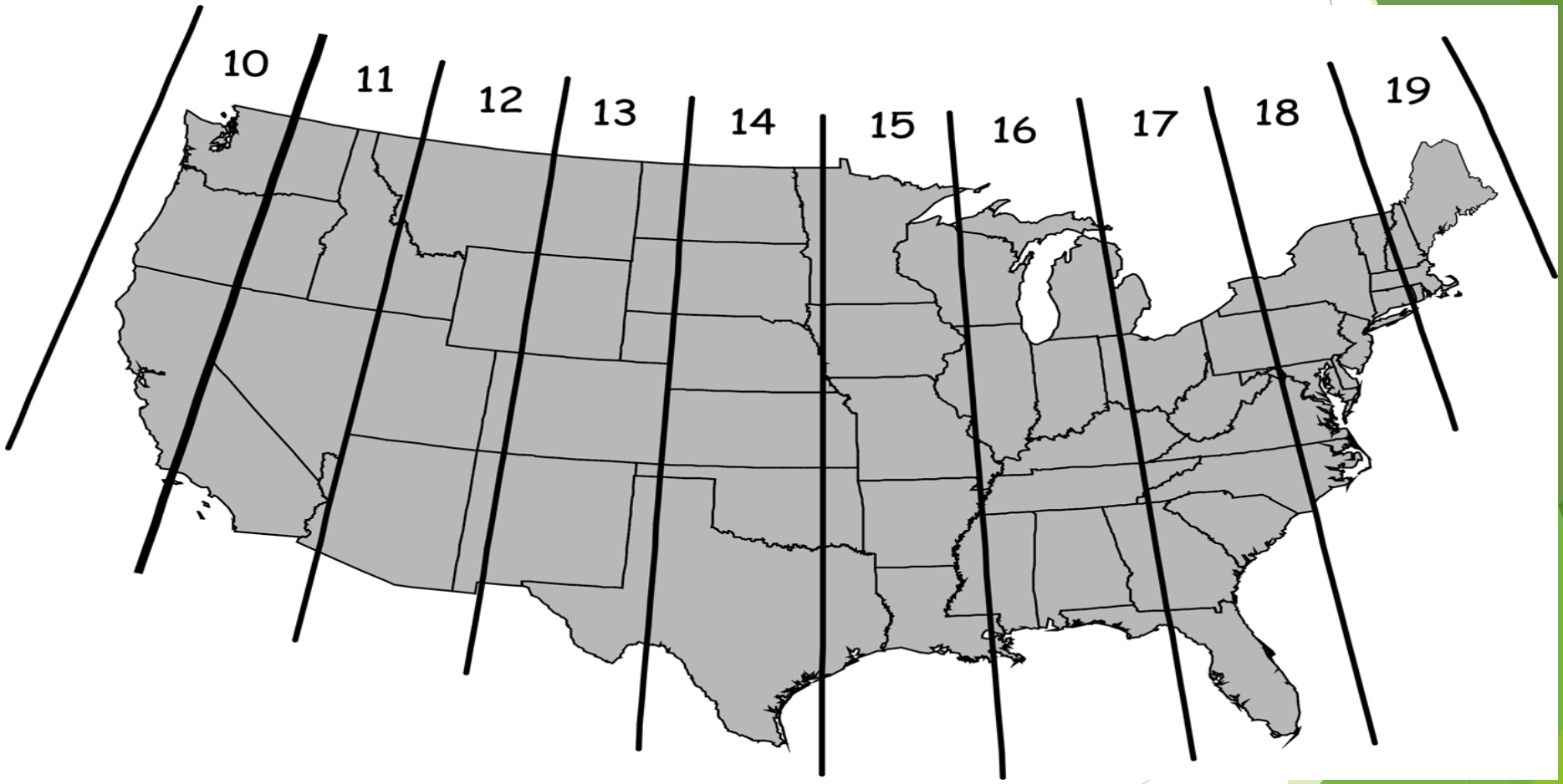
Bolstad 2012, Fig 3-41

Universal Transverse Mercator (UTM)



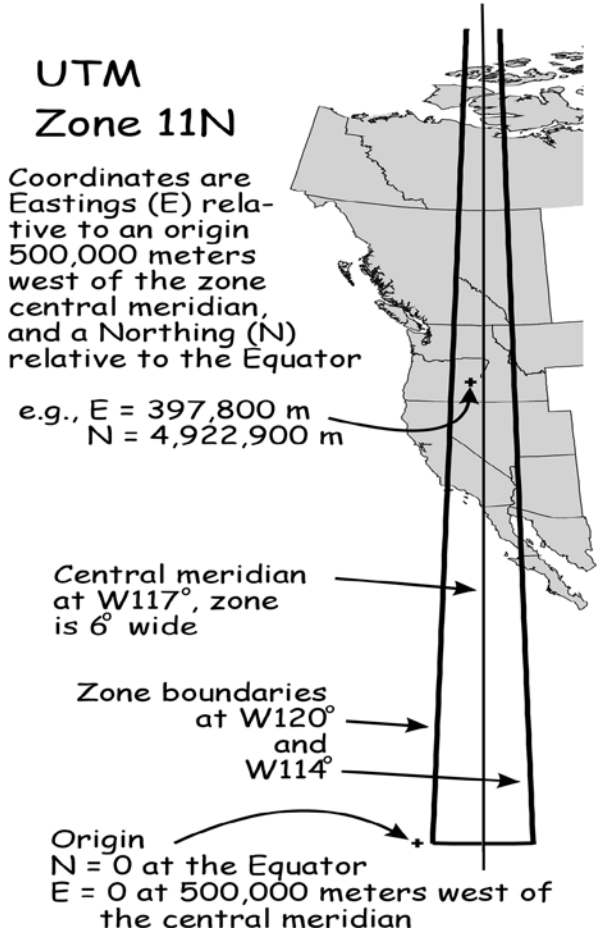
Bolstad 2012, Fig 3-42

UTM, continued



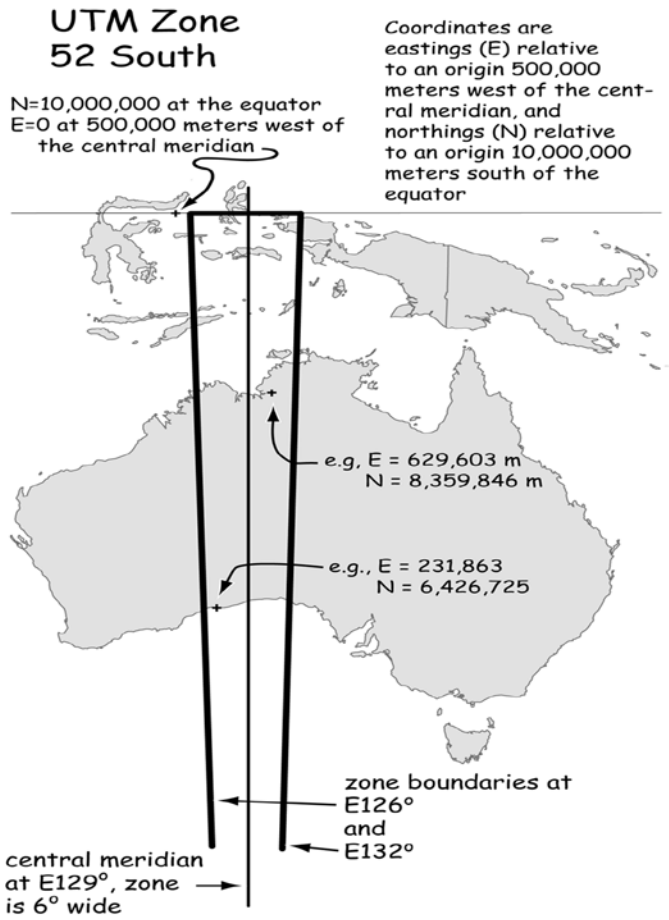
Bolstad 2012, Fig 3-43

UTM, continued



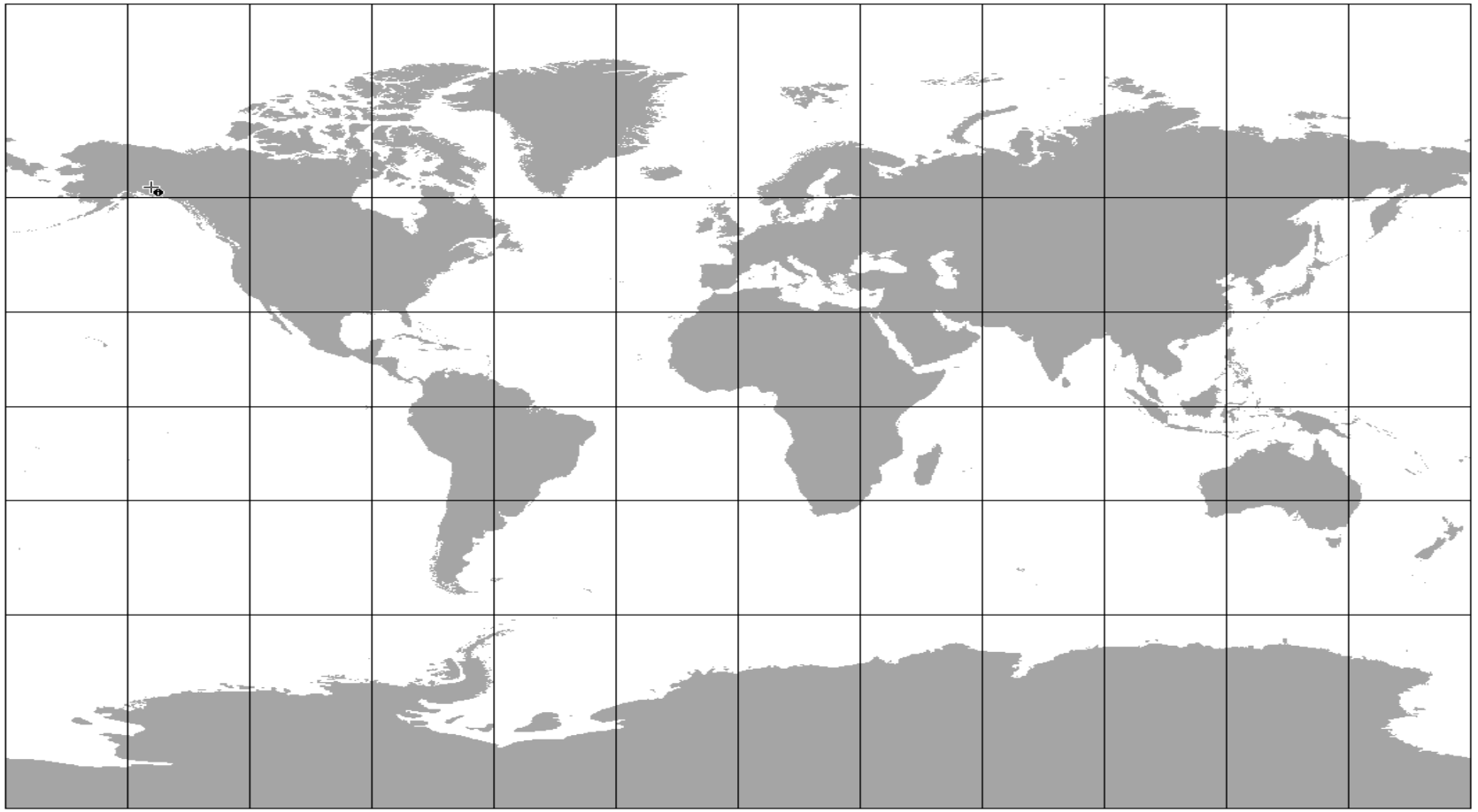
Bolstad 2012, Fig 3-44

UTM, continued



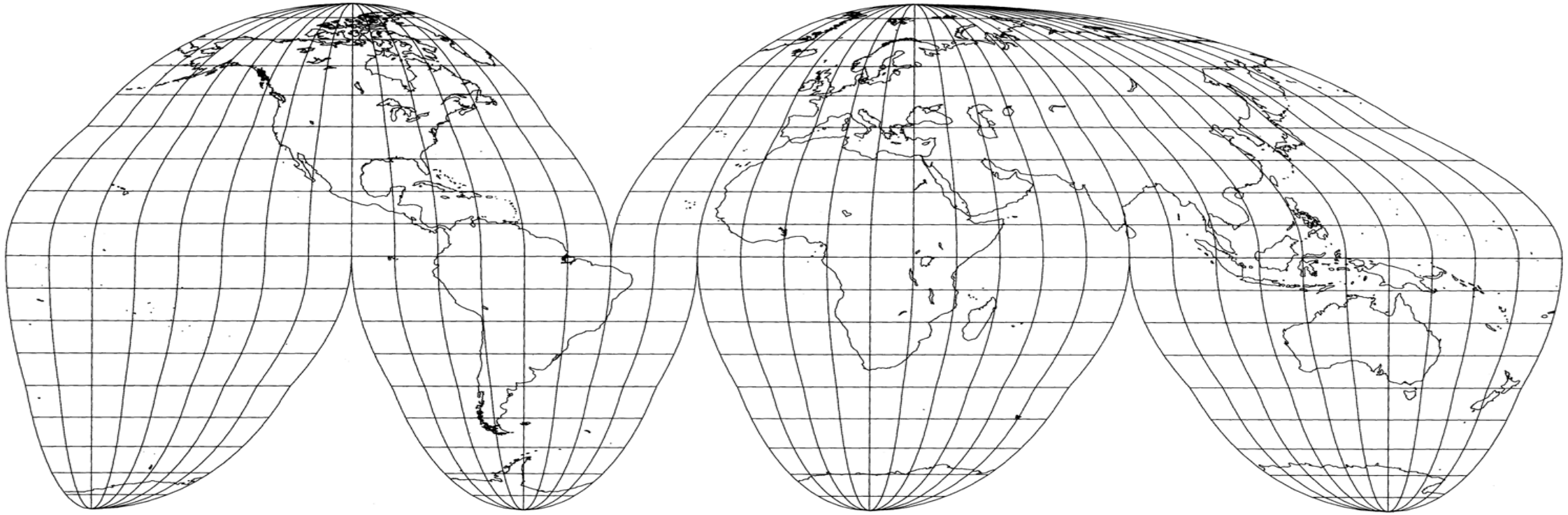
Bolstad 2012, Fig 3-45

Miller Cylindrical - Uninterrupted



Bolstad 2012, Fig 3-46

Goode Homolosine - Interrupted



Bolstad 2012, Fig 3-47

Differences in Projections

Projection Transitions by Bostock

It's automatically animated, but you can do manual transitions by changing the projection form the drop-down

http://bl.ocks.org/mbostock/3711652

Maps by Davies (lots of great maps, but look for "Projection Transitions")

Animated similarly but with a hypnotizing twist; fun to watch, but takes time to really understand what's happening

http://www.jasondavies.com/maps/

Projection Units

Conversion from geographic
(lon, lat) to projected coordinates

Given longitude = ϕ, latitude = λ

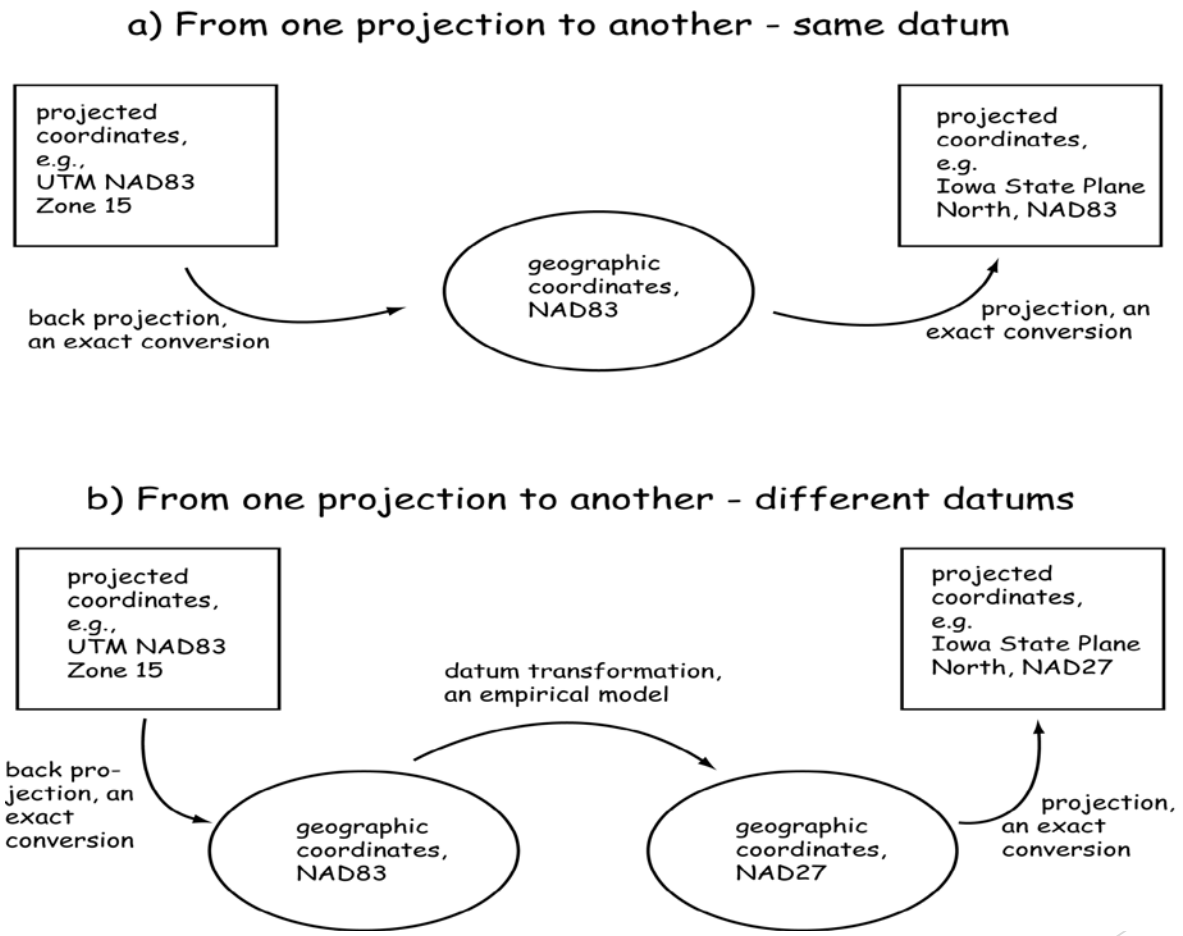
Mercator projection coordinates are:

$$x = R \cdot (\lambda - \lambda_o)$$
$$y = R \cdot \ln (\tan (90^\circ + \phi/2)$$

where R is the radius of the sphere
at map scale (e.g., Earth's radius),
ln is the natural log function, and
λ_o is the longitudinal origin (Green-
wich meridian)

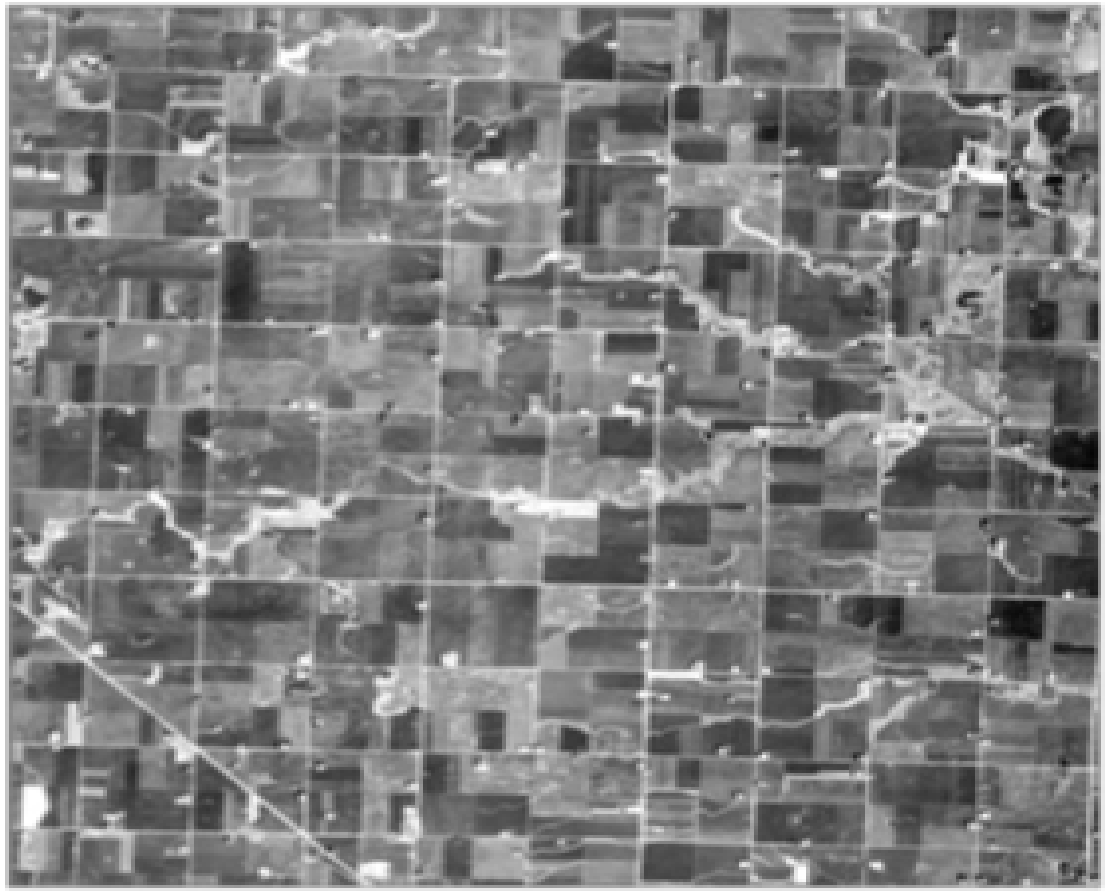
Bolstad 2012, Fig 3-48

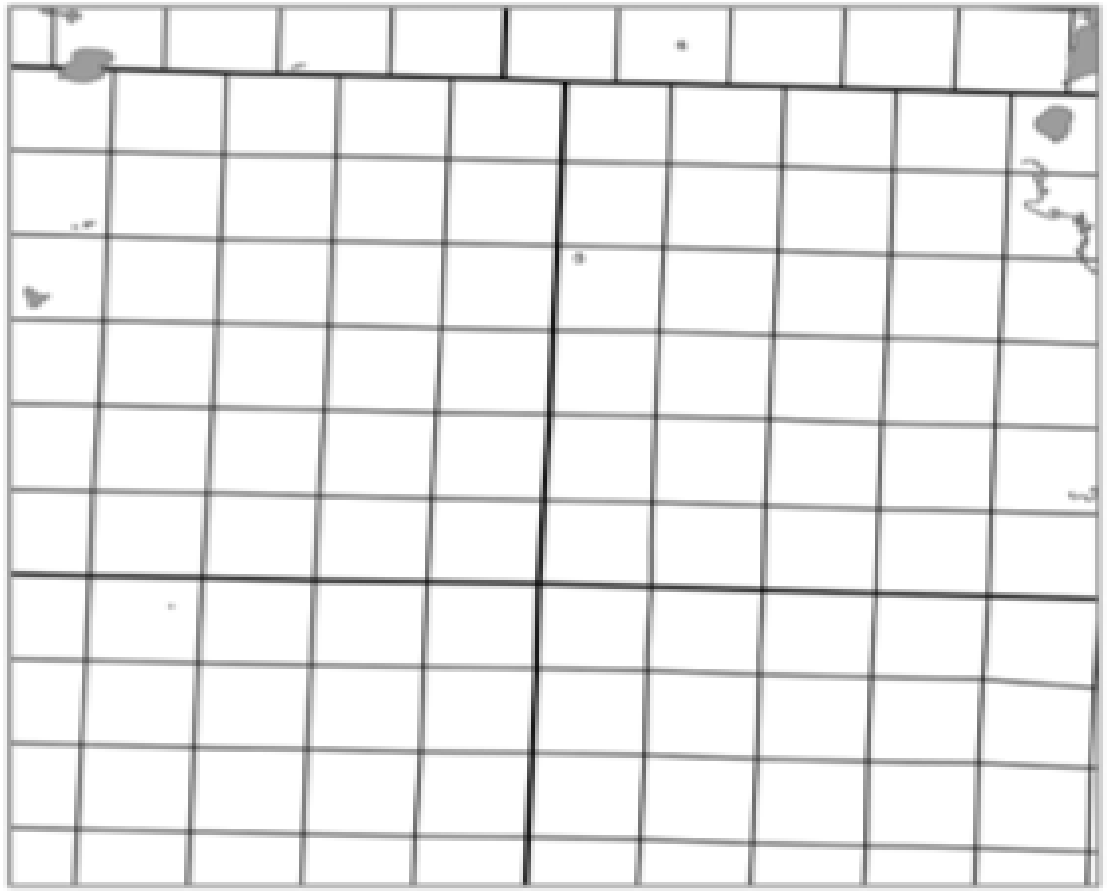
Reprojection



Bolstad 2012, Fig 3-49

Public Land Survey System (PLSS)



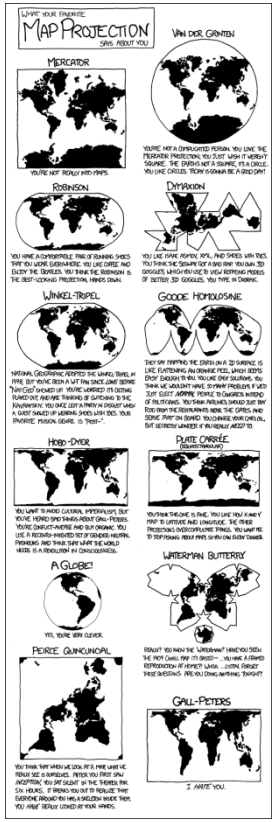


Bolstad 2012, Fig 3-52

PLSS Marker

Bolstad 2012, Fig 3-53

Extras: Projections on XKCD



http://xkcd.com/977/

Extras: Projections on the West Wing

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

Lesson Roadmap