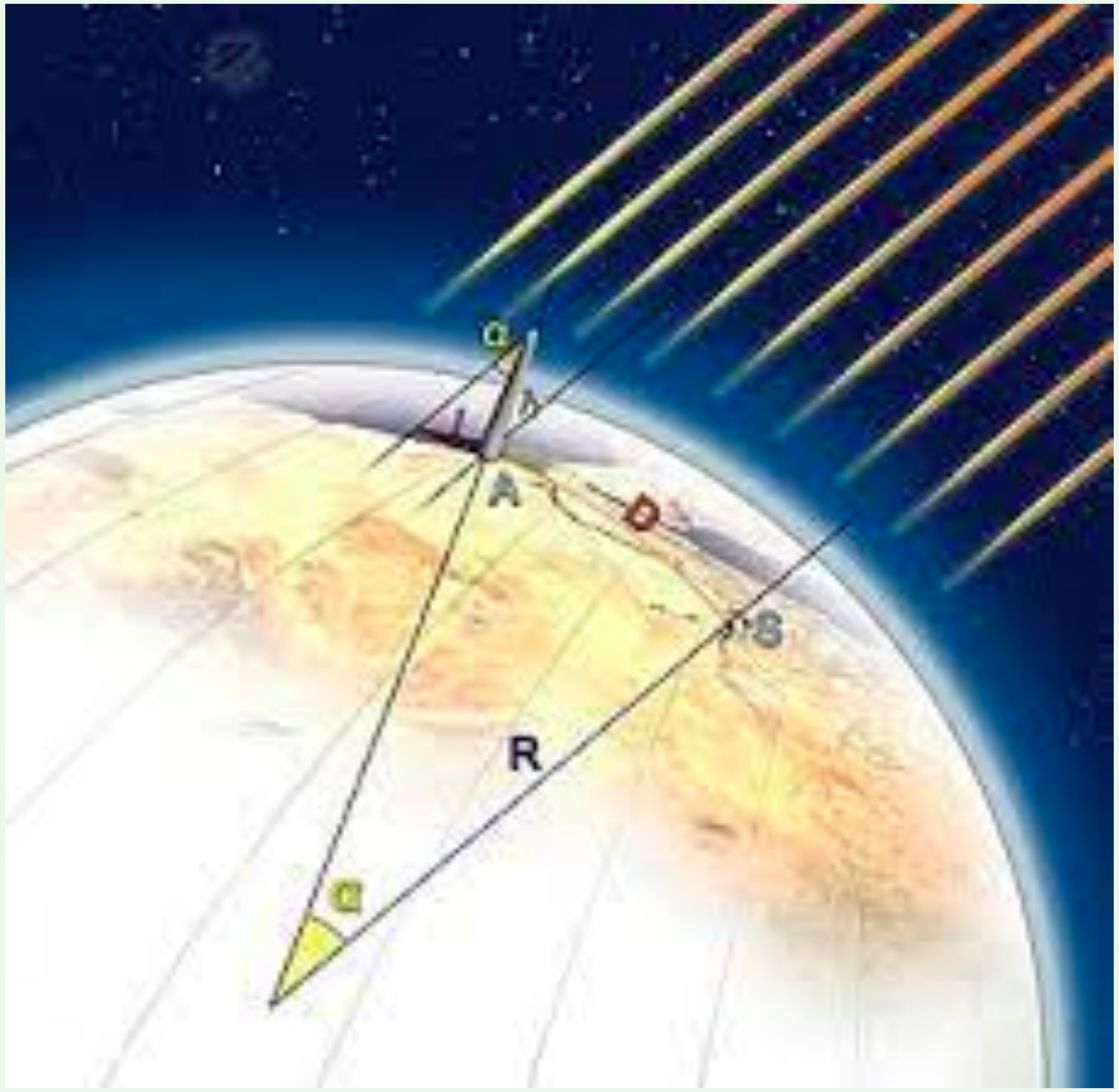
GEOG 358: Introduction to Geographic Information Systems

Measuring location on Earth's surface



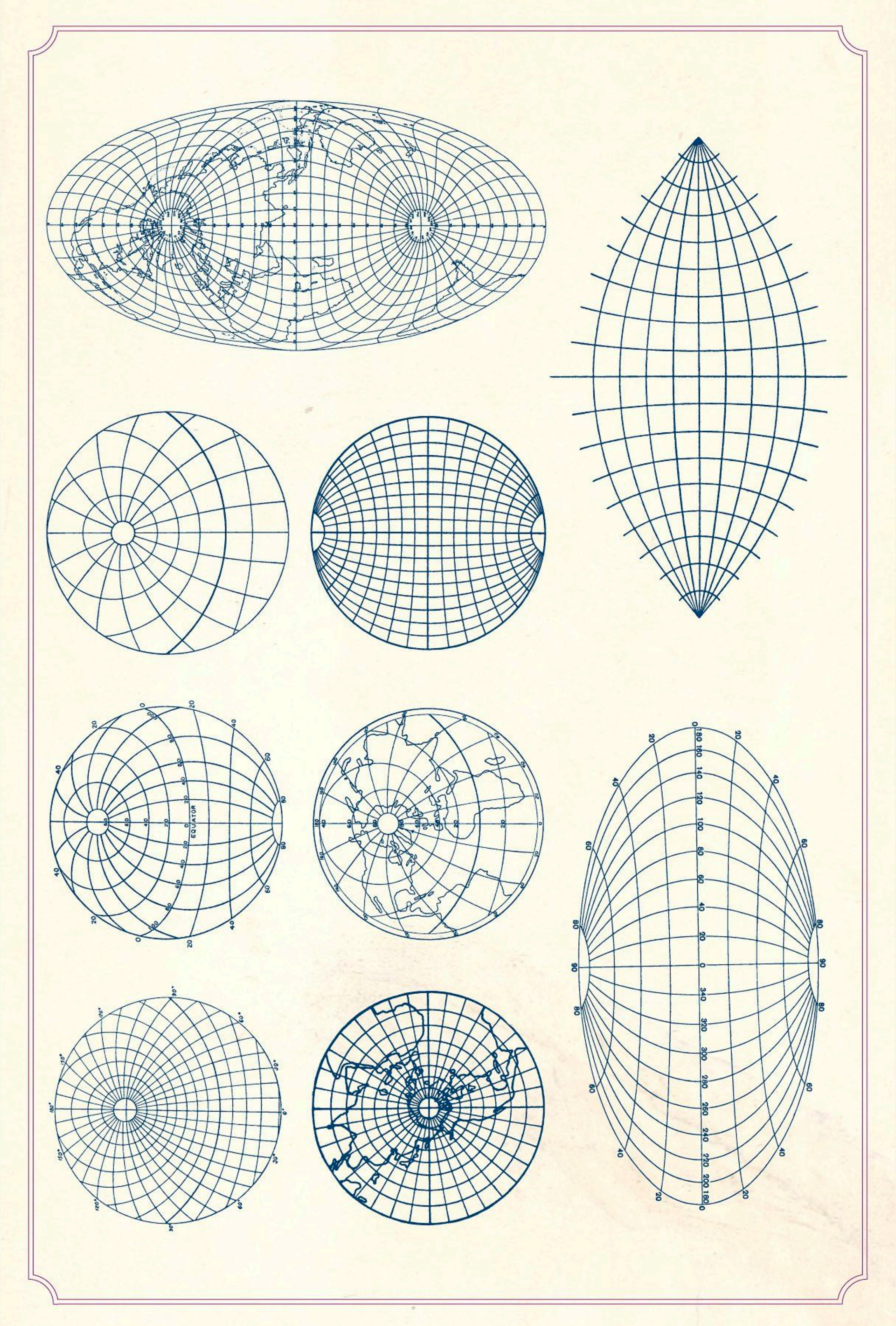
Measuring location on Earth's surface

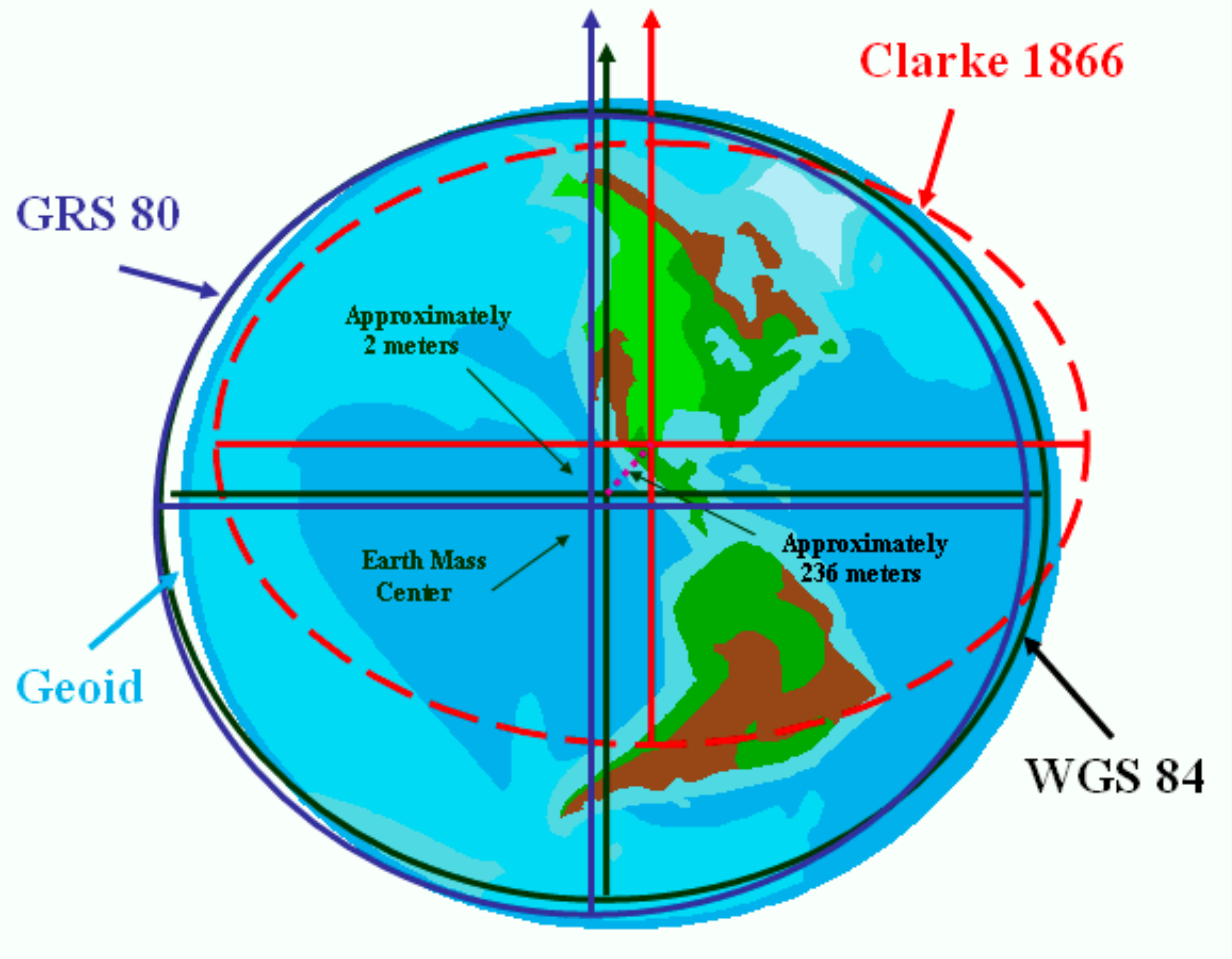
Topics

- Measurement
- Latitude and longitude
- Ellipsoids, datums, & geoids oh my!
- Geographic coordinate systems
- Map projections

Basic Coordinate Systems

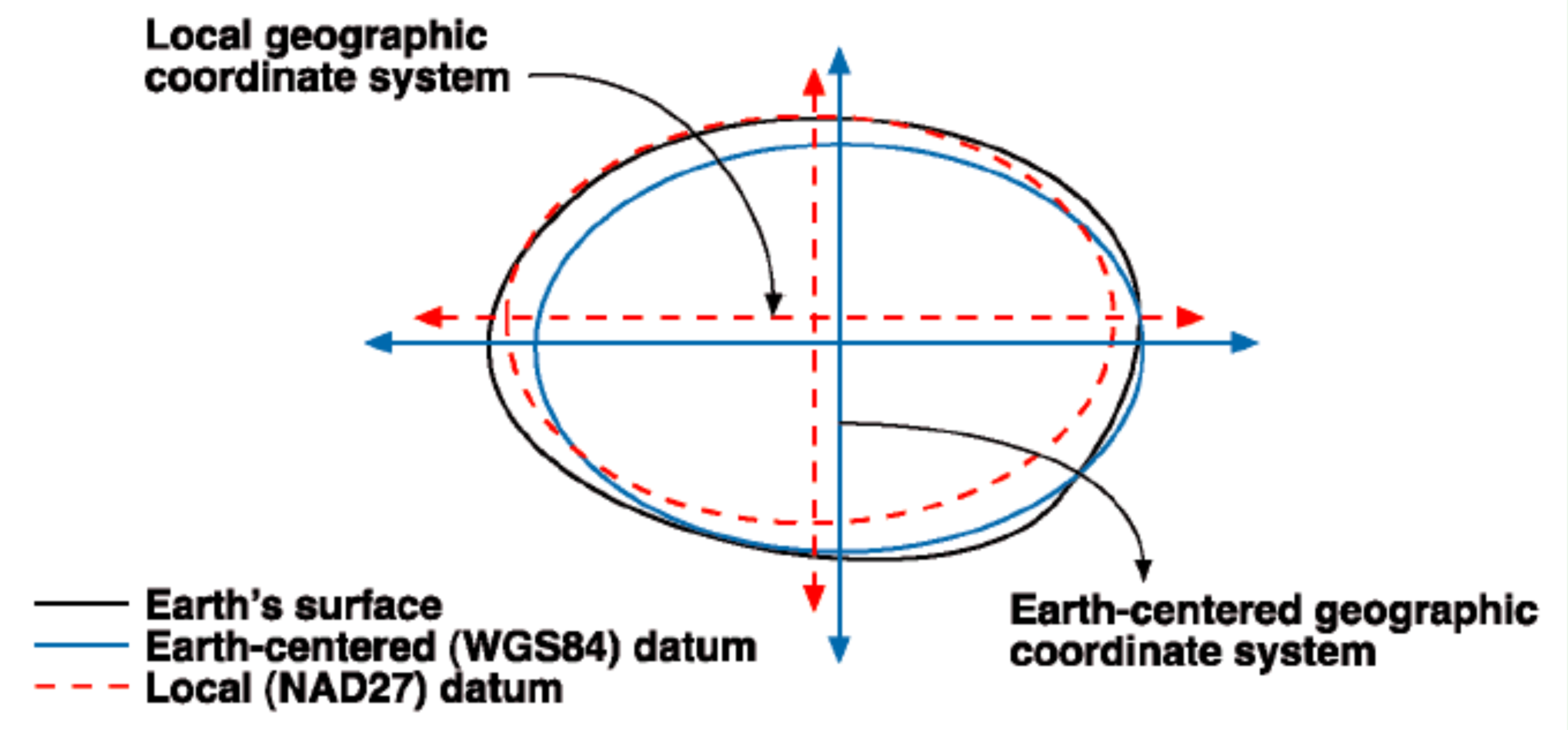
- unambiguously specify location in space
- relationships between locations can be calculated
  - distance
  - direction




Clarke 1866
GRS 80
Approximately
2 meters
Earth Mass
Center
Approximately
236 meters
Geoid
WGS 84

Datums control ellipsoid alignment

- Local datum--fitted to a certain region on earth (NAD27)
- Global datum--overall fitted to earth (NAD83 and WGS84)



Triangulation to build networks

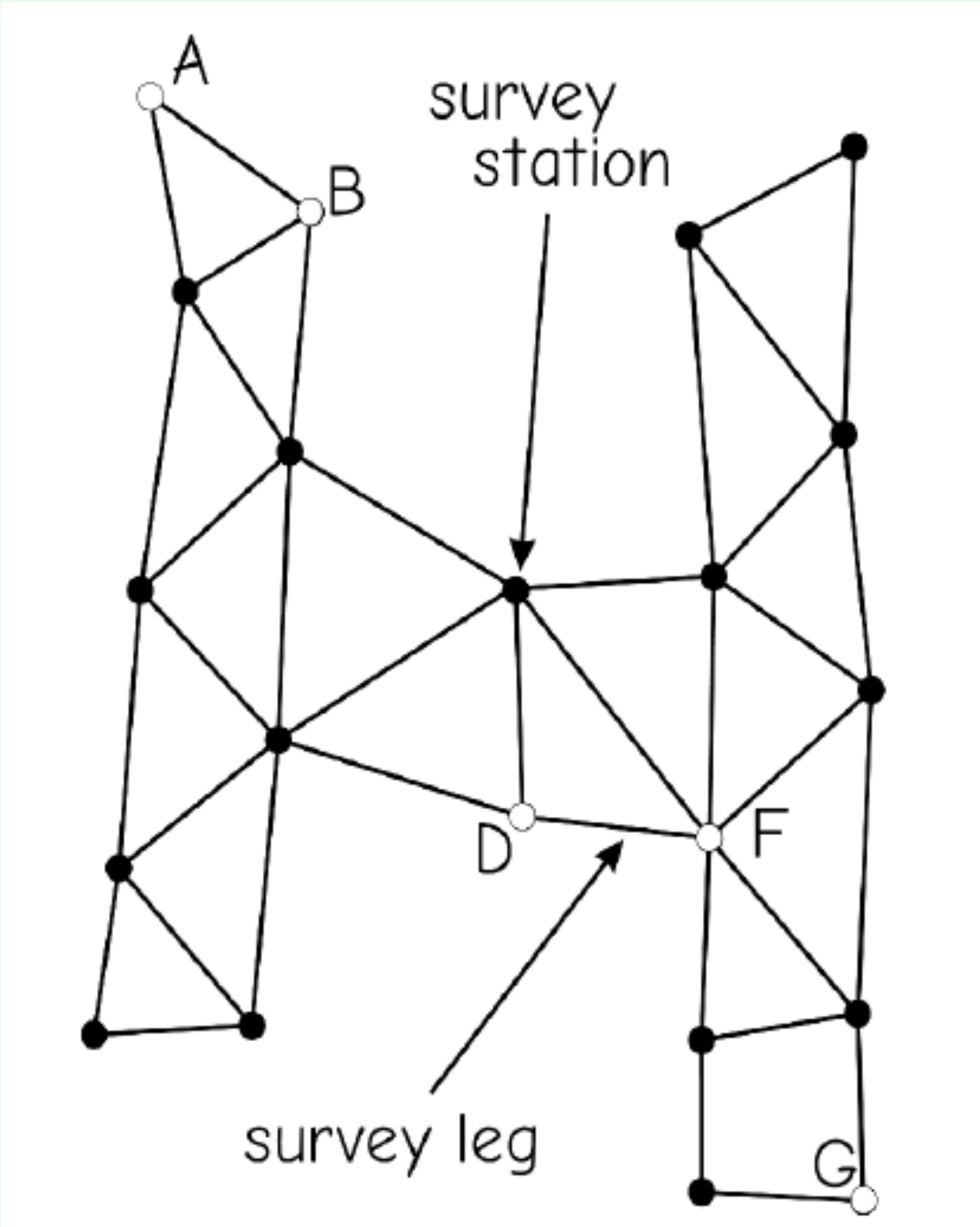


Figure 3-16: A triangulation survey network. Stations may be measured using astronomical (open circles) or surface surveys (filled circles).

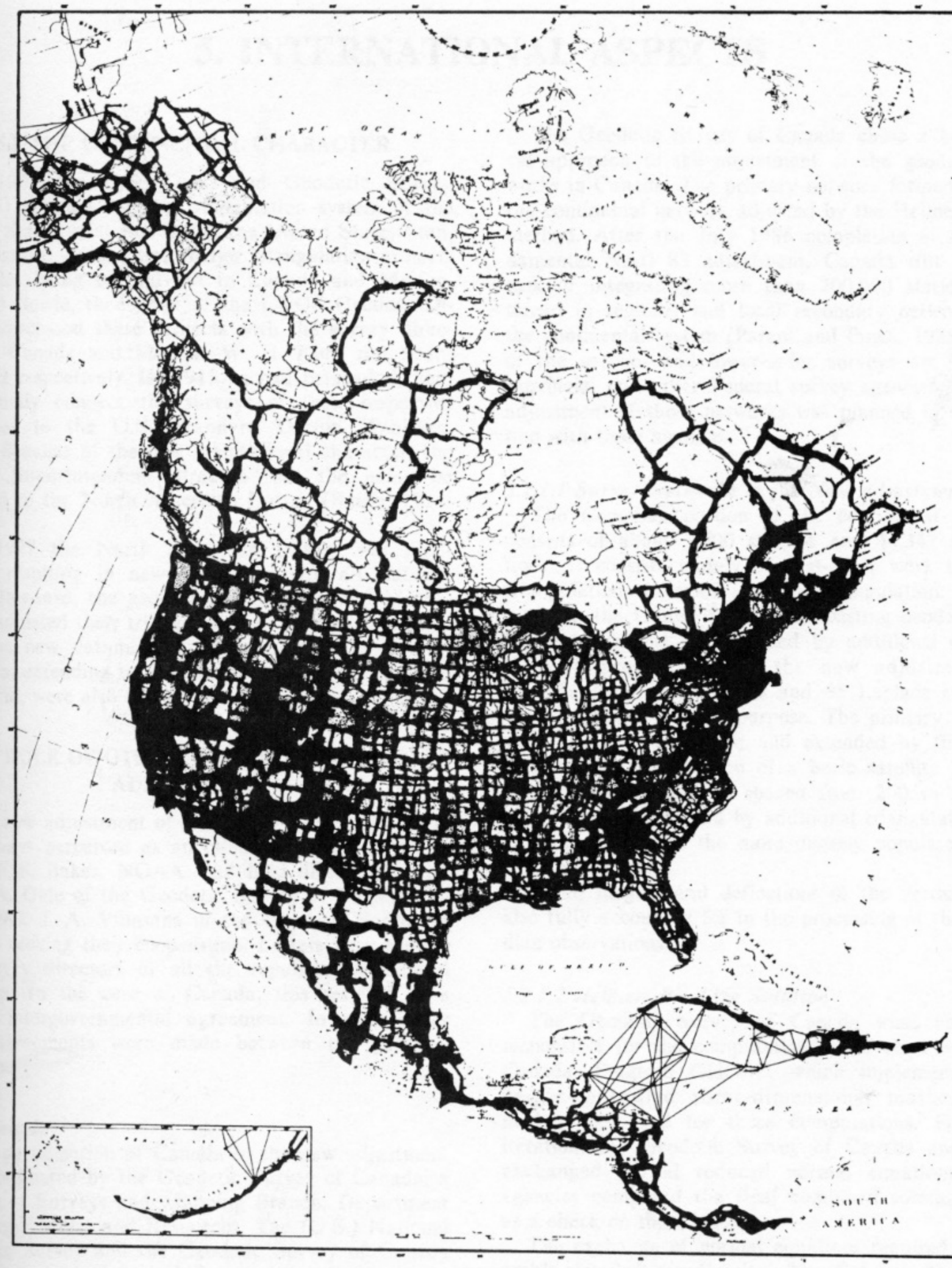
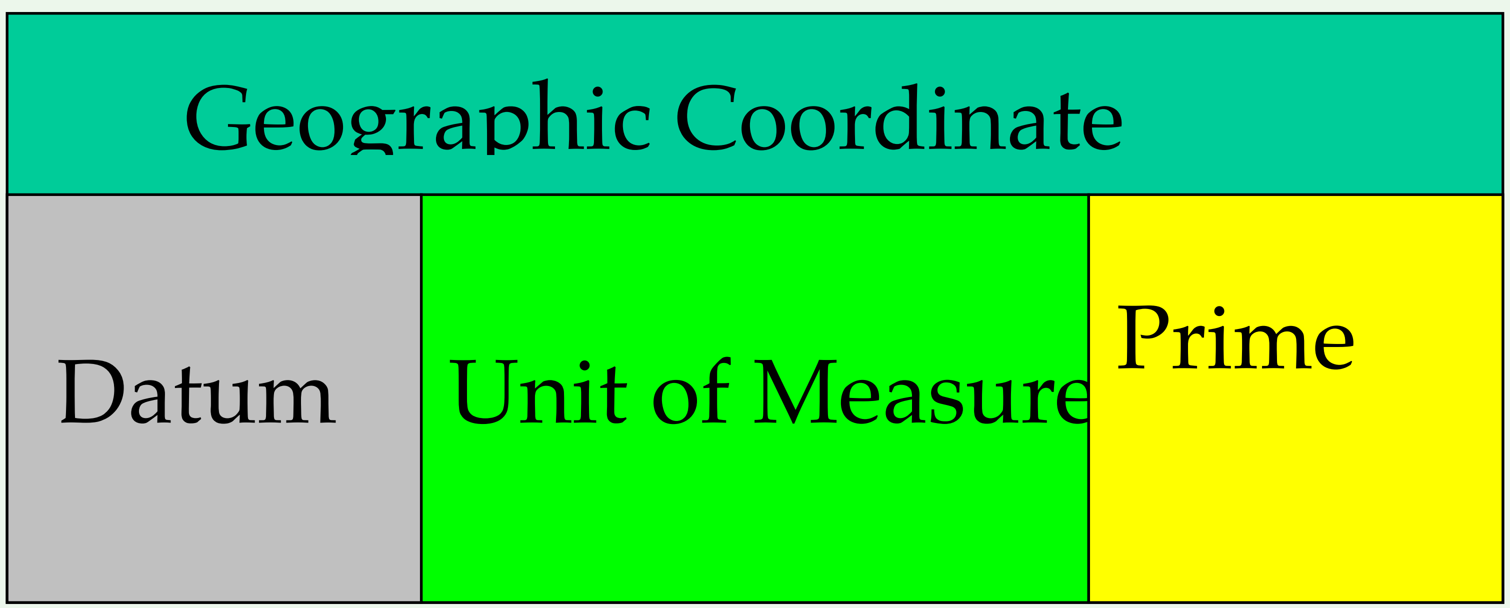


Figure 4.3. Status of geodetic control in North American in 1981.

Geographic Coordinate Systems (GCS)

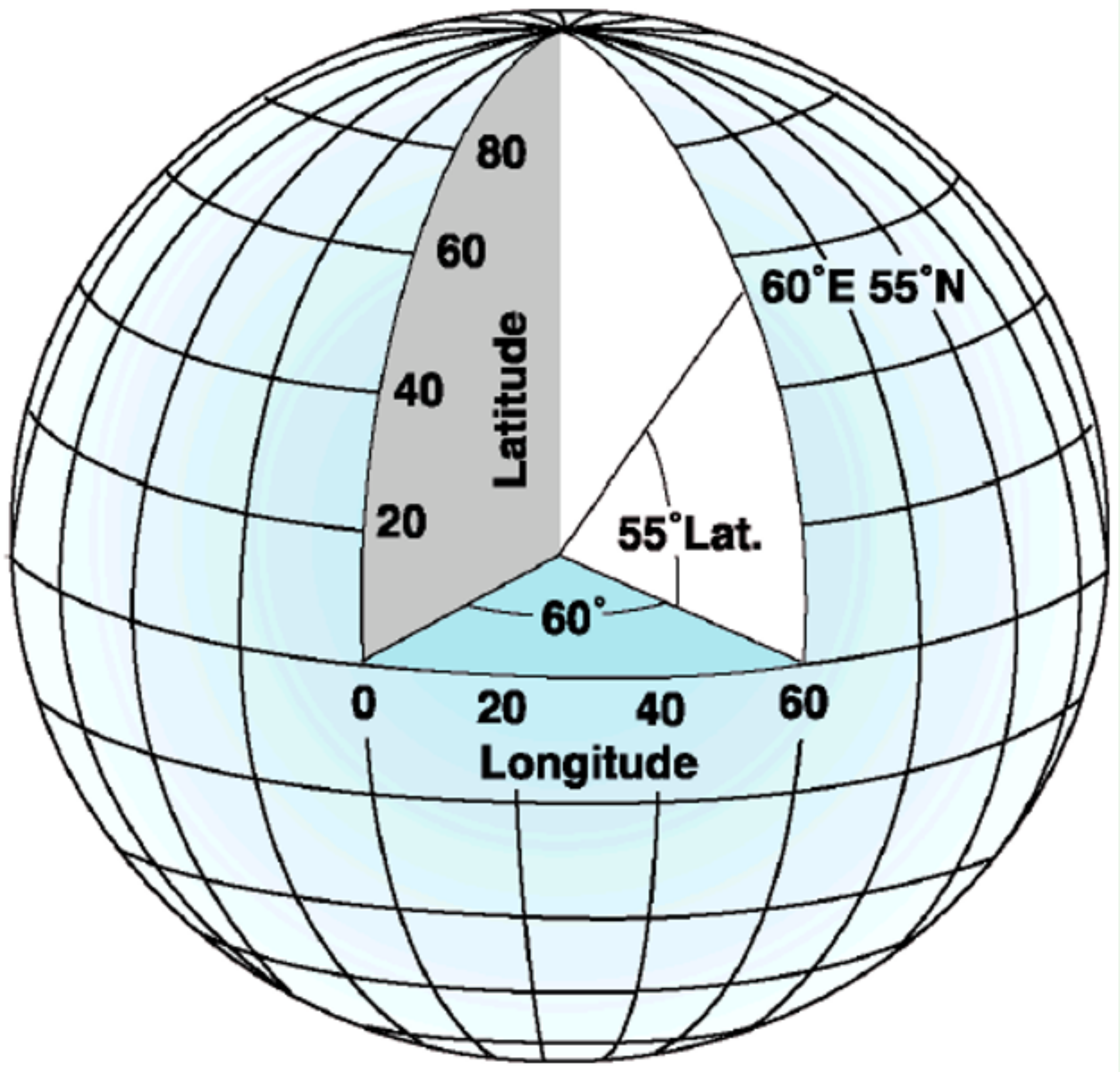
- Based on a spheroid model of the Earth
- Using two angular measurements (latitude and longitude) to specify a location on the model



Latitude & longitude

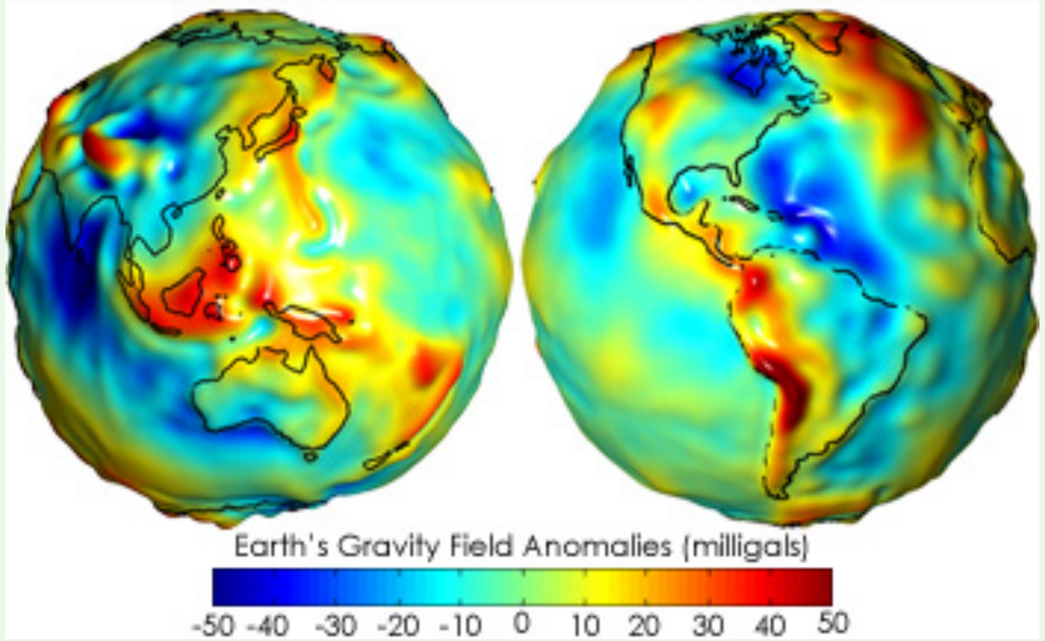
- Latitude (ϕ) is the angular measurement between the equatorial plane and the radius to a point on Earth's surface

- Longitude (λ) is the angular measurement between the prime meridian and the radius to a point on Earth's surface



Geoid and Global Vertical Datum

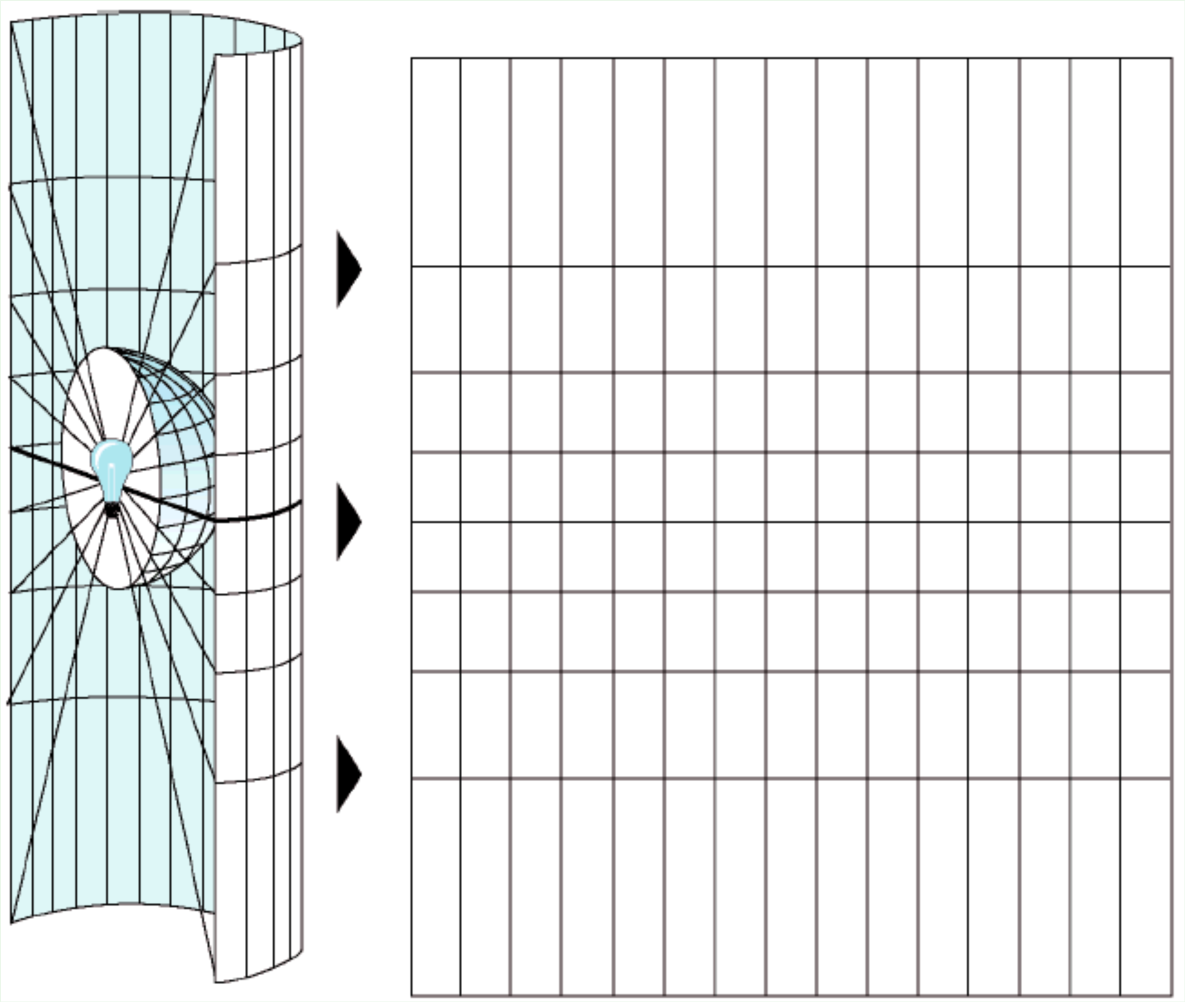
- A equipotential surface extended through land with effects of gravity
  - Calm and uniform water cover the earth surface
  - irregularities in the density of the Earth's crust and mantle
- A measured surface (not mathematically defined) using surface and satellite instruments
- A **global** vertical datum



Issues with geographic coordinate systems (GCS)

- Latitude and longitude are not uniform
    - the distance of one degree of longitude is different from the distance of one degree of latitude except along the equator
- Calculations (distance and area) on ellipsoid are more complex than on a 2D plane
- Most GIS analytical functions are implemented based on 2D coordinate systems
    - Early GIS data were digitized from paper maps which are in a 2D coordinate system
- A map projection converts GCS to 2D Cartesian coordinate system

Map Projections

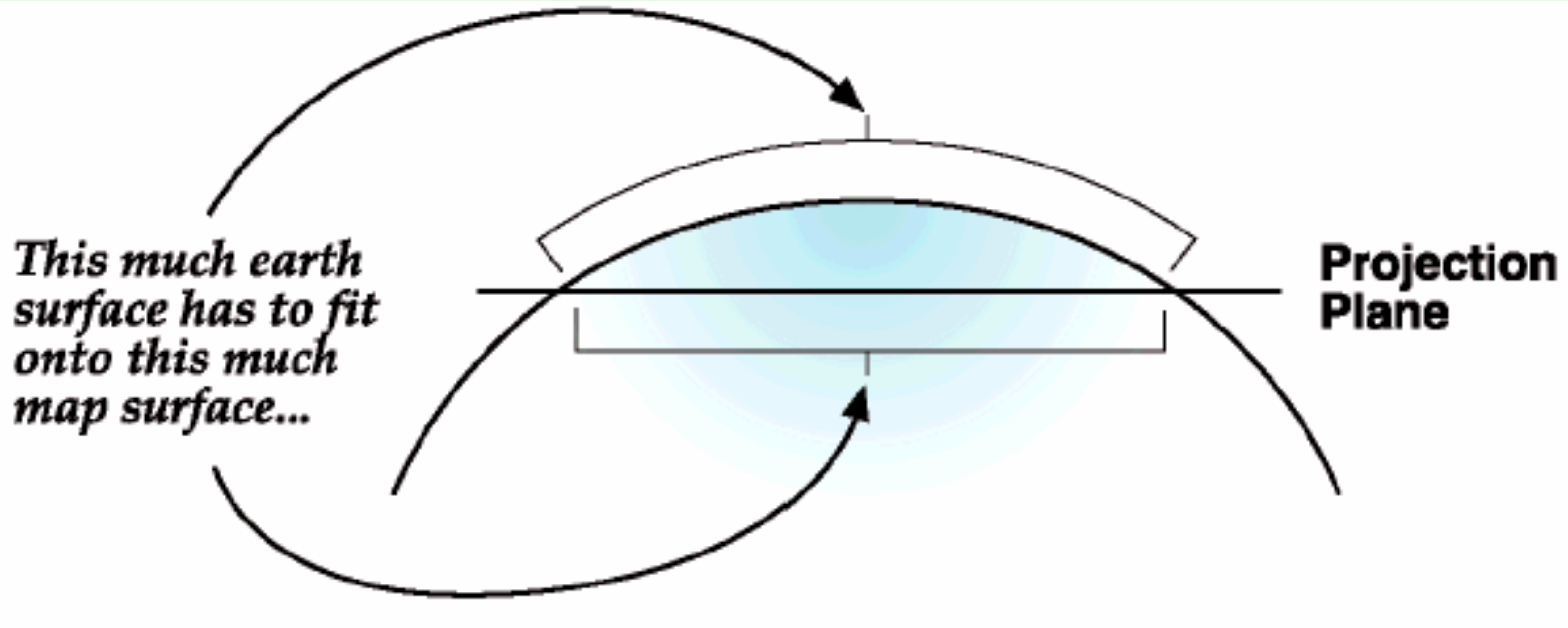


Area/distance is distorted but angles are preserved

Map projections

A map projection uses mathematical formulas to relate geographic coordinates on a sphere or ellipsoid to flat planar coordinates.

$(\varphi, \lambda) \leftrightarrow (x, y)$



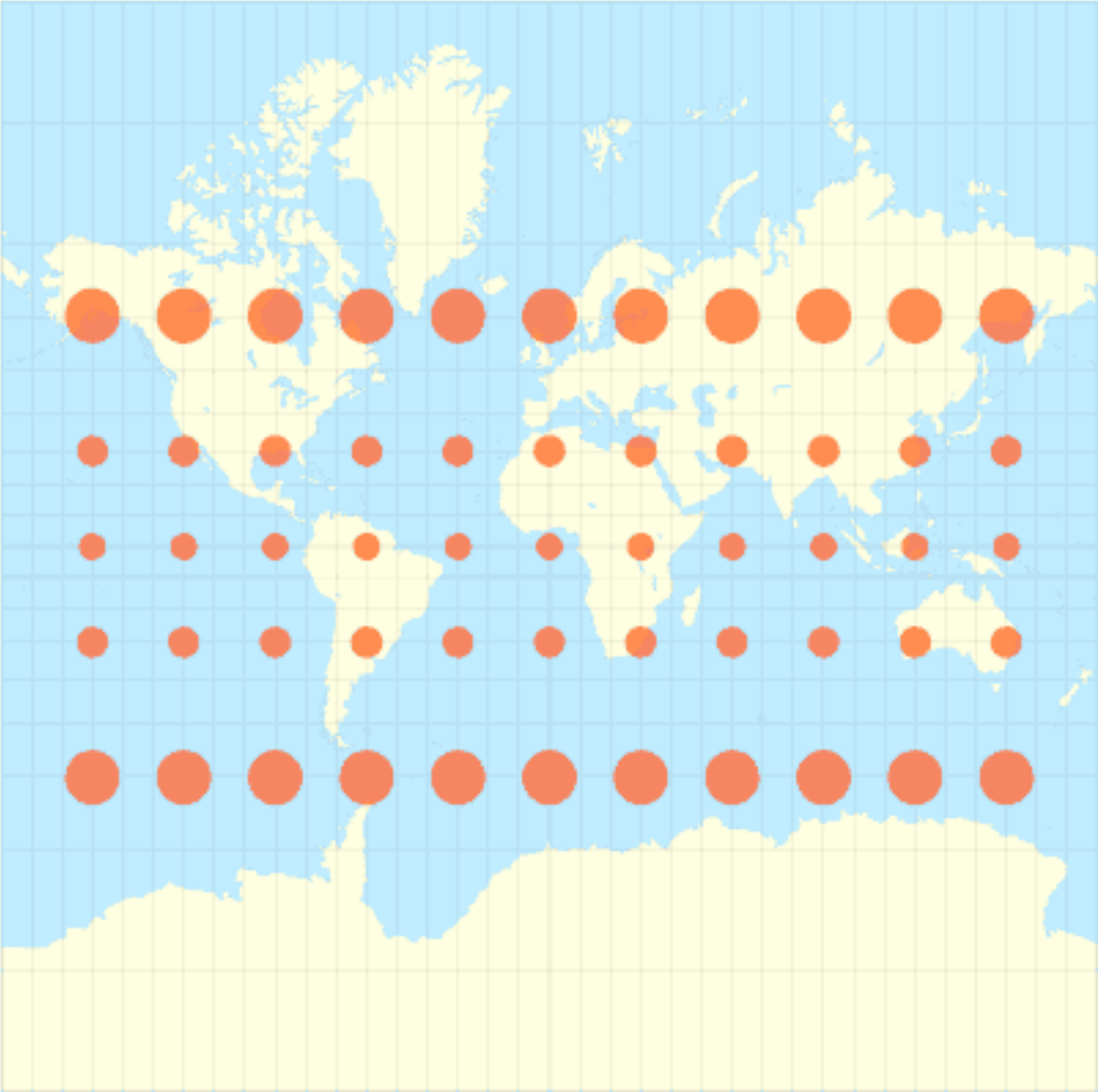
Distortions of Map Projections

- It's impossible to transform a spheroid surface on a flat plane without distortions
- Distortions may exist in shape, size, distance, and direction.
- Map projections by what properties are preserved
  - Shape – Conformal Projections
  - Area (size) – Equivalent (equal-area) Projections
  - Distance – Equal-distance Projections
  - Direction – True-direction Projections
  - Compromise—minimize distortion but preserve none truly
- There are several ways map projects can be designed to mitigate the problem.
  - Reduce one kind of distortion at the expense of another
  - Have the most distortion areas fall in the less important parts of the map


GREENLAND
(DENMARK)
RUSSIA
CANADA
ALASKA
(U.S.A.)
UNITED STATES
OF AMERICA
MEXICO
BRAZIL
ARGENTINA
CHINA
MONGOLIA
KAZAKHSTAN
INDIA
JAPAN
INDONESIA
MALAYSIA
PAPUA NEW GUINEA
NEW ZEALAND
WELLINGTON
ALGERIA
LIBYA
SUDAN
NIGER
CHAD
SAUDI ARABIA
IRAN
TURKEY
TANZANIA
ANGOLA
NAMIBIA
BEAUFORT SEA
NORWEGIAN SEA
LABRADOR SEA
BERING SEA
SEA OF OKHOTSK
CARIBBEAN SEA
MEDITERRANEAN SEA
BLACK SEA
ARABIAN SEA
Gulf of Mexico
Gulf of Alaska
Hudson Bay
Baffin Bay
Gulf of Guinea
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
INDIAN OCEAN
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
150° WEST
120° WEST
90° WEST
60° WEST
30° WEST
0°
30° EST
60° EST
90° EST
120° EST
150° EST
180° EST
75°
60°
45°
30°
15°
0°
15°
30°
45°
60°

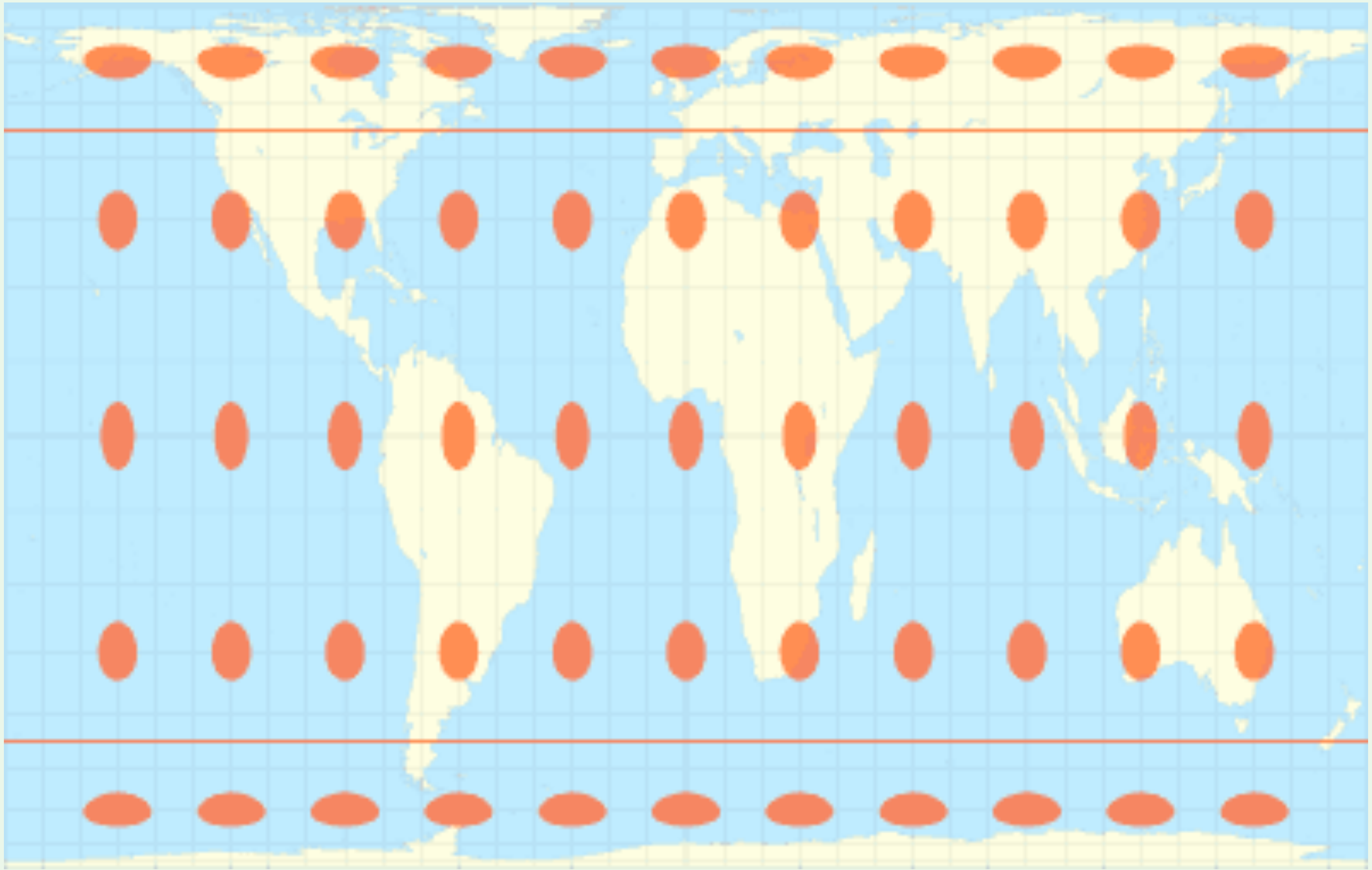
Conformal Projections

- Feature shapes preserved
- Perpendicular graticules intersect at right angles
- The sizes of features are distorted
  - Africa is 14 times larger than Greenland
  - South America is 9 times larger than Greenland
  - Australia is 3.5 times larger than Greenland



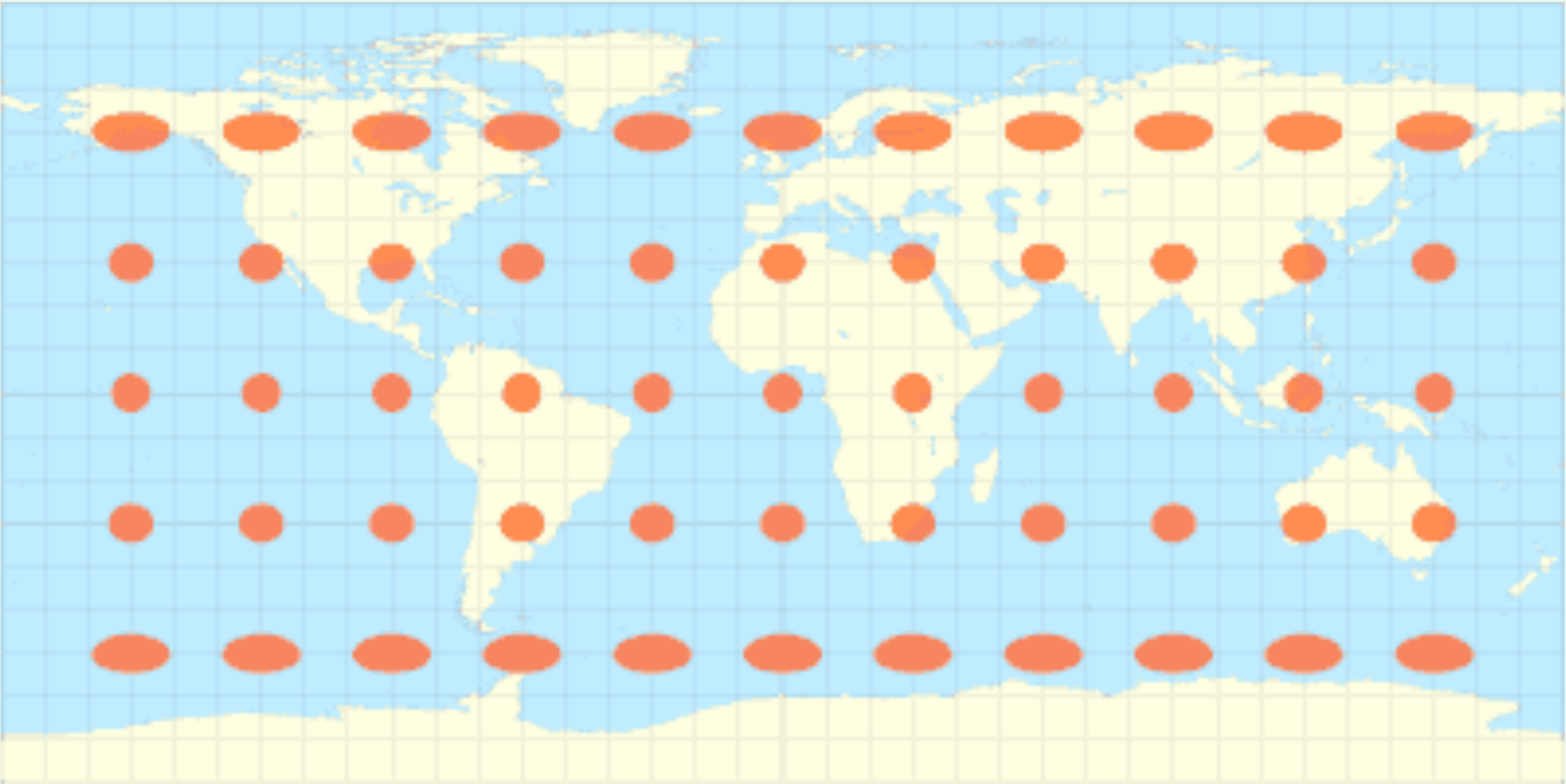
The **True Size** of **Africa**

Equivalent (Equal Area) Projections



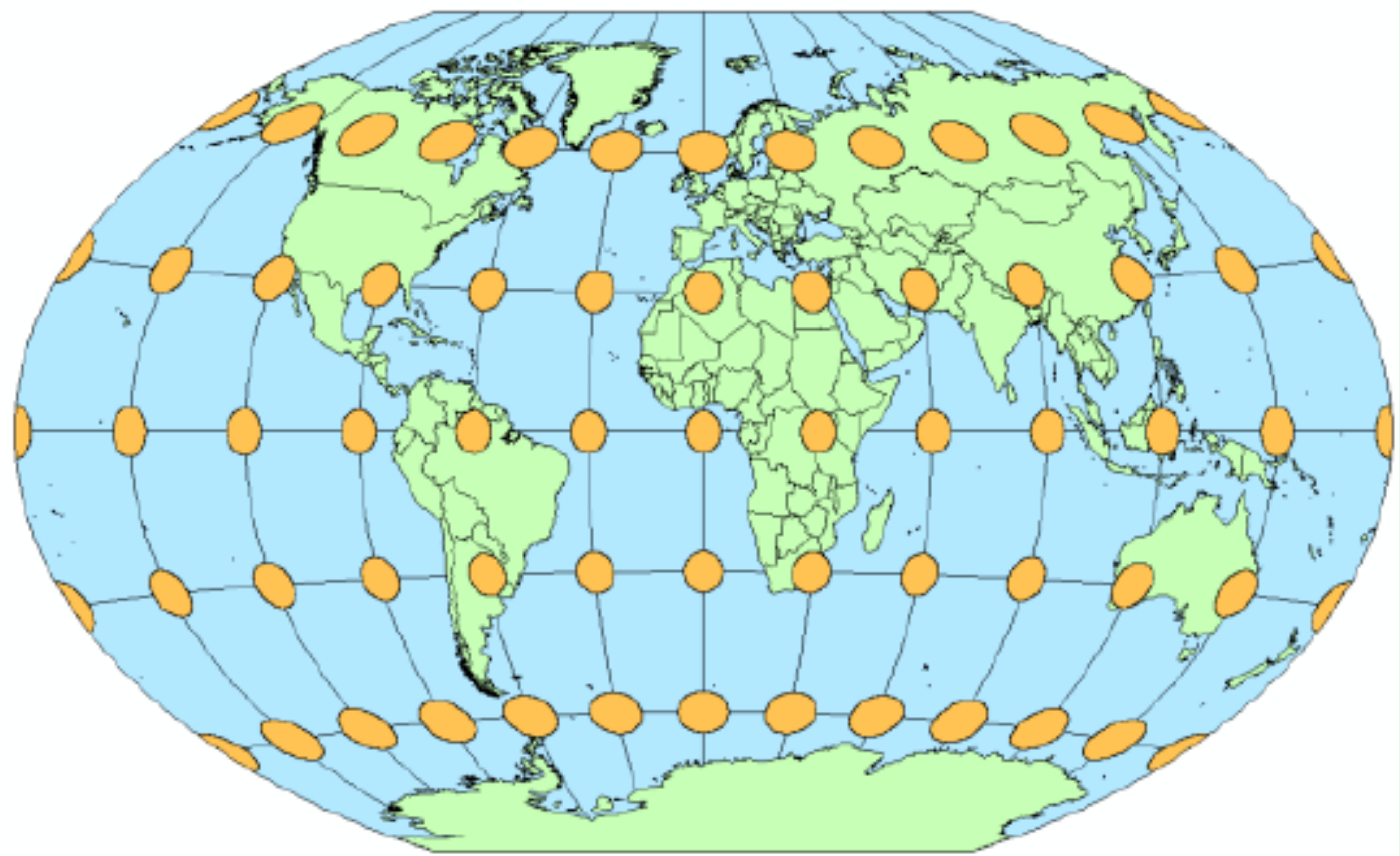
- Preserves the sizes of features
- Feature shapes are distorted

Equidistant Projection

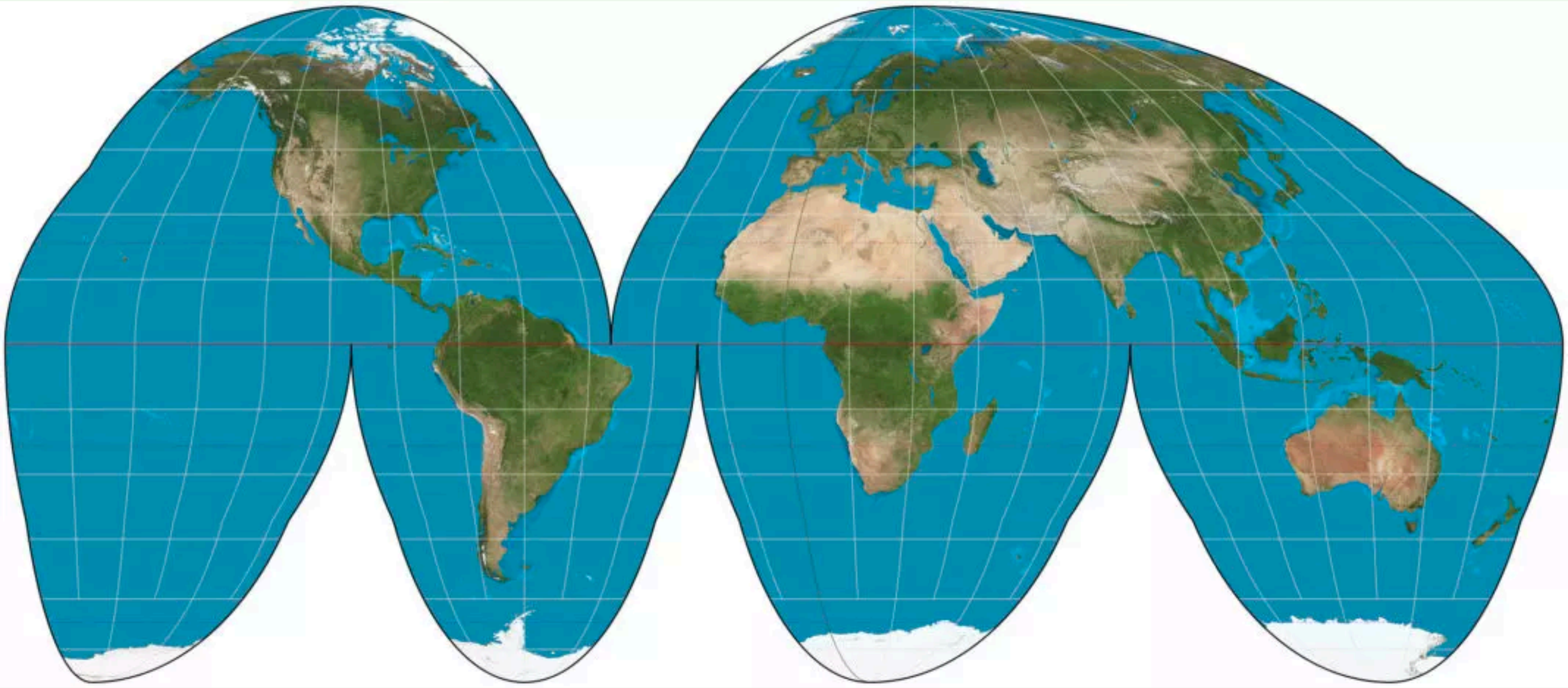


- Preserves the distance a point and all other points is maintained
- Feature shapes and sizes are distorted

Compromise Projection

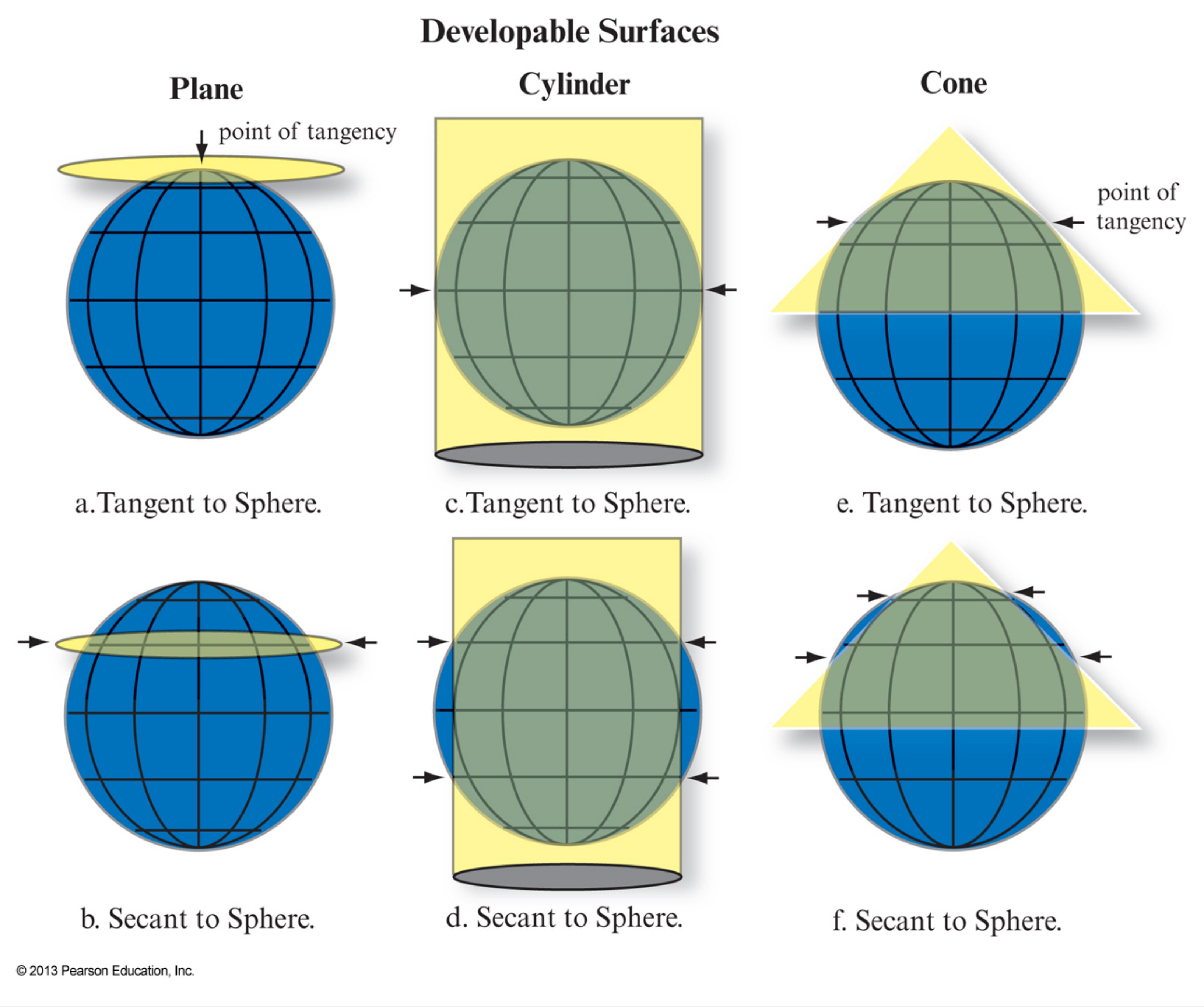


- Preserves no properties in true
- Maximizes “reality” in 2d
- Winkel Tripel

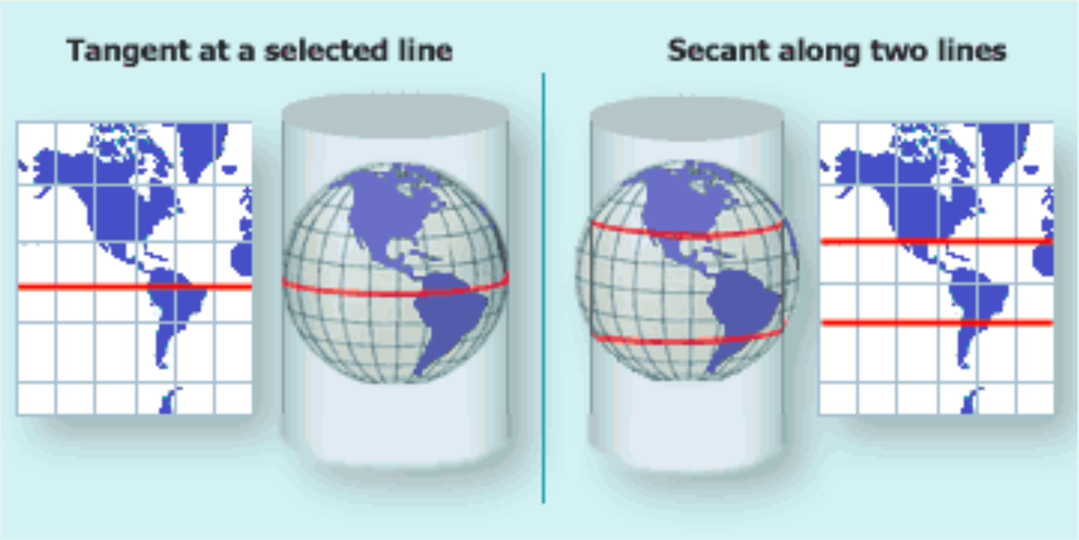


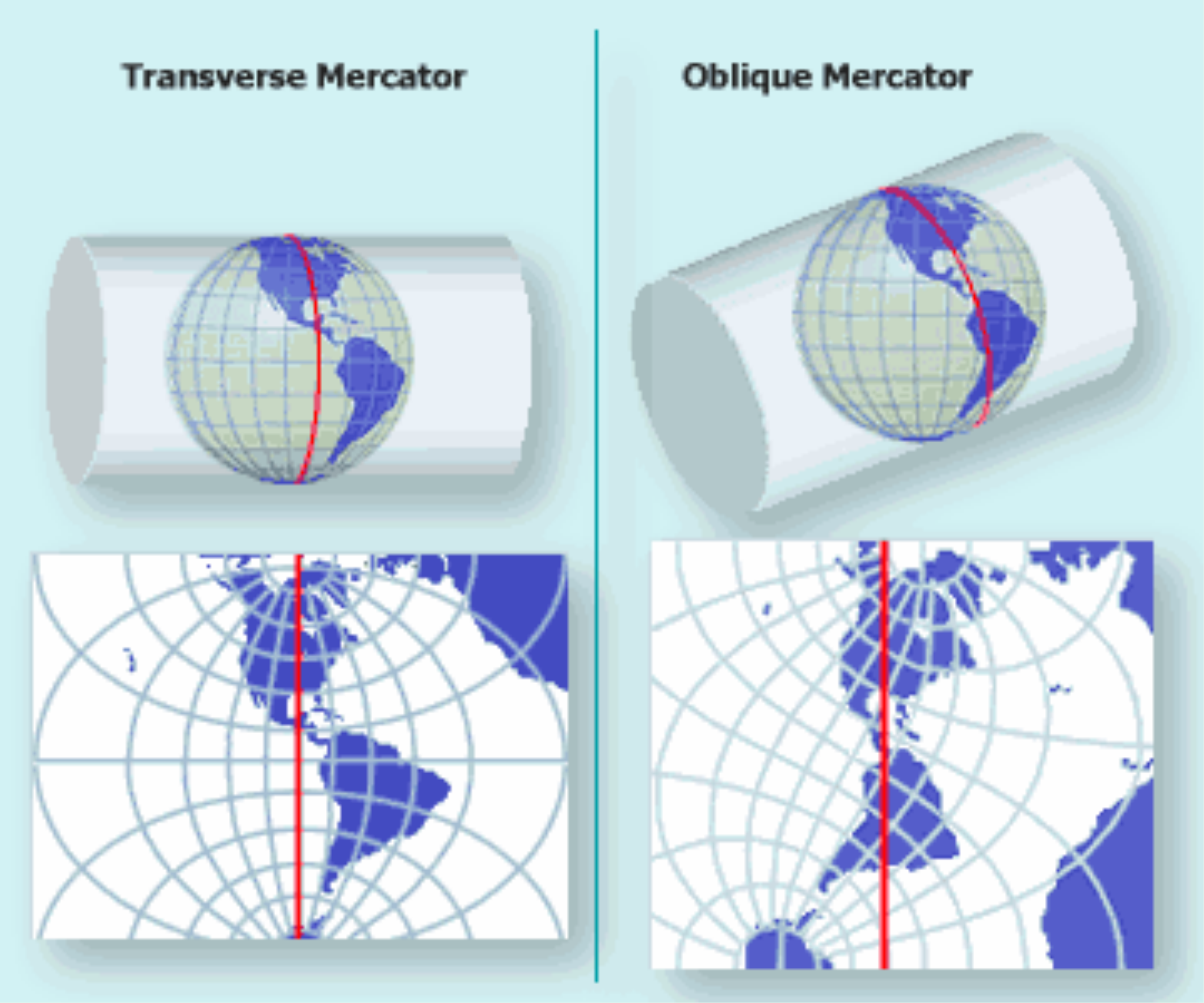
Goode homolosine

Developable Surfaces and Positions



Orientation of Developable Surfaces





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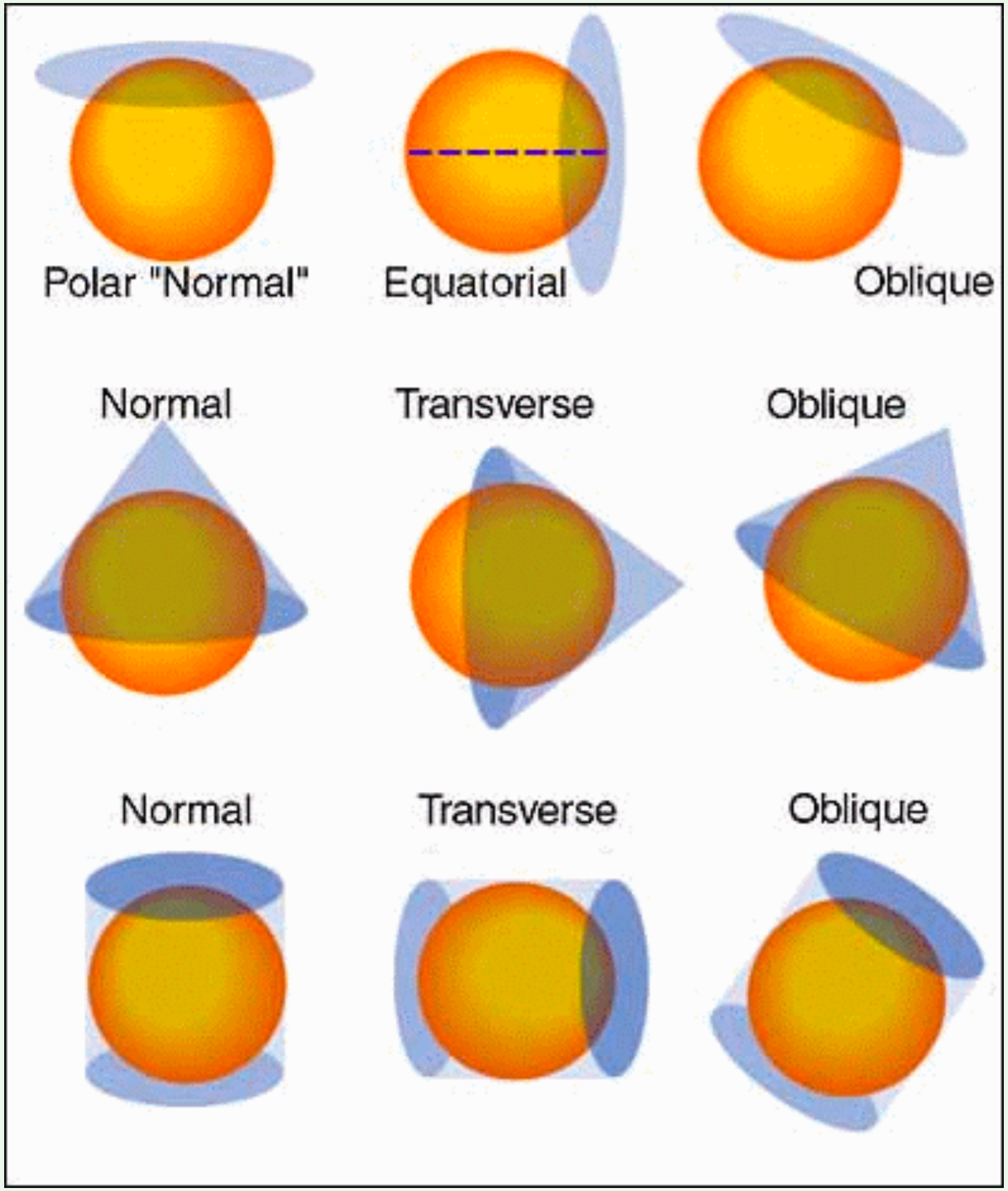
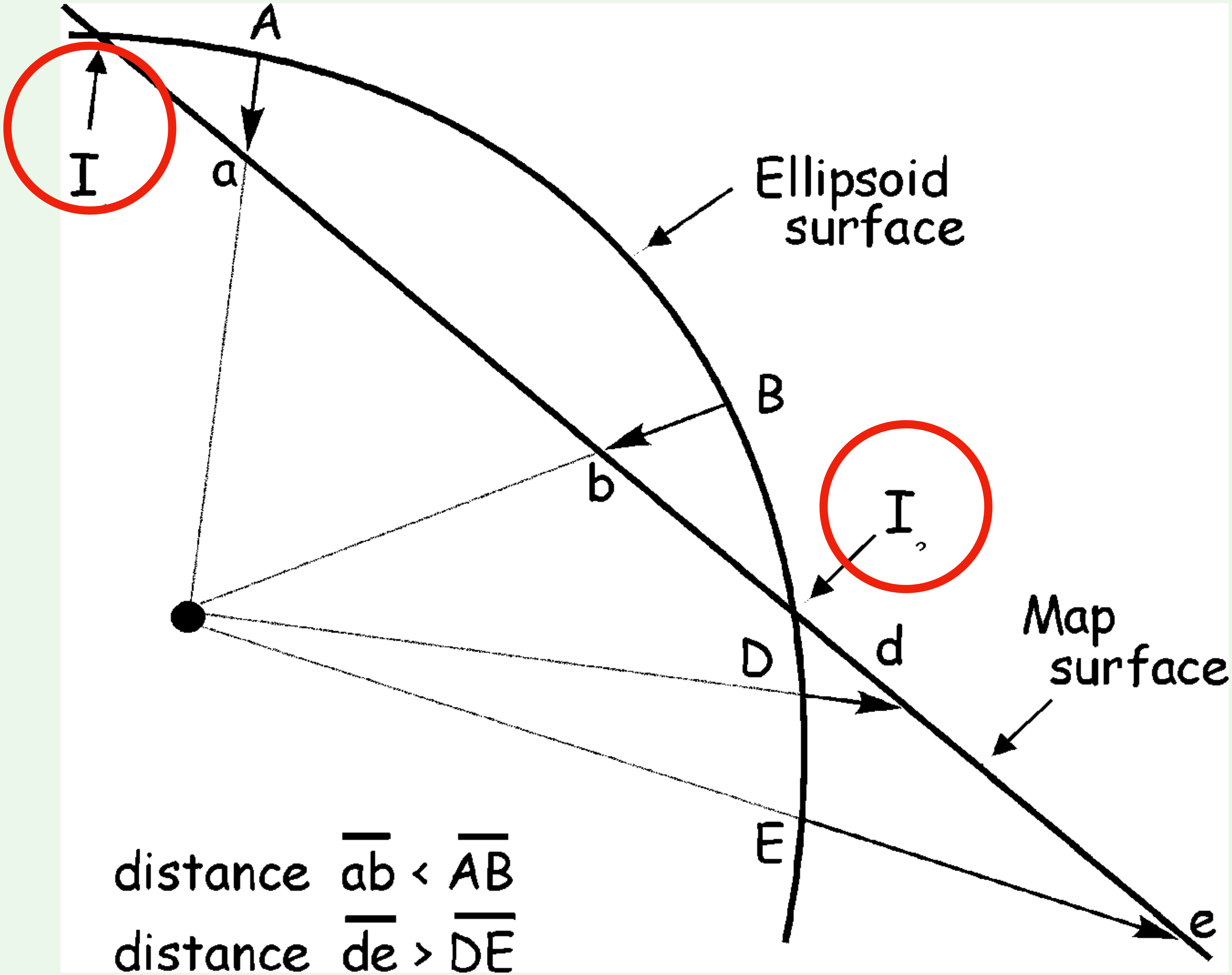


Spatial Variation of Distortion on a Map



Scale Variation on Map

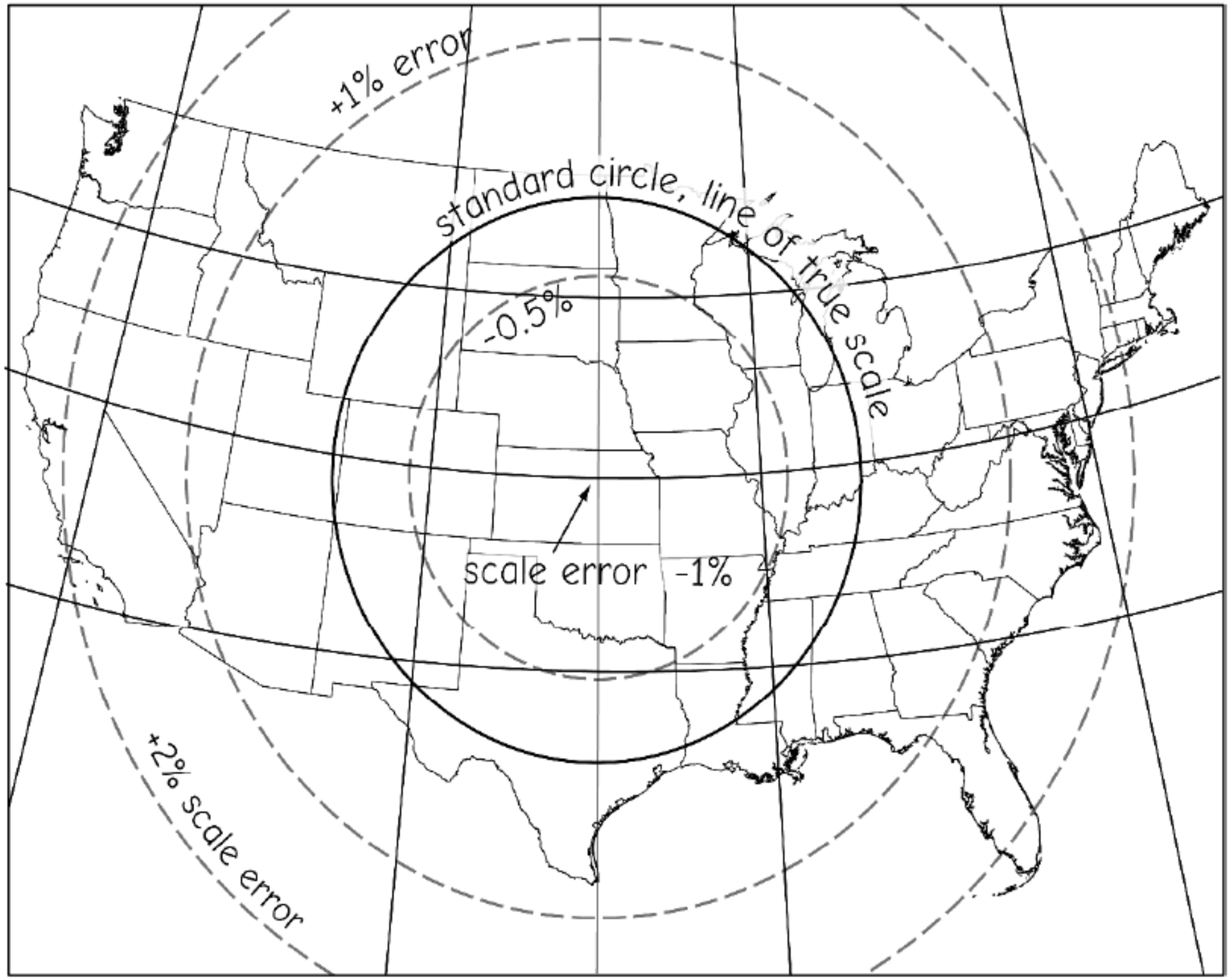
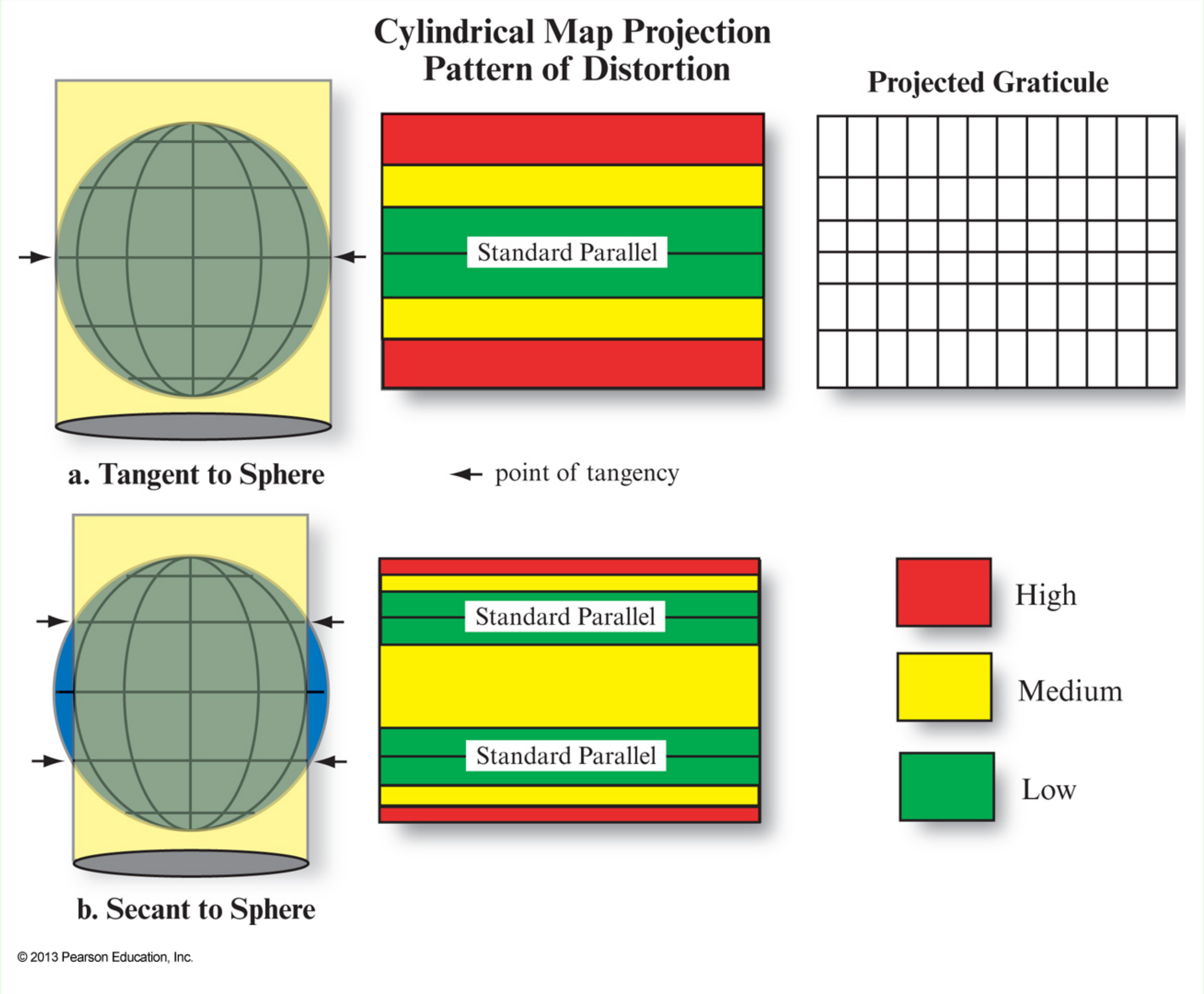


Figure 3-34: Approximate error due to projection distortion for a specific oblique stereographic projection. A plane intersects the globe at a standard circle. This standard circle defines a line of true scale, where there is no distance distortion. Distortion increases away from this line, and varies from -1% to over 2% in this example (adapted from Snyder, 1987).

Patterns of Distortions for Different Map Projections



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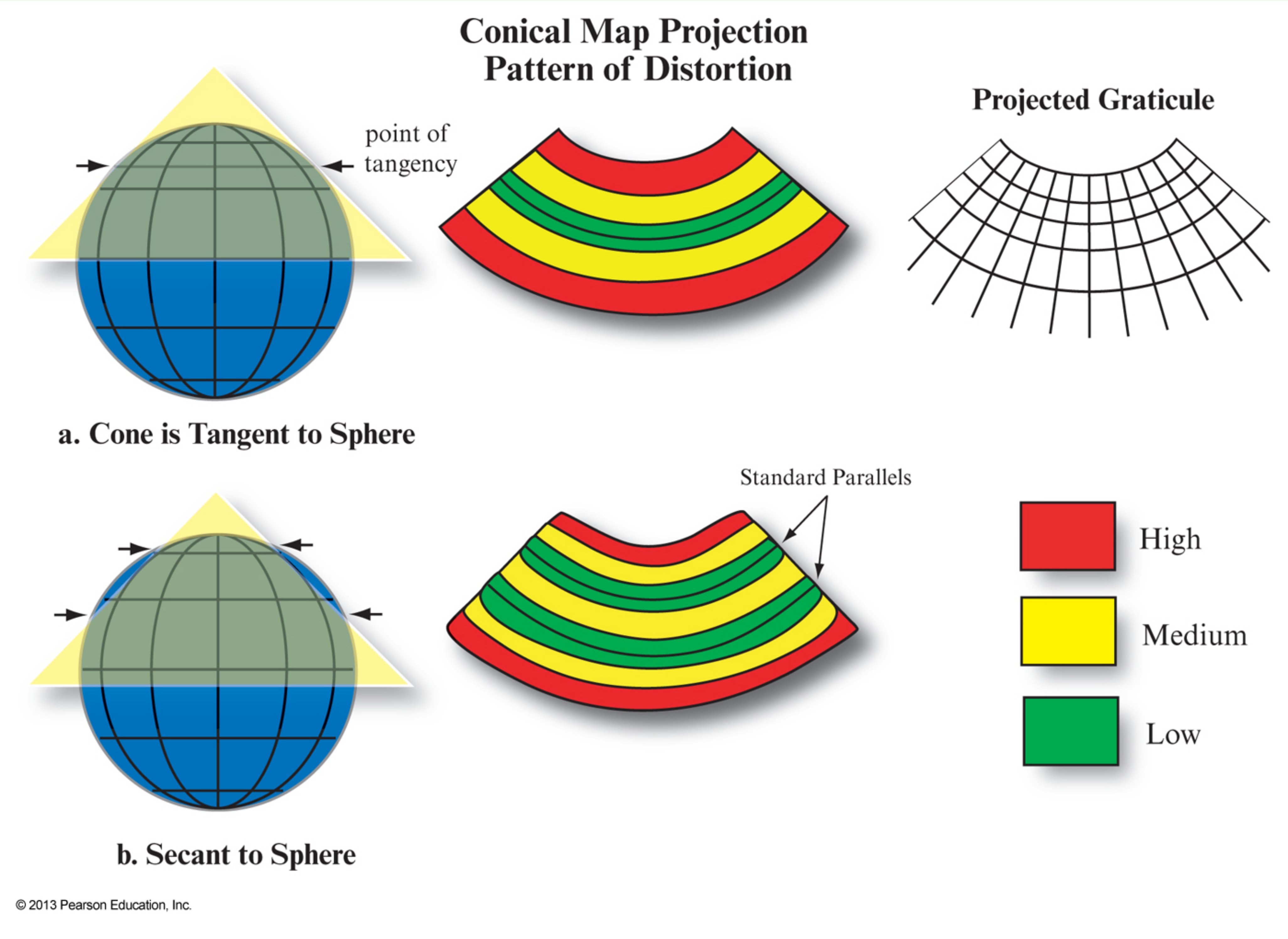

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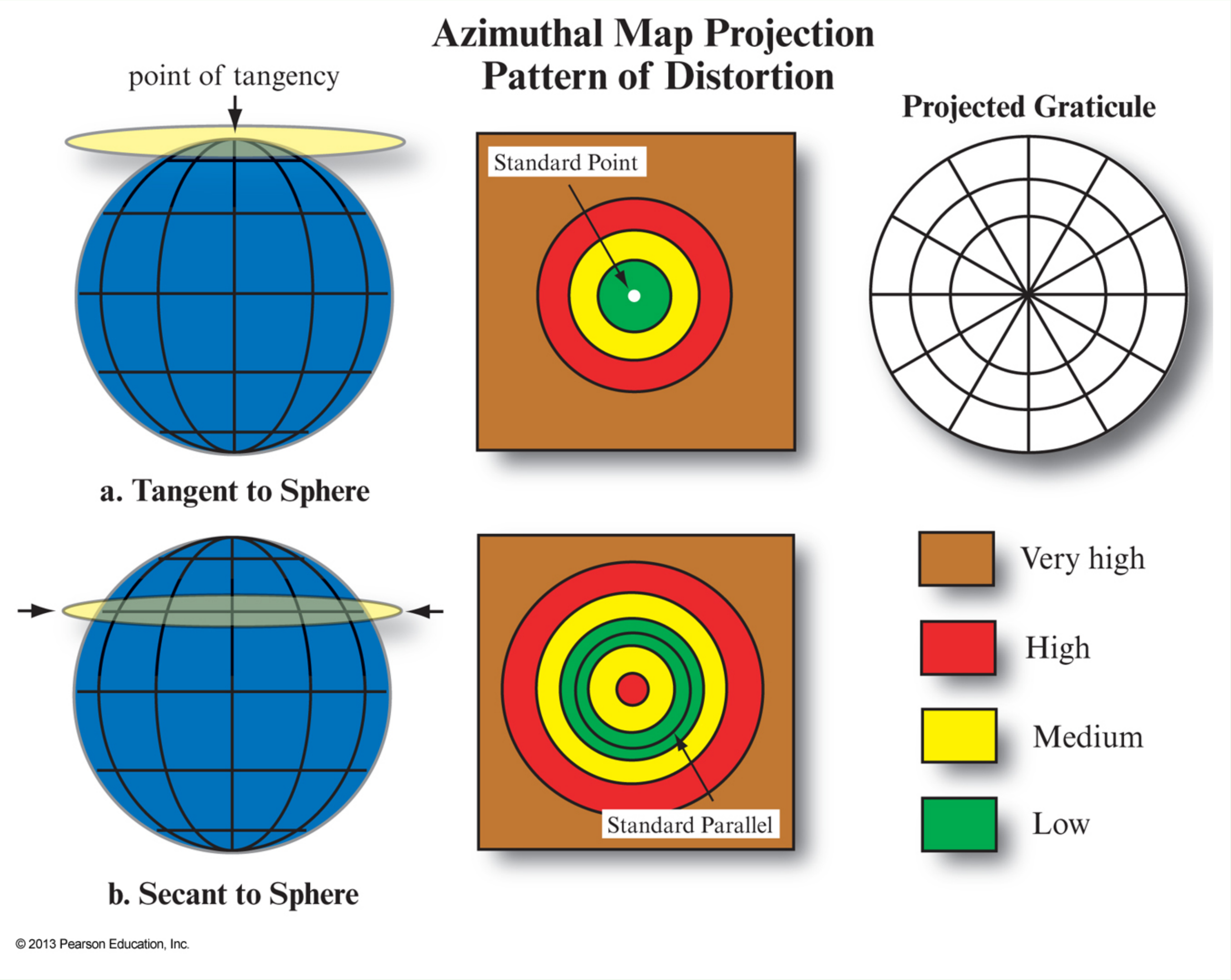
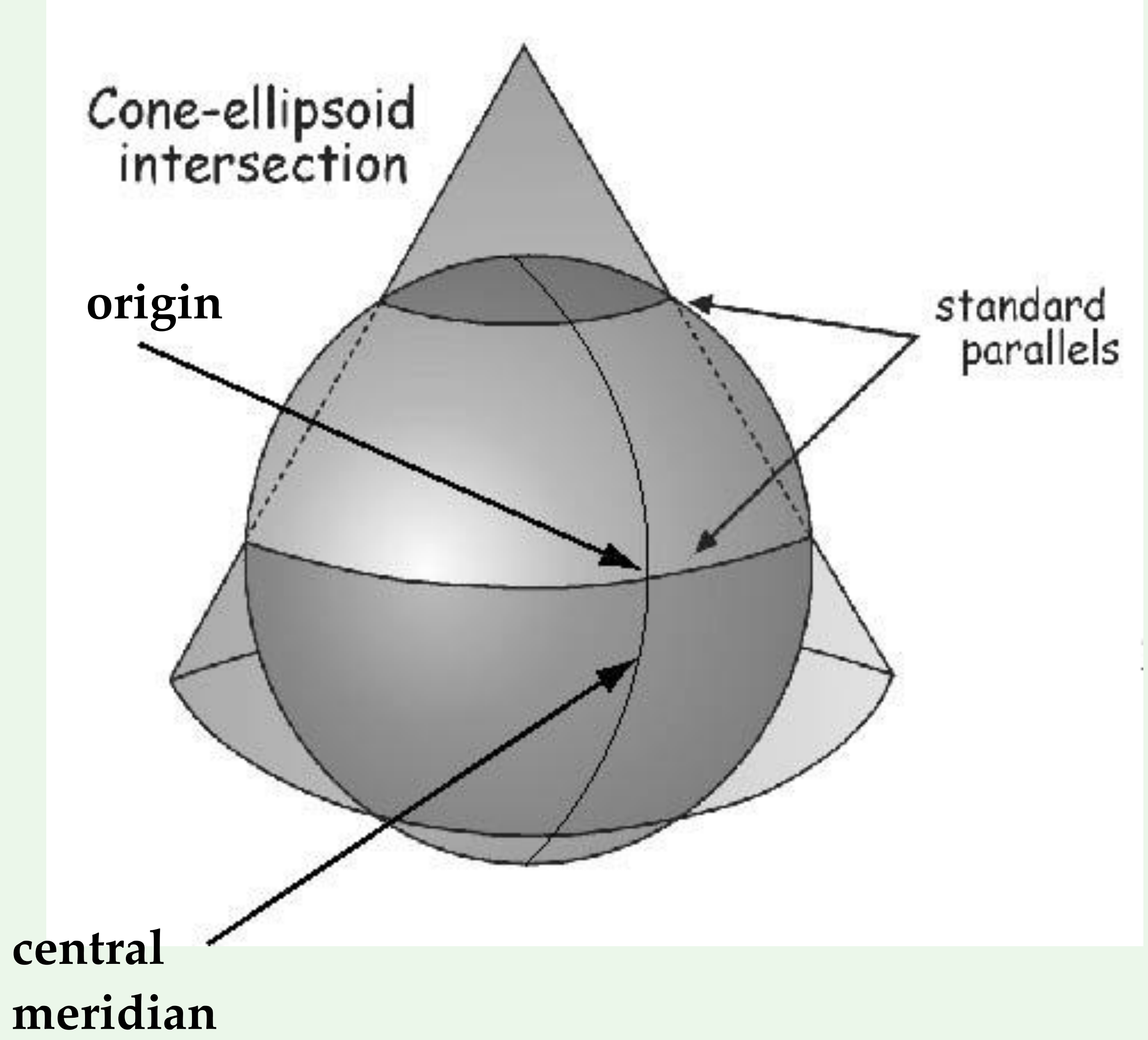


Parameters to Define a Map Projection

(Lambert Conformal Conic as an example)

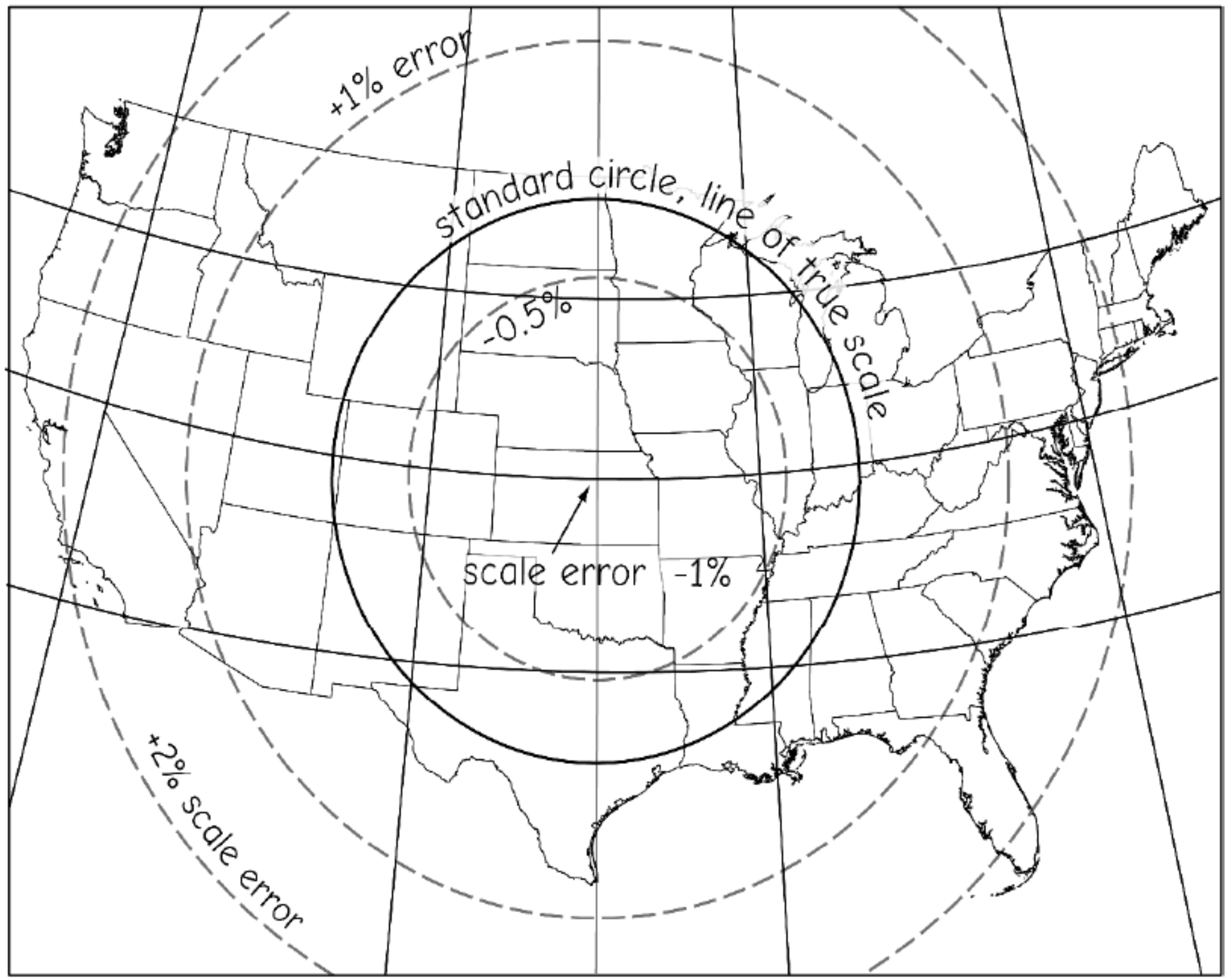
- Type of the developable surface
  - Plane, cylinder, or cone
- Tangent or secant (intersect) to the ellipsoid
  - One or two standard parallels
- Projection origin
  - Central meridian and reference latitude
- Distortions
  - Conformal or equivalent



Standard Projections

- Many possible projections
- Governments and organizations define "standard" projections to use
  - Impose uniformity
  - Facilitate data exchange

Which Map Projection is Better for the 48 lower states?



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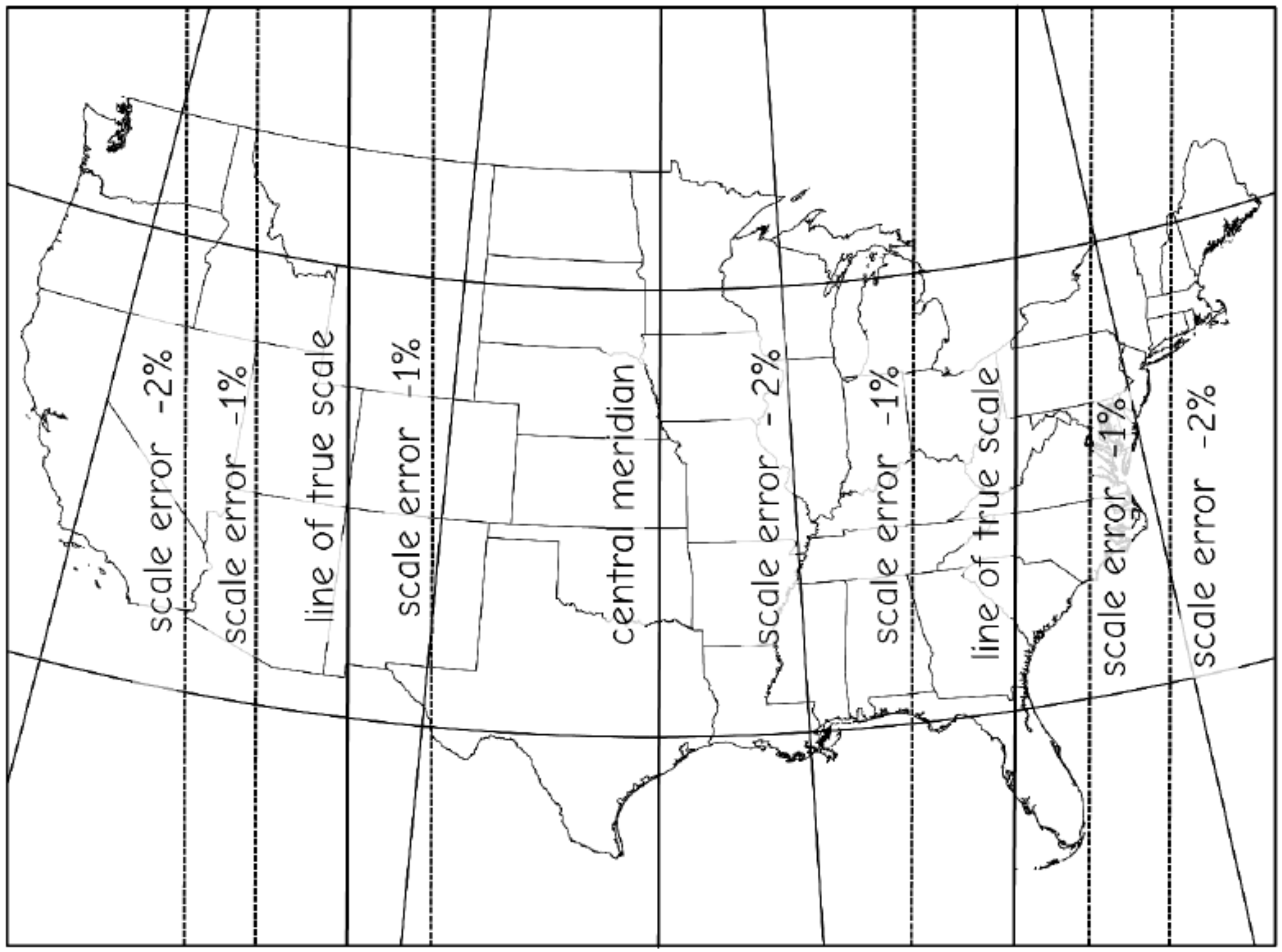


Figure 3-40: Transverse Mercator (TM) projection (top), and an illustration of the scale distortion associated with the projection (bottom). The TM projection distorts distances in an east-west direction, but has relatively little distortion in a north-south direction. This TM intersects the sphere along two lines, and distortion increases with distance from these lines (bottom, adapted from Snyder, 1987).

Which Map Projection is Better for the 48 lower states?

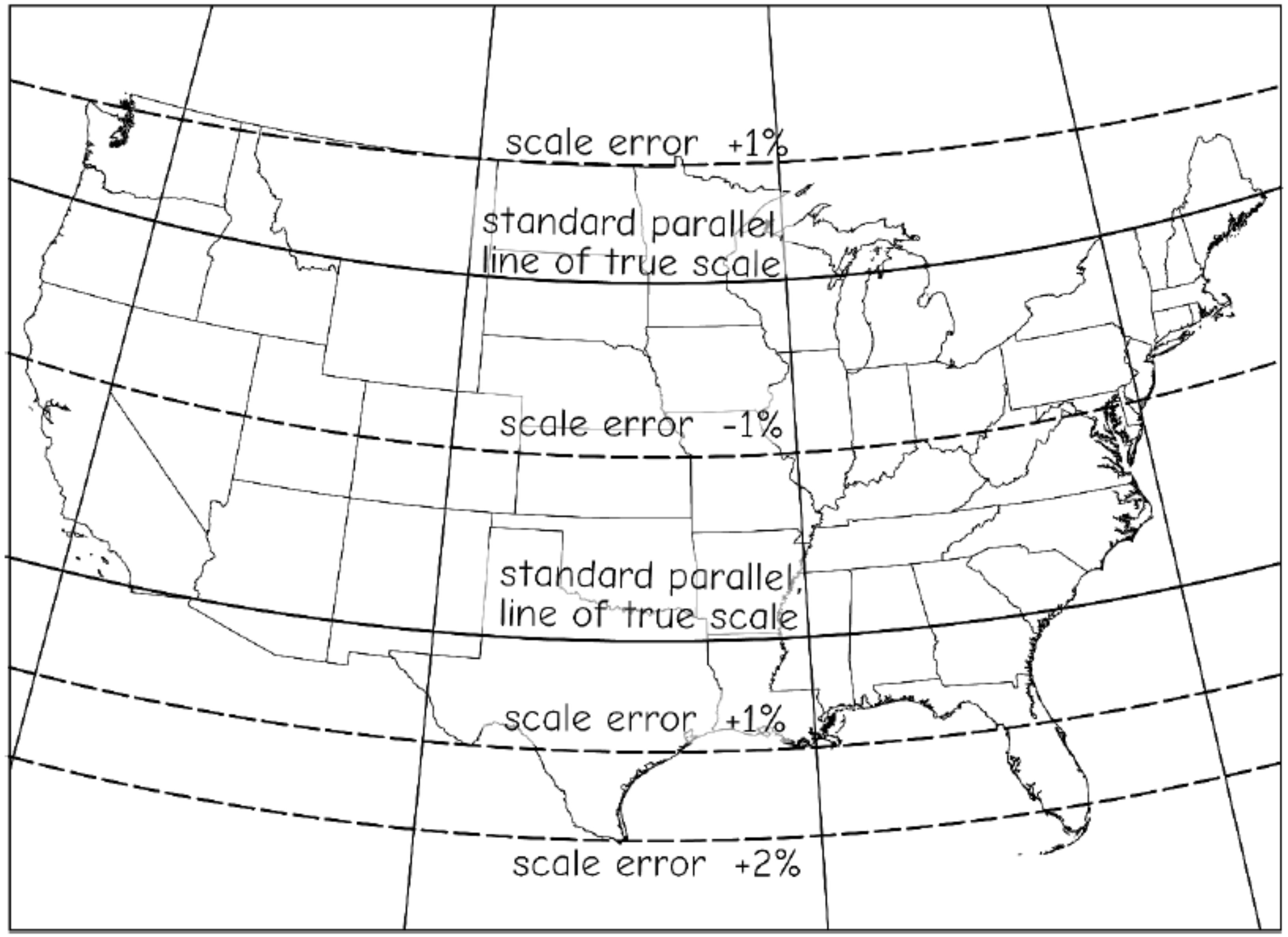
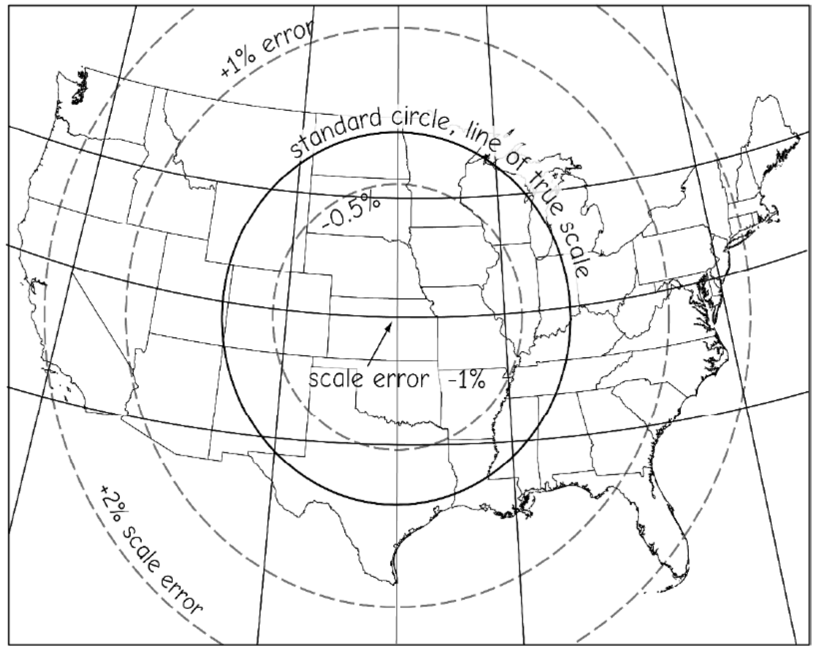


Figure 3-39: Lambert conformal conic (LCC) projection (top) and an illustration of the scale distortion associated with the projection. The LCC is derived from a cone intersecting the ellipsoid along two standard parallels (top left). The "developed" map surface is mathematically unrolled from the cone (top right). Distortion is primarily in the north-south direction, and is illustrated in the developed surfaces by the deformation of the 5-degree diameter geographic circles (top) and by the lines of approximately equal distortion (bottom). Note that there is no scale distortion where the standard parallels intersect the globe, at the lines of true scale (bottom, adapted from Snyder, 1987).



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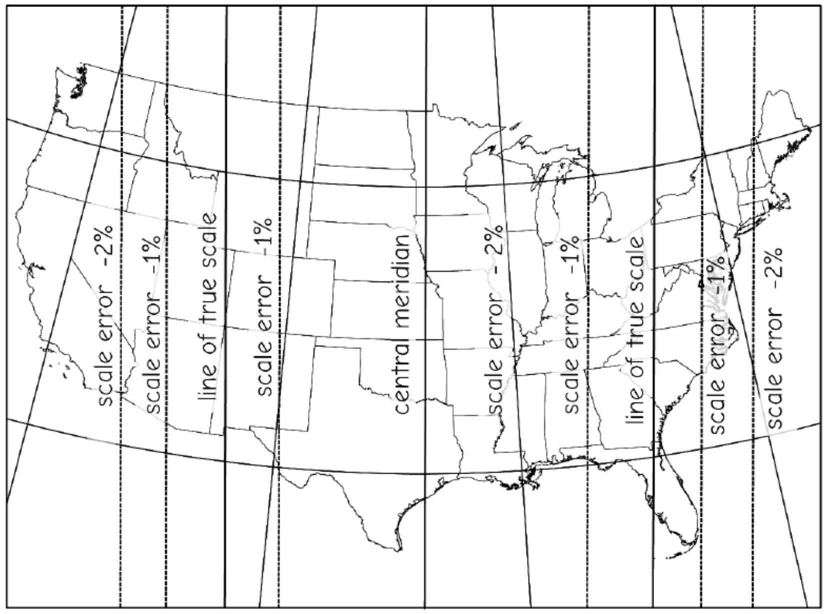

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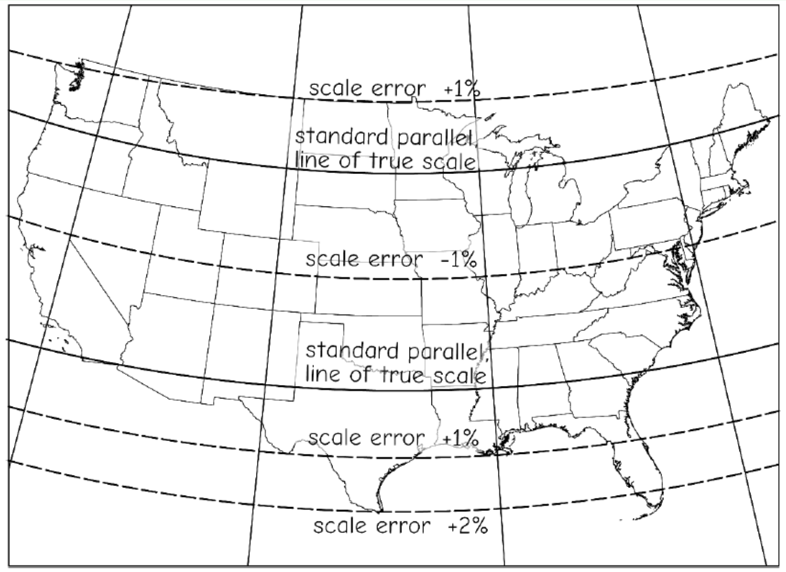

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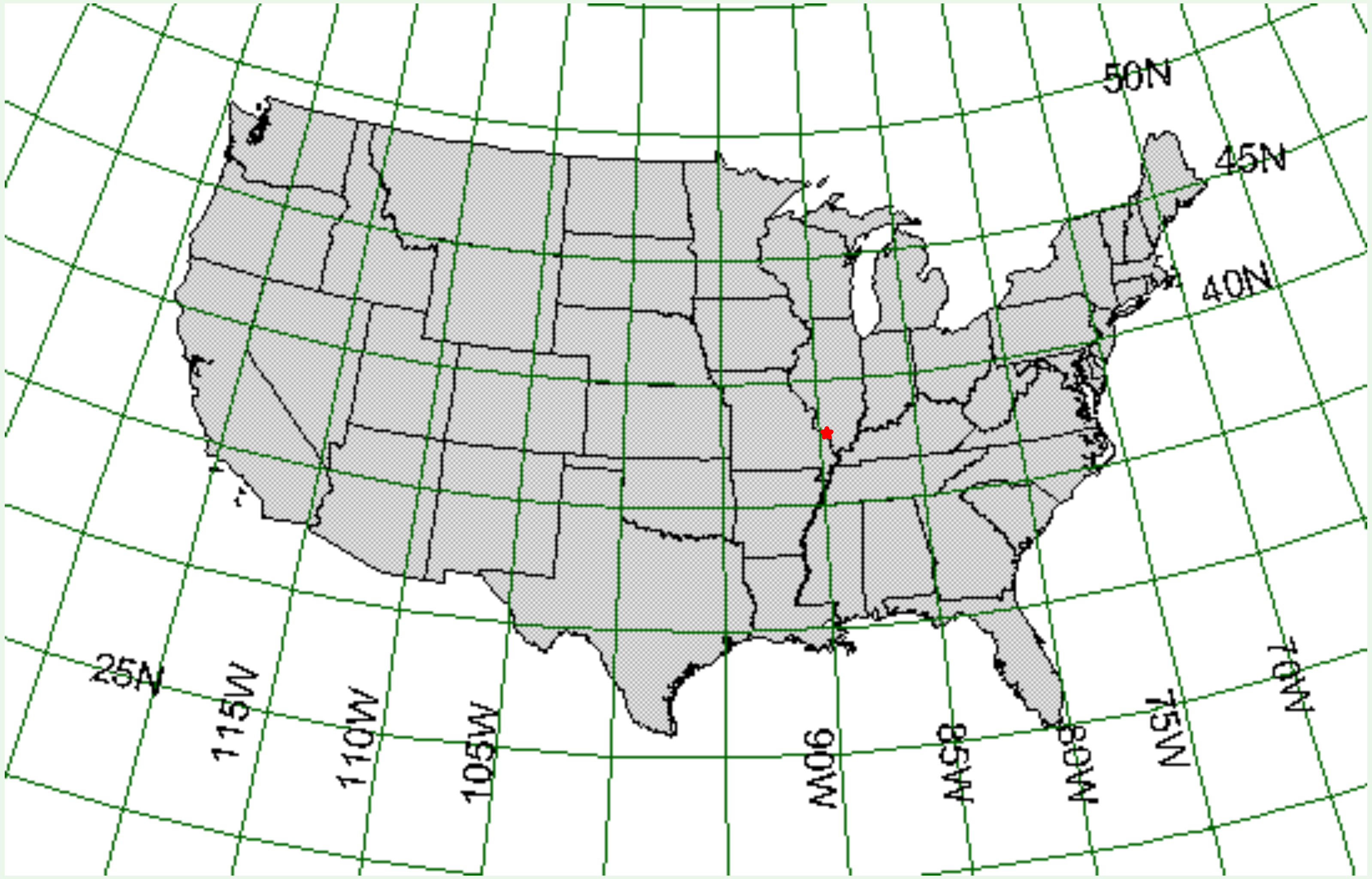
CONTUS USA Projection
(Lambert Conformal Conic Projection)

- Shape is preserved but area is not



Standard parallels:

45°N, 33°N

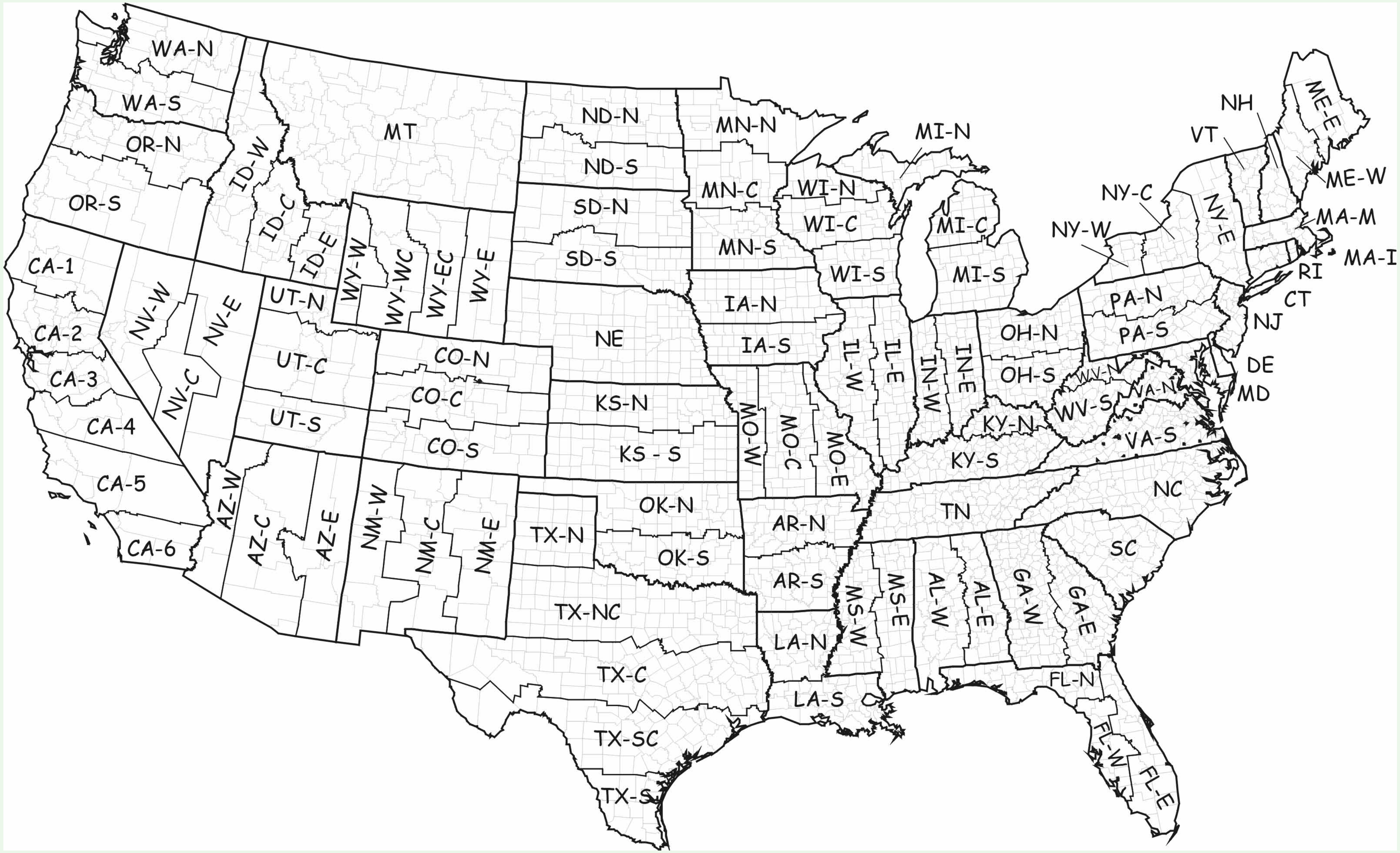
Origin:

96°W, 39°N

State Plane Coordinate Systems (SPCS)

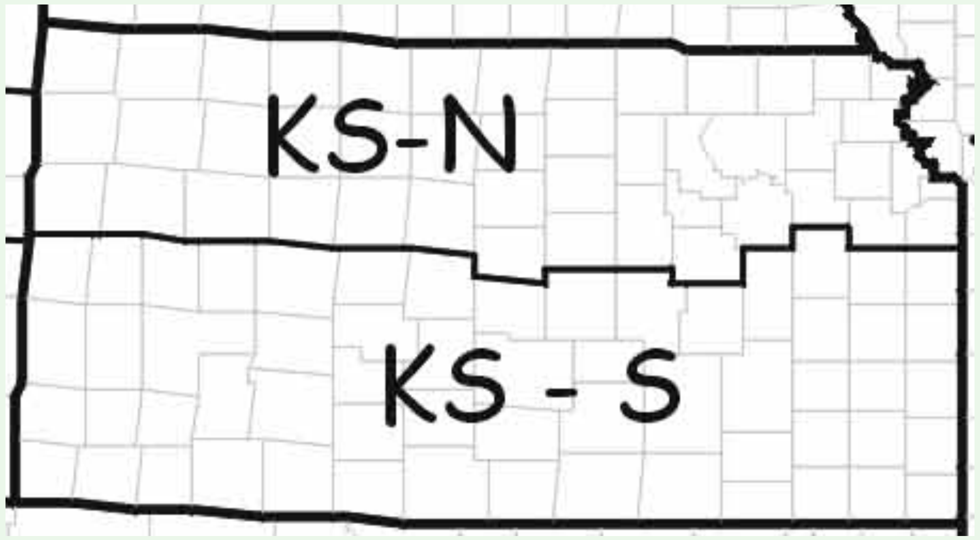
- Developed in the 1930s and based on the North American Datum 1927 (NAD27). Units are in feet.
- SPCS NAD27 has been superseded by North American Datum 1983 (NAD83) with coordinates in meters.
- But data in NAD27 coordinates are still in use.
- SPCS provides high accuracy and uses the same datum across the nation.

Zones and map projections in SPCS



- Lambert conformal conic (LCC)
- Transverse Mercator (TM) (conformal)

Kansas Zones SPCS NAD83



KS-N

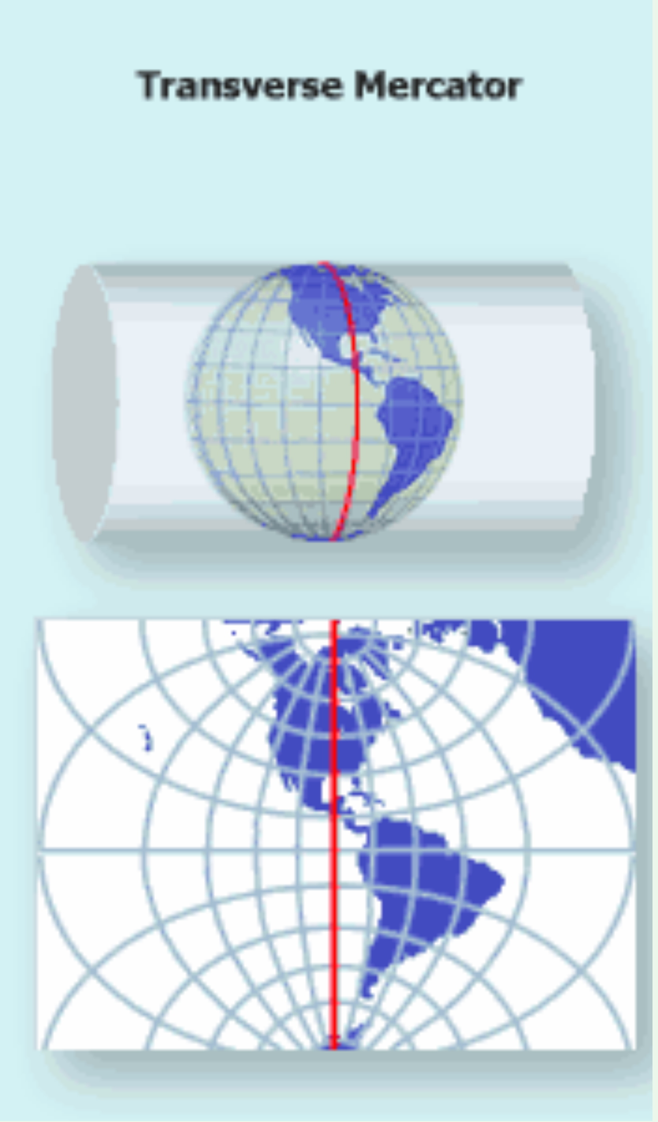
Projection type: Lambert Conformal Conic
Spheroid: GRS80
Central Meridian: -98
Reference Latitude: 38.333333
1st Standard Parallel: 38.716667
2nd Standard Parallel: 39.783333
False Easting: 400,000
False Northing: 0

KS-S

Projection type: Lambert Conformal Conic
Spheroid: GRS80
Central Meridian: -98.5
Reference Latitude: 36.666667
1st Standard Parallel: 37.266667
2nd Standard Parallel: 38.566667
False Easting: 400,000
False Northing: 0

Universal Transverse Mercator (UTM) Projection

- A systematic map projection
  - Covering the entire world
  - Used by USGS topographic maps since 1950s
- A **conformal** projection using a cylindrical developable surface
  - Area is distorted but not very serious within a zone
  - Secant to the spheroid



UTM Zones

- Each zone has 6°, 60 zones around world
  - Further divided into south and north zones (1N, 1S, …)
- First zone is 180°W - 174°W, central meridian is 177°W

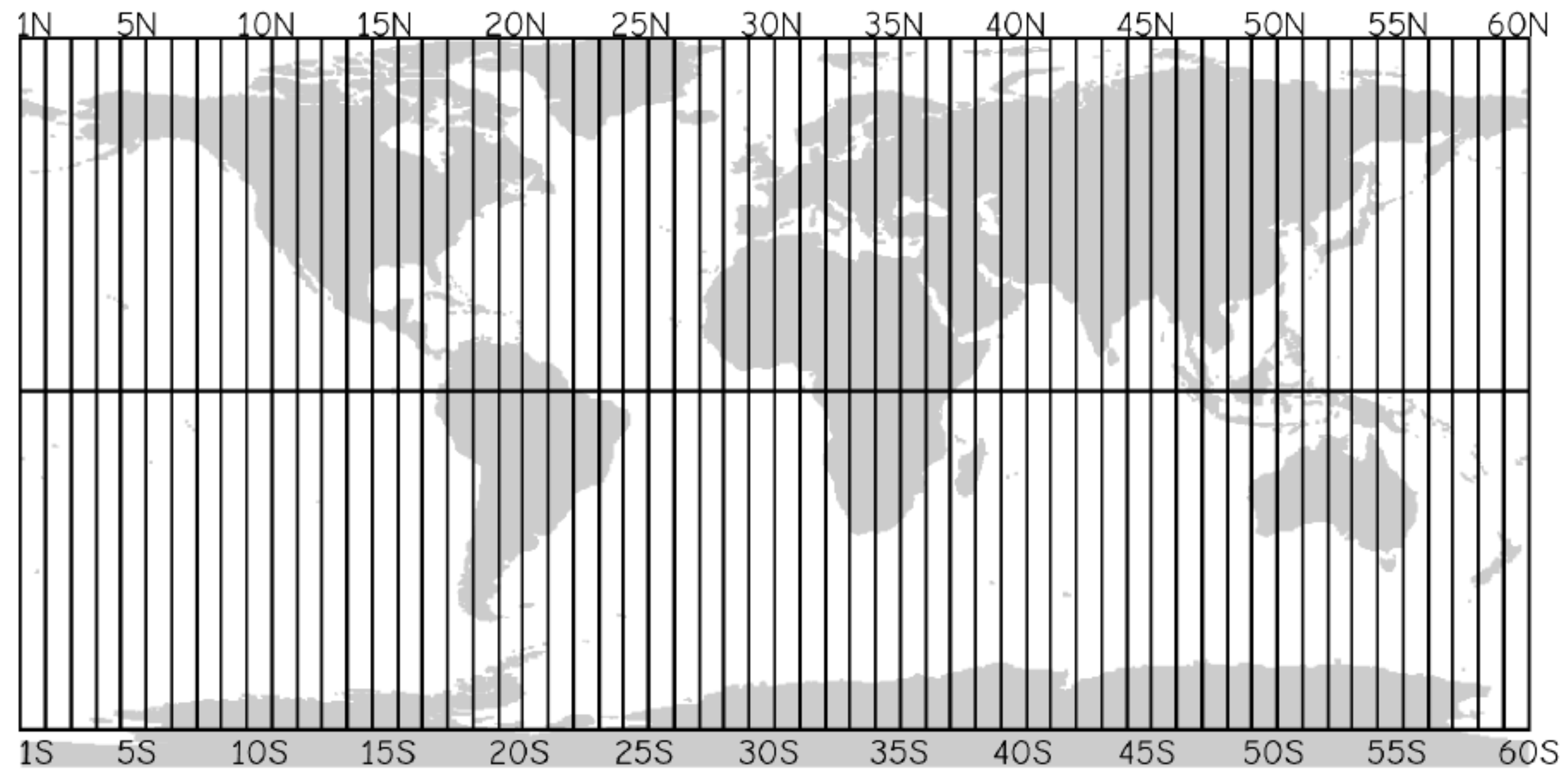
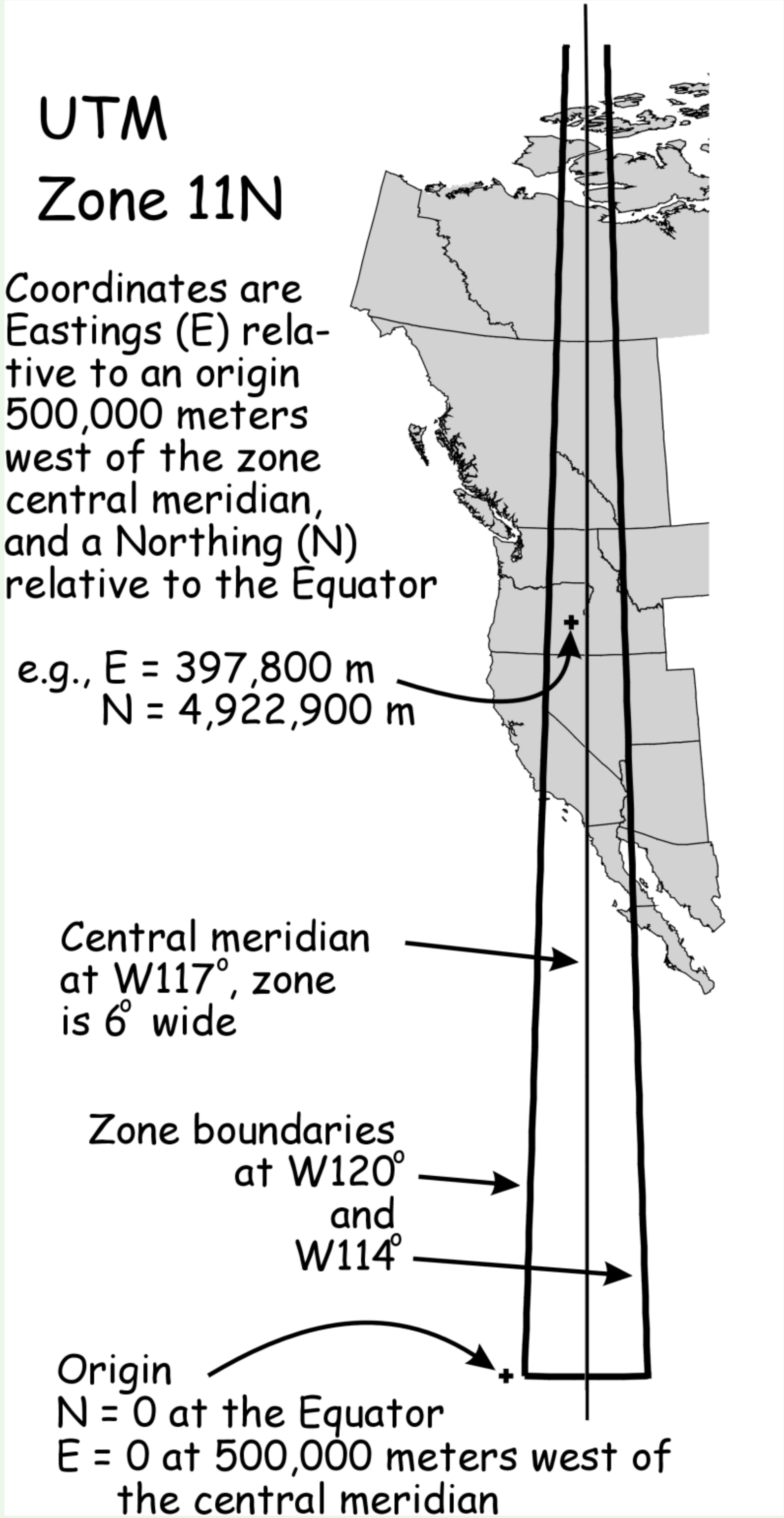


Figure 3-44: UTM zone boundaries and zone designators. Zones are six degrees wide and numbered from 1 to 60 from the International Date Line, 180°W. Zones are also identified by their position north and south of the Equator, e.g., Zone 7 North, Zone 16 South.

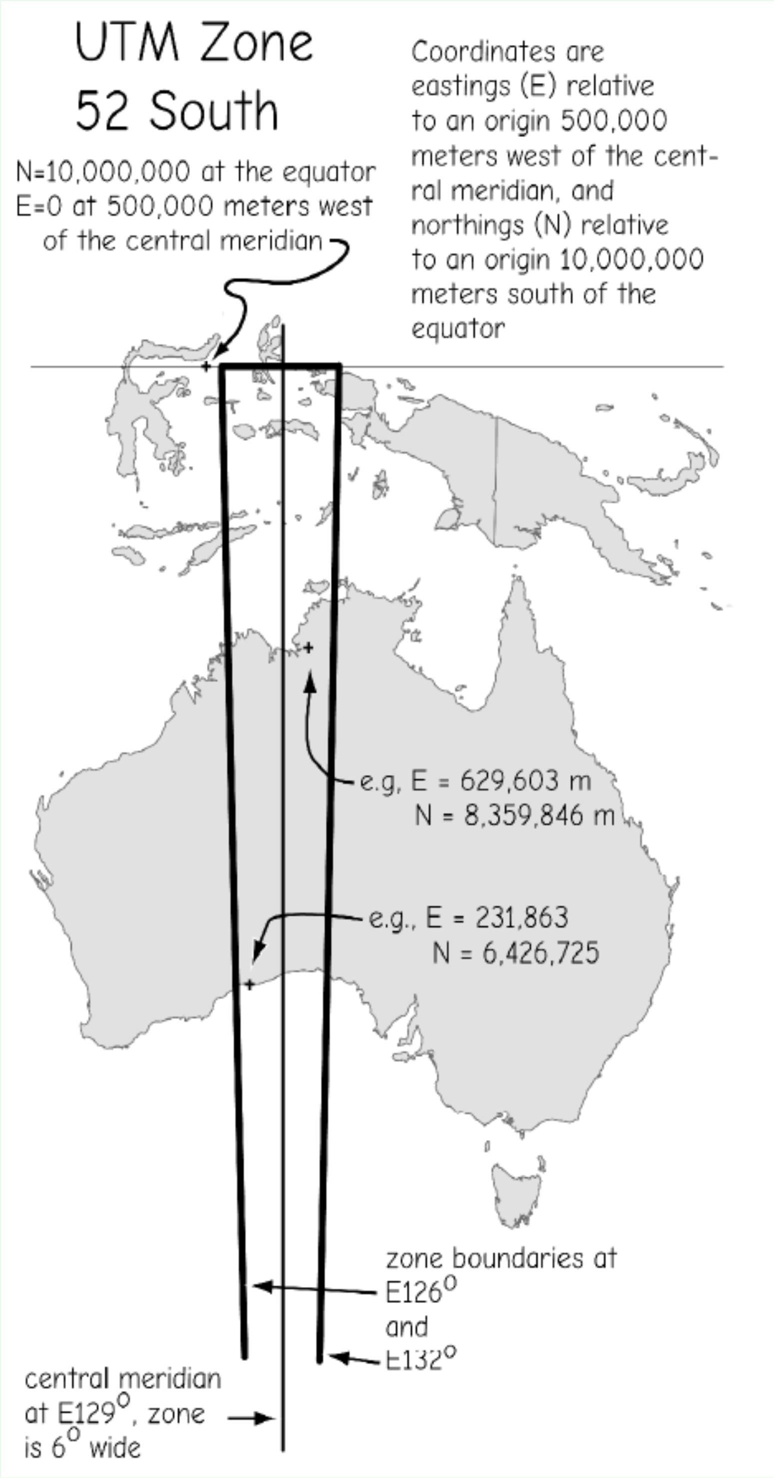
UTM North Zone Details

- Each Zone is 6 degrees wide (84ºN to 80ºS)
- Origin at the Equator, 500,000 m west of the zone's central meridian
- Coordinates discontinuous across zone boundaries

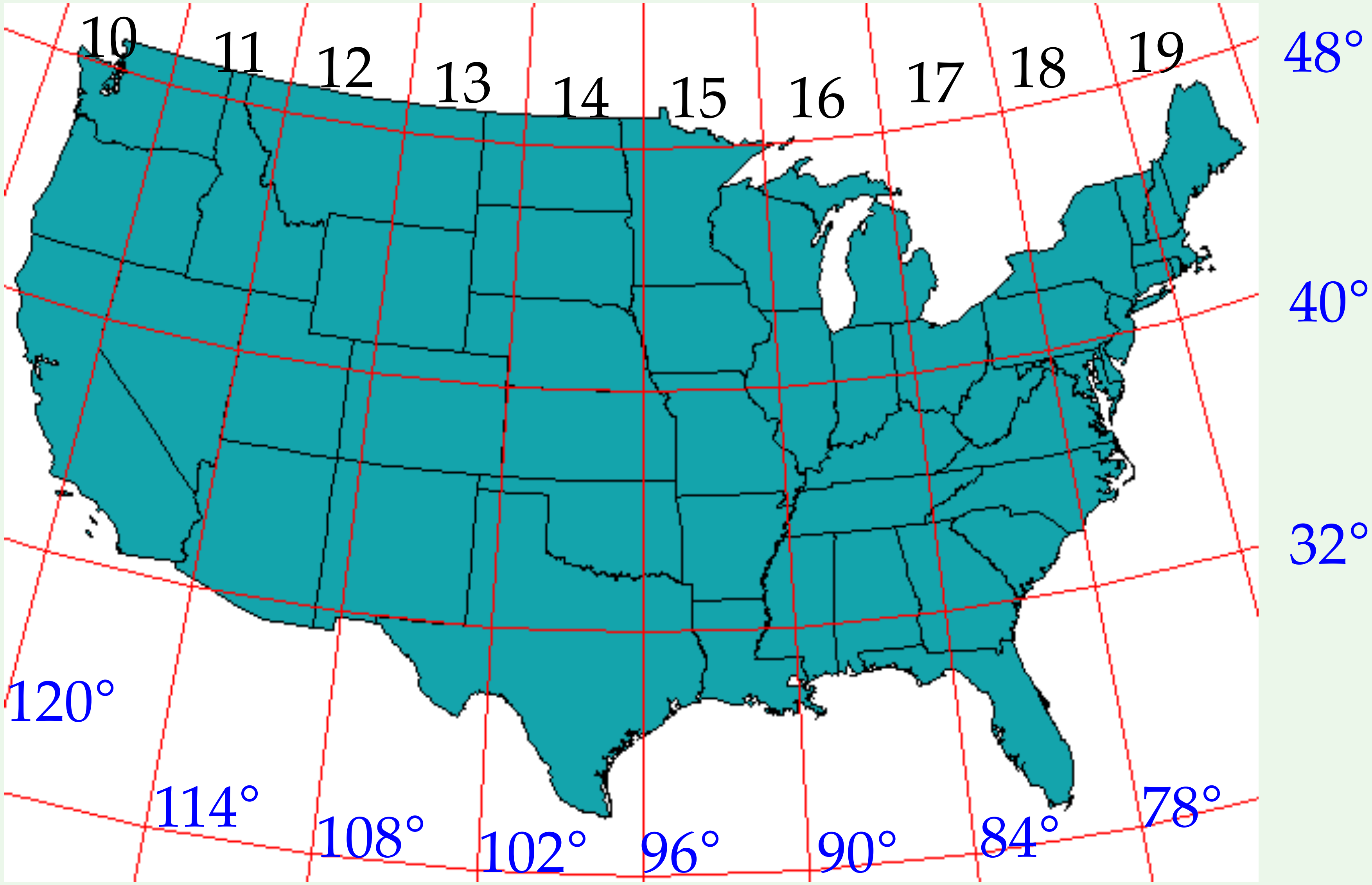


UTM South Zone Details

Origin at 500,000 m west of the zone's central meridian and 10,000,000 m south of equator



UTM Zones Covering Conterminous USA



Projected Coordinate Systems

A projected coordinate system consists of :

a linear unit of measure (usually in meters or feet),

a map projection (the specific parameters used in the map projection),

a geographic coordinate system

Projected Coordinate System
Unit of Measure
Map projection (parameters)
Geographic Coordinate System

An Example of Projected Coordinate Systems

[Name] North_Carolina SPCS NAD 83

[Unit of Measure] Meter

[GCS] GCS_North American_1983

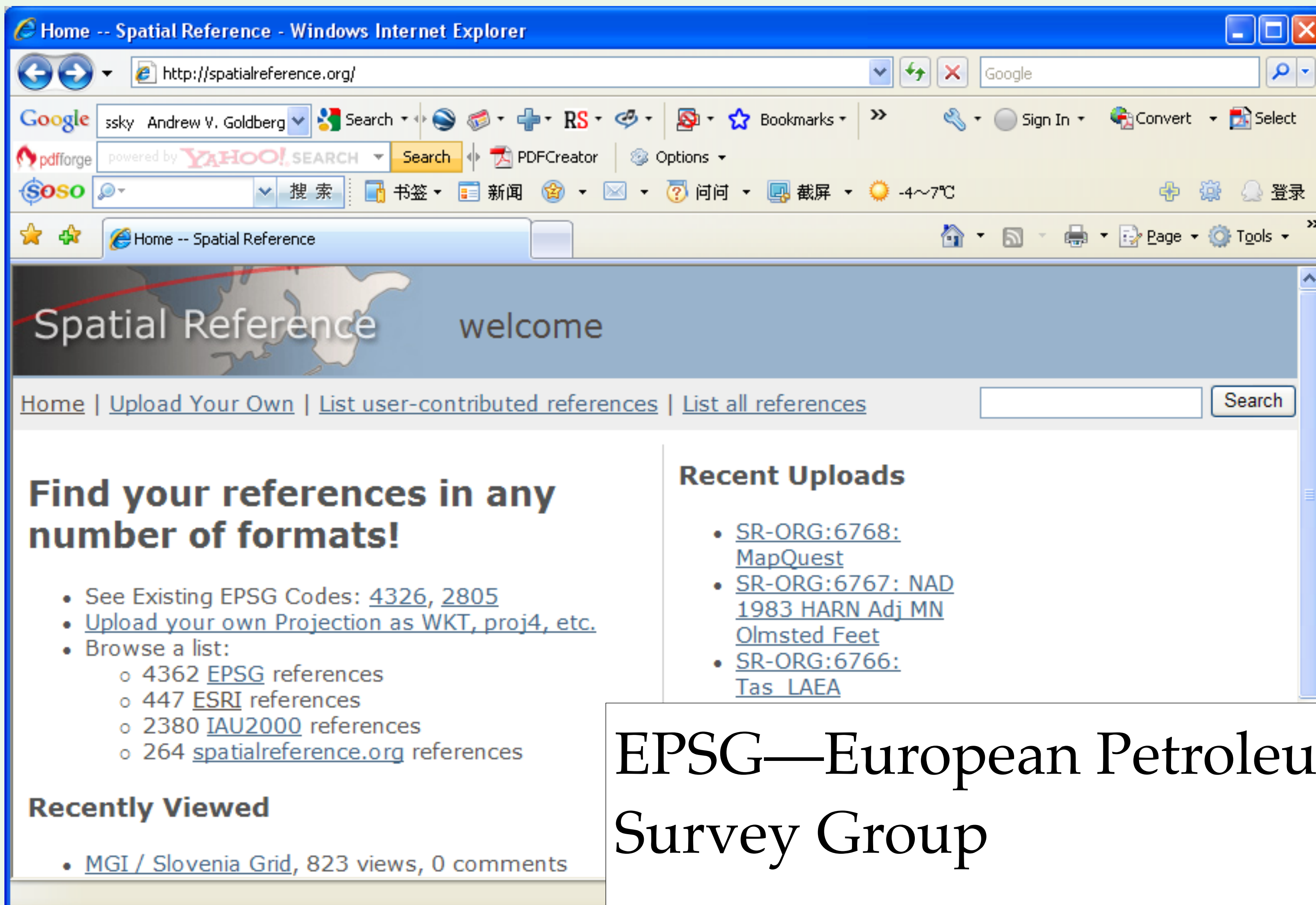
[Map Projection] Lambert Conformal Conic

[Central Meridian] –79 [Reference Parallel] 33.75°

[Standard Parallel 1] 34.33° [Standard Parallel 2] 36.17°

[False Easting] 609601.22 [False Northing] 0

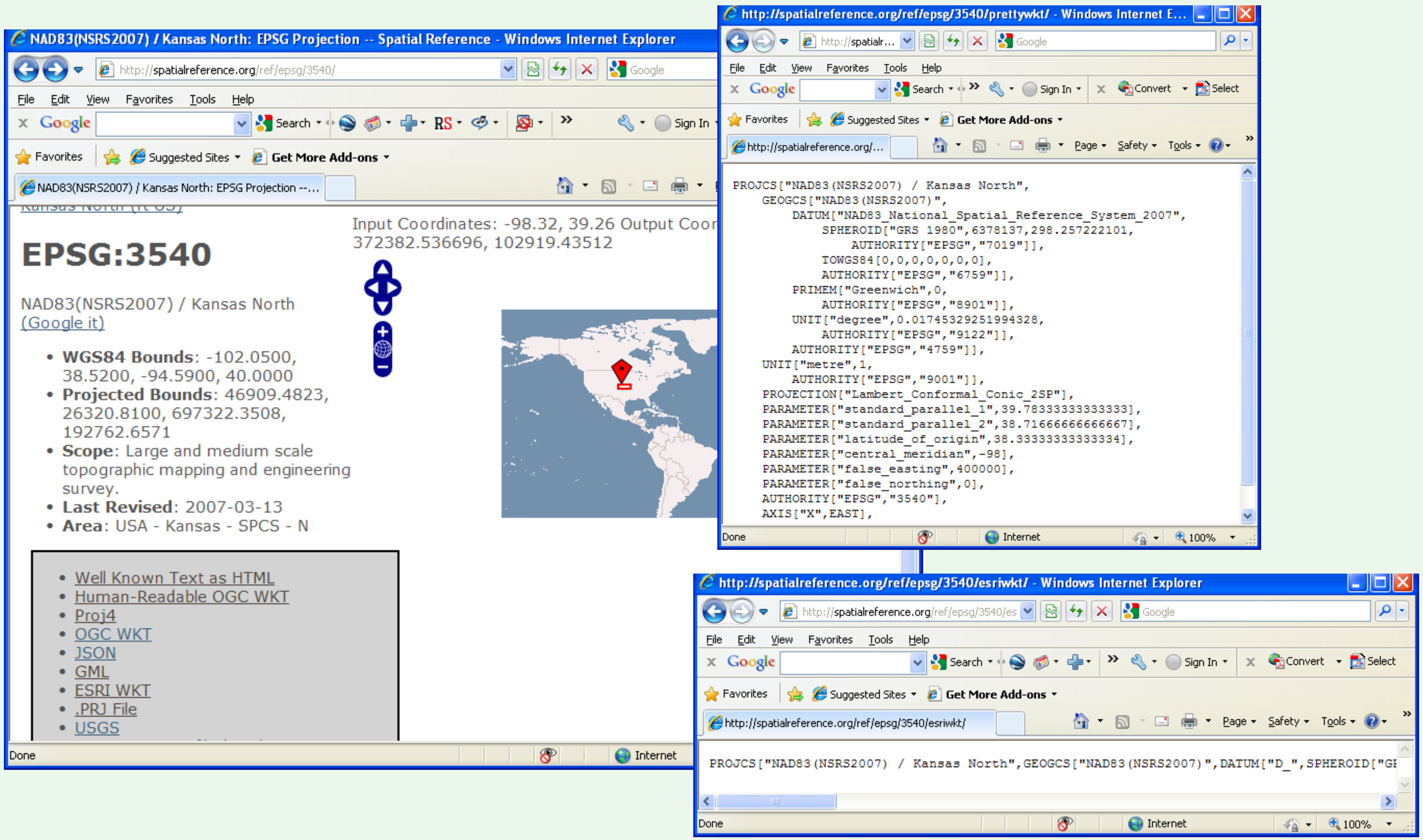
Coordinate (Spatial Reference) Systems in Different Organizations and Formats



EPSG—European Petroleum Survey Group

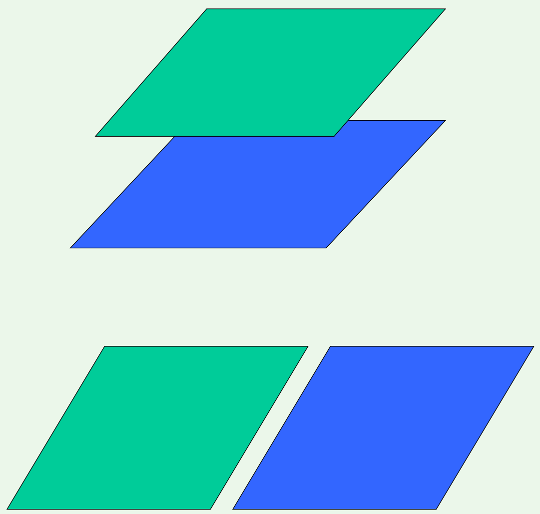
IAU—International Astronomy Union

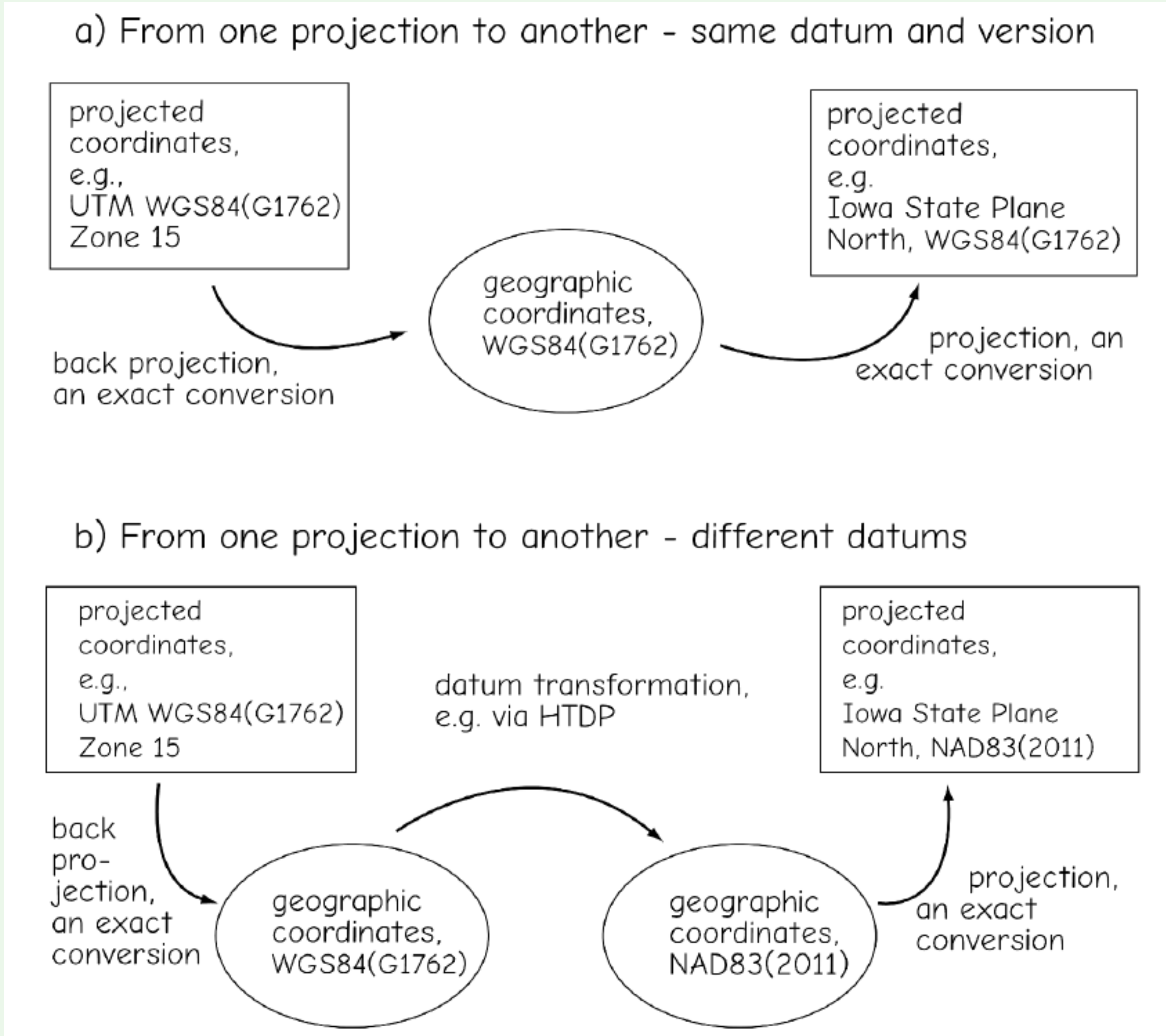
Coordinate (Spatial Reference) Systems in Different Formats



GIS Coordinate System Conversions

- Combining data from different sources for display and analysis.
  - Vertically (overlay)
  - Horizontally (appending)
- Cases that need conversions
  - GCS(A) -- GCS(B)
    - Different datum
  - PCS(A) – PCS(B)
    - Different map projection
    - Same or different datum
  - GCS(A) –PCS(B)
    - projection or unprojection
    - Same or different datum




a) From one projection to another - same datum and version
projected coordinates, e.g., UTM WGS84(G1762) Zone 15
back projection, an exact conversion
geographic coordinates, WGS84(G1762)
projection, an exact conversion
projected coordinates, e.g. Iowa State Plane North, WGS84(G1762)
b) From one projection to another - different datums
projected coordinates, e.g., UTM WGS84(G1762) Zone 15
back pro- jection, an exact conversion
geographic coordinates, WGS84(G1762)
datum transformation, e.g. via HTDP
geographic coordinates, NAD83(2011)
projection, an exact conversion
projected coordinates, e.g. Iowa State Plane North, NAD83(2011)

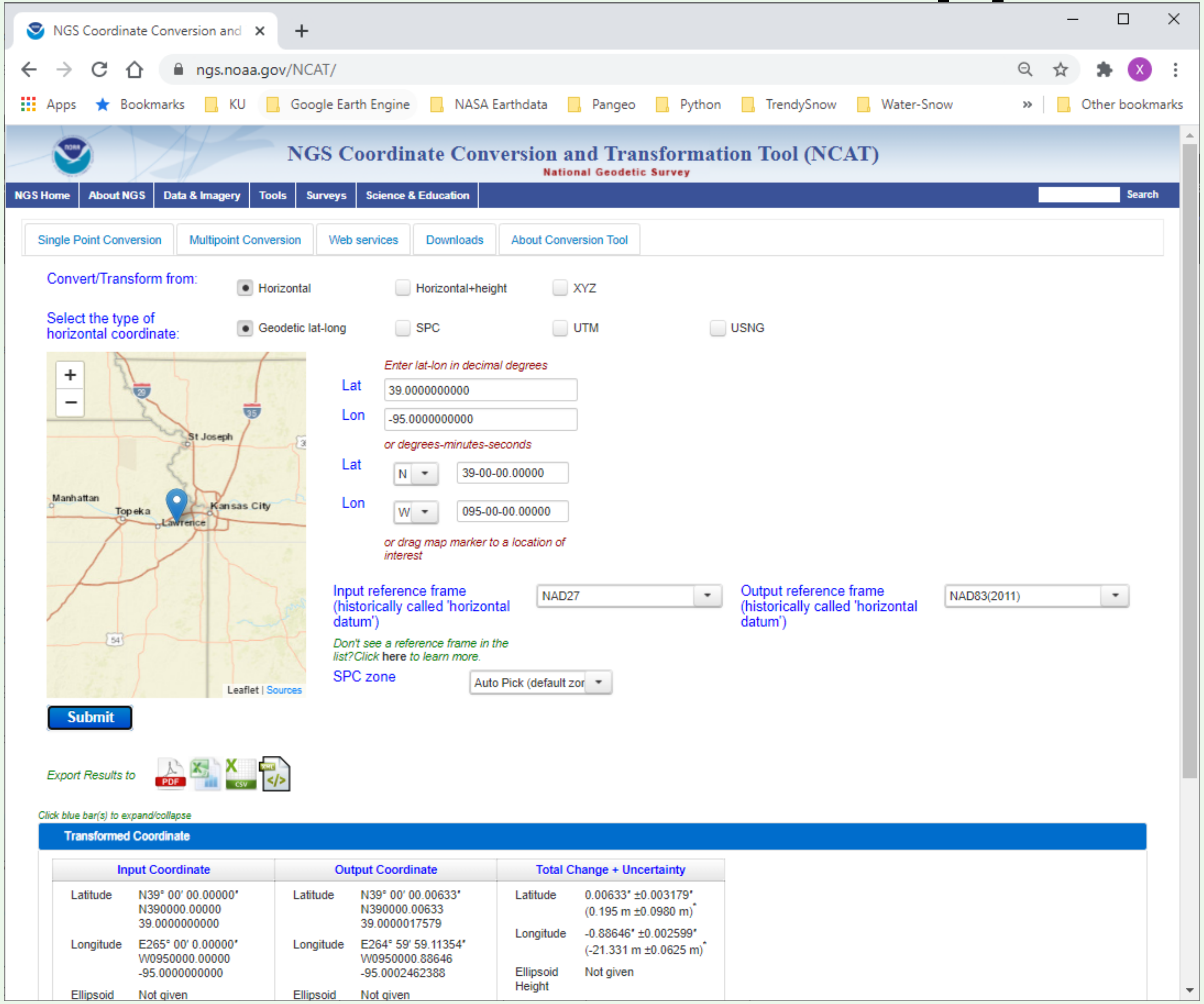
Datum Transformation

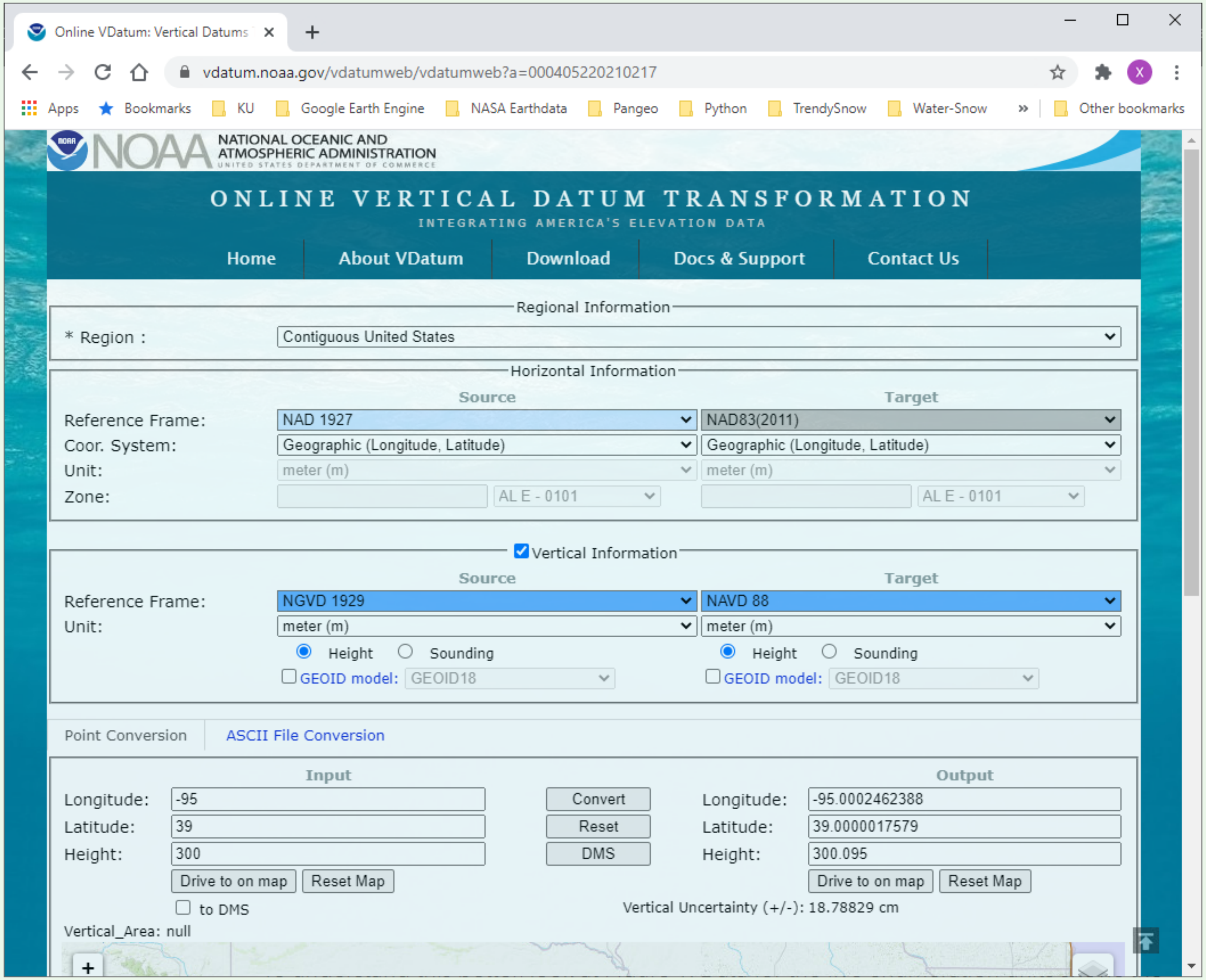
- Horizontal datum transformation methods
  - Interpolation (based on a grid of datum shift between two datums)
  - Mathematical models (3-parameter and 7-parameter)
- Interpolation methods are region/country based
  - USA
  - Canada: NTv1 and NT v2
  - Australia and New Zealand
- USA interpolation-based method
  - The best to convert between NAD 1927 and NAD 1983
  - The National Geodetic Survey (NGS) maintains the datum shift files
  - ArcGIS uses the files in its datum (NAD27 to NAD83) conversion function
  - Limited by the availability of grids
    - Can only transform between NAD27 and NAD83
- Vertical datum transformation
  - Interpolation based

Datum Transformation Tools

- Developed and maintained by the National Geodetic Survey (NGS)
- NGS Coordinate Conversion and Transformation Tool (NCAT)
  - Convert between different coordinate systems
    - conversion between lat/long/height, SPC, UTM
  - Transform between different datums
  - Uses NADCON to perform three-dimensional (latitude, longitude, ellipsoid height) coordinate transformations and VERTCON to perform orthometric height transformations
  - Web application
  - Supersede NADCON and VERTCON
- VDatum
  - More choice on vertical datums
  - Especially useful for costal regions
  - Web or desktop applications
- Horizontal Time-Dependent Positioning (HTDP)
  - Estimate horizontal displacement/velocity between two dates

NCAT and Vdatum Web Apps




Online VDatum: Vertical Datums
vdatum.noaa.gov/vdatumweb/vdatumweb?a=000405220210217
Apps Bookmarks KU Google Earth Engine NASA Earthdata Pangeo Python TrendySnow Water-Snow Other bookmarks
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ONLINE VERTICAL DATUM TRANSFORMATION
INTEGRATING AMERICA'S ELEVATION DATA
Home
About VDatum
Download
Docs & Support
Contact Us
Regional Information
* Region :
Contiguous United States
Horizontal Information
Source
Target
Reference Frame:
NAD 1927
NAD83(2011)
Coor. System:
Geographic (Longitude, Latitude)
Geographic (Longitude, Latitude)
Unit:
meter (m)
meter (m)
Zone:
AL E - 0101
AL E - 0101
Vertical Information
Source
Target
Reference Frame:
NGVD 1929
NAVD 88
Unit:
meter (m)
meter (m)
Height Sounding
Height Sounding
GEOID model: GEOID18
GEOID model: GEOID18
Point Conversion
ASCII File Conversion
Input
Output
Longitude: -95
Latitude: 39
Height: 300
Convert
Reset
DMS
Longitude: -95.0002462388
Latitude: 39.0000017579
Height: 300.095
Drive to on map
Reset Map
Drive to on map
Reset Map
to DMS
Vertical Uncertainty (+/-): 18.78829 cm
Vertical_Area: null

Coordinate System Conversion in ArcGIS

- Define your coordinate systems before you can convert
- Defining a coordinate system ONLY changes its coordinate system metadata (i.e., the .prj file of a shapefile)
  - Doesn’t change the coordinates
  - Define data’s current coordinate system, then project
- ALWAYS define the coordinate system
  - Good professional practice
  - Help others and yourself

Additional Ways of Specifying Location

- Public land survey system (PLSS)
  - Systematic and hierarchical division of land parcels
- Address
  - Street address, zip code
  - Geocoding—estimate the coordinates of an address
- Linear measurements in transportation
  - Distance measurement along linear features
    - Highways, rivers, …

Public Land Survey System (PLSS)

- Not a coordinate system
- Often used as reference system for describing the locat
- Townships and sect
  - 6-by-6 miles
  - 1-by-1 mile

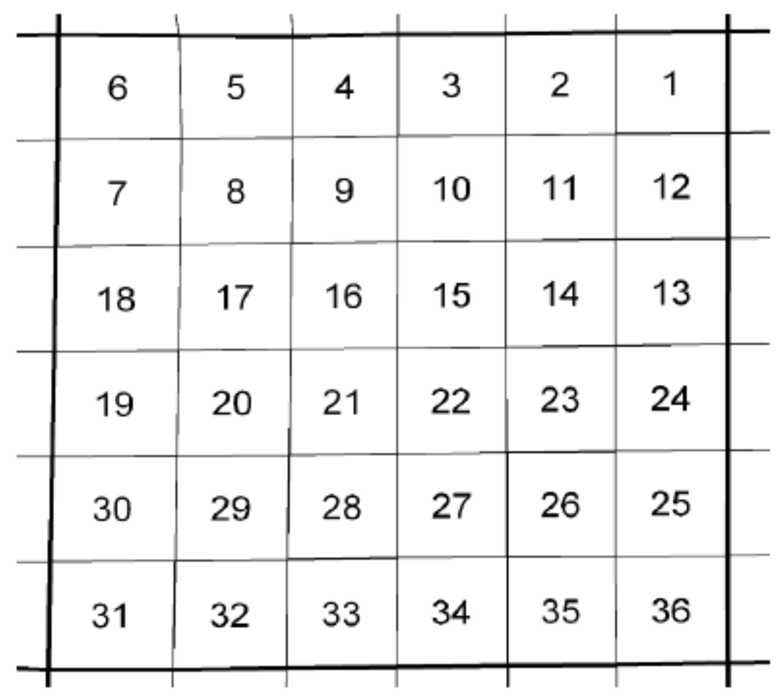
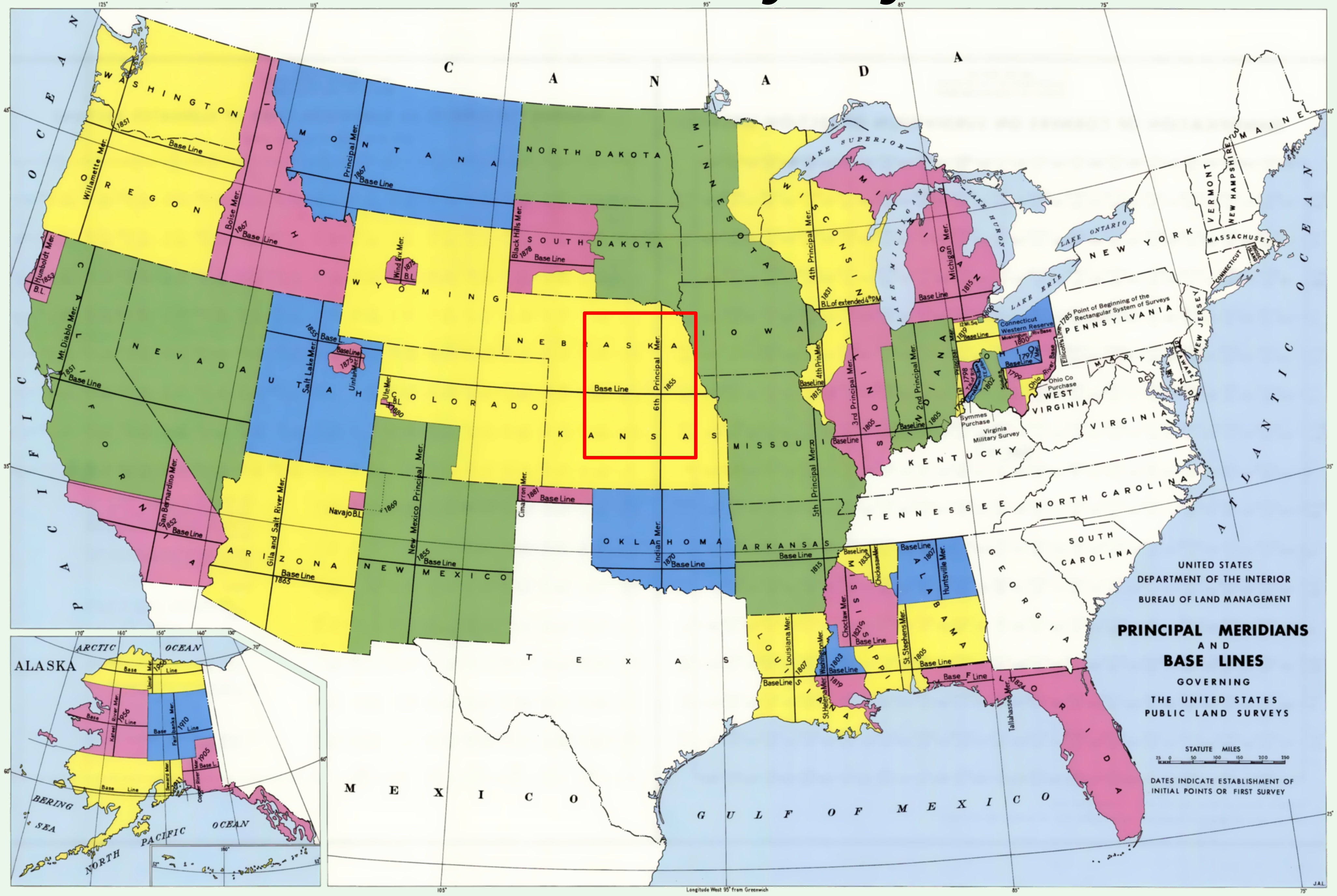


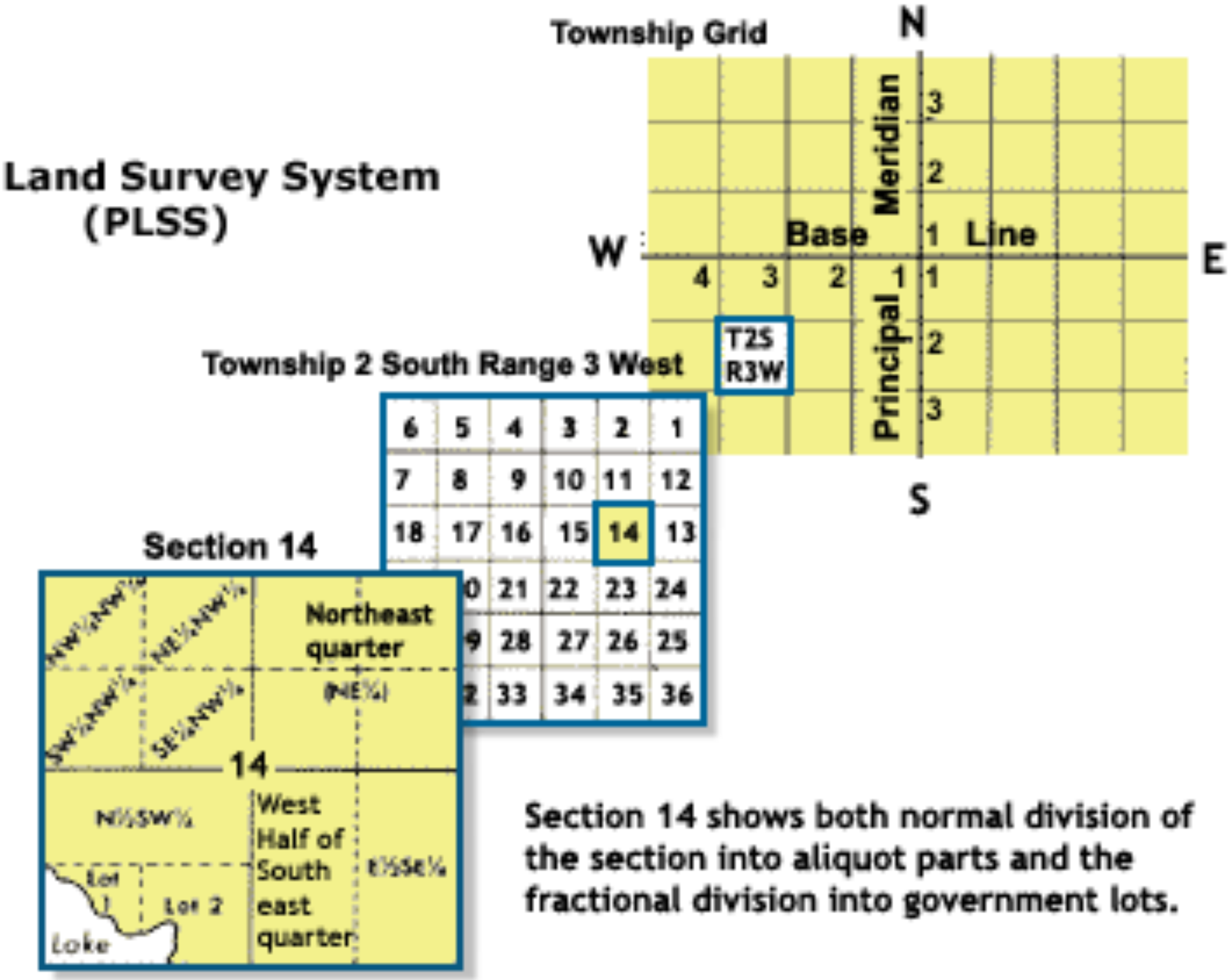
Figure 3-50: Typical layout and section numbering of a PLSS township.

The Public Land Survey System (PLSS)



Several regions and each has its own origin; Not all the states have PLSS

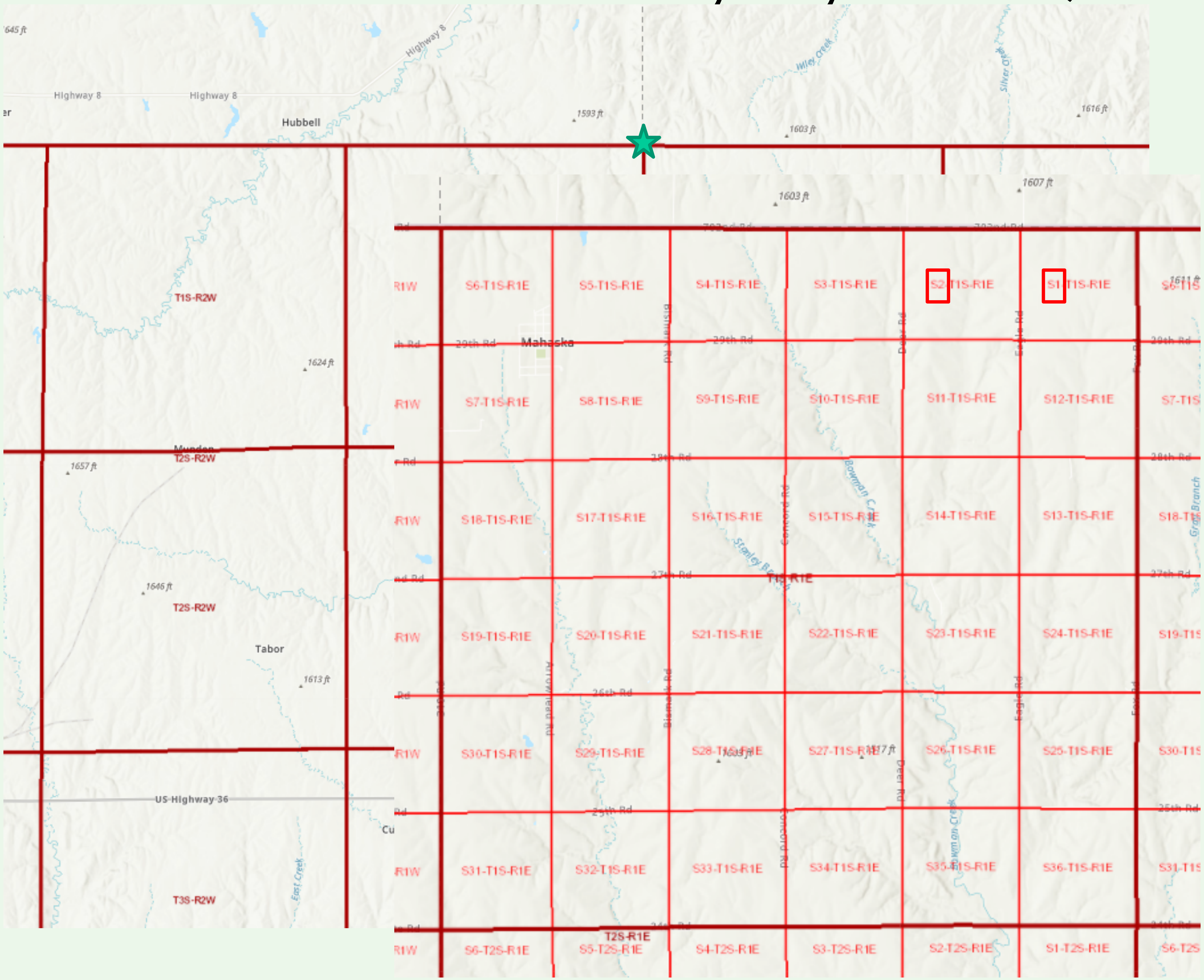
Public Land Survey System (PLSS)



Section 14 shows both normal division of the section into aliquot parts and the fractional division into government lots.

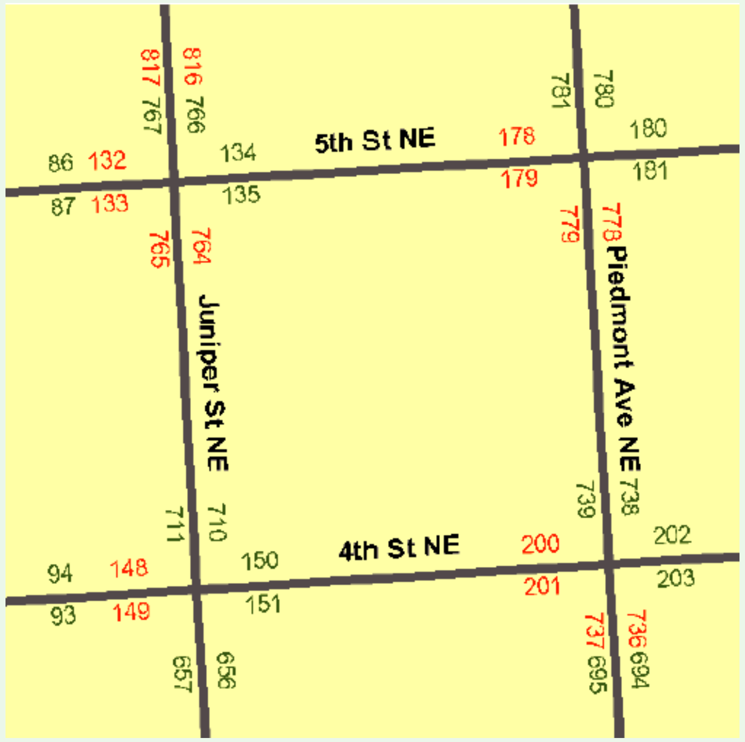

Fresno County
United States
Maps
Imagery ©2014, AMBAG, DigitalGlobe, USDA Farm Service Agency

The Public Land Survey System (PLSS)



Address and Geocoding

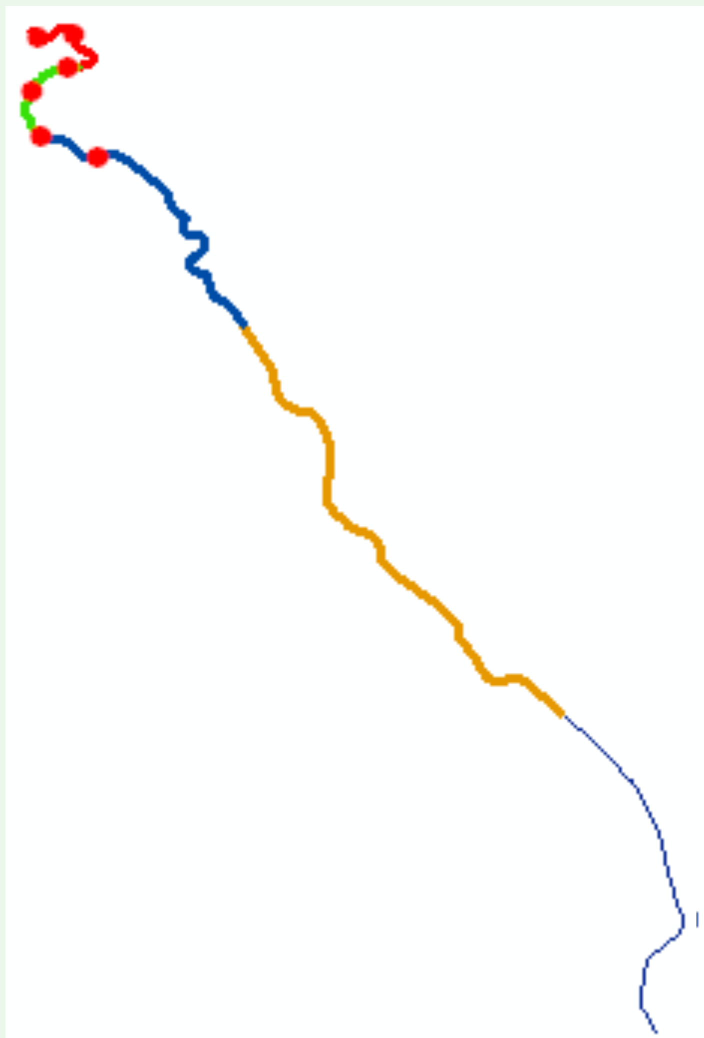
- The process of converting **addresses** to coordinates
  - An address → a point with x and y coordinate
- Useful in business and emergency applications
- Coordinates by interpolation
  - Reference data has both address information and coordinates
  - The location of the matching street is used to estimate the coordinates for an address.
  - May not be accurate
- New technologies
  - Mapped the addresses; reverse geocoding



Linear Reference Systems (LRS) in Transportation

- Events are measured based on the distance along linear features (roads and rivers)
- Two types of events
  - Point events (accidents)
    - Occur at individual locations
    - Record the distance from a reference point on a linear feature
  - Line events (speed limits or pavement types)
    - Occur at certain ranges on a linear feature
    - Record the start and end distance measures
- LRS → coordinates
  - Event table → Points or lines with (x, y) coordinates
  - Line segmentation

LRS → Coordinates



Attributes of accidents

Route	Distance
Blowing Rock Blvd	100.89
Blowing Rock Blvd	500.56
Blowing Rock Blvd	1078.24
Blowing Rock Blvd	1500
Blowing Rock Blvd	2000.24
Blowing Rock Blvd	2568.89

Record: 1 Show: All Sel

Attributes of speedlimits

Route	Speed	FDist	TDist
Blowing Rock Blvd	35	0	1000
Blowing Rock Blvd	45	1000	2000
Blowing Rock Blvd	55	2000	5000
Blowing Rock Blvd	65	5000	10000

Record: 1 Show: All Selected F