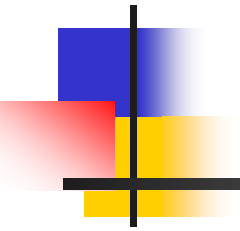


Ellipsoid and Datum, Projection, Coordinate system, and Map Scale



Lectures 4

Sept 14, 2006



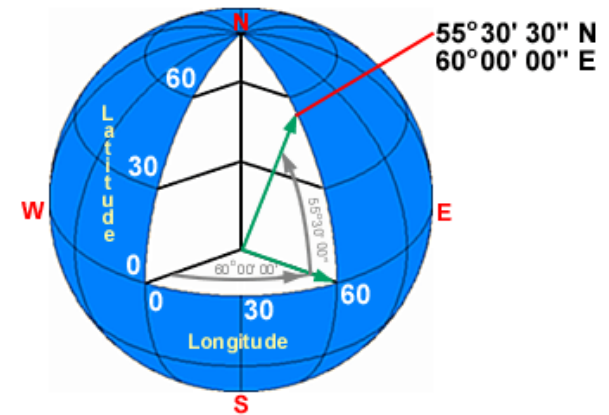
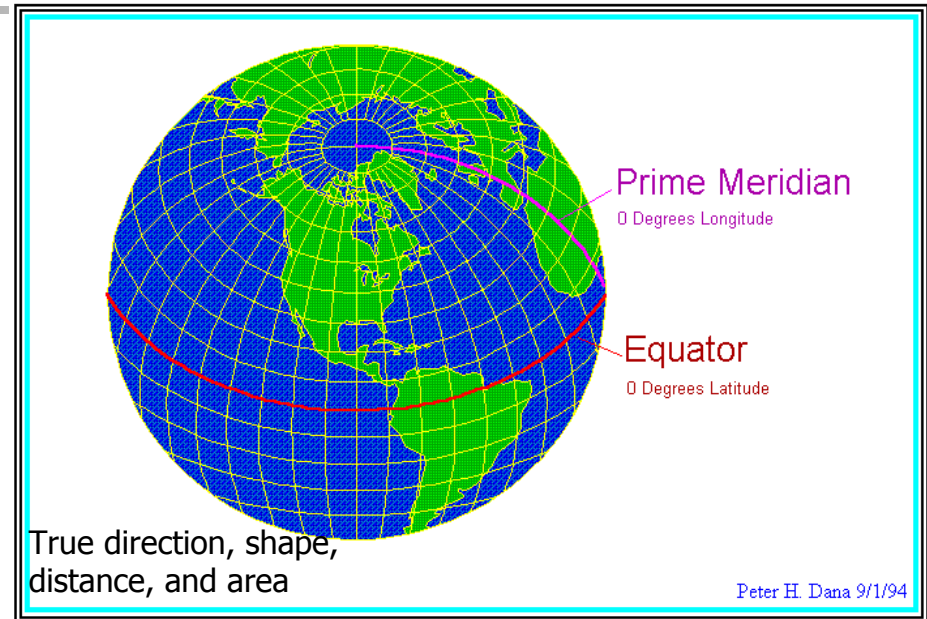
Why we need it?

Earth Shape Models

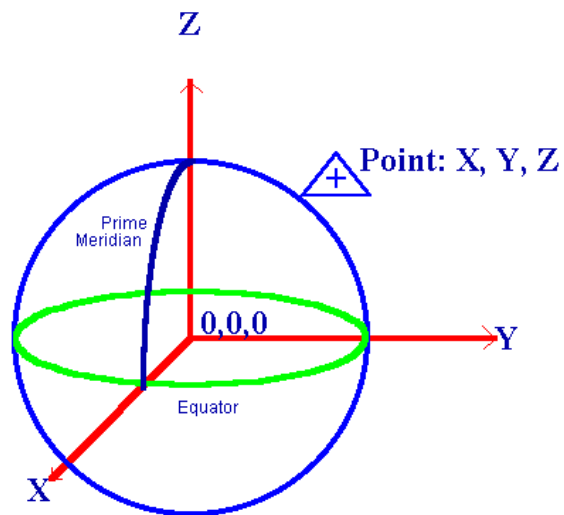
- **Flat earth models** are still used for plane surveying, over distances short enough so that earth curvature is insignificant (less than 10 km).
- **Spherical earth models** (Earth centered model) represent the shape of the earth with a sphere of a specified radius. Spherical earth models are often used for short range navigation (VOR-DME) and for global distance approximations. Spherical models fail to model the actual shape of the earth.
- **Ellipsoidal earth models** are required for accurate range and bearing calculations over long distances. Ellipsoidal models define an ellipsoid with an **equatorial** radius and a **polar** radius. The best of these models can represent the shape of the earth over the smoothed, averaged sea-surface to within about one-hundred meters.
- Although the earth is an ellipsoid, its major and minor axes do not vary greatly. In fact, its shape is so close to a sphere that it is often called a **spheroid** rather than an **ellipsoid**. But sometimes, the spheroid confused people. SO I often call ellipsoid.

Globe

- Spherical Earth's surface
 - radius 6371 km
- **Meridians** (lines of **longitude**)
 - passing through Greenwich, England as prime meridian or 0° longitude.
- **Parallels** (lines of **latitude**)
 - using equator as 0° latitude.
- degrees-minutes-seconds (**DMS**),
- decimal degrees (**DD**)

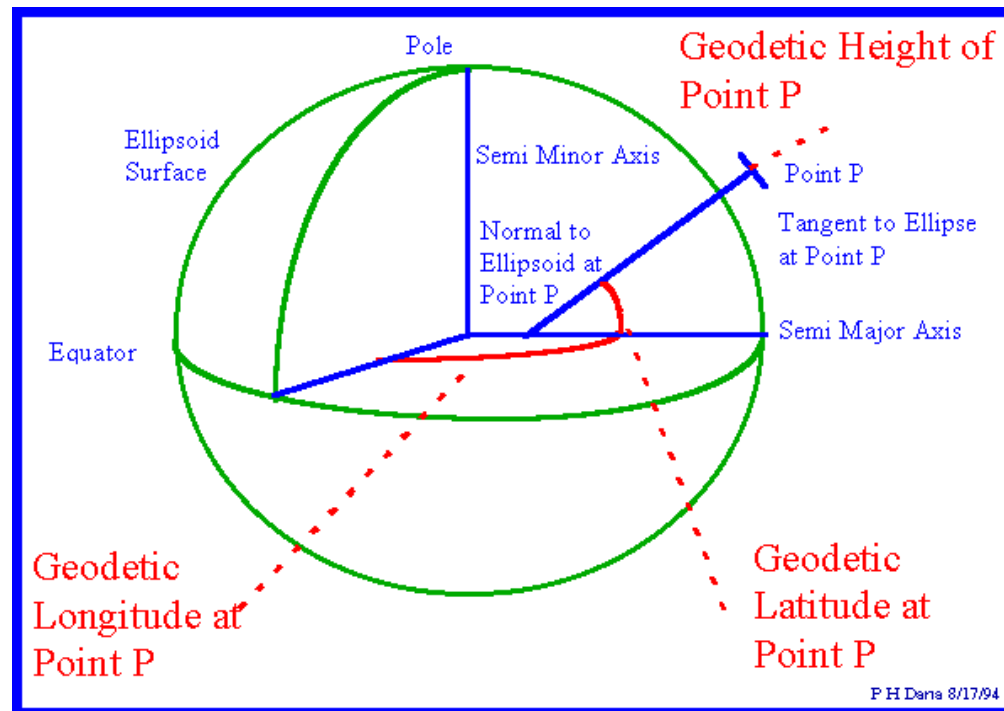


Spherical and Ellipsoidal Earth



Earth Centered, Earth Fixed X, Y, Z

P H Dana 8/17/94

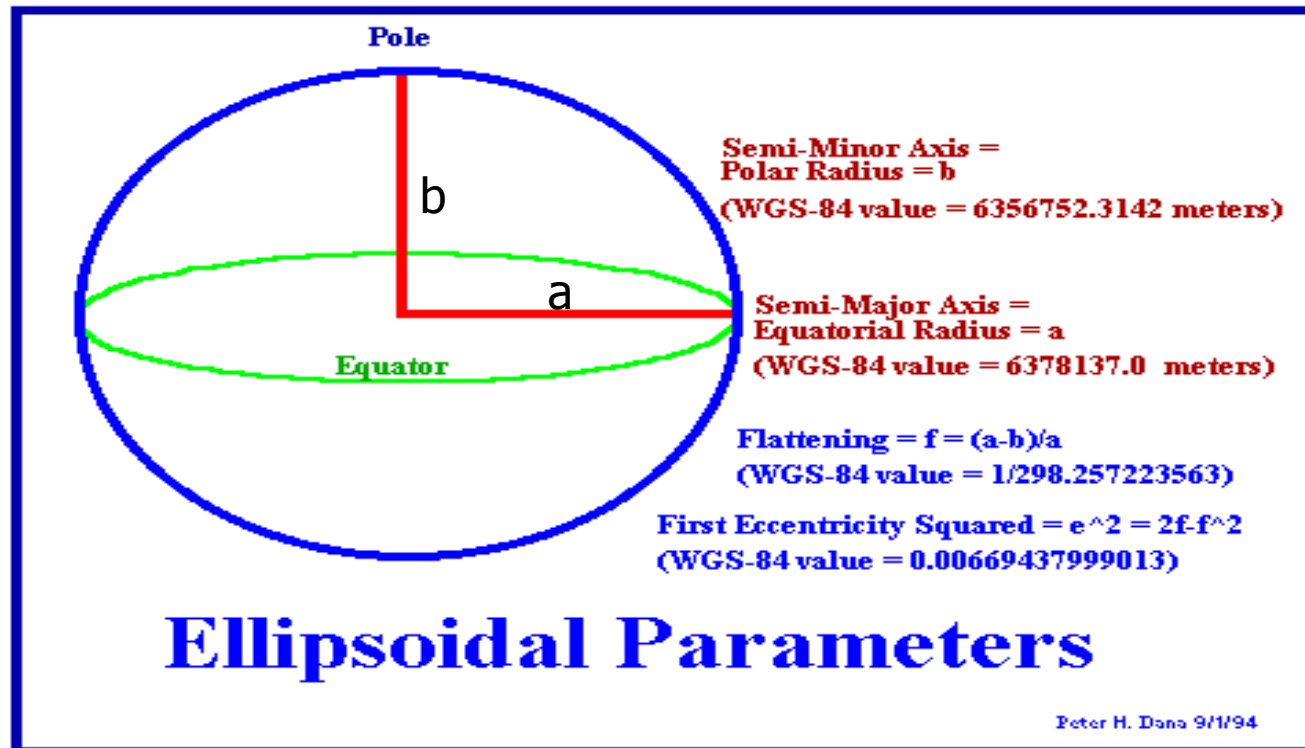


Geodetic Lat/Lon/Height

P H Dana 8/17/94

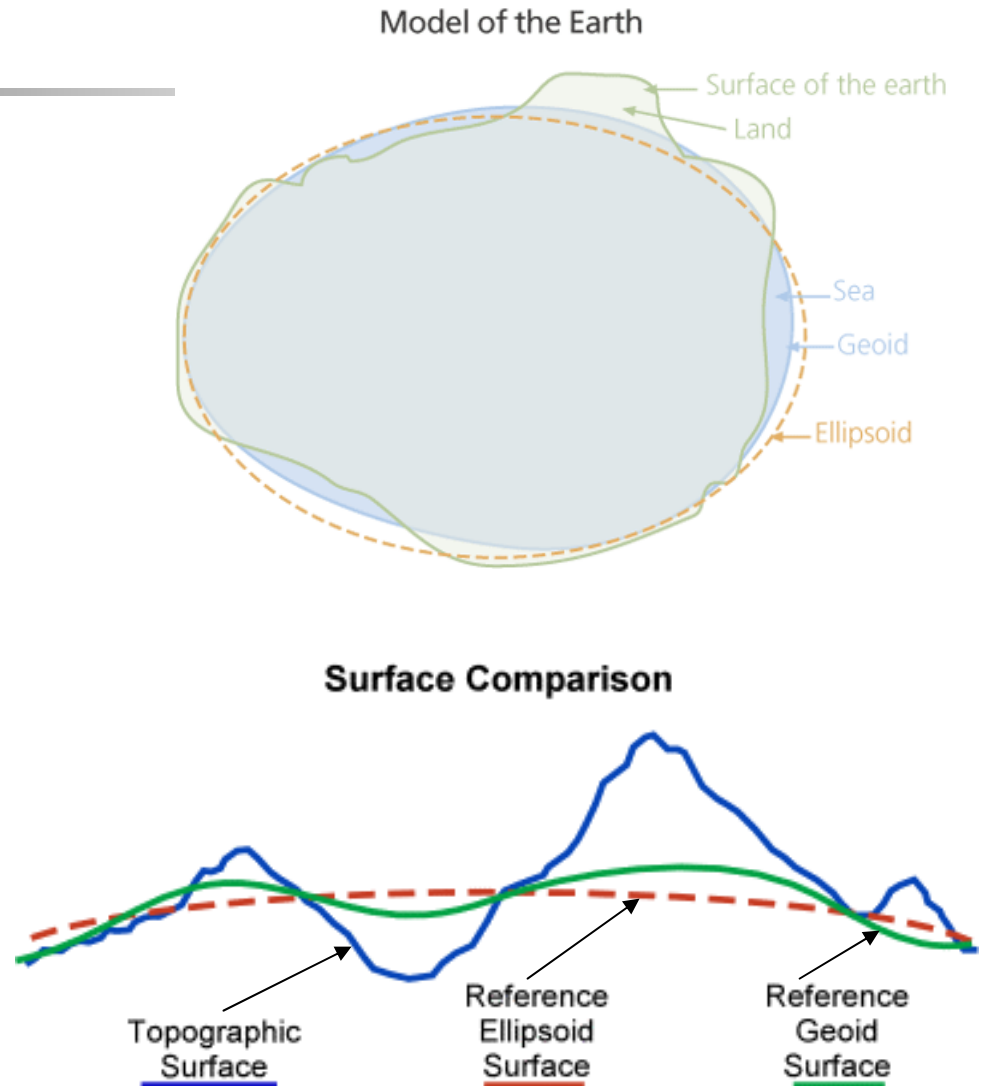
Earth Centered X/Y/Z

Ellipsoidal Parameters

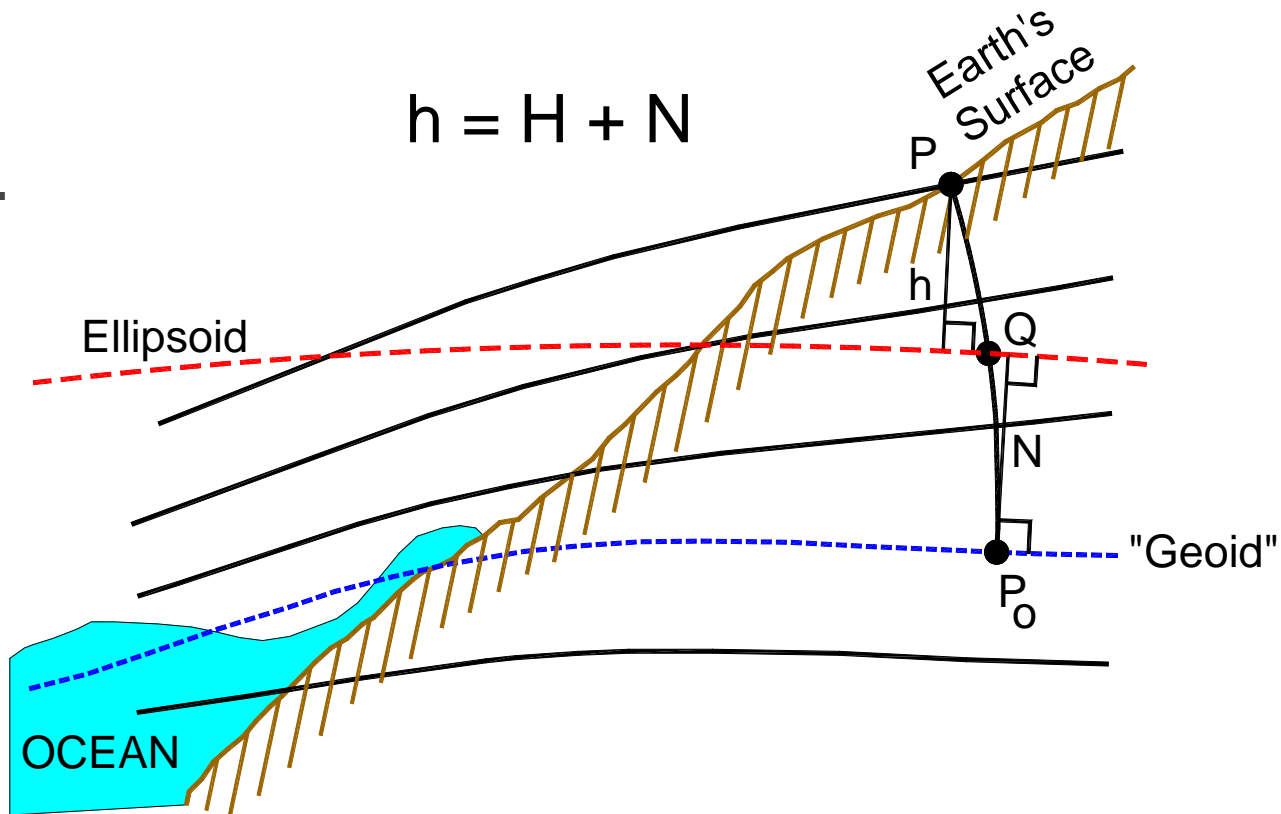


Earth Surface: Ellipsoid, Geoid, Topo

- The **reference ellipsoid** surface (a map of average sea level).
- The **reference geoid** surface (a mean sea level surface).
- The **real surface** of the Earth (the ground) also called the **topographic** surface.



THE GEOID and ELLIPSOID



h (Ellipsoid Height) = Distance along ellipsoid normal (Q to P)
 N (Geoid Height) = Distance along ellipsoid normal (Q to P_0)
 H (orthometric height) = Distance along Plumb Line (P_0 to P)

SOURCE: National Geodetic Survey
http://www.ngs.noaa.gov/GEOID/geoid_def.html



Geodetic Datum

- Geodetic datum defines the **size** and **shape** of the ellipsoid earth and the **origin** (or position) and **orientation** (or direction) with respect to the Earth.
- the **direction** of the minor axis of the ellipsoid. This is classically defined as being parallel to the mean spin axis of the earth
- the **position** of its centre, either implied by adopting a geodetic latitude and longitude (Φ, λ) and geoid / ellipsoid separation (N) at one, or more points (**datum stations**), or in absolute terms with reference to the **Earth centre of mass**; and
- the **zero of longitude** (conventionally the Greenwich Meridian).
- **True geodetic datums** were employed only after the late 1700s when measurements showed that the earth was ellipsoidal in shape. The **science of geodesy**.

Selected Ellipsoids and Datums

Selected Reference Ellipsoids

Ellipse	Semi-Major Axis (meters)	1/Flattening
Airy 1830	6377563.396	299.3249646
Bessel 1841	6377397.155	299.1528128
→ Clarke 1866	6378206.4	294.9786982
Clarke 1880	6378249.145	293.465
Everest 1830	6377276.345	300.8017
Fischer 1960 (Mercury)	6378166.0	298.3
Fischer 1968	6378150.0	298.3
G R S 1967	6378160.0	298.247167427
G R S 1975	6378140.0	298.257
→ G R S 1980	6378137.0	298.257222101
Hough 1956	6378270.0	297.0
→ International	6378388.0	297.0
Krassovsky 1940	6378245.0	298.3
South American 1969	6378160.0	298.25
WGS 60	6378165.0	298.3
WGS 66	6378145.0	298.25
WGS 72	6378135.0	298.26
→ WGS 84	6378137.0	298.257223563

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Table 1: Datums and their principle areas of use

Datum	Area	Origin	Ellipsoid
WGS 1984	Global	Earth center of mass	WGS 84
NAD 1983	North America, Caribbean	Earth center of mass	GRS 80
NAD 1927	North America	Meades Ranch	Clarke 1866
European 1950	Europe, Middle East, North Africa	Potsdam	International

Source: <http://maic.jmu.edu/sic/standards/datum.htm>

Basics of Map Projections



- A **map projection** is a mathematical model for conversion of locations from a **three-dimensional** earth surface to a **two-dimensional** map representation. This conversion necessarily **distorts** some aspect of the earth's surface, such as area, shape, distance, or direction.
- Every projection has its own set of advantages and disadvantages. There is **no "best" projection**. Some distortions of **conformality** (shape), **scale**, **distance**, **direction**, and **area** always result from this processes. Some projections **minimize distortions** in some of these properties at the expense of **maximizing errors** in others. Some projection are attempts to only moderately distort all of these properties
- The mapmaker must select the **one best** suited to the needs, reducing distortion of the most important features.
- Mapmakers and mathematicians have devised almost **limitless ways** to **project** the image of the globe onto a flat surface (paper).

Classes of Map projections

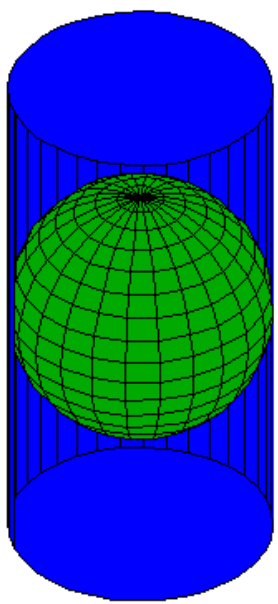


Physical models:

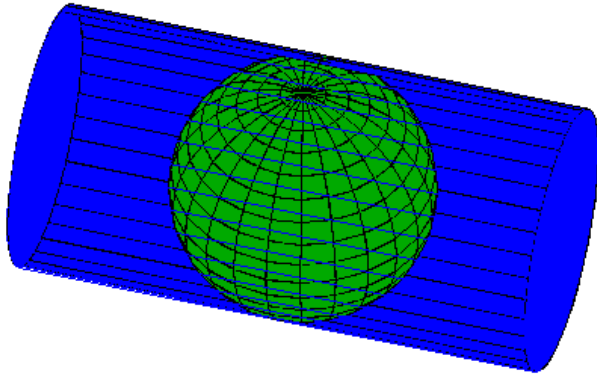
- Cylindrical projections (**cylinder**)
 - Tangent case
 - Secant case
- Conic Projections (**cone**)
 - Tangent case
 - Secant case
- Azimuthal or planar projections (**plane**)
 - Tangent case
 - Secant case

Distortion properties:

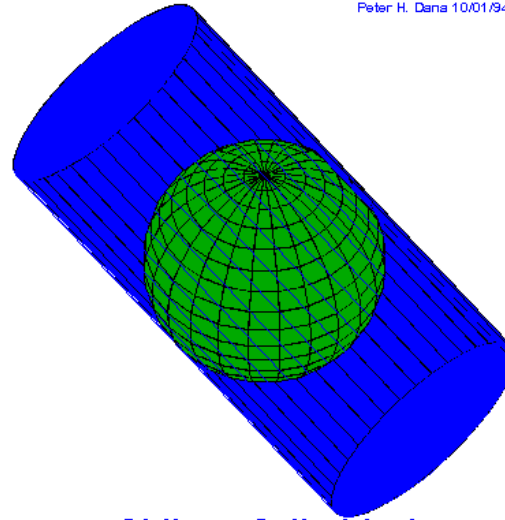
- Conformal (preserves **local angles and shape**)
- Equal area or equivalent (**area**)
- Equidistant (**scale** along a center line)
- Azimuthal (**directions**)



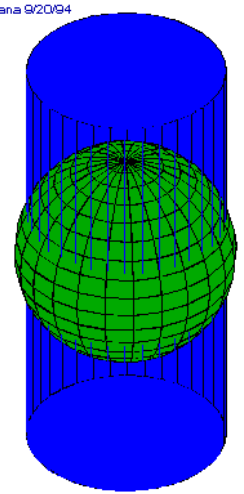
Cylindrical



Transverse Cylindrical

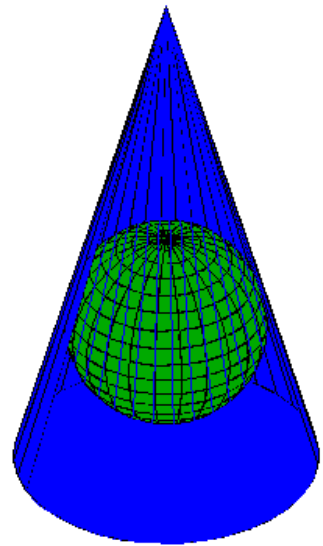


Oblique Cylindrical

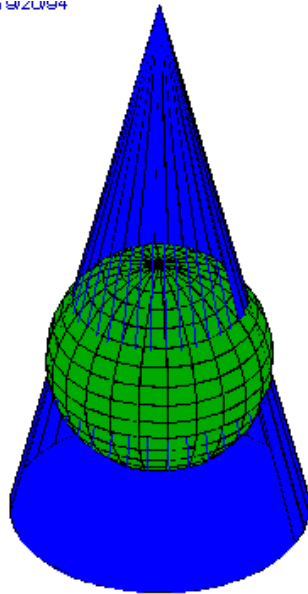


Secant Cylindrical Projection

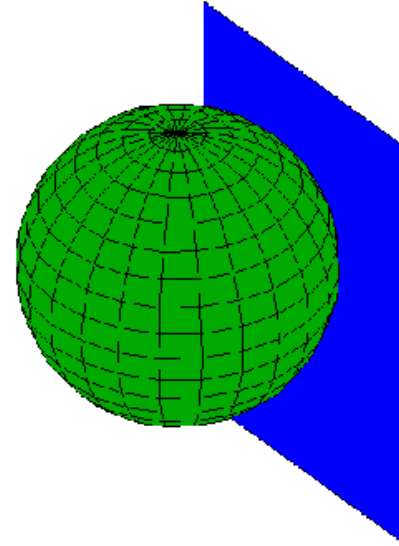
Secant Cylindrical



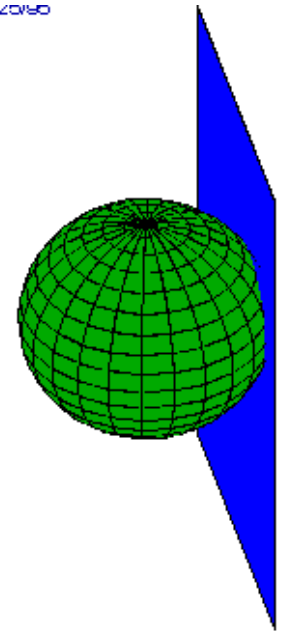
Conical



Secant Conical



Planar



Secant Planar

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Dynamic View of Projections

- http://www.cnr.colostate.edu/class_info/nr502/lg1/map_projections/form_case_aspect.htm
!
- http://www.cnr.colostate.edu/class_info/nr502/lg1/map_projections/developable_surfaces.html

Common Used Projections

■ Mercator Projection (1569)

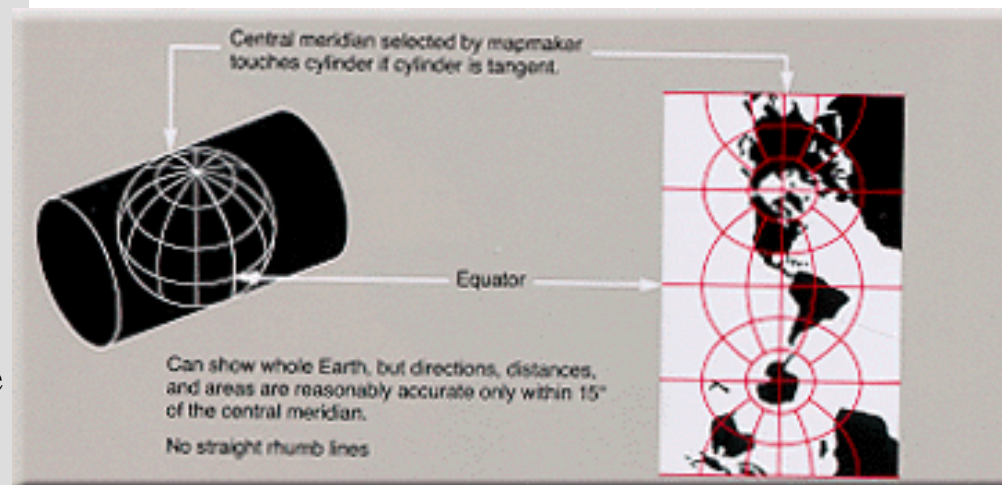
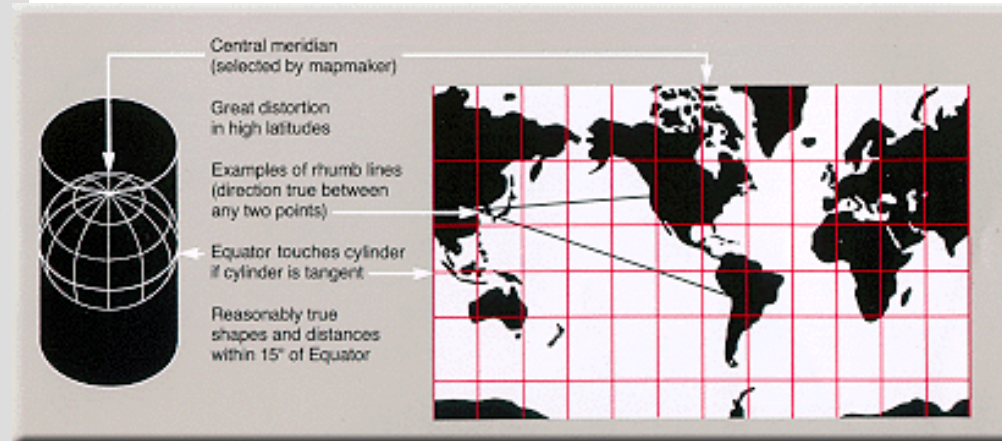
- **Directions** are true along straight line of any two points, **Distances** are true only along equator, and reasonable correct within 15° of equator, in secant model, distance along two parallels are correct in scale instead of the Equator. **Areas and shapes** of large area are distorted. Distortion increases away from Equator and is extreme in polar regions. However, map is **conformal** in that angles and shapes within any small area is essentially true.

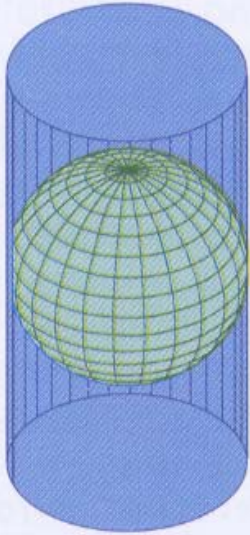
- Used for navigation or maps of equatorial regions.

■ Transverse Mercator Projection (Lambert 1772)

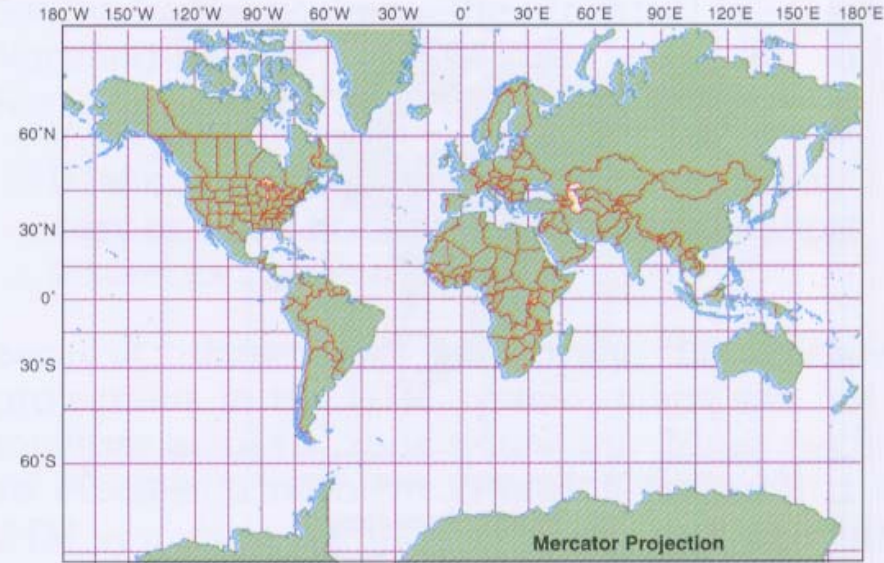
- **Distances** are true *only* along the central meridian selected by the mapmaker or else along two lines parallel to it, but all distances, directions, shapes, and areas are reasonably accurate within 15° of the central meridian. **Distortion** of distances, directions, and size of areas increases rapidly outside the 15° band. Because the map is **conformal**, however, shapes and angles within any small area (such as that shown by a USGS topographic map) are essentially true.

- Used for many USGS 1:24,000 to 1:250,000 map





Cylindrical Projection Surface



Common Used Projections

■ Albers Equal-Area Conic Projection (1805)

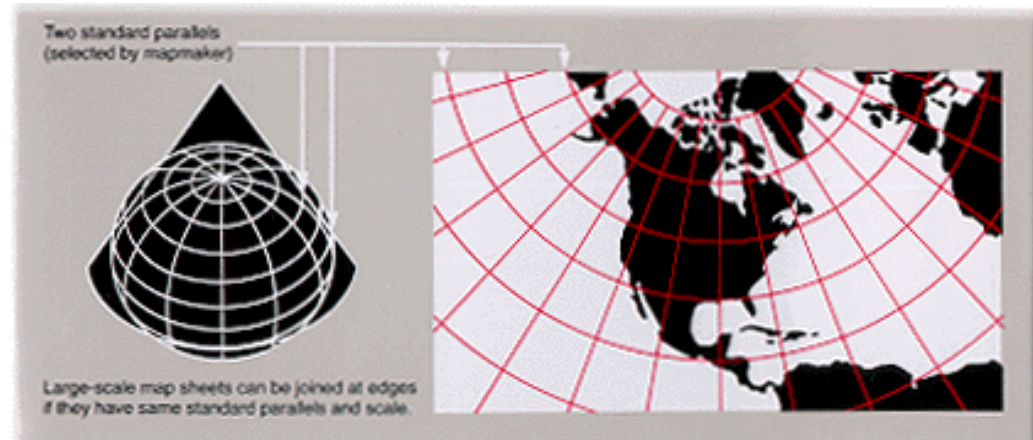
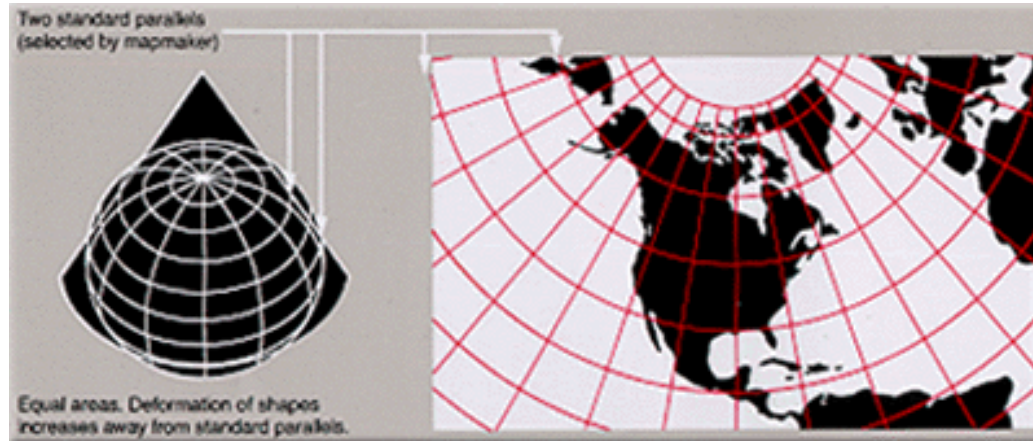
- **All areas** on the map are proportional to the same areas on the Earth. **Directions** are reasonably accurate in limited regions. **Distances** are true on both standard parallels. Maximum scale error is 1 1/4% on map of conterminous States with standard parallels of 29 1/2°N and 45 1/2°N. **Scale** true only along standard parallels

- Used for maps showing the conterminous United States.

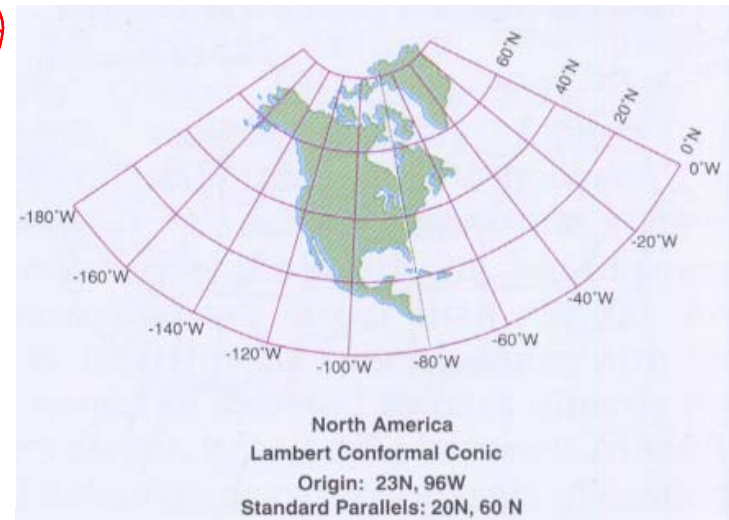
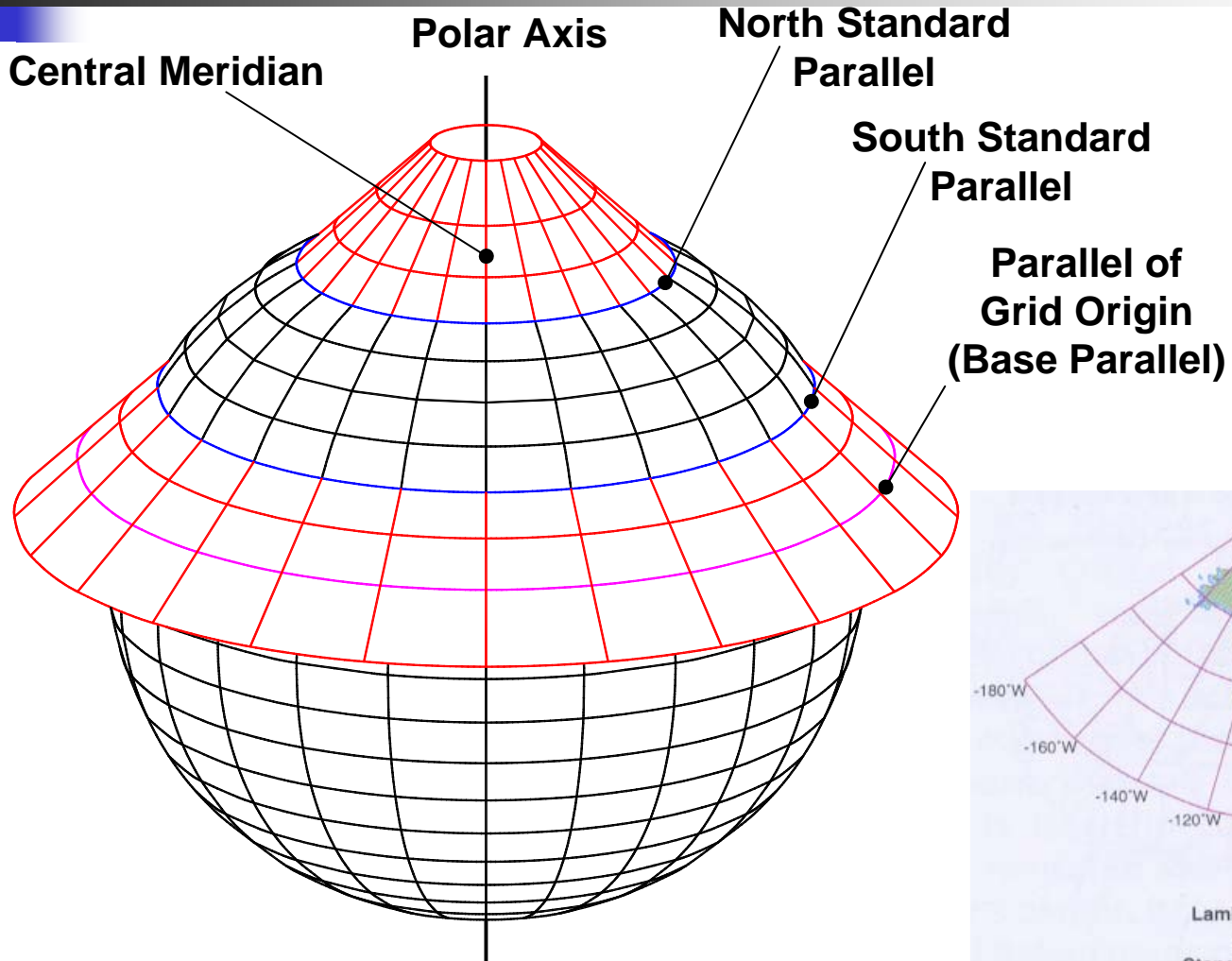
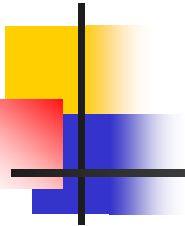
■ Lambert Conformal Conic Projection (1772)

- **Distances true** only along standard parallels; reasonably accurate elsewhere in limited regions. **Directions** reasonably accurate. **Distortion** of shapes and areas minimal at, but increases away from standard parallels. **Shapes** on large-scale maps of small areas essentially true. Used for maps of North America. USGS Base Maps for 48 conterminous States with standard parallels 33 N, and 45 N (maximum scale error 2 1/2 %). for TOPO maps, standard parallels vary.

- Used for many topographic maps and for State Base Map series.



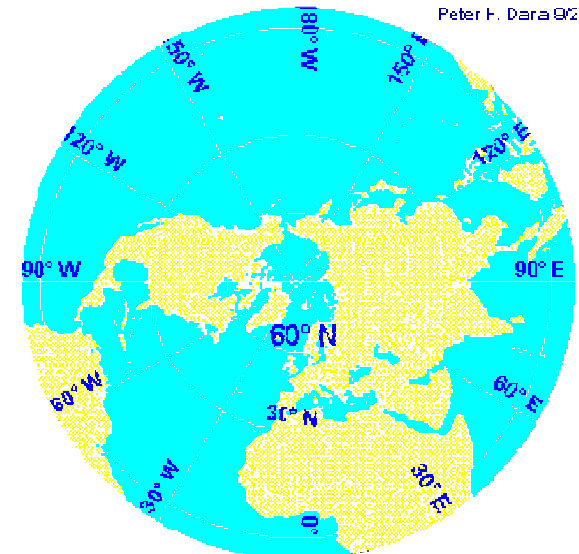
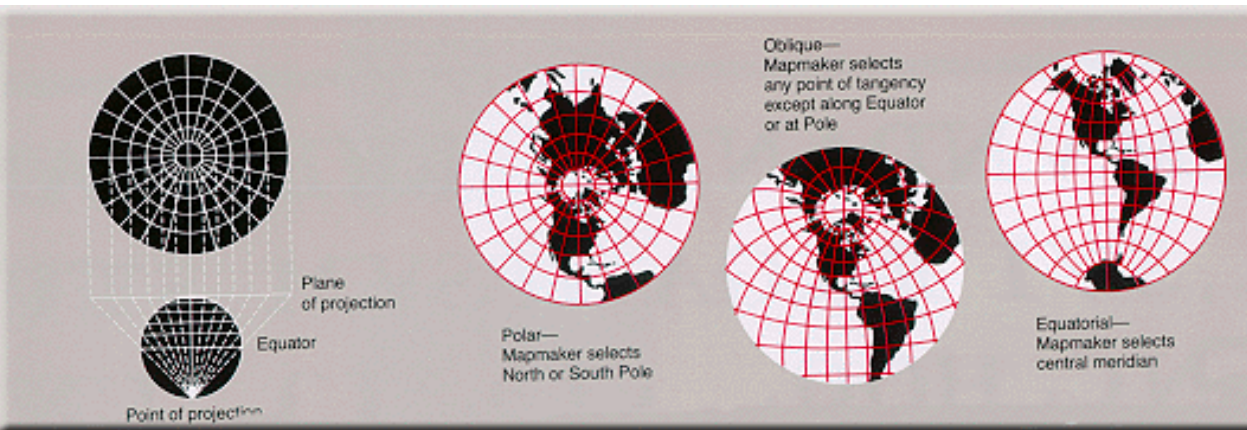
LAMBERT CONIC PROJECTION (Northern Hemisphere)



Common Used Projections

■ Stereographic Projection

- This is a Azimuthal projection
- **Directions** true *only* from center point of projection. **Scale** increases away from center point. Any straight line through center point is a **great circle**. **Distortion** of **areas** and large **shapes** increases away from center point.
- Used for maps of Antarctica and Arctic, for TOPO maps and navigating in latitudes above 80°, and for some geophysical maps and NEXRAD precipitation products.



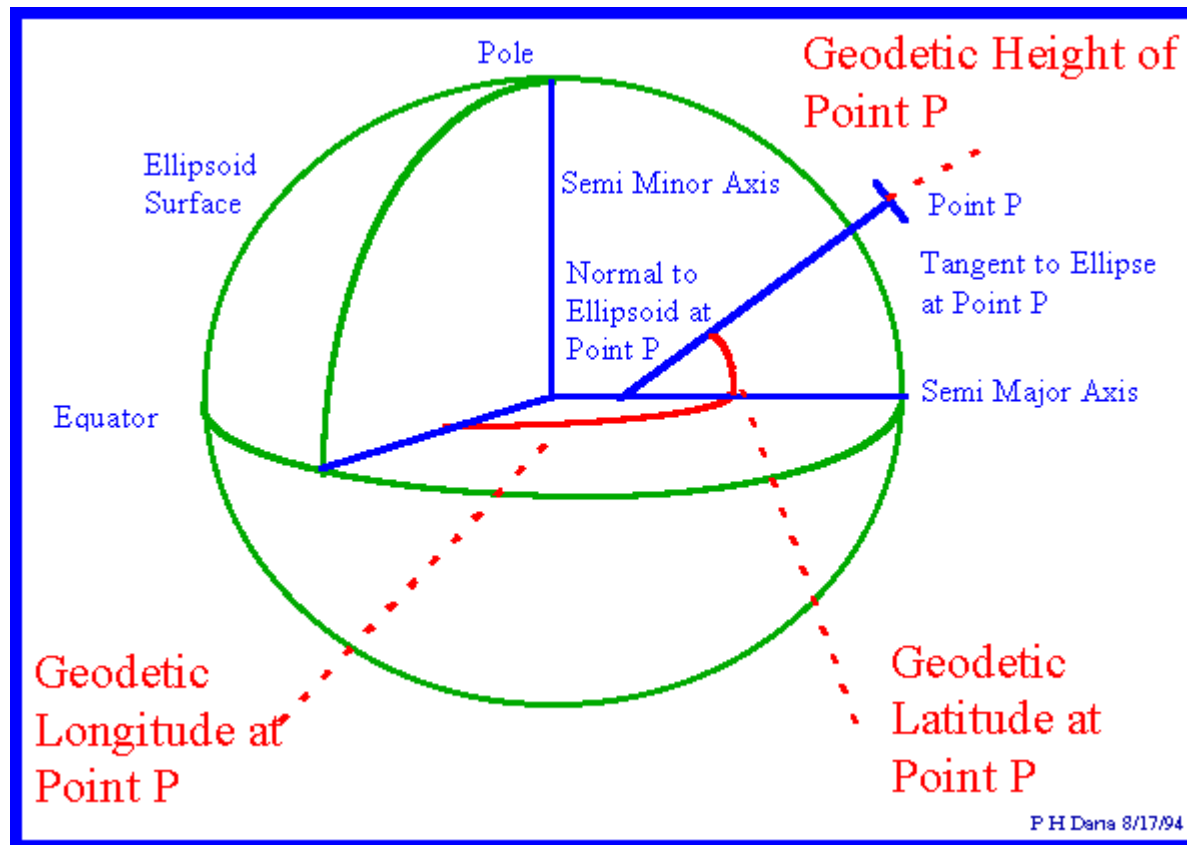
Stereographic
North Polar Aspect



Coordinate System

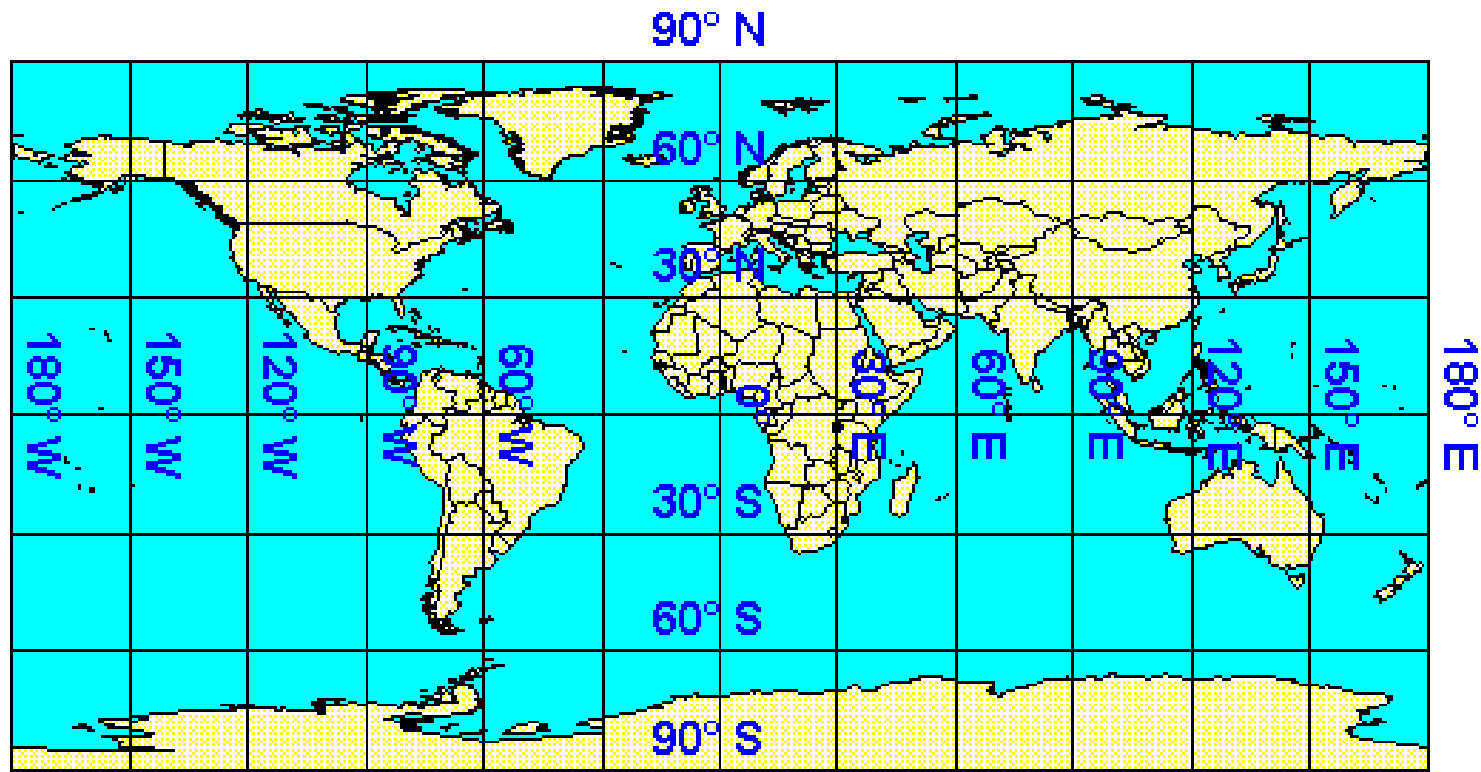
- There are many different coordinate systems, based on a variety of **geodetic datums**, **projections**, and units in use
- **Geographic** coordinate systems (no projection): Spheroid (or Ellipsoid)-based systems, local systems.
- **Projected** coordinate systems: world, continental, polar, US National Grids, UTM, state plane.

Geographic Latitude/Longitude Coordinate System



Geographic Latitude/Longitude on a flat surface (WGS 84 datum)

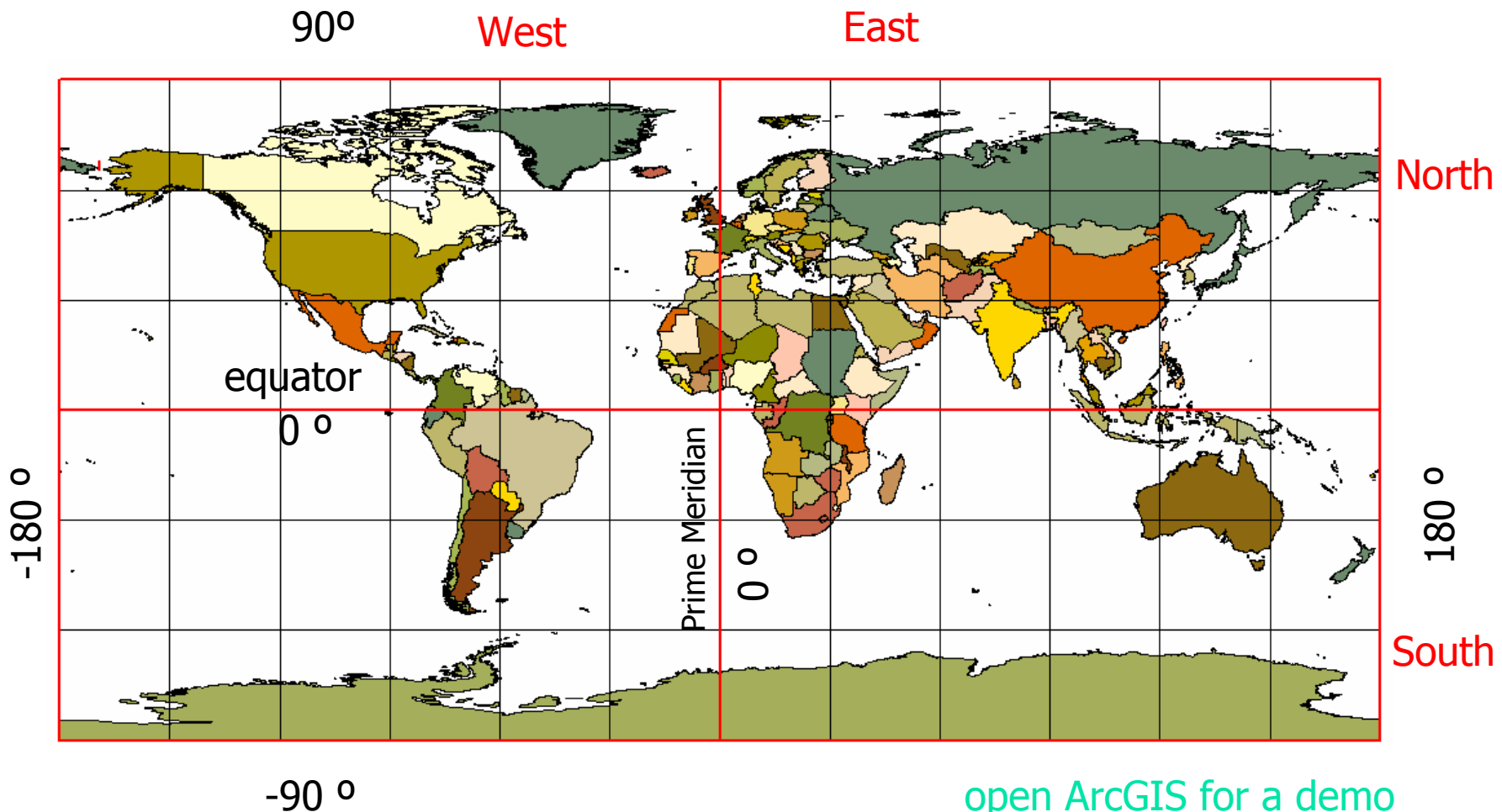
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Unprojected Latitude and Longitude

Scale, distance, area, and shape are all distorted with the distortion increasing toward the poles.

Geographic Latitude/Longitude in GIS system

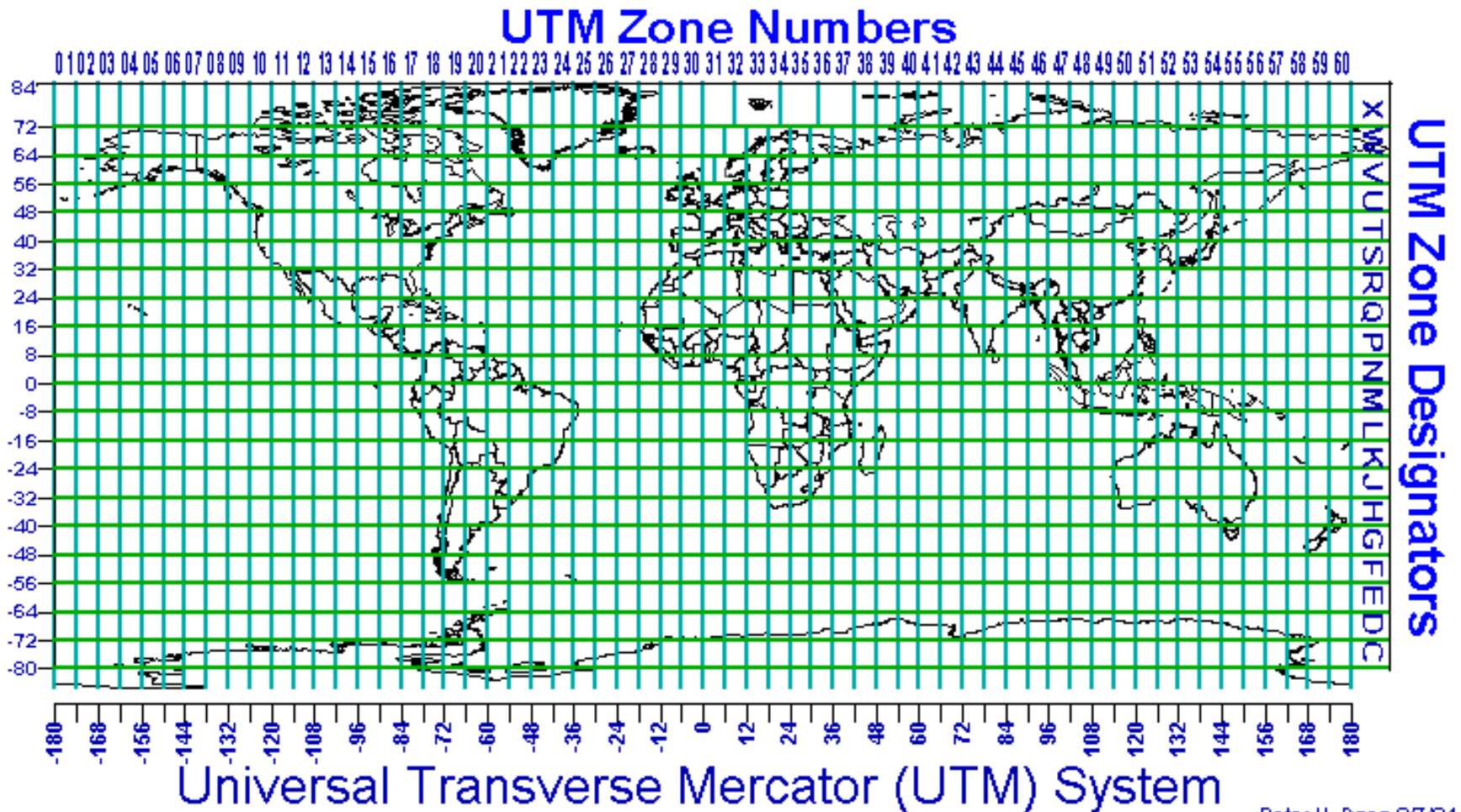


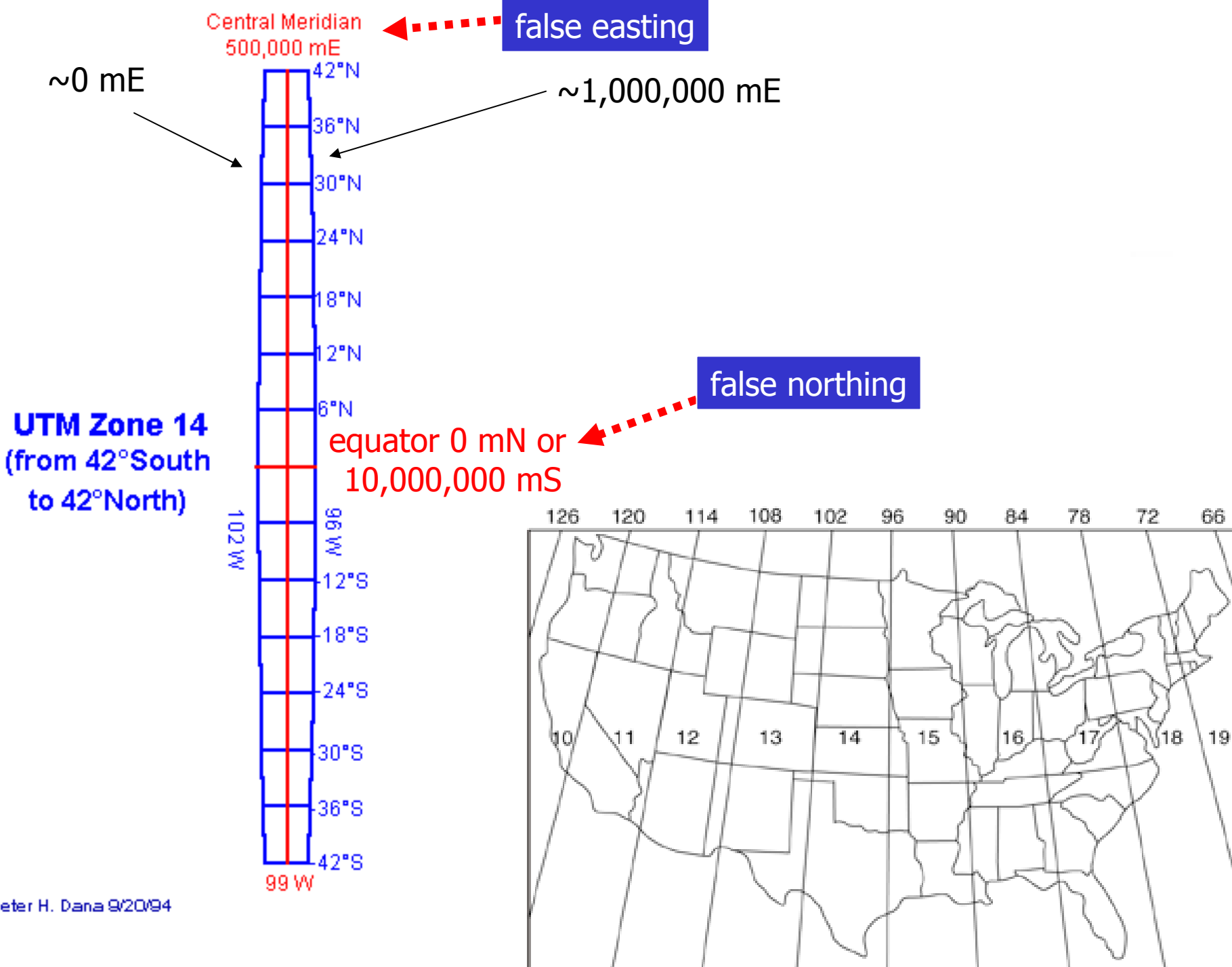


Universal Transverse Mercator (UTM) Coordinate System

- UTM system is **transverse-secant cylindrical projection**, dividing the surface of the Earth into 6 degree zones with a central meridian in the center of the zone. each one of zones is a different Transverse Mercator projection that is slightly rotated to use a different meridian. UTM zone numbers designate 6 degree longitudinal strips extending from 80 degrees South latitude to 84 degrees North latitude. UTM is a **conformal** projection, so small features appear with the correct shape and scale is the same in all directions. (**all distances, directions, shapes, and areas are reasonably accurate**). Scale factor is 0.9996 at the central meridian and at most 1.0004 at the edges of the zones.
- UTM coordinates are in meters, making it easy to make accurate calculations of short distances between points (error is less than 0.04%)
- Used in USGS topographic map, and digital elevation models (DEMs)
- Although the distortions of the UTM system are small, they are too great for some accurate surveying. zone boundaries are also a problem in many applications, because they follow arbitrary lines of longitude rather than boundaries between jurisdictions.

UTM Zone Numbers

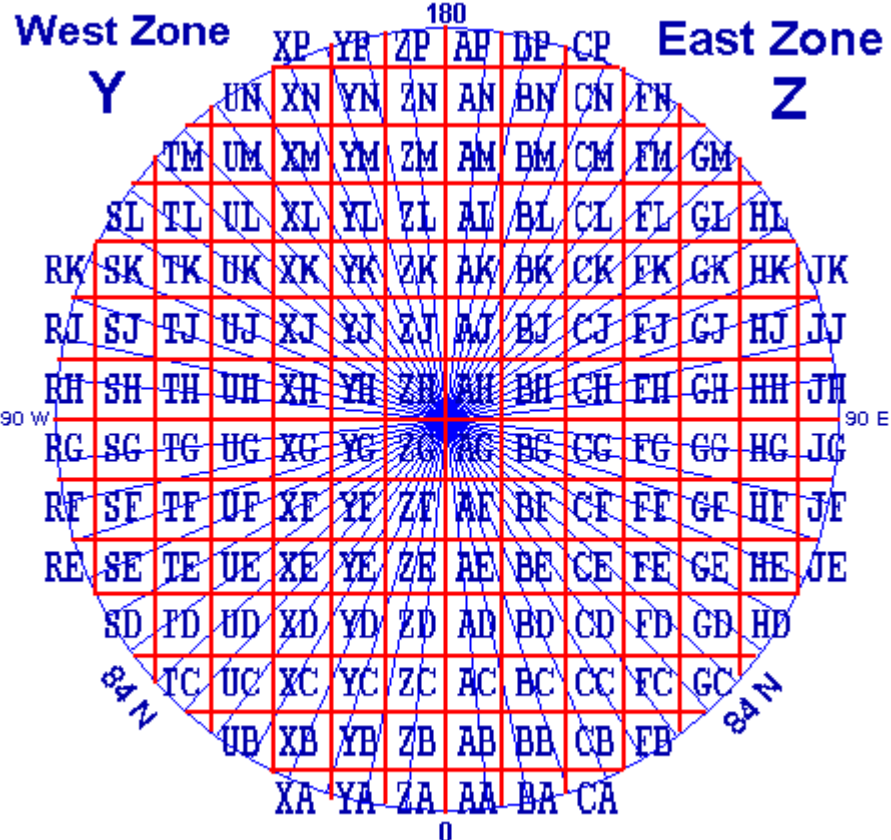




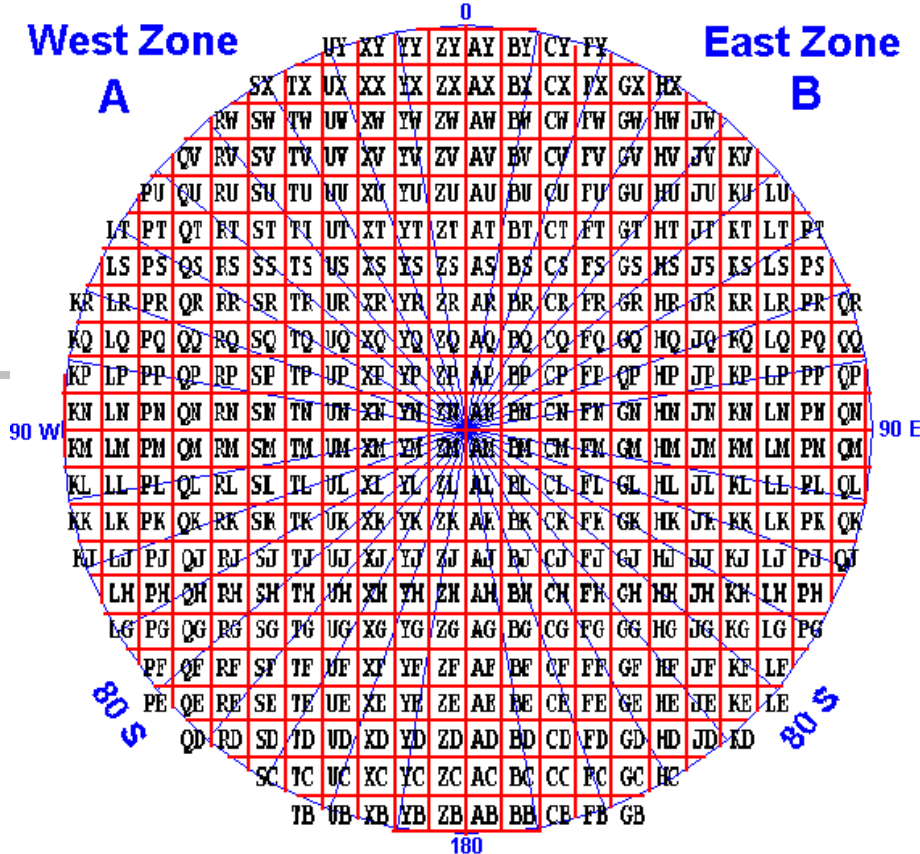


Universal Polar Stereographic (UPS) Coordinate System

- The UPS is defined above 84 degrees north latitude and south of 80 degrees south latitude.
- The eastings and northings are computed using a polar aspect stereographic projection.
- Zones are computed using a different character set for south and north Polar regions.



North Polar Area UPS Grid



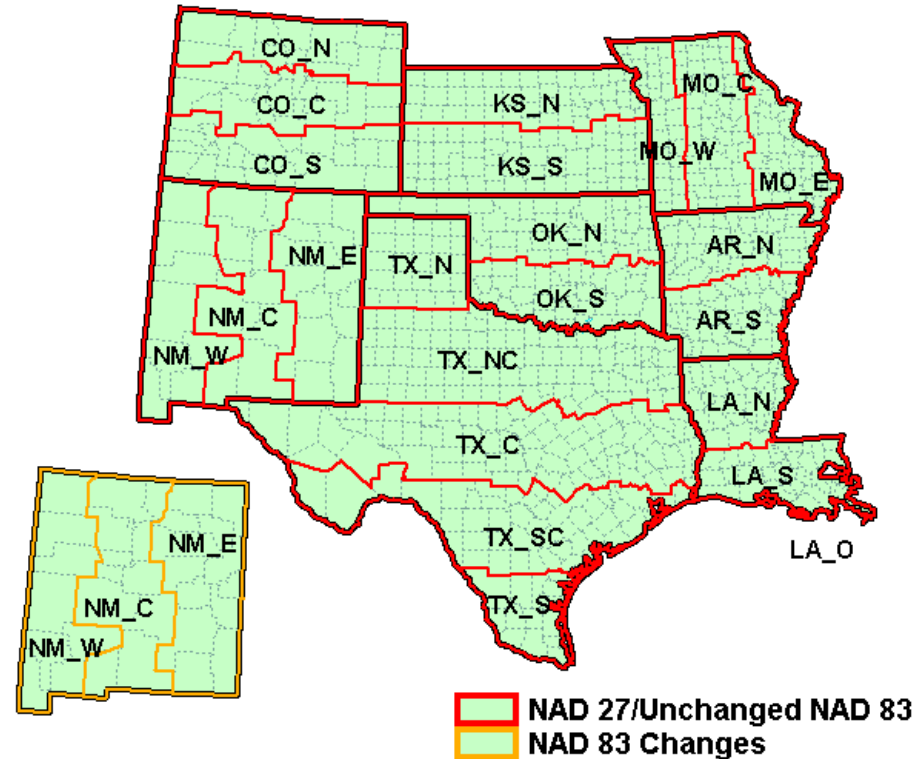
South Polar Area UPS Grid

WGS-84 Latitude, Longitude
 85:40:30.0 N 85:40:30.0 E
 Universal Polar Stereographic
 ZGG7902863771
**North Polar Area UPS
 Example**

WGS-84 Latitude, Longitude
 85:40:30.0 S 85:40:300.0 W
 Universal Polar Stereographic
 ATN2097136228
**South Polar Area UPS
 Example**

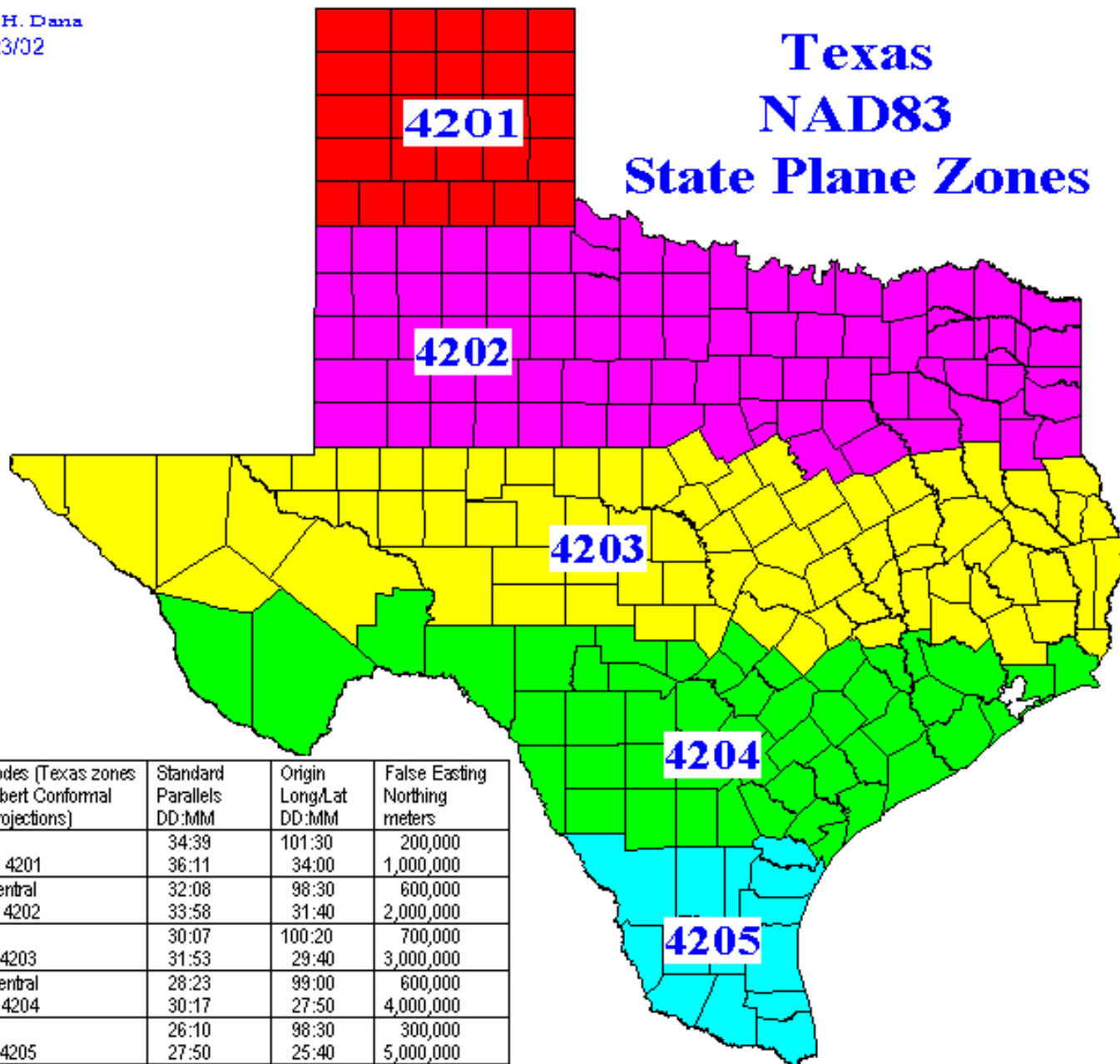
State Plane Coordinate System

- To support high-accuracy applications, all US states have adopted their own specialized coordinate systems: State Plane Coordinates. For example, Texas has five zones based on the Lambert **Conformal Conic projection**, while Hawaii has five zones based on **Transverse Mercator projection**.



Peter H. Dana
4/23/02

Texas NAD83 State Plane Zones



Zone Codes (Texas zones are Lambert Conformal Conic projections)	Standard Parallels DD:MM	Origin Long/Lat DD:MM	False Easting Northing meters
North TX N 4201	34:39 36:11	101:30 34:00	200,000 1,000,000
North Central TX NC 4202	32:08 33:58	98:30 31:40	600,000 2,000,000
Central TX C 4203	30:07 31:53	100:20 29:40	700,000 3,000,000
South Central TX SC 4204	28:23 30:17	99:00 27:50	600,000 4,000,000
South TX S 4205	26:10 27:50	98:30 25:40	300,000 5,000,000



Other common used projected coordinate systems

- **Albers:**

- Albers Equal-Area Conic + NDA 27 (NDA 83, or WGS 84). For example: [USGS Hydrologic unit maps](#)

- **Lambert:**

- Lambert Conformal Conic + NDA 27 (NDA 83, or WGS 84)

- **Equidistant:**

- Equidistant Conic: NDA 27 (NDA 83, or WGS 84)



Conversion of Projection, Datum, Coordinate System

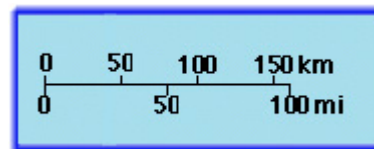
- In one GIS project or database, all layers should have the same coordinate system
- We need to do conversions
- ArcToolbox has full functions to do this

Map Scale

- Scale refers to the relationship or ratio between a distance on a map and the distance on the earth it represents. Maps should display accurate distances and locations, and should be in a convenient and usable size.
- Map scales can be expressed as
 - representative fraction or ratio:

1:100,000 or 1/100,000

- graphical scale:



- verbal-style scale:

**1 inch in map equal to 2000 feet on the ground or
1 inch = 2000 feet**



DMA: Saigon, Vietnam, 1968
City Map, Series L909
Scale 1:15,000

Large Scale



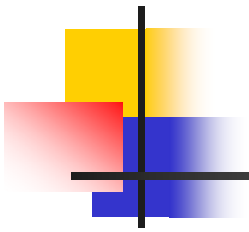
DMA: ONC G-4, 1986
Operational Navigation Chart
Scale 1:1,000,000

Small Scale

Figure 7: Illustration of different map scales

Table 3: Representative distances for map scales:

Scale:	1 inch on map represents:	1 centimeter on map represents:
1:24,000	2,000 feet	240 meters
1:50,000	4,166 feet	500 meters
1:63,360	1 mile	633.6 meters
1:100,000	1.6 miles	1 kilometer
1:250,000	4 miles	2.5 kilometers
1:500,000	8 miles	5 kilometers
1:1,000,000	16 miles	10 kilometers



A useful rule of thumb for features on paper maps

Map scale	accuracy, or resolution (corresponding to 0.5 mm map distance)
1:1,250	0.625 m
1:2,500	1.25 m
1:5,000	2.5 m
1:10,000	5 m
1:24,000	12 m
1:50,000	25 m
1:100,000	50 m
1:250,000	125 m
1:1,000,000	500 m
1:10,000,000	5 km



GIS is Scaleless

- In GIS, the scale can be easily enlarged and reduced to any size that is appropriate.
- However, if we get farther and farther from the original scale of the layer, problems appear:
 - details no appear in an enlarged map
 - too dense in a reduced map



Scale in attention

- The scale of the original map determines the largest map scale at which the data can be used.
- Road map 1:50,000 scale can **NOT** be used accurately at the 1:24,000 scale.
- Water coverage at 1:250,000 scale can **NOT** be used accurately at the 1:50,000 scale.

The earth on a computer screen



- Computer screen \sim 1 million pixels
- If entire earth displayed, each pixel would represent about 10 km x 10 km (100 km²)
- *Spatial resolution* is 10 km \rightarrow Anything less than 10 km across cannot be seen



Main References

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<http://mac.usgs.gov/mac/isb/pubs/factsheets/fs01502.html>
- ESRI, <http://www.esri.com>
- JMU, <http://maic.jmu.edu/sic/standards/scale.htm>
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