Georeferencing, Map Projections, Cartographic Concepts

-Map Projections

-Coordinate Systems

-Datum

Map projection is "the process of systematically transforming positions on the Earth's spherical surface to a flat map while maintaining spatial relationships.

This process is accomplished by the use of geometry or, more commonly, by mathematical formulas.

Map projection can be best visualized by imagining a light bulb placed at the center of a transparent globe and having its lines of longitude and latitude cast upon either a flat sheet of paper or a sheet of paper rolled into a cylinder or cone placed over the globe." (from *Glossary of cartographic terms*: map projection).

•Map projections fall into four general classes.

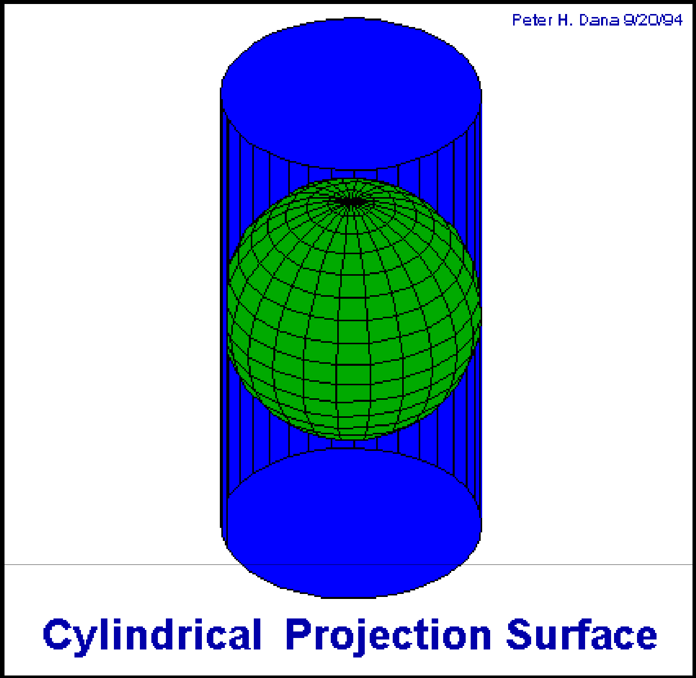
•Cylindrical projections result from projecting a spherical surface onto a cylinder.

•Conic projections result from projecting a spherical surface onto a cone.

•Azimuthal projections result from projecting a spherical surface onto a plane.

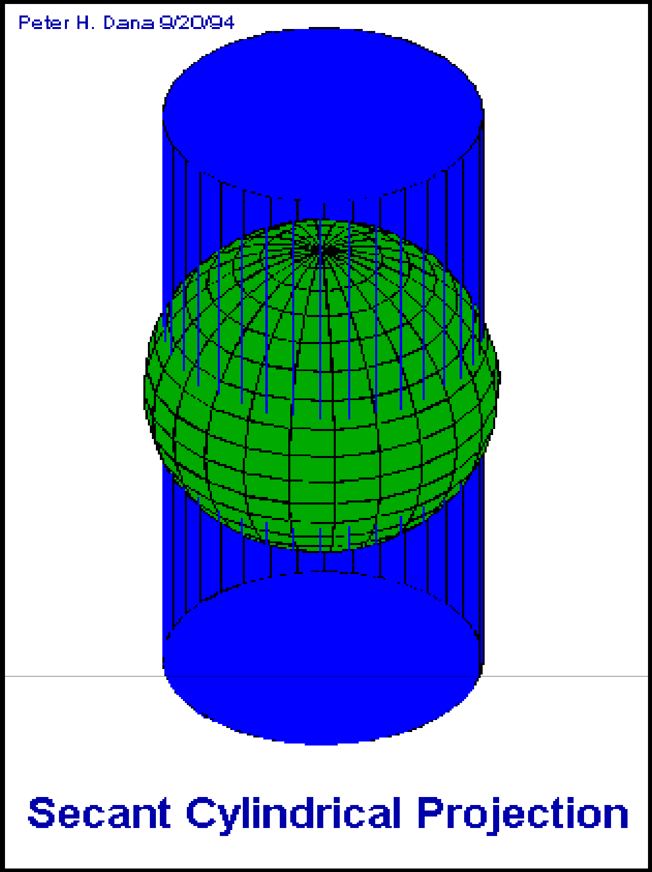
•Miscellaneous projections include unprojected ones such as rectangular latitude and longitude grids and other examples of that do not fall into the cylindrical, conic, or azimuthal categories

•Cylindrical projections



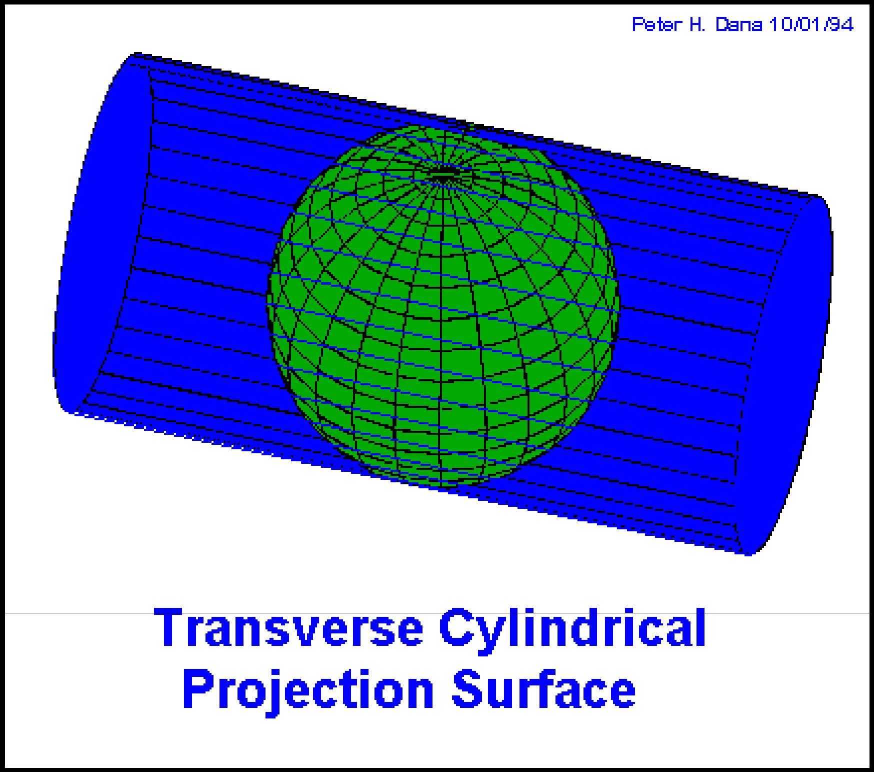
•When the cylinder is tangent to the sphere contact is along a great circle (the circle formed on the surface of the Earth by a plane passing through the center of the Earth).

•Cylindrical projections



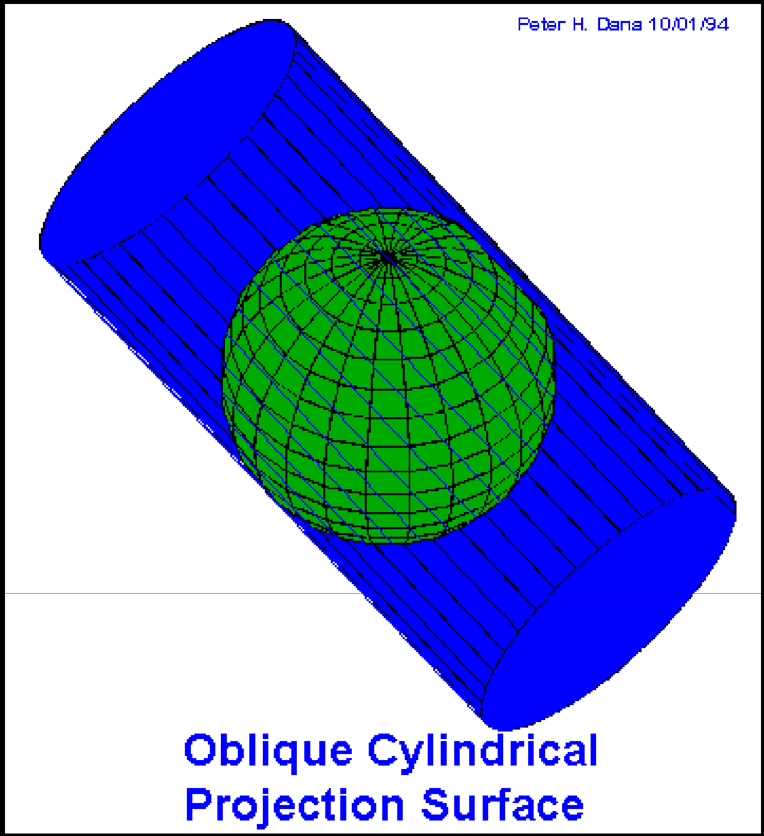
•In the secant case, the cylinder touches the sphere along two lines, both small circles (a circle formed on the surface of the Earth by a plane not passing through the center of the Earth).

•Cylindrical projections



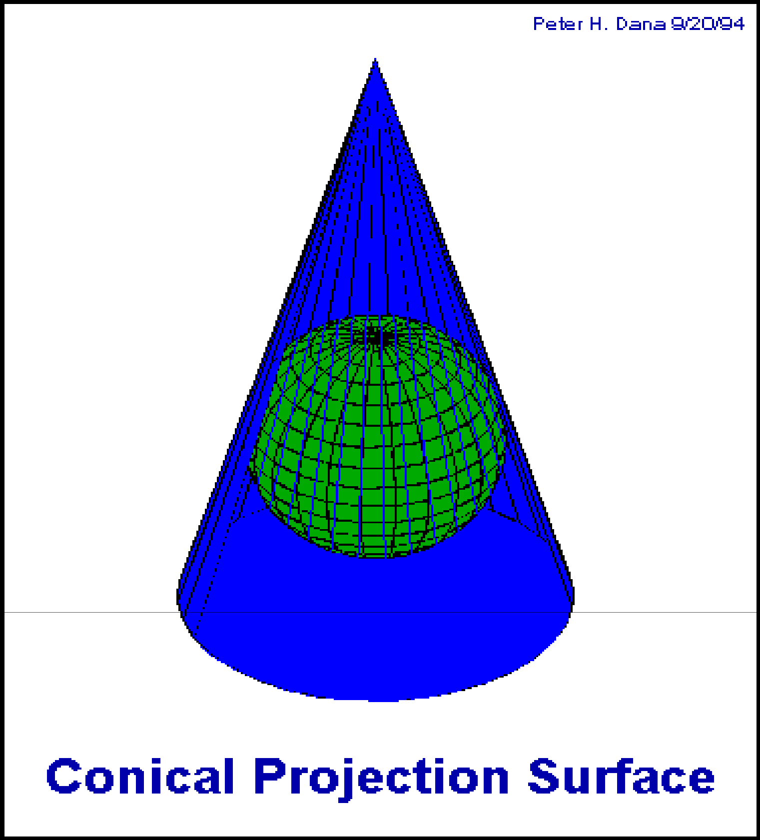
•When the cylinder upon which the sphere is projected is at right angles to the poles, the cylinder and resulting projection are transverse.

•Cylindrical projections



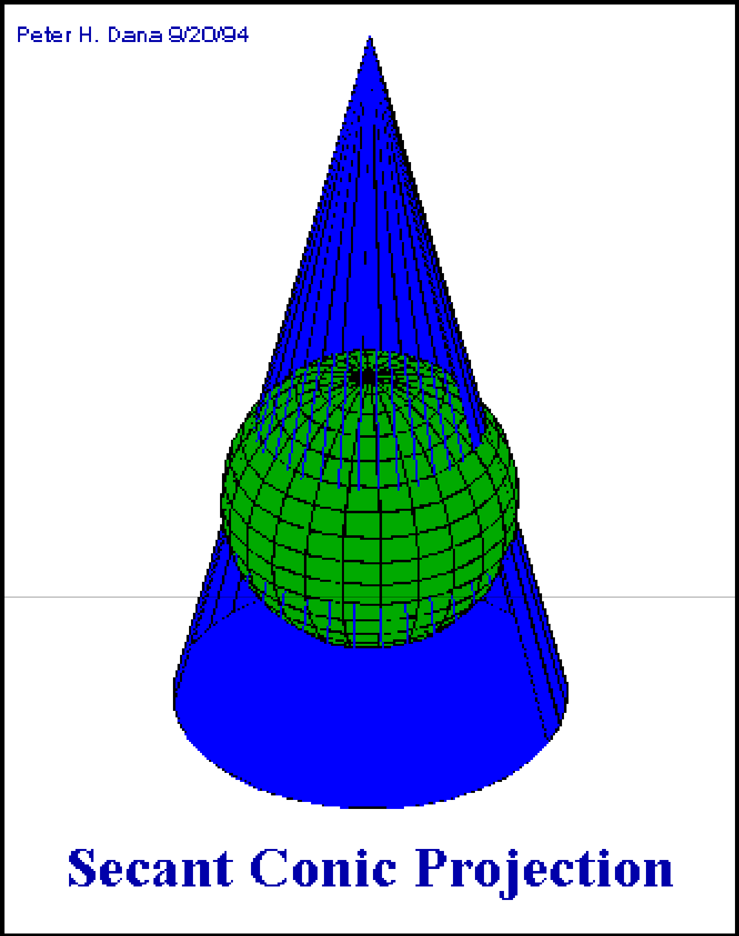
•When the cylinder is at some other, non-orthogonal, angle with respect to the poles, the cylinder and resulting projection is oblique.

•Conic projections



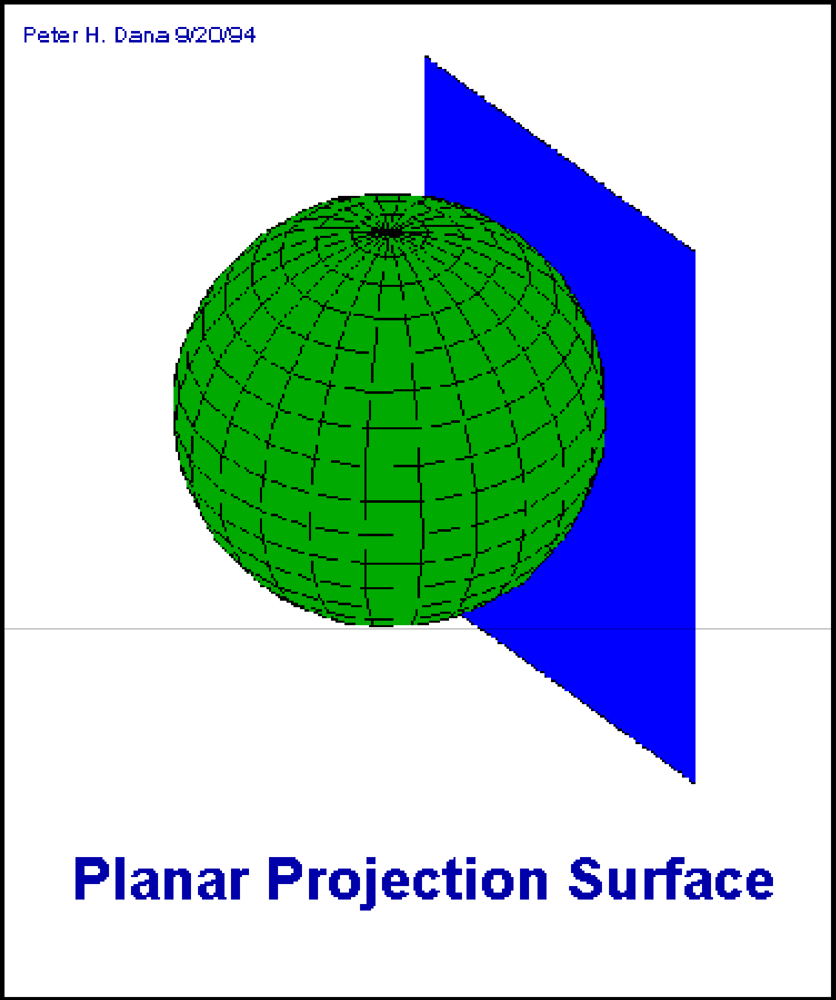
When the cone is tangent to the sphere contact is along a small circle.

•Conic projections



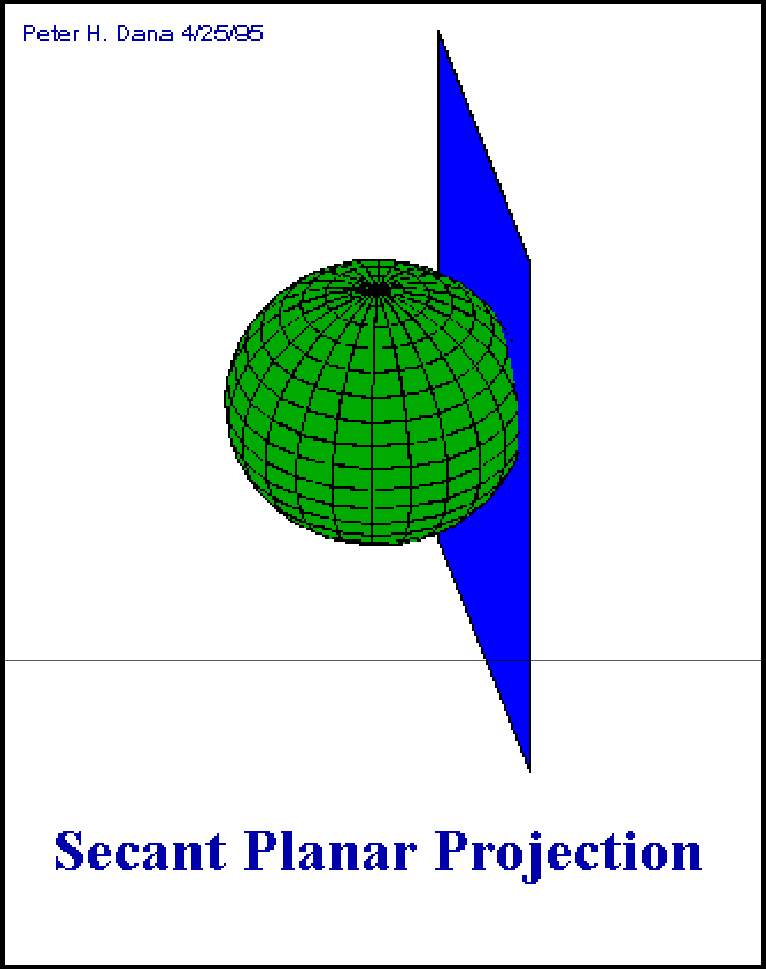
•In the secant case, the cone touches the sphere along two lines, one a great circle, the other a small circle.

•Azimuthal projections



•When the plane is tangent to the sphere contact is at a single point on the surface of the Earth.

•Azimuthal projections



•In the secant case, the plane touches the sphere along a small circle if the plane does not pass through the center of the earth, when it will touch along a great circle.

•Map projections are attempts to portray the surface of the earth or a portion of the earth on a flat surface.

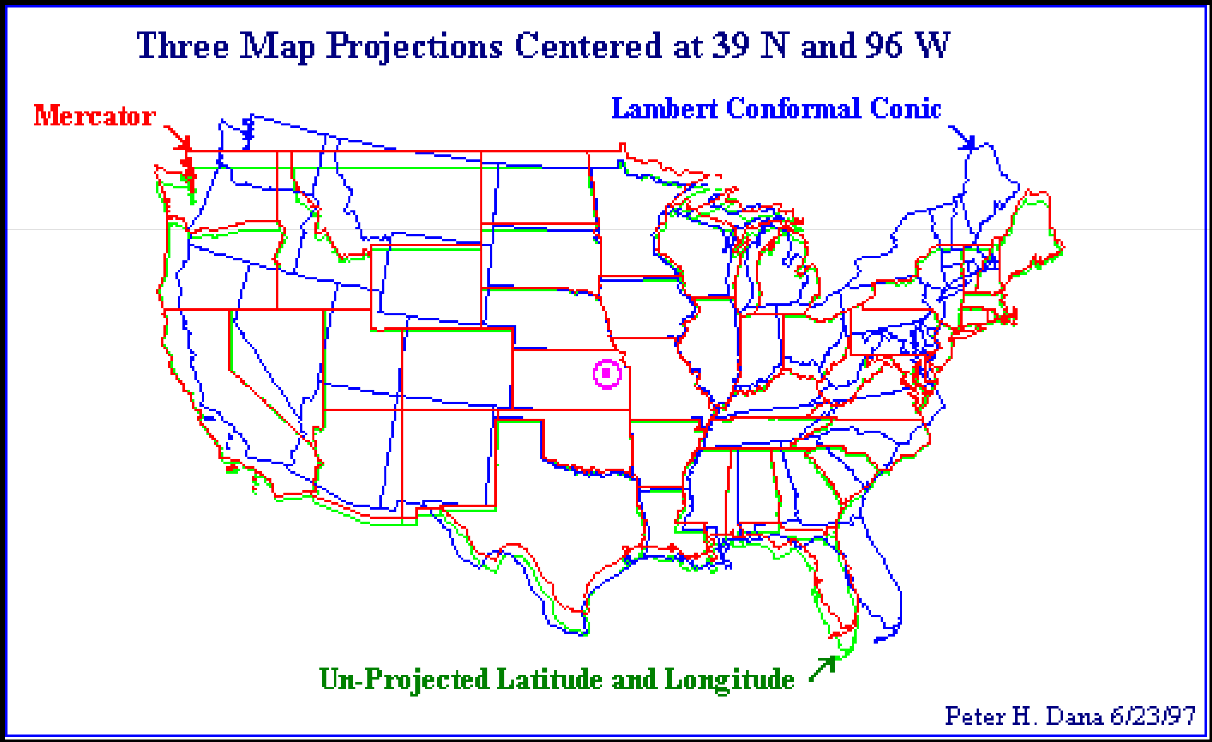
•Some distortions of conformality, distance, direction, and area always result from this process.

•Some projections minimize distortions in some of these properties at the expense of maximizing errors in others.

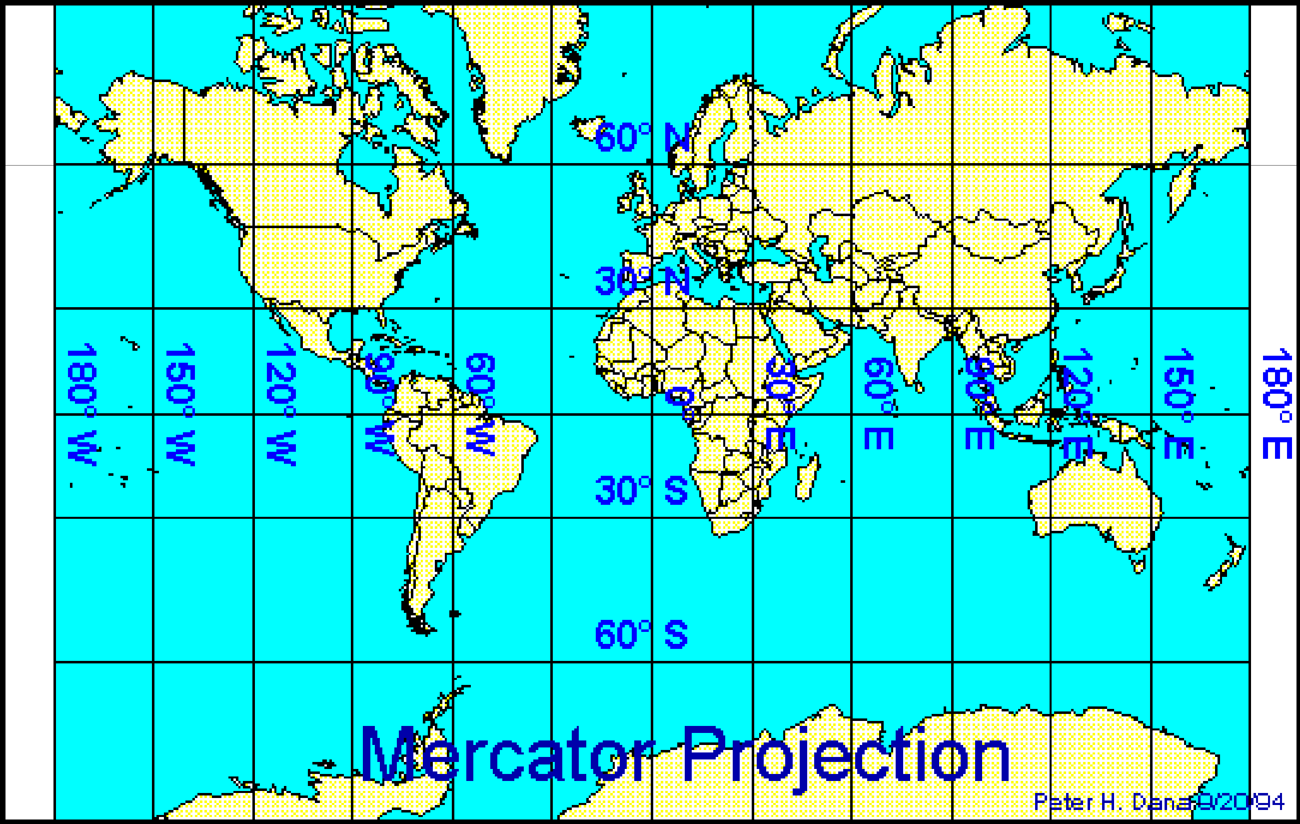
•Some projection are attempts to only moderately distort all of these properties.

•Conformality-When the scale of a map at any point on the map is the same in any direction, the projection is conformal. Meridians (lines of longitude) and parallels (lines of latitude) intersect at right angles. Shape is preserved locally on conformal maps.
•Distance-A map is equidistant when it portrays distances from the center of the projection to any other place on the map.
•Direction-A map preserves direction when azimuths (angles from a point on a line to another point) are portrayed correctly in all directions.
•Area-When a map portrays areas over the entire map so that all mapped areas have the same proportional relationship to the areas on the Earth that they represent, the map is an equal-area map.

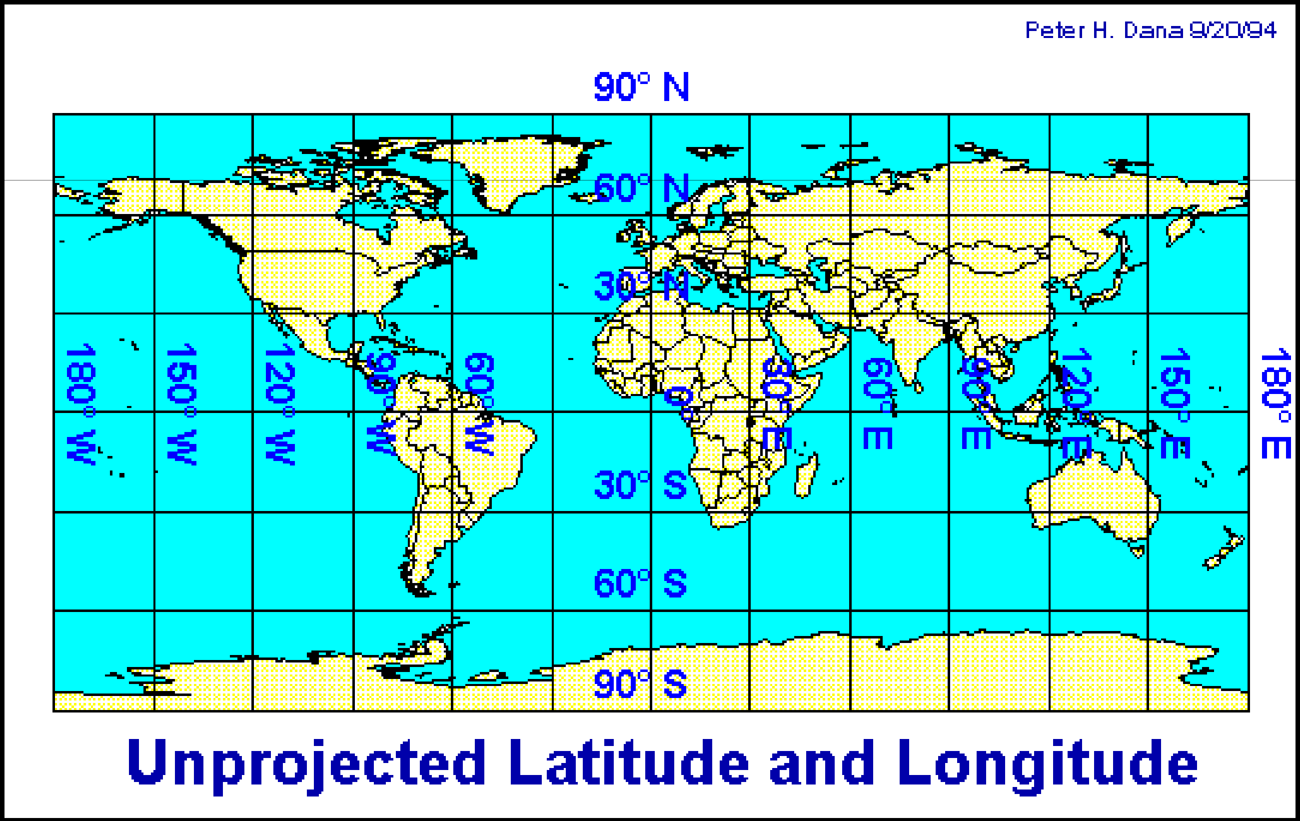
•Different map projections result in different spatial relationships between regions.



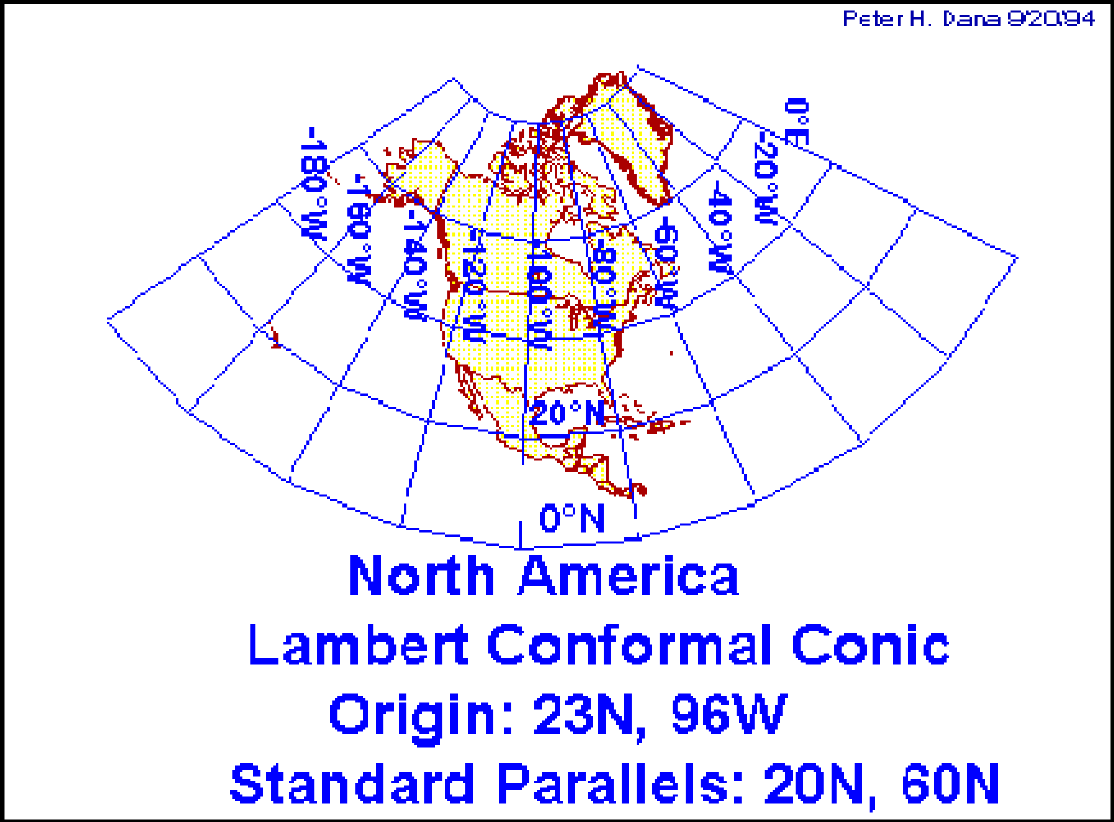
•Mercator-The Mercator projection has straight meridians and parallels that intersect at right angles. Scale is true at the equator or at two standard parallels equidistant from the equator. The projection is often used for marine navigation because all straight lines on the map are lines of constant azimuth.



- Unprojected Maps
  - Unprojected maps include those that are formed by considering longitude and latitude as a simple rectangular coordinate system. Scale, distance, area, and shape are all distorted with the distortion increasing toward the poles.



- Lambert Conformal Conic
  - Area, and shape are distorted away from standard parallels. Directions are true in limited areas. Used for maps of North America.



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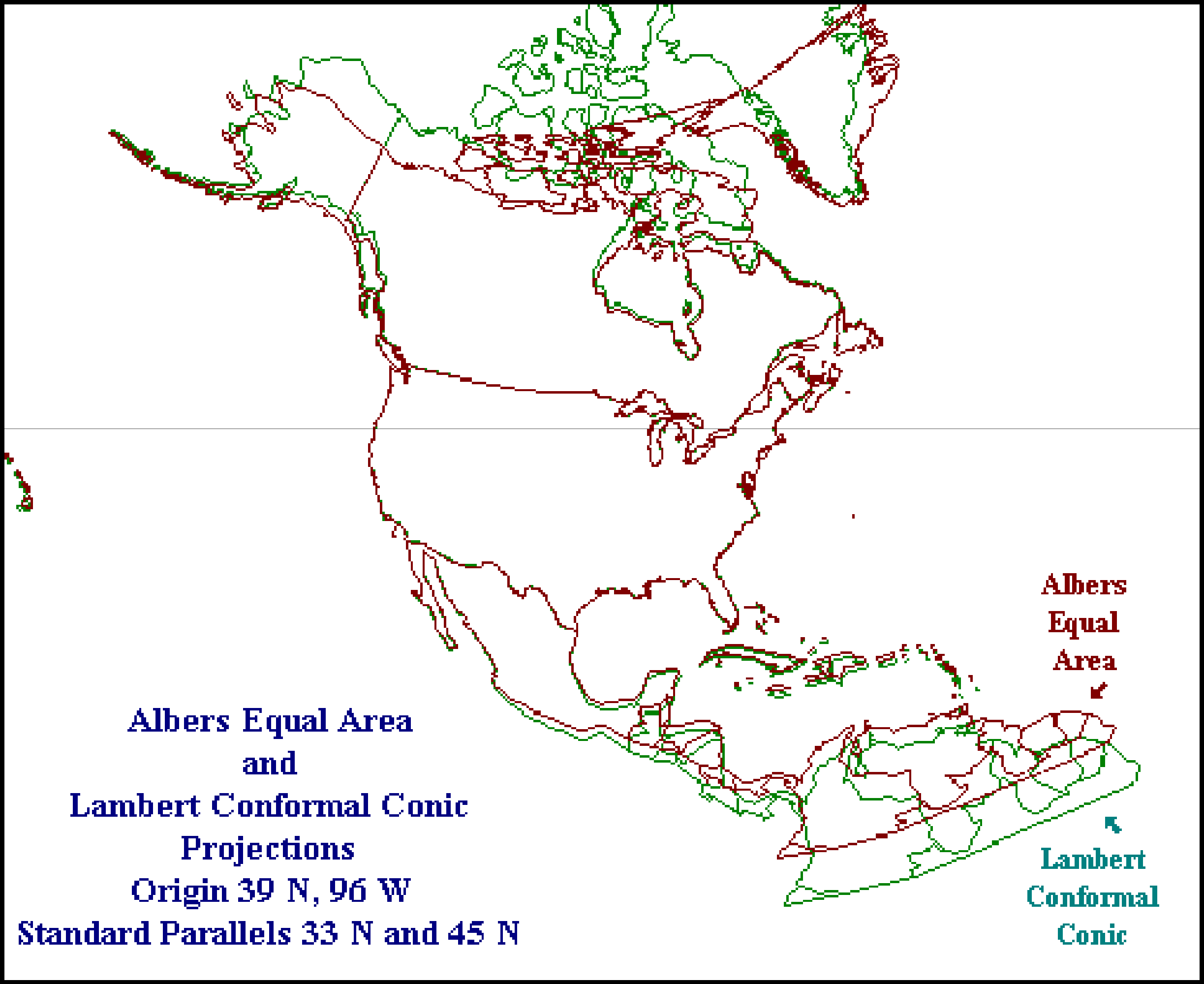
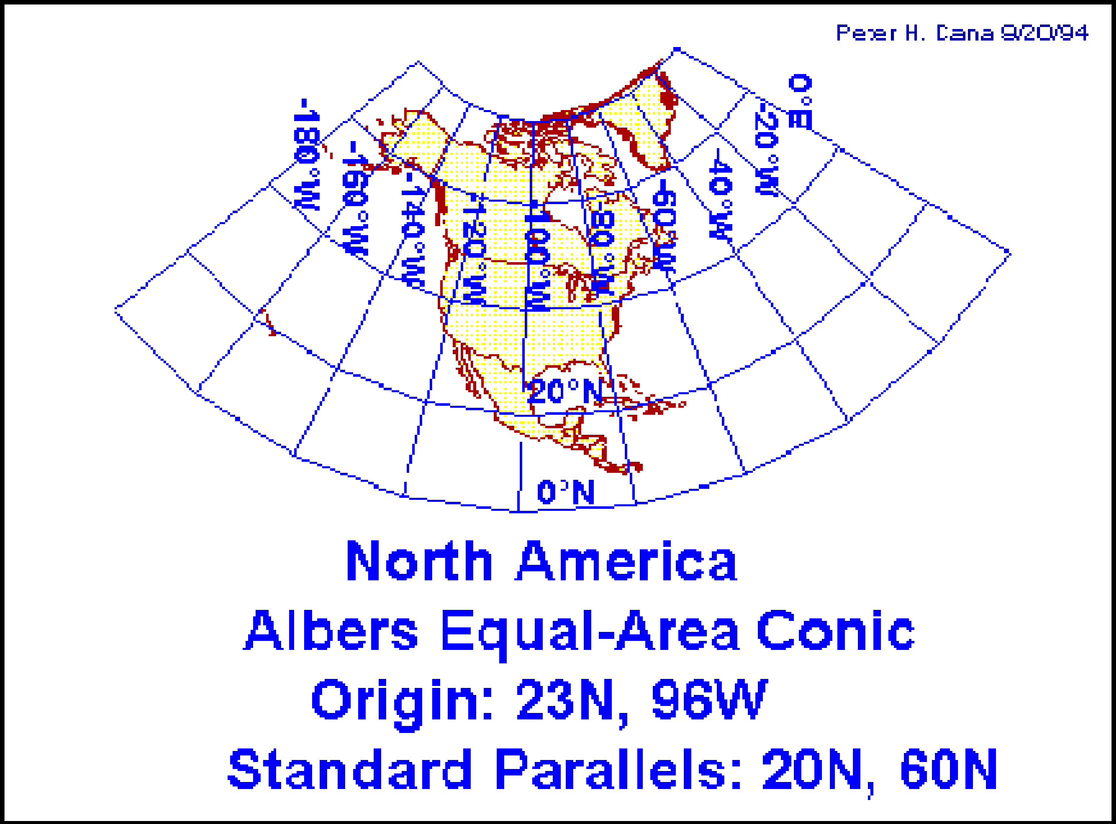


- Albers Equal Area Conic
  - A conic projection that distorts scale and distance except along standard parallels. Areas are proportional and directions are true in limited areas. Used in the United States and other large countries with a larger east-west than north-south extent.



- Transverse Mercator
  - Transverse Mercator projections result from projecting the sphere onto a cylinder tangent to a central meridian. Transverse Mercator maps are often used to portray areas with larger north-south than east-west extent. Distortion of scale, distance, direction and area increase away from the central meridian.
  - Many national grid systems are based on the Transverse Mercator projection
    - The British National Grid (BNG) is based on the National Grid System of England, administered by the British Ordnance Survey.

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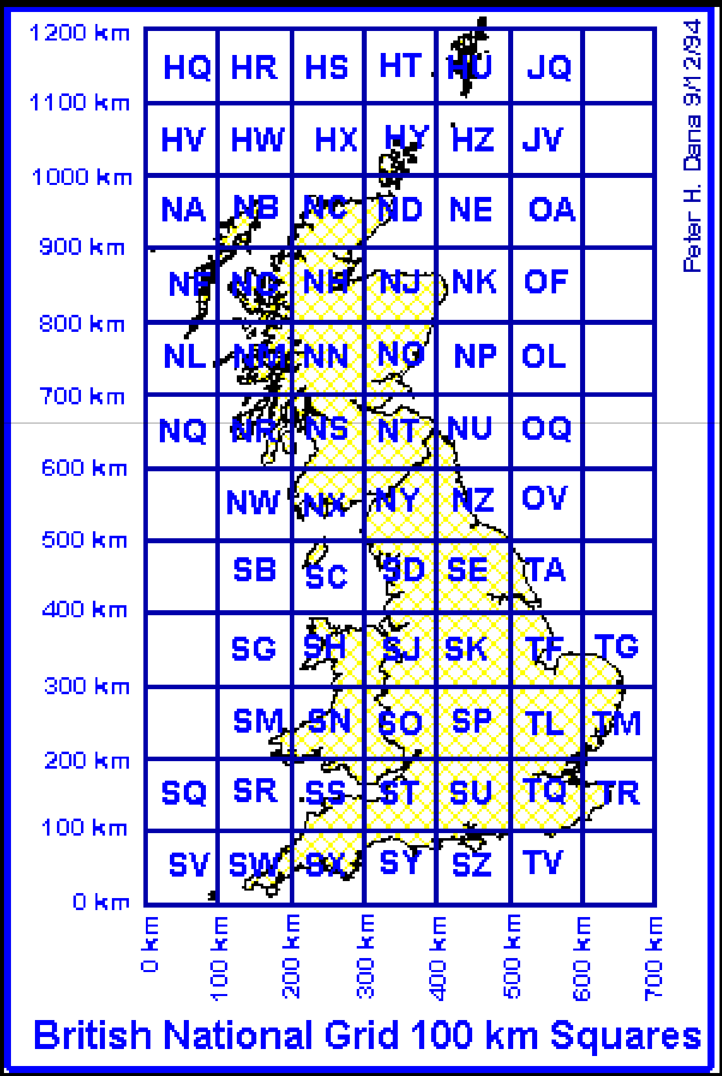
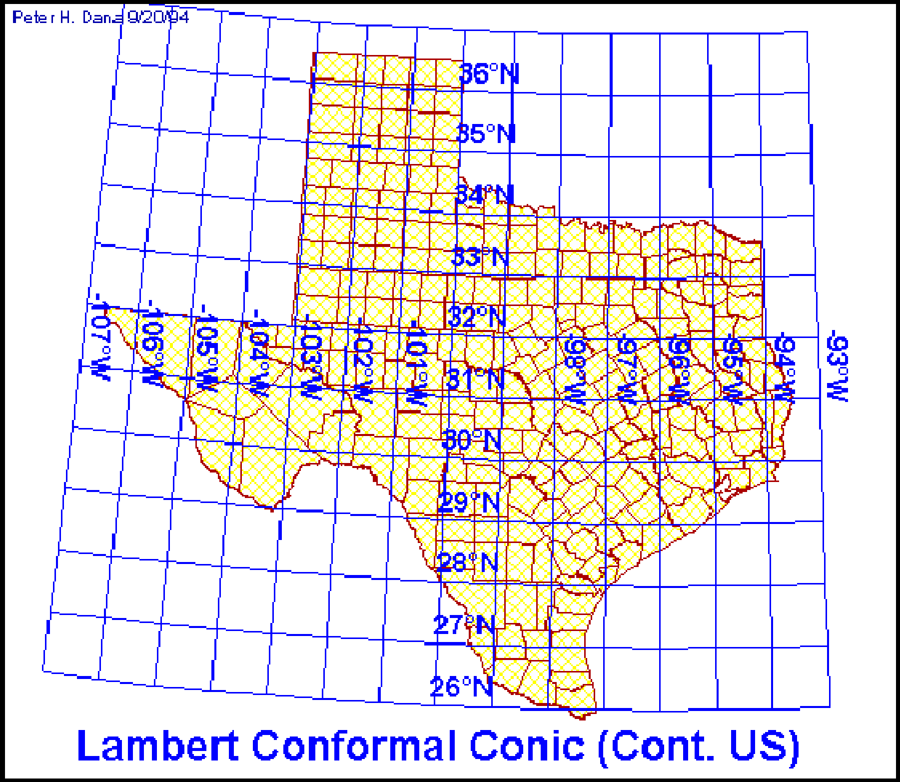


•The true origin of the system is at 49 degrees north latitude and 2 degrees west longitude. The false origin is 400 km west and 100 km north. Scale at the central meridian is 0.9996. The first BNG designator defines a 500 km square. The second designator defines a 100 km square. The remaining numeric characters define 10 km, 1 km, 100 m, 10 m, or 1 m eastings and northings.

- Texas State-Wide Projection
  - In 1992, the Cartographic Standards Working Group proposed a Texas State-Wide Map Projection Standard for the GIS Standards Committee of the GIS Planning Council for the Department of Information Sciences.
  - Earlier maps had often used projections designed for the continental United States



COORDINATE SYSTEMS

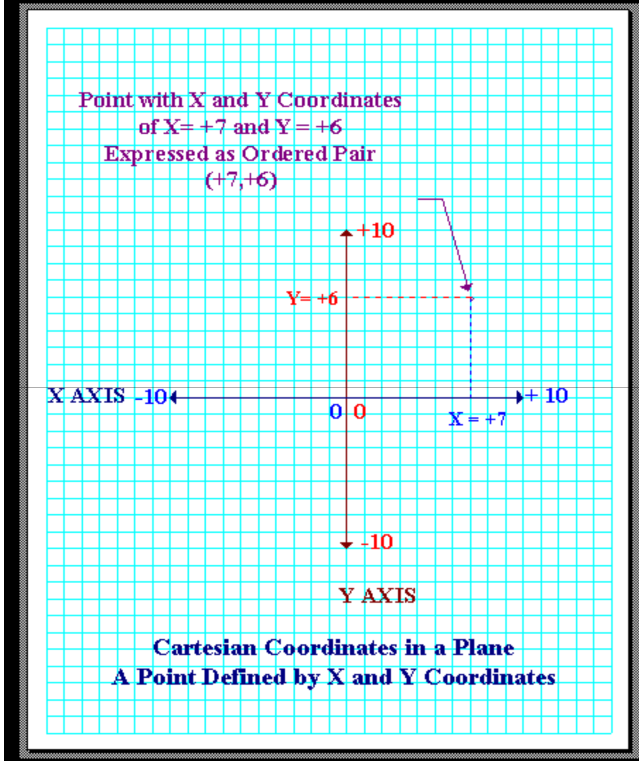
- An overview of coordinate systems for georeferencing provides a brief description of local and global systems for use in precise positioning, navigation, and geographic information systems for the location of points in space.
- There are many different coordinate systems, based on a variety of geodetic datums, units, projections, and reference systems in use today.

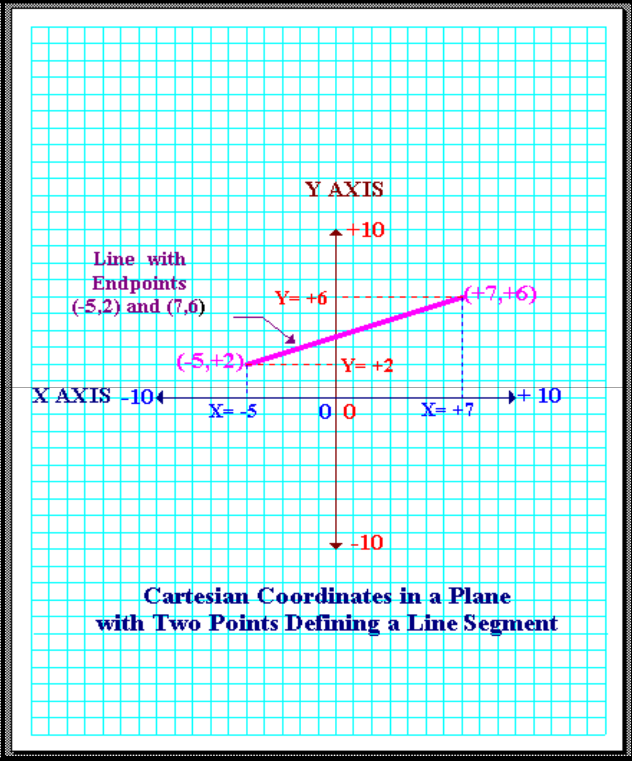
Basic Coordinate Systems

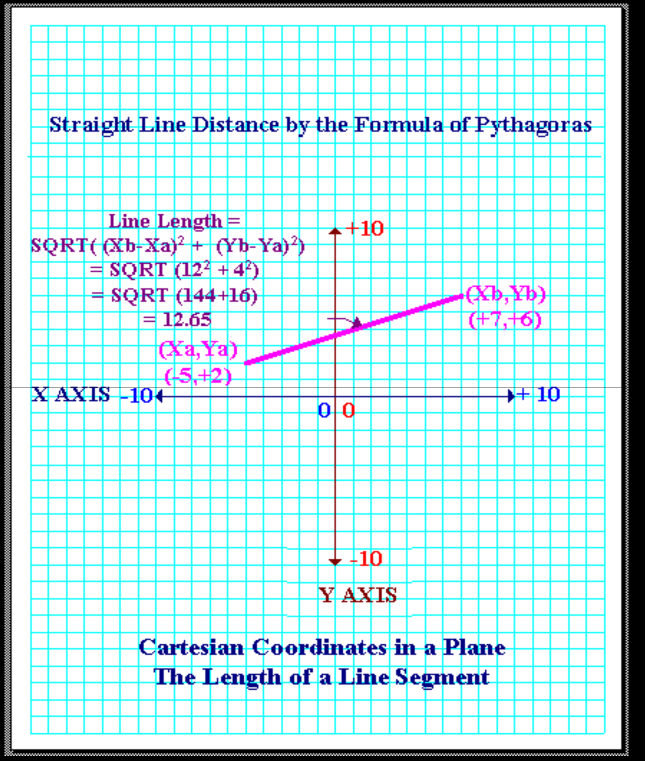
- There are many basic coordinate systems familiar to students of geometry and trigonometry.
- These systems can represent points in two-dimensional or three-dimensional space.
- René Descartes (1596-1650) introduced systems of coordinates based on orthogonal (right angle) coordinates.
- These two and three-dimensional systems used in analytic geometry are often referred to as Cartesian systems.
- Similar systems based on angles from baselines are often referred to as polar systems.

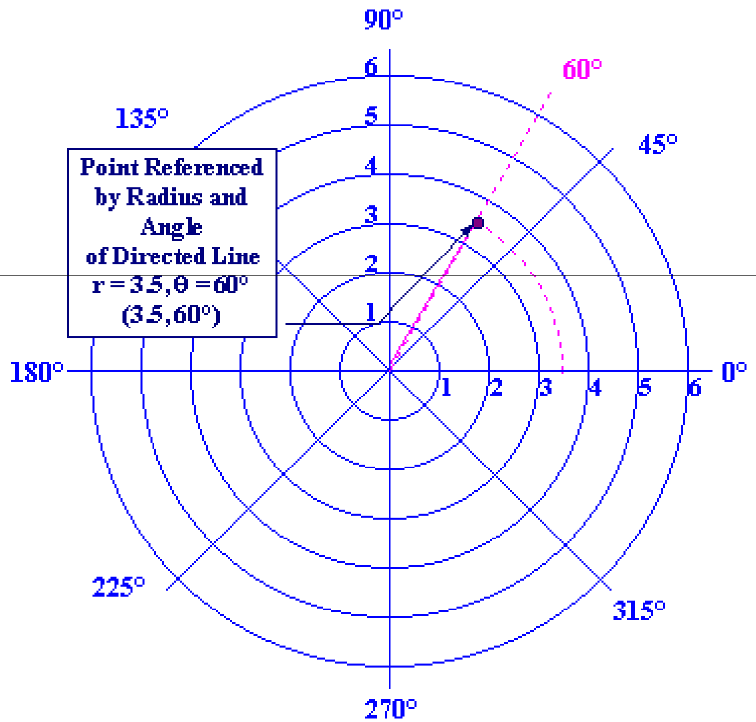
•Plane Coordinate Systems

•Two-dimensional coordinate systems are defined with respect to a single plane.

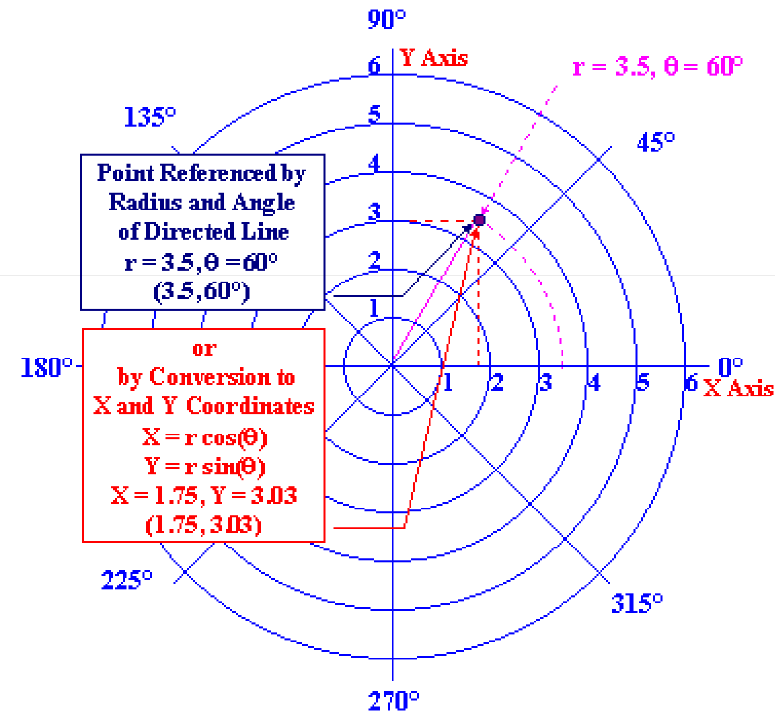






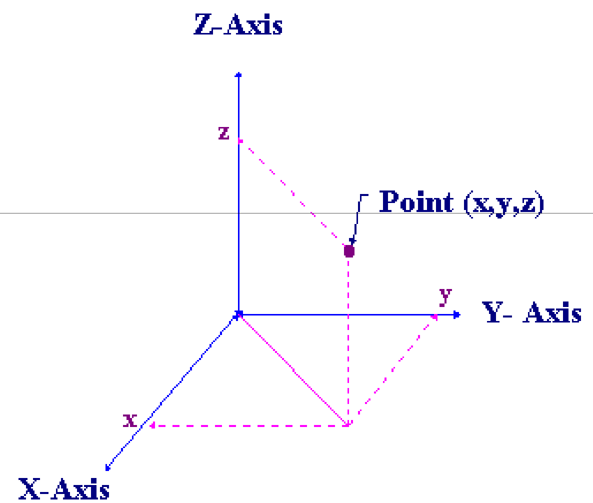


Polar Coordinates in a Plane

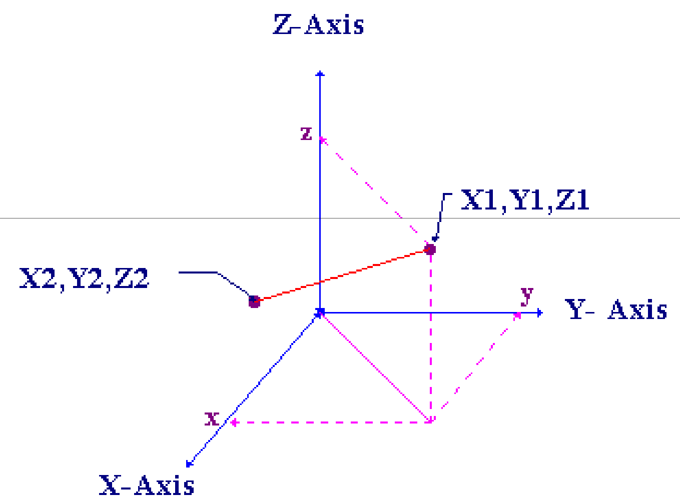


Polar Coordinates in a Plane and Conversion from Polar to Cartesian Coordinates

- Three-Dimensional Systems
  - Three-dimensional coordinate systems can be defined with respect to two orthogonal planes.



Three-Dimensional Cartesian Coordinates
X, Y, Z

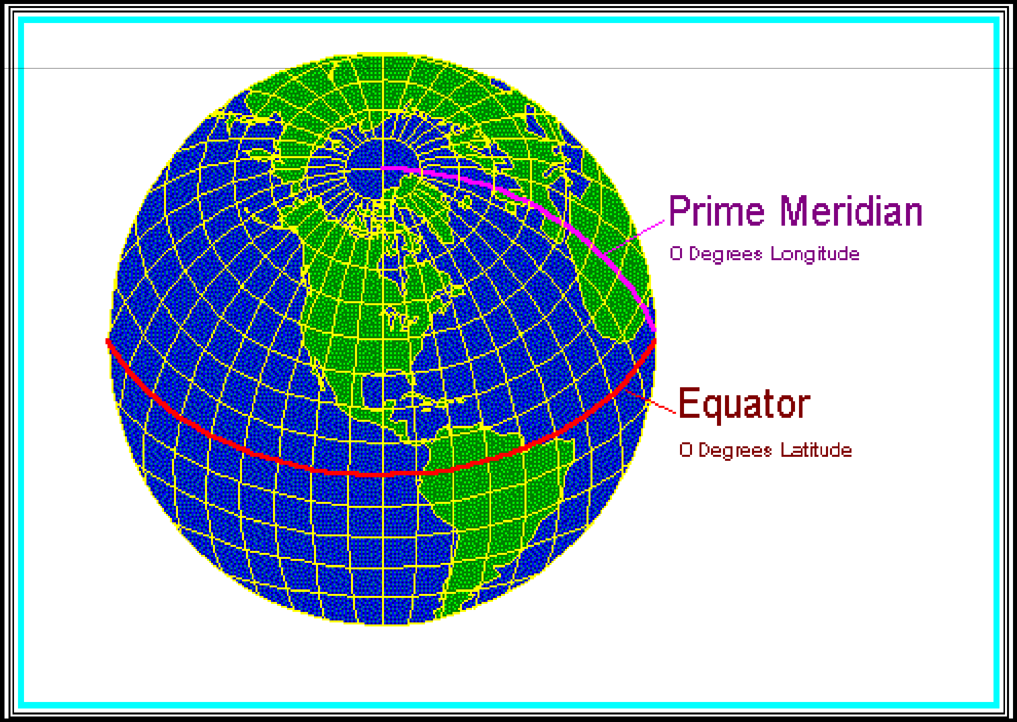


Distance Between
Three-Dimensional Cartesian Coordinates
(X1, Y1, Z1) and (X2, Y2, Z2)
=
SQRT((X1-X2)^2+(Y1-Y2)^2+(Z1-Z2)^2)

Coordinate Systems

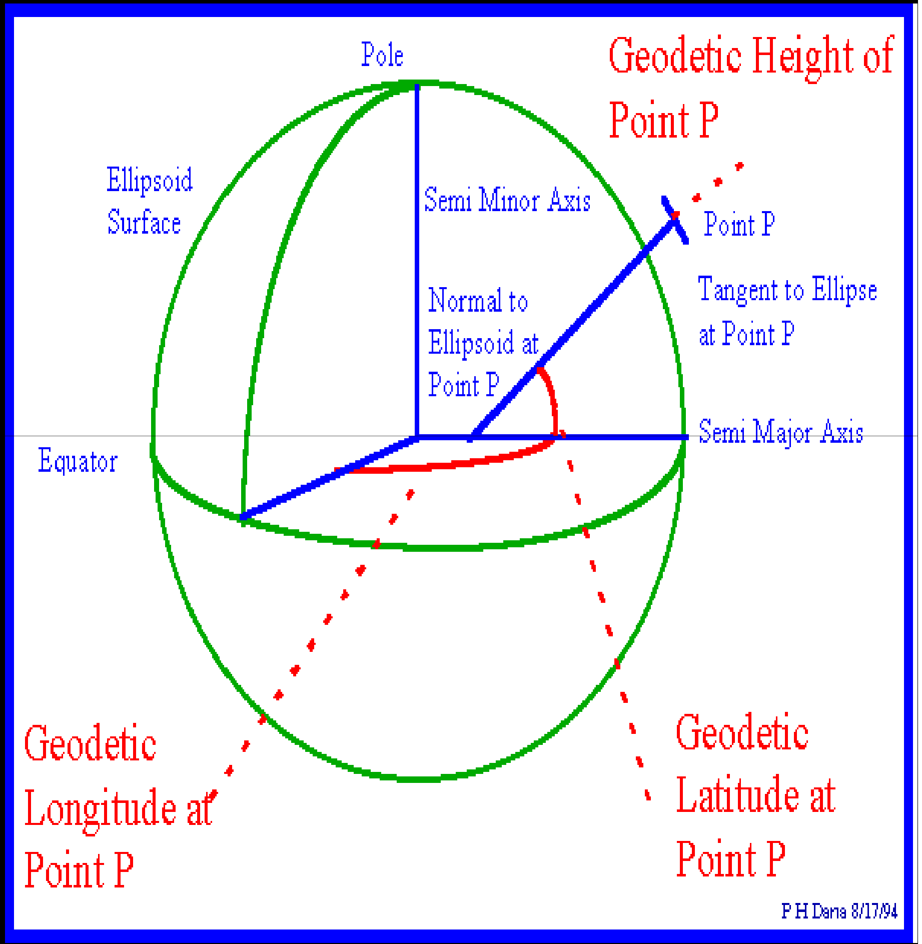
Global Systems

- **Latitude, Longitude, Height**
  - The most commonly used coordinate system today is the latitude, longitude, and height system.
  - The Prime Meridian and the Equator are the reference planes used to define latitude and longitude.
  - _ Equator and Prime Meridian

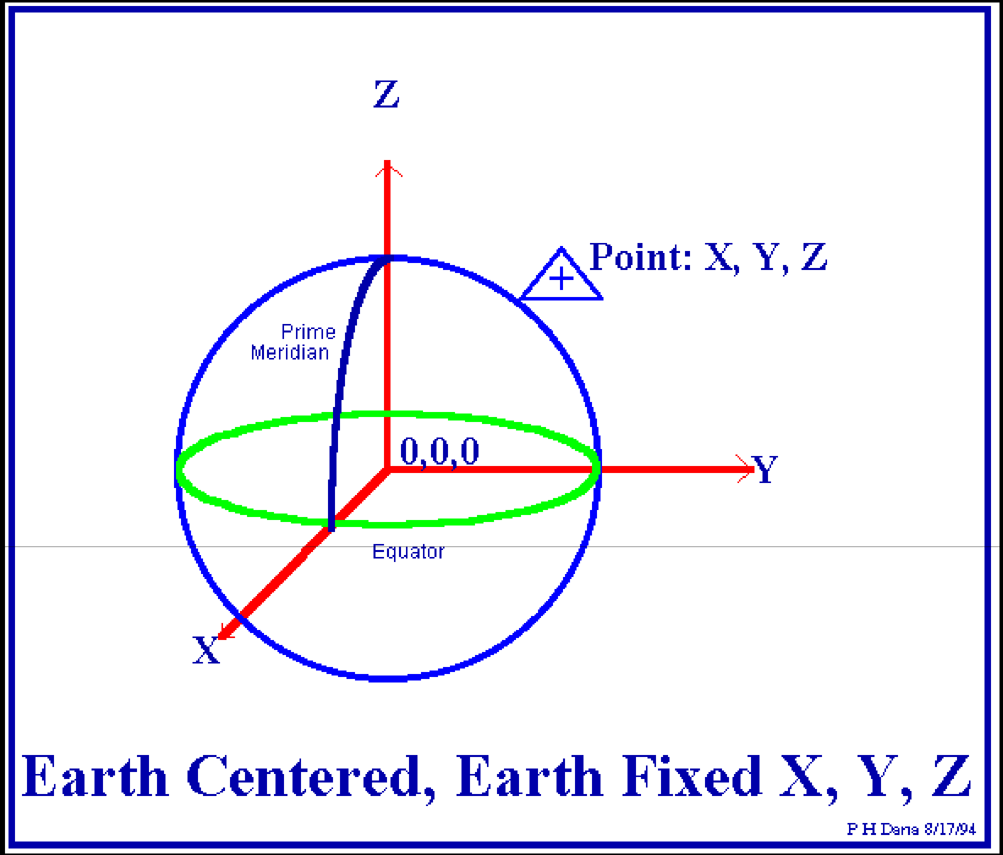


Geodetic Latitude, Longitude, and Height

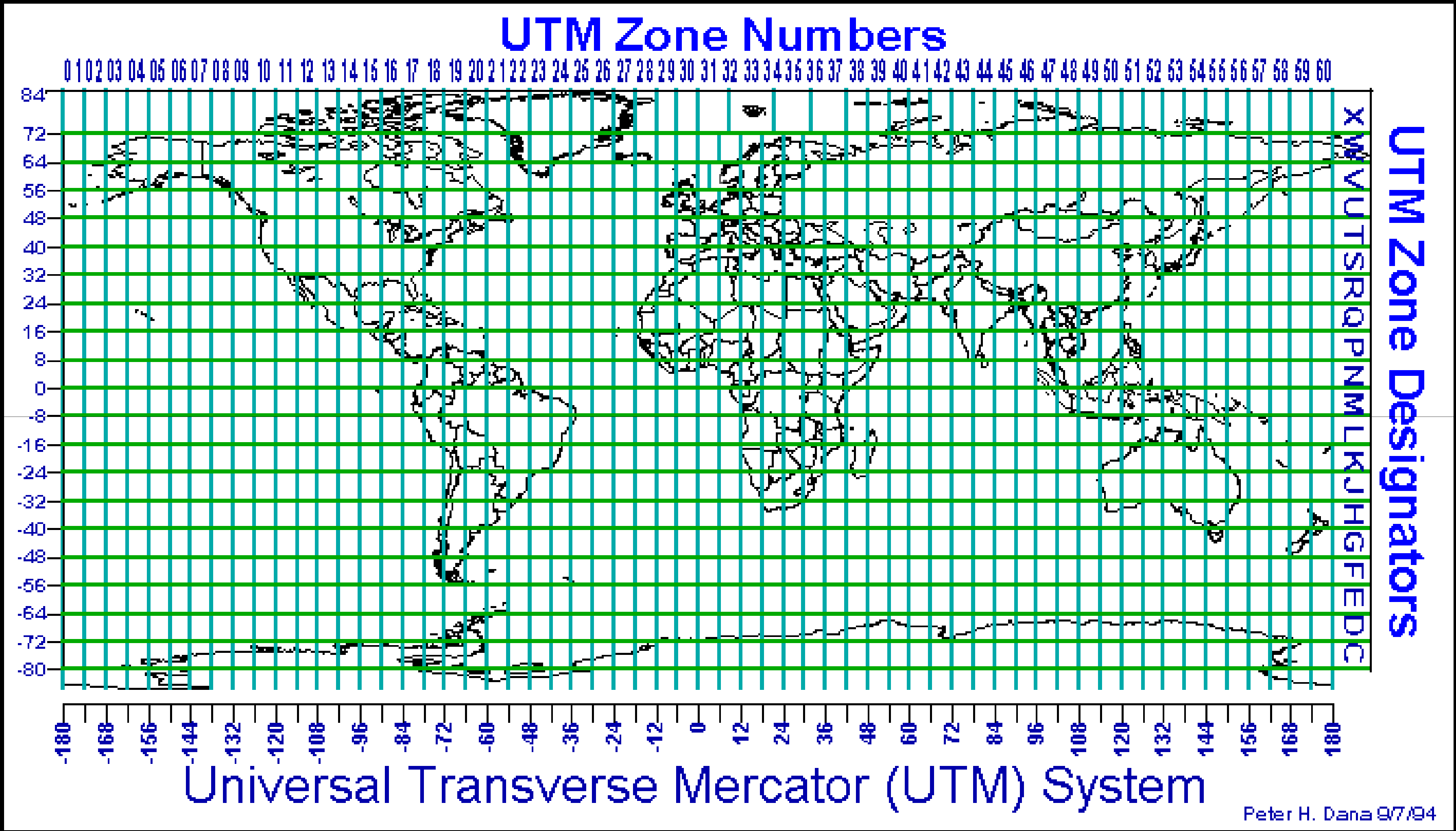
- The geodetic latitude (there are many other defined latitudes) of a point is the angle from the equatorial plane to the vertical direction of a line normal to the reference ellipsoid.
- The geodetic longitude of a point is the angle between a reference plane and a plane passing through the point, both planes being perpendicular to the equatorial plane.
- The geodetic height at a point is the distance from the reference ellipsoid to the point in a direction normal to the ellipsoid.



- ECEF X, Y, Z
  - Earth Centered, Earth Fixed Cartesian coordinates are also used to define three dimensional positions.
  - Earth centered, earth-fixed, X, Y, and Z, Cartesian coordinates (XYZ) define three dimensional positions with respect to the center of mass of the reference ellipsoid.



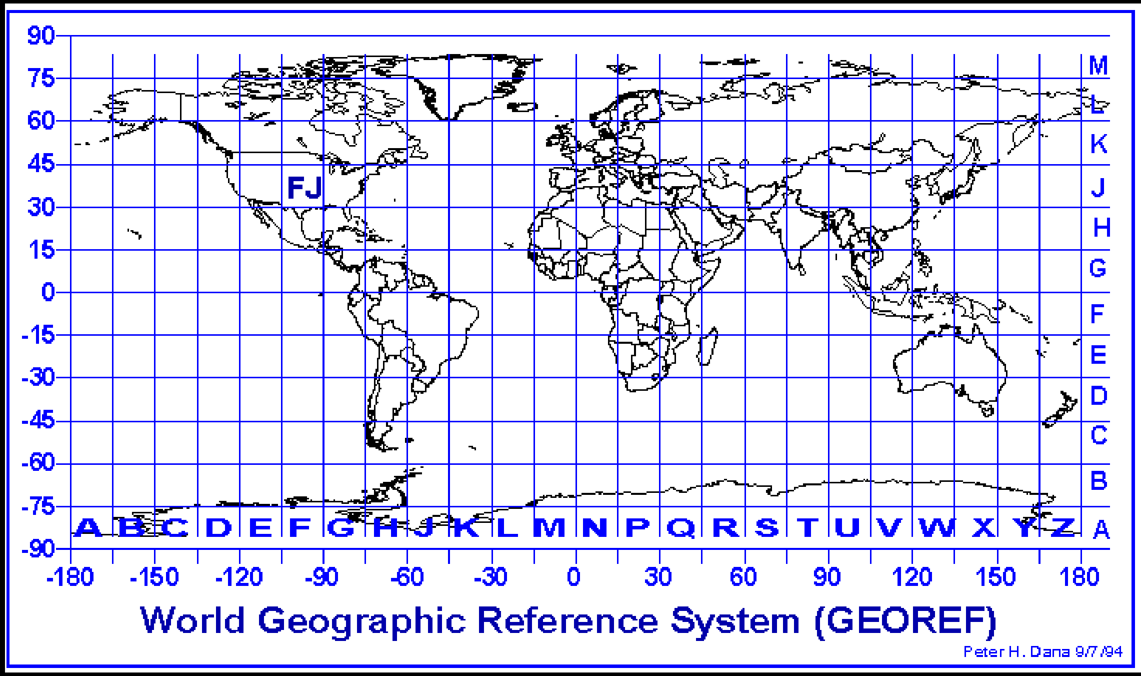
- Universal Transverse Mercator (UTM)
    - Universal Transverse Mercator (UTM) coordinates define two dimensional, horizontal, positions.
    - UTM zone numbers designate 6 degree longitudinal strips extending from 80 degrees South latitude to 84 degrees North latitude.
    - UTM zone characters designate 8 degree zones extending north and south from the equator.



UTM Zone Numbers
UTM Zone Designators
X W V U T S R Q P N M L K J H G F E D C
Universal Transverse Mercator (UTM) System
Peter H. Dana 9/7/94

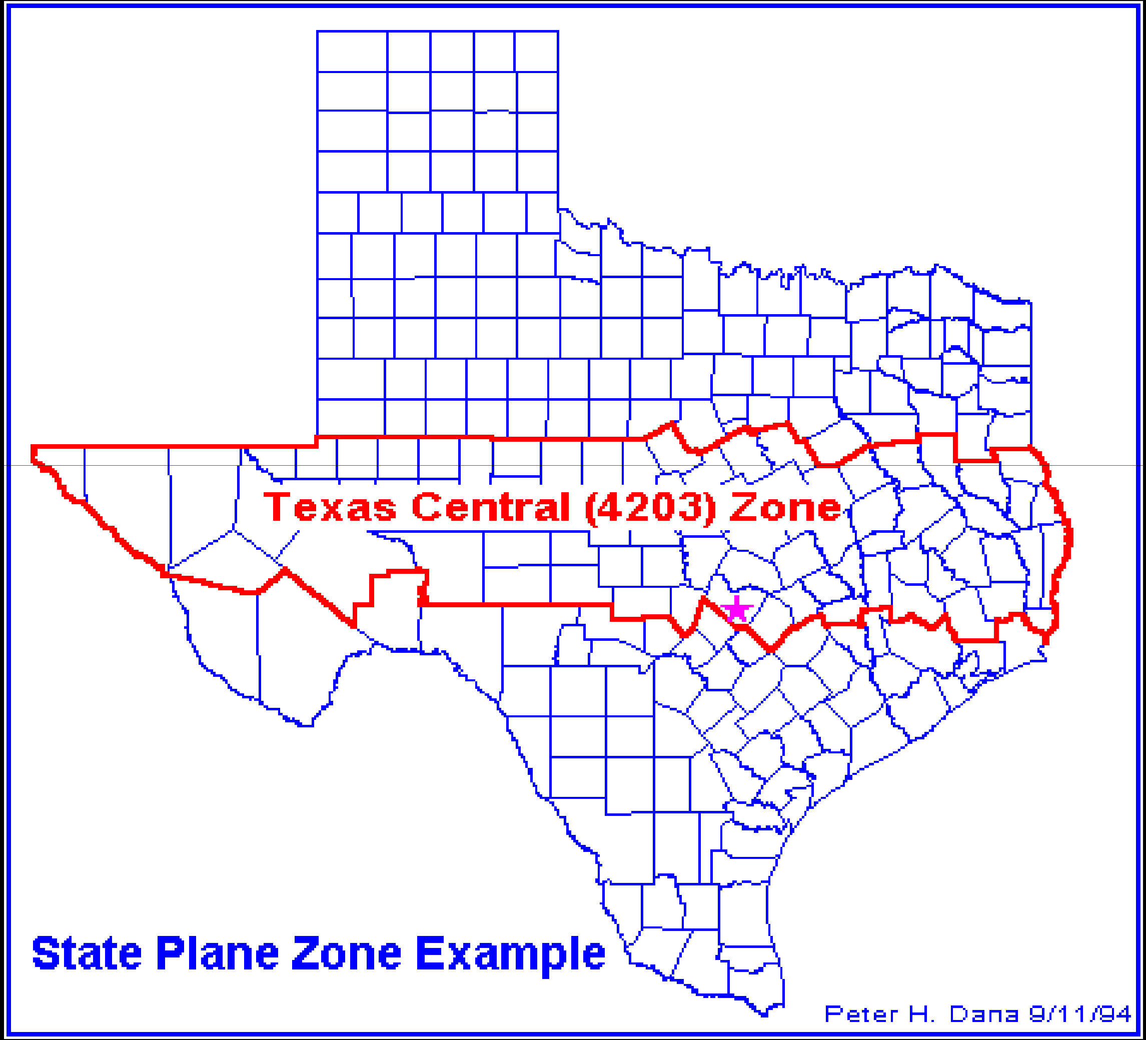
World Geographic Reference System Index (GEOREF)

- The World Geographic Reference System is used for aircraft navigation.
- GEOREF is based on latitude and longitude.
- The globe is divided into twelve bands of latitude and twenty-four zones of longitude, each 15 degrees in extent.



- State Plane Coordinates
  - In the United States, the State Plane System was developed in the 1930s and was based on the North American Datum 1927 (NAD27).
    - NAD 27 coordinates are based on the foot.
    - While the NAD-27 State Plane System has been superseded by the NAD-83 System, maps in NAD-27 coordinates (in feet) are still in use.

State Plane Zone Example



- Most USGS 7.5 Minute Quadrangles use several coordinate system grids including latitude and longitude, UTM kilometer tic marks, and applicable State Plane coordinates.

•The State Plane System 1983 is based on the North American Datum 1983 (NAD83).

- NAD 83 coordinates are based on the meter.

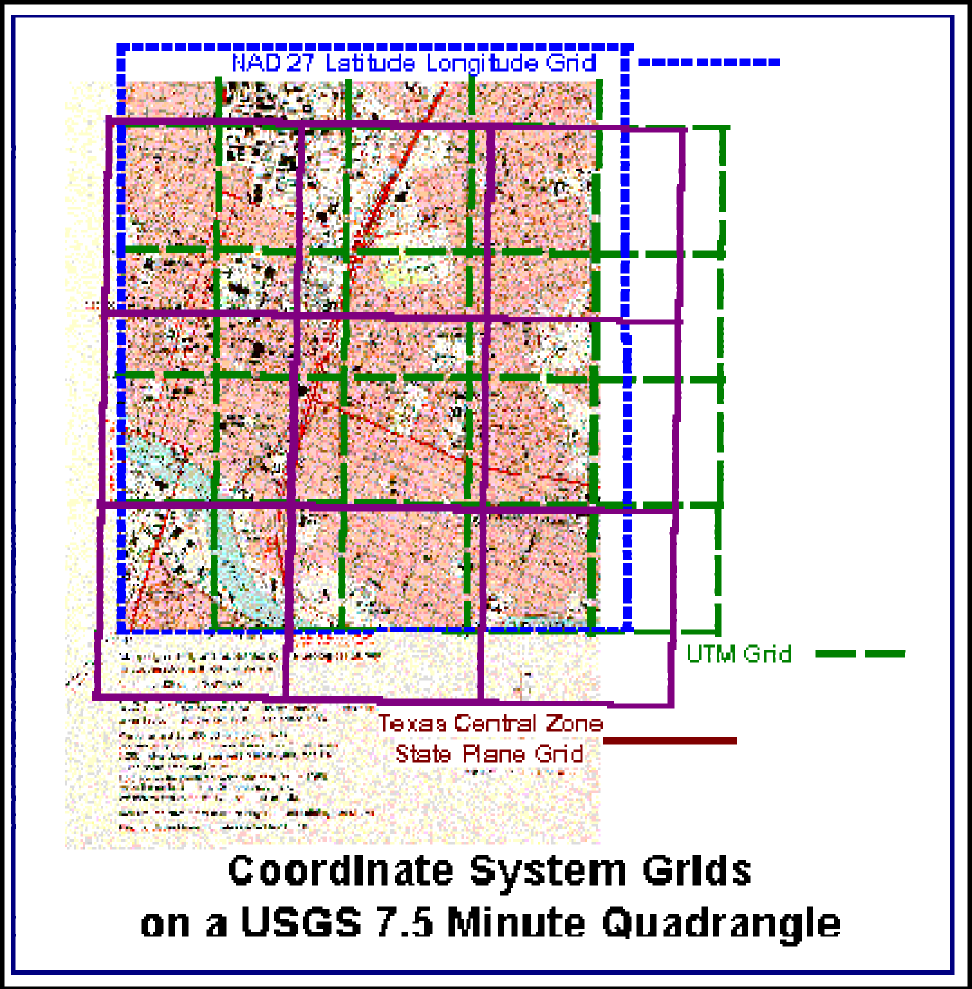
•State plane systems were developed in order to provide local reference systems that were tied to a national datum.

•Some smaller states use a single state plane zone.

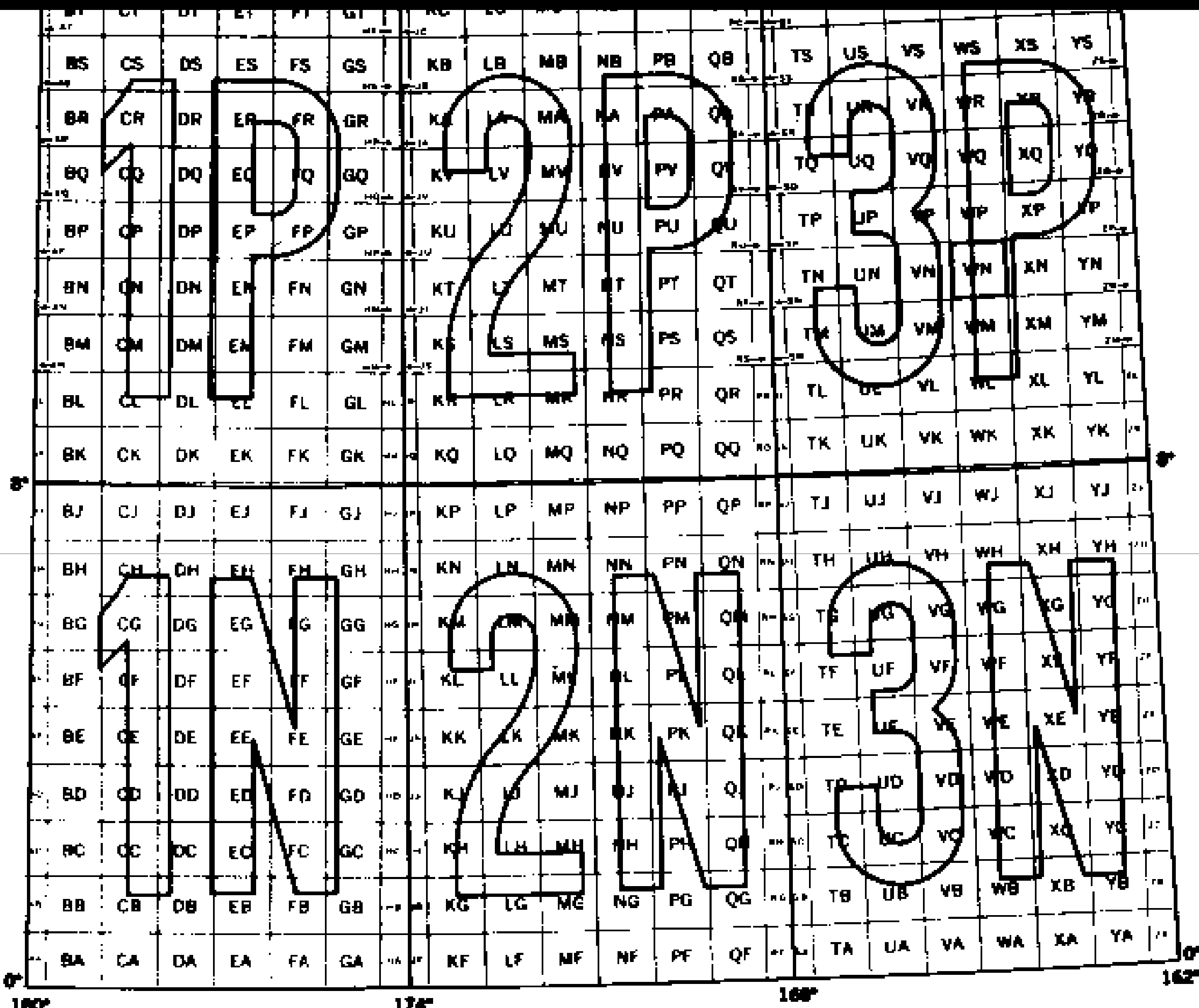
•Larger states are divided into several zones.

•State plane zone boundaries often follow county boundaries.

Three Coordinate Systems on the Austin, East USGS 7.5' Quadrangle



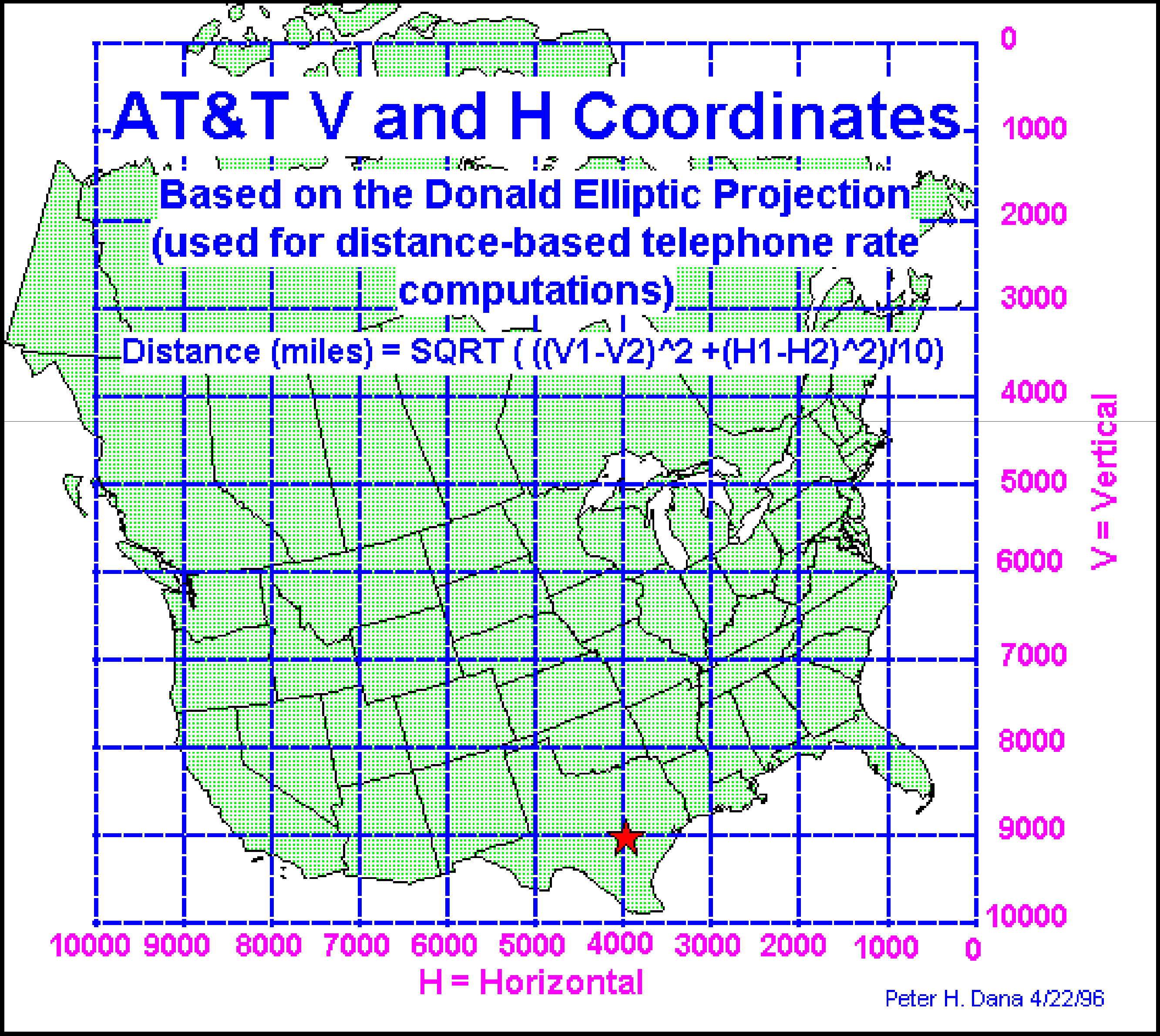
- Military Grid Reference System (MGRS)
  - The Military Grid Reference System (MGRS) is an extension of the UTM system. UTM zone number and zone character are used to identify an area 6 degrees in east-west extent and 8 degrees in north-south extent.
  - UTM zone number and designator are followed by 100 km square easting and northing identifiers.
  - The system uses a set of alphabetic characters for the 100 km grid squares.
  - Starting at the 180 degree meridian the characters A to Z (omitting I and O) are used for 18 degrees before starting over.
  - From the equator north the characters A to V (omitting I and O) are used for 100 km squares, repeating every 2,000 km.



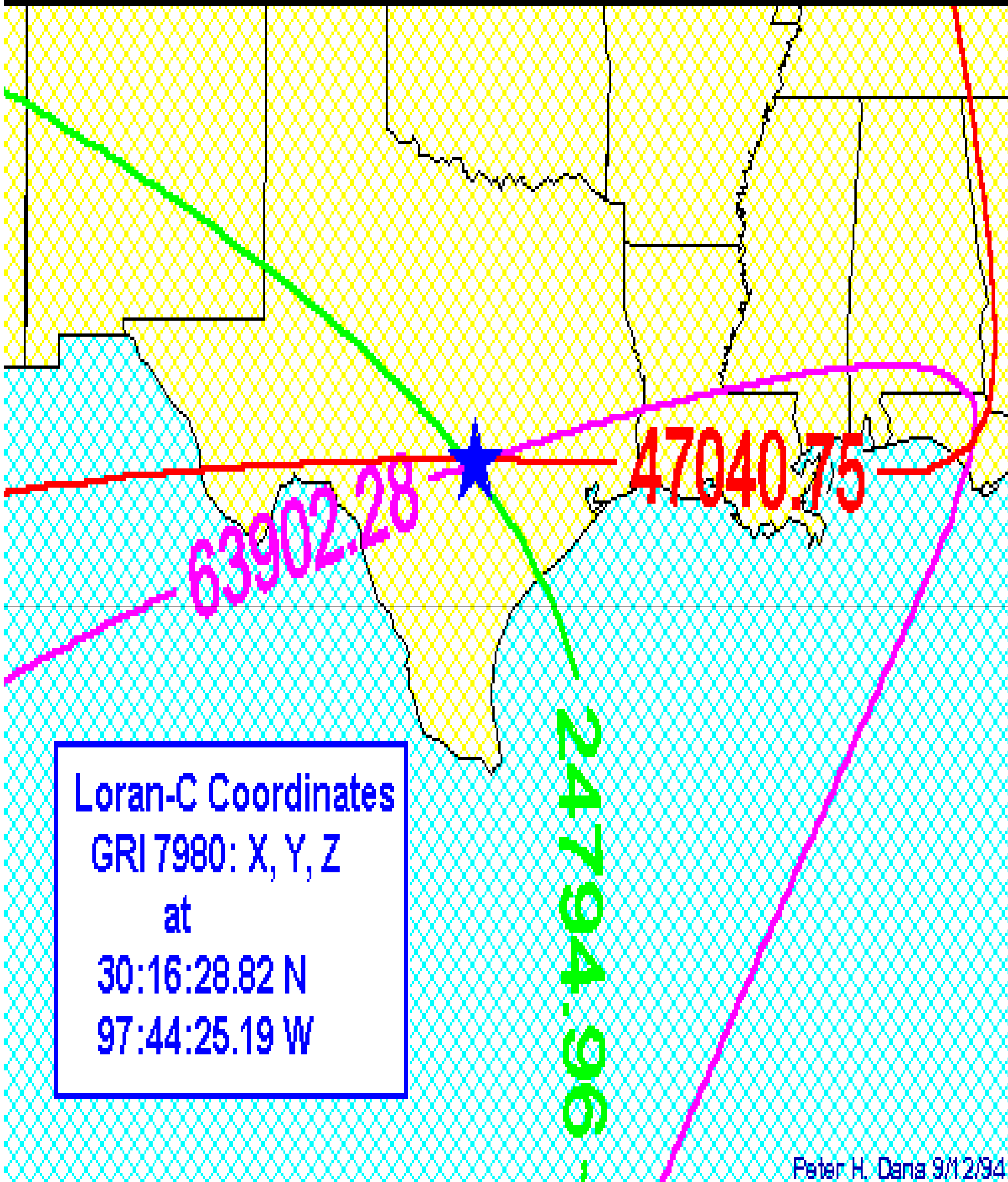
100,000 Meter MGRS Square Designators

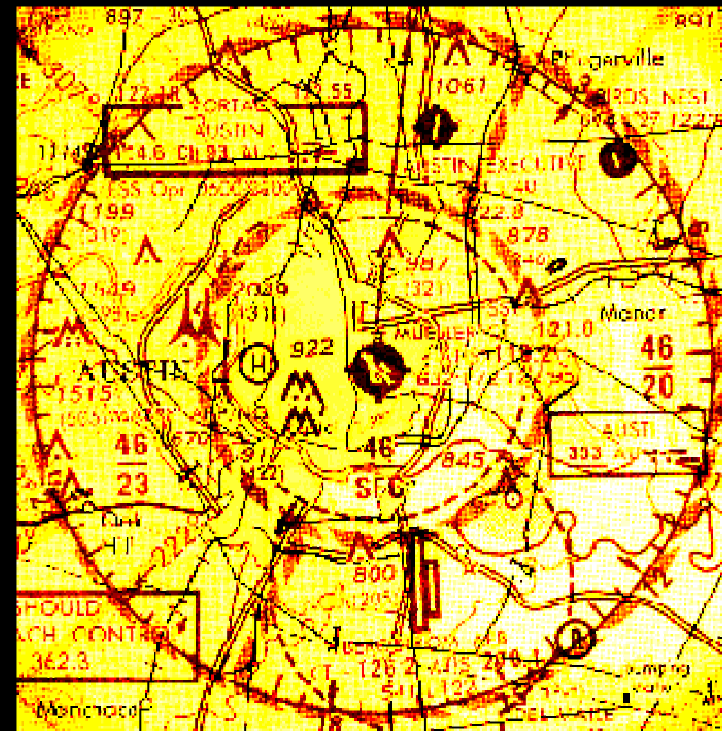
- AT&T V and H Coordinate System
- The AT&T V and H (Vertical and Horizontal) coordinate system was devised in 1957 by Jay K. Donald for the easy computation of distances between telephone switching centers. The system is based on the Donald Elliptic Projection, a two-point equidistant projection covering the land masses of the continental United States and Canada. The system is based on units of the square-root of one-tenth of a mile.

- AT&T V and H Coordinates - Donald Elliptic Projection



- Navigation systems can define locations by referencing measurements of electronic signals.
  - Loran-C time-differences can identify positions with an accuracy of one-quarter of a mile.
    - _ Loran-C Time Differences
  - Omega phase-differences can identify positions with an accuracy of 1-5 kms.
  - VOR-DME (Very high frequency Omni Range - Distance Measuring) measurements from an aircraft can identify locations with an accuracy of 0.5-3 kms.
    - _ VOR-DME Chart Detail
    - _ VOR - DME Coordinates





NAD-83 Latitude, Longitude
30:16:28.82 N 97:44:25.19 W

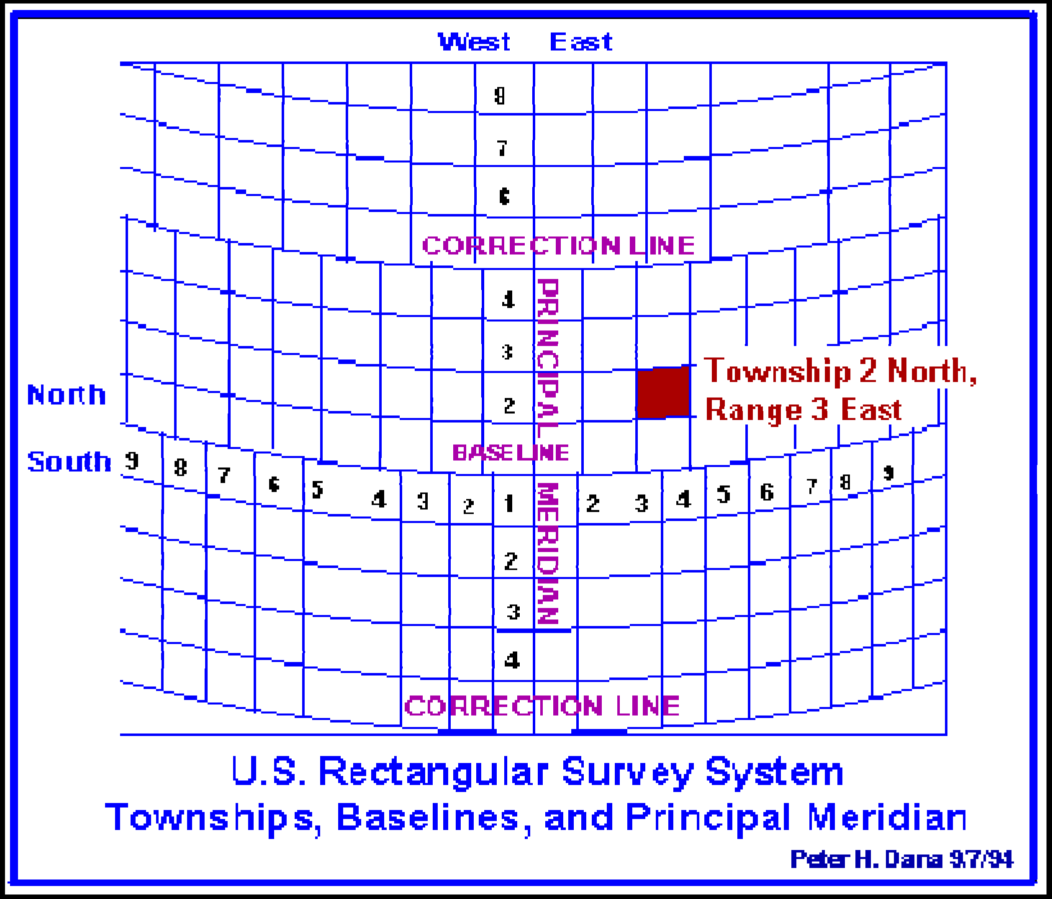
230.46 degrees
2.271 nmi
114.6 Ch. 93 AUS

VOR-DME Example

- Postal Codes
    - Postal codes such as the United States ZIP code can be used to identify areas.
    - Three digit codes identify large areas.

- Public Land Rectangular Surveys
    - Public Land Rectangular Surveys have been used since the 1790s to identify public lands in the United States.
    - The system is based on principal meridians and baselines.
    - Townships, approximately six miles square, are numbered with reference to baseline and principal meridian.
    - Ranges are the distances and directions from baseline and meridian expressed in numbers of townships.
    - Every four townships a new baseline is established so that orthogonal meridians can remain north oriented.

Public Land Rectangular Surveys



The Austin Capitol Dome Liberty Star Horizontal Control Station
(The star in the hand of the Goddess of Liberty)

Datum	Coordinate System	Coordinates	Units
NAD 83	Geodetic Latitude, Longitude	30:16:28.82 N, 97:44:25.19 W	deg:min:sec
NAD-27	Geodetic Latitude, Longitude	30:16:28.03 N, 97:44:24.09 W	deg:min:sec
WGS-72	Geodetic Latitude, Longitude	30:16:28.68 N, 97:44:25.75 W	deg:min:sec
NAD-83	UTM Easting, Northing, Zone	621160.98, 3349893.53 14 R	meters
NAD-27	UTM Easting, Northing, Zone	621193.18, 3349688.21	meters
NAD-83	Military Grid Reference System	14RPU2116149894	meters
NAD-27	Military Grid Reference System	14RPJ2119349688	meters
NAD-83	State Plane, TX C 4203 Easting, Northing	949465.059, 3070309.475	meters
NAD-27	State Plane, TX C 4203 Easting, Northing	2818560.55, 230591.76	feet
NAD-83	State Plane, TX SC 4204 Easting, Northing	721201.977, 4271229.432	meters
NAD-27	State Plane, TX SC 4204 Easting, Northing	2397741.25, 889749.98	feet
WGS-72	World Geographic Reference System	FJHA1516	deg. and min.
	VOR-DME Bearing, Distance, VOR ID	230.46, 2.271, 114.6 Ch.93 AUS	deg,nmi,id
	Loran-C GRI 7980 W, X, Y, Z TDs	10998.9,24795.0,47040.8,63902.3	microsec.
	U.S. Postal Zip Code (5-digits)	78705	

One Location Described by Different Coordinate Systems

P. H. Dana 8/20/98

•**What are NAD 27 and NAD 83?**

•The North American Datum of 1927 (NAD 27) is "The *horizontal control datum* for the United States that (was) defined by (a) location and azimuth on the Clarke spheroid of 1866, with origin at (the survey station) Meades Ranch." ... The geoidal height at Meades Ranch (was) assumed to be zero.

- "This datum, designated as NAD 83, is the new geodetic reference system. ... NAD 83 is based on the adjustment of 250,000 points including 600 satellite Doppler stations which constrain the system to a geocentric origin." (Geodetic Glossary, pp 57)

- The North American Datum of 1983 (NAD 83) is "The *horizontal control datum* for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the *Geodetic Reference System 1980*.

The NAD 27 was based on the Clarke Ellipsoid of 1866 and the NAD 83 is based on the Geodetic Reference System of 1980.

The NAD 27 was computed with a single survey point, MEADES RANCH in Kansas, as the datum point, while the NAD 83 was computed as a geocentric reference system with no datum point. NAD 83 has been officially adopted as the legal horizontal datum for the United States by the Federal government, and has been recognized as such in legislation in 44 of the 50 states.

The computation of the NAD 83 removed significant local distortions from the network which had accumulated over the years, using the original observations, and made the NAD 83 much more compatible with modern survey techniques

Geodetic Datums

Datum Types

•Datum types include horizontal, vertical and complete datums.

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Datums in Use

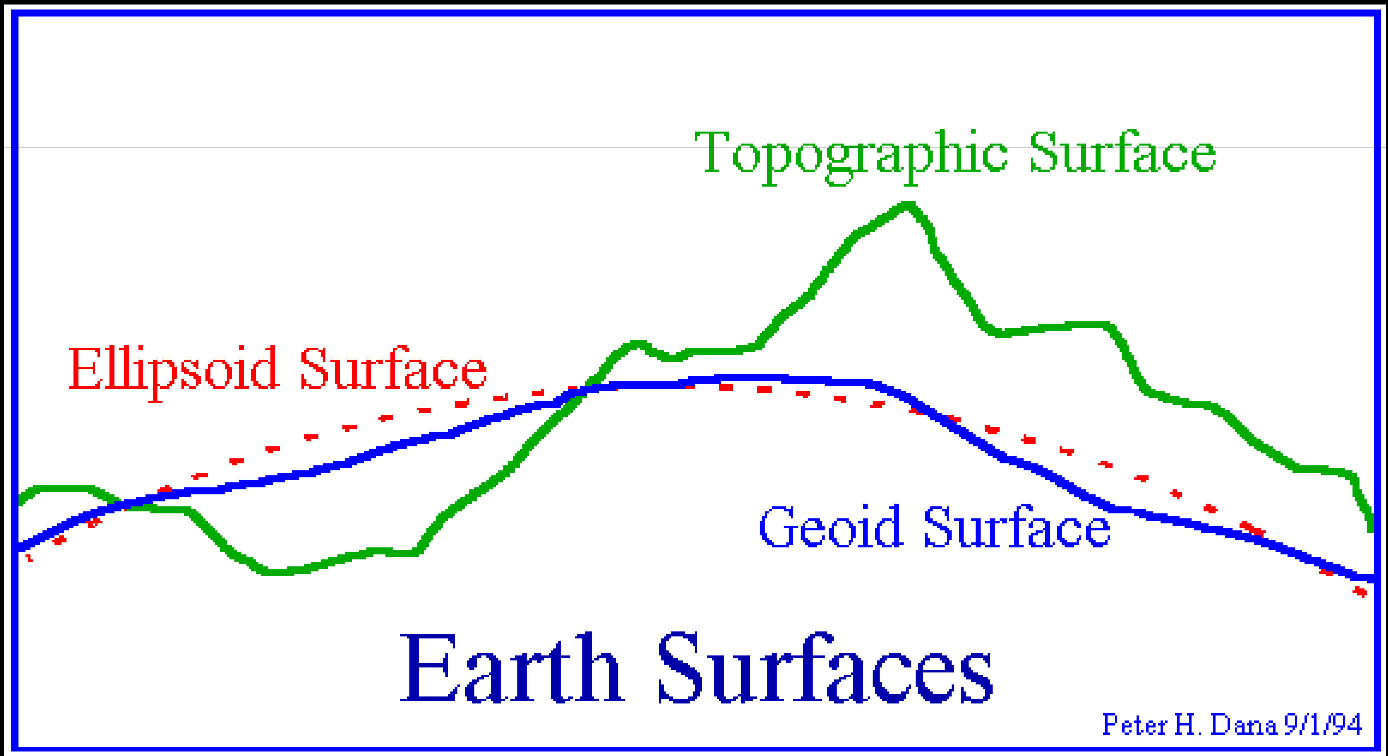
•Hundreds of geodetic datums are in use around the world.

•The Global Positioning system is based on the World Geodetic System 1984 (WGS-84).

•Parameters for simple XYZ conversion between many datums and WGS-84 are published by the Defense mapping Agency.

- Geodetic datums define
- size and shape of the earth
- the origin and orientation of the coordinate systems used to map the earth
- Hundreds of different datums have been used to frame position descriptions since the first estimates of the earth's size were made by Aristotle.
- Datums have evolved from those describing a spherical earth to ellipsoidal models derived from years of satellite measurements.

•The earth has a highly irregular and constantly changing surface. Models of the surface of the earth are used in navigation, surveying, and mapping. Topographic and sea-level models attempt to model the physical variations of the surface, while gravity models and geoids are used to represent local variations in gravity that change the local definition of a level surface



•Referencing geodetic coordinates to the wrong datum can result in position errors of hundreds of meters.

•Different nations and agencies use different datums as the basis for coordinate systems used to identify positions in geographic information systems, precise positioning systems, and navigation systems.

• The diversity of datums in use today and the technological advancements that have made possible global positioning measurements with sub-meter accuracies requires careful datum selection and careful conversion between coordinates in different datums.

- I hope you enjoyed the lecture today!