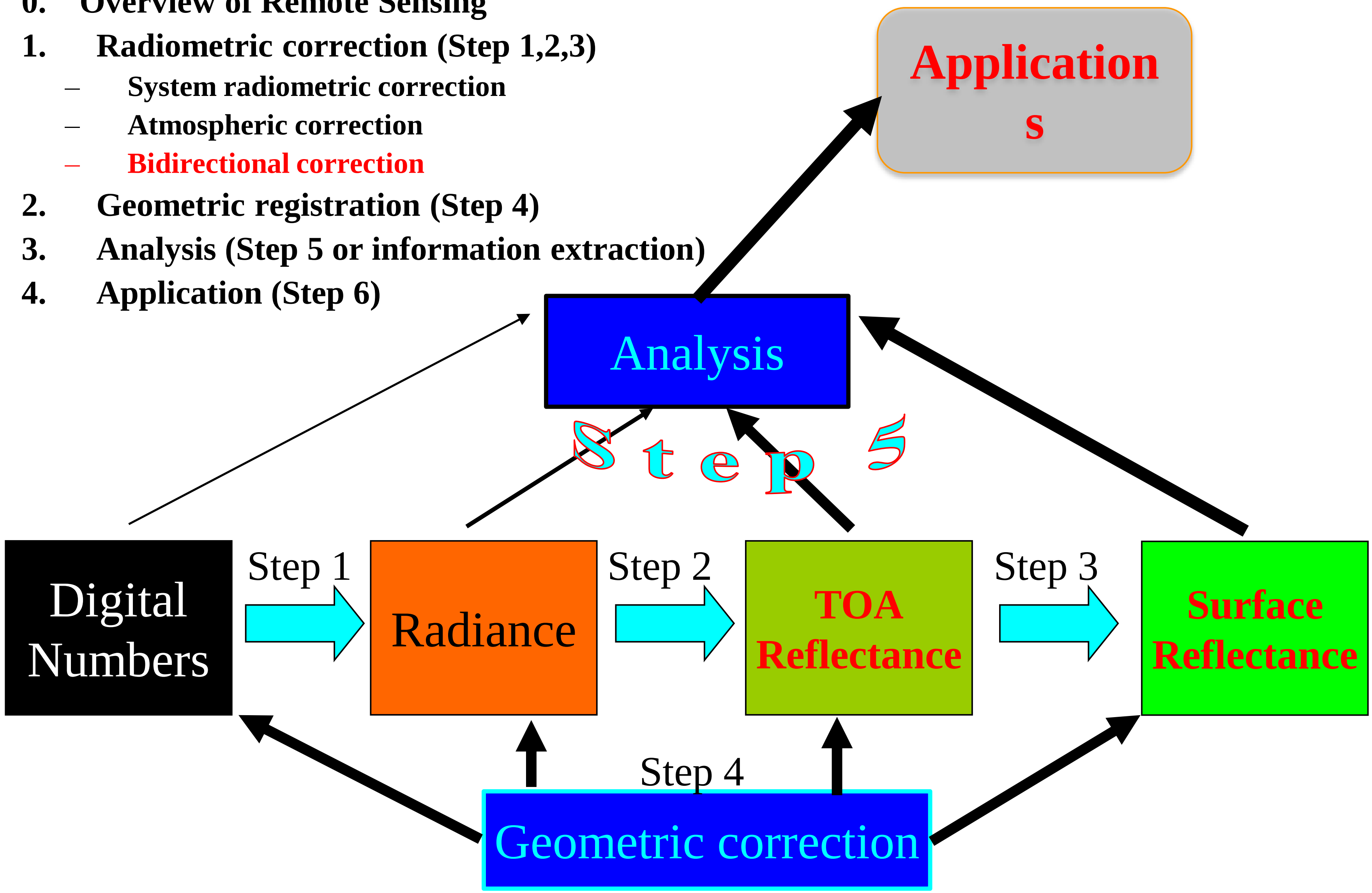
# DIPA Flowchart – All you need to know

0. **Overview of Remote Sensing**
1. **Radiometric correction (Step 1,2,3)**
   - **System radiometric correction**
   - **Atmospheric correction**
   - **Bidirectional correction**
2. **Geometric registration (Step 4)**
3. **Analysis (Step 5 or information extraction)**
4. **Application (Step 6)**



# Geometric Correction

Registering satellite imagery to earth coordinates

# Reading Assignment

- MODIS data products use different projection coordinate systems. Search MODIS web site to learn how the " Integerized Sinusoidal Projection" is different from the Sinusoidal project system.
- Download MRT (MODIS Reprojection Tools) to read the HDF-EOS format data.

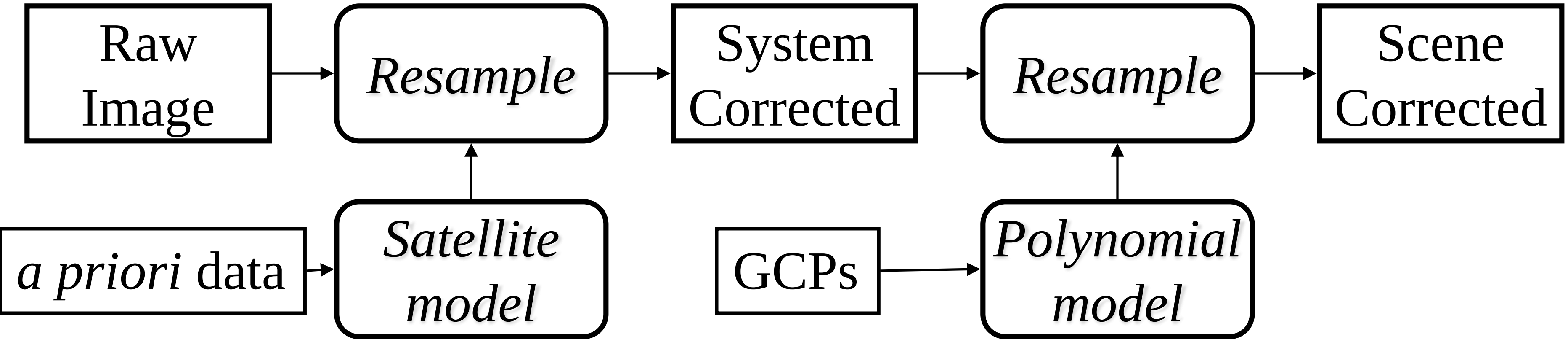
# Topics

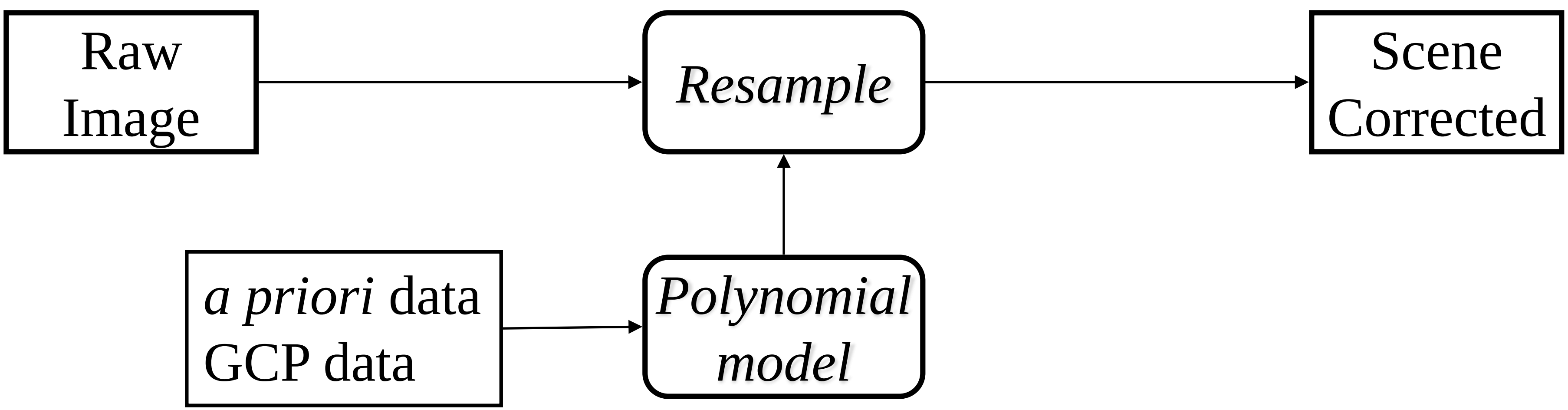
- Concept of geometric registration
  - Sources of errors
  - Common techniques
- Basic coordinate systems
  - Shape of the earth
- Examples of global and regional coordinate systems
- Rectification/Orthorectification

# Source of Geometric Distortion

- Variations in platform altitude, velocity and attitude (pitch, roll, yaw)
- Aspect ratio distortion: Mechanical reasons to cause distortion in the vertical direction, resulting overlaps.
- Sensor scan nonlinearities: mirror scanning rate changes – resulting in distortions

# General Process



# Terms You Heard

- Registration:
  - The process of making an image conform to another image; alignment of one image to another of the same area
- Rectification/Georeferencing:
  - The process of  assigning map coordinates to image data; The alignment of an image to a map so that the image is planimetric, just like the map

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# Terms You Heard

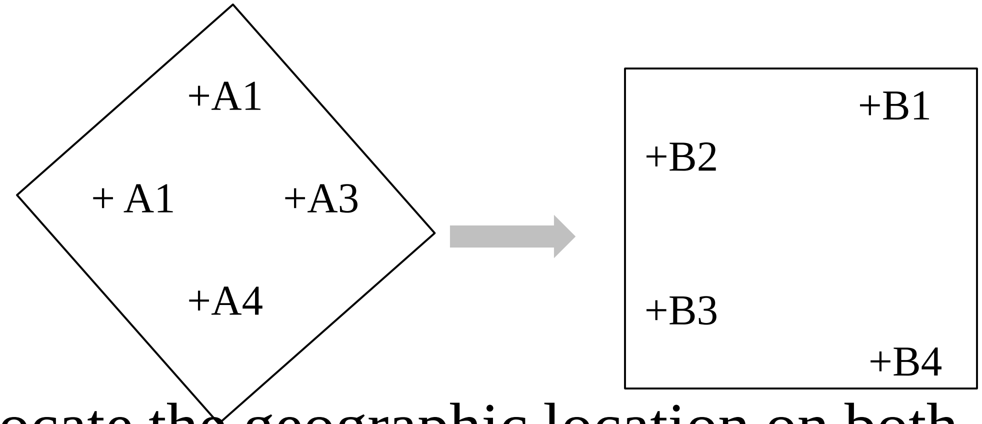
- Ortho-rectification:
  - A form of rectification that corrects for terrain displacement.  DEMs are necessary.

# Corrections of Geometric Distortion

- There are two ways to correct geometric distortions:
  - Model the nature and magnitude of the sources of distortion and use these models to establish correction equations
  - Establish mathematical relationships between the locations of pixels in an image and the corresponding geographic coordinates of those points (pixels) on the ground. This can be done in two ways:
    - Image to Map
    - Image to Image

# Registration/Rectification

**Image to image or image to map**




In either case, one has to locate the geographic location on both the image and the map (or pre-registered images) and perform a transformation.

There are many projections used and commonly used one is UTM (Universal Transverse Mercator).

NOTE: choice of projection system depends on a few things: geographic location, size of the areas of interest, focus of AOI, etc.

# Registration / Rectification

- Image to Map
  - Assumption: You have already had a map.

$$x = f(x_{ref}, y_{ref})$$

$$y = g(x_{ref}, y_{ref})$$

# Registration / Rectification

- Image to Map
  - Assumption: You have already had a map.
- Polynomial Distortion Model

$$x = \sum_{i}^{N} \sum_{j}^{N-i} a_{ij} x_{ref}^{i} y_{ref}^{j}$$

$$y = \sum_{i}^{N} \sum_{j}^{N-i} b_{ij} x_{ref}^{i} y_{ref}^{j}$$

*Note: No reason to believe that the transformation should be polynomial. However, polynomial is widely used for all types of data analysis*

# Registration / Rectification

- Polynomial Distortion Model
  - Third Order Polynomial Example:

$$x = a_{00} + a_{10}x_{ref} + a_{01}y_{ref} + a_{11}x_{ref}y_{ref} + a_{20}x^2_{ref} + a_{02}y^2_{ref}$$

$$y = b_{00} + b_{10}x_{ref} + b_{01}y_{ref} + b_{11}x_{ref}y_{ref} + b_{20}x^2_{ref} + b_{02}y^2_{ref}$$

*Where do you get those coefficients?*

# Warp Components

$$x = a_{00} + a_{10}x_{ref} + a_{01}y_{ref} + a_{11}x_{ref}y_{ref} + a_{20}x^2_{ref} + a_{02}y^2_{ref}$$

$$y = b_{00} + b_{10}x_{ref} + b_{01}y_{ref} + b_{11}x_{ref}y_{ref} + b_{20}x^2_{ref} + b_{02}y^2_{ref}$$

$a_{00}$ – shift in x

$a_{10}$ – scale in x

$a_{01}$ – shear in x

$b_{00}$ – shift in y

$b_{01}$ – scale in y

$b_{10}$ – shear in y

$a_{11}$ – y dependent scale in x

$b_{11}$ – x dependent scale in y

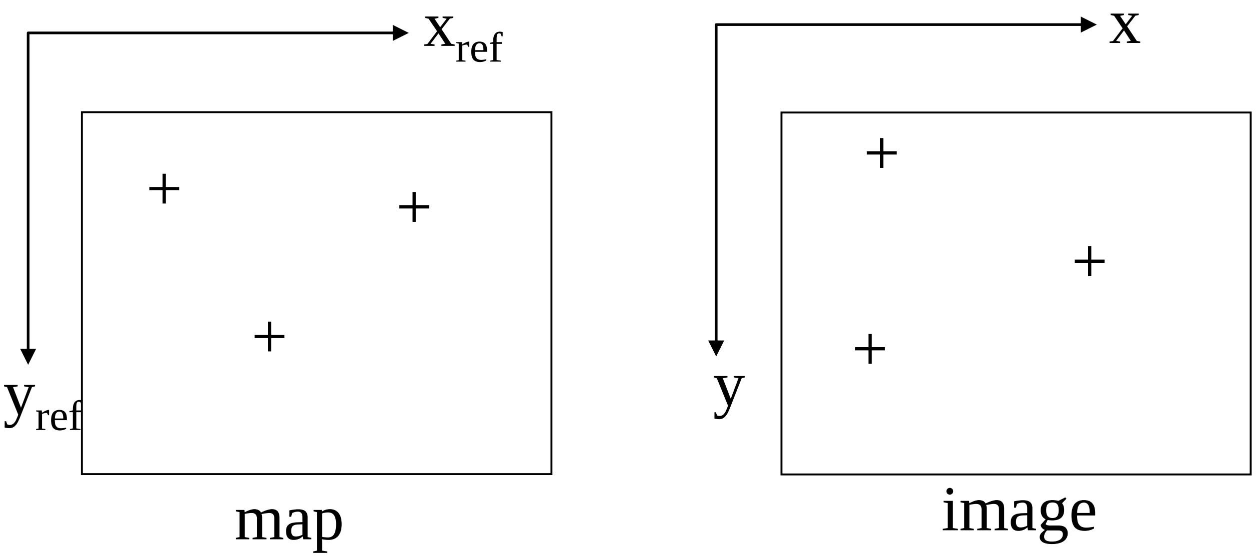
$a_{20}$ – nonlinear scale in x

$b_{20}$ – nonlinear scale in y

Schowendgerdt, Table 7-8?

# Determination of the polynomial coefficients

- Assuming that you have a map or geometrically registered image.




- Minimum # of GCPs:
  - $1^{st}$ order: 3 GCPs
  - $2^{nd}$ order 6 GCPs
  - $3^{rd}$ order 10 GCPs

# Re-sampling

- Once the coordinates are determined, what pixel values should you use in case the new coordinates are not at a center of pixel location
  - Nearest neighbor
  - Interpolation
    - Bilinear interpolation (uses 3 linear interpolations over the four pixels surrounding the point)
    - Cubic convolution interpolation (closest 16 pixels)

# Choosing GCPs

– Most obvious features found on both map and image

– Spatially distributed (very important!)

– Interpolation techniques

- Coordinate shift or georeferencing (one control point)

$$y = y' + c$$
$$x = x' + d$$

c and d are constants

- Scale and Rotation (two control points)
- Skew(three control points)

First order transformation or rectification

$$x' = ax + by + c$$
$$y' = dx + ey + f$$

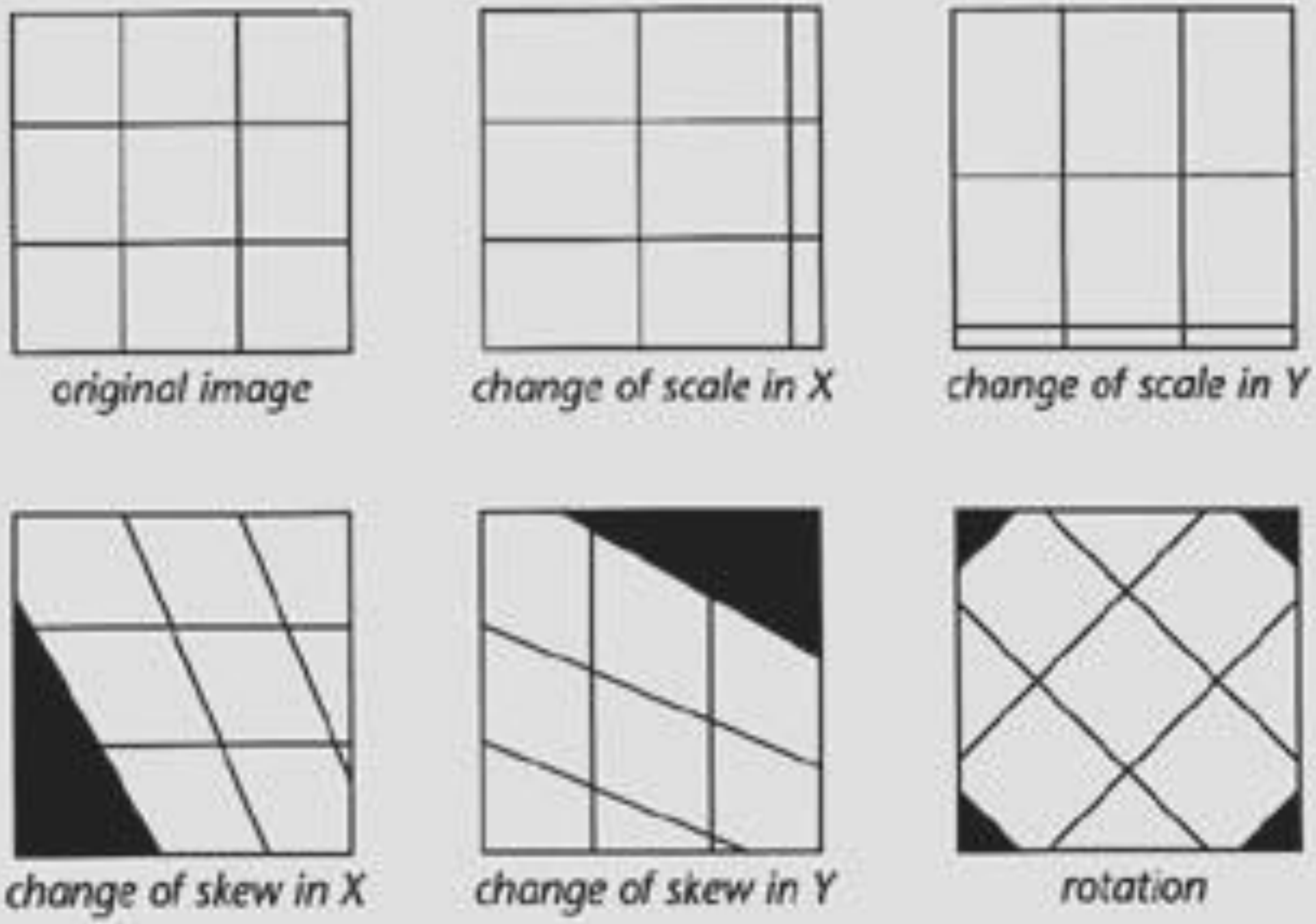



**Figure 2: Linear Transformations**

# First Order Transformation

transformation matrix may take a different form.

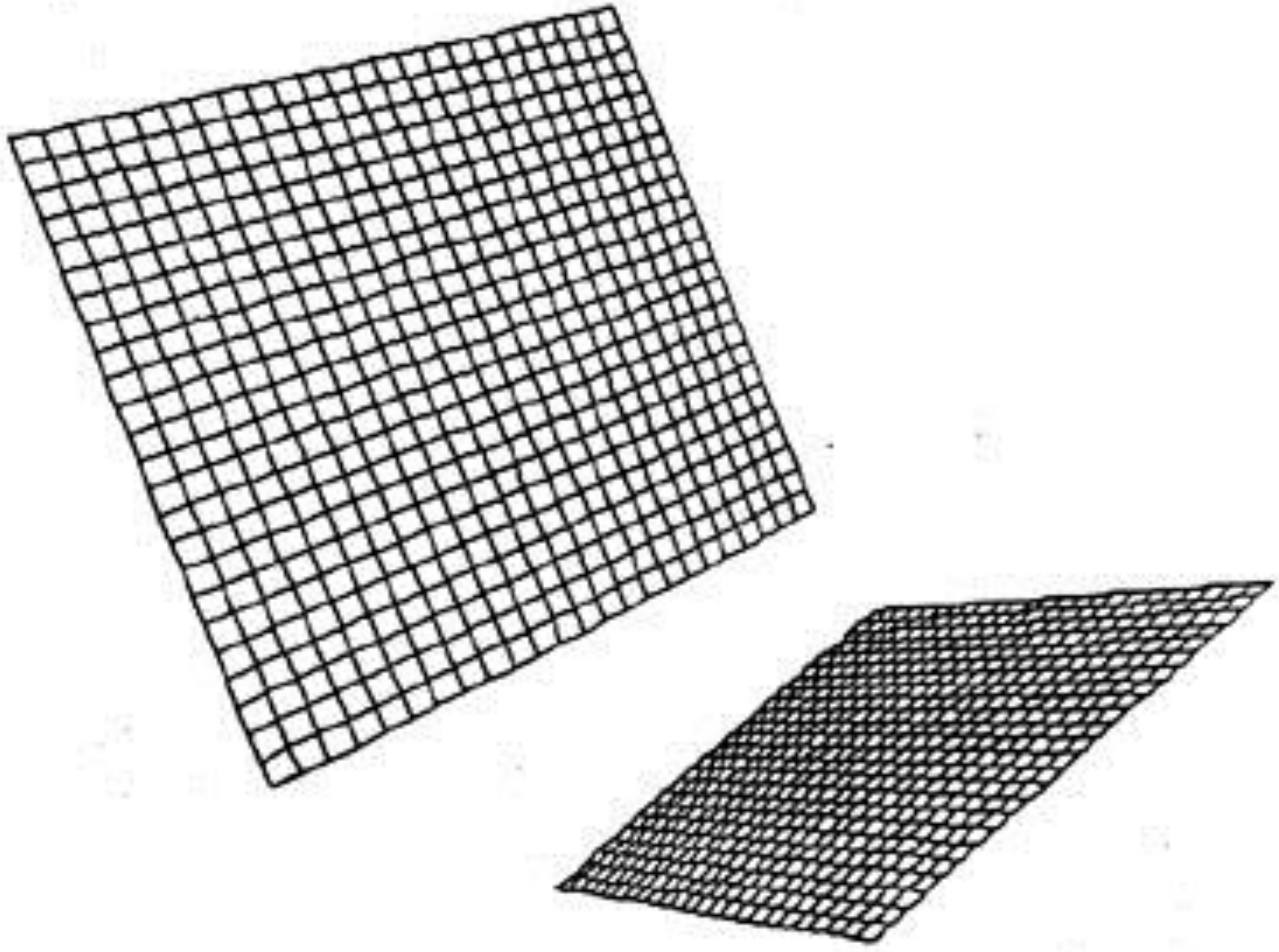


**Figure 3: 1st-Order Transformation**

- (RMS) Errors of Fit
- High order transformations (warps)

# High order transformation

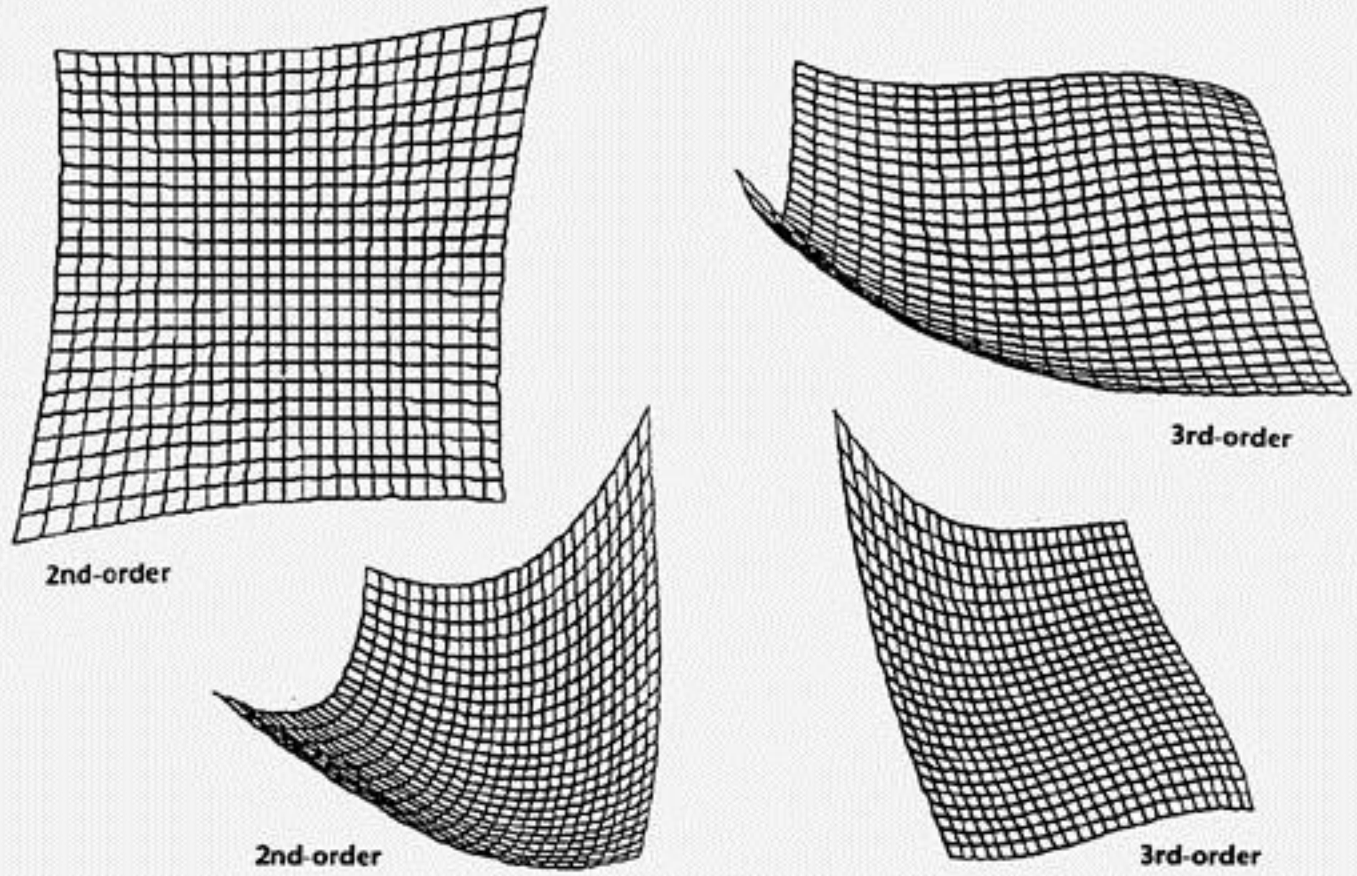



Figure 5: 2nd- and 3rd-Order Transformations

- How much is too much?
- Rubber sheeting

# When rectify

❖Comparing pixels scene to scene in applications such as change detection
❖Developing GIS data bases for modeling
❖Creating accurate scaled photomaps
❖Overlaying an image with vector data
❖Extracting accurate distance and area measurements
❖Mosaicking Images

**Disadvantages of Rectification**
❖Image must be resampled to fit into a new grid of pixel rows and columns
❖Spectral integrity of the data can be lost during rectification
❖An unrectified image is more spectrally correct that a rectified image

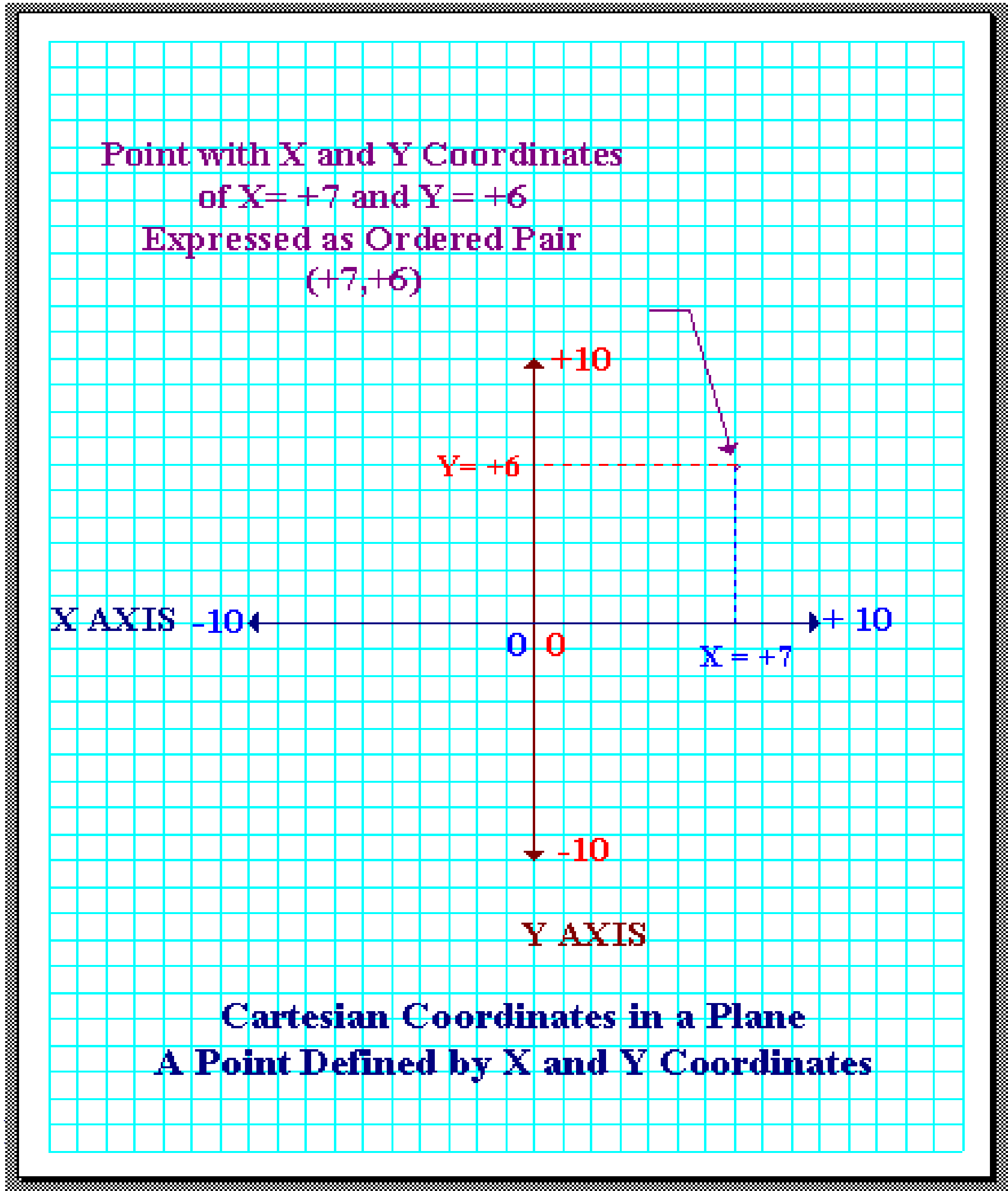
# Coordinate Systems

# Basic coordinate systems

- Represent points in two-dimensional or three-dimensional space
- Rene Decartes (1596-1650) introduced systems of coordinates based o orthogonal (right angle)
- Similar systems based on angles from baselines are often referred to a polar systems
- Two dimensional coordinate systems are defined with respect to a single plane, as demonstrated in the following slides.

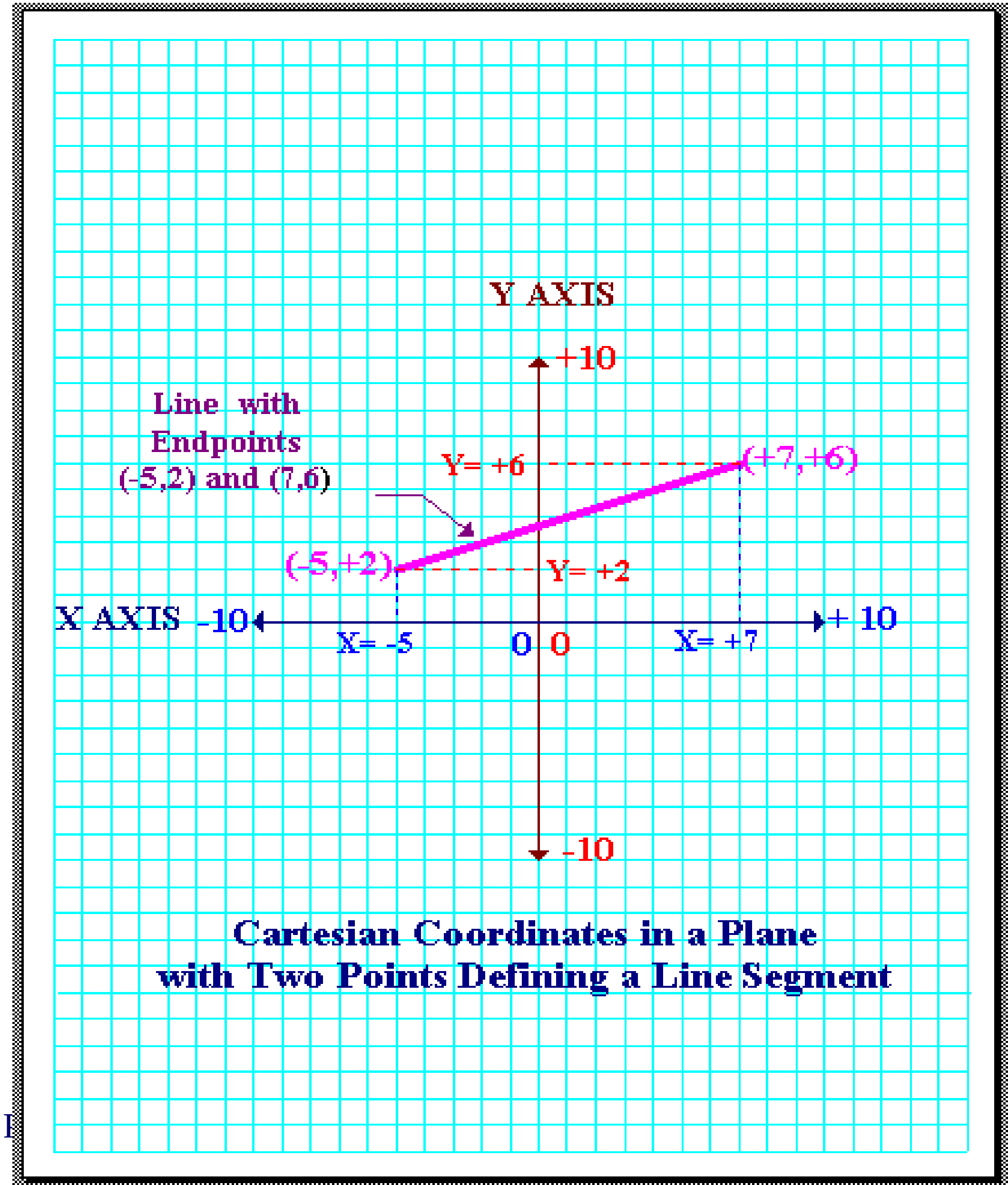
# Plane coordinate systems(Cartesian)

## POINT



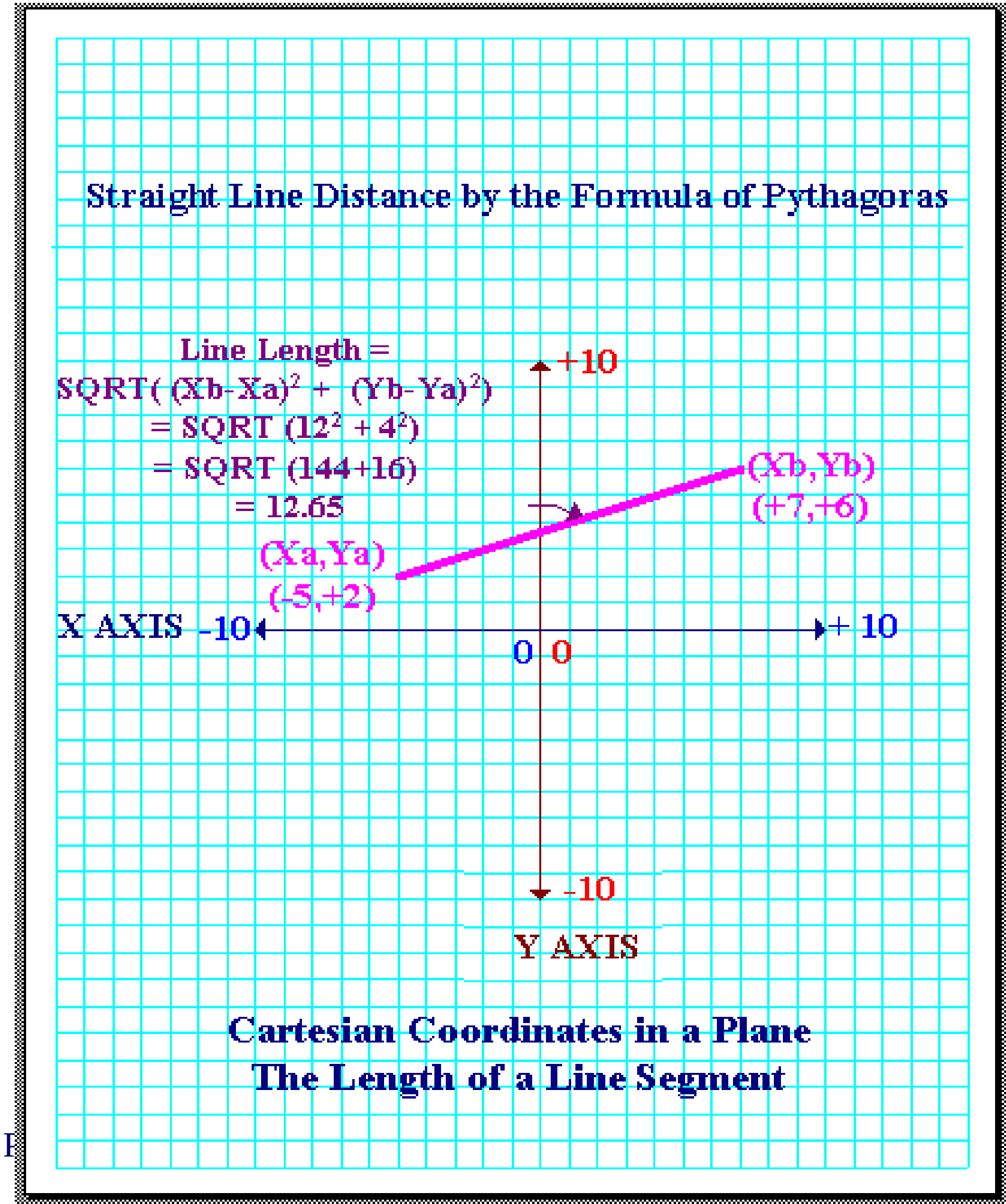
# Plane coordinate systems (Cartesian)

## LINE



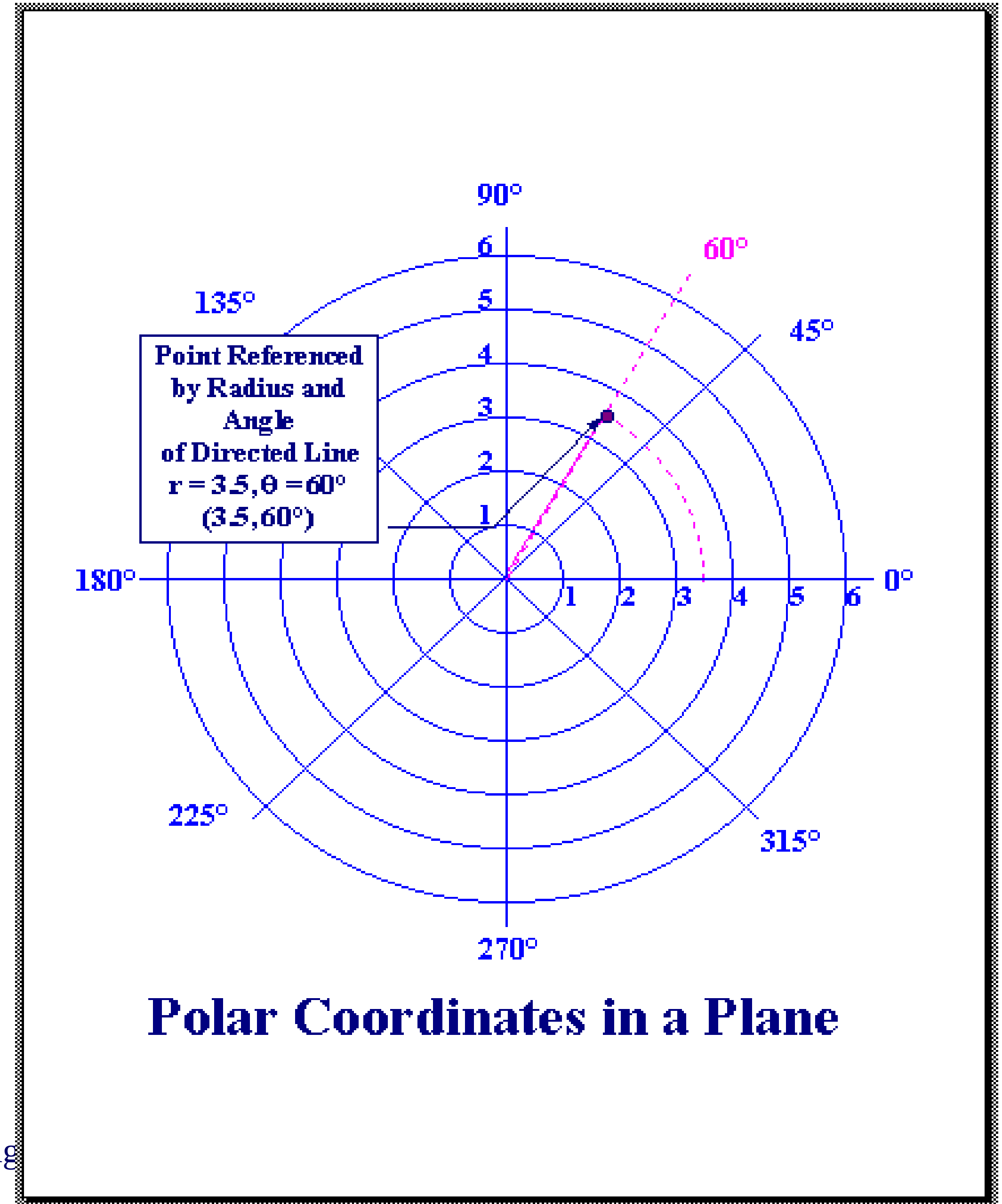
# Plane coordinate systems(Cartesian)

## DISTANCE



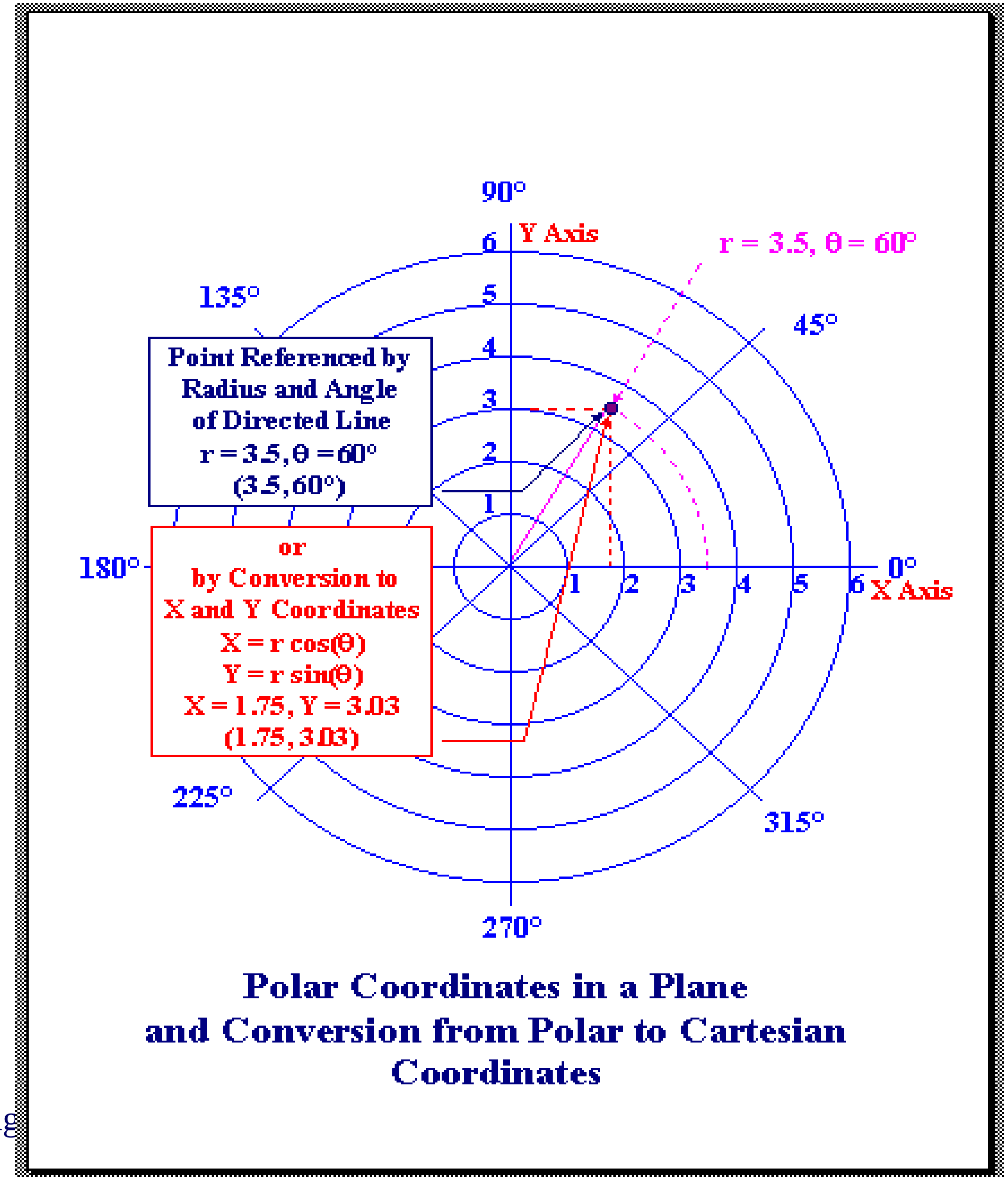
# Plane coordinate systems(Polar)

## POINT



# Plane coordinate systems

Polar to Cartesian

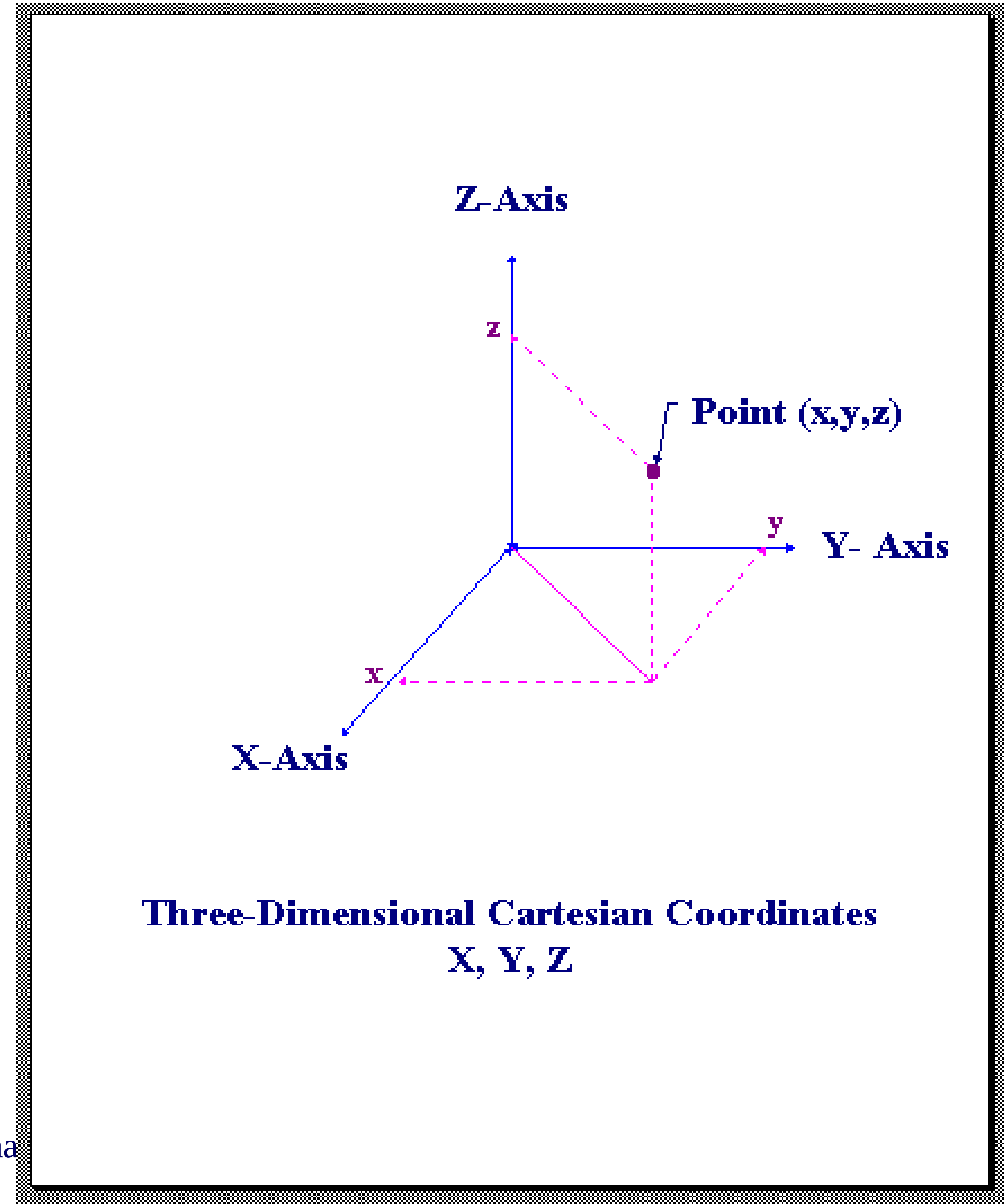


Polar Coordinates in a Plane and Conversion from Polar to Cartesian Coordinates

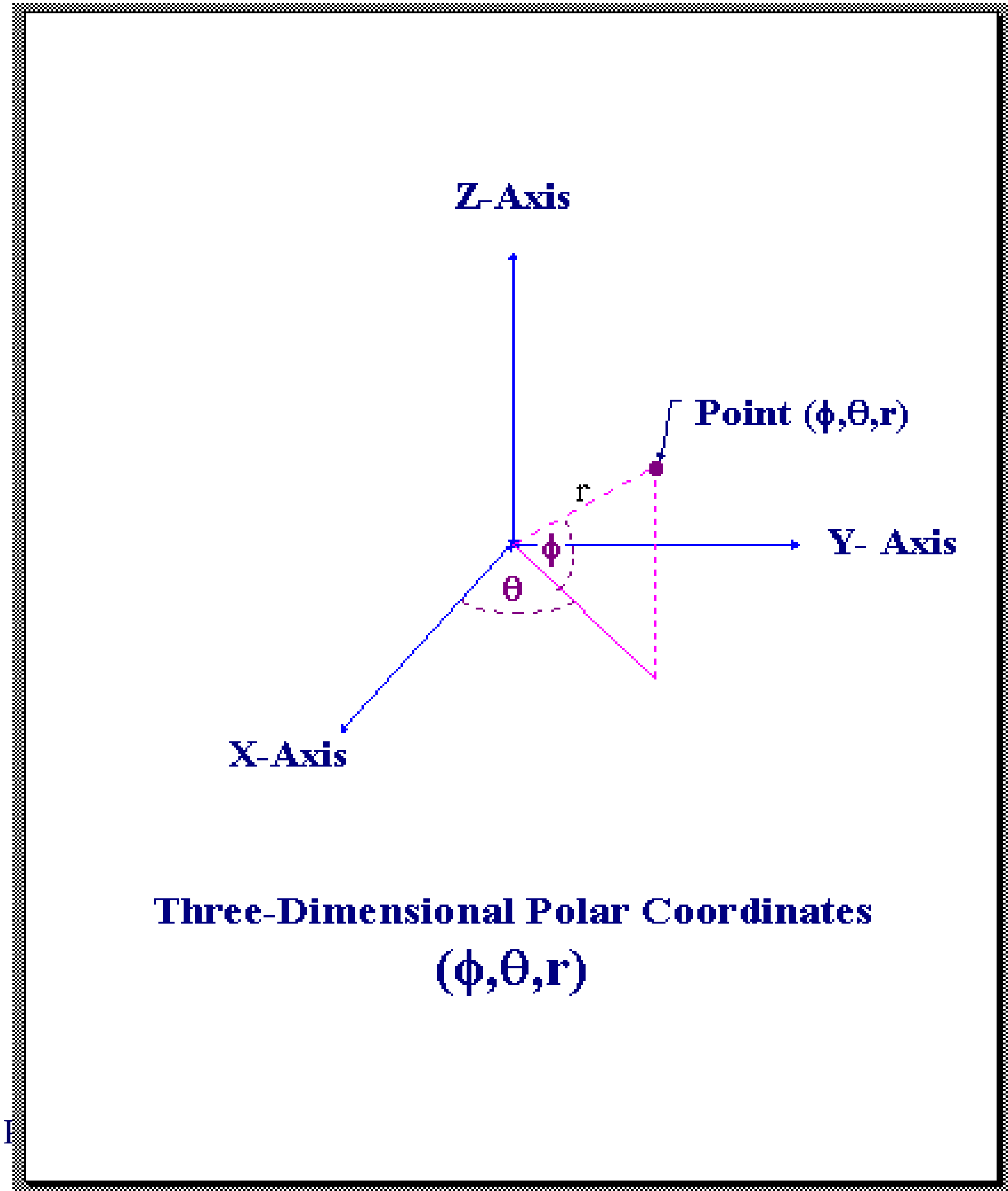
# Three-dimensional systems

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

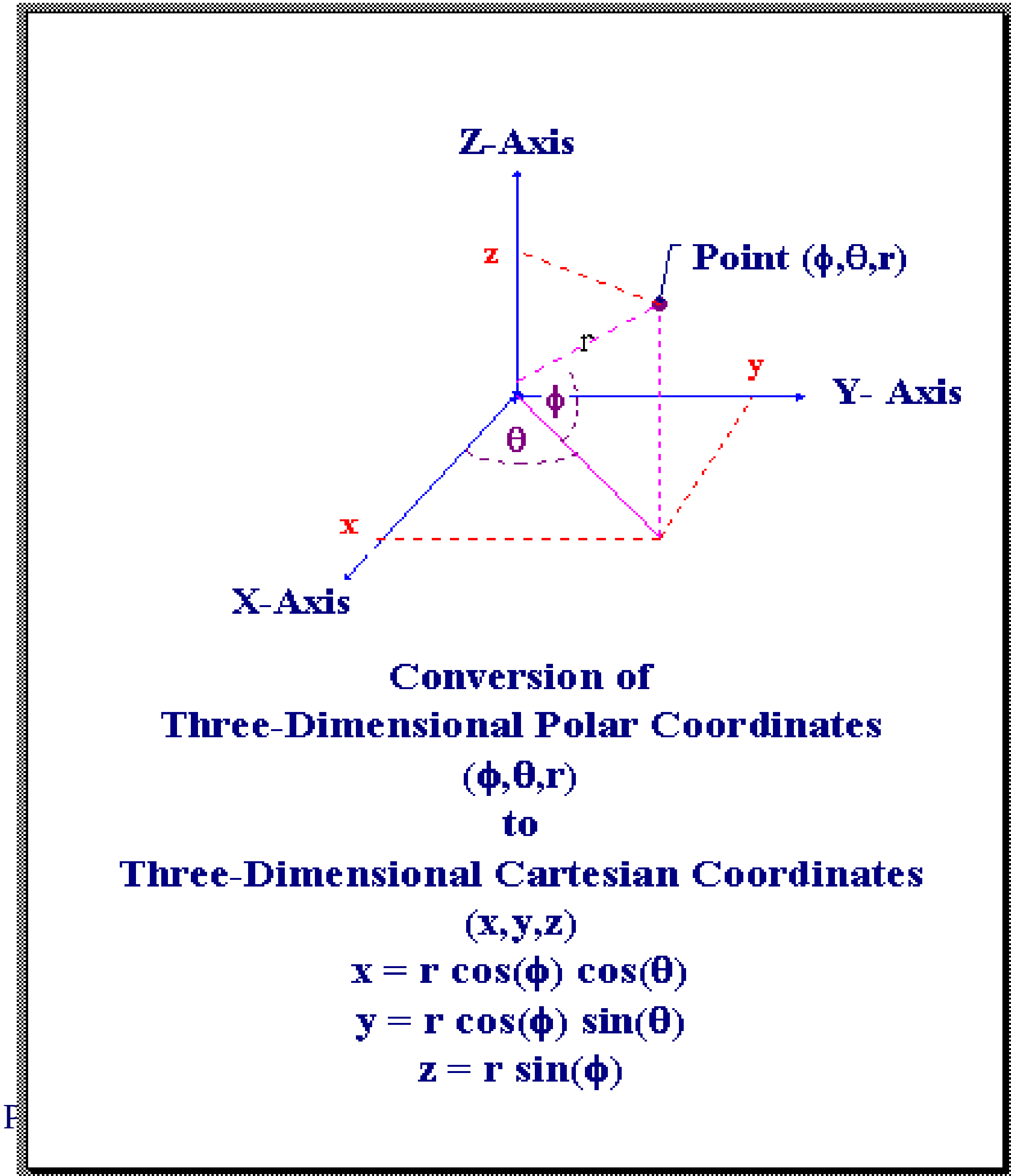
# 3-D Cartesian Point



# 3-D Polar Coordinate



# 3-D polar to Cartesian



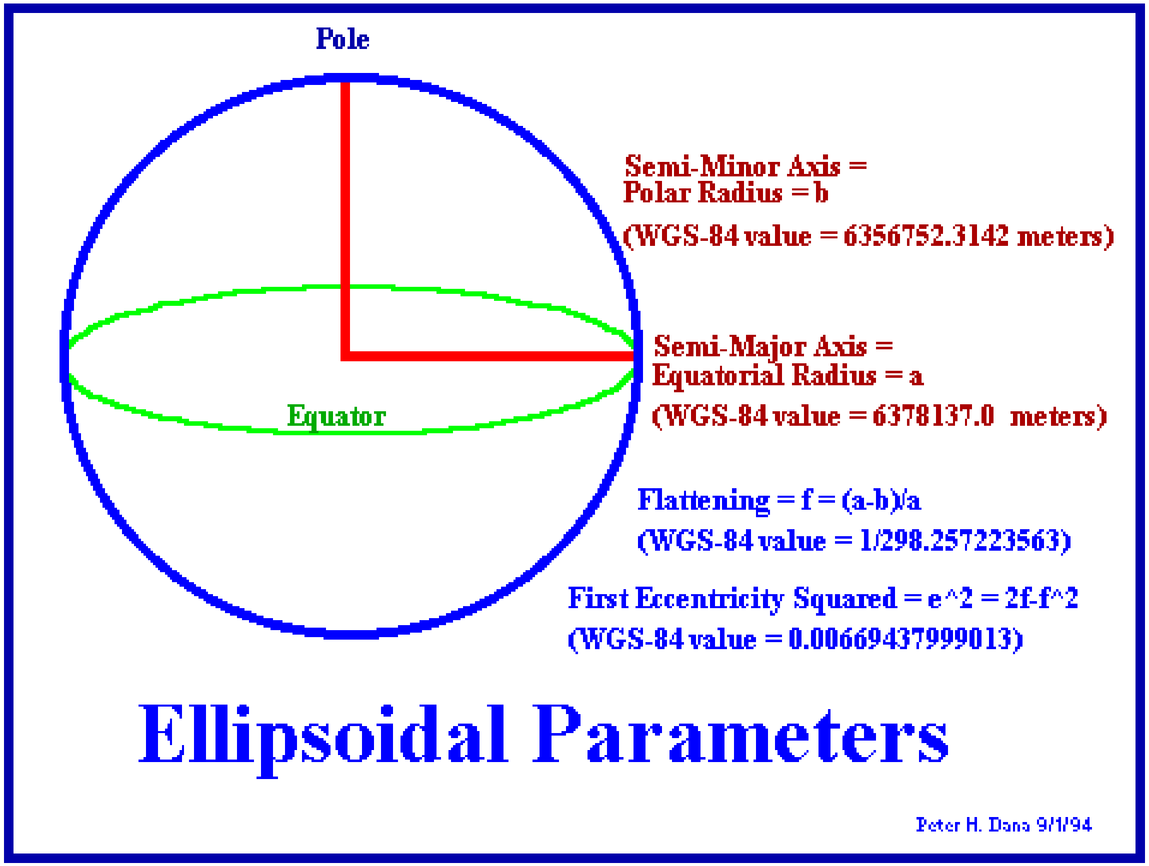
# Earth based locational reference systems

- ❖Reference systems and map projections extend the ideas of Cartesian and polar coordinate systems over all or part of the earth
  - ❖Map projections portray the nearly spherical earth in a two-dimensional representation
- ❖Earth-based reference systems are based on various models for the size and shape of the earth
  - ❖Earth shapes are represented in many systems by a sphere
  - ❖However, precise positioning reference systems are based on an *ellipsoidal earth* and *complex gravity models*.

# Reference Ellipsoids

- Ellipsoidal earth models are required for precise distance and direction measurement over long distances.
  - Ellipsoidal models account for the slight flattening of the earth at the poles. This flattening of the earth's surface results at the poles in about a twenty kilometer difference between an average spherical radius and the measured polar radius of the earth.
  - The best ellipsoidal models can represent the shape of the earth over the smoothed, averaged sea-surface to within about one-hundred meters.

- Reference ellipsoids are defined by either:
  - semi-major (equatorial radius) and semi-minor (polar radius) axes, or
  - the relationship between the semi-major axis and the flattening of the ellipsoid (expressed as its eccentricity).



- Many reference ellipsoids are in use by different nations and agencies.

- Reference ellipsoids are identified by a name and often by a year
  - for example, the Clarke 1866 ellipsoid is different from the Clarke 1858 and the Clarke 1880 ellipsoids.

# Selected Reference Ellipsoids

Ellipse Semi-Major Axis 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 298.3
Fischer 1968 6378150 298.3

G R S 1967 6378160 298.247167427
G R S 1975 6378140 298.257
G R S 1980 6378137 298.257222101
Hough 1956 6378270 297.0
International 6378388 297.0
Krassovsky 1940 6378245 298.3
South American 1969 6378160 298.25
WGS 60 6378165 298.3
WGS 66 6378145 298.25
WGS 72 6378135 298.26
WGS 84 6378137 298.257223563

# Geodetic Datums

- Precise positioning must also account for irregularities in the earth's surface due to factors in addition to polar flattening.
- Topographic and sea-level models attempt to model the physical variations of the surface:
  - The topographic surface of the earth is the actual surface of the land and sea at some moment in time.
    - Aircraft navigators have a special interest in maintaining a positive height vector above this surface.
  - Sea level can be thought of as the average surface of the oceans, though its true definition is far more complex.
    - Specific methods for determining sea level and the temporal spans used in these calculations vary considerably.
    - Tidal forces and gravity differences from location to location cause even this smoothed surface to vary over the globe by hundreds of meters.

- **Gravity models** and geoids are used to represent local variations in gravity that change the local definition of a level surface
    - Gravity models attempt to describe in detail the variations in the gravity field.
        - The importance of this effort is related to the idea of leveling. Plane and geodetic surveying uses the idea of a plane perpendicular to the gravity surface of the earth which is the direction perpendicular to a plumb bob pointing toward the center of mass of the earth.
        - Local variations in gravity, caused by variations in the earth's core and surface materials, cause this gravity surface to be irregular.
    - Geoid models attempt to represent the surface of the entire earth over both land and ocean as though the surface resulted from gravity alone.

- **Geodetic datums** define reference systems that describe the size and shape of the earth based on these various models.
  - While cartography, surveying, navigation, and astronomy all make use of geodetic datums, they are the central concern of the science of geodesy.
- Hundreds of different datums have been used to frame position descriptions since the first estimates of the earth's size were made by the ancient Greeks.
  - Datums have evolved from those describing a spherical earth to ellipsoidal models derived from years of satellite measurements.
  - Modern geodetic datums range from
    - flat-earth models, used for plane surveying
    - to complex models, used for international applications, which completely describe the size, shape, orientation, gravity field, and angular velocity of the earth.

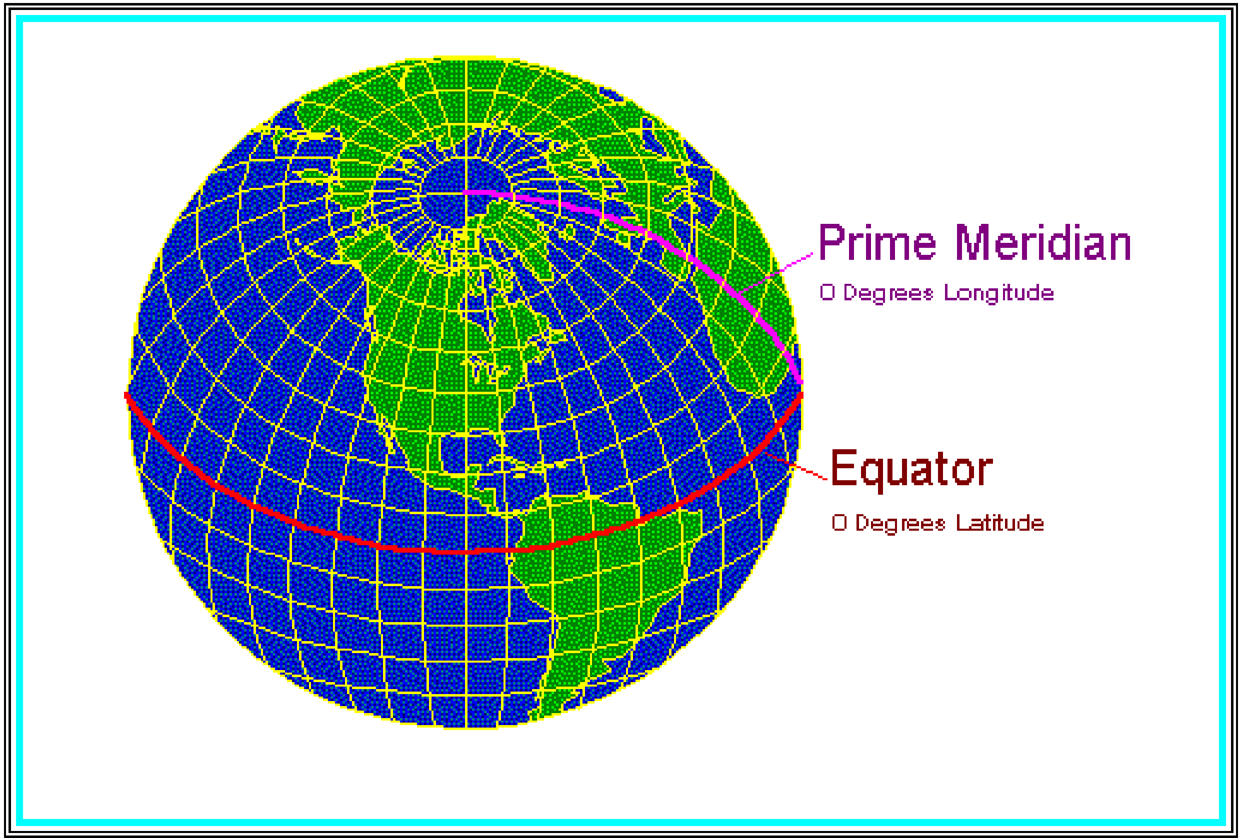
- Different nations and international agencies use different datums as the basis for coordinate systems in geographic information systems, precise positioning systems, and navigation systems.
  - In the United States, this work is the responsibility of the National Geodetic Survey (http://www.ngs.noaa.gov/).
  - Links to some of the NGS's counterparts in other nations are listed at the end of the presentation
- Linking geodetic coordinates to the wrong datum can result in position errors of hundreds of meters.
  - 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.
- For the purposes of this lecture, reference system can be divided into two groups:.
  - Global systems can refer to positions over much of the Earth.
  - Regional systems have been defined for many specific areas, often covering national, state, or provincial areas.

# Global Systems

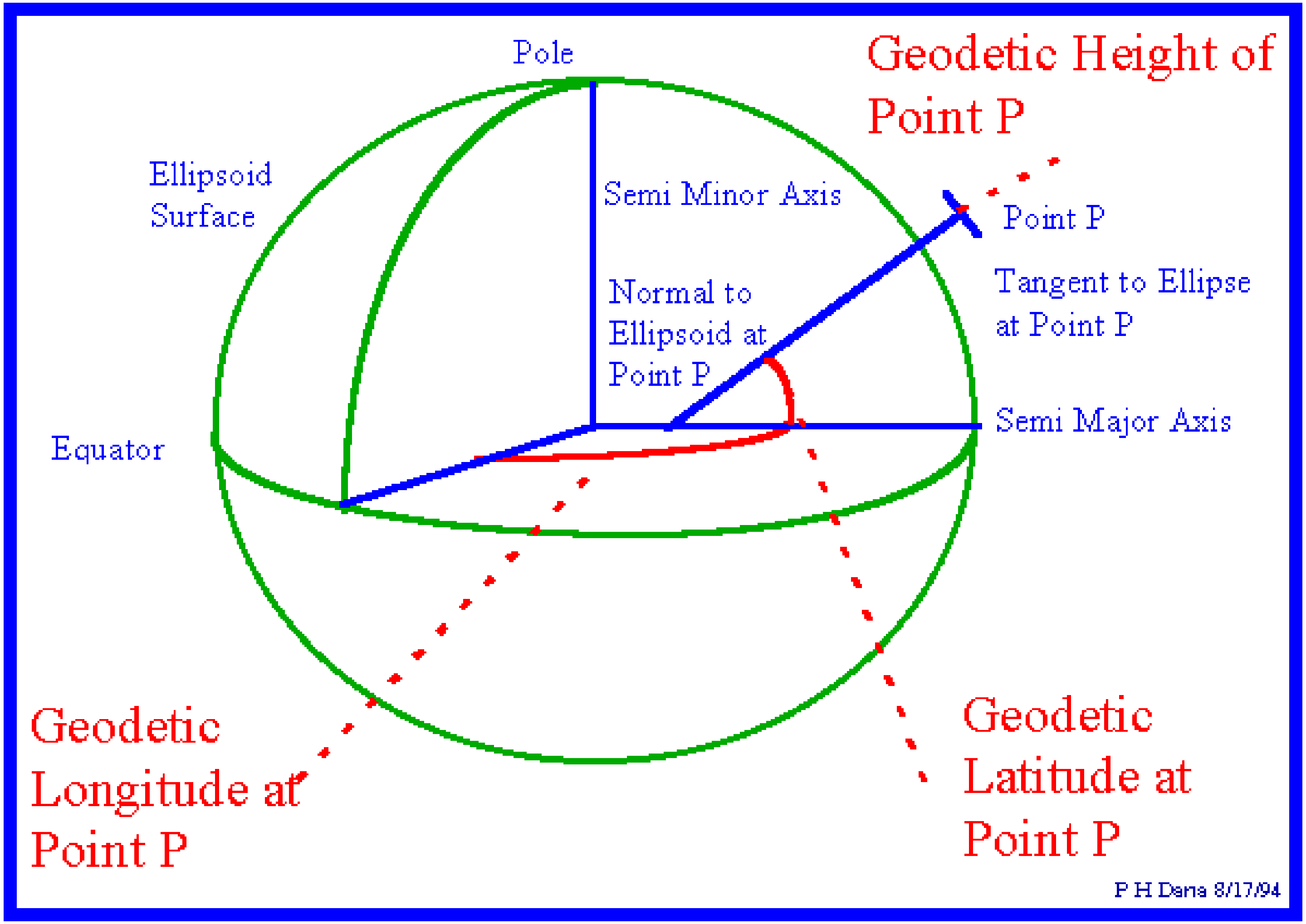
# Latitude, Longitude, Height

❖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.



- There are several ways to define these terms precisely. From the geodetic perspective these are:
  - The geodetic latitude of a point is the angle between the equatorial plane and 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.
- Geodetic Latitude, Longitude, and Height


Pole
Geodetic Height of Point P
Ellipsoid Surface
Semi Minor Axis
Point P
Tangent to Ellipse at Point P
Normal to Ellipsoid at Point P
Semi Major Axis
Equator
Geodetic Longitude at Point P
Geodetic Latitude at Point P
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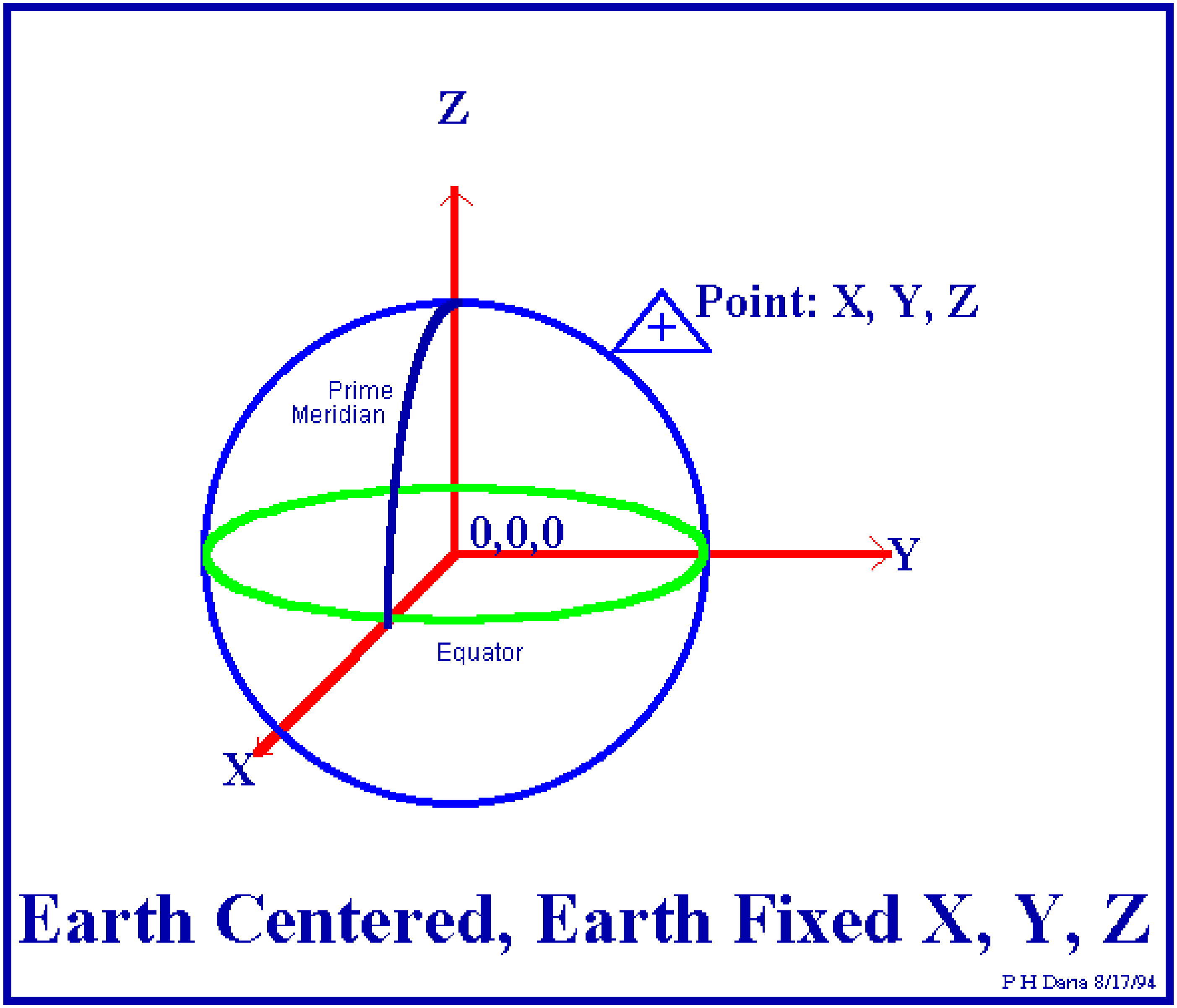
# ECEF X, Y, Z

- Earth Centered, Earth Fixed (ECEF) Cartesian coordinates can also be used to define three dimensional positions.
- ECEF X, Y, and Z Cartesian coordinates define three dimensional positions with respect to the center of mass of the reference ellipsoid.
  - The Z-axis points from the center toward the North Pole.
  - The X-axis is the line at the intersection of the plane defined by the prime meridian and the equatorial plane.
  - The Y-axis is defined by the intersection of a plane rotated 90° east of the prime meridian and the equatorial plane.
  - ECEF X, Y, and Z


Z
Point: X, Y, Z
Prime
Meridian
0,0,0
Y
Equator
X
Earth Centered, Earth Fixed X, Y, Z
P H Dana 8/17/94

# Earth Centered, Earth Fixed (ECEF) X, Y, Z Example

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

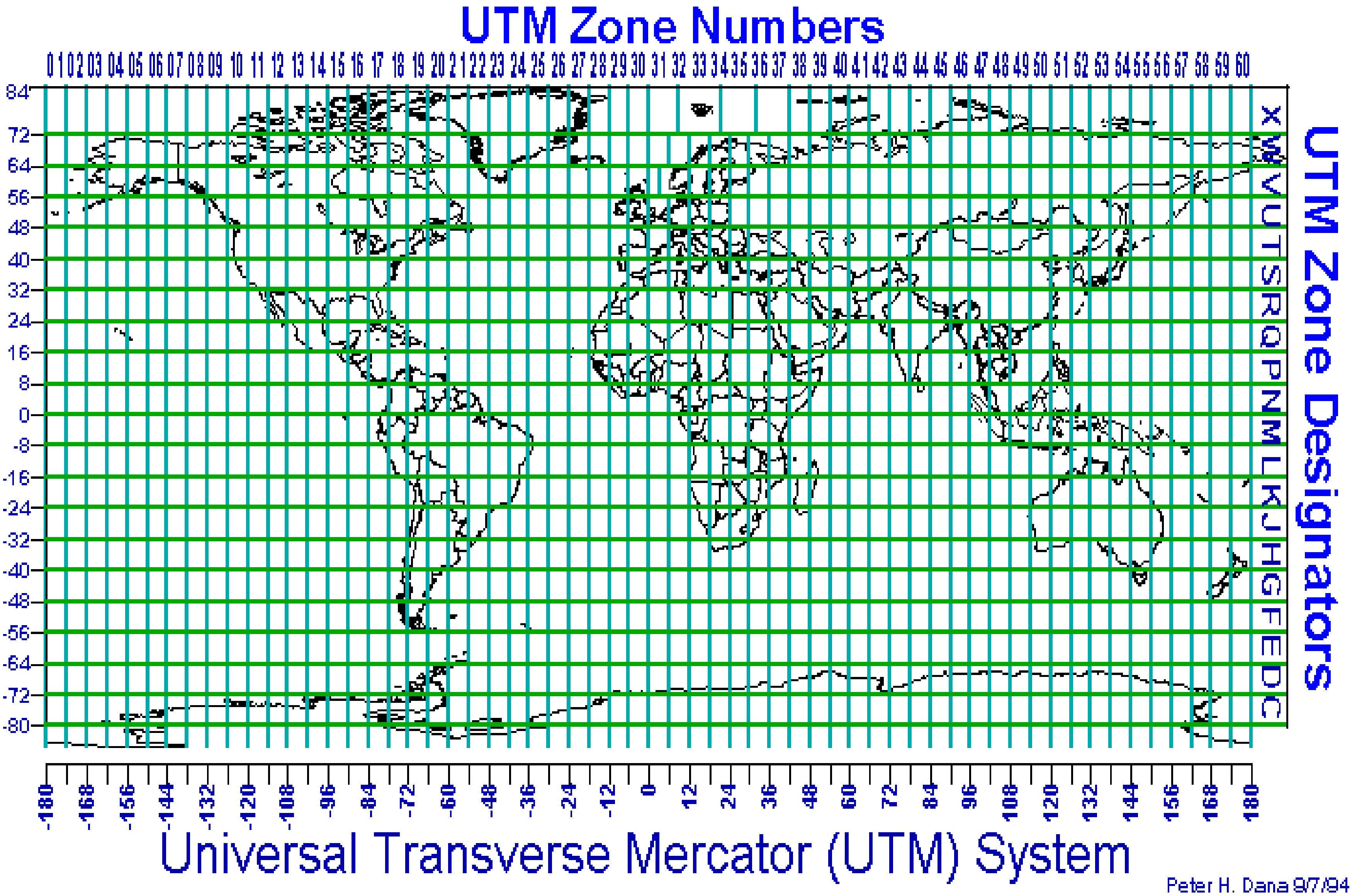
X = -742507.1

Y = -5462738.5

Z = 3196706.5

# Universal Transverse Mercator (UTM)

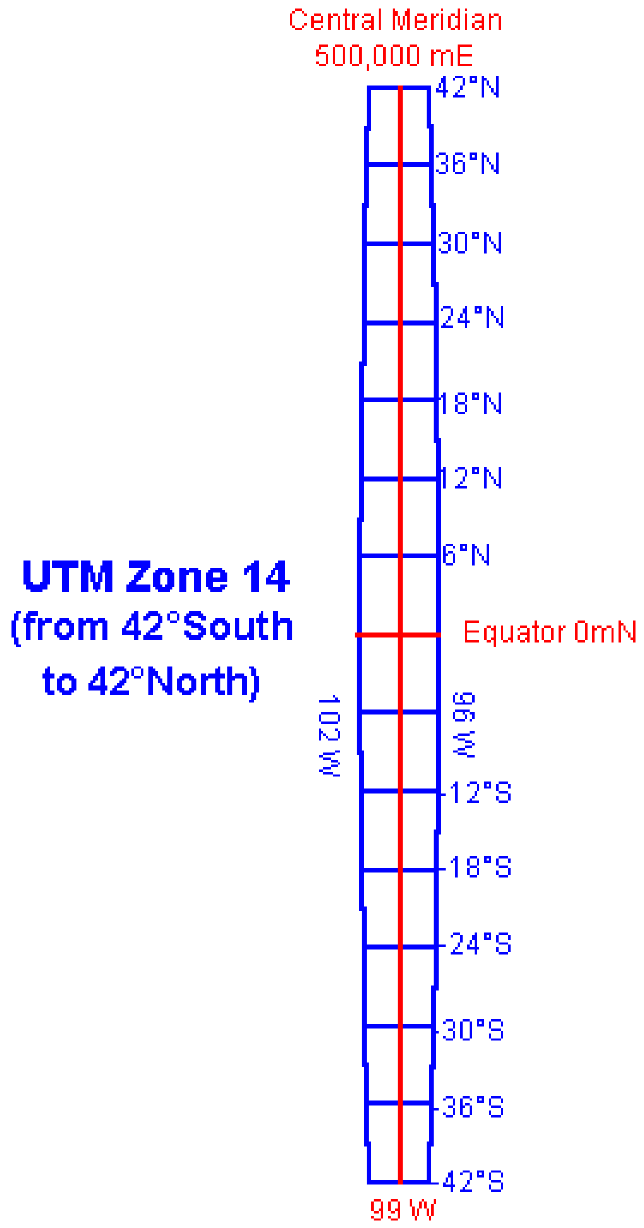
- Universal Transverse Mercator (UTM) coordinates define two dimensional, horizontal, positions.
- Each UTM zone is identified by a number
  - UTM zone numbers designate individual 6° wide longitudinal strips extending from 80° South latitude to 84° North latitude.
  - (Military UTM coordinate systems also use a character to designate 8° zones extending north and south from the equator, see below).
- UTM Zones



UTM Zone Numbers
UTM Zone Designators
Universal Transverse Mercator (UTM) System
Peter H. Dana 9/7/94

Each zone has a central meridian.

- ❖For example, Zone 14 has a central meridian of 99° west longitude.
- ❖The zone extends from 96 to 102° west longitude.
- ❖UTM Zone 14


Central Meridian
500,000 mE
42°N
36°N
30°N
24°N
18°N
12°N
6°N
Equator 0mN
UTM Zone 14
(from 42°South
to 42°North)
102 W
96 W
12°S
18°S
24°S
30°S
36°S
42°S
99 W

- Locations within a zone are measured in meters eastward from the central meridian and northward from the equator. However,
  - Eastings increase eastward from the central meridian which is given a false easting of 500 km so that only positive eastings are measured anywhere in the zone.
  - Northings increase northward from the equator with the equator's value differing in each hemisphere
    - in the Northern Hemisphere, the Equator has a northing of 0
    - for Southern Hemisphere locations, the Equator is given a false northing of 10,000 km
- Figure 15. UTM Zone 14 Example Detail
- Table 3. UTM Coordinate Example

# Universal Transverse Mercator (UTM) Example

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

NAD-83 UTM Easting, Northing

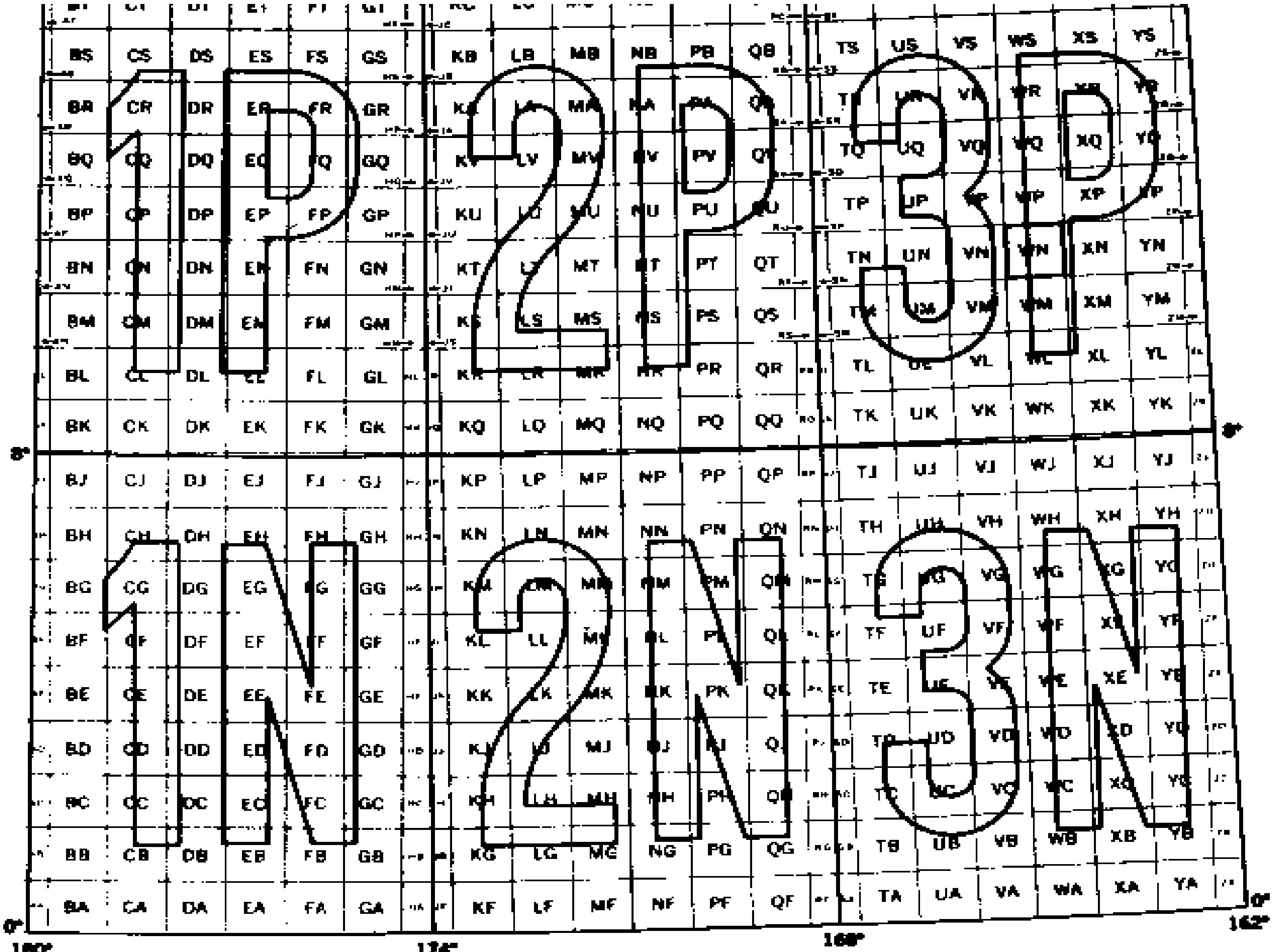
621160.98m 3349893.53m

Zone 14 R

# Military Grid Reference System (MGRS)

- The Military Grid Reference System (MGRS) is an extension of the UTM system.
- A UTM zone number and an additional zone character are used to identify areas 6° in east-west extent and 8° in north-south extent.
  - A few special UTM zones do not match the standard configuration (see Figure 13)
    - between 0° and 42° east longitude, above 72° north latitude in the area of the Greenland and Barents Seas, and the Arctic Ocean.
    - in zones 31 and 32 between 56° and 64° north latitude including portions of the North Sea and Norway.

- UTM zone number and character are followed by two characters designating the eastings and northings of 100 km square grid cells.
  - Starting eastward from the 180° meridian, the characters A to Z are assigned consecutively to up to 24 strips covering 18° of longitude (characters I and O are omitted to eliminate the possibility of confusion with the numerals 1 and 0). The sequence begins again every 18°.
  - From the equator northward, the characters A to V (omitting characters I and O) are used to sequentially identify 100 km squares, repeating the sequence every 2,000 km.
    - for odd numbered UTM easting zones, northing designators normally begin with 'A' at the equator
    - for even numbered UTM easting zones, the northing designators are offset by five characters, starting at the equator with 'F'.
    - South of the equator, the characters continue the pattern set north of the equator.
    - Complicating the system, ellipsoid junctions ("spheroid junctions" in the terminology of MGRS) require a shift of 10 characters in the northing 100 km grid square designators. Different geodetic datums using different reference ellipsoids use different starting row offset numbers to accomplish this.
- Military Grid Reference System




# 100,000 Meter MGRS Square Designators

- For a full MGRS location, UTM zone number and character and the two grid square designators are followed by an even number of digits representing more precise easting and northing values.
- 2 digits give a coordinate precision of 10 km.
- 10 digits give a coordinate precision of 1 m.
- MGRS Example
- MGRS and UTM systems are often employed in products produced by the US National Imagery and Mapping Agency (http://www.nima.mil/), formerly the Defense Mapping Agency.

# Military Grid Reference System (MGRS) Example

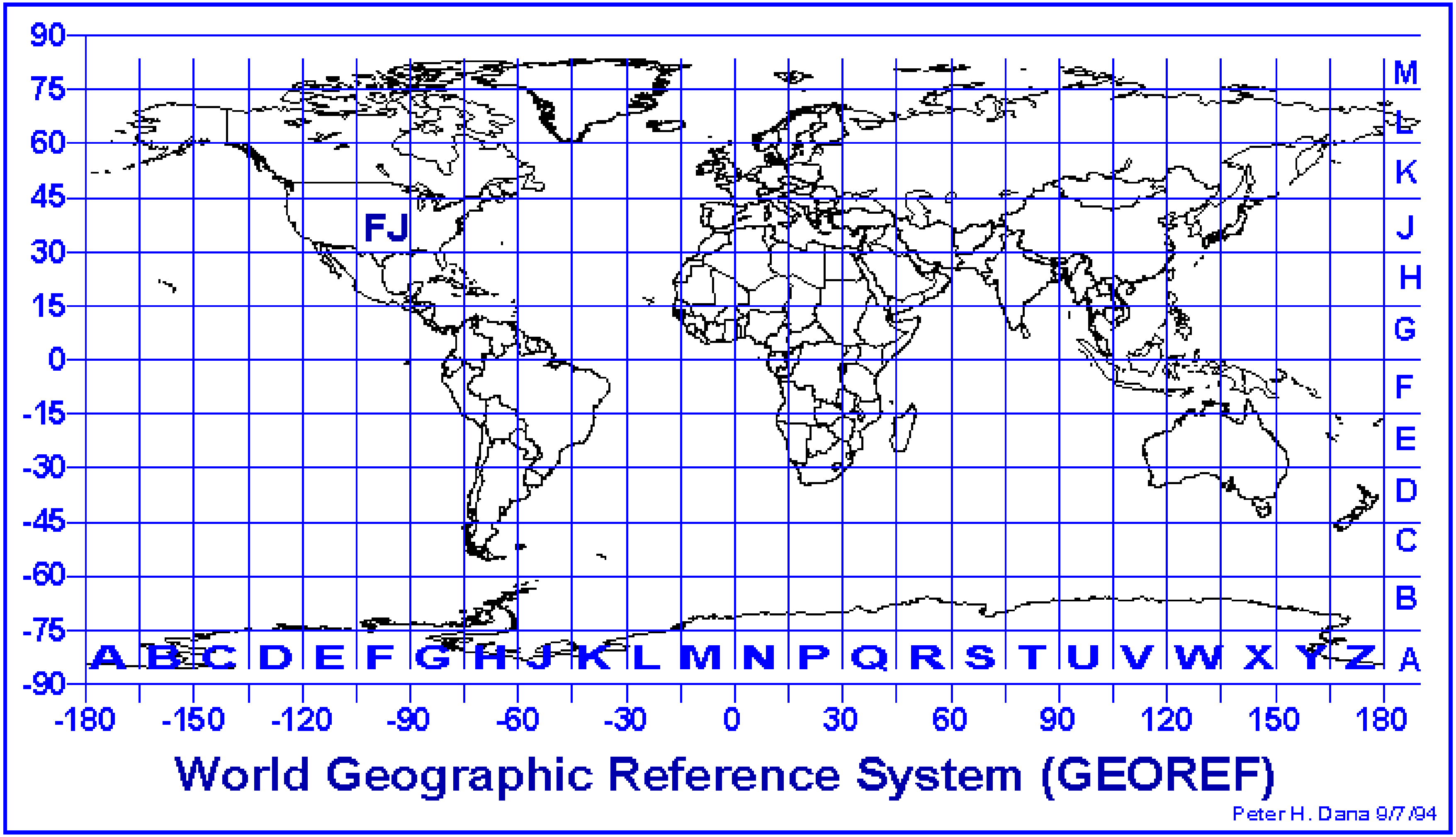
NAD-83 Latitude, Longitude of 30:16:28.82 N 97:44:25.19 W is

NAD-83 Military Grid Reference

14RPU2116149894

# World Geographic Reference System (GEOREF)

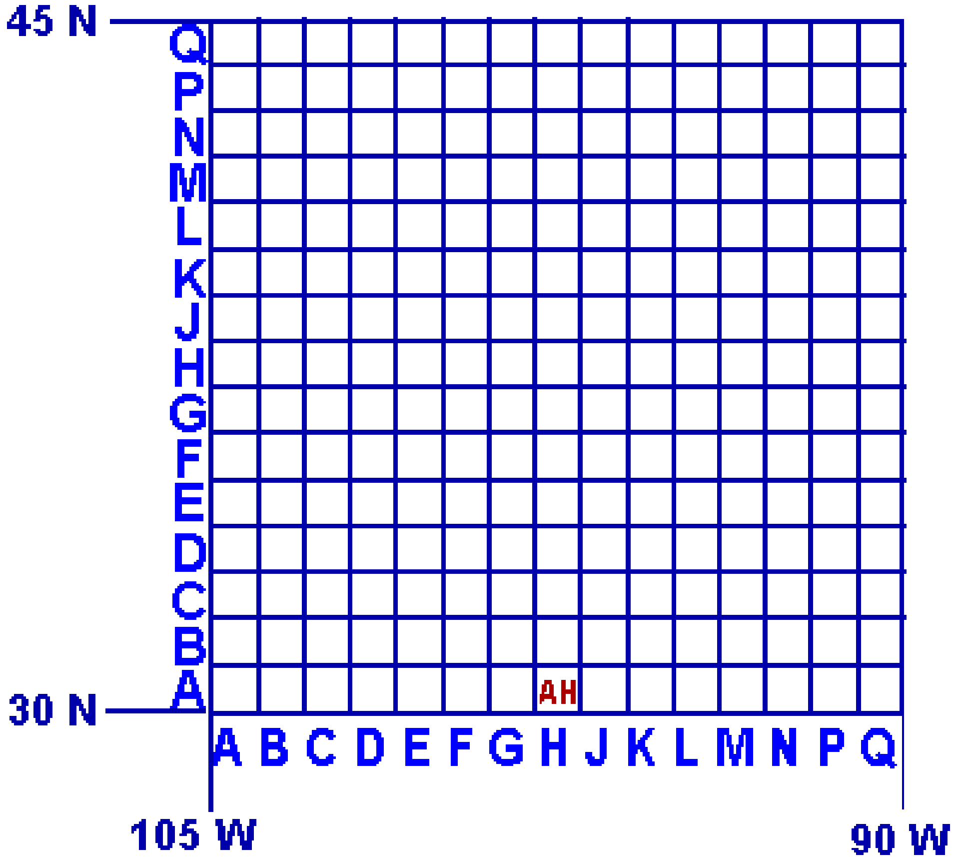
- The World Geographic Reference System is used for aircraft navigation.
- GEOREF is based on latitude and longitude.
- The globe is divided into twelve bands of latitude and twenty-four zones of longitude, each 15° in extent.
- World Geographic Reference System Index



90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
M
L
K
J
H
G
F
E
D
C
B
A
FJ
A B C D E F G H J K L M N P Q R S T U V W X Y Z
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
World Geographic Reference System (GEOREF)
Peter H. Dana 9/7/94

❖These 15° areas are further divided into one degree units identified by 15 characters.

❖GEOREF 1° Grid



GEOREF 15 Degree Square and 1 Degree Units

# World Geographic Reference (GEOREF) System Example

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

World Geographic Reference System

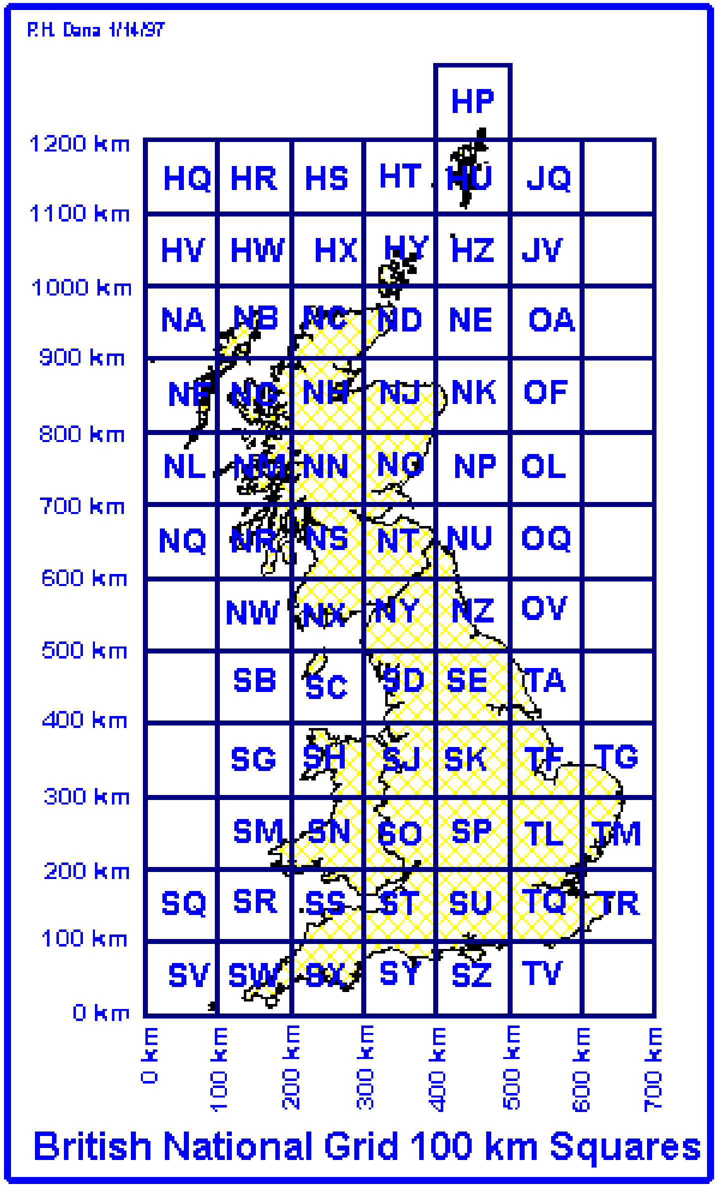
FJHA1516

# Regional Systems

- Several different systems are used regionally to identify geographic location
- Some of these are true coordinate systems, such as those based on UTM and UPS systems
- Others, such as the metes and bounds and Public Land Survey systems describe below, simply partition space

# Transverse Mercator Grid Systems

- The British National Grid (BNG) is based on the National Grid System of England, administered by the British Ordnance Survey (http://www.ordsvy.gov.uk/)
- The BNG has been based on a Transverse Mercator projection since the 1920s.
  - The modern BNG is based on the Ordnance Survey of Great Britain Datum 1936.
- The true origin of the system is at 49° north latitude and 2 degrees west longitude.
  - The false origin is 400 km west and 100 km north.
- Scale factor at the central meridian is 0.9996012717.
- The first BNG designator defines a 500 km square.
- The second designator defines a 100 km square.
- Figure 19. British National Grid 100 km Squares
- The remaining digits define 10 km, 1 km, 100 m, 10 m, and 1 m eastings and northings.



P.H. Dana 1/14/97
HP
HQ HR HS HT HU JQ
HV HW HX HY HZ JV
NA NB NC ND NE OA
NF NG NH NJ NK OF
NL NM NN NO NP OL
NQ NR NS NT NU OQ
NW NX NY NZ OV
SB SC SD SE TA
SG SH SJ SK TF TG
SM SN SO SP TL TM
SQ SR SS ST SU TQ TR
SV SW SX SY SZ TV
1200 km
1100 km
1000 km
900 km
800 km
700 km
600 km
500 km
400 km
300 km
200 km
100 km
0 km
0 km
100 km
200 km
300 km
400 km
500 km
600 km
700 km
British National Grid 100 km Squares

# British National Grid Example

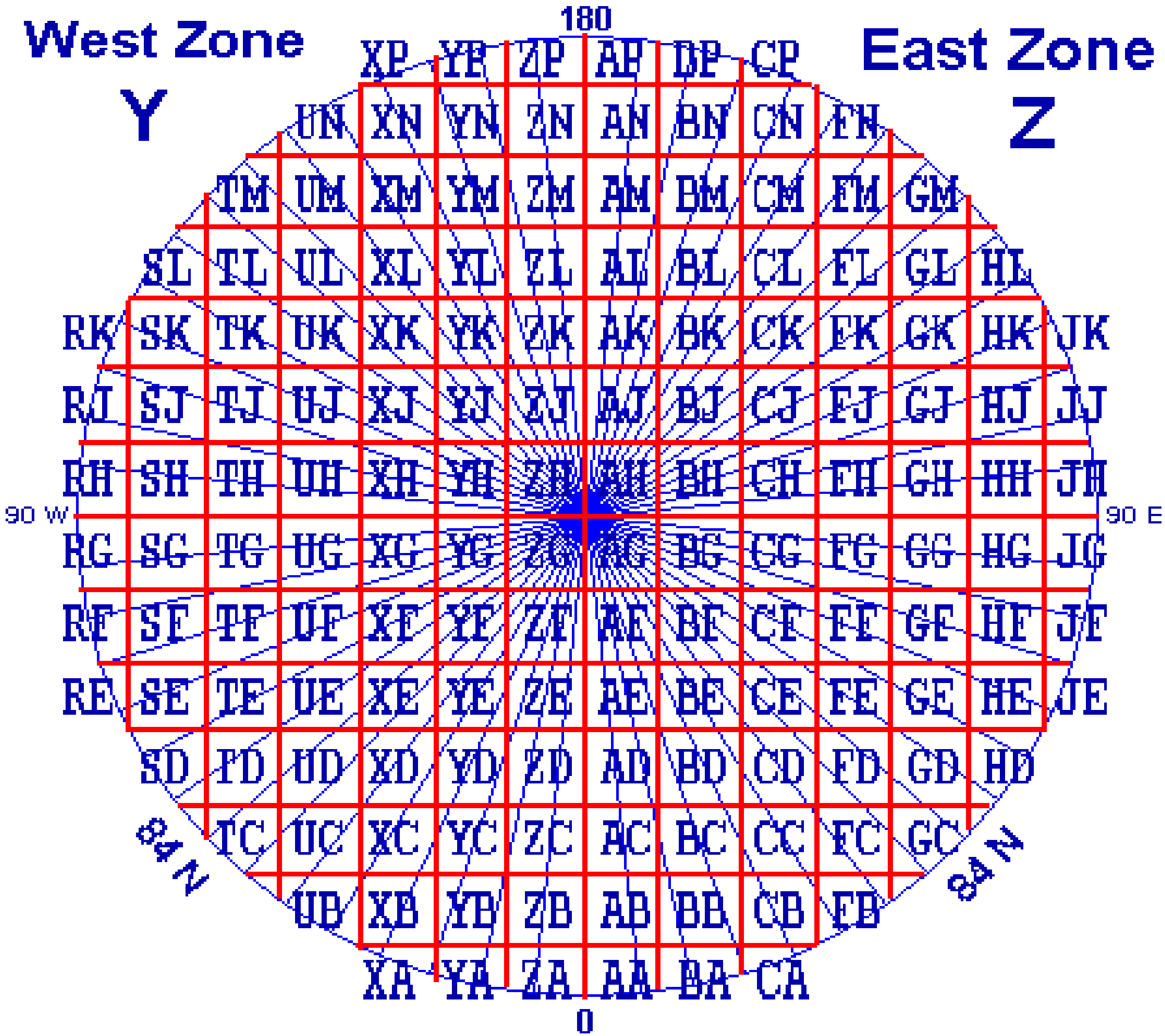
OS36 Latitude, Longitude of 54:30:52.55 N 1:27:55.75 W is

British National Grid

NZ3460013400

# Universal Polar Stereographic (UPS)

- The Universal Polar Stereographic (UPS) projection is defined above 84° north latitude and south of 80° 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



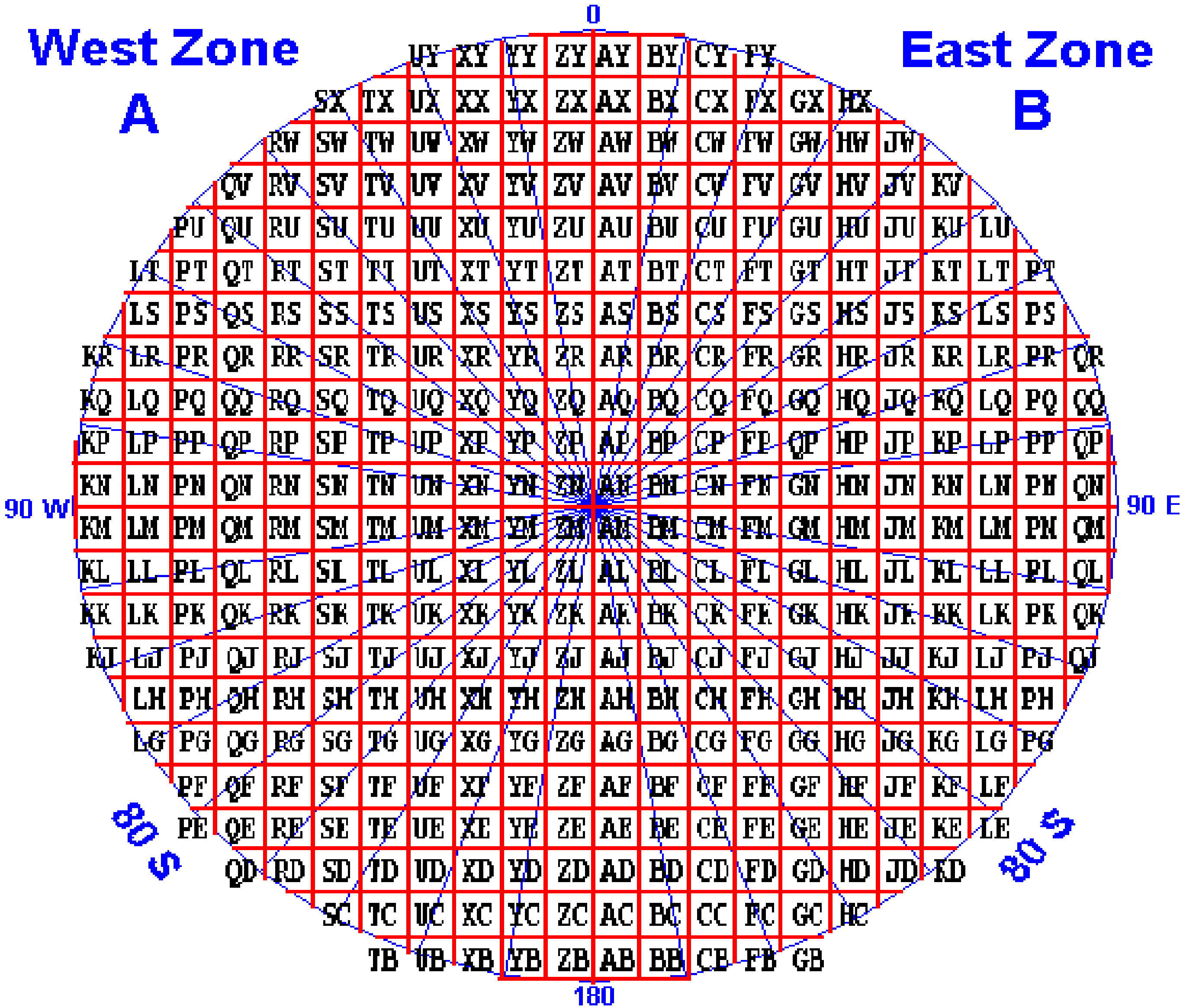

North Polar Area UPS Grid

# North Polar Area UPS Example

NAD-83 Latitude, Longitude of 85:40:30.0 N 85:40:30.0 W is

Universal Polar Stereographic

ZGG7902863771




# South Polar Area UPS Grid

# South Polar Area UPS Example

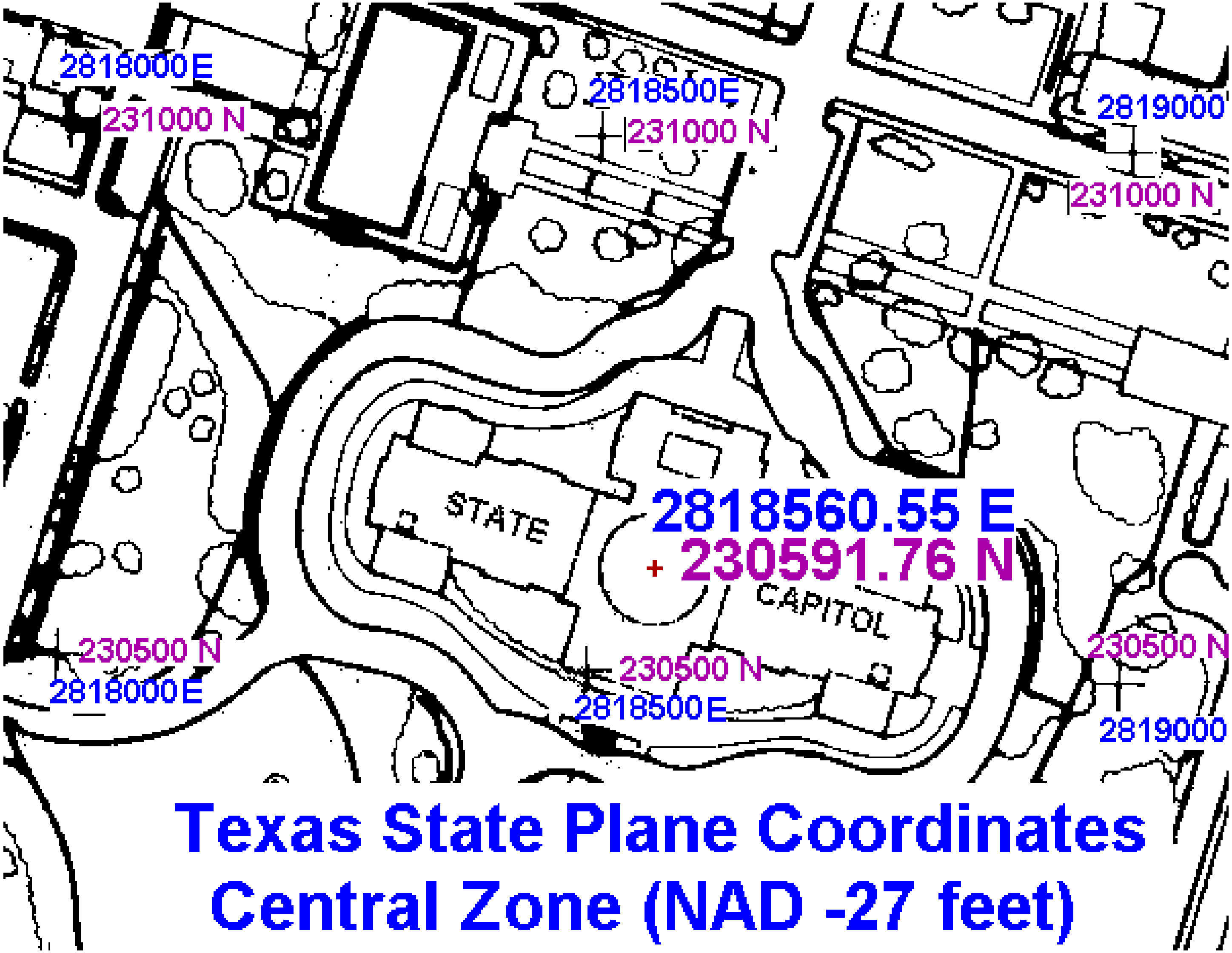
NAD-83 Latitude, Longitude of 85:40:30.0 S 85:40:30.0 W is

Universal Polar Stereographic

ATN2097136228

# State Plane Coordinates (SPC)

- State plane systems were developed in order to provide local reference systems that were tied to a national datum.
- In the United States, the State Plane System 1927 was developed in the 1930s and was based on the North American Datum 1927 (NAD-27).
  - NAD-27 coordinates are in English units (feet).
- NAD-27 State Plane Coordinate


2818000E
231000 N
2818500E
231000 N
2819000
231000 N
2818560.55 E
230591.76 N
STATE
CAPITOL
230500 N
2818000E
230500 N
2818500E
230500 N
2819000
Texas State Plane Coordinates
Central Zone (NAD -27 feet)

- The State Plane System 1983 is based on the North American Datum 1983 (NAD-83).
  - NAD-83 coordinates are metric.
  - NAD-83 State Plane Coordinate Example
  - While the NAD-27 State Plane System has been superceded by the NAD-83 System, maps in NAD-27 coordinates are still in use.

# State Plane Coordinate System Example

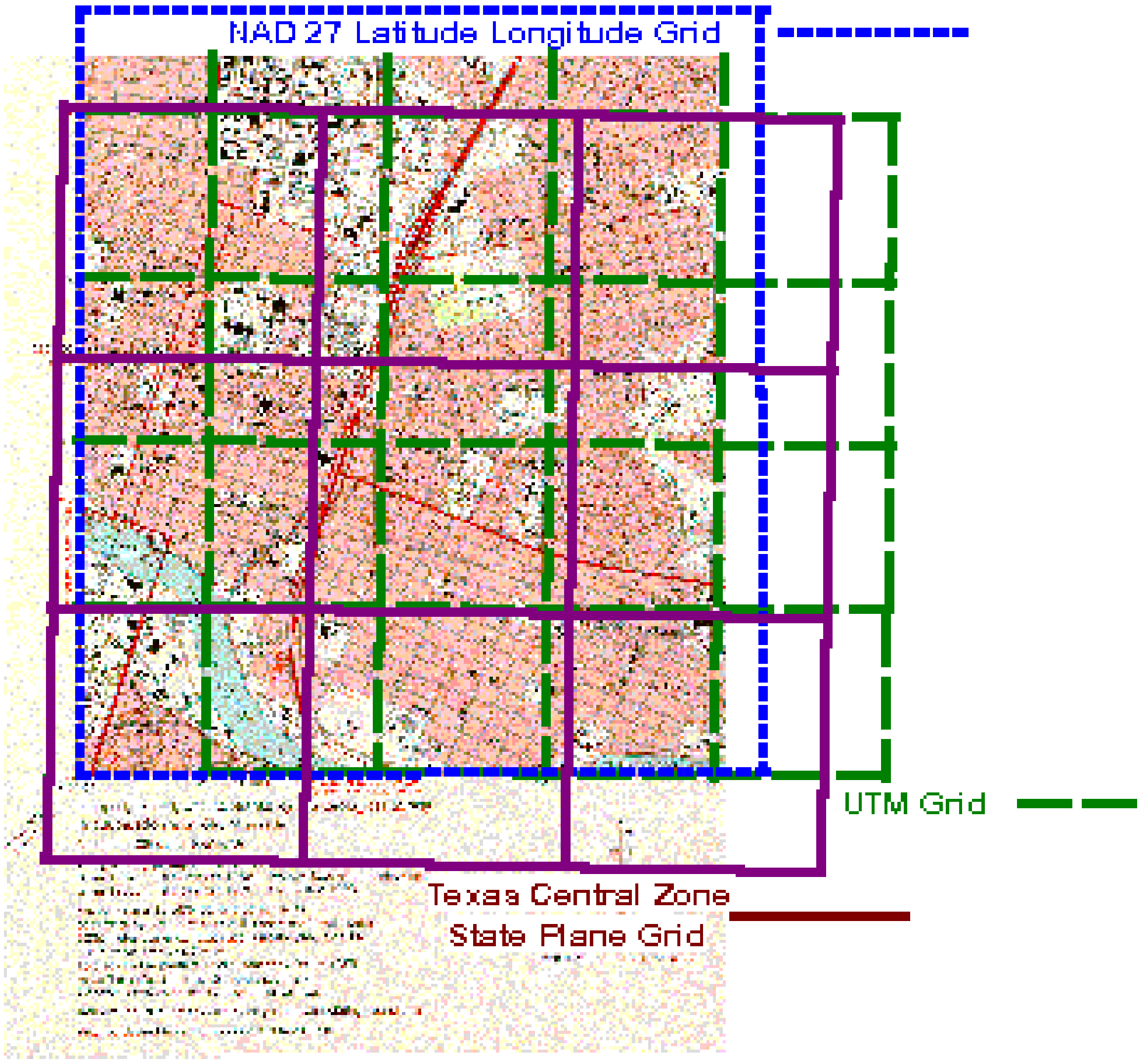
NAD-83 Latitude, Longitude of 30:16:28.82 N 97:44:25.19 W is

NAD-83 Texas Central Zone

State Plane Coordinates, Easting and Northing

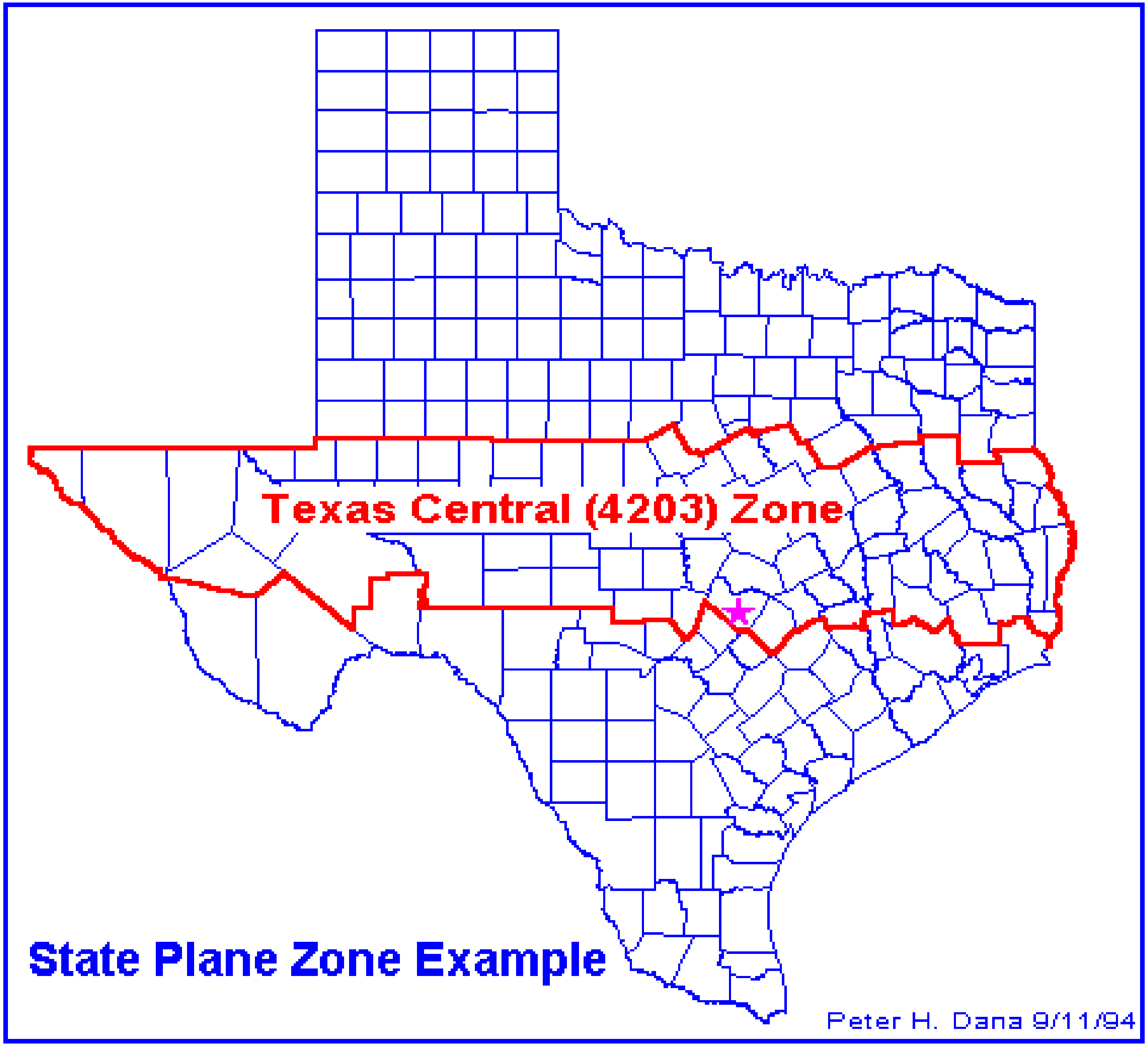
949465.059m, 3070309.475m

- Most USGS 7.5 Minute Quadrangles show several coordinate system grids including latitude and longitude, UTM kilometer tic marks, and applicable State Plane coordinates.
- Figure 23. Three Coordinate Systems on the Austin, East USGS 7.5' Quadrangle



NAD 27 Latitude Longitude Grid
UTM Grid
Texas Central Zone
State Plane Grid

- Each state has its own State Plane system with specific parameters and projections.
    - Software is available for easy conversion to and from latitude and longitude.
- A popular public domain software package, CORPSCON is maintained by the US Army Corps of Engineers
- Some smaller states use a single state plane zone while larger states are divided into several zones.
    - State plane zone boundaries often follow county boundaries.
- State Plane Zone Example


Texas Central (4203) Zone
State Plane Zone Example
Peter H. Dana 9/11/94

- Two projections are used in all State Plane systems, with one exception:
  - Lambert Conformal Conic projections are used for regions with a larger east-west than north-south extent.
    - examples are Nebraska and Michigan
  - Transverse Mercator projections are used for regions with a larger north-south extent.
    - examples are New Hampshire and Illinois
  - Some states use both projections
    - in Florida, the Lambert Conformal Conic projection is used for the North zone while the Transverse Mercator projection is used for the East and West zones.
  - The exception is one State Plane zone in Alaska which uses an Oblique Mercator projection for a thin diagonal area.
- Alaska State Plane Zone 5001

# What is the Michigan State Plane Coordinate System?

❖Prior to 1964, Michigan relied on a system that was based on three vertical projection zones. This system was the result of the federal government's initiative, the State Plane Coordinate System of 1927. This system, with it's vertically-oriented zones, created an unnecessarily large number of long boundaries between zones, and subdivided both the Lower and Upper Peninsulas.

❖Today, Michigan achieves the specified limits in distortions by breaking the state into three separate horizontally-oriented projections. The entire Upper Peninsula makes up the northern zone, the northern half of the Lower Peninsula is the central zone, and the southern half of the Lower Peninsula is the southern zone.

❖There have been two iterations of this system. The first was adopted by the Michigan Legislature in 1964. Then in 1983, the federal government made broad revisions to the entire set of state systems and published these revised standards as the State Plane Coordinate System of 1983.

# What is the Michigan GeoRef Coordinate System?

Michigan GeoRef is an alternative to the State Plane Coordinate System. But, unlike Michigan State Plane, GeoRef was designed to project the State using a single zone rather than three zones. Of course, something had to be compromised to achieve a single zone system.

❖The Michigan State Plane System specifies that 10,000 ft. on the ground can appear as no less than 9,999 ft. and no more than 10,001 ft. (1 part in 10,000) in the projected image or map. The Michigan GeoRef System, on the other hand, allows that same 10,000 ft. to vary from 9,996 ft. to 10,004 ft. (4 parts in 10,000) in apparent length.

❖Based on an Oblique Mercator projection with special parameters, the Michigan GeoRef System minimizes this increase in distortion by using a fundamentally different kind of map projection than is used by virtually all the State Plane Systems. The State Plane Systems make use of two basically different projection models. One of those projection methods favors regions that extend primarily north and south, and the other method favors regions that extend more in an east and west direction.

❖This choice for states such as Tennessee (east-west) and Vermont (north-south) was easy and uncompromising. However, Michigan is an odd-shaped state, expansive in a direction angling from the southeast to the northwest. The Map Projection Model used in GeoRef is well-suited to accommodating skewed regions such as Michigan.

# Michigan State Plane (NAD27)

Projection:  Lambert Conformal Conic

Datum: NAD27

Ellipsoid: Modified Clarke, 1866

Equatorial Radius: 6378450.04748448

Polar Radius: 6356826.62150116

Standard Units: US Survey feet

Standard Parallels: North 45° 29' N 47° 05' N

Central 44° 11' N 45° 42' N

South 42° 06' N 43° 40' N

Origin: North 87° 00' W 44° 47' N

Central 84° 20' W 43° 19' N

South 84° 20' W 41° 30'

# Michigan State Plane (NAD83)

Projection:  Lambert Conformal Conic

Datum: NAD83

Ellipsoid: GRS80

Standard Units: Meters

Standard Parallels: North 45° 29' N 47° 05' N

Central 44° 11' N 45° 42' N

South 42° 06' N 43° 40' N

Origin: North 87° 00' W 44° 47' N

Central 84° 22' W 43° 19' N

South 84° 22' W 41° 30' N

# Michigan Georef

Projection:  Oblique Mercator

Datum: NAD83

Ellipsoid: GRS80

Standard Units: Meters

Scale factor at projection's center: 0.9996

Longitude of projection's origin: 86° 00' 00'' W

Latitude of projection's origin: 45° 18' 33'' N

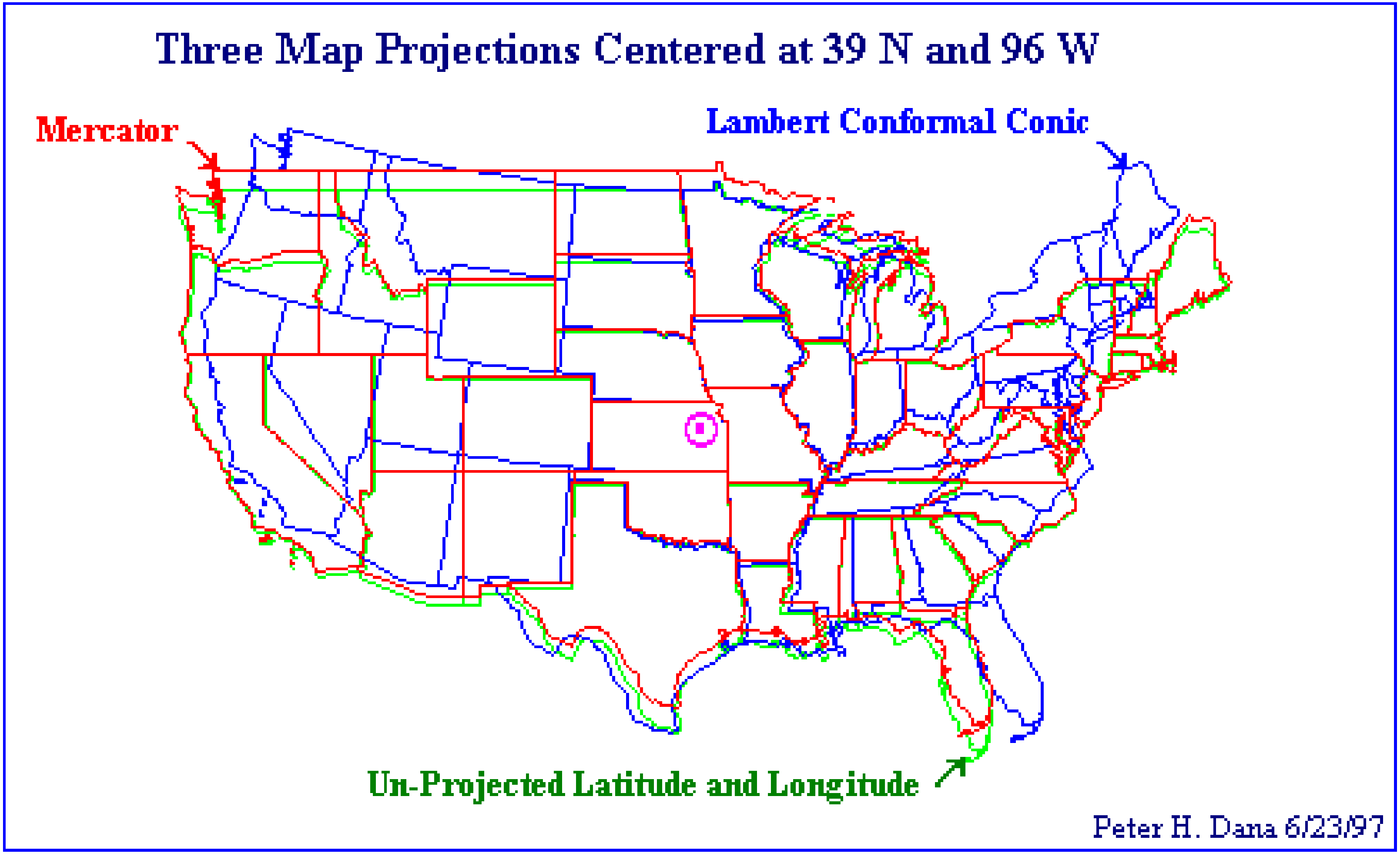
Azimuth at center of projection: 337.25556

False Easting: 2546731.496

False Northing: -4354009.816

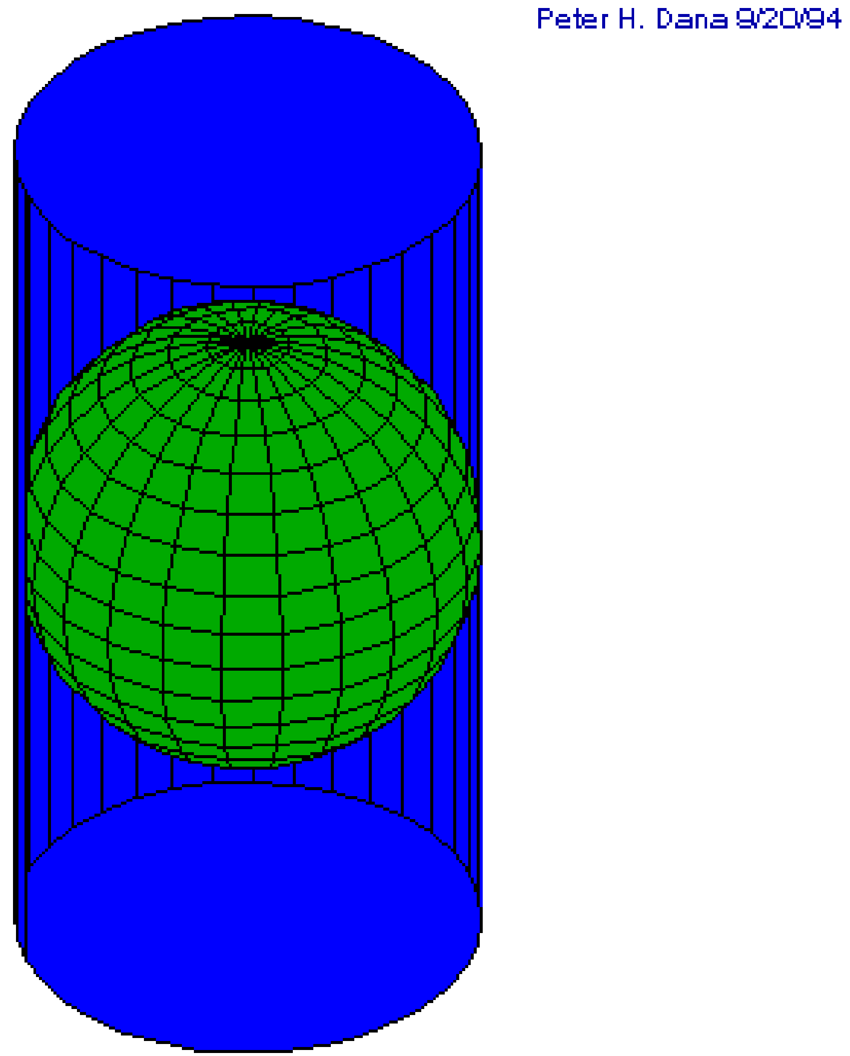
# Map Projections

- Cylindrical projections
- Conic projections
- Azimuthal projections
- Miscellaneous projectionis

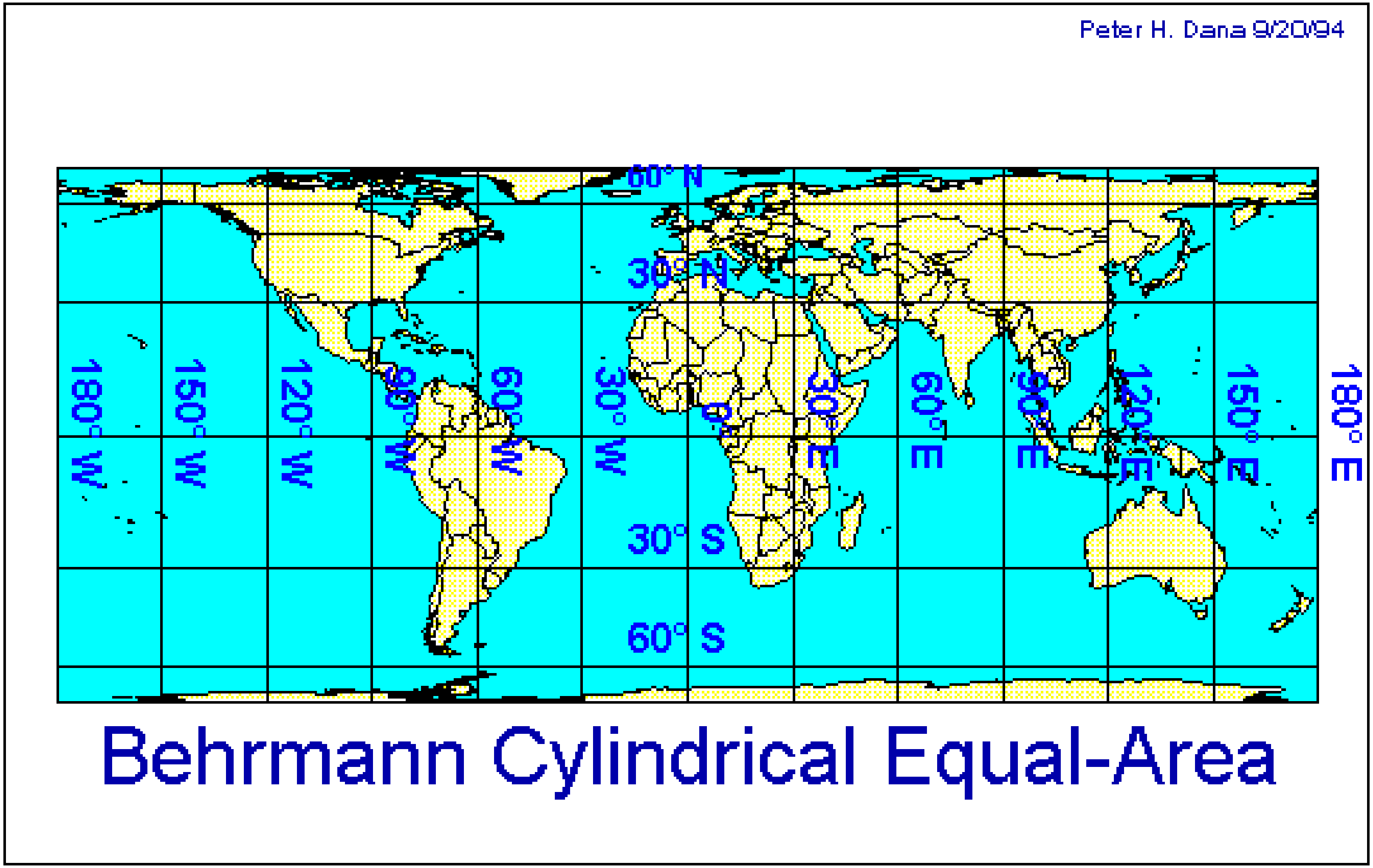


Three Map Projections Centered at 39 N and 96 W
Mercator
Lambert Conformal Conic
Un-Projected Latitude and Longitude
Peter H. Dana 6/23/97

# Cylindrical

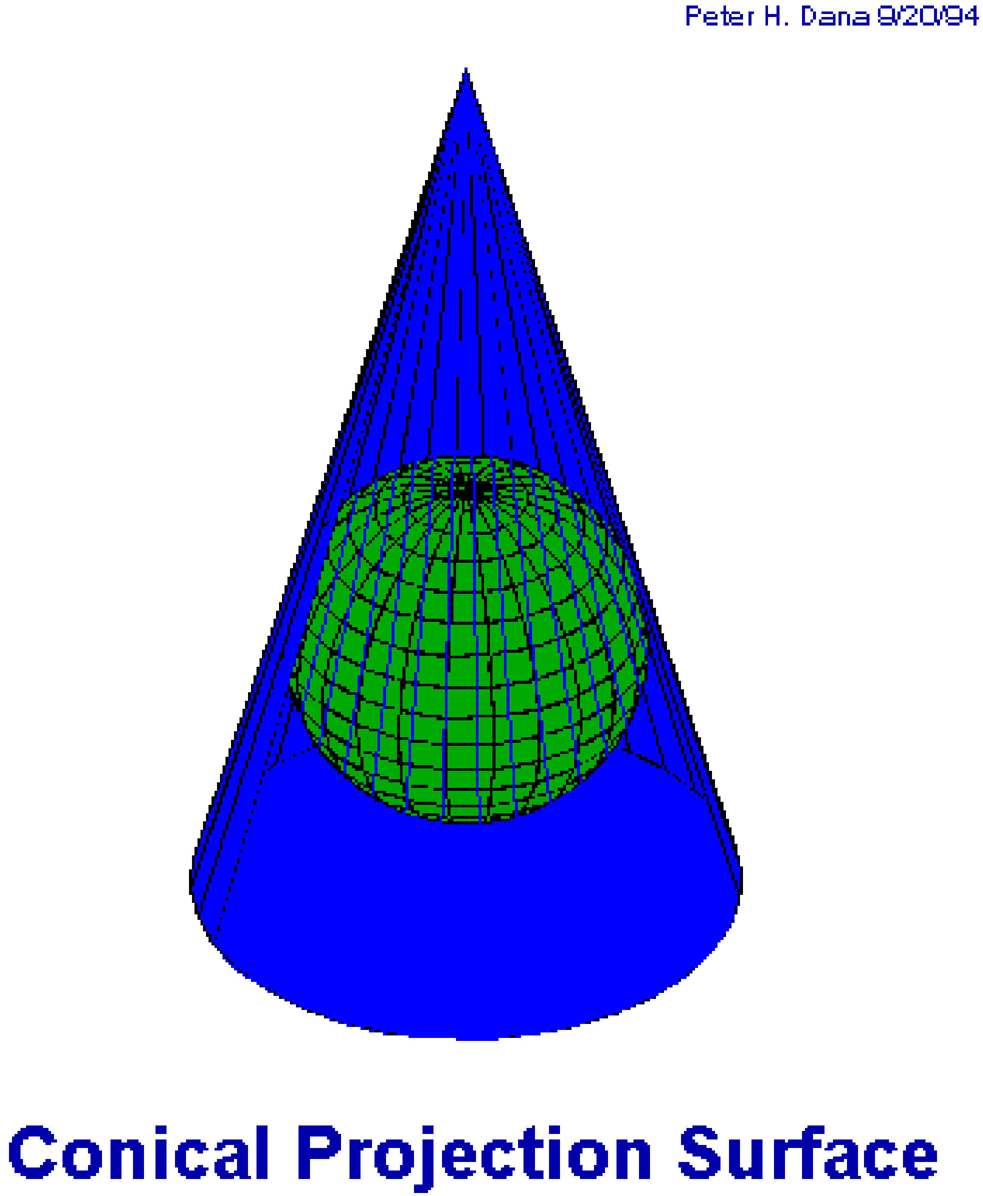


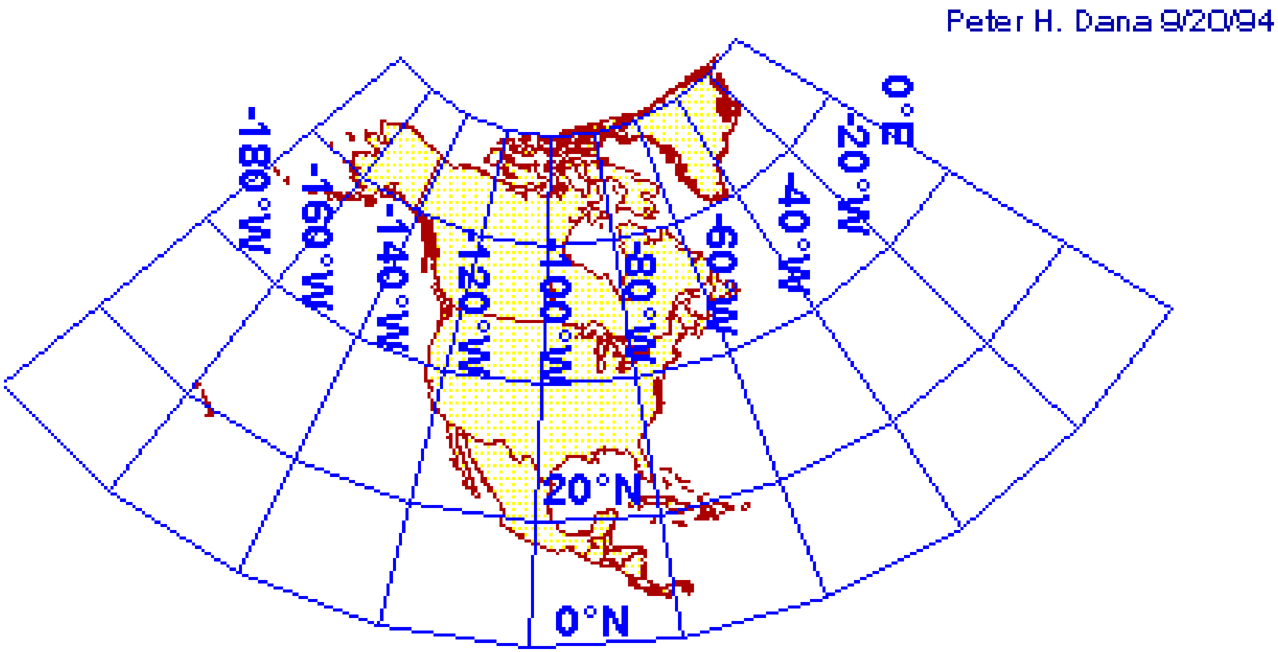

**Cylindrical Projection Surface**



Peter H. Dana 9/20/94
60° N
30° N
0°
30° S
60° S
180° W
150° W
120° W
90° W
60° W
30° W
30° E
60° E
90° E
120° E
150° E
180° E
Behrmann Cylindrical Equal-Area

# Conical



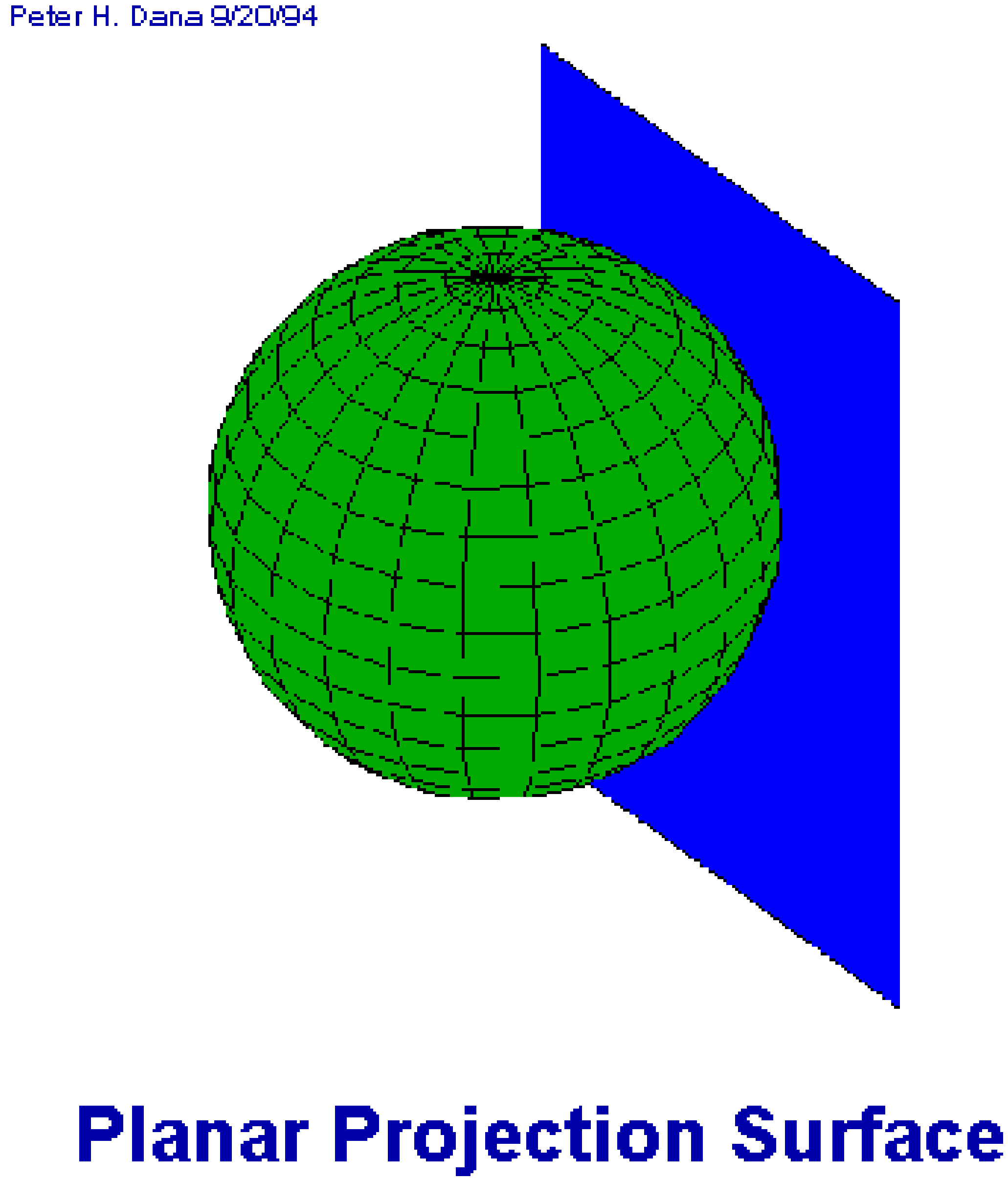


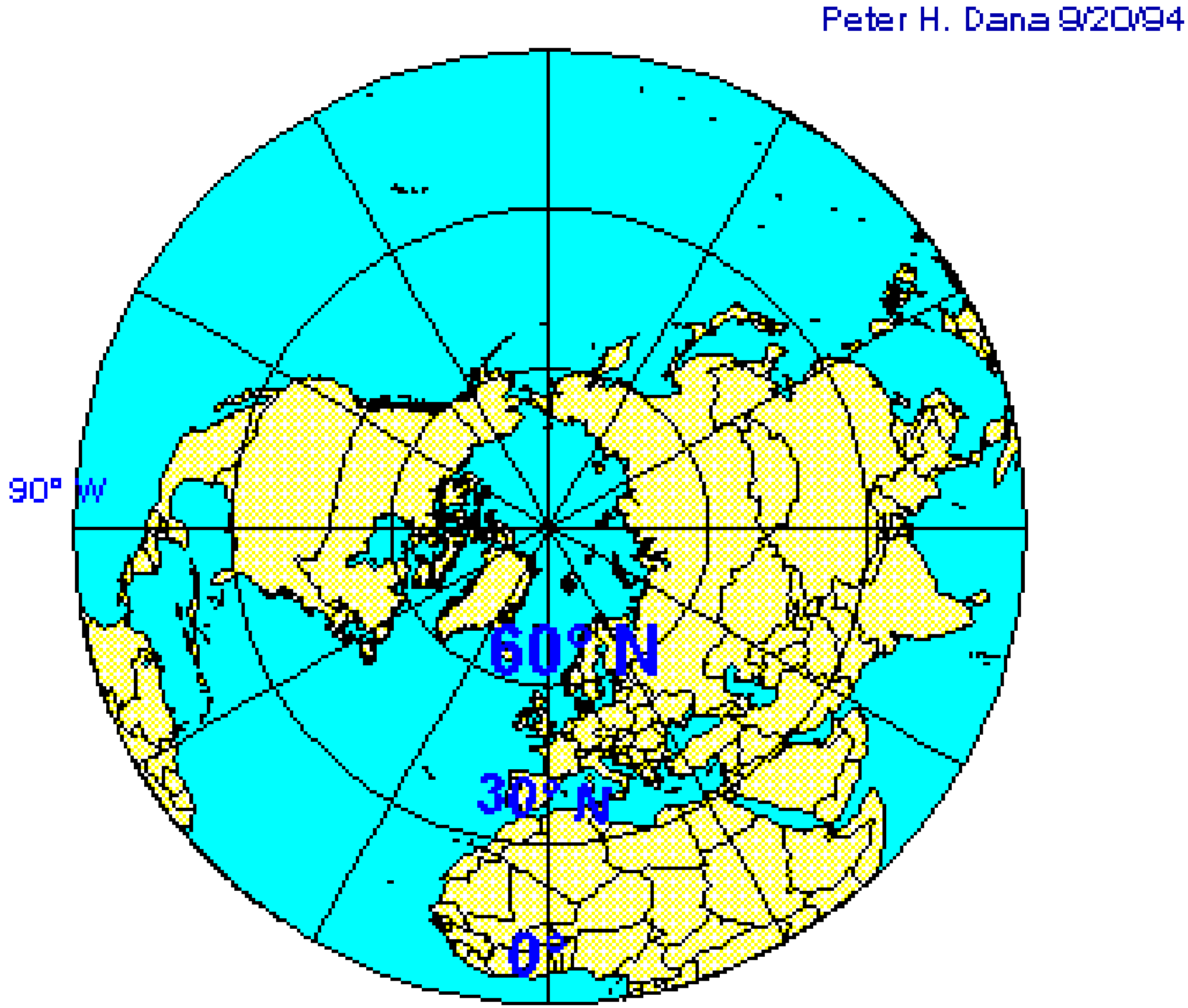

**North America**

**Albers Equal-Area Conic**

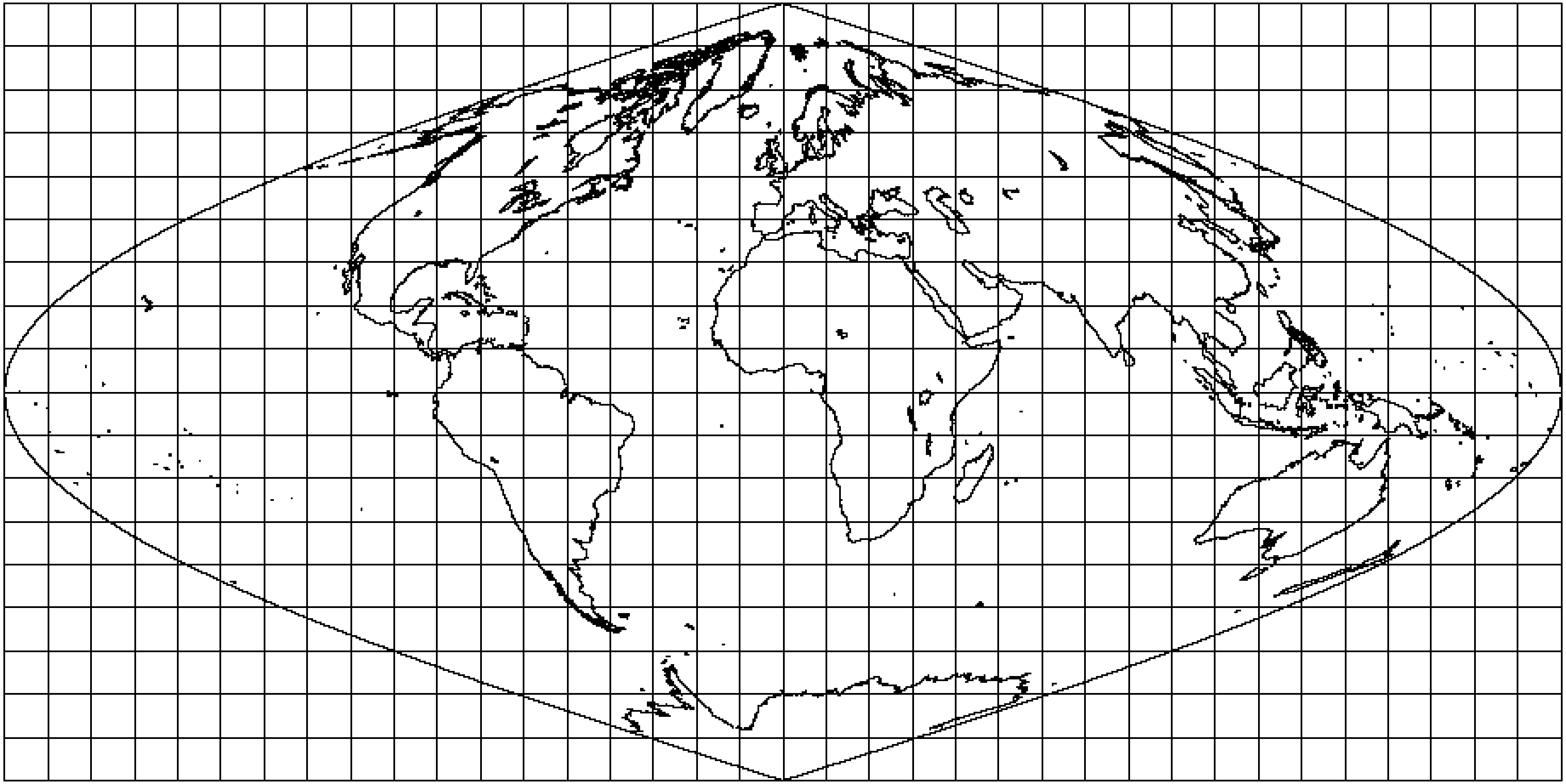
**Origin: 23N, 96W**

**Standard Parallels: 20N, 60N**


Peter H. Dana 9/20/94
Planar Projection Surface

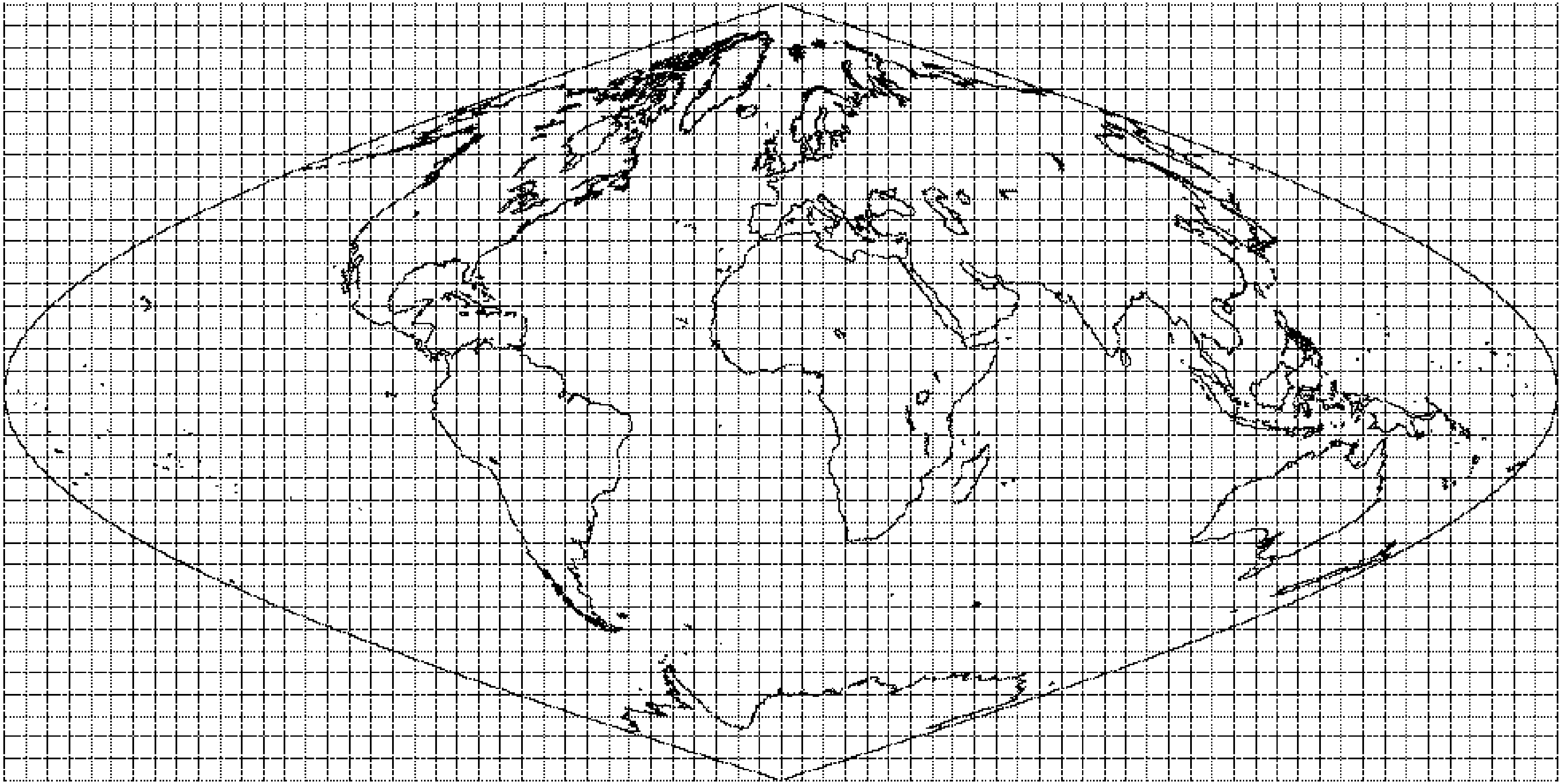



# Azimuthal Equidistant



# 10 degree Tiles:

- There are 460 non-fill 10 deg. by 10 deg. tiles in the grid.
- The tile coordinate system starts at (0,0) (horizontal tile number, vertical tile number) in the upper left corner and proceeds rightward (horizontal) and downward (vertical). The tile in the bottom left corner is (35, 17).



# 5 degree Tiles

**The tile coordinate system starts at (0,0) (vertical tile number, horizontal tile number) in the upper left corner and proceeds downward (vertical) and rightward (horizontal). The tile in the bottom left corner is (35, 71).**

# Integerized Sinusoidal Projection References


- "The WMO Format for the Storage of Weather Product Information and the Exchange of Weather Product Messages in Gridded Binary Form", John D. Stackpole, Office Note 388, GRIB Edition 1, U.S. Dept. of Commerce, NOAA, National Weather Service National Meteorological Center, Automation Division, Section 1, pp. 9-12, July 1, 1994.
- "The Michigan Earth Grid: Description, Registration Method for SSM/I Data, and Derivative Map Projections", John F. Galntowicz, Anthony W. England, The University of Michigan, Radiation Laborartory, Ann Arbor, Michigan, Feb. 1991.
- "Selection of a Map Grid for Data Analysis and Archival", William B. Rossow, and Leonid Garder, American Meteorological Society Notes, pp. 1253-1257, Aug. 1984.
- "Level-3 SeaWiFS Data Products: Spatial and Temporal Binning Algorithms", Janet W. Campbell, John M. Blaisdell, and Michael Darzi, NASA Technical Memorandum 104566, GSFC, Volume 32, Appendix A, Jan. 13, 1995.

https://lpdaac.usgs.gov/lpdaac/tools/modis_reprojection_tool

# MODIS Reprojection Tool

The MODIS Level-3 Land products are generated by the MODIS Adaptive Processing System (MODAPS), located at the NASA Goddard Space Flight Center, as gridded output in the Sinusoidal (SIN) projection. These data products are then sent to the LP DAAC for archive and distribution.

The LP DAAC contracted the South Dakota School of Mines & Technology to undertake software development of the MODIS Tool. The initial version of this software will enable users to read data files in HDF-EOS format (MODIS Level-2G, Level-3, and Level-4 land data products), specify a geographic subset or specific science data sets as input to processing, perform geographic transformation to a different coordinate system/cartographic projection, and write the output to file formats other than HDF-EOS.

The MODIS Reprojection Tool is available for use by all registered users. The MODIS Tool will undergo further development to correct problems as they are detected, incorporate additional functionality, and be modified to enhance computational performance. The funding support for this work comes from the NASA Earth Science Data and Information Systems (ESDIS) Project.

## Download

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- *Linux 64 **7 MB***
- *Solaris 2.7 **7 MB***
- *Macintosh OS X (Intel) **6 MB***

## Manuals

- MRT User Manual
- Release Notes