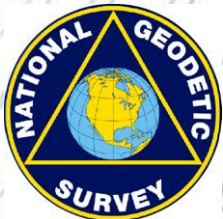


# Decoding the Mystery of Coordinates

NHLSA  
TOWN MONUMENT LOCATION  
WORKSHOP  
UNH – DURHAM, N.H.  
8-11-2007

## **PART 1: THE DIFFERENT COORDINATE SYSTEMS**

**Bob Moynihan**  
**UNH - TSAS**



UNIVERSITY of NEW HAMPSHIRE



# Decoding the Mystery of Coordinates

Objective of Presentation:

To introduce and discuss the common  
Surveying and Mapping Coordinate Systems  
used to establish the position of monuments

# PRESENTATION OUTLINE

- 4 SURFACES
- 3 HEIGHTS
- 2 DATUMS
- 4 COORDINATE SYSTEMS
- 3 DISTANCES
- 5 NORTHS

The background features a series of parallel teal lines that are slightly curved and converge towards the left side of the frame, creating a sense of depth and perspective. The lines vary in thickness and are set against a light, off-white background.

# **FOUR SURFACES**

# FOUR SURFACES

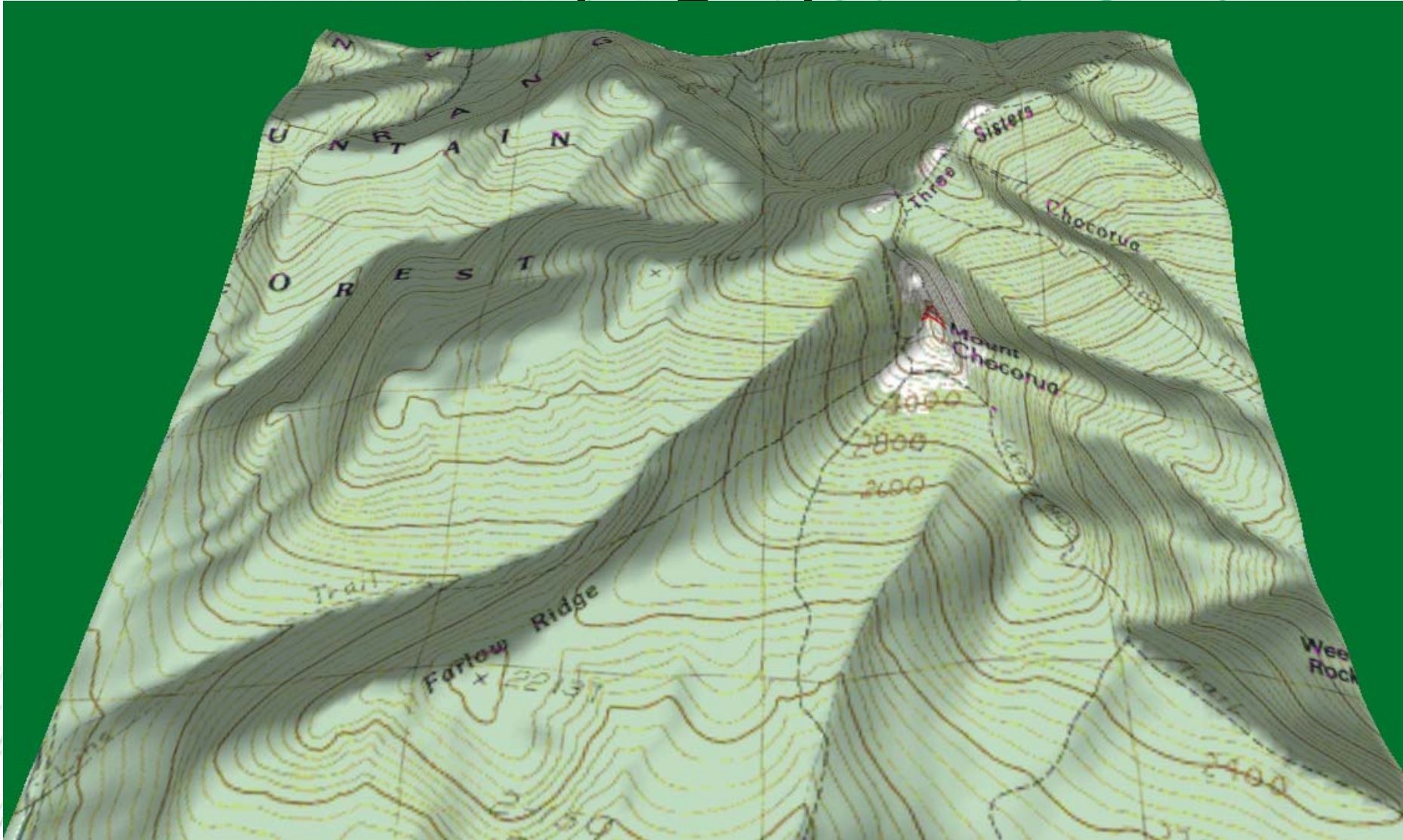
- 1- Earth - Topographic surface
- 2- Geoid - “Sea Level or “equipotential surf.
- 3- Ellipsoid - Mathematical surface
- 4- Grid - Projection, flat surface



# 1. Earth's Topographic Surface



# 1. Earth's Topographic Surface





# 2. Earth's "Sea Level" Surface

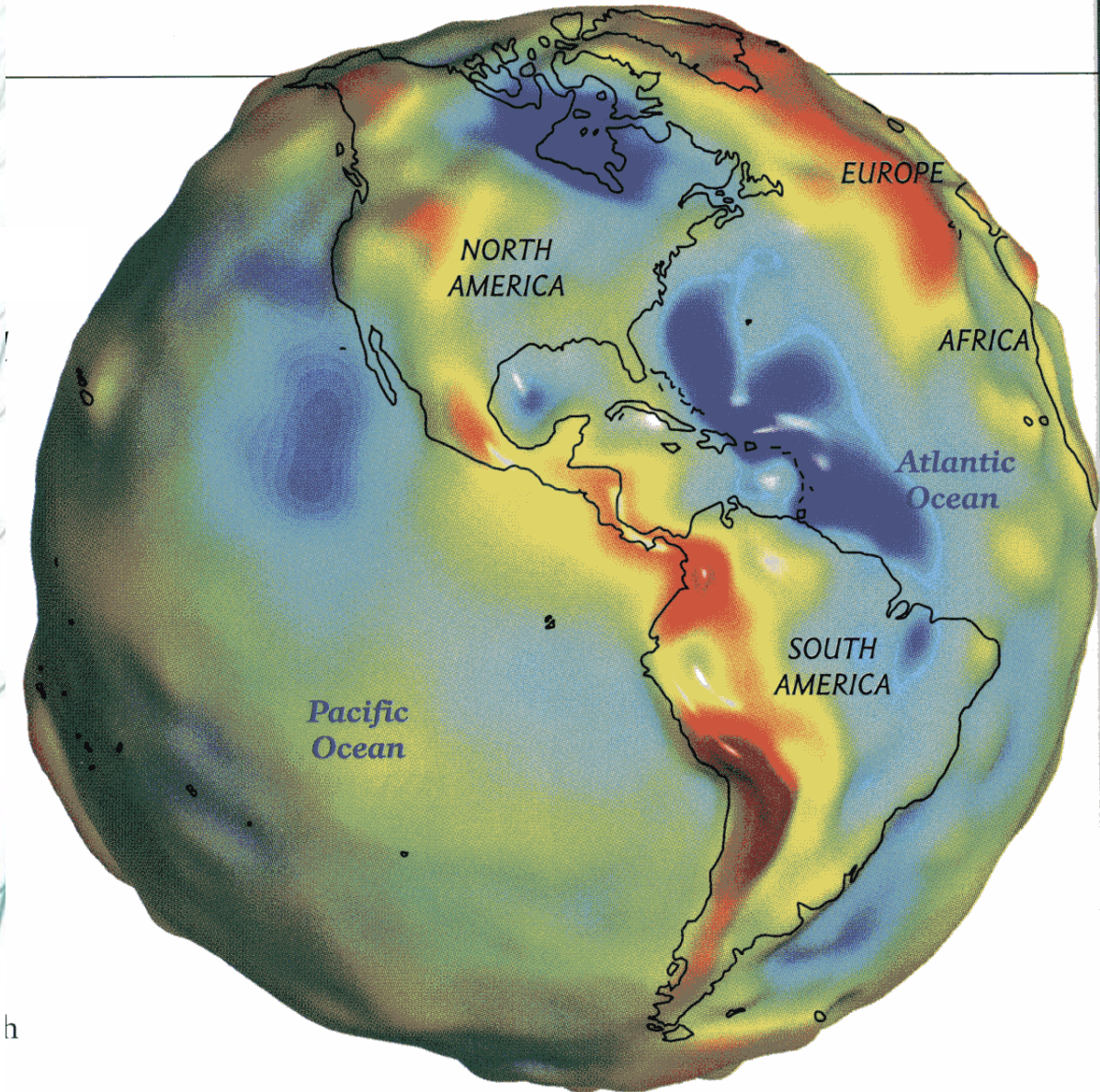
## THE GEOID:

Equipotential, or  
gravity surface

Current Model is  
Geoid 03

Gravity Recovery  
and Climate  
Experiment  
(GRACE)

Center for Space Research  
Univ. of Texas



h

s

# 3. Earth's "Mathematical" Surface

## THE ELLIPSOID:

World Geodetic System '84  
WGS '84

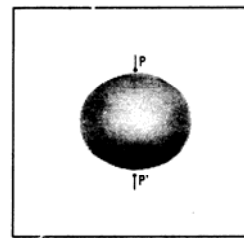
$a = 6,378,137$  meters

$b = 6,356,752.3142$  meters

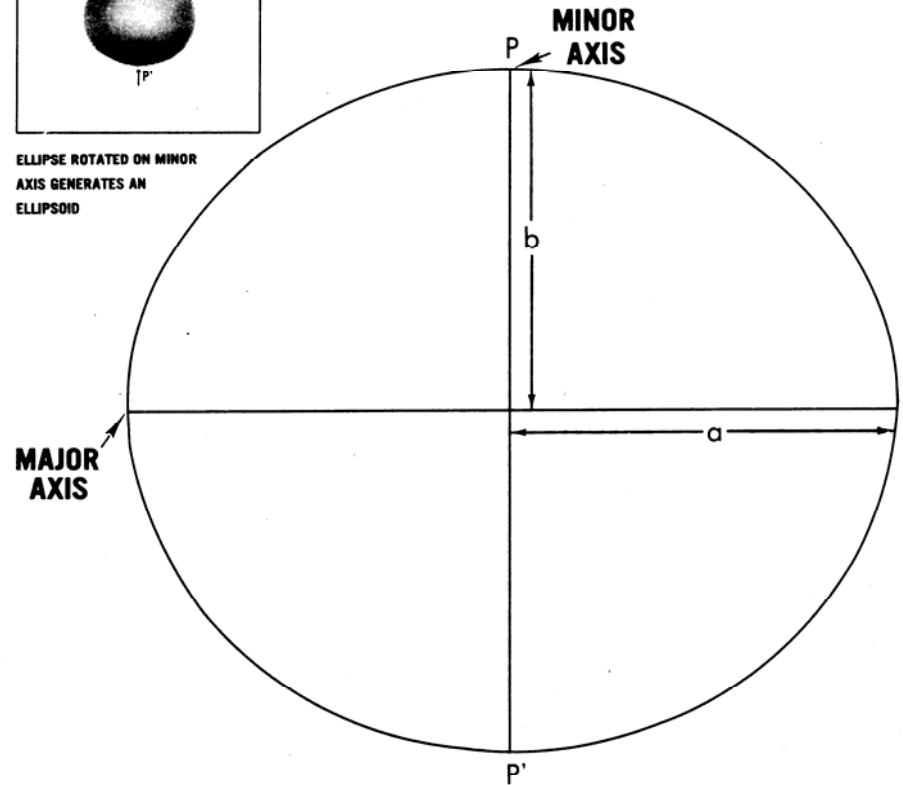
$f = 1 / 298.25722$

For a circle, flattening = 0

Coordin



ELLIPSE ROTATED ON MINOR  
AXIS GENERATES AN  
ELLIPSOID



$a$  = ONE-HALF OF THE MAJOR AXIS = SEMI-MAJOR AXIS

$b$  = ONE-HALF OF THE MINOR AXIS = SEMI-MINOR AXIS

$f$  = FLATTENING =  $\frac{a - b}{a}$

# Geodetic Coordinate Systems

A Set Of Rules For Specifying How Coordinates Are To Be Assigned To Positions On The Surface Of The Earth.  
Defined BY X,Y,Z On An Ellipsoid

What We  
Like To Think  
The Earth Is  
Shaped Like

Sphere

Equipotential  
Gravimetric  
Surface  
(Sea-Level)

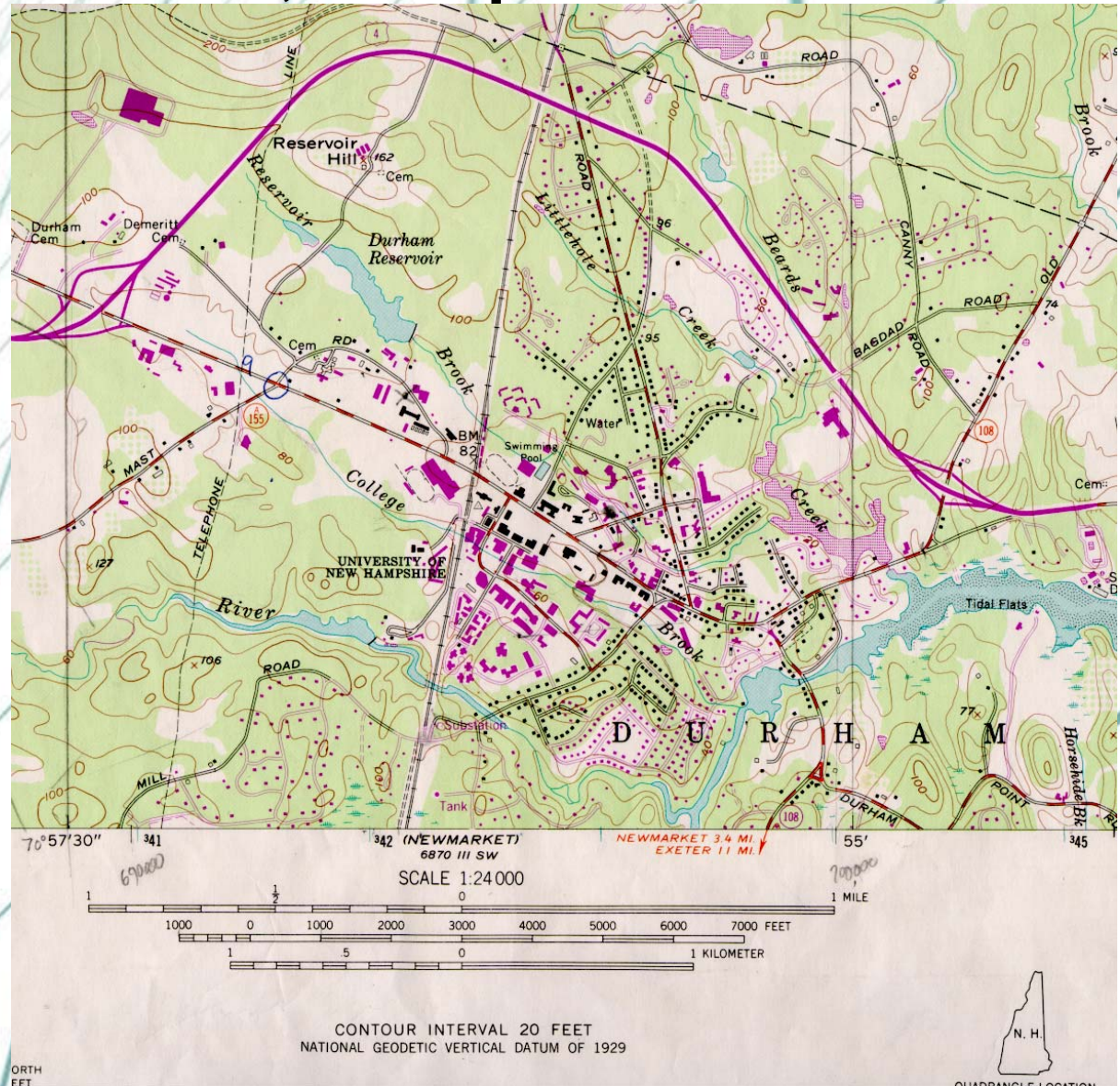
Geoid

Best Fitting Math-  
ematical Shape

Ellipsoid

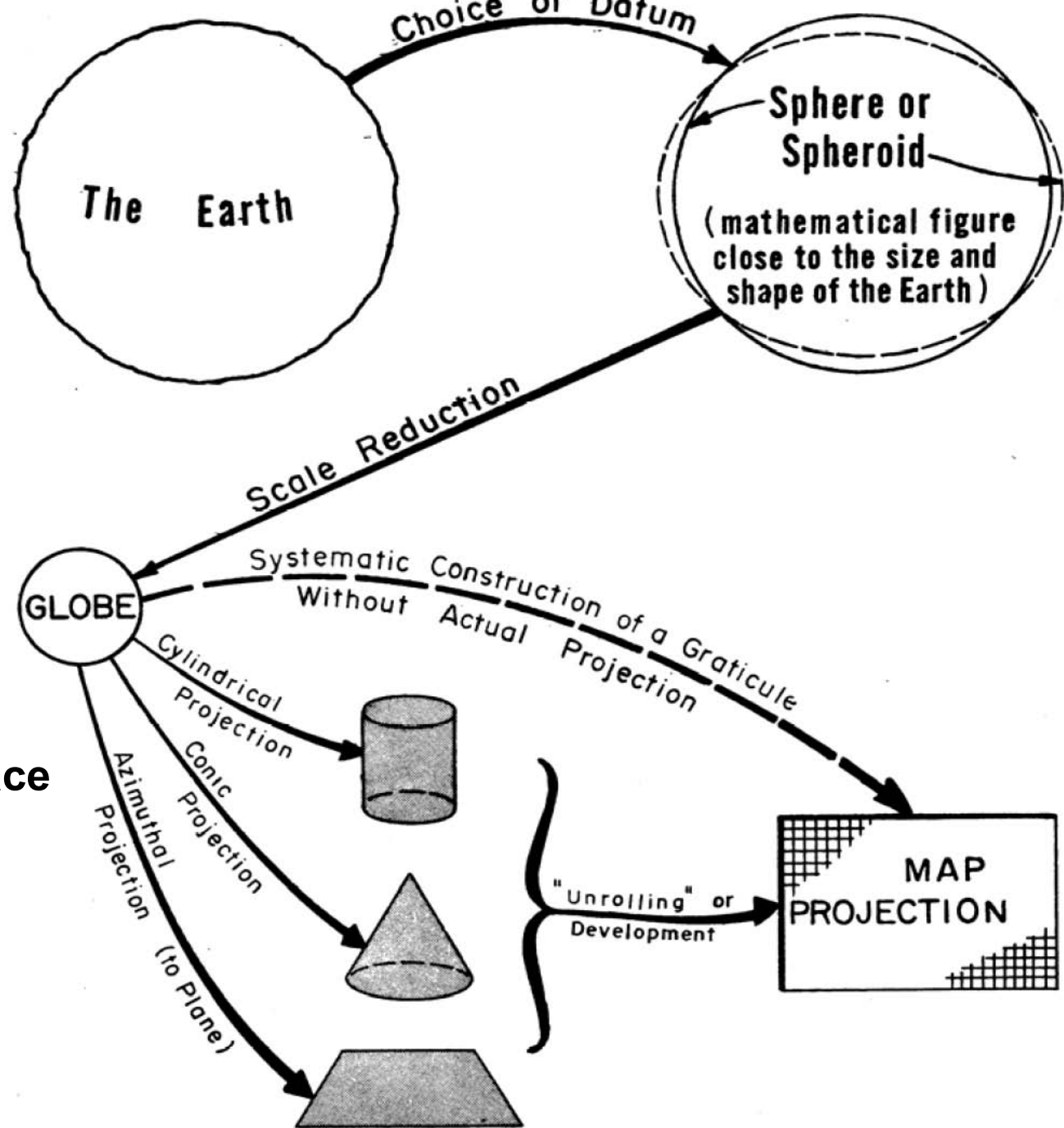
# 4. Earth's "Flat, Map" Surface

## THE GRID



# Creating The GRID:

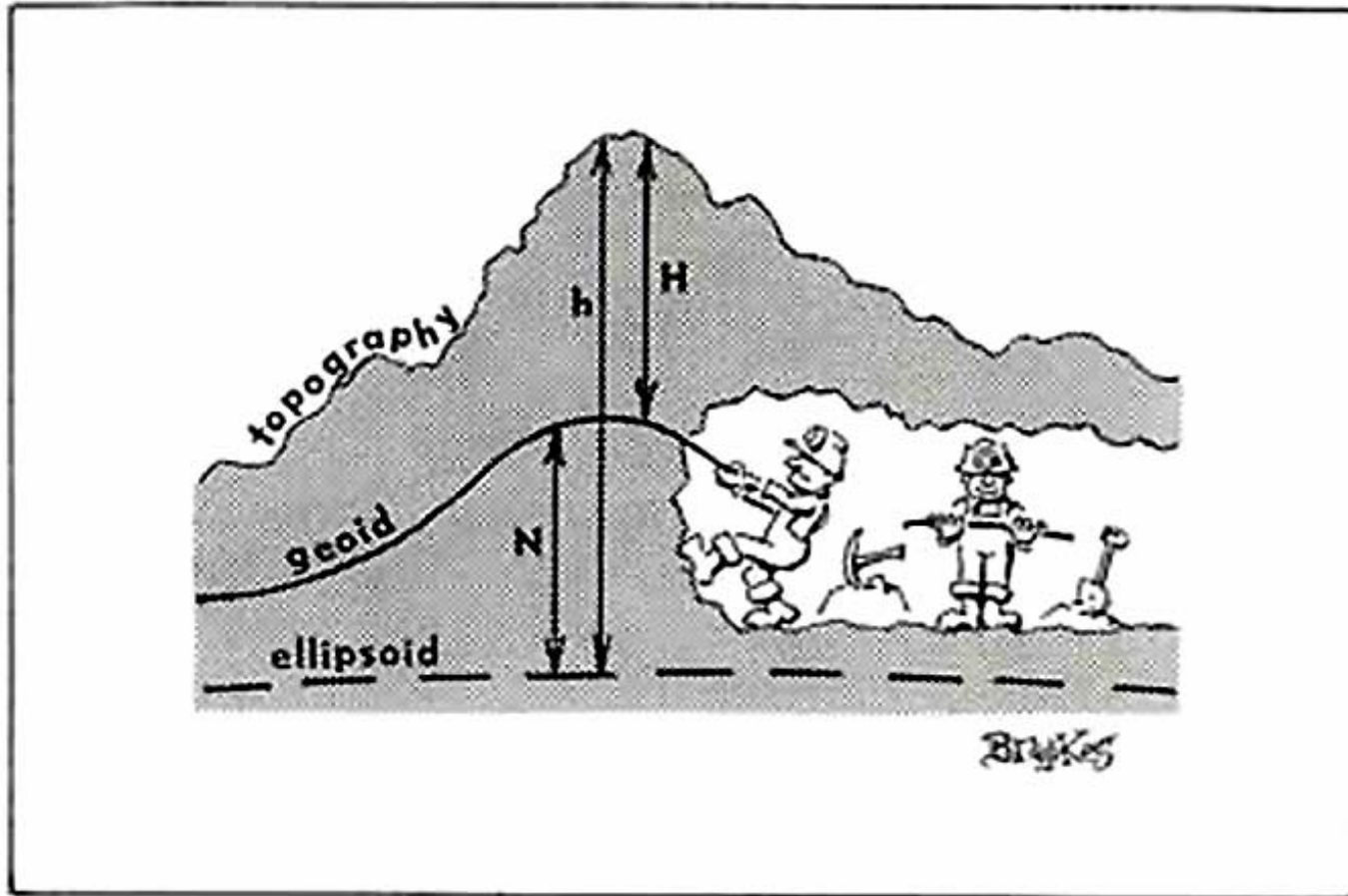
- 1 A Mathematical Surface
- 2 Reduce the Scale
- 3 Project on a surface
- 4 Unroll the surface



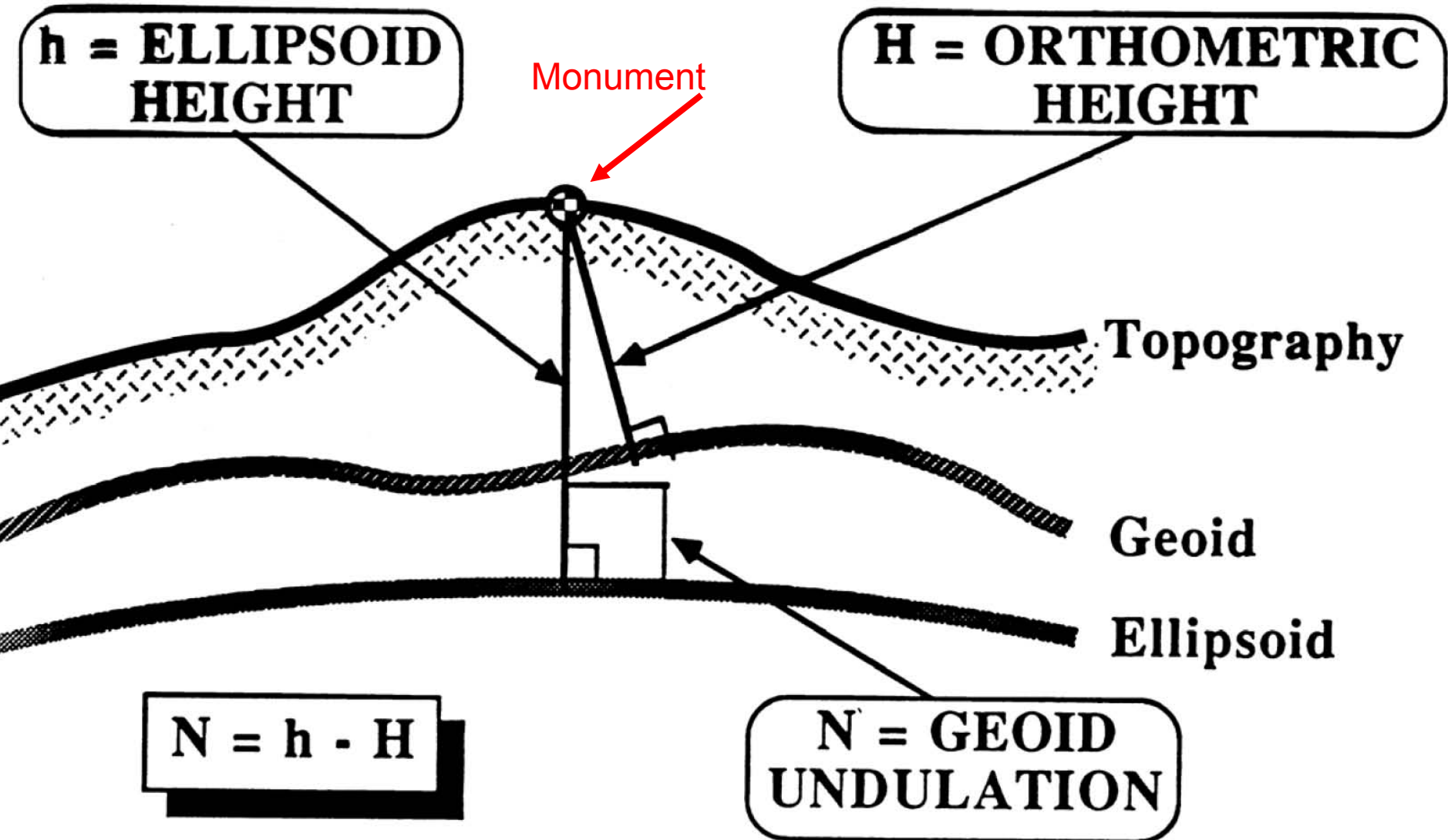
# THREE “HEIGHTS”

1. ORTHOMETRIC (elevation)
2. ELLIPSOID
3. GEOID

# In Search of the Geoid...



# THREE "HEIGHTS"





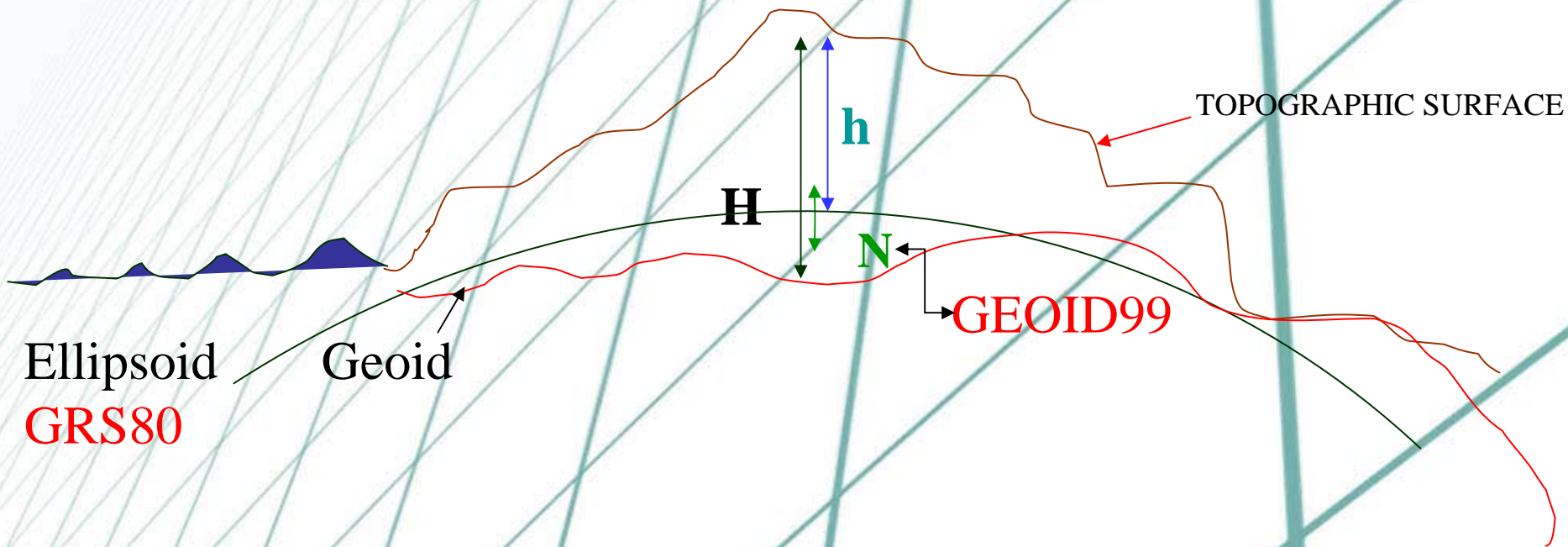
# Ellipsoid, Geoid, and Orthometric Heights

**H = Orthometric Height (NAVD 88)**

**h = Ellipsoidal Height (NAD 83)**

**N = Geoid Height (GEOID 03)**

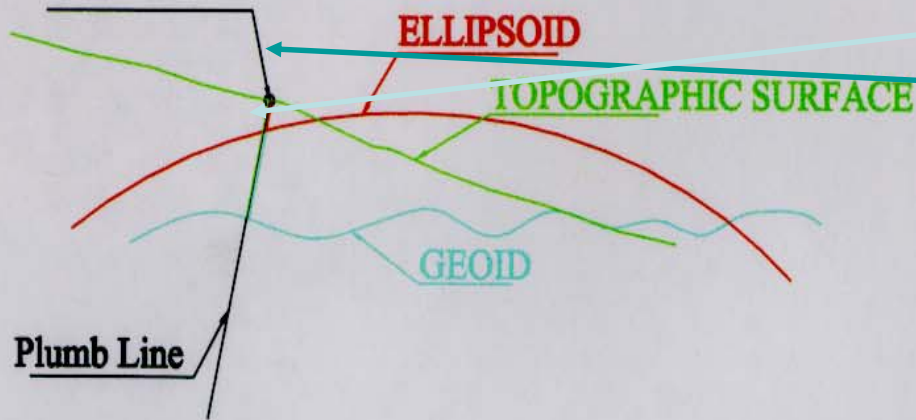
$$h = H + N$$



# Ellipsoid, Geoid, and Orthometric Heights

STATION "DURHAM 1943" : Has **THREE** "Heights"

Station "Durham 1943"



Station "Durham 1943"

Orthometric Height = 106.46'

Geoid Height = -89.19'

Ellipsoid Height = +17.27'

Ellipsoid Height = Orthometric Height + Geoid Height

$$h = H + N$$

$$17.27' = 106.46' + -89.19'$$

# TWO DATUMS

1. HORIZONTAL
2. VERTICAL

# TWO DATUMS

## A Datum:

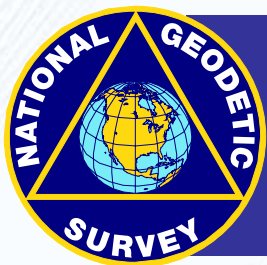
Any numerical or geometrical quantity or set of such quantities which serve as a reference or base for calculation of other quantities. (GMS)

1. Horizontal Geodetic Datum: An Ellipsoid
2. Vertical Geodetic Datum: “Mean Sea Level” ≈ Geoid

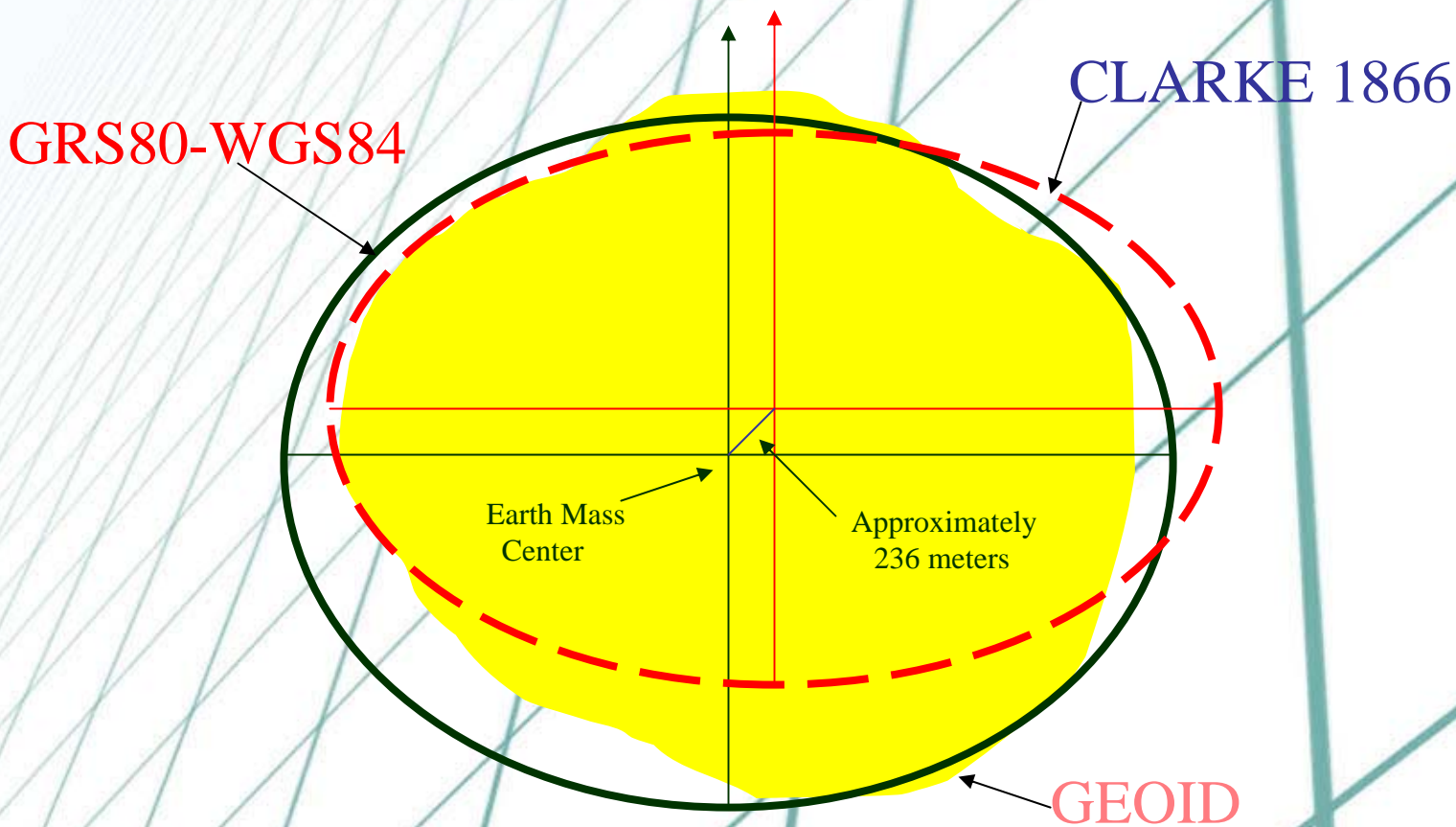
# 1. Horizontal Control Datum

- “A Geodetic Datum specifying the coordinate system in which horizontal control points are located.”
- Defined by 8 Constants
  - 3 – specify the location of the origin of the coordinate system.
  - 3 – specify the orientation of the coordinate system.
  - 2 – specify the dimensions of the reference ellipsoid.
- NAD 27, NAD 83

\*Definition from the Geodetic Glossary, September 1986



# THE GEOID AND TWO ELLIPSOIDS



# Comparison of Horizontal Datum Elements

## NAD 27

## NAD 83

ELLIPSOID

CLARKE 1866

GRS80

$a = 6,378,206.4 \text{ m}$

$a = 6,378,137. \text{ M}$

$1/f = 294.9786982$

$1/f = 298.257222101$

DATUM POINT

Triangulation Station  
MEADES RANCH, KANSAS

NONE  
EARTH MASS CENTER

ADJUSTMENT

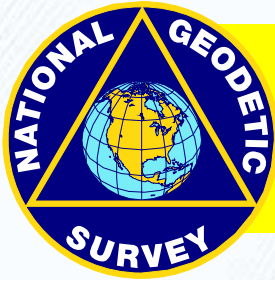
25k STATIONS  
Several Hundred Base Lines  
Several Hundred Astro Azimuths

250k STATIONS  
Appox. 30k EDM Base Lines  
5k Astro Azimuths  
Doppler Point Positions  
VLBI Vectors

BEST FITTING

North America

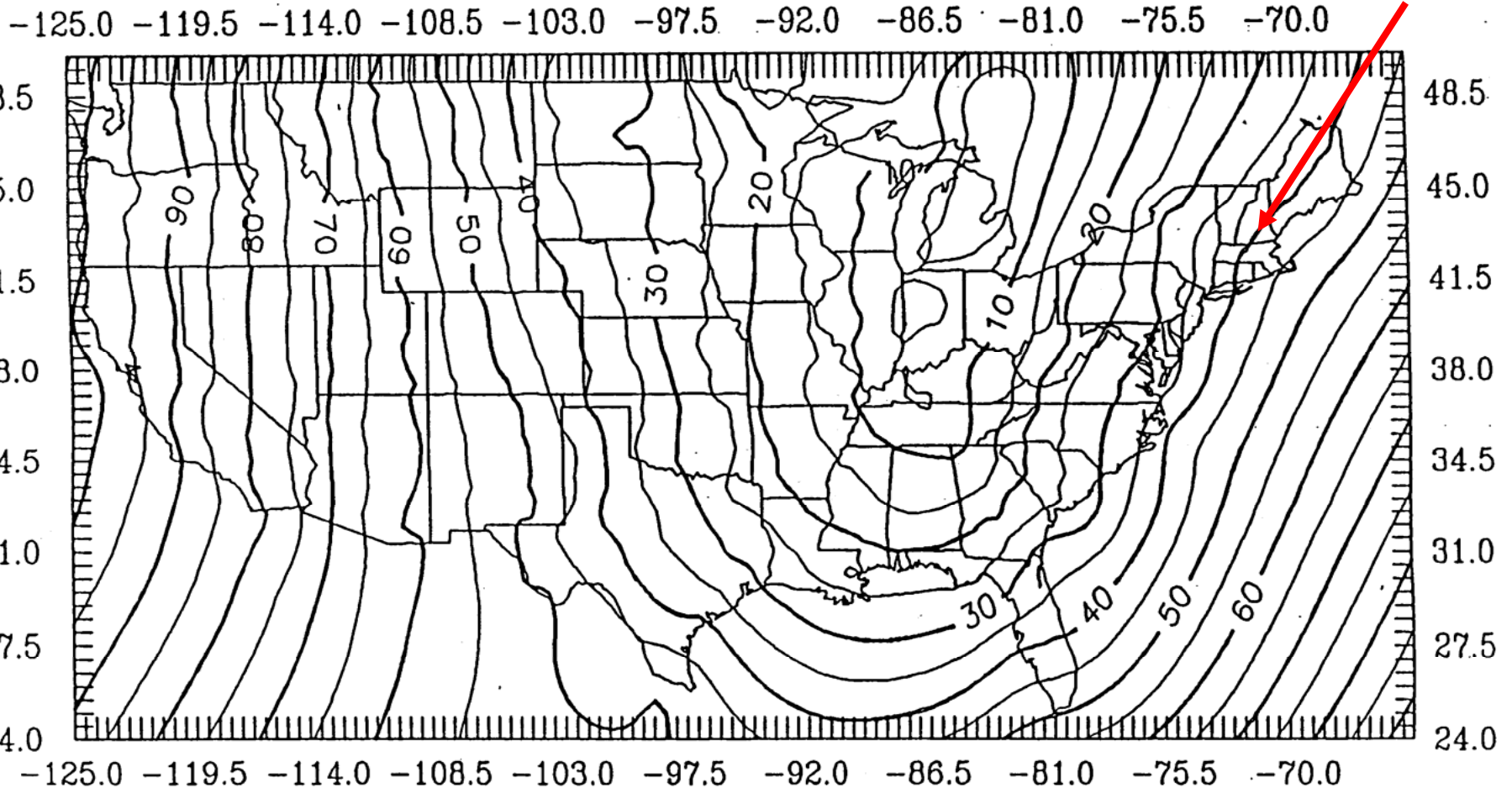
World-Wide



# NAD 27 and NAD 83

## MAGNITUDE OF DATUM SHIFT (METERS)

'83 Position ~ 40 meters ((131 ft.) SW of '27 position





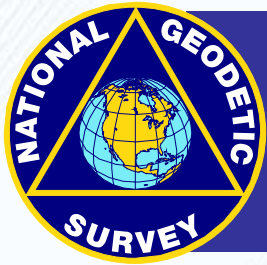
## 2. Vertical Control Datum

A set of fundamental elevations to which other elevations are referred

# Vertical Control Datum

- “A Geodetic Datum specifying the system in which vertical control points are located.”
- A set of fundamental elevations to which other elevations are referred
- NGVD 29, NAVD 88 – Orthometric, “Sea Level”
- Others – Cairo, Local Tidal

\*Definitions from the Geodetic Glossary, September 1986



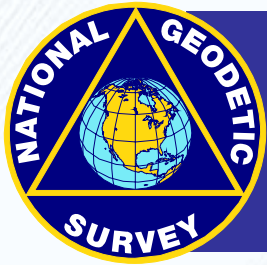
# VERTICAL DATUMS

MEAN SEA LEVEL DATUM OF 1929

NATIONAL GEODETIC VERTICAL DATUM OF 1929  
(As of July 2, 1973)

NORTH AMERICAN VERTICAL DATUM OF 1988  
(As of June 24, 1993)





# COMPARISON OF VERTICAL DATUM ELEMENTS

## NGVD 29

## NAVD 88

DATUM DEFINITION

26 TIDE GAUGES  
IN THE U.S. & CANADA

FATHER'S POINT/RIMOUSKI  
QUEBEC, CANADA

BENCH MARKS

100,000

450,000

LEVELING (Km)

102,724

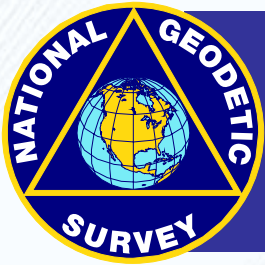
1,001,500

GEOID FITTING

Distorted to Fit MSL Gauges

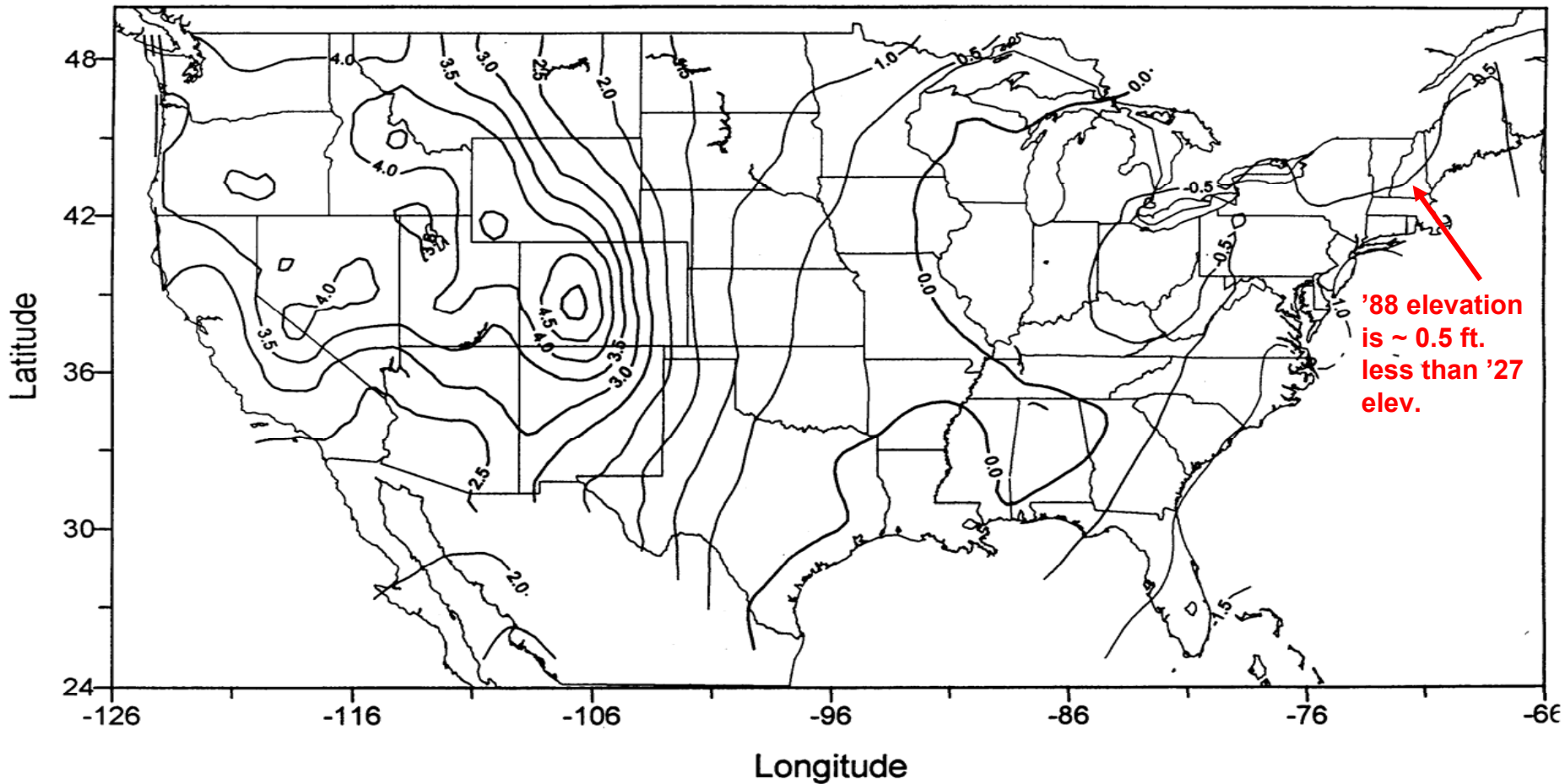
Best Continental Model





# NGVD 29 and NAVD 88

NAVD88 - NGVD29 (feet)





# **FOUR COORDINATE SYSTEMS**

# FOUR COORDINATE SYSTEMS (3D)

1. GEOCENTRIC COORDINATES:

**X,Y,Z**

2. GEODETIC COORDINATES

**$\Phi, \lambda, h$**

3. CARTESIAN (PLANE) COORDINATES

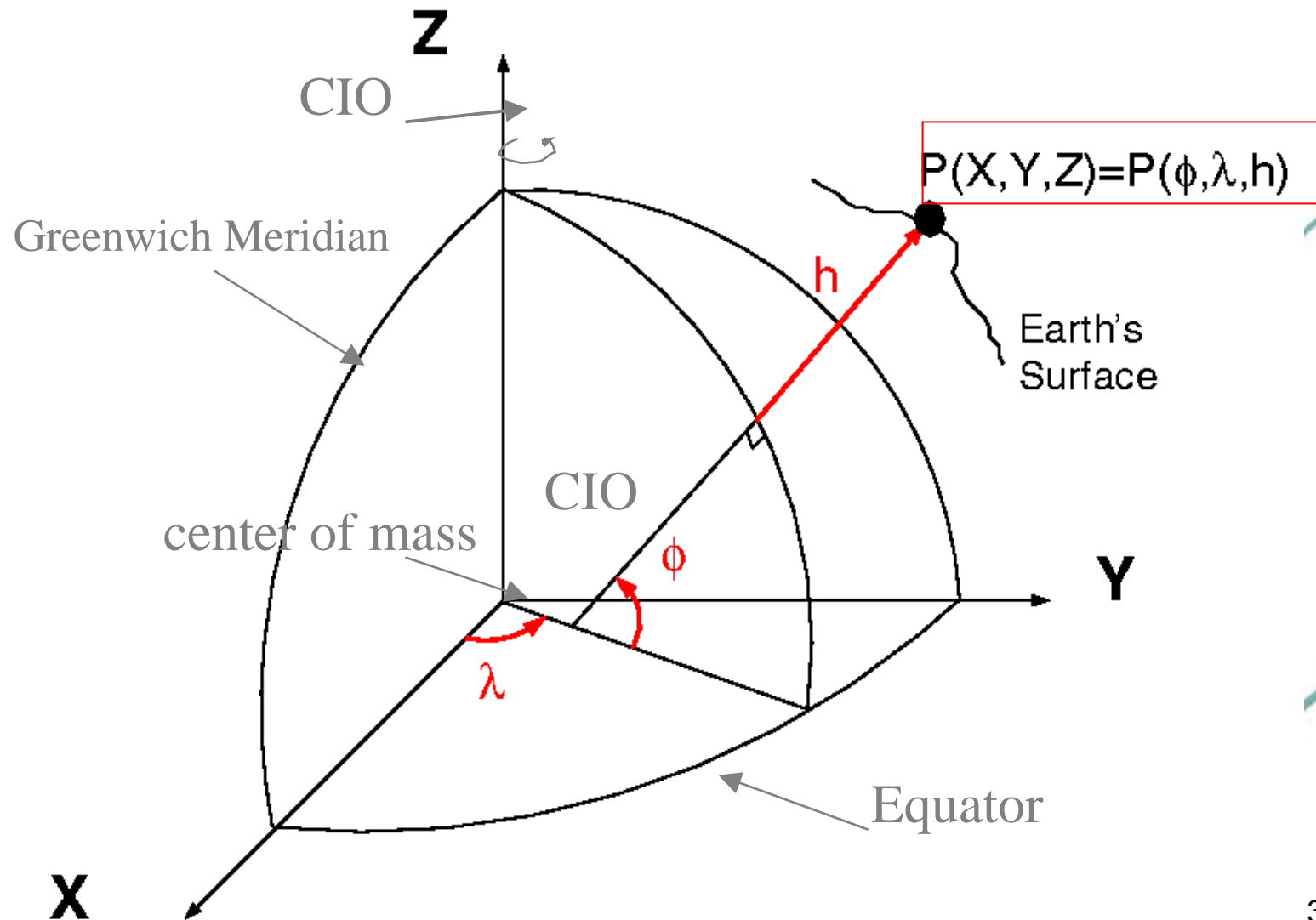
**N,E,H** (State Plane Coordinates., UTM coord.)

4. ASSUMED COORDINATES

**Y, X, Elevation**

# 1. Geocentric Coordinates

## Conventional Terrestrial System (CTS)



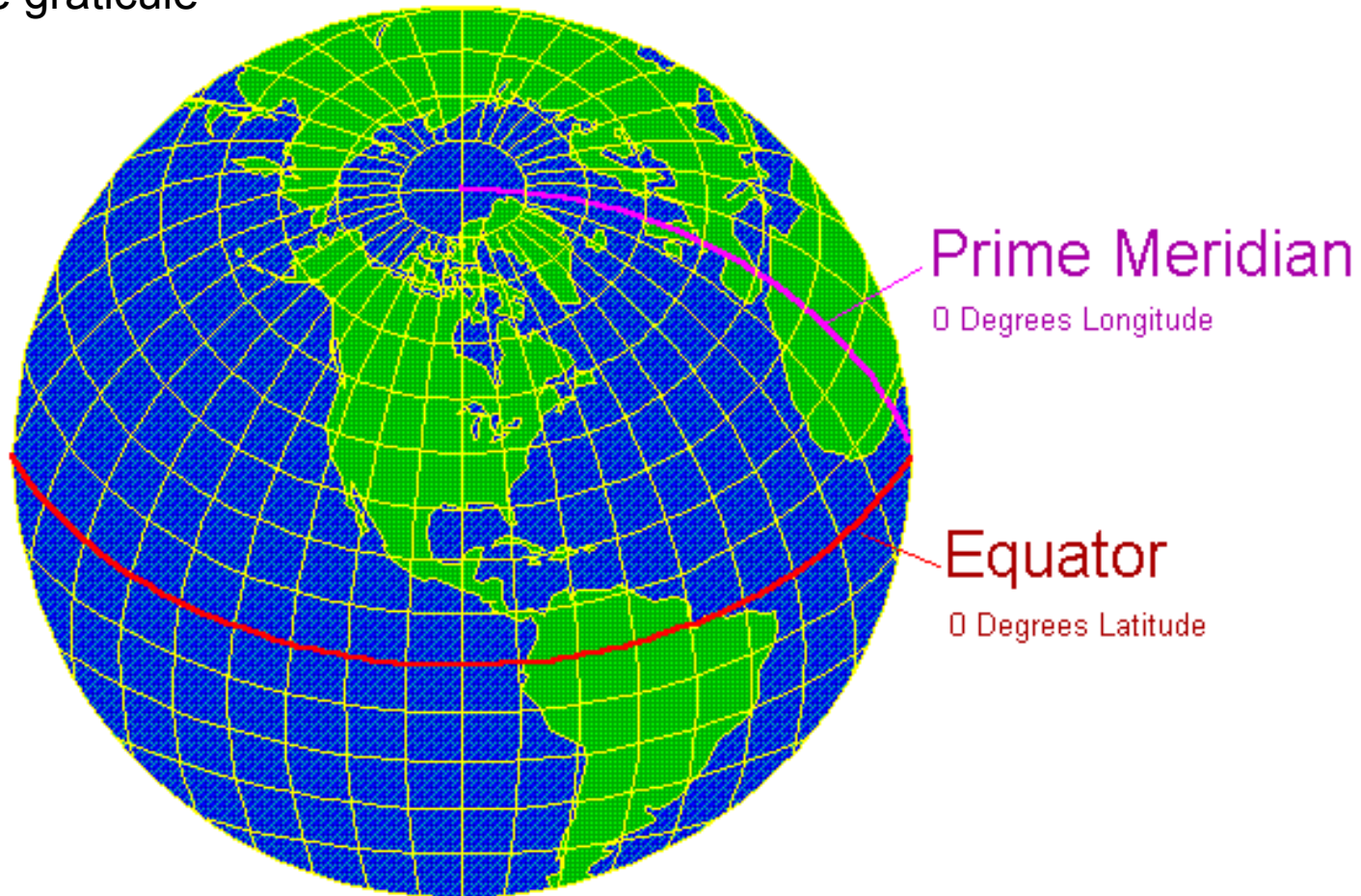


## 2. Geodetic Coordinates

- LATITUDE:  $\phi$  (PHI)
- LONGITUDE:  $\lambda$  (LAMBDA)
- Ellipsoid Height:  $h$

## 2. Geodetic Coordinates

The graticule

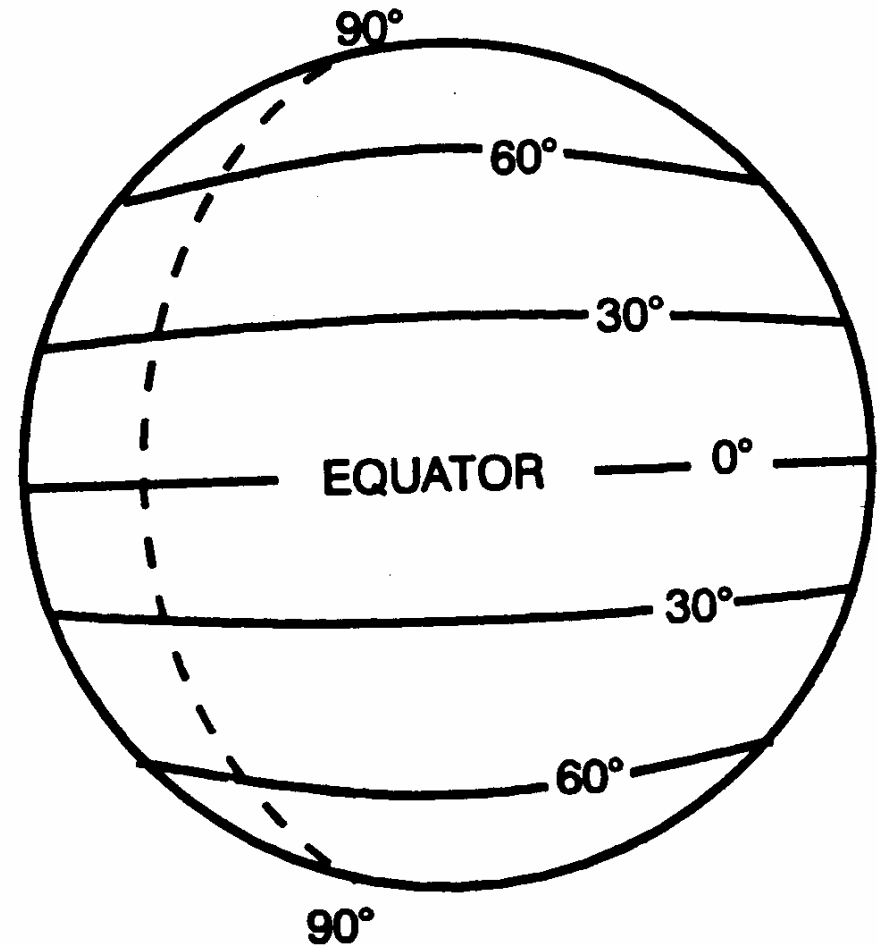


## 2. Geodetic Coordinates

- **LATITUDE:  $\phi$**

The north-south position on the Globe

“A Parallel”

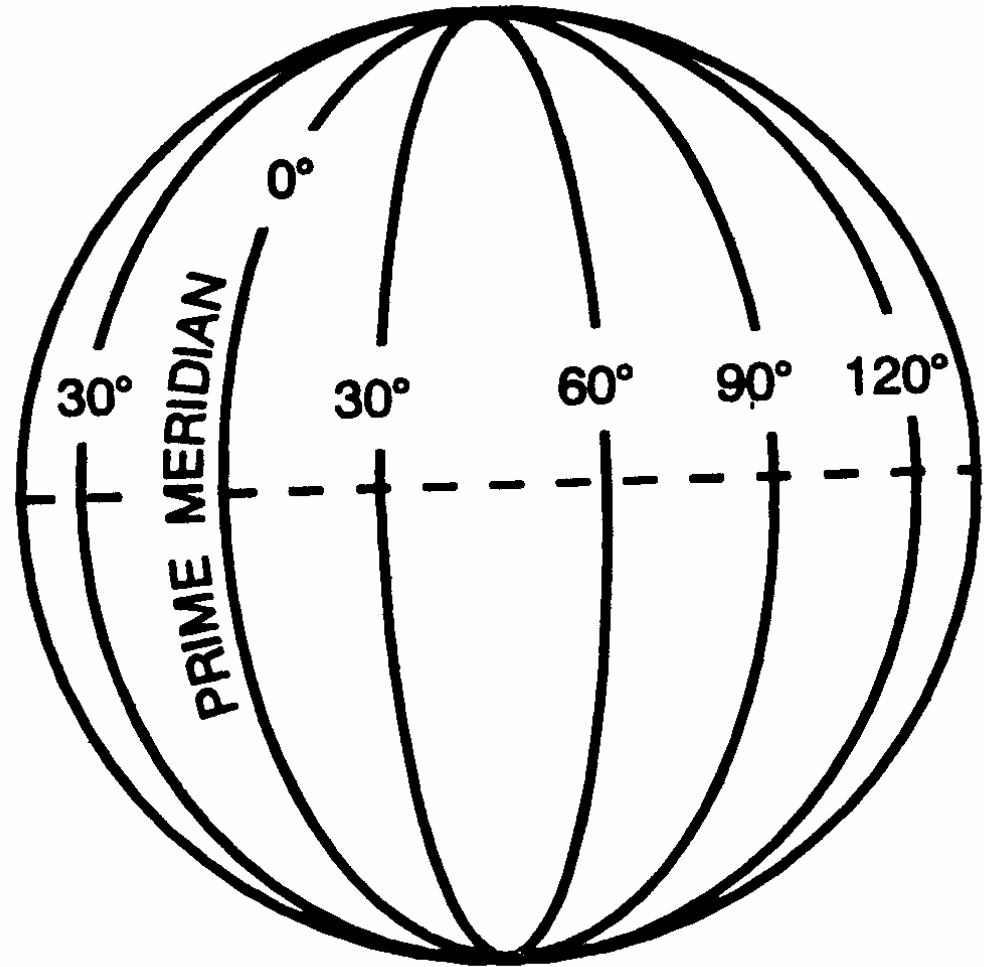


## 2. Geodetic Coordinates

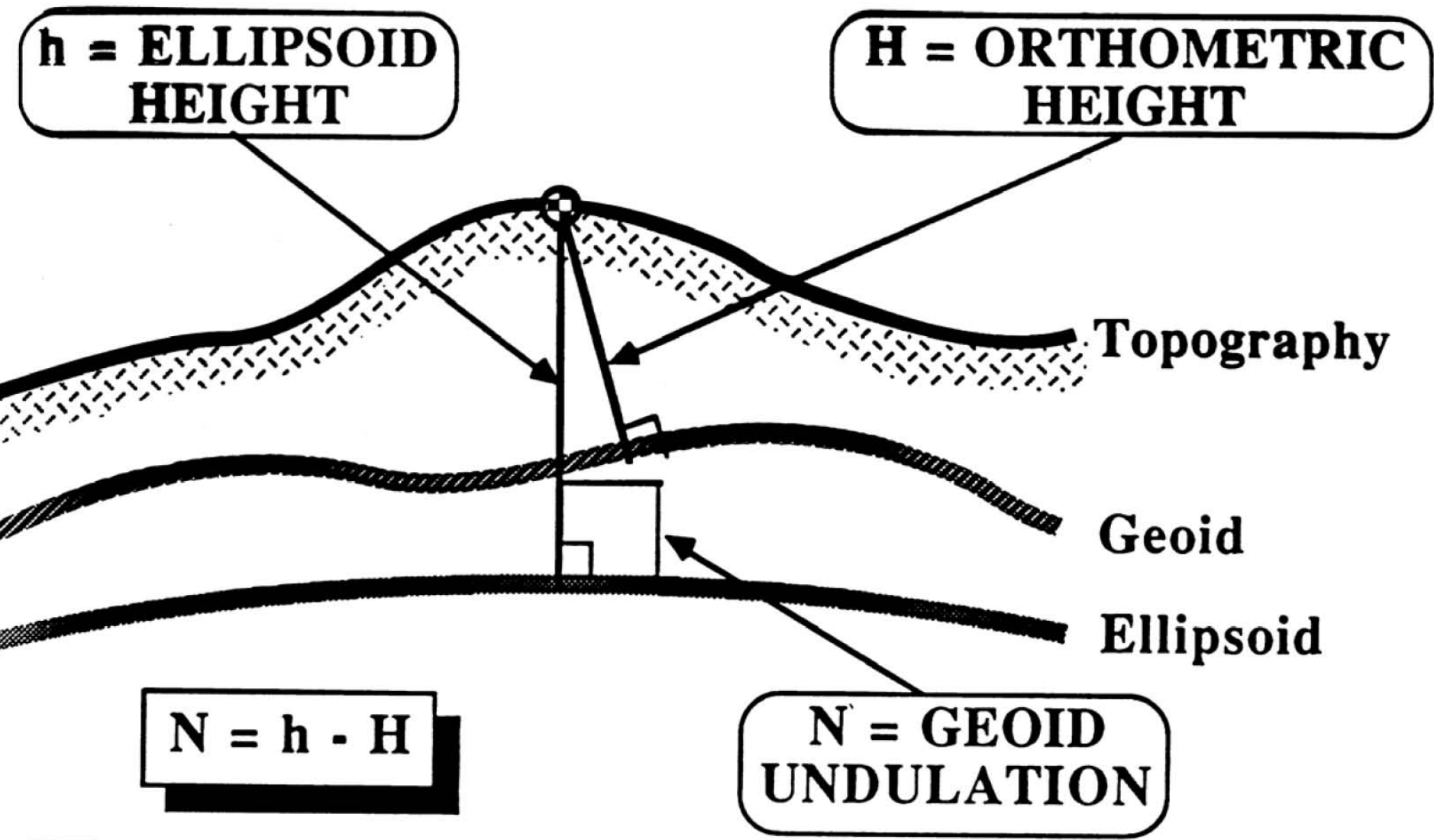
- **LONGITUDE:  $\lambda$**

The east - west position on the Globe

“A Meridian”



# Remember Ellipsoid Height (h)?



# 3. CARTESIAN (PLANE) COORDINATES

- **STATE PLANE COORDINATES (SPC):**
  - Transverse Mercator States
  - Lambert Conformal States
  - 2 Issues
    - Convergence/Mapping Angle
    - Ground → Geodetic → Grid Distances
- **UNIVERSAL TRANSVERSE MERCATOR COORDINATES (UTM):**
  - US National Grid (USNG)

# 3. CARTESIAN COORDINATES

- **NORTHING:**  $N (Y)$
- **EASTING:**  $E (X)$
- **Orthometric Height:**  $H$   
(elevation)

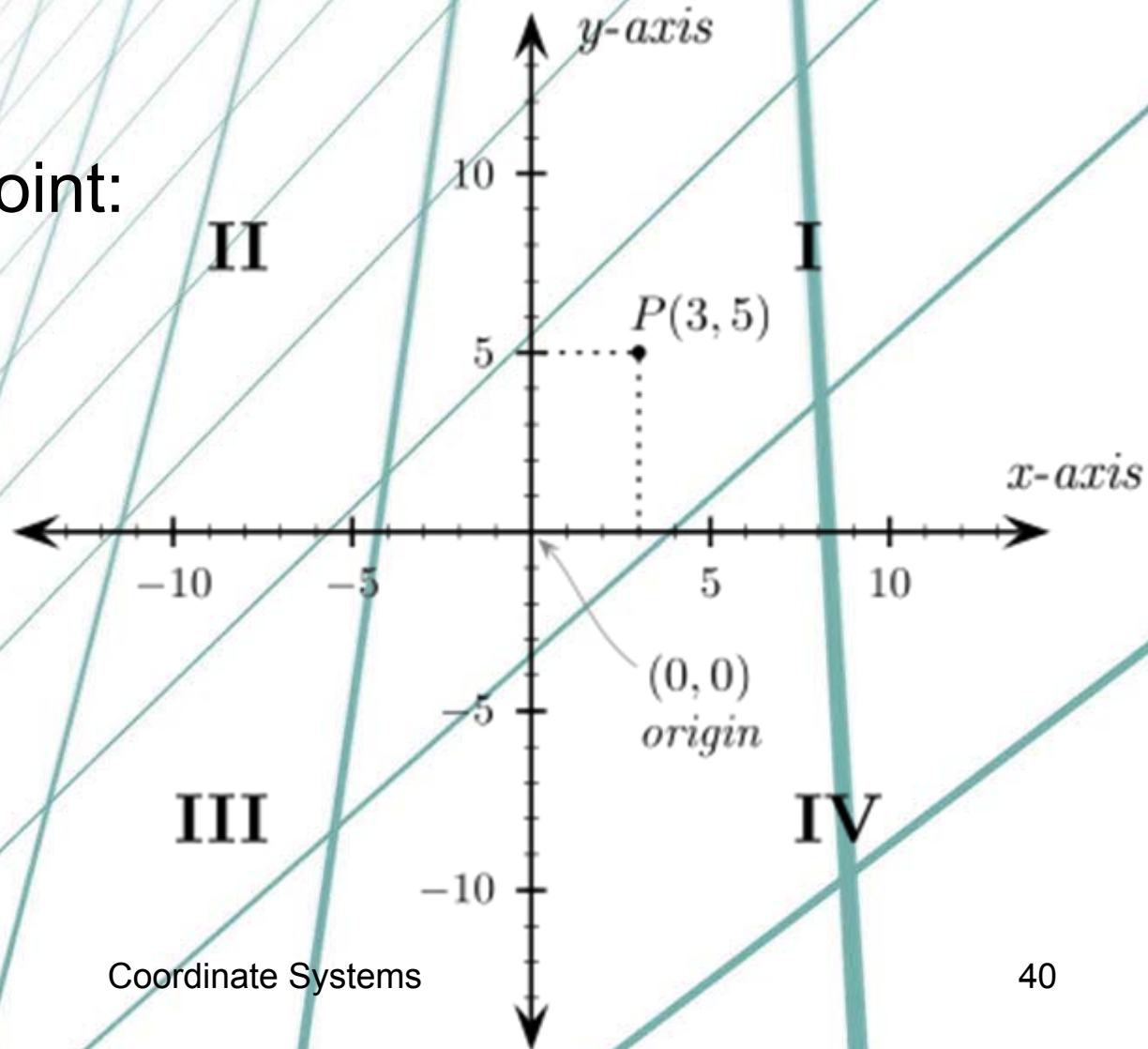
# 3. CARTESIAN COORDINATES

Two dimensional  
coordinates of a point:

X,Y

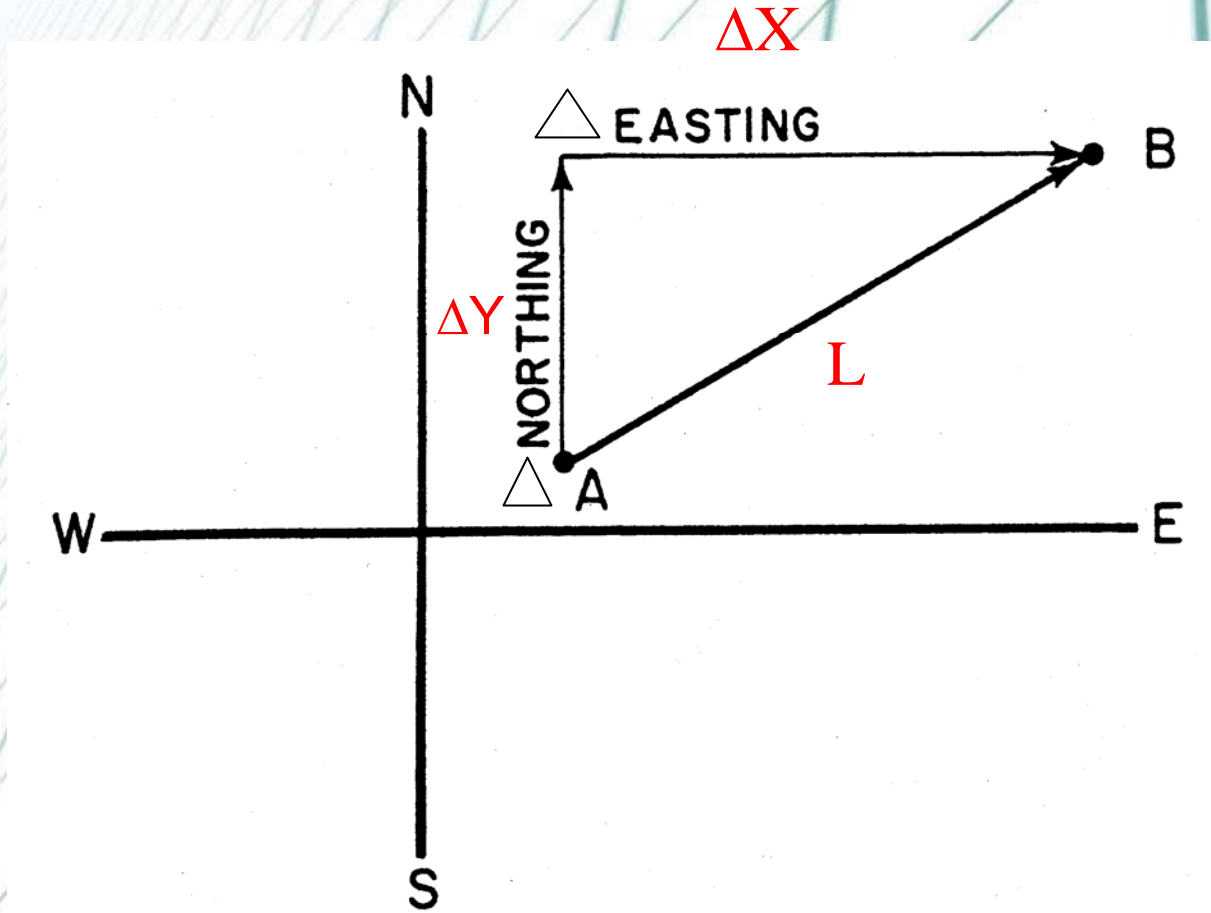
or

N,E (Y,X)





# 3. CARTESIAN COORDINATES



# 3. CARTESIAN COORDINATES

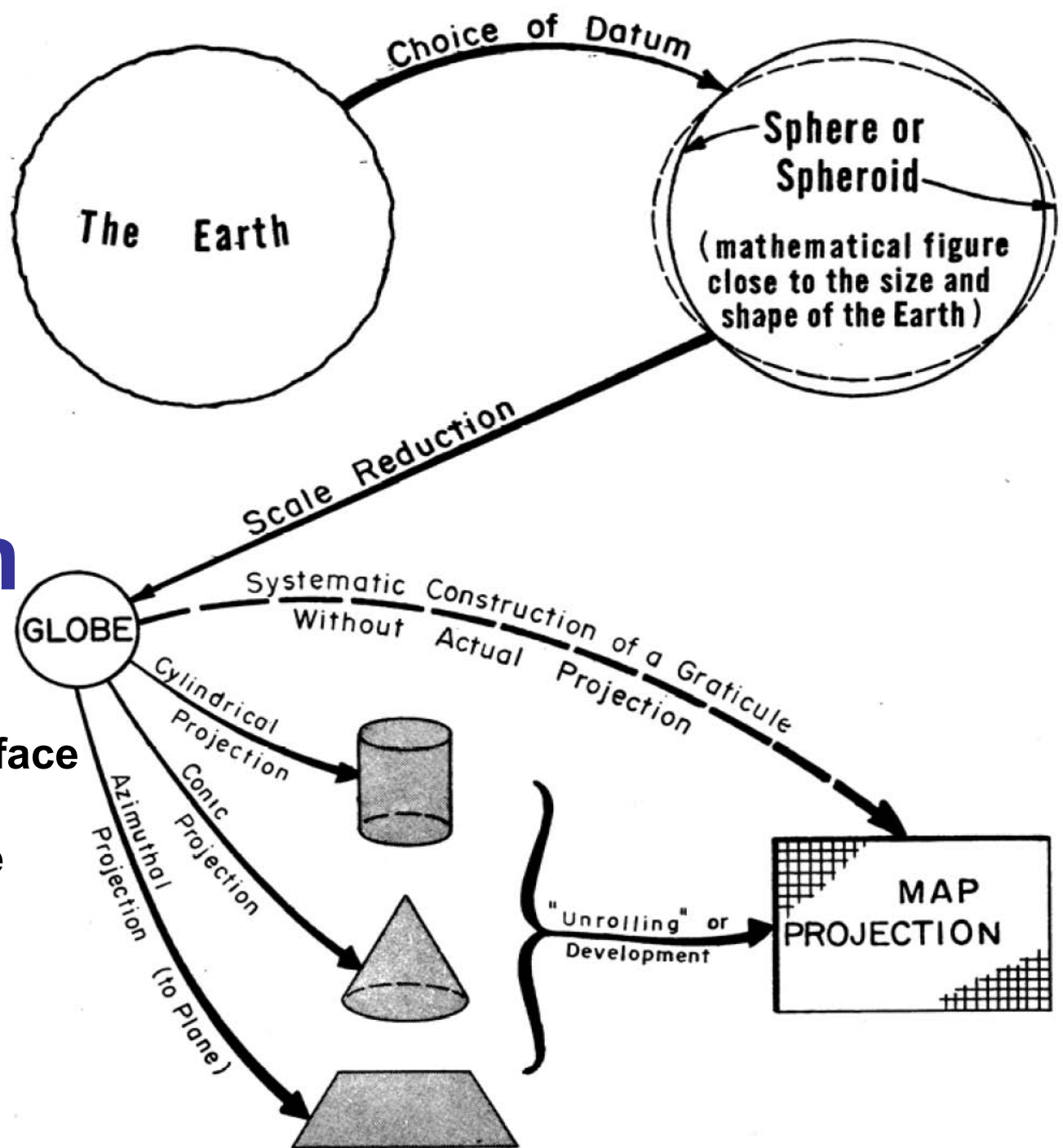
To obtain Cartesian (plane) coordinates from a round surface.

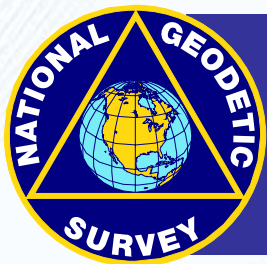
We must “Flatten” the earth by

**MAP PROJECTION**

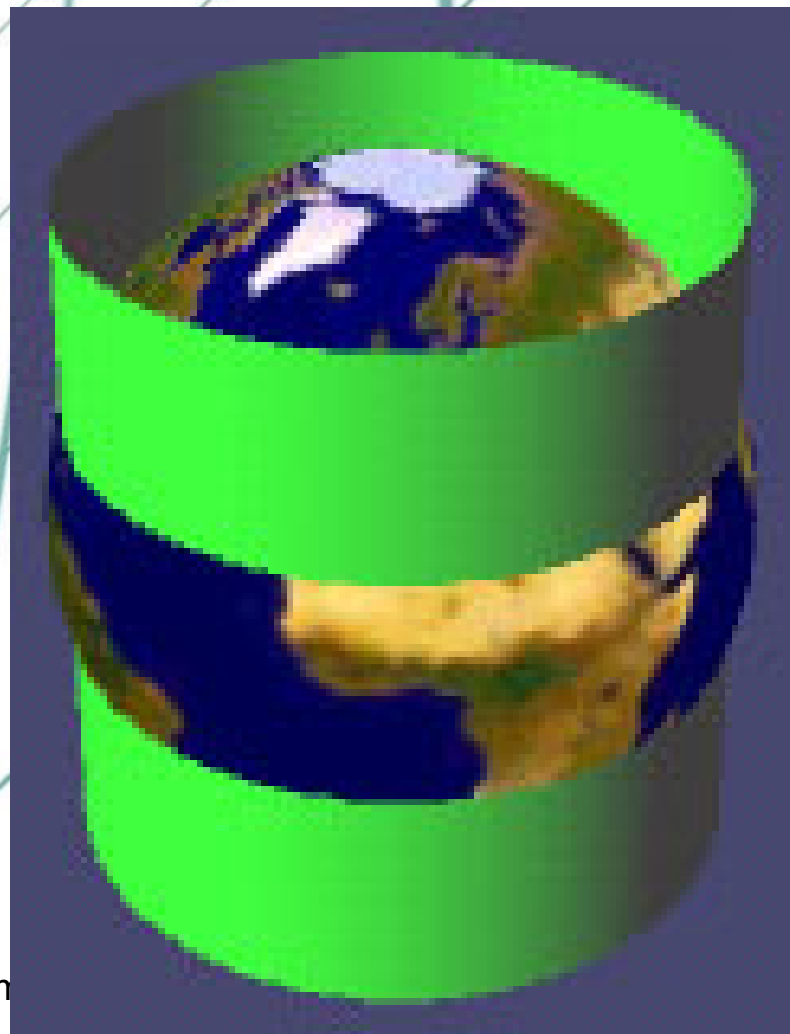
# The four steps in Map Projection

- 1 A Mathematical Surface
- 2 Reduce the Scale
- 3 Project on a surface
- 4 Unroll the surface





# MAP PROJECTIONS: CONIC AND CYLINDRICAL

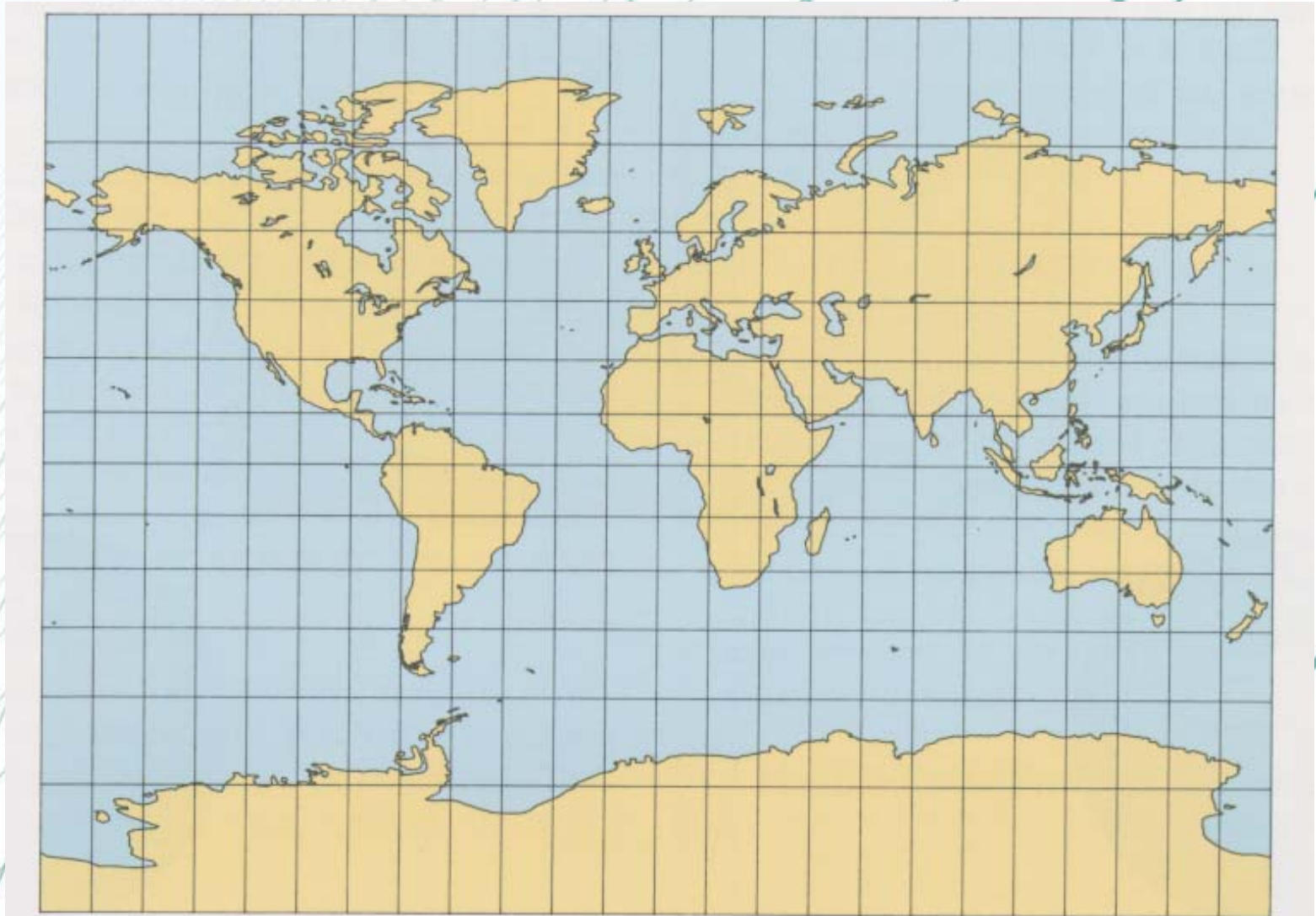


e System

# Globe



# Flat Map Projection (Mercator)



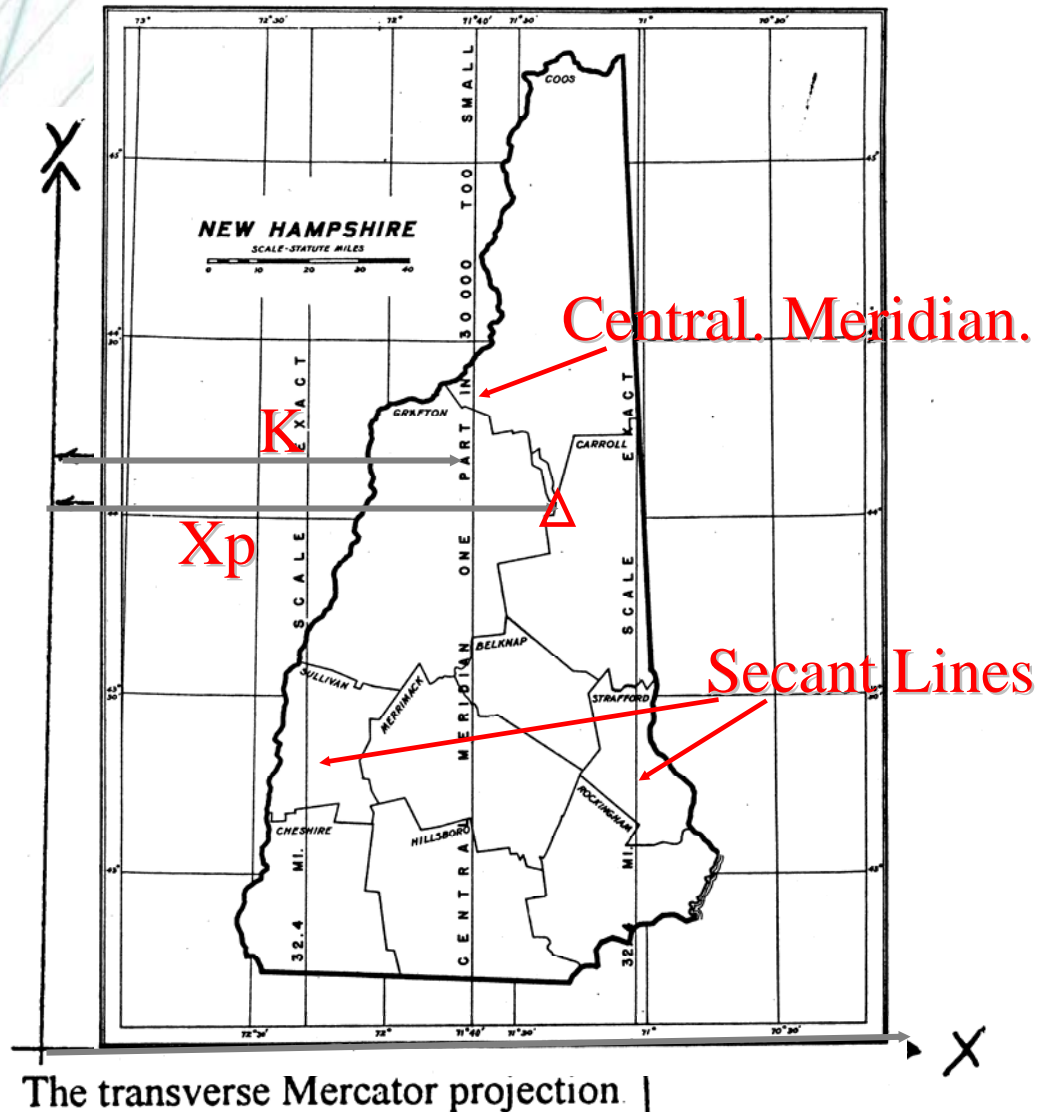
# 3a. The Transverse Mercator Projection System

New Hampshire State  
Plane Coordinates  
Based on the  
T M System:

Offset of the Central Meridian:

NAD27 System  $K = 500,000$  ft.

NAD83 System  $K = 300,000$  m



# 3a. The N.H. State Plane Coordinate System

CENTRAL MERIDIAN IN N.H.

$$\lambda = 71^{\circ} 40'$$

BETWEEN SECANT LINES:

**Scale Factor less than 1**

OUTSIDE SECANT LINES:

**Scale Factor greater than 1**

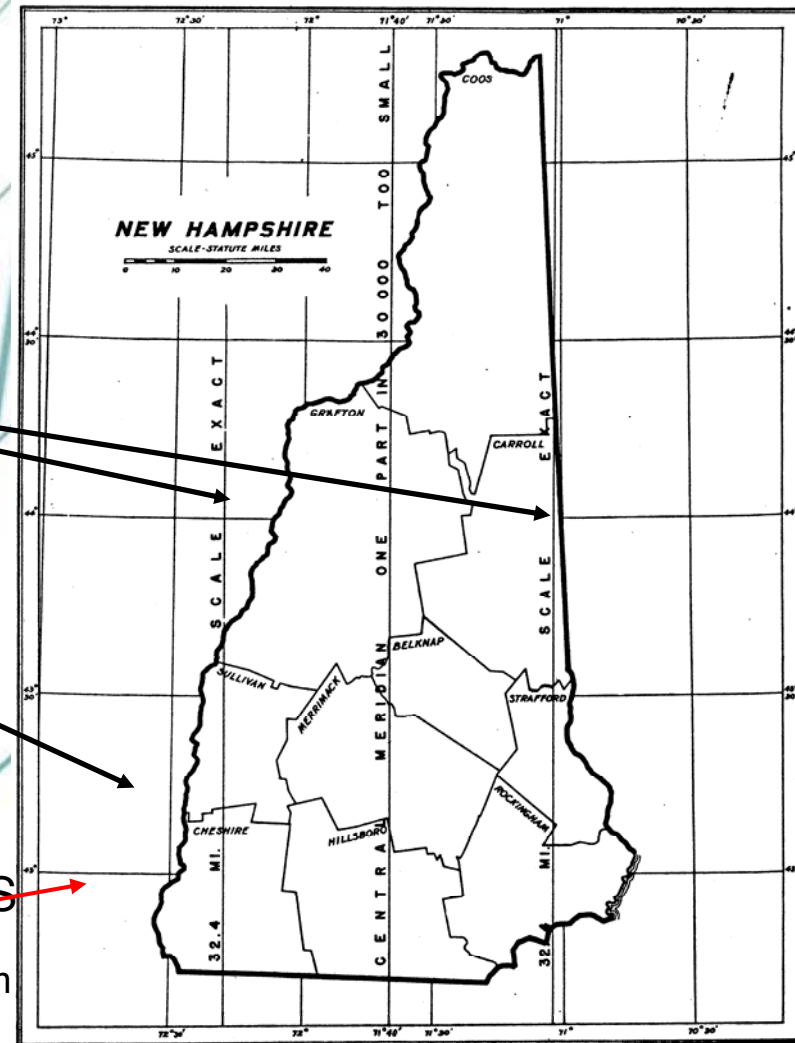
Scale factor constant in N - S direction

Scale Factor varies in the E - W direction

ALSO NOTICE: CONVERGENCE OF MERIDIANS

CURVATURE OF PARALLELS

Coordinate System





# Cross-section view of projection

## GEOID-ELLIPSOID RELATIONSHIP

$$\text{ELLIPSOID HEIGHT} = \text{ORTHOMETRIC HT} + \text{GEOID HT.}$$
$$h = H + N$$

GEOID UNDULATION

ELLIPSOID

MEAN-SEA-SURFACE-(GEOID)

OCEAN

EARTH'S SURFACE  
MOUNTAIN

ORTHOMETRIC HEIGHT OF P  
(SEE FIG. 27)

GEOID

GEOID UNDULATION  
(SEPERATION)  
(HEIGHT)

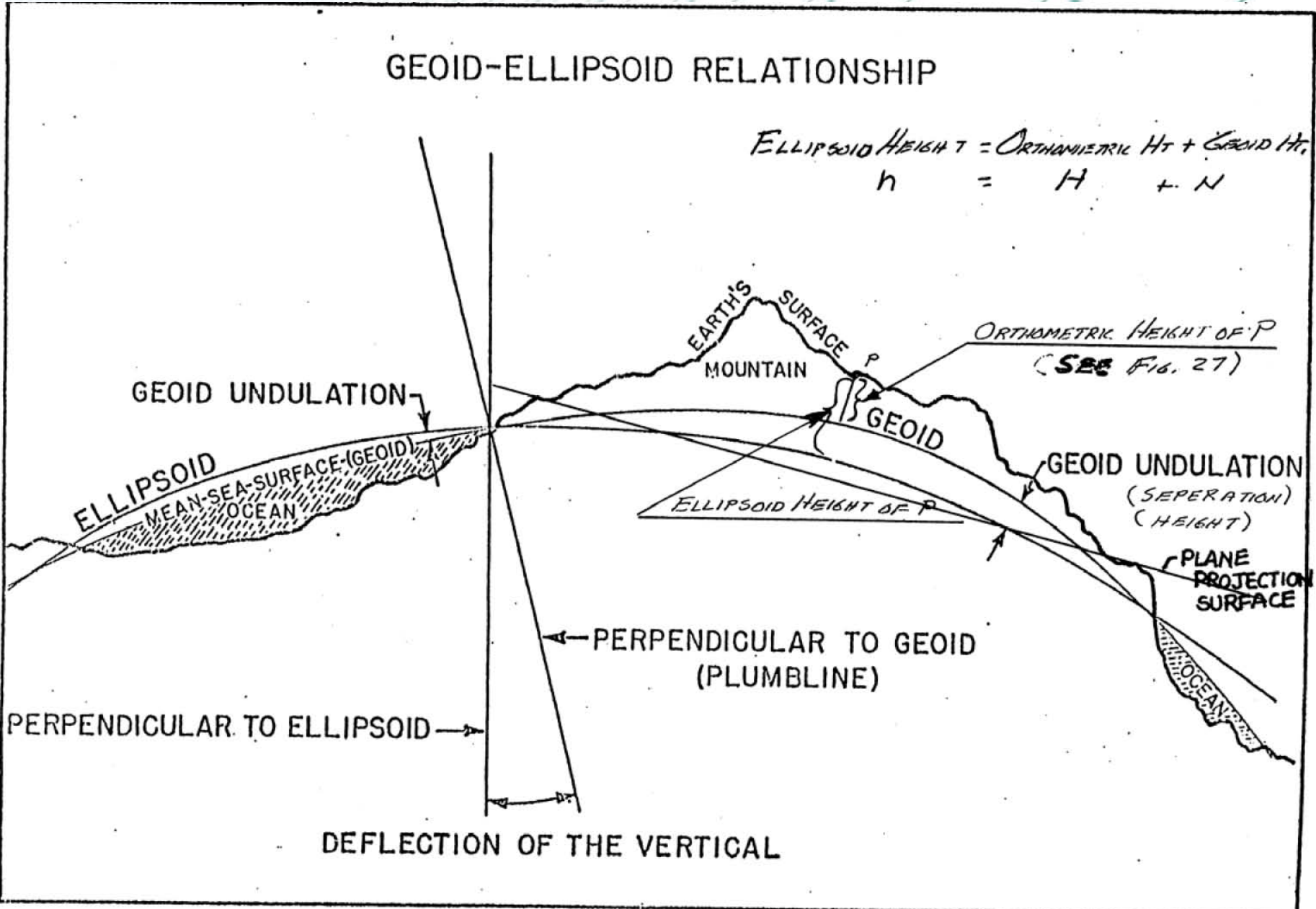
ELLIPSOID HEIGHT OF P

PLANE  
PROJECTION  
SURFACE

PERPENDICULAR TO GEOID  
(PLUMBLINE)

PERPENDICULAR TO ELLIPSOID

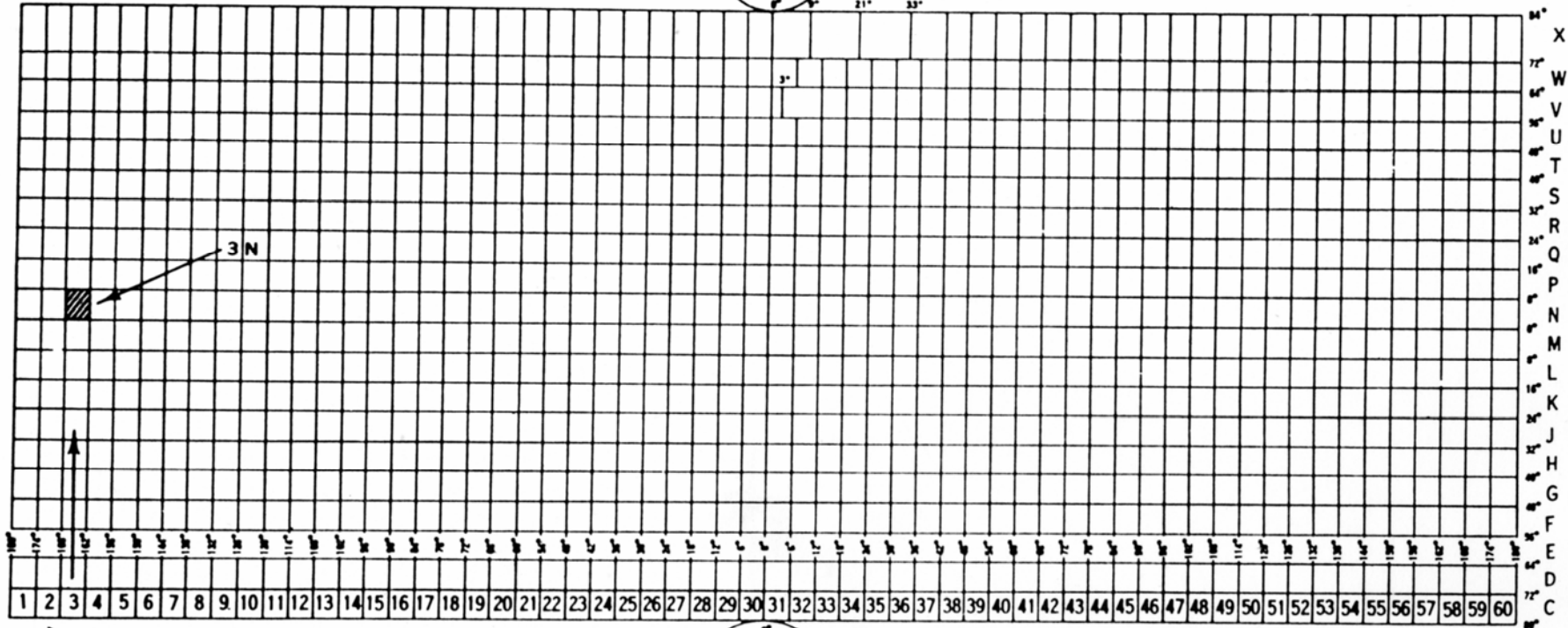
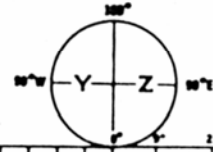
DEFLECTION OF THE VERTICAL



# 3b. Universal Transverse Mercator Projection System:

80°S to 72° N

6° wide Zones



#d from 1 to 60

starting at 180°λ

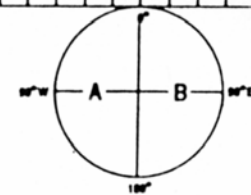


FIGURE 11. – Universal Transverse Mercator (UTM) grid zone designations for the world shown on an Equidistant Cylindrical projection index map.

# 3b. Universal Transverse Mercator Projection System :

(6° Zones)

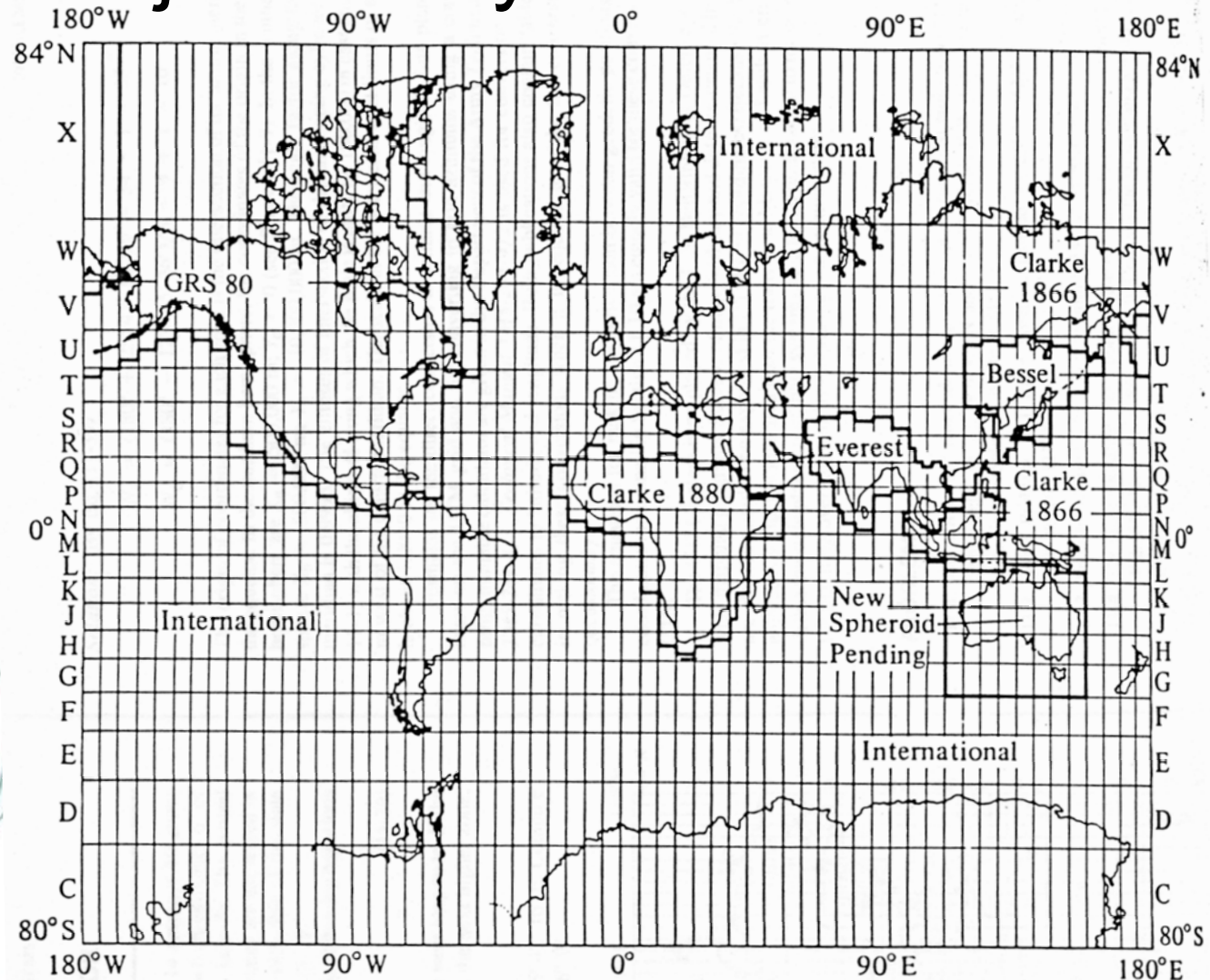
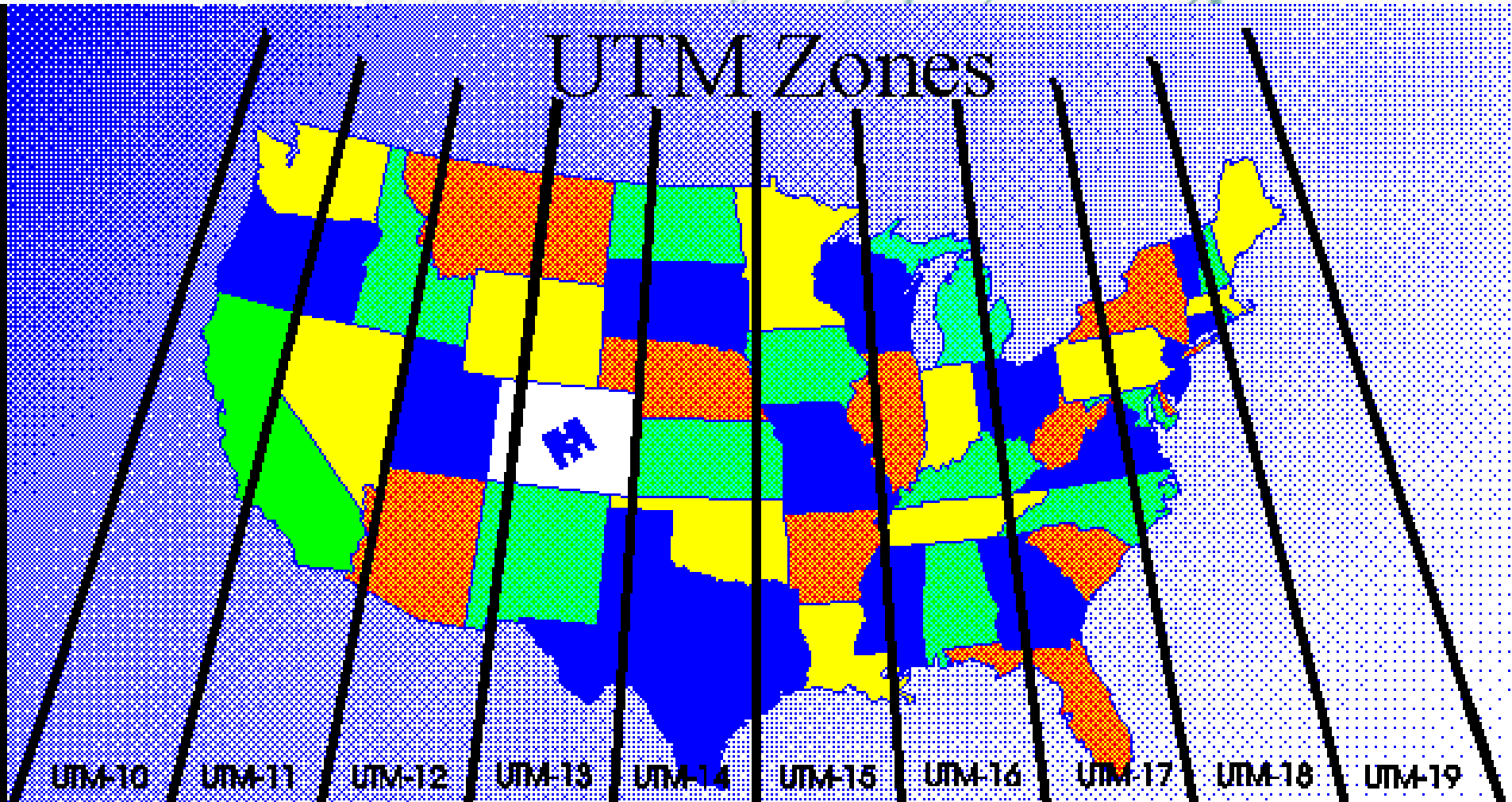


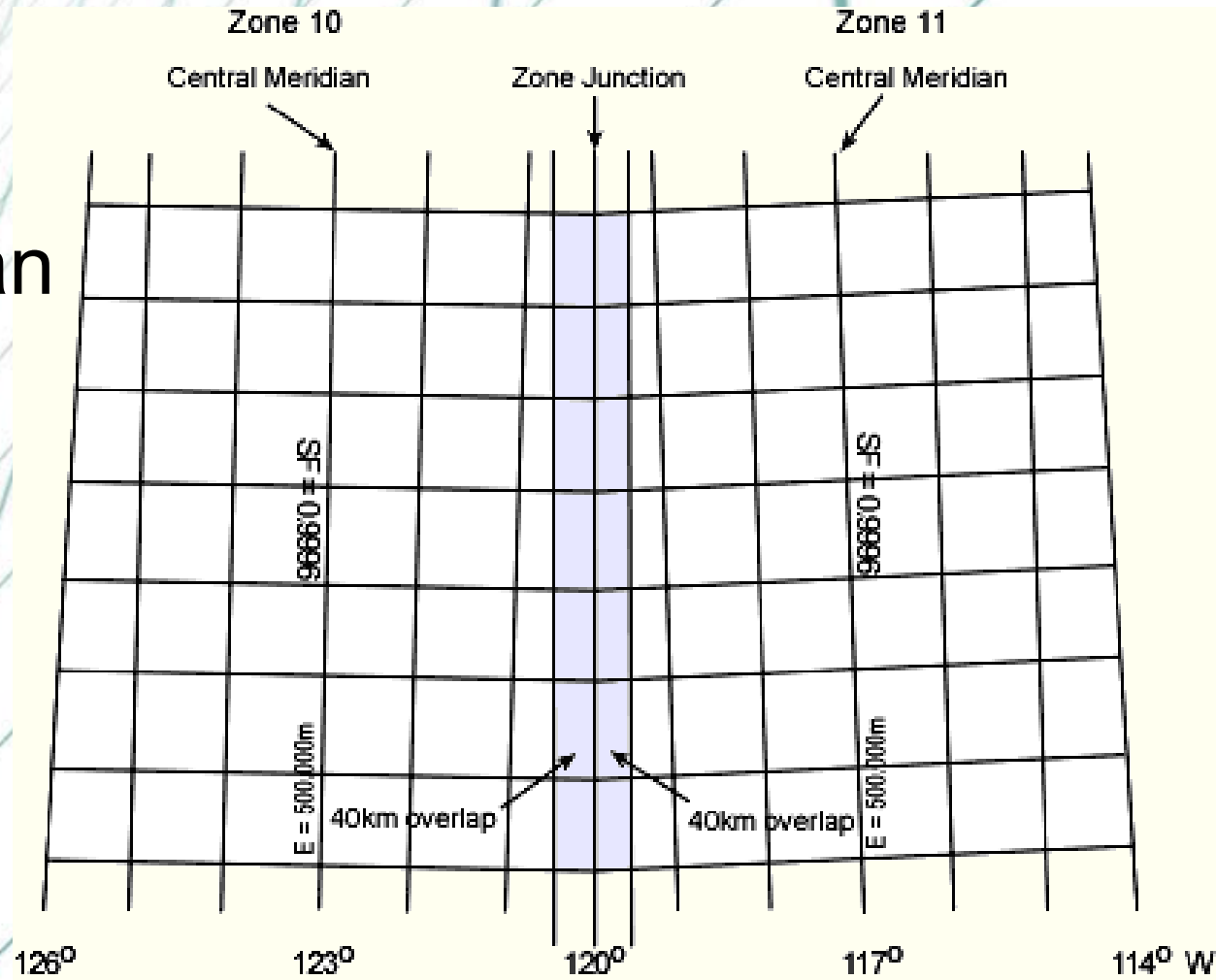
FIGURE 11-14 Universal transverse Mercator (UTM) system. The zones are numbered from 1 to 60 eastward from 180° west longitude.

# 3b. Universal Transverse Mercator Projection UTM Zones in lower 48 states



# 3b. Universal Transverse Mercator Projection System (6° Zones) :

Each zone has  
a Central Meridian  
with  
An Easting  
of 500,000 m



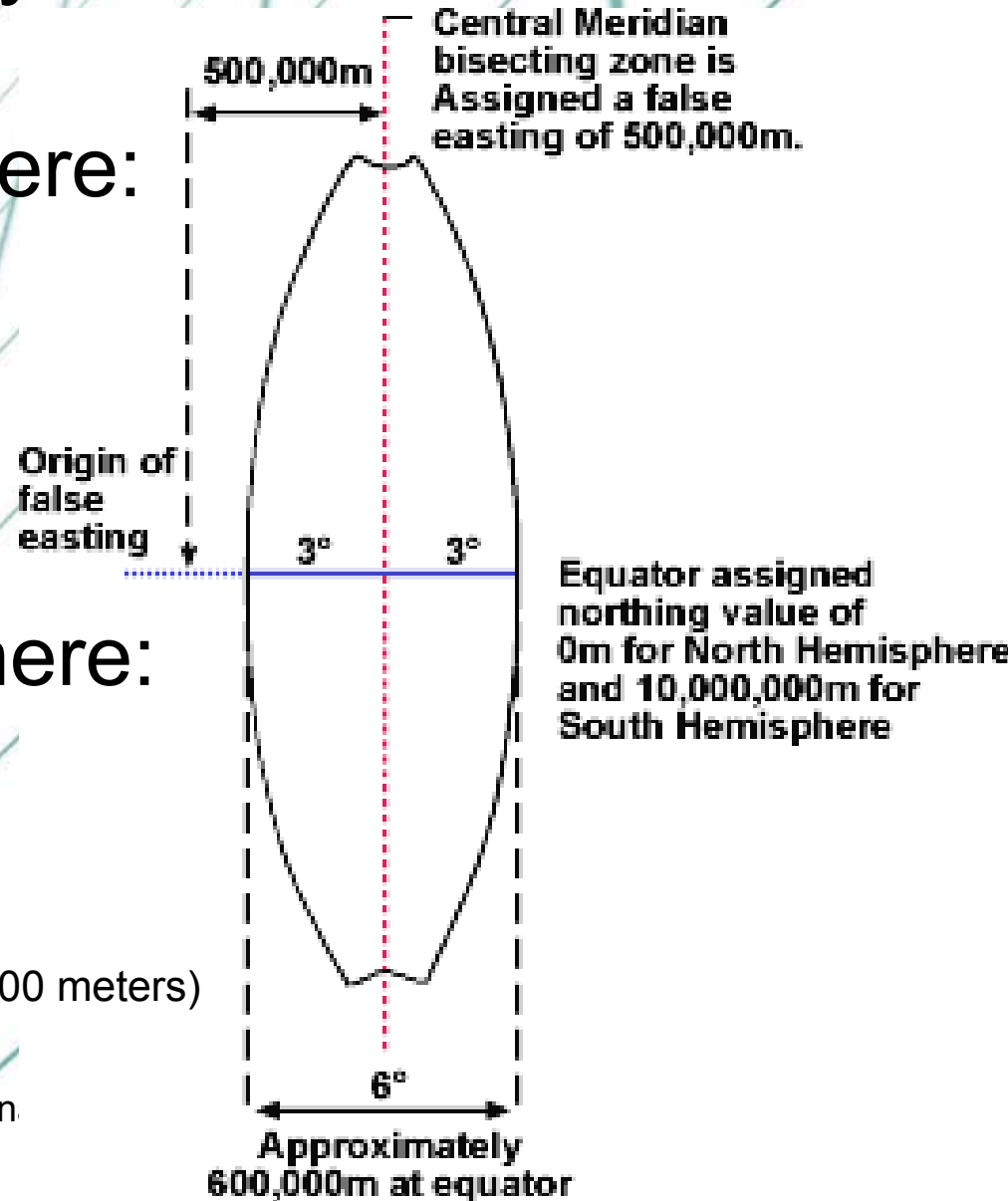
# 3b. Universal Transverse Mercator Projection System (6° Zones) :

In Northern Hemisphere:  
Northing (Y) = 0  
At the equator

In Southern Hemisphere:  
Northing (Y) = 0  
At the South Pole

(equator given a false nothing of 10,000,000 meters)

Coordin



# Universal Transverse Mercator Projection

NH in two  
different zones,  
18 & 19

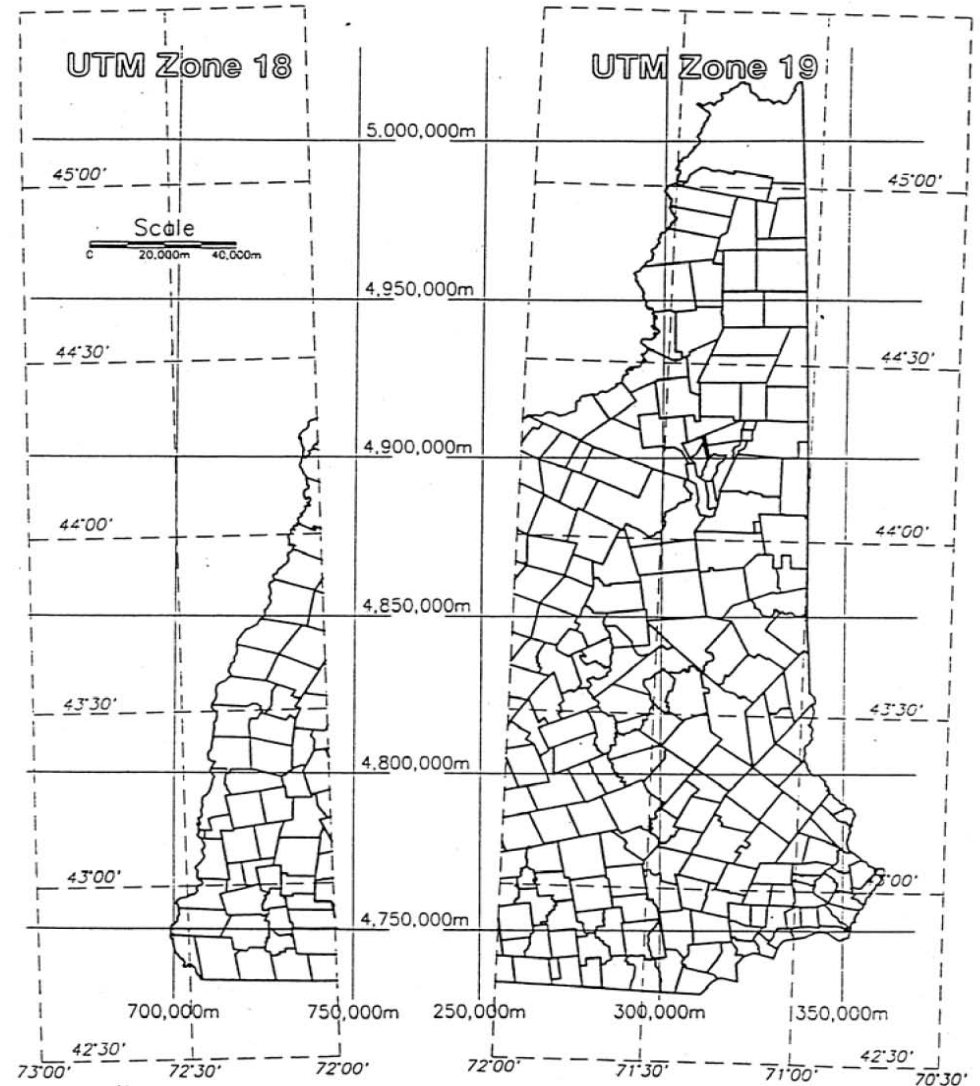


Figure 2.7 - State of New Hampshire (state and town boundaries), in UTM coordinates, Zones 18 and 19. Coordinate grid units are in meters.

The background features a series of teal-colored lines that create a perspective effect, appearing to recede into the distance from the bottom right towards the top left. The lines vary in thickness and are set against a white background.

# **THREE DISTANCES**



# THREE DISTANCES

## 1. GROUND DISTANCE

Slope distance between two points

## 2. ELLIPSOID (GEODETIC) DISTANCE

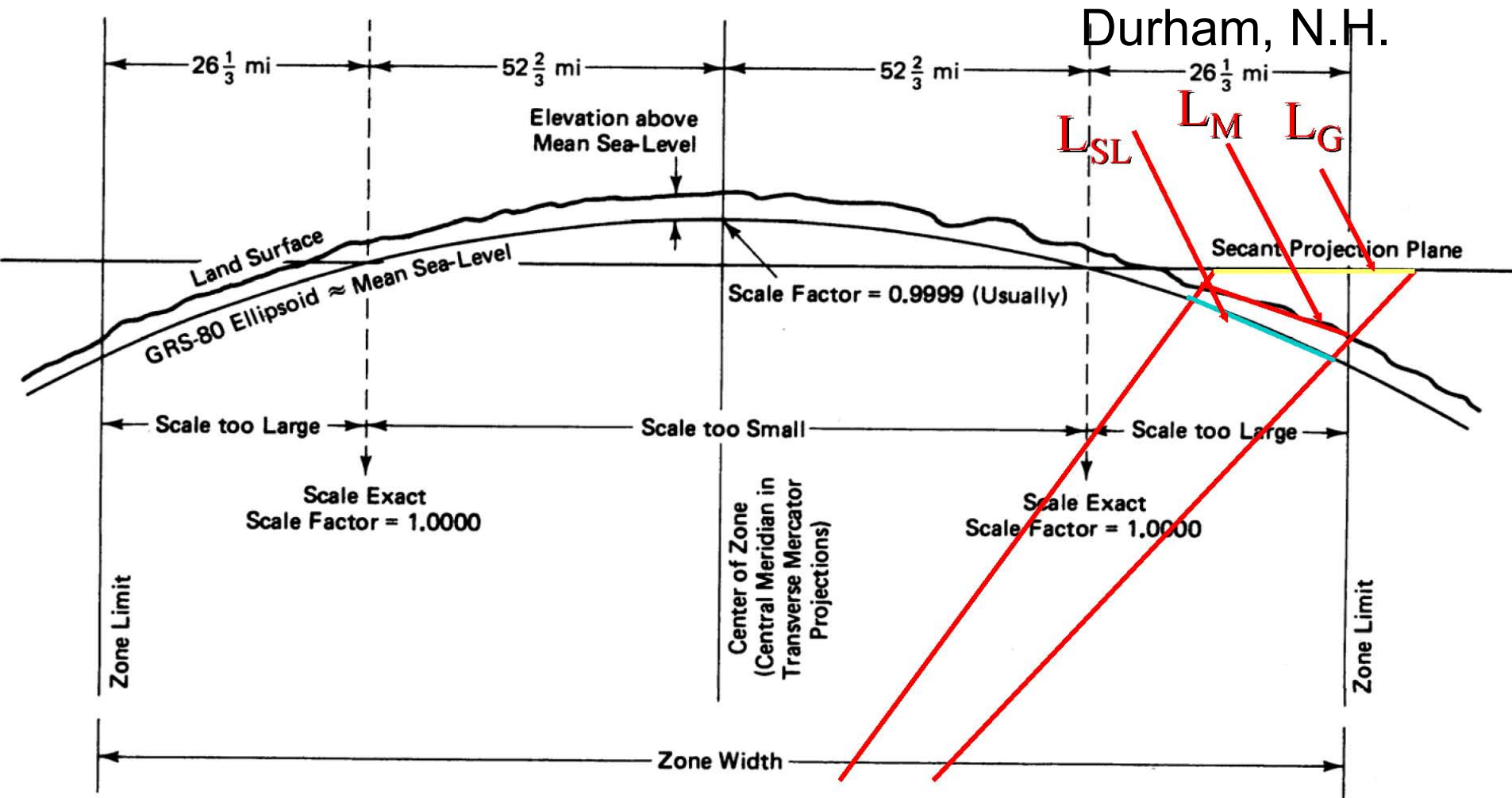
Curved distance on Ellipsoid between two points

## 3. GRID DISTANCE

Horizontal distance on Plane between two points

# Ground – Ellipsoid - Grid Distances

$L_{SL}$  = Sea Level (Geodetic) Dist.  $L_M$  = Ground Dist.  $L_G$  = Grid Dist.



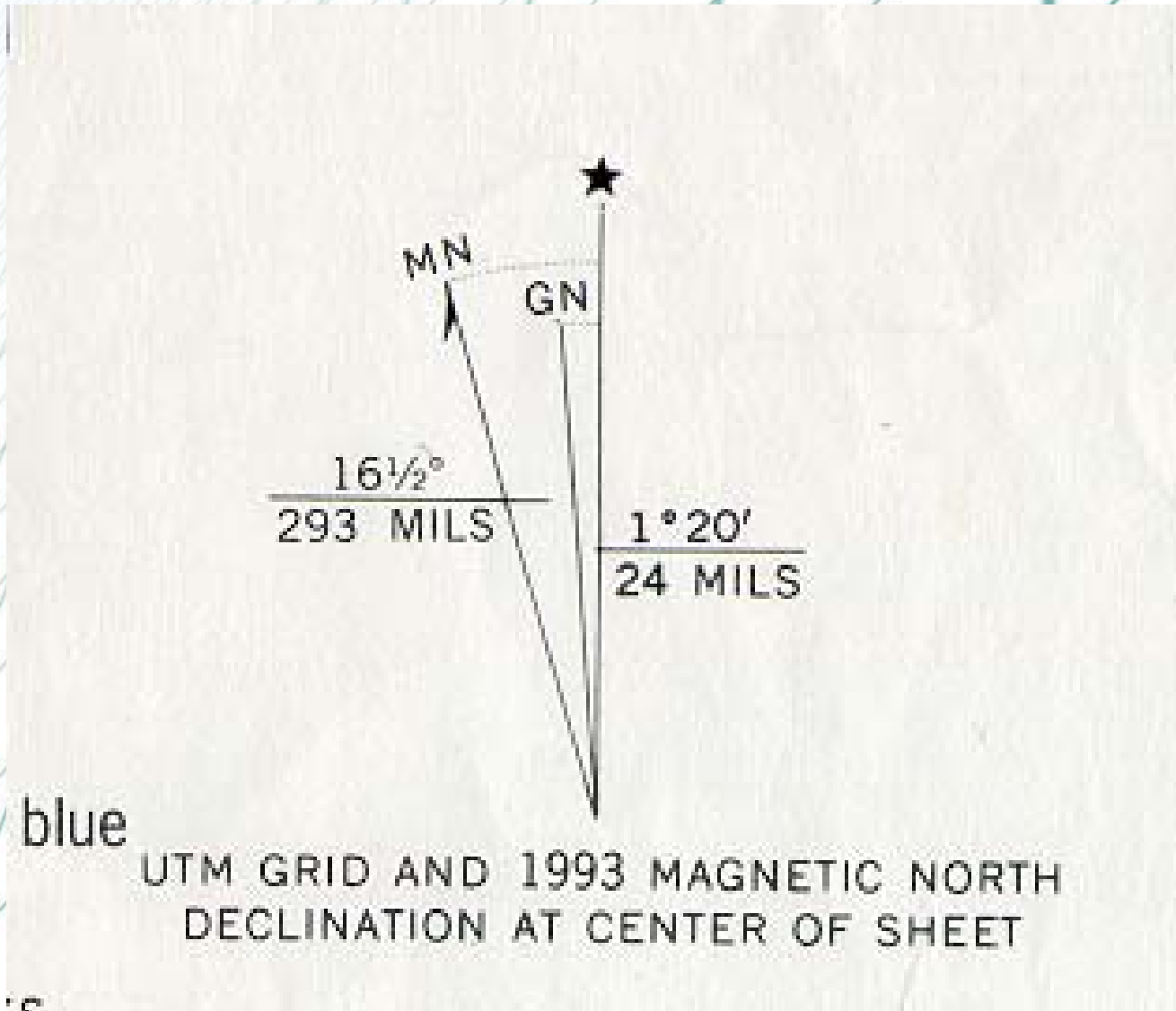
The background features a series of parallel teal lines that are slightly curved and converge towards the left side of the frame, creating a sense of depth and movement. The lines vary in thickness, with some being significantly thicker than others. The overall color palette is a mix of light and dark teal against a white background.

# **FIVE NORTHS**

# FIVE NORTHS

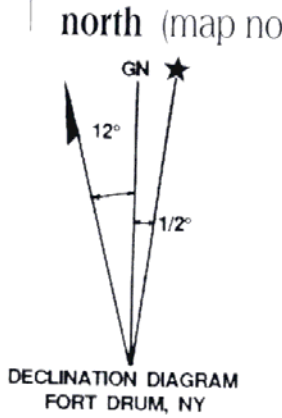
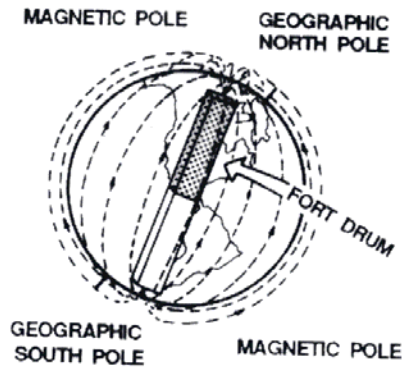
1. Astronomic North  
Based on Earth's Rotation Axis
2. Geodetic North  
Based on Ellipsoid's Rotation Axis
3. Grid North  
Based in Central Meridian of System
4. Magnetic North  
Based on magnetic lines of force
5. Assumed North  
Based on any convenient axis

# Geodetic –Grid –Magnetic North



# Other Map Information: Norths

Coordinate



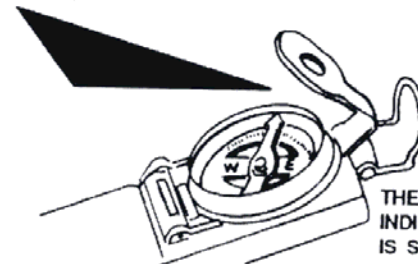
## TRUE NORTH

THE DIRECTION FROM ANY POSITION ON THE EARTH'S SURFACE TO THE NORTH POLE. ALL LINES OF LONGITUDE ARE TRUE NORTH LINES. THIS REFERENCE POINT IS SYMBOLIZED BY A STAR.



## GRID NORTH

THE NORTH THAT IS ESTABLISHED BY THE VERTICAL GRID LINES ON THE MAP. THIS REFERENCE POINT IS SYMBOLIZED BY THE LETTERS GN.



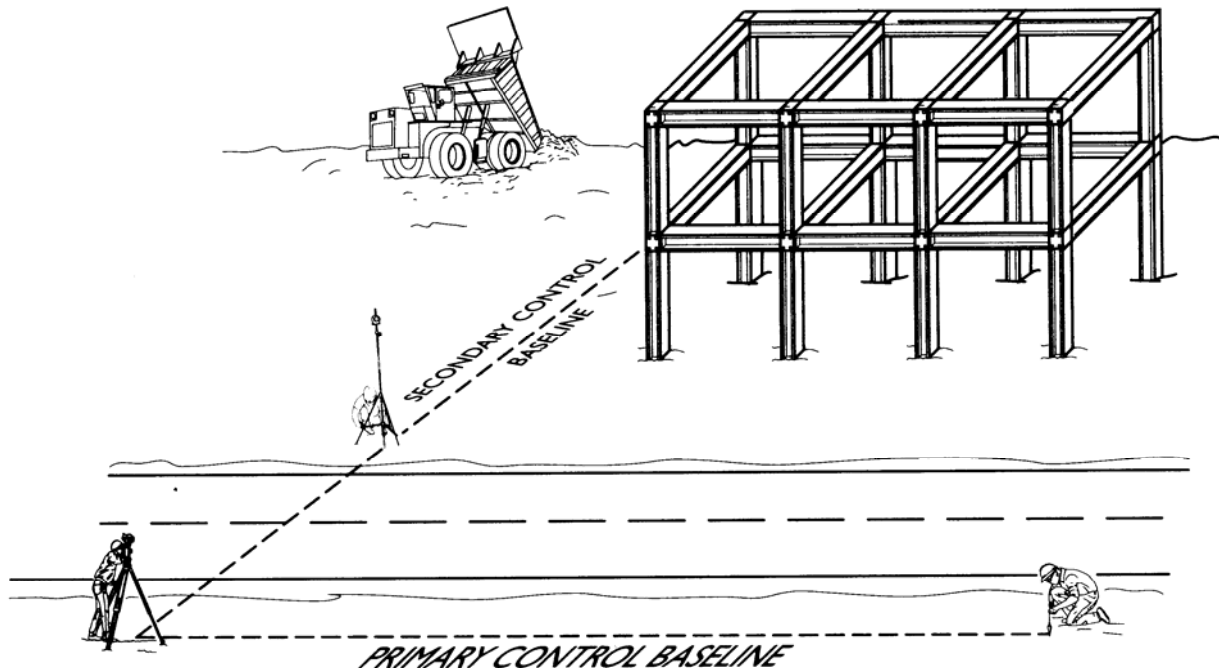
## MAGNETIC NORTH

THE DIRECTION OF THE NORTH MAGNETIC POLE IS INDICATED BY A COMPASS. THIS REFERENCE POINT IS SYMBOLIZED BY A HALF ARROWHEAD.

# Assumed North

## Assumed Coordinate System

Using any arbitrary direction (Building column line, center of pipeline, etc.) as a reference meridian from which directions (angles) will be measured.



# RECAP OF PRESENTATION OUTLINE

- 4 SURFACES
- 3 HEIGHTS
- 2 DATUMS
- 4 COORDINATE SYSTEMS
- 3 DISTANCES
- 5 NORTHS



# RECOMMENDED SYSTEM TO USE FOR MUNICIPAL BOUNDS

N.H. STATE PLANE COORDINATES, NAD 83  
(FEET OR METERS)

OR

LATITUDE( $\phi$ ), LONGITUDE ( $\lambda$ ), NAD 83