Establishing a Georeferencing Framework for Mapping Locations on Earth

DATUMS & PROJECTIONS

QUICK REVISION

- A suitable geometrical surface is to be defined for mapping Earth's surface as its surface is very complex making it unsuitable for computations and mapping

- This geometric surface is called reference surface (datum) which is based on some assumptions

ASSUMPTIONS

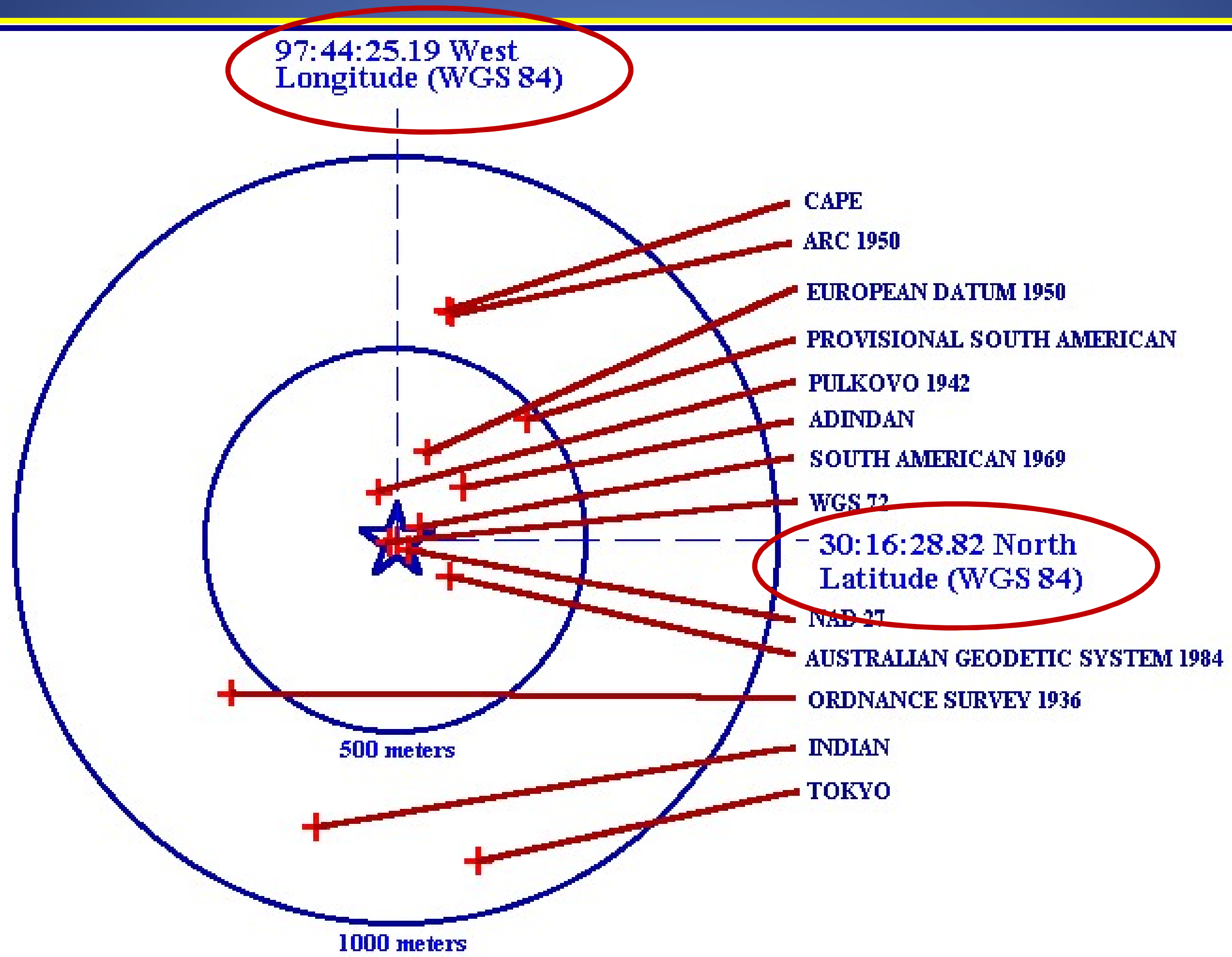
- It is an oblate spheroid of rotation formed by rotating an ellipse whose major and minor axis are nearly equal to that of the equatorial axis and polar axis of the Earth. Rotation of ellipse is about its minor axis.
- This reference surface is rotating from West to East with nearly same speed as that of the Earth
- Mass and volume of this surface is nearly equal to that of Earth
- Center of the ellipsoid coincides with the center of gravity of the Earth.
- Minor axis of the ellipsoid coincides with polar axis of the Earth.

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

Peter H. Dana 9/1/94

WHY IS THE DATUM IMPORTANT?



Position Shifts from Datum Differences

Texas Capitol Dome Horizontal Benchmark

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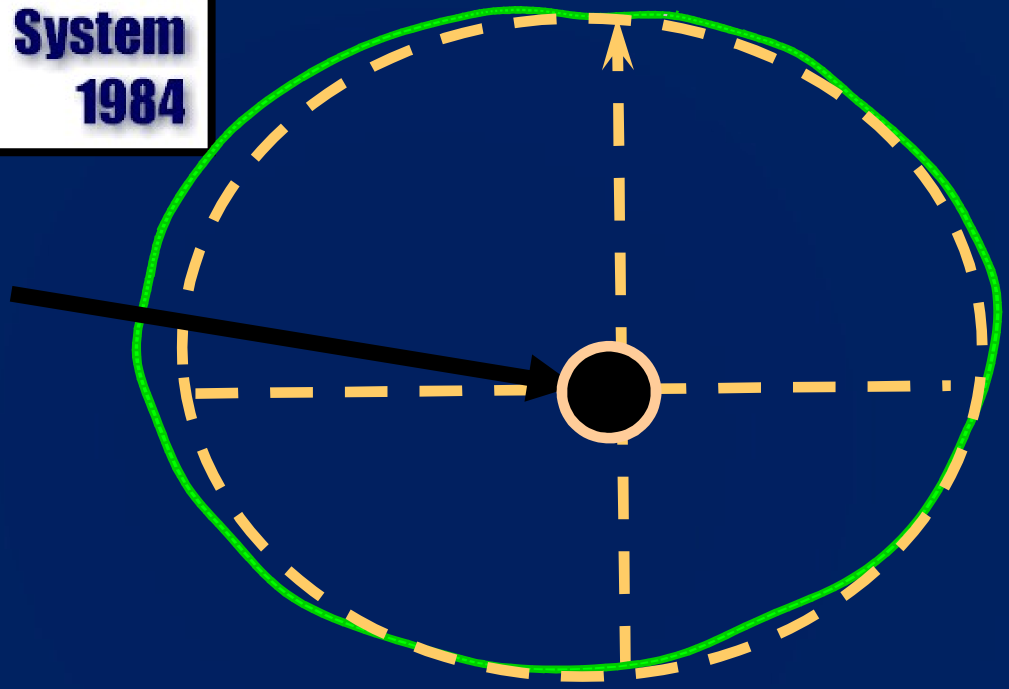
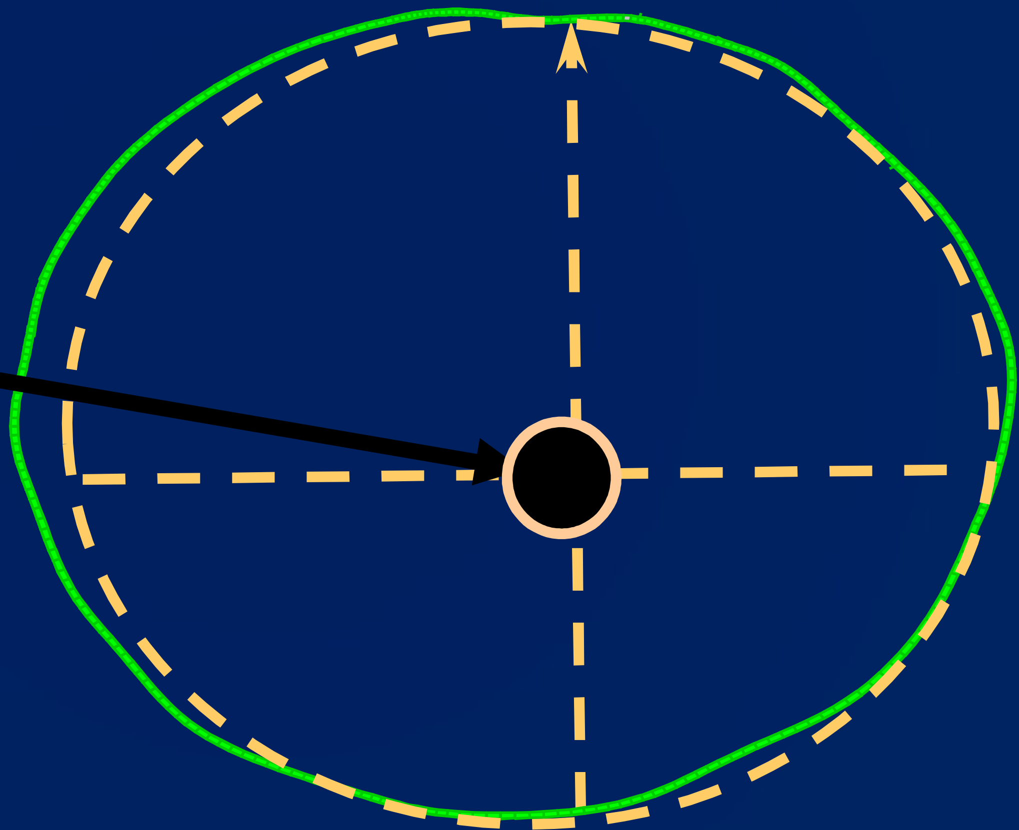
GPS Datum: WGS 84



- Origin is at the Earth's center of mass (geocentric)
- This is the datum used for the NAVSTAR GPS satellites

WGS84:WGS84 ellipsoid
Origin - center of earth

The origins of the WGS84 is at the center of the earth's mass, which makes it ideal for a GPS datum



WORLD GEODETIC SYSTEM 84 (WGS 84)

Coordinate System: Cartesian Coordinates (X, Y, Z). WGS 84 (G1674) follows the criteria outlined in the International Earth Rotation Service (IERS) Technical Note 21. The WGS 84 Coordinate System origin also serves as the geometric center of the WGS 84 Ellipsoid and the Z-axis serves as the rotational axis of this ellipsoid of revolution. WGS 84 geodetic coordinates are generated by using its reference ellipsoid.

Defining Parameters: WGS 84 identifies four defining parameters. These are the semi-major axis of the WGS 84 ellipsoid, the flattening factor of the Earth, the nominal mean angular velocity of the Earth, and the geocentric gravitational constant as specified below.

Parameter	Notation	Value
Semi-major Axis	a	6378137.0 meters
Flattening Factor of the Earth	1/f	298.257223563
Nominal Mean Angular Velocity of the Earth	ω	7292115×10^{-11} radians/second
Geocentric Gravitational Constant (Mass of Earth's Atmosphere Included)	GM**	$3.986004418 \times 10^{14}$ meter^3/second^2

**The value of GM for GPS users is 3.9860050×10^{14} m^3/sec^2 as specified in the references below.

Source: www.unoosa.org

INDIAN GEODETIC SYSTEM

- In India the reference surface was defined by Sir George Everest in 1830, who was Surveyor General of India from 1830 to 1843.
- Since then it has served as reference for all mapping in India
- The reference surface was called Everest Spheroid
- The initial point for mapping on the surface of the Earth was chosen at Kalyanpur (U.P.) in Central India

The Indian Datum is a regional geodetic datum based upon the Everest Spheroid and fits India and neighboring countries quite well.

	Everest	WGS 84	Difference
Latitude	24^0 07' 11.26" N	24^0 07' 8.56" N	2.7" (81 m)
Longitude	77^0 39' 17.63" E	77^0 39' 13.0" E	15.72" (471 m)

INDIAN GEODETIC DATUM

- Center of Everest Spheroid is nearly a kilometer from the center of gravity of the Earth
- Minor axis is also not parallel to polar axis but inclined to it by a few seconds
- It is a local datum.

Ellipsoid	Semi Major Axis	Flattening
Everest (India 1830)"	6377276.345	300.8017
Everest (Sabah Sarawak)	6377298.556	300.8017
Everest (India 1956)	6377301.243	300.8017

COORDINATE SYSTEMS

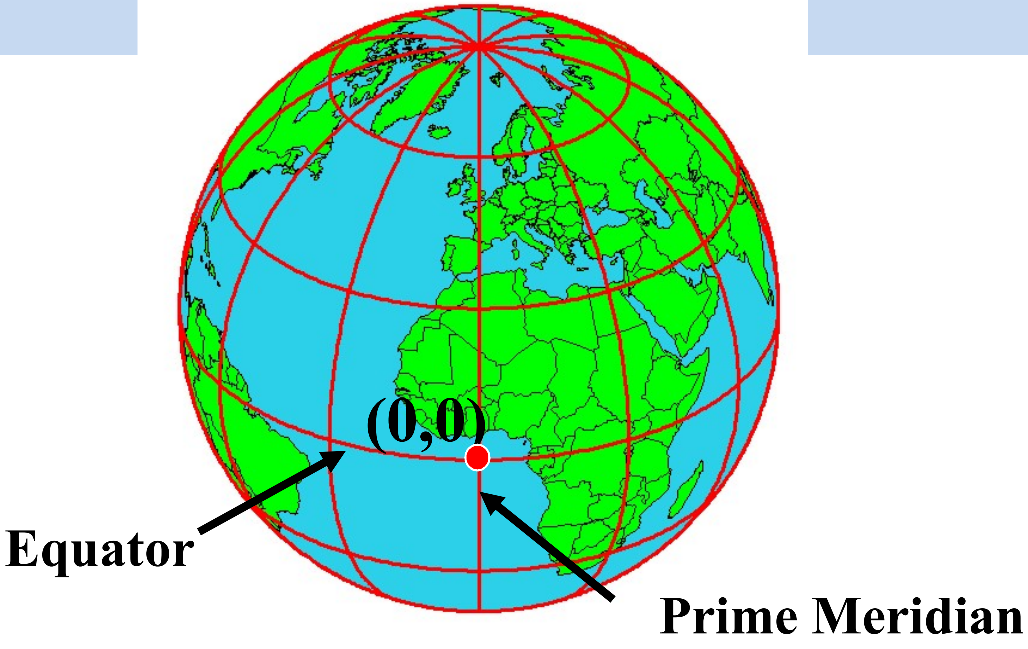
Any set of numbers, usually in sets of two or three, used to determine location relative to other locations in two or three dimensions.

There are 2 types of coordinate systems:

- Geographic Coordinate Systems
- Projected Coordinate Systems

GCS

Intersection of equator and prime meridian serve as the origin of latitude and longitude.The globe is then divided into four geographical quadrants that are based on compass bearings from the origin. North and south are above and below the equator, and west and east are to the left and right of the prime meridian..



DO NOT confuse GCS with DATUM....DATUM is only a part of GCS.

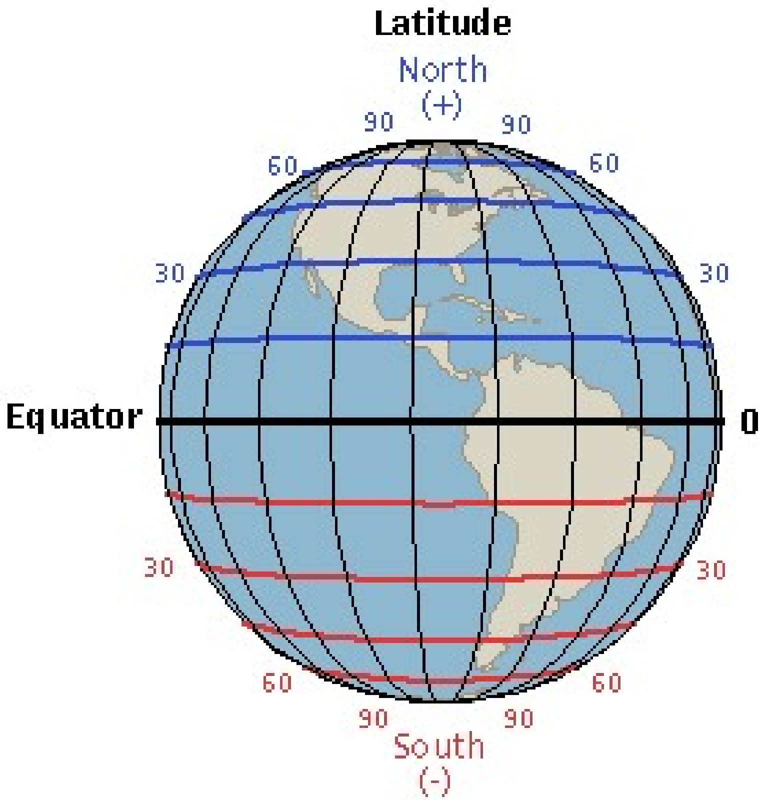
GCS= an angular unit of measure + prime meridian + datum (based on spheroid)

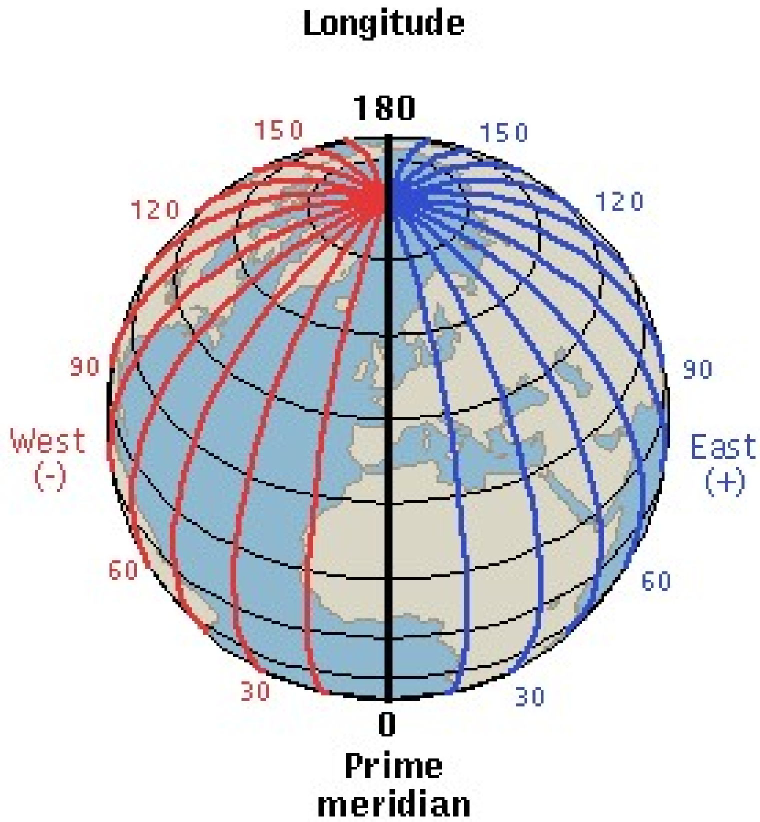
For most geographic coordinate systems, the prime meridian is the longitude that passes through Greenwich, England.

LATITUDE AND LONGITUDE

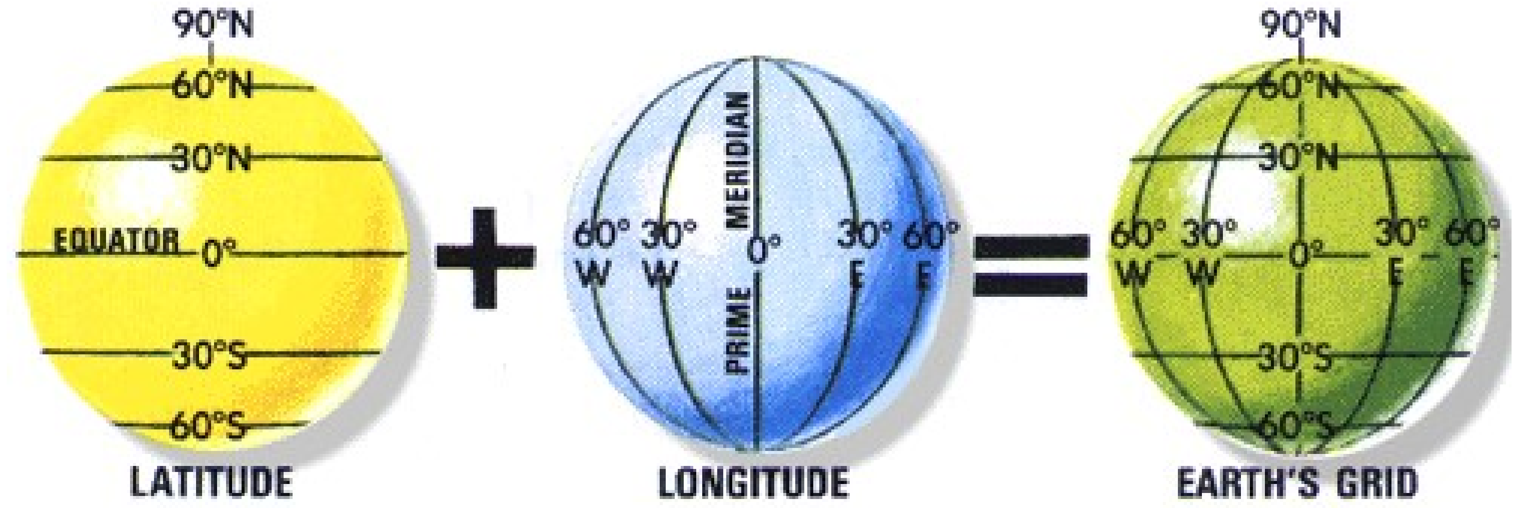
Latitude: is the angular distance, in degrees, minutes, and seconds of a point north or south of the Equator. Lines of latitude are often referred to as parallels.

Longitude: is the angular distance, in degrees, minutes, and seconds, of a point east or west of the Prime (*Greenwich*) Meridian. Lines of longitude are often referred to as meridians.





Latitude and Longitude…..



- Lat. & Long. Can locate exact positions on the surface of the Earth but…..
- Distances or areas cannot be measured exactly
- Latitude and longitude are not uniform units of measure

  One degree of longitude at equator = 111.321 km (Clarke 1866 spheroid)

  One degree of longitude at 60° latitude = 55.802 km (Clarke 1866 spheroid)
- Data cannot be displayed easily on a map or flat computer screen.

Geographic Coordinates
(ϕ, λ, z)

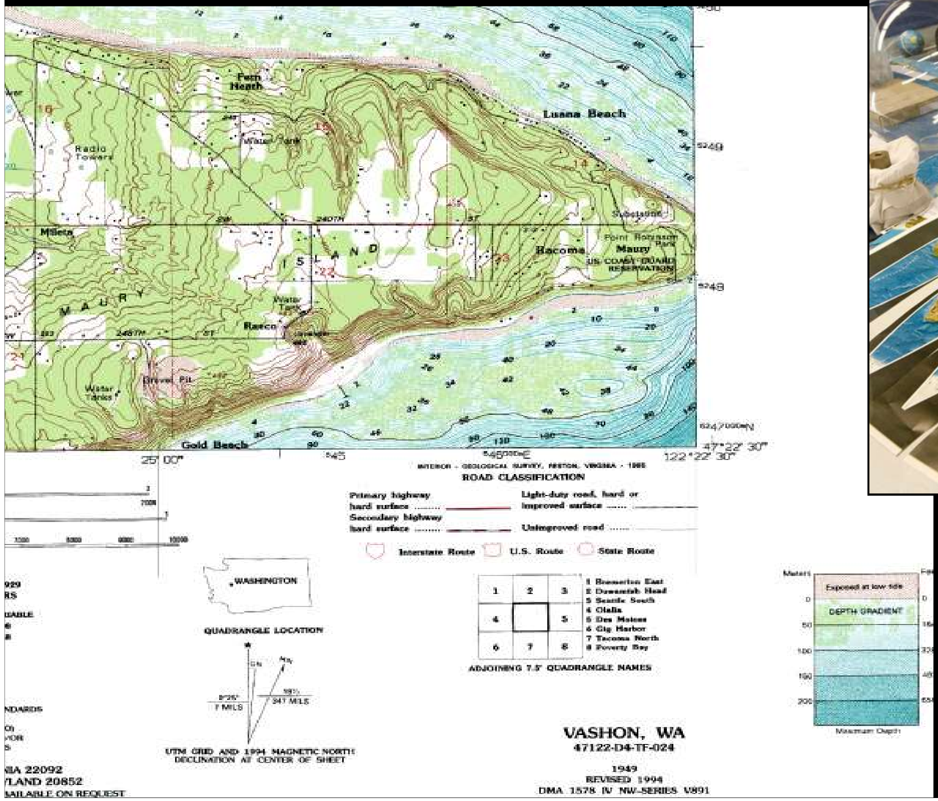
- Latitude (f) and Longitude (l) defined using an ellipsoid
- Elevation (z) defined using geoid, a surface of constant gravitational potential
- Earth datums define standard baseline values of the ellipsoid and geoid.

The earth is a spheroid

The best model of the earth is a globe

Drawbacks:

- not easy to carry
- not good for making planimetric measurements (distance, area, angle)



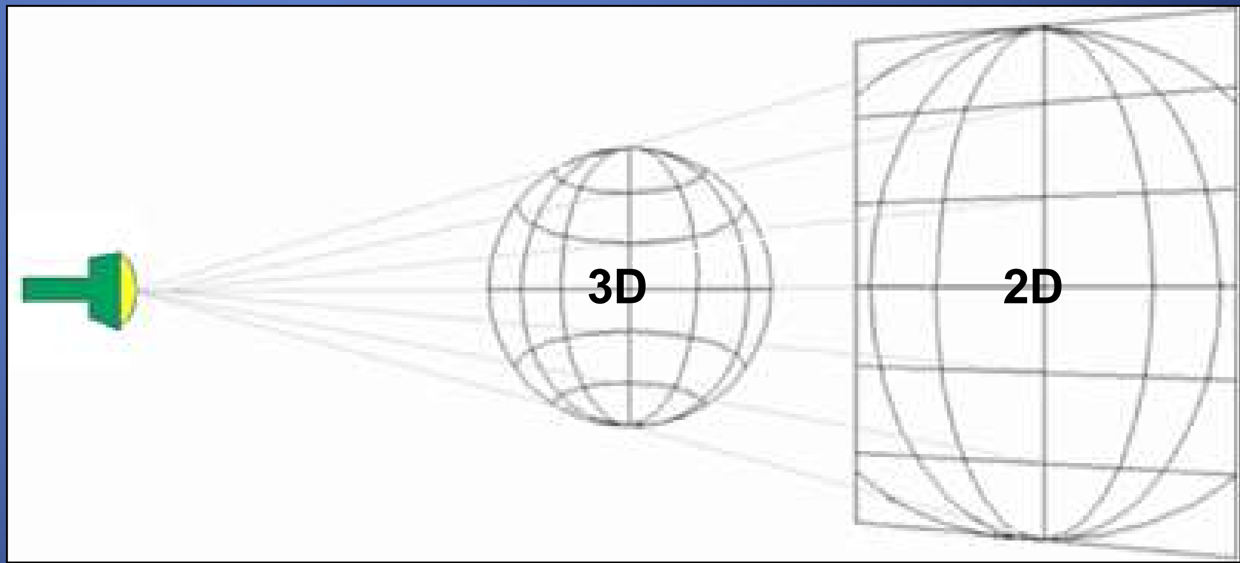
Maps are flat

- easy to carry
- good for measurement
- scaleable

Map Projection

- This is the method by which we transform the earth's spheroid (real world) to a flat surface (abstraction), either on paper or digitally
- Because we can't take our globe everywhere with us!
- Remember: most GIS layers are 2-D

Think about projecting a see-through globe onto a wall



Source: ESRI

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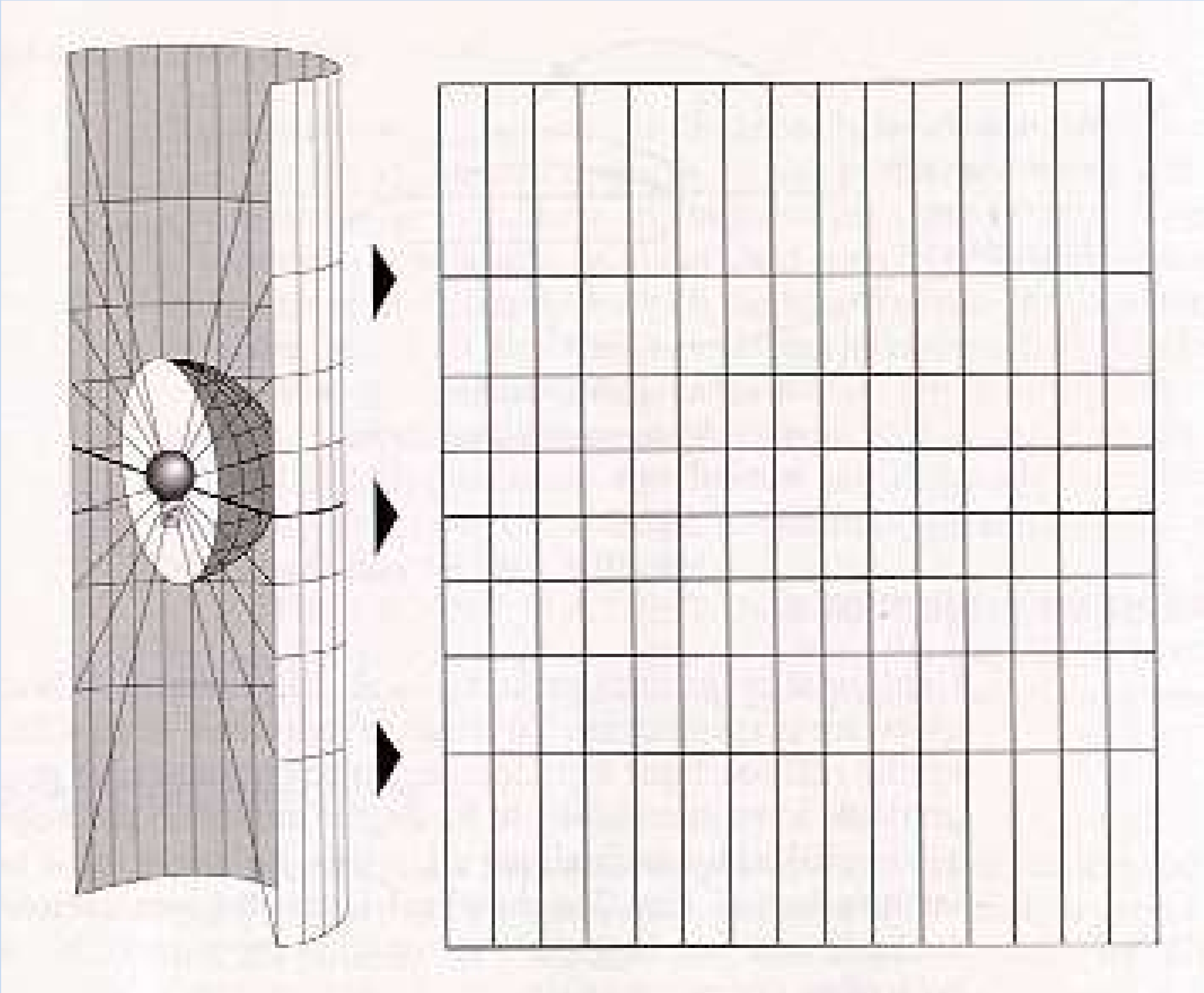
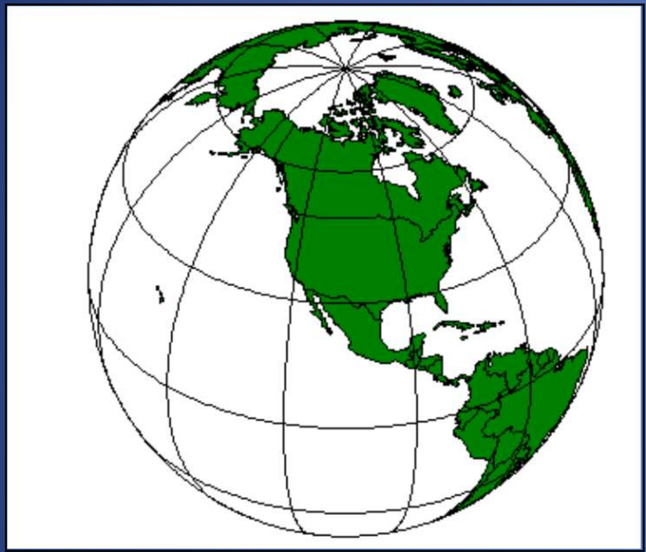


- an imaginary light is "projected" onto a "developable surface"
- a variety of different projection models exist

Map Projection

The transformation of a curved earth to a flat map.



Curved Earth

Geographic coordinates: ϕ, λ
(Latitude & Longitude)

Flat Map

Cartesian coordinates: x,y
(Easting & Northing)

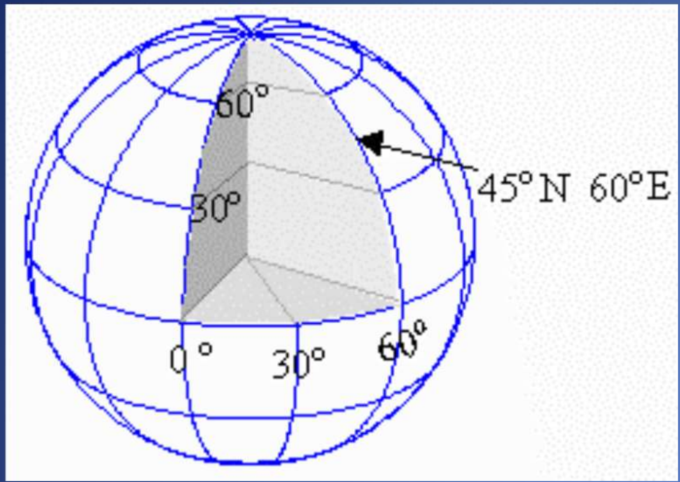
IMPORTANT!!!!

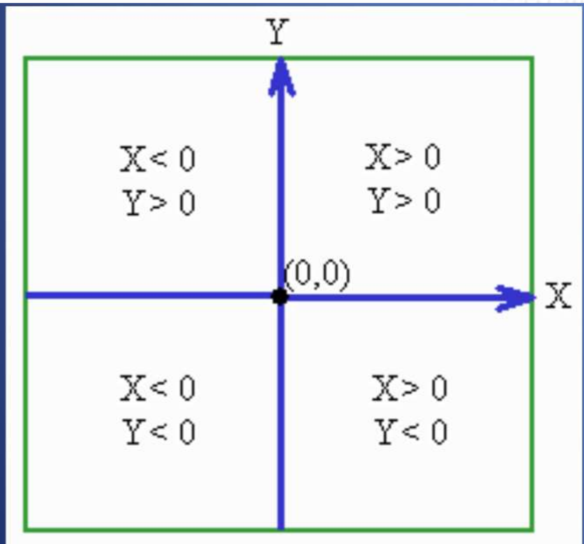
Projections only transform coordinates from one coordinate system to another

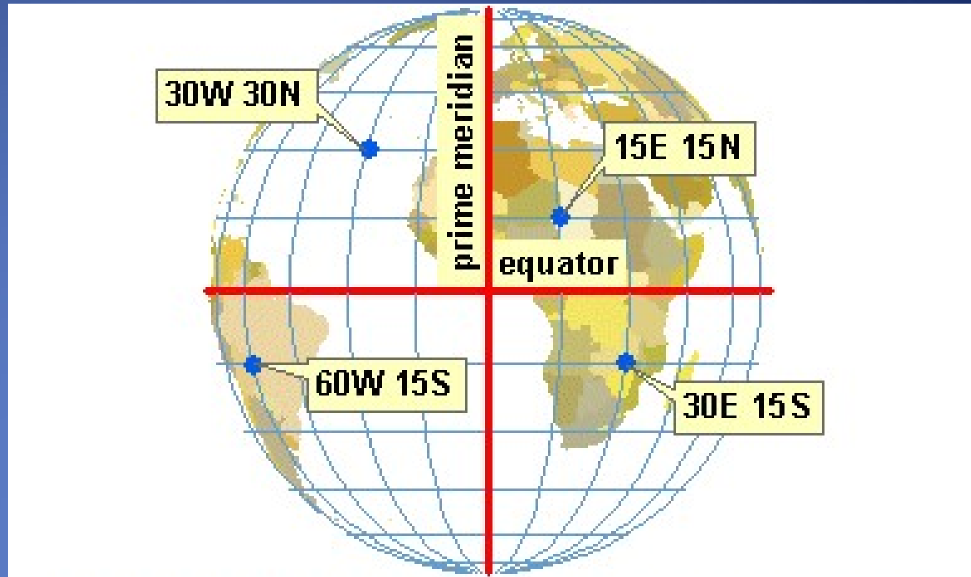
PROJECTED COORDINATE SYSTEMS

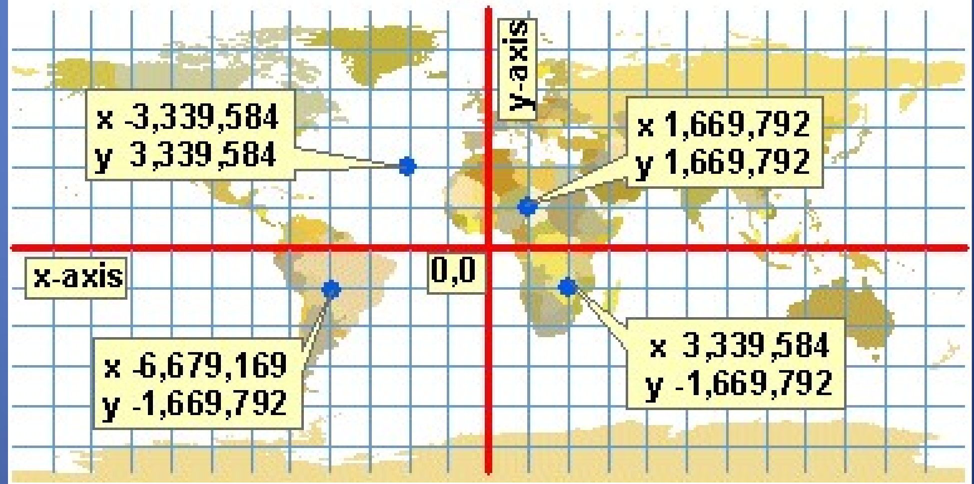
- Defined on a flat 2D surface.
- A map projection is the systematic transformation of locations on the earth - curved surface (latitude/longitude) - to planar coordinates.
- Are mathematical expressions
- Locations are identified by x, y coordinates on a grid with origin at the center of the grid.
- The basis for this transformation is the geographic coordinate system (which references a datum) - A PROJECTED COORDINATE SYSTEM IS ALWAYS BASED ON A GCS THAT IS BASED ON A SPHEROID.
- Map projections are designed for specific purposes

GEOGRAPHIC AND PROJECTED COORDINATES









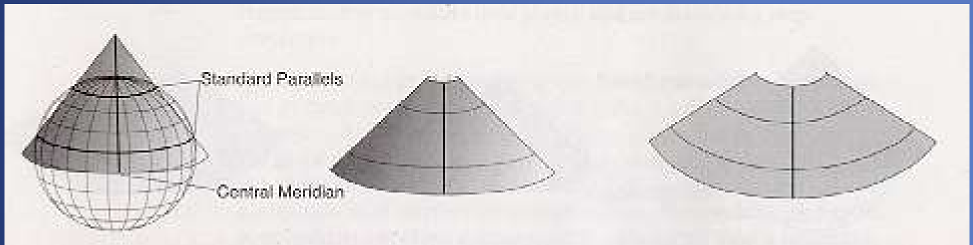
(ϕ, λ) ⟷ (x, y)

Map Projection

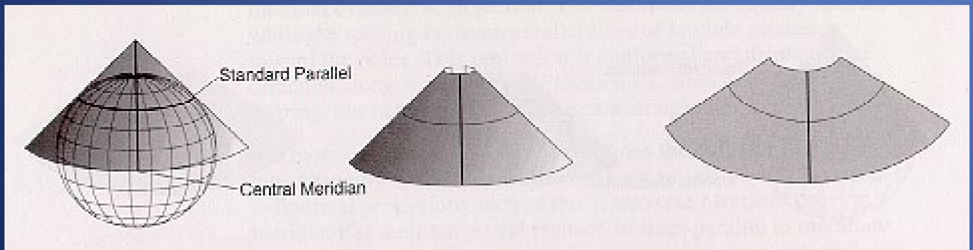
SOME PROJECTION PARAMETERS

- **Standard parallels and meridians** – the place where the projected surface intersects the earth – there is no scale distortion
- **Central meridian** – on conic projection, the center of the map (balances the projection, visually)

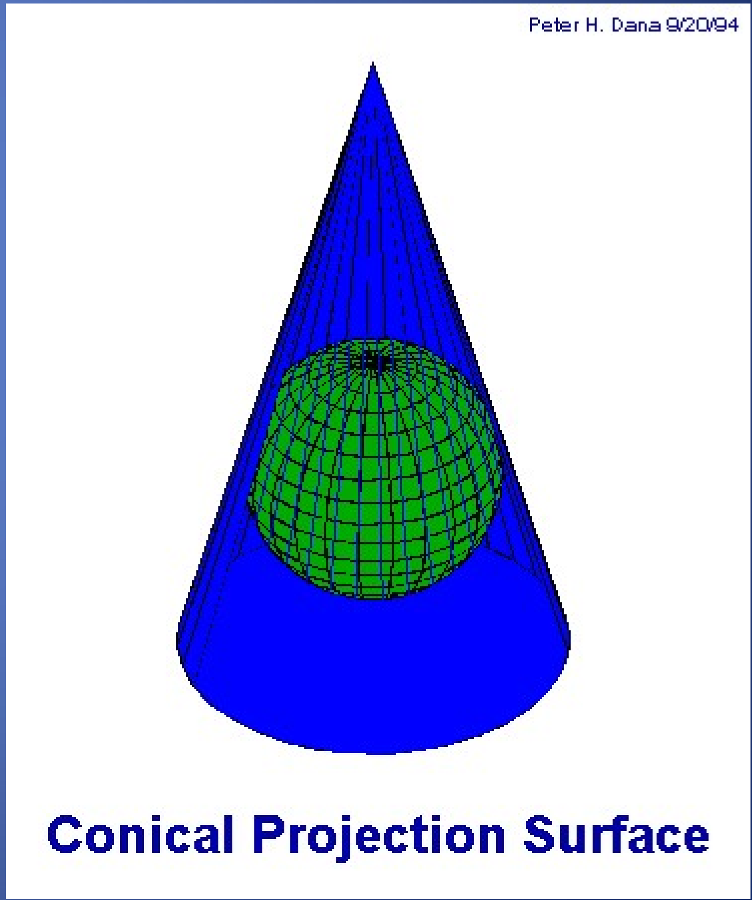
CONE AS DEVELOPABLE SURFACE



secant cone

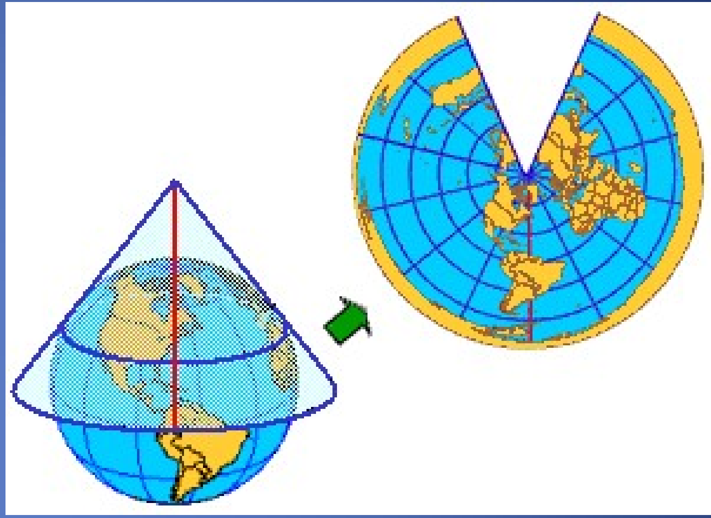


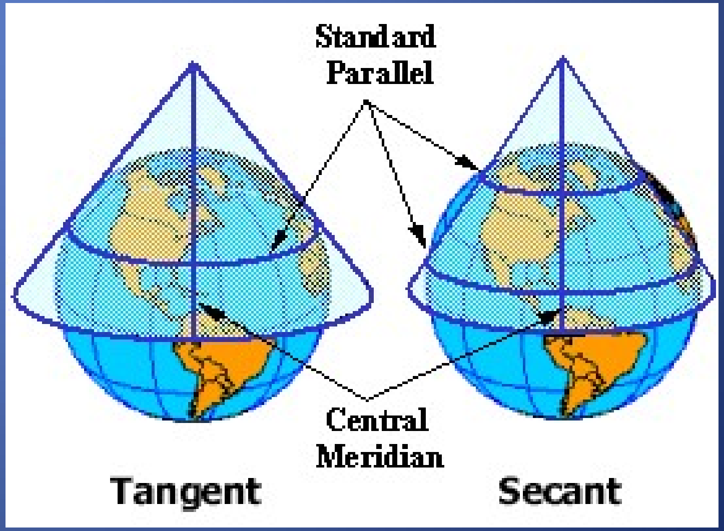
tangent cone



CONICAL PROJECTIONS

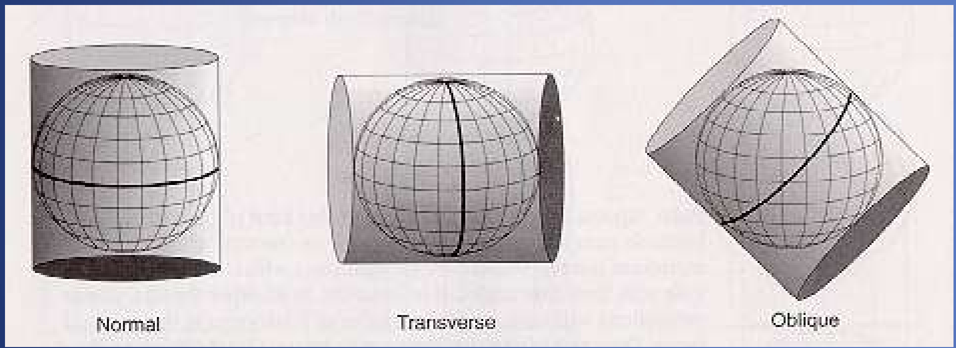
- Projects a globe onto a cone
- In simplest case, globe touches cone along a single latitude line, or tangent, called *standard parallel*
- *Can be secant too*
- Other latitude lines are projected onto cone
- To flatten the cone, it must be cut along a line of longitude (see image)
- The opposite line of longitude is called the *central meridian*



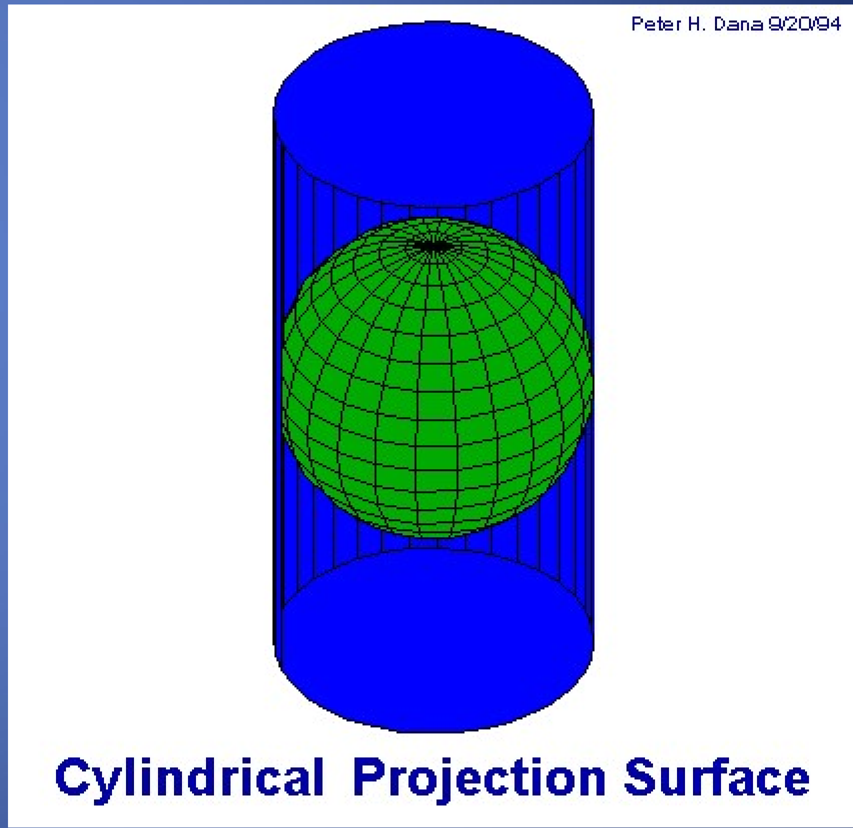


Source: ESRI

CYLINDER AS DEVELOPABLE SURFACE

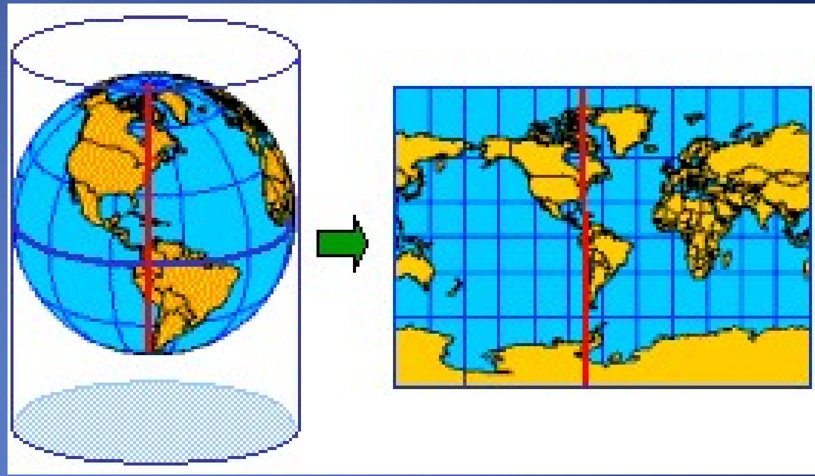


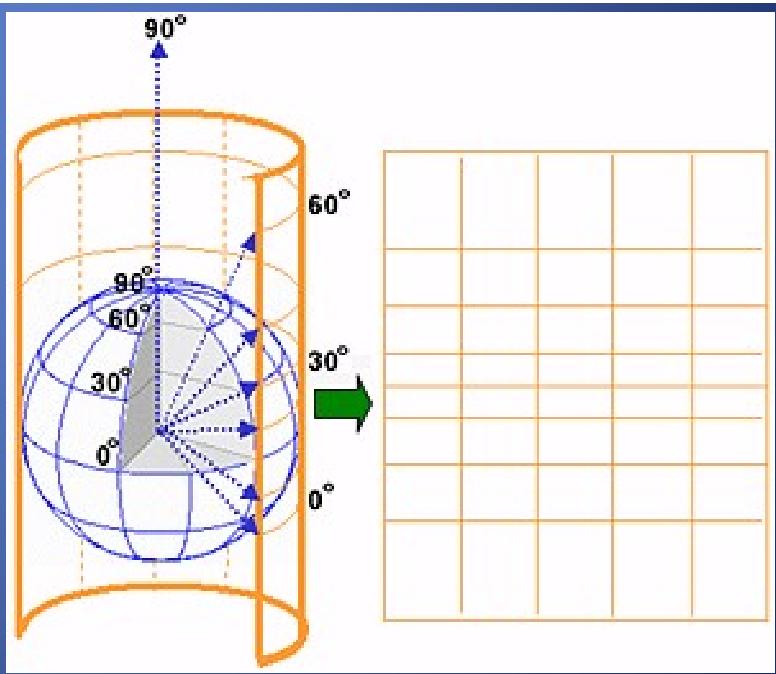
tangent cylinders



Cylindrical Map Projections

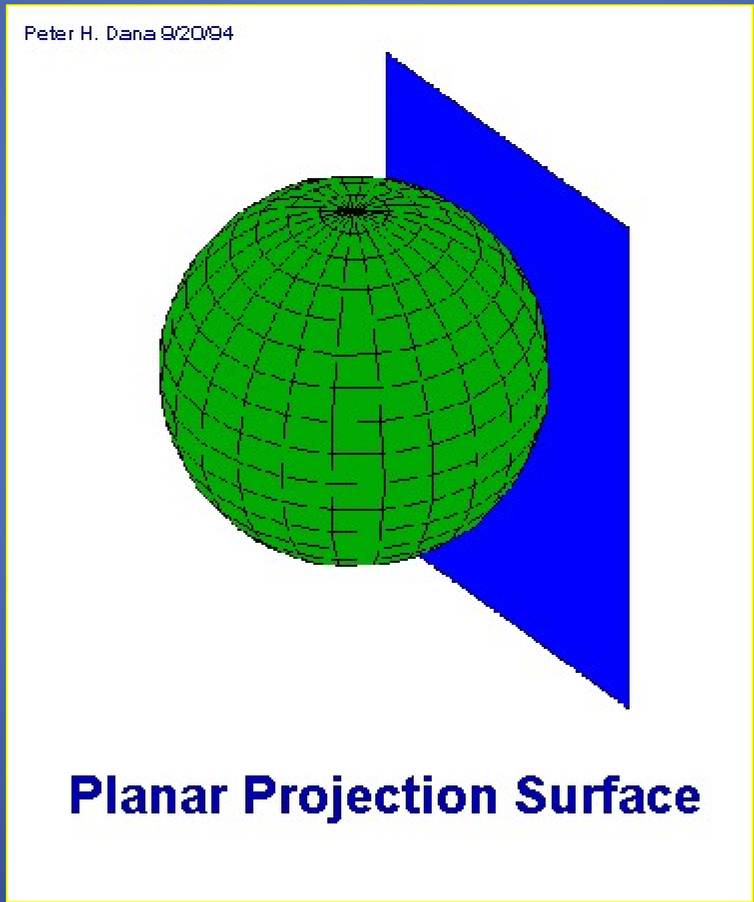
- Created by wrapping a cylinder around a globe and, in theory, projecting light out of that globe
- the meridians in cylindrical projections are equally spaced
- spacing between parallel lines of latitude increases toward the poles
- meridians never converge so poles can't be shown





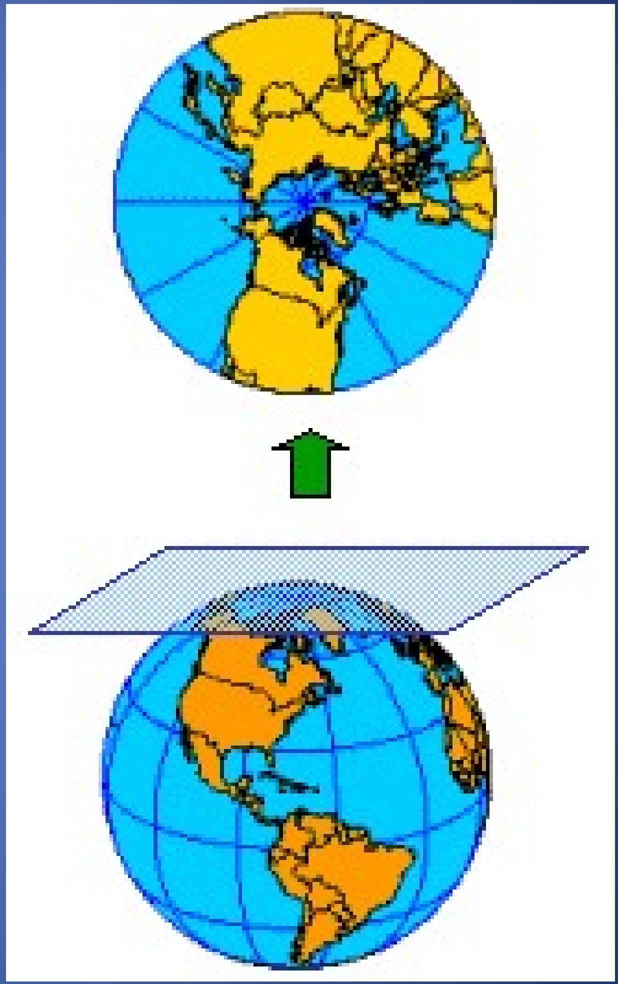
Source: ESRI

PLANE AS DEVELOPABLE SURFACE



AZIMUTHAL PROJECTIONS

- simply project a globe onto a flat plane
- The simplest form is only tangent at one point
- Any point of contact may be used but the poles are most commonly used
- When another location is used, it is generally to make a small map of a specific area
- When the poles are used, longitude lines look like hub and spokes



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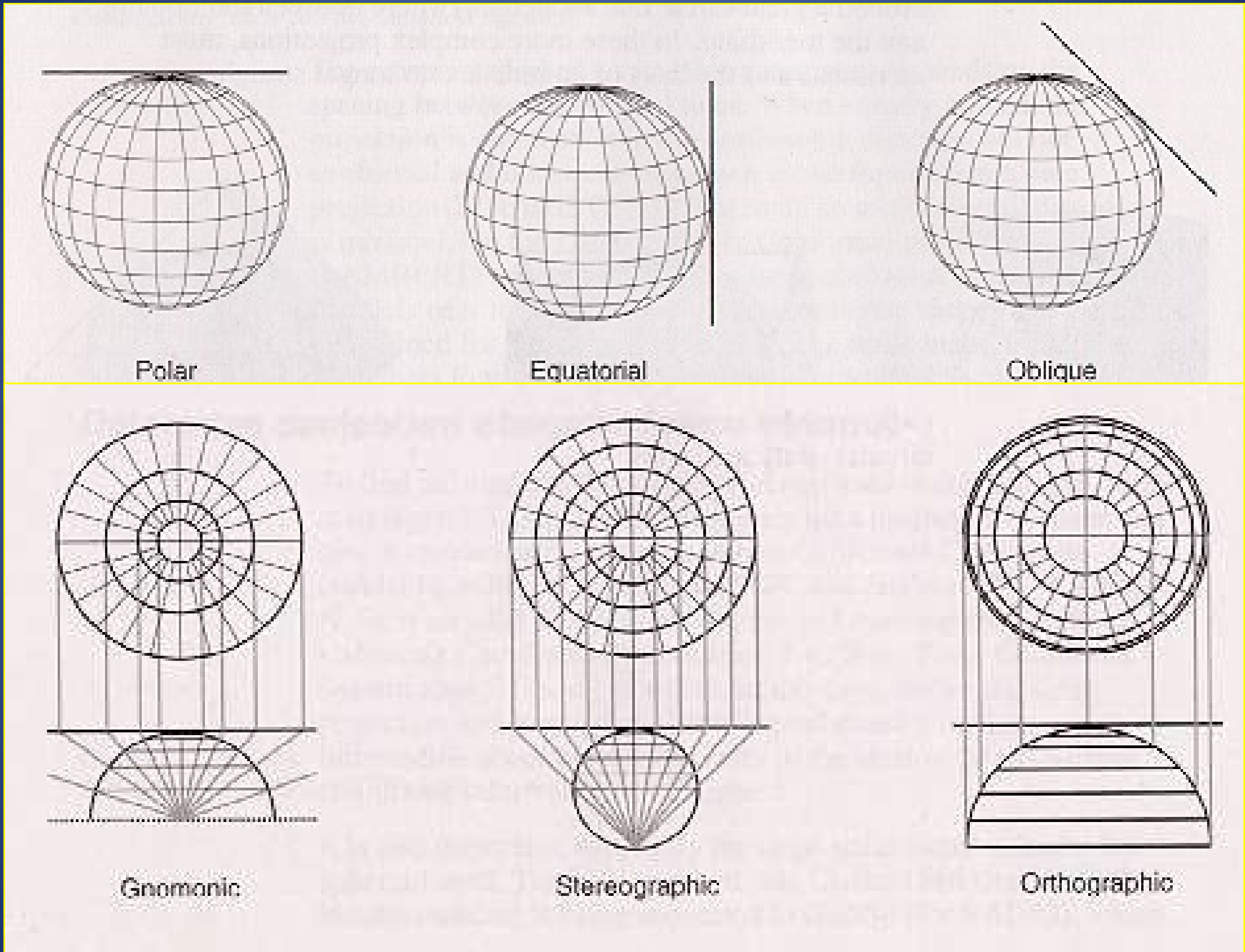


Polar
Equatorial
Oblique
Gnomonic
Stereographic
Orthographic

PROPERTIES & DISTORTIONS

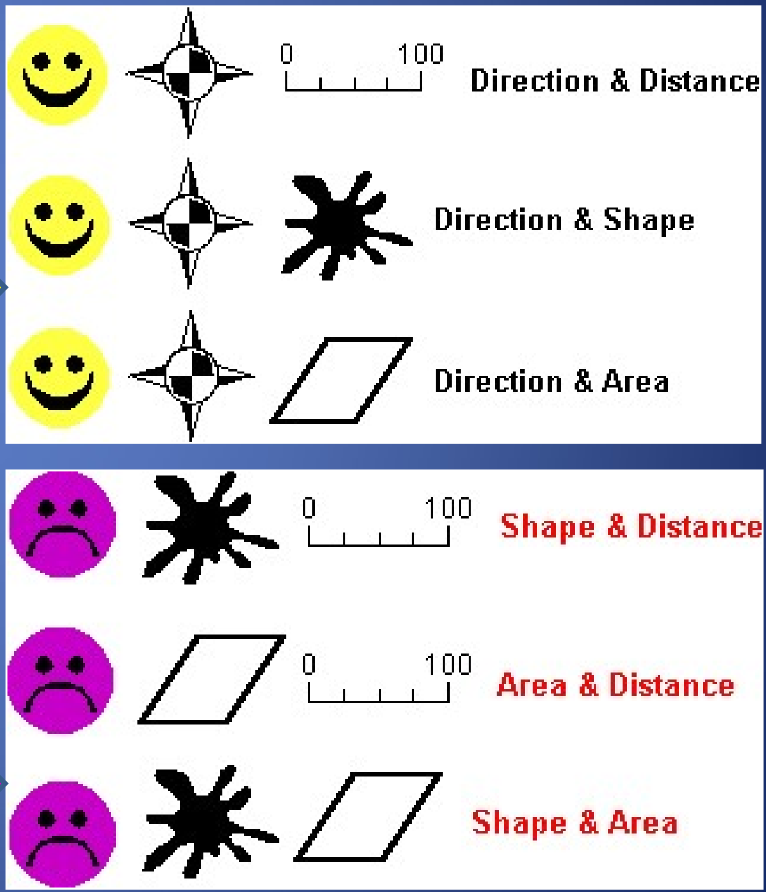
This process of flattening the earth will cause distortions in one or more of the following spatial properties

- Shape
  - Conformal map projections preserve shape
- Area
  - Equal area map projections preserve area
- Distance/Scale
  - Equidistant map projections preserve distance
- Direction/Angle
  - Azimuthal map projections preserve true direction

PRESERVING PROPERTIES

- If two properties are to be preserved then one is always direction

- These properties are incompatible



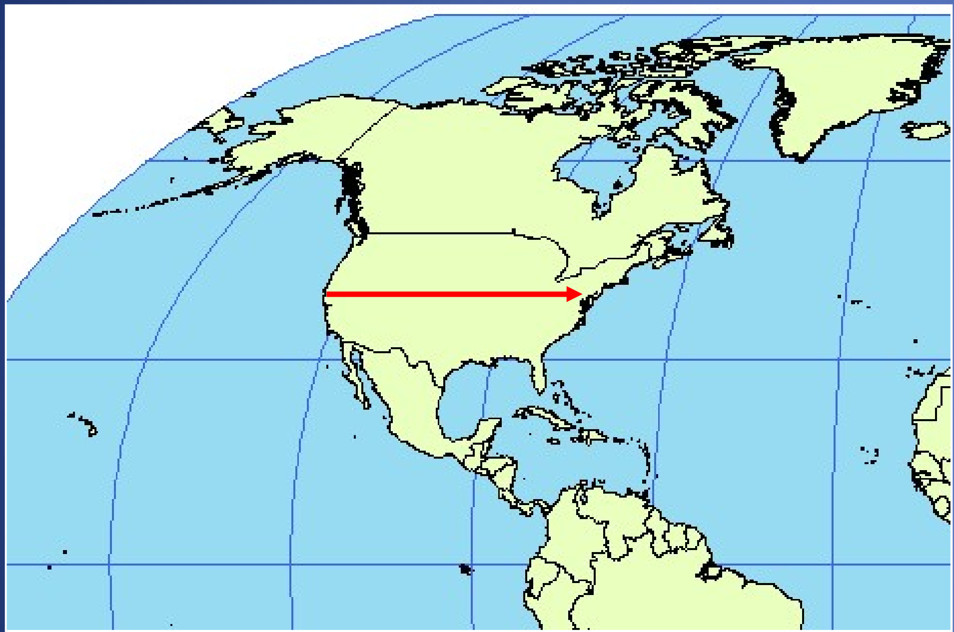
AREA DISTORTION

Mercator Projection

- 827,000 square miles
- 6.8 million square miles

Source: 2005, Austin Troy

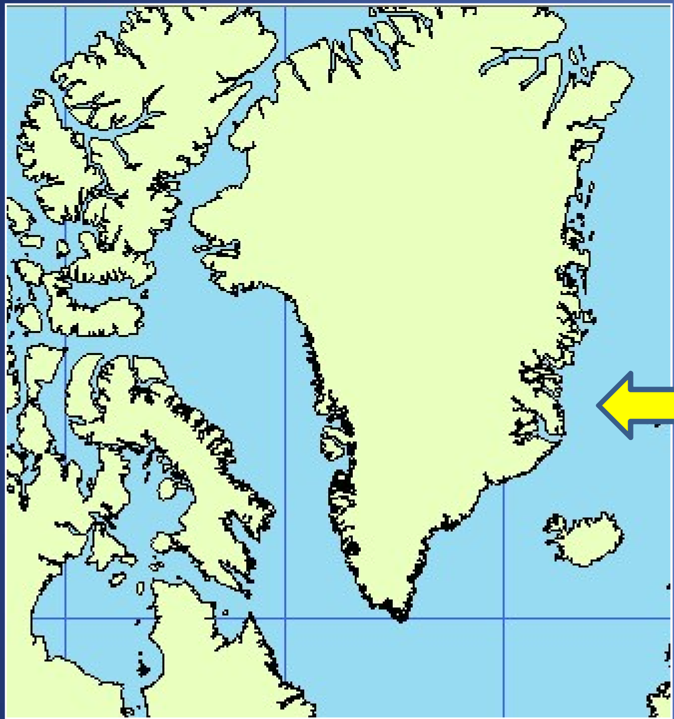
DISTANCE DISTORTION



- 4,300 km: Robinson
- 5,400 km: Mercator

Source: 2005, Austin Troy

SHAPE DISTORTION

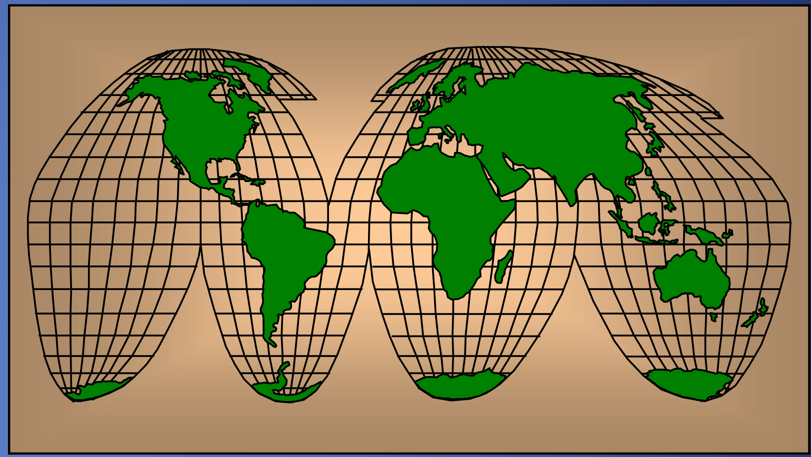


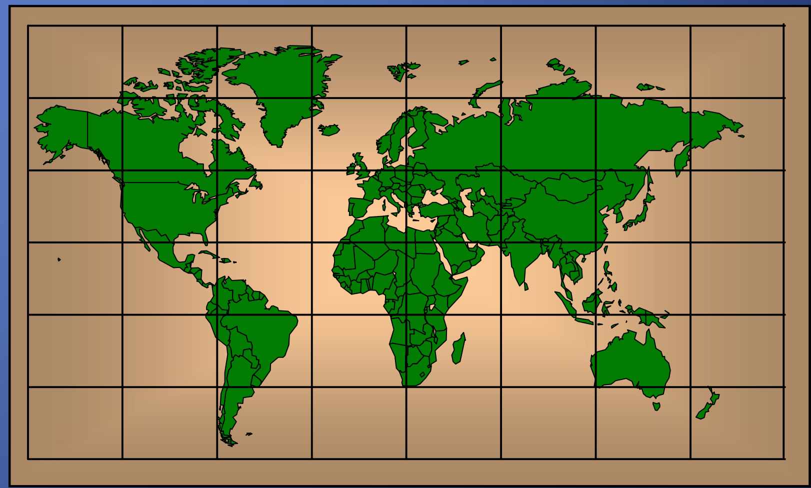
- Mercator
- World Cylindrical Equal Area
- The distortion in shape above is necessary to get Greenland to have the correct area
- The Mercator map looks good but Greenland is many times too big

Source: 2005, Austin Troy

PROJECTED COORDINATE SYSTEM

- Also c/a Plane Coordinate System
- Based on a map projection
- Relates the coordinates of points on earth's curved surface with the coordinates of the same points on a plane or flat surface
- Key consideration is accuracy in a feature's location and its position
- Defined not only by the parameters of map projection but also the parameters of the GCS it is derived from

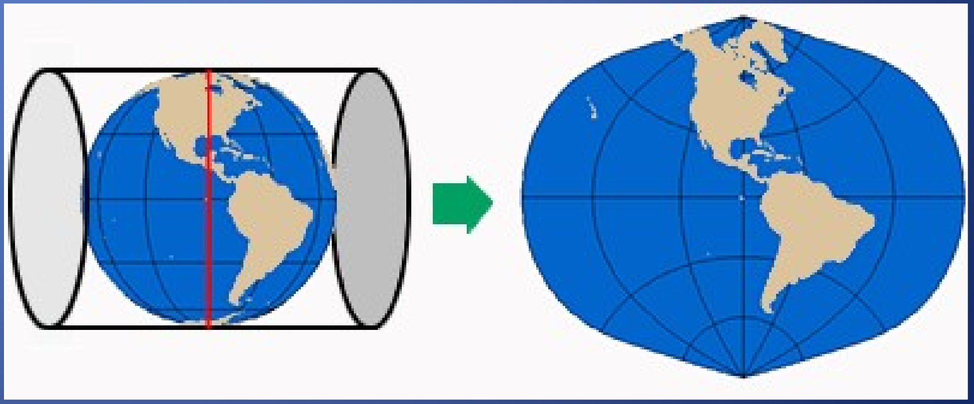




UNIVERSAL TRANSVERSE MERCATOR PROJECTION

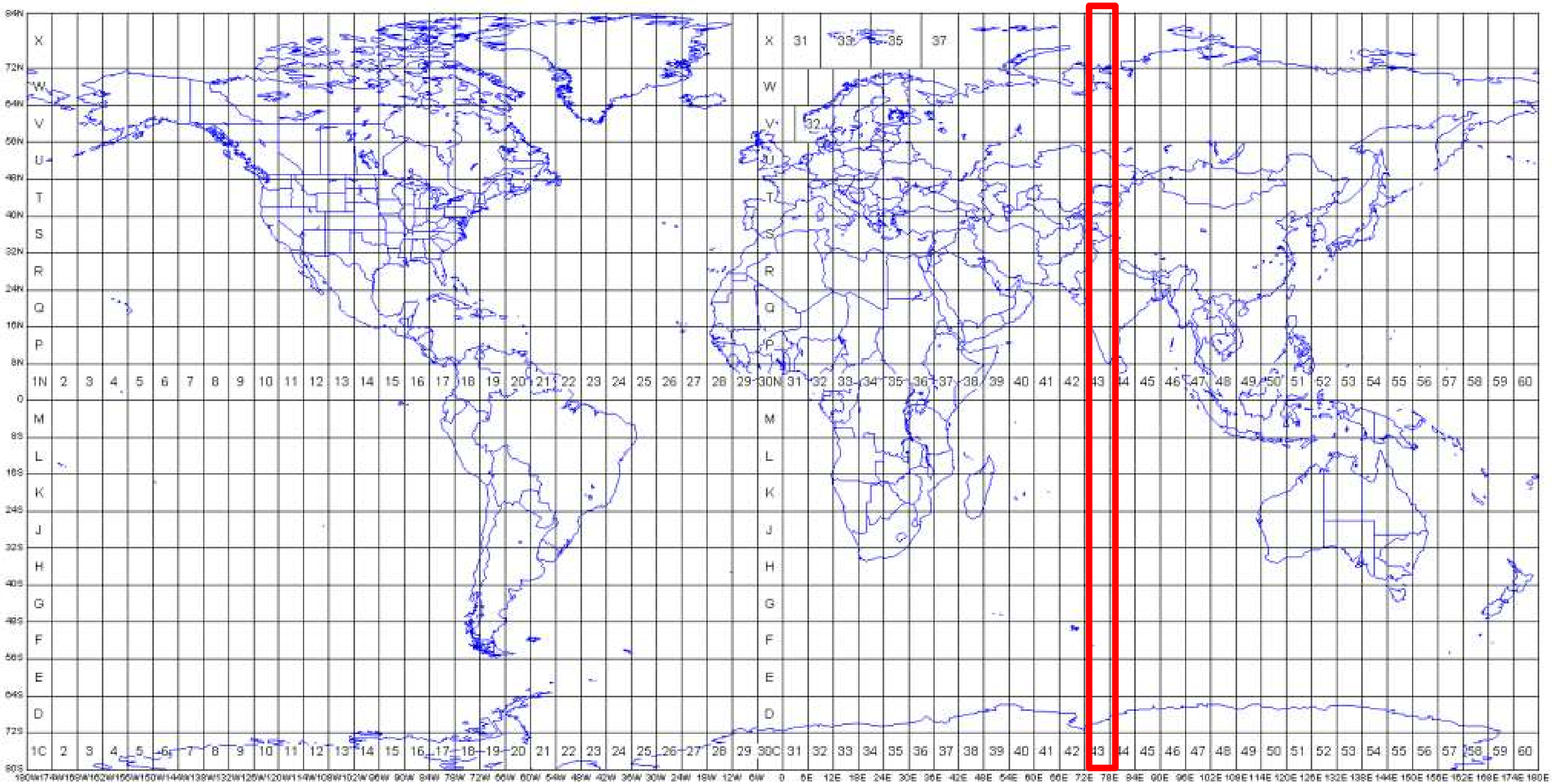
- UTM is based on the Transverse Mercator projection.
- Transverse Mercator: Invented by Johann Lambert in 1772, this projection is cylindrical, but the axis of the cylinder is rotated 90°, so the tangent line is longitudinal, rather than equatorial
- In this case, only the central longitudinal meridian and the equator are straight lines

All other lines are represented by complex curves: that is they can't be represented by single section of a circle



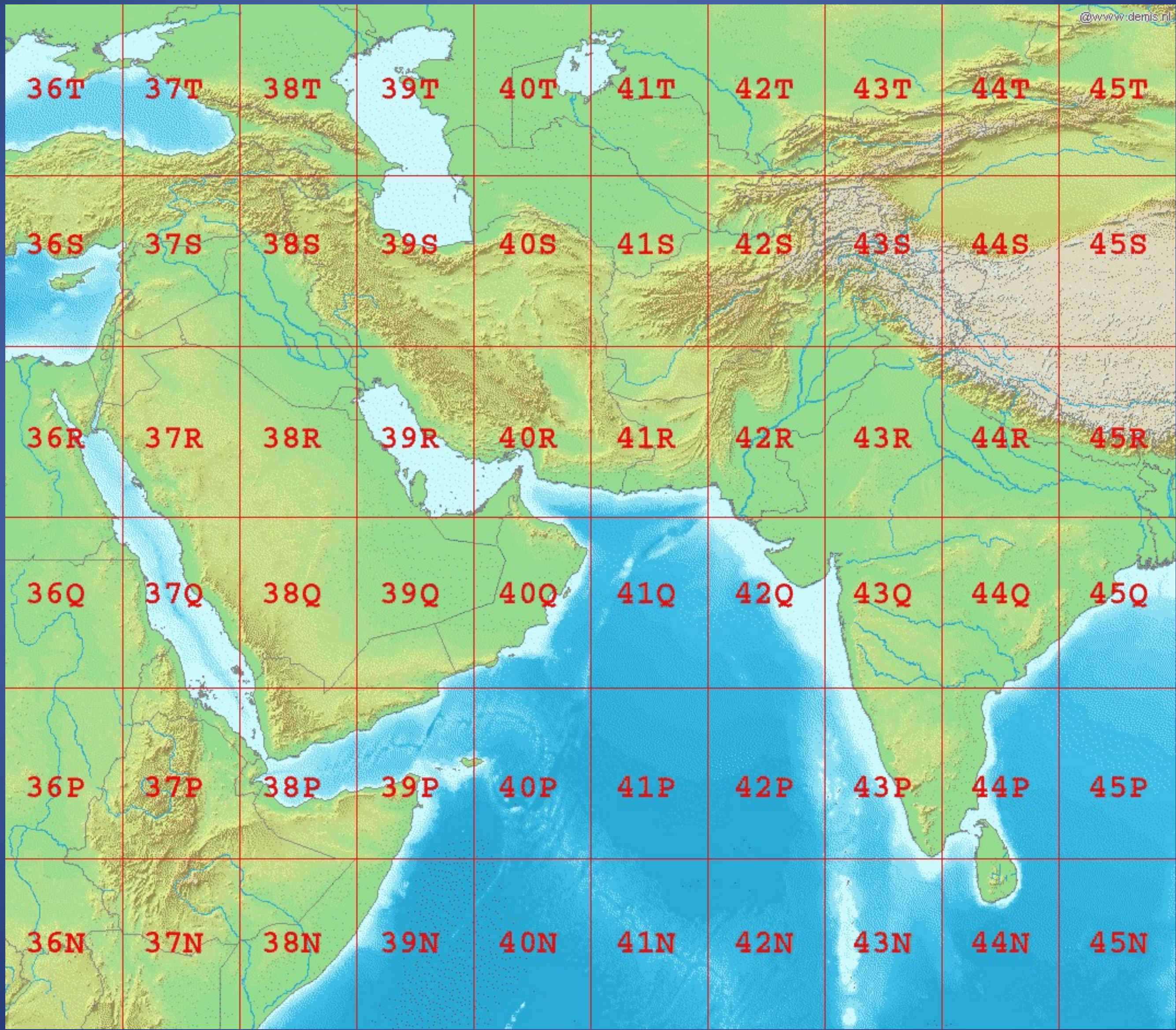
Source: ESRI

- UTM divides the earth between 84°N and 80°S into 60 zones, each of which covers 6 degrees of longitude



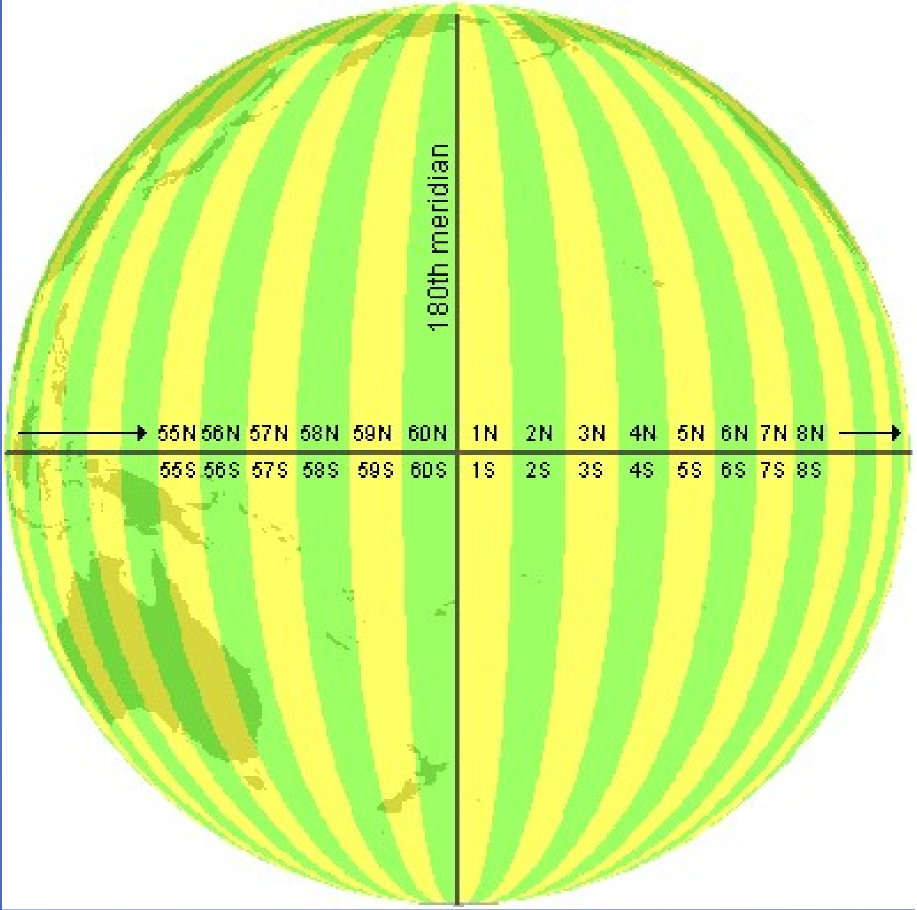
World UTM zones

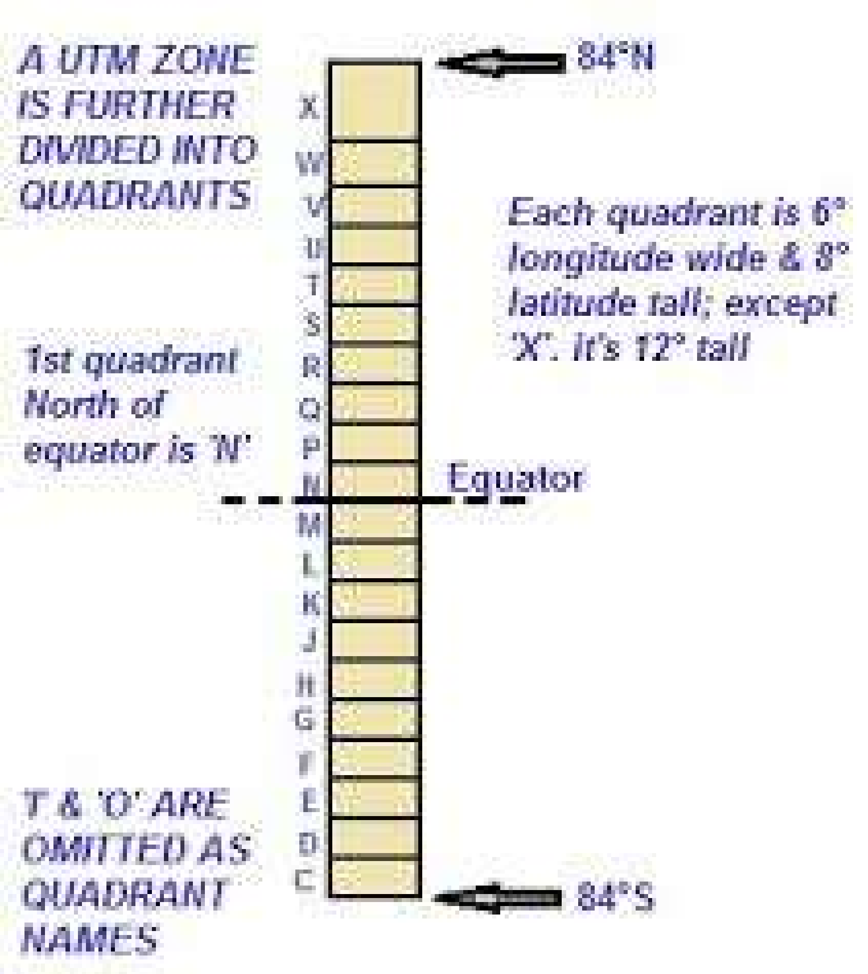
UTM GRID – INDIA

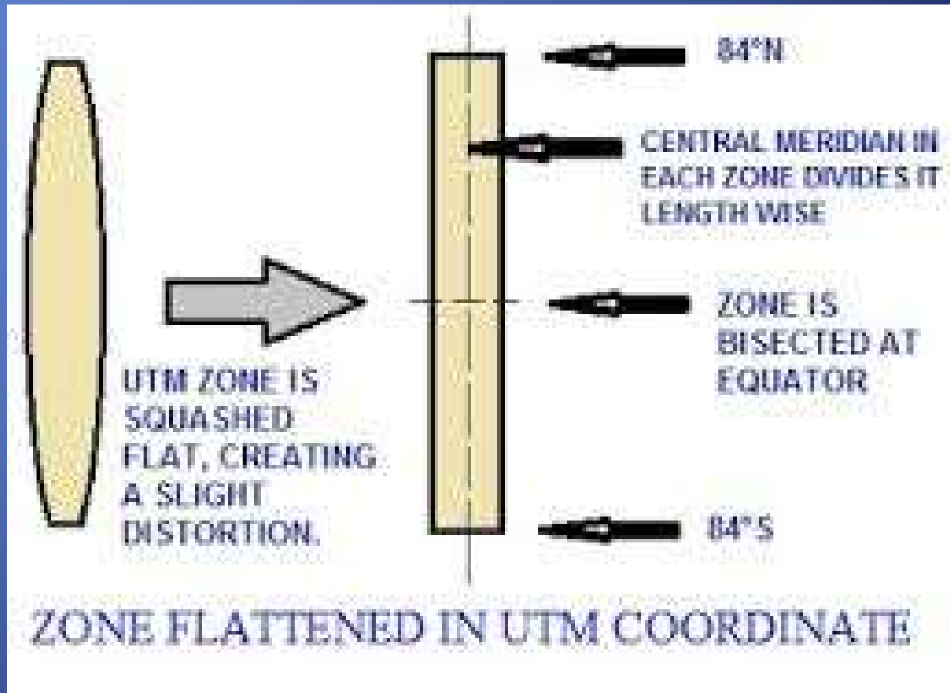


• UTM zones

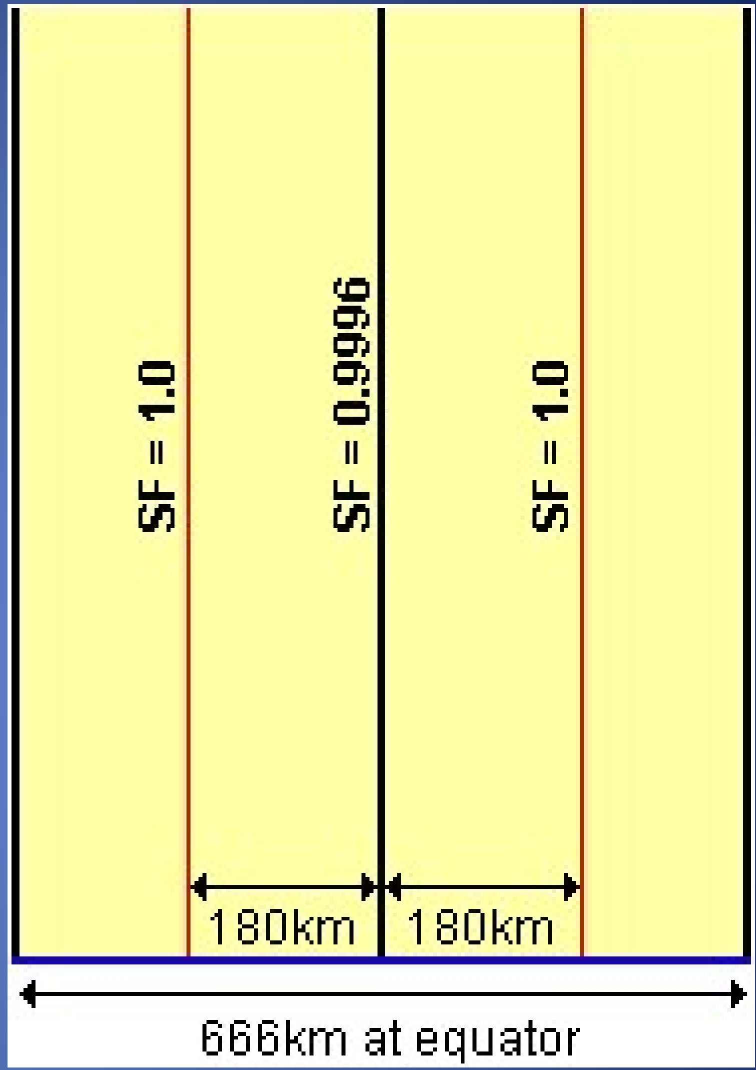
- There are 60 longitudinal projection zones numbered 1 to 60 starting at 180° W.
- Each of the zones is 6 degrees wide
- There are 20 latitudinal zones spanning the latitudes 80 ° S to 84 ° N denoted by letters 'C' to 'X', Omitting letter 'O'
- Each of the latitudinal zones is 8 degrees North –South, apart from zone 'X' which is 12 degrees N-S
- Areas are referenced by longitudinal zone number, followed by the latitudinal zone letter.
- Within each longitudinal zone, the transverse mercator projection is used to give co-ordinates (eastings and northings in meters)




A UTM ZONE IS FURTHER DIVIDED INTO QUADRANTS
84°N
X
W
V
U
T
S
R
Q
P
N
M
L
K
J
H
G
F
E
D
C
84°S
Each quadrant is 6° longitude wide & 8° latitude tall; except 'X'. It's 12° tall
1st quadrant North of equator is 'N'
Equator
'I' & 'O' ARE OMITTED AS QUADRANT NAMES


84°N
CENTRAL MERIDIAN IN EACH ZONE DIVIDES IT LENGTH WISE
ZONE IS BISECTED AT EQUATOR
UTM ZONE IS SQUASHED FLAT, CREATING A SLIGHT DISTORTION.
84°S
ZONE FLATTENED IN UTM COORDINATE

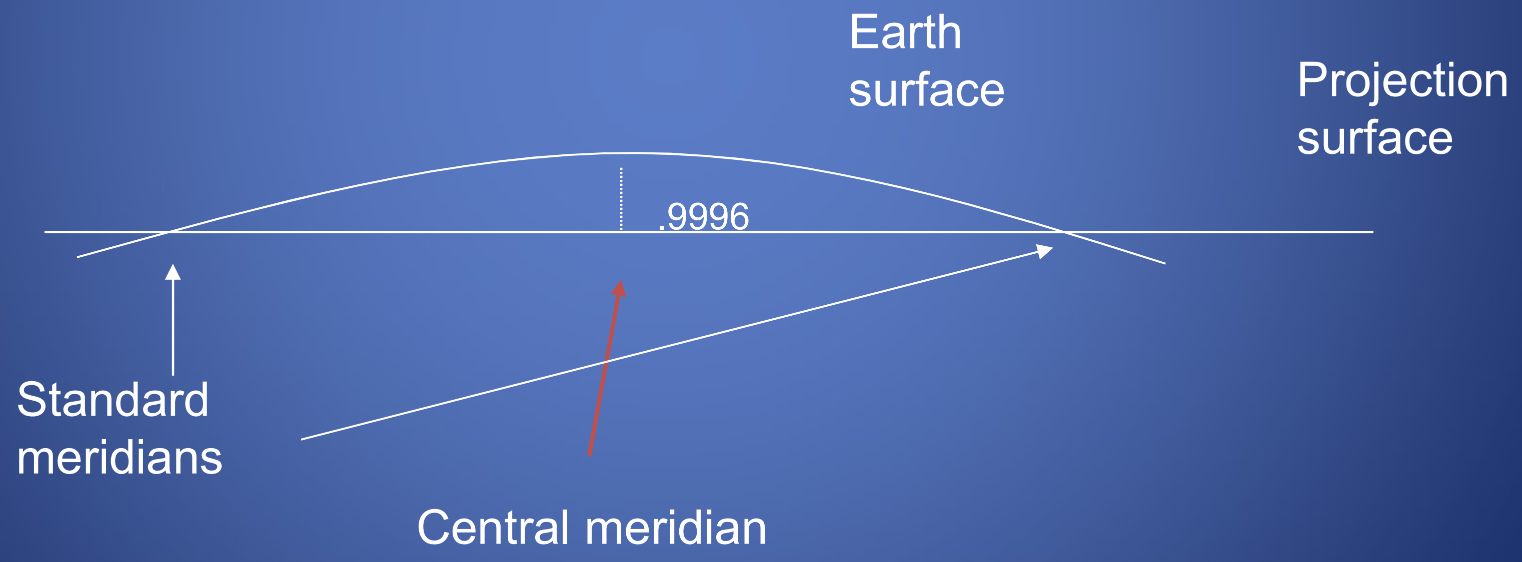
- Each UTM zone is projected separately
- There is a false origin (zero point) in each zone
- In the transverse Mercator projection, the “cylinder” touches at two secants, so there is a slight bulge in the middle, at the *central meridian*. This bulge is very slight, so the scale factor is only .9996
- The *standard meridians* are where the cylinder touches



Each zone uses a custom Transverse Mercator projection with its own central meridian

UTM

- Scale factors are .9996 in the middle and 1 at the secants



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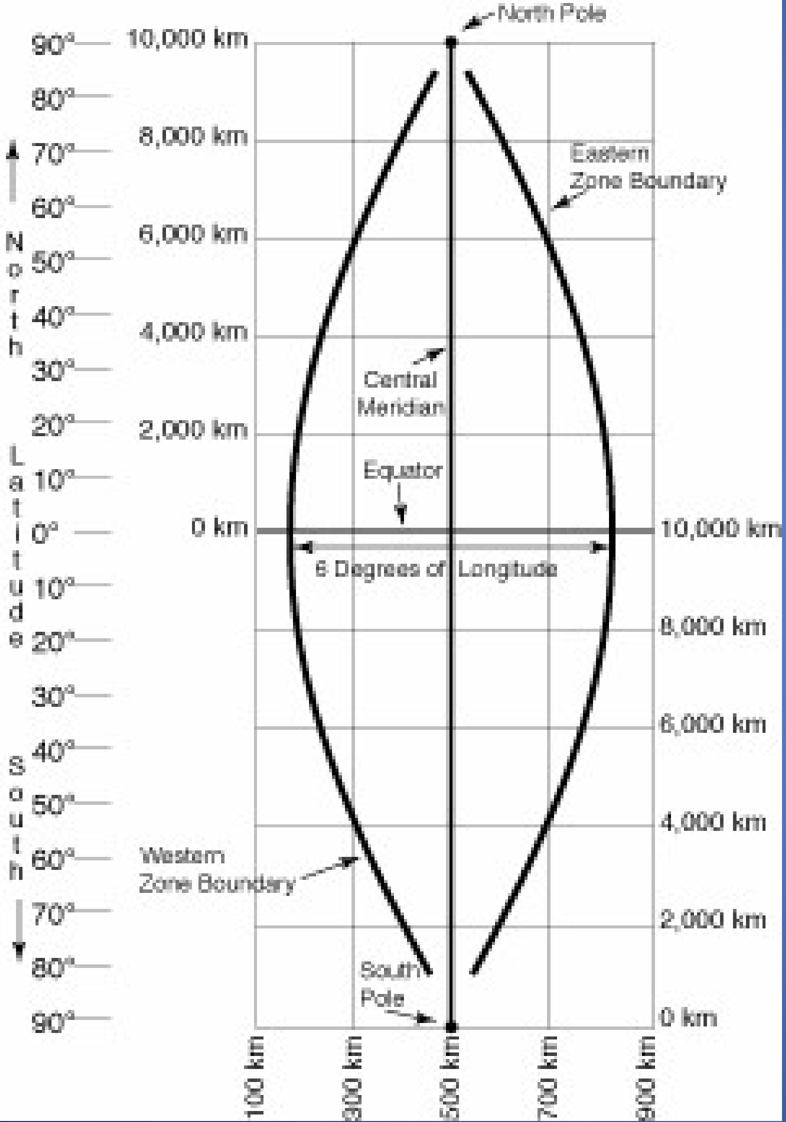
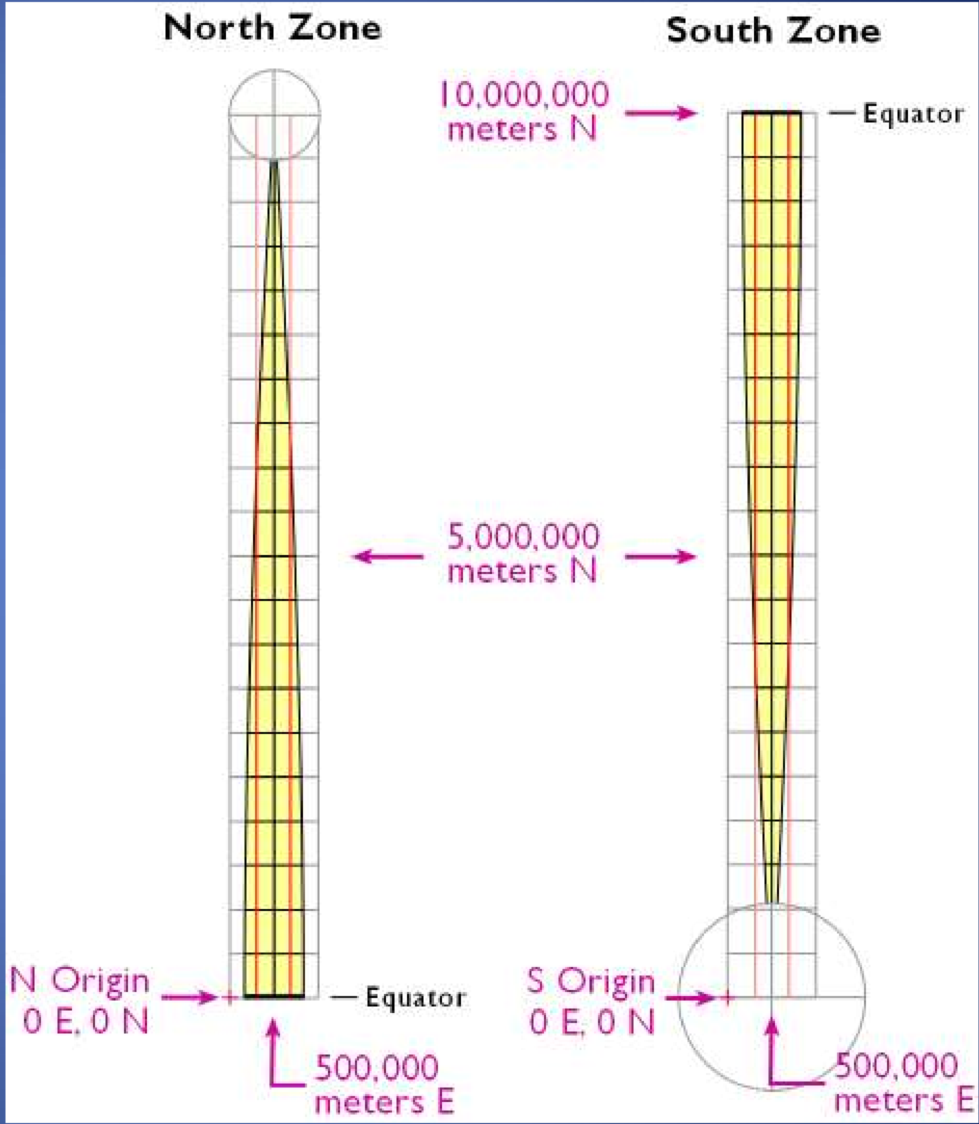
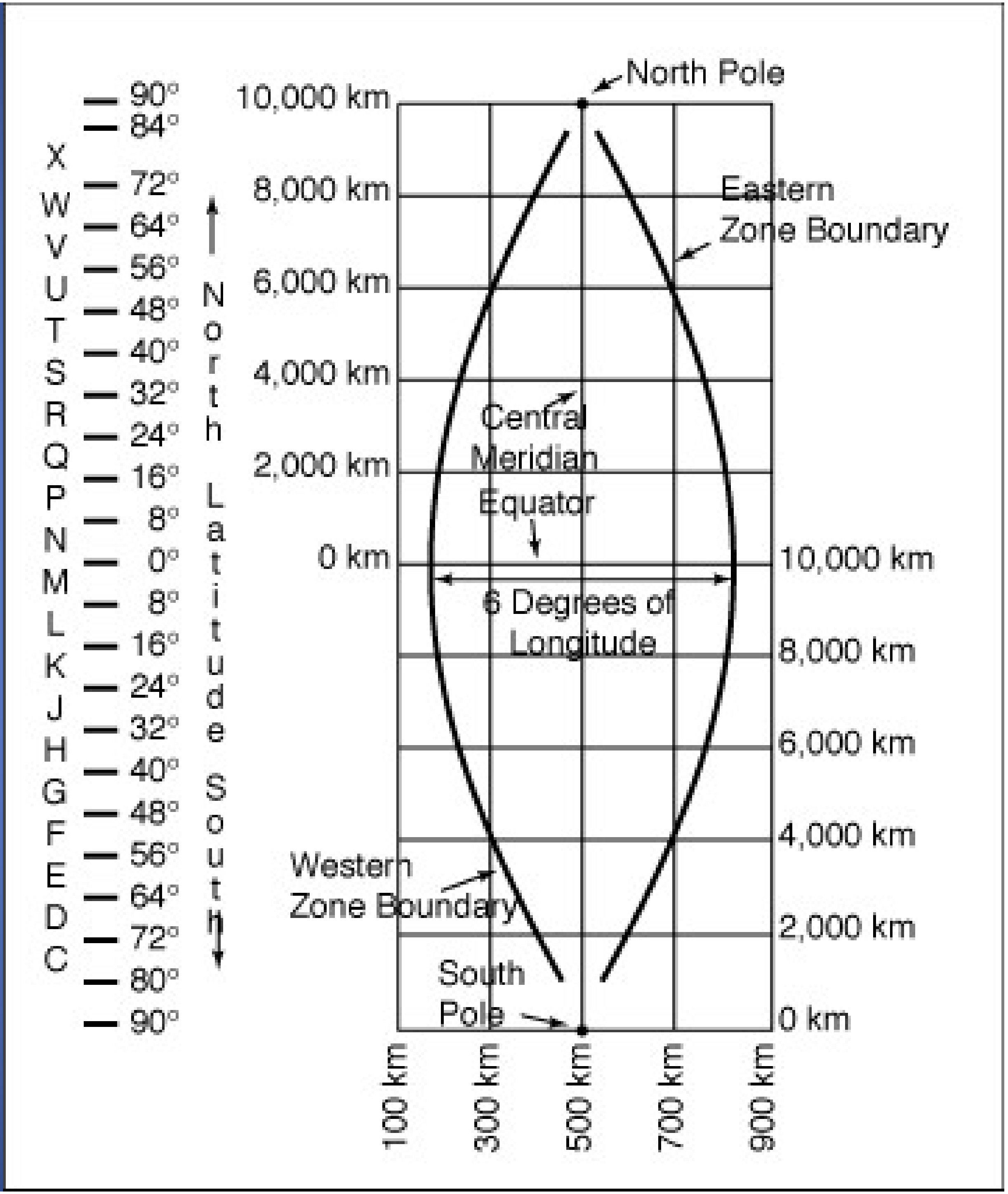


North Pole
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
North
Latitude
South
10,000 km
8,000 km
6,000 km
4,000 km
2,000 km
0 km
10,000 km
8,000 km
6,000 km
4,000 km
2,000 km
0 km
Eastern
Zone Boundary
Central
Meridian
Equator
6 Degrees of Longitude
Western
Zone Boundary
South
Pole
100 km
300 km
500 km
700 km
900 km



North Zone
South Zone
10,000,000
meters N
Equator
5,000,000
meters N
N Origin
0 E, 0 N
Equator
500,000
meters E
S Origin
0 E, 0 N
500,000
meters E

UTM Zone Details



UTM Projection

- For the eastings, the origin is defined as a point 500000 m west of the central meridian of each longitudinal zone, giving an easting of 500,000 m at the Central Meridian
- For the northings in the northern hemisphere, the origin is defined as the Equator
- For the northings in the southern hemisphere, the origin is defined as a point 10000000 meters south of equator
- The coordinates thus derived define a location within a UTM projection zone either North or South of Equator.
- But since the same coordinate system is repeated for each zone and hemisphere, it is necessary to additionally state the UTM longitudinal zone and either the hemisphere or the latitudinal zone to define the location uniquely world wide.

Coordinate Information of Udaipur

Udaipur Latitude:	24.58
Udaipur Longitude:	73.68
Latitude DMS:	24°34'48"N
Longitude DMS:	73°40'48"E
UTM Easting:	366,342.17
UTM Northing:	2,719,083.56
UTM Zone:	43R
Position from Earth's Center:	ENE
Elevation:	598.8 Meters (1964.55 Feet)

REMEMBER!!!!

- Coordinates on same projection may be referenced on different DATUMS .

  Such coordinates will have different coordinate values.

- Coordinate data may be unprojected but CANNOT be without a datum.

- Change of projection may result in change of Datum.

- It is possible to convert data from one Datum to another without projecting it.

EXAMPLE OF POINT COORDINATES REFERENCED TO DIFFERENT DATUMS.

Coordinates referenced to NAD_1927_CGQ77

```
19.048667  26.666038 Decimal Degrees
Spheroid: Clarke_1866
Semimajor Axis: 6378206.4000000004
Seminor Axis: 6356583.7999989809
```

Same point referenced to NAD_1983_CSRS

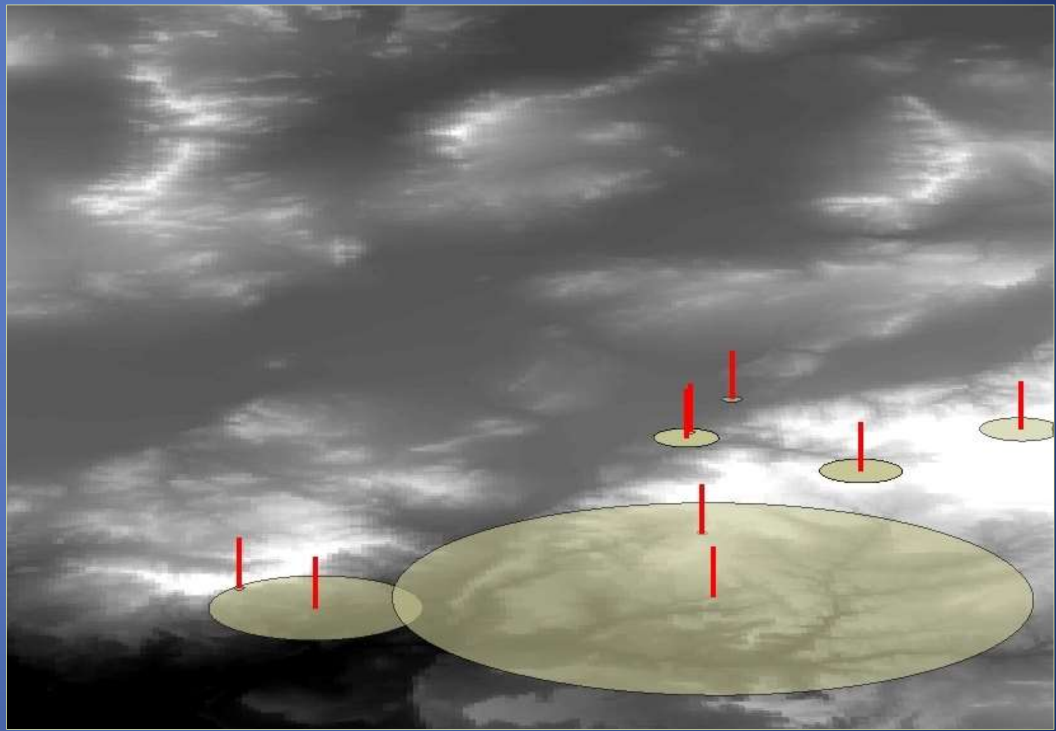
```
19.048248  26.666876 Decimal Degrees
Spheroid: GRS_1980
Semimajor Axis: 6378137.0000000000
Semiminor Axis: 6356752.3141403561
```

Coordinates alone are not enough

- Latitude and longitude (in a consistent format)
- Uncertainty (maximum error distance)
- Frame of Reference (i.e. datum)

Spatial Uncertainty

- The geographic area encompassing all possible locations for the point



What contributes to uncertainty?

- Locality extent
- GPS accuracy
- Unknown datum
- Imprecision in distance
- Imprecision in direction
- Imprecision in coordinates
- Map scale
- Combinations of the above

SUMMARY CONCEPTS

- ✓ Two basic locational systems: geometric or Cartesian (x, y, z) and geographic or gravitational (f, l, z)

- ✓ Mean sea level surface or geoid is approximated by an ellipsoid to define a horizontal earth datum which gives (f, l) and a vertical datum which gives distance above the geoid (z)

SUMMARY CONCEPTS (CONT.)

- To prepare a map, the earth is first reduced to a globe and then projected onto a flat surface
- Three basic types of map projections:
  - conic
  - cylindrical
  - Planar/azimuthal
- A particular projection is defined by a datum, a projection type and a set of projection parameters

SUMMARY CONCEPTS (CONT.)

- ✓ Standard coordinate systems use particular projections over zones of the earth's surface
- ✓ Types of standard coordinate systems:
  - ✓ UTM
  - ✓ State Plane
  - ✓ Others too numerous to mention
- ✓ Do not confuse the coordinate system of a set of datum for its projection
  - ✓ Example: A shapefile that uses the Texas State Plane Coordinate System is in the Lambert Conformal Conic Projection

WHAT DOES ALL THIS MEAN???

- Careful attention must be paid to the projection, datum and coordinate system for every piece of GIS data used.
- Failure to use data from the same system OR change the data (re-project) it to the desired system will result in overlay errors
  - Can range some small to SIGNIFICANT
  - Real danger is when the errors are small (possibly unnoticed)
- Shapefiles, images, grids all have this data inherent in their very creation.
  - Usually included in a system of files known as "metadata" or xxxxxx.PRJ file.