Unit Two

The Coordinate System of the Earth

What is a Coordinate System?

- A *coordinate* is a number set that denotes a specific location within a reference system.
- Typical coordinates are the *x*-*y* set ([*x*, *y*]), which is used in a two-dimensional system, and the *x*-*y*-*z* set ([*x*, *y*, *z*]), which is used in a three-dimensional system.
- A coordinate system is the reference system upon which coordinates are defined.
- A coordinate system is often structured in a two-dimensional or three-dimensional plane that consists of a set of reference points and rules that define the spatial position of points.

Types of Coordinate System

The two types of coordinate system are:

- ❖ **Geographical Coordinate System**
- ❖ **Cartesian Coordinate system**

1. <u>Geographical Coordinate System</u>

- ✓ A geographic coordinate system is a three-dimensional positional reference that utilizes latitude, longitude, and ellipsoidal height.

- ✓ The geographical coordinate system measures location from only two values, despite the fact that the locations are described for a three-dimensional surface.

- ✓ The two measures used in the geographic coordinate system are called latitude and longitude

Cont’d

- ✓ The values for the points can have the following units of measurement: degrees (0), minutes (‘), and$_0$seconds (") or decimal degree(0)
- ✓ Example DMS = 75 59’ 32.483’’ W
- ✓ equivalent DD = -75.9923564

- ✓ Procedure of converting Degree Minute Seconds (DMS) into Decimal Degrees (DD)

Decimal Degrees = Degrees + ((Minutes / 60) + (Seconds / 3600))

- ✓ NB: degree minute second is always followed by the hemispherical labels of N,S,E or W. when converting to decimal degrees, converting values that are in the western hemisphere or latitude values in the southern hemisphere to negative decimal degree values.

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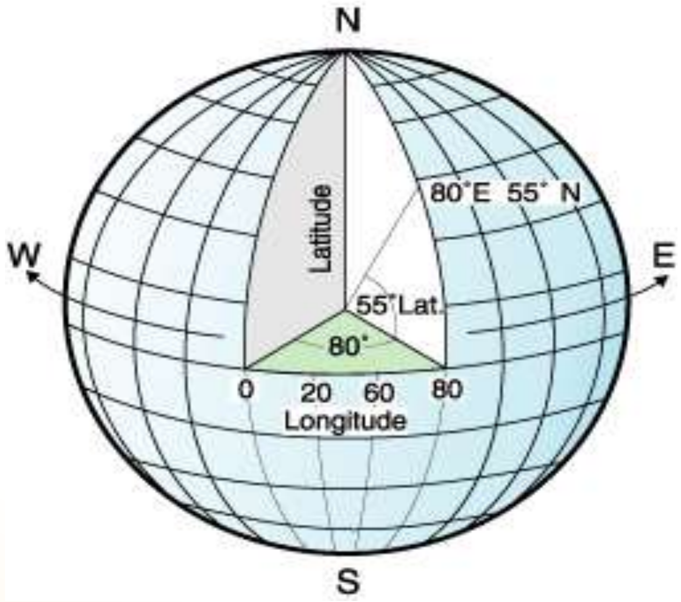
- The *prime meridian* is the line of longitude that defines the origin (zero degrees) for longitude coordinates
- One of the most commonly used prime meridian locations is the line that passes through Greenwich, England.



✓ The Geographical coordinates on the map shows longitude 80 degree East and latitude 55 degree North

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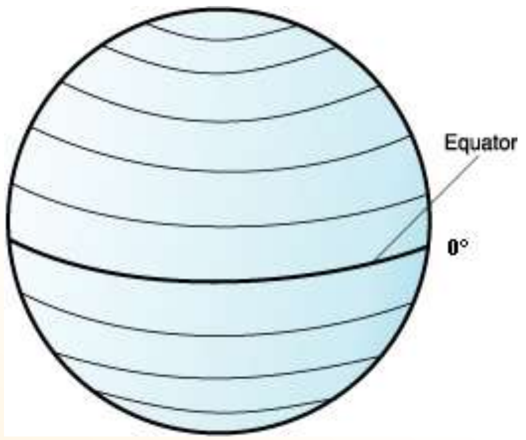
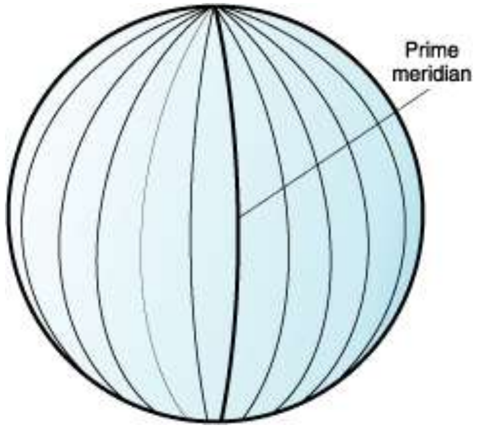
- Locations north of the equator have positive latitudes that range from 0 to +90 degrees, while locations south of the equator have negative latitudes that range from 0 to -90 degrees.



- Locations East of the prime meridian have positive longitudes ranging from 0 to +180 degrees
- Locations west of the prime meridian have negative longitudes ranging from 0 to -180 degrees



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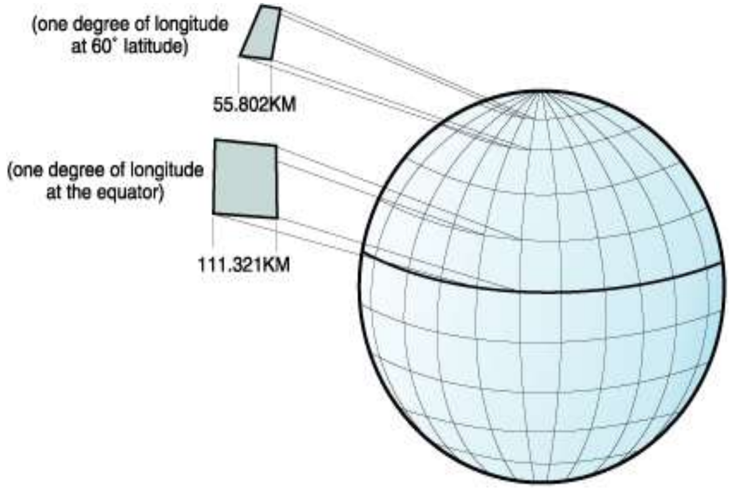
- At the equator, one degree of longitude is approximately 111.321 kilometers, while at 60 degrees of latitude, one degree of longitude is only 55.802 km (this approximation is based on the Clarke 1866 spheroid).
- Coordinate system can be defined by either a ***sphere*** or a ***spheroid*** approximation of the earth's shape.



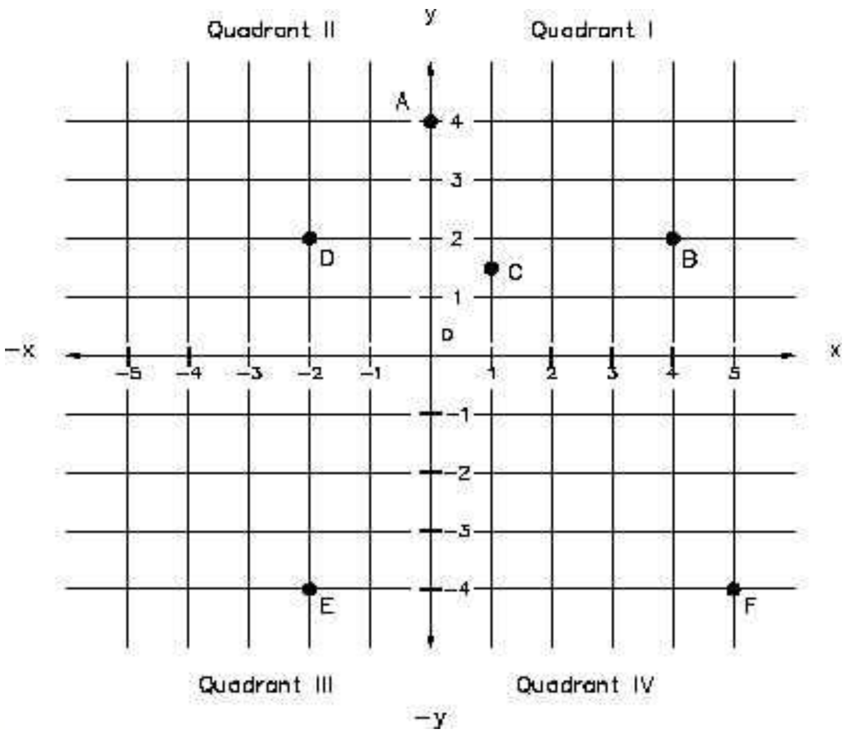
- Because the earth is not perfectly round, a spheroid can help maintain accuracy for a map, depending on the location on the earth.
- A *spheroid* is an ellipsoid that is based on an ellipse, whereas a sphere is based on a circle.

2. Cartesian Coordinate System

- The Cartesian Coordinate System, also known as the ***rectangular coordinate system***, consists of two number scales, called the x-axis (at y = 0) and the y-axis (at x = 0), that are perpendicular to each other.

- Cartesian coordinate system can be divided in to two types namely, Two-dimensional Coordinate System and Three-dimensional Cartesian System

Examples of simple Cartesian coordinate system with quadrant



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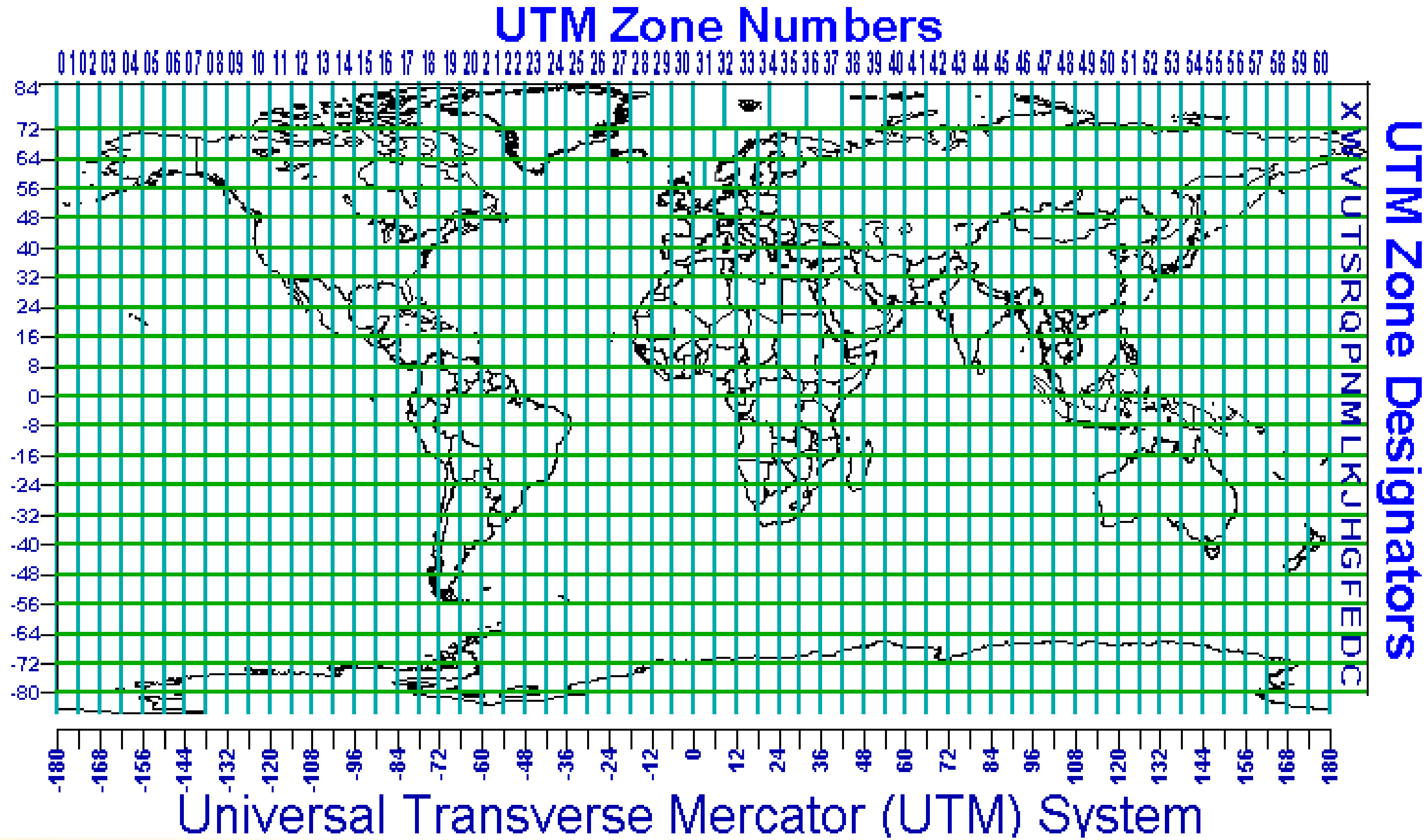
- One of the rectangular systems used to determine the position of an object in the surface of the Earth is the Universal Transverse Mercator (UTM) system.

- The Transverse Mercator projection is used, with the cylinder in 60 positions.

- It creates 60 zones around the world. Positions are measured using ***Eastings*** and ***Northings***, measured in meters, instead of Latitude and Longitude.

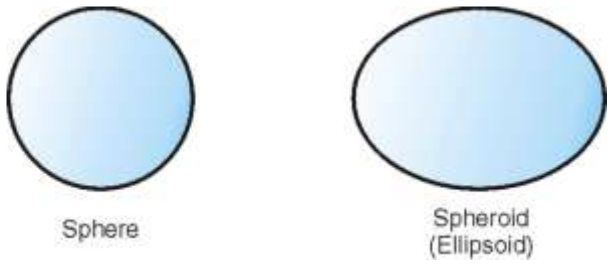
Universal Transverse Mercator Zones



Ellipsoid, Datum and Geoid

Ellipsoid

- A sphere is based on a circle, while a spheroid (or ellipsoid) is based on an ellipse.



- Note that ellipsoid and spheroid are being treated as equivalent and interchangeable words.

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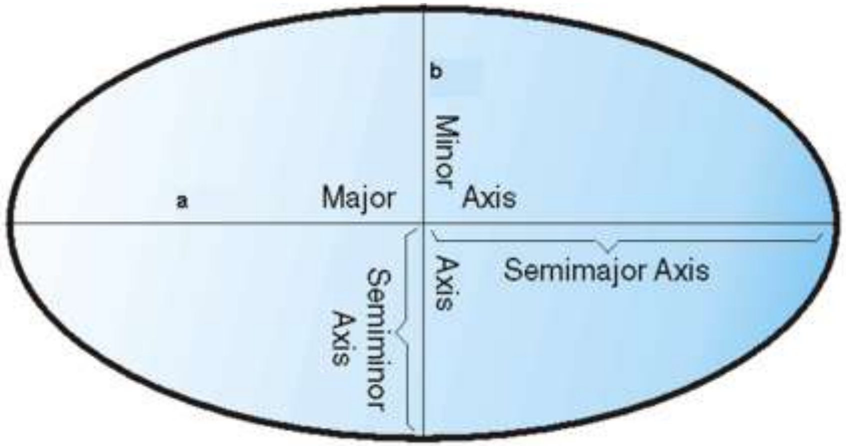
- The shape of an ellipse is defined by two radii. The longer radius is called the semimajor axis, and the shorter radius is called the semiminor axis.

- For the earth, the semimajor axis is the radius from the center of the earth to the equator, while the semiminor axis is the radius from the center of the earth to the pole.



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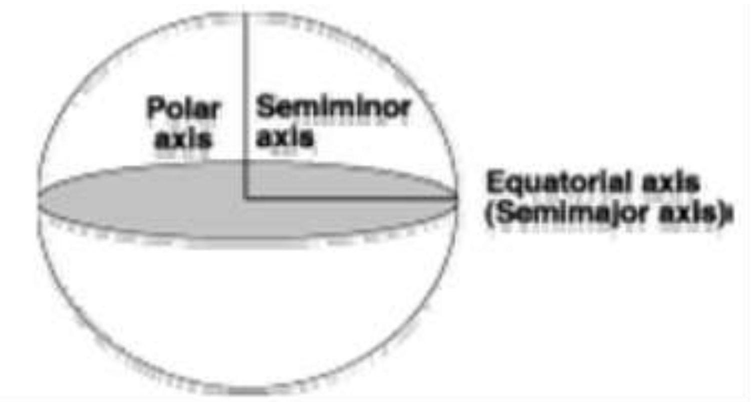
- Rotating the ellipse around the semiminor axis creates a spheroid.
- A spheroid is also known as an oblate ellipsoid of revolution.
- The following graphic shows the semimajor and semiminor axes of a spheroid.



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- A spheroid is defined by either the semimajor axis, a, and the semiminor axis, b, or by a and the flattening.
- The flattening is the difference in length between the two axes expressed as a fraction or a decimal.
- The flattening, f, is derived as follows:

$$f = (a - b) / a$$

- The flattening is a small value, so usually the quantity 1/f is used instead.
- These are the spheroid parameters for the World Geodetic System of 1984 (WGS 1984 or WGS84):

a = 6378137.0 meters

b = 6356752.31424 meters

1/f = 298.257223563

Cont’d

- ✓ The flattening ranges from 0 to 1. A flattening value of 0 means the two axes are equal, resulting in a sphere.
- ✓ The flattening of the earth is approximately 0.003353.
- ✓ Another quantity that, like the flattening, describes the shape of a spheroid is the square of the eccentricity, e2.
- ✓ It is represented by the following:

$$e^2 = \frac{a^2 - b^2}{a^2}$$

Cont’d

- The earth has been surveyed many times to better understand its surface features and their peculiar irregularities.
- The surveys have resulted in many spheroids that represent the earth.
- Generally, a spheroid is chosen to fit one country or a particular area.
- A spheroid that best fits one region is not necessarily the same one that fits another region.
    - Ethiopia uses the local ellipsoids called Clarke 1880.
- Until recently, North American data used a spheroid determined by Clarke in 1866.

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- Because of gravitational and surface feature variations, the earth is neither a perfect sphere nor a perfect spheroid.
- Satellite technology has revealed several elliptical deviations; for example, the South Pole is closer to the equator than the North Pole.
- Satellite-determined spheroids are replacing the older ground-measured spheroids.

Datums

- While a spheroid approximates the shape of the earth, a datum, is a set of values, defines the position of the spheroid relative to the center of the earth.
- Hundreds of different datum have been used to frame position descriptions since the first estimates of the earth's size were made by Aristotle.
- A datum provides a frame of reference for measuring locations on the surface of the earth.
- It defines the origin and orientation of latitude and longitude lines.
- Whenever you change the datum, or more correctly, the geographic coordinate system, the coordinate values of your data will change.

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- ❐ Here are the coordinates in degrees/minutes/seconds (DMS) of a control point in Redlands, California, on the North American Datum of 1983 (NAD 1983 or NAD83):
- ✓ 34 01 43.77884 -117 12 57.75961
- ❑ Here's the same point on the North American Datum of 1927 (NAD 1927 or NAD27):
- ✓ 34 01 43.72995 -117 12 54.61539
- ❑ The longitude value differs by approximately 3 seconds, while the latitude value differs by about 0.05 seconds.

Cont’d

Datum can be

a) Geocentric(global) datums
b) Local datums

a. Geocentric(global) datums

- ✓ In the last 15 years, satellite data has provided geodesists with new measurements to define the best earth-fitting spheroid, which relates coordinates to the earth's center of mass.
- ✓ An earth-centered,or geocentric datum uses the earth's center of mass as the origin.
- ✓ The most recently developed and widely used datum is WGS 1984.
- ✓ It serves as the framework for locational measurement worldwide.

b. Local datums

- A local datum aligns its spheroid to closely fit the earth's surface in a particular area.

- A point on the surface of the spheroid is matched to a particular position on the surface of the earth.

- This point is known as the origin point of the datum.

- The coordinates of the origin point are fixed, and all other points are calculated from it.

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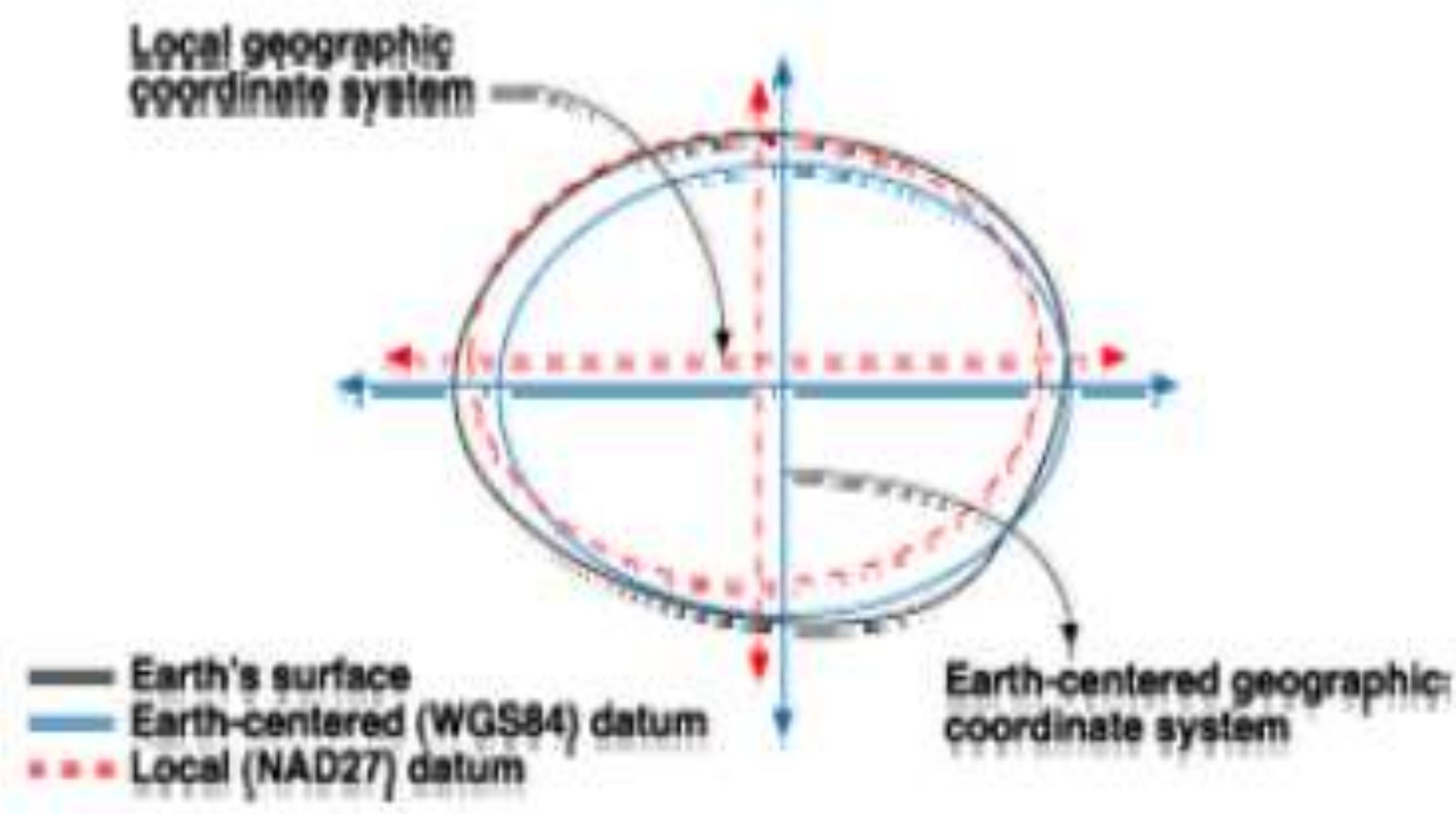
Local geographic
coordinate system
Earth's surface
Earth-centered (WGS84) datum
Local (NAD27) datum
Earth-centered geographic
coordinate system

Cont’d

- The coordinate system origin of a local datum is not at the center of the earth.
- The center of the spheroid of a local datum is offset from the earth's center.
- For example Ethiopia uses the local Datum Adindan, United States uses the North American Datum(NAD 1927), in Japan the Tokyo Datum, in some European countries the European Datum of 1950 (ED 1950), in Germany the Potsdam Datum and the global datum World Geodetic System 84 (WGS 84)
- Because a local datum aligns its spheroid so closely to a particular area on the earth's surface, it's not suitable for use outside the area for which it was designed.

Cont’d

- Datum can be two types: **Horizontal Datum** and **Vertical Datum**.

1. Vertical Datum

- It is defined as a natural reference surface of the land surface. It fits the mean sea level surface through out the area of interest & provides the surface to which height ground control measurements are referred

- Examples are the National Geodetic Vertical Datum of 1929 (NGVD29) based on sea-level measurements and leveling networks and the North American Vertical Datum of 1988 (NAVD88) based on gravity measurements.

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- **Vertical datum is used to fix a position, in a vertical direction up and down, in the Z values.**
- **Vertical datum is a line, value or a set of value from which height are measured.**

2. *Horizontal datum*

- **Horizontal Datum defines the relationship between the physical earth and horizontal coordinates such as latitude and longitude.**
- **Examples of horizontal datum include the North American Datum of 1927 (NAD27) and the European Datum 1950 (ED50)**
- Horizontal datum is used to fix a position, in a horizontal X and Y direction.
- It is also referred as geodetic datum or reference datum.

Geoid

- The geoid is defined as the surface of the earth's gravity field, which is approximately the same as mean sea level.

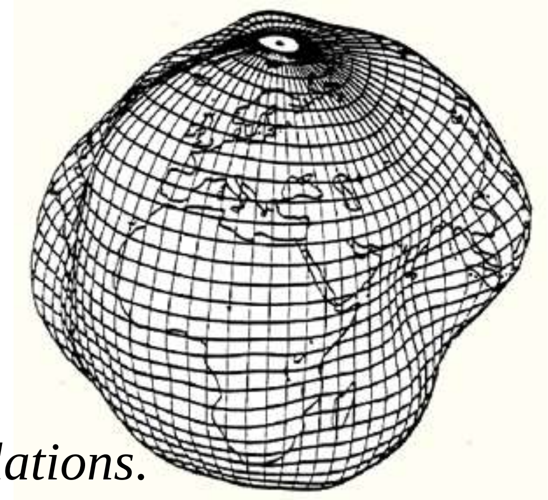
- It is perpendicular to the direction of gravity pull. Since the mass of the earth is not uniform at all points, and the direction of gravity changes, the shape of the geoid is irregular.

Geoid

- The earth's surface is not uniform. Only a part of it, the oceans, can be treated as reasonably uniform.

- The surface or topography of the land masses show large vertical variations between mountains and valleys which make it impossible to approximate the shape of the earth with any reasonably simple mathematical model.

- The zero surfaces to which elevations or heights are referred is called a **vertical datum.**



Perspective view of the Geoid or Geoid undulations.

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- **The mean sea level (MSL) then is defined as the zero elevation for a local or regional area.**

- **Geoid is the *true zero surface for measuring elevations.***

- **For practical purposes, we assume that at the coastline the geoid and the MSL surfaces are essentially the same.**

- **Nevertheless, as we move inland we measure heights relative to the zero height at the coast, which in effect means relative to mean sea level (MSL).**

Reference Surfaces

- The physical surface of the Earth is **complex shape** and in order to represent it on plane, it is necessary to move from the **physical surfaces** to a **mathematical one**.

- In mapping **three different surfaces** are used:

  1. A **geometric** or **mathematical** or **Topographic reference surface**
  2. The **ellipsoid or spheroid**, for **measuring locations**
  3. **Geoid reference or Vertical datum**: **for measuring heights**

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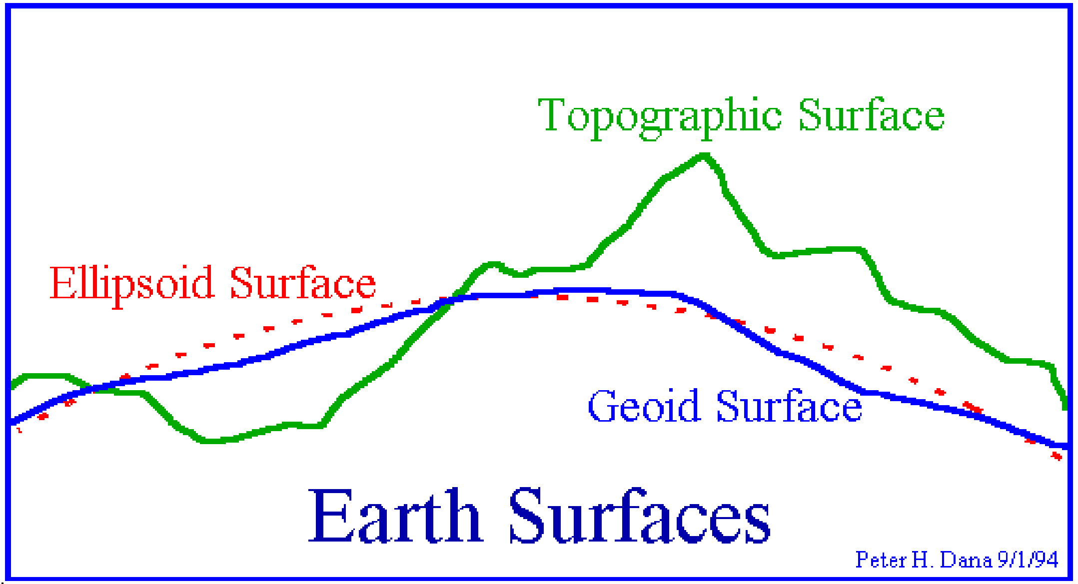
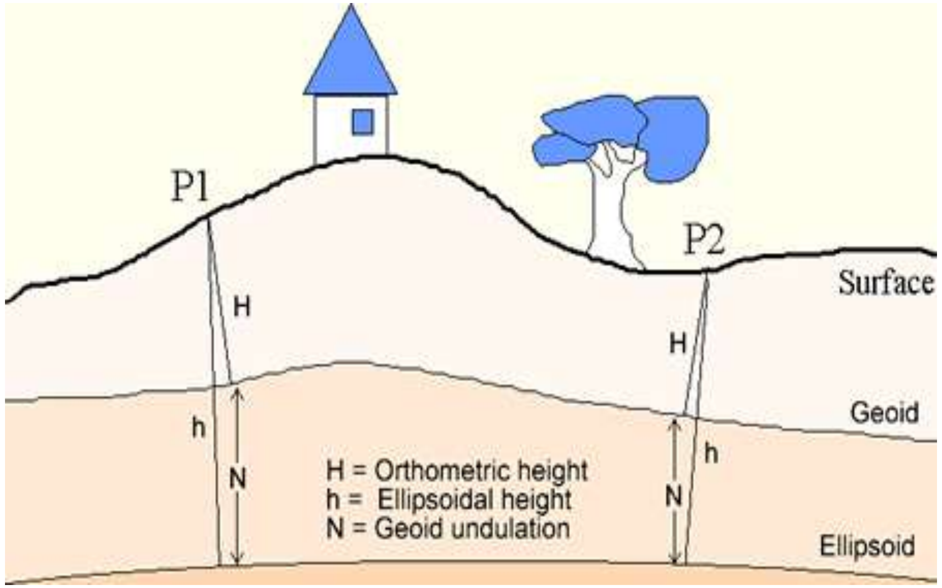
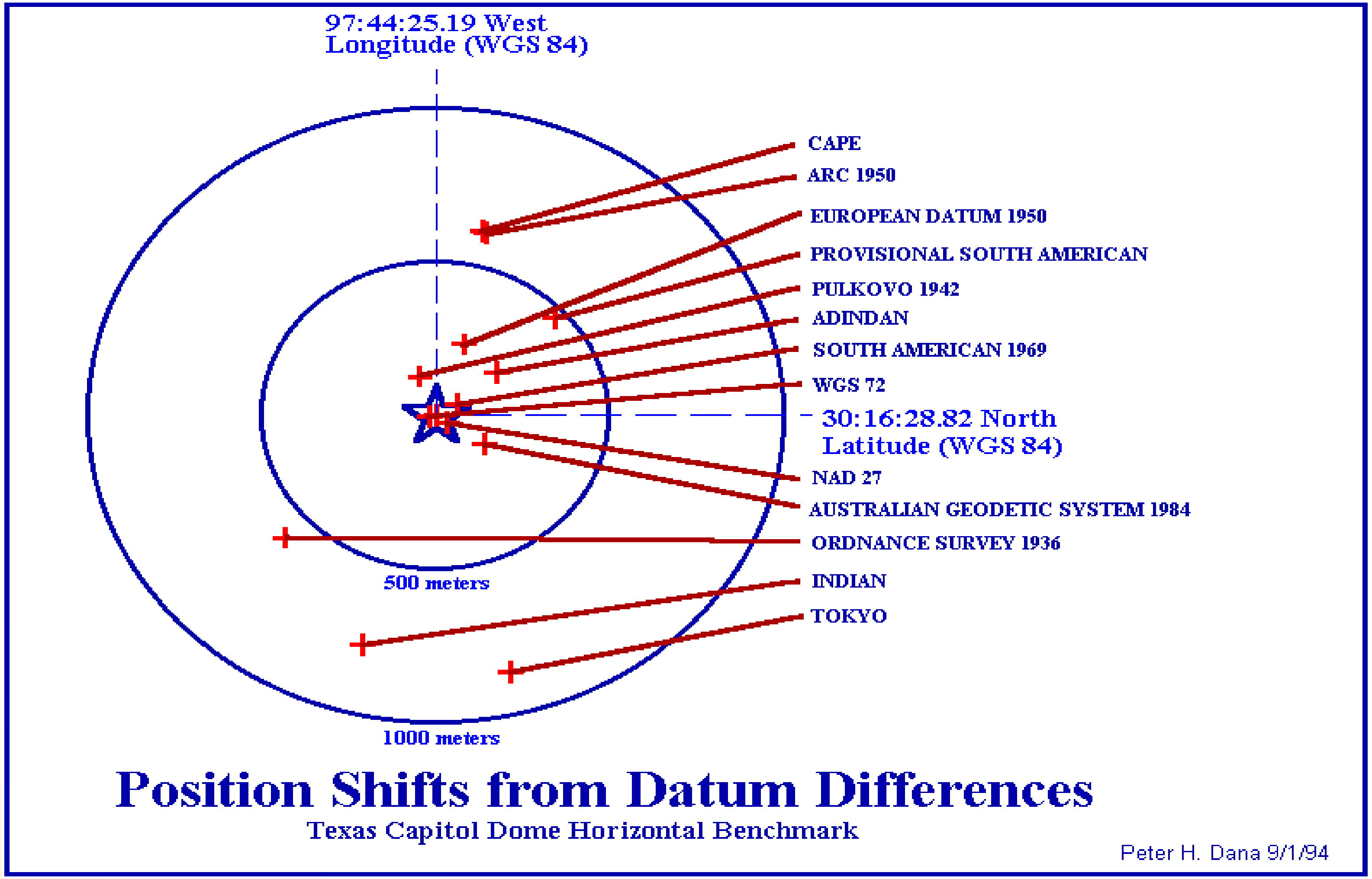




- ✓ The topography - the physical surface of the earth.
- ✓ The Geoid - the level surface (also a physical reality).
- ✓ The Ellipsoid - the mathematical surface for computations of locations

Position shifts using different datums



Grid and Graticule, Grid Reference

- Graticules are always expressed in geographic coordinates (latitude and longitude) while grids are expressed in the native X and Y coordinates of the coordinate system of the component.
- The graticule represents the projected positions of selected meridians (lines with constant longitude (λ) and parallels (lines with constant latitude (ϕ)).
- In other words, the imaginary network of parallels and meridians on the earth is known as graticule.

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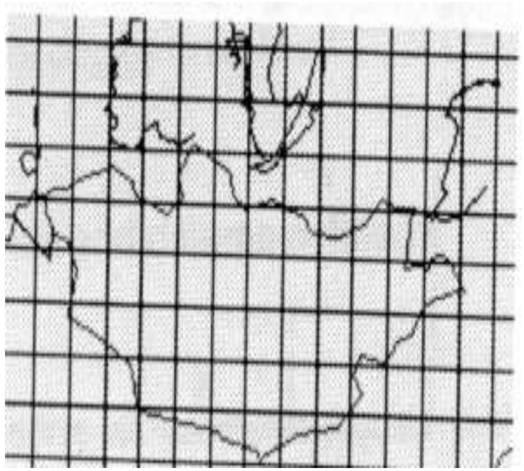
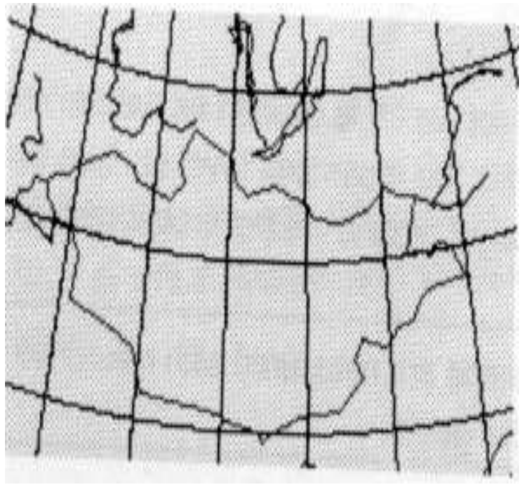
- The interval used for graticules are in ***Degrees***, ***Minutes***, and ***Seconds***



Grid System



Graticule System

Graticules

- The imaginary network of the lines of Meridians and Parallels upon which the map is drawn

Parallels:

- Are Imaginary lines drawn and run East-West direction, parallel to the equator and parallel to one another @ right angles to the meridians

- These are numbered in degrees North and South from the equator, which is given a value 0^0 with the maximum value 90^0 assigned to each pole – Parallels increasingly become smaller and smaller (so that Small Circle) closer towards the pole

- Parallels are used to define locations of points in the North-South direction – in terms of distance measured as an angle from the earth's center (Equator)

- These are also called **Lines of Latitudes –** defined as the measure of distance in degree North and South of the equator – or the angular distance from the equator

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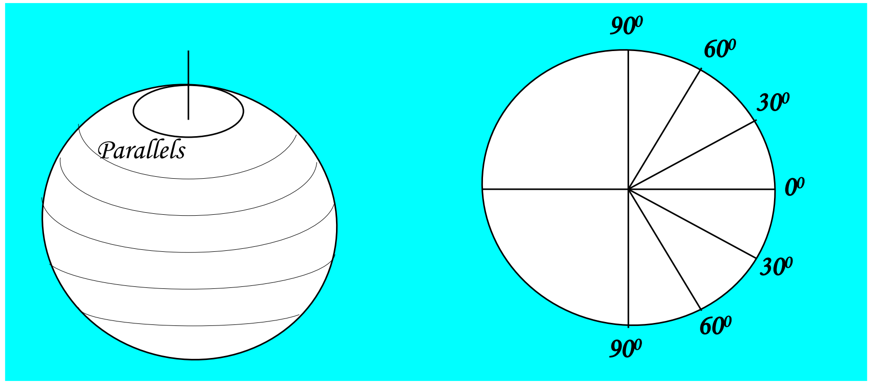
- Imaginary line drawn parallel to equator at 23 ½ ^{0} north is called Tropic of Cancer and line drawn 23 ½ ^{0} south is called Tropic of Capricorn.



Great Circle:

- ✓ Which is the Equator, located midway between the poles
- ✓ Is the line defined by the intersection of the plane with the earth’s surface, by visualizing a plane passing through the center of the earth

Meridians:

- Are each half of a Great Circle (Arc of the Great circle) that pass through and join the poles @ right angles to the parallels

- Imaginary lines drawn in North-South direction, since the distance North or South of the Equator is not enough to locate a point in space

- Meridians are farthest apart @ the Equator and come closer and closer together as latitude increases and totally converge @ the North and South poles
- Unlike parallels of latitude, all meridians are of the same length

- Since all the meridians are identical, one must be selected as a starting point called **Prime meridian** – The Prime Meridian is an arbitrary line and the starting point for East-West measurement

Cont’d

- ✓ Most maps use the Greenwich England as the Prime Meridian – which is an imaginary line passing through the Royal Observatory @ Greenwich – selected as 0^0 longitude

- ✓ The Prime Meridian given a value of $0^0$and remaining meridians are numbered in degrees east or west of the prime meridian

- ✓ This gives the values of Longitudes – defined as the angular distance East or West of a prime meridian and changes in East-West direction

- ✓ East-West measurements range from 0^0 to 180^0 from meridian to 180^{th} meridian in each direction on the opposite side of the Prime Meridian

- ✓ Like parallels of latitude, degrees of longitude can be subdivided into minutes and seconds – However, distance between adjacent degrees of longitude decreases away from the equator because the meridians converge @ poles

- ✓ **Time** depends on longitude – The earth, which makes a complete 360^0 rotation once 24 hours, is divided into 24 time zones roughly centered on meridians @ 15^0 interval – Greenwich Mean Time (GMT) is the time @ the Prime Meridian

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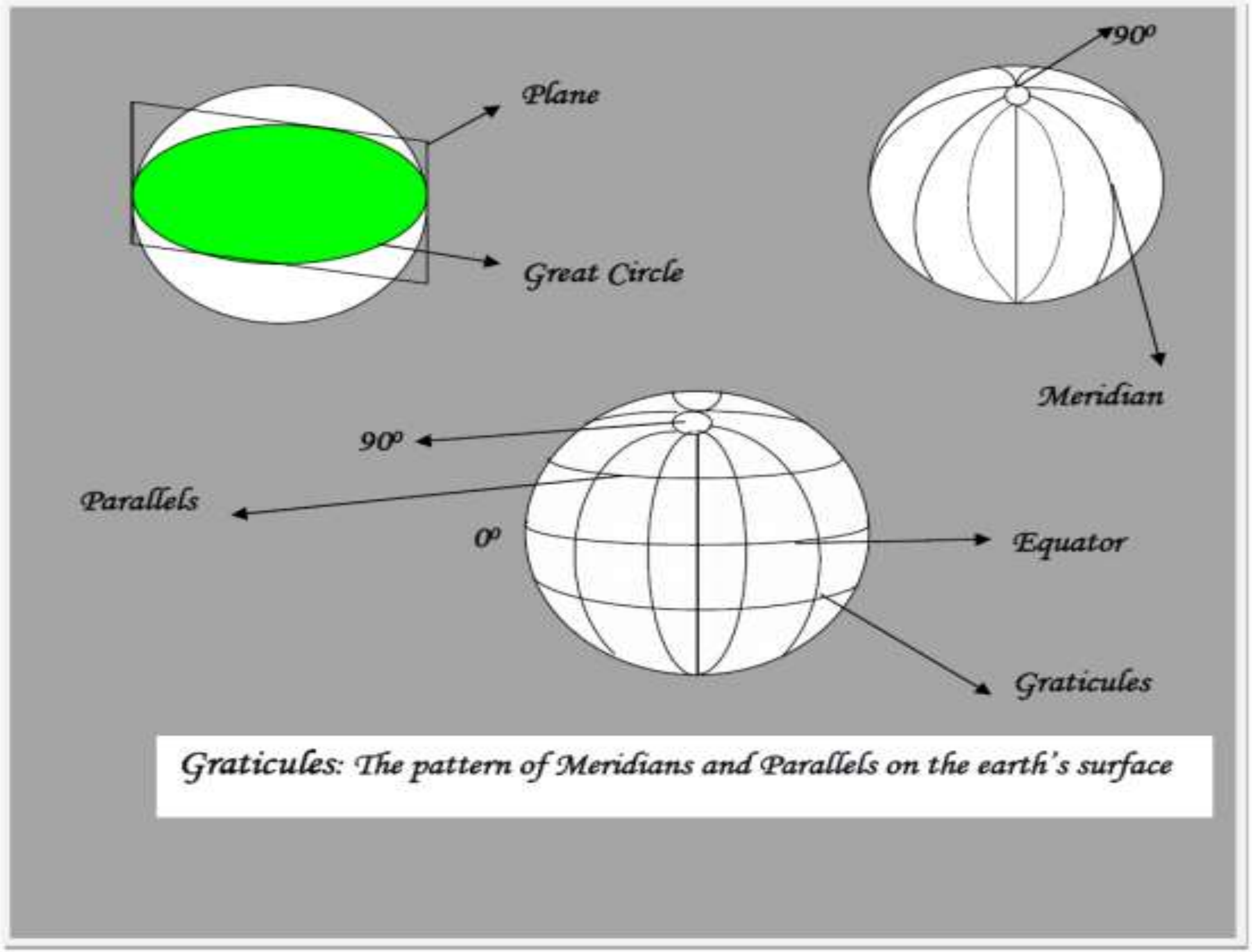
Plane
Great Circle
90⁰
Meridian
90⁰
Parallels
0⁰
Equator
Graticules
Graticules: The pattern of Meridians and Parallels on the earth’s surface

Cont’d

- *Characteristics of Graticules :*

- *Meridians are arcs of the great circle that meet @ the poles*
- *The Equator is a Great circle, located midway between the poles – Parallels (Lines of Latitude) are concentric small circles that are parallel to the equator*
  - *Parallels are true East-West lines*
  - *Parallels are equally spaced between the equator and poles*
  - *Parallels are always parallel to one another, so that any two parallels are always the same distance apart*
  - *Meridians are spaced farthest apart on the equator and converge to a single point at the poles*
  - *Parallels and Meridians cross one another at right angles*

The Grid Reference

- A Grid is an object that stores spatial data in a locational data format in which space is partitioned in a square cells with grid lines intersecting each other at right angles and numbered sequentially from the origin at the bottom left of the map.
- Grid Reference define locations on maps using Cartesian coordinates.
- Grid lines on a maps define the coordinate system, and are numbered to provide a unique reference to features.
- The north-south lines are called eastings and the east-west lines are called northings.
- When any reference point is given on the map, always take the easting number first and then the northing second.

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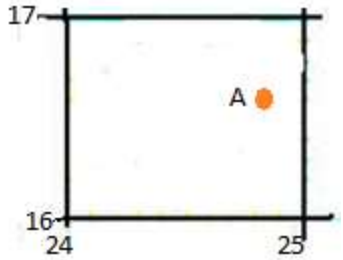
- In a 6 digit grid reference 123456, the Easting component is 123 and the Northing component is 456.

- Example, the square containing **point labeled A**, the normal kilometer reference is 2416. This is the four figure grid reference.



- Grids may be arbitrary, or can be based on specific distances, for example some maps use a one kilometer square grid spacing.

- A grid reference locates a unique square region on the map.
- The precision of location varies, for example a simple town plan may use a simple grid system with single letters for Eastings and single numbers for Northings. A grid reference in this system, such as 'H3', locates a particular square rather than a single point.

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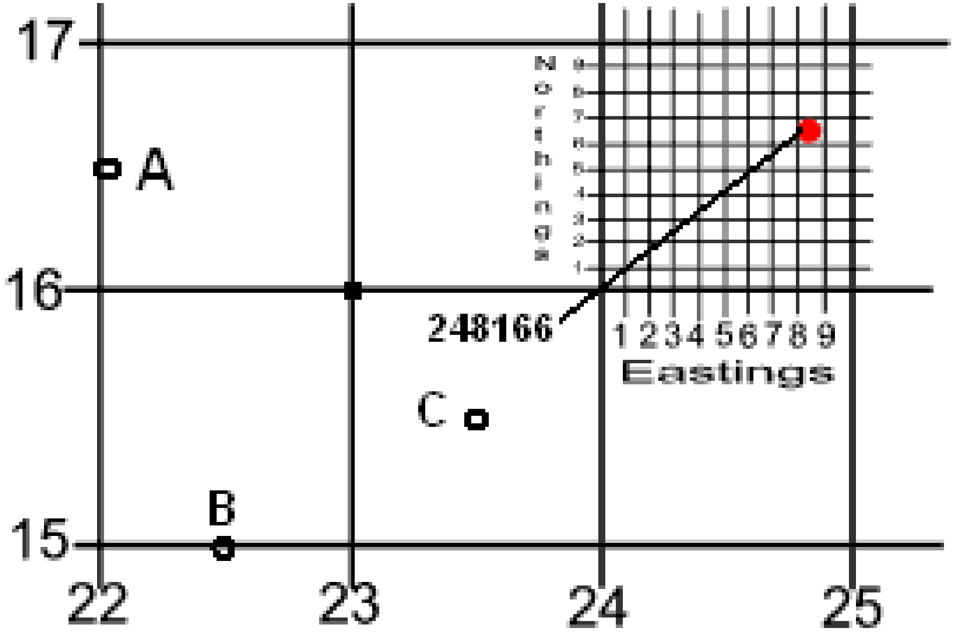
- The more digits added to a grid reference, the more precise the reference becomes.
- To locate a point in the previous figure, a further two digits are added to the four-digit reference to create a six-digit reference.
- The extra two digits describe a position within the 1-kilometre square. Imagine a further 10x10 grid within the current grid square.
- Any of the 100 squares in the superimposed 10×10 grid can be accurately described using a digit from 0 to 9 (with 0 0 being the bottom left square and 9 9 being the top right square).

Steps to assign a Normal National Grid Reference

1. Always refer to the south-west corner of the square in which the point lies (if it lies on a printed line, follow this line until the south-west corner is reached).
2. Write down the tens and units of the *Eastings* printed on the line running vertically through the corner.
3. Estimate the tenths eastward by dividing the square vertically in to ten parts, and add the figure to the previous one.
4. Write down tens and units of the *northing* printed on the line running horizontally through the corner.
5. Estimate the tenths north ward by dividing the square horizontally in to ten parts, and add the figure to the previous one.
6. Combine these two groups of figures. Always write the easting before the northing.

Example



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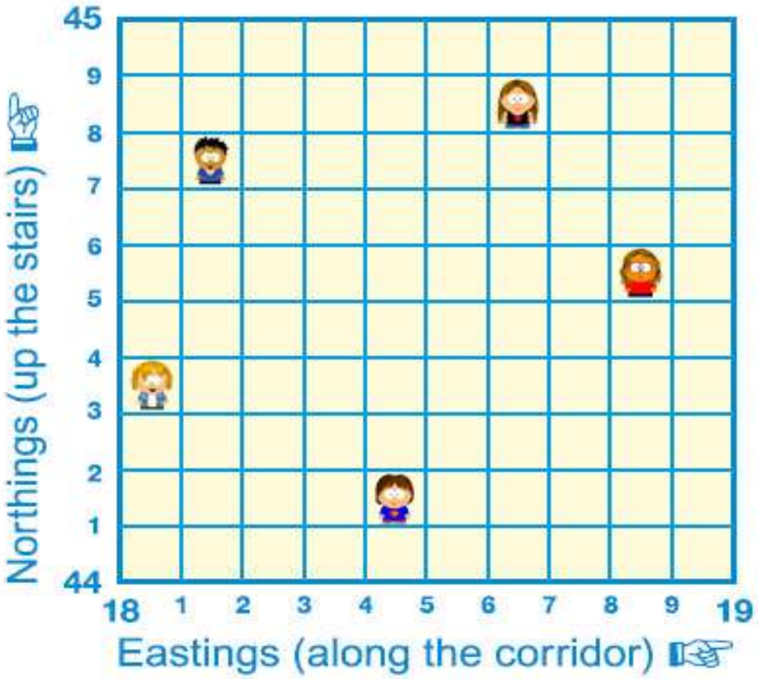
- In the Universal Transverse Mercator (UTM) system, grid reference is given by three numbers: zone, easting and northing. In the UTM system, the earth is divided into 60 zones.
- Northing values are given by the metres north, or south (in the southern hemisphere) of the equator.
- Easting values are established as the distance from the central meridian of a zone.
- The central meridian is arbitrarily set at 500,000 metres, to avoid negative numbers.
- A position 100 kilometres west of a central meridian would have an easting of 400,000 metres.
- Due to its popularity, and worldwide cover, the UTM system is used worldwide by many countries, including Australia and the USA.

Activity: Find the NNGR of the five points?



THE END OF THE UNIT