Contents of Digital Mapping Course for 2022-2023 Academic Year

By: Asst.Prof.Dr. Dleen M. S. Al-Shrafany

References recommended for this course :

1- Iliffe, J.C. 2003 "Datums and Map Projections for Remote Sensing, GIS and Surveying"; London, UK.

2- Peterson, G.N. 2009 "GIS Cartography, a guide to Effective Map Design"; USA.

Course Structure

- **Lecture**

Two-hours period lecture per week, students are encouraged to take careful notes based on lectures. These should include noting maps referenced in class, key concepts and definitions, core concepts related to maps, geography data, map interpretation, and map making technologies

- **Lab**

The lab exercises are aimed at reinforcing core concepts, themes, and skills introduced through the lectures and readings.

Students will engage in hands on experiences that involve:

1- analysis of web-maps,

2- use of web-tools to learn concepts related to digital mapping,

3- organizing and visualizing spatial information.

Students will also complete:

1- computer based assessments,

2- lab reports, and

3- web maps during their lab sections.

- Labs will be implemented by the graduate research assistants involved in the instruction of this course.

- Each lab will begin with a brief explanation of the lab assignment by the TA, including an overview of the learning objectives and materials, The remaining portion of the lab will devoted to completing the lab assignment.

Part I: Foundations

1- History and overview of Maps

- definitions
- coordinates and datums
- key concepts of maps

2- Coordinate Systems

- spherical coordinates
- spheroidal coordinates
- cartesian coordinate

3- Global, regional and local datums

- global datums
- regional and local datums

Part II: Map Projections

1- Aspects of datum transformations

- knowledge of separation, N
- knowledge of height, H
- knowledge of datum transformation parameters
- review questions

2- Fundamentals of map projections

- grids of map
- Scale factor
- development surfaces
- computational aspects
- designing a projection
- review questions

3- Direct transformations

- compatibility of coordinate systems
- ground control
- plan transformations
- unknown projections : measuring from maps
- review questions

Part III: Digital Mapping-based Systems

1- Global Positioning System (GPS)

- system overview
- positioning with codes
- differential GPS using codes
- GPS phase measurements

2- Geographic Information Systems (GIS)

- Introduction
- equipment for GIS
- data and data entry
- Alternative data structures
- data for GIS
- vector data

- raster data
- conversion between raster and vector data
- relationship between remotely sensed data and GIS
- modelling spatial processes with GIS
- web-based GIS
- Map production by GIS
- review questions

Digital Mapping Course- Lec.1

Lecture is focusing on:

1- History and overview maps

- key concept of maps
- coordinates and datums

2- Coordinate systems

- spherical coordinates
- spheroidal coordinates
- cartesian coordinates

Why Digital Mapping ?

The reasons for adopting digital mapping techniques vary widely. But there are certain objectives which are shared:

- **The first** is the desire to speed up the process of map production so as to shorten the period between the initial data collection in the field and the availability of the resulting map in digital or hard-copy form to be used by engineers and planners.
- It must be noted that the development of automated computer-based techniques for mapping is also a response to the vastly increased rates of survey data collection.

For example; the development and adoption of electronic theodolites, distance-measuring equipment for field survey and the development of electronic positioning systems.

Why Digital Mapping ?

- **The second** is the desire to reduce or even eliminate much of the tedious yet demanding cartographic work, such as compilation, scribing, mask-cutting, lettering and symbol generation, which requires highly skilled personal who are difficult to find.
- For example; an area of great engineering activity that has a very large requirement for maps is the industry concerned with water, gas, electricity , telephone, and sewerage services (public utilities). Such a project their networks of pipelines and cables are numerous, widespread and very complicated in structure, and their exact location and function need to be known for planning, operational and maintenance purposes.
- Much of this data needs to be recorded and displayed on maps and kept up to date for management purposes. And these kind of maps need to be revised continually.

Why Digital Mapping ?

- **The Third** is the reduction in the cost of map and plan production. In practice, this has been very much harder to achieve than the increased speed of map production.

- The costs of purchasing, installing, operating and maintaining computer-based mapping equipment have fallen, but are still quite high, especially if high accuracy is required.

- Furthermore, highly trained (and expensive) specialist personal capable of operating, programming and maintaining need to be acquired within the surveying organization.

- However, the costs will vary greatly from country to another.

The fundamental coordinate system for mapping and surveying is a set of geodetic coordinates related to a particular datum.

In order to arrange the geodetic data in two-dimensional surface:

- The first, and most obvious one, is presentational.
- The second reason for rearranging the geodetic coordinates in two dimensions is computational.

Coordinates and Datums

If you consider each of the following statements:

- The height of the point is 3.122 m.
- The height above mean sea level is 10.983 m.
- The latitude is 32° 10' 12.23" .
- The northings of the point are 152345.834.

All of these **express coordinates** with a great deal of precision

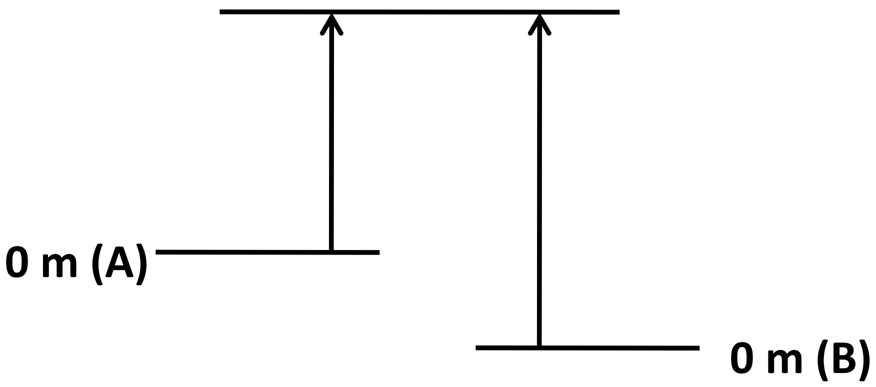
What is a Datum ?

• The expression with reference to **heights**: for example, in the statement 'this point is 3.2 m above the datum'

for example, an engineer is interested only in the relative heights of points within a construction project, and not in their relationship to the outside world,

then it will be acceptable to designate one point as having an arbitrary height - 100 m for example - and finding the heights of all others with respect to this.

“**Datum** “has established the position of the **origin** of the coordinate system.



A point with different heights in datum A and B

- Geodesists and surveyors use datums to create **starting** or **reference** points for maps, property boundaries, construction surveys, or other work requiring accurate coordinates that are consistent with one another.

- There are two main datums over the world:

1- Horizontal datums: measure positions (latitude and longitude) on the surface of the Earth,

2- vertical datums: are used to measure land elevations and water depths.

Horizontal Datum

- The horizontal datum can be accessed and used through a collection of specific points on the Earth whose latitude and longitude have been accurately determined by NOAA's National Geodetic Survey.

- One application of the horizontal datum is monitoring the movement of the Earth's crust.

- This type of monitoring is often used in places like the San Andreas Fault in California where many earthquakes occur.

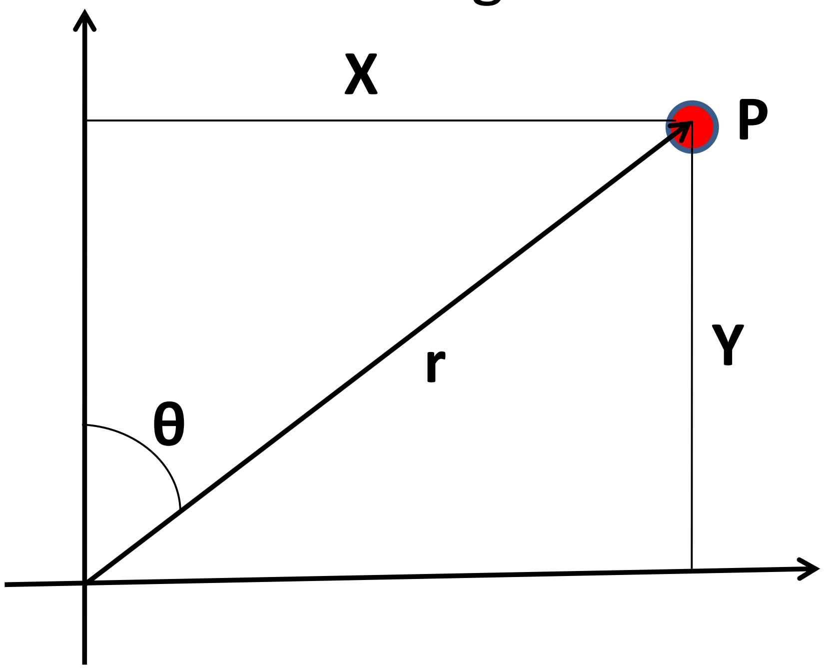
Vertical Datum

- The vertical datum is similarly "realized" through a collection of specific points on the Earth with known heights either above or below a nationally defined reference surface (e.g., mean sea level).

- Geodetic vertical datums are generally used to express land elevations.

- However, water level datums are a slightly different vertical datum, and are used as a reference level to which bathymetric soundings are referenced for nautical charts.

- It is possible to express the coordinates in a different way. A useful example of this is the two-dimensional coordinate system shown in Fig.



In this example, the coordinates of the point P may be quoted in either the rectangular form **(X, Y)** or the polar form **(r, θ)**: the point is that changing from one to the other is a relatively straightforward procedure that does not involve changing the point of origin, and does not imply a change of datum.

Coordinates System

The coordinates of spatial data may be expressed as

- a three-dimensional system as in cartesian and curvilinear form,
- two-dimensional in a map projection or a locally defined system,
- one dimensional coordinates for expressing height.

In order to follow the definitions of the systems used, it is first necessary to consider the **shape** and **size** of the Earth.

1- Spherical Coordinates

The first approximation that can be made to the shape and size of the Earth is that

- a **sphere** of radius **6371** km.

Three-dimensional spherical coordinates defined with respect to this shape

- *latitude: the angle north or south from the equatorial plane, ϑ*
- *longitude: the angle east or west from the Greenwich meridian, λ*
- *height: a distance in meters above (or below) the sphere, h.*

Spherical Coordinates

- The equator is the circle that bisects the two earth's Poles.

- The Greenwich meridian is a particular meridian that considered as a reference value.

The convention of using Greenwich is now universal.

- The determination of the longitude with respect to the Greenwich meridian could only be carried out with a precision equivalent to the establishment of Greenwich Mean Time (GMT) at the site of the datum.

Spherical Coordinates

1 s second error in the determination of time would translate to a 15 arc second rotation of the datum.

It is useful to define the following terms:

• *parallels of latitude: lines of equal latitude on the surface of the sphere*
• *meridians: lines of equal longitude.*

For many applications that do not require the highest accuracy such as small scale mapping purposes,

the **sphere** is an adequate representation of the Earth.

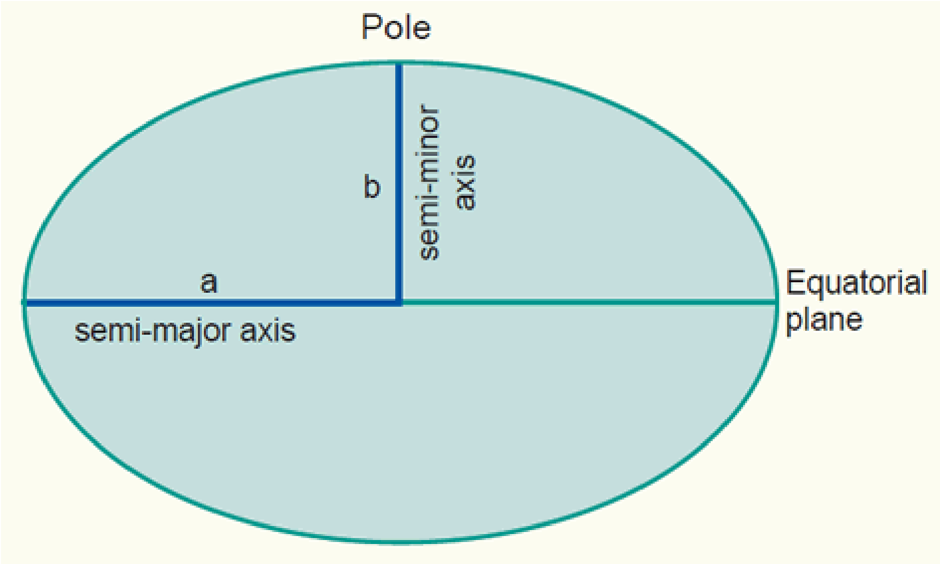
2- Spheroidal Coordinates

An ***ellipsoid*** *or* ***spheroid*** is a better approximation to the shape of the Earth.

• This surface is formed by an ellipse which has been rotated about its shortest (minor) axis, or by 'squashing' a sphere at the poles.

A spheroid is defined by the size of two parameters :

• the *semi-major axis, a*
• the *semi-minor axis, b.*



Spheroidal coordinates

From these two parameters, it is possible to define the shape of spheroid through derive

Flattening (f) *which is defined as*

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

The spheroid may also be defined by its semi-major axis *a* and ***eccentricity (e)*** which is given by:

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

(e) is define as a measure of the non-circularity of an elliptical orbit.

Spheroidal coordinates

Furthermore, (e, *f* and b) can be related to each other as follows:

$$e^2 = 2f - f^2 \quad ; \quad \sqrt{1 - e^2} = (1 - f) = \frac{b}{a}$$

Thus, a spheroid can be completely defined using two parameters either

- (*a and b), or (a and f), or (a and e),*

and the remaining parameters can be found as necessary.

A typical value for those parameters would be:

a= 6378 137 m and, ***f*** = 1/298.

Spheroidal coordinates

- *(latitude, longitude and height)* are also the set of coordinates that could be defined with respect to the spheroid.

- Coordinates defined in this way are known as *geodetic coordinates, and are the* basis for all mapping systems.

- It is possible to carry out computations in a spheroidal coordinate system, particularly in the region close to its surface.

- The definition of boundaries between states is an example of the areas where computations are needed in geodetic coordinates.

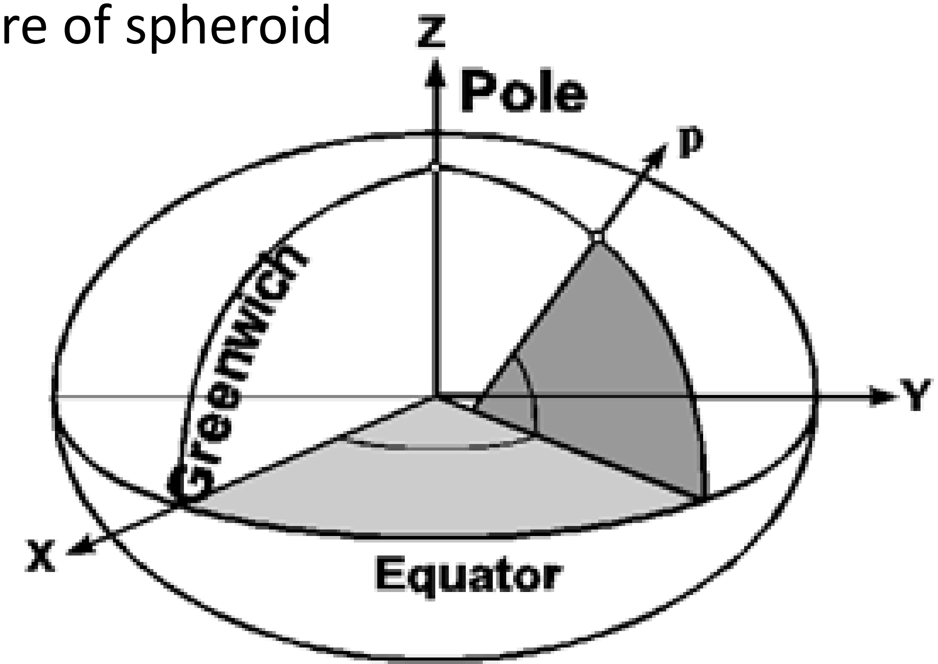
3- Cartesian coordinates

- The formulae involved in computations based on geodetic coordinates are complicated, and entirely inappropriate when considering observations made to satellites.

- Thus, an alternative set of coordinates defining 3-D position on the surface, known as **Cartesian coordinates *(X, Y, Z).***

- This system is called also as "**geocentric coordinates**",

because it has its origin at the centre of spheroid



Cartesian coordinates

- The Z axis is aligned with the minor axis of the spheroid (the 'polar' axis);
- the X axis is in the equatorial plane and aligned with the Greenwich meridian; the Y axis forms a right-handed system.
- Geodetic coordinates may be transformed to cartesian coordinates by a set of formula:

$$X = (v + h) \cos\Phi \cos\lambda$$

$$Y = (v + h) \cos\Phi \sin\lambda$$

$$Z = \{(1- e2) v + h\} \sin\Phi$$

Where,

$$v = \frac{a}{(1 - e^2 \sin^2 \emptyset)^{1/2}}$$

Cartesian coordinates

- The reverse computation, in which geodetic coordinates are found from cartesian ones, is also possible:

$$\tan \lambda = \frac{Y}{X}$$

$$\tan \phi = \frac{Z + \varepsilon b sin^3 u}{p - e^2 a\, cos^3 u}$$

$$h = (X^2 + Y^2)^{1/2}\, sec\phi - v$$

Where,

$$p = (X^2 + Y^2)^{1/2} \quad ; \quad \tan u = \frac{Za}{pb} \quad ; \quad \varepsilon = \frac{e^2}{1 - e^2}$$

Digital Mapping Course- Lec.2

Lecture will focusing on:

1- Two and Three dimensional coordinate systems

- spherical coordinates
- spheroidal coordinates
- cartesian coordinates

2- Global, regional and local datums

- global datums
- regional and local datums

Global Datums

On a **global** basis, the most appropriate version of spheroid is one that :

- has its origin at the center of mass of the earth (*geocentric*).
- Has a shape and size that it is the best possible approximation to the form of geoid.

Therefore, global datum is the basis of a satellite reference system as it is a necessary conditions for computations of satellite obits

- The most recent global datums is the ***World Geodetic System 1984*** (**WGS84**).

- The parameters of WGS84 are defined as:

$a = 6378137 \qquad f = 1/298.257223563$

Global Datums

There are two more parameters relating also:

- gravitational field and
- the rate of rotation.

Therefore, the shape and size of the WGS84 are defined to almost consistent with another commonly used global datum, that ***Geodetic Reference System 1980*** (**GRS80**), which is mainly used in gravitational applications.

- Due to a slight difference in the original terms used for the definition of these two datums,
- there is a difference in their flattening , *that amounts to:*

$$\Delta f = f_{GRS} - f_{WGS84} = 16 \times 10^{-12}$$

Global Datums

- For most practical purposes, this difference can be ignored and the spheroids considered equivalent.

- most users will encounter WGS84 reference system through the use of the GPS.

Another group of satellite datums are those associated with **GLONASS** (**Global Navigation Satellite System**), the Russian equivalent of GPS.

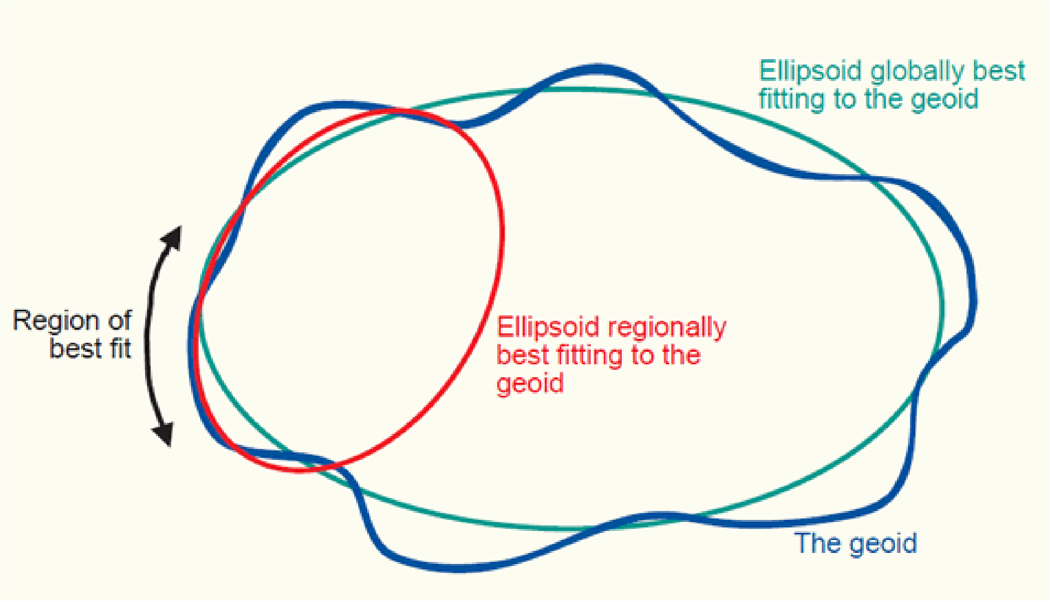
- The datums used for this are the Soviet Geodetic System 1985 (**SGS85**) and its successor SGS90 (introduced in 1995, and alternatively referred to as PZ90

Local and Regional Datums

A local/regional datum is defined by selecting an origin for a national or regional survey.

• fixing the chosen spheroid to the geoid (coincident and parallel) at the point of origin.

• So, at the coincident point the geoid-spheroid separation, *N, and the deviation of the vertical are considered* as zero.



Local and Regional Datums

- The local datum thus, is not geocentric spheroid.

- a local datum approximates the geoid in the region much more closely than does the global datum.

- Each local or regional datum therefore has a point of origin which is offset from the centre of the Earth.

- The size of this offset may be as much as 1 km, and usually expressed in components (ΔX, ΔY, ΔZ).

- Many countries may use the same spheroid, but they are on different datums as they have different points of origin.

Datum Transformation

- It was important to realized that all the **measurement errors** and computational approximations of the original survey, which would usually have been carried out by a process of triangulation using ground survey techniques, has included into the datum.

- errors resulted from the spheroid minor axis rotation is also should be included and considered when carried out transformation from local into global datum.

- The three most applied methods for a datum transformation via the 3-dimensional geocentric coordinates are:

1- the ***geocentric translation***,
2- the ***Helmert 7-parameter*** transformations, and
3- the ***Molodensky-Badekas 10-parameter*** transformation

Datum Transformation

1- The ***geocentric translation***

relates two datum systems through three translations. The method applies a shift between the centers of the two geocentric coordinate systems. This shift is defined by the parameters ΔX, ΔY and ΔZ,

So, coordinates transformation from a local system to WGS84 is given by:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{WGS84} = \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} + \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{local}$$

Datum Transformation

2- the ***Helmert 7-parameter*** transformations

• relates two datum systems through a rotation, an origin shift and a scale factor. The transformation is expressed with seven parameters:

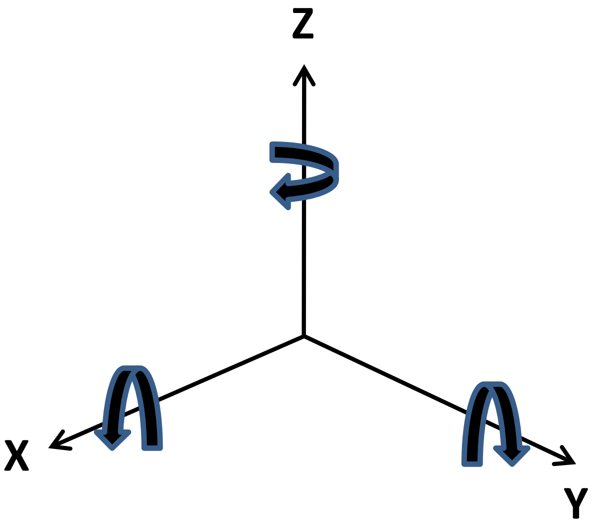
three rotation angles (α1, α2, α3), three origin shifts (ΔX, ΔY and ΔZ) and one scale factor (μ).

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{WGS84} = \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} + \mu R \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{local}$$

Where, μ is the scale factor between the two systems and R is a rotation matrix

Datum Transformation

Which for small angles α1, α2, α3 about the X, Y, Z axes.



- The ***Helmert 7-parameter*** transformation is considered to be reversible, i.e. the same parameter values can be used to execute the reverse transformation.

- Thus, the reverse parameters can be applied to transform from WGS84 to local datum.

Datum Transformation

3- The ***Molodensky-Badekas 10-parameter*** transformation

- relates two datum systems through a rotation, an origin shift and a scale factor.

- This is the same as for the Helmert transformation methods, but instead of deriving the rotations about the origin of the geocentric coordinate system, they are derived at a location within the points used in the determination of the parameters.

- Three additional parameters, the coordinates of the rotation point (*Xp*,*Yp*,*Zp*), are then required.

Datum Transformation

The transformation is therefore expressed with **10** parameters:

- three rotation angles ($\alpha1$, $\alpha2$, $\alpha3$),
- three origin shifts (ΔX, ΔY and ΔZ),
- one scale factor (μ), and
- the coordinates of the rotation point (*Xp*,*Yp*,*Zp*) given in the source geocentric coordinate system.

- Compared to the Helmert transformation, the Molodensky-badekas provides usually a better approximation, but the transformation is not reversible.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{WGS84} = \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} + \begin{pmatrix} X_p \\ Y_p \\ Z_p \end{pmatrix} + \mu R \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{local}$$

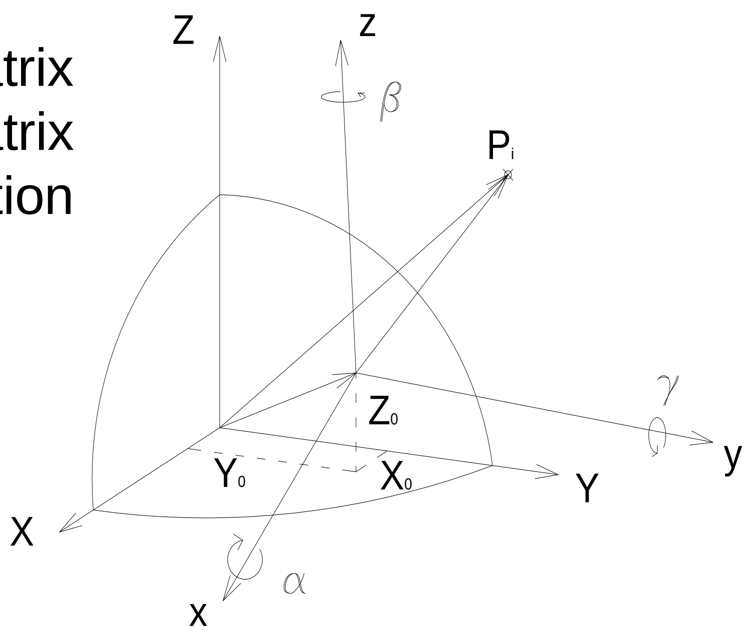
Datum Transformation

The rotation matrix in general is given by using 3 axial rotation angles (α, β, γ - Cardan angles), leading to the next rotation matrix:

$$R(\alpha,\beta,\gamma)=\begin{pmatrix} \cos\beta\cos\gamma & \cos\beta\sin\gamma & -\sin\beta \\ \sin\alpha\sin\beta\cos\gamma-\cos\alpha\sin\gamma & \sin\alpha\sin\beta\sin\gamma+\cos\alpha\cos\gamma & \sin\alpha\cos\beta \\ \cos\alpha\sin\beta\cos\gamma+\sin\alpha\sin\gamma & \cos\alpha\sin\beta\sin\gamma-\sin\alpha\cos\gamma & \cos\alpha\cos\beta \end{pmatrix}$$

Instead of the traditional form, the rotation matrix can be expressed with a skew-symmetric matrix (*S*) also, and this facilitates the symbolic solution of the problem.

$$S=\begin{pmatrix} 1 & -c & b \\ c & 1 & -a \\ -b & a & 1 \end{pmatrix}$$



Digital Mapping Course- Lec.3

Lecture will focusing on:

1- Fundamentals of map projections

- Grids and graticules
- Scale factor and features distortions
- Map projection maps

2- Designing a projection

- criteria used to design a projection

Fundamentals of Map Projections

1- WHY need projections?

- It is necessary to consider how to arrange surveying data so that it can be placed on a flat surface.
- Even a simple concept such as the distance between two points becomes excessively complex when expressed in spheroidal formula.

- A **projection**, is defined as an ordered system of meridians and parallels on a flat surface.
- It should be immediately apparent that it is impossible to convert a sphere or a spheroid into a flat plane without in some way distorting it.

Map Projection – Scale Factor

- Features on the surface of a sphere or a spheroid undergo distortions when projected onto a plane.

- It is necessary to have a precise definition of the amount of distortion that has resulted.

- This is provided by the definition of the *scale factor, which is*

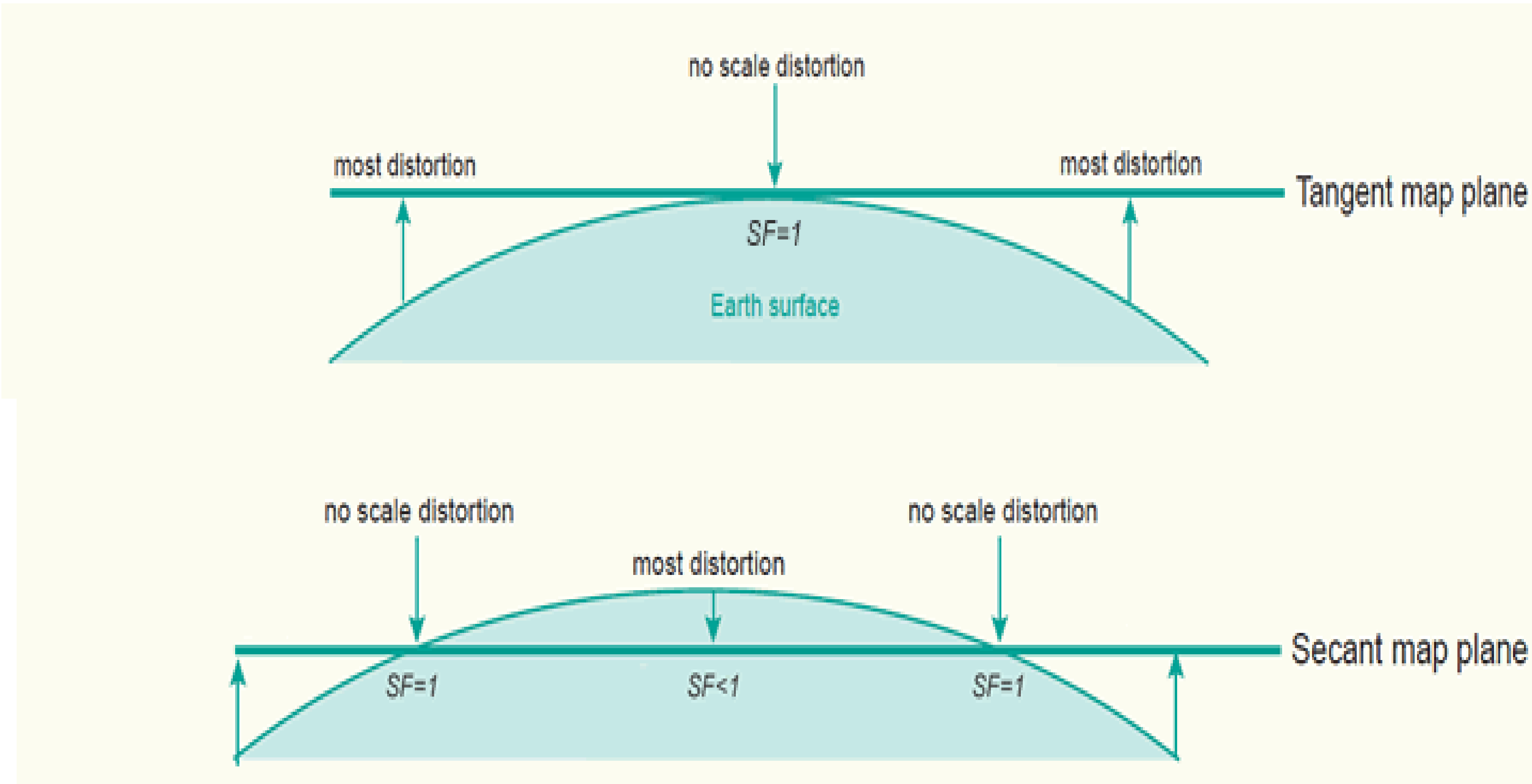
K= dist.(projection)/dist.(sphere)

- It is important to understand that this scale factor unrelated to the map scale (a number such as 1 : 50000).

- The ideal value of scale factor is 1, representing **no distortion**

Map Projection

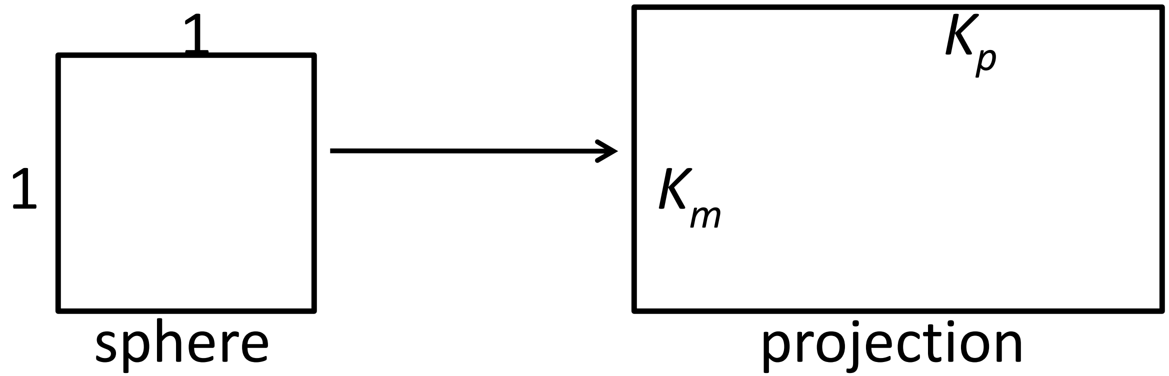
- Scale distortions for both, tangent and secant map surfaces, are illustrated in the figures below.



- Distortions increase as the distance from the central point (tangent plane) or closed line(s) of intersection increases

Map Projection

- It will often be useful to consider what happens to a small square of dimension (1 x1) on the sphere when it is projected.



- In the general case the distortion in the direction of the parallels will be different from the distortion in the direction of the meridians.

- *kp represent the scale factor along a parallel, and km* represent the scale factor along a meridian.

Map Projection

2- Preserved Features

- The (**shape, area and size**) of features on the sphere will be different when transformed to the projection, because of the "**Distortion**".

- Therefore, number of ways have been set for transferring coordinates from the sphere to a selected projection.

- The usual approach is to attempt to **preserve** *one of* these, feature's characteristics than others, depending on the purpose for which the projection is devised.

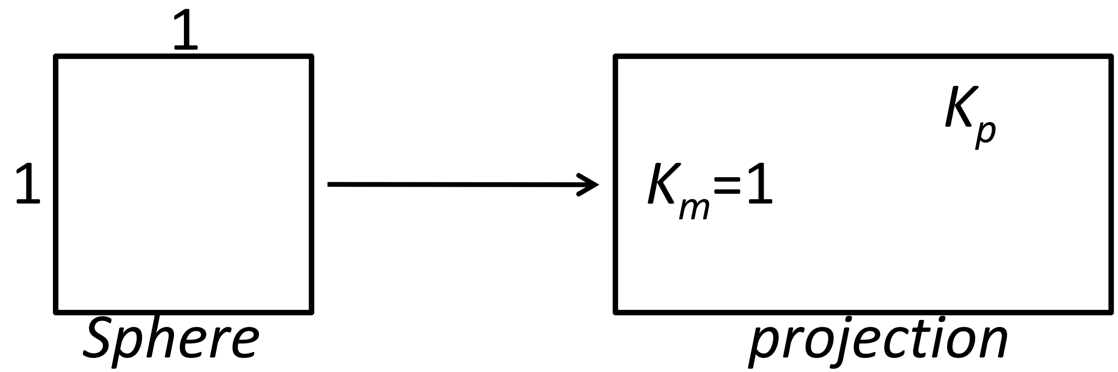
- For example, it may be required that certain of the distances as measured on the sphere should be undistorted when shown on the projection.

Map Projection

Or, it may be instead that the distances along all meridians should remain undistorted, which is means that:

$K_m = 1$ (i.e. Scale factor along meridians equal 1)

- Such a projection is known "**equidistant**"

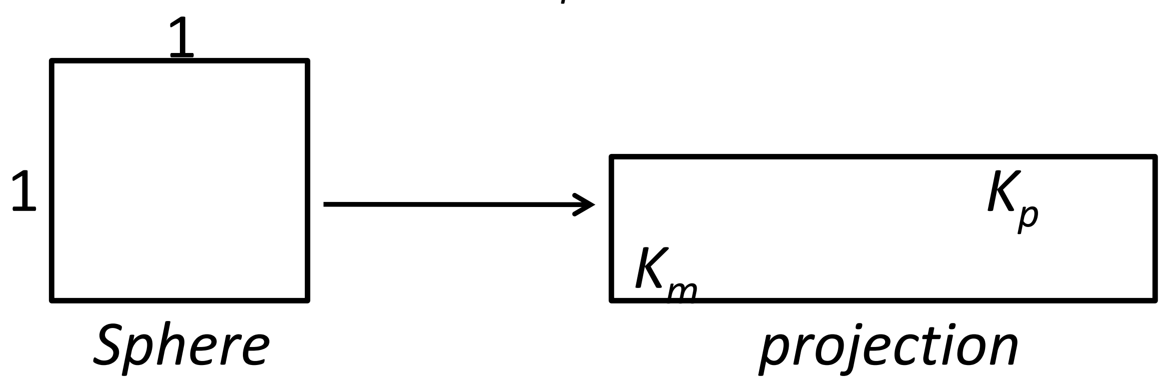


•It can be seen that there remains a scale factor along the parallel which is not equal to 1, and that the shape and area, of the square have both been distorted.

Map Projection

- An alternative to this type of projection is one that attempts to preserve area, and is therefore termed as an "***equal area***" *projection. In such a situation:*

$$K_m \; k_p = 1$$

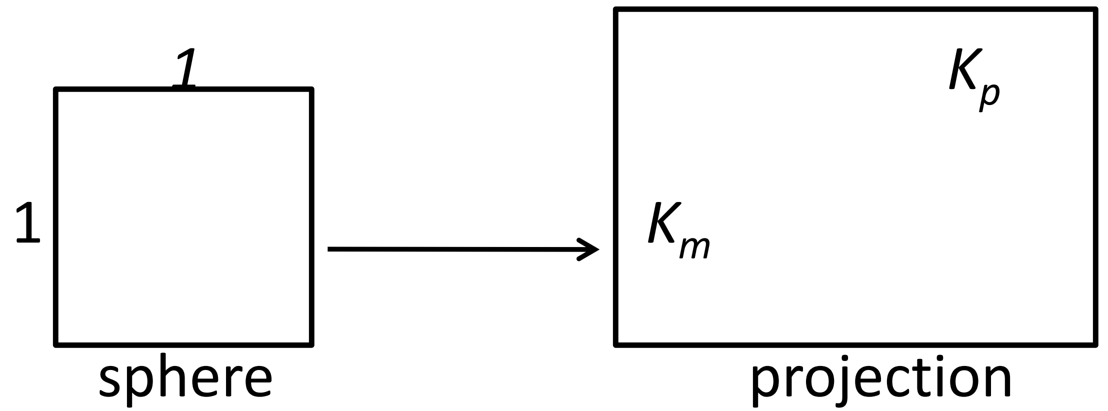


- The other principal classification of projections is that which preserves the ***shape*** of features. This is known as an *orthomorphic or, more commonly,* ***conformal*** *projection.*

Map Projection

- The relationship between the scale factors in this case will be:

$$K_m = K_p$$



- In preserving shape, a conformal projection is therefore preserving *angles* as well. For example, the angle between the side of the unit square and the diagonal is *45°.*

Map Projection

- For this reason, the conformal projection is the one of most significance in land surveying, as it means that angles measured on the ground can be transferred to the projection for use in computations.

- From a traditional land surveying point of view, there are two principal aspects to computing coordinates on projections.

➢ The first concerns distances, and
➢ The second concerns angles.

The basic principle of transferring a distance measured on the Earth to one to be used on a projection can be rearranged as:

Distance on the projection = *k x distance on the sphere*

Map Projection

The principal forms of projection surfaces are:

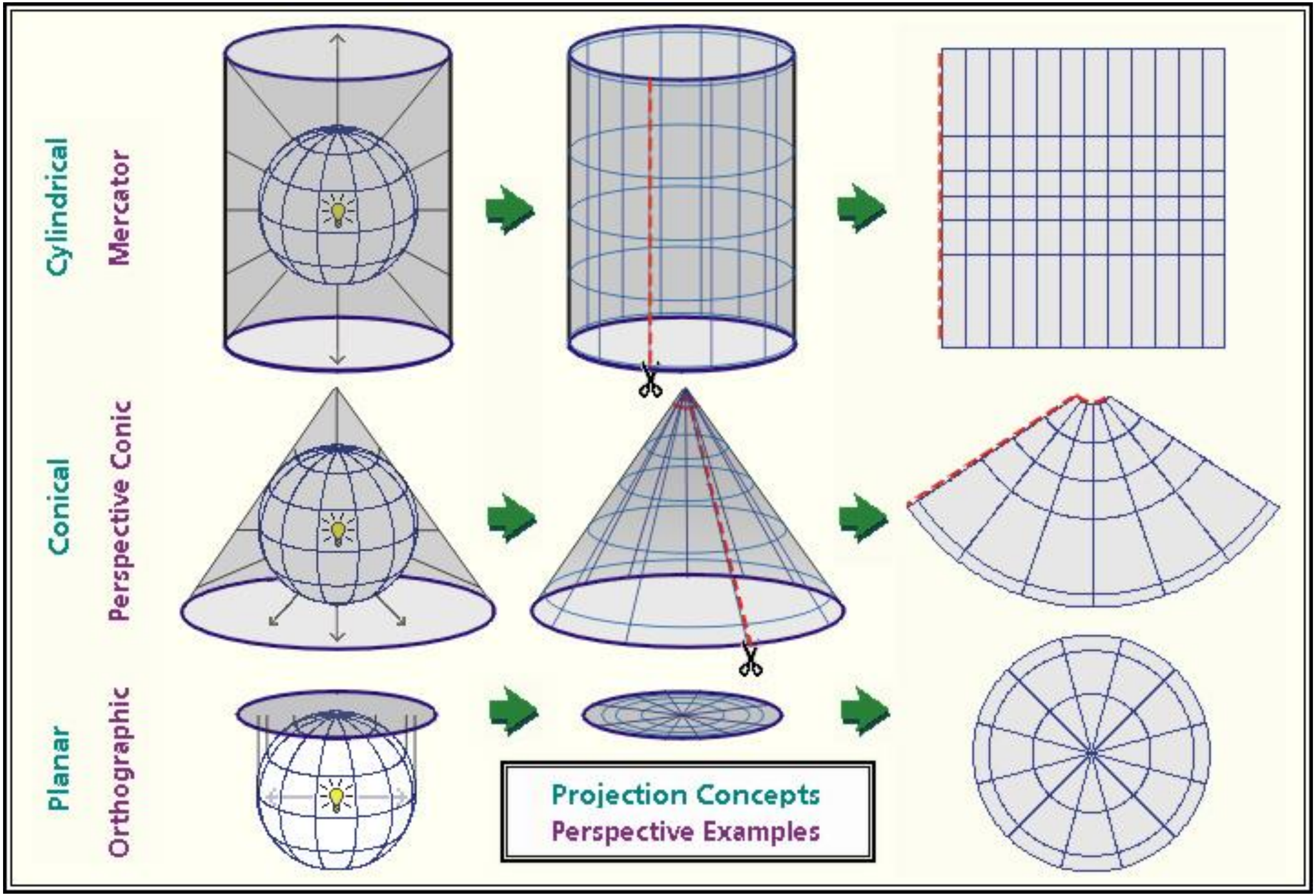
- cylinder
- cone, and
- the plane itself.

- The advantage of these shapes is that, their curvature is in one dimension only, they can be unraveled to a plane without any further distortion.

- In the region around the point or line of contact between the two surfaces the scale factor distortion will be minimal. In fact, where the two surfaces are touching the scale factor will be equal to 1.

- Most large scale mapping is likely to be based on transverse Mercator, Lambert conformal conic, and to a lesser extent the azimuthal and planar projections.

Map Projection Forms



Map Projection

3- Designing Projections

- In many applications, those working with map projections will be using an existing projected coordinate system, and the task will be to identify the projection method and the associated parameters.

- In other situations it is necessary to design a projection for a particular purpose, in which case the choice of projection method and parameters is up to the user.

Thus, there are suggested order of criteria given to define what is meant by a suitable projection. Those criteria as following: