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GEOLOGY	**Paper: Remote Sensing and GIS**
	Module: Map Projection, Coordinate System and Datum

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1. Map Projection

The shape of the earth is an ellipsoid, which is oblate spheroid or an ellipsoid. The mathematically described technique or systematic transformation method of the coordinates (latitude and longitude) of location from the 3D (3 dimensional) surface of the earth into Cartesian coordinates (Figure 1) on a 2D (2 dimensional) plane is known as map projection. This transformation method results in distortion (i.e. shape, size, distance and directions) of the 3D surface of the earth in 2D plane or maps (Fig. 2).

Some distortions are acceptable and others are not due to the purpose of the map. Therefore, various map projections are exist in order to preserve few properties of the sphere-like body at the expense of other properties. A good projection would depict the features of the earth in their true relationship to each other; that is, distance would be represented at a constant scale over the whole map and direction would be correct, resulting in correct shape of all parcels of land and equality of area. Because there is no exact solution has been found yet, the only solution has been to design map projections with prescribed distortion characteristics.

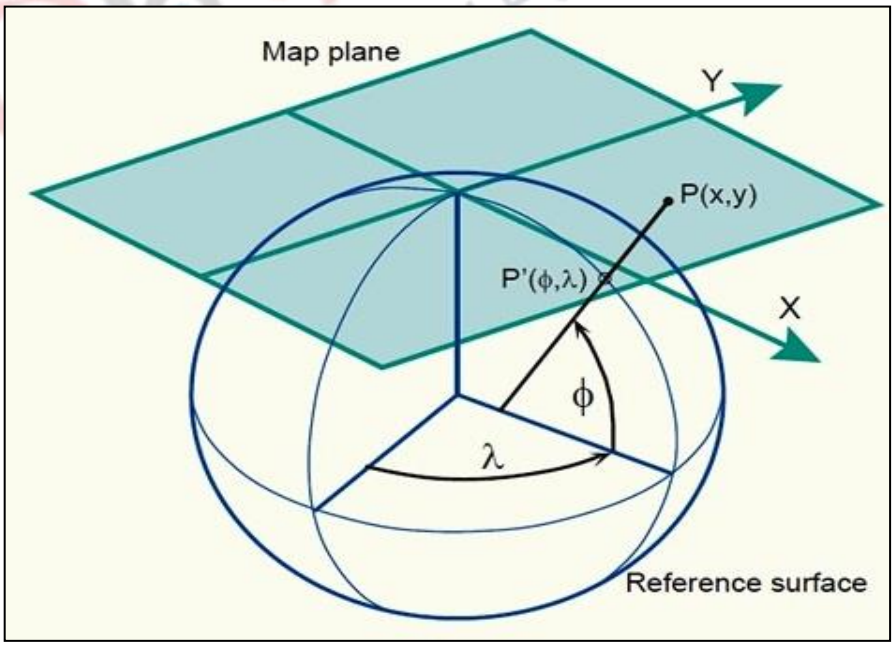

Fig. 1 Map projection with geographic coordinates (ϕ,λ) is projected on 2D mapping plane with 2D Cartesian coordinates (x, y) [Source: R. Knippers, 2009].

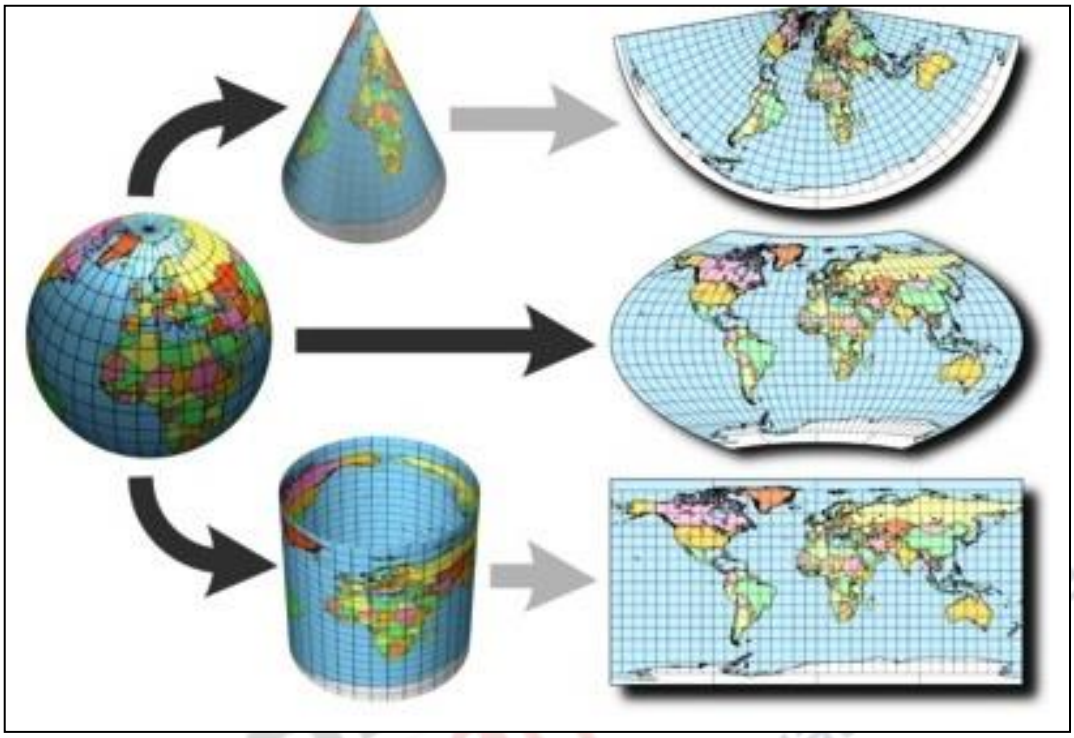

Fig. 2 An ellipsoid or sphere (left) to flat map (right). A conceptual intermediary surface (centre) may be useful for either actual construction or mere visualization [Source: Carlos A. Furuti, 2002].

The main characteristics of map projection are as follows:

- Conformal
- Constant scale
- Equidistant
- Correct Azimuthal (Direction)

2. Types of map projection

A variety of map projection have been developed and proposed in the past. Here are few important map projections are described. They are categorized into following three groups:

- Conic projections
- Cylindrical projections
- Azimuthal projections

2.1. Conic Projections

Tangent is the most simple conic projection to the globe along the parallel. This is known as standard parallel. The longitudes are projected upon the conical surface, intersect at the top of the cone. Along any meridian, the cone is cut then to make the final conic projection, which has straight lines of converging for longitudes and concentric circular arcs for latitudes. The meridian on the conic surface opposite the cut line is known as central meridian. Usually distortion increases away from the standard parallel.

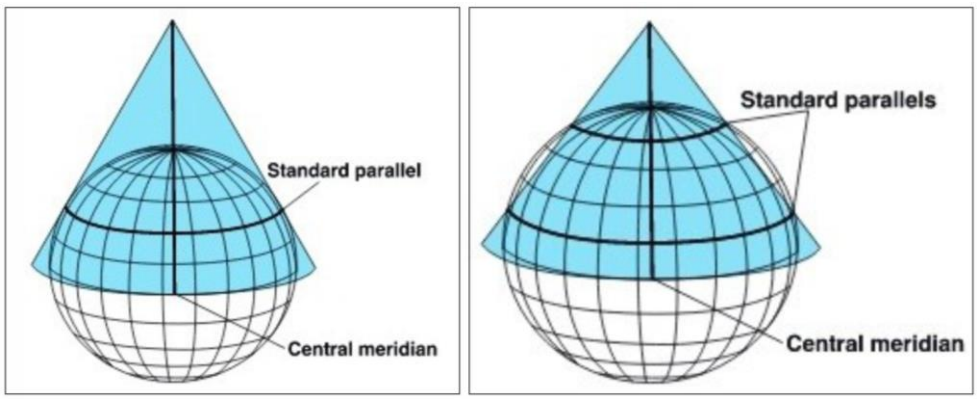

Fig. 3 Conic projection, (a) one standard parallel and (b) two standard parallel [Source: Kennedy M, 2000].

The conic projects are applied for the mid latitudes zones that have an orientation from East-to-West. The most complex conic projections are called secant and are known as two standard parallels. The conic projections are divided into following parts:

Simple conic projection: It is one standard parallel normal conic projection. All the circular parallels along the meridian are placed equally; result creates a correct scale along all longitudes. Therefore, the map is equidistant along the meridians.

Lambert conformal conic projection: It is conformal, the meridians and parallels are intersect at 90 degree. It is used for topographic maps.

Polyconic projection: It is neither conformal projection nor equal-area projection. It is comes from simple conic projection, but each parallel correct

to scale. This projection is projected on cones tangent to every parallel, therefore the longitudes are curved instead of straight line. The scale is correct along the mid longitude and along all latitudes. Hence, the distortion increases away from the central meridian.

Albert equal area projections: It is also known as conical projection with two standard parallels. It represents correct area and scale. Albert equal area projection is good for regions or area mainly East-West in extent and location in the mid parallels. It is used for small areas or countries and not suitable for big areas or continents.

Pseudo conical projections: In this projection, the longitudes are presented by curves and the latitudes are equidistance concentric circular arcs. The central meridian is straight among all meridians in this projection.

2.2. Cylindrical projections

It is can also have tangent or secant cases to the reference earth's surface. The circumference of the cylinder touches the reference surface of the globe along an equator (Great circle) in the tangent cases. While, the cylinder intersects at the place on the globe where the cylinder cuts by the globe and two tangent lines are formed. One of the most common cylindrical projection is the Mercator projection. The spacing between meridians are equal but the spacing between latitudes increases towards the pole. Cylindrical projection is conformal and shows correct direction along straight line. Cylindrical projection has following categories:

Equidistant Cylindrical Projection: It is also known as simple cylindrical or latitude/longitude projection has correct scale along all the meridians. The equidistant cylindrical projection being used by Google Earth for the depiction of its imagery.

Mercator Projection: It is a normal cylindrical projection with conformal property. All lines of parallels and medians are straight line intersecting at 90 degree. The space between parallels are increasing with distance from

equator. The main purpose for designing this projection is to display correct compass bearing for travel in sea.

Transverse Mercator Projection: It is a transverse cylindrical conformal projection and also called the Gauss conformal projection. As a result of conformity, angles and shapes of small areas are display accurately.

Universal Transverse Mercator (UTM) Projection: This projection uses a transverse cylinder. The UTM projection design to cover the whole world apart of the Arctic and Antarctic region and divided into 60 zones, each being a 6 degree of longitude.

Lambert's Cylindrical Equal-Area Projection: It represents shape and area accurately but examine some distortions in shape towards the poles. Meridians are placed equally. Latitudes are placed unevenly and farthest except close to the equator.

2.3. Azimuthal projections

It is also called a plane projection because with Azimuthal projection, the grids on globe is projected into a flat plane. In the polar cases, the plane is usually located above the North or South Pole. In general, only single hemisphere or a part of it, represented on Azimuthal projections. In the Azimuthal projections, the distinctive grid appearance shows the parallels are forming from the centric circle, while meridians come out from the centre of the circle. The gnomonic, orthographic and the stereographic projections are the example of Azimuthal projection. The Azimuthal projection system divided into following:

Gnomonic projection: It is also called central Azimuthal projection, and neither equal-area or conformal. The scale increases with increasing distance and increases scale distortions from the gnomonic projection's centre. The distortions are more in this projection related to area, shape, distance, and direction. This projection is helpful for defining the routes to sea and air

navigation because the route is short between two points in this projection is represented by straight line.

Orthographic projection: This projection is a perspective projection that views the earth from endless distance. Near the projection limit, the distortion in the area and size looks more realistic than any other projection. In general, polar areas, the longitudes are straight lines that come out from the centre, and the parallels are projected as concentric circles that become nearer to each other towards the projection limit. In this projection can be shown only one hemisphere.

Stereographic projection: In the stereographic projection, parallels and meridians are meet at 90 degree because it is a conformal projection. In the polar area, the longitudes are equally distributed in the form of straight lines whereas, the parallels are unequally distributed in the form of circles centred at the pole. An area increases with increasing distance from the centre of projection.

Azimuthal equidistant projection: It is also known as non-perspective postel projection. Distance measured and the bearing of any point from the centre of the projection is accurate. Some distortion related to others features increases away from the centre of the projection. The Azimuthal equidistant projection is used to show the distances of air route among places.

Lambert Azimuthal equal-area projection: This projection preserves areas and maintaining a precise direction from the centre of the projection simultaneously. The most common pattern of distortion in this projection is radial. Scale is decreases with increasing distance from the centre.

3. Coordinate system

A coordinate system is a reference system that helpful to shown the positions of geographic features in x and y space on a planar. There are so many coordinate systems are available but here we discussed about following coordinate systems:

Geographic Coordinate System (GCS): It is also known as global or spherical coordinate system like latitude and longitude. A GCS uses 3D spherical surface to determine the positions on the field (earth surface). A GCS consists of a datum, prime meridian and an angular unit of measure. The shape and size of the earth model define by the spheroid, while the spheroid of the earth model connected by the datum. Any point feature available on the earth surface is referenced by its coordinates (latitude and longitude). These coordinates are the angles measured from earth's centre to a point on the ground (Figure 4). The lines or horizontal lines of East-West are the lines of latitude or parallels in the spherical system. While the North-South line or vertical lines are the lines of longitude of meridians. The globe is encompass by these lines and form a gridded network, which is known as graticule. The line of latitude, which divides the earth into two hemispheres (North and South hemisphere), is known as the equator or zero latitude. The zero longitude is known as the prime meridian that passes through Greenwich (England). The graticule (0,0) is originate define by the place where the equator and the prime meridian intersect each other.

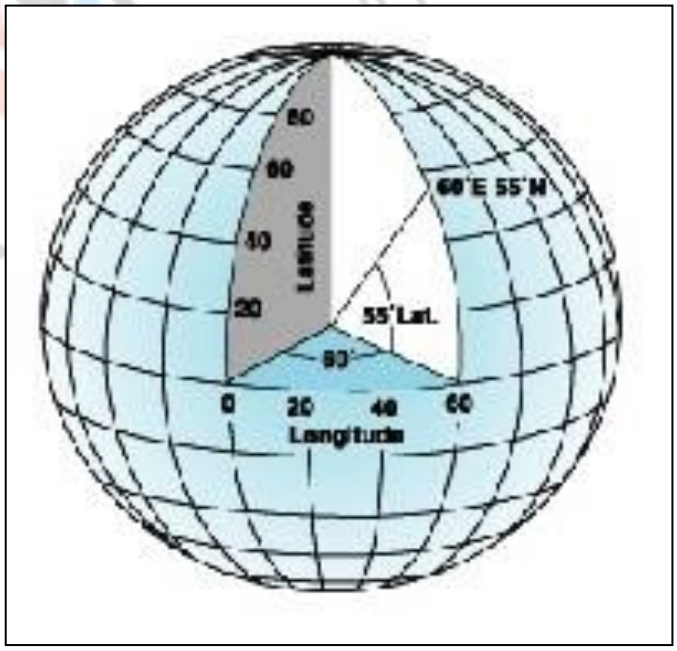

Fig. 4 Shows the latitude and longitude on the world as a globe [**Source:** ESRI.com].

The values of coordinate are measured either in degree, minutes and seconds (DMS) or in decimal degrees. The latitude or parallel values are measured relative to the great circle (equator) and range from -90 degree to +90 degree at South pole and North pole respectively. Whereas, the longitude or meridians values are measured relative to the prime meridian and range from -180 degree to +180 degree in order that when travelling towards West and East.

Projected Coordinate System: The projected coordinate system (PCS) is defined on a planar 2D surface. The PCS has constant areas, lengths and angles across the 2D, unlike a geographic coordinate system. The PCS is always based on a spheroid like geographic coordinate system. The PCS consist of map projection and set of projection parameters that modify the projection for a specific location and linear unit of measure, other than geographic coordinate system. The location of any geographic features are identified using X,Y coordinates (latitude and longitude) on a grid with the origin from the grid's centre. Each entity has 2 position values that reference to that central location. These 2 values are called the X-coordinate or longitude, which specifies its vertical position, and Y-coordinate or latitude specifies its horizontal position.

Vertical Coordinate System: The vertical coordinate system (VCS) defines the origin for depth or height values of features, whether the Z values shows as elevation (height) or depth. The positive Z values shows height and negative shows depth. Mostly information in a VCS is not necessary unless you want to show a dataset with other data that uses a different VCS. The unit of measure is always linear, is the most important part of VCS.

4. Datum

The shape of the earth is like a oblate sphere is called an ellipsoid. Datum is a mathematical model and used for the purpose of surveying and mapping the Earth. A datum includes series of numbers that define the size, shape and orientation (or direction) of the ellipsoid. Datum is selected to provide the accurate shape of the

earth model. There are various numbers of datum are being used. A datum is divided into 2 following categories:

Horizontal datum (HD): It determines the location of feature on the earth's surface related to the origin of X and Y coordinates. The North American Datum of 1927 (NAD27) has been used as this reference and existing maps prepared in NAD27 continue to be the main source for geographic information system (GIS) data. In the beginning of 1970s it became clear that the NAD27 would require replacement with advances satellite technology. The most recent datum North American Datum of 1983 (NAD83) being used in North America. The NAD83 is a unified geometric datum to providing a spatial reference for North America and successor to NAD27. Today, the most common used datum is World Geodetic System of 1984 (WGS84) maintained by the U.S. National Imagery and Mapping Agency (NIMA). It is a conventional terrestrial reference system. The global positioning system (GPS) used the reference coordinate systems of WGS84. It is same as the North American Datum of 1984 (NAD84).

Vertical datum (VD): It is a base measurement point from which determine the location of feature on the earth's surface related to an elevation like mean sea level. Different elevation values were calculated by the surveyors without use of common datum. Earlier, the common group of points has been the National Geodetic Vertical Datum of 1929 (NGVD29). When the advance technology was introduced an updated VD namely the North American Vertical Datum of 1988 (NAVD88) was created and adopted by the Federal Government for determining the heights as a new basis. The NAVD88 is more compatible and accurate than the NGVD29 with latest surveying and mapping technologies such as GPS. Today, the most important VDs are:

- **Tidal datum**: It is determine the averaging water level at a tide gage over a period of time. For example, Mean Low Water (MLW), Mean Higher High Water (MHHW) and Mean Sea Level (MSL).

- **Geodetic datum**: The Geodetic datum is measure through geodetic levelling, measuring the height differences among points on the ground. NOAA's National Geodetic Survey (NGS) has responsibilities to defining, providing access and the maintenance of geodetic vertical datum in the U.S. and its territories.

5. Summary

The shape of the earth is an ellipsoid, which is oblate spheroid or an ellipsoid. The mathematically described technique or method of a systematic transformation of the coordinates of location from the 3D surface of the earth into Cartesian coordinates on a 2D plane is known as map projection. A variety of map projection have been developed and proposed in the past. Here are few important map projections are described. They are grouped into following three: (I) Conic projection, (II) Cylindrical projection and (III) Azimuthal projection. A coordinate system is a reference system that helpful to shown the positions of geographic features in x and y space on a planar. There are so many coordinate systems are available but here we discussed about predominant coordinate systems such as Geographic Coordinate System (GCS), Projected Coordinate System (PCS) and Vertical Coordinate System (VCS). Datum is a mathematical model and used for the purpose of surveying and mapping the Earth. A datum includes series of numbers that define the size, shape and orientation (or direction) of the ellipsoid. Datum is selected to provide the accurate shape of the earth model. There are various numbers of datum are being used. A datum is divided into 2 categories: Horizontal datum (HD) and Vertical datum (VD).

Frequently Asked Questions-

Q1. Define the term map projection?

Ans: The shape of the earth is an ellipsoid, which is oblate spheroid or an ellipsoid. The mathematically described technique or method of a systematic transformation of the coordinates (latitude and longitude) of location from the 3D (3 dimensional) surface of the earth into Cartesian coordinates on a 2D (2 dimensional) plane is known as map projection

Q2. What is the difference between conic projection with one standard parallel and two standard parallel?

Ans: In conic projection with one standard parallel, all the circular parallels along the meridian are placed equally; result creates a correct scale along all longitudes. Therefore, the map is equidistant along the longitudes. While, conic projection with two standard parallel represents correct area and scale. It is good for regions or area mainly East-West in extent and location in the middle latitudes. It is used for small areas or countries and not suitable for big areas or continents.

Q3. What is coordinate system?

Ans: A coordinate system is a reference system that helpful to shown the positions of geographic features in x and y space on a planar.

Q4. What is the differences between geographic coordinate system (GCS) and projected coordinate system (PCS)?

Ans: GCS is also known as global or spherical coordinate system like latitude and longitude. A GCS uses 3D spherical surface to determine the positions on the earth surface. A GCS consists of a datum, prime meridian and an angular unit of measure. The shape and size of the earth model define by the spheroid, while the spheroid of the earth model connected by the datum. Whereas, The PCS is defined on a planar 2D surface. It has constant areas, lengths and angles across the 2D, unlike a GCS. It is always based on a spheroid like GCS. The PCS consist of map projection and set of projection parameters that modify the

projection for a specific location and linear unit of measure, other than GCS. The location of any geographic features are recognized using X,Y coordinates (latitude and longitude) on a grid with the origin from the grid's centre.

Q5. What do you understand by datum?

Ans: The shape of the earth is like an oblate sphere is called an ellipsoid. Datum is a mathematical model and used for the purpose of surveying and mapping the Earth. A datum includes series of numbers that define the size, shape and orientation (or direction) of the ellipsoid. Datum is selected to provide the accurate shape of the earth model.

Multiple Choice Questions-

1. What are the common shapes of map projections

a) Cylinder & Planes
b) Cone & Planes
c) Cylinder, Cones and Planes
d) Cylinder & Cones

Ans: c

2. Which of the following map projection shows an area between latitude and longitude equal in size to area on globe is known as

a) Equal Area Projection
b) Cylindrical Projection
c) Azimuthal Projection
d) Conic Projection

Ans: a

3. Which of the following coordinate system uses 3D spherical surface to determine the locations on the earth surface

a) Vertical Coordinate System
b) Geographic Coordinate System
c) Projected Coordinate System
d) None of above

Ans: b

4. Which of the following datum is used to determine the Mean Sea Level (MSL)

a) Tidal datum
b) Geodetic datum
c) Both of above
d) None of above

Ans: a

5. What is World Geodetic System of 1984 (WGS84)

a) Projection System
b) Coordinate System
c) Datum
d) All of above

Ans: c

Suggested Readings:

1. Rahman A & Fazal S 2017. Global Positioning System: Concept, Technique and Application, Fisrt Eds. New Age International, New Delhi.
2. Knippers, R. (2009). Geometric aspects of mapping. *International Institute for Geo-Information Science and Earth Observation, Enschede, http://kartoweb. itc. nl/geometrics*. 0.