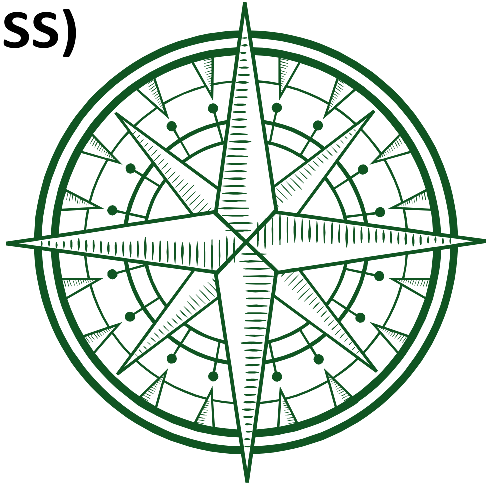
Bharathidasan University

Tiruchirappalli, Tamil Nadu

Programme: M. Tech Geoinformatics
Course: Global Navigation Satellite System (GNSS)
Title: Geodesy and Surveying



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GEODESY

Exploring the meaning and concept

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Introduction

- The word geodesy comes from Greek, literally meaning ‘dividing the earth’.
- The study of the size and shape of the earth’s surface, the measurement of the position and motion of points on the surface, and the configuration and area of large portions of its surface.
- The scientific objective of geodesy has determine the size, shape, and gravitational field of the earth. (Clarke 2001)
- Geodesy can be defined as the science which deals with the methods of precise measurements of elements of the surface of the earth.
- Traditional astronomical geodesy, that includes astronomical positioning, is not commonly considered a part of satellite geodesy.

Types of Geodesy

Geometrical Geodesy

Describing locations in terms of geometry. Coordinate systems are one of the primary product of geometrical Geodesy

Physical Geodesy

Determing with earth's gravity field, which is necessary for establishing height.

Satellite Geodesy

Measures dimensions of the earth, the location of objects on its surface and the figure of the earth's gravity field by means of satellite technique

Application of Geodesy

Navigation

Hazard Miigation

Environmental Studies

Construction

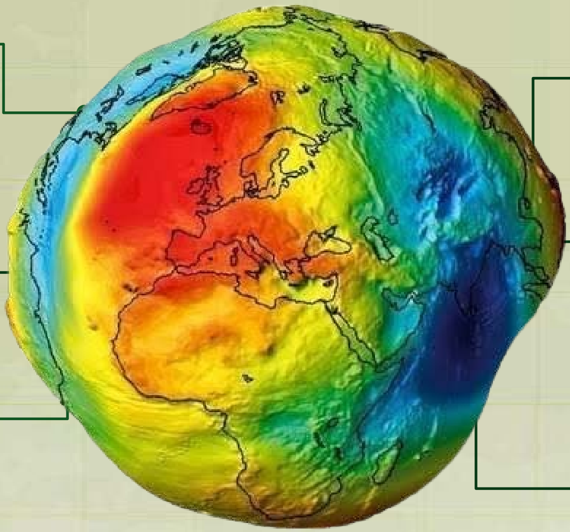
National Security

Resource Management

02

Shapes of Earth

GEOID



Hypothetical surface of the earth that coincides with sea level everywhere.

It is nearly ellipsoidal but a complex surface.

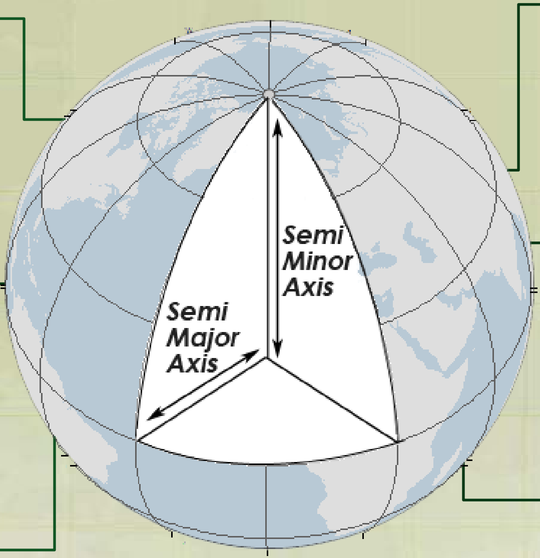
Not suitable as a surface on which to perform mathematical computations.

The geoid unfortunately has rather disagreeable mathematical properties.

The geoid is almost the same as mean sea level.

The elevations determined by level are elevation relative to geoid, called orthometric elevation.

Spheroid



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

The shape of an ellipse is defined by two radii. I.e. Semi-Major Axis & Semi-Minor Axis.

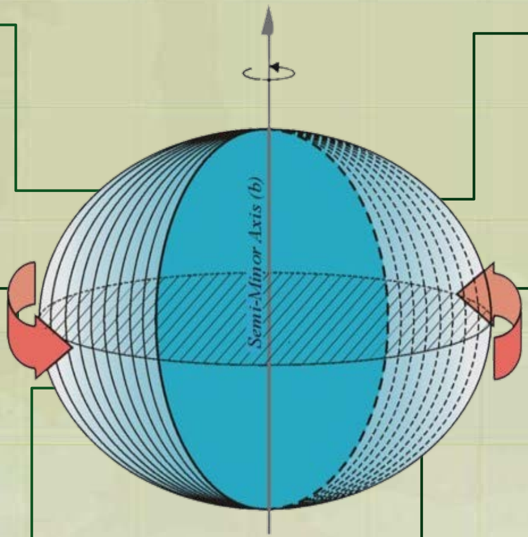
Rotating the ellipse around the semi-minor axis creates a spheroid.

The shape of a GCS's surface is defined by a spheroid.

A spheroid is defined flattening, is the difference in length between the two axes. The flattening is f=(a-b)/a

The earth is roughly an oblate spheroid, with semi axes of nearly 6378 and 6357 km.

Ellipsoid



A spheroid is also known as ellipsoid. The word ‘ellipsoid’ is used in America and Russia.

GNSS measures the relative elevations of points above the ellipsoid, called ellipsoidal height.

Ellipsoidal height, when combined with geoidal height, can give usable orthometric height. h =H + N

Ellipsoid is a three-dimensional shape created from a two-dimensional ellipse.

Thus, spheroid/ellipsoid model also does not represent the actual shape of the earth.

Differences in the Earth’s shape due to geoidal deviations will produce different best local ellipsoids.

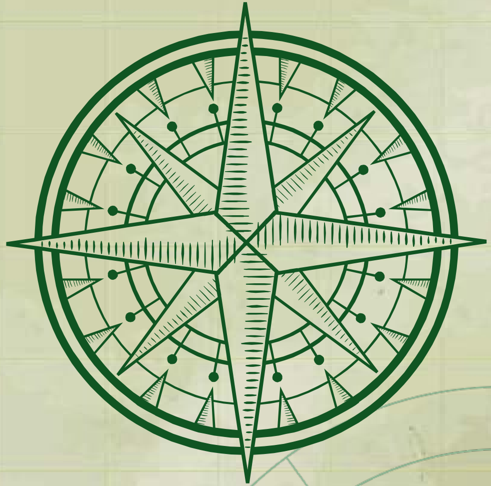
Use of Gravity in Geodesy

Gravity is the force that pulls all objects in the universe toward each other. On Earth, gravity pulls all objects "downward" toward the center of the planet. According to Sir Isaac Newton's Universal Law of Gravitation, the gravitational attraction between two bodies is stronger when the masses of the objects are greater and closer together.

i. Calculating Elevation
ii. Defining Geodesy
iii. Measuring mass loss

03

Coordinate System



In mathematics and applications, a coordinate (or referential) system is a system for assigning a tuple (ordered list) of numbers to each point in an n-dimensional space.

Coordinate systems are used to identify locations on a graph or grid or the system of assigning longitude and latitude to geographical locations is a coordinate system.

There are various coordinate systems available to represent the location of any point. However, all of them fall into two broad categories—curvilinear and rectangular.

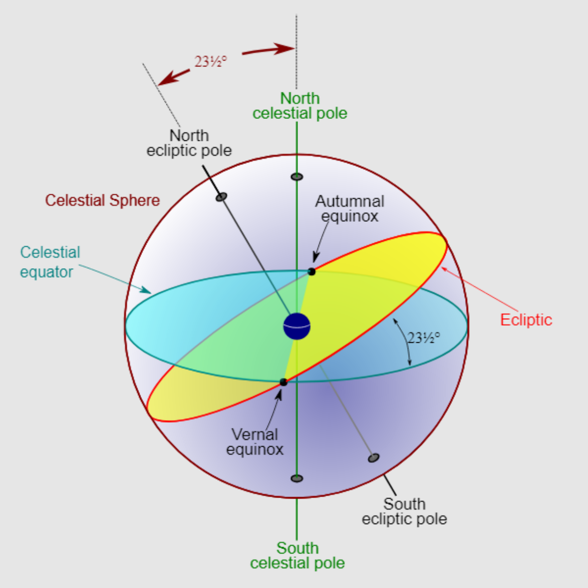
Curvilinear system uses angular measurements from the origin to describe one’s position, whereas rectangular coordinate system uses distance measurements from the origin.

One example of a curvilinear system is the geographic coordinate system that uses angular latitude/longitude measurements.

one example of rectangular coordinate system is the Cartesian co-ordinate system that uses linear measurements.

Celestial Coordinate System

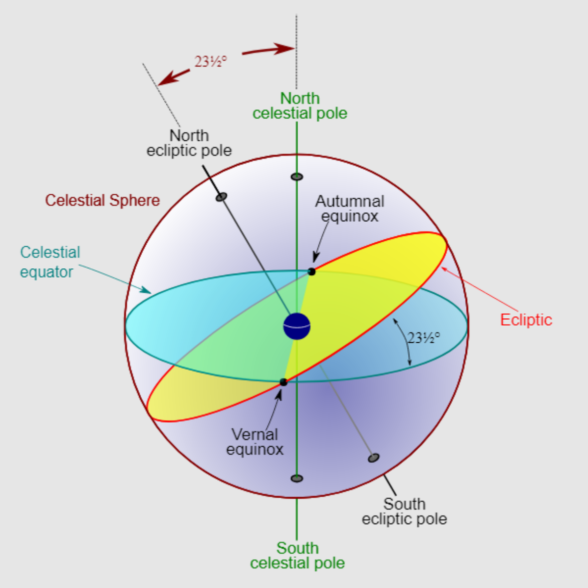
It is a curvilinear coordinate system for mapping positions in the sky. The celestial equatorial coordinate system is probably the most widely used celestial coordinate system. It is most closely related to the geographic coordinate system.



The orbit of the earth is an ellipse of low eccentricity ($e = 0.01673$), the sun being at one focal point. The earth rotates from west to east in 24 h on an ecliptic plane. Ecliptic plane is the geometric plane containing the mean orbit of the earth around the sun.

Celestial Coordinate System

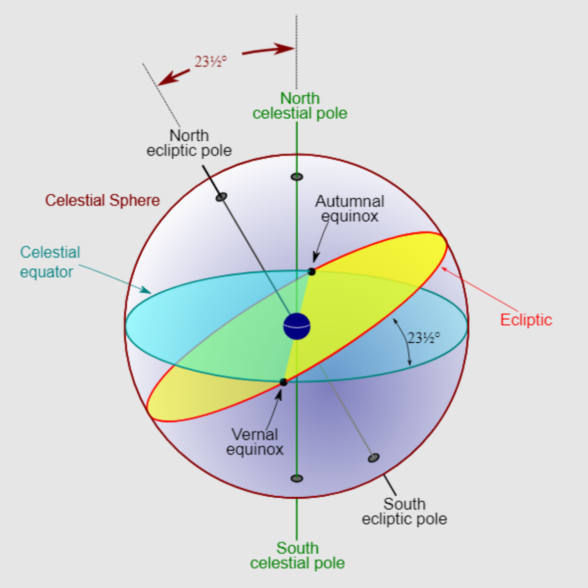
The rotation axis of the earth deviates from the perpendicular of the ecliptic plane by an angle equal to 23°27’; in other words, there is an angle of 23°27’ between the ecliptic plane and equatorial plane. The earth is also rotating around the sun in the same direction.



The vernal point (also called vernal equinox) is defined as being the point where the sun crosses the Equator when going from the southern hemisphere to the northern hemisphere. This apparent location of the sun is positioned directly over the earth’s Equator.

Celestial Coordinate System

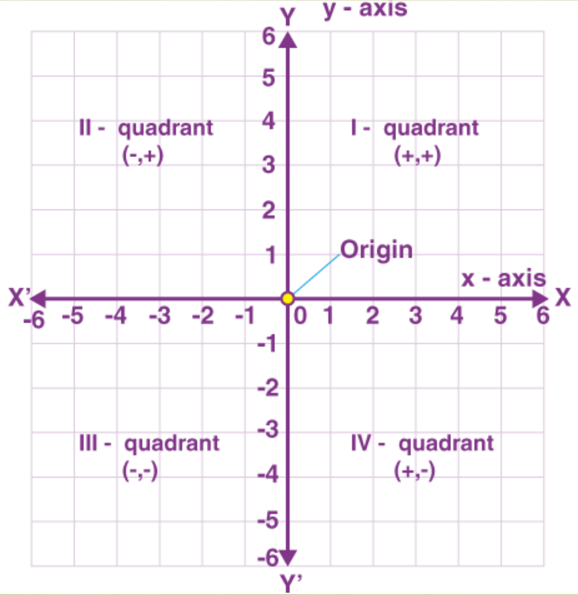
The intersecting line of the equatorial plane and the ecliptic plane indicates the direction of the vernal point. Considering the vernal point direction, a reference in the astronomical domain, a terrestrial location can be defined using both right ascension and declination, defined as follows.



The right ascension (α) is the angle between the meridian that crosses the location and the vernal point from the center of the earth. The declination (δ) is the angle of the direction of the location with the equatorial plane, evaluated on the local meridian, from 0° to 90° north or south.

Cartesian Coordinate System

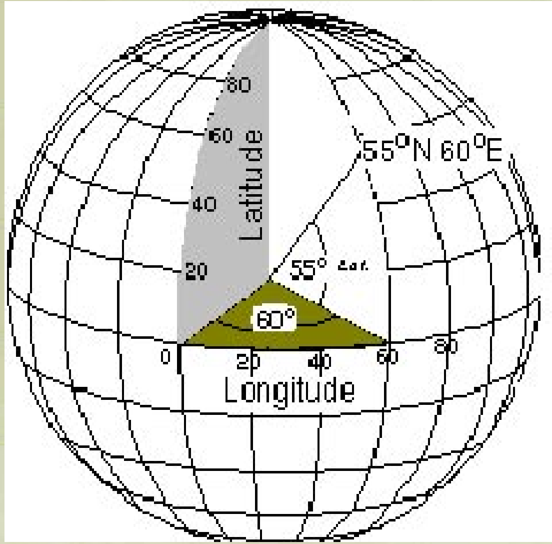
It is called the earth-cantered inertial (ECI) or rectangular coordinate system, commonly used in astronomical calculations. However, neither the celestial equatorial nor the ECI system is really practical for positioning. These systems are mainly used to define star locations.



The Centre of the earth is considered as the origin (O), the z-axis is the polar axis, x-axis is through the vernal point, the y-axis is chosen to form a right-handed system and lies in the equatorial plane at 90° counter clockwise from the x-axis.

Geographical Coordinate System

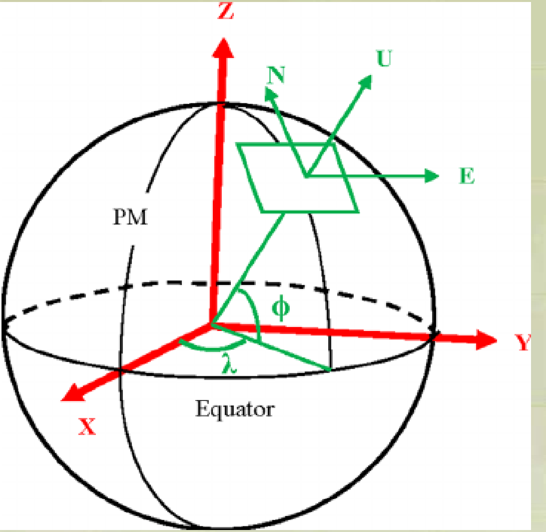
It expresses every location on earth by two of the three coordinates of a curvilinear coordinate system, which is aligned with the spin axis of earth. It uses a 3D spherical surface to define locations. The location defined by a reference using latitude and longitude.



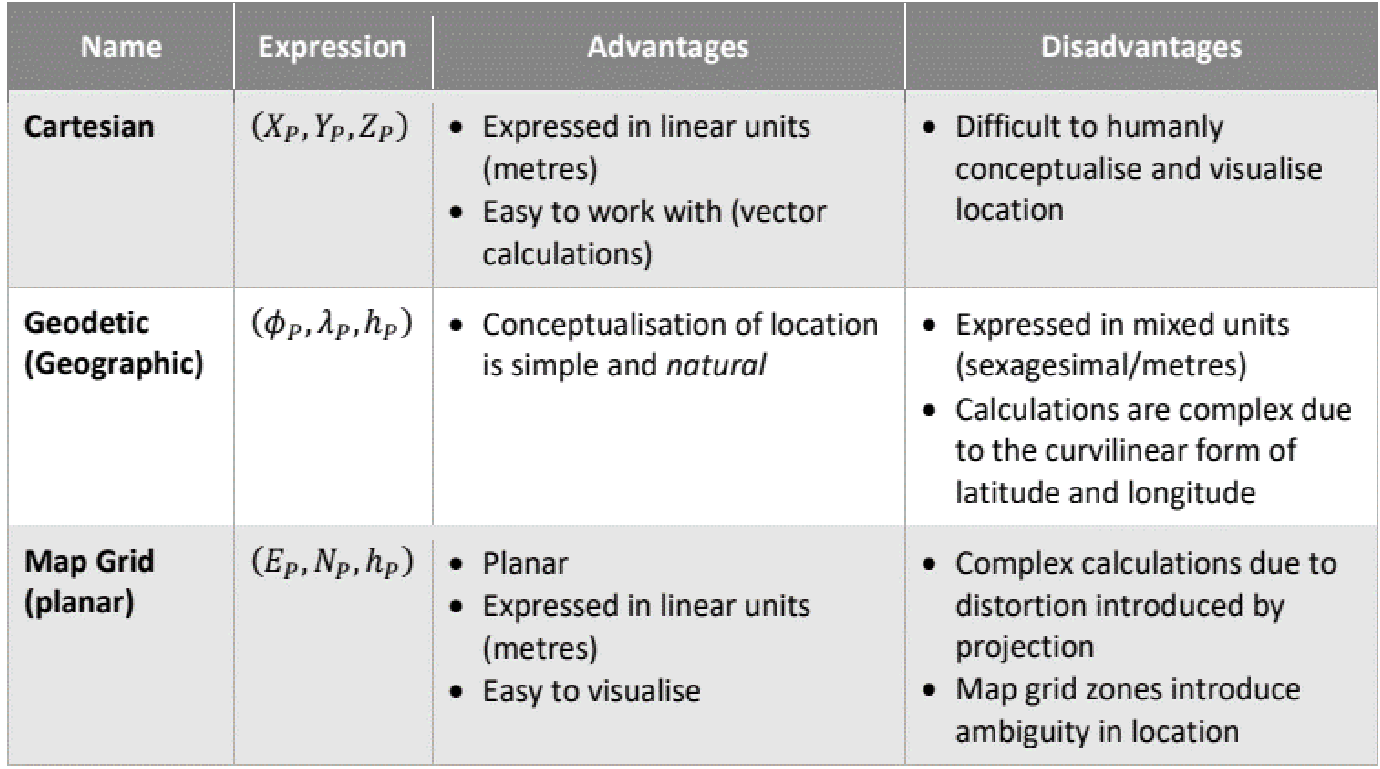
These lines encompass the globe and form a gridded network called a graticule. The origin of the graticule (0,0) is defined by where the Equator and prime meridian intersect. The globe is then divided into four geographical quadrants.

Earth-Cantered Earth-fixed Coordinate System

It’s main parameters are origin O is the Centre of the earth. The z-axis is the polar axis, oriented towards north. The x-axis is on the equatorial plane and passes through the Greenwich meridian.



The y-axis is chosen to form a right-handed system and lies in the equatorial plane at 90° counter clockwise from the x-axis. This is very practical for positioning and are two commonly used referential for satellite navigation systems.



Name	Expression	Advantages	Disadvantages
Cartesian	(X_P, Y_P, Z_P)	• Expressed in linear units (metres) • Easy to work with (vector calculations)	• Difficult to humanly conceptualise and visualise location
Geodetic (Geographic)	(ϕ_P, λ_P, h_P)	• Conceptualisation of location is simple and *natural*	• Expressed in mixed units (sexagesimal/metres) • Calculations are complex due to the curvilinear form of latitude and longitude
Map Grid (planar)	(E_P, N_P, h_P)	• Planar • Expressed in linear units (metres) • Easy to visualise	• Complex calculations due to distortion introduced by projection • Map grid zones introduce ambiguity in location

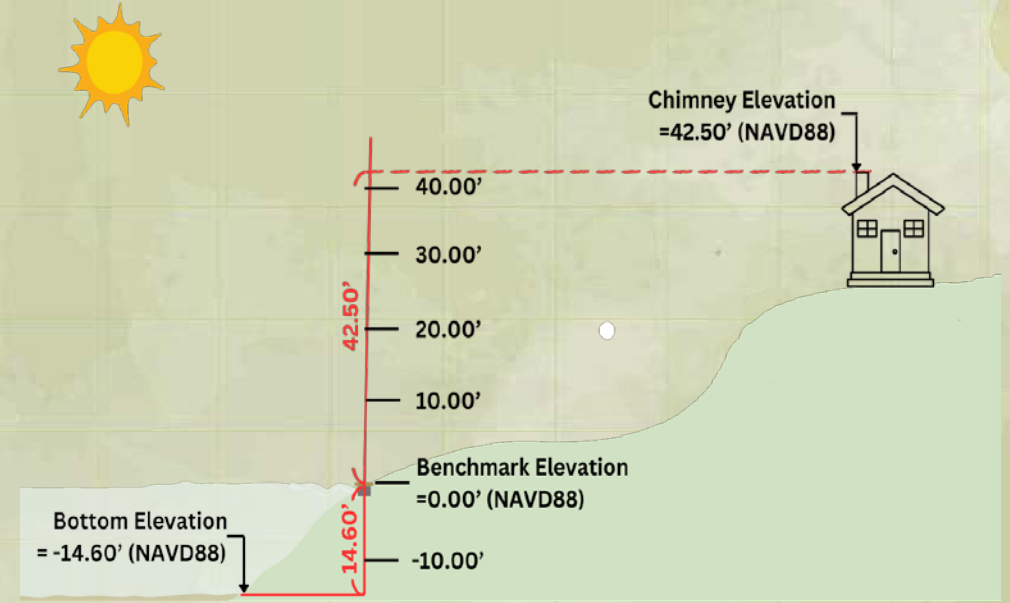
Geodetic Reference System / Geodetic Datum

A datum is a reference point on the earth's surface against which position measurements are made, and an associated model of the shape of the earth for computing positions. The most recently developed and widely used geocentric datum is WGS 1984. It serves as the framework for measurement of locations worldwide.

Two types of datum: horizontal datum and vertical datum. It defines the origin and orientation of latitude and longitude lines. A GCS is often incorrectly called a datum, but a datum is only one part of GCS. An earth-centered, or geocentric datum, uses the earth's center of mass as the origin of the spheroid.

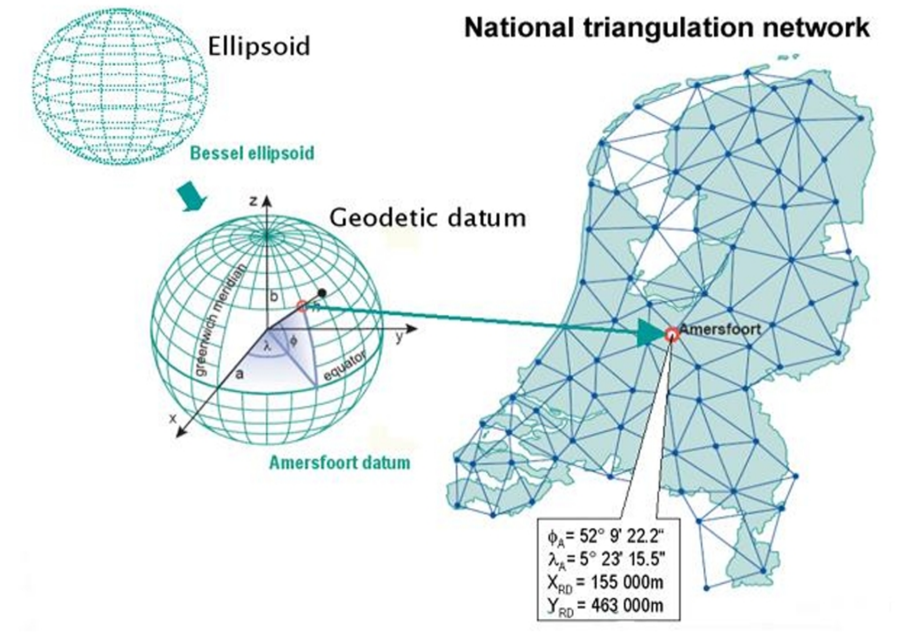
Geodetic Vertical Datum

The geodetic vertical datum uses ellipsoid as the reference surface. The surface of the ellipsoid is considered to represent zero altitude. Points above the ellipsoid represent positive altitude and points below the surface represent negative altitude. The altitude is also known as ellipsoidal or geodetic height. GPS devices furnish ellipsoidal heights.



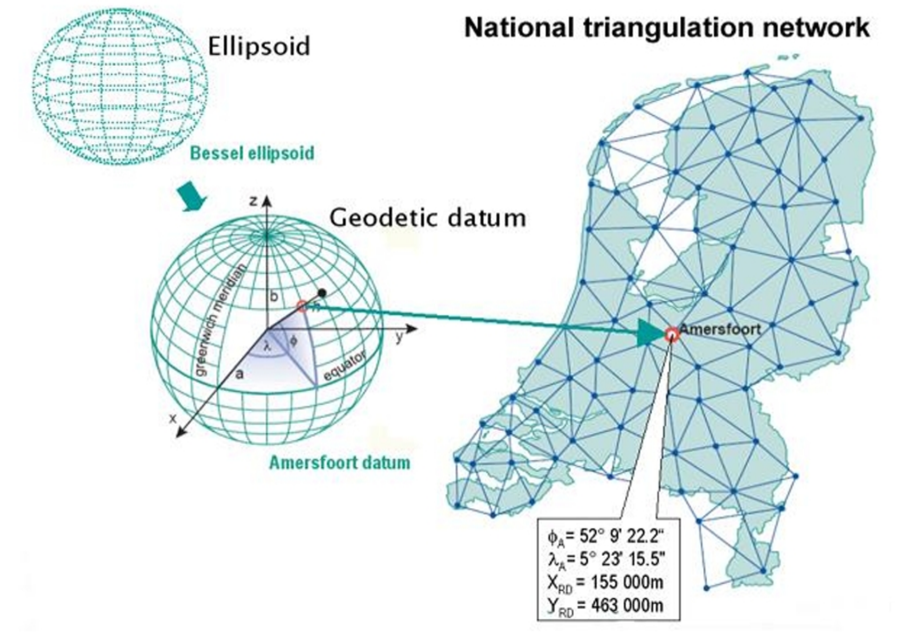
Geodetic Horizontal Datum

A horizontal geodetic datum is defined as an ellipsoid which is used as a reference surface for the planimetric measurements on the Earth surface usually expressed in latitudes and longitudes. It is based on an established zero meridian passing near the Greenwich Observatory, in England. Through surveying measurements, we establish a set of points on Earth for which the horizontal and vertical positions have been accurately determined.



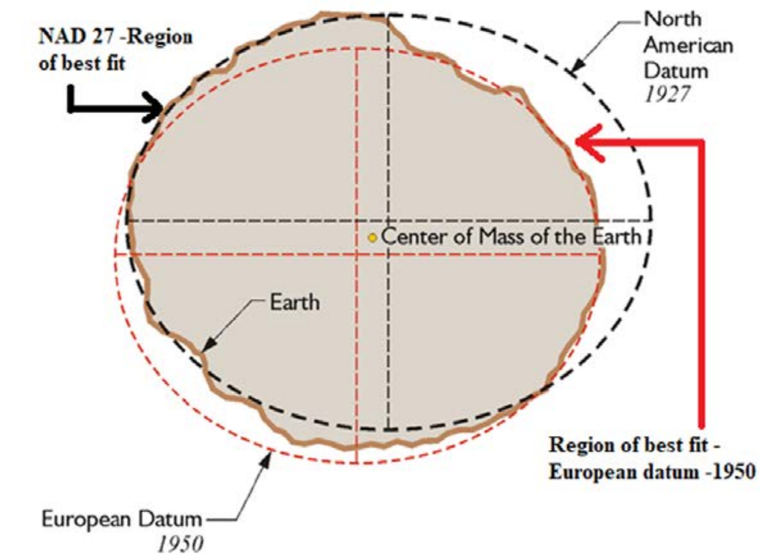
Geodetic Horizontal Datum

These accurately determined points and associated measured and mathematical surfaces are called horizontal datums. These well surveyed points allow us to specify a reference frame or a datum surface, including an origin or starting point. All other coordinate locations we use are measured with reference to the chosen reference frame known as datums. The reference frame defines the origin and orientation of latitude and longitude lines.



Local Geodetic Datum

It is the best approximates the size and shape of a particular part of earth’s sea level surface. The centre of this spheroid does not coincide with Centre of mass of the earth. 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.



Indian Geodetic Datum

Indian geodetic datum is a local datum and based on Everest spheroid as reference surface was defined piecemeal at various times. Astronomical observations were carried out at least twice. More precise observations carried out at a later date were accepted. Hence meridional and prime vertical deflection of vertical, were defined at Kalyanpur. Parameters of the datum are given below:

Initial point (origin):
Kalyanpur

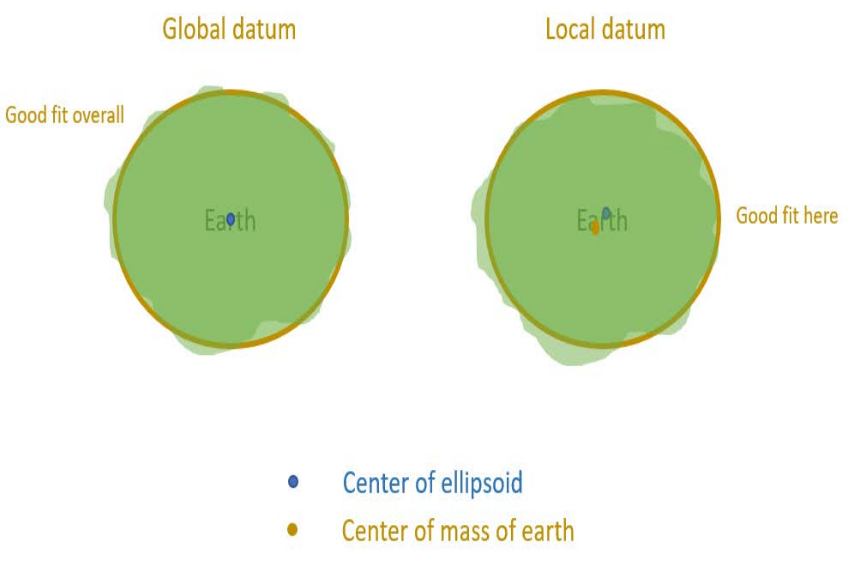
Geoidal undulation:
0m

Semi major axis:
6,377,301243 m

Flattening :
1/300.8017

Global Geodetic Datum

Unlike local geodetic datums, which are essentially defined by parameters associated with a single ‘origin’ terrestrial station, datums used in satellite navigation system are defined by a combination of physical models and geometric models. The characteristics of the datum are It is geocentric, because the geocentre is the physical point about which the satellite orbits. It is generally defined as a Cartesian system. There are a number of different satellite datums, each associated with different satellite tracking technology.



WGS 1984 Datum

The WGS84 is one such satellite datum, defined and maintained by the US National Imagery and Mapping Agency as a global geodetic datum. It is the datum to which all NAVSTAR GPS positioning information is referred by virtue of being the reference system of the broadcast ephemeris WGS84 is an ECEF system fixed to the surface of the earth. The defining parameters of the WGS84 reference ellipsoid are:

Semi-major axis: 6378137 m.

Ellipsoid flattening: 1/298.2572235633.

Angular velocity of the earth: 7292115 × 10-11 rad/sec.

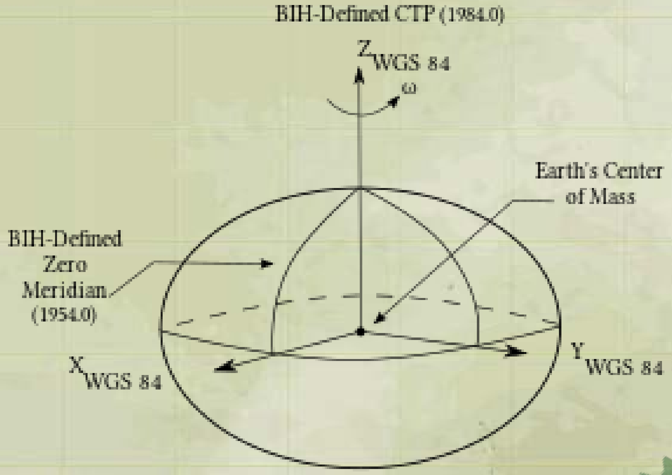


Figure 1.1 WGS 84 Reference Frame

WGS 1984 Datum

Such a datum has the following characteristics:

✓ • It is geocentric, because the geocentre is the physical point about which the satellite orbits.

✓ • It is generally defined as a Cartesian system, with axes oriented close to the principal axes of rotation (z-axis) and the intersection of the Greenwich meridian plane and the equatorial plane (x-axis), with the y-axis forming a right-handed system.

✓ • There are a number of different satellite datums, each associated with different satellite tracking technology and different combinations of gravity field model, earth orientation model, and tracking station coordinates used for orbit computation.

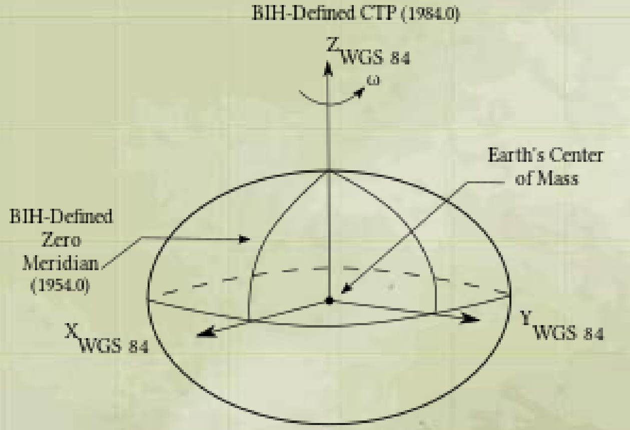
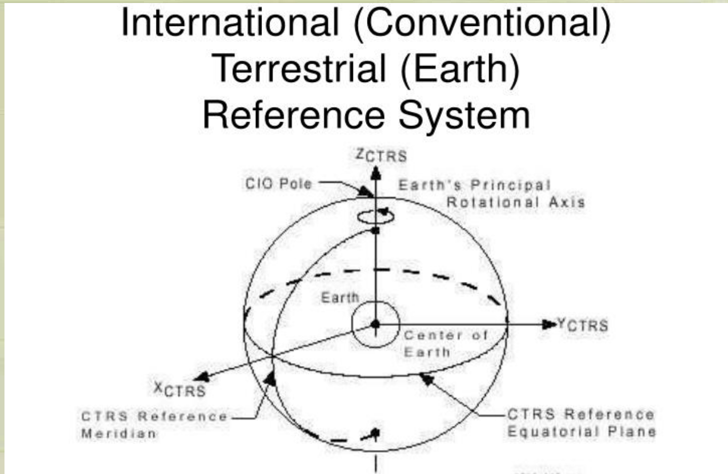


Figure 1.1 WGS 84 Reference Frame

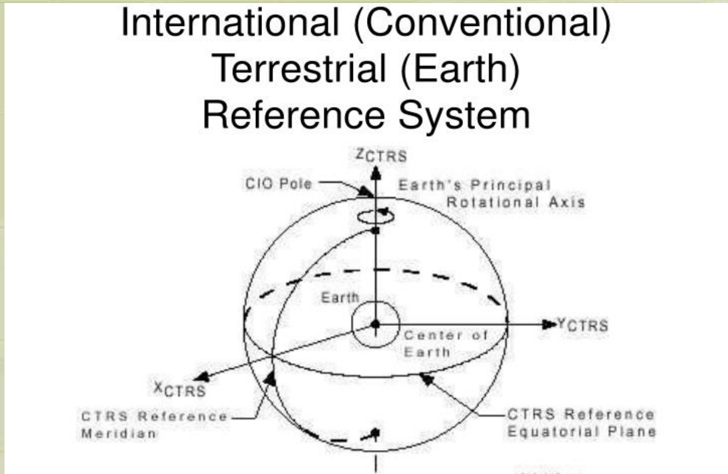
Terrestrial Reference Frame

The stations on the earth’s surface with known coordinates are sometimes known as the terrestrial reference frame (TRF). It is important to note that there is a difference between a datum and TRF. A datum is a set of constants with which a coordinate system can be abstractly defined, not the coordinated network of monumented reference stations themselves that embody the realization of the datum. However, instead of speaking of TRFs as separate and distinct from the datums on which they rely, the word ‘datum’ is often used to describe both the framework (the datum) and the coordinated points themselves (the TRF).



Terrestrial Reference Frame

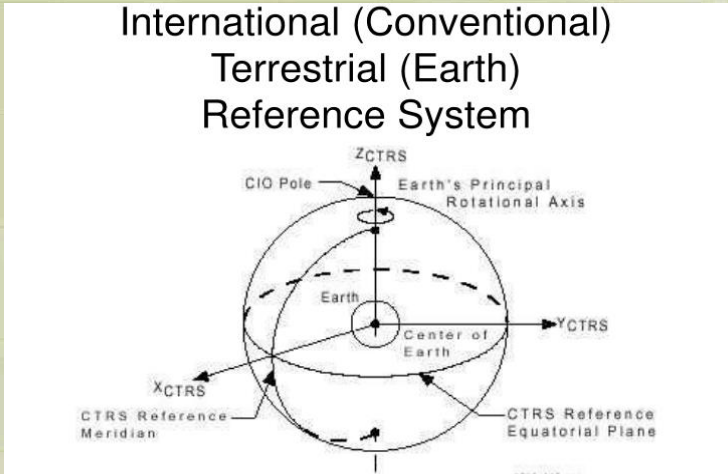
The reference system realization is known as the International Terrestrial Reference Frame. In 1991, the International Association of Geodesy decided to establish the International GNSS Service (IGS) to promote and support activities such as the maintenance of a permanent network of GNSS tracking stations, and the continuous computation of the satellite orbits and ground station coordinates (Dixon 1995). Both of these were preconditions to the definition and maintenance of a new satellite datum independent of WGS84.



Terrestrial Reference Frame

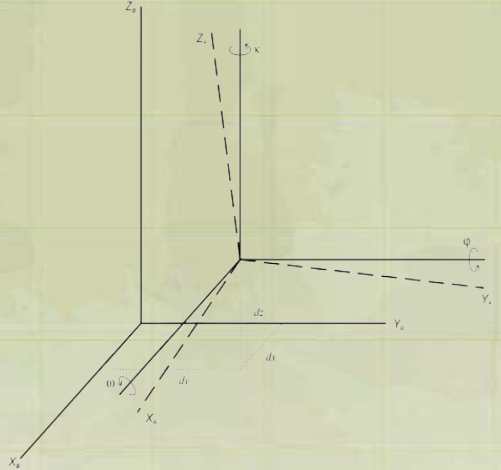
After a test campaign in 1992, routine activities commenced at the beginning of 1994. The network is an international collaborative activity consisting of about 50 core tracking stations located around the world supplemented by more than 200 other stations (some continuously operating, others only tracking on an intermittent basis).

The definition of the reference system in which the coordinates of the tracking stations are expressed, and periodically re-determined, is the responsibility of the International Earth Rotation Service. The reference system realization is known as the International Terrestrial Reference Frame (ITRF)



Ellipsoids & Datum used in GNSS

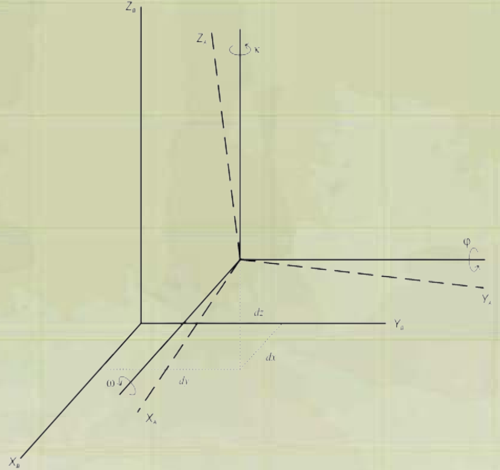
As GNSS is not a local positioning system, rather a global system for positioning and navigation, every GNSS uses earth-centred geocentric datum, not local datum. However, the spheroids they use are different. The geocentric datums used by GPS and GLONASS are, respectively, WGS84 and PZ-90 (Parametry Zemli 1990, English translation: Parameters of the Earth 1990, also known as PE-90).



The reference used by Galileo is Galileo Terrestrial Reference Frame (GTRF) aligned with the International Terrestrial Reference Frame (ITRF) and is covered by the ISO 19111 standard.Galileo GTRF is based on GRS80 ellipsoid. Chinese BeiDou uses China Geodetic Coordinate System 2000 (CGCS2000).

Ellipsoids & Datum used in GNSS

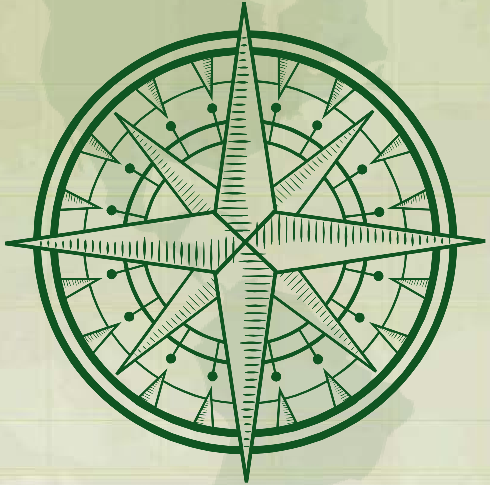
In the WGS84 model, the plane sections parallel to the equatorial plane are circular. The equatorial radius equals 6378.137 km. The plane sections perpendicular to the equatorial plane are ellipsoidal. The section containing the z-axis has its semimajor axis equal to 6,378,137 m (the equatorial radius) and its semi-minor axis is equal to 6,356,752.31 m.



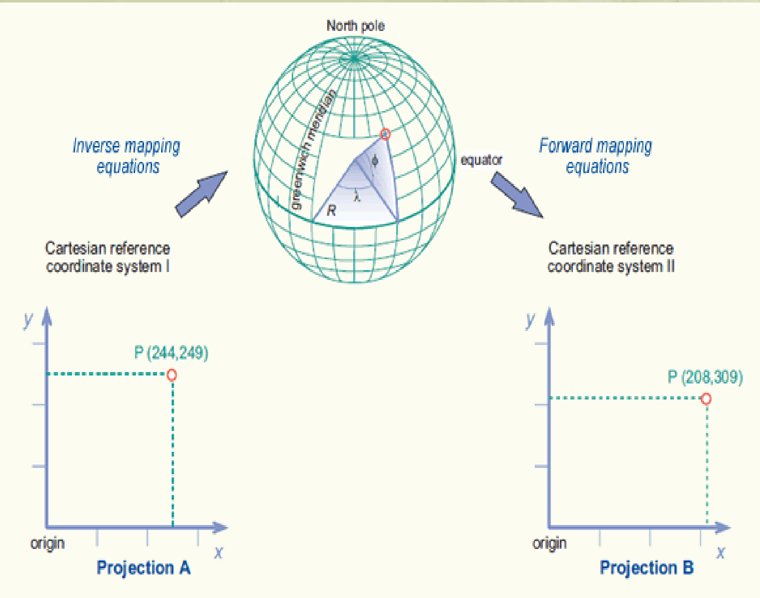
The PZ-90 model is similar to the WGS84, with a semi-major axis of the plane section of the equatorial plane being 6,378,136 m and a semi-minor axis of 6,356,751 m (GLONASS ICD 2002). The GTRF model is also similar (based on GRS80) with the semi-major axis of 6,378,137.31414 m and the semi-minor axis of 6,356,752 m.

04

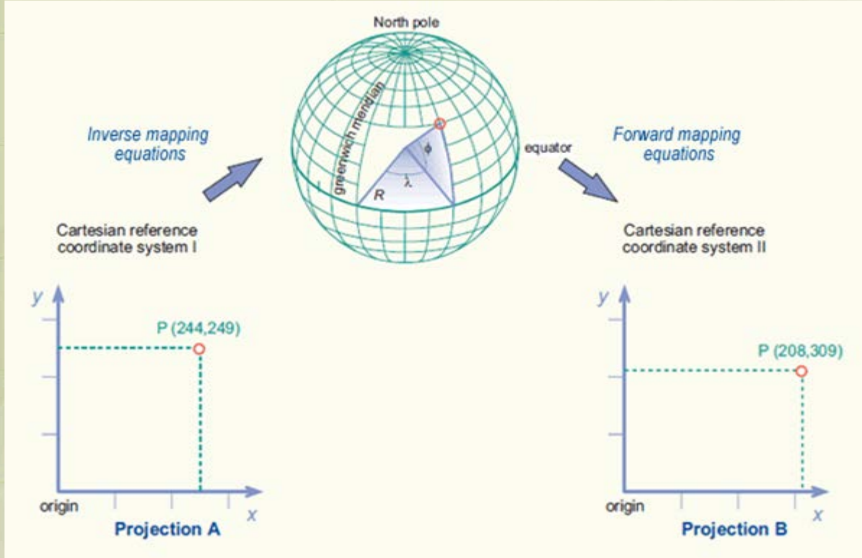
Transformation



For surveying purposes, it is wise to use the specific GNSS datum and spheroid (i.e., WGS84, or PZ-90, or GTRF, the applicable one), which can then be converted into any other local system with the help of software with no discernible loss of accuracy for virtually all situations (except for cases of very high accuracy requirements). A digitized map is measured in the same measurement unit as the source map but before using it in a GIS project, the digitized map must be converted to the real world coordinates such as UTM. It helps in making such data comparable and useful in overlay operations and mosaicking. The coordinate transformation techniques are also helpful in removing geometric distortions with respect to accurately positioned feature.



There are two ways to look at coordinate transformation i.e. either move objects on a fixed coordinate system so that the coordinates change diagram or hold the objects fixed and move the coordinate system. Based on the nature of the relationship between the coordinate systems, two methods of transformations are considered. These are Polynomial Transformation and Exact Transformation.



Types of Transformation

Polynomial Transformation	Exact Transformation
If the relationship between the coordinate system is derived through the control points in both the coordinate systems it is termed as polynomial transformation. The typical polynomial transformation is the Affine Transformation.	If the relationship could be expressed in terms of mathematical form, it is called as exact transformation. It has been divided into two categories • Projective Transformation • Planer transformation.

Parameters of Tranformation

The transformation of coordinates involves seven transformation parameters- three translations due to shift of origin, three rotations due to change in orientation, and a scale factor due to different dimensions of the two reference ellipsoids. These transformation parameters must be estimated using coordinates of several well-distributed stations in both the systems in order to obtain the geodetic coordinates in local reference system.

ω, φ, and κ

da and db

dx, dy, and dz

Parameters of Transformation

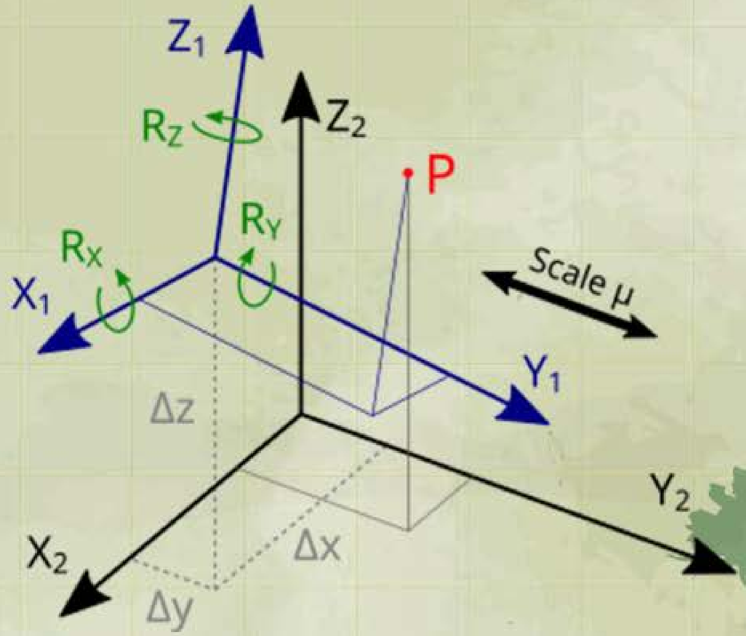
Types	Characteristics
dx, dy, and dz	The three coordinates of origin of local system with respect to origin of a geocentric system, known as translation parameters
• ω, φ, and κ	The three directions of axes of local system with respect to directions of axes of a geocentric system, known as rotation parameters
da and db,	The two differences in semi major axis and semi minor axes of the two systems, or simply ds the change in scale.

Helmert Transformation

The Helmert transformation (named after Friedrich Robert Helmert, 1843–1917) is a geometric transformation method within a three-dimensional space. It is frequently used in geodesy to produce datum transformations between datums. The Helmert transformation is also called a seven-parameter transformation and is a similarity transformation.

It can be expressed as:

$$\boxed{XT = C + \mu R X}$$



Steps of Transformation

Scaling

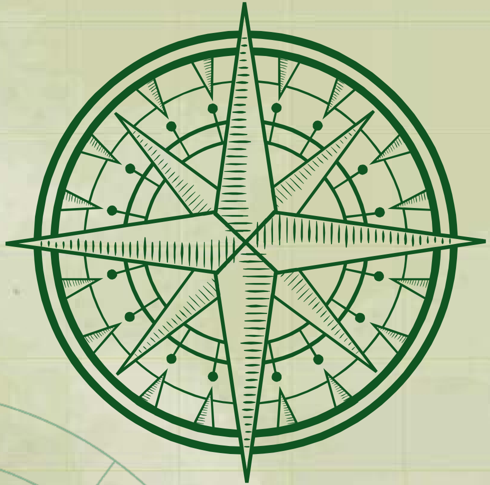
The scales of the two coordinate systems are unequal, scale of the XY system is made equal to that of the ground (EN) system by multiplying each X and Y coordinate by a scale factor s.

Rotation

It is necessary to rotate from the $X'Y'$ system to the $E'N'$ system, or in other words, to calculate $E'N'$ coordinates for the unknown points from their $X'Y'$ coordinates. This is done by using equations.

Translation

The final step in the coordinate transformation is a translation of the origin of the $E'N'$ system to the origin of the EN system. The translation done by using equations.



04

Conclusion

Throughout this slides, we explored the types and evolution of geodesy, shape of the earth, different types of coordinate systems and transformation process, their parameters and steps. Moreover, the application of geodesy in fields like navigation, engineering, environmental monitoring, and disaster management underscores its interdisciplinary importance. As geodesy continues to evolve with advancements in data collection and computational methods, it will remain indispensable for addressing global challenges such as climate change, natural hazards, and sustainable development. In conclusion, geodesy not only enhances our comprehension of Earth's physical properties but also provides critical tools for solving contemporary problems in various sectors. As technology advances, so will the scope of geodesy, making it an ever-more essential discipline for the future.

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THANKYOU