Chapter 1 : Introduction

- 1.1. The need for Positioning
- 1.2. Review of Co-ordinate system

The Need for positioning

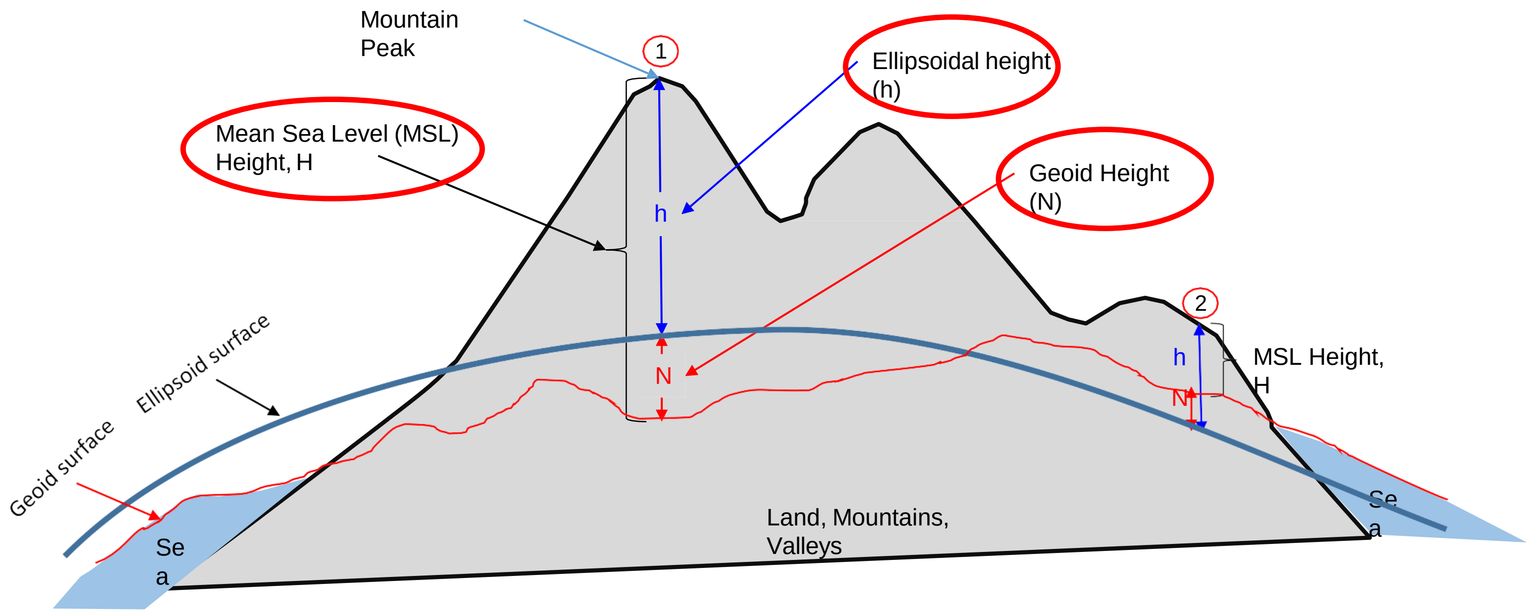
- Positioning: Determining position of any point relative to a reference point.
- Where are you??? Nepal? Pokhara? WRC? Room? Room number? Is it exact?
- How to identify a ship in the sea? Star in the sky?
- Control point establishment
- Maintenance of national geodetic networks (*comparative positioning study of Nagarkot Laplace station: 1.82 m elevation increase after earthquake 2072)*
- Taking as reference station
- Identification of physical shifting of earth (remember earthquake 2072)

How? → Horizontal and Vertical Components

- It requires distance from the point to the reference point (direct distance with the horizontal component that is horizontal distance and the vertical component that is vertical distance), direction, which has two components: horizontal component and vertical component).
- In classical geodesy, astronomical positioning is conducted by star observations. Parallel to positioning, to study the earth gravity field requires gravity data at the whole of the earth surface.
- In geodetic surveying, the computation of the geodetic coordinates of points is performed on an ellipsoid which closely approximates the size and shape of the earth in the area of the survey.
- Positioning are categorized into two types: Geodetic (local/global) and Astronomic Positioning

Positioning Component

- Ellipsoid and MSL



MSL Height (H) = Ellipsoidal height (h) – Geoid height (N)
Geoid Height is negative if its below Ellipsoidal height

Example at point (1) : h = 1200m, N = -30m
H = h – N = 1200 – (-30) = 1200 + 30 = 1230m

Example at point (2) : h = 300m, N = +15m
H = h – N = 300 – 15 = 285m

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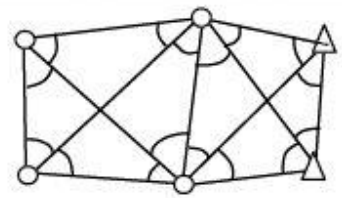
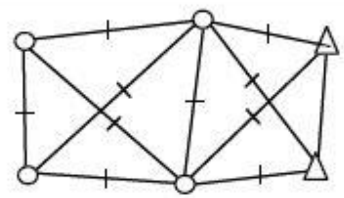
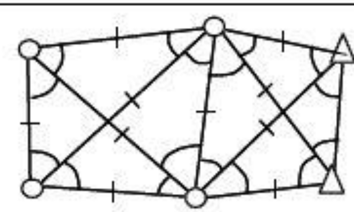
- There are three geodetic networks: geodetic traverse, triangulation and trilateration.

METHOD	GEOMETRY (Example)	OBSERVATION
Triangulation		*Angles* at all points
Trilateration		All *Distances*
Triangulateration		All *Angles* and *Distances*

▲ Points with known coordinates
○ Points to be positioned

Measured angles

Measured distances

The Need for positioning

1. Determination of precise global, regional and local three-dimensional positions (e.g. the establishment of geodetic control)
2. Determination of Earth's gravity field and linear functions of this field (e.g. a precise geoid)
3. Measurement and modeling of geodynamical phenomena (e.g. polar motion, Earth rotation, crustal deformation)

Fig : Positional Location

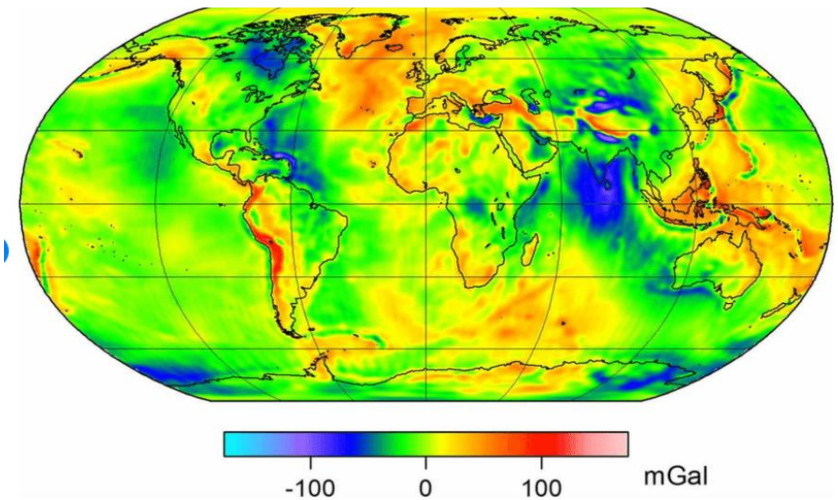


Fig : Gravity Field Model

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- <u>International Association of Geodesy(IAG)</u>

➢ scientific organization in the field of Geodesy

➢ promotes the scientific cooperation and research in geodesy on a global scale and contribute to it through its various research bodies

➢ promotes geodetic theory through research, by collecting, analyzing, modelling, and interpreting observational data, by stimulating technological development

➢ also consistently represent the figure, rotation, and gravity field of the earth and planets, and their temporal variation.

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https://www.iag-aig.org/

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IAG Commissions

Commission 1 - Reference Frames

Final Structure of Commission 1 for the period 2015-2019: President: Geoffrey Blewitt (USA) Vice President: Johannes Böhm (Austria) Terms of Reference Reference systems and frames are of primary importance for much Earth science based research and applications, satellite navigation as well as for practical applications in geoinformation.

Commission 2 - Gravity Field

The accurate determination of the gravity field and its temporal variations is one of the three fundamental pillars of modern geodesy (besides of geometry/kinematics and Earth rotation). This is essential for applications in positioning and navigation, civil engineering, metrology, but also for many geoscientific disciplines, because the Earth's gravity field reflects the mass distribution and its transport in the Earth's interior and on its surface.

Commission 3 - Earth Rotation and Geodynamics

Geodynamics is the science that studies how the Earth moves and deforms in response to forces acting on the Earth, whether they derive from outside or inside of our planet. This includes the entire range of phenomena associated with Earth rotation and Earth orientation in space. Commission 3 fosters and encourages research in the aforementioned areas.

Commission 4 - Positioning and Applications

The structure of Commission 4 - Positioning and Applications of the IAG: The document can be downloaded using the following link.

Fig : IAG commissions

Contd.....

- The International Association of Geodesy (IAG) has four commissions, which are;
- Commission 1 - Reference Frames
- Commission 2 - Gravity Field
- Commission 3 - Earth Rotation and Geodynamics
- Commission 4 - Positioning and Applications

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- Commission 4 mainly focuses on:

➢ determination of position on the space or on the surface of earth(planet) using different instrument (system) , such as:

Inertial Navigation System(INS)

Global Navigation Satellite System(GNSS)

➢ carries out research and other activities that address the broader areas of multi-sensor system theory and application, on integrated guidance, navigation, positioning and orientation of airborne and land-based platform.

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- **Reference System**
  - A reference system consists of the adopted coordinate system
  - In addition, it consists of a set of constants, models and parameters, that are required in order to achieve a certain degree of generality or idealization.
  - It could define the constants of a reference ellipsoid or the parameters of a reference gravity field.
  - Since positioning and navigation are global activities, it is important that the same set definitions is used everywhere.
  - Internationally adopted conventions are necessary.
  - The International Earth Rotation and Reference System Service (IERS), a joint service of the International Association of Geodesy (IAG) and of the International Astronomical Union (IAU) prepares the definition of conventional reference systems and their implementation.
  - The examples are conventional International Celestial Reference System (ICRS) is adopted by IAG and IAU, the international terrestrial reference system (ITRS) by IAG etc.

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- **Coordinate System**
  - Coordinate systems are the central - mathematical - element of any geodetic reference system.
  - It is also defined as the set of rules that dictates how the coordinates are assigned to particular locations.
  - The choice of a coordinate system in three dimensions requires:
    - the definition of its origin (three elements),
    - the orientation of the axes (three elements), and
    - the scale. (same along all axes)
  - It is convenient and common practice to choose orthonormal base vectors and the same scale along all three axes.
  - It is a matter of convenience to tie a system of curvi-linear coordinates, such as spherical, geographical or ellipsoidal coordinates to any such orthonormal system of base vectors.
  - The transformation between coordinates given in two systems consists of:
    - a shift of origin (three degrees of freedom)-translation
    - rotations of the base vectors (three degrees of freedom)
    - Scale change (some time)

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- **Reference Frame**
  - a reference frame contains all elements required for the materialization of a reference system in real world. (it is the library of all datasets that is to be used for defining the coordinate system)
  - In the case of space fixed or celestial frames it is essentially an adopted catalogue of celestial objects such as stars or quasars,
  - in the case of a terrestrial frame it is the catalogue of coordinates of terrestrial points (stations, observatories) etc.
  - The catalogues are chosen to be consistent with the conventions of the corresponding reference system.
  - The reference frames are changing almost every year because of the dynamic nature of the earth(geodynamic phenomenons).

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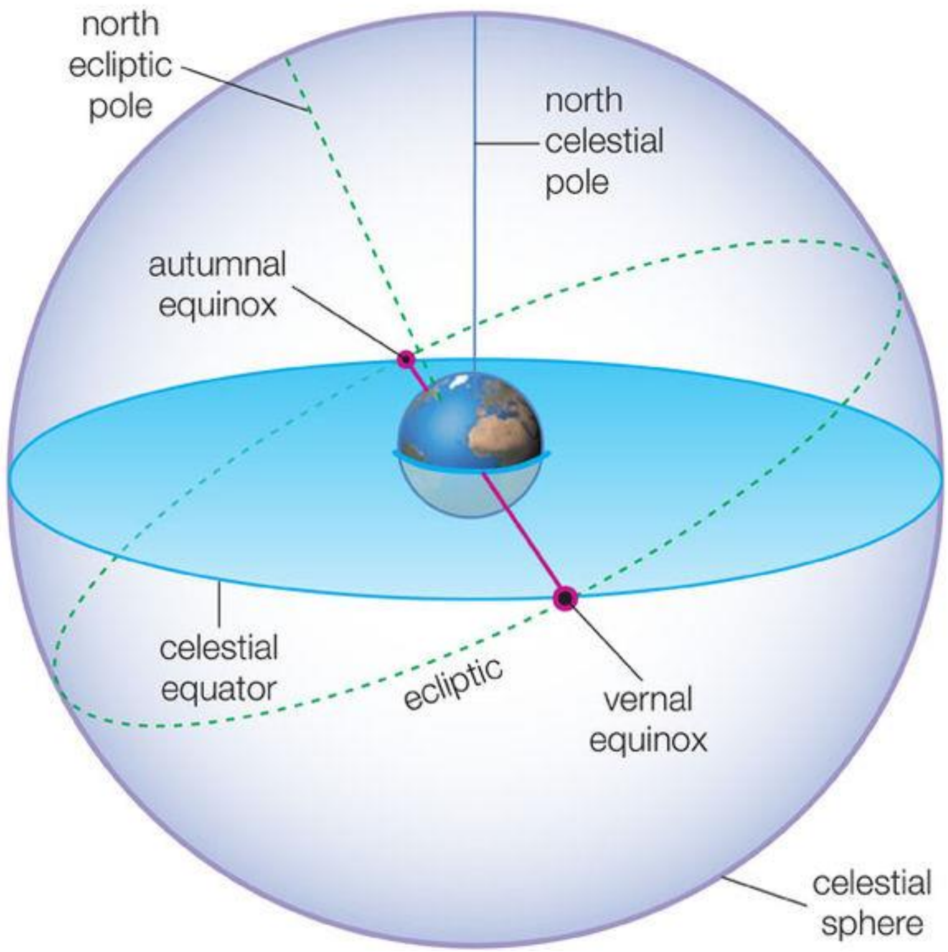
- Mainly three types of reference systems:
  - Space-fixed or inertial systems or Celestial reference system, in which the positions of stars are fixed or almost fixed and in which the motion of artificial satellites can be formulated.
  - Earth centered earth fixed systems, in which all terrestrial points can be expressed conveniently as well as vehicles in motion on the earth's surface.
  - Local horizon systems, fixed to observatories or instruments and often oriented horizontally with one axis pointing towards north.

Space-fixed reference systems (celestial reference systems (CRS))

- Origin is chosen either the barycenter (center of mass of the all the planet) of the solar system or the mass centre of the earth excluding the oceans.
- The coordinate system can be represented as (x,y,z) triad.
- The {x, y}-plane of a CRS could either be chosen to coincide with the plane of the ecliptic(path traced by the sun) or with the equator plane of the earth.
- The x-axis points in the direction of the vernal equinox.
- The z-axis points into the direction of the mean rotation axis of the earth.
- The y-axis completes a right-handed system.

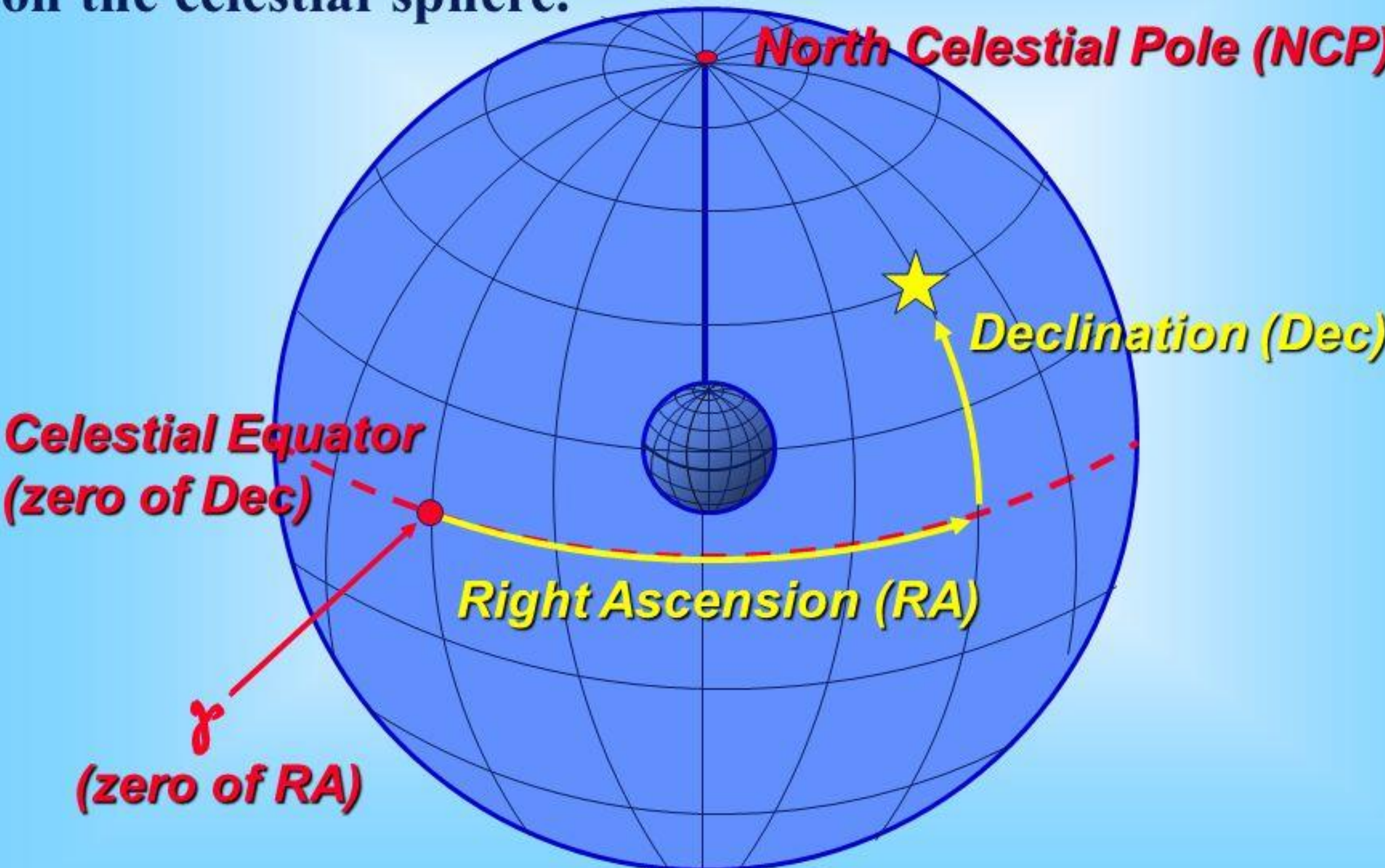
Space-fixed reference systems (celestial reference systems (CRS))

- the direction to any object/event is expressed by the two angles, right ascension α and declination δ
- right ascension α is angle in the equator plane counted from vernal equinox.
- declination δ is elevation angle counted from the equator plane.



Right Ascension & Declination

With these two directions, any object can be located on the celestial sphere.



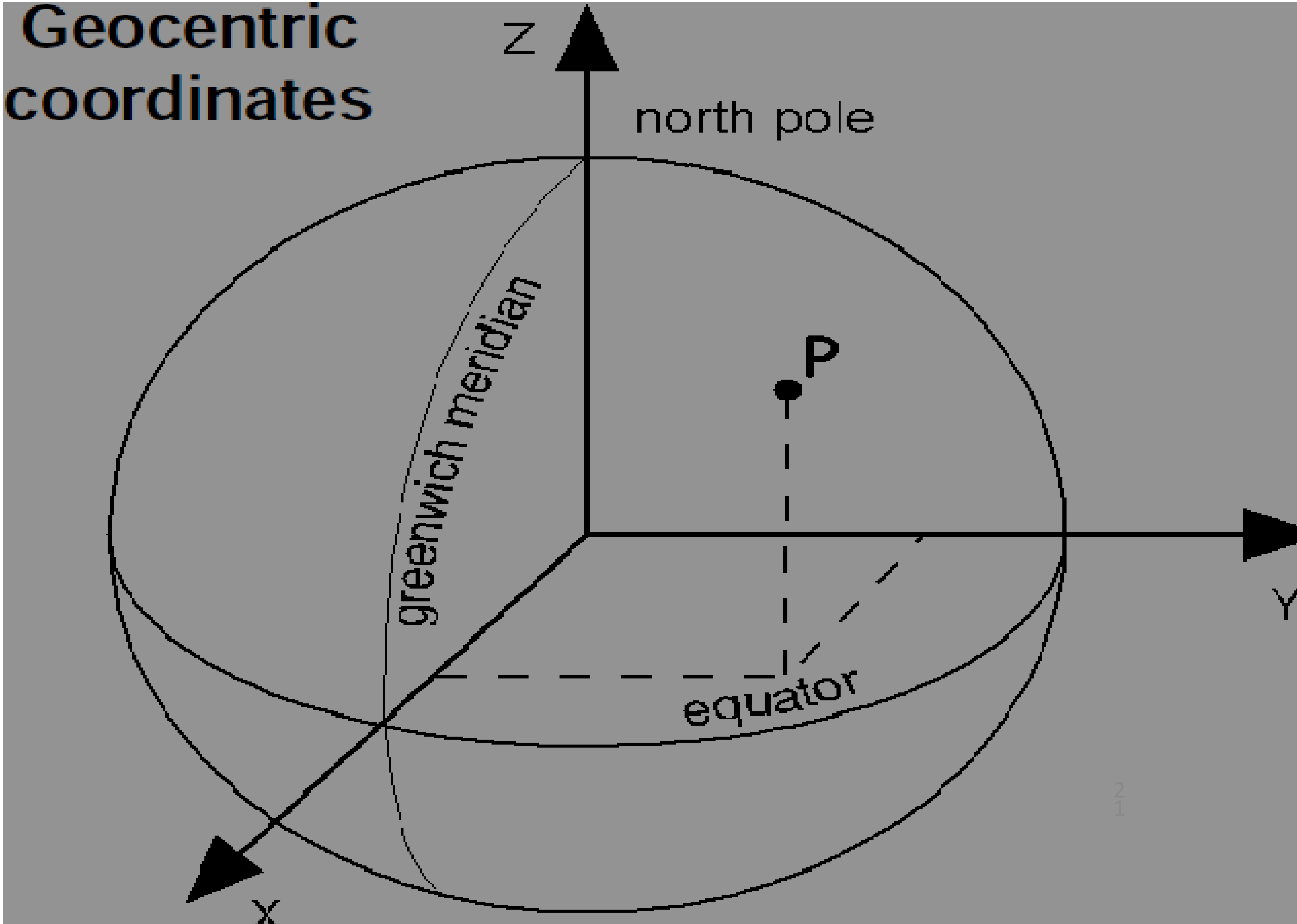
Earth-fixed reference systems (terrestrial reference System TRS)

- They serve the description of the position of points on the earth's surface or, in the case of navigation, that of the motion of a vehicle on the earth's surface or close to it.
- Also geophysical processes such as weather, temperature, magnetic or gravity field are expressed in earth fixed systems.
- All our maps are based upon an earth fixed reference system.
- Due to the advance of space techniques, precisions in positioning and navigation became so incredibly high that the earth's surface cannot be considered anymore solid and fixed.
- Temporal changes due to surface motions such as tectonic plate motions and deformations due to tides or ocean and atmosphere loading have to be taken into account.
- This complicates the definition and realization of an earth fixed reference system severely.
- Such a system can provide a framework for global geophysical monitoring and consequently play a prominent role in earth system studies.

Earth-fixed reference systems (terrestrial reference system TRS)

- The origin of the coordinate system is defined as the centre of mass of the earth including oceans and atmosphere.
- The coordinate system can be characterized by three mutually perpendicular base vectors, let's say (x,y,z)
- The {x, y}-plane coincides with a conventional equatorial plane of the earth.
- The x- axis lies by definition in the Greenwich meridian plane.
- The z- axis coincides the rotation axis of the earth, passes through the terrestrial pole.
- This terrestrial pole is denoted conventional terrestrial pole (CTP) or IERS reference pole (IRP).
- The y- axis completes the right-handed system.

TRS



Geocentric coordinates
Z
north pole
greenwich meridian
P
equator
Y
X

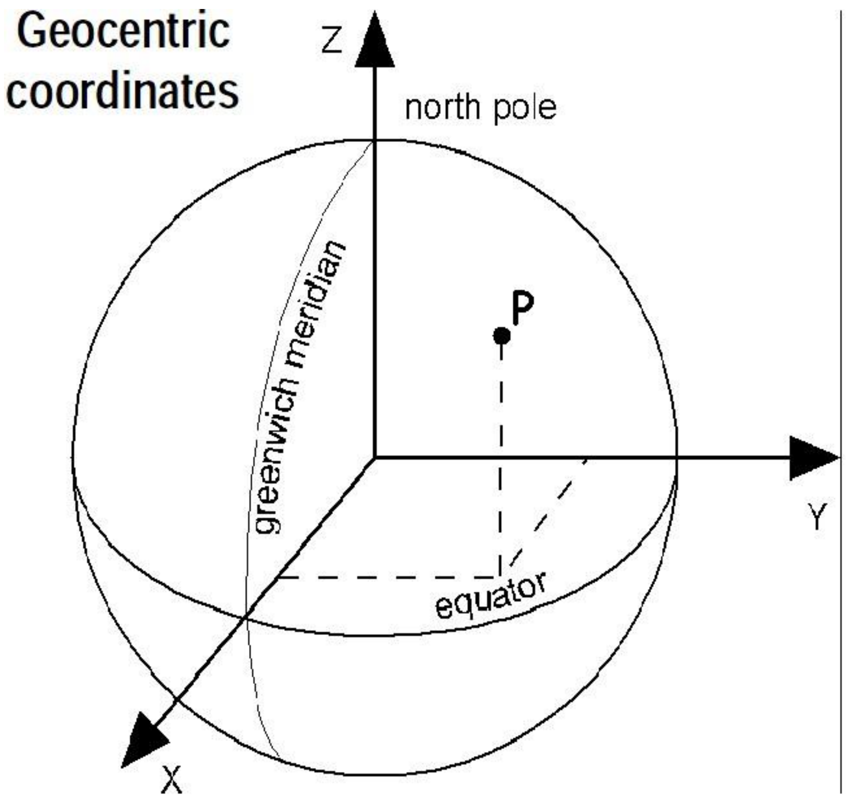
Earth-fixed reference systems (terrestrial reference system(TRS))

- The coordinate triad is accompanied by a mean earth ellipsoid with:
  - semi-major axis a = 6 378 137.0 m and
  - flattening f = 1 / 298.257 222 101.
- It allows an easy conversion of Cartesian into geographical coordinates

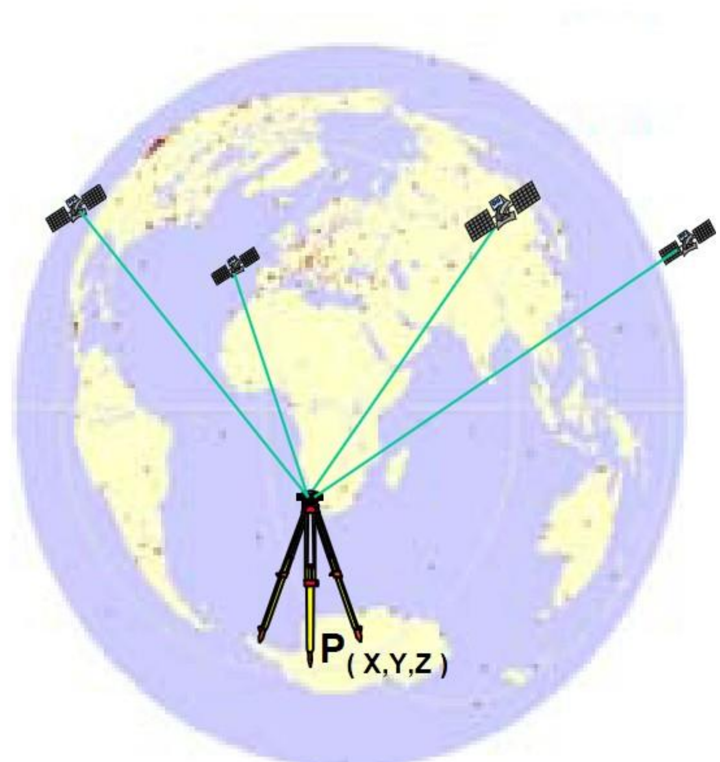
Earth-fixed reference systems (terrestrial reference system (TRS))

- The realization of the International Terrestrial Reference System (ITRS) is denoted as International Terrestrial Reference Frame (ITRF).
- It consists of an adopted global set of Cartesian station coordinates and velocities.
- Almost annually a new ITRF is produced, based upon newest observations and identified as ITRF.yy, where the numbers (yy) following the designation ITRF specify the last year whose data were used for the realization of the frame.

TRS and TRF



International Terrestrial Reference System (ITRS)



International Terrestrial Reference Frame (ITRF)
(E.g. ITRF96)

Change in ITRF

- Various time variable effects on ITRF station coordinates
  - tectonic plate motions
  - tides of the solid earth
  - loading effects due to ocean loading
  - atmospheric loading
  - rotational deformation due to polar motion
  - instrument effects (antenna deformation, motion of antenna phase centres etc.)

Space techniques contributing to ITRS

- very long baseline interferometry (VLBI)
  (high precision and long term stability)

- satellite laser ranging (SLR)
  (long term stability and geo-centricity)

- lunar laser ranging (LLR)
  (geo-centricity, long term stability, relativistic effects)

- the French tracking system DORIS
  (excellent global station distribution)

- Global Positioning System
  (densest global network, short term stability, high precision).

Local horizontal reference systems (Topocentric System)

- This class of systems is associated with an instrument such as a GPS receiver, a VLBI telescope or a camera.
- They are located in the origin or reference point of the instrument
- purpose is to determine the coordinates of this reference point, either in CRS or in TRS.
- Local horizontal systems are introduced in order to express the fixed or time variable pointing direction of the instrument to a target point and in order to predict when and under what angles a target will rise or fall.
- The orientation of base vectors of the local system can either be defined by the local horizontal plane, north direction and plumb line direction (zenith) or, in ellipsoidal or spherical approximation, by the corresponding ellipsoidal or spherical quantities.

Local horizontal reference systems (topocentric systems)

- The origin of the coordinate system is the instrument origin (topocentre).
- The base vectors can be denoted by a triad lets say (x,y,z).
- The {x, y}-plane coincides with the local horizon (level surface).
- It is often approximated by an ellipsoidal or spherical reference surface.
- The base vector x- points towards north.
- The z-axis points towards the zenith (or normal of the ellipsoid or sphere).
- Base vector y- completes the left-handed orthonormal triad; it points towards east.
- The angle to an object in the horizontal plane counted from north (towards east) is called azimuth A,
- the angle to an object from the zenith is denoted zenith distance z
- the elevation angle above the horizontal plane is called elevation angle b.
- Thus, when tracking a satellite at a station its changing direction in the horizontal system is expressed by the angles {A, z}.

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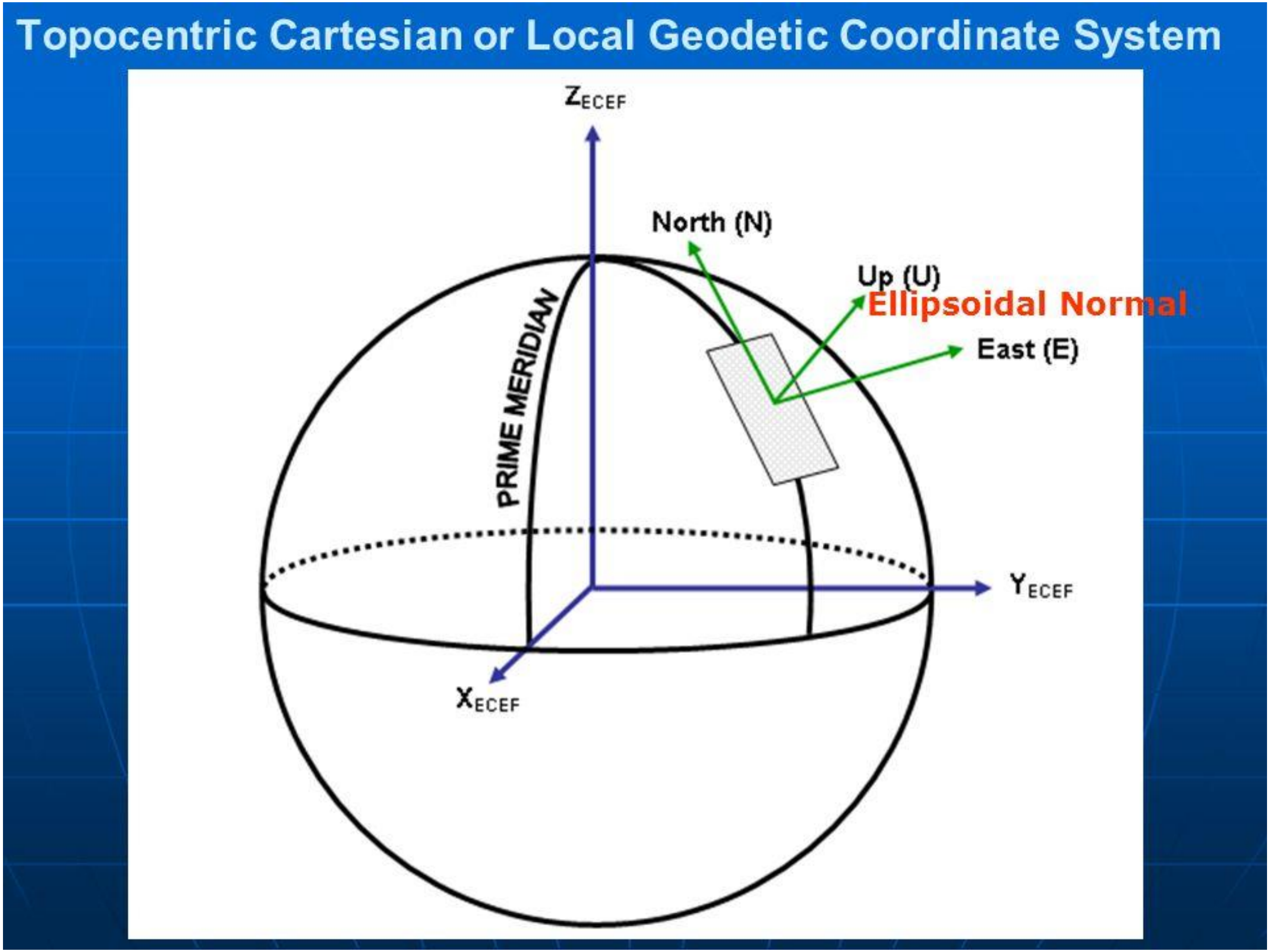
Topocentric Cartesian or Local Geodetic Coordinate System
Z_{ECEF}
North (N)
Up (U)
Ellipsoidal Normal
East (E)
PRIME MERIDIAN
Y_{ECEF}
X_{ECEF}

Coordinate System

- Broad category of Coordinate system are:
  1. Geocentric/3D-Cartesian Coordinate System
  2. Geodetic/Geographic/Ellipsoidal Coordinate System
  3. Astronomical Coordinate system

3D-Cartesian Coordinate system

- A concentric Cartesian coordinate system *X, Y , Z can be defined within the ellipsoid*
  - origin at the center O of the ellipsoid (geo center)
  - *Z-axis directed to the northern ellipsoidal pole (along the minor axis),*
  - *X-axis directed to the ellipsoidal zero meridian,*
  - *Y -axis completing a right-handed system.*

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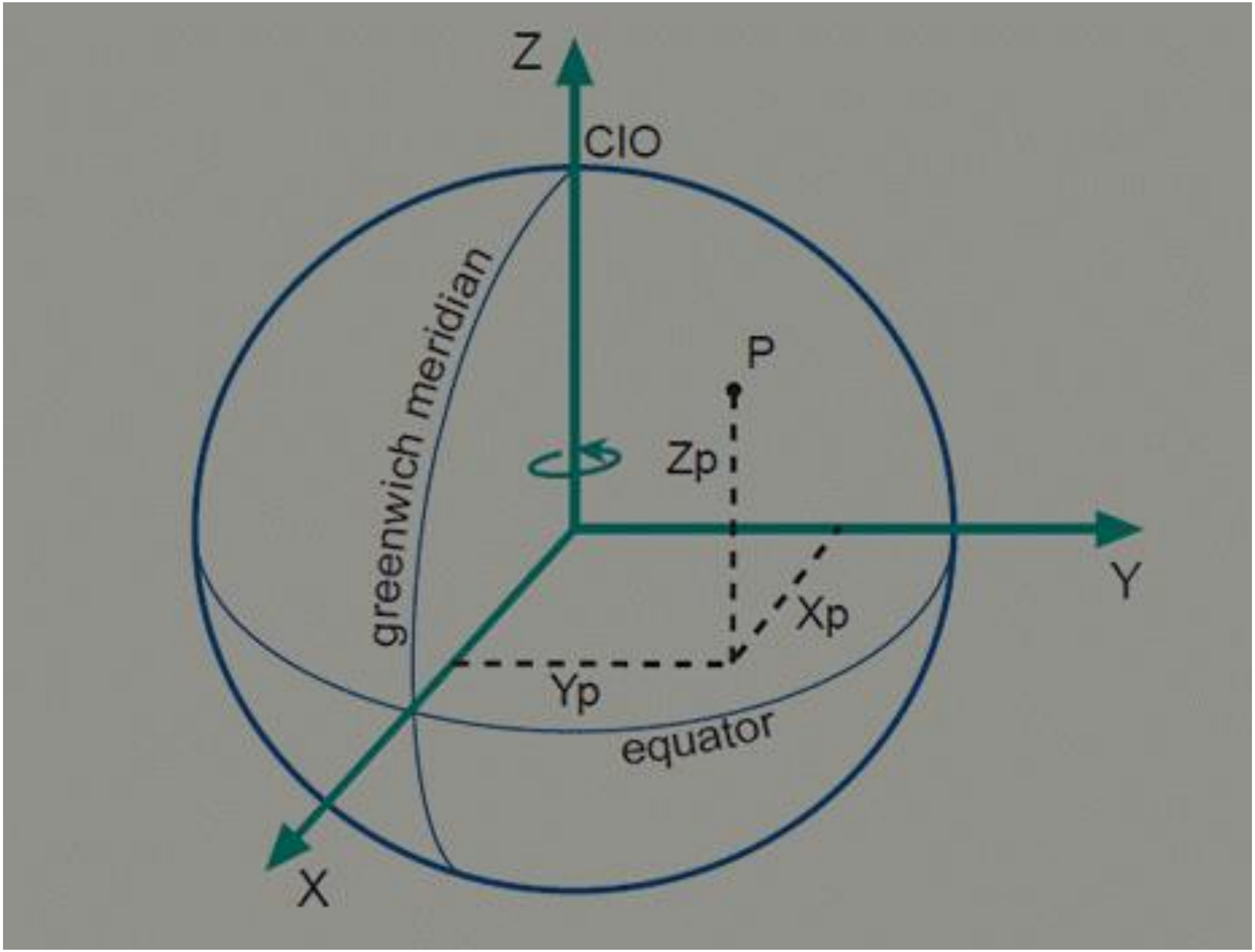


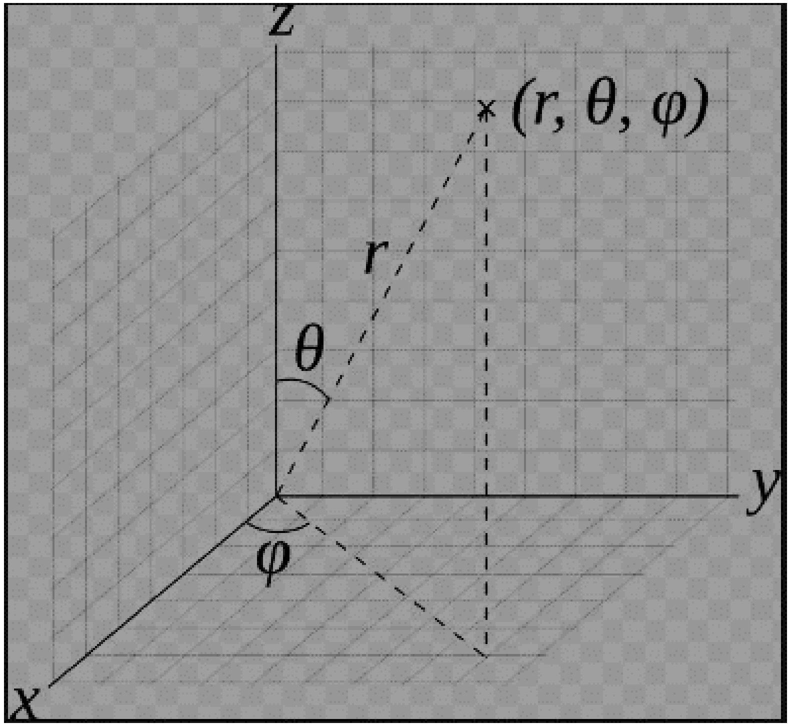
Spherical Co-ordinate system

- A spherical Co-ordinate system is a co-ordinate system for three-dimensional space where the position of a point is specified by three numbers:

  i. *radial distance(r)* of that point from a fixed origin,

  ii. *polar angle (θ)*measured from a fixed zenith direction,

  iii. azimuth angle(ϕ) of its orthogonal projection on a reference plane that passes through the origin and is orthogonal to the zenith, measured from a fixed reference direction on that plane.



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- The polar distance should be always greater of equal to Zero

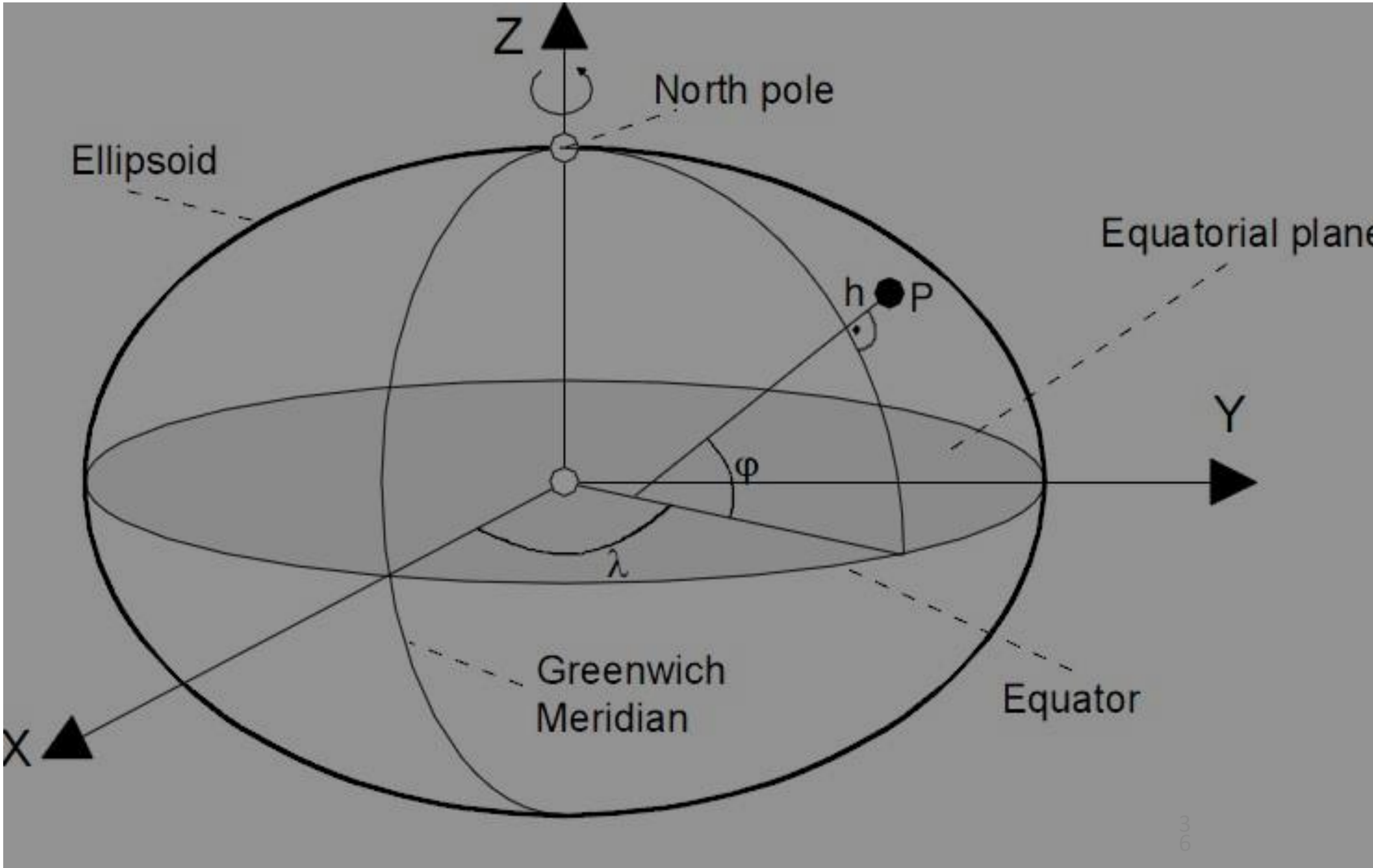
  $r \geq 0$

- The azimuthal angle is: $0 \leq \phi \leq \pi$
- The polar angel or Zenith angle : $0 \leq \theta \leq 2\pi$

Ellipsoidal Coordinate System

- A best possible approximation to the figure of the whole Earth is a *global ellipsoidal system.*
- *The ellipsoidal/geographic coordinates are represented as*
  - ϕ *ellipsoidal latitude*
  - λ *ellipsoidal longitude*
  - *h ellipsoidal height.*

Ellipsoidal Coordinate System



: Illustration of the ellipsoidal co-ordinates

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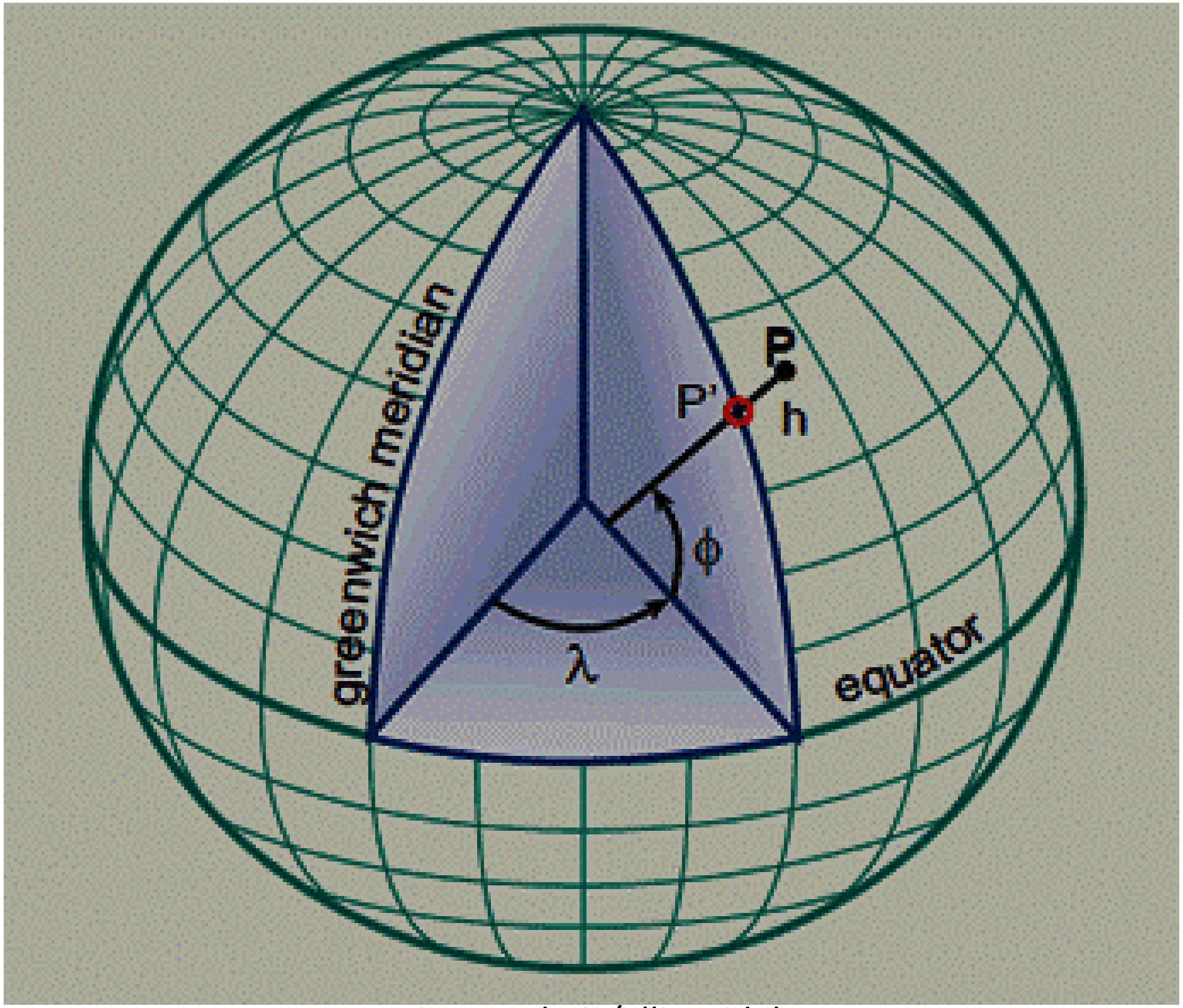

Fig: Geodetic/Ellipsoidal