राष्ट्रीय भू-सूचना विज्ञान एवं प्रौद्योगिकी संस्थान
भारतीय सर्वेक्षण विभाग
विज्ञान और प्रौद्योगिकी विभाग

National Institute for Geo-Informatics Science & Technology
Survey of India
Department of Science & Technology

Coordinate Systems

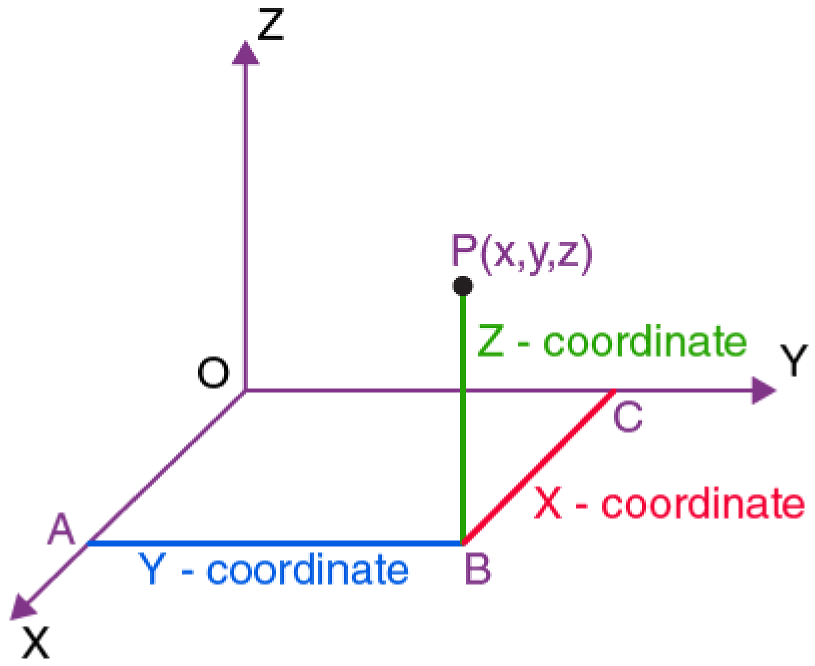
S. D. SHARMA, Officer Surveyor
Faculty of Topo. & GIS, NIGST,
Survey of India, Hyderabad
Email ID: sdsharma.soi@gov.in
Contact: +917097008906

Session Objectives

- **Understand how a coordinate system is defined** (origin, axis orientation, and coordinate parameters). Coordinate Systems
- **Explain terrestrial reference systems** and distinguish between **geocentric and topocentric systems**.
- **Understand Earth rotation effects,IRP and ITRF**.
- **Differentiate Average Terrestrial (A.T.) and Instantaneous Terrestrial (I.T.) systems** and their modern interpretations.
- **Define and use geodetic coordinates**—latitude (ϕ), longitude (λ), and ellipsoidal height (h).
- **Distinguish between normal sections and geodesics** and understand their practical significance in geodesy.

Coordinate System

- To define any **coordinate system**, the following three fundamental elements are required:
- **The location of the origin**
- **The orientation of the three coordinate axes**
- **The mathematical parameters** (Cartesian or curvilinear) used to define the position of a point with respect to these axes



Fundamental Reference Elements

Primary Pole

- The **Primary Pole** is the **axis of symmetry** of the coordinate system.
- It represents the physical or geometric axis.
- **Example:** The Earth's **axis of rotation**, passing through the North and South Poles.

Primary Plane

- The **Primary Plane** is the plane **perpendicular to the Primary Pole**.
- It serves as the fundamental reference plane.
- **Example:** The **Earth's equatorial plane**, perpendicular to the Earth's rotation axis.

Fundamental Reference Elements

Secondary Plane

- The **Secondary Plane**:
- is p**erpendicular to the Primary Plane**
- **Contains the Primary Pole**
- Often chosen **arbitrarily**, depending on convention
- **Example:**
- The **Greenwich meridian plane**, which contains the Earth's rotation axis and defines the reference longitude.

Secondary Pole

- The **Secondary Pole** is the **line of intersection** between the **Primary Plane** and the **Secondary Plane**.
- This pole defines a fixed reference direction within the primary plane.

Coordinate Axes

Primary Axis

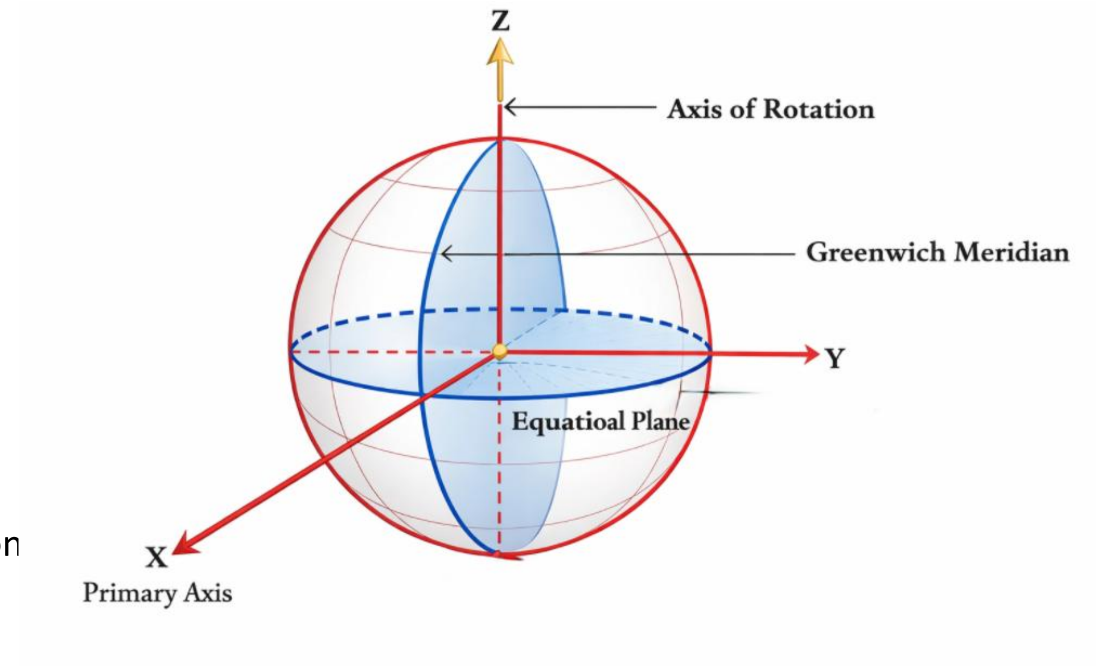
- Passes through the **Secondary Pole**
- Lies in the **Primary Plane**
- Acts as the principal reference direction in that plane

Tertiary Axis

- Passes through the **Primary Pole**
- Coincides with the **axis of symmetry** of the system
- **Example:** Earth's rotation axis (Z-axis in Earth-centered systems)

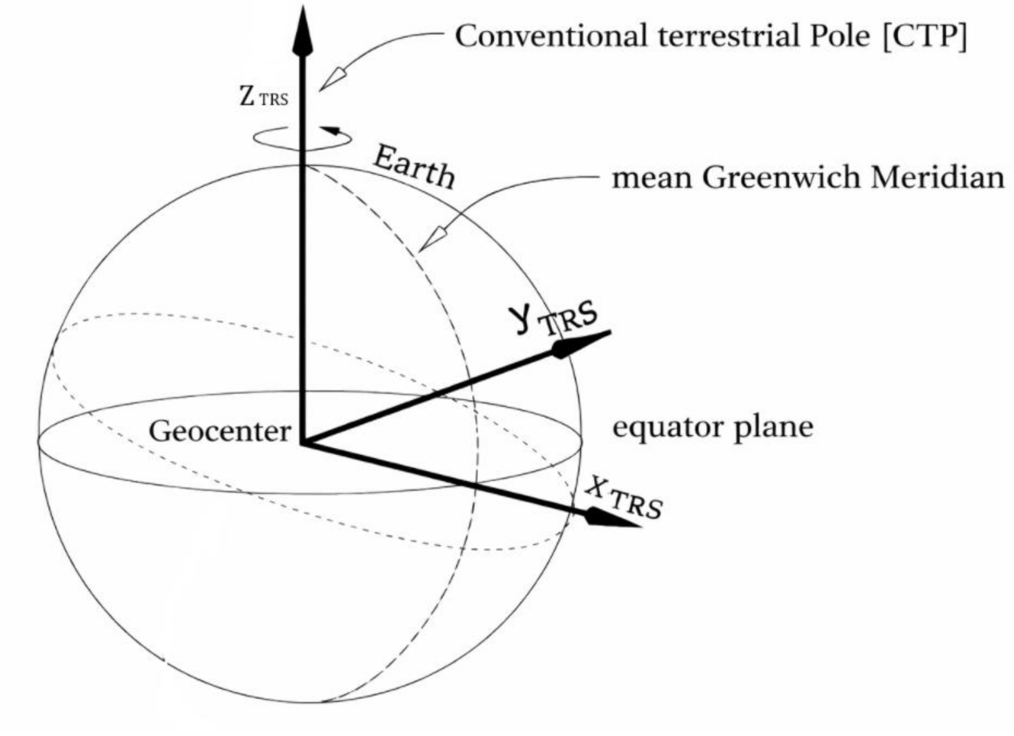
Secondary Axis

- Is **perpendicular to both the Primary and Tertiary axes**
- Its direction is chosen so that the coordinate system becomes either:
  - **Right-handed**, or
  - **Left-handed**
- This choice determines the mathematical orientation and sign convention the coordinate system.



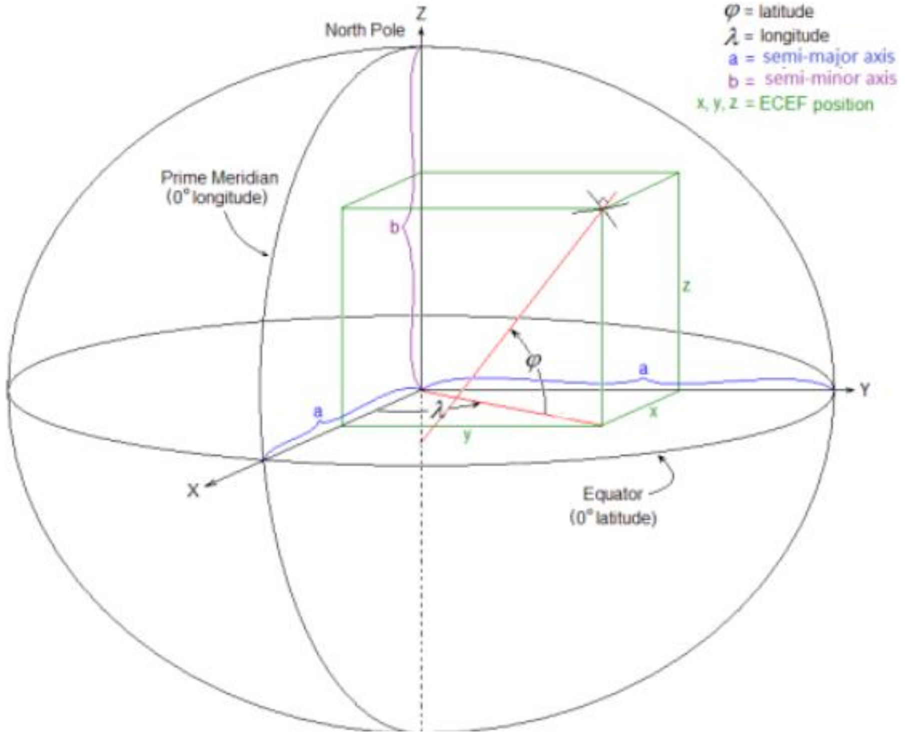
Terrestrial coordinate systems

- **Terrestrial coordinate systems** are **Earth-fixed systems**, meaning they **rotate with the Earth**. They are primarily used to define the **coordinates of points located on or near the Earth's surface**.
- Terrestrial coordinate systems are broadly classified into two types:
- **Geocentric coordinate systems**
- **Topocentric coordinate systems**



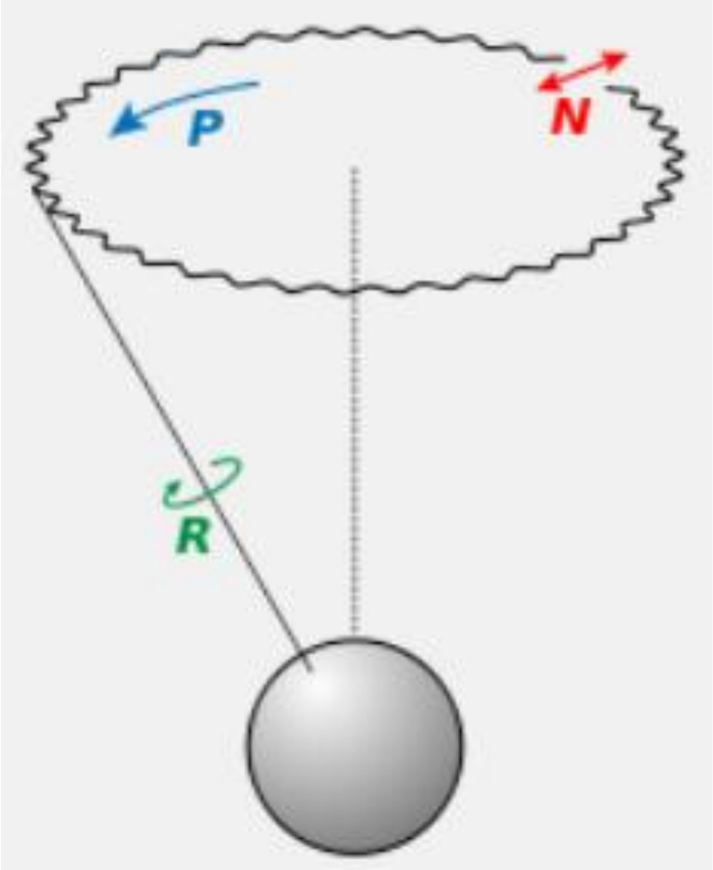
Terrestrial Geocentric Coordinate Systems

- A **terrestrial geocentric system** is a global reference system used to define positions with respect to the whole Earth.
- **Fundamental characteristics**
- **Origin**
  - Located **near the Earth's centre of mass**
- **Primary Pole**
  - Aligned with the **Earth's axis of rotation**
- **Primary Axis**
  - Defined as the **intersection of the primary plane (equatorial plane)** and the **plane containing the Greenwich meridian**
- **Handedness**
  - The system is defined as **right-handed.**



Polar Motion (Chandler Wobble)

- More than a century ago, it was discovered that the **Earth's rotation axis moves with respect to the Earth's surface**. This phenomenon is known as **polar motion**.
- **Key characteristics of polar motion:**
- Caused by the **non-coincidence of the Earth's rotation axis and its axis of maximum inertia**
- Motion is:
  - **Irregular**
  - Approximately **circular**



Polar Motion

- The monitoring of Earth's rotation and polar motion is carried out by the International Earth Rotation and Reference Systems Service (IERS), which has superseded the earlier organisations such as the International Polar Motion Service (IPMS) and the Bureau International de l'Heure (BIH).
- The IERS routinely determines polar motion and Earth orientation parameters using space-geodetic techniques, including:
    - GNSS
    - Satellite Laser Ranging (SLR)
    - Very Long Baseline Interferometry (VLBI)
    - DORIS
- These observations are obtained from a global network of continuously operating stations, providing millimetre-level accuracy.
- The position of the Earth's rotation axis is now expressed with respect to the IERS Reference Pole (IRP) and the International Terrestrial Reference Frame (ITRF), which together replace the historical Conventional International Origin

Average Terrestrial System

- It represents an **idealised global terrestrial reference system**, defined using **time-averaged Earth rotation parameters** to minimise the effects of short-period polar motion and rotational irregularities. In modern geodesy, its conceptual role is realised through **IERS-based terrestrial reference systems**.

a) Origin : It is located at the **Earth's centre of mass (centre of gravity)**, as realised by space-geodetic observations (GNSS, SLR, VLBI, DORIS).

b) Primary Pole and Primary Plane: The **primary pole** is directed towards the **IERS Reference Pole (IRP)**, which represents the **mean position of the Earth's rotation axis** .

- The **primary plane** is the plane:
  - **Perpendicular to the primary pole**, and
  - **Passing through the Earth's centre of mass**, corresponding to the **mean equatorial plane**.

c) Secondary Plane and Primary Axis: The **secondary plane** is the plane that:

- Contains the **primary pole**, and

The Instantaneous Terrestrial (I.T.) System

The **Earth-fixed reference system** that represents the **actual, instantaneous orientation of the Earth** at a given epoch. Unlike average systems, it reflects **real-time variations** in Earth rotation and polar motion.

a) **Origin**: The origin is located at the **Earth's centre of mass (centre of gravity)**, as determined using modern space-geodetic techniques.

b) **Primary Pole and Primary Plane**: The **primary pole** is directed toward the **instantaneous rotation axis of the Earth**, currently realised by the **Celestial Intermediate Pole (CIP)** as defined by the **International Earth Rotation and Reference Systems Service (IERS)**.

- The **primary plane** is the **true equatorial plane**, perpendicular to the instantaneous rotation axis.

c) **Primary Axis**: The **primary axis (X-axis)** is defined by the **intersection of the**

Geodetic Coordinate Systems

- In Cartesian terms, a **geodetic coordinate system** is defined as a coordinate system embedded within the Earth such that its three axes are **either coincident with or parallel to** the corresponding axes of a **terrestrial reference system** (historically the Average Terrestrial system, and today its modern realisation through ITRF)
- **Geocentric Geodetic System**
- If the three axes of the **geodetic coordinate system are coincident with the axes of the terrestrial reference system**, then the system is referred to as a **geocentric geodetic system**.
  - The **origin coincides with the Earth's centre of mass**
  - The axes are aligned with the terrestrial reference axes
  - This is the basis of **modern global datums**, such as those realised through **ITRF and WGS-84**
- **Relative (Local) Geodetic System**:
  - If the three axes of the **geodetic coordinate system are parallel to**, but **not coincident with**, the axes of the terrestrial reference system

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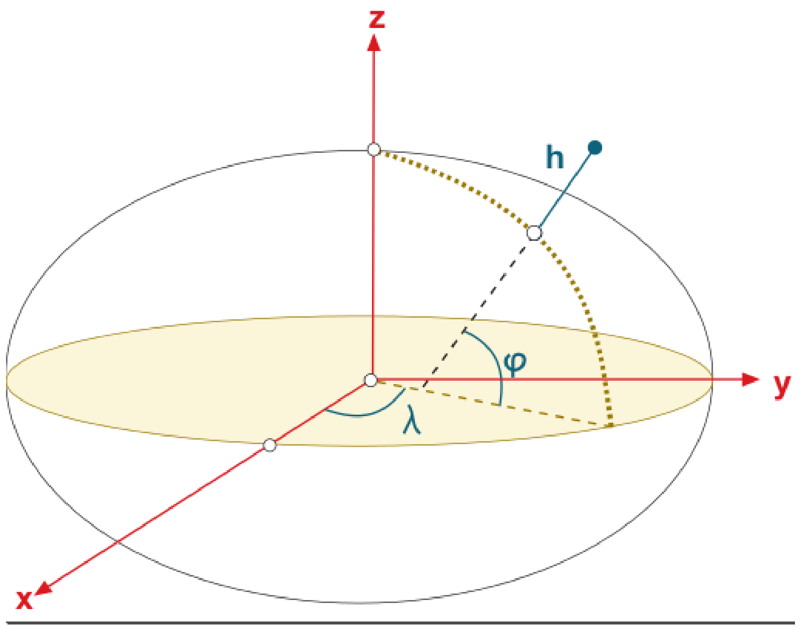


Geodetic Latitude & Longitude

Geodetic Latitude (ϕ)

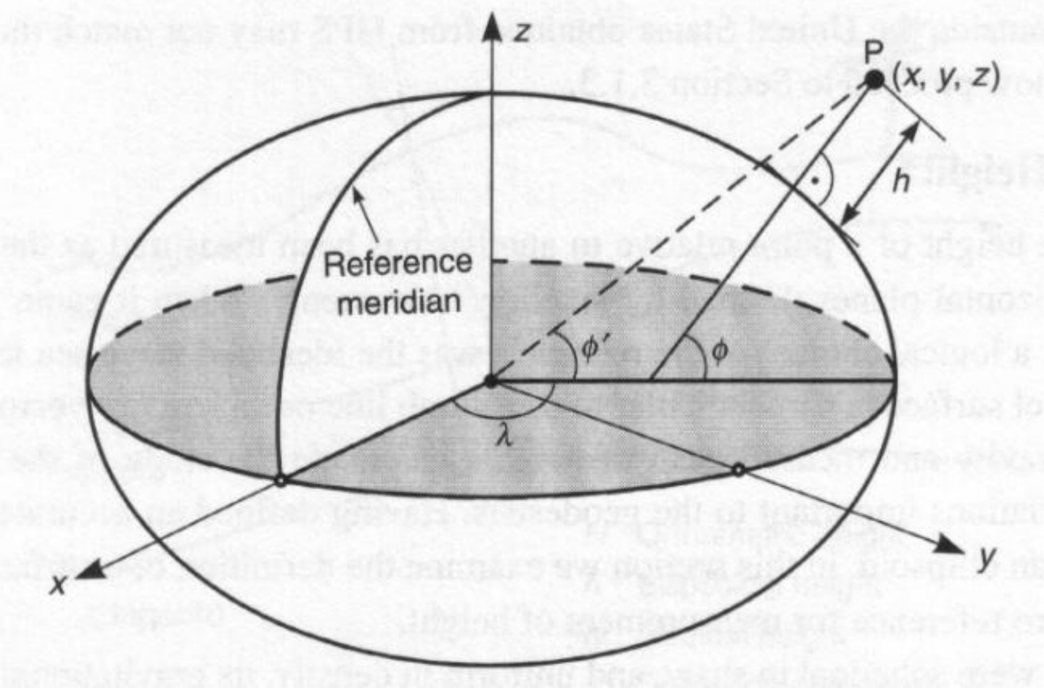
- The geodetic latitude (ϕ) of a point is defined as the acute angle between the equatorial plane and the normal to the reference ellipsoid at that point.

Geocentric Latitude (ϕ')

- The geocentric latitude (ψ) is the angle between the line joining the point to the centre of the ellipsoid (Earth's centre of mass) and the equatorial plane.

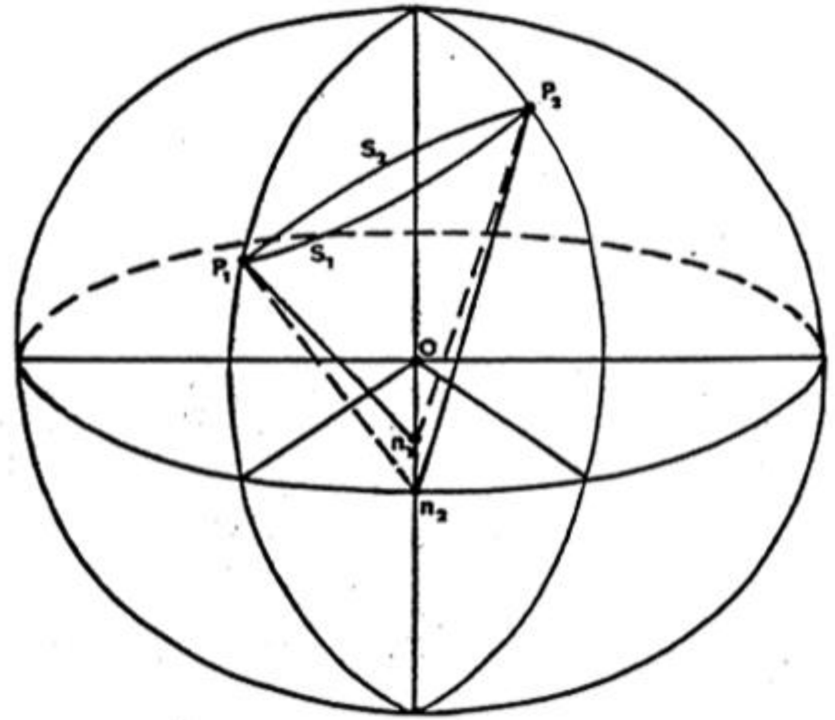
Longitude (λ)

- The longitude (λ) of a point is the anticlockwise angular distance, measured in the equatorial plan



Principal Curves on the Ellipsoid of revolution

- **Normal Section**
- It is a plane curve created by intersecting a plane containing the normal to the ellipsoid (a normal section plane) with the surface of the ellipsoid.
- The line of intersection of a normal plane (at a point P) and the surface of the ellipsoid.
- Consider two points on the surface of an ellipsoid (P1 and P2) which are on different meridians and are at different latitudes..
- The normal section from P1 to P2 (direct normal

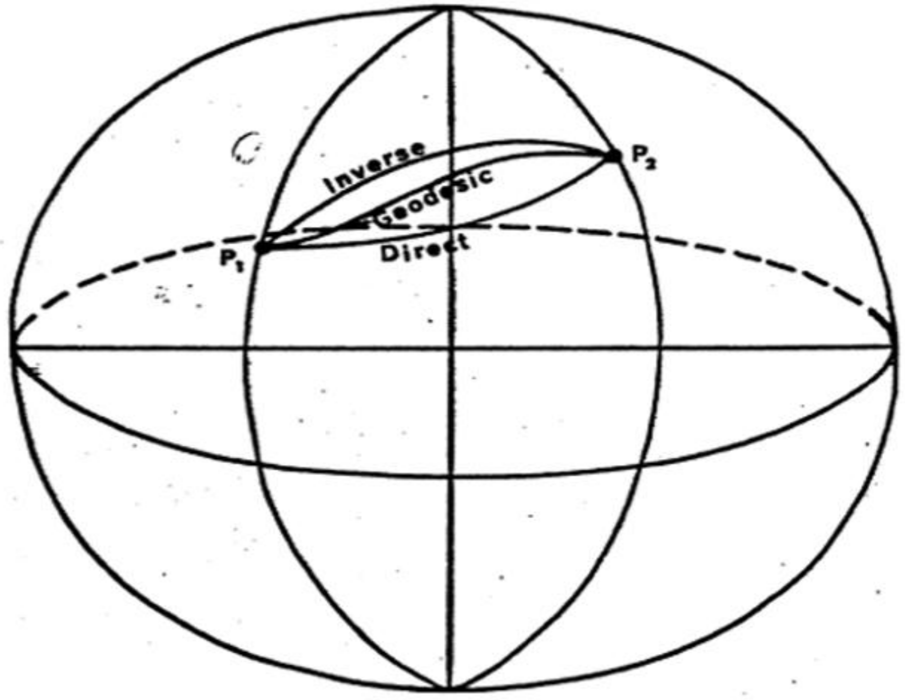


Normal Section

- It is similar to a geodesic, except that it is always a plane curve.
- It is different from a geodesic in that two normal sections exist between any two points, except in the cases of the meridians and the equator.
- The normal section does not give a unique line between two points.

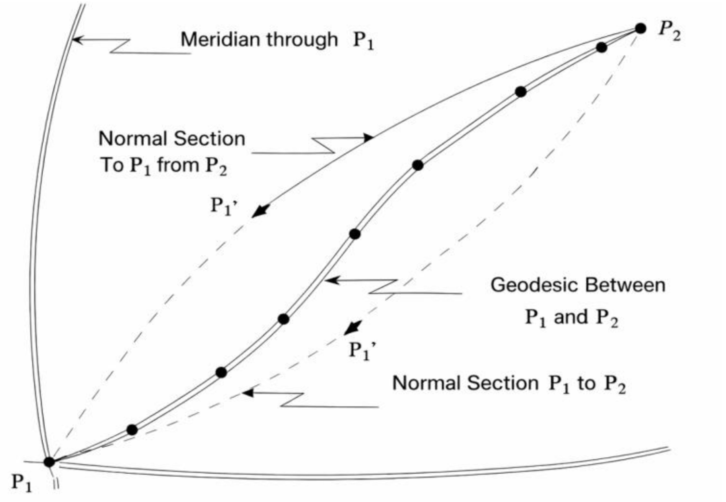
Geodesic

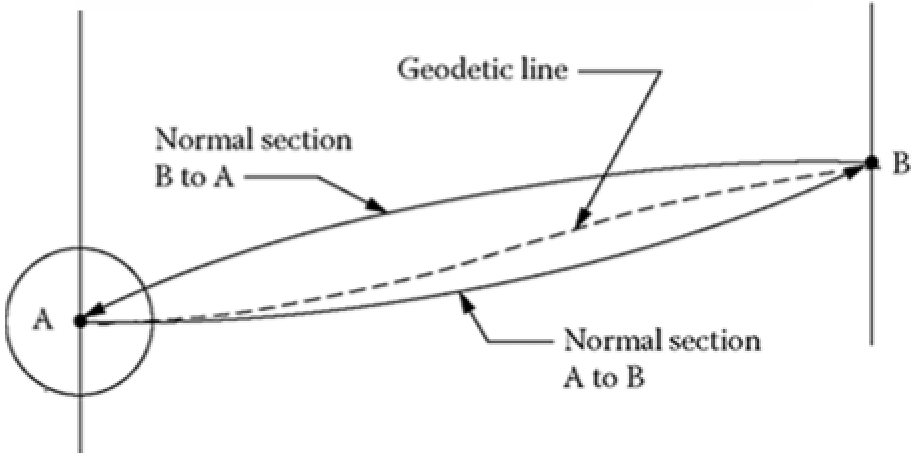
- The geodesic, or geodetic line:- is the unique surface curve between any two points on the surface of an ellipsoid.
- At every point along the geodesic, the principal radius of curvature vector is coincident with the ellipsoidal normal.
- The geodesic between two points P1, P2, is the shortest surface distance between these two



Geodesic

- It is a curve on a surface where at each point of the curve the principal normal of the curve coincides with the normal to the surface of the ellipsoid at this point.
- It lies between two plane curves “normal sections” and has a double curvature.





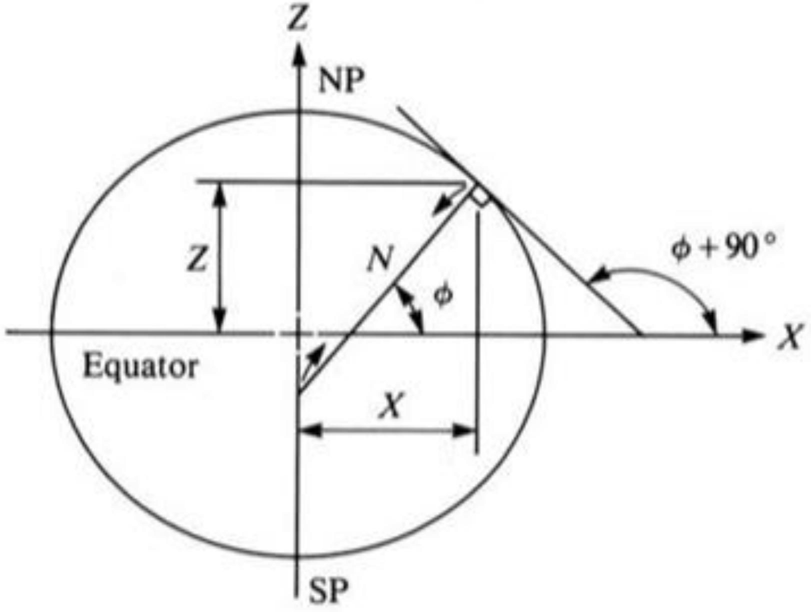
X AND Z COORDINATES ON ELLIPSOID

- X and Z coordinates are represented as a function of geodetic latitude φ.
- According to the shown figure, their

$$X = \frac{a \cos\varphi}{(1 - e^2 \sin^2\varphi)^{0.5}}$$

$$Z = \frac{a(1-e^2)\sin\varphi}{(1 - e^2 \sin^2\varphi)^{0.5}}$$

- ______________________________ (1)
- ______________________________ (2)



RADIUS OF CURVATURE IN PRIME VERTICAL DIRECTION

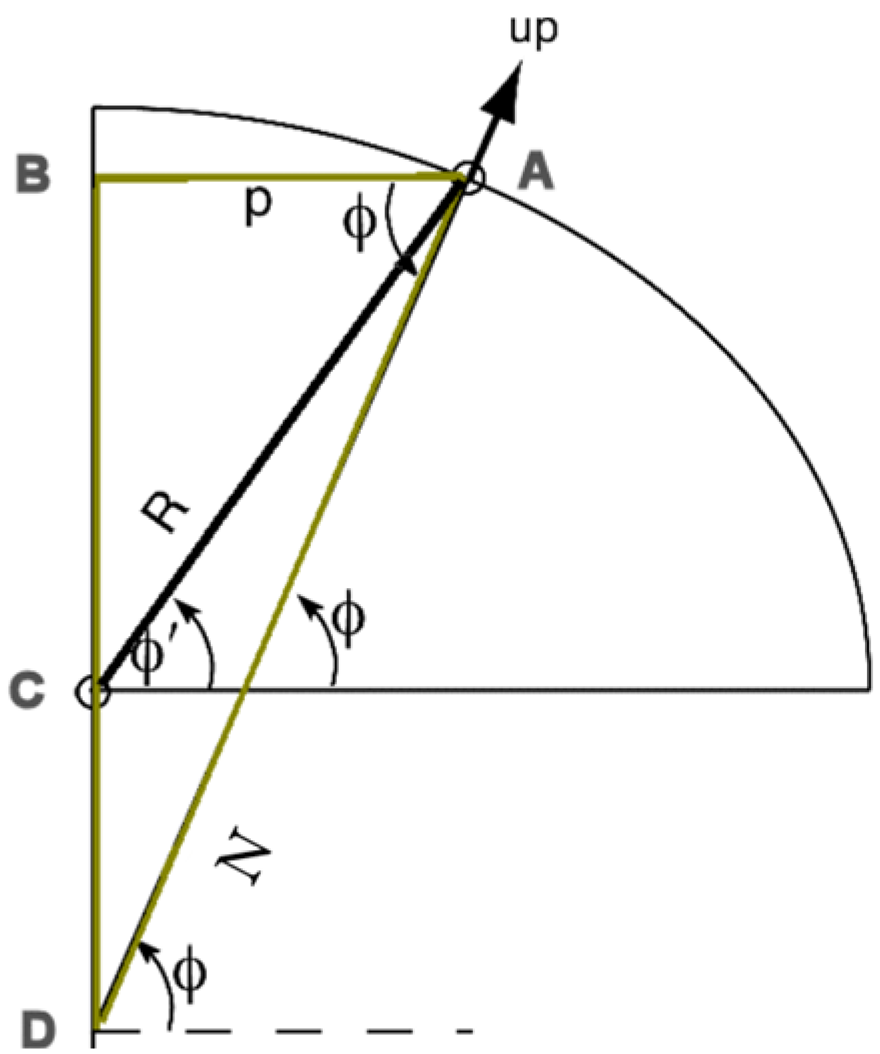
- The radius of curvature in the prime vertical (N) is the radius of the circle that lies in the prime vertical plane, is tangent to the ellipsoid at the point of interest, and has the same curvature as the ellipsoid in the east–

$$N = \frac{a}{\sqrt{1-e^2 sin^2\varphi}}$$

n.

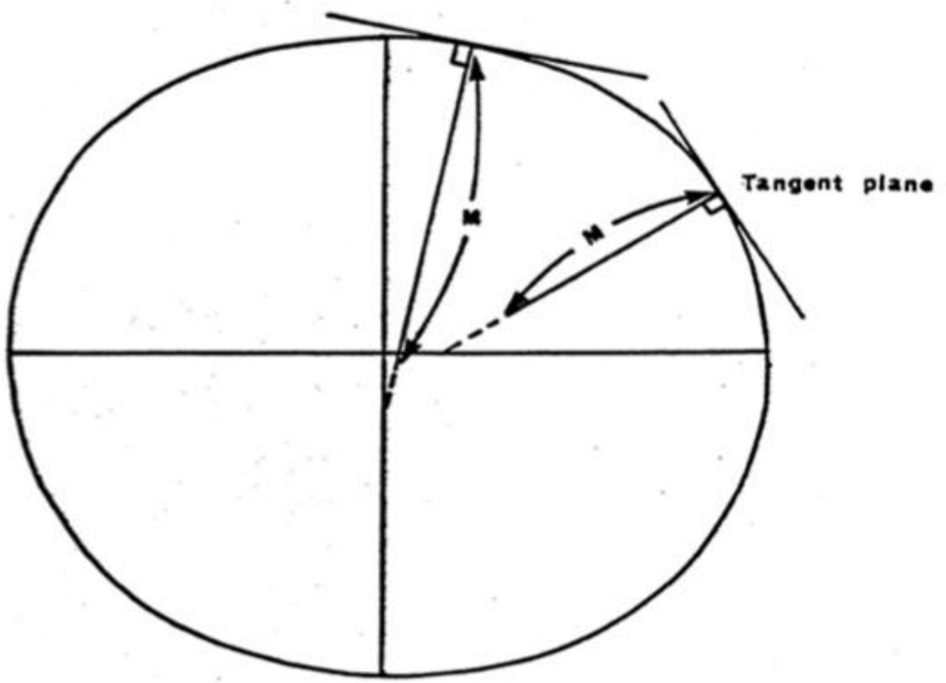
- $N = X / \cos\varphi$ ________________________________ (3)

- __________________________ (4)



RADIUS OF CURVATURE IN MERIDIAN DIRECTION

- The radius of the circle that lies in the meridian plane, is tangent to the reference ellipsoid at the point of $M = \frac{a(1-e^2)}{(1-e^2 sin^2\varphi)^{\frac{3}{2}}}$ d has the same curvature as the ellipsoid in the north–south direction.



Exercise

Problem 1 : For given X, Y, Z, find ϕ, λ, h? Take a and e of WGS-84

- X = 1204251.8202, Y = 5968509.9535, Z = 1894565.9482
- Given a= 6378137.0 and e^2 = 0.00669438002290

Problem 2:

- Compare between the values of M and N using a range of latitude from 0 to 90 degrees with a step of 15 degrees.
- Draw a line plot to show the results.
- Comment on your results to show their relationship (e.g., each of which is larger!).

Summary

End of Session – Thank You!