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

Horizontal Reference Frames

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Conventional Terrestrial Reference System (TRS)

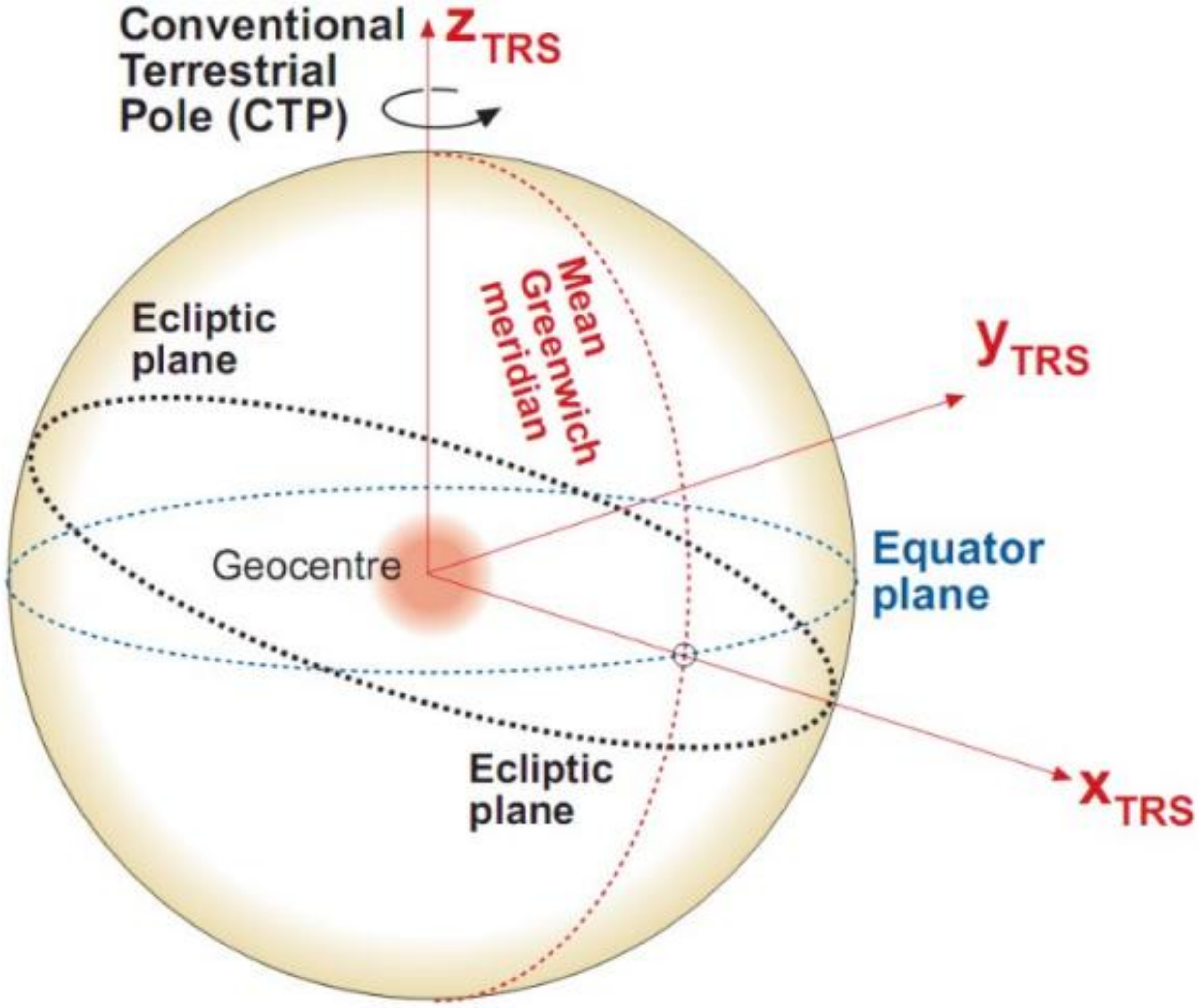
Earth Centered, Earth Fixed (ECEF).

Z-axis is identical to the direction of Earth's axis of rotation as defined by the CTP (Conventional Terrestrial Pole)

X-axis intersection of equatorial plane (orthogonal to Z-axis) with the mean Greenwich meridian.

Y-axis is orthogonal to both of them (right-handed oriented system).

The Earth's CTP was defined as the average of the poles from 1900 to 1905, by the Bureau Internat.de l'Heure



International Terrestrial Reference Frame(ITRF)

IAG International Association of Geodesy

IERS

ITRF

- The international standard TRF is the International Terrestrial Reference Frame (ITRF).
- The ITRF is accurate and precise enough to support even applications with the most demanding requirements for positioning.
- The ITRF is a product of the International Association of Geodesy (IAG).

What is ITRF?

ITRF is a set of points with their 3-dimensional cartesian coordinates which realize an ideal reference system, the International Terrestrial Reference System (ITRS), as defined by the IUGG resolution No. 2 adopted in Vienna, 1991.

Contents

- Cartesian stations coordinates and velocities
- Earth Orientation Parameters (ITRF2008 only)
- Site catalogue
- realizations: ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF96, ITRF97, ITRF2000, ITRF2005, ITRF2008, ITRF2014, ITRF2020, ITRF2020-u2023

ITRS and ITRF (Basis of Reference Ellipsoid)

International Terrestrial Reference System (ITRS)

- It is theoretical definition of geocentric Coordinate system
- It is a set of conventions, standards and models which describes how a global ECEF coordinate system is to be established

International Terrestrial Reference System (ITRF)

- It is a physical realization of the ITRS
- Consists of a set of physical points(Ground Station/Geodetic observing stations/ Global Network) on earth surface.
- Coordinates and velocities of the stations are precisely determined and periodically updated.
- Observations are made by various space geodetic techniques (VLBI, GNSS,SLR,DORIS)

Geodetic Techniques for realization of ITRF

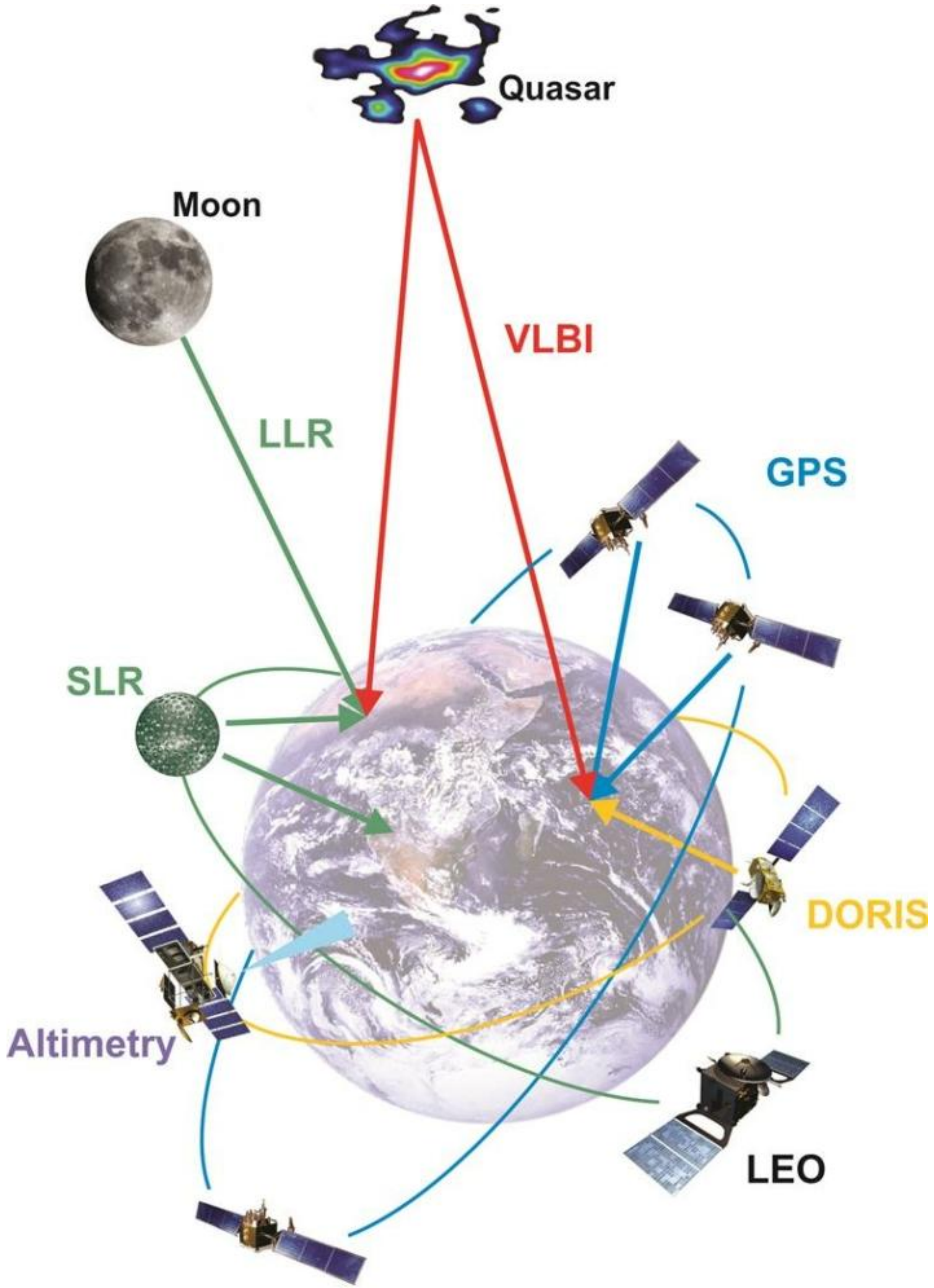
Geodetic Techniques for realization of ITRF

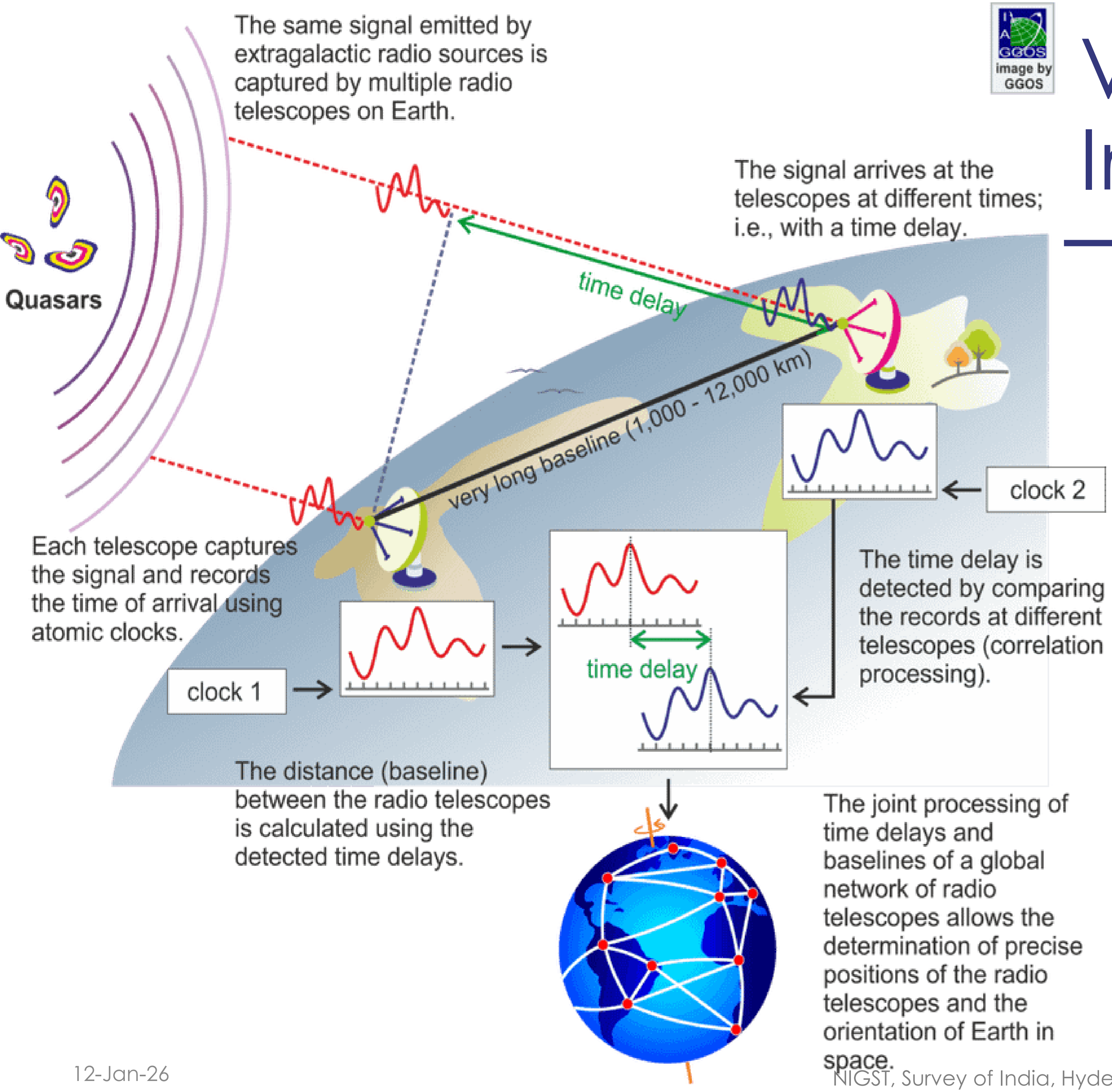
VLBI: Very Long Baseline Interferometry

DORIS: Doppler Orbitography and Radiopositioning Integrated by Satellite

SLR: Satellite Laser Ranging

GNSS: Global Navigation Satellite Systems





Very Long Baseline Interferometry (VLBI)

- Uses radio telescopes to receive signals from quasars
- Measures time difference of signal arrival between antennas
- Applications: Celestial Reference Frame, Earth Orientation Parameters, Plate tectonics

VLBI – Strengths & Limitations

Advantages: Stable reference frame, high precision Earth rotation parameters

Limitations: Complex, expensive infrastructure, requires global coordination

DORIS

- Ground beacons emit Doppler signals to satellites
- Onboard receiver measures frequency shifts → orbit determination
- Applications: Precise orbits, ionosphere studies, sea level monitoring

DORIS – Strengths & Limitations

Advantages: Continuous, autonomous tracking, works globally

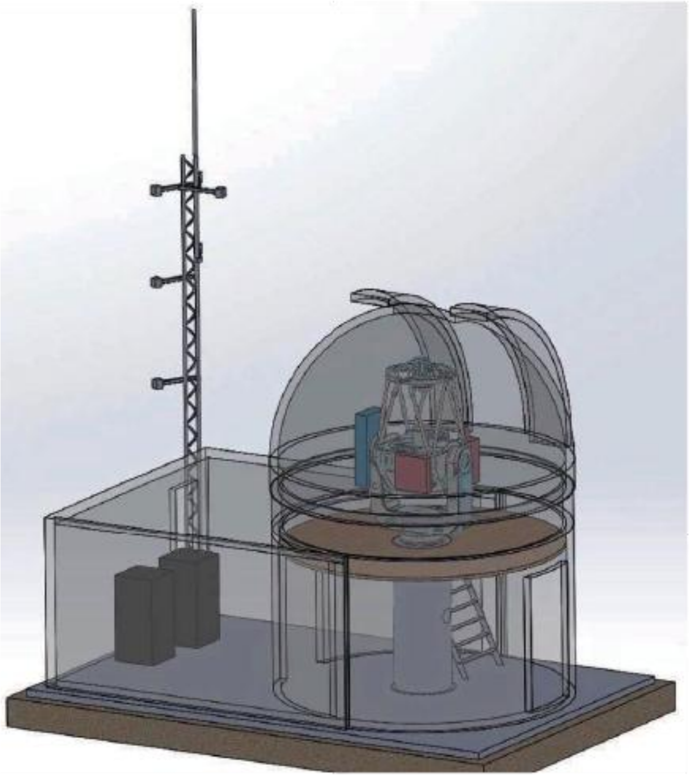
Limitations: Limited satellites equipped, lower coverage vs GNSS

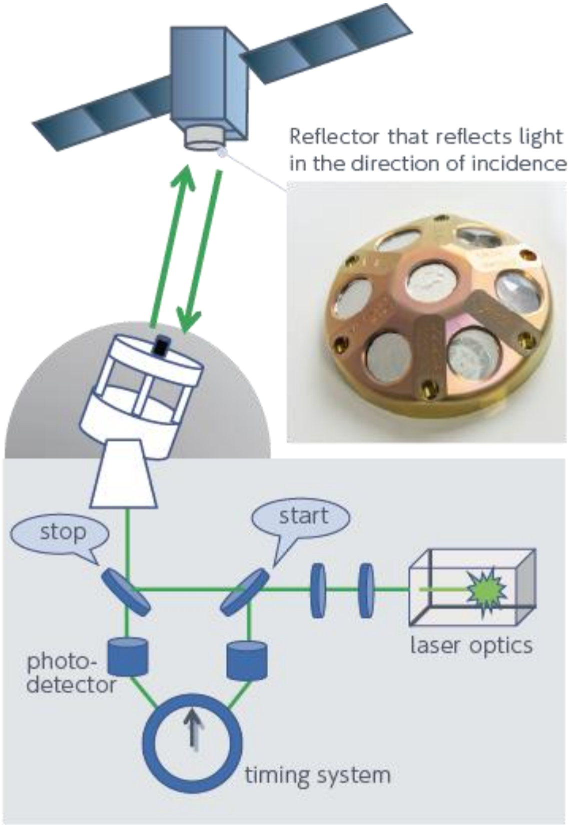
Satellite Laser Ranging (SLR)

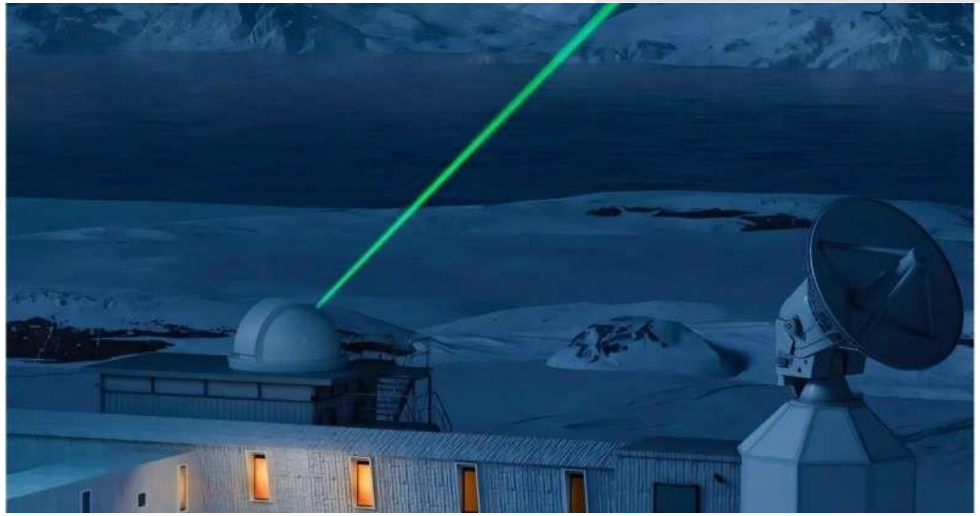
Ground stations fire laser pulses at retroreflectors

Measures two-way travel time → mm-level distance accuracy

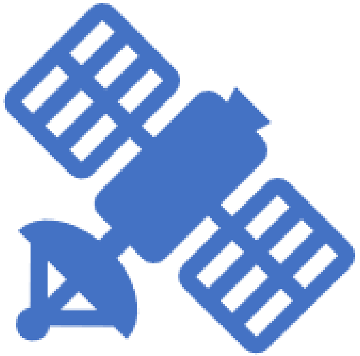
Applications: Geocenter definition, gravity field monitoring, LAGEOS tracking







SLR – Strengths & Limitations

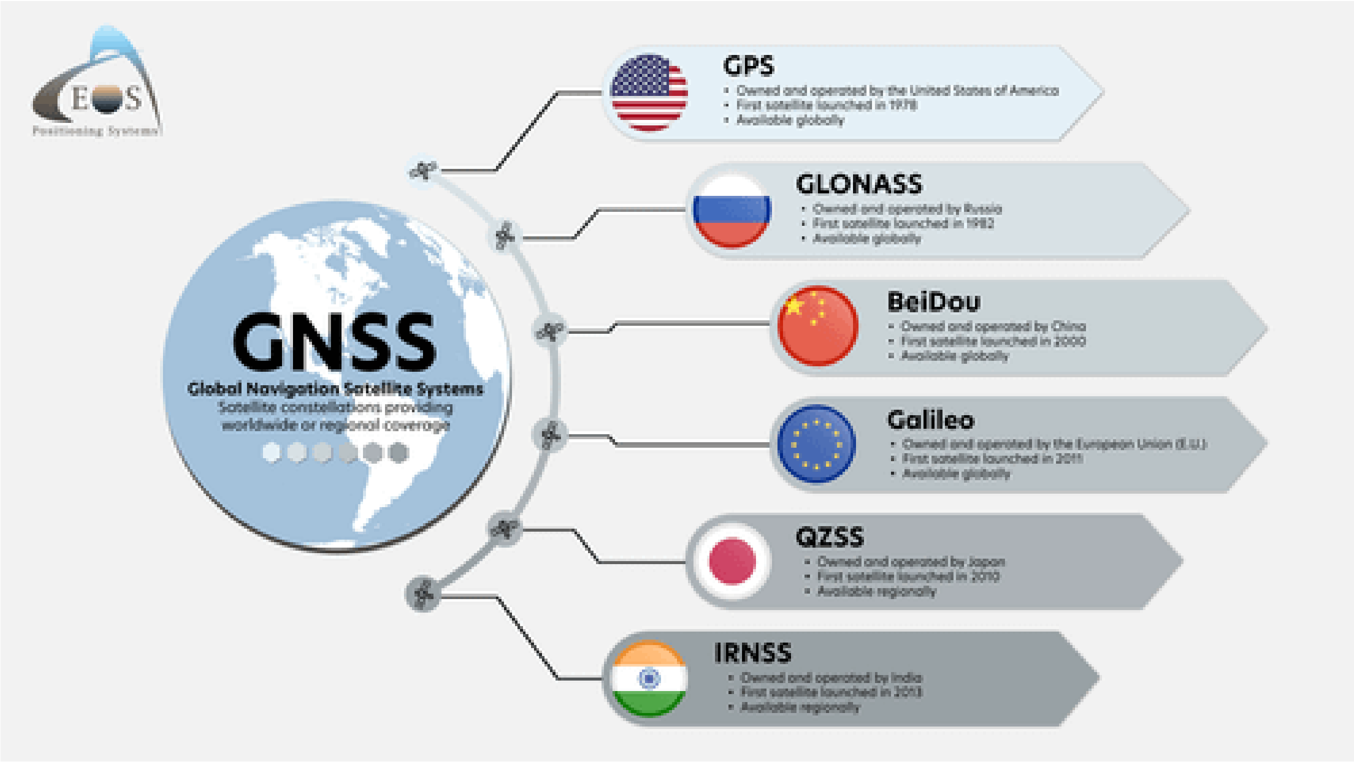


Advantages: Absolute geocenter, mm accuracy, passive satellites

Limitations: Weather-dependent, requires clear sky/line of sight

Global Navigation Satellite Systems (GNSS)

- Systems: GPS, GLONASS, Galileo, BeiDou, IRNSS, QZSS
- Measures pseudorange & carrier phase
- Applications: Positioning, crustal deformation, disaster monitoring



GNSS – Strengths & Limitations

Advantages: Global coverage, low-cost receivers, dense networks

Limitations: Atmospheric corrections, interference vulnerability

Comparison of Techniques

1

VLBI: Earth rotation, cm–mm accuracy, stable orientation

2

DORIS: Orbit determination, cm–dm accuracy

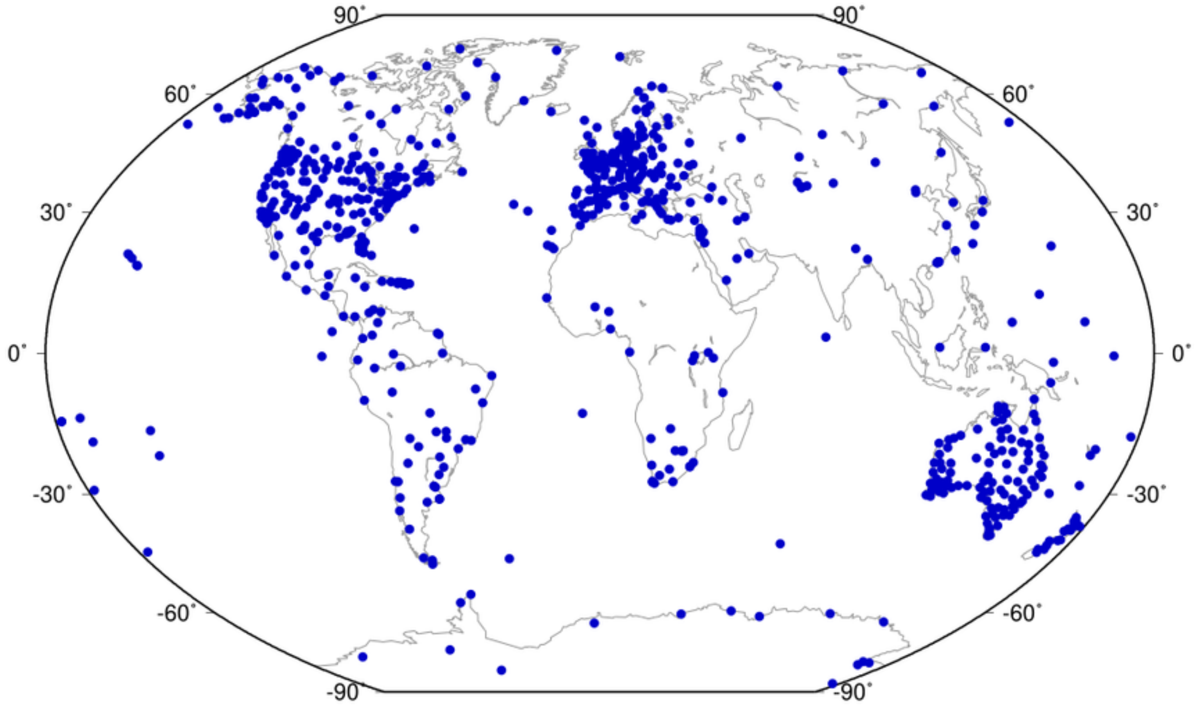
3

SLR: Geocenter, mm–cm accuracy, scale definition

4

GNSS: Positioning, mm–cm accuracy, dense global coverage

Integration in ITRF



Reference stations used for the alignment of ITRF2020-u2023 to ITRF2020

The International Earth Rotation and Reference Systems Service (IERS) and combined data from 4 Techniques to produce the ITRF.

This Combination ensures accuracy, stability, redundancy

IERS make it available for the international community to ensure consistency and interoperability of positioning systems.

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International Earth Rotation and Reference Systems Service (IERS)

IERS

The IERS was established as the International Earth Rotation Service in 1987 by the International Astronomical Union and the International Union of Geodesy and Geophysics.

It began operation on 1 January 1988. In 2003 it was renamed to International Earth Rotation and Reference Systems Service.

The primary objectives of the IERS are to serve the astronomical, geodetic and geophysical communities.

IERS: Services

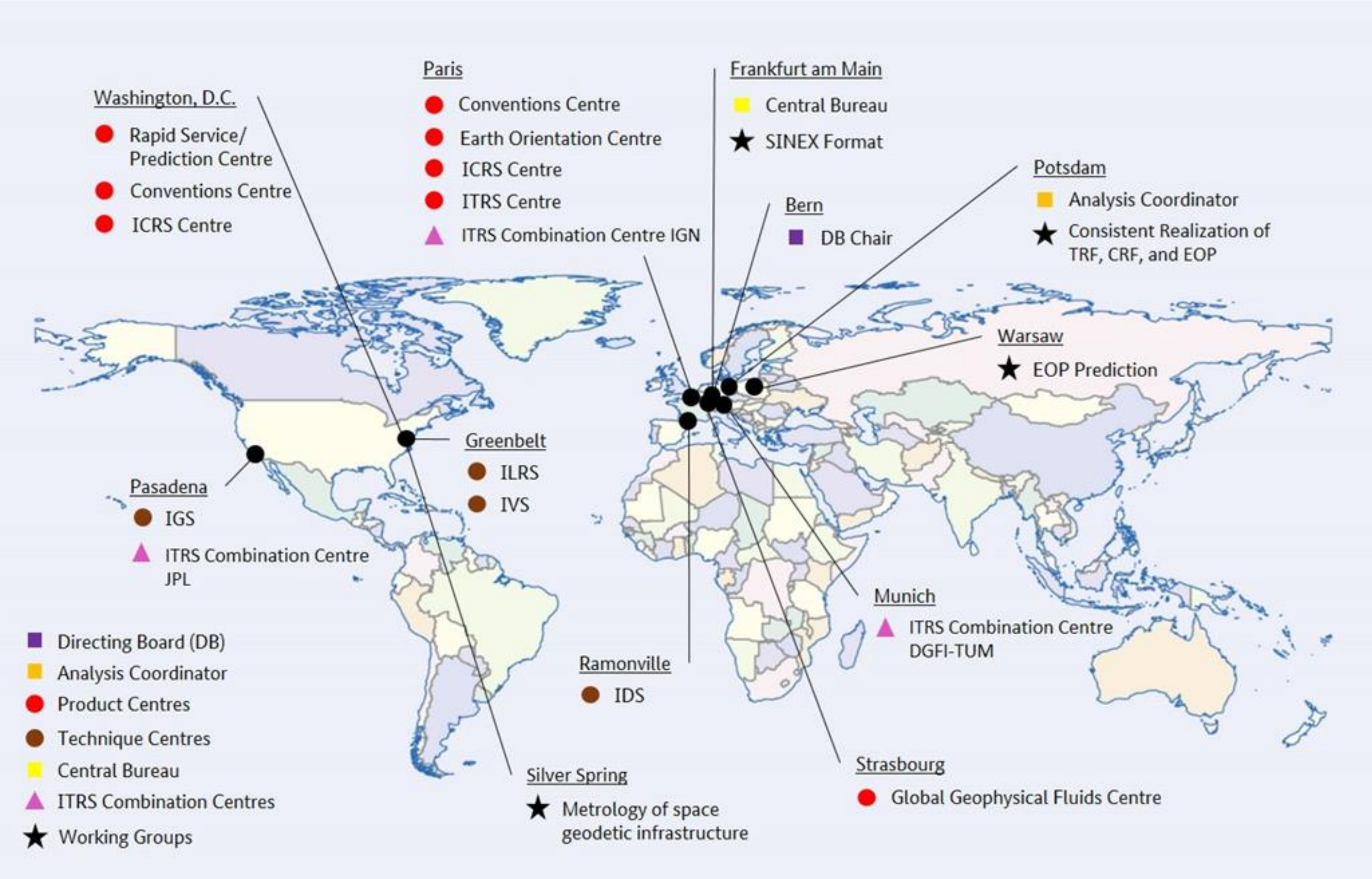
Earth orientation parameters required to study earth orientation variations and to transform between the ICRF and the ITRF.

Standards, constants and models (i.e., conventions) encouraging international adherence.

World map of IERS components

The Technique Centers are autonomous independent services, which cooperate with the IERS. They are responsible for developing and organizing the activities in each contributing ***observational technique.***

1. **International DORIS Service (IDS)**
2. **International GNSS Service (IGS)**
3. **International Laser Ranging Service (ILRS)**
4. **International VLBI Service (IVS)**



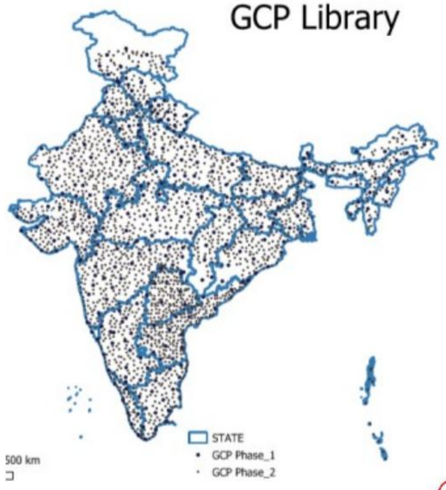
National Geodetic Reference Frame (NGRF)

In 2006, it was decided to establish horizontal (Planimetric) control stations based WGS-84 ellipsoid datum and ITRF using GNSS observations.

GCP and CORS Network

- 291 primary GNSS GCPs (~250–300 km spacing),
- 2260 secondary GCPs (~25–30 km spacing),
- 1042 CORS stations.

Coordinates are realized in ITRF 2008 at epoch 2005.0.



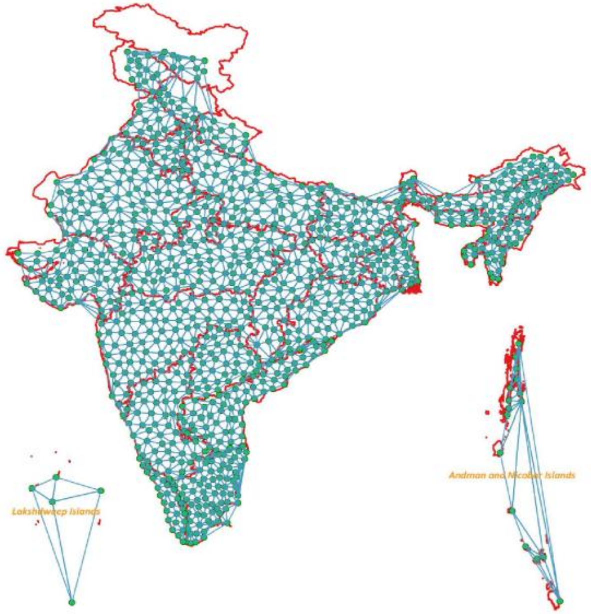


Figure 2 Schematic representation of location of CORS Stations

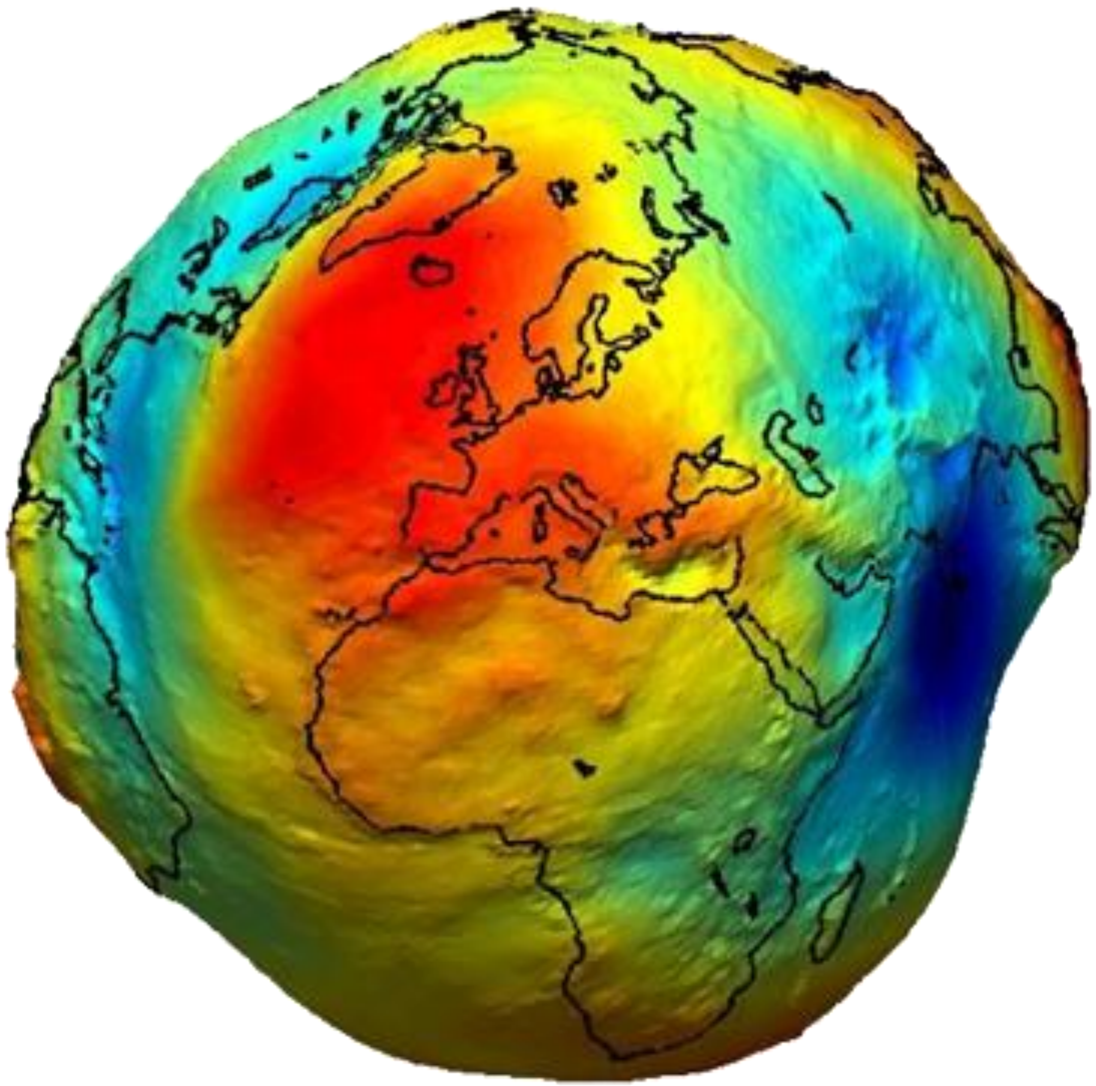
Concept of Datum

What is datum?

Datum is standardized reference framework for measuring positions, elevations.

It is the foundation for consistent and accurate geo-spatial measurement.

Shape of Earth



The shape of the earth is irregular due to

- topography and
- gravitational variations

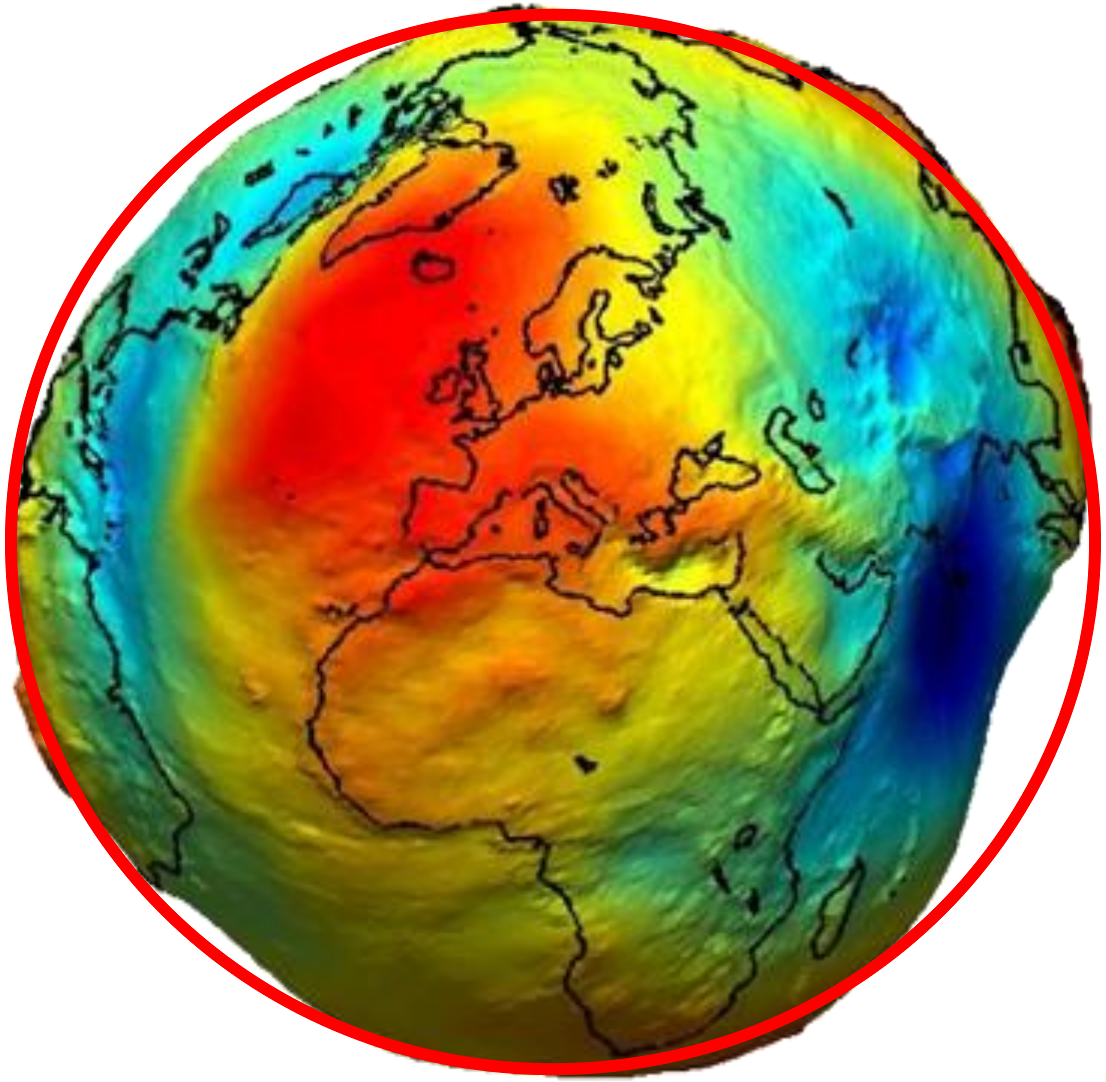
Can we use irregular shape for calculations?

- It would be impractical for most of the applications because calculations of Coordinates become too complex.

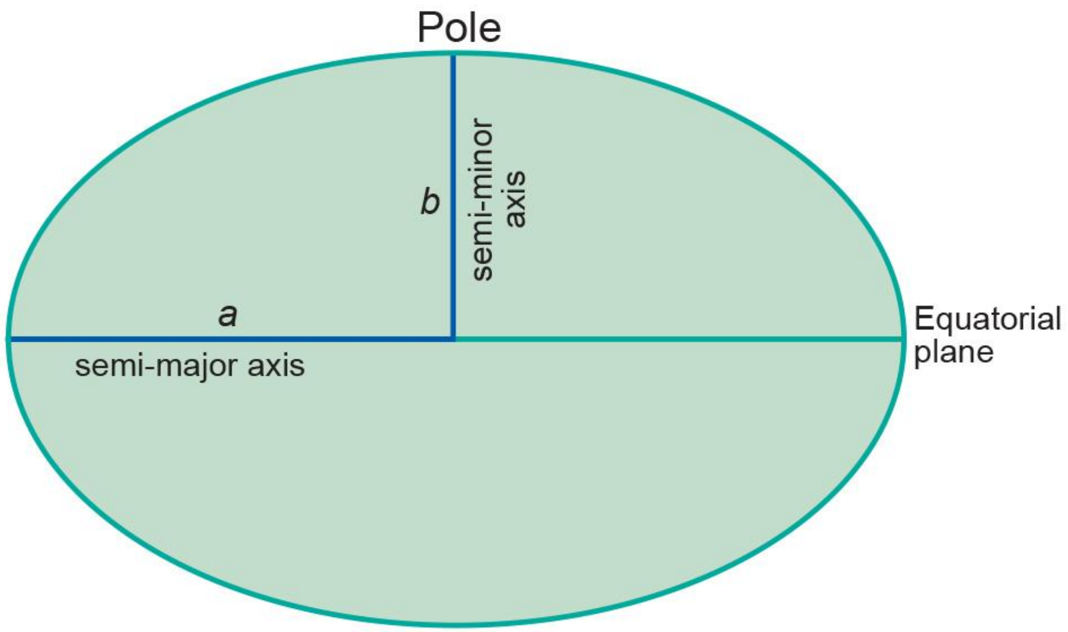
Shape of Earth

How to make calculations efficient?

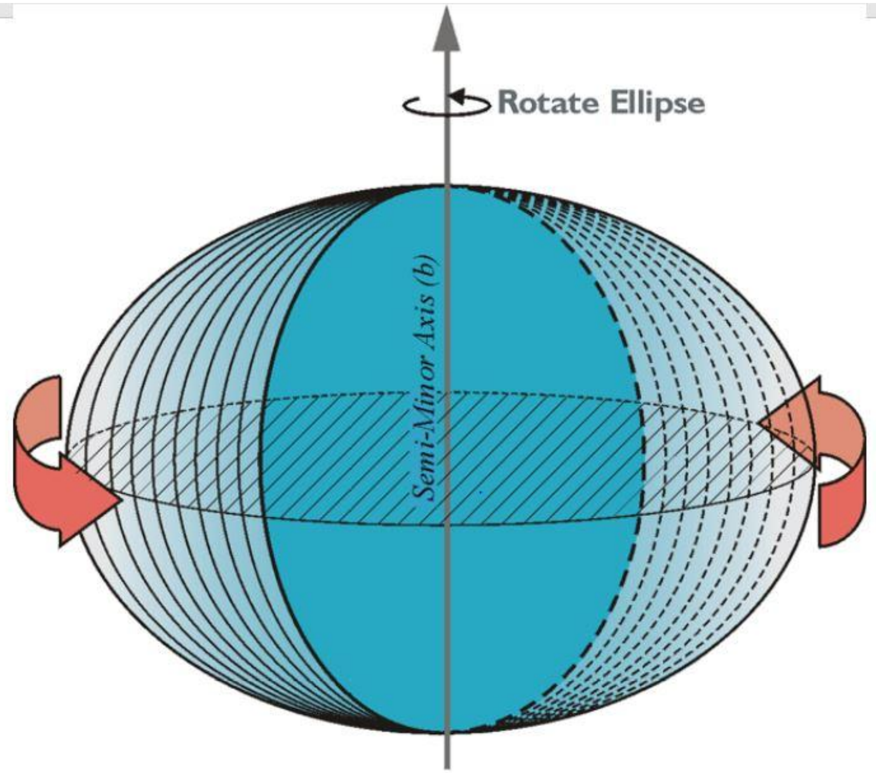
- A reference ellipsoid (simplified model of earth) can be used as Horizontal datum for measuring latitude and longitude.
- It is mathematically defined regular surface and approximates the overall shape of the earth.



Generation of a Reference Ellipsoid

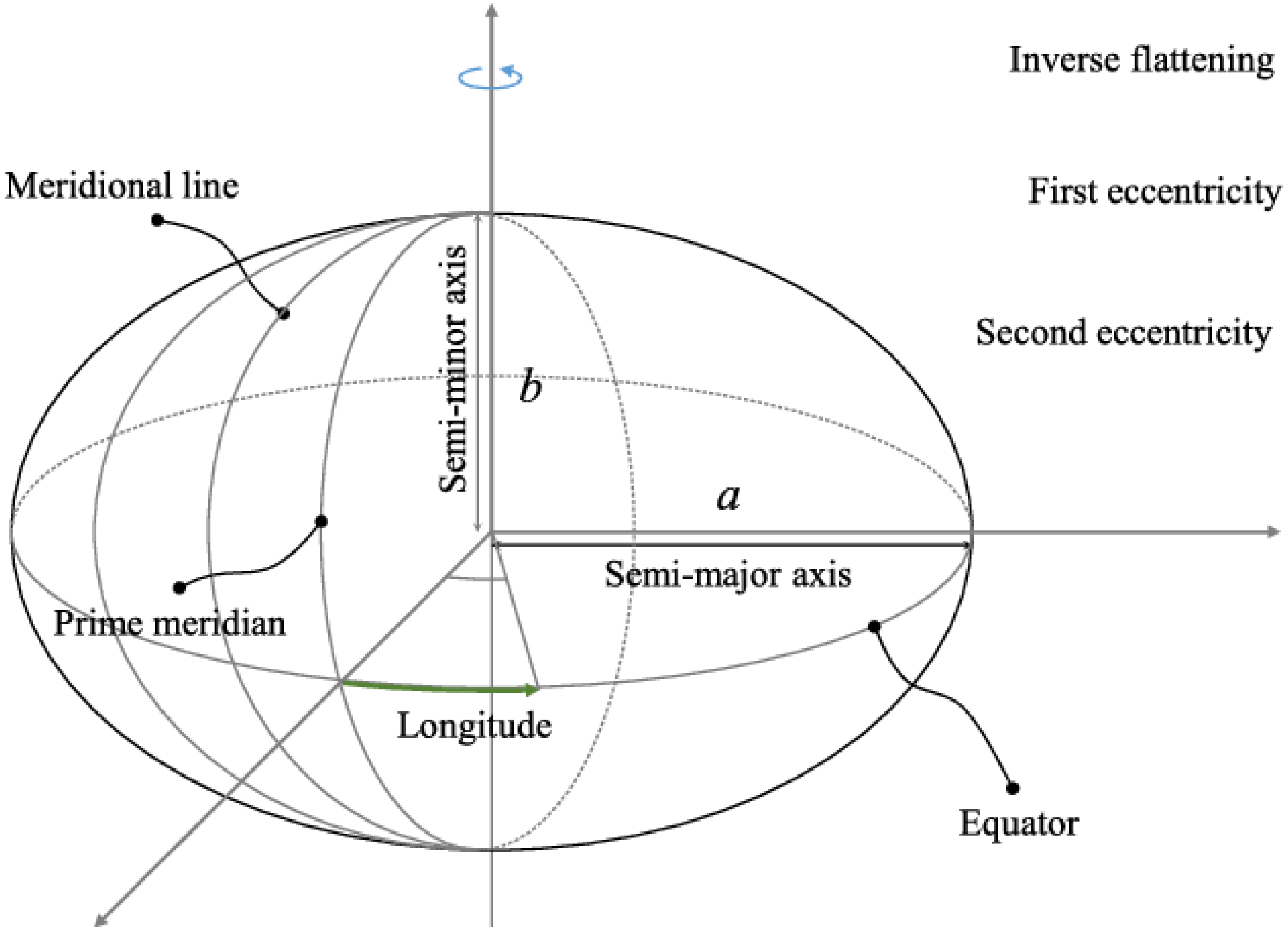


Ellipse



Ellipsoid

Ellipsoid as Mathematical surface of Earth

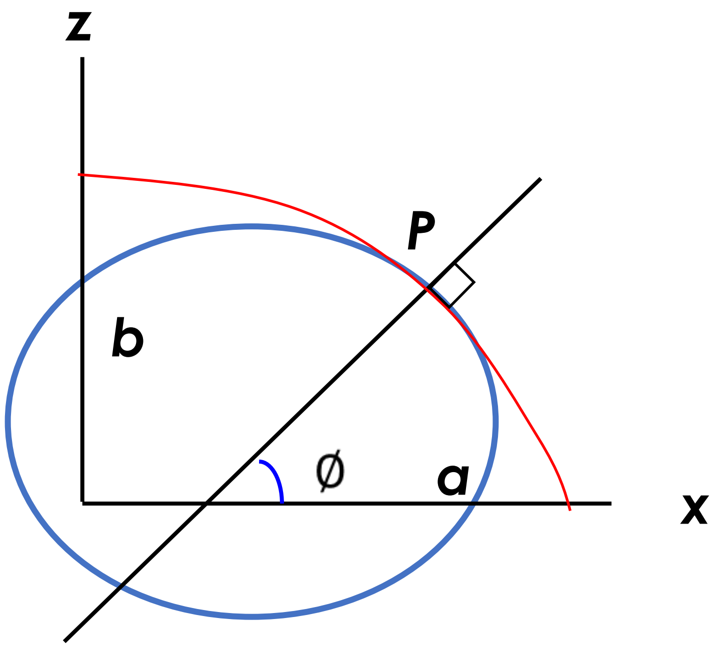


Inverse flattening $\frac{1}{f} = \frac{a}{a-b}$

First eccentricity $e = \sqrt{1 - \frac{b^2}{a^2}}$

Second eccentricity $e' = \sqrt{\frac{a^2}{b^2} - 1}$

Radius of Meridional section



$$M = \frac{a(1 - e^2)}{(1 - e^2 sin\emptyset)^{3/2}}$$

a-Semi major axis
e-Eccentricity
Φ-Geodetic latitude

Meridian Radius of Curvature

M is the radius of curvature at a point on the curve is just the radius of osculating circle in the meridional plane.

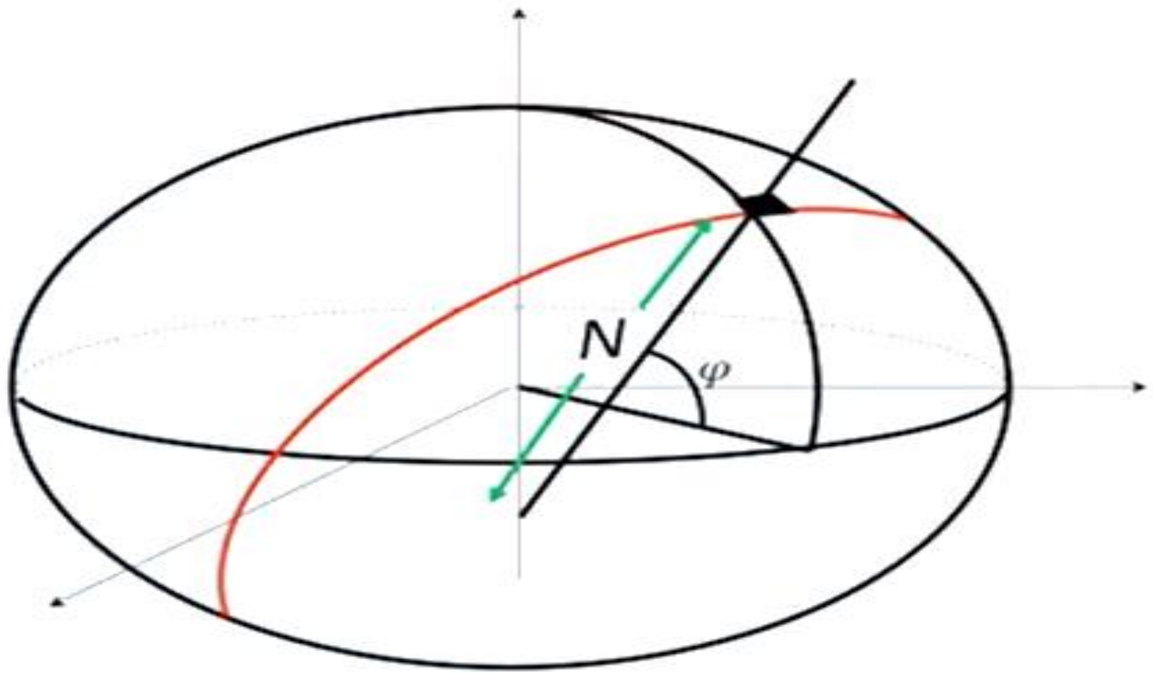
It is the measures how ‘curved’ the reference ellipsoid along a constant longitude(South-North direction).

At equator $\varphi=0°$,

M is the smallest.

At poles $\varphi=90°$,M is largest.

Radius of Prime Vertical



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

a-Semi major axis
e-Eccentricity
Φ-Geodetic latitude

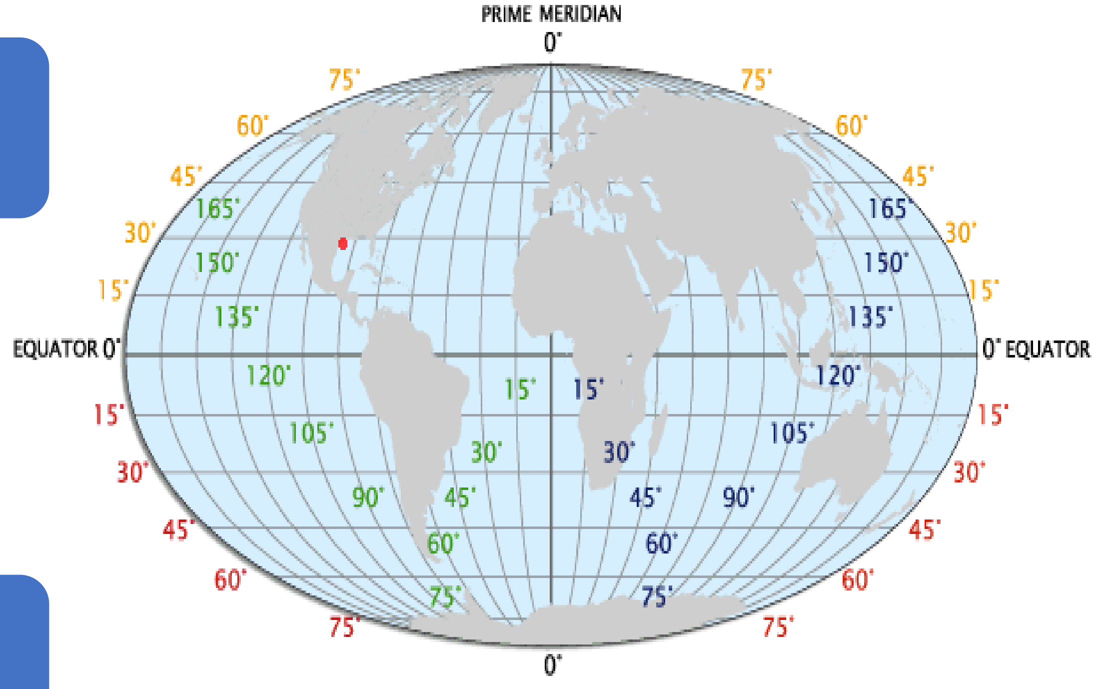
Development of Horizontal Reference System (ellipsoid)

Development of a Reference Ellipsoid

Collection of observation data

- Arc Measurement (distance between two known latitudes)
- Astronomical observations to find latitude, longitude and azimuth
- Satellite data (Orbital Tracking)
- Gravity measurement

The above determine how earth's curvature changes with latitude and direction



Development of a Reference Ellipsoid

Using the least square method , the ellipsoid parameters are adjusted so that

The difference between observed positions and calculated positions is minimum

The reference ellipsoid matches Geoid as closely as possible.

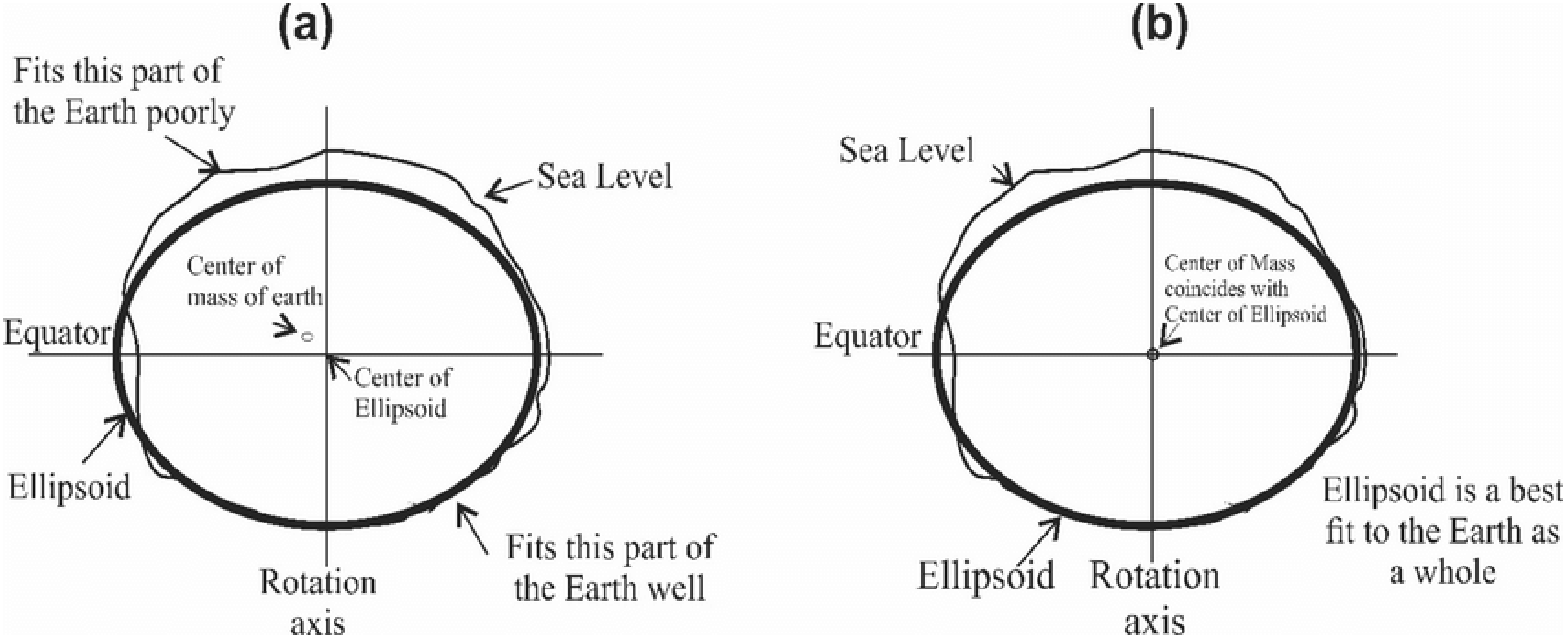
Elements of Horizontal datum

1.Reference Ellipsoid:This has usual ellipsoid Properties of semi and major Axes, Flattening which defines the shape

2.Reference Frame:It is a realization where physical measurements of known points on the earth surface are taken to determine the position and orientation of the reference ellipsoid.

3. Epoch-: Datums are referenced to a point in time, called epoch

Types of Horizontal Datum



Types of Horizontal Datum

Local Geodetic datum

- Approximates the size and shape of a particular part of the earth's surface.
- The center of ellipsoid will not coincide with earth's center of mass.
- Ex: Everest is a topocentric datum

Global Geocentric Datum

- Best approximates the size and shape of the earth as whole.
- It is a Geo-centic ellipsoid.
- Ex: WGS-84 GNSS uses Geocentric ellipsoid.

Parameters for the Reference Ellipsoid

TYPE of Datum	Semi-major axis (a) in metres	Flattening factor (1/f)	Remarks
WGS-84	6378137.0	298.2572	Geocentric
Everest	6,377,301.243	300.8017	Local

Elements of Horizontal datum

1.Reference Ellipsoid:This has usual ellipsoid Properties of semi and major Axes, Flattening which defines the shape

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Datum Transformation

Datum Transformation

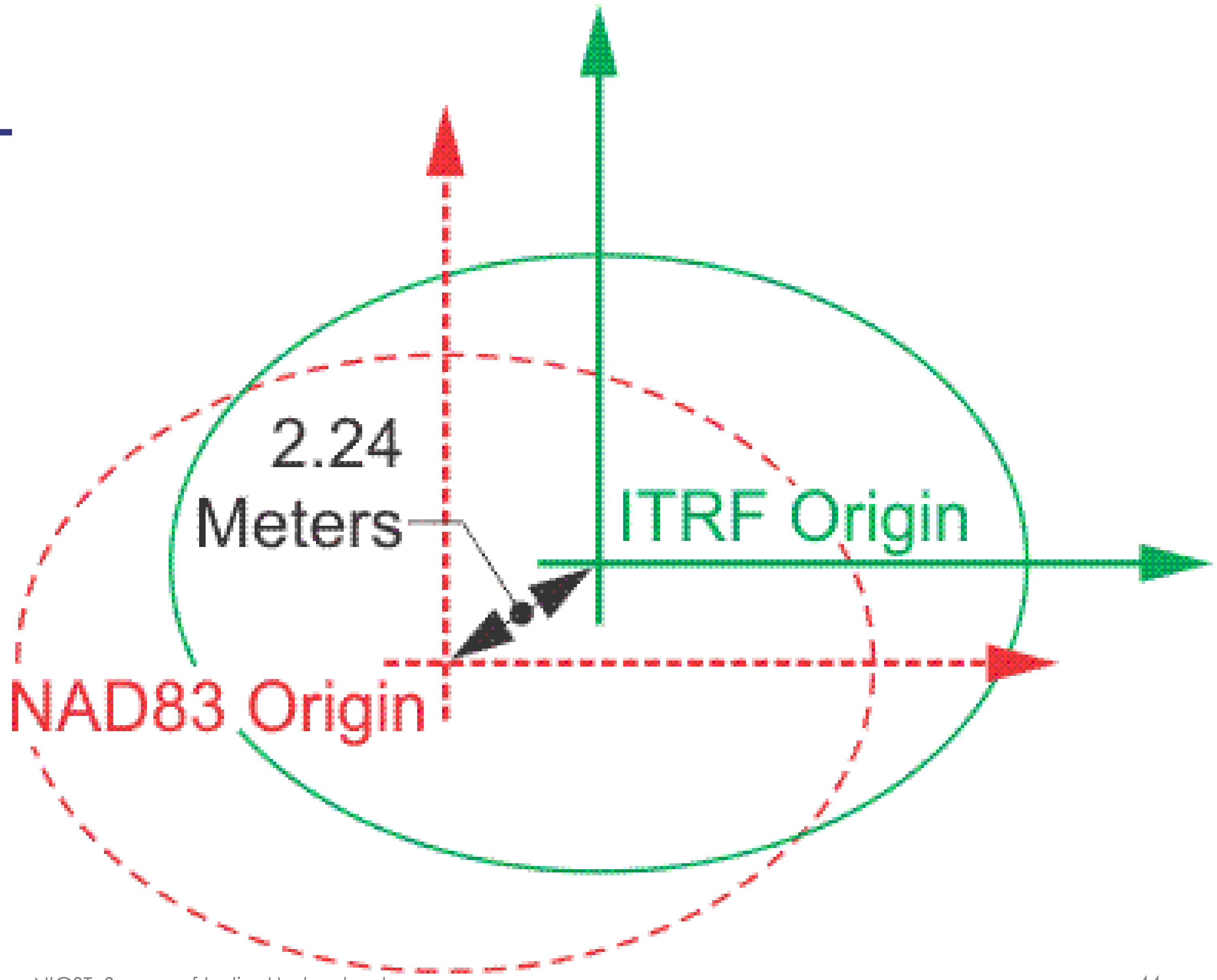
Different mapping agencies use different datums or same mapping agency uses different datums in different time or different areas have different datums.

Each datums defines size and shape of the earth differently.

So datums transformation is required to make the data consistent

Datum transformation is the process of converting geographic coordinates from one geodetic datums to other.

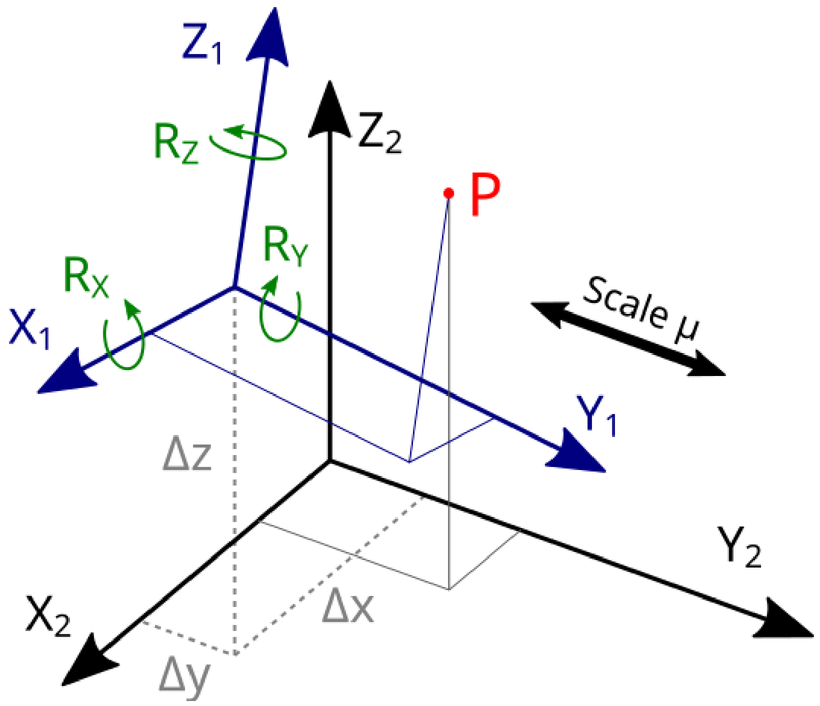
ITRF & NAD83



Types of Datum Transformation

- 3-parameter datum transformation
- 7-parmeter datum transformation (Helmert Transformation)

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = (1 + S) \begin{bmatrix} R_x \\ R_y \\ R_z \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} \triangle X \\ \triangle Y \\ \triangle Z \end{bmatrix}$$



Bursa-Wolf transformation

The Bursa-Wolf transformation uses seven parameters to convert coordinates between geodetic datums.

- Three translations (dX, dY, dZ in meters)
- Three small rotations (rX, rY, rZ in arc-seconds or radians)
- Scale factor (S in parts per million, ppm).

It is often used for shifting between global (like WGS84) and local systems.

The Bursa–Wolf model:

- Preserves shape and scale globally,
- Cannot locally bend or warp the coordinate space.

Bursa-Wolf transformation

Purpose and Applications

Transformation between global and regional datums (e.g., WGS 84 to a national datum such as Everest).

Integration of GNSS-derived coordinates with legacy geodetic networks.

Datum transformations in GIS software and spatial databases.

Limitations

Assumes a rigid-body transformation; local distortions are not modeled.

Accuracy decreases for large areas with non-uniform datum distortions.

Helmert vs Bursa–Wolf Transformation

A **3D, seven-parameter Helmert transformation** specifically designed for **geodetic datum transformations** between Earth-centered, Earth-fixed Cartesian coordinate systems.

Aspect	Helmert Transformation	Bursa–Wolf Transformation
Mathematical nature	General similarity transform	Specific geodetic case
Dimensionality	2D or 3D	3D only
Number of parameters	4 (2D) or 7 (3D)	7
Translations	Yes	Yes
Rotations	Yes	Yes
Scale factor	Yes	Yes
Primary domain	Geometry, photogrammetry, geodesy	Geodesy and GIS

Thanks