Latitude and longitude – A misunderstanding

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Today, even laypeople are aware of GPS used for locating in terms of latitude, longitude and height. Many people are aware of Google Earth and even GIS. In this scenario, however, majority of us misunderstands latitude and longitude. Authalic coordinates are what generally conceived as latitude and longitude, in which the Earth is assumed as spherical in shape. In day-to-day life, the coordinates we see on maps such as those from GPS are geodetic latitude and longitude. It is also imperative to know the datum of the map in use; and if the datum is changed, any selected location can have different geodetic coordinates.

Global Positioning System (GPS), Geographic Information System (GIS), Google Earth, etc. have penetrated to wider user spectrum. GPS is used for locating a feature in terms of longitude, latitude and height. The latitude and longitude of a feature on a map may not match with that on another map for the reason that both may use different datum. The topographic maps, usually called toposheets, from the Survey of India use Everest datum, but Google Earth uses WGS84 datum; thus the coordinates (latitude and longitude) of a location will not match in both the maps. Refer Sajeevan[1] for a case study.

It is commonly presumed that longitude is the angle from the Greenwich meridian and latitude is the angle from the equator to any selected location, measured at the centre of the earth. However, this presumption is incorrect.

Geoid and ellipsoid

The parameters involved in representing features on an irregular topographic surface (3D) on to a plane surface (2D) are geoid, spheroid and projection type.

Geoid is the equipotential surface of the earth's gravity on which gravity at every point is equal to its strength at mean sea-level. It is the shape the earth would assume at mean sea-level, if the entire surface at that level were liquid. Use of geoid as a basis for computation would be difficult as it has an irregular shape and has no complete mathematical expression. Hence, a smoother surface, an ellipsoid, which can best fit the geoid surface is considered.
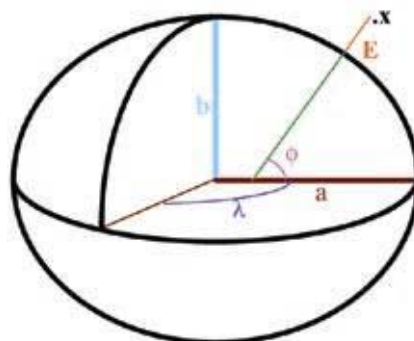
The terms 'ellipsoid' and 'spheroid' are frequently used interchangeably. An ellipsoid, also called a tri-axial ellipsoid, has unequal axes. Rotating an ellipse about its major or minor axis may generate a spheroid. An ellipsoid of revolution and the biaxial ellipsoid also describe a spheroid.

An ellipsoid is represented by a semi-major axis and a semi-minor axis (or eccentricity or flattening; Figure 1). The parameters of few ellipsoids are given in Table 1.

Orthometric height is measured from the geoid surface and geodetic (ellipsoid) height is measured from ellipsoid surface (Figure 2). While orthometric height of a location remains constant, geodetic height changes with datum. Hence it is important to calculate the new height along with latitude and longitude during projection transformation, in case the height is geodetic. Geoid height is the distance from the ellipsoid surface to the geoid surface and can have negative or positive value.

Ellipsoids can be categorized into local, regional and global. Various ellipsoids are formed to best-fit a certain region of the earth. An ellipsoid is selected depending on the application and accu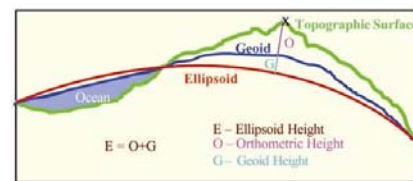racy requirements. For example, the global ellipsoid WGS84 may be used when the application is worldwide, as it best approximates the shape of the earth globally even though it may not give the best fit for a particular part of the earth.
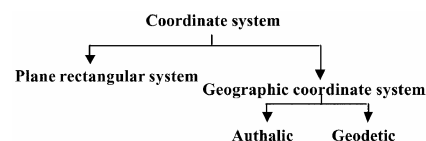
Coordinate system

Some important coordinate systems in the context of maps are shown in Figure 3. Plane rectangular (Cartesian coordinate) system is the well-known conventional X–Y–Z coordinate system. Authalic and geodetic coordinates are two categories of geographic coordinate systems.

Authalic coordinates are based on the spherical shape of the earth. Though the shape of the earth is more an ellipsoid than a sphere, cartographers still use the authalic sphere for geodetic mapping and calculations. A sphere with the same surface area as an ellipsoid that approximates the earth is called authalic sphere. The generally conceived latitude and longitude are in fact the authalic latitude and longitude.

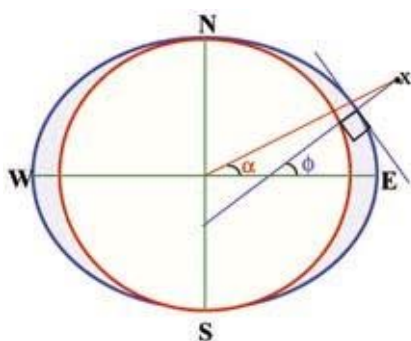Geodetic latitude at a location is the angle between the equatorial plane and a

Figure 1. Ellipsoid. a, Semi-major axis; b, Semi-minor axis; λ, Geodetic longitude at point x; ϕ, Geodetic latitude at point x; f, Flattening; e, Eccentricity. $f = (a - b)/a$, $e^2 = 1 - b^2/a^2$, $e^2 = f(2 - f)$.
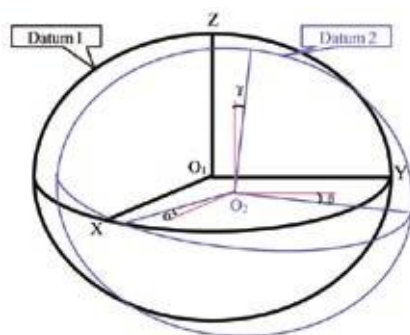

Figure 2. Measurement of heights.

Figure 3. Various coordinate systems.

Table 1. Parameters of two ellipsoids

Ellipsoid	Everest, India 1956	WGS 84
Semi-major axis	6377301.243	6378137
Semi-minor axis	6356100.228368	6356752.314245
1/flattening	300.8017	298.257223563

Figure 4. Authalic latitude (α) and geodetic latitude (ϕ) at a location *x*.

Figure 5. Two datums generated from a single ellipsoid.

line normal to the reference spheroid. Lines normal to a spheroid surface do not pass through the centre, except for 0° and 90° latitudes. But, the normal will always pass through the centre of a sphere, in the case of the authalic latitude. Thus, the geodetic and authalic latitudes at any location *x* are different (Figure 4). Geodetic longitude at a location is the angle between a reference plane and a plane passing through the location, both planes being perpendicular to the equatorial plane. Geodetic height (ellipsoid height) is the distance between a defined location and the surface of a reference ellipsoid in a direction normal to the ellipsoid.

As seen in Figure 4, the authalic latitude (α) is based on the sphere (red colour) and the geodetic latitude (ϕ) is based on the spheroid (blue colour). The geodetic coordinate system, which is based on the spheroid, is usually followed in GIS and related mappings. Maps from Survey of India, Google Earth and more accurate maps generally available from other sources are in geodetic latitude and longitude.

Datum

Datum describes the position, orientation and scale relationships of a reference ellipsoid to the earth. Hence, a number of datums can be generated using a single ellipsoid. WGS84 is the datum used in GPS and its centre is at the centre of mass of the earth.

Apart from the parameters of the ellipsoid, more parameters are required to define a datum – three to define the position and three to define the rotation angle – with reference to a three dimen-

sional Cartesian coordinate system with its origin coinciding with the centre of mass of the earth. In the earth-fixed spatial Cartesian system (*X*, *Y*, *Z*), the *Z*-axis coincides with the mean rotational axis of the earth, the *X–Y* plane is the mean equatorial plane perpendicular to this axis and the *X–Z* plane is the mean meridian plane of Greenwich. Figure 5 shows two datums generated from a single ellipsoid. Suppose datum 1 is an earth-centred, earth-fixed, spatial Cartesian system, then the coordinate of O_1 is (0, 0, 0). Translations along *X*, *Y* and *Z* from O_1 to O_2 represent position parameters and the angles α, β and γ represent rotation parameters of datum 2.

Map projection

Mapping involves transferring locations from the topographic surface to a geoid surface and subsequently to an ellipsoid surface. Information over the ellipsoid surface may be transferred to a plane surface using a suitable projection type.

Azimuthal, conical and cylindrical are the three main families of projection. No map maintains a uniform scale, direction, distance or area throughout. Google Earth uses simple cylindrical projection with a WGS84 datum for its imagery base.

Projection transformation in a software application is an important function required to alter the projection parameters of maps, since projection parameters of data available from diverse sources may be different from those for a particular purpose.

1. Sajeevan, G., Correct usage of projection parameters for spatial accuracy, Map India Conference, 2005.
2. Robinson, A. H., Morrison, J. L., Muehrcke, P. C., Jon Kimerling, A. and Guptill, S. C., *Elements of Cartography*,. John Wiley, 2002, 6th edn.
3. Dana, P. H., 1995, http://www.colorado.edu/geography/gcraft/notes/coordsys/coordsys_f.html

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