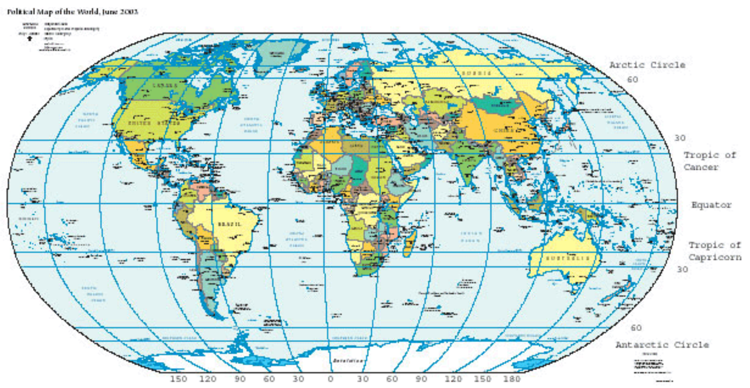
Geographic coordinate system



Map of Earth showing lines of latitude (horizontally) and longitude (vertically), Eckert VI projection; large version [1] (pdf, 3.12MB)

Geodesy
Fundamentals
Geodesy · Geodynamics Geomatics · Cartography
Concepts
Datum · Distance · Geoid Fig. Earth · Geodetic sys. Geog. coord. system Hor. pos. represent. Lat./Long. · Map proj. Ref. ellipsoid · Sat. geodesy Spatial ref. sys.
Technologies
GNSS · GPS · GLONASS
Standards
ED50 · ETRS89 · GRS 80 NAD83 · NAVD88 · SAD69 SRID · UTM · WGS84
History
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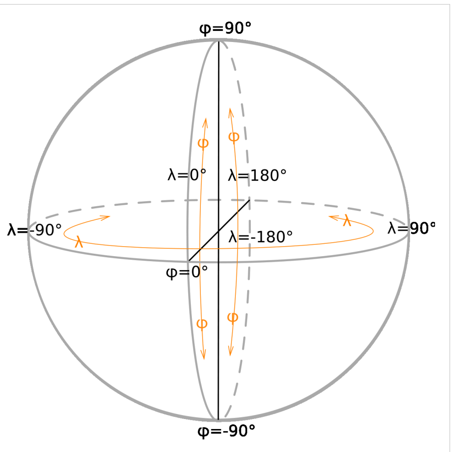
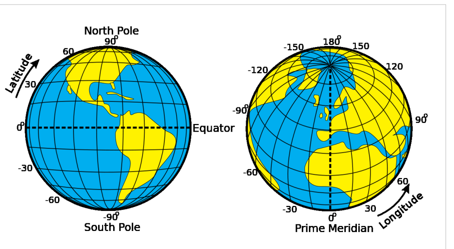
A **geographic coordinate system** is a coordinate system that enables every location on the Earth to be specified by a set of numbers. The coordinates are often chosen such that one of the numbers represent vertical position, and two or three of the numbers represent horizontal position. A common choice of coordinates is latitude, longitude and elevation.[2]

Geographic latitude and longitude



Latitude phi (φ) and Longitude lambda (λ)



Latitude and Longitude of the Earth

The geographic latitude (abbreviation: Lat., φ, or phi) of a point on the Earth's surface is the angle between the equatorial plane and a line that passes through that point and is normal to the surface of a reference ellipsoid which approximates the shape of the Earth.[3] This line passes a few kilometers away from the center of the Earth except at the poles and the equator where it passes through Earth's center.[4] Lines joining points of the same latitude trace circles on the surface of the Earth called parallels, as they are parallel to the equator and to each other. The north pole is 90° N; the south pole is 90° S. The 0° parallel of latitude is designated the equator, the fundamental plane of all geographic coordinate systems. The equator divides the globe into Northern and Southern Hemispheres.

The Longitude (abbreviation: Long., λ, or lambda) of a point on the Earth's surface is the angle east or west from a reference meridian to another meridian that passes through that point. All meridians are halves of great ellipses (often improperly called great circles), which converge at the north and south poles.

A line passing near the Royal Observatory, Greenwich (near London in the UK) has been chosen as the international zero-longitude reference line, the Prime Meridian. Places to the east are in the eastern hemisphere, and places to the west are in the western hemisphere. The antipodal meridian of Greenwich is both 180°W and 180°E. The zero/zero point is located in the Gulf of Guinea about 625 km south of Tema, Ghana.

In 1884 the United States hosted the International Meridian Conference and twenty-five nations attended. Twenty-two of them agreed to adopt the location of Greenwich as the zero-reference line. The Dominican Republic voted against the adoption of that motion, while France and Brazil abstained.[5] To date, there exist organizations around the world which continue to use historical prime meridians which existed before the acceptance of Greenwich became common-place.[6]

The combination of these two components specifies the position of any location on the planet, but does not consider altitude nor depth.

This latitude/longitude "webbing" is known as the ***conjugate graticule***.

In defining an ellipse, the short (vertical) diameter is known as the ***conjugate diameter***, and the long (horizontal) diameter—perpendicular, or "transverse", to the conjugate—is the ***transverse diameter***.[7] With a sphere or ellipsoid, the conjugate diameter is known as the ***polar axis*** and the transverse as the ***equatorial axis***. The graticule perspective is based on this designation: As the longitudinal rings — geographically defined, all great circles — converge at the poles, it is the poles that the conjugate graticule is defined. If the polar vertex is "pulled down" 90°, so that the vertex is on the equator, or transverse diameter, then it becomes the **transverse graticule**, upon which all spherical trigonometry is ultimately based (if the longitudinal vertex is between the poles and equator, then it is considered an ***oblique graticule***).

Latitude and longitude in practice

Say you set up your Wild T4 next to the water tank north of the airport at Hilo, Hawaii, intending to determine its latitude and longitude by the stars. NGS predicts you will find the tank to be at 19.7323 deg North, 155.0412 deg West.[8]

You cross the island and set the T4 next to the Keahole Point lighthouse; NGS estimates that by the stars the lighthouse will turn out to be 19.7244 N 156.0787 W. [9] Calculating the distance from the water tank to the lighthouse using those lat-lons we get about 108.8 km, but if we measure the actual distance it turns out to be 105.5 km. What went wrong?

Hawaii is an extreme case of a problem that exists everywhere: when trying to measure latitude and longitude by the stars we can only orient our measuring device by gravity. We'd like the T4's axis to point to the center of the Earth, but the T4's level vials don't know where that is — all they know is the direction of gravity, which is much affected by that 4000-meter mountain 50 km away. So when we measure the lat-lons for two points the relationship between those two points can be distorted, which renders their lat-lons fairly useless for most people. When we measure the lat-lons of two points we want to be able to use those lat-lons to calculate the distance and direction from one to the other; we want to be able to draw a scale map and plot points on it by their lat-lons, and the distance between any pair of points on the map is supposed to closely match the actual distance we would measure on the ground.

So we need a different plan — a different definition of latitude and longitude. What they did in Hawaii circa 1930 was call the marker "Oahu West Base"[10] 21 deg 18 min 13.889 sec North, 157 deg 50 min 55.796 West, and define the lat-lon of every other point by its distance and direction from there.[11] NGS now says that in 1993 that point was 21-18-02.54891 N 157-50-45.90280 W in the present NAD83 system. Was the old lat-lon off by 300+ meters? Well, yes, but the relationships between points in the islands were much more accurate than that. C&GS triangulated from island to island, calculating each successive point's lat-lon by its distance and direction from the previous points in the chain. Eventually they deemed the Hilo water tank to be at 19-43-54.526 N 155-03-26.463 W, which would make it 339191.7 meters from Oahu West Base on the Clarke 1866 spheroid. NGS now figures those two points are 339192.8 meters apart.

Similarly in North America. If in 1980 you had asked NGS for the lat-lons for the Empire State Building [12] and a certain water tank [13] in Anchorage, the NAD27 lat-lons they would have given you would be different from the current ones, but the distance you would have calculated then is 8.2 meters different from now. A transcontinental triangulation cannot do better than that.

UTM and UPS systems

The Universal Transverse Mercator (UTM) and Universal Polar Stereographic (UPS) coordinate systems both use a metric-based cartesian grid laid out on a conformally projected surface to locate positions on the surface of the Earth. The UTM system is not a single map projection but a series of map projections, one for each of sixty 6-degree bands of longitude. The UPS system is used for the polar regions, which are not covered by the UTM system.

Stereographic coordinate system

During medieval times, the stereographic coordinate system was used for navigation purposes. The stereographic coordinate system was superseded by the latitude-longitude system.

Although no longer used in navigations, the stereographic coordinate system is still used in modern times to describe crystallographic orientations in the fields of crystallography, mineralogy and materials science.

Geodetic height

To completely specify a location of a topographical feature on, in, or above the Earth, one has to also specify the vertical distance from the centre of the Earth, or from the surface of the Earth. Because of the ambiguity of "surface" and "vertical", it is more commonly expressed relative to a precisely defined vertical datum which holds fixed some known point. Each country has defined its own datum. For example, in the United Kingdom the reference point is Newlyn, while in Canada, Mexico and the United States, the point is near Rimouski, Quebec, Canada. The distance to Earth's centre can be used both for very deep positions and for positions in space.[2]

Cartesian coordinates

Every point that is expressed in ellipsoidal coordinates can be expressed as an x y z (Cartesian) coordinate. Cartesian coordinates simplify many mathematical calculations. The origin is usually the center of mass of the earth, a point close to the Earth's center of figure.

With the origin at the center of the ellipsoid, the conventional setup is the expected right-hand:

Z-axis along the axis of the ellipsoid, positive northward
X- and Y-axis in the plane of the equator, X-axis positive toward 0 degrees longitude and Y-axis positive toward 90 degrees east longitude

An example is the NGS data [14] for a brass disk near Donner Summit, in California. Given the dimensions of the ellipsoid, the conversion from lat/lon/height-above-ellipsoid coordinates to X-Y-Z is straightforward—calculate the X-Y-Z for the given lat-lon on the surface of the ellipsoid and add the X-Y-Z vector that is perpendicular to the ellipsoid there and has length equal to the point's height above the ellipsoid. The reverse conversion is harder: given X-Y-Z we can immediately get longitude, but no closed formula for latitude and height exists. However, using Bowring's formula in 1976 *Survey Review* the first iteration gives latitude correct within 10^{-11} degree as long as the point is within 10000 meters above or 5000 meters below the ellipsoid.

Shape of the Earth

The Earth is not a sphere, but an irregular shape approximating a biaxial ellipsoid. It is nearly spherical, but has an equatorial bulge making the radius at the equator about 0.3% larger than the radius measured through the poles. The shorter axis approximately coincides with axis of rotation. Map-makers choose the true ellipsoid that best fits their need for the area they are mapping. They then choose the most appropriate mapping of the spherical coordinate system onto that ellipsoid. In the United Kingdom there are three common latitude, longitude, height systems in use. The system used by GPS, WGS84, differs at Greenwich from the one used on published maps OSGB36 by approximately 112m. The military system ED50, used by NATO, differs by about 120m to 180m.[2]

Though early navigators thought of the sea as a flat surface that could be used as a vertical datum, this is far from reality. The Earth has a series of layers of equal potential energy within its gravitational field. Height is a measurement at right angles to this surface, roughly toward the centre of the Earth, but local variations make the equipotential layers irregular (though roughly ellipsoidal). The choice of which layer to use for defining height is arbitrary. The reference height we have chosen is the one closest to the average height of the world's oceans. This is called the geoid.[2][15]

The Earth is not static as points move relative to each other due to continental plate motion, subsidence, and diurnal movement caused by the Moon and the tides. The daily movement can be as much as a metre. Continental movement can be up to 10 cm a year, or 10 m in a century. A weather system high-pressure area can cause a sinking of 5 mm. Scandinavia is rising by 1 cm a year as a result of the melting of the ice sheets of the last ice age, but neighbouring Scotland is rising by only 0.2 cm. These changes are insignificant if a local datum is used, but are statistically significant if the global GPS datum is used.[2]

Expressing latitude and longitude as linear units

On the GRS80 or WGS84 spheroid at sea level at the equator, one latitudinal second measures *30.715 metres*, one latitudinal minute is *1843 metres* and one latitudinal degree is *110.6 kilometres*. The circles of longitude, meridians, meet at the geographical poles, with the west-east width of a second naturally decreasing as latitude increases. On the equator at sea level, one longitudinal second measures *30.92 metres*, a longitudinal minute is *1855 metres* and a longitudinal degree is *111.3 kilometres*. At 30° a longitudinal second is *26.76 metres*, at Greenwich (51° 28' 38" N) *19.22 metres*, and at 60° it is *15.42 metres*.

On the WGS84 spheroid, the length in meters of a degree of latitude at latitude φ (that is, the distance along a north-south line from latitude (φ - 0.5) degrees to (φ + 0.5) degrees) is about

$111132.954 - 559.822(\cos 2\varphi) + 1.175(\cos 4\varphi)$

(Those coefficients can be improved, but as they stand the distance they give is correct within a centimeter.)

To estimate the length of a longitudinal degree at latitude ϕ we can assume a spherical Earth (to get the width per minute and second, divide by 60 and 3600, respectively):

$$\frac{\pi}{180} M_r \cos\phi$$

where Earth's average meridional radius M_r is 6,367,449 m. Since the Earth isn't spherical that result can be off by several tenths of a percent; a better approximation of a longitudinal degree at latitude ϕ is

$$\frac{\pi}{180} a \cos\beta$$

where Earth's equatorial radius a equals *6,378,137 m* and $\tan\beta = \frac{b}{a}\tan\phi$; for the GRS80 and WGS84 spheroids, b/a calculates to be 0.99664719. (β is known as the parametric or reduced latitude). Aside from rounding, this is the exact distance along a parallel of latitude; getting the distance along the shortest route will be more work, but those two distances are always within 0.6 meter of each other if the two points are one degree of longitude apart.

Longitudinal length equivalents at selected latitudes

Latitude	Town	Degree	Minute	Second	±0.0001°
60°	Saint Petersburg	55.65 km	0.927 km	15.42 m	5.56 m
51° 28' 38" N	Greenwich	69.29 km	1.155 km	19.24 m	6.93 m
45°	Bordeaux	78.7 km	1.31 km	21.86 m	7.87 m
30°	New Orleans	96.39 km	1.61 km	26.77 m	9.63 m
0°	Quito	111.3 km	1.855 km	30.92 m	11.13 m

Datums often encountered

Latitude and longitude values can be based on different geodetic systems or datums, the most common being WGS 84, a global datum used by all GPS equipment.[16] Other datums are significant because they were chosen by a national cartographical organisation as the best method for representing their region, and these are the datums used on printed maps. The latitude and longitude on a map may not be the same as on a GPS receiver. Coordinates from the mapping system can sometimes be roughly changed into another datum using a simple translation. For example, to convert from ETRF89 (GPS) to the Irish Grid add 49 metres to the east, and subtract 23.4 metres from the north.[17] More generally one datum is changed into any other datum using a process called Helmert transformations. This involves converting the spherical coordinates into Cartesian coordinates and applying a seven parameter transformation (translation, three-dimensional rotation), and converting back.[2]

In popular GIS software, data projected in latitude/longitude is often represented as a 'Geographic Coordinate System'. For example, data in latitude/longitude if the datum is the North American Datum of 1983 is denoted by 'GCS North American 1983'.

Geostationary coordinates

Geostationary satellites (e.g., television satellites) are over the equator at a specific point on Earth, so their position related to Earth is expressed in longitude degrees only. Their latitude is always zero, that is, over the equator.

Notes

[1] https://www.cia.gov/library/publications/the-world-factbook/graphics/ref_maps/pdf/political_world.pdf
[2] A Guide to coordinate systems in Great Britain (http://www.ordnancesurvey.co.uk/oswebsite/gps/docs/A_Guide_to_Coordinate_Systems_in_Great_Britain.pdf) v1.7 October 2007 D00659 accessed 14.4.2008
[3] The surface of the Earth is closer to an ellipsoid than to a sphere, as its equatorial diameter is larger than its north-south diameter.
[4] The greatest distance between an ellipsoid normal and the center of the Earth is 21.9 km at a latitude of 45°, using Earth radius#Radius at a given geodetic latitude and Latitude#Comparison of selected types: (6367.5 km)×tan(11.67')=21.9 km.
[5] The International Meridian Conference (http://wwp.millennium-dome.com/info/conference.htm)
[6] The French Institut Géographique National (IGN) maps still use longitude from a meridian passing through Paris, along with longitude from Greenwich.
[7] Haswell, Charles Haynes (1920). *Mechanics' and Engineers' Pocket-book of Tables, Rules, and Formulas* (http://books.google.com/books?id=Uk4wAAAAMAAJ&pg=RA1-PA381&zoom=3). Harper & Brothers. . Retrieved 2007-04-09.
[8] The NGS (http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=tu2198) gives the NAD83 lat-lon at the water tank; (http://www.ngs.noaa.gov/cgi-bin/GEOID_STUFF/deflec99_prompt.prl) estimates the vertical deflection, the difference between NAD83 and lat-lon by the stars.
[9] The NGS (http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=tu2622) gives the NAD83 lat-lon and (http://www.ngs.noaa.gov/cgi-bin/GEOID_STUFF/deflec99_prompt.prl) again converts to astro lat-lon.
[10] http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=tu1252
[11] This is the "Old Hawaiian" datum; the NGS datasheets give the "OLD HI" lat-lons for Hawaiian points along with the current NAD83 lat-lons.
[12] http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=ku3602
[13] http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=uw7893
[14] http://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=aa3449
[15] DMA Technical Report (http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/geo4lay.pdf) Geodesy for the Layman, The Defense Mapping Agency, 1983
[16] WGS 84 is the *default* datum used in most GPS equipment, but other datums can be selected.
[17] Making maps compatible with GPS (http://www.osi.ie/GetAttachment.aspx?id=25113681-c086-485a-b113-bab7c75de6fa) Government of Ireland 1999. Accessed 15.4.2008

References

- *Portions of this article are from Jason Harris' "Astroinfo" which is distributed with KStars, a desktop planetarium for Linux/KDE. See* (http://edu.kde.org/kstars/index.phtml)

External links

- Mathematics Topics-Coordinate Systems (http://math.rice.edu/~lanius/pres/map/mapcoo.html)
- Geographic coordinates of countries (CIA World Factbook) (https://www.cia.gov/library/publications/the-world-factbook/index.html)
- FCC coordinates conversion tool (DD to DMS/DMS to DD) (http://www.fcc.gov/mb/audio/bickel/DDDMMSS-decimal.html)
- Coordinate converter, formats: DD, DMS, DM (http://www.sunearthtools.com/dp/tools/conversion.php)
- Latitude and Longitude (http://www.doogal.co.uk/LatLong.php)
- Find the GPS coordinates for a location or a place in several geocoding formats, which can be entered into a GPS device (http://www.map-gps-coordinates.com)

- Convert Address to Coordinates and vice-versa (http://www.gps-coordinates.net)

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