# Geodetic datum

From Wikipedia, the free encyclopedia
(Redirected from Geodetic system)

**Geodetic systems** or **geodetic data** are used in geodesy, navigation, surveying by cartographers and satellite navigation systems to translate positions indicated on their products to their real position on earth. The systems are needed because the earth is an imperfect ellipsoid.

A datum (plural *datums*) is a set of values used to define a specific geodetic system. The difference in co-ordinates between datums is commonly referred to as *datum shift*. The datum shift between two particular datums can vary from one place to another within one country or region, and can be anything from zero to hundreds of metres (or several kilometres for some remote islands). The North Pole, South Pole and Equator may be assumed to be in different positions on different datums, so True North may be very slightly different. Different datums use different estimates for the precise shape and size of the Earth (reference ellipsoids).

Because the Earth is an imperfect ellipsoid, localised datums can give a more accurate representation of the area of coverage than the global WGS 84 datum. OSGB36, for example, is a better approximation to the geoid covering the British Isles than the global WGS 84 ellipsoid.[*citation needed*] However, as the benefits of a global system outweigh the greater accuracy, the global WGS 84 datum is becoming increasingly adopted.

A **geodetic datum** (plural *datums*, not *data*) is a reference from which measurements are made. In surveying and geodesy, a *datum* is a set of reference points on the Earth's surface against which position measurements are made and (often) an associated model of the shape of the Earth (reference ellipsoid) to define a geodetic coordinate system. Horizontal datums are used for describing a point on the Earth's surface, in latitude and longitude or another coordinate system. Vertical datums measure elevations or depths. In engineering and drafting, a *datum* is a reference point, surface, or axis on an object against which measurements are made.

City of Chicago Datum Benchmark

## Contents

# Motivating theory

The earth is not an ellipsoid. This can be shown by differentiating the equation for an ellipsoid and solving for $dy/dx$. It is a constant multiplied by $x/y$. Then derive the force equation from the centrifugal force acting on an object on the earth's surface and the gravitational force. Switch the $x$ and $y$ components and multiply one of them by $-1$. This is the differential equation which when solved will yield the equation for the earth's surface. This is not a constant multiplied by $x/y$. Note that the earth's surface is also not an equal-potential surface, as can be verified by calculating the potential at the equator and the potential at a pole. The earth is an equal force surface. A one-kilogram frictionless object on the ideal earth's surface does not have any force acting upon it to cause it to move either north or south. There is no simple analytical solution to this differential equation.[*citation needed*]

The USGS uses a spherical harmonic expansion to approximate the earth's surface. It has about one hundred thousand terms.[*citation needed*]

# Datum

In surveying and geodesy, a *datum* is a reference point or surface against which position measurements are made, and an associated model of the shape of the earth for computing positions. Horizontal datums are used for describing a point on the earth's surface, in latitude and longitude or another coordinate system. Vertical datums are used to measure elevations or underwater depths.

# Horizontal datum

The horizontal datum is the model used to measure positions on the earth. A specific point on the earth can have substantially different coordinates, depending on the datum used to make the measurement. There are hundreds of locally-developed horizontal datums around the world, usually referenced to some convenient local reference point. Contemporary datums, based on increasingly accurate measurements of the shape of the earth, are intended to cover larger areas. The WGS 84 datum, which is almost identical to the NAD83 datum used in North America and the ETRS89 datum used in Europe, is a common standard datum.

For example, in Sydney there is a 200m (700 feet) difference between GPS coordinates configured in GDA (based on global standard WGS84) and AGD (used for most local maps), which is an unacceptably large error for some applications, such as surveying or site location for scuba diving.[1]

# Vertical datum

A vertical datum is used for measuring the elevations of points on the Earth's surface. Vertical datums are either: tidal, based on sea levels; gravimetric, based on a geoid; or geodetic, based on the same ellipsoid models of the earth used for computing horizontal datums.

In common usage, elevations are often cited in height above sea level, although what “sea level” actually means is a more complex issue than might at first be thought: the height of the sea surface at any one place and time is a result of numerous effects, including waves, wind and currents, atmospheric pressure, tides, topography, and even differences in the strength of gravity due to the presence of mountains etc.

Vertical datums in Europe

For the purpose of measuring the height of objects on land, the usual datum used is mean sea level (MSL). This is a tidal datum which is described as the arithmetic mean of the hourly water elevation taken over a specific 19 years cycle. This definition averages out tidal highs and lows (caused by the gravitational effects of the sun and the moon) and short term variations. It will not remove the effects of local gravity strength, and so the height of MSL, relative to a geodetic datum, will vary around the world, and even around one country. Countries tend to choose the mean sea level at one specific point to be used as the standard “sea level” for all mapping and surveying in that country. (For example, in Great Britain, the national vertical datum, Ordnance Datum Newlyn, is based on what was mean sea level at Newlyn in Cornwall between 1915 and 1921). However, zero elevation as defined by one country is not the same as zero elevation defined by another (because MSL is not the same everywhere), which is why locally defined vertical datums differ from one another.

A different principle is used when choosing a datum for nautical charts. For safety reasons, a mariner must be able to know the minimum depth of water that could occur at any point. For this reason, depths and tides on a nautical chart are measured relative to chart datum, which is defined to be a level below which tide rarely falls. Exactly how this is chosen depends on the tidal regime in the area being charted and on the policy of the hydrographic office producing the chart in question; a typical definition is Lowest

Astronomical Tide (the lowest tide predictable from the effects of gravity), or Mean Lower Low Water (the average lowest tide of each day), although MSL is sometimes used in waters with very low tidal ranges.

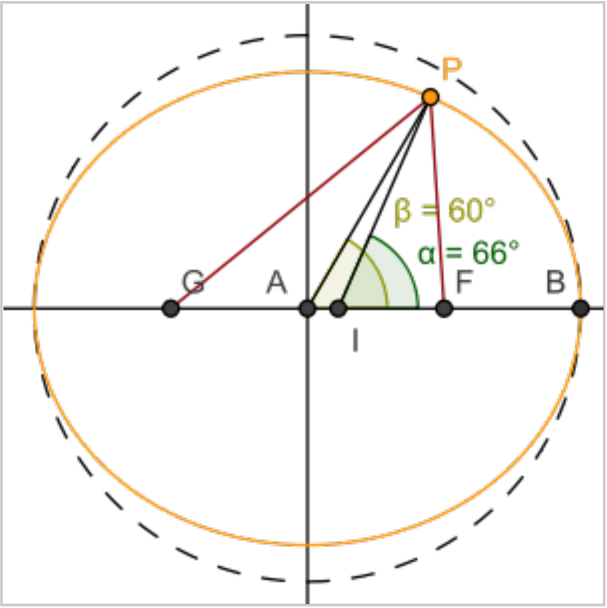
Conversely, if a ship is to safely pass under a low bridge or overhead power cable, the mariner must know the minimum clearance between the masthead and the obstruction, which will occur at high tide. Consequently, bridge clearances etc. are given relative to a datum based on high tide, such as Highest Astronomical Tide or Mean High Water Springs.

Sea level does not remain constant throughout geological time, and so tidal datums are less useful when studying very long-term processes. In some situations sea level does not apply at all — for instance for mapping Mars' surface — forcing the use of a different "zero elevation", such as mean radius.

A geodetic vertical datum takes some specific zero point, and computes elevations based on the geodetic model being used, without further reference to sea levels. Usually, the starting reference point is a tide gauge, so at that point the geodetic and tidal datums might match, but due to sea level variations, the two scales may not match elsewhere. An example of a gravity-based geodetic datum is NAVD88, used in North America, which is referenced to a point in Quebec, Canada. Ellipsoid-based datums such as WGS84, GRS80 or NAD83 use a theoretical surface that may differ significantly from the geoid.

# Geodetic coordinates

*Main article: Geodetic coordinates*



The same position on a spheroid has a different angle for latitude depending on whether the angle is measured from the normal (angle $\alpha$) or around the center (angle $\beta$). Note that the

In geodetic coordinates the Earth's surface is approximated by an ellipsoid and locations near the surface are described in terms of latitude ($\phi$), longitude ($\lambda$) and height ($h$).[footnotes 1]

The ellipsoid is completely parameterised by the semi-major axis $a$ and the flattening $f$.

## Geodetic versus geocentric latitude

*Main article: latitude*

It is important to note that geodetic latitude ($\phi$) (resp. altitude) is different from geocentric latitude ($\phi'$) (resp. altitude). Geodetic latitude is determined by the angle between the normal of the ellipsoid and the plane of the equator, whereas geocentric latitude is determined around the centre (see figure). Unless otherwise specified latitude is geodetic latitude.

"flatness" of the spheroid (orange) in the image is greater than that of the Earth; as a result, the corresponding difference between the "geodetic" and "geocentric" latitudes is also exaggerated.

## Defining and derived parameters

*Main article: Reference ellipsoid#Ellipsoid parameters*

| Parameter | Symbol |
|---|---|
| Semi-major axis | $a$ |
| Reciprocal of flattening | $1/f$ |

From $a$ and $f$ it is possible to derive the semi-minor axis $b$, first eccentricity $e$ and second eccentricity $e'$ of the ellipsoid

| Parameter | Value |
|---|---|
| semi-minor axis | $b = a(1 - f)$ |
| First eccentricity squared | $e^2 = 1 - b^2/a^2 = 2f - f^2$ |
| Second eccentricity squared | $e'^2 = a^2/b^2 - 1 = f(2 - f)/(1 - f)^2$ |

## Parameters for some geodetic systems

*Main article: Earth ellipsoid#Historical Earth ellipsoids*

Australian Geodetic Datum 1966 [AGD66] and Australian Geodetic Datum 1984 (AGD84)

AGD66 and AGD84 both use the parameters defined by Australian National Spheroid (see below)

Australian National Spheroid (ANS)

**ANS Defining Parameters**

| Parameter | Notation | Value |
|---|---|---|
| semi-major axis | a | 6 378 160.000 m |
| Reciprocal of Flattening | $1/f$ | 298.25 |

Geocentric Datum of Australia 1994 (GDA94)

GDA94 uses the parameters defined by GRS80 (see below)

Geodetic Reference System 1980 (GRS80)

**GRS80 Parameters**

| Parameter | Notation | Value |
|---|---|---|
| semi-major axis | a | 6 378 137 m |
| Reciprocal of flattening | $1/f$ | 298.257 222 101 |

see GDA Technical Manual (http://www.icsm.gov.au/icsm/gda/gdatm/index.html) document for more details; the value given above for the flattening is not exact.

World Geodetic System 1984 (WGS84)

The Global Positioning System (GPS) uses the World Geodetic System 1984 (WGS84) to determine the location of a point near the surface of the Earth.

**WGS84 Defining Parameters**

| Parameter | Notation | Value |
|---|---|---|
| semi-major axis | a | 6 378 137.0 m |
| Reciprocal of flattening | $1/f$ | 298.257 223 563 |

**WGS84 derived geometric constants**

| Constant | Notation | Value |
|---|---|---|
| Semi-minor axis | $b$ | 6 356 752.3142 m |
| First eccentricity squared | $e^2$ | $6.694\ 379\ 990\ 14 \times 10^{-3}$ |
| Second eccentricity squared | $e'^2$ | $6.739\ 496\ 742\ 28 \times 10^{-3}$ |

see The official World Geodetic System 1984 (http://earth-info.nga.mil/GandG/publications/tr8350.2/tr8350_2.html) document for more details.

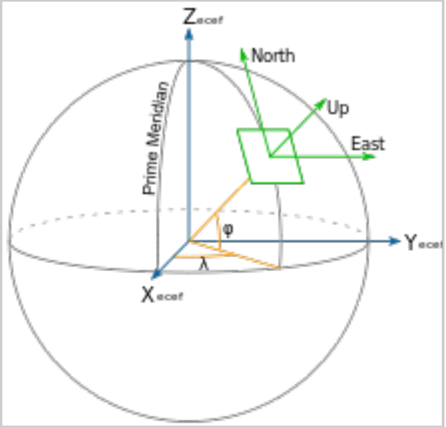
A more comprehensive list of geodetic systems can be found here (http://www.colorado.edu/geography/gcraft/notes/datum/elist.html)

# Other Earth-based coordinate systems

*Main article: axes conventions*

## Earth-centred earth-fixed (ECEF or ECF) coordinates

The earth-centered earth-fixed (ECEF or ECF) or conventional terrestrial coordinate system rotates with the Earth and has its origin at the centre of the Earth. The $X$ axis passes through the equator at the prime meridian. The $Z$ axis passes through the north pole but it does not exactly coincide with the instantaneous Earth rotational axis.[2] The $Y$ axis can be determined by the right-hand rule to be passing through the equator at 90° longitude.



Earth Centred Earth Fixed and East, North, Up coordinates.

## Local east, north, up (ENU) coordinates

In many targeting and tracking applications the local East, North, Up (ENU) Cartesian coordinate system is far more intuitive and practical than ECEF or Geodetic coordinates. The local ENU coordinates are formed from a plane tangent to the Earth's surface fixed to a specific location and hence it is sometimes known as a "Local Tangent" or "local geodetic" plane. By convention the east axis is labeled $x$, the north $y$ and the up $z$.

## Local north, east, down (NED) coordinates

In an airplane most objects of interest are below you, so it is sensible to define down as a positive number. The North, East, Down (NED) coordinates allow you to do this as an alternative to the ENU local tangent plane. By convention the north axis is labeled $x'$, the east $y'$ and the down $z'$. To avoid confusion between $x$ and $x'$, etc. in this web page we will restrict the local coordinate frame to ENU.

# Conversion calculations

Datum conversion is the process of converting the coordinates of a point from one datum system to another. Datum conversion may frequently be accompanied by a change of grid projection.

## Geodetic to/from ECEF coordinates

### From geodetic to ECEF

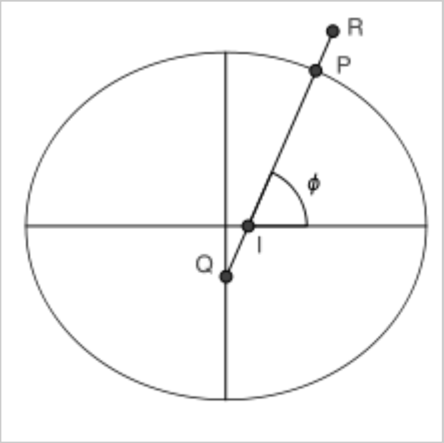
Geodetic coordinates (latitude $\phi$, longitude $\lambda$, height $h$) can be converted into ECEF coordinates using the following formulae:

$$X = (N(\phi) + h)\cos\phi\cos\lambda$$
$$Y = (N(\phi) + h)\cos\phi\sin\lambda$$
$$Z = \big(N(\phi)(1 - e^2) + h\big)\sin\phi$$

where

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

$a$ and $e$ are the semi-major axis and the first numerical eccentricity of the ellipsoid respectively.
$N(\phi)$ is called the *Normal* and is the distance from the surface to the Z-axis along the ellipsoid normal (see "Radius of curvature on the Earth"). The following equation holds:



The length PQ is called *Normal* ($N(\phi)$). The length IQ is equal to $e^2N(\phi)$. R = $(X, Y, Z)$.

$$\frac{p}{\cos\phi} - \frac{Z}{\sin\phi} - e^2 N(\phi) = 0,$$

where $p = \sqrt{X^2 + Y^2}$.

The orthogonality of the coordinates is confirmed via differentiation:

$$\begin{aligned}&\big(dX,\, dY,\, dZ\big)\\ =&\big(-\sin\phi\cos\lambda,\, -\sin\phi\sin\lambda,\, \cos\phi\big)\,\big(M(\phi)+h\big)\, d\phi\\ &+\big(-\sin\lambda,\, \cos\lambda,\, 0\big)\,\big(N(\phi)+h\big)\cos\phi\, d\lambda\\ &+\big(\cos\lambda\cos\phi,\, \cos\phi\sin\lambda,\, \sin\phi\big)\, dh,\end{aligned}$$

where

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

(see also "Meridian arc on the ellipsoid").

## From ECEF to geodetic

The conversion of ECEF coordinates to geodetic coordinates (such WGS84) is a much harder problem,[3][4] except for longitude, $\lambda$.

There exist two kinds of methods in order to solve the equation.

### Newton–Raphson method

The following Bowring's irrational geodetic-latitude equation[5] is efficient to be solved by Newton–Raphson iteration method:[6]

$$\kappa - 1 - \frac{e^2 a \kappa}{\sqrt{p^2 + (1-e^2) z^2 \kappa^2}} = 0,$$

where $\kappa = \frac{p}{z} \tan\phi$. The height is calculated as follows:

$$\begin{aligned} h &= e^{-2}(\kappa^{-1} - {\kappa_0}^{-1})\sqrt{p^2 + z^2\kappa^2}, \\ \kappa_0 &= \left(1 - e^2\right)^{-1}. \end{aligned}$$

The iteration can be transformed into the following calculation:

$$\kappa_{i+1} = \frac{c_i + (1-e^2)\, z^2 \kappa_i^3}{c_i - p^2} = 1 + \frac{p^2 + (1-e^2)\, z^2 \kappa_i^3}{c_i - p^2},$$

where $c_i = \frac{\left(p^2 + (1-e^2)\, z^2 \kappa_i^2\right)^{3/2}}{a e^2}$.

$\kappa_0$ is a good starter for the iteration when $h \approx 0$. Bowring showed that the single iteration produces the sufficiently accurate solution. He used extra trigonometric functions in his original formulation.

**Ferrari's solution**

The following[7] [8] solve the above equation:

$$\begin{aligned} \zeta &= (1-e^2) z^2 / a^2, \\ \rho &= (p^2/a^2 + \zeta - e^4)/6, \\ s &= e^4 \zeta p^2 / (4a^2), \\ t &= \sqrt[3]{\rho^3 + s + \sqrt{s(s + 2\rho^3)}}, \\ u &= \rho + t + \rho^2/t, \\ v &= \sqrt{u^2 + e^4 \zeta}, \\ w &= e^2(u + v - \zeta)/(2v), \\ \kappa &= 1 + e^2(\sqrt{u + v + w^2} + w)/(u + v). \end{aligned}$$

## Geodetic to/from ENU coordinates

To convert from geodetic coordinates to local ENU up coordinates is a two stage process

1. Convert geodetic coordinates to ECEF coordinates
2. Convert ECEF coordinates to local ENU coordinates

To convert from local ENU up coordinates to geodetic coordinates is a two stage process

1. Convert local ENU coordinates to ECEF coordinates
2. Convert ECEF coordinates to geodetic coordinates

### From ECEF to ENU

To transform from ECEF coordinates to the local coordinates we need a local reference point, typically this might be the location of a radar. If a radar is located at $\{X_r, Y_r, Z_r\}$ and an aircraft at $\{X_p, Y_p, Z_p\}$ then the vector pointing from the radar to the aircraft in the ENU frame is

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} -\sin\lambda_r & \cos\lambda_r & 0 \\ -\sin\phi_r\cos\lambda_r & -\sin\phi_r\sin\lambda_r & \cos\phi_r \\ \cos\phi_r\cos\lambda_r & \cos\phi_r\sin\lambda_r & \sin\phi_r \end{bmatrix} \begin{bmatrix} X_p - X_r \\ Y_p - Y_r \\ Z_p - Z_r \end{bmatrix}$$

**Note:** $\phi$ is the *geodetic* latitude. A prior version of this page showed use of the *geocentric* latitude ($\phi'$). The *geocentric* latitude is *not* the appropriate *up* direction for the local tangent plane. If the original *geodetic* latitude is available it should be used, otherwise, the relationship between *geodetic* and *geocentric* latitude has an altitude dependency, and is captured by:

$$\tan\phi' = \frac{Z_r}{\sqrt{X_r^2 + Y_r^2}} = \frac{N(\phi)(1-f)^2 + h}{N(\phi) + h}\tan\phi$$

Obtaining *geodetic* latitude from *geocentric* coordinates from this relationship requires an iterative solution approach, otherwise the *geodetic* coordinates may be computed via the approach in the section above labeled "From ECEF to geodetic coordinates."

The geocentric and geodetic longitude have the same value. This is true for the Earth and other similar shaped planets because their latitude lines (parallels) can be considered in much more degree perfect circles when compared to their longitude lines (meridians).

$$\tan\lambda = \frac{Y_r}{X_r}$$

**Note:** Unambiguous determination of $\phi$ and $\lambda$ requires knowledge of which quadrant the coordinates lie in.

### From ENU to ECEF

This is just the inversion of the ECEF to ENU transformation so

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} -\sin\lambda & -\sin\phi\cos\lambda & \cos\phi\cos\lambda \\ \cos\lambda & -\sin\phi\sin\lambda & \cos\phi\sin\lambda \\ 0 & \cos\phi & \sin\phi \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} X_r \\ Y_r \\ Z_r \end{bmatrix}$$

# Reference datums

A reference datum is a known and constant surface which is used to describe the location of unknown points on the earth. Since reference datums can have different radii and different center points, a specific point on the earth can have substantially different coordinates depending on the datum used to make the measurement. There are hundreds of locally-developed reference datums around the world, usually referenced to some convenient local reference point. Contemporary datums, based on increasingly accurate measurements of the shape of the earth, are intended to cover larger areas. The most common reference Datums in use in North America are NAD27, NAD83, and WGS84.

The North American Datum of 1927 (NAD 27) is "the horizontal control datum for the United States that was defined by a location and azimuth on the Clarke spheroid of 1866, with origin at (the survey station) Meades Ranch (Kansas)." ... The geoidal height at Meades Ranch was assumed to be zero. "Geodetic positions on the North American Datum of 1927 were derived from the (coordinates of and an azimuth at Meades Ranch) through a readjustment of the triangulation of the entire network in which Laplace azimuths were introduced, and the Bowie method was used." (http://www.ngs.noaa.gov/faq.shtml#WhatDatum ) NAD27 is a local referencing system covering North America.

The North American Datum of 1983 (NAD 83) is "The horizontal control datum for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the Geodetic Reference System 1980 (GRS80). "This datum, designated as NAD 83 ...is based on the adjustment of 250,000 points including 600 satellite Doppler stations which constrain the system to a geocentric origin." NAD83 may be considered a local referencing system.

WGS 84 is the World Geodetic System of 1984. It is the reference frame used by the U.S. Department of Defense (DoD) and is defined by the National Geospatial-Intelligence Agency (NGA) (formerly the Defense Mapping Agency, then the National Imagery and Mapping Agency). WGS 84 is used by DoD for all its mapping, charting, surveying, and navigation needs, including its GPS "broadcast" and "precise" orbits. WGS 84 was defined in January 1987 using Doppler satellite surveying techniques. It was used as the reference frame for broadcast GPS Ephemerides (orbits) beginning January 23, 1987. At 0000 GMT January 2, 1994, WGS 84 was upgraded in accuracy using GPS measurements. The formal name then became WGS 84 (G730), since the upgrade date coincided with the start of GPS Week 730. It became the reference frame for broadcast orbits on June 28, 1994. At 0000 GMT September 30, 1996 (the start of GPS Week 873), WGS 84 was redefined again and was more closely aligned with International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF) 94. It is now formally called WGS 84 (G873). WGS 84 (G873) was adopted as the reference frame for broadcast orbits on January 29, 1997.[9]

The WGS84 datum, which is almost identical to the NAD83 datum used in North America, is the only world referencing system in place today. WGS84 is the default standard datum for coordinates stored in recreational and commercial GPS units.

Users of GPS are cautioned that they must always check the datum of the maps they are using. To correctly enter, display, and to store map related map coordinates, the datum of the map must be entered into the GPS map datum field.

# Engineering datums

An engineering datum used in geometric dimensioning and tolerancing is a feature on an object used to create a reference system for measurement.[10]

# Examples

Examples of map datums are:

- WGS 84, 72, 64 and 60 of the World Geodetic System
- NAD83, the North American Datum which is very similar to WGS84
- NAD27, the older North American Datum, of which NAD83 was basically a readjustment [1] (http://www.ngs.noaa.gov/TOOLS/Nadcon/Nadcon.html)
- OSGB36 of the Ordnance Survey of Great Britain
- ED50, the European Datum
- Hong Kong Principal Datum, is 1.23m below the mean of 19 years (1965–83) observations of tide levels at North Point, Victoria Harbour.[11][12]

# See also

- World Geodetic System
- Ordnance Datum
- ECEF
- Shape of the Earth
- geoid
- data

# Footnotes

1. ^ About the right/left-handed order of the coordinates, i.e., $(\lambda, \phi)$ or $(\phi, \lambda)$, see Spherical_coordinate_system#Conventions.

# References

1. ^ McFadyen, GPS and Diving (http://www.michaelmcfadyenscuba.info/viewpage.php?page_id=80)
2. ^ Note on the BIRD ACS Reference Frames (http://www.weblab.dlr.de/rbrt/pdf/TN_0001.pdf)
3. ^ R. Burtch, A Comparison of Methods Used in Rectangular to Geodetic Coordinate

Transformations. (http://www.ferris.edu/faculty/burtchr/papers/cartesian_to_geodetic.pdf)

4. ^ Featherstone, W. E.; Claessens, S. J. (2008). "Closed-Form Transformation between Geodetic and Ellipsoidal Coordinates". *Stud. Geophys. Geod.* **52** (1): 1–18. doi:10.1007/s11200-008-0002-6 (http://dx.doi.org/10.1007%2Fs11200-008-0002-6).
5. ^ Bowring, B. R. (1976). "Transformation from Spatial to Geographical Coordinates". *Surv. Rev.* **23** (181): 323–327. doi:10.1179/003962676791280626 (http://dx.doi.org/10.1179%2F003962676791280626).
6. ^ Fukushima, T. (1999). "Fast Transform from Geocentric to Geodetic Coordinates". *J. Geod.* **73** (11): 603–610. doi:10.1007/s001900050271 (http://dx.doi.org/10.1007%2Fs001900050271). (Appendix B)
7. ^ Vermeille, H., H. (2002). "Direct Transformation from Geocentric to Geodetic Coordinates". *J. Geod.* **76** (8): 451–454. doi:10.1007/s00190-002-0273-6 (http://dx.doi.org/10.1007%2Fs00190-002-0273-6).
8. ^ Gonzalez-Vega, Laureano; PoloBlanco, Irene (2009). "A symbolic analysis of Vermeille and Borkowski polynomials for transforming 3D Cartesian to geodetic coordinates". *J. Geod* **83** (11): 1071–1081. doi:10.1007/s00190-009-0325-2 (http://dx.doi.org/10.1007%2Fs00190-009-0325-2).
9. ^ WGS84 on the site of National Geodetic Survey (http://www.ngs.noaa.gov/faq.shtml#WGS84)
10. ^ ANSI Y14.5M (ISBN 0-7918-2223-0) for engineering datums.
11. ^ "Vertical Datum used in China - Hong Kong – onshore" (http://georepository.com/datum_5135/Hong-Kong-Principal-Datum.html).
12. ^ http://www.info.gov.hk/landsd/mapping/tindex.htm

# Further reading

1. List of geodetic parameters for many systems (http://www.colorado.edu/geography/gcraft/notes/datum/elist.html)
2. Kaplan, Understanding GPS: principles and applications, 1 ed. Norwood, MA 02062, USA: Artech House, Inc, 1996.
3. GPS Notes (http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html)
4. Introduction to GPS Applications (http://www.redsword.com/gps/apps/index.htm)
5. P. Misra and P. Enge, Global Positioning System Signals, Measurements, and Performance. Lincoln, Massachusetts: Ganga-Jamuna Press, 2001.
6. Peter H. Dana: Geodetic Datum Overview (http://www.colorado.edu/geography/gcraft/notes/datum/datum.html) – Large amount of technical information and discussion.
7. UK Ordnance Survey (http://www.ordsvy.gov.uk/)
8. US National Geodetic Survey (http://www.ngs.noaa.gov/)

# External links

- GeographicLib (http://geographiclib.sourceforge.net) includes a utility CartConvert which converts between geodetic and geocentric (ECEF) or local Cartesian (ENU) coordinates. This provides accurate results for all inputs including points close to the center of the earth.
- A collection of geodetic functions that solve a variety of problems in geodesy in Matlab (http://www.mathworks.com/matlabcentral/fileexchange/15285-geodetic-toolbox).
- UK Ordnance Survey (http://www.ordnancesurvey.co.uk/)
- US National Geodetic Survey (http://www.ngs.noaa.gov/)

- NGS FAQ – What is a geodetic datum? (http://www.ngs.noaa.gov/faq.shtml#WhatDatum)
- About the surface of the Earth (http://kartoweb.itc.nl/geometrics/Reference%20surfaces/body.htm) on kartoweb.itc.nl (http://kartoweb.itc.nl)

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Categories: Coordinate systems | Cartography | Navigation | Geodesy | Surveying | Global Positioning System | Geodesic datums

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