A GPS Glossary: from Almanac to Zenith Delay

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As with any technically complicated system, GPS has many specialized terms and acronyms associated with it. Since a lot of these come from fields outside of geophysics (such as radionavigation) they tend to be unfamiliar to geophysicists. Part of learning GPS is learning these terms, so I offer this incomplete and opinionated set of definitions as a possible aid.[1] It includes some jargon used by surveyors because this is used in doing GPS fieldwork.

Almanac. See **ephemeris**.

Ambiguity resolution. Since the **carrier** of the GPS signal is a sine wave, all the peaks and troughs look alike. So if we measure that (say) for the carrier from a particular satellite we are at a peak (at some time), that tells us the distance to the satellite very precisely, except that since we can't tell the peaks apart, there are an unknown number of cycles: this is the ambiguity. Ambiguity resolution is the process of finding this out, aided by the following facts: (1) the number of cycles is an integer (2) we know from other information roughly where we are and (3) there are signals coming from different directions. Figuring out which integer this is for all the signals, and then fixing it, makes for a much more precise position estimate. This is also called "bias fixing", because until the ambiguity is resolved, ambiguities can be said to have introduced a bias – but this phrase, though shorter, is itself more ambiguous.

Antenna height. Height of the **antenna reference point** above the marker. Vital information, too often inadequately recorded.

Antenna reference point. (ARP). Physical location on the antenna which is used for measuring the **antenna height**. Must be specified in measuring this height, since for some antennas there is no universally agreed choice on what the ARP is.

Anti-Spoofing (AS). Encryption of the **P code**; the term arises because this encryption makes it impossible for anyone else to produce a fake (and possibly misleading) GPS signal. Having AS on (and it has been on since early 1994) degrades the accuracy with which most receivers measure the **L2 carrier**.

Aspect repeat time. Time between a GPS satellites occupying the same position in the sky, viewed from a particular location. On average, this is 86154 seconds: 4 minutes and 6 seconds less than a day.

Azimuth. Angular distance from North to the satellite, measured clockwise along the horizon; this and **elevation** describe where the satellite appears on the sky.

Baidou. Satellite navigation system deployed by the People's Republic of China.

Benchmark. A geodetic reference marker whose orthometric **height** is known. Sometimes used generically to refer to a **monument**.

[1] There are many others available on the Web; just Google "GPS glossary".

Bias fixing. See **ambiguity resolution**.

BINEX. Standard exchange and storage format for GPS observations, in binary; more compact than **RINEX**.

Block. Model of GPS satellite. Block I (**SVN** 1-11, launched 1978-85) were prototypes, Block II (**SVN** 13-21, launched 1989-90) were the first fully operational models, while Blocks IIA (**SVN** 22-40, launched 1993-97), Block IIR (**SVN** 41-61, launched 1997-2009), and Block IIF (**SVN** 62-63, launched 2010 on) are successively improved models. Some of Block IIR, called Block IIR-M, have an open signal on the **L2 carrier**. Block IIF is the current series and includes the **L5 carrier**. Certain aspects of the changes between blocks (such as the location of the antenna) need to be allowed for in modeling.

C/A code Coarse Acquisition code, which is one of the codes used to modulate the **L1 carrier**. Has an effective wavelength of 293 m and repeats every millisecond. This code is open (can be decoded by all receivers).

Campaign GPS. See **survey-mode.**

Carrier. The underlying sinusoidal variation of the transmitted radio wave, modulated by the various codes. GPS uses two frequencies, L1 (1575.42 MHz, wavelength 190 mm) and L2 (1227.6 MHz, wavelength 244 mm).

Carrier-beat-phase. One of the GPS observables: the phase of the beat frequency between the **carrier** as received, and the same (nominal) frequency from a **clock** inside the receiver.

Choke ring. Set of vertical rings included in some antenna designs to block **multipath** signals reflected from the ground surface.

Clock. Something that tells the time (what did you expect?), and also provides a reference frequency (actually, the frequency comes first). There are two sets of these to worry about: the ones in the receivers, and the ones in the satellite. Errors in both are significant and have to be corrected for or otherwise dealt with. Except at a few permanent sites that provide the time base for the GPS system, the clocks in receivers use crystal oscillators and are much inferior to those in the satellites, which use atomic oscillators.

Constellation. The full set of GPS satellites in orbit; or, those visible from some location at some time.

Code. Something used to modulate the GPS **carrier**. See **C/A code**, **P code**, and **Y code**.

CORS (Continuously Operating Reference Station) Term used by the surveying community (in the USA) for permanent GPS installations whose data can be used as a reference for some other survey.

Cutoff angle. Angle of **elevation** above which satellites must appear to be observed, or data from them processed. Low-angle data are noisy because of **multipath** (better reflection off the ground at grazing incidence) and **propagation delays** (more atmosphere to pass through), but help to improve the position solution, especially in the vertical. The usual cutoff is 15°.

Cycle Slip. A break in the **carrier-beat-phase** signal for one or more satellites, caused by noise or the blocking of the signal. The name arises because after such a break the **ambiguity** will be different by some (unknown) number of cycles.

Datum. Geodetic term for a particular definition of a terrestrial coordinate system. Datums now are defined globally, as Cartesian coordinates with a particular origin (ideally the Earth's center of mass) and orientation (which requires us to define where the North Pole and 0° Longitude are). In the US the datum now used is the North American Datum of 1983 (NAD83), which is fairly close to the international standard **ITRF**, as is the military reference, the World Geodetic System, 1984 (**WGS84**). However, the NAD83 datum takes the North American plate as fixed.

Differential GPS. Any system which combines the GPS signal received at one point (A) with that received at another (B, whose location is known) to get the location of A. This technique can reduce the errors in locating A, especially from short spans of data, because many of these errors will be common to A and B so long as they are not too far apart. Most such systems transmit the B information (sometimes called a "correction signal") in real time, allowing its immediate use for improved location of fixed or moving receivers. In the USA the **WAAS** system provides correction signals from over thirty ground stations, broadcast via geostationary satellite, to improve aircraft (and other) positioning. A receiver that can use the WAAS corrections will have about one-fifth the error of one that does not.

Dilution of Precision. A measure of how much some quantity derived from GPS data is affected by the particular appearance of the **constellation**; for example, if all the satellites were nearly directly overhead (and the satellite and receiver **clocks** were perfect), the vertical location could be determined very well, and the horizontal poorly; in GPS jargon, the Vertical Dilution of Precision (VDOP) would be small, and the Horizontal Dilution of Precision (HDOP) large. PDOP (Position Dilution of Precision) is an overall measure of quality, and it is best to avoid observations when this is large. (Given clocks with error, the VDOP would in fact be infinite for all satellites at the zenith).

Double Difference. Difference between two **single differences**, each computed for one receiver observing the same pair of satellites. This is unaffected by errors in either receiver **clock** and either satellite clock. Not to be confused with second differencing of a series of numbers.

Drilled-braced monument. Design for a **monument** that is meant to be unaffected by shallow soil motion; it uses several rods, cemented into drilled holes, and welded together to form a truss.

Dry delay. The **propagation delay** caused by all atmospheric gases other than water vapor. Since these gases are well-mixed and the atmosphere is very close to hydrostatic, this can be modeled by a single **zenith delay**.

Dual-frequency. A GPS receiver that can collect data on both frequencies emitted by the satellites (**L1** and **L2**) and thus can provide the **LC** observable, which is largely unaffected by the **propagation delay** caused by the **ionosphere**.

Earth Orientation Parameters (EOP). Description of how earth rotation departs from a steady rate of spin in a fixed direction because of changes in the length of day (**LOD**) and motions of the spin axis (**polar motion**).

ECEF. **E**arth-**C**entered **E**arth-**F**ixed. Reference frame that is centered at the Earth's center of mass and rotates with the Earth, on average.

Eclipse. When a GPS satellite is in the Earth's shadow, and hence not subject to solar **radiation pressure**, which makes **orbit integration** more difficult.

Elevation. Angular distance from the horizon (at some location) to a satellite; this and **azimuth** describe where the satellite appears on the sky.

Elevation Mask. Elevation, as a function of azimuth, below which the satellite signal will be blocked, for example by nearby buildings, trees, or topography; alternatively, the **cutoff angle** in processing.

Ellipsoid. A geometric shape that approximates the shape of the Earth, or more precisely the **geoid**. Location can be given relative to it using the coordinates geodetic latitude, geodetic longitude, and ellipsoidal **height** (rather than Cartesian XYZ). The standard ellipsoid in use for GPS is the WGS84 ellipsoid, with an equatorial radius (semimajor axis) of 6378137 m, and a flattening of 1/298.257223563; the international standard ellipsoid has a flattening of 1/298.257222101, negligibly but confusingly different.

Ephemeris. Table or set of formulas that describes the locations of a GPS satellite (or satellites) over some time span. Also, the same thing for the Moon, Sun (which is to say, really the Earth), or planets. For GPS, there are several levels of ephemerides:

The **almanac** is a very rough ephemeris for all satellites, transmitted by each one; it is accurate to about 1 km, and allows a GPS receiver to rapidly acquire the satellite signals (by computing the Doppler shift for each **carrier**).

The **broadcast ephemeris** is a more precise ephemeris, broadcast by each satellite for itself; it is predicted from prior data Currently it is accurate to around 2 m (radial distance, which is what matters most).

A **predicted ephemeris** is an ephemeris derived from past data, using **orbit integration** to predict where the satellites will be. The broadcast ephemeris is one example; the **ultra-rapid ephemeris** produced by the **IGS**, which is predicted for half of its (one day) span, is good to within 0.1 m.

A **precise ephemeris** is an ephemeris derived from data covering the same time span; current example of these have errors of less than 0.05 m.

Epoch. A particular moment in time; for example, when an observation is taken, or what date a set of coordinates refers to (in a time-varying coordinate system). In GPS measurement, the time at which the **carrier-beat phase** is sampled and given.

Galileo. Satellite navigation system deployed by the European Union.

GLONASS. **Glo**bal'naya **N**avigatsionnaya **S**putnikovaya **S**istema. Satellite navigation system deployed by the Soviet Union, maintained by Russia; most useful in the northern hemisphere.

Geodetic Term for more-expensive GPS receivers that are used by surveyors and scientists to determine positions to a centimeter or better The main differences between these and cheaper **navigation** grade receivers are: (1) processing of both the L1 and L2 frequencies, and (2) recording of the **carrier-beat-phase** as well as the **code**.

Geoid Irregular surface of constant gravitational potential, the particular value of the potential being chosen so that this surface will match a temporal and spatial average of sea level.

GNSS (Global Navigation Satellite Systems). Generic term for satellite navigation systems, used to include GPS, **GLONASS**, **Galileo**, and **Baidou**. Applied to a receiver, means that it can use signals from some or all of the systems other than GPS; this provides better **ambiguity resolution**, but makes the receiver more expensive.

GPS Week. See **time**.

Ground Plane. Flat horizontal plate included in some antenna designs to block **multipath** signals reflected from the ground surface.

Ground Track. The path on the ground that is followed by a point directly beneath the satellite. The GPS system is designed so that the satellites complete exactly two orbits in the time that the Earth rotates once (a **sidereal day**, very nearly), so that the ground track repeats; see **aspect repeat time**.

Hatanaka compression. Version of the **RINEX** format, with redundant information removed and differencing applied to make observation files shorter; they are still in ASCII but not human-readable. Not a general compression scheme like zip.

Height. Simply put, vertical distance from a reference surface; except that this turns out not to be simple at all. GPS measures locations relative to the center of mass of the Earth, in a coordinate system (see **datum**) whose orientation is set in part by the Earth's rotation; GPS positions do not contain anything related to the "vertical". If we express the coordinates of a point in ellipsoidal coordinates, and choose an **ellipsoid** that roughly matches the shape of the Earth, the radial distance minus the local radius of the ellipsoid will approximate height; it is in fact called the **ellipsoidal height**. This is the height given by (for example) a handheld GPS receiver. However, the vertical distance we usually have in mind is that measured along a vertical line from mean sea level (or where it would be on land), which is to say from the **geoid**. This, which is called **orthometric height**, is a better measure because it defines "downhill" in the same way as an equipotential; sea level (averaging over time) has an orthometric height of zero everywhere. The difference between these two heights is the geoid-ellipsoid separation, or **geoid height**. In southern California, the geoid is about 30 m below the standard ellipsoid, so an ellipsoidal height of zero is well above sea level.

Helmert Transformation. See **transformation.**

High-rate real-time. Term used for GPS data and processing that produces a **single-epoch** position at a sample rate higher than the usual rate (for geodetic receivers) of 30 or 15 seconds. Actually, this is just the "high-rate" part; the "real-time" refers to having the data from a receiver telemetered to an analysis center so that these positions can be obtained immediately.

Hockey puck. (More formally, a **tribrach** adaptor). Device for attaching an antenna to a **tribrach**; the antenna fits on a 5/8″×11 screw, and the puck is locked onto the tribrach mechanism.

ICRF International Celestial Reference Frame. A particular realization of the **ICRS**, chosen by defining celestial coordinates for particular objects.

ICRS International Celestial Reference System. The **reference frame** that defines "space" by taking axes whose directions are fixed relative to very distant celestial objects. This is presumed to be the frame for **inertial space** as well.

IERS International Earth Rotation Service: international body that combines data to produce **Earth orientation parameters**. Also responsible for the actual definitions of the **ICRF** and **ITRF**, and for standardizing some data-processing methods through the publication of the IERS Conventions. See `http://www.iers.org/`

IGS International GNSS Service, where GNSS stands for Global Navigation Satellite System (you can see why they compressed the acronym). International body that coordinates the collection, archiving, and distribution of GPS data and such products as **ephemerides**. Formerly the International GPS Service; the name change was made to cover **GLONASS** and other systems. See `http://www.igs.org/`

Inertial space. Space in which bodies move in accordance with Newton's laws (as modified by relativity theory). This is presumed (on good evidence) to match a **reference frame** with axis directions that are fixed relative to very distant celestial objects.

Ionosphere. Part of the atmosphere from about 70 to 500 km elevation, consisting of charged particles, which causes a frequency-dependent **propagation delay** of the GPS signals.

ITRF **I**nternational **T**errestrial **R**eference Frame. A realization of the **ITRS**, defined by choosing Cartesian coordinates and velocities for particular locations at which space-geodetic observations are made. Different realizations are related through **transformations**; at this time, the realizations have been ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF95, ITRF96, ITRF97, ITRF2000, ITRF2005, ITRF2008, and ITRF 2014.

ITRS International Terrestrial Reference System. The **reference frame** that defines "Earth-fixed" by taking axes whose directions are fixed (on average) relative to the Earth, with **no net rotation**.

JD (Julian date). Time reckoning system, used by some GPS processing software, that is based on a year count introduced by Joseph Scaliger in 1583. The Julian date is the count of days from 1 January, –4712 (4713 BCE) in the Julian proleptic calendar, this year being the most recent one in which the cycles of the indiction, the Golden Number, and the Julian-calendar solar cycle all coincided – not that you need to know what these are. The Julian date changes at noon UTC; so, for example, UTC noon on 19 January 2018 would be JD 2458137.500.

Kinematic. Applied to GPS measurements if the antenna is moves during the measurement.

L1. Frequency (1575.42 MHz, wavelength 190.3 mm) on which the GPS satellites transmit the **C/A code** and **P code**.

L2. Frequency (1227.6 MHz, wavelength 244.2 mm). on which the GPS satellites transmit the **P code** (and, starting with some satellites in 2005, a civilian code called L2C).

L3. Frequency (1381.01 MHz) used by the GPS satellites to transmit information on nuclear explosions. This term is also used for what we are calling **LC**.

L5. Frequency (1176.45 MHz, or 254.8 mm) used by the **Block** IIF GPS satellites.

LC. Combination of the L1 and L2 **carrier-beat phases** that is insensitive to the **propagation delay** caused by the **ionosphere**.

L2C. One of the codes used (in **Block IIR-M** and later) GPS satellites to modulate the **L2 carrier**. This code will be open (can be decoded by all receivers).

Leap second. Because of the irregularity of the **LOD** (spin rate) of the Earth, the Earth's orientation at a particular **UTC** time (given by an atomic clock) becomes different from what it would be expected to be if UTC was defined by the Earth's spin (see **Universal time**). To make UTC a good predictor of the Earth's position, leap seconds are occasionally inserted to shift the UTC time. This has been done 27 times, most recently on June 30, 2015 and December 31, 2016. How often it has to be done depends on how far the current **LOD** is the reference value, something that depends largely on motions in the Earth's core.

LOD. Length of day, used to describe the Earth's spin rate, which, with **polar motion**, is an **Earth orientation parameter**. For complicated historical reasons, the reference value for this corresponds to the average of the actual LOD between 1750 and the 1890's.

Mapping function. A function used to model the **propagation delay** as being $Z\,M(\theta)$, where Z is the **zenith delay** and the mapping function M depends on the elevation θ of the satellite above the horizon.

MJD. **M**odified **J**ulian **D**ate). The **Julian date** with 2400000.5 subtracted, so there are fewer decimals and the day will start at 0000 **UTC**. In this system the start of on 19 January 2018 would be MJD 58137.000.

Monument. An object that is attached to the Earth and over which (or to which) we can set an **antenna** precisely. May be a metal disk set in rock or in concrete, or a **drilled-braced monument**.

Multipath. The presence of GPS signals that arrive, not directly from the satellite to the antenna, but via a longer path involving reflection off something (often the ground). Important source of error in positioning, because difficult to reduce, though it also creates amplitude variations that can be used to determine properties of the ground surface. See `http://xenon.colorado.edu/portal/`.

Navigation. Finding out where you are, to a precision no better than a typical persons body size (2 m). "Navigation grade" was used as a term for inexpensive GPS receivers used for cars or by hikers. What this meant was that the receiver only used the **code** for positioning. Now that every smartphone does this such systems are less used.

No Net Rotation (NNR). A condition applied to the **ITRF**, that the plate velocities in this **reference frame**, integrating over the whole Earth, will be zero; this condition requires a specification both of the plate velociities (obtainable from GPS) and plate boundaries (from geology).

Orbit Integration. Given locations and velocities at some time, the positions of the GPS satellites can be found for later times by numerically integrating the equations $\mathbf{F} = m\mathbf{a}$ and $\mathbf{a} = \frac{d^2\mathbf{x}}{dt^2}$, where m is the mass of the satellite, $\mathbf{a}$ and $\mathbf{x}$ its acceleration and location, and $\mathbf{F}$ the forces acting on it. these forces include:

- Gravitational forces from the Earth, including the effects of its not being a sphere.
- Gravitational forces from the Moon and Sun, for which reason GPS orbit software needs an **ephemeris** for both.
- Non-gravitational forces, including solar **radiation pressure** (which changes during an **eclipse**), and of course any orbit adjustments intentionally applied.

The last set of forces are difficult to model accurately, and it is this that limits the precision of **predicted ephemerides** over times longer than 1-2 days.

P code. Precise (or protected) code, used to modulate the **L1** and **L2** carriers. Effective wavelength is 29.3 m. This code is encrypted (see **Y code**) and not available to most receivers.

PBO. Plate Boundary Observatory: network of over 1000 GPS receivers installed to measure motion on the Pacific/North-America plate boundary in the western US and Alaska.

Phase center. Point on the antenna where the GPS signal "on average" is in phase with the voltage detected by the receiver. Where this happens depends, in fact, on the direction from which the signal is coming, so the phase center taken is usually close to the average of this. An important parameter of an antenna is where the phase center is relative to the **antenna reference point.**

Point positioning. Locating a GPS receiver by itself, rather than as part of a network, using information (for example, clock corrections and orbits) derived from a network of other receivers, though not using their data explicitly. May be contrasted with **differential GPS**.

Polar motion. A pair of **earth rotation parameters**, used to describe the location of the Earth's spin axis relative to a fixed geographical location.

Post-processing. Refers to any method of analysing GPS data well after it has been collected, rather than in **real time.**

PRN. Pseudo-Random Noise: modulation applied to produce the different code signals. Since all GPS satellites transmit on the same frequency, different PRN sequences are used to allow a receiver to tell which signal comes from which satellite. Satellites are therefore usually identified by their PRN, which can run from 0 to 31, and may be reused as old satellites are replaced by new ones.

Propagation delay. The time delay the signal experiences because it is not traveling in a vacuum, but rather through the **ionosphere** and atmosphere (mostly the **troposphere**). See **dry delay**, **wet delay**, and **LC**.

Pseudorange. Apparent distance (see **range**). In practice used for the apparent distance found using the code messages, before corrections for **propagation delays** and **clock** errors. That is, if the signal sent at time t_1 (according to the satellite clock) is received at time t_2 (according to the receiver clock), the pseudorange is

$$\frac{t_2 - t_1}{c}$$

where c is the speed of light (299,792,458 m/s).

Radiation pressure. Force applied by sunlight shining on the satellite, difficult to model because the satellite has a complicated shape.

Radome. Plastic cover that fits over a GPS antenna to protect it from birds, leaves, snow, and vandalism. Common, but not universal, for permanently-installed antennas.

Range. Distance from the receiver to the satellite; use of this term shows the military heritage of the system, since it comes from by artillerists.

Real Time. Used to refer to data or processing results that are produced continuously and immediately as the data are received, subject only to small delays; compare **post-processing**.

Real Time Kinematic (RTK). Any method that allows positions from **kinematic** measurements to be obtained with no delay from when they are collected.

Reference Frame. Some set of coordinates which location (and things derived from them, such as velocities) are given in. It may be attached to distant galaxies, the Earth as a whole, or just a part of the Earth; for example, the NAD reference frame is chosen to be fixed relative to the stable part of North America; other common frames are **ICRF**, **ITRF**, and **NNR**.

RINEX. Standard exchange and storage format for GPS observations, in ASCII text files; it stands for Receiver INdependent EXchange format. There are also RINEX formats for the "navigation message" (an **ephemeris** for the satellite orbits) and for meteorological data. To save disk space, observation files are often reduced in size using **Hatanaka compression**.

RTCM. A data format for GPS observations, usually used in transmitting real-time data. It is named for the body that devised it (the Radio Technical Commission, Maritime).

Seismogeodesy. Use of GPS to measure seismic waves, usually in conjunction with a seismometer of some sort; GPS provides low-frequency information otherwise unavailable.

Selective Availability (SA). Method of making the GPS signal less useful by deliberately causing the satellite **clocks** to vary in ways known only to military users. It was turned on in 1991, but because it can be worked around for many purposes, was set to zero (though still "on") beginning in May 2000. This setting is why handheld receivers (including smartphones) work so well, with errors of a few meters instead of tens of meters.

Sidereal Day. Time required for the Earth to be oriented in the same direction relative to **inertial space** (which is to say, to the stars): this is 235.9 s less than the solar day of 24 hours. It is approximately the **aspect repeat time** of the GPS constellation.

SINEX. Standard exchange and storage format for GPS solutions, in ASCII text files; it stands for Solution INdependent EXchange format. Contains estimates of position (and possibly velocity) of all stations included in an analysis, and their covariances.

Single Difference. Difference between two **carrier-beat phases** observed from two satellites by one receiver. This is unaffected by errors in the receiver **clock**. Not to be confused with first differencing of a series of numbers.

Single-Epoch. A single-epoch position is one determined using only one **epoch** of data, independently of the data collected at other times. Analysis techniques that allow this are the basis of **high-rate real-time** and **seismogeodesy** uses of GPS, and require sophisticated approaches to **ambiguity resolution**.

Static. Applied to GPS measurements if the antenna does not move relative to the Earth.

Survey-mode. Applied to GPS measurements for crustal motion in which data are collected with portable equipment, in surveys spaced at long intervals relative to their durations (e.g., measuring for a weekend and remeasuring after a year). Also called "campaign GPS".

SVN. Space Vehicle Number. A unique identifier for each GPS satellite ever produced, up to 73 so far – though not all have made it into orbit.

TEC. Total electron count, a measure of how much **propagation delay** there will be for the GPS signal in the **ionosphere**.

TEQC. General-purpose program maintained by **UNAVCO** for translating from different receiver formats into **RINEX**, manipulating **RINEX** files, and doing quality control (hence the "QC") on them.[2]

Time. GPS time is reckoned in weeks, days of the week (Sunday 0, Saturday 6) and seconds of the day, with zero being the start (in **UTC**) of January 6, 1980. (So, for example, February 24, 2012 is GPS week 1676, day 5). The reckoning is in atomic time as measured by the U.S. Naval Observatory. GPS time is therefore *not* the same as **UTC** but is ahead by an

[2] `https://www.unavco.org/software/data-processing/teqc/teqc.html`

amount that depends on the number of **leap seconds** in UTC. This amount is now 18 seconds. See also **Julian date** and **Modified Julian date**.

Transformation. An operation that converts coordinates in one **reference frame** or **datum** to another. The simplest is to shift the origin (a translation); in geodesy this is called a 3-parameter transformation, for the motion in x, y, and z. The next most general is to shift the origin (a translation); and change the direction of the axes (a rotation); since it takes three parameters to describe a rotation, in geodesy this is called a 6-parameter transformation. If the scale is changed on all axes (one more parameter) we have a a 7-parameter transformation.

Tribrach. Device whereby an antenna can be set up level on a tripod, and centered over a particular point on a **monument**. Attached to the tripod with a screw, and to the antenna with a **hockey puck**.

Troposphere. The part of the atmosphere (the lowest 10 to 15 km) that contains almost all of the air and water vapor (which produce **dry delay** and **wet delay**), in which temperature decreases with elevation, and within which weather occurs.

UNAVCO. Organization (in the US) that provides facilities for academic researchers working in GPS; in particular, maintains a pool of receivers, and a centralized data-storage facility.

USNO. United States Naval Observatory, which makes available its own version of **Earth orientation parameters**. Also the Department of Defense portal for information about the status of the GPS satellites.

UTC. **U**niversal **T**ime, **C**oordinated. The time system used for regular timekeeping. It uses seconds defined by atomic clocks, but must be adjusted by introducing offsets, called **leap seconds**, to follow the vagaries of the Earth's rotation (se **LOD**).

WAAS. See **differential GPS**.

Wet delay. The **propagation delay** caused by water vapor in the atmosphere (not water droplets, as in clouds). Because the spatial distribution of water vapor is very uneven, the wet delay usually must be estimated separately for each location and allowed to vary over time.

WGS84. See **datum** or **reference frame**.

Y code. The encrypted version of the P-code, making it unreadable by most receivers – and allowing military receivers to decide if a signal is real, or a spoof.

Zenith delay. The **propagation delay** a signal would experience if the satellite were directly overhead; see **mapping function**. Most GPS analyses treat this as a time-varying parameter that is determined separately for each receiver.