

How to bring PNG94 into a project using GPS

These notes describe practical steps for surveyors required to bring PNG94 control into any projects they are working on using GPS equipment. Methods to compute local transformation parameters between earlier datums and establish Plane grids for construction are also described.

1 What is PNG94 and why should it be used?

1.1 Why PNG94?

PNG94 (The Papua New Guinea Geodetic Datum 1994) is a geocentric geodetic datum, gazetted by the PNG Government in 1996 to be used as the basis for all new surveys in PNG.

1.2 What is PNG94?

PNG94 is a network of 14 fiducial (absolute trust) geodetic stations in Papua New Guinea surveyed by GPS between 1992 and 1994 as part of a large regional campaign to establish high accuracy geocentric datums in Australia, New Zealand and PNG compatible with the GPS system. The PNG94 coordinates of the 14 stations are defined by their International Terrestrial Reference Frame 1992 (ITRF92) coordinates at epoch 1994.0 (1st January 1994). This is the same realisation as GDA94 in Australia. 1994.0 is called the reference epoch.

1.3 How accurate is PNG94?

The absolute uncertainty (accuracy with respect to the datum) of the 14 defining PNG94 stations is < 5 cm.

1.4 What is the difference between PNG94 and WGS84?

PNG94 coordinates are frozen in time, whereas WGS84 coordinates for survey control change by up to 10 cm per year due to the motion of the world's tectonic plates. WGS84 was in agreement with PNG94 in 1994, but since then, the differences between PNG94 and WGS84 are now almost 2 metres or more with the difference varying depending upon the location.

1.5 Why can't WGS84 be used as a precise datum for surveys?

WGS84 coordinates change constantly and the stations which define the WGS84 datum are very distant from PNG. Unless the connection to the external datum is done using precise orbits and the epoch of measurement is included in the datum definition, it becomes impossible to relate different WGS84 surveys conducted at different times with any accuracy. For this reason WGS84 should only be used for navigation and 2-3 metre accuracy mapping.

1.6 What is ITRF?

The International Terrestrial Reference Frame (ITRF) is the precise datum used by the global scientific and geodetic community. It has been updated several times as positioning technology and global networks have improved. The current version of ITRF is ITRF2005, which has an accuracy globally of a few millimetres. ITRF coordinates change constantly to reflect tectonic movement of the site. For this reason, a reference epoch and tectonic site velocity are required to define the datum at any epoch (point in time).

1.7 How close is WGS84 to ITRF?

WGS84 and ITRF are usually kept in agreement at less than 10 cm.

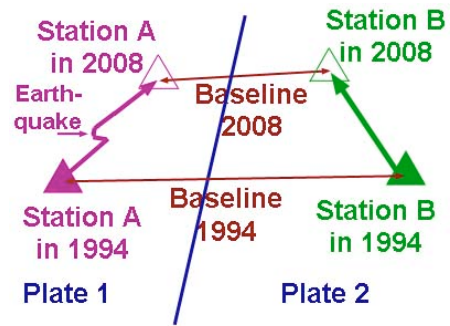
1.8 What effect does tectonic movement within PNG have on PNG94?

Internal tectonic deformation within PNG is very rapid (up to 12 cm per year). In addition, large earthquakes and volcanic activity can cause displacements of several metres. Baselines between the 14 primary PNG94 stations have changed by up to 2 metres since 1994. This means that errors of the same magnitude are introduced into surveys if the tectonic movement

is not modelled. At present, PNG94 does not have site velocities assigned to any stations, but where they are known, they should be used to improve the accuracy of the survey.

The guiding principle should be ***"The PNG94 coordinates of any point should describe where the point was in 1994, not where it is now"***. The reasoning behind this principle is that all surveys should be able to be connected together seamlessly, and this can only be achieved in a tectonically active environment by adopting a fixed reference epoch in which to relate surveys to the parent datum (Figure 1).

Figure 1. Effect of tectonic deformation on coordinates & baselines



2 How to establish PNG94 on a project

2.1 Planning

Obtain from the client any historical survey data, reports, coordinate lists, station summaries, sketches etc... if any exist. Quite often (almost always in fact) earlier spatial data in the form of plans, maps, geophysical information, ASCII coordinate files, databases and CAD files are based upon surveys using these older marks. Any new survey has to be able to be related to these earlier datums and the only way this can be achieved is by including older survey marks (especially older datum stations) in any new survey, even if they are no longer useful for construction. Existing station monumentation can sometimes be reused in new surveys, especially if the monumentation is in good condition and in an accessible or useful location.

Locate the nearest two PNG94 control stations which have validated PNG94 coordinates (refer to other conference paper on this subject and figure 2 below). These should be on the same tectonic plate as the project area, otherwise significant errors will be introduced into the survey if these stations are used. If there are no validated control points within 50 km of the project area then precise point positioning (PPP) methods or AUSPOS should be used.

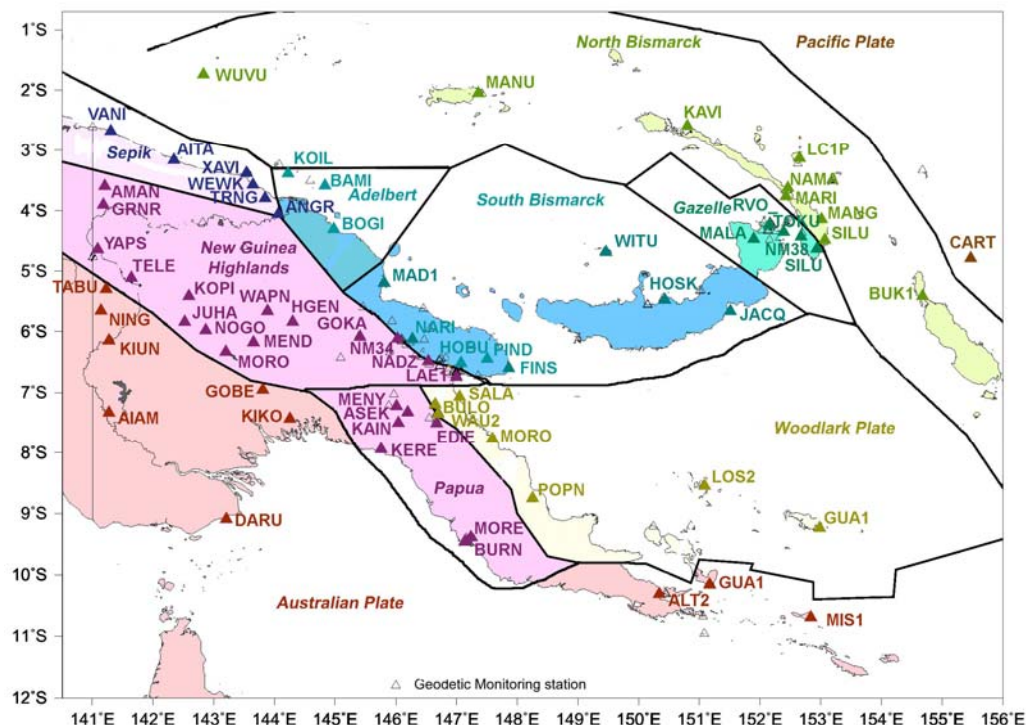


Figure 2. PNG geodetic monitoring network (primary stations) and plate zones

2.2 GPS Equipment required

If there is no validated PNG94 control within 10 km of the project area, then dual-frequency GPS receivers will be required. If the validated control is less than 10 km away, then single-frequency receivers can be used.

2.3 Observation procedure

Initially, a high accuracy datum station should be established reasonably central to the project area. Usually a PSM (plaque or star-picket set in concrete) near a helipad, airstrip or other open and secure area that is unlikely to be disturbed for the duration of the project. This will form the local realisation of PNG94 in the project area.

Setup the base receiver (the receiver with the most memory and battery capacity) on the new datum station. Setup the roving receiver at the first of the nearest existing PNG94 control stations and start the receiver. Gather sufficient observations (see table 1 below) to obtain a fixed baseline solution, shut down the receiver and move to the second nearby control station. Repeat the process. Measuring two baselines from existing control to the new station provides a good degree of quality assurance.

If the nearest PNG94 control is more than 50 km away, or is inaccessible, then run one of the receivers at the new datum station and the second receiver at another new station in the project area and use PPP (e.g. AUSPOS) to get coordinates.

If observing conditions are poor at any station, then the times recommended in Table 1 should be doubled. Bad conditions include: nearby trees, high grass, buildings, towers and periods of poor satellite availability or geometry (DOP) (use GPS planning software to identify when these periods are). In addition, if there is more than 400 metres elevation difference or if humidity levels vary significantly between the base and reference station, then the times should be doubled as well in order to mitigate tropospheric modelling errors. In ideal conditions, single-frequency receivers can measure fixed baselines up to 20 km, but 10 km is the maximum recommended range in practice.

Table 1. Occupation times for different baseline lengths (good observing conditions)

Baseline length	dual - frequency (minutes)	single - frequency (minutes)
0-5 km	15	30
5-10 km	20	40
10-20 km	30	60+ 50% chance
20-30 km	40	unlikely
30-40 km	50	
40-50 km	60	
> 50 km*	300	

** over 50 km requires PPP such as AUSPOS or precise orbit.
If using AUSPOS start obs after 10:00 PNG Time if possible.*

2.4 Receiver setup procedure

A few things need to be checked before starting a GPS receiver:

1. Battery levels must be good for the duration of the occupation
2. Check to see if there is sufficient data storage capacity (remove & backup old files if necessary)
3. The recording (epoch) interval should usually be set to 10 seconds (30 seconds is good for AUSPOS, as data file is smaller and quicker to send by dial-up)
4. Ensure that all observables are recorded (in particular carrier-phase and P-code)
5. The elevation mask should be set between 5 and 15 degrees (10 degrees is usually fine)
6. If possible, enter station name and antenna height into the receiver.

2.5 Antenna setup procedure

1. Cut down or trim any nearby branches, shrubs or high grass. Nearby trees and buildings adversely affect GPS measurements
2. Check the centering of the tribrach over the mark with a plumb-bob, or if a pole is being used, check that the spot-bubble is calibrated.
3. Carefully measure the antenna height (3 times around the rim of the antenna) and make a detailed note of where the height has been measured to (take a photo if possible)
4. Start the receiver and make a note of the start time in the log.
5. Take a photo of the mark being observed (if possible)

2.6 The log sheet or field notes must contain the following info:

1. Station number
2. Date and start time of observations (PNG time) & end time
3. Antenna height
4. Sketch of point on antenna where height has been measured to
5. Antenna type and serial number
6. Note any abnormal situations (e.g. bad observing conditions, unstable mark etc..)

GPS Occupation Log		Antenna sketch
Site ID or filename		show point where measurement to antenna is taken
Station Name		
Antenna type		
Antenna serial number		
Height measurement (start)		
Height measurement (end)		
Height to Phase Centre		
Date start		Approximate position
Time start (PNG Time)		
Time end (PNG Time)		
Date end		

Figure 3. Example of minimal GPS observation log

2.7 Antenna height measurement

GPS measurements are gathered at the phase centre within the antenna. This is the equivalent of the trunion axis of a theodolite, so the phase centre height has to be known in order to compute relative heights using GPS. More often than not, different antennas are used on the same job, so that antenna height measurements need to be converted to phase centre heights (true vertical) before the data are processed. Unless the base of the antenna (which is also usually the Antenna Reference Point or ARP) can be measured directly (e.g. pillars, poles) then a slant height has to be measured to some point on the edge of the antenna.

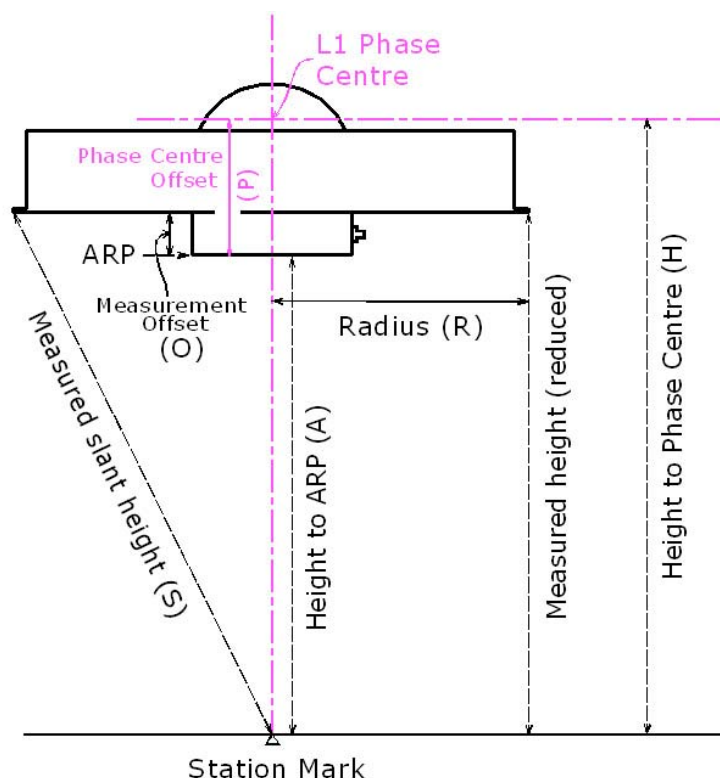


Figure 3. Antenna height measurements

Converting measured slant heights (S) to ARP heights (A)

$$A = \sqrt{S^2 - R^2} - O \quad (\text{Eq. 2.71})$$

Converting slant heights (S) to Phase Centre heights (H)

$$H = \sqrt{S^2 - R^2} - O + P \quad (\text{Eq. 2.72})$$

Where:

A is the height of the antenna reference point (ARP)

S is the slant distance from the ground mark to a point on the edge of the antenna

R is the radius of the antenna (radial distance from measured point to central axis of the antenna)

O is the vertical offset of the measured point from the base of the antenna (or ARP)

P is the phase centre offset (usually L1) or distance from ARP to the L1 Phase Centre

Formulae for commonly used antennas:

Ashtech Chokering (edge chokering)

$$H = \sqrt{S^2 - 0.19^2} - 0.035 + 0.11$$

Ashtech Whopper (ASH700718a) (notch at top)

$$H = \sqrt{S^2 - 0.174^2} - 0.064 + 0.097$$

Ashtech Geodetic (ASH700228D) (notch at top)

$$H = \sqrt{S^2 - 0.132^2} - 0.054 + 0.097$$

Trimble 4000SSE w/ ground plane (notch at top)

$$H = \sqrt{S^2 - 0.233^2} - 0.059 + 0.063$$

Sokkia GSR2700IS (outer lower rubber ring)

$$H = \sqrt{S^2 - 0.114^2} - 0.070 + 0.096$$

Sokkia Radian IS (outer lower rubber ring)

$$H = \sqrt{S^2 - 0.114^2} - 0.124 + 0.140$$

If the antenna is on a pole, the ARP height is usually the direct measurement from the base of the antenna to the end of the pole (A). To get the phase centre height, the L1 phase center offset (P) needs to be added on so:

$$H = A + P \quad (\text{Eq. 2.73})$$

2.8 Data Processing

The data from any receivers have to be downloaded. If different receiver models and manufacturers (i.e. different file formats) are used in the observing session then the raw data should be converted to Receiver Independent Exchange Format (RINEX). Any GPS data submitted to AUSPOS must be in RINEX format.

Antenna slant heights need to be converted to Phase Centre heights (using equations in Section 2.7), or if the processing software has antenna models included, the heights only need to be converted to Antenna Reference Point heights. In practice, it is better to use Phase Centre Heights if the Phase Centre Offsets are known for the different antennas used.

If the base station coordinates are unknown, use a PPP post-processing package such as AUSPOS. If the base station coordinates are validated zero order PNG94 coordinates, then use proprietary baseline processing packages to compute PNG94 using the tabulated data.

2.81 Using AUSPOS

RINEX data files can be directly uploaded to Geoscience Australia's AUSPOS website at:

<http://www.ga.gov.au/bin/gps.pl>

If the height to the Antenna Phase Centre is known, this should be entered in as the height with the Default antenna selected, otherwise the height to the Antenna Reference Point (ARP) can be entered and the correct Antenna type selected from the drop down list.

A minimum of one hour observations are required for an AUSPOS solution, however in practice at least 6 hours (preferably as many hours as possible) of observations should be submitted to get a 2 cm accurate solution. Below three hours, the computed position can be uncertain, especially if observing conditions, DOP and number of satellites visible are poor.

It is best to wait 2-3 days after the date of observations to submit data to AUSPOS to ensure that IGS data from nearby stations and IGS Rapid orbits are used in the processing. If data are submitted too soon, the Ultra-Rapid orbits are used and the solution might not be sufficiently accurate. The IGS Final orbit is available 2-3 weeks or so after the observations, and if possible the solution using this orbit should be used to achieve the highest accuracy.

Between 20 minutes and a few hours after submitting the data (depending upon the quantity of data submitted and the number of other users), a coordinate report is generated and submitted by email. The coordinates are provided in terms of both GDA94 and ITRF. At the end of the report an estimate of precision for the supplied coordinates is shown. If the precision is less than 15 mm, the solution is usually reliable, although the more realistic precision is typically between 2 and 3 times the indicated values. **The GDA94 solution must not be used in PNG** because most of PNG is not on the stable part of the Australian Plate. The ITRF coordinates (in Cartesian or Ellipsoidal format) need to be converted to PNG94 using a site velocity model (contact Richard Stanaway at richard.stanaway@quickclose.com.au or Paul Tregoning at paul.tregoning@anu.edu.au). The correction should be in the order of 1-2 metres. The EGM96 model is used by AUSPOS to estimate MSL elevations for submitted data outside Australia. Refer to section 2.9 to determine how these heights can be related to existing height datums.

Computing the epoch of measurement (Y_M)

The day of year (*doy*) of the survey is the number of days elapsed since the start of the year (e.g. 1st January is *doy* 1, and 31st December is usually *doy* 365 unless it is a leap year). The *doy* can be obtained from a Julian Day calendar, or more simply from the Rinex file submitted (e.g. RINEX file MORO0621.07o the day of year is 062 (number 5 to 7 in the filename))

The measurement epoch (Y_M) is the decimal of the year = $\text{year} + \text{doy}/365$ for a standard year
e.g. 3rd March 2007 epoch = $2007 + 62/365 = 2007.170$

PNGMG94 coordinates can be computed from AUSPOS using the following equations:

$$E_{PNGMG} = E_{UTM(ITRF)} + V_E(1994.0 - Y_M) \quad (Eq. 2.81)$$

$$N_{PNGMG} = N_{UTM(ITRF)} + V_N(1994.0 - Y_M) \quad (Eq. 2.82)$$

where,

E_{PNGMG} is the PNGMG Easting

N_{PNGMG} is the PNGMG Northing

$E_{UTM(ITRF)}$ is the ITRF UTM Easting derived from the AUSPOS solution

$N_{UTM(ITRF)}$ is the ITRF UTM Northing derived from the AUSPOS solution

V_E is the site velocity Easting component

V_N is the site velocity Northing component

Y_M is the epoch of measurement

Note: If the site has been displaced by earthquake or volcanic activity, then additional corrections are required to account for this.

2.82 Baseline post-processing

Most proprietary GPS baseline processing packages (e.g. GPPS, Trimble Geomatics Office, Sokkia Spectrum Survey etc..) initially compute baseline vectors between GPS antenna phase centres using a sequence of differenced code observations, triple differenced carrier phase and finally the double differenced carrier phase solution. The usual steps for processing a typical observing session in any baseline processing software package are:

Start a new project and setup the coordinate and height system

(It is recommended to use WGS84 UTM Southern Hemisphere processing parameters in PNG). Ensure that the UTM Grid zone matches the project area e.g.

Zone 54 South between the Indonesian border and 144° E

Zone 55 South between 144° E and 150° E

Zone 56 South between 150° E and 156° E

(For projects which straddle two zones, the zone adopted is usually the one where most of the project lies, e.g. PNG Oilfields are mostly in Zone 54, but at Kikori they overlap into Zone 55, so Zone 54 is adopted)

If a choice of geoid model is available, select EGM96.

Load in the GPS data

(either raw data in a format compatible with the processing software, or RINEX). If the raw data format is not compatible with the processing software the data will have to be converted to RINEX format either using software supplied with the receiver, or using the teqc program available from <http://facility.unavco.org/software/teqc/teqc.html>. Ensure that the loaded rover receiver data coincides in time (using table 1) with that of the base station. It is usually better to process baselines radially (in a single processing session) from a single base station, unless you have some confidence using the software's network adjustment utilities.

Fix the known station coordinates

Copy the coordinates from the master PNG94 control listing, or AUSPOS solution converted to PNG94 into the base station data entry in the processing software. In PNG it is better to enter the known ellipsoidal height for the reference station. If there is a space for orthometric heights (i.e., RL, MSL or height above geoid) leave this blank, or leave a "?" .

Run the baseline processing

Most packages generate a report of the baseline processing and reduced coordinates. Once the processing has finished, open these reports and review them.

2.83 Baseline processing assessment

If enough data has been gathered at each end of the baseline and there were no problems encountered in the baseline processing, the following conditions should be met for each baseline processed (exact description depends upon package used):

L1 fixed, narrow-lane fixed, L1/L2 fixed, ionospheric free fixed.

A fixed solution is usually reliable. Dual-frequency observations on short baselines are usually processed in single-frequency mode as higher precision is gained this way up to 5-8 km. Be very wary of "float" solutions and especially differenced pseudo-range code solutions. Float solutions indicate that the baseline is most likely to be fixed, but there is a distinct possibility that it has been incorrectly fixed, in which case the baseline measurement could be in error. Code only solutions are usually only accurate to between 40 cm and a metre or so.

If a float solution is shown, then it is highly recommended to reobserve that baseline for a longer period during better satellite conditions (low DOP and more satellites) and to improve site observing conditions if possible. If the repeat measurement is also a float solution and is within 40 mm of the first measurement, it is usually safe to mean the two values.

If a code only solution is shown it is essential to reobserve the baseline for a much longer period and ensure that site and satellite conditions are better.

Things to look for with baseline statistics

RMS (root mean square) should be less than 10 mm for L1 fixed, 15 mm for ionospheric free fixed (L1/L2 fixed) up to 20 km, and 30 mm up to 50 km.

Reference Variance should be close to 1. If the variance is high (above 10) it indicates poor observing conditions

Ratio 1:n - The higher the ratio the more reliable is the fixed solution. In PNG if the ratio is lower than 3 it is worth reobserving the baseline, even if the report shows "fixed". The ratio is the difference between different double-differenced carrier phase solutions in the session. If the ratio is low, the chance of an incorrect fix is high.

If the baseline processing report is favourable and all baselines are fixed with RMS < 30mm, Ratio > 10 and Variance < 10) then the next step is to independently check the accuracy of the solution. This is usually done by remeasuring baselines to each new station from a different base station. The baseline processing should be repeated and the coordinates compared with the initial solution. This can be done by combining the baseline solutions in a network adjustment, or by comparing/meaning the different solutions in a spreadsheet.

If large differences (greater than the tolerance of the survey) are noted between two fixed solutions, check the loop closures in order to isolate any problem baselines and make repeat or new measurements if necessary.

2.9 Obtaining MSL values

Once the baseline processing has been finalised, the next step is to estimate the MSL elevations of the stations. If a geoid model (such as one derived from EGM96) is built into the GPS processing software (it is in AUSPOS), then the coordinate report will show both ellipsoidal heights and height above geoid using the inbuilt model.

EGM96 derived MSL can differ from true MSL by up to a metre in PNG, however for inland projects that do not have accurate existing levels, using EGM96 is usually an acceptable strategy. In coastal areas, any PSMs at tide gauges or other 1st to 3rd order MSL stations should be observed by GPS in order to estimate any offsets between EGM96 and local height systems and this constant difference should be applied to all other EGM96 derived heights in the project.

For example, AUSPOS is used to obtain coordinates and EGM96 elevations of a PSM next to a tide gauge in Lae. The MSL elevation of the PSM is likely to be 1st order due to its proximity to the tide gauge. The EGM96 derived elevation of the PSM is 2.15 metres, however the MSL RL has been determined as 1.86 metres.) 0.29 metres needs to be subtracted from EGM96 derived elevations in the vicinity of the tide gauge to relate EGM96 derived heights to local sea level.

If an earlier height datum has been established in the project and is still used for height determinations, then the EGM96 derived height for the existing height datum station should be compared with the tabulated value in order to estimate the local offset to be applied to EGM96.

If the GPS processing software does not include a geoid model, then the separation between the ellipsoid and geoid (N value) needs to be obtained using the internet or other software packages. EGM96 N values can be obtained by entering site positions (latitude and longitude) into:

<http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/intpt.html>

Another earlier software package, the PNG geoid program developed Professor Bill Kearsley of UNSW can extract N values in PNG. This program is available from the National Mapping Bureau and the Department of Surveying and Land Studies at UniTech, and requires a Windows 98 or earlier operating system to run. PNG Geoid values are of equivalent accuracy to EGM96 in the PNG Oilfields and the Markham Valley, but are less accurate (up to approx 2-3 metres) elsewhere in PNG because they are based upon an earlier global gravity model OSU91.

To convert ellipsoidal heights to MSL heights, use the following expression:

$$MSL_{EGM96} = h - N_{EGM96} \quad (\text{Eq. 2.91})$$

or,

$$MSL_{PNG} = h - N_{PNG} \quad (\text{Eq. 2.92})$$

where,

MSL_{EGM96} is the elevation above Mean Sea Level using the EGM96 geoid calculator
 MSL_{PNG} is the elevation above Mean Sea Level using the PNG geoid calculator
 h is the ellipsoid height and
 N_{EGM96} is the N value (ellipsoid/geoid separation derived by EGM96)
 N_{PNG} is the n value (ellipsoid/geoid separation derived by the PNG geoid program)

If GPS measurements are made at an existing height datum station then use the following expression:

$$MSL_{local} = h - N_{EGM96} + c \quad (\text{Eq. 2.93})$$

where,

MSL_{local} is the elevation above Mean Sea Level (in terms of existing local datum)
 h is the ellipsoid height,
 N_{EGM96} is the N value (ellipsoid geoid separation using EGM96), and
 c is the local height datum correction
($c = MSL_{localdatum} - MSL_{EGM96}$)
where $MSL_{localdatum}$ is the fixed local height datum value

2.10 Using RTK for Control Surveys

Real-time kinematic GPS techniques can be used to provide quick coordinates of secondary control in a localised area. Typically, fixed solutions are available up to between 5 - 10 km from the base station depending upon local conditions and satellite geometry/availability. Because corrections are transmitted by radio link or through a mobile network, large hills in between the transmitter and receiver will prevent a fixed solution being obtained. In order for the MSL

heights to be determined correctly, it is important that the RTK system has a geoid model (usually EGM96) configured within the system. If the RTK survey is required to produce elevations related to the local height datum (which may be offset from EGM96 or the PNG geoid) then some care needs to be taken when entering height values for the base station. In most systems the local height datum value can be entered.

A local site calibration can align an RTK survey with the local control, but some care needs to be taken that at least 3, preferably 4 stations are used surrounding the project area to do the calibration. If the geometry of the calibration is poor, then significant errors can be introduced outside the calibration figure.

It is very important that any stations surveyed by RTK are checked by repeat surveys from another station in the network, on a different day at a different time of the day. For example, if the initial survey was conducted on Monday afternoon, then the repeat (check) survey should be conducted on Tuesday morning, to ensure that a different selection of satellites are used. Occasionally (especially in poor observing conditions) RTK solutions are incorrect.

At the start of any RTK survey, it is essential to take the first measurement at another control station (2 if possible), in order to verify that the datum, projection system, geoid model and antenna measurements have been setup correctly into the system. The difference between the RTK solution and the control should be less than 15 mm. If possible, other existing control stations should be included in any RTK survey wherever possible, to verify the performance of the system.

3 Computing local transformations from earlier datums

Very often on projects, relationships between earlier datums have to be established in order that a transformation strategy can be developed to enable older surveys to be related to newer datums. The most effective way of doing this is to resurvey earlier primary control stations with respect to a new datum such as PNG94. Once a sufficient number of older datum stations (surrounding the project area if possible) have been surveyed on PNG94, a number of different strategies can be employed to estimate transformation parameters between the old and new datums. One of the simplest and most common strategies used is to estimate the four parameter transformation (translation in Eastings, translation in Northings, rotation and scale) between the old and new datums. These parameters can be estimated by doing a least squares fit of a selection of older station coordinates to the coordinates of the same stations surveyed in PNG94. In many instances, usually in much smaller project areas there is no significant rotation and scale difference between the two systems, in which case a two parameter transformation (block-shift) can be used. All the block shift is, is the mean difference between the sets of coordinates in the two systems. If least-squares analysis tools are unavailable, the rotation and scale parameters can be estimated by comparing bearings and distances between a selection of lines between primary stations in the project area on the different datums. The rotation can be adopted as the mean difference between the bearings, and the scale can be adopted as the scale factor difference between the distances.

It is very inadvisable to use standard transformation parameters used by most GPS and GIS software packages, such as the NGA parameters, as these can be inaccurate to up to several metres. In fact, many surveyors have already used these parameters in error on projects in PNG and caused significant problems in design and construction. **Do not use these default parameters.** Each project will have specific parameters unique to the project and these can only be computed by surveying stations common to both old and new datums in the project area.

4 Establishing a local Plane datum

Geodetic datums are nearly always unsuitable for feature surveys, engineering design, construction setout and as-built surveys. The reason for this is simple. Because of the necessary distortions involved projecting the earth's surface (which is spheroidal) onto a flat surface or cylinder (projection surface or plane), distances on the grid projection plane can be significantly different to the equivalent distances on the ground. The difference (scale factor) increases the larger the area of the earth's surface that is projected. Engineering surveys require coordinates to be as distortion free as possible, so that design and measured distances match those of the plan as close as possible to a scale factor of 1. For this reason, a projection system for these surveys should be centred on the survey area to ensure a scale of 1 can be used. Projection systems covering large areas such as UTM (including AMG66 and PNGMG94) have scale factors varying from 0.9996 at the central meridian to 1.0004 at the edge of the zone. A kilometre line on the ellipsoid surface (about 70 metres below sea level in PNG) would be 999.6 metres and 1000.4 metres long on the grid projection at these locations respectively. The higher one gets above the ellipsoid surface and sea-level, the smaller the scale factor gets. For example at an elevation of 3000 metres on the central meridian, the scale factor becomes as small as 0.999129, so that a 10 metre square building on the ground would be only 9.991 metres square in PNGMG94!

Many surveys use UTM/PNGMG94 coordinates with a scale factor of 1. **This is a very bad practice**, as local Plane coordinates resemble Grid coordinates, even though they are not. Plane coordinates should be distinguishable from grid coordinates (for example by being a lot smaller in magnitude) to prevent confusion.

4.1 How to derive a Plane Grid System from PNG94

A local datum origin (can be a survey station, or a virtual point in space) should be chosen close to the centre of the project area (particularly in terms of Eastings). A height datum plane should be chosen that is close to the average elevation of the project area.

For example, a project area in the Highlands of PNG is bounded by E 520000 and E 540000, N 9060000 and N 9080000 and has a minimum elevation of 1600 metres and a maximum elevation of 2200 metres. The best fitting local Plane grid would have a central meridian of 530000 (mean of project bounding eastings), a Northing origin of 9070000 and a height datum plane of 1900 metres (mean of project height). At this location, the scale factor would be 1 exactly. The further one gets away from this location (in terms of Eastings and elevation), the further the scale factor differs from 1.

In this example, the local coordinate origin would have PNGMG coordinates of
E 530000 N 9070000 RL 1900

The local Plane coordinates of this location could be
E 30000 N 70000 RL 1900

(by subtracting 500000 from Eastings & 9000000 from Northings)

Bearings in Plane should be the same as PNGMG94 bearings, to make transformations easier.

Using a Plane coordinate system not only keeps scale factors close to 1, but the magnitude of the coordinates is easier to manage, with a smaller chance of typographical errors occurring (e.g. when entering coordinates into total stations etc.).

The combined PNGMG94 and height scale factor (k_p) at the datum origin would be 0.9993127 in the example above, so to convert between PNGMG94 coordinates and Plane coordinates the following expressions can be used:

$$E_{PLANE} = E0_{PLANE} + \frac{1}{k_p}(E_{PNGMG} - E0_{PNGMG}) \quad (\text{Eq. 4.11})$$

$$N_{PLANE} = N0_{PLANE} + \frac{1}{k_p}(N_{PNGMG} - N0_{PNGMG}) \quad (\text{Eq. 4.12})$$

$$E_{PNGMG} = E0_{PNGMG} + k_p(E_{PLANE} - E0_{PLANE}) \quad (\text{Eq. 4.13})$$

$$N_{PNGMG} = N0_{PNGMG} + k_p(N_{PLANE} - N0_{PLANE}) \quad (\text{Eq. 4.14})$$

where,

E_{PLANE} & N_{PLANE} are the local plane coordinates

E_{PNGMG} & N_{PNGMG} are the PNGMG coordinates to be converted

$E0_{PLANE}$ & $N0_{PLANE}$ are the Plane coordinates of the Plane datum origin

$E0_{PNGMG}$ & $N0_{PNGMG}$ are the PNGMG coordinates of the Plane datum Origin

k_p is the is the combined PNGMG Grid and Height scale factor at the Plane Origin

4.2 How far can a Plane Grid be extended in order to satisfy engineering tolerances?

Assuming that a maximum error of 20 mm across the project area is permissible, a Plane grid can be extended 10 km in Eastings either side of the Plane datum origin with an assumption that the scale factor will be 1. The elevation range is more critical as a 1 km line will change in projection length by 8 mm for every 100 metres difference in elevation at each end of the line. This is an important consideration for engineering projects with large changes in elevation. For example, a 600 metre line (horizontal component at mean ground elevation) with a difference in elevation of 400 metres, would be 600.019 metres at the upper ground elevation and 599.981 metres at the lower ground elevation. Food for thought maybe (Figure 4).

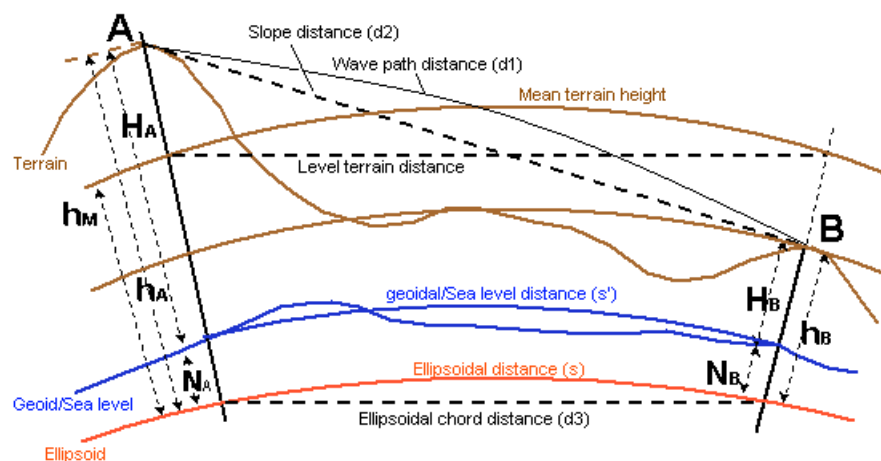


Figure 4. Difference between different distances

5 Worked example of establishment of PNG94 Project: MORO

5.1 Requirement

1. Establish PNG94 control in the Moro area
2. Compute transformation parameters from AGD66 to PNG94 in the Moro area
3. Establish a Moro Plane Grid to be used for construction in the Moro area

5.2 Planning

Two earlier PSMs (PSM 17742 and PSM 17741) on AGD66 have been located at each end of the Moro Airstrip. These can also be used as datum stations on PNG94 and because they are also the AGD66 datum in the area, they can also be used to compute transformation parameters

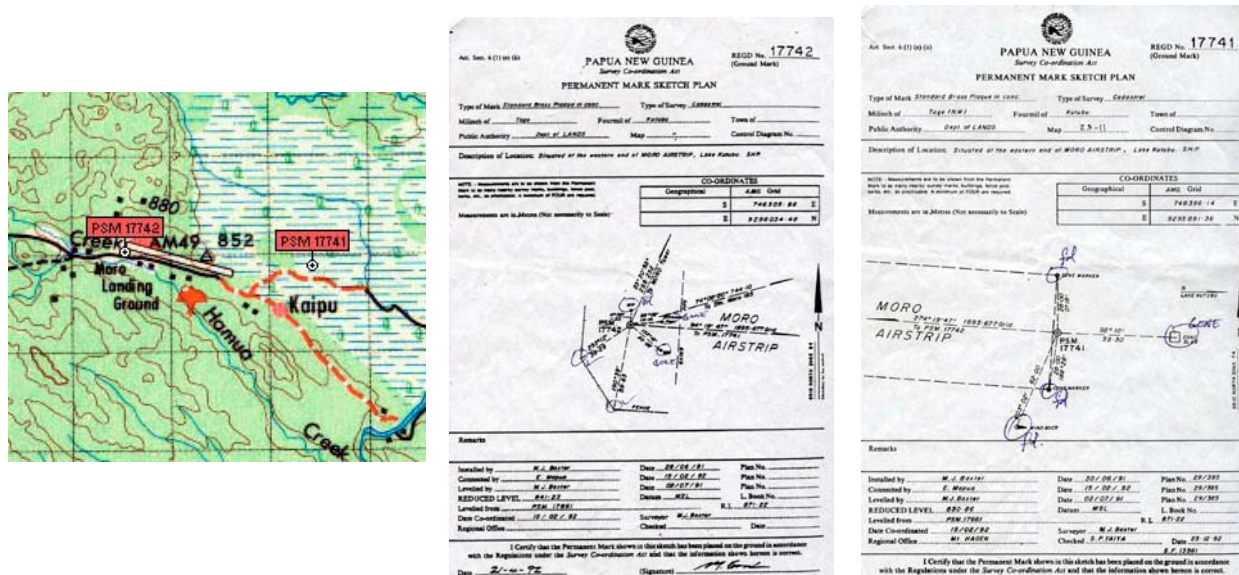


Figure 5. Location diagram and PSM sketches

5.3 Observations

At the time of the survey, there was no fiducial PNG94 control point within 50 km of Moro, so AUSPOS will be used to establish PNG94 in the area.

A dual-frequency receiver is setup on PSM 17742.

5.31 The following receiver checks are done beforehand:

1. The receiver has enough memory (old jobs backed up and deleted)
2. The batteries are charged and voltage tested
3. The elevation mask is set to 10 degrees
4. The epoch interval is set to 30 seconds
5. The receiver is set to record all observables



5.32 The antenna is setup over the PSM and the following things are checked:

1. Check that the site is clear of trees and obstructions (trim & cut down vegetation)
2. Check that the tripod is stable
3. Check the optical plummet centering with a plumb-bob
4. Check that the antenna is levelled correctly (check that spot bubble is in adjustment)
5. Measure the height to the edge of the antenna at three places around the antenna
6. The measurement should not differ by 1-2 mm. Log the measurement in the site log
7. Sketch the antenna in the site log and identify the point where measurement was made
8. Note down the antenna type and serial number in the log
9. Start the receiver and note the PNG start time and date in the log
10. Check that the receiver has acquired satellites and is logging data

GPS Occupation Log		Antenna sketch
Site ID or filename	7742	show point where measurement to antenna is taken
Station Name	PSM 17742	
Antenna type	Ashtech Chokering	
Antenna serial number	860	
Height measurement (start)	1.450	
Height measurement (end)	1.450	
Height to Phase Centre	1.512	
Date start	5/12/07	
Time start (PNG Time)	12:24	
Time end (PNG Time)	3:35	Approximate position
Date end	6/12/07	Latitude S 6°21'45"
		Longitude E143°13'46"

Figure 6. GPS Occupation data log for occupation

5.33 Compute the Height to the phase centre:

Converting slant heights (S) to Phase Centre heights (H)

The general formula is (Eq. 2.72): $H = \sqrt{S^2 - R^2} - O + P$

For an Ashtech Chokering (outer edge of chokering) use: $H = \sqrt{S^2 - 0.19^2} - 0.035 + 0.11$

S (Slant height measurement) is 1.450 then $H = 1.512$ using the above equation

Transcribe this phase centre height onto the log sheet

The receiver is run for at least seven hours in order to obtain sufficient observations for AUSPOS

5.34 Shutdown and download

Check the following things before packing up:

1. Check that the bubble is still centered (in case setup was disturbed during observations)
2. Recheck the antenna heights to verify that the antenna has not been disturbed
3. Shutdown the receiver and note the end time and date on the log sheet
4. At the office, download the raw data from the receiver using download software
5. Convert the raw data file to RINEX format using Rinex conversion software
(The receiver download software often has a RINEX converter included, or use **teqc.exe**)
6. Compute the height to the Antenna Phase Centre if not already done in the field

5.4 Processing with AUSPOS

Two days after the observations, submit the RINEX file to the AUSPOS web-site,
<http://www.ga.gov.au/bin/gps.pl>

By waiting 2 days after the observations have been completed, the data will be processed using the IGS Rapid Orbit

Type in antenna phase centre height measurement (1.512) in the height box

Leave the antenna type as **"Default"**

Type in your email address, so that you can receive the report.

5.41 Evaluating the AUSPOS solution

Review the AUSPOS processing report that is emailed back.

1. First check that the entered antenna height is correct.

Because you have selected the Default antenna type, the entered height is assumed to refer to the phase centre

1 User and IGS GPS Data

All antenna heights refer to the vertical distance from the Ground Mark to the Antenna Reference Point (ARP). *(Ignore this statement, you have already calculated the height to Phase Centre)*

User File	Antenna Type	Antenna Height (m)	Start Time	End Time
77423391.070	DEFAULT (NONE)	1.5120	2007-12-05 02:24:00	2007-12-05 17:36:00



2. Check that the IGS Rapid or Final orbit is used

(Final Orbit available between 2-3 weeks after observations)

2 Processing Summary

Should be IGS Rapid or Final (Not Ultra-Rapid)

Date	IGS Data	User Data	Orbit Type
2007-12-05	jab1 tow2 darw	7742	IGS Final

3. Check the coordinate precision statistics at the end of the report.

The sigmas should be less than 0.015 for a reliable solution.

5.2 Apriori Coordinate Updates - Cartesian, per day

	dX(m)	dY(m)	dZ(m)	yyyy/mm/dd
7742	-0.028	0.033	-0.002	2007/12/05

5.3 Coordinate Precision - Cartesian, per day

1 Sigma	sX(m)	sY(m)	sZ(m)	yyyy/mm/dd
7742	0.009	0.009	0.005	2007/12/05

Should be better than 0.015

5.4 RMS, Observations, Deletions per day

Data	RMS (m)	# Observations	% Obs. Deleted	Date
darw	0.0094	9940	4 %	2007-12-05
tow2	0.0086	9971	3 %	2007-12-05
jab1	0.0102	8995	5 %	2007-12-05
7742	0.0094	28906	4 %	2007-12-05

5.5 Compute the PNG94 coordinates of the site from AUSPOS

1. Extract the ITRF2000 ellipsoidal coordinates of the site from the report.
DO NOT USE THE GDA94 SOLUTION IN PNG!!

4.2 Geodetic, GRS80 Ellipsoid, ITRF2000

The height above the Geoid is computed using the GPS Ellipsoidal height and subtracting a Geoid-Ellipsoid separation. Geoid-Ellipsoid separations, in this section, are computed using a spherical harmonic synthesis of the global EGM96 geoid. More information on the EGM96 geoid can be found at earth-info.nga.mil/GandG/wgsegm/egm96.html

	Latitude(DMS)		Longitude(DMS)		Ellipsoidal Height(m)	Above-Geoid Height(m)
darw	-12-50	-37.3329	131 7	57.8646	125.142	74.992
tow2	-19-16	-9.4037	147 3	20.4798	88.165	30.118
jab1	-12-39	-31.8491	132 53	38.0363	82.161	27.824
7742	-6-21	-44.8827	143 13	46.1084	917.863	838.288

ITRF2000 / WGS84 Coords of site (Not PNG94 coordinates)

2. Convert these coordinates to UTM coordinates using a Geographical Calculator, Redfearn's program, or online at http://www.ga.gov.au/geodesy/datums/redfearn_geo_to_grid.jsp
Ensure that the WGS84 or GRS80 ellipsoid is used.

The ITRF2000 UTM coordinates at the epoch of observation are:

7742 UTM Zone 54 E 746627.938 N 9296195.280

3. Determine what the site velocity is for the location
A recent report has the following ITRF site velocity for the Kutubu area.

Eastings +33 mm/yr Northings +54 mm/yr

4. Compute the epoch of measurement

The date of the survey is 5th December 2007, so the day of year is 339. This can be obtained from a Julian Day calendar, or more simply from the Rinex file submitted check the RINEX file submitted ->:

The measurement epoch is 2007 + 339/365
= **2007.929**

The number of years since the PNG94 reference epoch (1st January 1994) is 1994.0 - 2007.929
= **-13.929**

1 User and IGS GPS D

All antenna heights refer to the vertice (ARP).

User File	Antenna Ty
77423391.070	DEFAULT(NONE)

Day of Year



The displacement in Eastings is computed by multiplying the site velocity by the difference in epoch between the reference epoch and epoch of measurement.

This can be computed using the equations (2.81 and 2.82):

$$E_{PNGMG} = E_{UTM(ITRF)} + V_E(1994.0 - Y_M)$$
$$N_{PNGMG} = N_{UTM(ITRF)} + V_N(1994.0 - Y_M)$$

where,

E_{PNGMG} is the PNGMG Easting

N_{PNGMG} is the PNGMG Northing

$E_{UTM(ITRF)}$ is the ITRF UTM Easting derived from the AUSPOS solution

$N_{UTM(ITRF)}$ is the ITRF UTM Northing derived from the AUSPOS solution

V_E is the site velocity Easting component

V_N is the site velocity Northing component

Y_M is the epoch of measurement

Substituting the values into the equations above gives us:

$$E_{PNGMG} = 746627.938 + 0.033(1994.0 - 2007.929)$$
$$N_{PNGMG} = 9296195.280 + 0.054(1994.0 - 2007.929)$$

so the final coordinates are:

PSM 17742 PNGMG94 Zone 54 E 746627.478 N 9296194.528

5.6 Compute the local height datum offset to be applied

AUSPOS has used the EGM96 derived geoid model to compute the MSL elevation of PSM 17742, which is 838.288 metres. Inspection of the existing survey control for the PSM gives an MSL RL of 841.23 metres. Since this value forms the basis of existing level control in the area, a correction should be computed so that other GPS surveys that initially use EGM96 can be adjusted to fit the existing level datum.

The correction to be applied to subsequent GPS surveys is $841.23 - 838.288 = 2.94$ metres

In other words EGM96 derived MSL is 2.94 metres less than the existing height datum (which can be called the Moro Height Datum). So 2.94 metres needs to be added to all other EGM96 derived surveys in the Moro area in order to maintain parity.

5.7 Datum verification and local connections by baseline processing

Once the PNG94 origin has been established, survey another earlier datum point

1. Set up the base station at PSM 17742 (repeat the observation procedure described earlier)
 2. Set up the rover station at PSM 17741 (repeat the observation procedure described earlier)
- Change the epoch interval to 10 seconds for shorter occupation times.

Because the baseline is short, only 20 minutes of observations are required

Download and process the baseline

1. Download the base receiver raw data (and convert to RINEX if necessary)

2. Download the rover receiver raw data (and convert to RINEX of necessary)

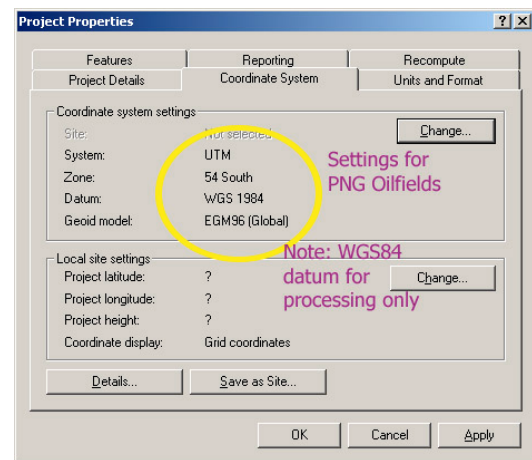
3. Start up the baseline processing software
(Trimble Geomatics Office used in example)

4. Start a new project called "MORO"

5. Setup the datum, projection and height system
(see ->)

Units:
Proj. System:
Zone:
Datum:
Geoid Model:

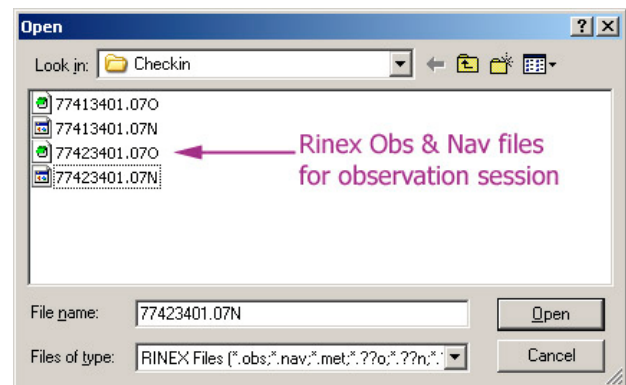
Metric
UTM
54 (Southern Hemisphere)
WGS1984 (for processing is OK)
Use EGM96



6. Load in the data from each end of the baseline (Import RINEX, or load raw file directly)

Note: Nav files are required

7. Check that the heights are correct, select
"antenna phase centre"

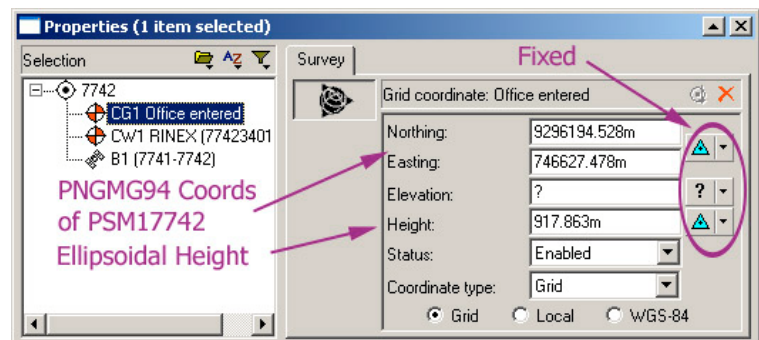


DAT Checkin										
	Use	Name	Filename	Start Time	Stop Time	Receiver Type	Receiver	Antenna Height	Antenna Type	Measured To
1	<input checked="" type="checkbox"/>	7742	77423401.07O	09:01:47 7 Dec 2007	10:59:17 7 Dec 2007	Z-12	371	1.480m	Unknown External	Antenna Phase Center
2	<input checked="" type="checkbox"/>	7741	77413401.07O	09:43:27 7 Dec 2007	12:06:57 7 Dec 2007	Unknown	SVA0321	1.520m	Unknown External	Antenna Phase Center

Phase Centre Heights

8. Hold the base station fixed by editing the coordinates with the PNG94 / PNGMG94 coordinates

Use ellipsoidal height for processing
Leave elevation (MSL) blank
at this stage



9. Process the baseline

10. View the baseline processing report. Check to see if the baseline is fixed. Look at the RMS, Variance and Ratio

GPS Processing								
	ID	From station	To station	Baseline length	Solution type	Ratio	Refvar	RMS
<input checked="" type="checkbox"/>	B1	7742	7741	1895.004m	Narrow lane fixed	37.3	7.003	0.007m

Fixed OK → >10 OK → <10 OK → <0.015 OK

11. Print off or copy the computed coordinates

PSM 17741
PNGMG94 Zone 54
E 748517.451 N 9296051.435

12. Apply the local height datum correction

Moro Height Datum = EGM96 + 2.94

= 827.428 + 2.94 = **830.37**

Summary

Point name: 7741

Northing: 9296051.435m

Easting: 748517.451m

Elevation: 827.428m (EGM96)

Height: 907.032m

☒ Grid ☐ Local ☐ WGS-84

5.8 Computing MORO area AGD66 to PNG94 transformation parameters

The tabulated AGD66/AMG66 coordinates for the two PSMs are:

PSM 17742 AMG66 Zone 54 E 746505.88 N 9296034.48
PSM 17741 AMG66 Zone 54 E 748396.14 N 9295891.36

The PNG94/PNGMG coordinates for the same PSMs are:

PSM 17742 PNGMG94 Zone 54 E 746627.478 N 9296194.528
PSM 17741 PNGMG94 Zone 54 E 748517.451 N 9296051.435

Compare the differences in Eastings and Northings at the two stations:

PSM 17742 ΔE 121.60 ΔN 160.05
PSM 17741 ΔE 121.31 ΔN 160.08

Compare the AMG and PNGMG bearings and distances between the two stations:

PSM 17742 to PSM 17741	PNGMG	Brg 94°19'47"	Dist 1895.382
PSM 17742 to PSM 17741	AMG	Brg 94°19'47"	Dist 1895.670

The bearing difference between the two datums is the same, so no rotation transformation is required. There is a scale difference of 0.999848 which is larger than expected, however PSM17742 is much more stable than PSM17741 and subsequent checks to other PSMs in the area show scale differences closer to 1, so the difference at PSM 17742 is adopted.

To convert AMG66 coordinates to PNGMG94 in Moro

add 121.60 m to Eastings and 160.05 to Northings.

This is a simple block shift that can be used locally.

5.9 Establish a Moro Plane Datum for construction in the Moro area

PSM 17742 is fairly central to the Moro area and the elevation difference is mostly < 100 m in the areas where any construction is likely to occur. The following strategy can be used to establish a Moro Plane Datum using PSM 17742 as a datum origin.

The PNGMG94 coordinates are of the Moro Plane Datum origin are:

PSM 17742 PNGMG94 Zone 54 E 746627.478 N 9296194.528

The equivalent Moro Grid coordinates could be:

PSM 17742 Moro E 46627.478 N 96194.528 (PNGMG E - 700000, PNGMG N - 9200000)

Azimuth same as PNGMG94 at origin

Moro Scale Factor 1.0000000 at PSM 17742 RL 841.23 (Moro Height Datum)

The combined height and PNGMG Grid Scale factor at PSM 17742 is 1.000208 (using ellipsoid height)

Using formulae (4.11 to 4.14):

$$E_{MORO} = E0_{MORO} + \frac{1}{k_p}(E_{PNGMG} - E0_{PNGMG}), \text{ or}$$

$$E_{MORO} = 46627.478 + \frac{(E_{PNGMG} - 746627.478)}{1.000208}$$

$$N_{MORO} = N0_{MORO} + \frac{1}{k_p}(N_{PNGMG} - N0_{PNGMG}), \text{ or}$$

$$N_{MORO} = 96194.528 + \frac{(N_{PNGMG} - 9296194.528)}{1.000208}$$

$$E_{PNGMG} = E0_{PNGMG} + k_p(E_{MORO} - E0_{MORO}), \text{ or}$$

$$E_{PNGMG} = 746627.478 + 1.000208(E_{MORO} - 46627.478)$$

$$N_{PNGMG} = N0_{PNGMG} + k_p(N_{MORO} - N0_{MORO}), \text{ or}$$

$$N_{PNGMG} = 9296194.528 + 1.000208(N_{MORO} - 96194.528)$$