WGS84 and the Geocentric Datum of Australia 1994

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BIOGRAPHY

Jim Steed has worked in AUSLIG's the Geodesy Program, and its predecessors, since 1972 and is currently the Director of the Geodetic Information Centre. He was involved in the 1984 upgrading of the Australian Geodetic Datum and has played an important part in the introduction of Australia's new coordinate system, the Geocentric Datum of Australia.

Geoff Luton is currently a member of the Australian Surveying and Land Information Group's Geodesy Program. He has been involved with Australian Geodetic network activities since 1980 and with GPS processing and analysis since 1987. His recent responsibilities include high precision processing and analysis of regional GPS networks and coordination of GPS observation campaigns.

ABSTRACT

The Geocentric Datum of Australia 1994 (GDA94) is based on the International Terrestrial Reference Frame 1992 (ITRF92) positions at 1st January 1994, computed for the eight Australian Fiducial Network (AFN) sites. GDA94 replaces the former Australian Geodetic Datum (AGD) and was developed to be directly compatible with the Global Positioning System (GPS). However, the relationship between GDA94 and WGS84 is subject to ongoing assessment.

In 1993 the National Imagery and Mapping Agency (NIMA) used their GASP software (Malys et al, 1993) to compute WGS84 positions for nineteen Australian sites, five of which are part of the AFN. In 1999 a similar exercise was repeated using data from the eight AFN sites that now form part of the Australian Regional GPS Network (ARGN). These WGS84 positions have been compared with the equivalent GDA94 positions and recently computed ITRF positions and have been used to compute transformation parameters between theses reference frames. The results indicate that GDA94 is compatible with WGS84 for most practical applications, but tectonic plate movement and the future availability of accurate positions, independent of nearby coordinated positions (absolute positions) will put increasing pressure on the static GDA94 coordinate system.

INTRODUCTION

The World Geodetic system 1984 (WGS84) was introduced by the United States Defense mapping Agency (DMA), initially for use with the Doppler positioning system, but later with the Global Positioning System (GPS). It is a Conventional Terrestrial System, initially realised by modifying the United States Navy Navigation (Doppler) satellite system (NSWC 9Z-2) (DMA, 1987). However it has been updated on at least two occasions, in 1994 and again in 1997 and is now closely aligned with the International Terrestrial Reference Frame (ITRF) maintained by the International Earth Rotation Service (IERS) (Malys, 1997).

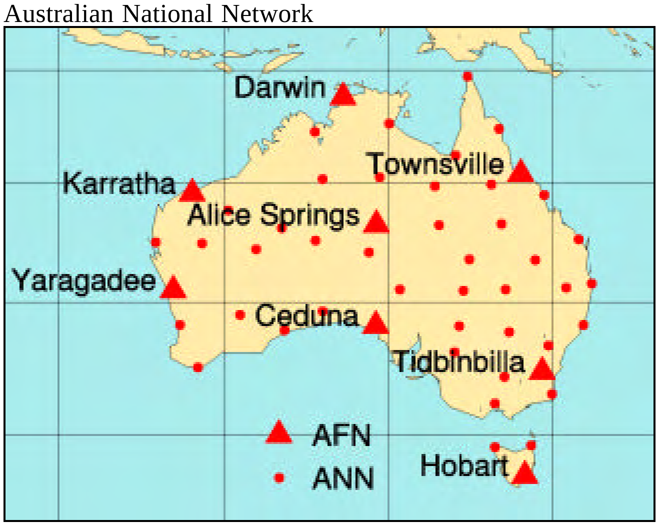
In 1966 Australia adopted the Australian Geodetic Datum (AGD) for mapping and surveying throughout the country (Bomford, 1967). This datum was designed to be a best fit for the Australian region and included an astronomically determined origin. Although the AGD coordinates were upgraded in 1984 (Allman & Veenstra, 1984) the datum remained the same and both the 1966 and the 1984 versions of AGD were offset by about two hundred metres from the WGS84 system used by GPS. DMA produced Moldodensky transformation parameters to convert from both AGD66 and AGD84 to WGS84, based on about 100 precise Doppler positions (DMA, 1987), but these transformations have an accuracy of no better than 5 metres. The same Doppler positions were also used to produce a set of similarity transformation parameters from AGD84 to WGS84 (Higgins, 1987) and these parameters had an accuracy of about 1 metre. Similarity transformation parameters have also been derived to transform from AGD66 to WGS84 (Langley, 1992) but these were expected to be of low accuracy due to the inconsistent nature of the AGD66 coordinates. Limited tests with these parameters, using twenty test points, showed residuals of up to 8 metres.

In 1992, as a first step in the introduction of a GPS compatible datum, Australia participated in the International GPS Service (IGS) pilot project (Epoch92) (Manning & Harvey, 1992). Epoch92 involved continuous GPS observations at about ninety global sites from 27 July until 8

August 1992 and included eight Australian sites known as the Australian Fiducial Network (AFN) (Manning & Morgan, 1992). During the period 1992 to 1994, additional multi-day GPS observations were made at seventy-eight geodetic survey marks at approximately 500 km intervals across Australia. These stations are known collectively as the Australian National Network (ANN).

The GPS observations collected at both the AFN and ANN sites were then included in a regional GPS solution constrained to the International Terrestrial Reference Frame 1992 (ITRF92). The resulting positions provided the geocentric positions for the AFN and ANN sites with an estimated accuracy of a few centimetres (Morgan et al, 1996). These positions, at an epoch of 1994.0, provide the basis for the Geocentric Datum of Australia 1994 (GDA94) (Steed, 1995). These positions were later used in an adjustment of the Australian Geodetic Network, to propagate GDA94 positions throughout Australia. (www.anzlic.org.au/icsm/spine/spine.htm).

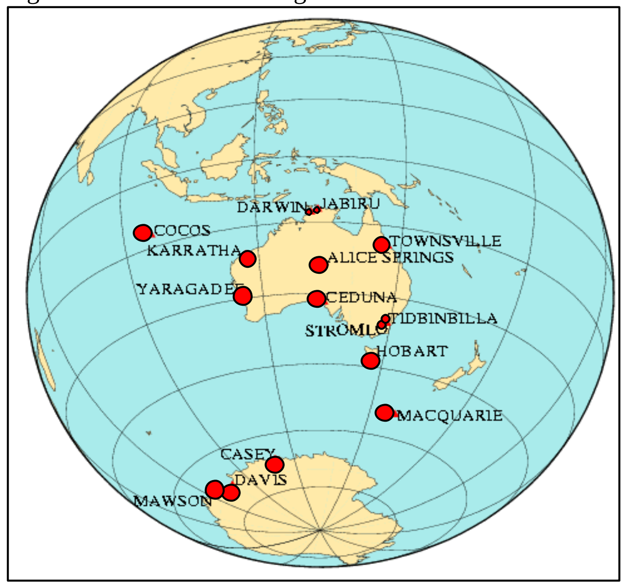
Figure 1: The Australian Fiducial Network and the Australian National Network



After the IGS Epoch92 campaign, the permanent GPS systems at the AFN sites were expanded and enhanced into a network of permanent GPS sites known as the Australian Regional GPS Network (ARGN) (Steed & Twilley, 1999). The ARGN continues to contribute to the IGS global network and the monitoring of the GDA94 and the data is available from AUSLIG's web (www.auslig.gov.au/geodesy/argn/argn.htm).

In 1997, several hundred geodetic survey marks with both GDA94 and AGD coordinates were used to produce Molodensky transformation parameters from both AGD66 and AGD84 to GDA94. A set of Similarity transformation parameters were also produced to transform from AGD84 to GDA94 (ICSM, 1997). These transformation parameters supersede the previous mentioned parameters between AGD and WGS84, by DMA and by Higgins, on the basis that GDA94 and WGS84 are the same at the level of accuracy of these parameters.

Figure 2: the Australian Regional GPS Network



Since its introduction, WGS84 has been refined on at least two occasions. The first occasion included, among other things, a revised set of station coordinates for the Department of Defense GPS tracking network, bringing WGS84 into close alignment with ITRF91. Swift (1994) estimated the coincidence between the refined WGS84 and ITRF to be of the order of 10 cm. This updated version of WGS84 "*was implemented in DMA's GPS orbit processing on 2 January 1994*" (Malys & Slater, 1994). It is known as WGS84 (G730) where G730 refers to the GPS week it was introduced. This change was not implemented at the GPS Master Control station until 29 June 1994, but most GPS users would not have noticed the change due to their coarse navigation positions or because they were using differential techniques.

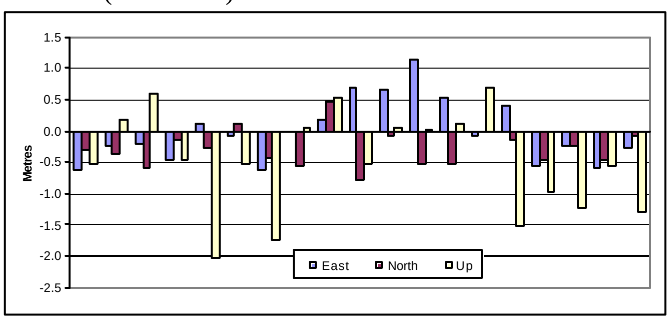
The second refinement to WGS84 occurred on 29 January 1997 when "*refined station coordinate sets were implemented in the GPS Operational Control Segment*." This version of the WGS84 reference frame is known as WGS (G873) (Malys et al, 1997). Orbit comparisons indicated that WGS84 (G873) and ITRF coincide at the level of a few centimetres and further tests with seventeen geodetic stations which had both WGS84 (G873) and ITRF94 coordinates, showed a level of coincidence better than 10 centimetres. (ibid)

GDA94 AND WGS84 COMPARISONS

An initial requirement of GDA94 was that it should be compatible with WGS84 at one metre or better. To ensure this had been achieved, 24 hours of GPS data from each of nineteen AFN & ANN sites was supplied to the United States Defense Mapping Agency (DMA, now the National Imagery and Mapping Agency - NIMA) via the Australian Department of Defence. DMA processed this data using their GPS Absolute Sequential Positioning software (GASP) (Malys et al, 1993) and provided AUSLIG with the WGS84 positions. As the observations were collected on 4 September 1993 (1993.67) prior to the first refinement to the WGS84 system, the WGS84 positions were expected to have an estimated accuracy of about a metre. This was confirmed by DMA's processing summaries that showed a standard deviation of 1 metre for each component of the positions.

These WGS84 positions were directly compared with the equivalent GDA94 positions to produce differences in latitude, longitude and ellipsoidal height, which were subsequently converted to local east, north and height differences. The results of this comparison, shown in Figure 3, demonstrate that the east and north components, with one minor exception, are all less than one metre, with some of the heights slightly worse. As the GDA94 positions have an uncertainty of just a few centimetres, the differences shown in figure 3 are mostly attributable to the uncertainty in the WGS84 positions.

Figure 3: Comparison of GDA94 (ITRF92 at 1994.0) and WGS84 (at 1993.67) at 19 AFN and ANN sites



As a further check on this comparison, a set of 7 similarity transformation parameters was derived by least squares estimation. This process uses positions known in WGS84 and GDA94, each with their full covariance matrix, to derive three origin shifts, three rotations and a scale change (Δx, Δy, Δz Rx, Ry, Rz, Sc) to relate the two reference frames (Harvey 1991). In fact, only the diagonal elements of the covariance matrices were used due to a lack of other information. However previous experience had shown that this was unlikely to significantly affect the resulting transformation parameters, provided the relative weighting of the two sets of positions was appropriate. In this particular case each component of the ITRF positions was assigned a standard deviation of two centimetres and each component of the WGS84 positions was assigned a standard deviation of one metre. This is a ratio of 1:50 and truly reflects the relative accuracy of the positions used.

The transformation parameters resulting from this process are shown in Table 1. These parameters should not be used as their magnitude is generally smaller than their uncertainty and because the WGS84 system has changed since this data was acquired. However it does confirm that there is no significant transformation between GDA94 and WGS84 positions obtained in this manner and at this time (1993).

Table 1: Transformation parameters from GDA94 (ITRF92@1994.0) to WGS84 at 1993.67, based on 19 AFN & ANN sites

Parameter	Value	Standard Deviation
Δx	-1.501 m	1.38 m
Δy	0.667 m	1.06 m
Δz	0.845 m	1.63 m
Rx	0.025 sec	0.05 sec
Ry	0.026 sec	0.05 sec
Rz	0.027 sec	0.04 sec
Sc	-0.055 ppm	0.146 ppm

GDA94 and WGS84 (G873) COMPARISONS

Based on the results of the evaluation just described, the Australian Inter-governmental Committee on Surveying and Mapping (ICSM) has maintained that for most practical applications, GDA94 positions may be used as WGS84. However, the changes to WGS84 in 1994 and 1996 meant that the situation had to be reassessed.

As GDA94 is based on ITRF92 as it was at 1 January 1994, and the differences between ITRF92 and ITRF94 are of the order of about two centimetres (M^{c}Carthy, 1996) and WGS84 (G873) and ITRF94 have been shown to be closely aligned, it would be expected that GDA94 and WGS84 (G873) are also closely aligned. However, both ITRF and WGS84 allow for the changing station positions due to plate tectonics (up to 7 cm per year) while the GDA94 positions are fixed at their position on 1 January 1994. ITRF positions are published with vectors that allow them to be "mapped" to any required epoch (Boucher et al, 1999) and WGS84 has used plate tectonic models since 1991 (Cunningham et al, 1998).

In 1994, when the GDA positions were adopted at an epoch of 1 January 1994, there was insufficient knowledge of the plate movement to accurately predict to a future date. In any case the Australian plate was understood to be moving uniformly so that the relative accuracy of the GDA94 positions would be maintained. The expected accuracy and availability of absolute positions was such that the change in position due to plate tectonics was not expected to be noticeable for about fifteen years (15 years at about 7 cm per year = 1 m).

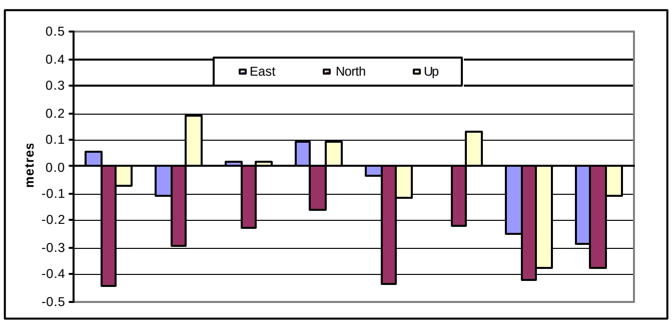
However, technology has improved more rapidly than expected and the switching off of GPS Selective Availability in May 2000 and the availability of accurate on-line ITRF GPS processing has again raised the issue of the relationship between GDA94 and WGS84. A further assessment of GDA94 and the latest version of WGS84 was therefore carried out.

Three days of data, from 22 to 24 October 1998 (1998.81) from each of eight mainland ARGN stations had previously been supplied to NIMA via the Australian Department of Defence, and they again computed WGS84 positions using the GASP software.

These WGS84 (G873) positions were compared with the equivalent GDA94 positions in the same way as the 1994 assessment previously described. The only change was that as the data was observed and processed after the G873 refinement, the WGS84 (G873) positions were now assigned an uncertainty of 25 cm in each component (Malys et al, 1997) rather than the 1 metre previously used.

A comparison of the differences in the east, north and height component is shown in Figure 4. The differences are of the same order of magnitude as the uncertainty in the WGS84 positions, but there also appears to be a bias in the north component. This apparent bias will be addressed later.

Figure 4: Comparison of GDA94 (ITRF92 @ 1994.0) and WGS84 (G873) at 8 ARGN sites, at 1998.81.



A set of similarity transformation parameters was again estimated by least squares to confirm the information from Figure 4. The resulting parameters, shown in Table 2, are smaller than those in table 1, and they are still not statistically significant. This seems to support the original statement, that for most practical applications, GDA94 positions may be used as WGS84. Again, <u>the parameters shown in Table 2 should not be used to transform between GDA94 and WGS84 (G873) as they are not statistically significant</u>.

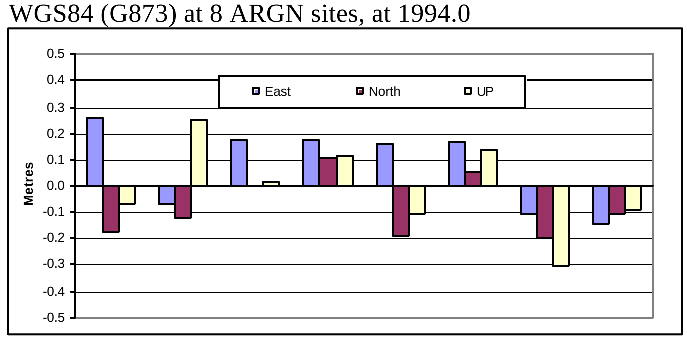
AUSLIG's Space Geodesy Analysis section is a Regional Network Associate Analysis Center of the International GPS Service and submits weekly GPS solutions that include the Australian Regional GPS Network sites. These solutions clearly show the movement of the Australian tectonic plate at a rate of about 7 cm per year in a north easterly direction (www.auslig.gov.au/geodesy/sgc/gps/gps.htm). In the period between the GDA94 coordinate epoch (1994.0) and the GPS observations being used (1998.8) this amounts to about 30 cm (7 cm * 4.8 years=34 cm) and corresponds well with the bias shown in the north component in Figure 4.

Table 2: Transformation parameters from GDA94 (ITRF92@1994.0) to WGS84 (G873) at 1998.81, based on 8 ARGN sites

Parameter	Value	Standard Deviation
Δx	0.427 m	0.870 m
Δy	0.091 m	0.687 m
Δz	0.158 m	0.946 m
Rx	-0.007 sec	0.025 sec
Ry	-0.006 sec	0.030 sec
Rz	-0.016 sec	0.027 sec
Sc	0.047 ppm	0.059 ppm

To check whether the bias in Figure 4 was due to plate tectonics, the WGS84 (G873) positions were adjusted back to the same epoch as the GDA94 coordinates (1994.0) using the plate motions computed from AUSLIG's weekly solutions. These adjusted positions were then compared with the GDA94 positions to produce the north, east and height residuals shown in Figure 5. The residuals are now random and within the uncertainty of the WGS84 positions. This indicates that although there is no significant transformation between GDA94 and WGS84 (G873), there is an increasing separation due to plate tectonics.

Figure 5: Comparison of GDA94 (ITRF92 @ 1994.0) and WGS84 (G873) at 8 ARGN sites, at 1994.0



WGS84 and ITRF COMPARISONS

As previously mentioned Malys (1997) concluded that WGS84 (G873) and ITRF were closely aligned. As the data was readily available, it was opportune to confirm this finding with Australian data. The same eight WGS84 positions computed by NIMA were therefore compared with two different sets of ITRF values.

The first set of ITRF values were computed using the same GPS data as that used by NIMA when computing the WGS84 (G873) positions. The data was processed using AUSLIG's new on-line GPS processing service, which is to be released, following rigorous testing, in October 2000 (www.auslig.gov.au/geodesy/sgc/wwwgps/wwwgps.htm). This service uses a processing strategy compliant with IGS standards. The nearest three IGS sites are constrained in the solution that uses the IGS products (satellite orbits, earth orientation parameters and coordinates) to produce results with an accuracy of a few centimetres. For sites within the Australian region, this service also transforms the ITRF97 results to GDA94, using a 7-parameter transformation estimated from the GDA94 and current ITRF97 positions of the ARGN sites. For the purposes of this comparison, the ITRF97 positions at the time of observation were adopted.

The WGS84 (G873) and ITRF97 positions, both at the same epoch of 1998.81 were compared to produce the residuals shown in Figure 6. They clearly demonstrate that the horizontal component of the positions agree within a range of ±0.2 metres, which agrees well with the uncertainty of the WGS84 (G873) positions. The height component is only slightly worse. The Similarity transformation parameters that were again estimated for these two sets of positions are shown in Table 3 and demonstrate a close alignment of the two reference frames. The scale parameter is the only one to approach statistical significance and the parameters are not recommended for use in transforming between WGS84 (G873) and ITRF97.

Figure: 6: Comparison of WGS84 (G873) and ITRF97 both at 1998.81, at 8 ARGN sites

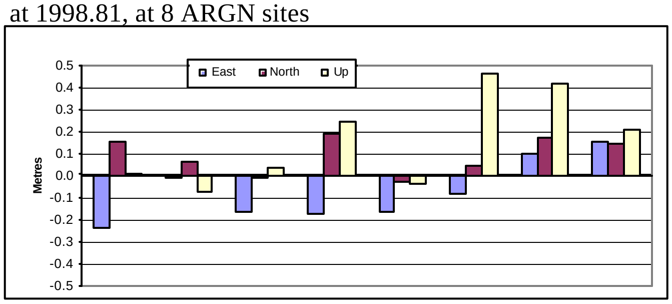


Table 3: Transformation parameters from ITRF97@1998.81 to WGS84 (G873) at 1998.8,1 based on eight ARGN sites.

Parameter	Value	Standard Deviation
Δx	0.204 m	0.90
Δy	-0.138 m	0.80
Δz	0.324 m	1.23
Rx	0.002 sec	0.03
Ry	0.003 sec	0.03
Rz	0.001 sec	0.03
Sc	0.072 ppm	0.07

The second set of ITRF positions was taken from one of AUSLIG's recent solutions submitted to IGS and is at an epoch of 2000.47. The usual comparison of positions produced the residuals is shown in Figure 7 and simply indicates that the differences are within the uncertainty of the WGS84 positions. The subsequently estimated transformation parameters shown in Table 4 are very similar to those in Table 3 and should not be used because of their lack of statistical significance.

Figure: 7: Comparison of WGS84 (G873) at 1998.81 and ITRF97 at 2000.47, at 8 ARGN sites

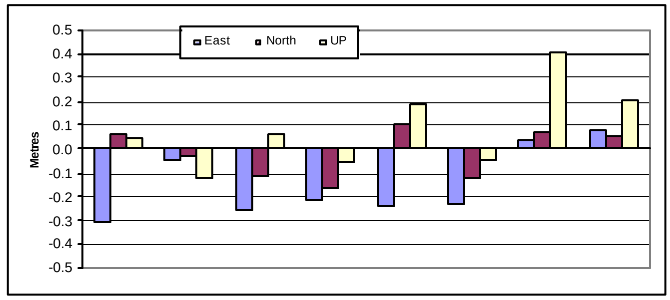


Table 4: Transformation parameters from ITRF97@2000.47 to WGS84 (G873) at 1998.81 based on eight ARGN sites.

Parameter	Value	Standard Deviation
Δx	0.313 m	0.87 m
Δy	0.051 m	0.69 m
Δz	0.234 m	0.95 m
Rx	0.003 sec	0.03 sec
Ry	0.004 sec	0.03 sec
Rz	-0.004 sec	0.03 sec
Sc	0.054 ppm	0.06 ppm

CONCLUSION

A comparison of WGS84 (G873) positions computed by NIMA using their GASP software, with accurate ITRF positions computed by AUSLIG, supports Malys' (1997) conclusion that WGS84 and ITRF are aligned, at least within the few decimetre uncertainty of the computed WGS84 positions.

Similar comparisons of WGS84 positions computed by NIMA with GDA94 positions have also confirmed that for most practical applications, where an accuracy of no better than a metre is required, GDA94 positions may be used as WGS84, as no significant transformation can be determined.

Where a WGS84 position with an accuracy of better than a metre is required, ITRF positions computed at the required epoch may be used, as the two reference frames are aligned at the level of a few centimetres. In this case the epoch of the position should be stored with the coordinates for future reference. The accepted alignment of WGS84 and ITRF is also evidenced by the on-line GPS processing service provided by SOPAC, where ITRF97 results are provided as Earth-centred Cartesian coordinates (X, Y, Z) but are referred to as WGS84 when converted to latitude, longitude and ellipsoidal height (http://lox.ucsd.edu/cgi-bin/Pythagoras.cgi).

Accurate ITRF positions can be readily obtained from suitable GPS observations and will show the increasing difference due to plate tectonic motion, between GDA94 and currently computed ITRF positions.

In Australia an on-line GPS positioning service is being introduced that will not only compute accurate ITRF positions, but will also transform them to GDA94 (www.auslig.gov.au/geodesy/sgc/wwwgps/wwwgps.htm).

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