HOW STABLE IS GDA94 AND WHEN WILL AN UPDATE BE NECESSARY?

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Abstract
The Geocentric Datum of Australia 1994 (GDA94) is now in its 14th year since realisation. Since 1994 precise point positioning technology has improved significantly and several realisations of the International Terrestrial Reference Frame (ITRF) that defined GDA94 have come and gone. GDA94 is a static datum in a dynamic world. This paper examines the effect of intraplate deformation on GDA94 and its effect on the stability of the datum. The relationship between GDA94 and ITRF2005 and longevity of GDA94 are also discussed. When will GDA94 need to be updated? What are the implications of a change of datum for the spatial sciences and what are the drivers? The paper addresses these issues with reference to typical problems faced by GPS professionals and spatial analysts.

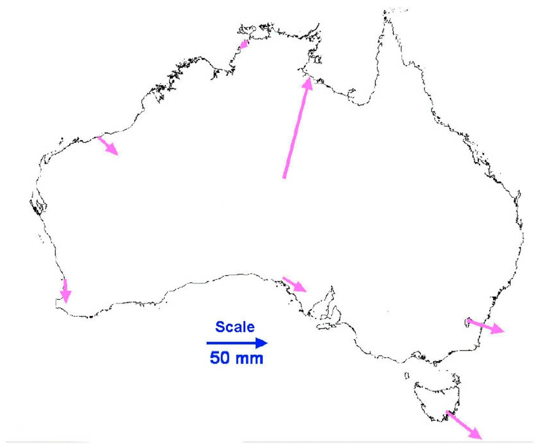
Introduction
Since the inception of GDA94 there have been significant advances in the precision of GNSS positioning techniques and accessibility to the datum by an increasingly wide spectrum of users. Precise point positioning services such as AUSPOS, OmniStar, VICpos, SunPOZ and SydNet enable locations almost anywhere on the Australian continent to be estimated with an accuracy of up to several millimetres using the right GNSS technology and observation strategy. Densification and unification of both State and National Continuously Operating Reference Station (CORS) networks is currently underway as part of the AuScope Infrastructure Program and when fully operational, will provide users better access to GDA94, even in the most remote areas of Australia, with significantly enhanced precision.

However, is GDA94 sufficiently accurate and stable enough to support a nationwide CORS network and the ever-increasing demands in precision from its users? What level of precision can be expected from GDA94 defined CORS networks? What agreement should there be between GDA94 and global datums and reference frames such as WGS84 and ITRF2005 which are regularly aligned with one another? What are the practical implications of any readjustment or realignment of GDA in the future? What really are the main drivers for datum change anyway? This paper examines these important issues and provides practical solutions to these problems.

How accurate is GDA94?
GDA94 is defined by the coordinates of the Australian Fiducial Network (AFN) which have remained unchanged since GDA94 was gazetted. The AFN by definition has been assumed to be error free for all practical geodetic purposes with a stated precision of 2-4 cm. It has also been assumed that internal deformation of the Australian Plate within the AFN has been negligible at this level of precision (Tregoning, 2003).

When GDA94 was realised, GPS technology as well as the ITRF on which GDA is aligned (ITRF92 at Epoch 1994.0), were still in their infancy. Since 1994, absolute positional accuracy has improved from the order of several cm to 1-2 mm. A comparison (this study) between the current (most accurate) realisation of ITRF (ITRF2005) at Epoch 1994.0 and GDA94 for the AFN show differences of between 1 cm and 10 cm across the network (Figure 1). The agreement is typically less than 4 cm, with ALIC (Alice Springs) in Central Australia being the outlier. In most developed areas of Australia, GDA94 does have an absolute accuracy of a 2-4cm as stated.

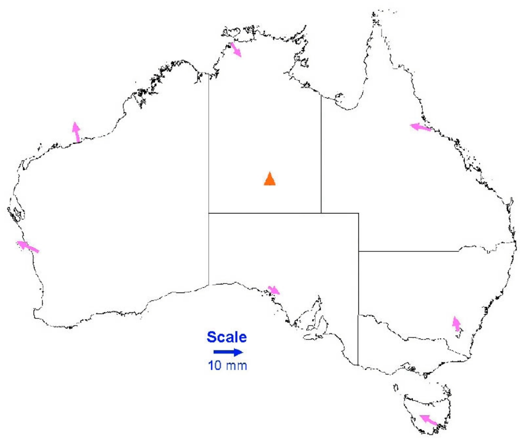
Figure 1. Difference between GDA94 and ITRF2005 at Epoch 1994.0 for AFN stations



How stable is GDA94?

The Australian continent is a remarkably stable land mass (Tregoning, 2003). With the exception of larger recent intraplate earthquakes (e.g., Newcastle 1989, Meckering 1968 and Tennant Creek 1988) and other localised deformation events such as subsidence, soil creep and landslides, baselines between stations in the primary geodetic network and AFN are changing at less than 1 mm a year. The latest ITRF2005 solution based upon a decade or more of geodetic measurements has been analysed and indicates convergence between AFN and other geodetic stations in Eastern Australia of 1.0 +/-0.3mm/yr in both North-South and East-West directions (Figure 2). The convergence is likely to be attributable to the compressive stress regime within the Australian Plate arising from the collision with New Zealand and New Guinea (Sandiford, 2003). The majority of this deformation is likely to be diffuse, in areas of higher than average seismicity such as the Flinders Ranges in South Australia, the South-West seismic zone of Western Australia and South-Eastern Australia. Geoscience Australia has established geodetic monitoring networks in these areas in order to constrain localised intraplate deformation in these regions.

Figure 2. Internal deformation of the Australian Plate & AFN between 1994 and 2007



By comparison, countries straddling major plate boundaries such as Papua New Guinea, New Zealand and Indonesia are subject to a much higher frequency of large earthquakes which often result in episodic coseismic displacements of up to several metres in magnitude often accompanied by significant post-seismic deformation. Datums in these countries are also subject to rapid continuous interplate deformation of up to 10 cm per year. As a consequence of this, geodetic agencies in these countries are obliged to introduce a velocity field and earthquake displacement "patches" into their geodetic networks in order to prevent degradation of the integrity of the network, even over short periods of time (Stanaway, 2004; Blick *et al*., 2005). Compared to its Pacific neighbours, the relative geological stability of the Australian continent allows for a stable geodetic datum where such strategies are not required.

This stability is advantageous for users of a static datum such as GDA94, because relative motion between the fiducial stations is insignificant for most users of the datum on a decadal timescale. As Global Navigation Satellite Systems (GNSS) technology and CORS networks continue to improve and become more widely available, GDA94 coordinates of the geodetic infrastructure can be expected to converge on their "true" GDA94 values (notwithstanding the localised deformation events mentioned previously) as the positional uncertainty decreases. This is a very desirable situation that will hopefully prolong the life of GDA94.

What accuracy is really required?

Is an error of 2-4 cm acceptable for all users? For most users of spatial data, an absolute accuracy or positional uncertainty of this magnitude is acceptable, although smaller relative uncertainties are usually required, e.g. for deformation monitoring, engineering surveys and cadastral surveys in Central Business Districts (CBDs). Continental scale geodynamic monitoring, however, requires and absolute accuracy of 1-2 mm or better, and GDA94 in its current form is not sufficiently accurate for this purpose. Geodynamic monitoring should continue to be related to the latest realisation of ITRF in order to account for both interplate and intraplate deformation of the external reference frame. Integration of existing State managed CORS networks into a nation-wide CORS network tied to GDA94 would be compromised by holding the existing AFN coordinates fixed as they are (especially ALIC). For example, a CORS network tied to ALIC would eventually intermesh with a South Australian CORS network perhaps for example tied to CEDU (Ceduna in South Australia). The ITRF2005 baseline between two adjoining CORS stations on the edge of both networks would differ from the GDA94 baseline by 10 cm which would compromise fixing of the user's position should they hold the adjoining CORS station coordinates fixed. Some update of GDA94 is required in order to ensure homogeneity of integrated CORS networks at the cm level, especially where they intermesh.

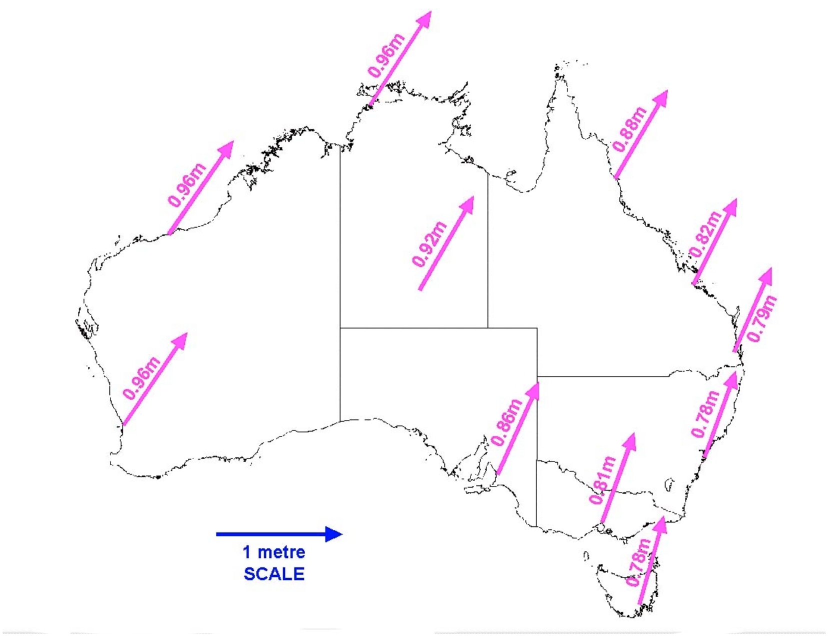
Can GDA94 be improved to mm accuracy?

A unified and seamless national CORS network aligned with GDA94 with millimetre precision can only be achieved by redefining the coordinates of the AFN stations in terms of ITRF2005 at Epoch 1994.0. This would result in a coordinate jump of a few centimetres for most existing CORS stations. An alternative strategy is to distribute the 2-4 cm error (excluding ALIC) over the network in order to achieve conformity using least squares parametrisation. This is the strategy currently adopted by Geoscience Australia in order to transform ITRF coordinates to GDA94 (e.g. with AUSPOS). This adjustment of GDA94 could be called GDA94b in order to differentiate the two coordinate sets. If such a strategy were adopted, the difference between GDA94 and GDA94b would be less than a cm in most areas of Australia except for the southern Northern Territory where there would be a 10 cm offset. A localised block shift would be required there in order to maintain agreement with the existing local GDA94 network.

How closely aligned should GDA94, WGS84 and ITRF2005 be?

Many users of GNSS technology mistakenly consider GDA94 and WGS84 to be coincident, however this flawed assumption is causing difficulties for many users of spatial data and GNSS, especially as higher accuracy positions are becoming ever more readily attainable. One of the main drivers for moving from AGD66/84 to GDA94 in the first place was to align the new datum with WGS84 and ITRF in order to facilitate the use of emerging GNSS technology and GIS software. GDA94 is a static datum, however the Australian continental landmass on which GDA94 sits is moving NE at a rate of around 6 cm every year, and as a consequence WGS84 and ITRF2005 coordinates for fixed points change at the same rate. So, although GDA94 coordinates remain frozen in time at the beginning of 1994, by 2008, Australia has migrated towards PNG by almost a metre and as a consequence so to has the difference between GDA94 and WGS84/ITRF2005 coordinates for any location Australia (Figure 3). Since the first permanent European settlement of Australia in 1788, the continent has moved NE by about 14 metres. The great concrete towers of Surfers Paradise will have moved over 250 metres towards the Equator if they happen to survive as long as the Great Pyramids of Giza (and aren't claimed by the sea by then)! The first human settlers in Australia 60,000 years ago might have had to sail an extra 3.5 km to reach Australia's northern shore. Global reference frames and datums such as ITRF and WGS84 account for this constant, inexorable motion of the Earth's tectonic plates by incorporating site velocities and reference epochs into the datum definiton. As a result coordinates for "fixed" positions are constantly changing within these reference frames.

Figure 3. Difference between GDA94 and WGS84 / ITRF2005 in 2008



How often should static datums such as GDA94 be aligned with ITRF to ensure congruence of coordinates in both systems? Should coordinates change by a millimetre every week to reflect these tectonic movements? What are the implications for constant datum changes on our burgeoning tomes and Terabyte storage drives of spatial data?

Unfortunately, software development for most GIS and GNSS systems have lagged behind associated hardware development. Inclusion of dynamic transformation parameters in these systems between WGS84, ITRF2005 and static geodetic datums such as GDA94 to account for tectonic movements of the underlying plates are still in the early stages of development. The logical question is; Should static datums be updated regularly in order to maintain agreement with WGS84, or should this movement be modelled in the system software? Common sense would dictate that the software should include a model of motion of the principal tectonic plates to ensure transformation accuracy is maintained at any epoch. Several models of global plate motions exist e.g. APKIM, NUVEL etc... The dynamic components for each primary plate can be incorporated into the system software so that cm accurate transformations can be computed for most regions of the world within nearly rigid plates such as Australia. In active plate boundary zones where deformation is more diffuse and localised, such as New Zealand, California and Japan, blocks of a size related to the relative deformation rate and desired accuracy could be defined with specific parameters to account for this. If these software improvements are implemented, there is no requirement to keep GDA94 in alignment with ITRF2005 and WGS84. As long as users of GNSS and GIS are aware of the need to correctly configure the datum in the systems they are using and overcome the technological blindness that is becoming increasingly commonplace. This is an educational issue that warrants further attention.

How much intraplate deformation can be accommodated within GDA94?

The convergence between fiducial stations across the Australian continent due to intraplate deformation is small enough to be accommodated without the need for readjustment at less than 20 year intervals. For example an adjustment in 2014 (GDA2014?) would account for the 15-20 mm deformation that has occurred across Australia since 1994 in order to maintain internal integrity of the system. In instances where coseismic displacement resulting from an earthquake might shift a CORS station significantly, then new GDA coordinates would need to be assigned to the station. Some localised transformation or block-shift would then be required to be applied to subsequent surveys in close proximity to the CORS station in order to maintain integrity of existing spatial data.

What are the implications of a datum change in the near future?

The implementation cost of a change in datum would be considerable. All maps, survey plans, digital spatial data, DCDBs, positioning equipment and software would need to be updated and upgraded. Implementation of any new datum must be evaluated considering any economic or safety benefits that might arise from it. Readjustment of GDA94 should not be confused with realignment of a new GDA with the latest epoch of ITRF or WGS. Readjustment would result in an improvement of the precision of the network, whereas realignment of GDA would result in 0.8-1.0 metre coordinate offsets from the existing datum with no real improvement in accuracy. The potential for confusion of such a small change and risk to the economy would be considerable, especially where datum metadata are absent (an unfortunately common problem). Even in 2008 there are still a number of legacy issues with the large archive of AGD/AMG spatial data still used by many organisations, especially outside the spatial sciences. A number of projects initiated before the advent of GDA94 are still based upon AGD. Implementing a new datum would drape an extra layer of complexity over our spatial systems without providing any added economic benefit or improvement in accuracy.

Conclusions

GDA94 is already internally homogenous at the level of 2-4 cm with an outlier of up 10 cm at Alice Springs. An adjustment of GDA94 to ITRF2005 at epoch 1994.0 is required in order to homogenise the datum and unified CORS networks defined by it. Analysis of intraplate deformation within the Australian continent has shown that deformation is insignificant at less than a centimetre for users of GDA94 on decadal time scales. It is in the interests of government at all levels to maintain GDA94 until there are sound practical and economic reasons to warrant a change. This might occur when the separation between GDA94 and WGS84 and ITRF becomes significant for navigation users at the 10 metre level (circa 2120). Already, sub-metre point positioning accuracy is being mooted when the European Galileo system becomes available and it is just a matter of time before centimetre accurate point positions are attainable for most users of GNSS technology. How will these advances impinge on our concept of static datums?

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