GDA94, ITRF, WGS84: WHAT'S THE DIFFERENCE? WORKING WITH DYNAMIC DATUMS

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ABSTRACT

There is a widespread misconception within the spatial science community that the three geocentric datums widely used in Australia, GDA94, ITRF and WGS84 are identical "for all practical purposes". This is a fair assumption for navigation and many mapping purposes, however users of wide area differential GPS and precise positioning services with a precision of less than a metre are beginning to notice discrepancies between the datums. This is due to the tectonic movement of the Australian plate.

While all three are geocentric datums, WGS84 and ITRF are dynamic in nature with site coordinates constantly changing to reflect tectonic movement on a global scale. Conversely, GDA94 is a static datum with coordinates fixed at the beginning of 1994 to the ITRF realisation at that time. During the intervening 13 years, the Australian Plate has moved by up to a metre and as a consequence GDA94 coordinates are now offset from WGS84 and ITRF.

This paper discusses the implications of use and misuse of positioning technology with regard to the integrity and longevity of survey coordination and spatial data. Practical methods of dealing with the divergence of GDA94 and ITRF/WGS84 are presented.

BIOGRAPHY

Richard Stanaway is the Director of Quickclose, a geodesy consultancy specialising in the development of surveying and geodetic software. Since graduating from QUT in 1998, Richard has worked as a surveyor in Papua New Guinea, Australia and Antarctica In 2004, he completed a Master of Philosophy in Geodesy at the Australian National University in Canberra. His Masters research examined the feasibility of implementation of a dynamic geodetic datum in PNG. Richard is a Certified Practitioner (Surveyor) with the Spatial Sciences Institute and a Member of the Association of Surveyors in Papua New Guinea.

Introduction

During the last ten years, GPS and related satellite based positioning systems have become the primary tools for navigation, positioning and mapping. Precise positioning services such as OMNISTAR can now provide real-time accuracy at 10 cm over much of the land surface of the globe (http://www.omnistar.com.au/services/hp/services.html). Post-processing of GPS data by services such as AUSPOS (http://www.ga.gov.au/geodesy/sgc/wwwgps/), SCOUT and AUTO-GIPSY can provide users positioning on a global scale at an accuracy of 1-2 cm. The primary coordinate datum used by these services is typically the latest realisation of the International Terrestrial Reference Frame (ITRF), currently ITRF2005.

It is widely believed that ITRF and the closely tied World Geodetic System 1984 (WGS84) are identical to Australia's Geocentric Datum of Australia 1994 (GDA94) at the order of less than 10 cm. This is an incorrect and potentially dangerous assumption. Because of tectonic movement of the Australian Plate since GDA94 was realised on the 1st January 1994, the difference between GDA94 and ITRF/WGS84 coordinates for any location in Australia are now (in 2007) almost a metre and increasing by up to 8 cm per year (Figure 1). Where users of precise positioning systems are unaware of the requirement to transform ITRF and WGS84 coordinates to GDA94, or any other static datum (e.g. NAD83 in North America) for that matter, they will find that coordinates of survey monuments and other fixed features will change noticeably every year.

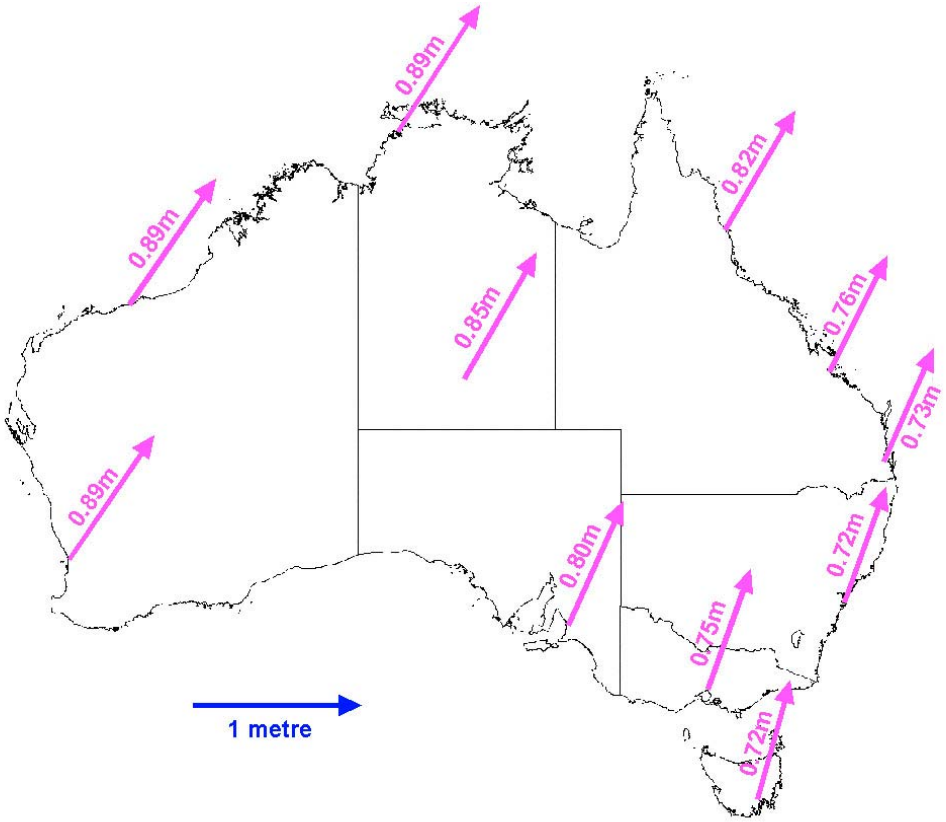

Fig. 1: Displacement of ITRF2005 & WGS84 from GDA94 at epoch 2007.0

This paper describes the fundamental differences between the three commonly used geocentric datums and the implications of misuse of positioning technology on a static datum such as GDA94. Strategies to deal with the conversion of ITRF coordinates to GDA94 are discussed with a view to prolonging the life of GDA94 and maintaining the integrity of GDA94 (and derived MGA94) spatial data.

ITRF, WGS84 and GDA94

ITRF is a global datum used primarily by the scientific community and is realised by a large network of fiducial (i.e. fundamental trust) sites around the globe. ITRF sites are typically continuously operating GPS stations (including the Australian Regional Geodetic Network (ARGN) managed by Geoscience Australia), Very Long Baseline Interferometry (VLBI) and Satellite Laser ranging (SLR) stations. The ITRF is defined by the coordinates and velocities of the stations at a specified reference epoch. ITRF sites are located on different tectonic plates which move at up 10 cm per year with respect to each other (Figure 2). As a consequence, the velocity for each ITRF site with respect to a stable earth enables ITRF coordinates to be computed for any specified epoch. Because ITRF coordinates are constantly changing, ITRF is referred to as a dynamic datum. The latest realisation of ITRF is ITRF2005 (http://itrf.ensg.ign.fr/ITRF_solutions/2005/ITRF2005.php).

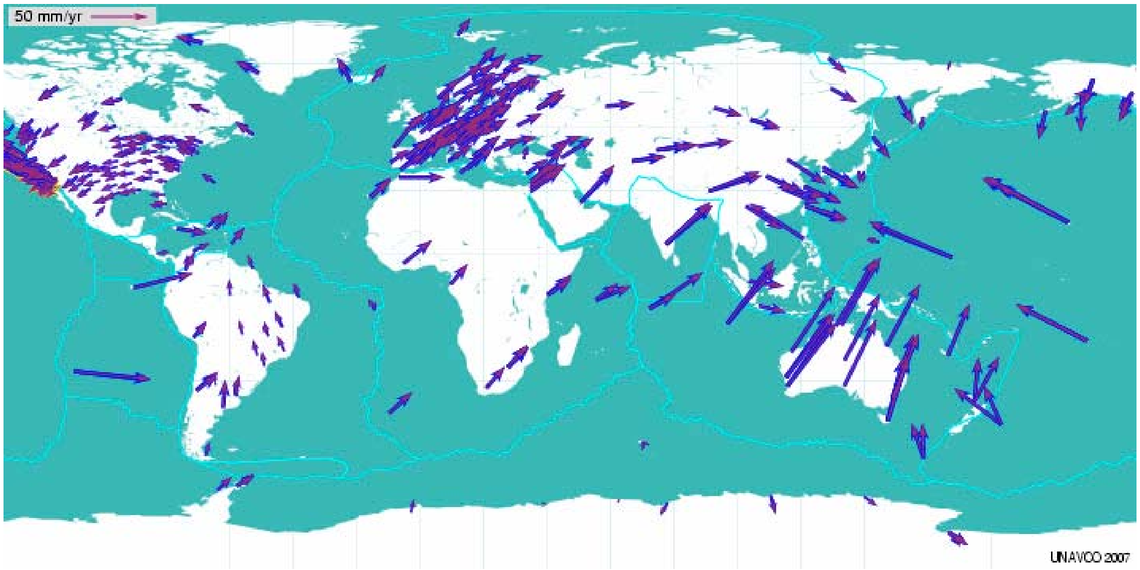

Fig. 2: Global plate motions (Unavco)

WGS84 is a global datum used by the United States' Global Positioning System. The datum is currently defined by the coordinates and velocities of 18 GPS tracking stations maintained by the US Air Force (USAF) and US National Geospatial Intelligence Agency (NGA). The latest realisation of WGS84 is WGS84(G1150) where 1150 refers to the GPS week of realisation. WGS84 is now coincident with the latest realisation of ITRF at the 10 cm level (NGA, 2003). WGS84 is kept in alignment with ITRF to ensure that the GPS broadcast ephemeris is not degraded by holding coordinates of the GPS tracking stations fixed when they are subject to relative deformation of up to 10 cm a year.

GDA94 is the current geodetic datum gazetted in Australia and is defined by the ITRF92 coordinates of the Australian Fiducial Network (AFN) of 8 stations at epoch 1994.0 (1st January 1994). At the time of realisation, GDA94 was aligned with ITRF and for the sake of consistency and traceability the coordinates have been "frozen" at their gazetted values. GDA94 is then by definition a static datum even though the Australian plate as a whole is moving within the ITRF at up to 8 cm per year (and as a consequence so too are the ITRF coordinates of the AFN).

How stable is GDA94 internally?

The Australian continent is a remarkably stable land mass (Tregoning, 2003). With the exception of larger 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 are changing at less than 1 mm a year. An analysis of the latest ITRF2005 solution based upon a decade or more of continuous GPS measurements indicates convergence between ARGN stations in Eastern Australia of 1.0 +/-0.3mm/yr in both North-South and East-West directions. 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 recently established geodetic monitoring networks in order to establish the rate of deformation in these areas.

Countries straddling major plate boundaries such as New Zealand, Papua New Guinea and Indonesia are subject to a much higher frequency of large earthquakes which result in episodic displacements of up to several metres in magnitude. Datums in these countries are also subject to rapid continuous deformation of up to 10 cm per year across plate boundaries. 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 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 positioning technology improves and becomes more widely available, GDA94 coordinates of the geodetic infrastructure can be expected to converge on their "true" GDA94 values (notwithstanding localised deformation events mentioned previously) as the positional uncertainty decreases. This is a very desirable situation that will hopefully prolong the life of GDA94. Most Australian states have active campaigns to improve the positional uncertainties of the coordinates of their geodetic control. Virtual Reference Station (VRS) networks and real-time kinematic

(RTK) networks (e.g. VICpos, MELBpos, SydNET and SunPOZ) enable users to connect to GDA94 at an accuracy of 1-2 cm in most larger urban areas of Australia.

Why we should retain GDA94 for the foreseeable future

A significant number of spatial data sets, maps (digital and printed), plans and coordinate listings have already been migrated from the earlier AGD66/AGD84 datum to GDA94 (or its MGA94 projection equivalent). The move was necessitated by the need to bring all spatial data in Australia into a unified and homogenous datum closely tied to native GNSS datums. There may proposals in the future to update GDA94 to say GDA2*yyy* in order keep Australia's geodetic datum in close alignment with the ITRF. The cost of doing this would be considerable. Furthermore GDA2*yyy* coordinates would be similar to GDA94 coordinates at the metre level, a magnitude small enough for misinterpretation in the absence of datum metadata. There are 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. It is in the interests of government authorities to maintain GDA94 until either of the following occurs; either, the internal deformation of the Australian continent becomes significant at the sub 0.1m level (c. 2060), or the separation between GDA94 and WGS84 becomes significant for navigation users at the 10 metre level (c. 2120). In either instance, this is long way into the future, and who can predict what our spatial systems and requirements will be like then? A comparison of the gazetted GDA94 coordinates of the AFN with their ITRF2005 values at epoch 1994.0 indicates an agreement of 30 mm at most sites. A future refinement of GDA94 could be achieved by computing ITRF2005 coordinates of the AFN at epoch 1994.0.

A homogeneous and stable datum will become an important component of the cadastre in the future. As cadastral monumentation decays or is destroyed over time, there will be increasing reliance on geodetic coordination in the absence of other evidence. If it is currently possible to connect the cadastre to the underlying datum routinely at the centimetre level, it becomes a matter of great importance to maintain legal traceability of the coordinates over very long periods of time, particularly where the datum is stable at that same order of accuracy. Already we are seeing boundaries that are not marked in a traditional way by fences, walls and other occupations. Densification of geodetic control and widespread use of RTK, VBS and PPP services will enable surveyors in the future to re-establish boundaries with some degree of accuracy and repeatibility from anywhere in the country so that the reinstated boundaries match those of the original intent at the prescribed level of accuracy. In effect, the entire Australian geodetic network becomes a network of reference marks for any cadastral boundary with the benefit of large redundancy (in contrast to existing cadastral surveys, for example). Improvements in the accuracy and accessibility of GNSS systems have enabled the possibility of extending a reference mark (RM) to anywhere in the country. The forensic nature of many conventional cadastral surveys where reference marks and occupational evidence are either non-existent or unreliable would be greatly assisted by a stable, accurate and accessible geodetic network, tied at the centimetre level to the original intent of the survey or deed.

Misuse of positioning technology

There are many users of positioning technology (alas, including many surveyors) who misinterpret WGS84 or ITRF coordinates as GDA94 (Stanaway and Dawson, 2005). As positioning technology improves, the GDA94 coordinates misinterpreted in such a way, will diverge from their true values as a function of time, due to tectonic movement. This is a very undesirable outcome as it will degrade the homogeneity of GDA94 spatial data and also perhaps undermine the integrity of the surveying profession. Users of traditional relative positioning methods are fast adopting global or absolute positioning systems and many of these users are unaware of the dangers of not accounting for global deformations not apparent in their local reference frame. Users of GPS guidance systems such as those being used in agriculture and mining will start to notice their ground tracks creeping over several years because they are misinterpreting the datum used by their systems, or not applying epoch dependent corrections to transformation parameters. This is in important issue for developers of GPS and mapping software.

Epoch dependent transformation parameters are essential

Many surveying and mapping software packages and GPS units still have fixed transformation parameters between geodetic datums preset into the software. Fixed parameters ignore the reality of plate tectonics and this leads to a false representation of the accuracy of the transformed coordinates, even where distortion models are used. Distortions in datum transformations have traditionally arisen as a result of unmodelled ground deformation and propagation of survey errors in the datum definition arising from terrestrial surveying methods. Distortion corrections have to be applied for highest accuracy transformations from AGD66/84 to GDA94 (both of which are static datums). There is an urgent requirement for GNSS positioning equipment and transformation software to incorporate time dependent parameters to the existing static parameters in order to account for motion of the tectonic plate encompassed by the datum. Users should not expect their coordinates to change continuously where the underlying tectonic setting is stable in a localised reference frame.

With the exception of plate boundary zones and areas of broad diffuse deformation a rigid plate model is sufficient for computation of dynamic parameters between ITRF and a static datum.

Strategies to account for tectonic motion

The motion of rigid tectonic plates such the Australian plate can be defined by a rotation about an axis in two ways; a rotation rate (in degrees per million years) about an axis defined by the latitude and longitude of one of its poles (an Euler pole), or by a rotation of the plate pole Cartesian components about the axes. A number of different plate models can be used including the NUVEL 1A no-net-rotation (NNR) model used by the ITRF. The NUVEL 1A – NNR model defines the poles and rotation rates of 15 tectonic plates including the Australian plate.

The online GPS processing facility at Geoscience Australia (GA) produces both ITRF2005 and GDA94 coordinates for submitted RINEX observation files. The methodology used at GA is to apply time dependent parameters (largely derived from the NUVEL 1A NNR model and differences between the ITRF92 and ITRF2005 reference frames) to the classical seven parameter conformal transformation model to account for the tectonic motion of the Australian Plate. In essence, they use a 14 parameter model (Dawson and Steed, 2004). This methodology could easily be applied to other positioning systems and GPS software in order to transform ITRF/WGS84 coordinates to GDA94 (and other static datums) at the epoch of observation.

Another strategy, is to compute the horizontal velocity within the ITRF of the observation station using a plate motion calculator (e.g. http://sps.unavco.org/crustal_motion/dxdt/model) . This velocity is fairly constant over the order of hundreds of years. The horizontal displacement between the epoch of observation, and the reference epoch (in the case of GDA94, 1994.0) can then be computed and applied to the observations. Similarly, for smaller areas such as cities and smaller regions, the horizontal velocity could be considered to be consistent at the mm/yr level, and a time dependant horizontal block shift applied to ITRF data to bring the coordinates into GDA94.

For example, the NUVEL 1A – NNR velocity of the Hobart CBD is 53.6 mm/yr North and 14.7 mm/yr East. Assuming this velocity is the same within a radius of 20 km of the CBD, the maximum error in the computed GDA94 coordinates would be 6 mm in 2007.

REFERENCES

Blick G., Crook, C., Grant D., Beavan, J., Implementation of a Semi-Dynamic Datum for New Zealand, *International Association of Geodesy Symposia, Volume 128*, Springer, 2005.

Dawson, J. and Steed, J, *International Terrestrial Reference Frame (ITRF) to GDA94 Coordinate Transformations*, Geoscience Australia, 2004.

Sandiford, M., Neotectonics of southeastern Australia: linking the Quaternary faulting record with seismicity and in situ stress, *Evolution and Dynamics of the Australian Plate, Geological Society of Australia Special Publication 22 and Geological Society of America Special Publication 372*, 2003.

Stanaway, R., *Implementation of a Dynamic Geodetic Datum in Papua New Guinea: A case study*, MPhil thesis, The Australian National University, 2004

Stanaway, R., and Dawson, J., The Divorce of Two Datums, *Position Magazine, No. 20,* 2005

Tregoning, P., Is the Australian Plate Deforming? A space geodetic perspective, *Evolution and Dynamics of the Australian Plate, Geological Society of Australia Special Publication 22 and Geological Society of America Special Publication 372,* 2003.

US National Geospatial Intelligence Agency (NGA), *Addendum to NIMA TR 8350.2:Implementation of the World Geodetic System 1984 (WGS 84) Reference Frame G1150*, 2003.