Proceedings of the 22nd Association of Public Authority Surveyors Conference (APAS2017)
Shoal Bay, New South Wales, Australia, 20-22 March 2017

GDA2020, AUSGeoid2020 and ATRF: An Introduction

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ABSTRACT

The Geocentric Datum of Australia 2020 (GDA2020) is a new, much improved Australian national datum that will replace the current GDA94 by 1 January 2020. This new datum is to be used in conjunction with the new AUSGeoid2020 in order to connect to the Australian Height Datum (AHD). By 2020, GDA2020 will be complemented (and eventually replaced) by the time-dependent Australian Terrestrial Reference Frame (ATRF). This paper provides some background on coordinate systems and datums before explaining these terms in general. It outlines how important this change is for users intending to benefit from the improved geodetic infrastructure. The efforts undertaken by DFSI Spatial Services to support this datum modernisation in New South Wales are also summarised.

KEYWORDS: *Datum modernisation, geodetic infrastructure, GDA2020, AUSGeoid2020, ITRF, ATRF.*

1 INTRODUCTION

The Geocentric Datum of Australia 1994 (GDA94) has been our national datum since its adoption in 2000, providing fundamental positioning infrastructure for Australia (ICSM, 2014). Vertical coordinates are referred to the Australian Height Datum (AHD) (Roelse et al., 1975). Significant improvements in positioning technology in the recent past now enable centimetre-level positioning capability via Global Navigation Satellite System (GNSS) techniques such as Network Real Time Kinematic (NRTK) and Precise Point Positioning (PPP) (e.g. Janssen and Haasdyk, 2011; Rizos et al., 2012), while decimetre-level accuracy or better will soon be available to the mass-market. These developments have revealed that GDA94 is not capable of providing the required quality of datum into the future. Consequently, Federal and State Governments have worked towards modernising Australia's datum for some time (ICSM, 2016a).

Datum modernisation is required in order to accommodate the increasing accuracy and improved spatial and temporal resolution available from modern positioning technologies to an ever-broadening user base concerned with surveying, mapping, navigation, engineering, machine guidance and precision agriculture, to name but a few. The goal of datum modernisation is to supply all users with the most complete yet most straightforward datum products that can define a locally consistent set of coordinates, such that their positioning device agrees with the physical world and associated spatial data to an acceptable level of accuracy (Haasdyk et al., 2014b).

In this context, it is important to remember that geodetic control underpins *all* spatial data, including water, boundaries, addresses, utilities, transport, elevation and imagery, but also that most revenue and GNSS data consumption will come in the near future from applications such as location-based services and transport (GSA, 2015, 2016).

The Geocentric Datum of Australia 2020 (GDA2020) is a new, much improved Australian national datum that will replace the current GDA94 by 1 January 2020. While the GDA2020 technical manual has not been released publicly at the time of writing, this is expected to happen soon. Figure 1 illustrates the difference between GDA94 and GDA2020, both in regards to the coordinate shift and the respective uncertainty. The effect of tectonic motion since 1994, resulting in a shift of approximately 1.8 m towards the north-east, and the improvement in coordinate quality are clearly visible.

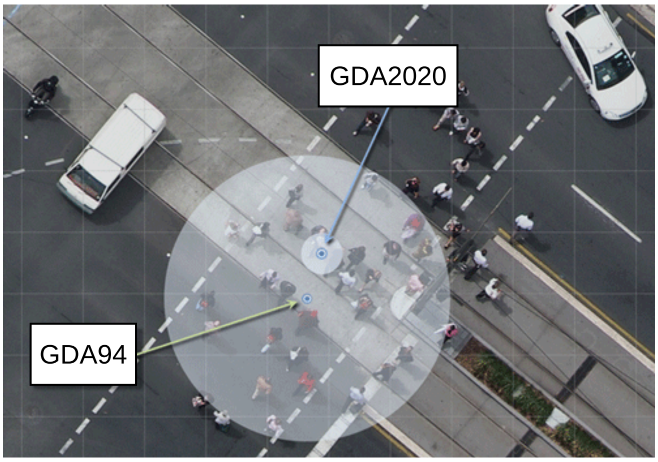


Figure 1: Artistic illustration of GDA94 and GDA2020 coordinates and their uncertainties (adapted from Jaksa, 2015).

GDA2020 is expected to be released soon and is to be used in conjunction with the new AUSGeoid2020 (released at the same time) in order to connect to AHD. By 2020, GDA2020 will be complemented (and eventually replaced) by the time-dependent Australian Terrestrial Reference Frame (ATRF).

This paper provides some background on coordinate systems and datums before explaining the terms GDA2020, AUSGeoid2020 and ATRF in general and outlining how important this change is for users intending to benefit from the improved geodetic infrastructure. The efforts undertaken at DFSI Spatial Services to support this datum modernisation in NSW are also summarised.

2 COORDINATE SYSTEMS AND DATUMS

A coordinate system (or coordinate reference system) is a methodology to define the specific location of a feature in space. As illustrated in Figure 2, positions on the ellipsoid are usually expressed in Cartesian coordinates (X, Y, Z) or curvilinear geographic coordinates (ϕ, λ, h), i.e. latitude, longitude and ellipsoidal height. In a geocentric, rectangular Cartesian coordinate system, the origin is the earth's centre of mass, and the Z-axis coincides with the position of the earth's rotation axis at a certain instant in time (epoch). The X-axis passes through the intersection of the Greenwich meridian and the equator, and the Y-axis completes a right-handed coordinate system by passing through the intersection of the 90°E meridian and the equator. In regards to curvilinear geographic coordinates, latitude is defined as the angle in the meridian plane between the equatorial plane and the ellipsoid normal through a point P.

Longitude is measured in the equatorial plane as the angle between the Greenwich meridian (*X*-axis) and the meridian through P, while the ellipsoidal height is measured from the ellipsoid surface along the ellipsoid normal. It is important to note that a single ground point can have different curvilinear coordinates depending on which ellipsoid the coordinate system refers to.

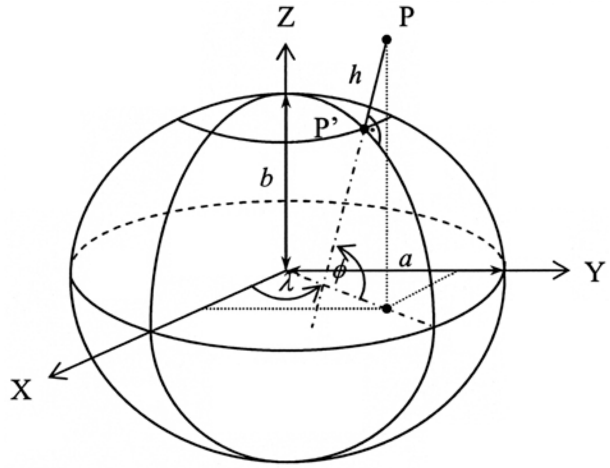


Figure 2: Ellipsoidal coordinate systems (Janssen, 2009b).

Since coordinate systems are idealised abstractions, they can only be accessed through their physical materialisation (or realisation) called reference frames or datums. The datum effectively defines the origin and orientation of the coordinate system at a certain epoch, generally by adopting a set of station coordinates. Over time, different techniques with varying levels of sophistication have been applied to define the shape of the earth's surface, resulting in the adoption of many different datums.

In practice, it is often required to express positions on a flat surface in the form of grid coordinates, i.e. in a 2-dimensional Cartesian coordinate system such as Easting and Northing. This is achieved by map projections according to a recognised set of mathematical rules, resulting in an ordered system of meridians (lines of constant longitude) and parallels (lines of constant latitude). The most common projection used in Australia is the Universal Transverse Mercator (UTM) projection, which utilises a zone width of 6° (Figure 3).

The UTM projection ensures that the scale is very close to unity across the entire zone by defining a central scale factor of 0.9996 for the central meridian (CM), resulting in a scale of 1.0010 at the zone boundary located 3° away from the CM. In order to ensure positive coordinate values across the entire zone, the UTM system applies false coordinates to the origin by adding 500,000 m to the true Easting and, in the southern hemisphere, 10,000,000 m to the true Northing. The conversion between curvilinear and grid coordinates was traditionally performed using Redfearn's (1948) formulae. However, now it is preferred to use the much more accurate Karney-Krueger equations (e.g. Deakin et al., 2012; Deakin, 2014).

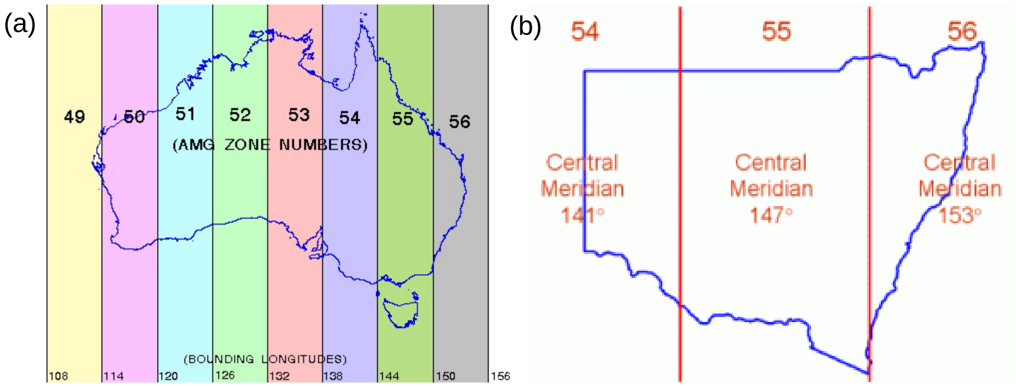


Figure 3: Map Grid of Australia (MGA) zones across (a) Australia and (b) NSW.

Transformation parameters are required to transfer data between datums. These are commonly provided by national or international agencies, generally in form of a 7-parameter or 14-parameter similarity transformation or as a transformation grid. As new datums are defined (or existing datums are refined) based on increased amounts of data and improved processing techniques, new and better transformation parameters are published. While it is acknowledged that there may be a significant delay between their initial availability and eventual adoption in software via updates or patches, it is important for users to apply the latest set of transformation parameters in order to achieve the highest possible quality of output coordinates (e.g. Dawson and Woods, 2010; Haasdyk and Janssen, 2012a).

For a review of coordinate systems, datums and associated transformations in the Australian context the reader is referred to Janssen (2009a, 2009b). A review of Australian height systems and vertical datums can be found in Featherstone and Kuhn (2006), while general background information on datums and map projections is available, for example, in Torge (2001) and Iliffe and Lott (2008).

3 DRIVERS FOR DATUM MODERNISATION

The world around us is ever-changing, so it is obvious that datum modernisation is required from time to time to benefit from technological improvements (e.g. terrestrial vs. satellite surveying techniques and advanced computing capabilities), include recent observations (e.g. larger number and increased precision), remove existing distortions, achieve a denser realisation of the datum, and provide a homogenous nationwide datum that meets the needs of today’s society.

Figure 4 illustrates the following drivers for datum modernisation in Australia:

- Including up-to-date geodetic observations and increased precision: A significant amount of additional data has been gathered since GDA94 was introduced. As an example, Figure 4a shows approximately 90,000 new GNSS baselines (blue) overlying the network of GPS observations that were used in the GDA94 adjustment in NSW (green).
- Removing known distortions: Systematic distortions of up to 0.3 m (horizontally) and ±0.3 m (vertically) have been demonstrated in GDA94 across NSW (Figure 4b). For example, currently a site transformation is required in NSW to relate CORSnet-NSW derived positions to the legal datum as realised by the Survey Control Information Management System (SCIMS – see Kinlyside, 2013) (e.g. Haasdyk et al., 2010; Janssen and McElroy, 2010; Haasdyk and Janssen, 2012b).

- Providing seamless coordinates across state borders through a nationwide simultaneous adjustment: This removes coordinate jumps at jurisdictional boundaries often introduced by running separate adjustments using different methods (Figure 4c).
- Accounting for tectonic plate motion since 1994: The Australian tectonic plate is moving at up to 7 cm/yr (~6 cm/yr in NSW) and has moved about 1.5 m north-east since 1994. By 2020, it will have moved by approximately 1.8 m (Figure 4d).
- Accounting for tectonic plate rotation: If ignored, errors of up to 7 mm are introduced for baseline lengths of only 30 km over a 20-year period (Stanaway et al., 2012) (Figure 4e).
- Introducing a truly 3-dimensional datum by appropriately considering ellipsoidal heights in the definition: This is crucial in order to realise the benefits of precise satellite-based positioning across the nation and unlock the potential for GNSS heighting (Figure 4f).

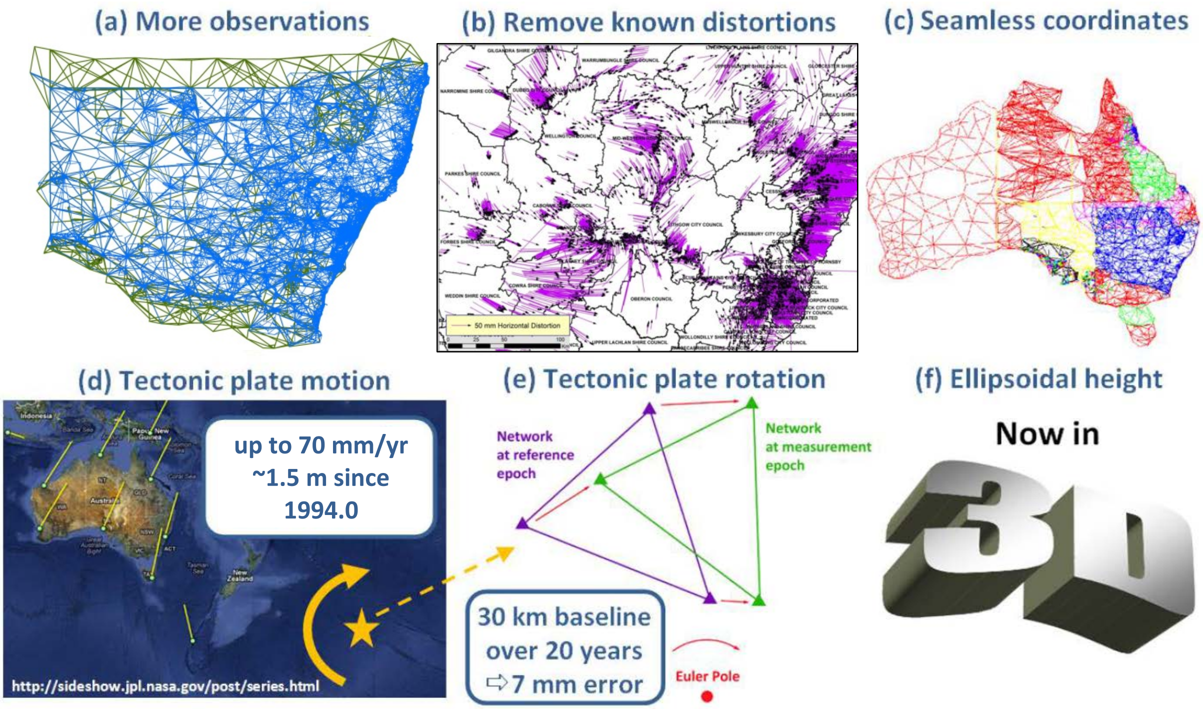
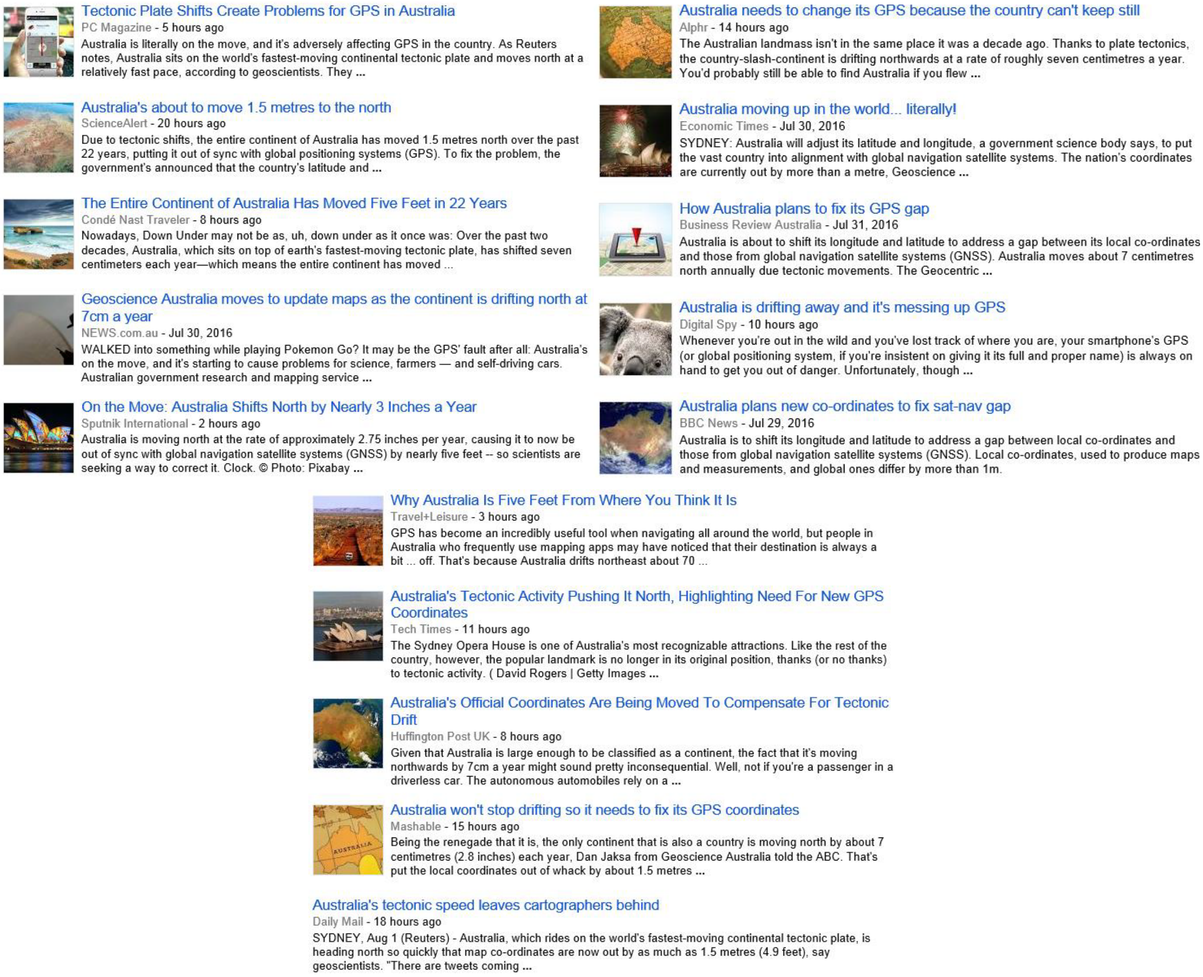


Figure 4: Some drivers for datum modernisation in Australia (adapted from Haasdyk and Watson, 2013).

In mid-2016, the plan to modernise Australia's national datum was embraced by the mainstream media, creating an international media storm about Australia moving to GDA2020 (Figure 5). Of particular note is the BBC's graphical representation of the difference between GDA94 and the current position of the Australian plate (Figure 6). The surveying and spatial information community was quite surprised to see such media hype related to a well-known and understood phenomenon, but also well aware of the sensationalism employed in the mainstream media (e.g. Wallace, 2016a, 2016b).

While unexpected, this media coverage shows that precise satellite-based positioning is set to become commonplace in the mass market. Soon any mobile device, such as a smartphone or iPad, will be able to provide positioning to the layperson at the sub-metre level. These mass-market applications will utilise a global time-dependent reference frame, so it is imperative that Australia's national datum can cater for these future needs.


Tectonic Plate Shifts Create Problems for GPS in Australia
PC Magazine - 5 hours ago
Australia is literally on the move, and it's adversely affecting GPS in the country. As Reuters notes, Australia sits on the world's fastest-moving continental tectonic plate and moves north at a relatively fast pace, according to geoscientists. They ...

Australia's about to move 1.5 metres to the north
ScienceAlert - 20 hours ago
Due to tectonic shifts, the entire continent of Australia has moved 1.5 metres north over the past 22 years, putting it out of sync with global positioning systems (GPS). To fix the problem, the government's announced that the country's latitude and ...

The Entire Continent of Australia Has Moved Five Feet in 22 Years
Condé Nast Traveler - 8 hours ago
Nowadays, Down Under may not be as, uh, down under as it once was: Over the past two decades, Australia, which sits on top of earth's fastest-moving tectonic plate, has shifted seven centimeters each year—which means the entire continent has moved ...

Geoscience Australia moves to update maps as the continent is drifting north at 7cm a year
NEWS.com.au - Jul 30, 2016
WALKED into something while playing Pokemon Go? It may be the GPS' fault after all: Australia's on the move, and it's starting to cause problems for science, farmers — and self-driving cars. Australian government research and mapping service ...

On the Move: Australia Shifts North by Nearly 3 Inches a Year
Sputnik International - 2 hours ago
Australia is moving north at the rate of approximately 2.75 inches per year, causing it to now be out of sync with global navigation satellite systems (GNSS) by nearly five feet -- so scientists are seeking a way to correct it. Clock. © Photo: Pixabay ...

Australia needs to change its GPS because the country can't keep still
Alphr - 14 hours ago
The Australian landmass isn't in the same place it was a decade ago. Thanks to plate tectonics, the country-slash-continent is drifting northwards at a rate of roughly seven centimetres a year. You'd probably still be able to find Australia if you flew ...

Australia moving up in the world... literally!
Economic Times - Jul 30, 2016
SYDNEY: Australia will adjust its latitude and longitude, a government science body says, to put the vast country into alignment with global navigation satellite systems. The nation's coordinates are currently out by more than a metre, Geoscience ...

How Australia plans to fix its GPS gap
Business Review Australia - Jul 31, 2016
Australia is about to shift its longitude and latitude to address a gap between its local co-ordinates and those from global navigation satellite systems (GNSS). Australia moves about 7 centimetres north annually due tectonic movements. The Geocentric ...

Australia is drifting away and it's messing up GPS
Digital Spy - 10 hours ago
Whenever you're out in the wild and you've lost track of where you are, your smartphone's GPS (or global positioning system, if you're insistent on giving it its full and proper name) is always on hand to get you out of danger. Unfortunately, though ...

Australia plans new co-ordinates to fix sat-nav gap
BBC News - Jul 29, 2016
Australia is to shift its longitude and latitude to address a gap between local co-ordinates and those from global navigation satellite systems (GNSS). Local co-ordinates, used to produce maps and measurements, and global ones differ by more than 1m.

Why Australia Is Five Feet From Where You Think It Is
Travel+Leisure - 3 hours ago
GPS has become an incredibly useful tool when navigating all around the world, but people in Australia who frequently use mapping apps may have noticed that their destination is always a bit ... off. That's because Australia drifts northeast about 70 ...

Australia's Tectonic Activity Pushing It North, Highlighting Need For New GPS Coordinates
Tech Times - 11 hours ago
The Sydney Opera House is one of Australia's most recognizable attractions. Like the rest of the country, however, the popular landmark is no longer in its original position, thanks (or no thanks) to tectonic activity. (David Rogers | Getty Images ...

Australia's Official Coordinates Are Being Moved To Compensate For Tectonic Drift
Huffington Post UK - 8 hours ago
Given that Australia is large enough to be classified as a continent, the fact that it's moving northwards by 7cm a year might sound pretty inconsequential. Well, not if you're a passenger in a driverless car. The autonomous automobiles rely on a ...

Australia won't stop drifting so it needs to fix its GPS coordinates
Mashable - 15 hours ago
Being the renegade that it is, the only continent that is also a country is moving north by about 7 centimetres (2.8 inches) each year, Dan Jaksa from Geoscience Australia told the ABC. That's put the local coordinates out of whack by about 1.5 metres ...

Australia's tectonic speed leaves cartographers behind
Daily Mail - 18 hours ago
SYDNEY, Aug 1 (Reuters) - Australia, which rides on the world's fastest-moving continental tectonic plate, is heading north so quickly that map co-ordinates are now out by as much as 1.5 metres (4.9 feet), say geoscientists. "There are tweets coming ...

Figure 5: Snapshot of worldwide online media coverage taken on 2 August 2016.

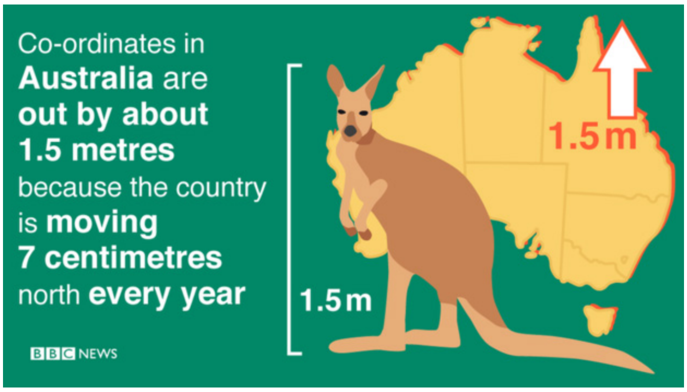


Figure 6: Mainstream media representation of Australia's tectonic motion since 1994 (Foxx, 2016).

4 PLATE-FIXED GEOCENTRIC DATUMS IN AUSTRALIA

A plate-fixed datum is attached to the tectonic plate and therefore also known as a static datum. It is 'frozen' at a certain instant in time (the reference epoch), essentially preventing the coordinates from changing over time due to tectonic plate motion. A geocentric datum uses the earth's centre of mass as its origin and is therefore compatible with GNSS-based positioning. However, as the time difference between the reference epoch and the current epoch increases, the plate-fixed datum deviates more and more from the earth-fixed datum used for GNSS (see section 6). Consequently, it needs to be updated at frequent intervals in order to meet user requirements into the future.

4.1 GDA94

The Geocentric Datum of Australia 1994 (GDA94) has been our national datum since its adoption on 1 January 2000, providing fundamental positioning infrastructure for Australia (ICSM, 2014). The resulting coordinates are based on the Geodetic Reference System 1980 (GRS80) ellipsoid, a geocentric ellipsoid designed to approximate the earth on a global scale.

GDA94 was defined in the then state-of-the-art global reference frame, the International Terrestrial Reference Frame 1992 (ITRF92) at epoch 1994.0 (see section 6.1), realised by the eight Australian Fiducial Network (AFN) sites, and has since been 'frozen' in a geodetic sense in order to avoid changing coordinate values. This definition was justified by the relatively uniform drift of the Australian continent at ~7 cm/yr to the north-east. However, tectonic plate motion causes the difference between absolute ITRF coordinates and GDA94 coordinates to increase over time, amounting to about 1.5 m at present. This is generally not an issue for differential GNSS applications within Australia, as both ends of a baseline move at the same rate if we ignore rotation. However, the ever-increasing number of mass-market applications routinely operates in the ITRF, causing this offset to be a confusing annoyance for the layperson. While GDA94 was recently re-gazetted with improved accuracy for 21 AFN sites, it remains only indirectly linked to the current global reference frame via ITRF92 (ICSM, 2014).

4.2 GDA2020

The Geocentric Datum of Australia 2020 (GDA2020) is a new and more homogeneous conventional static datum, fixed to the Australian plate. The resulting coordinates continue to be based on the GRS80 ellipsoid. While GDA94 is constrained to a small set of static gazetted coordinates, GDA2020 is constrained to the best-available ITRF coordinates for a subset of GNSS Continuously Operating Reference Stations (CORS) contributing to the Asia-Pacific Reference Frame (APREF – see GA, 2017a) – the Australian Regional GNSS Network (ARGN) and Tier 2 AuScope sites (GA, 2017c). Consequently, for GDA2020, the coordinates of 109 GNSS CORS are to be gazetted.

GDA2020 is defined in the global ITRF2014 frame (see section 6.1) at epoch 2020.0, i.e. the coordinates are extrapolated into the future to 1 January 2020 in order to extend the lifespan of the datum. GDA2020 is expected to be released soon, along with associated products such as GDA94-GDA2020 transformation parameters and AUSGeoid2020 (see section 5). AUSPOS, Geoscience Australia's free online GPS processing service, will provide solutions in GDA94, GDA2020 and ITRF2014 (GA, 2017b).

Following a transition period, it is envisioned that GDA2020 will be adopted by all users by 1 January 2020, although several jurisdictions may decide to move to the new datum earlier. The move from GDA94 to GDA2020 will cause the horizontal coordinates of a mark to shift by approximately 1.8 m to the north-east, while the ellipsoidal height will decrease by about 0.1 m. In order to connect to the Australian Height Datum, it is therefore crucial to apply AUSGeoid2020 to GDA2020 ellipsoidal heights, while AUSGeoid09 must be used to convert GDA94 ellipsoidal heights. Under *no* circumstance should a user combine GDA2020 with AUSGeoid09 or GDA94 with AUSGeoid2020.

The Universal Transverse Mercator (UTM) projection (e.g. Janssen, 2009a, 2009b) will continue to be used to project latitude and longitude to grid coordinates (Easting, Northing, Zone). In regards to GDA2020, these grid coordinates will be expressed in the Map Grid of Australia 2020 (MGA2020).

It is important to note that differences of up to several centimetres in both horizontal and vertical coordinates can result from following different transformation paths between two datums (Haasdyk and Janssen, 2012a). The highest and most consistent coordinate quality is obtained by following the most direct transformation path and applying the latest transformation parameters to the original, raw data. Geoscience Australia will publish a paper detailing the transformation parameters between GDA94, GDA2020 and ITRF2014. The transformation between GDA94 and GDA2020 will include a distortion grid option that accounts for the significant distortions inherent in GDA94 – this is particularly important for users in NSW. This distortion grid will also account for localised deformation, e.g. due to subsidence caused by mining or groundwater extraction.

It is anticipated that the national GDA2020 adjustment will be re-run periodically to improve the datum by incorporating new measurements, fixing problem areas and possibly retiring older, superseded measurements.

4.3 NSW's Contribution to GDA2020

CORSnet-NSW is Australia's largest state-owned and operated network of permanent GNSS reference stations. It is built, owned and operated by Spatial Services, a unit of the NSW Department of Finance, Services and Innovation (Janssen et al., 2016; DFSI Spatial Services, 2017). As of February 2017, the network consists of 189 reference stations, providing fundamental positioning infrastructure that is accurate, reliable and easy-to-use for a wide range of users (Figure 7).

This network also provides the backbone for GDA2020 across NSW. The GNSS baselines observed as part of the CORSnet-NSW local tie surveys (Gowans and Grinter, 2013) are crucial to link the GDA2020 coordinates of the CORS to the existing survey ground control network in the national adjustment. This provides a homogeneous national datum realisation across NSW, thereby significantly improving the State's geodetic infrastructure for years to come.

In support of these efforts, DFSI Spatial Services has performed extensive data-mining and cleaning of archived GNSS and terrestrial observations (e.g. Haasdyk and Watson, 2013; Haasdyk et al., 2014a) and conducted targeted state-wide new GNSS observing campaigns (e.g. Gowans et al., 2015).

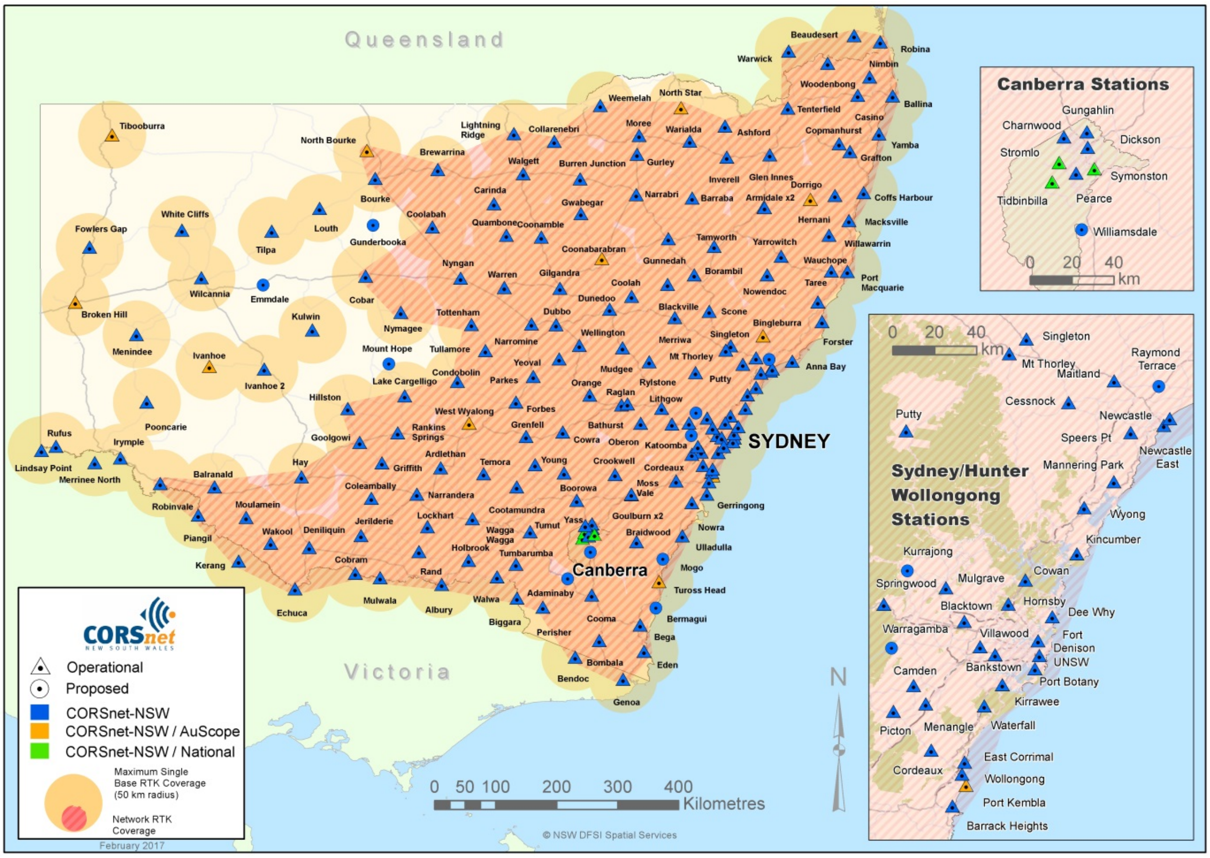


Figure 7: CORSnet-NSW network map as of February 2017 (DFSI Spatial Services, 2017).

NSW's contribution to GDA2020 version 1.0 was delivered to Geoscience Australia on 30 September 2016. The current contribution (version 1.2), incorporating additional data, was delivered to Geoscience Australia on 6 February 2017 (Gowans, 2017). It included 31,000 stations, 96,000 GNSS baselines, 3,700 6+ hour long AUSPOS sessions, 26,000 directions and 4,600 distances (Figures 8 & 9). While Figure 8 appears very busy, it clearly illustrates the vast amount of data involved in this adjustment: GNSS baseline cluster (National GNSS Campaign Archive, NGCA – purple), GNSS baselines (blue), directions (red), MSL/ellipsoidal distances (dark red), point cluster (APREF – large red circles) and all nodes (any point in the adjustment – small red circles).

This dataset was combined with the contributions from the other States and Territories to produce, for the first time, a nationwide simultaneous network adjustment for Australia. In fact, Australia is the first country in the world to attempt a continental network adjustment of this size in a single step that rigorously propagates uncertainty. The results were also used to generate the first version of official GDA2020 products, such as AUSGeoid2020 and the GDA94-GDA2020 transformation parameters and distortion grid, and then interrogated, analysed and validated by experts around the country before their initial publication. For more details about the NSW contribution, the reader is referred to Gowans (2017).

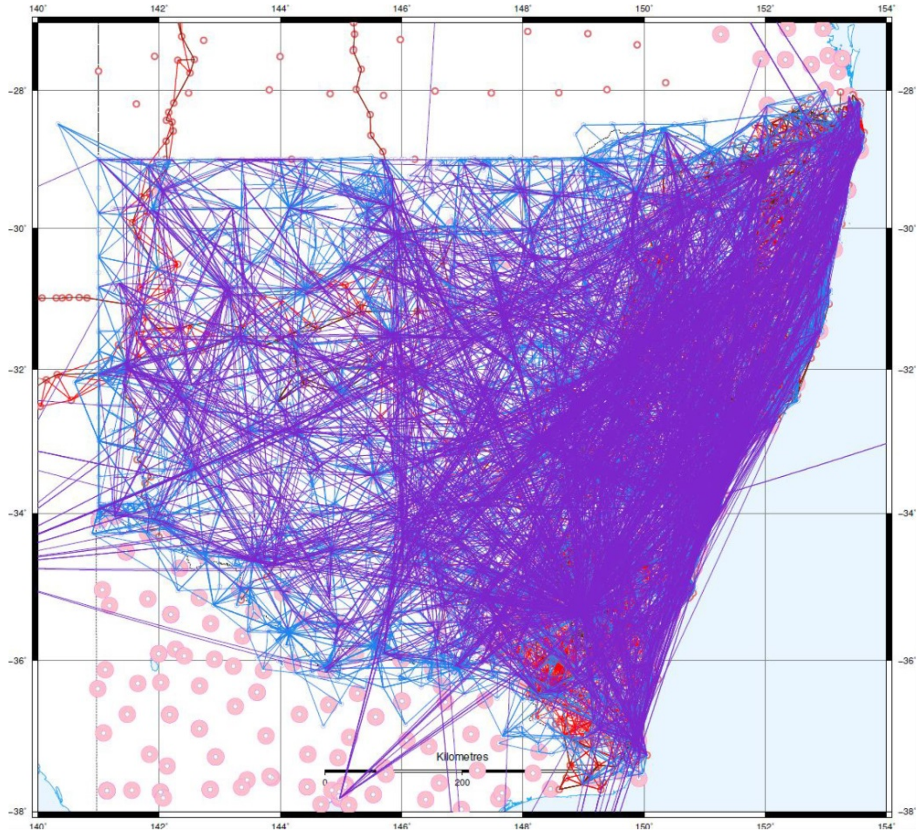


Figure 8: NSW's contribution to GDA2020 version 1.2, submitted on 6 February 2017.

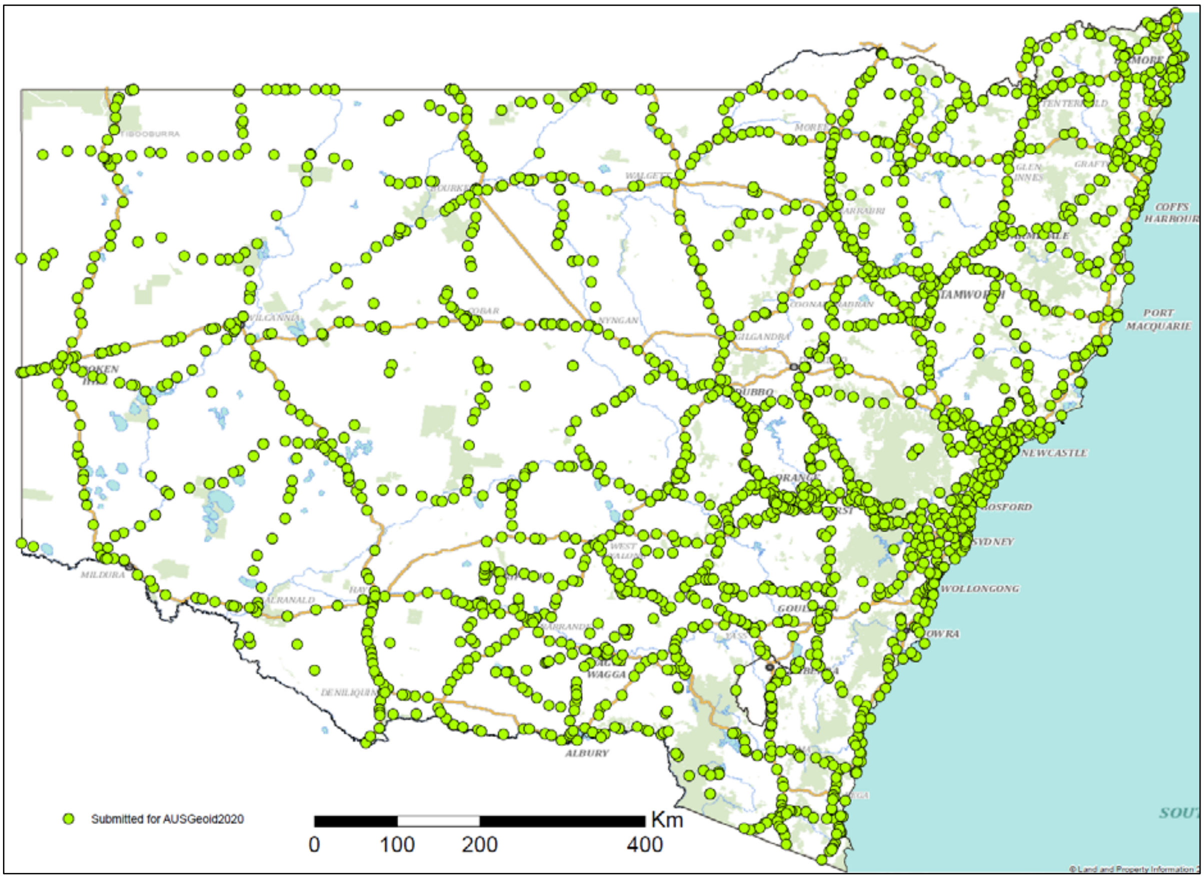


Figure 9: AUSPOS sessions (6+ hours) collected on established level marks in NSW and contributing to AUSGeoid2020 (as of February 2017).

5 AUSGeoid2020

Vertical coordinates continue to be referred to the Australian Height Datum (AHD) (Roelse et al., 1975). It is well known that shortcomings in the AHD realisation (AHD71 for mainland Australia and AHD83 for Tasmania) resulted in considerable distortions of up to about 1.5 m into AHD across Australia, which is therefore considered a third-order datum (e.g. Morgan, 1992; Featherstone and Filmer, 2012; Watkins et al., 2017). However, in the immediate future AHD continues to be a practical height datum that provides a sufficient approximation of the geoid for many surveying and engineering applications. In the longer term, the Intergovernmental Committee on Surveying and Mapping (ICSM) will consider updating AHD or replacing it potentially with a new national gravity-based vertical reference frame.

The growing use of CORS networks for GNSS-based height transfer has substantially increased the importance of accurate, absolute N values (or geoid undulations). These N values (N) can be used to convert ellipsoidal heights (h) to AHD heights (H) and vice versa, provided N and h refer to the same ellipsoid:

$$H = h - N \tag{1}$$

Fortunately, the AUSGeoid09 model has been shown to provide N values with unprecedented absolute accuracy across NSW and Australia (e.g. Janssen and Watson, 2010, 2011; Brown et al., 2011; Allerton et al., 2015; Sussanna et al., 2017).

As outlined in section 4.2, the move from GDA94 to GDA2020 causes ellipsoidal heights to decrease by about 0.1 m. Consequently, a new AUSGeoid model is necessary to connect GDA2020 ellipsoidal heights to AHD. AUSGeoid2020 is expected to be released soon together with GDA2020. While AUSGeoid2020 has the same extent (between 108ºE and 160ºE longitude and between 8ºS and 46ºS latitude) and density (1’ by 1’ grid, i.e. approximately 1.8 by 1.8 km) as its predecessor AUSGeoid09, it is based on a much larger and much more homogeneous dataset and expected to provide a significant improvement for GNSS-based heighting across the nation. However, it is crucial that AUSGeoid2020 is *only* used in conjunction with GDA2020 ellipsoidal heights. Users wishing to convert GDA94 ellipsoidal heights to AHD *must* continue to use AUSGeoid09.

Over the last few years, DFSI Spatial Services has conducted several targeted GNSS observing campaigns (e.g. ‘Saving AHD’ and ‘Positioning Rural NSW’) to collect long-duration GNSS datasets on levelled benchmarks in order to improve the AUSGeoid product across the State (see Figure 9). These efforts continue to date in order to maintain and upgrade the State’s fundamental levelling infrastructure and increase the density of levelled benchmarks occupied with GNSS across the State. So far, some 600-800 original 1970s Australian National Levelling Network (ANLN) marks (i.e. typically about 6 marks per level run in rural areas) were preserved and upgraded to meet current and future requirements. In addition, long GNSS sessions have been observed at more than 70 existing LAL1 (first order) and LBL2 (second order) levelling marks, covering the area from north of Newcastle to south of Wollongong at an average density of about one mark every 10 km.

6 EARTH-FIXED GEOCENTRIC DATUMS IN AUSTRALIA

An earth-fixed datum accounts for the earth's dynamics by allowing tectonic plates to move within it. It is fixed to the earth but not its crust and therefore also known as a dynamic datum. Consequently, the coordinates of a given ground mark are constantly changing. Hence it is critical to attach a time stamp to each position given in an earth-fixed datum, so a position given at a reference epoch can be propagated to the current or any other epoch using station velocities. The reference epoch represents a date and time that is conveniently agreed upon to assist with the meaningful transfer of coordinates, measurements and other parameters.

6.1 ITRF

The International Terrestrial Reference Frame (ITRF) is the most precise earth-centred, earth-fixed datum currently available and was first introduced in 1988. It is maintained by the International Earth Rotation and Reference Systems Service (IERS) and realised by an extensive global network of accurate coordinates and their velocities derived from geodetic observations using GNSS, Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) (Altamimi et al., 2016).

The ITRF is a *time-dependent* (or dynamic) datum and changes according to temporal variations of its network coordinates and their velocities due to the effects of crustal motion, earth orientation, polar motion and other geophysical phenomena such as earthquakes and volcanic activity (Bock, 1998). It is updated regularly in order to account for the dynamics of the earth and now sufficiently refined to ensure that the change between successive ITRF versions is in the order of a few millimetres. So far the following 13 versions have been released: ITRF88, ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF96, ITRF97, ITRF2000, ITRF2005, ITRF2008 and ITRF2014.

Figure 10 illustrates the ITRF2014 network, consisting of 1,499 stations located at 975 sites, with about 10% collocated with up to four distinct space geodetic instruments. The resulting coordinates are based on the GRS80, a geocentric ellipsoid designed to approximate the earth on a global scale. It is worth noting that the current realisation (ITRF2014 with reference epoch 2010.0) incorporates, for the first time, the non-linear motion of the earth's surface caused by post-seismic relaxation after earthquakes, resulting in a significant improvement. The origin shift from ITRF2008 to ITRF2014 amounts to a mere 3.5 mm (Altamimi et al., 2016).

Coordinates given in any of the ITRF realisations are referred to a specific *epoch* in order to enable appropriate consideration of the earth's dynamics. Unlike GDA94 and GDA2020, which are fixed to the Australian plate and therefore ignore crustal motion, point coordinates given in the ITRF change over time as the tectonic plate they sit on is moving. As a result, it is important to time-stamp each set of coordinates in order to specify which epoch the position refers to. When combining data observed at different points in time (e.g. during a longer-term infrastructure project), all data have to be propagated to the same (arbitrary) epoch to enable comparison. This can be achieved, for example, via utilising a global plate motion model or a local deformation model based on GNSS CORS time series.

The epoch should be declared in decimal years, e.g. ITRF2014(2017.218) indicates a positon in ITRF2014 valid at 12:00 UT on 21 March 2017. The decimal is calculated by day of year

(80) minus one, plus time in the day (0.5 days), divided by the number of days in the year (365, considering that 2017 is not a leap year).

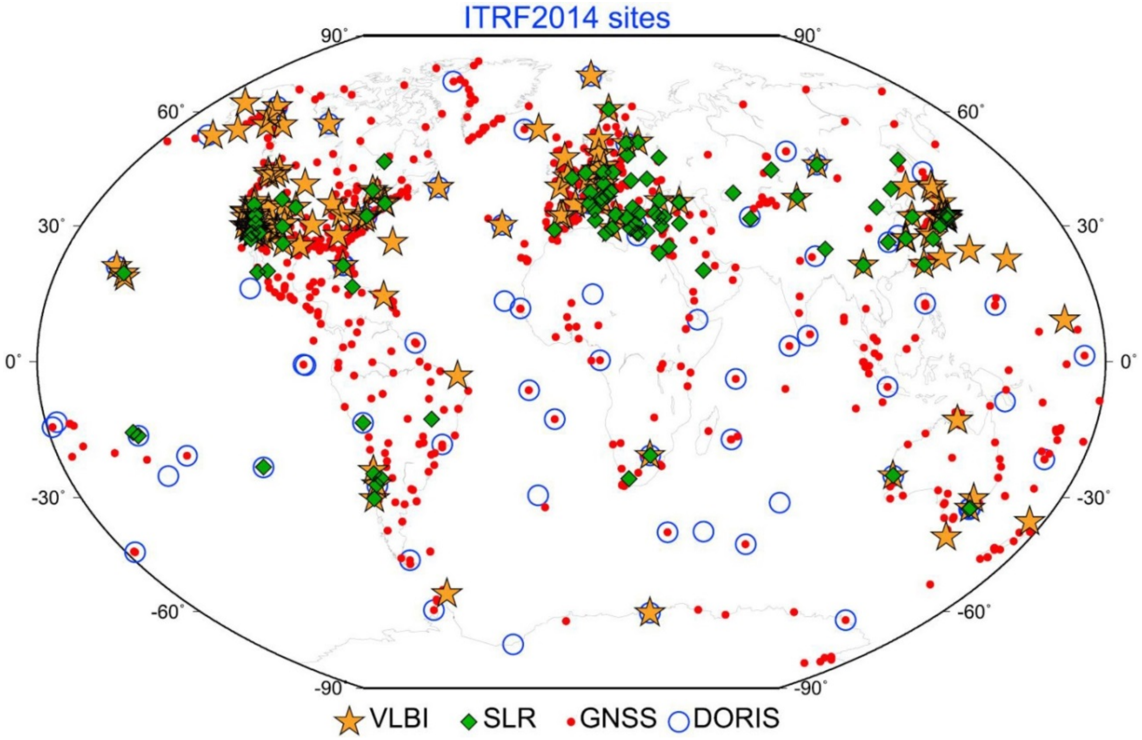


Figure 10: ITRF2014 network, highlighting VLBI, SLR and DORIS sites collocated with GNSS (Altamimi et al., 2016).

6.2 ATRF

The Australian Terrestrial Reference Frame (ATRF) is basically a regional realisation of the ITRF, based on almost 200 globally distributed International GNSS Service (IGS) stations and the Asia-Pacific Reference Frame (APREF) network consisting of about 500 stations (GA, 2017a). As a consequence, Australian spatial information will be directly interoperable with GNSS measurements, i.e. mass market applications will not see a discrepancy between global coordinates and ATRF.

It is anticipated that the ATRF will be implemented from January 2020 with adoption planned to be complete by 2023. However, it is important to note that GDA2020 and ATRF will exist in tandem for the foreseeable future. Practically, GDA2020 and ATRF can really be thought of as one product – the former being fixed to epoch 2020.0, while the latter refers to the current epoch (or any other user-specified epoch).

6.3 WGS84

The World Geodetic System 1984 (WGS84) was developed for the U.S. Defense Mapping Agency (DMA), later named NIMA (National Imagery and Mapping Agency) and now called NGA (National Geospatial-Intelligence Agency), and is the nominal datum used by GPS (NIMA, 2004). It is based on the WGS84 ellipsoid which can generally be assumed identical to the GRS80. The WGS84 datum was introduced in 1987 and has since been refined several times to be closely aligned with the ITRF in order to prevent degradation of the GPS broadcast ephemerides (i.e. orbit parameters) due to plate tectonics. The following refinements have been released to date: WGS84(G730), WGS84(G873), WGS84(G1150) and WGS84(G1674) (Donnelly et al., 2014). In this context, G1674 denotes the GPS week in which the latest realisation of WGS84 was implemented. For all mapping and charting purposes, WGS84 and the most current ITRF can be assumed identical. However, it should be noted that WGS84 is based on a much smaller number of globally distributed reference stations than the ITRF, and the level of agreement worsens as the time gap between WGS84 and the latest realisation of ITRF grows.

It is also worth noting that, in single point positioning mode, the datum of the satellite orbits determines the datum of the resulting coordinates. Consequently, in practice, a user's stand-alone *absolute* GNSS position is nominally in WGS84 if broadcast orbits are used and nominally in ITRF if precise orbits are used (e.g. via online Precise Point Positioning services). A transformation can then be applied to refer the position to a national datum. Users connecting to the Australian control network (such as SCIMS in NSW) or an Australian CORS network (such as CORSnet-NSW) via *relative* measurements will, of course, obtain positions in Australia's national datum. While relative measurements often utilise broadcast orbits during processing, these are not used to determine the datum of the coordinates being generated.

7 TRANSITION TO GDA2020 AND ATRF

The ICSM's GDA Modernisation Implementation Working Group (GMIWG) is responsible for assisting with the transition to GDA2020 and ATRF (ICSM, 2017). This is achieved through stakeholder engagement and the development of tools, technical resources and educational material in order to facilitate a smooth transition with minimal disruption to existing systems and processes (Jaksa, 2015; ICSM, 2016b).

It is anticipated that the transition from GDA94 to GDA2020 will be complete by 1 January 2020, i.e. the date ATRF is planned to be released. However, most State and Territories are expected to move to GDA2020 before this date. The GDA94-GDA2020 transformation parameters and the new AUSGeoid2020 model, along with relevant information on their correct use, will soon be available from ICSM and Geoscience Australia.

In the context of datum modernisation, it is crucial to stress the importance of metadata. Unfortunately, metadata management is often not approached with appropriate rigour and datasets are often manipulated without keeping the metadata records up to date. However, considering the transition period between GDA94 and GDA2020 (and then towards ATRF), it is obvious that metadata is becoming just as important as the datasets themselves. Appropriate metadata records are essential to enable datasets to be traced back to their source, thereby allowing improved models to be applied in the future. All datasets should include complete metadata about the epoch, datum, method of collection and estimated uncertainty. Ideally, the original data should be archived unchanged at the observation epoch (or at least by recording any transformations or alterations applied to the raw data) in order to allow reprocessing of the original data at a later stage.

Looking further ahead, it is important to note that GDA2020 and ATRF will operate together as a dual frame system for the foreseeable future. This means that generally it will be up to the user to decide whether they would like to adopt GDA2020 or ATRF as the datum for their data holdings or a particular job, although some spatial information will be legally mandated in GDA2020 and eventually ATRF. GDA94 will continue to exist in a legal and practical sense for some time, but it is anticipated that the requirement for higher precision and accuracy will strongly drive the move to GDA2020 and ATRF.

8 CONCLUDING REMARKS

On behalf of the Surveyor General, DFSI Spatial Services has a legislative, regulative responsibility to maintain the geodetic control network in NSW. As such, DFSI Spatial Services is the custodian of some 250,000 marks in SCIMS, which includes about 6,000 traditional ‘passive’ trigonometrical stations as well as about 190 ‘active’ GNSS CORS belonging to CORSnet-NSW. Keeping the geodetic component of the survey control network current and ready for utilisation requires regular maintenance and upgrade. Australian datum modernisation will provide significant improvements for all users of spatial information across the State and the nation.

The new Australian datum, GDA2020, is expected to be released soon, along with associated products such as GDA94-GDA2020 transformation parameters and AUSGeoid2020. It is anticipated that it will be adopted by most jurisdictions before the target date 1 January 2020. Consequently, users need to be aware of the change and its importance in regards to making the most of the improved geodetic infrastructure by relating their datasets to the new datum.

This paper has provided some background information on coordinate systems, datums and map projections before briefly exploring the need for datum modernisation in Australia. It has explained the terms GDA2020, AUSGeoid2020 and ATRF (along with related terms) in general and related them to the future move from a plate-fixed datum (GDA2020) to an earth-fixed datum (ATRF). The considerable efforts undertaken at DFSI Spatial Services to support datum modernisation in NSW have also been summarised.

The ongoing datum modernisation will provide a much improved Australian national datum that will ensure that Australia is well positioned into the future.

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