The Status of the National Geospatial Reference System and its Contribution to Global Geodetic Initiatives

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SUMMARY

Australia's National Geospatial Reference System (NGRS) is a continually evolving system of infrastructure, data, software and knowledge. The NGRS serves the broader community by providing an accurate foundation for positioning, and consequently all spatial data. The NGRS is administered by the Intergovernmental Committee on Surveying and Mapping (ICSM) and maintained by its Federal and State jurisdictions.

Increasingly, the role of Global Navigation Satellite Systems (GNSS) in positioning has required the globalisation of national coordinate systems. In the early 1990's ICSM endorsed the adoption of the Geocentric Datum of Australia (GDA94) which was aligned to the International Terrestrial Reference Frame (ITRF) with an uncertainty of 30mm horizontally and 50mm vertically. Since that time crustal deformation and the demand for higher accuracies has resulted in GDA94 no longer adequately serving user requirements. ITRF has continued to evolve in accuracy and distribution to the extent that it now requires very accurate modelling of linear and non-linear crustal deformation. Even the Australian Plate, which has long been considered by the geodetic community to be rigid, is now known to be deforming at levels detectable by modern geodesy.

Consequently, infrastructure development programs such as AuScope have been implemented to ensure that crustal deformation can be better measured. The AuScope program also aims to improve the accuracy of the ITRF by contributing to the next generation of the Global Geodetic Observing System (GGOS) in our region. This approach will ensure that the ITRF continues to evolve and that Australia's NGRS is integrally connected to it with equivalent accuracies. Ultimately this will remove the need for national reference systems, with a globally homogenous and stable reference system (e.g., ITRF) being far more beneficial to society. This paper reviews Australia's contribution to GGOS and how this impacts on positioning in Australia.

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1. INTRODUCTION

The NGRS is at the core of all positioning activities and the collection and management of spatial data. The drive for better accuracies in industry require that the governments responsible for maintaining the geodetic datum continually assess the suitability of the datum for the current and potential applications that rely on it. Updating a national datum is an extensive task. As such the custodians of the datum, the Intergovernmental Committee on Surveying and Mapping (ICSM), need to monitor industry requirements very closely and wherever possible preempt future requirements so that work can begin on developing the next datum well in advance of it being required.

This paper will discuss the current NGRS and how changing requirements are making its use problematic. It will also develop options for the future of the NGRS based on current activities within the Global Geodetic Observing System (GGOS), including Australia's contribution to GGOS through AuScope.

2. AUSTRALIA'S NATIONAL GEOSPATIAL REFERENCE SYSTEM

The National Geospatial Reference System (NGRS) is a combination of infrastructure, data, software and knowledge. It includes all aspects of a coordinate datum, along with tools, utilities and a series of standards and recommended practices that facilitate its use.

Historically the NGRS infrastructure has consisted of physical ground survey marks of varying types and densities distributed across the continent. Table 1 illustrates the number of marks currently maintained by those State government agencies responsible for geodesy. It does not include marks placed and maintained for specific projects by other government agencies (e.g. State Rail) and the private sector. Clearly the placement and maintenance of these survey marks is an expensive exercise.

The marks have served two primary purposes. The first was to provide recoverable reference points from which datum definition observations could be taken. The second was to provide users with access to the datum.

The Geocentric Datum of Australia 1994 (GDA94) is based on continuous GPS observations at 8 sites across Australia – a network known as the Australian Fiducial Network (AFN). This was supplemented by further campaign-based GPS observations at 70 sites that had a nominal spacing of 500km – a network known as the Australian National Network (ANN).

Table 1. Audit of survey marks. These numbers are conservative and include only those marks maintained by the relevant geodetic authority.

Authority	**Horizontal**	**Vertical**
New South Wales	230,000	229,000
Victoria	140,000	44,000
South Australia	150,000	-
Western Australia	30,000	25,000
Northern Territory	20,000	10,000
Queensland	23,000	51,000
Tasmania	8,000	2000
ACT	200	-
New Zealand	100,000	25,000

The GPS observations from both the AFN and ANN sites were combined in a single regional GPS solution in terms of ITRF 1992@1994.0. The coordinates in latitude, longitude and ellipsoidal height of the 8 AFN stations were then gazetted as the recognised value standard for GDA94 position in Australia under the National Measurement Act. These GDA94 coordinates were subsequently propagated to the thousands of ground marks across the nation through a least squares adjustment of GPS baselines and existing terrestrial observations. The grid coordinate system adopted for GDA94 is the Map Grid of Australia 1994 (MGA94), which is based on the Transverse Mercator Projection. The GDA94 coordinates of the AFN were gazetted in September 1995; however it took another 5 years to implement the datum.

Whilst the derivation of GDA94 coordinates for the AFN and ANN were of a high standard for the time, the observations used in the subsequent adjustment of ground marks varied in quality, so it is important to know the uncertainty of any coordinate to ensure that it satisfies a fitness for purpose criteria. The estimation of absolute uncertainty of a GDA94 coordinate must take into account the uncertainty of the constraining coordinates as well as the accumulated uncertainty of the observations used to determine the position.

Typically, those stations adjacent to the constraining stations and with high quality observations will have the smallest positional uncertainties and the stations distant from the constraining stations will likely have accumulated additional positional uncertainty. It should be noted however that regardless of the quality of the observations to a station it would never obtain a positional uncertainty better than the constraining stations (in an absolute sense). This is one of the current issues with GDA94 whose constraining stations have a stated positional uncertainty at 95% confidence of 30mm, 30mm and 50mm in latitude, longitude and ellipsoidal height respectively (Morgan et al, 1996).

Coordinates are meaningless without defining the datum used. There are however a large variety of datums in use globally and several that are still in common use within Australia. An integral component of the NGRS is the ability to transform between GDA94 and these other datums. The transformation between GDA94 and ITRF is best achieved through the use of a

14-parameter similarity transformation (i.e. 7 parameters with rates to allow for tectonic motion) (Dawson and Steed, 2004).

This paper will not attempt to discuss the relationship of the Australian Geodetic Datum 1966 (AGD66) and the Australian Geodetic Datum 1984 (AGD84) to GDA94. Readers are referred to Collier (2002) for this material. Of more confusion currently is the relationship between GDA94, the World Geodetic System 1984 (WGS84) and ITRF. The latest version of the WGS84 datum is closely aligned to ITRF by the US National Imagery and Mapping Agency (NIMA) (NIMA, 2000) (now the National Geospatial Intelligence Agency). The resultant WGS84 is a semi-dynamic datum. Therefore except for the most accurate scientific applications WGS84 can be considered to be equivalent to ITRF since 2002. Care should be taken when using older versions of WGS84. They were not aligned to ITRF and coordinate differences of many metres can be expected.

Both ITRF and consequently GDA94 use the Geodetic Reference System 1980 (GRS80) as the reference ellipse to represent geographical coordinates. WGS84 (the datum) uses the WGS84 reference ellipse that is slightly different to GRS80, however for all intents and purposes can be considered equivalent.

GDA94 is a static datum based on the 1994 epoch derivation of the AFN. Since the 2000 implementation of GDA94, some jurisdictions have undertaken local or regional readjustments based on new measurements that result in changes to some coordinates, but they are still based on the 1994 epoch derivation of the AFN.

Coupled with every coordinate datum exists an amount of knowledge that is intended to provide a framework in which the datum can be used. This includes the standards, recommended practices and procedures for the propagation of, and connection to, the datum. Readers are referred to Abbey and Morgan (2010) for a description of work currently being completed to update the Standards and Practices for Control Surveys in Australia.

Another key component of the NGRS are the databases and systems used to manage, store and deliver to users the information, coordinates, observations and metadata that relate to the physical marks that form the basis of the NGRS. Currently each jurisdiction (Federal and State/Territory) has a system of managing this information and there is some overlap. However some progress has been made on standardising the databases and systems for the exchange, delivery and archiving of geodetic information between Australia and New Zealand's State and Federal agencies. This initiative is broadly referred to as eGeodesy (Fraser and Donnelly, 2010).

Collectively this infrastructure, data, software and knowledge form the National Geospatial Reference System. More detail on GDA94, its predecessors and the equivalent system in New Zealand can be found in Blick and Sarib (2010).

3. HOW AUSTRALIA'S NGRS HAS CHANGED SINCE 1994

The requirements imposed on the NGRS are continually evolving. Long gone are the days when geodesy served only to provide a coordinate framework for series mapping across Australia. The advent of GPS and its subsequent infiltration into broader public use has resulted in positioning becoming ubiquitous. More recently, the ability to undertake precision positioning and navigation has become the expectation of many users of GPS who are not trained geodesists or even surveyors. Similarly, there is an expectation that spatial data sets used in positioning devices will be accurate within the tolerances of the positioning accuracy of the GPS unit. This results in more stringent requirements on the NGRS, particularly the software, documentation, standards and other procedures that make the use of accurate coordinates possible.

3.1 Accuracy

It has been said that accuracy is addictive. Clearly there is an ever-increasing desire for higher accuracies. The evolution of positioning over the last 40 years has shown that the achievable accuracy improves by an order of magnitude every decade. It is also fair to note that the cost of deriving a position has followed a parallel trend, with costs plummeting. Positioning with a handheld GPS chip in a mobile phone today would yield accuracies comparable to geodetic surveying in the 1970's, but for a fraction of the cost.

Table 2. Positioning accuracy trends.

Decade	Positioning Accuracy
1970's	10 metres
1980's	1 metre
1990's	0.1 metre
2000's	0.01 metre

Positioning accuracy should be broken into two distinct components:

1. The first is the user's ability to connect to the reference system or datum.
2. The second is the inherent accuracy of the underlying reference system.

For instance, 1cm accurate positioning is not possible if the user is unable to use techniques that can recover this type of accuracy, despite the existence of a very accurate reference system. Of greater concern is that users can never achieve 1cm accuracy positioning if the underlying reference system is of a lower accuracy regardless of how hard they try. Users are often misled into believing that the internal precision of the technique / software being used is an estimator of accuracy, when clearly it is not. Within the Australian geodetic community coordinate uncertainty has been separated into two types, Positional Uncertainty and Relative Uncertainty (Steed and Allman, 2005), to deal with this issue. Relative Uncertainty is within the control of positioning practitioner. Positional Uncertainty is partially the responsibility of the positioning practitioner and partially reliant on the underlying datum.

GDA94 has a stated uncertainty of 30mm horizontally and 50mm vertically at the definition points (Australian National Network) (Morgan et al, 1996). These uncertainties are relative to ITRF92 at the epoch of 1994, which itself has uncertainties compared to later versions of ITRF that are considered to be more stable. The GDA94 coordinates resulting from the national GDA adjustment, and subsequent subsidiary adjustments are considerably worse due to accumulation of measurement technique errors. This results in positional uncertainty at some remote GDA94 stations being several decimetres. Unfortunately there are also some semi-urban areas where the uncertainties are also quite large (approx 0.4m) due to network geometry. As a separate issue the Australian continent has also continued its relentless march northeast at a rate of approximately 70mm per year due to tectonic plate motion. So the original GDA94 uncertainties are large and variable, and the difference with ITRF is growing continuously and now is well over a metre. While a simple 14-parameter transformation (see Dawson and Steed (2004) or Dawson and Woods (in Preparation)) will remove the majority of the uncertainty caused by plate motion it does nothing to remove the original 30mm and 50mm uncertainties. Nor does it do anything to remove the local uncertainties in GDA94 coordinates caused by the original propagation technique. As such we see examples where GDA94 coordinates produced by transforming ITRF coordinates are significantly different to these propagated through the original GDA adjustment (e.g. Kinlyside et al, 2010).

3.2 A Dynamic Continent

The concept of a static datum, like GDA94, has served Australia and many other countries well. It offers an ease of use that is simply not possible with a truly dynamic datum. Unfortunately it also requires the use of tools and strategies to mitigate the effects of the Australian landmass moving due to tectonics, which results in the coordinates changing within the global coordinate frame. Nor does it allow for stations within the network to move in a localised way. This has been acceptable at the level of accuracy with which geodesists were working in the Australian context until recently, because dynamic stations were considered to be unusual, and removed as outliers. The convergence of accuracy means this premise no longer holds. For instance long held is the adage that a benchmark in ‘black soil’ is likely to move with variable soil moisture content. Very few people understood that a similar problem existed on the scale of whole basins where the water table varied due to natural causes, or more recently due to anthropogenic causes. The Perth basin for instance is now understood to subside by 5mm per year as a consequence of ground water extraction. This variation has been accumulating since extraction commenced in the early 1990’s. The net effect is that the observations to the points that were taken prior to water extraction no longer hold true. Similarly we have very little understanding of how the continent is deforming due to neotectonics. Accumulation of elastic strain on faults is indicated by seismicity and the existence of landscape features formed by crustal deformation. This strain is subsequently released during earthquakes, of which Meckering, Tennant Creek and Newcastle Earthquakes are all contemporary examples. Measuring surface deformation using geodetic techniques may provide insights into the manner of strain accumulation and release. Globally, geodetic observations have been able to provide important constraints on crustal rheology, including estimates of the stresses required to produce earthquakes and also what proportion of deformation occurs seismically (Stein, 2007). In fact this field of science is one of the key drivers for the refinement of the ITRF, and the establishment of the Global Geodetic Observing System (GGOS). The same logic, however, has not previously been extended to the refinement of the NGRS in Australia.

4. THE GLOBAL GEODETIC OBSERVING SYSTEM

The Global Geodetic Observing System (GGOS) is an initiative of the International Association of Geodesy (IAG). It integrates the three fundamental 'pillars of geodesy', i.e. the Earth's geometry (reference frame and surface profiling), the Earth's rotation (polar motion, rotation rate, nutation, etc) and the Earth's gravity field (gravity and geoid) (Plag and Pearlman, 2009). It is through the combination of these three pillars of geodetic science, and the prerequisite infrastructure networks underpinning them, that the true strength of GGOS is realised. Collectively they have the potential to contribute significantly to many of the key scientific challenges facing society like sea level rise, hazard monitoring, and understanding the stability of the Earth's crust as we utilise its resources (i.e. anthropogenic deformation of the Earth's crust including subsidence caused by fluid extraction, local uplift caused by CO_2 sequestration and hot rock utilisation).

GGOS brings together the existing IAG services. Of particular interest to this paper are the International Earth Rotation and Reference Systems Service (IERS), the International Very Long Baseline Interferometry Service (IVS), the International Laser Ranging Service (ILRS) and the International GNSS Service (IGS). Collectively the latter three services contribute observations and analysis of geodetic observations to the IERS for combination into the ITRF. The ITRF is reviewed regularly and new versions are publicly released when quality assurance processes are satisfied. The latest version will be ITRF2008 (pers. comms. Altamimi). The IERS also publish transformation parameters between each of the ITRF versions. ITRF now has a conservatively estimated accuracy of 5mm globally. The IAG aims to see this number converge to 1mm accuracy within the next decade. This level of accuracy is required to provide a stable frame from which, e.g., sea level rise can be measured. It also allows a new insight into the accumulation of tectonic strain over periods of several years at levels of accuracy previously unimaginable. This attribute is seen as a precursor to unlocking the ability to map earthquake hazard and the subsequent societal risk.

The ITRF is a dynamic datum in two senses. The first and most obvious is that the coordinate values for points have an associated velocity estimate or rate. The ITRF itself is published with a reference epoch so that the coordinates are meaningful in a four dimensional sense. In the case of ITRF2005 the reference epoch was 2000.0. This allows the user to map (or project) a coordinate to the date of use. For instance a point in ITRF2005 has an X, Y, Z coordinate (Earth-Centred Cartesian coordinates) and $\Delta X, \Delta Y, \Delta Z$ (rates or velocities). To derive a coordinate at the time of application the user needs to apply the rates to the coordinates at the reference epoch:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{user} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{ref} + \begin{pmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{pmatrix} (T_{user} - T_{ref})$$

This of course assumes linear velocities at the stations. Unfortunately the Earth is not accommodating in that respect and often works in a non-linear way. We regularly see GPS time series estimates of station positions step due to tectonic activity. We also see time series steps occur as a result of instrument changes which introduce unmodelled effects into the coordinate derivation (for example Altamimi et al, 2007).

In the case of GNSS, the IGS has developed a methodology whereby the reference frame is promulgated through a global set of core stations. These stations are chosen based on geographical distribution and station characteristics, both physical and numerical (i.e. time series stability). The ITRF values for these core stations are developed as part of the full multi-technique reference frame combination. They are then used as constraint for the daily IGS analysis activities. If one of these core stations is found to subsequently suffer a time series discontinuity it is removed from the list of constraining core stations. In this way the analysis solution's alignment to ITRF is not contaminated by a station that is no longer coincident with the originally determined position. In the case of the IGS network (Figure 1) this process is being used to manage reference frame stability; although the strict application of this methodology is rapidly reducing the number of suitable core stations as tectonics and instrument modifications introduce discontinuities – so much so that operators of core stations are now being requested to delay instrument upgrades until ITRF2008 is released and the full list of core stations is refreshed.

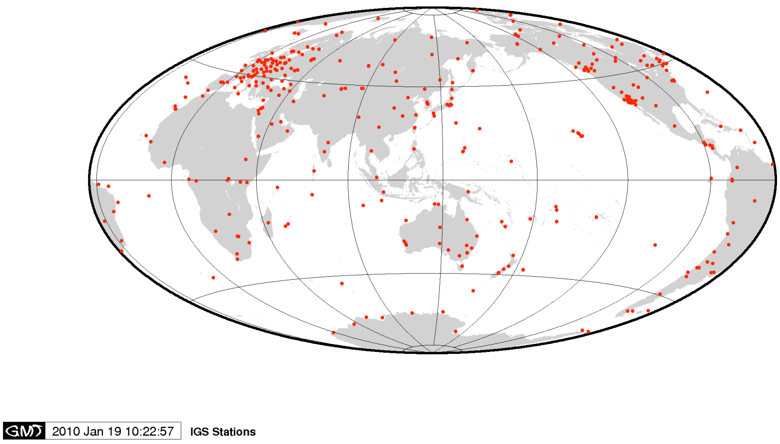

Figure 1. The distribution of stations in the IGS network.

The ILRS analysis centres face exactly the same phenomena, although the total number of stations is far smaller so simply de-constraining these stations quickly results in a very loosely constrained global network, so alternative approaches are taken where discontinuities (step functions, particularly at the core sites) are introduced into the time series. In this case care is taken to distinguish between a coordinate step function which is often caused by instrument changes and which may appear as measurement biases, and a velocity step function which is more likely to be a physical change either due to tectonics or site deformation.

The second dynamic attribute of the ITRF is its ability to evolve and converge in accuracy and precision. Even between formal releases of the ITRF it is being modified and tested by the IAG services. It is also being densified by the IAG Sub-Commission 1.3 for Regional Reference Frames. The working groups under Sub-Commission 1.3 apply the ITRF estimates for a number of stations within their region as constraint for a regional GPS solution. In our region this process is referred to as APREF (Asia Pacific Reference Frame). The result is ITRF coordinates and velocities are produced for significantly more stations than is numerically possible (or at least feasible currently due to matrix size) in the global Least Squares ITRF solution.

As an aside, it is also often underestimated the impact the IAG services (now encapsulated by GGOS) have on domestic geodesy and positioning more broadly. For instance the Earth rotation and orientation parameters produced by VLBI are used extensively in transforming the inertial orbital parameters used in all satellite systems (including GNSS) into the terrestrial Earth fixed system that we are accustomed to using. The geocentre estimates produced from SLR observations are fundamental to reference frame definition. The reference frame scale estimates now jointly produced by VLBI and SLR control the stability of the height estimates in the ITRF as the planet constantly changes shape, and GNSS models the tectonic processes at a greater density than is possible with SLR and VLBI due to cost. It also obviously makes the reference frame accessible to users.

Despite the complications of time series discontinuities the IAG services are continually refining the accuracy of the ITRF and the IAG Commission 1 regional GNSS solutions are significantly densifying the ITRF. Consequently new fields of science and positioning applications are being facilitated. In fact it could be said that facing these challenges opens fields of research in both the instrumental and geophysics disciplines. This continued drive to find solutions to the accuracy limitations, and modelling the dynamics of the planet, focuses the global geodetic community on the issues involved and keeps a healthy research sector engaged on geodetic problems. It feeds the insatiable quest for accuracy that is now prevalent in the general public. It also offers a benchmark against which other global reference frames rely. The World Geodetic Reference System 1984 (WGS84) for instance now relies on ITRF for constraint (Merrigan et al, 2002; NIMA, 2000). As WGS84 is the reference frame intrinsically used for the GPS constellation and the resultant user equipment, the many millions of GPS users globally now use a coordinate system that is closely aligned to ITRF. The Galileo, Compass, QZSS, and Glonass system operators plan to do the same (ICG, 2009).

By acknowledging the dynamic nature of the Earth, and continually refining the coordinate systems we use to represent it, positioning practitioners find that inconsistencies between reality and adopted coordinates systems are minimised. The authors propose to use this methodology when dealing with Australia's National Geospatial Reference System.

5. AUSCOPE

AuScope is a $42.8 million project funded under the National Collaborative Research Infrastructure Strategy (NCRIS) of the Australian Government Department of Innovation, Industry Science and Research. The key driver for AuScope is to understand the structure and evolution of the Australian continent. The Geospatial component of AuScope, with $15.4 million of NCRIS funding and a further $4.5 million from Federal, State and Territory Governments and several universities, is an Australian initiative to mimic the goals of GGOS. It was recognised that to facilitate the continuous drive for greater accuracies, Australia would need to do two things. The first is to contribute to the global observing system so the ongoing refinement of ITRF can continue and the Australian region is better represented in the derivation of ITRF. The second is to facilitate the use of ITRF in Australia, and in fact densify it in our region.

As such the funds are being used to procure or construct:

- 3 new 12m radio telescopes for Very Long Baseline Interferometry (VLBI)
- A VLBI observation correlation facility at Curtin University of Technology
- 4 new Gravity instruments (1 Microg FG5 absolute gravimeter plus 3 gPhone Earth Tide Meters) including funding for an annual observation program around a national network between 2007 and 2011
- A laser power upgrade at the Mt Stromlo Satellite Laser Ranging observatory
- A Mobile Satellite Laser Ranging campaign at Burnie, Tasmania
- Approximately 100 new Continuously Operating Reference Station (CORS) GNSS sites

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Importantly, the project has also accelerated collaboration amongst ICSM members and industry partners to share CORS GNSS data for the purpose of reference frame determination and densification. Figure 2 illustrates the GNSS sites currently under construction and/or contributing data to Geoscience Australia for inclusion in regional ITRF densification solutions. The number of sites in this network is expected to exceed 250 within twelve months and 350 within two years.

Clearly the SLR and VLBI component will contribute data to the IAG services. Mt Stromlo and Yarragadee SLR stations currently provide approximately 25% of the global SLR data volume despite being only two of a global network of 40 stations. VLBI observations have been undertaken at Tidbinbilla and Hobart for several decades. These observations are, however, quite sparse and on large telescopes that have relatively slow slew rates. More recently, Parkes ("The Dish") has also taken geodetic VLBI observations, but again the observation are not very regular and slew rates restrict the number of quasars observed. The three new telescopes that are located at Hobart (Tasmania), Yarragadee (Western Australia) and Katherine (Northern Territory) are 12m Patriot systems, which are designed to have fast slew rates compliant with the VLBI 2020 plan (e.g., Behrend et al, 2007). The fast slew rate means the telescope can move from one quasar to the next quickly so a larger percentage of time is used observing, rather than moving. Auckland University of Technology has also recently followed the AuScope lead and installed a Patriot 12m telescope for inclusion in the Australasian network. The Australasian network will initially operate 180 days a year compared to the current 40 days of observations made at Hobart. The large telescopes at Parkes, Hobart and Ceduna will continue to be used for mapping the celestial reference system, which requires higher instrument sensitivity only available in larger telescopes.

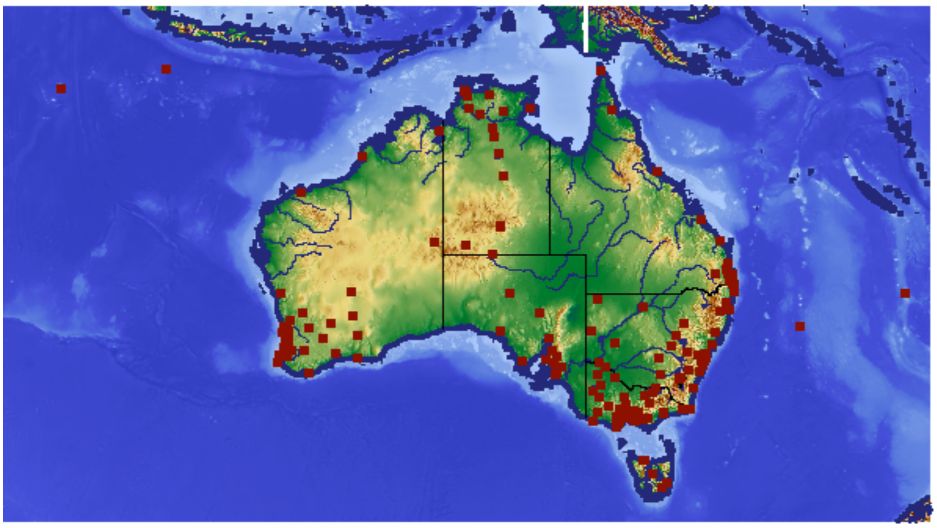

Figure 2. GNSS sites currently under construction and/or contributing data to Geoscience Australia.

The gravity equipment will have two distinct applications. The first, based on FG5 absolute gravity observations, is to provide an independent estimate of station uplift rates produced from the space geodetic techniques that are sensitive to the reference frame geocentre and scale estimates. A change in gravity, if you remove environmental effects, can be inferred as a change in height. The same FG5 data can be used for a series on geophysical research topics, and to quantify the site-specific environmental effects (e.g. a variation in ground water will alter the observed gravity value; therefore gravity observations can infer ground water variations). The second set of instruments, the three gPhone Earth Tide Meters, will be used to measure site-specific gravimetric potential variations caused by earth tide and ocean tide loading. These observations will be used initially to quantify the suitability of various ocean tide models for use in the space geodetic analysis software packages at Australian sites. Ultimately the data will feed into the computation of new models as calibration data.

The GNSS component of AuScope is a significant undertaking for Australian Geodesy. It is the largest collaborative project in Australian Geodesy since the GDA94 derivation in the early 1990's. Approximately 100 GNSS sites built to identical standards (Burns and Sarib, 2010) at a nominal spacing of 200km along key transects distributed across the country. While the establishment of this infrastructure is currently the focus it is the subsequent analysis of the GNSS data that will result in quantum leaps in accuracy of the Australian coordinate systems. The Australian Regional GNSS Network (ARGN) (Tier 1) will be supplemented by the AuScope network (Tier 2), and Tier 3 stations (State and Private Networks) (see Rizos (2008) for an explanation of GNSS network tiers), and collectively they will allow modelling of the intraplate deformation of the Australian plate at a continental scale. It is estimated that coordinate and velocity parameterisation of CORS stations converge vertically after 4.2 years of continuous data and 2.5 years for the horizontal components (Blewitt and Lavallee, 2002). It is a reasonable expectation that within several years of operation of the AuScope GNSS network the reference stations for the Australian NGRS will have an accuracy equivalent to the current ITRF stations (i.e. the Australian Regional GNSS Network (ARGN)), but at a far greater station density.

These reference stations will not only allow the monitoring of crustal deformation, but will increase the access to ITRF quality coordinates, which will then have a flowon effect of enhancing the accuracy of other GNSS data observed episodically. While currently the recognised value standard for GDA94 has an estimated uncertainty of 30mm horizontally and 50mm vertically this network will produce coordinates with uncertainties well under 5mm with respect to ITRF and better than 1mm in terms of precision. They will also be used to generate a velocity field model for continental Australia that will be used to map (or project) the large volume of single epoch GPS points observed since 1995 to a common epoch.

Importantly the AuScope network, and those subsidiary (Tier 3) networks being combined as part of the larger project, are continuous, hence coordinate estimates will not rely on assumptions about linear velocities. In the same way that the IGS estimates weekly coordinates for all stations, researchers in Australia will be able to monitor the coordinates of the AuScope stations within the umbrella of the IGS network. So station motion will no longer be a nuisance to datum management, rather an intricacy that is managed by constant observation. It is also envisaged that CORS operated by industry will eventually be incorporated into this network so as to facilitate homogeneity across all CORS networks at the coordinate level, if not at the organisational level.

6. LOOKING FORWARD TOWARDS GDA2020

There are two components that will drive the need for a new datum in Australia – these are the quest for higher accuracies and the need to account for the absolute difference between GDA94 and ITRF. Both of these factors are complicated by the localised distortions of

GDA94 as a result of intraplate deformation and errors or inaccuracies in the original propagation of GDA94.

The proliferation of GNSS CORS through the AuScope project and National and State initiatives to build denser CORS networks to provide precise real time positioning services will not only provide the means of better refining GDA, it will also highlight the need to improve the positional uncertainty of the coordinates within the datum. Currently a mixture of ground marks and real time positioning services are used to propagate the datum into new projects and applications and this will continue for a time until there is full, redundant and robust national coverage of precise real time positioning infrastructure and services. It is the ability of these precise real time positioning services to deliver accuracies at the centimetre-level over a relatively wide area, and the need for real time positioning service providers to use a homogenous coordinate set within their software that will provide the impetus to develop a new datum.

In addition, offsets between GDA94 and ITRF/WGS84 are now well over the one-metre level and are becoming perceivable even to users of navigation-quality GNSS units. The practice at the moment is to apply transformation parameters to the ITRF/WGS84 coordinates to produce GDA94 equivalent coordinates. As stated previously this can leave residual errors of the order of several decimetres to those GDA94 coordinates produced through the original national adjustment. Philosophically the practice is also flawed in that the most accurate dataset (i.e. the ITRF coordinates) is being transformed backward to a datum with known uncertainties an order of magnitude larger so that they can be integrated with spatial datasets of lower accuracy. This practice stems from an era when GIS platforms were incapable of easily performing transformations. That has now changed and transforming GIS datasets forward is now routine. Considering the technology and mobile computing power we have today it is quite conceivable that deriving and managing dynamic coordinate systems and datasets in the future will be a seamless automated process, and possibly invisible to all but sophisticated users.

The authors propose a National Geospatial Reference System that maintains the highest possible accuracies and homogeneity across Australia. By necessity this will be closely aligned to ITRF, which will have the net effect of making Australia's NGRS compatible at the coordinate level with New Zealand and our other Asia Pacific neighbours who participate in the APREF regional reference frame project. The consequence of this adoption of a dynamic datum is that Australia will benefit from the attributes of a dynamic datum as described above. The coordinates will always be current despite tectonics, surface deformation or instrumentation improvement. The second consequence is that accuracy refinements in the ITRF will continually flow through to the NGRS, thus removing the quantum steps in coordinate accuracy and value that has been experienced previously. The final move to a dynamic datum would be the last datum redefinition required. Any future changes would be automatic and not perceivable.

Applying a reference epoch to the existing geo-referenced information and applying the appropriate transformations to the current epoch if required would achieve integration with spatial data. It should be remembered that the majority of current spatial data have an uncertainty in excess of several metres. For example, features on a 1:250K map are estimated to have an accuracy of 100m, 1:100K mapping - 40m accuracy, 1:25K mapping - 10m. Therefore there would be no immediate need to transform any of these datasets to correct for the 7cm tectonic motion per year. There are however more accurate datasets that need the best quality coordinate control to underpin them. This need can only be served by an ITRF-based coordinate realisation. The use of a coordinate system compatible with WGS84 for instance (which is aligned to ITRF and serves the GPS community) will mean that collection of spatial data via 'crowd sourcing' (e.g. Crooks et al, 2009) from any GNSS positioning device becomes a possibility with no correction required for the reference frame.

There will be some applications that require the maintenance of a static set of coordinates because of practical or legislative requirements. The Cadastre for instance may fall into this category. In this case the survey practice directions could stipulate the transformation technique used to derive coordinates in the legislated datum. This scenario already exists to some extent in Australia where some jurisdictions still rely on the AGD for cadastral purposes.

The complexity of heighting systems will not be explored in this paper beyond the following points. The dynamic datum described above is based purely on Cartesian coordinates that can be represented with ellipsoidal heights by choosing an appropriate ellipsoid. Therefore a new datum for Australia would be truly three-dimensional. The ICSM has, however, resolved to maintain the Australian Height Datum (1971 for mainland Australia, and 1984 for Tasmania) as the adopted working height datum for the foreseeable future. This decision was based on a series of very pragmatic justifications including the wealth of data that is currently held with reference to the AHD and the ongoing suitability of this datum for the majority of users. Therefore an integral component of the NGRS will be a model to transform ellipsoidal heights to AHD71 heights. This model is currently being developed and will be referred to as AusGeoid2009 (Brown, 2010).

Clearly there are some compelling arguments for a more accurate datum. The most pressing is the application of CORS networks. Currently some network operators attempt to define base station coordinates in GDA94 coordinates derived from local control whose coordinates have been propagated through the national adjustment, to make them coincident with the surrounding geodetic control and spatial data. Often the CORS network management software (e.g., Spider, VRS3net) will reject these coordinates because of apparent network inconsistencies. This is a very clear example where application accuracy on a regional scale is exceeding datum accuracies. Geoscience Australia can supply homogeneous GDA94 coordinates produced by analysing the GPS data from the network in an ITRF-based solution, and transforming the resultant ITRF coordinates back to GDA94 using the national 14-parameter transformations. This removes the coordinate inconsistency detected by the CORS software. It does not however resolve the discrepancy with GDA coordinates derived from local survey marks. Additionally, CORS operators should be cautious of using GDA94 coordinates with the IGS precise or broadcast ephemerides which are generated from the ITRF / WGS84 reference frames respectively. The dynamics of the Australian continent are not simply a 7cm North East shift per year. There also exists a continental clockwise rotation that manifests itself into baseline errors when inappropriate mixing of GDA94 coordinates and ITRF-based orbits are used. The adoption of an ITRF-based dynamic datum would eliminate this complexity.

It is acknowledged that much work needs to be done in convincing the spatial industry in Australia that a dynamic datum is the best option for the future. New Zealand has used what they refer to as a semi dynamic datum for the last decade, and it has been broadly accepted as the best option for a country whose dynamics are complex and obvious. The option of Australia implementing a similar system has been discussed over the years. Only now have the accuracy requirements prompted serious discussion on the topic. A solution may be to use preliminary results from the AuScope network, and the other CORS stations discussed previously, to determine a velocity field that can be use to promulgate ITRF coordinates forward to 2020, and create tools and services that can administer a new static datum that at the time of determination is 0.42 metres from reality. By 2020 the continent will have ‘caught up’ with the datum. From that time a dynamic datum would align with reality and move forward seamlessly into the future, thus removing the normal step function when datums change. So in summary it is proposed to adopt a semi-dynamic datum referred to as GDA2020 in the coming years. This datum would transition into a fully dynamic datum in 2020. The impact on users would be minimal. For all intents and purposes the shift to GDA2020 would be the last datum change for Australia that resulted in a step function in coordinates. Redefinitions may be required in the future but the impact on the user community would be minimal.

7. CONCLUSION

The drive for greater accuracy in positioning applications is presenting challenges for the National Geospatial Reference System that need to be met if Australian industry is to remain globally competitive. Clearly some of the long held assumptions about the stability of our continent need to be reassessed as we move into this new paradigm of accurate positioning.

The Global Geodetic Observing System, and more specifically the IAG services, offer the experience gained through developing and maintaining the ITRF as an example of how this quest for accuracy can be achieved. Australia is well placed to follow this example with active investment in the necessary geodetic infrastructure currently taking place. Importantly this investment in infrastructure is also being coupled with policy formulation and the establishment of robust governance structures nationally and regionally. The net result over the coming years will be a rapid development of the capability to transition to this new era of positioning in our region.

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9. BIOGRAPHICAL NOTES

Gary Johnston is the Project Leader of the National Geospatial Reference Systems Project within Geoscience Australia (GA). GA is a key contibutor to Australian Geodesy and leads the AuScope Geospatial Project. Gary chairs the Geodesy Technical Sub-Committee of the Intergovernmental Committee on Surveying and Mapping. He is also a member of the Governing Board of the International GNSS Service (IGS) and a member of the Steering Committee of the International Association of Geodesy's (IAG) Global Geodetic Observing System (GGOS). Gary was also recently elected to chair the Geodetic Infrastructiure of Antarctica (GIANT) working group under the Scienctific Committee on Antarctic Research (SCAR).

Linda Morgan has 31 years experience in the land information environment, with a primary focus on geodetic data analysis, systems management and technology and has managed the Landgate Geodetic Data Section for the past 9 years. She is the WA representative on two national committees - the Intergovernmental Committee on Surveying and Mapping – Geodesy Technical Sub-Committee and the AuScope Global Navigation Satellite System Sub Committee. In the last 3 years Linda has been a key contributor to a successful business case to build a network of Global Navigation Satellite System sites throughout Western Australia as part of a national initiative. Linda recently used this knowledge to provide consultancy to Vietnam on a similar project. She holds a Diploma in Cartography with distinction and was recently certified as a Geographic Information Systems Professional – Asia Pacific.

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