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Using an Avalanche of Measurements to Improve National Datums

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ABSTRACT

Within the next decade, Global Navigation Satellite Systems (GNSS), with corrections from internet or satellite communications, will permit national coverage of positioning services with several centimetre or better accuracy in real-time. Given that location-based data can only be as accurate as the datum to which it is aligned, there is a widespread need for a millimetre-level accurate national datum that disparate, high-accuracy datasets can be aligned to. The new national datum, the Geocentric Datum of Australia 2020 (GDA2020) and national geoid model, AUSGeoid2020, go a long way to meeting the requirements of many users seeking to geo-reference spatial information accurately and precisely. The respective improvements from their predecessors (GDA94 and AUSGeoid09) are in large part due to the increased number of high-quality observations, and software capable of analysing and combining them. The national adjustment to produce GDA2020 was developed using approximately two million measurements to rigorously propagate coordinates and uncertainties to ~250,000 points across Australia. AUSGeoid2020 is a by-product of the national adjustment, developed using ~7,500 collocated GNSS-levelling points, 1.75 million land gravity observations and a global gravity model. This paper describes the new techniques applied to develop GDA2020 and AUSGeoid2020 in a rigorous manner. Furthermore, it explores the future of Australian datums and time dependent reference frames from which to commence discussion about the requirements of future users of positioning, including those from new and emerging industries (e.g. intelligent transport services and precision agriculture) to improve productivity, efficiency and safety, and those from fields of science (e.g. climate change) to improve our understanding of the Earth and to assist with making important decisions. This paper also explores how the ever increasing number of observations from the expanding community of users of spatial data can be best used to feed back into the development of time-dependent reference frames.

KEYWORDS: *National datums, GDA2020, AUSGeoid2020, emerging industries, future requirements of positioning.*

1 INTRODUCTION

The use of positioning data and applications is no longer limited to spatial professionals. By 2023, location based services (e.g. augmented reality and emergency services) and intelligent transport services (road, rail, maritime and aviation) are expected to account for 93.5% of Global Navigation Satellite System (GNSS) chipset sales. In contrast, the traditional GNSS chipset market of precision agriculture, surveying and timing is expected to only account for 6.5% (GSA, 2015).

This growing user base of non-spatial users expects real-time, accurate, high-integrity positioning services and applications. They should be abstracted from the complexities of coordinate transformations, coordinate conversions, datums and geoid models. The challenge for governments and spatial professionals is to develop high-quality, robust infrastructure, tools, services and communication services, which will enable industry, scientists and the public to capitalise on this technology and maximise its benefit.

Evidence of this changing and diverse user base is demonstrated by the projects currently being tested under the National Positioning Infrastructure Capability (NPIC) Satellite-Based Augmentation System (SBAS) trial in Australia and New Zealand. This 2-year trial is testing the advantages of precise positioning from corrections over the internet and space-based communications at the centimetre-level in a range of industries and mass-market applications such as marine, agriculture and smart cities. To enable the best use of this emerging precise positioning technology, Australia requires datums or reference frames which are more accurate than the data, closely aligned to the global coordinate reference frame and, in some cases, time-dependent.

2 DEVELOPING GDA2020 FROM AN AVALANCHE OF OBSERVATIONS

2.1 Drivers for an Update to the National Geometric Datum

The key driver for a new national geometric datum is the expectation that centimetre-level mobile positioning technology will be available within the next decade. The advent of this technological advancement follows many changes within the geospatial industry including the regeneration or launch of satellite navigation constellations such as GLONASS (Russia), Galileo (Europe), QZSS (Japan), BeiDou (China) and IRNSS (India) in addition to GPS (UNOOSA, 2016). Australia is well placed both geographically and strategically to take advantage of these systems including the regional networks from Japan and India. Given that there is a growing number of users and applications reliant on GNSS for positioning, navigation and timing, there is also a clear driver to be more closely aligned to the International Terrestrial Reference System (ITRS), the international standard for positioning in which GNSS and precise positioning services inherently operate.

A further reason to modernise the national geometric datum stems from the fact that we are attempting to measure things more accurately. As a result, we can no longer make the assumption that we live in a static environment. The Earth is stressed and strained by numerous geophysical processes such as plate tectonic motion of ~7 cm/yr (Dawson and Woods, 2010), hydrological cycles (Brown and Tregoning, 2010), earthquakes (Tregoning et al., 2013) and post-glacial rebound (Thomas et al., 2011). As we attempt to measure these geophysical processes with greater precision, we need to continually improve the datum to which our observations are referenced. The previous Australian datum, the Geocentric Datum of Australia 1994 (GDA94), was unable meet this requirement for some current and future users.

GDA94 was based on the International Terrestrial Reference Frame 1992 (ITRF92) and constrained to eight Australian Fiducial Network (AFN) marks. Since then there have been many revisions and improvements to ITRF which better define the shape of the Earth. For example, between ITRF92 (GDA94 was based on the realisation of ITRF92 at epoch 1994.0) and ITRF2014 (GDA2020 was based on the realisation of ITRF2014 at epoch 2020.0) there is ~9 cm change in ellipsoidal heights in Australia (GDA2020 heights are ~9 cm less than GDA94 ellipsoidal heights).

A further issue with GDA94 was the lack of rigour in uncertainty propagation caused by performing a hierarchical adjustment. For example, to compute Australian National Network (ANN) coordinates at 78 sites across Australia, the AFN sites were held fixed (zero positional uncertainty) in the adjustment (Figure 1). The ANN sites were then held fixed in the combined state/territory adjustments and so on. As a result, state and territory survey control marks lower in the hierarchy have an unrealistic uncertainty value (Haasdyk and Watson, 2013).

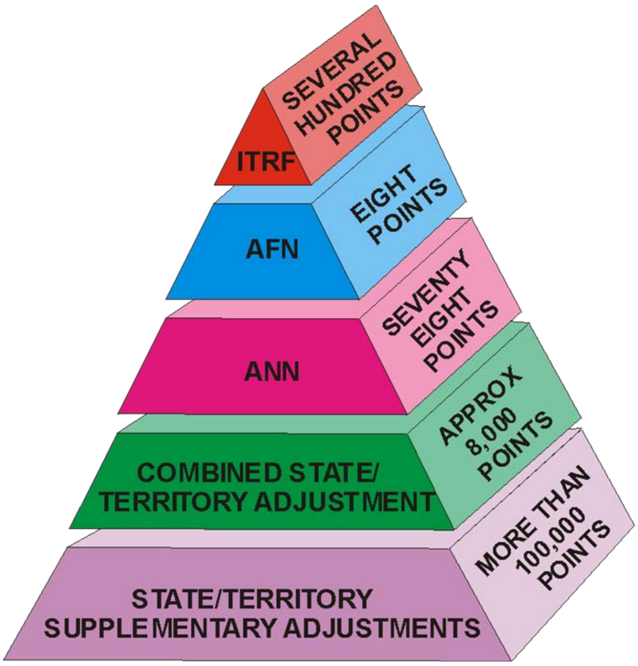

Figure 1: Constraint was not rigorously applied to the least squares adjustment of coordinates for GDA94.

To overcome this issue, the Intergovernmental Committee on Surveying and Mapping's (ICSM's) Permanent Committee on Geodesy (PCG) adopted the use of least squares adjustment software (DynaNet – see Fraser et al., 2017) capable of performing a continental-scale rigorous adjustment of all GNSS and terrestrial data from Commonwealth, state and territory governments (see section 2.2). Since the development of GDA94, there has been significant investment in infrastructure including the construction of the AuScope Continuously Operating Reference Station (CORS) network (GA, 2018b), state and territory government CORS networks, privately operated CORS networks and improvements in GNSS hardware and analysis including absolute antenna modelling (Riddell et al., 2015). These infrastructure and technological developments have led to higher-quality geodetic measurements and improved realisations of the ITRS which cannot be accurately modelled with a transformation from ITRF to GDA94.

2.2 How GDA2020 Was Developed

GDA2020 coordinates were computed using a rigorous, 3D Cartesian network adjustment of all available GNSS and terrestrial data from Commonwealth, state and territory jurisdictional archives. This adjustment enables the determination of GDA2020 coordinates and supports the computation of positional uncertainty and relative uncertainty between any survey control marks in Australia. The national GDA2020 network adjustment was undertaken by Geoscience Australia with input from geodetic specialist representatives from all jurisdictional survey organisations.

The GDA2020 network adjustment involved a rigorous least squares adjustment of all data. In the past, adjustments were undertaken with higher-order data being held fixed in lower-order adjustments. This resulted in distortions in the datum that have become more apparent when compared with high-accuracy GNSS data observed in ITRF2008 or ITRF2014 and transformed back to 1994 using a 7-parameter similarity transformation. By performing a single, national, rigorous adjustment, these distortions have been reduced and relative uncertainty can be computed for any given points on the datum.

The national GDA2020 network adjustment includes all available GNSS and terrestrial data from the jurisdictional archives, constrained using the Asia-Pacific Reference Frame (APREF) time series combination solution. This solution is calculated weekly by Geoscience Australia for approximately 450 APREF stations within Australia's jurisdiction and provides a link between ITRF2014 and GDA2020. The development of GDA2020 has also seen the creation of the National GNSS Campaign Archive (NGCA) stored at Geoscience Australia. This archive contains all GNSS observations provided by state and territory jurisdictions that are greater than 6 hours in duration. The data were processed (and will continue to be processed as new data becomes available) by Geoscience Australia to create a national high-quality GNSS network.

To define GDA2020, International Terrestrial Reference Frame 2014 (ITRF2014) coordinates and velocities of the 109 Australian Fiducial Network (AFN) stations were mapped forward to the epoch of 1 January 2020 using a plate motion model (explained in detail in section 3). The plate motion model can be expressed as a 3-parameter Euler plate model expressed as a 14-parameter transformation with only rates of change for the rotation components (Table 1; ICSM, 2018).

Table 1: Transformation parameters for ITRF2014 to GDA2020 along with their one-sigma uncertainties (1σ). Units are in metres (m) and m/yr for the translation and their rates, respectively, parts-per-million (ppm) and ppm/yr for scale and its rate, respectively, and arcseconds and arcseconds/yr for rotations and their rates, respectively. The reference epoch t_0 is 2020.0.

	$t_x, \dot{t}_x$	$t_y, \dot{t}_y$	$t_z, \dot{t}_z$	$s_c, \dot{s}_c$	$r_x, \dot{r}_x$	$r_y, \dot{r}_y$	$r_z, \dot{r}_z$
	0.00	0.00	0.00	0.00	0.00	0.00	0.00
uncertainty	0.00	0.00	0.00	0.00	0.00	0.00	0.00
rates	0.00	0.00	0.00	0.00	0.00150379	0.00118346	0.00120716
uncertainty	0.00	0.00	0.00	0.00	0.00000417	0.00000401	0.00000370

The production of GDA2020 and its associated products (AUSGeoid2020 and the GDA94-GDA2020 transformation grids) were the result of an iterative process that spanned more than four years. This iterative process was necessitated by the fact that AUSGeoid2020 was developed in parallel with GDA2020, which required the results from one process being input into the other process, and vice versa. It was crucial for the development of the national adjustment as it allowed measurement blunders to be identified and corrected, as well as ensuring every station had a single, unique name.

Each development cycle consisted of several steps: GNSS baseline processing (NGCA), jurisdictional adjustments, a combined national adjustment and product development (AUSGeoid2020 and transformation grids). Following each iteration, quality assurance was carried out by members of the PCG Adjustment Working Group (AWG).

The NGCA contains all the high-quality GNSS observations that are used to densify the APREF network and serve as the backbone of the national geodetic network. Data submitted to this archive are RINEX files between 6-48 hours in duration and sampled at 30-second epochs. The NGCA data from each state or territory are currently processed individually to avoid cross-border issues which are dealt with later in the process. Given the large number of submitted RINEX files, they are arranged into clusters for processing based on the overlap in observation times. Processing of the data is then undertaken using a modified version of the AUSPOS software (GA, 2018a).

The output from the AUSPOS analysis is a SINEX file for each cluster which is then converted to a GNSS baseline cluster. Each GNSS baseline cluster is a set of relative baselines, i.e. the datum constraint on the baselines is removed. Constraint in the national least squares adjustment (performed using DynaNet) is provided by the APREF solution. The output of the combined APREF and NGCA adjustment is supplied to the jurisdictions who add their jurisdictional data archive to ensure their data which has not yet been included in the adjustment (e.g. RINEX files less than 6 hours and terrestrial data) fit the APREF and NGCA data. Once jurisdictions are satisfied, the APREF network, NGCA and jurisdictional adjustments were combined in a national adjustment to compute GDA2020.

2.3 DynaNet: Handling Many Observations

While the task of estimating unknown station coordinates and their uncertainties for relatively small survey control networks can be achieved in a matter of seconds using a modern computer, the computation of extremely large geodetic networks (comprising hundreds of thousands of stations and measurements) is a computationally intensive and time-consuming task. In some cases, the size of national and continental networks presents an impenetrable obstacle to network adjustment, which has often led to non-rigorous approaches to their computation.

For this reason, DynaNet was adopted to compute the GDA2020 national adjustment. DynaNet is a rigorous, high-performance least squares adjustment application designed to handle both small and extremely large geodetic networks – whether on a standard desktop or a supercomputer. The means by which DynaNet is able to efficiently manage large geodetic networks, without compromising on the rigour of the solution, is the technique of phased adjustment. In order to simplify the task of running phased adjustments on a network that is continually evolving (with new stations and measurements appearing almost weekly), DynaNet provides a highly efficient automatic approach to network segmentation – an essential prerequisite task for successful phased adjustment.

On account of the phased adjustment approach used by DynaNet, the maximum network size which can be adjusted is effectively unlimited, other than by the limitations imposed by a computer's processor, physical memory and operating system memory model (Fraser et al., 2017). It follows that by having an automated segmentation procedure which permits the user to quickly and easily segment a geodetic network of almost any size and configuration, DynaNet offers extreme versatility to the ongoing maintenance of the national adjustment. Versatility primarily comes as a result of being able to (a) reproduce the same coordinate estimates and uncertainties despite how the network has been segmented and which stations appear in each block and (b) efficiently re-segment the network at will using different segmentation parameters, or whenever new stations and measurements are introduced to the network.

In addition to these two primary features, DynaNet offers the ability to integrate a diverse range of survey measurement types, manage the rigorous transformation of coordinates and measurements between multiple reference frames, and compute detailed statistical information for all station estimates and adjusted measurements – an essential component for the effective evaluation of the quality of the network and the computed results. The evaluation of uncertainty includes Positional Uncertainty (PU) of all stations across the network, as well as relative uncertainty between two or more stations in the network, as described in the Standards and Practices (SP1) document (ICSM, 2014).

Given the size of the Australian geodetic network (~2 million measurements and ~250,000 stations) it would take days, if not weeks, to perform a single iteration of adjustment on a standard PC. For this reason, the national adjustment was computed on the National Computational Infrastructure (NCI) supercomputer, Raijin. The multi-thread capabilities of DynaNet allowed segments of the national adjustment to be distributed across Raijin and then combined to form a rigorous adjustment. A single iteration of the national adjustment can be performed in less than 2.5 hours, uses eight cores and requires almost 2.8TB of RAM.

3 THE FUTURE OF AUSTRALIA'S GEOMETRIC DATUM

Location-based data can only be as accurate as the datum to which it is aligned. For some applications which require real-time, high-precision positioning aligned to GNSS such as the intelligent transport sector (e.g. autonomous vehicles and mining) and location-based services (e.g. asset management and emergency services), ICSM has endorsed a plan to introduce a time-dependent reference frame in 2020. This time-dependent reference frame will be called the Australian Terrestrial Reference Frame (ATRF). As opposed to GDA2020, which is a static datum (i.e. coordinates are fixed to a given epoch), ATRF coordinates will change with time. This reference frame will be an accurate and densely realised geodetic framework based on continuous observation and analysis of GNSS data and will provide the Australian community with traceable, high-precision coordinates, closely aligned to ITRF and capable of meeting the most demanding positioning requirements.

Time-dependent reference frames are not new – nine International Terrestrial Reference Frame solutions (realisations of the International Terrestrial Reference System, ITRS) have been developed with the first in 1992. The origin of the reference frames are the centre of the mass of the Earth and the X, Y, Z axes co-rotate with the Earth (Petit and Luzum, 2010; Altamimi et al., 2016). As the tectonic plates move on the Earth (e.g. the Australian plate moves ~7 cm/yr to the NNE), the coordinates of points change with time to reflect this motion. With each new ITRF realisation, new and improved models, analysis strategies and geodetic techniques are applied to improve the realisation of the size and orientation of the Earth.

3.1 Difference Between ITRF and ATRF

There will be very close alignment between ATRF and ITRF – in fact the 13 Australian sites that contributed to ITRF2014 will be a subset of the reference sites constrained in ATRF (see section 3.2). The increased number of reference sites will provide a denser and more representative reference frame and velocity field for a more robust positioning capability and improved interoperability of spatial data in Australia. Due to computational limitations, it is not currently possible for countries to submit hundreds of sites to include in analysis and definition of ITRF realisations. Therefore, when countries, continents or regions require denser reference frames, it is necessary to establish regional and national reference frames (e.g. European Terrestrial Reference System 1989, ETRS89).

3.2 Realising ATRF

The National Measurement (Recognized-value Standard of Measurement of Position) Determination 2017 (the Determination) states the coordinates of 109 AFN sites, which are the basis of the Geocentric Datum of Australia 2020 (NMI, 2017). ATRF coordinates are anticipated to be generated in an automated fashion with a new national adjustment being triggered as any new data is detected within Commonwealth, state or territory government databases. The adjustment will run on the National Computational Infrastructure supercomputer using machine-to-machine protocols. Following the operationalisation of the process, it is also expected that spatial professionals will be able to submit data to this national adjustment using a cloud service to have their data used in the definition of the reference frame.

The results of a national adjustment will be new coordinates, coordinate uncertainties, velocities, and velocity uncertainties in GDA2020, which will be projected forward in time using the Australian plate motion model (section 2.2) to be ATRF coordinates at the epoch of the adjustment.

3.3 Legal Traceability of GDA2020 and ATRF

Historically, the recognized-value standard of position of measurement determinations only included coordinates (X, Y, Z), however, the 2017 Determination also includes coordinate uncertainty, coordinate velocity and coordinate velocity uncertainty. Furthermore, it includes equation 1 which enables coordinates of the AFN to be expressed at any epoch t (years) through the application of the following linear model using the coordinates (X, Y, Z) and velocities (V_x, V_y, V_z):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_t = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{2020} + (t - 2020) \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} \quad (1)$$

This model is valid for 15 years either side of 2020: $|t - 2020| \leq 15$.

Internal deformation of the Australian plate is less than 1 mm/yr with the exception of isolated areas of intraplate earthquakes and subsidence (Tregoning et al., 2013). As a result, a rigid plate motion model is appropriate to describe the dynamics experienced by the Australian tectonic plate and is sufficient to maintain compatibility with ITRS realisations in which GNSS operate. The difference between the coordinates computed using velocities described in the Determination and those computed from the Australian plate motion model are within the uncertainty of sites defined in the Determination. The Australian plate motion model can therefore be used to propagate coordinates and maintain traceability to the Determination. The inclusion of the additional parameters in the Determination and equation 1 has established the framework for users to implement the ATRF.

In recognition of the fact that many users do not require a time-dependent reference frame, GDA2020 will continue to be supported for the foreseeable future. As explained above, from a legal traceability perspective, the Determination has been designed to support both GDA2020 and ATRF.

4. THE FUTURE OF AUSTRALIA'S PHYSICAL HEIGHT DATUM

Heights derived from GNSS are precise and efficient. However, they are not always practical. For example, when dealing with water flow for drainage systems or assessing flood risk, it is necessary to use a physical height datum. Geometric height datums, such as the ellipsoid, ignore Earth's gravity field and use straight-line paths (e.g. GNSS). Physical height datums are based on Earth's gravity field and measured along the curved plumbline (e.g. normal-orthometric heights used for AHD), and are often measured relative to mean sea level. As we innovate and improve the geometric reference systems, we need to ensure we also innovate and improve our national height datum and geoid model to enable users to convert ellipsoidal (geometric) heights to physical heights efficiently and accurately.

4.1 AHD and the Geoid

The Australian Height Datum (AHD) is the official national vertical datum for Australia and refers to Australian Height Datum 1971 (AHD71, Australian mainland) and Australian Height Datum (Tasmania) 1983 (AHD-TAS83). Prior to AHD, many local height datums were used in the states and territories. The datum surface passes through mean sea level (MSL) realised between 1966-68 at 30 tide gauges around the Australian mainland and from 1972 at two tide gauges in Tasmania.

AHD heights were derived across Australia via a least squares adjustment of 97,320 km of 'primary' levelling (used in the original adjustment) and 80,000 km of 'supplementary' levelling (applied in a subsequent adjustment) (Roelse et al., 1975). The interconnected network of level sections and junction points was constrained at the tide gauge sites, which were assigned a value of zero AHD. A least squares adjustment was performed to propagate AHD heights across the level network.

A number of known biases and distortions exist within AHD. The primary bias with respect to the geoid is due to the manner in which AHD was realised. In the adjustment of the levelling network data, each of the tide gauge sites was constrained to zero AHD. Due to the effect of the ocean's time-mean dynamic topography, AHD is ~0.5 m above the geoid in north-east Australia and ~0.5 m below the geoid in south-west Australia (e.g. Featherstone, 2004, 2006; Featherstone and Filmer, 2008). Secondary causes of the difference between AHD and the geoid are uncorrected gross, random and systemic levelling errors in the levelling network data (e.g. Roelse et al., 1975; Morgan, 1992; Filmer and Featherstone, 2009).

4.2 AUSGeoid2020

AUSGeoid2020 enables the determination of AHD height estimates H_{AHD} from GNSS ellipsoidal heights h by providing ellipsoid-to-AHD separation values ζ_{AHD} with uncertainty (Figure 2):

$$H_{AHD} = h - \zeta_{AHD} \quad (2)$$

AUSGeoid2020 is a combined gravimetric-geometric model. The gravimetric component is a $1'$ by $1'$ grid of ellipsoid to Australian Gravimetric Quasigeoid 2017 (AGQG2017 – see Featherstone et al., 2018) separation values and the geometric component is a $1'$ by $1'$ grid of AGQG2017 to AHD separation values computed using a dataset of collocated GNSS ellipsoidal height and AHD heights. The geometric component can be viewed as a correction surface which attempts to account for the biases and distortions in the AHD.

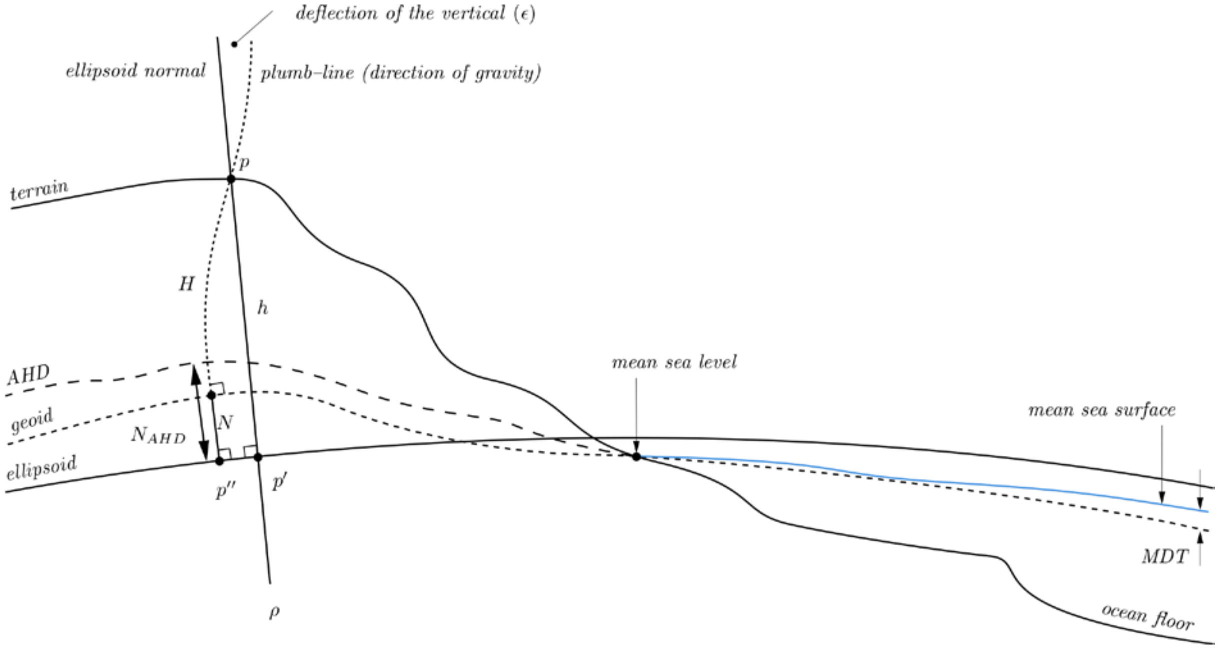

Figure 2: Reference and working surfaces for height in Australia.

4.3 New Australian Vertical Working Surface

A datum needs to meet user requirements for accuracy, integrity and accessibility. Ignoring the primary bias from time-mean dynamic topography, the secondary effects reveal the mean standard error of AHD heights used in the development of AUSGeoid2020 is 0.038 m (Featherstone et al., 2018). For some users, particularly those interested in absolute heighting and scientific and industrial heighting applications on a regional or basin scale, the distortions in the AHD are problematic and make it inadequate for their requirements. One such example of this is converting Light Detection and Ranging (LiDAR) ellipsoidal height data to a physical height datum. The distortions and uncertainty in the AHD make it difficult to determine if LiDAR data misfits are in the data or the datum. As a result, ICSM guidelines recommend using the smoother AGQG to convert ellipsoidal heights to physical heights.

With respect to accessibility, without performing a levelling connection to the reference points used to define AHD, it is difficult to accurately connect to the datum. AUSGeoid2020 assists with this accessibility issue and provides ellipsoid-to-AHD separation values, however, the uncertainty of AUSGeoid2020 is approximately 10 cm (95% CI) in built-up areas and up to 22 cm (95% CI) in more remote regions of Australia (Brown et al., in prep.). In light of the accuracy, integrity and accessibility challenges for some in the user community, Geoscience Australia plans to lead the development of a new vertical working surface. It is important to note that this is not a new national datum to replace AHD, but an alternative vertical working surface.

The vertical working surface (working title) will provide heights above AQGQ2017. Unlike AHD, it will not be constrained to mean sea level, but instead to AQGQ2017 heights at CORS sites. Following each national adjustment, new ellipsoidal heights will be computed at each of the national CORS sites. At these sites, ellipsoid-to-quasigeoid separation values will be interpolated from AGQG2017 and used to compute the vertical working surface height and uncertainty using equations 3 and 4:

$$H_{VWS} = h - \zeta_{AQGQ2017} \tag{3}$$

$$\sigma_{H_{VWS}} = \sqrt{{\sigma_h}^2 + {\sigma_{\zeta_{AGQG2017}}}^2} \tag{4}$$

The vertical working surface height at CORS sites (and associated uncertainty) will be used as the constraint in a national adjustment of the Australian National Levelling Network (ANLN) which was used to produce AHD. It is anticipated that the ANLN will not be used in its entirety. Instead, work will be undertaken in consultation with the state and territory geodetic agencies to identify which portions of the ANLN are best to include and which can be left out. In regions where no levelling data is available, or levelling data has been removed from the process, the vertical working surface will revert back to AGQG2017.

The vertical working surface will be continually refined as new gravity, levelling and GNSS data become available, and as improved analysis techniques are developed. At this point in time, PCG and ICSM do not see a strong push from the user community to update the national vertical datum. However, the work undertaken on the vertical working surface will benefit the user community as it provides a working surface more closely aligned to the geoid with the bias and some of the distortions in the AHD removed.

It is hoped that the vertical working surface will meet the requirements of users not being met by AHD, while alleviating the fear associated with changing the national height datum. Furthermore, it will continue to promote collaboration between academia, government and industry.

5 FUTURE WORK AND CHALLENGES

5.1 Deformation Models

Surface deformation caused by natural events (e.g. earthquakes – Wright et al., 2004) or anthropogenic activities (e.g. groundwater extraction – Featherstone et al., 2012) can be significant over a small area and is often non-linear. This complex deformation cannot be adequately represented by conventional static datums or monitored using the tools traditionally used in the geodetic surveying community. For example, GNSS data has high temporal resolution but low spatial resolution. In an attempt to overcome these problems, Geoscience Australia is planning to include Interferometric Synthetic Aperture Radar (InSAR) data in the development of 4D national scale deformation model to describe motion of the crust over time.

InSAR is a geodetic remote sensing technique that can identify relative movements of the Earth's surface over large areas (100s of km) with millimetre precision and multiple observations per month. Radar images contain information on the Earth's surface in the form of the amplitude and phase components of the returned energy. The amplitude image records information about the terrain slope and surface roughness, while the phase image records information about the distance between the satellite and the Earth's surface. It is the precision of this phase information which the geodetic community can exploit.

The complimentary GNSS, levelling and InSAR observations can be combined in a least squares adjustment to create displacement estimates in a 3D velocity field with high spatial resolution and accuracy (Fuhrmann, 2016). When combined with the plate motion model to describe the secular motion of the continent, the deformation model will enable ITRF2014 coordinates to be converted to ATRF coordinates for high-accuracy positioning applications (Figure 3).

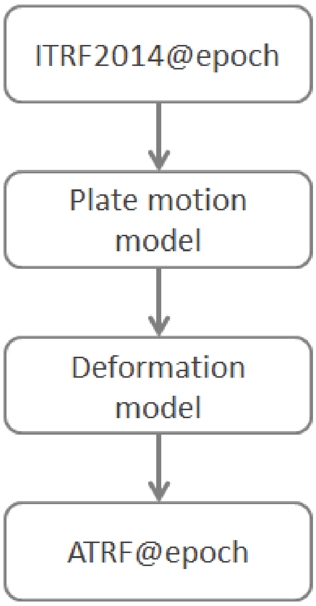

Figure 3: ATRF coordinates computed by applying the secular motion from a plate motion model with the deformation model.

5.2 Standards and Automation

Under this avalanche of observations, there is a growing need for machine-to-machine communication, automated quality checking of data and national adjustments being triggered with the delivery of new data. These processes require significant improvements to the standards and software we use. In an effort to improve our capability for databases to share data and metadata at a machine-to-machine level, the Permanent Committee on Geodesy has been developing the Geodesy Markup Language (GeodesyML) as a standard way of describing (encoding) and sharing geodetic data and metadata. In the same way people from all over the world speak different languages, so do geodesists. For example, some people use the term 'GNSS station' and others use the term 'GNSS site'. GeodesyML is a common language. By mapping your database to GeodesyML, when your data is shared with others, it is easy for the user to discover and combine it with other data.

The geodetic community needs such a standard as it is frequently called upon to provide data, products and services to support a broad spectrum of government, industry, science and societal applications. Coupled with this is the ubiquitous uptake across society of accurate and reliable Positioning, Navigation and Timing (PNT) information. In order to service these user demands in a robust way, geodetic data and the associated metadata need to be standardised, discoverable and interoperable. The continual increase in the volume and complexity of data means that we also need to generate, transfer and use data and metadata via a machine-readable form. In order to achieve these stated goals, it is clear that the time has come to develop a XML-based standard for geodesy. In recognition of these benefits, the IGS Central Bureau, UNAVCO, Geoscience Australia and Australian jurisdictional governments are currently testing machine-to-machine transfer of IGS site logs using GeodesyML.

In years to come, when new data is observed, the objective is to have an end-to-end system developed that will enable new observations from a user to be automatically uploaded, quality-checked and used to trigger the development of a new national adjustment and version of ATRF. This would further trigger the development of new products such as AUSGeoid models, transformation grids and deformation models. Finally, notifications will be sent to subscribers. At that point it becomes a business decision to determine whether the changes are significant to them, whether or not to adopt them, and how to communicate this change with their stakeholders.

6 CONCLUDING REMARKS

Technology, big data, computing power, user requirements and user expectations continue to drive down the uncertainty of positioning data. This in turn highlights the requirement to continually improve the accuracy and integrity of datums and reference frames. This is a new era for the geodetic community – more people than ever are reliant on the work we do, but just as many do not understand it. This is not to say they should understand it – in fact, they should be abstracted from it by spatial professionals. It is our role to improve the technology, understand the user requirements, and meet the user expectations.

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