WHERE IS POSITIONAL UNCERTAINTY?

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ABSTRACT

Satellite positioning technology has improved so much in the last decade that absolute positioning accuracy anywhere on Earth at cm level accuracy is now readily available to users. Government and commercial wide area augmentation systems such as WAAS, OmniSTAR and Starfire promise decimetre accuracy to users in near real-time. Other web-based services such as AUSPOS, the Canadian NRCan service and OPUS provide an absolute coordinate in a few minutes to an accuracy of a few centimetres using the International GNSS Service (IGS) ground station network. Continuously Operating Reference Station (CORS) networks also provide a range of positioning services to users, predominantly in GDA. However the heritage of our national coordinate system, the Australian Geodetic Datum (AGD), was built on older techniques. The incredible precision of new satellite based positioning has revealed many distortions, even in the modern GDA94 datum. So how do we quantify the accuracy of coordinates?

The Intergovernmental Committee on Surveying and Mapping (ICSM) have introduced a new term called Positional Uncertainty (PU) which refers to connection to datum (GDA94). Class will remain as a relevant measure and another new term, Local Uncertainty (LU), will replace Order. According to the ICSM Special Publication for Control Surveys (SP1), this change was to occur in 2005 (ICSM 2007). So how many states have implemented PU to their geodetic networks and made these numbers freely available to users?

This paper will present an overview of PU and call for a national approach to implementing this important piece of meta-data across Australia.

INTRODUCTION

The heritage of the nationwide geodetic network in Australia has evolved from a combination of terrestrial and astronomical observations. These historical observations are still included in geodetic adjustments which produce coordinates used daily by a growing range of professional and non-professional users.

The precursor to our current national datum, the Australian Geodetic Datum (AGD), was first produced in 1966 and was built on high precision triangulation and microwave electronic distance measuring techniques combined with astro-geodetic Laplace stations (Geoscience Australia, 2009). At the time, the precision of these measurements was state of the art, but over a continent the size of Australia many distortions in the measurements were known to exist.

Long line measurements from the Transit Doppler system (the forerunner to GPS), Satellite Laser Ranging (SLR) and Very Long Baseline Interferometry (VLBI) were included in a re-adjustment of AGD in 1982 to produce AGD84 (Ibid, 2009, Morgan et al 1996). The effect of including these new, higher accuracy measurements was to reduce regional and localised distortions in AGD66 brought about by the limited precision of terrestrial techniques. AGD was not a geocentric datum, that is its origin was not based on the Earth's geocentre. Rather, it was one which provided the closest approximation to the geoid over the Australian continent. Only WA, SA and QLD adopted the 1982 readjustment. This was due in part to the fact that significant improvements were not realised nationally, but more so that a new geocentric datum compatible with future satellite positioning techniques was already on the horizon.

In the mid to late 1980s, the Global Positioning System (GPS) (and techniques to process GPS data) moved from being a developmental system to a mature, globally reliable positioning system. Consequently, GPS observation campaigns were conducted in the early 1990s to produce a new geocentric datum for Australia. Geoscience Australia (then called AUSLIG) constructed permanent pillars with continuously operating GPS receivers at selected locations around Australia and this became the Australian Fiducial Network (AFN). These pillars formed the definition of the new Geocentric Datum of Australia (GDA94). Morgan et al, (1996) performed the adjustment to produce coordinates for the AFN and a 500 km network called the Australian National Network (ANN). Morgan et al, (1996) claim the accuracy of AFN coordinates to be around 2 cm at 1σ (~3 cm 95% CI).

GDA94 is based upon the International Terrestrial Reference Frame (ITRF) realisation ITRF92 and is held fixed at epoch Jan 1, 1994.0. Accordingly, GDA coordinate sets are locked in time. Whilst the Australian tectonic plate advances at approximately 7 cm per year in a north easterly direction with the ITRF (and WGS84, the datum for GPS), GDA coordinates remain fixed. In the early 1990s, point positioning accuracy from GPS was at the 100m level, so 7 cm/yr was considered negligible.

Prior to the 1990s, most cadastral and engineering survey work was less concerned with connection to a national datum, rather local connection to surrounding control: "working from the part to the whole". Geographic Information Systems (GIS) were also

in their infancy, however the implementation of the new GDA datum and the improved utility of GPS techniques motivated a move toward "whole to the part" thinking. State governments began improving their geodetic networks through connection to the ANN and requiring surveyors to connect cadastral surveys to local control. Coordinates on boundaries challenged the thinking of the day (Roberts, 2006).

Nowadays satellite positioning technology has improved so much in the last decade that absolute positioning accuracy at centimetre level accuracy is now readily available to users anywhere on Earth. Examples of such services include the US Government Wide Area Augmentation System (WAAS) and the commercial DGPS style services such as OmniSTAR and Starfire where users can achieve decimetre accuracy in near-real time. Other web-based bureau style services such as AUSPOS, the Canadian NRCan service and OPUS (IGS, 2009) request raw RINEX data and antenna information and return an absolute coordinate in a few minutes to an accuracy of a few centimetres using the International GNSS Service (IGS) ground station network.

Continuously Operating Reference Station (CORS) networks are being established to modernise state geodetic networks: GPSNet (Victoria), SydNET/ CORSnet-NSW (NSW), SunPOZ (QLD) and the privately owned GPSnet Perth (WA). These CORS networks provide a densification to the existing national network (AFN & ANN) as well as a range of positioning services in GDA, such as realising three dimensional coordinates in real time.

As a consequence of these improvements, the variety and number of users of positioning services is growing. Initially a major motivation of state governments was to reduce the maintenance costs of survey marks in the ground. However delivering high precision coordinates "over the air" has proved valuable to a number of fields and industries. For instance, real time positioning is being used by precision farmers to increase yields and reduce wastage of fuel and fertilizers. GIS teams within local government routinely use real time positioning for asset management. Mining operations are controlling large machinery with global navigation satellite systems (GNSS) and conducting many of their daily positioning tasks using CORS data. Large civil construction projects rely on CORS positioning services for machine control. Environmental monitoring requires layers of spatially related data to be stored and monitored over time. Emergency managers must have accurate data in real-time to manage disaster relief and fire fighting. In urban environments, new applications in location based services and "info-mobility" will rely on wireless positioning not to mention the improved productivity of existing surveying, mapping and geodetic tasks carried about by state and council land authorities.

Clearly, high accuracy real time positioning has become far more accessible and widely available than previously anticipated. In this light, it is imperative that the quality of positioning information be understood by a wide range of users, not just the geodesist or spatial information professional. This naturally begs the question - how do we quantify the accuracy of coordinates in our network in a consistent and reliable way that is simple to understand? For example, how does a set of AUSPOS-derived coordinates

(computed from a base station up to 1000 kilometres away with a precision of 2 cm) fit with local control?

The Geodesy Technical Sub Committee (GTSC) of the Intergovernmental Committee on Surveying and Mapping (ICSM) has sought to address this issue by introducing a new term called Positional Uncertainty (PU) which refers to connection to the datum: in Australia's case GDA94.

According to the ICSM Special Publication for Control Surveys (SP1), this change of language occurred in 2005 (ICSM, 2007). But how many surveyors and spatial professionals now exclusively use the term local uncertainty? How many states have implemented Positional Uncertainty across their geodetic networks and made this information freely and readily available to the public?

The following paper will revisit the adopted definitions for the terms Class, Order, Positional and Local Uncertainty, and will discuss how they are intended to be used. Issues relating to the implementation of PU will then be presented. An overview of the current status of the various states and territories will then be given with some concluding remarks encouraging the implementation of PU nationwide.

DEFINITIONS

Class and Order are terms familiar to all surveyors and geodesists. These are specialist terms for specialist users. The following definitions are given in the ICSM Special Publication 1, Standards and Practices for Control Surveys (ICSM, 2007).

Class

Class is a function of the planned and achieved precision of a survey network and is dependent upon the following components:

- ➢ *the network design*
- ➢ *the survey practices adopted*
- ➢ *the equipment and instruments used*
- ➢ *the reduction techniques employed*

all of which are usually proven by the results of a successful, minimally constrained least squares network adjustment computed on the ellipsoid associated with the datum on which the observations were acquired.

Order

Order is a function of the Class of a survey, the conformity of the new survey data with an existing network coordinate set and the precision of any transformation process required to convert results from one datum to another. Stations in horizontal control surveys are assigned an Order commensurate with the Class of the survey and the conformity of the survey data with the existing coordinate set.

The Order assigned to the stations in a new survey network following constraint of that network to the existing coordinate set may be:

> ➢ *Not higher than the Order of existing stations constraining that network*
> ➢ *Not higher than the Class assigned to that survey*

The above definitions are rigorous and have served the specialist surveying and geodetic communities well. However with the growing number of non-specialist spatial users attracted to the utility of high precision wireless positioning, a simpler method of quantifying the accuracy of position was required.

The terms Local and Positional Uncertainty have been adopted for use by the ICSM. The term Local Uncertainty will replace Order and Positional Uncertainty is a new term which refers to connection to datum. For Australia this means with respect to the Geocentric Datum of Australia.

PU and LU are compatible with the ISO TC 211 "Geographic Information & Geomatics" quantities "Absolute External Positional Accuracy" & "Relative Positional Accuracy" respectively. SP1 defines these terms as:

Positional Uncertainty

PU is the uncertainty of the coordinates or height of a point, in metres, at the 95% confidence level, with respect to the defined reference frame (ie GDA94).

Local Uncertainty

LU is the average measure, in metres at the 95% confidence level, of the relative uncertainty of the coordinates, or height, of a point(s), with respect to adjacent points in the defined frame (ie similar to Order).

Therefore PU is total uncertainty propagated from the Zero Order network (AFN/ANN) or, in the case of AHD heights, propagated from the AHD benchmarks, at the 95% confidence interval. LU is the average measure of relative uncertainty of coordinates of a point(s) with respect to adjacent points, at the 95% confidence interval.

PU and LU should be sufficiently simple for non-specialist users of satellite positioning devices. A PU value of 50 cm therefore indicates that at a 95% confidence interval, this point is within a 50 cm radius circle of the true GDA datum (defined by the AFN stations which could be over 1000 km away). Usually the average user will not calculate PU. Rather they will use values calculated by land authorities as meta-data to indicate the quality of the marks or methodologies used.

COMPUTING POSITIONAL UNCERTAINTY

Calculating positional and local uncertainty values is more complicated than was first anticipated. Positional Uncertainty can be calculated using the Leenhouts formula and the semi major and semi minor axes of error ellipses which are given as a result of a

least squares adjustment program based on the network input data provided. The error ellipses must be in terms of the national geodetic datum (ICSM, 2007).

The radius of an uncertainty circle with a 95% confidence interval can be calculated using error ellipses with reference to the datum and the following formula (Leenhouts, 1985):

$$C = b/a$$
$$K = q_0 + q_1C + q_2C^2 + q_3C^3$$
$$Radius = aK$$

where:
a = semi-major axis of the standard error ellipse
b = semi-minor axis of the standard error ellipse
q_0 = 1.960790
q_1 = 0.004071
q_2 = 0.114276
q_3 = 0.371625

It is also important to remember that jurisdictions and organisations across Australia have different survey methods and/or business processes for deriving positioning information. For Positional Uncertainty to be implemented across Australia, a simple, yet consistent approach is required – independent of the positioning methodology – to avoid mis-use, ambiguity and potentially, error in the use of the reported values. These characteristics should encourage national adoption.

Positional Uncertainty can be calculated in one of three methods. The following method descriptions are summarised from documentation by AUSLIG (2002) on "The Implementation of Positional Uncertainty".

1) The ideal method would be a single rigorous least squares adjustment involving all observations right back to the national datum. However this would involve implementing new methods of carrying out adjustments, data storage and delivery. A software program that can handle large adjustments without segmentation would need to be created. Currently a program called DynaNet (DNA) is being developed for this purpose.

2) The second method involves constraining the control to the known error ellipses of the geodetic datum calculated from previous methods. When processing an adjustment using this method, the higher level of control is fixed therefore incorrectly stating it as error-free. This method provides reasonable uncertainty values but the aim is to have option 1 implemented in the future.

3) The final option involves making sensible judgement according to statistical data, Class and Order and professional knowledge. Positional Uncertainty would be assigned

based on error ellipses of higher levels of adjustment down to the point in question. This option is only applicable if the positions in question are consistent and the relationship between them is well understood.

Local Uncertainty is calculated with the same Leenhouts method except that the error ellipses are the relation "*between the two points in question, or the average of those from the point in question to adjacent points in the network*" (ICSM, 2007).

The biggest issue with local uncertainty is that it is based on the relationship between any two (or more) marks. If one mark has six connections, does it get one average local uncertainty value or six separate values? Actually this has always been an issue with Order (the term to be replaced by LU). Local Uncertainty depends on how "far" a surveyor might go to define a boundary, and therefore how many points might influence the Order (or LU) of the new points defined in a survey.

NETWORK ADJUSTMENT SOFTWARE

NEWGAN

NEWGAN, a Win32 console application, is a least squares adjustment program that was originally developed from the merger of previous adjustment programs written by J.S Allman (Allman, 1994). Typically, NEWGAN has been used by Australian jurisdictions, except by Western Australia and NSW, to maintain state geodetic networks. However, as geodetic networks have grown in density and size, together with advances in PC technology, some disadvantages of NEWGAN have arisen.

In the first instance, the maximum number of stations that can be handled within a NEWGAN adjustment is 999. Accordingly, manual division (or segmentation) of networks comprised of more than 999 marks must be carried out before data can be imported into NEWGAN. Secondly, NEWGAN requires a large amount of available memory. Thirdly, and perhaps the most widely recognised problem, NEWGAN does not run on versions of Windows later than Windows 2000. Whilst NEWGAN has well served the needs of network adjustment across Australia for more than a decade, it is inevitable that it will be superseded by more modern packages.

GEOLAB

GEOLAB is a Geodetic Laboratory of tools designed to provide solutions to survey adjustment problems. The primary function of GEOLAB is to provide the user with a 3D least squares adjustment of observations, final coordinates and a detailed evaluation of the quality of the measurements. GEOLAB is a modern network adjustment package offering many features and, significantly, can handle a virtually unlimited number of stations or observations to be adjusted in a network (Bitwise Ideas Incorporated, 1998). GEOLAB is used in New South Wales and Western Australia.

DYNANET

DynaNet is a Windows based least squares adjustment program originally developed by Phil Collier and Frank Leahy of the Department of Geomatics, University of Melbourne (Leahy & Collier, 1998). The motivation for producing this software was primarily the recognition of the increasing size of geodetic data sets. It was also designed to manage a dynamic, continually updating network, and to cater for non-static point coordinates

caused by tectonic or ground movement or even natural disasters such as landslides or earthquakes (Ibid, 1998).

Whilst DynaNet performs least squares adjustment in a fashion similar to most traditional network adjustment programs, DynaNet is unique in that it uses a technique known as phased adjustment. Phased adjustment incorporates an automatic segmentation algorithm for breaking a network into a series of blocks of a manageable size. The need for an automated approach is important because manual segmentation is often a time consuming and complex task, and more importantly, one which leads to a degradation in the final variance matrix of the computed coordinates. This method has been shown to improve the calculation speed drastically due to the fact that the time taken to adjust a number of small blocks is more efficient than adjusting the aggregate as a whole (Fraser, R. 2009 personal communication). One of the intentions behind the development of DynaNet was to provide an adjustment capability that placed no limits on the quantity of data input. In theory, the program can handle an unlimited amount of data, however recent tests indicate that the phased adjustment component of DynaNet is experiencing difficulties when networks of more than 13,500 stations and 55,000 measurements are adjusted (Ibid, 2009). (Traditional, simultaneous adjustments do not experience this difficulty.)

Originally known as DNA, DynaNet was first developed using FORTRAN. Under the auspices of an Australian Research Council (ARC) funded project, DynaNet was re-developed using Visual Basic 6 (VB6), the major outcomes of which were a Microsoft Windows user interface and the capability to take in a much wider range of measurement types. However, some problems have arisen as a result of using VB6 as the development platform. For instance, large data sets are known to reduce the speed of network adjustments due to VB6 run-time capability and graphics management. Limited computer RAM is also a contributor to run-time speed (Phil Collier, 2007 personal communication). In an effort to overcome these limitations, DynaNet is currently being rewritten in C++ but this process is not complete.

DynaNet will read and write files in Extensible Markup Language (XML), Comma Separated Files (CSV) and traditional DNA formats. Neither NEWGAN or GEOLAB can handle the input or output of XML. To assist existing NEWGAN users in the transition to DynaNet, a Translator has been developed by GTSC (ICSM 2008).

SNAP

The Survey Network Adjustment Package (SNAP) is a suite of programs for adjusting station coordinates in a survey network to best fit the observed data created and used in New Zealand. Geoscience Australia also uses the program for calculating vertical Positional Uncertainty. SNAP is a similar program to DNA and runs on most recent versions of Microsoft Windows. The program was updated in March 2004 to "correctly test horizontal accuracies against specifications" by converting error ellipses to 95% confidence limits (LINZ, 2009a).

Some Discussion of Network Adjustment Software

All of these network adjustment softwares rigorously compute error ellipses describing the quality of points within a network adjustment. Positional Uncertainty can be computed using Leenhouts formula from the semi-major and semi-minor axes resulting from these network adjustments. PU describes connection to datum so all adjustments must relate back to the AFN network. The best possible PU value in Australia can therefore be no better than 20mm at the one sigma level.

When computing PU, the network adjustments from which the semi-major and semi-minor axes derive must also propagate this uncertainty in the AFN coordinates to truly reflect the connectedness of a point to the GDA datum.

## POSITIONAL UNCERTAINTY IN THE STATES AND TERRITORIES

Survey methods and calculations will vary between states and territories which may impact PU for data that stretches across borders. If PU is to be implemented nationwide, then a standard means of computing and presenting these accuracy measures needs to be adopted to ensure all users have confidence in their positioning.

Research showed that of the six states and two territories in Australia only NSW, Western Australia and Tasmania have taken a step towards implementing Positional Uncertainty (Ozdemir, 2008). All three of these states have taken their own methods and approaches towards implementing PU which are detailed below. The remaining states and territories have made limited progress towards applying Positional Uncertainty.

New South Wales

Each state or geodetic organisation has their own database for the storage and maintenance of all their survey control marks. The Survey Control Information Management System (SCIMS) database is an oracle database used in NSW which can be accessed online for all relevant information, locality and accuracy data regarding each survey mark. Currently marks are assigned with a Class and Order according to monumentation type and stability, measurement techniques used, calculation process and method and other similar factors.

While awaiting the completion of DynaNet, NSW has updated the SCIMS database internally to show horizontal and vertical, positional and local uncertainty values in readiness for when the values become available. Modifications need to be made to accommodate ellipsoidal height as the database currently only holds AHD vertical uncertainties. NSW has determined horizontal and vertical Positional Uncertainty values that have been entered into the SCIMS database for OmniSTAR GPS positioning only. These values were determined based on extensive field testing against SCIMS values throughout the state. The values are 0.7m for horizontal Positional Uncertainty and 2m for vertical Positional Uncertainty (Fig. 1).
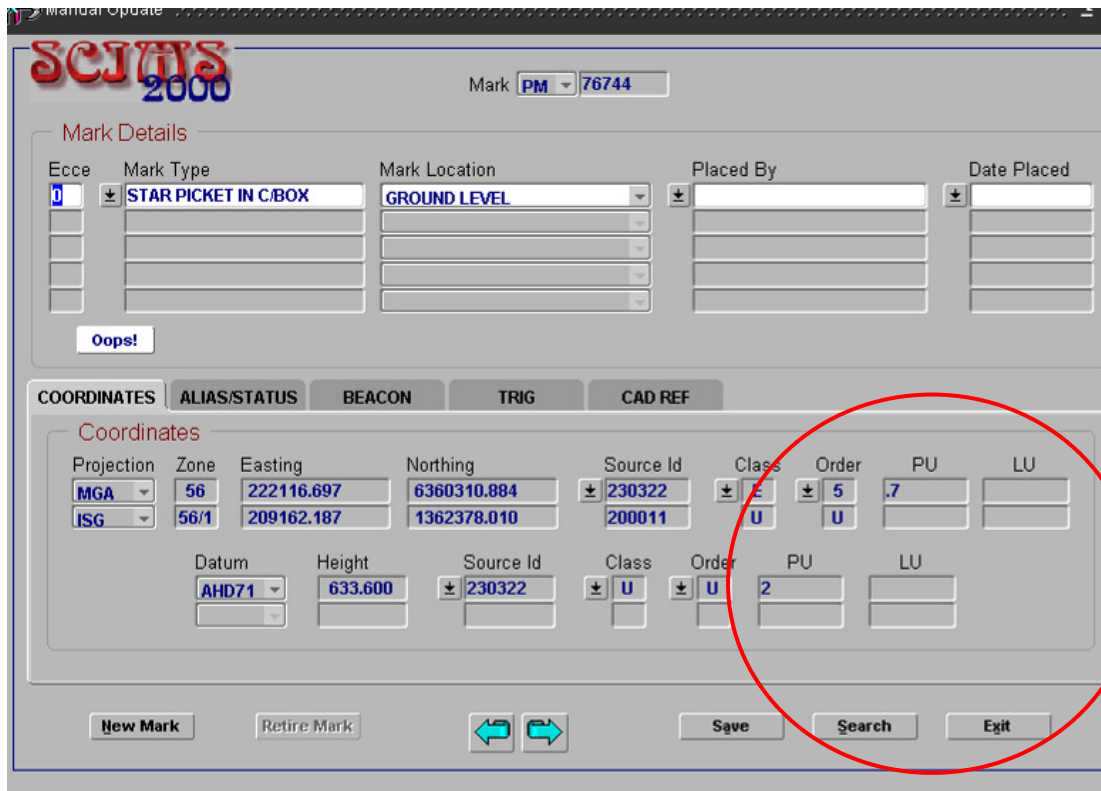
Fig. 1: SCIMS Oracle (DoL NSW, 2007)

Recalculation of the Spine network is currently in process using software adjustment programs Trimble Geomatic Office (TGO) and GEOLAB. NSW has also developed and is testing an in-house method to calculate both positional and local uncertainty. The calculation process is based upon simulation techniques to simplify practical implementation by representing variance co-variance (VCV) information.

As is evident in Figure 1, there is currently only one local uncertainty value that can be placed against a survey mark in NSW. Local uncertainty is determined by the connections to local marks. NSW is looking into a clarified and refined definition of local uncertainty but is focusing on making progress towards the practical implementation of Positional Uncertainty.

Tasmania

Tasmania has adopted a simple concept in keeping with the original intention of a straightforward accuracy measure (Option 3 from section "Computing Positional Uncertainty" above). They have completed a generalised approach towards implementing Positional Uncertainty into their database known as the Survey Control Marks Database (SurCoM) while awaiting the completion of DynaNet (Bowden, 2007). Now that DynaNet has been completed, this approach may be re-visited.

Rather than appointing an individual and rigorously calculated Positional Uncertainty value to each survey mark, Tasmania has categorised marks into set groups according to their Class and Order. Marks are assigned a Class of A, B or C and an Order of 1st, 2nd, 3rd or 4th.

Tab. 1: Tasmania's PU values corresponding to Order (Bowden, 2007)

Order	Positional Uncertainty (m)
1st	0.03
2nd	0.04
3rd	0.15
4th	0.15

The above Positional Uncertainty values were determined based on prior NEWGAN calculations of Tasmania's GDA network. First Order (using GPS) results were good to 0.025m which was rounded to 0.03m. Second Order was estimated, based on constraining First Order stations, to have a higher Positional Uncertainty than First Order by approximately 0.01m. Hence, 0.035m is rounded to 0.04m.

The Primary GDA network adjustment contained both GDA and AGD coordinates. Many of these adopted AGD coordinates were of 3rd and 4th Order. Precise transformation parameters were determined and in turn all AGD control marks were transformed to GDA. It was estimated that these 3rd and 4th Order coordinates had positional uncertainties of 0.15m at a 95% confidence interval. The difference between 3rd and 4th Order uncertainty was not an appreciable difference hence the values are the same.

Class and Order are assigned according to the judgment of cadastral surveyors. All cadastral boundary surveys conducted by both government and private surveyors must have at least two corners coordinated on the MGA. Surveyors are required to use the knowledge of Local Uncertainty (Order) in the locality and their professional judgment to give marks down to street corner level an appropriate Positional Uncertainty value from the above values.

Tasmania also has a maintenance program which states that approximately 3000 marks with Positional Uncertainty of 0.04m and better be visited every 5 years. These Positional Uncertainty values have been stored and internal databases updated accordingly for their own use. It is not being released as public accessible data at this stage.

Their work is restricted to horizontal Positional Uncertainty only. Vertical Positional Uncertainty and local uncertainty have not been investigated thus far. For vertical Positional Uncertainty, Tasmania and all states are awaiting the completion of the Height Modernisation Project by Geoscience Australia and Curtin University (Ibid, 2007).

Western Australia

Western Australia has established a rigorous calculation of horizontal Positional Uncertainty which has become a routine task with every adjustment performed. Western Australia has taken a method of implementation which is sufficient for their needs. Unlike the other states and territories, they have not awaited the completion of DynaNet.

With the development of in-house software and the 3D adjustment program GEOLAB, adjustments have all been segmented and reprocessed. Approximately 900 adjustments were recomputed when Western Australia began implementing horizontal Positional Uncertainty to a geodetic network level of 2-5 km separation. Vertical uncertainty is yet to be established and currently horizontal local uncertainty is only provided as accuracy statements (Morgan, 2007).

Databases have been modified accordingly to incorporate Positional Uncertainty values for each survey mark according to the ICSM regulations. All input and output data involved in the process including observations and error ellipses are also being stored based on hierarchy.

Figure 2 shows a section of a report from Western Australia's public "MyLandgate" database showing users a survey mark's details. Horizontal accuracy is essentially a best estimate of the relative accuracy. Also shown is the Horizontal method, Horizontal order and Positional Uncertainty. Note that the PU value of 0.011m is more accurate than that of the AFN. PU given in WA does not propagate the 20mm uncertainty of the AFN into its state geodetic network (Morgan, L. 2009 personal communication), so is incompatible with the approaches used in NSW and Tasmania.

LU has also not been implemented as WA is awaiting policy direction from the ICSM GTSC – ie do they compute an average of all measured lines or all points within x km? Similarly, vertical uncertainty is still described in terms of Order.

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SSM    APPLECROSS 1
Alternate names :                        Map ref.: APPLECROSS BG34 3.4
Stamp name:   APP 1                      Physical Status : destroyed (Landgate)
                                         Phys. Status Date : 22/10/2007

Geographical Coordinates                 MGA Coordinates
Horizontal datum :  GDA94                Zone :     50
Latitude :   S 31 59 26.97818            Easting (m):   395873.024
Longitude : E 115 53 51.88593            Northing (m): 6460050.365
                                         Convergence :     -0 35 2.43
                                         Point scale factor : 0.999733710

Horizontal accuracy : 3 ppm
Horizontal method :  Global Position System
Horizontal order :    0 SP1 horizontal   Cadastral connection : Exists
Positional Uncertainty (m):    0.011 (95% Confidence
Level)
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Fig. 2: WA Survey mark report (Morgan, 2007)

South Australia

Currently in South Australia, the existing public database of survey marks is being modernised. It is intended that this new database will accommodate PU values, however at this stage there is no indication as to how those values will be derived.

Australian Capital Territory

At present the ACT still uses Class and Order and will do so into the foreseeable future. Indeed the ACT does not use MGA coordinates rather they use the old AGD66 with a transverse mercator projection, nominally with a 6 degree zone width, to produce the

ACT Standard Grid coordinates. The central meridian (CM) passes through Mt. Stromlo and because the ACT is quite small, users never depart more than 50 km (0.5°) away from the CM. ACT grid coordinates are therefore considered to be "on the plane" and surveyors do not apply scale factor changes (similar to the old ISG in NSW). With the growing CORS infrastructure beginning to surround the ACT, perhaps surveyors will be required to change to MGA and the ACT Land Information will need to consider PU.

Northern Territory

The Northern Territory has not progressed PU implementation mainly due to a lack of software or a utility that would allow propagation of PU through the state, regional, town or suburb and cadastral network control marks. Existing survey control networks still rely on NEWGAN as the primary adjustment tool, which does not accommodate PU/ LU computation. NT authorities have been examining DynaNet through the ICSM GTSC, and believe this program will be able to manage PU and LU. Some testing of DynaNet by GTSC state/territory members has occurred, and the process of converting existing NEWGAN datasets via a translator has begun. This will enable migration of the majority of the NEWGAN derived survey control datasets into DynaNet. The Northern Territory land authorities believe most people who use and understand 'position' will use PU and LU. It is hoped that they will find these terms much easier to understand instead of the term 'Order'.

Queensland

Natural Resources and Water (NRW) is in the process of implementing PU. PU is not readily available to the public for a couple of reasons. Historically, the majority of the network adjustments carried out by NRW have been performed using NEWGAN, which does not support PU. NRW is in the process of migrating all its existing NEWGAN datasets to DynaNet and carrying out tests to validate the conversion and process. Whilst extensive testing has been done with the primary network data sets, the land authorities are not yet in a position to adopt it for all adjustments. The second issue is that the current geodetic database, the Survey Control Data Base (SCDB), does not support PU. Since the preferred option is implementation of eGeodesy rather than adding additional fields to an already aging database, SCDB will not be modified to support PU. eGeodesy is a very innovative step whereby the management of observations and adjustments rather than solutions would be accessible to data managers. This would facilitate much simpler access to old and new observations to allow targeted readjustments using all data in a region. PU would naturally be another output from such a readjustment and DynaNet is the preferred option. At this stage PU is limited to "The Geodetic Unit of the Dept of Natural Resources & Water" and is restricted for testing of DynaNet rather than production datasets or products for public use (Cislowski, G. 2009 personal communication).

Victoria

The Office of Surveyor General (OSG) of the Department of Sustainability and Environment (DSE) is in the process of converting all existing NEWGAN data sets (sub-networks) to DynaNet, with the intention being to produce a single, homogeneous dataset for the entire network. (Like most other jurisdictions, the majority of the network adjustments carried out by OSG have been performed using NEWGAN.) At

this stage, preliminary values have been computed for a number of stations across Victoria, however they will not be made public until the entire conversion and readjustment process is complete. The Survey Marks Enquiry System (SMES) currently manages Class and Order. Minor modifications are required to incorporate PU within the SMES database. It is anticipated that these modifications, together with populating the respective fields with data, will be undertaken when the readjustment process is complete. Additional modifications to store the State's geodetic measurements, including automated procedures for monitoring the network are currently being investigated.

DISCUSSION

Despite DynaNet already being capable of computing PU for many years, it is clear from the above section that all states and territories have been either waiting for the completion of DynaNet and its translators to compute PU or have gone ahead and computed PU by other means. Curiously, Victoria *has* computed PU *using* DynaNet. At a recent ICSM GTSC meeting (ICSM 2008), it was made clear that all previous problems restricting the use of DynaNet to compute PU had been resolved (NEWGAN $\rightarrow$ XML translators fixed, GEOLAB $\rightarrow$ XML translators fixed, ability to compute PU implemented) (Fraser, R. 2009 personal communication).

However, in the absence of DynaNet, both New South Wales and Western Australia had developed their own add-on software to propagate PU values using their existing network adjustment results. These softwares take the semi-major and semi-minor axes from previously adjusted regions and propagate Positional Uncertainty using Leenhouts formula. However, it is not clear if (or how) PU is propagated from the AFN and if the 20mm of uncertainty in the solution of the AFN coordinates is included in the final computation. Also, WA does not include cross-correlations in their solutions (Morgan, L. 2009 personal communication) whereas NSW will attempt to do this.

It is important that if PU is to be propagated nationwide, that the method used by all states and territories is consistent and well understood.

Additionally, ANZLIC's MetaData Working Group has these items under consideration for inclusion in their updated MetaData Guidelines (Weaver, J. 2009 personal communication).

The proposal is compatible with the draft ISO 19115 (MetaData) that provides for 'absolute external accuracy' & 'relative internal accuracy' for positions (ANZLIC, 2009).

ANZLIC will include Positional Uncertainty as a part of their MetaData guidelines to be used across all sectors dealing with spatial data.

Given that jurisdictions now have a capability to compute Positional Uncertainty, whether through DynaNet, custom software or other manual means, it is clear that the remaining factors inhibiting the implementation in the states and territories are the upgrade of existing public databases to include PU, lack of clarity as to who will benefit

from this extra information (as this informs those who supply funding for such new implementations) and the promise of ePlan/ eGeodesy in the near future.

Land Information New Zealand (LINZ) have implemented eGeodesy across the entire country with their innovative LandOnline website (LINZ, 2009b). Surveyors submit observations rather than solutions giving data managers the ability to readjust targeted regions at any time. This is particularly important given the high geodynamic activity experienced in NZ (Stanaway, R. 2009), however this infrastructure offers great advantages to spatial data managers in Australia as well such as targeted readjustments in problem regions could be easily implemented by land authorities using up-to-date observations.

CONCLUSIONS

The motivation for implementing Positional Uncertainty is to provide a simple accuracy measure for a growing variety of users and applications predominantly using satellite based positioning.

Previously the implementation of PU across the states and territories has been hindered by problems with DynaNet, the best placed software to handle large datasets and propagate PU through geodetic networks. However these issues have now been solved and the major inhibiting factors are the ability of land authorities to either accommodate PU measures in existing public databases or move to an ePlan/ eGeodesy style architecture which also includes PU values. It is crucial that PU propagated nationwide by all land authorities is consistent and well understood. DynaNet is clearly the best software to achieve this aim.

ANZLIC's meta-data standards, when completed, will also create an impetus for a much wider range of spatial users to assess the quality of their positioning. Specialist high-precision users such as Surveyors will continue to use Class and Order for a while yet and recognise the importance of error ellipses for network adjustment tasks.

As evermore applications reference their data spatially with respect to the GDA datum, PU will become the "currency of positioning" to inform users of their positioning accuracy. Indeed with the rapid advances in GNSS technology (GPS modernization, GLONASS rejuvenation, the promise of the European Galileo and the Chinese Compass systems) and the new signals, improved accuracy, lower multipath and increased power that they will provide, positioning accuracy in real-time will improve to decimetre level in the coming decade. These advances coupled with the ever growing CORS networks (supported by state/ territory land authorities and the national AuScope project) will see wireless positioning become another infrastructure that users will expect to work and will want to know the quality.

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