CORSnet-NSW: Towards State-wide CORS Infrastructure for New South Wales, Australia

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Key words: CORSnet-NSW, infrastructure, Network RTK, datum, legal traceability, APCV

SUMMARY

CORSnet-NSW is a network of Global Navigation Satellite System (GNSS) continuously operating reference stations (CORS) that will cover New South Wales and is an expansion of SydNET, which has been successfully operating in the Sydney metropolitan region since 2004. CORSnet-NSW is fully funded and managed by Land and Property Information (LPI), a division of the NSW Land and Property Management Authority (LPMA). In excess of seven million Australian dollars have been committed for capital investment in the Survey Infrastructure Improvement Project – the majority of which will be invested in the CORS network – plus additional recurrent funds to operate the network. CORSnet-NSW currently (January 2010) consists of 29 CORS and is being expanded to include 70 stations by 2013 in order to provide state-wide coverage.

As part of this expansion, LPI has purchased Trimble Navigation's VRS^{3}Net CORS network management software which will significantly enhance the range and quality of services that LPI can provide to its customers. Work is being undertaken to integrate VRS^{3}Net with LPI's existing accounting and delivery systems, which is a first for this system. Currently, dual network control centres are being built at LPI's data centres in Sydney and Bathurst. Once completed, these control centres will provide a fully redundant network with ample capabilities for many years to come. This new infrastructure will also facilitate a wide range of research projects in the areas of geodesy, surveying, positioning, navigation and telecommunications.

CORSnet-NSW will provide users with network real time kinematic (NRTK) services in the extended Sydney metropolitan area as well as other populated regions of the state and single-base RTK elsewhere, as well as supplying GNSS data for post-processing. RTK and NTRK correction data are available in RTCM 3.1 format via the internet using NTRIP (Networked Transport of RTCM via Internet Protocol), providing centimetre-level horizontal positioning in real time. This paper introduces CORSnet-NSW and discusses several issues that need to be addressed in order to provide a reliable GNSS positioning service of homogeneous and high accuracy across the state. These issues include the direct connection to the national datum, legal traceability of CORS coordinates, compatibility with online GNSS processing services and CORS networks in neighbouring states, and the correct use of Antenna Phase Centre Variation (APCV) models.

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1. INTRODUCTION

Land and Property Information (LPI), a division of the NSW Land and Property Management Authority (LPMA), is investing in positioning infrastructure for NSW to support the spatial community and provide stimulus for innovative spatial applications and research using satellite positioning technology. Our vision is for a self-sustaining Continuously Operating Reference Station (CORS) network which undergoes a continuous program of renewal to ensure the best possible positioning infrastructure is available to NSW, while maintaining national and international standards and best practice (e.g. ICSM, 2002; 2007; Lands, 2006) to accommodate established and developing positioning and navigation applications. With Global Navigation Satellite System (GNSS) technology being intrinsically linked to surveying and geodesy, it is appropriate for LPI to take a leading role and provide guidance for applications of CORS in NSW.

LPI's first CORS was installed in 1992 in Bathurst to support internal survey and aerial photography operations (Kinlyside and Yan, 2005). In 2004 a network of seven CORS was installed in the Sydney metropolitan area, and in 2005 this was made available to the public under the name SydNET (Roberts et al., 2007). A renewed effort of expansion to extend the coverage of CORS throughout NSW commenced in 2009 and corresponded with the rebranding of the network as CORSnet-NSW (LPMA, 2009a; White et al., 2009). This renewed effort will expand the network from currently 29 CORS to 70 by no later than 2013, extend the range of services available and upgrade the service quality in order to provide state-of-the-art, state-wide positioning infrastructure to NSW.

This paper introduces CORSnet-NSW and presents the elements necessary to best deliver CORS to NSW, including a sustainable positioning infrastructure, seamless positioning across NSW and system integration. Several issues that need to be addressed in order to provide a reliable GNSS positioning service of homogeneous and high accuracy across the state are discussed. These issues include the direct connection to the national datum, legal traceability of CORS coordinates, compatibility with online GNSS processing services and CORS networks in neighbouring states, and the correct use of Antenna Phase Centre Variation (APCV) models.

2. BUILDING STATE-WIDE CORS INFRASTRUCTURE FOR NSW

2.1 Status and Rollout of CORSnet-NSW

LPI has committed $7.25 million Australian dollars in capital investment for the Survey Infrastructure Improvement Program. The majority of this investment will go directly towards

the CORS network, while other equipment will also be upgraded to support survey functions including CORS. This investment is deemed necessary to avoid future duplication of GNSS reference station equipment and encourage uptake of GNSS positioning for a wide range of applications. Other benefits of state-wide CORS coverage include standardised levels of service, homogeneous connectivity to the datum and the ability to provide a degree of legal traceability for GNSS positioning. The operating costs for the CORS network are substantial, and in order to ensure a sustainable and permanent CORS network for NSW, fees for user access were introduced on 1 July 2009. These fees aim to cover the operational costs of the network.

The network currently (January 2010) consists of 29 CORS, mainly located in the highly populated coastal region of the state. Figure 1 illustrates the coverage of CORSnet-NSW, showing stations that are operational (indicated by triangles) as well as planned stations (indicated by circles). A 50 km radius around active stations is shown in order to indicate the coverage area for Real Time Kinematic (RTK) operation. CORSnet-NSW will integrate ten AuScope CORS sites that are being built in collaboration with Geoscience Australia as part of the federal government's National Collaborative Research Infrastructure Strategy (AuScope, 2009; Janssen, 2009b). In addition to working together with local councils hosting CORSnet-NSW stations, LPI collaborates with the ACT Planning and Land Authority to provide CORS services across the Australian Capital Territory.

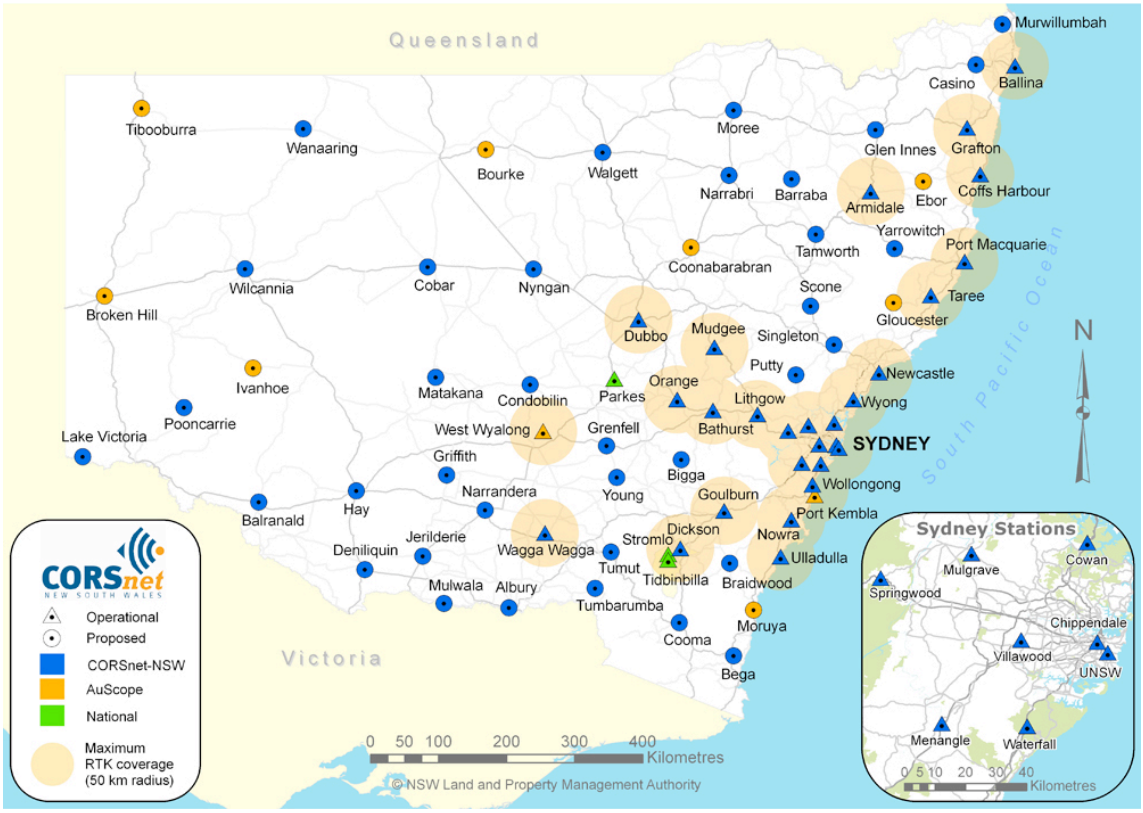

Figure 1: Current coverage of CORSnet-NSW (January 2010).

It is planned to expand the coverage to 40 CORS by mid 2010 and to achieve a state-wide network of 70 CORS by no later than 2013. Station density will be much greater in the east of the state than the west due to application requirements and potential user benefits. As LPI progresses with the rollout of CORS, more users will have services available to them and the level of service may also improve from its current levels. It is for this reason that LPI has offered new users a free three-month trial in order for them to evaluate whether the CORSnet-NSW service is suitable to their needs. All CORSnet-NSW reference stations bar one currently in operation are equipped with the most recent dual or triple constellation GNSS hardware. In addition to the currently received GPS and GLONASS signals, this potentially allows triple frequency observations and signals from future GNSS such as the European Union's Galileo and China's Compass to be utilised.

2.2 Seamless Positioning across NSW

While users of CORS in NSW have benefited from high accuracy, real time GNSS positioning for some time, it has been limited to single reference station solutions. These single-base RTK solutions degrade the further away a user is from the base station and high accuracy solutions are generally limited to a distance of 20 km (Zhang et al., 2006), although tests conducted by LPI have shown that acceptable results can be achieved over up to 50 km. The only area where the current inter-station spacing provides complete coverage, considering this distance restriction, is in Sydney.

Providing high accuracy GNSS solutions state-wide using single-base RTK would require many hundreds of CORS and is not feasible due to the extreme cost involved. As part of LPI's investment, Trimble Navigation's VRS^{3}Net CORS management software has been purchased to, among other benefits, provide network RTK (NRTK) solutions. These NRTK solutions enable reliable modelling of the distance dependent errors (i.e. the ionospheric and tropospheric delays and orbit errors) across the network and allow the correction data provided to a user to be optimised based on their location within the network. The NRTK solution is generally based on between three and five of the closest CORS with respect to the user and allows much greater inter-station distances between the reference stations (up to 70-100 km) while maintaining the same level of accuracy (Figure 2). In addition to single-base RTK, CORSnet-NSW will provide users with NRTK correction data according to both the Virtual Reference Station (VRS) approach and the Master-Auxiliary Concept (MAC). For a comparison of these two techniques the reader is referred to Janssen (2009a). The correction data are transmitted in RTCM 3.1 format via the internet which can be accessed by users in the field via wireless networks such as Telstra's NextG cellular network (Yan et al., 2009). CORSnet-NSW will also provide GNSS data for post-processing (single-base and virtual reference station).

Initial tests carried out by LPI show that horizontal accuracies achieved using NRTK solutions are as good as or better than those achieved from single-base RTK solutions. Initialisation times were reduced by as much as 50% and, although the sample size is not yet large enough to draw any conclusive results, vertical accuracies appear to improve as well. Due to the lower density of CORSnet-NSW stations in the west of the state, NRTK services

will initially not be available state-wide. However, the ongoing modernisation of GPS and full operational capability of Russia's GLONASS with 24 satellites planned by 2011, paired with the deployment of additional GNSS such as Galileo and Compass, is expected to support NRTK with larger inter-station spacing in the future. CORSnet-NSW is also well-suited to support efforts to improve cadastral infrastructure in rural areas with RTK GNSS techniques (Janssen et al., 2010).

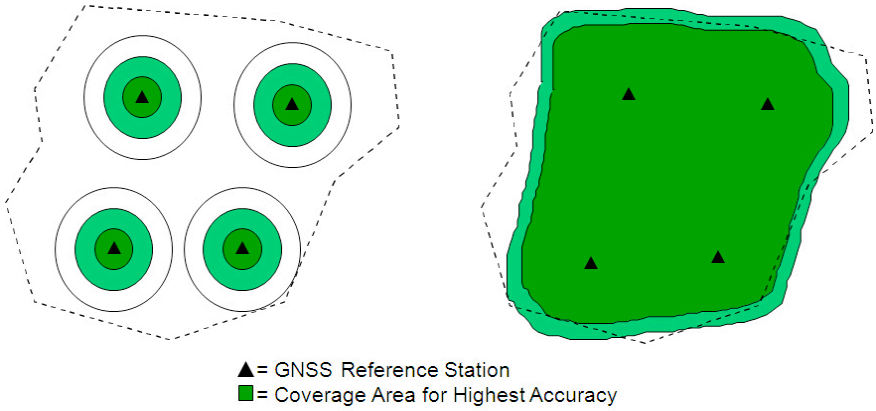

Figure 2: RTK vs. NRTK coverage.

VRS^{3}Net includes a range of other advanced features in CORS network management which will further empower LPI in providing a world-class spatial infrastructure for NSW. This includes a comprehensive user management and billing system, highly customisable SQL-based reporting functions, alert services, RSS feeds, virtual RINEX and real time network integrity monitoring.

In order to provide the highest possible level of service availability, the network control centres are designed with full redundancy by utilising two independent sites located in Sydney and Bathurst (to be completed in March 2010). Such system architecture allows for load balancing and backup between the two control centres. Within these control centres, the system architecture is also designed to mitigate any single points of failure that may exist in the system through the distribution of redundant software modules on multiple servers. Both control centres use the latest server virtualisation technology to maximise hardware utilisation and at the same time minimise power consumption, space and carbon footprint. Other forms of redundancy and backup are also being implemented with uninterrupted power supply units being installed at all CORSnet-NSW sites as well as dual communication links at several CORS. The weakest link will continue to be the GNSS receivers and antennas themselves since each site is equipped with a single GNSS receiver only and the network density is far less than in other parts of the world, e.g. in Europe and the United States.

2.3 System Integration

As an internationally renowned centre for spatial information, LPI is well placed to deliver positioning infrastructure services to the state. Systems developed in-house allow for users to easily access a range of products and services efficiently through online interfaces. LPMA's

Spatial Information eXchange (SIX) portal (http://six.lands.nsw.gov.au/) is an effective and flexible delivery system that LPI uses as an interface between users and a variety of product areas, while e-commerce capabilities allow for online ordering, billing and payment for these products. It is planned to link CORSnet-NSW with SIX to provide consistency with the delivery mechanisms of other LPI products and to achieve a one-stop-shop for all LPI data.

The overarching objective of integrating CORS with other systems is to deliver a quality user experience in a cost effective and timely manner. Integration offers the potential to leverage the capabilities in LPMA software, i.e. the accounting/resource management system (SAP), the web portal and e-commerce exchange (SIX) and the new CORS management system (VRS^{3}Net). The aim is for CORSnet-NSW users to benefit from a single familiar point of entry (via SIX), consistent 'look and feel' with single logon and seamless transfer between SIX and VRS^{3}Net, flexibility in payment using the expanding e-commerce services (in SIX) and the ability to buy either longer term subscriptions or small quantities of user specified CORS data. The integration design minimises the need to adapt VRS^{3}Net functionality or data, defines primary data stores and minimises data duplication. Handover points between systems have been minimised by modularising the functions so they could be performed within a single system. Implementing this design will require continuing effective communications between a range of LPMA professional staff, contractors and specialist support from the developers of VRS^{3}Net at Trimble Navigation.

3. REQUIREMENTS FOR HOMOGENEOUS GNSS POSITIONING ACROSS NSW

This section discusses several issues that need to be addressed in order to provide a reliable GNSS positioning service of homogeneous and high accuracy across the state. These issues include the direct connection to the national datum, legal traceability of CORS coordinates, compatibility with online GNSS processing services and CORS networks in neighbouring states, and the correct use of Antenna Phase Centre Variation (APCV) models.

3.1 Direct Connection to the National Datum through 'Global' GDA94 Coordinates

It is well known that significant distortions exist in the Geocentric Datum auf Australia 1994 (GDA94) and the Australian Height Datum 1971 (AHD71). Currently, the antenna reference point (ARP) of each CORSnet-NSW antenna is coordinated relative to the local geodetic ground mark network, leading to network distortions being incorporated into end user corrected RTK and post-processed positions. Initially, this pragmatic approach seems to be an adequate response as CORS users in a local area would experience the same distortion whether by positioning using ground marks or CORS sites, leading to compatibility regardless of the positioning solution (Hale and Ramm, 2005). In Victoria, using at least seven days of data, Ramm and Hale (2004) compared several solutions of GPSnet coordinates against published values obtained from local ties. Results showed the consistency of the CORS coordinate solutions and revealed distortions of up to 0.179 m in the local coordinates. In NSW, AUSPOS solutions submitted by LPI have revealed horizontal distortions of up to 0.3 m in the local GDA94 and up to 0.5 m in the AHD71. As an example, Figure 3 shows

distortions across eastern NSW, calculated using Bernese processing of up to 60 days of GPS data by Haasdyk et al. (2010).

However, the move from single-base to network solutions (NTRK and virtual RINEX) necessitates the shift both in thinking and in practice from local to 'global' (or, more correctly, 'regional' or 'national') coordinates that are directly tied to the Australian Fiducial Network (AFN) (GA, 2005a). For a reliable NRTK or virtual RINEX solution to be possible, reference station coordinates must have a homogenous accuracy of better than 15 mm (Ramm and Hale, 2004). In order to use the VRS^{3}Net software to its full potential, global GDA94 coordinates are therefore required for all CORSnet-NSW sites to enable the distortion-free generation of high-quality NRTK and virtual RINEX corrections accounting for ionospheric and tropospheric effects as well as geometric errors across the network. Internally, the software performs its calculations in the ITRF2005 (Altamimi et al., 2007) at the current epoch, which is directly compatible with global GDA94 coordinates, while local GDA94 coordinates introduce unwanted distortions.

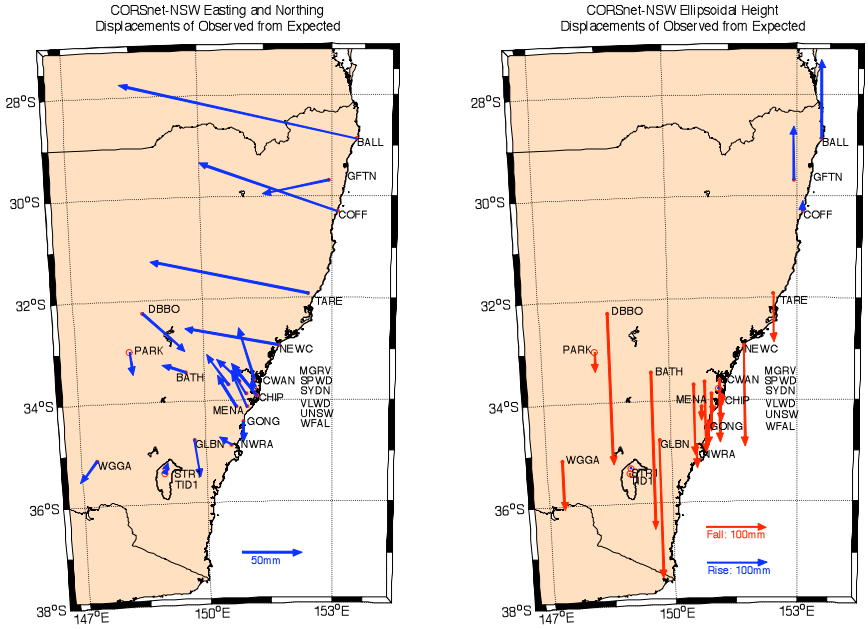

Figure 3: Horizontal and vertical distortions between global and local GDA94 across eastern NSW (Haasdyk et al., 2010).

Victoria has already adopted global GDA94 horizontal coordinates and GDA94 ellipsoidal heights for its GPSnet (Hale et al., 2007) CORS sites. A state-wide geodetic adjustment of global GDA94 coordinates has provided excellent comparisons with global CORS coordinates and NRTK positions across the entire state, typically better than a couple of centimetres (Hale, 2009, pers. comm.). SmartNet Aus (Leica Geosystems, 2010) currently consists of CORS sites located in Queensland and South Australia but plans are underway to extend the network into other areas. In October 2009, SmartNet Aus adopted global GDA94 horizontal coordinates and GDA94 ellipsoidal heights.

In Queensland, the small SunPOZ network (DERM, 2010) uses a hybrid solution for the GDA94 horizontal coordinates and GDA94 ellipsoidal heights in the network software, i.e. they are neither perfectly global, nor perfectly local (Burns, 2009, pers. comm.). Initially, coordinates from the local ties for each of the four stations at the time were used. However, this was not a feasible solution because the network management software had to distort the baseline lengths. So it was decided to utilise the coordinates obtained from a minimally constrained adjustment, holding fixed the (not quite) local coordinates calculated by the Queensland University of Technology for the central station. As new stations were brought into the network to expand the coverage area, new adjustments were undertaken, constraining all existing SunPOZ stations to determine the coordinates for each new station. While the GPSnet (Vic) and SmartNet Aus model rigorously uses global GDA94 coordinates, the SunPOZ (Qld) model provides a temporary solution feasible for smaller networks in areas where the distortions in the local GDA94 are rather uniform.

A re-computation of CORSnet-NSW sites with highly accurate, global GDA94 coordinates will connect it directly to the Australian Regional GPS Network (ARGN) (GA, 2005a), the successor of the AFN, without the need for an intervening cascade of adjustments. The directness of this connection and the use of high-accuracy and high-quality GNSS alone will remove many potential sources of error and provide at least an order of magnitude improvement in the positioning framework (Ramm and Hale, 2004). The use of global GDA94 coordinates will facilitate virtually distortion-free spatial control across the state and ensure that high-accuracy NRTK and virtual RINEX processes function correctly. It will also position NSW for a smooth and efficient transition of its geospatial infrastructure to an updated version of the GDA which is expected to be released in the next decade (GDA201x). In this context, it is important to note that while GDA94 is essentially a 2-dimensional datum, its successor GDA201x will most likely be truly 3-dimensional, lending further support to adopt global GDA coordinates across NSW.

3.2 Legal Traceability of CORS Coordinates

Legal acceptance of position is an important consideration for some GNSS users and also managers of CORS networks (Hale et al., 2007). Geoscience Australia is accredited by the National Association of Testing Authorities Australia (NATA) and as such able to issue Regulation 13 (Reg 13) certificates for CORS base stations. These Reg 13 certificates are valid for five years, providing global GDA94 horizontal coordinates and GDA94 ellipsoidal heights based on the very latest modelling and Bernese processing. Consequently, Reg 13 certification provides a recognised value standard and thus assists surveyors and others in establishing legal traceability of GNSS positions when CORS base station data are incorporated into an appropriate correction regime. In Victoria it was found that non-surveyors such as police (speed cameras and radars), aquaculture farmers and aboriginal/heritage GIS specialists demand legal sign-off on GNSS base station coordinates. However, the Reg 13 certificates must be issued with coordinates that are compatible with the national standard and therefore cannot be based on local coordinates.

Global GDA94 coordinates for GPSnet (Vic) and SmartNet Aus are determined via Reg 13 certification, and SunPOZ (Qld) is preparing to do the same. LPI is currently in the process of obtaining Reg 13 certification for all CORSnet-NSW sites.

3.3 Compatibility with AUSPOS

AUSPOS, the online geodetic-quality GNSS processing service provided by Geoscience Australia, has had a major impact since its introduction in November 2000 and can easily provide highly accurate positions within Australia (GA, 2009). Typically, a good quality geodetic receiver and antenna with 24 hours of data will give results to better than 10 mm horizontally and 10-20 mm in the vertical (GA, 2005b). However, in NSW, these positions are currently incompatible with those derived from both the geodetic ground mark network and the previously accepted CORSnet-NSW base station coordinates. There is a clear need to remove this conflict and adopt a more nationally consistent reference frame which global GDA94 coordinates will be able to provide. It should be noted, however, that AUSPOS solutions do not fully propagate the uncertainties of the ARGN, which is one of the reasons why they cannot provide legal traceability.

3.4 Interoperability between States and Commercial Providers

Interoperability with CORS networks in our neighbouring states (e.g. GPSnet in Victoria, SunPOZ in Queensland, and SmartNet Aus in Queensland and South Australia) and the national AuScope CORS (AusCORS) network is highly desired, especially in the state border regions. This will also facilitate a possible future integration of these state networks to provide a homogeneous, nationwide CORS infrastructure. Issues that need to be resolved include the sharing of base stations in the border regions as well as making sure that a user will get the same positioning result for a certain location regardless of which CORS network is being utilised. LPI will actively seek arrangements with its neighbouring states and commercial network providers.

3.5 Site Calibrations or Localisation Surveys

In the future, it can be expected that high-accuracy users will demand that the real time satellite positioning accuracy (horizontally at the 2 cm level) is compatible with coordinates specified on local survey ground marks, hence a homogeneous, state-wide geodetic infrastructure based on global GDA94 coordinates is required. The 3-dimensional GNSS accuracy in the future is envisaged to be represented by the size of a cork (Hale and Ramm, 2005).

However, a re-adjustment of the geodetic ground control network in NSW to global GDA94 coordinates will not take place in the immediate future. Hence, global CORSnet-NSW coordinates will need to be related to existing local ground control marks in order to provide compatibility. Intuitively, the solution is to strongly recommend to high-accuracy users such as cadastral and engineering surveyors that a site calibration be performed at the beginning of every survey in order to account for the difference between transmitted global GDA94

position and correction data from CORSnet-NSW and the local ground control that surveyors are required to connect to. The use of site calibrations (or localisation surveys) is already good survey practice and has been included in the NSW Surveyor General's Direction No. 9 (LPMA, 2009b) but will be essential in order to account for the larger differences between global and local GDA94 coordinates.

3.6 Adoption of Absolute APCV Models

GNSS observations refer to the antenna phase centre (APC) which is not constant but undergoes variations depending on the direction of the received signal and its frequency. The published coordinates of a CORS generally refer to the antenna reference point (ARP), which is usually identical to the actual survey mark for CORSnet-NSW sites. In order to correctly account for the offset between the ARP and the phase centre as well as the antenna phase centre variation (APCV), GNSS antenna types currently in use have been calibrated and models have been generated by worldwide organisations (providing North, East, Up offsets as well as azimuth- and elevation-dependent corrections).

In the past, 'relative' APCV models have been used, using the Allen Osborne Associates Dorne Margolin Model T (AOAD/M_T) choke ring antenna as a reference. However, these are now being replaced by 'absolute' APCV models because International GNSS Service (IGS) products such as rapid and precise orbits are now based on absolute calibrations. The IGS is a voluntary federation of more than 200 worldwide agencies that pool resources and permanent GPS & GLONASS station data to generate precise GPS & GLONASS products, e.g. for reference frame realisation (IGS, 2009).

GNSS antenna calibrations (both relative and absolute) are performed by several organisations, e.g. the German company Geo++ GmbH (Geo++, 2009) and the U.S. National Geodetic Survey (NGS, 2009). Once approved by the IGS, the absolute APCV model parameters are listed in a file that is made available to the spatial community on the web (ftp://igscb.jpl.nasa.gov/igscb/station/general/igs05.atx). While more than one parameter set can exist for a particular antenna type, only one set (generally the best available) is included in the IGS list which is updated regularly to include new antennas. Using the parameters approved by the IGS therefore allows consistency and avoids confusion in regards to which APCV parameter set is the most appropriate. While the use of relative APCV models provides correct results if (and only if) no IGS products are used, the combination of relative and absolute APCV models in one project will lead to significant errors, especially in the vertical, and therefore needs to be avoided.

For real time operation, CORSnet-NSW will transmit data specifying all CORS antennas as a null antenna, i.e. the absolute APCV corrections obtained from the IGS are reduced to the ARP (resulting in zero APCV parameters) and the user does not need to worry about which antenna is used at the CORS site(s). The user only has to ensure that the rover equipment applies the absolute APCV model of its antenna. In order to provide consistency, users will be advised to use the absolute APCV models provided by the IGS.

For post-processing, data files from CORSnet-NSW sites or a virtual reference station will indicate which antenna has been used. The user should ensure that absolute IGS APCV models for both the reference station(s) and the rover are imported and selected in the data processing software. It should be noted that the APCV parameter settings only need to be changed to absolute once and updates are only necessary when a new antenna is added or in the rare event that the parameters approved by the IGS are updated.

4. CONCLUDING REMARKS

This paper has introduced CORSnet-NSW, LPI's continuously operating reference station (CORS) network that is currently being expanded to provide state-of-the-art, state-wide GNSS positioning infrastructure across NSW. The elements necessary to effectively deliver CORS services to NSW, ensuring a sustainable positioning infrastructure, seamless positioning across NSW, system integration and on-going contributions to research and development, have been presented. Several issues that need to be addressed in order to provide a reliable GNSS positioning service of homogeneous and high accuracy across the state were discussed. These issues include the direct connection to the national datum via 'global' GDA94 coordinates, legal traceability of CORS coordinates through Regulation 13 certification, the utilisation of site calibrations or localisation surveys to account for the difference between global CORS-derived positions and the local ground control mark network, compatibility with the AUSPOS online GPS processing service and CORS networks in neighbouring states, and the use of absolute Antenna Phase Centre Variation (APCV) models.

With a strong background in GNSS technology, LPI is ideally suited to deliver high-quality CORS services to NSW. The significant efforts being undertaken to roll-out the CORSnet-NSW network and streamline the delivery of data to users will ensure maximum benefits to GNSS users in NSW. CORSnet-NSW will be sustainable and undergo a continuous program of technological upgrades in order to reduce the duplication of positioning infrastructure across the state.

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BIOGRAPHICAL NOTES

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