CORSnet-NSW: Improving Positioning Infrastructure for New South Wales

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ABSTRACT

CORSnet-NSW is a rapidly expanding network of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) providing fundamental positioning infrastructure for New South Wales that is accurate, reliable and easy to use. It is built, operated and managed by Land and Property Information (LPI), a division of the NSW Department of Finance & Services. Currently (September 2011) consisting of 68 reference stations, the network will grow to more than 120 CORS within the next two years. CORSnet-NSW supports a wide range of GNSS applications in areas such as surveying, agriculture, mining and construction, and provides a solid platform for research and innovation involving satellite positioning technology. It undergoes a continuous program of maintenance to ensure the best possible positioning infrastructure is available to NSW. This paper presents the current status of the CORSnet-NSW rollout and discusses several issues critical to providing (and achieving) reliable GNSS positioning of homogeneous and high accuracy across the State. These issues include the direct connection to the national datum via GDA94(2010) coordinates, the importance of site transformations and absolute GNSS antenna models, considerations regarding GNSS-based height determination using CORS, and the automated monitoring of CORSnet-NSW sites for quality control. Efforts to support regional geodesy in the Asia-Pacific region and future plans are also outlined.

KEYWORDS: CORSnet-NSW, CORS, positioning infrastructure, datum, Network RTK, APCV.

1 INTRODUCTION

Global Navigation Satellite System (GNSS) Continuously Operating Reference Station (CORS) networks are being introduced across Australia and internationally to provide improved access to positioning infrastructure for a wide range of GNSS applications in areas such as surveying, mapping and asset management, precision agriculture, engineering and construction, airborne imaging and sensors, and utilities management. Benefits include datum definition, rationalisation of infrastructure, establishment of multi-user systems, positioning services that are similar across and between networks, consistent and reliable connectivity to the national datum, and the ability to provide a degree of legal traceability for satellite-based positioning. Real Time Kinematic (RTK) GNSS in particular, once initialised, provides high-precision coordinates and allows 'real-world digitising' with the ability to significantly enhance productivity. It has been shown that CORS networks are well-suited to support improving cadastral infrastructure with RTK GNSS techniques (Janssen et al., 2011a).

CORSnet-NSW is a rapidly growing network of GNSS CORS providing fundamental positioning infrastructure for New South Wales that is accurate, reliable and easy to use (Janssen et al., 2010; LPI, 2011a). This network aims to support the spatial community and provide stimulus for innovative spatial applications and research using satellite positioning technology. It is built, owned and operated by Land and Property Information (LPI), a division of the NSW Department of

Finance & Services. CORSnet-NSW undergoes a continuous program of maintenance to ensure principal positioning infrastructure is available across all of NSW, while maintaining national and international standards and best practice (e.g. ICSM, 2006, 2007; Lands, 2006) to accommodate established and developing positioning, navigation and timing applications. Acknowledging that other reference station providers, both private and government, may need to establish, operate and co-exist in the State, CORSnet-NSW forms the backbone of datum realisation for all spatial applications in NSW, ensuring seamless, consistent and accurate positioning across the State. LPI accepts the inclusion of all other suitable reference stations in its network, including in areas already serviced by CORSnet-NSW, to ensure redundancy and continuation of services (LPI, 2011b).

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 made available to the public one year later 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 (Janssen et al., 2010).

This paper presents the current status of CORSnet-NSW and discusses several issues critical to providing (and achieving) reliable GNSS positioning of homogeneous and high accuracy across the State. These issues include the direct connection to the national datum via GDA94(2010) coordinates, the importance of site transformations and absolute GNSS antenna models, considerations regarding GNSS-based height determination, and the automated monitoring of CORSnet-NSW sites for quality control. Efforts to support regional geodesy and future plans are also outlined.

2 CURRENT NETWORK STATUS AND ROLLOUT

The network currently (September 2011) consists of 68 CORS tracking multiple satellite constellations, mainly located in the highly populated coastal region and the eastern part of the State. Efforts are underway to expand CORSnet-NSW to over 120 stations within the next two years. Figure 1 illustrates the coverage of CORSnet-NSW, showing stations that are operational (indicated by small triangles) as well as some planned stations (indicated by small circles). A 150 km radius around active stations is shown to illustrate sub-metre Differential GPS (DGPS) coverage, while a 50 km radius indicates the maximum coverage area for single-base RTK operation at the 2-cm level (horizontally). Network RTK (NRTK) coverage at the 2-cm level (horizontally) is shown as a pink polygon extending from the Sydney metropolitan area towards the north and south, in areas that have sufficient station density to support this technique.

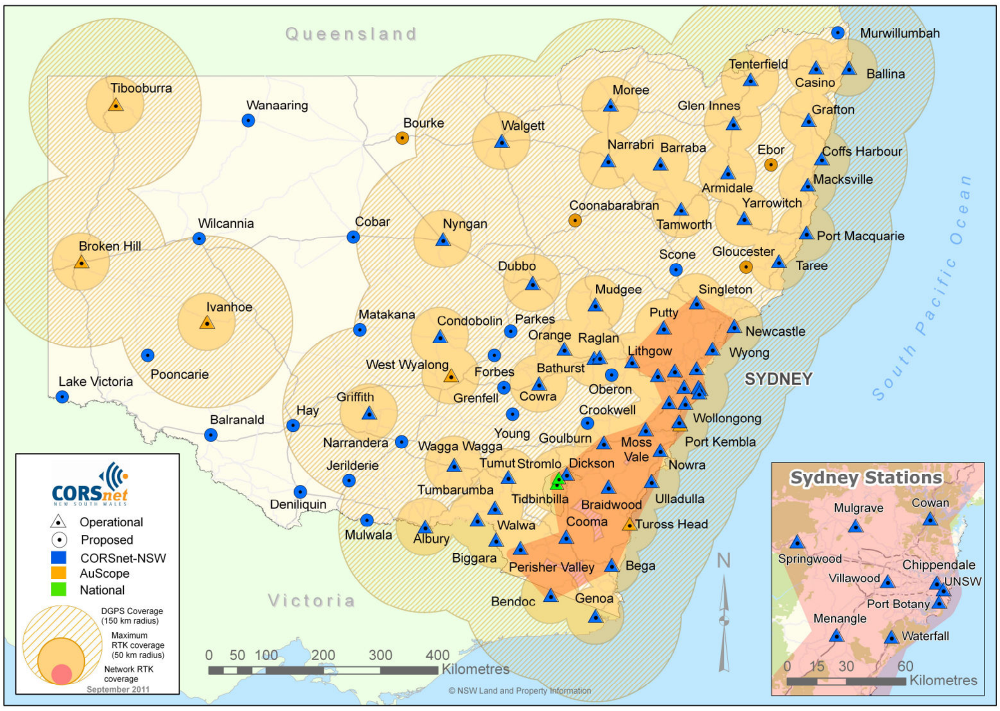

Figure 1: Current coverage of CORSnet-NSW (September 2011).

Currently 83% of the area of NSW is covered by the DGPS service, while single-base RTK is available to 35% of NSW. It should be noted that the State covers a very large area of about 802,000 km^2, most of which is sparsely populated. As a result, the single-base RTK service is not expected to reach 100% state-wide coverage since dense CORS coverage cannot be justified in all areas. Currently the DGPS service is available to 99.5% of the population, while 94% of the population is covered by single-base RTK.

CORSnet-NSW is operated and managed by a multi-disciplinary specialist team consisting of a technical group (eight staff) and a customer support group (three staff). The network is fully funded by LPI who has committed 7.25 million Australian dollars in capital investment for the Survey Infrastructure Improvement Program of which CORSnet-NSW is a major part. Over the last two years, LPI has invested one million Australian dollars in software, being the second institution in the world to install Trimble Navigation's VRS^{3}Net CORS management software. Several CORSnet-NSW stations have been built to geodetic specifications with support from federal sources, allowing their participation in the scientific, national AuScope CORS network (Janssen, 2009a).

A large number of CORSnet-NSW stations are hosted by local councils, and in the near future several sites will be hosted by private industry. LPI collaborates with the ACT Planning and Land Authority to provide CORS services across the Australian Capital Territory. LPI also collaborates with the Victorian Department of Sustainability and Environment in order to ensure consistent positioning services in the border region between the two states. Currently 80% of CORSnet-NSW stations are hosted by our partners, and this percentage is expected to rise.

All CORSnet-NSW reference stations are equipped with the most recent dual or triple constellation GNSS hardware, purposely mixing GNSS equipment from different manufacturers. In order to provide a legally traceable survey monument that allows the GNSS antenna to be oriented to True North without the need to introduce an antenna height, the new CORSnet-NSW Adjustable Antenna Mount (CAAM) was developed by LPI and a patent submission has been accepted.

Recently, guidelines providing recommendations for the technical design, installation, operation and maintenance of GNSS CORS used in CORSnet-NSW have been published with the objective of ensuring interoperable GNSS CORS across New South Wales (LPI, 2011b). It is anticipated that these guidelines may be adopted by other CORS network operators and may become a national standard.

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. Due to the lower station density in the State's west, NRTK services will initially not be available state-wide. However, the ongoing modernisation of GPS and the delayed but imminent full operational capability of GLONASS, paired with the deployment of additional GNSS, are expected to support 2-cm level NRTK with larger inter-CORS spacing in the future. Feng and Li (2008) have shown that the use of triple-frequency signals offered by next-generation GNSS will allow maximum distances between CORS to be doubled from currently about 70-90 km to about 140-180 km while maintaining positioning accuracy at the 2-cm level.

Wang et al. (2010) presented a comprehensive study of NRTK user performance, outlining the risks involved in pushing inter-CORS distances beyond 70-90 km for dual-frequency operation. It was also shown that the GNSS rover's Coordinate Quality (CQ) indicators are generally overly optimistic, especially in larger NRTK cells, confirming earlier findings from Edwards et al. (2010) and agreeing well with a recent study carried out in NSW (Janssen et al., 2011b; Janssen and Haasdyk, 2011b).

3 CORSNET-NSW PRODUCTS

Available CORSnet-NSW products include 2-cm level single-base RTK and NRTK services, real-time DGPS, and the provision of RINEX data for post-processing applications. RINEX data for virtual reference stations are expected to be available at the end of 2011. Users can choose from a range of subscriptions available through the major GPS/GNSS equipment suppliers and LPI. Subscription fees contribute to covering the operating and maintenance costs in order to ensure a sustainable and permanent CORS network for NSW well into the future.

Real-time data are provided via Radio Technical Commission for Maritime Services (RTCM) data streams (Heo et al., 2009) at 1-second intervals via the Internet, accessed by users in the field via wireless cellular networks (Yan et al., 2009). NRTK data are provided according to both the Virtual Reference Station (VRS) approach and the Master-Auxiliary Concept (MAC). Compared to single-base RTK, the NRTK solution enables the distance dependent errors (i.e. ionospheric and tropospheric delays and orbit errors) to be modelled more reliably across the network (Janssen, 2009b). It also allows the correction data provided to a user to be optimised based on their (changing) location within the network, thus effectively eliminating the degradation of RTK positioning accuracy with increasing distance from a single base station (Janssen et al., 2011b; Janssen and Haasdyk, 2011b). Should a CORS go down for any reason, an automatic switch is made to utilise an alternative reference station for the NRTK solution, without the need for the user to manually switch to another RTK reference station. NRTK operation thereby improves real-time service availability and reliability.

4 PROVIDING AND ACHIEVING HOMOGENEOUS GNSS POSITIONING ACROSS NSW

Several issues are critical to providing (and achieving) reliable GNSS positioning of homogeneous and high accuracy across the State. This section discusses the direct connection to the national datum via GDA94(2010) coordinates, the importance of site transformations, GNSS-based height transfer considerations, the use of absolute GNSS antenna models, and the automated monitoring of CORSnet-NSW sites for quality control.

4.1 GDA94(2010) vs. GDA94(1997)

The Geocentric Datum of Australia (GDA94) is the basis for geodetic infrastructure in Australia (ICSM, 2006). For a review of coordinate systems, datums and associated transformations in the Australian context the reader is referred to Janssen (2009c). The introduction of CORS or 'active' control marks has revolutionised positioning for spatial professionals. However, these CORS must work in tandem with traditional 'passive' marks in the ground. Issues arise for high-accuracy applications simply because the new control marks are far more accurate than the old. Today we find ourselves working in this challenging transition period between old and new, which will continue until the introduction of a new national datum sometime in the next decade.

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) because multiple CORS are used to model the distance dependent errors across the network. In order to provide CORS users with these new services and to ensure that they are accurate, reliable and easy to use, it was essential to introduce a new set of highly accurate and consistent 3-dimensional coordinates for use in CORSnet-NSW. It was also important to ensure that these new coordinates are consistent with those from other states, particularly Victoria and its state-wide GPSnet CORS network (Hale et al., 2007), so it is possible to share CORS infrastructure and provide seamless positioning across the nation. Victoria completed a state-wide geodetic re-adjustment of its ground control network a few years ago, which provides excellent comparisons with GPSnet-derived positions across the entire state, typically at about a centimetre in metropolitan areas and at the sub-decimetre level in rural areas.

In NSW, a complete re-adjustment of the geodetic ground control network will not take place until a new national datum has been introduced. This is due to the large amount of marks involved (SCIMS currently contains 237,000 survey marks) and the enormous work effort that would be required. Another reason is that users dealing with large datasets (e.g. those handling GIS datasets) should not be forced to transform these multiple times.

Instead, a new ad-hoc realisation of the national datum, GDA94(2010), was introduced by LPI for CORSnet-NSW (Janssen and McElroy, 2010). In order to avoid confusion, the original definition of GDA94 is now referred to as GDA94(1997) in NSW. The concept of different and regular realisations of the same datum is very familiar to geodesists, scientists and surveyors working with International Terrestrial Reference Frame (ITRF) coordinates. This global datum is refined, or realised, every three or so years in order to improve its accuracy, based on increasing amounts of data, and improved modelling and processing techniques (Altamimi et al., 2011).

Legal acceptance of position is an important consideration for some GNSS users and also managers of CORS networks (Hale et al., 2007). Since spatial professionals must work within the constraints of current NSW legislation which requires them to connect to local ground control, all CORSnet-NSW sites are coordinated with both GDA94(1997) and GDA94(2010) coordinates.

GDA94(1997) is the original realisation of the current national datum which was adjusted in 1997. It is sometimes also termed ‘local’ GDA94 because it is based on local connections between control marks. Many of these coordinates were derived from pre-1980 terrestrial observations. Shortcomings in the initial datum definition (that were not obvious at the time) and the process of propagating coordinates through many layers of measurements and adjustments over the years have caused significant distortions in GDA94(1997), rendering it unsuitable for CORS network operation. Across NSW, known distortions reach up to 0.3 metres in the horizontal component. GDA94(1997) coordinates for each CORSnet-NSW site are determined by LPI through a GNSS-based local tie survey in order to provide connections to the existing ground control network. These coordinates are made available via the Survey Control Information Management System (SCIMS) database (LPI, 2011c).

GDA94(2010) is a later realisation of the national datum. The year in brackets was chosen somewhat arbitrarily to set it apart from the earlier realisation and indicates the date of its introduction. It is sometimes also termed ‘global’ GDA94, although ‘regional’ or ‘national’ would be more correct. GDA94(2010) provides a direct connection to the Australian Fiducial Network (AFN) and its successor, the Australian Regional GPS Network (ARGN), exclusively via GNSS observations. The directness of this GNSS-based connection removes many biases and facilitates virtually distortion-free (a millimetre or two every ten kilometres) spatial control across the network, thereby providing at least an order of magnitude improvement in the positioning framework (Ramm and Hale, 2004). This realisation should also ensure the viability of CORSnet-NSW well into the future, as it is designed to be highly compatible with the planned new national datum.

GDA94(2010) coordinates for all CORSnet-NSW sites are obtained via Regulation 13 certification. These so-called ‘Reg 13’ certificates are issued by Geoscience Australia, a facility accredited by the National Association of Testing Authorities (NATA). Geoscience Australia determines 3-dimensional site coordinates, which are stated on these certificates, based on one complete week of GNSS data and highly traceable, standardised, scientific processing. Certificates are valid for five years and provide a Recognised Value Standard for positioning infrastructure with respect to the national datum. Through this facility the site coordinates are linked to a standard of measurement in accordance with the National Measurement Regulations 1999 and the National Measurement Act 1960. Consequently, it assists users in establishing some legal traceability of GNSS positions when CORS data are used. GDA94(2010) coordinates also provide interoperability between existing CORS networks and Geoscience Australia's online GNSS processing service, AUSPOS (GA, 2011). These GDA94(2010) coordinates are available from the CORSnet-NSW website only (LPI, 2011a).

4.2 Importance of Site Transformations

The GDA94(2010) realisation is essential to provide real-time users with reliable, horizontal positioning at the 2-cm or better level. This, of course, means that CORSnet-NSW users obtain positions referenced to GDA94(2010). While this is suitable for applications where users are interested only in absolute accuracy and repeatability (e.g. precision agriculture), spatial professionals are generally required to connect to the existing local survey control network due to legislative requirements or to be compatible with spatial data already referenced to local control. In order to obtain output that is consistent with local ground control marks, it is therefore essential to perform a site transformation (also known as site calibration or localisation) for *every* real-time survey where existing survey control is located nearby.

The site transformation is performed by observing several established ground control marks surrounding the survey area and calculating a locally valid transformation between the CORSnet-NSW reference frame, GDA94(2010), and the local ground control network, GDA94(1997). This is typically done via a menu tool incorporated in the GNSS rover software. Once the site transformation is performed and found acceptable, it is automatically applied and real-time GNSS positioning then refers to the existing local control network. The use of site transformations is already established good practice to reduce the extent of distortions in GDA94(1997). However, in NSW it is now essential to account for the larger differences in coordinates between the two realisations of GDA94.

In an ideal world, real-time GNSS positioning should be directly compatible with coordinates specified on local survey ground control marks. Therefore a consistent, state-wide geodetic infrastructure based on GDA94(2010) coordinates, or something similar, is the ideal solution. The planned introduction of a new national datum for Australia, based in large part on GNSS observations, is expected to solve this problem. Theoretically, this will remove the need for site transformations.

4.3 GNSS-based Height Transfer Considerations for CORS Users

In regards to vertical coordinates, GNSS-based height transfer is possible by converting ellipsoidal heights (h) determined by GNSS to orthometric heights (H) that refer to the Australian Height Datum (AHD71) (Roelse et al., 1971). This is achieved by applying the geoid undulation (N), also known as geoid-ellipsoid separation, geoid height or N value (e.g. Featherstone and Kuhn, 2006; Janssen, 2009c):

$$H = h - N \qquad (1)$$

In practice, geoid undulation information plays two crucial roles (Rizos, 1997): On the one hand, N values are necessary to convert (non-GNSS) geodetic control information (i.e. orthometric heights) into a mathematically equivalent reference system to which GNSS results refer (i.e. ellipsoidal heights). On the other hand, N values are required to obtain orthometric heights (i.e. physical meaning) from GNSS-derived ellipsoidal heights (i.e. geometrical meaning). The growing use of CORS networks for GNSS-based height determination has substantially increased the importance of accurate, absolute N values.

In the traditional base-rover field scenario, the published, local AHD71 height of a temporary GNSS reference station set up on a local ground control mark is converted to an ellipsoidal height using equation (1). The ellipsoidal height of the rover is then determined via RTK or post-processing techniques and converted back to AHD71 using the same equation. The entire process is based on the *calculated* ellipsoidal height of the reference station. Most of the error in the absolute N values cancels since the conversion is applied from AHD71 to ellipsoidal height and back again (Figure 2). The absolute N values involved may have large errors (*e*) but by applying the height conversion twice (forward and backward), the AHD71 height of the rover is only contaminated by the small difference in relative N value errors (ignoring any GNSS observational errors).

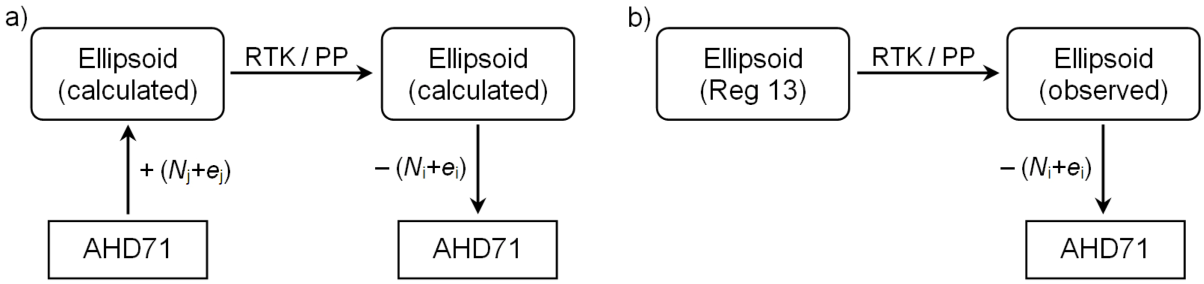

Figure 2: GNSS height transfer methodology using RTK or post processing (PP) in the traditional base-rover scenario (a) and using CORS (b).

In the CORS scenario, the height conversion is only applied once (at the rover end). It is based on an *observed* ellipsoidal height at the CORS, which is generally determined via Regulation 13 certification in Australia (see section 4.1). As the height conversion is only applied once (from ellipsoidal height to AHD71), any error (*e*) in the absolute N value will fully propagate into the AHD71 height of the rover. Consequently, the absolute accuracy of N values is now more important than ever for AHD71 height determination using GNSS techniques. Fortunately, the recently released AUSGeoid09 geoid model (Brown et al., 2011; Featherstone et al., 2011) provides N values with unprecedented absolute accuracy across NSW (Janssen and Watson, 2010).

4.4 Absolute GNSS Antenna Modelling

Since multiple CORS, often with different antenna types, are used to model the distance dependent errors across the network, appropriate GNSS antenna modelling is crucial for CORS network operators (Janssen and Haasdyk, 2011a). Consequently, it is also an important issue for users of CORS data.

GNSS observations are measured to the antenna phase centre (APC). The APC is not only offset from the actual survey mark but also undergoes variations depending on the azimuth and elevation of the GNSS satellites and the signal frequency (Figure 3). These antenna phase centre variations (APCV) are deviations from the mean APC and can cause additional errors of up to 20 mm in the measurement to a single GNSS satellite. The all-important antenna reference point (ARP), generally located at the bottom of the antenna, is the reference point for measuring instrument heights and for antenna models. Users can confirm its exact location by consulting readily available documentation from the International GNSS Service (IGS, 2011a) to ensure the rover's antenna height to the ARP is correctly measured in the field. The published coordinates of a CORS typically refer to the survey mark which is identical to the ARP if no antenna height is present.

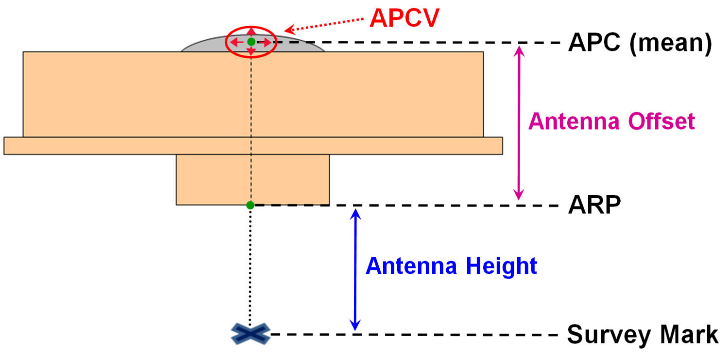

Figure 3: Antenna reference point (ARP), antenna phase centre (APC) and its variation (APCV).

In order to correctly account for the antenna offset as well as any phase centre variations, GNSS antenna types have been calibrated by a number of organisations around the world to generate models. These antenna models provide North, East, Up offsets between the ARP and the mean APC as well as variations dependent on the azimuth and elevation of the received satellite signal, for each frequency. While the North and East offsets for modern GNSS antennas are generally less than a millimetre, they can reach 7 mm for older antennas. The Up offset is very much dependent on the size and design of the antenna and can exceed 200 mm, thus introducing a large error into the height component of the positioning result if not considered.

Not surprisingly, the size, material and design of the antenna have a large effect on the magnitude and distribution of the antenna's phase centre variations. Since GNSS antenna manufacturers have become very good at designing and building symmetric antennas, the azimuth-dependent component is less of a concern than the elevation-dependent component of the variations. However, there are significant differences between antenna types. While the average rover antenna shows a much smaller magnitude of variations than the more expensive CORS choke ring antenna (especially for low elevations), its variations are far less symmetric and show larger differences in the pattern between frequencies (Figure 4).

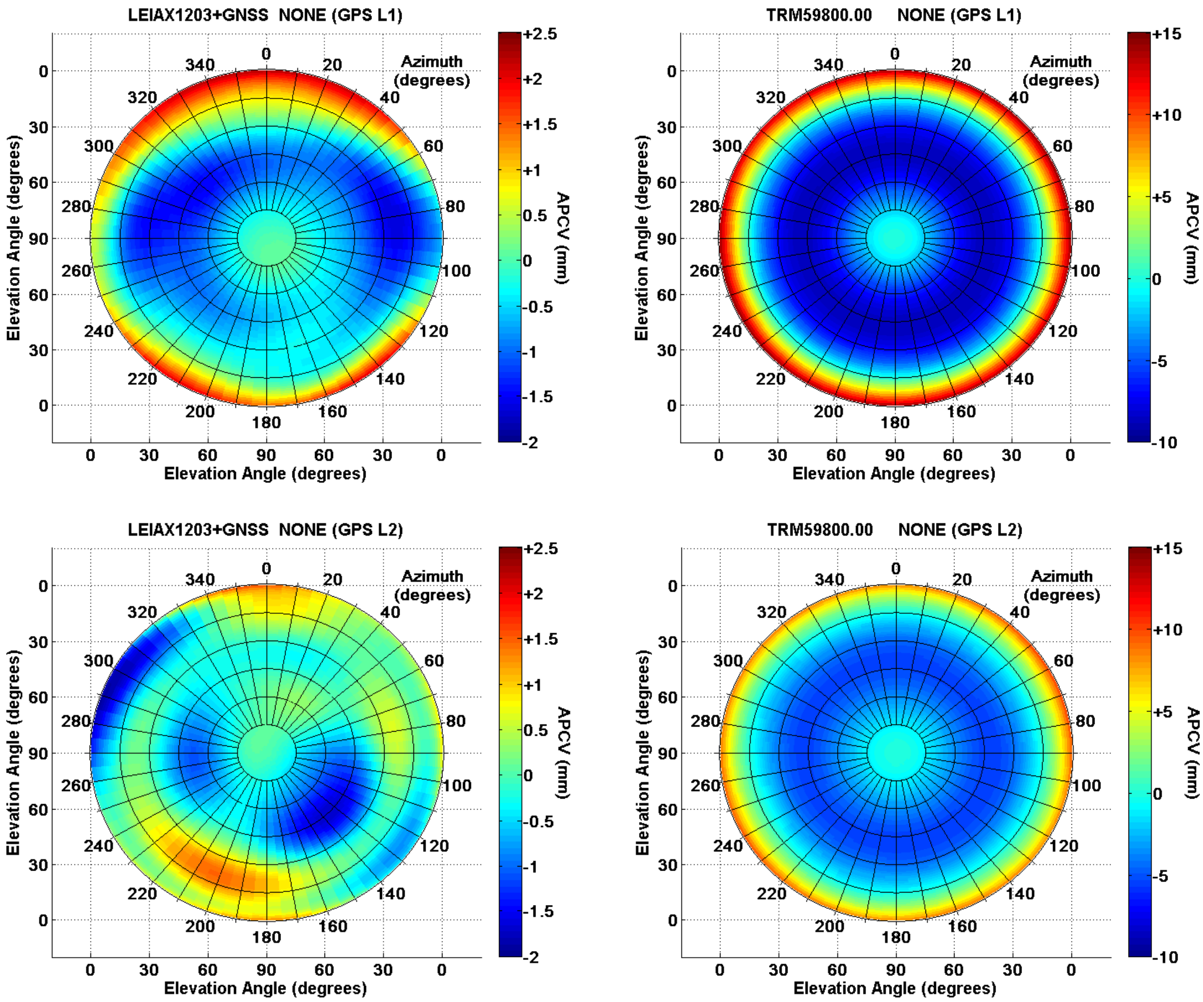

Figure 4: Absolute APCV as a function of satellite azimuth, elevation and frequency for the LEIAX1203+GNSS rover antenna (left) and the TRM59800.00 choke ring antenna (right), both without radome.

In the past, ‘relative’ APCV models were used based on one specific antenna type with assumed zero APCV as a reference antenna (the Dorne Margolin choke ring antenna from Allen Osborne Associates known as AOAD/M_T). However, these have been replaced by ‘absolute’ APCV models because the products of the International GNSS Service (IGS), such as rapid and precise orbits used by CORS operators, are now based on the more rigorous absolute calibrations. 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 component.

Absolute GNSS antenna calibrations are performed by several organisations, ideally with a robot rotating and tilting the antenna in an anechoic (i.e. echoless) chamber. Once approved by the IGS, the absolute APCV model parameters, often determined by combining the values obtained from calibrating several antennas of the same type, are made freely available to the spatial community (IGS, 2011b). The published IGS antenna models have recently experienced significant improvement, due to the inclusion of more antenna calibrations and GNSS frequencies, coinciding with the release of ITRF2008 (Altamimi et al., 2011). These models use the ANTEX file format (Rothacher and Schmid, 2010) and follow the international naming convention for GNSS equipment (IGS, 2011c).

While more than one APCV 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. CORSnet-NSW users are strongly advised to use the absolute antenna models provided by the IGS for both post-processing and real-time operations.

For real-time operations, CORSnet-NSW transmits data specifying all CORS antennas as a ‘null antenna’, i.e. an antenna with zero antenna offsets and zero APCV. This is achieved by using the absolute APCV corrections obtained from the IGS to reduce the observations to the ARP. Any CORS antenna heights present are automatically considered by the rover through the transmitted RTK/NRTK messages. Therefore, the user does not need to take into account which antenna is used at the CORS site(s) because modelling is taken care of behind the scenes. This considerably simplifies the user’s fieldwork because no CORS antenna models have to be uploaded into the rover. The user only has to ensure that the rover equipment applies the appropriate *absolute* IGS APCV model of the rover antenna used in the field.

For post-processing, null antennas are not utilised. Following the RINEX standard, data files from CORS sites or a virtual reference station continue to have observations measured to the APC and will indicate which antenna type has been used. The user should ensure that *absolute* IGS APCV models for both the CORS and the rover are imported and selected in the data processing software. It should be noted that the absolute APCV parameter settings only need to be imported once into the post-processing software and updates are only necessary when a new antenna type is added or in the rare event that the parameters approved by the IGS are updated.

CORSnet-NSW users should apply the following ‘golden rules’ in regards to GNSS antenna modelling (Janssen and Haasdyk, 2011a):

- Absolute antenna models are GNSS best practice and should be used for real-time and post-processing applications.
- Relative and absolute antenna models should never be mixed.
- IGS absolute antenna models are available from IGS (2011b) or GNSS equipment suppliers.
- CORSnet-NSW uses IGS absolute antenna models, IGS products, and the null antenna principle. Therefore, all CORS ‘look the same’ from a user perspective. In order to avoid confusion and provide consistency, users are strongly advised to use IGS absolute antenna models.
- Setting the elevation mask at the rover to 10-15° not only reduces atmospheric and multipath errors but also APCV effects.
- All antenna heights should be measured vertically to the ARP, in millimetres and inches, and converted between the two as a check.
- For high-accuracy static surveys, the rover antenna should be oriented to True North.

4.5 Automated Monitoring of CORSnet-NSW

Quality control and integrity monitoring of CORS infrastructure is becoming increasingly important for legal traceability of data and measurements as well as for long-term stability studies of station coordinates. CORSnet-NSW is monitored by determining high-precision daily coordinate solutions using the Bernese 5.0 software (Dach et al., 2007) in an automated process (Haasdyk et al., 2010). Station coordinates are obtained in ITRF and transformed into GDA94. The ongoing analysis of these coordinates can reveal (1) site specific velocities of the network at higher densities than those provided by the global IGS network, allowing comparisons with existing tectonic plate models, (2) medium density sampling of the local distortions present in GDA94(1997) and the distortions in ellipsoidal heights derived from AHD71 in conjunction with AUSGeoid09, and (3) trends in site coordinates which can reveal local ground deformation.

For each CORSnet-NSW site, the resulting coordinate time series showing the difference of the observed station coordinates from the official coordinates is made available on the CORSnet-NSW website (Figure 5). Results show that station coordinates are calculated with millimetre-level precision, while velocities are obtained with 2-4 mm/yr precision and agree with the expected tectonic motion across NSW.

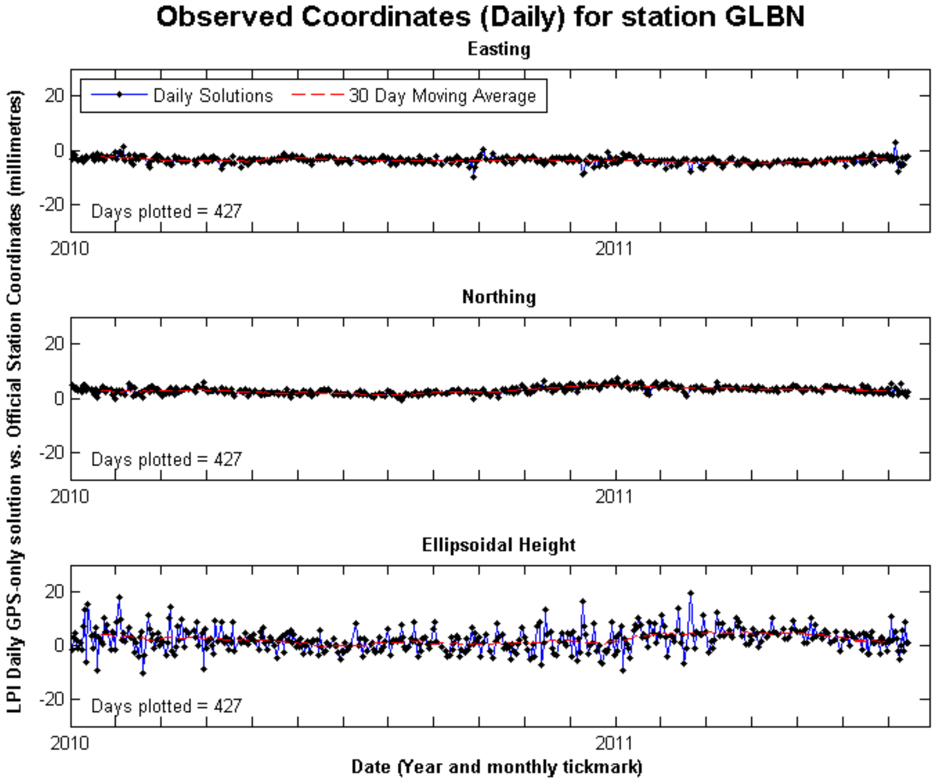

Figure 5: Observed position vs. official position of Goulburn CORS.

5 CONTRIBUTION TO APREF

All modern geodetic datums use reference systems closely aligned with ITRF. The latest realisation of ITRF (ITRF2008) has a precision of a few millimetres (Altamimi et al., 2011), forming a robust basis for any regional or national geodetic datum. The Asia-Pacific Reference Frame (APREF) initiative aims to improve the geodetic infrastructure in the Asia-Pacific region by creating and maintaining a modern regional geodetic framework closely linked to ITRF and based on continuous GNSS data (Dawson and Hu, 2010). Benefits include the development of geodetic datums and CORS networks to support regional development, monitor geophysical hazards and sea level change as well as to synchronise geodetic activities across the region (Stanaway and Roberts, 2010). All CORSnet-NSW sites are contributing data to APREF, thus not only strengthening the regional framework but also allowing the independent monitoring of all CORSnet-NSW sites.

In order to support APREF, all 4-character CORSnet-NSW site IDs have been checked (and changed in a few cases) to avoid conflict with existing national and international CORS sites. In addition, each CORSnet-NSW site has been assigned a 9-digit APREF DOMES number by Geoscience Australia. The DOMES (Directory of MERIT Sites) number was introduced in the early 1980s during the Monitoring of Earth Rotation and Intercomparison of the Techniques (MERIT) campaign, which investigated the relationship between several new space-geodetic techniques, to unambiguously identify each mark involved in this campaign (Wilkins and Mueller, 1986). Nowadays the DOMES number is generally used to provide a unique identifier for each CORS in a particular network.

An IGS site log (IGS, 2011d) has also been generated for each CORSnet-NSW site. It contains detailed station information such as site identification of the GNSS monument (including 4-character ID and DOMES number), site location, and GNSS receiver and antenna information. IGS site logs are international standard for providing up-to-date information on CORS sites, including the history of receiver hardware and firmware updates as well as GNSS antenna changes at the site. This information is frequently updated and the current IGS site log files are available from the CORSnet-NSW website (LPI, 2011a).

6 FUTURE PLANS

CORSnet-NSW will likely grow to over 120 CORS within the next two years, integrating stations from other CORS networks where appropriate in order to help avoid duplication of CORS infrastructure. The planned rollout will focus on substantially expanding availability of the NRTK service from the current coverage area into other regions of the State. It has been shown that NRTK solutions are more robust and achieve accuracies better than those achieved from single-base RTK solutions (e.g. Janssen et al., 2011b; Janssen and Haasdyk, 2011b).

In order to provide the highest possible level of service availability, a second network control centre with full redundancy will be completed in Bathurst in 2011. Such system architecture allows for load balancing and backup between the two control centres in Sydney and Bathurst. Both control centres will use server virtualisation technology to maximise hardware utilisation and at the same time minimise power consumption, space requirements and carbon footprint.

Other forms of redundancy and backup are implemented with uninterruptible power supply (UPS) units being installed at all CORSnet-NSW sites as well as dual communication links at most CORS. The main area of concern continues to be the (generally very reliable) GNSS receivers and antennas themselves since each site is equipped with a single GNSS receiver-antenna pair only and the network density is far less than in other parts of the world. Users continue to be dependent on a reliable connection to the Internet which can be a problem in parts of rural NSW where mobile communications can be limited.

Remote access to the CORS receivers is essential to enable firmware upgrades and trouble-shooting in a time-efficient manner. The use of virtual private network (VPN) tunnels will allow direct and secure access to CORS receivers through the firewalls of the host organisations.

In addition to the ongoing monitoring of CORSnet-NSW sites for small, long-term trends (see section 4.5), the commercial Trimble Integrity Manager (TIM) module will be implemented in VRS^{3}Net to enable real-time detection of larger, sudden movements of the CORS antennas. Combining these two state-of-the-art methods ensures that the CORSnet-NSW team is always aware of any motion that the CORS network may be subjected to, whether it is slow tectonic plate motion, land subsidence, or a sudden movement caused by an earthquake or a host removing an antenna from its monument. These tools also ensure continuous validation and quality control of the CORS network and its services, e.g. via the use of continuous RTK/NRTK rover installations and the generation of various quality monitoring statistics.

7 CONCLUDING REMARKS

This paper has presented the current status of CORSnet-NSW, LPI's rapidly expanding CORS network that already provides state-of-the-art GNSS positioning infrastructure across much of NSW. Several issues critical to providing (and achieving) reliable GNSS positioning of homogeneous and high accuracy across the State have been discussed.

These issues include the direct connection to the national datum via GDA94(2010) coordinates, the importance of site transformations and absolute GNSS antenna models, considerations regarding GNSS-based height determination, and the automated monitoring of CORSnet-NSW sites for quality control and integrity monitoring. Efforts to support regional geodesy via the APREF initiative and future developments have also been outlined.

CORSnet-NSW will continue to grow from currently 68 CORS to more than 120 stations within the next two years, providing seamless CORS infrastructure across NSW that is accurate, reliable and easy to use for a wide range of applications. It supports the spatial community across the State, is a valuable resource for major infrastructure projects, and provides stimulus for innovative spatial applications and research using satellite positioning technology.

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