# Technical Challenges Faced by CORS Network Operators: Experiences from New South Wales, Australia

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**Abstract**

*Global Navigation Satellite System (GNSS) Continuously Operating Reference Station (CORS) networks are being introduced across many countries to provide improved access to positioning infrastructure for a wide range of applications and a solid platform for research and innovation involving satellite positioning technology. This paper discusses the challenges involved in establishing a CORS network, using the experiences from CORSnet-NSW as an example. The purpose of a CORS network determines the required network density and station monumentation. The logistics involved in physically building the monument and installing the electronic equipment are some of the easiest issues requiring consideration. Collaboration with other organisations hosting a CORS, long-term tenure of the land and/or building to be used, site access, system redundancy and communications all play crucial roles. In addition, several operational aspects need to be addressed in order to provide (and achieve) reliable GNSS positioning of homogeneous and high accuracy across the network. These include the consistent connection to a high-quality datum, GNSS-based height transfer considerations, the use of absolute GNSS antenna models, stability and integrity monitoring, and the possible contribution to regional or global geodesy initiatives.*

## 1. Introduction

The advent of Global Navigation Satellite Systems (GNSS), such as the United States' Global Positioning System (GPS), Russia's GLONASS, the European Union's Galileo and China's Beidou (Compass), as well as a number of regional satellite systems, has revolutionised the way 3-dimensional positions are determined on and above the Earth's surface. Continuously Operating Reference Station (CORS) networks are being introduced across many countries to provide improved access to positioning infrastructure for a wide range of GNSS applications in areas such as surveying, agriculture, mining and construction. The technology has also been adopted in areas such as emergency, fleet and asset management, aviation, marine and land transport. 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). Establishing a CORS network, however, is not an easy task. Aside from selecting a suitably stable location and the logistics of physically building the monument and installing the electronic equipment, a multitude of other issues needs to be addressed. These issues include funding, collaboration with government or industry partners hosting the CORS, land and/or building tenure and site access, as well as system redundancy and communications. In addition, decisions need to be made in regards to the operation of the CORS network in order to provide (and achieve) reliable GNSS positioning of homogeneous and high accuracy across the network area and between existing (or abutting) CORS networks. This involves the consistent connection to a high-quality national datum and its relationship to a global datum, GNSS-based height transfer considerations, absolute GNSS antenna modelling, stability and integrity monitoring, and the possible contribution to regional and global geodesy. This paper outlines these challenges, using as an example the experiences gained during the ongoing establishment and expansion of CORSnet-NSW, a GNSS CORS network covering the state of New South Wales (NSW), Australia.

## 2. CORSnet-NSW

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 and 2011c). 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 and Services. CORSnet-NSW undergoes a continuous program of maintenance to ensure principal positioning infrastructure is available across all of NSW, while following national and international standards and best practice 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 encourages 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'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). The network is operated and managed by a multi-disciplinary expert team consisting of a technical group (seven staff) and a customer support group (three staff). CORSnet-NSW currently (August 2011) consists of 65 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. Currently almost 80% of the area of NSW is covered by the DGPS service, while single-base RTK is available to almost 35% of NSW. It should be noted that the State covers a very large area of about 802,000 km$^2$ (i.e. more than one and a half times the size of Thailand or Spain), 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% of the population, while 92% of the population is covered by single-base RTK. 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, 2009a). It also allows the correction data provided to a user to be optimised based on their (changing) location within the network, thus effectively reducing the degradation of RTK positioning accuracy with increasing distance from a single base station (Janssen et al., 2011b and 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. In support of post-processing applications, RINEX data at sampling rates of up to 1 second is available from all CORS. RINEX data for virtual reference stations is expected to be available by the end of this year.

## 3. Establishing a CORS Network

This section discusses several issues critical in the establishment of a CORS network. The importance of carefully considering the GNSS antenna's skyview (i.e. minimising obstructions and multipath), possible signal interference, site security and the provision of a reliable, continuous power source (e.g. by using a battery bank and solar panels in remote regions) when selecting a CORS site is assumed common knowledge and will not be considered.

*3.1 Collaboration and Interoperability*

Collaboration between federal, state and local government agencies and private industry is important in order to avoid unnecessary duplication of positioning infrastructure. A number of CORSnet-NSW stations have been built to geodetic specifications, allowing their participation in the scientific, national AusCORS network managed by the federal agency for surveying and mapping, Geoscience Australia (see section 3.4). In addition, a large number of CORSnet-NSW stations are hosted by local councils, and in the near future several sites will be hosted or owned by private industry. LPI also collaborates with authorities in neighbouring states to ensure consistent positioning services in the border regions. Currently 80% of CORSnet-NSW stations are hosted by our partners, and this percentage is expected to rise. Interoperability between existing reference stations within NSW, in neighbouring states and the overarching national CORS network is highly desired. This will facilitate a possible future integration of these CORS to provide a homogeneous, nationwide positioning infrastructure. Issues that need to be resolved include the sharing of base stations in the border regions between abutting networks and the use of a consistent datum to ensure that a user will get the same positioning result for a certain location regardless of which CORS network is being utilised.

*3.2 CORS Network Density*

Network density largely depends on the size of the area to be covered, the funding available and the intended purpose(s). While a sparse CORS network is sufficient for datum definition, the provision of real-time positioning services requires a much denser network. Other important aspects include redundancy, reliability, continuation of service and the possible inclusion of real-time network integrity monitoring stations. In regards to CORSnet-NSW, NRTK services may not be available state-wide due to the lower station density in the west of the State. Wang et al. (2010) outlined the risks involved in pushing inter-CORS distances beyond 70-90 km for dual-frequency operation. 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 distances of up to 140-180 km in the future (Feng and Li, 2008).

*3.3 Land Tenure and Site Access*

Arranging long-term tenure of and/or access to the land (or building) hosting a new CORS can be a long (6-12 months) and complex process, depending on the number of parties involved and the location of the site. Collaboration with various agencies and the organisation hosting the CORS is critical. In NSW, a detailed site plan for each CORS must be generated and signed by all parties involved to ensure the longevity of the chosen site. A products and services agreement identifying arrangements for the management of CORS information and services is generally also part of this process. In NSW, it is necessary to exercise the due diligence code of practice for the protection of Aboriginal objects, i.e. it needs to be confirmed that a proposed CORS in a remote area does not disturb a nearby Aboriginal site or object.

*3.4 CORS Monumentation and GNSS Equipment*

The monumentation of CORS sites is very much dependent on the intended purpose(s) of the network. The concept of a tiered hierarchy of permanent GNSS reference stations was proposed by Rizos (2007) and has since been widely accepted across Australia (Burns and Sarib, 2010). Tier 1 stations contribute to international or global geodesy initiatives, Tier 2 stations provide primary national geodetic infrastructure for datum definition, and Tier 3 stations are secondary state or private GNSS networks, often established for real-time precise positioning services. Potentially, further tiers of GNSS CORS can be introduced, e.g. a CORS operated for the purpose of controlled traffic farming may be considered Tier 4 or lower (LPI, 2011b). A stable monument (< 2 mm) including a clearly identifiable, fixed reference point (i.e. survey mark) with the antenna oriented to True North is preferred in all cases. While Tier 1 and Tier 2 sites generally require state-of-the-art GNSS choke ring antennas and solid pillar monuments firmly anchored to bedrock, Tier 3 sites are often mounted on buildings and use more light-weight antennas (Figure 2). Naturally, CORSnet-NSW falls into the Tier 3 category, although it contains a small number of Tier 1 sites built and managed by Geoscience Australia. In addition, several CORSnet-NSW sites are being built to Tier 2 specifications as part of the federal government's National Collaborative Research Infrastructure Strategy (AuScope, 2011). Specifications for Tier 2 sites include the addition of an automatic weather station and the high-precision monitoring (< 1 mm horizontally and generally < 0.5 mm vertically) of the pillar monument at regular intervals (Janssen, 2009b).

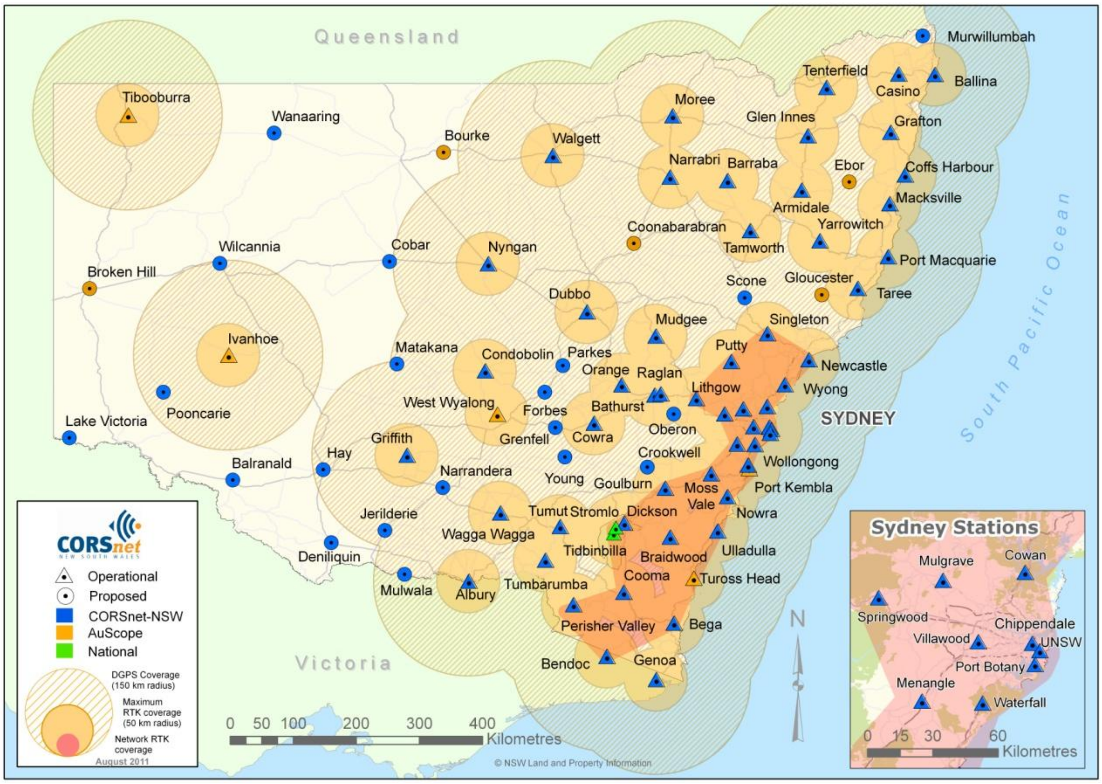


Figure 1: Current coverage of CORSnet-NSW (August 2011)

Figure 2: Typical CORSnet-NSW monumentation and auxiliaries at Tier 2 (left) and Tier 3 (right) sites

The use of radomes to protect the GNSS antenna from the environment (e.g. wind, sand, rain, snow and human intervention) is common for Tier 1 and Tier 2 CORS in the harsh Australian environment. Building mounts used for Tier 3 sites should consist of stainless steel masts securely attached to a wall or the roof of the building. All CORSnet-NSW sites are equipped with the most recent dual or triple constellation GNSS hardware. CORS antennas are carefully selected to support GNSS modernisation and ensure a long life span in order to help avoid discontinuities in time series of observed CORS coordinates for scientific applications.

Receivers are generally easier to replace, although any hardware change can cause time series discontinuities and changes should therefore be kept to a minimum, particularly for Tier 1 and 2 sites. 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 CORSnet-NSW Adjustable Antenna Mount (CAAM) was developed in-house and a patent submission has been accepted (LPI, 2011b). Auxiliary equipment may include digital cameras, temperature sensors, fans, power sensors and door alarms, all of which are capable of sending real-time alerts to the system administrator via the site's internet connection.

### 3.5 System Redundancy and Communications

Sufficient redundancy in all aspects of the CORS system design is required to provide the highest possible level of service availability. Generally, two network control centres should be designed with full redundancy by utilising two independent sites. Such system architecture should allow for load-balancing and backup between the two control centres as well as hot-swapping of data and connected users, invisible to the user in the field. Using the latest server virtualisation technology can maximise hardware utilisation and at the same time minimise power consumption, space requirements and carbon footprint. Uninterruptible power supply (UPS) units and independent, dual communication links (e.g. high-speed internet and wireless cellular network) are also implemented at CORSnet-NSW sites. Remote access to the GNSS receivers is essential to enable maintenance (e.g. firmware upgrades) and trouble-shooting in a time-efficient manner. The use of virtual private network (VPN) tunnels allows direct and secure access to CORS receivers through the firewalls of the host organisations.

## 4. Providing and Achieving Homogeneous GNSS Positioning

This section discusses several issues essential for providing (and achieving) reliable GNSS positioning of homogeneous and high accuracy across the CORS network, using CORSnet-NSW as an example. Considerations to support regional geodesy are also outlined.

### 4.1 Direct Connection to the National Datum

The Geocentric Datum of Australia (GDA94) is the basis for any geodetic infrastructure in Australia (ICSM, 2006). For a review of coordinate systems, datums and associated transformations the reader is referred to Janssen (2009c). The introduction of CORS or 'active' control marks has revolutionised positioning for spatial professionals. However, 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. In Australia, we currently find ourselves working in this challenging transition period between old and new, and this 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. Shortcomings in the initial GDA94 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 considerable distortions in GDA94, rendering it unsuitable for CORS network operation. Across NSW, known distortions reach up to 0.3 m in the horizontal component. It was therefore essential to introduce a new set of highly accurate and consistent 3-dimensional coordinates for use in CORSnet-NSW. This new realisation of the national datum is known as GDA94(2010), while the original definition of GDA94 is now referred to as GDA94(1997) in NSW (Janssen and McElroy, 2010). GDA94(2010) coordinates not only provide interoperability between existing CORS networks but also with Geoscience Australia's online GNSS processing service, AUSPOS (GA, 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.

### 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) at the start of *every* real-time survey. The site transformation is performed by observing several established ground control marks surrounding the survey area and calculating a local 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, most countries utilise an approximation of the orthometric height system referenced to the geoid. The Australian Height Datum (AHD71) is no exception (Roelse et al., 1971). GNSS-based height transfer is possible by converting ellipsoidal heights ($h$) determined by GNSS to orthometric heights ($H$) that refer to AHD71. 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 and Janssen, 2009c):

$$H = h - N$$

Equation 1

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 3). 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). 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 (Janssen et al., 2011c). 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, in Australia, the recently released AUSGeoid09 geoid model (Brown et al., 2011) provides N values with unprecedented absolute accuracy (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 plays a crucial role for CORS network operators (Janssen and Haasdyk, 2011a). Consequently, it is also an important issue for users of CORS data. GNSS antenna models provide offsets between the antenna reference point (ARP), generally located at the bottom of the antenna, and the mean antenna phase centre (APC) to which GNSS observations are measured. 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. The models also describe the antenna phase centre variation (APCV) which is dependent on the azimuth and elevation of the received satellite signal, and its frequency. This variation can cause additional errors of up to 20 mm in the measurement to a single GNSS satellite. Not surprisingly, the size, material and design of the antenna have a large effect on the magnitude and distribution of the APCV. Since manufacturers have become very good at designing and building symmetric GNSS antennas, the azimuth-dependent component is less of a concern than the elevation-dependent component of the variation. However, there are significant differences between antenna types. While the average rover antenna shows a much smaller magnitude than the more expensive CORS choke ring antenna (especially for low elevations), its variation is far less symmetric and shows larger differences in the pattern between frequencies (Figure 4).

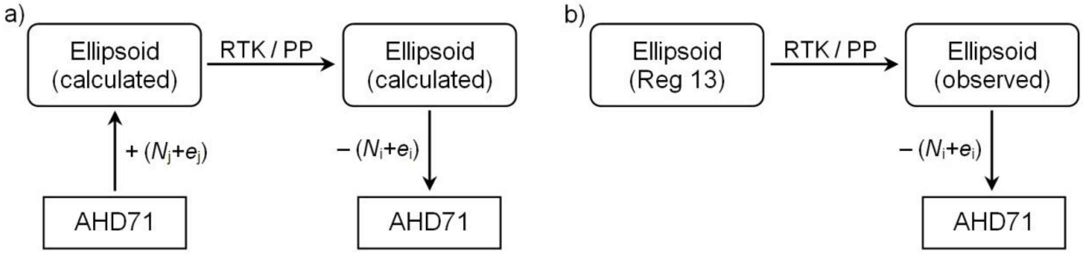


Figure 3: GNSS height transfer methodology using RTK or post processing (PP)
in the past (a) and using CORS (b)

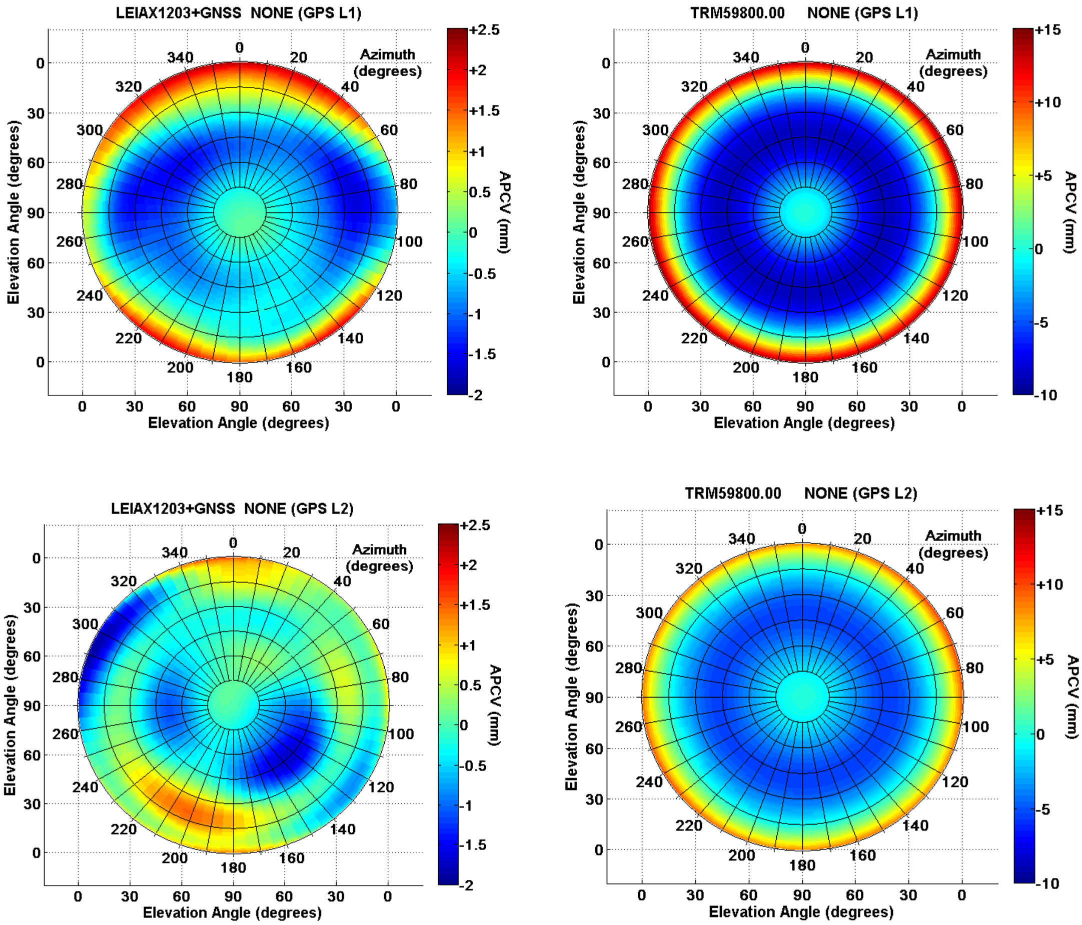


Figure 4: Absolute APCV as a function of satellite azimuth, elevation and frequency for the
LEIAX1203+GNSS rover antenna (left) and the TRM59800.00
choke ring antenna (right), both without radome

In the past, ‘relative’ APCV models were used based on one specific antenna type with assumed zero APCV as a reference antenna. 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. 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. In order to avoid confusion, it is advised to only use the absolute antenna models available from IGS (2011a). These published IGS models have recently experienced significant improvement, coinciding with the release of ITRF2008 (Altamimi et al., 2011). 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 IGS APCV corrections 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 apply 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.

*4.5 Automated CORS Network Monitoring*

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 GDA94(2010) 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. In addition to the ongoing monitoring of CORSnet-NSW sites for these small, long-term trends, commercial modules are available for integration into the CORS network management software in order to enable real-time detection of larger, sudden movements of the CORS antennas.

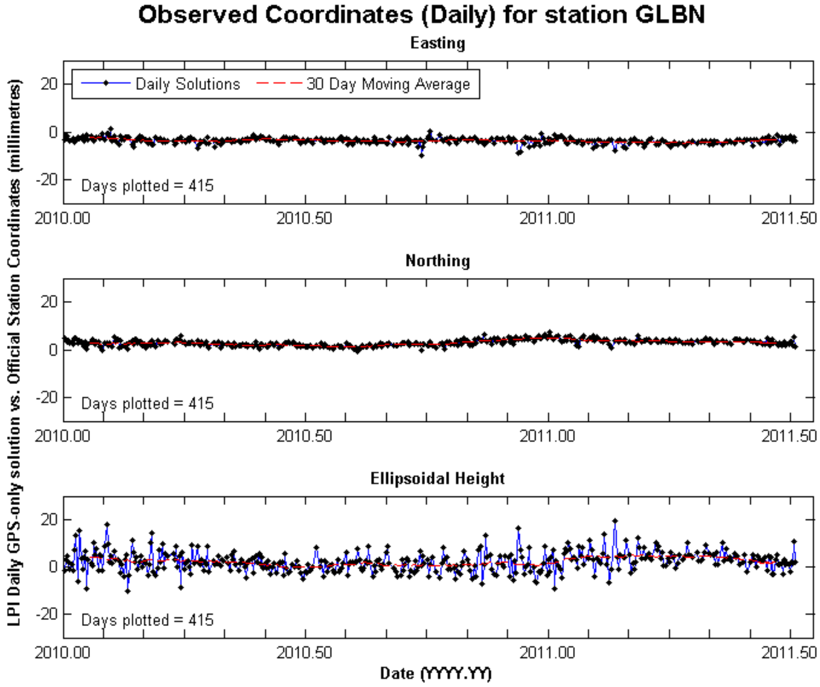


Figure 5: Observed position vs. official position for Goulburn CORS (LPI, 2011a)

Combining these two state-of-the-art methods ensures that the CORS operator 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 or quality control of the CORS network and services, e.g. via the use of continuous RTK/NRTK rover installations.

*4.6 Contribution to Regional Geodesy*

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. New CORS networks have the opportunity to contribute to regional or even global geodesy, provided the often very stringent monumentation specifications are met. 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 coordinate 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 an 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, 2011b) 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).

## 5. Concluding Remarks

The ever-increasing uptake of GNSS technology has revolutionised the way 3-dimensional positions are determined on and above the Earth's surface. CORS networks are being introduced across many countries to provide improved access to positioning infrastructure for a wide range of applications. This paper has outlined and discussed the technical challenges faced by CORS network operators, using CORSnet-NSW as an example. The purpose of a CORS network is closely linked to the required network density and the station monumentation to be used. Apart from the logistics of physically building the monument and installing the electronic equipment at suitable locations, a number of other issues need to be considered. These include funding arrangements, collaboration with other organisations hosting the CORS, long-term tenure of the land and/or the building to be utilised, access to the site, system redundancy and communications, and the integration of existing CORS networks. In order to provide (and achieve) reliable GNSS positioning of homogeneous and high accuracy across the network area, decisions regarding the operation of the CORS network are required. Important aspects include the consistent connection to a high-quality datum, GNSS-based height transfer considerations, the use of absolute GNSS antenna modelling, stability and integrity monitoring, and the possible contribution to regional or global geodesy initiatives.

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