Standards and Practices for GNSS CORS Infrastructure, Networks, Techniques and Applications

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SUMMARY

Over the course of the last decade the use of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) to provide positioning services in Australia has become more prevalent. These GNSS CORS have been established by federal, state and territory governments and private companies for a variety of purposes. For example from a geosciences perspective GNSS CORS have been used to maintain geodetic reference frames or measure and monitor the movement of the earth, whereas other organisations have set up such facilities to realise and provide access to the national horizontal and vertical datum through positioning services.

As a consequence, and to ensure a unified approach to the expansion of GNSS CORS, the Intergovernmental Committee on Surveying and Mapping Geodesy Technical Sub-Committee (ICSM GTSC) is preparing standards, guidelines and recommended practices for establishing and operating GNSS CORS sites to define or access the datum in Australia. The document is based on the tiered hierarchy of permanent GNSS reference stations proposed by Rizos (2007) where 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.

The standards describe maximum uncertainty and stability requirements for the three tiers described above. The guidelines and recommended practices provide information on methods and considerations for the construction and operation of the GNSS CORS sites in order to achieve recognition within a particular tier. The creation of these guidelines is complicated by the need to consider not only the requirements of the tiered structure of GNSS reference stations, but also the potential variation of local site factors such as remote location, available budget, monument foundation, power requirements and available communication technologies. Additional complications arise when considering that, irrespective of tier, a site may offer real-time precise positioning services, and those services may be offered as either a single station service or part of a networked solution.

This paper describes the content of the draft standards, guidelines and recommended practices document and the considerations made in its creation. It discusses why such a document is required in Australia, and the intended use of the document in creating and operating GNSS reference stations to provide precise positioning services aiding datum definition, densification, and access.

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1. INTRODUCTION

The role of the Intergovernmental Committee on Surveying and Mapping (ICSM) is to provide leadership, coordination and standards for surveying, mapping/charting and national datasets (ICSM, 2010a). The Intergovernmental Committee on Surveying and Mapping Geodesy Technical Sub-Committee (GTSC) coordinates geodetic projects across Australia and assists ICSM to meet its objectives (ICSM, 2010b).

Beginning in 1990, the GTSC has maintained the ICSM publication *"Standards and Practices for Control Surveys (SP1)"*. This document provides clear standards of accuracy for control surveys, and a guide to recommended survey and reduction practices. SP1 has incorporated another ICSM publication "*Best Practice Guidelines for the Use of the Global Positioning System (GPS) for Surveying Applications"* since Version 1.4, released in 2000 (ICSM, 2010c).

The GTSC continually revises SP1 to improve the clarity of the document and to keep the content relevant to current control survey practices and any revision to the national datum. A new version of SP1, designated Version 2.0, is currently in draft format and is scheduled to replace the current Version 1.7 in 2010. For more information about the proposed SP1 Version 2 refer to the paper by Abbey (2010) – *"SP1 – A New Standard for Control Surveys in Australia"*. As part of the latest SP1 revision it was recognised that there is a need to produce standards and guidelines regarding the installation and maintenance of Global Navigation Satellite System Continuously Operating Reference Stations (GNSS CORS). It is therefore anticipated that the standards for GNSS CORS accuracy and stability will be defined in SP1 Version 2, and the guidelines on GNSS CORS outlined in a subsidiary document that reference the SP1 standards.

Tentatively titled *"Guidelines for Continuously Operating Reference Stations"*, the guidelines and recommendations for GNSS CORS discussed in this paper are nearing a final draft at the time of writing, and are not expected to be finalised prior to the FIG 2010 Congress. Once completed and endorsed by ICSM the document will be publically available to assist those operating or intending to establish GNSS CORS in Australia, and the users of data and services from these GNSS CORS.

2. MOTIVATION

Initially GNSS CORS were established in Australia by federal, state and territory government agencies with responsibility for defining, implementing, maintaining and providing access to the geodetic reference frame. Early examples were the Australian Regional GPS Network (ARGN) established by Geoscience Australia, and state based networks in Victoria

(GPSnet™) and Queensland (SunPOZ). These agencies, through their representatives on the GTSC, shared knowledge and experience on establishing and maintaining GNSS CORS sites. More recently numerous GNSS CORS have been established by private entities and local government, either for their own needs, or to provide positioning services to others. These private entities often work with GTSC members on issues such as how best to implement GNSS CORS ensuring that the data and services were consistent with the national reference frame, and discussing how best to implement GNSS CORS services. This increased interaction and construction of GNSS CORS was a major driver behind the GTSC decision to draft GNSS CORS guidelines.

It is hoped that the guidelines will provide potential GNSS CORS operators with assistance in planning the installation and operation of their sites, and will provide users of data from these GNSS CORS an understanding of the quality of the data they are using, and the suitability of data from a particular GNSS CORS site or service for their intended application. While the guidelines have been written specifically for Australia, a number of existing international standards and guidelines on GNSS CORS establishment, operation and use have provided valuable background contributions to the document.

3. TIERED GNSS CORS

Rizos (2007) introduced the concept of a tiered approach to GNSS CORS. The first three tiers are described as follows:

- *Tier 1*: the International GNSS Service[1] (IGS) stations or equivalent, that is those GNSS CORS contributing to the development of the International Terrestrial Reference Frame for the globe or region;
- *Tier 2*: the primary national geodetic network or the backbone of a national geospatial reference system and frame or datum;
- *Tier 3*: the state (or secondary) and private GNSS networks, which primarily provide access to and realisation of the datum through positioning services.

The guidelines use this tiered approach to separate the site requirements for GNSS CORS. For example the guidelines require Tier 1 and 2 sites to use choke ring antennae, where Tier 3 sites may use other styles of GNSS antennae.

Australia has a number of existing Tier 1 GNSS CORS sites that contribute to international geodesy through IGS, and a subset of these are IGS Reference Frame sites that contributed to the IGS realization of ITRF (IGS, 2010). Many of these IGS Reference Frame stations are part of the ARGN operated by Geoscience Australia. IGS has produced *"IGS Site Guidelines"* (IGS, 2007) which provide the required and recommended specifications for GNSS CORS sites that may be included in the network. The Australian guidelines for Tier 1 stations have, therefore, been written to complement the specifications required for IGS stations.

[1] Refer to website http://igscb.jpl.nasa.gov/

The ARGN also contributes to the primary national geodetic network, and these stations are therefore also Tier 2 stations. Therefore a GNSS CORS installation can be in more than one tier as defined above, though the guidelines treat the site as being in the higher tier (in this case Tier 1). The federal, state, and territories are currently densifying Australia's Tier 2 network through the AuScope[2] project. AuScope is one of a number of federally funded projects under the National Collaborative Research Infrastructure Strategy. A subcomponent of AuScope involves the installation and operation of approximately 100 GNSS CORS sites across Australia. These stations are being constructed to Tier 2 specifications, though a select few may also contribute data to IGS, and will therefore also be Tier 1 stations in a similar manner to the ARGN stations.

There are a number of Tier 3 GNSS CORS networks operating in Australia. For example, the state and territory governments operate GPSnet™ (Victoria), CORSnet (New South Wales), SunPOZ (Queensland), and networks over Darwin and Alice Springs (Northern Territory). There are also an expanding number of GNSS CORS networks and single station GNSS CORS operated by private industry. Where Tier 1 and 2 GNSS CORS are often established primarily to provide static data for datum definition through post-processed analysis, the Tier 3 networks are often implemented to provide real-time precise positioning services that access and realise the datum. It should be noted that this does not preclude Tier 1 and 2 stations from offering real-time precise positioning, nor Tier 3 from providing static data for post processing applications.

Potentially there are further tiers of GNSS CORS. For example a farm operating a GNSS CORS for the purpose of automated tractor steering that is not using the national datum might be considered Tier 4 or lower. While the information in the guidelines may assist this farmer to construct or maintain their installation, the guidelines have been created primarily to assist those who are using GNSS CORS to define, implement or access the national reference frame, and therefore only specifically refer to Tier 1 to Tier 3.

GNSS CORS operators planning on establish a large network of Tier 3 GNSS CORS sites are encouraged to install approximately 10% of those stations to Tier 2 standards, contributing data from these stations to federal and state government agencies responsible for the geodetic datum. In doing so the GNSS CORS operator establishes a traceable link between the services offered from their GNSS CORS and the national reference frame, assists geodetic reference frame improvement, and ensures that GNSS CORS are unified on a common reference frame thus enabling interoperability and integration of data. From a geodetic perspective and "whole to the part" concept, this also assists the GNSS CORS operator in monitoring the stability of their Tier 3 GNSS CORS sites relative to the higher standard Tier 2 GNSS CORS sites.

4. ORGANISATIONAL MODEL IMPACTS

[2] AuScope is a non-profit company formed to facilitate the implementation of a world-class infrastructure system for earth science through the delivery of a range of technologies and capabilities in data acquisition, management, modelling and simulation across the geospatial and geoscience spectrum. . Refer to website – http://www.auscope.org.au/index.php

It may not be immediately apparent that an organisational model, that articulates the roles and responsibilities of GNSS CORS stakeholders, can affect the production of guidelines for GNSS CORS. The primary organisational model drivers for the GNSS CORS guidelines have been the development of the GNSS component of the AuScope project, and the interaction between government agencies and private institutions regarding the establishment, operation and maintenance of private and private/public GNSS CORS networks.

In order to ensure that the GNSS component of the AuScope project was collaboratively and suitably implemented the AuScope GNSS Sub-Committee (AGSC) with representatives from the federal, state and territory governments was established. Since its inception in early 2007, the AGSC has produced a number of policies in relation to AuScope GNSS data access, network management, organisational, product, finance and business issues including policy statements on:

- AuScope CORS Network Data Access and Management
- AuScope GNSS Project Organisational Model
- AuScope GNSS Project Product Specification
- AuScope GNSS Project Data Agreement
- AuScope GNSS Project Financial and Business Model

These policies not only deal with the interaction of the agencies and personnel involved in the AuScope GNSS project, but also the method by which data is produced and accessed, remote site access provisions, GNSS CORS monumentation, and the manner in which the Tier 2 AuScope GNSS CORS interact with existing and future Tier 1 and Tier 3 stations. The policies, therefore, have influenced the preparation of the GNSS CORS guidelines. The AuScope GNSS policies use the organisational principles that originated from the Cooperative Research Centre for Spatial Information (CRC-SI) Project 1.04 "*Delivering Precise Positioning Services in Regional Areas*" (Higgins, 2008).

The model developed by Higgins divides the production of data and services from GNSS CORS into five roles. These roles are: System Specification; Station Ownership; Data Networking; Network Processing, and; Service Delivery as shown in Figure 1. While most of these roles will be carried out by the entities involved in providing the network, the System Specification role is deemed to be primarily the task of the federal, state and territory government agencies that are responsible for geodesy through the ICSM-GTSC. The GNSS CORS guidelines subsequently provide a mechanism for System Specification to be publically available to GNSS CORS operators and their clients. They provide the framework for all GNSS CORS operators to establish and maintain their infrastructure and services in a unified manner.

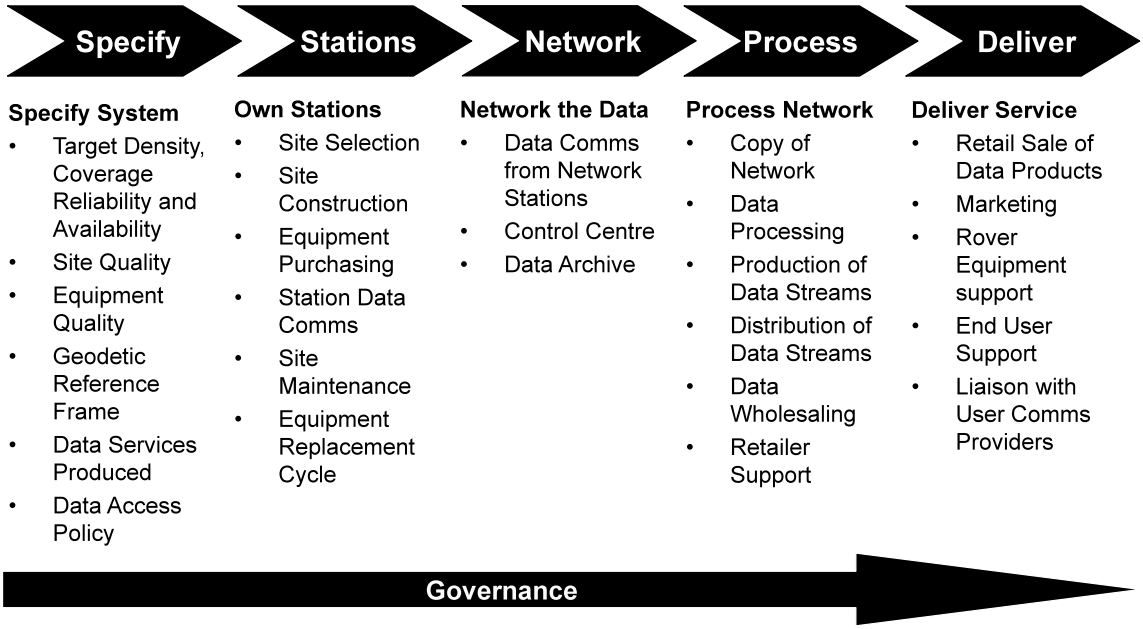

Figure 1: A Model for Describing Organisational Roles in Precise Positioning Services (Source: Higgins (2008))

5. CHALLENGES

The production of the guidelines for GNSS CORS in Australia is challenging for a range of reasons. Some of the main issues that influenced the drafting of the guidelines are briefly described below.

From a survey and geodetic infrastructure perspective, the implementation of GNSS CORS is expensive, and compared with many other smaller countries can be considered more expensive in a country with the large area and relatively small population of Australia. Consider, for example, the concept of creating a real-time positioning network across the Australian continent, similar to the SAPOS network in Germany[3]. The area of Australia is twenty times that of Germany, so it might be expected that Australia requires twenty times more GNSS CORS sites than Germany, costing twenty times as much to construct and operate. Additionally, the population of Australia is approximately a quarter that of Germany, therefore the cost of establishing the Australian network per head of population might be considered eighty times that of SAPOS. While there are significant simplifications in this comparison, it does show that there are important cost considerations in establishing GNSS CORS infrastructure in a country such as Australia.

The increased desire for ubiquitous positioning in both the traditional and non traditional geospatial sectors has created a proliferation of GNSS CORS in Australia over the last 5 years. As a consequence this has instigated a collaborative approach amongst the geoscience

[3] Data Source for comparison: World Bank – World Development Indicators 2008.
Australia – Population 21374000, Area 7741220 square kilometres.
Germany – Population 82140043, Area 357050 square kilometres.
Refer to website - http://devdata.worldbank.org/data-query/

and positioning industry to examine a variety of 'unification' issues that are associated with the establishment of GNSS CORS networks and operators' obligations or drivers to meet the needs of numerous sectors. These issues needed to be taken into consideration when developing these GNSS CORS best practice guidelines. The primary unification issues were:

- The realisation of positions on a single reference frame (datum) rather than a local datum so as to avoid multiple positions on multiple datums at the same points;
- A seamless transition from one GNSS CORS network or positioning service to another;
- Positional accuracy of coordinates;
- Minimising the duplication of GNSS CORS infrastructure;
- Balancing commercial or business based activity with public 'benefit and good'; and
- Developing widely accepted standards that suit the variety of applications that use GNSS CORS data.

As has been stated there are a number of existing GNSS CORS installations in Australia, such as the ARGN, various state/territory and private networks. Some of these sites have existed for a long period of time and thus have a long time series of data that is of great use in understanding the global and national reference frame, while others have been established for more localised or regional scientific, research or commercial purposes and have meet their obligations. During the development of the guidelines, it soon became apparent that some of these existing GNSS CORS, that were originally considered to be in a certain category of the tiered hierarchy of GNSS CORS, did not actually satisfy all of the proposed criterion for each tier. As a consequence there was a challenge to articulate guidelines that would cater for this circumstance and accommodate existing perceptions of status within the tier structure. It is important that the recommendations outlined in the subject guidelines are adopted for all new GNSS CORS. It is also acknowledged, however, that some of the existing GNSS CORS may not comply with all of the recommendations in the guidelines, although operators or owners of these sites should have the intention to take action to ensure compliance. Nevertheless, in all situations it is imperative there are co-operative attitudes and behaviours with respect to management of and best practice for GNSS CORS infrastructure, as this will assist with the unification of such networks in the near future.

Apart from the tier of a GNSS CORS site a principal driver for many GNSS CORS operators is the provision of real-time precise positioning services. For example, the ARGN sites were installed primarily for reference frame definition, and were established to provide static data for post-processing applications, whereas CORSnet, GPSnet™ and SunPOZ were established to provide access to the reference frame through real-time precise positioning (commercially oriented) services. The issue of static versus real-time data provision cuts across the tiered breakdown of GNSS CORS, and the requirements of real-time positioning services must be considered irrespective of tier. For example, modern GNSS CORS receivers have on board data storage, and if communications to a site are cut for an extended time, say a few days, this is not a major problem for sites providing static data only, as long as the data can be retrieved from the receiver when communication capability returns and a continuous archive of the data is achieved. The same communications outage at a GNSS CORS site offering real-time positioning services, however, represents an irretrievable denial of real-time service from that

site. Therefore, while the guidelines are structured around tiers, it was important to ensure that the guidelines also recognise the issues associated with real-time positioning, and create balanced minimum recommendations that accommodate a multitude of purposes.

The final challenge in producing the guidelines and recommendations for GNSS CORS is the future maintainability of the document. The GNSS equipment, communications technology, data transfer protocols and data format standards used by GNSS CORS is continually evolving and at a rapid pace. As such the GTSC is planning to review and update the standards document on an annual basis and are considering interactive web based technologies as a means of undertaken this function.

6. THE GUIDELINES

The proposed ICSM guidelines for GNSS CORS are separated into two sections. The first section contains information impacting the establishment of GNSS CORS. The second section outlines recommended practices for the maintenance and operation of the GNSS CORS, though the ongoing considerations of operating a GNSS CORS may influence the establishment of the site. As the guidelines are not yet endorsed by ICSM, and may alter in the final rounds of editing, the following is a summary of the factors that the guidelines will address.

6.1 Site Establishment

GNSS CORS establishment can be broadly split into the two overarching criterion of site selection and equipment selection. After a preliminary office based assessment of a potential GNSS CORS location, site selection requires reconnaissance to determine site suitability. Equipment selection requires an informed understanding of available equipment capabilities in relation to the site environment and the intended output from the site (for example data formats or the availability and reliability of communications at the site).

6.1.1 Site Selection

Site selection covers guidelines for the site foundation, sky visibility, multipath issues, site security, radiofrequency interference sources, and power and communications issues. The application of the guidelines to an individual site will depend on the proposed tier for the site and business based decisions such as the cost of site establishment and operation.

Site foundation considerations include whether the site is intended primarily to define the reference frame, or to provide access to the datum through a positioning service. This in turn defines whether the GNSS CORS antenna mounting structure needs to be engaged into competent bedrock with a very stable monument, or whether the foundation requirement can be relaxed to be a more cost effective foundation such as a concrete building roof or similar structure.

All GNSS CORS sites require the greatest sky visibility possible. Obstructions above the GNSS antenna prevent GNSS signals from the satellites reaching the GNSS antenna and should be minimised as much as possible. The guidelines propose the level of obstruction that is deemed acceptable at a GNSS CORS site.

Multipath, the effect of GNSS signals arriving at a GNSS antenna via paths other than direct line of site to the satellite, reduces the performance of GNSS receivers, whether they are GNSS CORS, mobile reference stations or rovers. The guidelines provide information on sources of multipath to be avoided, such as metal rooves, fences and wet tree canopy, and provide recommendations on the minimum distance from the GNSS antenna to these sources.

The guidelines examined site security and advocate that generally this aspect is independent of the tier of GNSS CORS to be established. That is, physical site security conditions - protection from theft, vandalism, animals and weather are applicable to all Tiers. For example, Tier 1 and 2 GNSS CORS sites will often be in remote locations, exposed to humans, weather and animals. Security at these sites can be improved by placing the site in an unobtrusive location, providing fencing to protect the GNSS CORS installation from human and animal based interference, and ensuring cabling on the site is installed in durable tubing and preferably buried to improve protection against pests, fire and weather. Equipment such as the GNSS receiver and communications equipment should be installed in a nearby secure enclosure or building. GNSS CORS sites installed on suitable buildings or similar structures (such as Tier 3 GNSS CORS) may have existing manned and/or electronic security either around the clock, or during business hours. In this case GNSS CORS equipment should be placed in a manner that prevents inadvertent disruption of the receiver settings, power supply or communications devices by ensuring only authorised personnel have access to the equipment.

GNSS CORS are established to provide a long continuous time series of data with a typical life span of at least 20 years, and thus this requirement invokes another facet of site security which is ensuring land tenure and access is secure for this length of operation. This facet is detailed in the guidelines however in brief terms the options that provide security of land tenure and access to the equipment include obtaining freehold title, a long term lease, easement, or a formal agreement with a site owner, though this last option should include rights to renegotiate if there is a change of ownership of the underlying parent parcel or land tenure.

The guidelines describe some of the primary causes of radiofrequency interference to be avoided at GNSS CORS sites. These sources include mobile phone repeater towers, television transmission towers, microwave data links, and overhead electrical lines, all of which can interrupt or “wash out” signals from GNSS satellites. Particular care should be taken to avoid sites with sources that are known to interfere with the portion of radio spectrum in which GNSS signals operate, and sites placed in the path of directional transmitters such as microwave data links.

GNSS CORS sites require conditioned continuous power to provide an uninterrupted service. This important site characteristic is also discussed in the guidelines and focuses on the major primary power sources for GNSS CORS sites, which are mains power and solar cells coupled with a battery array. The power production from a solar installation needs to be carefully calculated based on available sunlight at the site, the power draw of the site equipment, and the length of time the batteries need to provide power at the site in the event of prolonged overcast weather. The decision on which primary power source will be used will often be determined by the availability of existing 'power' infrastructure, and any subsequent establishment, maintenance and operation cost. Site operators also need to consider secondary power supplies such as generators and Uninterrupted Power Supplies (UPS). It is highly recommended that secondary power supplies can be brought online automatically or manually through remote methods, to ensure the site can continue operating when the primary power source fails. Continuous power is required whether a site is providing real-time positioning services, or static data for post processing and geodetic reference frame monitoring.

In a similar manner to the considerations described for power, a GNSS CORS site operator nowadays has a number of methods to provide communications from the site to a user. This technical component is deemed crucial to the expansion of GNSS CORS infrastructure and the connectivity of the various networks across the continent. Consequently the guidelines were compelled to explain the various communication options. A summary of this section is as follows. Some GNSS CORS sites will offer real-time positioning through radio transmitters, while others will use internet based protocols requiring communications through mobile phone digital networks or satellite services (such as '3G', 'Wi-Fi', 'VSAT'), or cabled internet connections, possibly via a central control computer in the case of GNSS networks. In these cases the GNSS CORS operator will need to assess the availability of various communications methods at a site, bearing in mind that data with a latency of greater than 2 seconds may not be of use to an end user. GNSS CORS operators providing data for static services may be able to use the on board logging functionality of modern GNSS receivers to retrieve data in the event of a communications outage, so long as the data can be retrieved from the receiver once communications service resumes. The issue of the best communications method for the site needs to be considered during the GNSS CORS planning stage.

6.1.2 Equipment Selection

The selection of GNSS CORS site equipment depends on the service to be provided from the site. The guidelines provide recommendations on receiver, antenna, cabling, and monumentation requirements for a site. An overview of these main requirements is as follows.

Most professional grade GNSS manufacturers have developed a range of GNSS receivers that are specifically designed for use at GNSS CORS sites. While other forms of GNSS receivers can be used with additional equipment to provide services from a site, the dedicated GNSS CORS equipment is recommended as it contains the hardware and software required for GNSS CORS applications. GNSS CORS receivers should:

- Track GNSS signals from multiple GNSS constellation satellites;
- Have in built communications capabilities either through dedicated internet ports or radio transmitters;
- Have remote configuration capability;
- Provide industry standard data output through RTCM and RINEX, though additional proprietary outputs may be used;
- Be capable of logging at least one week of data locally to provide a continuous data time series in the event of a prolonged communications outage;
- Be suitably weatherproof (dust/humidity/water/shock resistant);
- Be capable of recording data from additional sensors such as meteorological or tilt sensors;
- Have in built data security and administration capability through client authentication and secure administrative controls.

The type of antenna installed at a GNSS CORS site is a function of the intended tier. All GNSS CORS sites require antennae that have well understood antenna reference points and phase centre gain patterns through the IGS absolute antenna files (IGS, 2008). Tier 1 and 2 sites require choke ring antennae with Dorne Margolin style elements. It is recommended that Tier 3 sites also use this style of antenna, though there are alternative "geodetic grade" antennae that may be used on Tier 3 GNSS CORS installations.

It is important to ensure that a GNSS CORS site has suitable cabling between the GNSS antenna and receiver. There are various grades of cabling available for GNSS installations and an increase in the distance between the antenna and receiver will require an increased grade of cabling or the insertion of in line signal amplifiers. Higher grade cables suffer less data loss, are more expensive and less flexible than lower grade cables. Cables should be protected against weather and pest intrusion, and contain in line lighting arrestors to prevent lightning based power surges from affecting the receiver. Tension in the antenna cable should be avoided, particularly at the interfaces with the antenna and receiver.

GNSS CORS antenna monuments should never use tribrachs as their levelling screws cannot be fixed to ensure maximum antenna stability. Antenna monuments on buildings or similar structures need to be designed for the individual installation and be made of stainless or galvanised mild steel. Tier 1 and 2 GNSS CORS sites should always use reinforced concrete pillars or braced deep driven monuments firmly engaged in bedrock to increase monument rigidity and ensure that any movement in the antenna reflects movement of the underlying stable foundation.

6.2 Recommended Practices for GNSS CORS Operation

Once a GNSS CORS is constructed there are a number of issues the operator must address and monitor for the purpose of site operation and maintenance. The guidelines address the issues of coordination, stability monitoring, data formatting, data access, and metadata requirements. The following is a synopsis of the issues just mentioned.

When claiming to operate within the national reference frame, the coordinates of the site need to be calculated in a traceable manner. The guidelines recommend that GNSS CORS operators submit a substantial time series of Receiver INdependent EXchange (RINEX) data (either by providing months of recorded data, or ongoing data streams) to Geoscience Australia[4] for processing and analysis. If all GNSS CORS stations were to be coordinated in this manner then all services from GNSS CORS could be said to be on a unified realisation of the national reference frame, and provide the greatest consistency in coordinates between different GNSS CORS sites, minimising the positional uncertainty of the coordinates, as defined in SP1. This method of coordination, particularly when data submission is via an ongoing stream, provides the greatest geodetic benefit in regard to improving geodetic accuracy in future revisions of the national reference frame.

An alternative method of providing coordinates for a GNSS CORS site is through local surveys to coordinated marks held in the registries (or geodetic databases) of state and territory agencies with responsibility for geodesy. This method will minimise the local uncertainty of the coordinates as defined by SP1, and give the best fit to the national reference frame as currently implemented in the area surrounding the GNSS CORS.

GNSS CORS operators should note, however, that there may be a difference between the 'unified' coordinates derived through Geoscience Australia analysis, and coordinates derived through the local determination. The reason for this difference is that the analysis of data from networked GNSS CORS is proving more accurate than the original implementation of the reference frame. It is important for GNSS CORS operators to inform users of how the coordinates of the GNSS CORS site were determined, and why there might be a difference between coordinates determined by a using the GNSS CORS station and either the locally implemented datum or the result using a larger area service such as Geoscience Australia's AUSPOS[5] online processing tool.

GNSS CORS operators should also be continually monitoring the stability of their GNSS CORS antenna reference point. This may be undertaken through discrete campaigns analysing the movement of the reference point relative to local ground marks, by submitting ongoing data streams to Geoscience Australia for analysis and monitoring, or through the software used to manage a GNSS CORS network. Tier 3 site stability can be monitored through comparison to nearby Tier 2 sites, and the stability of Tier 2 sites can be monitored with reference to Tier 1 sites. Tier 1 sites are monitored in a global sense through the IGS. It is recommended that GNSS CORS sites archive data in the RINEX format to ensure compatibility for post-processed applications with the greatest range of equipment and processing software available. Currently RINEX Version 2.11 is considered standard, with Version 3.0 being finalised to incorporate additional features and developments in GNSS. GNSS CORS operators may also choose to archive the raw data from the GNSS CORS equipment in a proprietary format which provides additional functionality, but may restrict its use for users with equipment from a different brand of GNSS manufacturer.

[4] Geoscience Australia is a national government agency who facilitates the operation and maintenance of Australia's national geospatial reference system or geodetic framework.
[5] Refer to website - http://www.ga.gov.au/geodesy/sgc/wwwgps/

The situation is similar for real-time precise positioning data. The industry standard method of providing real-time corrections is through the format devised by the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC104. Again, most manufacturers GNSS equipment can decode and utilise corrections provided in the RTCM format. The GNSS CORS operator may also provide services in a proprietary format, and these services may provide additional functionality to users who have equipment that can decode that format. Again, however, users with equipment from alternative manufacturers may not be able to decode the proprietary format data.

The guidelines also provide recommendations on the metadata requirements for a GNSS CORS site. The GNSS CORS operator should keep a comprehensive metadata set that includes all relevant information for the site including metadata on the:

- Site;
- Receiver;
- Antenna;
- Monument;
- Coordinate derivation;
- Power;
- Communications;
- Data Formats;
- Reliability of service;
- Stability;
- Additional Site Sensors;
- Data Access.

This information should include, as relevant, key contacts, agreements, tenure, equipment vendors, models, serial numbers, firmware versions, equipment warranties, purchase dates, photographs of the site, repairs and upgrades. The metadata should be kept current, with changes logged as soon as they are made, and historical logs maintained to ensure that an understanding of the site conditions at any given moment is available. A subset of this metadata should be provided to all users of data from the GNSS CORS site, with sufficient information for the user to make an informed choice on whether data from the GNSS CORS site will be suitable for their intended application.

7. CONCLUDING REMARKS

In concluding, the primary purpose of this paper was to provide an overview of the content in the draft document *"Guidelines for Continuously Operating Reference Stations"*. It was also intended that this paper deliver an insight into the challenges experienced, why such a document was required, and the consideration of many associated technical and non technical issues during its creation. More importantly, the authors hope the GNSS CORS industry in Australia are now aware that a such document is being produced and will be available 'sooner rather than later'.

Ultimately these guidelines will be incorporated into an ICSM – GTSC publication similar to SP1, and be a dynamic document that will be used to manage the technical specifications for the unification of GNSS CORS and positioning infrastructure to assist datum definition, densification, realisation and access.

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BIOGRAPHICAL NOTES

Darren Burns, Senior Spatial Information Officer in the Land and Vegetation Division of the Queensland Department of Environment and Resource Management, member of the newly formed Surveying and Spatial Sciences Institute.

Darren Burns obtained his degree in Bachelor of Surveying and Spatial Information Systems from the University of New South Wales in 2004. He has undertaken cadastral, engineering and control surveys in a private firm in Sydney prior to his employment with the Queensland Government, and now works in the Geodesy and Positioning Unit of the Spatial Information Group. He is currently Queensland's representative on the Intergovernmental Committee on Surveying and Mapping – Geodesy Technical Sub Committee.

Robert Sarib, Manager, Survey Services in the Land Information Division of the Northern Territory Government's Department of Lands and Planning, Licensed Surveyor, member of the Surveying and Spatial Sciences Institute, and Vice Chair of Administration for FIG Commission 5 – Position and Measurement.

Robert Sarib obtained his degree in Bachelor Applied Science – Survey and Mapping from Curtin University of Technology Western Australia in 1989. He was registered to practice as a Licensed Surveyor in the Northern Territory, Australia in 1991 and achieved this during his employment with the Northern Territory Government. Since then he has work in the private sector as a cadastral surveyor, and more recently re-employed by the Northern Territory Government to manage the Northern Territory Geospatial Reference System and administer the Survey Services work unit of the Office of the Surveyor General. He also holds a Graduate Certificate in Public Sector Management received from the Flinders University of South Australia.

Mr Sarib is currently a member of the FIG Commission 5.2 Working Group – Reference Frame in Practice, and the Northern Territory delegate for both the Australian Inter-governmental Committee on Survey and Mapping - Geodesy Technical Sub Committee and the AuScope GNSS Sub Committee. He is the Northern Territory representative on the Land Survey Commission of the Surveying and Spatial Sciences Institute. He is also a board member of the Surveyors Board of Northern Territory for Licensed or Registered surveyors.

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