GNSS at NSW tide gauges... *of CORS!*

VOLKER JANSSEN, RUSSELL COMMINS AND SIMON MCELROY

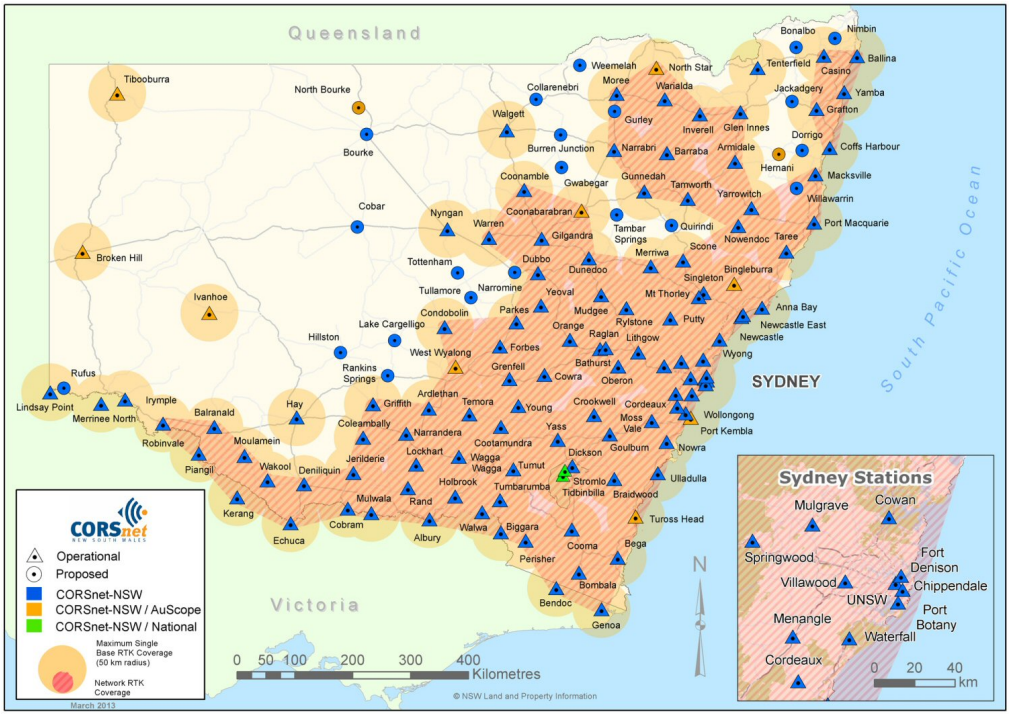


Figure 1: CORSnet-NSW network map as of March 2013.

Tide gauges measure and record the water level over time. The tide gauge records available from Fort Denison, Sydney Harbour and the Pilot Station, Newcastle in New South Wales (NSW) are two of the longest continuous records in the southern hemisphere. By virtue, these are of considerable national and international importance in relation to sea level rise and climate change research.

For the precise determination of any sea level change, it is fundamental to know whether or not the land upon which the tide gauge is located is actually moving. Is the sea level rising or the land falling? Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) are the ideal candidates to provide accurate and continuous measurements of land movement at tide gauge locations.

This article outlines the high value of augmenting tide gauge records with GNSS CORS. It also provides an insight into the considerable difficulties encountered in the installation of such CORS in sensitive, heritage-listed and harsh marine environments. We focus on the recent construction of two CORS at the aforementioned tide gauges, which have been integrated into the CORSnet-NSW network to deliver high-accuracy positioning infrastructure for NSW.

The coastal zone

Owing to its rich diversity of beaches, estuaries, headlands and foreshore landscapes, the coastal zone is one of the key environmental assets in Australia. It is also one of the key national recreational amenities, tourism drivers and peak economic margins.

With some 85% of the population residing within 50 km of the coast, Australia faces significant threats into the future from projected sea level rise. Over 710,000 addresses are located within 3 km of the coast and lower than 6 m elevation. A projected global rise in mean sea level (MSL) of up to 1 m over the 21st century is therefore likely to have profound economic, social, environmental and planning consequences.

In this context, it is essential to monitor trends emerging from local (regional) sea level records to enhance global average measurements and future projections. Long-term changes in MSL relate to variations in ocean currents, changes in the volume of water in the oceans and thermal expansion of the ocean water mass.

Land motion at tide gauges

Long-term tide gauge records provide a measure of the water level relative to a fixed, land-based reference mark. Dynamic oceanographic and meteorological effects can be averaged out (or isolated) over time to reveal the comparatively small underlying change in MSL.

However, in order to allow a rigorous estimation of sea level change, it is essential

to determine whether the tide gauge records are contaminated by any vertical land motion. Processes that can contribute to such land movement include plate tectonics (e.g. earthquakes and volcanic eruptions), glacial isostatic adjustment (the ongoing rise of land masses that were depressed by the large weight of ice sheets during the last ice age) and factors caused by humans that mainly contribute to subsidence (e.g. groundwater extraction, land reclamation and development loadings).

The vertical land motion can be as large as the sea level change. Obviously, this greatly complicates the determination of any apparent trends. Sea level trends obtained from tide gauge records are in general only corrected for glacial isostatic adjustment because this can be readily modelled. The other vertical land motion components are often unknown.

Several studies have highlighted the necessity to better understand and monitor land movements so that they can be adequately considered when tide gauge data are analysed. For example, land subsidence at the Port Adelaide and Outer Harbour tide gauges in South Australia (caused by soil compaction associated with wetland reclamation and groundwater withdrawal) accounts for 75% of the MSL rise recorded by these tide gauges. The Pilot Station tide gauge in Newcastle is significantly affected by land subsidence due to underground mining, having subsided by about 60-70 mm over the period from 1940 to 2000 alone.

CORS to the rescue

CORS networks are being introduced and expanded across Australia and internationally to provide improved access to positioning infrastructure for a wide range of applications. These CORS are the ideal candidates to provide accurate and continuous measurements of land movement at tide gauge locations. Following analysis of the resulting land motion time series, relative tide gauge observations can be readily adjusted to measure the absolute changes in ocean water levels over time.

GNSS has long been used to determine horizontal land movements to high accuracy. Nowadays it can also provide vertical land motion monitoring with an accuracy of better than 1 mm/yr, thereby improving the estimation of sea level rates both regionally and globally. This vertical accuracy is achieved by carefully taking into account geophysical factors that cause the Earth's crust to deform periodically (with periods ranging from several hours to several years) due to mass-redistributions in the atmosphere, continents and oceans.

CORS technology can provide continuous monitoring of absolute land motion in an automated fashion. This offers substantial advantages over episodic, relative monitoring methods based on terrestrial surveying techniques.

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. It is built, owned and operated by Land and Property Information (LPI). As of March 2013, CORSnet-NSW consists of 120 stations. Efforts are underway to expand the network to over 150 CORS by mid 2014 (Figure 1).

Currently, 55% of the area of NSW (and 98% of the population) is covered by the single-base RTK service. Network RTK is available to 37% of the area of NSW (and 94% of the population). All CORSnet-NSW reference stations are equipped with the most recent dual or triple constellation GNSS hardware, purposely mixing equipment from two different manufacturers.

CAAM

The new CORSnet-NSW Adjustable Antenna Mount (CAAM) was developed and patented by LPI for use within CORSnet-NSW (Figure 2). Unlike conventional antenna mounts, it provides a legally traceable survey monument that allows the GNSS antenna to be oriented to True North without the need to introduce an antenna height. All Tier 3 CORSnet-NSW sites installed since March 2011 incorporate the CAAM. LPI encourages adoption of the CAAM for use in other CORS networks.

Figure 2: Internal workings of the CAAM.

WALIS Forum 2013

More and more companies around the world are using the power of location-based information and technology to integrate information across their operations to transform and grow their business.
WALIS will show you how they're doing it!

THURSDAY 7 AND FRIDAY 8 NOVEMBER
AT THE CROWN COMPLEX PERTH

Including the WA Spatial Excellence Awards 2013 Dinner

WALIS FORUM 2013

For more information: **http://www.walis.wa.gov.au/forum**

Installing CORS at tide gauges

The Fort Denison and Pilot Station tide gauges provide two of the most important continuous sea level records available for the southern hemisphere. Perhaps surprisingly, these critical tide gauges are not part of the Australian Baseline Sea Level Monitoring Project nor the South Pacific Sea Level and Climate Monitoring Project.

Instead, they are managed by port authorities to facilitate the day-to-day operational requirements of commercial ports and not for scientific purposes. Consequently, they do not utilise consistent technologies or operating procedures or contain sufficient survey records to consider vertical land motion at each individual tide gauge over the record length. The installation of GNSS CORS at tide gauge locations can overcome these issues.

When choosing a new CORS site, careful consideration needs be given to the surrounding environment. This includes access to bedrock, no radio interference, a clear skyview and low multipath. However, in the case of a tide gauge, the conditions are usually far from ideal, particularly in a busy port. In addition, considerable difficulties may have to be overcome if the new CORS is to be installed in sensitive, heritage-listed, harsh marine environments.

Figure 3: Fort Denison tide gauge (the historic Harrison tide gauge is visible on the left).

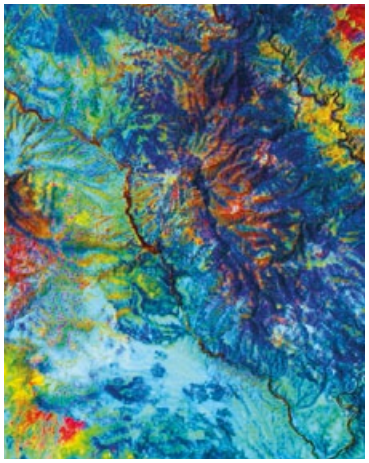
Ideally, the CORS should be co-located with the tide gauge (i.e. be right next to it). However, in practice this is often not possible due to factors such as the physical location of the tide gauge (e.g. in a building at Fort Denison or on top of a stilling well in Newcastle), jetties being subject to physical disturbances from vessels, the marine environment being extremely challenging (e.g. negative effects of salt, wind and water), and special workplace health and safety issues.

CORS construction at any tide gauge is known to be the most challenging of all such constructions. It requires the use of special materials and techniques to protect the sensitive electronic equipment from the harsh environment (e.g. marine-grade stainless steel mounts, dual air filters and sealed cabinets). For CORS placed in public view, security concerns (e.g. installation of security cameras and tamper-proof antenna monuments, cabling and cabinets) and aesthetic considerations are generally also required. Things get really complicated when heritage constraints have to be considered as well.

Understandably, these factors contribute to significantly higher installation costs. They also ensured that the planning, preparation, hardware requirements, associated approvals and installations for the Fort Denison and Newcastle East (Pilot Station) CORS were not straightforward exercises.

GIS in Mining & Exploration
www.gisinmining.com.au

Main Conference 31st July – 1st August 2013
Workshops 31st July – 2nd August 2013
Networking Dinner & Drinks 31st July 2013
Venue Duxton Hotel, Perth, WA, Australia



OVER 10 SPEAKERS!
KEY SPEAKERS INCLUDE:
Jason Schaafsma, GIS Manager, **RIO TINTO**
Ben Sommerville, Spatial Systems Manager, **THIESS**
Dhan Prabhu, Senior GIS Geologist, **ILUKA RESOURCES**
Geoff Peters, Senior Geophysicist, **INTERNATIONAL GEOSCIENCE PTY LTD**

9 SP POINTS AWARDED TO EACH ATTENDEE BY THE **AUSTRALIAN INSTITUTE OF MINE SURVEYORS (AIMS)!**

BOOK NOW!
T: +61 2 9229 1000
E: registration@iqpc.com.au
W: www.gisinmining.com.au

Mining iQ
a division of IQPC

Fort Denison CORS

Fort Denison is a historic fortification that remains an enduring iconic feature in Sydney Harbour. It is part of Sydney Harbour National Park and listed on both the State Heritage Register and the Register of the National Trust. The Fort Denison tide gauge records date back to 1886, and the current tide gauge is located in a dedicated room (Figure 3).

Under NSW heritage legislation, a heritage impact statement addressing the principles of the Fort Denison Conservation Management Plan was required for the CORS construction to go ahead. Although development consent for a tide gauge CORS is not required under the State Environmental Planning Policy, a review of environmental factors had to be prepared due to the prominent nature of the site.

Several constraints were imposed in addition to the standard selection criteria for CORS sites. These included:

- Must have a negligible effect on the silhouette of the island (i.e. short mount with a low-profile antenna).
- Must not cause any damage or change to the original fabric of the fort (i.e. drilling sandstone is prohibited).
- Must involve minimal changes to any part of the island.
- Must not involve any excavation.

Figure 4: Fort Denison CORS antenna monument (including CAAM).

It took six months to complete the attainment of all relevant approvals, facilitation of all necessary heritage considerations and rigorous, successful pre-testing of alternative hardware setups. The Fort Denison CORS was constructed within 75 m of the tide gauge and became operational in May 2012.

It consists of a 3.3 m tall sandblasted, marine-grade stainless steel pillar with integrated CAAM (Figure 4). The CORS monument was secured by stainless steel rods penetrating through the existing modern concrete slab into the bedrock below and braced with stainless steel rods set into a brick wall embedded in the original stonework of the Fort during the latter half of the 20th century.

Newcastle East CORS

The Newcastle Pilot Station tide gauge records date back to 1925. The current tide gauge is mounted on top of a stilling well adjacent to the Pilot Station Finger

WELCOME TO GITA ANZ 18th ANNUAL GEOSPATIAL SOLUTIONS CONFERENCE

05–07 AUGUST 2013, BRISBANE

WISDOM THROUGH THE SPATIAL SPHERE

BUILDING ON FUNDAMENTALS

This year GITA is launching a new conference format providing an excellent educational platform for delegates whilst keeping the traditional networking opportunities offered in the past.

By integrating workshops into the main program, delegates will be able to get more out of the conference via a larger selection of topics and speakers on offer.

We welcome the **Lord Mayor of Brisbane, Cr. Graham Quirk** who will open the conference and you to be a part of GITA ANZ 18th Annual Geospatial Solutions Conference 05–07 August 2013.

We are proud to announce our renowned keynote speakers for this year:

- Lord Mayor Graham Quirk – Brisbane
- Terry Effeney, CEO – ENERGEX
- Ian McLeod, CEO – Ergon Energy
- George Theo, CEO – Unitywater
- Martin Betts, Executive Dean – Queensland University of Technology
- Talbot Brooks, Director – Center for Interdisciplinary Geospatial Information Technologies, Delta State University

Visit **www.gitaconference.org.au** to learn more about our keynote speakers.

GITA 2013 EXCELLENCE AWARDS

Have you or your organisation as a team done something worthy of peer/ industry recognition? Visit **www.gitaconference.org.au** to learn about the GITA excellence awards and nominate your organisation for these prestigious awards.

SPONSORSHIP AND EXHIBITION OPPORTUNITIES AVAILABLE

Apply now to maximise your exposure! The sponsorship & exhibition prospectus is available at **www.gitaconference.org.au.**

Get in early to avoid missing the exciting opportunities available.

Register online now at www.gitaconference.org.au

Jetty, about 1.5 km inside the Hunter River breakwater entrance (Figure 5).

The Pilot Station site also presented considerable heritage issues. The Newcastle Local Environmental Plan (LEP) identified almost the entire area as being within the Coal River Heritage Precinct (listed on the State Heritage Register). The boat harbour was specifically identified as a heritage item, which also fell within the Newcastle East Heritage Conservation Area.

During the reconnaissance phase, an old crane foundation was noticed but initially discounted due to possible heritage significance (and an accompanying council plaque). However, further investigation revealed that it was not listed on the State Heritage Register (unlike 14 others), nor in the relevant LEP.

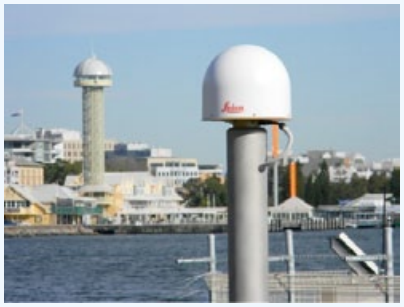
The crane base was also located outside the Coal River Heritage Precinct, the Newcastle East Heritage Conservation Area and the Stone Boat Harbor heritage item. Consequently, formal approval under the Heritage Act was not required. Nonetheless, LPI formally consulted council and there were no objections.

Even though we did not require heritage approval, the crane foundation obviously holds some historical significance. Consequently, great care was taken in preparing a design and installation method that ensured minimal permanent impact on the structure.

Again, it took six months to complete the attainment of all relevant approvals, facilitation of all necessary heritage considerations and pre-testing of hardware setups. The Newcastle East CORS was constructed within 30 m of the Pilot Station tide gauge and became operational in June 2012.

Figure 5: Pilot Station tide gauge.

Figure 6: Newcastle East CORS antenna monument (including CAAM).



It consists of a 3.0 m tall sandblasted, marine-grade stainless steel pillar with integrated CAAM (Figure 6). The monument was secured to the old crane foundation by several stainless steel rods. It was specifically designed to be difficult to climb or vandalise.

Tie surveys

Since both CORS could not be co-located with their respective tide gauges, it is crucial to provide a highly accurate survey connection between these two continuously measuring instruments. This so-called tie survey continues to be performed episodically (generally every year or two), representing a weak link that cannot be avoided at this stage.

Such tie surveys have been performed by LPI at another tide gauge, the Port Kembla site, for the last 20 years to connect the tide gauge to surrounding survey control marks (and now the Port Kembla CORS). They are either performed using spirit levelling or the EDM heighting technique, meeting particular specifications.

GNSS CORS observations are generally referenced to the Antenna Reference Point (ARP), which is identical to the top of the CAAM in this case. However, the ARP is not accessible once the antenna has been installed. Removal of the antenna would introduce jumps or discontinuities into the time series and interrupt real-time CORS users.

These CORS monuments therefore include a bench mark (BM), which is connected to the ARP during the initial tie survey performed during installation. This provides the height differences between the CORS ARP, the CORS BM and the tide gauge BM. Future tie surveys utilise the CORS BM and the tide gauge BM only, allowing the GNSS antenna to remain undisturbed.

Collaboration

The successful installation of the Fort Denison and Newcastle East CORS has been the result of considerable collaborative effort by a range of NSW Government agencies to meet challenging technical, environmental and heritage constraints. LPI gratefully acknowledges the Office of Environment and Heritage (who initiated and primarily funded these CORS installations), Sydney Ports Corporation and Newcastle Port Corporation.

Conclusion

This article has outlined the high scientific value of augmenting tide gauge records with GNSS CORS technology to separate the land motion and sea level change signals contained in relative tide gauge records. It has also provided an insight into the considerable difficulties encountered in the installation of CORS in sensitive, heritage-listed and harsh marine environments.

The Fort Denison and Newcastle East CORS will provide valuable continuous measurements on land movements at two of the longest running tide gauges in NSW and the southern hemisphere. Including Port Kembla CORS and Port Botany CORS, the CORSnet-NSW positioning infrastructure now incorporates four CORS in close proximity to tide gauges.

These measurements will become increasingly important over time, providing significantly improved estimates of regional sea level change into the future.

Dr Volker Janssen <Volker.Janssen@lpi.nsw.gov.au>, Russell Commins <Russell.Commins@lpi.nsw.gov.au> and Simon McElroy <Simon.McElroy@lpi.nsw.gov.au> are with the Survey Infrastructure and Geodesy branch of NSW Land and Property Information, which operates CORSnet-NSW. ■