Update on the Asia-Pacific Reference Frame (APREF) processing enhancements and Continuously Operating Reference Stations (CORS) monitoring in Australia

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Key words: APREF, ITRF, GNSS, CORS Monitoring

SUMMARY

The Asia-Pacific Reference Frame (APREF) is the backbone for geodetic information in the Asia-Pacific and plays a vital role in the realisation of the International Terrestrial Reference Frame (ITRF) in the region. The APREF is based on the routine, ongoing processing and analysis of the Global Navigation Satellite System (GNSS) Continuously Operating Reference Station (CORS) network across Asia-Pacific. In Australia, APREF GNSS processing solutions are used as the foundation for the Australian Geospatial Reference System (ARGS), including the Geodetic Datum of Australia 2020 (GDA2020) and the Australian Terrestrial Reference Frame 2014 (ATRF2014). The reliability of APREF solutions is dependent on the quality of the processing, monitoring and analysis of GNSS CORS within the network. To ensure the reliability and efficacy of the APREF processing, regular maintenance and system improvements are conducted by the Central Bureau in Geoscience Australia. The APREF solution is supported through processing contributions from participating Local Analysis Centres (LAC). The Department of Environment, Land, Water and Planning (DELWP) in Victoria is the only LAC in Australia that contributes to the APREF processing and maintains a state-wide GPSnet CORS network. This paper provides an update on the system enhancements implemented by the Central Bureau and LAC, including the transition of its Bernese processing capabilities into the Cloud and the Central Bureau's contribution to precise clocks and orbits. This paper informs the audience about the independent APREF processing, notification and coordinate analysis used by DELWP to monitor the integrity of CORS within Victoria. Downstream applications of APREF solutions in Victoria are also covered.

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1. INTRODUCTION

Since its establishment in 2011, the Asia-Pacific Reference Frame (APREF) project has provided a foundation for reliable geodetic infrastructure throughout the Asia-Pacific region. The APREF project offers the technical leadership and capacity necessary for the definition, realisation, and maintenance of the regional reference frame to densify the International Terrestrial Reference Frame (ITRF) (Huisman et al., 2011; Hu et al., 2011; Nardo et al., 2014). Physically, the APREF consists of a network of Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) that are routinely processed and monitored to estimate the station positions and velocities.

The APREF project is a collaboration between the United Nations Global Geospatial Information Management for Asia and the Pacific (UN-GGIM-AP) and the International Association of Geodesy (IAG). The Australian Government actively contributes to the project through Geoscience Australia and State Government Departments. This paper provides an overview and update on the APREF applications, activities, and enhancements in Australia.

2. APREF APPLICATIONS

Australia is currently in the process of modernising its national reference frame to support ongoing advancement in positioning technology and the seamless alignment of these technologies with a wide variety of spatial information. The data, products, and services provided from the APREF are fundamental to the definition of the modernised Australian Geospatial Reference System (AGRS) (ICSM, 2022). The AGRS includes the static Geodetic Datum of Australia 2020 (GDA2020), the dynamic time-dependent Australian Terrestrial Reference Frame 2014 (ATRF2014) and the Australian Vertical Working Surface (AVWS). The connection of these datums, via the APREF, to the ITRF2014, is designed to ensure that high-precision geospatial data are coherent and in alignment with positioning services.

The APREF GNSS processing solutions are used to derive the official coordinates GNSS CORS in Australia, which in-turn enable high quality positioning services. Examples of commercial positioning services that rely on this infrastructure include AllDayRTK (n.d.), HxGn SmartNet (n.d.), Mondo Pin (n.d.) and VRSnow (n.d.). All APREF GNSS CORS stations in Australia are continuously monitored to ensure that they comply with the official certified coordinates and associated uncertainties, published in the form of Regulation 13 Certificates (Hu & Dawson, 2020). Ensuring the stability and integrity of GNSS CORS is vital for real-time positioning services and to capture long-term station movements or trends.

APREF solutions for Australian GNSS CORS also serve as constraints in the national least squares adjustment, used to derive the coordinates of survey control marks at street-level (ICSM, 2018). Direct connection of the survey control mark network to the GNSS CORS network ensures harmony between terrestrial and satellite-based positioning systems.

These initiatives and the APREF project are part of the Positioning Australia program, which aims to deliver accurate, reliable and instantaneous positioning capability throughout Australia (Geoscience Australia, n.d.-a). The Positioning Australia program has accelerated the adoption of high-quality positioning technologies by modernising and densifying ground and space-based positioning infrastructure.

3. OVERVIEW OF THE APREF OPERATION

The APREF operation consists of the Central Bureau, CORS network operators, data centres and local analysis centres. The Central Bureau, within Geoscience Australia is the coordinating body that maintains the overall operations of the APREF, conducts automated routine data analysis and processing, and provides centralised access to the APREF products and data. As part of the Positioning Australia program, Geoscience Australia which is APREF's data centre, also provides free access to all Australian GNSS CORS data (state-government-owned and contributing private operators) through the GNSS Data Repository (https://data.gnss.ga.gov.au/). In 2022, three active Local Analysis Centres (LACs) contribute to the APREF operations, these are the Department of Environment, Land, Water and Planning (DELWP) in the state of Victoria, the Institute of Geophysics and Geodesy, Chinese Academy of Science, China (IGG), and Geoscience Australia.

All LACs utilise the Bernese GNSS Processing Software (Version 5.2) (Dach et al, 2012) to generate daily and weekly solutions that comply with the International Earth Rotation and Reference Systems Service (IERS) convention (Petit and Luzum, 2010). The recommended IERS processing convention includes the use of final International GNSS Service (IGS) clocks and orbits, differential code bias corrections, ionospheric models and ocean tide loading models. Each LAC implements different processing strategies to provide independent processing and solutions. Differences include varying Bernese process control file workflows and the selection of IGS core sites. The Combination and Analysis of Terrestrial Reference Frames (CATREF) software (Altamimi et al., 2006) is used to combine the weekly solutions from all LAC to generate a combined weekly APREF solution and identify any difference in the LAC APREF solutions. The relationship between the four APREF components is illustrated in Figure 1.

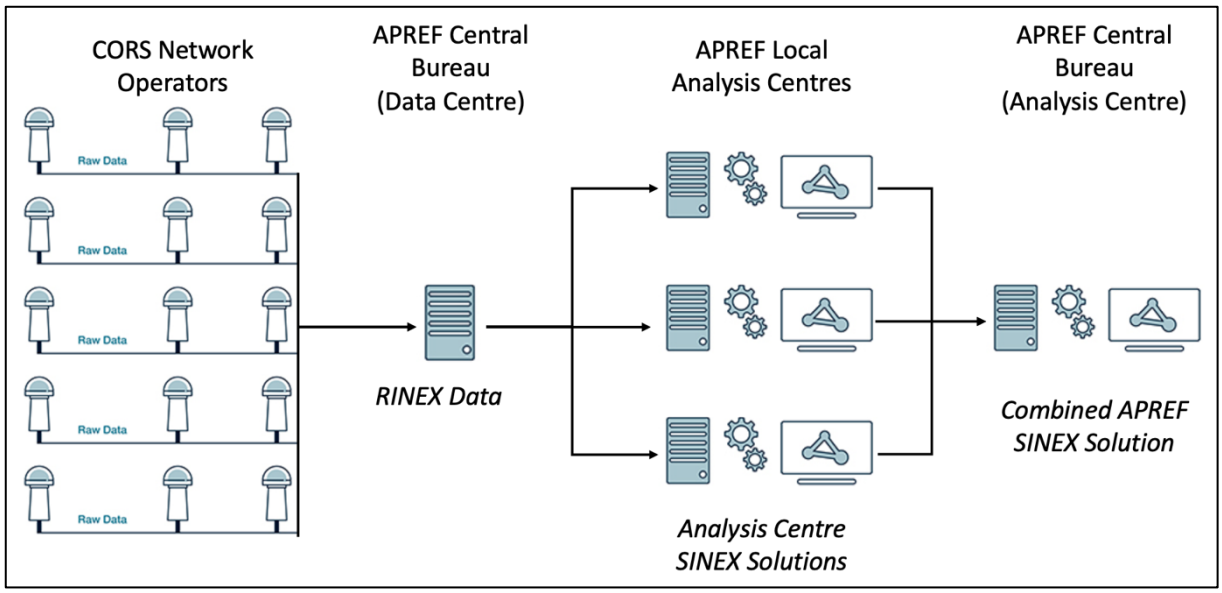

Figure 1. APREF product flowchart and the relationship between network operators, data centres, local analysis centres and central bureau. Adapted from Dawson and Hu, 2013.

The APREF project benefits from having a denser network of CORS distributed throughout the region and more contributing LAC. Interested parties are encouraged to contact the authors for further details and participation.

4. GNSS PROCESSING ENHANCEMENTS AND UPDATES

The APREF GNSS data management and processing strategies are continually enhanced to improve system performance, deliver accurate and reliable APREF solutions, and support CORS position monitoring. A recent example of such an enhancement has been the transition of the Central Bureau and the DELWP LAC to a cloud computing environment.

The operational aspects of APREF depend on a variety of underlying IT systems so that the Central Bureau and LACs can provide continuous service, timely routine analysis and reliable data access. To meet growing user demands, Geoscience Australia and DELWP have transitioned from hosting physical Bernese processing servers on premises to cloud-computing environments. The cloud environment has provided greater flexibility and scalability for APREF operations as it is less reliant on physical infrastructure. This transition did not impact any of the routine maintenance and processing activities.

In 2021, DELWP developed the cloud APREF processing routine from the ground up to incorporate the latest processing scripts, atmospheric models and strategies recommended by the University of Bern. The main motivation of this exercise was to provide a more independent solution which allows better outlier detection when determining the final combined APREF solutions. Custom Bernese process control files were also written to improve workflow efficiency and identify any process errors. The redeveloped APREF processing routine also yielded cleaner solutions in comparison to the solutions generated by the older physical

DELWP server. Therefore, historical CORS data in Victoria were reprocessed to provide a more consistent time-series, allowing easier identification of systematic trends and discontinuities. Historical reprocessed data is only used for DELWP-based analysis but will be available to the public in the future.

5. CORS MONITORING

CORS network operators utilise long-term time series data to determine the stability of a site. In addition to APREF processing solution products, the APREF Central Bureau generates time-series plots from the CATREF software (as shown in
Figure 2) that allows identification of station movement trends.

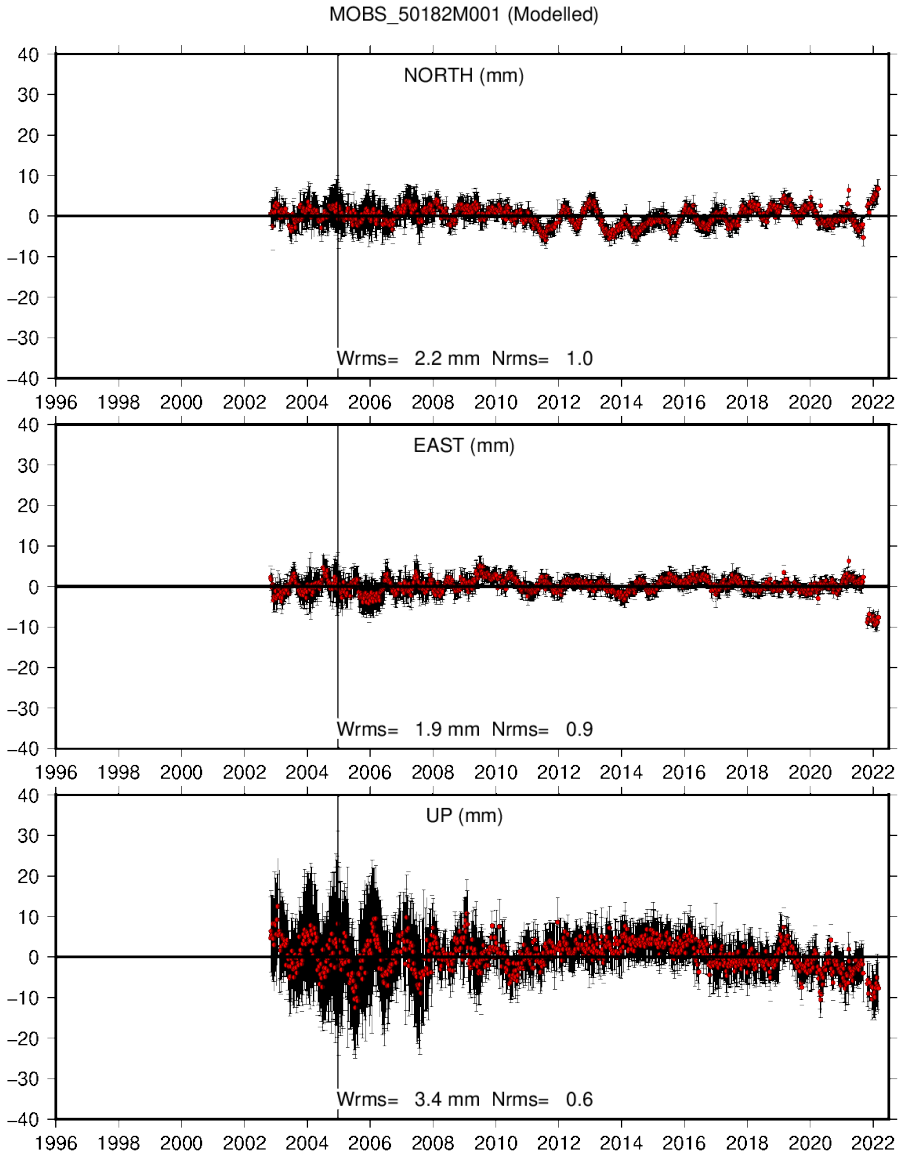

Figure 2. Example static time-series plot of Melbourne Observatory CORS (MOBS). All APREF CORS plots are routinely generated by the APREF Central Bureau.

All APREF CORS in Australia are closely monitored to determine whether positions are compliant within certified coordinates and uncertainties (Hu & Dawson, 2020). CORS positions that exceed certified coordinate uncertainty bounds are investigated and if unresolved, the CORS may have a new certified position issued or be withdrawn from further APREF processing.

From a CORS network operator's perspective, it is important that abnormal systematic CORS movement or behaviour is detected before a station is non-compliant with the certified values. An unstable or unreliable CORS station has both real-time and long-term implications. Trend abnormalities or discontinuities from a time-series stem from many factors, including defective hardware or firmware, signal obstruction and interference, unstable monumentation, or actual crustal deformation. CORS network operators aim to perform preventive maintenance instead of reactive repairs. However, detecting and interpreting time series to direct preventive maintenance is an exceedingly challenging task, especially for the Central Bureau as the APREF CORS network continues to expand. The Central Bureau processes over 950 APREF stations in the routine analysis including 120 IGS core stations around the world as shown in Figure 3.

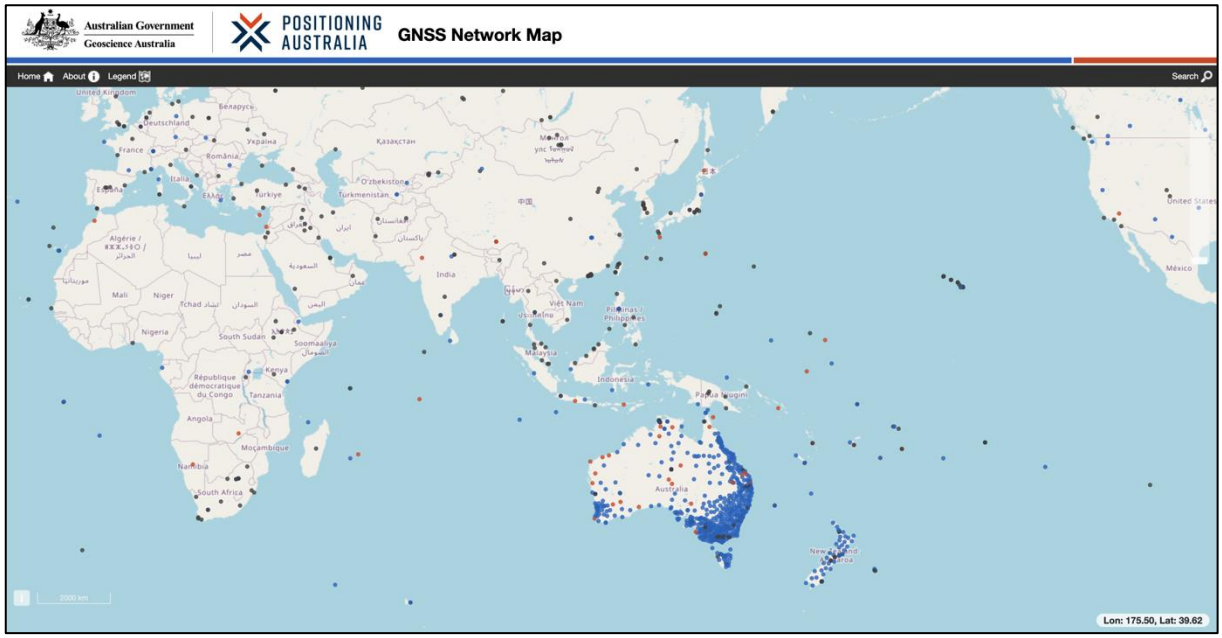

Figure 3. Distribution of CORS Stations processed by APREF Central Bureau. Full distribution and interactive map available from https://gnss.ga.gov.au/network.

5.1 Victorian CORS Monitoring

In Victoria, DELWP maintains the Vicmap Position - GPSnet network which consists of 140 CORS, with its distribution shown in Figure 4. The routinely derived APREF coordinate solutions, provided to the Central Bureau, are also used by DELWP to perform independent CORS monitoring. DELWP utilises

Position++ as a platform to collate SINEX data, analyse trends and deliver automated alerts. The DELWP LAC uploads data to Position++ within the Bernese automated workflow.

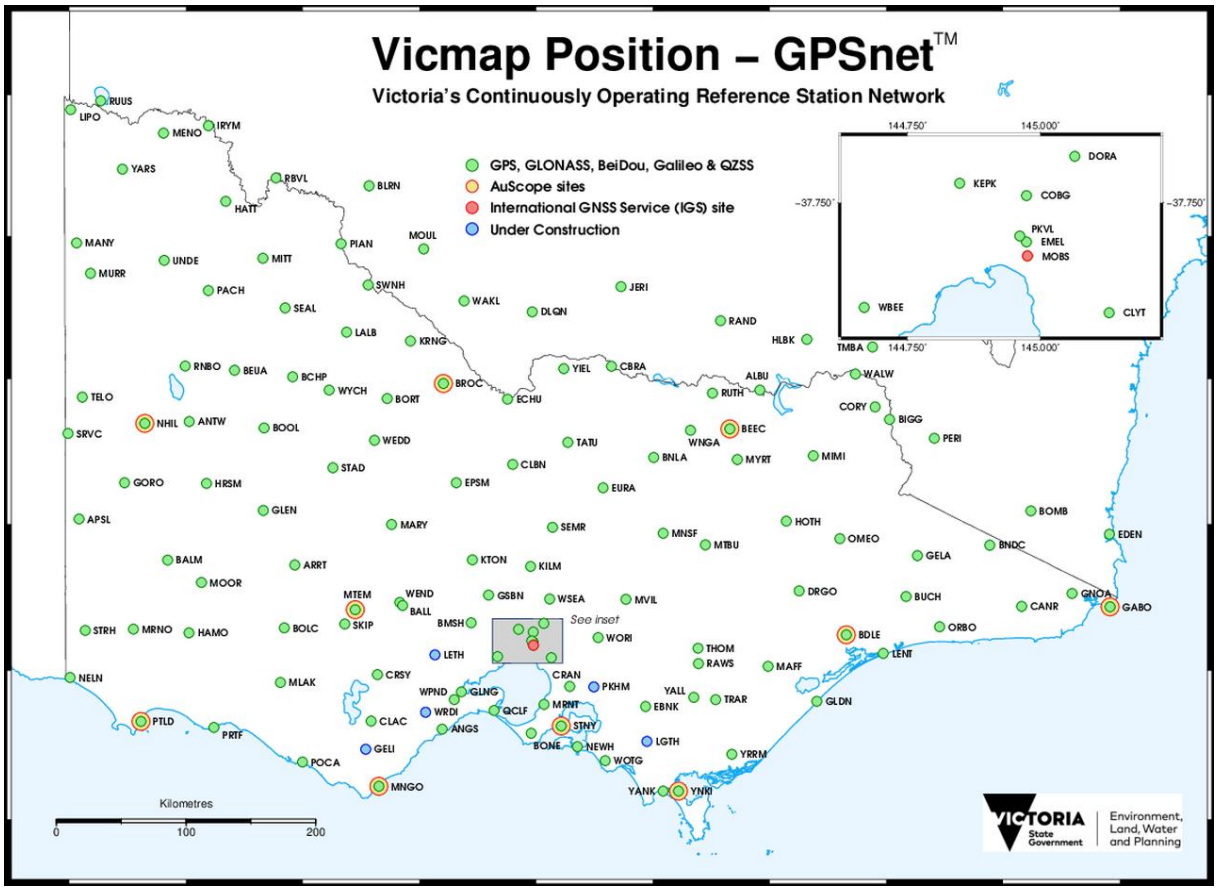

Figure 4. Spatial Distribution of Vicmap Position - GPSnet CORS.

The Position++ application provides a suite of interactive chart components which complements the static APREF product plots generated by the Central Bureau. As demonstrated in Figure 5, Position++ web application offers a simple and intuitive interface that allows users to zoom into a time series plot to focus on any identified trends and discontinuities. The independent solution can be cross validated against the combined APREF solutions to determine its consistency. Position++ also provides the flexibility for data to be displayed in various reference frames, coordinate systems, and solution types (daily, weekly, monthly).

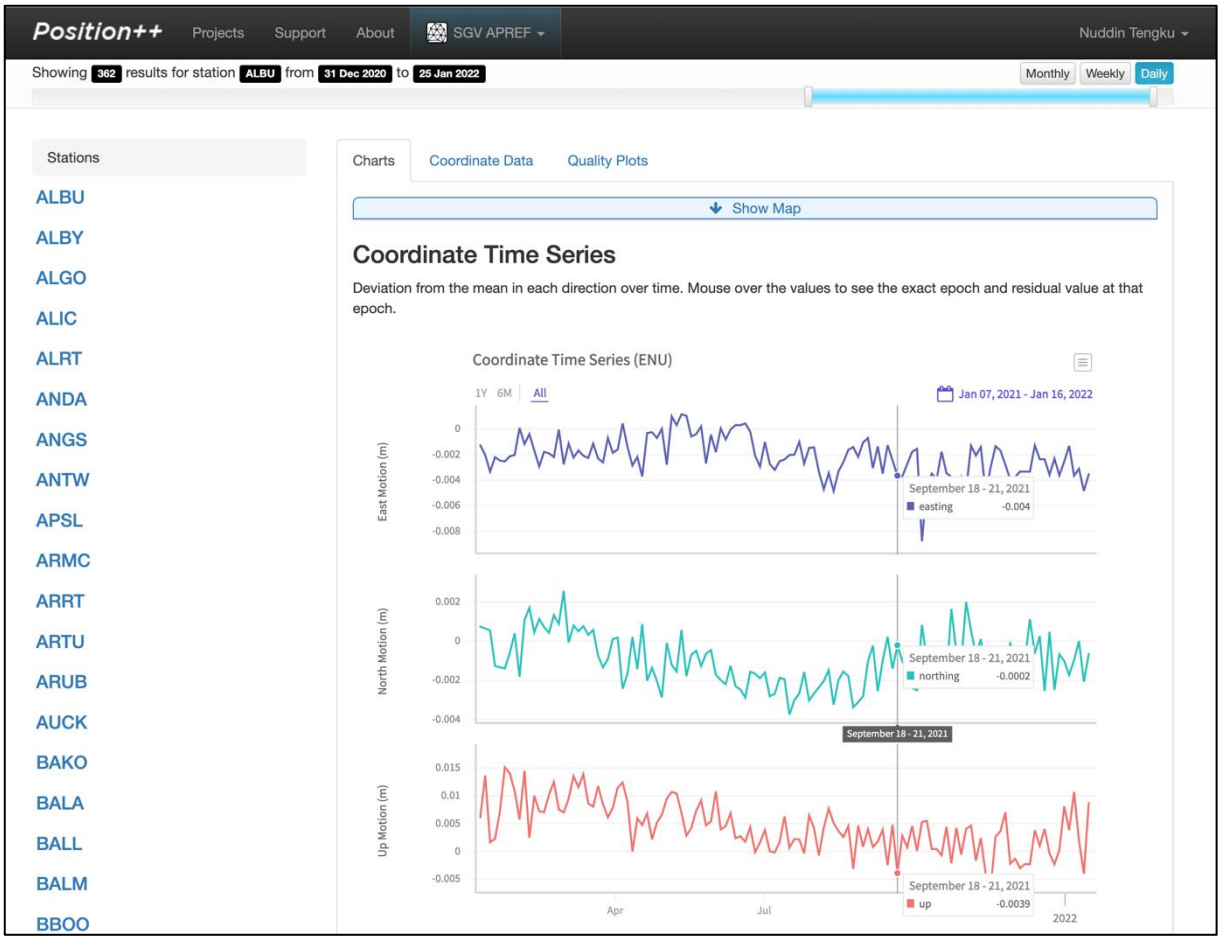

Figure 5. A screenshot of the Position++ platform displaying interactive time series plots and chart tooltips.

The Position++ alerting service is used to provide any notifications for daily station movements that exceed specified thresholds. The GPSnet team utilises this service along with other off-the-shelf GNSS monitoring software to identify potential disturbance or malfunction at CORS. The advantage of Position++ is its simplicity and the availability of independent and rigorous scientific-grade GNSS processing from the DELWP LAC.

In addition to the processing capabilities, The GPSnet Web App (https://mon.vicpos.com.au/) (shown in Figure 6) was developed as a centralised portal that enables users to monitor real-time CORS availability, data completeness, and access APREF time series products. DELWP-based APREF analysis products will also be made available to the public through this portal.

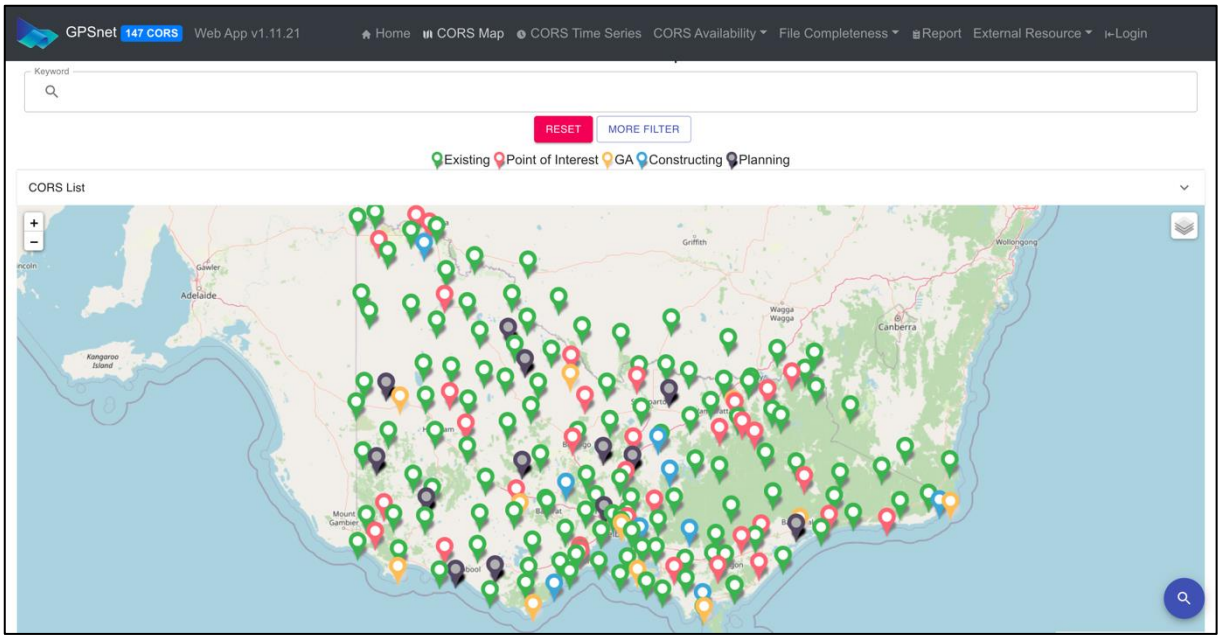

Figure 6. A screenshot of the CORS Map from GPSnet Web App (https://mon.vicpos.com.au/). This web application is used to display all CORS data and coordinate monitoring information within the network.

6. FUTURE ANALYSIS AND MONITORING WORK

The APREF GNSS processing and CORS monitoring activities will continue to be enhanced. Within the DELWP LAC, the current goal is to develop and promote the GPSnet WebApp as a centralised, publicly available portal for access to station availability, coordinate monitoring, data quality, and station logs. To do so, DELWP will utilise existing tools (GNSS Site Manager) and services (Position++) that can be integrated into the GPSnet WebApp through modern and open REST APIs. These integrations provide the DELWP LAC (and those accessing the GPSnet WebApp) with access to information and analysis capabilities that would not otherwise be available, or would be difficult/costly to develop internally.

Current CORS monitoring is performed through long-term coordinate analysis, compliance against Regulation 13 certification, and movement alerting beyond specified thresholds. DELWP recognises that movement of each CORS station is a combination of factors such as the CORS physical monumentation, geographic location, equipment, and processing. Thus, DELWP intends to investigate CORS-specific time-series modelling and alerting, which may provide improved identification of abnormal CORS behaviour and discontinuities.

Finally, whilst varying GNSS processing strategies are implemented by each LAC, the derived solutions are generated by identical GNSS processing software. Geoscience Australia is developing the Ginan GNSS Analysis Centre Software (Geoscience Australia, n.d.-b) which will eventually complement processing and analysis capabilities performed by the Bernese software. Ginan is an open-sourced software that is developed to fully leverage all multi-GNSS constellations available within the region and promote Australia's unique processing models. Once fully developed, the Ginan processing engine will also be used to generate precise orbits

and clock products. The APREF project will benefit from having more independently robust models and processing algorithms to determine any processing outliers to generate more accurate and precise APREF combined solutions.

7. CONCLUSION

As the demand for high precision geospatial products continues to grow, it is important to ensure that the underlying infrastructure technology is robust and reliable. This paper provided an overview of the various activities conducted by Geoscience Australia and DELWP to improve the reliability, availability and efficacy of its positioning services within Australia and Asia-Pacific by extension. Apart from showcasing the need to update infrastructure to cater to the growing number of needs, users and applications, this paper also highlights the role of CORS operators and LAC to value-add products delivered by the APREF project. Localised products and analysis provide better understanding of the quality products delivered to end-users. These insights allow CORS operators to perform more effective and strategic infrastructure maintenance.

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BIOGRAPHICAL NOTES

Nuddin Tengku is a Geodetic Technical Specialist with an honours degree in Geomatics Engineering from The University of Melbourne. He conducts regular geodetic-related analysis within Surveyor General Victoria at the Department of Environment Land Water and Planning and maintains the digital survey mark infrastructure in Victoria. He is completing a PhD in GNSS receiver testing and his previous work include GNSS research and development and the Satellite Based Augmentation System (SBAS) Test Bed project.

Simon Fuller is the founder and director of Position++. His company provides specialised GNSS processing services and consultation, and geodetic adjustment solutions. Position++ clients include corporations and government agencies worldwide. Simon is also lecturer and Surveying Specialist at the Royal Melbourne Institute of Technology (RMIT), Victoria.

Alex Woods is the Manager of Geodesy, within Surveyor-General Victoria at the Department of Environment Land Water and Planning. He leads the maintenance and enhancement of the GNSS positioning infrastructure and information services in Victoria, as well the technical development and implementation of the national datum modernisation program. He has an honours degree in Geomatics Engineering from the University of Melbourne.

Dr Guorong Hu is geodetic scientist who has a PhD degree from the Institute of Geodesy & Geophysics, Chinese Academy of Sciences. He has worked with Geoscience Australia since 2006, managing the APREF CORS network routine analysis and position verification of issuing regulation 13 certificates for the CORS sites across Australia.

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