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REVIEW

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Overview of legal traceability of GPS positioning in Australia

Guorong Hu* and John Dawson

Abstract

Global Positioning System (GPS) position verification and legal traceability in Australia supports industry, trade, science and innovation and is trusted and recognized domestically and internationally. At the end of 2017, the Australia's national datum was transitioned from the Geocentric Datum of Australia 1994 (GDA94) to the Geocentric Datum of Australia 2020 (GDA2020). As such, the datum for the legal traceability of GPS positions in Australia has also moved to GDA2020. This paper highlights the importance of legal metrology and measurement in terms of GPS positions in accordance with the National Measurement Act 1960 (Commonwealth of Australia). Here we provide an overview of the process of issuing the so-called 'Regulation 13 Certificates' for Continuously Operating Reference Stations (CORS) across Australia. The position verification methodology is detailed, including the quality control, metadata assurance, and dynamic management of the certificates as well as positional uncertainty determination of CORS with varying quality. A quality monitoring system of positions is also discussed along with how measurement traceability is ensured including short-term and long-term position monitoring schemes.

Keywords: GPS, Regulation 13 certificate, Legal traceability, GDA2020, Position verification

Introduction

The national measurement system in Australia ensures a basis for legally traceable, consistent and internationally recognized measurements. With the growing societal dependency on Global Positioning System (GPS), the need for the legal traceability of GPS positions with respect to the Geocentric Datum of Australia (GDA), currently GDA2020 (Hu and Dawson 2018; ICSM 2018), has become increasingly apparent. In the interest of ensuring consistency of positions derived from private and government Continuously Operating Reference Stations (CORS), Geoscience Australia maintains an appointment as a legal metrology authority in accordance with the National Measurement Act 1960 (Commonwealth of Australia) and provides legally traceable positions (Hu and Dawson 2013; Hu 2019).

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Geoscience Australia's role in the national measurement system is to operate the Australia Fiducial Network (AFN) to appropriate standards, for example, to meet the highest requirements of all kinds of applications (Beavan 2005; Firuzabdi and King 2011), and to ensure key CORS across Australia that are operated by other agencies such as state survey authorities are appropriately linked to the AFN (Dawson and Woods 2010; Hu and Dawson 2013). Geoscience Australia can issue certificates of verification under Regulation 13 of the National Measurement Regulations 1999 in accordance with the National Measurement Act 1960. These are commonly referred to as Regulation 13 Certificates. Regulation 13 Certificates provide coordinates and their uncertainties with respect to the Recognized-Value Standard (RVS) of measurement of position in Australia (Hu and Dawson 2013, 2018). In Australia, the GPS position of a station with legal traceability is defined as at the time of measurement and with the stated instrumentation of a GPS monument with respect to the Geocentric Datum of Australia.

The measurement traceability is ensured by comparing the computed solution against the RVS for position of the AFN stations, as well as weekly combined solutions computed by the International GNSS service (IGS) in the International Terrestrial Reference Frame (ITRF), currently ITRF2014, and the individual global analysis centres of the IGS. The validity and traceability of GPS is ensured via its link to the global Satellite Laser Ranging (SLR) and Very Long Baseline Interferometry (VLBI) observing networks through the ITRF. As the AFN is a reference for national geodetic networks, reliable and up-to-date coordinates must be available for all the AFN stations. This requires that we not only detect and identify timing of position offsets at the AFN sites, but we also estimate the offset magnitude which is used for the position update (Hu et al. 2019).

Geoscience Australia is responsible for maintaining a consistent set of geodetic position and velocity estimates for the 109 AFN GNSS sites across Australia. In order to ensure the long term reliability and quality control of the legal traceability of the GPS position in Australia, a thorough site performance monitoring system has been initiated and carried out in addition to the meta-data management and routine analysis (Owen et al. 2018; Hu et al. 2011, 2019).

This paper overviews Geoscience Australia's approach to the legal traceability of GPS positions, and the process of legal certification including the quality standards and the quality management system of the position verification process. The quality management includes our approach to monitoring the impact of: equipment configuration changes; antenna malfunctions; crustal deformation; and processing strategy and modelling updates. Some examples are given based on experience within the Asia Pacific Reference Frame (APREF) community (Hu et al. 2019). Finally, the structured maintenance and continual improvement program for the verifying laboratory are also discussed.

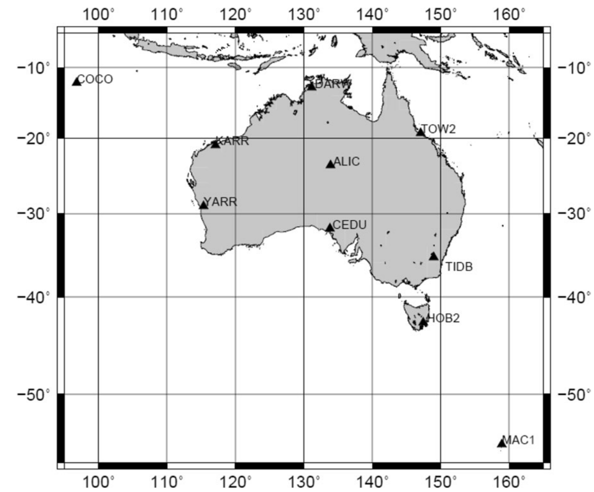


Fig. 1 AFN stations across the Australian plate with RVS in 1998, including seven mainland Australia stations, one Tasmanian station and two stations on Macquarie and Cocos Islands

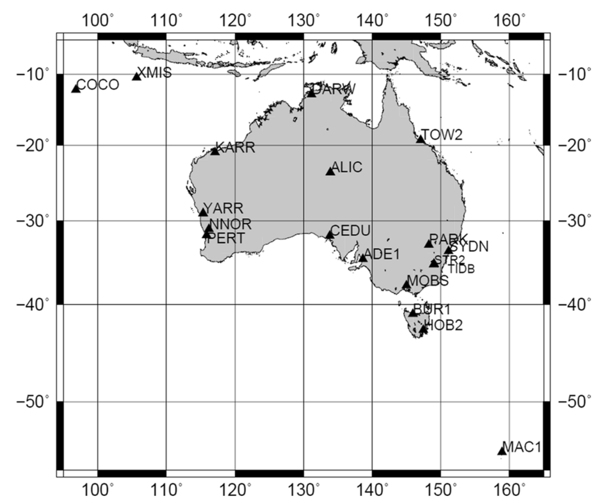


Fig. 2 The extended 21 AFN sites for GDA94 RVS across the Australian plate in 2012. For clarity, stations YAR1 and STR1 are not plotted as they are collocated with stations YARR and STR2 respectively

History of the recognized-value standard for measurement of GPS position

To align the Australian datum to the ITRF, which is a global reference frame, Australia adopted the Geocentric Datum of Australia (GDA). The first geocentric datum in Australia was GDA94 which originally consisted of 10 stations in the Australian Fiducial Network (AFN) as shown in Fig. 1; seven stations are located on mainland Australia, one station in Tasmania and two stations are on Macquarie and Cocos Islands. The Recognized-Value Standard (RVS) of measurement of position in GDA94 was determined from GPS campaign data observed in 1992, 1993 and 1994 and aligned to the ITRF1992 at epoch 1994.0. The GDA94 positions of the 10 AFN stations were estimated to have an absolute accuracy of about 2 cm at 95% confidence level in the horizontal components (Morgan et al. 1996; ICSM 2018).

To improve the consistency of GDA94 with the realization of ITRF2008, on 4 April 2012, the AFN was extended to include 21 sites as shown in Fig. 2. The coordinates of the updated 21 AFN stations were adopted directly from ITRF2008 then subsequently transformed to GDA94 using the transformation parameters published in Dawson and Woods (2010). The main reason for the update was the large differences between the 1998 RVS and the ITRF2008 after Helmert transformation, which were up to 15 mm for horizontal and 60 mm for vertical components.

During this period, the scope of accreditation for the Regulation 13 certificate changed from 32 mm for horizontal and 54 mm for vertical components of least uncertainty to 7 mm for horizontal and 15 mm for vertical components, respectively. The least uncertainty means the smallest uncertainty of measurement that can realistically be expected under ideal conditions, and the change of the scope also reflects the precision of the updated recognized-value standard of measurement of position (ICSM 2018).

Due to the motion of the Australian tectonic plate, the above updated GDA94 coordinates have continued to diverge from ITRF92 coordinates. By 2020, the difference would be approximately up to 1.8 m in the horizontal components. Complementary to this, there have been many improvements and updated realizations of the ITRF. For instance, the differences between ITRF1992 and ITRF2014 causes about 9 cm change in ellipsoidal heights in Australia and parts of the Australian crust have deformed (ICSM 2018). Therefore, it is necessary to update the RVS and align GDA to the current ITRF2014. As such, the GDA94 RVS was updated in October 2017 to GDA2020 and the AFN was extended further to include 109 stations across the Australian plate as shown in Fig. 3. The 109 AFN stations were selected from the Australia Regional GNSS Network (ARGN) and AuScope CORS network based on the following criteria (Hu et al. 2019):

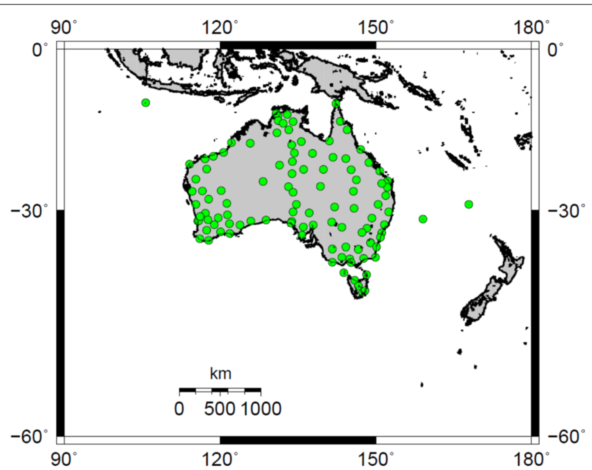


Fig. 3 The distribution of the extended 109 AFN stations in 2017 of GDA2020

- are operated by Geoscience Australia or similar agency;
- are located on the Australian Tectonic Plate, within Australia's jurisdiction
- are on a high quality survey monument (such as a concrete pillar); and
- have residual velocity less than 1 mm/year relative to the Australian rigid plate motion model.

The RVS GDA2020 coordinates and velocities for the 109 AFN stations are derived from the cumulative solutions of the long-term position time series which are the ITRF2014 coordinates and velocities and were mapped forward to the epoch of 2020.0 using the derived Australian plate motion model. The cumulative solutions are part of the products of the Asia–Pacific Reference Frame (APREF) project with more than 20 years data since 1996 (Hu et al. 2019). These coordinates and velocities can be found in the GDA2020 technical manual (ICSM 2018) and refer to National Measurement Act 1960 - Recognized-value standard of measurement of position determination 2017 F2017L01352 (https://www.legislation.gov.au/Details/F2017L01352).

GPS position of a station in Australia with legal traceability is a set of point coordinates with stated instrumentation installed on a stable monument with respect to the Geocentric Datum of Australia (GDA2020) referred to the GRS80 ellipsoid at the epoch 2020.0.

The methodology of GPS position verification

We used CATREF software (Altamimi et al. 2002, 2016; Hu et al. 2019) to estimate station velocities while combining 1210 weekly solutions into a long-term solution. Only those stations having more than 2.5 years of observations are considered noting that velocity estimates can be biased due to unreliable estimated seasonal signals (Blewitt and Lavallée 2002). The coordinates and velocities of these sites are originally determined in ITRF2014 at epoch 2010.0, then propagated forward to epoch 2020.0 using the Australian plate motion model. This means the adopted coordinates of GDA2020 for a CORS corresponds to the position on January 1, 2020. The GDA2020 site velocity needs to be applied to compute the position of the site at another date.

Daily solutions of the APREF stations were processed using Bernese GNSS Software version 5.2 (Dach et al. 2012). We applied up-to-date models and procedures following the International Earth Rotation Service (IERS) standards 2010 (Petit and Luzum 2010) and IGS recommendations. We used the absolute satellite and receiver antenna phase calibration model (Schmid et al. 2007), elevation cutoff angle of 10° for observation selection, VMF1 grids (Boehm et al. 2006) for tropospheric delay, and the FES2004 model (Lyard et al. 2006) for ocean tide loading. IGS final GPS satellite ephemerides and earth orientation parameters were used in the computations. The double difference carrier phase observables at 30-s epoch intervals were used for GPS data processing. Other measurement modelling and parameter estimation included (Hu et al. 2011; Hu and Dawson 2018; Hu et al. 2019) solid earth tide displacements and Ocean tide loading displacements (Lyard et al. 2006); receiver clock corrections as well as absolute antenna phase centre variation and offset corrections; troposphere zenith delays estimated at 1-h intervals for all stations. Quasi-Ionosphere-Free (QIF) integer ambiguity resolution strategy is used for routine analysis with elevation dependent observation weighting and minimum constraint condition for daily network solution in terms of the ITRF2014 using subset of the IGS14 reference stations (Dach et al. 2012).

The daily solutions are stacked into weekly solutions using Bernese software based on the daily normal equations. Then the weekly solution was transformed from ITRF2014 to GDA2020 using the approach recommended in the GDA2020 Technical Manual (ICSM 2018). Before generating the Regulation 13 certificates for the sites, the GDA2020 solutions are checked to ensure the quality of the computed solution to meet the following requirements:

- metadata in the Software Independent Exchange Format (SINEX) solution file is consistent with the site log files;
- ensuring that there are no excessive data deletions where at least 80% data accepted per station for data processing;
- the Root Mean Squares (RMS) of daily coordinate repeatability of all user supplied stations for the weekly solutions must be less than 5 mm for horizontal components and less than 10 mm in vertical component (Dach et al. 2012);
- checking the minimally constrained solution against the IGS14 reference frame and/or the IGS combined analysis for the corresponding time period, to ensure RMS less than 5 mm for horizontal components and less than 10 mm for vertical component before Helmert transformation;
- checking the final GDA2020 solution against the RVS coordinates of 109 AFN stations to ensure RMS less than 7 mm for horizontal components, and less than 15 mm for vertical component.

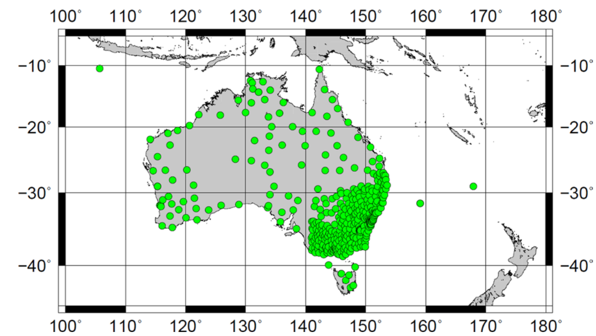


Fig. 4 The locations of all CORS on the Australian plate that have a Regulation 13 position verification certificate as of February 2020

Following the above process, we have issued Regulation 13 certificates for 450 CORS sites on the Australian plate as shown in Fig. 4. Based on the 2017 data set, Hu and Dawson (2018) detailed the results of the Australian CORS position verification analysis that has led to the creation of certificates of verification of the reference standard of measurement for position in accordance with Regulation 13 of the National Measurement Regulations 1999, National Measurement Act 1960. GDA2020 coordinates and uncertainties are also reported. An example of Regulation 13 certificate for the site WWLG is given in Appendix 1.

Uncertainty of GPS positions

Position uncertainties were calculated in accordance with the principles of the International Standardization Organization (ISO) Guide to the Expression of Uncertainty in Measurement (GUM 1995), with an interval estimated to have a confidence level of 95% at the time of verification. The combined standard uncertainty was converted to an expanded uncertainty using a coverage factor, *k*, of 2. Position uncertainties are divided into type A and type B sources. Table 1 summarizes the major type A and B uncertainty sources for GPS analysis of the position verification.

Type A uncertainty sources were evaluated by adopting an a priori sigma of 0.001 m for the precision (1 sigma) of the L1-frequency, one-way, phase observation, at zenith (Dach et al. 2012). The corresponding uncertainties of all parameters were determined, by standard error propagation theory, in the least-squares estimation process used in the GPS analysis. Since the formal (internal) precision estimates of GPS solutions are well known to be optimistic, a factor of 10 (i.e. variance scale factor of 100) was subsequently applied to the variance–covariance matrix

Table 1 Uncertainty sources (95% confidence level) for position, determined from GPS, and the total uncertainty, assuming the normal distribution of the uncertainty sources, high degrees of freedom and a coverage factor, *k*, of 2

Uncertainty source	Position uncertainty horizontal (mm)	Position uncertainty vertical (mm)
Type A—Experimental error	2	6
Type B—Antenna phase centre	3	10
Type B—Monument stability	1–20	1–40
Type B—Other sources including un-modelled crustal loading, satellite orbit variations, atmosphere, tectonics, signal multi-path	6	10
Total	7–21	15–43

of the computed GDA2020 coordinates (Hu and Dawson 2018). This factor was selected based on an empirical assessment of the routine APREF analysis and is also largely with consistent previous research, see for example Blewitt and Lavallée (2002), Altamimi et al. (2002, 2016) and Firuzabdi and King (2011).

Type B uncertainty sources, which in practice contribute to position uncertainty, cannot be estimated from the statistical analysis of short-period (i.e. 7-day) observations; these include environmental effects, such as long-period station loading (deformation) processes (Johnson and Agnew 1995; Altamimi et al. 2002; Blewitt and Lavallée 2002; King and Williams 2009).

Quality control of GPS position verification

Knowing the long-term stability of each CORS is necessary for ensuring the internal consistency and stability of the national datum as well as the reliability of the legal traceability of GPS position (Hu and Dawson 2013; Hu et al. 2019). The quality control of GPS position verification can be performed through long-term position time series monitoring and short-term positioning performance (Hu et al. 2013; Hu 2019).

The use of the long-term position time series allows a better geophysical interpretation of the observed site motion, in particular to understand the residual signal or so-called non-linear motion which may be related to site stability or local geophysical phenomena (King and Williams 2009). The horizontal component is assumed to be primarily related to tectonic plate motion, while the height component is associated with local or regional uplift or subsidence (Feissel-Vernier et al. 2007) which can be caused by both geophysical and anthropogenic sources.

As part of the products of the APREF project, Geoscience Australia estimate weekly coordinates for more than 450 CORS within the Australian plate with issued Regulation 13 certificates of GDA2020 coordinates (Hu et al. 2011, 2019). Each weekly solution is derived based on daily 24-h data in terms of GPS week. The above CORS network is based on voluntary contributions from more than 10 companies and State and Territory Governments entities across Australia. Each site is operated in accordance with those belonging to the IGS network, with the same conflicting goals of inclusiveness and selectivity (Altamimi et al. 2002). This means that although guidelines exist for equipment changes, different institutes use different practices. For example, some antenna or equipment changes within the Australian network are not always communicated to Geoscience Australia, who ensures the daily network management. In addition, when erroneous behavior is detected at one of the sites, Geoscience Australia cannot do more than inform the site operator of the change in behavior and request proper action to be taken (Hu et al. 2011). This can create issues with data availability, metadata consistency and cause unknown coordinate changes.

Therefore, a set of quality control systems is designed to detect significant deviation from published position and velocities, whereupon the published coordinates and velocities may be updated if the new estimates differ from the adopted values by pre-specified tolerances. The quality control starts from the metadata checking, Receiver Independent Exchange Format (RINEX) header information validation against the site log files, and progresses to the solution quality checking through comparison with the official IGS weekly solutions using the residuals from the Helmert transformation (Owen et al. 2018; Hu et al. 2011, 2019).

For short-term variations, we monitor the published Regulation 13 coordinates with weekly monitoring of solutions difference after routine analysis. The GDA2020 coordinates at epoch 2020.0 for the recognized value of 109 stations across Australia plate are used as reference for ensuring the measurement traceability as detailed in Hu and Dawson (2018). The differences between the computed and the reference coordinates were calculated and subsequently transformed to the North, East and up components. Taking GPS week 2063 as an example, we found that 3% of coordinates for the RVS stations exceeding the position uncertainty bounds. There are several reasons to explain this finding: (1) some RVS stations are determined from short position time series of just over 2.5 years with noiser velocity uncertainties; (2) some sites contain discontinuities caused by equipment changes including antenna type and antenna radome changes; and (3) site instability caused by local environmental effects (Beavan 2005; King and Williams 2009). It is well known that the vertical component is the most sensitive component to equipment changes in particularly antenna changes or site environment changes (i.e. trees growing over or near the antenna blocking the sky view). Figure 5 presents a typical RVS site with Regulation 13 certificate where its antenna radome had been damaged at the end of year 2018. The resulting damage caused a jump of the position time series for the vertical component as shown in Fig. 6. In this case, the issued Regulation 13 certificate was cancelled and removed from public access, and a new Regulation 13 certificate was re-issued after the site operator removed the antenna radome.

For long-term quality control, we monitor the CORS site stability through the position time series analysis using CATREF software (Altamimi et al. 2002) based on weekly solutions of the routine analysis for the APREF CORS network. The weekly coordinates in the combined APREF solution are linked to the ITRF2014 by minimally constraining the coordinates of a set of IGS core stations to the IGS14 position (Hu et al. 2019). For the first step, we generate raw position time series which allow identification of discontinuities and outliers. For this purpose, we remove the original constraints from each weekly APREF solutions and calculate a cumulative solution estimating position and velocity along with the position offsets. The resulting position time series i.e. so-called modelled time series are actually the residuals between the cumulative solution and each weekly solution after removing 14 parameter transformation (Hu et al. 2011, 2019). As already shown by Kenyeres and Bruyninx (2004), the Helmert transformation absorbs the common network velocity, the reference frame changes and any periodic signals such as annual signal common to the whole network and it allows identification of outliers and offsets. From long-term time series, all offsets and discontinuities due to equipment changes, e.g., antenna problems are estimated in the final cumulative solutions to obtain a set of coordinates and velocities, these discontinuities are stored in a SINEX file for the combination of position time series (Kenyeres and Bruyninx 2004; Altamimi et al. 2016).

We use the CATREF software package to do the combination of weekly solutions and generate the position time series (Altamimi et al. 2002, 2016). The output of the position time series contain information such as geophysical signals, mismodelled effects, outliers and discontinuities. Based on the raw time series the outliers and offsets are treated and discontinuities are set up. Each station was independently checked (e.g. Hu et al. 2011, 2019).

There are many factors degrading the site stability and the reliability of the position series including site environment changes which can cause an inconsistency in the position time series and even change the position repeatability. We can set up them as offsets or outliers. If unaccounted for, these effects can degrade the quality of the estimated parameter such as velocities and coordinates in terms of biases or higher uncertainties. A typical example is the station TELO, one of the Victorian CORS network. The issued Regulation 13 certificate was cancelled as this site is no longer suitable for legal traceability because of instability caused by the building movement. As shown in Fig. 7, the position time series for this site in both the east and vertical components demonstrate large variability. The site operator has confirmed this special case and decided to relocate the CORS to a more stable installation. In this case, the issued Regulation 13 certificate had to be cancelled and removed from public access. We call this type of CORS sites as a non-conforming case which cannot meet the quality requirements of GPS legal traceability of position verification.

Fig. 5 Site WWLG in New South Wales, Australia. The antenna radome was damaged at the end of year 2018. Photo courtesy of Simon Eyles

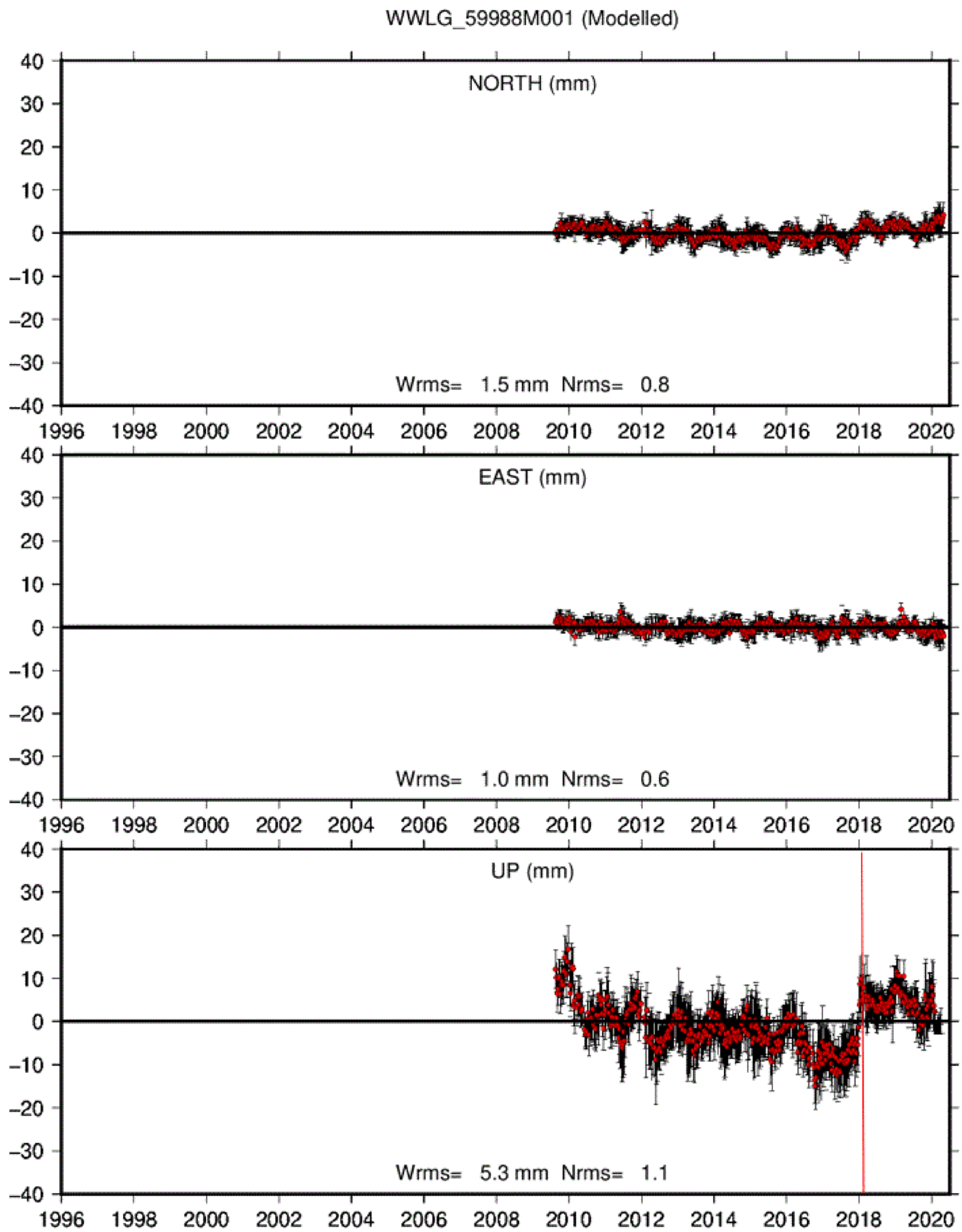


Fig. 6 The offset in the vertical component position time-series at station WWLG caused by damage to the antenna radome, the position time-series generated after removing the plate motion model and outliers as well as offset estimation

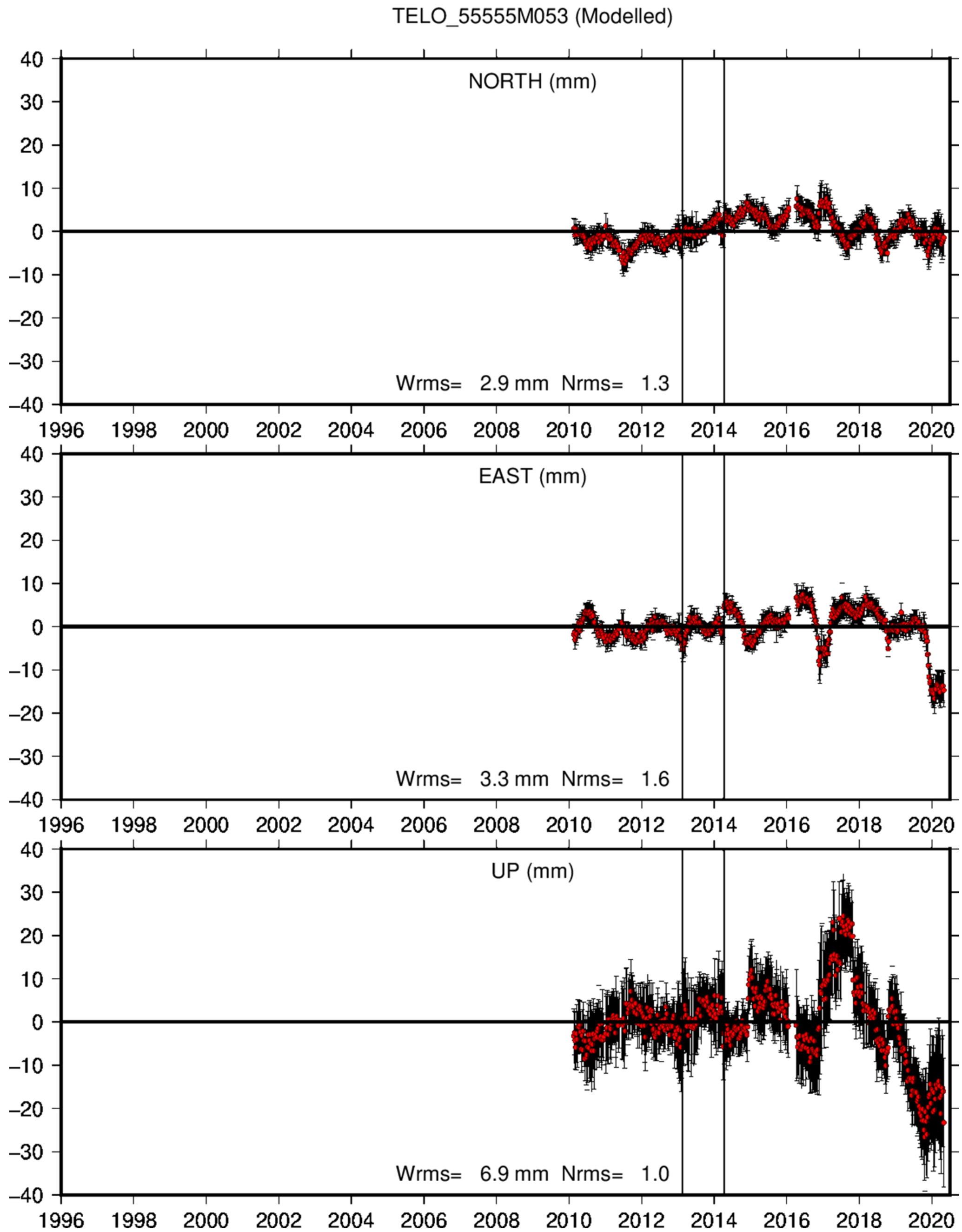


Fig. 7 Anomaly behavior in the east and vertical components of the position time-series at station TELO in Victoria, Australia, the position time-series generated after removing the plate motion model and outliers as well as offset estimation

We have found several sites appearing to exhibit strange behaviour in either horizontal components or the vertical component. There are many phenomena that contribute to non-linear motion at a site, these include local subsidence or hydrological instabilities related to the periodic circulation of underground water; thermal expansion of the GPS stations (e.g., Johnson and Agnew 1995; van Dam et al. 2001; Caporali 2003; Romagnoli et al. 2003); monumentation problems such as the antenna being attached to an unstable building. These are possible explanations of the long and short term variability of the position time series. Geophysical processes such as earthquakes may produce significant displacement offsets that should be estimated or corrected (Altamimi et al. 2016). This information is critical for the CORS users if they want to derive accurate relative position for the other new sites from the CORS. Feissel-Vernier et al. (2007) define the site stability to include possible geophysical instabilities, as well as equipment or the monument foundation (i.e. attached to a building), and found the level of stability to be consistently lower than 3.5 mm for horizontal component and 4 mm vertical component.

The weekly solutions and combined SINEX files are the starting point for long term monitoring the CORS performance and consequently the position time series of each site. The official APREF products consists of weekly position solutions in the SINEX format (Hu et al. 2019). We update the APREF weekly cumulative position and velocity estimation and associated position time series, where the detected position offset or outliers are taken into account. We also maintain a database of metadata management as well as discontinuities in SINEX format (Hu et al. 2011, 2019; Owen et al. 2018). A flowchart of legal traceability of issuing regulation 13 certificate for a site is illustrated in Appendix 2.

Concluding remarks

Geoscience Australia recognizes the implications and promise of GPS technology and is progressing the adaptation of GPS methods to improve the Geocentric Datum of Australia since 1992 along with the constant improvement in our knowledge of terrestrial reference frames (Altamimi et al. 2002; Hu et al. 2019). We have advised and updated several new realizations of GDA, refining at each time the recognized values of GDA coordinates (Dawson and Woods 2010; ICSM 2018).

The rigorous realization of geodetic frames based on CORS networks requires continuous monitoring of the set of position and velocity estimates defining the particular datum. Where coordinate changes are noted, whether caused by human or natural effects, the position of the CORS is re-estimated. We monitor the GDA2020 coordinates and velocities through weekly solutions of the APREF GPS CORS network.

The final goal of the study is to achieve reliable traceability of the GPS position in Australia. We create a SINEX file including the IGS discontinuities for the APREF CORS network. We update the position time series weekly, however the related discontinuity or offsets requires several weeks of data after the event or even longer to identify changes in the coordinates. When estimating the site velocity, we introduce the offset and re-estimate a set of coordinates for the site while assuming the velocity is identical before and after the offsets.

Our position and velocity estimation are compared with the IGS published weekly solutions to ensure the traceability of GPS position. We found excellent agreement both in the position and velocity estimation in 2-4 mm for horizontal components and 3-6 mm for vertical components (Hu et al. 2019). The compiled discontinuities SINEX file allows estimating the offsets along with the position and velocity estimation. The position time series analysis enables visualising the long-term behaviour of the station as a whole to detect and identify the hardware malfunctioning as well as monitoring the site stability.

Acknowledgements
Special thanks go to the site operators of the CORS network who continue to provide the highest quality GNSS data to all users, Dr Minghai Jia for the routine combination of APREF CORS network position time series, and Anna Riddell and Dr Woolf Martine for their depth review of the original manuscripts and helpful suggestions that have greatly contributed to improving the paper. We thank Zuheir Altamimi for CATREF and his training for using it for this study. This paper is published with the permission of the CEO, Geoscience Australia.

Authors' contributions
Both GH and JD proposed the idea and prepared the main review, read and approved the manuscript.

Authors' information
Dr. Guorong Hu geodetic scientist, who has a Ph.D. degree from the Institute of Geodesy & Geophysics, Chinese Academy of Sciences, and has worked with Geoscience Australia since 2006. Dr. John Dawson director of Positioning Section in Geoscience Australia, who has a Ph.D. degree from the Australian National University.

Funding
Not applicable.

Availability of data and materials
The used data showed in the plots are obtained from the ftp link: ftp://ftp.ga.gov.au/geodesy-outgoing/gnss/ and they are duly referenced in the text.

Competing interests
The authors declare that they have no competing interests.

Appendix 1: an example of issued regulation 13 certificate for the site WWLG is shown as below

Australian Government

Geoscience Australia

Certificate of Verification of a Reference Standard of a Position-Measurement in Accordance with Regulation 13 of the National Measurement Regulations 1999 and the National Measurement Act 1960

Name of Verifying Authority:

Name: National Positioning Infrastructure Branch
Organisation: Geoscience Australia
Address: Corner Jerrabomberra Ave and Hindmarsh Drive, Symonston ACT 2609 Australia
Telephone: (02) 6249 9111
Email: geodesy@ga.gov.au

Client detail:

Name: Brandon Owen
Organisation: GNSS Infrastructure and Informatics Section, Geoscience Australia
Address: Symonston ACT 2609 Australia
Telephone: (02) 6249 9192
Email: Brandon.Owen@ga.gov.au
Date of request: 04 March 2020

Description and denomination of standard of measurement:

The measurement was undertaken using an antenna `LEIAT504GG NONE` (International GNSS Service antenna naming convention) with the serial number 200525 and refers to a point located 0.0000 m below the antenna reference point. The antenna is attached to a pillar on a concrete block via a stainless steel plate, threaded spigot. The station (4 character ID: WWLG) is located at West Wyalong, New South Wales. The certificate was determined using data from 16 February 2020 to 22 February 2020 inclusive. Analysis was undertaken following the procedures detailed in Geoscience Australia's GPS Analysis Manual for the Verification of Position issue 2.2. The reference number of this certificate is WWLG12032020.

Permanent distinguishing marks:

Exempt under Regulation 16 (4)

Date of verification: 12 March 2020

Date of expiry of certificate: 12 March 2025

NATA

Accredited for compliance with ISO/IEC 17025 - Calibration. Accreditation No. 15002.

Value of standard of measurement:

Station (4 character ID): `WWLG`

South Latitude and its uncertainty of value:

`33° 42’ 12.32033" ± 0.00026" (0.008 m)`

East Longitude and its uncertainty of value:

`147° 19’ 18.05190" ± 0.00026" (0.008 m)`

Elevation above Ellipsoid and its uncertainty of value:

`359.644 ± 0.020 m`

Geocentric Datum of Australia (GDA2020) coordinates referred to the GRS80 ellipsoid being in the ITRF2014 reference frame at the epoch 2020. The uncertainties are calculated in accordance with the principles of the ISO/IEC 98-3 Uncertainty of Measurement - Part 3: Guide to the Expression of Uncertainty in Measurement (2008), with an interval estimated to have a confidence level of 95% at the time of verification. The combined standard uncertainty was converted to an expanded uncertainty using a coverage factor, k, of 2. Measurement traceability is ensured against the recognised value standard for position of the Australian Fiducial Network.

Details of any relevant environmental or other influence factor(s) at the time of verification:

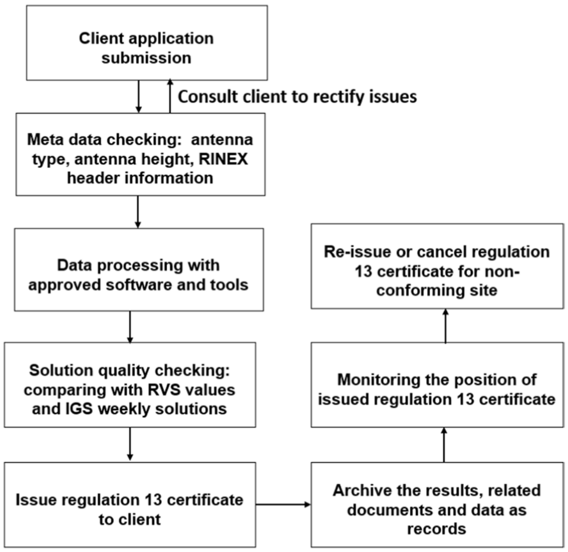
Uncertainty of the coordinates of the recognized-value standard of measurement of position (i.e. GDA2020); and Uncertainty due to instability of the GPS antenna mounting and modelling of the antenna phase centre variations.

Signature:
12 March 2020
Dr John Dawson
Geoscience Australia approved signatory

Director of Positioning
National Positioning Infrastructure Branch
Geoscience Australia

Being a person, or a person representing a body, appointed as a verifying authority under Regulations 71 and 73 of the National Measurement Regulations 1999 in accordance with the National Measurement Act 1960, I hereby certify that the above standard is verified as a reference standard of measurement in accordance with the Regulations, by the above-named authority.

Appendix 2: the flowchart of the legal traceability of issuing regulation 13 certificate for a station is illustrated as below



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