A Practical Guide to AUSPOS

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ABSTRACT

AUSPOS is Geoscience Australia's free online Global Positioning System (GPS) processing service and has successfully processed more than 1 million jobs worldwide over the last 10 years or so. It takes advantage of the International GNSS Service (IGS) core network station data and products together with Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS) in and around Australia to compute precise coordinates and their uncertainties, using static dual-frequency GPS carrier phase and code data of at least 1 hour duration (recommended minimum of 2 hours duration). This paper provides an in-depth practical guide for AUSPOS users, explains how over 12,000 AUSPOS solutions have so far been used to help maintain and improve the NSW survey control network and outlines our desire and the requirements for the inclusion of industry-observed AUSPOS datasets to be submitted to DCS Spatial Services for potential update of the Survey Control Information Management System (SCIMS) and inclusion in the growing GDA2020 state adjustment. It also offers some practical tips and tricks related to measuring the antenna height, observation data recovery and AUSPOS cluster processing.

KEYWORDS: *AUSPOS, GDA2020, datum modernisation, SCIMS, best practice*.

1 INTRODUCTION

Geoscience Australia's free online Global Positioning System (GPS) processing service, AUSPOS, was developed to provide an online positioning service based on Continuously Operating Reference Stations (CORS) primarily for Australian users, although it can process data collected anywhere on Earth (GA, 2022a). Initially released in 2000, it remains GPS-only and has been frequently upgraded to incorporate improvements. For example, in support of national datum modernisation efforts leading to the introduction of the Geocentric Datum of Australia 2020 (GDA2020 – see ICSM, 2022a), AUSPOS started delivering results in both GDA94 and GDA2020, as well as ITRF2014 (Altamimi et al., 2016), with version 2.3 in November 2017. The current version 2.4 was released in August 2020, now running in the Amazon Web Services (AWS) cloud environment with scalability and reliability (rather than on physical servers) to accommodate the increasing use of AUSPOS. Over 10 years from 2011 to 2020, AUSPOS successfully processed more than 1 million jobs worldwide. After AUSPOS was launched in the cloud, more than 200,000 jobs were processed in 15 months, including about 100,000 submissions for the National GNSS Campaign Archive (NGCA).

AUSPOS takes advantage of the International GNSS Service (IGS) core network station data and products (e.g. final, rapid or ultra-rapid orbits depending on availability – see IGS, 2022a) together with CORS in and around Australia to compute precise coordinates, using static dual-frequency GPS carrier phase and code data of at least 1 hour duration (recommended minimum of 2 hours, maximum of 7 consecutive days). When submitting 30-second Receiver Independent Exchange (RINEX – see IGS, 2022b) data (version 2 and 3 are both accepted), users are required to specify the antenna type (using the IGS naming convention) and the vertically measured antenna height from the ground mark to the Antenna Reference Point (ARP). Following processing, an AUSPOS report (pdf) is emailed to the user (generally within a few minutes), which includes the computed coordinates and their uncertainties, ambiguity resolution statistics, and an overview of the GPS processing strategy applied. For advanced users, Solution Independent Exchange (SINEX) files containing more detailed information are also available for download.

In NSW, all 202 CORSnet-NSW sites comprise a fundamental, high-density and long-term component of AUSPOS infrastructure. CORSnet-NSW is Australia's largest state-owned and operated Global Navigation Satellite System (GNSS) CORS network providing fundamental positioning infrastructure for a wide range of applications (e.g. Janssen et al., 2016; DCS Spatial Services, 2022a). It is built, owned and operated by DCS Spatial Services, a business unit of the NSW Department of Customer Service (DCS). All CORSnet-NSW sites are part of the Asia-Pacific Reference Frame (APREF – see GA, 2022b), including 13 concrete-pillared NSW stations incorporated in the IGS network, and subject to the Regulation 13 certification process providing legal traceability with respect to the Recognised-Value Standard (RVS) of measurement of position in Australia (Hu and Dawson, 2020). The Survey Control Information Management System (SCIMS) is the state's database containing more than 250,000 survey marks on public record, including coordinates, heights, accuracy classifications and other metadata, provided in GDA94, GDA2020 and the Australian Height Datum (AHD – see Roelse et al., 1971; Janssen and McElroy, 2021).

This paper provides an in-depth practical guide for AUSPOS users, explains how AUSPOS solutions are used to maintain and improve the NSW survey control network and outlines the requirements for successful industry-observed AUSPOS datasets to be submitted to DCS Spatial Services for potential update of SCIMS and inclusion in the growing GDA2020 state adjustment. It also offers some practical tips and tricks related to measuring the antenna height, observation data recovery and AUSPOS cluster processing.

2 AUSPOS PROCESSING STRATEGY AND PERFORMANCE

2.1 AUSPOS Processing Strategy

AUSPOS uses the Bernese software version 5.2 (Dach et al., 2015) for data processing. As stated in the AUSPOS report, the carrier phase data is cleaned during pre-processing in baseline-by-baseline mode using triple-differencing. In most cases, cycle slips are fixed by the simultaneous analysis of different linear combinations of L1 and L2. If a cycle slip cannot be fixed reliably, bad data points are removed or new ambiguities are set up. While data cleaning is performed at a sampling rate of 30 seconds, the basic observable used is the carrier phase with a sampling rate of 3 minutes and an elevation angle cut-off at 7°. Elevation-dependent weighting is applied according to $1/\sin(e)^2$ where e is the satellite elevation. A-priori coordinates for the user data are obtained via Precise Point Positioning (PPP) using zero-difference carrier phase measurements (between the L1 and L2 frequencies at a single site).

AUSPOS then uses up to 15 surrounding CORS as the reference stations, generally the 7 closest IGS core sites and the 8 closest APREF sites (Jia et al., 2014). This approach provides a relatively dense network for generating a reliable regional ionospheric delay model and tropospheric delay corrections to support ambiguity resolution. Ambiguities are resolved in baseline-by-baseline mode using the following strategies depending on baseline length (stated in order of increasing accuracy):

- Code-based wide-lane/narrow-lane (L5/L3) strategy for 200-6,000 km baselines.
- Phase-based wide-lane/narrow-lane (L5/L3) strategy for 20-200 km baselines.
- Quasi-Ionosphere-Free (QIF) strategy for 20-2,000 km baselines.
- Direct L1/L2 strategy for 0-20 km baselines.

Based on these reference stations, a precise solution for the user data is then computed using double-differencing techniques. The coordinates of the IGS stations (i.e. tier 1 and 2 CORS) are constrained with uncertainties of 1 mm for horizontal position and 2 mm for the vertical component (ellipsoidal height), while lower-tier CORS coordinates are constrained with uncertainties of 3 mm for horizontal position and 6 mm for the vertical (due to the shorter CORS operation time span, lower data quality and/or lower-grade monumentation).

The GPS data is processed in the IGS realisation of the ITRF2014 reference frame and then transformed to GDA2020 via the Australian Plate Motion Model. Derived AHD heights are computed by applying a gravimetric-geometric quasigeoid model (AUSGeoid2020 – see Brown et al., 2018; Janssen and Watson, 2018; Featherstone et al., 2019) to the GDA2020 ellipsoidal heights. It is worth noting that AUSGeoid2020 only extends 33 km offshore. Between 33 km and 50 km offshore, the AUSGeoid2020 N-values are linearly blended with the DTU15 Mean Sea Surface (MSS) model produced by the Technical University of Denmark (DTU) (Andersen et al., 2016), i.e. the weighting of AUSGeoid2020 diminishes to zero at 50 km offshore. Legacy GDA94 coordinates are obtained from GDA2020 by coordinate transformation. More information about GDA94 and GDA2020, along with their technical manuals, can be found on the Intergovernmental Committee on Surveying and Mapping (ICSM) website (ICSM, 2022a).

It is important to note that AUSPOS performs true simultaneous multi-baseline processing, i.e. it combines GPS baseline processing of data collected at several sites in the same time window (which is therefore correlated) with a 3D least squares network adjustment before the results are delivered to the user. Commercial off-the-shelf software packages routinely used by industry and even DCS Spatial Services only mimic this ideal, requiring a 2-step process of single-baseline processing followed by a network adjustment. Simultaneous multi-baseline processing also neatly solves the problem of trivial baselines, which industry tends to struggle with in large networks. Even if the user only submits one RINEX file, AUSPOS still performs simultaneous multi-baseline processing because it uses data from up to 15 CORS. While the traditional 2-step process tends to focus on the delivery of coordinates, simultaneous multi-baseline processing delivers both coordinates and uncertainties, thereby providing better and more realistic uncertainty values. The fact that AUSPOS both processes baselines and adjusts them is often overlooked by novice users who focus on AUSPOS delivering 3D coordinates, which may appear like a ‘fancy’ point position to the uninitiated. However, there is a lot going on under the bonnet.

Positional Uncertainty (PU) is defined as the uncertainty of the horizontal and/or vertical coordinates of a point, at the 95% confidence level, with respect to the defined reference frame (datum). AUSPOS calculates PU based on the East, North and ellipsoidal height coordinate uncertainties according to the Guideline for Adjustment and Evaluation of Survey Control, which is part of ICSM's Standard for the Australian Survey Control Network (SP1), version 2.2 (ICSM, 2020). The coordinate uncertainties of the East, North and ellipsoidal height components are scaled using an empirically derived model, which is a function of duration, data quality and geographical location (latitude and CORS density), and expressed at the 95% confidence level (Jia et al., 2016).

PU can then be stated as Horizontal PU (HPU) for horizontal GDA2020 coordinates, Vertical PU (VPU) for GDA2020 ellipsoidal heights and AHD-PU for derived AHD heights. The PU values for AUSPOS-derived coordinates published in SCIMS are typically larger than those obtained directly by a user because (1) type B uncertainties (those not based on a statistical analysis of data) are applied to CORS (and other survey marks) in the GDA2020 national and state adjustments (see section 4.1), and (2) PU values in SCIMS are rounded up and displayed to the nearest centimetre (causing 0.02 m and 0.03 m to be very common HPU values in SCIMS).

2.2 AUSPOS Performance in NSW

Based on more than 2,400 successful datasets observed by DCS Spatial Services and incorporating observation sessions ranging from 2 hours to 48 hours in length, Janssen and McElroy (2020) showed that AUSPOS routinely delivers PU values at the 0.02-0.03 m level for the horizontal component and about 0.05-0.06 m for the vertical (ellipsoidal) component in NSW. As expected, it was evident that a longer observation span improves PU, particularly in the vertical component. The derived AHD-PU values reported by AUSPOS appeared to be overly conservative for the data investigated, which was attributed to the conservative AUSGeoid2020 uncertainty grid values applied (the best-case official AUSGeoid2020 uncertainty in NSW is about 0.14 m at the 95% confidence level). While AUSPOS uncertainty is known to be affected (scaled) by latitude, it was found that the variation is negligible for user results within the bounds of NSW.

These results illustrated why Geoscience Australia stipulates, and NSW supports, a minimum observation span of 6 hours for direct inclusion into the national GDA2020 adjustment via the National GNSS Campaign Archive (NGCA) to propagate the survey control network. They also showed that shorter observation sessions are of sufficient quality to improve and strengthen state survey infrastructure, provided sky view conditions are reasonable. This justifies the approach taken by DCS Spatial Services to use AUSPOS as one of several suitable methods to maintain and improve the state's survey control network as well as the request for NSW users to submit industry-observed data via the DCS Spatial Services Customer Hub (DCS Spatial Services, 2022b) for the benefit of all (see section 4.2).

3 USING AUSPOS

AUSPOS accepts dual-frequency, geodetic-quality GNSS data in RINEX format that was observed in static mode. While the submitted RINEX file may contain data from multiple GNSS constellations (e.g. GPS, GLONASS, BeiDou and Galileo), only GPS data is used for processing. Similarly, submitted data is resampled (thinned) to a 30-second epoch interval regardless of the initial sampling rate. The AUSPOS website (GA, 2022a) contains background information, a submission checklist, a step-by-step submission guide and frequently asked questions to help users submit data, understand the results and aid trouble shooting. It should be noted that datasets submitted to AUSPOS are neither retained by Geoscience Australia nor passed on to any third party.

3.1 Preparing Data

The thorough preparation of RINEX data files not only facilitates smooth AUSPOS processing but also allows efficient and unambiguous archiving of the data and associated metadata in one place. This paper mainly refers to RINEX version 2.11 because AUSPOS remains GPS-only at present, and this is the format currently used for archiving by DCS Spatial Services. However, it should be noted that the more recent RINEX version 3 format was developed to better support multi-GNSS observations, with version 4 now also available but not yet implemented in most software (IGS, 2022b). The raw observation file in (binary) proprietary format collected by the GNSS receiver needs to be converted to RINEX format and ideally should be decimated to a sampling interval of 30 seconds to decrease the file size.

3.1.1 RINEX File Naming and Editing

The RINEX file name must not contain any spaces, parentheses or symbols. It is beneficial to use the international RINEX v2.11 file naming convention XXXXDDDS.YYO, where XXXX is a 4-character site name, DDD is the day of year (i.e. 001 to 365, or 366 during a leap year), S is the session identifier (i.e. 0 to 9, or A to X indicating the first observation epoch's hour of the day with A = 0 hours and X = 23 hours), YY is the 2-digit year (i.e. 22 for the year 2022) and O indicates that this is an observation file.

It should be noted that the RINEX v3.05 file naming convention stipulates a much longer file name (along with additional header information). For example, the file name BATH00AUS_R_20220501000_03H_30S_MO.rnx would indicate a RINEX observation file for Bathurst CORS (being the first CORS located at this site in Australia), sourced from a receiver, observed in 2022 on day of year 050 and starting at 10:00 UTC, that contains 3 hours of data at a 30-second sampling rate and mixed GNSS observation data (i.e. from more than one satellite constellation) – see IGS (2022b) for details.

For data archival, or more importantly data sharing or submission to third parties (especially where machine-to-machine processes are likely to be employed), the RINEX header should then be checked and edited. Particular attention should be paid to marker name and number, receiver type and serial number, antenna type and serial number, and vertical antenna height to the ARP (Figure 1). Each RINEX file must only include a single occupation on a single mark.

```
1      2.11           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
2 teqc  2016Nov7                          20210617 05:02:57UTCPGM / RUN BY / DATE
3 Linux2.6.32-279.el6.x86_64|x86_64|gcc|Win64-MinGW64|=       COMMENT
4 BIT 2 OF LLI FLAGS DATA COLLECTED UNDER A/S CONDITION       COMMENT
5 48DE                                                        MARKER NAME
6 PM183662                                                    MARKER NUMBER
7 NSW                 NSW                                     OBSERVER / AGENCY
8 1516405             LEICA GS15          8.00/7.500          REC # / TYPE / VERS
9 1516405             LEIGS15.R2      NONE                    ANT # / TYPE
10  -4585969.9235  2736510.8223 -3477269.8581                  APPROX POSITION XYZ
11        1.5190        0.0000        0.0000                  ANTENNA: DELTA H/E/N
12     1     1                                                WAVELENGTH FACT L1/2
13     6    L1    L2    C1    P2    S1    S2                  # / TYPES OF OBSERV
14    30.0000                                                 INTERVAL
15 Source: 6405_0601_103528.m00                               COMMENT
16 Forced Modulo Decimation to 30 seconds                     COMMENT
17 DefaultJobName                                             COMMENT
18 DefaultUserDiscription                                     COMMENT
19 Project creator:                                           COMMENT
20  SNR is mapped to RINEX snr flag value [0-9]               COMMENT
21   L1 & L2: min(max(int(snr_dBHz/6), 0), 9)                 COMMENT
22   2021     6     1     0    37   30.0000000     GPS        TIME OF FIRST OBS
23     18                                                     LEAP SECONDS
24                                                            END OF HEADER
```

Figure 1: Typical RINEX v2.11 header.

3.1.2 Antenna Height

If the antenna height was not measured directly and vertically to the ARP in the field, e.g. when using a vertical height hook measurement or a slant measurement to the bumper or the Slant Height Measurement Mark (SHMM) on the instrument, then it must be converted to the vertical distance between the ground mark and the ARP using the offsets and method (generally applying Pythagoras) specified in the GNSS equipment manual or provided by the manufacturer (see section 5.1 for examples). Third parties, including the authors, often struggle to figure this out when this information is not included. The correctness of antenna height and antenna type is crucial to allow the correct antenna model to be applied correctly. An error in the antenna height will directly translate into an error in the resulting GNSS-derived ellipsoidal height and AHD height. The antenna height should therefore be measured to the millimetre at the start and at the end of the observation session. A useful independent check is to always take a second measurement using imperial units (inches) and convert to metres (multiply by 0.0254).

3.1.3 Antenna Type

Using the incorrect GNSS antenna type for AUSPOS processing can cause the resulting height to be in error by several centimetres and introduce noise into the computed coordinates. Using the default null antenna can easily introduce a 10 cm error in height. The authoritative source for resolving antenna queries are the frequently updated IGS files *rcvr_ant.tab* and *antenna.gra* (IGS, 2022c). The file *rcvr_ant.tab* details the international naming conventions for GNSS receivers, antennas and radomes (antenna covers), which are also used by AUSPOS. Note that the RINEX format stipulates the antenna type as a 20-character name (columns 21-40 of line 9 in Figure 1) including several spaces and ending with a 4-character indication of the radome used (NONE meaning that no radome is present). The file *antenna.gra* provides graphs with physical dimensions of GNSS antennas, including the position of the ARP (generally the bottom of the antenna) and vertical offsets to other features such as the centre of bumper or bottom of choke ring. As an aside, the file *igs14.atx*, containing the IGS antenna models recommended for baseline processing, can be found at the same location (it is frequently updated to include new antennas). If still in doubt, users should contact their equipment provider for the required antenna information.

3.1.4 GNSS Observations

If session length is critical to contractual arrangements and/or data acceptance by a third party (e.g. DCS Spatial Services), always extend session lengths by a few minutes. Also visually inspect the start and end of the GNSS observation section in the RINEX file (the data following the header), particularly to ensure that the first and last few epochs contain reasonably complete data blocks. This may lead to a few epochs at the start or end of the observation window being deleted due to incomplete data or obstructions caused by the observer. Note that AUSPOS may further trim poor data (like missing or incomplete epochs as the receiver struggles to acquire satellites when first turned on under trees) and thin the submitted data to a 30-second sampling rate – this may help explain why a few minutes of data are sometimes mysteriously missing (and can therefore put the acceptance of your data by a third party at risk). If epochs at the start/end of the observation are deleted, the time of the first/last observation in the RINEX header should be modified accordingly. Frequent dropouts of satellite signals in the RINEX file may also indicate poor sky view conditions (e.g. tree cover).

Figure 2 shows a typical RINEX observation data block for the epoch 00:37:30 hours on 1 June 2021. In this epoch, 18 satellites were observed (8 GPS, 6 GLONASS and 4 Galileo) with six types of observations recorded for all but the Galileo satellites (the L2 frequency is not used by Galileo) – see line 13 in Figure 1 for the corresponding observation types in the RINEX header (L1, L2, C1, P2, S1, S2 – i.e. carrier phase measurements, code measurements and signal strengths on the L1 and L2 frequency, respectively).

```
 21  6  1  0 37 30.0000000  0 18G01G03G04G10G21G22G31G32R02R03R04R13
                                R18R19E05E09E11E36
 110137934.272 8  85821775.74248  20958552.220    20958554.400          53.300
        53.550
 119766659.544 7  93324688.12247  22790840.660    22790843.240          45.200
        45.100
 124156873.931 7  96745619.03746  23626267.600    23626269.980          43.200
        40.100
 130281153.04615 101517801.02255  24791680.380    24791685.800          35.450
        34.100
 107660051.087 8  83890939.09847  20487029.500    20487028.240          51.400
        45.600
 109924937.177 8  85655784.12247  20918020.040    20918017.020          52.900
        44.550
 109426889.942 8  85267704.15548  20823245.920    20823244.660          53.300
        53.250
 122182552.628 7  95207188.87447  23250567.920    23250568.700          47.650
        42.200
 122656371.420 6  95399420.181 6  22985753.460    22985758.360          38.500
        39.000
 109283847.384 8  84998559.602 8  20415141.460    20415142.640          52.450
        48.900
 114565531.929 6  89106523.251 5  21394302.360    21394302.020          38.150
        33.950
 110306911.273 6  85794276.777 7  20656940.920    20656944.020          39.850
        42.650
 114943294.330 8  89400354.336 7  21532750.260    21532755.080          50.650
        47.400
 112735465.036 6  87683135.364 6  21074705.120    21074707.020          38.950
        41.550
 129830473.839 8                  24705917.480                          48.750

 117250086.174 9                  22311949.220                          54.400

 133045175.973 7                  25317654.460                          42.450

 128710168.325 8                  24492734.840                          52.900

 21  6  1  0 38  0.0000000  0 20G01G03G04G10G21G22G31G32R02R03R04R12
                                R13R14R18R19E05E09E11E36
```

Figure 2: Typical RINEX v2.11 observation block.

3.2 Submitting Data

Up to 20 RINEX files can be submitted to AUSPOS simultaneously, provided all their observation sessions contain an overlap of at least 1 hour. These are then processed together in a cluster, using an observation window that contains the collected data at all sites (see section 5.3). However, for simplicity, this section assumes submission of a single RINEX file.

3.2.1 When to Submit

When you submit your data will affect your results, in two ways. Firstly, AUSPOS uses the best available IGS orbit product for processing, having a choice of three (final, rapid and ultra-rapid). The final orbit product is available approximately 2-3 weeks after the observation day (with the weekly final orbit product generally being made available to AUSPOS on Monday morning), while the rapid orbit product is available two days after the observation. If both are unavailable, the much less accurate ultra-rapid orbit product is used. Consequently, it is recommended to submit data to AUSPOS at least two days after the observation to get the benefit of the IGS rapid orbits. DCS Spatial Services almost exclusively uses final orbits (i.e. the best available product) for AUSPOS processing. However, AUSPOS solutions using the rapid orbit product are typically very close to final-orbit solution quality and are therefore likely to be more suited to industry due to their much faster availability.

Secondly, the data from local and international CORS needs to be delivered to Geoscience Australia in order to be used by the AUSPOS service. This data can be either streamed (live) or pushed at regular intervals (e.g. hourly). However, on occasion, Information and Communications Technology (ICT) systems may go down, resulting in the missing CORS data being pushed to the AUSPOS service with a delay. This is very rare in NSW because CORSnet-NSW contains a dense network of CORS with reliable primary and backup communications at each site, so local CORS should generally not be affected. Nevertheless, waiting a little longer before submission increases the chance of using the maximum number of 15 CORS in the solution (provided there are no issues with data quality).

3.2.2 Ticking Boxes

After selecting the RINEX file for upload, the user needs to manually input the antenna height (vertically measured between ground mark and ARP) and select the antenna type (IGS naming convention) from the drop-down menu. Alternatively, clicking the 'scan' button will scan the RINEX file header for the required information – this option should only be used if it has been confirmed that the RINEX header is correct.

Note that the RINEX header often contains incorrect or incomplete information when initially generated (e.g. the manufacturer's receiver and antenna names not following the IGS naming convention, a default antenna type or a zero antenna height), so thorough data preparation is very important. Using an incorrect antenna type can introduce significant bias (more than 10 cm in the vertical component) and noise into the computed coordinates.

Finally, the user provides their email address and submits the data. A status message then appears indicating successful submission and stating the job number, e.g. 1627262153022-99999999 in Figure 3.

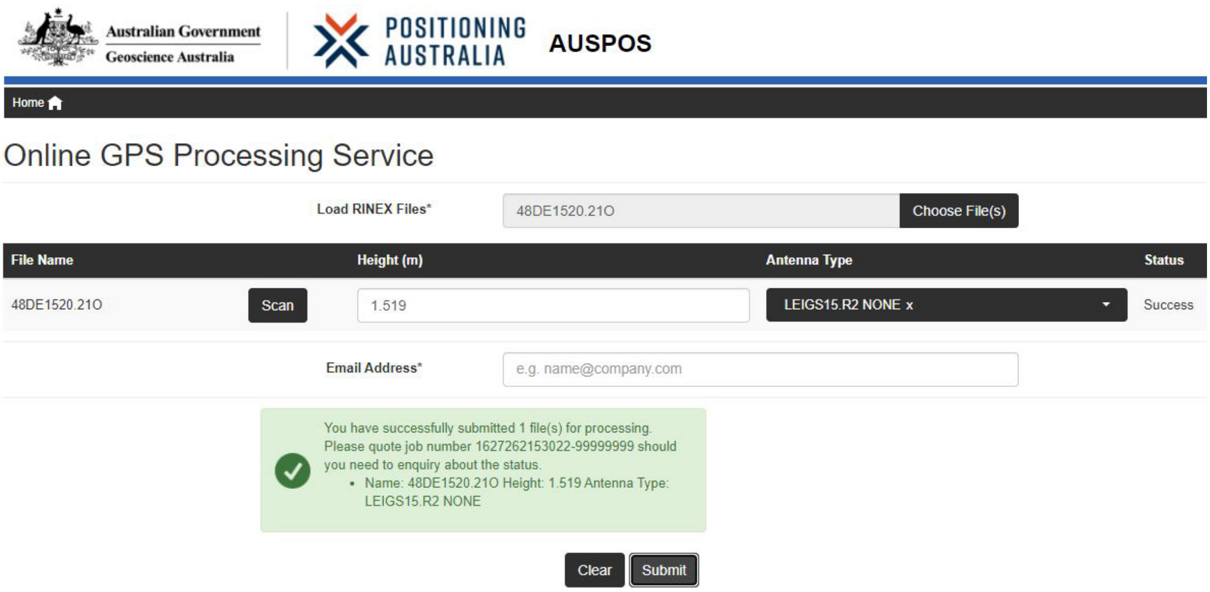


Figure 3: AUSPOS submission page after successful submission of a single RINEX file.

This is followed by an email sent to the user when AUSPOS starts processing the data, generally within a few minutes but depending on current workload, which also includes a list of reminders to ensure successful processing (identical to the submission checklist available on the AUSPOS website):

- AUSPOS only provides a network solution (relative positioning) using a double-difference strategy. Dual-frequency (L1 and L2) measurements are necessary.
- Ensure all RINEX files submitted to the same job contain an overlapping period of more than one hour. Otherwise, submit them individually to different jobs.
- Do not submit measurements for the current UTC day. Please wait until the next UTC day after 03:00 UTC time (i.e. 13:00 AEST or 14:00 AEDT). This allows the RINEX files of reference stations to be downloaded for the current UTC day.
- Do not submit receiver raw binary files (e.g. files with extension M00, T01, T02, DAT, SBF, TPS, etc.).
- Only submit RINEX observation files (e.g. RINEX v2 files with extension O).
- RINEX file names should not contain any special characters, symbols or spaces.
- The station name will be read from the first 4 characters of the MARKER NAME line in the RINEX header.
- Ensure the measurement interval (integer only) is equal to or larger than one second. It is recommended to have the same interval for all RINEX files submitted together.
- Do not use special characters for MARKER NAME and MARKER NUMBER in the RINEX header. Only use numbers and/or letters from the modern English alphabet.
- After the END OF HEADER line in the RINEX header, only observation data should be present (epoch time and measurements).
- If both C1 and P1 (C2 and P2) code measurements exist in a RINEX v2 file, P1 (P2) is given priority to be processed. Ensure that all GPS satellites contain P1 (P2) measurements.
- If only C1 (C2) code measurements exist in a RINEX v2 file, ensure that all GPS satellites contain C1 (C2) measurements.
- For RINEX v3 files, C2S (code measurement) and L2S (phase measurement) from the L2 frequency will not be accepted.
- For RINEX v3 files, the currently accepted L1 frequency measurements are C1P and L1P, C1W and L1W, C1C and L1C, and C1X and L1X.

- For RINEX v3 files, the currently accepted L2 frequency measurements are C2P and L2P, C2W and L2W, C2C and L2C, C2D and L2D, and C2X and L2X.
- If the RINEX files are Hatanaka compressed, use the lower case ‘d’ for the file name extension.

If AUSPOS encounters problems during processing, a further email is sent to the user providing some indication of the issue in the subject, such as:
- ERROR (Please check the format of RINEX file including RINEX header which might be with merging or format errors).
- ERROR (Today’s measurements are not available yet).
- ERROR (Please check whether you submitted different type of RINEX file or not).
- ERROR (Please check whether you submitted receiver raw binary file or not).
- ERROR (PrePPP-Processing).
- ERROR (Final-Processing, RINEX file may be submitted twice or deleted by quality issue).

These errors are generally caused by RINEX format issues (e.g. RINEX header information not in the correct columns or multiple observation sessions present in a single RINEX file) or bad data quality (e.g. short observation session at a site severely affected by tree cover). Furthermore, AUSPOS is limited to accept a maximum total of 130 GNSS satellites in each submitted RINEX file. Geoscience Australia aims to assess the cause of the failure and contact the user if further processing is possible. The AUSPOS website also includes information to aid trouble shooting.

3.3 Interpreting the Results

As mentioned earlier, an AUSPOS report (pdf) is emailed to the user following processing (generally within a few minutes but depending on current workload). This report includes the computed coordinates and their uncertainties, ambiguity resolution statistics, and an overview of the GPS processing strategy applied. For advanced users, or those interested in machine-to-machine applications, SINEX files containing more detailed information about the solution are also available for download.

The reported AUSPOS processing results should be checked to ensure that the solution is reliable:
- Section 1: User Data
  - Is the antenna type correct?
  - Is the antenna height (measured vertically from ground mark to ARP) correct?
- Section 2: Processing Summary
  - Is the number of reference stations used appropriate (i.e. close to 15 CORS)?
  - Is there a good mix of local and distant CORS, i.e. about 8 local CORS and 7 distant CORS (Figure 4)?
  - Are IGS final or rapid orbits used for processing (final orbits are better)?
- Section 3.4: Positional Uncertainty (95% CL) – Geodetic, GDA2020
  - Are the PU values of the GDA2020 coordinates and derived AHD height reasonable, considering observation session length and sky view conditions? (DCS Spatial Services aims for HPU < 0.02 m and ellipsoidal VPU < 0.05 m under good sky view conditions and routinely obtains a reported AHD-PU < 0.19 m.)
  - Is the report void of any warning messages (e.g. large uncertainty)?

- Section 6: Ambiguity Resolution – Per Baseline
  - Are the ambiguity resolution statistics reasonable (i.e. at least 50% of ambiguities resolved per baseline, particularly those to your rover)? (DCS Spatial Services routinely encounters values above 70% in its work.)

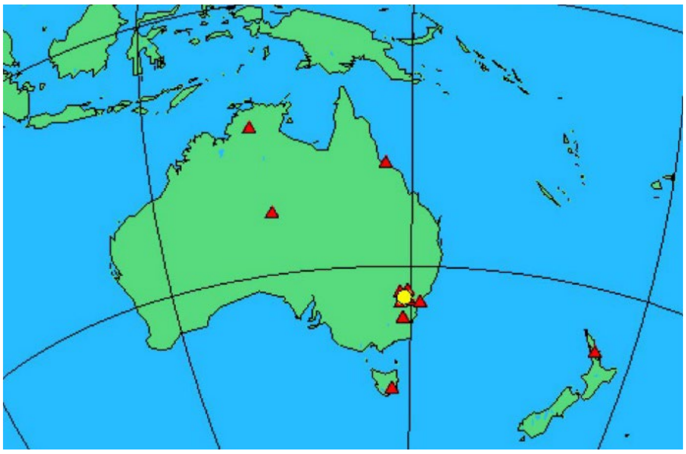


Figure 4: Typical distribution of CORS used as shown in the AUSPOS report (yellow dot indicates user position).

If warning messages occur, the problem needs to be assessed by investigating the magnitude of PU values, session length, sky view conditions and data quality. In most cases, warning messages are due to short or 'dirty' sessions at sites affected by tree cover or other obstructions, resulting in poor sky view conditions and bad data quality (including low or failed ambiguity resolution). Repeating the observation with a longer observation session length will generally result in a better result without any warning messages. Even at heavily treed sites, DCS Spatial Services routinely achieves Class E (sub-metre) results in both the horizontal and vertical component with overnight sessions.

As shown by Janssen and McElroy (2020), most of the improvement in the quality of AUSPOS solutions is gained by increasing the observation length from 2 hours to about 4-5 hours, with minor but not insignificant improvement when the observation span is further increased. Observation sessions exceeding 12 hours provide AUSPOS solutions of substantially higher quality in the vertical component.

Showing the cumulative distribution of PU values to quantify the percentage of AUSPOS solutions meeting a particular PU threshold, Figure 5 can be used as a simple look-up tool to estimate the likelihood of achieving any specified HPU or VPU threshold with 2-6 hour and 6+ hour observation sessions. For example, it shows that about 39% of the 2-6 hour AUSPOS solutions investigated had HPU values of 0.02 m or better, i.e. these survey marks have an absolute horizontal accuracy slightly larger than the size of a 50c piece (radius of 16 mm) with respect to the national datum, while 95% of the 6-24 hour solutions had HPU values at this level. Similarly, about 91% of the 2-6 hour solutions and 99.5% of the 6-24 hour solutions had HPU values of 0.03 m or better.

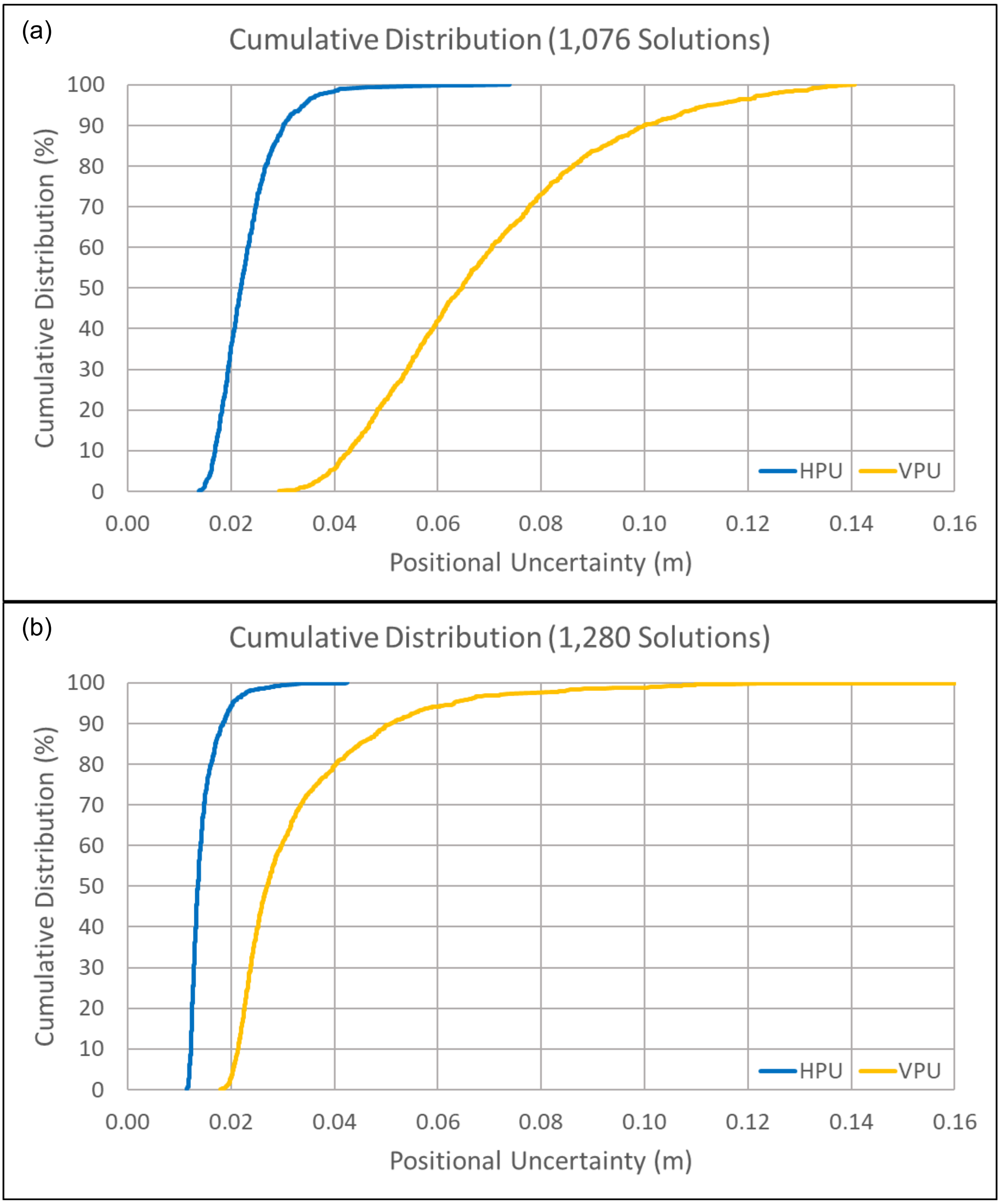


Figure 5: Cumulative distribution of PU reported by AUSPOS in NSW for (a) 2-6 hour datasets, and (b) 6-24 hour datasets (Janssen and McElroy, 2020).

4 MAINTAINING AND IMPROVING THE STATE'S SURVEY CONTROL NETWORK

DCS Spatial Services is responsible for the maintenance of the NSW survey control network. Datum modernisation and further improvement of survey infrastructure is required to accommodate the increasing accuracy and improved spatial and temporal resolution available from modern positioning technologies to an ever-broadening user base. With all CORSnet-NSW stations contributing to the AUSPOS service, it delivers high-quality positioning results even for shorter observation sessions of at least 2 hours across NSW, provided sky view conditions are reasonable (Janssen and McElroy, 2020). Consequently, in some situations, the use of AUSPOS campaigns has developed into a capable and reliable alternative to conducting traditional static GNSS baseline surveys (e.g. Gowans et al., 2015; Janssen and Watson, 2018), simplifying field work logistics and providing significant time savings in regard to processing, adjustment and survey report writing. AUSPOS also forms a new and fundamental component of vertical datum modernisation and the propagation of the Australian Vertical Working Surface (AVWS – see ICSM, 2022b; Janssen and McElroy, 2021) across the state.

4.1 AUSPOS and the NSW Survey Control Network

While traditional GNSS baseline surveys continue to be performed and adjusted by DCS Spatial Services, it also applies, expands and accelerates the use of AUSPOS to improve the state's survey infrastructure. To this end, AUSPOS data of at least 6 hours duration is used to propagate the datum in NSW, while AUSPOS data of less than 6 hours duration strengthens the datum.

Following successful AUSPOS processing of each dataset individually by DCS Spatial Services (GPS-only, using final IGS products), GNSS data of more than 6 hours duration (with a maximum observation length of 48 hours) is submitted to Geoscience Australia toward the National GNSS Campaign Archive (NGCA) of 6+ hour AUSPOS datasets. Currently, this data is then grouped into simultaneously observed sessions and processed by Geoscience Australia using the same online AUSPOS engine in clusters. The results are expressed as baselines to nearby CORS, rather than absolute measurements of position, to avoid introducing additional GDA2020 adjustment constraints outside of APREF.

GNSS data of 2-6 hours duration is handled by DCS Spatial Services according to a similar principle but brought about by slightly different means. Again following successful, individual AUSPOS processing by DCS Spatial Services to verify the required data quality, the AUSPOS results are converted to be expressed as baselines to nearby CORS and then included in the GDA2020 adjustment as part of the state's Jurisdictional Data Archive (JDA). To date, more than 12,000 AUSPOS solutions have been used to help maintain and improve the NSW survey control network.

Currently, DCS Spatial Services allocates a maximum Class D to any survey mark coordinated via AUSPOS as it generally represents only a single occupation with limited redundancy. Marks occupied multiple times, by AUSPOS only, still only receive Class D maximum. The immediate purpose is to upgrade unestablished marks to established marks and make them available to SCIMS users in a timely manner (monthly), until these initial values are updated via the GDA2020 state adjustment (6-monthly). To achieve this, DCS Spatial Services has developed and introduced a monthly workflow to automate as much as possible the update of survey mark coordinates, heights and their uncertainties in SCIMS based on AUSPOS data. Since June 2020, more than 3,200 SCIMS updates for more than 1,600 marks have been undertaken via the new automated workflow, providing a quicker way to deliver more accurate information to our customers as we continue to upgrade the state's survey control network.

The assessment of Class is performed in accordance with ICSM (2007) and Surveyor-General's Direction No. 12 (Control Surveys and SCIMS) (DCS Spatial Services, 2021), and uncertainty as described in Janssen et al. (2019). Table 1 summarises the PU range applicable for the assignment of Class for horizontal coordinates, ellipsoidal height and derived AHD height, based on a single AUSPOS solution.

Table 1: Assigning Class for unestablished survey marks based on the Positional Uncertainty (PU) of a single AUSPOS session.

Class Type	Class	PU Range
Horizontal	D	HPU (95% CL) ≤ 0.1 m
	E	0.1 m < HPU (95% CL) ≤ 1 m
	U	HPU (95% CL) > 1 m
Vertical (ellipsoidal)	D	VPU (95% CL) ≤ 0.1 m
	E	0.1 m < VPU (95% CL) ≤ 1 m
	U	VPU (95% CL) > 1 m
AHD	D	AHD-PU (95% CL) ≤ 0.2 m
	E	0.2 m < AHD-PU (95% CL) ≤ 1 m
	U	AHD-PU (95% CL) > 1 m

Before AUSPOS datasets are processed by DCS Spatial Services, they are subject to a quality assurance process, which ensures a minimum observation session length of 2 hours, certainty about antenna type used and antenna height measured, and involves RINEX file screening and editing to ensure correct header information and sufficient data quality. The AUSPOS results then go through a quality check to ensure that the solution is reliable and suitable for SCIMS update (see section 3.3).

At present, the GDA2020 state adjustment incorporates approximately 96,000 survey control marks across NSW, i.e. 38% of the 250,000 marks on public record in SCIMS. Consequently, 62% of the marks have been transformed from the now superseded GDA94 to GDA2020. Uncertainties of these transformed GDA2020 coordinates cannot be computed until the underlying measurements are sourced and readjusted with a well-defined connection to datum in the GDA2020 state adjustment.

As mentioned in section 2.1, type B uncertainties are applied to CORS (and other survey marks) in the GDA2020 state adjustment. This is to allow for areas of uncertainty which cannot be modelled through least squares (e.g. monument stability). DCS Spatial Services applies two types of type B uncertainty in the state adjustment:

- RVS stations (tier 2 CORS only): 3 mm, 3 mm and 6 mm in East, North and ellipsoidal height respectively.
- Non-RVS stations (everything else): 6 mm, 6 mm and 12 mm in East, North and ellipsoidal height respectively.

These type B uncertainties are added in quadrature to the a-posteriori variance matrix of the adjustment:

$$SD_{final} = \sqrt{{SD_{adjusted}}^2 + (type\ B\ uncertainty)^2} \quad (1)$$

While this is a 'broad-brush' technique, it is suitable in practice and follows the same process as the GDA2020 national adjustment. It is important to emphasise that:

- DCS Spatial Services does not add type B uncertainty to AUSPOS solutions published in SCIMS through the monthly update process.
- Initially, DCS Spatial Services accepts and publishes the AUSPOS-reported uncertainty results without alteration (but rounded up and displayed to the nearest centimetre).
- When the AUSPOS results are converted into correlated baselines and included in the GDA2020 state adjustment, type B uncertainty is applied before the 6-monthly SCIMS update.

In order to support further survey infrastructure improvement, DCS Spatial Services is currently building an updated 'passive' survey control network (in the Eastern and Central Divisions) with a minimum of one fundamental survey mark observed by 6+ hour AUSPOS every 10 km. Its vision is to ensure that any future user is no further than 5 km (and often much less) from such a fundamental mark providing direct connection to datum. Similarly, levelled AHD marks are observed by 6+ hour AUSPOS every 10 km, often at a far greater density. This will allow users to achieve DCS Spatial Services' vision of a PU of 20 mm in the horizontal and 50 mm in the vertical (ellipsoidal height) component anywhere in the state and to easily apply transformation tools to move between current, future and various historical datums and local working surfaces (e.g. railway datum or standard datum).

Using AUSPOS sessions of at least 6 hours duration in this way has several advantages. The field work is quick, logistically simple and very efficient, with multipath effectively being averaged out over the observation session and reliable solutions achieved even under challenging sky view conditions. Data processing via AUSPOS is consistent, of the highest possible standard and very time-efficient, providing a direct connection to the datum via a sophisticated, scientific software package using the best products and models available at the time. The processing results can be ingested by the GDA2020 state adjustment in an automated fashion with minimal effort and without the need for a survey report. Rather than archiving the results, the data is archived and able to be reprocessed at any time to investigate issues or take advantage of improved modelling. While it is recognised that AUSPOS represents an absolute positioning technique because it connects to the surrounding CORS rather than adjacent ground marks, the NSW survey control network is becoming so tight that the authors anticipate there will soon be little difference between relative and absolute positioning.

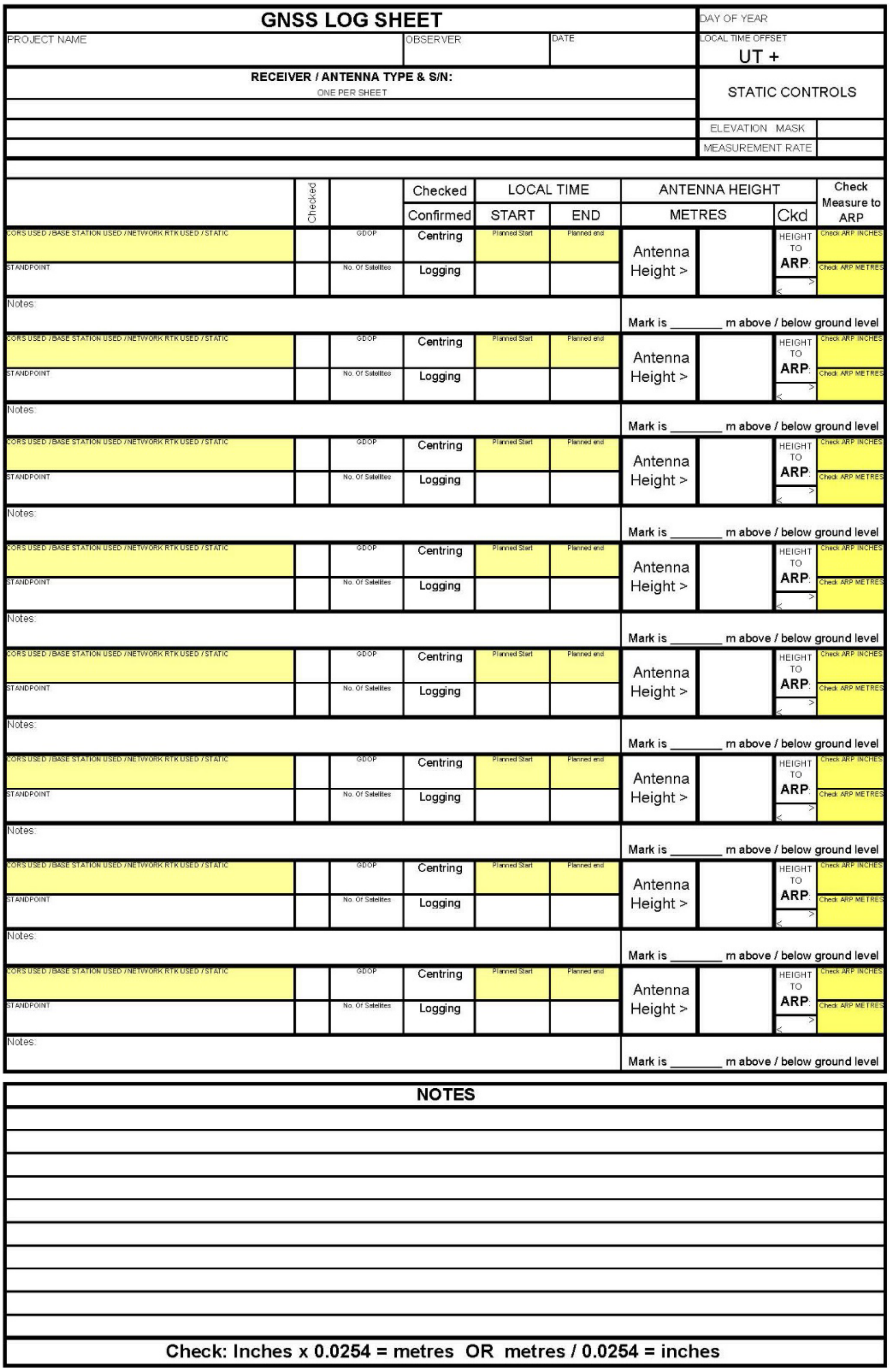
4.2 Submitting AUSPOS Datasets to DCS Spatial Services

The profession is encouraged to contribute to maintaining, expanding and improving the NSW survey control network by submitting suitable AUSPOS datasets of at least 2 hours duration and related metadata via the DCS Spatial Services Customer Hub on our website (DCS Spatial Services, 2022b). The DCS Spatial Services Customer Hub is a new, user-friendly platform providing a central contact point to interact with DCS Spatial Services staff. It is now the primary way for customers to make an enquiry, submit a data request and provide feedback. Similarly, Survey Operations can (soon) be contacted through the Customer Hub to submit AUSPOS datasets, Locality Sketch Plans (LSPs), Preservation of Survey Infrastructure (POSI) applications, trig station approvals, exemption applications and regulation approvals. Access to the Customer Hub is free and simple, after creating a one-time username and password. Through a ticketed system, users can track the status of their requests at any point in time, which enables DCS Spatial Services to manage these more efficiently and effectively.

AUSPOS data submissions to DCS Spatial Services must include the following:

- RINEX observation file (currently, RINEX v2.11 is preferred) of at least 2 hours duration. Also including the raw binary file in the manufacturer's native format is optional but strongly recommended.
- Completed log sheet or field notes, clearly indicating observation date/time, mark observed, receiver and antenna type used, and antenna height measured vertically to the ARP.
- AUSPOS processing report.
- Locality Sketch Plan for any new mark placed (submitted separately to the AUSPOS data).
- Photographs of the mark, indicating mark type and sky view conditions (optional but recommended).

For clarity and ease of operation, it is recommended to use the generic DCS Spatial Services GNSS log sheet (Figure 6), available as part of the resource pack for Surveyor-General's Direction No. 12 (DCS Spatial Services, 2021), because it indicates the minimum details to be captured.


GNSS LOG SHEET
DAY OF YEAR
PROJECT NAME | OBSERVER | DATE | LOCAL TIME OFFSET: UT +
RECEIVER / ANTENNA TYPE & S/N: (ONE PER SHEET)
STATIC CONTROLS
ELEVATION MASK
MEASUREMENT RATE
Checked | Checked / Confirmed | LOCAL TIME: START, END | ANTENNA HEIGHT: METRES, Ckd | Check Measure to ARP

CORS USED / BASE STATION USED / NETWORK RTK USED / STATIC | GDOP | Centring | Planned Start | Planned end | Antenna Height > | HEIGHT TO ARP | Check ARP INCHES
STANDPOINT | No. Of Satellites | Logging | Check ARP METRES
Notes: | Mark is _______ m above / below ground level

CORS USED / BASE STATION USED / NETWORK RTK USED / STATIC | GDOP | Centring | Planned Start | Planned end | Antenna Height > | HEIGHT TO ARP | Check ARP INCHES
STANDPOINT | No. Of Satellites | Logging | Check ARP METRES
Notes: | Mark is _______ m above / below ground level

CORS USED / BASE STATION USED / NETWORK RTK USED / STATIC | GDOP | Centring | Planned Start | Planned end | Antenna Height > | HEIGHT TO ARP | Check ARP INCHES
STANDPOINT | No. Of Satellites | Logging | Check ARP METRES
Notes: | Mark is _______ m above / below ground level

CORS USED / BASE STATION USED / NETWORK RTK USED / STATIC | GDOP | Centring | Planned Start | Planned end | Antenna Height > | HEIGHT TO ARP | Check ARP INCHES
STANDPOINT | No. Of Satellites | Logging | Check ARP METRES
Notes: | Mark is _______ m above / below ground level

CORS USED / BASE STATION USED / NETWORK RTK USED / STATIC | GDOP | Centring | Planned Start | Planned end | Antenna Height > | HEIGHT TO ARP | Check ARP INCHES
STANDPOINT | No. Of Satellites | Logging | Check ARP METRES
Notes: | Mark is _______ m above / below ground level

CORS USED / BASE STATION USED / NETWORK RTK USED / STATIC | GDOP | Centring | Planned Start | Planned end | Antenna Height > | HEIGHT TO ARP | Check ARP INCHES
STANDPOINT | No. Of Satellites | Logging | Check ARP METRES
Notes: | Mark is _______ m above / below ground level

CORS USED / BASE STATION USED / NETWORK RTK USED / STATIC | GDOP | Centring | Planned Start | Planned end | Antenna Height > | HEIGHT TO ARP | Check ARP INCHES
STANDPOINT | No. Of Satellites | Logging | Check ARP METRES
Notes: | Mark is _______ m above / below ground level

CORS USED / BASE STATION USED / NETWORK RTK USED / STATIC | GDOP | Centring | Planned Start | Planned end | Antenna Height > | HEIGHT TO ARP | Check ARP INCHES
STANDPOINT | No. Of Satellites | Logging | Check ARP METRES
Notes: | Mark is _______ m above / below ground level

NOTES

Check: Inches x 0.0254 = metres OR metres / 0.0254 = inches

Figure 6: Generic GNSS log sheet (DCS Spatial Services, 2021).

The Excel version of the log sheet can easily be modified to accommodate individual needs (e.g. inserting equipment details), which makes it very efficient when printed for use in the field or converted to pdf format. If the antenna height is routinely measured using a height hook or slant measurement, the relevant antenna diagram and offset calculations to convert this value to the ARP can also be included as an image (generally sourced from the equipment manual), e.g. in the notes/comments section at the bottom of the log sheet or by reducing the number of rows allocated to multiple observation sessions. Surveyors who opt to submit cadastral-type field notes need to ensure that all required information is noted. In this regard, a little preparation provides great benefits in the field and further downstream. We found this very valuable when revisiting log sheets from many years ago to mine data for purposes that were not envisaged when the data was originally collected.

It is worth noting that the local time offset for most of NSW is either +10 hours or +11 hours (if Daylight Saving Time is active). The day of year is simply that, counting from 1 onwards with 1 January being 1 and 31 December being 365 (or 366 in a leap year) – see NGS (2022) for a GPS calendar showing the day of year and GPS week. It is recommended to book start and end times in the 24-hour format, i.e. 16:23 rather than 4.23 pm. The notes section of the log sheet is useful for documenting any antenna height measurement conversions and sky view conditions or unforeseen circumstances that may be relevant.

5 PRACTICAL TIPS AND TRICKS

5.1 Reduction of the Antenna Height to the ARP

One of the two most common reasons for DCS Spatial Services to reject AUSPOS data submissions by third parties is a missing or ambiguous antenna height (the other is an unknown or ambiguous antenna type). Is the provided antenna height the required vertical measurement to the ARP or a slant measurement to some mark on the housing of the antenna? Has it been measured directly or calculated by applying a particular reduction procedure? The ARP is generally the bottom of the antenna, and the antenna height to the ARP should not be confused with a vertical height hook or slant height measurement commonly applied in GNSS baseline processing software.

This section provides selected examples illustrating the offset calculations that need to be applied when the initial antenna height measurement is not a direct, vertical measurement between the ground mark and the ARP. It should be emphasised that the antenna height must be measured with utmost care as any error will directly translate into an error of the resulting GNSS-derived ellipsoidal height (and thus the derived AHD height). If in doubt about the antenna type used and the height reduction required, the equipment manufacturer should be contacted for clarification.

5.1.1 Height Hook Measurement

The height hook allows a vertical measurement from the ground mark to a point below the tripod set up on a mark. A vertical offset is then applied (added) to obtain the height to the ARP (Figure 7). However, this offset depends on the equipment used, i.e. the type of tribrach and antenna carrier (which may include a screw-to-stub adapter). When standard equipment is used, the offset can be obtained from the GNSS equipment manual and the manufacturer. This offset may then be automatically applied in the rover for real-time applications or the GNSS baseline processing software for post-processing applications, provided the software is supplied by the same manufacturer.

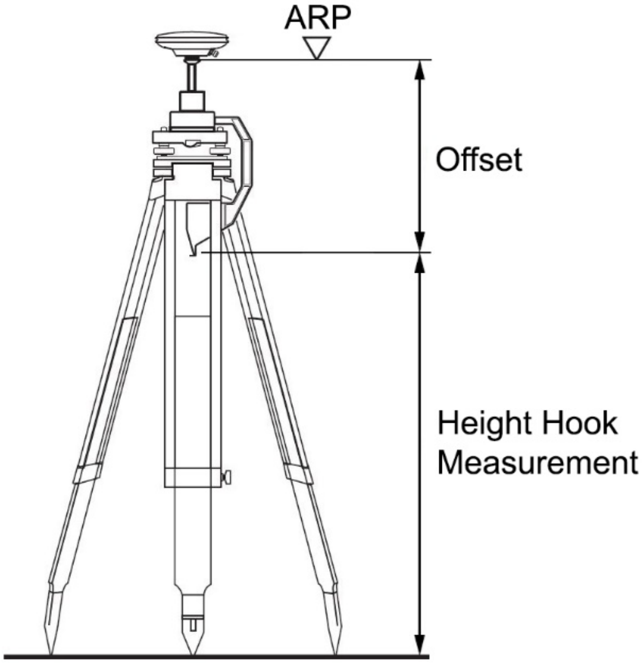


Figure 7: Determining the vertical antenna height to the ARP from a height hook measurement (adapted from Leica Viva Series Technical Reference Manual).

However, AUSPOS does not apply any such offsets because this is simply not workable for the vast number of GNSS antenna makes and models supported. Any comments in the RINEX header pertaining to the antenna height measurement are useful for data archiving but ignored during AUSPOS processing. Following the international standard, AUSPOS expects input of the antenna height vertically measured between the ground mark and the ARP because all antenna phase centre variation models (applied during processing) refer to the ARP.

Consequently, when non-standard equipment is combined, the individual offset for a particular combination needs to be carefully determined and confirmed to avoid antenna height errors. For example, if the Leica Viva GS15 ('LEIGS15.R2 NONE' antenna) is used in conjunction with the standard (small) antenna carrier, the offset to be added to the height hook measurement is 0.254 m. However, if it is combined with the larger antenna carrier, the offset is 0.360 m.

5.1.2 Slant Height to SHMM

Some instruments include a Slant Height Measurement Mark (SHMM), located either on the housing of the antenna or at the tip of a horizontal bar attached to the bottom of the antenna. The GNSS equipment manual should include instructions on the required calculations, including the applicable offsets. For example, Figure 8 illustrates the dimensions and offsets relevant for Topcon's 'TPSHIPER_II NONE' antenna.

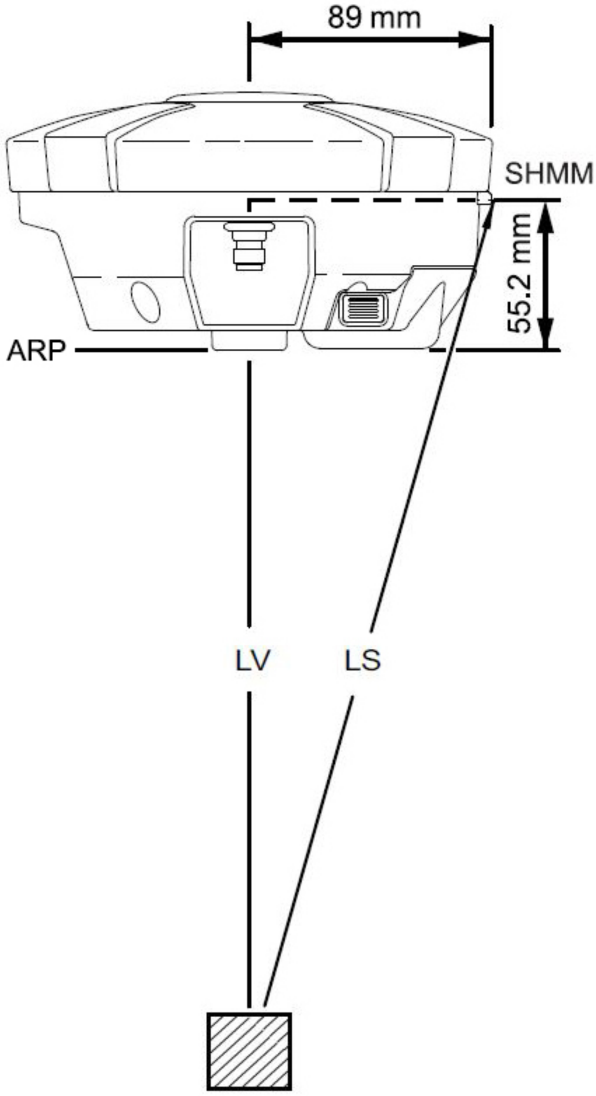


Figure 8: Determining the vertical antenna height to the ARP from a SHMM measurement to the housing of the antenna (adapted from TPS Hiper II Operator's Manual).

Using Pythagoras, the following calculation is required to convert the slant measurement to the SHMM (denoted as *LS*) to the vertical height from the ground mark to the ARP (LV_{ARP}):

$$LV_{ARP}\ (m) = \sqrt{LS^2 - 0.089^2} - 0.055 \qquad (2)$$

In this case, for typical instrument heights ranging from 1.400 m to 2.000 m, ignoring Pythagoras and applying only the vertical offset introduces an error of about 2-3 mm in the antenna height (i.e. the antenna height is too large). While this may be acceptable for cadastral purposes, this approximation should be avoided for control surveys and geodetic purposes because this error will translate directly into the resulting GNSS-derived height.

Similarly, Figure 9 illustrates the offsets relevant for Topcon's 'TPSHIPER_HR NONE' antenna. Since the SHMM and the ARP are on the same horizontal plane, only Pythagoras is required to obtain the vertical height to the ARP from the slant measurement to the SHMM, which is located at the end of a horizontal bar:

$$LV_{ARP}\ (m) = \sqrt{LS^2 - 0.100^2} \qquad (3)$$

In this case, for typical instrument heights ranging from 1.400 m to 2.000 m, using the slant height measurement without reduction to the vertical introduces an error of about 3-4 mm in the antenna height (i.e. the antenna height is too large). Again, this should be avoided in practice.

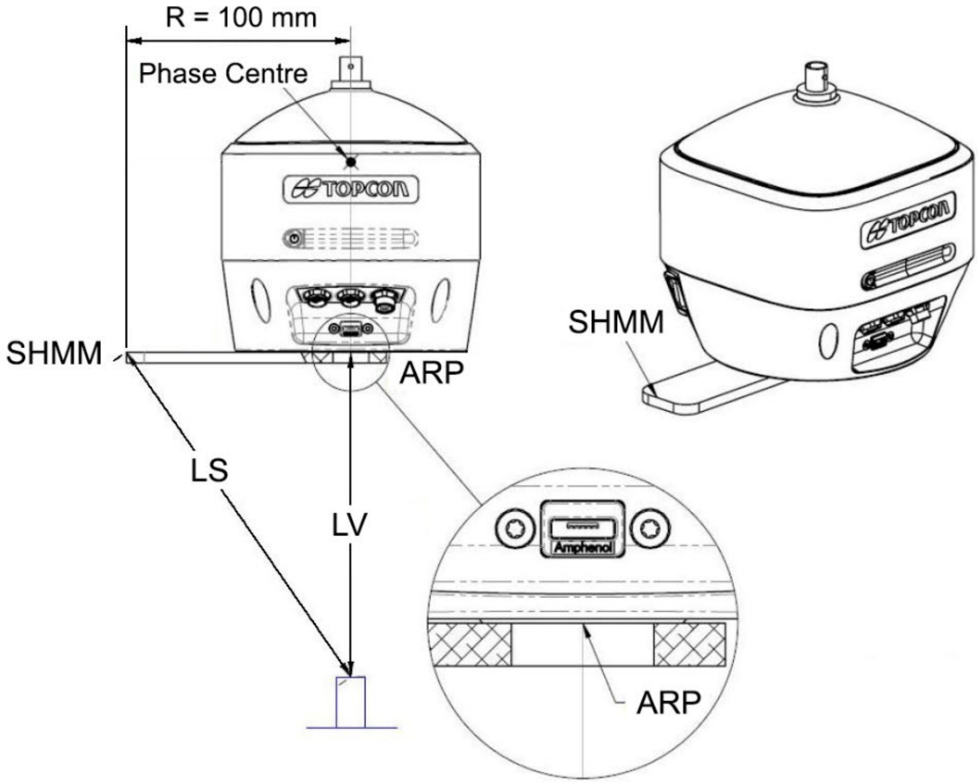


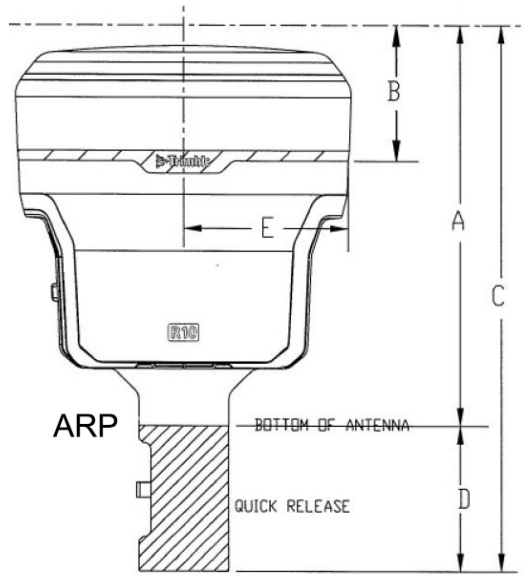
Figure 9: Determining the vertical antenna height to the ARP from a SHMM measurement to a horizontal bar (adapted from TPS Hiper HR Operator's Manual).

5.1.3 Slant Height to Bumper

Other GNSS antennas utilise a distinct marking on the housing of the antenna instead of a specific SHMM as a reference for the slant height measurement. For example, Trimble's 'TRMR10 NONE' antenna features a yellow ring around the housing of the antenna, which is known as the bumper (Figure 10). Using Pythagoras in conjunction with a vertical offset, the measured slant height to the bottom of the bumper is then converted to a vertical antenna height measurement between the ground mark and the ARP:

$$LV_{ARP}\ (m) = \sqrt{LS^2 - 0.058^2} - 0.094 \qquad (4)$$

For typical instrument heights ranging from 1.400 m to 2.000 m, ignoring Pythagoras and applying only the vertical offset introduces an error of about 1 mm in the antenna height (i.e. the antenna height is too large). Compared to the previous two cases, the smaller magnitude of the error is due to the smaller radius of the antenna. Consequently, in this particular case, it is acceptable to approximate equation (4) with simply applying a vertical offset of -0.095 m to reduce the measurement from the bottom of the bumper to the ARP. Obviously, the validity of any such approximation needs to be assessed on a case-by-case basis and should be clearly stated on the GNSS log sheet because this approximation may not be suitable when the data is later used for other purposes (e.g. SCIMS update or geodesy).



	DIMENSIONS		DESCRIPTION
A	0.4892 FT	0.1491 M	BOTTOM OF ANTENNA TO NOMINAL PHASE CENTER
B	0.1790 FT	0.0546 M	BOTTOM OF BUMPER TO NOMINAL PHASE CENTER
C	0.6532 FT	0.1991 M	BOTTOM OF QUICK RELEASE TO NOMINAL PHASE CENTER
D	0.1640 FT	0.0500 M	QUICK RELEASE HEIGHT
E	0.1915 FT	0.0584 M	RADIAL: CENTERLINE OF ANTENNA TO OUTER EDGE OF BUMPER BOTTOM

Figure 10: Determining the vertical antenna height to the ARP from a slant measurement to the bumper (adapted from Trimble R10 User Guide).

Furthermore, as indicated in Figure 10, this antenna may also be used in conjunction with a quick release adapter. The antenna height is then sometimes measured vertically from the ground mark to the bottom of the quick release, only necessitating a vertical offset of +0.050 m to be applied for reduction to the ARP. This illustrates the importance of clearly stating what type of measurement was taken (vertical or slant) to where and how this was then reduced to the ARP. The importance of this type of metadata cannot be understated, particularly if multiple survey crews are involved. Thankfully, the required information can easily and effectively be provided by adapting the generic log sheet provided by DCS Spatial Services (see Figure 6) for a specific GNSS receiver-antenna combination with a particular antenna height measuring process.

5.2 Observation Data Recovery

In some cases, the instrument may be disturbed during the observation session, e.g. by failing to tighten the tripod leg screws enough or by people, livestock or storm events bumping the tripod, pushing it over or removing it altogether. For longer observation sessions, useful data may still be salvaged if it can be determined when the unfortunate intervention occurred. Processing the data in kinematic mode (i.e. epoch by epoch) using the PPP technique can be very useful in identifying when the disturbance event occurred.

One option is the CSRS-PPP online positioning service provided by Natural Resources Canada (NRCan), which requires registration but is free (NRCan, 2022). It works similar to AUSPOS but is able to process data in both static and kinematic mode, delivering ITRF2014 positions and graphs that can be used to identify the time of intervention. For example, Figure 11 shows the kinematic (epoch-by-epoch) CSRS-PPP output for a 24-hour observation session where the tripod was intentionally placed on the ground by an unknown person (presumably a good Samaritan) at around 16:15 UTC. Inspecting the observation data blocks of the RINEX file corresponding to this time clearly identified the epoch of intervention through the loss of satellite signals, resulting in almost 19 hours of usable data being retained. Using a variety of software, the offending epochs can then simply be edited out.

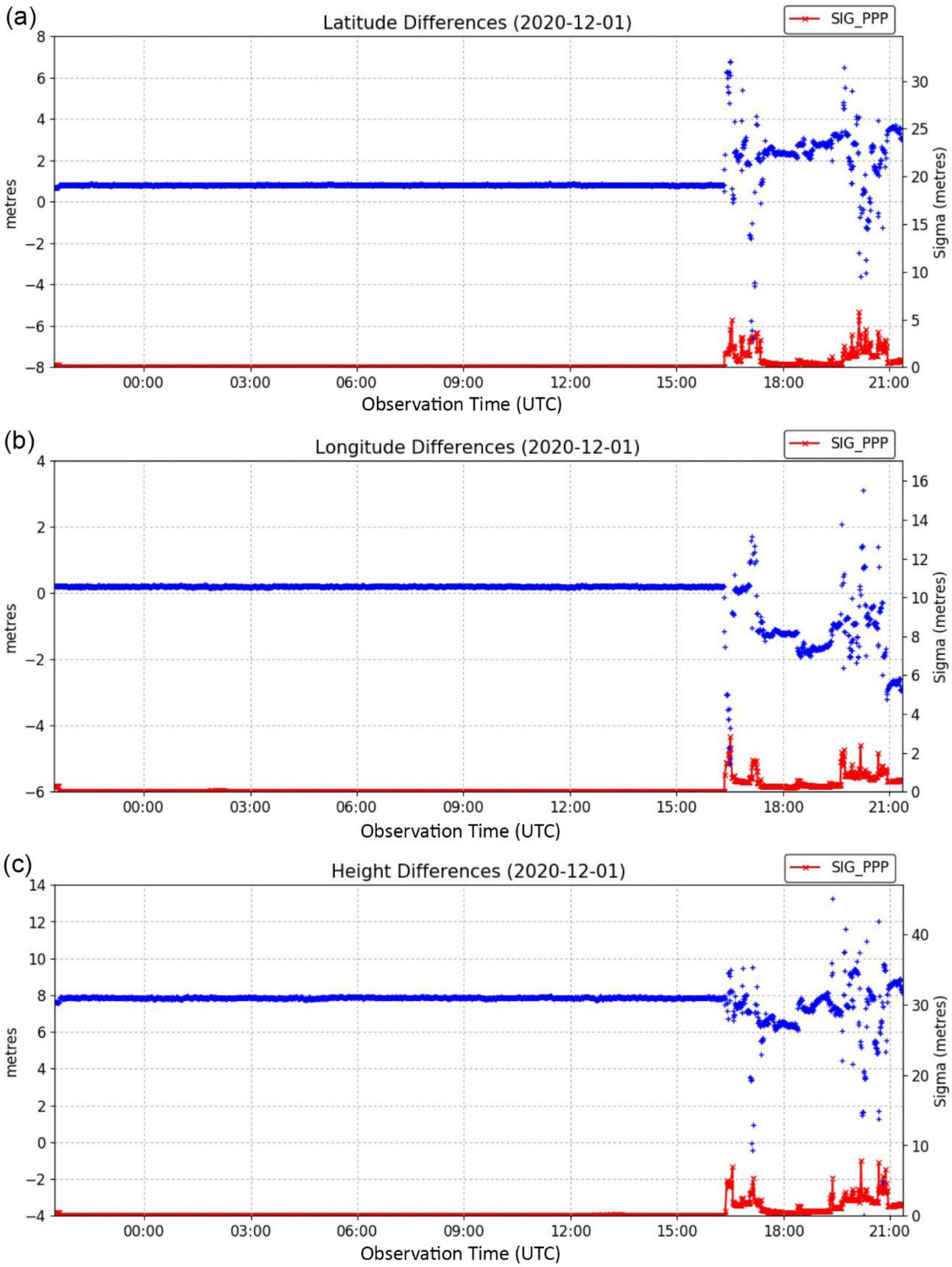


Figure 11: Kinematic CSRS-PPP output for a 24-hour observation session where the tripod was intentionally placed on the ground at around 16:15 UTC, showing (a) latitude, (b) longitude and (c) height differences in blue and their standard deviations in red.

When an accidental disturbance occurs at the end of a survey, e.g. forgetting to correctly turn off the receiver before removing it from the tribach, common sense should be applied. Hopefully, the surveyor will quickly notice the issue as they pack up their equipment, make a note on their log sheet and later delete the last few epochs when the RINEX file is generated. In reality, this issue should not last more than a minute until noticed, so only one or two 30-second epochs may be affected, which should be automatically removed or smoothed out by AUSPOS as noise anyway, considering the hours of good data you have collected. Similarly, a receiver operating in a transport case will not observe any satellites, so the data should not be corrupted, although the end time in the file will be incorrect.

5.3 Cluster Processing

Simply put, AUSPOS data can be submitted and processed either individually (mark by mark) or collectively (in sessions, like it was observed in the field). This paper has so far focused on individual AUSPOS processing, i.e. the data collected at one mark is processed relative to the surrounding CORS with no direct relationship to any other rover that was operating at the same time. Collectively, AUSPOS is a little smarter. It first detects which rover observed the longest, and this becomes the hub for the user data. Basically, the position of the hub is determined relative to the surrounding CORS, and then all other rovers are processed relative to the hub (provided there is sufficient data overlap). Importantly, this places increased emphasis on local relatively between survey marks, which is probably what the surveyor or client generally prefers. Clustered AUSPOS solutions are easily identifiable in the AUSPOS report, as the report is (1) longer, (2) lists multiple stations and files in Section 1: User Data, (3) lists multiple user stations in Section 2: User Stations, and (4) contains results for multiple user stations rather than one.

Digging a little deeper, AUSPOS accepts submissions of up to 20 RINEX files in one job, which are then processed together as a cluster, using an observation window that contains the collected data at all sites (between earliest start time and latest end time). When submitting multiple files, it is important to ensure that the marker name (particularly its first four characters) in the RINEX header is different for each site and does not include special characters. Furthermore, individual observation sessions should overlap by at least 1 hour with respect to the hub, as this overlap is used to compute the baselines between user sites (and the direct L1/L2 ambiguity resolution strategy applied for short baselines is more reliable for data exceeding 1 hour). It should be emphasised that DCS Spatial Services only accepts industry-observed GNSS datasets of more than 2 hours duration, regardless of any overlaps with other user data.

AUSPOS cluster processing considers that the multiple data files were collected during the same time window and are therefore correlated. This means that, rather than individually connecting each user site to the surrounding CORS network, processing includes baselines between the user sites, which provides a stronger local connection. If the survey is planned accordingly, the user site with the longest dataset acts as a hub connecting to all other user sites. However, it should be noted that this can potentially result in baseline lengths that are shorter than the minimum length recommended by legislation (100 m), so sufficient planning prior to observing such a cluster is required. If the data overlap of a particular user site with respect to the hub (or another user site) is too short, AUSPOS attempts to compute a baseline to a CORS instead (a strategy based on the maximum number of single-difference observations is used to form the baselines computed in the cluster), thereby losing the desired local connection. If its data quality is insufficient, the user site may be deleted from the cluster.

In theory, and if the survey is planned appropriately, the AUSPOS cluster should therefore provide a stronger connection between the user sites compared to processing each dataset individually. The savvy reader is encouraged to think about the permutations and combinations of network design and potential advantages of clustering. For instance, if the hub had a good AHD height, could I block-shift all the other rovers' heights and get better AHD for them as well? Or, reversing the scenario, if all the rover sites had good AHD and I made the hub the mark I want to derive good AHD for, can I get a good AHD height via AUSPOS clustering and block shifts? Is this fit-for-purpose for my survey or client? Or what happens if the rover site in the first session becomes the hub for my second session and I start daisy-chaining clusters? Further research is required to investigate the effect cluster processing has on the positioning result in surveying practice and the inclusion of such clusters in the GDA2020 state adjustment via the JDA.

6 CONCLUDING REMARKS

The use of AUSPOS campaigns has developed into a capable and reliable alternative or addition to conducting traditional static GNSS baseline surveys in some situations, particularly in NSW with all CORSnet-NSW stations contributing to the AUSPOS service. AUSPOS has been shown to deliver high-quality positioning results even for shorter observation sessions of at least 2 hours across the state, provided sky view conditions are reasonable (Janssen and McElroy, 2020).

This paper has provided a practical guide for AUSPOS users and explained how AUSPOS solutions are used to help maintain and improve the NSW survey control network. It has outlined the requirements for successful industry-observed AUSPOS datasets to be submitted to DCS Spatial Services via its new Customer Hub for potential update of SCIMS and inclusion in the GDA2020 state adjustment. Finally, we have also offered some practical tips related to the all-important antenna height measurement, observation data recovery and AUSPOS cluster processing. It is hoped that this contribution has shown how easy it is to use AUSPOS and will encourage the profession to contribute to further improve the NSW survey control network for the benefit of all.

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