GETTING THE MOST OUT OF AUSPOS

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AUSPOS is Geoscience Australia's free, cloud-based, online Global Positioning System (GPS) processing service. Its uptake and use all over the globe, by new users and dedicated fans, continues to accelerate. AUSPOS has repeatedly proven its capability and reliability, with over 270,000 jobs processed in just the first 18 months after the latest version (v2.4) was released in August 2020 and more than 1 million jobs processed in the decade before. Following the recent release of ITRF2020, a new AUSPOS version is planned for this year. Recognising this tool's importance, all CORSnet-NSW sites contribute to AUSPOS and over 12,000 AUSPOS solutions have been used in the NSW survey control network.

This article provides a detailed practical guide for novice and regular AUSPOS users, mixed in with a few interesting scientific facts. It outlines how your (industry-observed) AUSPOS datasets can help maintain and improve the NSW survey control network and the Survey Control Information Management System (SCIMS). We offer some clarifications, reminders, tips and tricks related to common recurring issues (those damn antennas!), challenges like observation data recovery and finish by highlighting the potential benefits of cluster processing for advanced users.

AUSPOS IN BRIEF

AUSPOS accepts static, dual-frequency GPS data of at least 1 hour duration (recommended minimum 2 hours, maximum 7 consecutive days) in Receiver Independent Exchange (RINEX) format. While the submitted RINEX file may contain data from multiple GNSS constellations, only GPS data is used for processing and thinned to a 30-second epoch interval regardless of the initial sampling rate. The user's antenna type is selected from a drop-down menu, and the height of instrument (measured vertically to the Antenna Reference Point, ARP) is specified.

AUSPOS uses the International GNSS Service (IGS) core network station data and products together with local Continuously Operating Reference Stations (CORS) to compute precise coordinates based on up to 15 surrounding CORS. An AUSPOS report (pdf) is then emailed to the user, which includes the computed coordinates (GDA2020 and derived AHD height, GDA94, ITRF2014) and their uncertainties, ambiguity resolution statistics, and an overview of the processing strategy applied. Advanced users can download Solution Independent Exchange (SINEX) files containing more detailed information.

The sophisticated, scientific Bernese software is used for data processing. Importantly, 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. Commercial off-the-shelf software routinely used by industry and DCS Spatial Services only mimics this ideal, requiring a 2-step process of single-baseline processing followed by a 3D network adjustment.

Simultaneous multi-baseline processing also neatly solves the problem of trivial baselines, which industry tends to struggle with in large surveys. 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. This 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.

The AUSPOS website 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. Datasets submitted to AUSPOS are neither retained by Geoscience Australia nor passed on to any third party.

PREPARING RINEX DATA

The thorough preparation of RINEX data files, whilst tedious, not only facilitates smooth AUSPOS processing but also allows efficient and unambiguous archiving of the data and associated metadata in one place. This article refers to RINEX v2.11 because AUSPOS remains GPS-only and DCS Spatial Services currently uses this format for archiving. However, the RINEX v3 format was later developed to better support multi-GNSS observations, with RINEX v4 approved in December 2021 and yet to be implemented in most commercial software. The raw observation file in (binary) proprietary format collected by the GNSS receiver needs to be converted to RINEX and ideally should be decimated to a sampling interval of 30 seconds to decrease the file size.

The RINEX file name must not contain 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. The RINEX v3.05 file naming convention stipulates a much longer file name, along with additional header information.

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). 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). Each RINEX file must only contain a single occupation on a single mark. Raw binary data files are compact and should always be permanently archived – they can be re-converted to RINEX and edited again if required.

Figure 1: Typical RINEX v2.11 header

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), then it must be converted to the vertical distance between the ground mark and the ARP using the offsets and method specified in the GNSS equipment manual or provided by the manufacturer. 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 (decimal inches) and convert to metres (multiply by 0.0254).

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 IGS files *rcvr_ant.tab* and *antenna.gra* (available at https://files.igs.org/pub/station/general/). 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 radome type (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). The file *igs14.atx* (and now *igs20.atx*), containing the IGS antenna models recommended for baseline processing, can be found at the same location. These files are frequently updated to include new antennas. If still in doubt, users should contact their equipment provider for the required antenna information.

If session length is critical to contractual arrangements and/or data acceptance by a third party, always extend it by a few minutes. Visually inspect the start and end of the 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 can be an issue when GNSS receivers struggle to track satellites, or the stored ephemeris message is old or has been deleted by a factory reset. AUSPOS may further trim poor data (like missing or incomplete epochs as the receiver struggles to acquire satellites when first turned on under trees), which may 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. Eighteen 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). Line 13 in Figure 1 specifies 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

SUBMITTING RINEX DATA

Up to 20 RINEX files can be submitted to AUSPOS simultaneously and processed as a cluster, provided all their observation sessions contain an overlap of at least 1 hour. However, for simplicity, we will initially discuss submission of a single RINEX file.

The timing of submission affects 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 product generally being 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 (the best available product) for AUSPOS processing. However, AUSPOS solutions using rapid orbits are typically very close to final-orbit solution quality and are therefore more suited to industry due to their much faster availability.

Secondly, data from local and international CORS needs to be delivered to Geoscience Australia, either streamed (live) or pushed at regular intervals (e.g. hourly). On occasion, communication links may go down, resulting in the missing CORS data being pushed to AUSPOS with a delay. This is very rare in NSW because CORSnet-NSW comprises a dense network 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 data quality issues).

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 interrogate 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 (junk-in-junk-out principle). 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.

This is followed by an automated 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 on the AUSPOS website). On a side note, this is a key benefit of cloud computing as extra grunt can be 'spun up' in times of heavy usage, so users should always get timely results. If AUSPOS encounters problems during processing, a further automated email is sent to the user providing some indication of the issue in the subject. 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). 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.

INTERPRETING THE RESULTS

Following processing, an AUSPOS report (pdf) is emailed to the user. The results should be checked to ensure that the solution is reliable:

- Section 1 (User Data): Check antenna type and antenna height (measured vertically from ground mark to ARP) are correct.
- Section 2 (Processing Summary): Check the number of reference stations is appropriate (close to 15 CORS). Check there is a good mix of local and distant CORS (about 8 and 7). Check IGS final or rapid orbits are used.
- Section 3.4 (Positional Uncertainty): Check the PU values of the GDA2020 coordinates and derived AHD height are reasonable, considering session length and sky view conditions. (DCS Spatial

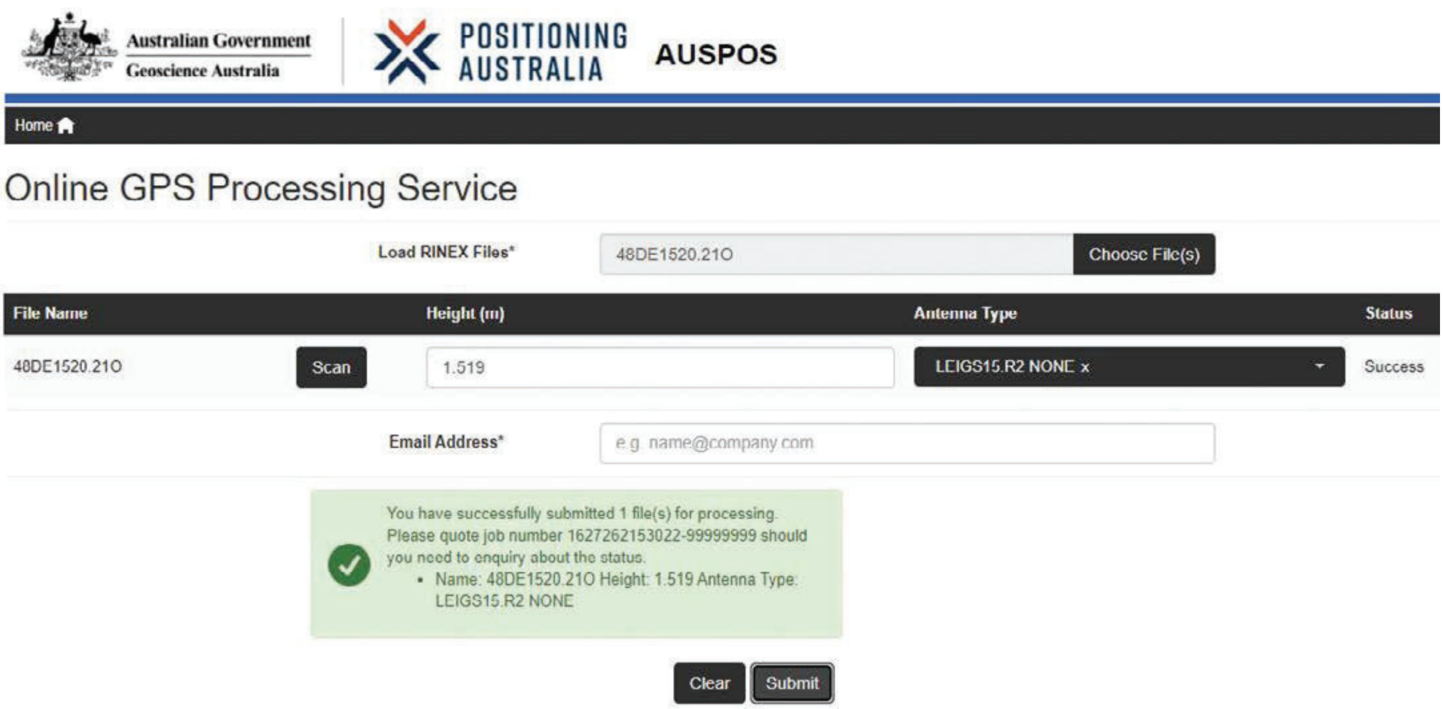

Figure 3: AUSPOS submission page after successful submission of a single RINEX file.

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.) Check the report is void of any warning messages (e.g. large uncertainty).
- Section 6 (Ambiguity Resolution): Check the ambiguity resolution statistics are reasonable (at least 50% of ambiguities resolved per baseline, particularly those to your rover). (DCS Spatial Services routinely encounters values above 70% in its work.)

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, warnings 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). Remember that AUSPOS is GPS-only, so the solution does not use as many satellites as you may be accustomed to. Repeating the observation with a longer session length generally provides a better result without any warning messages (e.g. increasing duration from 2 hours to about 4-5 hours). 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.

AUSPOS FOR DATUM MODERNISATION

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. Datasets of at least 6 hours duration propagate the datum in NSW via the National GNSS Campaign Archive (NGCA) hosted by Geoscience Australia, while datasets of less than 6 hours duration strengthen the datum via 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. These are then expressed as baselines to nearby CORS for inclusion in the GDA2020 national and state adjustments.

Currently, DCS Spatial Services allocates a maximum Class D to any survey mark coordinated via AUSPOS as it generally represents a single occupation with limited redundancy. Marks occupied multiple times, by AUSPOS only, still receive Class D maximum. The immediate purpose is to upgrade unestablished marks to established and make them available via SCIMS 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 4,300 SCIMS updates for more than 2,100 marks have been undertaken via this monthly 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 SP1 v1.7 and Surveyor-General's Direction No. 12 (Control Surveys and SCIMS). 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) at the 95% confidence level 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

The PU values for AUSPOS-derived coordinates published in SCIMS are typically larger than those obtained directly by a user. This is 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, 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).

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 and antenna height, 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 assess whether the solution is reliable and suitable for SCIMS update.

Using AUSPOS to support these datum modernisation efforts has several advantages. The field work is quick, logistically simple and very efficient, with reliable solutions achieved even under challenging sky view conditions (particularly for sessions exceeding 6 hours duration). AUSPOS processing is consistent, of the highest possible standard and very time-efficient, providing a direct connection to the datum (CORS) 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 one can anticipate there will soon be little difference between relative and absolute positioning.

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 (https://customerhub.spatial.nsw.gov.au/servicedesk/). The Customer Hub is a new, user-friendly platform providing a central contact point to interact with DCS Spatial Services. It is now the primary way for customers to make enquiries, submit data requests and provide feedback. Survey Operations can be contacted through the Customer Hub to submit AUSPOS datasets, Locality Sketch Plans (LSPs), survey mark status reports, 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, customers 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 and serial number 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, available as part of the resource pack for Surveyor-General's Direction No. 12. 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 be included as an image (generally sourced from the equipment manual). Surveyors opting 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), easily determined via online GPS calendars (https://www.ngs.noaa.gov/CORS/Gpscal.shtml) or apps. We recommend booking 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 antenna height reductions, sky view conditions or unforeseen circumstances that may be relevant.

PRACTICAL TIPS AND TRICKS

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). First-time or ad-hoc submissions are usually the most challenging. You know what you did, but we don't unless it is clearly stated. Is the provided antenna height the required vertical measurement to the ARP or a slant measurement to some mark on the antenna? Has it been measured directly or calculated by applying a particular reduction? 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. If in doubt about the antenna type used and the height reduction required, the equipment manufacturer should be contacted for clarification.

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 added to obtain the height to the ARP. However, this offset depends on the equipment used, i.e. the type of tribrach and antenna carrier (possibly including a screw-to-stub adapter). When standard equipment is used, the offset can be obtained from the 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.

However, AUSPOS does not apply 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. If it is combined with the larger antenna carrier, the offset is 0.360 m.

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 provide instructions on the required calculations, including the applicable offsets. For example, Figure 4 illustrates the dimensions relevant for Topcon's 'TPSHIPER_II NONE' antenna.

Figure 4: 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 in conjunction with a vertical offset, the following calculation is required to convert the slant measurement (denoted as LS) to the vertical height from the ground mark to the ARP (LV_{ARP}):

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

For typical instrument heights between 1.400 m and 2.000 m, ignoring Pythagoras and applying only the vertical offset introduces an error of about 2-3 mm (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.

Other instruments include a SHMM located at the end of a horizontal bar attached to the bottom of the antenna, e.g. Topcon's 'TPSHIPER_HR NONE.' Since the SHMM and the ARP are on the same horizontal plane, only Pythagoras is required to obtain the vertical height to the ARP. In this case, for typical instrument heights between 1.400 m and 2.000 m, using the slant height measurement without reduction to the vertical introduces an error of about 3-4 mm (antenna height is too large).

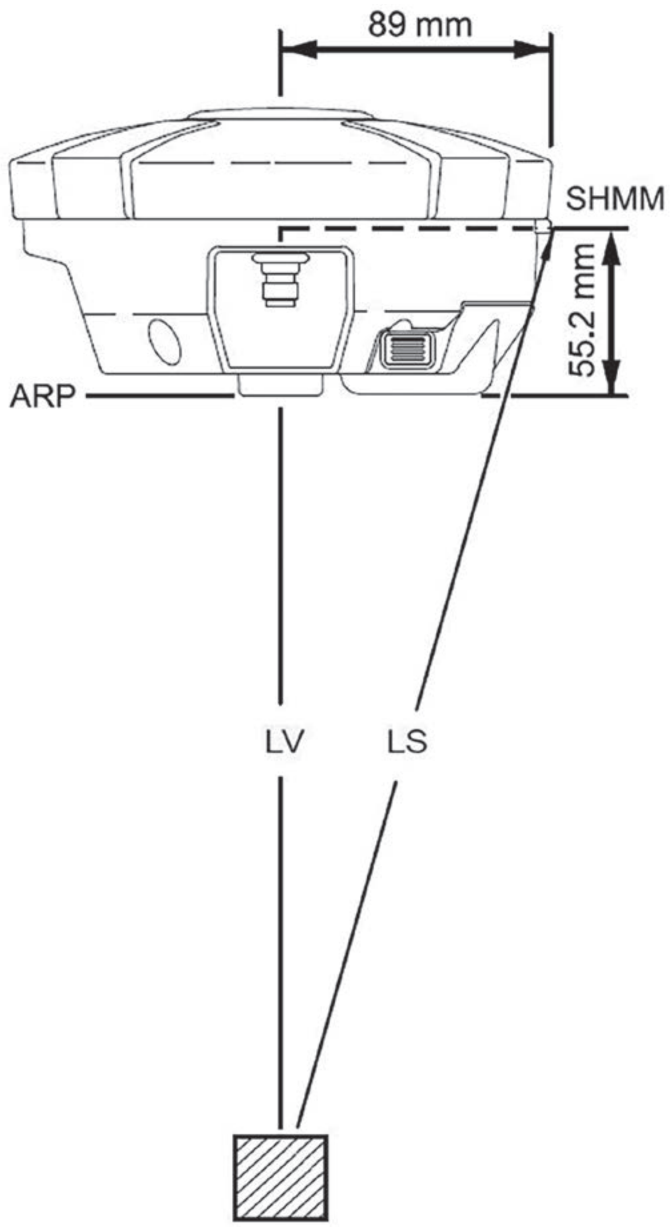

Figure 4

SLANT HEIGHT TO BUMPER

Other GNSS antennas utilise a distinct marking on their housing instead of a specific SHMM. For example, Trimble's 'TRMR10 NONE' antenna features a yellow ring around its housing, which is known as the bumper. Using Pythagoras in conjunction with a vertical offset of -0.094 m, the measured slant height to the bottom of the bumper is then converted to a vertical antenna height between the ground mark and the ARP.

For typical instrument heights between 1.400 m and 2.000 m, ignoring Pythagoras and applying only the vertical offset introduces an error of about 1 mm (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 the reduction by simply applying a vertical offset of -0.095 m. 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 it may not be suitable when the data is later used for other purposes (e.g. SCIMS update or geodesy).

Furthermore, this particular 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 included by adapting the generic GNSS log sheet provided by DCS Spatial Services for a specific receiver-antenna combination with a particular antenna height measuring process.

OBSERVATION DATA RECOVERY

Sometimes the instrument is disturbed during the observation session, e.g. by failing to sufficiently tighten the tripod leg screws 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 (epoch by epoch) using the Precise Point Positioning (PPP) technique can be very useful in identifying when the disturbance occurred.

One option is the CSRS-PPP online positioning service provided by Natural Resources Canada, which requires registration but is free. It works similar to AUSPOS but is able to process data in both static and kinematic mode, delivering ITRF2020 positions and graphs that can be used to identify the time of intervention. For example, Figure 5 (see over page) shows the kinematic CSRS-PPP output for a 24-hour 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.

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 tribrach, 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. 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.

AUSPOS 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). So far, we have focused on individual AUSPOS processing, i.e. the data collected at one mark is processed relative to the surrounding CORS without considering any other rover operating at the same time. Collectively, AUSPOS is a little smarter. It first detects which rover observed the longest and makes it the hub for the user data. 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

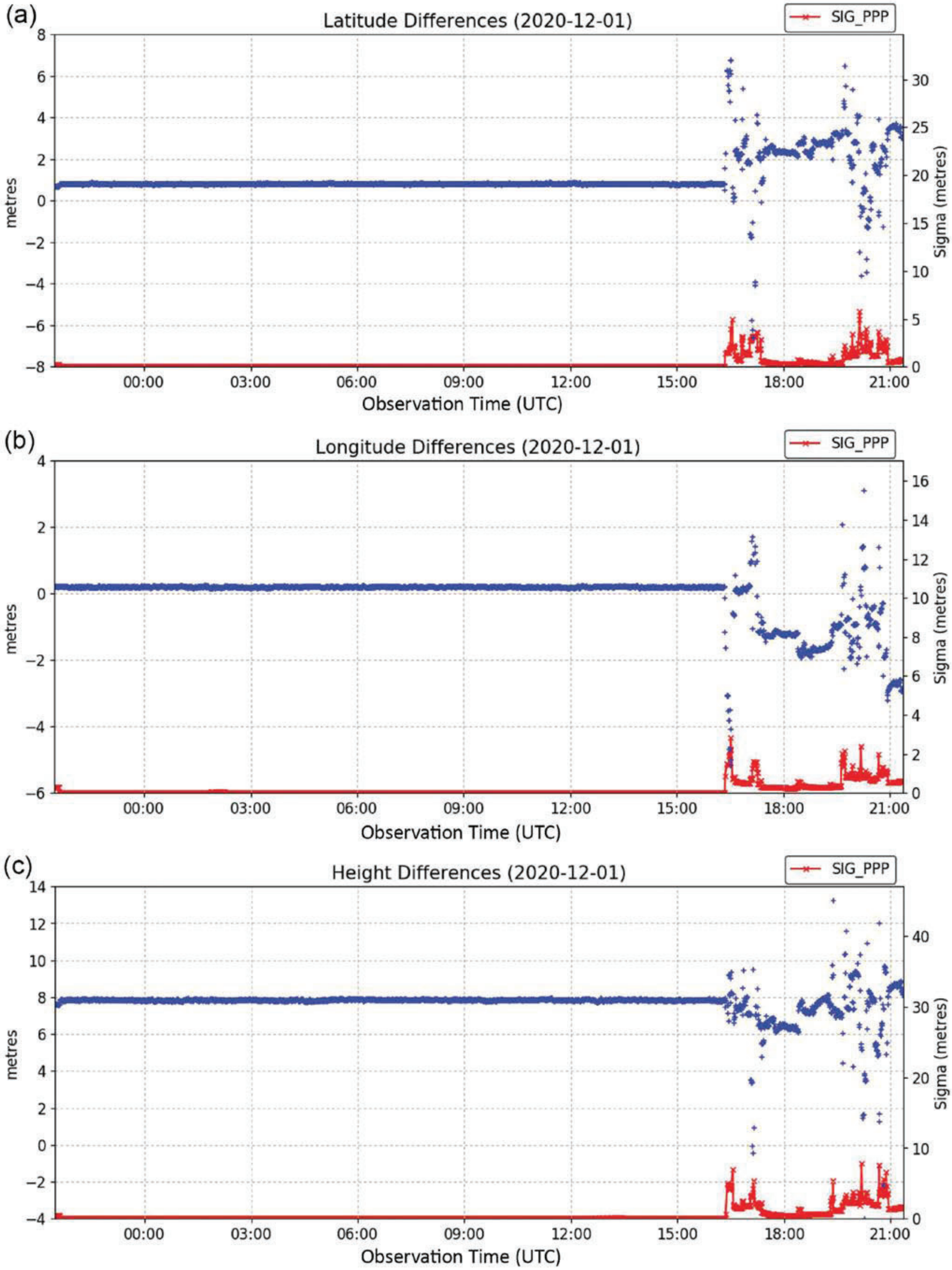

Figure 5: Kinematic CSRS-PPP output for a 24-hour observation session where the tripod was intentionally placed on the ground at around 16:15 UTC, showing (a) latitude, (b) longitude and (c) height differences in blue and their standard deviations in red

sufficient data overlap). Importantly, this places increased emphasis on local relatively between survey marks, which is probably what the surveyor or client generally prefers.

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. 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. Note that DCS Spatial Services only accepts industry-observed GNSS datasets exceeding 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. 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, this can potentially result in baselines shorter than the minimum length recommended by legislation (100 m), so sufficient planning 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, thereby losing the desired local connection. If its data quality is insufficient, the user site may be deleted from the cluster.

In theory, and with appropriate survey planning, the AUSPOS cluster should therefore provide a stronger local connection between user sites. 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? 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, is this achievable via AUSPOS clustering and block shifts? Is it 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 real-world research is required to investigate the effect cluster processing has on the positioning result in surveying practice.

CONCLUSION

In some situations, the use of AUSPOS has developed into a capable and reliable alternative or addition to conducting traditional static GNSS baseline surveys, particularly with all CORSnet-NSW stations contributing to the AUSPOS service. AUSPOS can deliver high-quality positioning results even for shorter observation sessions of at least 2 hours, provided sky view conditions are reasonable.

This article has outlined how to get the most out of AUSPOS in practice and how it is used to help maintain and improve the NSW survey control network. It has described the requirements for industry-observed AUSPOS datasets to be submitted to DCS Spatial Services for potential update of SCIMS and inclusion in the GDA2020 state adjustment. Finally, we have offered practical tips related to the all-important antenna height measurement, observation data recovery and cluster processing. Hopefully, 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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