CORS networks:

absolute antenna models are absolutely vital

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Continuously Operating Reference Station networks are being introduced across Australia and internationally. They provide improved access to positioning infrastructure for a wide range of Global Navigation Satellite System (GNSS) applications, in industries such as surveying, agriculture, mining and construction.

Benefits include the rationalisation of infrastructure, establishment of multi-user systems, uniform positioning services, and consistent and reliable connectivity to the national datum. They can also provide a degree of legal traceability for satellite-based positioning.

Antenna models are vital to CORS network operators, but often these are not fully understood by CORS users. To achieve maximum benefit from this technology, users need to apply the appropriate antenna models at their Real Time Kinematic (RTK) rover and in post-processing. The good news is that, once implemented, the models take care of all the complexity, enabling the user in the field to focus on the GNSS survey at hand.

After all, CORS network services should be accurate, reliable and easy to use! But users should also be aware of the negative effects when antenna models are ignored, or inappropriate models are applied at the rover. This article explains why the so-called 'absolute' antenna models are vital when data from CORS networks is used for high-accuracy positioning.

Spatial professionals will be very familiar with the additive constant of an Electronic Distance Measurement (EDM) prism and its effect on the measured distance. If you want more 'bang for your buck', you can get precise prisms with a zero offset. The same principle applies to GNSS observations, but here a zero offset is physically impossible and the issue is complicated by variations in the offset. This means – no matter how expensive our GNSS antenna – that we have to model these effects. Such complex issues are mostly handled behind the scenes by CORS network operators, but users on the ground working to configure a rover accurately still need to be aware of the situation.

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Antenna terminology

GNSS observations are measured to the antenna phase centre. The APC is not only offset from the actual survey mark; there are also variations that depend on the azimuth and elevation of the GNSS satellites and the signal frequency (Figure 1). Such antenna phase centre variations (APCV) are deviations from the mean APC. They can cause additional errors of up to 20 millimetres in the measurement to a single GNSS satellite.

The all-important antenna reference point is the point for measuring instrument heights, and for antenna models. The ARP is generally at the bottom of the antenna, but it is important for users to confirm its exact location. By consulting the file *ftp://igs.org/igscb/station/general/antenna.gra*, operators can ensure that the rover's antenna height to the ARP is correctly measured in the field. The published coordinates of a CORS typically refer to the survey mark. Where no antenna height (i.e. height of instrument) is present, this is identical to the ARP.

For high-accuracy Network RTK (NRTK) and Virtual RINEX processes to function correctly, GNSS reference station coordinates must be consistent and highly accurate. This can be achieved through GDA94(2010) coordinates determined by Regulation 13 certification (see *Position 50*, Dec 2010). Multiple CORS, often with different antenna types, are used to model ionospheric and tropospheric effects, as well as geometric errors across the network. Appropriate GNSS antenna modelling has begun to play a crucial role for CORS network operators. Consequently, it is now an important issue for users of CORS data.

Antenna models

In order to correctly account for the offset between the ARP and the APC – as well as any phase centre variations (APCV) – GNSS antenna types have been calibrated by a number of organisations overseas to generate models. These models provide North, East, and Up offsets between the ARP and the mean APC for each frequency, along with variations dependent on the azimuth and elevation of the received satellite signal. While the North and East offsets for modern GNSS antennas are generally less than a millimetre, they can reach 7 millimetres for older antennas. The Up offset is very much dependent on the size and design of the antenna, and can exceed 200 millimetres. If not considered, this can introduce significant errors into the height component of the positioning result (Figure 2).

Not surprisingly, the size, material and design of the antenna have a large effect on the magnitude and distribution of its phase centre variations. GNSS antenna manufacturers have become pretty good at designing and building symmetric antennas. As a result, the azimuth-dependent component is less of a concern than the elevation-dependent component of the variations, but there are significant differences between antenna types. While the average rover antenna shows a much smaller magnitude of variations than the more expensive CORS choke ring antenna

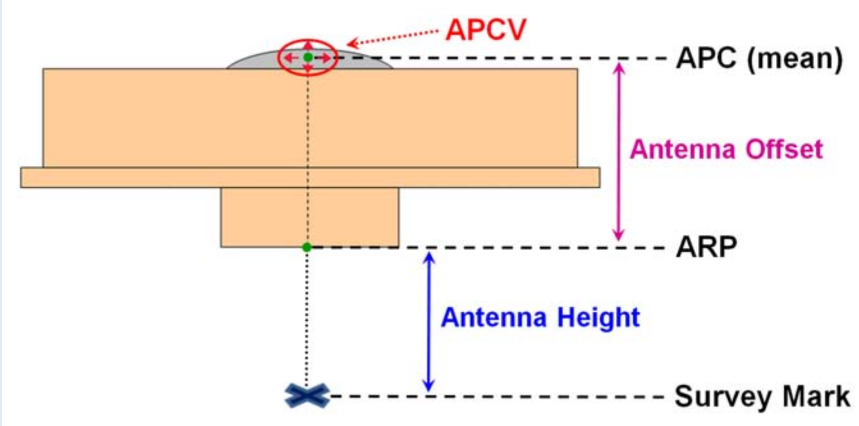

Figure 1: Antenna reference point (ARP), antenna phase centre (APC) and its variation (APCV).

Figure 2: Different antenna designs: (left) a typical rover antenna (LEIAX1203+GNSS), and (right) a typical choke ring antenna (TRM59800.00), often used for CORS (US National Geodetic Survey).

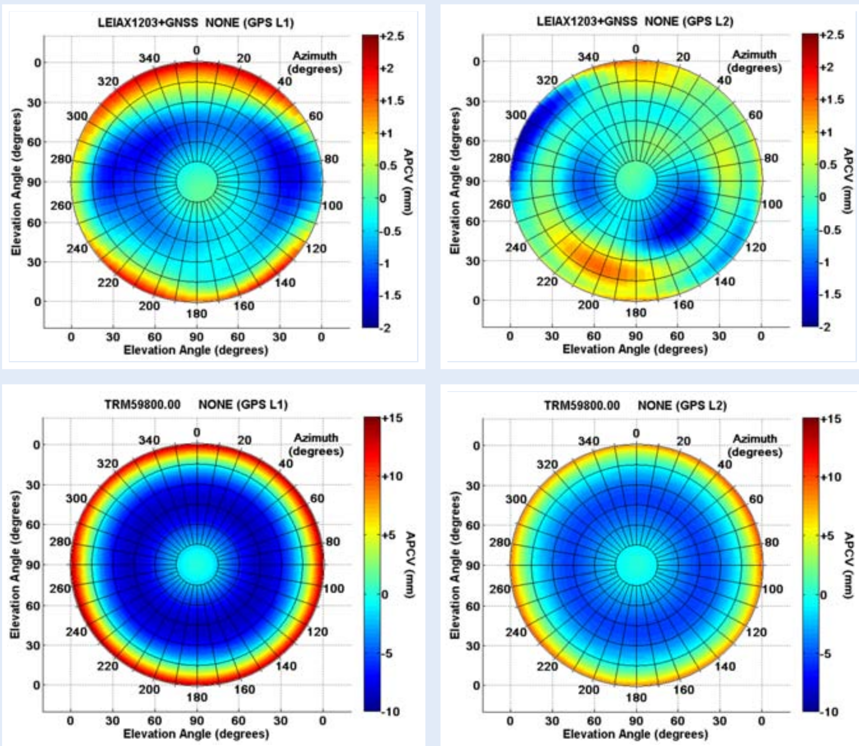

Figure 3: APCV as a function of satellite azimuth, elevation and frequency for LEIAX1203+GNSS (top) and TRM59800.00 (bottom), both without radome.

(especially for low elevations), its variations are far less symmetric, and show larger differences in the pattern between frequencies (Figure 3).

In addition, any antenna height between the survey mark and the ARP has to be considered. For lower accuracy work, users may elect to use a simplified model, neglecting the azimuth-dependent component (the 'NOAZI' model). Alternatively, they could ignore phase centre variations altogether by accounting only for the antenna offset. With antenna models more readily available and easily implemented, however, it is just as convenient to make use of the full models, which include the 'bells and whistles' for all jobs. This is also GNSS best practice.

Relative and absolute models

In the past, 'relative' APCV models were based on one specific antenna type with assumed zero APCV – the Dorne Margolin choke ring antenna from Allen Osborne Associates, known as AOAD/M_T. Recently, these have been replaced by 'absolute' APCV models, a result of International GNSS Service (IGS) products – such as rapid and precise orbits used by CORS providers – which are based on the more rigorous absolute calibrations.

The use of relative APCV models provides correct results if, and only if, no IGS products are used. But using a combination of relative and absolute APCV models in one project will lead to significant errors, especially in the vertical component, and must therefore be avoided.

> *'It can introduce significant errors into the height component of the positioning result.'*

Absolute GNSS antenna calibrations are performed by several organisations, ideally with a robot rotating and tilting the antenna in an anechoic (i.e. echoless) chamber (Figure 4). Once approved by the IGS, the absolute APCV model parameters are listed in a file that is freely available to the spatial community (*ftp://igscb.jpl.nasa.gov/igscb/station/general/igs05.atx*). The parameters for a particular antenna type are often determined by combining the values obtained from calibrating several antennas of the same type. The igs05.atx file also includes models for the transmitting antennas on the GNSS satellites, although these can be ignored by non-scientific users. A description of the ANTEX file format used for the antenna models is also readily available (*ftp://igs.org/igscb/station/general/antex14.txt*). ANTEX stands for Antenna Exchange Format and 1.4 is the current version.

It should be noted that rather than determining a mean absolute antenna model for each antenna type, it is, of course, possible to determine a separate antenna model for each individual antenna. While such individual antenna calibrations are slowly being introduced into some CORS networks, this is currently not practised in Australia.

Digging a little deeper

As the filename *igs05.atx* hints, the antenna models are tied to IGS05, the reference frame currently used for IGS products. For all practical purposes, it is identical to the globally used ITRF2005. Once the new ITRF2008 reference frame is fully implemented and IGS products are tied to IGS08, a new file igs08.atx will be introduced. This new file may also contain updated parameters for GNSS receiver antennas based on the latest calibration results, but let's cross that bridge when we get to it.

So, how are the different antenna types identified in the *igs05.atx* file? The IGS absolute APCV parameter file follows the international convention for naming GNSS antennas. The advantage of this convention is that it eliminates ambiguous equipment names and enables processing software to easily identify the equipment used. On first inspection, the antenna codes may seem a little cryptic, but they clearly specify the manufacturer, antenna type, and the antenna radome used. Radomes are dome-like shells, transparent to radar and radio waves, which are used to protect the GNSS antenna from environmental factors such as wind, sand, rain, snow and human intervention. They are therefore quite common for Tier 1 and Tier 2 CORS antennas in the harsh Australian environment.

For instance, "LEIAX1203+GNSS NONE" and "TRM57971.00 NONE" refer respectively to the Leica Geodetic AX1203+GNSS and Trimble Zephyr Geodetic II antennas, both without a radome. Note that the 4-character long radome type is always stated at the end of the strictly 20-character-long antenna code, and may therefore be preceded by several blank spaces.

It is very important to be rigorous here. If the processing software does not recognise the antenna code, it may default to not using an antenna model at all. As previously mentioned, this can cause an error of up to 200 millimetres in the vertical offset alone! A list of all valid GNSS receiver and antenna names has been compiled by the IGS (*ftp://igscb.jpl.nasa.gov/igscb/station/general/rcvr_ant.tab*). Most CORS network operators around the world follow this naming convention. It should be noted that although these names differ from those routinely used by default in commercial

Golden rules for GNSS antenna modelling

- Absolute antenna models are GNSS best practice and can be used for RTK and post processing.
- Do not mix relative and absolute antenna models.
- IGS absolute antenna models are available from:
  > ftp://igscb.jpl.nasa.gov/igscb/station/general/igs05.atx, or
  > your GNSS equipment supplier.
- CORS providers such as CORSnet-NSW use IGS absolute antenna models, IGS products, and the null antenna principle. Therefore all CORS 'look the same' from a user perspective.
- Setting the elevation mask at the rover to 10-15° not only reduces atmospheric and multipath errors but also phase centre variation effects.
- Measure all antenna heights vertically to the ARP, in millimetres and inches, and convert between the two as a check.
- For high-accuracy static surveys, orient the rover antenna to True North.

GNSS processing software, they can easily be implemented.

The use of different calibration methods by several organisations can lead to the existence of more than one APCV parameter set for a particular antenna type. Only one set – generally the best available – is included in the IGS list, which is updated regularly to include new antennas. Using the parameters approved by the IGS allows consistency and avoids confusion over which APCV parameter set is the most appropriate. For example, users of CORSnet-NSW – currently being rolled out across NSW, see *http://www.corsnet.com.au* – are strongly advised to use the absolute antenna models provided by the IGS for both post-processing and real-time operations.

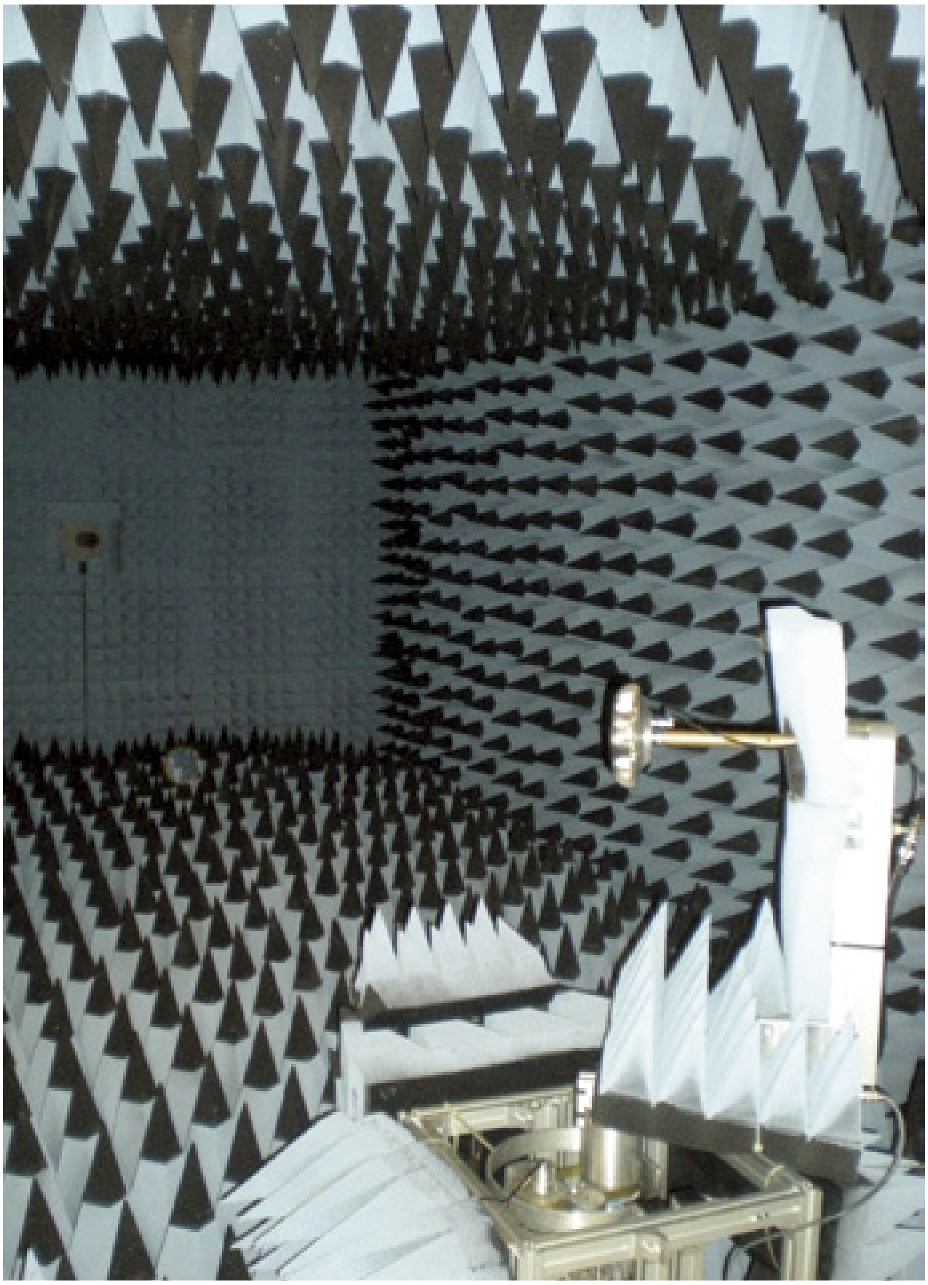

Figure 4: Absolute antenna calibration chamber in Bonn, Germany.

Making it easier for users

For real-time operations, CORS networks usually transmit data specifying all CORS antennas as a null antenna, i.e. an antenna with zero antenna offsets and zero APCV. This is achieved by some very smart software coding. The null antenna principle is comparable with using precise prisms with a zero offset for an EDM survey. It means that the absolute APCV corrections obtained from the IGS are used to reduce the observations to the ARP, resulting in zero antenna offsets and variations. Basically, we are changing the observations before the data are transmitted to the rover.

Any CORS antenna heights present are automatically considered by the rover through the transmitted RTK messages. Therefore, the user does not need to worry about which antenna is used at the CORS site(s) – all that is taken care of behind the scenes. This considerably simplifies the fieldwork because no CORS antenna models have to be uploaded into the rover. The user has only to ensure that the rover equipment applies the appropriate absolute IGS APCV model of the antenna used in the field. GNSS equipment is often sold with this already set up by the supplier.

For post-processing, null antennas are not utilised. As per the RINEX standard, the data files from CORS sites or a virtual reference station continue to have observations measured to the APC, and will indicate which antenna type has been used. The user should ensure that absolute IGS APCV models for both the CORS and the rover are imported and selected in the data processing software. It should be noted that the absolute APCV parameter settings only need to be imported once into the post-processing software. Updates are only necessary when a new antenna type is added or in the rare event that the parameters approved by the IGS are updated. Your preferred GNSS equipment supplier can be asked for help in setting this up.

It is worth noting that, for post-processed static surveys, users should orient their rover antennas to True North in order to get the maximum benefit from absolute antenna modelling. For real-time users with modern GNSS equipment this is generally not practical, and the resulting error will be much smaller than the achievable real time accuracy anyway.

In summary, to correctly account for the effects of antenna phase centre variations when using CORS network data, absolute GNSS antenna modelling is absolutely crucial for use in high-accuracy positioning applications. These models can be easily implemented. They will take care of all the complexity and ensure that users gain maximum benefit from the expanding, high-quality CORS infrastructure, leaving them to concentrate on the fieldwork at hand.

In order to avoid confusion and provide consistency, it is strongly advised to use the absolute models provided by the IGS. Ignore absolute antenna models at your own risk. ■

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