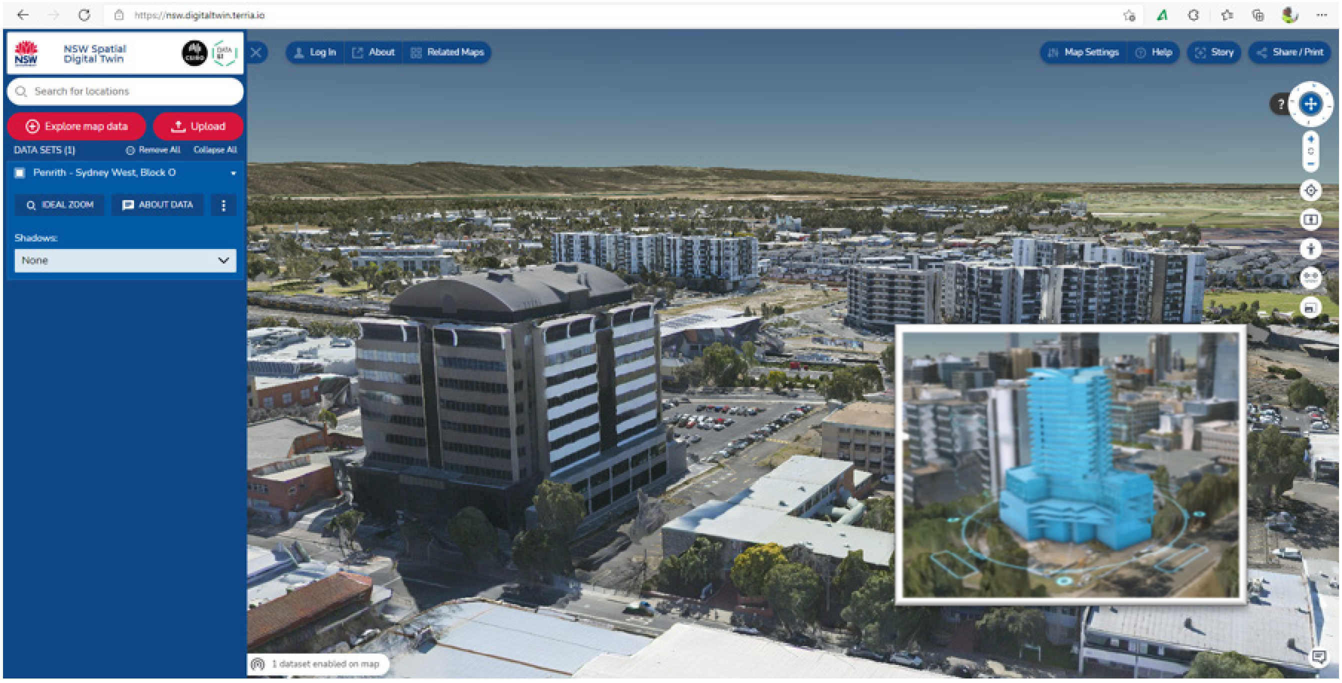
Spatial Services

3D spatial data and 3D transformations

Information Sheet

December 2021



3D data displayed in the NSW Spatial Digital Twin.

What is 3D (and 4D) spatial data?

Three-dimensional (3D) spatial data allows us to make realistic digital representations of the real world to support improved measurement, modelling, planning and design of our built and natural environment. 3D data extends to 4D by adding time-stamped data, including real-time streams, which gives us the capability to display and analyse past conditions and future scenarios. 3D spatial data is fundamental to emerging 4D digital twins such as the NSW Spatial Digital Twin.

3D spatial data is best defined using a 3D Coordinate Reference System (CRS), but is often recorded instead as 3D GIS data. As discussed in Fundamentals of 3D data, 3D GIS data (x,y,z) simply adds an extra dimension to traditional 2D (x,y) spatial data. Although this z value is often used to represent elevation or height information, 'z' could stand for anything. Examples include a z value representing diverse variables like local chemical concentration, date/time of planned maintenance, or a rating of sites for development suitability. 3D feature data may even store multiple z values for each x,y location, such as multiple heights representing interior foundation, floors and roof within a building.

A 3D CRS on the other hand explicitly defines an unambiguous CRS for both horizontal and vertical coordinates (or other useful 3D system), usually by reference to a well-established registry such as the EPSG Geodetic Parameter Dataset (EPSG). With the increasing number of height CRS available to Australian users, recording the CRS metadata for both vertical and horizontal spatial data, as well as any lineage of data transformations, becomes crucial.

In a similar manner, 4D data is commonly defined as 3D spatial data with time-stamped attributes at defined location(s). Three examples are a bus leaving 'breadcrumbs' along its route, a water-level gauge recording river height over time, and deformation monitoring of a dam by periodically reobserving the same points, all using GDA2020 location(s) plus time stamp(s). A less common alternative (to date) is to explicitly define time as the fourth dimension of the CRS itself in which x,y,z and time are all required to unambiguously define '4D spatial location(s)'. This definition is used by the new time-dependent Australian Terrestrial Reference System (ATRF), which will become increasingly common for geodesy and high-accuracy real-time positioning applications.

Are there many different vertical coordinate reference systems (CRS)?

Just as there are multiple choices for defining a horizontal CRS (for example GDA94 in latitude, longitude; GDA2020 in MGA Easting, Northing; Web Mercator in North, East or x,y coordinates), there are different vertical CRS which define different types of height. Official definitions are collated within the EPSG registry.

It is common to encounter a variety of height data in Australia, including:

- **AHD (H): Australian Height Datum.** An orthometric height datum, giving a 'physical height' above a geoid. Fluid flows downhill in an orthometric datum. AHD is currently the most common height datum used in Australia, but other authoritative height datums have been used historically, such as Standard Datum in NSW.
- **AVWS (H*): Australian Vertical Working Surface.** A new high accuracy 'physical height' to supplement AHD.
- **Ellipsoidal height (h):** Height above an ellipsoid (an ellipsoid approximates the size and shape of the earth). Most often obtained by GNSS methods. In contrast to physical heights, fluid often does not flow downhill in an ellipsoidal datum. Ellipsoidal height is CRS-specific and differs by ~0.1 m (in NSW) between GDA94 and GDA2020.
- **Local height:** For example height above ground level or any other local height reference surface or datum.
- **A variety of hydrographic, port-specific and tidal heights:** see ICSM – Tides and Mean Sea Level.

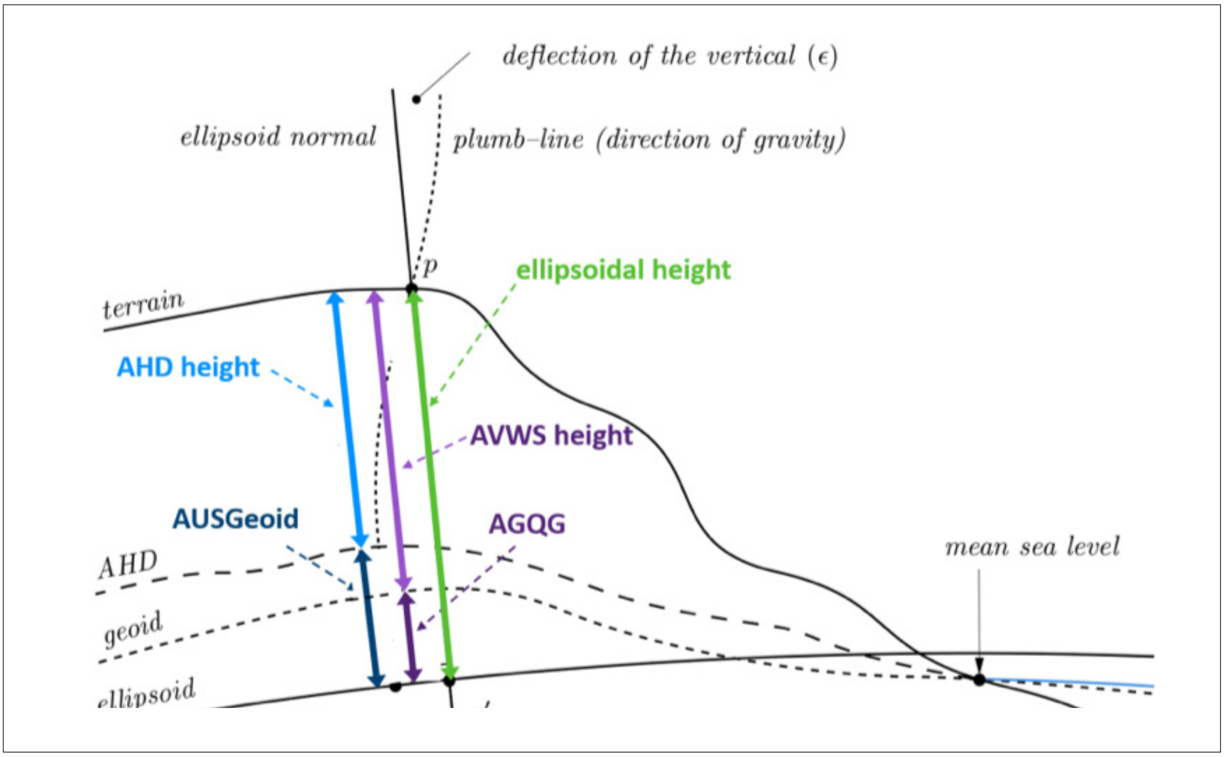
Most contemporary and many historical datasets managed by DCS Spatial Services define height in terms of AHD which remains the legal height datum in NSW. However, AHD is known to suffer from inconsistencies which limit its accuracy over larger distances compared to GNSS-based methods. AVWS has been developed to supplement AHD for larger projects and provides an efficient method to obtain physical heights by using GNSS.

The following colloquial terms are also commonly used to describe CRS which support height:

- A CRS is **3D** when it is explicitly defined in three dimensions, generally with x,y,z mutually perpendicular. For example GDA2020 in latitude and longitude with ellipsoidal height (EPSG:7843 – 3D Geographic).
- **'2D+1D'** intuitively describes a compound CRS, which combines 2D data with an unrelated vertical CRS. For example GDA2020 horizontal plus AHD (EPSG:9463 = [EPSG:7844 – 2D Geographic plus EPSG:5711 – AHD]).

While GDA94 and GDA2020 are both defined as 3D CRS including ellipsoidal height (h), they are often expressed as 2D horizontal datasets (Latitude and Longitude, or MGA Easting and Northing) plus a separate height value in AHD.

For more information, these publications provide an interesting insight into the history and future of height in NSW: Fifty years of the AHD in NSW, A new era of vertical datum determination, Saving the Australian Height Datum.



The AUSGeoid model (dark blue) enables users to convert between ellipsoidal heights (green) and AHD heights (light blue). The AGQG model (dark purple) enables users to convert between ellipsoidal heights (green) and AVWS heights (light purple). Figure is copied from the AVWS Technical Implementation Plan available at ICSM – AVWS

How do I transform between different types of height or 3D data (different vertical CRS)?

Special care must be taken when transforming 3D spatial data. Please contact DCS Spatial Services to confirm appropriate transformation methods for particular datasets. In general, 3D data should be transformed according to the following rules in NSW. Note that in many cases, the horizontal (2D) and height components may need to be transformed separately, and later recombined. This approach may not yet be explicitly supported by all software.

- **3D ⇔ 3D: Separately transform 2D and height data. Alternative 3D method for low-accuracy data only.**
  For example GDA94 (3D Geographic) ⇔ GDA2020 (3D Geographic) [both including GDAxx ellipsoidal height]:
  - Horizonal component: Use NTv2-CPD grid (2D, EPSG:8447)[1].
  - Vertical component: Use 7P conformal (3D, EPSG:8048), but retain only transformed height component.
  - Note: 7P conformal (3D) is an alternative single-step 3D ⇔ 3D method for low-accuracy data only.

- **[2D + AHD] ⇔ [2D + AHD]: Separately transform 2D and height data. AHD height does not change.**
  For example GDA94 (2D Geographic) + AHD ⇔ GDA2020 (2D Geographic) + AHD:
  - Horizonal component: Use NTv2-CPD grid (2D, EPSG:8447)[1].
  - Vertical component: AHD requires no transformation.

- **[2D + AHD] ⇔ 3D: Separately transform 2D and height data.**
  For example GDA94 (2D Geographic) + AHD ⇔ GDA2020 (3D Geographic):
  - Horizonal component: Use NTv2-CPD grid (2D, EPSG:8447)[1].
  - Vertical component (2 step transformation):
    (1) Transform AHD to ellipsoidal height via appropriate model (in this example, AUSGeoid09)[2] and
    (2) Use 7P conformal (3D, EPSG:8048), retain only transformed height component.
  - Combine the horizontal and vertical components into a 3D dataset and nominate the 3D CRS in metadata.
  - Note: 7P conformal (3D) is an alternative method (after AHD > ellipsoidal height) for low-accuracy data only.

- **Transformations involving other datums or height systems (for example AVWS, ATRF): Use published transformations.**
  - For example GDA2020 (3D Geographic) ⇔ GDA2020 + AVWS Height (See EPSG:9693)
  - For example GDA2020 (3D) ⇔ ATRF (4D) (See EPSG:9459)
    - See ICSM - Australian Terrestrial Reference Frame for more information.
    - The Australian Plate Motion model is currently a 2D model only, so height does not change over time. Deformation model(s) may be introduced in future to describe (localised, 3D) deformation events.

1 The NTv2-CPD transformation grid (EPSG:8447) is recommended for all 2D spatial data transformations in NSW. Please refer to DCS Spatial Services information on Transformation Methods and the NSW GDA2020 and AGRS Implementation Policy.

2 Orthometric and ellipsoidal height can be interconverted via AUSGeoid models, see EPSG:5656, 9467, 8451, 9466, and Geoscience Australia's Australian Height Datum and Geoid Models. WARNING: Always use AUSGeoid09 with GDA94 and AUSGeoid2020 with GDA2020.

Does software support the 3D transformations described above?

In general, software is already capable of common height conversions using a variety of implementations to cater for 1D, [2D+1D] and 3D data. However, much software does not (yet) explicitly require a vertical CRS, does not (yet) support [2D+1D] compound CRS, or may not willingly apply separate horizontal and vertical transformations to 3D data. Review how your software treats 3D data transformations and use EPSG identifiers where possible (see examples in the table below).

1D Vertical CRS	EPSG:5711 – AHD Height EPSG:9458 – AVWS Height
[2D+1D] CRS	EPSG:9464 – [GDA94 (2D) with AHD Height] EPSG:9463 – [GDA2020 (2D) with AHD Height] EPSG:9462 – [GDA2020 (2D) with AVWS Height]
3D CRS	EPSG:4939 – GDA94 (3D) (defined with ellipsoidal height) EPSG:7843 – GDA2020 (3D) (defined with ellipsoidal height) EPSG:9308 – ATRF2014 (3D + time) (defined with ellipsoidal height)
Height Transformations	EPSG:8048 – GDA94 (3D) <7-parameter Tf> GDA2020 (3D) EPSG:9466 – GDA2020 (3D) < AUSGeoid2020 > [GDA2020 + AHD Height] EPSG:9693 – GDA2020 (3D) < AGQG > [GDA2020 + AVWS Height] EPSG:9459 – GDA2020 < No change in height in current model > ATRF2014

A comprehensive list of EPSG codes and preferred transformations in NSW is available at the Common Australian EPSG Codes and Transformations InfoSheet.

Refer also to ANZLIC's Preparing Metadata for GDA2020 and the AGRS and consider using or checking against reference software such as Geoscience Australia's AGRS Tools, Models and Resources.

Questions, enquiries and additional information?

For further information and enquiries, please contact our Service Delivery team via the Customer Hub.