AUSGeoid09: Improving the Access to Australia's Vertical Datum

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Key Words: pacity building;GNSS/GPS;Positioning;

SUMMARY

Geoid09 now allows GPS users to derive Australian Height Datum 1971 (AHD71) heights more directly from ellipsoidal heights. Unlike previous versions of AUSGeoid ('93, '98) which were gravimetric only quasigeoids, AUSGeoid09 is a combined gravimetric – geometric quasigeoid providing height separation values from ITRF to AHD71. This allows for the more direct determination of AHD heights from GPS surveys, and avoids the need for post-survey adjustments AUSGeoid09 consists of two components combined together into a single national grid at a 1'x1' resolution between 108E and 160E and 8S and 48S. The first is the gridded offset between the latest gravimetric quasigeoid (referred to as AG09grav) and AHD71. This offset is predominantly caused by sea surface topography including the differential heating of the oceans. The warmer / less dense water off the coast of northern Australia is approximately 1 m higher than the cooler / denser water off the coast of southern Australia. The second component is the gravimetric-only quasigeoid model produced by the Western Australian Centre for Geodesy at Curtin University. This provides the gridded height offset between the ITRF and the quasigeoid surface. The optimal offset grid between AG09grav and AHD71 was calculated by empirical testing using a cross validation least squares technique. The primary dataset comprises of ~1000 points with accurate ellipsoidal height and published third order or better AHD71 heights. A secondary dataset of ~4250 junction points, for which AHD71 heights are available, were also used in the analysis to model the localised AHD71 variations across the continent. All input data points were independently weighted according to GPS processing results, known levelling uncertainties and the inaccuracies of the horizontal positions of the junction points. The AUSGeoid09 product allows users to interrogate the combined gravimetric - geometric quasigeoid model using GDA94 horizontal coordinates at a specified location. The output is the offset from the ITRF2005@2000 ellipsoidal height to the AHD71 height with accuracy well within the uncertainty of the existing AHD71. AUSGeoid09 allows GPS users to establish more accurate AHD vertical control in remote areas of Australia, assist with natural hazard modelling and improve the vertical accuracy of airborne and spaceborne imagery by aligning them with Australia's national vertical datum.

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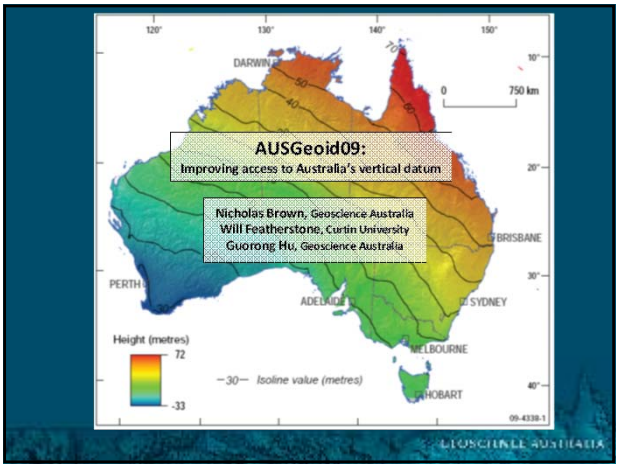


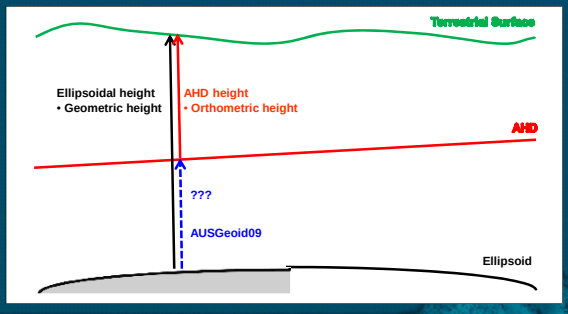
Reference Frames

- Types of Geodetic Reference Frames
  - International Terrestrial Reference Frame (ITRF)
  - Geocentric Datum of Australia (GDA94)
- These frames were developed to work well with GPS observations
- However, these reference frames ignore gravity
  - GPS heights are measured relative to ellipsoid
  - Basic elliptical representation of Earth
- Users still need an orthometric height datum
  - Australian Height Datum
  - Onshore realisation of MSL

Overview

- AUSGeoid09 allows you to convert between reference frames
- Discuss why AUSGeoid09 is different to previous AUSGeoid models
- Computing AUSGeoid09
  - Gravimetric component
  - Geometric component
- The accuracy of AUSGeoid09

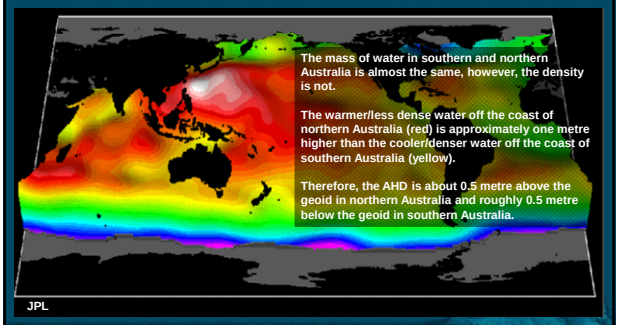
GPS doesn't provide AHD heights



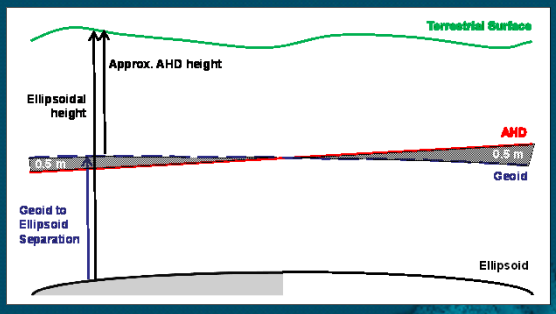
AUSGeoid09

- AUSGeoid09 converts GPS heights to AHD heights to within 0.05 m across most of Australia
- Subtract the AUSGeoid09 value from ellipsoidal height (GPS height) to acquire AHD heights
- Combines the speed of GPS data acquisition and the practicality of the having mean sea level as the reference surface
- So how does this differ to previous versions of AUSGeoid?

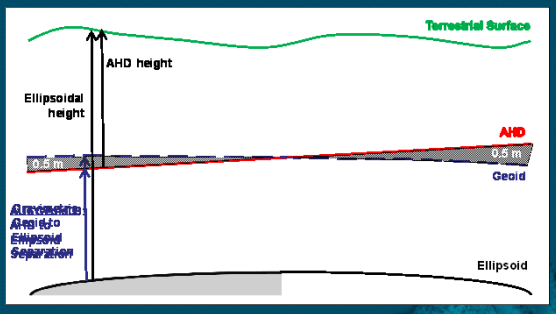
The cause of the offset



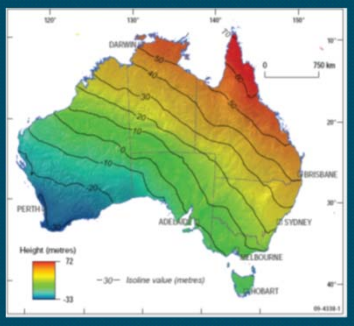
AUSGeoid09: Similar but different



AUSGeoid09: similar yet different



AUSGeoid09: Gravimetric + Geometric



The gravimetric component
- Ellipsoid to Geoid
- Based on similar principles to previous AUSGeoid versions

The geometric component
- Geoid to AHD offset
- Model the ~1 m trend

Two components are combined into a single national grid of ~2 km resolution to model the ellipsoid to AHD separation.

The ~100 m variation from SW to NE Australia is caused by gravitational variability caused by:
- crust thickness
- crust type
- magma distribution etc.

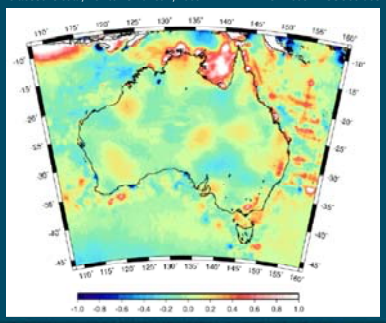
Geometric component

- The offset between the AHD and geoid
- Approximate 1 m trend
- This requires points in Australia on which both the AHD height and ellipsoidal height are known

... at as many locations as possible

Gravimetric Component

Claessens et al, Newton's Bulletin, 2009 **EGM2008 – AUSGeoid98**



Developed by Will Featherstone (Curtin Uni)

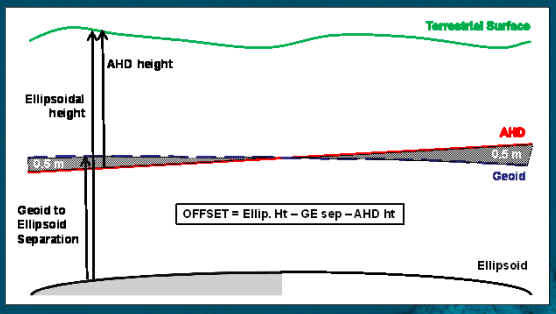
Spherical harmonic synthesis of:
- EGM2008
- 1.3 million gravity obs.

Major improvements from GRACE data

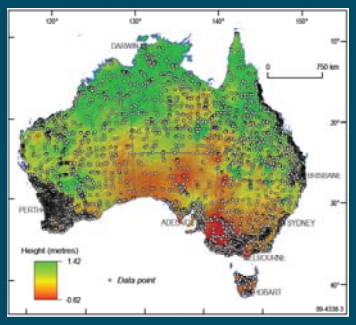
Removed long wavelength anomalies

Removed terrain modelling errors of AUSGeoid98 in mountainous regions

AUSGeoid09: similar yet different



Offset between AHD and the geoid



Offset computed at 5333 points

Primary dataset
1100 GPS & AHD collocated
$N_{ahd} = h - H_{ahd}$

Offset = $N_{ahd} - N_{ag}$

Secondary dataset
4233 AHD points

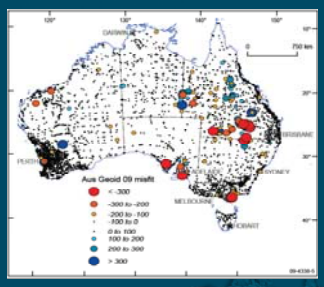
Offsets derived by adjustment of the Australian National Levelling Network (ANLN)

Orthometric heights of primary dataset held fixed

AHD heights of ANLN warped onto the geoid

Accuracy of AUSGeoid09

- Accurate to within 0.05 m across most of Australia
- Some areas still have misfits
- Red – AHD height is **below** interpolated surface
- Blue – AHD height is **above** interpolated surface
- Misfits computed using Cross Validation method
- Predominant cause of misfit is distortions of ANLN



Combining the two surfaces

- Ellipsoid to AHD (N_{ahd}) offset was defined at 5333 positions
- Bilinear interpolator used to determine the corresponding gravimetric geoid value at each of the 5333 points
- Offset between AHD and gravimetric geoid was computed
- Least-Squares Collocation method used to interpolate an AHD to gravimetric geoid offset value at every node on a ~2 km grid
- The gravimetric geoid value was also computed at each of these nodes
- Gravimetric geoid value + geometric offset = AUSGeoid09

Dealing with misfits

- Some errors can be rectified if State Survey Authorities wish to change the AHD height of the point
- Others we know are there but we can't change
  - These are AHD heights which have been used for many years
  - You can't simply change these heights. This is a reference for the community
- This is therefore a **WARTS AND ALL MODEL**
  - Advantage of having dense dataset
- Important to note that the majority of these large misfits occur in relatively sparsely populated areas

Benefits of AUSGeoid09

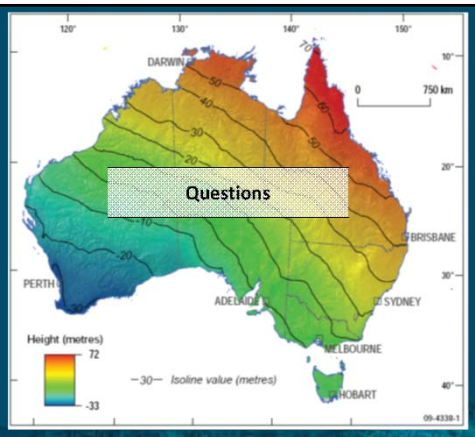
- In the past, if GPS users needed higher accuracy than 0.5 m, they would have to perform expensive surveys to estimate the offset between the AHD and the geoid
- This involved performing lengthy levelling surveys to transfer AHD heights and hours of GPS data acquisition in the work area
- Upon release of AUSGeoid09, AHD heights can be computed in real time to within 0.05 m across most of Australia

AUSGeoid09 summary

- AUSGeoid09 has greatly improved GPS users ability to compute AHD heights in Australia
- Previous versions of AUSGeoid were predominantly based on gravity observations and had an error of up to 0.5 m
- AUSGeoid09 has an additional geometric component to model the AHD to geoid offset
- Modelling the north-south trend and underlying improvements to the gravimetric geoid has improved the accuracy from 0.5 m to 0.05 m across most of Australia

How to use AUSGeoid09

- Once available users can either:
  - Download the AUSGeoid09 data file from the Geoscience Australia website and install it in their GPS receiver to perform GPS to AHD corrections in real time, or
  - Perform the computation online either interactively, or by submitting a batch file



Secondary dataset

- Offset between Hag and Hahd
- At GPS locations (Hag = h – Nag)

- Hag points held fixed in adjustment of ANLN
- Warps ANLN onto the geoid
  - Converts ANLN Hahd heights to Hag heights

- Offers great number of offsets across the country
- Levelling follows the geoid
- Only uncertainty in the derived Hag heights comes from the uncertainty in the levelling data
- This is accounted for in the adjustment with lower weighting than the GPS & AHD collocated points

Transformation from ITRF to GDA94

- ITRF coordinates are transformed back from ITRF2005 to GDA94 using Dawson & Steed parameters
- The homogeneity of the baseline lengths is preserved in this transformation
- The transformation does not degrade the accuracy of the solution
  - Precise orbits preserved
  - Absolute antenna modelling preserved

Potential sources of misfit

1. Levelling network
   - Levelling errors, one way levelling
   - Bound to occur in > 200,000 km of levelling
2. Geoid anomalies
   - Unlikely to be the cause given that the GRACE data has greatly improved gravity modelling capability
3. GPS errors
   - Antenna height – MAYBE – have already found examples

Future Work

- Understand the relationship of AHD relative to contemporary sea level

- Understand dynamics of AHD
  - e.g. caused by subsidence (Perth 5 mm / yr)
  - e.g. changes within the Murray – Darling Basin

- Stronger understanding of links between AHD and chart datums
  - Onshore to offshore connection to link bathymetry to DEM's
  - Need associated uncertainties

Why do you need to use the geoid?

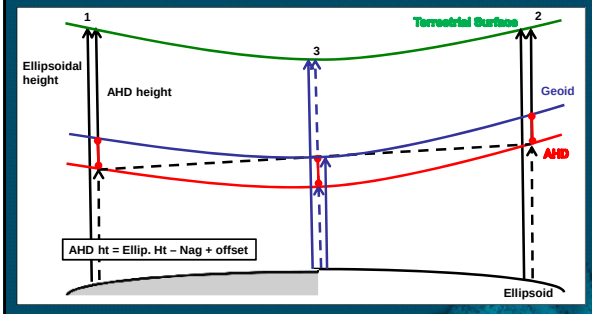
- Often get asked why you can't just have an ellipsoid to AHD correction surface without using the geoid.
- The AHD is based on gravity
- Without the north – south trend AHD would very closely match the geoid
- All levelling is done on the geoid
- Geoid provides higher resolution information
- Collocated GPS & AHD datasets only provide limited offsets to the ellipsoid

Web Statistics

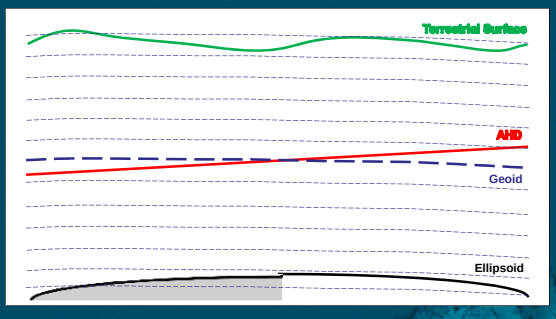
- In 2009 ...
- 28,210 - hits looking for AUSGeoid98 information.
- 6,177 - hits computing AUSGeoid98 values online.
- 3,373 - downloaded AUSGeoid98 data files for use in GPS receivers.

– **Sawmill: Geoscience Australia web statistics**

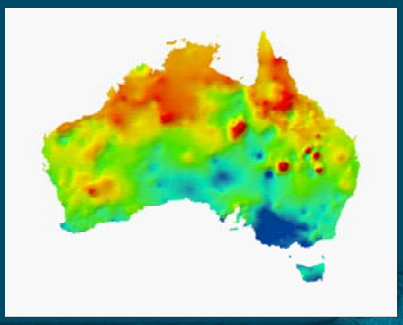
AHD without the geoid



There are an infinite number of geoids (equipotential surface). The term "The Geoid" is often reserved for the equipotental surface that coincides with mean sea level.

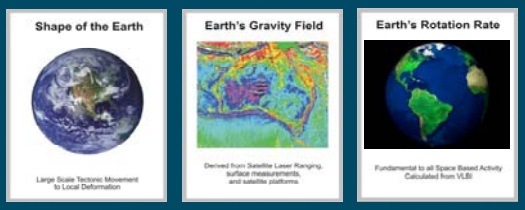


1. Levelling Network



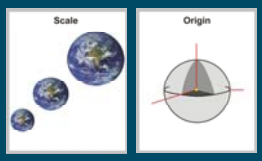
Geodesy

Geodesy is measuring and modelling …



Reference Frame

- All measurements of the Earth's shape, rotation rate and geopotential field need a frame of reference



- For example, we can define a reference frame for the Earth's shape with basic information such as the scale (size) and the origin
- This provides an accurate reference surface / datum on which our science is based

Height above sea level

- Apart from advantage of being based on gravity
- Knowing your height above sea level is also useful & practical

- Coastal vulnerability / tsunami inundation studies
  - Only by knowing the heights of infrastructure relative to the sea level can we model impact / cost

Height above sea level

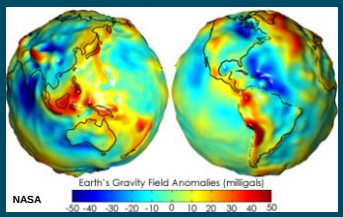
- Satellite / Airborne data
  e.g. Engineering – large scale LiDAR surveys of new highways, subdivisions etc.
  - Most useful to have this information relative to the same vertical datum as the roads, infrastructure etc.

Height above sea level

- Town Planning
  - Avoid placing hospitals in flood zones
  - Ensure heights of crocodile fences exceed flood high water marks

What is a geoid?

- **Geoid is an surface of equal gravitational potential at each point**
  - **e.g. surface of the water if Earth stopped spinning**
- **Computed from combination of space borne and terrestrial gravity observations**
- **An irregular surface**
  - **magma distributions, mountain ranges, deep sea trenches, etc.**



Why is a geoid useful?

- It provides a reference surface for geophysical and geodetic surveys
  - e.g. airborne geophysics surveys
- It's a reference surface which **approximates** MSL / AHD

  ...but not exactly

AUSGeoid09 in use: Scenario

- LiDAR data
  - Reference surface of airborne data is the ellipsoid
  - Using AUSGeoid09 you can shift the LiDAR datum to the AHD
- Bathymetry data
  - Reference surface - chart datum or ellipsoid
  - AUSGeoid09 doesn't work offshore
  - However, it links with onshore data through strong knowledge of offsets between AHD and chart datums at tide gauges
- Satellite Imagery
  - Reference surface of satellite imagery is the ellipsoid
  - Using AUSGeoid09 you can shift the imagery datum to the AHD

AUSGeoid09 in use: Scenario

- Exposure modelling in Perth for flooding or storm surge
- Data you need
  - LiDAR data (to produce 0.1 m accurate DEM)
  - Bathymetry data
  - Satellite imagery to drape over DEM
  - Exposure database containing heights of infrastructure

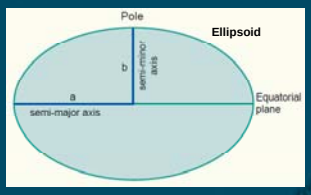
AUSGeoid09 in use: Scenario

- Exposure Database
  - Heights of hospitals, houses, schools, crocodile farms etc are all stored within the exposure database
  - These heights can be observed by GPS and AHD heights can be obtained in real time
  - Simple way of augmenting your infrastructure database

AUSGeoid09 in use

The problem

- Global Positioning System (GPS) receivers, which are now widely used for accurate positioning **DO NOT** provide heights relative to mean sea level / AHD
- GPS receivers provide you with a height above the ellipsoid



What is the AHD?

The Australian Height Datum (AHD) is the reference surface for heights in Australia

AHD is an onshore realisation of mean sea level

Orthometric surface i.e. based on gravity

Mean sea level value observed at 32 tide gauges from set to 0.000 m AHD

Over 200,000 km of levelling was performed to transfer heights relative to mean sea level across the country

Previous AUSGeoid models

- All AUSGeoid models have been designed to assist users in converting GPS heights to AHD heights
- Previous versions of AUSGeoid ('93, '98) are known as gravimetric geoids
  - based predominantly on gravity
  - did not model one metre trend between AHD and geoid
  - provided you with a height above the geoid, not AHD heights.
  - In error by as much as 0.5 m

Overview – Part 2 – AUSGeoid09

- Gravimetric component
- Geometric component
- The accuracy of AUSGeoid09
- Future work
- Scenario showing how AUSGeoid09 can be used