Australian Government
Geoscience Australia

Heighting Fundamentals and Ellipsoidal Height System

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Part 1: Introduction to Height Systems

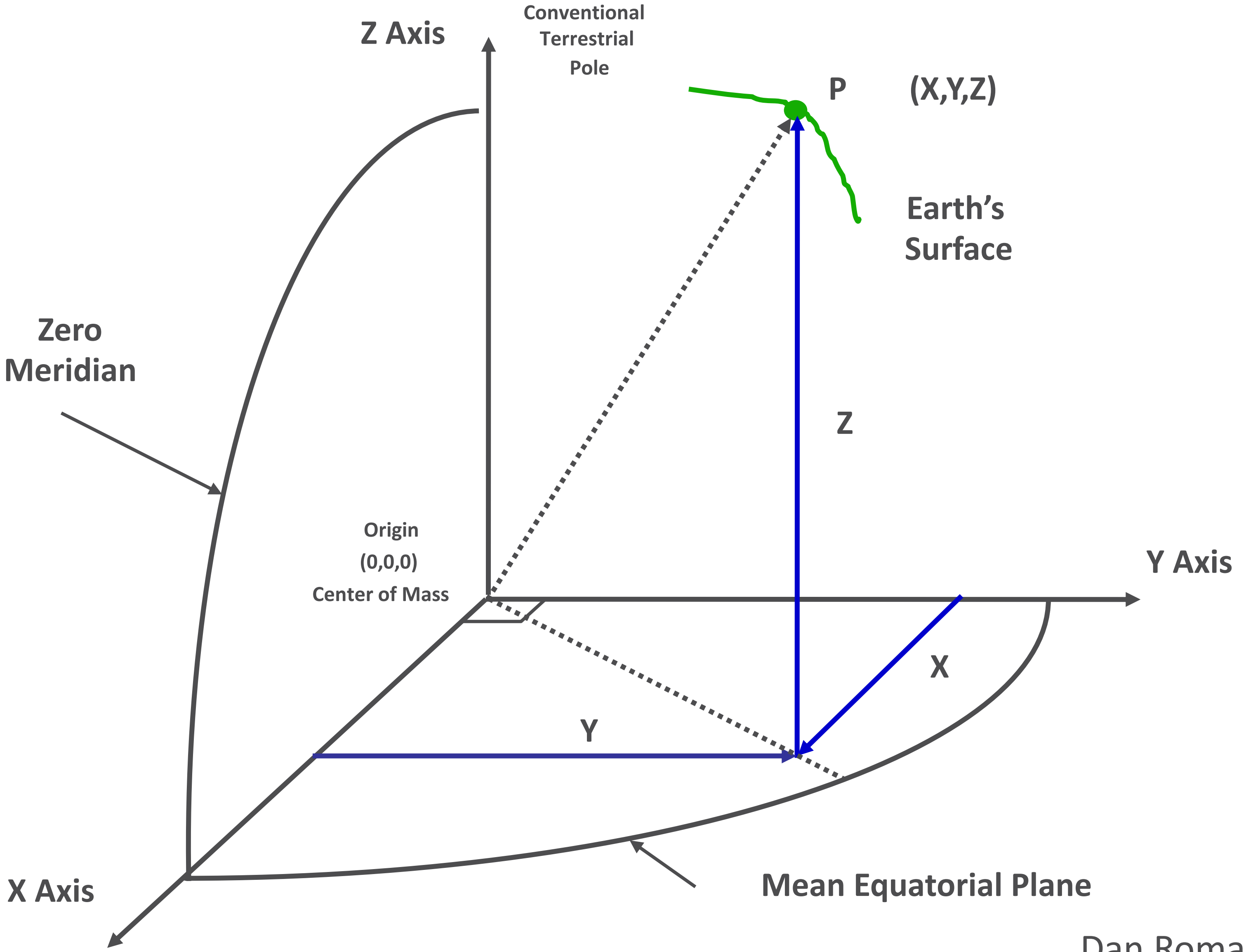
Height Systems – Introduction

- One dimensional coordinate system used to define the distance of a point from a reference surface along a well defined path
- Complex description because there are a number of **reference surfaces** and a number of **well defined paths**
- Two types of height systems:
  1. Physical – based on Earth's gravity field and measured along the curved plumbline (e.g. orthometric heights)
  2. Geometric – not based on gravity field (e.g. GNSS ellipsoidal heights)
- Purpose: become more aware of the different **reference surfaces** and different **paths**

Height Systems – Introduction

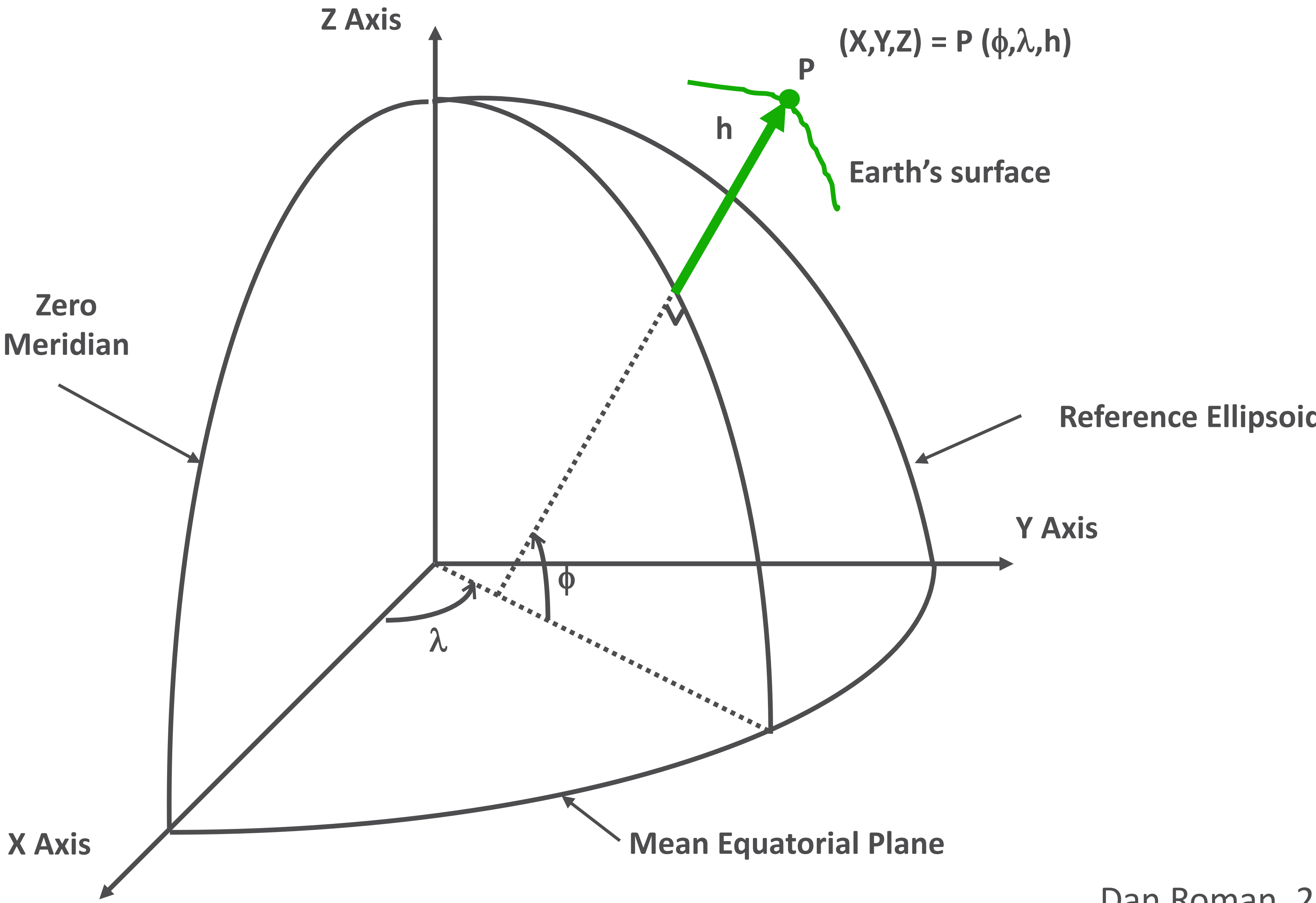
- Traditionally people prefer to know their height relative to sea level (physical height surface):
  - Water flow for drainage systems
  - Height of buildings above a flooding river
- Satellite positioning systems (GNSS and remote sensing) determine heights relative to the ellipsoid (geometric)
- These height systems aren't aligned, but can be connected (e.g. using geoid models)
- It is important to understand how these systems are different and how data from these systems can be used together

Earth-Centered, Earth-Fixed (XYZ)



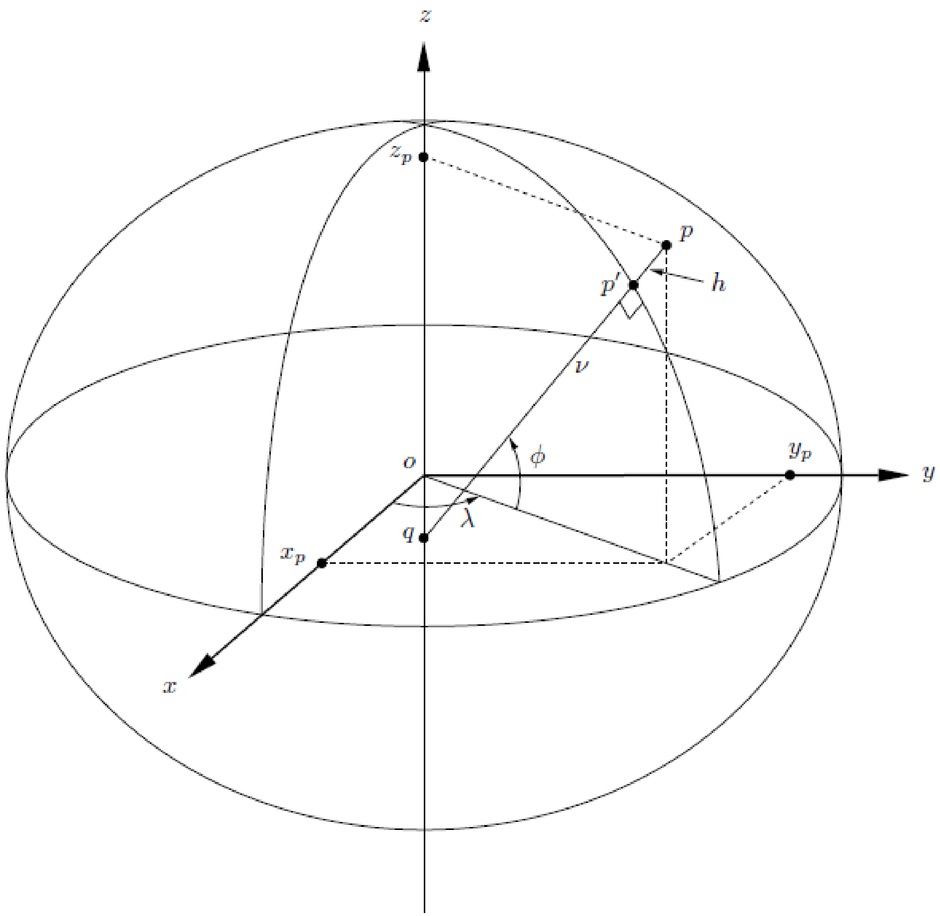
Dan Roman, 2007

Latitude, Longitude, Ellipsoidal Height (LLH)



Dan Roman, 2007

Geometric Height System



Ellipsoid
simplified mathematical representation of the Earth's shape.

Not a surface on which water always flows downhill

Not an ideal working surface for a national height datum

Reference surface for GNSS

Good surface to collect data in and store data in

Geometric Reference Systems

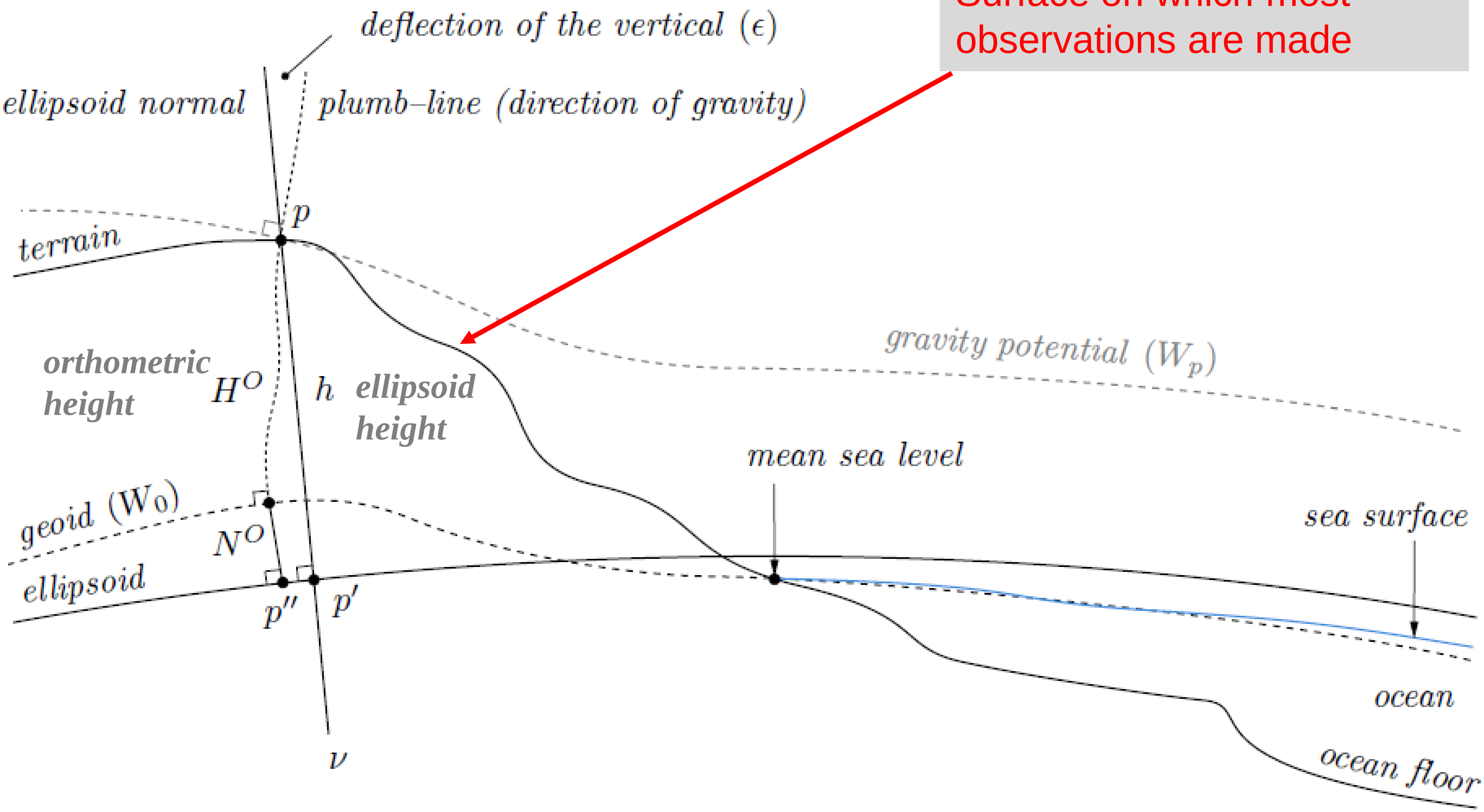
- Geo… s a best fit to…
- It's…

Ellipsoid Name (year computed)	Semi-Major Axis, a, [m]	Inverse Flattening, $1/f$
Airy (1830)	6377563.396	299.324964
Everest (1830)	6377276.345	300.8017
Bessel (1841)	6377397.155	299.152813
Clarke (1866)	6378206.4	294.978698
Clarke (1880)	6378249.145	293.465
Modified Clarke (1880)	6378249.145	293.4663
International (1924)	6378388.	297.
Krassovski (1940)	6378245.	298.3
Mercury (1960)	6378166.	298.3
Geodetic Reference System (1967), GRS67	6378160.	298.2471674273
Modified Mercury (1968)	6378150.	298.3
Australian National	6378160.	298.25
South American (1969)	6378160.	298.25
World Geodetic System (1966), WGS66	6378145.	298.25
World Geodetic System (1972), WGS72	6378135.	298.26
Geodetic Reference System (1980), GRS80	6378137.	298.257222101
World Geodetic System (1984), WGS84	6378137.	298.257223563
TOPEX/Poseidon (1992) (IERS recom.)[2]	6378136.3	298.257

Jekeli - 2006

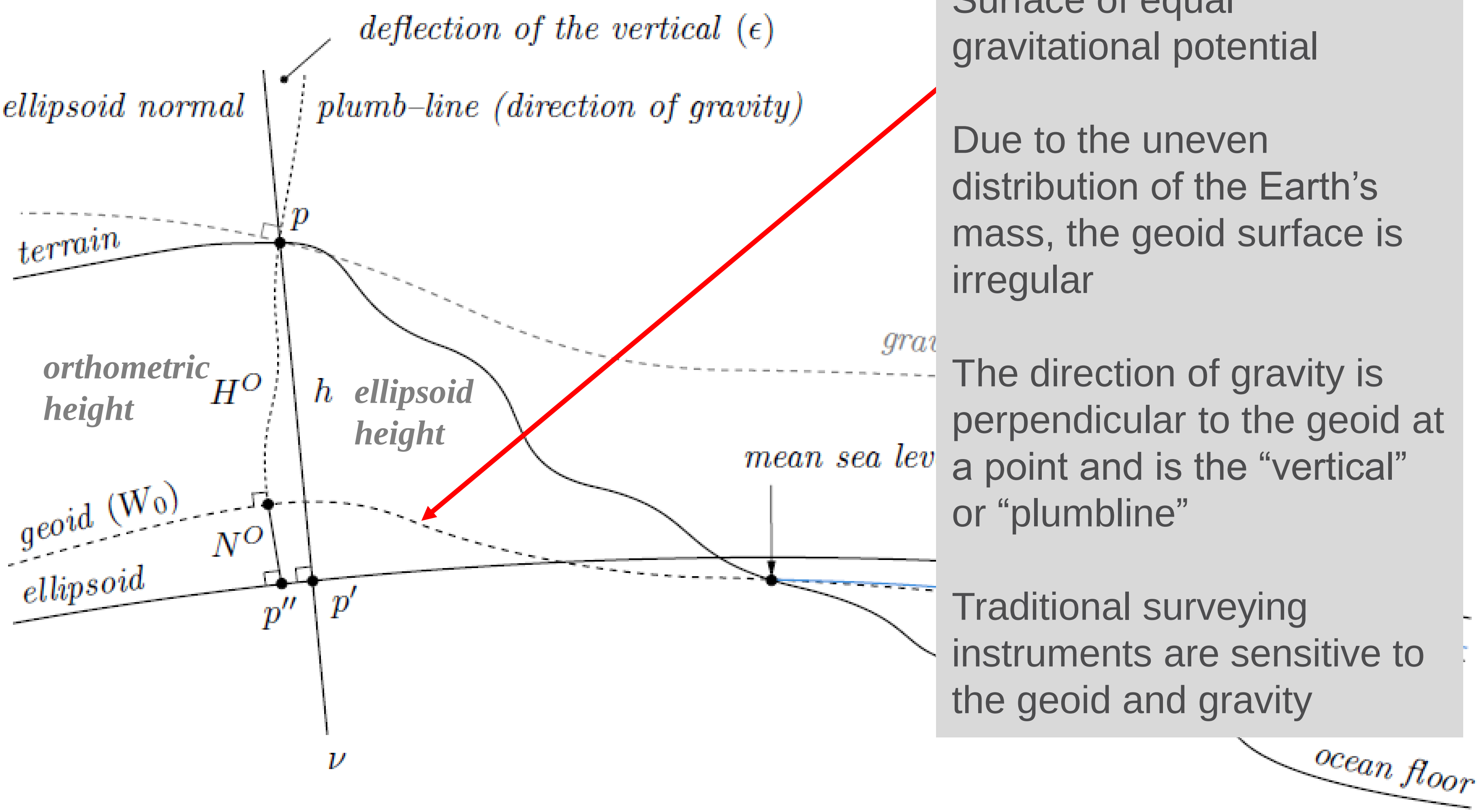
Physical Height Systems

Terrain
Surface on which most observations are made



DynaNet User Guide (Fraser, in draft)

Physical Height Systems



Geoid

Surface of equal gravitational potential

Due to the uneven distribution of the Earth's mass, the geoid surface is irregular

The direction of gravity is perpendicular to the geoid at a point and is the "vertical" or "plumbline"

Traditional surveying instruments are sensitive to the geoid and gravity

DynaNet User Guide (Fraser, in draft)

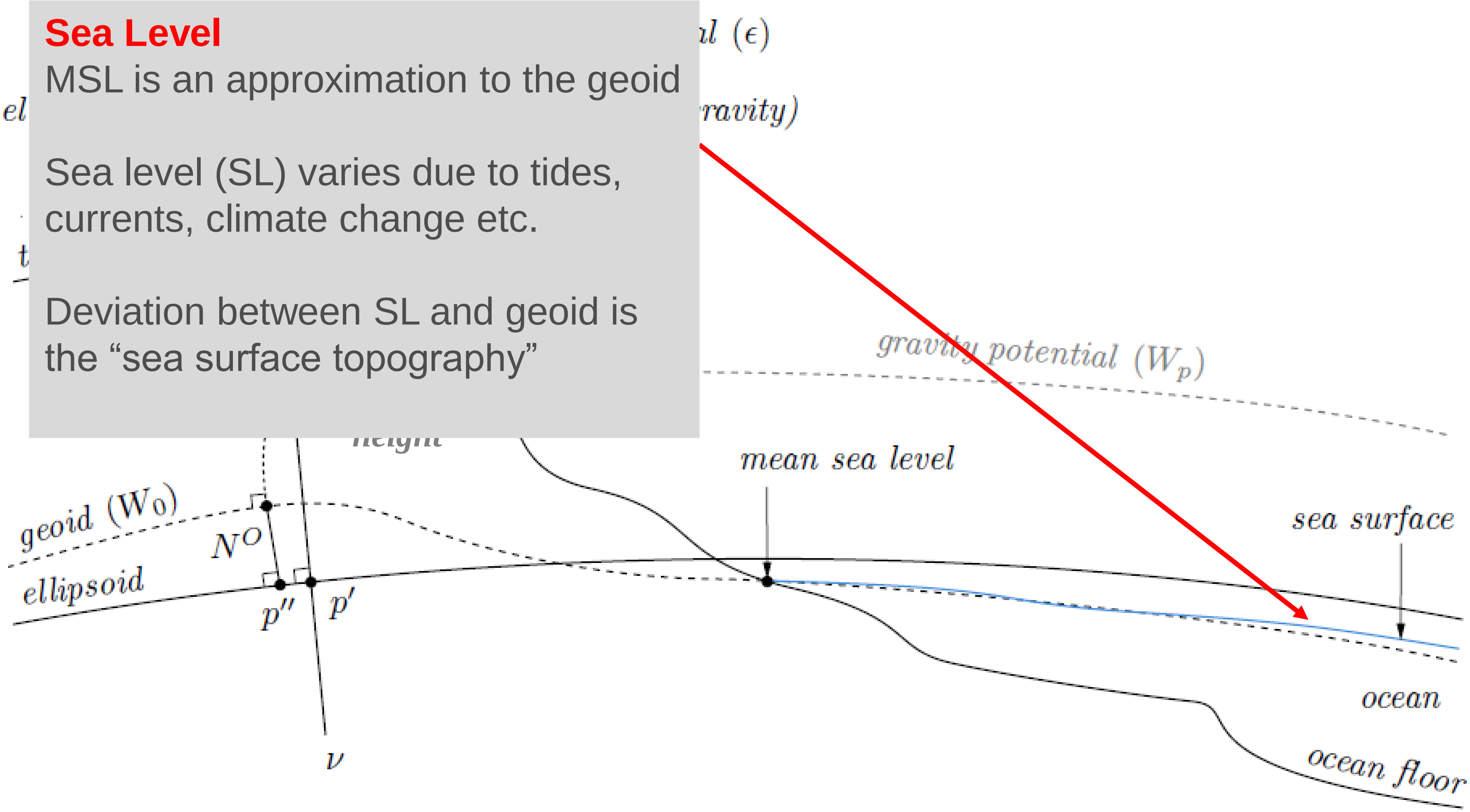
Physical Height Systems

Sea Level

MSL is an approximation to the geoid

Sea level (SL) varies due to tides, currents, climate change etc.

Deviation between SL and geoid is the "sea surface topography"



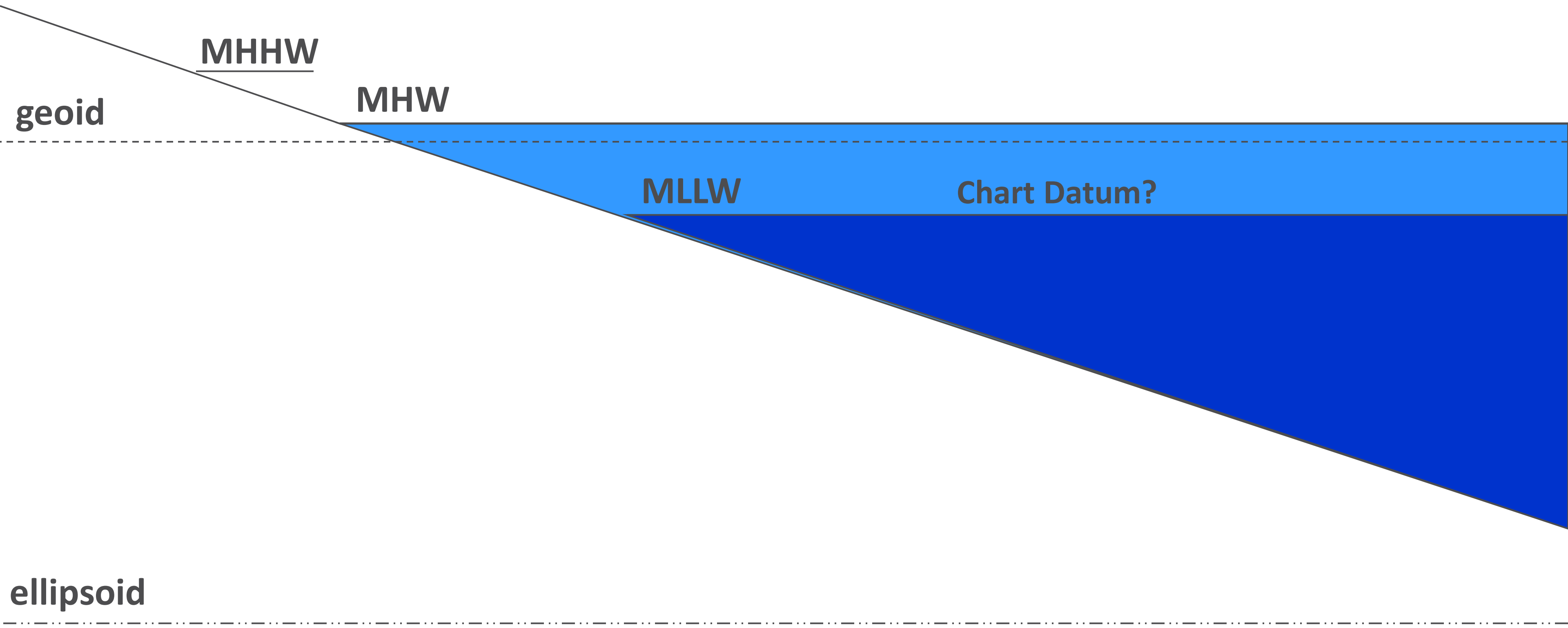
DynaNet User Guide (Fraser, in draft)

Physical Height System – tidal

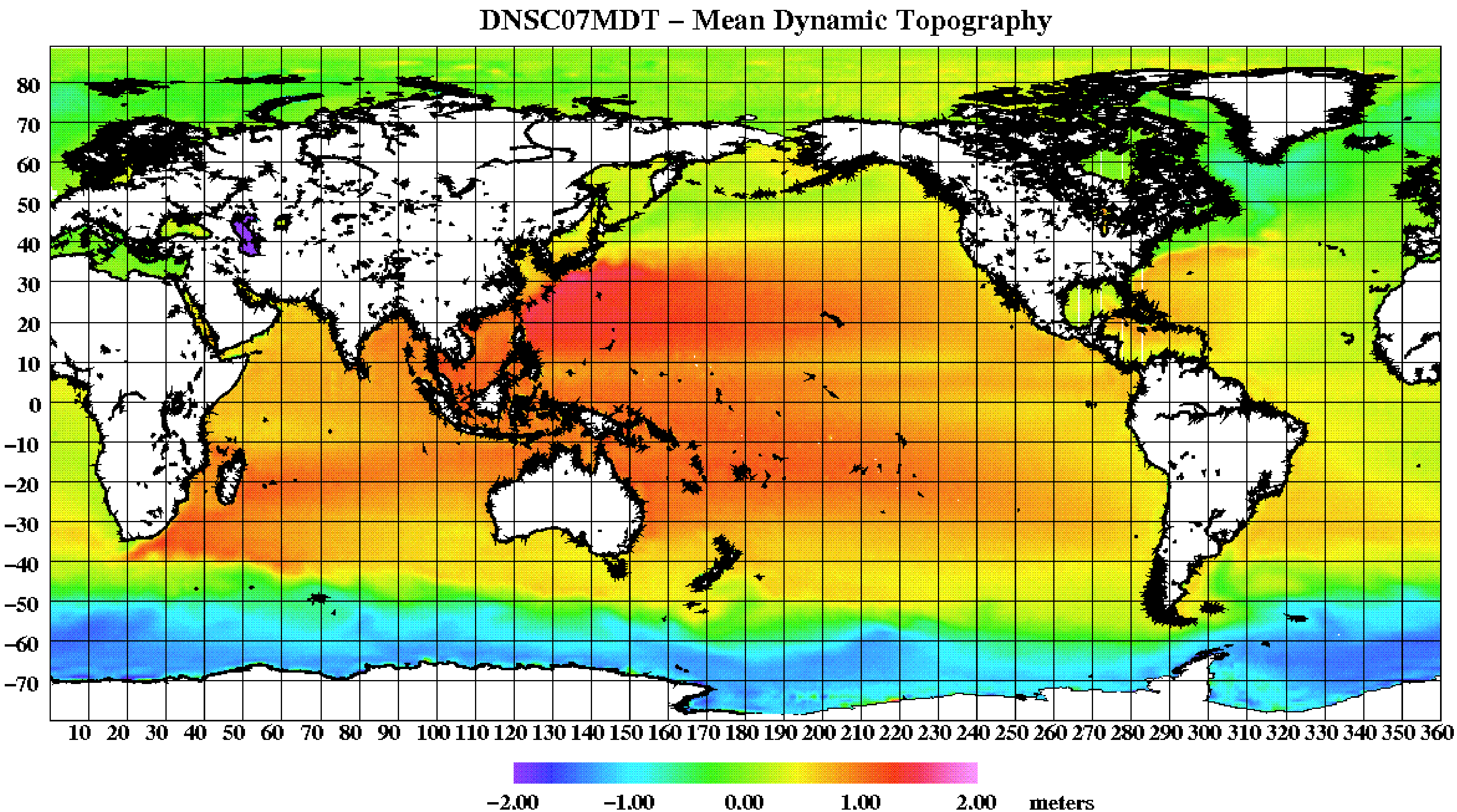
- Heights Measured Above Local Mean Sea Level
- Should be based on 18.6 year period to account for all significant tidal periods
- Averages out nearly all meteorological, hydrological, and oceanographic variability
- Levelling is used to determine relationship between bench marks and tide gauges

Dan Roman, 2007

Physical Height System – tidal



Mean Dynamic Topography (MSS – geoid)



Part 2: Observing & Computing Ellipsoidal Heights

Observing and computing ellipsoidal heights

Ellipsoidal heights are generally measured using GNSS

Kiribati

Tonga

Tuvalu

Observed data sent to GA (RINEX files) and processed

Weekly solutions in the form:

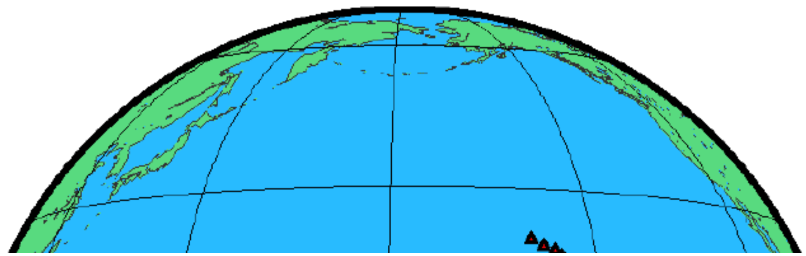
TUVA XYZ -6307543.7852 88455.1443 -939277.7039

TUVA LLH 179 11 47.5924 -8 -31 -31.0356 38.3938

Computing GNSS results

Many options including AUSPOS, RTKLIB, BERNESE

1. AUSPOS

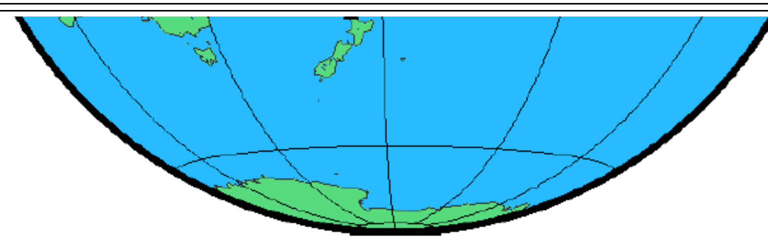


3.2 Geodetic, GRS80 Ellipsoid, ITRF2008

Geoid-ellipsoidal separations, in this section, are computed using a spherical harmonic synthesis of the global EGM2008 geoid. More information on the EGM2008 geoid can be found at http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/

Station	Latitude (DMS)	Longitude (DMS)	Ellipsoidal Height(m)	Derived Above Geoid Height(m)
TUVA	-8 31 31.03555	179 11 47.59248	38.380	3.541

- Gobal Navigation Satellite System Networks
- Geodetic Datums
- Regulation 13 Certificates
- Asia-Pacific Reference Frame

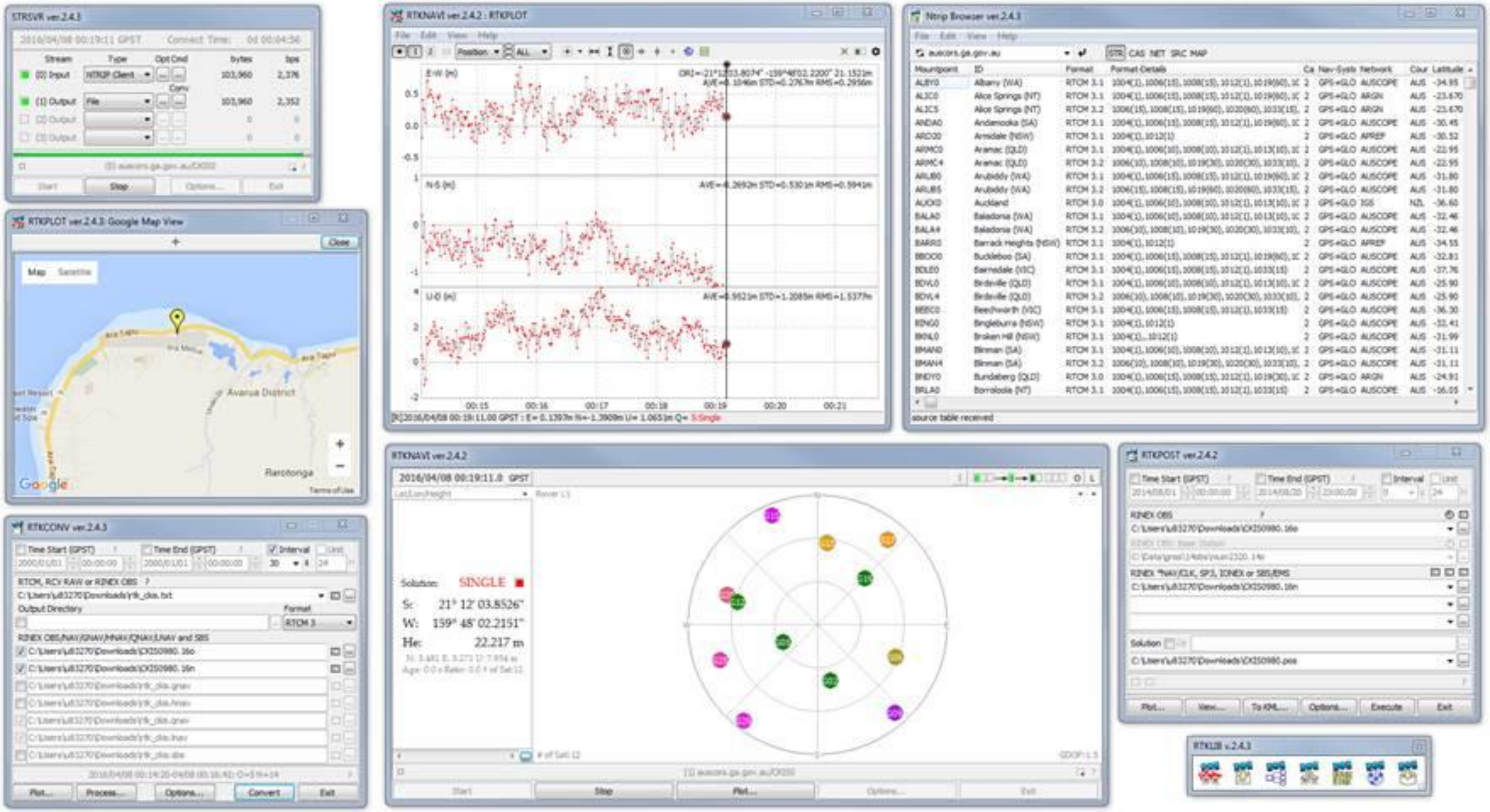


Date	User Stations	Reference Stations	Orbit Type
2016/10/01 00:00:00	TUVA	ASPA AUCK HNLC KIRI KOKB KOUC LAUT MAUI MKEA NAUR NIUM PTVL SAMO TONG TOW2	IGS final

Computing GNSS results

2. RTKLIB

- Open source GNSS package (free)
- Windows and UNIX
- Good tutorials online and user manual
- Real-time or post processing
- Data visualisation tools



Computing GNSS results

3. BERNESE

- GNSS processing software
- Network processing
- Rigorously handles covariance in the data
- Used by Geoscience Australia to process APREF solutions (650+ sites) daily and weekly
- Output in SINEX files and made available on GA ftp server

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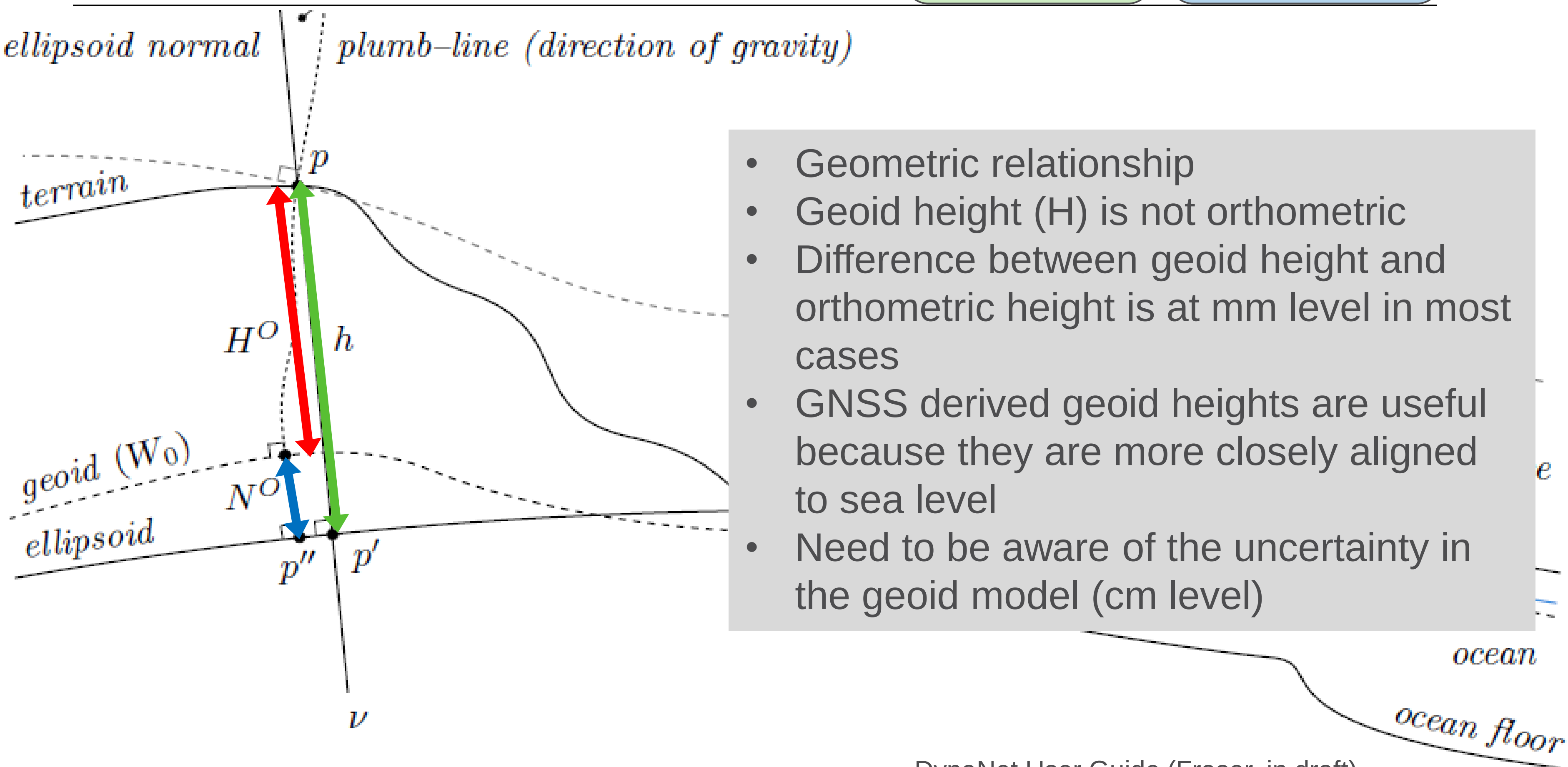
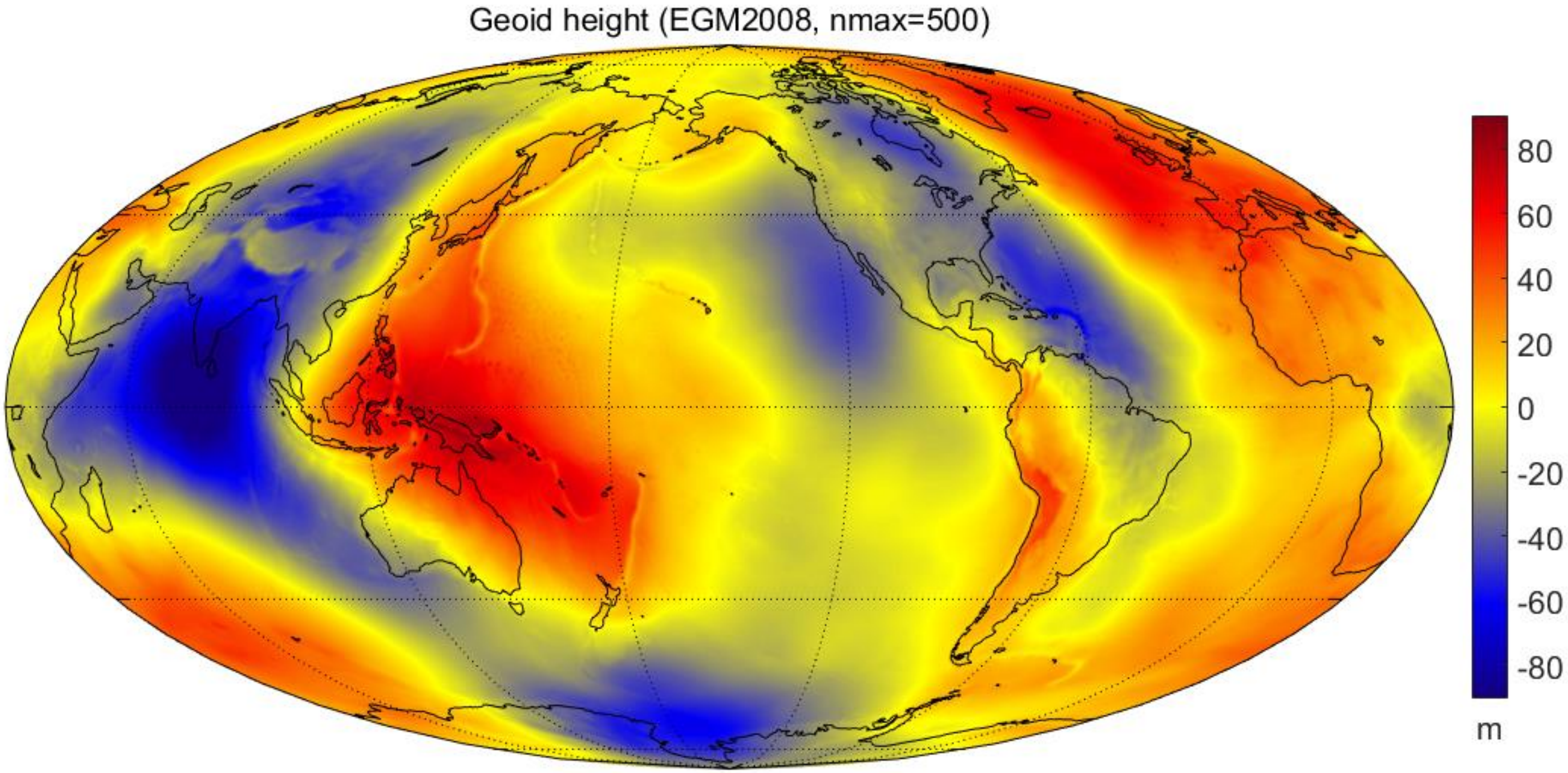


- Geometric relationship
- Geoid height (H) is not orthometric
- Difference between geoid height and orthometric height is at mm level in most cases
- GNSS derived geoid heights are useful because they are more closely aligned to sea level
- Need to be aware of the uncertainty in the geoid model (cm level)

DynaNet User Guide (Fraser, in draft)

Earth Geopotential Model 2008



Example: Tuvalu GNSS CORS

Converting from ellipsoid height to above geoid height

$H = h - N$

H = above geoid height

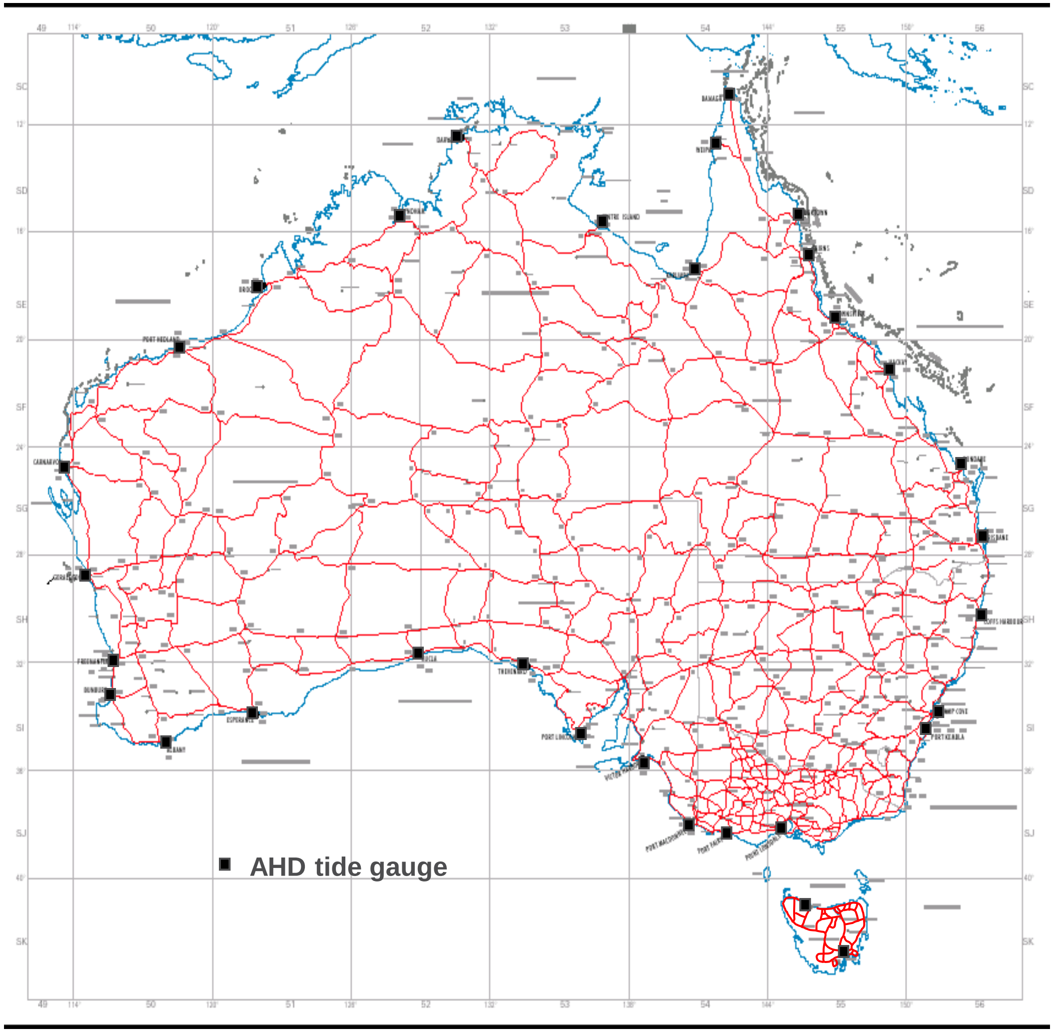
h = ellipsoid height

N = geoid to ellipsoid separation (using a model)

$H = 38.380 - 34.839$

$H = 3.541$ m

Australian Height Datum



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

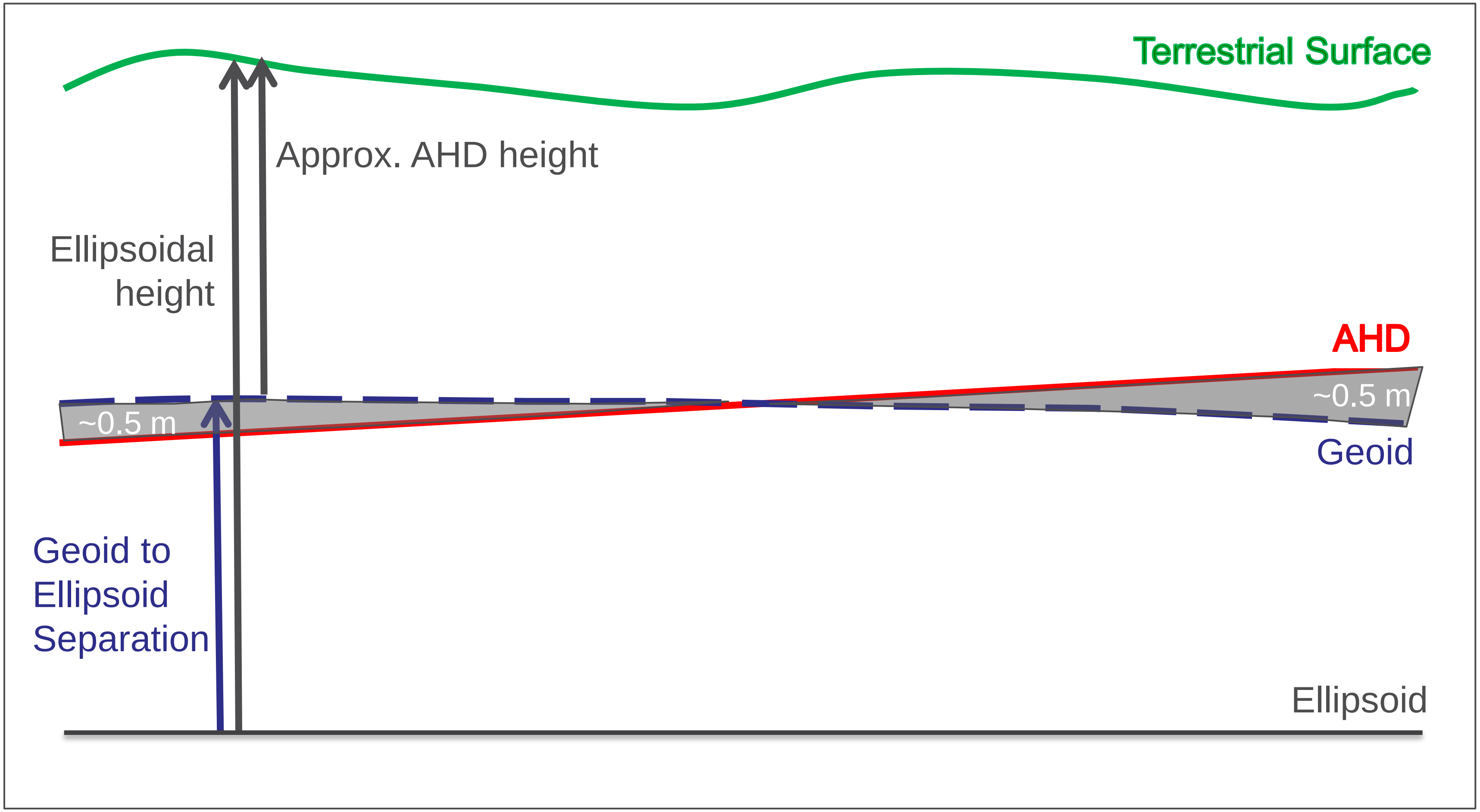
AHD is an onshore realisation of mean sea level

Normal - orthometric surface i.e. based on normal gravity

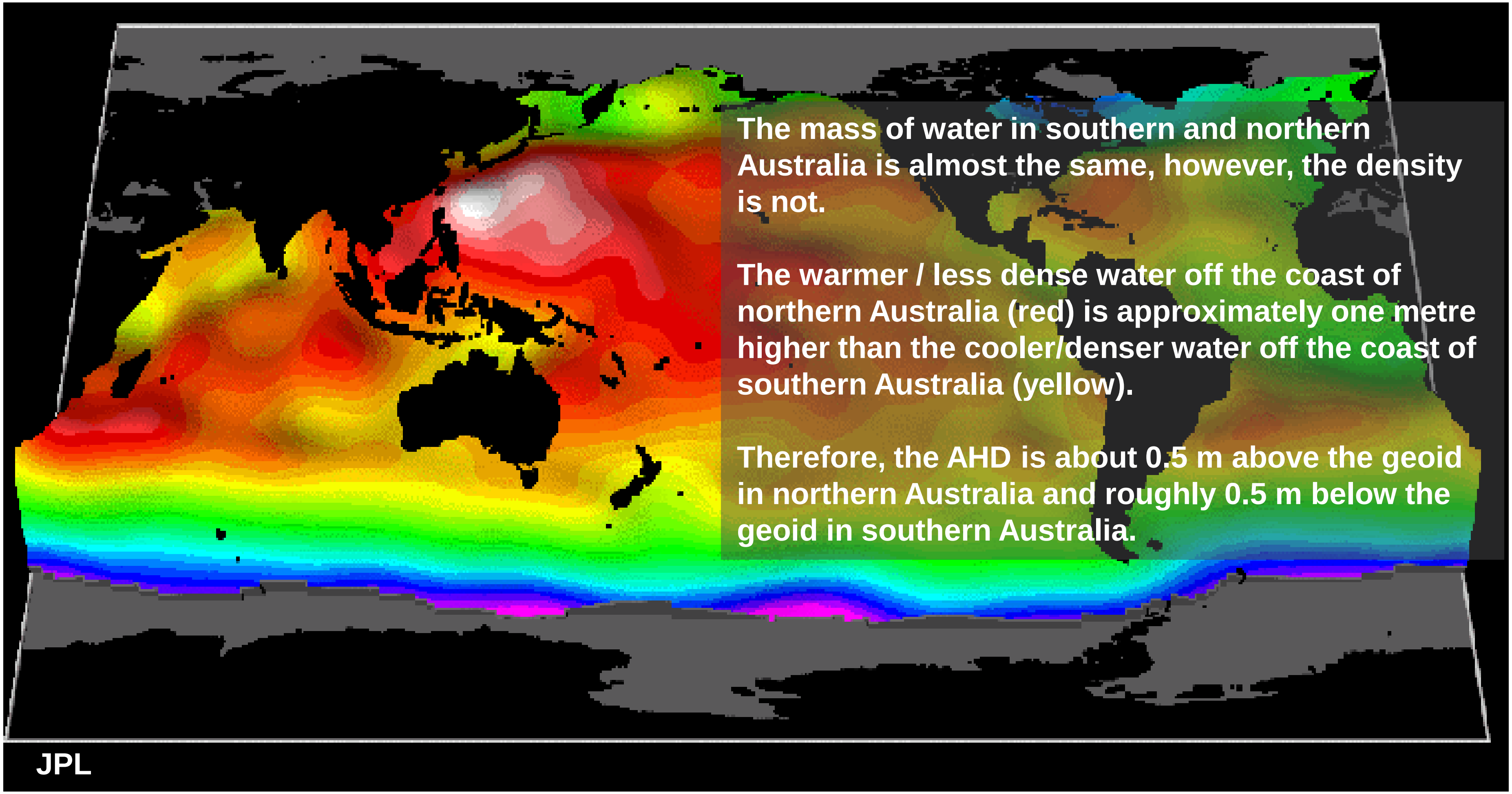
Mean sea level value observed at 30 tide gauges from 1966-1968 set to 0.000 m AHD

~300,000 km of levelling has been performed to transfer heights relative to mean sea level across the country

Geoid height vs. Mean Sea Level (MSL)



The cause of the offset



The mass of water in southern and northern Australia is almost the same, however, the density is not.

The warmer / less dense water off the coast of northern Australia (red) is approximately one metre higher than the cooler/denser water off the coast of southern Australia (yellow).

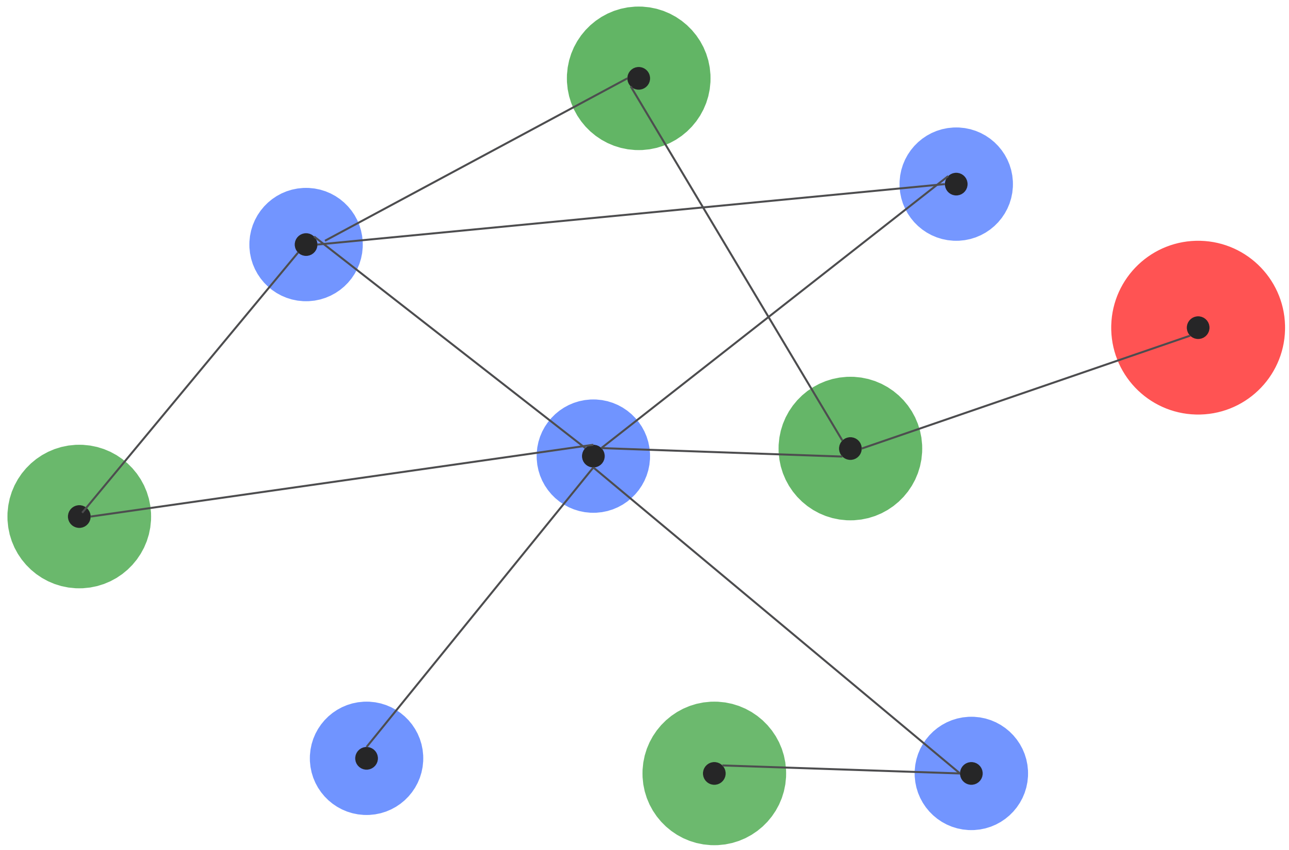
Therefore, the AHD is about 0.5 m above the geoid in northern Australia and roughly 0.5 m below the geoid in southern Australia.

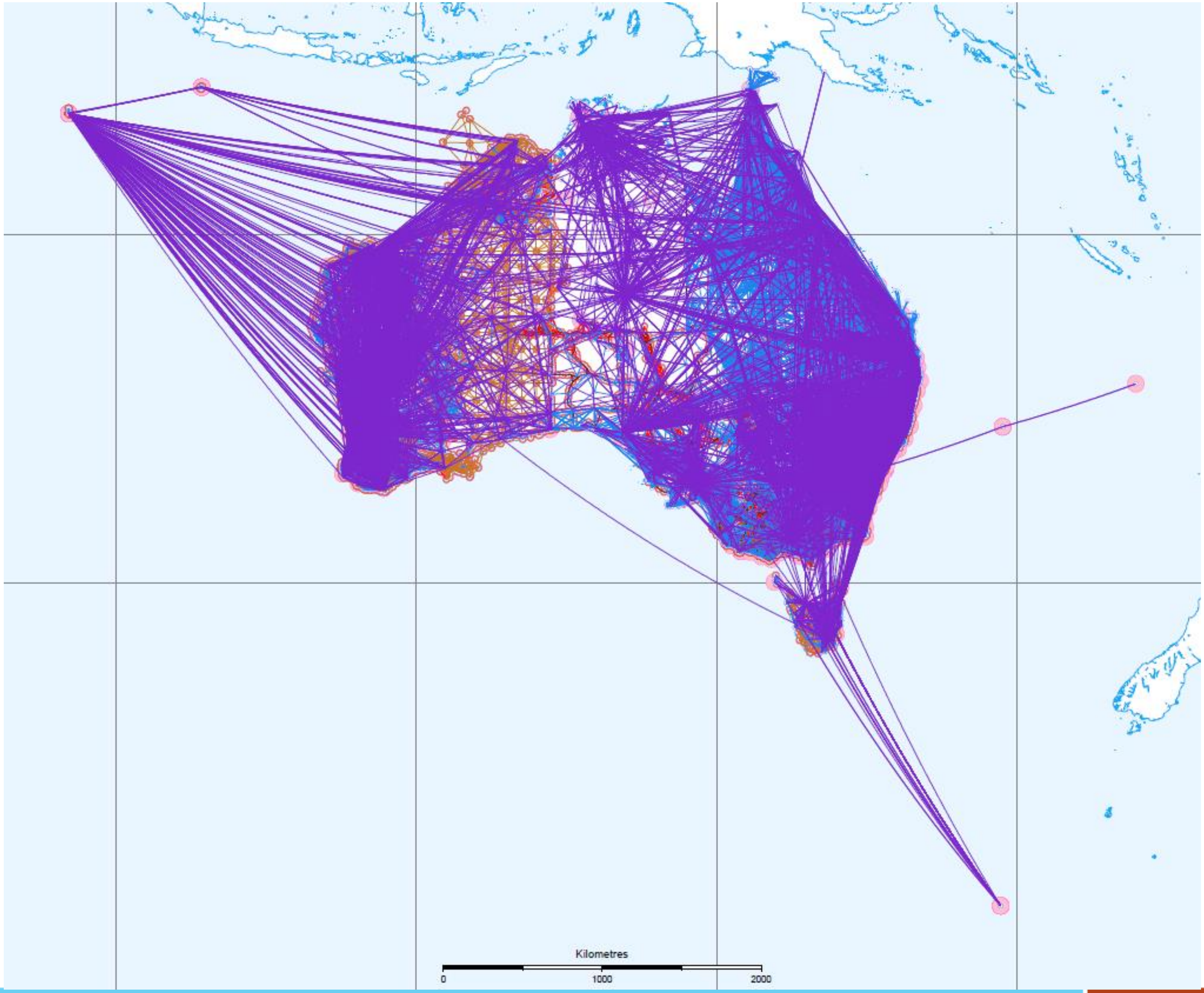
Part 3: Adjustment of Data

Adjustment of data

- e.g. development of a datum
- GNSS data from a number of points
  - Primary – CORS
  - Secondary – GNSS on survey marks
  - Tertiary – Terrestrial observations

Adjustment of data



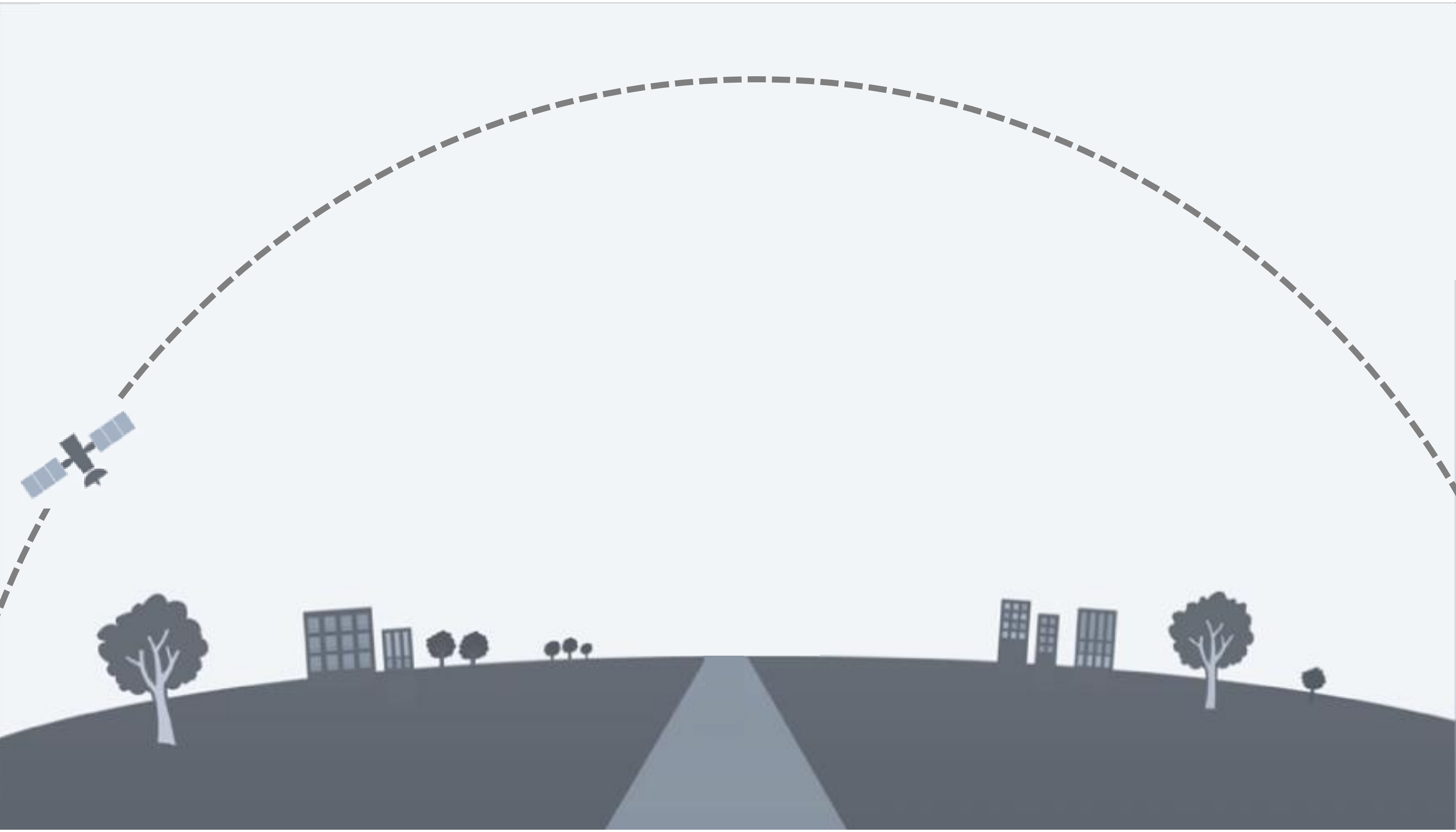

Kilometres
0
1000
2000

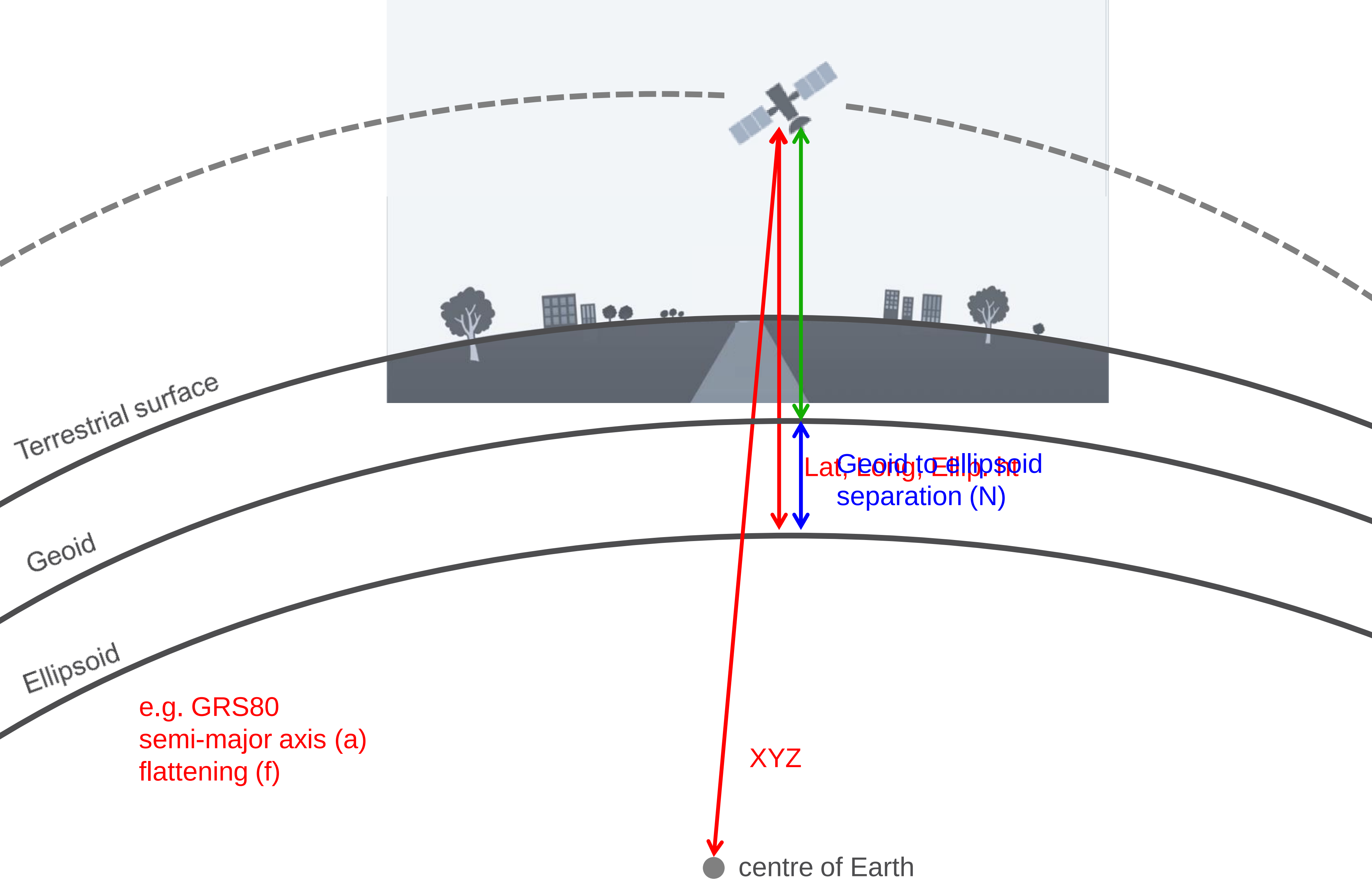
Adjusting ellipsoidal heights

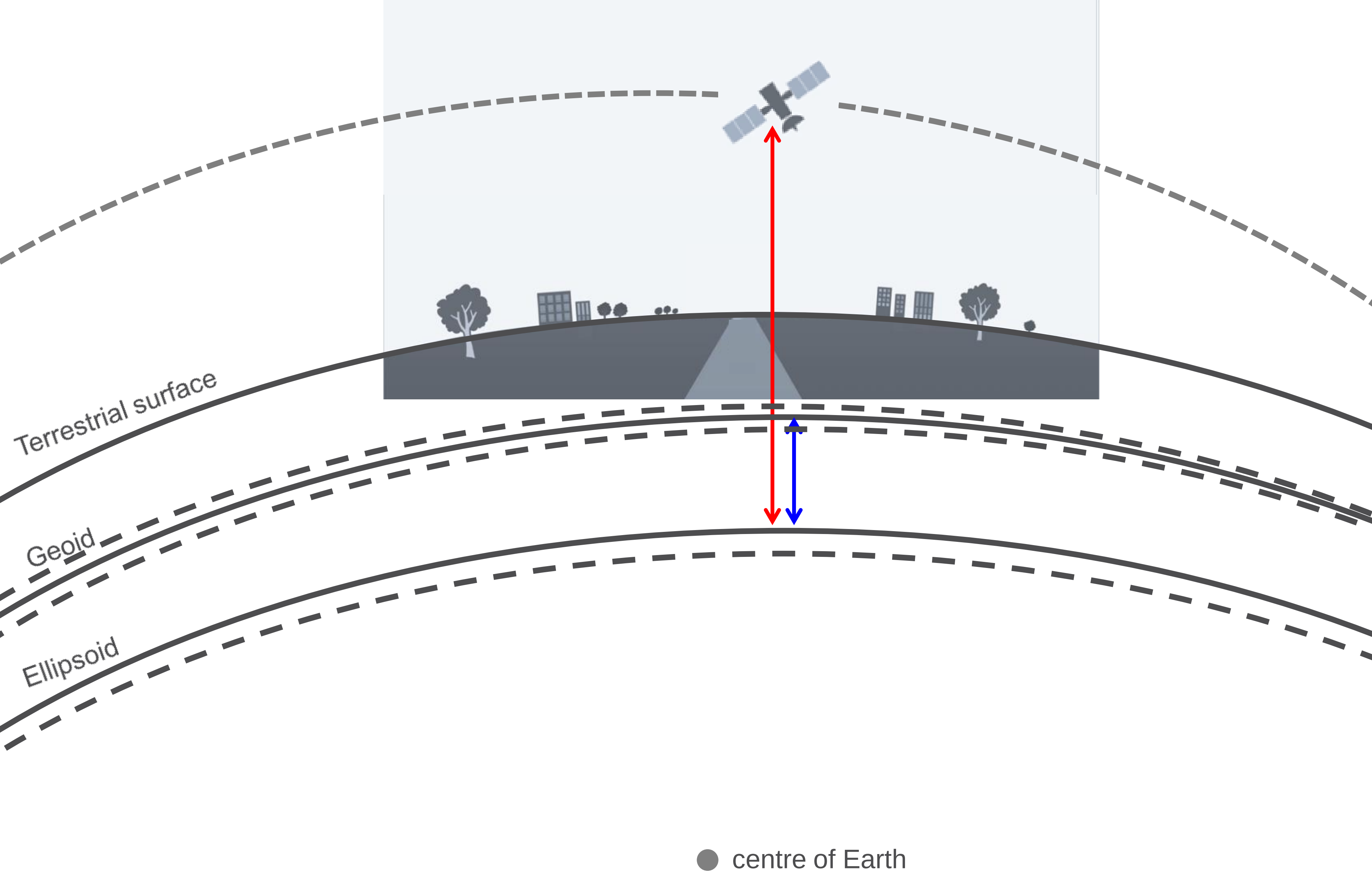
- Network adjustment
- In Australia we are performing a 3D adjustment
- New datum (GDA2020)
- 3D adjustment using national archive of survey data
- Rigorous adjustment of all data constrained to these CORS using least squares
- ~300,000 stations and ~2 million measurements
- Output is coordinates (and datum) which more closely aligned to global satellite systems (e.g. GPS) and global reference frame (ITRF).

Part 4: Combining data from geometric and physical height systems

UAV / Drone example

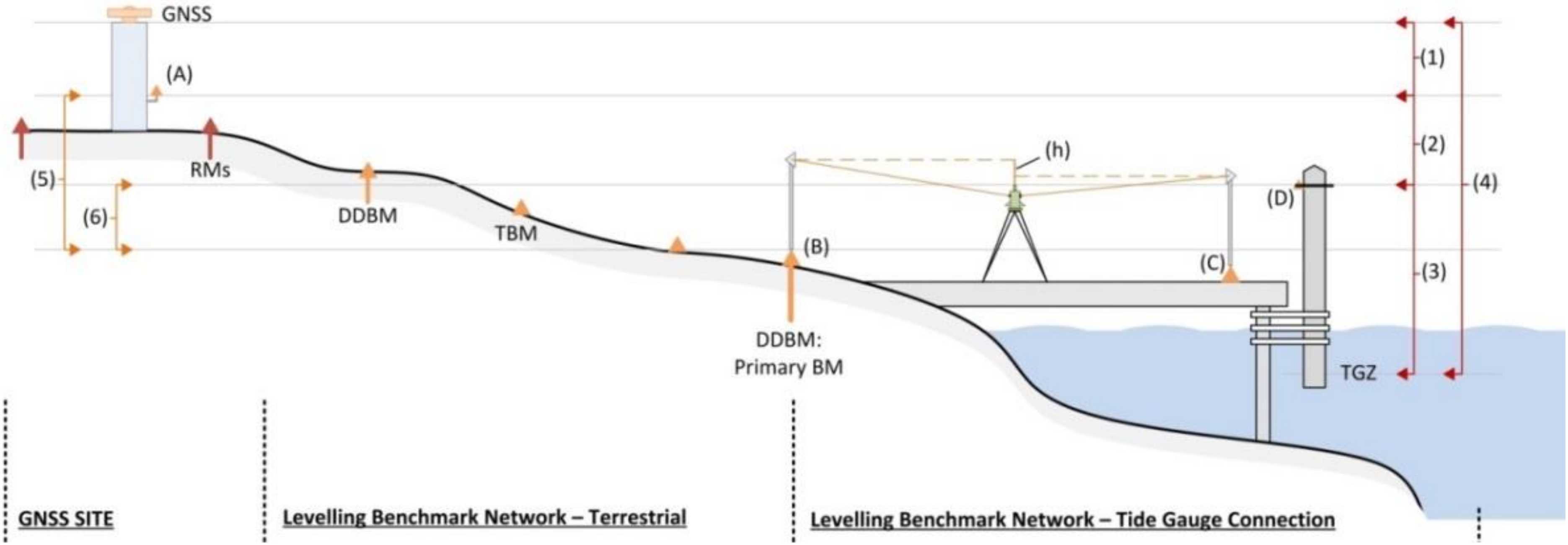



Terrestrial surface
Geoid
Ellipsoid
Lat, Long, Ellip. ht
Geoid to ellipsoid
separation (N)
e.g. GRS80
semi-major axis (a)
flattening (f)
XYZ
centre of Earth

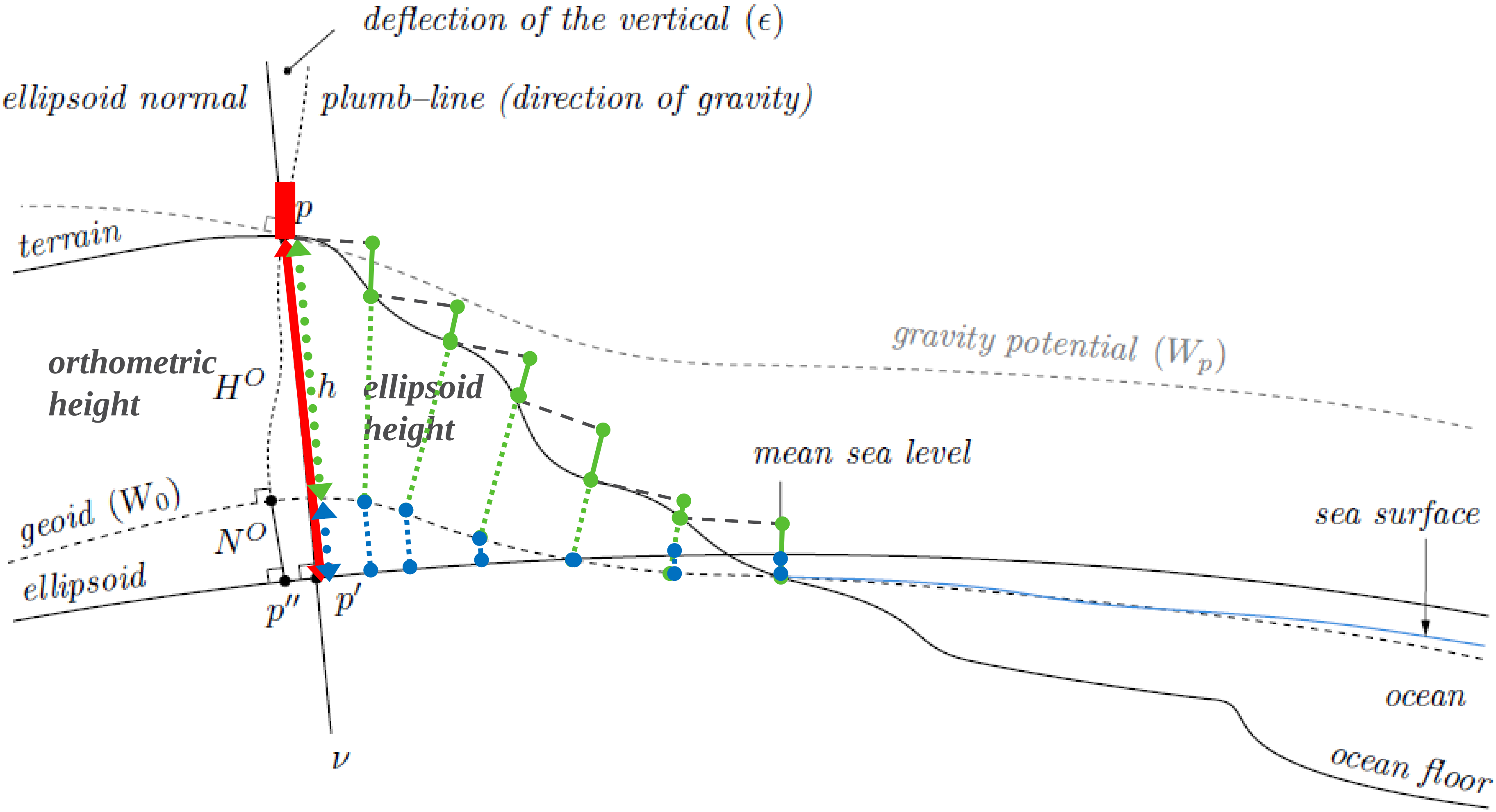

Terrestrial surface
Geoid
Ellipsoid
centre of Earth

Sea Level Monitoring Example

GNSS data combined with levelling data and tide gauge data



Sea Level Monitoring Example



DynaNet User Guide (Fraser, in draft)

Aligning datums

1. Choose a geometric vertical reference system (e.g. GRS80)
   - Ellipsoidal based – maintain data in this form
2. Choose a geoid
   - Make sure it is aligned with the ellipsoid chosen
   - There are multiple versions of WGS84 and EGM2008
3. Understand the connection between working surfaces (e.g. tidal, local height datums) and the geometric and physical reference systems chosen in 1 and 2.

Australian example

1. Geometric height system (GDA2020 based on GRS80)
2. Physical height system
   - Global gravity model (EGM2008) with local gravity data
   - Fitted to Australian Height Datum (AHD)
3. Relationship to Mean Sea Level
   - AHD is MSL from 1966-68

Conclusions (1)

- The increasing use of geometric GNSS techniques encourages countries to develop a method to convert between geometric and physical height systems
- Physical heights have traditionally been obtained using terrestrial optical levelling techniques ... but in a world of GNSS, "uphill-and-downhill", and direction of gravity, remain important for many users of height systems
- Standard optical levelling is expensive, laborious and time-consuming... in addition, it is difficult in remote and mountainous areas and the systematic errors grow very quickly over large distances (allowable misclose, need for orthometric corrections)

Conclusions (2)

- On the other hand, ellipsoidal heights from GNSS can be obtained quickly and inexpensively, and converted to physical heights using geoid models (e.g. EGM2008)
- High expectations of continued improvement in determination of global and regional geoid models (e.g. EGM2008 has a uncertainty of 10 cm at best (Pavlis 2008))
- To transition to using GNSS to derive physical heights we need to ensure we have accurate geoid models with rigorous uncertainty

Conclusions (3)

- The gravity field model information derived from CHAMP, GRACE and GOCE has advantages such as global consistency, high accuracy geoid height, etc ... although over wavelengths of 100km or more
- Fine resolution geoid information can be derived from the processing of airborne, terrestrial and ship gravity data
- The challenge is how to best integrate this data to develop a geoid model with uncertainties that meet user requirements (e.g. 1 cm, 3 cm, 5 cm?)

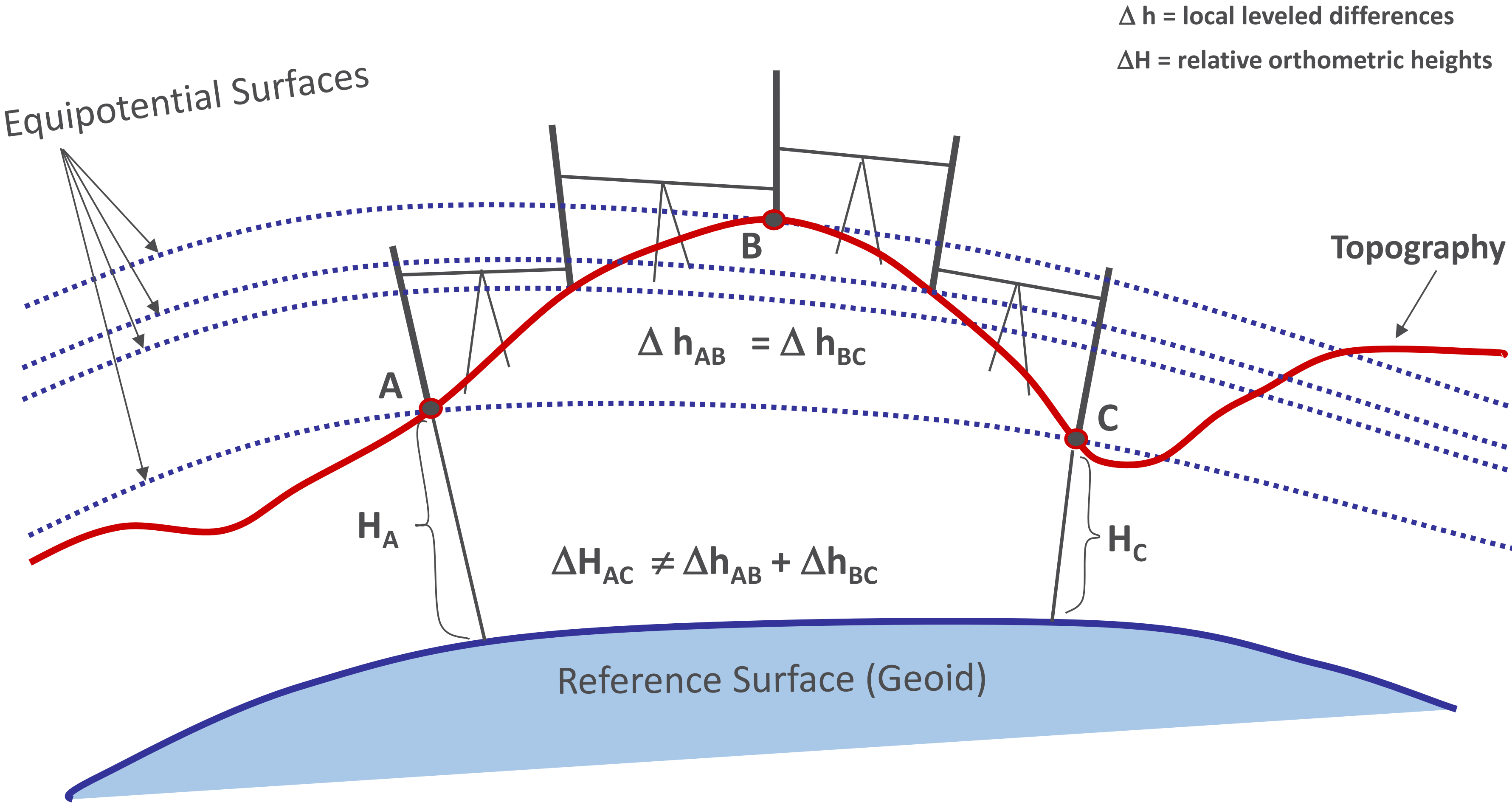
Discussion / Questions

Discuss the heighting requirements of Pacific Island nations

- What heighting data is available?
- What needs to be done to make the data ready?
- What can we do to help?
- …

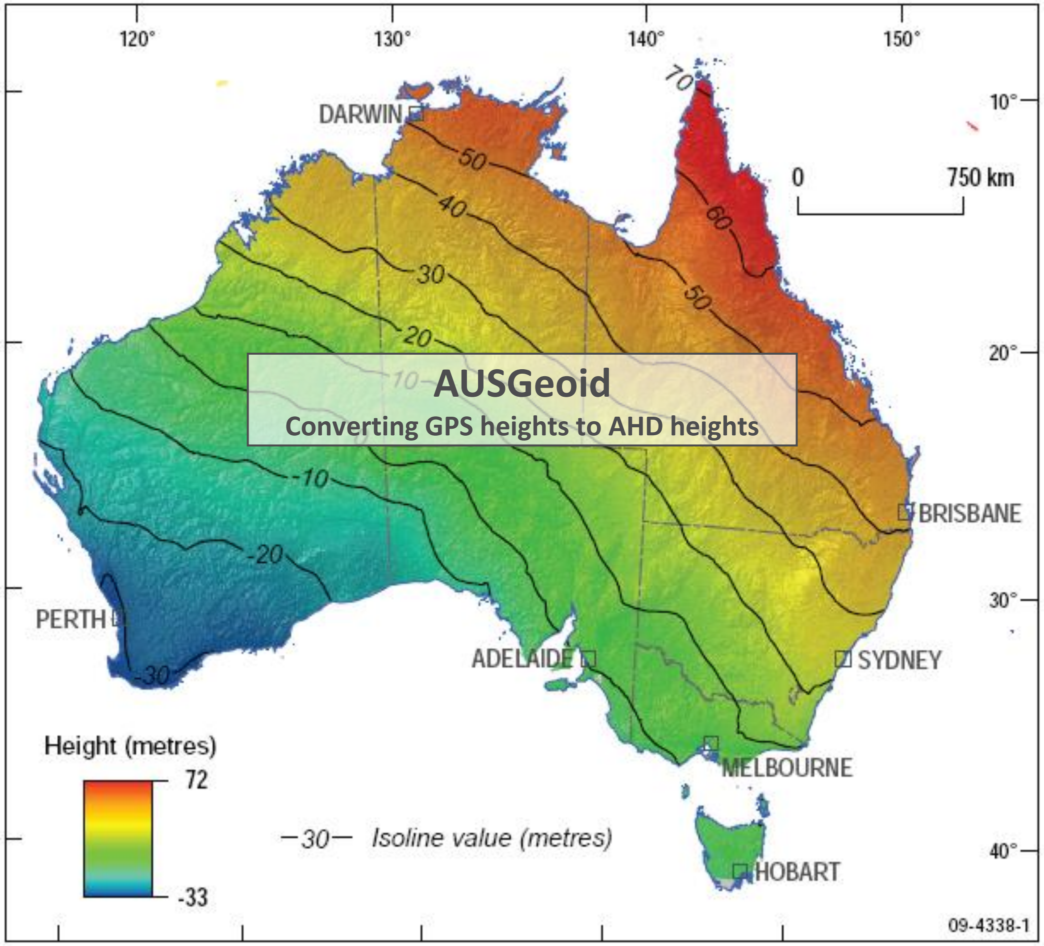
GNSS on tide gauges

Levelled height vs. orthometric height



Observed difference in orthometric height, ΔH, depends on the leveling route.

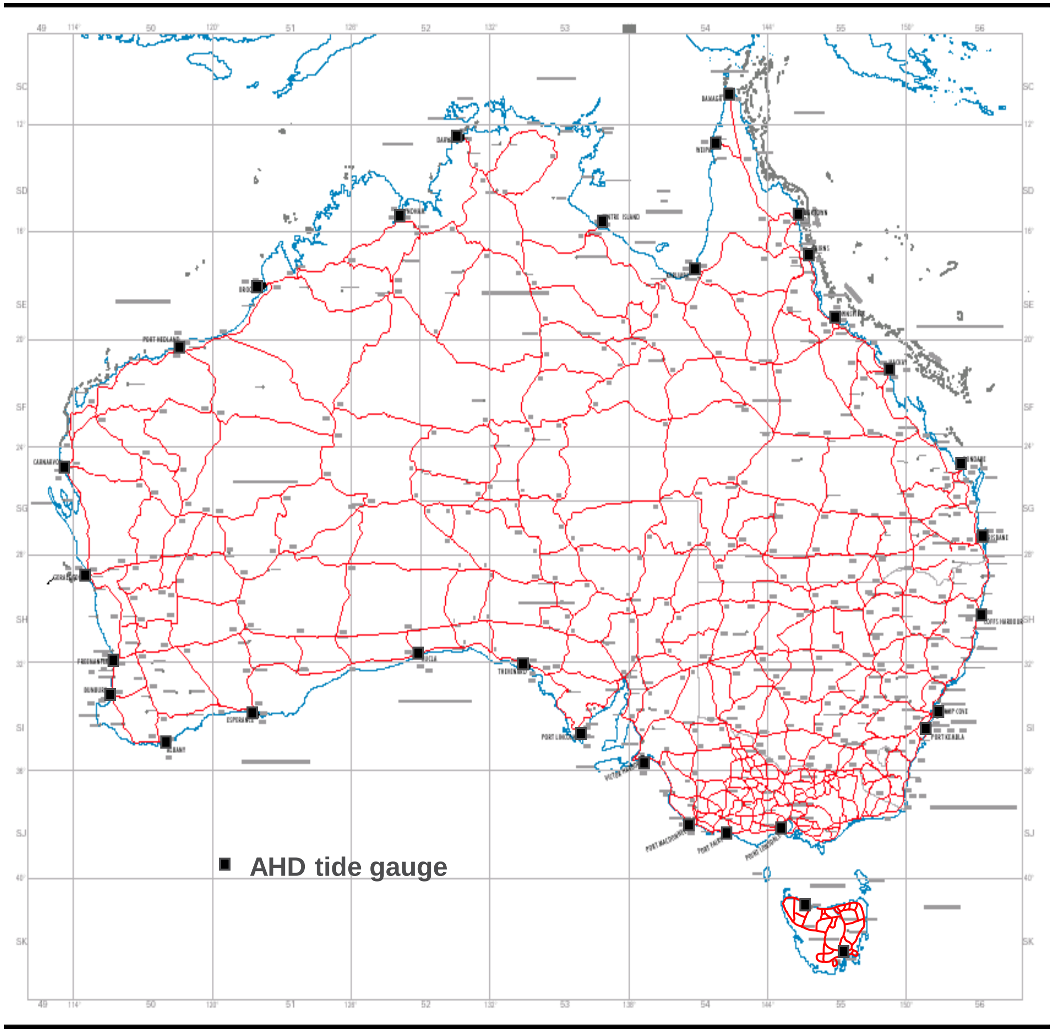
Dan Roman, 2007



AUSGeoid

Converting GPS heights to AHD heights

What is the AHD?



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Orthometric surface
i.e. based on gravity

Mean sea level value observed at 30 tide gauges from 1966-1968 set to 0.000 m AHD

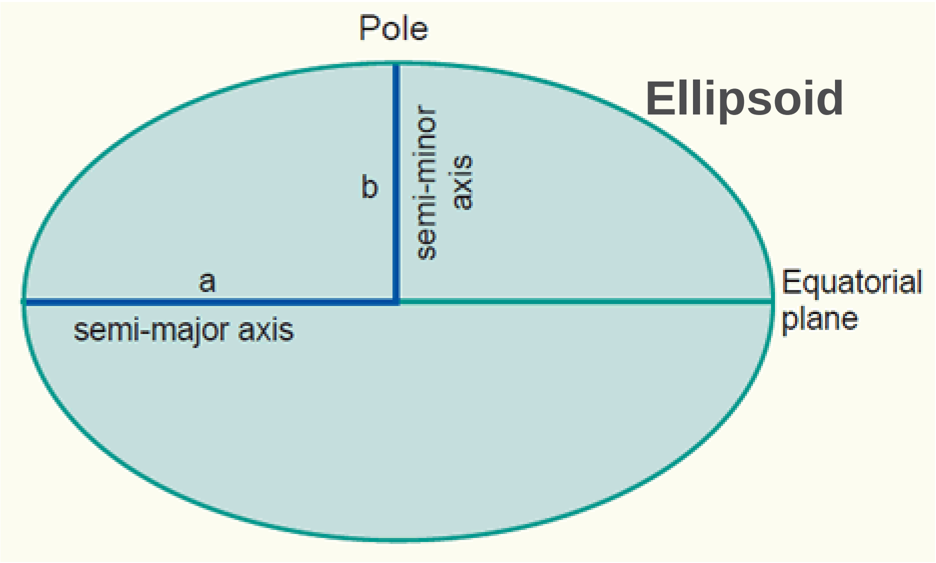
Over 200,000 km of levelling was performed to transfer heights relative to mean sea level across the country

The problem

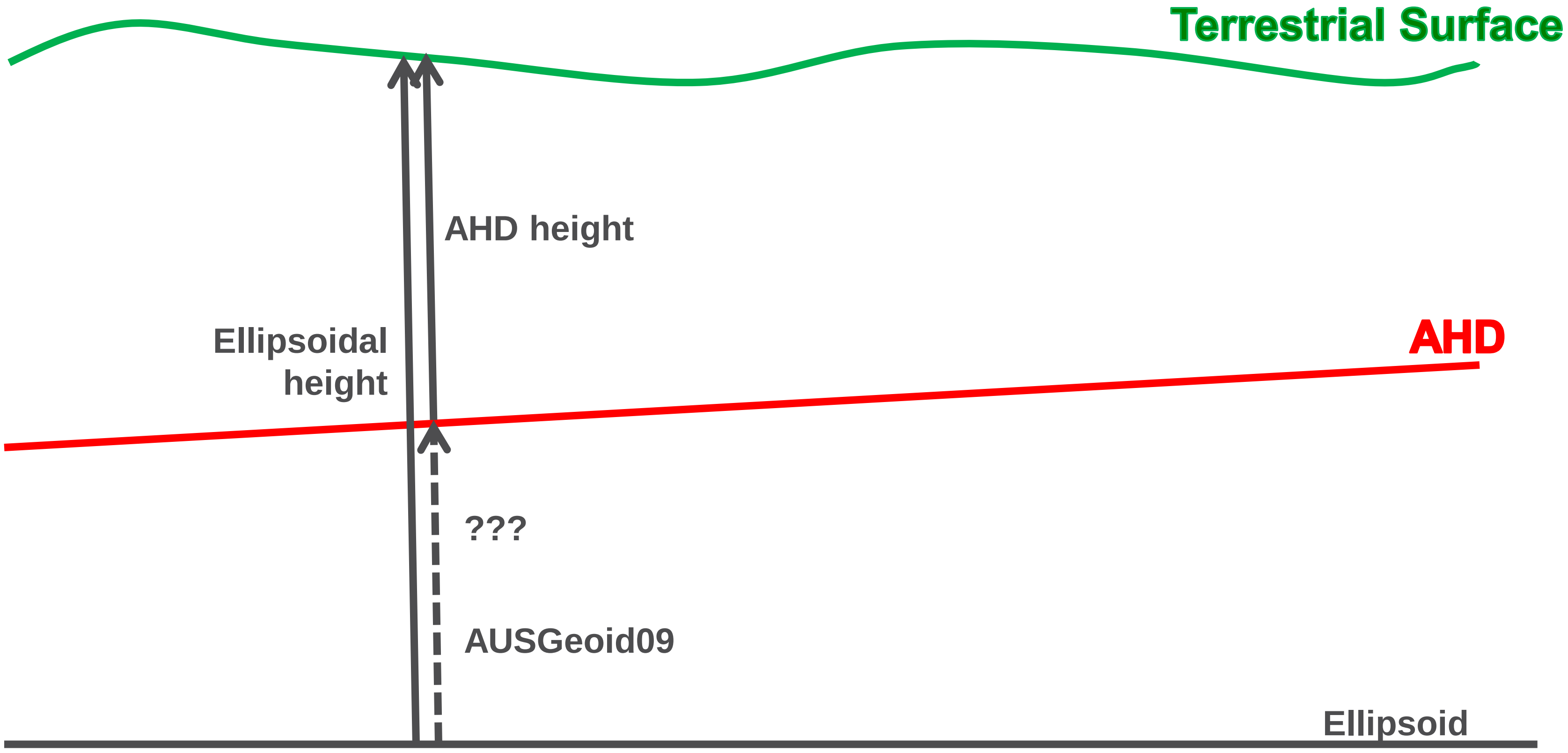
GNSS receivers are now one of the most popular ways to capture positioning data

GNSS **DOES NOT** provide heights relative to mean sea level / AHD

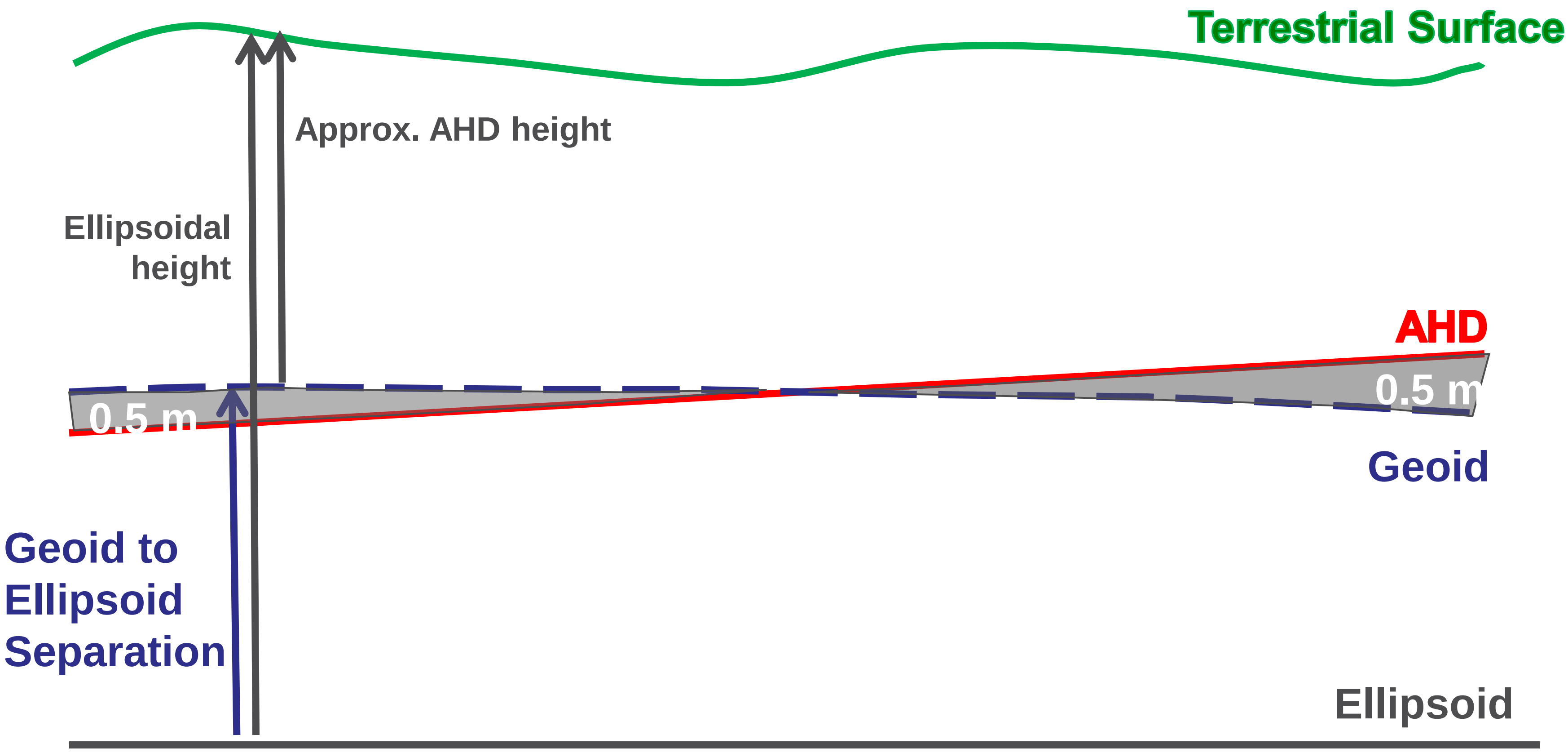
GNSS receivers provide you with a height above the ellipsoid



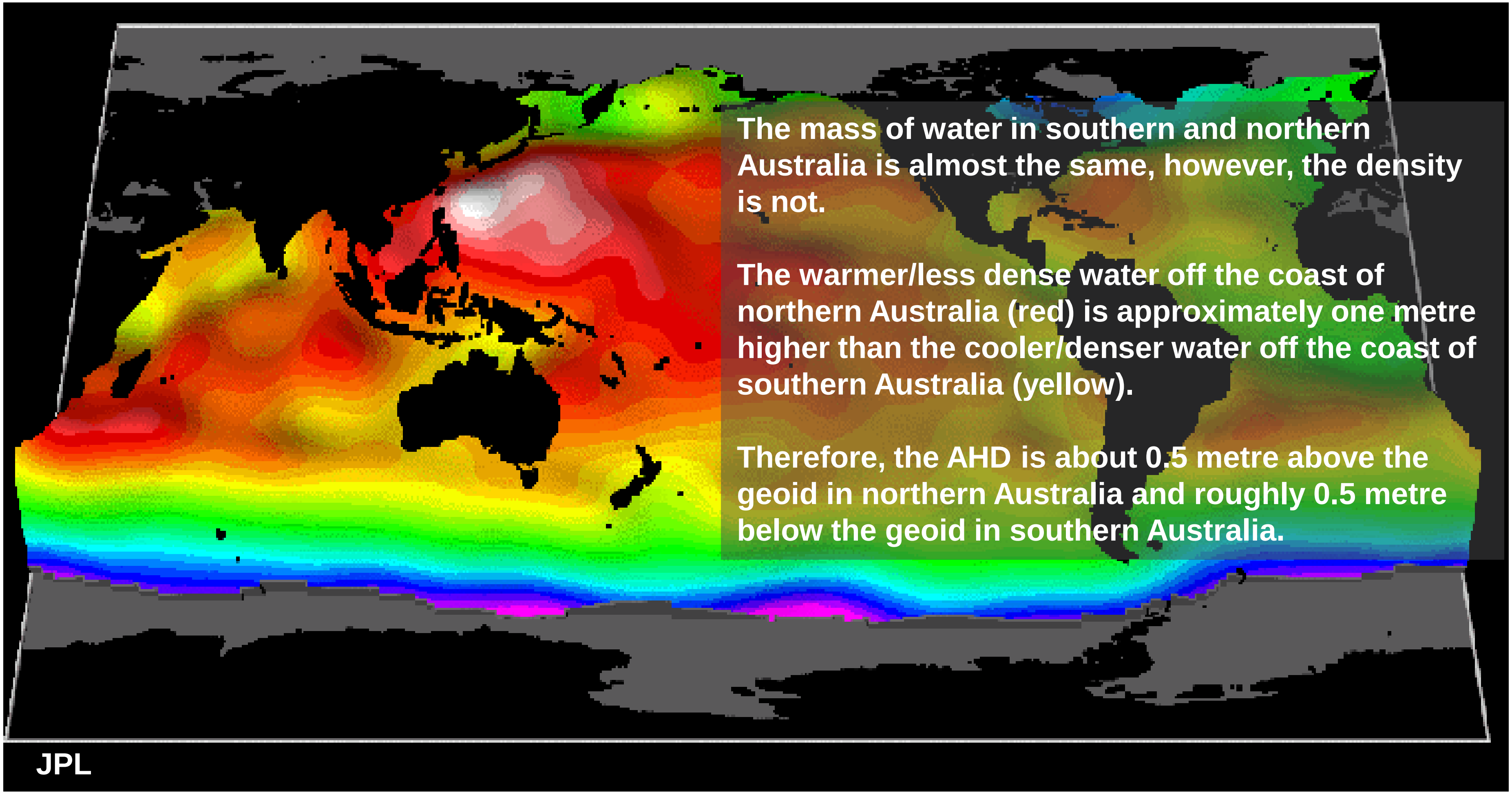
GPS doesn't provide AHD heights



Previous AUSGeoid models



The cause of the offset – Primary



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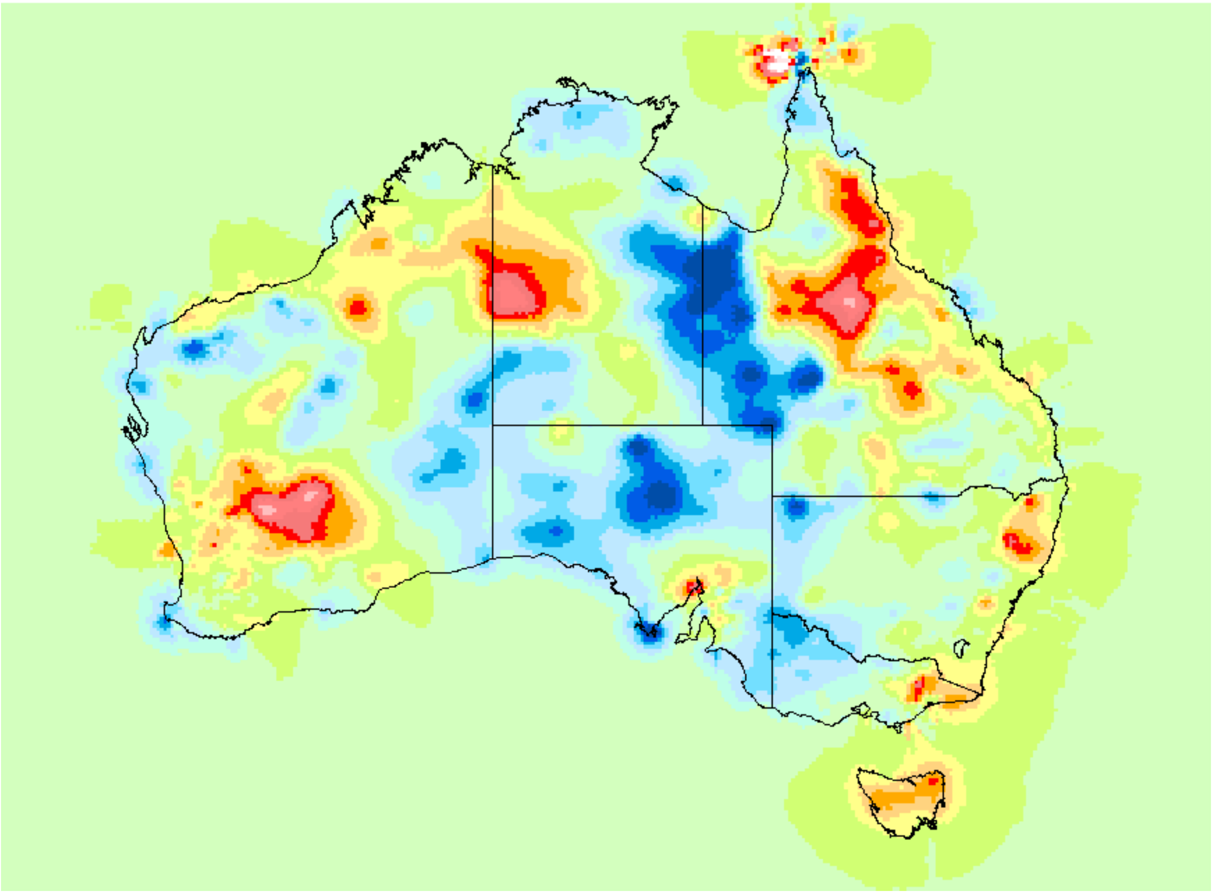
Therefore, the AHD is about 0.5 metre above the geoid in northern Australia and roughly 0.5 metre below the geoid in southern Australia.

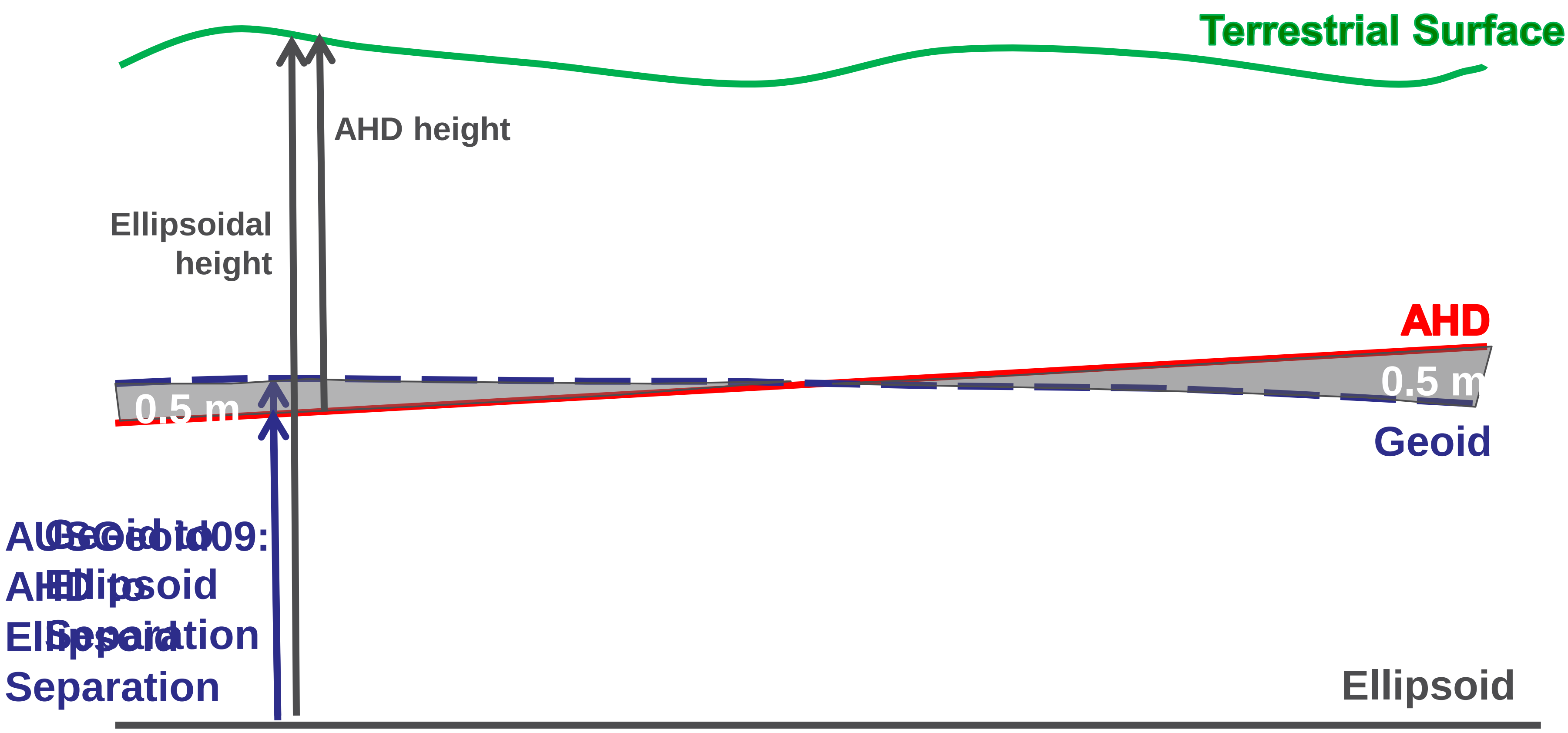
The cause of the offset – Secondary



removing the trend in x and y reveals secondary sources

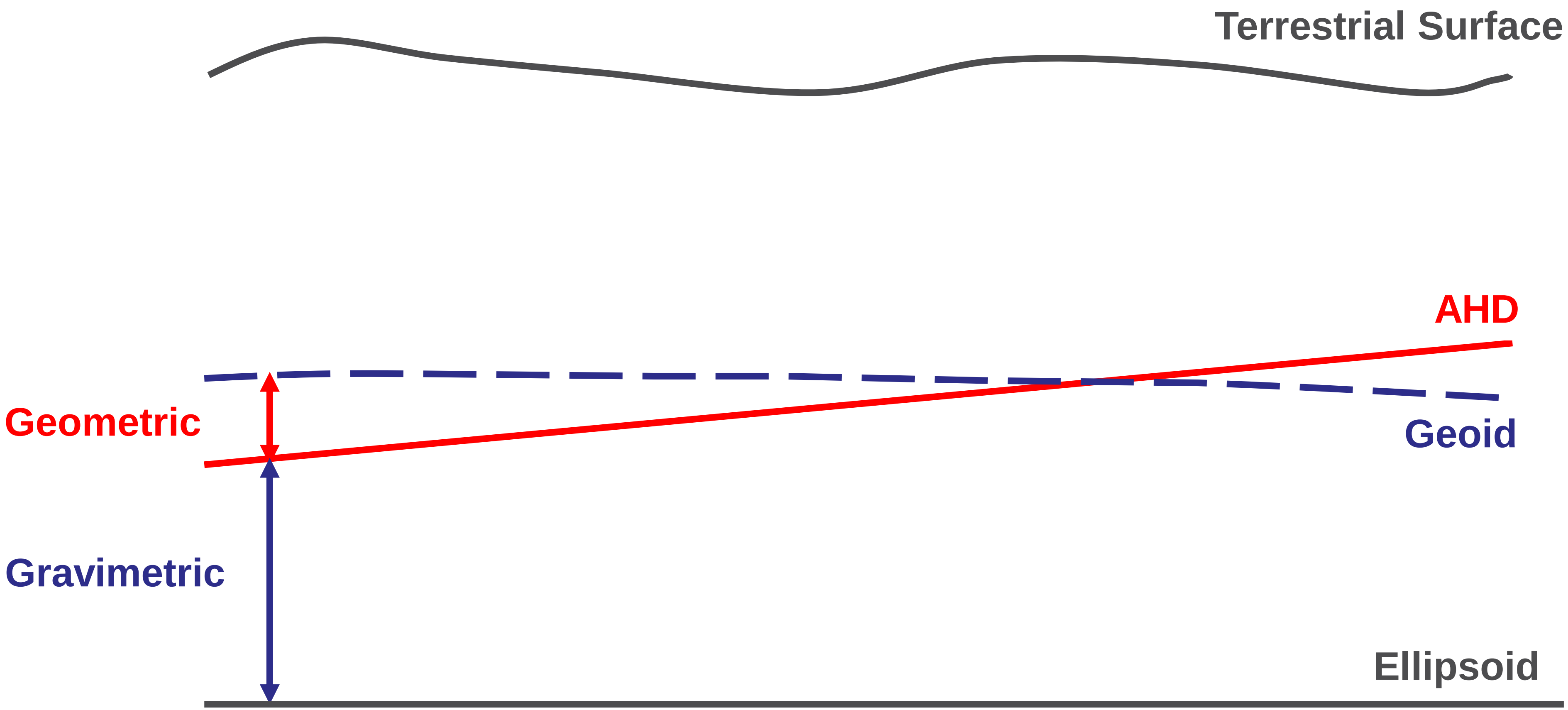
1. quality of the, mainly third-order, spirit levelling observations
2. neglect of observed gravity corrections to the spirit-levelling observations.
3. GNSS heighting errors caused by metadata errors.

AUSGeoid09: similar yet different



AUSGeoid09 is gravimetric + geometric

The gravimetric and geometric (AHD to geoid offset) components are combined into a single national grid of ~2 km resolution.



Gravimetric Component

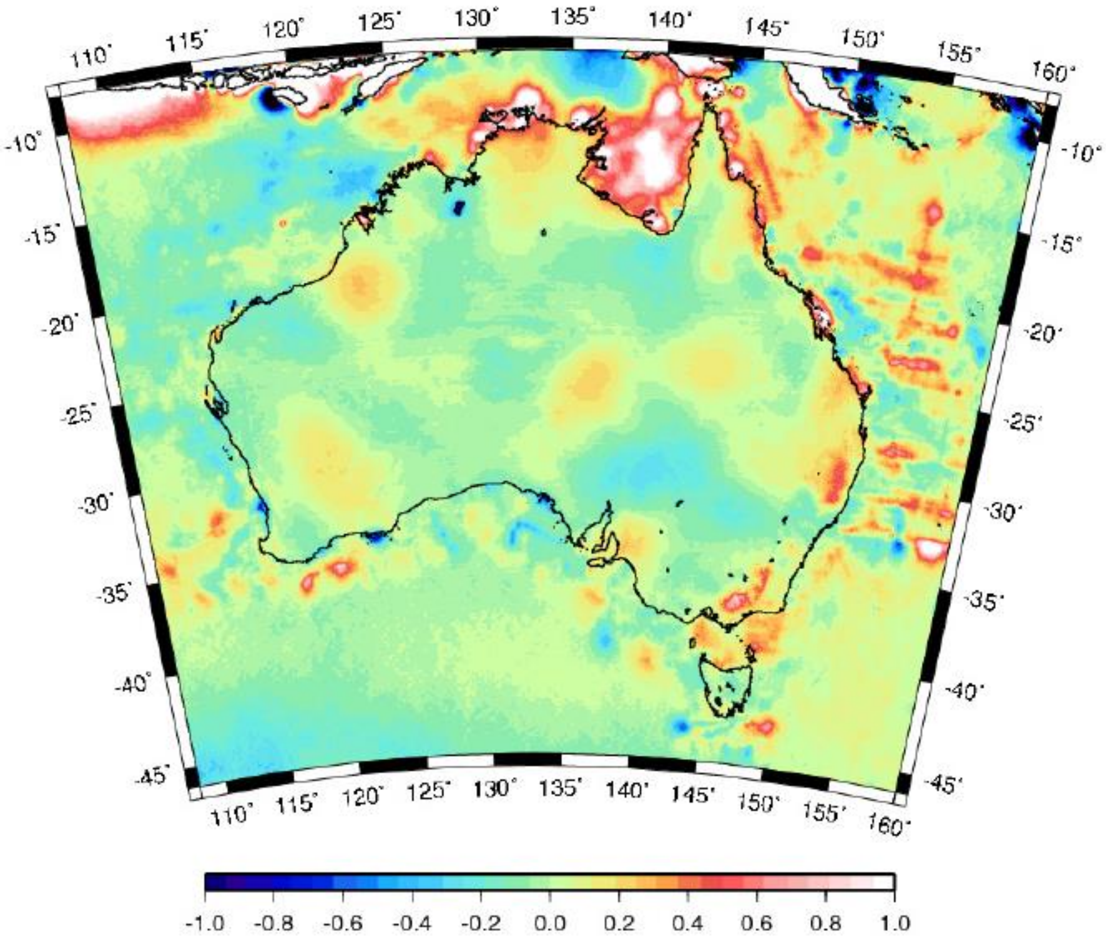
Work undertaken by Will Featherstone from Curtin University

Spherical harmonic synthesis of

- Earth Geopotential Model 2008 (EGM2008)
- 1.3 million points from Geoscience Australia’s land gravity database

Gravimetric Component

Claessens et al, Newton's Bulletin, 2009



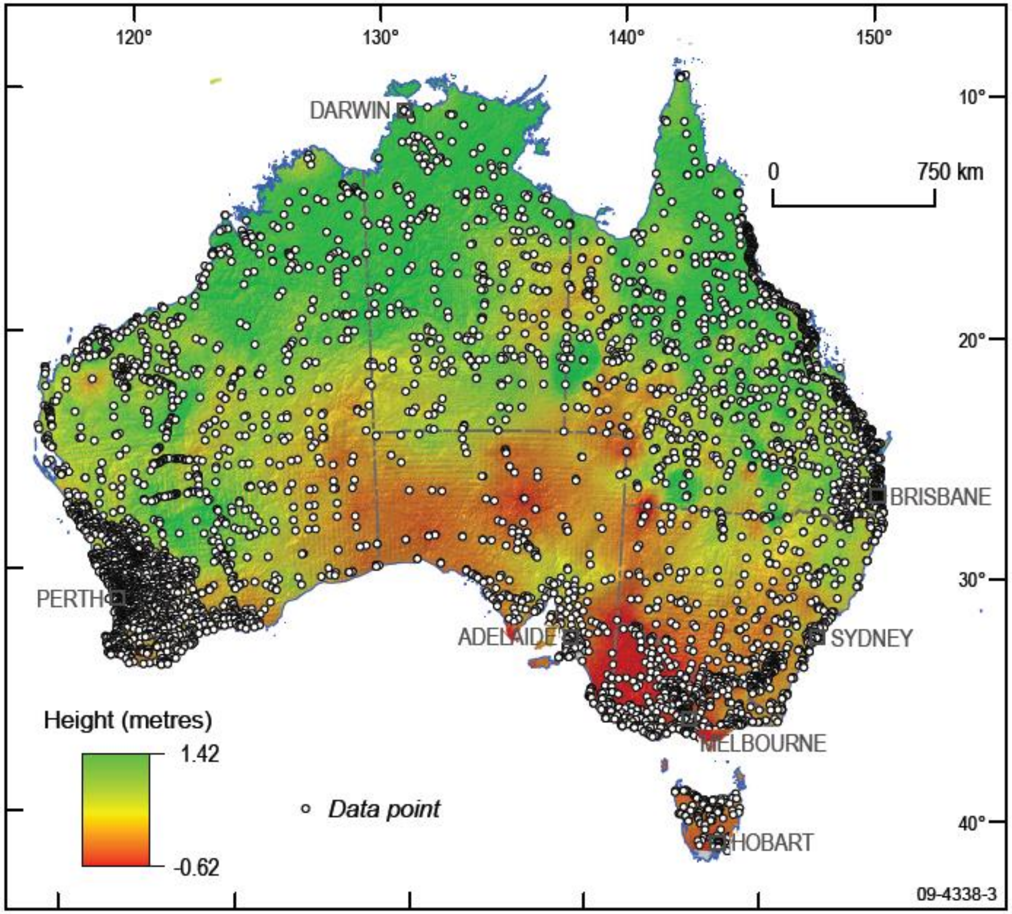
Comparing AUSGeoid98 and AUSGeoid09 gravimetric models

Major improvements from GRACE data

Removed long wavelength anomalies

Removed some terrain modelling errors of AUSGeoid98 in mountainous regions using new version of 9" DEM

Offset between AHD and the gravimetric geoid



Offset between gravimetric geoid and AHD computed at 6871 pts across Australia.

Linear Least Squares Interpolation used to compute the gravimetric geoid to AHD Offset at 1' interval across Australia.

AUSGeoid09

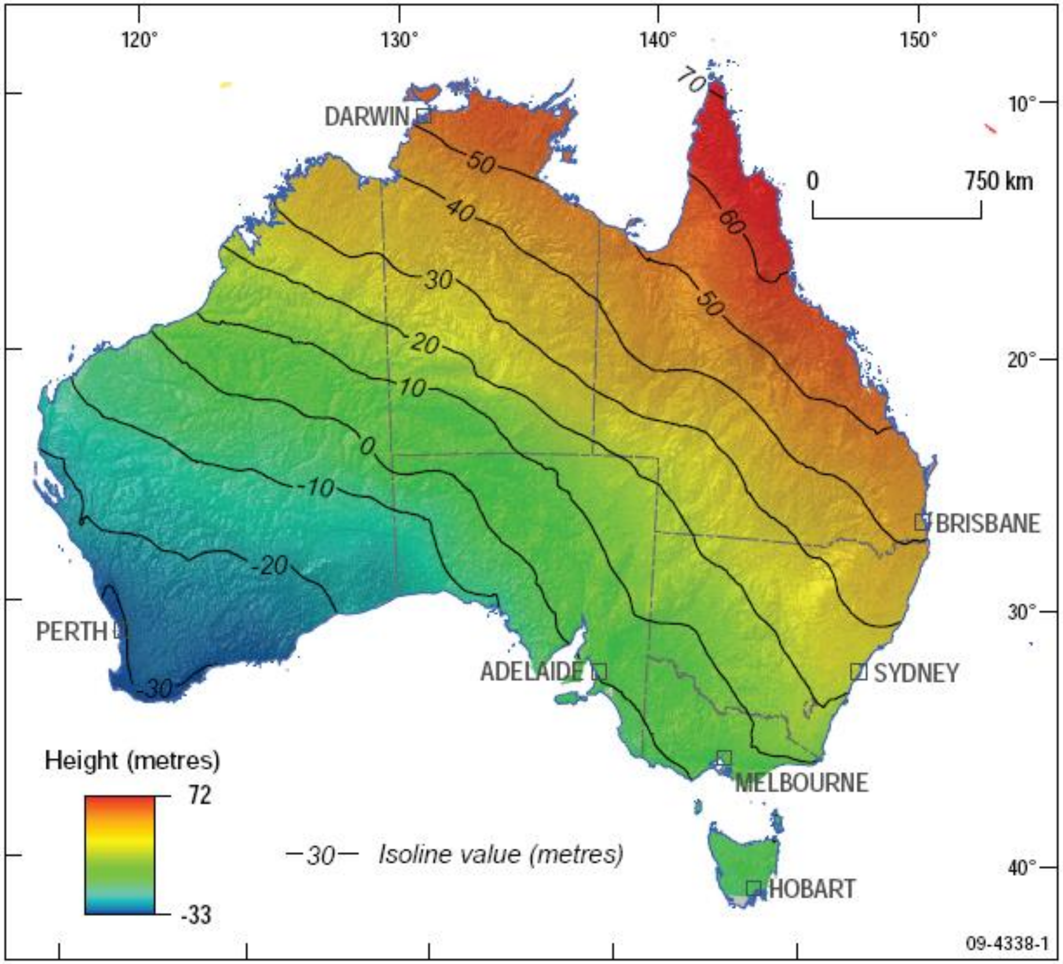


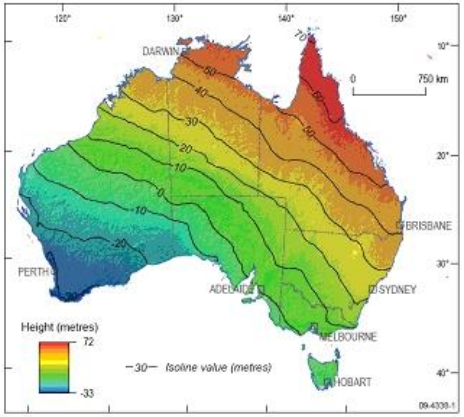
Figure depicts the offset between the ellipsoid and AHD

CAUSE:
AHD is based on gravity
Ellipsoid is purely mathematical

The higher mass value in NE Australia causes larger geoid values than in SW Australia.

Caused by crust thickness, crust type, magma distribution etc.

AUSGeoid09



AUSGeoid09 is a 1' by 1' (approximately 1.8 km) grid used to transfer heights between the ellipsoid (GDA94) and the Australian Height Datum (AHD). Unlike previous versions of AUSGeoid ('93/'98), AUSGeoid09 provides users with the height offset between the ellipsoid and AHD as opposed to the ellipsoid and the geoid.

Use the tools provided below to convert your data interactively (left tab) or submit a file to process multiple points at once (right tab).

AUSGeoid09 Version Control

The version of AUSGeoid09 currently in use on this website is:

Version: AUSGeoid09 V1.01
Release Date: 11 April 2011

Note: The only difference between the current version and previous version (V1.00) is a slight improvement in the accuracy of the deviations of the vertical. There is no change to the N values (ellipsoid to AHD).

Download a full history of changes in AUSGeoid09 versions.

Compute a AUSGeoid09 value on line | Batch Processing

Enter your data in the fields below in the format of decimal degrees.

AUSGeoid09 extents are lat [-8 and -46] lon [108 and 160].

GDA94 Latitude:	GDA94 Longitude:	GDA94 Ellipsoidal Height (m):
e.g. -35.12345	e.g. 145.12345	e.g. 12.345

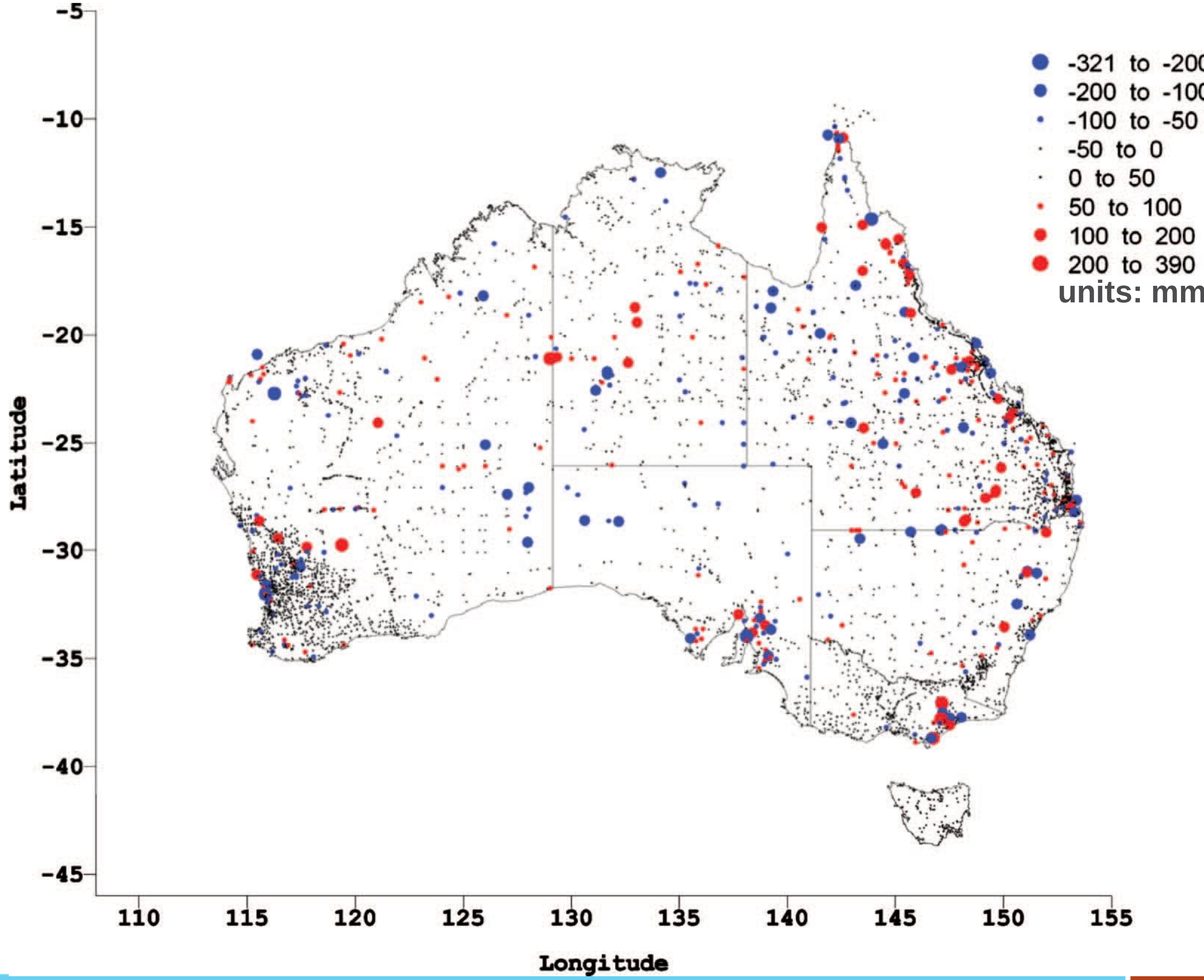
compute reset

Download AUSGeoid09 grid files

The national AUSGeoid09 grid file or components of it can be downloaded and used to compute AHD heights in real time when used in Real Time Kinematic GNSS receivers. Alternatively, a batch processing system is available above to interpolate an AHD value from the GNSS data in the office.

AUSGeoid09 data files contain data covering the Australian region. The data is available for each State and in 1:250K map sheets in unix and text format which you can use to interpolate geoid-ellipsoid separations for the positions required. You can use your own interpolation software, or you can use the interpolation software developed by Roger Fraser (Geoid_Interpolator). This can be downloaded from the ICSM website.

Misfit of AUSGeoid09

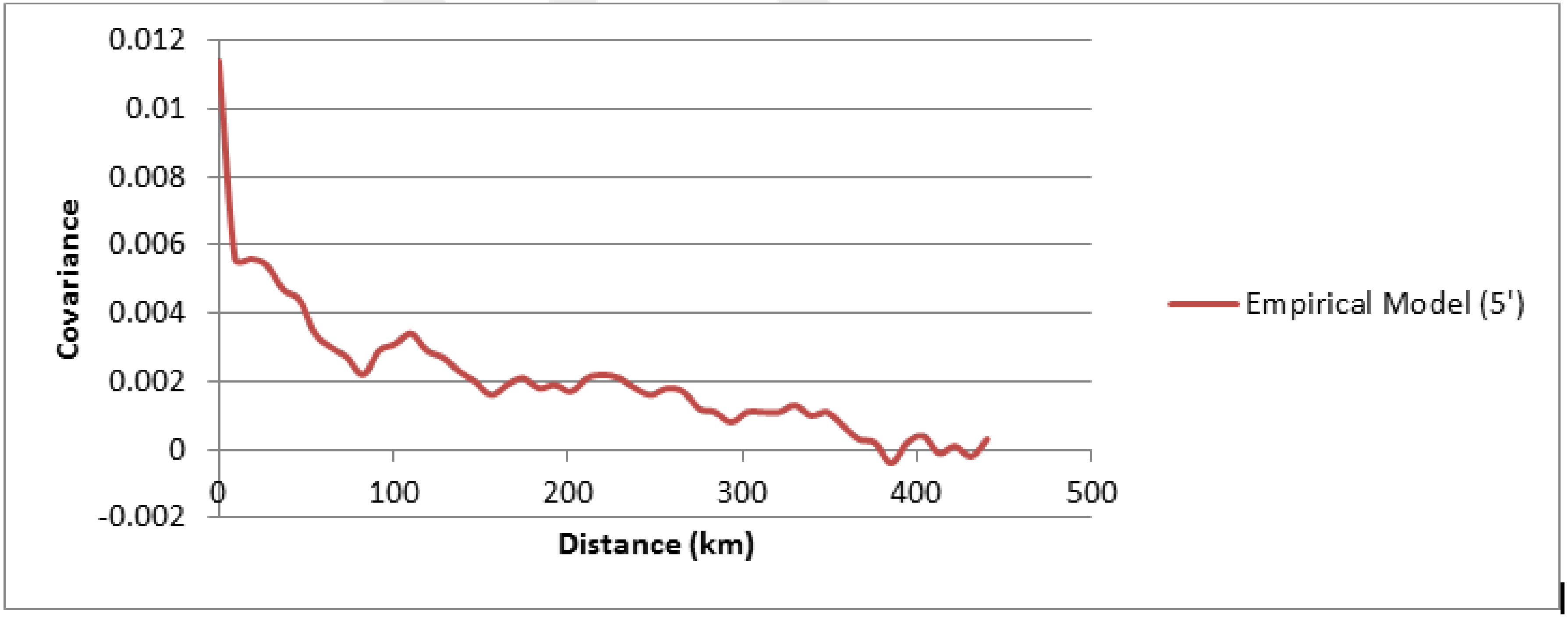


New Version of AUSGeoid

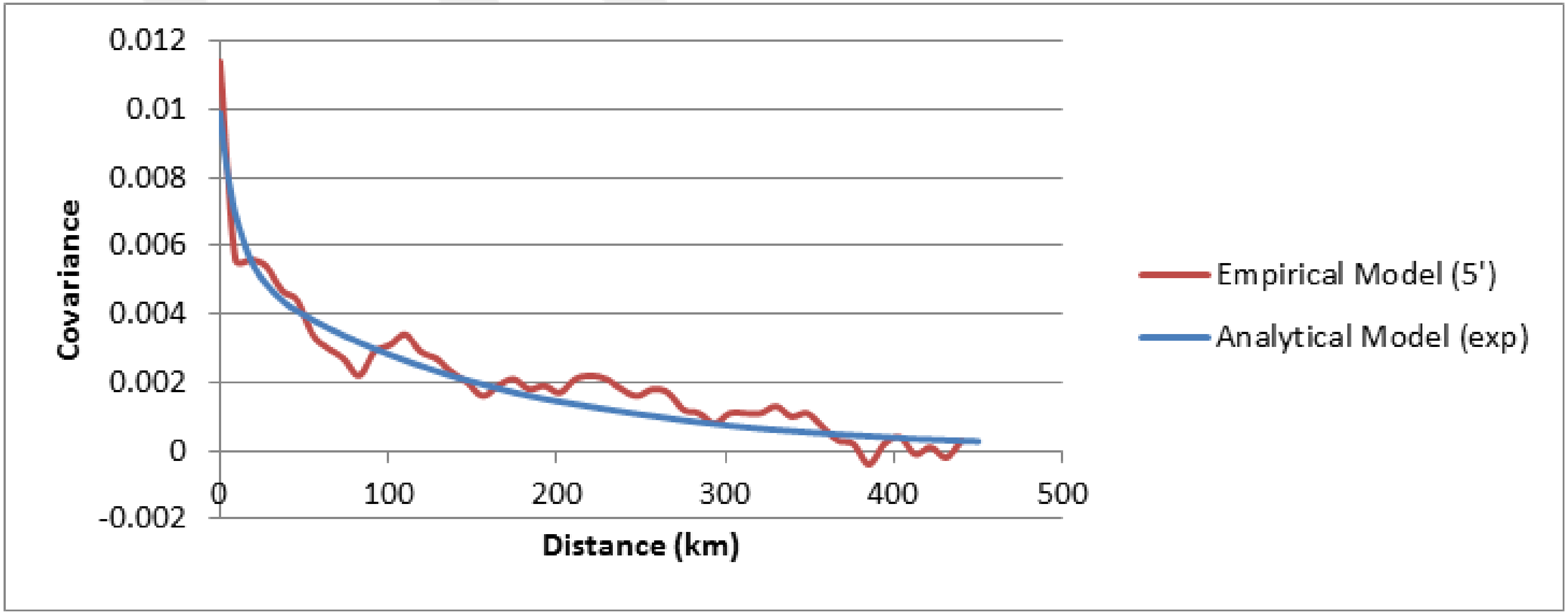
Introduction of rigorous uncertainty

- Current version has no uncertainty associated with it.
- Difficult to quantify the accuracy of the AHD and gravimetric geoid.
- Philosophy will be to adopt some of the points in the AHD as a reference standard with zero uncertainty.
- Attempt to quantify the uncertainty associated with the gravimetric geoid.
- Compute rigorous uncertainty in accordance with the "Guide to Uncertainty on Measurement".

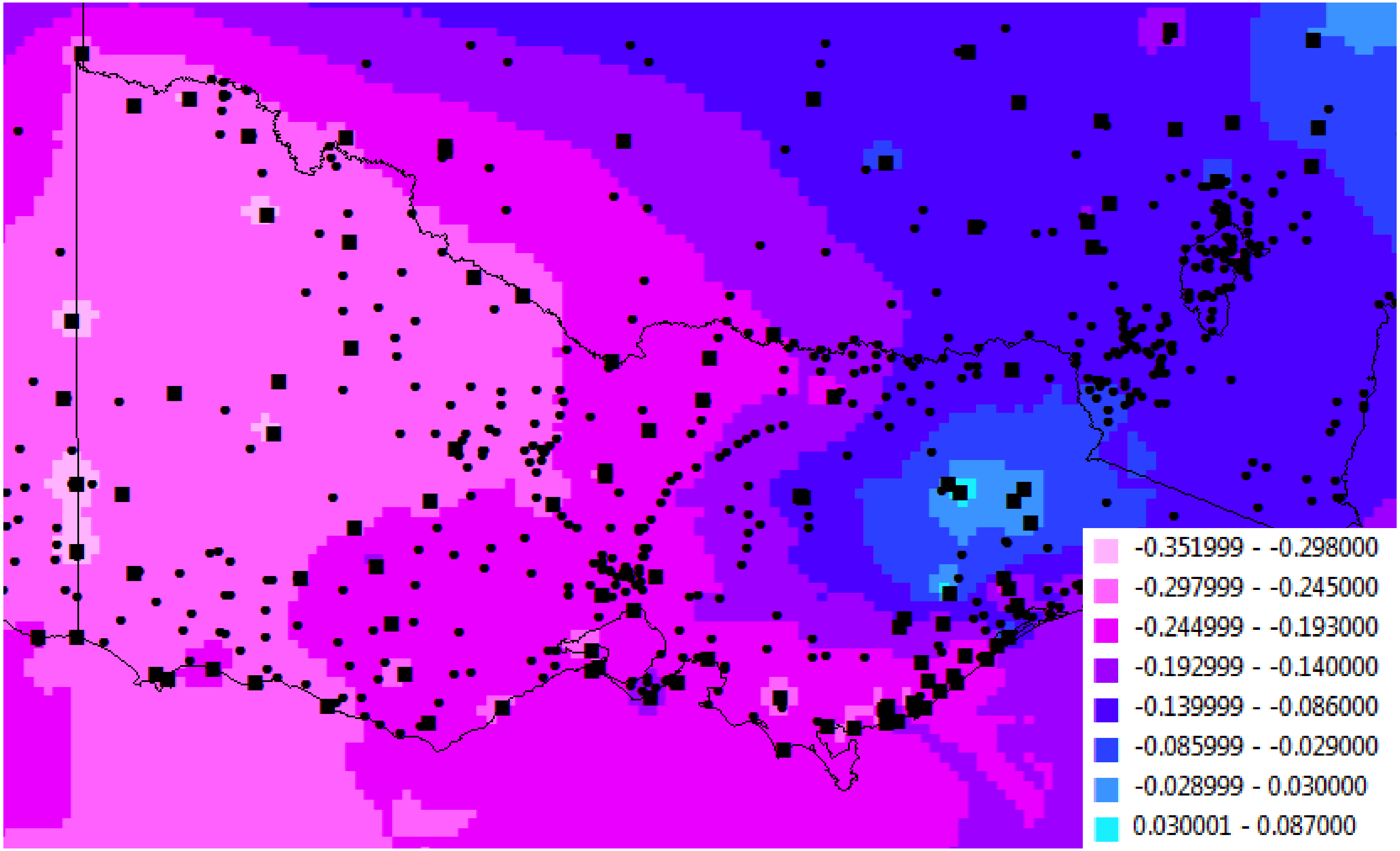
Linear Least Squares Interpolation



Linear Least Squares Interpolation

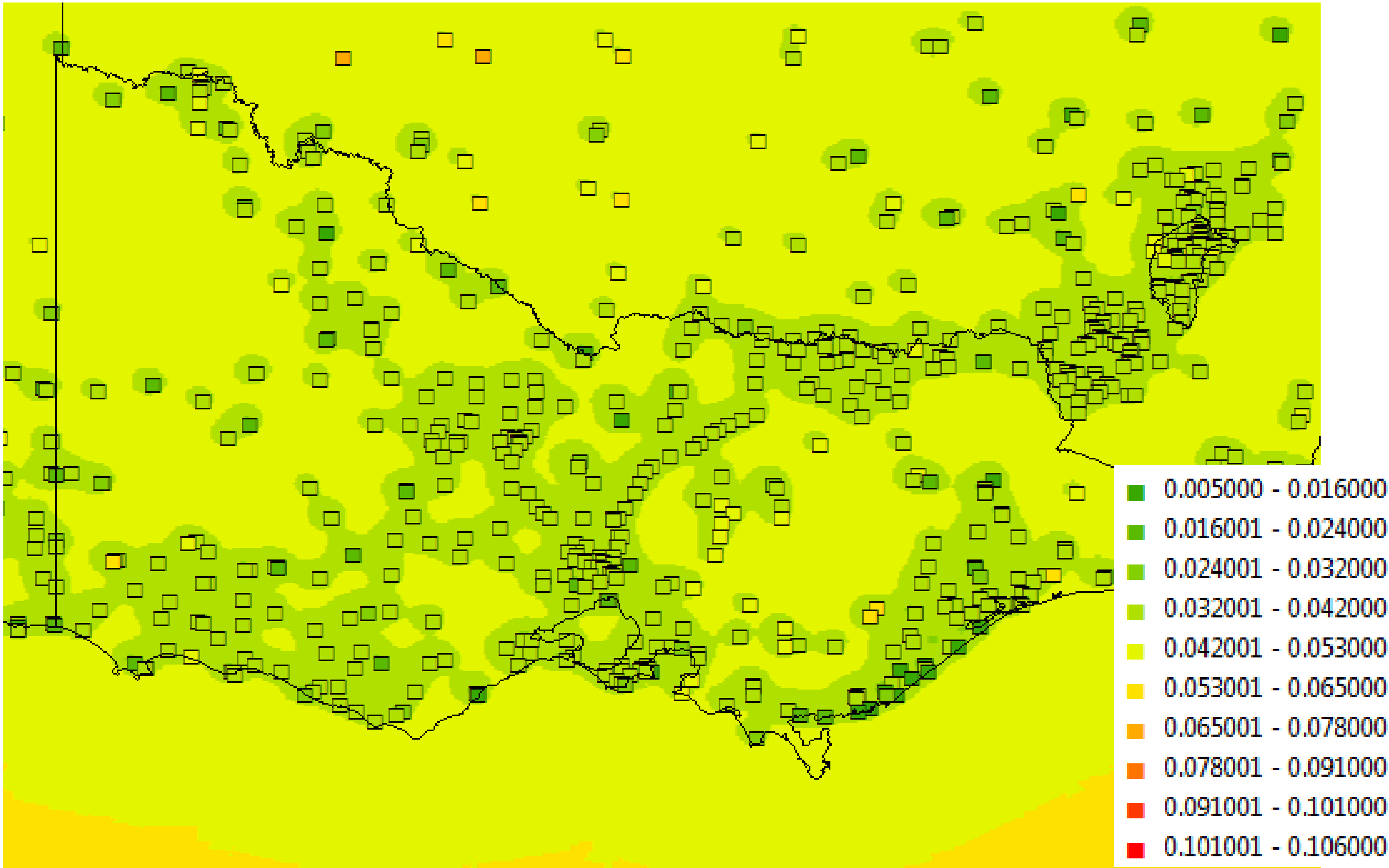


Exponential Model (geometric component)



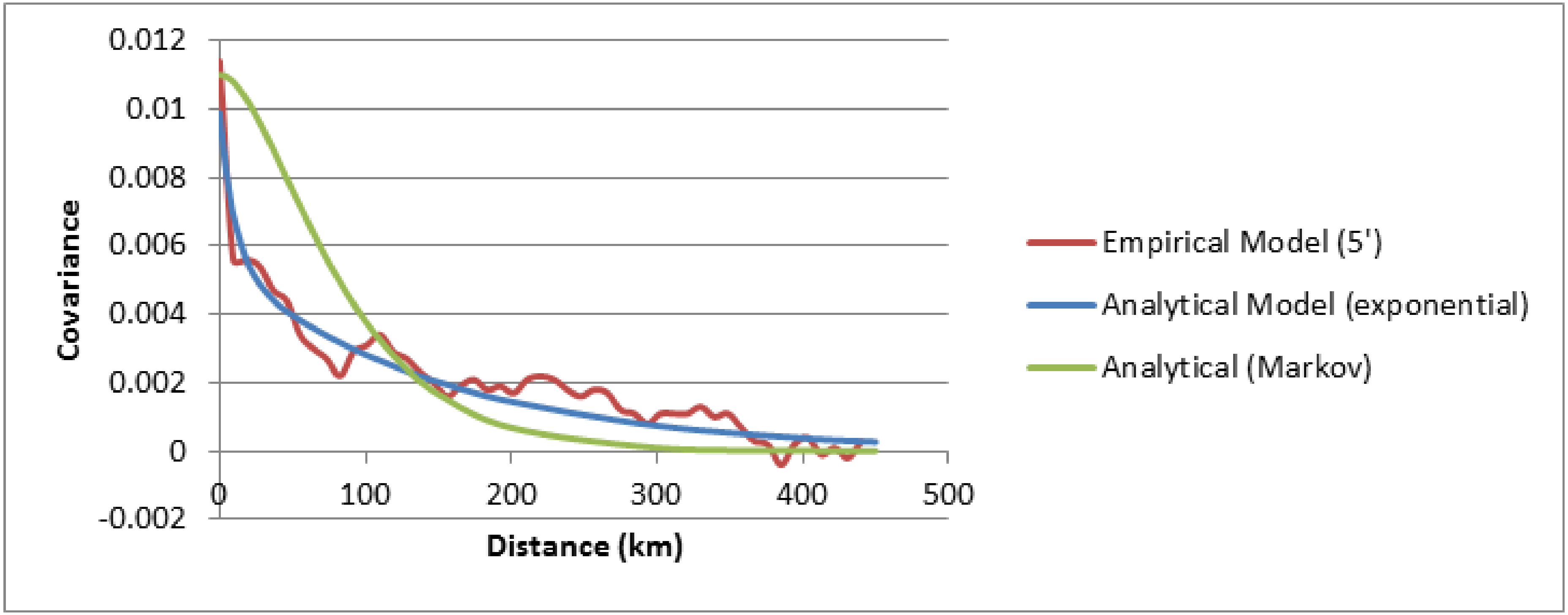
units (m)

Exponential Model (Uncertainty – 1 sigma)

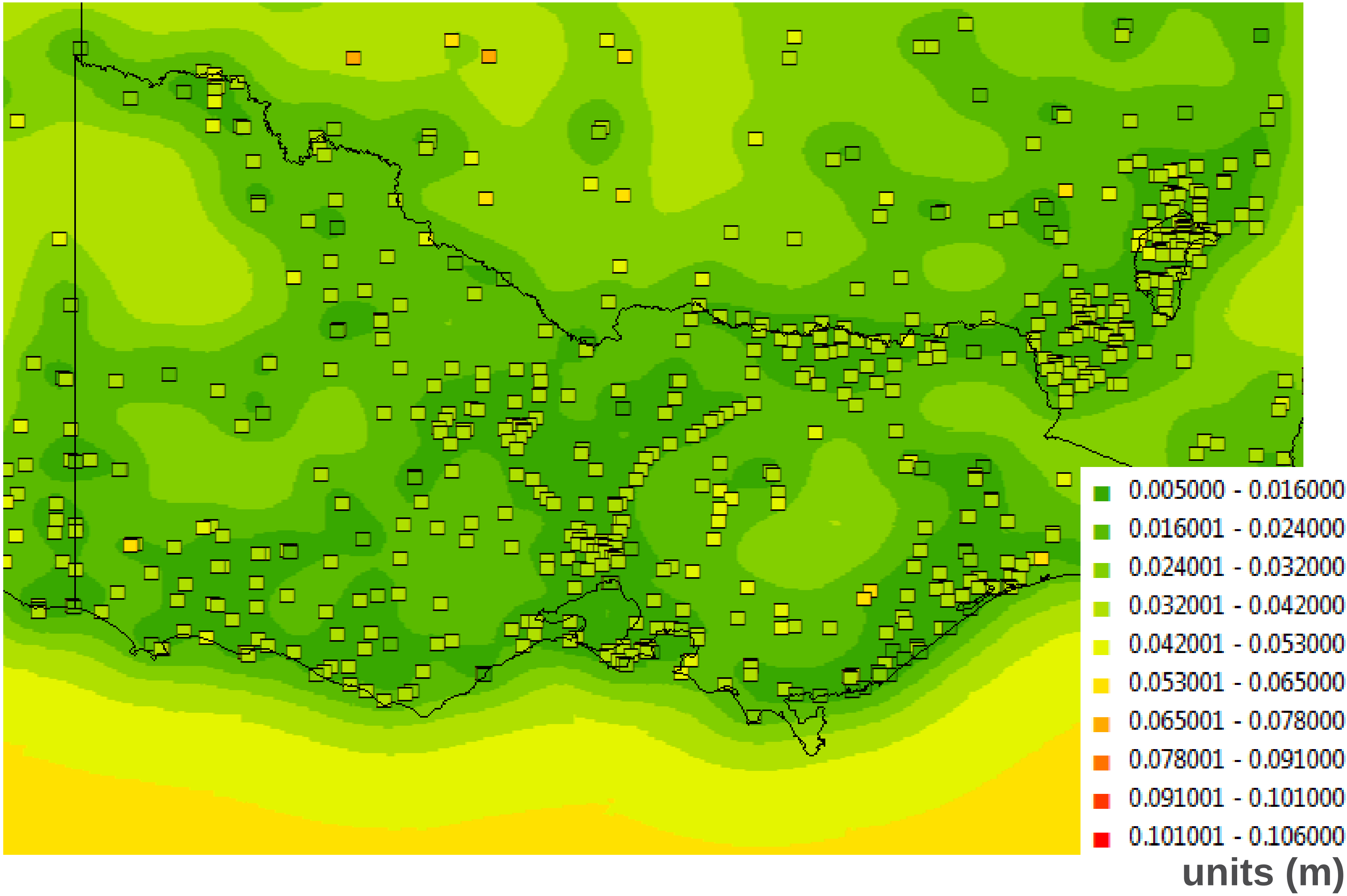


units (m)

Linear Least Squares Interpolation



Markov Model (Uncertainty – 1 sigma)



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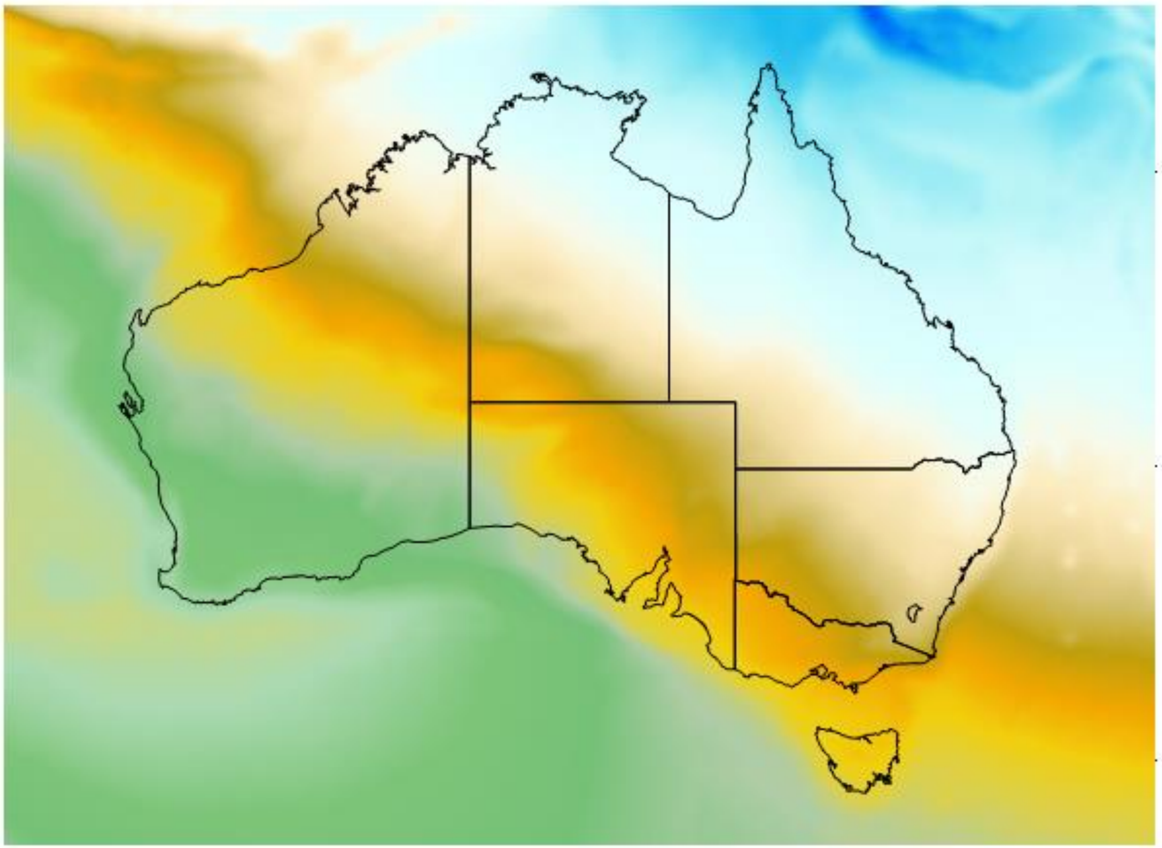
AUSGeoid Update

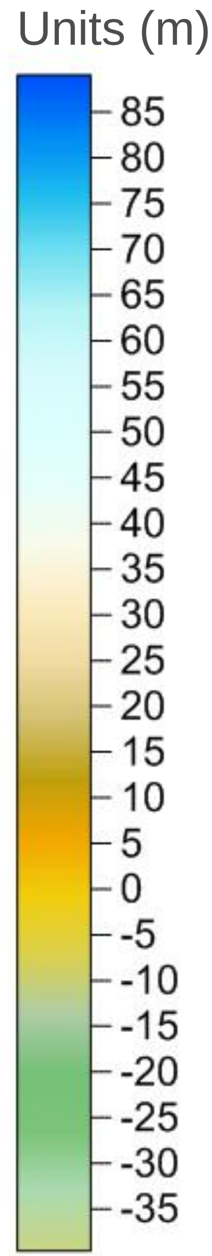
Current Status

AUSGeoid2020_BETAV0.6 is available

- 4854 collocated GNSS+AHD data provided
- ~20% provided with uncertainty
- Computes uncertainty for geometric component
  - Propagation of uncertainty of ellipsoidal height and AHD height
- Gravimetric model is still AGQG2009
  - Uncertainty of 0.036 m everywhere

AUSGeoid2020 BETAV0.6

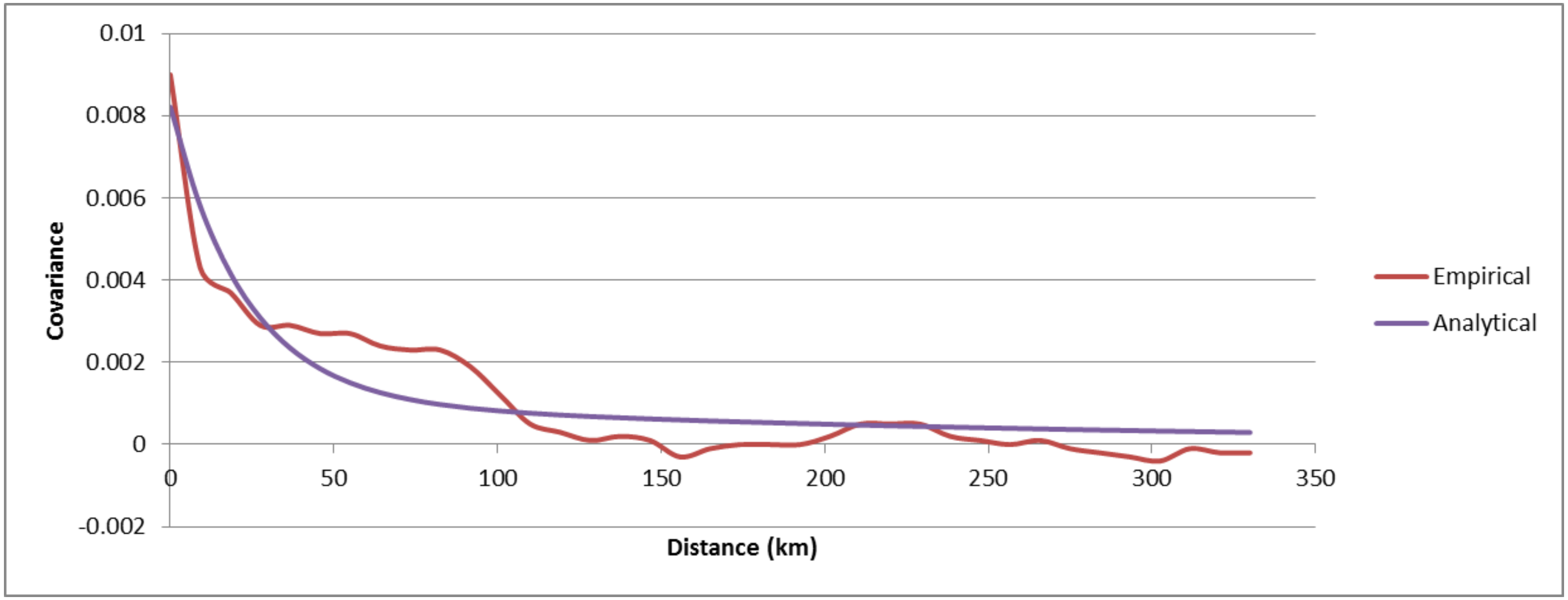




Multiple Gaussian Function Model

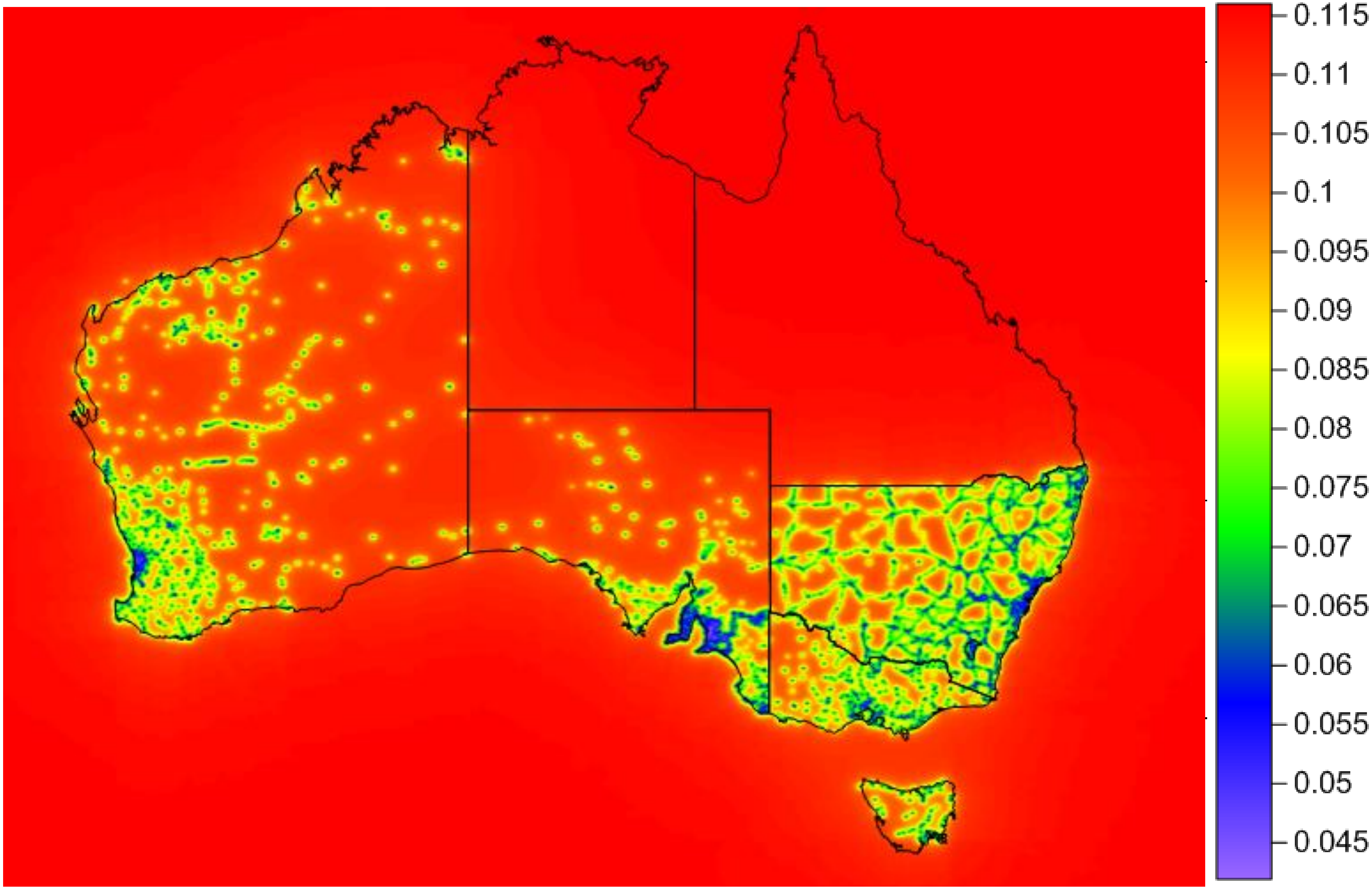
- This analytical model is the best fit to the empirical data

$$cov = \frac{2}{3}Coexp^{\left(-\frac{(d)^2}{L1^2}\right)} + \frac{1}{3}Coexp^{\left(-\frac{(d)^2}{L2^2}\right)}$$



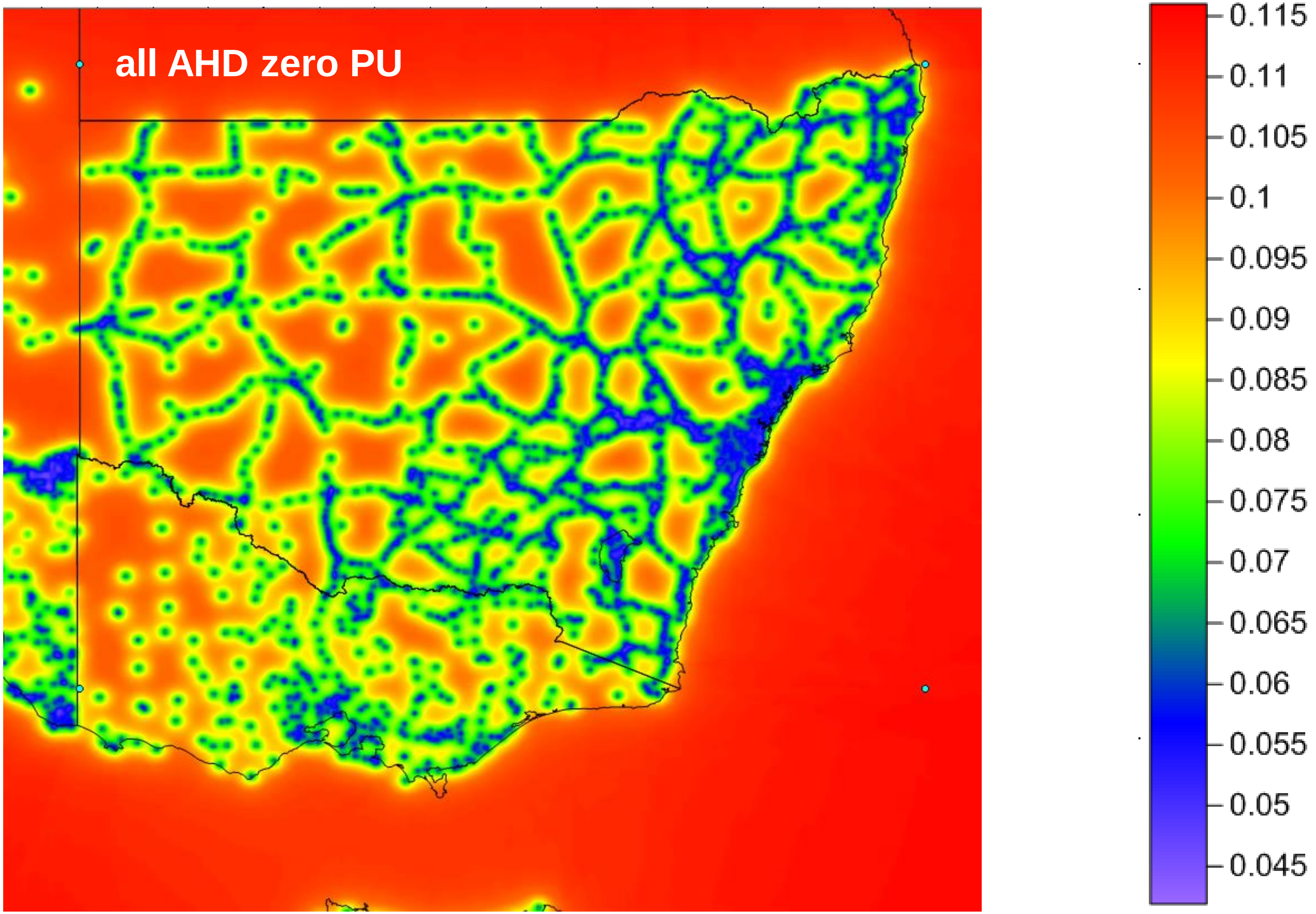
PU supplied by jurisdiction / 12 rt k from JP

Uncertainty (m) (1 std dev)

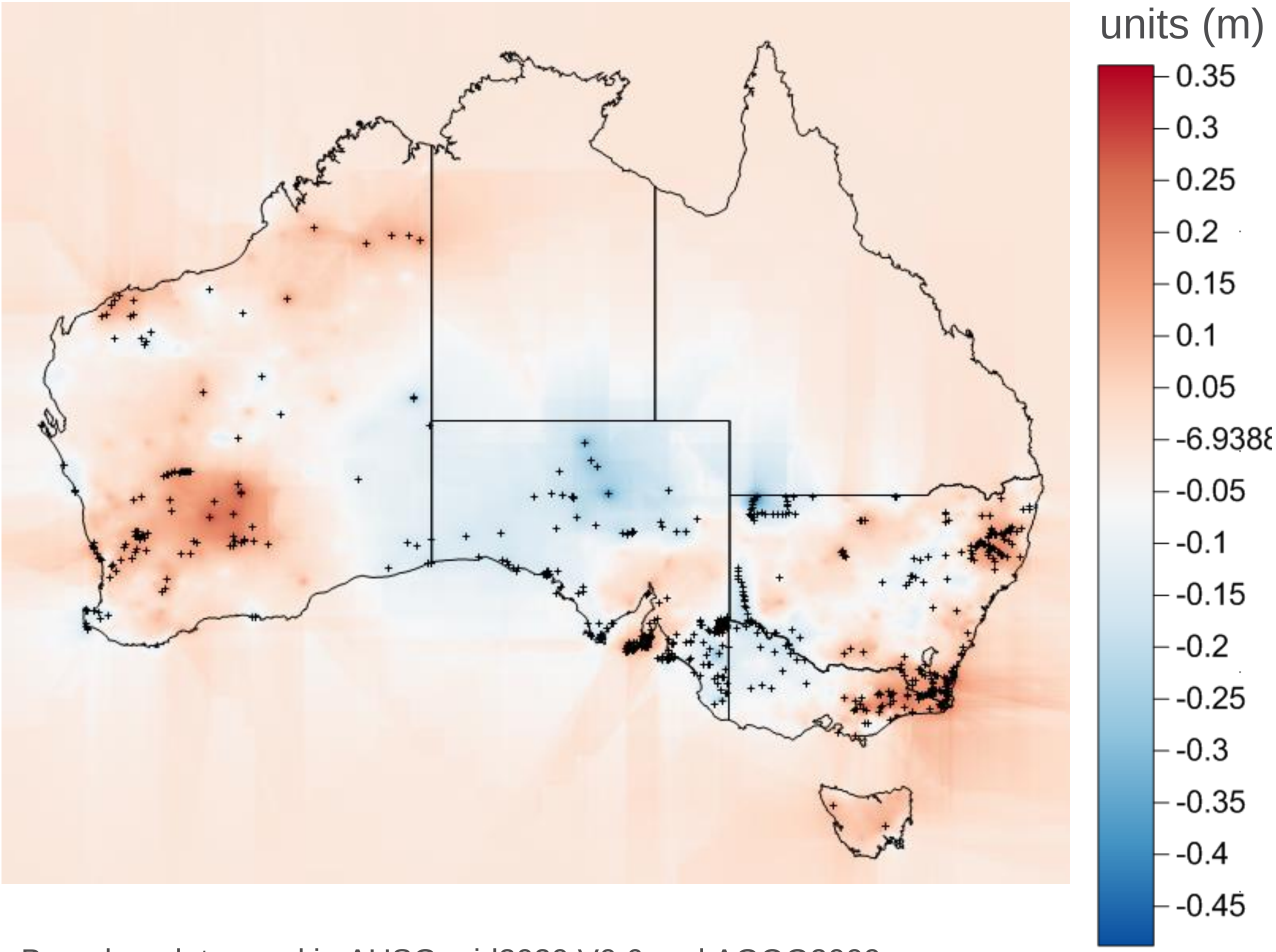


Only AHD JP zero PU vs all AHD zero PU

Uncertainty (m) (1 std dev)



Detrended offset between AHD and gravimetric geoid



removing the trend reveals:

1. Poor quality of AHD
2. GNSS heighting errors caused by metadata errors
3. Issues in AGQG2009

Based on data used in AUSGeoid2020 V0.6 and AGQG2009

Residuals bigger than 15 cm shown with +

Data available

ftp://ftp.ga.gov.au/geodesy-outgoing/gravity/ausgeoid/AUSGeoid2020_BETAV0.6/

Name	Size	Date Modified
[parent directory]		
AUSGeoid2020_BETAV0.6_high_residuals.txt	26.8 kB	10/20/16, 4:50:00 AM
AUSGeoid2020_BETAV0.6_outliers.txt	155 B	10/19/16, 5:16:00 AM
AUSGeoid2020_BETAV0.6.txt	197 MB	10/19/16, 5:16:00 AM
AUSGeoid2020_BETAV0.6_uncertainty.txt	197 MB	10/19/16, 5:16:00 AM
readme.txt	912 B	10/20/16, 4:55:00 AM

AHD Reference Standard

Australian National Levelling Network Junction Points (primary and supplementary)

- ANLN JPs have zero Positional Uncertainty (PU).
- Survey Uncertainty (SU) and Relative Uncertainty (RU) can be used to evaluate or specify the uncertainty of survey control marks relative to any AHD mark.
- However, PU can only be evaluated for those marks with a well understood connection to the ANLN.

Australian Government

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