Development of Geoid Based Vertical Datums, A New Zealand Perspective

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Land Information New Zealand

Part I – Vertical Datums and Geoids

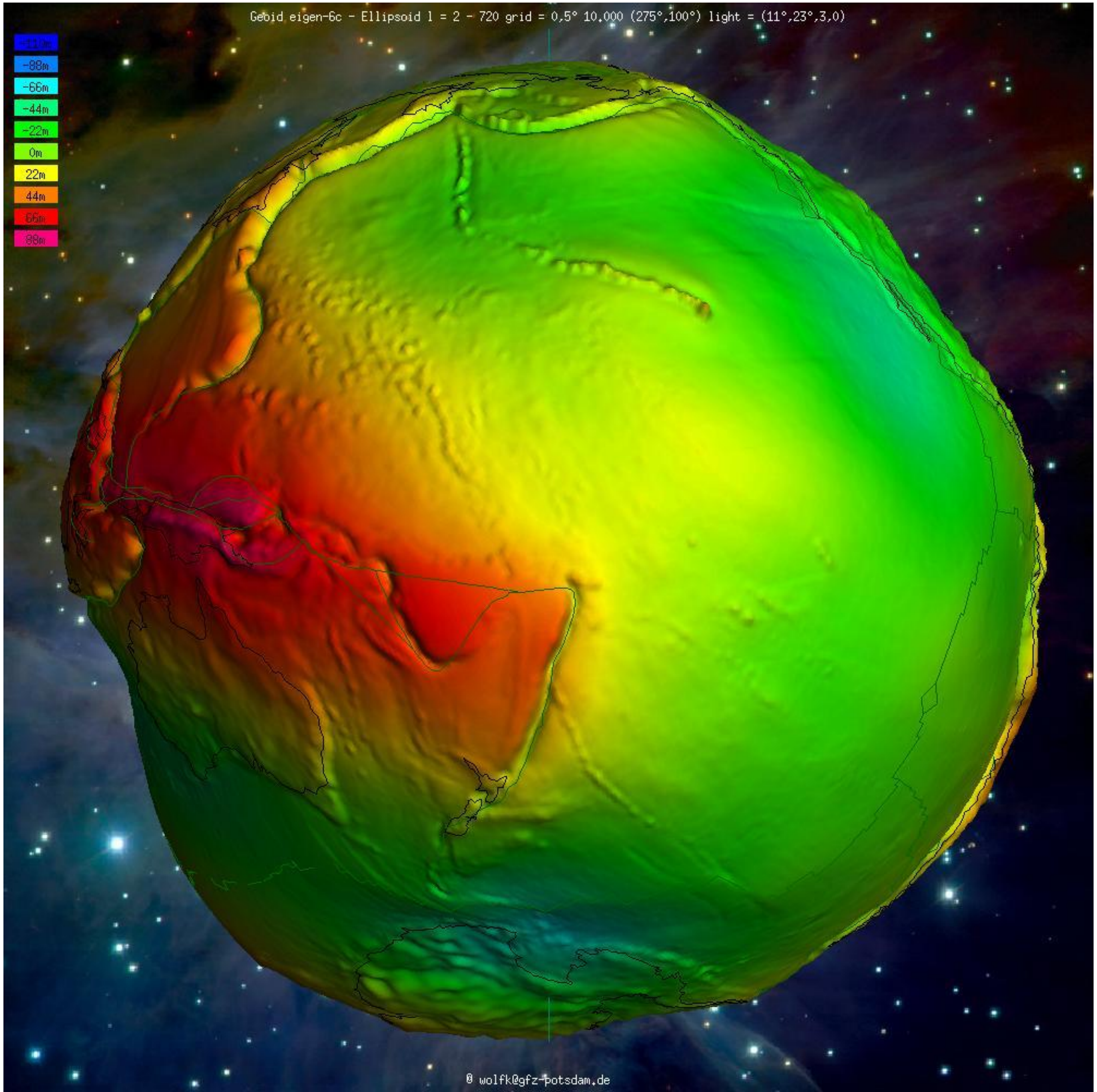
Reference Surface Selection

- Type of height being used
  - Orthometric
  - Normal-orthometric
  - Ellipsoidal
- Method of height transfer
  - Levelling
  - GNSS
- Scale of datum
  - Local vs National
- Purpose of datum
  - Mapping vs engineering

Reference Surfaces

- Physical surface
  - Frequently mean sea level
  - Fix MSL at a single point
  - Fix MSL at several points
  - Arbitrary level at a single point
- Equipotential surface
  - Geoid
  - Quasigeoid
- Geometric
  - Ellipsoid

The Geoid


Geoid eigen-6c - Ellipsoid l = 2 - 720 grid = 0,5° 10,000 (275°,100°) light = (11°,23°,3,0)
-88m
-66m
-44m
-22m
0m
22m
44m
66m
88m
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Geoid Based Datums

- Advantages:
  - No more national-scale levelling
  - Accessibility to the vertical datum using GNSS
  - Better spatial coverage of datum
- Disadvantages:
  - Low reliability in areas with poor gravity data coverage
  - Lower accuracy over short distances compared to levelling
  - Must minimise GNSS height errors (e.g. long occupation sessions, high precision post-processing)
  - Need to consider access by users without GNSS equipment

Global Geoids

- Derived from analysis of satellite measurements
- Some include surface gravity data, e.g. EGM2008
- Long wavelength (low resolution)
- Described by spherical harmonic coefficients
- Modern GGMs to very high degree & order
  - EGM96 (D/O 360) = 55 km
  - EGM2008 (D/O 2160) = 9 km
- Often sub-decimetre accuracy, but low resolution
- Most are purely satellite-based

ICGEM

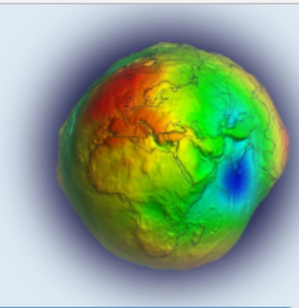
ICGEM International Center for...

icgem.gfz-potsdam.de/home

Apps | DaaS Logon | OPA Logon | LINZ email | Facebook | Gmail | Metservice | Stuff | Dropbox | Geodesy Links | Personal Links | Other

I C G E M

GFZ Helmholtz Centre POTSDAM



International Centre for Global Earth Models (ICGEM)

ICGEM is one of five services coordinated by the International Gravity Field Service (IGFS) of the International Association of Geodesy (IAG).
The other services are:

- BGI (Bureau Gravimetrique International), Toulouse, France
- ISG (International Service for the Geoid), Politecnico di Milano, Milano, Italy
- IGETS (International Geodynamics and Earth Tide Service), EOST, Strasbourg, France
- IDEMS (International Digital Elevation Model Service), ESRI, Redlands, CA, USA

Services of ICGEM

- collecting and archiving of all existing global gravity field models
- web interface for getting access to global gravity field models
- web based visualization of the gravity field models their differences and their time variation
- web based service for calculating different functionals of the gravity field models
- web site for tutorials on spherical harmonics and the theory of the calculation service
- *new service since 2016:* providing a Document Object Identifier (DOI) for the data set of the model (the coefficients)

Some ICGEM related documents

- Definition of Functionals of the Geopotential and Their Calculation from Spherical Harmonic Models
- Article about Global Models
- Description of the ICGEM-format
- IGFS and ICGEM in Geodesists Handbook 2016
- ICGEM-Report 2003-2007

ICGEM Home

Gravity Field Models
- Static Models
- Temporal Models
- Topography related Models

Calculation Service

3D Visualisation
- Static Models
- Temporal Models
- Trend & Amplitude
- Spherical Harmonics

Evaluation
- Spectral domain
- GNSS Leveling

FAQ
Theory
References
Latest Changes

ICGEM Geoid Repository

Nr	Model	Year	Degree	Data	References	Download	Calculate	Show	DOI
161	XGM2016	2017	719	A, G, S(GOCO05s)	Pail, R. et al, 2017	gfc zip	Calculate	Show	✔
160	Tongji-Grace02s	2017	180	S(Grace)	Chen, Q. et al, 2016	gfc zip	Calculate	Show	✔
159	NULP-02s	2017	250	S(Goce)	A.N. Marchenko et al, 2016	gfc zip	Calculate	Show	✔
158	HUST-Grace2016s	2016	160	S(Grace)	Zhou, H. et al, 2016	gfc zip	Calculate	Show	✔
157	ITU_GRACE16	2016	180	S(Grace)	Akyilmaz, O. et al, 2016	gfc zip	Calculate	Show	✔
156	ITU_GGC16	2016	280	S(Goce), S(Grace)	Akyilmaz, O. et al, 2016	gfc zip	Calculate	Show	✔
155	EIGEN-6S4 (v2)	2016	300	S(Goce), S(Grace), S(Lageos)	Förste, C. and Bruinsma, S.L., 2016	gfc zip	Calculate	Show	✔
154	GOCO05c	2016	720	(see model), A, G, S	Fecher, T. et al, 2016	gfc zip	Calculate	Show	✔
153	GGM05C	2015	360	A, G, S(Goce), S(Grace)	Ries, J. et al, 2016	gfc zip	Calculate	Show	✔
152	GECO	2015	2190	EGM2008, S(Goce)	Gilardoni, M. et al, 2016	gfc zip	Calculate	Show	
151	GGM05G	2015	240	S(Goce), S(Grace)	Bettadpur, S. et al, 2015	gfc zip	Calculate	Show	
150	GOCO05s	2015	280	(see model), S	Mayer-Gürr, T. et al, 2015	gfc zip	Calculate	Show	
149	GO_CONS_GCF_2_SPW_R4	2014	280	S(Goce)	Gatti, A. et al, 2014	gfc zip	Calculate	Show	
148	EIGEN-6C4	2014	2190	A, G, S(Goce), S(Grace), S(Lageos)	Förste, Christoph et al, 2014	gfc zip	Calculate	Show	✔
147	ITSG-Grace2014s	2014	200	S(Grace)	Mayer-Gürr, T. et al, 2014	gfc zip	Calculate	Show	
146	ITSG-Grace2014k	2014	200	S(Grace)	Mayer-Gürr, T. et al, 2014	gfc zip	Calculate	Show	
145	GO_CONS_GCF_2_TIM_R5	2014	280	S(Goce)	Brockmann, J. M. et al, 2014	gfc zip	Calculate	Show	
144	GO_CONS_GCF_2_DIR_R5	2014	300	S(Goce), S(Grace), S(Lageos)	Bruinsma, S. L. et al, 2013	gfc zip	Calculate	Show	
143	JYY_GOCE04S	2014	230	S(Goce)	Yi, Weiyong et al, 2013	gfc zip	Calculate	Show	
142	GOGRA04S	2014	230	S(Goce), S(Grace)	Yi, Weiyong et al, 2013	gfc zip	Calculate	Show	
141	EIGEN-6S2	2014	260	S(Goce), S(Grace), S(Lageos)	Rudenko, Sergei et al, 2014	gfc zip	Calculate	Show	
140	GGM05S	2014	180	S(Grace)	Tapley, B.D. et al, 2013	gfc zip	Calculate	Show	
139	EIGEN-6C3stat	2014	1949	A, G, S(Goce), S(Grace), S(Lageos)	Förste, C. et al, 2012	gfc zip	Calculate	Show	
138	Tongji-GRACE01	2013	160	S(Grace)	Shen, Y. et al, 2013	gfc zip	Calculate	Show	
137	JYY_GOCE02S	2013	230	S(Goce)	Yi, Weiyong et al, 2013	gfc zip	Calculate	Show	
136	GOGRA02S	2013	230	S(Goce), S(Grace)	Yi, Weiyong et al, 2013	gfc zip	Calculate	Show	
135	ULux_CHAMP2013s	2013	120	S(Champ)	Weigelt, M. et al, 2013	gfc zip	Calculate	Show	
134	ITG-Goce02	2013	240	S(Goce)	Schall, Judith et al, 2014	gfc zip	Calculate	Show	

Regional Geoids

- Locally enhanced global models
- Incorporate additional gravity observations from multiple sources: terrestrial, shipborne, airborne and altimetry
- Various computational techniques:
  - Least squares collocation
  - FFT
  - Numerical integration
- Must account for terrain and other corrections to gravity anomalies

Regional Geoids

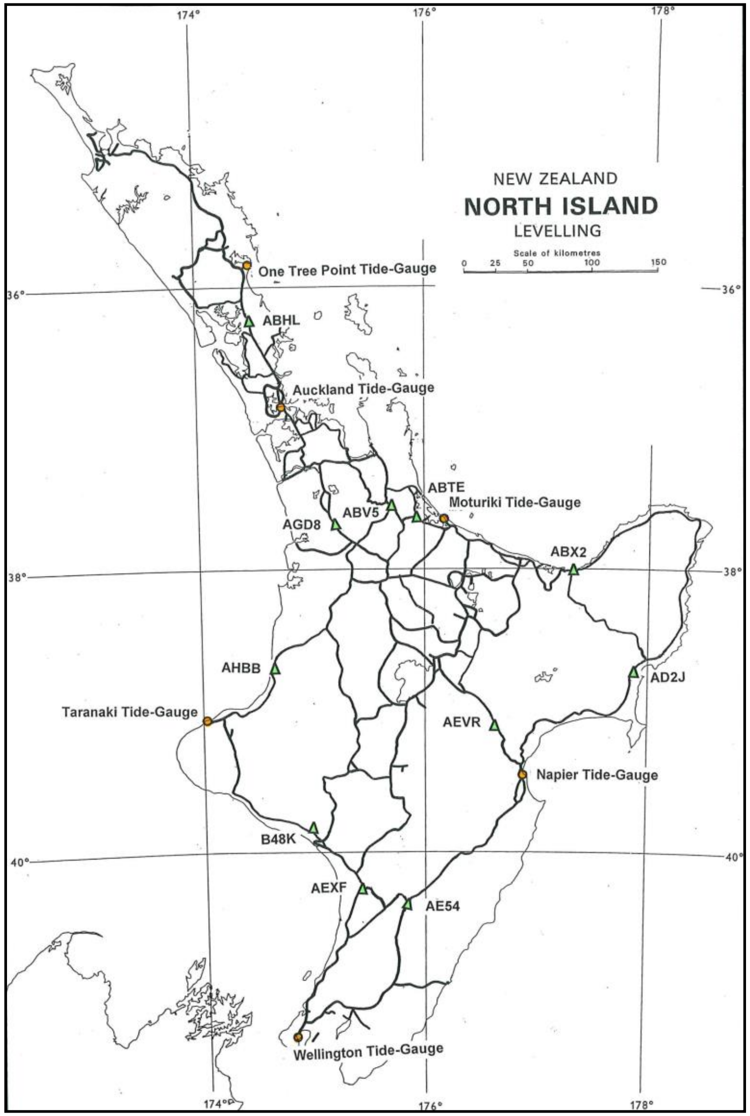
- Gravimetric
  - Gravity only
- Geometric
  - GNSS-levelling
- Combined or fitted
  - Gravity based geoids combined with GNSS-levelling

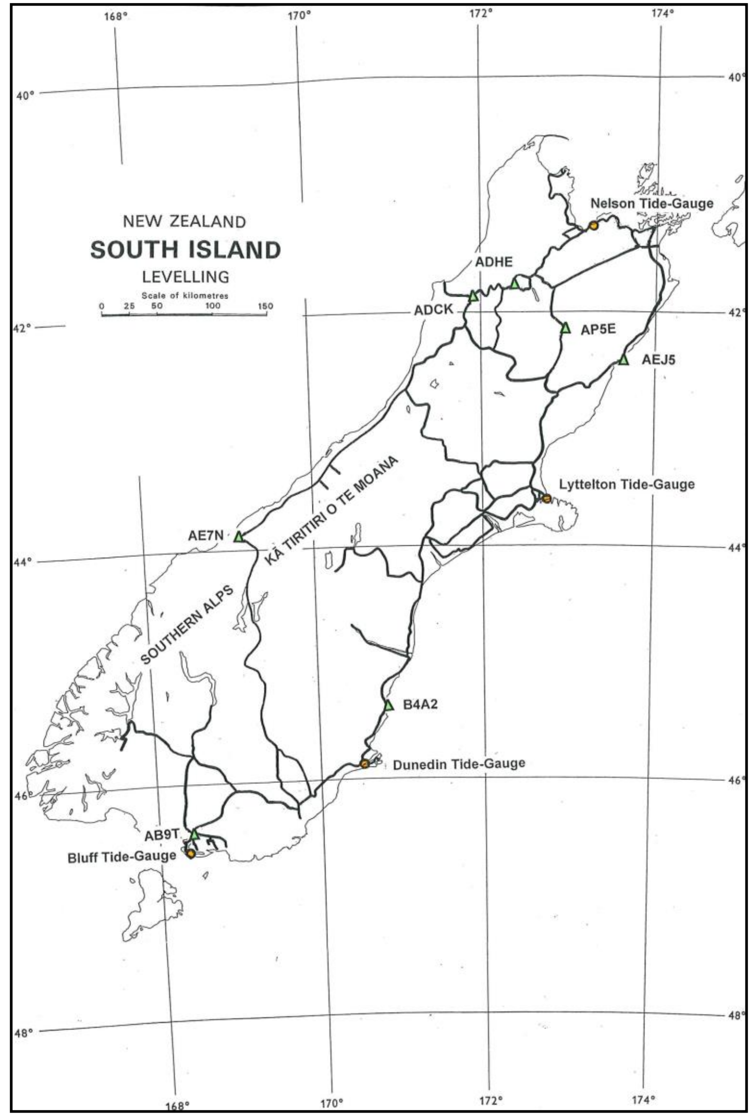
Vertical Datum Choices

- Why do you want a datum?
- What applications will it be used for?
- How accurate does it need to be?
- What is your budget?
- How quickly do you need it?

Part II – Datum Development from a NZ Perspective

NZ's Legacy Datums



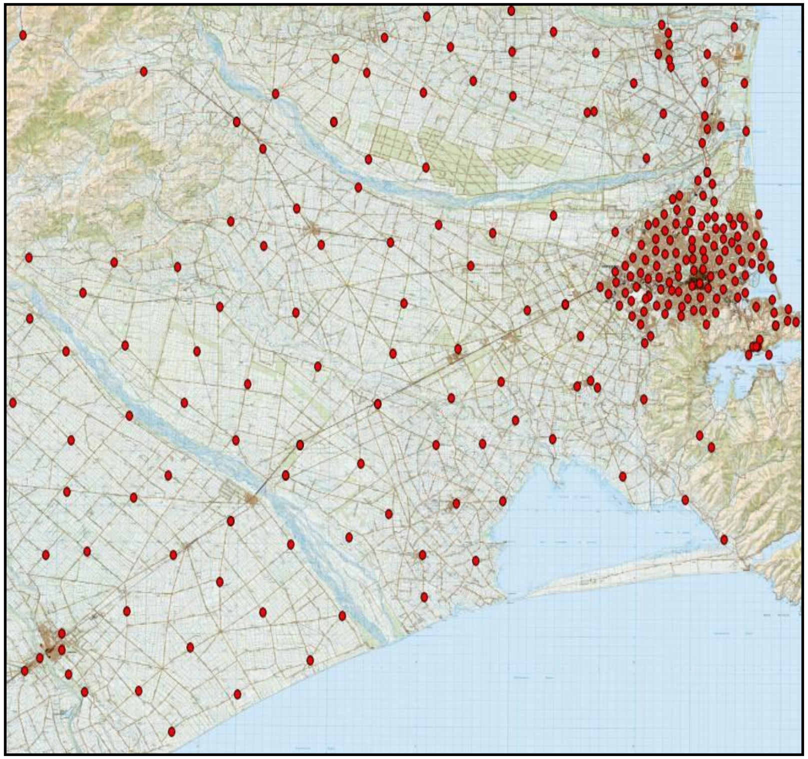


New Zealand's Why

- Levelling networks not maintainable
- Benchmarks only available in urban areas and along state highways
- Need compatibility with NZGD2000
- Consistent heights needed across land and sea
  - Economic development
  - Decision making
  - Disaster impact mitigation and recovery

Disaster recovery

- Heights re-established by levelling
- 400 marks, 500 km

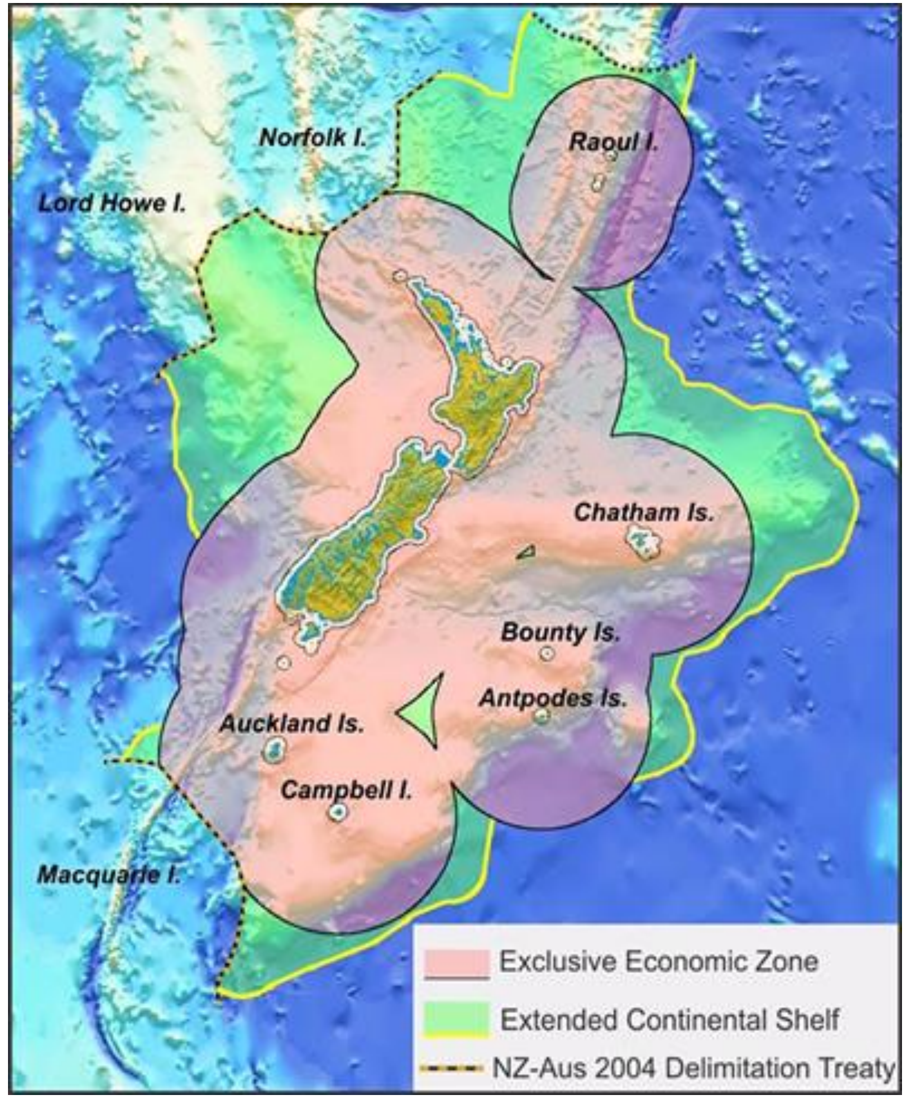


- NZGD2000 control re-established by GNSS Survey
- 250 marks

An accurate geoid would have reduced the need for extensive levelling

Desirable Attributes for NZ

- Accessible - anywhere
- Consistent reference system
- Compatible with geometric datum (NZGD2000)
- Fit for purpose – meets user needs
- Maintainable and assessable

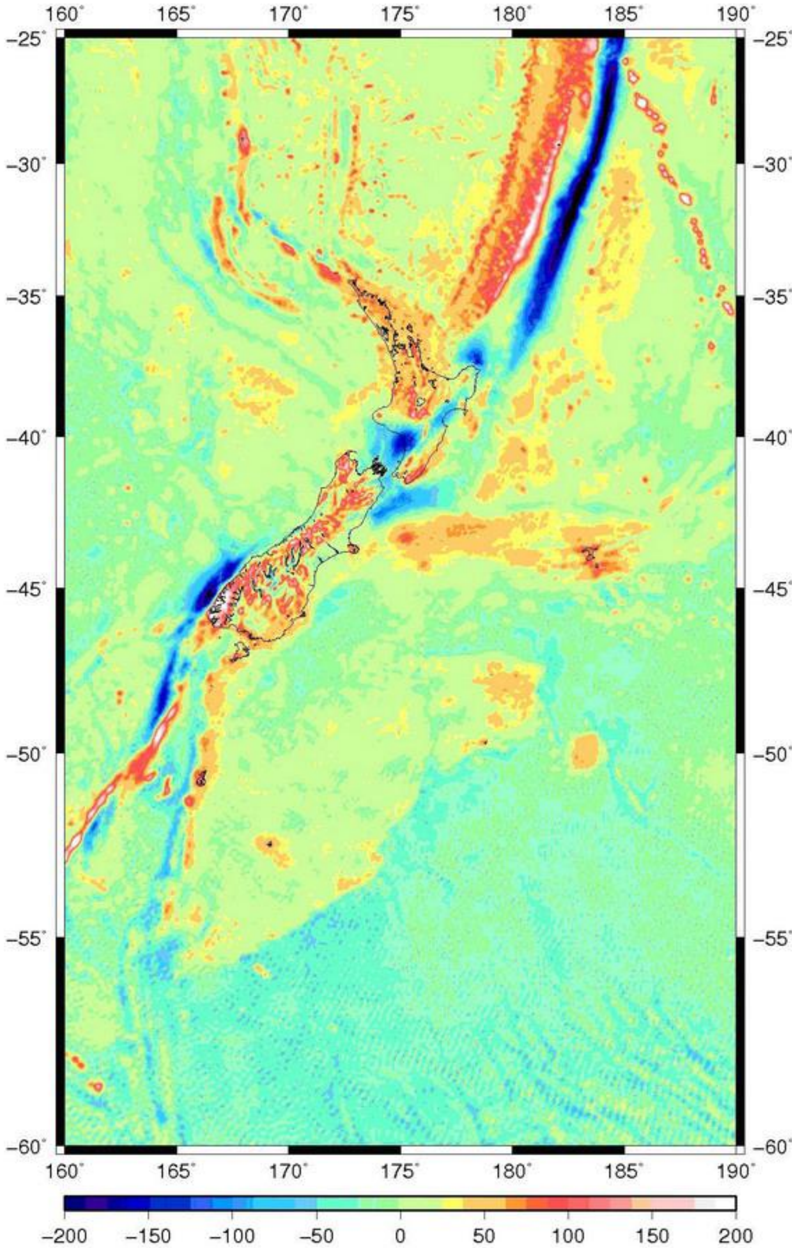


NZVD2009 Development

- Needed gravimetric reference frame to operate with geometric datum
- Geoid based datum chosen approach
- Limited budget
- Computed geoid from existing datasets
- Developed transformations to local datums

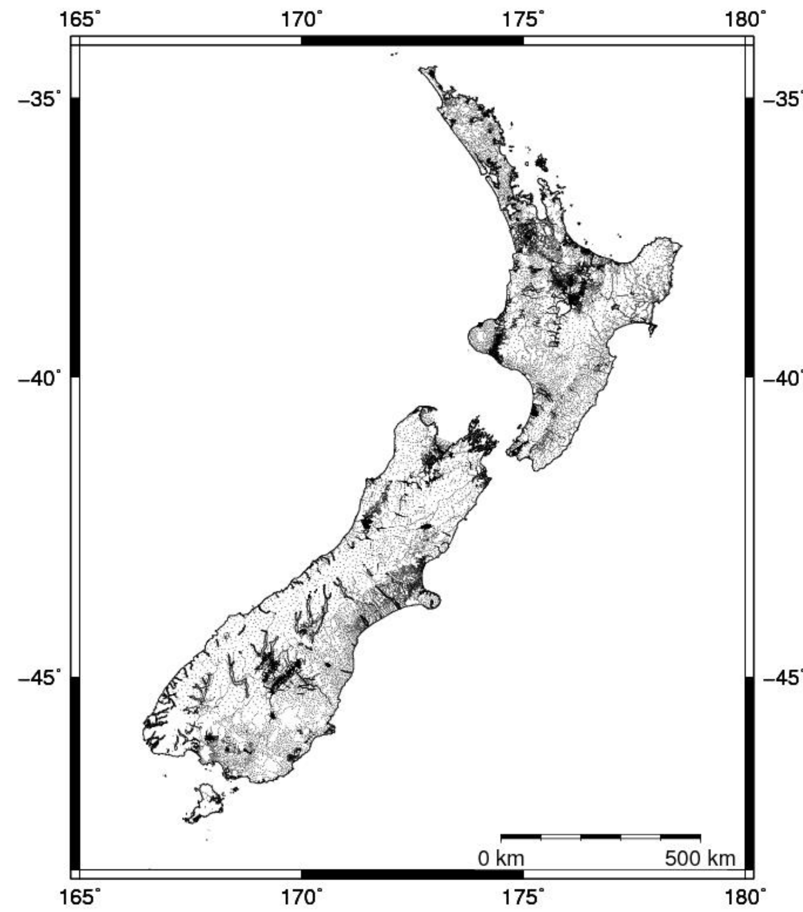
NZ Quasigeoid 2009

- Datasets
  - EGM2008



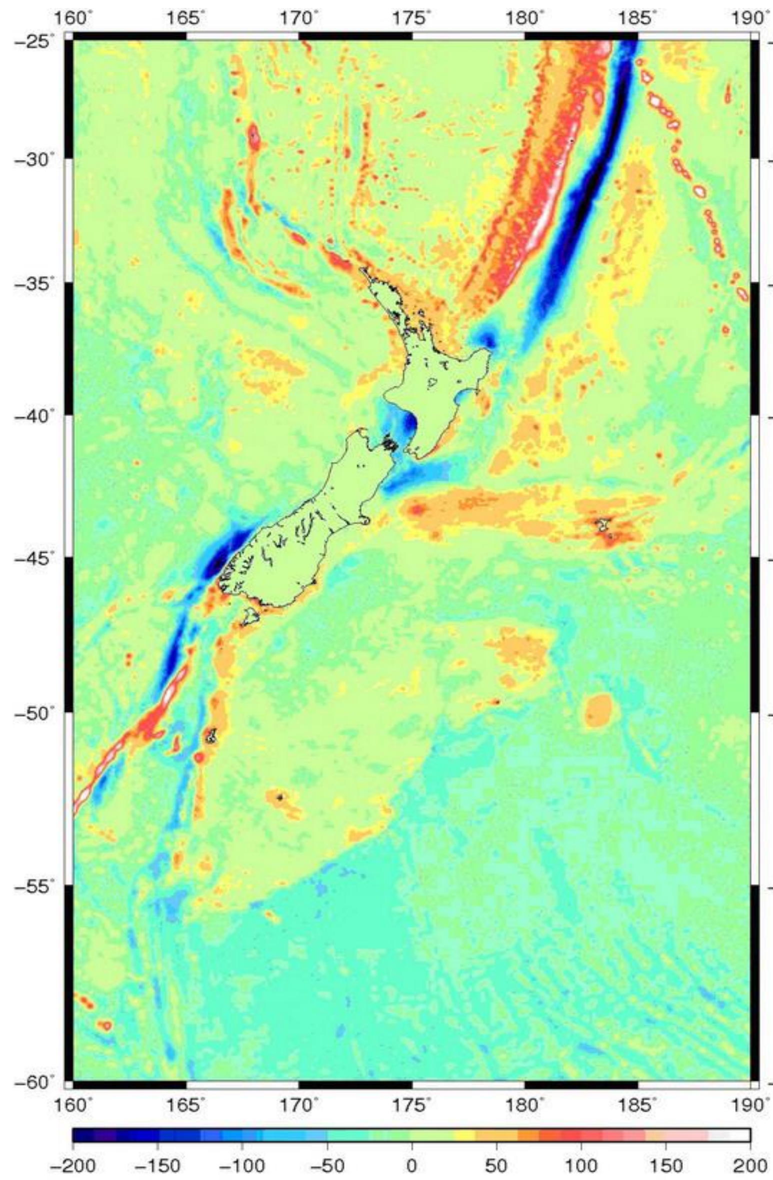
NZ Quasigeoid 2009

- Datasets
  - EGM2008
  - Land Gravity Data



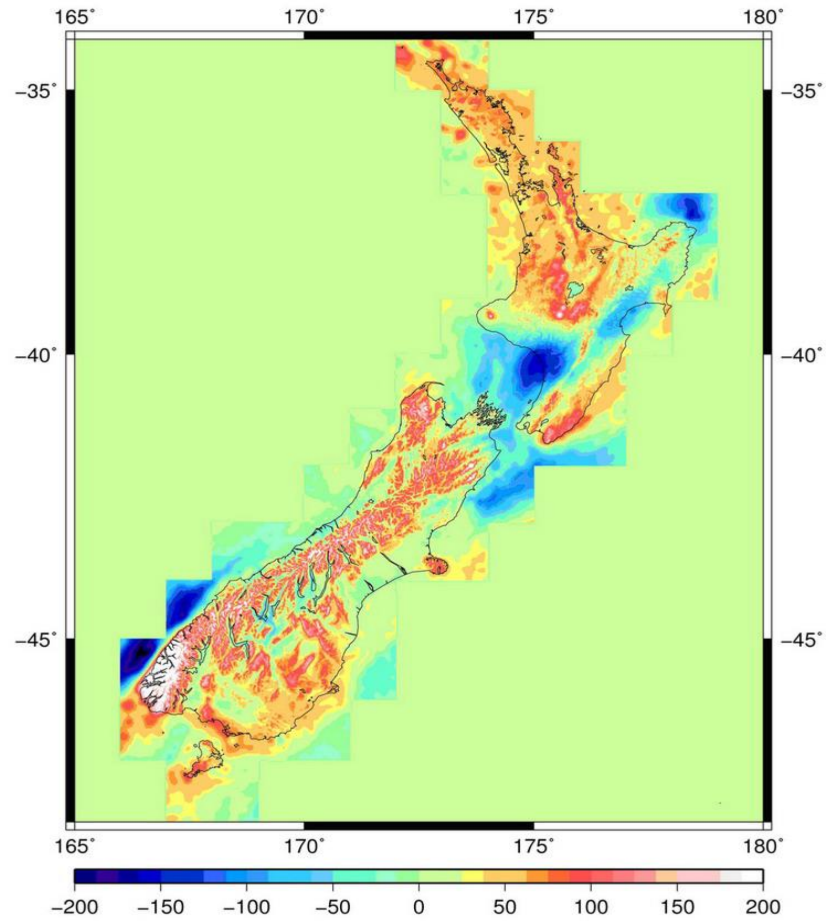
NZ Quasigeoid 2009

- Datasets
  - EGM2008
  - Land Gravity Data
  - DNSC08 Altimetry



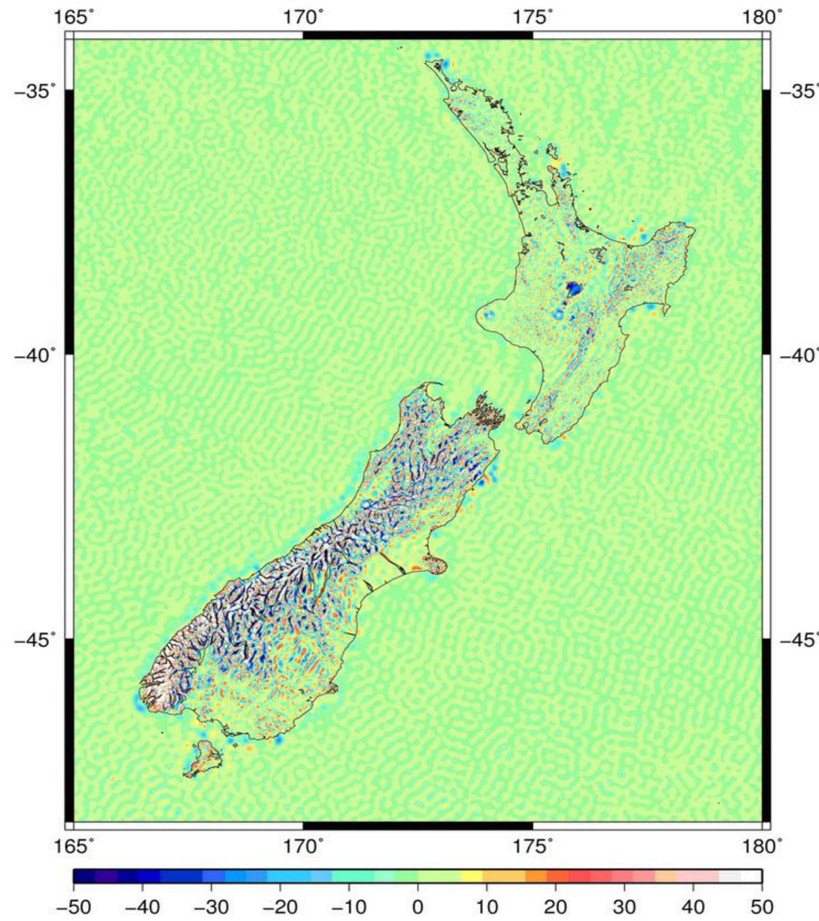
NZ Quasigeoid 2009

- Datasets
  - EGM2008
  - Land Gravity Data
  - DNSC08 Altimetry
  - Digital Elevation Model



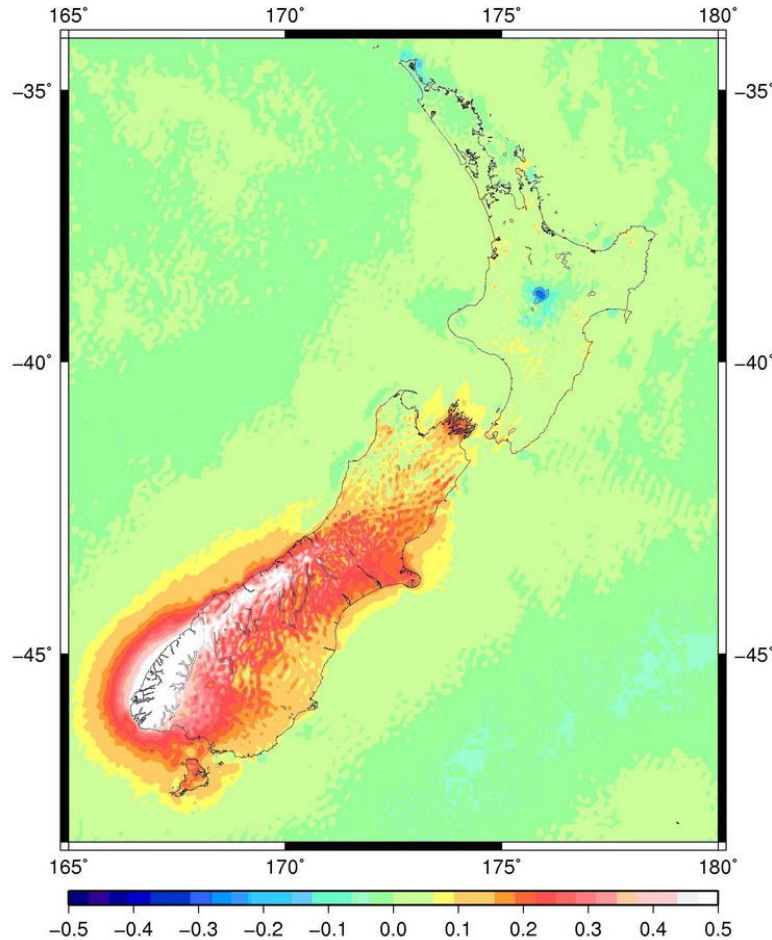
NZ Quasigeoid 2009

- Datasets
  - EGM2008
  - Land Gravity Data
  - DNSC08 Altimetry
  - Digital Elevation Model
- Subtract EGM2008



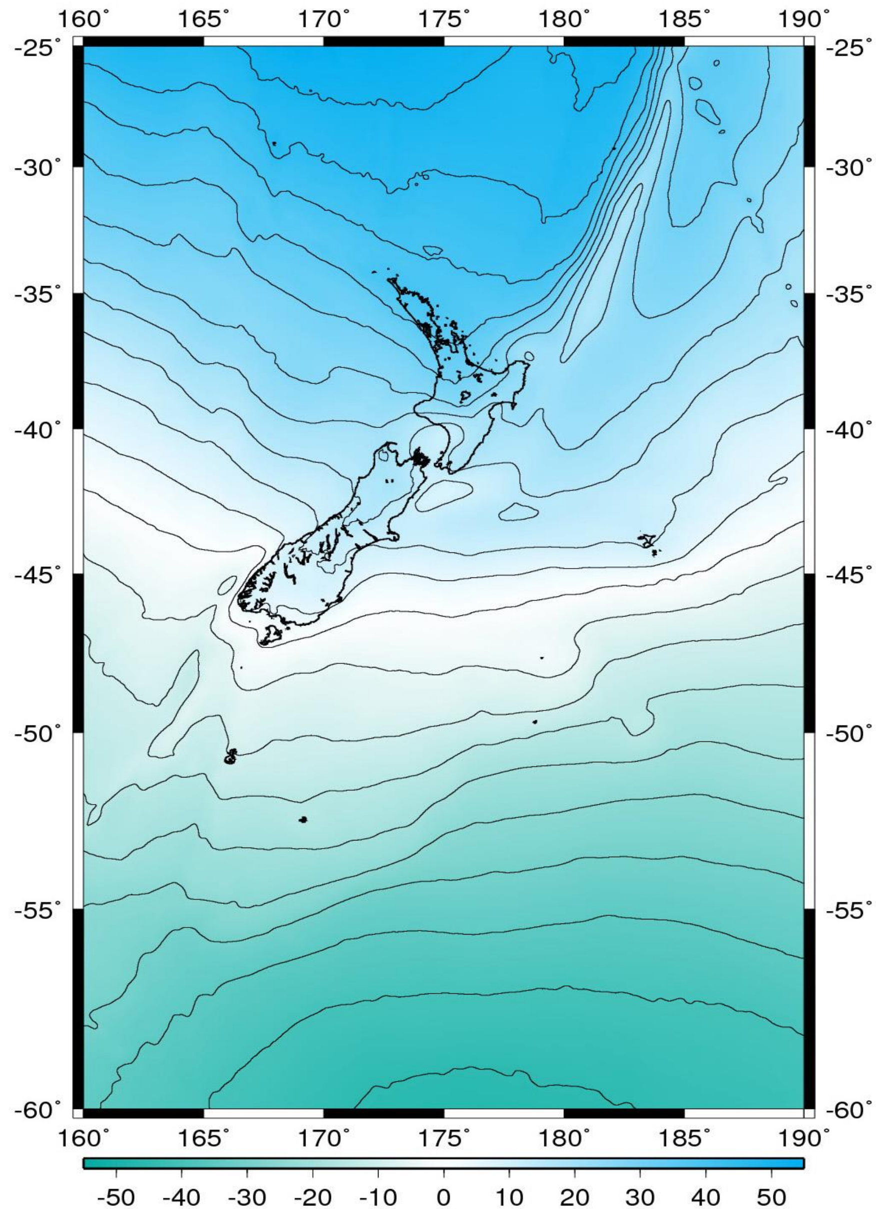
NZ Quasigeoid 2009

- Datasets
  - EGM2008
  - Land Gravity Data
  - DNSC08 Altimetry
  - Digital Elevation Model
- Subtract EGM2008
- Fourier transform to residual geoid



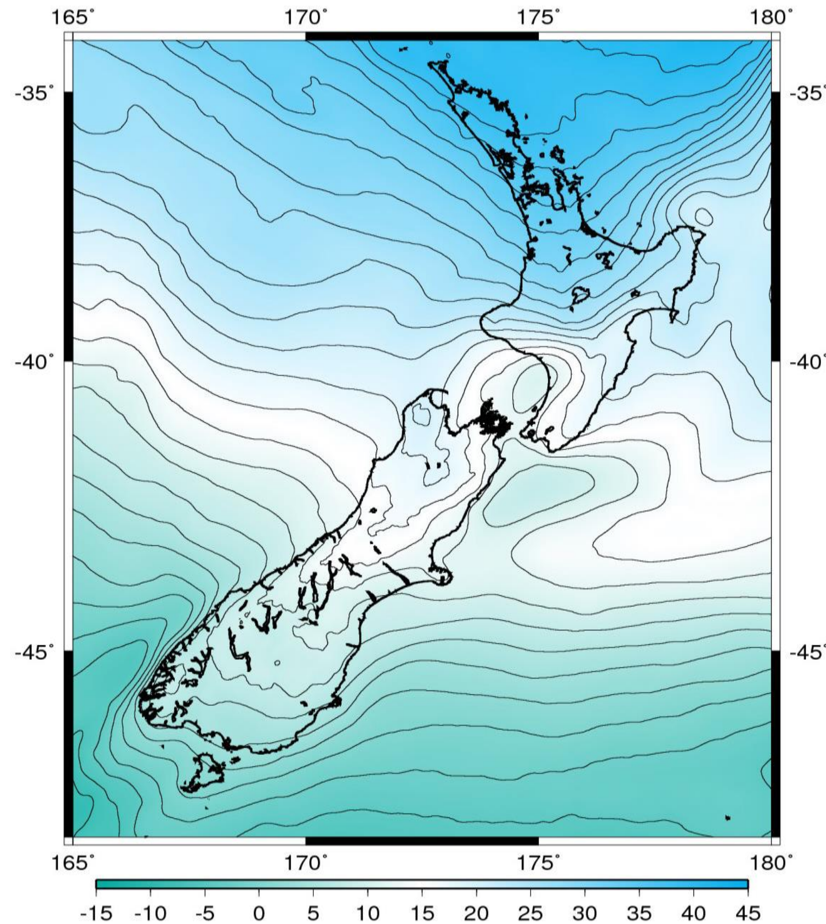
NZ Quasigeoid 2009

- Datasets
  - EGM2008
  - Land Gravity Data
  - DNSC08 Altimetry
  - Digital Elevation Model
- Subtract EGM2008
- Fourier transform to residual geoid
- Add back EGM2008



NZ Quasigeoid 2009

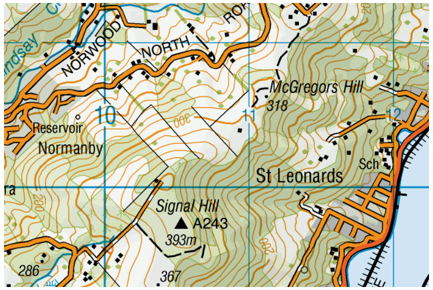
- Datasets
  - EGM2008
  - Land Gravity Data
  - DNSC08 Altimetry
  - Digital Elevation Model
- Subtract EGM2008
- Fourier transform to residual geoid
- Add back EGM2008
- NZGeoid2009



NZ Vertical Datum 2009

- Computed from existing datasets
- Provided nationally consistent vertical datum across the NZ continental shelf
- First consistent national vertical datum
- Included offsets to 13 local datums
  - 6 cm nominal accuracy (assessed from GPS-levelling)
  - Local accuracy 3-15 cm

Datum Improvement



Cadastral Surveyors

Local Government

Hydrographic Charting

Topographic Mapping

NZVD2016

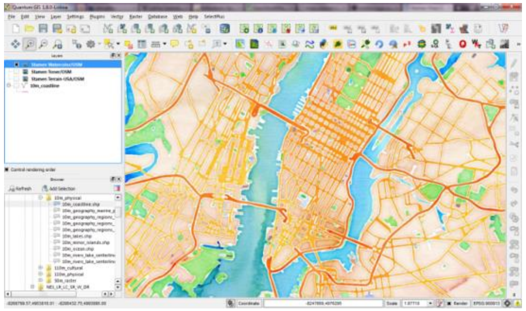
0.001 | 0.03 | 0.10 | 0.15 | 0.25 | 0.5 | 1.0

NZVD2009

Scientific Monitoring

GIS

Recreational GNSS



NZVD2016 Development

- Needed better accuracy
- New data needed
  - Land-sea gap
  - Mountainous areas
- Airborne gravity survey to provide national coverage
- Integrate airborne with existing gravity data
- Better integration with local datums
- Three year upgrade project

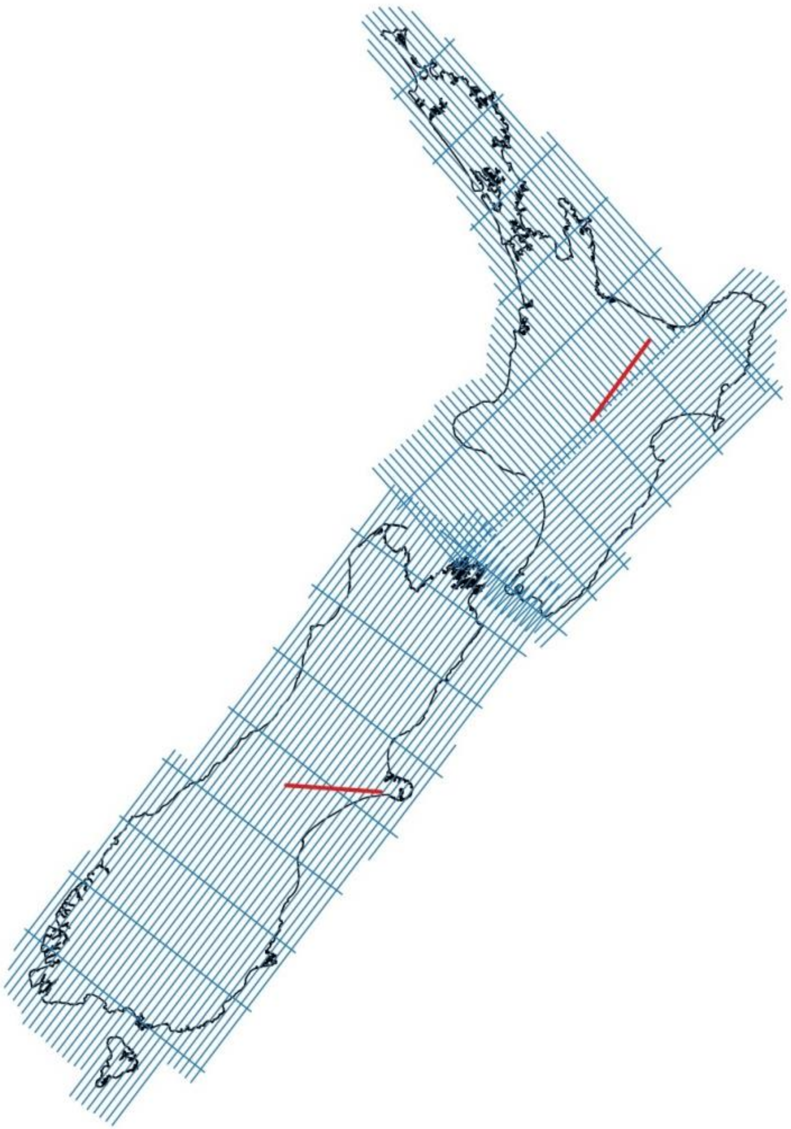
Airborne Gravity Survey

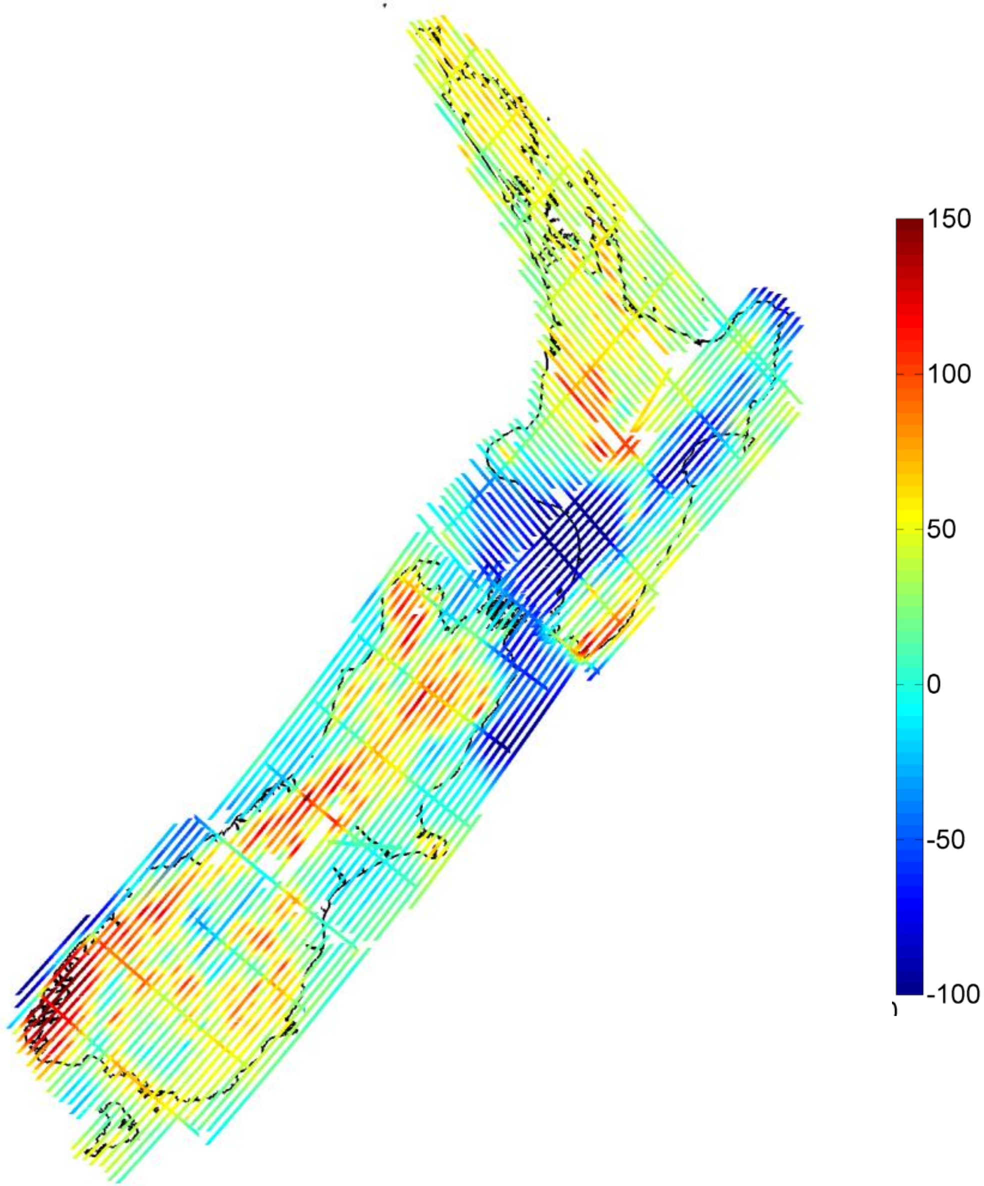
- Eight month campaign
  - August – October 2013
  - February – June 2014
- 75 flights / 425 flying hours
- 50,000 line km

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

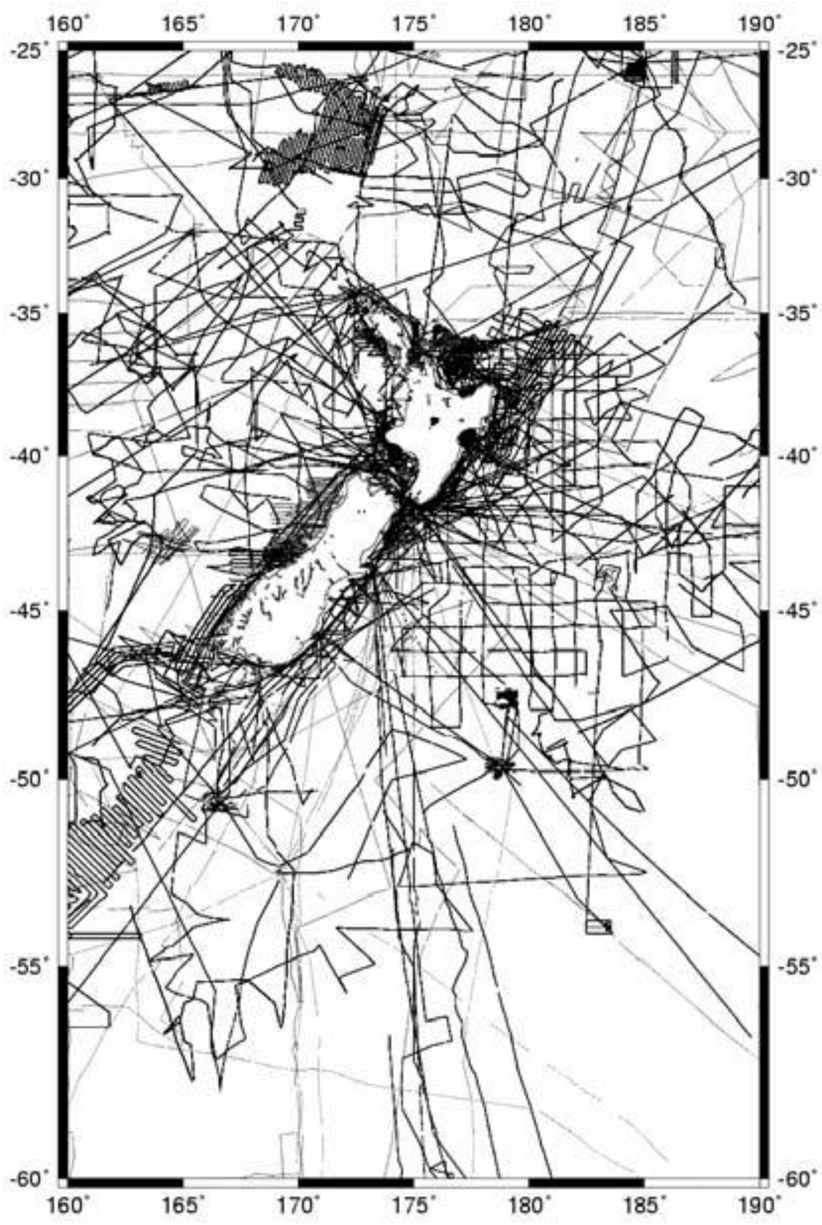
GNS SCIENCE
TE PŪ AO

Airborne Gravity Anomalies

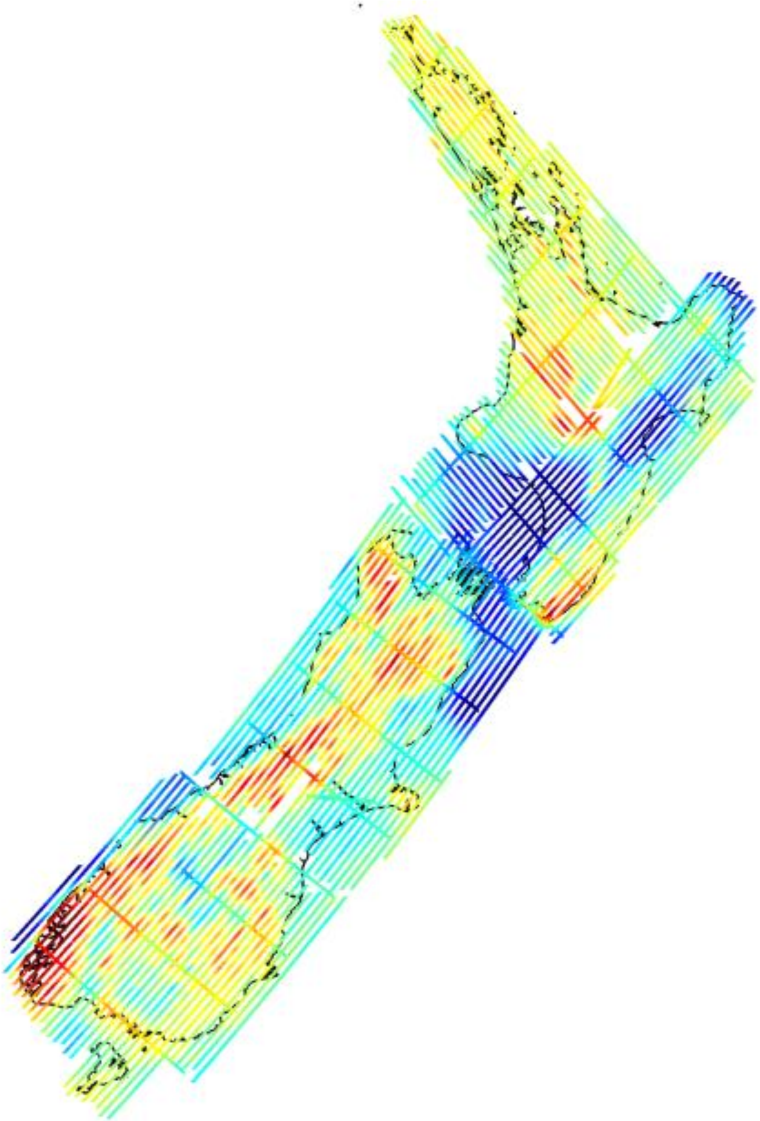


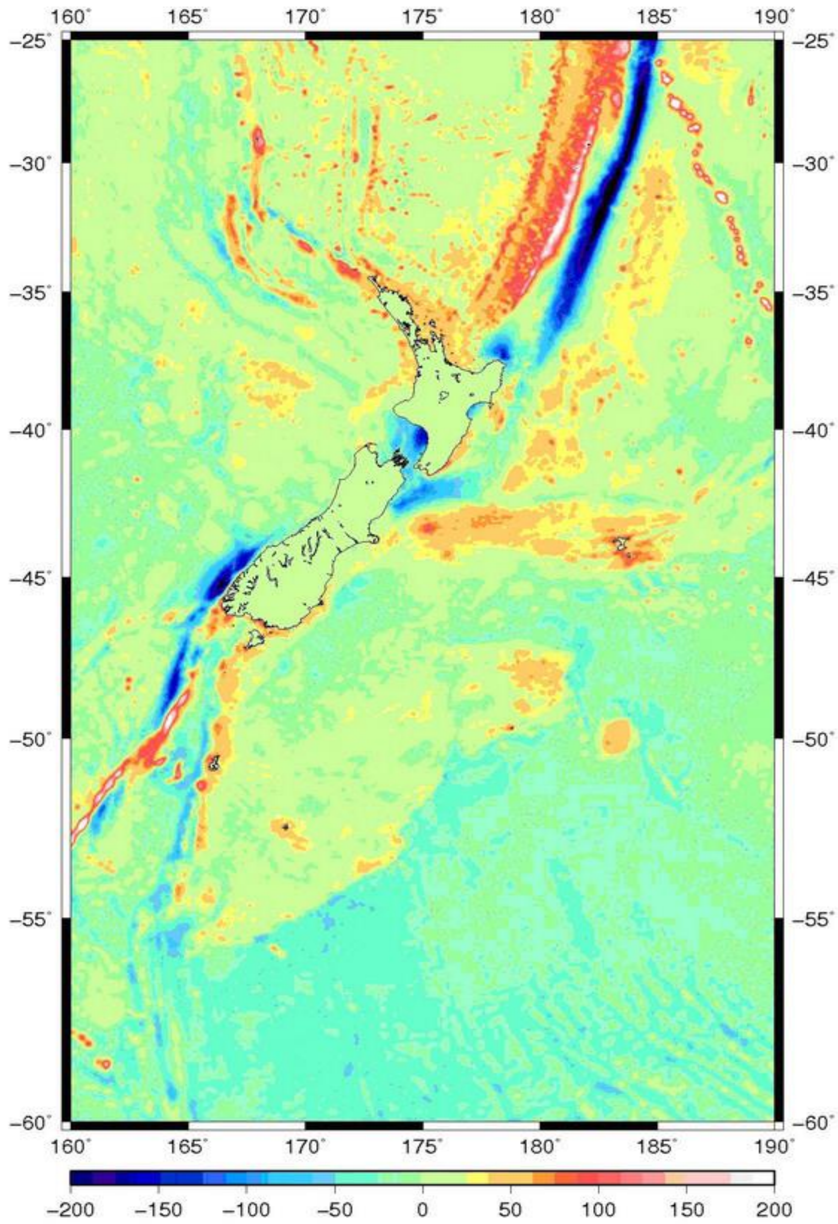


NZGeoid2016 Source Data

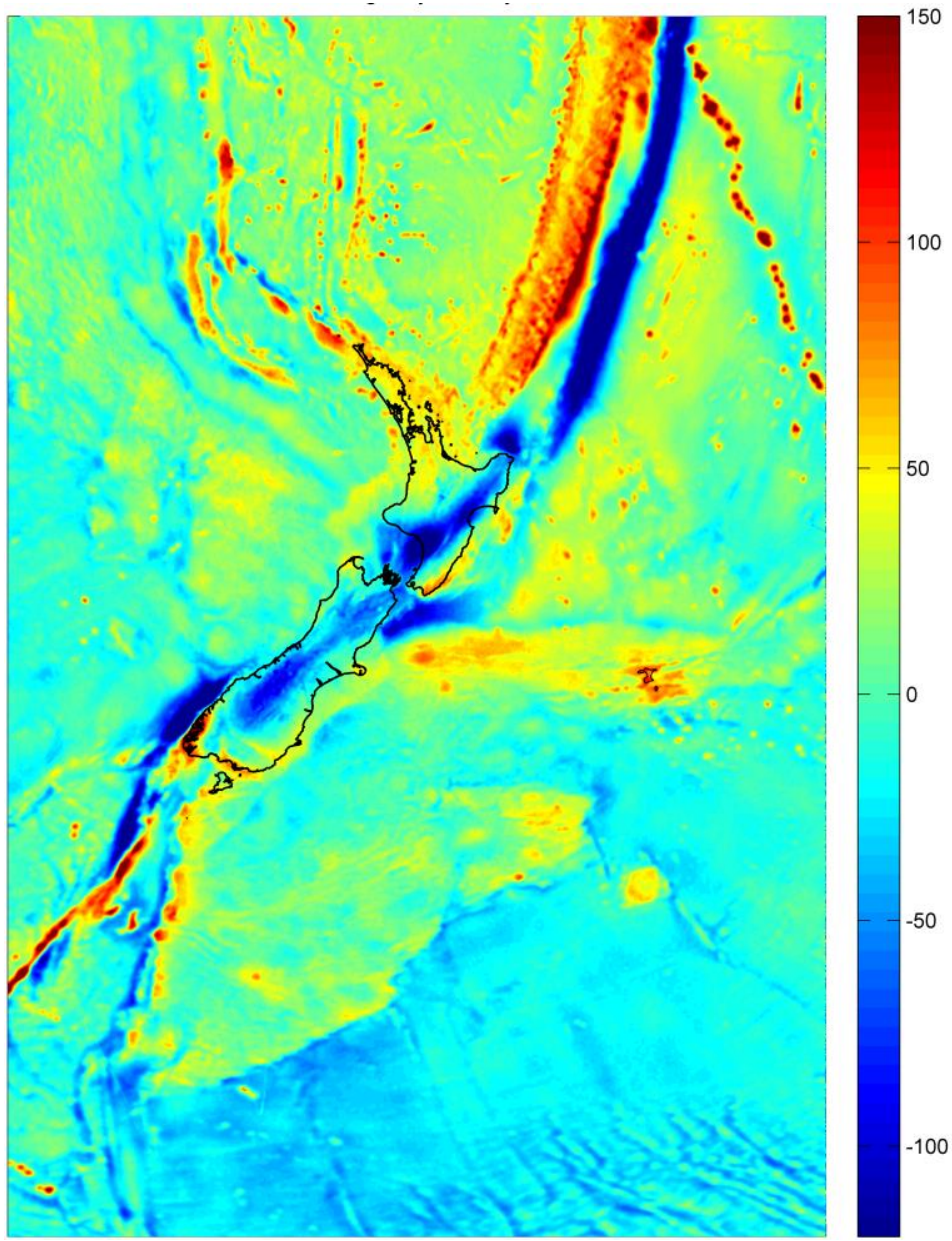


NZGeoid2016 Source Data



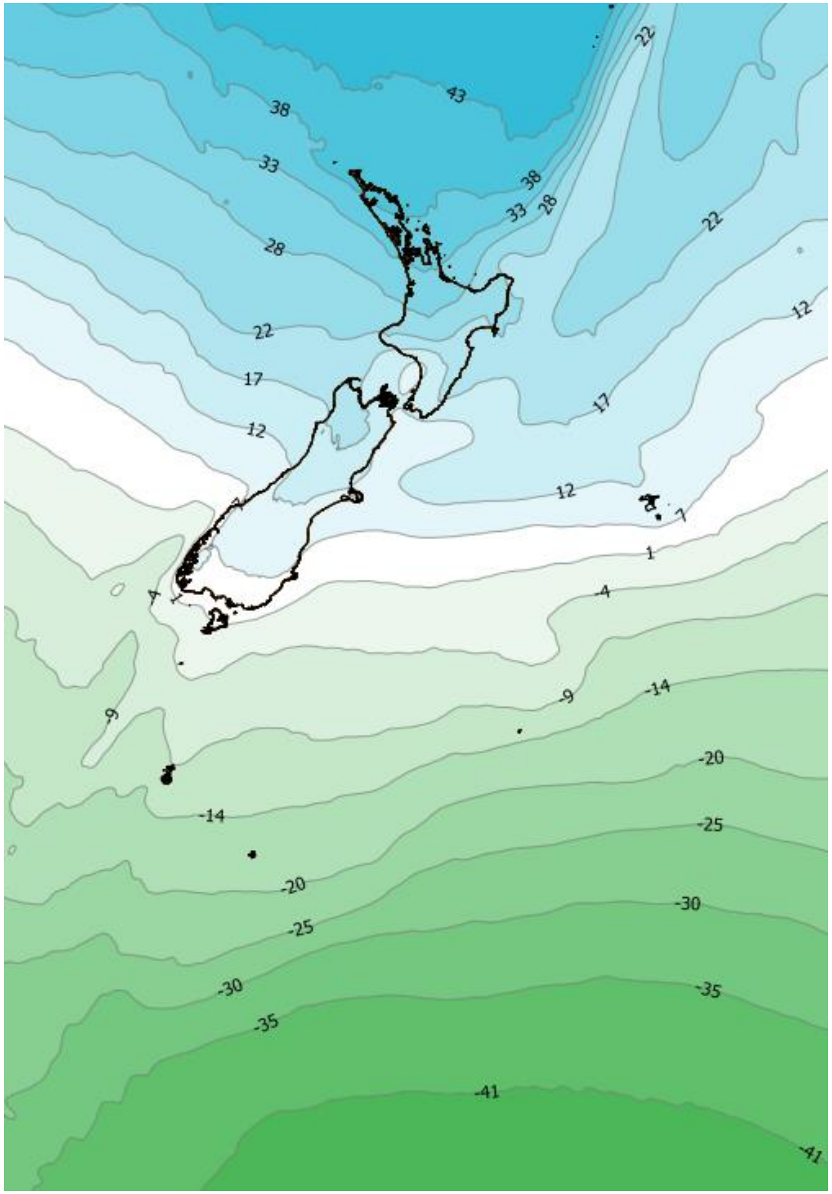


Combined Gravity Data



NZ Quasigeoid 2016

- Eigen-6C4 global model
- Modified Stokes kernel
  - $\psi_0 = 1.5°$
  - $L = 180$
- Published on 1′ grid (1.8 km)
  - 160° E to 170° W
  - 25° S to 60° S



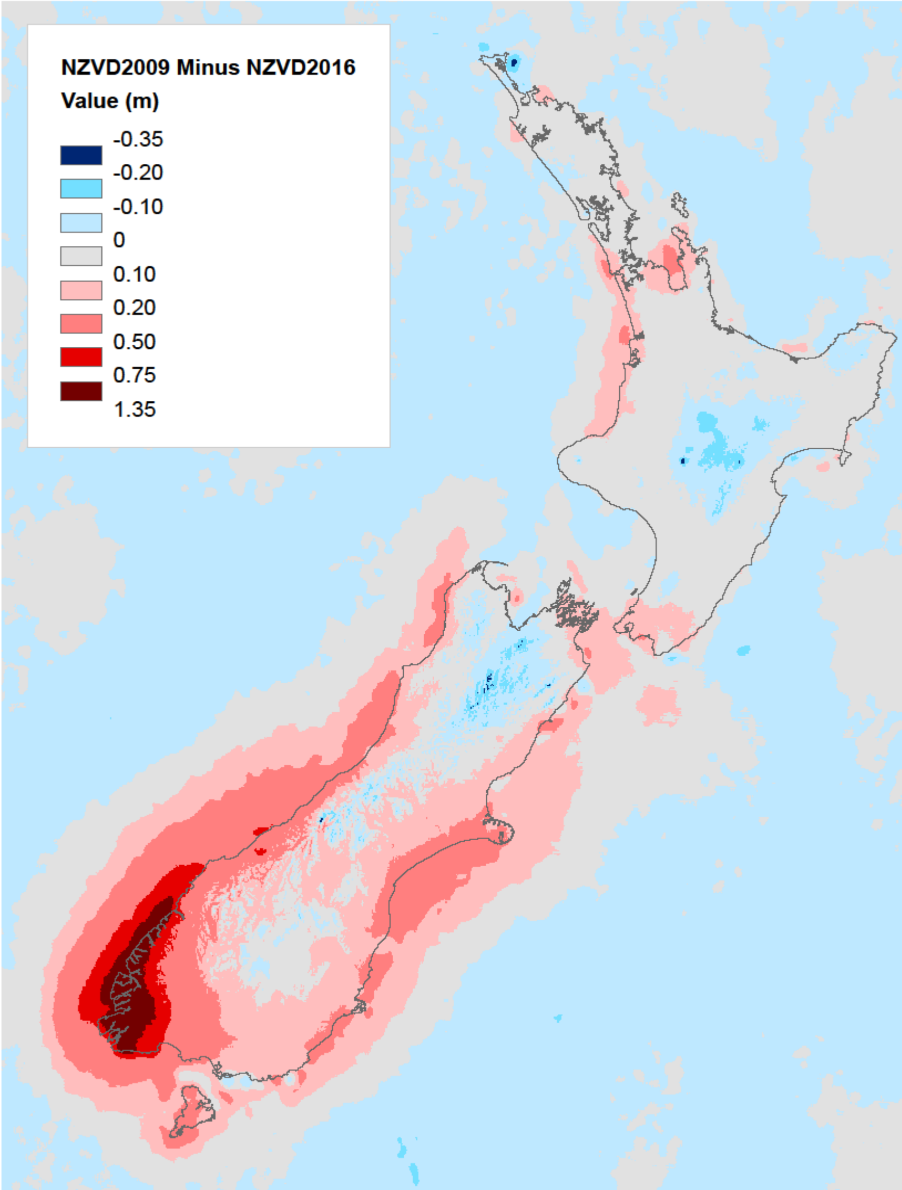
NZGeoid 09/16 Differences

Most significant changes:

- Coastal areas
- Mountainous regions
- New global gravity model

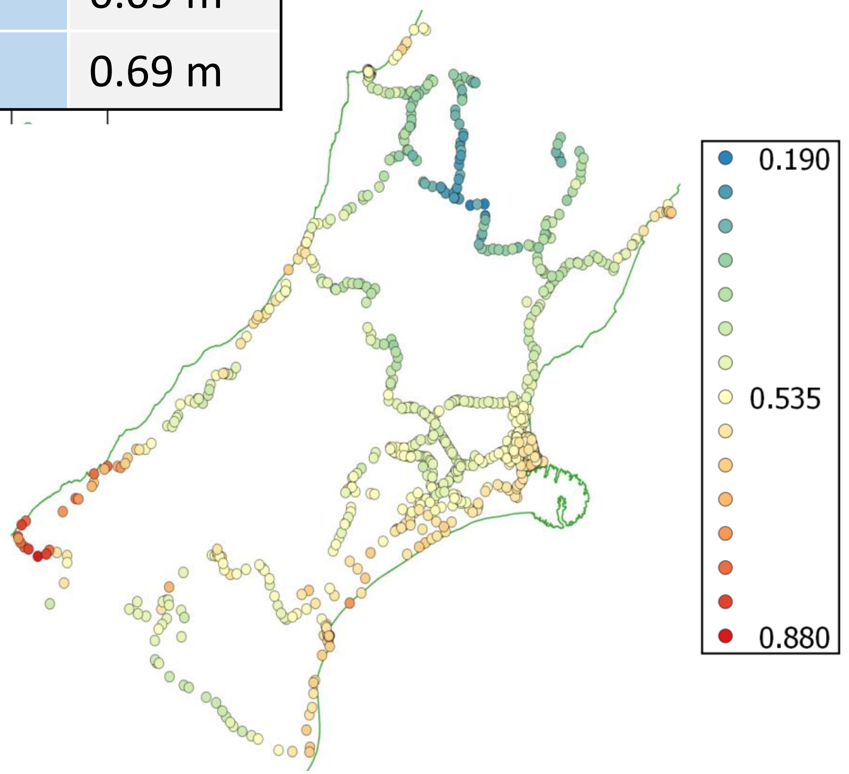
GPS/Levelling height changes:

- Average: 0.10m
- Range: -0.11m to 0.57m



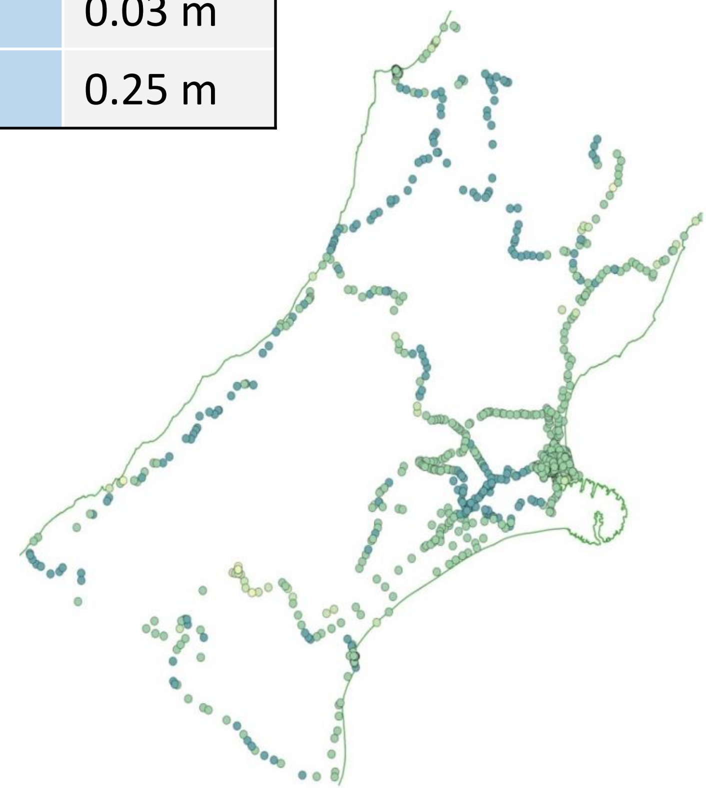
Changes Between Geoids

Mean	0.47 m
SD	0.09 m
Range	0.69 m



NZGeoid2009

Mean	0.34 m
SD	0.03 m
Range	0.25 m



NZGeoid2016

Offset Comparisons

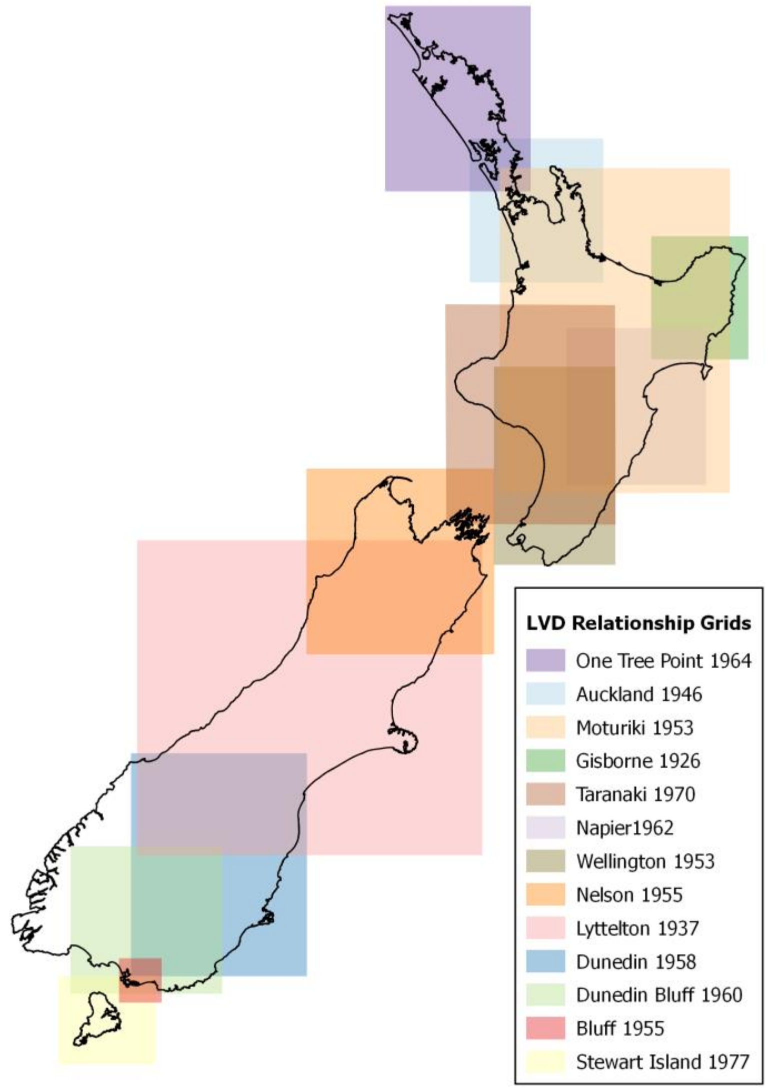
Datum	2009 Offset (m)	SD (m)	Range (m)	2016 Offset (m)	SD (m)	Range (m)
Auckland	0.34	0.05	**0.22**	0.29	0.04	**0.12**
Bluff	0.36	0.05	**0.23**	0.27	0.04	**0.12**
Dunedin-Bluff	0.38	0.04	**0.33**	0.25	0.04	**0.16**
Dunedin	0.49	0.07	**0.30**	0.33	0.03	**0.25**
Gisborne	0.34	0.02	**0.19**	0.34	0.02	**0.12**
Lyttelton	0.47	0.09	**0.69**	0.34	0.03	**0.25**
Moturiki	0.24	0.06	**0.34**	0.31	0.06	**0.32**
Napier	0.20	0.05	**0.25**	0.20	0.03	**0.15**
Nelson	0.29	0.07	**0.41**	0.33	0.03	**0.20**
One Tree Point	0.06	0.03	**0.18**	0.08	0.04	**0.16**
Taranaki	0.32	0.05	**0.17**	0.29	0.03	**0.11**
Wellington	0.44	0.04	**0.26**	0.41	0.05	**0.16**
Stewart island	0.39	0.15	**0.35**	0.30	0.18	**-0.30**

Linking to local datums

- Essential to assist users to migrate to new datum to encourage uptake
  - No compelling legislation in NZ
- Offset approach simplistic
- NZVD2016 defines fitted grids for each datum
  - Determined from GNSS-levelling differences
  - Model “error” in GNSS and levelled heights

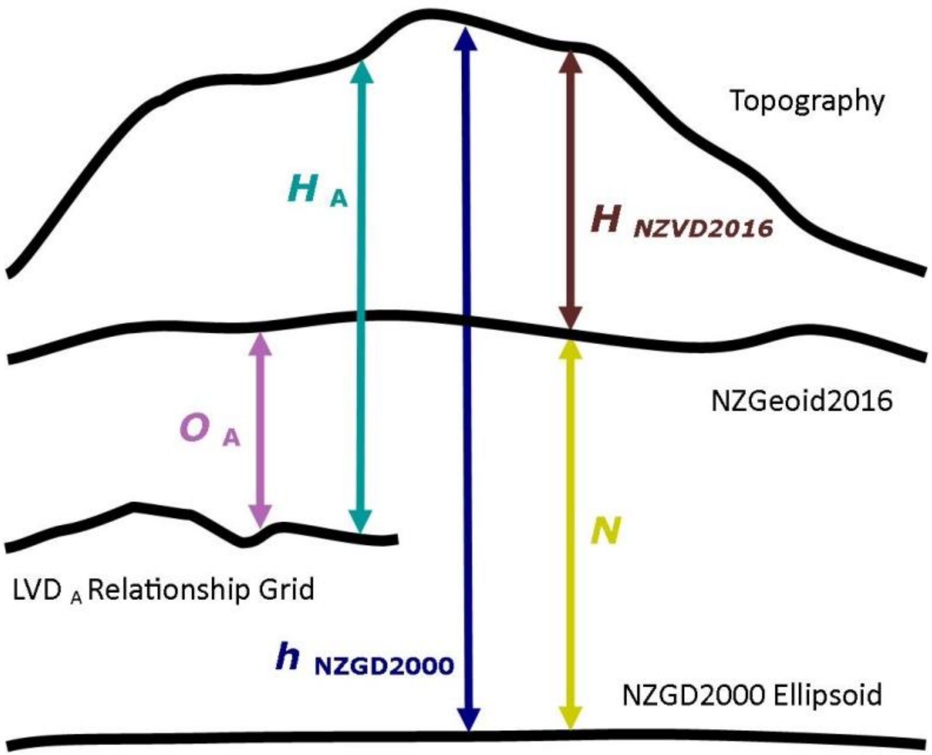
Local datum relationships

Datum	Range (m)	STD (m)
Auckland	0.23 - 0.35	0.02
Bluff	0.22 - 0.34	0.02
Dunedin-Bluff	0.17 - 0.33	0.02
Dunedin	0.19 - 0.44	0.02
Gisborne	0.27 - 0.39	0.02
Lyttelton	0.22 - 0.47	0.01
Moturiki	0.17 - 0.49	0.02
Napier	0.14 - 0.29	0.02
Nelson	0.23 - 0.43	0.02
One Tree Point	-0.01 - 0.15	0.01
Taranaki	0.23 - 0.34	0.02
Wellington	0.34 - 0.50	0.02
Stewart Island	0.30	0.18



Part III – Accessing the Datum

NZVD2016 transformations



NZVD2016 heights (**H**) can be determined by subtracting a NZGeoid2016 height (**N**) from an ellipsoid/GNSS height (**h**)

$$H = h - N$$

The LVD Relationship Grids (**O_A**) transform NZVD2016 heights (**H**) from LVD heights (**H_A**)

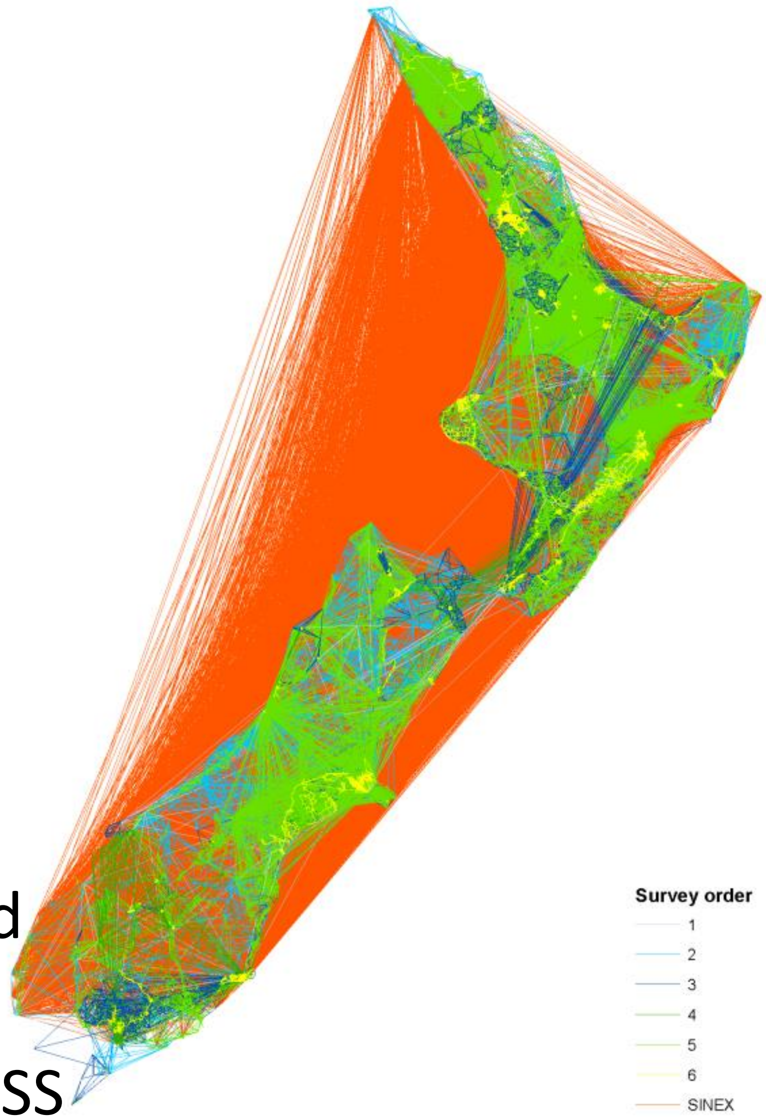
$$H_A = H + O_A$$

Better access to NZVD2016

- LINZ Geodetic Database & Landonline
  - www.linz.govt.nz/gdb
- LINZ coordinate converter
  - apps.linz.govt.nz/coordinate-conversion/
- LINZ Data Service – www.data.linz.govt.nz
- LINZ website - www.linz.govt.nz

National Geodetic Adjustment

- Provides consistency across country
  - 83,000 marks
  - 700,000 observations
- Includes:
  - All GPS/GNSS data since 1990s
  - Terrestrial geodetic observations
  - Levelling observations
- Consistent coordinates now maintained for entire geodetic network
- NZVD2016 heights published for all GNSS heighted marks



Geodetic Database

C66G: Mark details

MARK IDENTIFICATION

Code:	**C66G**	Country:	**New Zealand**
Name:	**SS M594 SO 48265**	Land District:	**North Auckland**
Alternatives:		Topo50 sheet:	**BA32**
		NZTM:	**5922849.750 1758324.090**

NZGD 2000 COORDINATES

Latitude:	**36° 49' 37.15291" S**	Order:	4	
Longitude:	**174° 46' 31.10079" E**	Authorised:	**30-Jun-2016**	Historical values
Ellipsoidal height (m):	**57.193**	Reference:	**National Geodetic Adjustment 2016-07-16**	

Circuit	Northing (m)	Easting (m)	Scale Factor	Convergence	
Mount Eden Circuit 2000	**805851.651**	**400993.653**	**0.9999000**	**+0° 00' 24"**	Historical values

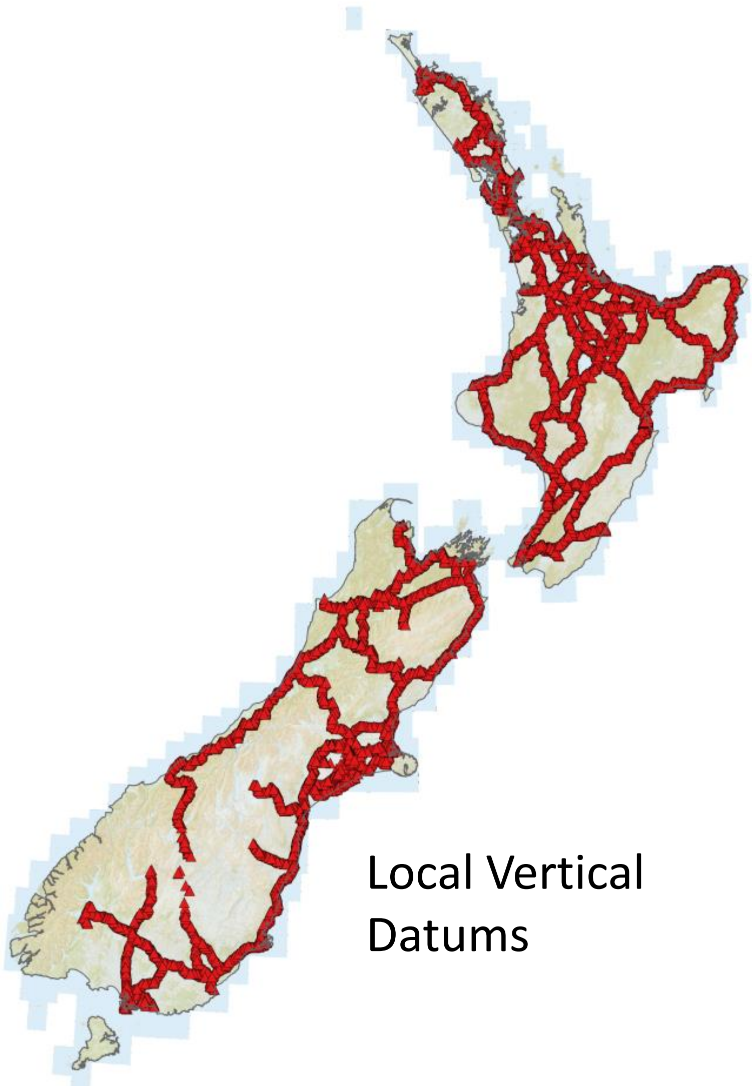
ORTHOMETRIC HEIGHTS

Height datum	Height (m)	Order	Calculation Date	Reference	Historical values
New Zealand Vertical Datum 2016	**22.605**	2V	**18-Nov-2016**	**NZVD2016 heights from National Geodetic Adjustment 9-11-2016**	
Auckland Vertical Datum 1946	**22.94**	3V	**22-Jan-1980**	**SO 54469 (Orthometric height order fixed 02-09-2014)**	

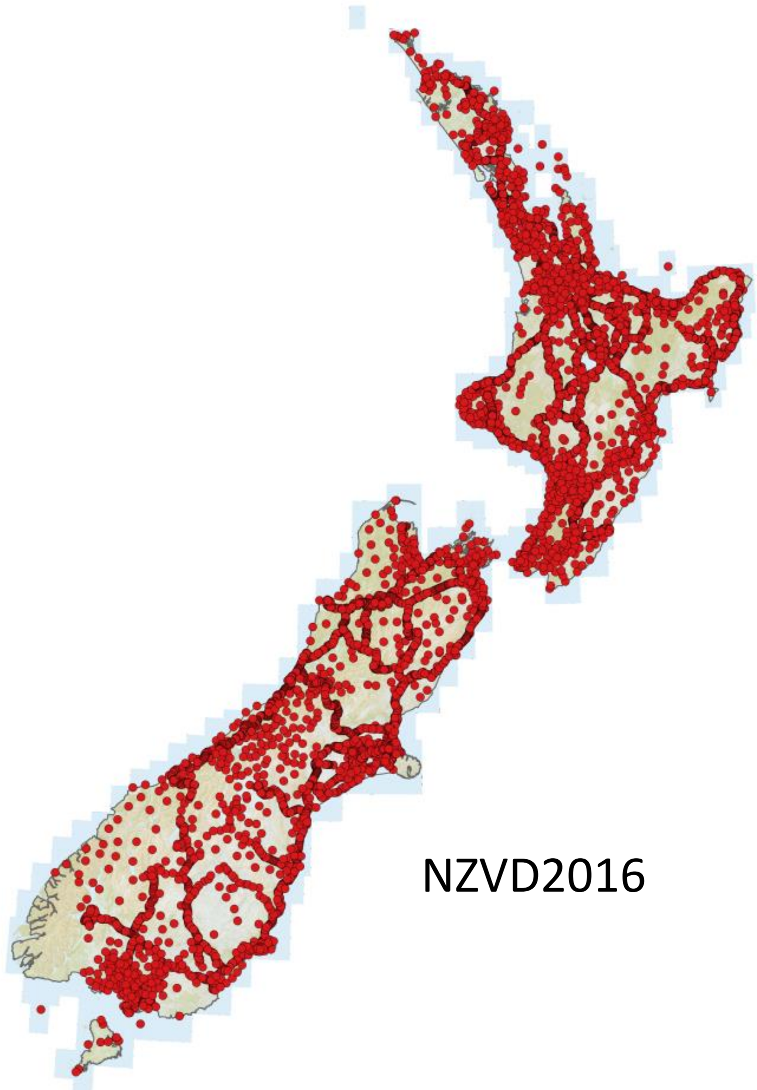
MARK DETAILS

Last maintained: **14-Jan-2010**

High Order Height Control

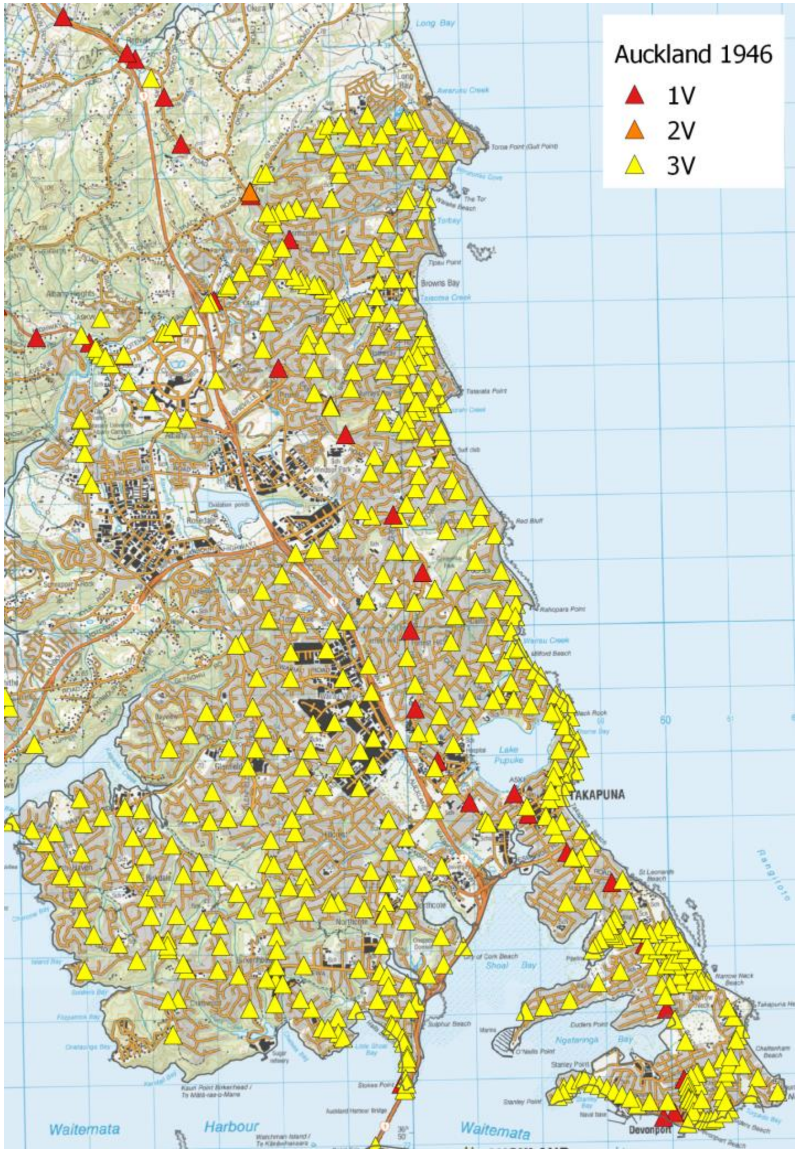


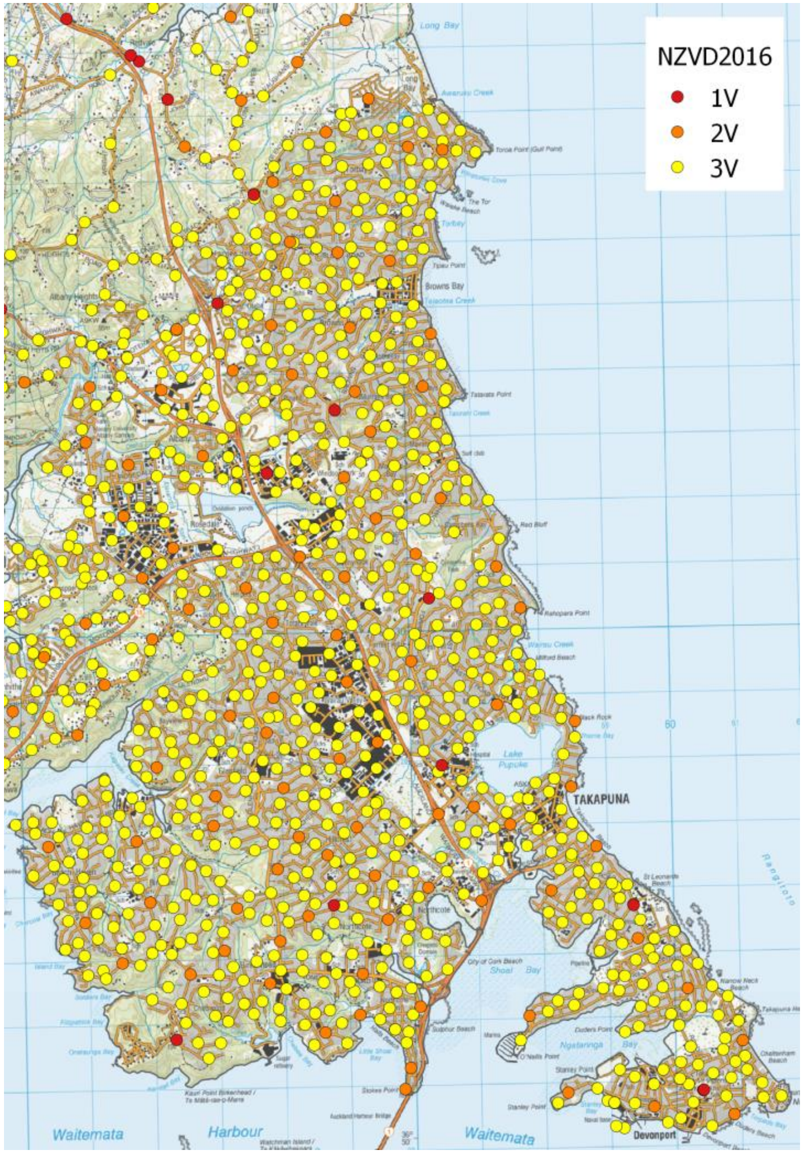
Local Vertical Datums



NZVD2016

Local Height Control





Online conversions / calculator

Online Conversions - advanced

The coordinate converter has been upgraded to account for the tectonic movement of New Zealand. This means that converting coordinates from global systems such as WGS84 and ITRF realisations to New Zealand coordinate systems requires a transformation date, and that the resulting coordinates are different to those from the previous less accurate version of the coordinate converter.

The LINZ website has more information on the changes

The previous version of the converter will be available until the end of 2016.

Convert between pre-selected geodetic datums and projections using default input and output parameters.

Use the basic online conversion to choose between pre-selected datums and projections using default input and output parameters.

Use the vertical datum conversion to convert between New Zealand vertical datums - see instructions for carrying out height conversions for more information.

Input coordinate system

New Zealand Geodetic Datum 2000 (version 20160701) | Details

Coordinate order — Choose whether input coordinates have northing (latitude) or easting (longitude) coordinates first.
- North/East (selected)
- East/North

Coordinate format — Choose whether latitudes and longitudes are entered as degrees, minutes, and seconds (eg 41 30 25.3 S) degrees and minutes (eg 41 30.42 S) or decimal degrees (eg -41.50703). (This is ignored for projection coordinate systems)
- Degrees/minutes/seconds (selected)
- Degrees/minutes
- Decimal degrees

Height coordinate system — Select the height coordinate to enter - none, ellipsoidal, or an orthometric system. Note: Ellipsoidal heights are in terms of the ellipsoid of the input coordinate system.
- Ellipsoidal

Output coordinate system

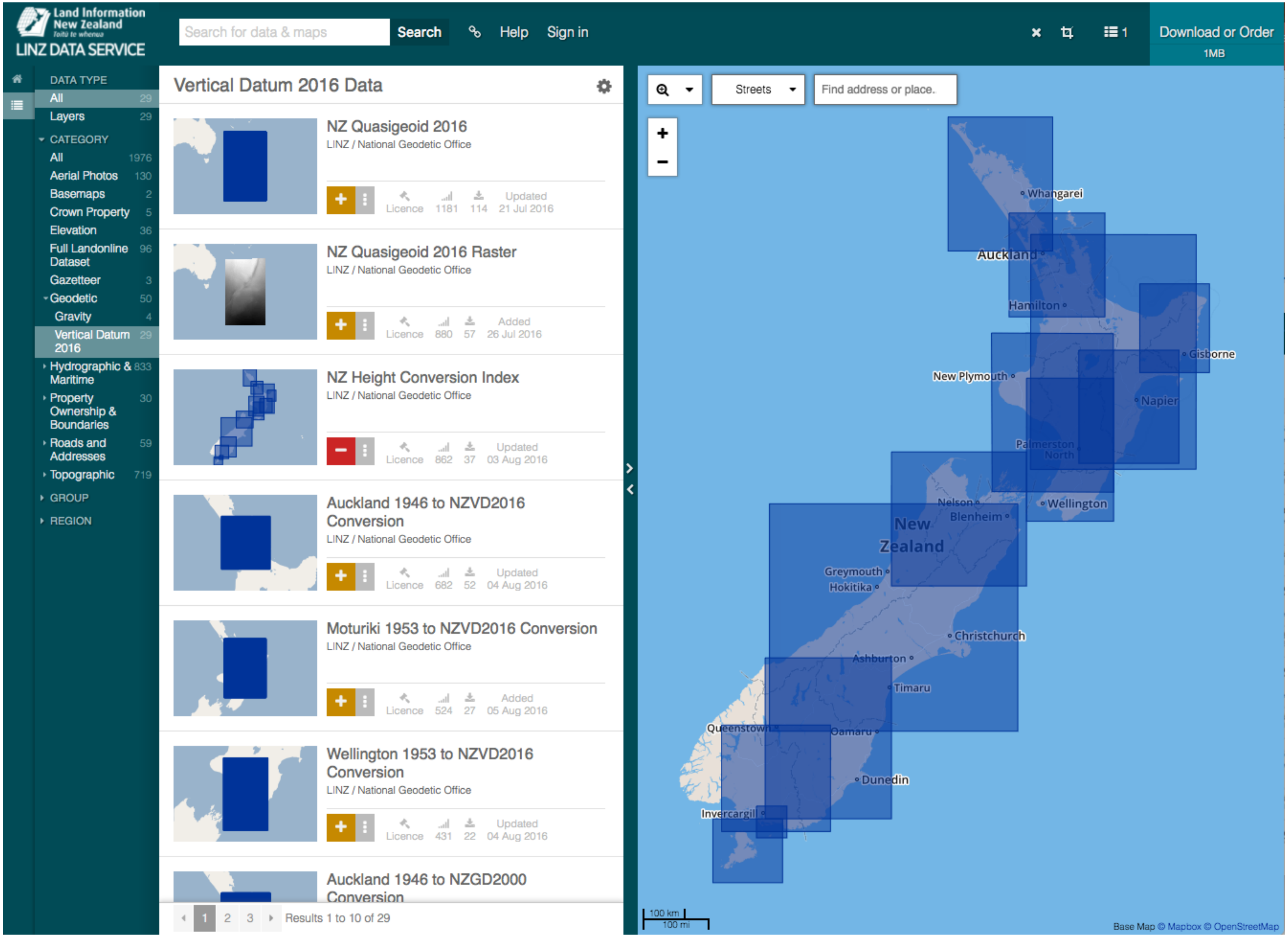
New Zealand Geodetic Datum 2000 (version 20160701) | Details

Coordinate order — Choose whether output coordinates have northing (latitude) or easting (longitude) coordinates first.
- North/east (selected)
- East/north

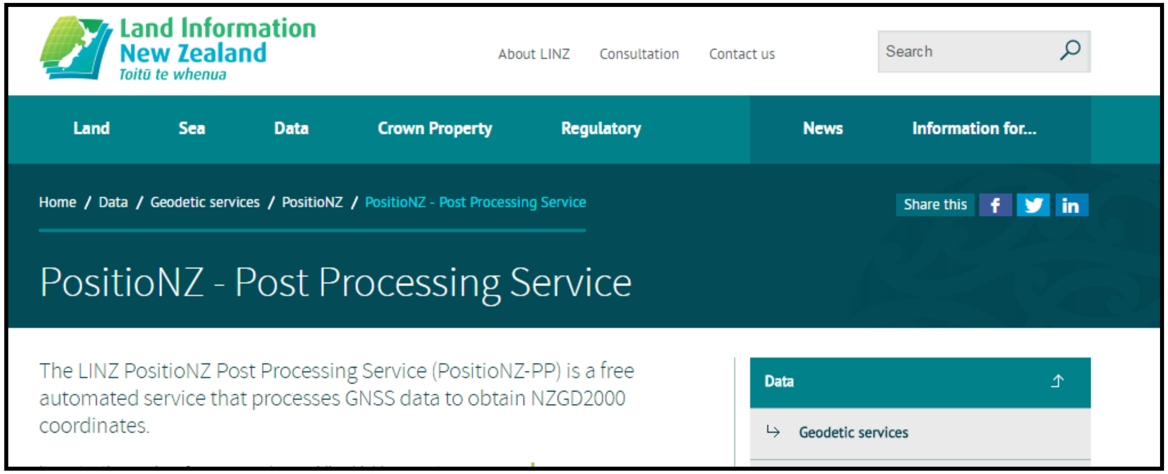
Coordinate format — Choose whether latitudes and longitudes are output as degrees, minutes, and seconds (eg 41 30 25.3 S), degrees and minutes (eg 41 30.42 S) or decimal degrees (eg -41.50703) (This is ignored for projection coordinate systems)
- Degrees/minutes/seconds (selected)
- Degrees/minutes
- Decimal degrees

Height coordinate system — Select the height coordinate to calculate - none, ellipsoidal, an orthometric height coordinate, or geoid heights. Note: The geoid height option calculates the height of the geoid at the point - not the height of the point above the geoid. To get the height of the point above the geoid you must pick an orthometric height system (eg New Zealand Vertical Datum 2009). Ellipsoidal and geoid heights are in terms of the ellipsoid of the output coordinate system.
- New Zealand Vertical Datum 2016

LINZ Data Service



Establishing vertical control

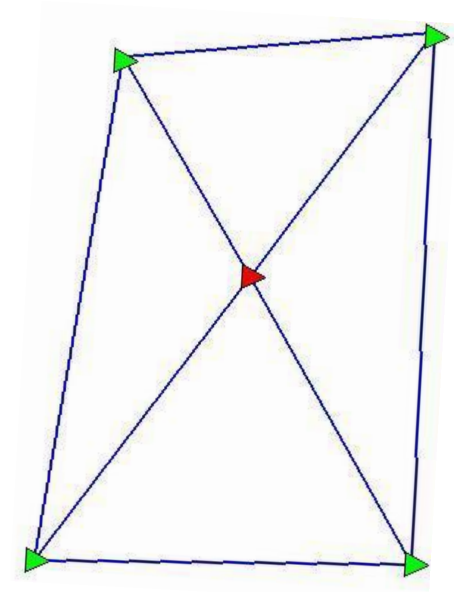


http://www.linz.govt.nz/positionzpp

- Computes control points for free
- Uses nearest 3 PositioNZ sites
- ~6 hours data needed

Linking to other local datums

- Official relationships only provided to 13 main local datums
- Users need to compute local offsets by site transformation:
  - Observe a number locally heighted marks with GNSS
  - Calculate the NZVD2016 heights for the marks
  - Determine difference between NZVD2016 and local height
- Only applicable over small areas
- Dependent on choice of marks



Part IV – The Future

Geoid Maintenance



Geoid Maintenance

- Maintenance may or may not be needed
  - More data acquired
  - Mass changes
- Extra data can be incrementally added
  - In NZ case more likely to be with datum relationships
- Geoid changes caused by mass movements
  - Mega-thrust earthquakes causing significant uplift
  - Glacial Isostatic Adjustment (not in NZ)

Part V – Summary

How to Develop a Datum?

- Decide what you want from a datum
  - Regional interoperability
  - MSL alignment
  - Accuracy
  - Support for existing data and datums
- Funding
- Implementation
  - All at once
  - Develop in stages
- How will you effect uptake?

Things to Consider

- What data is available in your country
  - Gravity
  - GNSS-levelling
  - Tide gauges
  - Elevation models
- What datums are currently used
- What do the users of your datum want/need?
  - Accuracy
  - Spatial coverage
  - GNSS compatibility