the power of where drives NZ's success

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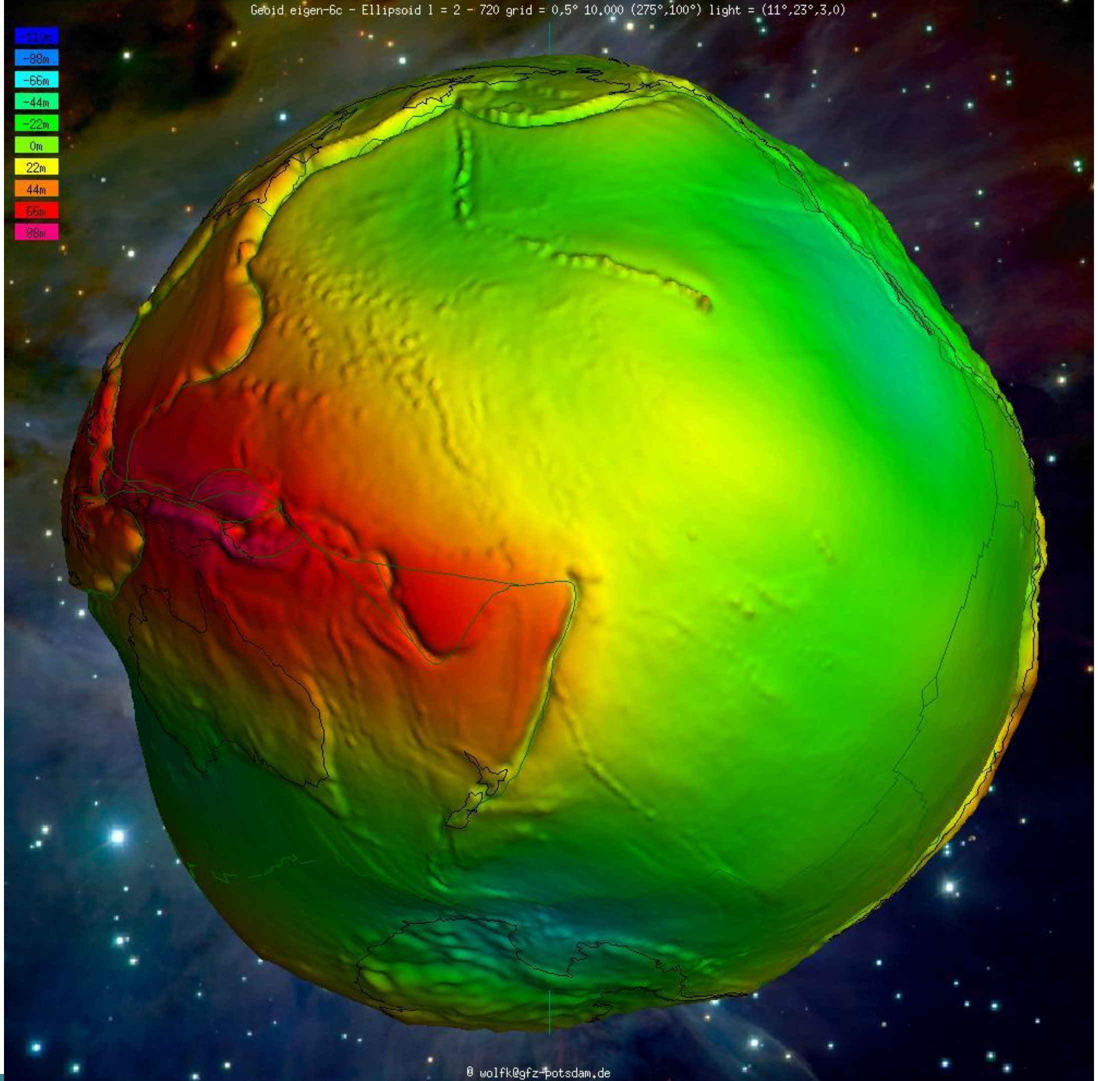
Geoids and Vertical Datums

Matt Amos | Deputy Chief Geodesist
Location Information

PGSC Height Datum Workshop, Suva, November 2016

Part I – Geoids


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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Global Geoids

- Derived from analysis of satellite measurements
- Long wavelength (low resolution)
- Consist of spherical harmonic coefficients (SHM)
- Modern GGMs to very high degree & order
- Geoid, gravity & geopotential quantities can be computed from SHM
- Some include surface gravity data, e.g. EGM2008
- Most are purely satellite-based


ICGEM International Center for
Matt
icgem.gfz-potsdam.de/ICGEM/
IAG
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Helmholtz Centre
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International Centre for Global Earth Models (ICGEM)
GFZ Potsdam
ICGEM Home
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3D Visualization of Spherical Harmonics
Time varying gravity (G³ Browser)
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

Nr ▲	Model ⇅	Year ⇅	Degree ⇅	Data ⇅	Reference ⇅	download	calculate	show	doi
158	HUST-Grace2016s	2016	160	S(Grace)	Zhou Hao et al, 2016	gfc zip	calculate	show	✔
157	ITU_GRACE16	2016	180	S(Grace)	Akyilmaz et al, 2016b	gfc zip	calculate	show	✔
156	ITU_GGC16	2016	280	S(Grace,Goce)	Akyilmaz et al, 2016a	gfc zip	calculate	show	✔
155	EIGEN-6S4v2	2016	300	S(Goce,Grace,Lageos)	Förste et al, 2016	gfc zip	calculate	show	✔
154	GOCO05c	2016	720	S,G,A (see model)	Pail, et al. 2016	gfc zip	calculate	show	✔
153	GGM05C	2016	360	S(Grace,Goce),G,A	Ries et al, 2016	gfc zip	calculate	show	✔
152	GECO	2015	2190	S(Goce),EGM2008	Gilardoni et al, 2015	gfc zip	calculate	show	
151	GGM05G	2015	240	S(Grace,Goce)	Bettadpur et al, 2015	gfc zip	calculate	show	
150	GOCO05s	2015	280	S(see model)	Mayer-Gürr, et al. 2015	gfc zip	calculate	show	
149	GO_CONS_GCF_2_SPW_R4	2014	280	S(Goce)	Gatti et al, 2014	gfc zip	calculate	show	
148	EIGEN-6C4	2014	2190	S(Goce,Grace,Lageos),G,A	Förste et al, 2015	gfc zip	calculate	show	✔
147	ITSG-Grace2014s	2014	200	S(Grace)	Mayer-Gürr et al, 2014	gfc zip	calculate	show	
146	ITSG-Grace2014k	2014	200	S(Grace)	Mayer-Gürr et al, 2014	gfc zip	calculate	show	
145	GO_CONS_GCF_2_TIM_R5	2014	280	S(Goce)	Brockmann et al, 2014	gfc zip	calculate	show	
144	GO_CONS_GCF_2_DIR_R5	2014	300	S(Goce,Grace,Lageos)	Bruinsma et al, 2013	gfc zip	calculate	show	
143	JYY_GOCE04S	2014	230	S(Goce)	Yi et al, 2013	gfc zip	calculate	show	
142	GOGRA04S	2014	230	S(Goce,Grace)	Yi et al, 2013	gfc zip	calculate	show	
141	EIGEN-6S2	2014	260	S(Goce,Grace,Lageos)	Rudenko et al. 2014	gfc zip	calculate	show	
140	GGM05S	2014	180	S(Grace)	Tapley et al, 2013	gfc zip	calculate	show	
139	EIGEN-6C3stat	2014	1949	S(Goce,Grace,Lageos),G,A	Förste et al, 2012	gfc zip	calculate	show	
138	Tongji-GRACE01	2013	160	S(Grace)	Shen et al, 2013	gfc zip	calculate	show	
137	JYY_GOCE02S	2013	230	S(Goce)	Yi et al, 2013	gfc zip	calculate	show	
136	GOGRA02S	2013	230	S(Goce,Grace)	Yi et al, 2013	gfc zip	calculate	show	
135	ULux_CHAMP2013s	2013	120	S(Champ)	Weigelt et al, 2013	gfc zip	calculate	show	
134	ITG-Goce02	2013	240	S(Goce)	Schall et al, 2014	gfc zip	calculate	show	
133	GO_CONS_GCF_2_TIM_R4	2013	250	S(Goce)	Pail et al, 2011	gfc zip	calculate	show	
132	GO_CONS_GCF_2_DIR_R4	2013	260	S(Goce,Grace,Lageos)	Bruinsma et al, 2013	gfc zip	calculate	show	

Global Geoids

- Determined by degree and order of GGM
  - EGM96 (D/O 360) = 55 km
  - EGM2008 (D/O 2160) = 9 km
- Often accurate to sub-decimetre
  - But at low resolution

Regional Geoids

- Locally enhanced global models
- Incorporate additional gravity observations from multiple sources: terrestrial, shipborne, airborne and altimetry
- Various computational techniques: LS 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

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Part II – Datum Development from a NZ Perspective

Reference Surfaces

- Choice of reference surface depends on:
  - Type of height being used
  - Method of height transfer
  - Scale of datum
  - Purpose of datum

Reference Surfaces

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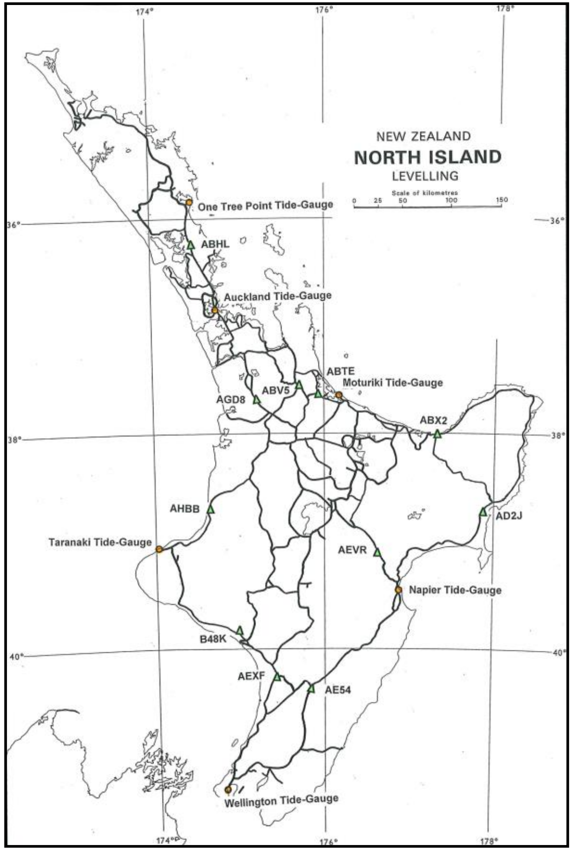
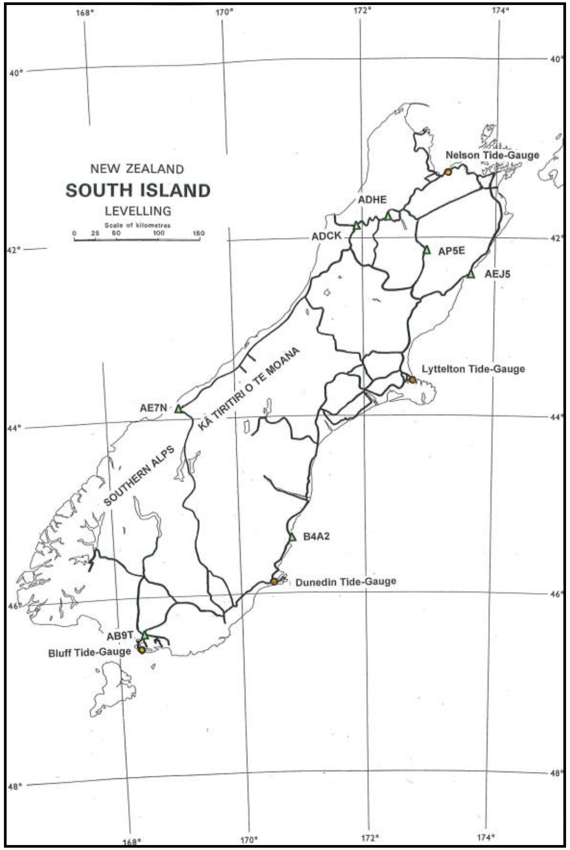
- Physical reference surface
  - Frequently mean sea level
  - Fix MSL at a single point
  - Fix MSL at several points
  - Arbitrary level at a single point
- Virtual reference surface
  - Geoid/quasigeoid model
  - Ellipsoid

NZ’s legacy datums





Why did NZ develop datum?

- 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

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Disaster recovery

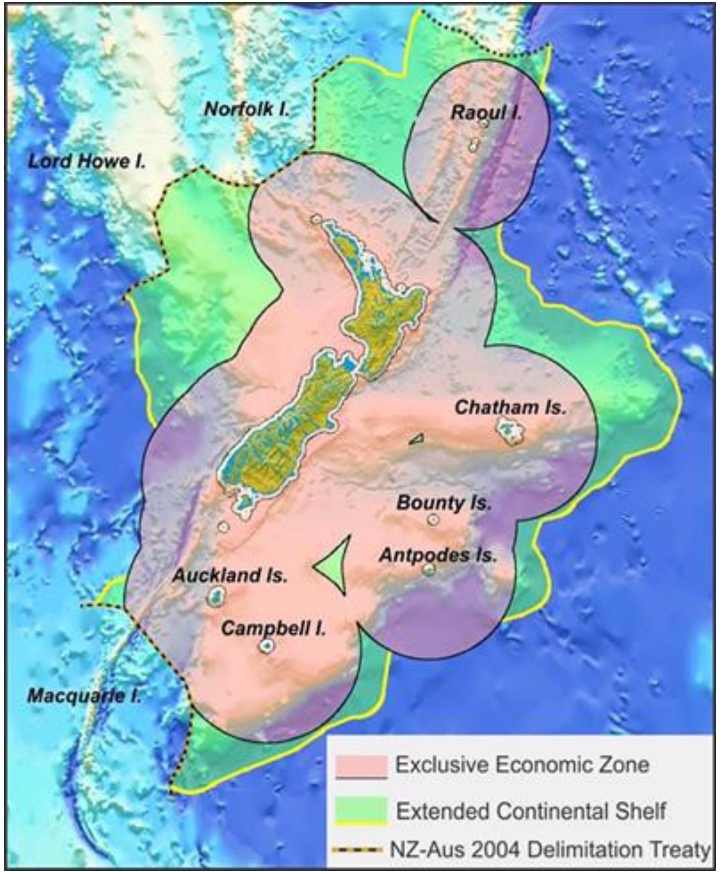
- Heights re-established by levelling
- 400 marks, 500 km

- 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



Geoid based vertical datums

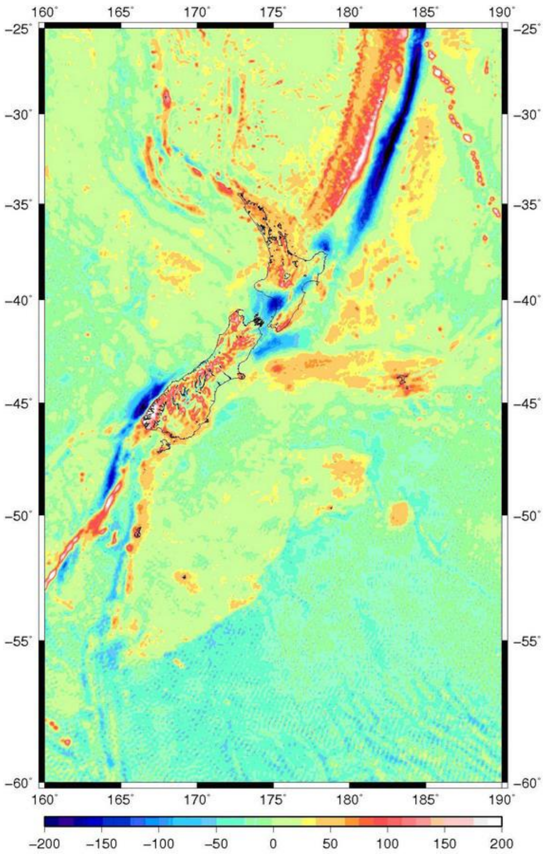
- Advantages:
  - No more national-scale levelling
  - Accessibility to the vertical datum using GNSS
- Disadvantages:
  - Low reliability in areas with poor gravity data coverage
  - Lower accuracy over short distances compared to levelling
  - Must minimise GNSS height errors (e.g. long occupation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

NZVD2009 Development

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

New Zealand Quasigeoid 2009

- Datasets:
  - EGM2008



New Zealand Quasigeoid 2009

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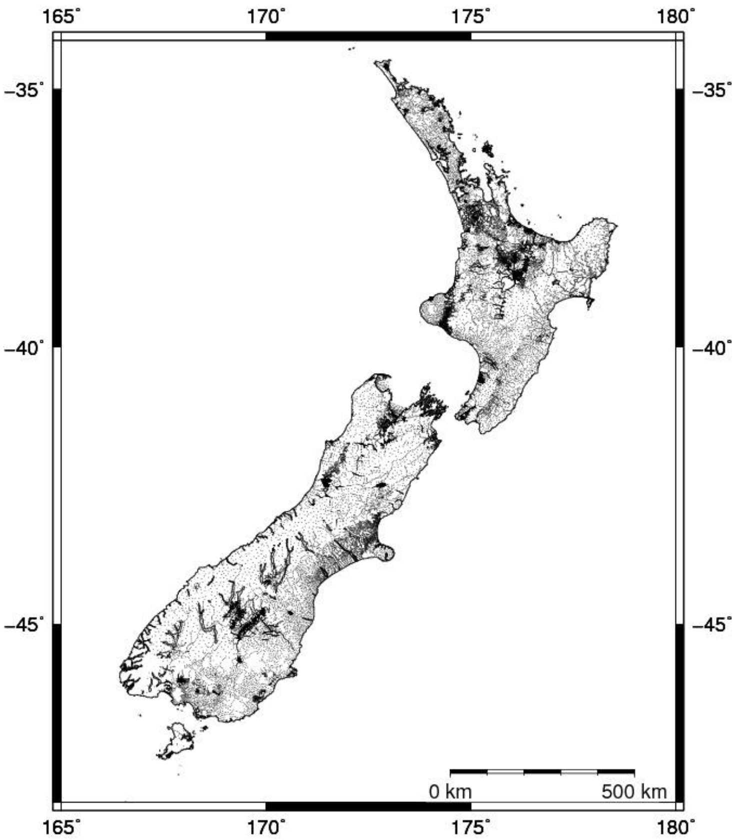
- Datasets:
  - EGM2008
  - Land gravity data



New Zealand Quasigeoid 2009

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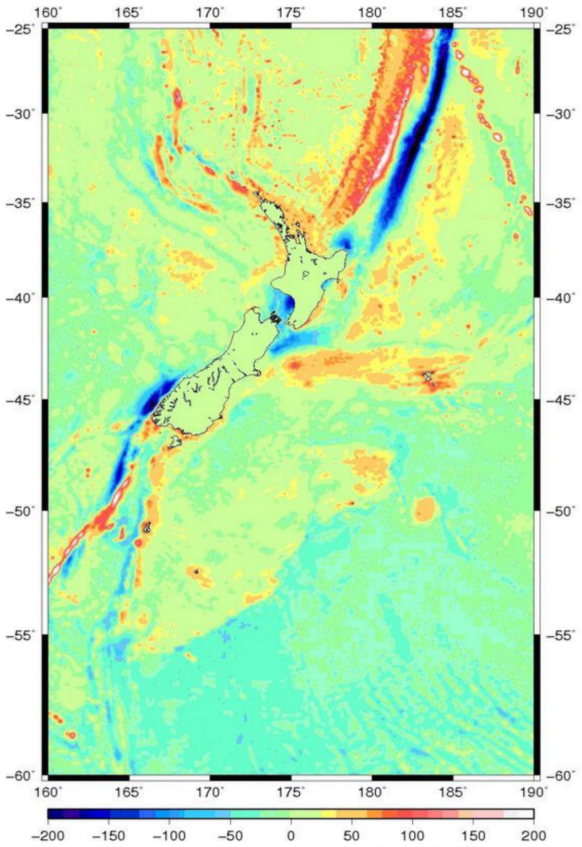
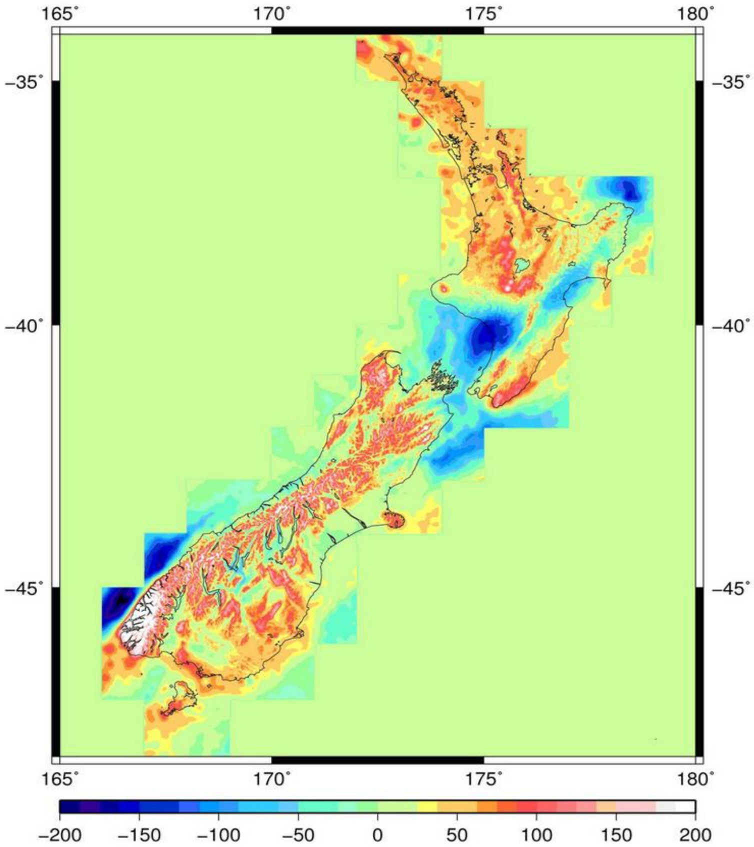
- Datasets:
  - EGM2008
  - Land gravity data
  - DNSC08 altimetry



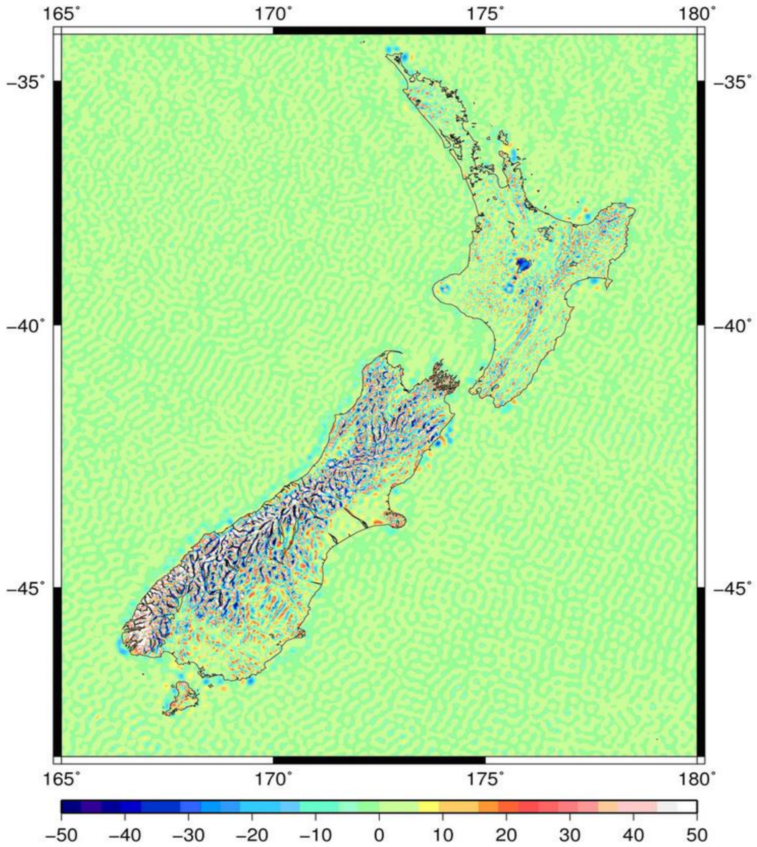
New Zealand Quasigeoid 2009

- Datasets:
  - EGM2008
  - Land gravity data
  - DNSC08 altimetry
  - Digital elevation model



New Zealand Quasigeoid 2009

- Datasets:
  - EGM2008
  - Land gravity data
  - DNSC08 altimetry
  - Digital elevation model
- Subtract EGM2008



New Zealand Quasigeoid 2009

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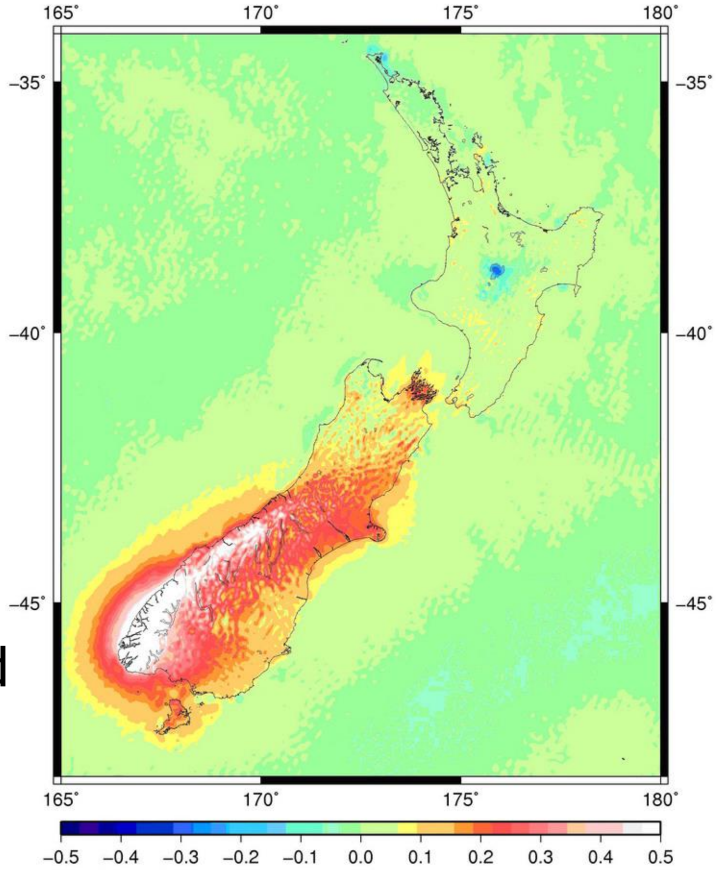
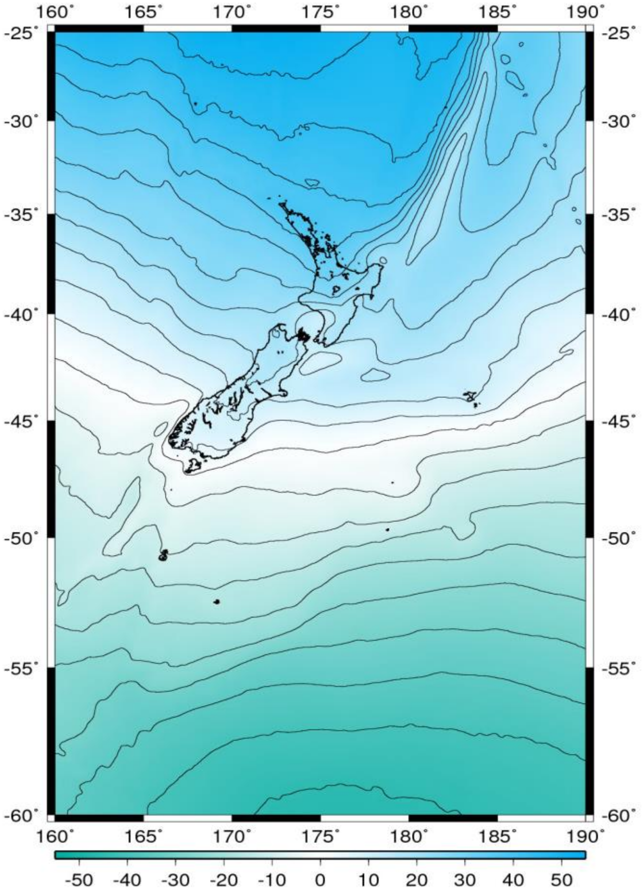
- Datasets:
  - EGM2008
  - Land gravity data
  - DNSC08 altimetry
  - Digital elevation model
- Subtract EGM2008
- Fourier transform to residual geoid



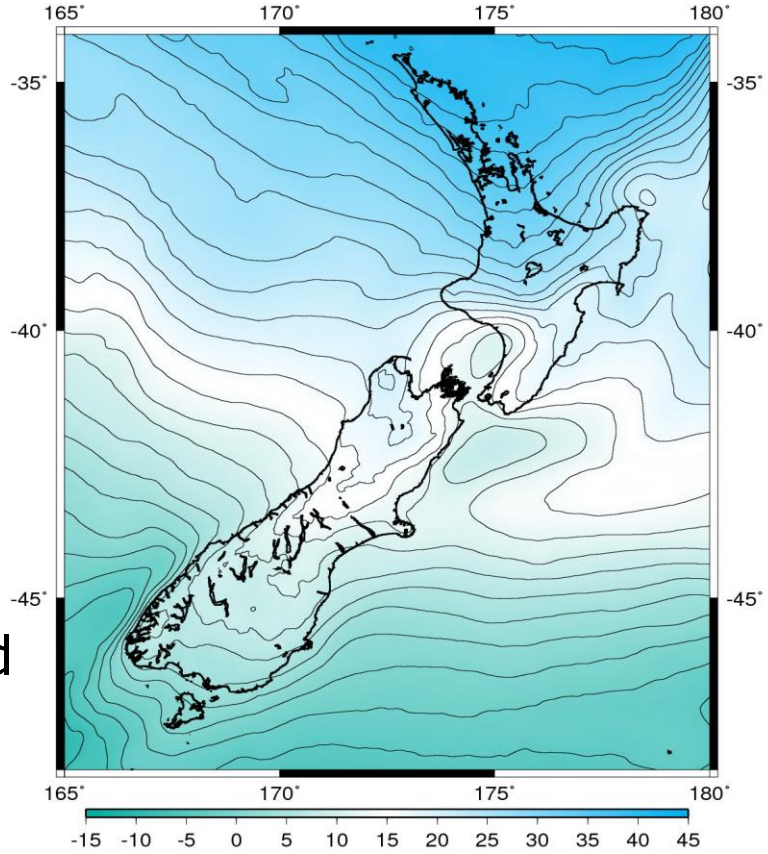
New Zealand Quasigeoid 2009

- Datasets:
  - EGM2008
  - Land gravity data
  - DNSC08 altimetry
  - Digital elevation model
- Subtract EGM2008
- Fourier transform to residual geoid
- Add back EGM2008



New Zealand Quasigeoid 2009

- Datasets:
  - EGM2008
  - Land gravity data
  - DNSC08 altimetry
  - Digital elevation model
- Subtract EGM2008
- Fourier transform to residual geoid
- Add back EGM2008
- NZGeoid2009



New Zealand Vertical Datum 2009

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- 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 (2012 – 2016)

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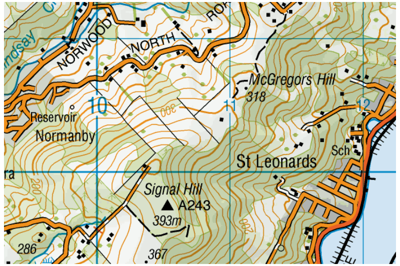
Cadastral Surveyors

Local Government

Hydrographic Charting



Topographic Mapping

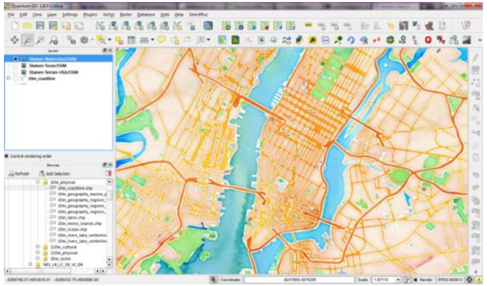
NZVD2016

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

NZVD2009

Scientific Monitoring

GIS



Recreational GNSS

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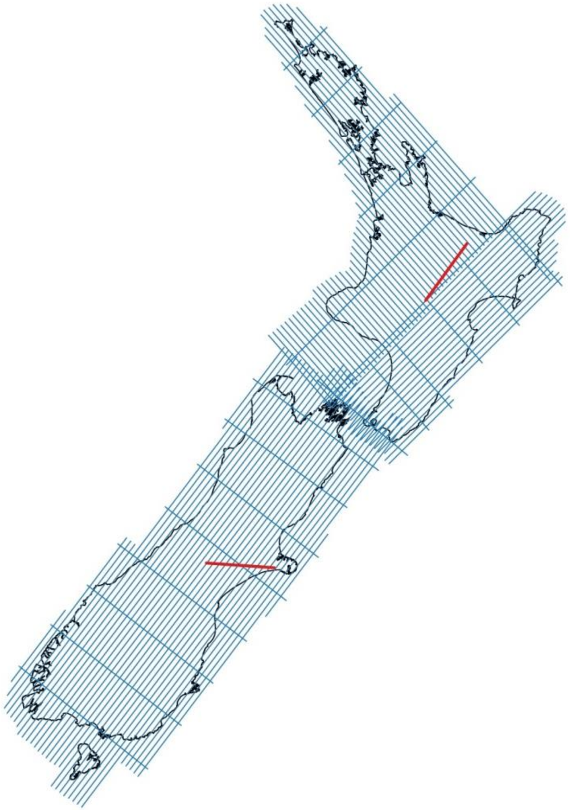
Airborne gravity survey

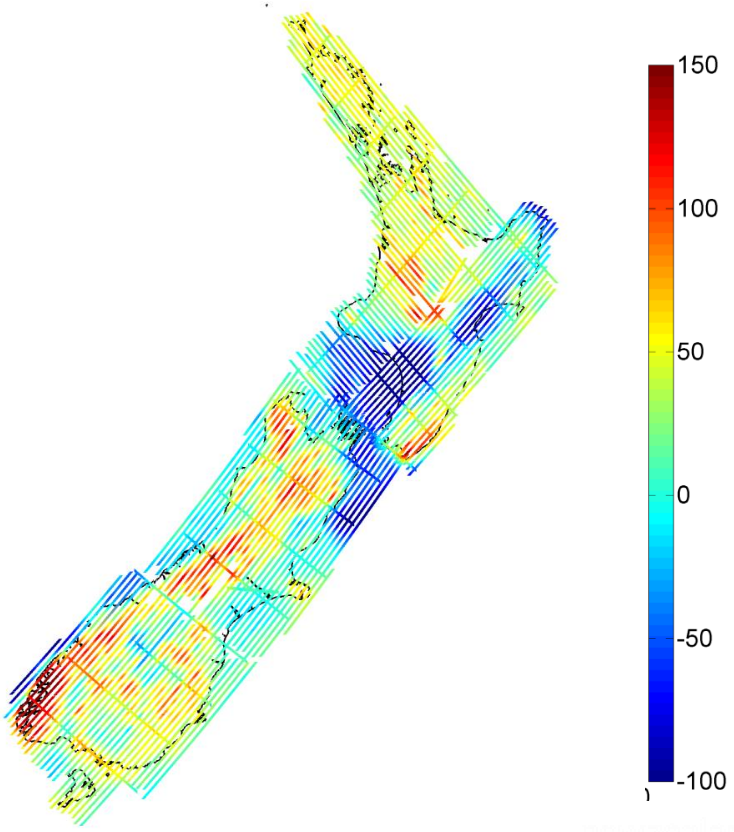
- Eight month campaign
  - August – October 2013
  - February – June 2014
- 75 flights / 425 flying hours
- 50,000 line km

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

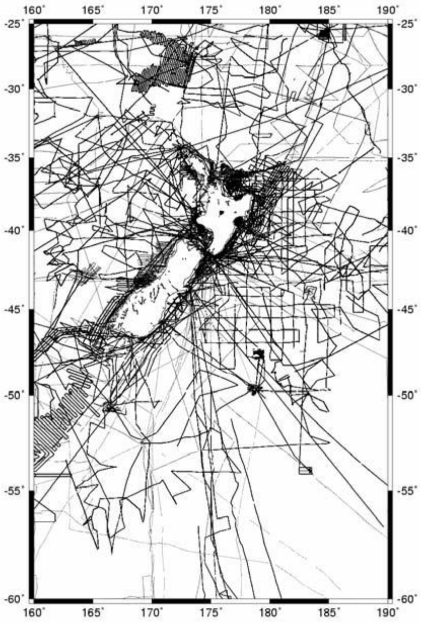
GNS SCIENCE
TE PŪ AO

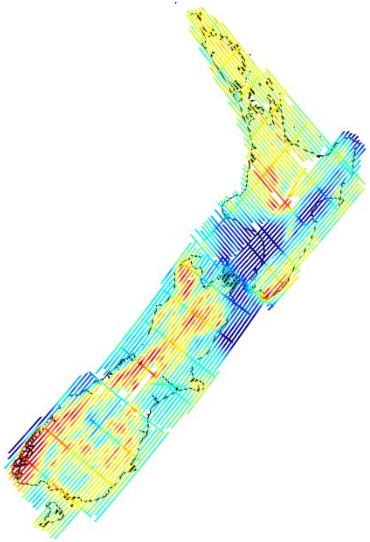
Airborne gravity anomalies

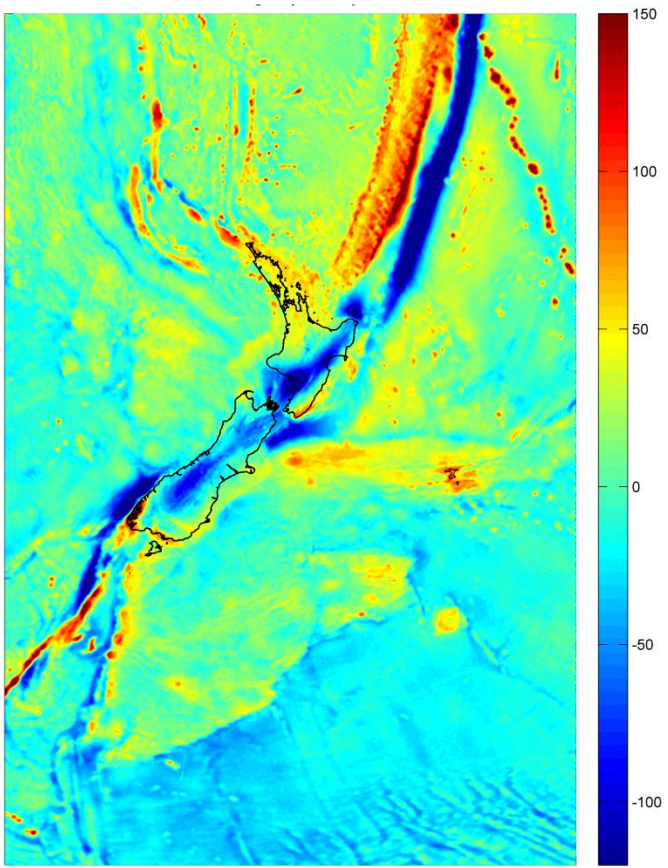




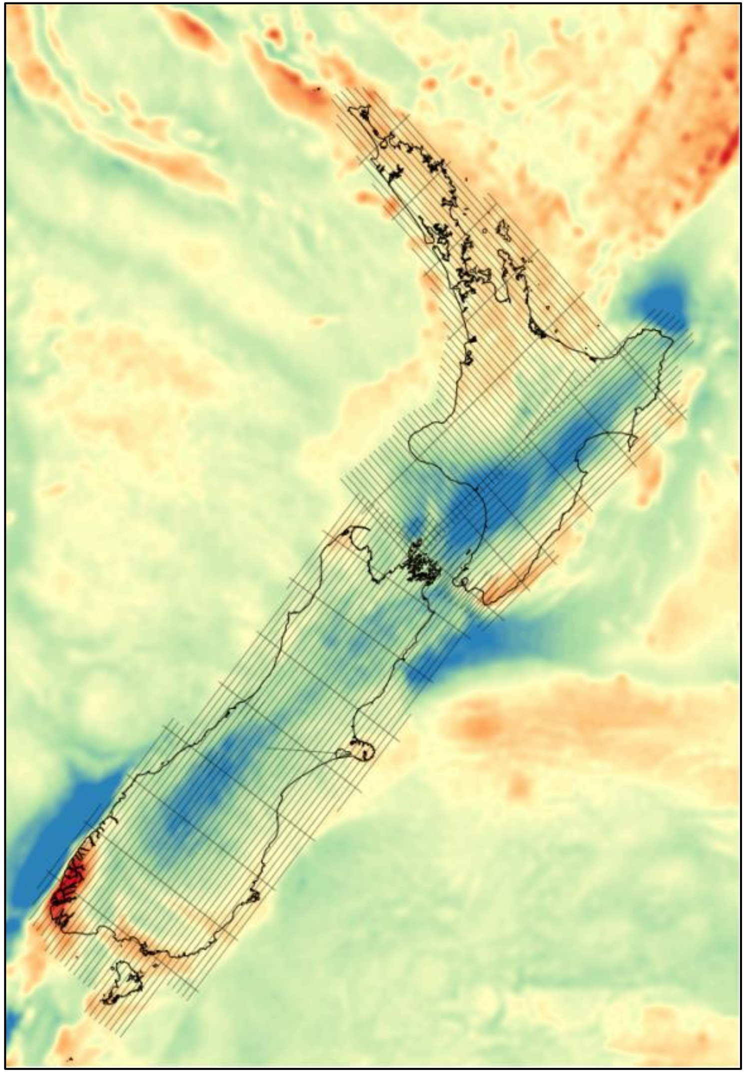
NZGeoid2016 source data





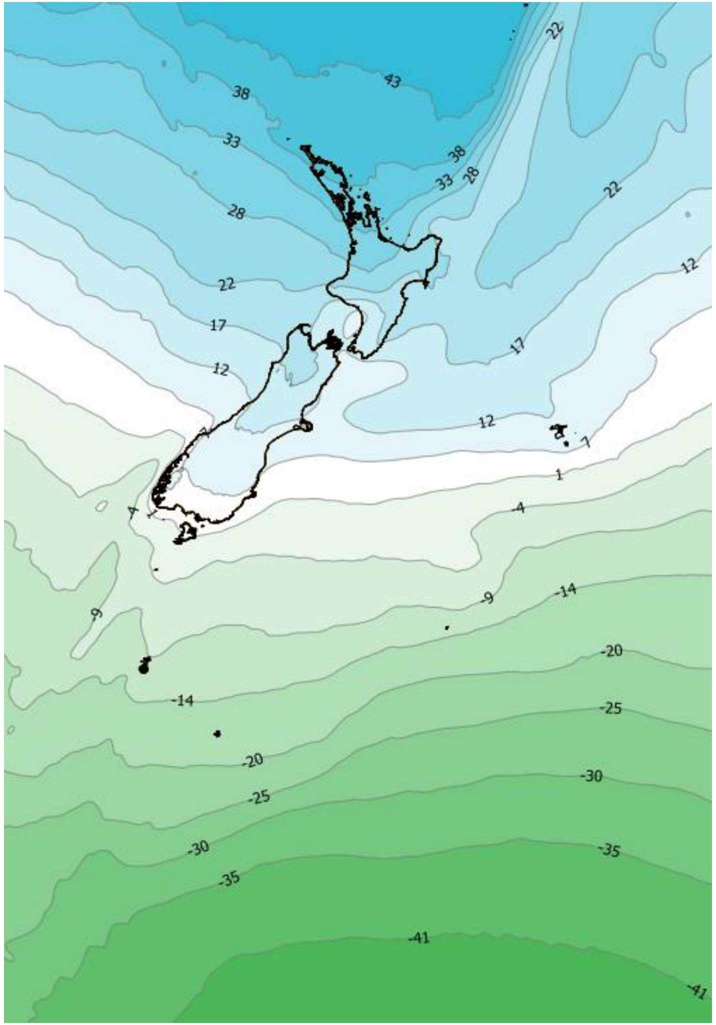


National gravity anomaly map



New Zealand 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



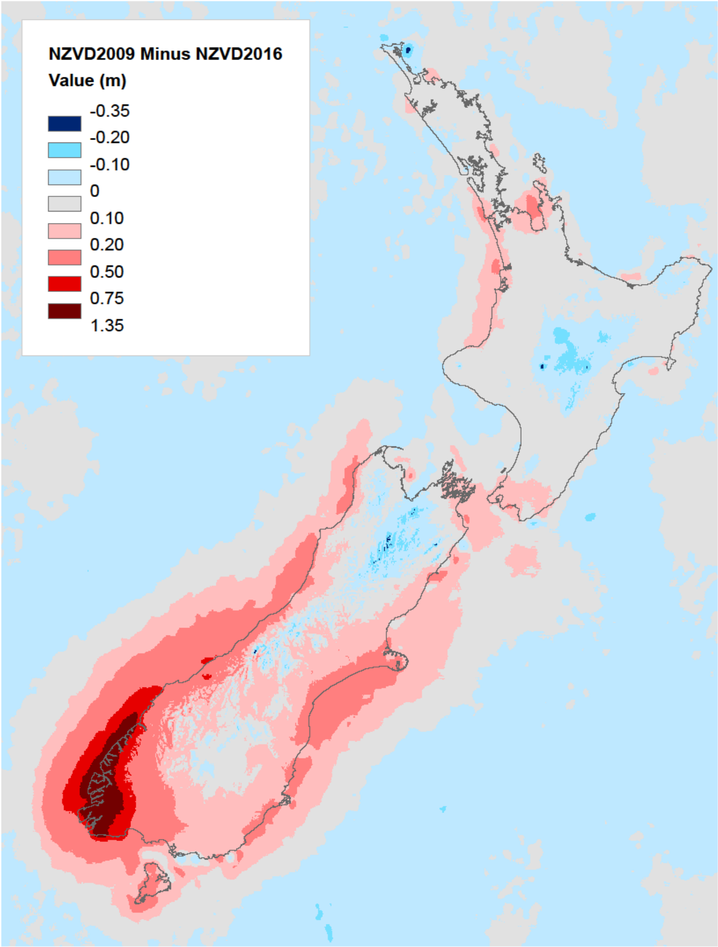
Differences between NZGeoid2009 and NZGeoid2016

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

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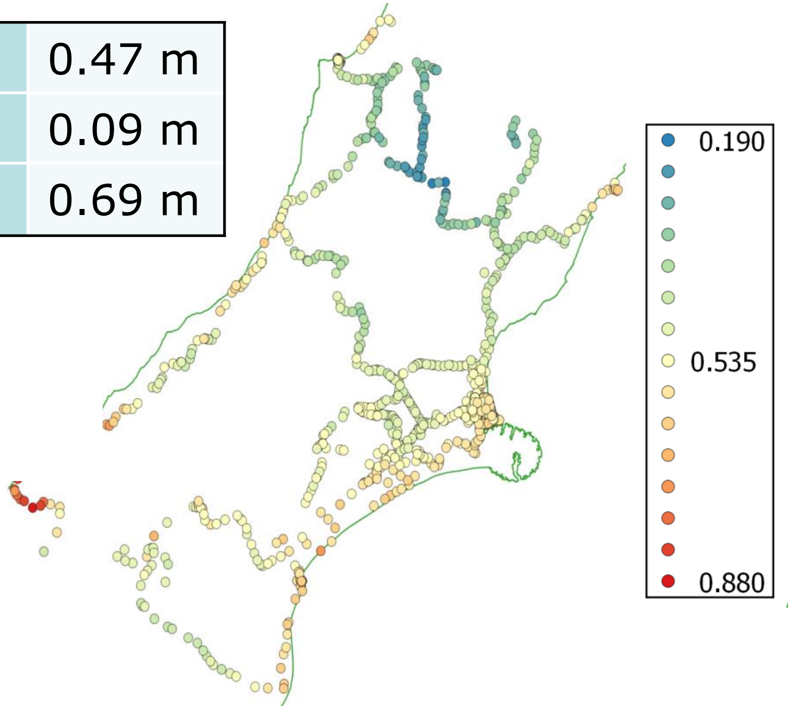
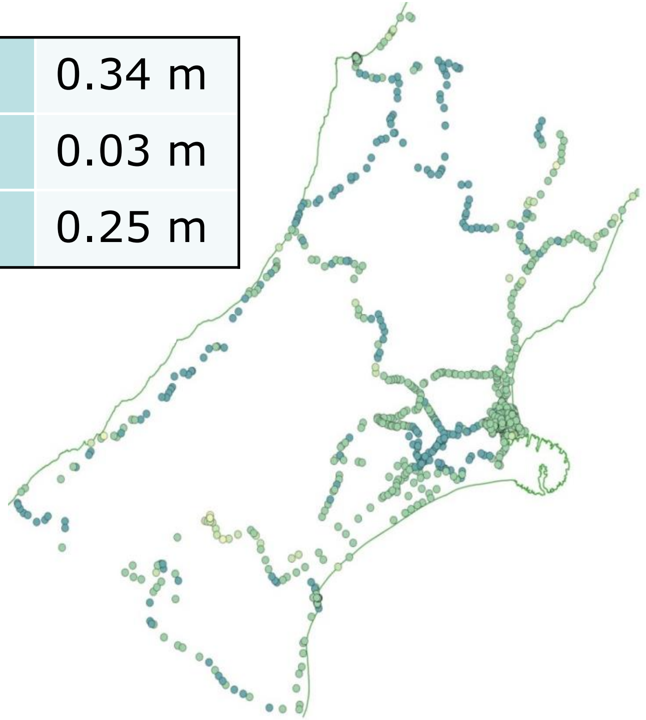
Mean	0.47 m
SD	0.09 m
Range	0.69 m



NZGeoid2009

Mean	0.34 m
SD	0.03 m
Range	0.25 m



NZGeoid2016

Offset comparison table

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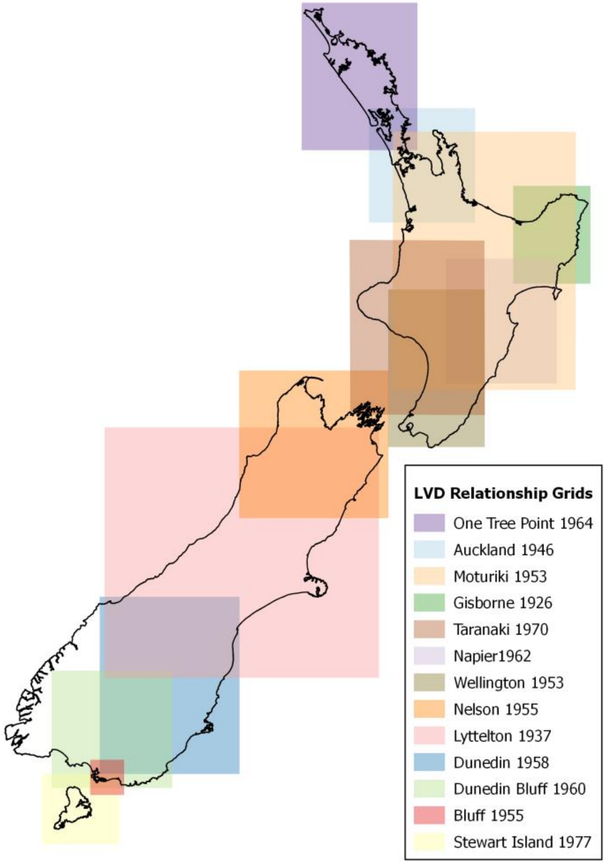
Datum	2009 Offset (m)	SD (m)	Range (m)	2016 Offset (m)	SD (m)	Range (m)
Auckland	0.34	0.05	**0.22**	0.29	0.04	**0.12**
Bluff	0.36	0.05	**0.23**	0.27	0.04	**0.12**
Dunedin-Bluff	0.38	0.04	**0.33**	0.25	0.04	**0.16**
Dunedin	0.49	0.07	**0.30**	0.33	0.03	**0.25**
Gisborne	0.34	0.02	**0.19**	0.34	0.02	**0.12**
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	STD
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

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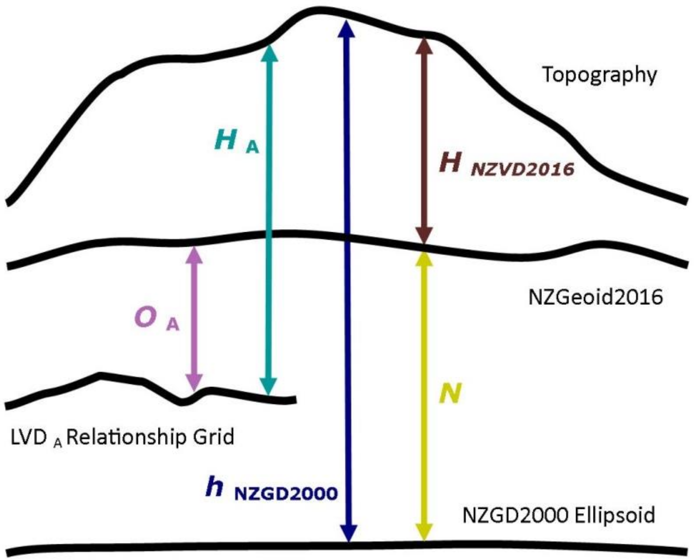


NZVD2016 heights (**H**) can be determined by subtracting a NZGeoid2016 height (**N**) from an ellipsoid/GNSS height (**h**)

$$H = h - N$$

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

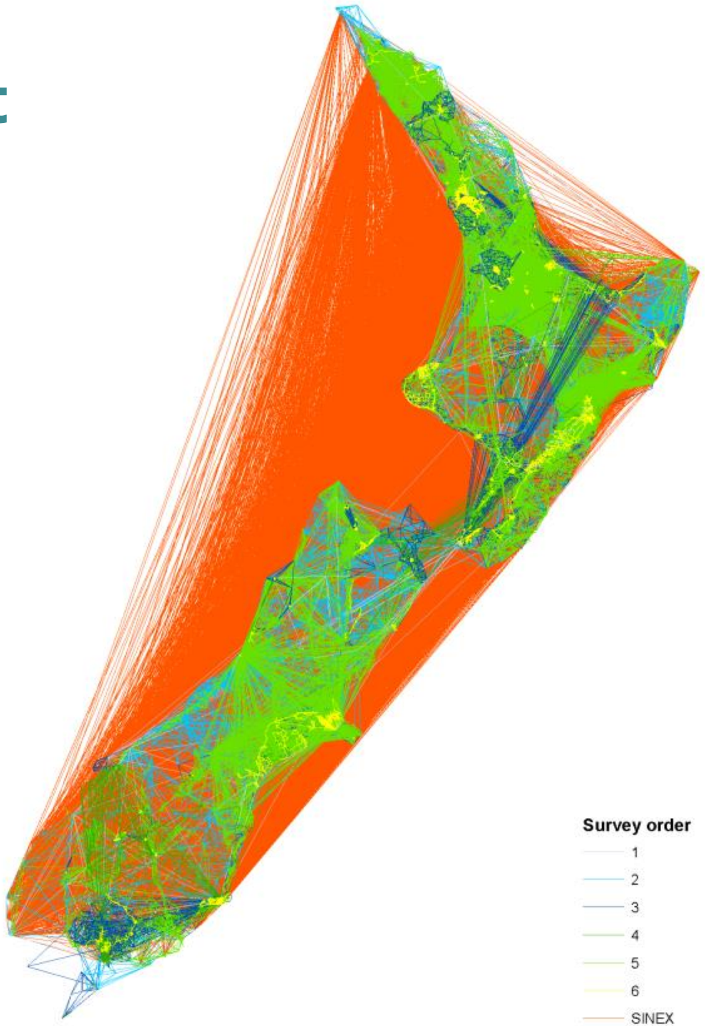
$$H_A = H + O_A$$

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

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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**	
Ellipsoidal height (m):	**57.193**	Reference:	**National Geodetic Adjustment 2016-07-16**	Historical values

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

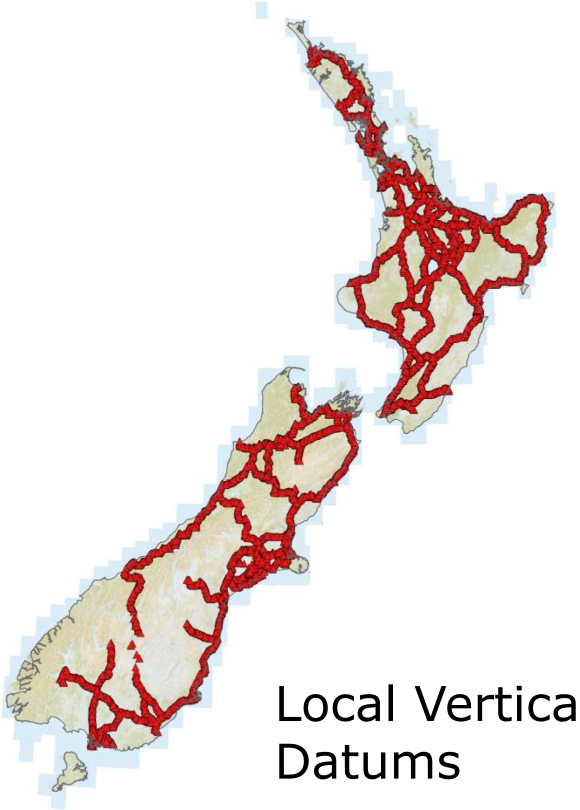
ORTHOMETRIC HEIGHTS

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)**	

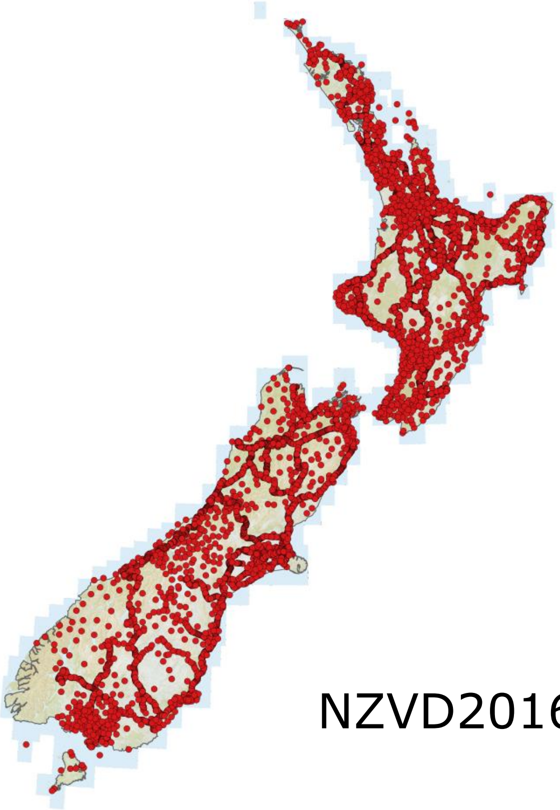
MARK DETAILS

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

High Order Height Control

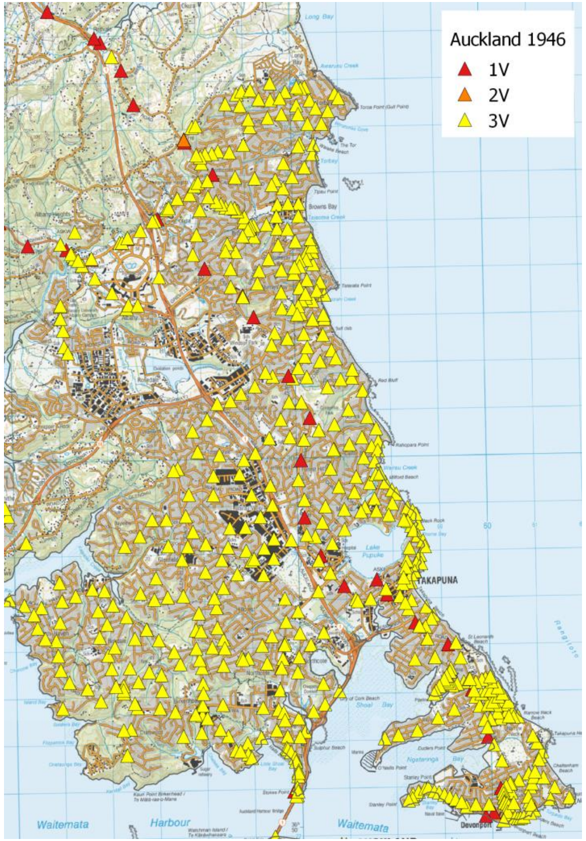


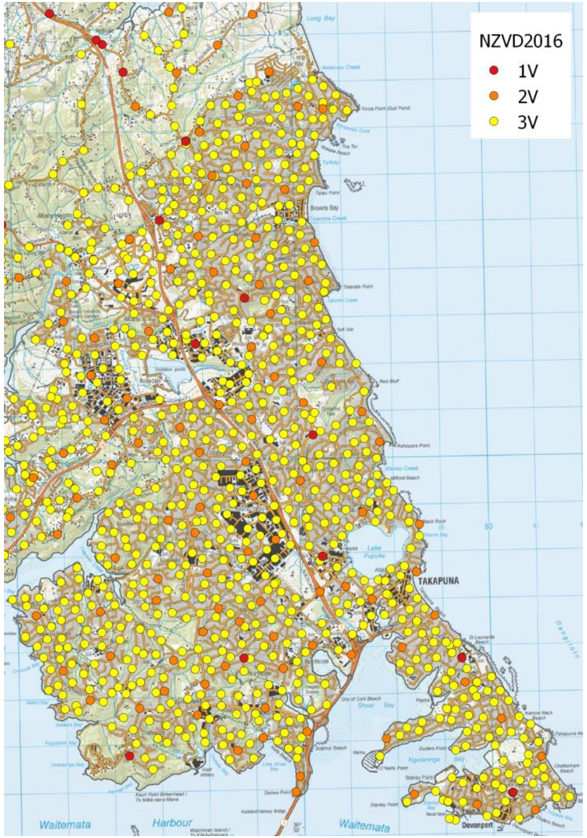
Local Vertical Datums



NZVD2016

Local Height Control





Online conversions and calculator

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output formats (including bulk options) that are more suited to users with an understanding of coordinate and height conv

Input height system

[Ellipsoidal ▾]

Select the height coordinate to enter - none, ellipsoidal, or an orthometric system. N
in terms of the ellipsoid of the input coordinate system.

Output height system

[Ellipsoidal ▾]

Select the height coordinate to calculate - none, ellipsoidal, an orthometric height co
Note: The geoid height option calculates the height of the geoid at the point - not the
the geoid. To get the height of the point above the geoid you must pick an orthomet
Zealand Vertical Datum 2009). Ellipsoidal and geoid heights are in terms of the ellip
system.

Horizontal coordinate system

[New Zealand Geodetic Datum 2000 (version 20160701) ▾] [Details]

Coordinate order
- ○ North/East
- ◉ East/North

Choose whether input coordinates have northing (latitude) or easting (longitude) coo

Coordinate format
- ◉ Degrees/minutes/seconds
- ○ Degrees/minutes
- ○ Decimal degrees

Choose whether latitudes and longitudes are entered as degrees, minutes, and secon
degrees and minutes (eg 41 30.42 S) or decimal degrees (eg -41.50703). (This is ig
coordinate systems)

[Enter coordinates] [Basic options]

LINZ Data Service

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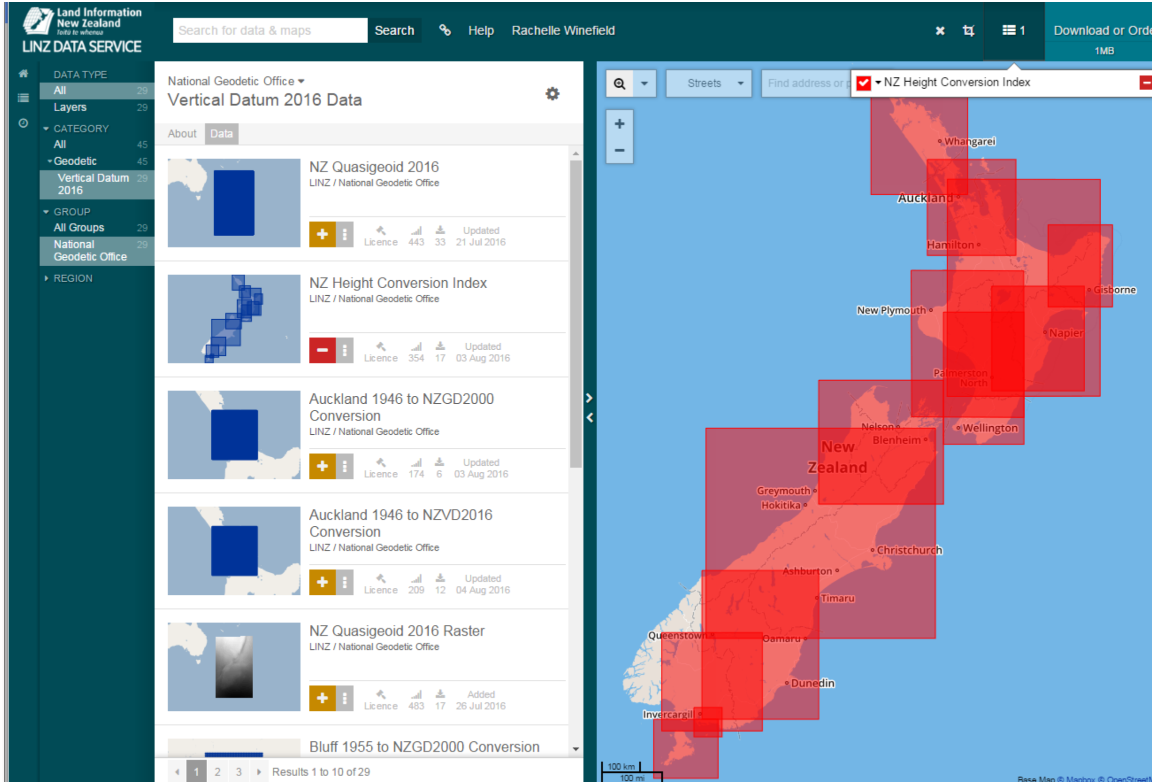

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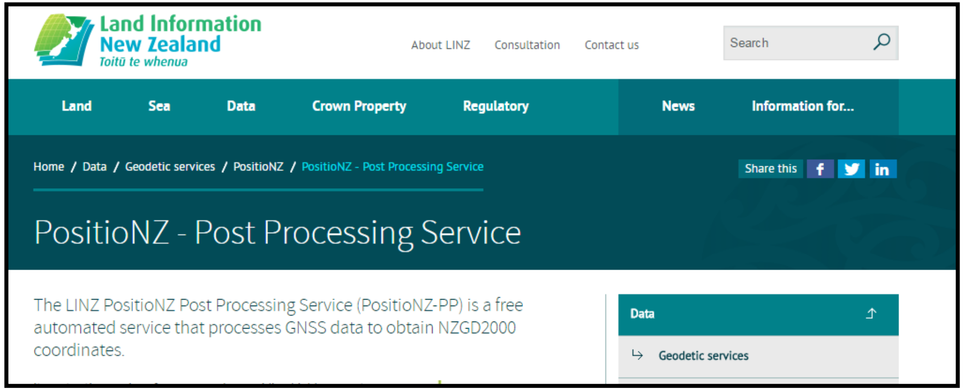
Establishing vertical control

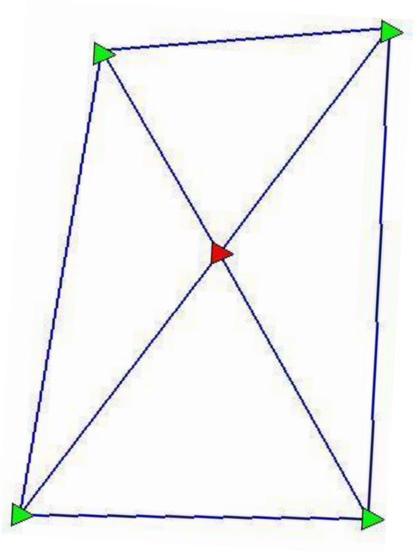


http://www.linz.govt.nz/positionzpp

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

Linking to other local datums

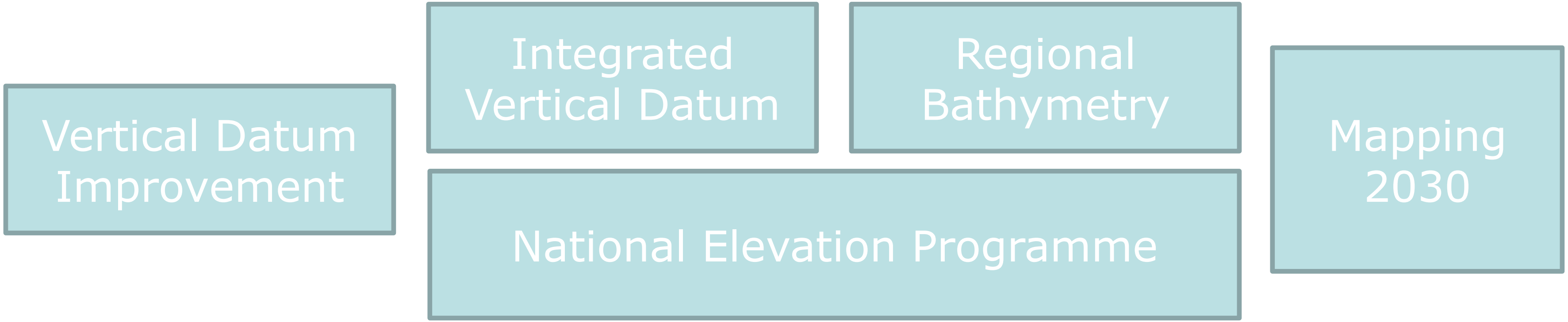
- Official relationships only provided to 13 main local datums
- Users need to compute local offsets by site transformation:
  - Observe a number locally heighted marks with GNSS
  - Calculate the NZVD2016 heights for the marks
  - Determine difference between NZVD2016 and local height
- Only applicable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



Part IV – The Future

Geoid Maintenance

Integrated Vertical Datum



- Vertical datum enables land and sea mapping programme
- Incorporates land and sea datums
- Ellipsoid and geoid are key reference surfaces
- Critical to disaster impact mitigation (e.g. tsunami, sea level)

Part V – Questions for you

How to develop a datum?

- Decide what you want from a datum
  - Regional interoperability
  - MSL alignment
  - Accuracy
  - Support for existing data and datums
- Implement/develop in steps
- How will you effect uptake?

Things to consider

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- 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?

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Questions?