Definition and use of the New Zealand Vertical Datum 2009

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Overview

- Height Theory
- Heights in New Zealand
- New Zealand Vertical Datum 2009
- Use of NZVD2009
- Summary
- Questions

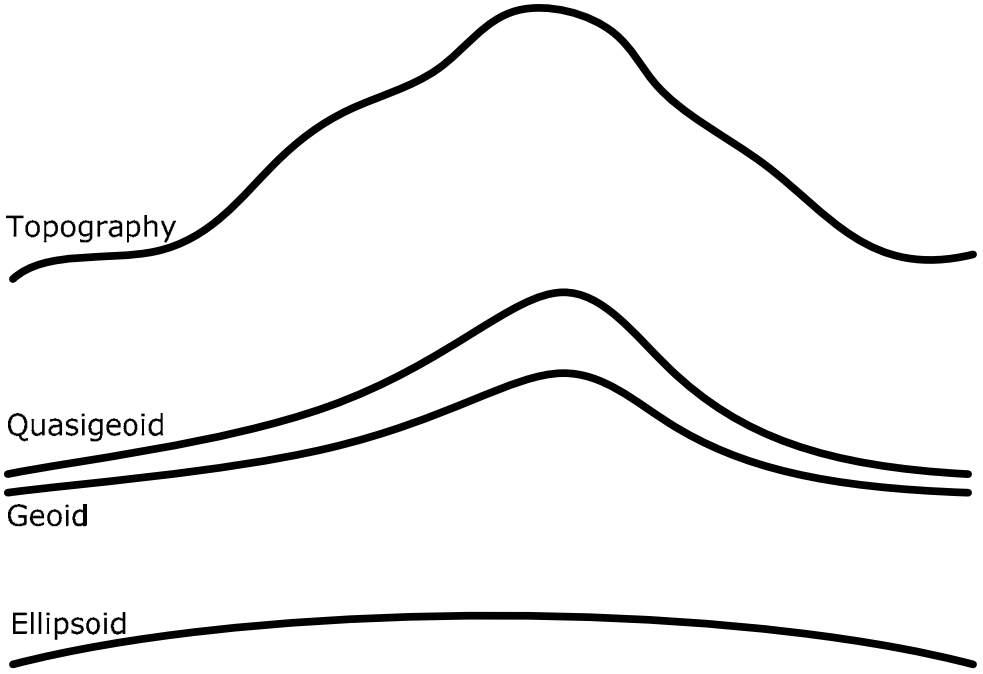
Part I – Height Theory

Height Systems

- Two requirements to define a vertical datum
  - Height system
  - Reference surface
- Heights fall into two main categories:
  - Gravimetric, relate to the gravity field of Earth
  - Geometric, relate to a geometric figure of Earth
- Heights refer to different surfaces
- Make different assumptions about structure and composition of Earth

Height System Surfaces

- Ellipsoid
  - Geometric figure of Earth
- Geoid
  - Level of equal potential
  - Coincides with global level of the sea
- Quasigeoid
  - Not equipotential
  - Equal to geoid over oceans
  - Close over land
- Topography
  - Earth's surface

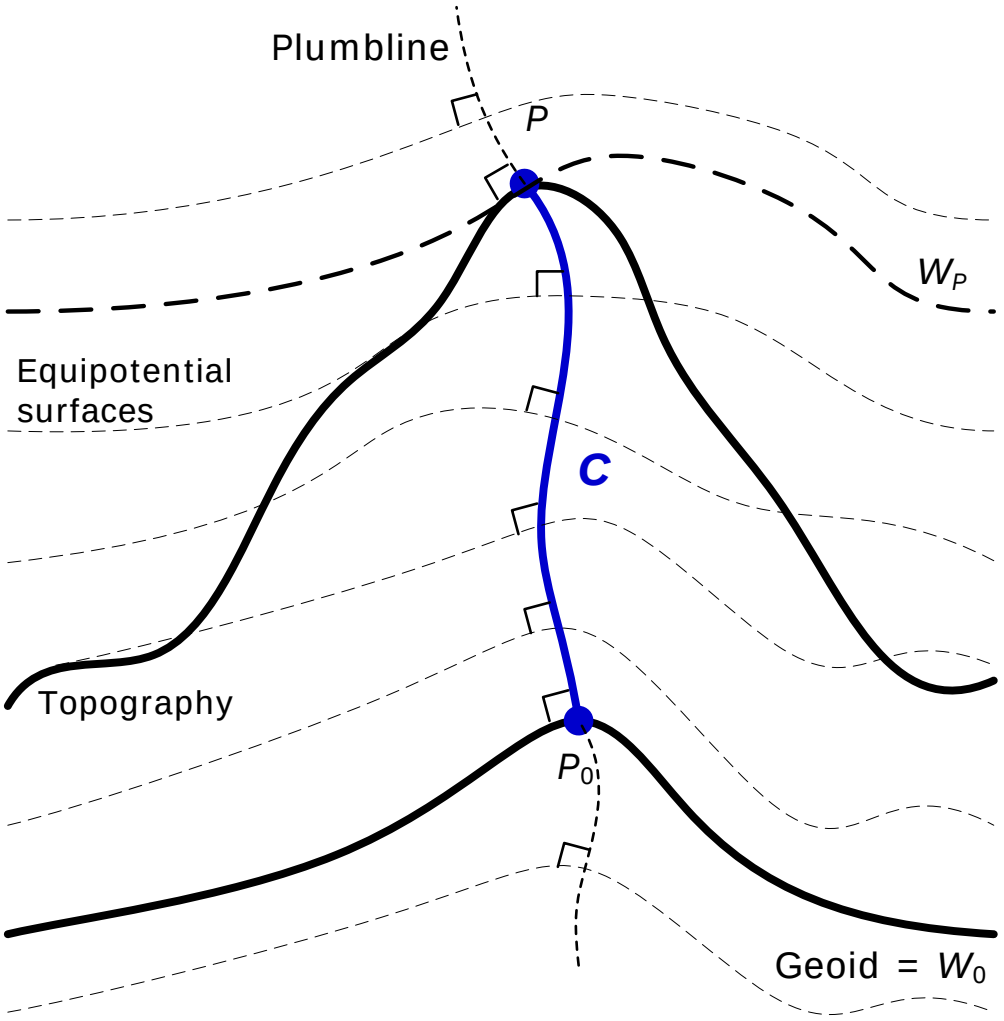


Geopotential Numbers

- Difference in potential from a reference equipotential surface

  (W_0 usually = geoid)
- Holonomic
- Can not be directly observed
- Derived from levelling and gravity observations
- Geopotential units

  (1 GPU = 10 m^2s^{-2})



$$C = W_0 - W_P$$

Dynamic Heights

- Heights with units of length
- *Units NOT metres*
- Constant gravity (g_0) usually normal gravity at 45° (γ_{45})
- Holonomic
- No geometrical meaning
- Not used in practise

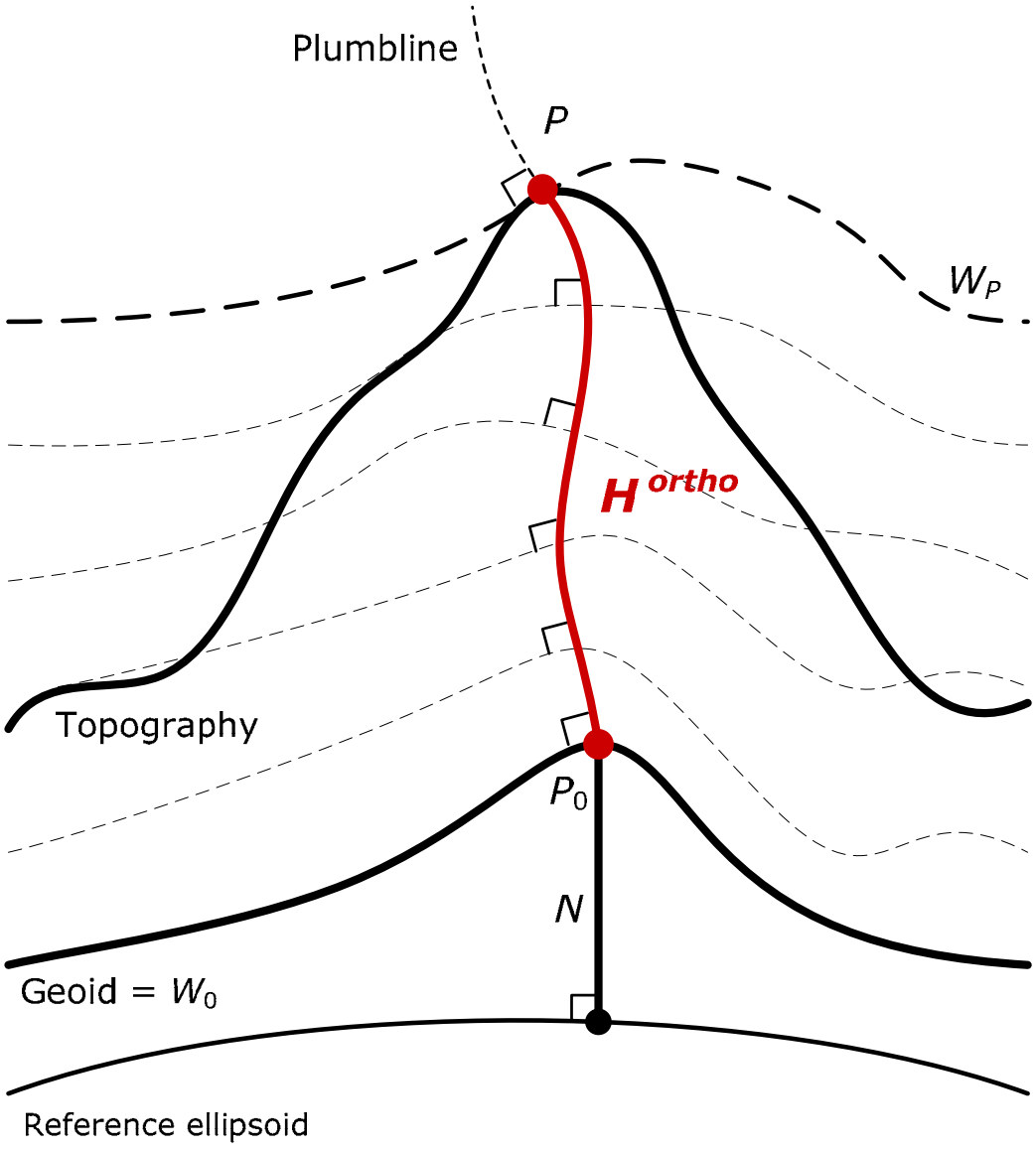
$$H^{dyn} = \frac{C}{g_0}$$

Orthometric Heights

- Length of plumbline from geoid to point
- To determine $\bar{g}$ requires:
  - Path of plumbline
  - Gravity values along plumbline
- Not possible to compute *true* orthometric height
- Units of metres

$$H^{ortho} = \frac{C}{\bar{g}}$$

$$\bar{g} = \frac{1}{h} \int_0^H g(z)\, dz$$



Helmert Orthometric Heights

- Integral mean gravity along plumbline estimated from surface gravity observation
- Simple to compute
- Assumes constant density and no terrain effect
- Not holonomic
- Most common “orthometric” height

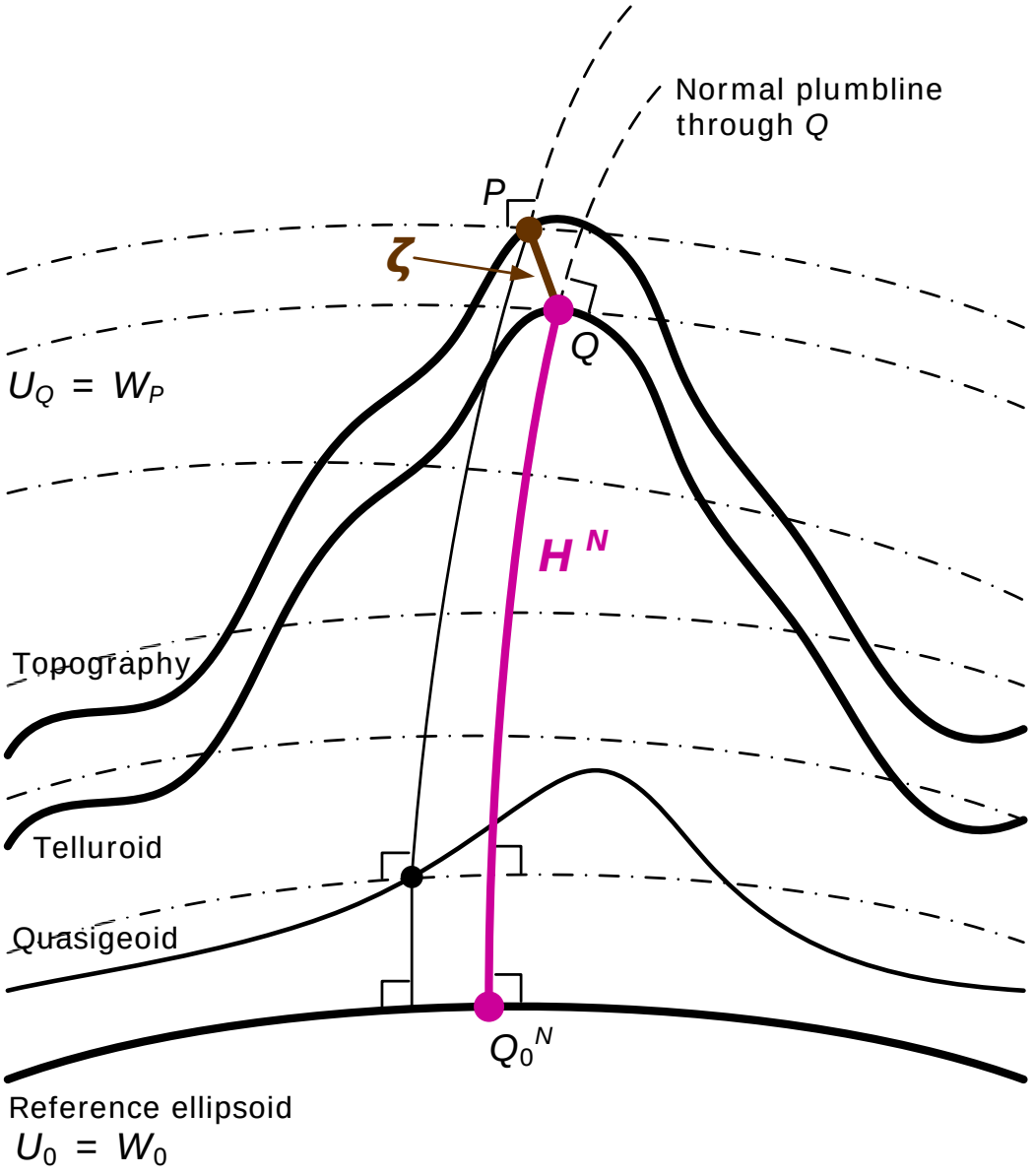
$$H^{Helmert} = \frac{C}{\overline{g}^{Helmert}}$$

$$\overline{g}^{Helmert} = g^{S} + \frac{1}{2}\frac{d\gamma}{dh} H - 2\pi G \rho H$$

Normal Heights

- Replaces “integral mean gravity” with “normal gravity” (ellipsoidal model of Earth’s mass
- Requires surface gravity observations to compute geopotential numbers
- Simple to compute
- No physical meaning (relate to telluroid)
- Not holonomic

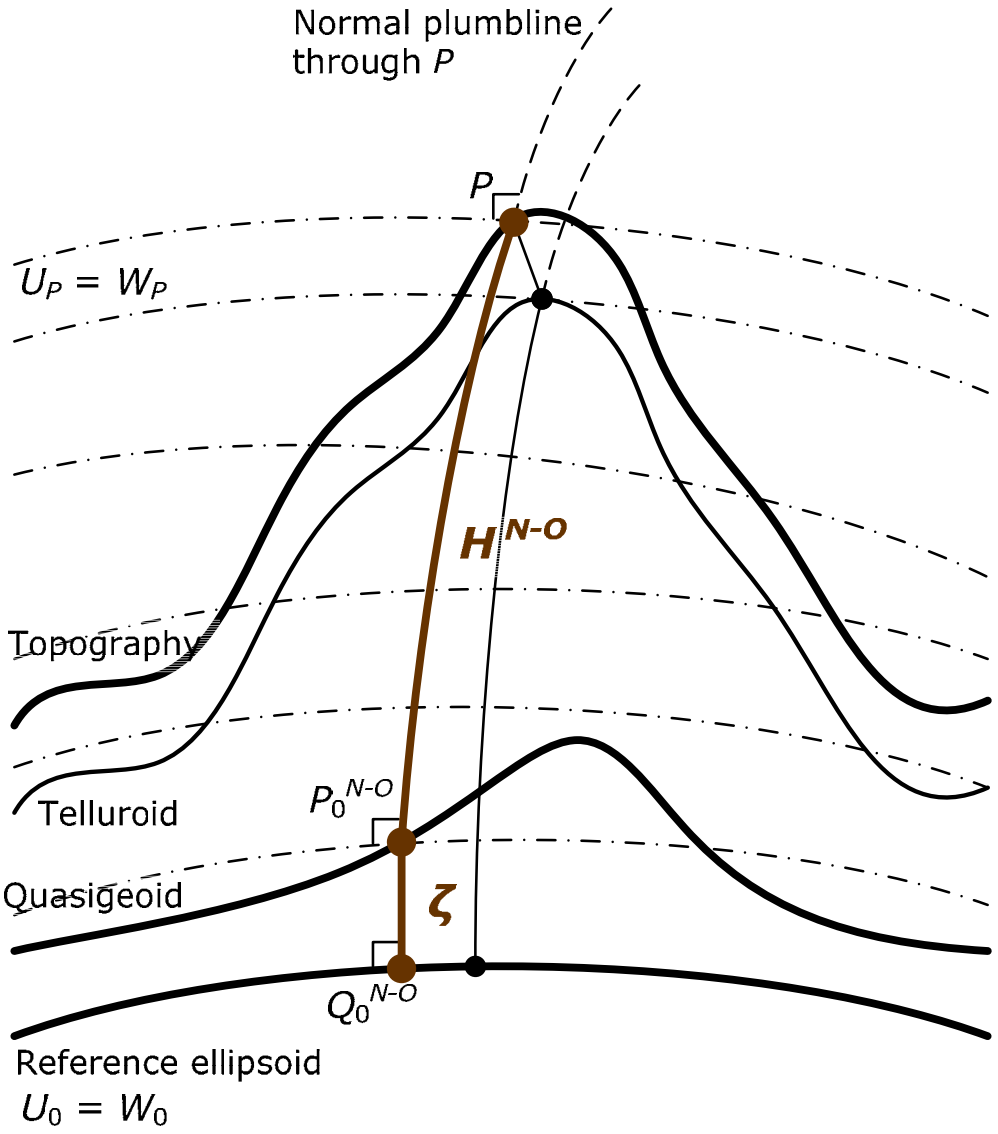
$$H^N = \frac{C}{\overline{\gamma}}$$



Normal-Orthometric Heights

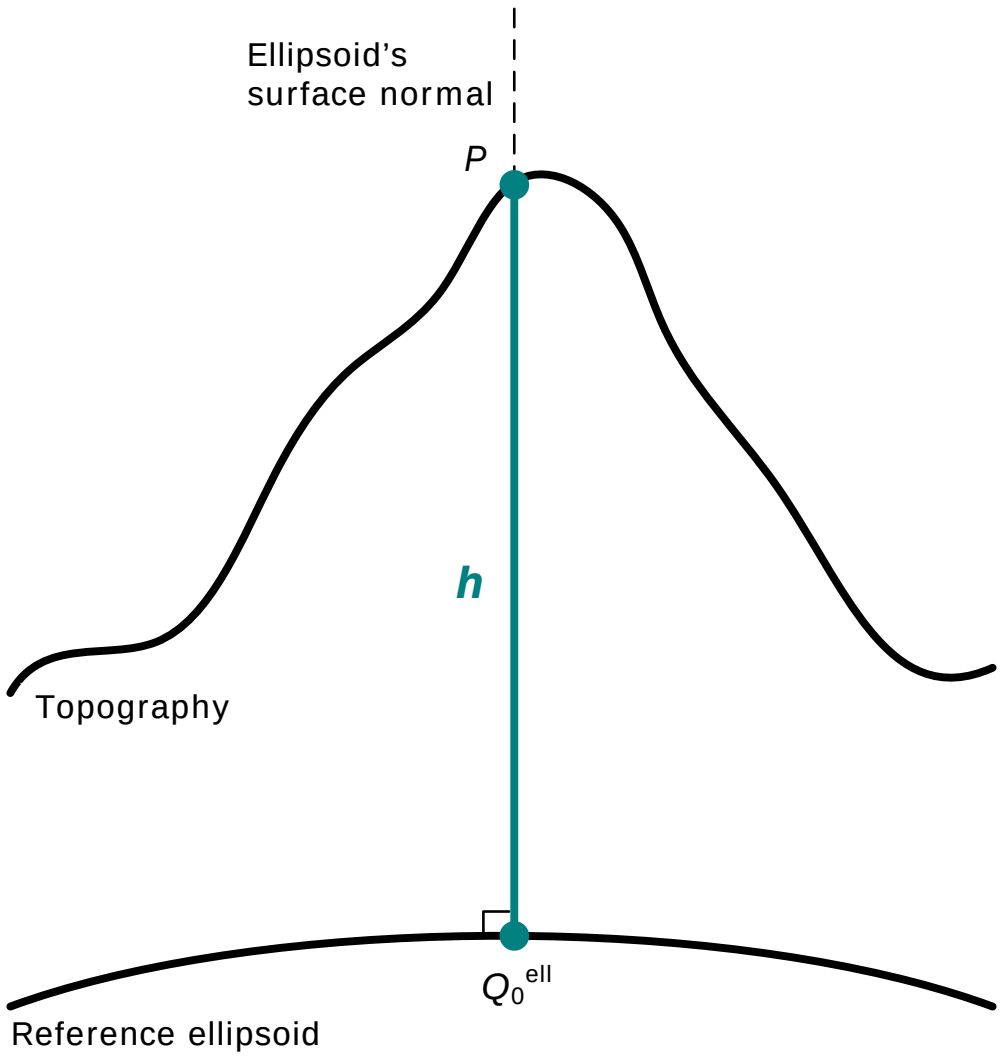
- Uses spheropotential numbers instead of geopotential numbers
- Does not require gravity observations
- Not holonomic
- Will not reflect local gravity field
- Computed by applying correction to levelling
- Used in New Zealand

$$H^{N-O} = \frac{C'}{\bar{\gamma}} \qquad C' = \int_{P_0}^{P} \gamma \, dn$$

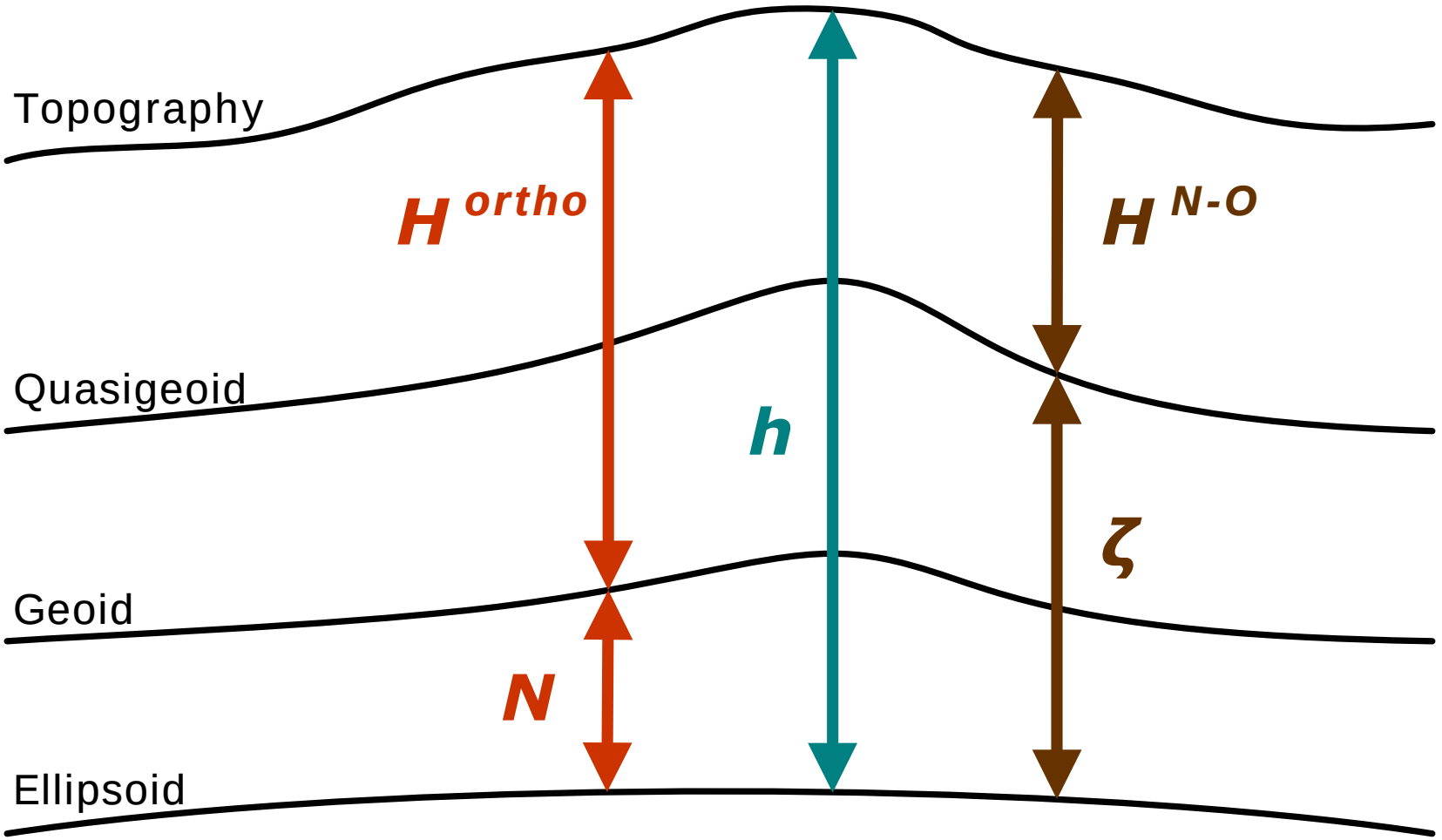


Ellipsoidal Heights

- Straight-line distance along ellipsoidal normal
- Not holonomic
- Will not reflect local gravity field
- Need to determine using GNSS
- NZGD2000 heights



Height System Summary



Vertical Datum Reference Surfaces

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

Vertical Datum Reference Surfaces

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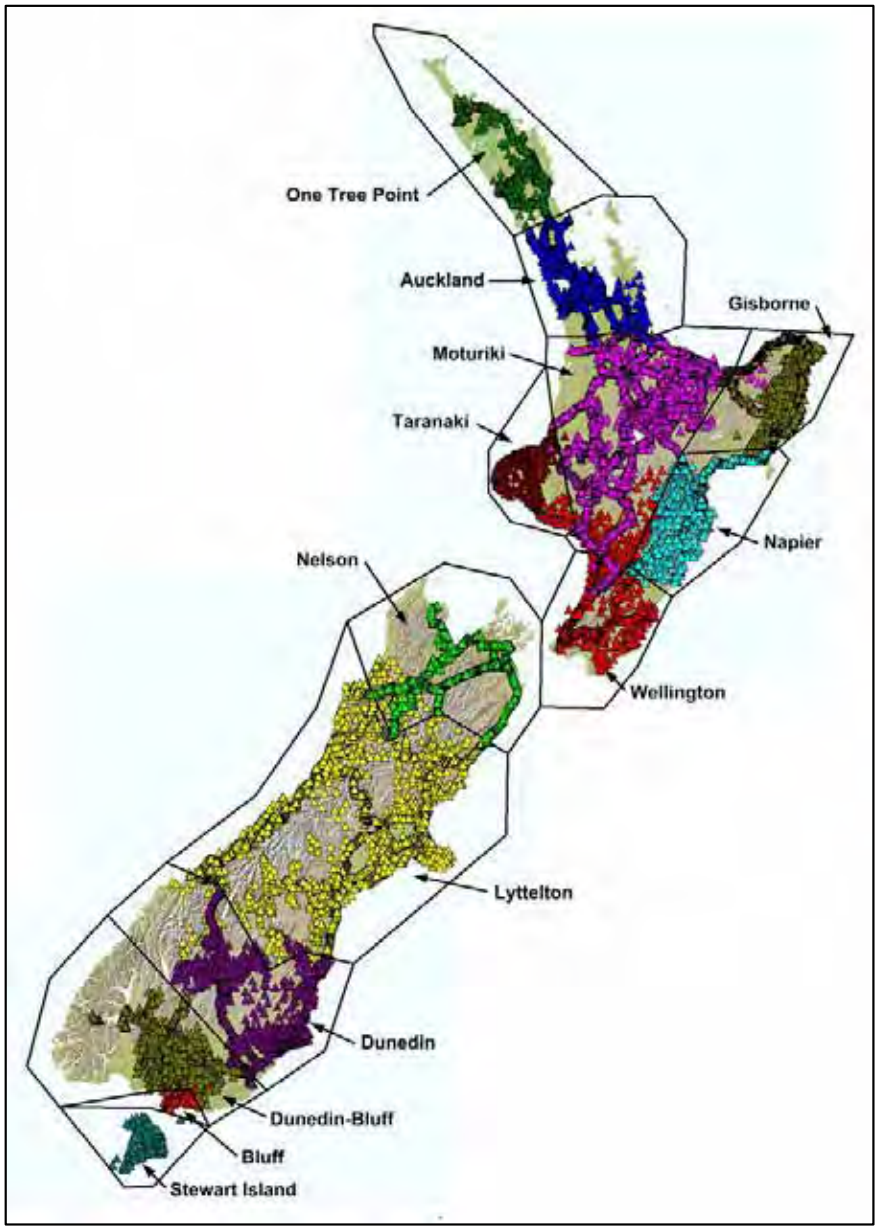
- Physical reference surface
  - Frequently mean sea level
  - Fix MSL at a single point
  - Fix MSL at several points
  - Arbitrary level at a single point
- Virtual reference surface
  - Geoid/quasigeoid model
  - Ellipsoid

Part II – Heights in New Zealand

New Zealand's Height Systems

- 13 major levelling datums
- Many other datums
  - Power schemes
  - Local authority datums
  - Local purpose datums
- Generally based on MSL
- Extended by levelling
- NZGD2000
  - Ellipsoidal heights

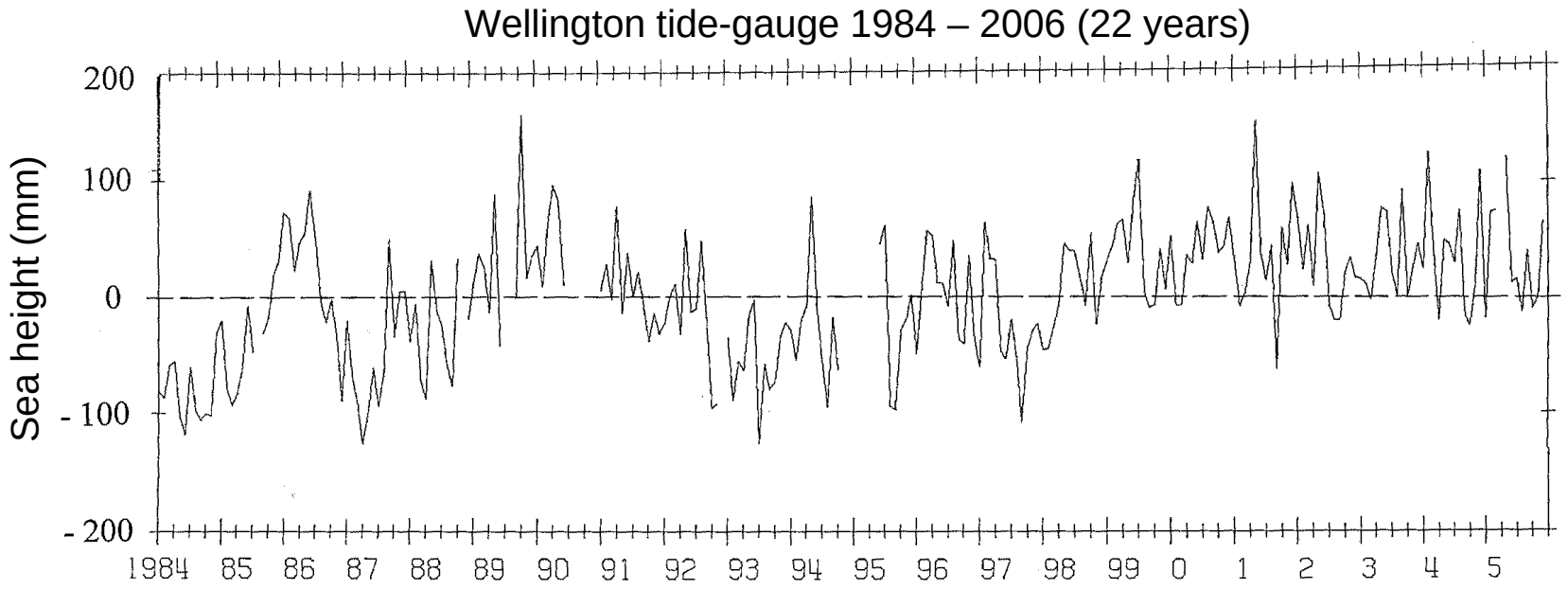


Mean Sea Level Determination

- Sea level observed at tide-gauges
- Observations averaged to give MSL
- Ideally over 18.6 years to cover complete metonic cycle
- Typically 2-3 years used
- Gauge location can make MSL determinations highly site-specific

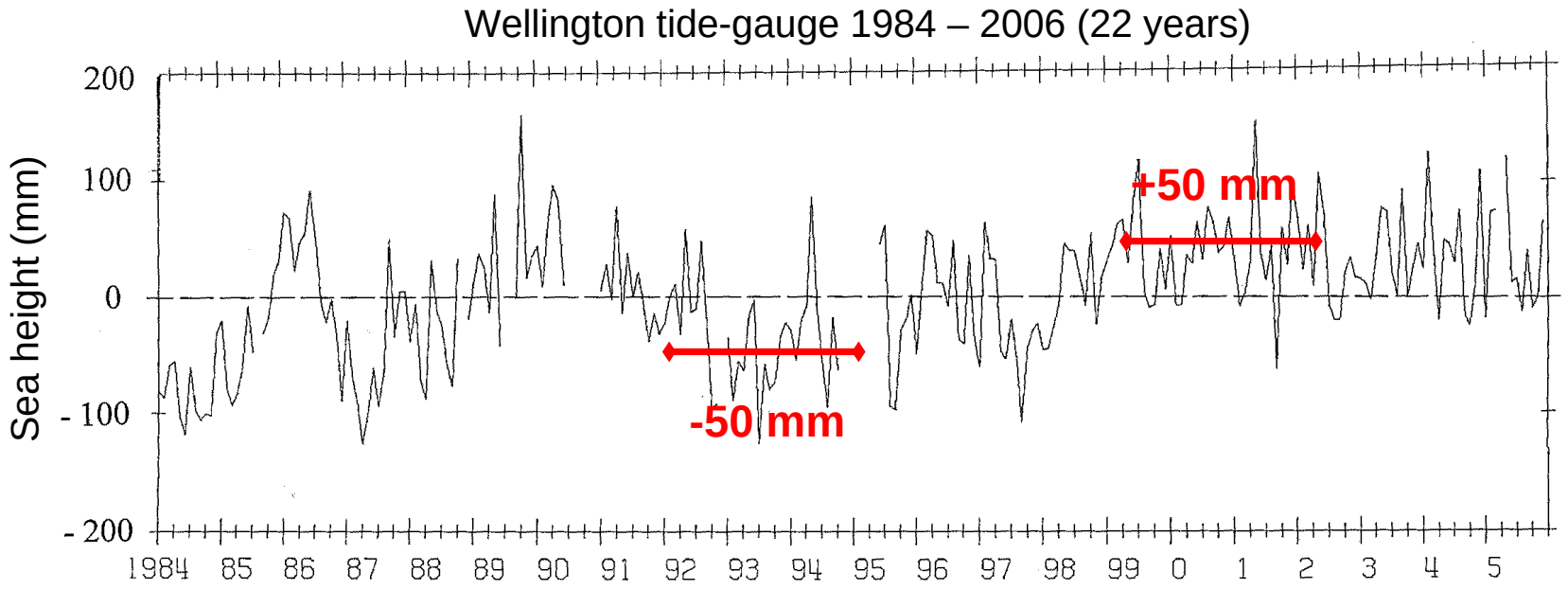
Sea Level Variation

- Sea level varies over time
- Observation period affects MSL determination



Sea Level Variation

- Sea level varies over time
- Observation period affects MSL determination
- “Level” in Wellington differs by 100mm depending on 3-year observation period chosen



Sea Level Observation Duration

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Datum	Observation Period	Duration
One Tree Point 1964	1960 – 1963	3 Years
Auckland 1946	1909 – 1923	14 Years
Moturiki 1953	1949 – 1952	3 Years
Gisborne 1926	1926	1 Year
Napier 1962	*Unknown*	?
Taranaki 1970	1918 – 1921	3 Years
Wellington 1953	1909 – 1946	**37 Years**
Nelson 1955	1939 – 1942	3 Years
Lyttelton 1937	1918 – 1933	15 Years
Dunedin 1958	1918 – 1937	**19 Years**
Dunedin-Bluff 1960	*None*	–
Bluff 1955	1918 – 1934	16 Years
Stewart Island 1977	1976 – 1977	3 *Tides*

Precise Levelling Networks

- Datums extended by precise levelling from tide-gauges 1960-1980 (~16,000 km)
- Approximate normal-orthometric correction applied to levelling
- Least-squares adjustment performed on each datum
- Some very large loops, particularly in South Island

Precise Levelling Networks

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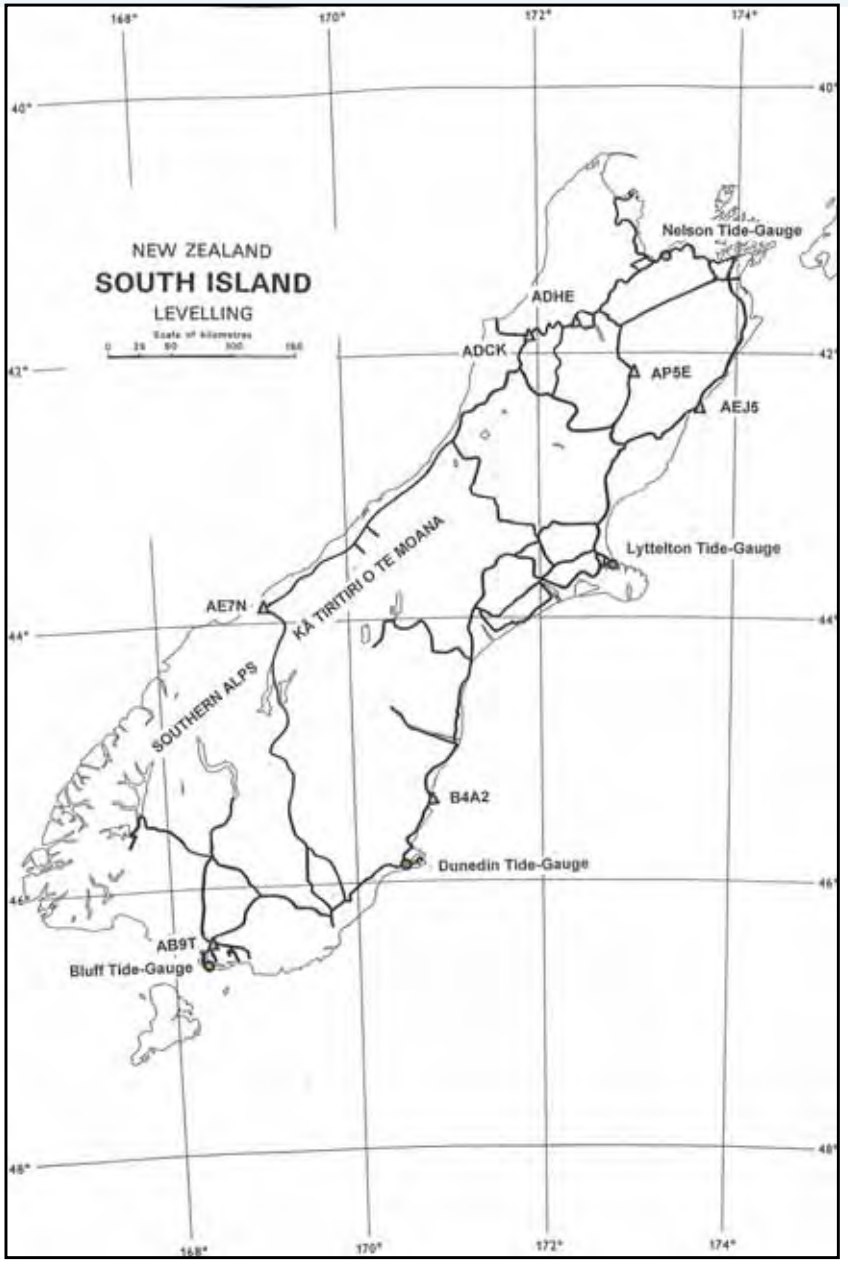

New Zealand Geodetic Datum 2000

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- The official *geodetic* datum
- Implemented in 1998
- Ellipsoidal heights
- GRS80 ellipsoid (very similar to WGS84)
- Heights normally determined by GPS

Height Accuracy

- Normal-orthometric
  - Five height orders (1V – 5V)
  - Based on method of determination, not accuracy of height
- Ellipsoidal
  - Six orders include height component (0 – 5)
  - Based on accuracy of overall coordinate
  - Coordinate must achieve both horizontal and vertical requirements
- Order classifications to be updated in May 2010

Normal-Orthometric Height Orders

Order	Current Accuracy Description	Tier (m)	Class (m + m/m)
1V	1st Order levelling $\left(\pm 2\,\text{mm}\sqrt{k}\right)$	0.30	$0.01 + 3 \times 10^{-6}$
2V	2nd Order levelling $\left(\pm 7\,\text{mm}\sqrt{k}\right)$	0.35	$0.01 + 1 \times 10^{-5}$
3V	Less accurate with 1V/2V/3V origin	0.35	$0.02 + 1 \times 10^{-4}$
4V	Systematic levelling with poor origin	0.50	$0.03 + 1.5 \times 10^{-4}$
5V	Unknown quality or origin	1.00	$0.30 + 6 \times 10^{-4}$
6V	N/A	*undefined*	*undefined*

k is the distance between marks in kilometres

Tiers and classes will replace current accuracy descriptions in May 2010

Ellipsoidal Height Orders

Order	Absolute (m)	Tier (m)	Relative / Class (m + m/m)
0	0.15	0.05	$0.003 + 3 \times 10^{-8}$
1	0.21	0.05	$0.003 + 3 \times 10^{-7}$
2	0.26	0.10	$0.01 + 3 \times 10^{-6}$
3	0.30	0.10	$0.01 + 1 \times 10^{-5}$
4	0.34	0.15	$0.01 + 3 \times 10^{-5}$
5	0.37	0.15	$0.01 + 1 \times 10^{-4}$

Tiers and classes will replace absolute and relative accuracy in May 2010

Common Misconceptions

- "LINZ provides orthometric heights"
  - Reality : *LINZ provides normal-orthometric heights*
  - Gravity observations have not been made at benchmarks
  - Not possible to determine geopotential numbers or gravity gradient
- "LINZ datums reflect current MSL"
  - Reality : *Datums reflect MSL at the epoch of the datum*
  - Datum zero's have not been updated
  - Short observation periods may make some datums unrepresentative of MSL at the datum epoch as well

Problems with Levelling Datums

- Do not represent MSL today
  - Sea level variability and rise
  - MSL value only relevant at the origin gauge

    (e.g. MSL in Lyttelton is not the same as Greymouth)
- Coverage is mainly limited to roads
- Levelling networks have not been re-observed or adjusted for many years
- Expensive to maintain and extend networks

Problems with Levelling Datums

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- Multiple datums causes confusion
- Offsets between datums is unknown or poorly defined
- Not compatible with NZGD2000 or GNSS
  - Relate to GRS67 (NZGD2000 is GRS80)
- Many local datums not formally defined or related to other datums in their vicinity
- No single consistent datum that can be used nationally

Desirable Datum Attributes

- Single consistent reference system
- Consistent with NZGD2000 geodetic datum
- Compatible with GNSS heighting
- Accessible across all of New Zealand and offshore
- Easily adopted by users
- Cost-effective to implement and maintain

Vertical Datum options

- Update MSL values and readjust networks
- Update MSL values and readjust to form new network
  - Fix one level per island (e.g. EUVN/UELN)
  - Fix multiple levels per adjustment (e.g. Australia, Canada, USA)
- Define datum using fitted geoid
  - Excellent transformation surface between levelling and ellipsoid
- Define datum using gravimetric geoid

Part III

New Zealand Vertical Datum 2009

New Zealand Vertical Datum 2009

- Normal-orthometric height system
- NZGeoid09 reference surface
  - No physical origin
  - Coincides reasonably closely to MSL
- Defined offsets to 13 major levelling datums
- Transformations between NZVD2009, NZGD2000 and 13 LVDs
- NZ is first country to use this approach
  - Most countries still base height systems on tide-gauges
  - Trend towards using geoid based height system

Normal-Orthometric Height System

- Heights measured above quasigeoid (NZGeoid09)
- Does not require gravity observations to determine heights
- Uses GRS80 normal gravity field
- Precisely levelled height differences require normal-orthometric correction

$$NOC = -\frac{f^*}{R}\sum_{P_1}^{P_2}\left(H_k^s \sin 2\phi_{av} \cos\alpha_k \, \delta s_k\right)$$

Where: f^* = GRS80 gravity flattening constant (0.005 302 440 112)

R = mean Earth radius (6 371 000 m)

H = height difference

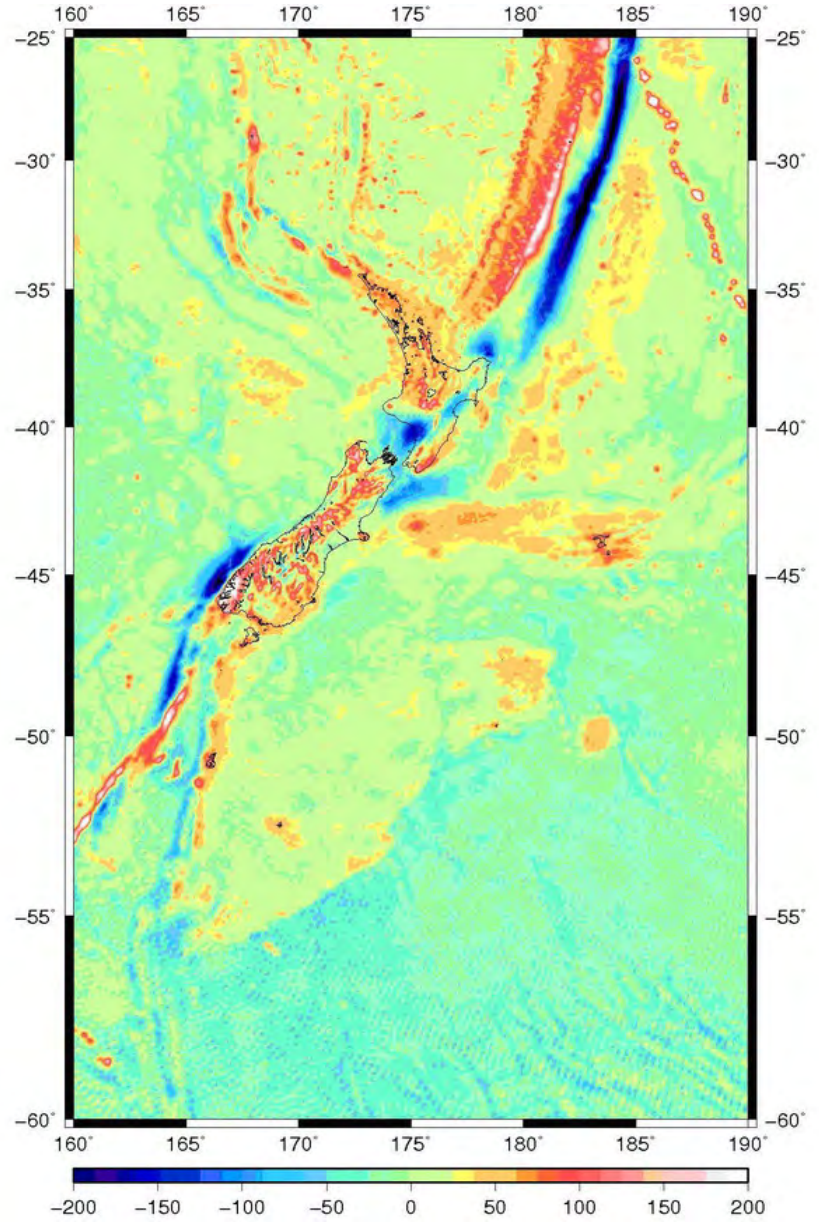
ϕ = average latitude

α = azimuth between stations

δs = distance between stations

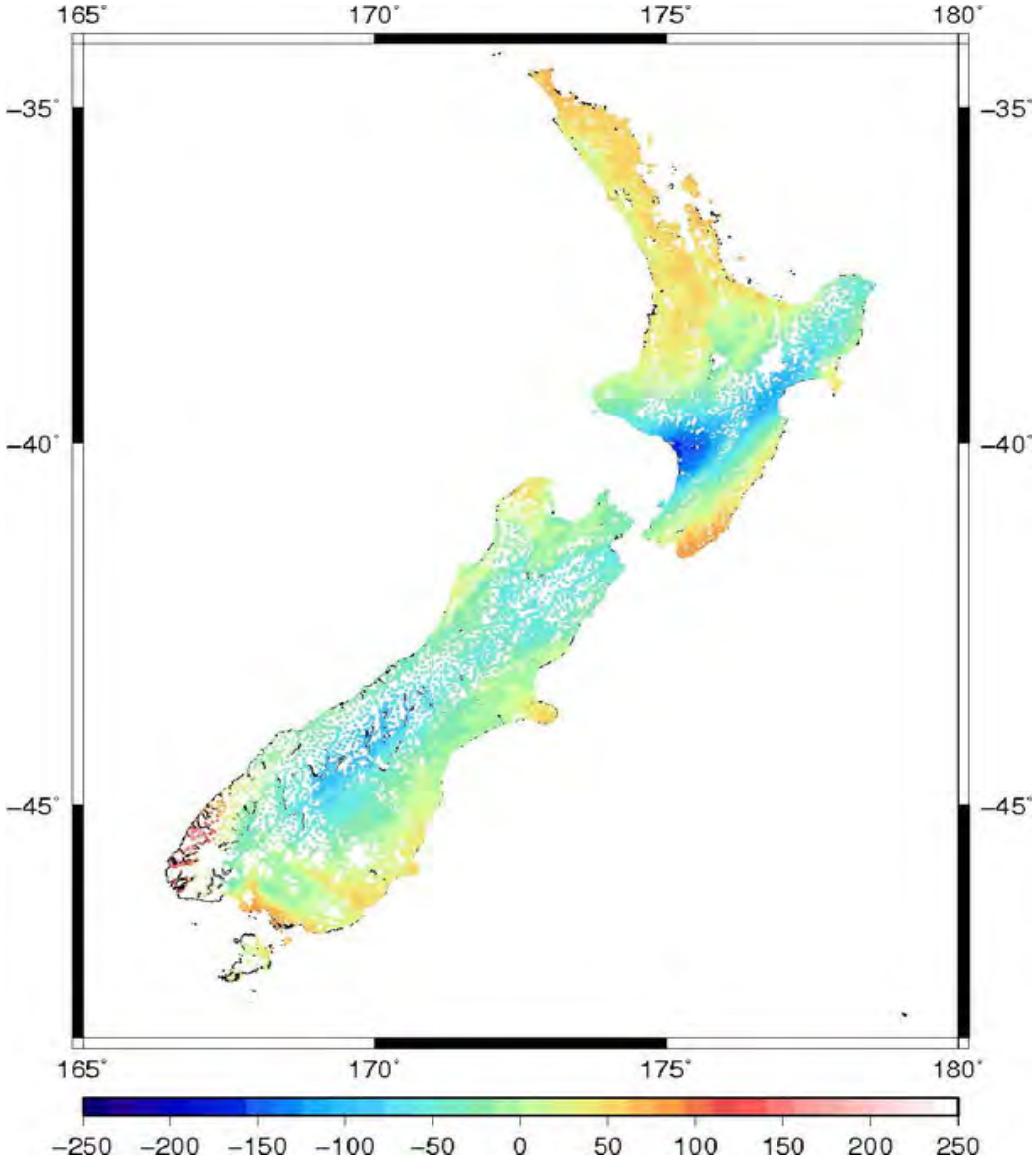
New Zealand Quasigeoid 2009

- Gravimetric quasigeoid computed from:
  - EGM2008



New Zealand Quasigeoid 2009

- Gravimetric quasigeoid computed from:
  - EGM2008
  - Land gravity data



New Zealand Quasigeoid 2009

- Gravimetric quasigeoid computed from:
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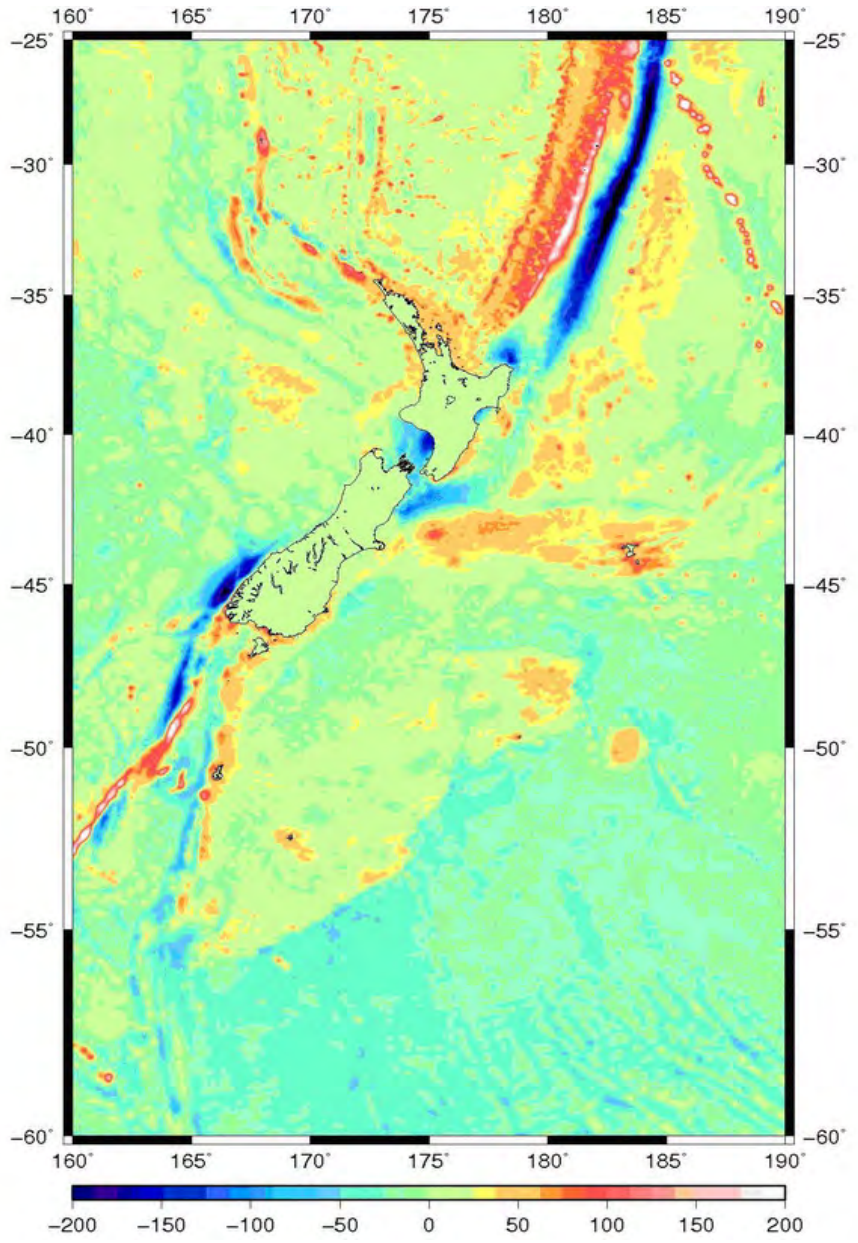
  - Land gravity data
  - DNSC08 altimetry



New Zealand Quasigeoid 2009

- Gravimetric quasigeoid computed from:
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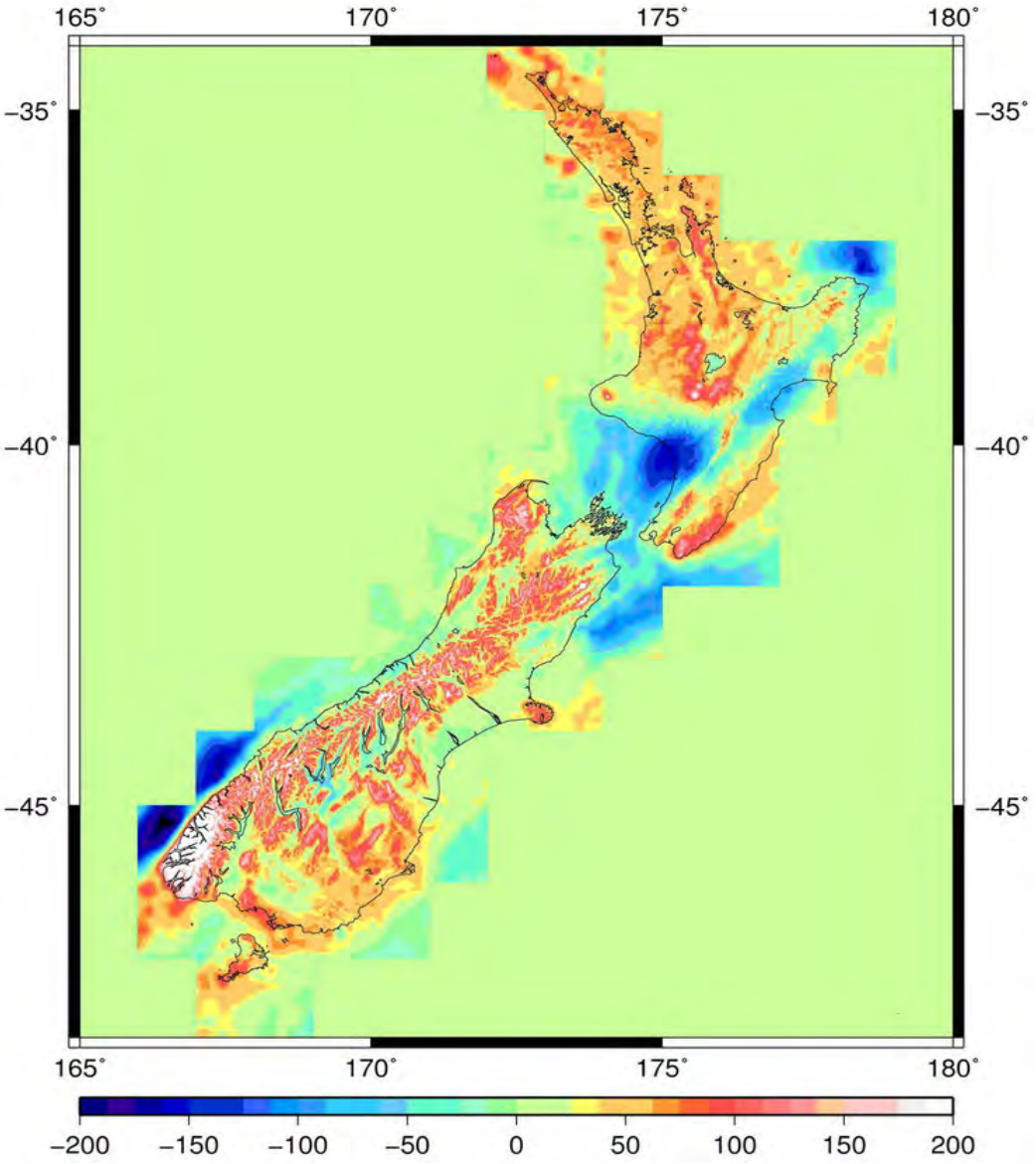
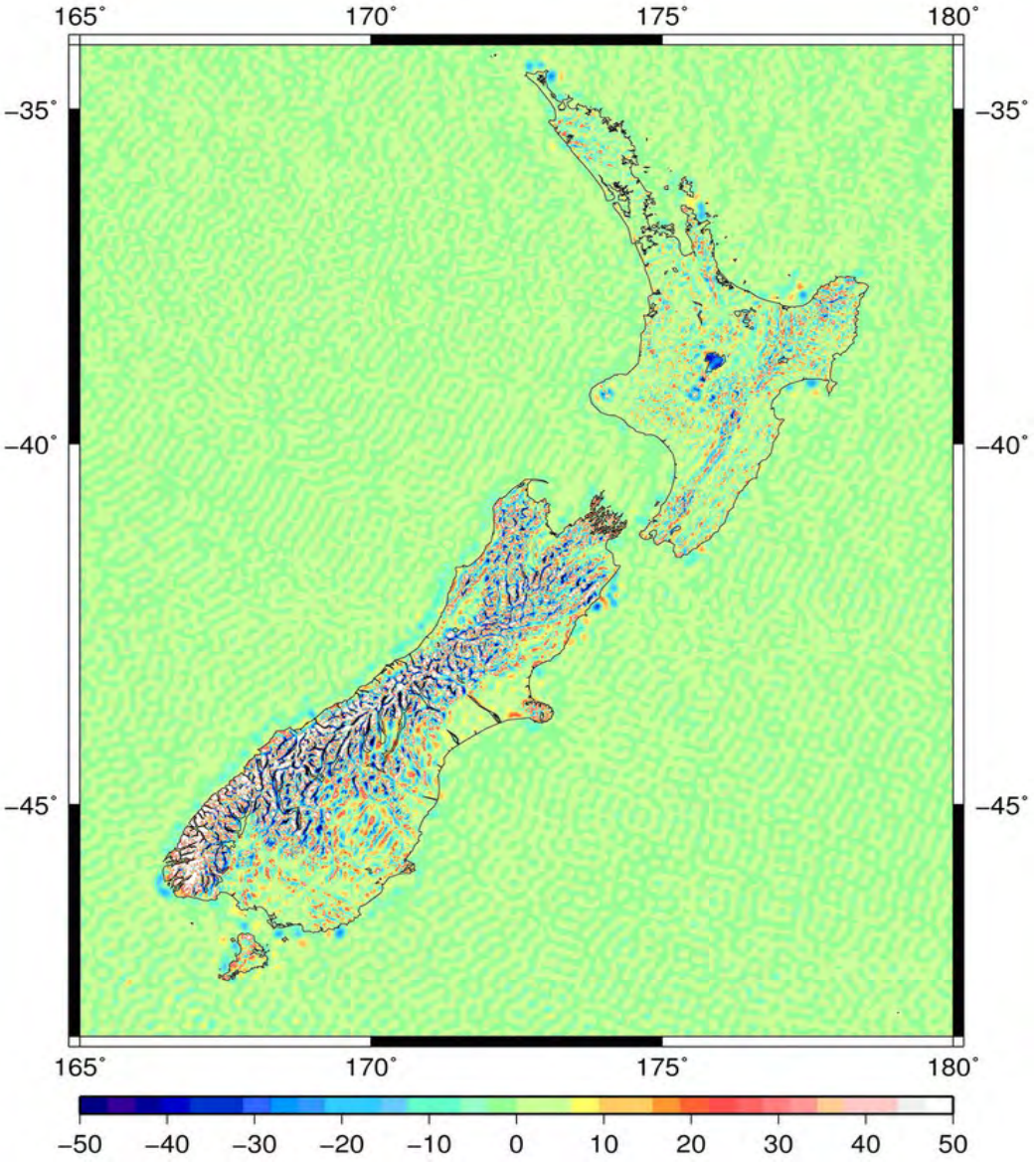


New Zealand Quasigeoid 2009

- Gravimetric quasigeoid computed from:
  - EGM2008
  - Land gravity data
  - DNSC08 altimetry
  - Digital elevation model
- Subtract EGM2008 to give residual gravity anomalies



New Zealand Quasigeoid 2009

- Gravimetric quasigeoid computed from:
  - EGM2008
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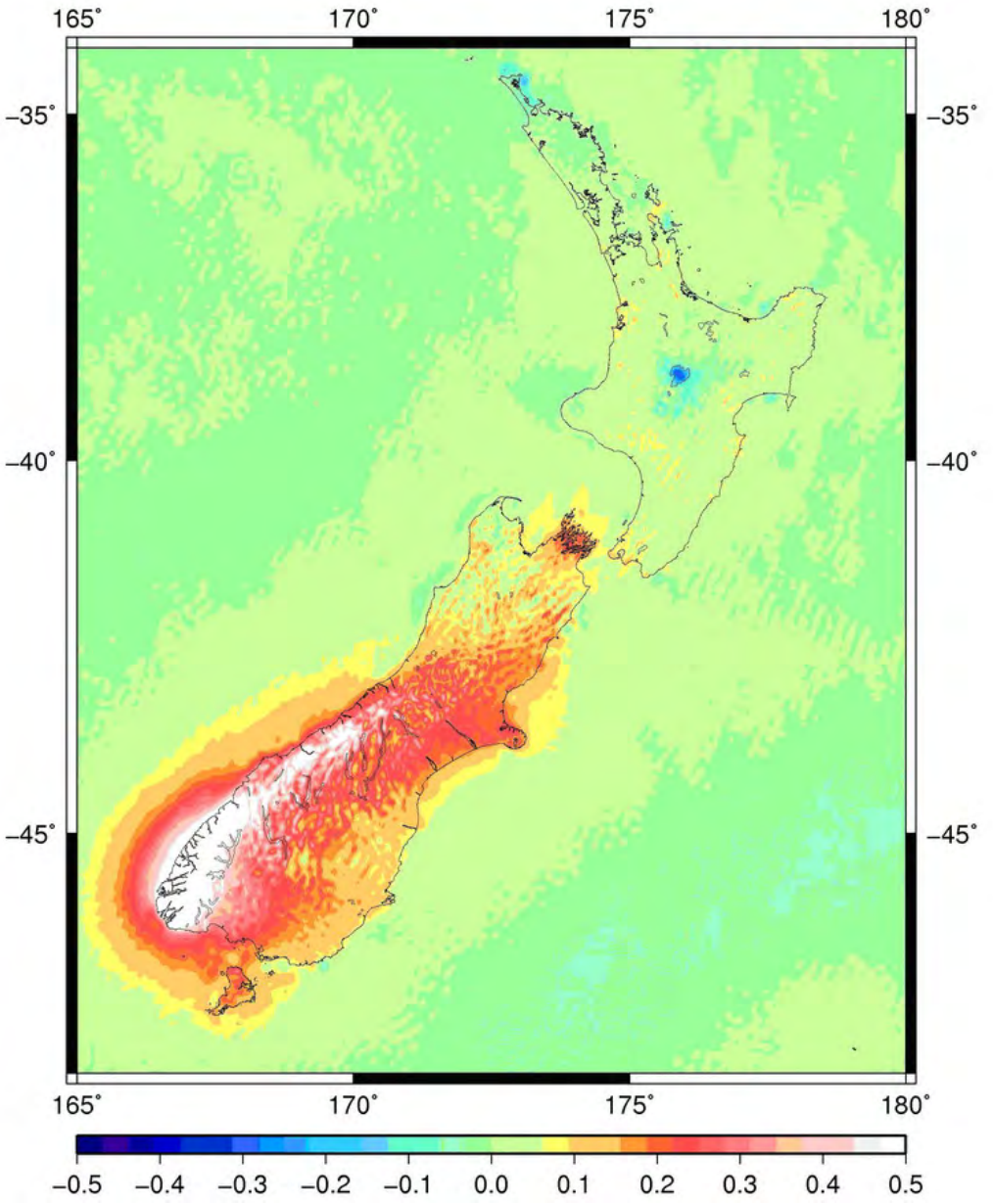
- Subtract EGM2008 to give residual gravity anomalies
- Fourier transform to convert gravity to geoid



New Zealand Quasigeoid 2009

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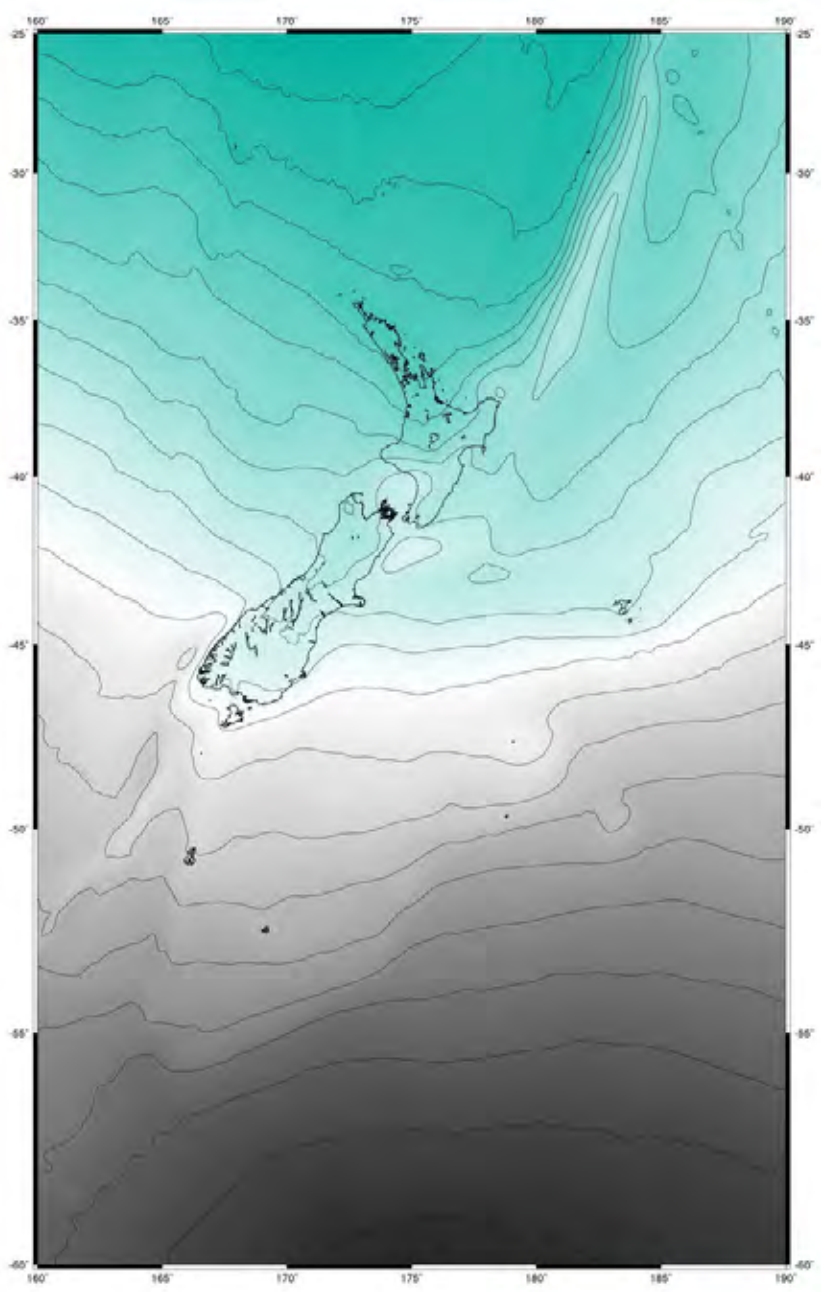
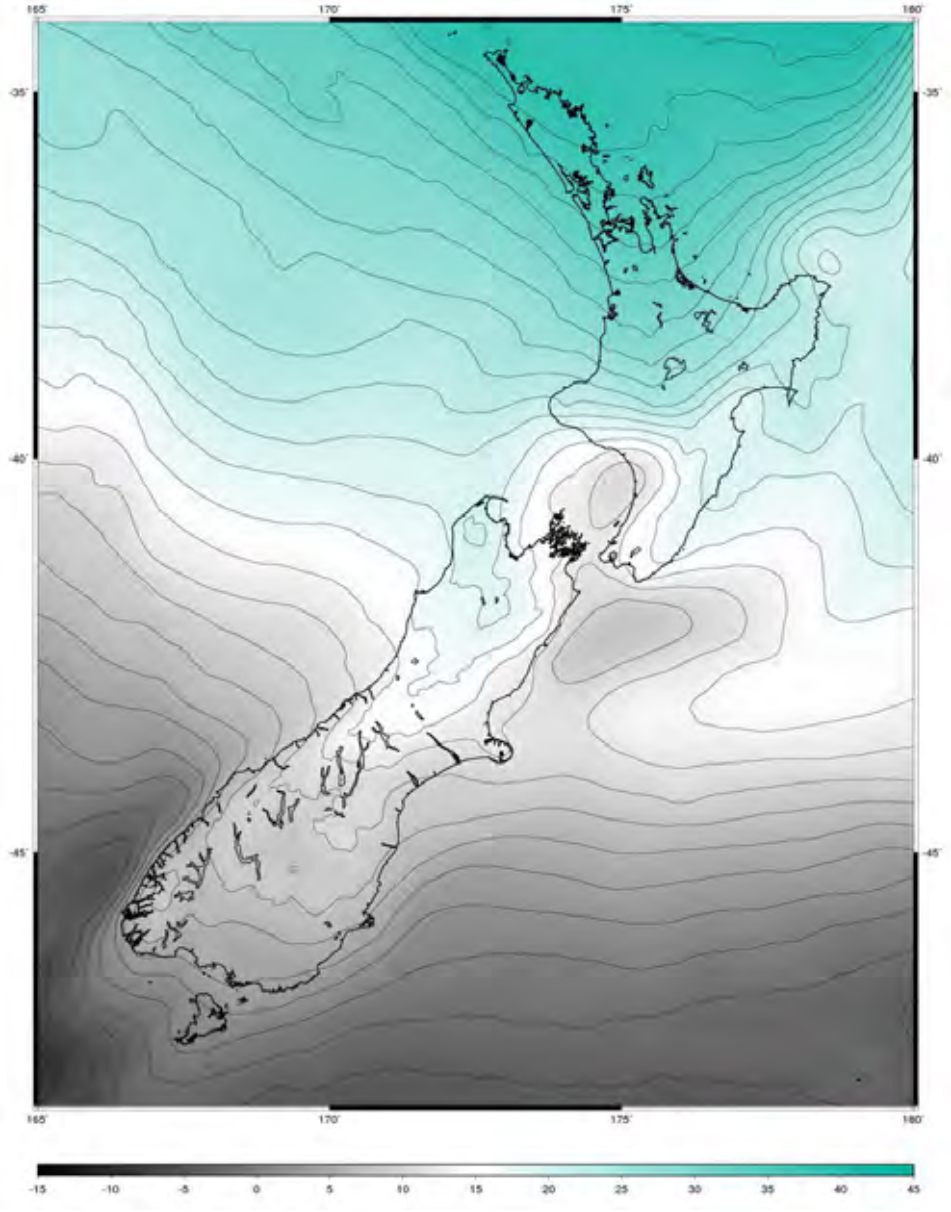
- Gravimetric quasigeoid computed from:
  - EGM2008
  - Land gravity data
  - DNSC08 altimetry
  - Digital elevation model
- Subtract EGM2008 to give residual gravity anomalies
- Fourier transform to convert gravity to geoid
- Add back EGM2008 geoid



New Zealand Quasigeoid 2009

- Gravimetric quasigeoid computed from:
  - EGM2008
  - Land gravity data
  - DNSC08 altimetry
  - Digital elevation model
- Subtract EGM2008 to give residual gravity anomalies
- Fourier transform to convert gravity to geoid
- Add back EGM2008 geoid
- Result is NZGeoid09

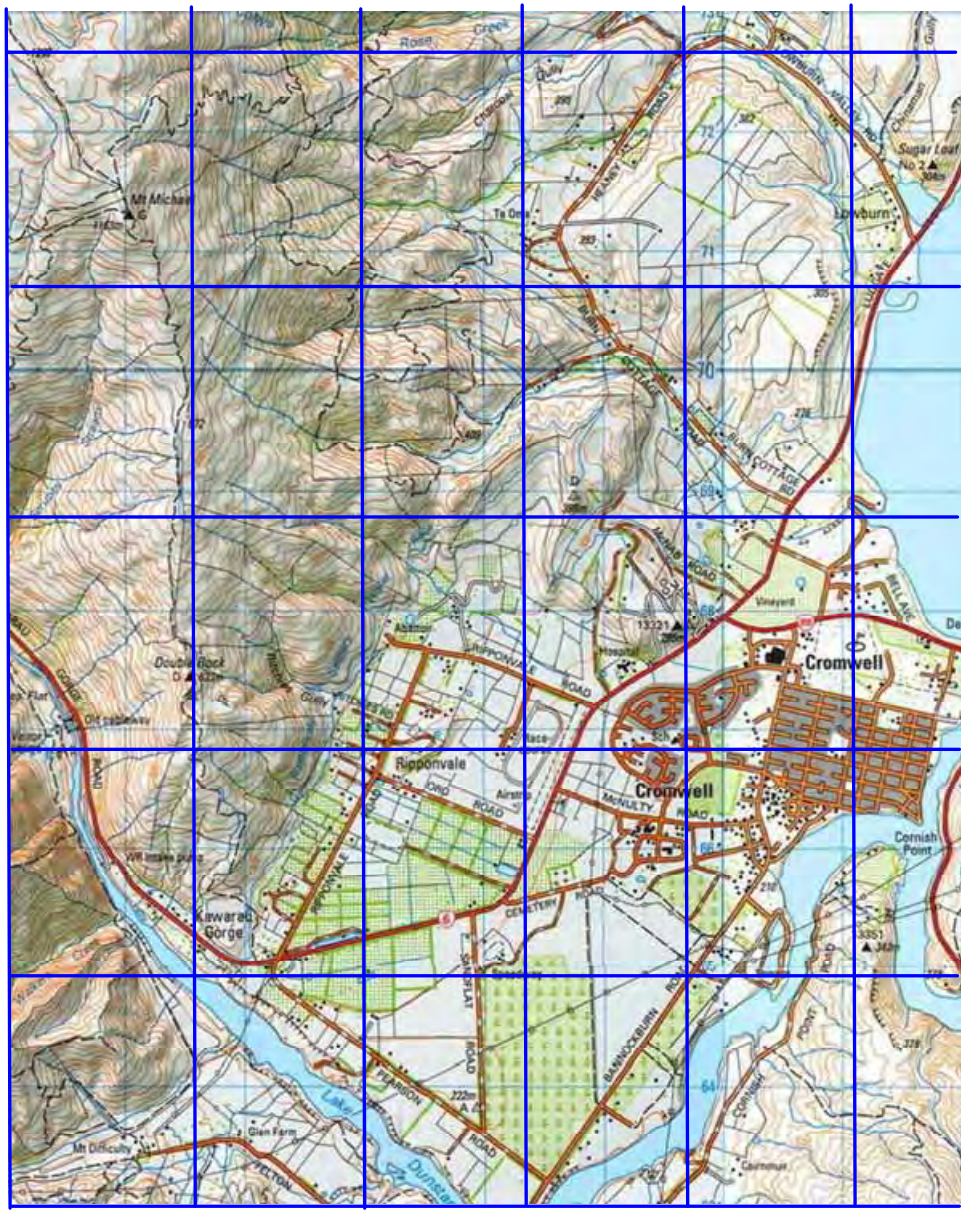


New Zealand Quasigeoid 2009

- Computation area:

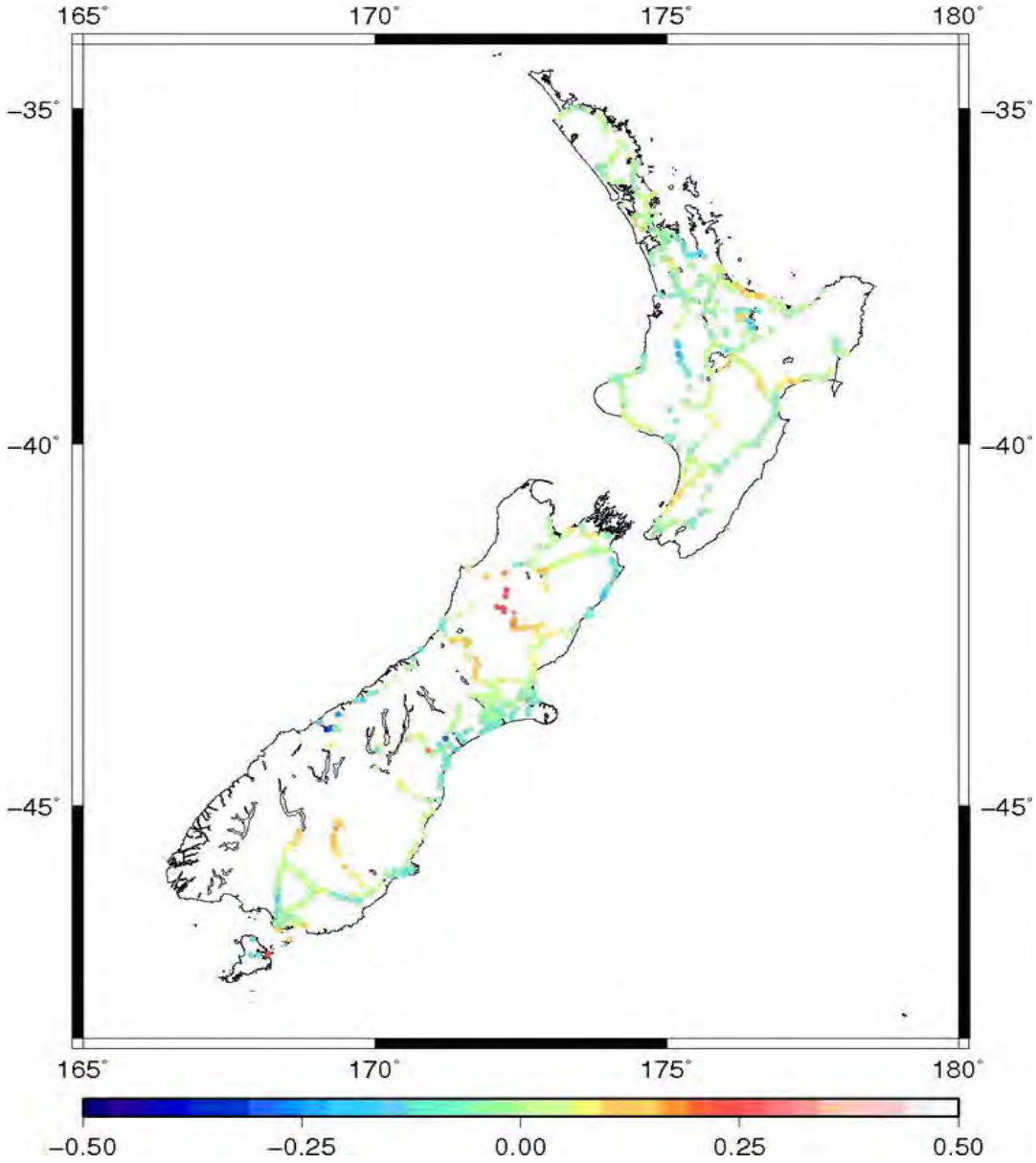
  160° E – 170° W, 25° S – 60° S
- ~40m range over NZ
- Provided on 1’ x 1’ grid

  ~1.9 km over NZ
- NZGeoid09 value linearly interpolated from grid
- Geoid changes smaller than 2 km will not be represented



New Zealand Quasigeoid 2009

- NZGeoid09 evaluated and offsets determined from GPS-levelling observations
- Spatial coverage poor, especially in mountainous areas
- Accuracy of GPS-levelling *absolute* heights ~0.14 m



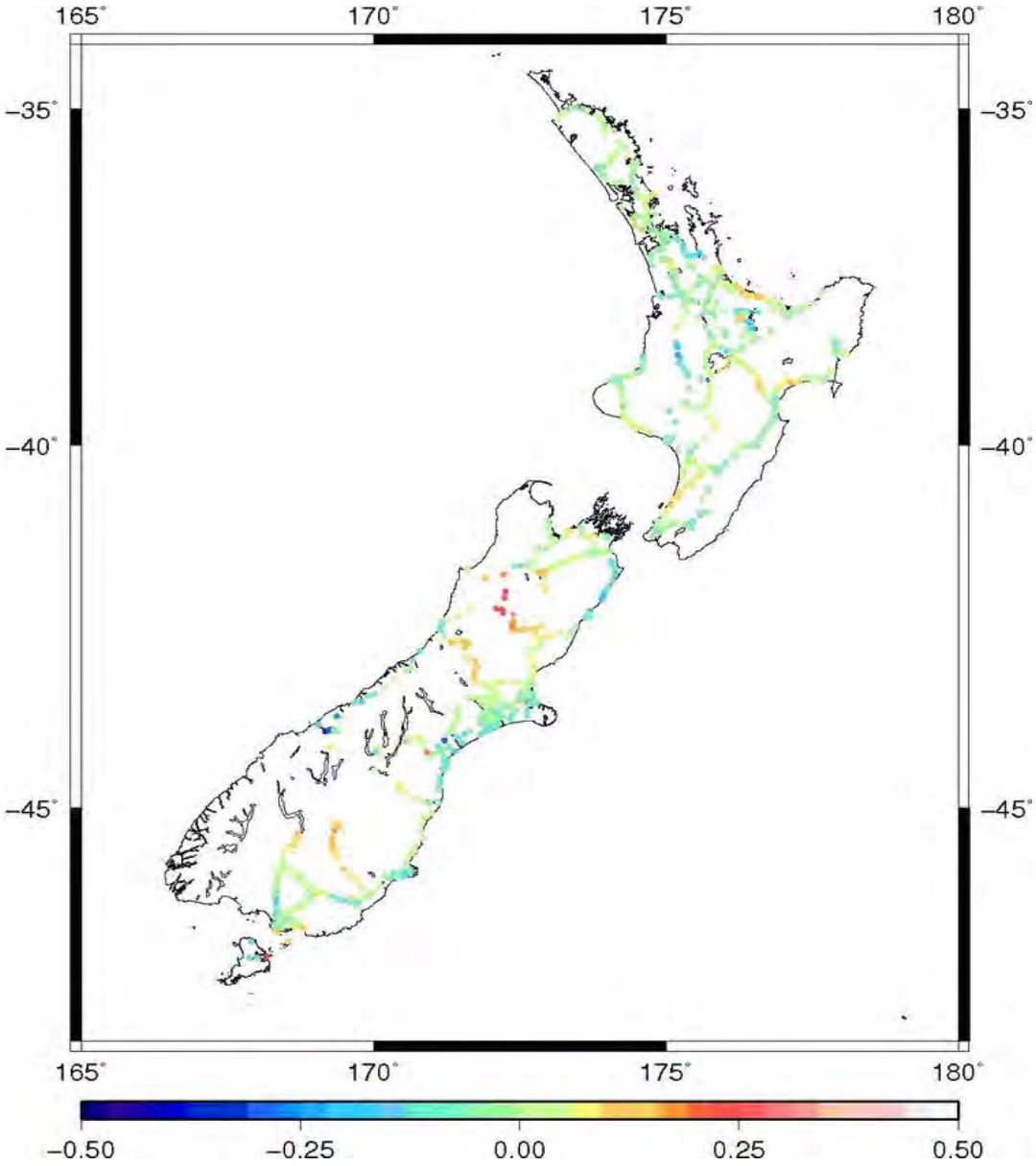
NZGeoid09 GPS-levelling

- GPS-Lev fit to NZGeoid09:

  0.062 m
- GPS-Lev fit to EGM2008:

  0.064 m
- GPS-Lev fit to NZGeoid05:

  0.081 m
- Largest difference in mountainous South Island with few GPS-Lev points
- Relative accuracy will be better than this



NZVD2009 Offsets

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Datum	Offset to NZVD2009	Standard Deviation
One Tree Point 1964	0.06	0.03
Auckland 1946	0.34	0.05
Moturiki 1953	0.24	0.06
Gisborne 1926	0.34	0.02
Napier 1962	0.20	0.05
Taranaki 1970	0.32	0.05
Wellington 1953	0.44	0.04
Nelson 1955	0.29	0.07
Lyttelton 1937	0.47	0.09
Dunedin 1958	0.49	0.07
Dunedin-Bluff 1960	0.38	0.04
Bluff 1955	0.36	0.05
Stewart Island 1977	0.39	0.15

NZGeoid09 and Levelling Offsets

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- Offsets are an average value across the entire datum
- Difference between offsets can be compared with levelled values
- Levelled offsets are different depending on where the datums connect
- Levelling offset accuracy ±0.07 m
- NZVD2009 offset accuracy ~±0.06 m

NZGeoid09 and Levelling Offsets

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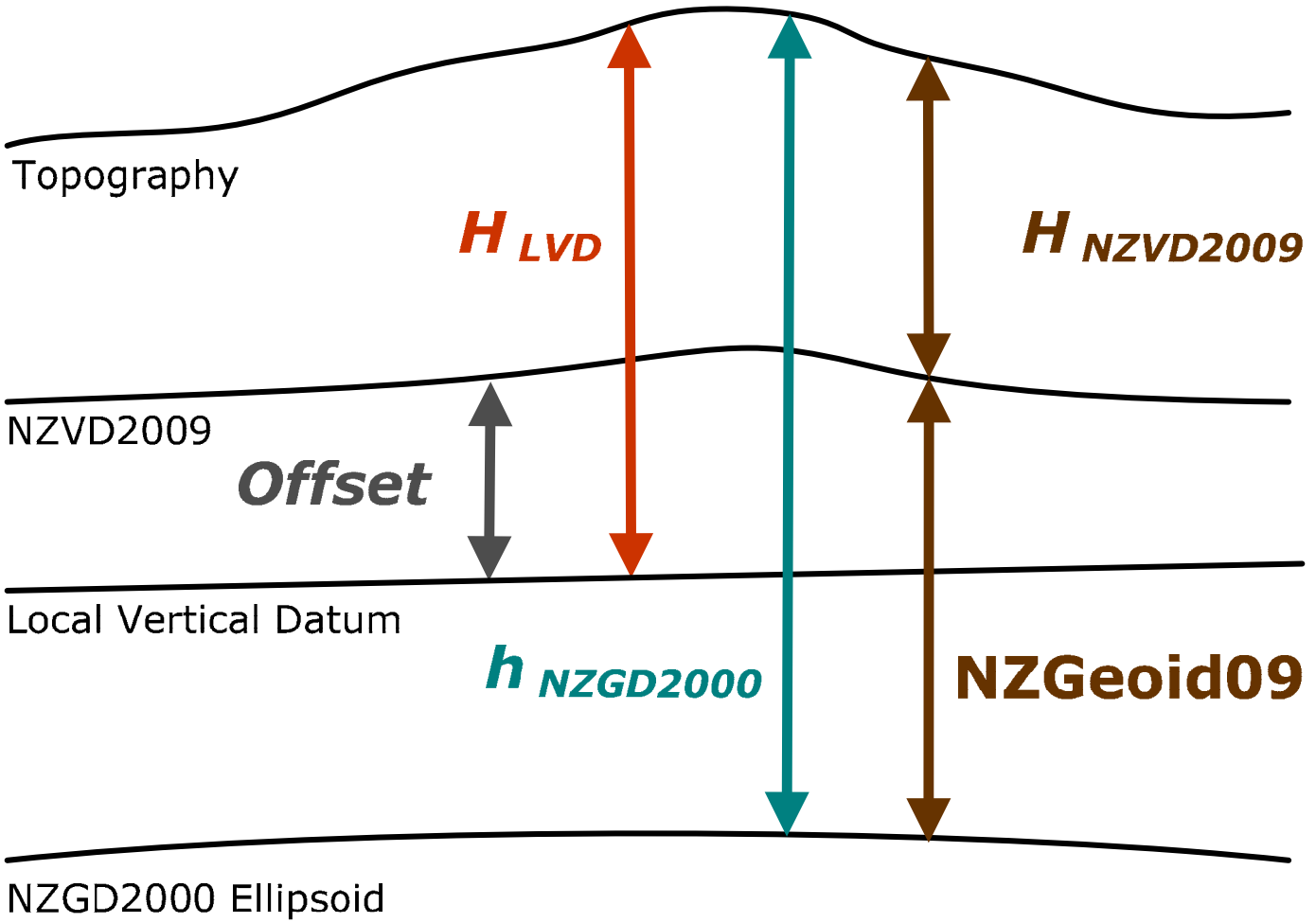
From	To	NZGeoid09	Levelling	Agree?
Auckland	One Tree Point	-0.276	-0.206	Yes
Auckland	Moturiki	-0.098	-0.070	Yes
Gisborne	Moturiki	-0.103	-0.075	Yes
Gisborne	Napier	-0.141	-0.166	Yes
Moturiki	Napier	-0.038	-0.099	Yes
Taranaki	Napier	-0.112	-0.046	Yes
Taranaki	Wellington	+0.121	+0.147	Yes
Taranaki	Moturiki	-0.074	-0.162	Yes
Napier	Wellington	+0.233	+0.237	Yes
Nelson	Lyttelton	+0.172	-0.027	*No*
Lyttelton	Dunedin	+0.019	-0.071	Yes
Dunedin-Bluff	Dunedin	+0.104	-0.019	Yes
Dunedin-Bluff	Bluff	-0.021	-0.001	Yes

NZVD2009 Height Relationships



NZVD2009 Height Transformations

- NZGD2000 » NZVD2009 $H_{NZVD2009} = h - N$
- LVD » NZVD2009 $H_{NZVD2009} = H_A - o_A$
- LVD » LVD $H_B = H_A - o_A + o_B$
- LVD » NZGD2000 $h = H_A + N - o_A$

Example: NZGD2000 to Wellington 1953

$$H_A = h - N + o_A$$

$h_{NZGD2000}$ = 52.193

$o_{Wellington\ 1953}$ = 0.44

N = 14.28

$H_{Wellington\ 1953}$ = 52.193 – 14.28 + 0.44

= 33.353

= 33.35 m

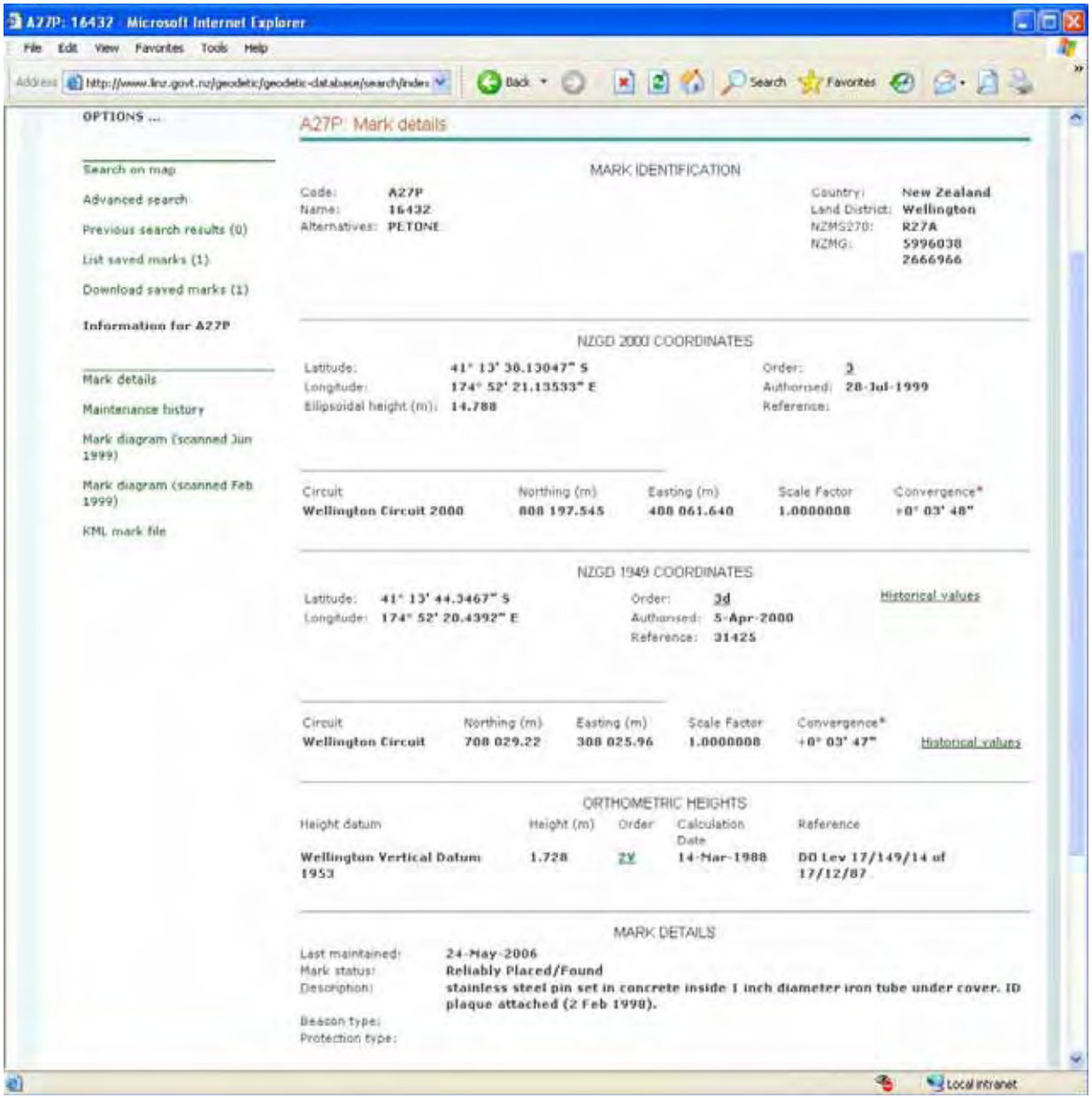
Part IV – Use of NZVD2009

Use of NZVD2009

- Not compulsory to use NZVD2009
- Uptake encouraged by:
  - LINZ services
  - GNSS/software integration
- Issues when using NZVD2009
- Mean high water springs
- Cadastral surveys
- Use with “other” local datums

LINZ Geodetic Database

Toitu te Land whenua Information New Zealand

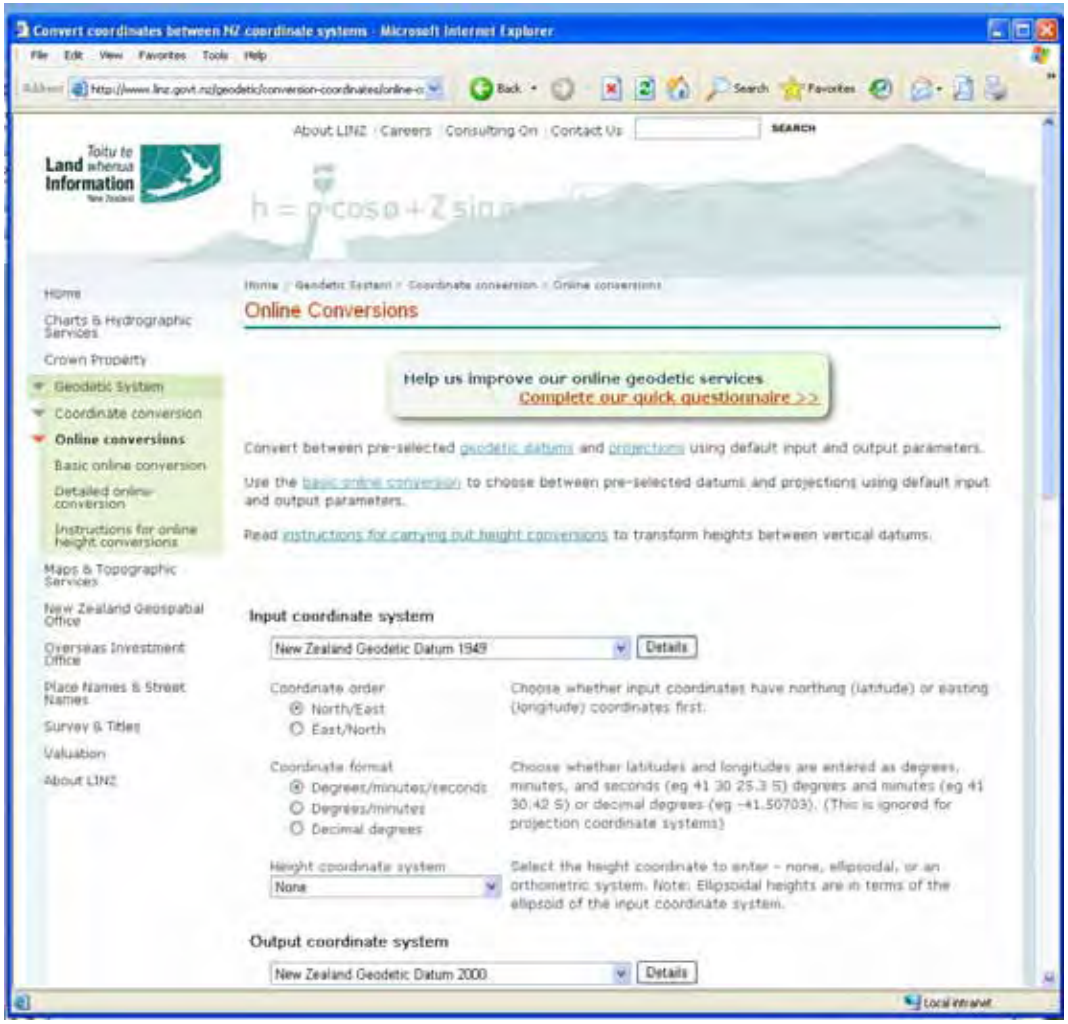


LINZ Geodetic Database

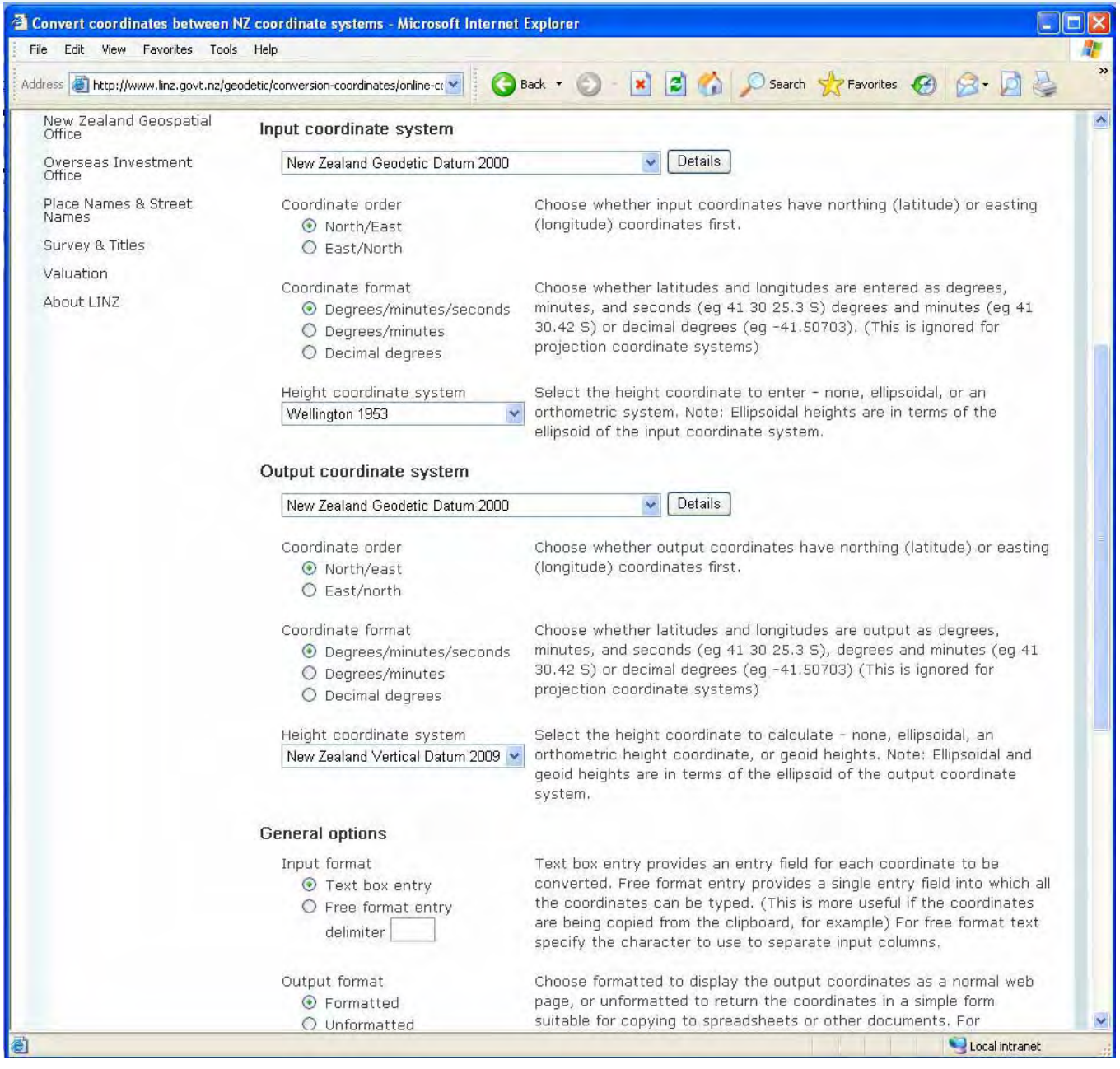
- www.linz.govt.nz/gdb
- Currently provides:
  - NZGD2000 ellipsoidal heights
  - *Normal*-orthometric heights from LVDs (1V-3V)
  - *Normal*-orthometric heights in relation to MSL (4V-5V)
- Will provide NZVD2009 heights from May 2010
  - Change required to Landonline to generate them
  - Provided for NZGD2000 Order 5 marks and better (marks with GPS determined heights)

LINZ Online Height Conversion

www.linz.govt.nz/coordinateconversion > detailed conversion

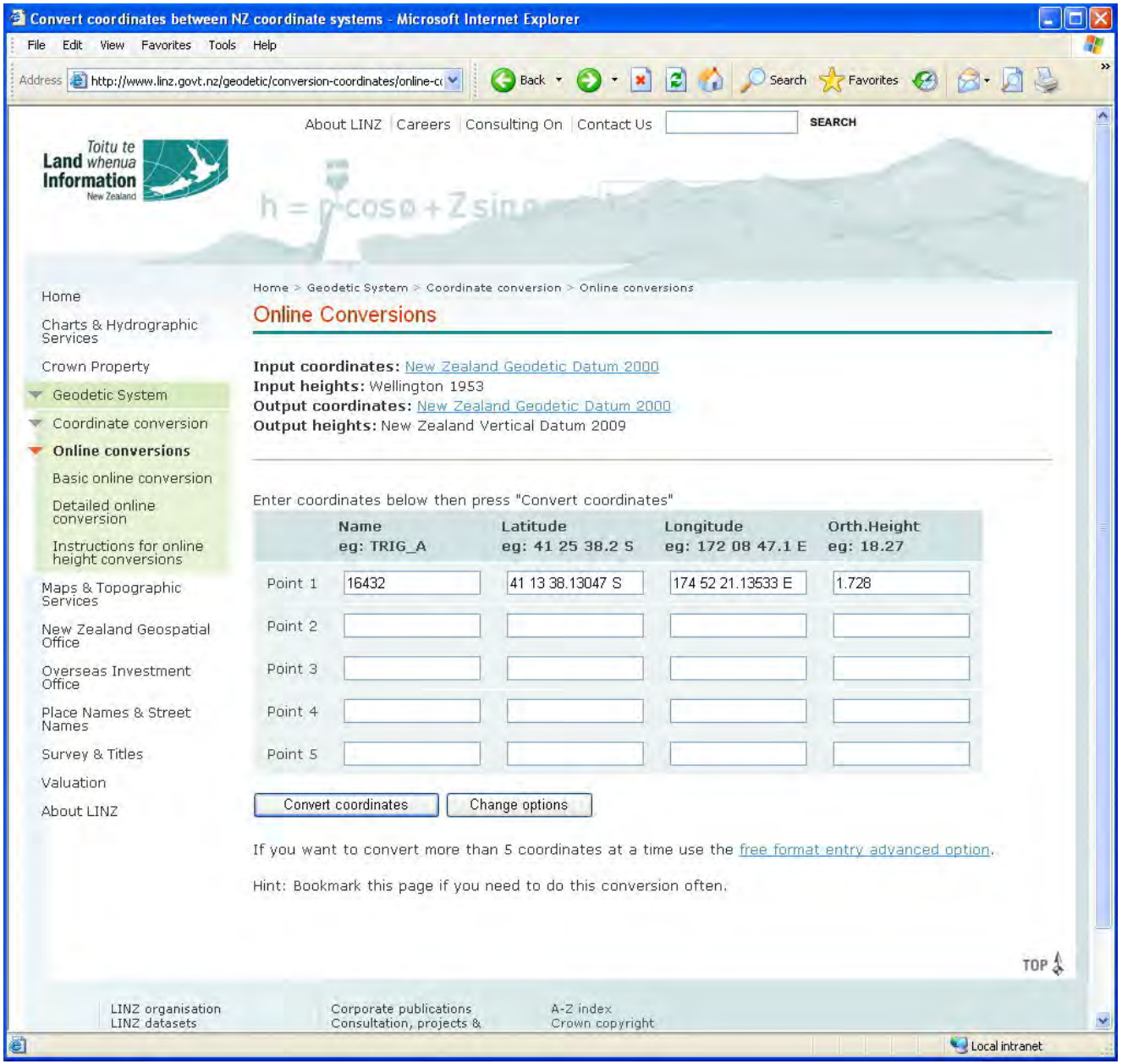


LINZ Online Height Conversion

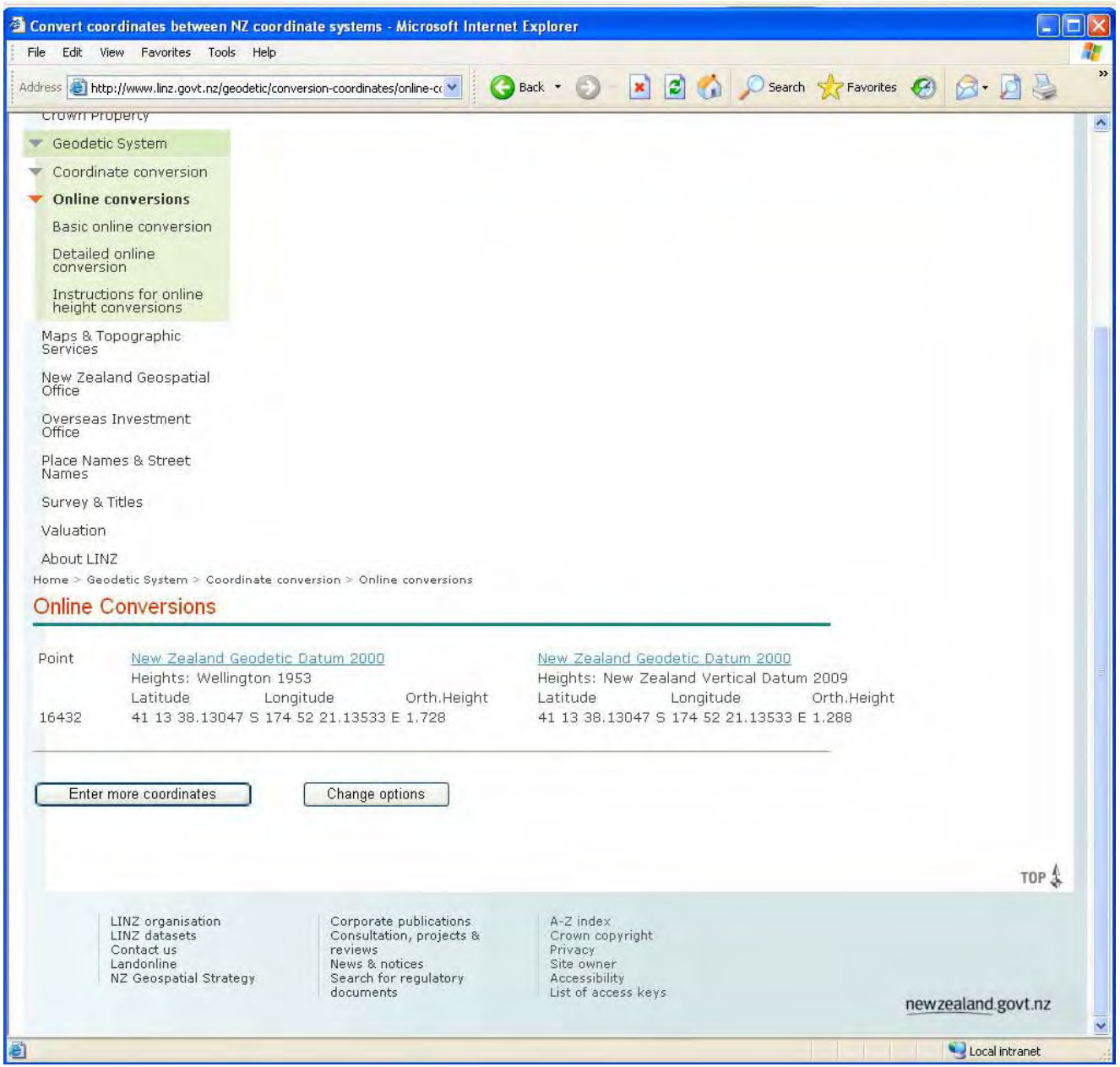


LINZ Online Height Conversion

Toitu te Land whenua Information New Zealand



LINZ Online Height Conversion



GNSS and Third Party Software

- NZVD2009 can be implemented into GNSS and third party software
- Allows users to directly interpolate NZGeoid09 values and apply offset
- This will be discussed by the next presentation

Height Conversion Issues

- Adjacent NZVD2009 heights may not be in terms if they are determined using different methods:
  - Transformation of ellipsoidal heights
  - Direct levelling from NZVD2009 benchmark
- NZVD2009 height errors are a combination of:
  - Original height error
  - NZGeoid09 and offset error
- NZGeoid09 on a 1’ (1.9 km) grid so will not model local geoid changes

MHWS Determination

- Like the existing LVDs NZVD2009 generally can not be used to define MHWS
- Still need to use evidence based approaches to establish MHWS
- NZVD2009 may be appropriate to transfer MHWS levels over short distances with similar tidal conditions
- MHWS is a horizontal depiction of seaward property extent, so does not need a height definition

Use With Cadastral Surveys

- NZVD2009 will be an official vertical datum in terms of the Rules for Cadastral Survey 2010
- Heighted boundary marks need to be in terms of an official vertical datum if a control mark is within:
  - 200 m of class A boundary point
  - 500 m of class B boundary point
- Important to state source of vertical datum in survey report
  - Direct levelling
  - GPS-levelling
  - Precise point positioning/Network RTK

“Other” Local Datums

- TA’s often require data in terms of “other” datums
- Offsets to “other” datums can be computed by:
  - Observe a number of points with GPS
  - Ellipsoidal heights can be used to calculate NZVD2009 heights
  - Local offset will be difference between NZVD2009 and local height
- Only applicable over small areas
- LINZ is considering how to include “other” datums
  - Need to know what datums are being used
  - Please email me details: mamos@linz.govt.nz

Part V – Summary

Summary

- New Zealand currently does not have a nationally consistent height system
- NZVD2009 is based on the NZGeoid09 quasigeoid
- NZVD2009 can be accessed nationally using modern technology
- Heights can be obtained from LINZ online services
- Care needs to be taken converting heights to ensure that accuracy is retained
- LINZ is considering how to include “other” datums
  - Please provide information to: mamos@linz.govt.nz

Part VI – Questions