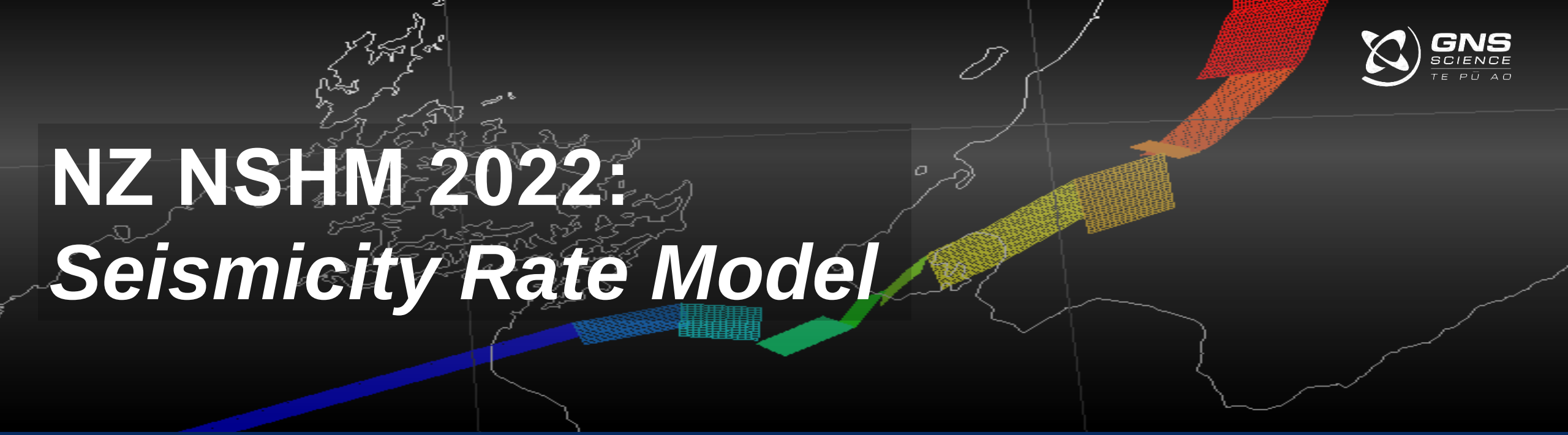

NZ NSHM 2022:
Seismicity Rate Model

Presented by Russ Van Dissen (on behalf of the NZ NSHM 2022 Team)

Te Tauira Matapae Pūmate Rū i Aotearoa
NSHM The New Zealand National Seismic Hazard Model
A GNS Science Led Research Programme

E mahi ana me
In collaboration with

Wellington Earthquake Resilience Collaboration Workshop, 10 November 2022

Ngā hoa tuku pūtea
Funding partners

NZ NSHM 2022: Seismicity Rate Model

- What is the Seismicity Rate Model (**SRM**)
- Where does the **SRM** fit into the overall NZ NSHM 2022 project
- What are the components of the **SRM**
- How are the components of the **SRM** combined to estimate hazard

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NZ NSHM 2022: Seismicity Rate Model

- What is the Seismicity Rate Model (SRM)
  - Provides the ***location***, ***rate*** and ***size*** of the earthquake from which hazard is calculated

- Where does the SRM fit into the overall NZ NSHM 2022 project

Seismicity Rate Model **+** Ground Motion Characterization Models **=** Probabilistic forecasts of the strength of earthquake ground shaking throughout New Zealand

NZ NSHM 2022: Seismicity Rate Model

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NZ NSHM 2022: *SRM components (overview)*

- Guidance Documents (*setting the scene and the path to follow*)
- Foundational Datasets, and Input Models and Scaling Relations
- Earthquake Rupture Forecasts
  - Distributed Seismicity-based (*Distributed Seismicity Model* – ***DSM***)
  - Fault-based (*Inversion Fault Model* – ***IFM***)
- Testing and Evaluation (*including rate and hazard sensitivity*)
- Final SRM Model

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A veritable gold mine of earthquake hazard data and information all freely available for download at:
https://nshm.gns.cri.nz/Resources/ScienceReports

NZ NSHM 2022: *SRM components (overview)*

- Scene-Setting Guidance Document
  - NZ NSHM Framework Plan – *Gerstenberger et al.*
- Foundational Datasets, and Input Models and Scaling Relations
  - Revised EQ catalogue with consistent magnitudes – *Christopherson et al*.
  - Updated EQ catalogue with re-evaluated depths, event classifications and wider geographic coverage – *Rollins et al*.
  - Country-scale geodetic strain rate maps – *Johnson et al*.
  - Regional fault orientation analysis – *Rattenbury et al*.
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  - Paleoseismic site database (fault slip rates, and paleoEQ timings and single-event displacement sizes – *Litchfield et al*.
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  - NZ Community Fault Model – *Seebeck et al*.
  - Average coseismic slip profiles – *Thingbaijam et al*.
  - Magnitude - area scaling relations (along with accompanying average displacements) – *Stirling et al*. and *Shaw et al*.

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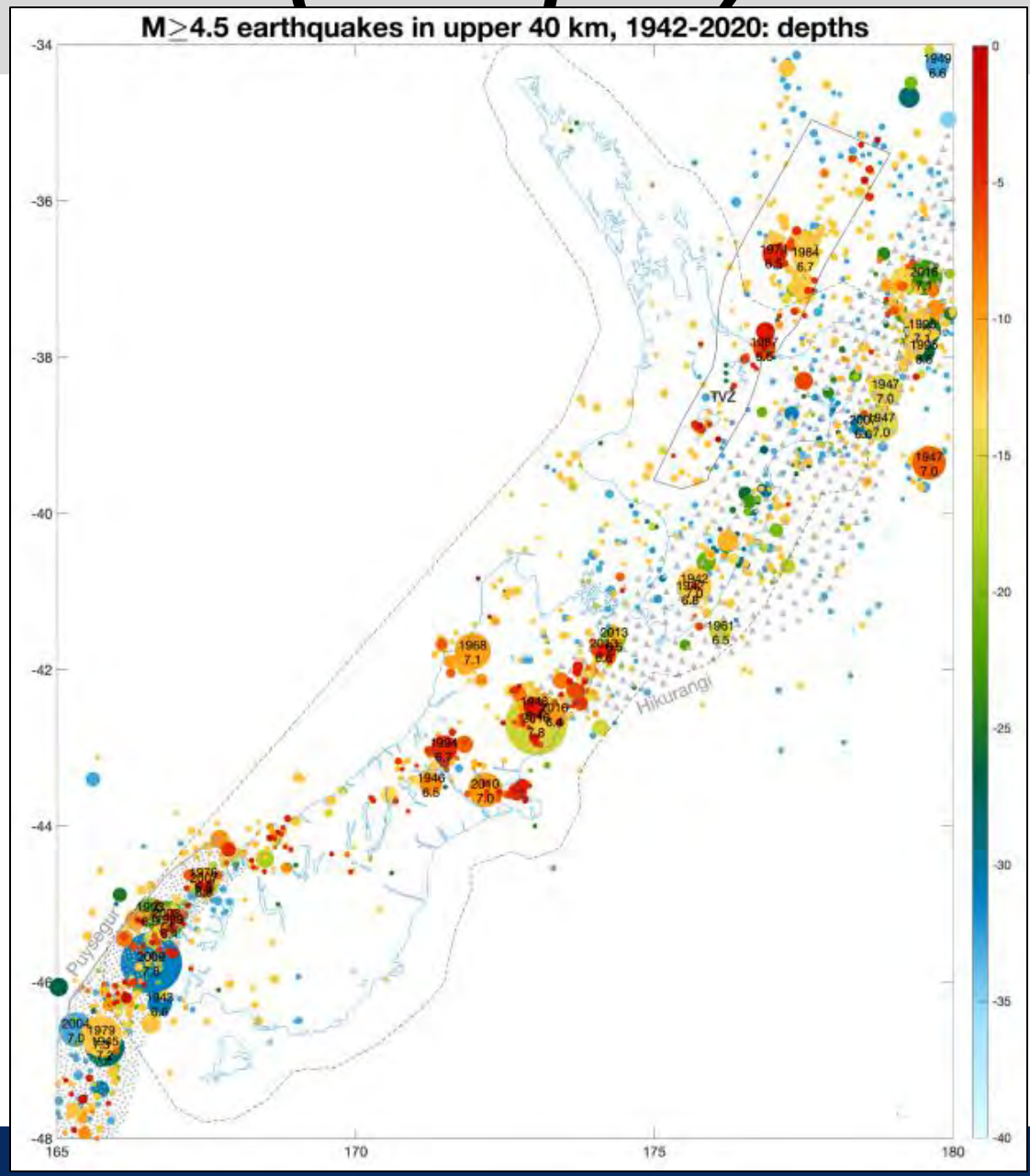
NZ NSHM 2022: *SRM components (examples)*

Revised and updated Earthquake Catalogue

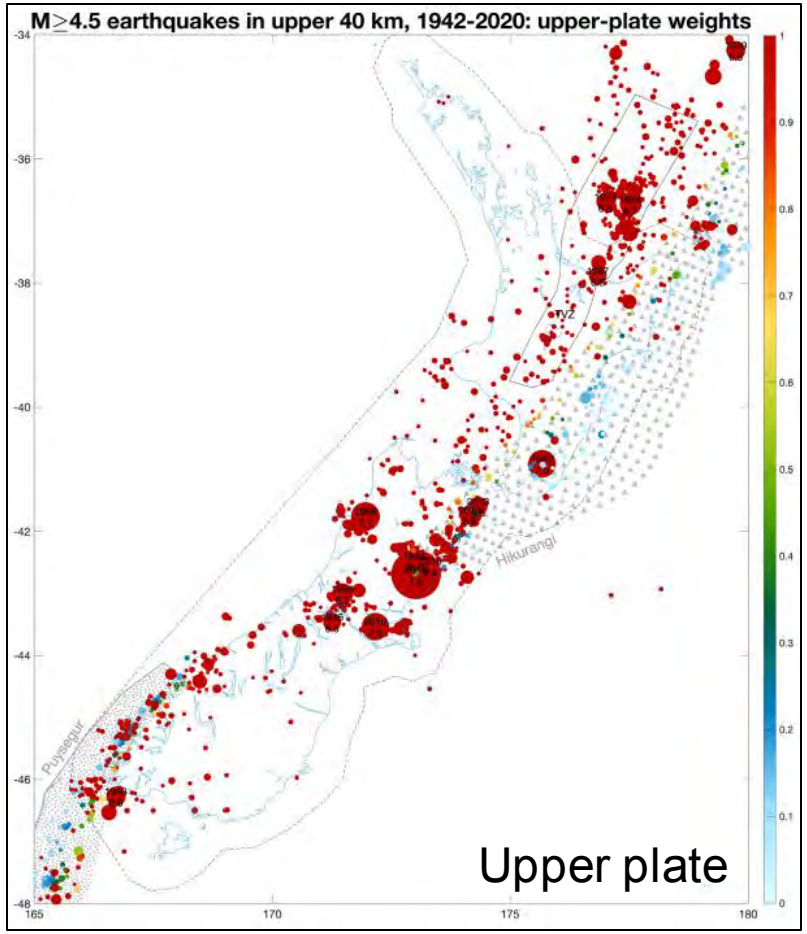
- Consistent magnitude (M_w) estimates through time
- Updated depths (including uncertainties)
- Tectonic type classifications
  - Upper plate
  - Subduction interface
  - Intra-slab
- Extended geographic coverage

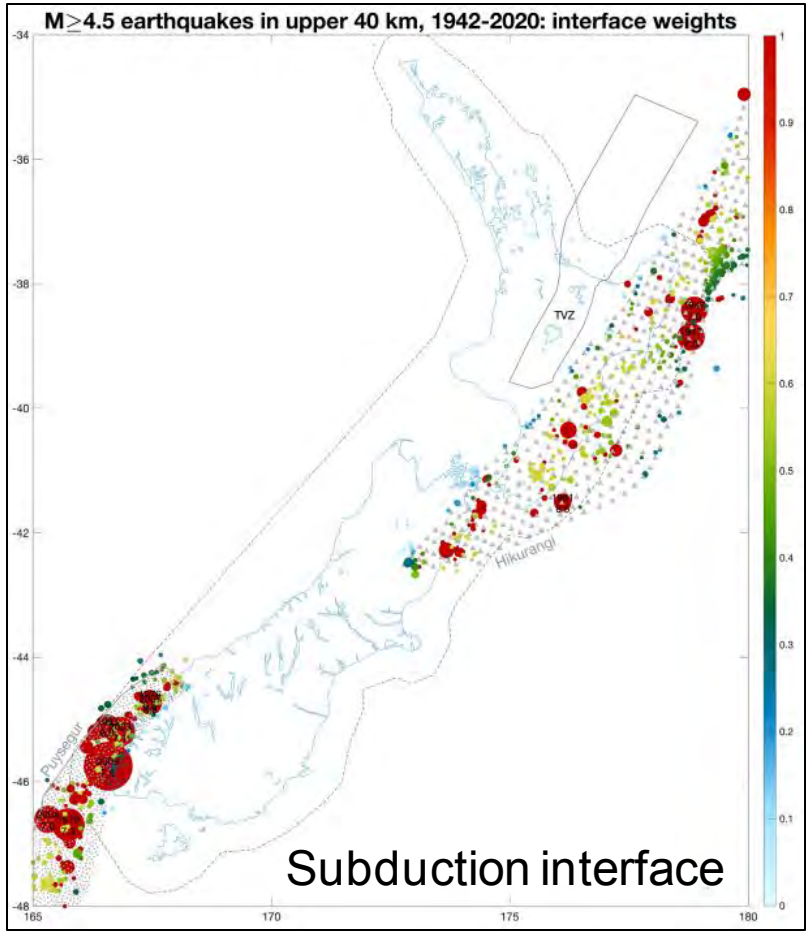


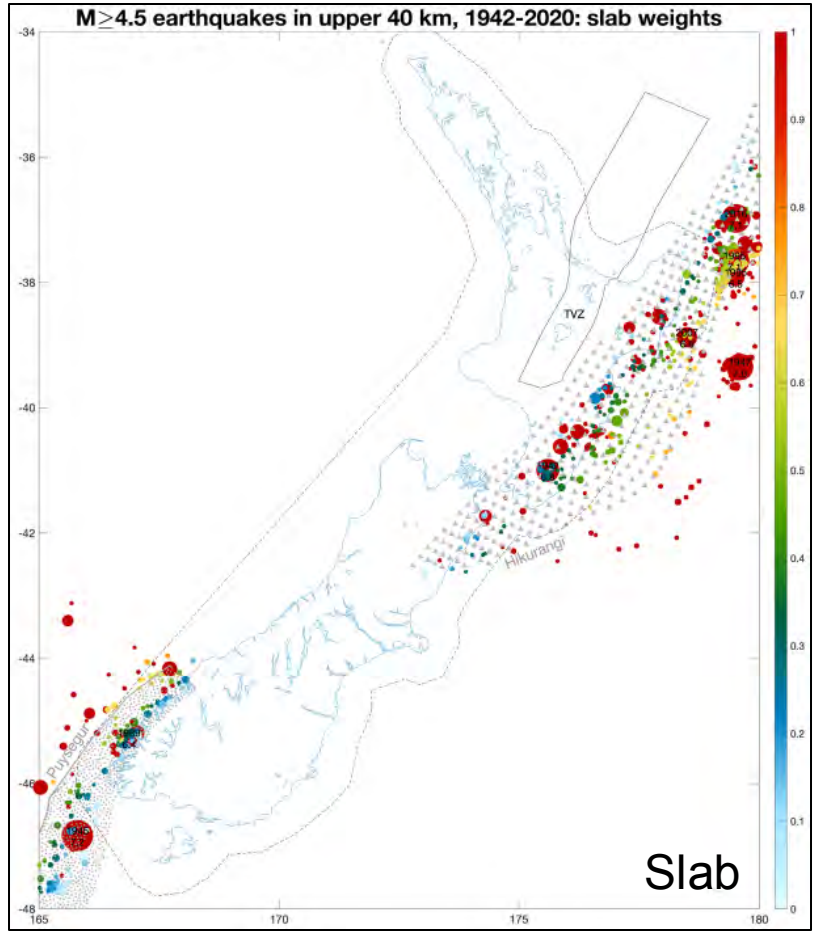
(Christopherson et al. 2022; Rollins et al. 2022a)

NZ NSHM 2022: *SRM components (examples)*

Tectonic type classification



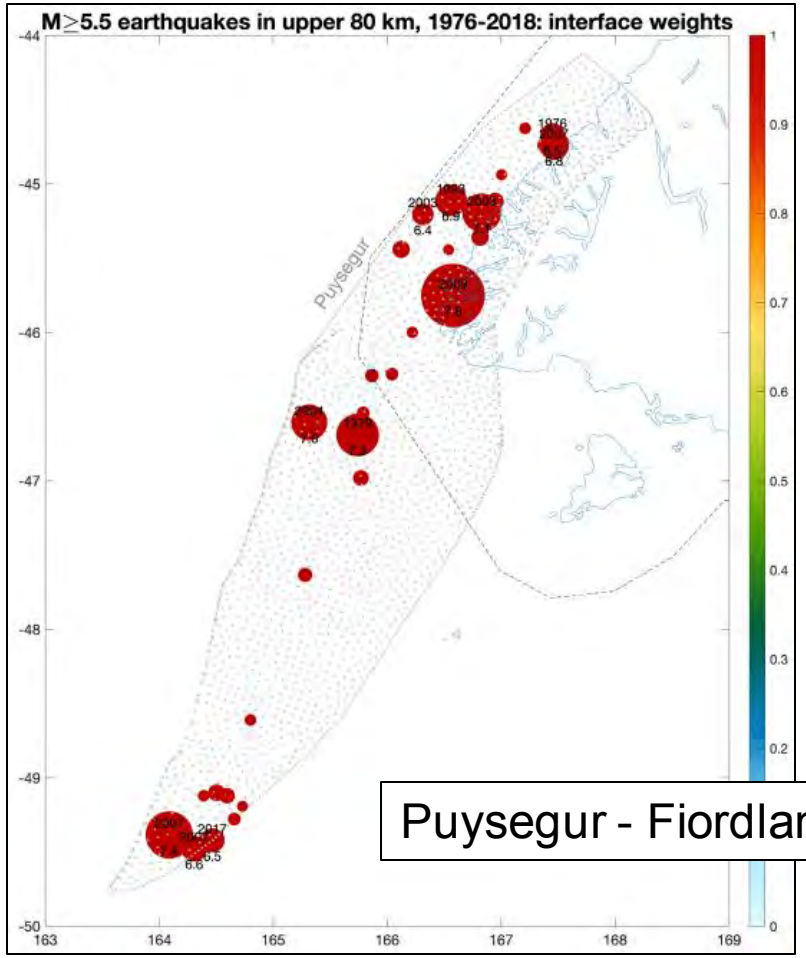




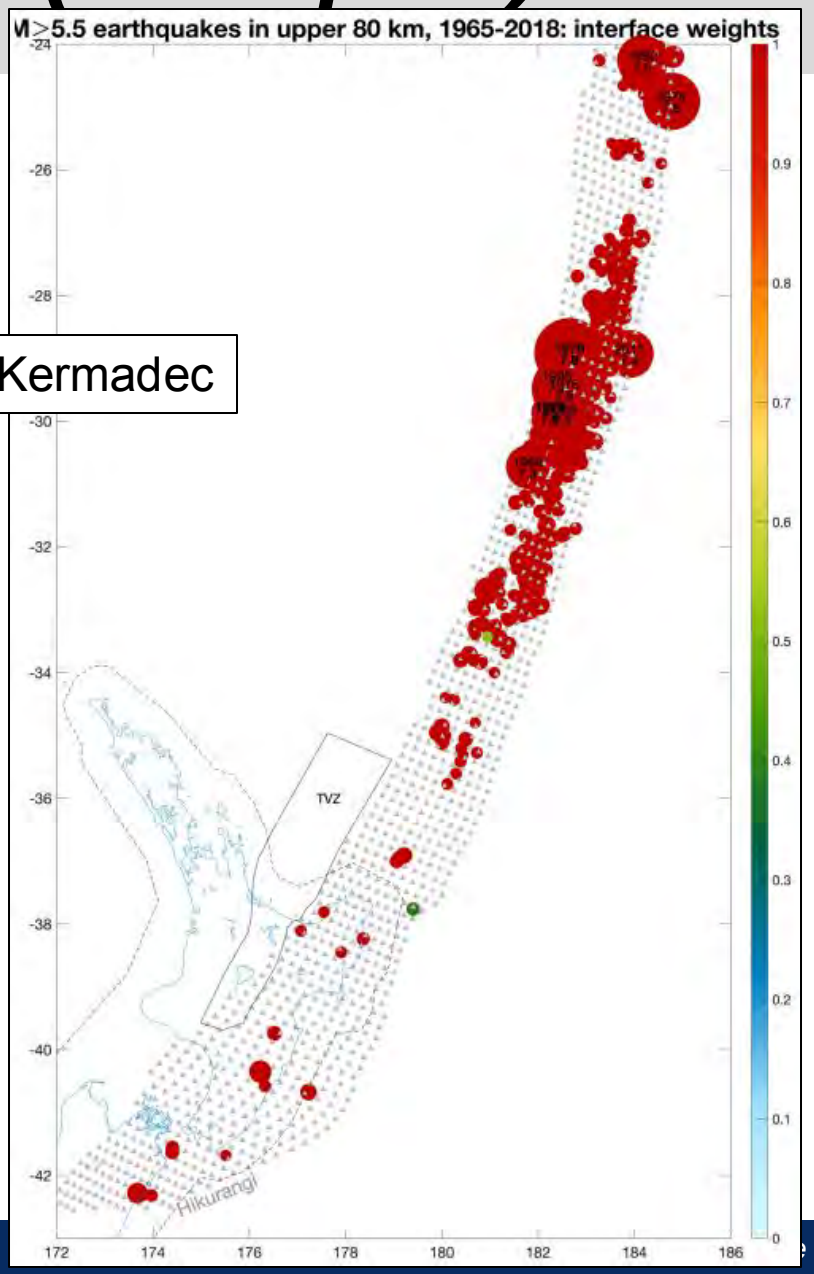
(Christopherson et al. 2022; Rollins et al. 2022a)

NZ NSHM 2022: *SRM components (examples)*

Extended geographic coverage for interface events



Puysegur - Fiordland



Hikurangi - Kermadec

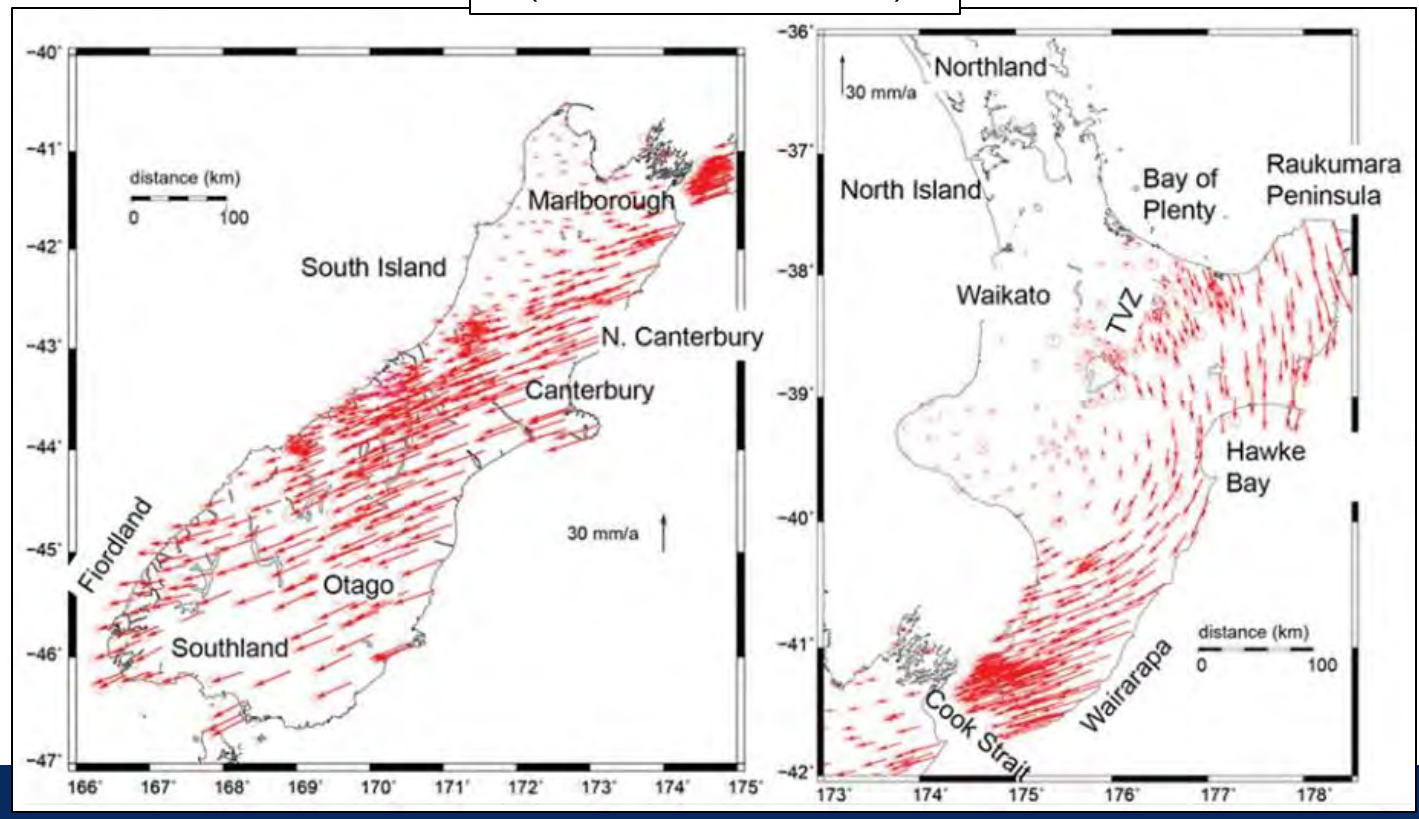
(Christopherson et al. 2022; Rollins et al. 2022b)

NZ NSHM 2022: *SRM components (examples)*

Country-scale geodetic strain rate maps

- Derived from GNSS velocity field of Beavan et al. (2016)
  - Covering 1998 - 2013
  - Corrected to remove co-seismic signal from encompassed large earthquakes
- Multiple methods used to derive strain rate
  - VDoHS
  - Body-force
  - VELMAP
  - Geostatistical

GNSS velocity field
(Australian Plate fixed)

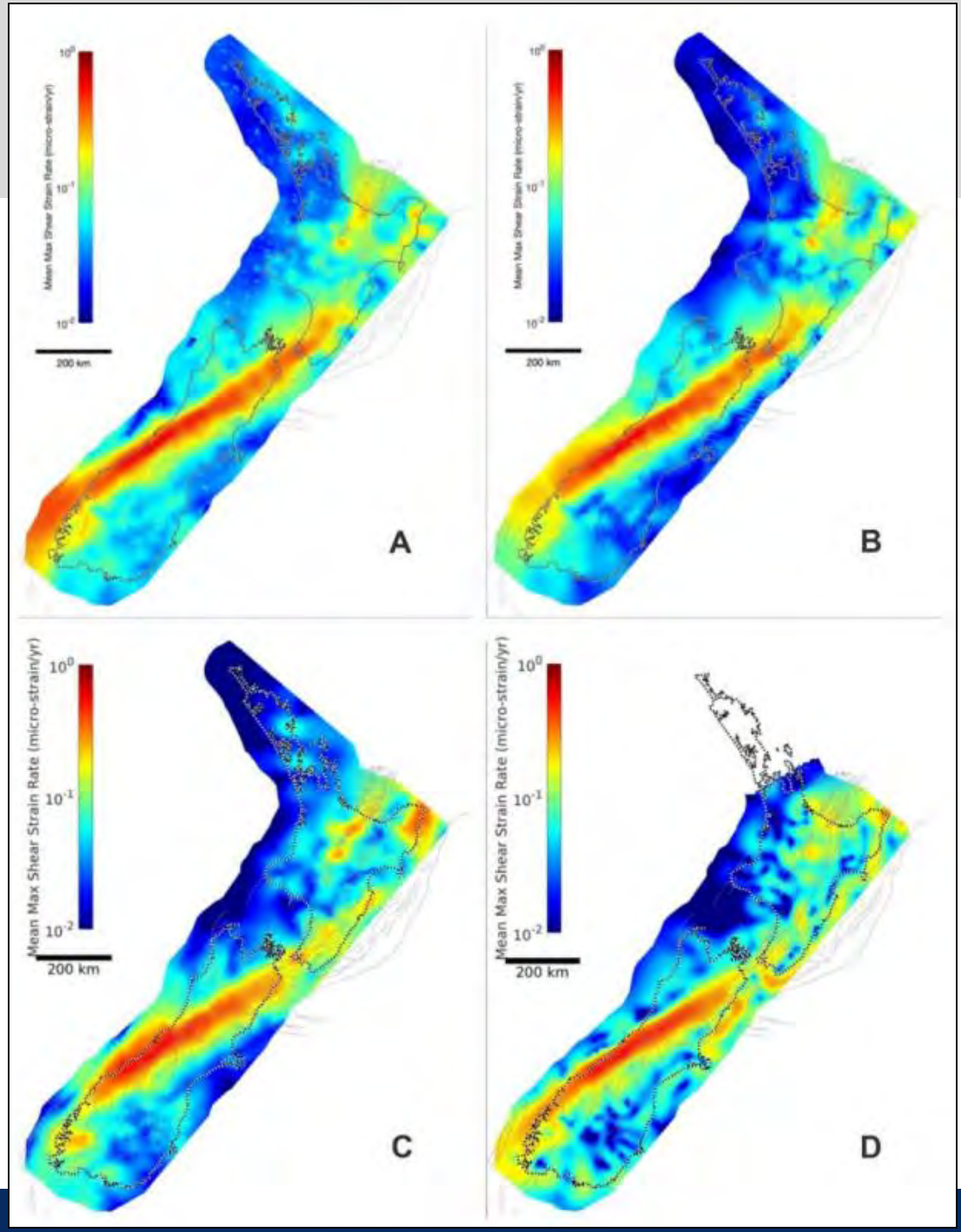


(Johnson et al. 2022)

NZ NSHM 2022: *SRM*

Country-scale geodetic strain rate maps

- Maximum shear strain rate
- Corrected for:
  - Interseismic locking on Hikurangi subduction interface
  - Suspected sill cooling in the Taupō Volcanic Zone
- Strain rate methods
  A. VDoHS
  B. Body-force
  C. VELMAP
  D. Geostatistical

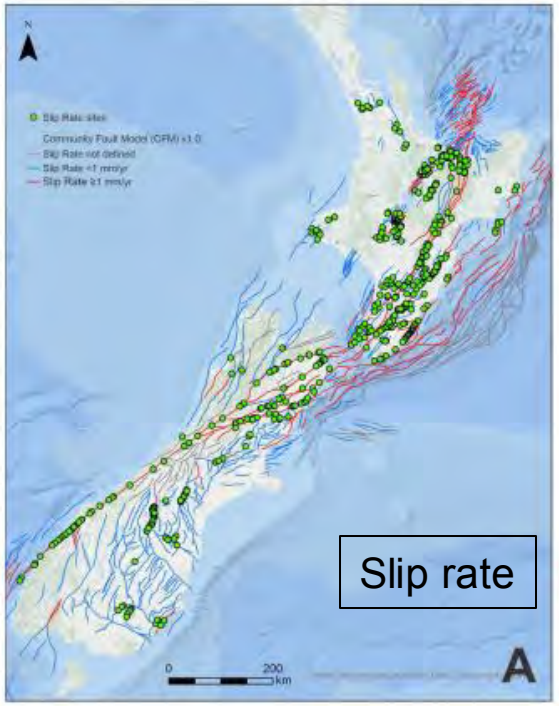


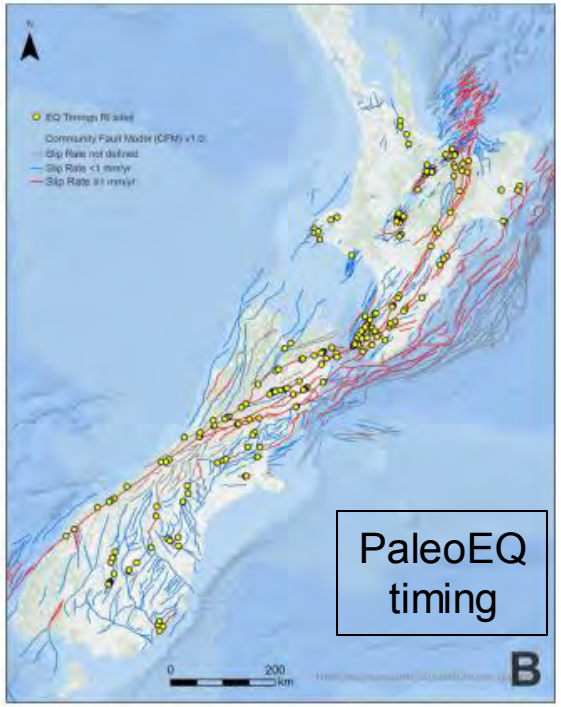
(Johnson et al. 2022)

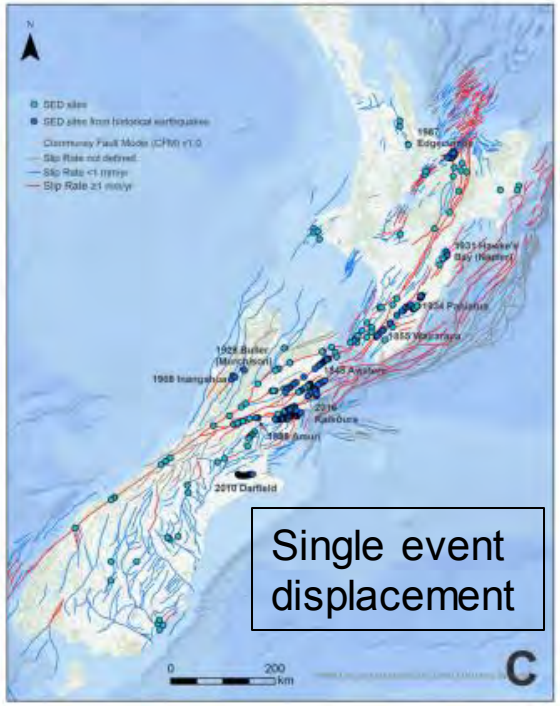
NZ NSHM 2022: *SRM*

NZ Paleoseismic site database

- Fault slip rates
  - 862 sites
  - 189 different fault sections
- Paleoearthquake timings
  - 304 sites
  - 953 paleo earthquake timing records
  - 99 different fault section
- Single-event co-seismic displacements
  - 970 sites
  - Mostly from 2010 Darfield and 2016 Kaikōura earthquakes





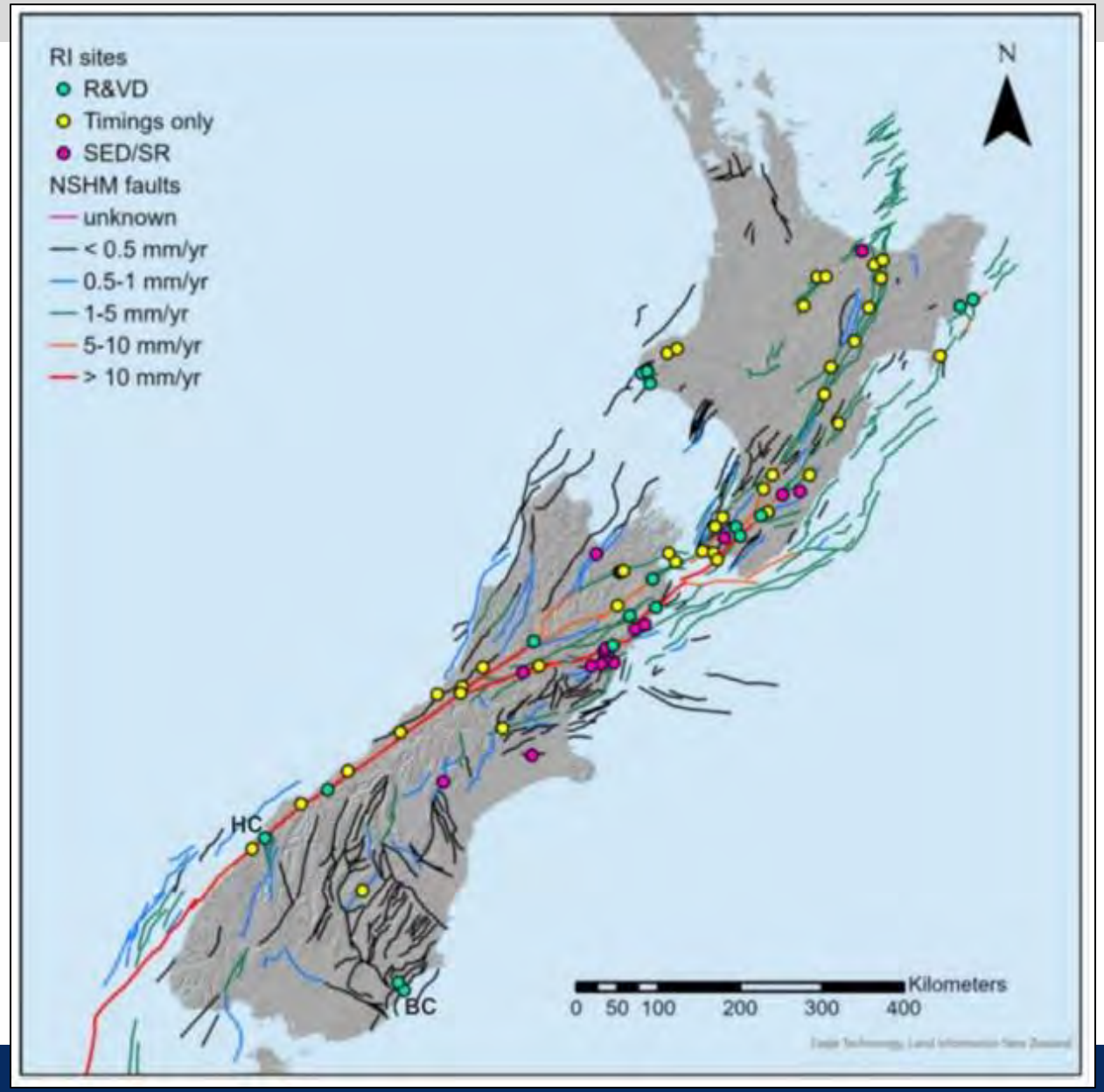


(Litchfield et al. 2022)

NZ NSHM 2022: *SRM components (examples)*

Paleoearthquake recurrence intervals

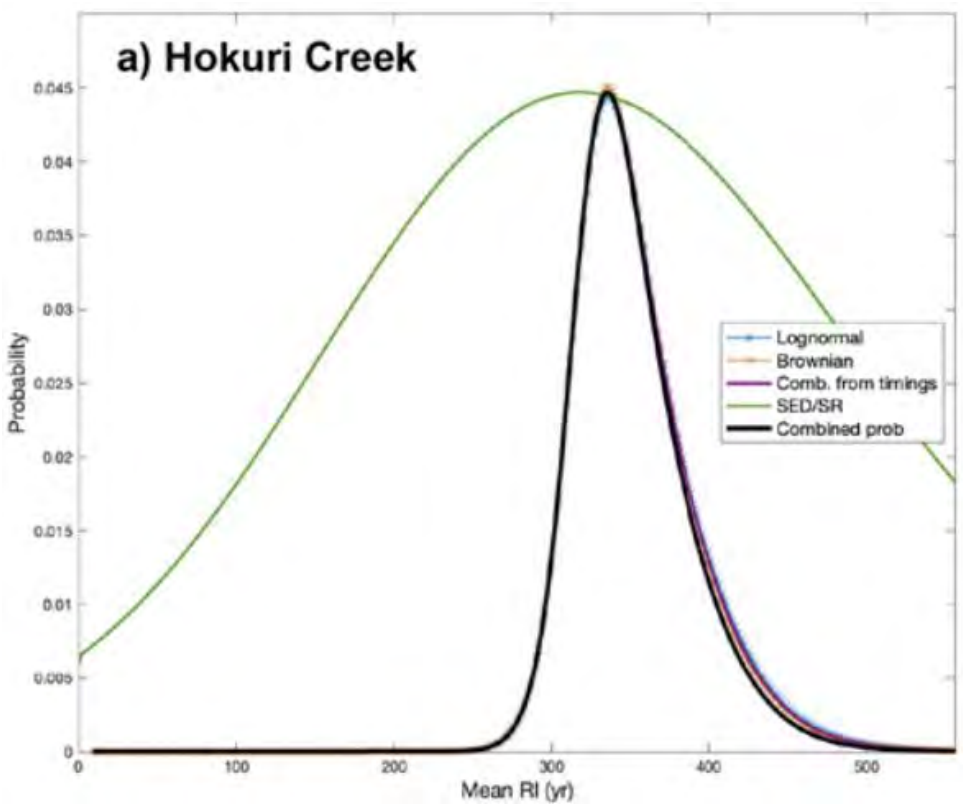
- 81 locations
- Derived from weighted combinations of:
  - Multiple input data sets
    - PaleoEQ timings
    - Single-event co-seismic displacements
    - Fault slip rates
  - Multiple recurrence-time models
    - Log-normal
    - Brownian Passage Time
    - Poisson



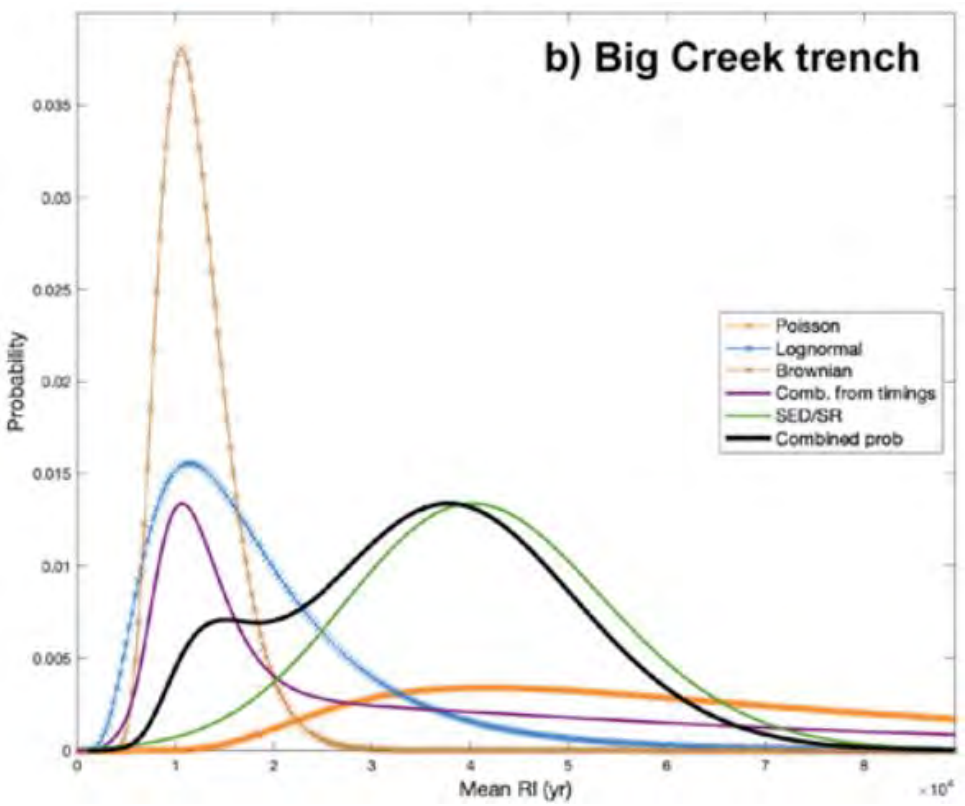
(Coffey et al. 2022)

NZ NSHM 2022: *SRM components (examples)*

Paleoearthquake recurrence intervals



Alpine Fault

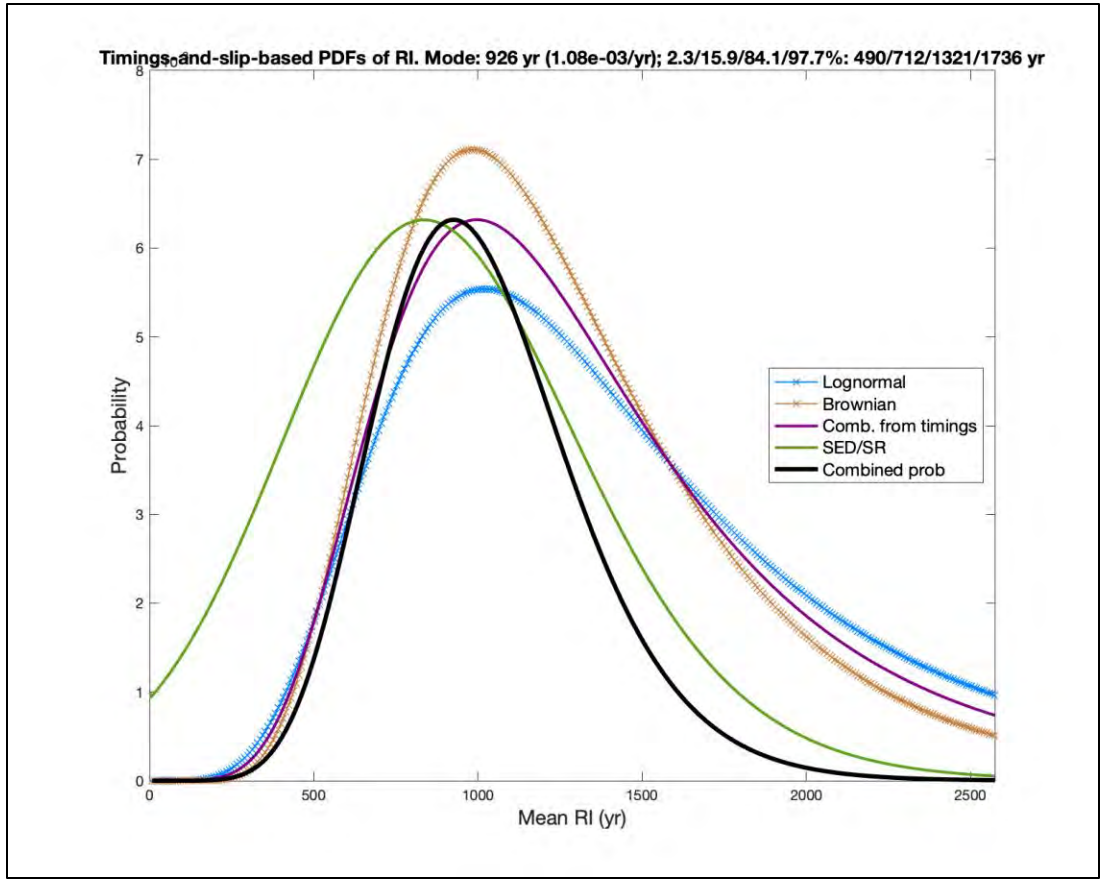


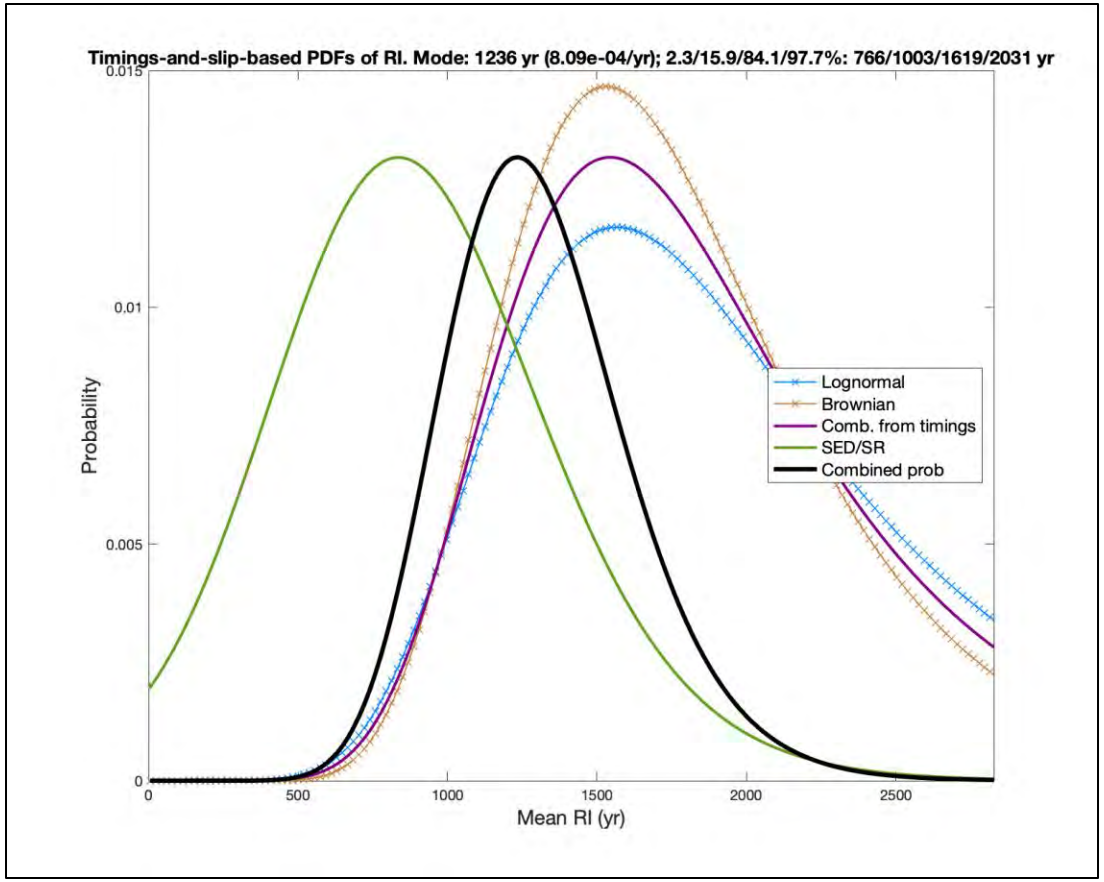
Akatore Fault

(Coffey et al. 2022)

NZ NSHM 2022: *SRM components (examples)*

Paleoearthquake recurrence intervals





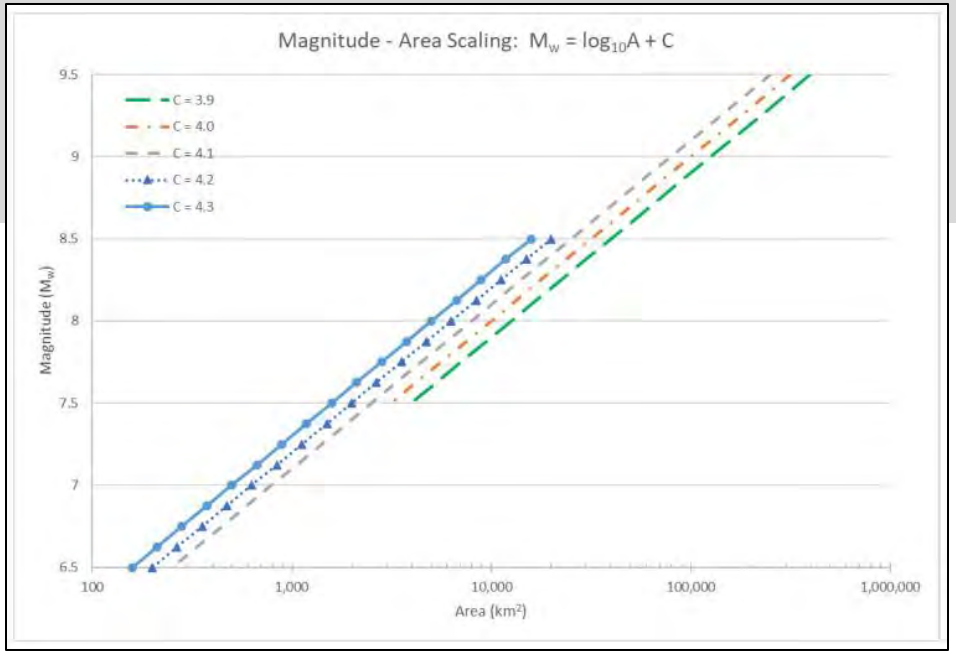
Wellington Fault

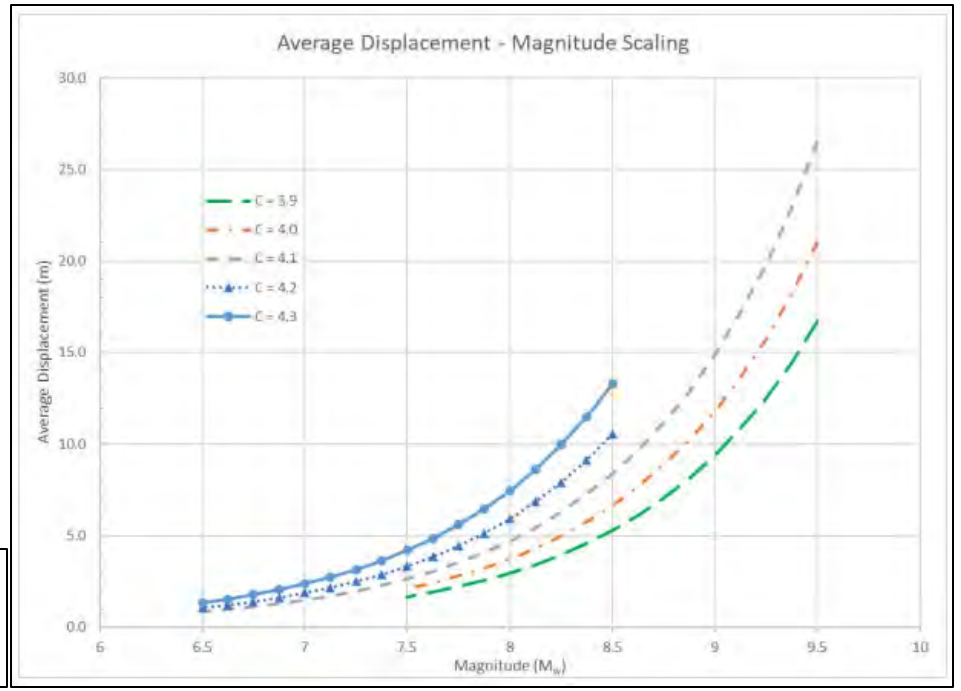
(Coffey et al. 2022)

NZ NSHM 2022: *SRM*

Magnitude – Area scaling relations

- Used to derive a magnitude and displacement for every fault rupture in the NSHM
- Backbone-type relation
  - $M_w = \log_{10}A + C$
    - A = rupture area in km^2
    - For Upper Plate ruptures, C = 4.1, 4.2 & 4.3
    - For Interface ruptures, C = 3.9, 4.0 & 4.2
    - Single-event co-seismic displacements





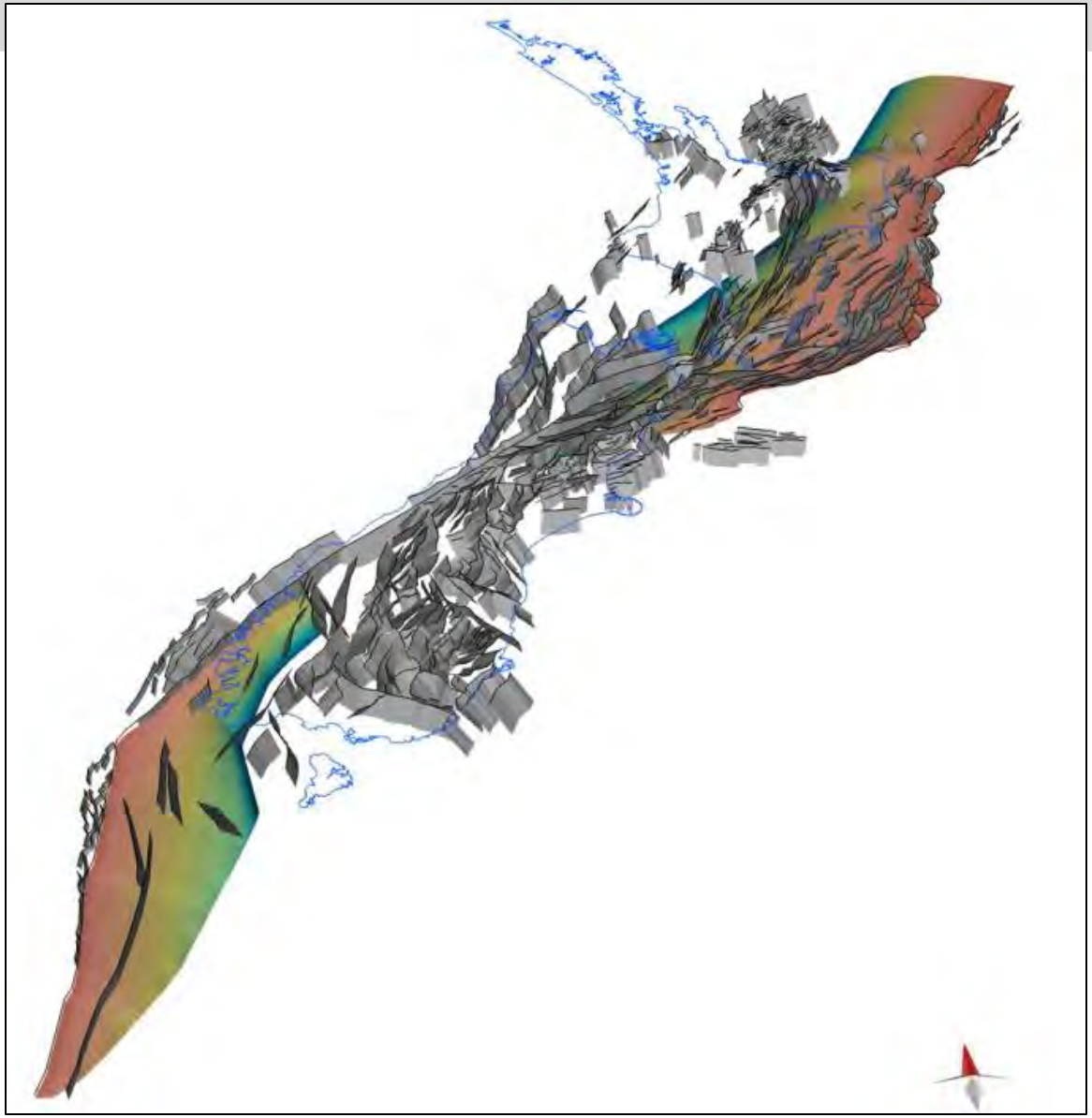
$D = m_o / (A \times \mu)$
$m_o = 10^{(1.5Mw + 9.5)}$
$M = 3.0 \times 10^{10}$ N/m^2

(Stirling et al. 2022; Shaw 2022)

NZ NSHM 2022: *SRM components (examples)*

NZ Community Fault Model v1.0

- Community-derived simplified representation of active (and potentially active) faults throughout NZ
  - Fault location
    - 2D and 3D
      - Dip
      - Depth of rupture
  - Fault kinematics
    - Movement style (sense of displacement)
    - Slip rate

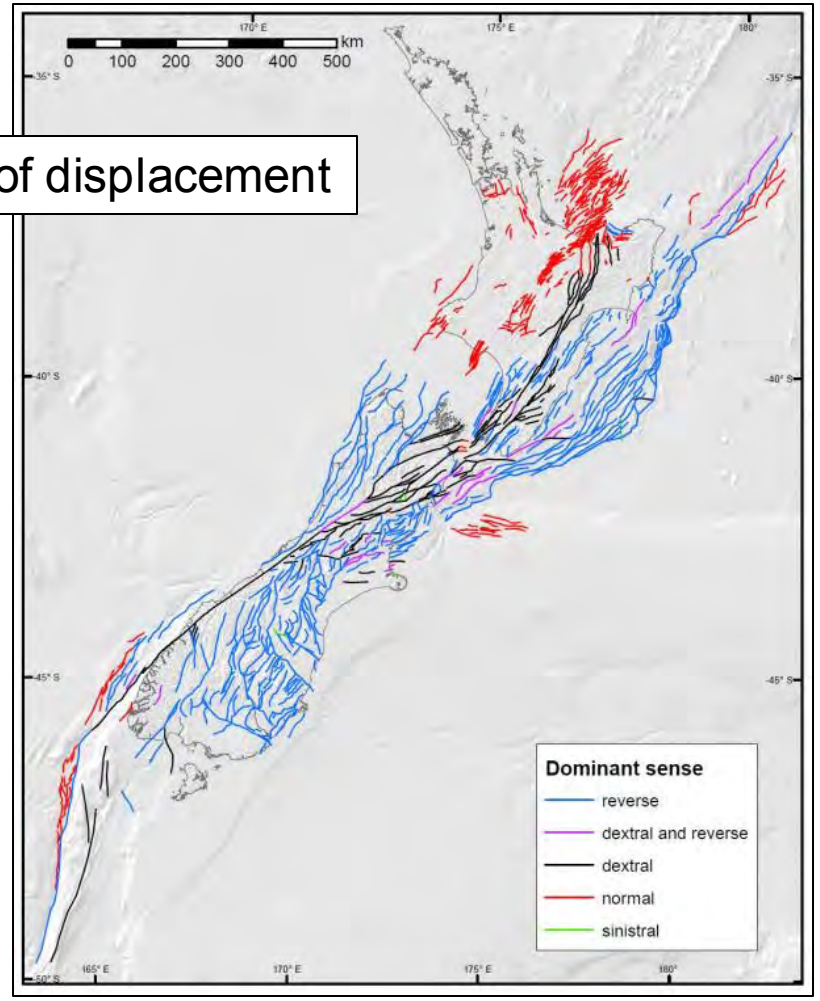


(Seebeck et al. 2022)

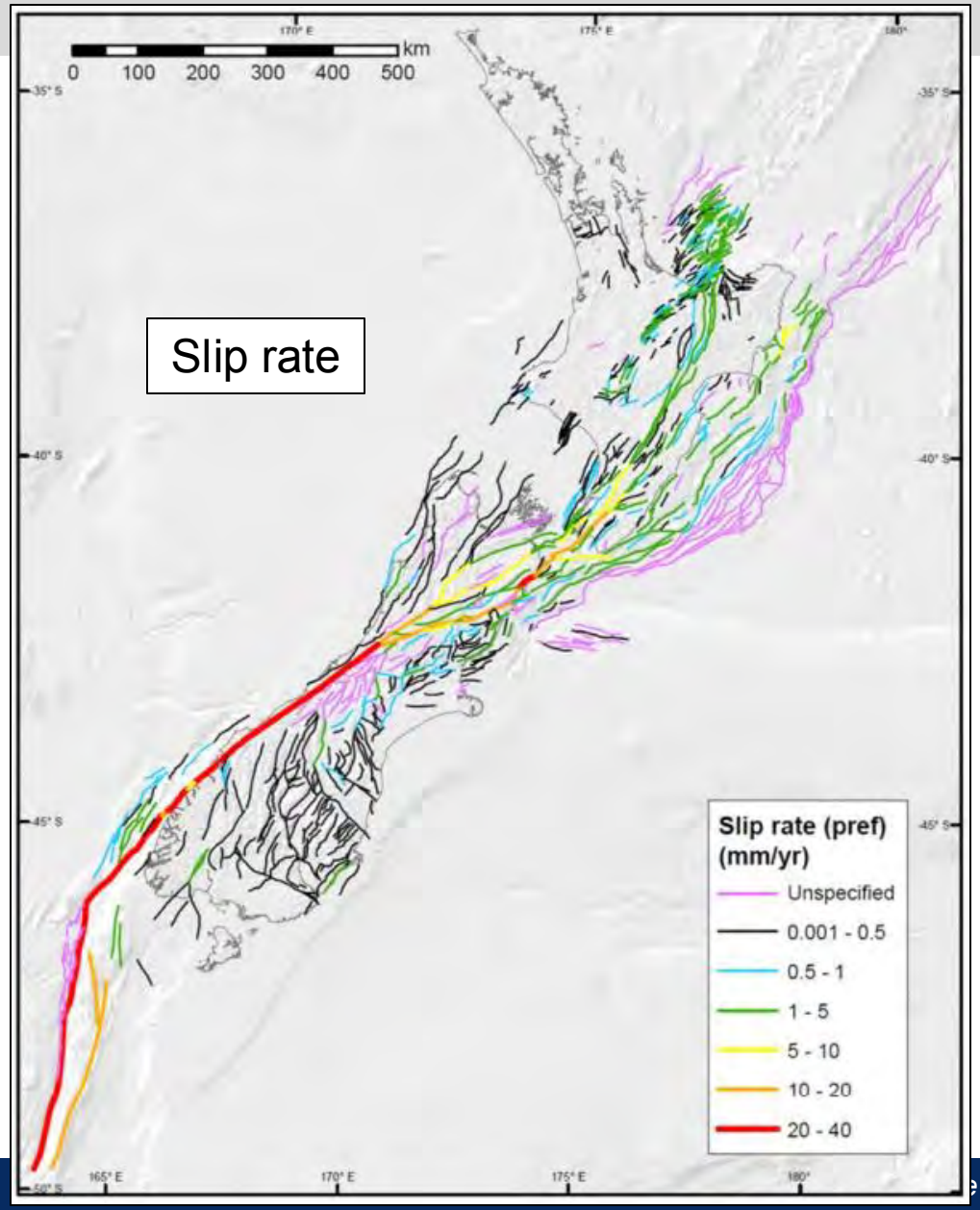
NZ NSHM 2022: *SRM components (examples)*

NZ Community Fault Model v1.0

Sense of displacement



Slip rate



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    - The hybrid distributed seismicity model – *Rastin et al*.
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Distributed Seismicity Models

- Slab model
- Interface Model (M < 7.5)
- Crustal Uniform Rate Zones
- Hybrid Model (<40 km depth)

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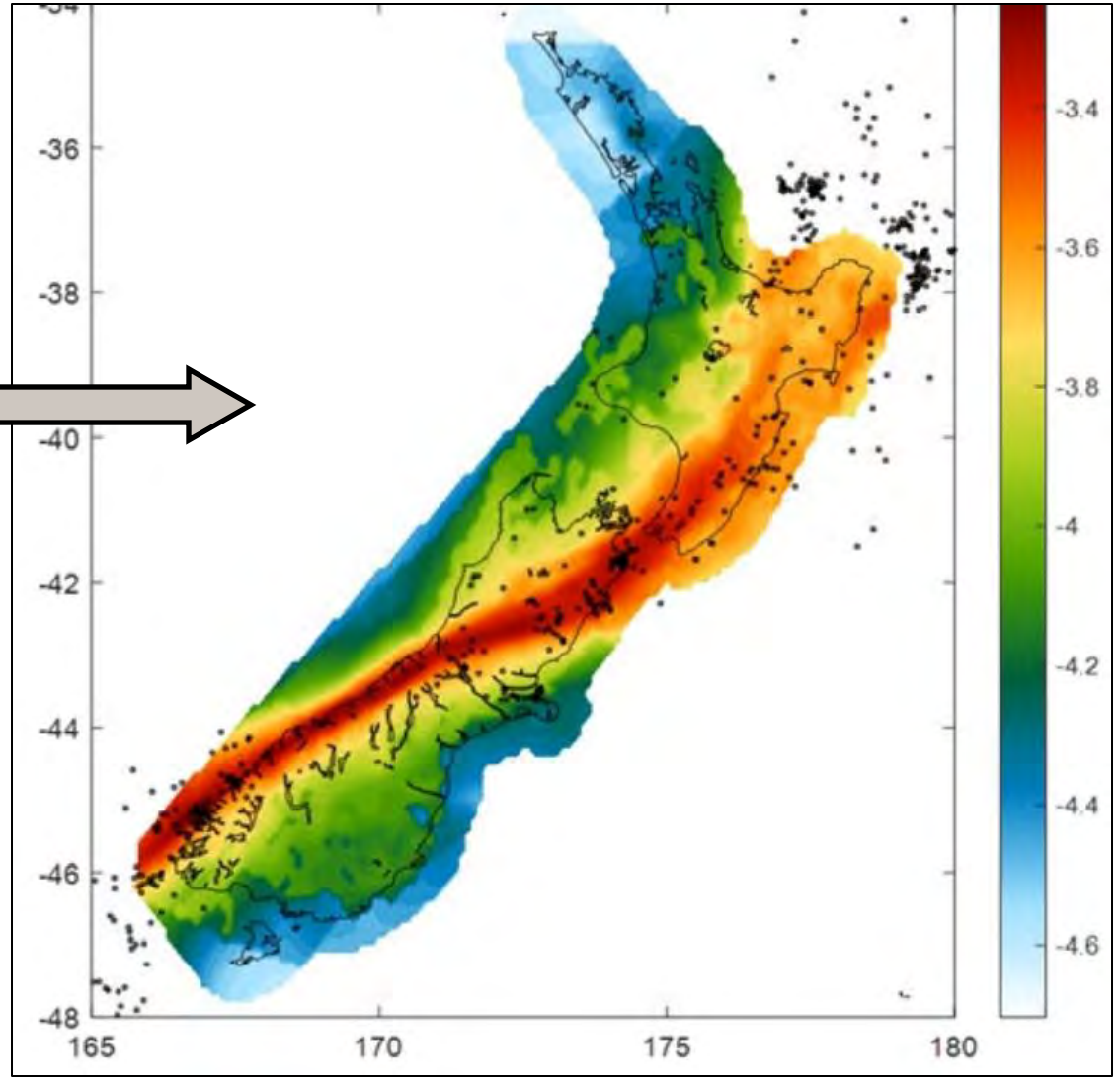
  - Proximity to plate interface
  - Proximity to mapped faults (including slip rate)
  - Geodetic strain rate
  - Fault location
  - Proximity of past earthquakes
  - Two smoothed seismicity models
    - 50 km kernel
    - Density-based adaptive kernel
  - Integration with EEPAS contribution (medium-term EQ clustering)



(Rastin et al. 2022)

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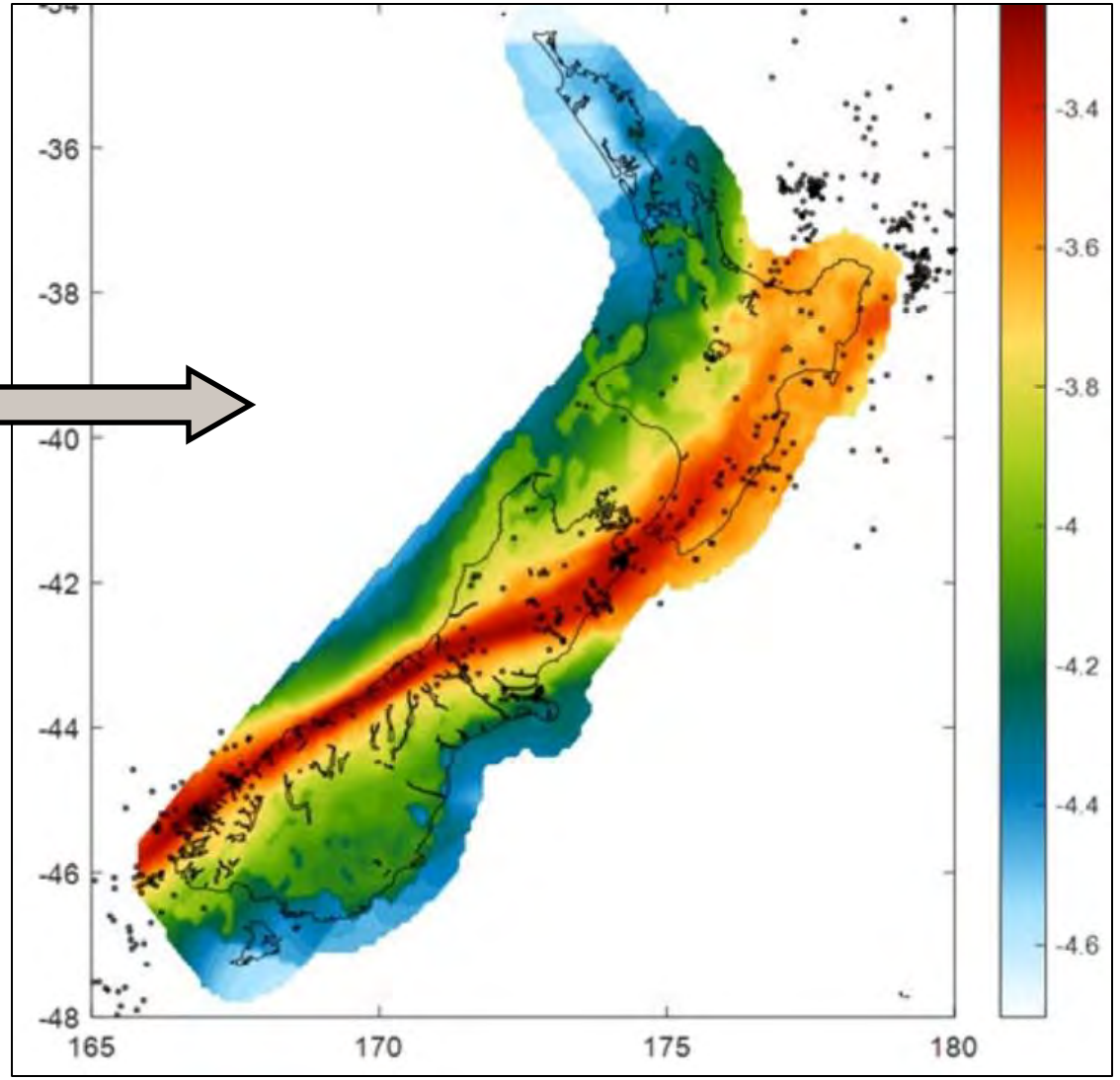

NZ NSHM 2022: *SRM components (examples)*

Inversion Fault Models

Deformation Models - Provide the **locations** and **slip rates** of the explicitly modelled earthquake producing faults in the NSHM

- Upper plate (crustal) deformation models
  - Geologic deformation model (slip rates based on geologic considerations)
  - Geodetic deformation model (slip rates based on geodetic strain rate considerations)

- Subduction Interface deformation models
  - Hikurangi-Kemadec
  - Puysegur

NZ NSHM 2022: *SRM components (examples)*

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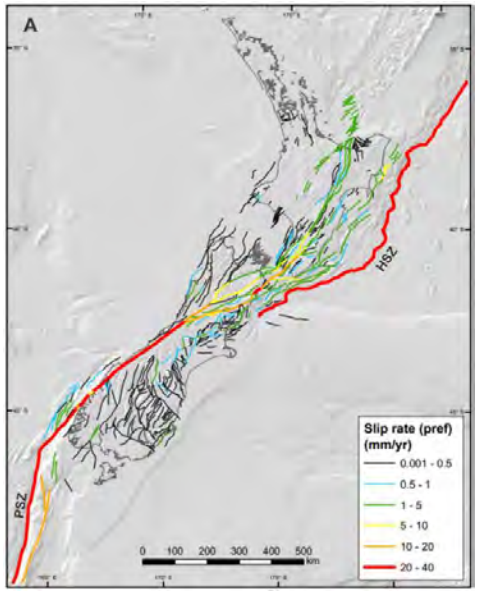
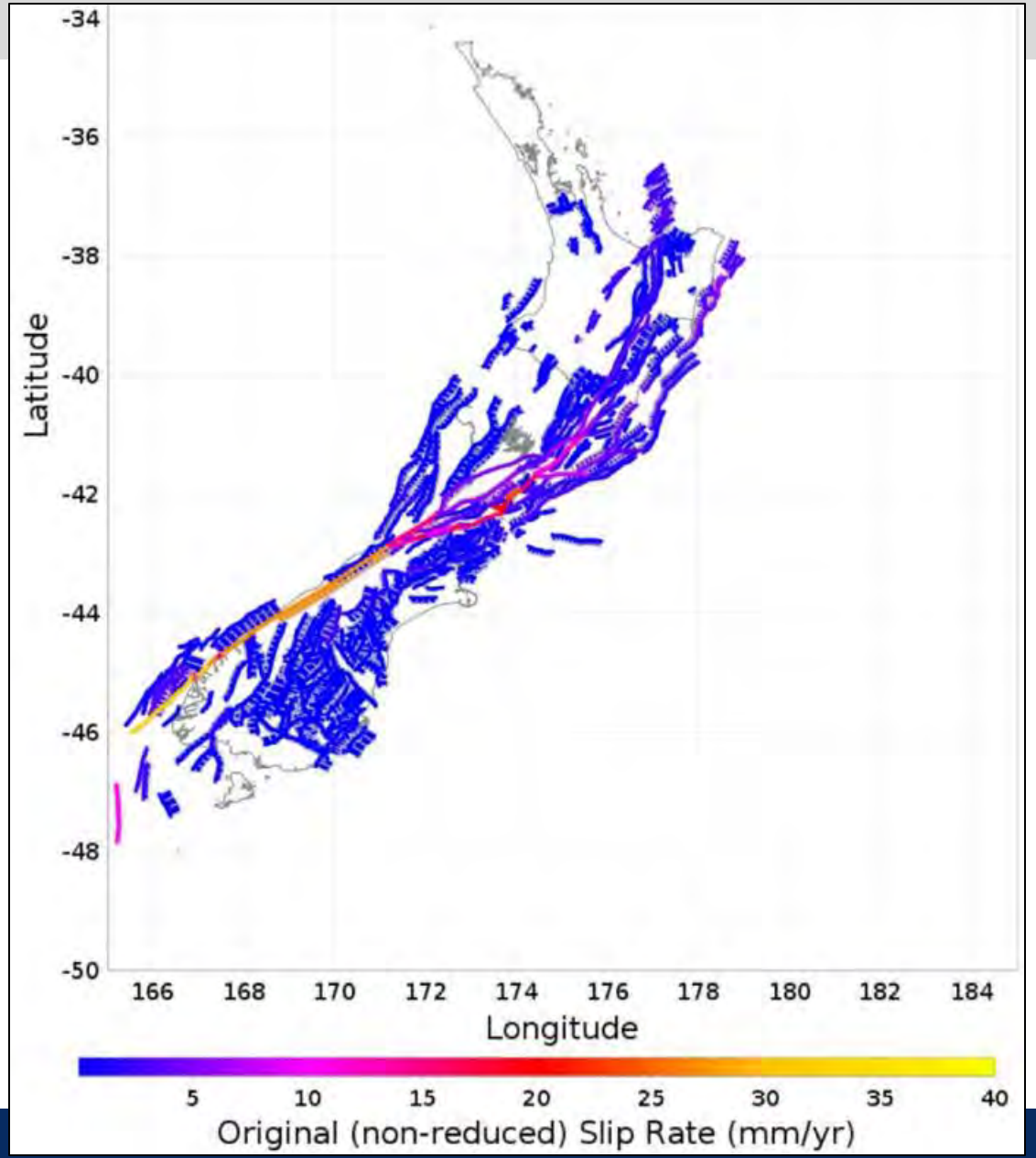
NZ NSHM 2022: *SRM components (examples)*

upper plate Geologic Deformation Model

- Derived exclusively from the NZ CFM v1.0
- Excluding
  - Faults with no geologic-based slip rate determination
  - Faults in the TVZ with slip rates <1.8 mm/yr
  - Faults in the CFM that are not considered capable of generating large earthquakes



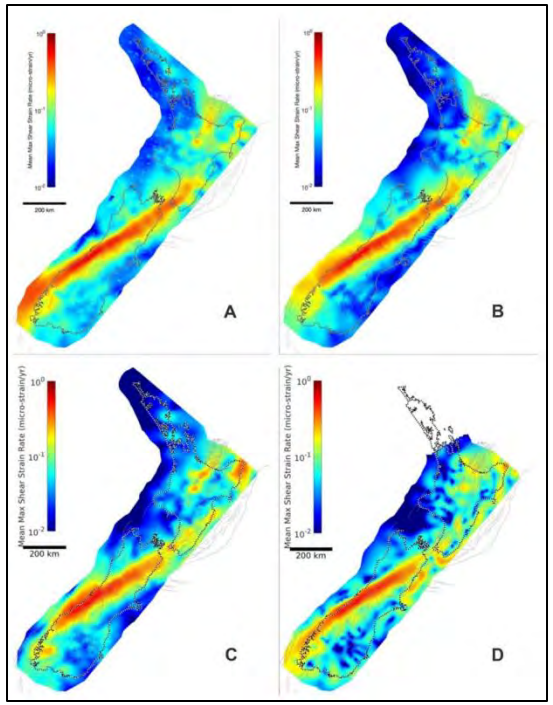


(Van Dissen et al. 2022)

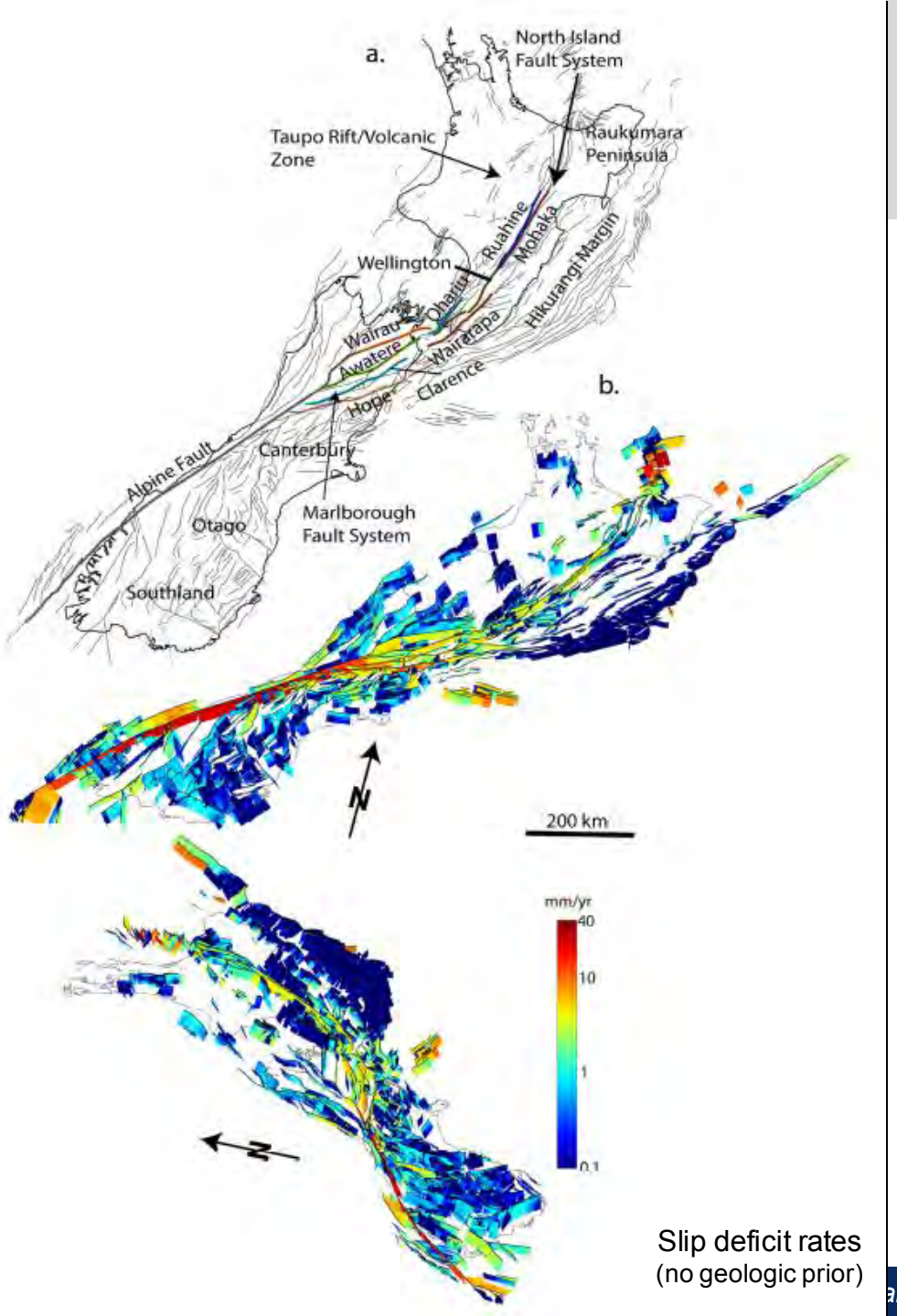
NZ NSHM 2022: *SRM*

upper plate Geodetic Deformation Model

- Fault geometry from NZ CFM v1.0
- Fault slip deficit rate (slip rate) solved by inverting geodetic strain rate



strain rate maps



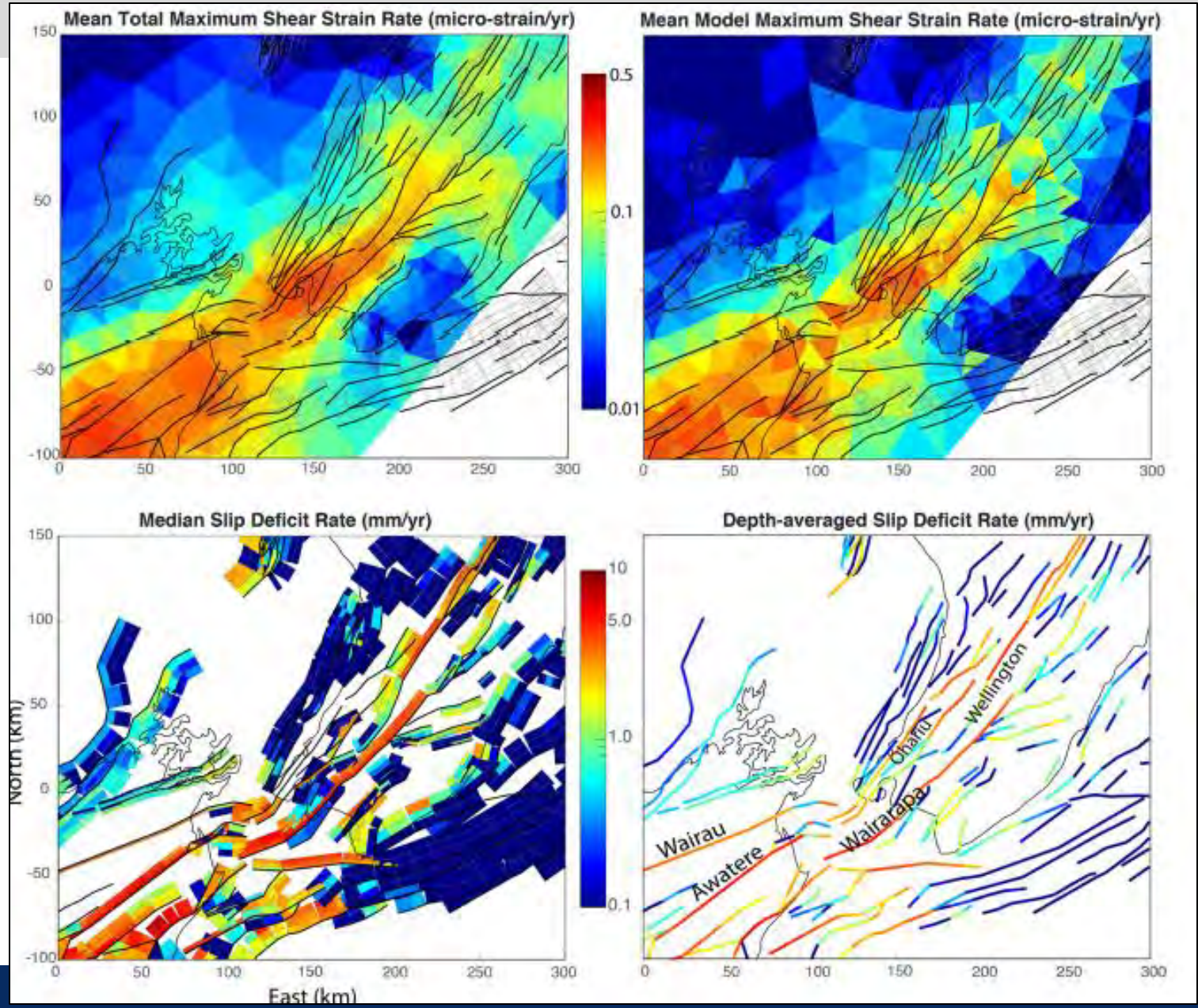
Slip deficit rates
(no geologic prior)

(Johnson et al. 2022)

NZ NSHM 2022: *SRM*

upper plate
Geodetic Deformation Model

Central NZ example
(no geologic prior)



(Johnson et al. 2022)

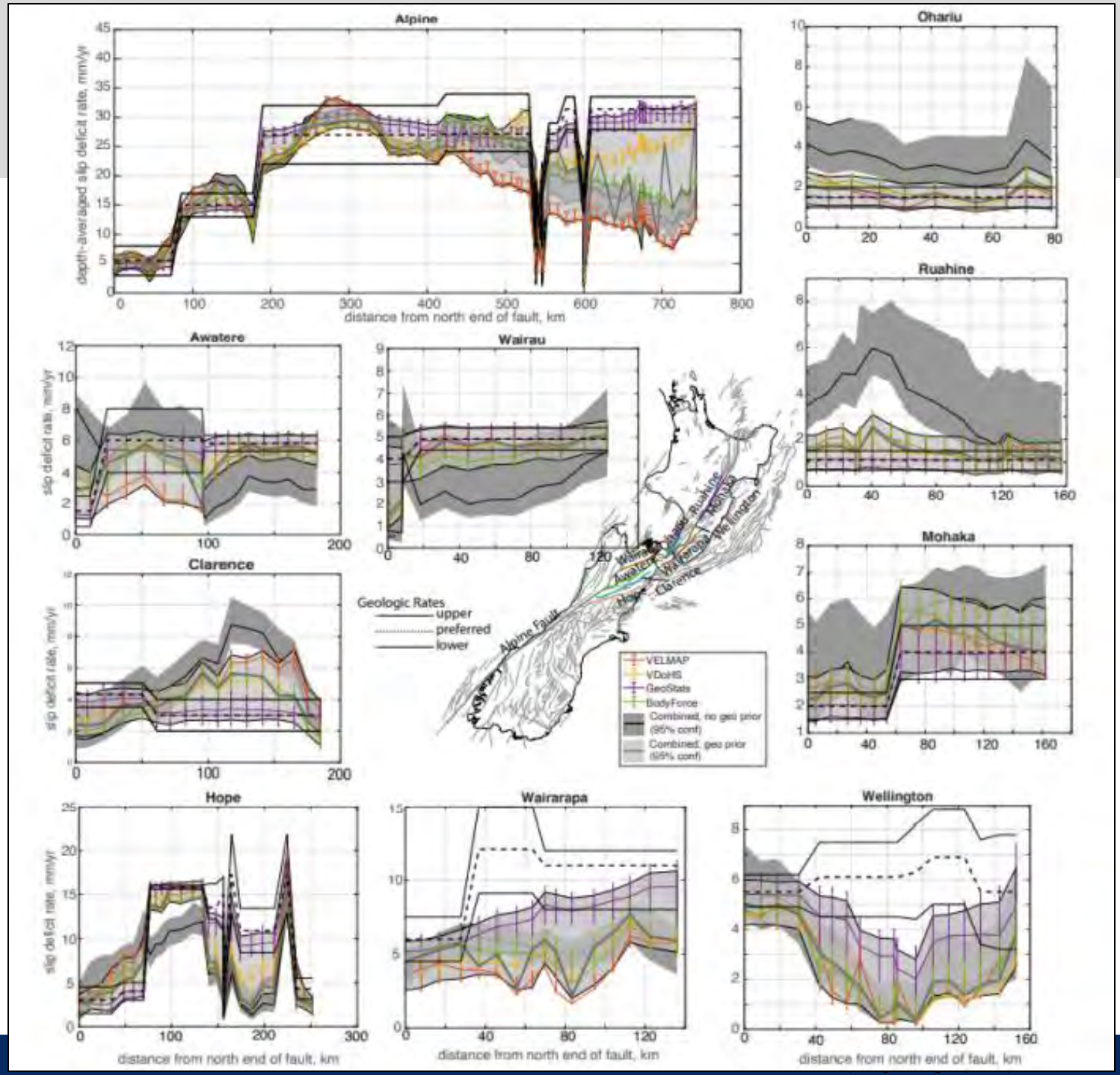
NZ NSHM 2022: *SRM*

Comparison

Geodetic Deformation Model

v.

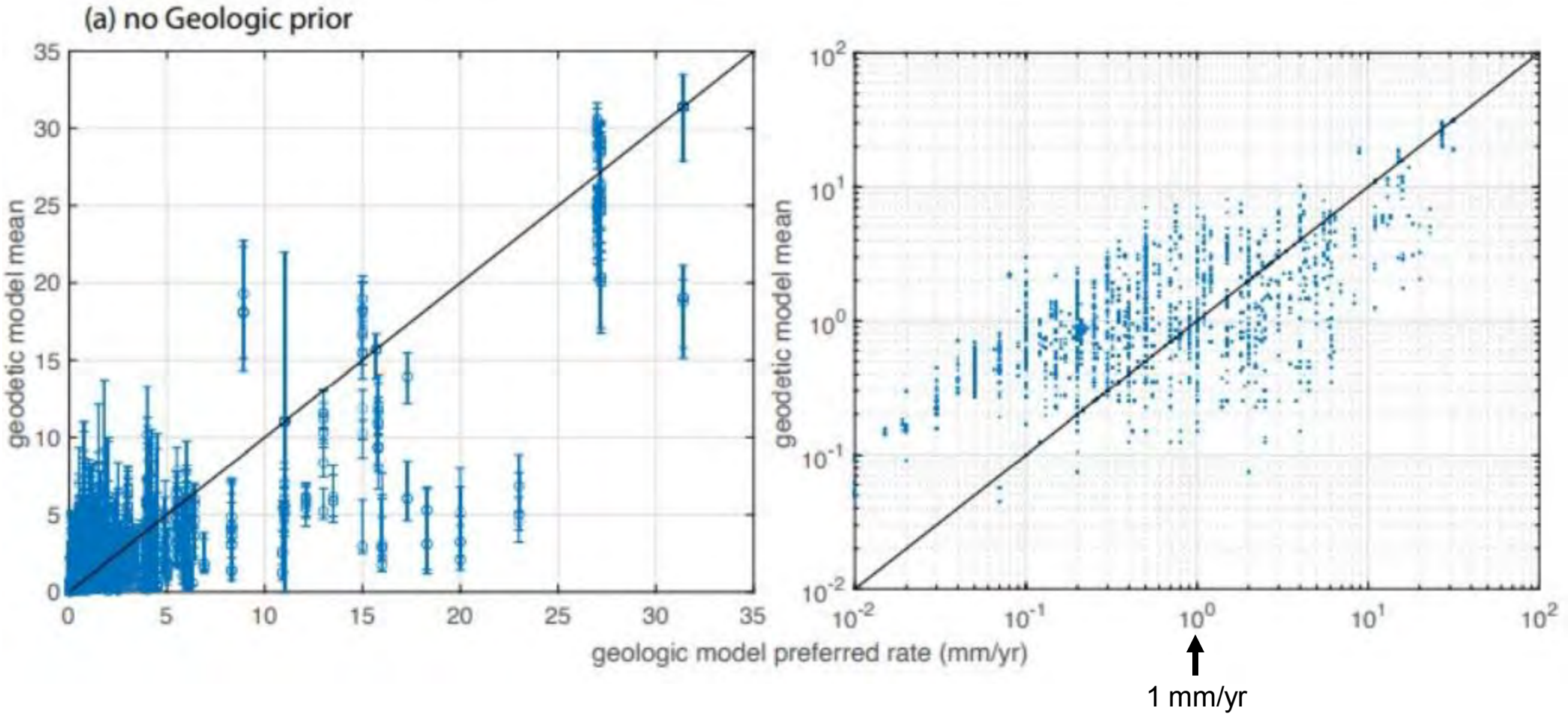
Geologic Deformation Model



(Johnson et al. 2022)

NZ NSHM 2022: *SRM components (examples)*

Comparison: Geodetic Deformation Model v. Geologic Deformation Model

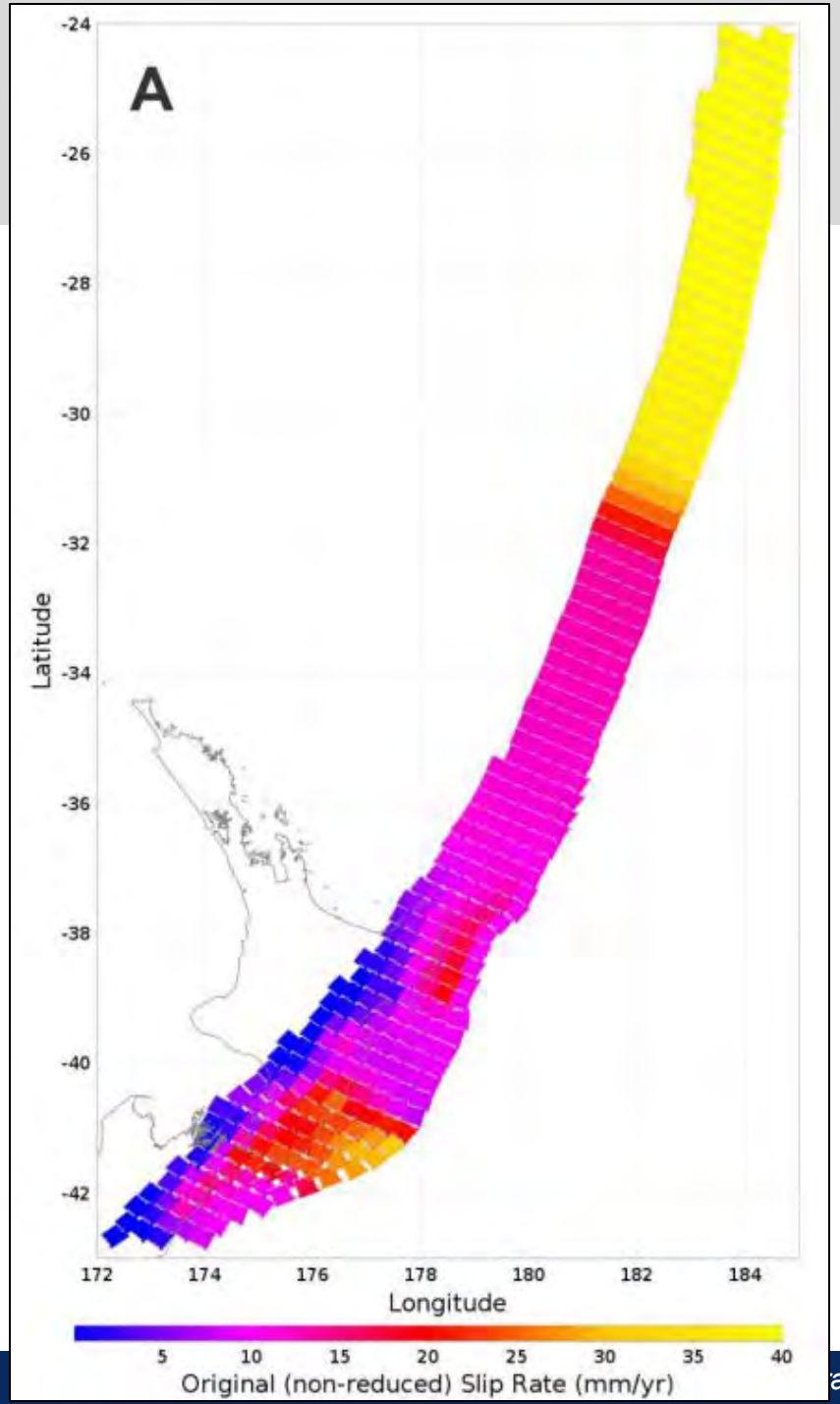


(Johnson et al. 2022)

NZ NSHM 2022: *SRM*

Hikurangi-Kermadec Subduction Interface Deformation Model

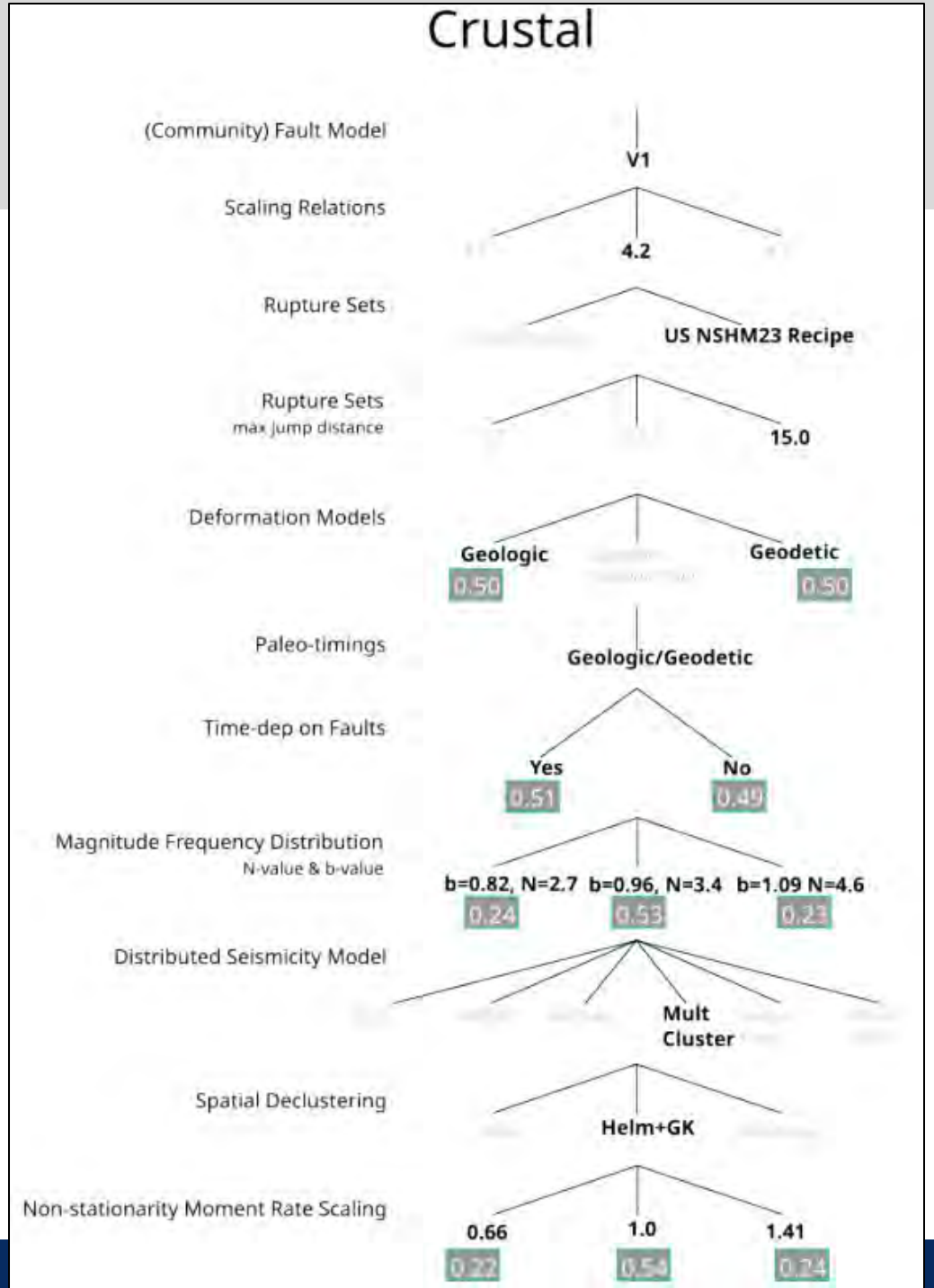
- Extends north from base of Chatham Rise to Louisville Seamount Chain (>2000 km long)
- Hikurangi slip deficit rate
  - Based on Wallace's block modelling results of joint inversion of geodetic velocities and geologic fault slip rates (represented as block boundary rates)
- Kermadec slip deficit rate
  - Based on plate convergence rate and locking coefficient considerations

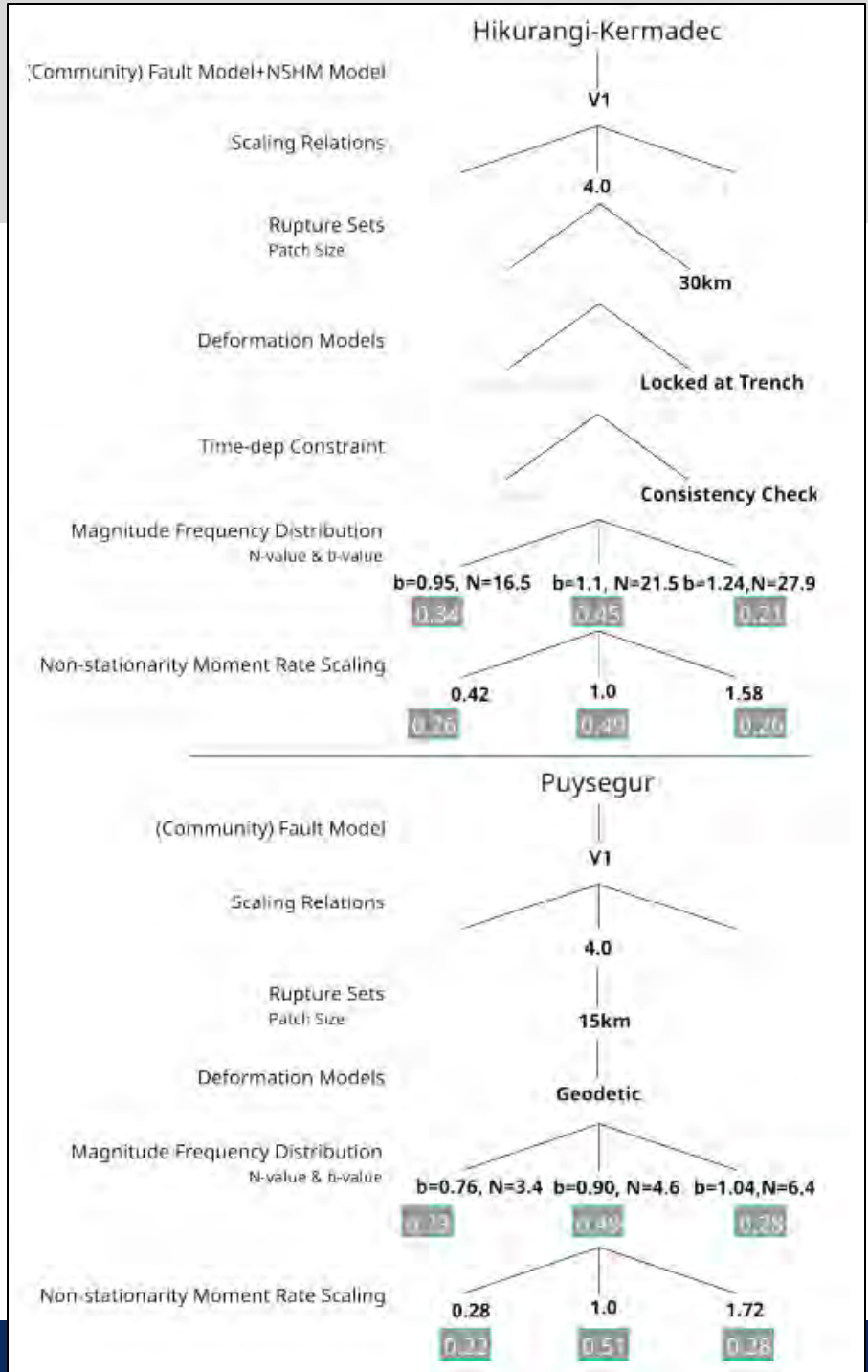


(Van Dissen et al. 2022)

amme

NZ NSHM 2022: *SRM logic trees*

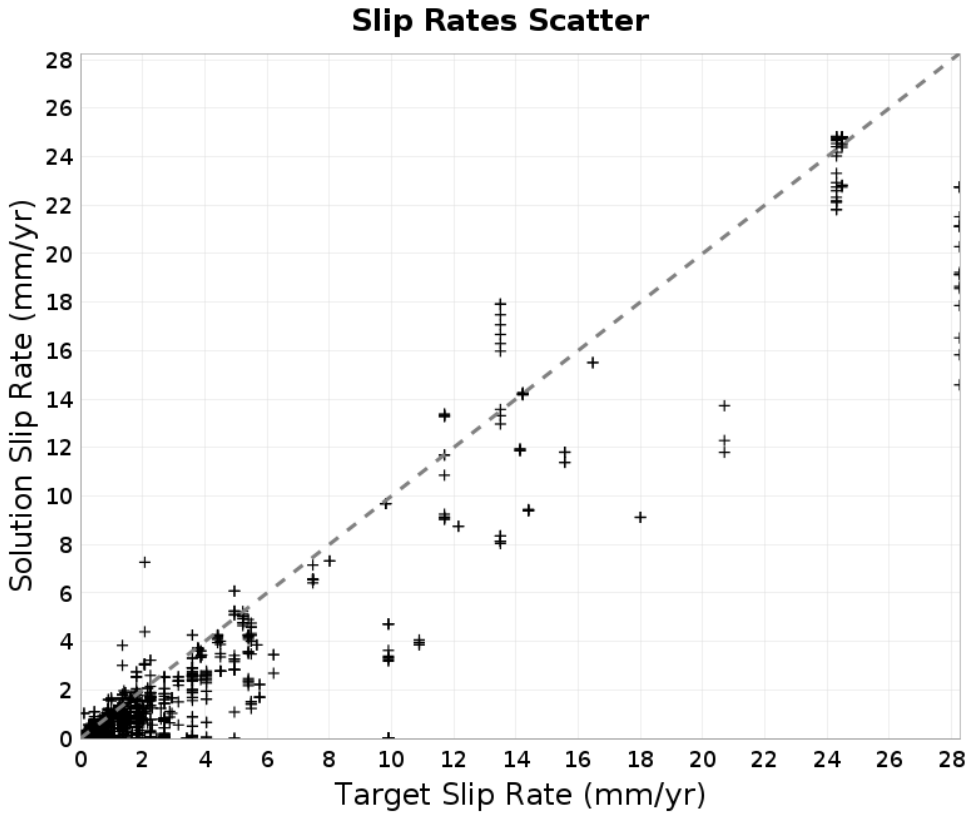


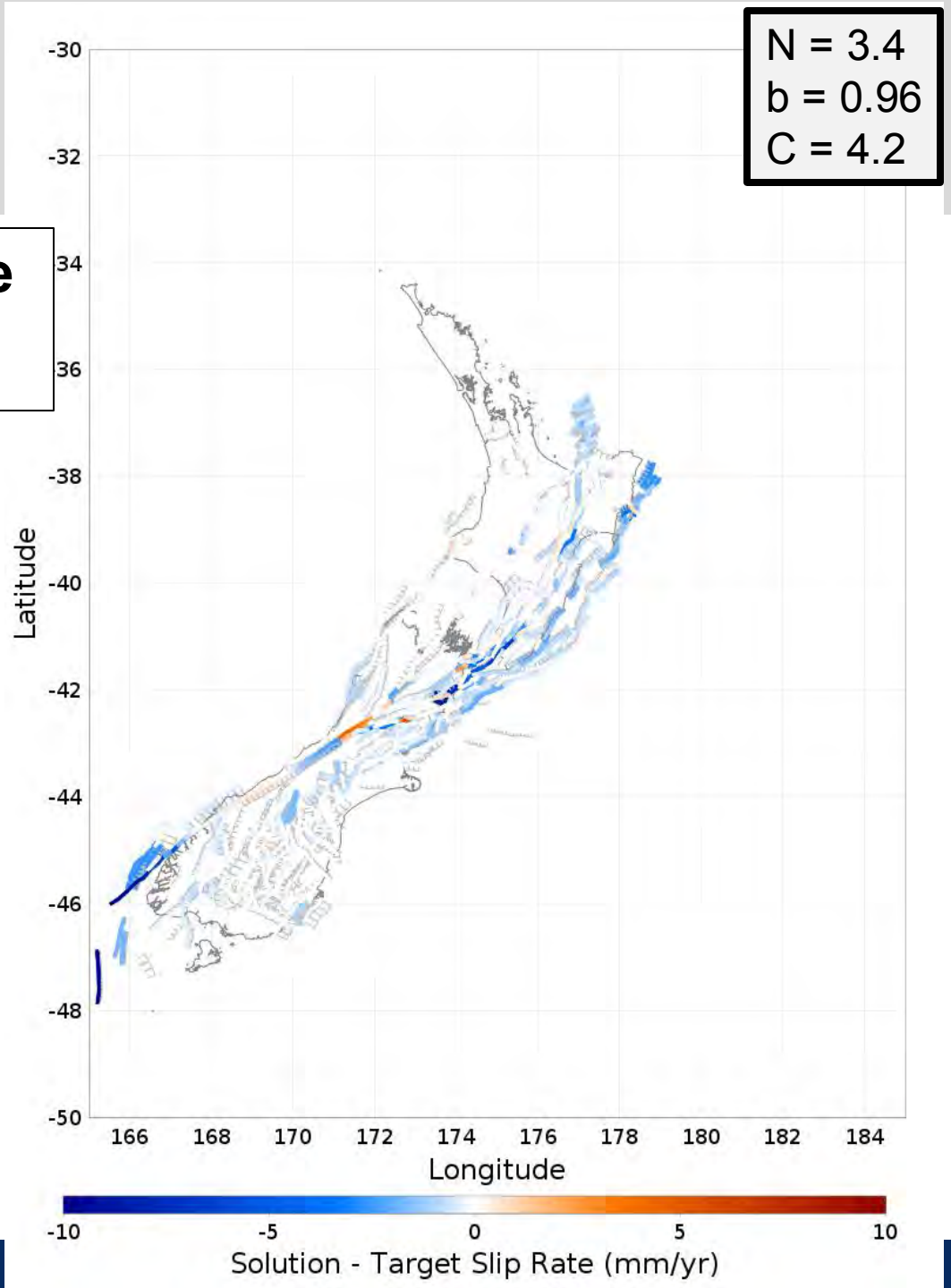


(Gerstenberger et al. 2022)

NZ NSHM 2022: *SRM results*

Some examples of inversion fits to fault slip rate Geologic Deformation Model





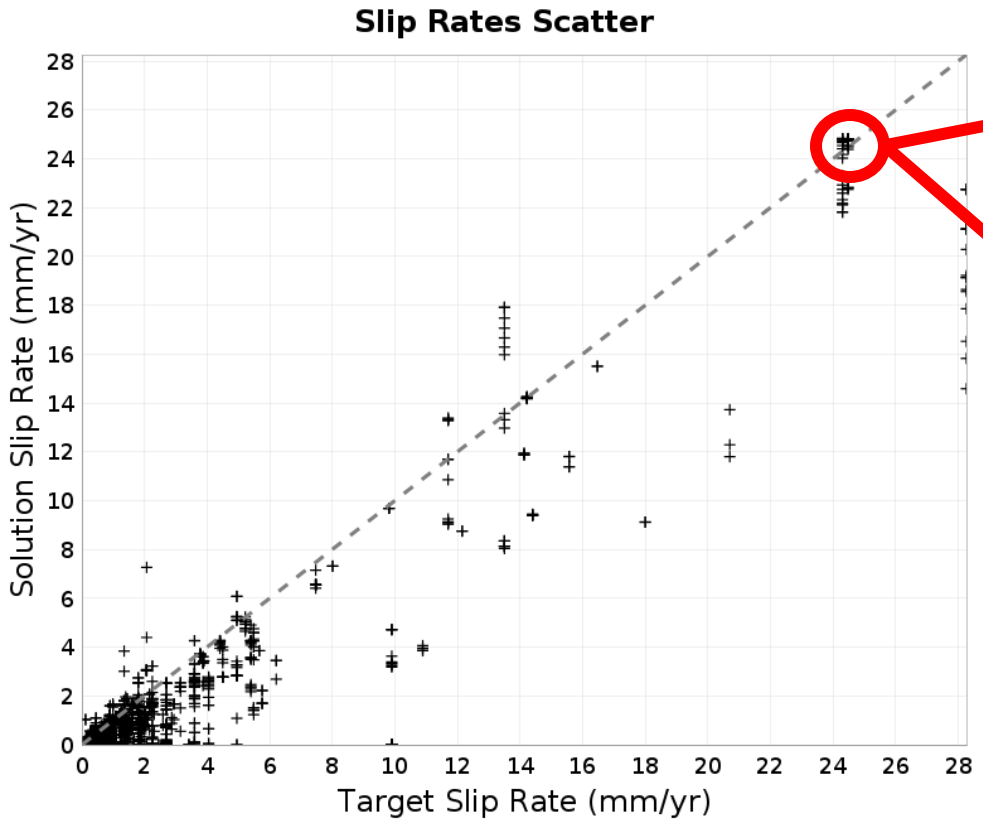
(Gerstenberger et al. 2022)

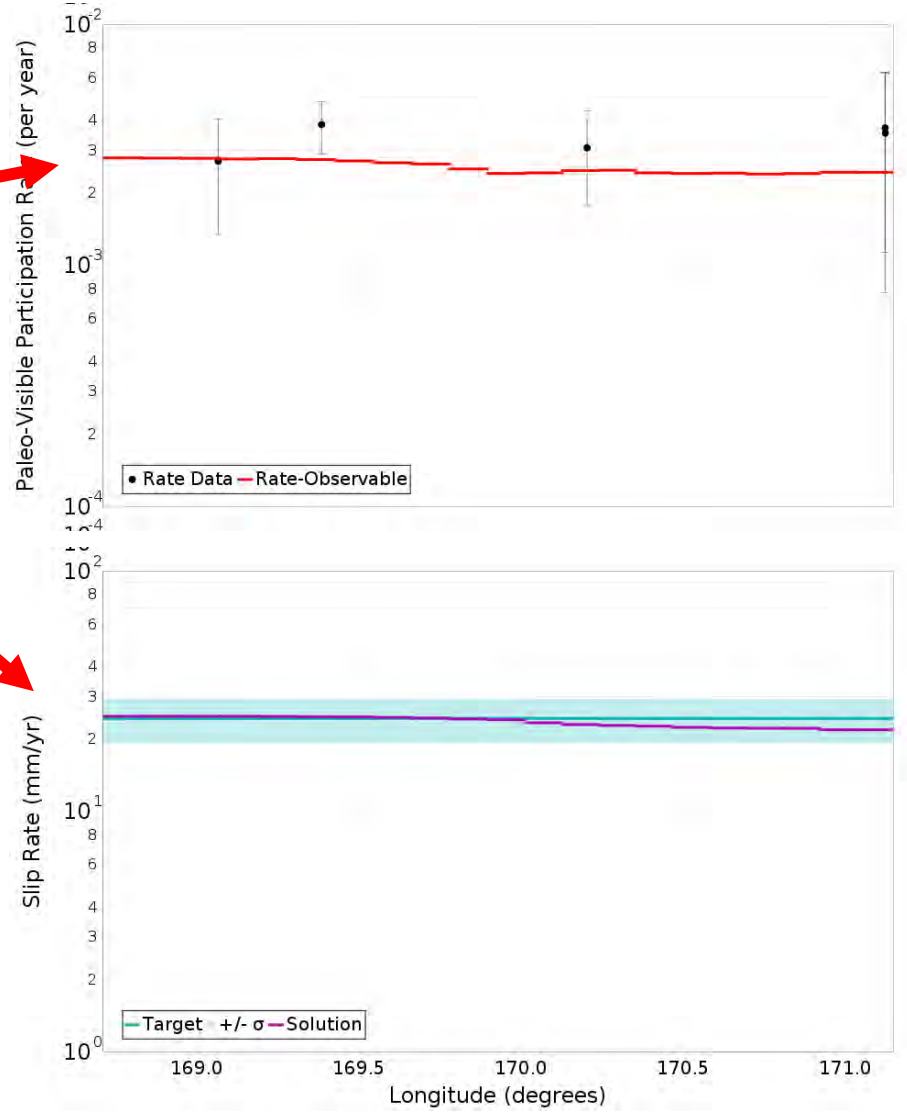
Some examples of inversion fits to fault slip rate

Geologic Deformation Model

Alpine: Jackson to Kaniere

N = 3.4
b = 0.96
C = 4.2



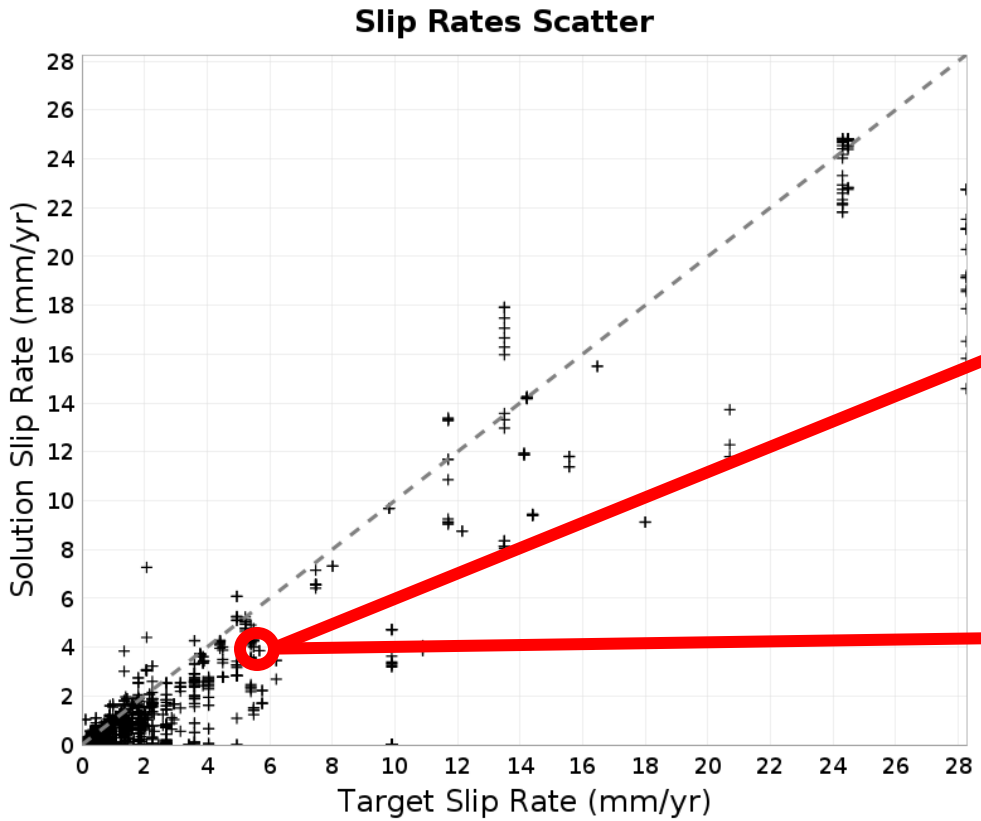


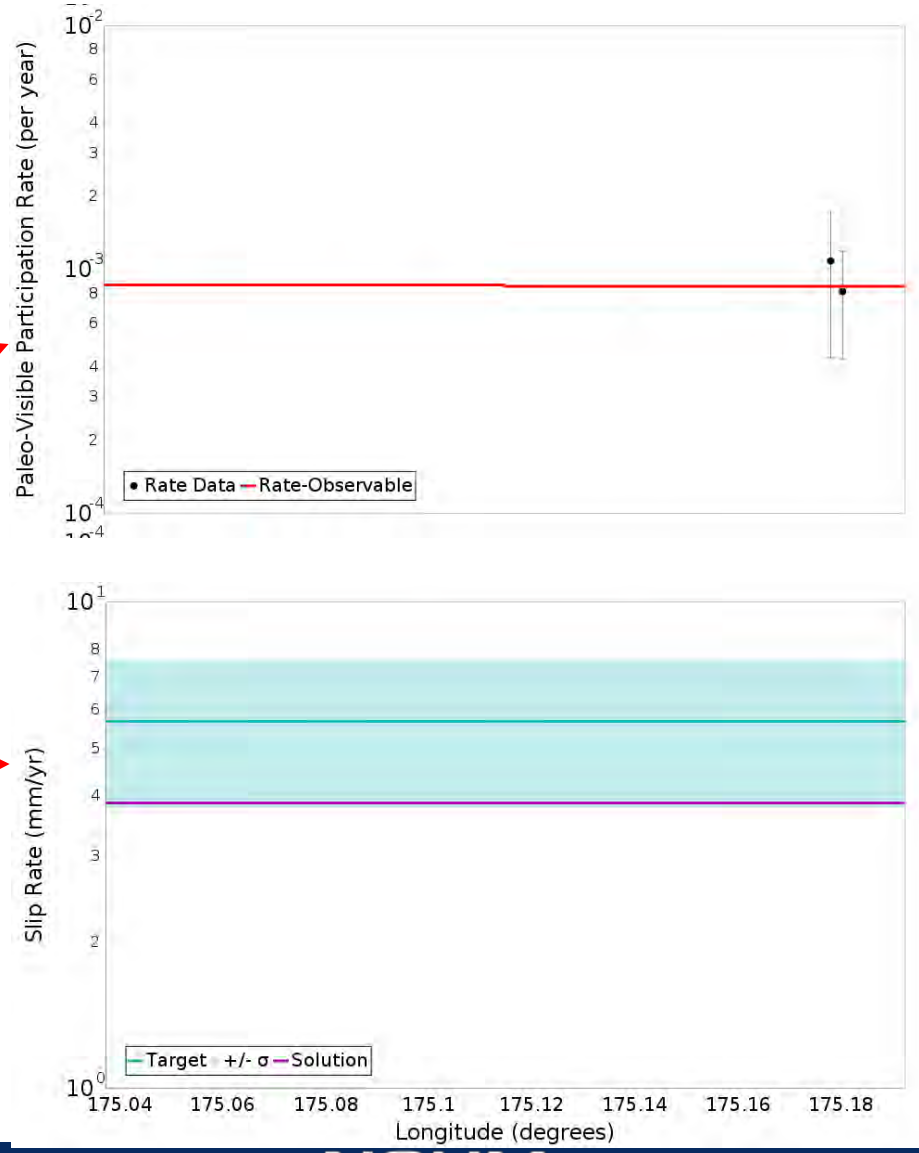
Some examples of inversion fits to fault slip rate

Geologic Deformation Model

N = 3.4
b = 0.96
C = 4.2

Wellington Hutt Valley 5



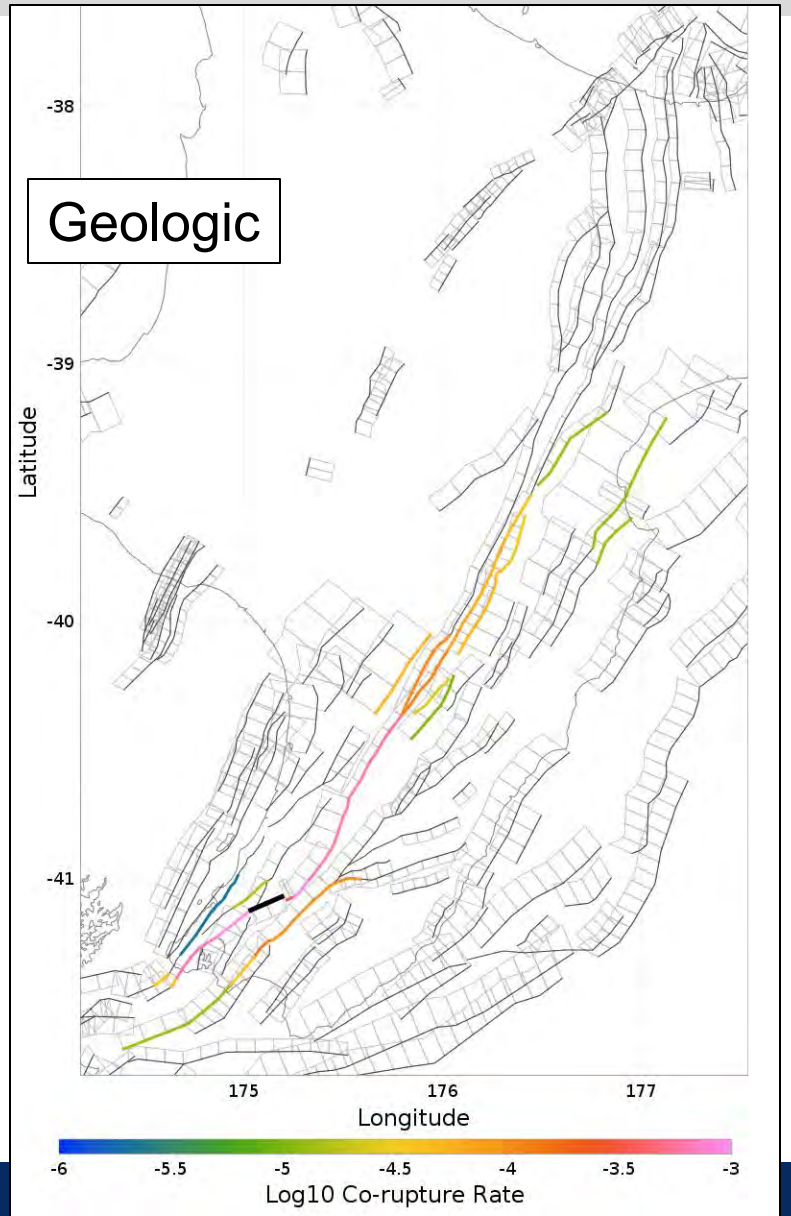


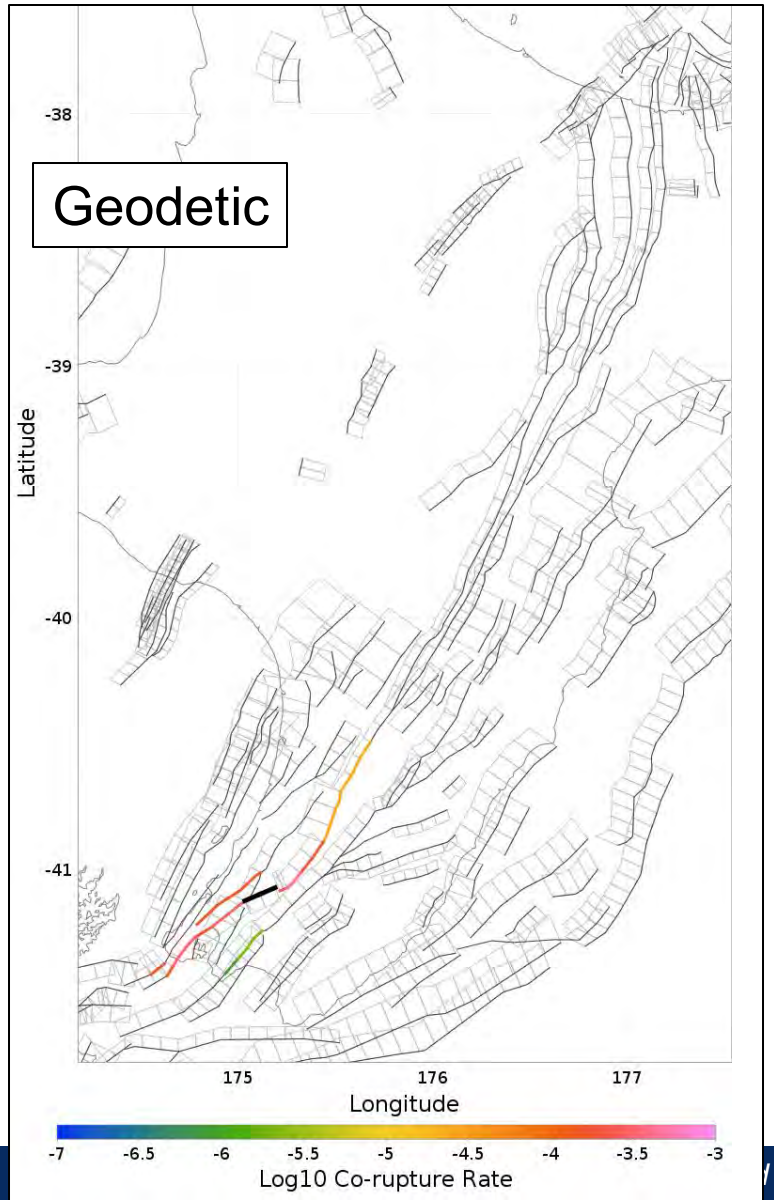
A couple fault connectivity comparisons

Geodetic v Geologic Deformation Model

N = 3.4
b = 0.96
C = 4.2

Wellington Hutt Valley 5





No longer only one Wellington Fault rupture with one magnitude and one rupture length

Many earthquakes can impact the Wellington Region, and the Wellington Fault is an important source

In the past only a M7.6 earthquake rupture was considered on the Wellington fault

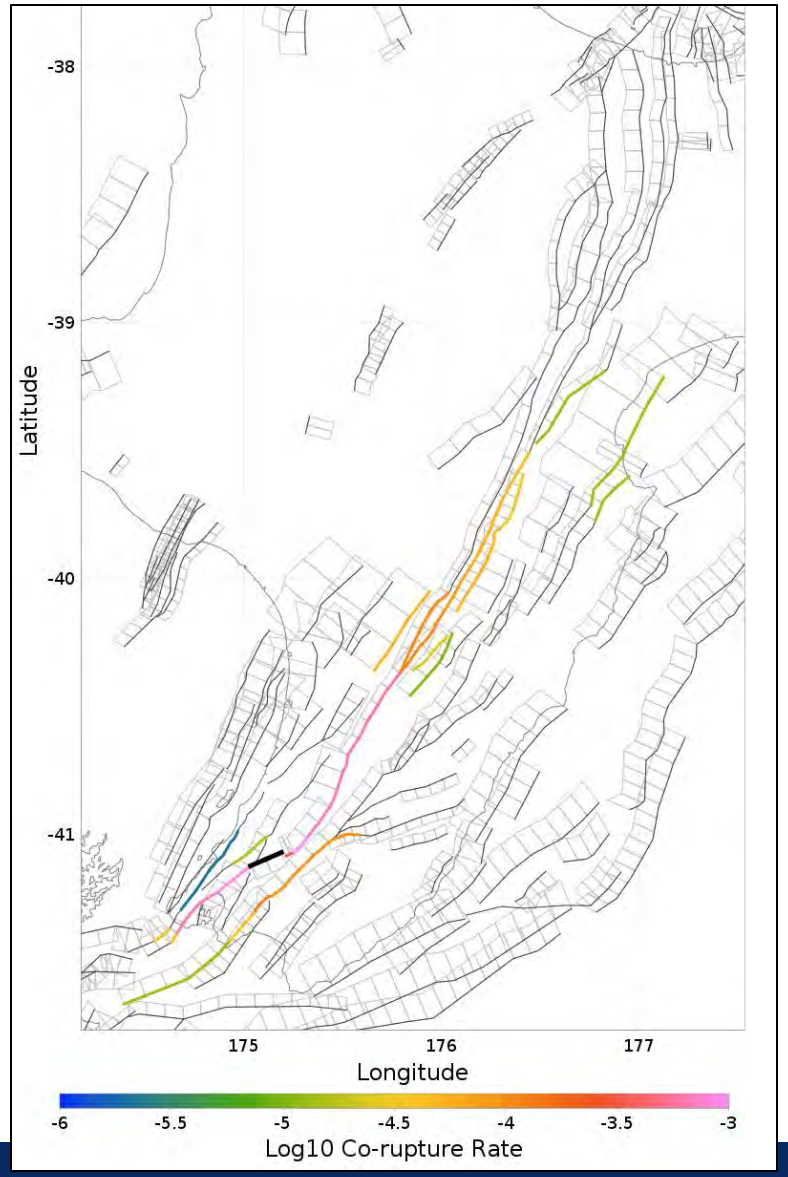
Only one rupture length: M7.6 ~60km

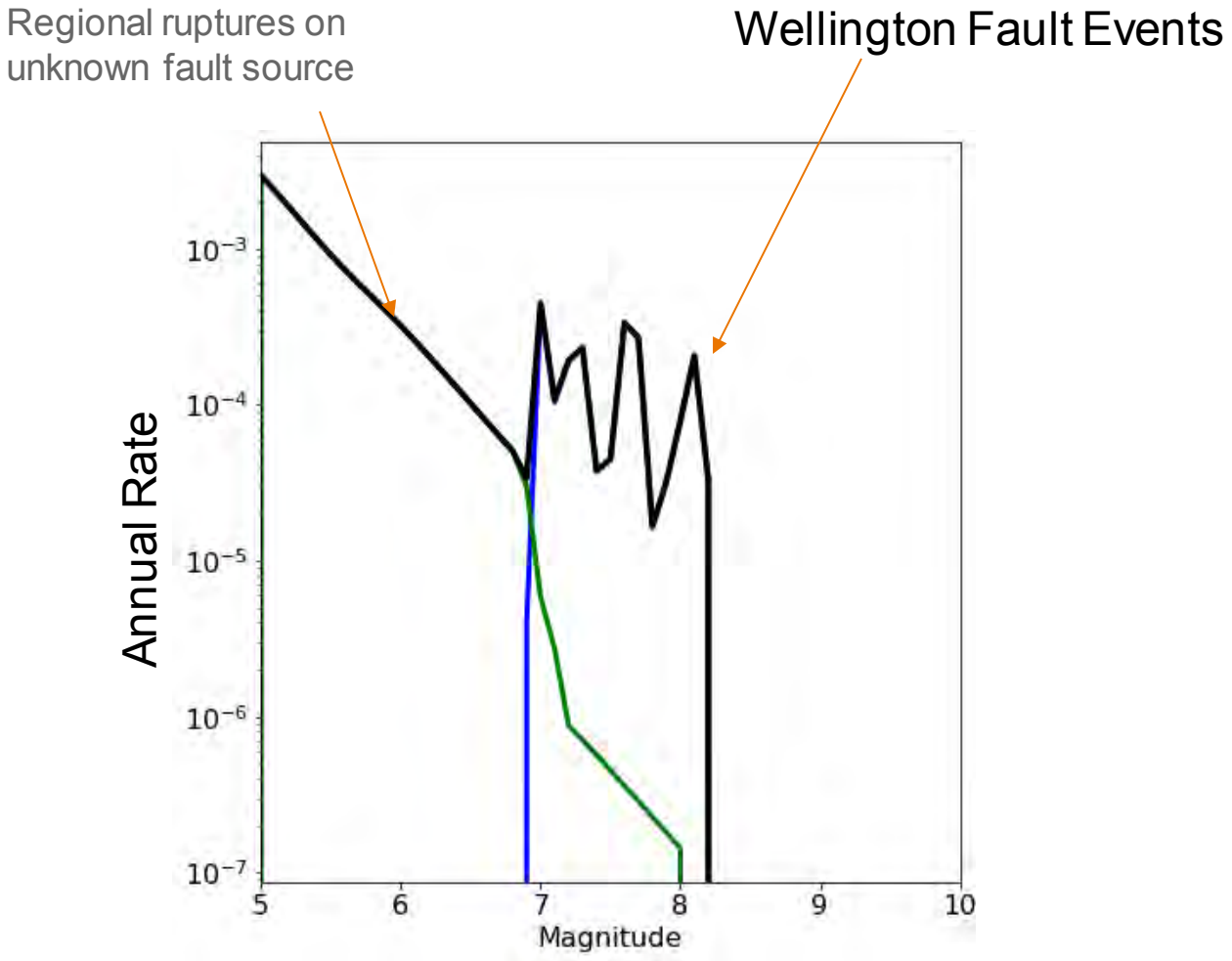
- No uncertainty on magnitude
- A much narrower range of potential shaking

Now numerous possible Wellington Fault ruptures are considered

- Many magnitudes
- M7 ~25km, M8 ~160km

No longer only one Wellington Fault rupture with one magnitude and one rupture length





2022 NSHM Rates of ruptures on the Wellington Fault

Does not include Hikurangi or other known faults In the Wellington region

High Impact Low Probability Events

The 2016 M7.8 Kaikoura earthquake, which ruptured more than 20 faults, demonstrated that many faults can rupture in a single earthquake affecting multiple regions.

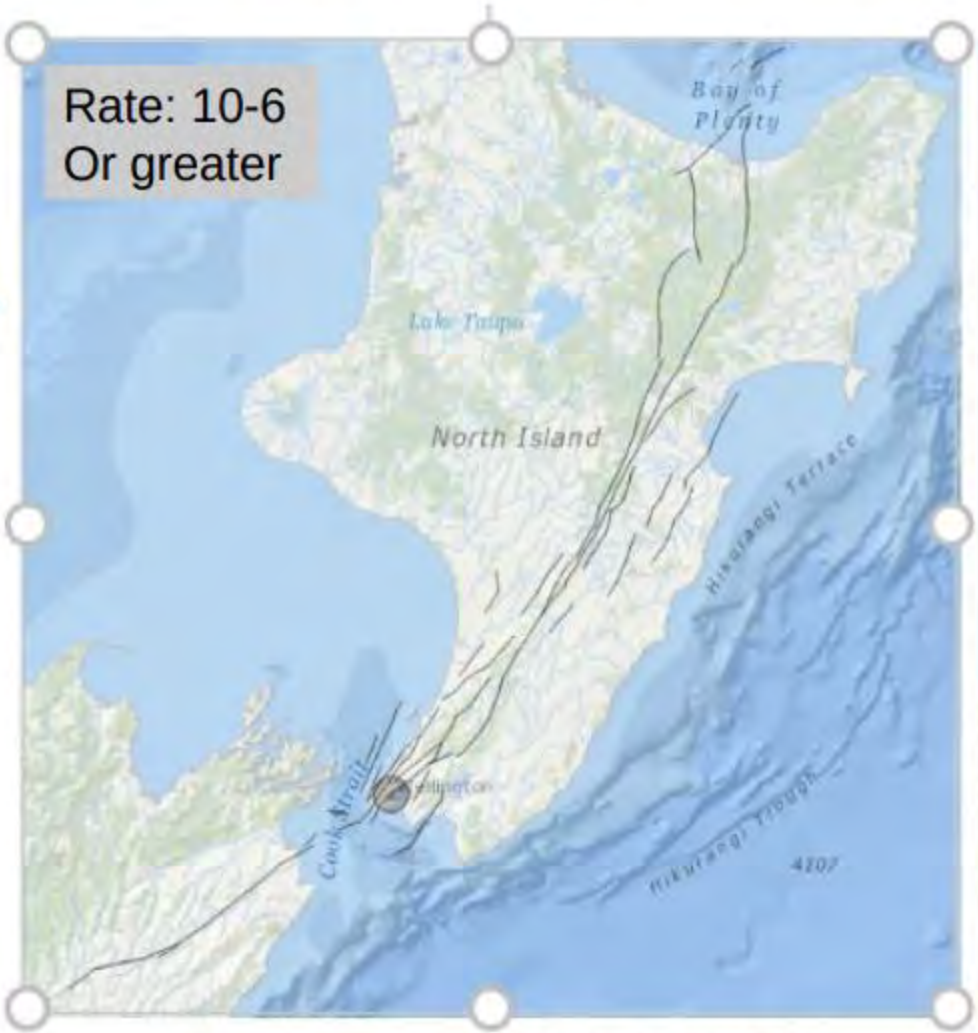
This has been difficult to model in the past, but we are now able to model such complex ruptures. Now we have:

- More realistic hazard estimates
- Modelling of very low probability, but potentially high impact ruptures.

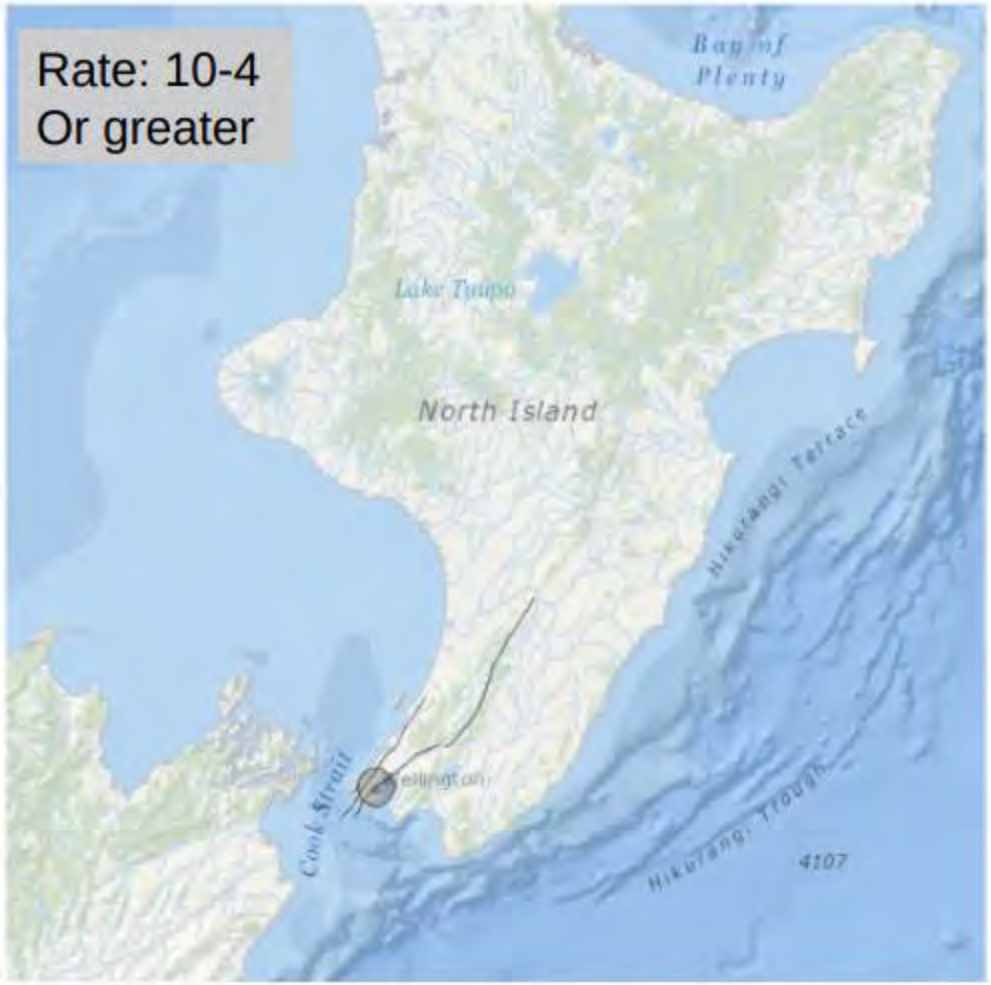
Large earthquakes can happen anywhere in New Zealand
The map here shows one example of a very low probability but high impact rupture.
This is an M8.3 event with a rate of about 1-in-1 million years.
We expect around two M8.3+ crustal earthquakes every 1,000 years.

High Impact Low Probability Events: Wellington Region Events

Each panel shows *many* earthquake ruptures



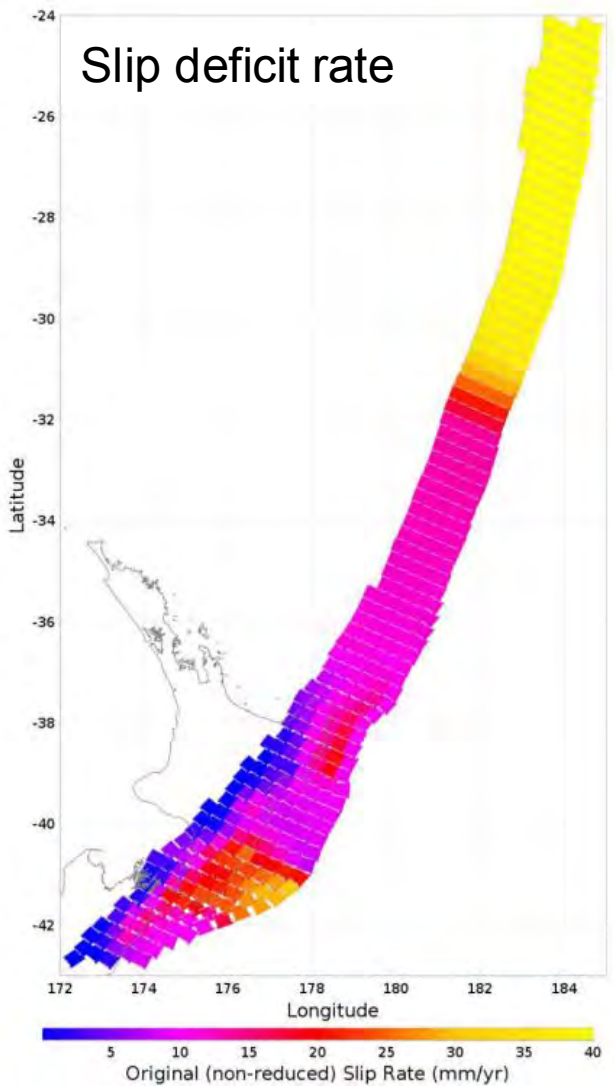
All including very low probability

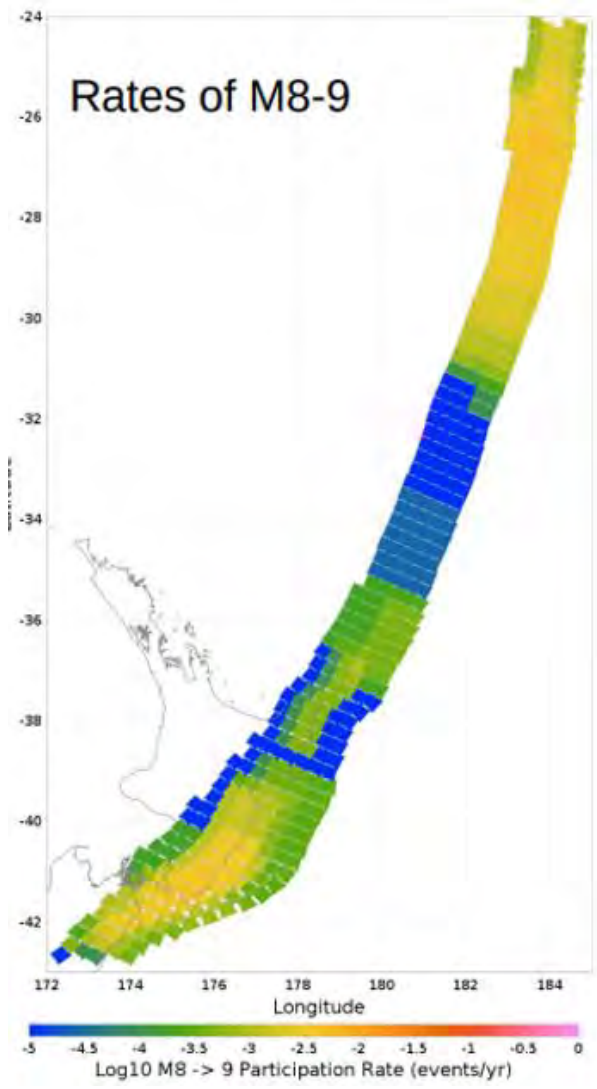


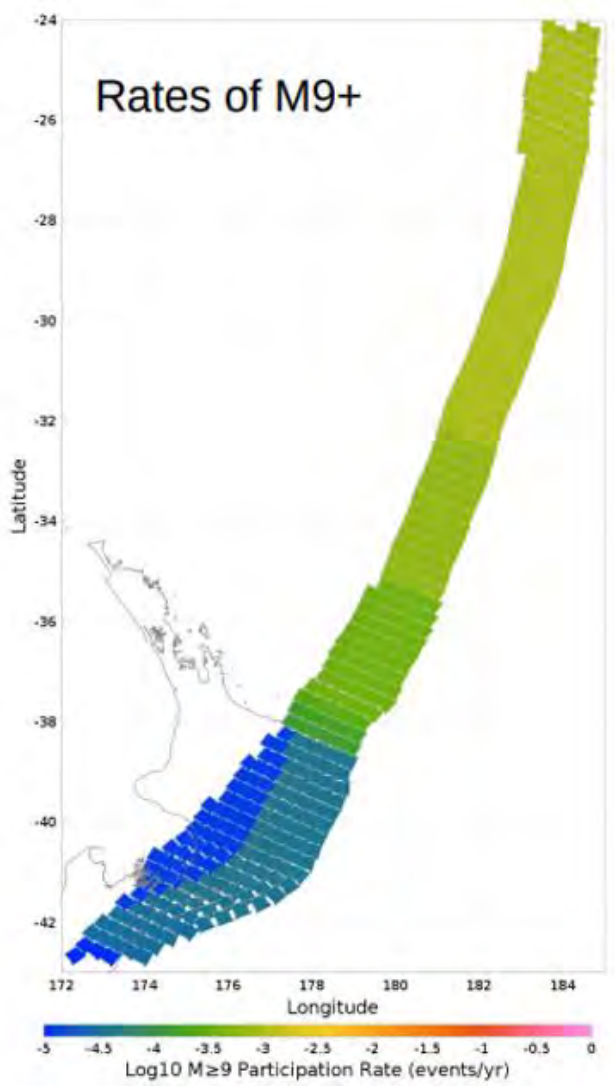
less low probability

All ruptures pass within 10km of Wellington

Large earthquake of the Hikurangi – Kermadec subduction zone







NZ NSHM 2022: *Seismicity Rate Model*

- Guidance Documents (*setting the scene and the path to follow*)
- Foundational Datasets, and Input Models and Scaling Relations
- Earthquake Rupture Forecasts
  - Distributed Seismicity-based (*Distributed Seismicity Model*)
  - Fault-based (*Inversion Fault Model*)
- Testing and Evaluation (*including rate and hazard sensitivity*)
- Final SRM Model

A veritable gold mine of earthquake hazard data and information all freely available for download at:
https://nshm.gns.cri.nz/Resources/ScienceReports

NZ NSHM 2022: *SRM Science Reports*

- Scene-Setting Guidance Document
  - NZ NSHM Framework Plan

    Gerstenberger MC, Van Houtte C, Abbott ER, Van Dissen RJ, Kaiser AE, Bradley B, Nicol A, Rhoades DA, Stirling MW, Thingbaijam KKS, NSHM Team. 2020. New Zealand National Seismic Hazard Model framework plan. Lower Hutt (NZ): GNS Science. 25 p. (GNS Science report; 2020/38). doi:10.21420/NB8W-GA79.

- Foundational Datasets, and Input Models and Scaling Relations
  - Revised EQ catalogue with consistent magnitudes

    Christophersen A, Bourguignon S, Rhoades DA, Allen TI, Salichon J, Ristau J, Rollins C, Gerstenberger MC. 2022. Consistent magnitudes over time for the revision of the New Zealand National Seismic Hazard Model. Lower Hutt (NZ): GNS Science. 76 p. (GNS Science report; 2021/42). doi:10.21420/A2SN-XM76.
  - Updated EQ catalogue with re-evaluated depths, event classifications and wider geographic coverage

    Rollins C, Thingbaijam KKS, Hutchinson J, Gerstenberger MC, Christophersen A, Eberhart-Phillips D, Rastin SJ, Van Dissen RJ. 2022a. An augmented New Zealand earthquake catalogue, event classifications, and models of the depth distribution of shallow earthquakes in the greater New Zealand region. Lower Hutt (NZ): GNS Science. 83 p. (GNS Science report; 2021/58). doi:10.21420/XT4Y-WY45.
  - Country-scale geodetic strain rate maps

    Johnson KM, Wallace LM, Maurer J, Hamling IJ, Williams CA, Rollins C, Gerstenberger MC, Van Dissen RJ. 2022. Geodetic deformation model for the 2022 update of the New Zealand National Seismic Hazard Model. Lower Hutt (NZ): GNS Science. 62 p. (GNS Science report; 2021/37). doi:10.21420/P93X-8293.

NZ NSHM 2022: *SRM Science Reports*

- Foundational Datasets, and Input Models and Scaling Relations - *continued*
  - Regional fault orientation analysis

    Rattenbury MS. 2022. Regional fault orientation nd length analysis, Aotearoa New Zealand. Lower Hutt (NZ): GNS Science. 49 p. (GNS Science Report; 2022/13). doi: 10.21420/V2MV-R640.
  - Maximum fault rupture depths

    Ellis SM, Bannister S, Van Dissen RJ, Eberhart-Phillips D, Holden C, Boulton C, Reyners ME, Funnell RH, Mortimer N, Upton P. 2021. New Zealand Fault Rupture Depth Model v1.0: a provisional estimate of the maximum depth of seismic rupture on New Zealand's active faults. Lower Hutt (NZ): GNS Science.47 p. (GNS Science report; 2021/08). doi:10.21420/4Q75-HZ73.
  - Paleoseismic site database (fault slip rates, and paleoEQ timings and single-event displacement sizes)

    Litchfield NJ. 2022. New Zealand Paleoseismic Site Database: data dictionary. Lower Hutt (NZ): GNS Science. 42 p. (GNS Science report; 2021/40). doi:10.21420/G5K4-ES33.

    Litchfield NJ, Humphrey J, Morgenstern R, Langridge RM, Coffey GL, Van Dissen RJ. 2022. New Zealand Paleoseismic Site Database: design and overview of version 1.0. Lower Hutt (NZ): GNS Science. 27 p. (GNS Science report; 2021/52). doi:10.21420/VTPT-KB52.
  - PaleoEQ recurrence intervals and probabilities of detection

    Coffey GL, Rollins C, Van Dissen RJ, Rhoades DA, Thingbaijam KKS, Clark KJ, Gerstenberger MC, Litchfield NJ, Nicol A. 2022. New Zealand National Seismic Hazard Model 2022: earthquake recurrence derivation from paleoseismic data and probability of detection. Lower Hutt (NZ): GNS Science. 57 p. (GNS Science report; 2022/32). doi:10.21420/2YWK-ZE30.

NZ NSHM 2022: *SRM Science Reports*

- Foundational Datasets, and Input Models and Scaling Relations - *continued*
  - NZ Community Fault Model

    Seebeck H, Van Dissen RJ, Litchfield NJ, Barnes PM, Nicol A, Langridge RM, Barrell DJA, Villamor P, Ellis SM, Rattenbury MS, Bannister S, Gerstenberger MC, Ghisetti F, Sutherland R, Fraser J, Nodder SD, Stirling MW, Humphrey J, Bland KJ, Howell A, Mountjoy JJ, Moon V, Stahl T, Spinardi F, Townsend DB, Clark KJ, Hamling IJ, Cox SC, de Lange W, Wopereis P, Johnston M, Morgenstern R, Coffey GL, Eccles JD, Little TA, Fry B, Griffin J, Townend J, Mortimer N, Alcaraz SA, Massiot C, Rowland J, Muirhead J, Upton P, Hirschberg H, Lee JM. 2022. New Zealand Community Fault Model – version 1.0. Lower Hutt (NZ): GNS Science. 97 p. (GNS Science report; 2021/57). doi:10.21420/GA7S-BS61.
  - Average coseismic slip profiles

    Thingbaijam KKS, Van Dissen RJ, Shaw BE, Gerstenberger MC. 2022. Average coseismic slip profiles. Lower Hutt (NZ): GNS Science. 33 p. (GNS Science report; 2021/24). doi:10.21420/S6ED-JN06.
  - Magnitude - area scaling relations (along with accompanying average displacements)

    Stirling M, Shaw B, Fitzgerald M, Ross C. 2021. Selection and evaluation of magnitude – area scaling relations for update of the New Zealand National Seismic Hazard Model. Dunedin (NZ): University of Otago. 49 p. (Including addendum 'Mean and bounding Mw = logA + C scaling relations for NSHM' by M Stirling.)

    Shaw BE. 2022 – in review. Magnitude and slip scaling relations for fault based hazard. Bulletin of the Seismological Society of America (submitted).

NZ NSHM 2022: *SRM Science Reports*

- Earthquake Rupture Forecasts
  - Distributed Seismicity Model(s)
    - The hybrid distributed seismicity model

      Rastin SJ, Rhoades DA, Rollins C, Gerstenberger MC, Christophersen A, Thingbaijam KKS. 2022. Spatial distribution of earthquake occurrence for the New Zealand National Seismic Hazard Model revision. Lower Hutt (NZ): GNS Science. 65 p. (GNS Science report; 2021/51). doi:10.21420/YKQ8-1C41.
    - Uniform rate models and Negative Binomial temporal mode

      Iturrieta P, Gerstenberger MC, Rollins C, Van Dissen RJ, Wang T, Schorlemmer D. 2022. Accounting for earthquake rates' temporal and spatial variability through least-information uniform rate zone forecasts. Lower Hutt (NZ): GNS Science. 50 p. (GNS Science report; 2022/14). doi:10.21420/HYDZ-8W17.
    - Seismogenic slab source model

      Thingbaijam KKS, Gerstenberger MC, Rollins C, Christophersen A, Williams CA, Ristau J, Rastin SJ, Fraser J, Van Dissen RJ. 2022. A seismogenic slab source model for New Zealand. Lower Hutt (NZ): GNS Science. 31 p. (GNS Science report; 2021/50). doi:10.21420/CDMK-3F30.
    - Earthquake rate derivation and variability (N-value and N-scaling)

      Rollins C, Rhoades DA, Rastin SJ, Gerstenberger MC, Christophersen A, Thingbaijam KKS, Van Dissen RJ, Graham K, Fraser J. 2022b. The magnitude-frequency distributions of earthquakes in the greater New Zealand region and along the Hikurangi–Kermadec and Puysegur subduction zones, and their uncertainties, with application to the 2022 New Zealand National Seismic Hazard Model. Lower Hutt (NZ): GNS Science. 77 p. (GNS Science report; 2022/48). doi:10.21420/SXPX-8C68.

NZ NSHM 2022: *SRM Science Reports*

- Earthquake Rupture Forecasts - *continued*
  - Inversion Fault Model(s)
    - Geologic-based upper plate fault deformation model

      Van Dissen RJ, Seebeck H, Wallace LM, Rollins C, Gerstenberger MC, Howell A, DiCaprio C, Williams CA. 2022. New Zealand National Seismic Hazard Model 2022: geologic and subduction interface deformation models. Lower Hutt (NZ): GNS Science. 23 p. (GNS Science report; 2022/31). doi:10.21420/CEXY-AB93.
    - Geodetic-based upper plate fault deformation model

      Johnson KM, Wallace LM, Maurer J, Hamling IJ, Williams CA, Rollins C, Gerstenberger MC, Van Dissen RJ. 2022. Geodetic deformation model for the 2022 update of the New Zealand National Seismic Hazard Model. Lower Hutt (NZ): GNS Science. 62 p. (GNS Science report; 2021/37). doi:10.21420/P93X-8293.
    - Subduction interface deformation models

      Van Dissen RJ, Seebeck H, Wallace LM, Rollins C, Gerstenberger MC, Howell A, DiCaprio C, Williams CA. 2022. New Zealand National Seismic Hazard Model 2022: geologic and subduction interface deformation models. Lower Hutt (NZ): GNS Science. 23 p. (GNS Science report; 2022/31). doi:10.21420/CEXY-AB93.
    - Fault connectivity plausibility filters – taken from UCERF4

      Milner KR, Shaw BE, Field EH. 2022. Enumerating plausible multifault ruptures in complex fault systems with physical constraints. Bulletin of the Seismological Society of America 112 (4): 1806-1824.
    - Slip rate aseismicity factors – adapted from UCERF3

      Field EH, Arrowsmith RJ, Biasi GP, Bird P, Dawson TE, Felzer KR, Jackson DD, Johnson KM, Jordan TH, Madden C, et al. 2014. Uniform California earthquake rupture forecast, version 3 (UCERF3) – the time-independent model. Bulletin of the Seismological Society of America. 104 (3): 1122–1180. doi: 10.1785/0120130164.
    - Fault polygons – modified from UCERF3

      Gerstenberger MC, Van Dissen RJ, Rollins C, DiCaprio C, Chamberlain C, Christophersen A, Coffey GL, Ellis SM, Iturrieta P, Johnson KM, et al. 2022. The Seismicity Rate Model for the 2022 New Zealand National Seismic Hazard Model. Lower Hutt (NZ): GNS Science. 156 p. (GNS Science report; 2022/47). doi:10.21420/2EXG-NP48.

NZ NSHM 2022: *SRM Science Reports*

- Testing, Evaluation and Hazard Sensitivity
  - The Seismicity Rate Model for the 2022 NZ NSHM

    Gerstenberger MC, Bora S, Bradley BA, DiCaprio C, Van Dissen RJ, Atkinson GM, Chamberlain C, Christophersen A, Clark KJ, Coffey GL, et al. 2022. New Zealand National Seismic Hazard Model 2022 revision: model, hazard and process overview. Lower Hutt (NZ): GNS Science. 106 p. (GNS Science report; 2022/57). doi:10.21420/TB83-7X19.
  - Testing and evaluation of hazard results

    Stirling M, Gerstenberger M, Manea E, Bore S. in review. Testing and evaluation of the New Zealand National Seismic Hazard Model. University of Otago report.
- Final SRM Model
  - The Seismicity Rate Model for the 2022 NZ NSHM

    Gerstenberger MC, Bora S, Bradley BA, DiCaprio C, Van Dissen RJ, Atkinson GM, Chamberlain C, Christophersen A, Clark KJ, Coffey GL, et al. 2022. New Zealand National Seismic Hazard Model 2022 revision: model, hazard and process overview. Lower Hutt (NZ): GNS Science. 106 p. (GNS Science report; 2022/57). doi:10.21420/TB83-7X19.