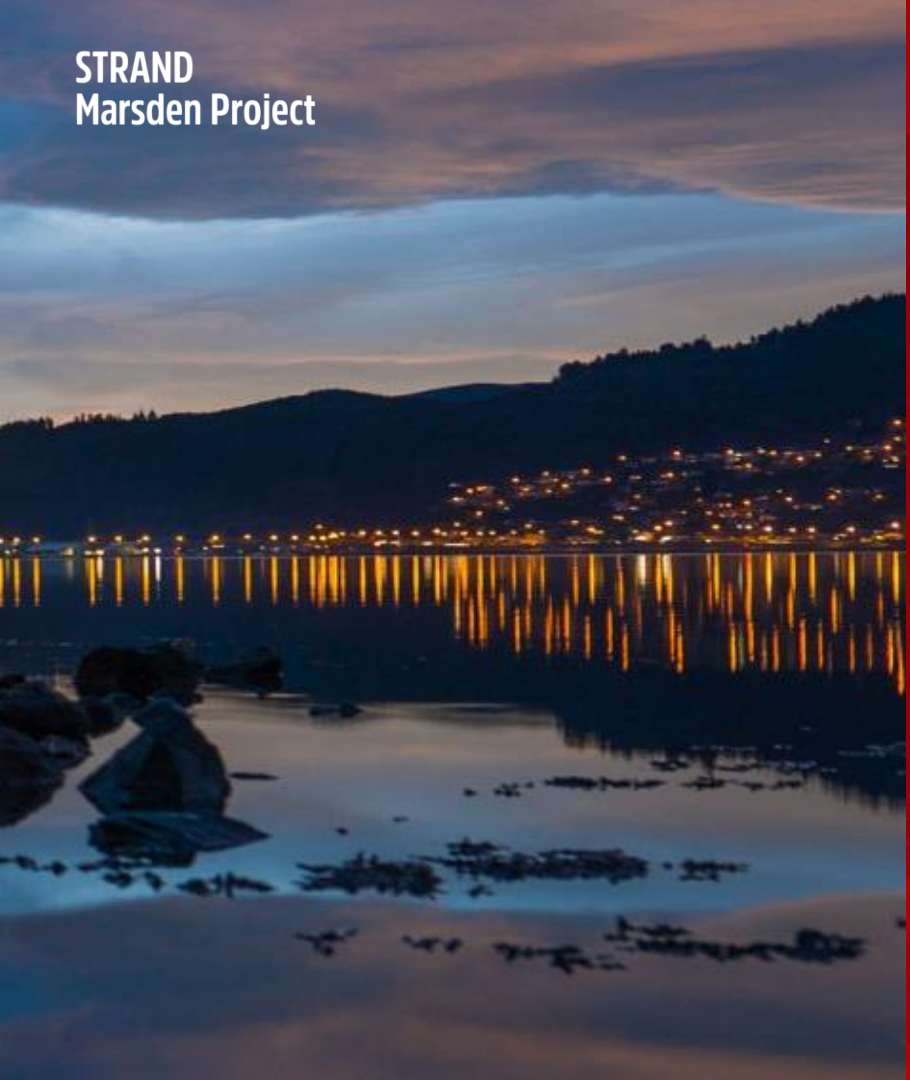

Extreme seas, climate change and banking stability: A bottom-up temporospatial stress test in the context of domestic real estate

Ivan Diaz-Rainey

JRC Summer School in Sustainable Finance

27-28 June 2024, Ispra

Griffith UNIVERSITY
Griffith Business School
Queensland, Australia

Outline

STRAND Marsden Project
Griffith UNIVERSITY Queensland, Australia

1. Introduction
    - Project Scope
    - Paper: bottom-up temporospatial stress test
2. Literature
3. Data and Methods
4. Results
5. Conclusions

1. Introduction: Project Scope

- Flooding risk to real estate and banking stability
- Very interdisciplinary (hydrogeology; climatology, surveying (GIS), data science, finance)
- Funded by Royal Society of NZ (Marsden fund) NZ$869,000
- May 2021 to November 2024
- Blue skies (only translational bit is financial stability) [reality different]
- Focus on mortgages & banking stability
  - Macro prudential
  - Micro prudential
  - Pricing of risk [not originally in proposal but because of flooding banks and insurance companies starting to do 'risk based' pricing and policymakers came knocking at the door]
- Emerging climate stress testing literature
- Bottom-up and forward looking [to end of the century]
- Climate intelligence arms race

Interdisciplinary Team & Partners

Prof. Ivan Diaz-Rainey, Former Lead PI, Finance

Associate Prof. Antoni Moore, PI, Surveying

Dr. Paul Thorsnes, Urban Economics

Dr Simon Cox, Geology

Dr Greg Bodeker, Climate change, Atmospheric Science

Dr Quyen Nguyen, Postdoctoral Fellow, Finance

Dr Murray Cadzow, Scientific Programmer, Research Teaching IT Support

Owyn Otis Aitken, Junior Researcher, University of Otago

UNIVERSITY of OTAGO

TE PŪ AO GNS SCIENCE

Bodeker Scientific

Griffith UNIVERSITY Queensland, Australia

Reserve Bank of New Zealand Te Pūtea Matua

CoreLogic

NeSI New Zealand eScience Infrastructure

NIWA Taihoro Nukurangi

RISKSCAPE™

Climate Disclosure: Volume 19—Mortgage Finance

IFRS S1 and S2 - sector specific

- Materiality test
- FN-MF-450a.1. (1) Number and (2) value of mortgage loans in 100-year flood zones …. disclose the (1) number and (2) value of mortgage loans in the entity's portfolio underwritten on properties located in 100-year flood zones.
- FN-MF-450a.2. (1) Total expected loss and (2) Loss Given Default (LGD) attributable to mortgage loan default and delinquency because of weather-related natural catastrophes, by geographical region
- FN-MF-450a.3. Description of how climate change and other environmental risks are incorporated into mortgage origination and underwriting

The multi-components of flooding hazard

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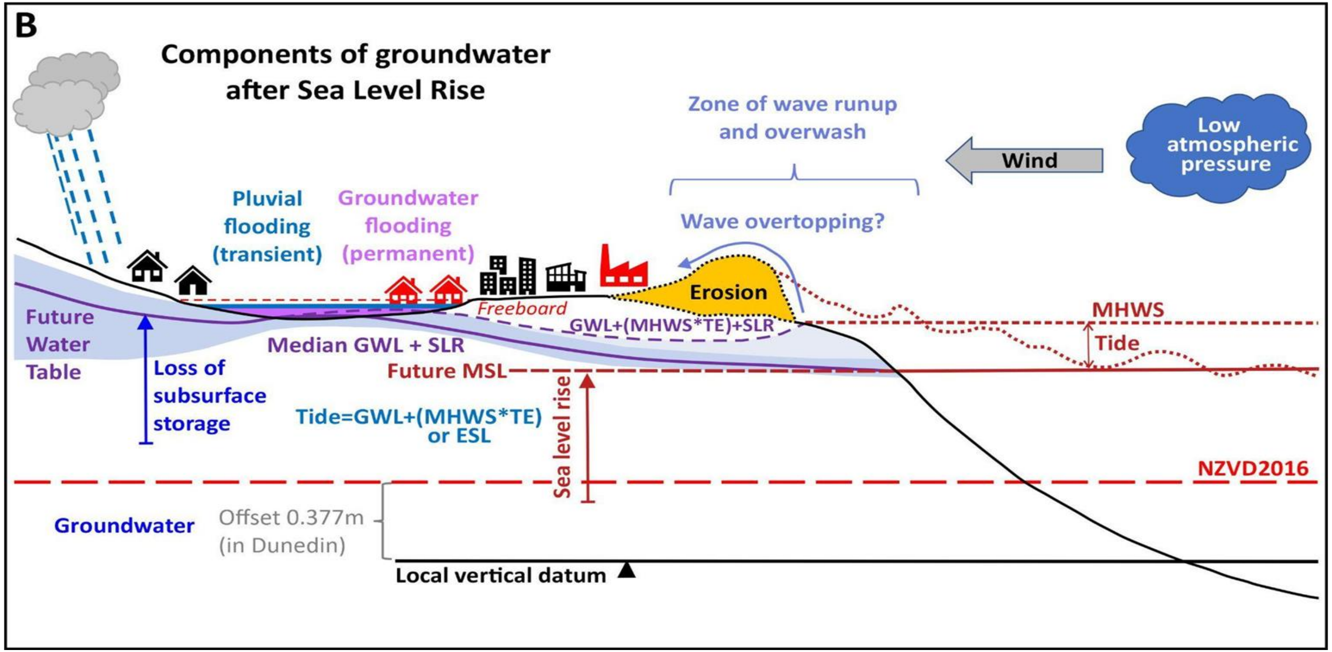
Hazards – With Climate Change

- Sea Level Rise
- Extreme Sea Level (storm surge and wave set up) (tied to SLR and surge exacerbated by CC)
- Rising groundwater (tied to SLR, land motion)
- Pluvial (extreme precipitation) (exacerbated by CC)
- Fluvial (tied to extreme precipitation) (exacerbated by CC)



Source: Cox (2023) adapted from Bell et al. 2017 MfE Coastal Hazards and Climate Change Guidance

The paper: bottom-up temporospatial stress test

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- **Two approaches emerged: top-down and bottom-up stress testing with top-down dominating** (Financial Stability Board 2022)
  - Top-down: use representative asset portfolios in climate scenario analyses with macro-financial-environment modelling
  - Bottom-up: account for physical risks use asset-level data since these are defined by geography

This paper conducts a bottom-up & deterministic climate stress test to explore risk from changes in extreme sea levels [ESL] due to climate change to residential properties across New Zealand

  - IPCC SSP-RCP scenarios are mapped to local SLR projections from NZ SeaRise (Narsh et al, nd) with vertical land motion to obtain the **time** of SLR (0 cm- 200 cm)
  - Flow-on effect to the banking sector due to 'Overvaluation' in the real estate market: NPV of efficient flood discount due to annual losses – observed flood discount (Gourevitch et al, 2023)

- **Research Questions**
- (1) What is the exposure of the NZ residential property market to climate change related flooding hazards?
- (2) What is the potential overvaluation of NZ residential markets due to unpriced climate change related flood hazards?
- (3) Are there material flow-on effects to the mortgage loan portfolios of the NZ banking sector (micro-prudential risk) which may threaten the country's financial stability (macro-prudential risks)?

2. Literature Review

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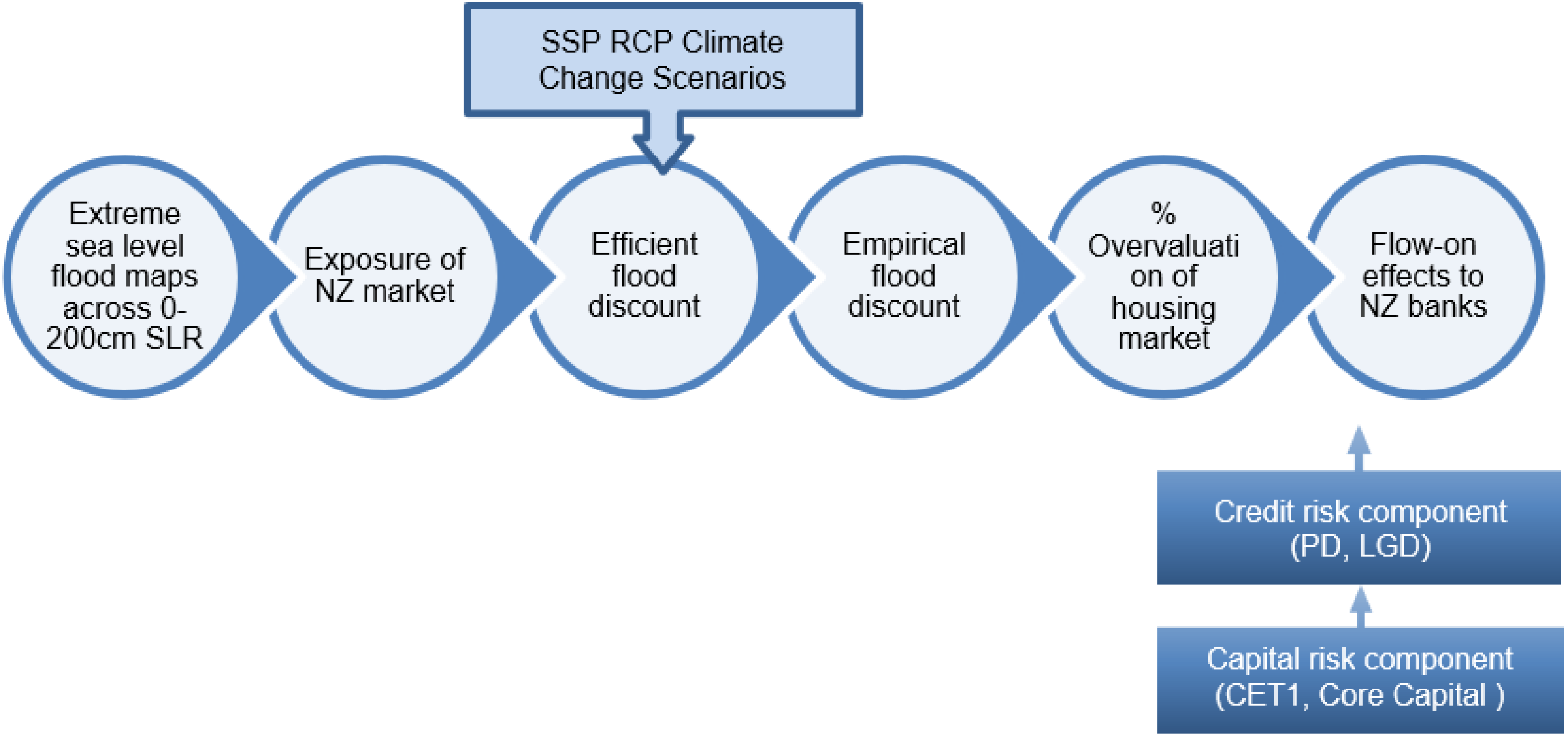
Climate stress testing: Empirical pricing of climate change + Climate risk assessment

Papers	Market	Flood Hazard	Impact Variable	Scenarios & timeline	Result
Gourevitch et al. (2023, Nature Climate Change)	US house market	Pluvial Fluvial Coastal flood	NPV of overvaluation due to unaccounted changes in flood risk : * Empirical flood discount * Flood loss via depth- damage function	2020 and RCP 4.5 2050 (First Street Flood Model)	Residential properties exposed to flood risk are overvalued by US$121–US$237 billion, depending on the discount rate
Calabrese et al (2024, European Journal of Operational Research).	US – Florida house market	Heavy rain and tropical cyclones	Residential mortgage: • Probability of mortgage default • Prepayment	2020 and RCP 4.5 2050 (First Street Flood Model)	A significant & non-linear impact of tropical cyclone intensity on default and significant impact of heavy rains in areas with large exposure to flood risks. PD increased from 0.3% to 1.12%-1.14% in FS2020 and 2040
Caloia & Jansen (2021, Netherlands Central Bank Working Paper)	Netherlands house market	Existing flood zones and catchment	Capital loss of banks (CET1)	A set of 6 adverse scenarios based on 2 flood types & 3 level of water stresses	Dutch banking sector has sufficient capital to withstand scenarios with floods in unprotected area (additional capital depletion 1.1 -1.32%), most extreme (>7%)
Le Guenedal et al (2021, SSRN Working paper)	Global and emerging countries' bond spreads	Cyclone related risks	Spread sensitivity to the debt to GDP ratio	RCP 2.6 – RCP 8.5 Monte Carlo in the Couple Model Intercomparison Project (CMIP5)	RCP8.5 + SSP2 leads to global average annual damages 142% larger than RCP2.6
Pastor-Paz, J et al (2020, Journal of Environmental Management)	New Zealand residential housing market	Flood from extreme precipitations	Insurance claims • Likelihood of claim • Number of claims • Value of claims	Using 6 Couple Model Intercomparison Project (CMIP5) models across RCP 2.6 – RCP 8.5 scenarios	% change between projected and past damages ranges between an increase of 7%–8% in liabilities for 2020 - 2040, and between 9%-25% higher for 2080 -2100

3. Data & methods

Fig 2. Climate Stress Testing Framework



Data & Methods 1: Exposure

- **NZ house market and banking sector to ESL risk:**
- CoreLogic property geo-datasets (1.8 million) overlayed with ESL flood maps (NIWA)
- 7 different annual return intervals (ARI 1-in-2 years -> 1-in-1000 years) at
- 21 SLR increments (0- 2m SLR)
- Synthetic outstanding mortgage portfolios for banks are built based on active mortgage data (1.03 million transactions) and assumptions on Loan to Values & straight-line depreciations

$$\%Exposure_b^{ESL,SLR} = \sum OutstandingLoanValue_{i,j,b,t} * \left(1\ if\ Flood_{i,ESL_{SLR}} = 1, 0\ if\ otherwise\right) * \frac{1}{Portfolioo_{b,T}}$$

Hazards: Extreme Sea Level (NIWA models)

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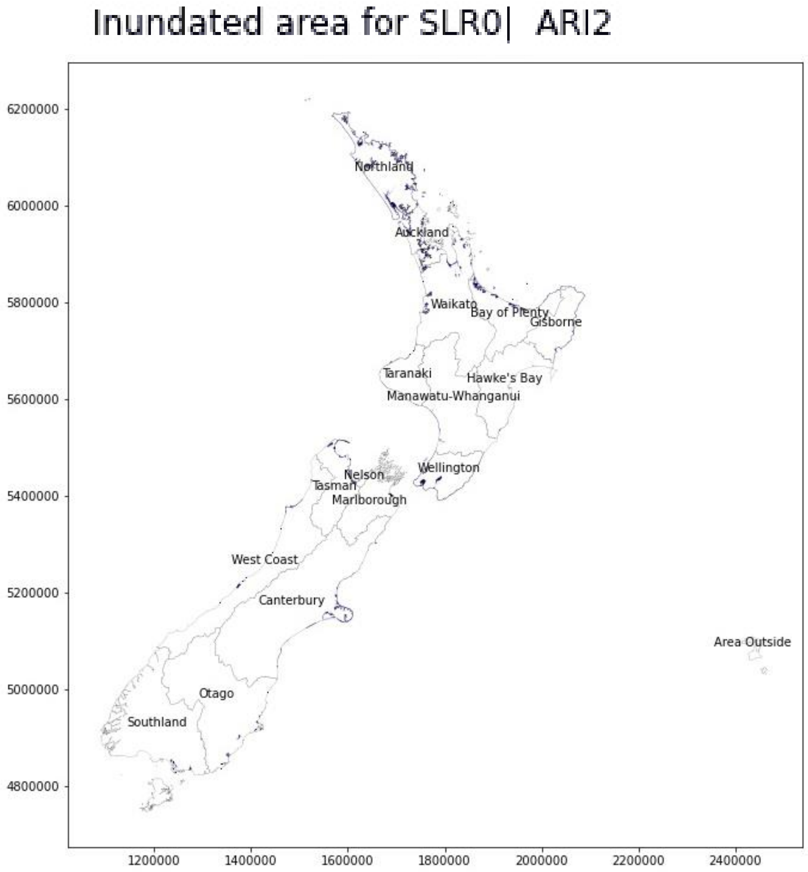

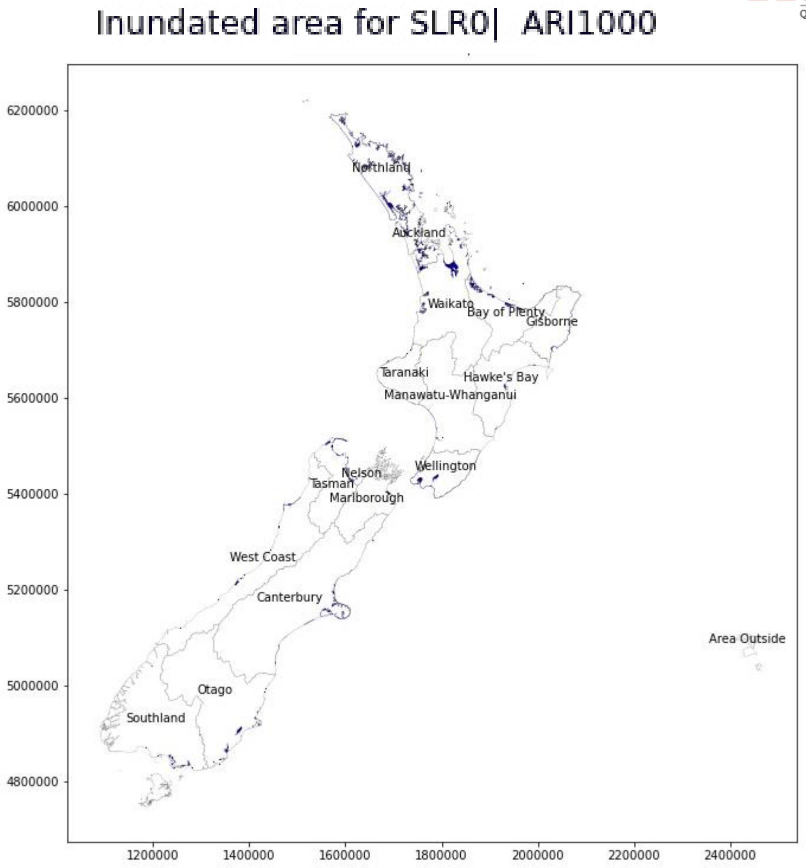

Data & Methods 2: ‘Observed’ flood discount

- **Existing ‘observed’ flood discount due to present-day ESL risk**
  - ‘observed price’ is imperfect, as it may be influenced by market lack of foresight or lack of information about potential flood losses, cognitive biases in risk perceptions and/or socialization of flood-related costs (Gourevitch et al., 2023) and deep uncertainty about the future (pathway or scenario).
  - Hedonic price mode.: Matching strategies: 1:1 nearest neighbours, 3:1 nearest neighbours & 1:1

$$Price_{jt} = \propto_0 + \propto_1 Structure_{jt} + \propto_2 Neighborhood_{jt} + \propto_3 Location_j + \beta Flood_{j,ESL_{SLR=0}} + Suburb + \delta_t + \varepsilon_{it}$$

- $Price_{jt}$: natural logarithm transformation of real sale price of property j at transaction date t,
- $Structure_{jt}$: property structure characteristics, $Neighborhood_{jt}$: neighbourhood characteristics
- $Location_j$: locational attributes
- $Flood_{j,ESL_{SLR=0}}$: a dummy indicator that indicates a property j located inside the flood extents of present-day ESL.
- δ_t: time fixed effect, ε_{it}: the clustered residual errors at suburb level to account for serial correlation

Data & Methods 3: 'Efficient' flood discount

- **Future 'efficient' flood discount due to change in ESL risk due to SLR**
  - Depth – damage function to obtain loss at different SLR increments and ARIs:
  - **Damages (SLR, ARI) = f(Flood depth, Floor height, Number of storeys)**
  - Trapezoidal Riemann sums to obtain Average Annual Loss by integrating the estimated damages over the range of recurrence interval probabilities
  - Average Annual Loss proportion of the total value expected to be lost annually

$$
\begin{aligned}
AAL_{j,SLR} = {} & (P_{ARI2} - P_{ARI5}) * (Loss_{j,SLR,ARI2} + Loss_{j,SLR,ARI10}) * 1/2 \\
& + (P_{ARI5} - P_{ARI10}) * \left(Loss_{j,SLR,ARI5} + Loss_{j,SLR,ARI10}\right) * \frac{1}{2} \\
& + (P_{ARI10} - P_{ARI20}) * \left(Loss_{j,SLR,ARI10} + Loss_{j,SLR,ARI20}\right) * \frac{1}{2} \\
& + (P_{ARI20} - P_{ARI50}) * \left(Loss_{j,SLR,ARI20} + Loss_{j,SLR,ARI50}\right) * \frac{1}{2} \\
& + (P_{ARI50} - P_{ARI100}) * \left(Loss_{j,SLR,ARI50} + Loss_{j,SLR,ARI100}\right) * \frac{1}{2} \\
& + (P_{ARI100} - P_{ARI200}) * \left(Loss_{j,SLR,ARI100} + Loss_{j,SLR,ARI200}\right) * \frac{1}{2} \\
& + (P_{ARI200} - P_{ARI500}) * \left(Loss_{j,SLR,ARI200} + Loss_{j,SLR,ARI500}\right) * \frac{1}{2} \\
& + (P_{ARI500} - P_{ARI1000}) * \left(Loss_{j,SLR,ARI500} + Loss_{j,SLR,ARI1000}\right) * \frac{1}{2} \\
& + P_{ARI1000} * Loss_{j,SLR,ARI1000}
\end{aligned}
$$

Data & Methods 4: 'Efficient' flood discount & Overvaluation

- AALs for the property j in year t in each climate scenario using a simple linear interpolation

$$AAL_{j,t,Scenario} = AAL_{j,t} + t * \frac{\left(AAL_{j,t2,Scenario} - AAL_{j,t1,Scenario}\right)}{t2 - t1}$$

$$NPV_{j,Scenario} = \sum AAL_{j,t,Scenario} \; (1 + DiscountRate)^{-t}$$

- **Overpricing due to climate change: difference in NPV of 'efficient' flood discount – 'observed' flood discount' at 3% discount rate** (Gourevitch et al, 2023 , *Nature Climate Change*)

$$Overvaluation_{j,Scenario} = \left(RateableValue_j - EfficientPrice_{j,Scenario}, 0\right)$$

- $EfficientPrice_{j,Scenario}$: The efficient prices are the difference between their market value in the absence of flood risk (risk-free market value) and the NPV of AALs across climate change scenarios.

Data & Methods 5

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- Flow-on effects to the banking sector model via BASEL III Internal Ratings Based Approach
  - Five credit risk parameters: probability of default (**PD**), loss given default (**LGD**), the exposure at default (**EAD**), effective maturity (**M**), and regulatory correlation factor (**R**).
  - Overprice due to climate change impacts is assumed to impact **PD** (collateral repricing risk) & **LGD** (collateral repricing risk, insurance coverage risk, business risk, interest rate risk)

>>> Ideal approach: Credit risk model that models PD or LGD based on flood risk and collateral price (LTV), mortgage characteristics, borrower characteristics, macro-economic indicators ,etc …

>>> Naïve approach: Change in PD due to technical default from insurance retreat > % Loss in loan portfolios > % Loss in core capital values (approach used by RBNZ 2022)

$$LGD_{i,j,b,Scenario} = LGD_{i,j,b} + [Overvaluation_{j,Scenario} - (1 - LTV_{i,j,b}) * RateableValue_j) \; if \; PD_{i,j,b,Scenario,very\ severe} = 1$$

$$Loss_{b,Scenario,T} = \frac{\sum PD_{i,j,b,Scenario} * LGD_{i,j,b,Scenario} * OustandingLoanValue_{i,j,b,t}}{Portfolio_{b,T}}$$

$$CET1_{b,Scenario,T} = Loss_{b,Scenario,T} * \frac{1}{Y}$$

4. Result: New Zealand housing market exposure to ESL

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Minimal exposure to ESL flooding risk currently.
However, exposure increase substantially with sea rise.

	Rateable values of exposed properties									Fraction of rateble values of exposed properties								
SLR amount	MHWS	ARI2	ARI5	ARI10	ARI50	ARI100	ARI200	ARI500	ARI1000	MHWS	ARI2	ARI5	ARI10	ARI50	ARI100	ARI200	ARI500	ARI1000
0 cm	2,009	4,320	5,275	6,096	9,307	10,485	13,973	17,927	19,220	0.1%	0.3%	0.3%	0.4%	0.5%	0.6%	0.8%	1.0%	1.1%
10 cm	2,260	6,033	7,274	8,223	11,790	16,551	18,194	20,213	21,817	0.1%	0.3%	0.4%	0.5%	0.7%	1.0%	1.1%	1.2%	1.3%
20 cm	2,692	7,446	9,697	11,840	17,328	19,014	20,799	23,437	25,210	0.2%	0.4%	0.6%	0.7%	1.0%	1.1%	1.2%	1.4%	1.5%
30 cm	3,208	11,014	13,864	15,399	20,422	22,264	23,718	26,225	28,042	0.2%	0.6%	0.8%	0.9%	1.2%	1.3%	1.4%	1.5%	1.6%
40 cm	3,860	14,083	16,563	18,784	23,185	24,906	26,767	29,447	31,569	0.2%	0.8%	1.0%	1.1%	1.3%	1.4%	1.6%	1.7%	1.8%
50 cm	4,786	16,754	19,496	22,002	26,235	28,531	32,549	35,586	37,507	0.3%	1.0%	1.1%	1.3%	1.5%	1.7%	1.9%	2.1%	2.2%
60 cm	6,049	19,741	23,125	25,084	32,247	34,333	36,164	39,866	41,685	0.4%	1.1%	1.3%	1.5%	1.9%	2.0%	2.1%	2.3%	2.4%
70 cm	8,637	22,947	28,700	31,018	36,076	38,627	40,854	44,026	46,819	0.5%	1.3%	1.7%	1.8%	2.1%	2.2%	2.4%	2.6%	2.7%
80 cm	10,616	29,391	32,313	35,108	39,980	42,856	45,281	50,672	52,438	0.6%	1.7%	1.9%	2.0%	2.3%	2.5%	2.6%	2.9%	3.0%
90 cm	12,731	33,249	36,452	39,151	46,780	50,063	51,577	54,462	56,777	0.7%	1.9%	2.1%	2.3%	2.7%	2.9%	3.0%	3.2%	3.3%
100 cm	15,486	38,355	42,079	45,221	51,846	54,141	55,907	59,156	60,867	0.9%	2.2%	2.4%	2.6%	3.0%	3.1%	3.2%	3.4%	3.5%
110 cm	18,853	43,213	47,586	51,043	55,832	58,498	60,111	63,242	65,058	1.1%	2.5%	2.8%	3.0%	3.2%	3.4%	3.5%	3.7%	3.8%
120 cm	22,699	49,086	52,557	55,012	60,366	62,911	64,623	67,333	69,309	1.3%	2.8%	3.0%	3.2%	3.5%	3.6%	3.7%	3.9%	4.0%
130 cm	24,311	52,983	56,508	59,825	64,586	67,104	68,644	71,767	74,323	1.4%	3.1%	3.3%	3.5%	3.7%	3.9%	4.0%	4.2%	4.3%
140 cm	32,592	57,565	61,288	64,076	69,084	71,513	73,207	76,616	78,484	1.9%	3.3%	3.6%	3.7%	4.0%	4.1%	4.2%	4.4%	4.6%
150 cm	36,759	61,762	65,489	68,382	73,640	76,249	77,742	80,461	82,526	2.1%	3.6%	3.8%	4.0%	4.3%	4.4%	4.5%	4.7%	4.8%
160 cm	40,831	66,295	69,919	72,825	78,005	80,221	82,177	85,367	87,340	2.4%	3.8%	4.1%	4.2%	4.5%	4.7%	4.8%	5.0%	5.1%
170 cm	45,079	70,712	74,352	77,483	83,213	85,396	87,613	91,070	93,478	2.6%	4.1%	4.3%	4.5%	4.8%	5.0%	5.1%	5.3%	5.4%
180 cm	49,533	75,383	79,687	82,773	88,856	91,361	93,053	95,814	97,817	2.9%	4.4%	4.6%	4.8%	5.2%	5.3%	5.4%	5.6%	5.7%
190 cm	55,545	80,700	85,654	88,378	93,202	95,483	97,006	100,281	102,137	3.2%	4.7%	5.0%	5.1%	5.4%	5.5%	5.6%	5.8%	5.9%
200 cm	60,550	86,727	90,298	92,843	97,052	99,788	101,679	104,153	106,027	3.5%	5.0%	5.2%	5.4%	5.6%	5.8%	5.9%	6.0%	6.1%

Result: New Zealand housing market exposure to ESL

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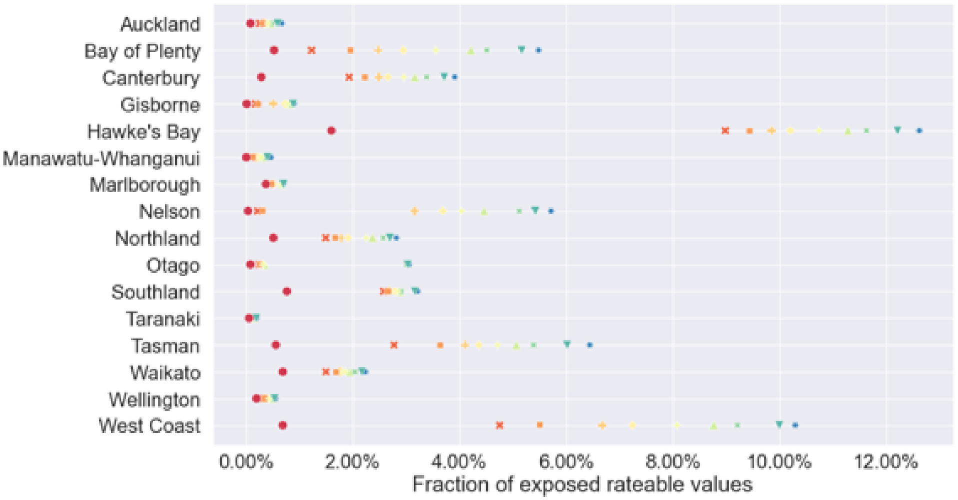
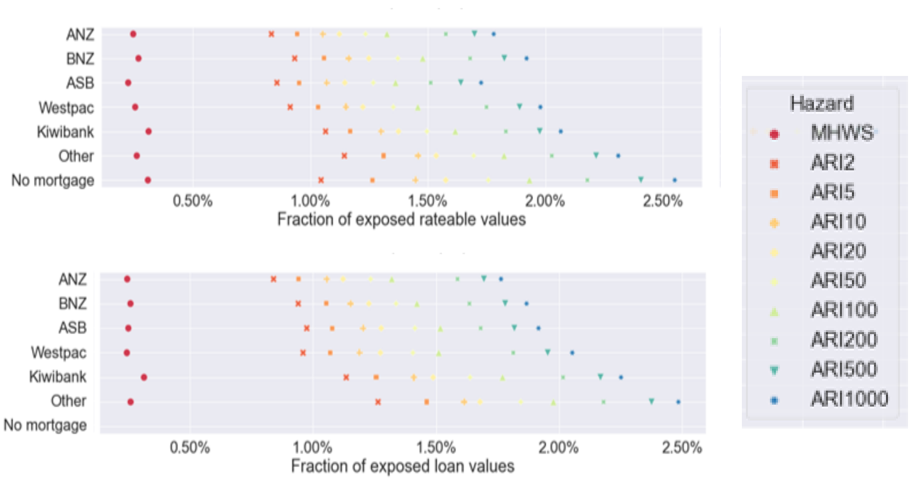
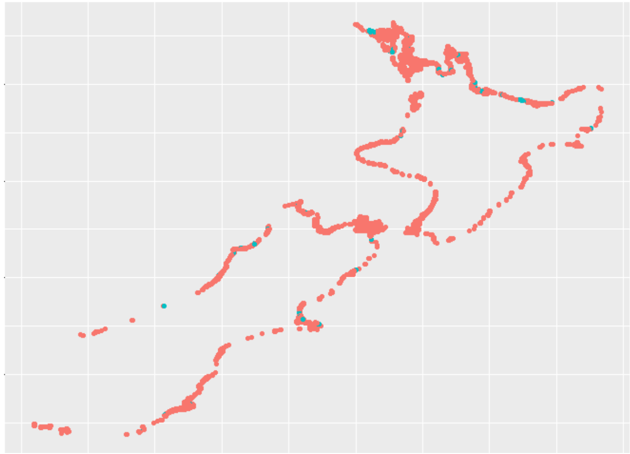
Coastal flood exposure is concentrated in certain areas (Hawke's Bay, West Coast, Tasman), and smaller banks are more vulnerable to ESL risk.

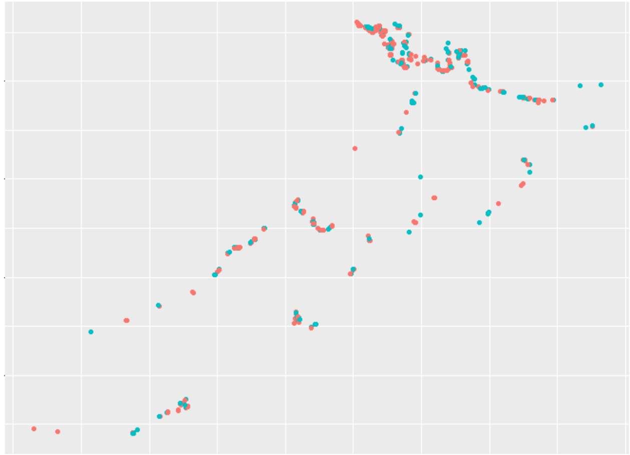




Result: Geographical presentation of present-day ESL risk in the housing dataset across different matching strategies



Full sample: 2 km from the sea

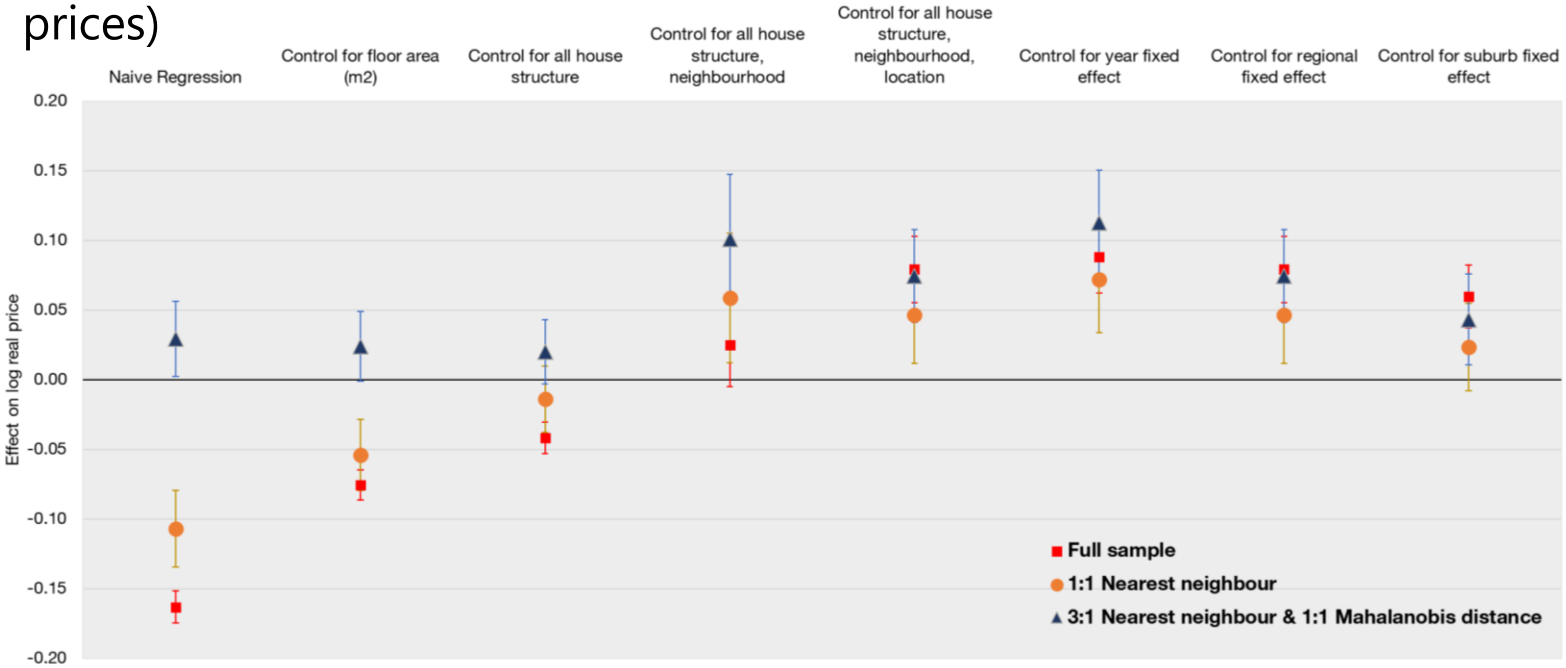


Matched sample: 1:1 nearest neighbor sample on geo-locations

Matched sample: 3:1 nearest neighbor on geo-coded locations + 1:1 Mahalanobis distance on observable characteristics

Result: Mixed 'observed' price signals

Mixed evidence of the 'observed' price effect due to periodic coastal flooding (ARI100) across empirical identification strategies (between – 0.16 to a + 0.11 price premium on log real prices, or -14.8% to 11.6% on real prices)



Result: Mixed 'observed' price signals

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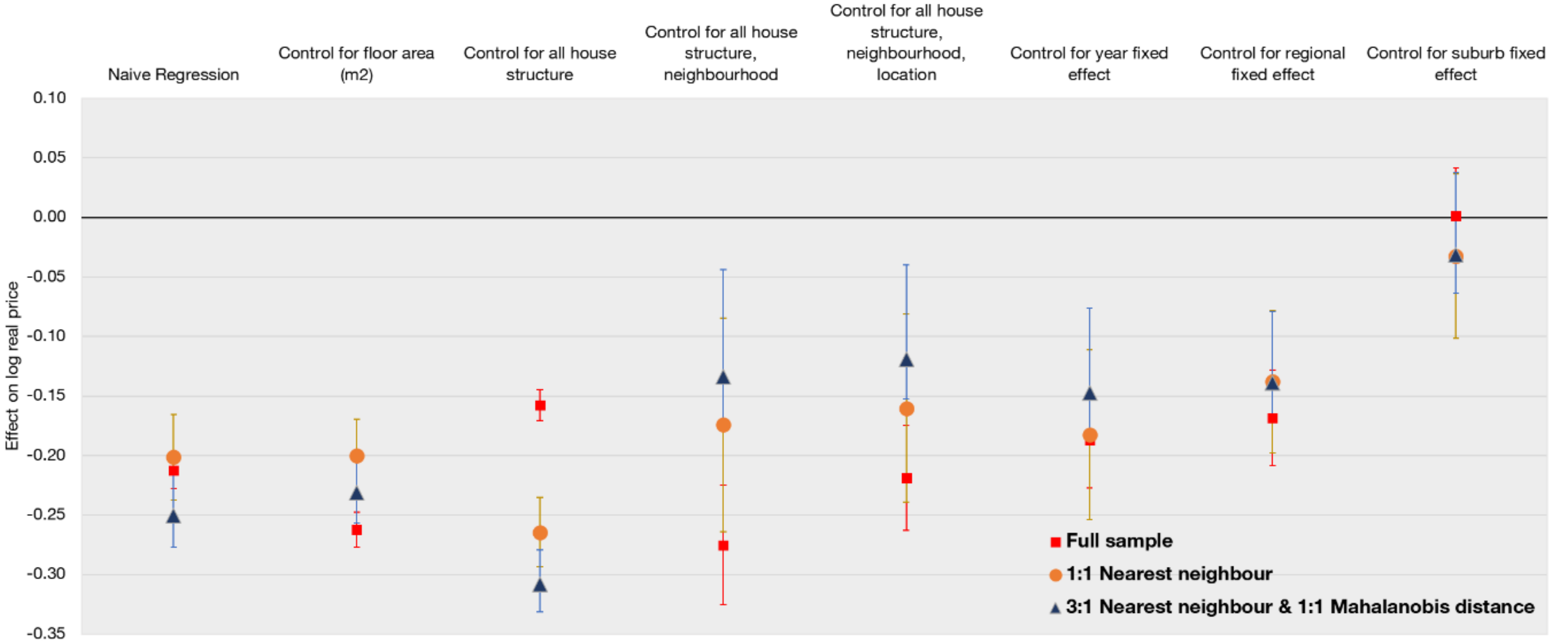
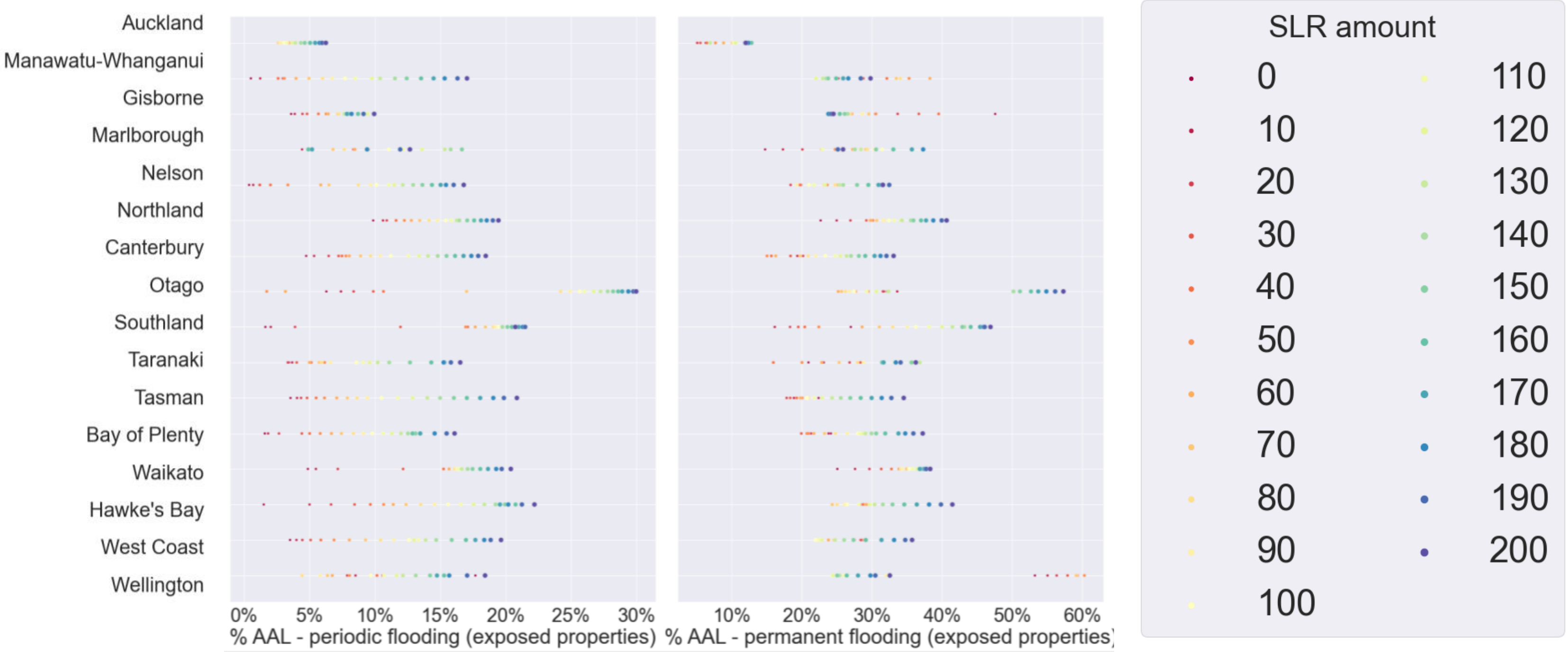
…But stronger effect for permanent flooding (signaled by MHWS flood zone) (– 0.31 to a + 0.00 on log transformed real prices, or -29.2% to 0% on real prices)



Result: Substantial 'efficient' prices

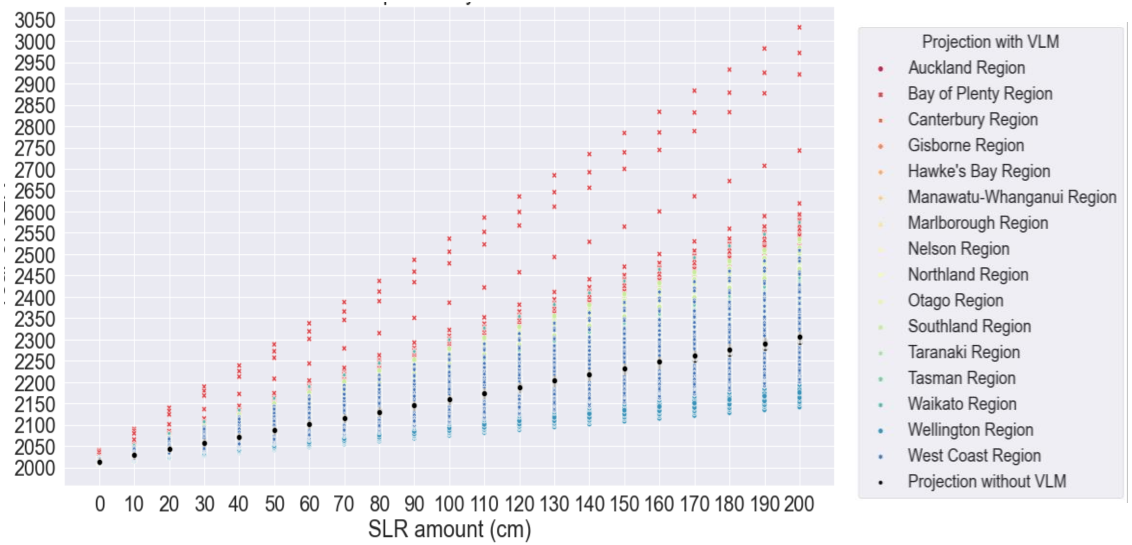
When the sea level rises from 0-200 cm, it will raise the average annual loss

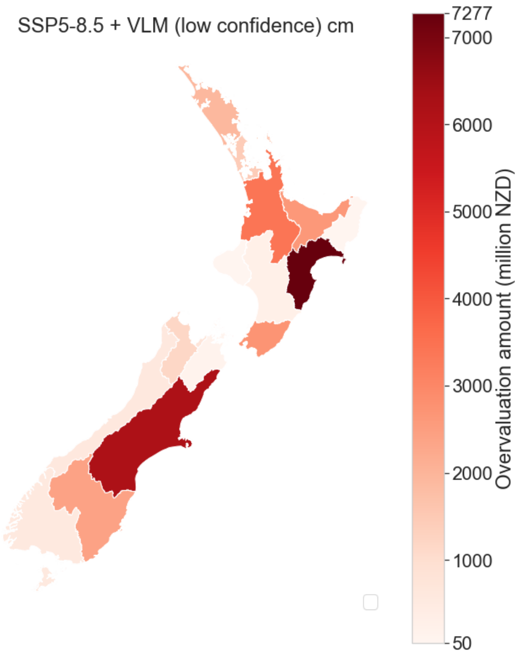
- **Periodic flooding** ranges from 5.3% to 15.6% of replacement values of exposed properties across New Zealand
- **Permanent flooding** ranges from 20.8% to 29.5%.



Result: Overvaluation

Timing plays a crucial role in determining market overvaluation





The year of reaching SLR amounts changes substantially due to climate change scenarios and vertical landmotion…

… lead to substantial changes in NPV of overvaluation $.

Result: Substantial flow-on effects to the banking sector

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Each bank are exposed to substantial loss in their portfolios across climate change scenarios and empirical identification strategies (assuming technical default due to 'full insurance retreat' where house prices drop by 50%)

Result: Substantial flow-on effects to the banking sector

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The entangled vulnerability in financial risk and climate risk

Bank	Ex-ante risk profile					The averaged change in risk profile to ESL				
	Credit risk component			Capital risk component		Very severe (house prices >50%)				
	Probability of default (PD)	Loss given default (LGD)	Non-performing loan ratio	CET1	Core Capital	Change in PD	Change in LGD	Loss to Loan Values	Loss to CET1	Loss to core capital
ANZ	0.9%	19.0%	0.6%	12.5%	15.5%	1.0%	85.8%	0.5%	4.7%	3.8%
BNZ	0.9%	20.0%	0.2%	12.8%	15.2%	0.9%	86.3%	0.6%	4.8%	4.0%
ASB	2.5%	19.0%	0.4%	14.3%	15.7%	0.9%	85.0%	0.6%	4.3%	3.9%
Westpac	1.3%	18.2%	0.3%	11.3%	13.9%	1.1%	87.0%	0.6%	5.9%	4.8%
Kiwibank*	n.a.	n.a.	0.1%	10.3%	14.3%	1.2%	86.1%	0.8%	8.3%	6.0%
Other*	n.a.	n.a.	n.a.	n.a.	n.a.	1.3%	85.7%	0.8%	6.9%	5.7%
All	1.4%	19.0%	0.3%	12.2%	14.9%	1.0%	86.0%	0.6%	5.3%	4.4%

Summary

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- **Climate stress testing shows that the NZ's exposure to ESL flood risk will rise significantly as sea level rise.**
  - The market fails to account for the increasing in frequency and severity of future flood losses due to climate change.
  - Residential properties exposed to ESL are overvalued by 9.9 –32.2 billion NZD, with flow-on effects to the banking sector.
  - The impact seems to be **relatively low ,** however,
    - Top-down impact has not been considered (second order macroeconomic effects)
    - Only two hazards (ESL and SLR).
    - Groundwater, fluvial, pluvial and interaction of hazards
  - There is differential impact across the banks: Kiwi bank's exposure (CET1 x2 of big four)

Thank you

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