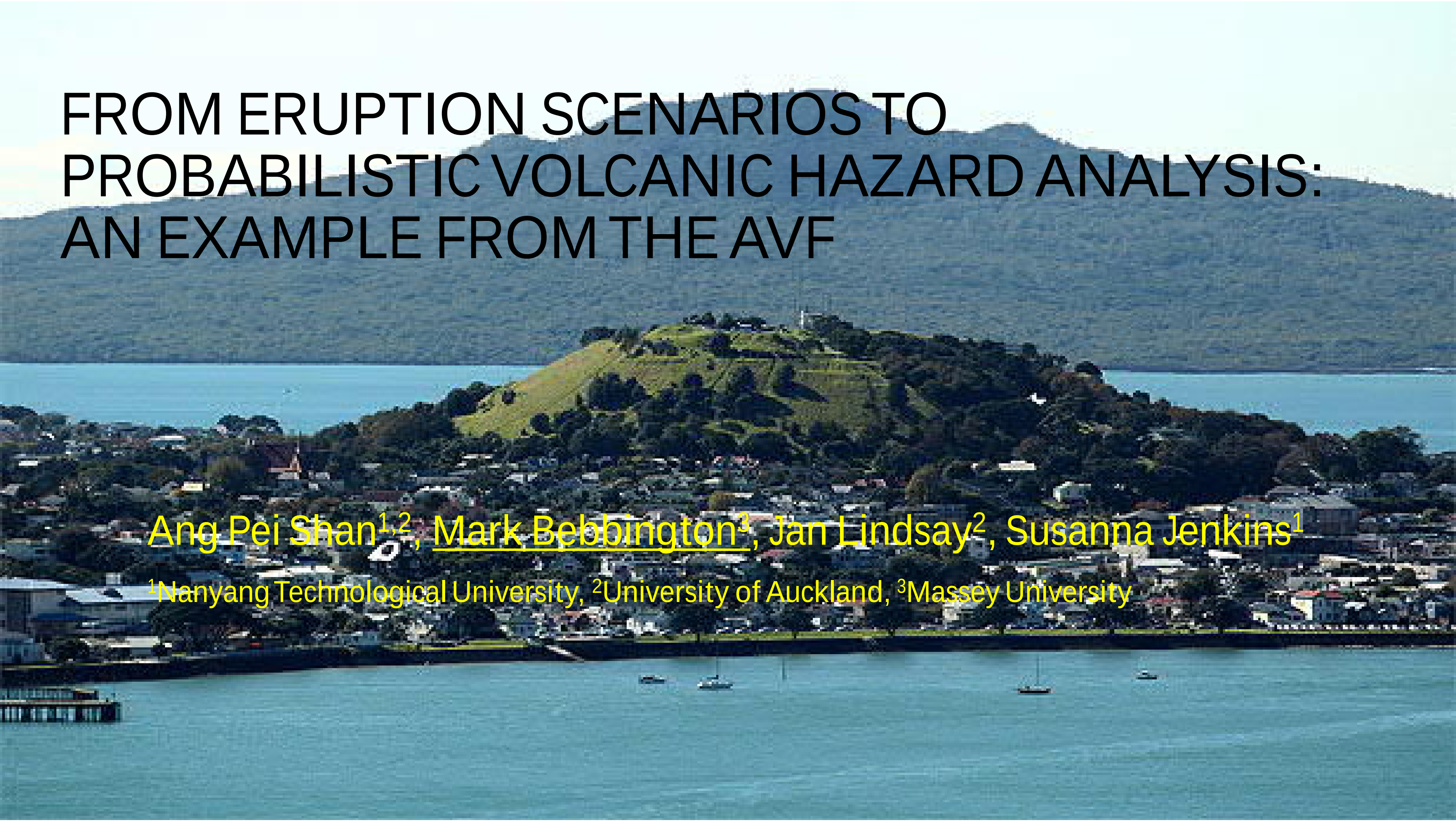


# FROM ERUPTION SCENARIOS TO PROBABILISTIC VOLCANIC HAZARD ANALYSIS: AN EXAMPLE FROM THE AVF

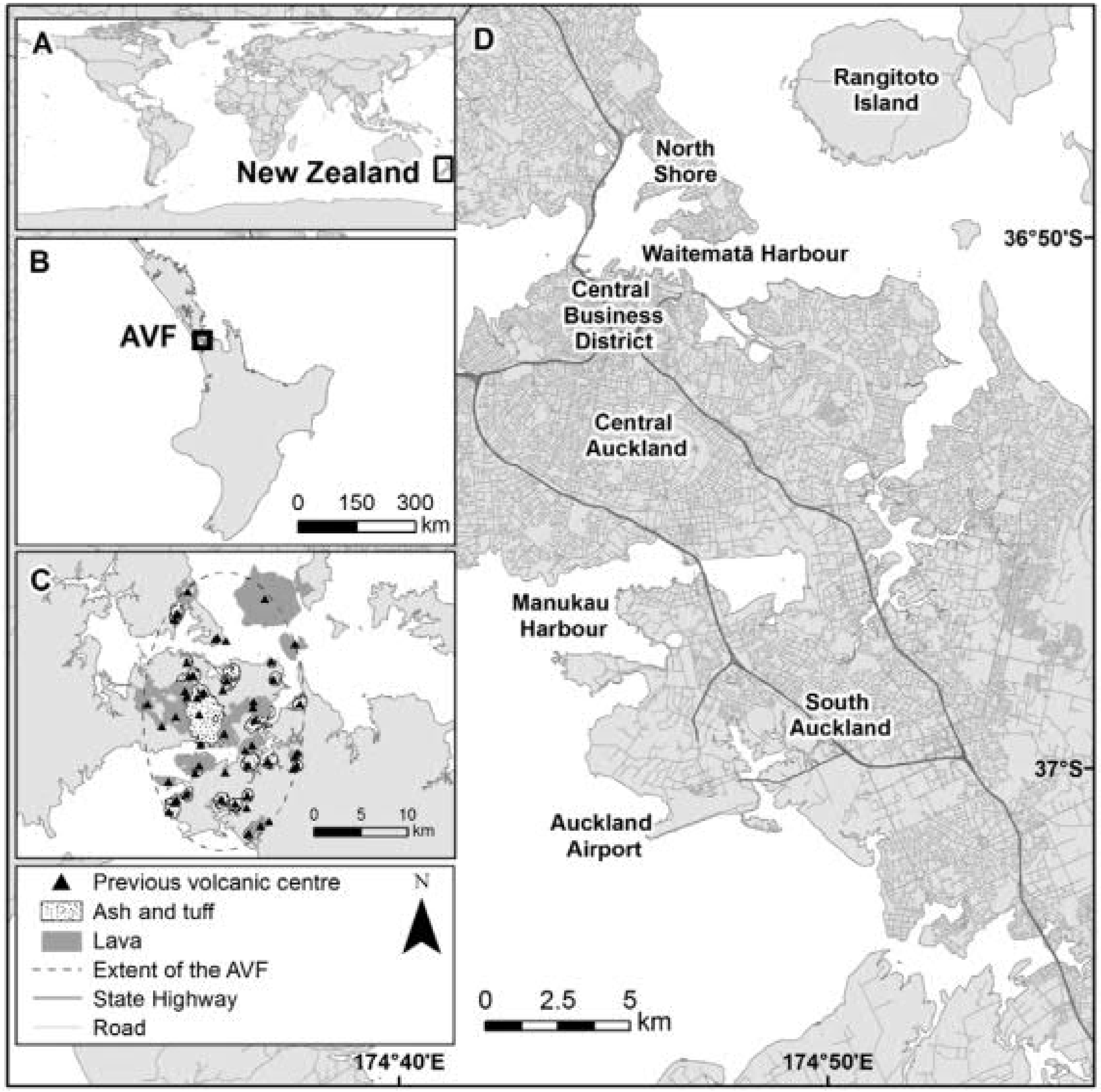
Ang Pei Shan[1,2], Mark Bebbington[3], Jan Lindsay[2], Susanna Jenkins[1]

[1]Nanyang Technological University, [2]University of Auckland, [3]Massey University

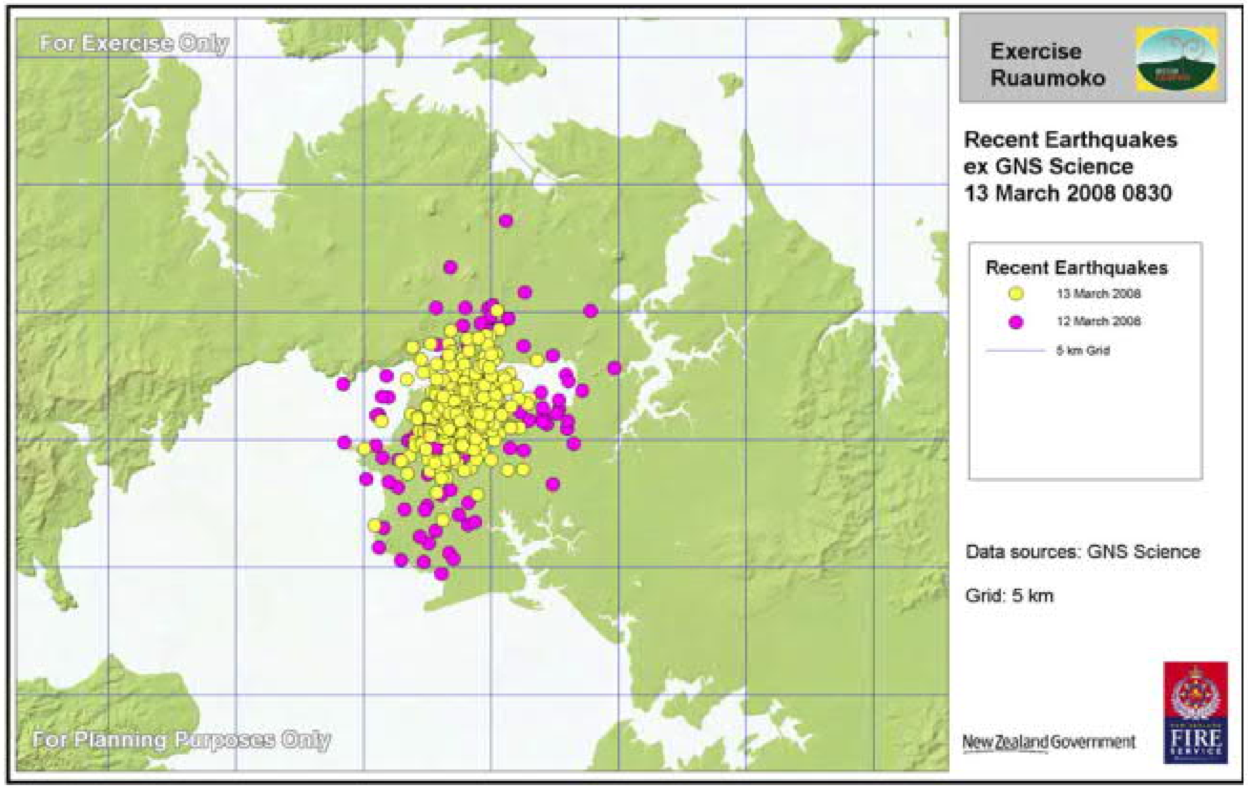
# Auckland Volcanic Field

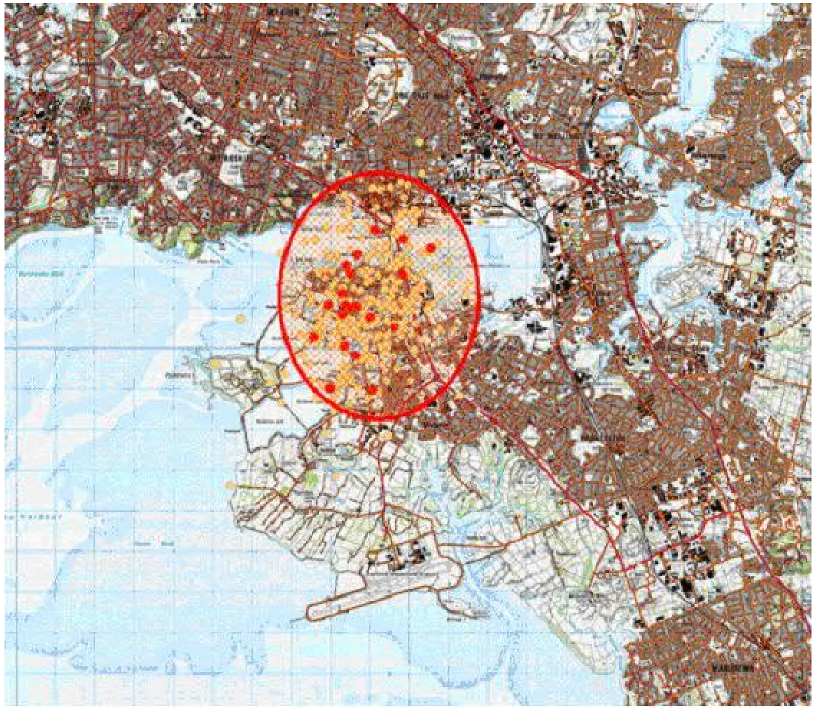
- c. 1.5 Million population
- 50+ known vents over last c. 250 ky
- Most recent eruption c. 1400CE (Rangitoto)
- High probability of a phreatomagmatic phase – base surge
- Low altitude tephra column
- Scoria / lava likely

(Hayes et al. 2020)



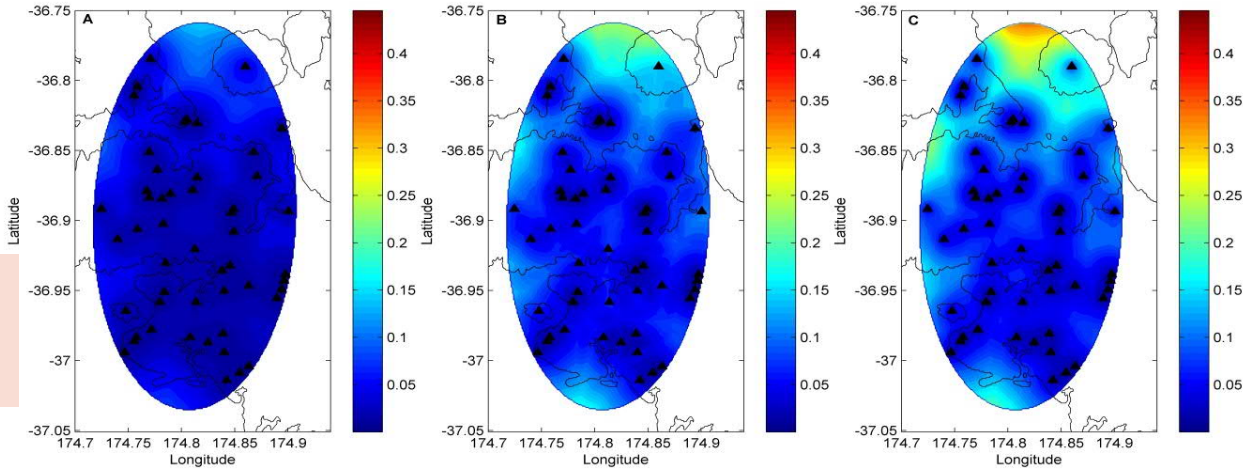
# Ruaumoko Civil Defense Exercise 2007/8



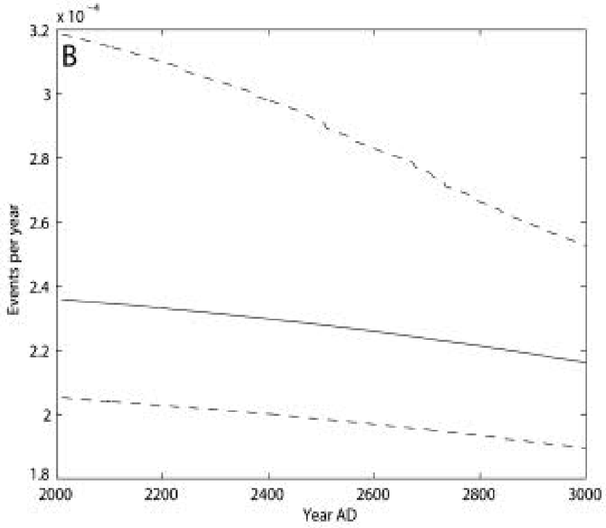



# Probabilistic Forecasts

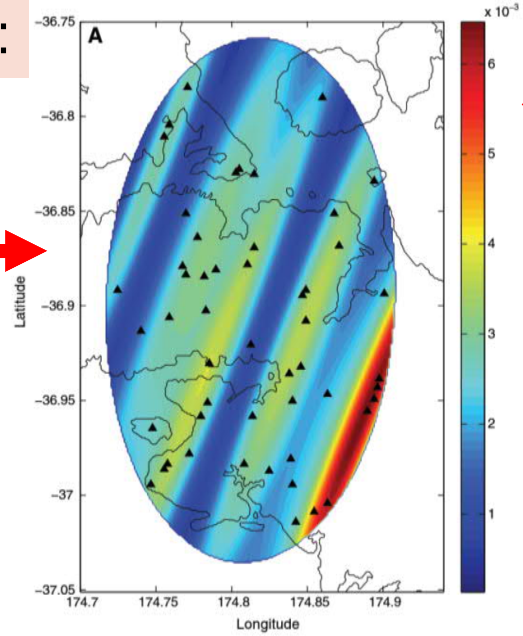
How much (Mean/SD/90th percentile):



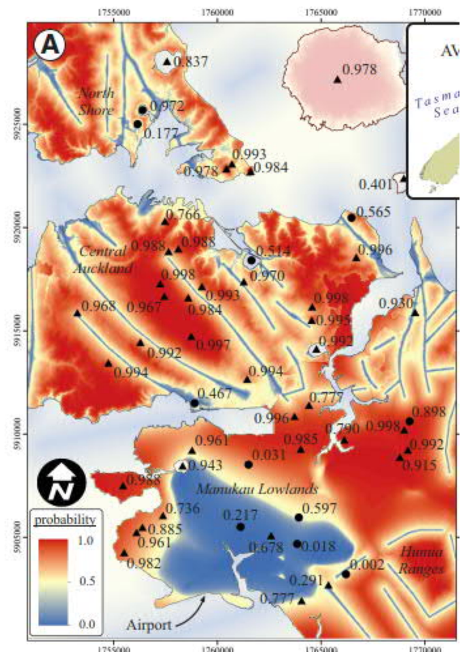

When:




Where:




What (Prob of phase transition):



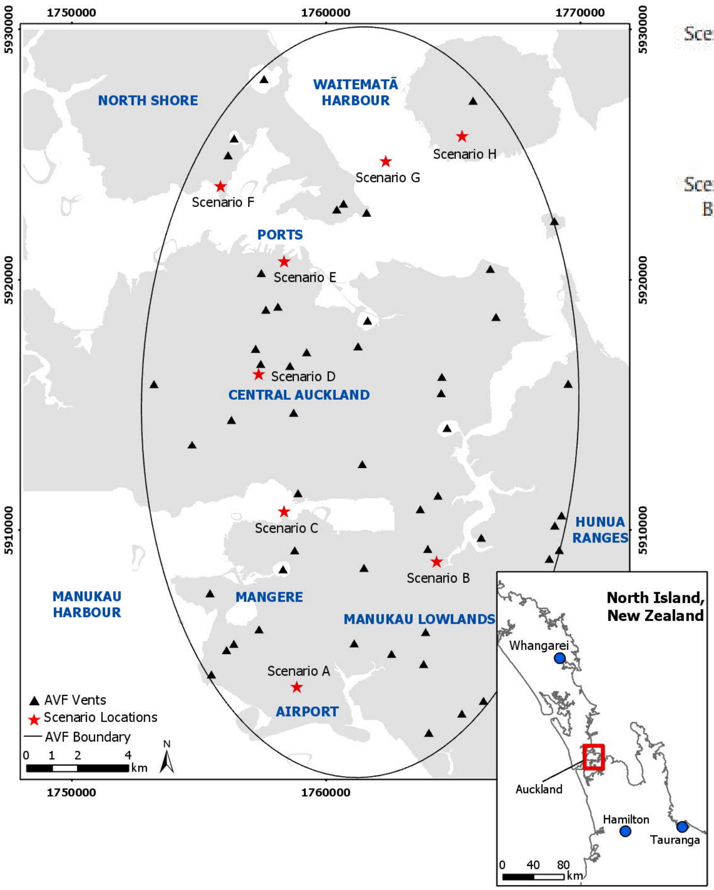
# Two approaches to volcanic hazard and risk mitigation: Scenarios v. PVHA

Each approach has strengths and weaknesses.

- PVHA
  - Better quantifies range of possibilities and likelihoods
  - High dimensional, difficult to communicate
  - Complete range of hazard magnitudes
- Scenarios
  - Only one (or a very few) specific possibility
  - Likelihood not quantified
  - Built around a narrative and easily communicated
- Can we create a ‘hybrid’ approach by calculating the relative likelihoods among a sufficiently large set of scenarios?

# Eight DeVoRA Scenarios: Design

(Hayes et al. 2020)

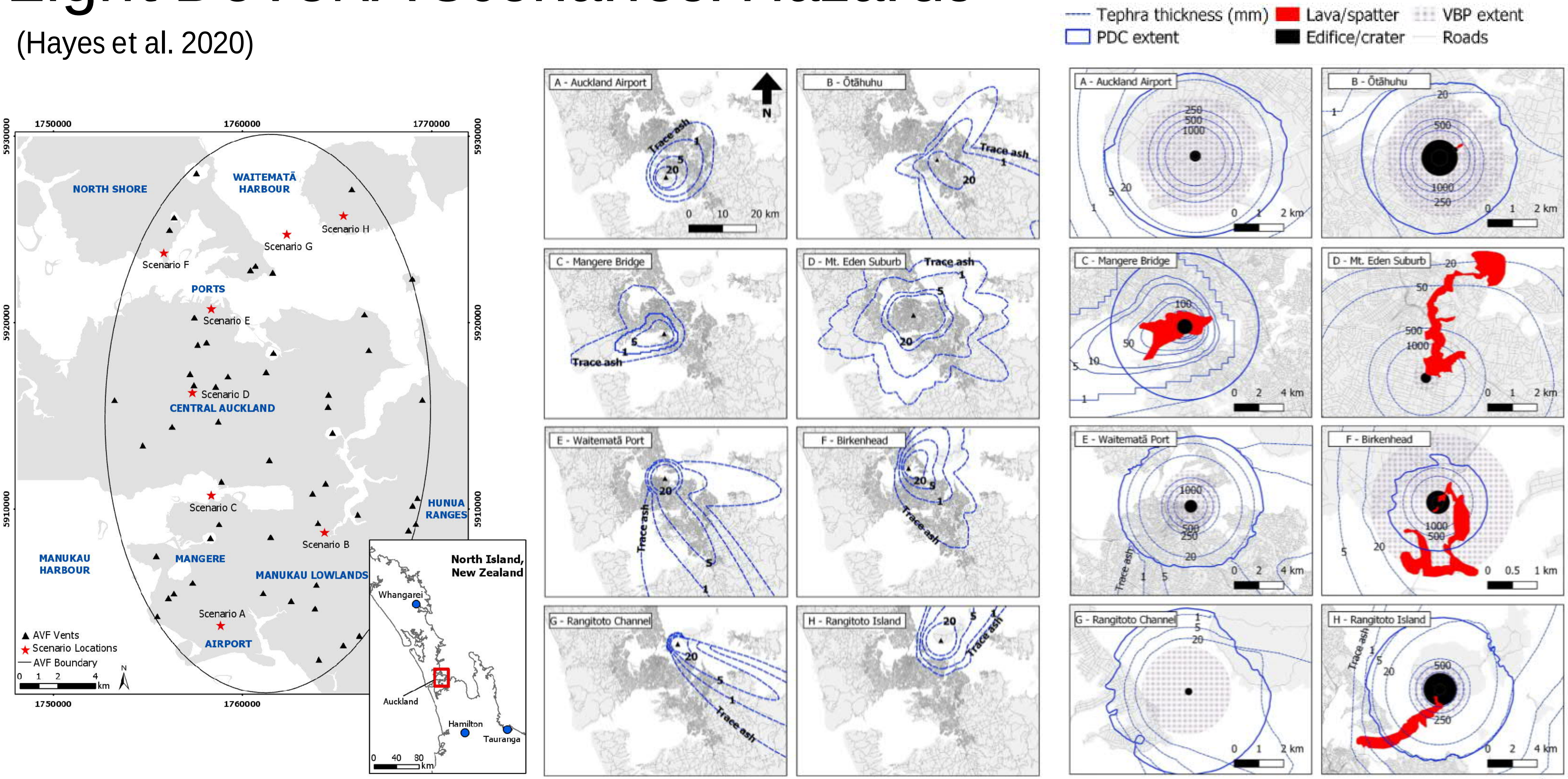



| Scenario name | Reasoning |
|---|---|
| Scenario A: Auckland Airport | ● Proximity to Auckland Airport (nationally significant infrastructure)<br>● Environmental conditions conducive to phreatomagmatic eruptive activity (Kereszturi et al., 2014, 2017). |
| Scenario B: Ōtāhuhu | ● Proximity to an area with a high density of critical infrastructure<br>● Environmental conditions conducive to phreatomagmatic activity but could also allow for transition to magmatic eruptive activity (Kereszturi et al., 2014, 2017). |
| Scenario C: Māngere Bridge | ● Exercise Ruaumoko eruption location. This was a highly socialised scenario location because it was used for an all-of-nation civil defence exercise (Lindsay et al., 2010).<br>Criteria given to 'the volcano' in 2008 (Deligne et al., 2015b):<br>● Eruption should start in shallow water to consider range of possible eruption types.<br>● Eruption site should be in an area of mixed socioeconomic groups;<br>● Eruption site could not force closure of State Highway 1 nor Northwestern Motorway given expected response actions. |
| Scenario D: Mt. Eden Suburb | ● Eruption site likely to result in largest evacuation population.<br>● Eruption site located in a residential area.<br>● Environmental conditions conducive to magmatic eruption styles (Kereszturi et al., 2014, 2017). |
| Scenario E: Waitematā Port | ● Proximity to Waitematā Port operations.<br>● Environmental conditions conducive to phreatomagmatic eruptive activity (Kereszturi et al., 2014, 2017). |
| Scenario F: Birkenhead | ● Proximity to Auckland Harbour Bridge.<br>● On the North Shore.<br>● Environmental conditions conducive to hybrid eruption style (Kereszturi et al., 2014, 2017). |
| Scenario G: Rangitoto Channel | ● Proximity to shipping channel.<br>● Environmental conditions most likely to allow for Surtseyan style eruptive activity (Agustín-Flores et al., 2015b). |
| Scenario H: Rangitoto Island | ● Proximity to most recent site of an AVF eruption, potentially important to consider event clustering.<br>● Environmental conditions conducive to hybrid eruption style (Kereszturi et al., 2014, 2017). |

- Focus on possible impacts
- Geographic spread
- 'Everyone gets to play'

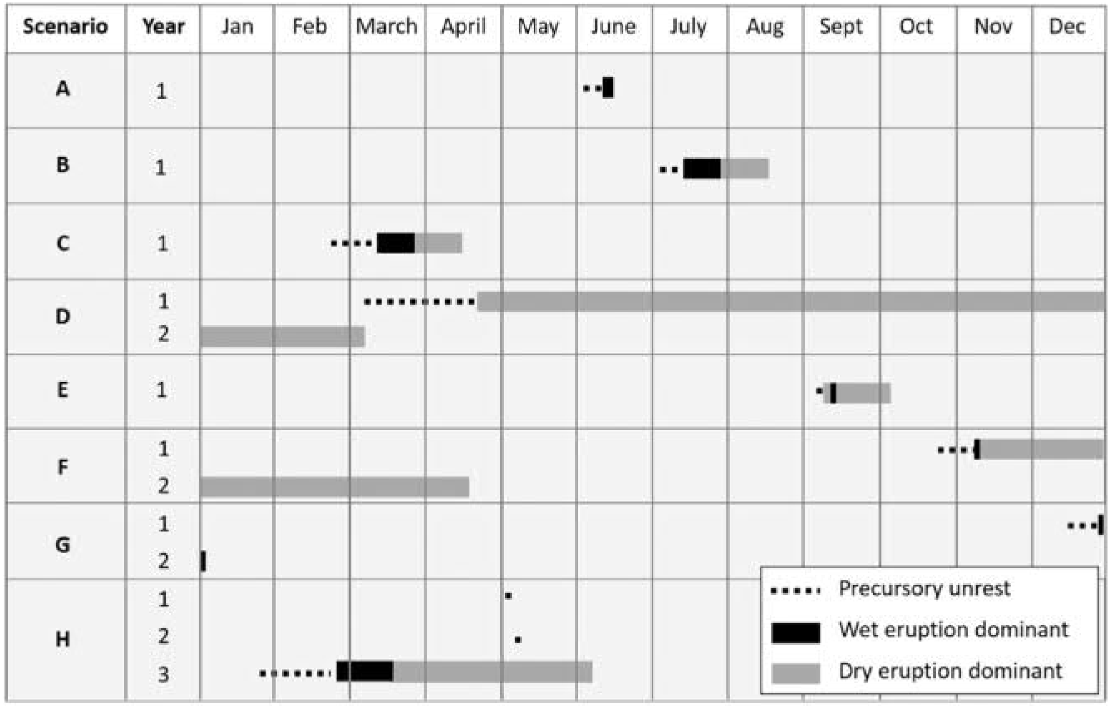
# Eight DeVoRA Scenarios: Hazards

(Hayes et al. 2020)



# ‘Wet’ (Phreatomagmatic) and ‘Dry’ (magmatic) styles

| Scenario | Location | Eruption Style |
|---|---|---|
| A | Auckland Airport | Phreatomagmatic |
| B | Otahuhu | Phreatomagmatic → Magmatic |
| C | Māngere Bridge | Phreatomagmatic → Magmatic (Offshore) |
| D | Mt Eden Suburb | Magmatic |
| E | Waitematā Port | Magmatic → Phreatomagmatic |
| F | Birkenhead | Phreatomagmatic → Magmatic |
| G | Rangitoto Channel | Surtseyan (Offshore) |
| H | Rangitoto Island | Phreatomagmatic → Magmatic |




Wet hazards

- PDC (Surge)
- Tuff Ring
- Tephra
- Ballistics

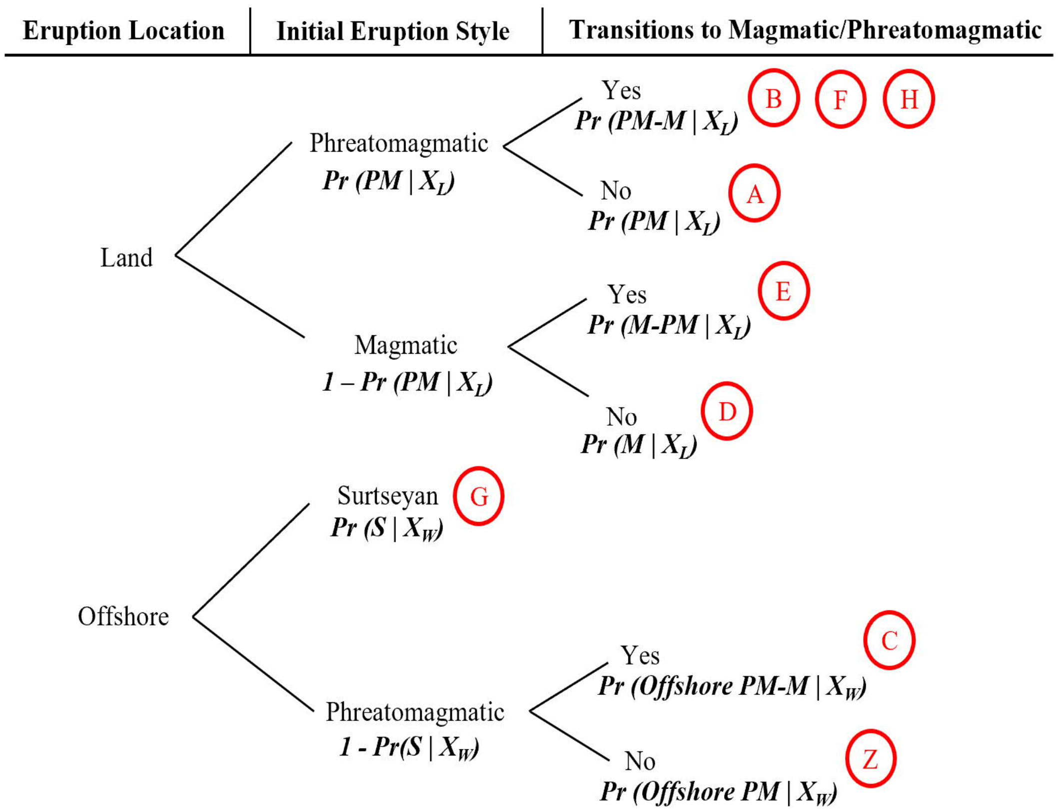
Dry hazards

- Lava
- Scoria Cone
- Tephra
- Ballistics

# Probability tree for location-dependent scenario probability

- Probabilities are conditional:
  - The likelihood of the first style is location dependent
    - Different branches are used for on-shore and off-shore, as the possibilities differ
  - The likelihood of a style transition depends on location and the original style

- Need to add a nominal 9th scenario:
  - Z: Purely phreato-magmatic offshore



# Filling in the probabilities

- Kereszturi et al. (2017) calculated the present day probabilities (Q) of a phreato-magmatic to magmatic transition

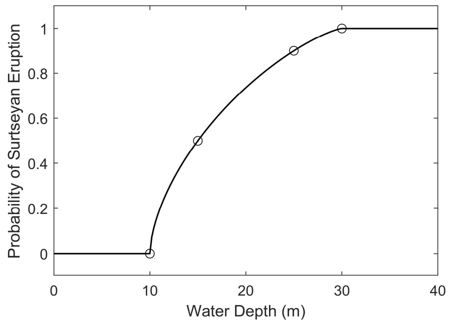
$$\log\frac{Q}{1-Q} = -0.694\sqrt{\bar{A}} + 1.908\log D_f - 10.74\, I_H V_{ph}^{-0.25}(z+5)^{-0.5}$$
$$-2.675\,(1 - I_H)V_{ph}^{-1} - 0.0226\,(1 - I_H)\exp(T_S / 10)$$

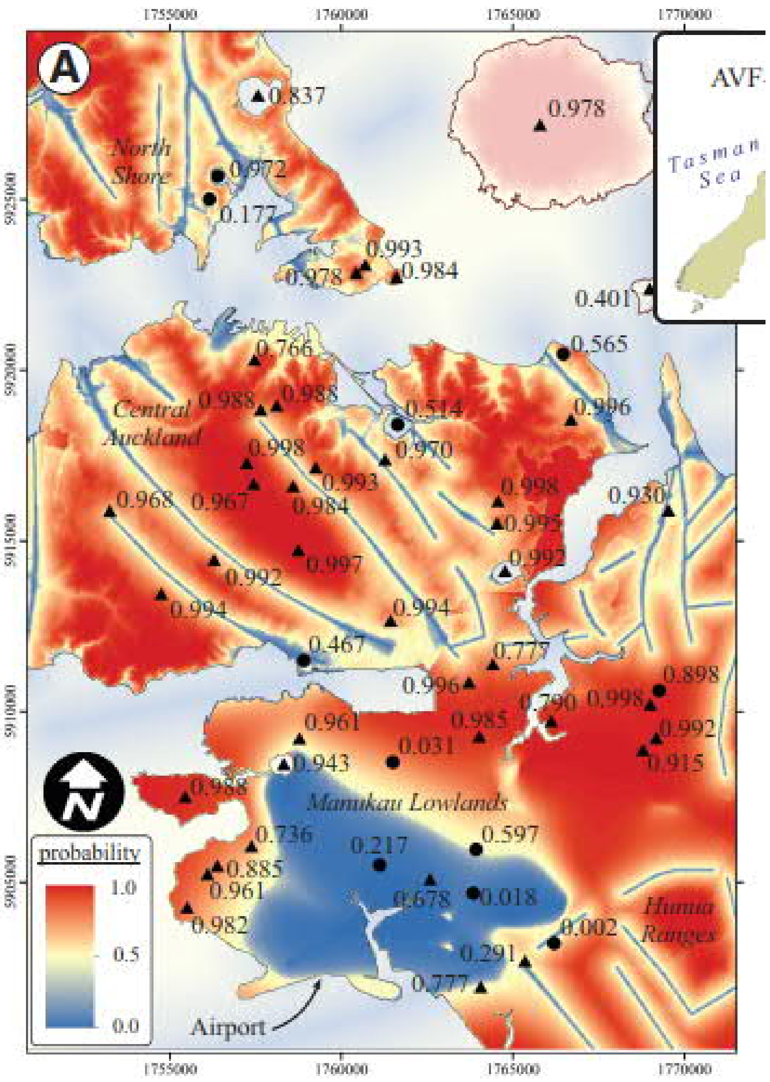
- A similar analysis gives probabilities (P) for an initial phreato-magmatic phase

$$\log\frac{P}{1-P} = -0.045\,z + 1.17\,T_S^{\,0.25} + 0.227\, I_H \log(D_f)$$

- The probability of a Surtseyan event was calculated by fitting a beta function to elicited probabilities

| Water depth (m) | Probability of Surtseyan eruption |
|---|---|
| 10 | 0 |
| 15 | 0.5 |
| 25 | 0.9 |
| 30 | 1 |



# A couple of curlicues

- A magmatic to phreato-magmatic transition was assumed if the vent intersects a large body of water
- Several scenarios (B,F, and H) are all characterized by phreatomagmatic-magmatic transitions.
  - To apportion probabilities between these, we used the likelihood of total scenario volume dependent on location from Bebbington (2015) as weights

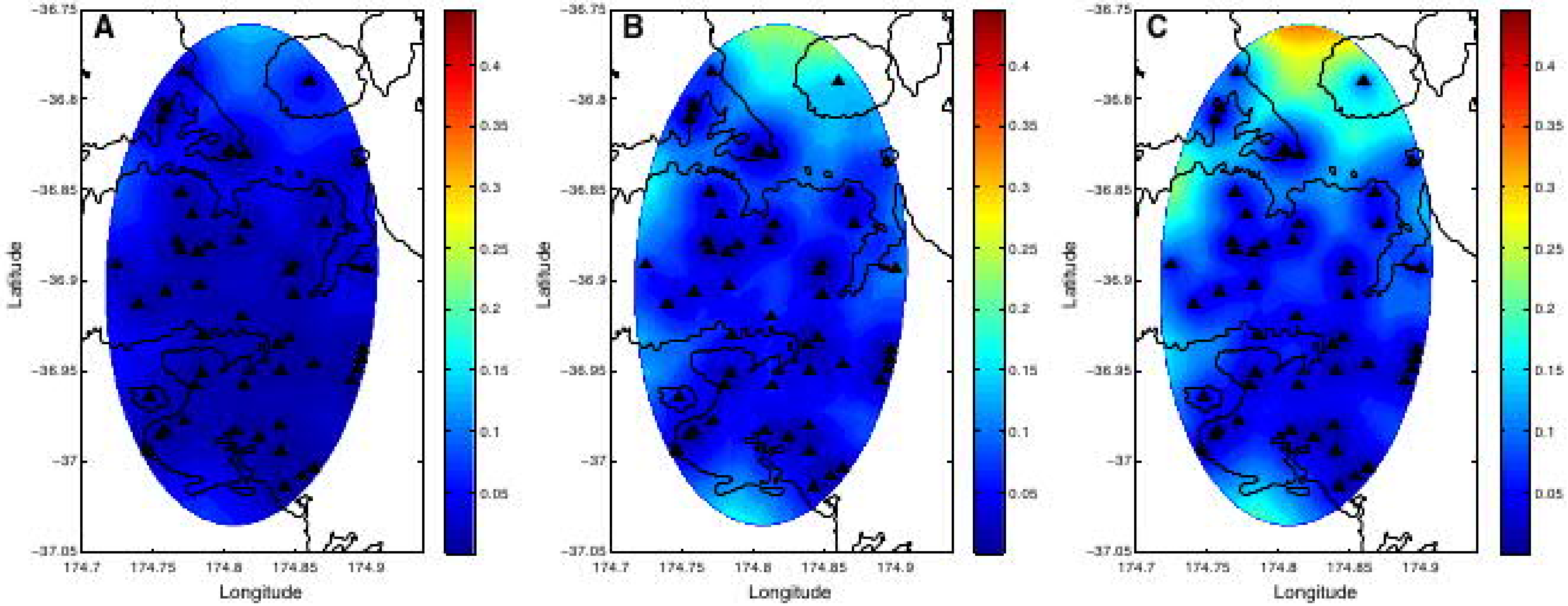
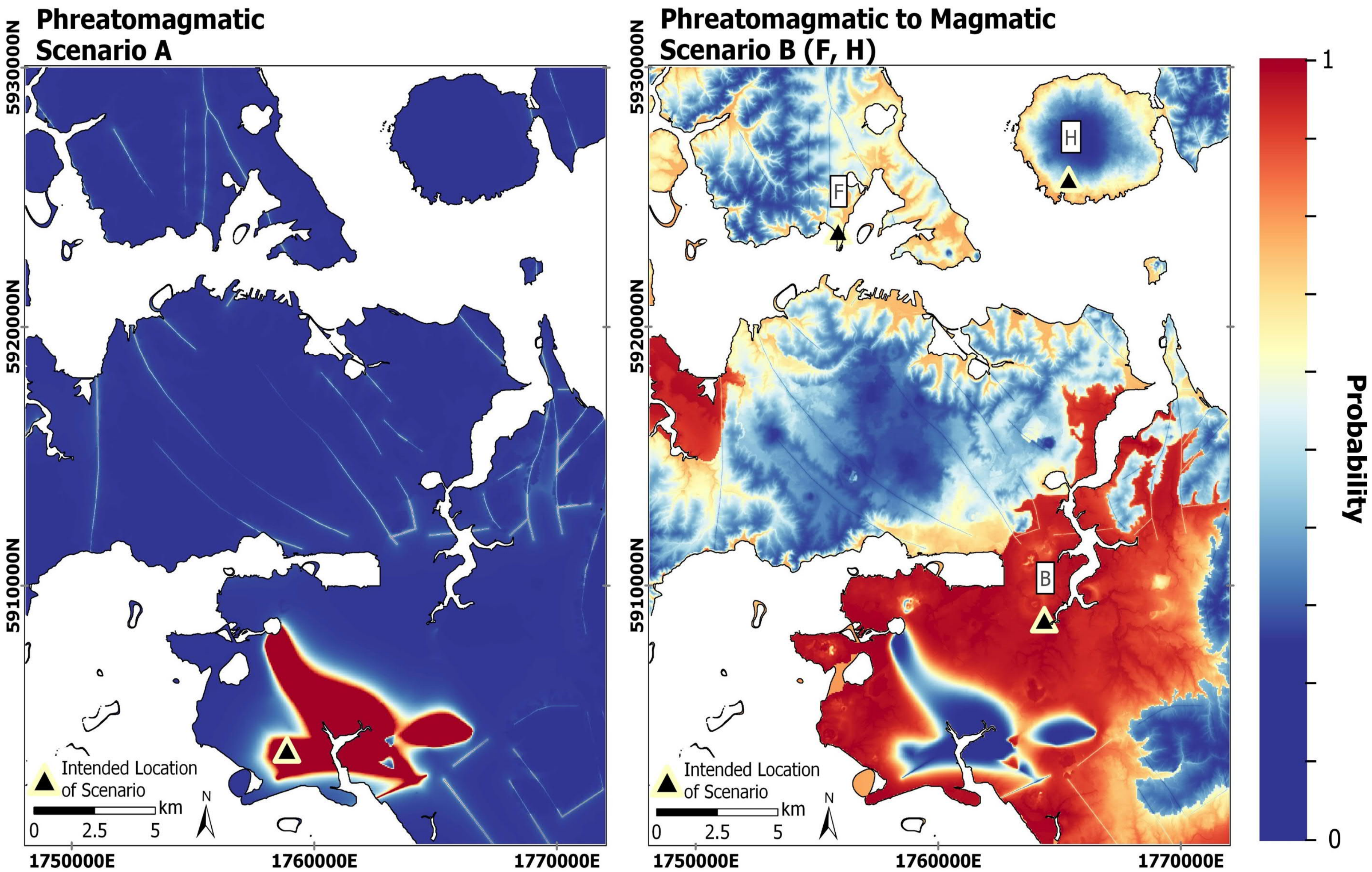


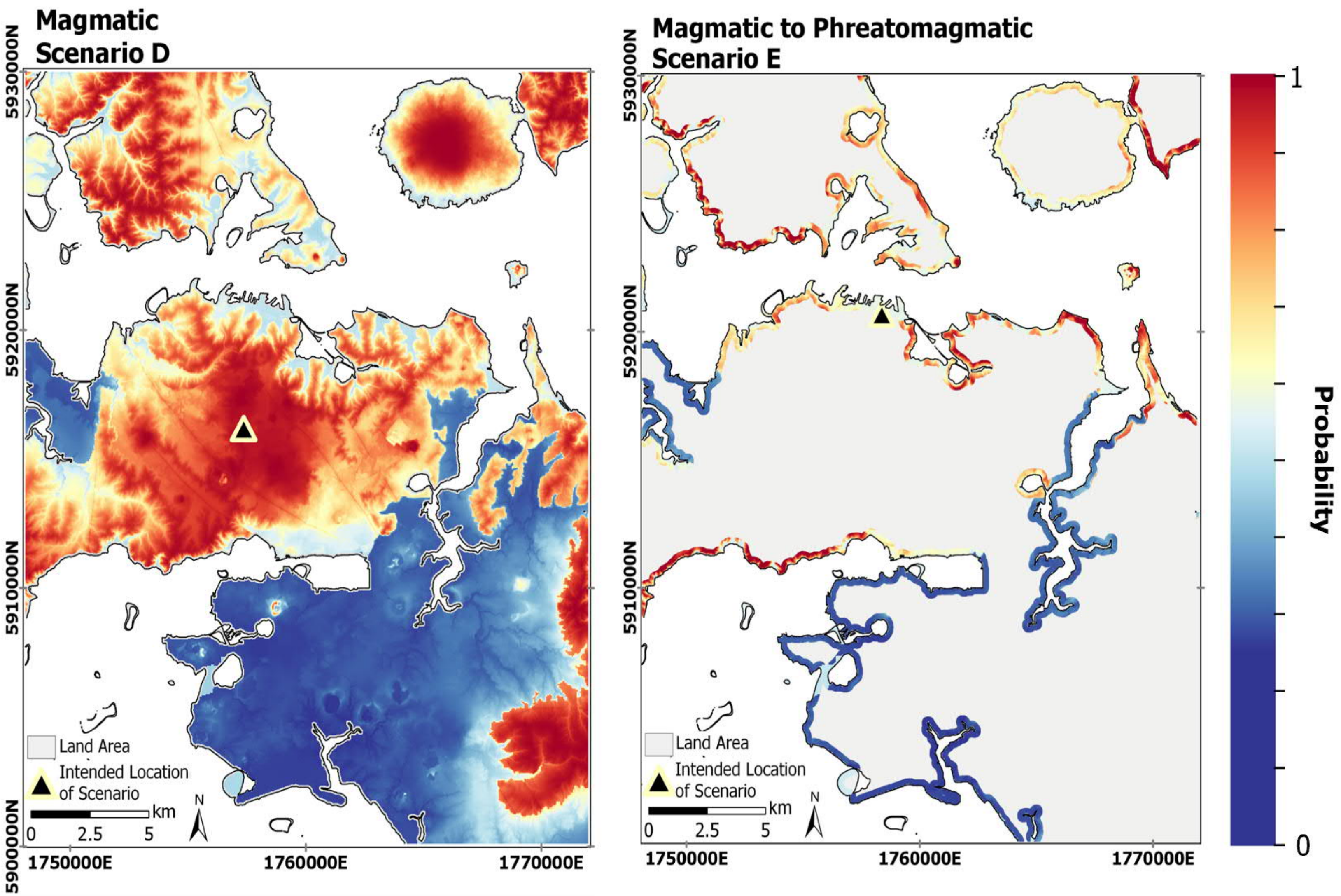

**Fig. 9** Spatial variation in the forecast volume (in $km^3$) distribution. **a** Mean, **b** standard deviation, **c** 90th percentile

# Results 1



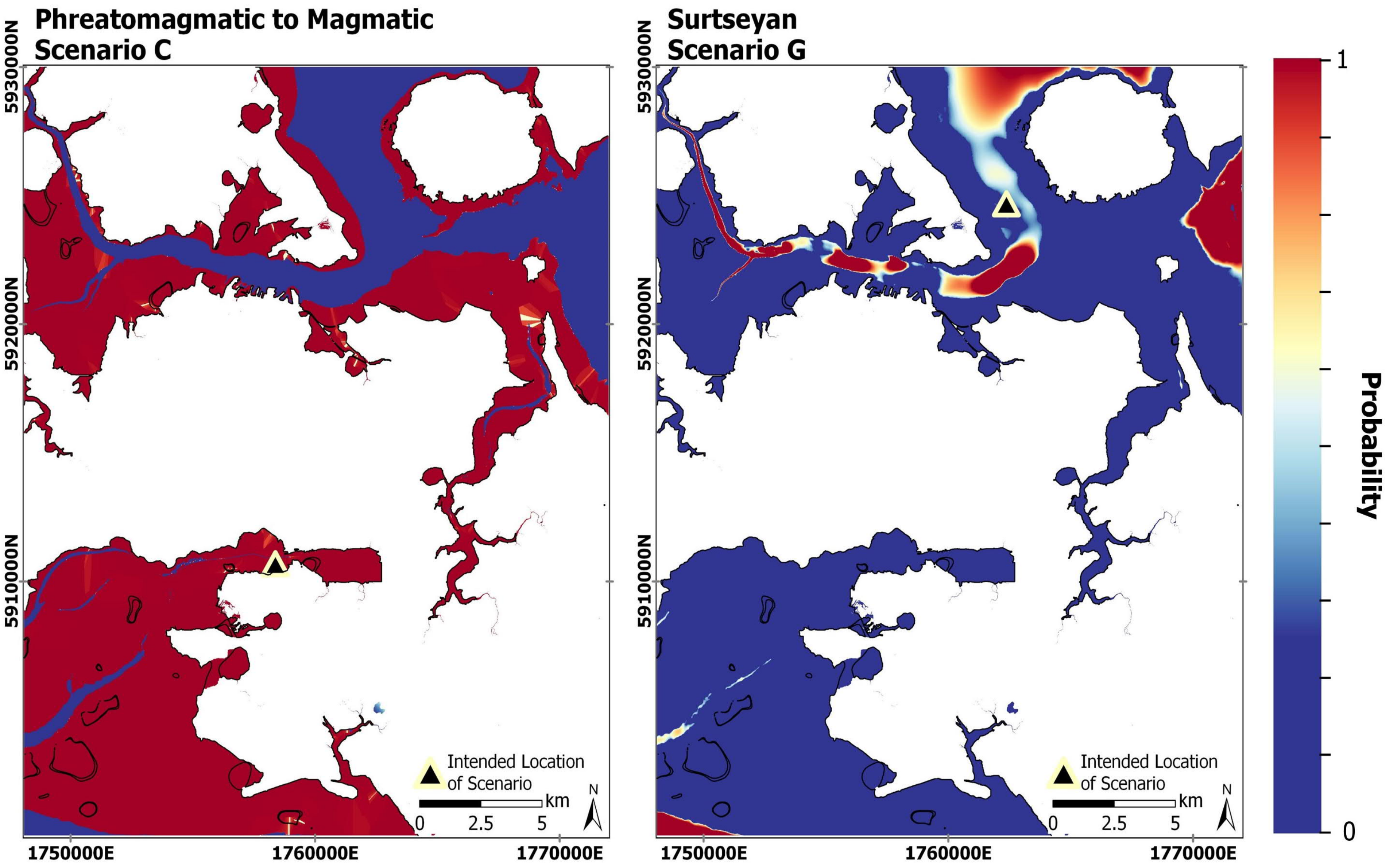
Phreatomagmatic
Scenario A
Phreatomagmatic to Magmatic
Scenario B (F, H)
5930000N
5920000N
5910000N
1750000E
1760000E
1770000E
F
H
B
Intended Location
of Scenario
km
0
2.5
5
N
Probability
1
0

# Results 2



Magmatic
Scenario D
Magmatic to Phreatomagmatic
Scenario E
5930000N
5920000N
5910000N
5900000N
1750000E
1760000E
1770000E
Land Area
Intended Location of Scenario
km
0
2.5
5
N
Probability
1
0

# Results 3




Scenario Z (offshore phreatomagmatic) not shown

# AVF Risk Recipe

(thanks to Tom Wilson / Rebecca Fitzgerald)

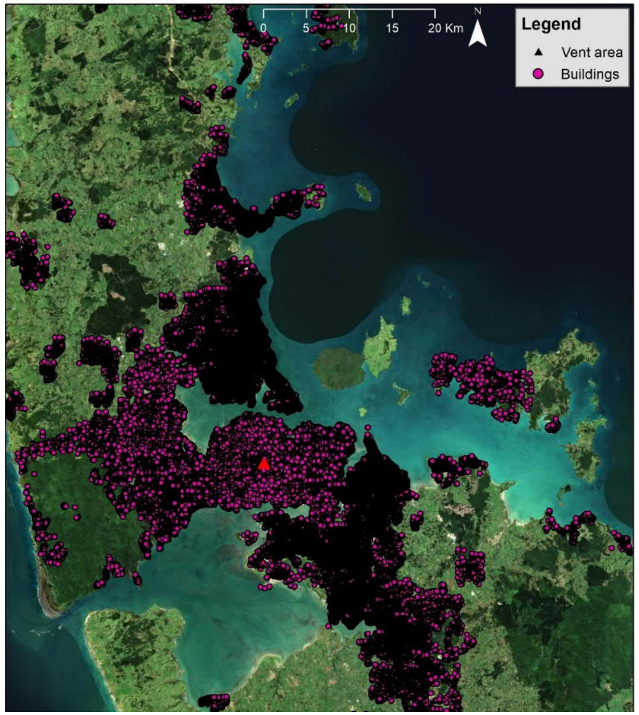
## Hazard

- Complex multi-hazard eruptions of indeterminate duration
- Strong influence of environment effects on hazard impact

## Vulnerability

- how to address cascading & compounding impacts?

## Impact/Risk




## Exposed Elements

- Large urban environment c. 526,500 buildings of diverse type and usage in Auckland (2013 data)

# Scenario D: Timeline / Impacts

VOLCANIC ACTIVITY

MINOR EXPLOSIVE ERUPTION (HAWAIIAN)

MINOR EXPLOSIVE ERUPTION (STROMBOLIAN)

EFFUSIVE LAVA FLOWS

UNREST

MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | JAN | FEB | MAR

2020 | 2021

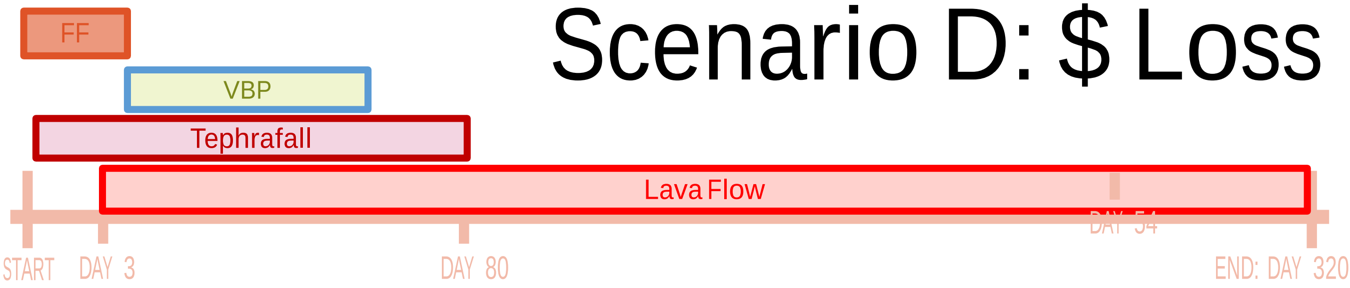
HAZARDS

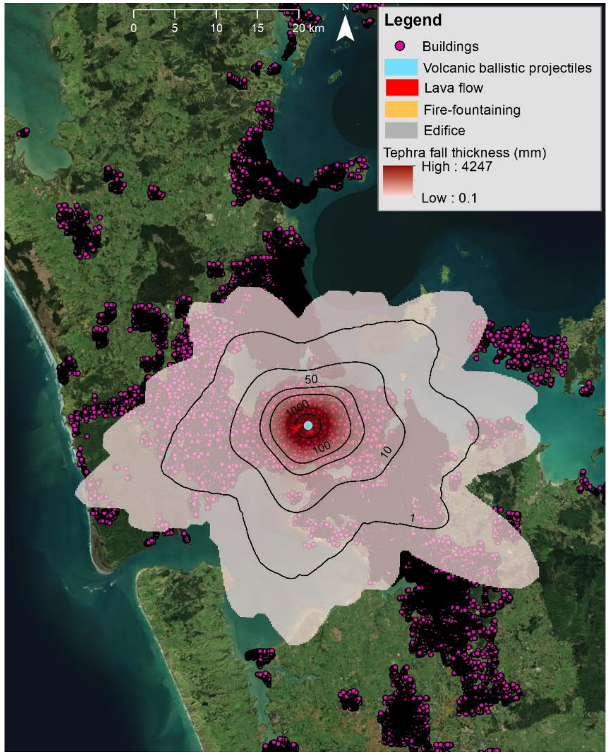
APR: Ash fall; LAVA; Fire-fountaining

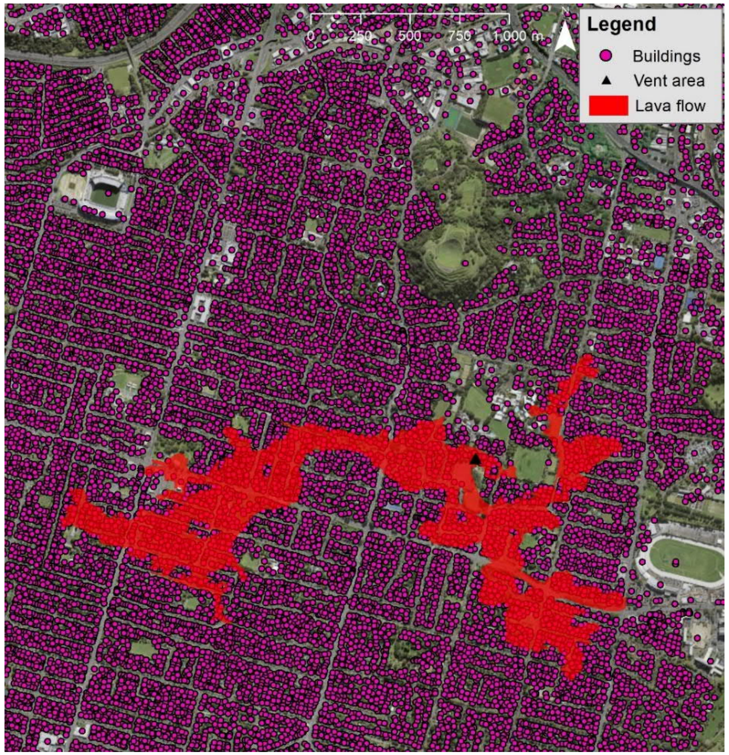
JUN: Ash fall; VOLCANIC BALLISTIC PROJECTILES; LAVA

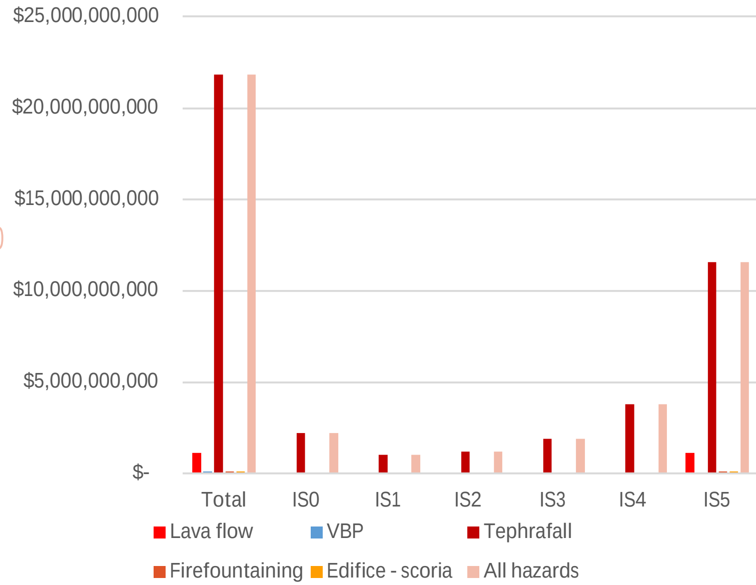
NOV: LAVA

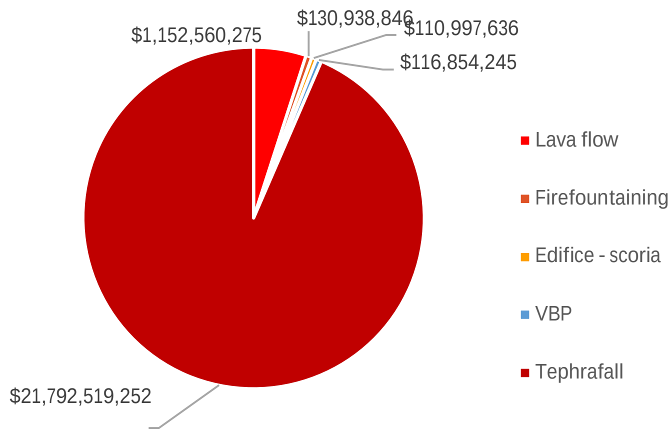
# Scenario D: $ Loss



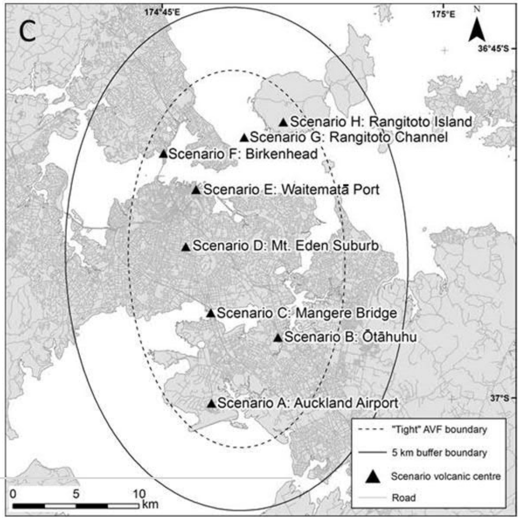



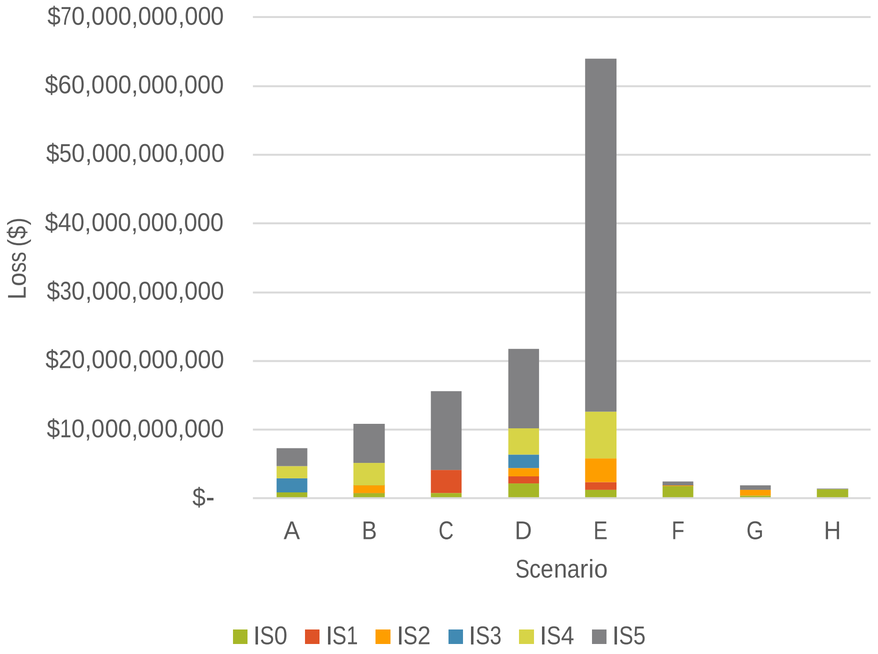



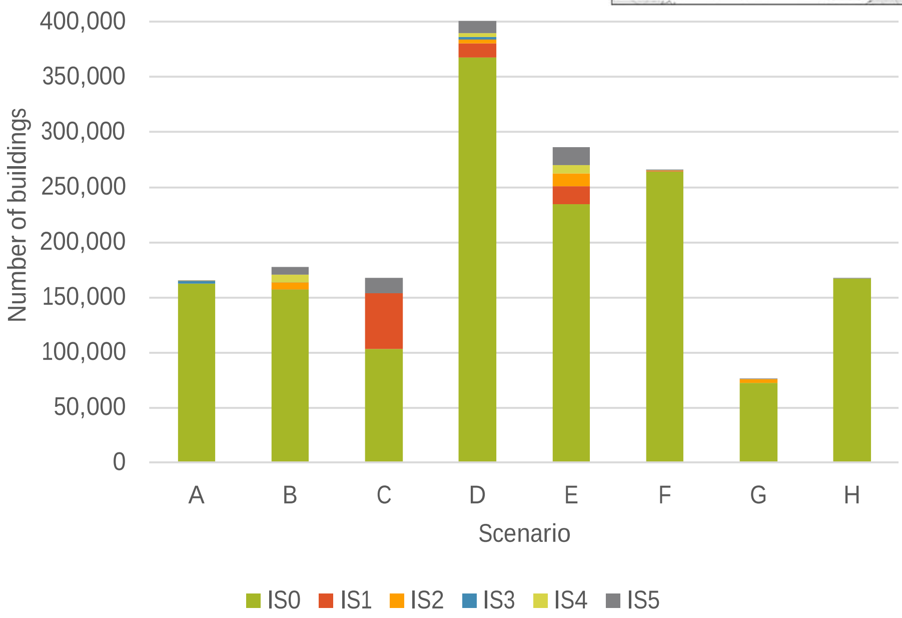



# Modelled Scenario Loss Summary
# … from a single vent location



# Next Steps

Eruption Location -> Eruption Styles -> Eruption Impacts

- Eruption location has been modelled by (e.g.) Bebbington and Cronin (2011), Bebbington (2013, 2015)
- This work presents a model for the eruption given the location, and for damage given the model at one location.
- For a probabilistic assessment, we need to simulate hazards from each scenario on a dense location grid, and weight the results by the scenario likelihoods
  - Ashfall is relatively simple, as we just need to translate the entire thing spatially without recalculation
  - Flow hazards are more difficult
    - Because we will need to calculate on a dense grid, a computationally simple scheme is recommended
    - Any misfit resulting from the choice of a simple scheme should be insignificant in the context of the location uncertainty and the discretization into scenarios

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