Fragility functions for buried pipelines in liquefaction-prone areas based on Canterbury earthquake sequence data

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Motivation

This poster aims to present fragility functions for pipelines buried in liquefaction-prone soils. Existing fragility models used to quantify losses can be based on old data or use complex metrics. Addressing these issues, the proposed functions are based on the Christchurch network and soil and utilizes the Canterbury earthquake sequence (CES) data, partially represented in Figure 1. Figure 1 (a) presents the pipe failure dataset, which describes the date, location and pipe on which failures occurred. Figure 1 (b) shows the simulated ground motion intensity median of the 22nd February 2011 earthquake. To develop the model, the network and soil characteristics have also been utilized.

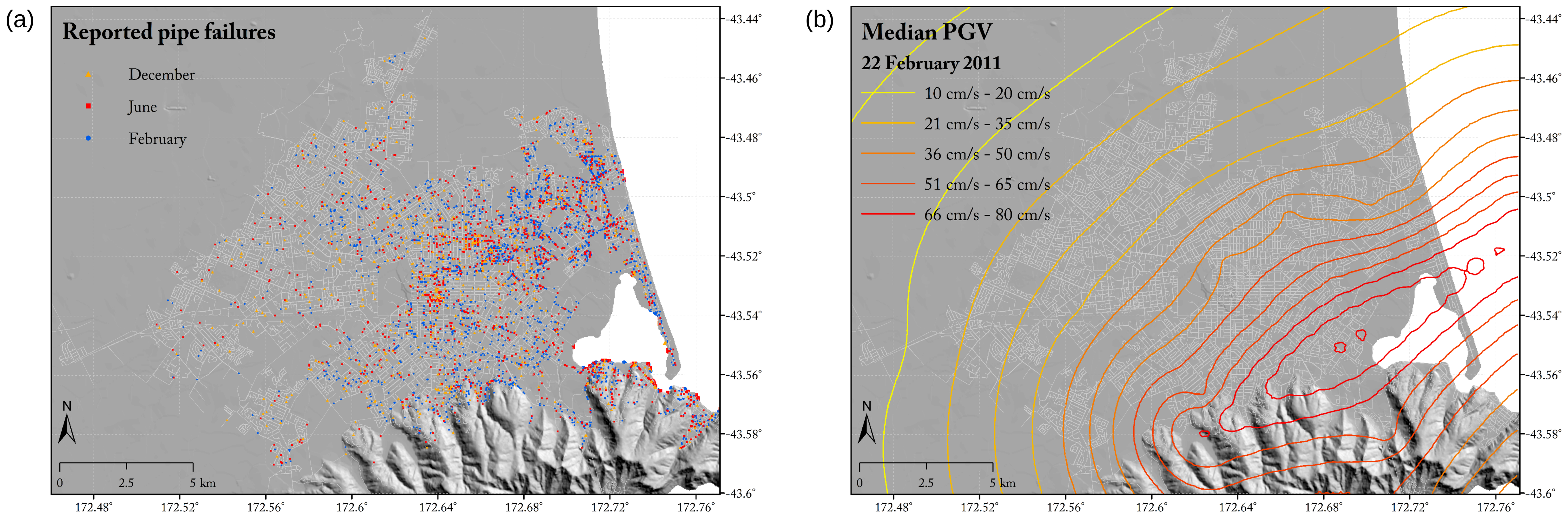

Figure 1: Data used to develop the model (a) Reported pipe failures after the 2011 February, June and December earthquakes; and (b) Simulated ground motion for the 2011 February earthquake

Pipeline fragility and vulnerability models

In total, 63 different vulnerability functions have been developed. Figure 2 shows some of the developed functions. On Figure 2 (a), ductile pipes show a drastically smaller seismic vulnerability than brittle ones. Regardless of their ductility, pipes laying in a ground with a high cyclic resistance ratio (CRR) value experience smaller failure rates as shown in Figure 2 (b-d). The proposed vulnerability model is additive (i.e. adapts the vulnerability of the studied asset based on known characteristics). The peak ground velocity (PGV) is used as intensity measure in the backbone function f_0. Other model inputs C_i are the pipe material ductility, the pipe material, the pipe diameter and the CRR. Unknown characteristics increase the model uncertainty ϵ. This allows the proposed model to be applied even using partial information. Equation 1 gives the fully-developed vulnerability model.

$$\ln(FR) = f_0(PGV) + \sum_{i=1}^{N} C_i + \epsilon \quad (1)$$

A fragility function defines the probability that a certain damage state is reached given some ground motion intensity. Failure occurrence is assumed to follow a Poisson distribution. Hence, the fragility depends on the known length of the asset and its vulnerability.

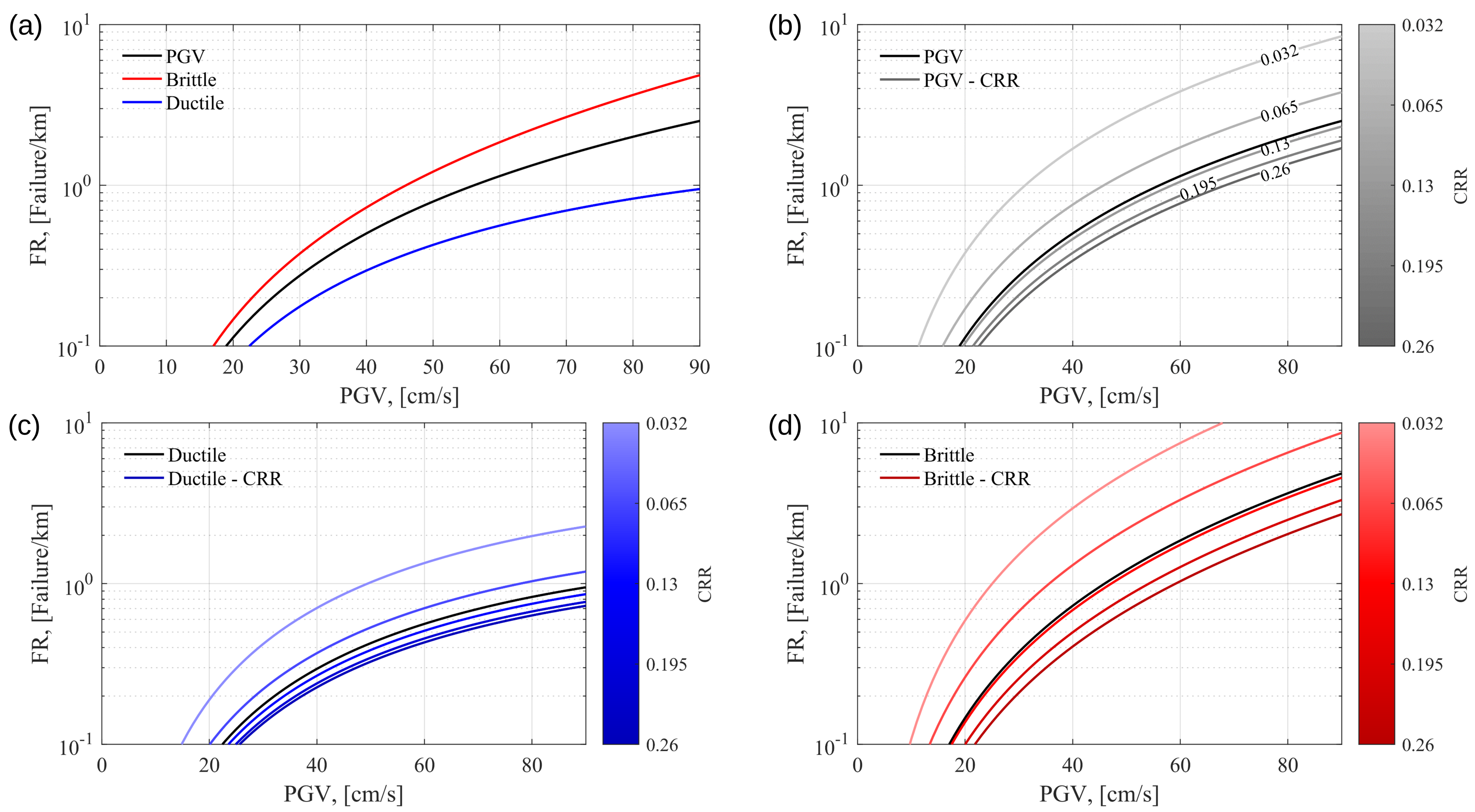

Figure 2: Vulnerability functions depending on PGV, CRR and pipe material ductility

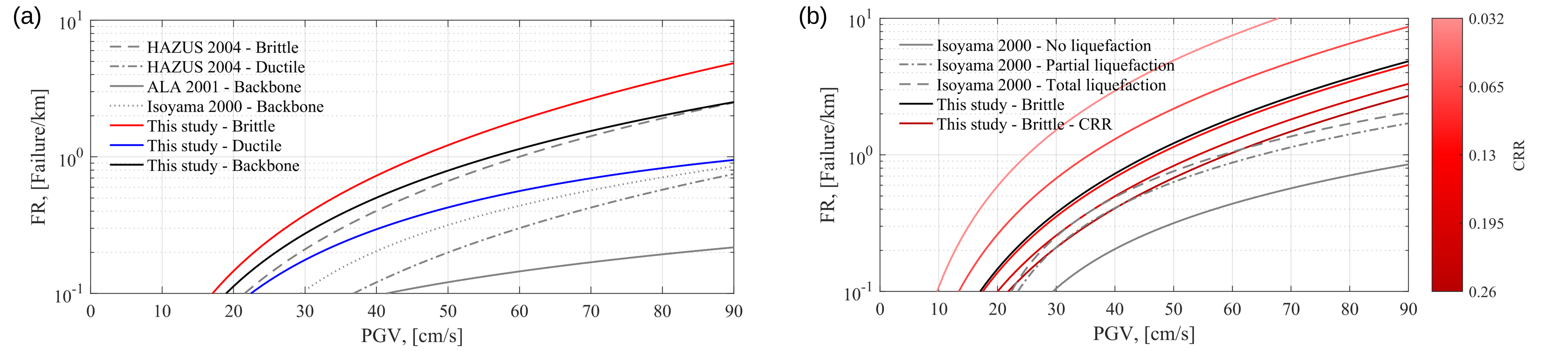

Figure 3: Comparison with existing vulnerability functions (a) CRR-independent ; and (b) CRR-dependent

Comparison with existing PGV-based vulnerability models

Figure 3 presents the vulnerability function comparisons. For similar pipe characteristics and for both CRR-independent and CRR dependent functions, the proposed model returns higher vulnerability. The models selected for comparison use PGV as intensity measure. The HAZUS (FEMA, 2004), ALA (2001) and Isoyama (2000) models are compared with the ductility-dependent and CRR-independent functions. Only the Isoyama (2000) model is compared with the ductility-dependent and CRR-dependent functions. The HAZUS (2004) and ALA (2001) models have permanent ground displacement vulnerability functions. These generally yield greater vulnerability.

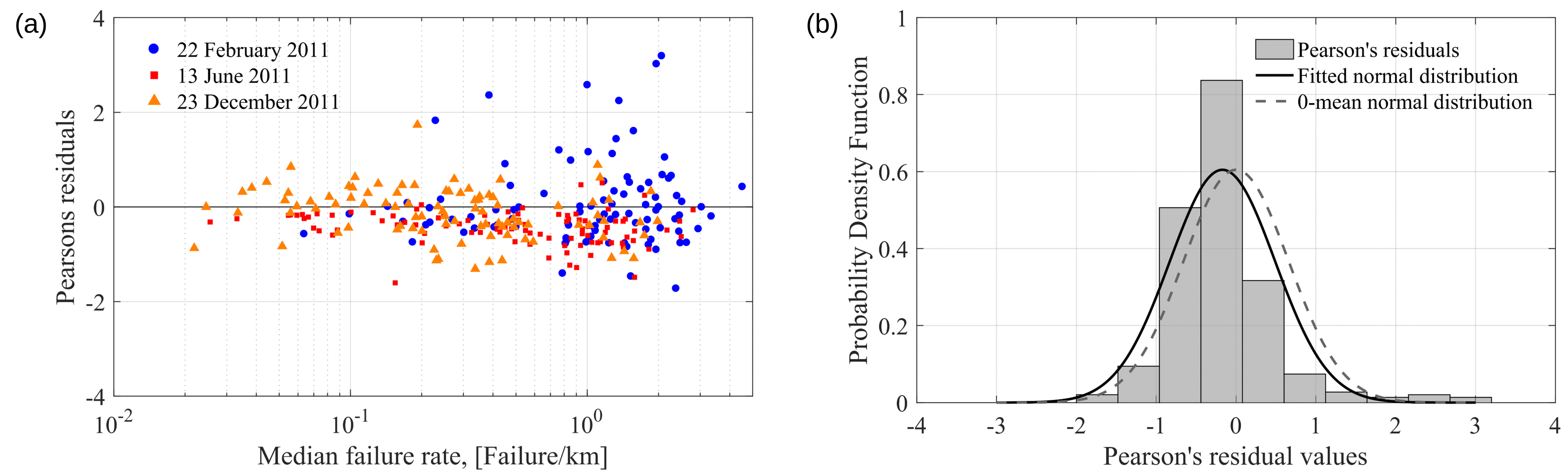

Figure 4: Statistical analysis of the Pearson's residuals (a) Plotted against the simulated median failure rate ; and (b) Presented as an histogram

Statistical significance and performance of the model vs. the 22nd February 2011 earthquake damage

Figure 4 shows the statistical significance analysis of the model as a scatter plot of Pearson's residuals against the simulated failure rates as well as their distribution. The model has a small negative bias and tends to be slightly heteroskedastic. Figure 5 geospatially shows the results for the 2011 February event. It can be observed that the simulated failure rates tend to underestimate the failure rate in areas along the Avon river. Known as the *Red Zone*, these areas possess a very low CRR and experienced severe lateral spreading. To obtain these results, fragility functions were tested in a Monte-Carlo simulation (MCS) scheme using the 2011 February, June and December simulated ground motions. The network is split in areas representing the SCIRT repair catchments.

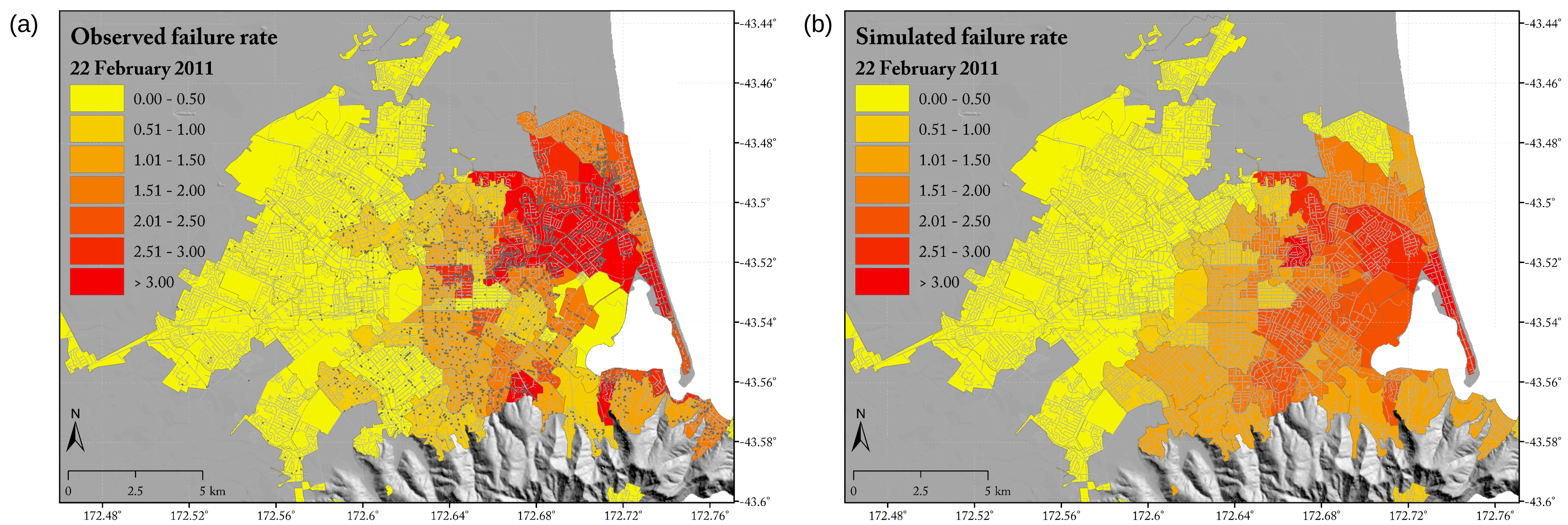

Figure 5: Retrospective analysis comparing (a) Observed ; and (b) Simulated failure rates for the 2011 February earthquake