Guidance on the utilization of earthquake-induced ground motion simulations in engineering practice

Guidance document structure

Document contents (draft)

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Focus of earlier presentations/ discussions today

Focus of this session

Verification, validation, and utilization documentation

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Verification:

- Verification is the assessment of the accuracy of the solution of the computational model.
- To ensure that there are no programmatic errors (i.e. bugs) in the code that implements the methodology, and also that the numerical methods are suitable for the problem being considered (i.e. they converge).
- Obvious means by which to verify a computational algorithm are via comparison with known (analytical solutions), where not possible then against benchmark solutions

Verification, validation, and utilization documentation

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Validation:

- Validation is assessment of the accuracy of a computational simulation of reality as measured using experimental observations
- Unlike verification, which is a computer science and mathematical modelling problem, validation is a physics problem – does the conceptual model actually provide a realistic representation of reality?
- Because earthquake-induced ground motions naturally involve a multi-faceted array of physical processes then ground motion simulation validation (GMSV) should occur in a hierarchical fashion

Verification, validation, and utilization documentation

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Utilization documentation:

In addition to information on V&V, there are several additional pieces of information to provide transparency (and potentially reproducibility), these are:

- Specifics of the earthquake rupture(s)
- Computational domain (size and spatial discretization of the 3D crustal model)
- Temporal discretization
- Version number for the software algorithm, crustal model and rupture generator. Locations/sources of archived software and data.
- Specific computational resource(s) that the simulations are performed on, the number of compute cores that have been utilized, and the required CPU hours to perform the simulations.

Verification, validation, and utilization documentation

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Focus for the workshop discussion is on validation

- Simulated ground motions will never perfectly match observations, so what is the 'acceptable' level?
- My opinion: Performance better than empirical models relative to observational data (i.e. better = lower bias, higher precision)

Validation matrix

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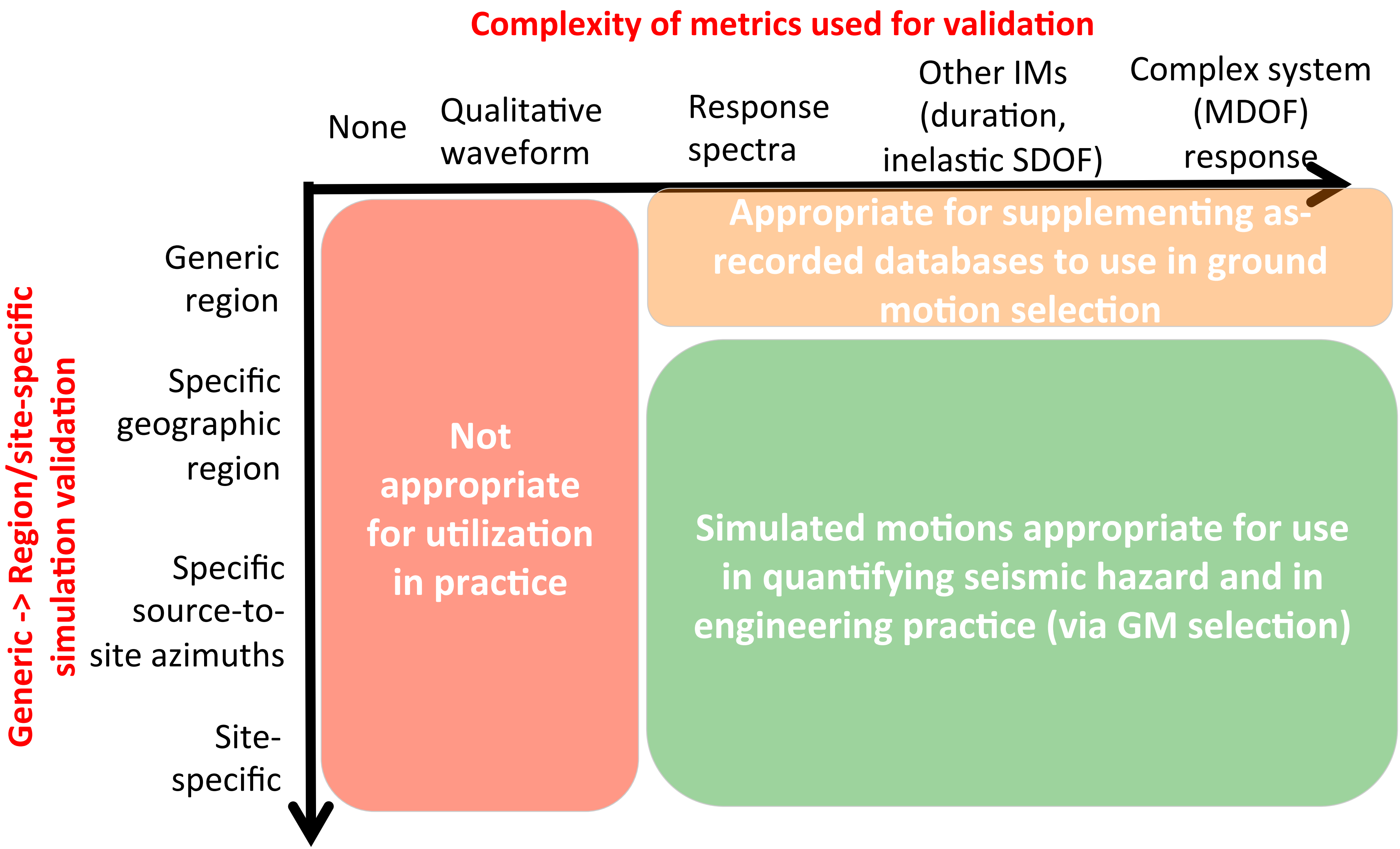
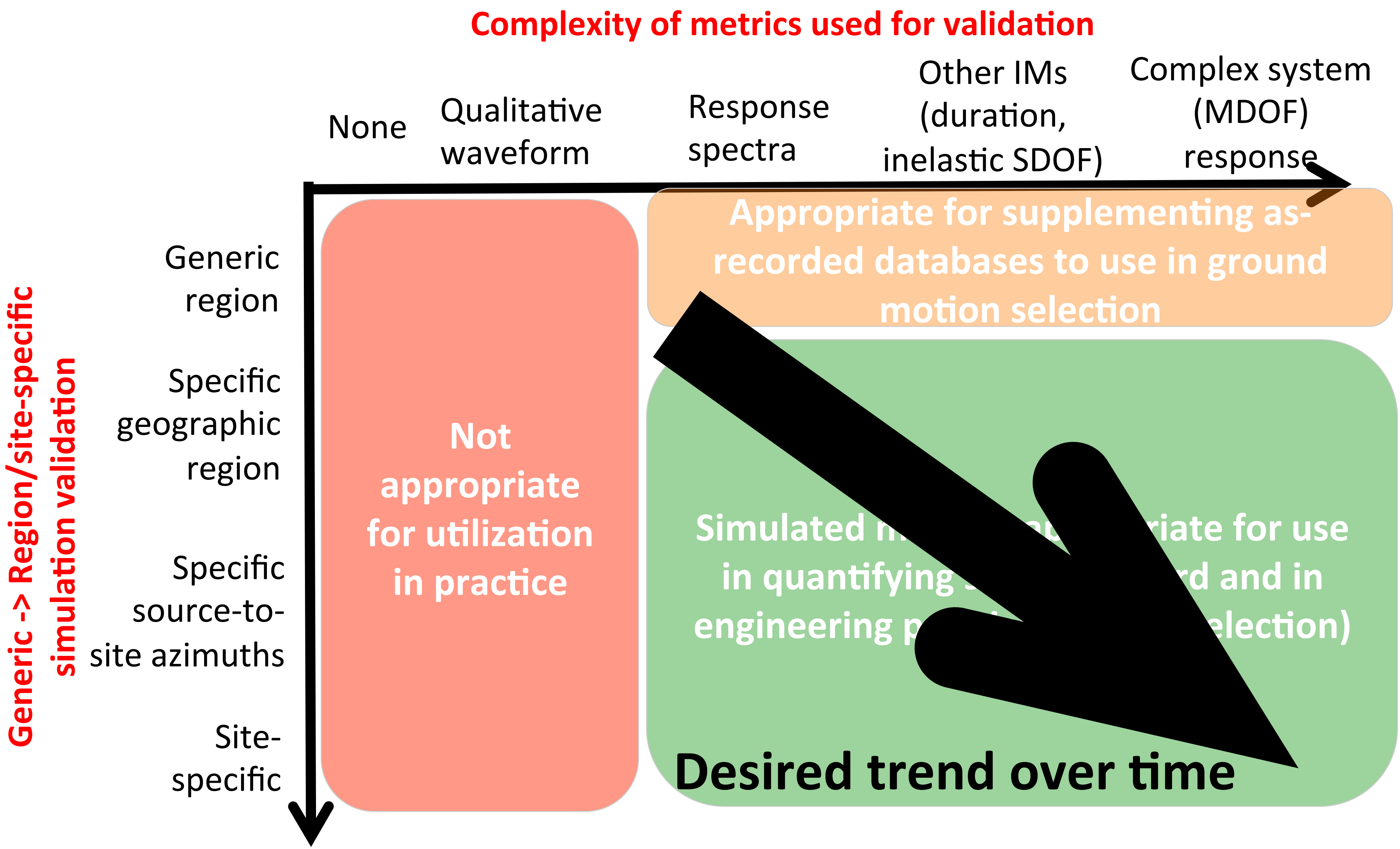


Validation matrix



draft wording (outdated)

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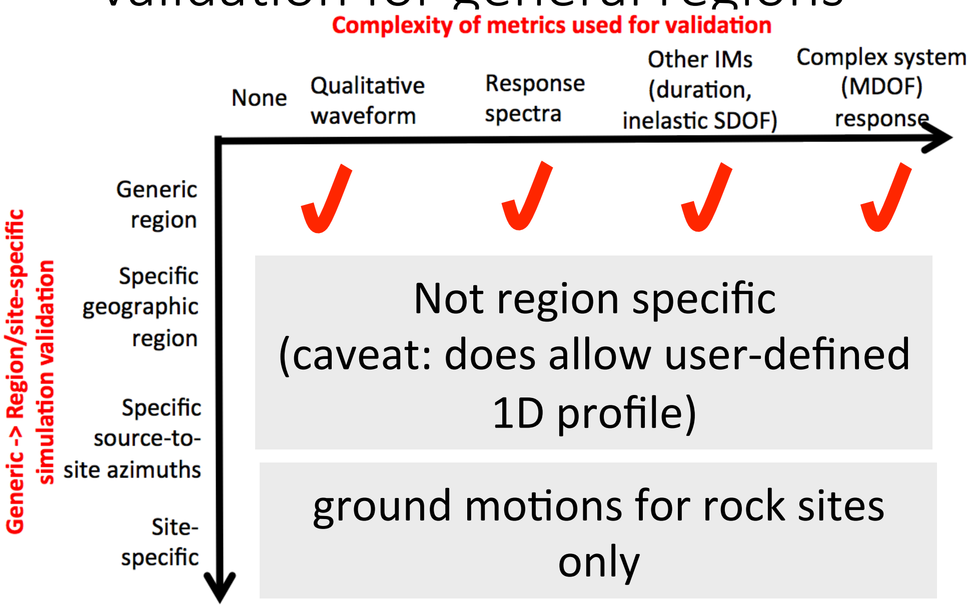
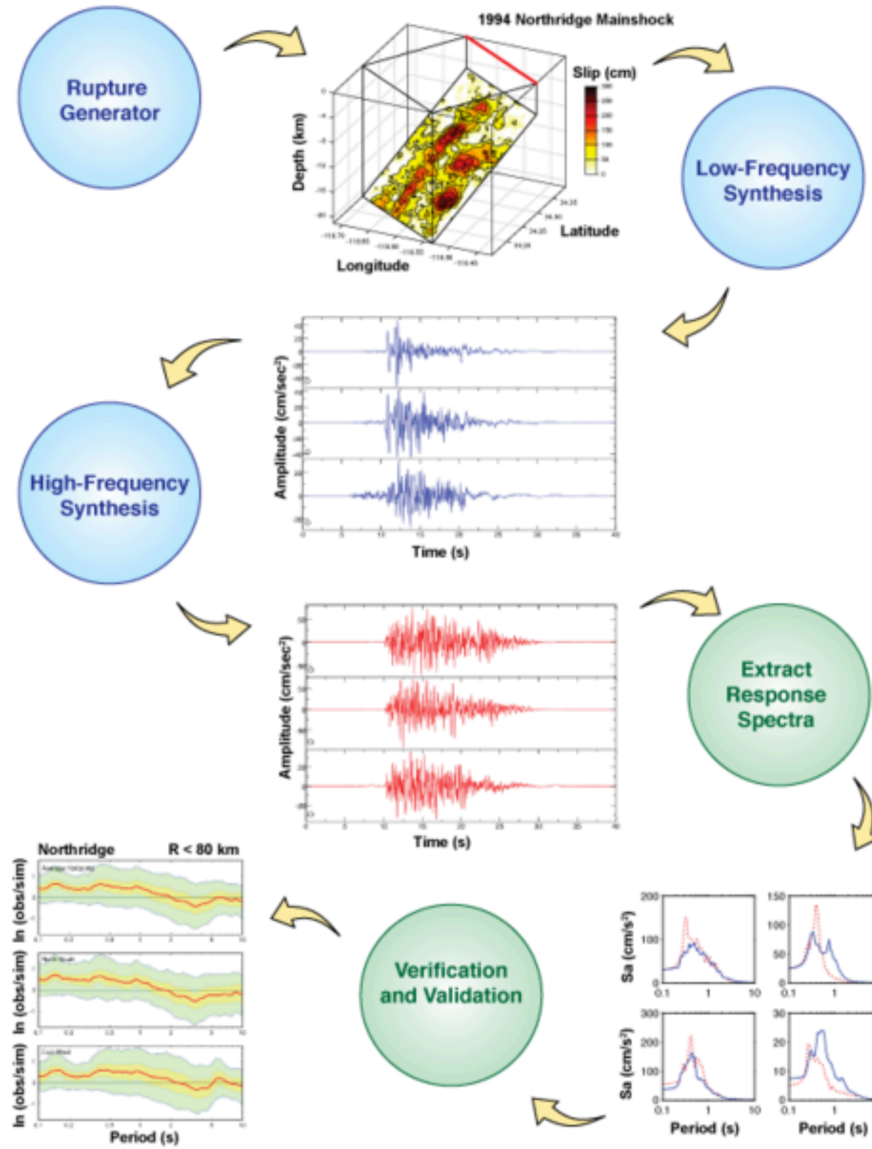
In the context of ground motion simulation, the multi-hierarchical nature of validation can be performed in the following contexts:

1. Validation of the 'general' ground motion simulation methodology against relevant worldwide historical earthquakes (validation of the methodology in general)
2. Validation of the methodology for earthquakes of a magnitude similar to that expected from the rupture to be considered (validation of the earthquake rupture generator)
3. For the particular geographical region in question, validation of the simulation method against observations from regional earthquakes (validation of the regional crustal model)
4. For the particular fault rupture considered, validation of the simulation method for small-to-moderate magnitude earthquakes in the vicinity of the fault of interest (validation of the regional crustal model for the specific wave propagation paths from the source to the sites of interest)
5. If explicit site response analyses are utilized, then appropriate validation of the adopted constitutive models should also have been considered (i.e. the equivalent of points 1-4 specifically for site response).
6. Validation metrics by which the simulated and observed ground motions are compared including: elastic response spectral ordinates over a broadband period range, inelastic-to-elastic spectral displacement ratios, significant duration, directionality of orientation-dependent spectra, and inter-period spectral ordinate correlations (validation via metrics which provide insight into the realism of the simulated ground motions for use in nonlinear inelastic response history analyses).

Case study 1: Ground motions from SCEC Broadband Platform

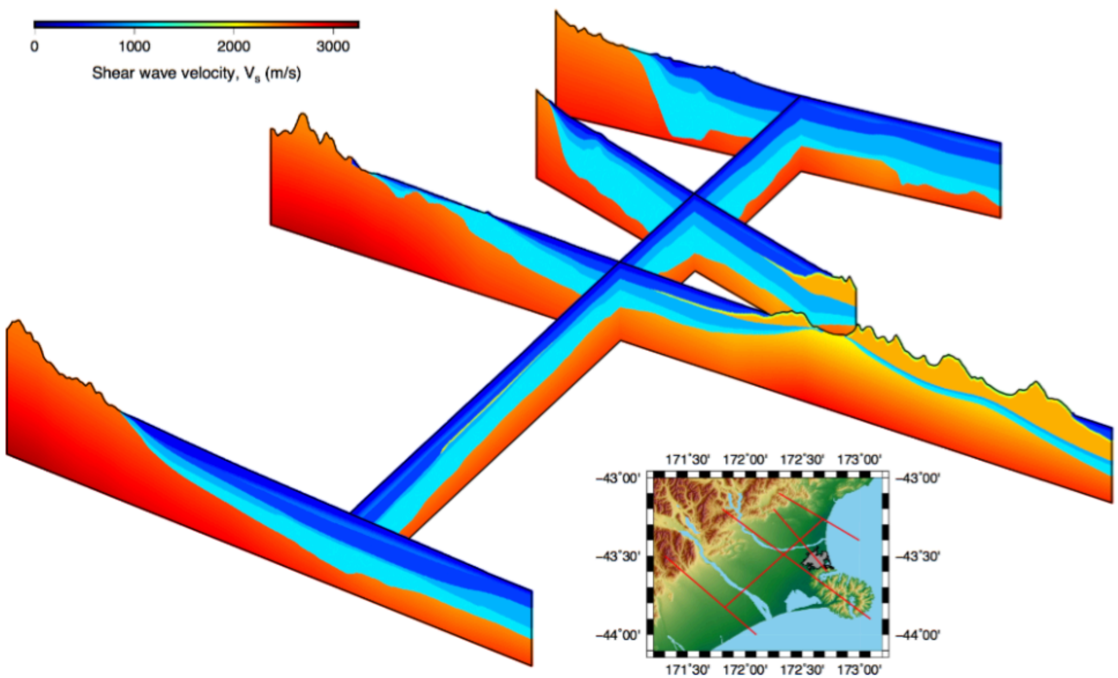
- An open-source platform providing simulated ground motions for general 1D velocity models
- 4 methodologies available, all of which have had significant validation for general regions

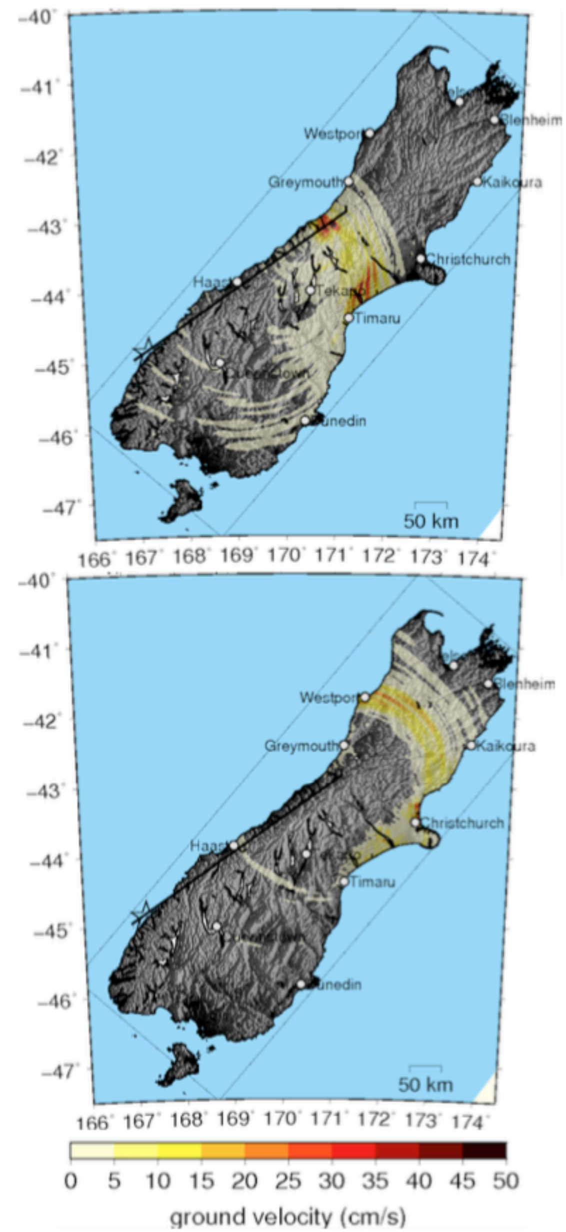




Case study2 : Simulation of major Alpine fault earthquakes for Canterbury

<u>Situation:</u> There are few precedents for prediction of ground motions in Canterbury from a large Alpine fault earthquake





Case study 2: Simulation of major Alpine fault earthquakes for Canterbury

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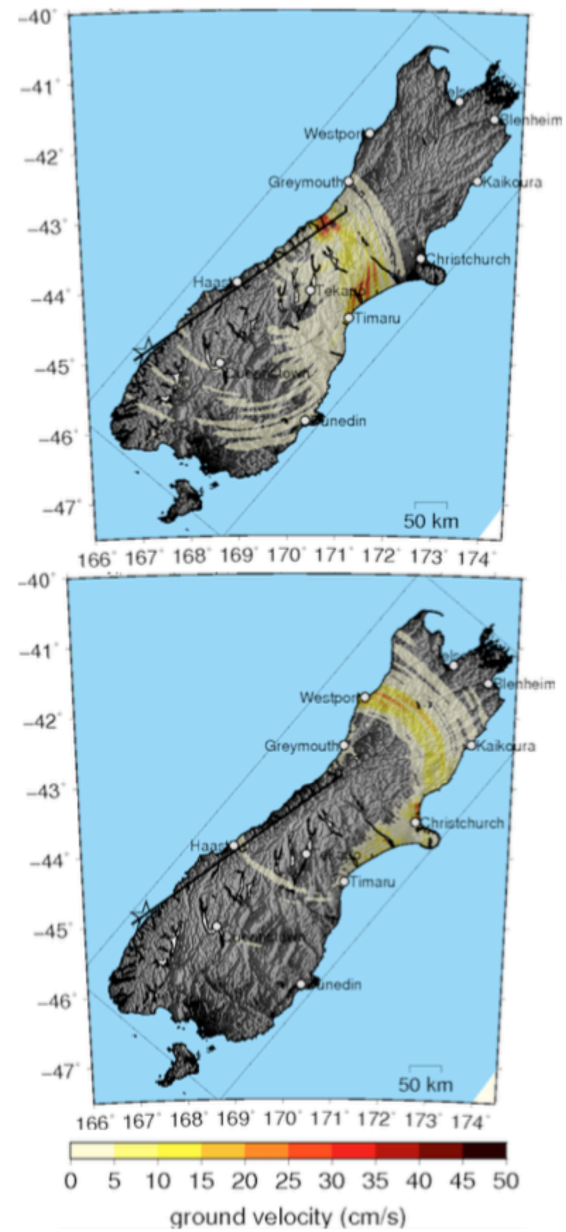
<u>Situation:</u> There are few precedents for prediction of ground motions in Canterbury from a large Alpine fault earthquake

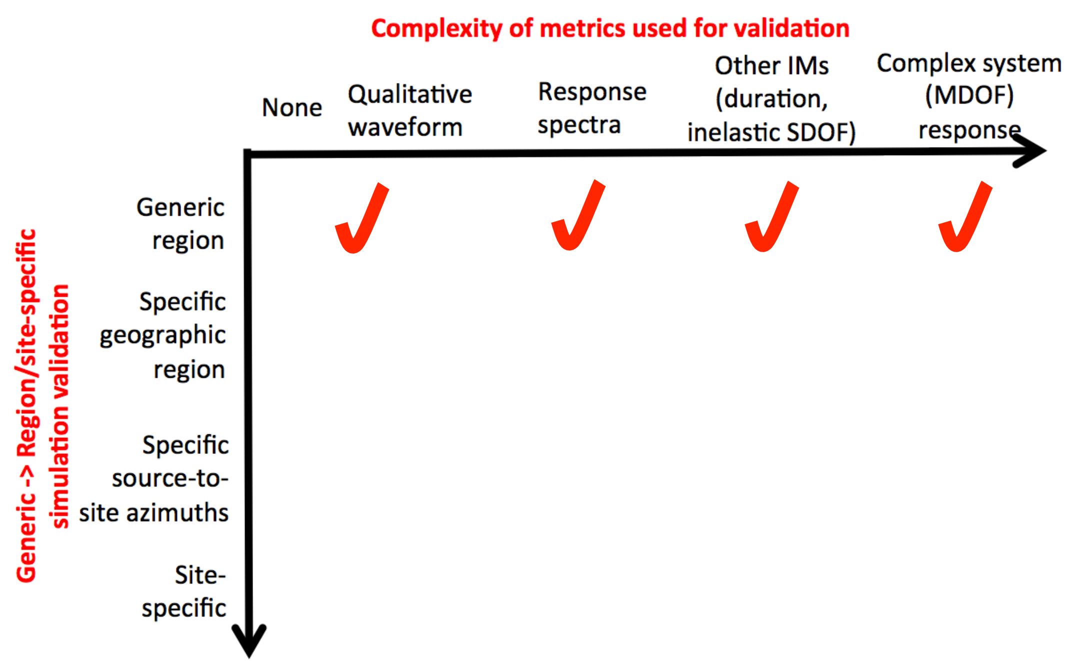
Q: How can we develop confidence that the results from ground motion simulation are robust? (i.e. equal to, or better than, the alternative of using conventional empirical models)

A: **<u>Verification and Validation</u>**



Case study 2: Simulation of major Alpine fault earthquakes for Canterbury

1. Adopt a methodology (Graves & Pitarka 2010, 2015) that has been extensively validated for multiple earthquakes in different geographic regions using multiple metrics [lots of work by SCEC researchers]



Case study 2: Simulation of major Alpine fault earthquakes for Canterbury

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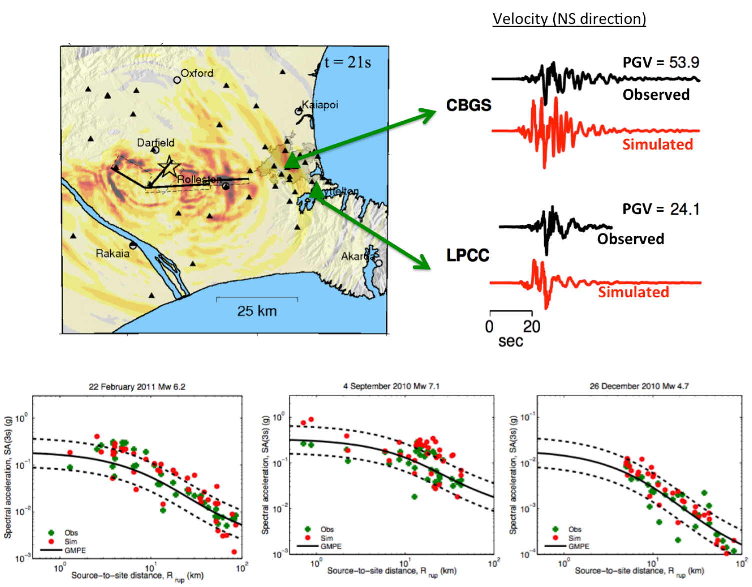
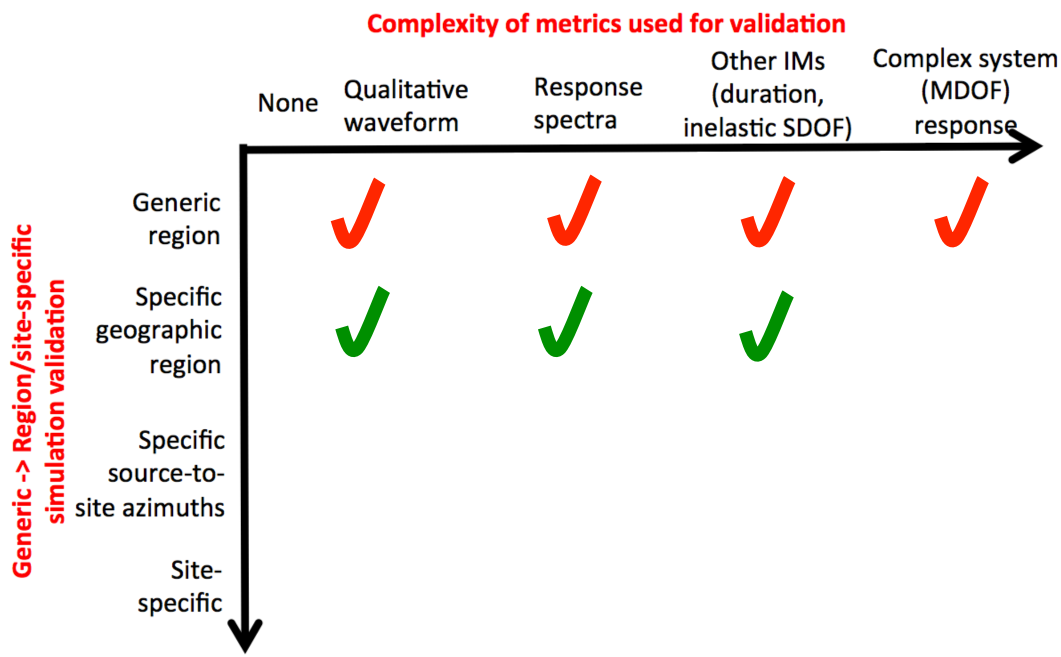
2. Perform ground motion simulations using moderate-to-large magnitude earthquakes in the specific region of interest

Ground motion simulation of 10 main events in the 2010-2011 Canterbury earthquake sequence (Bradley, Razafindrakoto et al. 2015, 2016)





Case study 2: Simulation of major Alpine fault earthquakes for Canterbury

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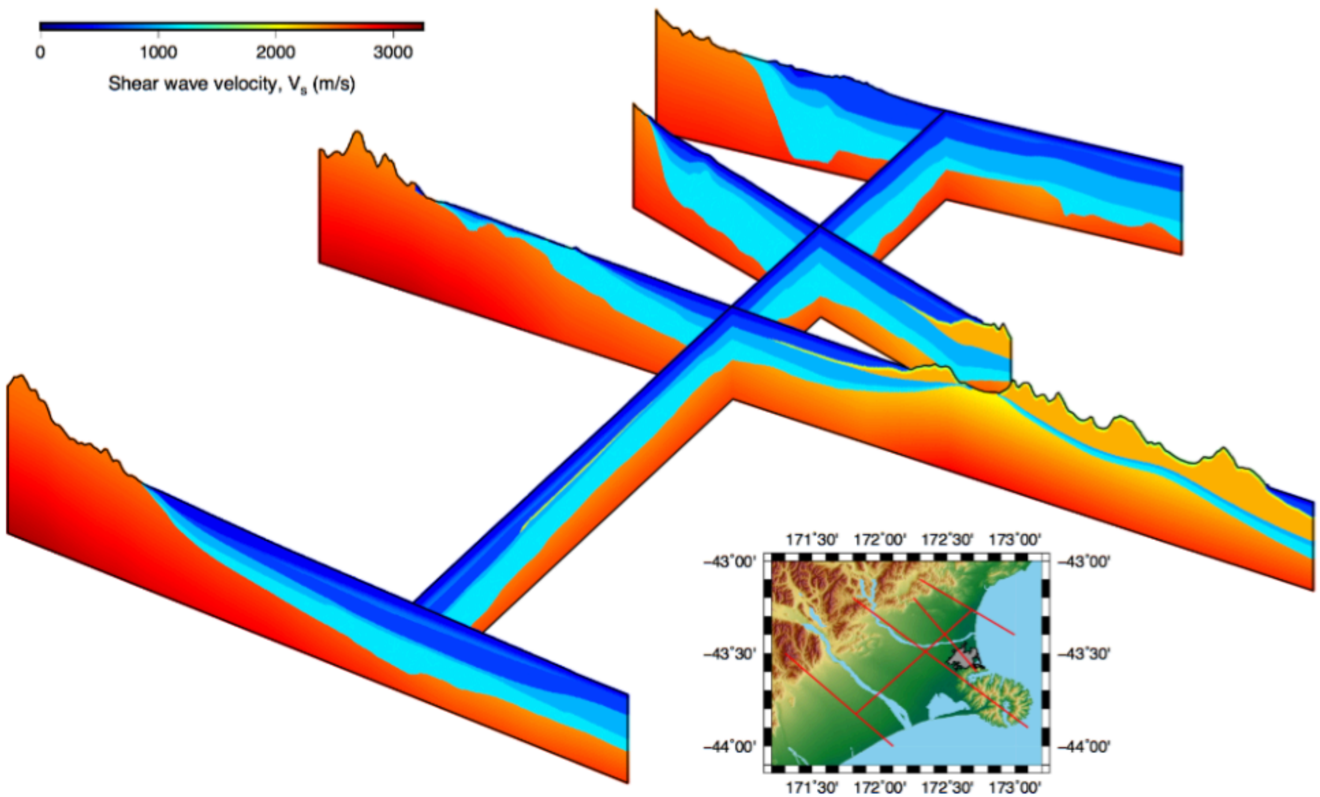
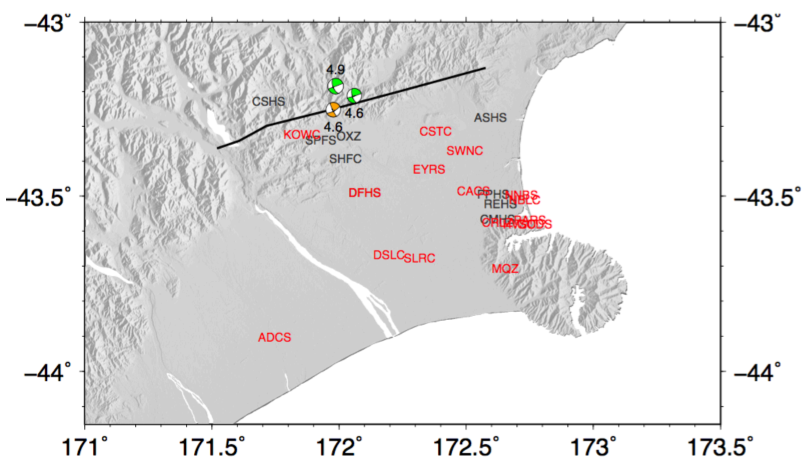
3. Perform ground motion simulation for other events (small magnitude, larger magnitude if available) which are located outside the Canterbury basin to examine wave propagation into the basin

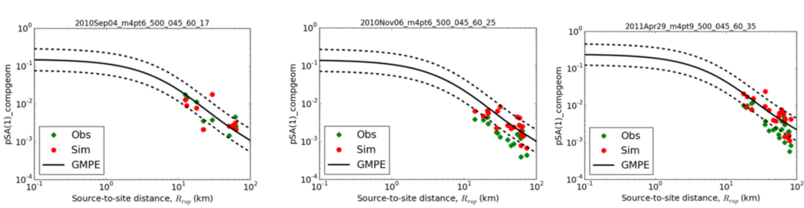


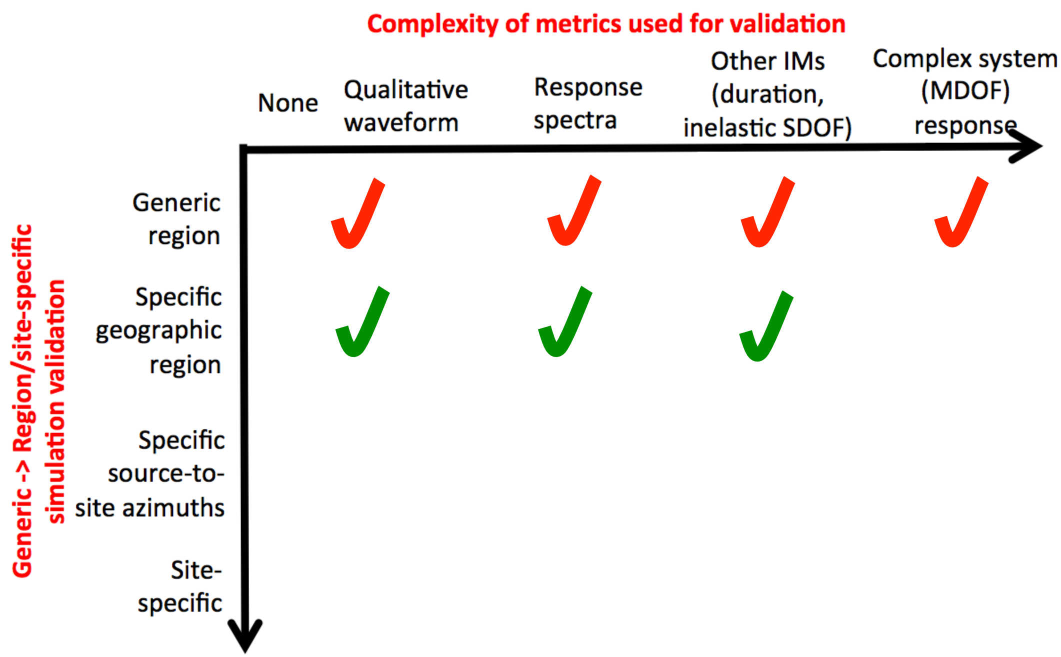
Case study 2: Simulation of major Alpine fault earthquakes for Canterbury

3. Perform ground motion simulation for other events (small magnitude, larger magnitude if available) which are located outside the Canterbury basin to examine wave propagation into the basin

(a) Ground motion simulation of recent events near Porters Pass (Nazer et al. ongoing)







Case study 2: Simulation of major Alpine fault earthquakes for Canterbury

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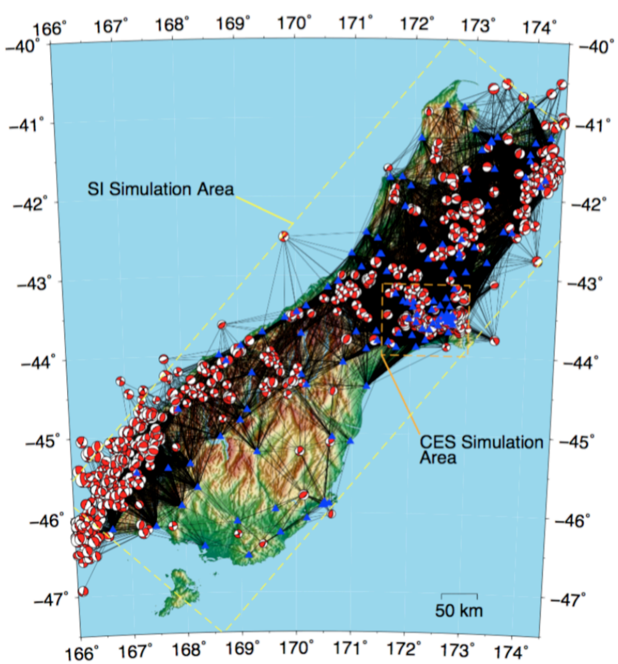
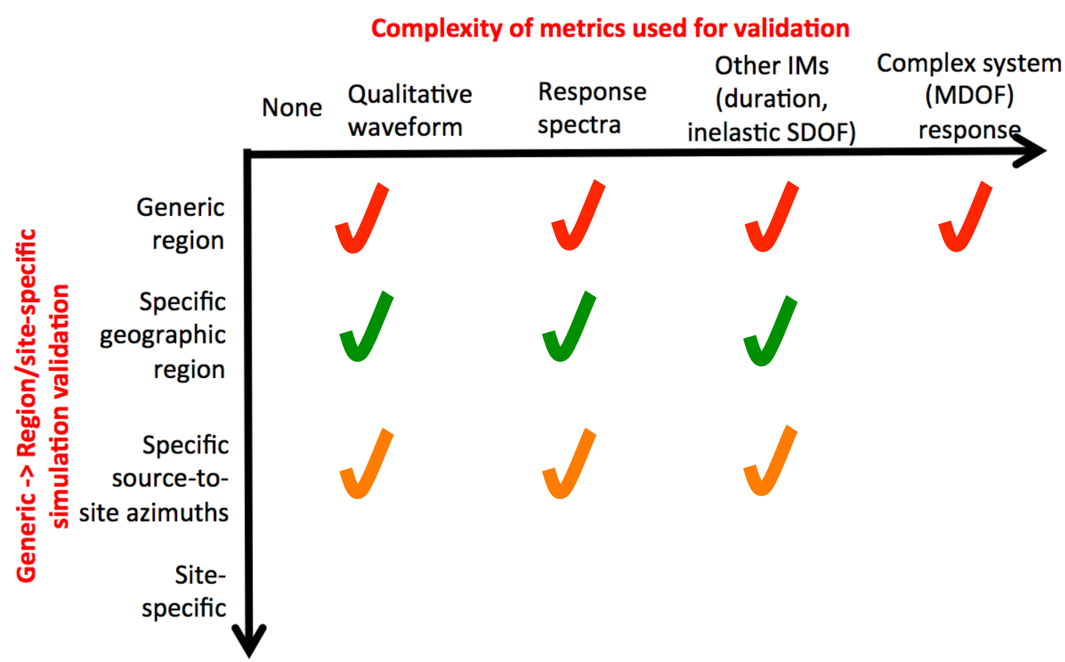
3. Perform ground motion simulation for other events (small magnitude, larger magnitude if available) which are located outside the Canterbury basin to examine wave propagation into the basin

(b) Ground motion simulation of many small magnitude events (Lee et al. ongoing)





Case study 2: Simulation of major Alpine fault earthquakes for Canterbury

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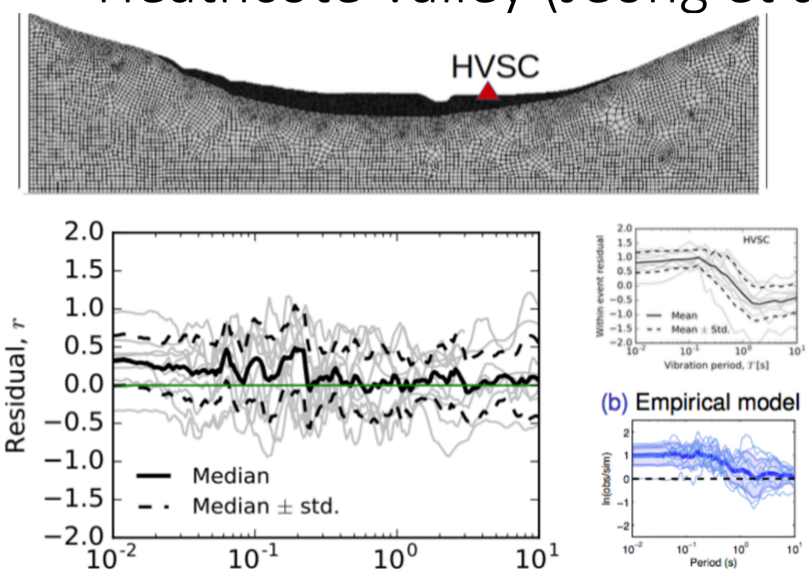
4. If site-specific response analysis (i.e. not simply Vs30) is used, validation of the general methodology, as well as its application to this specific site (e.g. lab testing, downhole array validation, deployed SM instruments at the specific site)

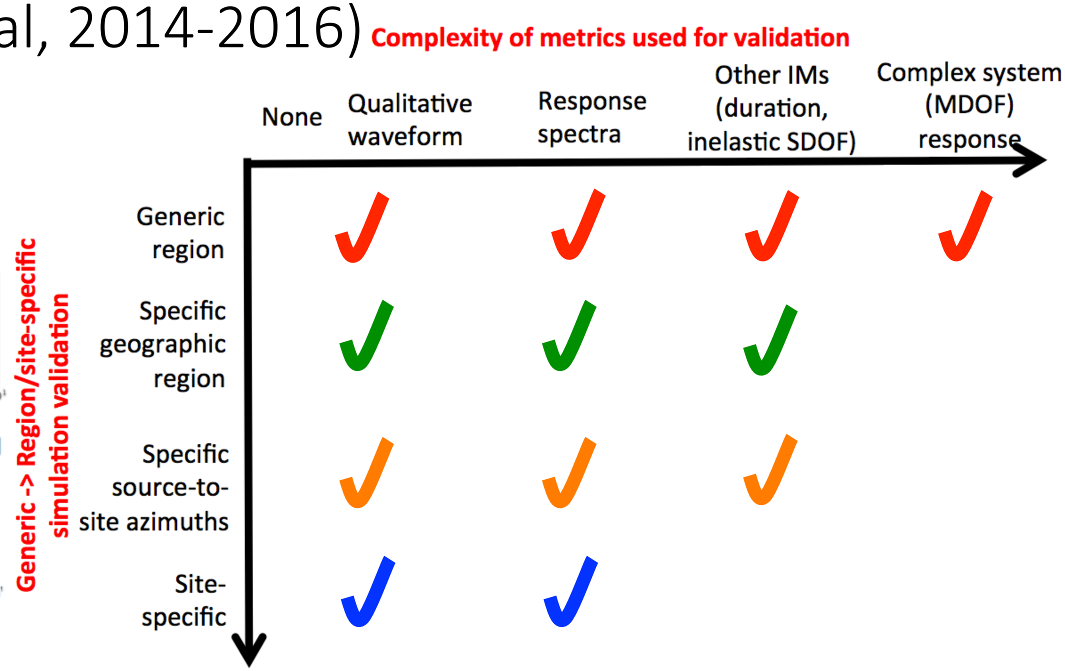
Heathcote Valley (Jeong et al, 2014-2016)



(a) 2D nonlinear site response analyses

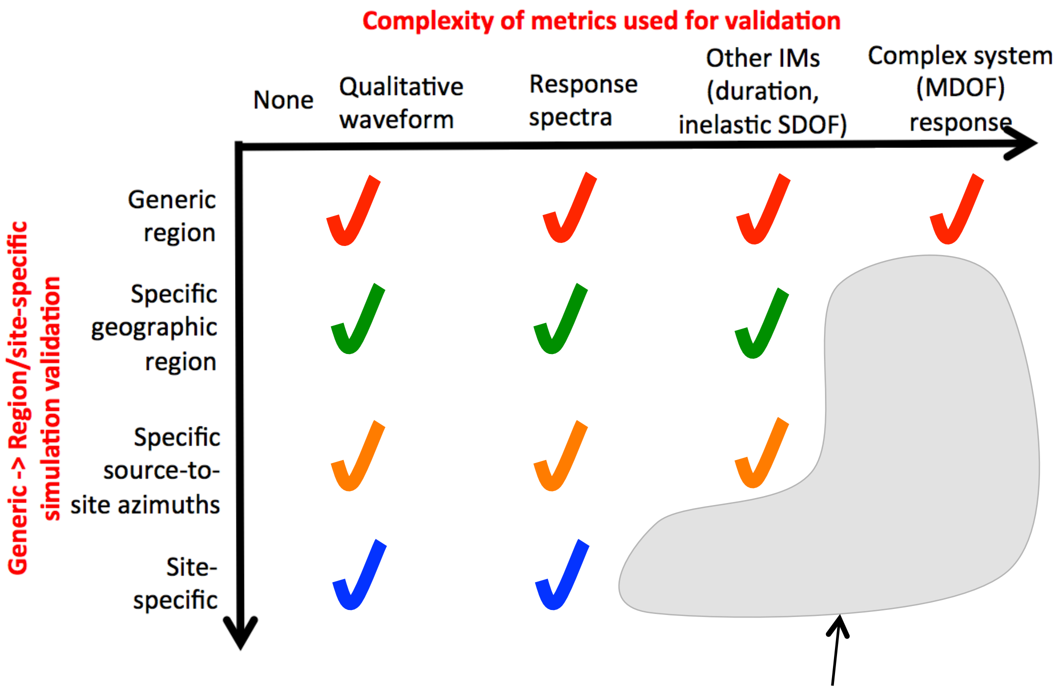
(b) Empirical model

(c) Ground motion simulation with 3D velocity model

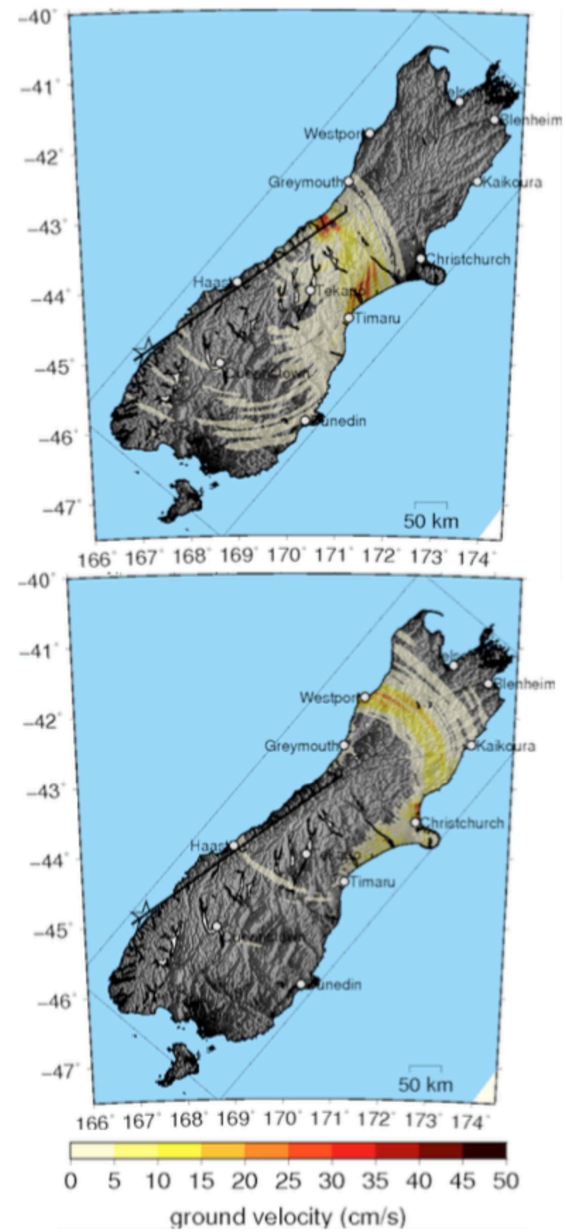


Case study 2: Simulation of major Alpine fault earthquakes for Canterbury

Summary of validation



Areas for further work
(as well as improving bias/precision for each type of validation)



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