Ground motion simulations of damaging recent and future earthquakes using NeSI HPC resources

Brendon Bradley[1,2]

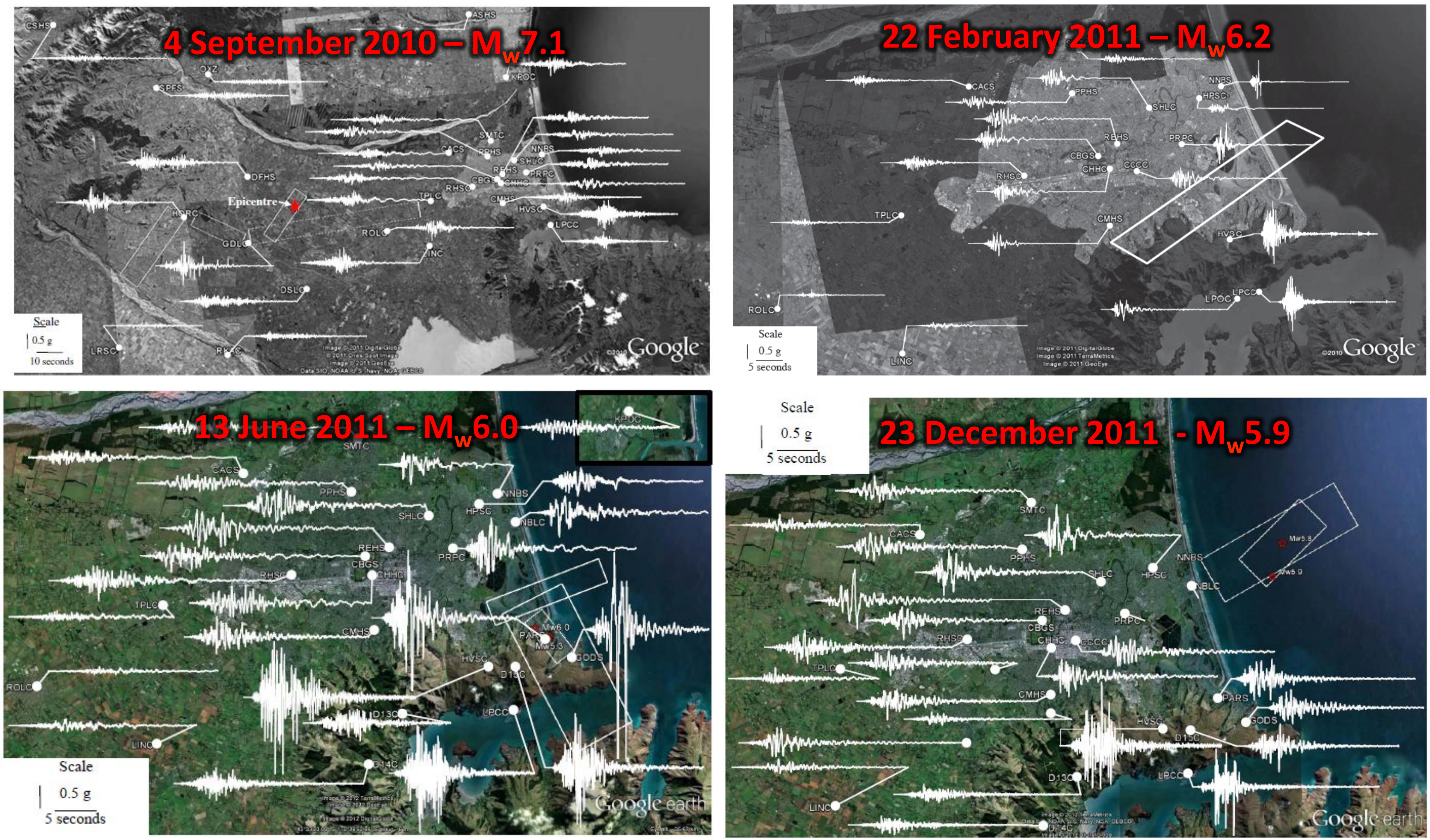
[1]Civil & Natural Resources Engineering, UC

[2]Deputy Director, QuakeCoRE

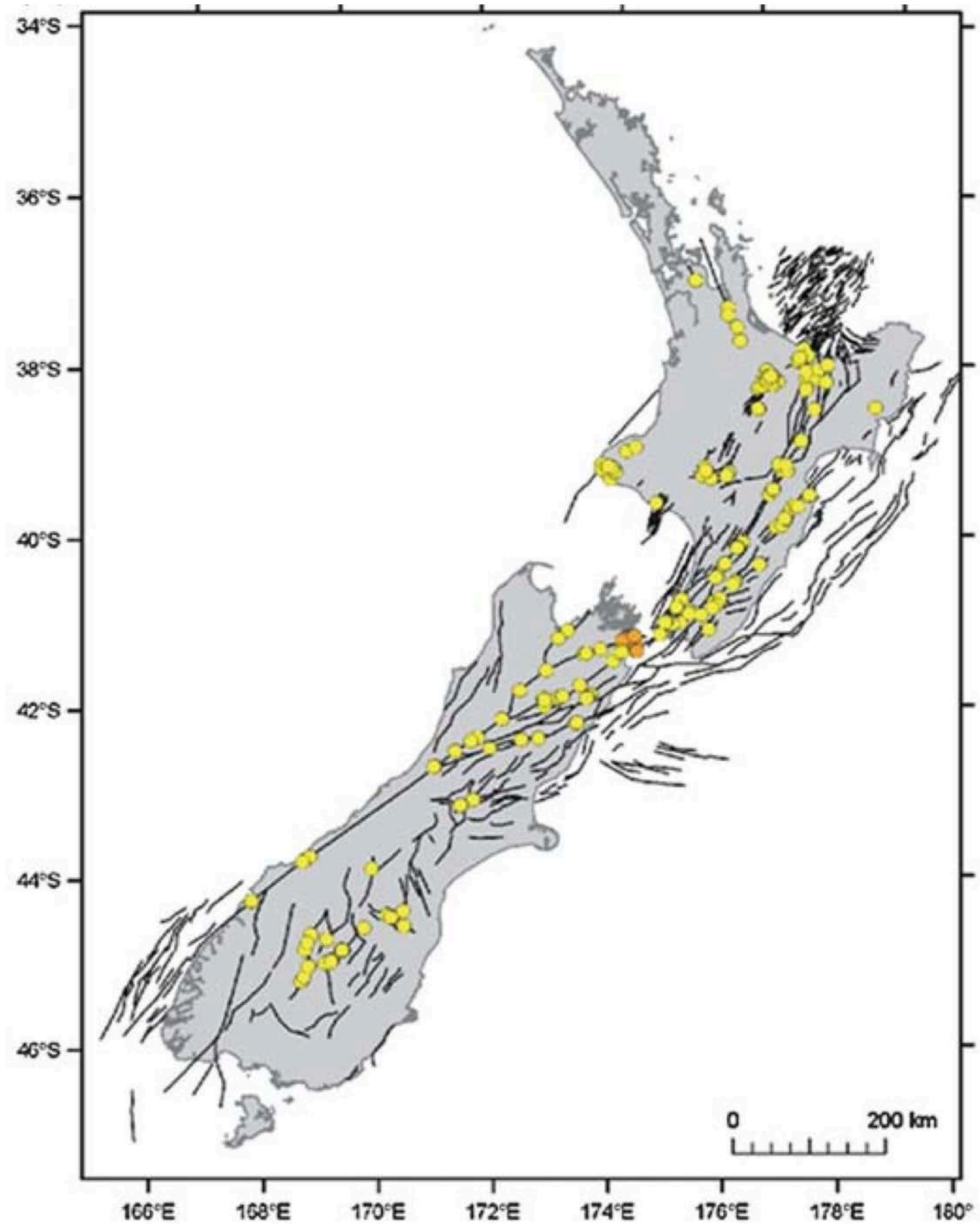
Outline

1. Motivation
2. Ground motion prediction
3. Simulations of the Canterbury earthquakes
4. Validation and model improvements
5. 'Forward' simulations of an Alpine Fault EQ
6. Domain-specific computational and data challenges

1. Motivation



Impacts of the next big EQ?



There are over 500 faults which have been mapped in NZ

These are the 'larger' faults, in that they leave a surface expression, there are many other (smaller) faults that do not

2. Empirical ground motion models

Regression models are developed from the recorded ground motions

Year: 1980's

Records: 230

Models:
Variables: 2
Regression constants: 5

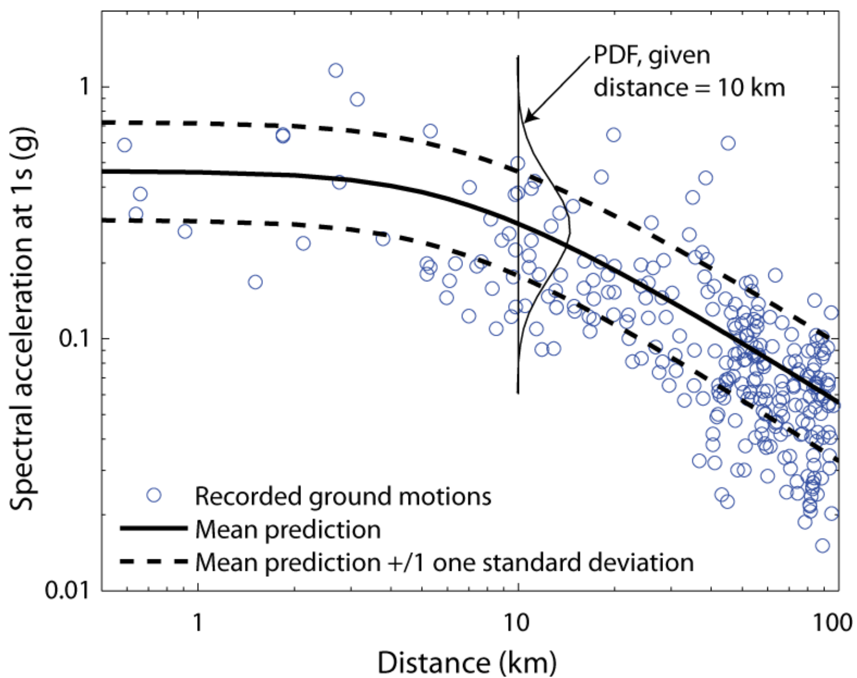
30 yrs →

Year: 2010's

Records: 21,000

Models:
Variables: 12
Regression constants: 29+

A measure of ground motion intensity



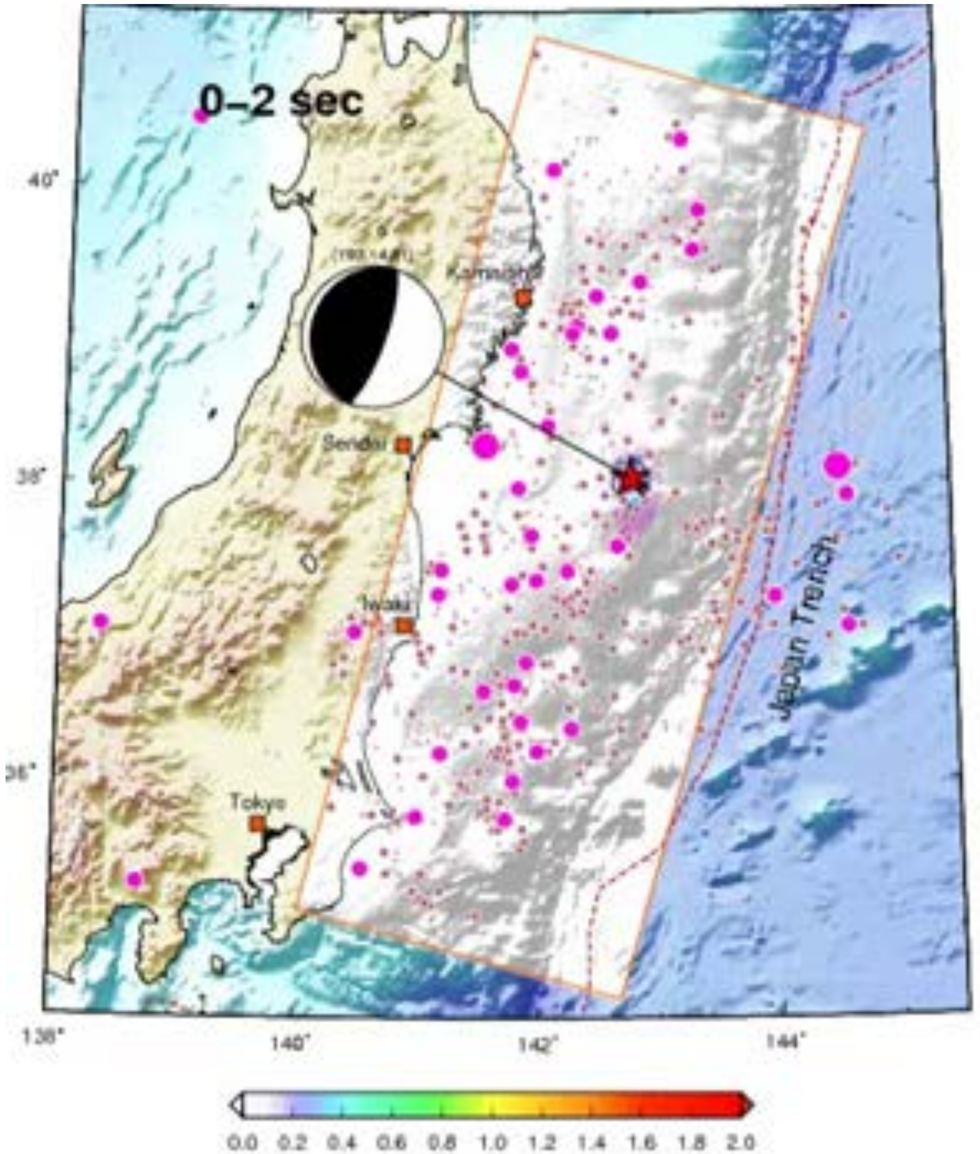
Note the large uncertainty -> the 84th percentile is over 3 times the 16th percentile!

Physics-based ground motion prediction

- The numerical solution of the wave equation is quite straightforward in concept ...... but the following complexities have stifled progress until recently:
  a. Source: Complex rupture in space and time
  b. Path: Wave propagation in 3D heterogeneous media
  c. Site: Nonlinear response (incl liquefaction)

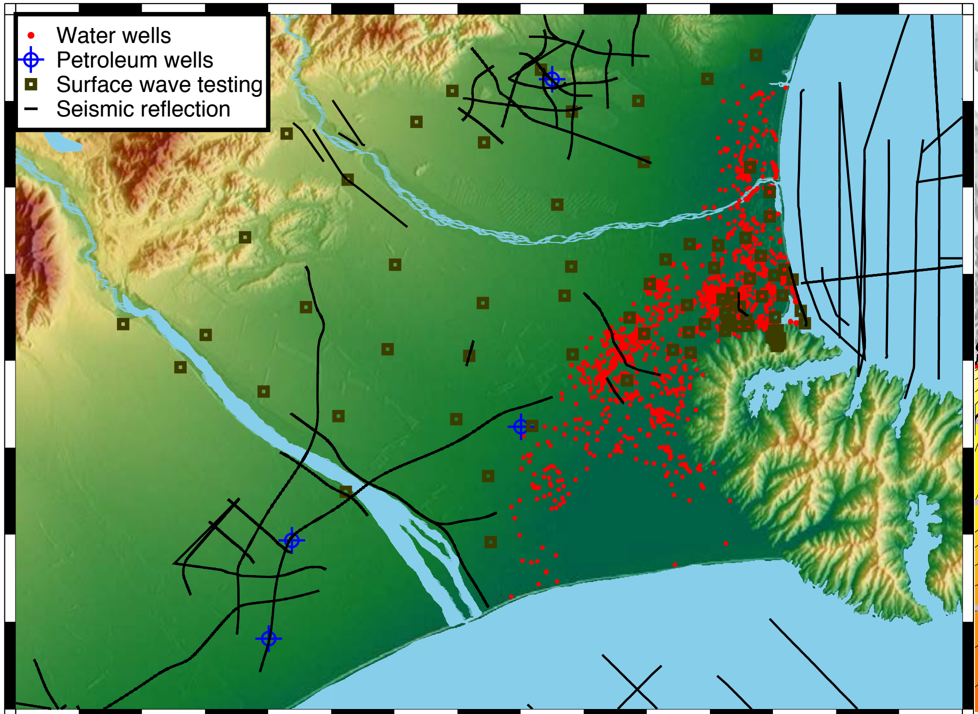
  Significant recent progress because of the rapid growth of supercomputing capacities: The need to simulate *frequencies up to 10Hz* requires very small computational mesh sizes –> requiring the worlds fastest supercomputers

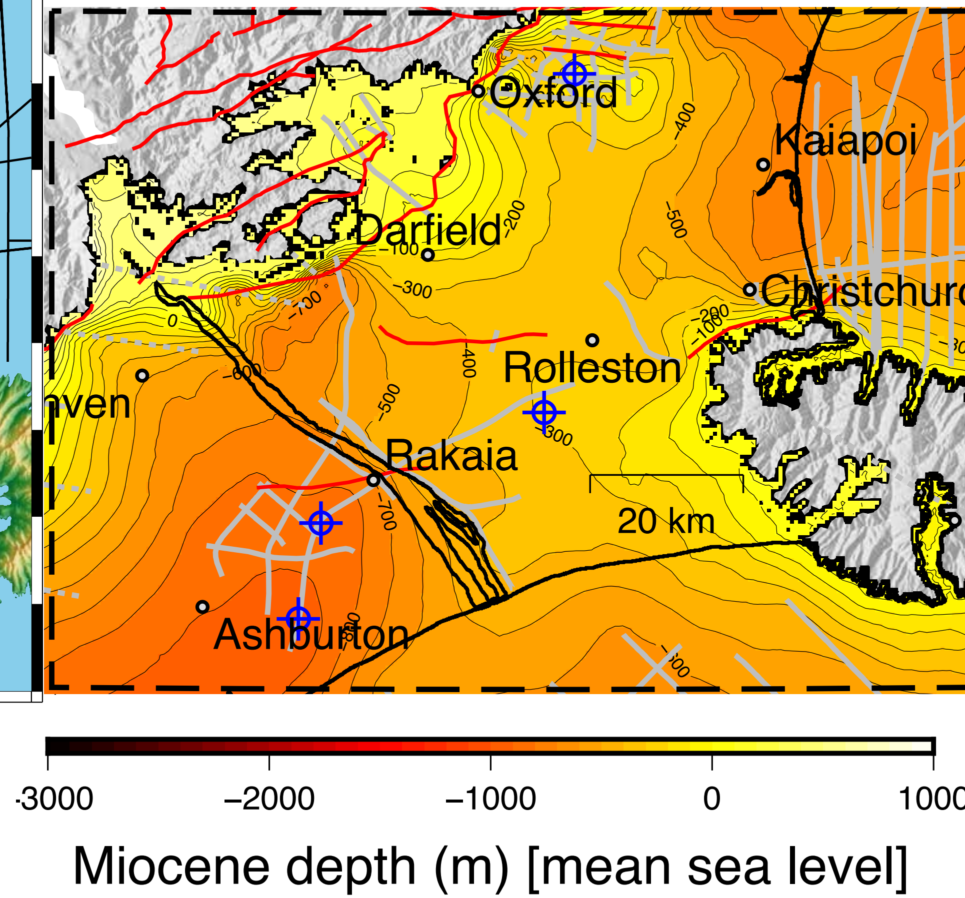
a. Source: complexity – 2011 Tohoku EQ

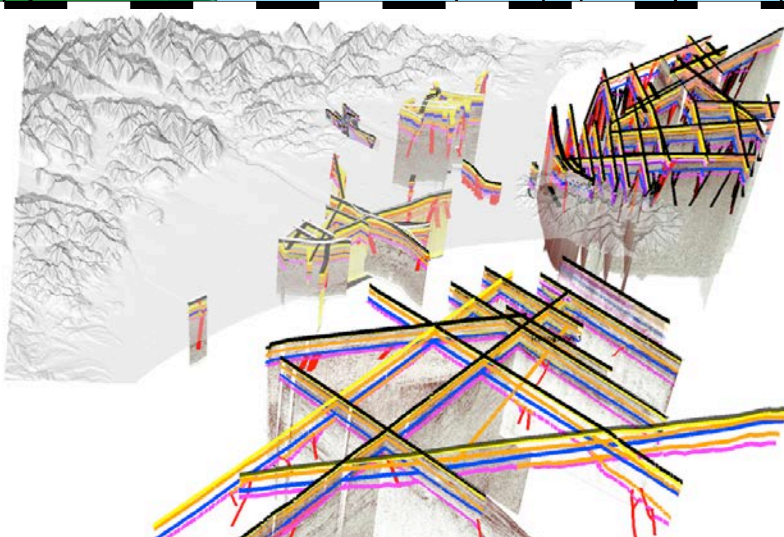


Instantaneous disp.

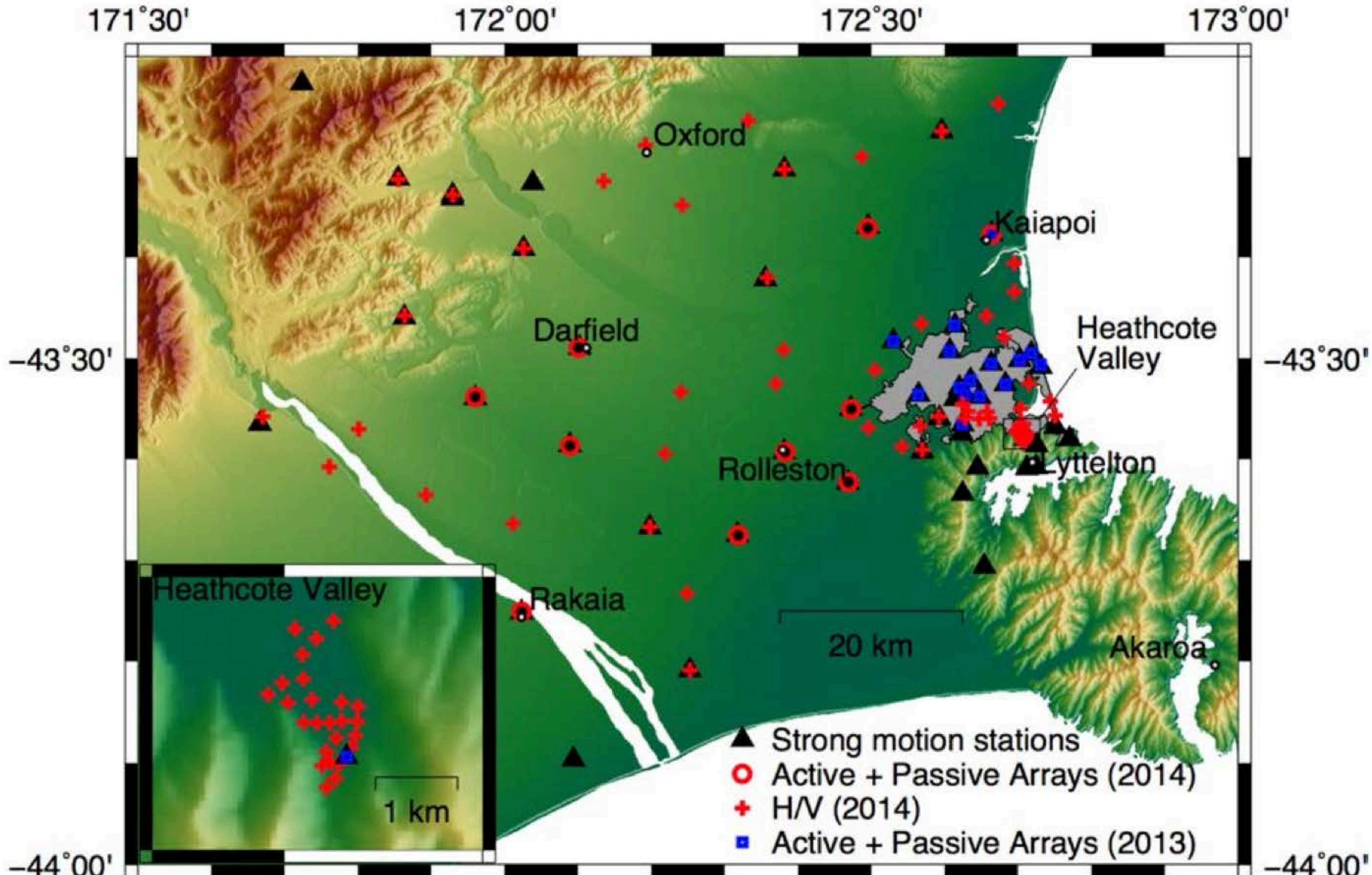
b. Path: Complex 3D geology - Canterbury





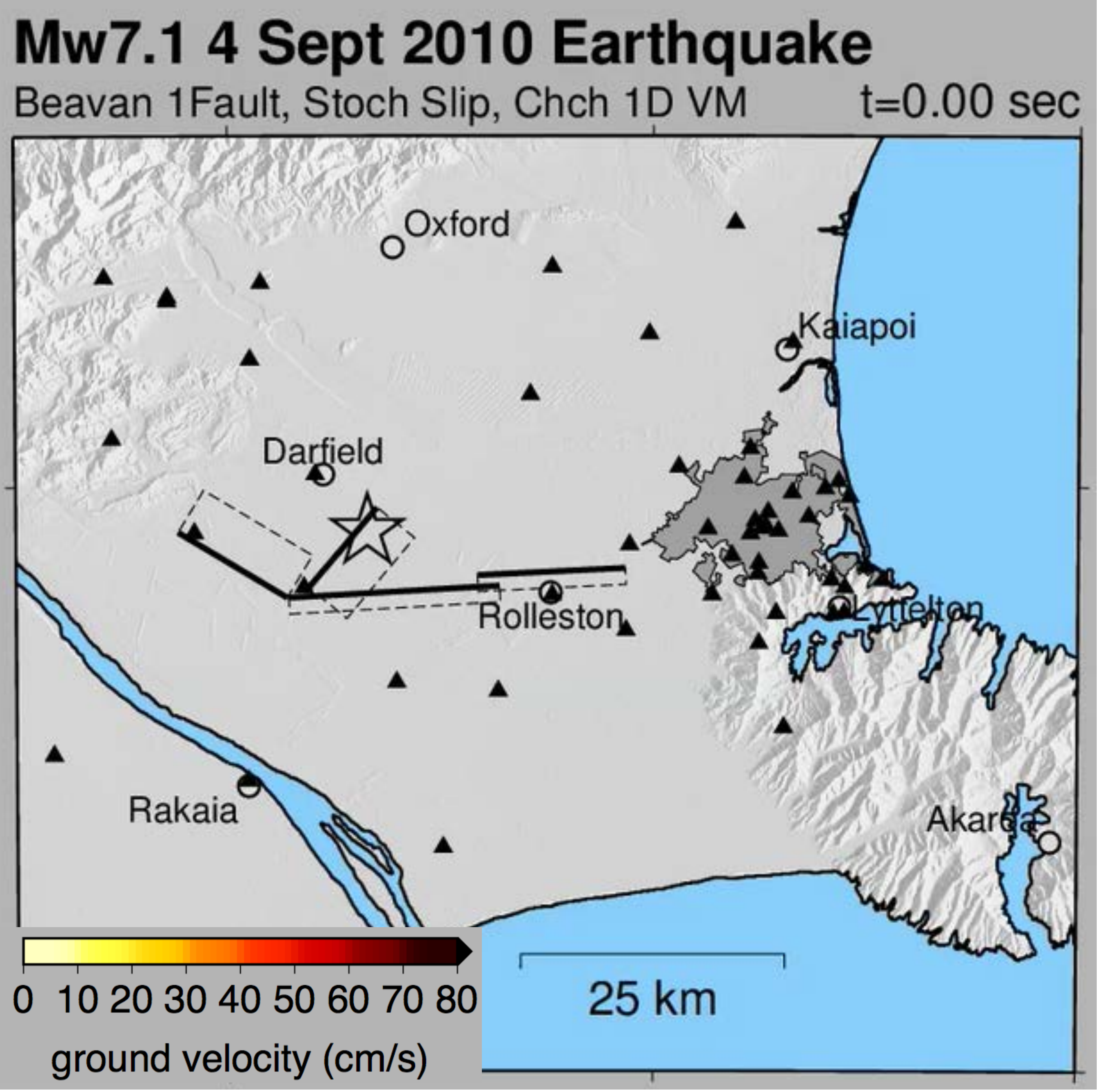


c. Site: Soil field measurements



3. Ground motion simulations of the Canterbury earthquakes

videos at: https://sites.google.com/site/brendonabradley/videos



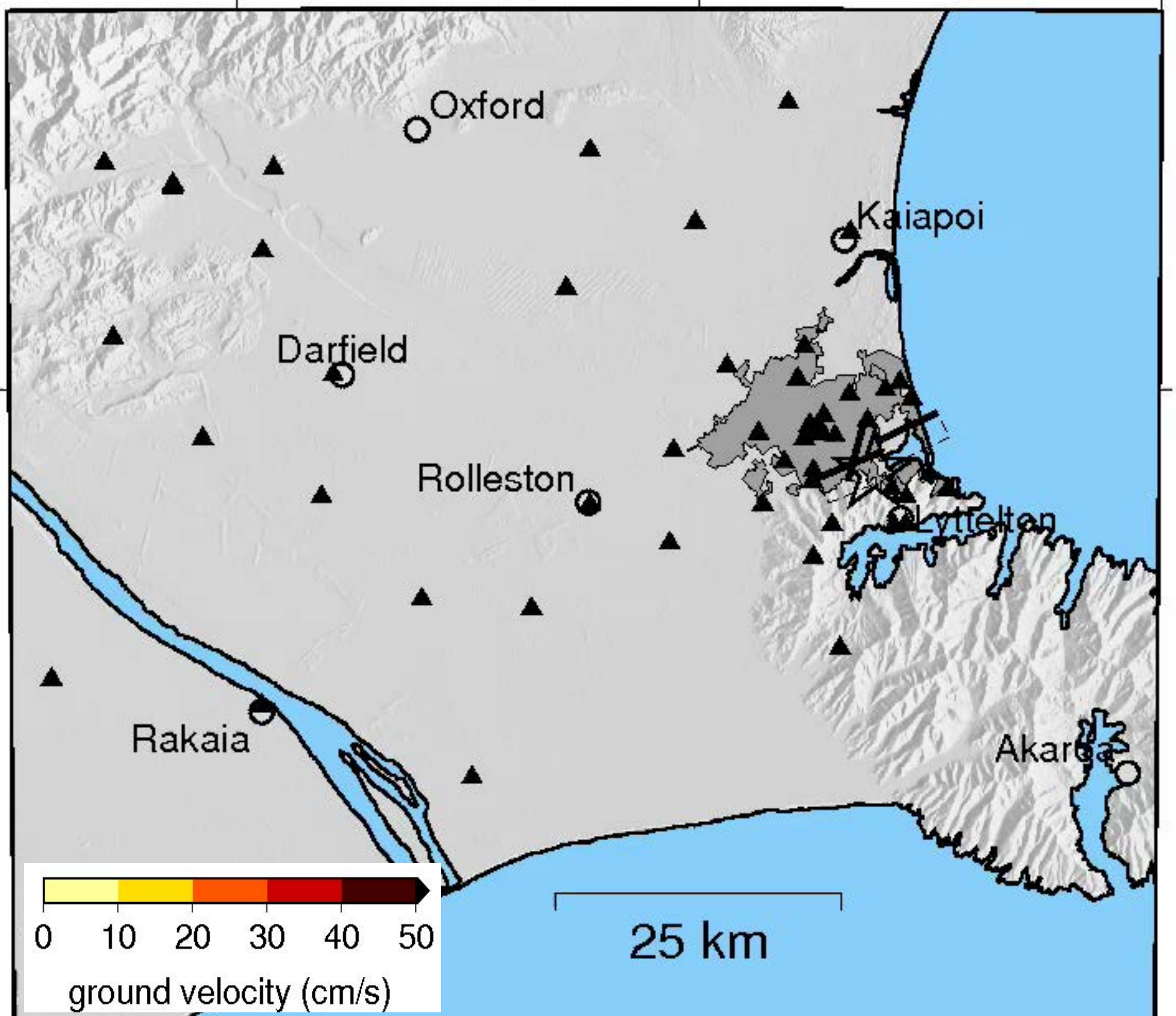
Simulation on UC's BlueGeneP supercomputer

- 'Relatively' small runs
- ~8,000 core hours per simulation [25% of BGP capacity for 4 hours]
- Multiple runs performed to understand model sensitivity

Blender rendering (collab w Nick Young, UA eResearch)

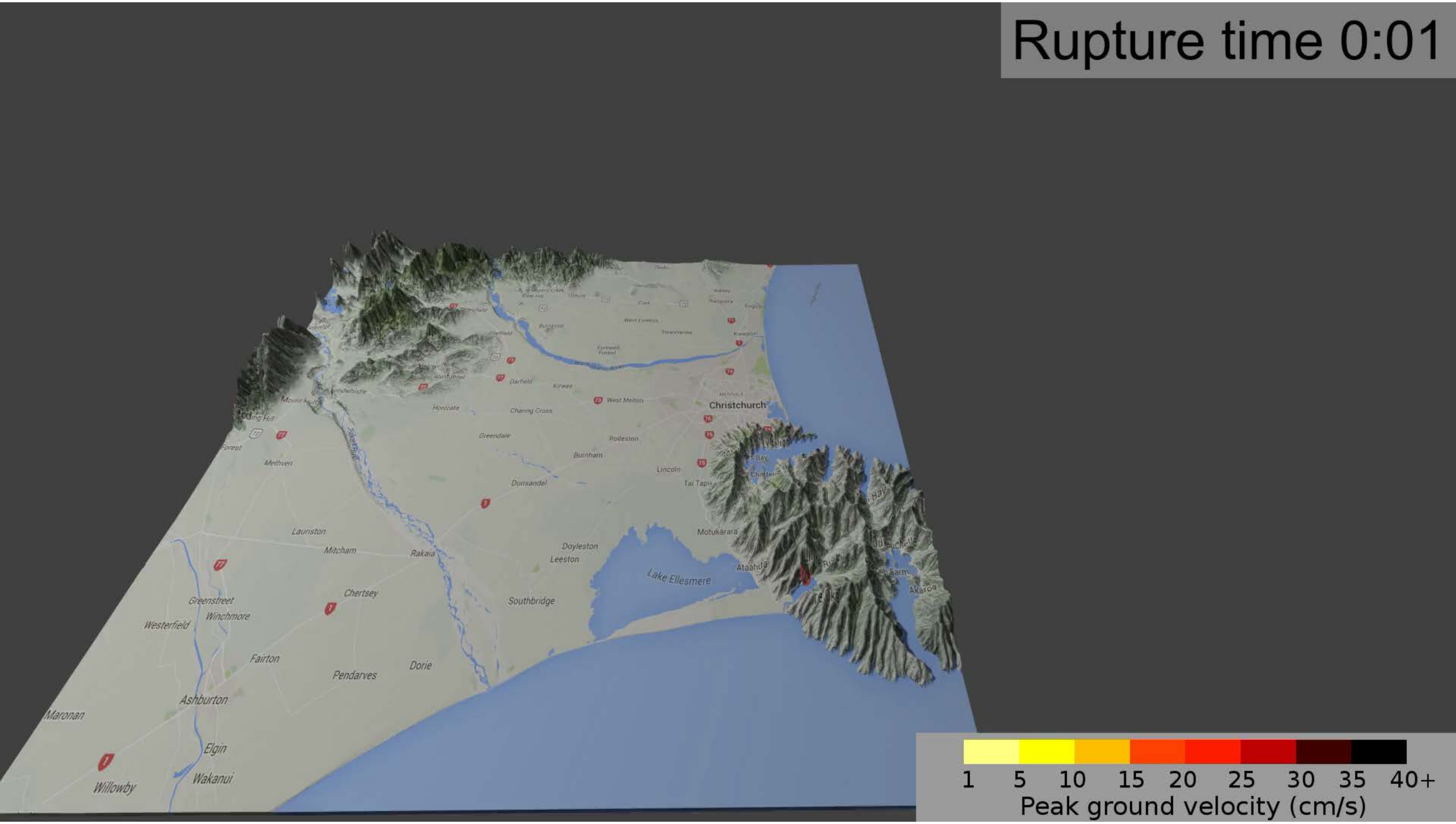
Mw6.2 22 Feb 2011 Earthquake

Beavan 1Fault, Stoch Slip, v1.64 t=0.00 sec



B.A. Bradley

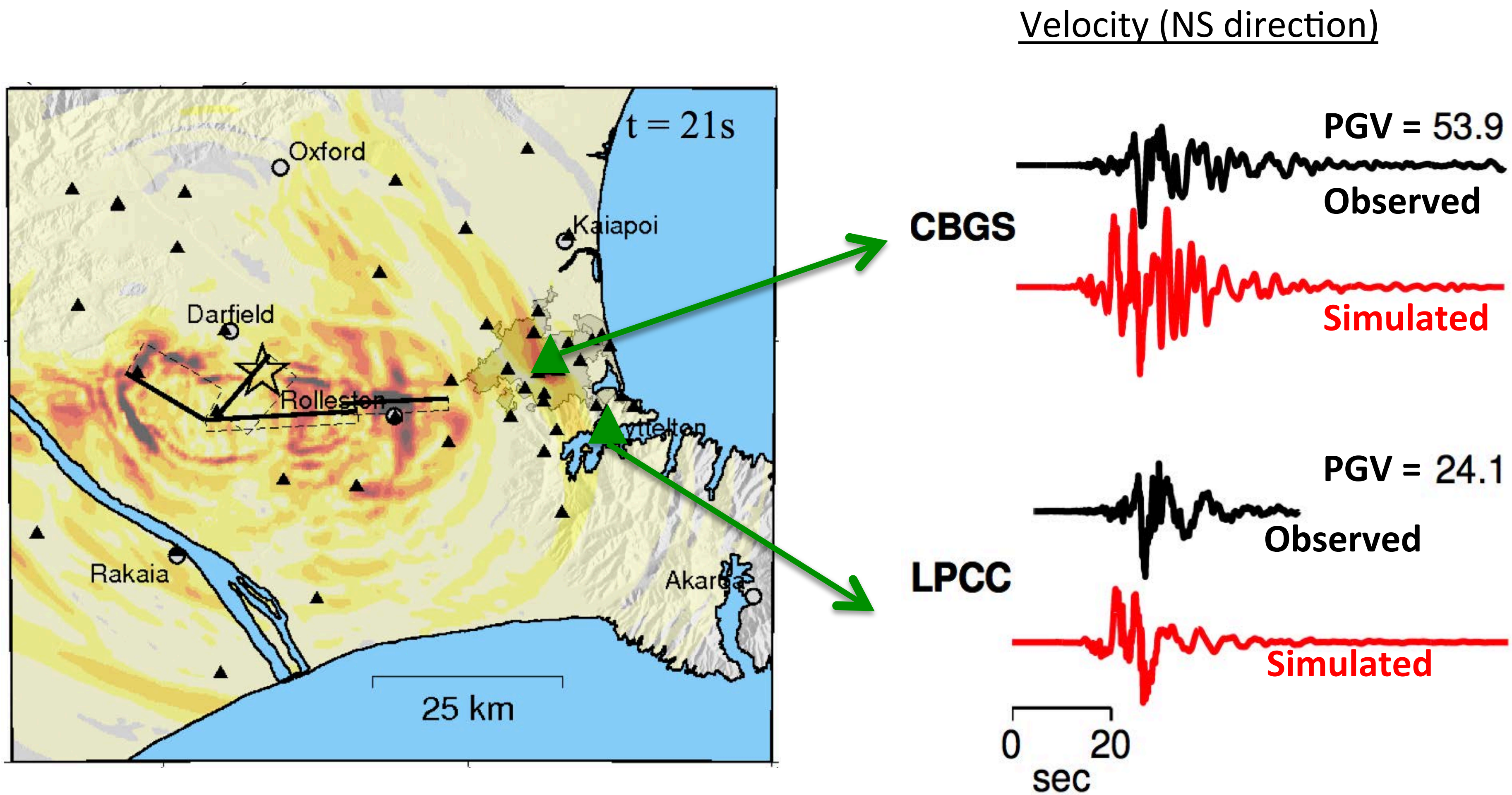
Blender rendering (collab w Nick Young, UA eResearch)



4. Simulation validation and model improvement

B.A. Bradley

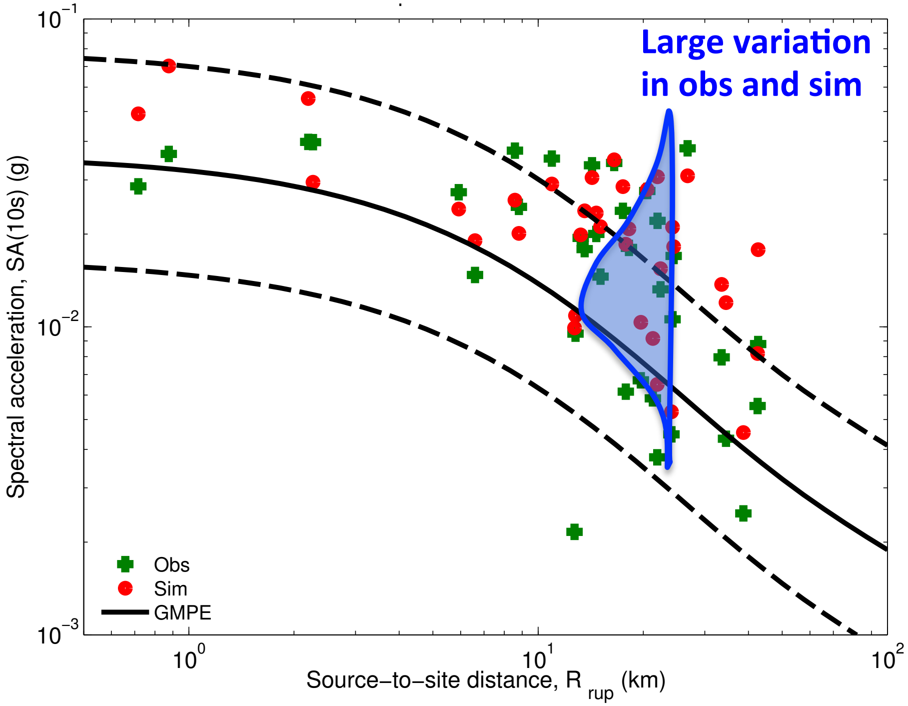
Observed vs Simulated velocity (4 Sept 2010) (qualitative validation)



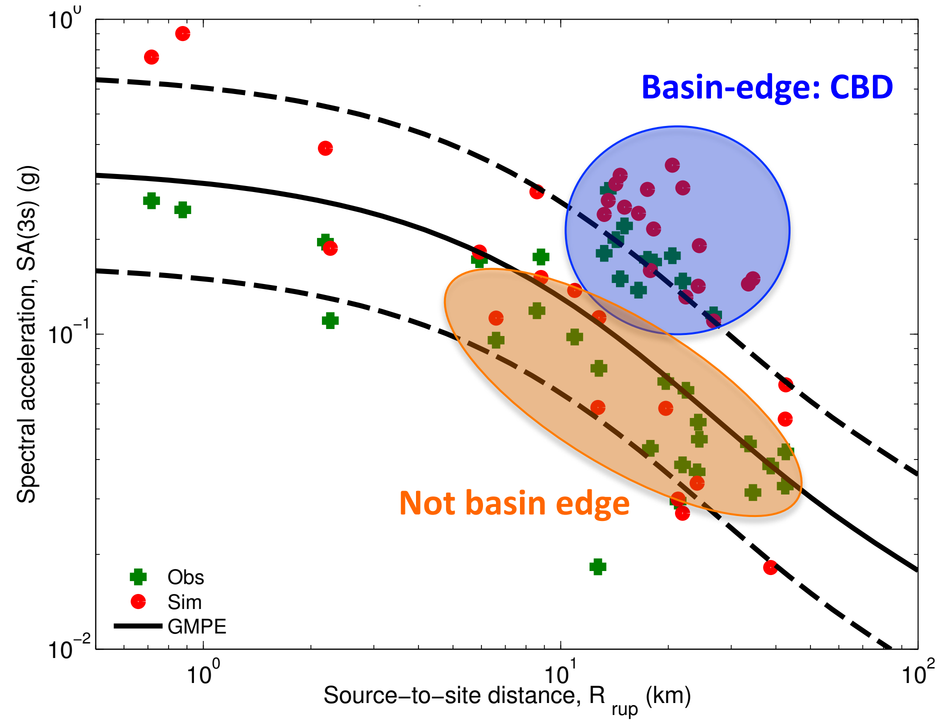
B.A. Bradley

Spectral accelerations vs Distance (4 Sept 2010) (qualitative validation)

SA, period T=10s

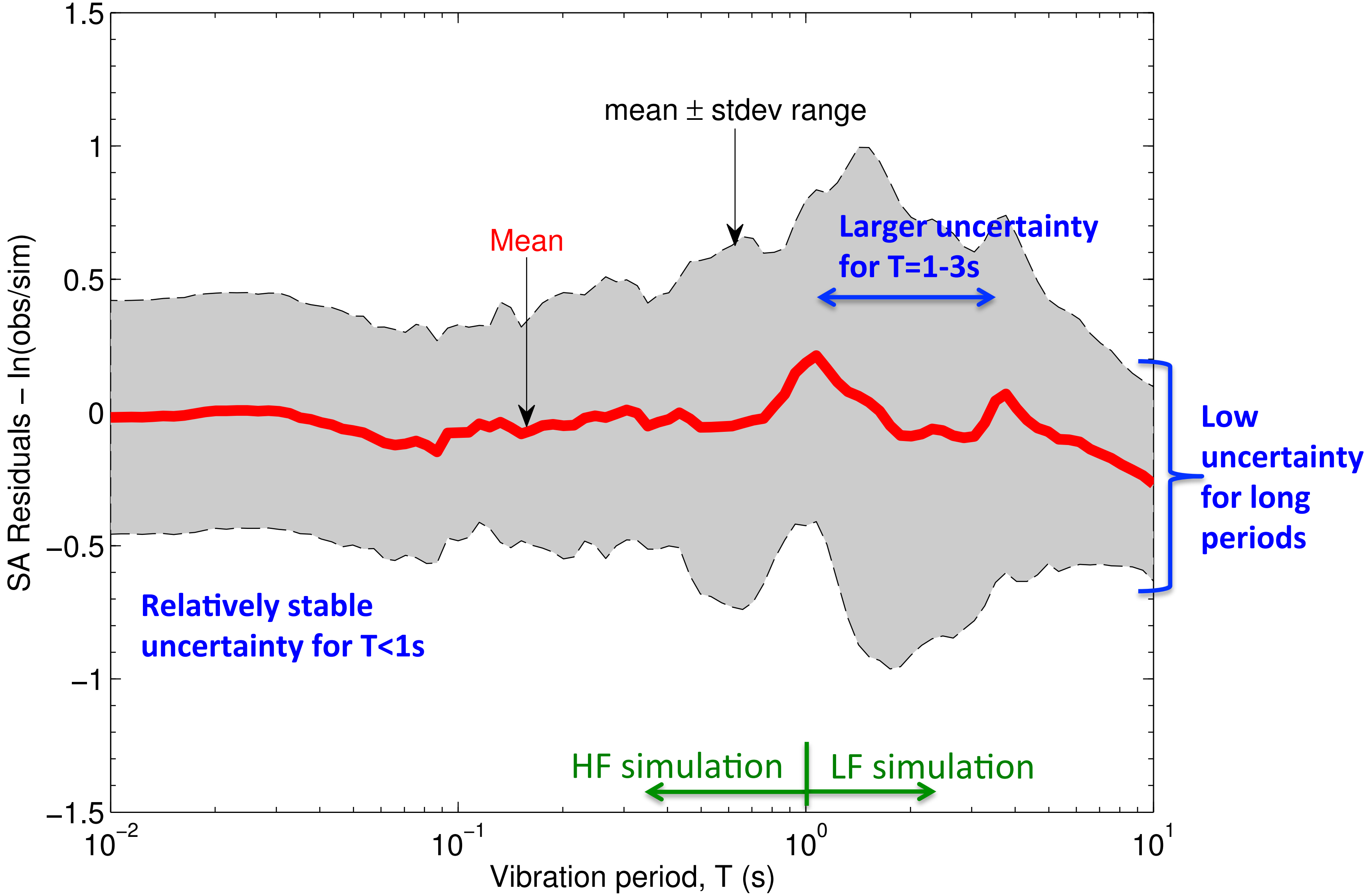


SA, period T=3s

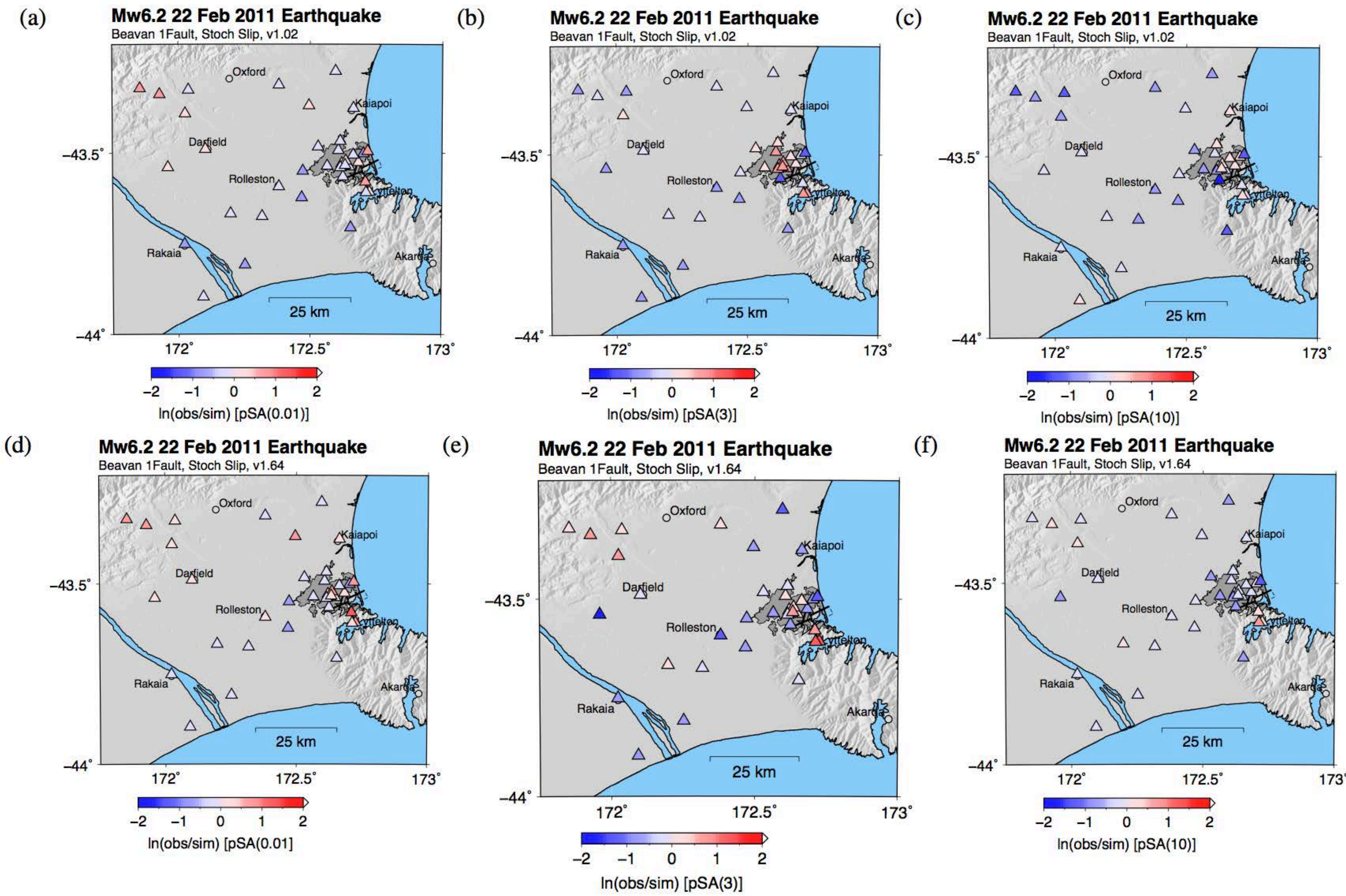


B.A. Bradley

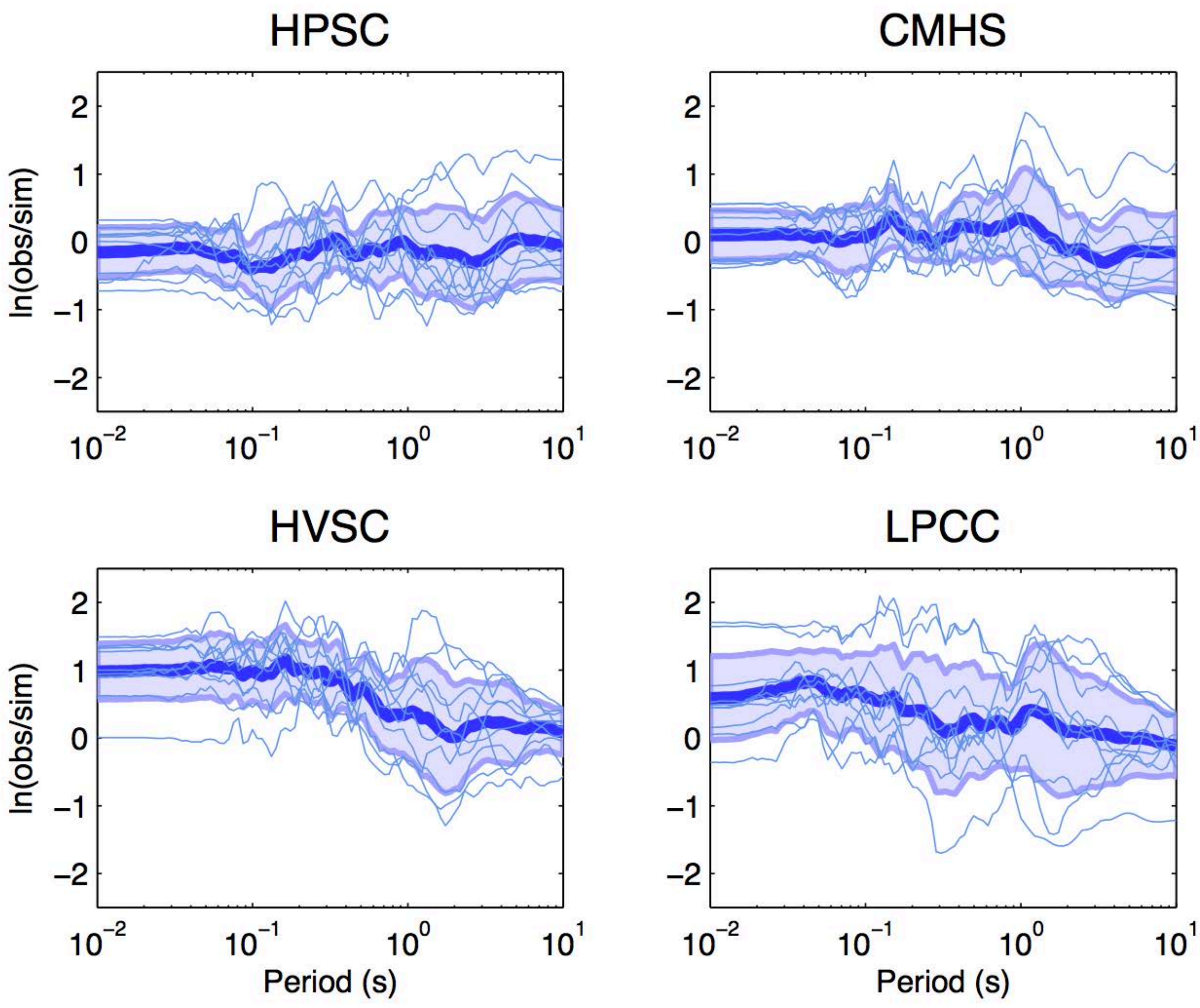
Quantitative overall bias (22 Feb 2011)



Spatial variation of bias

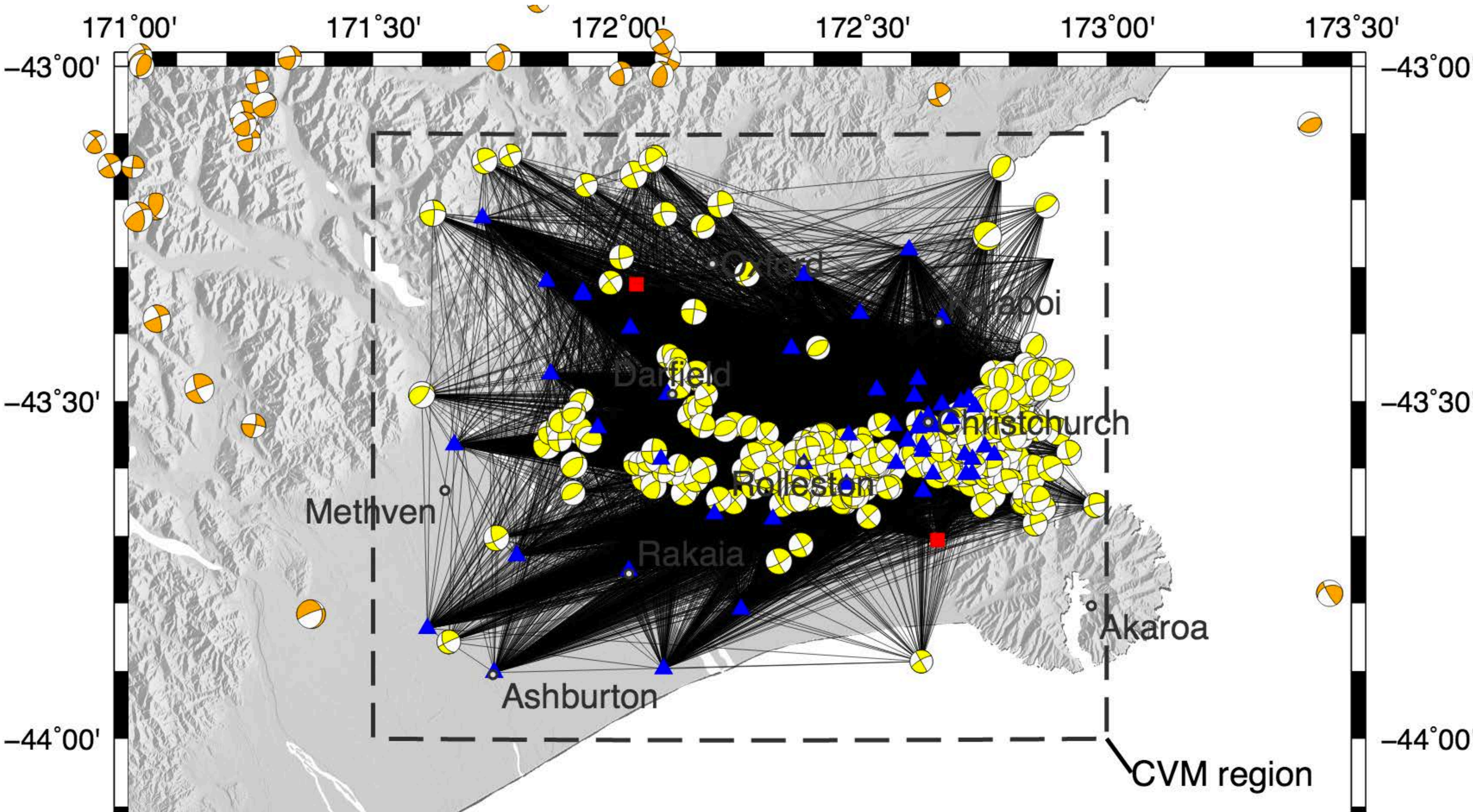


Bias at specific locations



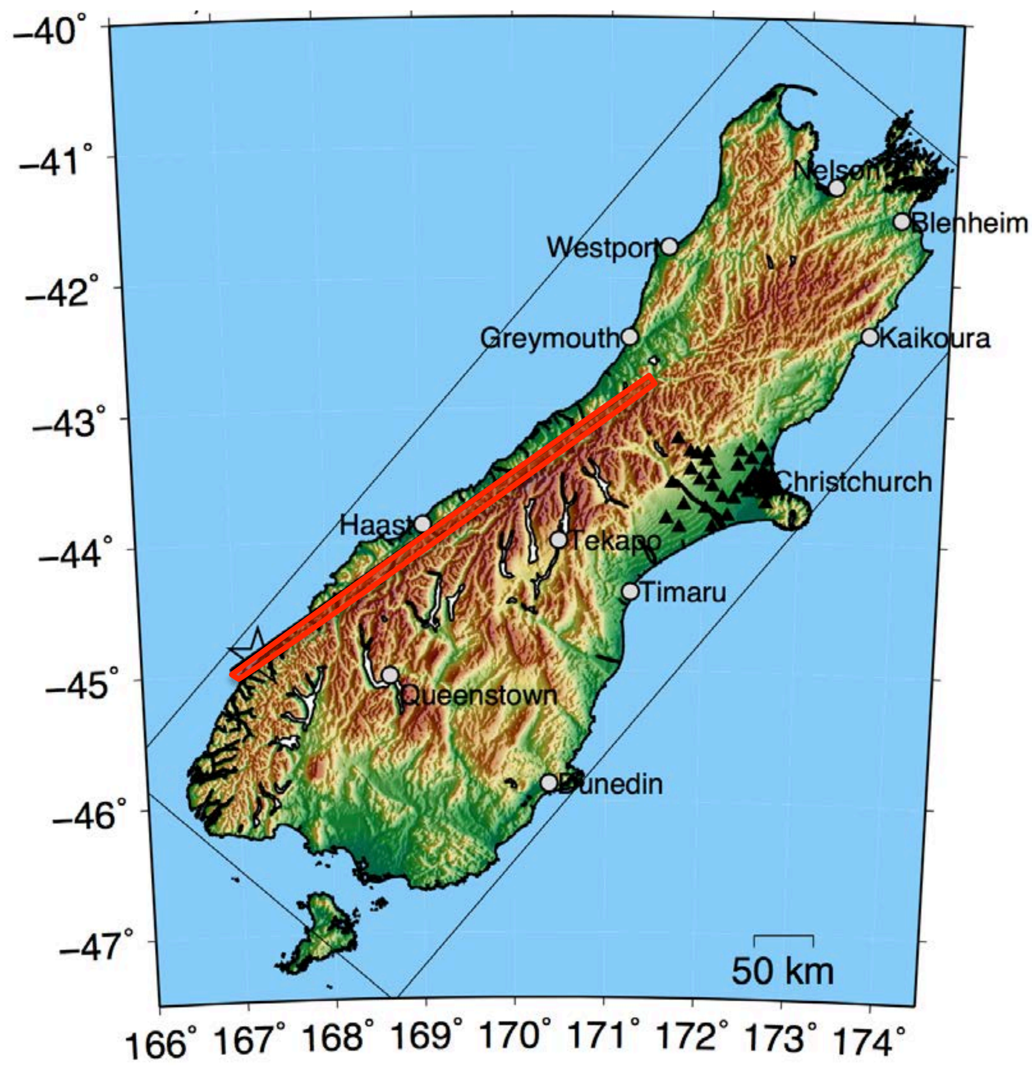
Formal improvement through inversion

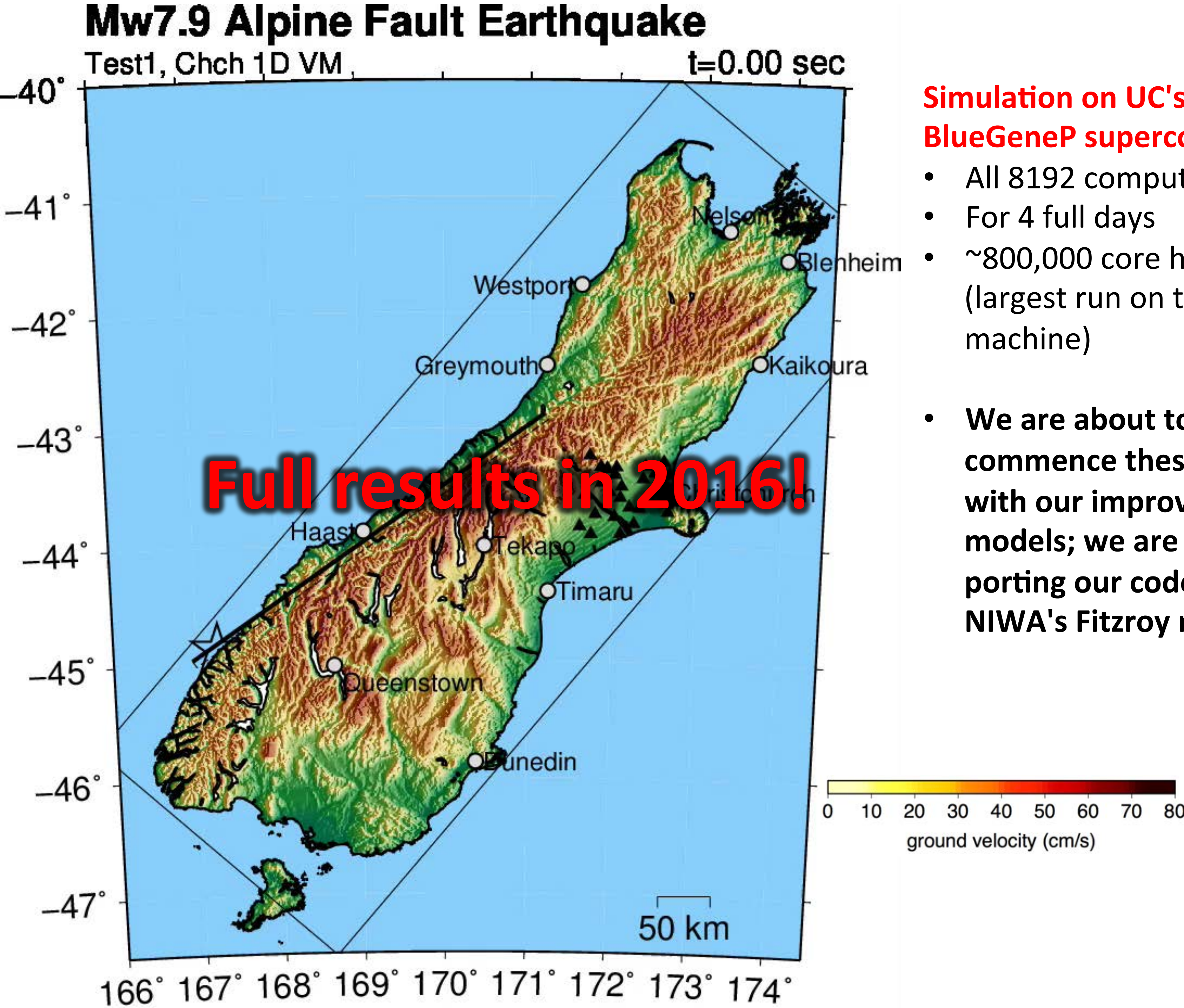
We are currently undertaking inversion of 350+ earthquakes of M3.5-4.5 to improve our model of the Canterbury region using adjoint inversion methods
(requires 700+ 'runs'/iteration with an expectation to perform 10-20 iterations).



5. What can such simulations tell us about the future?

- Alpine fault can produce M_w8+ earthquakes
- Last end-to-end rupture in 1717 (298yrs ago); 26 major events inferred over past 8000 years (~310yrs/event)
- We actually know very little about what severity of ground shaking the Alpine Fault will cause in Canterbury and the wider South Island





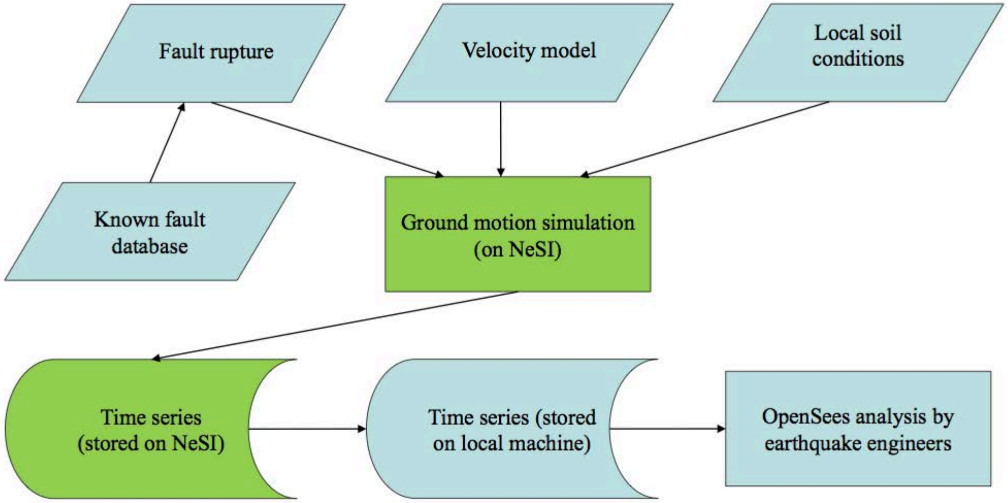
Simulation on UC's BlueGeneP supercomputer

- All 8192 compute cores
- For 4 full days
- ~800,000 core hours (largest run on this machine)

- **We are about to re-commence these analyses with our improved crustal models; we are also porting our codes over to NIWA's Fitzroy machine**

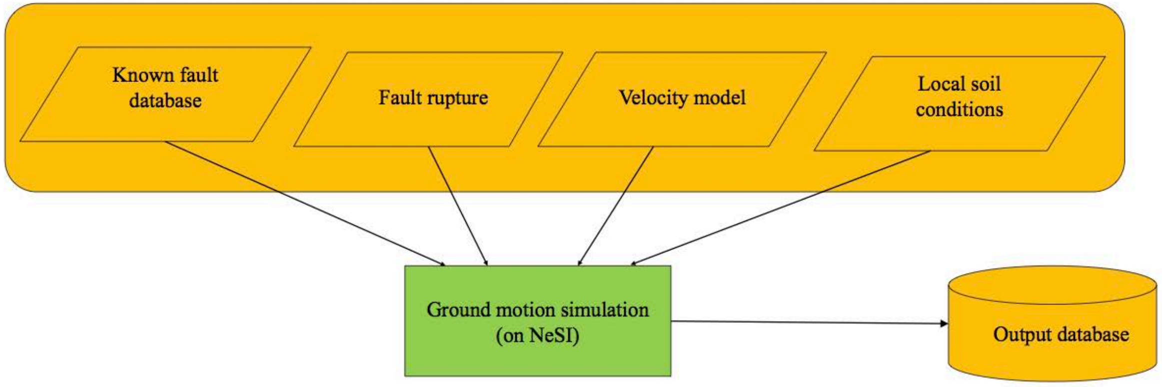
QuakeCoRE interaction with NeSI

(further details on Clare et al. poster at this meeting)



Current workflow requires excessive use of adhoc codes for:
(a) preparation of simulation input models; and
(b) utilization of outputs by 3rd parties

In collaboration with NeSI/UCHPC we have been streamlining our workflow to enable model pre-/post-processing to be user-independent



6. Domain-specific challenges

- Computation:
  - Currently 100m grid spacing to give fmax=1Hz calculations. To get to f=10Hz will require 1000x the amount of computation (Moore's law & Intel's focus on energy efficiency over speed)
  - Considering many EQ sources and statistical uncertainties in order to utilize such simulations in a risk analysis framework
- Data:
  - Archival of, and access to, simulation data/ outputs performed in a research environment for 3rd parties (easier to solve than the computation problem)

Acknowledgements

the ROYAL SOCIETY of NEW ZEALAND
TE APĀRANGI

MARSDEN FUND
TE PŪTEA RANGAHAU A MARSDEN

EQC

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

NHRP

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HIKINA WHAKATUTUKI

NeSI
New Zealand eScience Infrastructure

NSF

CERA
Canterbury Earthquake Recovery Authority

SCEC
an NSF+USGS center

USGS
science for a changing world

IBM

Thank you for your attention

https://sites.google.com/site/brendonabradley/
brendon.bradley@canterbury.ac.nz

Collaborations: