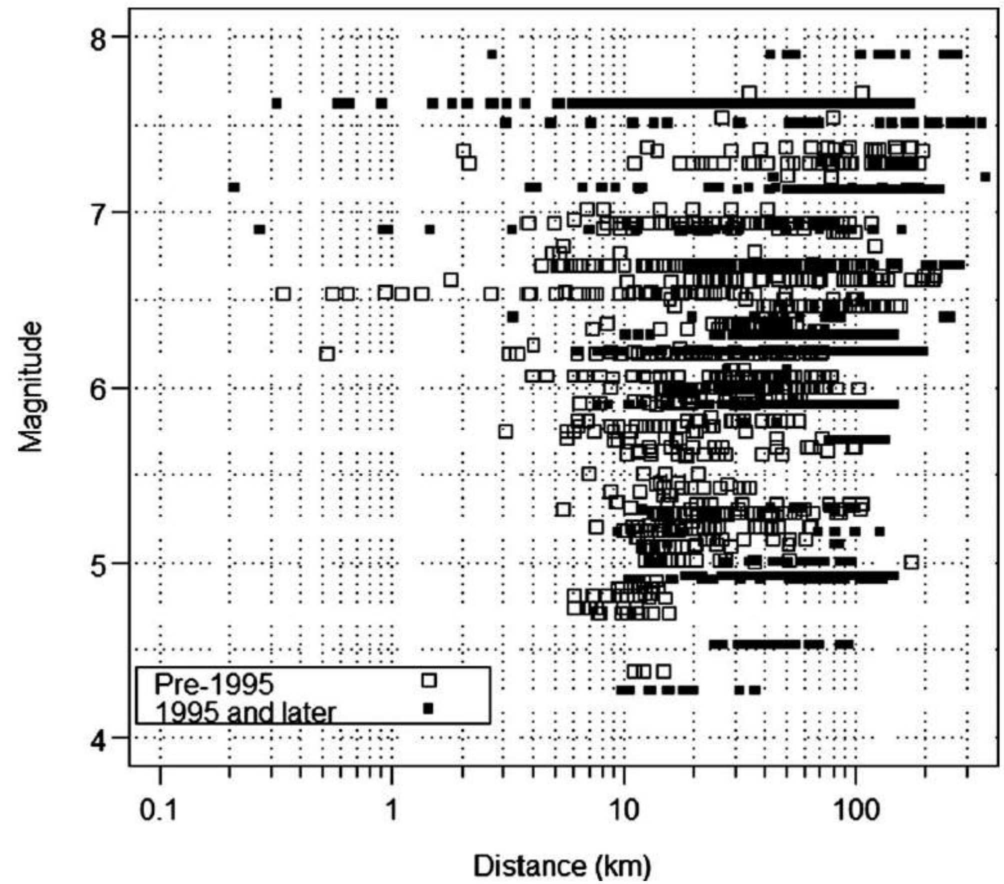
# Guidance on the utilization of earthquake-induced ground motion simulations in engineering practice

## Simulation basics

# The need for GM simulations

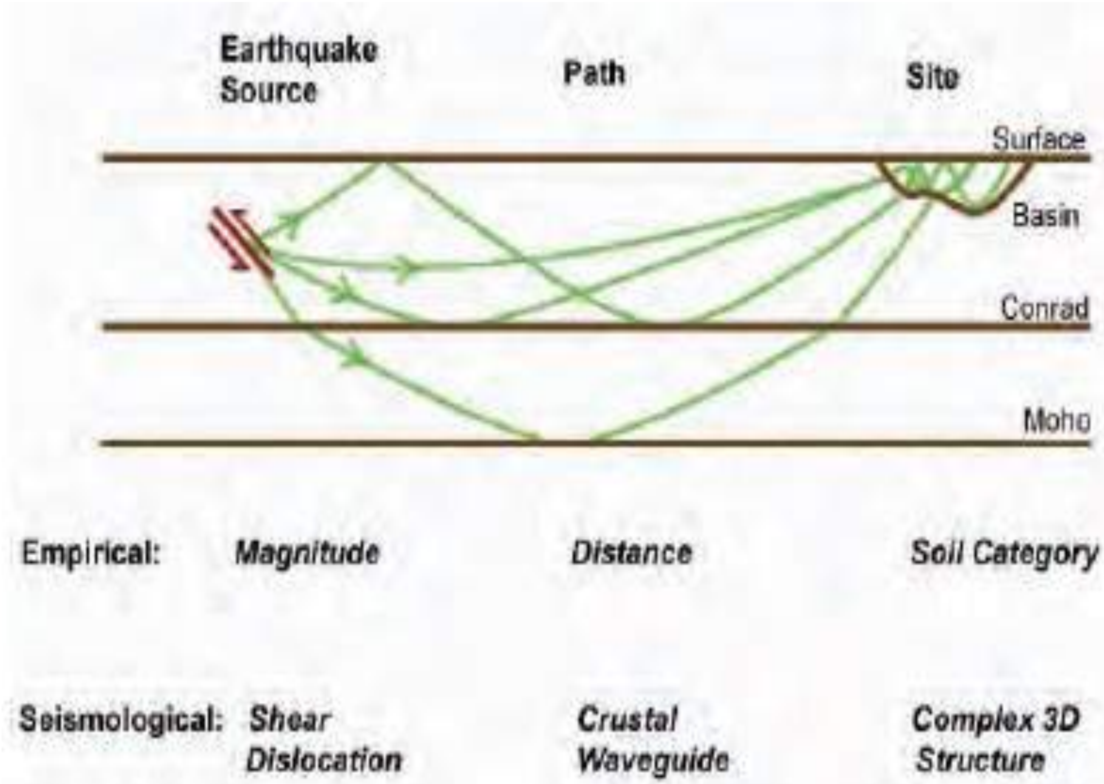
- Lack of as-recorded ground motions
    - Few large Mw
    - Few small Rrup
- Implications:
    - Empirical models poorly constrained for such scenarios
    - Difficult to find appropriate time series to use in dynamic analyses



# Advantage of physics-based site-specific simulations

- Enables modelling of complex rupture, and regional- and site-specific wave propagation and site response;

- As compared to simplified empirical models and recorded ground motions from elsewhere



# Key simulation considerations

- Governing wave equation

$$\rho \frac{\partial^2 u_i}{\partial t^2} = \partial_j \sigma_{ji}$$

**Conservation of momentum**

$$\sigma_{ij} = \lambda \delta_{ij} \partial_k u_k + \mu\left(\partial_i u_j + \partial_j u_i\right)$$

**Constitutive relation (stress-strain)**

# Numerical solution of the wave equation

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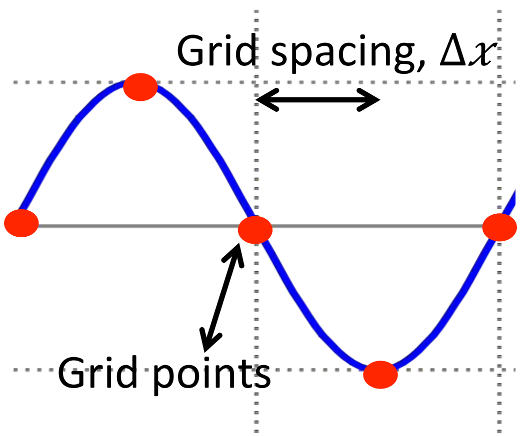
- Finite Difference (FD) – approximate the derivatives using finite differences
- Finite Element (FE) – approximate the solution of the PDE (using elements with basis functions)
- Spectral Element (SE) – high order finite element solution using high degree polynominals as basis functions

# Maximum frequency of simulation

- Discretization means that there is a limit to the maximum frequency that can be considered.
  - This is the same as how the time step in a ground motion affects the maximum (Nyquist) frequency
- In order to accurately simulate a particular frequency, N points are usually required per wavelength (N depends on the type of numerical solution and order)




maximum frequency

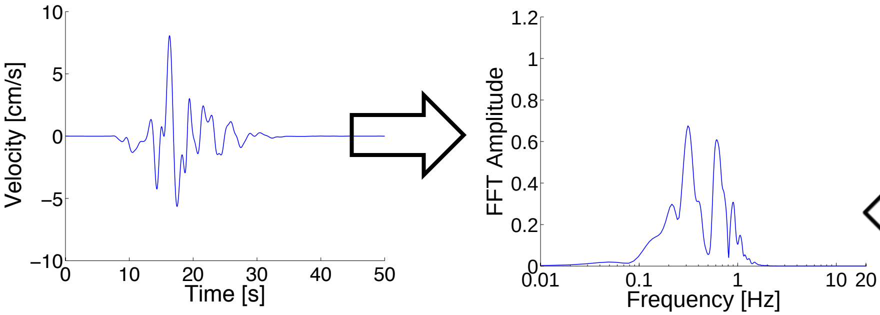
$$f_{max} = \frac{V_s}{N\Delta x}$$

# *Hybrid broadband* simulations

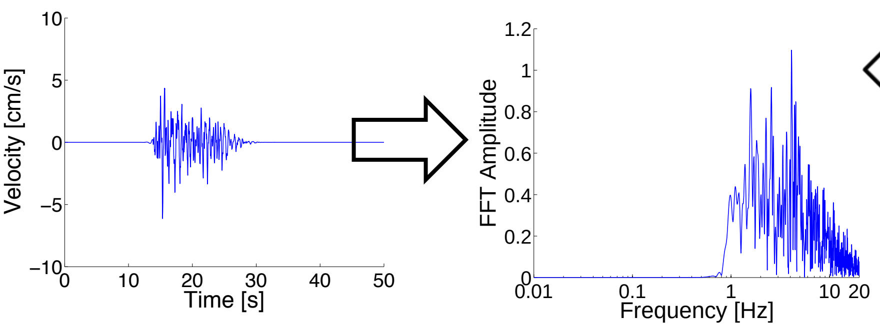
- Most physics-based simulations limited to low frequency (typ $f_{max} \leq 1 Hz$).
- Due to: (i) computational demands; but also inability to accurately model (ii) the 3D velocity structure; and (iii) the earthquake source at wavelengths required for high frequency simulations
- Consequently in order to simulate *broadband* ground motions (high and low frequencies) it is necessary to use different simulation methods for each (i.e. a *hybrid* simulation).

# Hybrid broadband

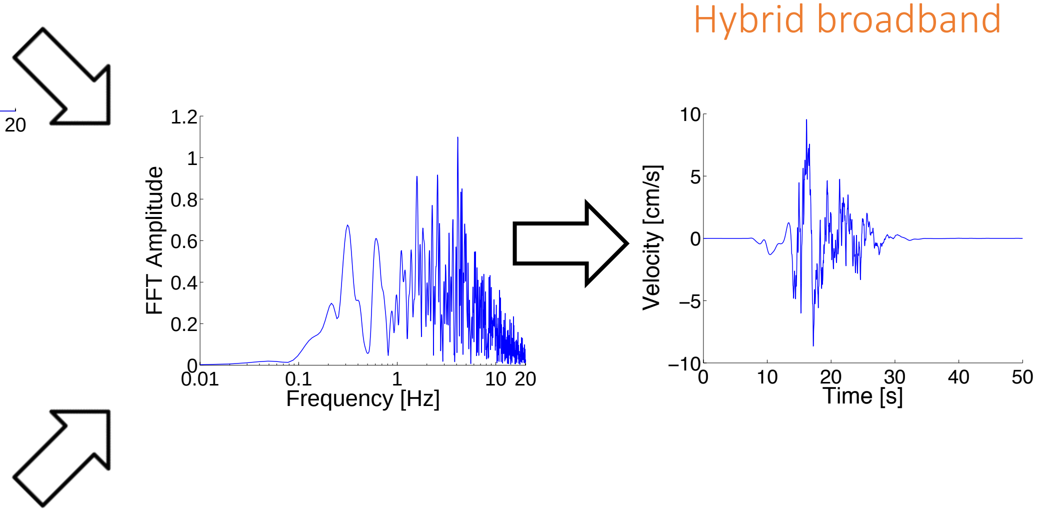
Low-frequency (e.g., kinematic source)




High-frequency (e.g., stochastic finite-fault)




Hybrid broadband




GP (Graves & Pitarka, 2010)

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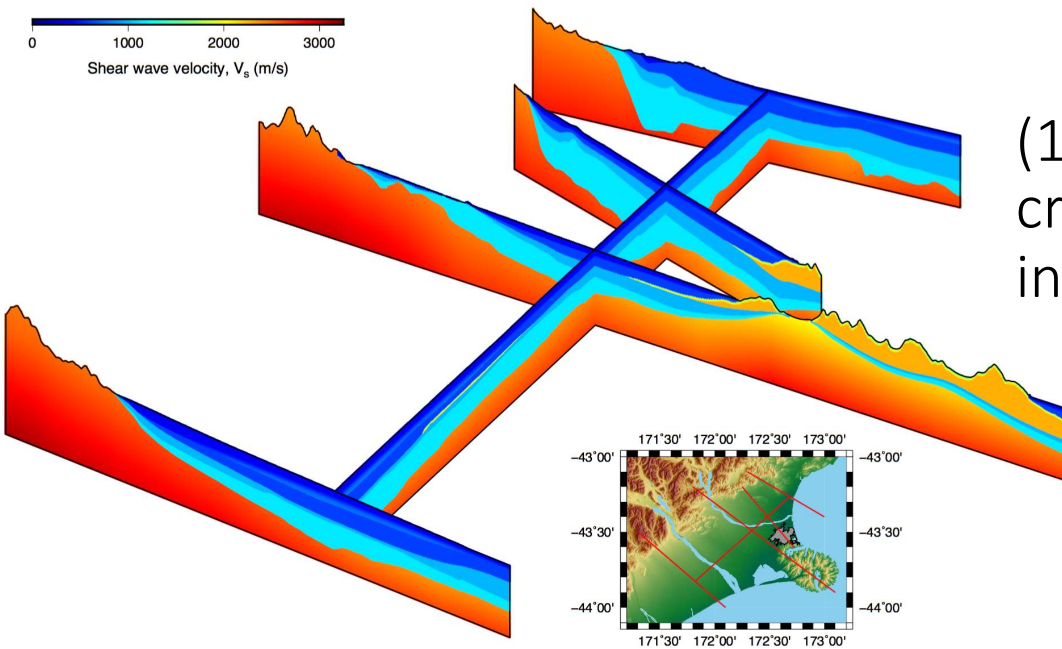
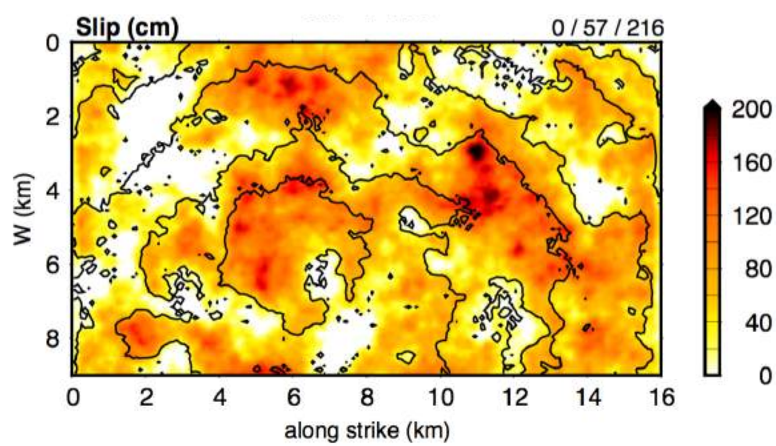
# Ingredients for physics-based ground motion simulation

Key Ingredients:




(1) A model for the earth's crust in the region of interest

(2) a model that describes the earthquake rupture on the fault(s)



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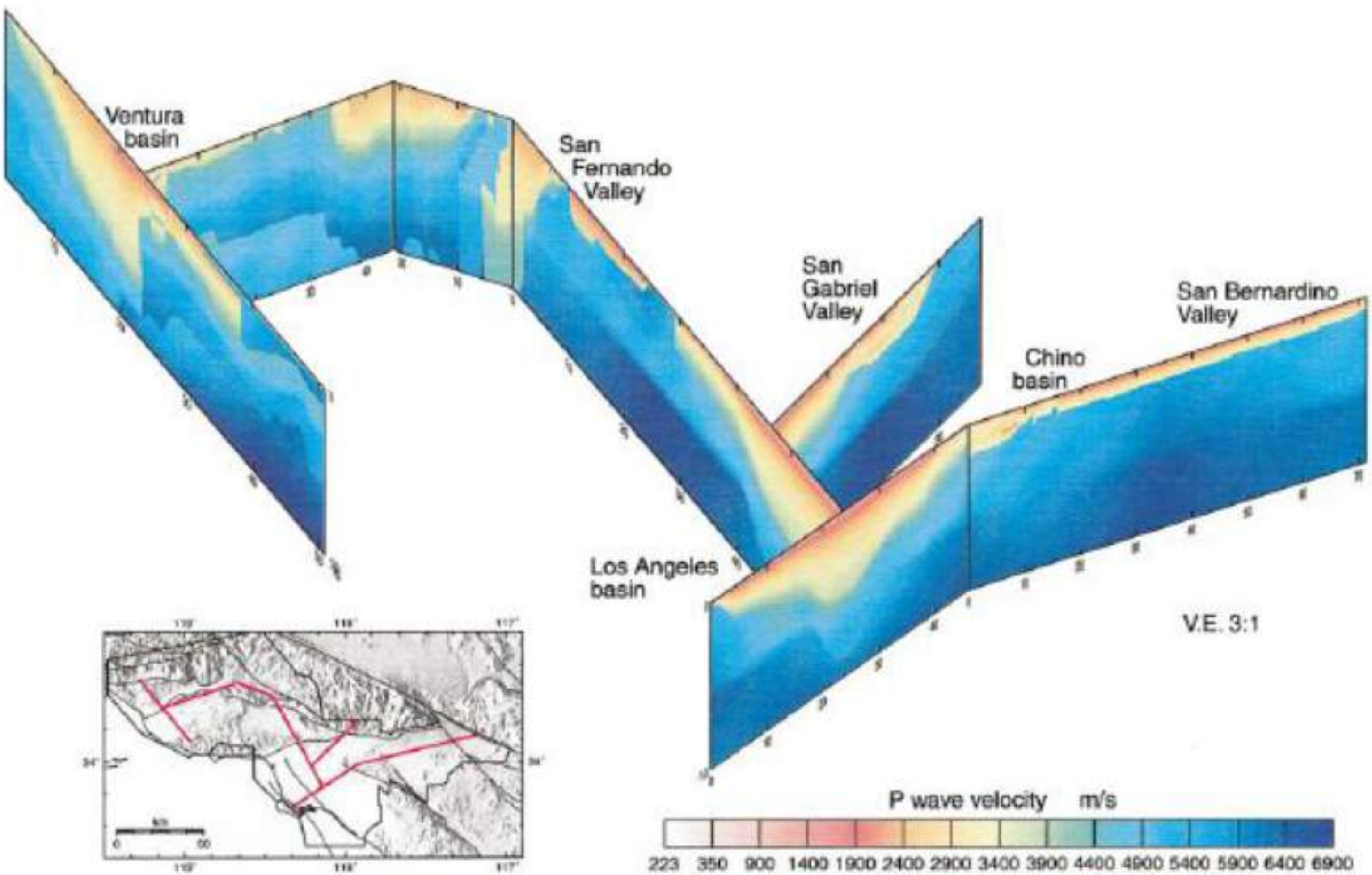
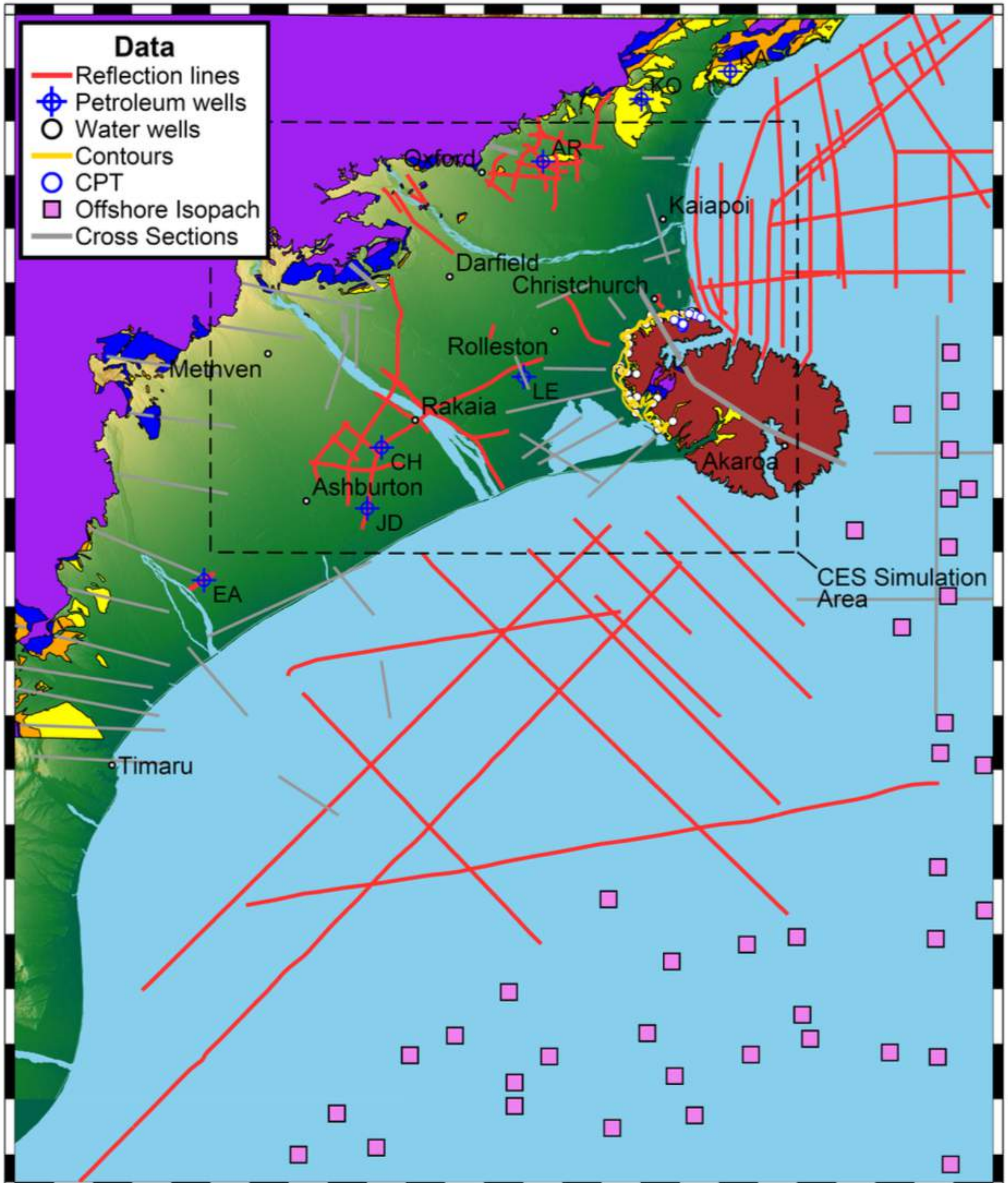
# Development of 3D velocity models

- Multi-disciplinary datasets at different depths and different spatial resolutions






# Example: different data used in Canterbury Velocity Model

# Data sets lead to development of geologic surfaces

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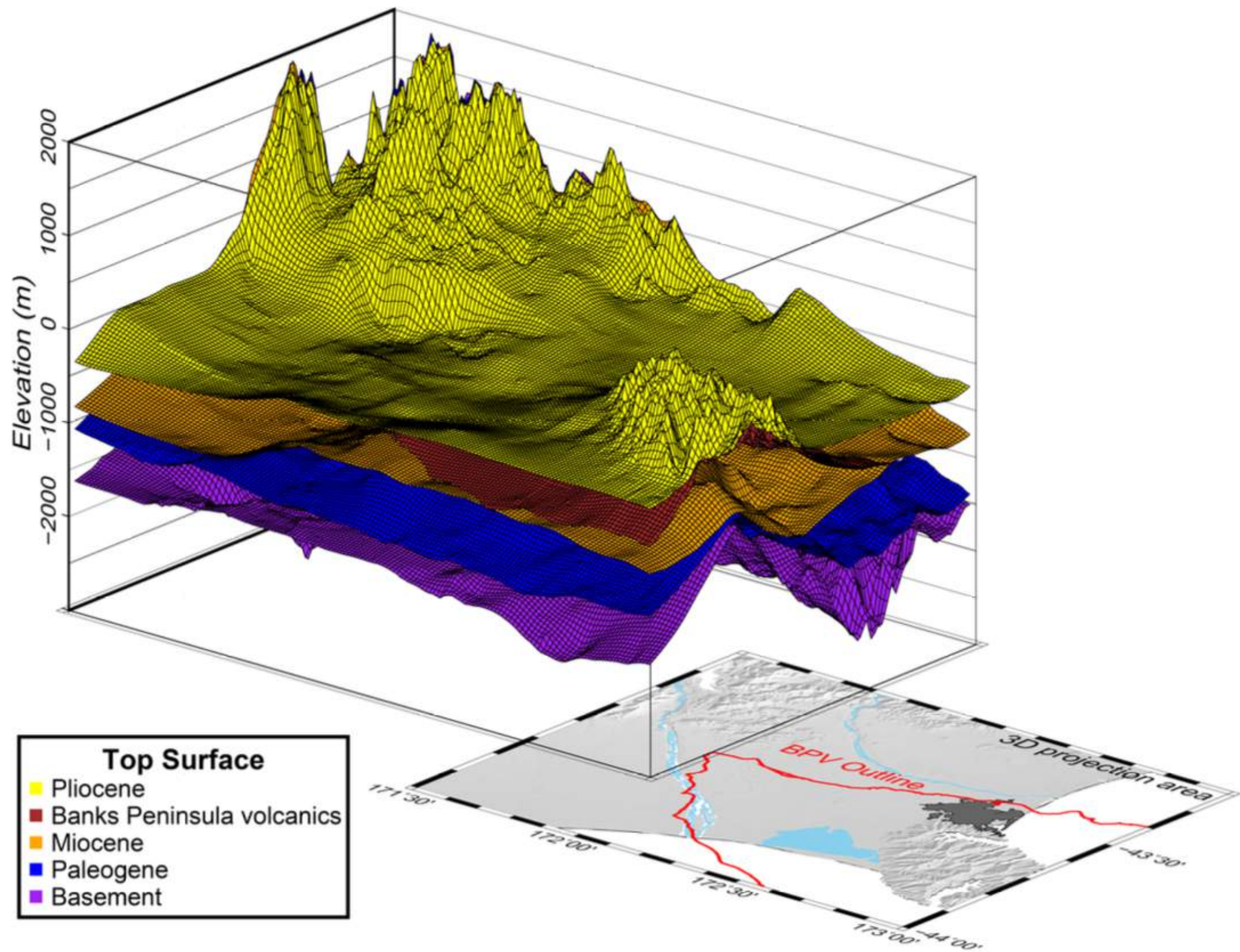

# Combine with geologic unit-specific constitutive models

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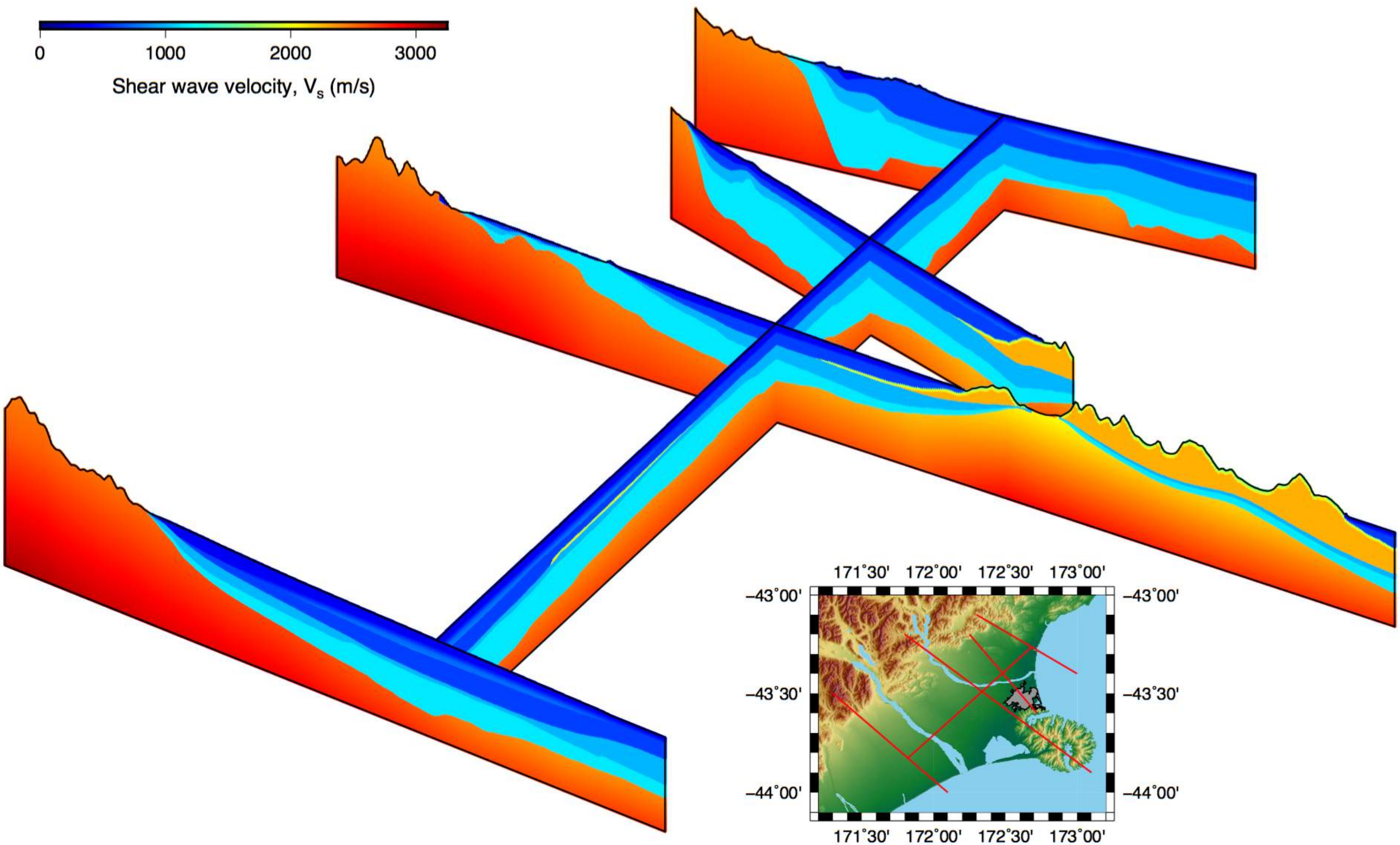

# Representation of the earthquake source

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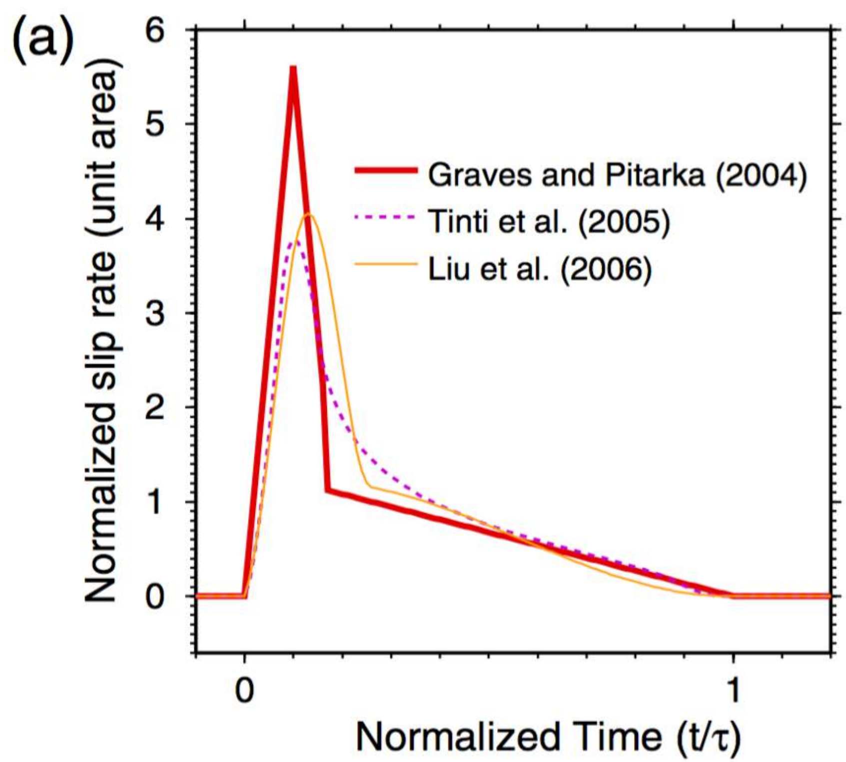
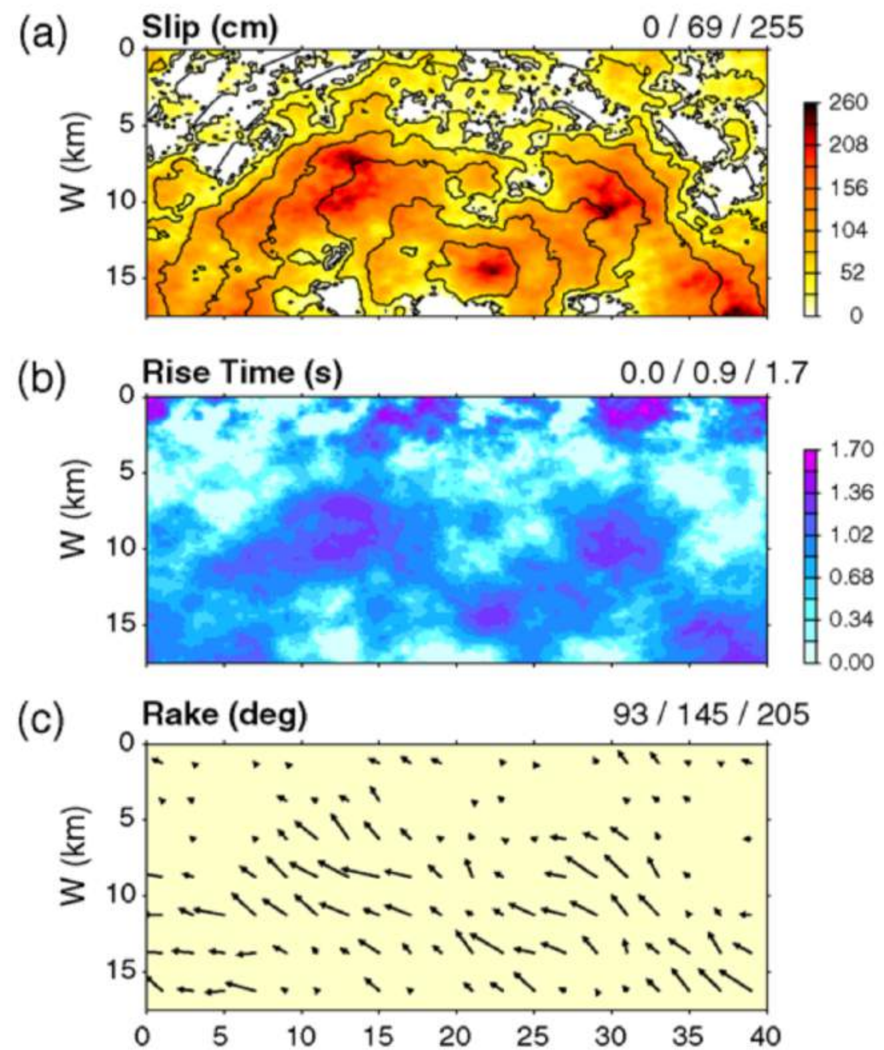
- The earthquake source rupture represents the ‘initial disturbance’ in the wave propagation problem.
- Need to define:
  - Geometry
  - Kinematics
  - Dynamics
- Can represent source in two ways using so-called 'Kinematic' and 'Dynamic' approaches

# Kinematic source representation

- Prescribe:
- (i) Slip amplitude and direction (rake)
- (ii) rupture initiation time
- (iii) rise time over which rupture occurs
- (iv) variation of slip with time (slip function)



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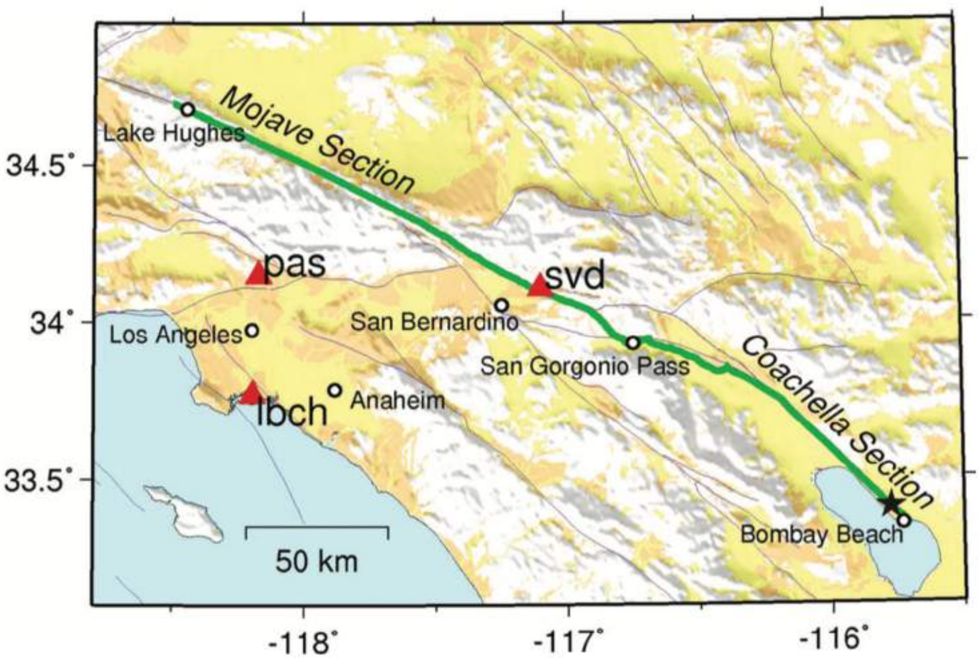
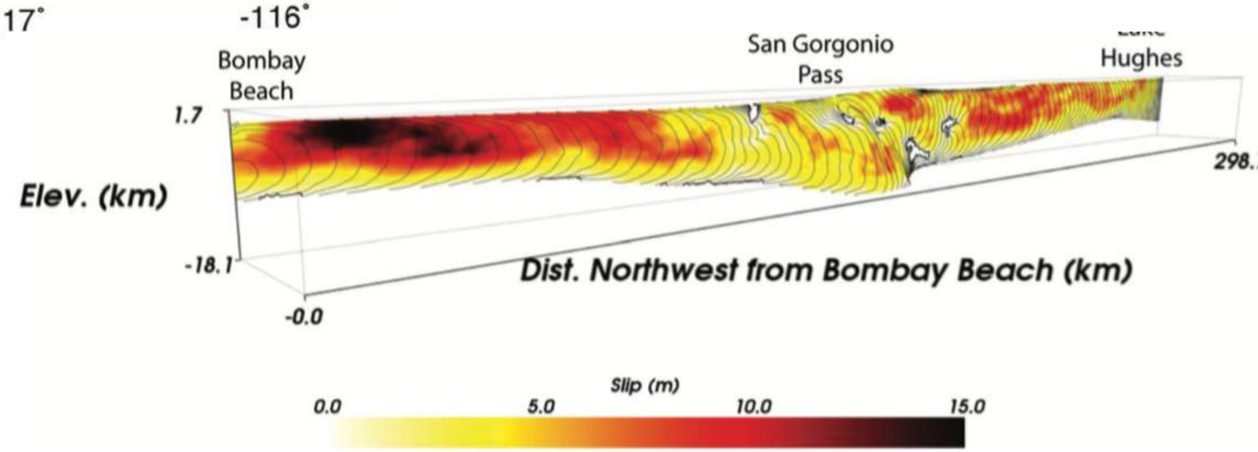
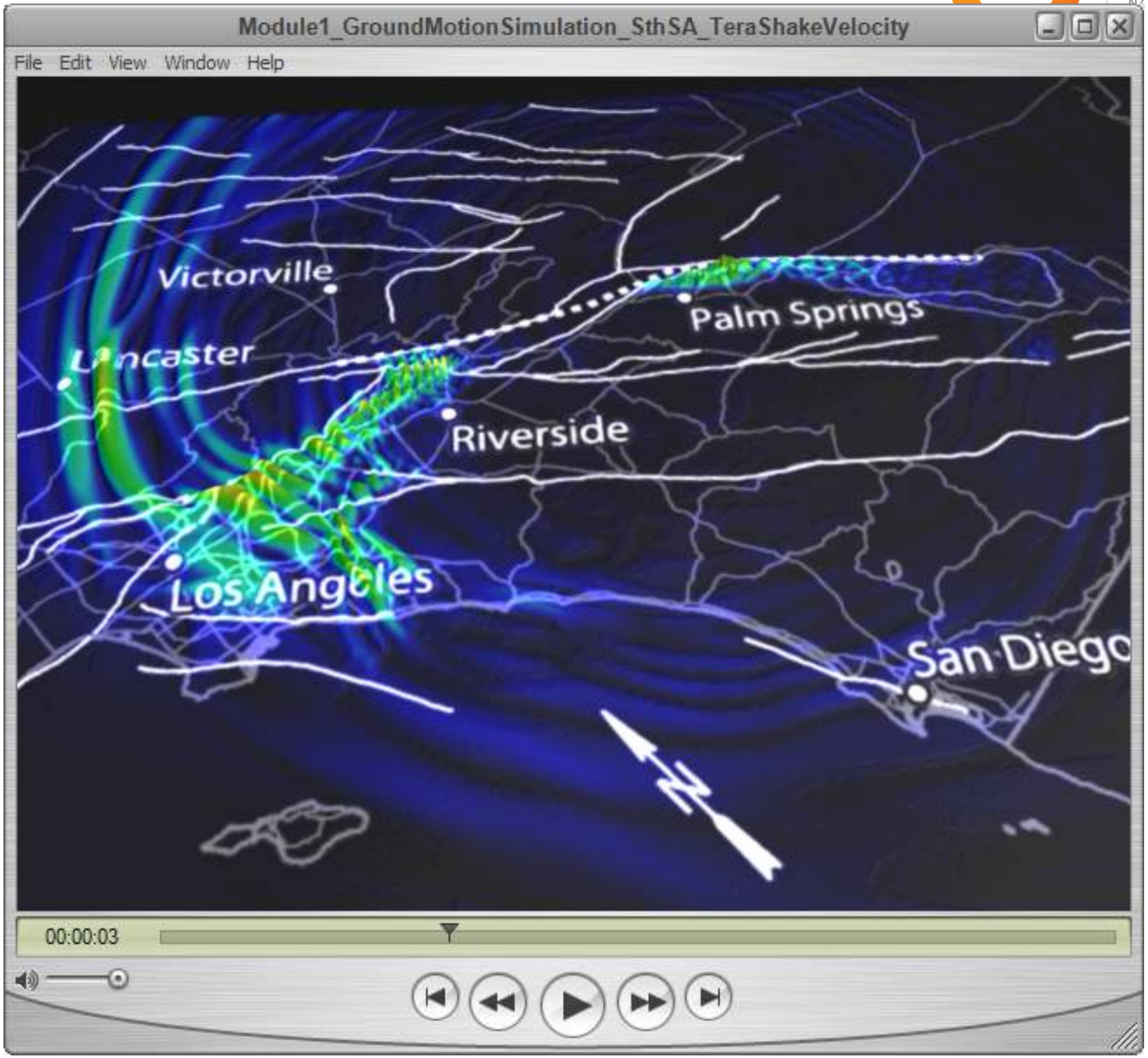
# Examples of ground motion simulation

- A full rupture of the Sth San Andreas Fault




Module1_GroundMotionSimulation_SthSA_TeraShakeVelocity
File Edit View Window Help
Victorville
Palm Springs
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Los Angeles
San Diego
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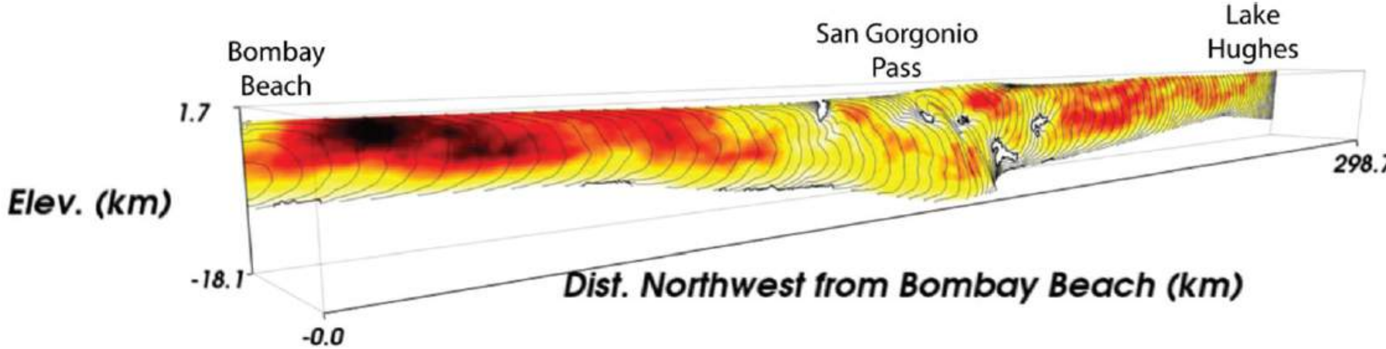
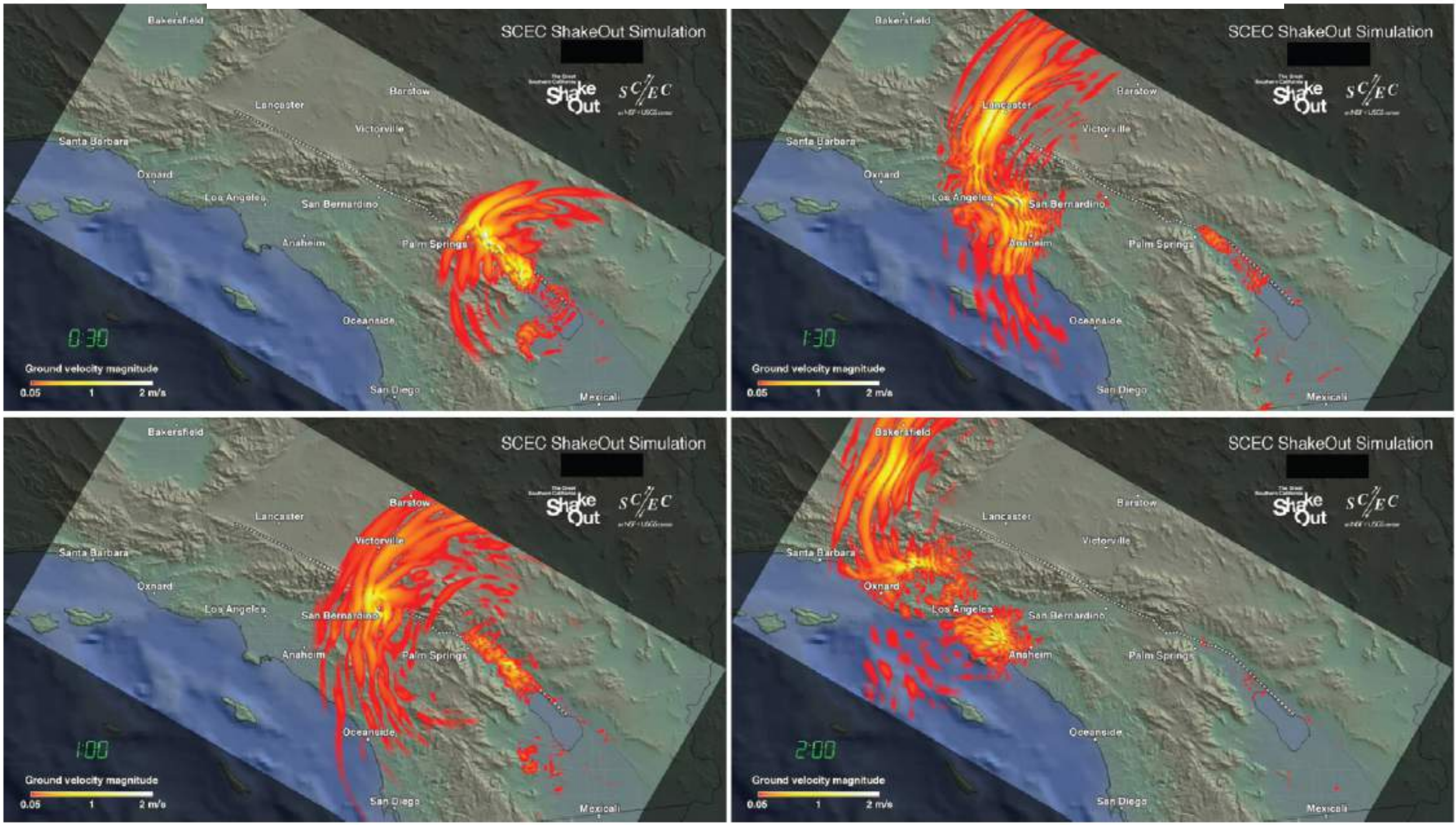
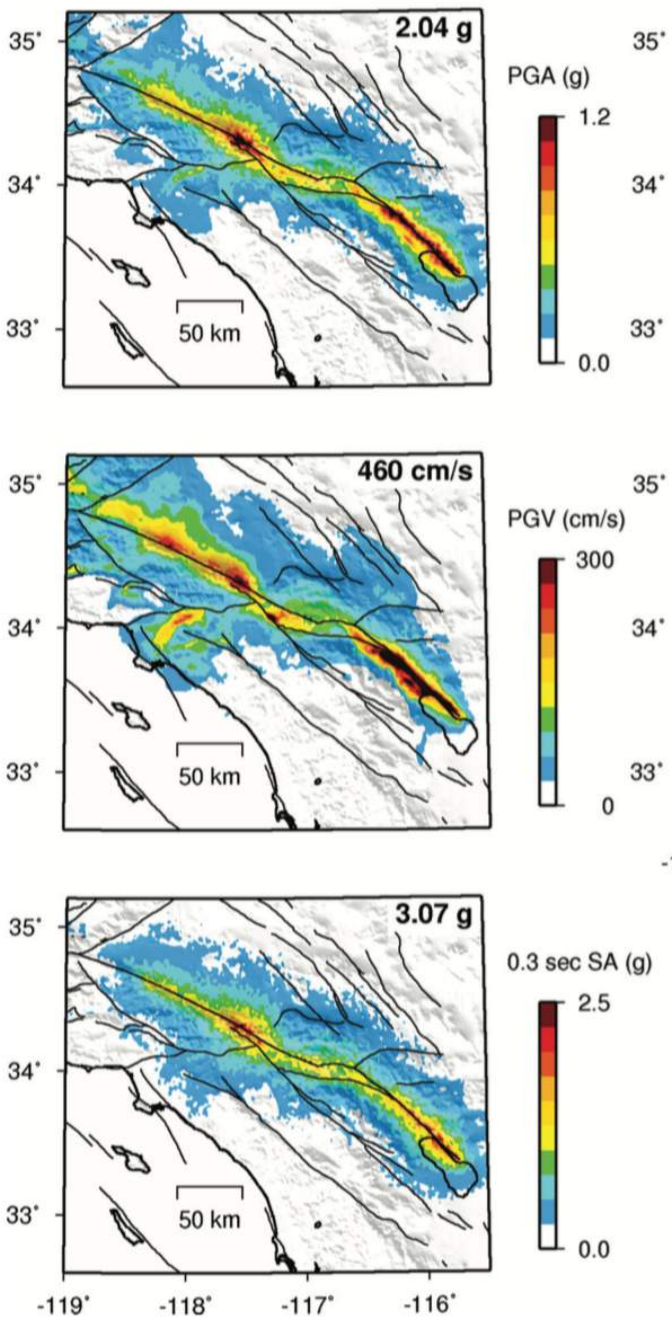


# RWG ShakeOut (v1.2.0)

Broadband (0-10 Hz)

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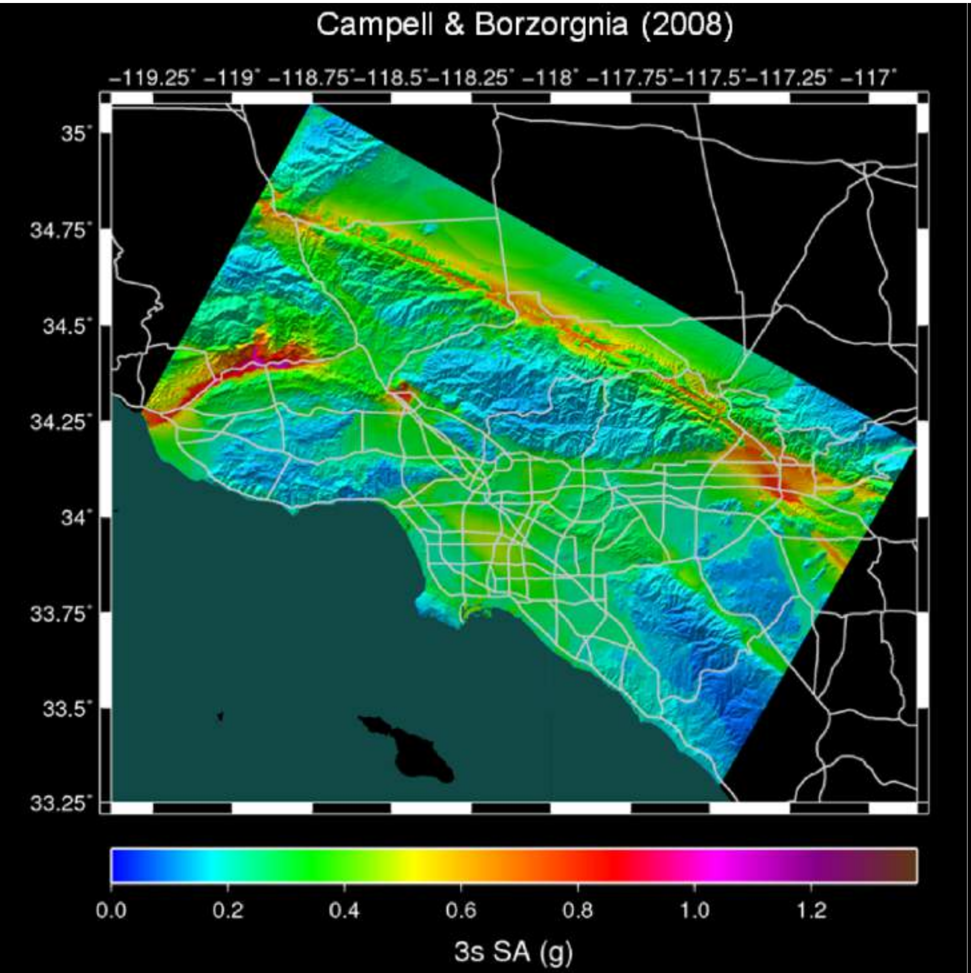
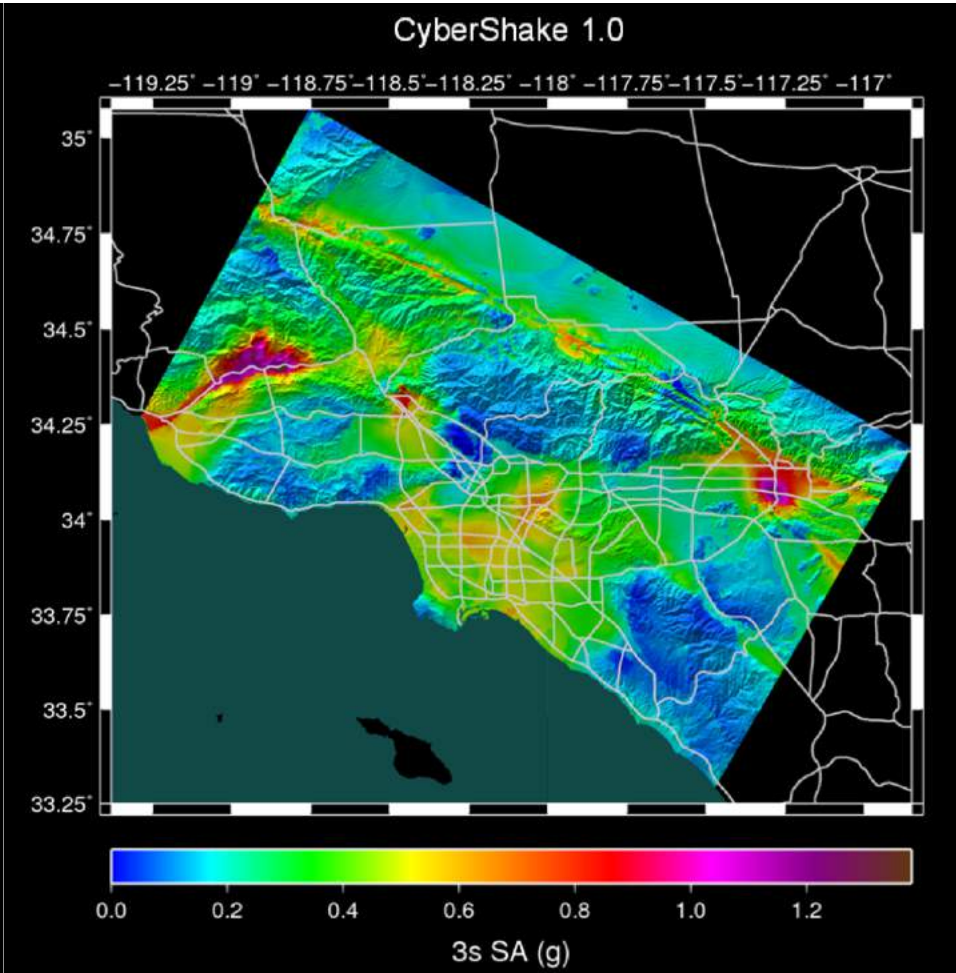
**Empirical**

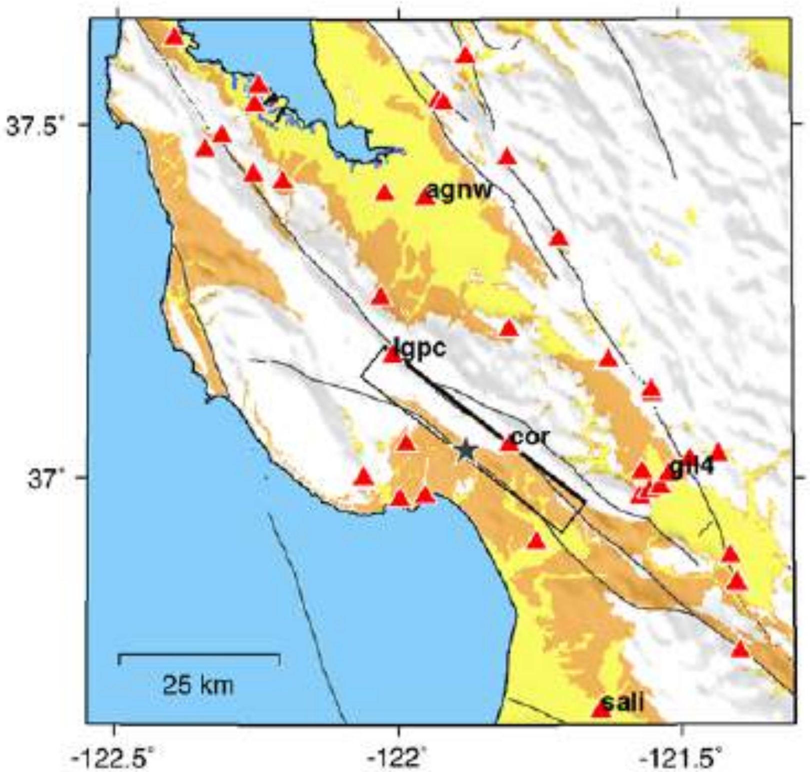
**Physics-based**

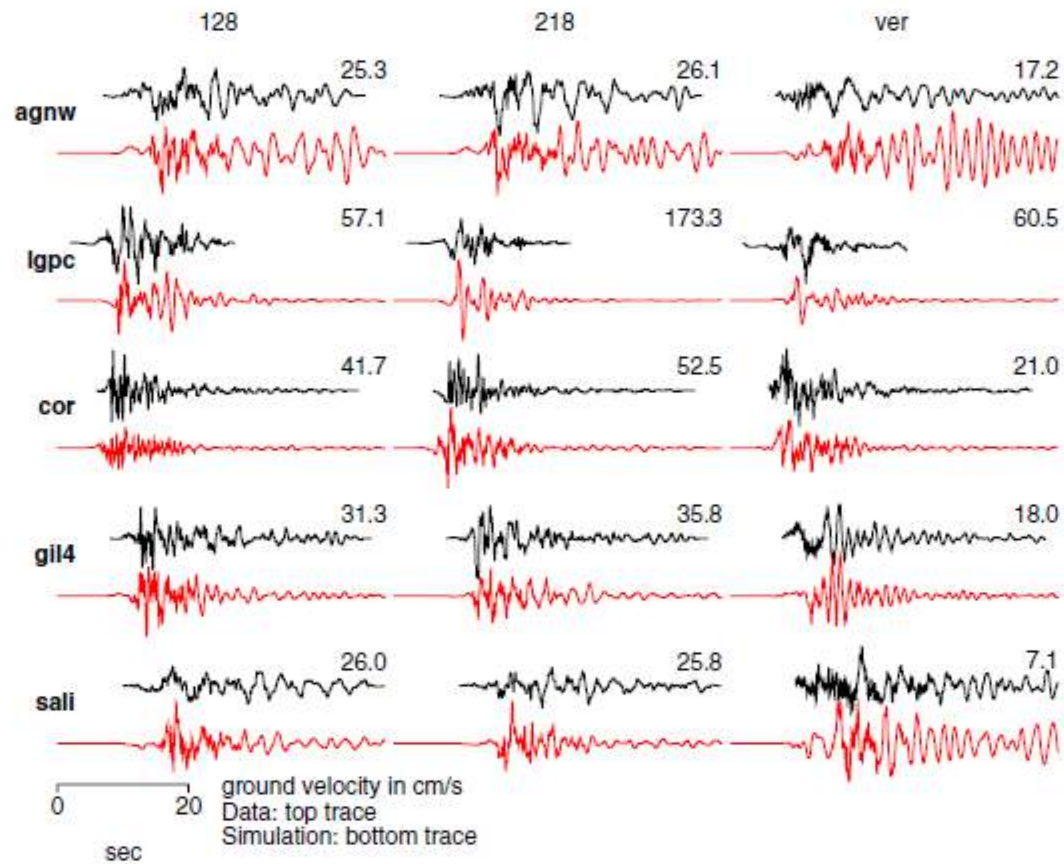


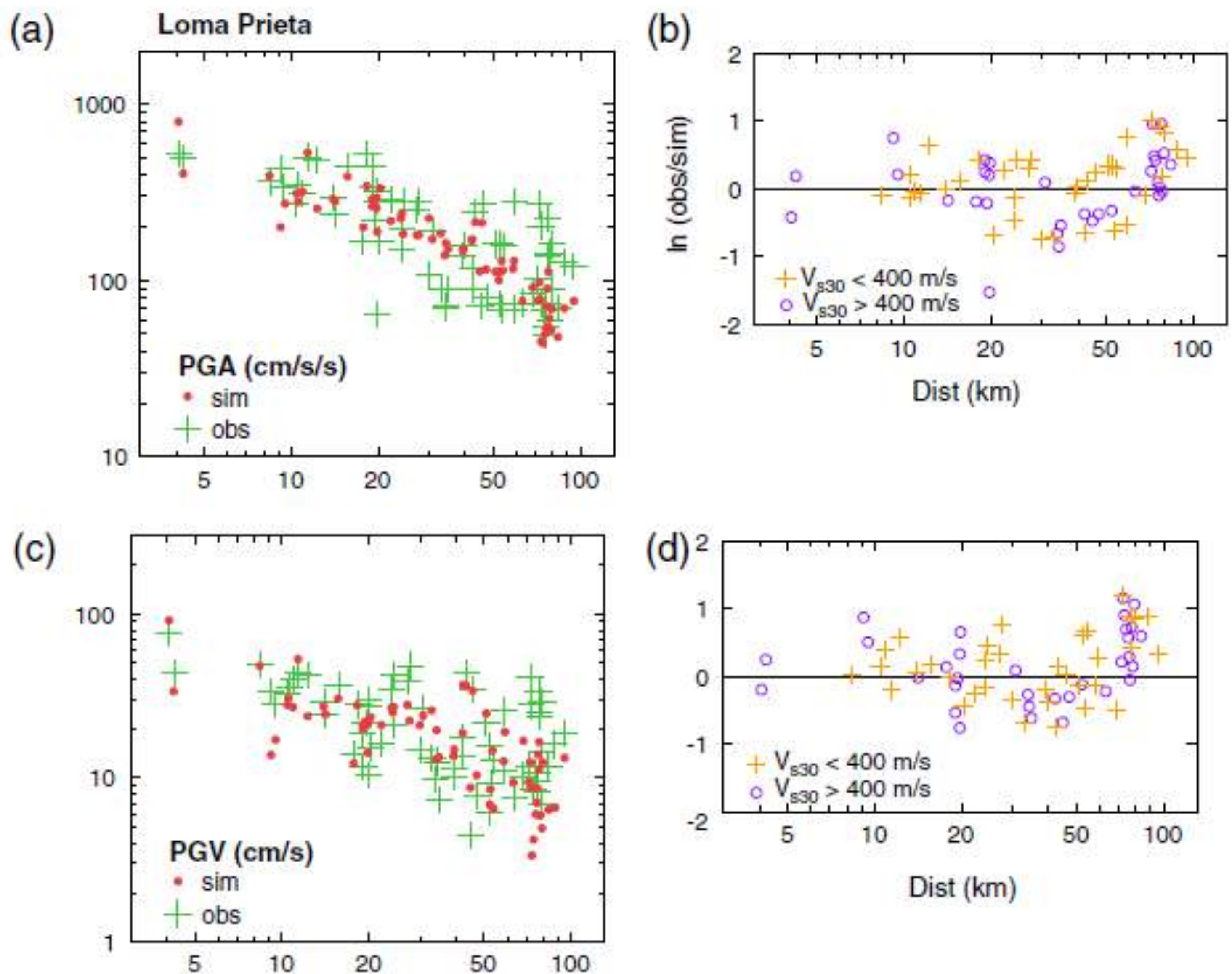
# The 1989 Loma Prieta Eq (Graves and Pitarka, 2010)

Qualitative validation based on waveforms between prediction and observations



# Quantitative validation with intensity measures



# Alpine fault rupture

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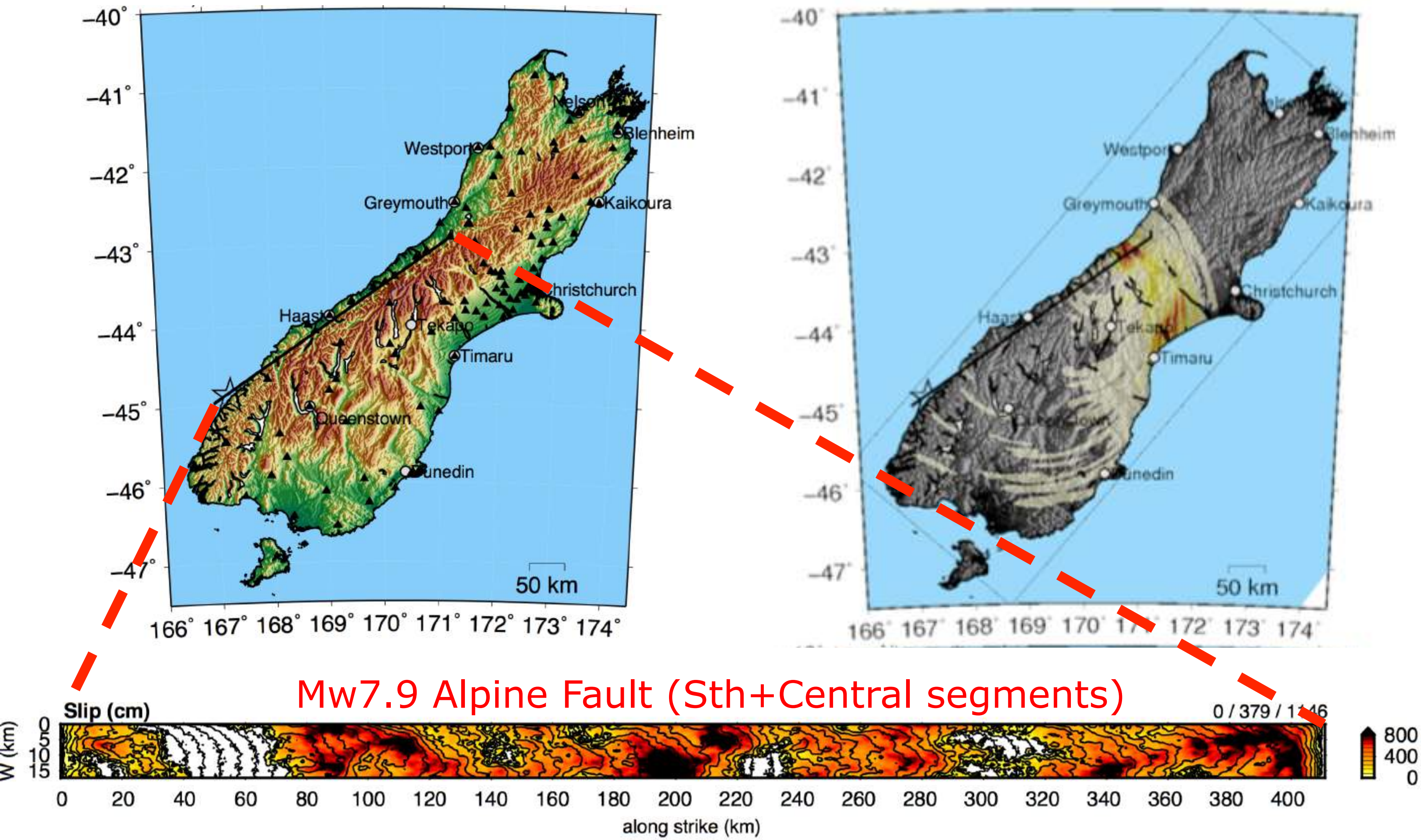
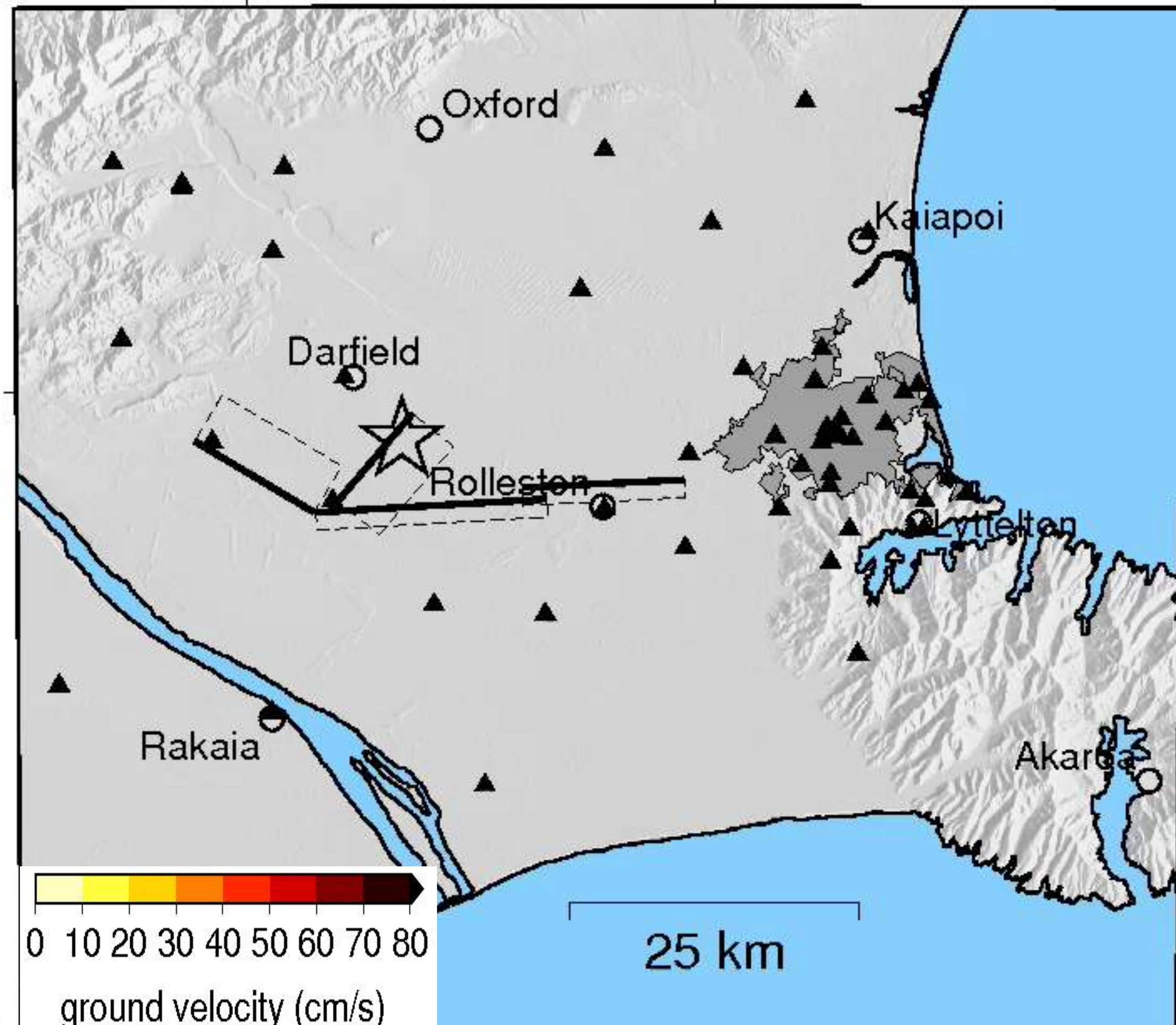


# Mw7.1 4 Sept 2010 Earthquake

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

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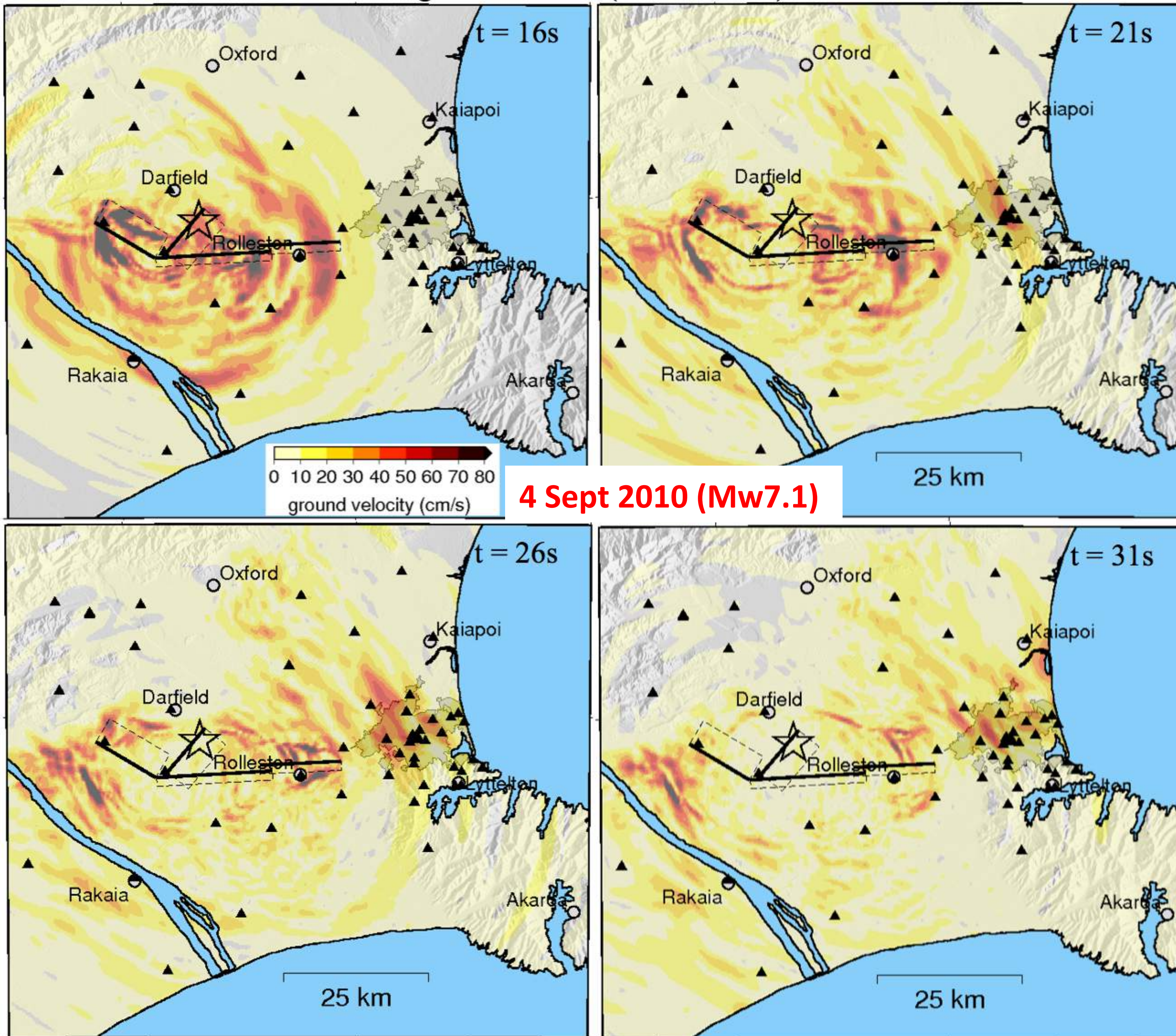
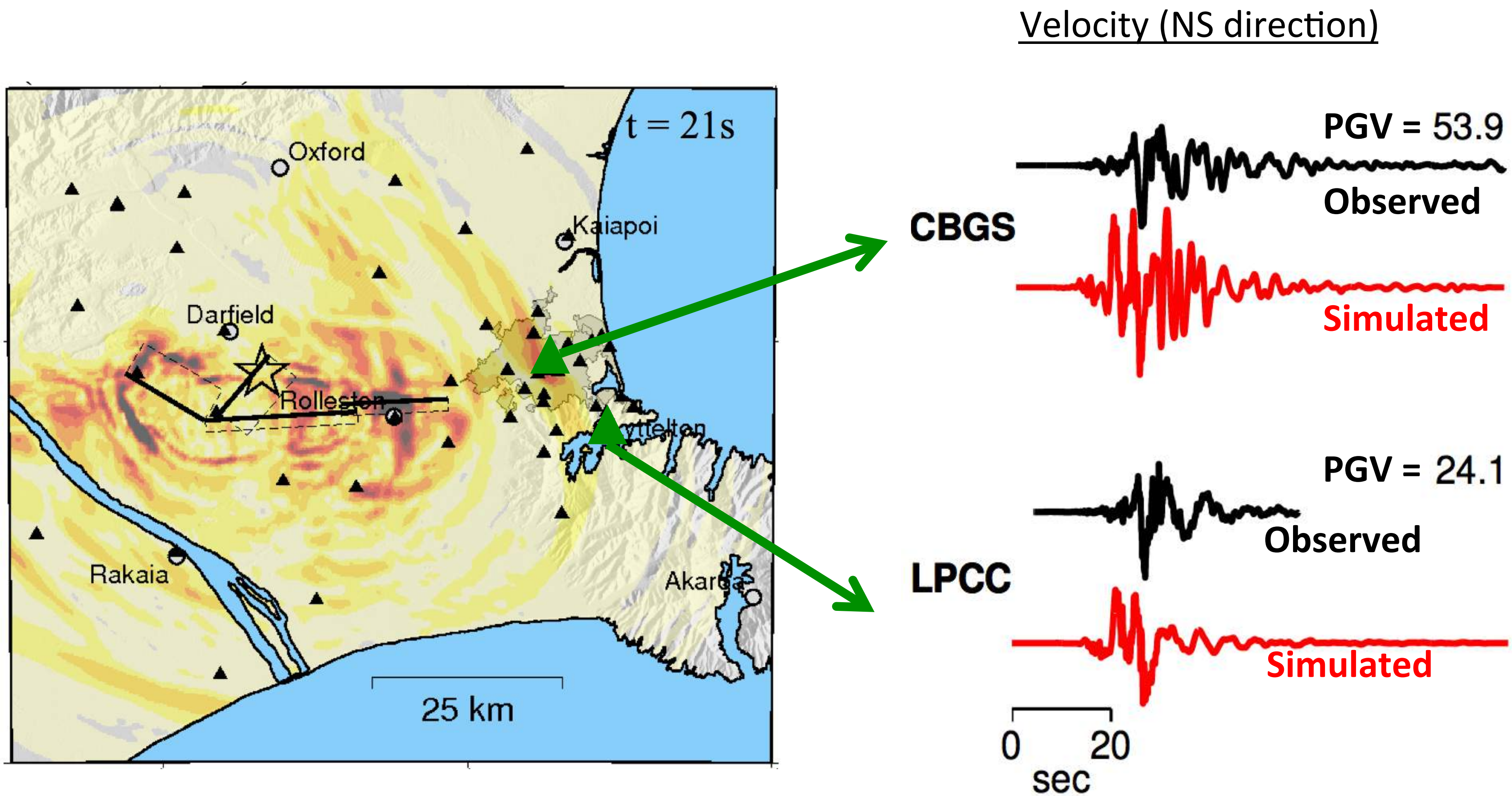
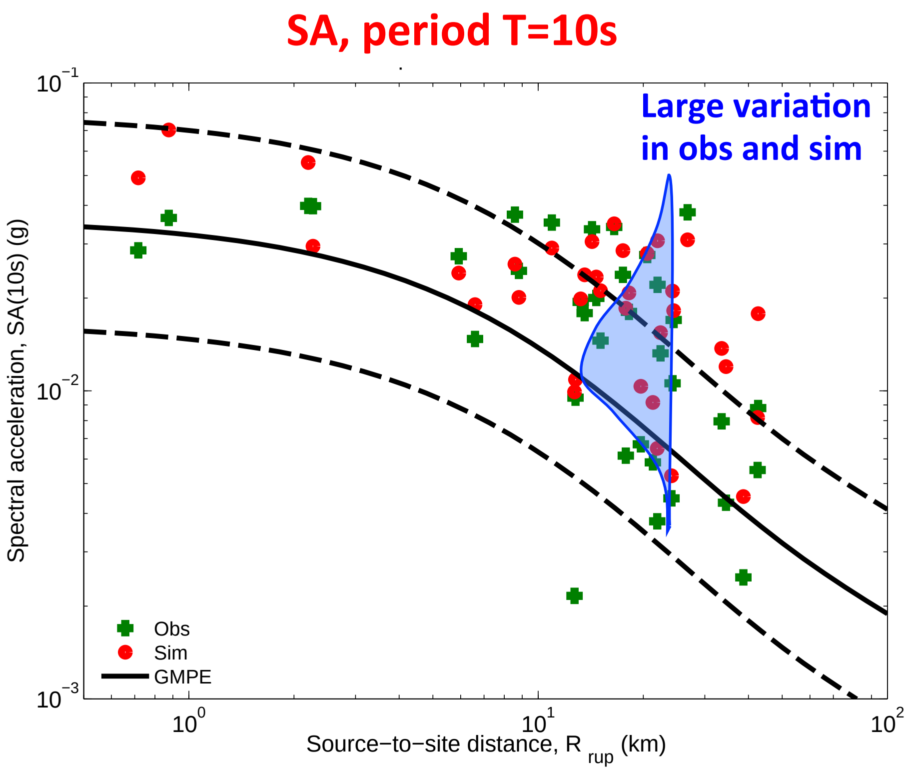
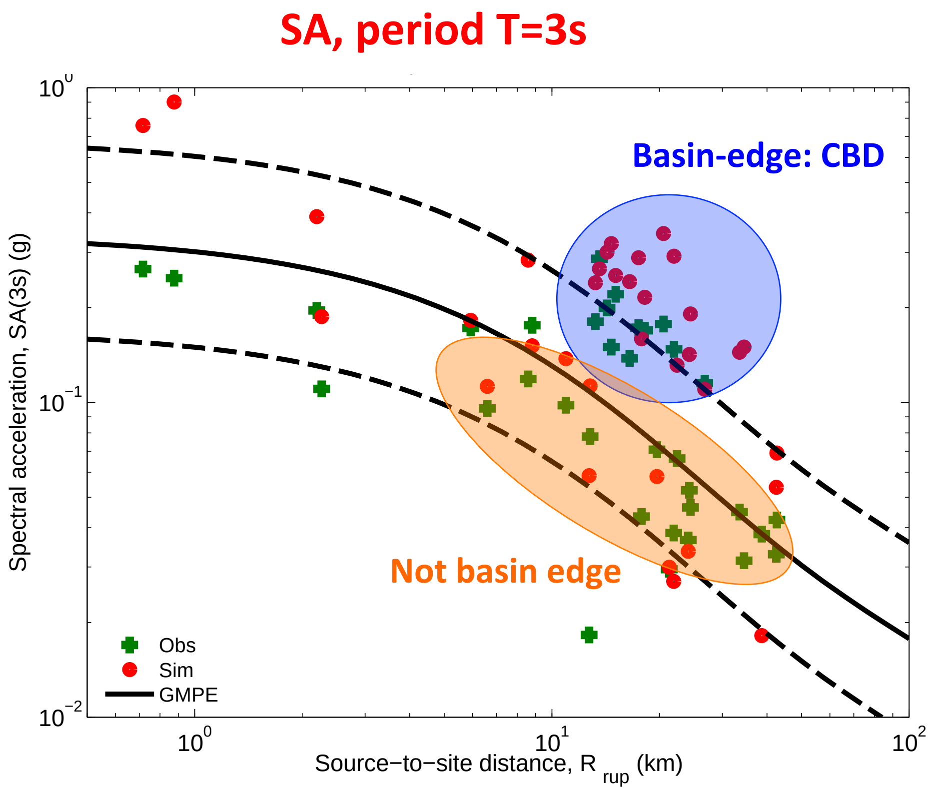

t = 16s
t = 21s
t = 26s
t = 31s
Oxford
Kaiapoi
Darfield
Rolleston
Lyttelton
Rakaia
Akaroa
0 10 20 30 40 50 60 70 80
ground velocity (cm/s)
25 km
4 Sept 2010 (Mw7.1)

# Observed vs Simulated velocity (4 Sept 2010)



Spectral accelerations vs Distance (4 Sept 2010)



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