DETERMINISTIC MODELING OF 3D SEISMIC SCENARIOS: WHEN TECHNICAL CHALLENGE MEETS INDUSTRY REQUIREMENTS

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15th April 2013 – Stuttgart – Germany

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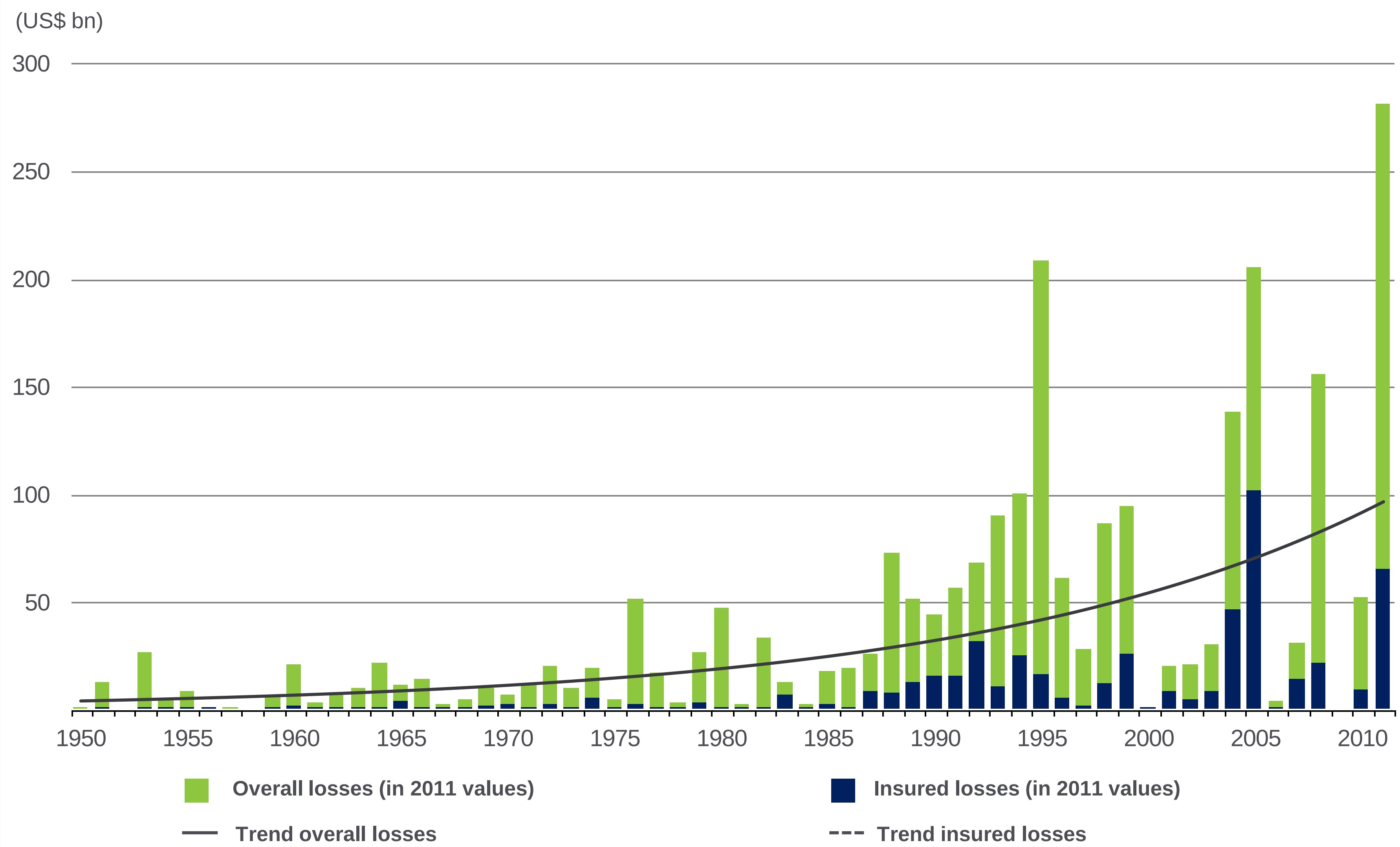
NatCatSERVICE

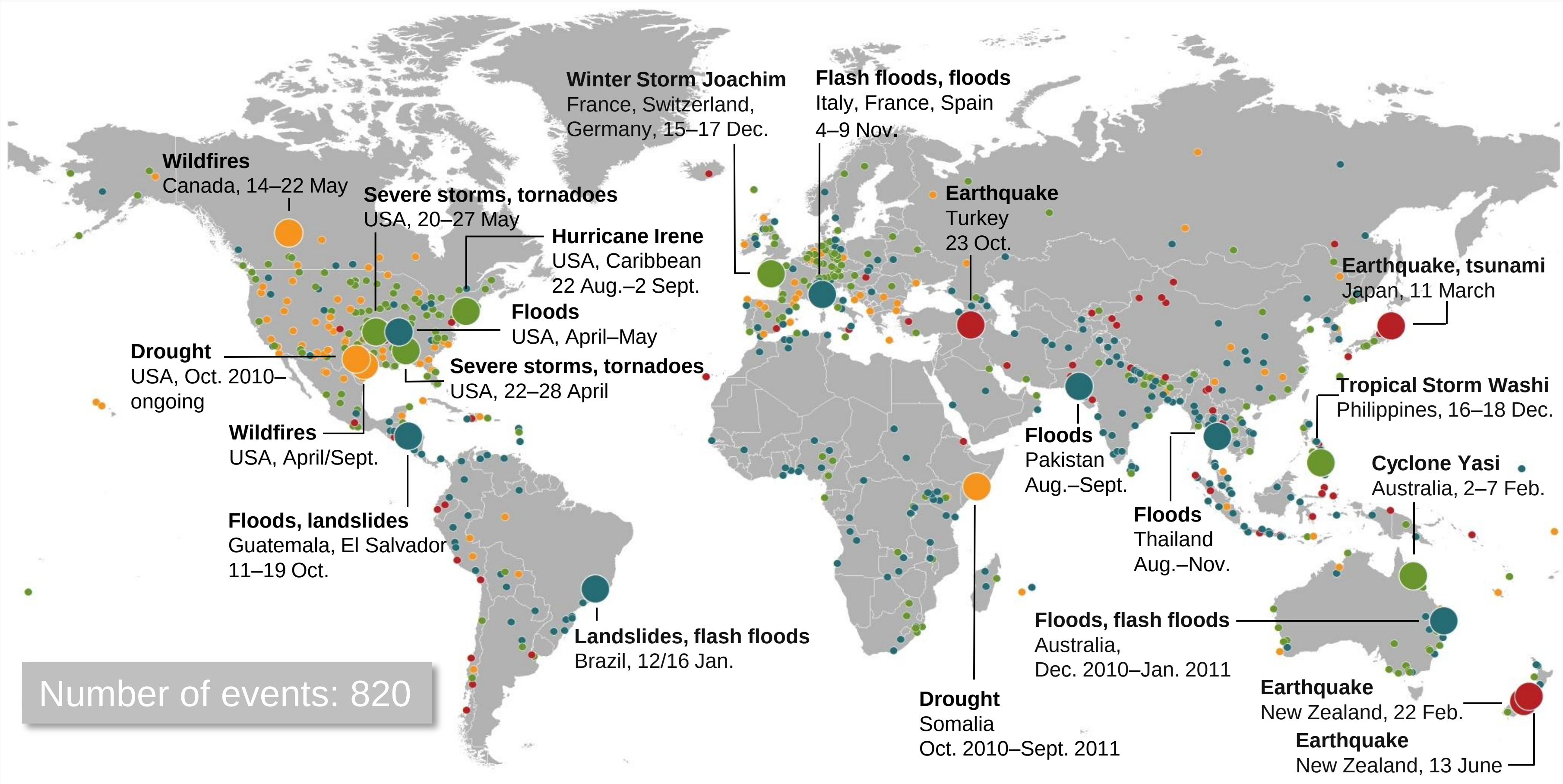
Great natural catastrophes worldwide 1950 – 2011

Overall and insured losses with trend



Natural Catastrophes 2011

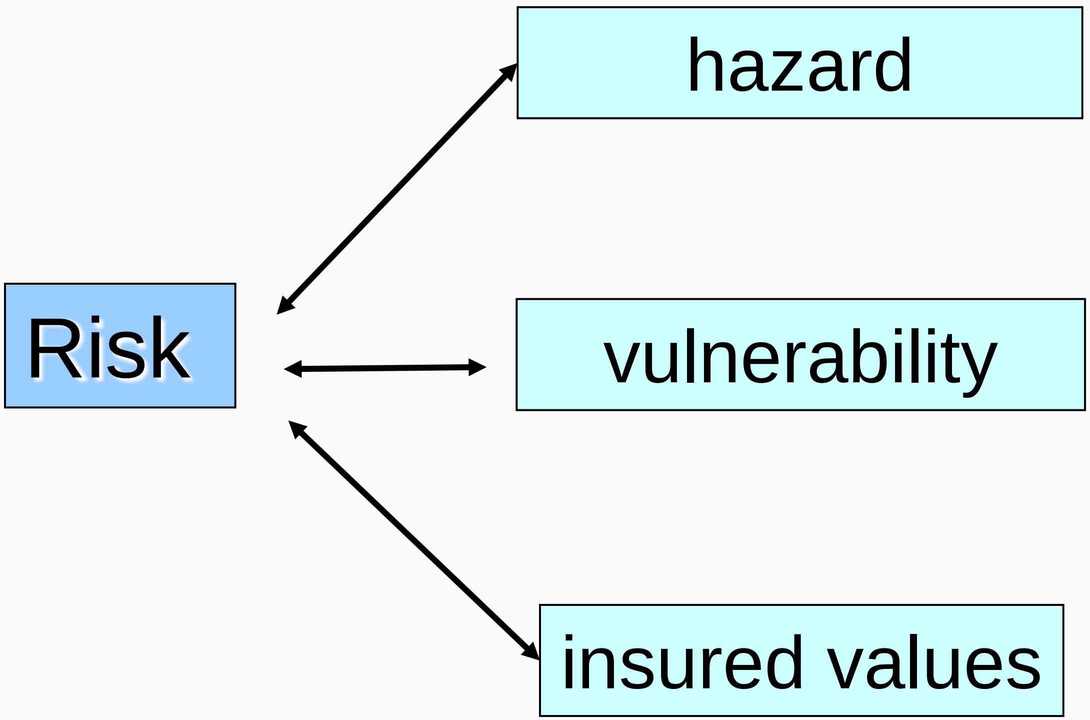
World map



Natural catastrophes	**Geophysical events** (earthquake, tsunami, volcanic activity)	**Hydrological events** (flood, mass movement)
Selection of significant loss events	**Meteorological events** (storm)	**Climatological events** (extreme temperature, drought, wildfire)

2. Hazard

How can we assess the Risk?



NATHAN World Map of Natural Hazards

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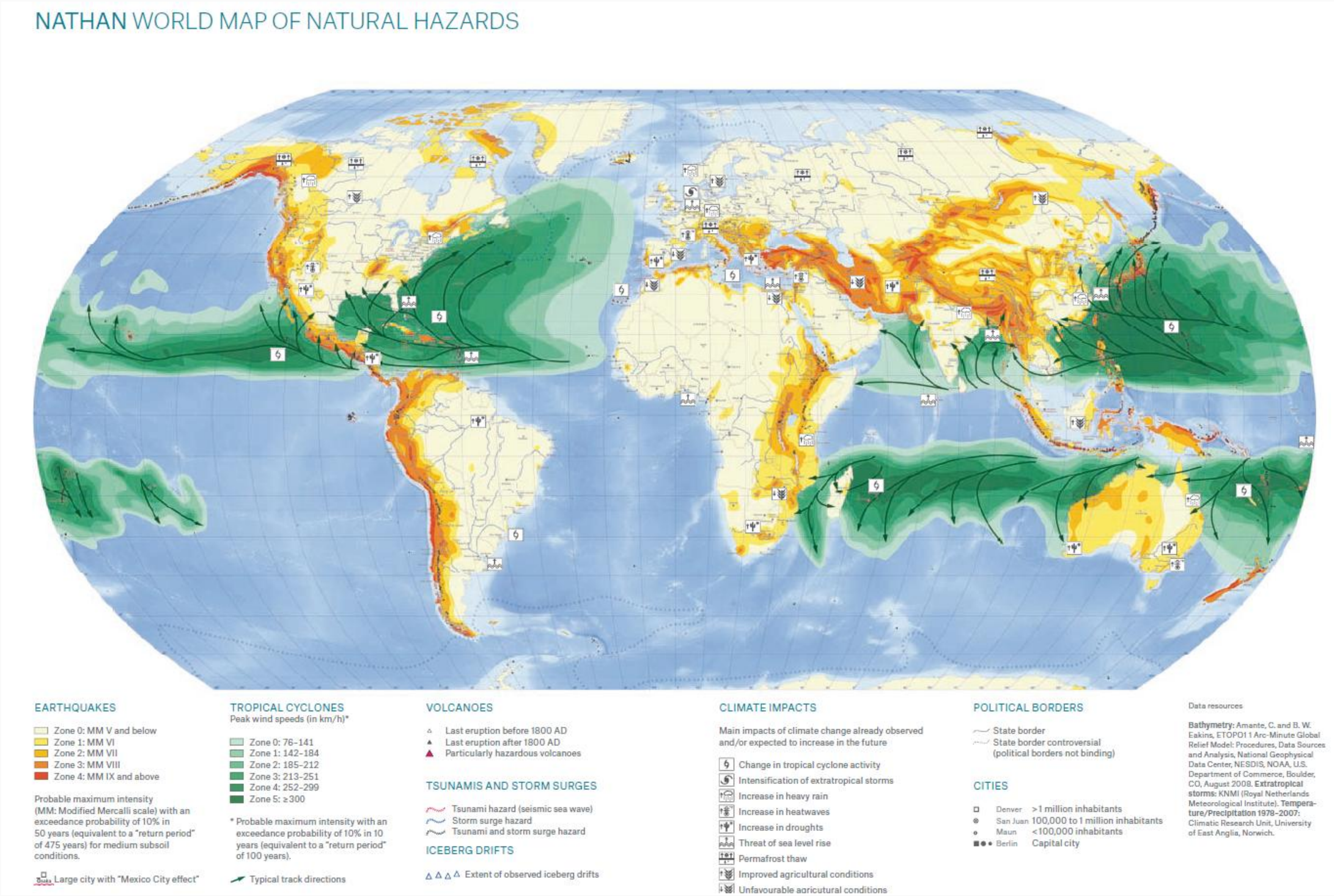
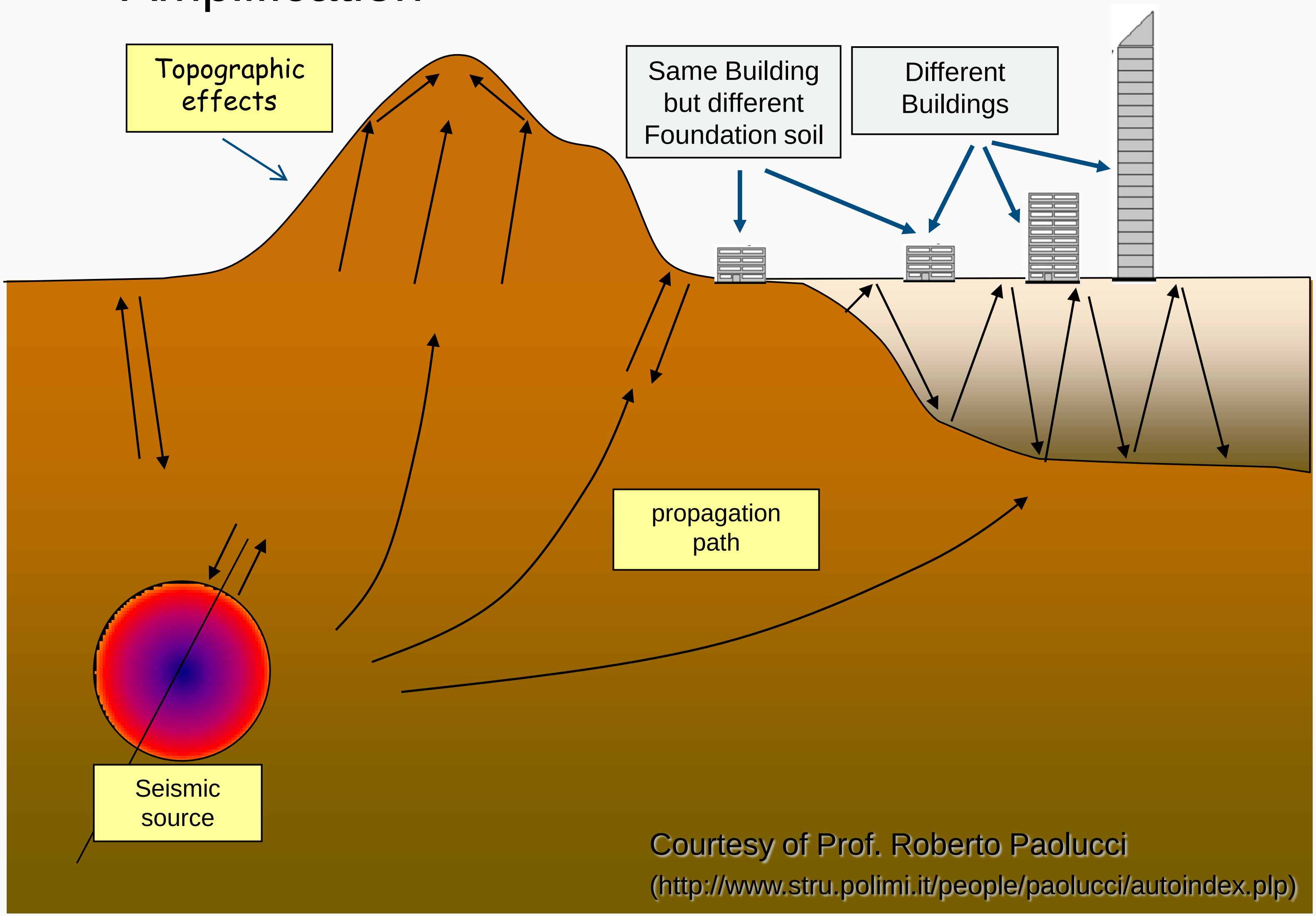


Hazard

Microzonation and secondary effects

Amplification



SPEED high performance numerical code

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The mathematical model

Equilibrium equations for an elastic bounded medium subjected to an external force $\mathbf{f}$

$$\begin{cases} \rho \partial_{tt}\mathbf{u} - \nabla \cdot \underline{\sigma}(\mathbf{u}) + \mathbf{c}(\partial_t \mathbf{u}, \mathbf{u}) = \mathbf{f} & \text{in } \Omega \times (0, T], \\ + \text{B.C.s} & \text{on } \partial\Omega \times [0, T], \\ + \text{I.C.s} & \text{in } \Omega \times \{0\}. \end{cases}$$

- $\mathbf{u}$ displacement of the medium
- $\underline{\epsilon}(\mathbf{u}) = \frac{1}{2}(\nabla \mathbf{u} + \nabla \mathbf{u}^{\top})$ strain tensor
- $\underline{\sigma}(\mathbf{u}) = \lambda \nabla \cdot \mathbf{u}\, \underline{I} + 2\mu \underline{\epsilon}(\mathbf{u}) = \underline{\underline{\mathbf{D}}}\, \underline{\epsilon}(\mathbf{u})$ stress tensor
- ρ material density, λ, μ Lamé elastic coefficients
- $\mathbf{c}(\partial_t \mathbf{u}, \mathbf{u}) = 2\rho\zeta\, \partial_t \mathbf{u} + \rho\zeta^2 \mathbf{u}$ viscous forces

In applications the decay factor ζ is typically $\approx 0.01 s^{-1}$

Variational Formulation

For any time $t \in (0, T]$ find $\mathbf{u} = \mathbf{u}(t) \in V = \mathbf{H}^1_{\Gamma_D}(\Omega)$ such that

$$\mathrm{d}_{tt}\,(\rho \mathbf{u}, \mathbf{v})_\Omega + (\underline{\sigma}(\mathbf{u}), \underline{\varepsilon}(\mathbf{v}))_\Omega + (\mathbf{c}(\partial_t \mathbf{u}, \mathbf{u}), \mathbf{v})_\Omega = \mathcal{L}(\mathbf{v}) \quad \forall \mathbf{v} \in V$$

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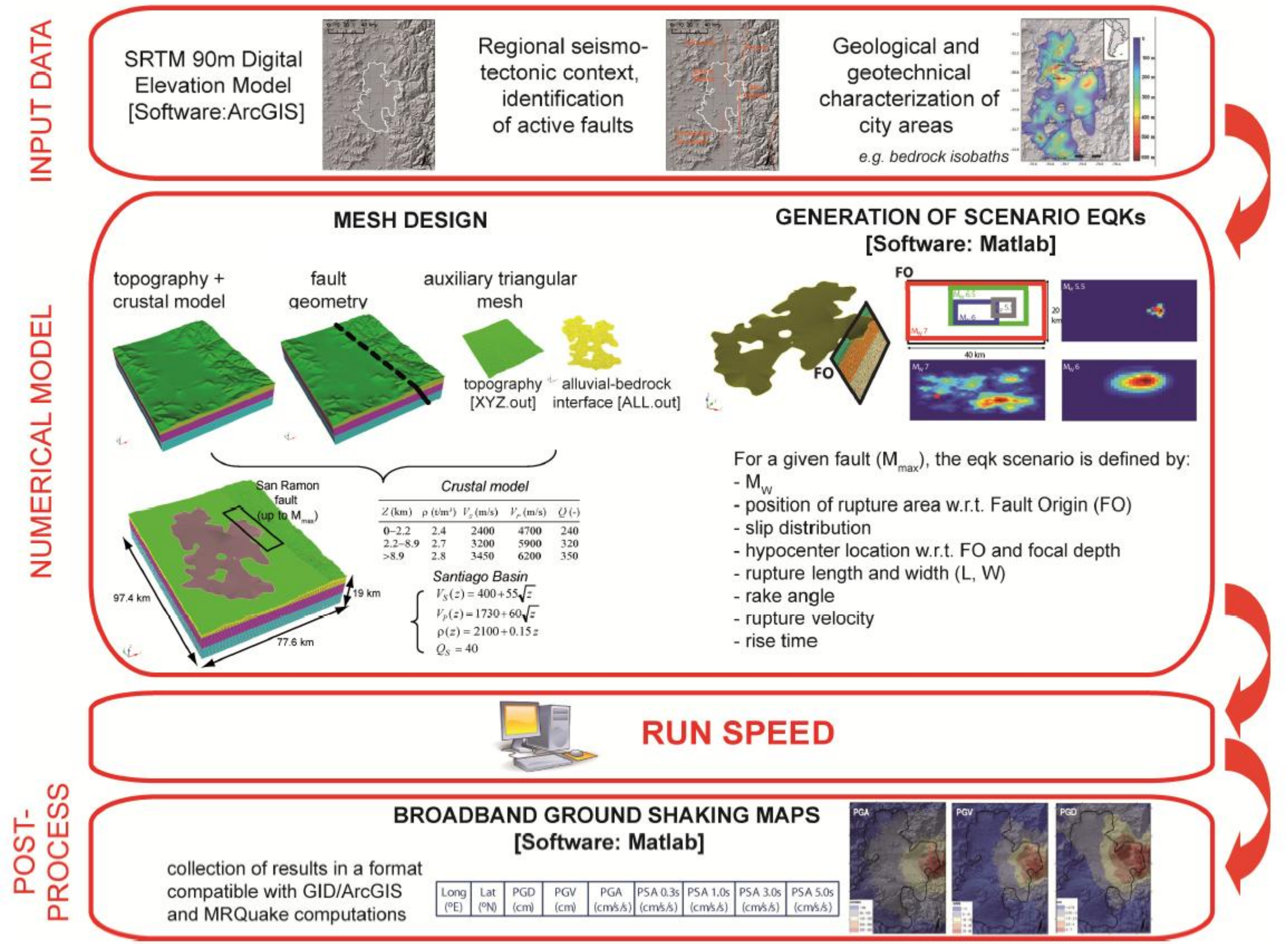
Requirement on the numerical solution

- Accurate description of the behaviour at interfaces
  $\Longrightarrow$ high-order accuracy
- Waves are typically propagated over many periods
  $\Longrightarrow$ control the numerical dispersion and dissipation errors
- Complex geometries and strong contrasts in wave speeds
  $\Longrightarrow$ methods that accommodate non-conforming grids
- The size of the bodies excited is large relative to the wavelengths of interest
  $\Longrightarrow$ efficient and scalable implementation

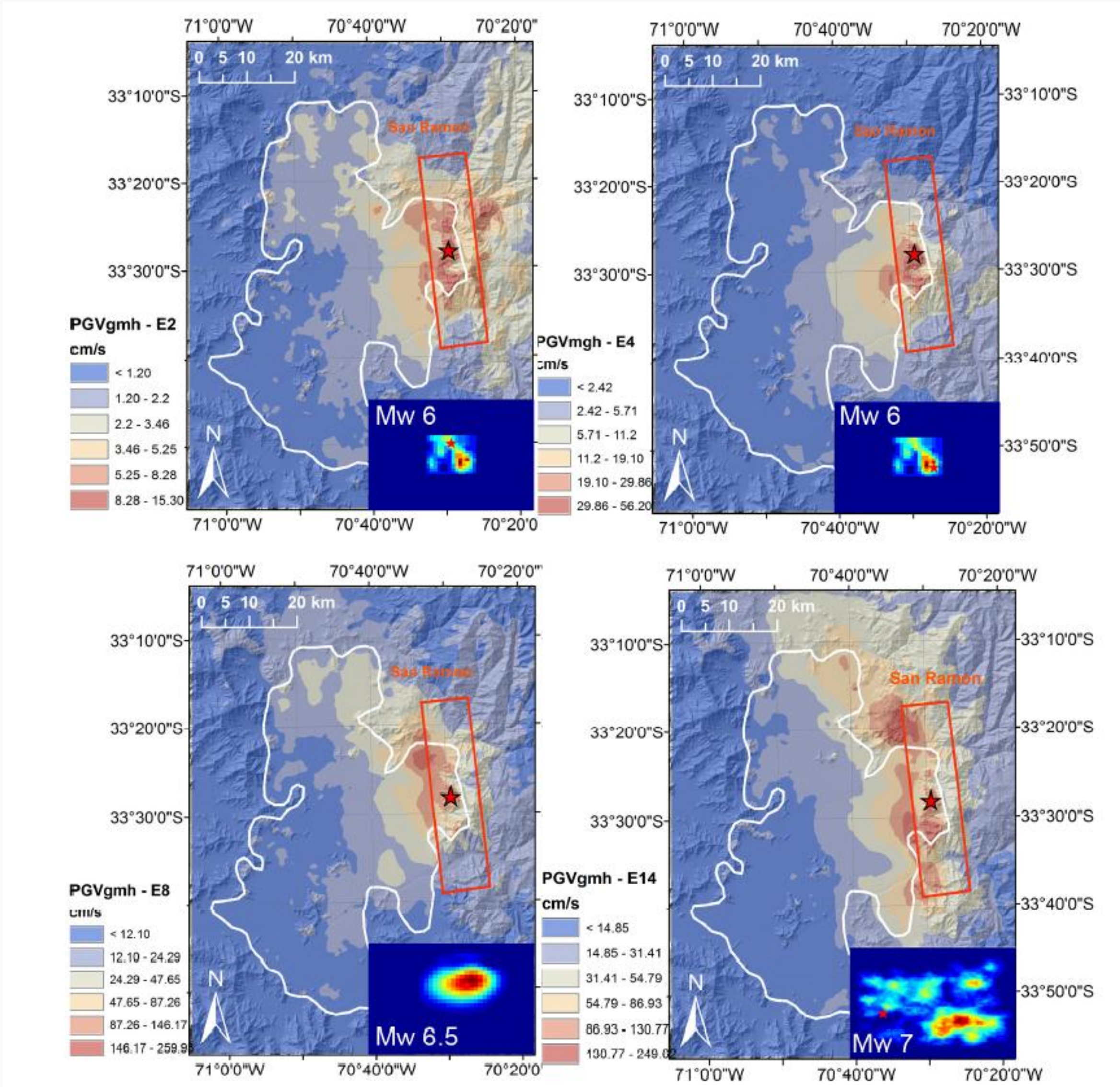
Release of the new code SPEED
SPectral Elements in Elastodynamics with Discontinuous Galerkin
jointly developed at MOX and DIS - PoliMI
`http://mox.polimi.it/it/progetti/speed/SPEED/Home.html`

Santiago de Chile

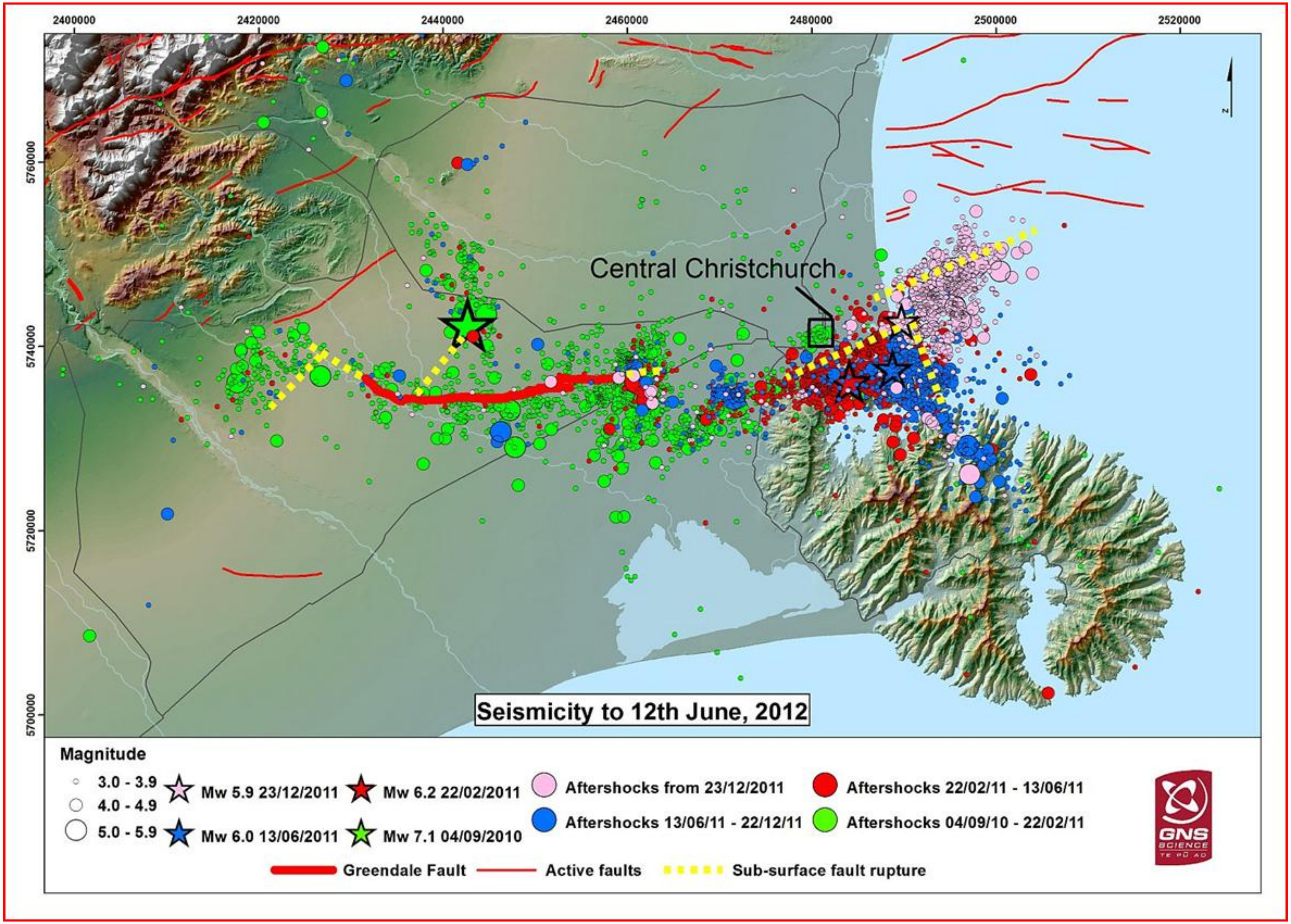


Santiago de Chile and San Ramon Fault

Examples of seismic scenarios in the Santiago metropolitan area, San Ramon fault: horizontal (geometric mean) PGV in the frequency range 0.05-2 Hz



Christchurch (New Zealand)



Christchurch (New Zealand)
LIQUEFACTION

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Christchurch (New Zealand)
ROCKFALL

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3. 3D numerical simulation

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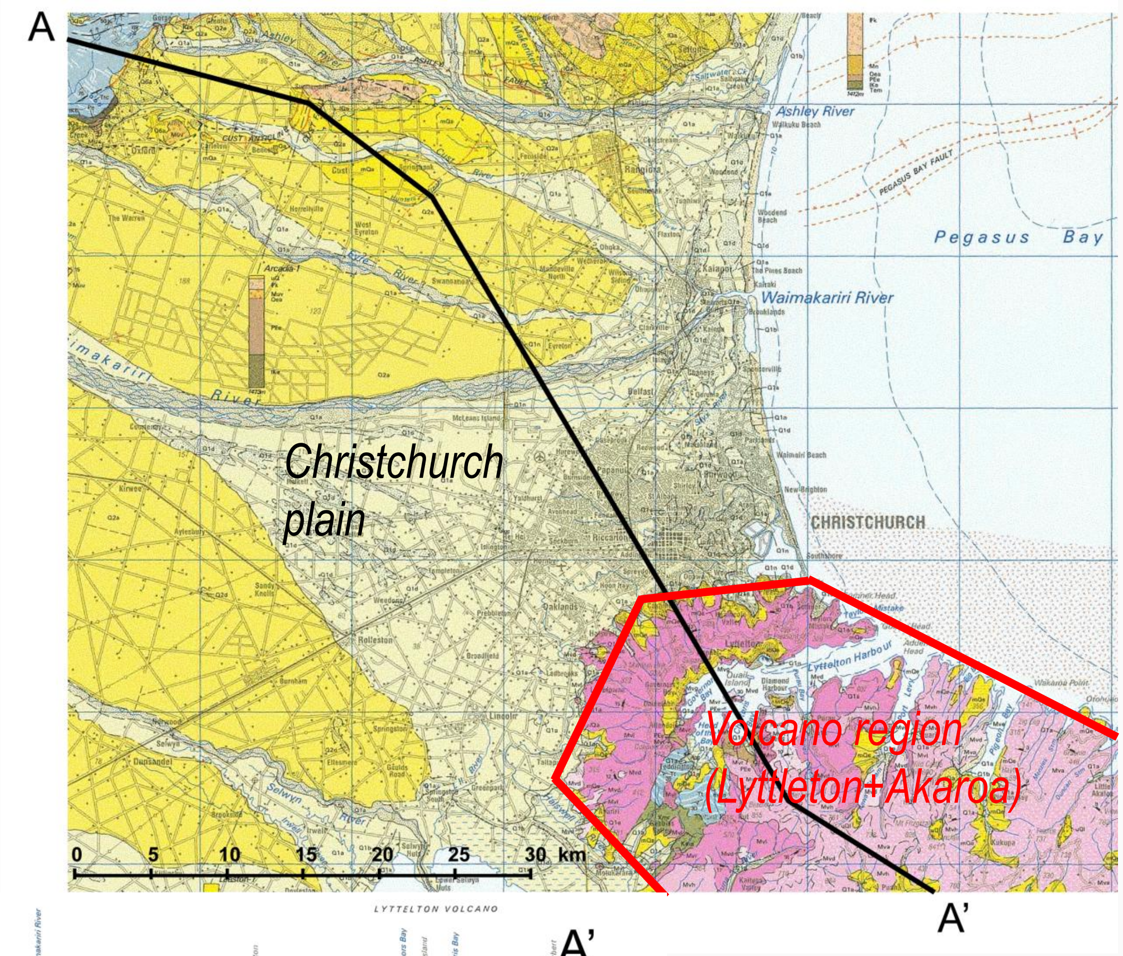
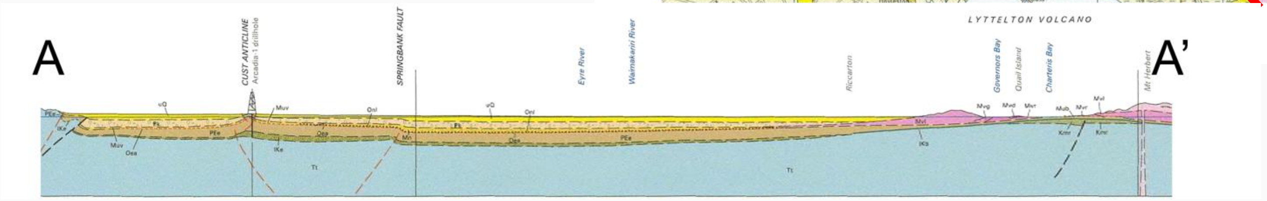
Simulation of the Mw 6.3 Christchurch earthquake on February 22nd, 2011

Geological Map 16
1:250'000

GNS Science
(Forsyth et al., 2008)





3. 3D numerical simulation

Simulation of the Mw 6.3 Christchurch earthquake on February 22nd, 2011

Numerical model characteristics

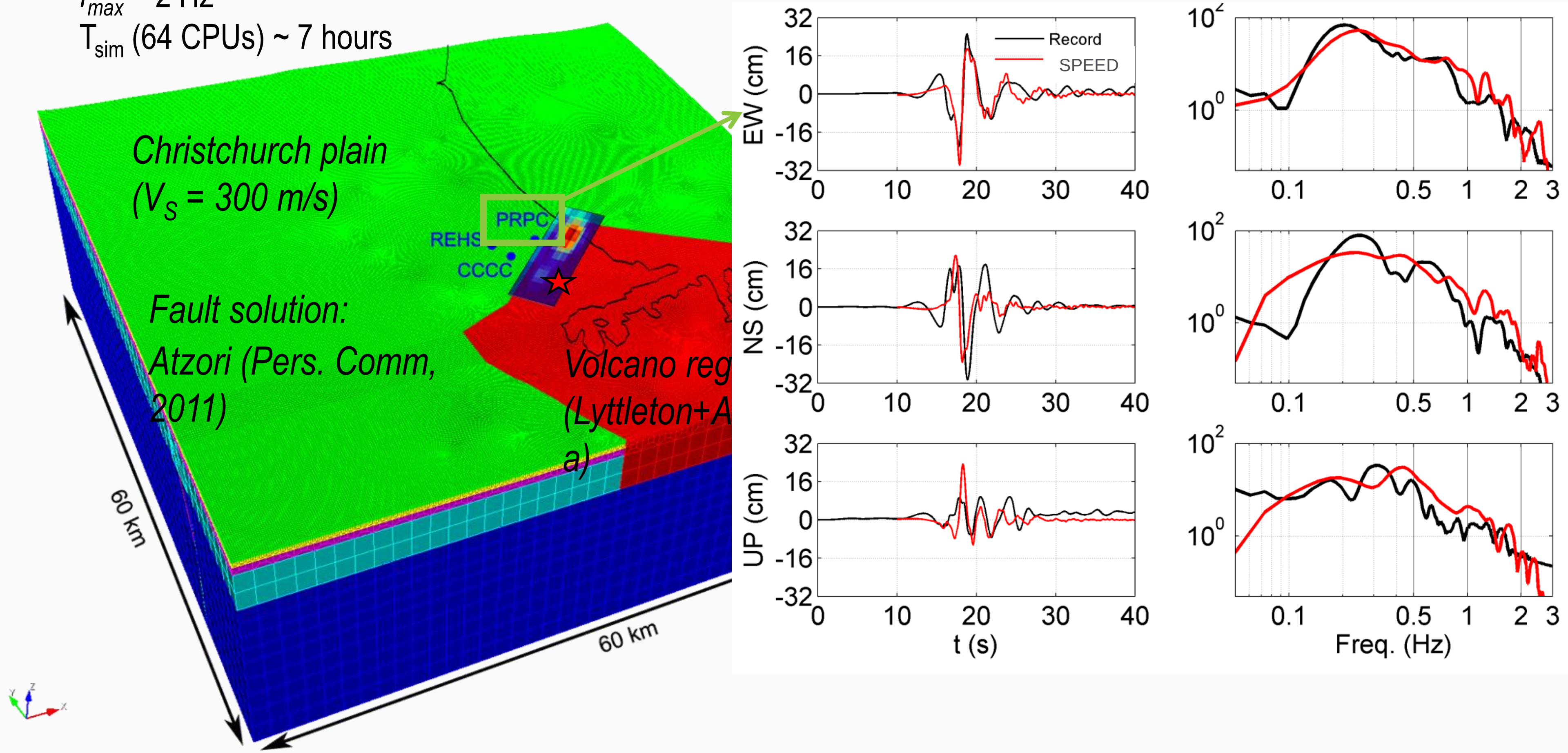
\# of elem.: 475'992

\# of nodes: ~$13.5 \cdot 10^6$

f_{max} = 2 Hz

T_{sim} (64 CPUs) ~ 7 hours

PRPC ($R_{epi} \cong$ 6 km)



3. 3D numerical simulation

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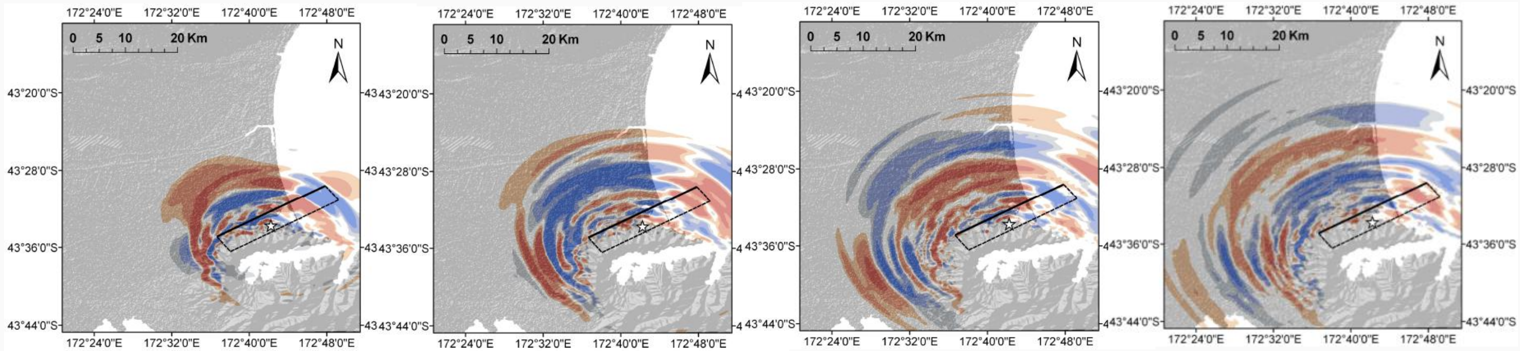
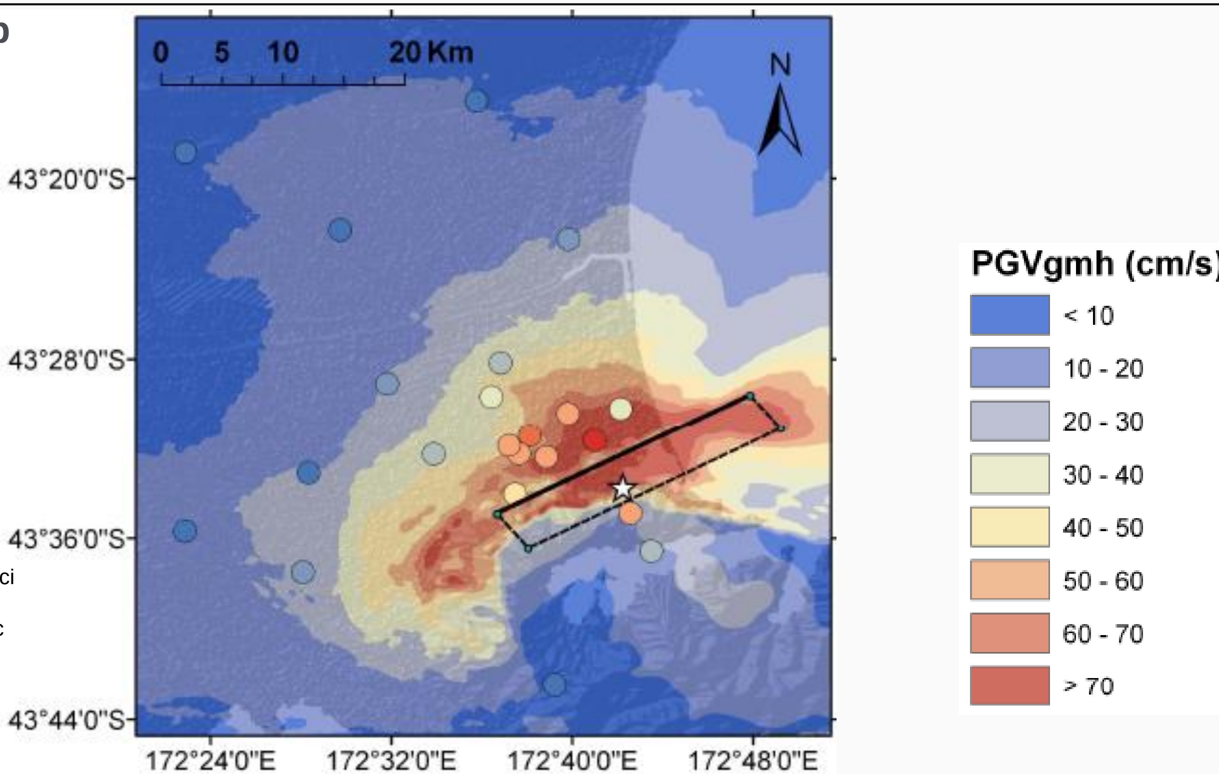
Simulation of the Mw 6.3 Christchurch earthquake on February 22nd, 2011

Snapshot sequence



Peak Ground Velocity Map



Guidotti R, Stupazzini M, Smerzini C, Paolucci R, Ramieri P (2011). Numerical study on the role of basin geometry and kinematic seismic source in 3d ground motion simulation of the 22 February 2011 MW 6.2 Christchurch earthquake. SEISMOLOGICAL RESEARCH LETTERS, vol. 82, p. 767–782.

4. 3D numerical simulation

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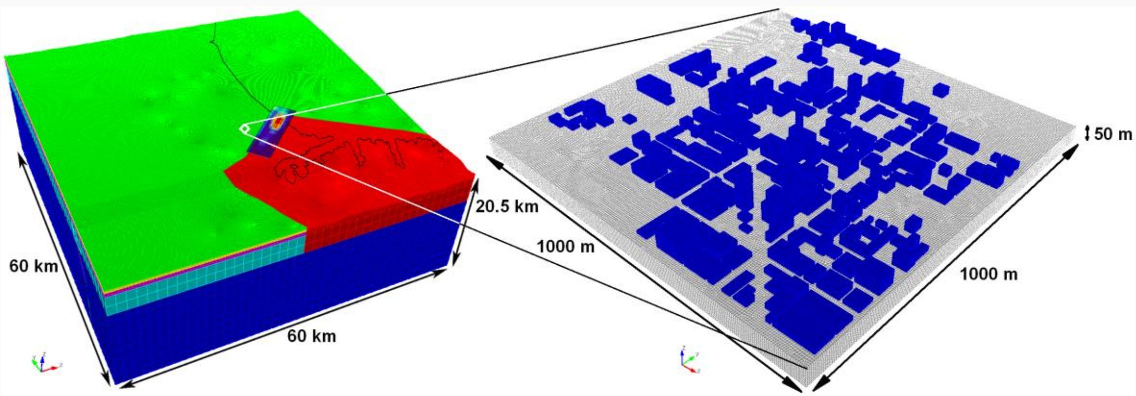
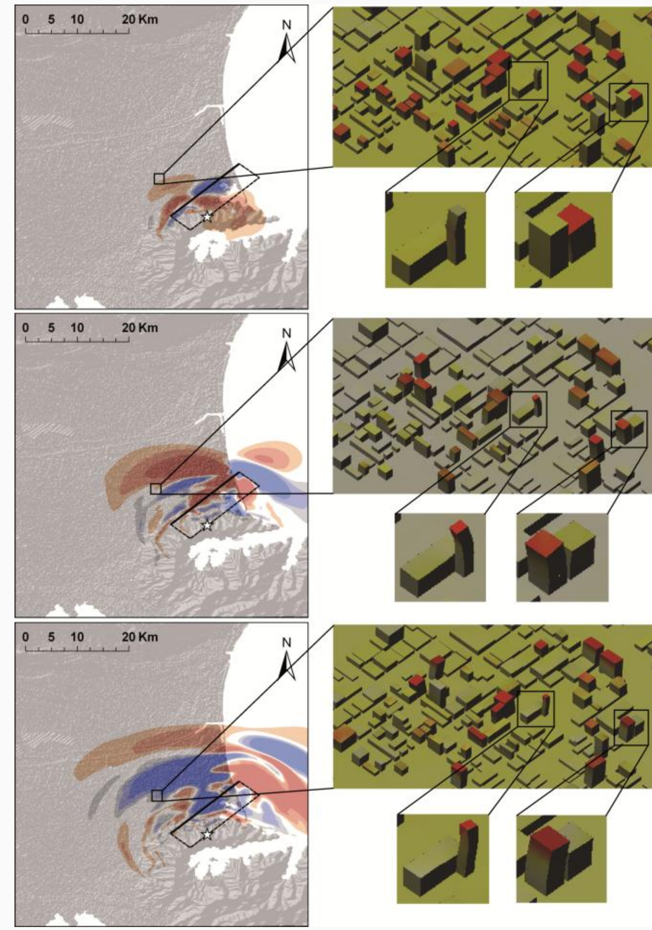
Simulation of the Mw 6.3 Christchurch earthquake on February 22nd, 2011





I. Mazzieri, M. Stupazzini, R. Guidotti, C. Smerzini, SPEED-SPectral Elements in Elastodynamics with Discontinuous Galerkin: a non-conforming approach for 3D multi-scale problems, accepted for publication to Int. J. Numer. Meth. Engng.

Authors&Thanks for your attention

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Marco Stupazzini obtained in 1999 his Master in Engineering in Politecnico di Milano (Italy) and in 2004 the Ph.D. title in Seismic and Earthquake Engineering.
He worked as a Post-Doc at the Ludwig Maximilians Universität of Munich (Germany) in the framework of the European Research Project SPICE with Marie-Curie fellowship. From 2008 to 2009 was Assistant Professor of Continuum Mechanics and Seismic Engineering at the Department of Structural Engineering of Politecnico di Milano. Since 2009 he works with Munich Re, world leader company in Reinsurance market, as a developer of Seismic Risk models.

His research interests are focused on the study of the seismic response of alluvial basins or in general complex 3D geological structures, the high performance computing, the study of earthquake "near-field" effects and the soil-structure dynamic interaction.