Workshop

Numerical Modeling of Earthquake Motions: Waves and Ruptures

July 5-9, 2015

Smolenice Castle near Bratislava, Slovakia

POLITECNICO DI MILANO

Strong motion records and 3D physics-based numerical simulations of the M_w6.0 May 29, 2012 Po Plain earthquake, Italy

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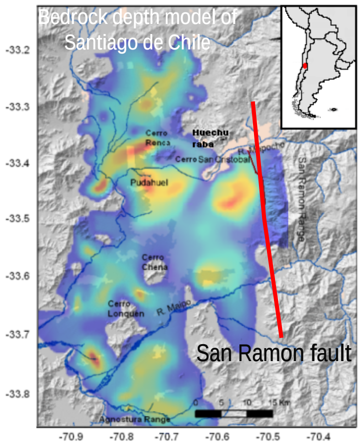
Contents

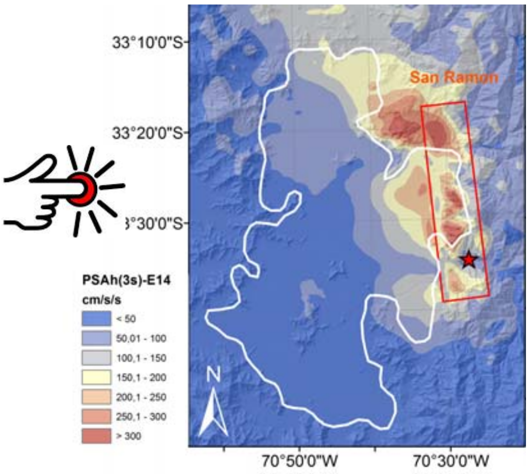
- ✓ Motivation for 3D physics-based earthquake ground motion simulations
- ✓ the spectral element code SPEED
- ✓ numerical simulation of near-source ground motions during the Mw6 Po Plain earthquake of May 29 2012

Earthquake ground motion prediction

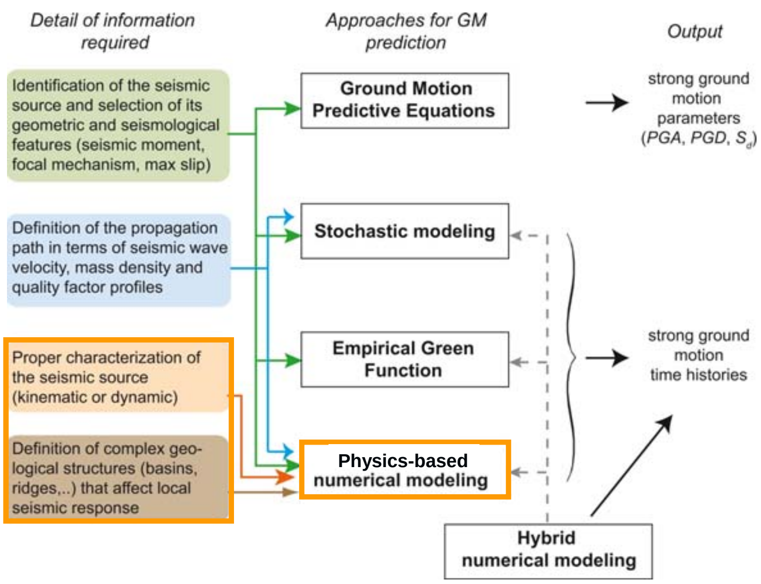
Santiago de Chile



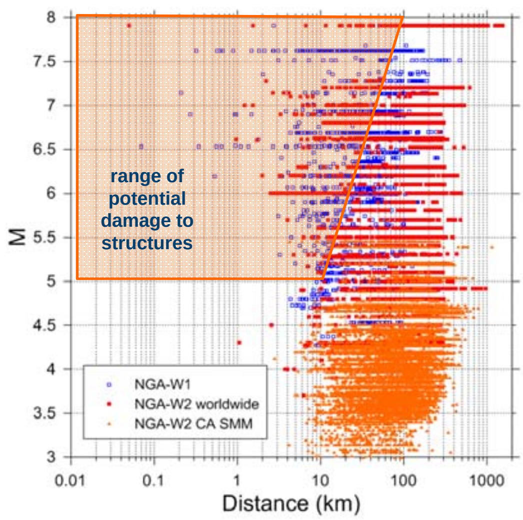
Earthquake ground shaking scenario for a M7 earthquake on the San Ramon fault



Approaches to earthquake ground motion prediction

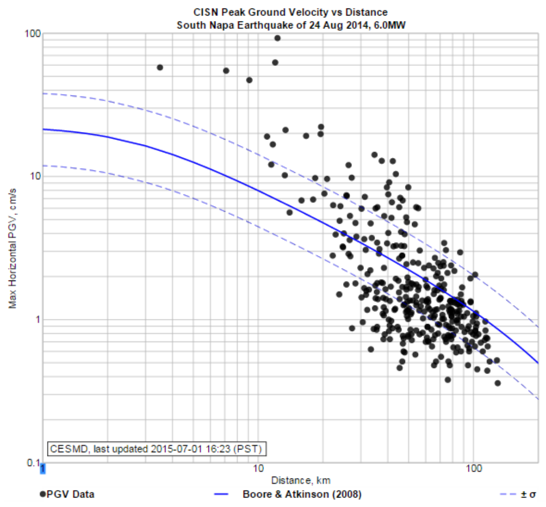


Limitations in the use of GMPEs



NGA West2 database (Ancheta et al., 2013)

Limitations in the use of GMPEs



Limitations in the use of GMPEs

GMPEs → 3D physics based GM simulations

… but you need
- ✓ 3D numerical models
- ✓ high frequency
- ✓ verifications on real earthquakes

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SPEED (Spectral Elements in Elastodynamics with Discontinuous Galerkin)

cooperation PoliMi - MunichRe

Munich RE

http://speed.mox.polimi.it/

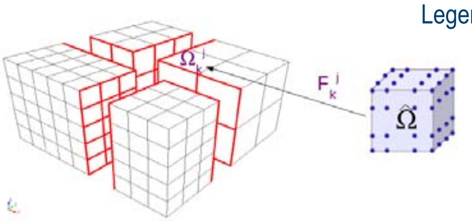
SPEED: some references

Faccioli E, Maggio F, Paolucci R, Quarteroni A.
2D and 3D elastic wave propagation by a pseudo-spectral domain decomposition method
Journal of Seismology, 1997

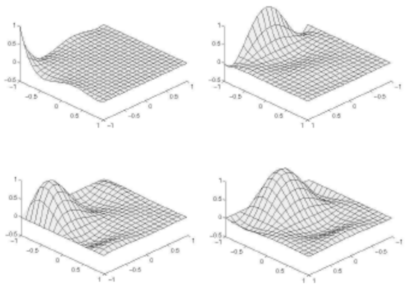
Stupazzini M., Paolucci R., Igel H.
Near-fault earthquake ground motion simulation in the Grenoble Valley by a high-performance spectral element code
Bulletin of the Seismological Society of America, 2009

Mazzieri I., Stupazzini M., Guidotti R., Smerzini C.
SPEED-Spectral Elements in Elastodynamics with Discontinous Galerkin. A non-conforming approach for 3D multi-scale problems.
International Journal for Numerical Methods in Engineering, 2013

SPEED: SPectral Elements in ElastoDynamics with Discontinuous Galerkin



Legendre-Gauss-Lobatto points



Lagrange polynomials

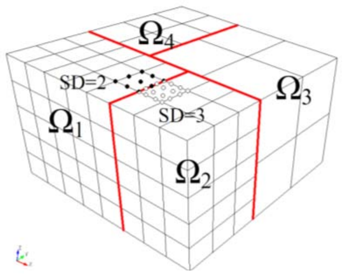
SPEED: SPectral Elements in ElastoDynamics with Discontinuous Galerkin

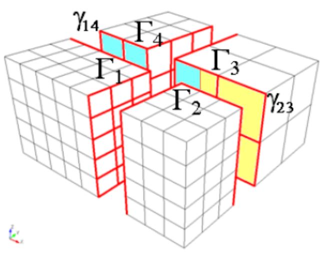
Features

- 3D unstructured conforming and non-conforming hexahedral meshes (e.g., between sub-domains $\Omega_{1,2}$, Ω_3 and Ω_4)
- Non uniform polynomial approximation orders (e.g., between sub-domains Ω_1 and Ω_2)
- leap-frog FD time advancing scheme
- visco-elastic and non-linear elastic soil behaviour

Kernel

- hybrid parallel programming based on MPI and Open-MP
- METIS software library to handle partitioning and load balancing
- designed for multi-core machines or large clusters - optimized for HPC clusters (e.g., FERMI Blugene/Q)





Treatment of seismic input in SPEED

Kinematic modeling of an extended seismic source

$$m_{ij}^{\,k}(\underline{x},t) = \frac{M_0^{\,k}(\underline{x},t)}{V^k}\left(v_i^k n_j + v_j^k n_i\right)$$

volume of the k^{th} subfault

slip and normal fault vectors $f(\delta_f, \lambda_f, \varphi_f)$

$$M_0^{\,k}(\underline{x},t) = \mu^k \Delta u^k A^k s(t - \Delta t^k; \tau_R^k)$$

area

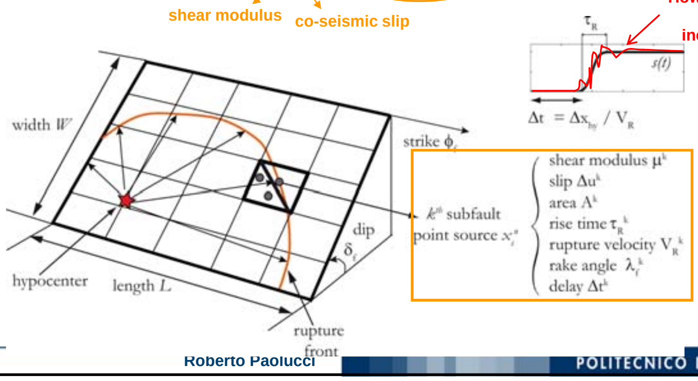
shear modulus

co-seismic slip

Slip source function

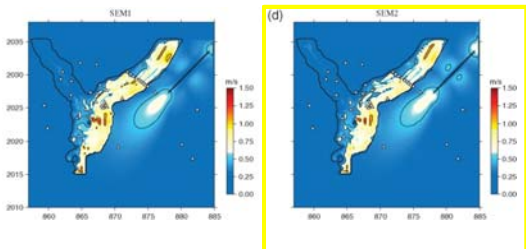
How to introduce high-frequency components ?

How to introduce spatial incoherency?

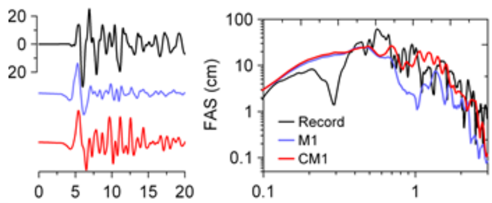


Previous applications of SPEED (1)

Stupazzini M, Paolucci R, Igel H (2009)
Near-fault earthquake ground-motion simulation in the Grenoble valley by a high-performance Spectral Element code. *BSSA , 99: 286–301*.



Smerzini C, Villani M (2012)
Broadband numerical simulations in complex near field geological configurations: the case of the M_W 6.3 2009 L'Aquila earthquake, *BSSA, 102: 2436–2451*



Previous applications of SPEED (2)

- ✓ Gubbio (Central Italy)
- ✓ Sulmona (Central Italy)
- ✓ Marsica earthquake 1915 (Central Italy)
- ✓ Wellington (New Zealand)
- ✓ Santiago de Chile
- ✓ Istanbul
- ✓ Christchurch (New Zealand)
- ✓ Po Plain earthquake May 29, 2012 (Northern Italy)

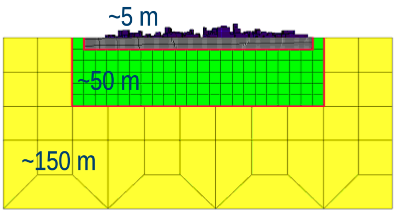
3D modelling of site-city interaction: Christchurch

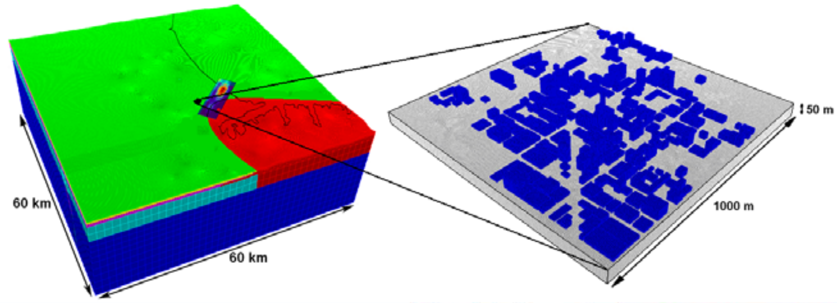
22 Feb 2011 Christchurch earthquake (Mw 6.2)

New Zealand | Canterbury Plains | Central Christchurch

3D modelling of site-city interaction : Christchurch

Exploiting the non-conforming meshing feature of SPEED





3D modelling of site-city interaction : Christchurch

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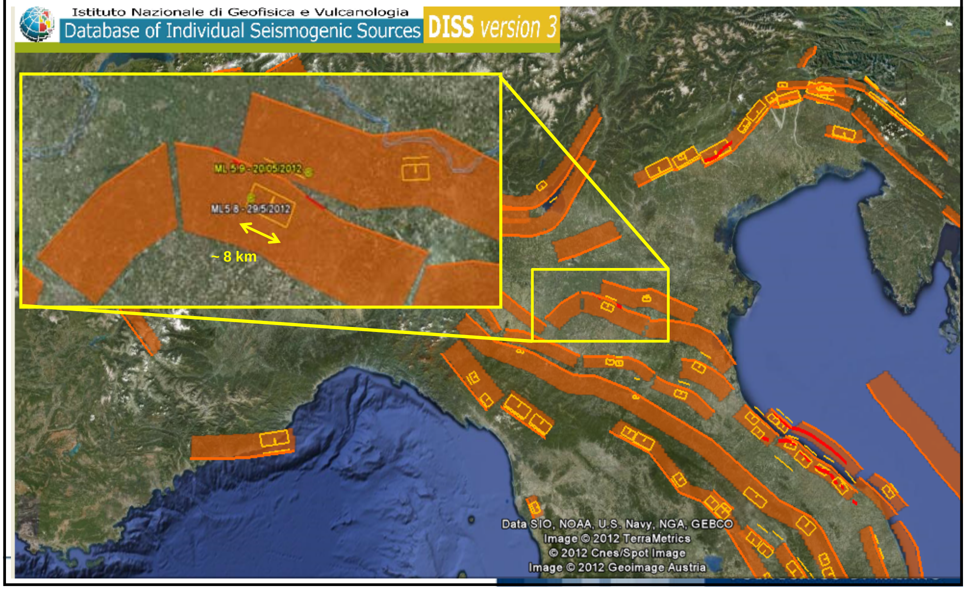
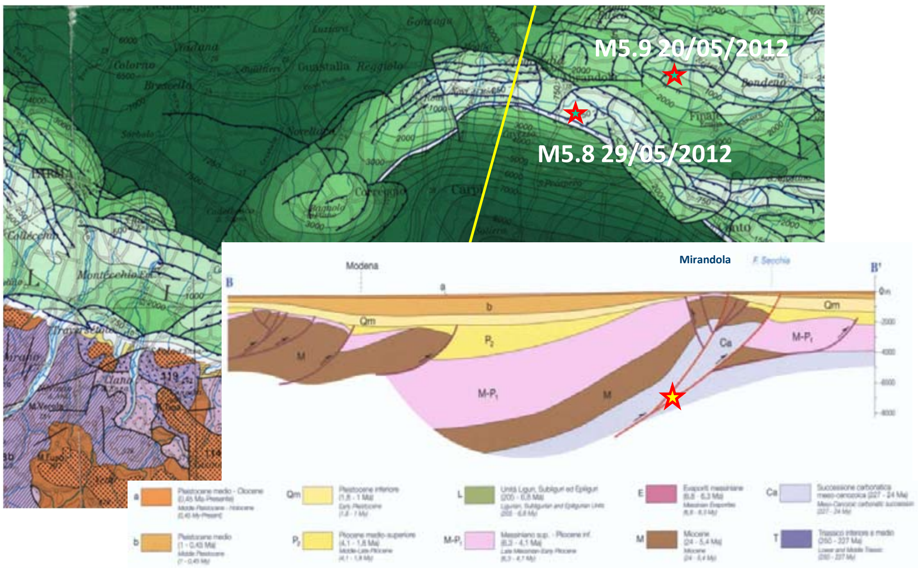
The Emilia earthquake sequence of May-June 2012

Italian Seismogenic Sources Database DISS 3.1.1



The Emilia earthquake sequence of May-June 2012



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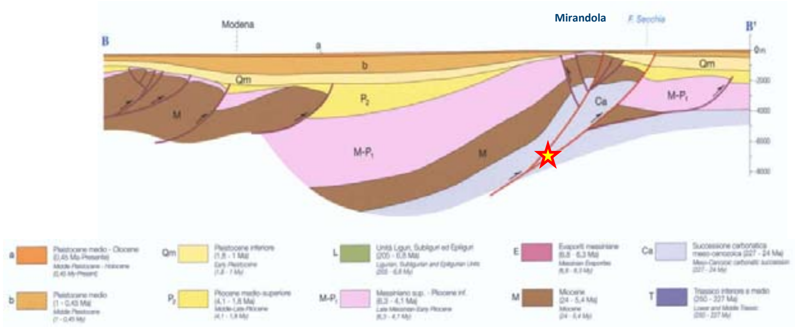
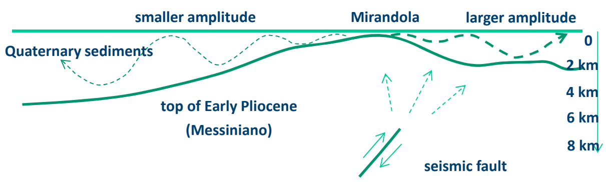
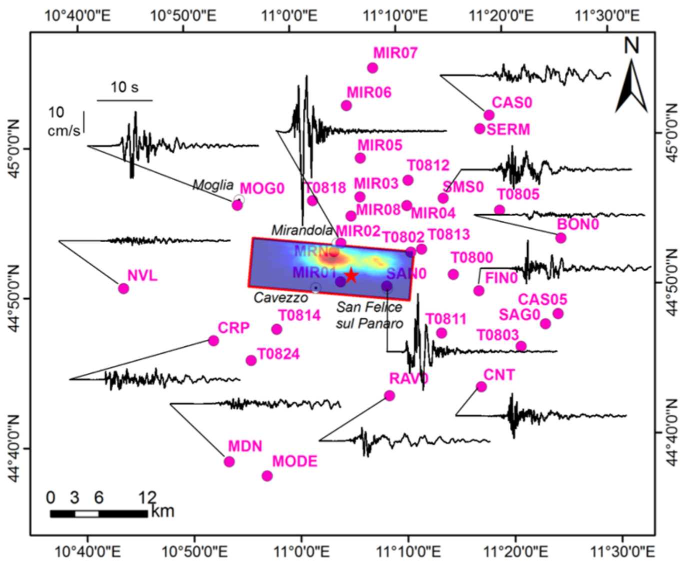




Near-source records of May 29 earthquake

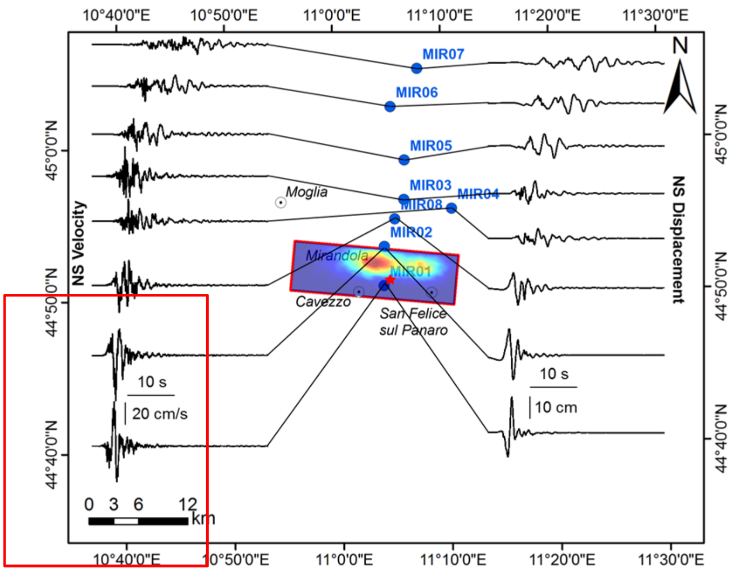
NS components of velocity



Near-source records of May 29 earthquake

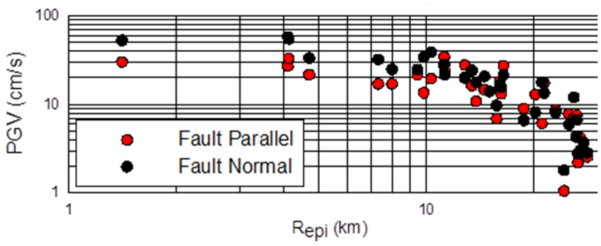
Records along a NS (nearly Fault normal) aligned network

out-of-phase motion in 3 km distance!



Near-source records of May 29 earthquake

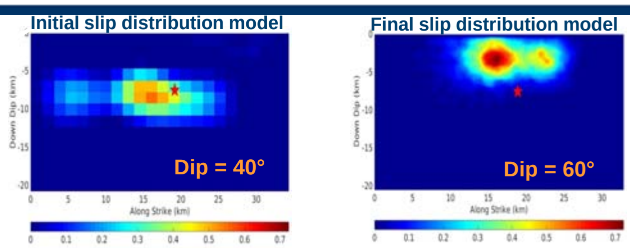
Prevailing FN components for R < 10 km

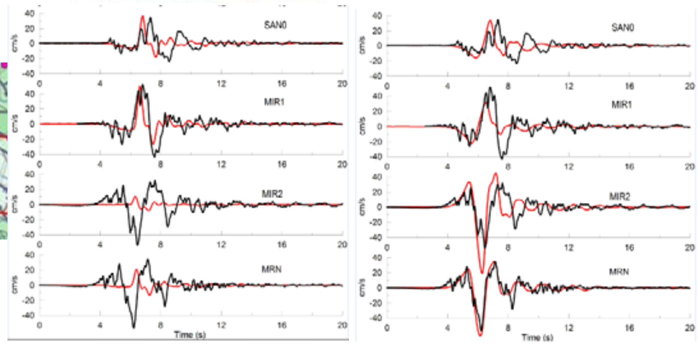


Church of San Francesco, Mirandola (courtesy A. Penna)

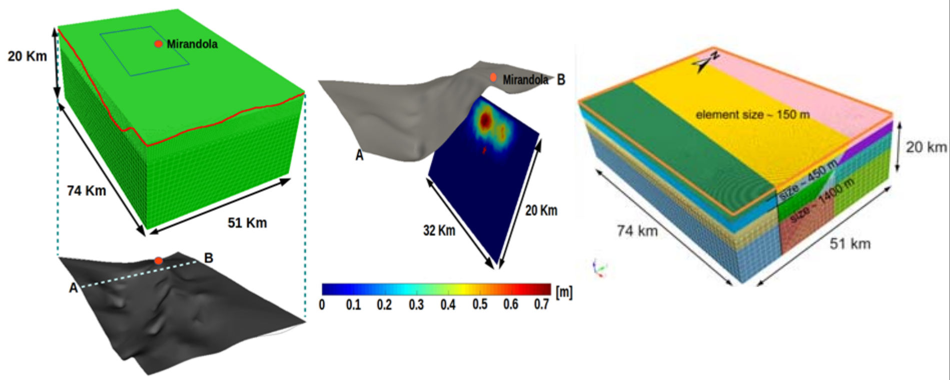
Adjustment of a slip distribution model by Hisada method

main parameters
Strike = 95°
Dip = 40° → 60°
Rake: 90°
Vrup = 0.85 Vs
Rise-time = 0.7 s





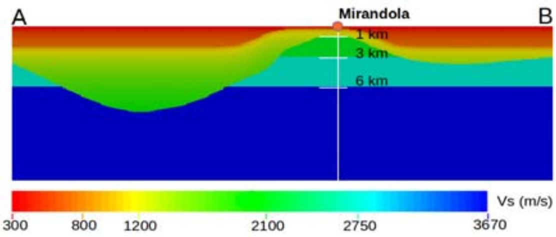
Construction of a 3D model for SPEED simulations

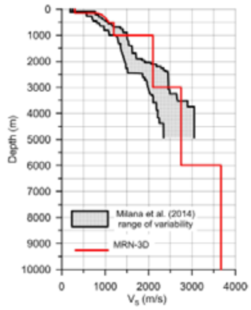


SD	Elements #	Nodes #	Δt (s)	Duration (s)	f_{max} (Hz)
3	1'975'240	51'914'494	0.001	30	~1.5

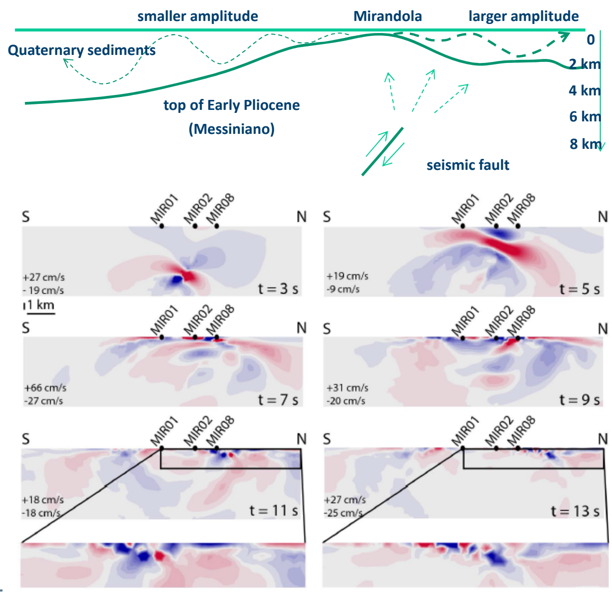
Construction of a 3D model for SPEED simulations

Geologic Unit	Depth z (m)	ρ (kg/m^3)	V_S (m/s)	V_P (m/s)	Q_S $(-)$
Quaternary	$z < 150$	1800	300	1500	30
	$150 < z < z_Q$	$1800 + 6\sqrt{z-150}$	$300 + 10\sqrt{z-150}$	$1500 + 10\sqrt{z-150}$	$V_S(z)/10$
Pliocene	$z_Q < z < z_P$	$2100 + 4\sqrt{z-z_Q}$	$800 + 15\sqrt{z-z_Q}$	$2000 + 15\sqrt{z-z_Q}$	$V_S(z)/10$
before Pliocene	$z > z_P$	see seismic model in Table 2 at corresponding depth			

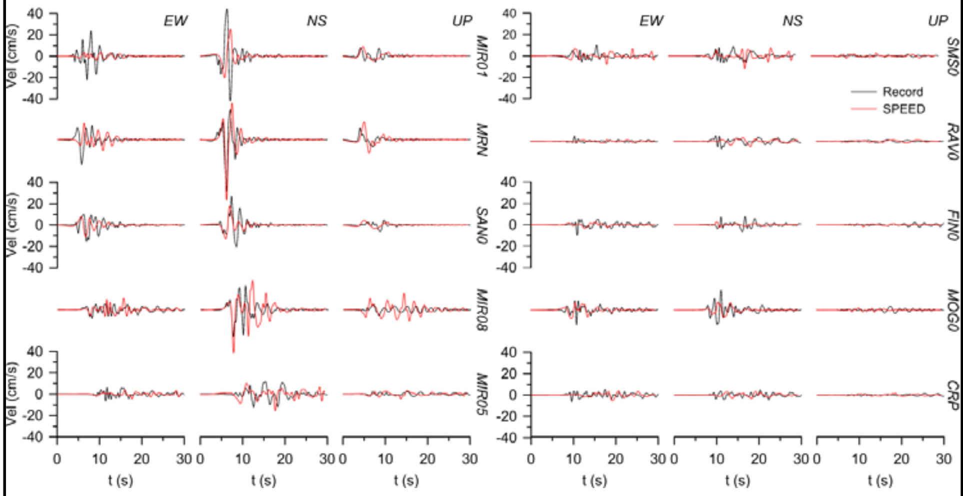




Snapshots of velocity field

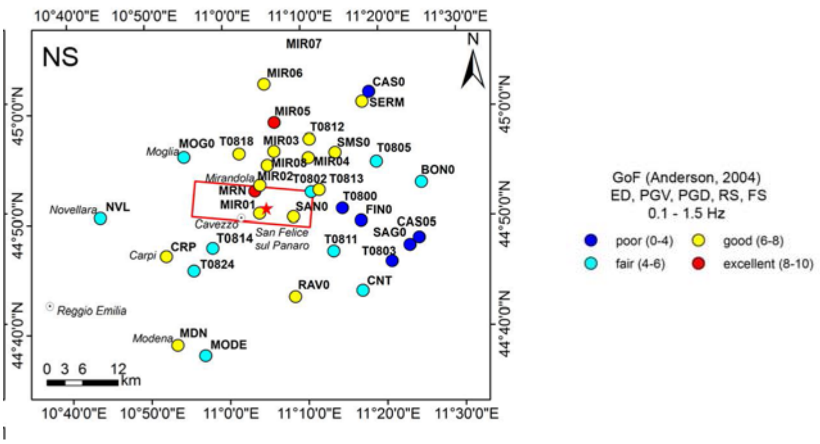


Comparison with strong motion records (0-1.5 Hz)



Comparison with strong motion records (0-1.5 Hz)

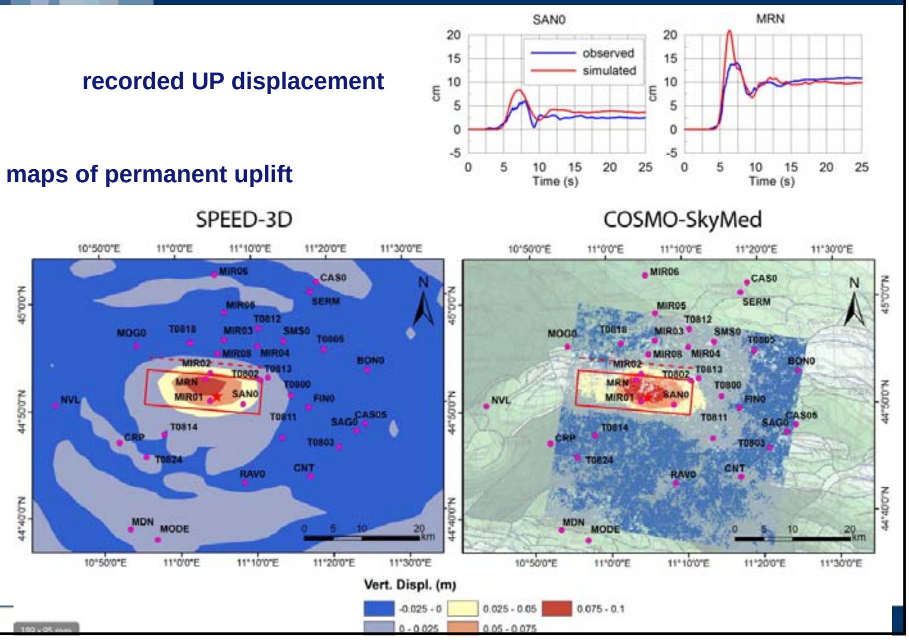
Simulations vs records: goodness of fit



Comparison with strong motion records (0-1.5 Hz)

recorded UP displacement

maps of permanent uplift

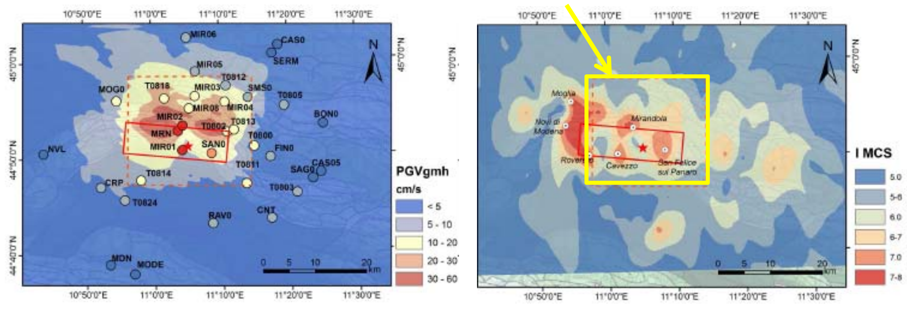


PGV map vs I_{MCS} map

areas affected by the May 29 earthquake

PGV

I_{MCS}



the "two-lobed" spatial variability of the damage distribution is likely to be related to the focal mechanism of the earthquake, rather than to amplification effects associated to local site conditions

Conclusions

✓Generation of realistic, physics-based earthquake ground shaking scenarios within complex tectonic and geological environments by 3D numerical simulations is becoming more and more feasible, but needs verifications from real earthquakes

✓This will provide improved knowledge for characterization of near-source earthquake ground motion (improved GMPEs, small scale spatial variability, fault normal vs fault parallel components, V/H)

Thank you!