EuroseisTest (Volvi, Greece) Verification and Validation Project

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The CASHIMA project

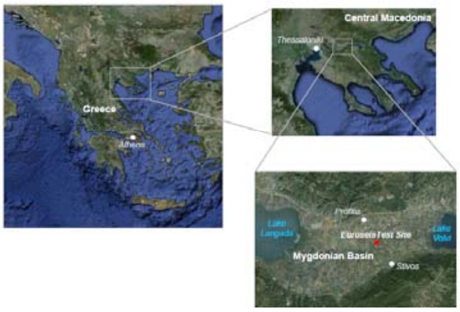
- Cadarache Seismic Hazard Integrated Multidisciplinary Assessment-

Two research topics :

– *Middle Durance Fault*
  - study of the local source of seismic hazard for Cadarache,

– *Site Effects*
  - Taking into account site effects within the framework of the French nuclear regulation rule :
  - – focus on French regulation rule itself,
  - – **development of simulation capabilities**.

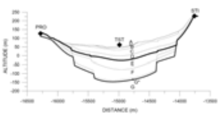
The EuroseisTest Site



Geological, geophysical, geotechnical characterization

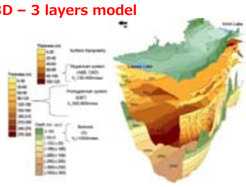
- A high characterisation effort:
  - – boreholes
  - – surface and boreholes seismic surveys
  - – electric surveys
  - – array microtremor measurements
  - – H/V measurements
  - – laboratory measurements on samples
  - – etc.

2D – 7 layers model



Raptakis et al. 2000

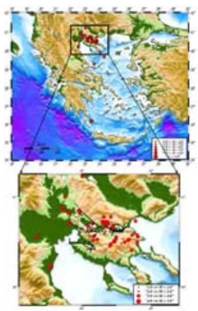
3D – 3 layers model



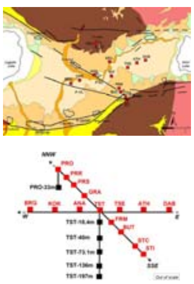
Manakou, 2007

The EuroseisTest Site: instrumentation and records

~ 50 recorded earthquakes



21 accelerometric stations

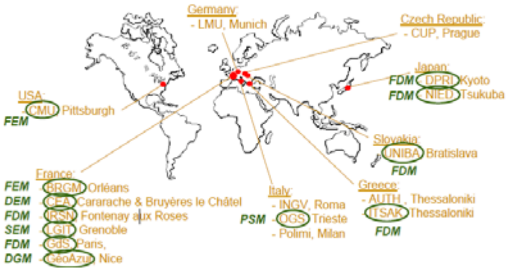


Initial objectives

- Improvements with respect to ESG2006
  - – Benefitting from the ESG2006 lessons
    - (technical, organization)
  - – Learning from the participants experience and feedback
  - – More interaction, more time, start with simple cases
  - – Wider participation
- Challenges
  - – Increasing fmax
    - Computational requirements
    - Implications for geophysical surveys
  - – Smart and meaningful comparison of 1D-2D-3D cases
  - – Non-Linear issue
  - – (Extended source, realistic kinematics, …)
  - – Getting ready for the next events at Volvi/Euroseistest

The “participating teams”

- Invitation were sent to most of known potentially interested teams.
  - 17 participating teams (Europe, USA, Japan)
  - 12 “modeling” team with 6 different numerical approaches



Validation and Verification

- Verification: evaluating the accuracy of numerical methods when applied to realistic applications where no reference solution exists
  - compare the results of numerical simulation with each
  - allow the identification of implementation errors, meshing Problems
- Validation: quantifying the agreement between recorded and numerically simulated data
  - needs real field data
  - needs a site where the geological, geophysical, geotechnical characterization is good

Computing cases

- Verification:
  - 3D (up to 4 Hz):
    - pure elastic / visco-elastic (Q-factor)
    - 3 layers with homogenous properties / gradient based model
    - different excitation.
  - 2D (up to 10 Hz):
    - pure elastic / visco-elastic / “fully” non-linear,
    - 7 layers / 3 layers / gradient based model,
    - different excitation.
- Validation:
  - 3D (up to 4 Hz):
    - 6 different earthquakes (visco-elastic, 3 layers model).

Organisation

- An “iterative” work in 3 phases, with many interaction and discussion:
  - one “Kick-off Meeting” (may 2008)
  - 3 intermediate workshop (nov. 2008 – may 2009 – oct. 2009)
  - one final meeting (june 2010)
    - allow fruitful discussions
    - better iteration and convergence between results
    - a better definition of the needed computing cases of the following phase

« Kick-off », Cadarache (may 2008)

Workshop 2, Cadarache (may 2009)

Contributing institutions				
CUB 3D01	FDM	Comenius Univ. Bratislava	Bratislava	Slovakia
UJF 3D02	SEM	Université Joseph Fourier	Grenoble	France
DPRI 3D03	FDM	Disaster Prevention Res. Inst.	Kyoto	Japan
OGS 3D04	PSM	Istituto Nazionale di Oceanografia e Geofisica Sperimentale	Trieste	Italy
NIED 3D05	FDM	Natl. Res. Inst. for Earth Science and Disaster Prevention	Tsukuba	Japan
CEA 3D06	DEM	Commissariat à l Energie Atomique	Bruyères Le Chatel	France
CMU 3D07	FEM	Carnegie Melon Univ.	Pittsburgh	USA
UNICE 3D09	DGM	Université de Nice Sophia Antipolis	Valbonne	France

Applied Methods	
FDM	Finite-difference method
SEM	Spectral-element method
PSM	Pseudo-spectral method
DEM	Discrete-element method
FEM	Finite-element method
DGM	Discontinuous Galerkin method

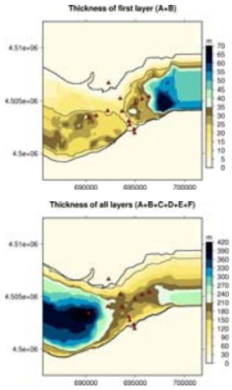
POLIMI-3D08 (Milano, SEM) & LMU-3D10 (Munich, ADER-DGM) contributed to a few cases

Methods (all 2nd-order in time)

		characterization	attenuation	ABC
CUB	FDM	finite-difference, 4th-order velocity-stress volume arithmetic and harmonic averages of density and moduli, respectively arbitrary discontinuous staggered grid	GZB 4 rel. mechanisms	CPML
UJF	SEM	spectral-element, Legendre 4th-order polynomial Gauss-Lobatto-Legendre integration	GZB 3 rel. mechanisms	Lysmer & Kuhlemeyer
DPRI	FDM	finite-difference, 4th-order velocity-stress non-uniform staggered grid	linear Q(f) f_0 = 2 Hz	Clayton & Engquist A1 + Cerjan
OGS	PSM	Fourier pseudospectral, vertically stretching staggered grid	GZB 3 rel. mechanisms	CPML
NIED	FDM	finite-difference, 4th-order velocity-stress discontinuous staggered grid	linear Q(f) f_0 = 2 Hz	Clayton & Engquist A1 + Cerjan
CEA	DEM -SEM	hybrid discrete-element – spectral element, Voronoï particles (6 dof - 3 in translation, 3 in rotation), 2nd-order	hysteretic damping	Lysmer & Kuhlemeyer
CMU	FEM	finite-element, tri-linear elements, octree-based discontinuous mesh	Rayleigh att. in the bulk	Lysmer & Kuhlemeyer
UNICE	DGM	discontinuous Galerkin, 2nd-order polynomial	n.a.	CPML

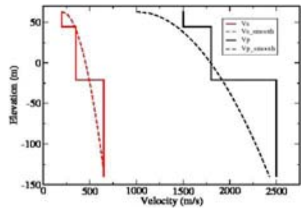
rheology of GZB (generalized Zener (i.e. SLS) body) == rheology of the generalized Maxwell body in definition by Emmerich and Korn (1987)

Volvi 3-layers basin model



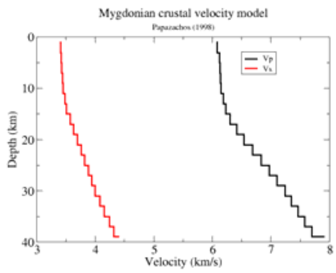
3D heterogeneous model (3 irreg. homog. layers)					
Layer	V_S (m/s)	V_P (m/s)	ρ (kg/m³)	Q_S	Q_K
A+B	200	1500	2100	20	∞
C+D	350	1800	2200	35	∞
E+F	650	2500	2200	65	∞
Bedrock	2600	4500	2600	260	∞

Volvi smooth basin model



3D heterogeneous model (3 irreg. constant-gradient layers)					
Layer	V_S (m/s)	V_P (m/s)	ρ (kg/m³)	Q_S	Q_K
A+B	200 - 250	1500 - 1600	2100	20 - 25	∞
C+D	250 - 500	1600 - 2200	2100 - 2130	25 - 50	∞
E+F	500 - 900	2200 - 2800	2130 - 2250	50 - 90	∞
Bedrock	2600	4500	2600	260	∞

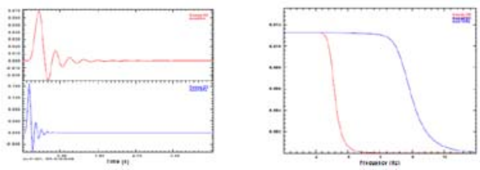
Crustal model



Seismic sources

1. Vertically incident plane S wave
2. Hypothetical point-source located beneath the Volvi basin

Event	Mag	Depth	Strike	Dip	Rake
Ver	1.3	3 km	268°	45°	-94°



Combination of plane wave & models

Model configurations for the vertically impinging plane SV wave				
ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I1a	n.a.	n.a.	homog.	elastic
I1b	3D heterog. (3 irreg. homog. layers)	viscoelastic	homog.	elastic

Combination of point-source & models

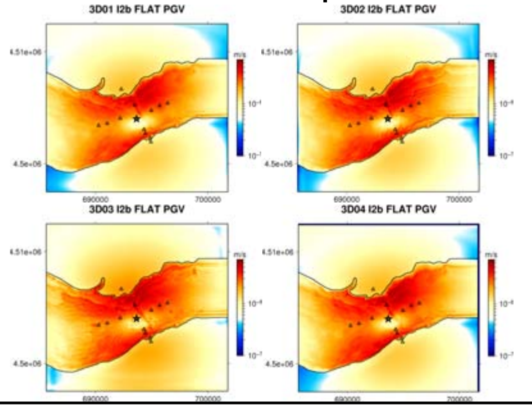
Model configurations for the hypothetical point DC source				
ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I2a	n.a.	n.a.	homog.	viscoelastic
III1	laterally homog., vertical gradient	elastic	1D	elastic
I2c	3D heterog. (3 irreg. homog. layers)	elastic	1D	elastic
I2b		viscoelastic		Viscoelastic
IV2	smooth 3D heterog.	elastic	1D	Elastic
IV1		viscoelastic		viscoelastic

Contributions

Table of submitted solutions								
	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I1a	✓	✓		✓				
I1b	✓	✓		✓				
I2a	✓	✓	✓	✓	✓	✓		
III1	✓	✓	✓	✓	✓		✓	✓
I2c	✓	✓	✓	✓	✓	✓	✓	✓
I2b	✓	✓	✓	✓	✓	✓	✓	
IV2	✓	✓	✓	✓	✓			✓
IV1	✓	✓		✓	✓			

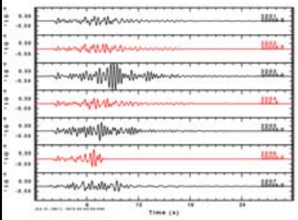
✓: Finalized cases ✓: To be confirmed ✓: Ongoing cases

Verification of 3D numerical predictions : I2b - PGV map -

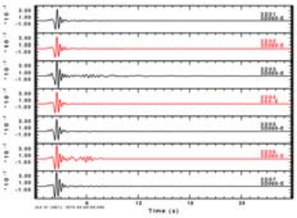


Verification of 3D numerical predictions : I2b - Traces (E) -

TST(058)

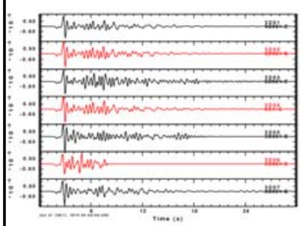


PRO(060)

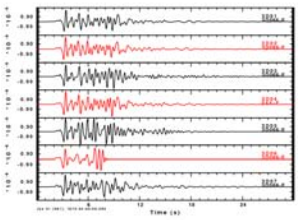


Verification of 3D numerical predictions : I2b - Traces (E) -

E03(061)

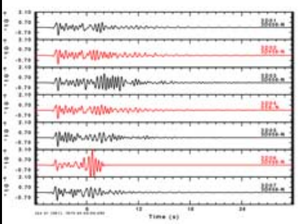


W03(066)



Verification of 3D numerical predictions : I2b - Traces (N) -

TST(058)



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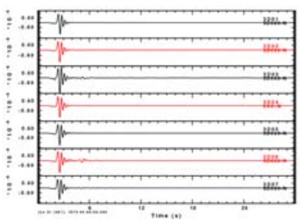
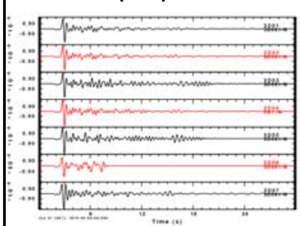


Verification of 3D numerical predictions : I2b - Traces (N) -

E03(061)



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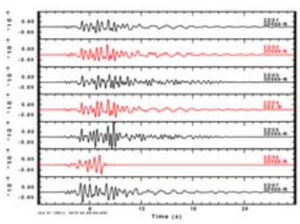
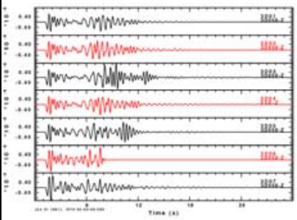


Verification of 3D numerical predictions : I2b - Traces (Z) -

TST(058)



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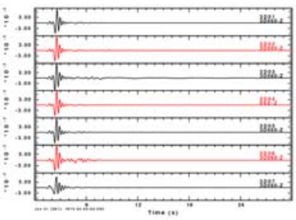

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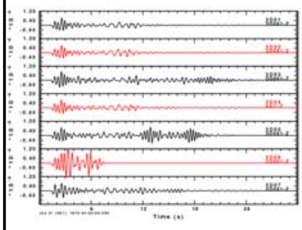
E03(061)



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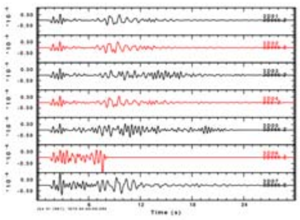
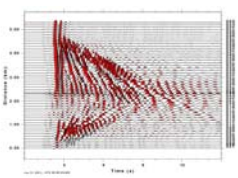
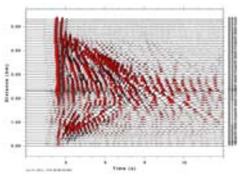


Verification of 3D numerical predictions : I2b - Profile (SH) -

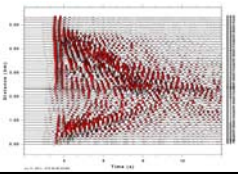
3D01



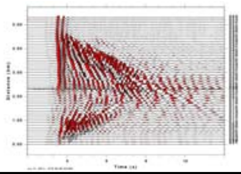
3D02



3D03

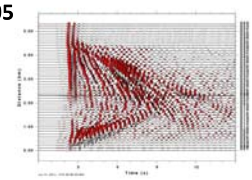


3D04

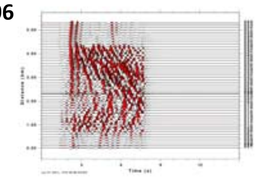


Verification of 3D numerical predictions : I2b - Profile (SH) -

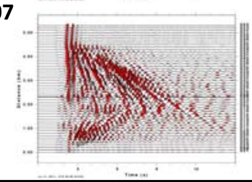
3D05



3D06

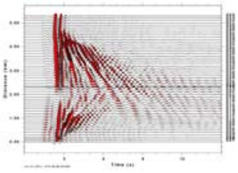


3D07

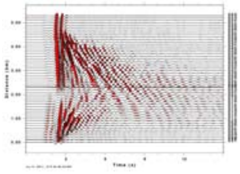


Verification of 3D numerical predictions : I2b - Profile (SV) -

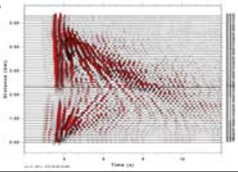
3D01



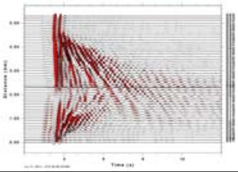
3D02



3D03

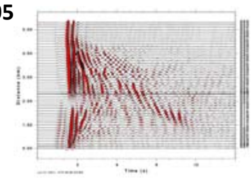


3D04

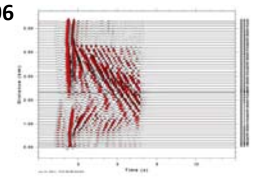


Verification of 3D numerical predictions : I2b - Profile (SV) -

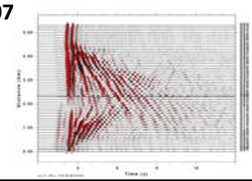
3D05



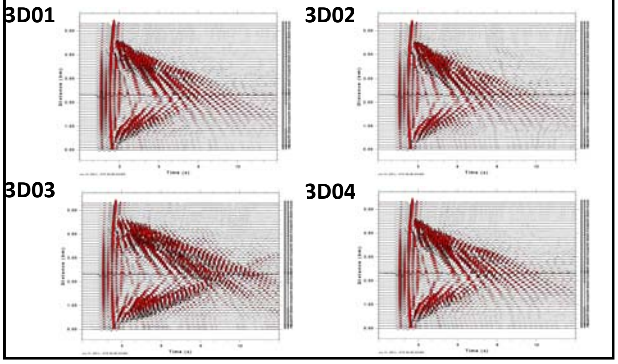
3D06



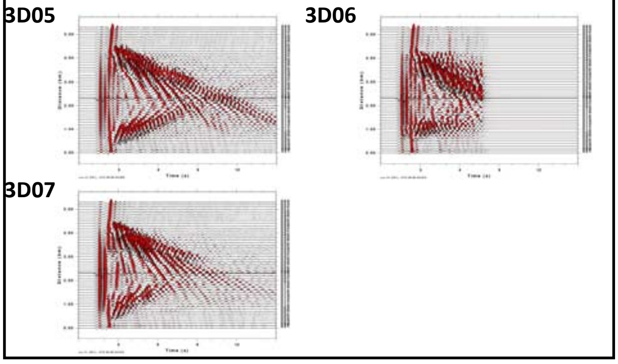
3D07



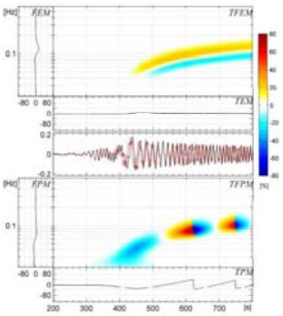
Verification of 3D numerical predictions : I2b - Profile (Z) -



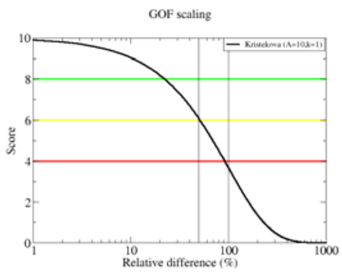
Verification of 3D numerical predictions : I2b - Profile (Z) -



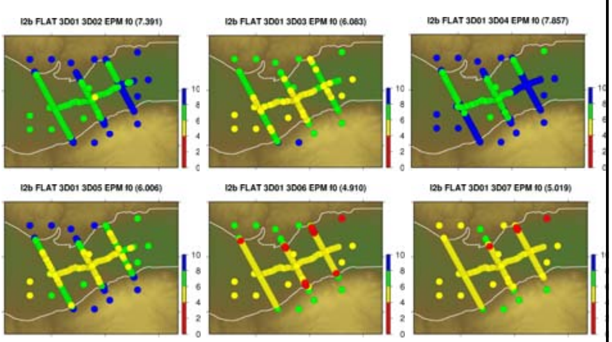
Quantitative measure of misfit using Time Frequency Misfit criteria (Kristekova et al., 2009)



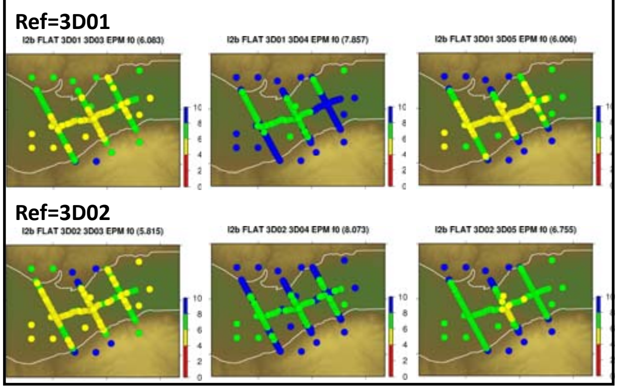
From Misfit to Goodness-of-Fit



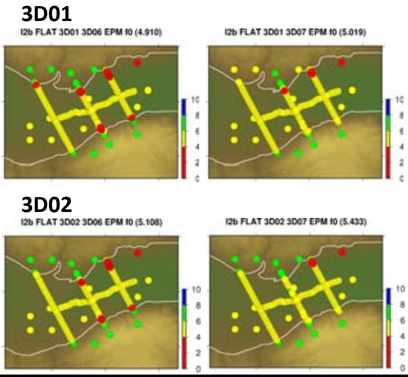
Verification of 3D numerical predictions : I2b - GOF (EPM, f0=[0-4Hz], ref:3D01) -



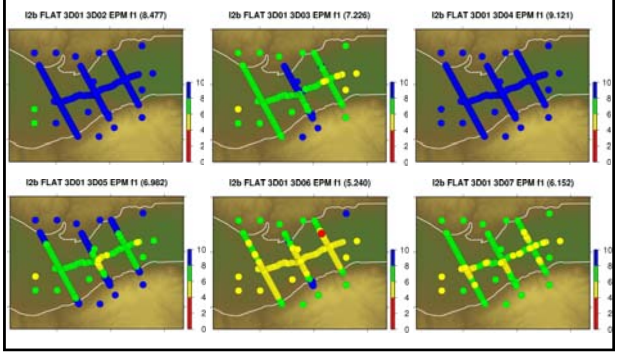
Verification of 3D numerical predictions : I2b - GOF (EPM, f0, ref:3D01&3D02) -



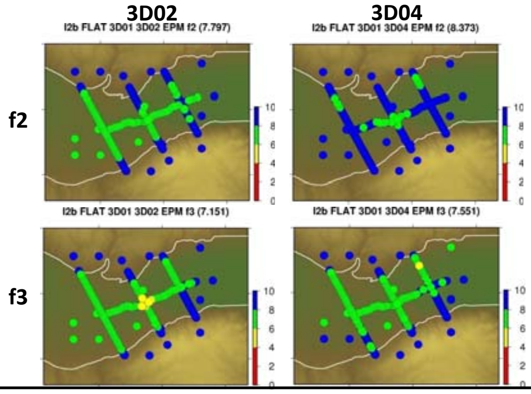
Verification of 3D numerical predictions : I2b - GOF (EPM, f0, ref:3D01&3D02) -



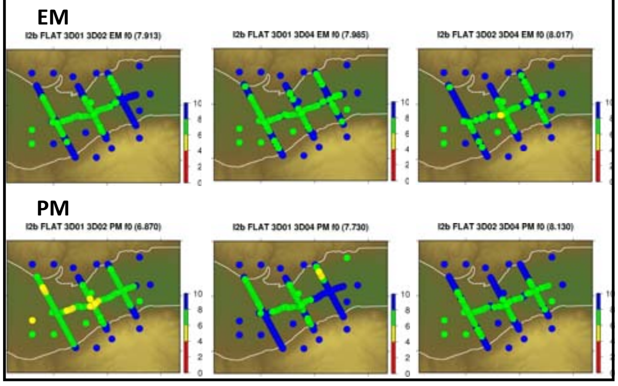
Verification of 3D numerical predictions : I2b - GOF (EPM, f1=[0-1Hz], ref:3D01) -



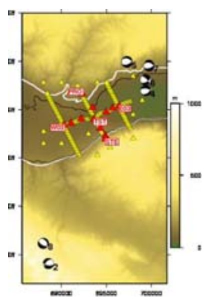
Verification of 3D numerical predictions : I2b - GOF (EPM, f2&f3, ref:3D01) -



Verification of 3D numerical predictions : I2b - GOF (EM&PM, f0, 3D01/3D02/3D04) -



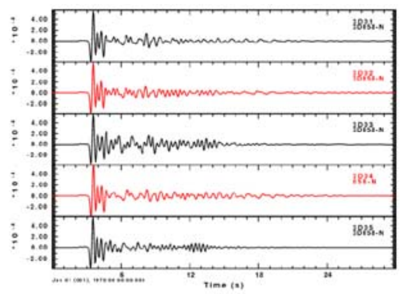
Validation of 3D numerical predictions



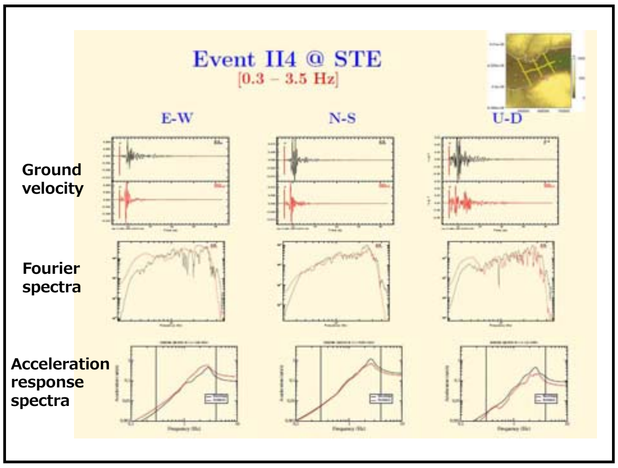
Comparison of the simulated ground motion with the recordings of the Euroseistest Array (19 accelerometers, 6 at depth) from 6 local events

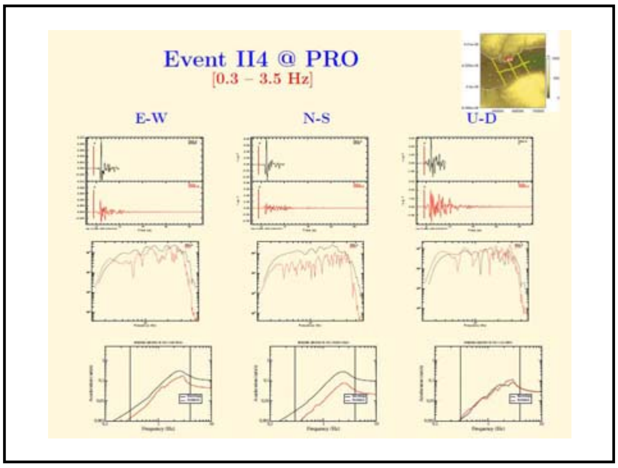
Event	Mag	Depth	Strike	Dip	Rake
Val2	2.8	6.9 km	100°	60°	-50°
Val4	4.4	5 km	53°	43°	-127°
Val5	3.1	6 km	72°	55°	-113°
Val6	3.9	6 km	61°	55°	-115°
Val7	3.4	5 km	72°	55°	113°
Val8	3.8	10 km	329°	34°	-64°

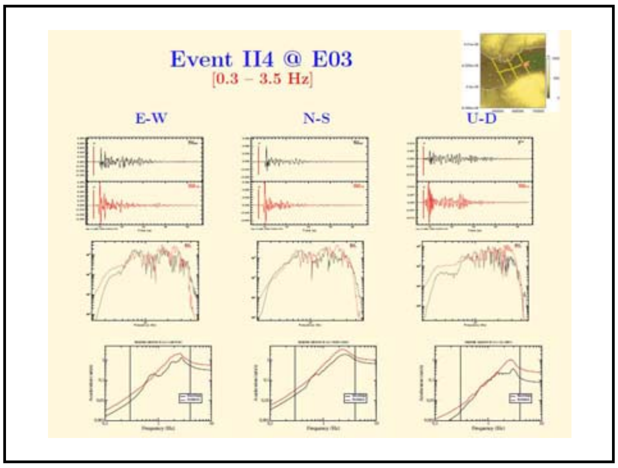
II4: Verification of simulated Ground motion

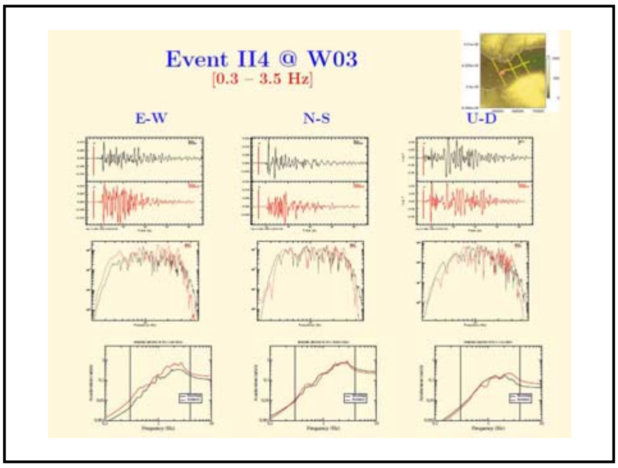


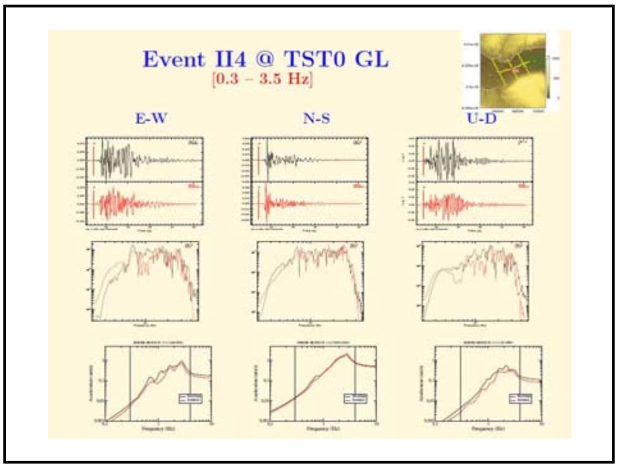
Example of NS ground velocity computed at TST0 for event II4
3-layers model with attenuation (constant Q=Vs/10)
We choose one solution (3D02) to compare time-series to recordings.

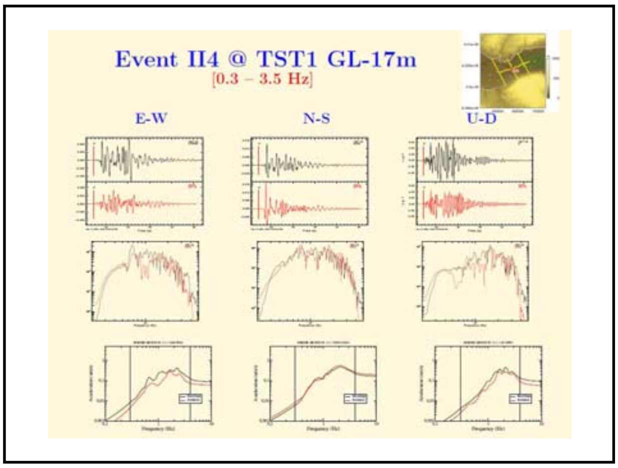

Event II4 @ STE
[0.3 – 3.5 Hz]
E-W
N-S
U-D
Ground velocity
Fourier spectra
Acceleration response spectra

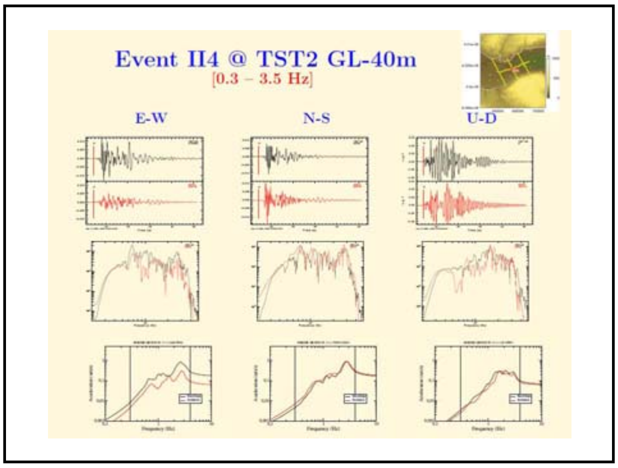

Event II4 @ PRO
[0.3 – 3.5 Hz]
E-W
N-S
U-D

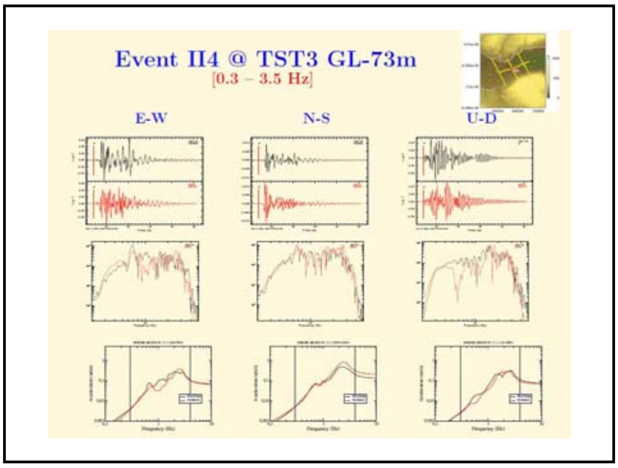

Event II4 @ E03
[0.3 – 3.5 Hz]
E-W
N-S
U-D

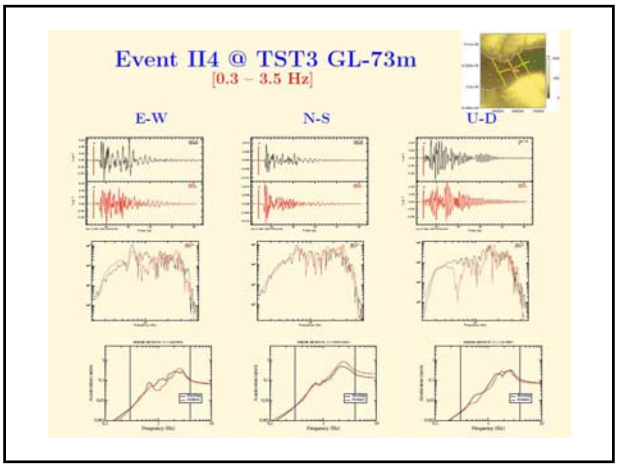

Event II4 @ W03
[0.3 – 3.5 Hz]
E-W
N-S
U-D

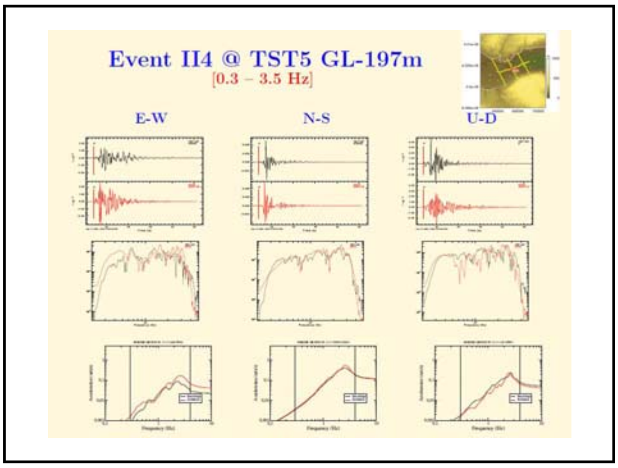

Event II4 @ TST0 GL
[0.3 – 3.5 Hz]
E-W
N-S
U-D

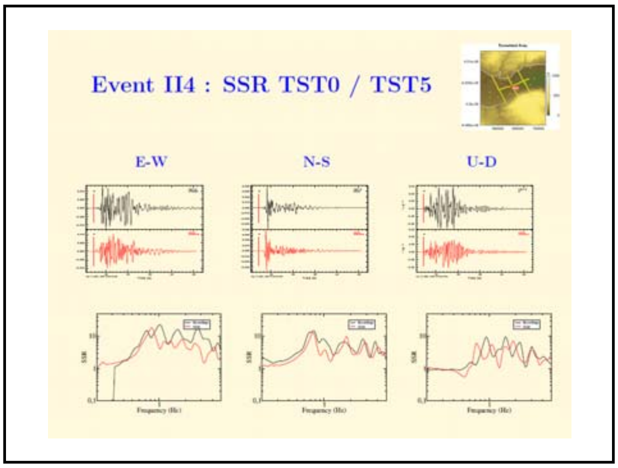

Event II4 @ TST1 GL-17m
[0.3 – 3.5 Hz]
E-W
N-S
U-D

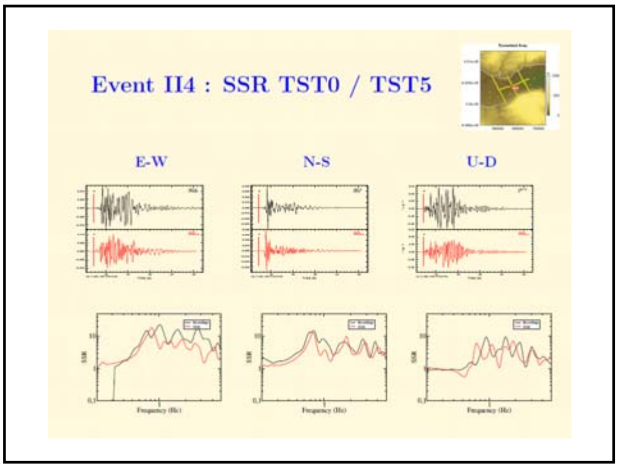

Event II4 @ TST2 GL-40m
[0.3 – 3.5 Hz]
E-W
N-S
U-D


Event II4 @ TST3 GL-73m
[0.3 – 3.5 Hz]
E-W
N-S
U-D

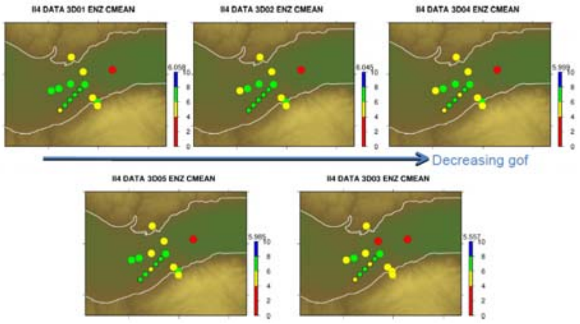

Event II4 @ TST3 GL-73m
[0.3 – 3.5 Hz]
E-W
N-S
U-D


Event II4 @ TST5 GL-197m
[0.3 – 3.5 Hz]
E-W
N-S
U-D

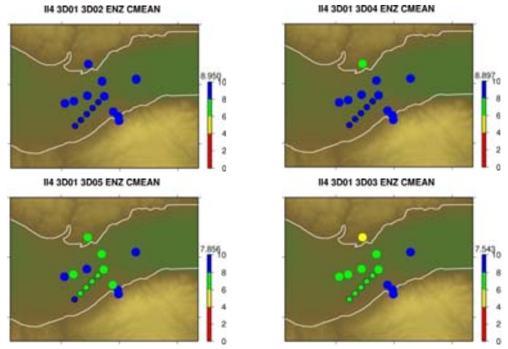

Event II4 : SSR TST0 / TST5
E-W
N-S
U-D


Event II4 : SSR TST0 / TST5
E-W
N-S
U-D

Event II4: global gof - all predictions



Event II4: gof between predictions



Differences between predictions are smaller than distance to recordings

All Events: TST0/TST5 spectral ratios