EuroseisTest (Volvi, Greece) Verification and Validation Project についての最終結果報告

津野靖士（TIT）, Pierre-Yves Bard（LGIT）,
Emmanuel Chaljub（LGIT）, Fabrice Hollender（CEA）

EuroseisTest (Volvi, Greece) Verification and Validation Project は、異なる数値計算手法の精度検証（Verification）と観測地震動との整合性評価（Validation）を目的に、第 3 回 ESG 国際シンポジウム（2006 年 8 月 30 日〜9 月 1 日、グルノーブル）で報告された地震動の Numerical Benchmark Test を引き継ぐ形で、the Aristotle University of Thessaloniki, Greece 及び the CEA and the Laue-Langevin Institute、the Joseph Fourier University, France の主導のもとに行われた。ESG（Effect of Surface Geology on Seismic Motion）では同様の地震動予測テストが、足柄平野および神戸、Parkfield 近傍の Turkey Flat に於いて実施されており、いずれのテストも参加者から提出された予測結果と強震記録との整合性を評価する Blind Prediction（目隠し予測）としての特徴がある。しかし、Grenoble に於いて実施された地震動予測テストでは、厚い堆積盆地構造による地震動の増幅効果が期待される強震記録が得られていないことから、Numerical Benchmark（ベンチマーク）としての性格が強く反映されている。今回の地震動予測テストを実施した Volvi では観測記録が得られており、予測結果のベンチマークとしての検討のみならず地震動との整合性の評価も行っている。特筆すべきは、3D modeling の参加者に周波数 4Hz までの予測結果を求めていることである。European Project である SPICE（Seismic wave Propagation and Imaging in Complex media）では Code Validation として均質等方性無限媒質や半無限媒質を対象とした数値計算結果の比較が行われ、フランス主導のプロジェクト SISMOVALP（Seismic hazard and alpine valley response analysis）では平面波を仮定した 2 次元の計算結果が比較検討されている。

2008 年 5 月から 2010 年 7 月の約 2 年間を通して蓄積された EuroseisTest (Volvi, Greece) Verification and Validation Project の最終結果を 3D modeling の予測結果を主として報告させていただく。

SSA 2010 Annual Meeting Abstract

Session: Numerical Prediction of Earthquake Ground Motion
Schedule: Thu 22 Apr – 1:30 PM
Location: Salon E
Presentation Type: Oral
Presenter: Hollender, Fabrice

EUROSEISTEST VERIFICATION AND VALIDATION PROJECT: AN INTERNATIONAL EFFORT TO EVALUATE GROUND MOTION NUMERICAL SIMULATION RELEVANCE

HOLLENDER, F., CEA, Cadarache / France, fabrice.hollender [AT] cea [DOT] fr; MANAKOU, M., AUTH, Thessaloniki / Greece, manakou [AT] civil.auth.gr; BARD, P.-Y., LGIT,CNRS,LCPC,J. Fourier Univ., Grenoble / France, bard [AT] obs.ujf-grenoble [DOT] fr; CHALJUB, E., LGIT,CNRS,OSUG,J. Fourier Univ., Grenoble / France, Emmanuel.Chaljub [AT] obs.ujf-grenoble [DOT] fr; RAPTAKIS, D., AUTH, Thessaloniki / Greece, raptakis [AT] civil.auth.gr; PITILAKIS, K., AUTH, Thessaloniki / Greece, kpitilak [AT] civil.auth.gr; TSUNO, S., LGIT,CNRS,J. Fourier Univ., Grenoble / France, Seiji.Tsuno [AT] obs.ujf-grenoble [DOT] fr

Numerical simulations are often used to evaluate local ground motion amplification (site effects). Before using these approaches for civil engineering design purposes, it is necessary to evaluate their reliability. Within the framework of this evaluation effort, an ongoing international collaborative work was organized, jointly by the Aristotle University of Thessaloniki, Greece, the Cashima research project (supported by the CEA and the Laue-Langevin institute), and the Joseph Fourier University, France. We decided to focus the study on a site (1) where the site geometry and geotechnical properties are well known and (2) where accelerometric time histories are available. The EuroseisTest site, located few tens of km East of Thessaloniki, was chosen since it provides a detailed 3D model of the sedimentary basin (about 5 km wide, 15 km long, sediments reach about 400 m depth) and the signals of 8 local earthquakes with magnitude from 3 to 5, recorded on 19 surface and borehole accelerometers. The project involves more than 10 international teams from Europe, Japan and USA, employing different numerical techniques (FDM, FEM, SEM, DGM, PSM, DEM). It consists in computations of different 2D, 3D, linear or non-linear cases. Through these exercises, it is possible to evaluate (1) the accuracy of numerical methods when applied to realistic applications where no reference solution exists (verification) and (2) quantify the agreement between recorded and numerically simulated data (validation). We will present the site, the objectives, the 3D model construction strategy, the different computing cases and main results of this project. The verification work allows us to clearly identify and understand the discrepancies between the predictions of the different simulation methods. The validation work shows surprisingly good agreement for the largest magnitude event, even at high frequencies (up to 4 Hz).

This abstract appears in *Seismological Research Letters* Volume 81, No. 2 on page 322.

SSA 2010 Annual Meeting Abstract

Session: Numerical Prediction of Earthquake Ground Motion
Schedule: Wed 21 Apr – PM Poster #38
Location: Exhibit Hall
Presentation Type: Poster
Presenter: Moczo, Peter

NUMERICAL MODELING OF EARTHQUAKE GROUND MOTION IN THE MYGDONIAN BASIN, GREECE: VERIFICATION OF THE 3D NUMERICAL METHODS

MOCZO, P., Comenius University Bratislava, Bratislava, Slovakia, moczo [AT] fmph.uniba.sk; KRISTEK, J., Comenius University Bratislava, Bratislava, Slovakia, kristek [AT] fmph.uniba.sk; FRANEK, P., Geophysical Institute SAS, Bratislava, Slovakia, geofpefr [AT] savba.sk; CHALJUB, E., LGIT UJF, Grenoble, France, Emmanuel.Chaljub [AT] obs.ujf-grenoble [DOT] fr; BARD, P.-Y., LGIT UJF, Grenoble, France, Pierre-Yves.Bard [AT] obs.ujf-grenoble [DOT] fr; TSUNO, S., LGIT UJF, Grenoble, France, Seiji.Tsuno [AT] obs.ujf-grenoble [DOT] fr; IWATA, T., DPRI Kyoto University, Kyoto, Japan, iwata [AT] egmdpri01.dpri.kyoto-u.ac [DOT] jp; IWAKI, A., DPRI Kyoto University, Kyoto, Japan, iwaki [AT] egmdpri01.dpri.kyoto-u.ac [DOT] jp; PRIOLO, E., INOGS, Trieste, Italy, epriolo [AT] inogs [DOT] it; KLIN, P., INOGS, Trieste, Italy, pklin [AT] inogs [DOT] it; AOI, S., NIED, Tsukuba, Japan, aoi [AT] bosai.go [DOT] jp; MARIOTTI, C., CEA, Arpajon, France, christian.mariotti [AT] cea [DOT] fr; BIELAK, J., CMU, Pittsburgh PA, USA, jbielak [AT] cmu [DOT] edu ; TABORDA, R., CMU, Pittsburgh PA, USA, rtaborda [AT] cmu [DOT] edu ; KARAOGLU, H., CMU, Pittsburgh PA, USA, hkaraogl [AT] cmu [DOT] edu ; ETIENNE, V., GEOAZUR, Nice, France, Vincent.ETIENNE [AT] unice [DOT] fr; VIRIEUX, J., LGIT UJF, Grenoble, France, Jean.Virieux [AT] obs.ujf-grenoble [DOT] fr

The capability of numerical methods to predict earthquake ground motion is investigated through the ongoing Euroseistest verification and validation project. The project focuses on the Volvi Mygdonian basin (Greece) which has been a subject of extensive geophysical and geotechnical investigations for more than two decades. A new detailed 3D model of the basin (5 km wide, 15 km long, with maximum sediment thickness 400 m and minimum S-wave velocity 200 m/s) as well as recordings of local earthquakes by the Euroseistest instruments provide a reasonable basis for the verification and validation of the numerical methods. Here we present the results of the verification phase of the project for 3D numerical methods.
Numerical-modeling teams from Europe, Japan and USA employ the finite-difference method (FDM), finite-element method (FEM), global pseudospectral method (GPSM), spectral- element method (SEM), discrete-element method (DEM) and discontinuous Galerkin method (DGM). The problem configurations include elastic and viscoelastic rheologies, basin models built from smooth velocity gradients or composed of three homogeneous layers, one hypothetical event and six local events with magnitude between 3 and 5. Numerical predictions for frequencies up to 4 Hz are compared using quantitative time-frequency envelope and phase goodness-of-fit criteria computed at 288 receivers. Solutions are also analyzed with respect to rheology, geometry of the interface and source parameters, and their representations in the computational models. In particular, it is shown that the agreement between numerical predictions of ground motion duration strongly depends on the ability of each method to model accurately the surface waves diffracted off the basin edges and propagating within the basin.

This abstract appears in *Seismological Research Letters* Volume 81, No. 2 on page 310.

SSA 2010 Annual Meeting Abstract

Session: Numerical Prediction of Earthquake Ground Motion
Schedule: Wed 21 Apr – PM Poster #32
Location: Exhibit Hall
Presentation Type: Poster
Presenter: Chaljub, Emmanuel

EUROSEISTEST NUMERICAL SIMULATION PROJECT: COMPARISON WITH LOCAL EARTHQUAKE RECORDINGS FOR VALIDATION.

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The ultimate goal of the Euroseistest verification and validation project is to assess the capability of numerical simulation to accurately predict seismic ground motion up to relatively high frequencies . This presentation will focus on the validation step, consisting in comparing numerical predictions with actual recordings up to 4 Hz. The exercise has been performed for 6 local, weak to moderate magnitude events, spanning various azimuths, depth and distances, and recorded by a local array of 19 surface and borehole accelerometers. In general, while the detailed waveforms do not match, the overall amplitude, duration, and spectral shape exhibit a relatively satisfactory agreement. The level of agreement is however found to be event-dependent, as a combined result of the large sensitivity of waveform details to the source location and mechanism, the geometry of the sediment-basement interface, and the internal sediment layering, and of the uncertainties in the source parameters and basin structure. The best agreement is found indeed for the largest – and thus best known- event. In order to remove the errors due to source parameter uncertainties, the instrumental site to reference spectral ratios derived from the available recordings were compared with those derived from 1D and 3D synthetics. The best fit is obtained for 3D simulations, which do account for both the broad band amplification due to lateral reverberations, and the scatter due to the sensitivity of the diffraction pattern to the source location. There is however a trend for underestimating the actual amplification, in probable connection with incorrect estimates of damping and internal sediment layering structure. The next challenge in view of deterministic simulation of ground motion at intermediate frequency thus consists mainly in improving the performance of shallow geophysical investigations.

This abstract appears in *Seismological Research Letters* Volume 81, No. 2 on page 308.

EuroseisTest (Volvi, Greece) Verification and Validation Project についての最終結果報告

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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.

• Site effect evaluation = a major component of seismic hazard assessment

• Numerical simulation: "only" one of the several approaches to estimate site effects but it becomes important for:
  • low seismicity area (only few and weak earthquakes for a reasonable recording time)
  • non-linearity consideration

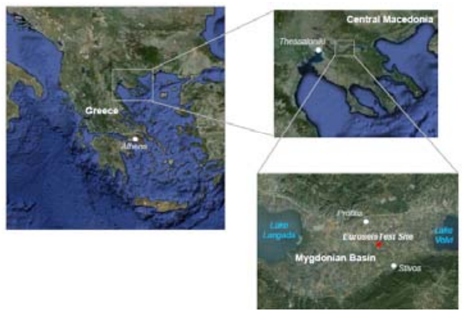
Are the « state of the art » of site effect simulation method mature enough to be applied for facility design ?

• The "ideal" site features:
  – a site where we could observe site effects (basin configuration)
  – good geological, geophysical, geotechnical knowledge of the site, if possible, a "3D geological model" already available
  – well instrumented site, where earthquakes (as strong as possible) were already recorded on a maximum of stations
  – ease to obtain, use and share the data (records, geological model…) within a broad collaborative project

• EuroseisTest Verification and Validation Project

Cashima Project

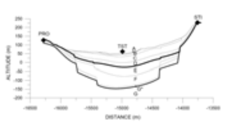
The EuroseisTest Site



Geological, geophysical, geotechnical characterization

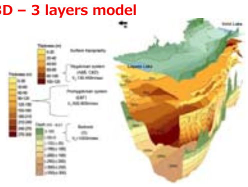
• A high characterisation effort:
  – boreholes
  – surface and boreholes seismic surveys
  – electric surveys
  – array microtremor measurements
  – H/V measurements
  – laboratory measurements on samples
  – etc.

2D – 7 layers model



Raptakis et al. 2000

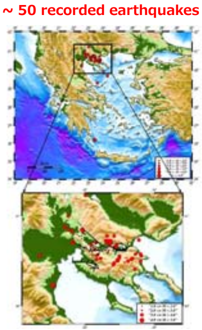
3D – 3 layers model



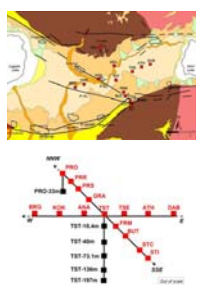
Manakou, 2007

The EuroseisTest Site: instrumentation and records

~ 50 recorded earthquakes



21 accelerometric stations

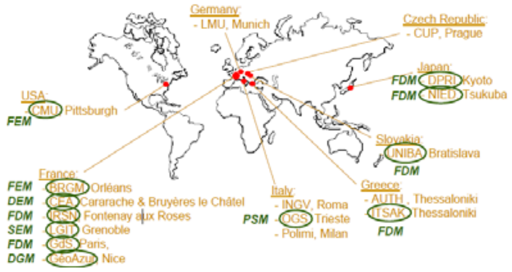


Initial objectives

- 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)

Verification of 3D numerical predictions

Goals:

・Compare 3D numerical simulations of earthquake ground motion in the **Volvi basin for different seismic sources and frequencies up to 4 Hz**

・Identify the important parameters for accurate numerical modelingof seismic wave propagation in 3D basins (site effects):
- Free-surface condition
- Absorbing boundary conditions
- Representation of 3D heterogeneities
- Numerical dispersion
- …

This is a long-term effort, the E2VP has allowed us to improve our knowledge and expertise.

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 á l Energie Atomique	Bruyéres Le Chatel	France
CMU 3D07	FEM	Carnegie Melon Univ.	Pittsburgh	USA
UNICE 3D09	DGM	Université de Nice Sophia Antipolis	Valbonne	France

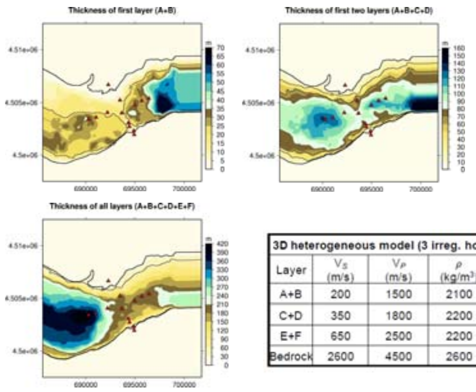
Applied Methods	
FDM	Finite-difference method
SEM	Spectral-element method
PSM	Pseudo-spectral method
DEM	Discrete-element method
FEM	Finite-element method
DGM	Discontinuous Galerkin method

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, Voronoi 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

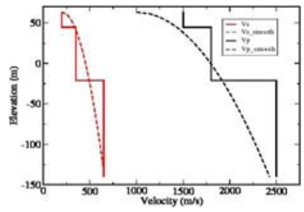
rheology of GZB (generalized Zener (i.e. SLS) body) == rheology of the generalized Maxwell body in definition by Emmerich and Korn (1987)

Volvi 3-layers basin model



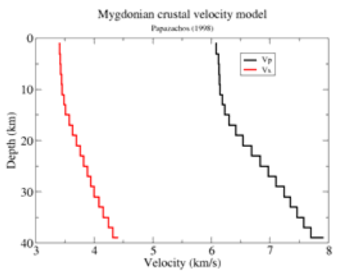
3D heterogeneous model (3 irreg. homog. layers)					
Layer	V_S (m/s)	V_P (m/s)	ρ (kg/m³)	Q_S	Q_K
A+B	200	1500	2100	20	∞
C+D	350	1800	2200	35	∞
E+F	650	2500	2200	65	∞
Bedrock	2600	4500	2600	260	∞

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	∞

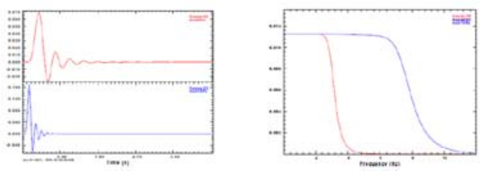
Crustal model



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

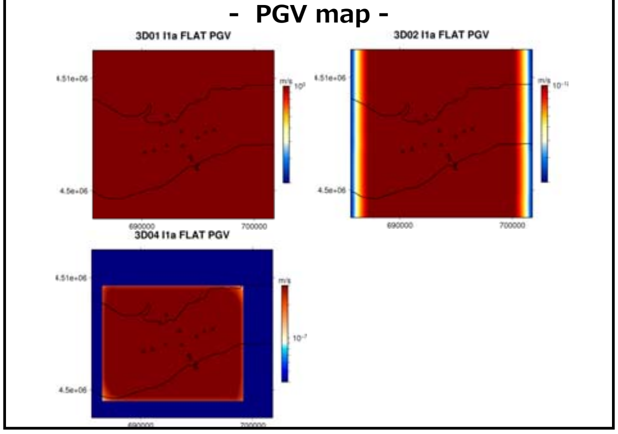
Table of submitted solutions								
	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I1a	✓	✓		✓				
I1b	✓	✓		✓				
I2a	✓	✓	✓	✓	✓	✓		
III1	✓	✓	✓	✓	✓		✓	✓
I2c	✓	✓	✓	✓	✓	✓	✓	✓
I2b	✓	✓	✓	✓	✓	✓	✓	
IV2	✓	✓	✓	✓	✓			✓
IV1	✓	✓		✓	✓			

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

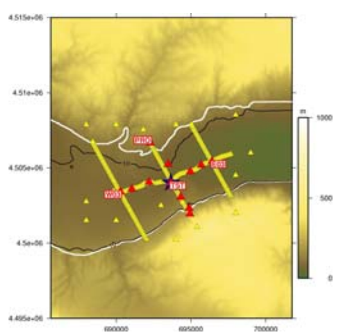
Model configurations for the vertically impinging plane SV wave				
ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I1a	n.a.	n.a.	homog.	elastic

Table of submitted solutions								
	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I1a	✓	✓		✓				

Verification of 3D numerical predictions : I1a - PGV map -



Verification of 3D numerical predictions: receivers

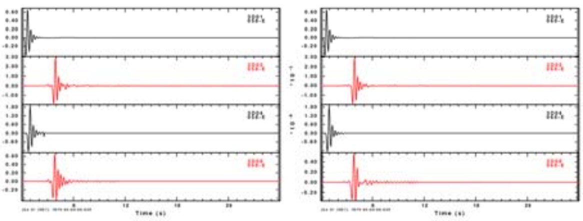


288 receivers :
Depth (7)
Basin (274)
Rock (7)

Comparisons shown at:
PRO
TST
E03
W03

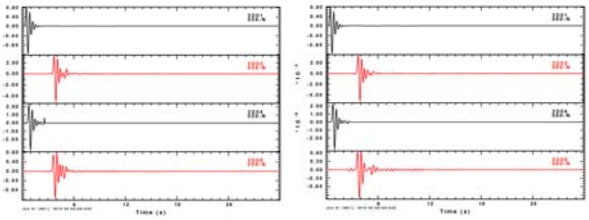
Verification of 3D numerical predictions : I1a - Traces (E, normalized) -

TST(058) PRO(060)

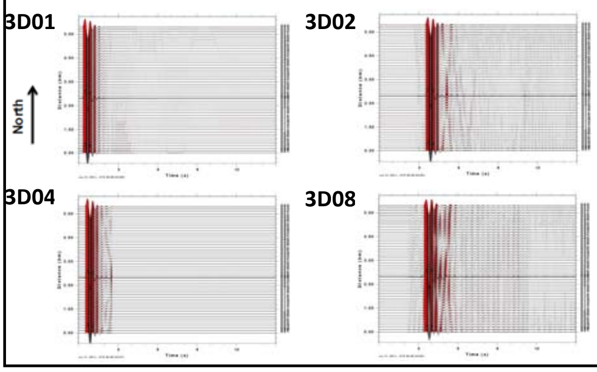


Verification of 3D numerical predictions : I1a - Traces (N, normalized) -

TST(058) PRO(060)



Verification of 3D numerical predictions : I1a - Profile (SV) -



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

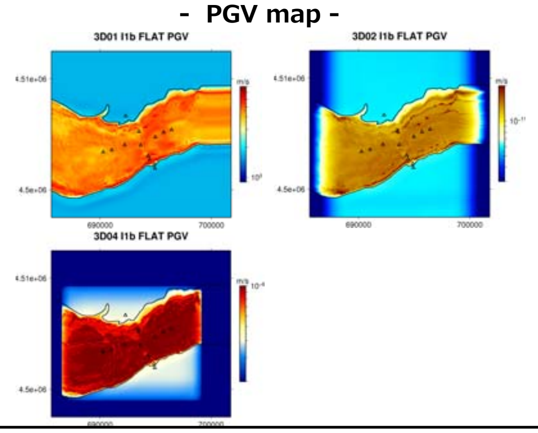
Table of submitted solutions								
	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I1a	✓	✓		✓				

- I1a critical case for ABC+plane wave implementation
- No quantitative comparison because of differences in input motion
- Need for iterations ??

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

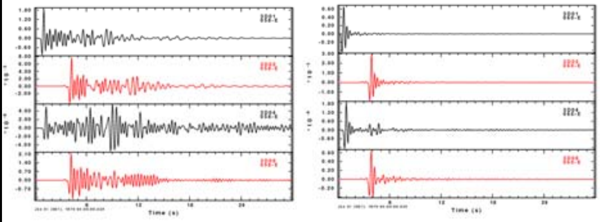
Table of submitted solutions								
	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I1b	✓	✓		✓				

Verification of 3D numerical predictions : I1b - PGV map -



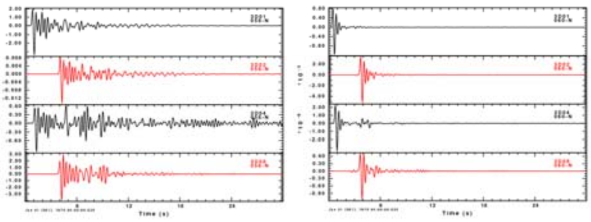
Verification of 3D numerical predictions : I1b - Traces (E, normalized) -

TST(058) PRO(060)



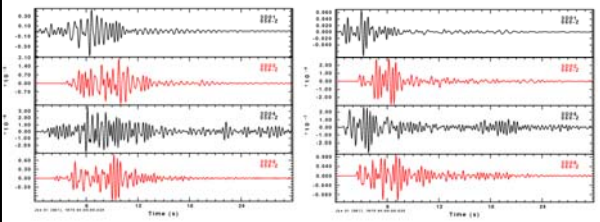
Verification of 3D numerical predictions : I1b - Traces (N, normalized) -

TST(058) PRO(060)

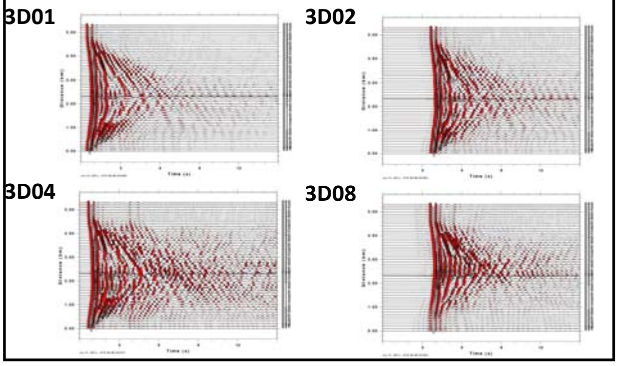


Verification of 3D numerical predictions : I1b - Traces (Z, normalized) -

TST(058) PRO(060)



Verification of 3D numerical predictions : I1b - Profile (SV) -



Model configurations for the vertically impinging plane SV wave

ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I1b	3D heterog. (3 irreg. homog. layers)	viscoelastic	homog.	elastic

Table of submitted solutions

	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I1b	✓	✓		✓				

- I1b critical case for ABC+plane wave implementation
- No quantitative comparison because of differences in input motion
- Differences in basin response
- Need for iterations ?

Model configurations for the hypothetical point DC source

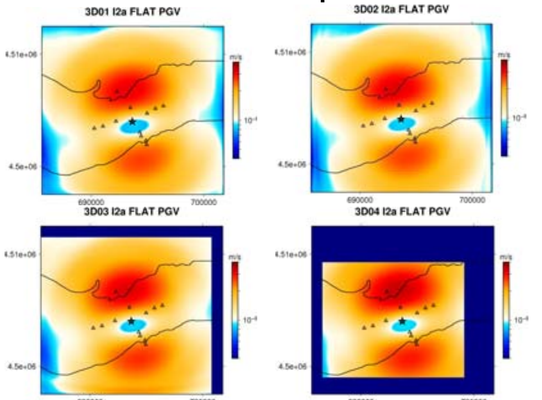
ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I2a	n.a.	n.a.	homog.	viscoelastic

Table of submitted solutions

	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I2a	✓	✓	✓	✓	✓	✓		

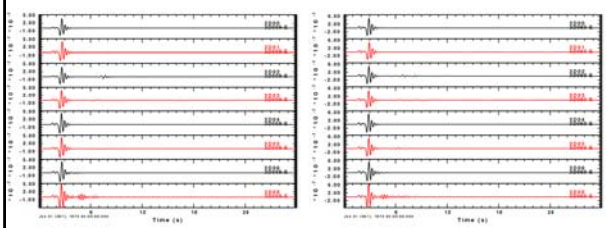
Additional request: use the basin mesh even if model is homogeneous

Verification of 3D numerical predictions : I2a - PGV map -



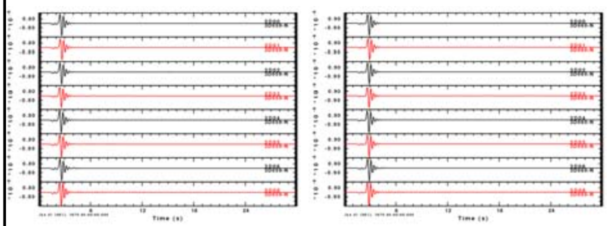
Verification of 3D numerical predictions : I2a - Traces (E) -

GRA(059) PRO(060)



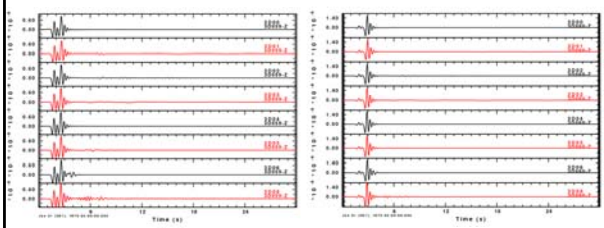
Verification of 3D numerical predictions : I2a - Traces (N) -

GRA(059) PRO(060)

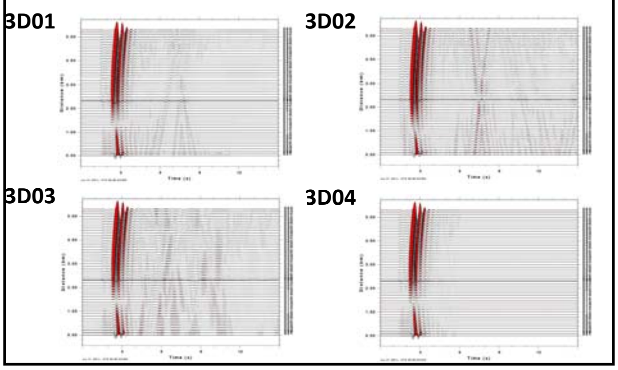


Verification of 3D numerical predictions : I2a - Traces (Z) -

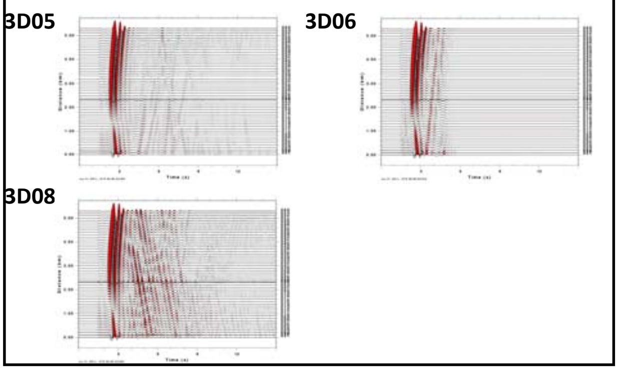
GRA(059) PRO(060)



Verification of 3D numerical predictions : I2a - Profile (SH) -

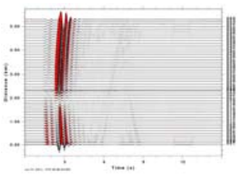


Verification of 3D numerical predictions : I2a - Profile (SH) -

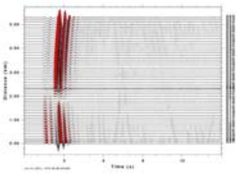


Verification of 3D numerical predictions : I2a - Profile (SV) -

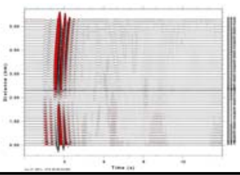
3D01



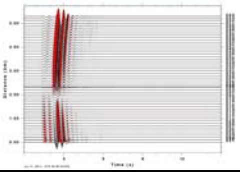
3D02



3D03

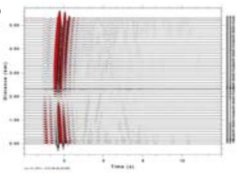


3D04

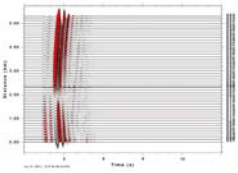


Verification of 3D numerical predictions : I2a - Profile (SV) -

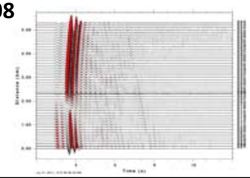
3D05



3D06

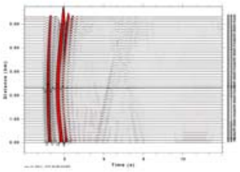


3D08

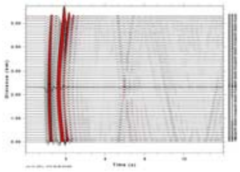


Verification of 3D numerical predictions : I2a - Profile (Z) -

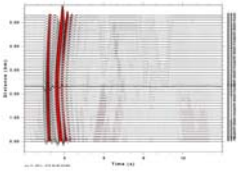
3D01



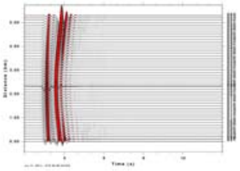
3D02



3D03

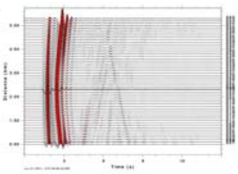


3D04

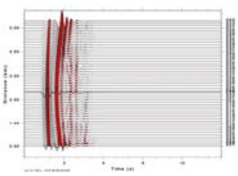


Verification of 3D numerical predictions : I2a - Profile (Z) -

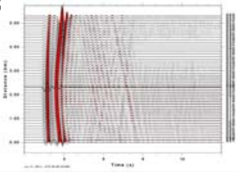
3D05



3D06



3D08



Model configurations for the hypothetical point DC source

ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I2a	n.a.	n.a.	homog.	viscoelastic

Table of submitted solutions

	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I2a	✓	✓	✓	✓	✓	✓		

- I2a case reveals the performance of ABC (good for 3D04, 3D01)
- Implementation of DC point-source is validated
- Mesh creation has been tested (at least for FEM, SEM and DGM)
- No need for iteration

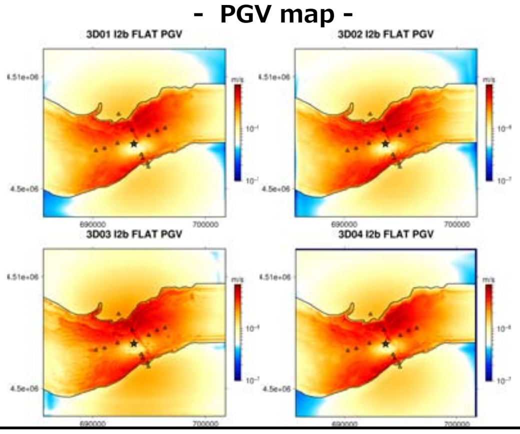
Model configurations for the hypothetical point DC source

ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I2b	3D heterog. (3 irreg. homog. layers)	viscoelastic	1D	Viscoelastic

Table of submitted solutions

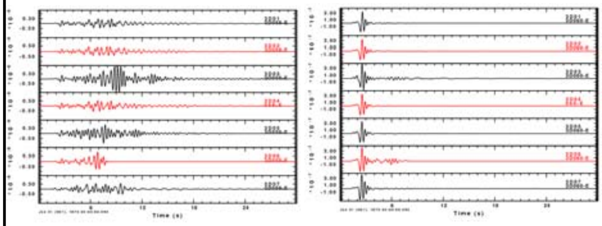
	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I2b	✓	✓	✓	✓	✓	✓	✓	

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



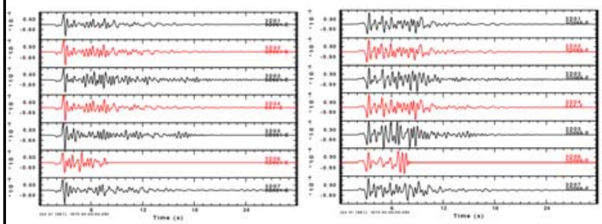
Verification of 3D numerical predictions : I2b - Traces (E) -

TST(058) PRO(060)



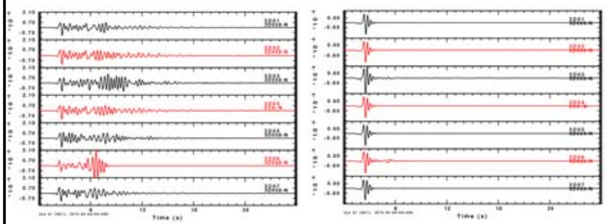
Verification of 3D numerical predictions : I2b - Traces (E) -

E03(061) W03(066)



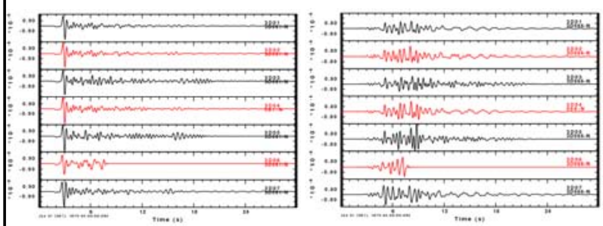
Verification of 3D numerical predictions : I2b - Traces (N) -

TST(058) PRO(060)



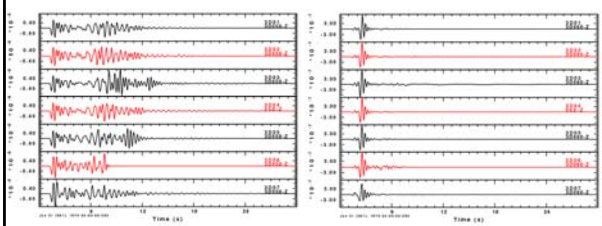
Verification of 3D numerical predictions : I2b - Traces (N) -

E03(061) W03(066)



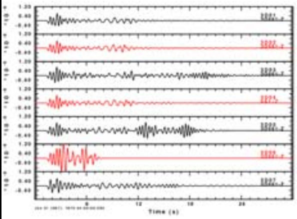
Verification of 3D numerical predictions : I2b - Traces (Z) -

TST(058) PRO(060)

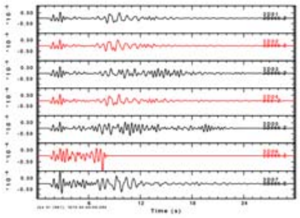


Verification of 3D numerical predictions : I2b
- Traces (Z) -

E03(061)

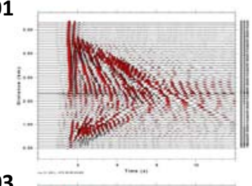


W03(066)

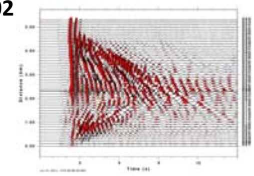


Verification of 3D numerical predictions : I2b
- Profile (SH) -

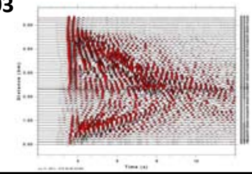
3D01



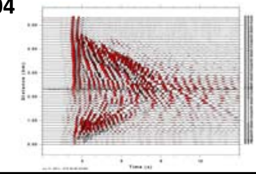
3D02



3D03

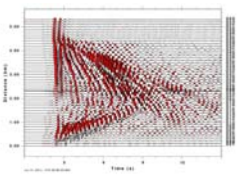


3D04

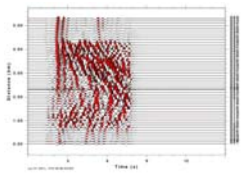


Verification of 3D numerical predictions : I2b
- Profile (SH) -

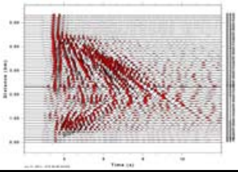
3D05



3D06

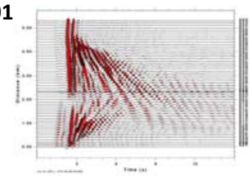


3D07

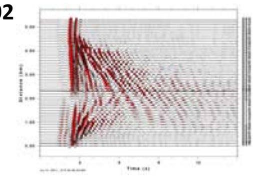


Verification of 3D numerical predictions : I2b
- Profile (SV) -

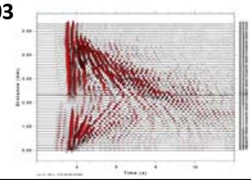
3D01



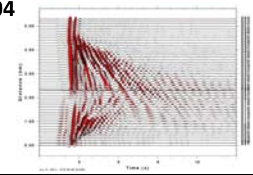
3D02



3D03

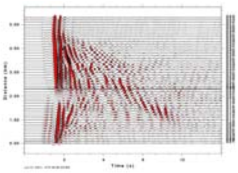


3D04

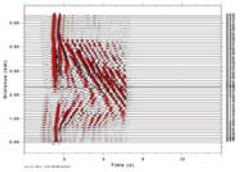


Verification of 3D numerical predictions : I2b
- Profile (SV) -

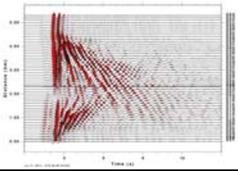
3D05



3D06

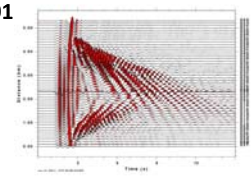


3D07

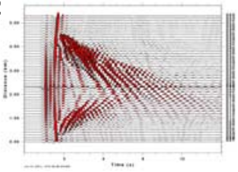


Verification of 3D numerical predictions : I2b
- Profile (Z) -

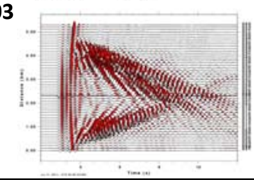
3D01



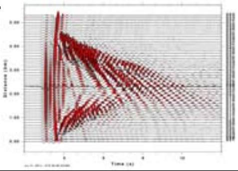
3D02



3D03

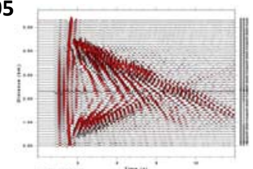


3D04

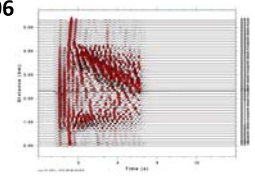


Verification of 3D numerical predictions : I2b - Profile (Z) -

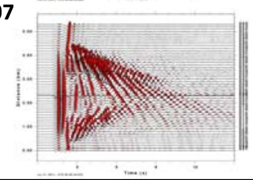
3D05



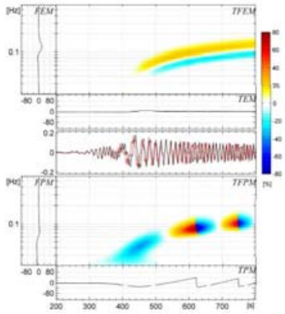
3D06



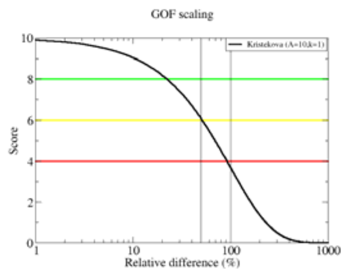
3D07



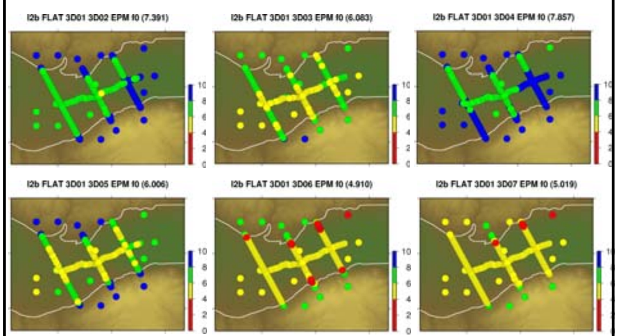
Quantitative measure of misfit using Time Frequency Misfit criteria (Kristekova et al., 2009)



From Misfit to Goodness-of-Fit

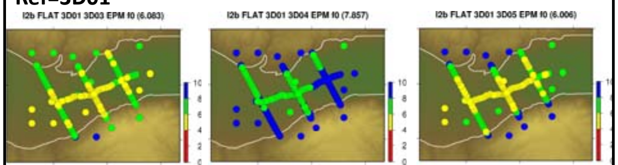


Verification of 3D numerical predictions : I2b - GOF (EPM, f0=[0-4Hz], ref:3D01) -

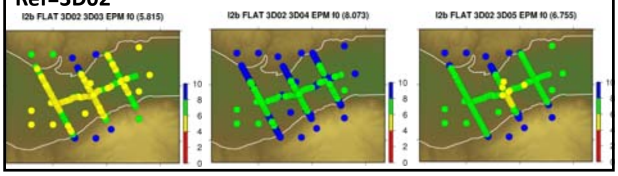


Verification of 3D numerical predictions : I2b - GOF (EPM, f0, ref:3D01&3D02) -

Ref=3D01

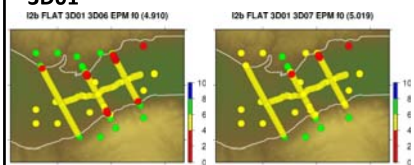


Ref=3D02

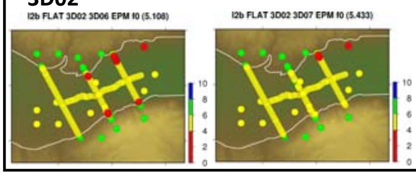


Verification of 3D numerical predictions : I2b - GOF (EPM, f0, ref:3D01&3D02) -

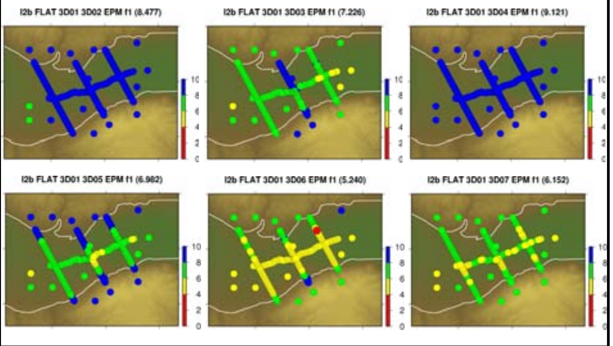
3D01



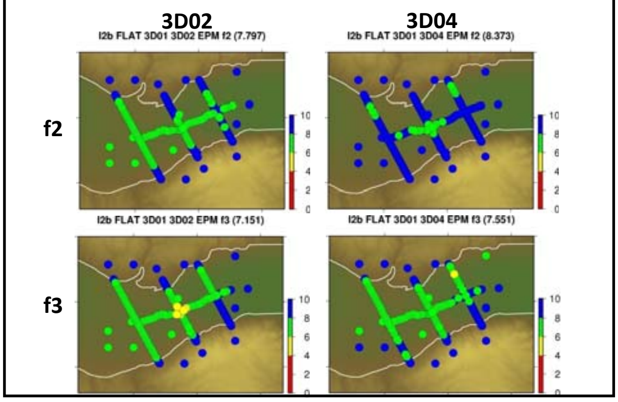
3D02



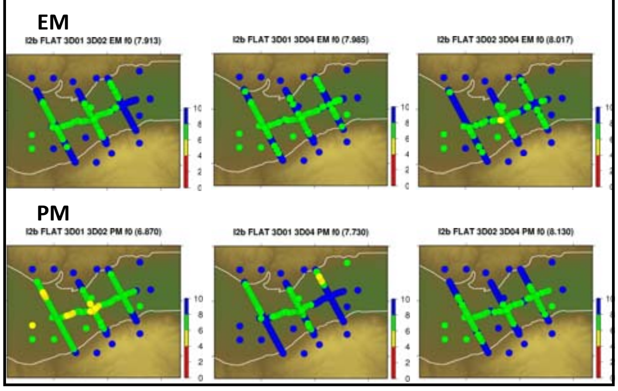
Verification of 3D numerical predictions : I2b - GOF (EPM, f1=[0-1Hz], ref:3D01) -



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) -



Model configurations for the hypothetical point DC source

ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I2b	3D heterog. (3 irreg. homog. layers)	viscoelastic	1D	Viscoelastic

Table of submitted solutions

	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I2b	✓	✓	✓	✓	✓	✓	✓	

・Very good level of agreement between 3 solutions: 3D01,3D02,3D04
・TF gof are useful to understand differences (especially phase)
・Differences with 3D03 & 3D05: Implementation of attenuation, bedrock model (3D03).
・Differences with 3D07: limited Vp/Vs ratio, bedrock model.
・Differences with 3D06: method under developement

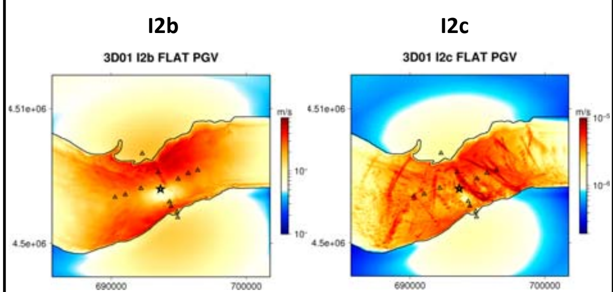
Model configurations for the hypothetical point DC source

ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I2c	3D heterog. (3 irreg. homog. layers)	elastic	1D	elastic

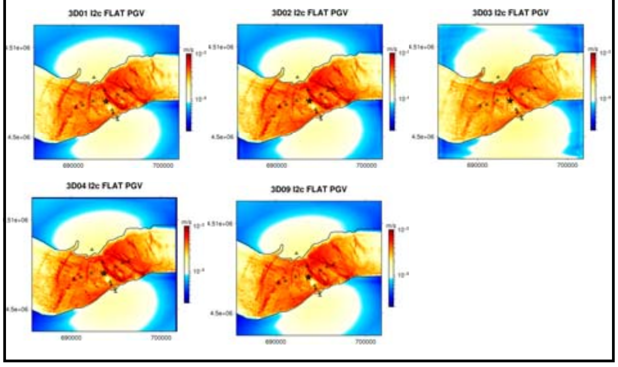
Table of submitted solutions

	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I2c	✓	✓	✓	✓	✓	✓	✓	✓

Verification of 3D numerical predictions : I2c - PGV map (I2b & I2c, 3D01) -

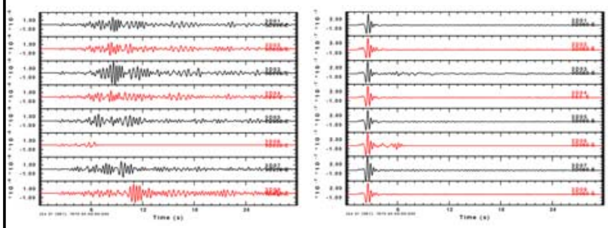


Verification of 3D numerical predictions : I2c
- PGV map -



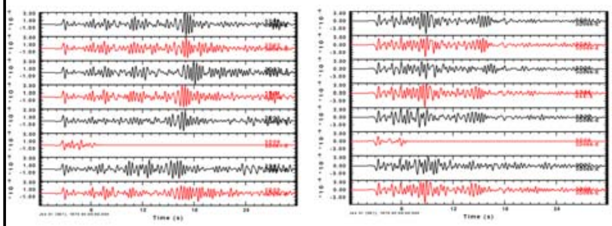
Verification of 3D numerical predictions : I2c
- Traces (E) -

TST(058) PRO(060)



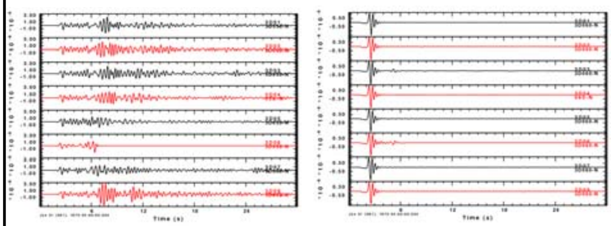
Verification of 3D numerical predictions : I2c
- Traces (E) -

E03(061) W03(066)



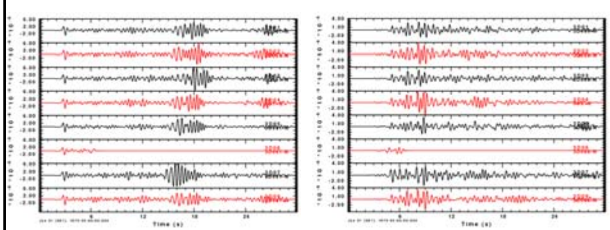
Verification of 3D numerical predictions : I2c
- Traces (N) -

TST(058) PRO(060)



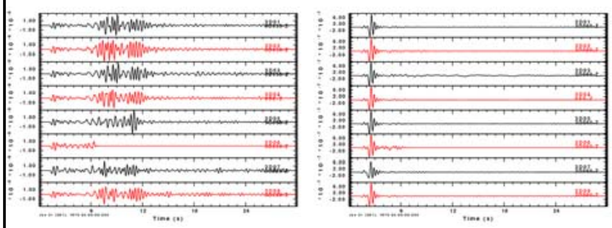
Verification of 3D numerical predictions : I2c
- Traces (N) -

E03(061) W03(066)



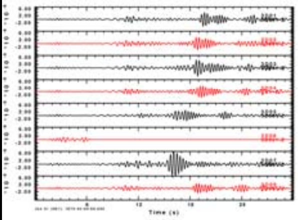
Verification of 3D numerical predictions : I2c
- Traces (Z) -

TST(058) PRO(060)

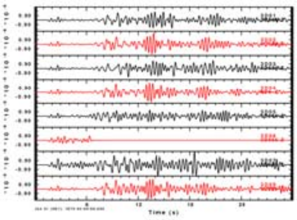


Verification of 3D numerical predictions : I2c
- Traces (Z) -

E03(061)

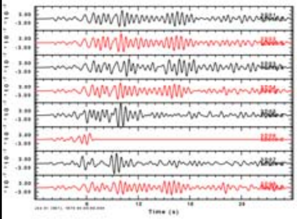


W03(066)

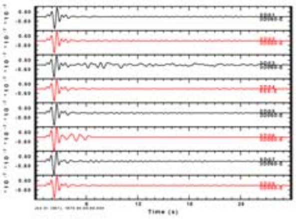


Verification of 3D numerical predictions : I2c
- Traces (E, low pass filter) -

TST(058)

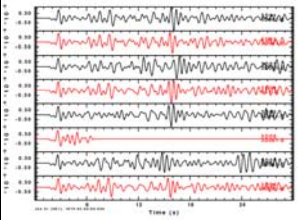


PRO(060)



Verification of 3D numerical predictions : I2c
- Traces (E, low pass filter) -

E03(061)



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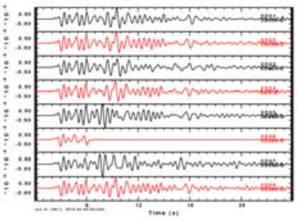
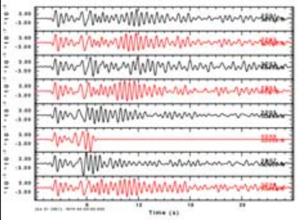
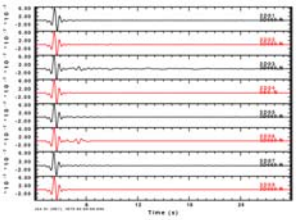


Verification of 3D numerical predictions : I2c
- Traces (N, low pass filter) -

TST(058)

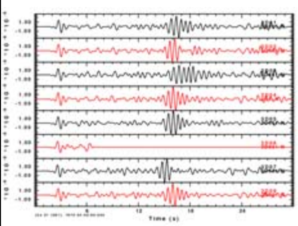


PRO(060)



Verification of 3D numerical predictions : I2c
- Traces (N, low pass filter) -

E03(061)



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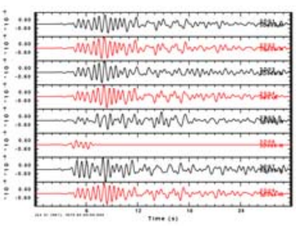
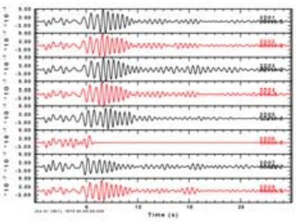
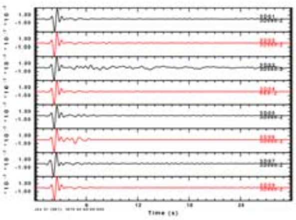


Verification of 3D numerical predictions : I2c
- Traces (Z, low pass filter) -

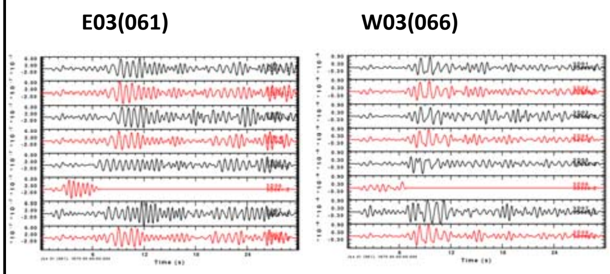
TST(058)



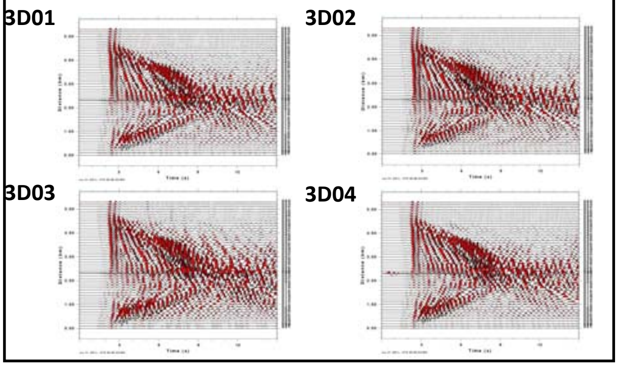
PRO(060)



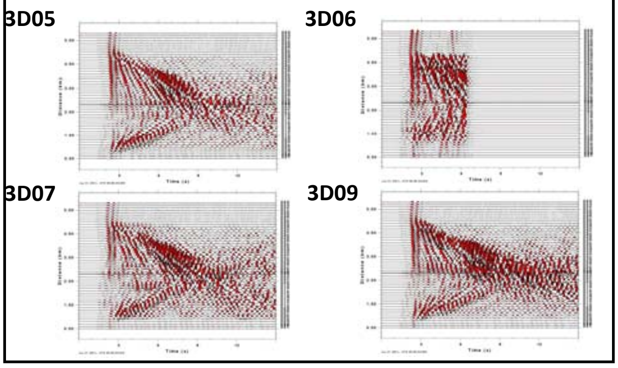
Verification of 3D numerical predictions : I2c
- Traces (Z, low pass filter) -



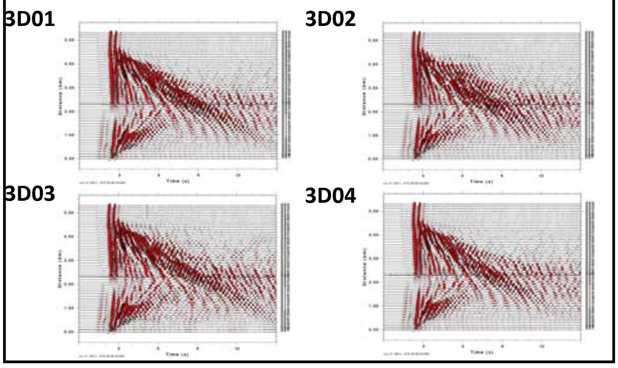
Verification of 3D numerical predictions : I2c
- Profile (SH) -



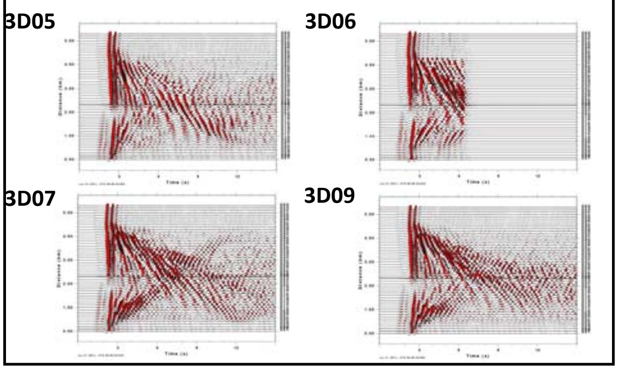
Verification of 3D numerical predictions : I2c
- Profile (SH) -



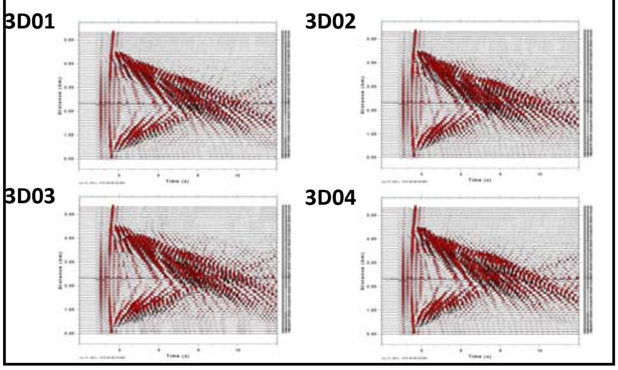
Verification of 3D numerical predictions : I2c
- Profile (SV) -



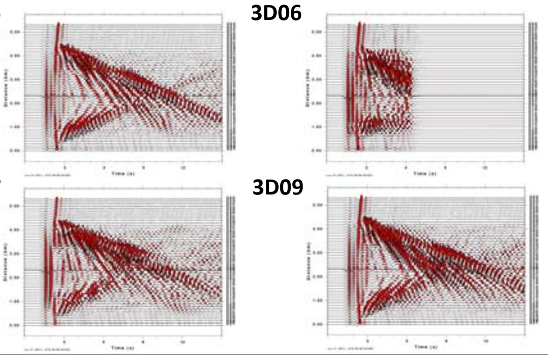
Verification of 3D numerical predictions : I2c
- Profile (SV) -



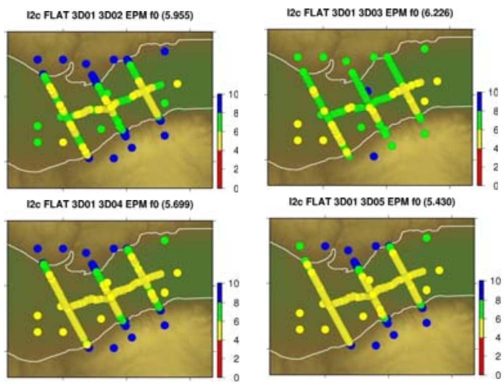
Verification of 3D numerical predictions : I2c
- Profile (Z) -



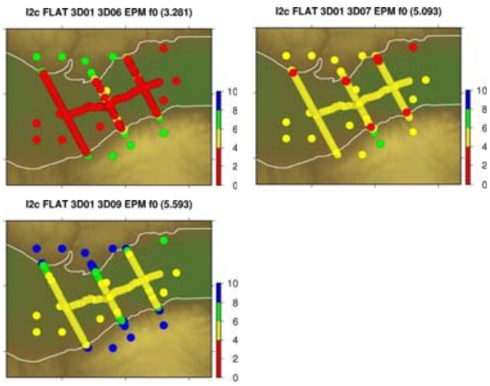
Verification of 3D numerical predictions : I2c - Profile (Z) -



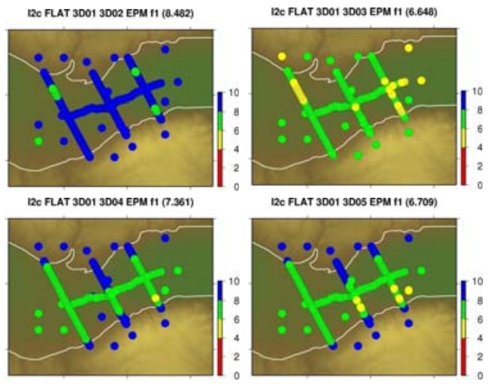
Verification of 3D numerical predictions : I2c - GOF (EPM, f0, ref:3D01) -



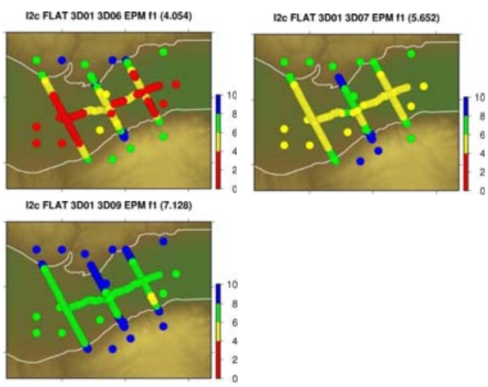
Verification of 3D numerical predictions : I2c - GOF (EPM, f0, ref:3D01) -



Verification of 3D numerical predictions : I2c - GOF (EPM, f1, ref:3D01) -



Verification of 3D numerical predictions : I2c - GOF (EPM, f1, ref:3D01) -



Model configurations for the hypothetical point DC source

ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
I2c	3D heterog. (3 irreg. homog. layers)	elastic	1D	elastic

Table of submitted solutions

	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
I2c	✓	✓	✓	✓	✓	✓	✓	✓

・ Very large differences are seen on late arrivals
・ Better fit on vertical component
・ Gof decreases quickly with frequency
・ Reveals numerical challenge to handle physical discontinuities or/and related complexity in wave propagation?
・ Need for verification in smooth velocity models

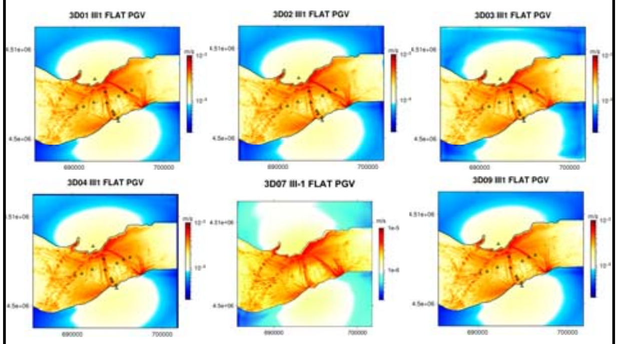
Model configurations for the hypothetical point DC source

ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
III1	laterally homog., vertical gradient	elastic	1D	elastic

Table of submitted solutions

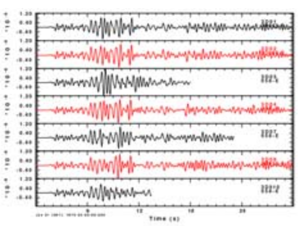
	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
III1	✓	✓	✓	✓	✓		✓	✓

Verification of 3D numerical predictions : III1 - PGV map -

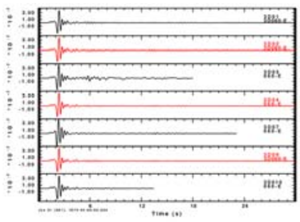


Verification of 3D numerical predictions : III1 - Traces (E) -

TST(058)

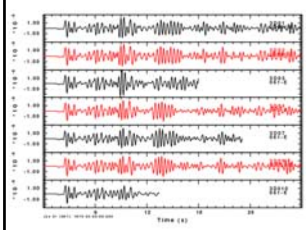


PRO(060)

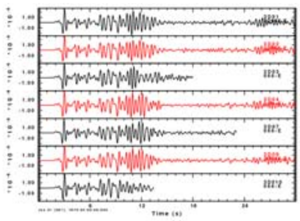


Verification of 3D numerical predictions : III1 - Traces (E) -

E03(061)

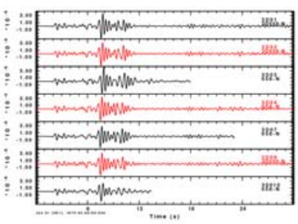


W03(066)



Verification of 3D numerical predictions : III1 - Traces (N) -

TST(058)



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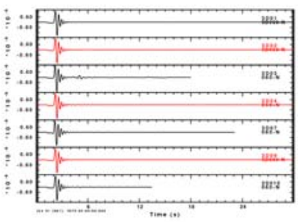
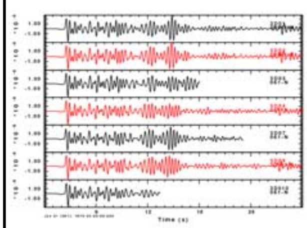
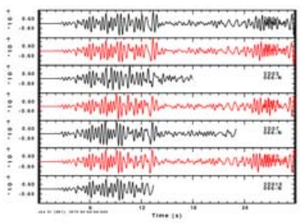


Verification of 3D numerical predictions : III1 - Traces (N) -

E03(061)

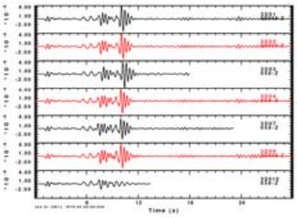


W03(066)

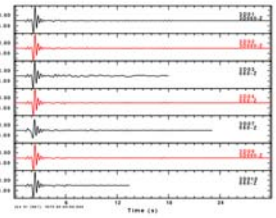


Verification of 3D numerical predictions : III1 - Traces (Z) -

TST(058)

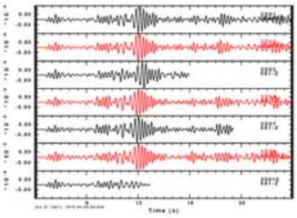


PRO(060)

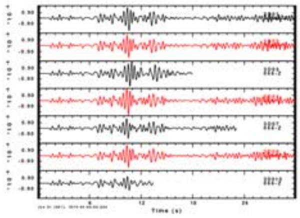


Verification of 3D numerical predictions : III1 - Traces (Z) -

E03(061)

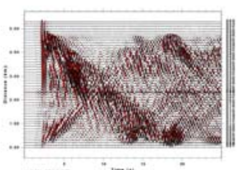


W03(066)

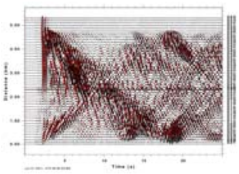


Verification of 3D numerical predictions : III1 - Profile (SH) -

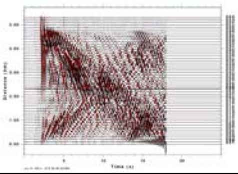
3D01



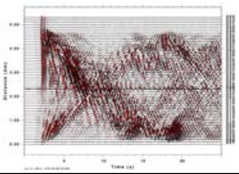
3D02



3D03

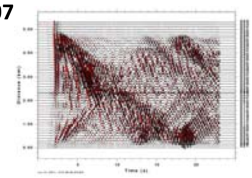


3D04

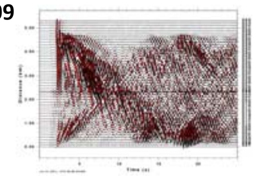


Verification of 3D numerical predictions : III1 - Profile (SH) -

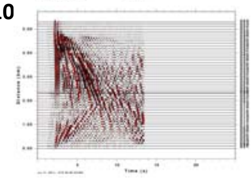
3D07



3D09

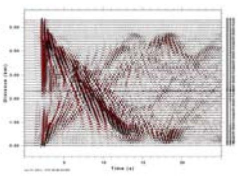


3D10

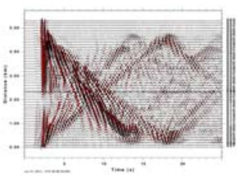


Verification of 3D numerical predictions : III1 - Profile (SV) -

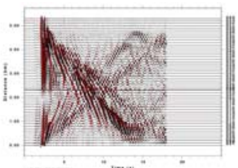
3D01



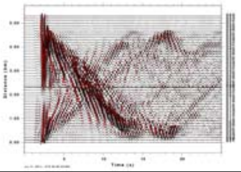
3D02



3D03

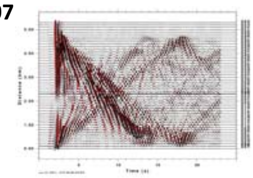


3D04

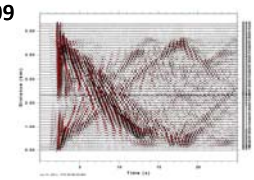


Verification of 3D numerical predictions : III1 - Profile (SV) -

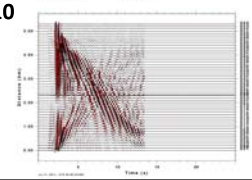
3D07



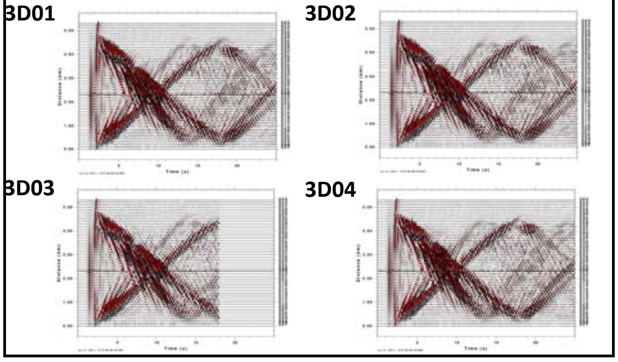
3D09



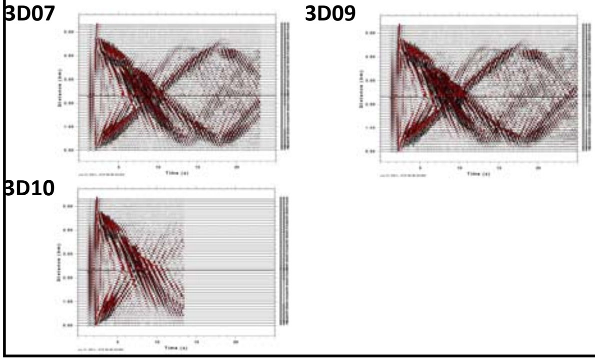
3D10



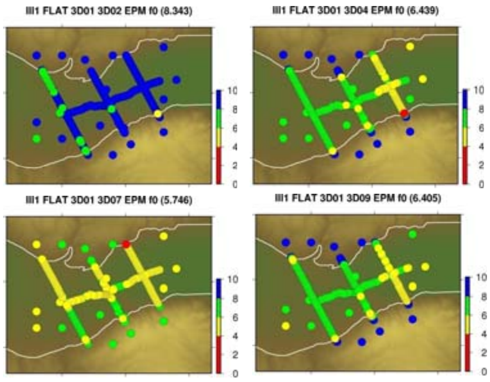
Verification of 3D numerical predictions : III1 - Profile (Z) -



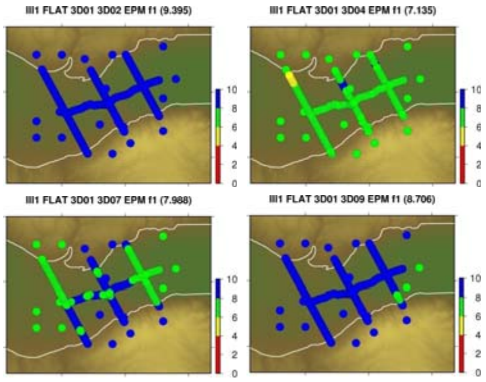
Verification of 3D numerical predictions : III1 - Profile (Z) -



Verification of 3D numerical predictions : III1 - GOF (EPM, f0, ref:3D01) -



Verification of 3D numerical predictions : III1 - GOF (EPM, f1, ref:3D01) -



Model configurations for the hypothetical point DC source				
ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
III1	laterally homog., vertical gradient	elastic	1D	elastic

Table of submitted solutions								
	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
III1	✓	✓	✓	✓	✓		✓	✓

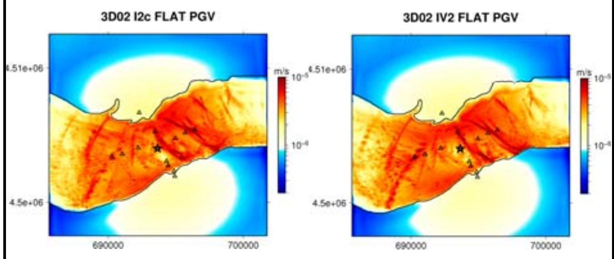
- Very good level of agreement
- Would this hold if lateral heterogenities are included?

Model configurations for the hypothetical point DC source				
ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
IV2	smooth 3D heterog.	elastic	1D	Elastic

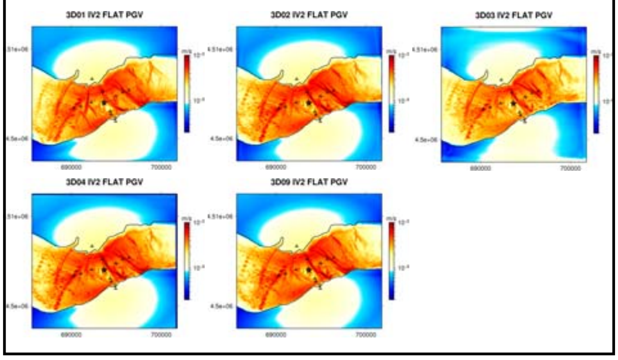
Table of submitted solutions								
	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
IV2	✓	✓	✓	✓	✓			✓

Verification of 3D numerical predictions : IV2
- PGV map (I2c & IV2, 3D02) -

I2c　　IV2

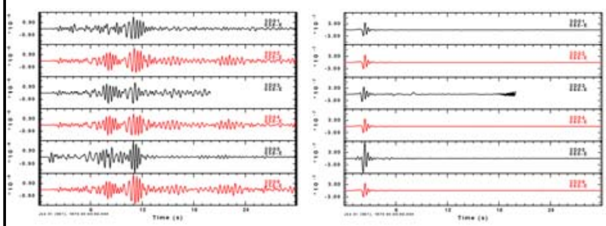


Verification of 3D numerical predictions : IV2
- PGV map -



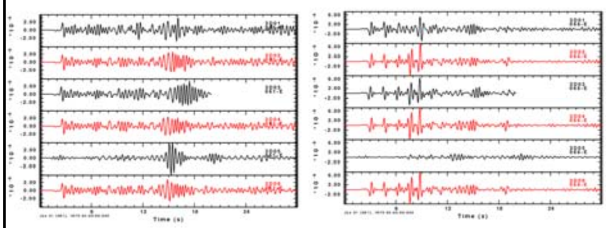
Verification of 3D numerical predictions : IV2
- Traces (E) -

TST(058)　　PRO(060)



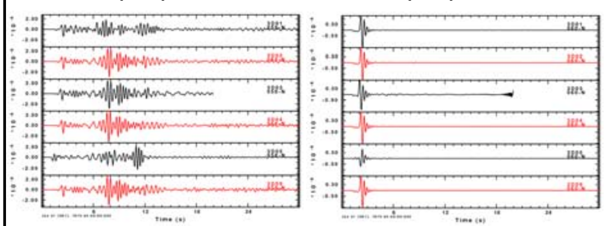
Verification of 3D numerical predictions : IV2
- Traces (E) -

E03(061)　　W03(066)



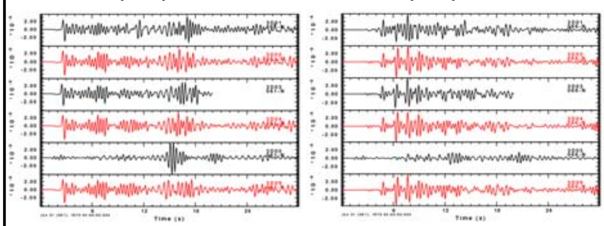
Verification of 3D numerical predictions : IV2
- Traces (N) -

TST(058)　　PRO(060)



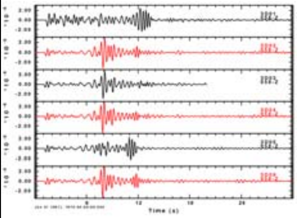
Verification of 3D numerical predictions : IV2
- Traces (N) -

E03(061)　　W03(066)

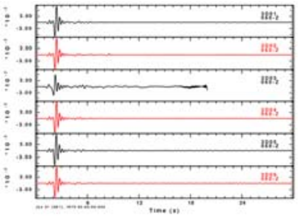


Verification of 3D numerical predictions : IV2 - Traces (Z) -

TST(058)

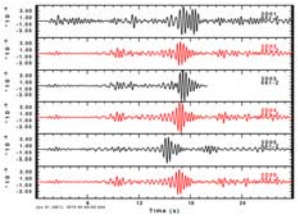


PRO(060)

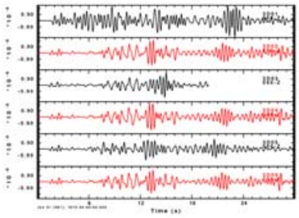


Verification of 3D numerical predictions : IV2 - Traces (Z) -

E03(061)

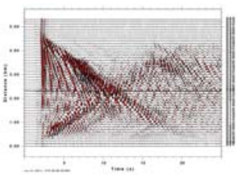


W03(066)

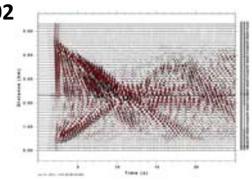


Verification of 3D numerical predictions : IV2 - Profile (SH) -

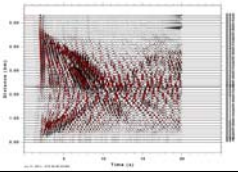
3D01



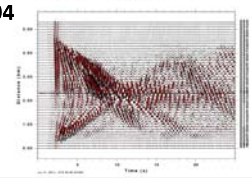
3D02



3D03

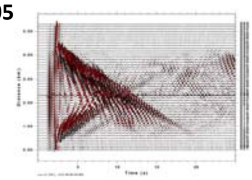


3D04

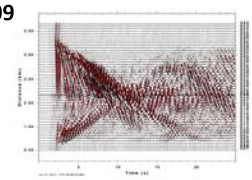


Verification of 3D numerical predictions : IV2 - Profile (SH) -

3D05

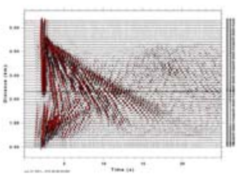


3D09

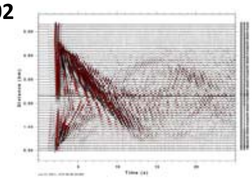


Verification of 3D numerical predictions : IV2 - Profile (SV) -

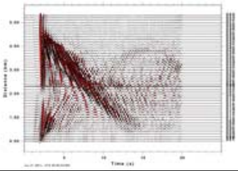
3D01



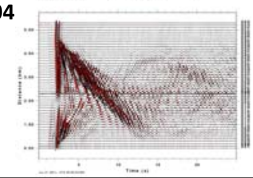
3D02



3D03

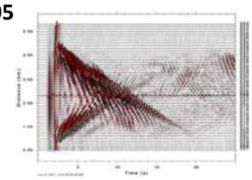


3D04

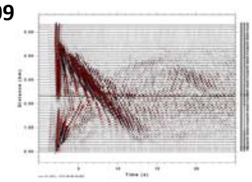


Verification of 3D numerical predictions : IV2 - Profile (SV) -

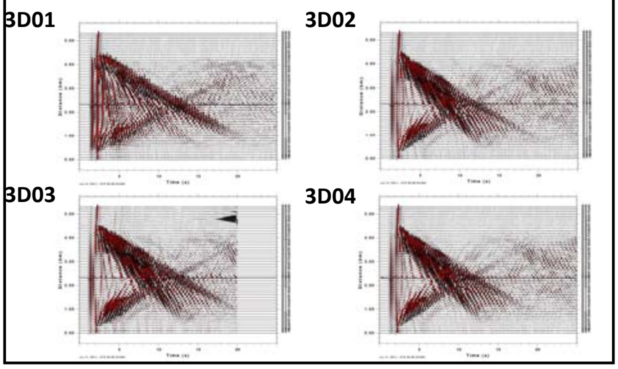
3D05



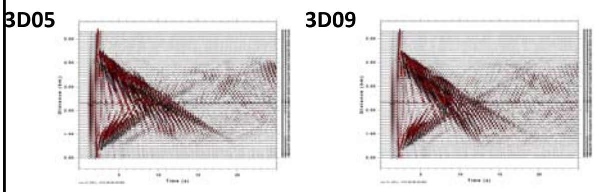
3D09



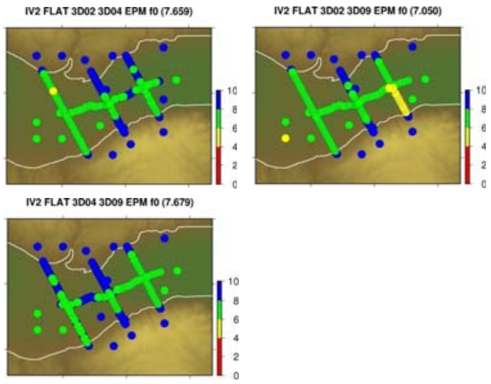
Verification of 3D numerical predictions : IV2 - Profile (Z) -



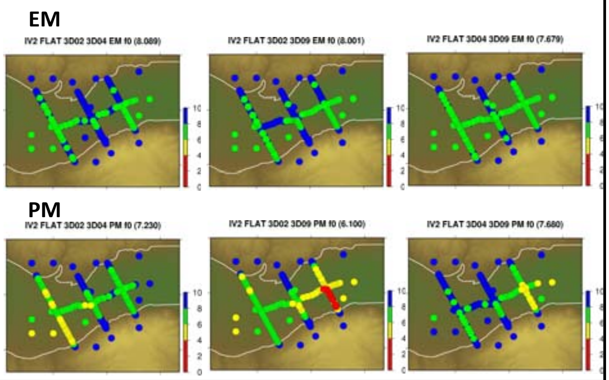
Verification of 3D numerical predictions : IV2 - Profile (Z) -



Verification of 3D numerical predictions : IV2 - GOF (EPM, f0, 3D02/3D04/3D09) -



Verification of 3D numerical predictions : IV2 - GOF (EM&PM, f0, 3D02/3D04/3D09) -



Model configurations for the hypothetical point DC source

ID	sediments		bedrock	
	geometrical heterogeneity	rheology	geometrical heterogeneity	rheology
IV2	smooth 3D heterog.	elastic	1D	Elastic

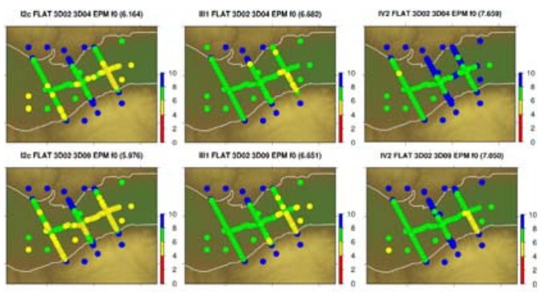
Table of submitted solutions

	CUB FDM	UJF SEM	DPRI FDM	OGS PSM	NIED FDM	CEA DEM	CMU FEM	UNICE DGM
IV2	✓	✓	✓	✓	✓			✓

- Needfor iteration(3D01, 3D05[source])
- Betterfit canbeachievedcomparedto elastic3-layerscase

Verificationof 3D numericalpredictions: I2c-III1-IV2 - GOF (EPM, f0, 3D02/3D04/3D09) -

I2c (3L) III-1(GBM1) IV2(GBM2)



Summary& discussion

・ Why should we build velocity models made of homogeneous layers if not supported by geological/geophysical constraints?

・ Given a starting discontinuous model, can we build a smooth, equivalent model (homogeneization)?

・ What is the difference between ground motion predictions of the layered and smooth models?