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The Usage of HPC Systems for Simulation of Dynamic Earthquake Process

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Earthquake Consequences

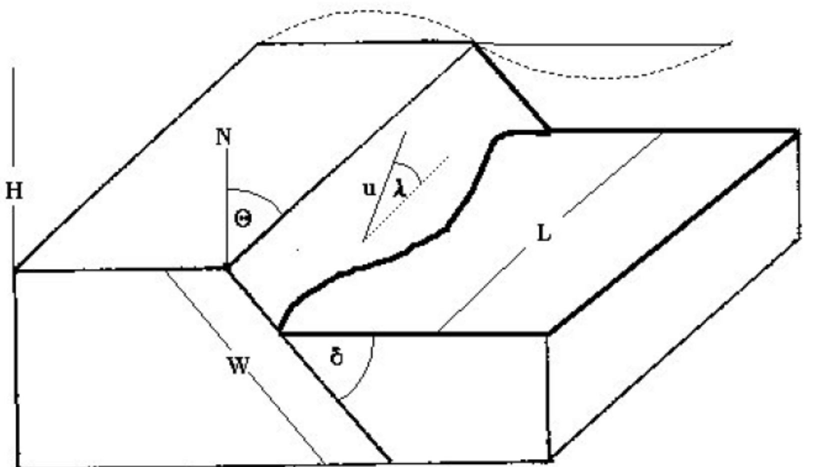
Russia

Japan

Turkey

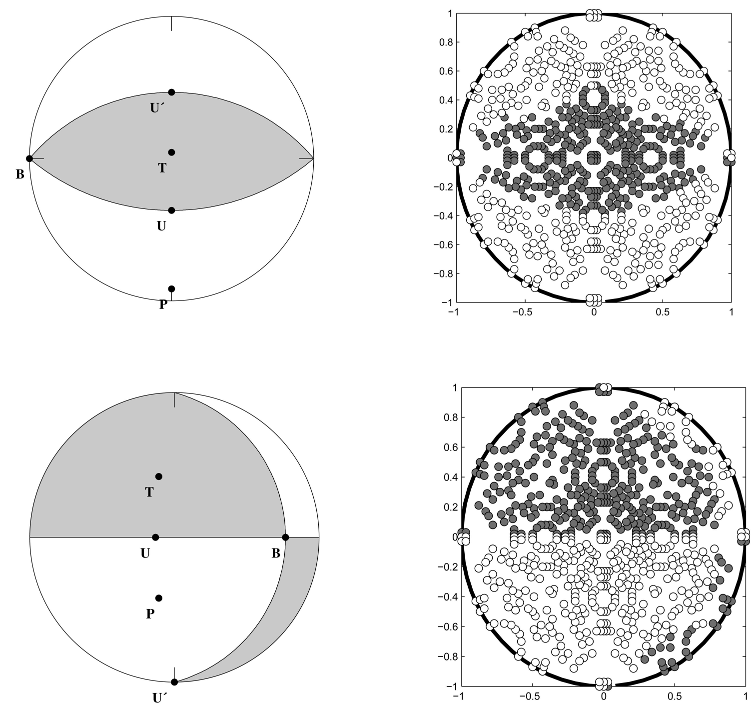
Model Description and Verification

Model «Moving along the fault»



Θ = strike angle (measured clockwise from north)
λ = rake angle (angle between strike direction and slip direction; $-\pi < \lambda \leq \pi$)
δ = dip angle (measured from the horizontal; $0 \leq \delta \leq \pi/2$)
u = slip direction and magnitude

Numerical and semi-analytical solutions comparison

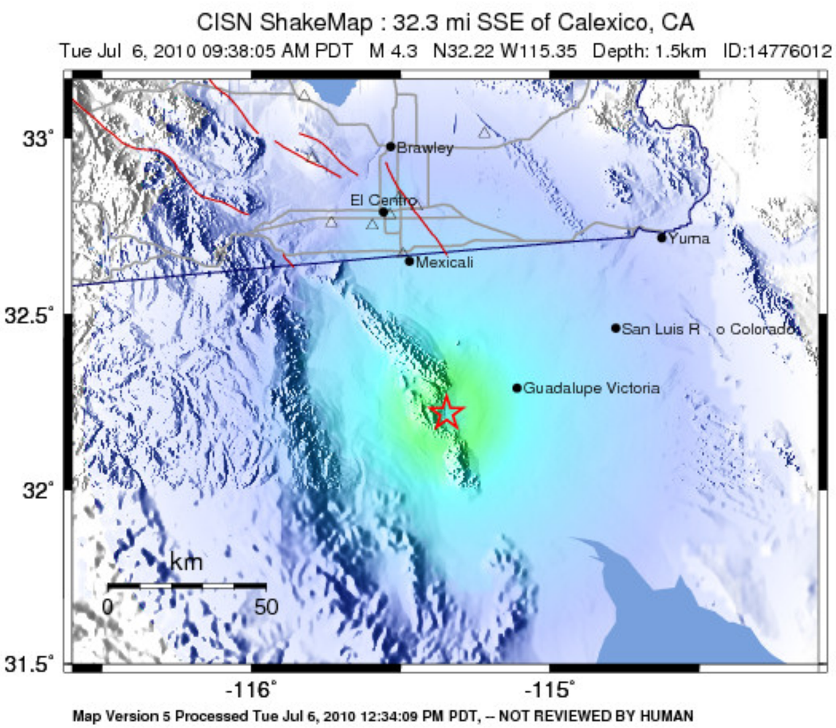


Semi-analytical solution: http://www1.gly.bris.ac.uk/~george/focmec.html

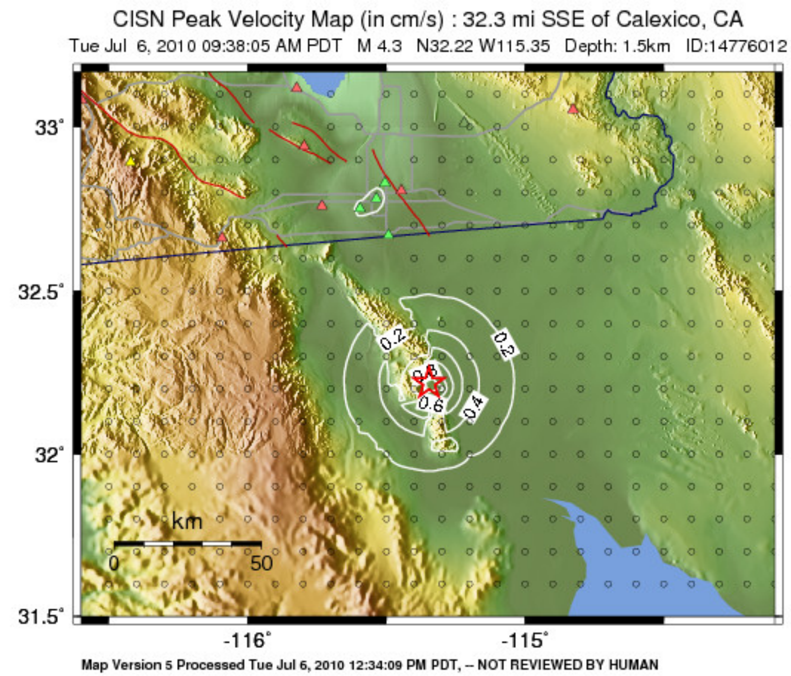
Model Parameters Estimation

Location of Epicenter

(Guadalupe Victoria)



Maximum velocity map (cm/s)



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Hypocenter depth – 1,5 rm

Maximum ground velocity – 1 cm / s

Online web services with data for earthquakes occurred are available now

Mathematical Model and Numerical Method

Elastic Parameters:

- ρ – density
- λ, μ – Lame parameters
- V – velocity
- T – stress tensor

$$
\begin{cases}
\rho \dfrac{\partial V_x}{\partial t} = \dfrac{\partial T_{xx}}{\partial x} + \dfrac{\partial T_{xy}}{\partial y} + \dfrac{\partial T_{xz}}{\partial z}, \\
\rho \dfrac{\partial V_y}{\partial t} = \dfrac{\partial T_{yx}}{\partial x} + \dfrac{\partial T_{yy}}{\partial y} + \dfrac{\partial T_{yz}}{\partial z}, \\
\rho \dfrac{\partial V_z}{\partial t} = \dfrac{\partial T_{zx}}{\partial x} + \dfrac{\partial T_{zy}}{\partial y} + \dfrac{\partial T_{zz}}{\partial z}, \\
\dfrac{\partial T_{xx}}{\partial t} = (\lambda + 2\mu)\dfrac{\partial V_x}{\partial x} + \lambda(\dfrac{\partial V_y}{\partial y} + \dfrac{\partial V_z}{\partial z}), \\
\dfrac{\partial T_{yy}}{\partial t} = (\lambda + 2\mu)\dfrac{\partial V_y}{\partial y} + \lambda(\dfrac{\partial V_x}{\partial x} + \dfrac{\partial V_z}{\partial z}), \\
\dfrac{\partial T_{zz}}{\partial t} = (\lambda + 2\mu)\dfrac{\partial V_z}{\partial z} + \lambda(\dfrac{\partial V_x}{\partial x} + \dfrac{\partial V_y}{\partial y}), \\
\dfrac{\partial T_{xy}}{\partial t} = \mu(\dfrac{\partial V_x}{\partial y} + \dfrac{\partial V_y}{\partial x}), \\
\dfrac{\partial T_{xz}}{\partial t} = \mu(\dfrac{\partial V_x}{\partial z} + \dfrac{\partial V_z}{\partial x}), \\
\dfrac{\partial T_{yz}}{\partial t} = \mu(\dfrac{\partial V_y}{\partial z} + \dfrac{\partial V_z}{\partial y}).
\end{cases}
$$

We use grid-characteristic method on structured meshes to solve direct seismic problem

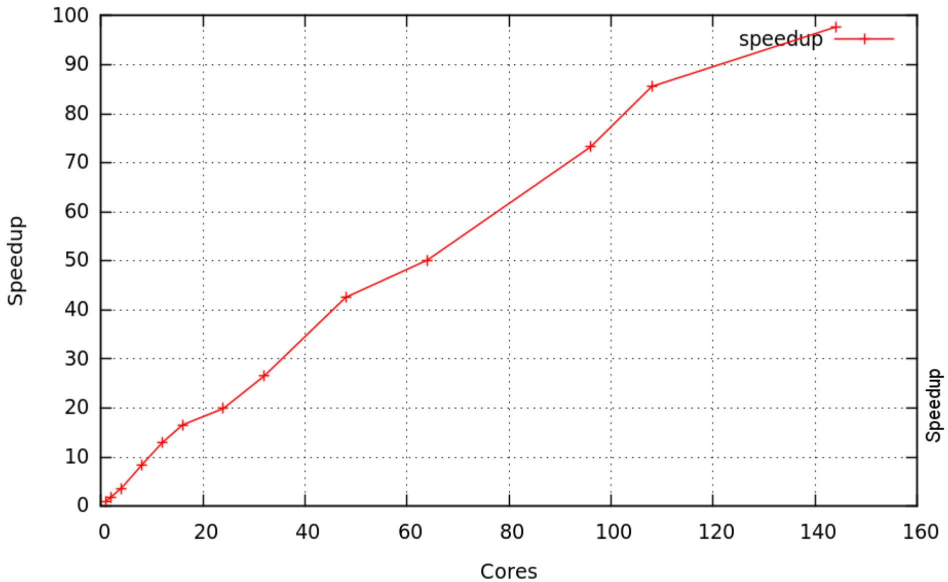
Research Software*

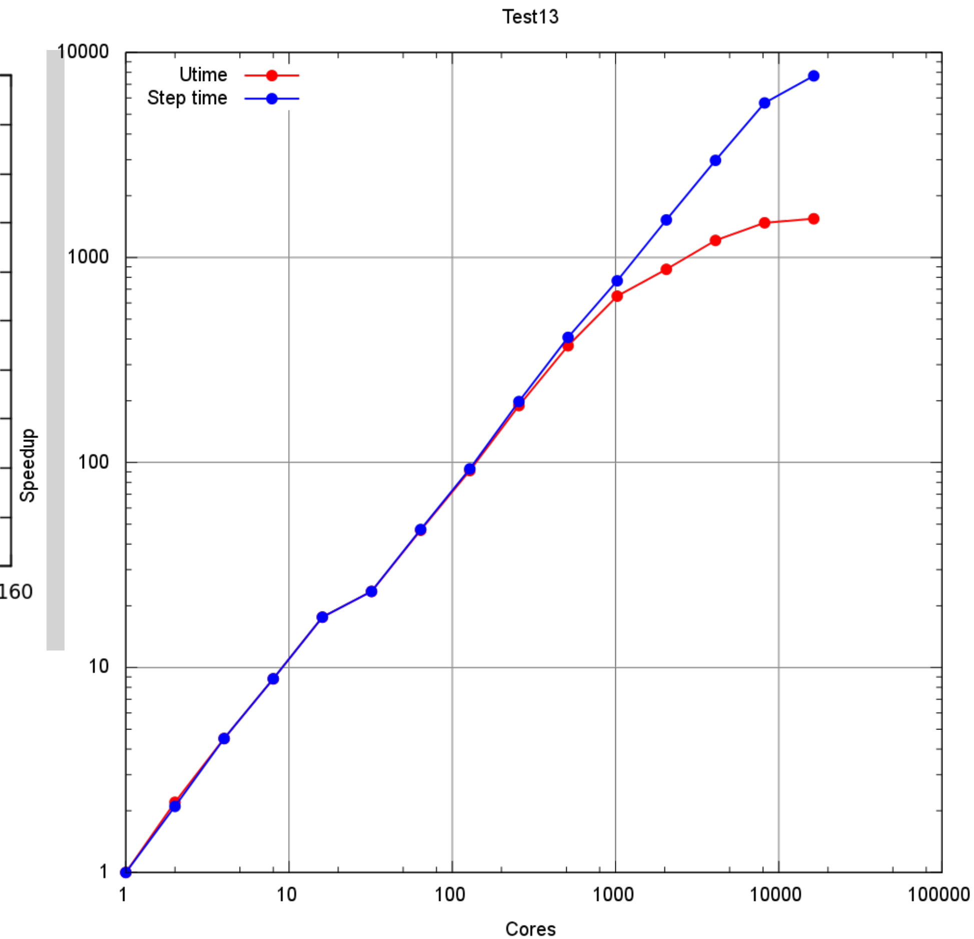
- Seismic waves simulation in elastic media
- Taking into account heterogeneities (cavities, layers, fractures)
- Discreet model of destruction (correction of stress tensor)
- C++, micro-optimisations (SIMD, SSE, AVX)
- Parallelization with OpenMP and MPI

(~ 80 % up to 16 000 cores)

* Khokhlov N.I., MIPT

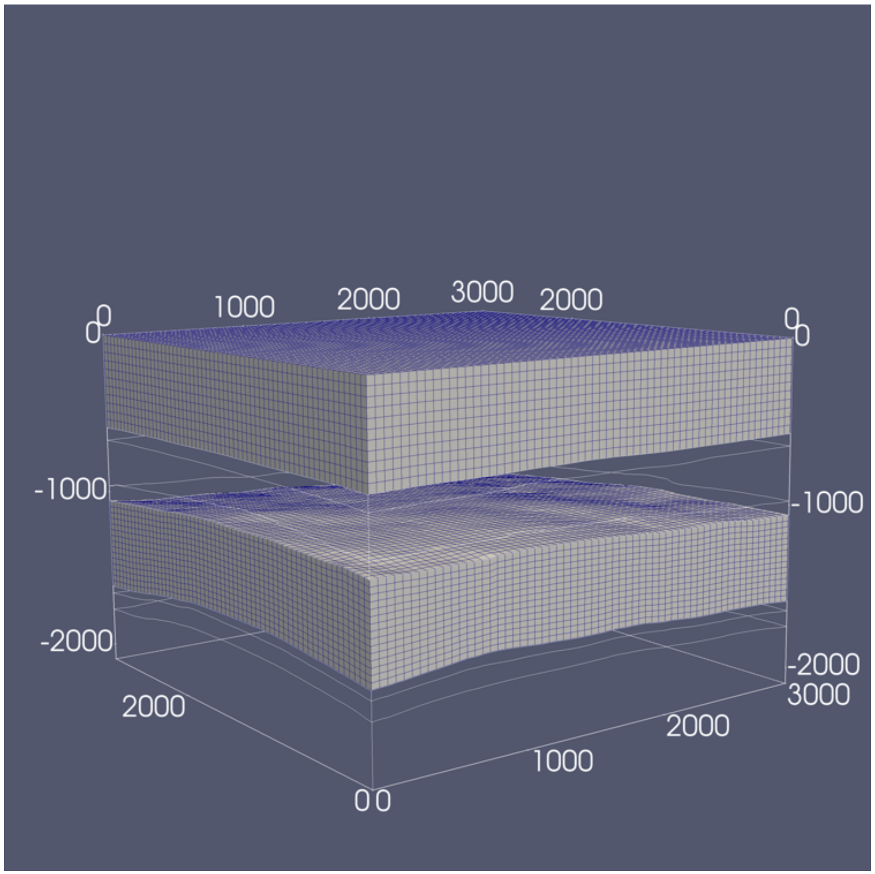
HPC Scalability





- **Computer Systems: MIPT-60, HECToR**
- **Up to 16 000 cores**
- **Scalability 80 %**

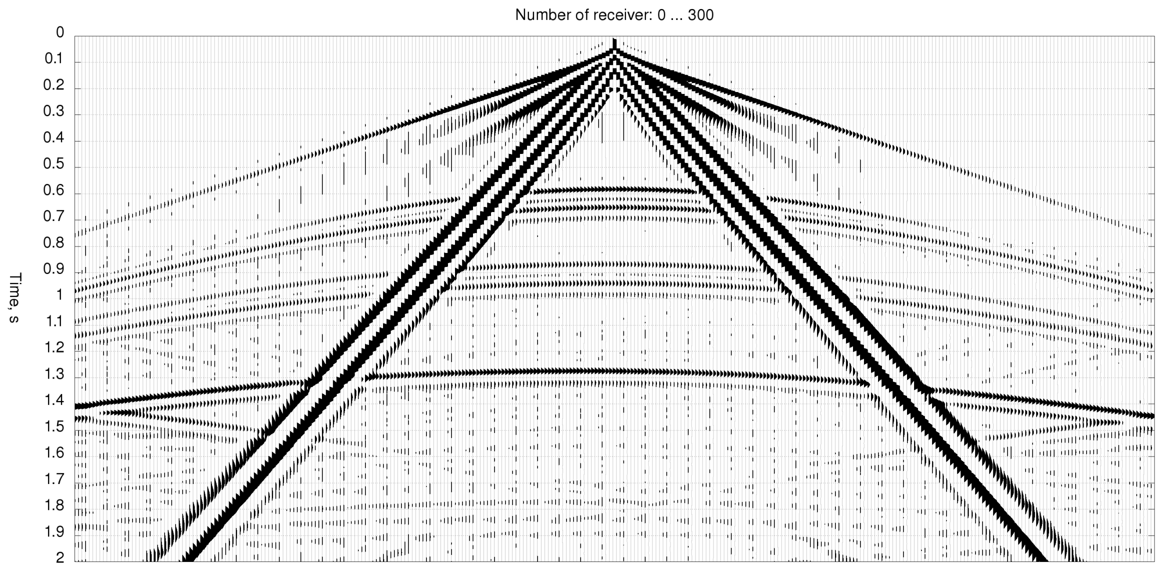
Seismic survey. 3D example application



No	V_p, m/s	V_s, m/s	ρ, kg/m^3
1	2170	674	2000
2	2130	795	2300
3	2500	1090	2200
4	2680	1220	2300
5	3000	1385	2400
6	5550	3144	2700
7	6000	1250	2800
8	6000	1550	2850

The site is located in the north-east of the European part of the Russian Federation in the Arkhangelsk region within the Nenets Autonomous District, north of the Arctic Circle practically on the coast of the Barents Sea

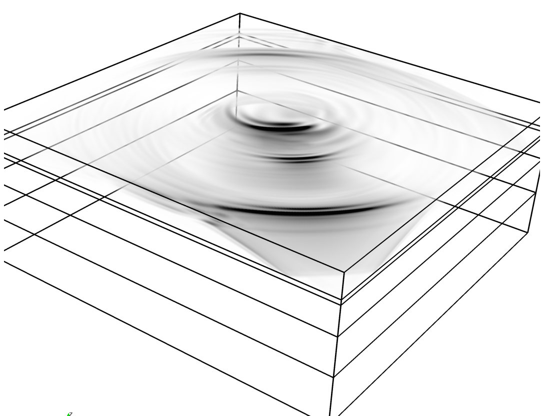
Synthetic seismograms. Comparison



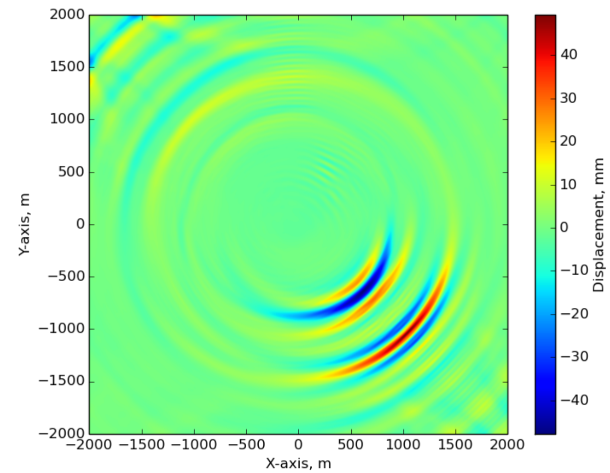
	A1, A(r)	**A1, explicit**	**A2, A(r)**	**A2, explicit**
Computing time, s	815	7415	210	1908
RAM, Gb	21,7	47,5	31,3	68,5
Δ_1	22 %		39 %	
Δ_2	26 %		36 %	
Δ_3	30 %		34 %	

Sea Shelf Simulation

#	Depth, m	Density	Vp, m/s	Vs, m/s
1	250	1000	1500	-
2	50	1500	1600	60
3	300	2100	2500	1000
4	400	2500	3500	1300
5	500	2500	4000	2500



3D acoustic waves in water



Maximum displacement on the ground

Direct acoustic-elastic contact simulation with grid-characteristic approach

Results

- As the begin of the project the simplest model of hypocenter was introduced. It was compared with the semi-analytical approach (“spherogram”). It was added in the research software and a set of calculations was carried out.
- The key-feature of grid-characteristic method was demonstrated on the geological problem in 3D.
- The sea-shelf problem was simulated and maximum displacement on the ground was estimated.

Thank you for your attention

Seismic resistance estimation for: water-power plant, nuclear power plant, skyscrapers, etc.