Istituto Nazionale di
Geofisica e Vulcanologia,
Roma, Italy

Computational Infrastructure for Geodynamics

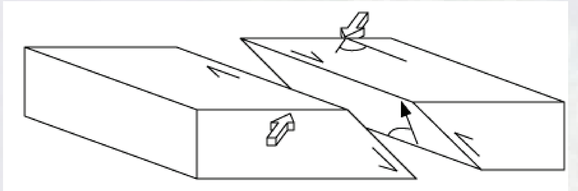
FINITE ELEMENT MODELING OF THE STATIC AND QUASI-STATIC DEFORMATION ASSOCIATED WITH THE 2004 SUMATRA EARTHQUAKE

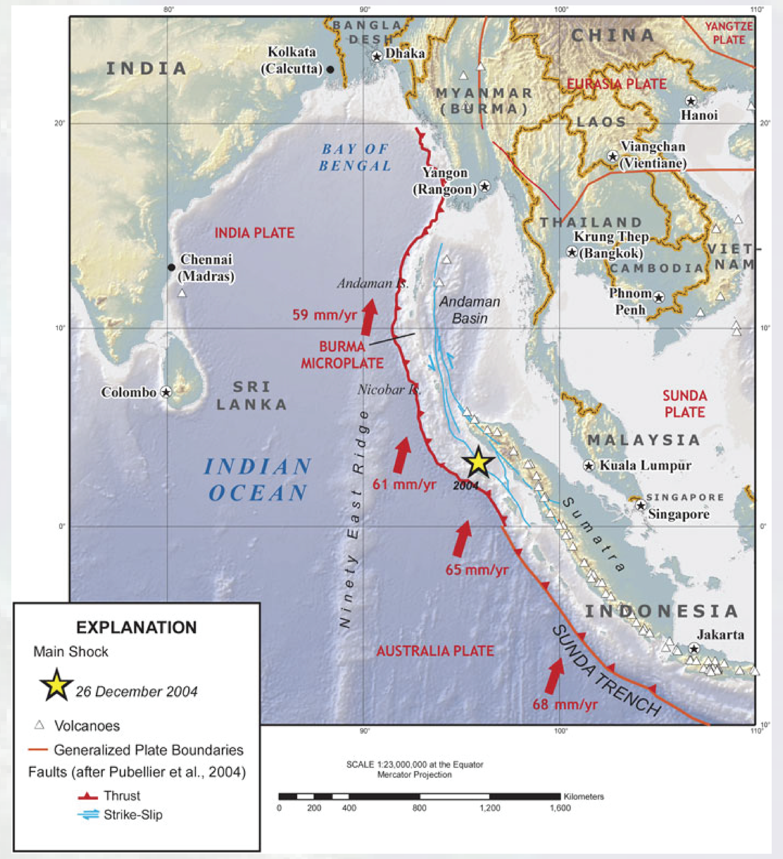
Manuela Volpe, Emanuele Casarotti, Antonio Piersanti

volpe@ingv.it; emanuele@gps.caltech.edu; piersanti@ingv.it

INTRODUCTION

The great Sumatra-Andaman earthquake of December 26, 2004 was one of the largest earthquakes ever recorded since 1900. The earthquake resulted from complex slip on the fault along the subduction zone where the oceanic portion of the Indian Plate slides under the Eurasian Plate, by the Indonesian island of Sumatra. The direction of convergence of the subducting plate relative to the overriding plate is oriented oblique to the trench axis and the rupture occurred for 1200 km along the interplate megathrust.





In the present work we use a new computational FEM strategy to model the co- and post-seismic deformation field associated with the Sumatra earthquake. We are able to study the joint effects of sphericity and 3D geometrical and rheological heterogeneities on the investigated observables. The comparison between our synthetic results and the available deformation data will allow us to ascertain if complexities in the physical properties of the medium could play an important role in assessing the deformation field besides source properties.

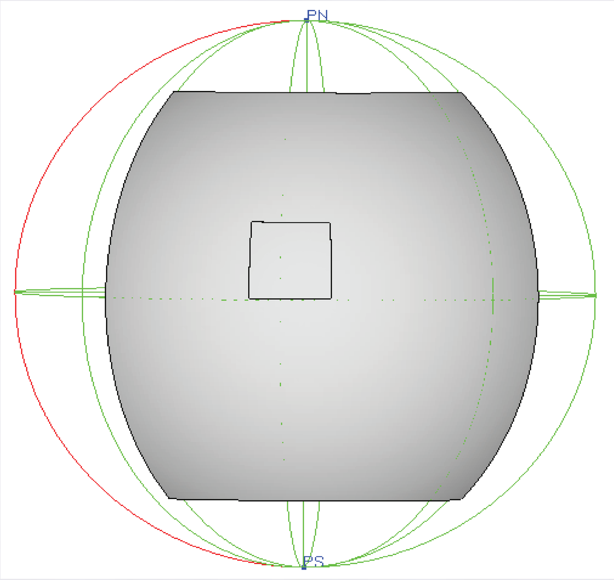
THE MODEL

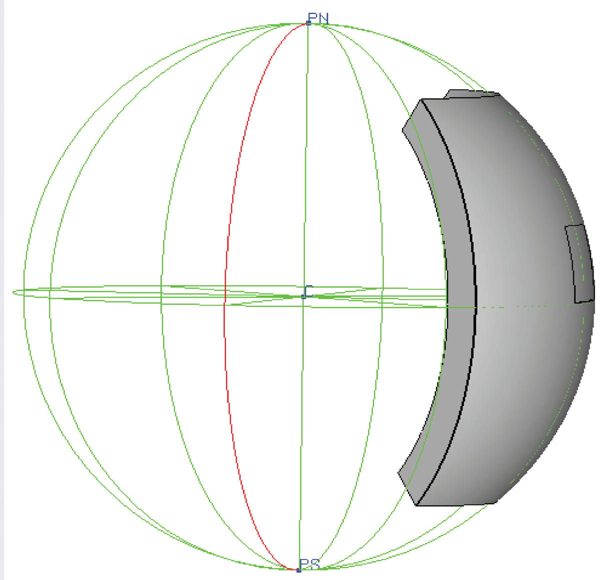
We developed a flexible, versatile, robust and reliable computational tool to model static and quasi-static deformation generated by faulting sources (FEMSA, Finite Element Modeling for Seismic Applications; see http://hdl.handle.net/2122/2062), based on a free 3D finite element software (CalculiX, see http://www.calculix.de).

We built up a spherical domain consisting of a portion of spherical zone ~1000 km thick spanning about 90×10^6 km^2 on the Earth surface.

For the present study, the domain was meshed with 38348 20-nodes brick elements resulting in a mesh containing 171534 nodes. Such a mesh takes 44 minutes for each simulation on a 64-bit Intel Xeon 3.2 GHz, 8 GB RAM.

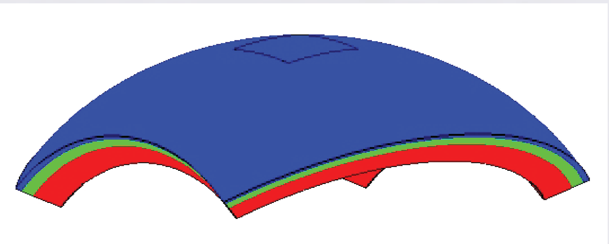
Next investigations will require the same domain discretized with a much finer mesh to increase resolution and capture more detailed features.





The co-seismic deformation was calculated on the basis of a multi-layered model having elastic rheology.

For the post-sesimic deformation, a three-layered model was introduced, composed by an elastic lithosphere 125 km thick, a viscoelastic asthenosphere 250 km thick having viscosity $\eta=10^{18}$ Pa/s and a viscoelastic mantle for the remaining thickness (650 km) having $\eta=10^{21}$ Pa/s.



In both cases, the elastic parameters were determined from the volume averaged mean values of the Lamè parameters according to the Preliminary Reference Earth Model (PREM, Dziewonski & Anderson, 1981).

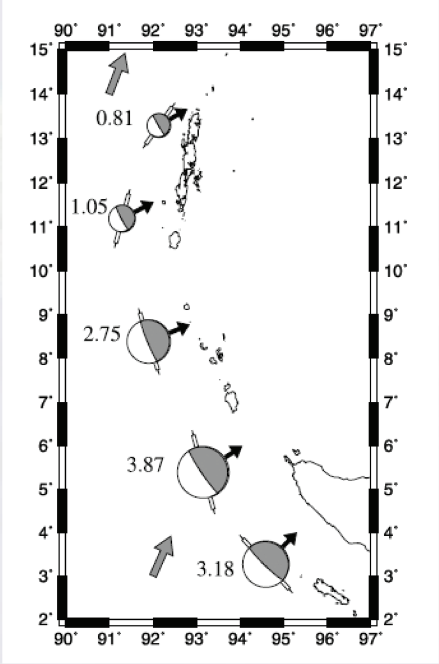
As far as the SOURCE is concerned, we adopted the model proposed by Tsai et al. 2005, consisting of five CMT point sources.

V.C. Tsai, M. Nettles, G. Ekstrom and A.M. Dziewonsky, GRL 32 (2005): L17304

Table 2. Source Parameters for the Final, Five-Source Model[a]

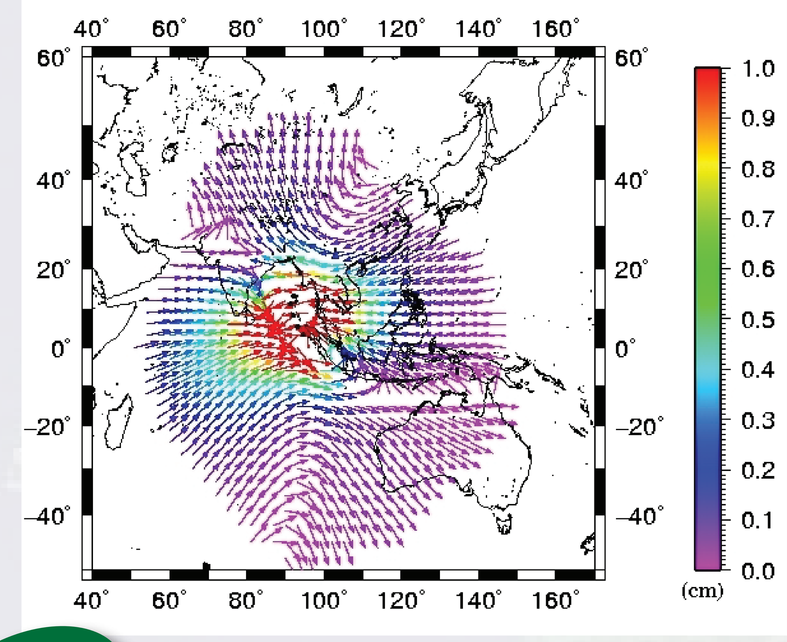
Source	Strike	Dip	Rake	Moment	M_W	ε
I	318	6.4	94	0.318	8.94	0.00
II	345	6.3	109	0.387	9.00	0.00
III	343	5.8	95	0.275	8.90	0.02
IV	15	8.4	132	0.105	8.62	0.04
V	35	8.1	155	0.081	8.54	0.01
Comp	343	6.1	107	1.15	9.31	0.02

[a]Strike, dip and rake are given in degrees. Moment is given in units of 10^{30} dyne-cm. ε describes the relative size of the non-double-couple component of the moment tensor and is calculated as $-e_2/\max(|e_1|,|e_3|)$ where e_i are the ordered eigenvectors of the moment tensor. Values for a composite ("Comp") solution obtained by summing the moment-tensor components of the individual sources are also listed. The centroid location and time for the composite source are 6.6°N, 93.0°E and 214 s.

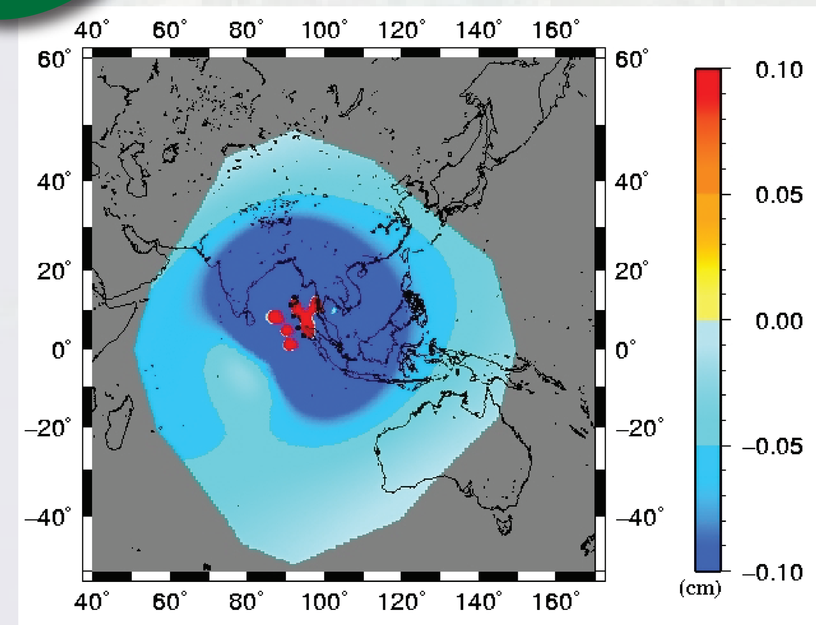


CO-SEISMIC DEFORMATION

t=0



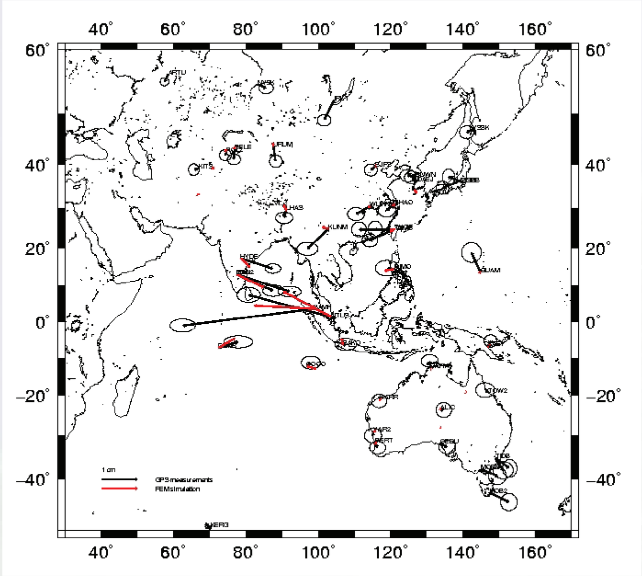
Horizontal displacement



Radial displacement

comparison with GPS data

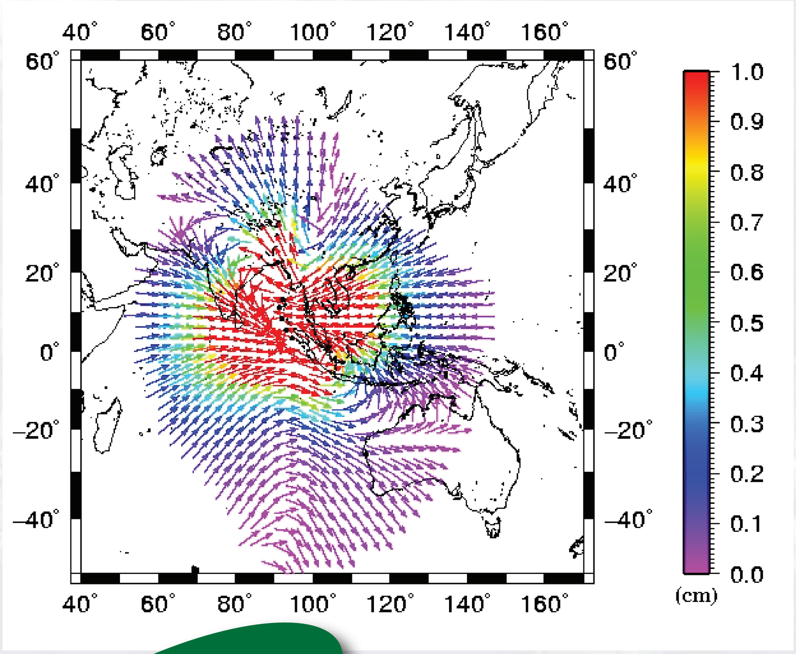
registered from permanent stations



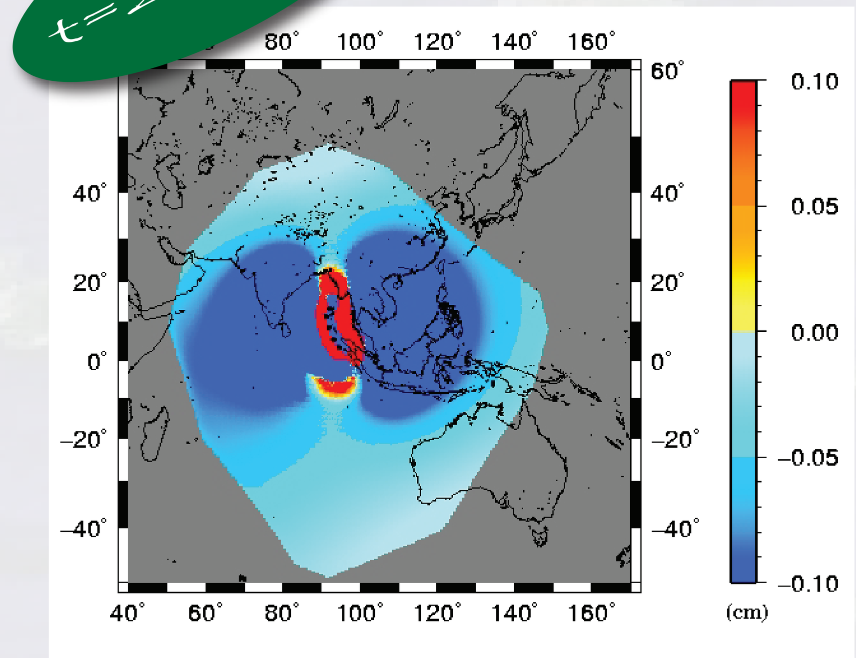
NOTE: We also investigated more complex fault geometries going towards next level of approximation, i.e. linear and planar sources, without obtaining any substancial change in the deformation pattern. Standing on this evidence, it seems that the fault geometry (as far as a homogeneous moment release is considered) is not crucial in defining the displacement field generated by the earthquake, at the spatial scale involved in our analysis and at this level of rheological description.

POST-SEISMIC DEFORMATION

t=2 years



Horizontal displacement



Radial displacement

CONCLUSIONS

We started to investigate the 2004 Sumatra earthquake by means of a novel 3D finite element approach to evaluate the co- and post-seismic displacement fields associated with the event.

At first, a quite rough model based on an elastic layered spherical domain was used, obtaining promising and encouraging results, as confirmed by the comparison with GPS measurements.

Secondly, a quasi-static analysis, within a time window of 2 years, was performed to calculate the viscoelastic relaxation, which induces an evident amplification of both the horizontal and vertical components of the displacement field.

Obviously the model needs to be improved, introducing a more realistic rheology and adding lateral variations of the medium properties as well as heterogeneous moment release. It could be expected that such geometrical and rheological complexities play a relevant role.

WORK IN PROGRESS

We are working with a new and powerful mesher (CUBIT, see http://cubit.sandia.org) to be linked together with CalculiX in order to build up more complex and realistic models, marked by a real 3D meshing (mechanical and rheological lateral heterogeneities).

As a first step, we introduced a rheological contrast between continental and oceanic lithosphere. To retrieve the continental margins we (conservatively) extracted the -500 m interface from a global topography model.

WHAT DO WE WANT TO DO IN THE NEXT FUTURE?

- heterogeneous moment release
- modeling of the slab
- mantle and asthenosphere lateral viscosity contrasts
- surface topography
- internal interface topography