Waveform inversion of the CALIXTO dataset in Vrancea : moment tensor inversion

Baron Julie[1], Danececk Peter[1], Morelli Andrea[1], Tondi Rosaria[1] and Calo Marco[2]

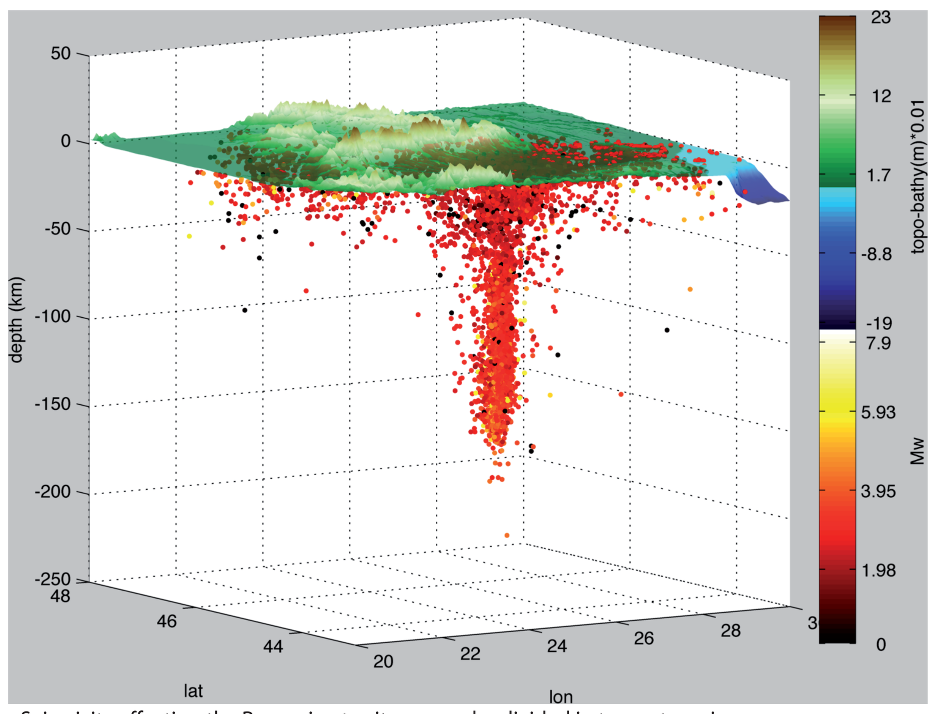
1) INGV Bologna, Italy julie.baron@bo.ingv.it, peter.danecek@bo.ingv.it, andrea.morelli@bo.ingv.it, rosaria.tondi@bo.ingv.it
2) IPG Strasbourg, France

MOTIVATION

The Vrancea region, in the south-east Carpathians, represents one of the most seismically active zones of Europe.

Into improve knowledges on its geodynamics and enlighten the relations between the shallow and deep structure beneath Vrancea several studies have ben carried out in the last decades.

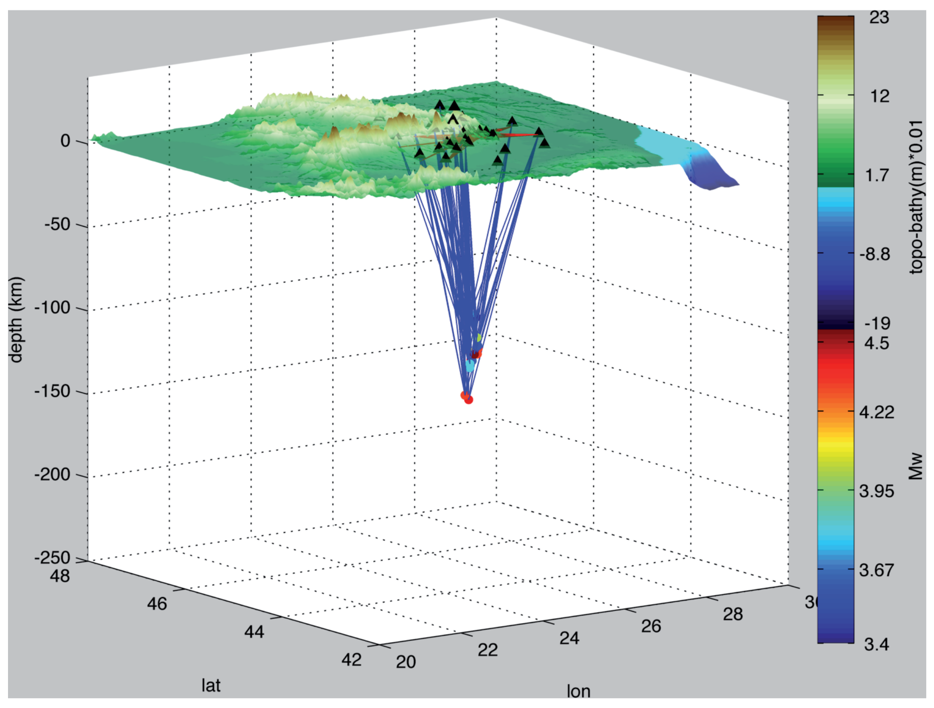
Tomographic models reveal the presence of a high velocity body beneath Vrancea. Its NE part contains strong earthquakes occuring in a limited seismogenic volume at intermediate depth (70 to 180km).



Seismicity affecting the Romanian territory may be divided in two categories:
- shallow seismicity spread over the territory and consisting of small to intermediate magnitude events.
- intermediate-depth seismicity concentrated in the Vrancea subduction zone with the occurrence of stronger events.

Local travel time tomography uses first arrival times and is based on ray tracing. Our goal is to use adjoint based tomographic inversion to assess the benefits of using full waveforms and associated 3D finite-frequency sensitivity kernels in the inversion.

DATA



Our database is built on the broad-band data records from the 1999 CALIXTO experiment which took place in Vrancea for 6 months.
It consists of 21 events with magnitude from Mw=3.2 to Mw=4.5, at depth ranging from 15km to 154km recorded at least by 3 stations.
These events have acceptable signal-to-noise ratio only in a rather limited frequency band (period from 1.25 to 2.5 seconds).

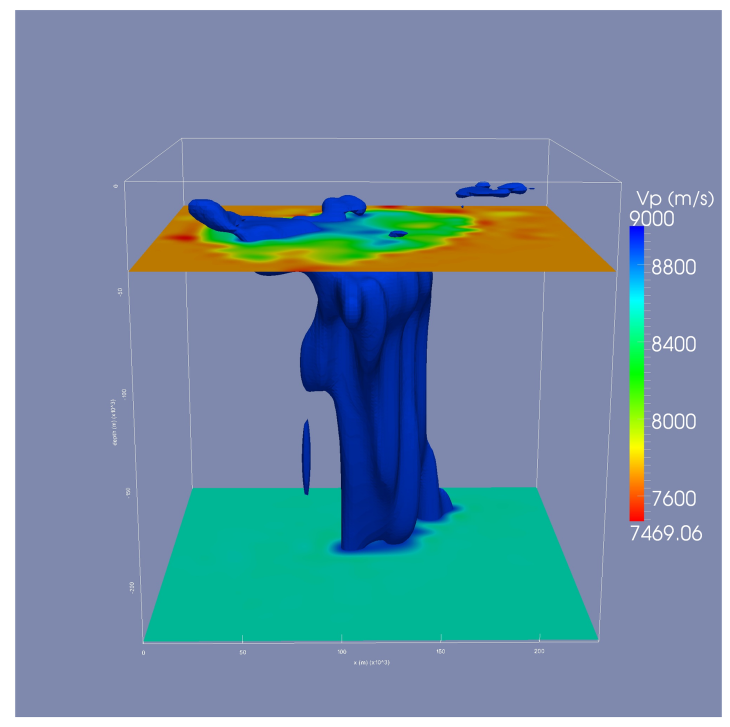
VELOCITY MODEL AND COMPUTATIONAL MESH

The initial model has been derived by Tondi et al. (2009) using a P and S wave first arrival tomography in combination with the sequential integrated inversion of land gravity data.

The velocity distribution underneath Vrancea is characterized by the presence of a NW-SE high velocity deepening volume which encloses the intermediate depth seismicity of the region in its NE part.

The nature and origin of this deep intracontinental seismic volume is still under debate. Until now, two main geodynamical models intend to explain the geodynamic of the area: a subduction related process and a delamination process.

High resolution seismic tomography could help to reveal the properties of this downgoing seismogenic body.



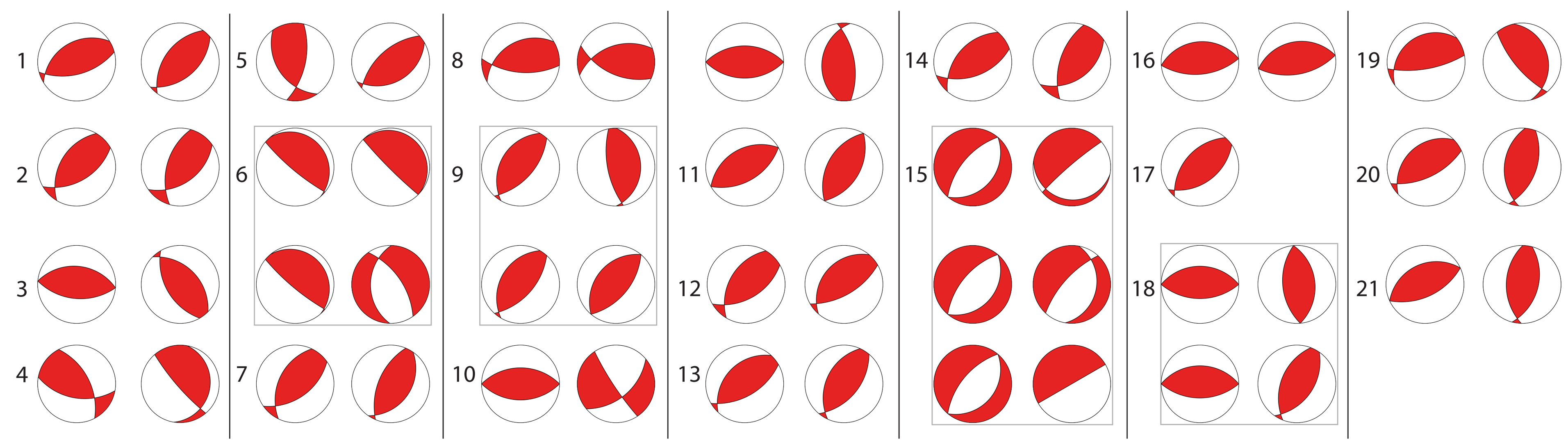
mesh size	element size at top mesh	nb spectral elements
500km^3	0,9km	14 Millions
BG size	rank per node	MPI tasks
256	16	4096

SPECFEM3D (SPECtral Finite Element Method in 3D domain, Tromp et al., 2008) has been implemented on the new BGQ computer of the CINECA supercomputing center to define the regional grid and to compute synthetic seismograms.

CORRECTING LOCATION AND MOMENT TENSOR SOLUTIONS ..

.. with phase picking

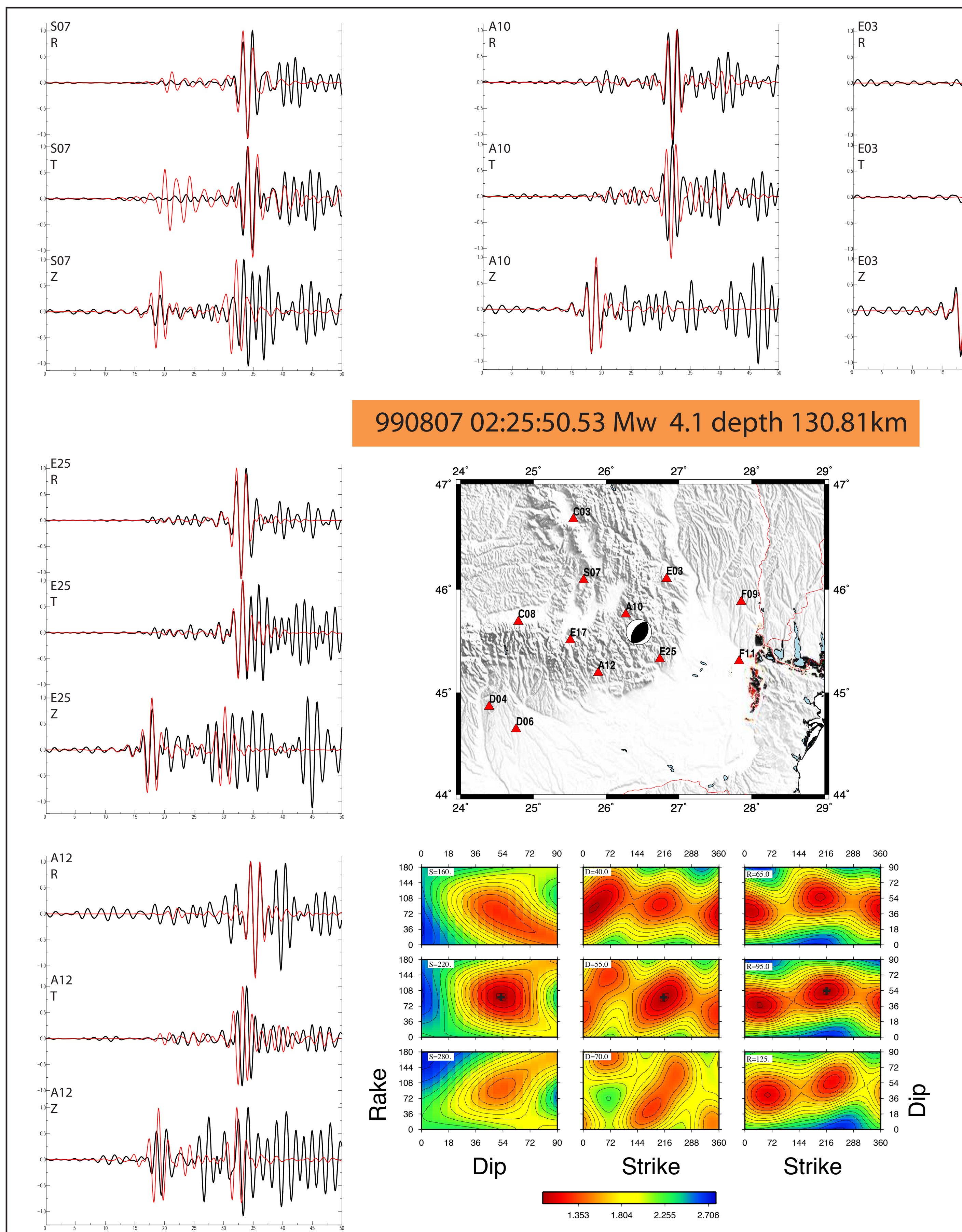
	event ID	Mw	OLD			NEW		
			s	d	r	s	d	r
1	990525_093553	4,5	75	55	100	50	45	100
2	990611_082004	3,8	60	50	110	55	45	120
3	990620_000907	4,3	95	50	90	150	50	100
4	990622_080206	4,4	100	50	50	10	15	140
5	990629_200407	4,3	145	40	50	60	35	100
6	990712_234752	3,2	320	10	100	135	85	90
6	990712_234752	3,2	320	10	100	-35	60	-110
7	990713_131057	4,4	55	50	110	35	35	100
8	990715_025203	3,4	95	60	110	115	55	120
9	990715_073623	3,8	210	35	80	0	25	100
9	990715_073623	3,8	210	35	80	55	40	90
10	990722_100750	3,8	90	45	90	50	50	-10
10	990722_100750	3,8	90	45	90	-10	60	80
11	990801_055650	3,6	60	50	90	30	45	90
12	990803_080705	3,4	60	50	110	60	60	100
13	990807_022549	4,1	60	55	100	40	50	100
14	990809_071616	3,9	70	50	110	55	40	120
15	990809_232430	3,3	40	30	-90	100	10	-40
15	990809_232430	3,3	40	30	-90	10	25	-120
15	990809_232430	3,3	40	30	-90	60	90	90
16	990828_053228	3,6	85	55	90	80	55	90
17	990831_021112	3,6	55	45	100			
18	990914_234810	4	90	50	90	175	50	90
18	990914_234810	4	90	50	90	35	45	100
19	991012_192339	3,4	80	70	100	140	70	80
20	991012_234833	4,3	65	60	100	20	50	100
21	991016_093318	3,5	65	55	90	15	45	100



We need to compute moment tensor solutions of the selected events. In a first step we relocate the events using the NonLinLoc algorithm (Lomax et al., 2000) based on phase picks evaluated at the CALIXTO short-period stations. Using first-motion polarities and FPFIT (Reasenberg and Oppenheimer, 1985) we then compute the focal mechanisms.
The results for our dataset are presented here together with the table of the events description. The mechanisms from Tondi et al. (2009) are given in the left side column and our solutions in the right one. Besides, we highlight with grey boxes the events for which we have obtained multiple solutions.

The re-location leads, in average, to a depth correction of about 10km up for our selected events.
The focal mechanism estimation shows some unstabilities :
1) from the Tondi et al. set-up to the new one, as for events 5,10,18,19
2) with the pop up of multiple solutions for events 6,9,15 and 18.
This can be explained by the scarse station coverage that leads to uncertainty in the nodal plane choice.
For the remaining non-cited events, both solutions are in good agreement.

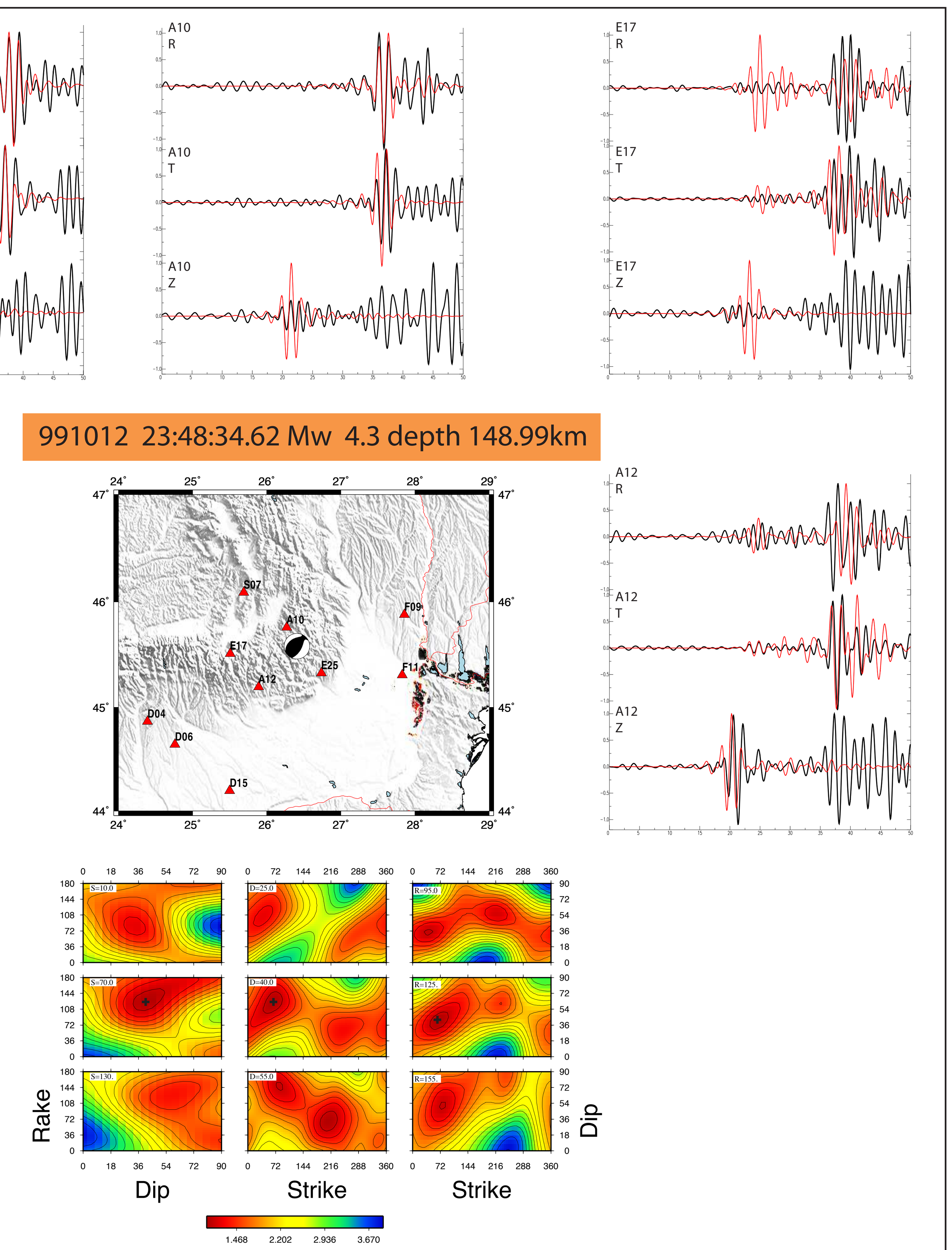
.. with waveform misfit



We then compute moment tensor using a full waveform misfit -computed in manually defined windows- between data and synthetics.
The method employs a global grid search around the different values of strike/dip/rake and use the elementary moment tensor component seismograms computed at the starting location solution to build each solution candidate.
The re-constructed synthetics leading to the best misfit give the best combination of strike/dip/rake for the event.

We present here two results obtained with this method for two main events recorded by the CALIXTO experiment.
The distribution of the stations and the focal mechanisms are described in the central figure and several station records (black) are compared with synthetics seismograms (red) .
The seismograms have been normalized to improve the comparison of the waveforms.
In this inversion we allow for a small time shift adjustment between data and synthetic, as given by cross-correlation measurement in the computational windows.
We obtain a good waveform fit although some traveltime discrepancies indicate the need to improve the tomographic model. This will come at the next step.

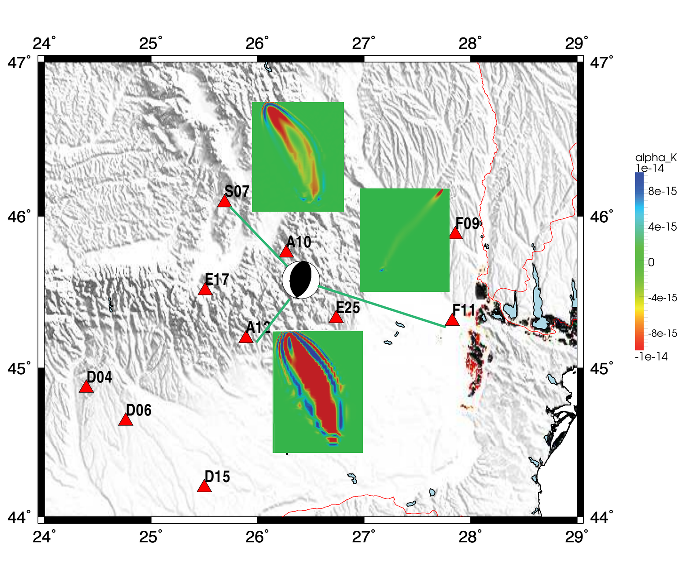
Panels at the bottom of the maps give a representation of the misfit distribution as a function of the strike/dip/rake values tested. These representations point out the uncertainty of the resulting solutions.



CONCLUSIONS

The calculation of moment tensors is delicate in our case, as we do not benefit from a strong coverage of the CALIXTO stations and as we have to work at small period range (from 1.25 to 2.5 seconds).
The search for the best moment tensor mechanism point out that multiple solutions can give very similar misfit measurements.
The traveltime shift may be corrected by the following tomographic inversion for structure.
The challenge here is to retrieve enough information from full waveform traveltime misfit inversion at such high frequency range.

AN INSIGHT INTO STRUCTURE INVERSION



We have done a preliminary study of the kernels sensitivity and ray coverage at high frequency.

Here we present the results obtained for a test at the event 991012 23:48:34.62 with an initial MT solution at depth 154km. The kernels are here obtained at the frequency range [0,5 - 0,8]Hz and do not contain any value of the misfit. Vertical cuts profiles have been done along the moment kernel from three surrounding stations.

These first tests confirm that we are able to retrieve more information from a full waveform inversion using the adjoint method than a ray based inversion, even if we are working at high frequencies.

REFERENCES

VRANCEA : Rosaria Tondi, Achauer U., Landes M., Davi R. and Besutiu L. (2009). Unveiling seismic and density structure beneath the Vrancea seismogenic zone, Romania, J. Geophys. Res., 114, B11307, doi:10.1029/2008JB005992.

SPECFEM3D : Jeroen Tromp. Komatitsch D. and Liu K. (2008). Spectral-Element and Adjoint Methods in Seismology. Communications in Computational physics. vol. 3, n 1, pp 1-32.

MOMENT TENSOR INVERSION :
Phase picking : FPFIT Reasenberg, P., and Oppenheimer, D., 1985. FPFIT, FPPLOT, and FPPAGE: Fortran computer programs for calculating and displaying earthquake fault plane solutions. U.S. Geol. Surv. Open File Rep., 1-25.
NLLOC Lomax, A., J. Virieux, P. Volant and C. Berge, 2000. Probabilistic earthquake location in 3D and layered models: Introduction of a Metropolis-Gibbs method and comparison with linear locations, in Advances in Seismic Event Location Thurber, C.H., and N. Rabinowitz (eds.), Kluwer, Amsterdam, 101-134

Waveform misfit : GRID3D http://geodynamics.org/svn/cig/seismo/3D/GRD_CMT3D/grid3d/
Liu, Q., J. Polet, D. Komatitsch, and J. Tromp (2004). Spectral-element moment tensor inversions for earthquakes in southern California, Bull. Seism. Soc. Am. 94,1748 –1761

Aknowledgments
Numerical simulations have been run at the CINECA supercomputing center in Bologna (Italy), through grants awarded in the framework of the ISCRA program, and in the INGV local computing facility.