SYSTEMATIC DETERMINATION OF MOMENT TENSOR OF THE APRIL 6, 2009 L'AQUILA EARTHQUAKE SEQUENCE

Poster: U23A-0029

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Objective

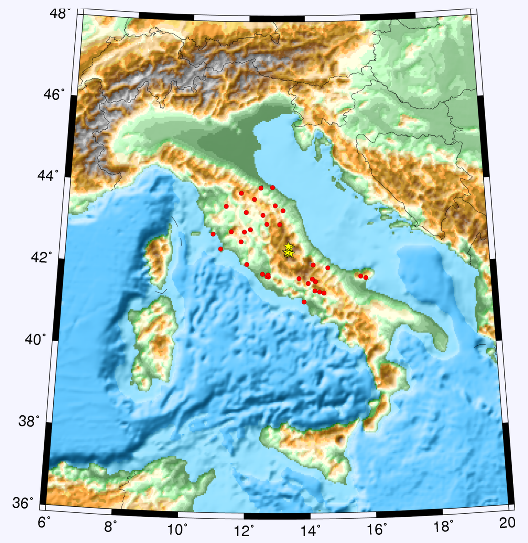
Although the 2009 L'Aquila, Italy, and 2008 Wells, Nevada, earthquakes have similar moment magnitudes, the L'Aquila sequence had over 230 events with ML ≥ 3.0. In addition the L'Aquila events were within a dense broadband seismic network that was augmented immediately after the mainshock. As soon as events were automatically located, digital data were available through the Italian Seismological Instrumental and parametric Data-basE – ISIDE. Because of the rapid availability of waveforms, we focused on developing procedures for rapid source parameter estimation, usually within 1-hour because of remote access.

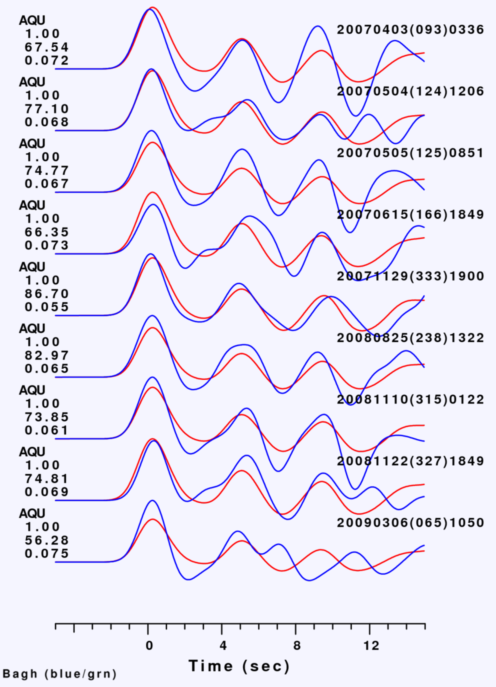
This poster addresses

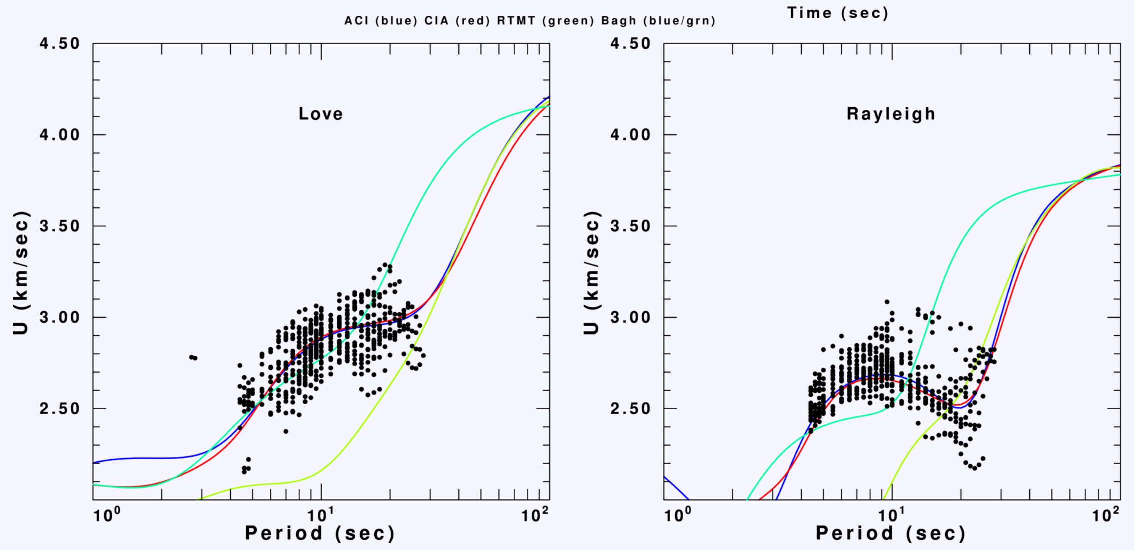
- The development of a regional velocity model
- Moment tensor inversion of 169 events with 3 ≤ ML ≤ 6.13
- A special investigation of the mainshock through a finite fault simulation

Derivation of Velocity Model

Initial waveform QC for the inversion showed the presence of well dispersed surface waves. We developed the CIA model using 1200 group velocity measurements from paths to stations in the map and then created the ACI model by adding receiver function data from the MedNet station AQU.



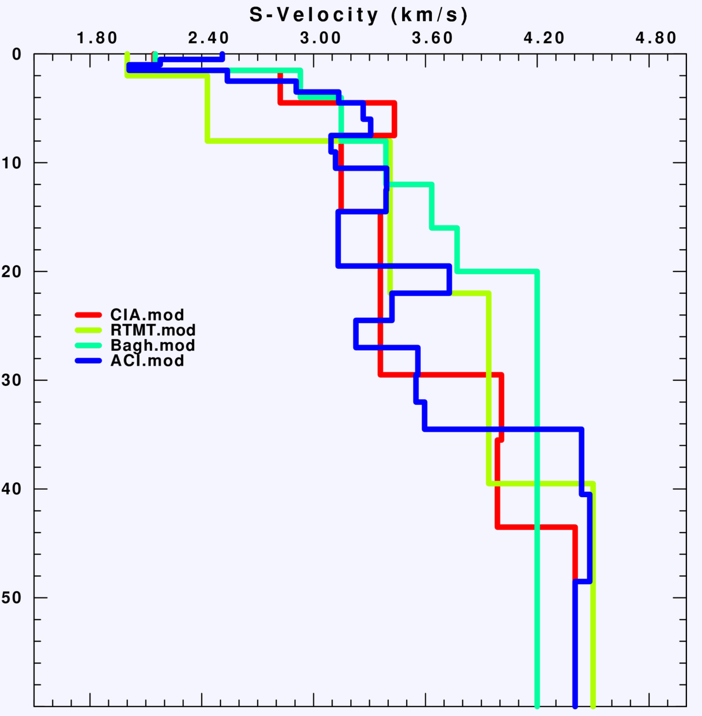




Observed dispersion compared to predictions from the CIA and ACI models developed here, the Bagh model based on body-wave tomography and the model used for RTMT inversions at INGV. The ACI model predictions (red) are plotted on top of the observed RFTNs (black). The reverberations in the RFTNs are controlled in part by the low velocity gradient in the upper 10 km of the model; such ringing makes determination of depth to the Moho very difficult, showing the importance of a joint inversion of dispersion and RFTNs with crustal sounding constraints.

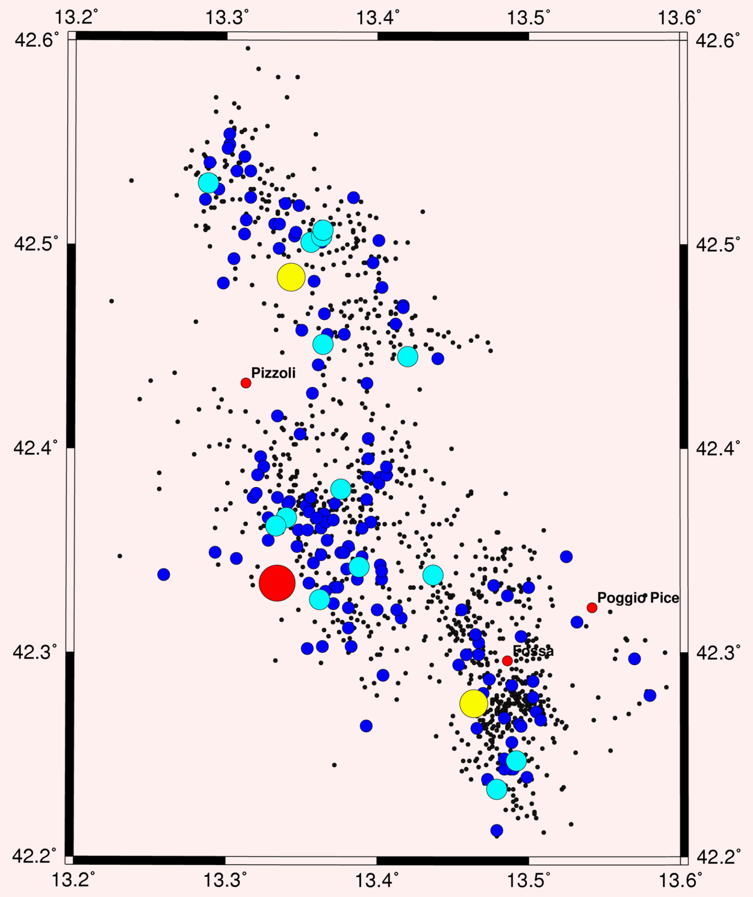
Model Comparison

We computed Green's functions for the CIA and ACI models and found them to be very similar in the 0.02 – 0.10 Hz band used for inversion. For reasons of computational speed, we precomputed Green's functions at 1 km increments in distance and depth. The CIA model is essentially a smoothed version of the ACI model. Waveform fits for M=3 are superb with the CIA model.



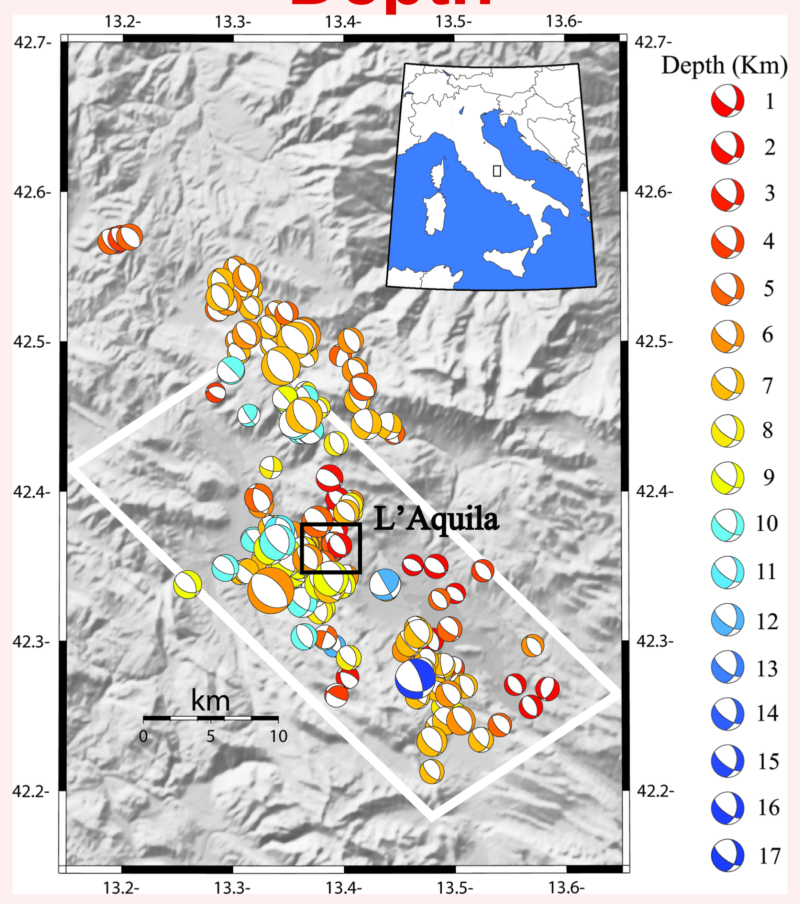
Inversion Data Set

We examined waveforms of all events with ML ≥ 3 for source inversion, and missed smaller events only in the first 24 hours because of enhanced background noise due to the mainshock coda.



The figure shows all ISIDE events with ML > 2. The blue, blue-green, yellow and red symbols indicate events with ML > 3, 4, 5 and 6, respectively. Note that the mainshock is at the edge of the aftershocks.

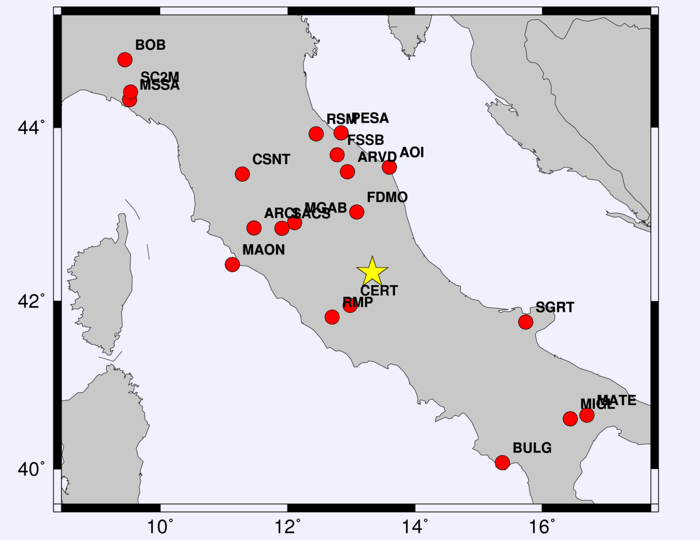
Moment Tensors and Depth



Moment tensor solutions obtained using a rapid grid search and the CIA model. The orientation of the T-axis is uniform, although dip angles vary. Beachball size is function of Mw and color indicates source depth – dipping fault planes are seen. Solutions from March 30 through October 20 are shown. The location of the city of L'Aquila is given by the black box. The white outline indicates the surface projection of the finite fault simulation.

Mainshock Data

These broadband stations are used for the mainshock inversion. Nearer stations were clipped.



Open Documented Software

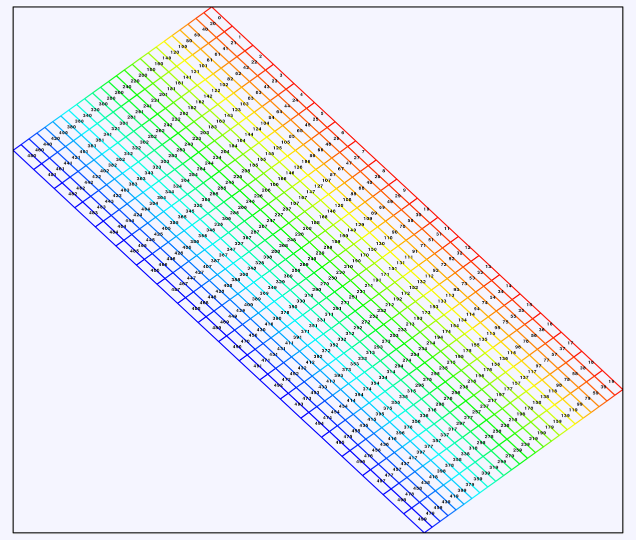
Computer Programs in Seismology:
http://www.eas.slu.edu/People/RBHerrmann/CPS330.html
Tutorials, Documentation, Q&A

The Mainshock

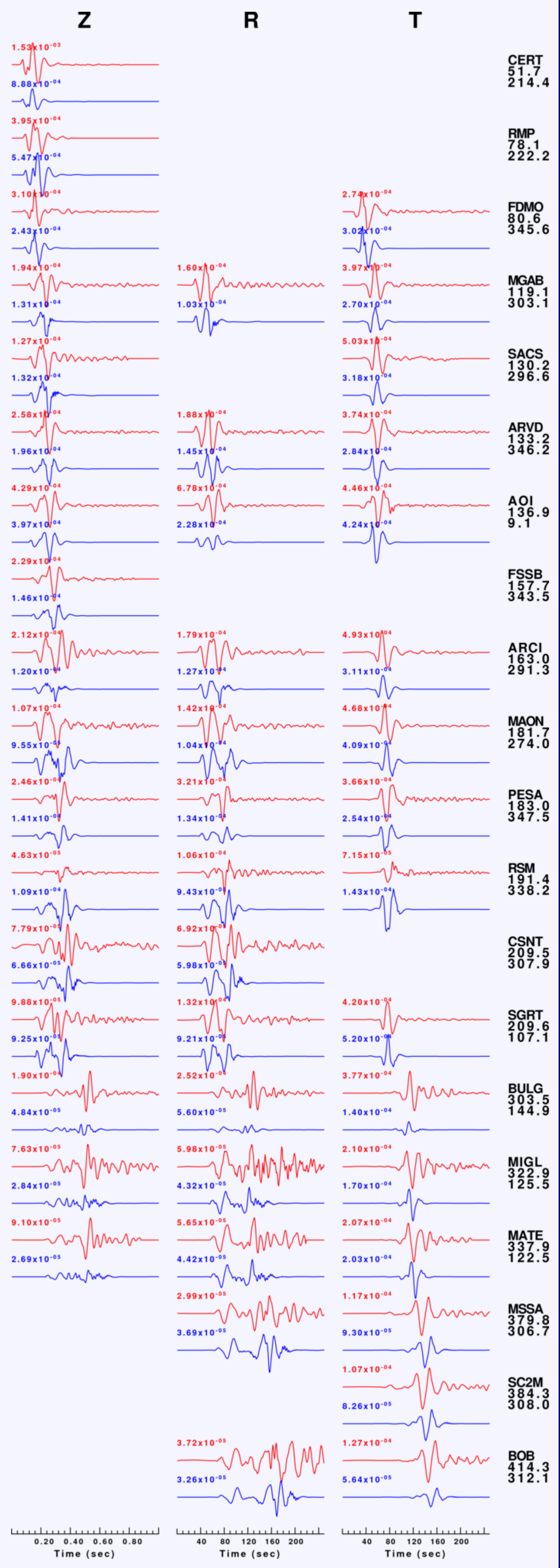
We successfully used the 0.02 – 0.10 Hz ground velocity band for all events except the mainshock, for which only the 0.01-0.025 Hz band led to an upper crustal depth. The use of higher frequencies led to a lower crustal depth, required to fit reduced high frequency spectra. In addition time shifts on the order of 5-6 seconds were required for a fit. The point source solution using the CIA model is Mw=6.13, strike 135, dip 55, rake -95 and depth 5 km.

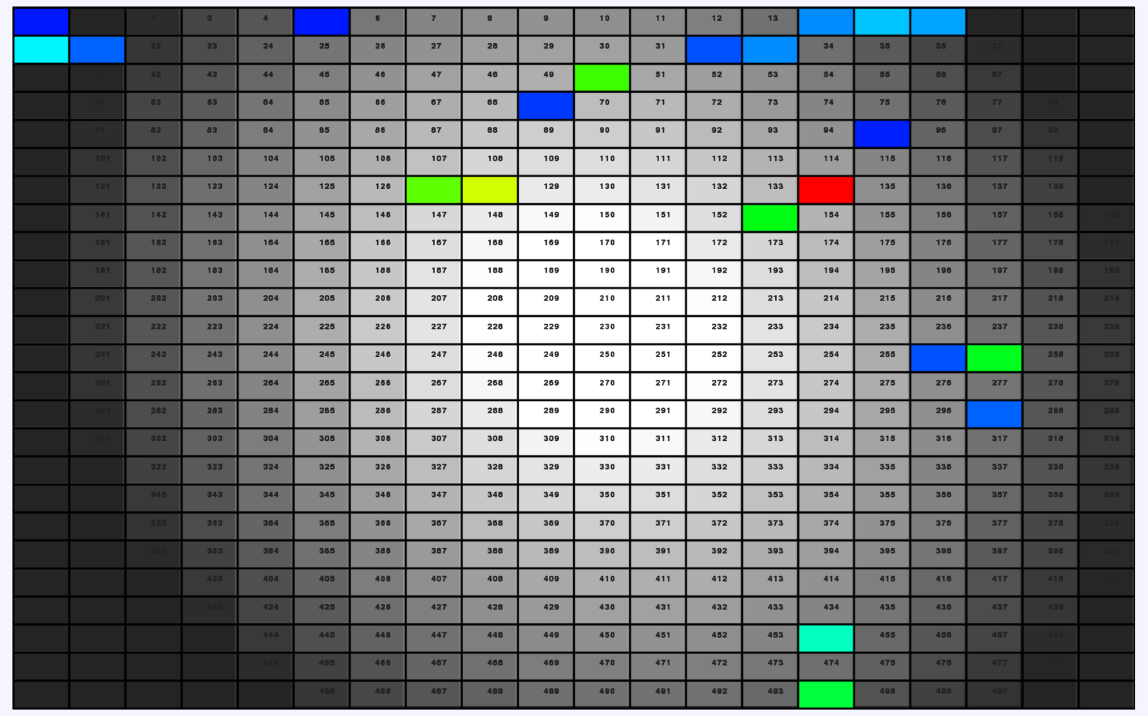
Reading first arrival times. we determined a hypocenter using the CIA model to get coordinates 42.34N, 13.37E and H=13 km, slightly east of the INGV location, which cannot explain needed time shift.

Given confidence in our Green's functions, to resolve the inability to use higher frequencies for the mainshock, we used the fault plane solution given to define the fault plane and slip angle, and solved for moment release as a function of rupture initiation, rupture velocity and frequency band using NNLS. As expected, in the 0.01 – 0.025 Hz band, we get greater variance reduction (72%) than for the point source inversion (69%), but also 65% in the 0.01-0.05 Hz band vs 52% for a point source. We sampled a large suite of rupture velocities and initiation points. All finite fault simulations show significant moment release at shallow depth. The best result for the 0.01 – 0.05 Hz band requires near-simultaneous moment release at several shallow patches. Variance reduction is now a function of the model rather than the source.



Map view of finite Fault [Red=shallow, blue= deep]
Cell 0: 42.40N 13.31E
Cell 19: 42.27N 13.65E
Cells are 2 km x 1 km
Rupture initiates at patch 230 and VR=2.6 km/s





Overlay of finite fault solution (color: red largest Mo, blue smallest Mo) over rupture time (gray: light early, dark late)

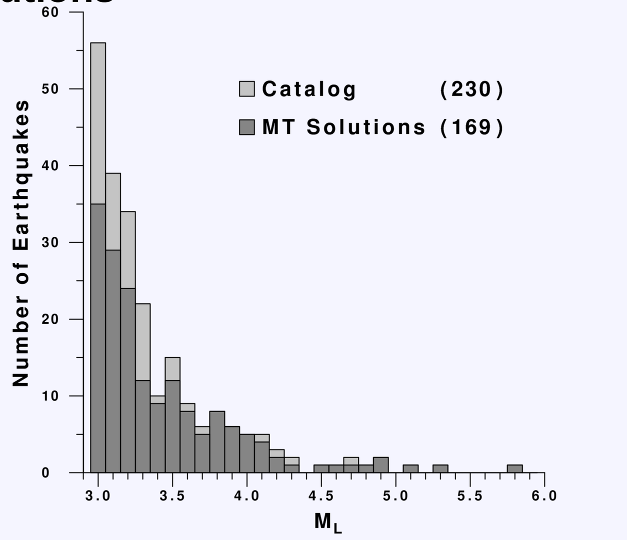
Note major moment release to SE of hypocenter and near surface

SOLUTION ORDERED BY DECREASING MOMENT RELEASE

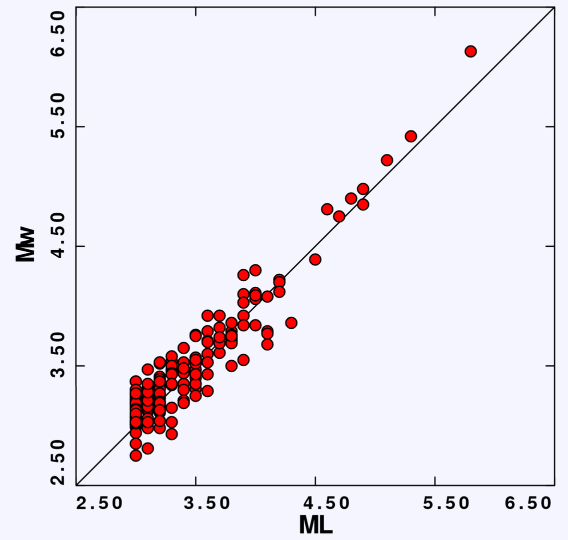
Cell	lat	lon	H(km)	t0	Moment(nt-m)	Mw	(%)
134	42.3062	13.5199	5.39	3.92	3.4304e+17	5.66	17
128	42.3798	13.4128	5.39	2.43	2.3892e+17	5.55	12
127	42.3921	13.3950	5.39	2.91	1.9976e+17	5.50	10
50	42.3700	13.4761	2.07	3.75	1.8950e+17	5.49	10
153	42.3148	13.4952	6.22	3.01	1.6437e+17	5.44	8
257	42.2474	13.5321	10.36	5.35	1.5884e+17	5.43	8
494	42.2400	13.3958	20.31	5.89	1.4994e+17	5.42	8
454	42.2474	13.4095	18.65	5.19	1.0294e+17	5.31	5
20	42.4963	13.3046	1.24	8.28	7.9079e+16	5.23	4
15	42.3160	13.5791	0.41	6.34	6.4651e+16	5.17	3
16	42.3038	13.5970	0.41	6.90	5.1882e+16	5.11	3
14	42.3283	13.5613	0.41	5.83	4.3623e+16	5.06	2
33	42.3369	13.5365	1.24	5.01	4.1419e+16	5.04	2
21	42.4841	13.3224	1.24	7.62	3.0020e+16	4.95	2
297	42.2400	13.5183	12.02	5.37	2.9574e+16	4.95	1
32	42.3491	13.5187	1.24	4.62	2.5668e+16	4.91	1
256	42.2596	13.5142	10.36	4.58	2.4517e+16	4.89	1
69	42.3786	13.4514	2.90	3.33	1.4590e+16	4.74	1
95	42.3013	13.5515	3.73	5.11	9.3612e+15	4.61	0
5	42.4387	13.4007	0.41	5.61	5.4168e+15	4.46	0
0	42.5000	13.3115	0.41	8.45	5.3900e+15	4.45	0

Results

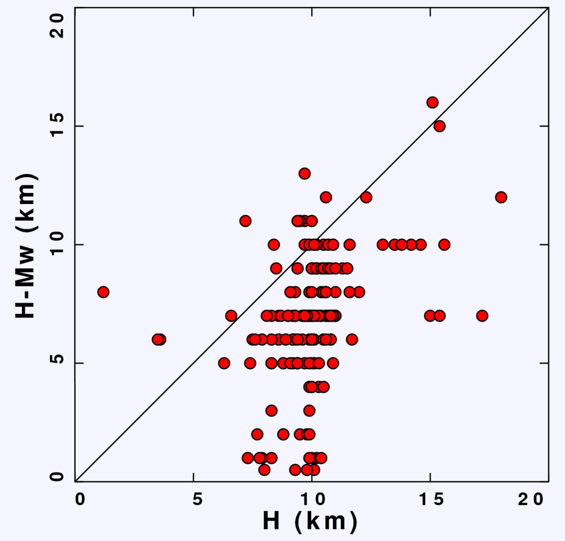
- Very complete set of moment tensor solutions



- INGV ML compares well to Mw



- Automatic depths lack resolution



- Mainshock moment release was not at hypocenter, but much shallower and to SE
- Mainshock is complex with two zones of moment release about 13 km apart. The shallow Mw 5's at upper left coincide with secondary fault
- Velocity model provides detailed fit to high frequency ground velocity throughout Apennines and can be used for future large earthquake inversions until superceded
- Finite fault specification can be used for forward modeling of teleseismic observations
- Forward modeling of velocity in 0.01 – 0.10 Hz band matches observed amplitude and waveform shapes, but could not be used for inversion because of time shifts due to slightly imperfect Green's functions
- Grid search MT inversion was efficient