Project_S5_RU4 - Broadband Waveform Inversion for Mechanisms of Moderate Earthquakes In the Messina Straits, Southern Italy

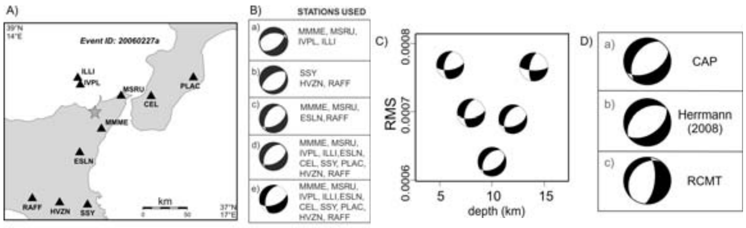
D'Amico S.[1], Orecchio B.[2], Presti D.[3], Zhu L.[1], Herrmann R.[1], Neri G.[3, 4]

[1] Department of Earth and Atmospheric Sciences, Saint Louis University, 3642 Lindell Boulevard, 63108 St. Louis, MO, USA
[2] Dipartimento di Fisica, Università della Calabria, Ponte P. Bucci, Arcavacata di Rende (CS), Italy
[3] Dipartimento di Scienze della Terra, Università di Messina, Salita Sperone 31, Messina, Italy (dpresti@unime.it)
[4] Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, Roma, Italy

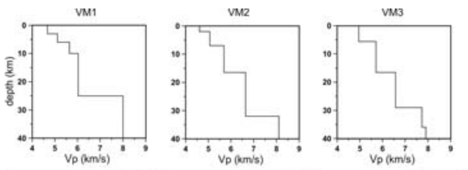
The Cut and Paste method (CAP; Zhu and Helmerger, 1996) computes focal mechanisms of earthquakes in a wide magnitude range by waveform inversion of Pnl and surface wave segments. CAP has proven to be effective for analyzing earthquakes even with magnitudes between 2.5 and 4 (see e.g., Zhu et al., 2006) for which traditional P-wave focal mechanisms fail because of the lack of sufficient observations. We analyzed earthquakes with magnitudes between 3 and 4 occurring in the Messina Straits in the last few years, recorded by the broadband stations of the Italian National Seismic Network and by the Mediterranean Very Broadband Seismographic Network. The solutions show that normal faulting is the prevailing style of seismic deformation in the northern part of the study area while coexistence of normal faulting and strike-slip has been detected in the southern part. In the whole area of investigation the T-axes of focal mechanisms display a preferential northwest-southeast direction of extension also evidenced by stress inversion results. Combined with the findings of previous investigations, this improved database of focal mechanisms allows us to better detail the transitional area between the extensional domain related to subduction trench retreat (southern Calabria) and the compressional one associated with continental collision (western-central Sicily). The observed spatial change of seismic deformation regime offers new data to current seismotectonic and seismic hazard investigations in the area of Messina Straits where a magnitude 7.2 earthquake caused more than 60,000 casualties on 28 December 1908.

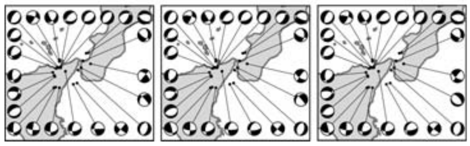
DATA AND METHOD

Our data set consists of waveforms from 23 earthquakes collected from the INGV seismic catalogue (http://iside.rm.ingv.it) for time period from October 2004 to October 2008 with focal depths less than 25 km and magnitudes ML larger than 3. In this study we used the 1-D velocity model obtained from the 3-D model by Barberi et al. (2004). We computed the moment tensor solutions using the "Cut And Paste" (CAP) method originally proposed by Zhao and Helmerger (1994) and later modified by Zhu and Helmerger (1996). Each waveform is broken into P-Pnl and surface-wave segments. The source depth and focal mechanisms are determined using a grid search technique.



In order to have and additional check of the CAP focal mechanisms for this area we performed several tests. The panel A shows the location of the event ID 20060227a and of the stations used in the tests displayed here. The beach balls in the panel B represent the solution obtained using some nearby stations (a), some farther stations (b), a combination of them with an azimuthal gap of almost 180 degrees (c), forcing the epicenter to lie 5 km south of the true location (d) and using only the surface wave segments (e). The solutions obtained at different depth levels around the CAP focal depth of the event are displayed in the panel C with the corresponding values of the predicted-observed waveform misfit. Finally the panel D shows, for comparison, our CAP solution, the focal mechanism we estimated by the method of Herrmann (2008) and the regional CMT solution released by INGV (http://www.bo.ingv.it/RCMT/searchRCMT.html).



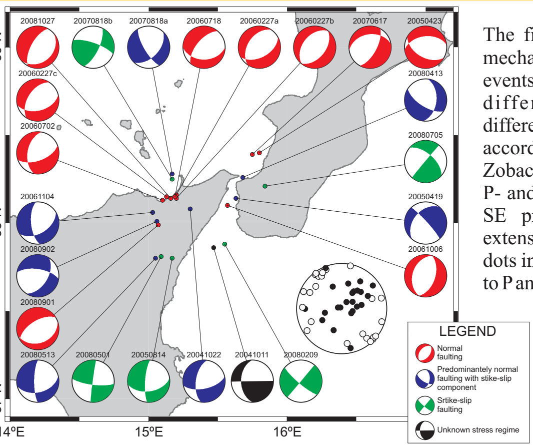


The figure above shows the comparison of the CAP mechanisms of the earthquakes listed in Table 1 estimated with different velocity models (VM1, VM2, Vm3). We have checked the stability of the mechanisms varying the earth structure parameters within ranges defined according to the most recent tomographic inversions and velocity models available for the study area. For this test we started from the tomographic models of Barberi et al. (2004) and Neri et al. (2010) and computed in both structures the P-wave theoretical travel-times corresponding to the source-station pairs used for the CAP inversion in this work. Then, from the time-distance plots obtained for the respective structures we derived the 1D velocity models indicated as VM2 and VM3. The same figure shows also the VM1 model used for computation of the focal mechanisms reported in Table 1. The differences among these models represent wave propagation across the laterally heterogeneous crust of the study area (Neri et al., 2002; Finetti, 2005; Pontevivo and Panza, 2006). The high stability of CAP solutions when the model changes is evident.

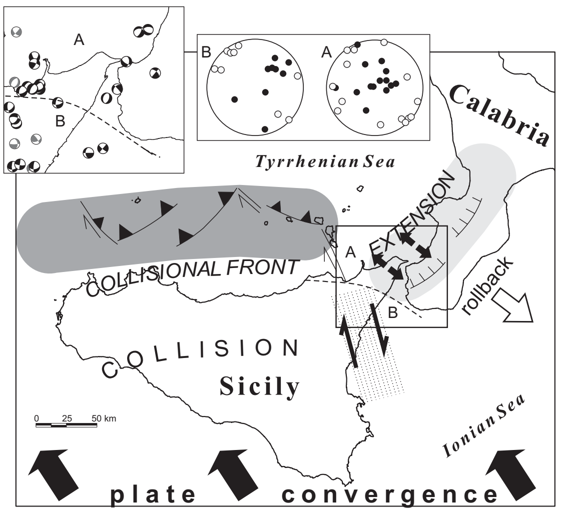
RESULTS AND DISCUSSION

Event ID	O.T.	Lon (°E)	Lat (°N)	H (km)	ML	Mw	Strike(°)	Dip(°)	Rake(°)
20041011	7.31.41	15.48	37.88	6.6	3.5	3.6	89	90	-45
20041022	21.10.13	15.32	38.08	10.7	3.5	3.4	78	61	-37
20050419	22.36.23	15.66	38.14	7.1	3.2	3.1	220	42	-10
20050423	19.10.48	15.82	38.43	13.6	3.0	2.8	120	50	-64
20050814	22.02.27	15.12	37.80	6.7	3.0	3.1	82	50	-18
20060227a	4.34.01	15.17	38.10	10.1	4.1	4.1	62	50	-71
20060227b	9.11.59	15.18	38.14	10.5	3.5	3.1	39	48	-90
20060227c	14.16.06	15.18	38.14	9.1	3.3	3.1	76	48	-58
20060702	17.52.00	15.10	38.13	10	3.0	2.6	70	59	-49
20060718	7.42.40	15.17	38.12	9.1	3.3	3.1	90	41	-49
20061006	21.16.23	15.57	38.10	9.6	3.2	3.2	18	52	-90
20061104	5.59.22	15.01	38.03	10.6	3.1	3	59	49	-37
20070617	12.11.58	15.79	38.37	10	3.3	2.9	262	38	-43
20070818a	14.04.07	15.13	38.23	9.4	4.0	3.9	44	50	-23
20070818b	14.21.11	15.12	38.19	10	3.2	3.4	26	69	18
20080209	7.46.36	15.56	37.84	6.9	3.1	3	40	90	-10
20080413	13.06.57	15.70	38.25	14.3	3.3	2.8	6	51	-30
20080501	21.05.49	15.07	37.80	2	3.4	3.4	96	76	2
20080513	21.28.30	15.06	37.80	12	3.3	3.5	76	46	-20
20080705	17.04.36	15.87	38.20	2	3.0	2.6	311	59	2
20080901	14.45.40	15.06	37.97	8.1	3.1	3.1	70	31	-80
20080902	9.16.45	15.06	37.99	10.3	3.4	3.3	279	64	-44
20081027	10.55.55	15.13	38.11	2	4.0	3.5	50	28	-71

Table 1: earthquake parameters of the final data-set. The hypocenter parameters are from the INGV catalogue (http://iside.rm.ingv.it). H indicates the hypocenter depth found by minimization of synthetic-to-experimental waveform misfit during CAP's application. Ml and Mw indicate, respectively, the local magnitude reported by the INGV catalogue and the magnitude derived from CAP waveform inversion.



The figure reports all the focal mechanisms computed for the events reported in table 1. The different colours identify different types of mechanism according to the classification of Zoback (1992). The polar plot of P- and T-axes evidences a NW-SE preferential orientation of extension axes. Black and white dots in the polar plots correspond to P and T axes, respectively.



Sector	N. of events	σ_1-az	σ_1-pl	σ_2-az	σ_2-pl	σ_3-az	σ_3-pl	Average misfit F
study area	25	211°	68°	34°	21°	304°	1°	6.2°
A	14	211°	68°	34°	21°	304°	1°	4.4°
B	9	341°	65°	187°	22°	93°	10°	3.1°

Table 2: Results of stress inversion of the focal mechanisms performed by using the Gephart and Forsyth (1984) algorithm.

Data indicates a sub-vertical attitude of $\sigma 1$ and an approximately WNW-ESE orientation of $\sigma 3$ in the whole study area.The misfit of 6.2° indicates a moderate stress heterogeneity (Wyss et al., 1992; Neri et al., 2004). Stress field of sub-volume A is the same of the entire area and shows a lower misfit value (4.4°) and smaller uncertainty areas. The stress axes orientation of sub-volume B, even if poorly constrained because of the few FMs, still indicates a prevalently extensive regime but with a different orientation of extension (c.a. E-W). Similar results have been obtained including in the datasets fault plane solutions coming from the RCMT catalog.

The data in the polar plots of P- and T-axes of focal mechanisms outline a clear north-to-south variation of the seismic deformation style marked by the dashed line separating the sub-volumes A and B. The polar plots of P- and T-axes in A and B show the different styles of deformation, with the P-axes more clustered near the center in the case of plot A. This behavior is also supported by the stress inversion of the focal mechanisms performed by using the Gephart and Forsyth (1984) algorithm (see table 2). The basic geodynamic information given in the figure (direction of plate convergence, continental collision domain, retreating subduction hinge, transition domain) should clarify why normal faulting resulted to be dominant in sector A, more favourably positioned with respect to the southeast-ward retreat of subduction hinge, while strike-slip components become evident in sector B located across the transfer zone between the extensional and compressional domains. The inset on the left shows focal mechanismscomputed in this work and CMT and RCMT data for the study area (http://www.bo.ingv.it/RCMT/).