Workbook
The 2012 seismic sequence in Emilia (Northern Italy)

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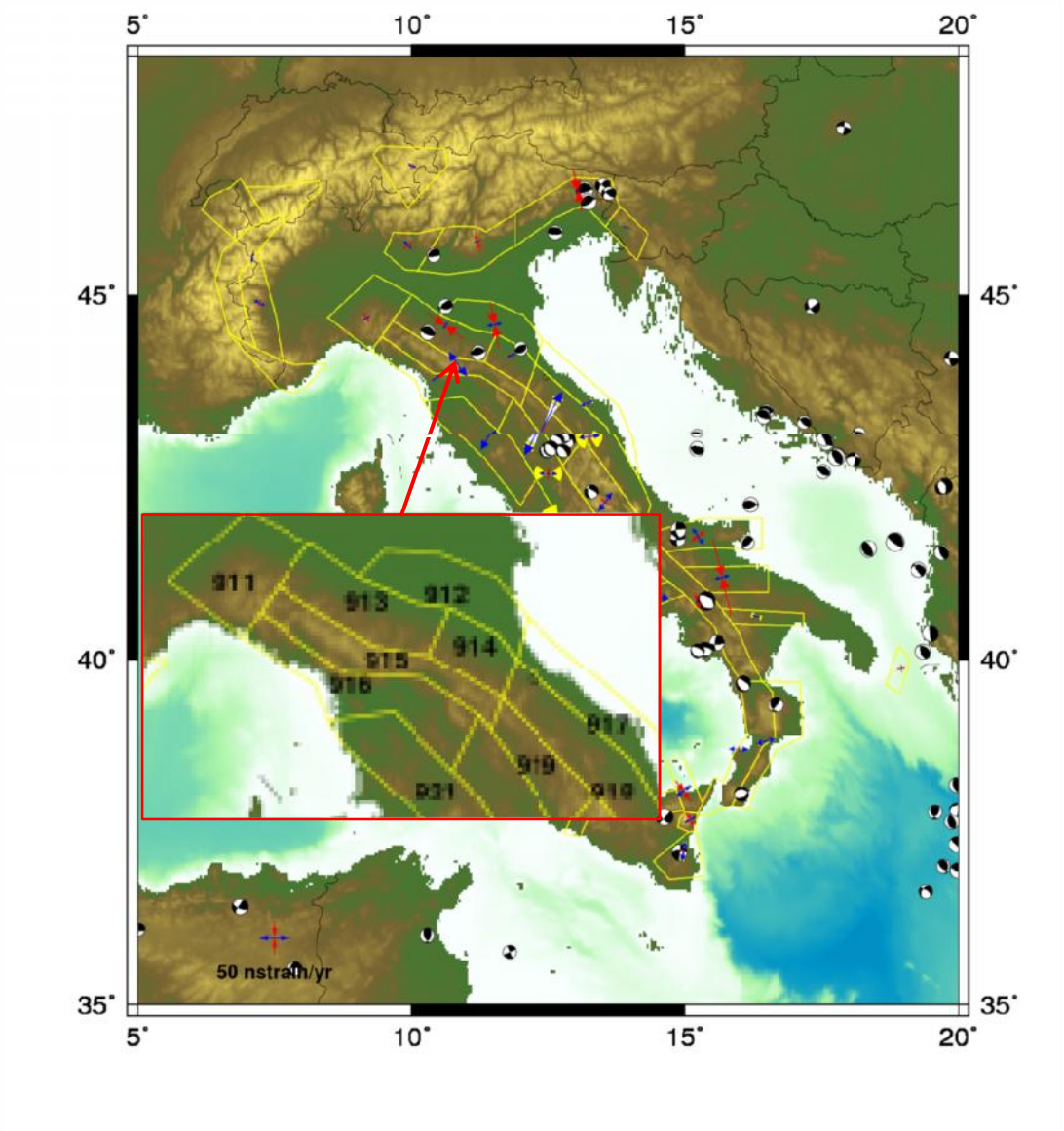
Padova, June 2012

Seismic Zonation in Italy



- Official Zonation based on 36 Seismic Zones and the CPTI04 Historical Catalogue (INGV – DPC) Additional detail in the DISS 3 database

- Each seismic zone is homogeneous from the point of view of geology and evolution

- Strain regime of each seismic zone is constrained by GPS data

- Gutenberg Richter parameters a and b are computed for each seismic zone

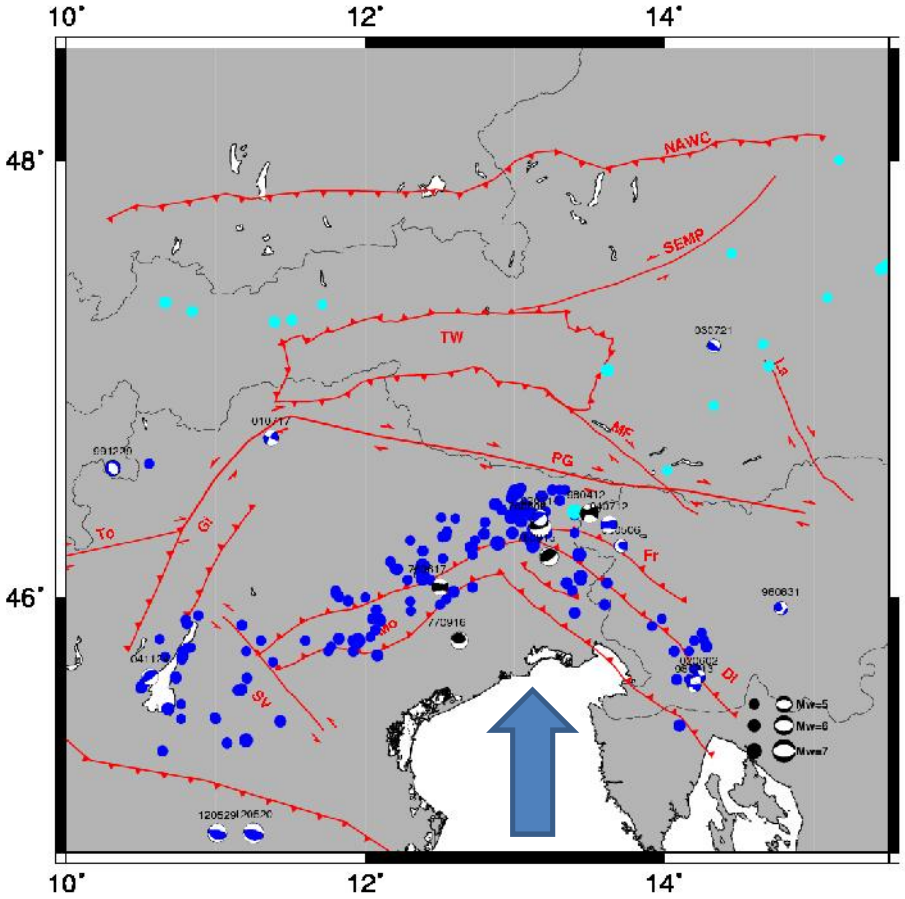
- PGA's (expected maximum ground acceleration in a given time lapse, e.g. 50 years) are computed based on historical seismicity and propagation laws

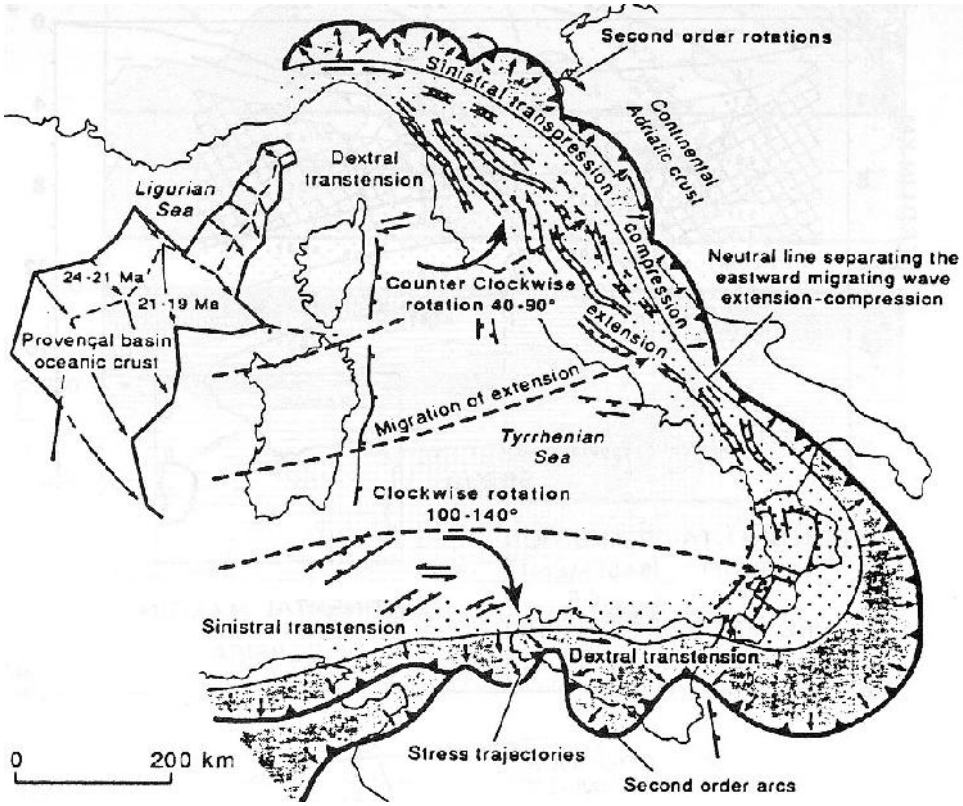
Tectonic setting

<u>Two concurrent active processes</u>:

• counterclockwise rotation of the Apennines related to the opening of the Thyrrenian sea

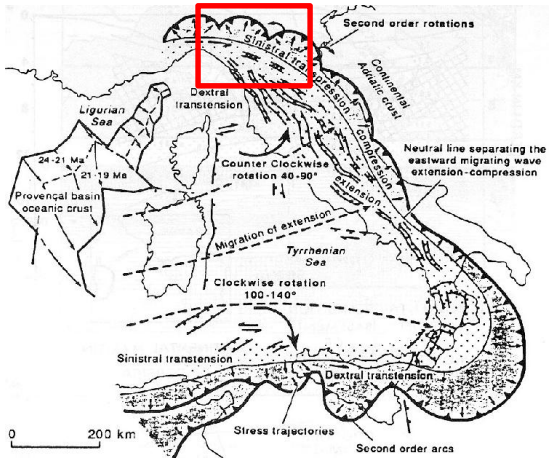
• Northwards convergence of the Adria microplate towards the stable European foreland

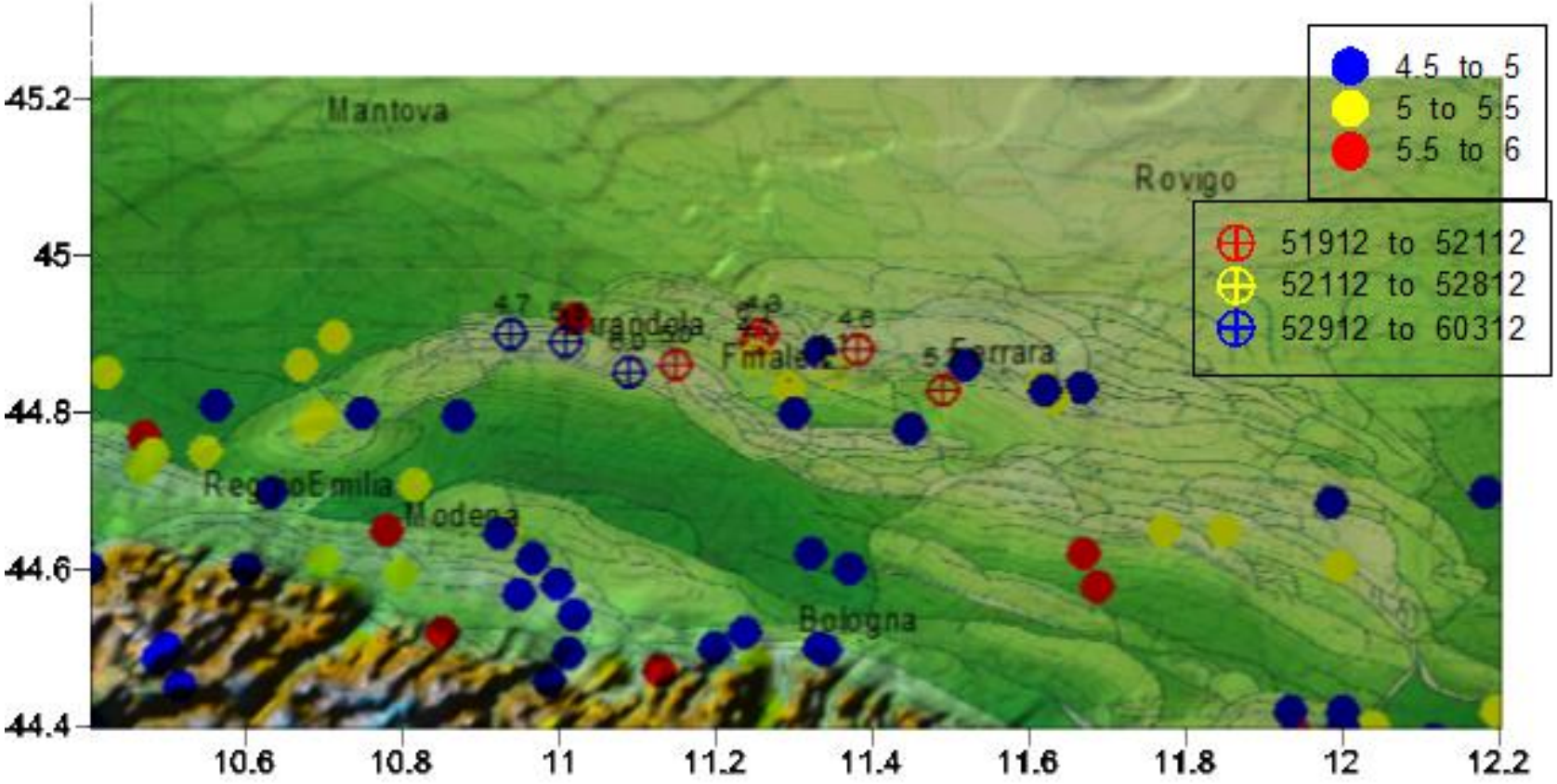




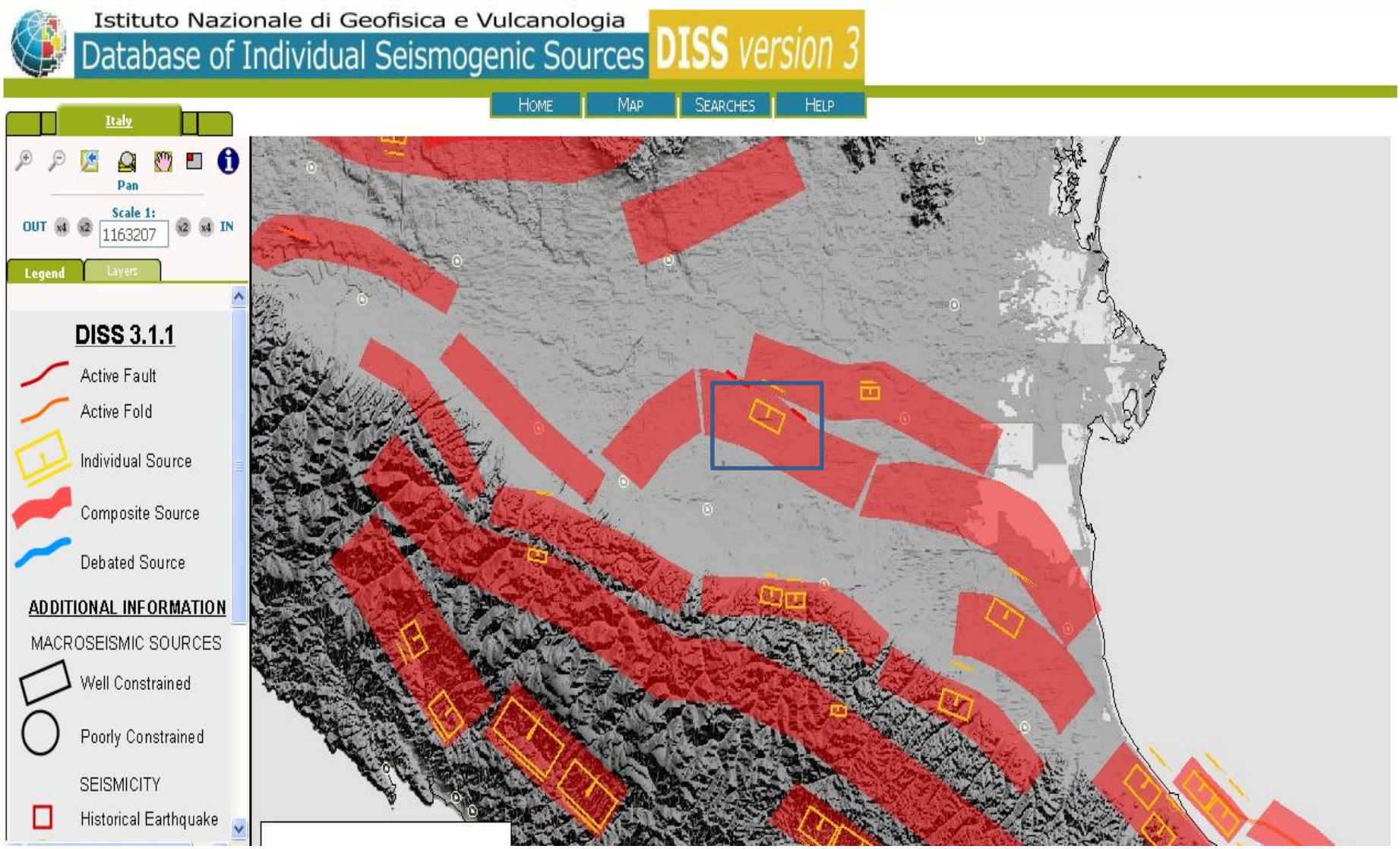
Historical Seismicity:

-91 (bC) M5.6 Modena Reggio Emilia
1346 M 5.8 near Ferrara
1570 M 5.5 Ferrara
1909 M 5.5 Lower Po plain
2012 sequence: fits the geographical pattern very well





The Mirandola Fault



Information from the DISS of INGV

General information

DISS–ID	ITIS107 **Name** Mirandola		
Compiled By	Burrato, P., E. Carminati, C. Doglioni and D. Scrocca	**Latest Update**	19-Sep-2007
Display map …			

Parametric information

Location [Lat/Lon]	44.84 / 11.14	OD	Based on geological and geomorphological observations.
Length [km]	8.7	OD	Based on geological and geomorphological observations.
Width [km]	5.8	OD	Based on geological and geomorphological observations.
Min depth [km]	3.9	LD	Based on geological and seismological data.
Max depth [km]	7.6	LD	Based on geological and seismological data.
Strike [deg]	113	OD	Based on geological and geomorphological observations.
Dip [deg]	40	LD	Based on surface displacement modeling constrained by subsurface data.
Rake [deg]	90	EJ	Inferred from geological data, constrained by orientation of T axes.
Slip [m]	0.45	ER	Calculated from Mo using the relationship from Hanks and Kanamori (1979).
Slip rate [mm/y] min…max	0.25…0.5	OD	Based on growth strata analysis.
Recurrence [y] min…max	900…1800	EJ	Inferred from slip rate and average displacement.
Magnitude [Mw]	5.9	ER	Inferred from slip rate and average displacement.

LD=Literature Data; OD=Original Data; ER=Empirical Relationship; AR=Analytical Relationship;EJ=Expert Judgement;

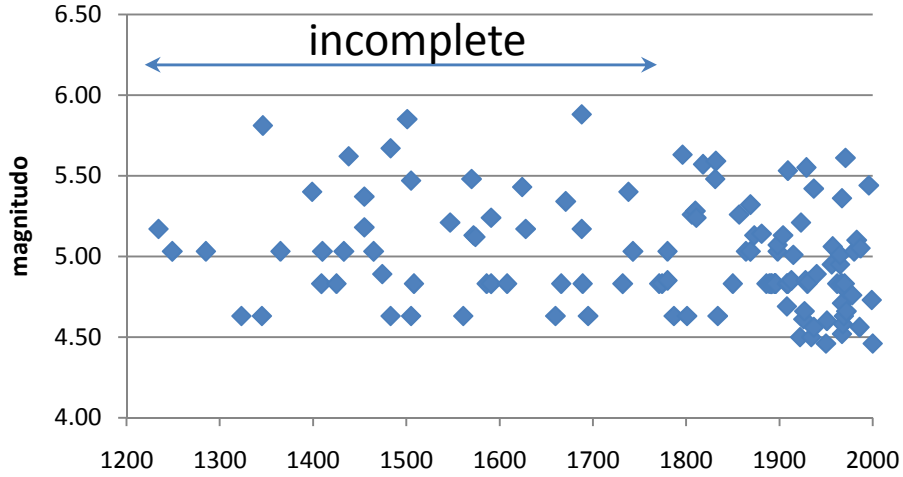
From the Commentary of the Mirandola Fault in the DISS (dated 2007)

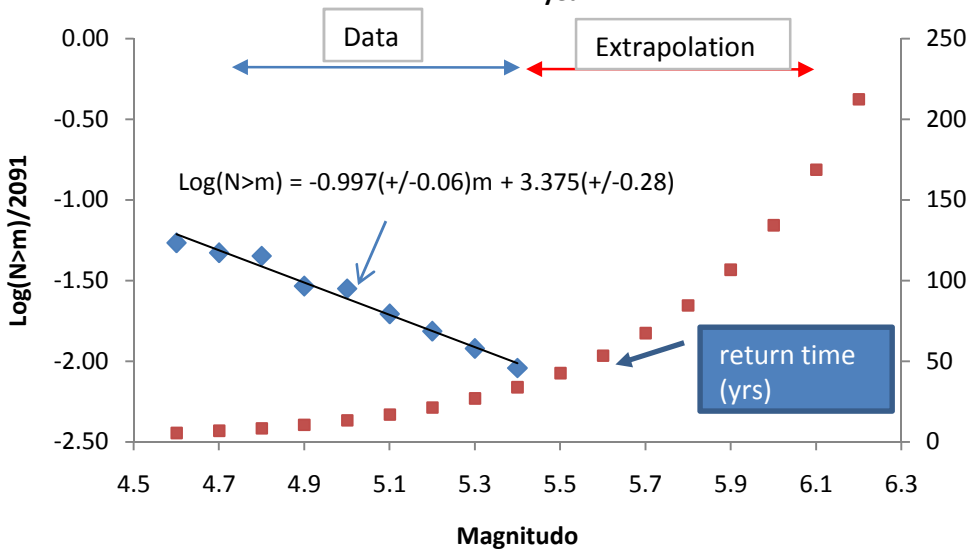
- … The Mirandola Source is not associated to any historical and/or instrumental earthquake, and as such it may represents a seismic gap. Given its dimension this source is able to generate earthquakes of Mw 5.9. The low slip rate suggests long recurrence interval for the potential earthquake. OPEN QUESTIONS 1) Considering that the Mirandola Source is not associated with any earthquake, is it possible that the current Italian seismic catalogue missed an earthquake generated by this source? 2) What is the recurrence interval for the earthquakes generated by the Mirandola Source..
- (june 2012): the same (?)fault is likely to have generated **two** M=6. earthquakes **in 9 days** (and several other M=5 events in the area)!

Probability of an event, recurrence time, completeness of a catalogue

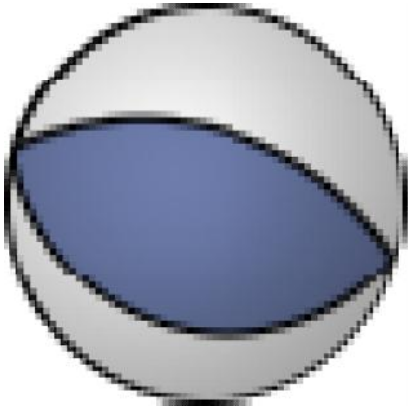
Seismic Zone 912-913

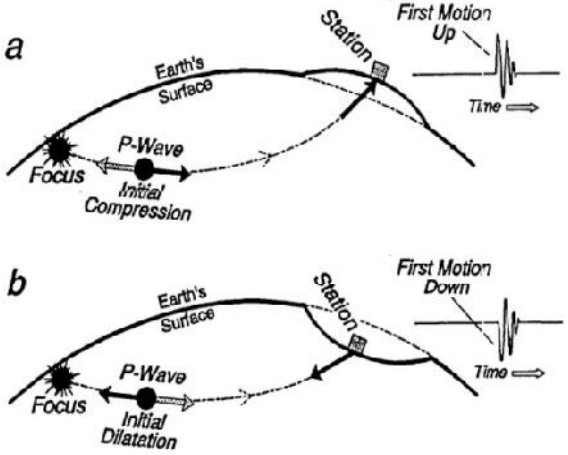
-Catalogue clearly incomplete
-Maximum Magnitude M=5.8 +/- 2
-Theoretical recurrence time for M=6 is 150-200 yrs (extrapolated!)
-The 2012 is (vaguely!) consistent with the historical data, both as magnitude and return time

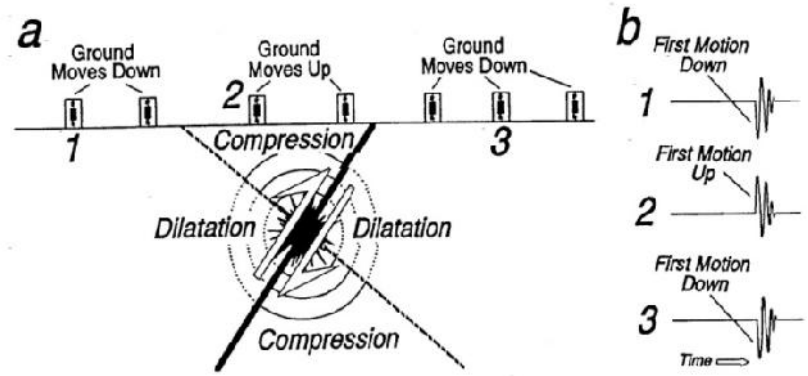




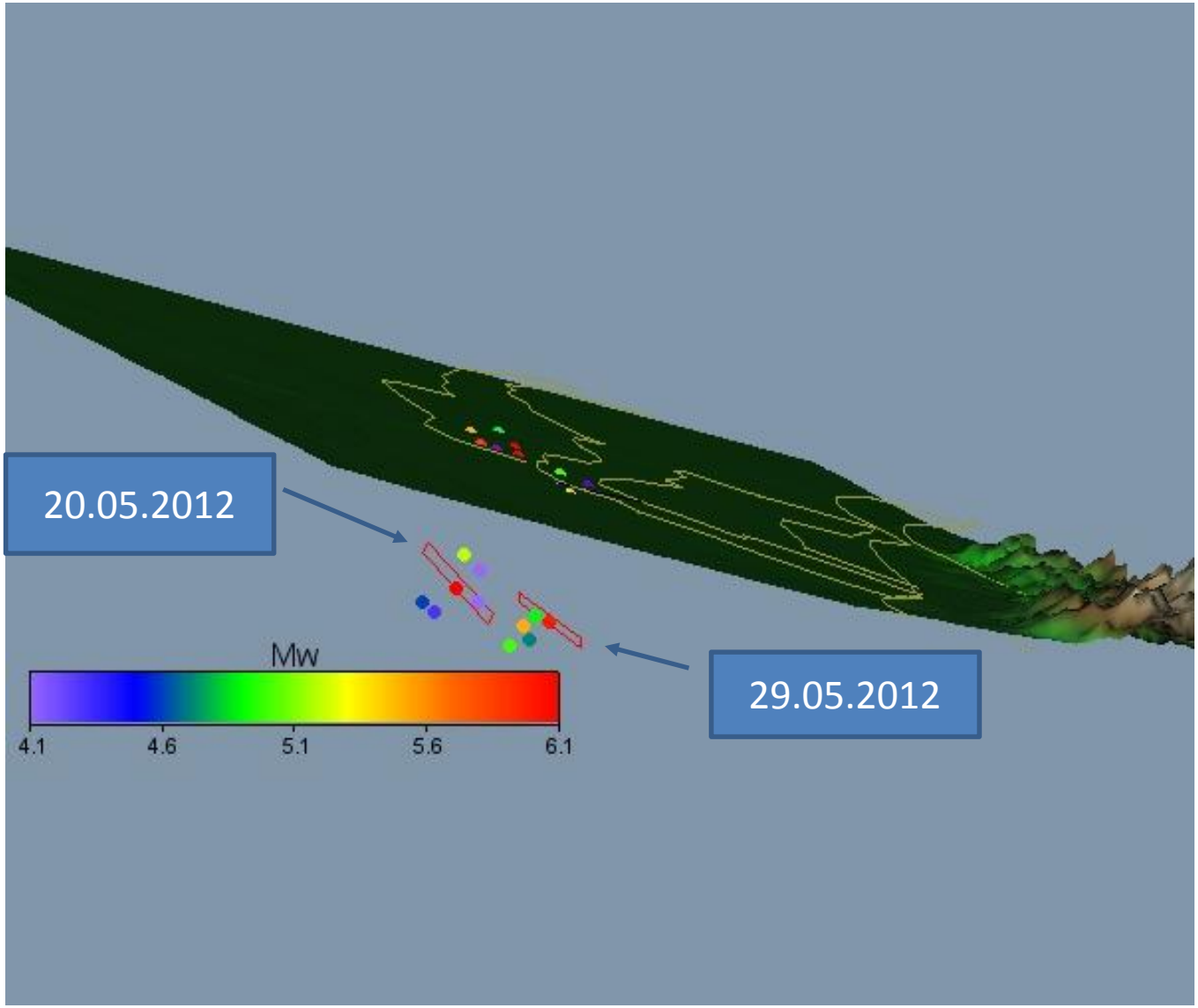
Pressure and Tension axes of the Fault Plane Solution indicate a reverse faulting: coherent with structural setting



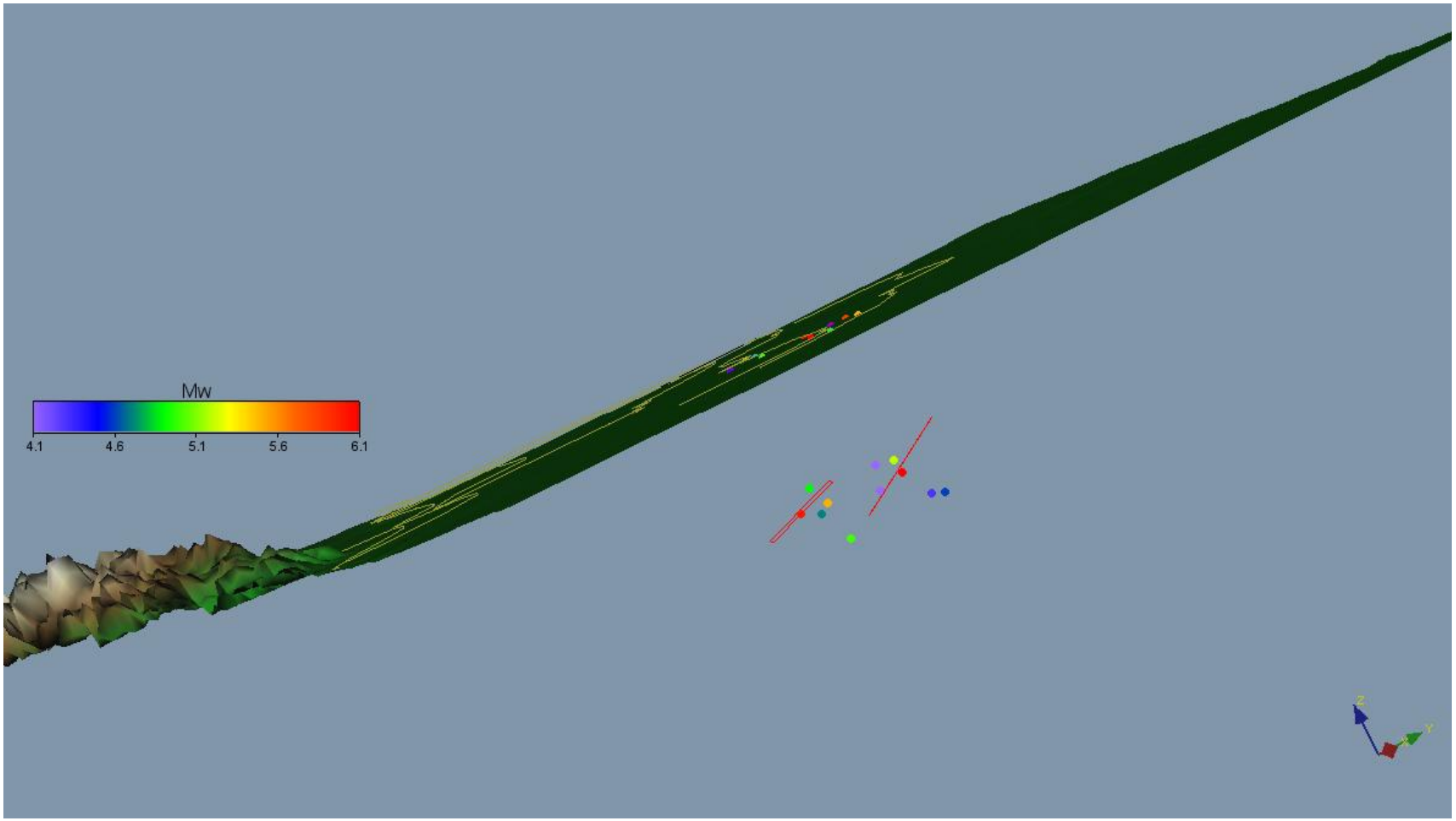




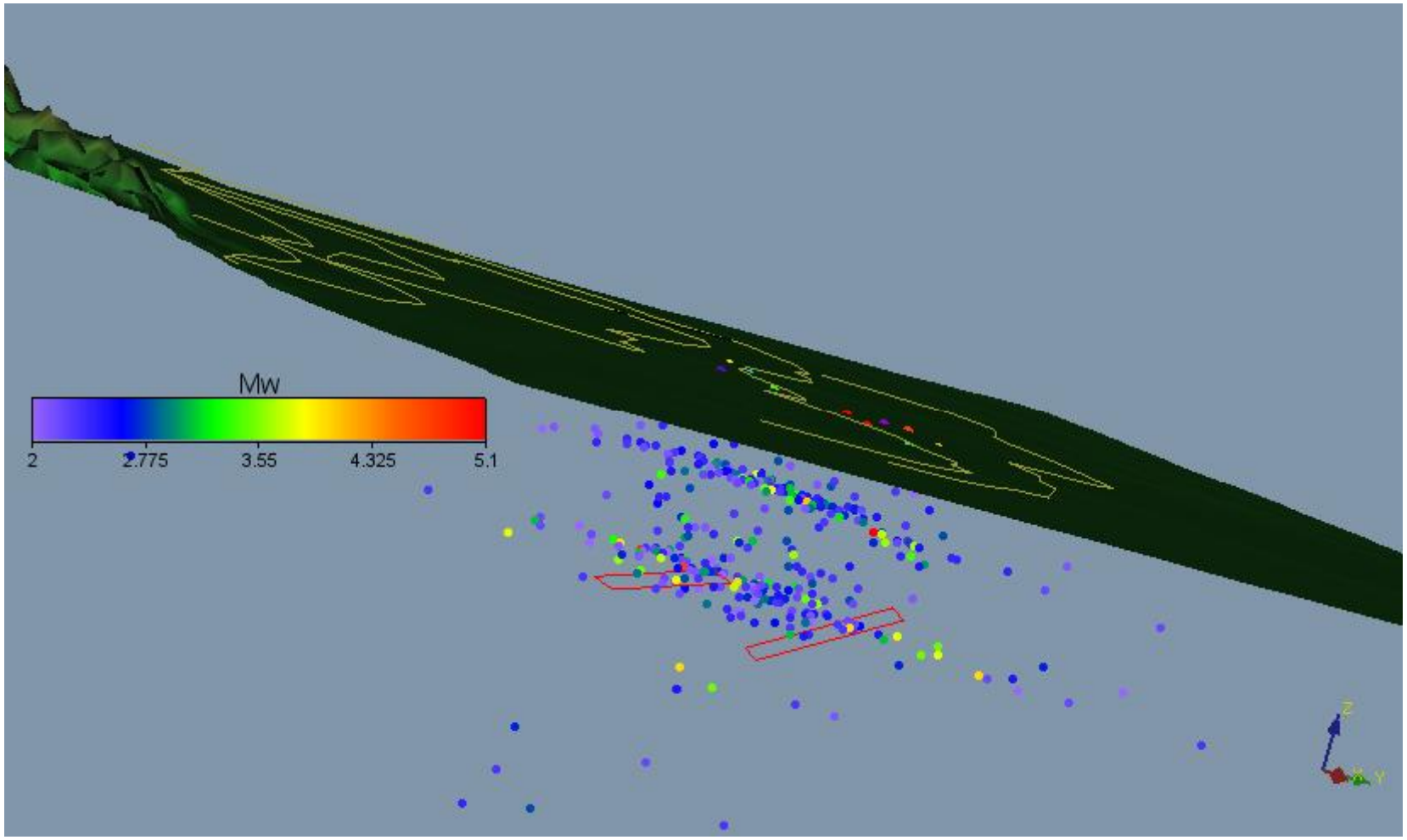
Sequence of 2012: fault plane orientation and size (expected)



View from East

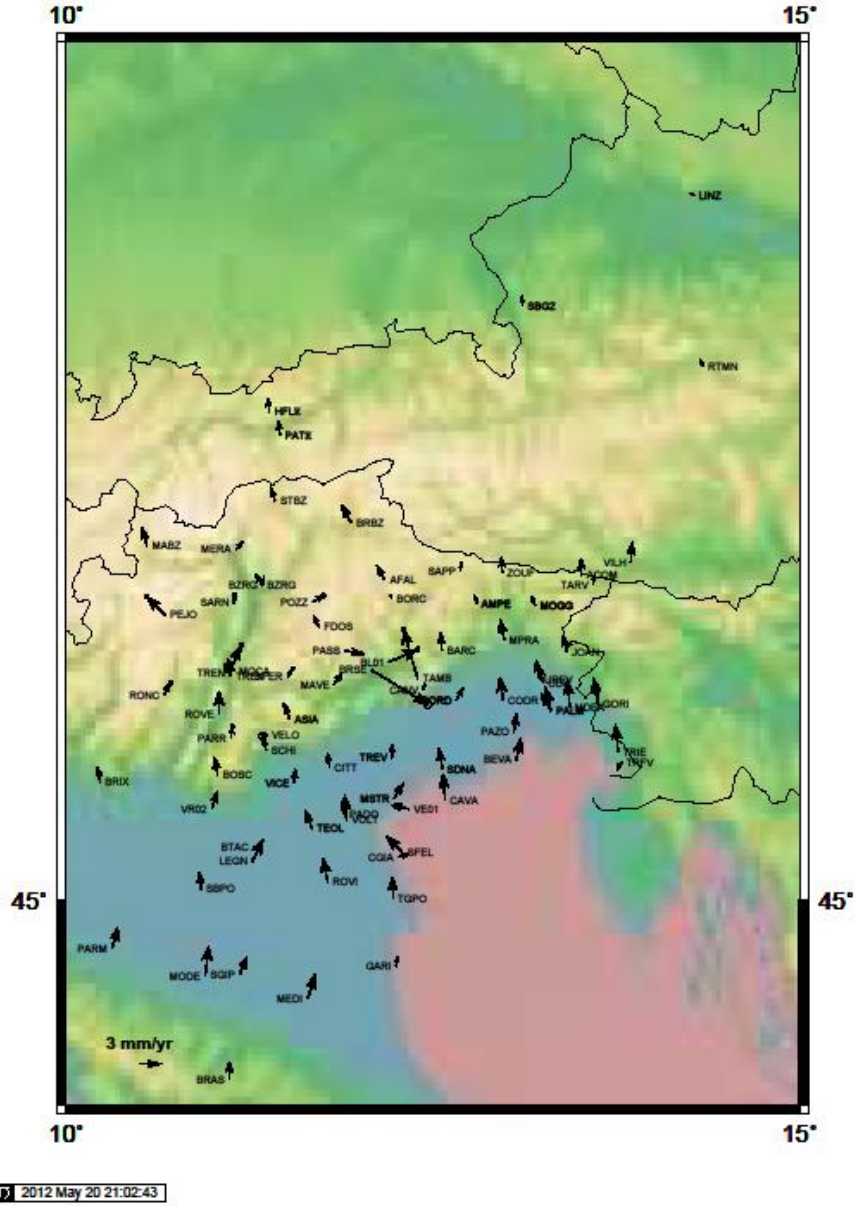


Distribution of the smaller events



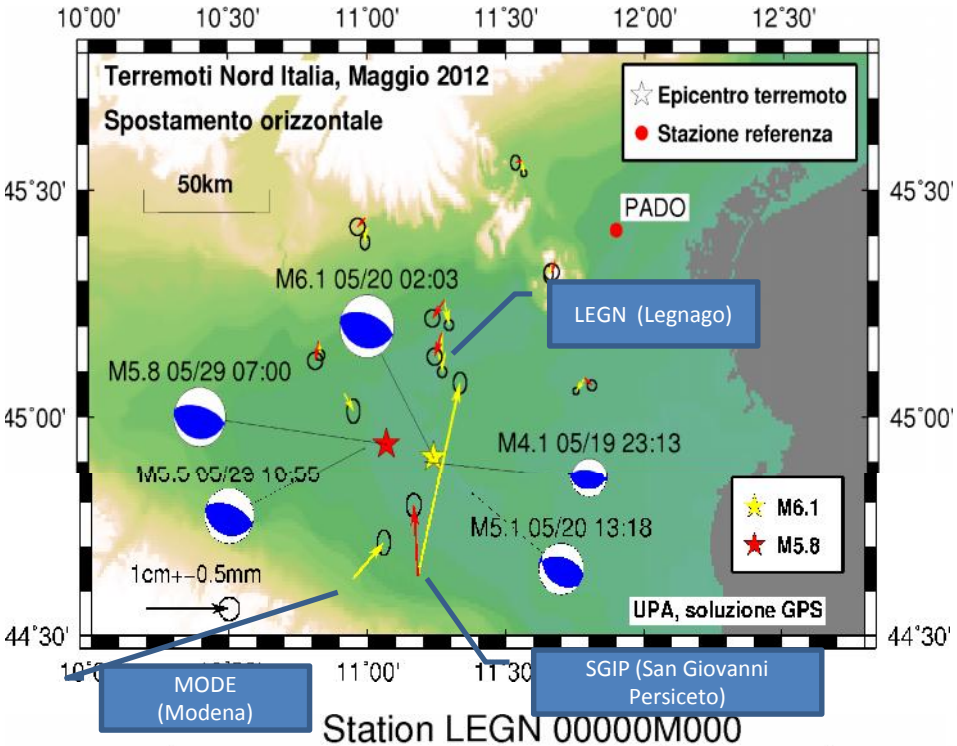
Velocity and strain rate from GPS data

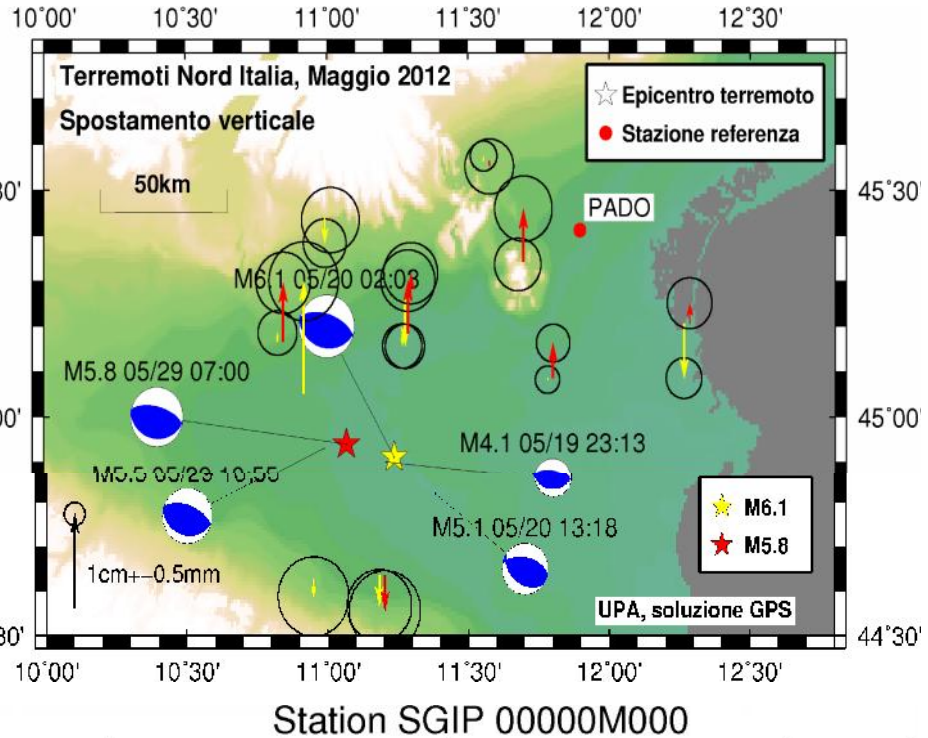
- Compressional status results from the velocities of MODE, SGIP, BOLG … being higher than those of LEGN, SBPO, ROVI ..
- Strain rate is the frame independent, geologically meaningful quantity
- Typical regional strain rates are of the order of 10-20 nstrain/yr, which means a rate of stress buildup in the rocks of the order of 0.7-1.4 kPa/yr (E=70 GPa)
- If the stress drop of a moderate earthquake is typically a few Mpa, then the times it takes to regenerate that stress in the rocks **<u>of the causative fault</u>** is of the order of 1000 years
- The recurrence of an earthquake of that magnitude in an area is in general shorter, because the yielding fault is in general different

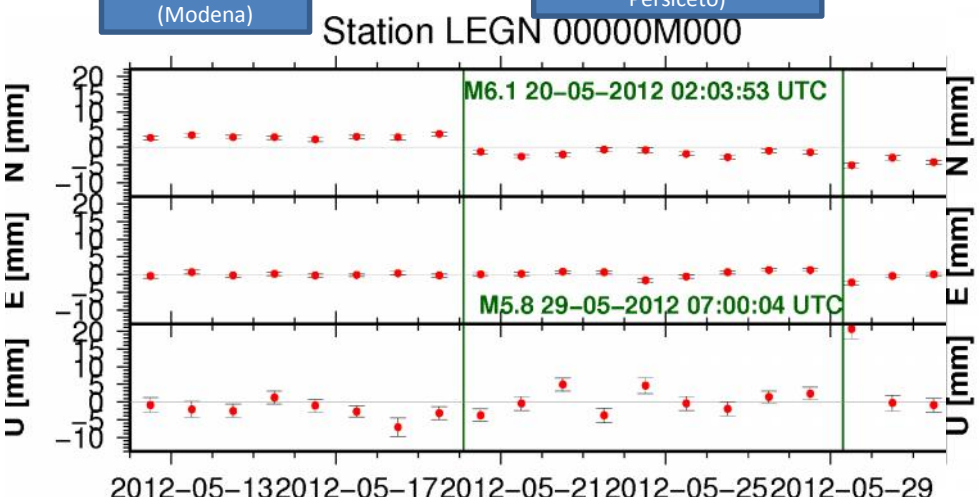


Time series of permanent GPS stations

offsets detected within 24 h; vertical lines in the time series indicate occurrence of seismic event







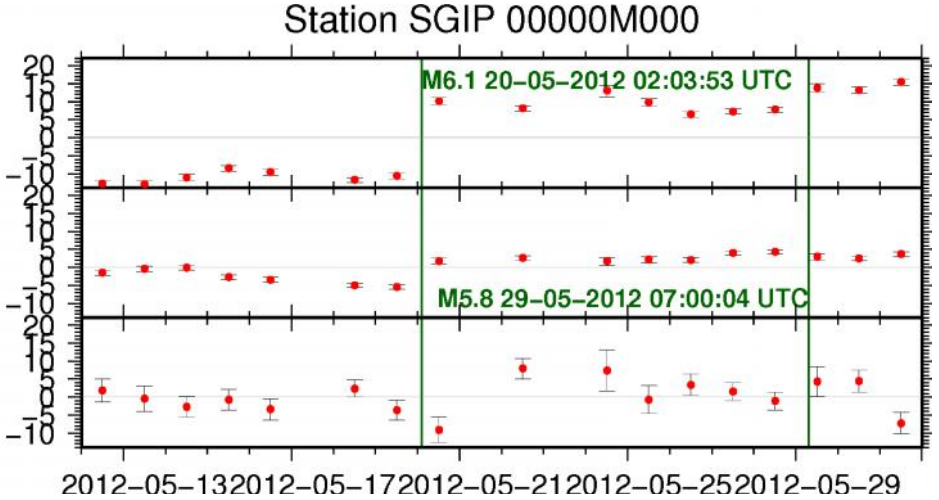


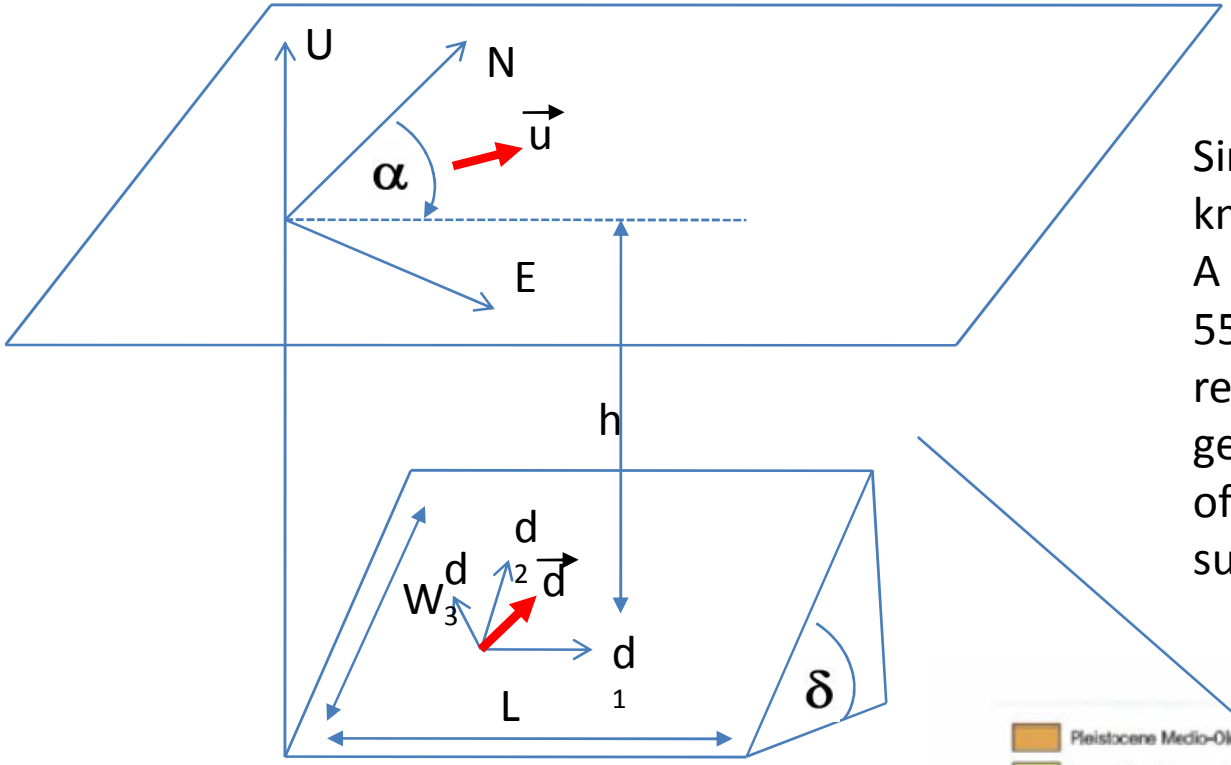
Table of displacements as a function of distance from epicenter of the 20.05.2012 event

Longitudine	Latitudine	Delta Est (m)	Delta Nord (m)	DeltaVerticale (m)	distanza da epicentro	Stazione
11.202	44.655	0.0051	0.0206	-0.0032	29	SGIP
10.940	45.071	0.0011	-0.0018	0.0117	30	SBPO
11.288	45.204	0.0001	-0.004	-0.0013	33	LEGN
10.968	44.649	0.0037	0.0038	-0.0019	36	MODE
11.298	45.278	0.0006	-0.0026	-0.0048	41	BTAC
10.847	45.186	0.0002	-0.0014	0.0009	44	LDNS
11.802	45.107	-0.001	-0.0014	-0.0002	49	ROVI
11.697	45.363	-0.0008	-0.0013	-0.0003	62	TEOL
11.014	45.458	0.0000	-0.0025	-0.0026	64	VR02
11.576	45.584	0.0003	-0.0013	0.0005	80	VICE
12.285	45.226	-0.0013	-0.0006	-0.0057	89	CGIA
11.24	44.91					epicentro

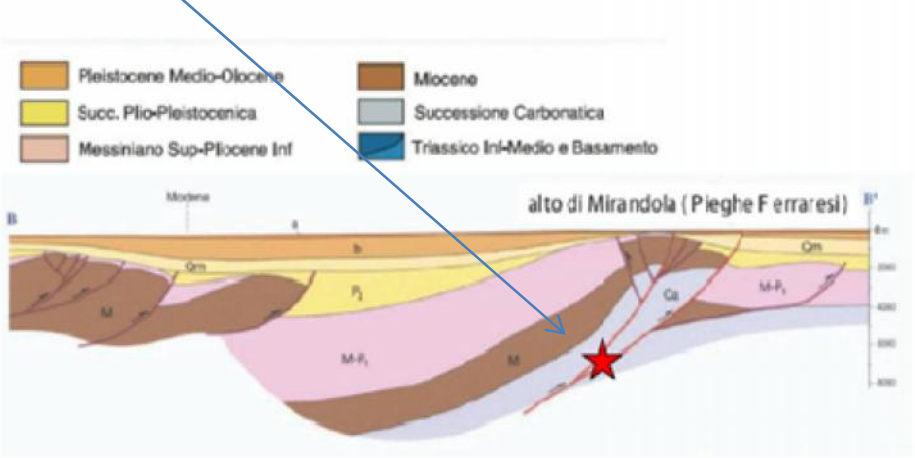
Table of displacements as a function of distance from epicenter of the 29.05.2012 event

Longitudine	Latitudine	Delta Est [m]	Delta Nort [m]	Delta Verticale [m]	Distanza da epicentro (km)	Stazione
11.288	45.204	-0.0008	-0.0024	0.0062	26	LEGN
10.847	45.186	-0.0003	-0.0019	0.0072	30	LDNS
11.298	45.278	-0.0014	-0.002	0.0041	34	BTAC
11.202	44.655	-0.0004	0.0073	-0.0028	39	SGIP
10.968	44.649	0.006	0.0099	0.0054	41	MODE
11.014	45.458	-0.0011	-0.0008	0.0011	52	VR02
11.802	45.107	0.0009	-0.0009	0.004	55	ROVI
11.697	45.363	-0.0005	-0.0011	0.0064	61	TEOL
11.576	45.584	-0.0007	-0.0004	-0.0001	74	VICE
12.285	45.226	0.001	-0.0007	0.0023	95	CGIA
11.12	45.00					epicentro

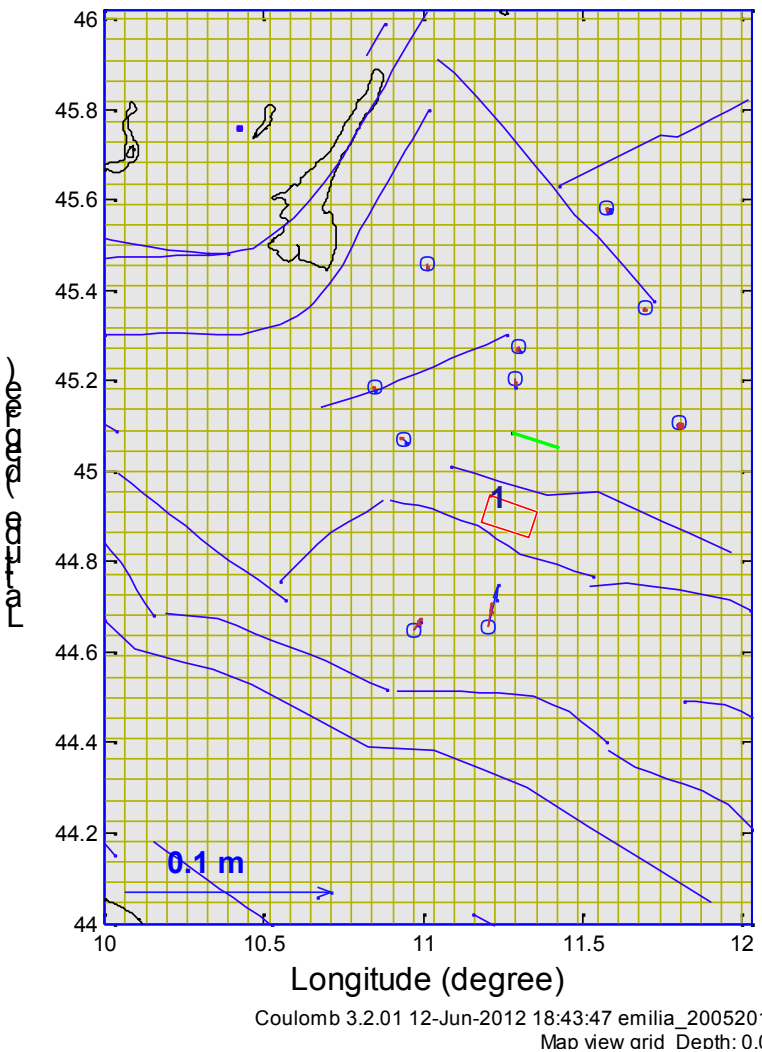
Modeling surface displacement in terms of elastic dislocation at depth



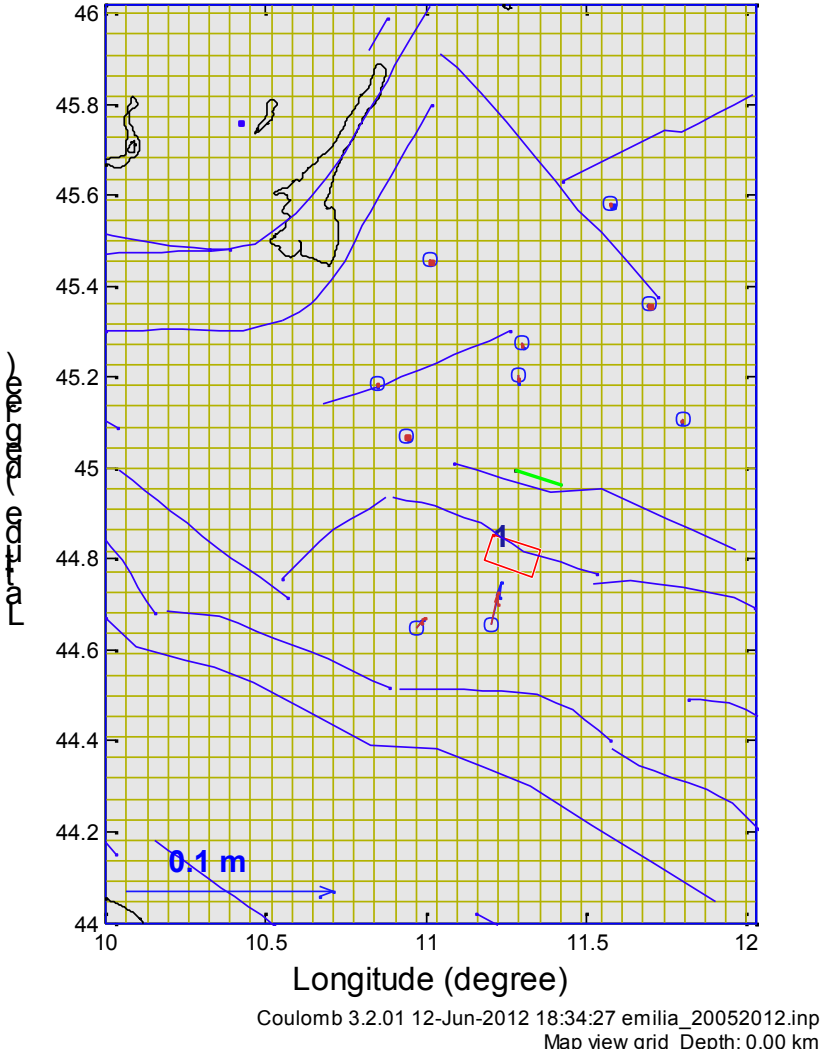
Single rectangular fault 12 x 8 km, ca 8 km deep
A constant dislocation of 50 to 55 cm along the fault plane in reverse direction ('updip') generates the observed pattern of GPS displacements at the surface



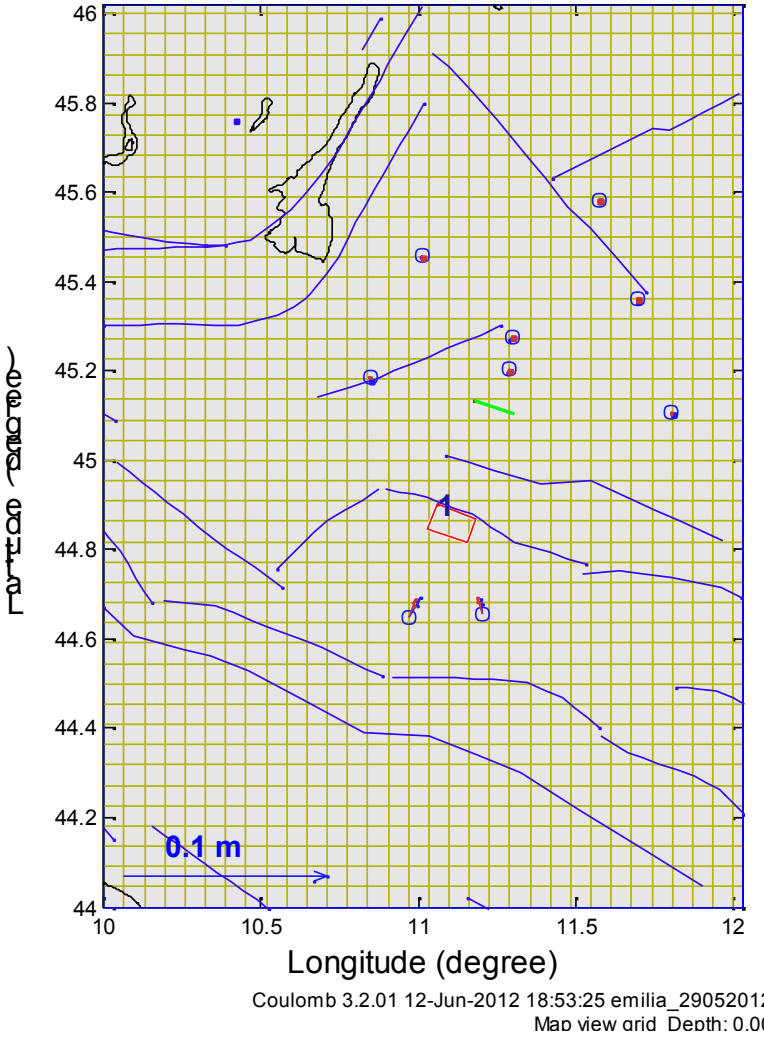
Apriori model from seismology (left); improved model with GPS data (right) : how to make seismology and GPS working together – 20.05.2012 event

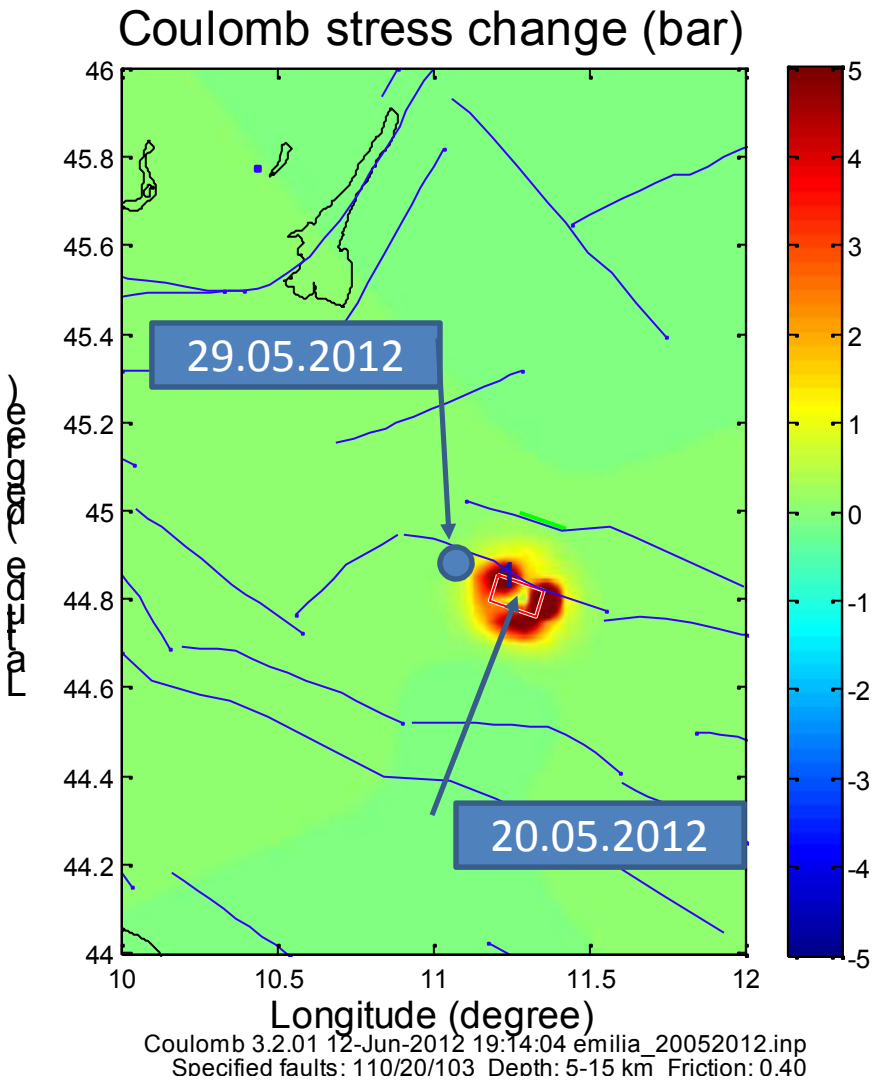


- Fit improves by shifting center latitude 10 km south relative to seismo value
- Other parameters are left constant (too few data and need to keep the seismic moment equal to seismological value!)

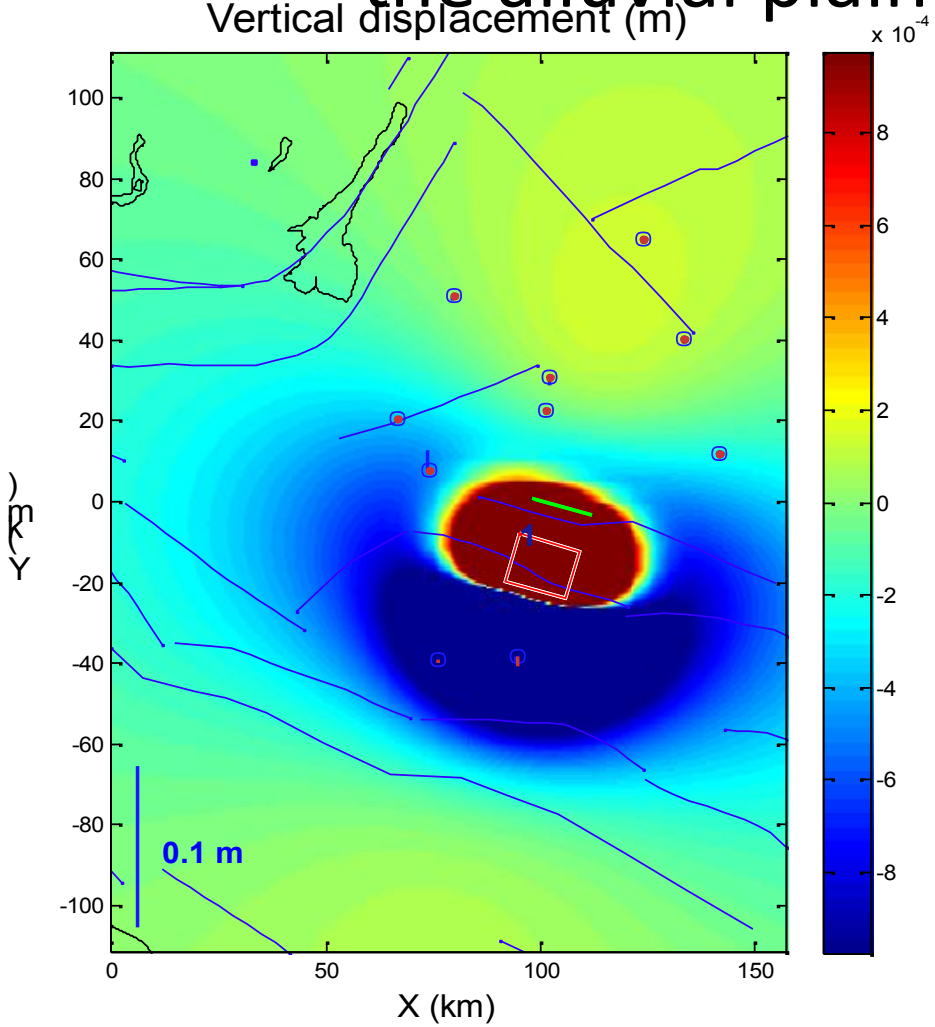


Seismological and GPS data agree well for the 29.05.2012 event- Coulomb stress transfer from the 20.05 to the 29.05 should be not larger than 6 bar (0.6Mpa)





Expected vertical model (to be validated with DInSAR data) agrees with neotectonic studies of the alluvial plain since the iron age



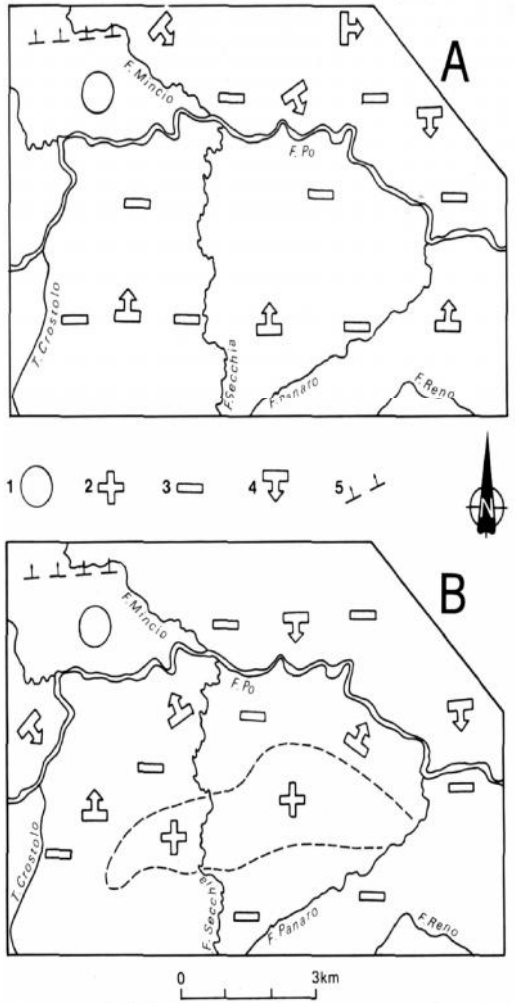


Fig. 26. Example of a final synthetic map for morpho-neotectonic studies in alluvial plains (from PANIZZA et al., in press) A) neotectonic situation around 3000 years B.P.; B) neotectonic situation attributable to the Iron Age, Roman period and Middle Ages; 1) stable area; 2) area undergoing uplift; 3) area undergoing subsidence; 4) differential subsidence (arrow points towards lowest area); 5) axis of deformation held to be active (arrow points towards area undergoing subsidence).

How do the InSAR data fit into the picture?

Interferograms are available only for the 29.05 event

Elongated form, uplift of ca. 12 cm near Medolla

8 Giugno 2012

Secondo report analisi dati SAR e modellazione della sorgente del terremoto dell'Emilia

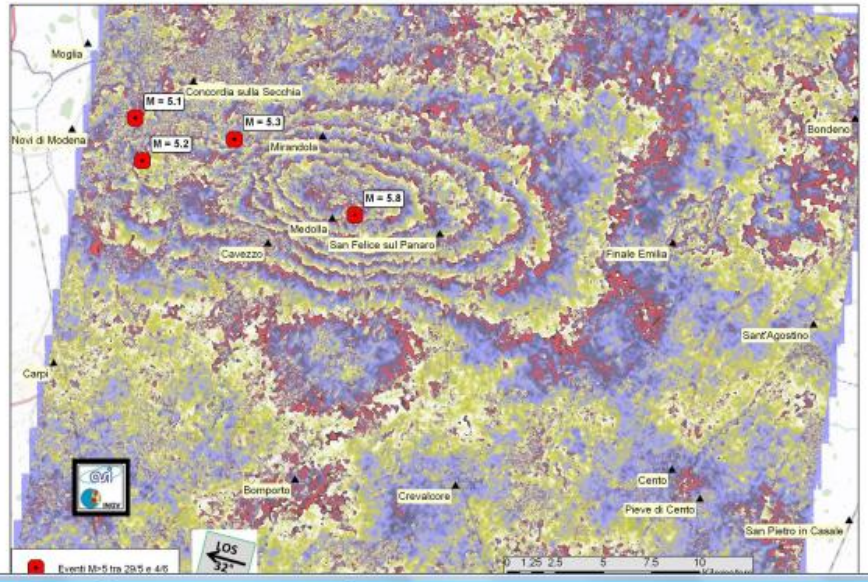
S. Atzori, J. Merryman Boncori, G.Pezzo, C. Tolomei, S.Salvi (si ringrazia Luigi Improta per i suggerimenti sui thrust)

Insieme ad IREA-CNR, dopo l'evento del 29/5 abbiamo proposto a DPC una modifica della pianificazione COSMO, in modo da ottenere una immagine post-evento il più rapidamente possibile. DPC ha chiesto quindi ad ASI di implementare questa pianificazione, con la quale è stata acquisita l'immagine da orbita discendente del 4/6 (ore 19:22 italiane). Il dato è arrivato fisicamente in INGV alle ore 19 del 5/6, ed è stato subito elaborato, accoppiandolo con una immagine del 27/5.

Interferogramma 27/5-4/6

Grazie alla corta baseline temporale (8 gg), l'interferogramma (Figura 1) è molto coerente. La baseline perpendicolare è 420 m e l'angolo di incidenza 32°.

Si contano 7- 8 frange, che indicano un sollevamento (in linea di vista) di circa 12 cm centrato su Medolla, ovvero sull'epicentro dell'evento di Mw 5.8 del 29/5.



Linear inversion and coseismic slip

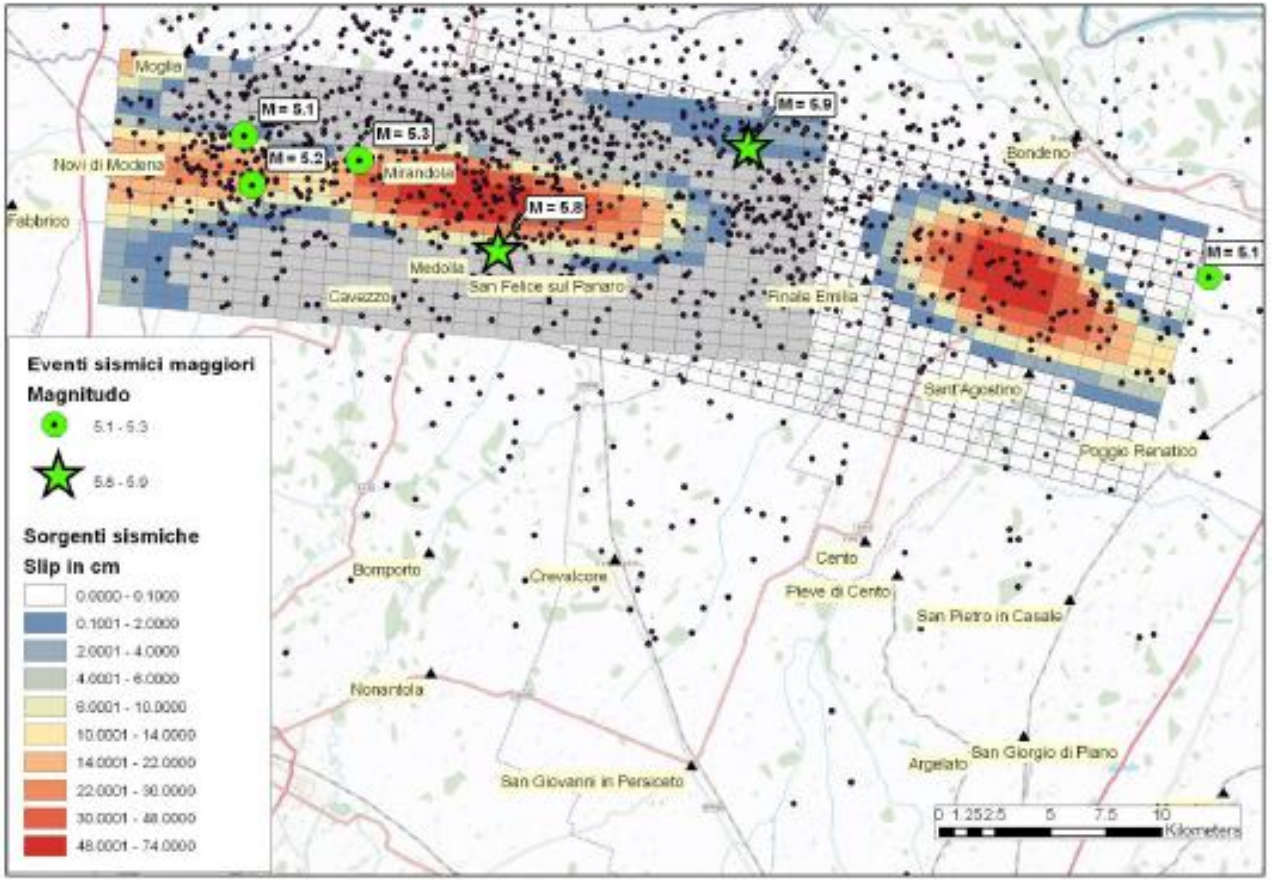


Figura 5 - Modello preliminare delle sorgenti dei principali eventi della sequenza emiliana. Per la sorgente del mainshock manca gran parte della distribuzione di slip (aree trasparenti) in quanto in quelle aree manca il dato SAR COSMO-SkyMed.

Preliminary comparison of SAR to geology, GPS and seismological data

Source model inferred from SAR implies large size, magnitude and surface displacements

Tabella 1

Source	Length	Width	Top depth	Strike	Dip	Rake	Slip max
20/5	35 km	20 km	500 m	105°	50°	85°	>68 cm
29/5	32 km	20 km	1000. m	95°	55°	90°	72 cm

•Size slip and dip are larger than those listed in the DISS for the Mirandola fault

•Seismic moment and magnitudo are also larger than those given by seismological data:

$$Log(M_0) = 1.5 m_w + 9.1$$

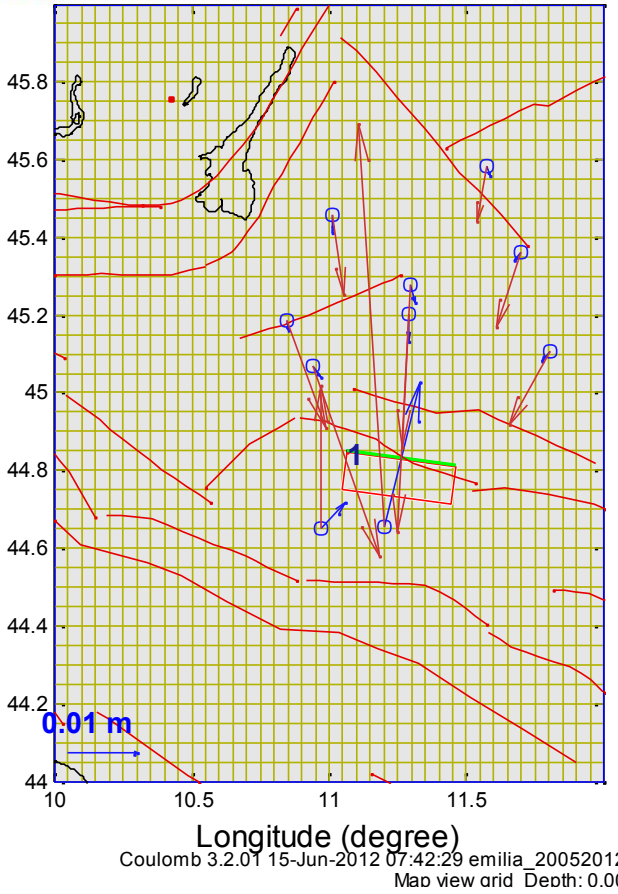
$$\text{SAR}: M_0 = 35000 \times 20000 \times 0.7 \times 30 \bullet 10^9 \, Nwm = 1.47 \bullet 10^{19} \, Nwm$$

$$m_w = 6.7$$

$$Seismo: M_0 = 12000 \times 8000 \times 0.5 \times 30 \bullet 10^9 \, Nwm = 1.44 \bullet 10^{18} \, Nwm$$

$$m_w = 6.0$$

The surface displacements predicted for this large fault area (red arrows) are considerably larger than the GPSmeasured displacements (blue arrows).



Summary table 2012 Emilia sequence (unresolved conflict with SAR!)

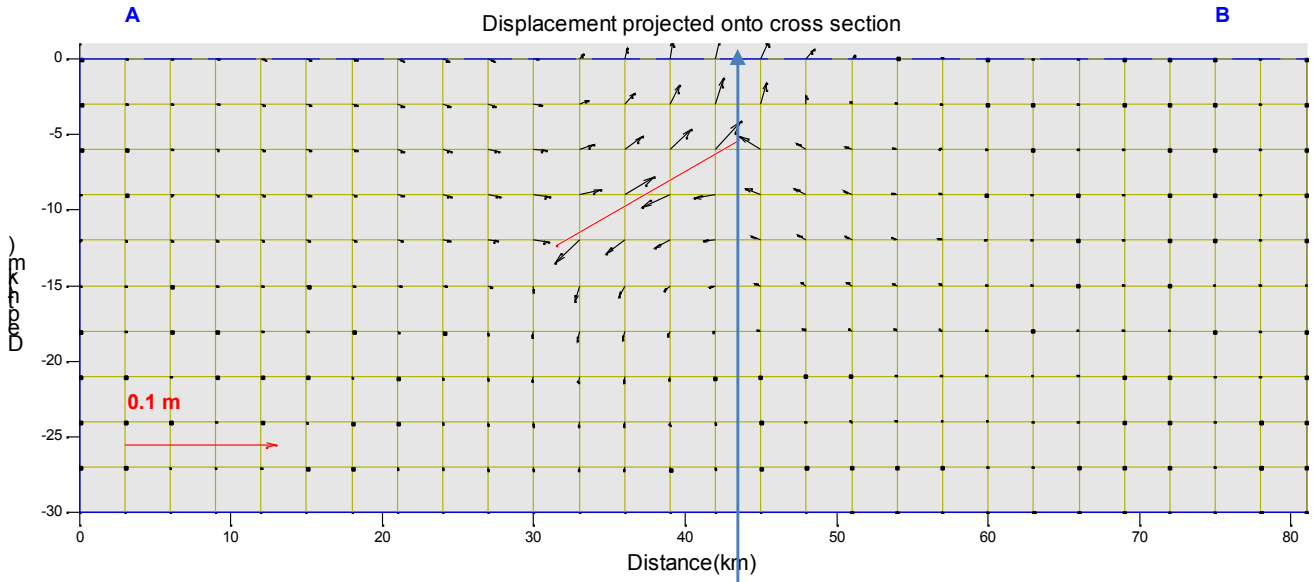
Lat	Lat adj with GPS	Lon	Depth (km)	strike	dip	rake	seismic moment	exponent	date (mmddyy)	Mw
44.9		11.26	13.6	85	32	50	3.37	22	51912	4.3
44.89	44.80+/-.3	11.25	11.4	109	30	99	1.81	25	52012	6.1
44.86		11.15	14.1	103	27	89	4.6	23	52012	5
44.83		11.49	10.0	100	37	64	7.25	23	52012	5.2
44.88		11.38	13.8	231	37	61	0.89	23	52012	4.6
44.85		11.35	10.0	243	37	92	1.93	22	52112	4.1
44.87		11.25	11.9	77	43	63	1.96	22	52312	4.1
44.85		11.09	11.1	110	20	103	1.07	25	52912	6
44.9		10.94	12.0	105	21	94	1.36	23	52912	4.7
44.89		11.01	11.4	112	32	101	2.42	24	52912	5.5
44.9		10.94	10.0	92	16	37	2.68	23	60312	4.9

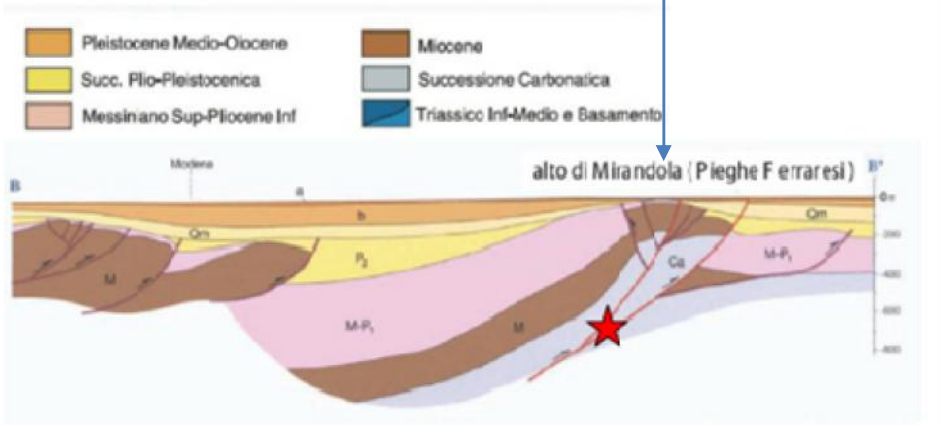
Size of slip area is 12x8 km and slip is ca 0.50 to 0.55 m. updip and 0.09 to 0.12 m right lateral for both the 20 and 29 May 2012 events of M 6.1,6.0 respectively. Excellent agreement with DISS data for the Mirandola fault. Only for the May 20 event the GPS data require a S shift of ca 10 km of the epicenter relative to the seismological value

More refined processing is incompatible with the strength of the data

In conclusion: what happened at depth?

Displacement of ca. 50 cm updip, along a 30 deg south dipping plane LxW 12 x7 km, 11 km depth of the center. On the 29.05 the fault and displacement were very similar.

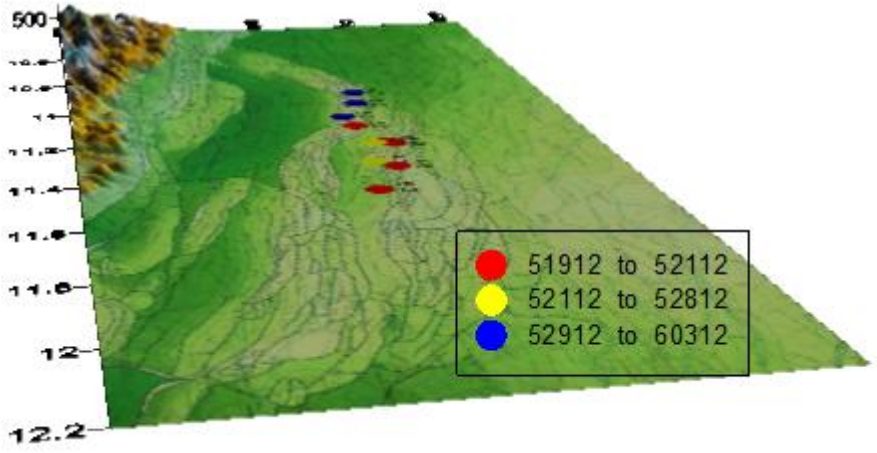


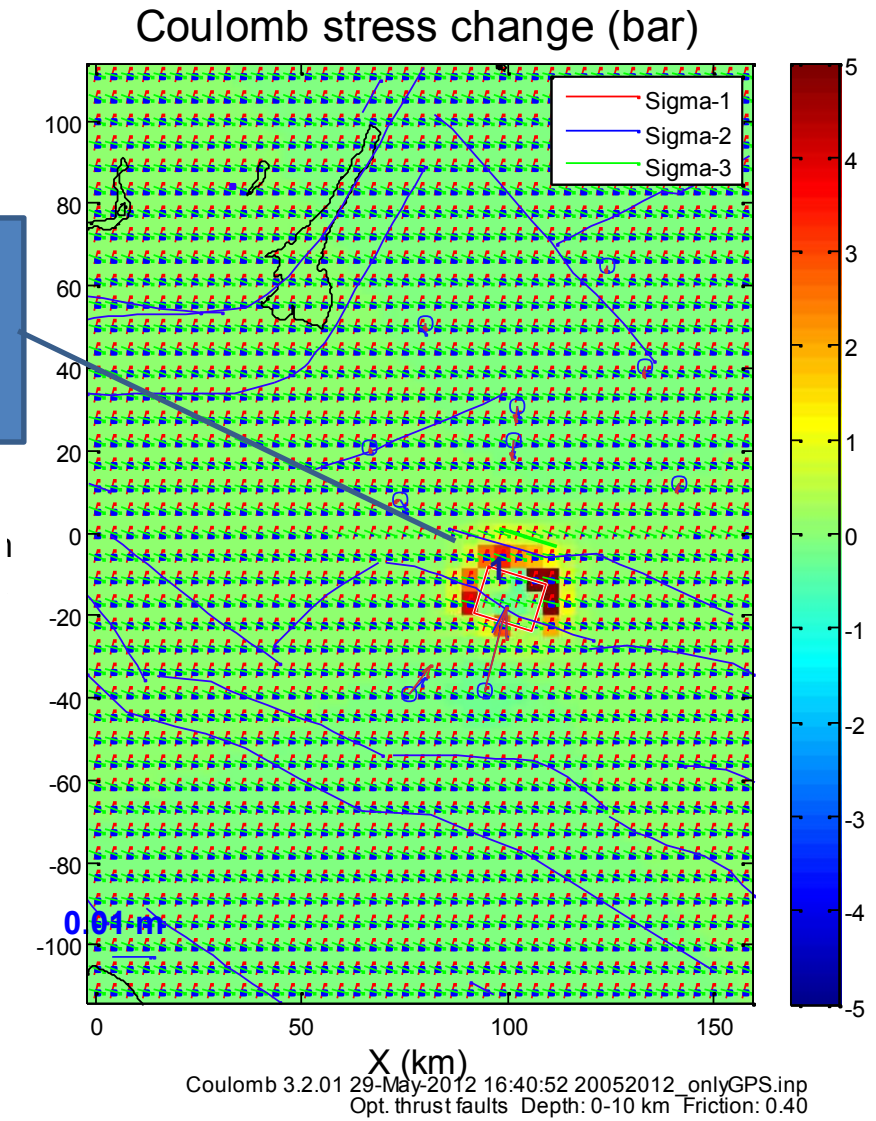


How much stress was transferred to nearby faults?

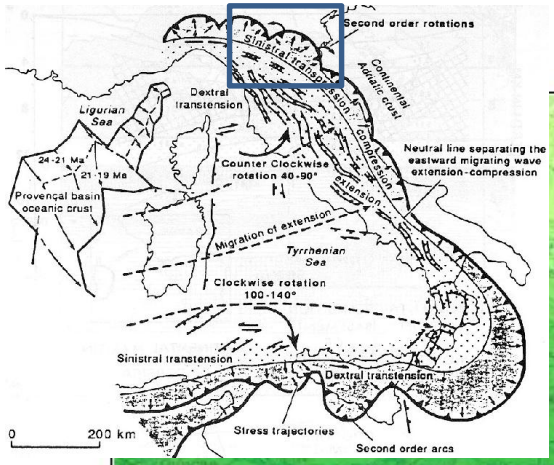
- Depends an assumed friction coefficient (0.4) and the distribution of slip on the fault plane (constant in our model)
- Could be of the order of a few bar (or few 100 kPa) within few tens of km
- Sufficient to trigger the May 29 Mw=5.9 event?
- Could the events of the 20 and 29 jointly transfer to nearby faults sufficient stress to trigger additional events?
- Should we concentrate on reverse faults or consider also sinistral strike slip faults, which do exist in the area?
- Were the faults to the East of the May 20 fault 'unloaded'?

Load added at the fault of the May 29 5.8 event?





Westwards drift of the seismicity



Summary

- Mirandola fault likely candidate: silent for >1000 yrs
- Event in a seismic region, among the highest intensity if not the most intense; large replica 9 days later: 'receiver' fault activated by Coulomb stress transfer?
- Similarity with San Giuliano di Puglia events?
- GPS stations give crucial data within few hours (processing on Sunday!): fault plane solution can be better constrained with GPS data than with seismological data alone.
- Geology, Seismology and GPS agree well.Apparent conflict with SAR data which imply larger faults and slips both for the 20.05 and 29.05 events.
- Daily updates using IGS rapid orbits. Georeferencing coherent with Datum from Class A EPN stations
- Discontinuity observed in EPN station MOPS (Modena). MEDI unreliable. Smaller effects in BOLG.
- Good practice for readiness in case of future events