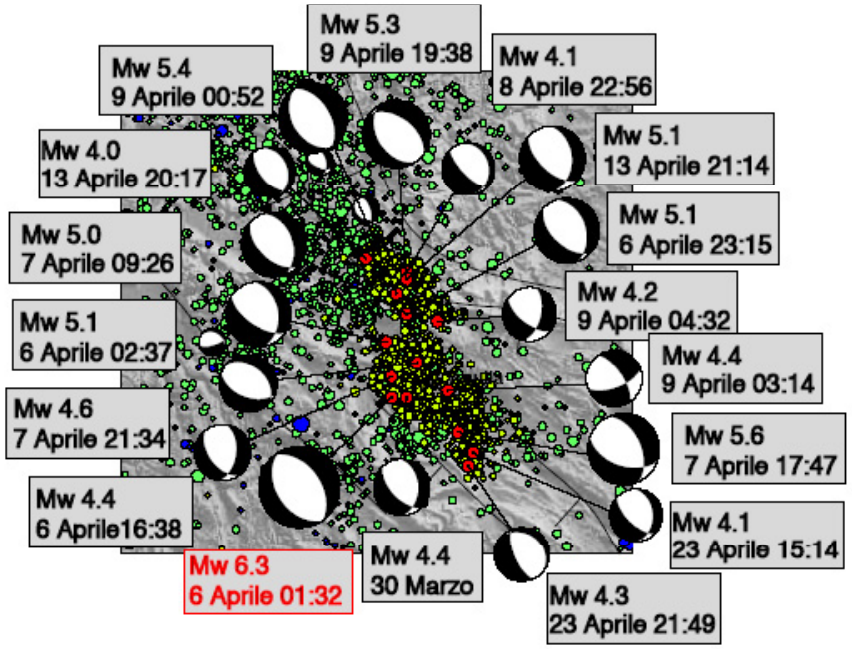
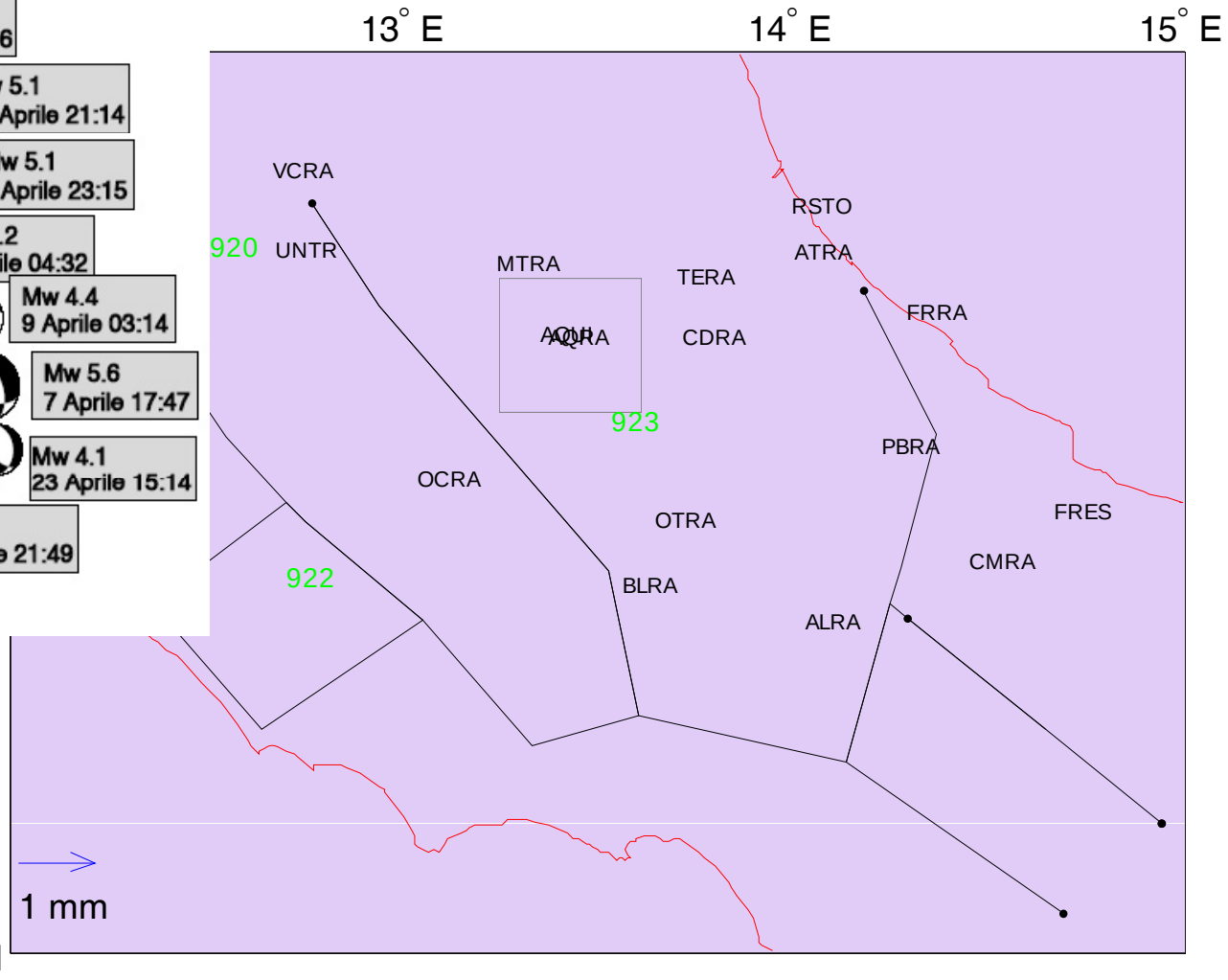
Time series of coordinates of CGPS stations in the area of the Abruzzo earthquakes

Alessandro Caporali

Department of Geosciences,
University of Padova

Sensitivity of CGPS coordinates in a 100x100 km area to seismicity in the Mw 4.4-6.2 range and in a 30x30 km area?

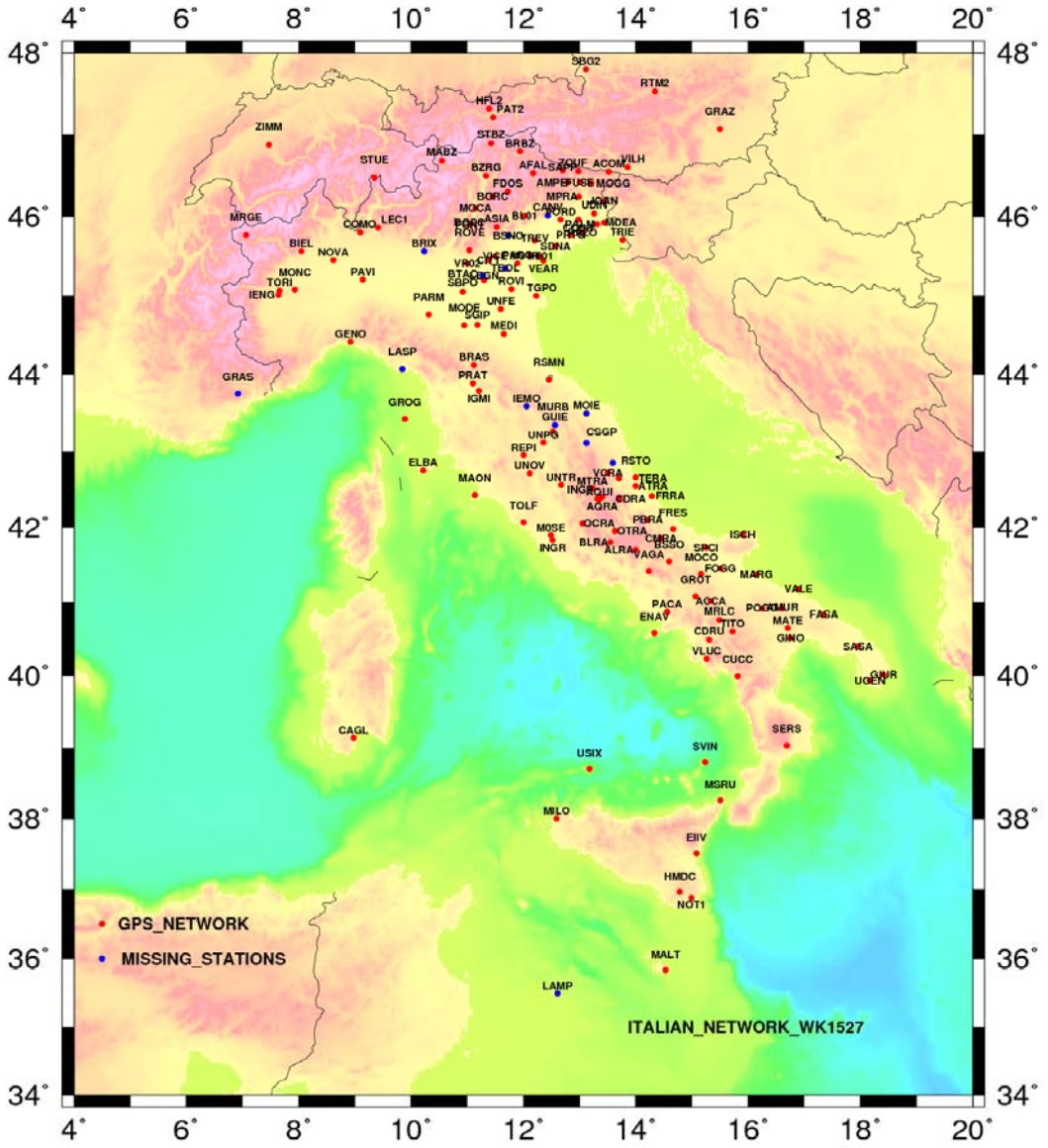




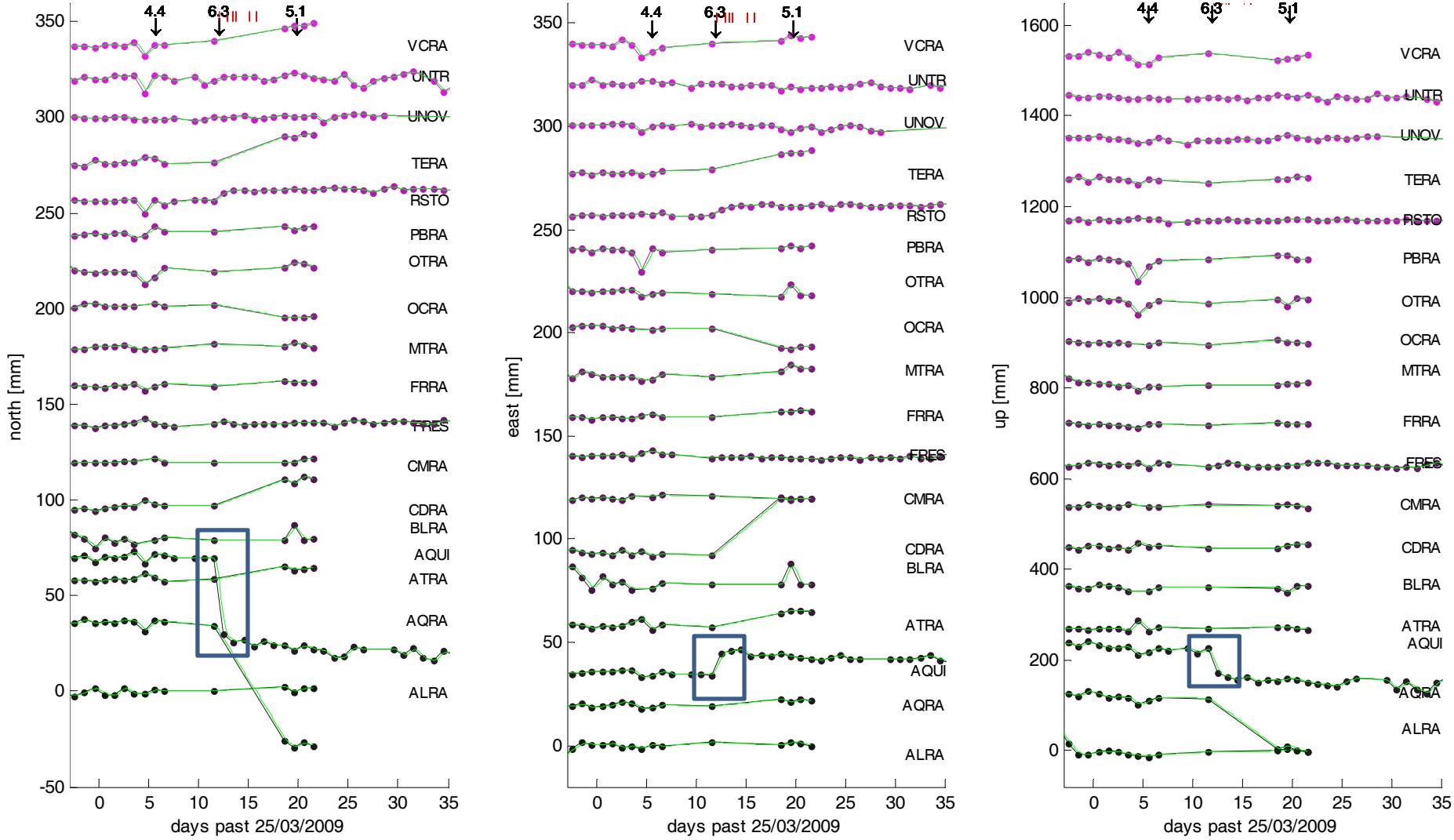
Available:
-RING stations
-ASI station AQUI (EPN/IGS)
-Regione Abruzzo stations
-Regione Umbria stations

Analysis of CGPS data at Padova

- UPA-LAC: Analysis Center of EUREF
- Routine analysis of ca 130 CGPS stations in Italy done with Bernese 5.0 and IGS/EUREF standards (Precise Orbits, EOP's, Ocean tides, absolute antenna models)
- Rigorous Network solutions , no PPP
- Stacking of daily and 6 hrs solutions
- Homogenous constraints (ITRF2005)

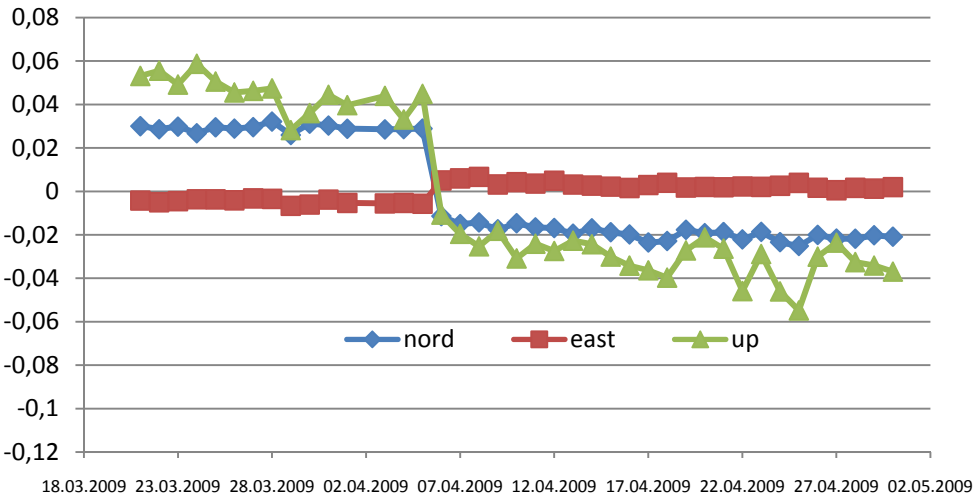


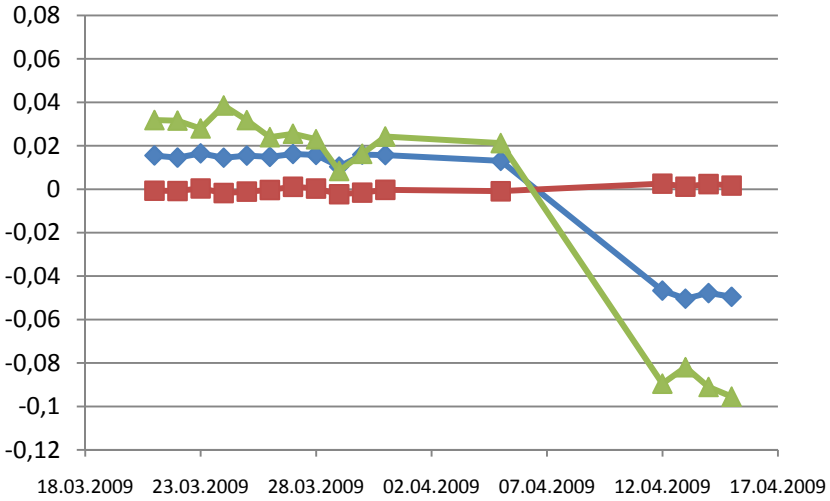
Part 1: daily solutions
2009-03-21:2009-05-02



AQUI

AQRA





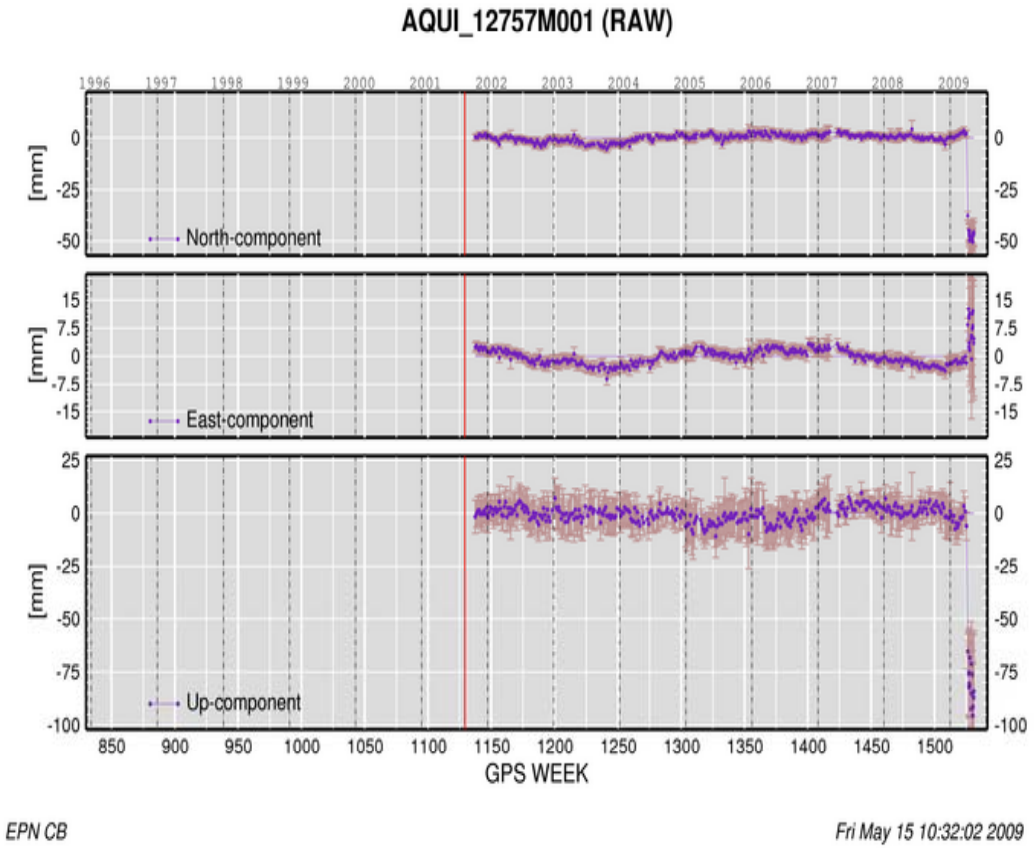
Mean displacement (difference of average post – pre):

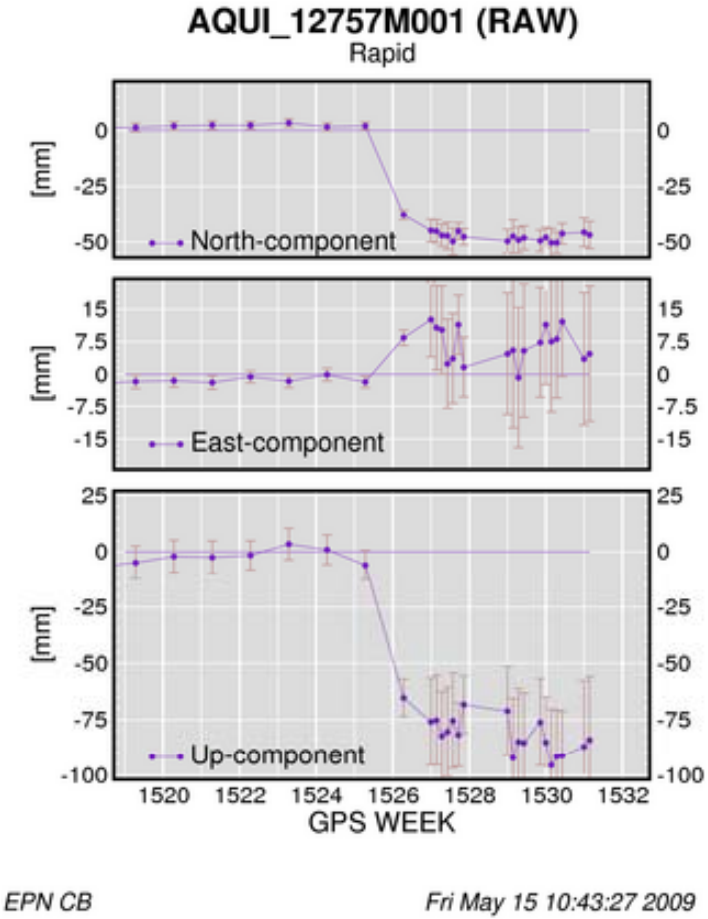
- North : -48.3 mm
- East :+ 7.6 mm
- Up : -75.2 mm (not stabilized yet!)

- North : -63.5 mm
- East :+ 2.6 mm
- Up : -115.0 mm

Difference in height change is ca. 4 cm
in a few km: SAR calibration?

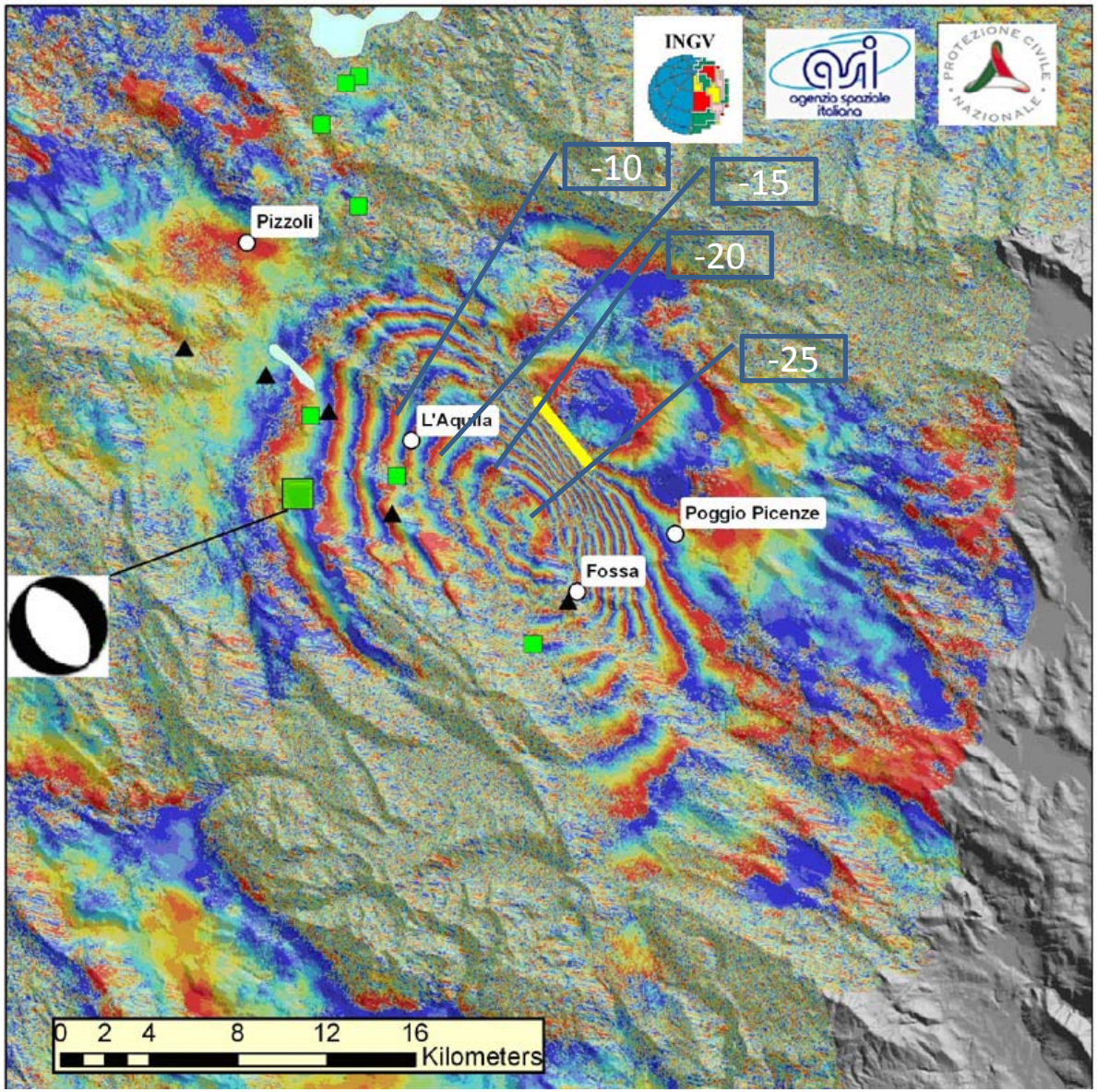
EPN CB solution





Comparison with DInSAR

- Inteferogram obtained by comparison of Envisat images for the days Feb 01 and Apr 12 2009
- Contour interval 2.5 cm
- Max vertical displacement 25 cm between Aquila and Fossa
- Displacement estimated by GPS corresponds to 75/25 = 3 contours (fringes), which seems somewhat short relative to SAR
- Unknown structural effects (building stability)

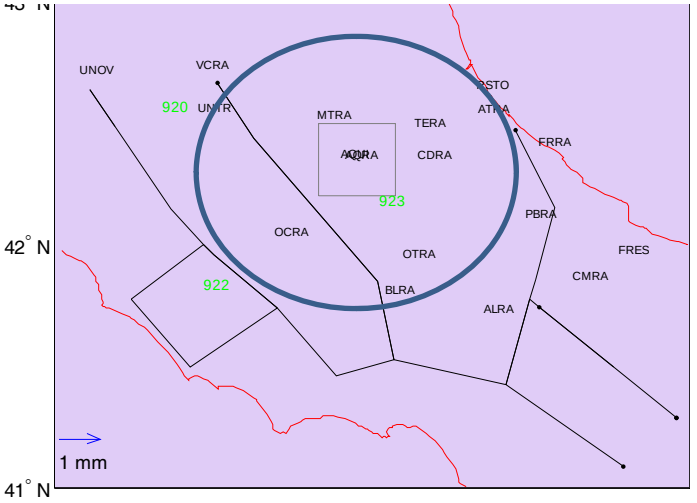


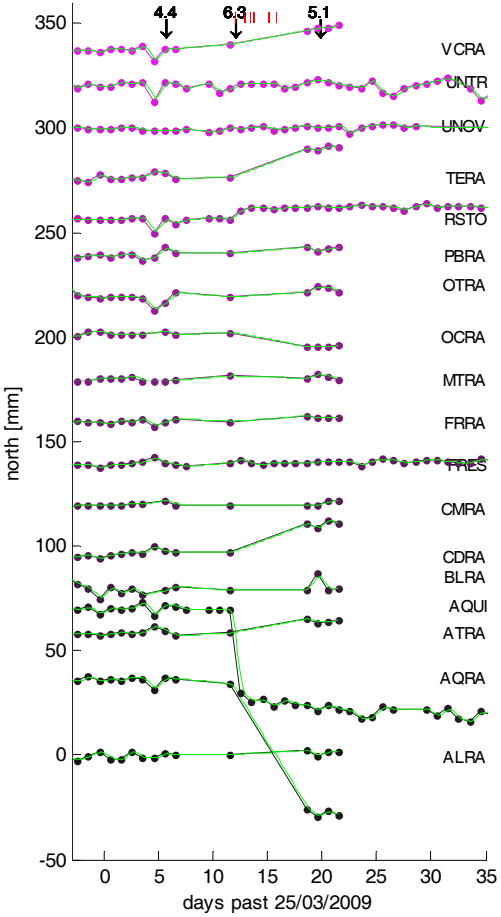
Conclusions (from strictly geodetic network standpoint)

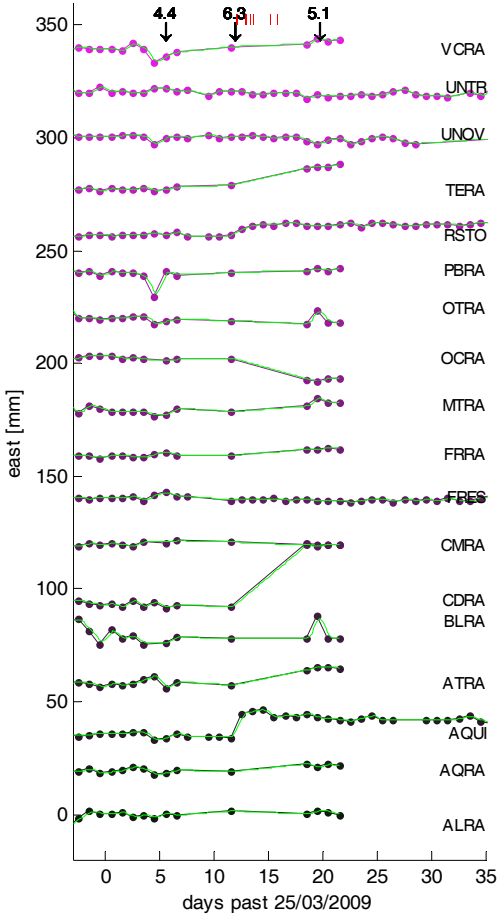
- Earthquake generated permanent offsets in the coordinates of EPN station AQUI
- Values are < 10 cm
- Consistency with nearby site AQRA
- Agreement with EPN rapid product based on CATREF
- InSAR seems to give vertical displacements between 10 and 15 cm at AQUI
- Data from other permanent sites in the region suggest that creep deformation is currently affecting the entire area
- Bottom line: new soln needed for AQUI past April 6, 2009!

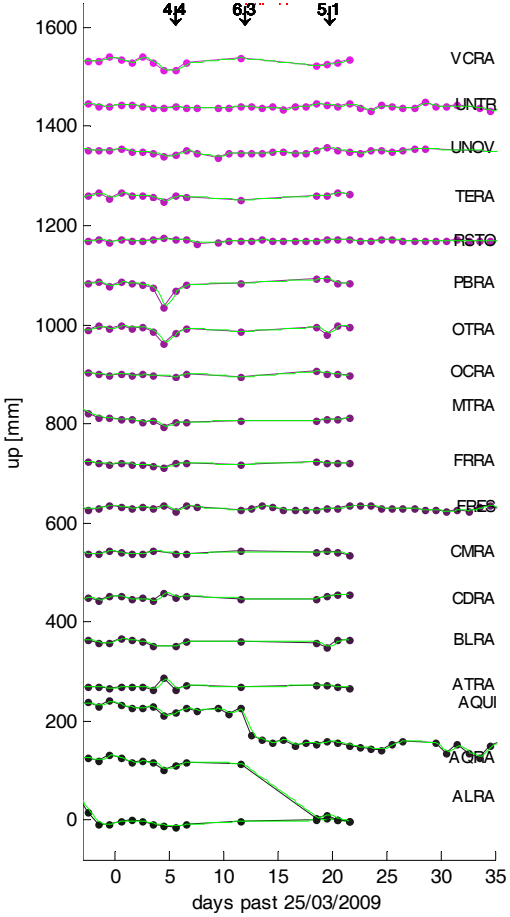
Some issues on horizontal deformation

1. Post seismic effects visible at several stations (VCRA, TERA, OCRA, CDRA, ATRA, besides AQRA, AQUI)
2. Coordinate changes on March 29 predate the Mw=4.4 March 30 event
3. Several Mw>5 events past the April 6 (red lines) show no appreciable effect, except the April 13, Mw=5.1







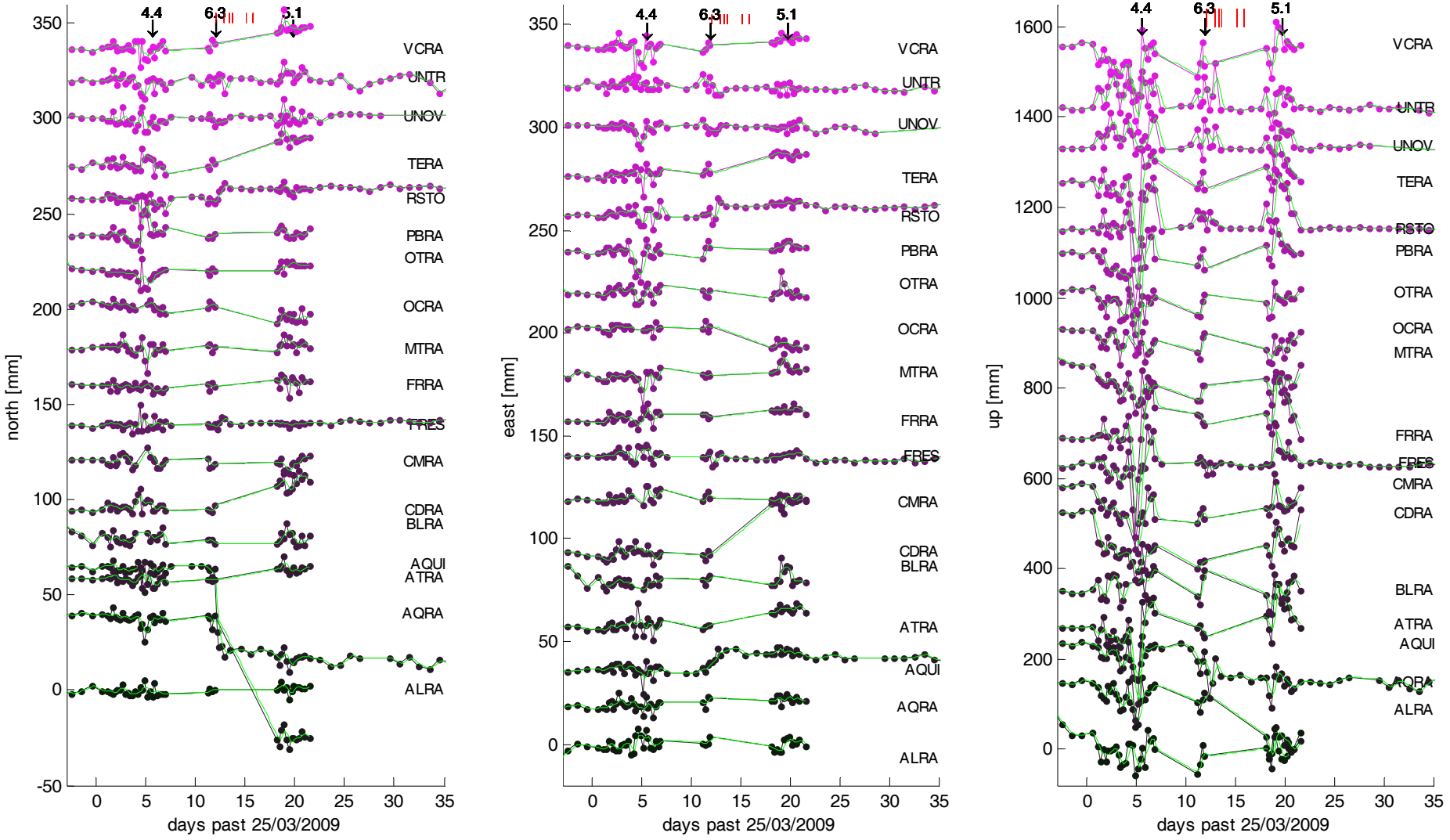


Part 2: solutions @ 6 hrs

- 26 - 31 March: includes M4.4 event of March 30
- 5 - 6 April: includes M=6.3 event of April 6.
- 12 - 14 April: includes M=5.1 event of April 13

- 6 hrs NEQ's locally densify the daily NEQ's → this makes it possible to compare visually the stability of the 6 hr solutions vs the daily solutions (question: how noisier are the 6 hrs relative to the daily solutions?)

Displacements at 18 stations correlated with the Mw=4.4 event of March 30, Mw=6.3 event of April 6 and Mw=5.1 event of April 13; green line: 18 hrs moving average



Convert displacements into strain changes (horizontal)

- Theory: (Caporali, GJI 2003)
  - Covariance function with scale d_0=50 km
  - LP filtering by least squares collocation of the velocities

$$\begin{bmatrix} v_n \\ v_e \end{bmatrix}_P = \sum_s C(d_{P,s}) \sum_{s'} \left[C(d_{s,s'}) + W_{ss'} \right]^{-1} \cdot \begin{bmatrix} v_n \\ v_e \end{bmatrix}_{s'} \qquad s, s' = station \quad indeces$$

$$\begin{bmatrix} \sigma^2{}_n \\ \sigma^2{}_e \end{bmatrix}_P = I\sigma^2 - \sum_s C(d_{P,s}) \sum_{s'} \left[C(d_{s,s'}) + W_{ss'} \right]^{-1} C^T(d_{P,s'}) \cdot \begin{bmatrix} \sigma^2{}_n \\ \sigma^2{}_e \end{bmatrix}_{s'}$$

$$W_{ss'} = \frac{\frac{1}{\sigma^2{}_s}}{\sum_{s''} \frac{1}{\sigma^2{}_{s''}}} \delta_{ss'} \qquad C(d) = \frac{1}{1 + \left(\frac{d}{d_0} \right)^2}$$

  - Differentiation and eigenvalues

$$\begin{bmatrix} v_{n,n} & v_{n,e} \\ v_{e,n} & v_{e,e} \end{bmatrix}_P = \sum_s \begin{bmatrix} \frac{\partial C}{\partial n} & \frac{\partial C}{\partial e} \\ \frac{\partial C}{\partial n} & \frac{\partial C}{\partial e} \end{bmatrix}_{P,s} \sum_{s'} \left[C(d_{s,s'}) + W_{ss'} \right]^{-1} \cdot \begin{bmatrix} v_n \\ v_e \end{bmatrix}_{s'} \qquad s, s' = station \quad indeces$$

$$\dot{\varepsilon}_1 = \frac{v_{n,n} + v_{e,e}}{2} + \sqrt{\left(\frac{v_{e,e} - v_{n,n}}{2} \right)^2 + \left(\frac{v_{e,n} + v_{n,e}}{2} \right)^2}$$

$$\dot{\varepsilon}_2 = \frac{v_{n,n} + v_{e,e}}{2} - \sqrt{\left(\frac{v_{e,e} - v_{n,n}}{2} \right)^2 + \left(\frac{v_{e,n} + v_{n,e}}{2} \right)^2}$$

$$\sin 2\theta = \frac{v_{e,n} + v_{n,e}}{\dot{\varepsilon}_2 - \dot{\varepsilon}_1}; \cos 2\theta = \frac{v_{e,e} - v_{n,n}}{\dot{\varepsilon}_1 - \dot{\varepsilon}_2}$$

Noise and uncertainties

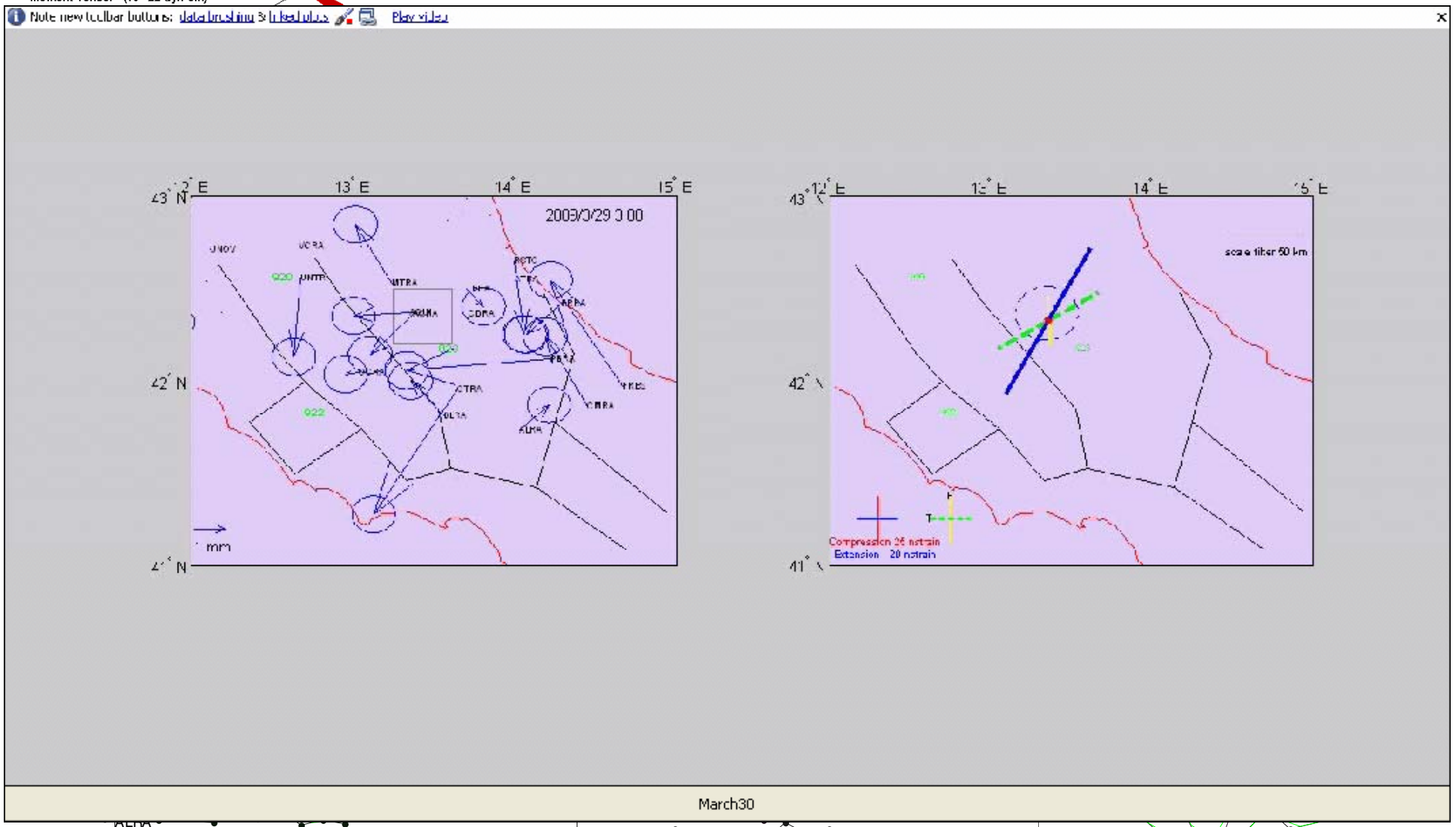
- Noise in repeated coordinate estimates: smooth by moving average over 3 epoch (18 hrs)
- Correlation function with scale d_0=50 km
- Individual random uncertainty in coordinate estimate: 0.5 mm → strain threshold set to 0.5mm*$2^{1/2}$/50km= 14 nstrain
- Smoothing term W=5 (forces the collocated velocity not to coincide with the raw value at each observation point)

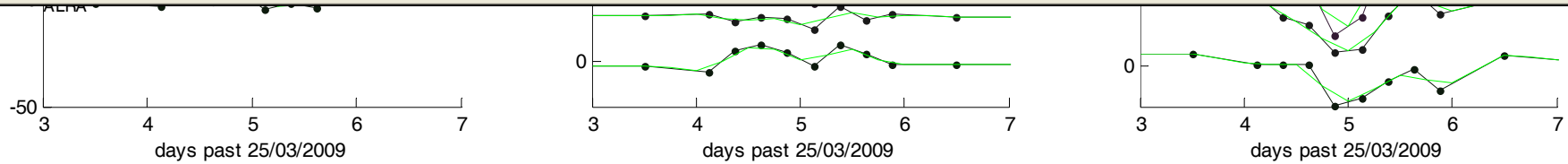
Date 03/30/09 Region CENTRAL ITALY MI 4.0 Mw 4.4
Centroid Location:
Or. Time13:38:42.7 Lat. 42.33 N Long. 13.36 E Dep 14.

Best Double Couple M0: 4.9*10**22
P1 str: 358 dip: 40 slip: -56
P2 137 58 -115 033009A

Moment Tensor (10**22 dyn-cm)

March 30 13:38 Mw=4.4





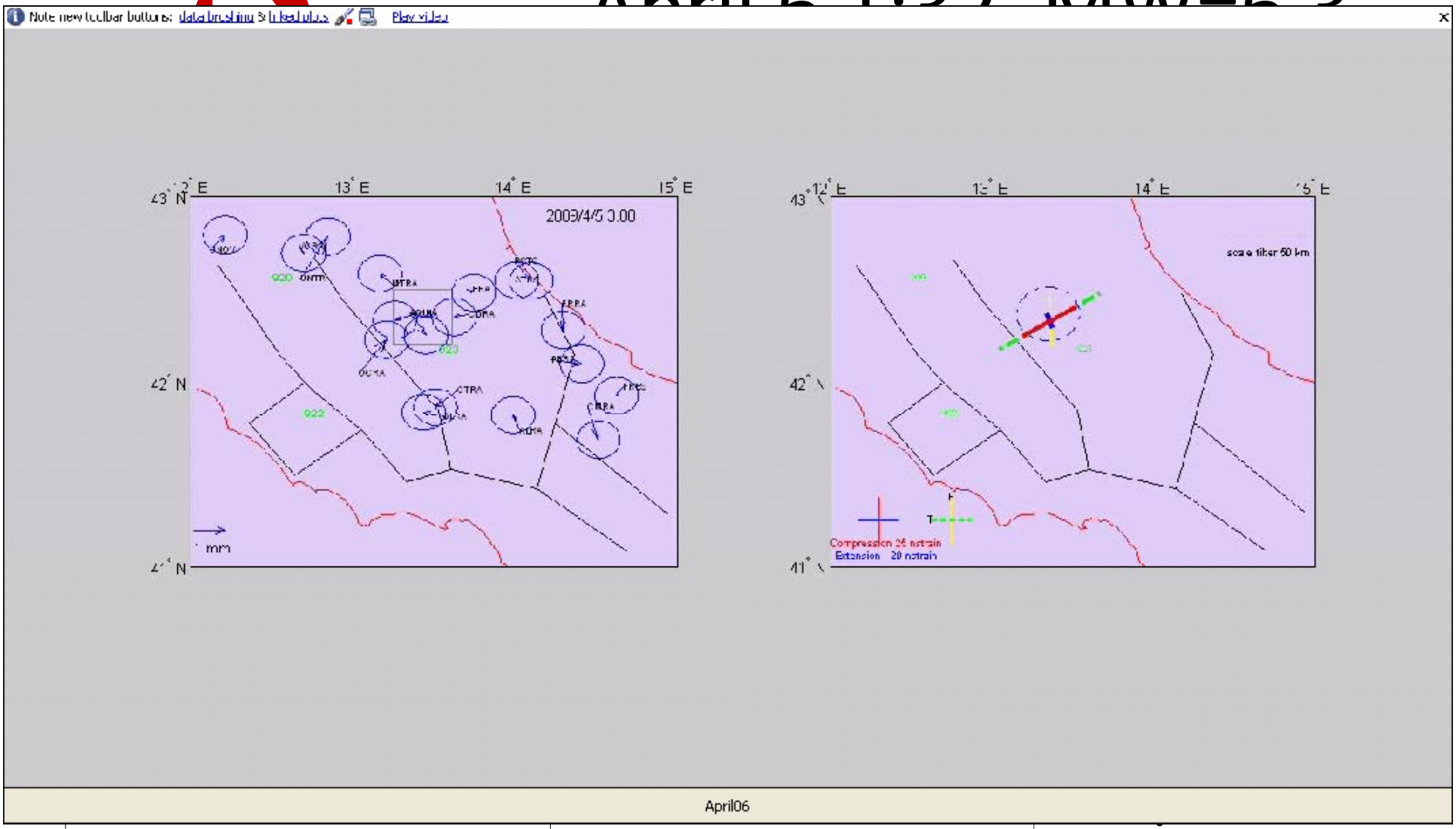
Date 04/06/09 Region CENTRAL ITALY MI 6.2 Mw 6.3
Centroid Location:
Or. Time 1:32:47.2 Lat. 42.32 N Long. 13.32 E Dep 12. fixed

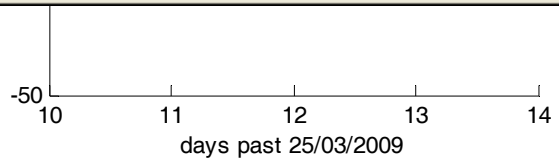
Best Double Couple M0: 3.7*10**25
P1 str: 147 dip: 43 slip: -88
P2 324 47 -92

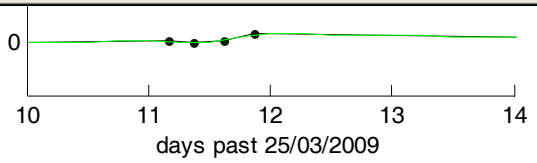
Moment Tensor (10**25 dyn-cm)
mrr: -3.75 mtt: 1.22 mpf: 2.53
mrt: 0.23 mrf: -0.16 mtf: -1.71

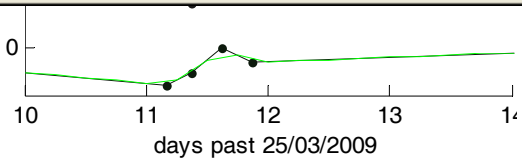
040609A

April 6 1:32 MW=6.3





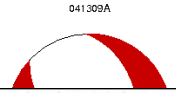




Date 04/13/09 Region CENTRAL ITALY MI 4.9 Mw 5.1
Centroid Location:
Or. Time21:14:29.6 Lat. 42.24 N Long. 13.25 E Dep 16.

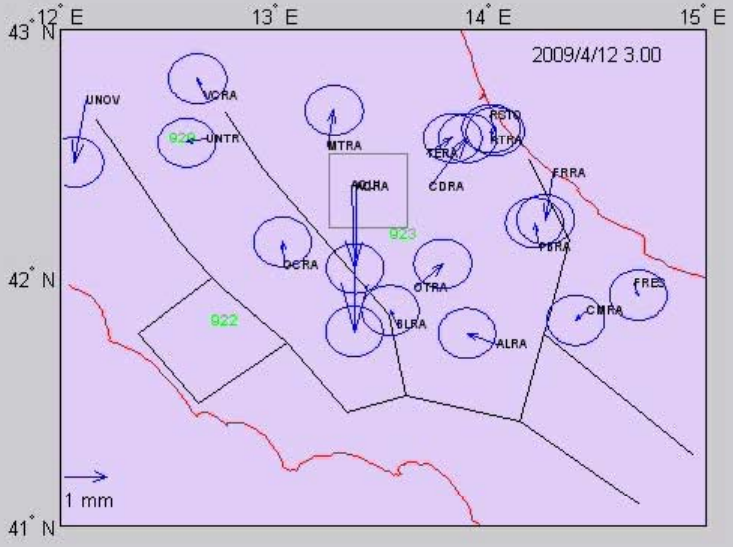
Best Double Couple M0: 5.7*10**23
P1 str: 357 dip: 40 slip: -54
P2 133 59 -116

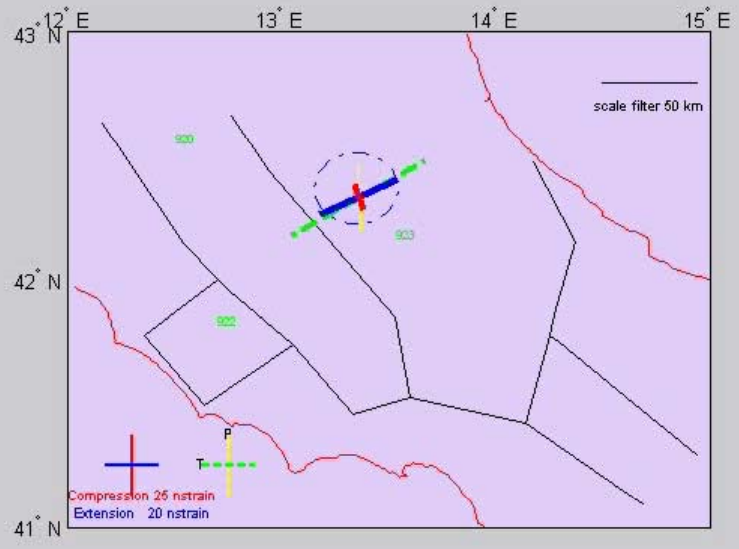
Moment Tensor (10**23 dyn-cm)
mrr: -5.11 mtt: 1.08 mff: 4.03
mrt: -3.52 mrf: 0.17 mtf: -1.25

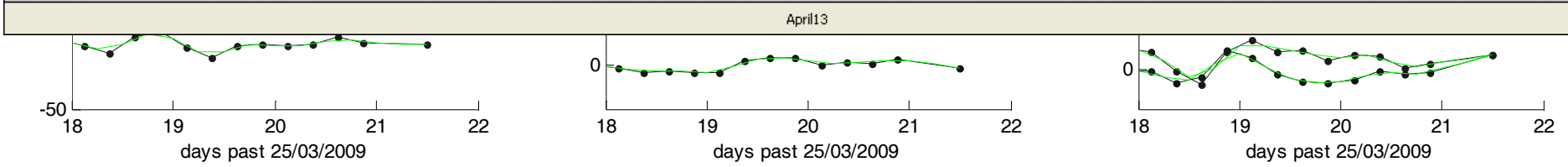


April 13 21:14, Mw=5.1

Note new toolbar buttons: data brushing & linked plots Play video







Preliminary conclusions

•Millimetric scale displacements are correlated over a wide area before, at and after the event of April 6

•Diplacements and deformation may set on ca 1 day before the event;

•Deformation style agrees with CMT in orientation.

•Geodetic approach: enables the energy exchanges to be estimated and correlated with the mechanical work required to shift the hanging wall relative to the foot wall (seismic moment); need to filter random noise by correlation

•Vertical still under evaluation, but in progress – Do we understand InSAR calibration? (I am not sure about myself…)