

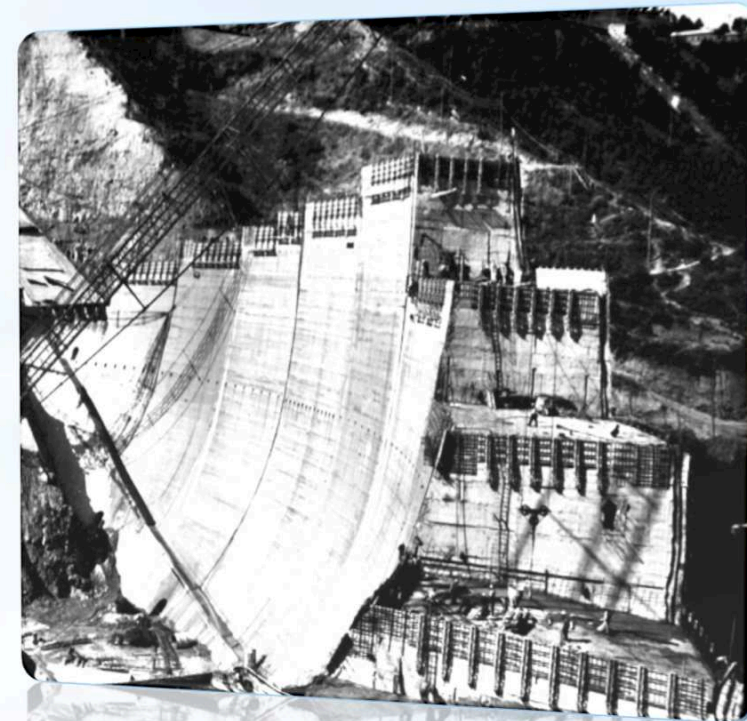


Geoitalia 2013

LE GEOSCIENZE PER LA SOCIETÀ

IX Forum Italiano di Scienze della Terra
Pisa, 16-18 settembre 2013

Relationship between seismicity and water level of the Pertusillo reservoir (Southern Italy)



T. A. Stabile¹, A. Giocoli^{1,2}, V. Lapenna¹, A. Perrone¹, S. Piscitelli¹, L. Telesca¹

¹ Istituto di Metodologie per l'Analisi Ambientale, CNR-IMAA, Tito (PZ), Italy

² Now at: Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Centro Ricerche Casaccia (RM), Italy

Reservoir-induced seismicity (RIS): a brief overview

Bell and Nur (1978):

the mechanisms associated with RIS can be subdivided into (1) the instantaneous undrained elastic response to the reservoir load, and (2) the diffusion of pore pressures from the reservoir that decreases the effective strength of the rocks around the reservoir.

Simpson et al. (1988):

Rapid response for (1) and a delayed response for (2)

Roeloffs (1988); Talwani (1997):

The oscillation of reservoir load can also affect the fault stability change, which is dependent on (a) the location of the reservoir with respect to the faults, (b) the fault orientation, and (c) the stress field

Gupta (2002):

The most common observations of RIS are generally associated with the initial impoundment of the lake or the lake level increase above a previous maximum level. After these events, the seismicity drops to the pre-event level.

Protracted (Talwani, 1997) or continued (Gupta, 2002) RIS:

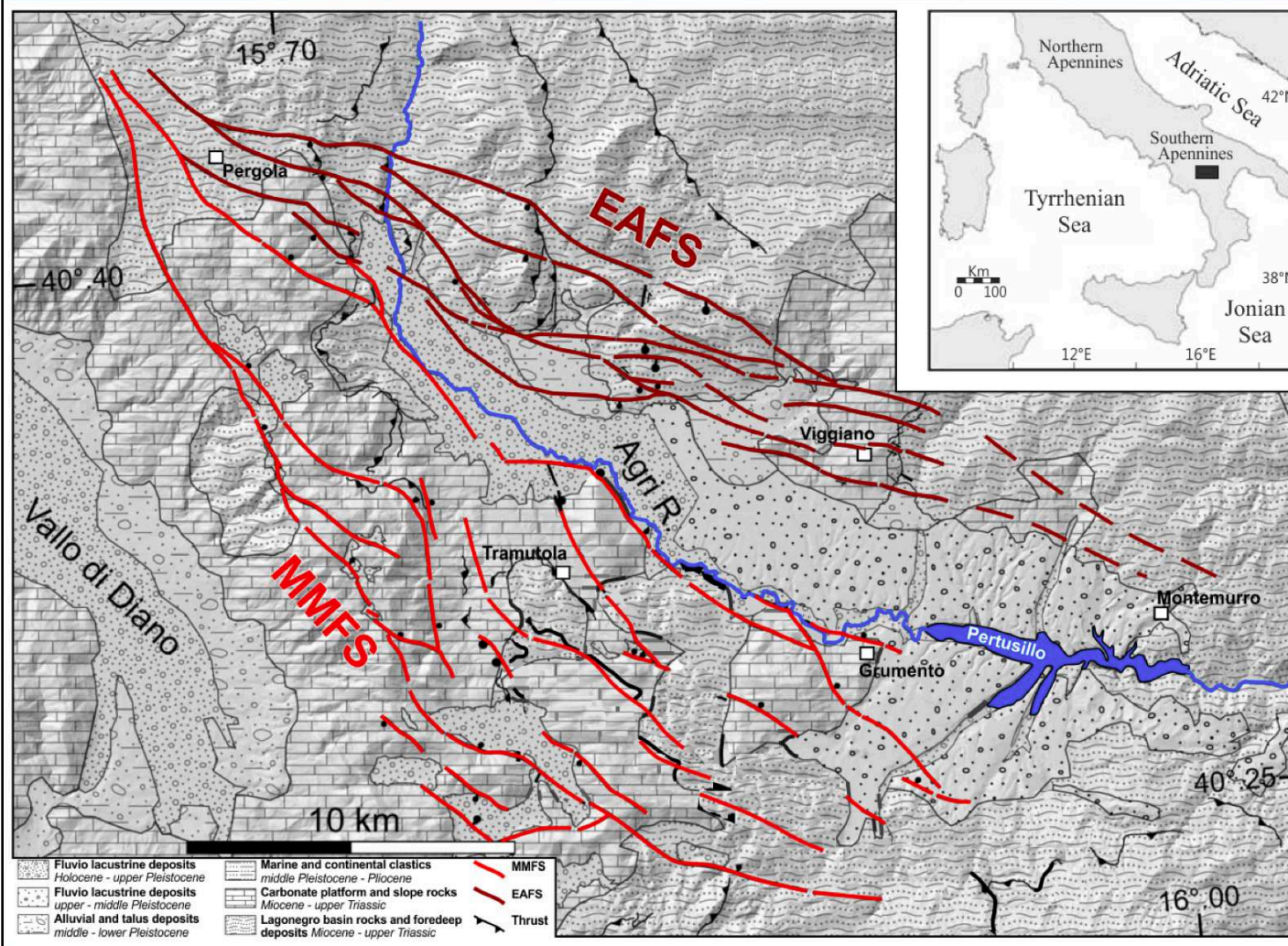
There are reservoir sites, such as Lake Mead (Carder, 1945), Koyna-Warna (Gupta and Combs, 1976), or Nurek Dam (Simpson and Negmatullaev, 1981), that exhibit RIS year after year at a given site or in some places after a gap of few years.

New case of continued RIS → Seismicity nearby the Partusillo reservoir (Sothern Italy)

Geological setting

The High Agri Valley (HAV) is a NW-SE trending intermontane basin formed during the Quaternary age along the axial zone of the Southern Apennines thrust belt chain. This basin is about 30 km long and 12 km wide.

The most destructive historical earthquake was the M 7.0, 1857 Basilicata earthquake (Branno et al., 1985; Burrato and Valensise, 2008).

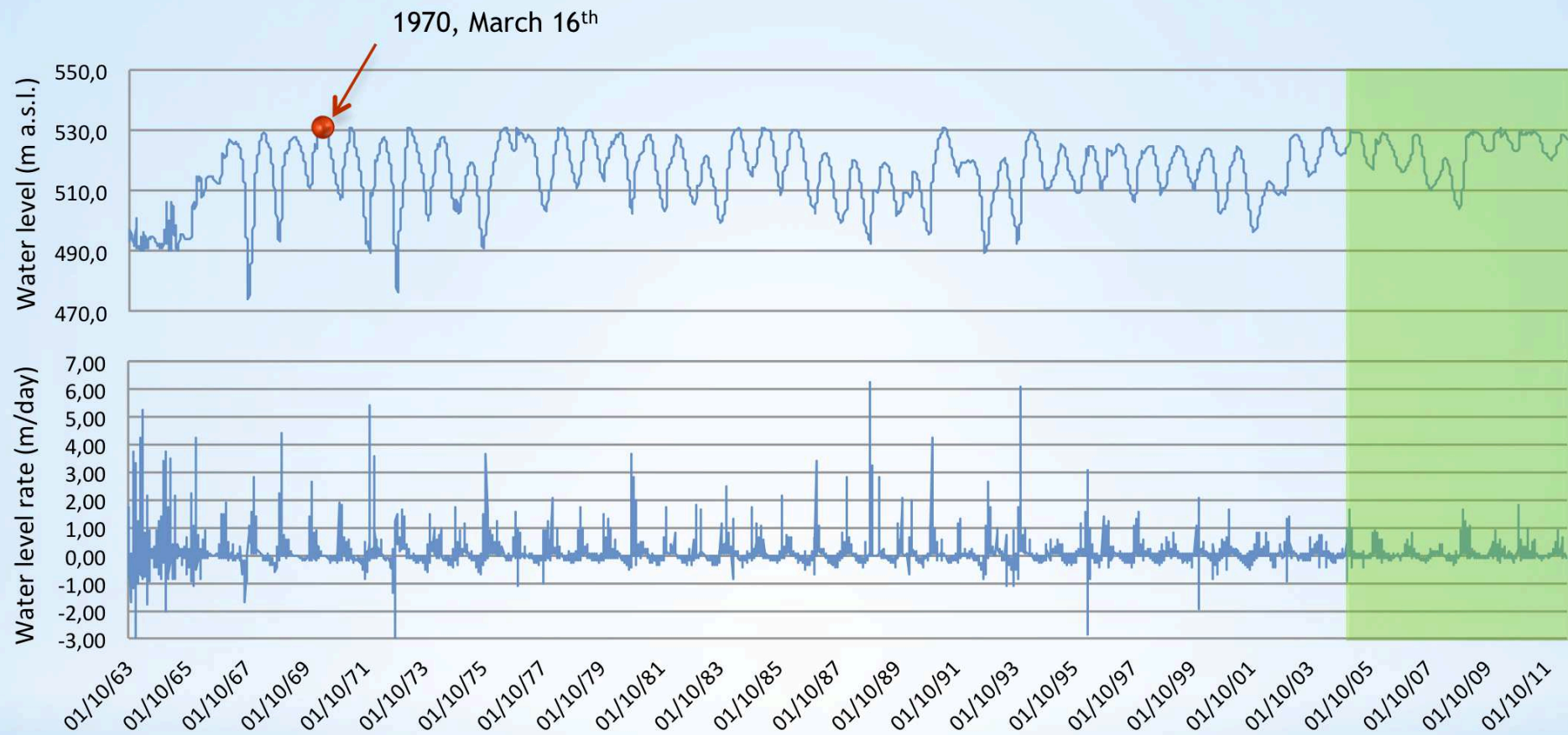


Two fault systems:

- NW-trending, SW-dipping Eastern Agri Fault System (EAFS) (Benedetti et al., 1998; Cello et al., 2003)

- NW-trending, NE-dipping Monti della Maddalena Fault System (MMFS) (Maschio et al., 2005; Improta et al., 2010)

Water level history of the Pertusillo reservoir



The maximum daily filling rate was 6.21 m/day during November 22, 1988 with an increment of water volume of 6.7 million cubic meters. The seasonal annual fluctuation of the water level is about 10-15 m, but in some few cases it reached higher values up to 50 m. Such fluctuations of the water column produce pressure perturbations of about 0.10-0.15 MPa (for water level variations of 10-15 m), and up to 0.5 MPa (for water level variations of 50 m), at the bottom of the lake.

All the reservoir data have been provided by "Ente per lo Sviluppo dell'Irrigazione e la Trasformazione Fondiaria" of Potenza, Italy.

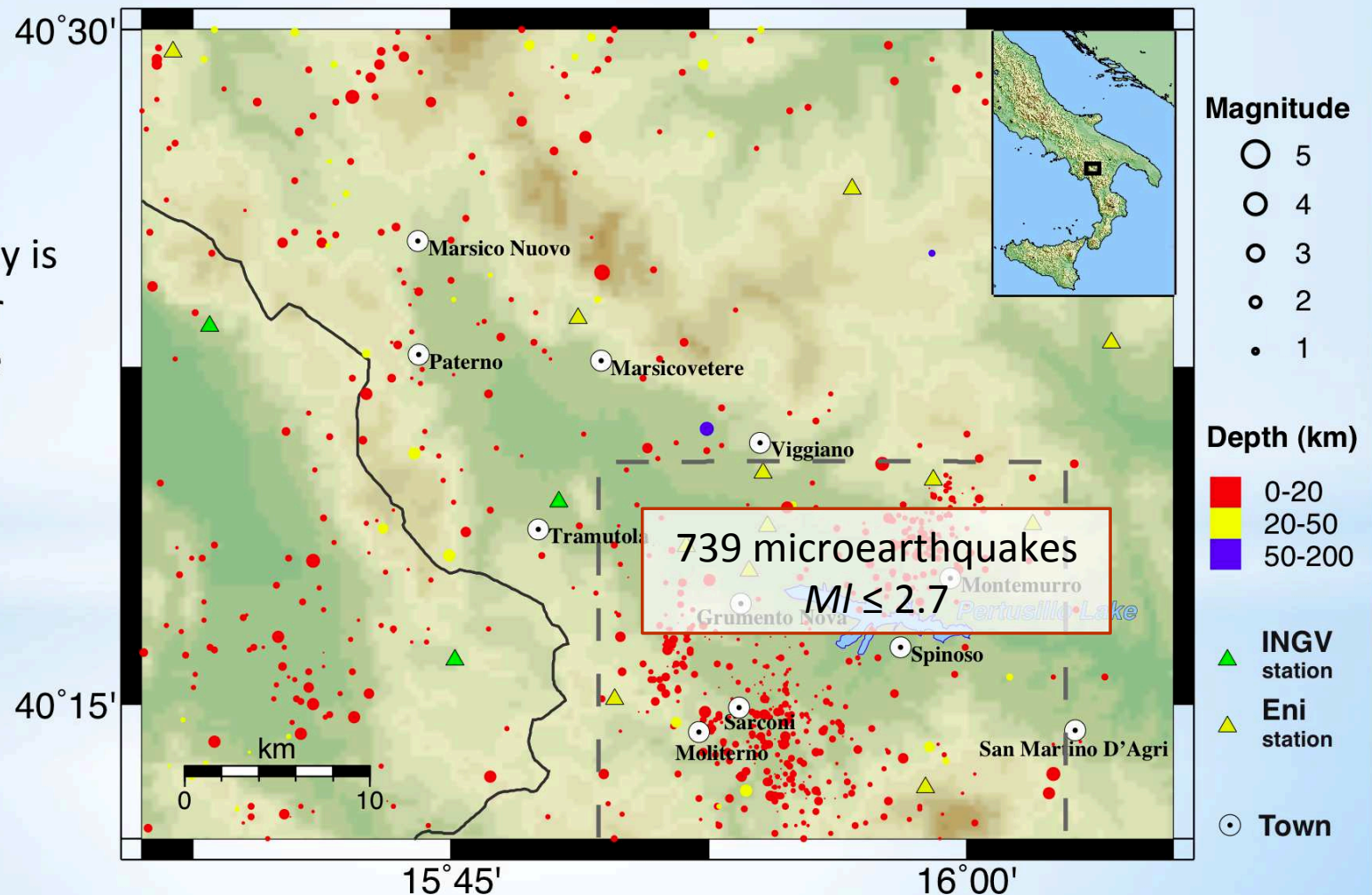
Seismicity in HAV from January 2005 to June 2012

Catalogues:

- Italian Seismological Instrumental and parametric Data-base (ISIDe) <http://iside.rm.ingv.it/>
- Eni S.p.A. seismic catalogue (available at Osservatorio Ambientale della Val d'Agri)

Collected data indicate that the majority of the recorded seismicity is concentrated near the Pertusillo Lake

Valoroso et al. (2009) suggested RIS associated with the reservoir during an experiment from May 2005 to June 2006.

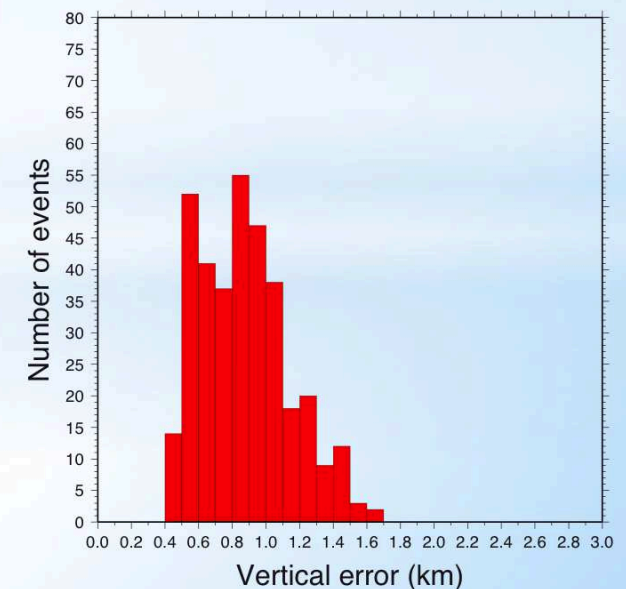
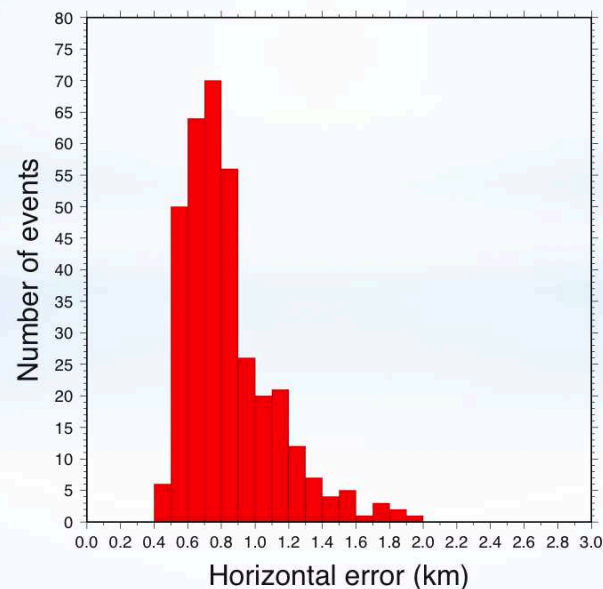
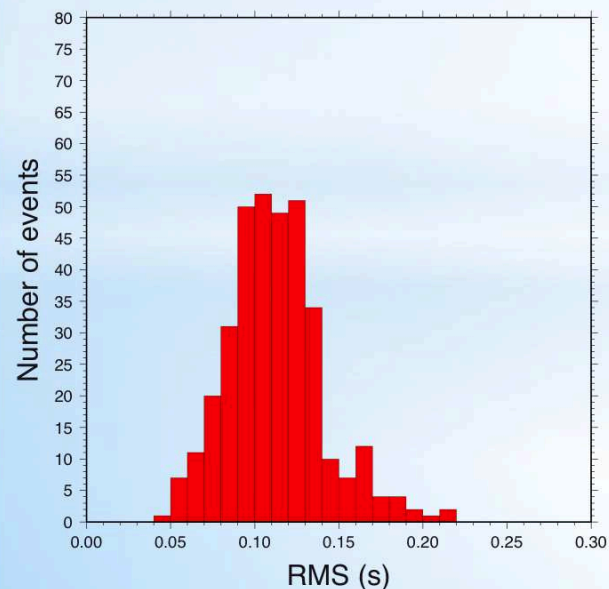
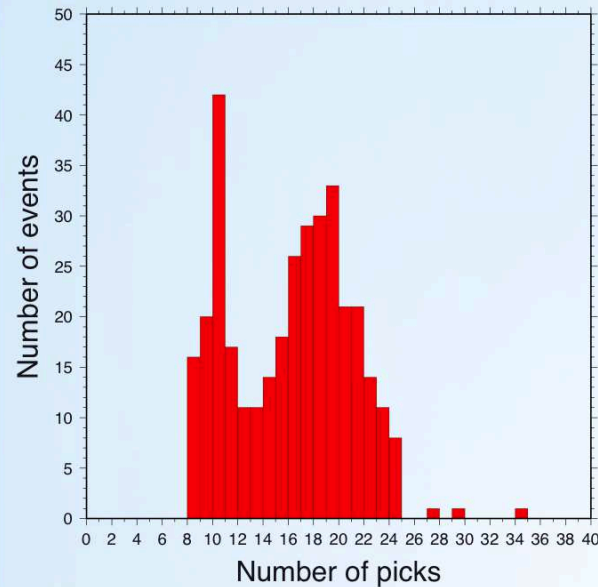


Relocation of 348 well-recorded events

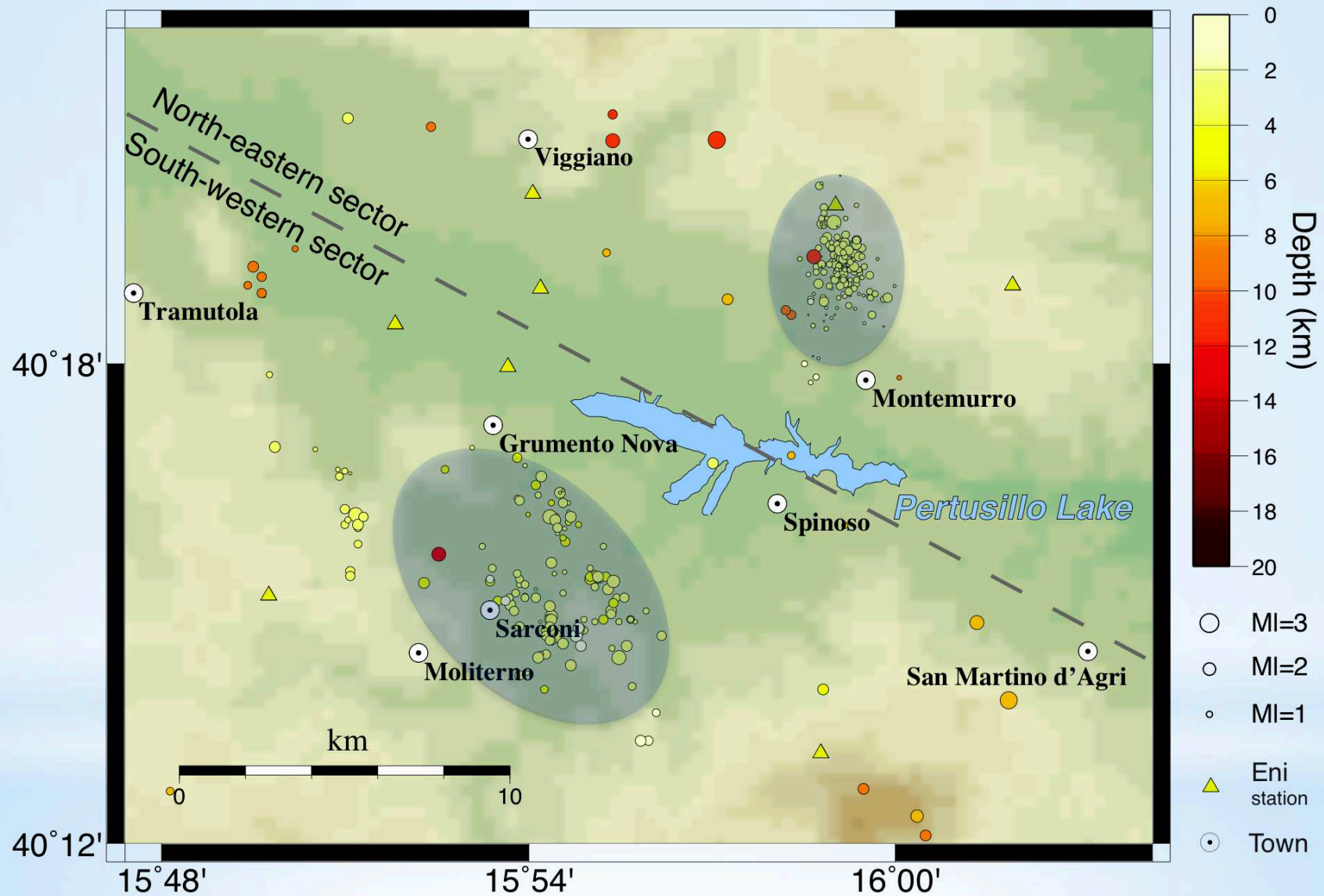
Locations were performed by using a nonlinear global approach (NonLinLoc, Lomax et al., 2000) in the 1-D velocity model of the area proposed by Valoroso et al. (2009). After a first location we relocated events by using station corrections obtained in the first step, and we repeated this processing till we did not find significant difference between two consecutive iterations.

We relocated only microearthquakes with at least 8 picks and we retrieved locations that satisfied the following constraints:

- RMS lower than 0.25 s;
- horizontal and vertical location errors lower than 2 km.



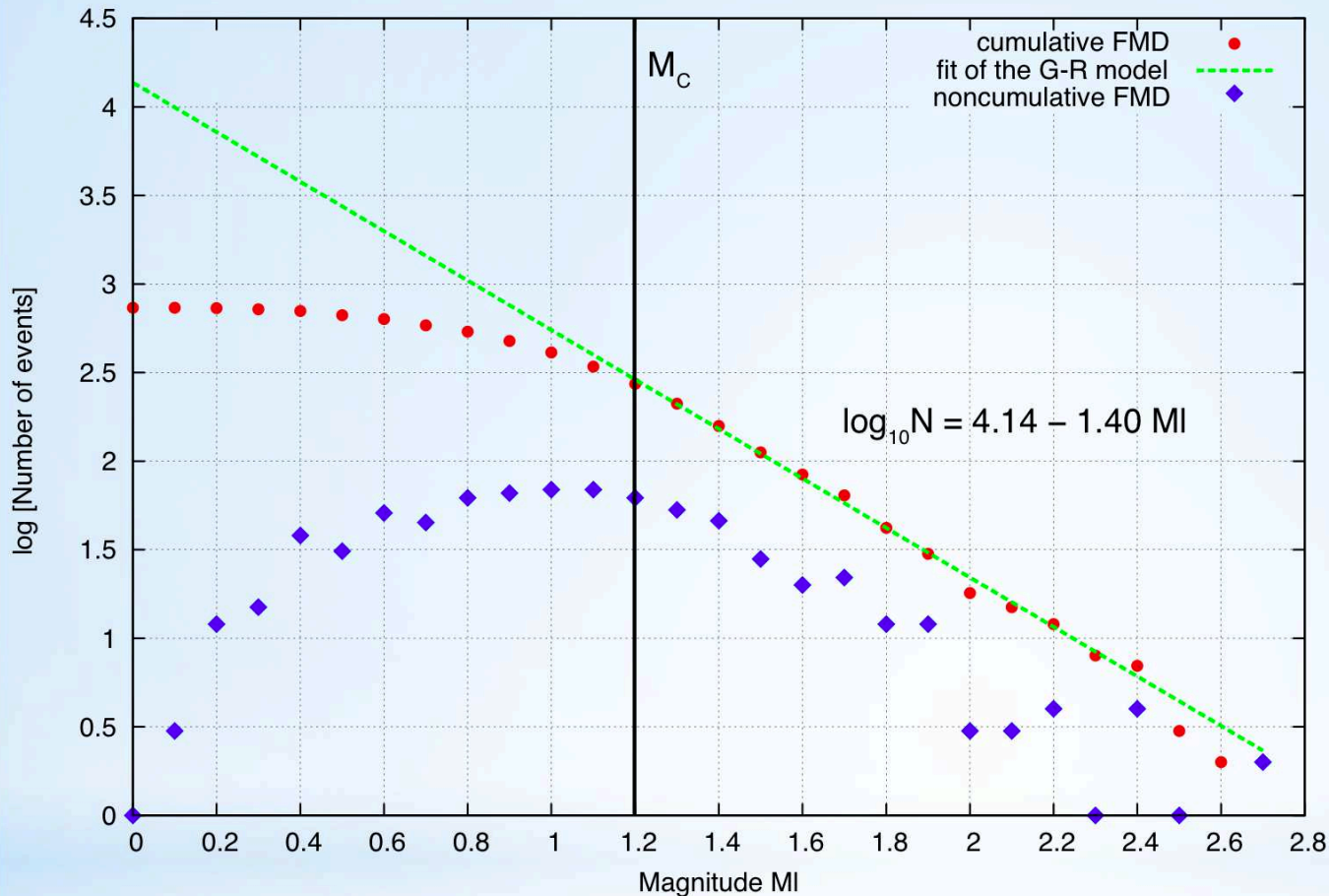
Relocation of 348 well-recorded events



After relocation the seismicity shrank into 2 clusters with shallow event depths, swarm-type distribution, and epicentral distances $> Rh-max \sim 3.2$ km (*)

(*) 3-4 times $W=0.8$ km (Talwani, 2007)

Frequency-Magnitude Distribution



M_C estimation:

- Maximum Curvature method
- Entire-magnitude-range method (EMR)

(Woessner and Wiemer, 2005)

Fit of the Gutenberg–Richter model:

- non-linear Levenberg–Marquardt least-squares algorithm

(Marquardt, 1963)

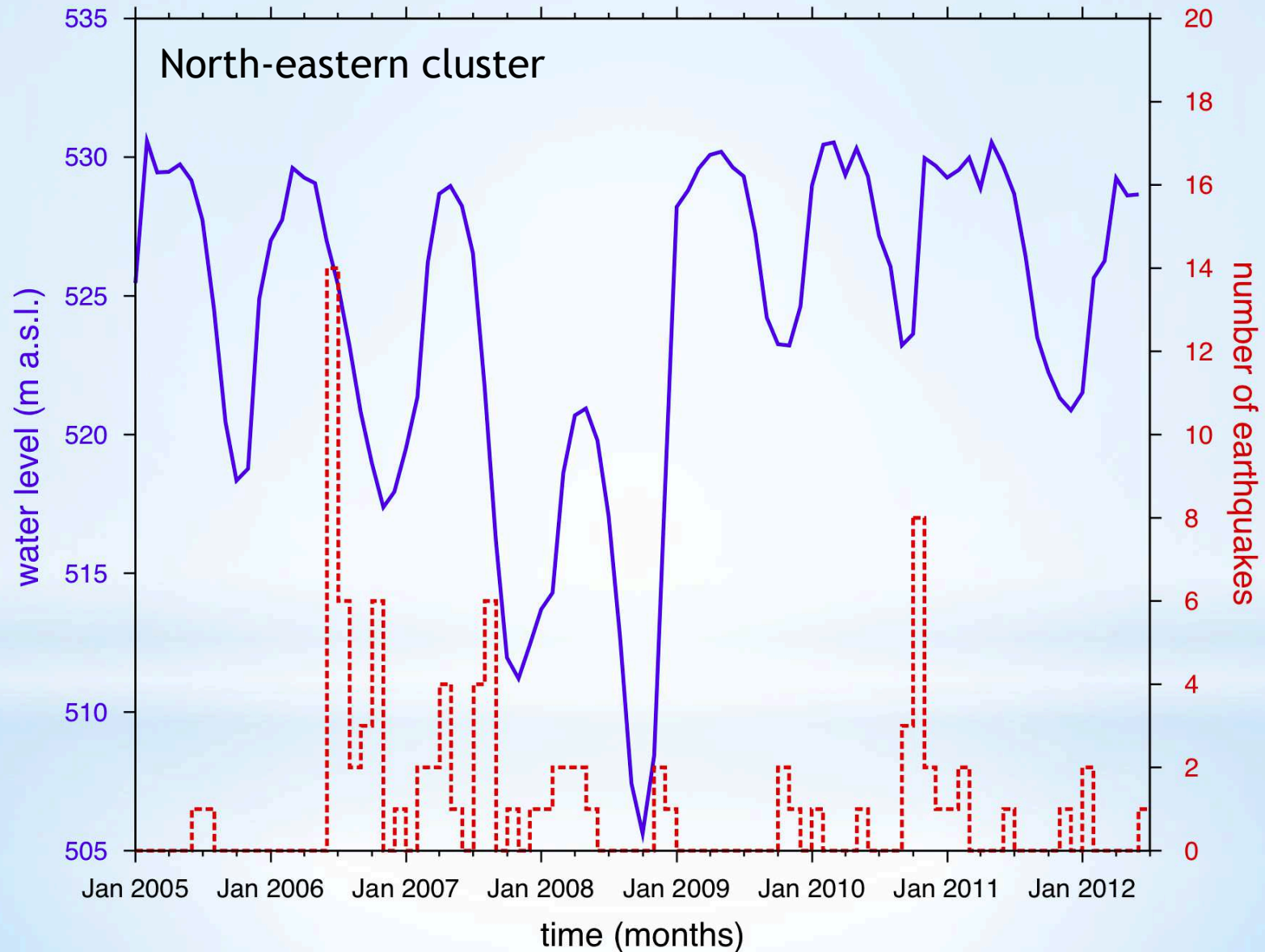
Whole seismicity: $M_C = 1.2 \pm 0.1$; $a = 4.14 \pm 0.05$; $b = 1.40 \pm 0.03$

North-eastern sector: $M_C = 1.1 \pm 0.1$; $a = 3.43 \pm 0.13$; $b = 1.37 \pm 0.07$

South-western sector: $M_C = 1.2 \pm 0.1$; $a = 4.08 \pm 0.06$; $b = 1.43 \pm 0.03$

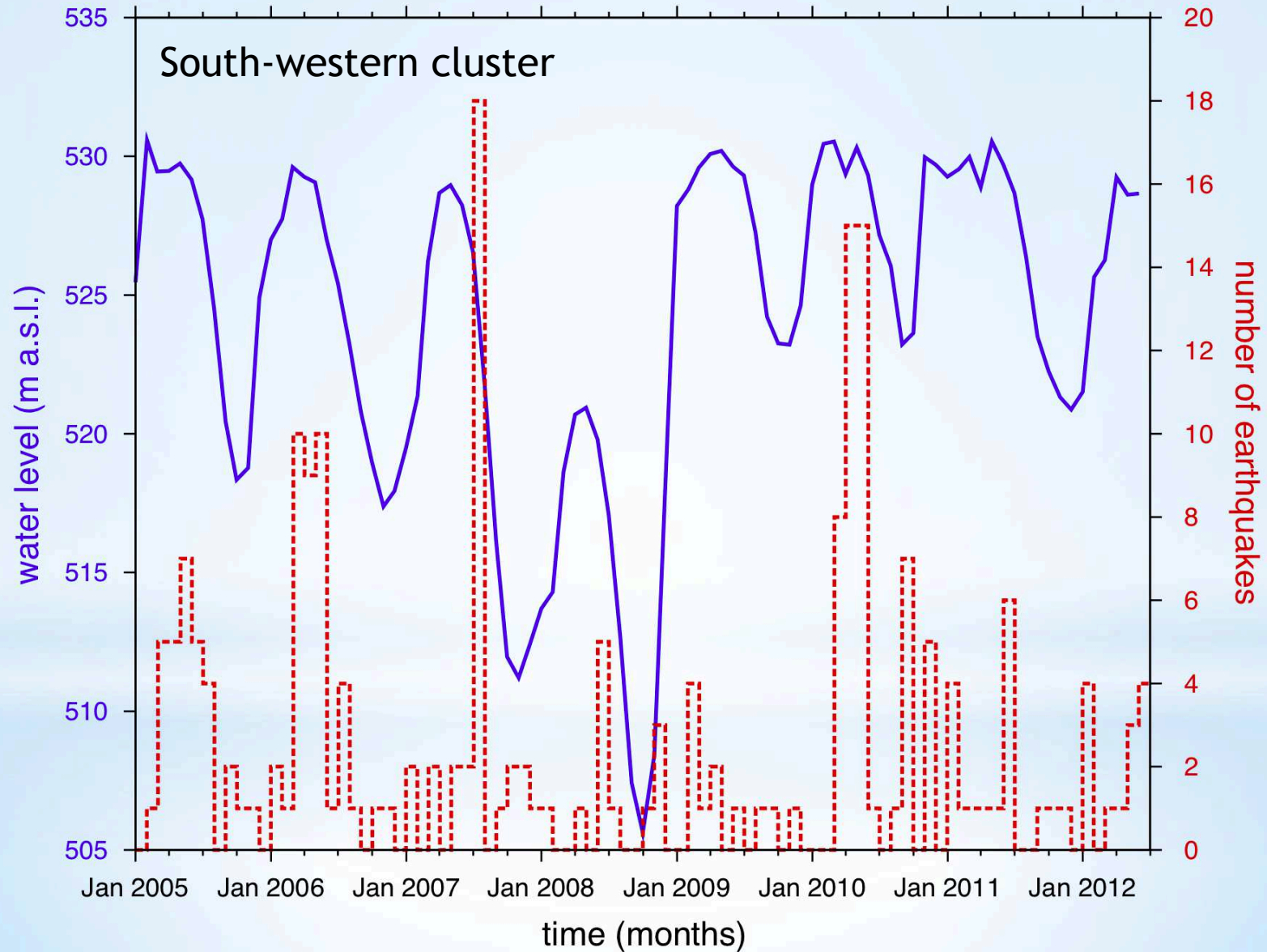
Water level vs number of earthquakes

Seismicity started in June 2006 and stopped from June 2008 to September 2009



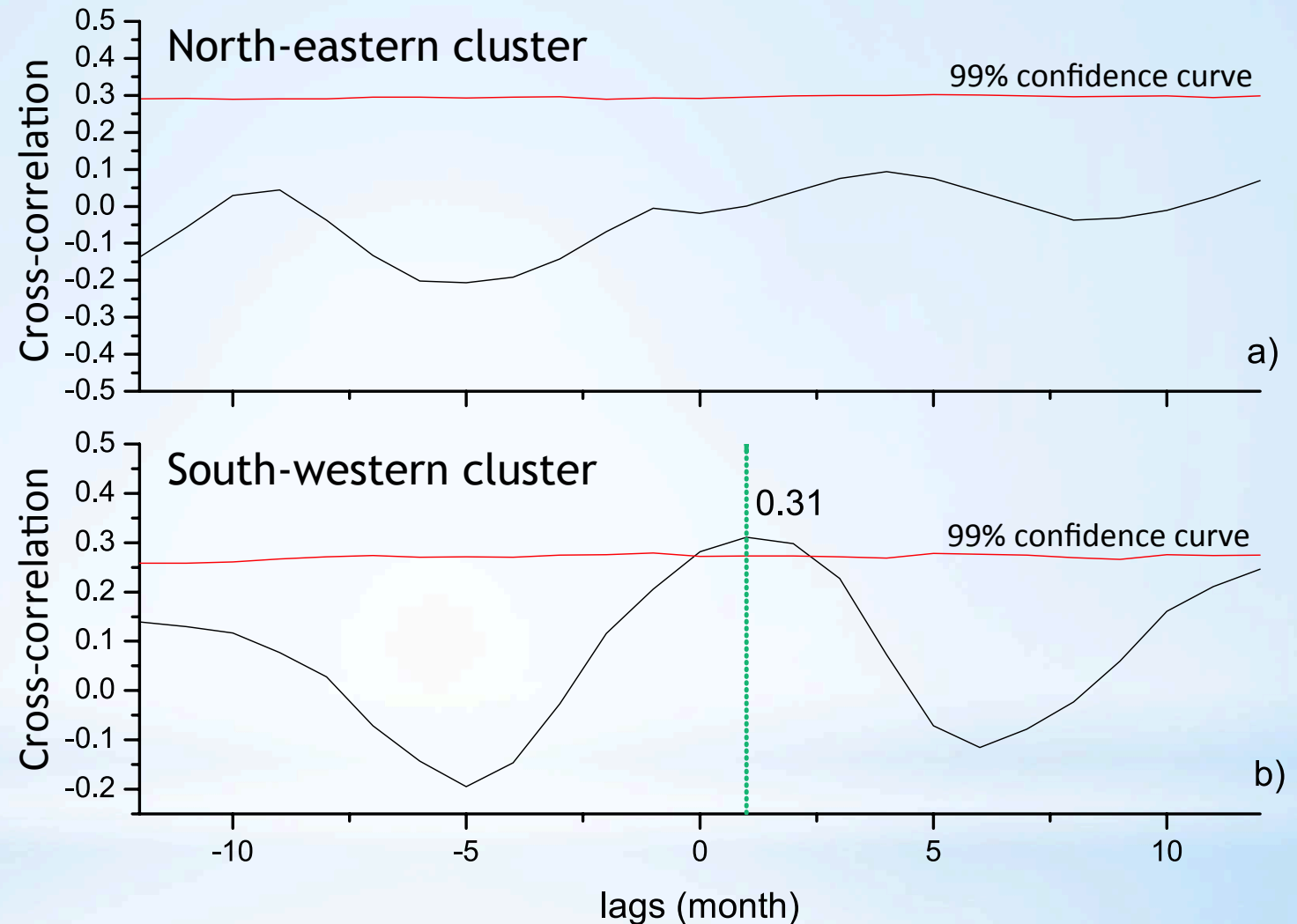
Water level vs number of earthquakes

Seismicity lasts for about 2-3 months between March and July of each year



Cross-correlation results

Even if both the clusters exhibit similar characteristics (e.g. high b -value, shallow depth, swarm-like sequences), only the south-western cluster is significantly correlated with the water-level fluctuations of the reservoir with maximum cross-correlation of 0.31 at 1 ± 0.5 month

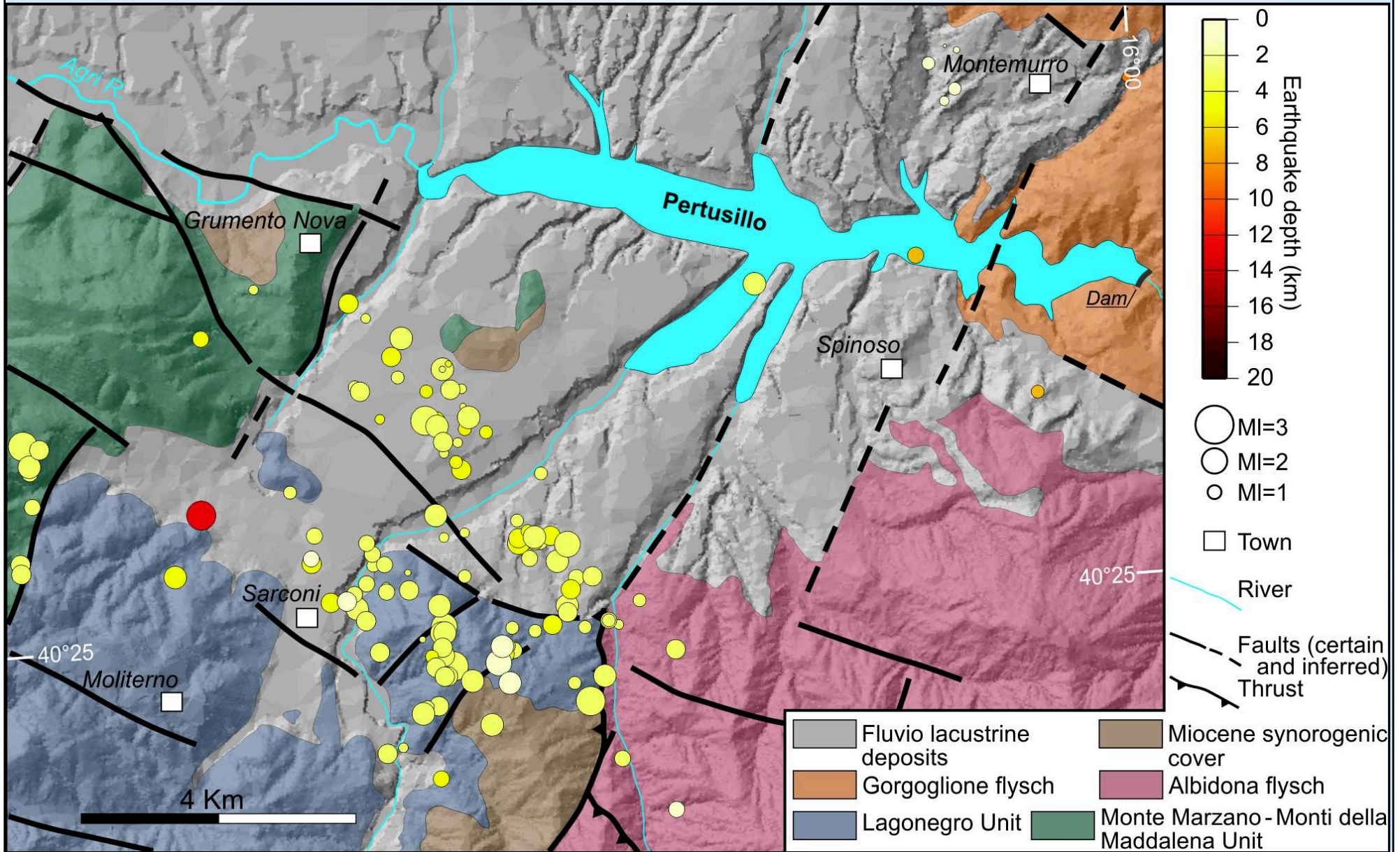


For the south-western cluster we have:

- delayed response with a time lag $\Delta t = 1.0 \pm 0.5$ months
- continued RIS that follows the variations of the reservoir water level

Results and discussion

Seismicity does not occur on a single fault but in a volume of 9 km x 4 km up to 4 km depth, inside the allochthonous units and at about 9 km distance from the dam.



Results and discussion

1. The south-western cluster can be defined as a continued reservoir-induced seismicity since it occurs year after year following the variations of the reservoir water level and it is not related neither to the initial impoundment of the lake (started in October 1963) nor to the highest water level in filling history. Water column fluctuates every year in the range of about 10 to 15 m on average, hence a pressure perturbation of 0.10 to 0.15 MPa at the bottom of the lake is applied. Moreover, a continued RIS is observed because the annual fluctuations are a large fraction of the least depth of the water.
2. The location of the south-western cluster is outside the volume within which the instantaneous undrained elastic response to the loading of the reservoirs occurs (reservoir-cluster epicentral distance larger than $Rh-max \sim 3.2$ km), then only delayed responses due to diffusion of pore pressure away the reservoir and along discrete fractures are possible.
3. Seismicity does not occur on a single fault but in a volume of 9 km x 4 km up to 4 km depth, inside the allochthonous units at the southern termination of MMFS.
4. Assuming 1-D pore fluid pressure diffusion from the reservoir to hypocentres along fractures, it is possible to estimate the hydraulic diffusivity c (Talwani et al., 2007):

$$c = r^2 / 4 \Delta t = 8.5 \pm 4.2 \text{ m}^2/\text{s}$$

where r (= 9.4 km) is the distance from the deepest place of reservoir (adjacent to the dam) to the average hypocentre of the cluster, and Δt is the time lag estimated from the cross-correlation analysis. This value is in the range of hydraulic diffusivity from 0.1 to 10 m²/s that corresponds to *seismogenic permeability* values (Talwani et al., 2007).



Geoitalia 2013

LE GEOSCIENZE PER LA SOCIETÀ

IX Forum Italiano di Scienze della Terra
Pisa, 16-18 settembre 2013

Thank you for your attention

Tony Alfredo Stabile: tony.stabile@imaa.cnr.it