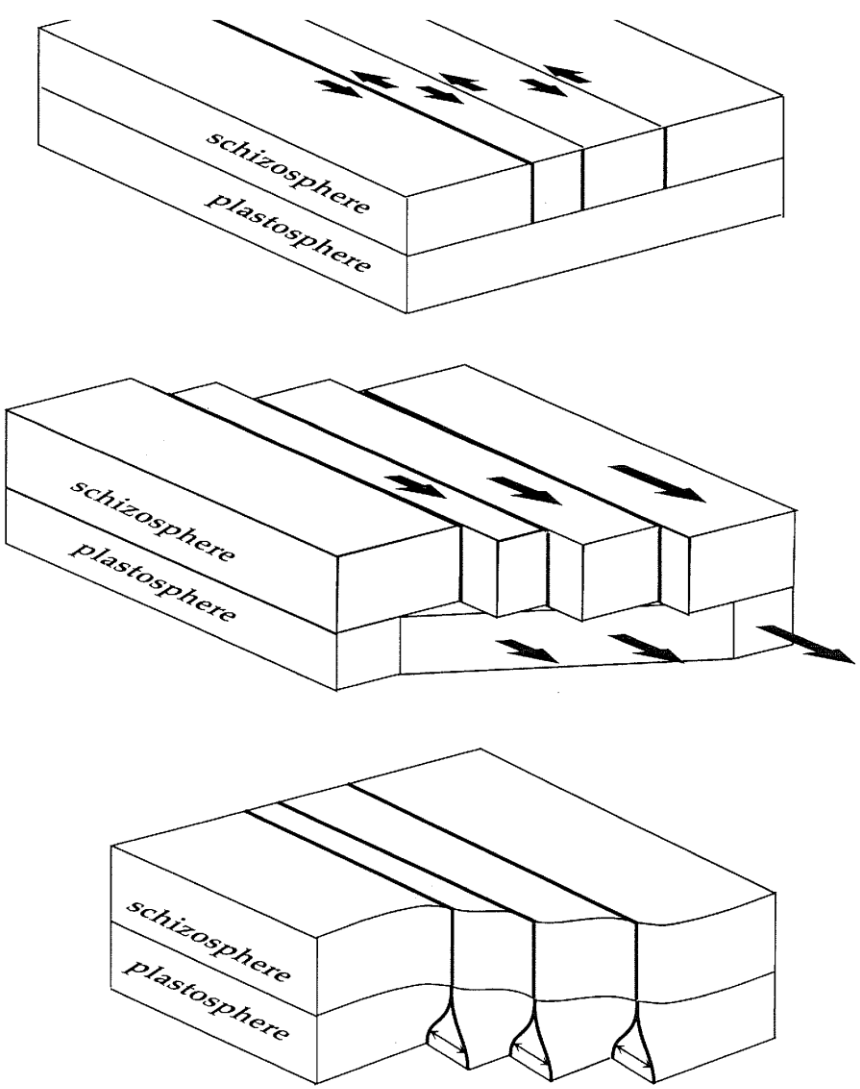
Length and time scales of the active deformation

Distributed and localized deformation are
two end member models of deformation

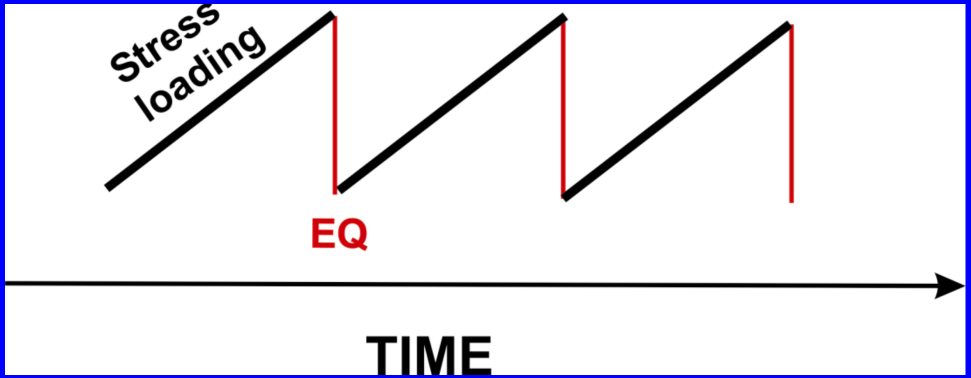


Seismic slip and aseismic faulting are **end members** of a **continuous spectrum**

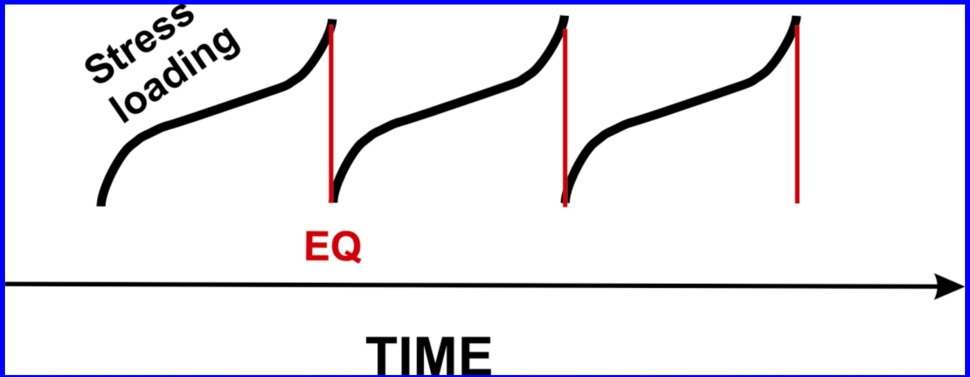
- Aseismic slip
- Creep events
- Strain transients
- Slow earthquakes
- Episodic tremor
- Silent earthquakes
- Afterslip and transient postseismic deformation
- Slow precursors to "normal" earthquakes
- Earthquakes with a distinct nucleation phase
- Normal (fast) earthquakes
- Earthquakes with supersonic rupture velocity

Hypothetical stress evolution on the fault

... without transient deformation



... with transient deformation



Continental deformation framework

- *Velocity field for Continuous deformation:* ***GPS – SLR - VLBI***
- *Faulting for Discontinuous deformation:*

  Seismology, GPS, DinSAR,

  direct observations

Crucial to this framework is the knowledge of the structure of the earth at the required length scale,

and an appreciation of the nature and scale of the mechanical properties of the continental lithosphere.

Earth Rheology

Improved understanding of the rheology of the Earth's crust and upper mantle and faults is fundamental to studies of:

- **mantle flow & plate tectonics**
- **earthquake cycle, fault interaction & earthquake hazard**

From the laboratory ....

By necessity, rock and fault mechanics lab experiments have to be run on spatial and temporal scales and under conditions far from natural environment

From the laboratory ....

.... to the Natural Laboratory

an earthquake initiates a lithosphere-scale rock mechanics experiment:

- **establish geometry, initial and boundary conditions:**

  (e.g. surface geology and geomorphology, kinematic parameters of faulting, Earth structure through surface wave tomography and non-linear inversion)

- **take relevant deformation measurments:**

  (e.g. seismicity, continuous and campaign GPS, plaeoseismology)

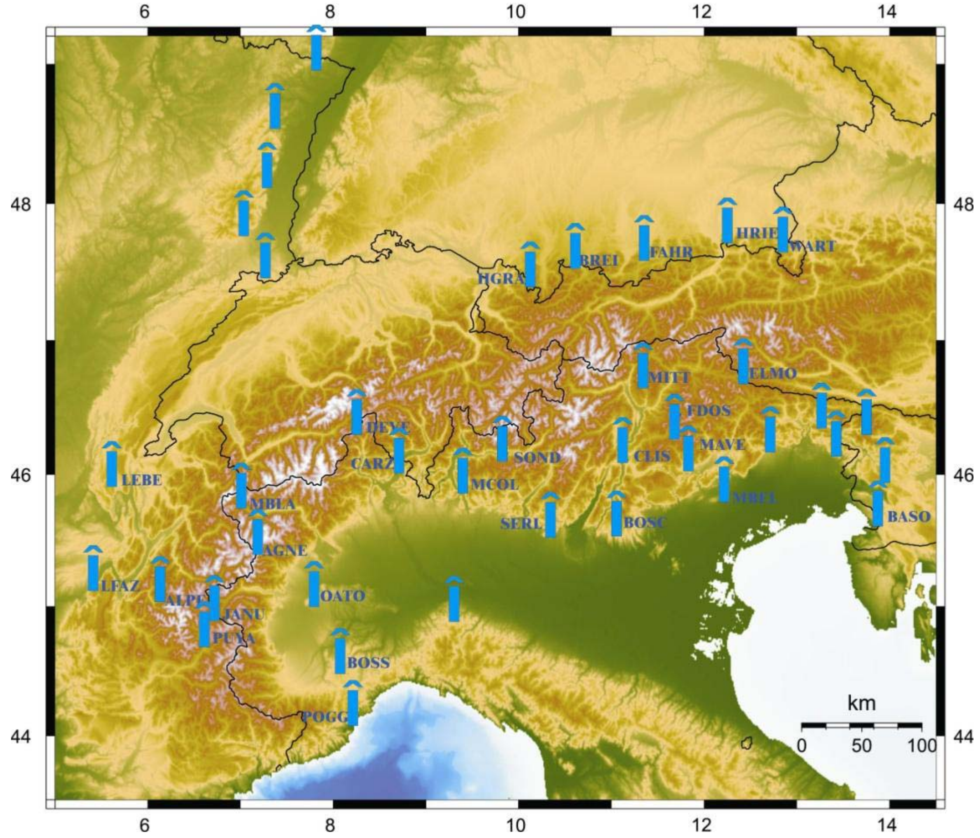
- **use models to resolve fault/rock constitutive properties:**

  (e.g. visco-elastic modeling, rate and state friction laws)

A physical model for strain accumulation that carries predictive power for future stress patterns

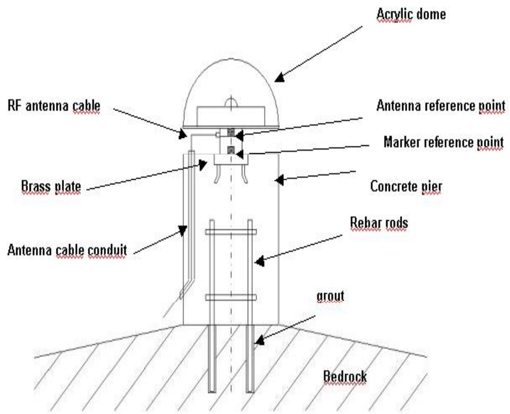
ALPS GPS QUAKENET

GAIN -
Geodetic Alpine Integrated Network



Need to monitor crustal deformation at a wide range of spatio-temporal scales

GAIN CGPS data will very likely revolutionize our understanding of the Alpine crustal deformation, including fault friction and the rheology of deformation

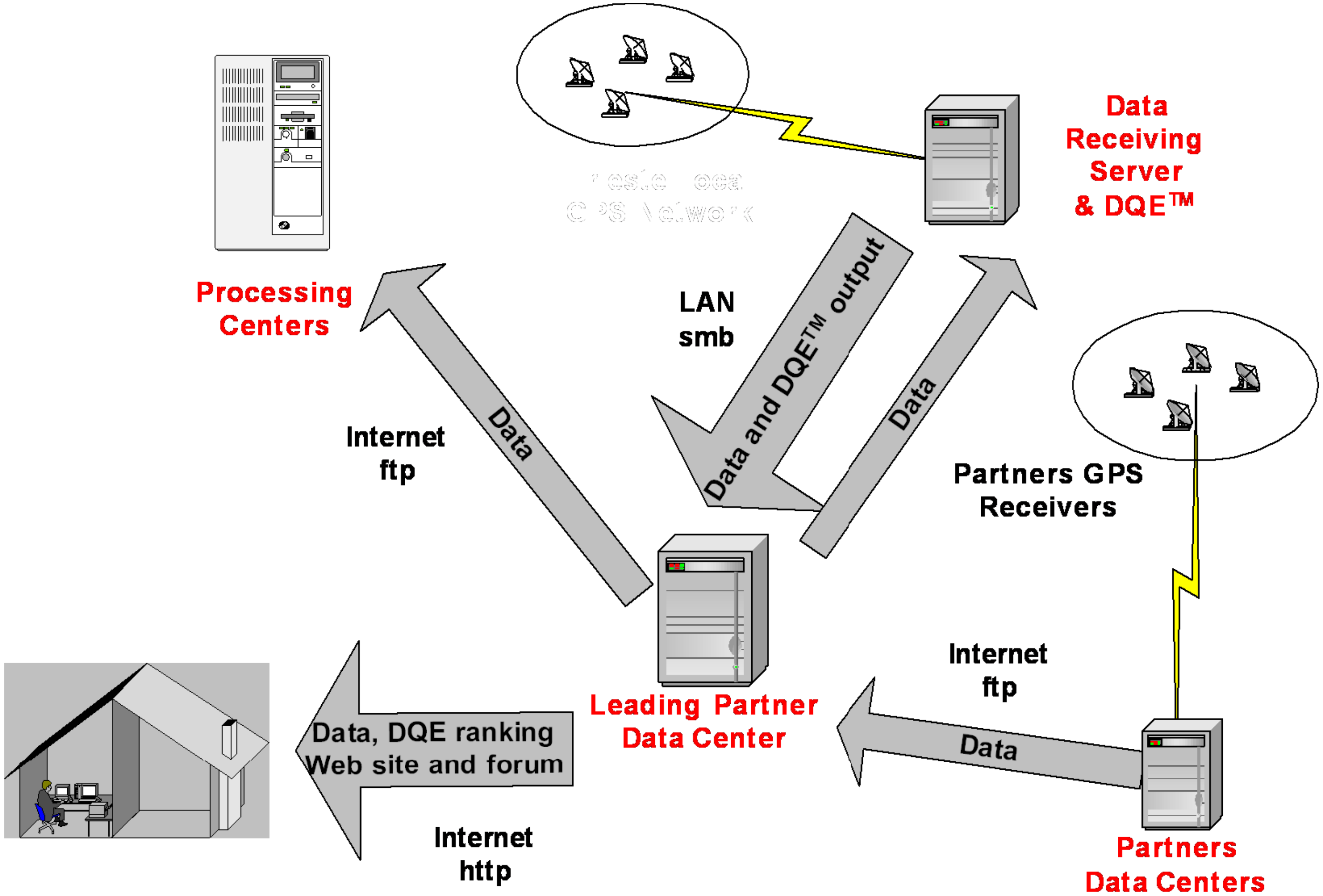


Alpine Integrated GPS Network: Real-Time Monitoring and Master Model for Continental Deformation and Earthquake Hazard

Una rete di stazioni GPS per il controllo geodinamico dell'area alpina

TRIESTE
FEBRUARY 26° and 27th

System Architecture



Alpine Integrated GPS Network: Real-Time Monitoring and Master Model for Continental Deformation and Earthquake Hazard

Una rete di stazioni GPS per il controllo geodinamico dell'area alpina

TRIESTE
FEBRUARY 26° and 27th

ALPS GPSQUAKENET Project

Alpine integrated GPS network: real-time monitoring and master model for continental deformation and earthquake hazard

- Home
- Project
- Partnership
- GAIN
- Events
- News
- Contacts
- Links
- Data Archive
- Stations Quality Ranking (DQE™)

Home » DQE

Analysis of all the RINEX data received

Help

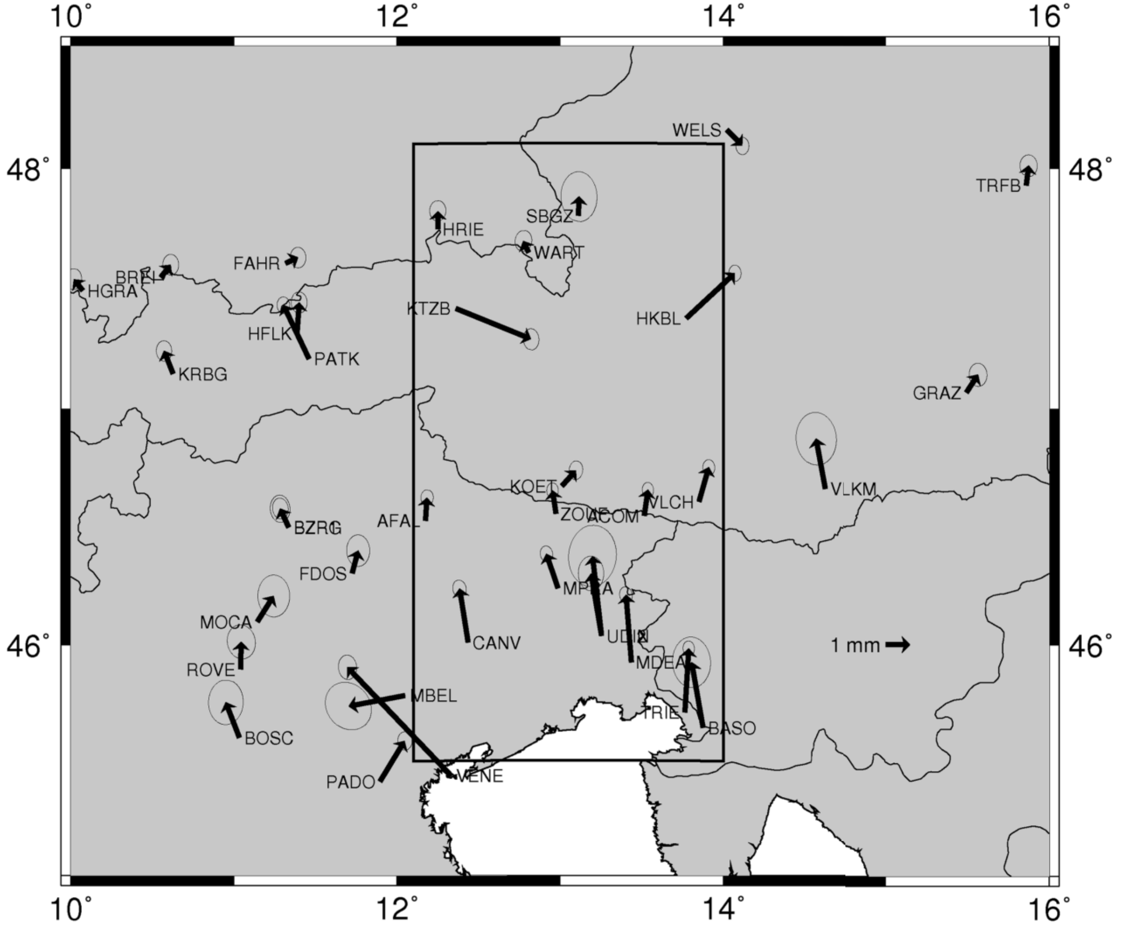
Station	Maintainer	Files found	Files expected	Ratio Files found/Files expected	Start Acq.	Acq/Exp	DF/Acq	Ed/DF	CS	N/L1 [mm]	N/L2 [mm]	N/C1 [mm]	N/P2 [mm]
FAHR	DGFI	504	504	100%	2005/280	95.58%	99.95%	99.84%	19.4	0.131	0.103	199.7	194.8
MOCA	GST	163	164	99%	2006/255	97.43%	99.95%	99.85%	20.5	0.176	0.138	290.1	253.1
HGRA	DGFI	498	504	99%	2005/280	93.89%	99.53%	99.75%	31.1	0.097	0.077	132.0	154.5
BREI	DGFI	490	504	97%	2005/280	96.39%	99.97%	99.87%	18.6	0.103	0.081	145.2	160.3
WART	DGFI	489	504	97%	2005/280	92.93%	99.74%	99.82%	17.4	0.101	0.080	134.0	160.0
HRIE	DGFI	489	504	97%	2005/280	90.99%	98.85%	99.76%	20.9	0.090	0.072	91.6	154.3
FDOS	GST	346	358	97%	2006/61	97.58%	99.97%	99.83%	19.5	0.118	0.092	172.3	176.5
OATO	ARPA Piemonte	330	343	96%	2006/76	91.78%	99.48%	98.28%	256.4	0.277	0.217	391.7	410.2
MAVE	ARPA Veneto	267	281	95%	2006/138	96.89%	99.97%	99.83%	36.0	0.219	0.172	332.4	317.1
BASO	DST-UNITS	564	603	94%	2005/181	95.46%	99.92%	99.57%	77.2	0.167	0.132	229.4	257.0
SOND	IREALP	199	218	91%	2006/201	87.67%	99.44%	99.98%	4.0	0.239	0.187	435.2	357.6
ROSD	LGIT	393	436	90%	2005/348	90.84%	99.12%	99.90%	1.7	0.386	0.303	893.6	598.9
MBEL	ARPA Veneto	293	348	84%	2006/71	83.97%	96.97%	97.95%	286.4	0.359	0.284	468.0	574.4
BOSC	ARPA Veneto	285	349	82%	2006/70	97.09%	99.82%	99.53%	77.2	0.193	0.152	271.5	291.9
LFAZ	LGIT	548	774	71%	2005/10	97.84%	99.84%	99.92%	5.8	0.328	0.258	852.7	515.8
PUYA	LGIT	316	448	71%	2005/336	90.36%	99.71%	99.89%	7.8	0.355	0.279	585.5	529.1
CARZ	ARPA Piemonte	177	283	63%	2006/136	92.24%	99.94%	99.40%	98.3	0.119	0.093	160.5	183.8
JANU	LGIT	279	496	56%	2005/288	97.12%	99.98%	99.90%	9.3	0.298	0.234	475.3	451.4
CLTN	IREALP	89	163	55%	2006/256	94.59%	99.79%	99.98%	24.2	0.516	0.402	1433.6	639.1
SERL	IREALP	80	175	46%	2006/244	92.36%	99.21%	99.99%	3.6	0.243	0.191	440.3	366.6
AGNE	ARPA Piemonte	156	343	45%	2006/76	82.14%	99.93%	99.36%	78.8	0.098	0.077	126.0	158.8
LEBE	LGIT	263	643	41%	2005/141	94.25%	99.88%	99.90%	1.3	0.322	0.253	598.2	480.1
POGG	RLG	58	353	16%	2006/66	97.89%	99.99%	99.84%	20.8	0.155	0.122	231.4	232.9
DEVE	ARPA Piemonte	58	507	11%	2005/277	80.89%	99.93%	99.72%	22.4	0.117	0.092	155.2	187.0

Alpine Space
Interreg III B

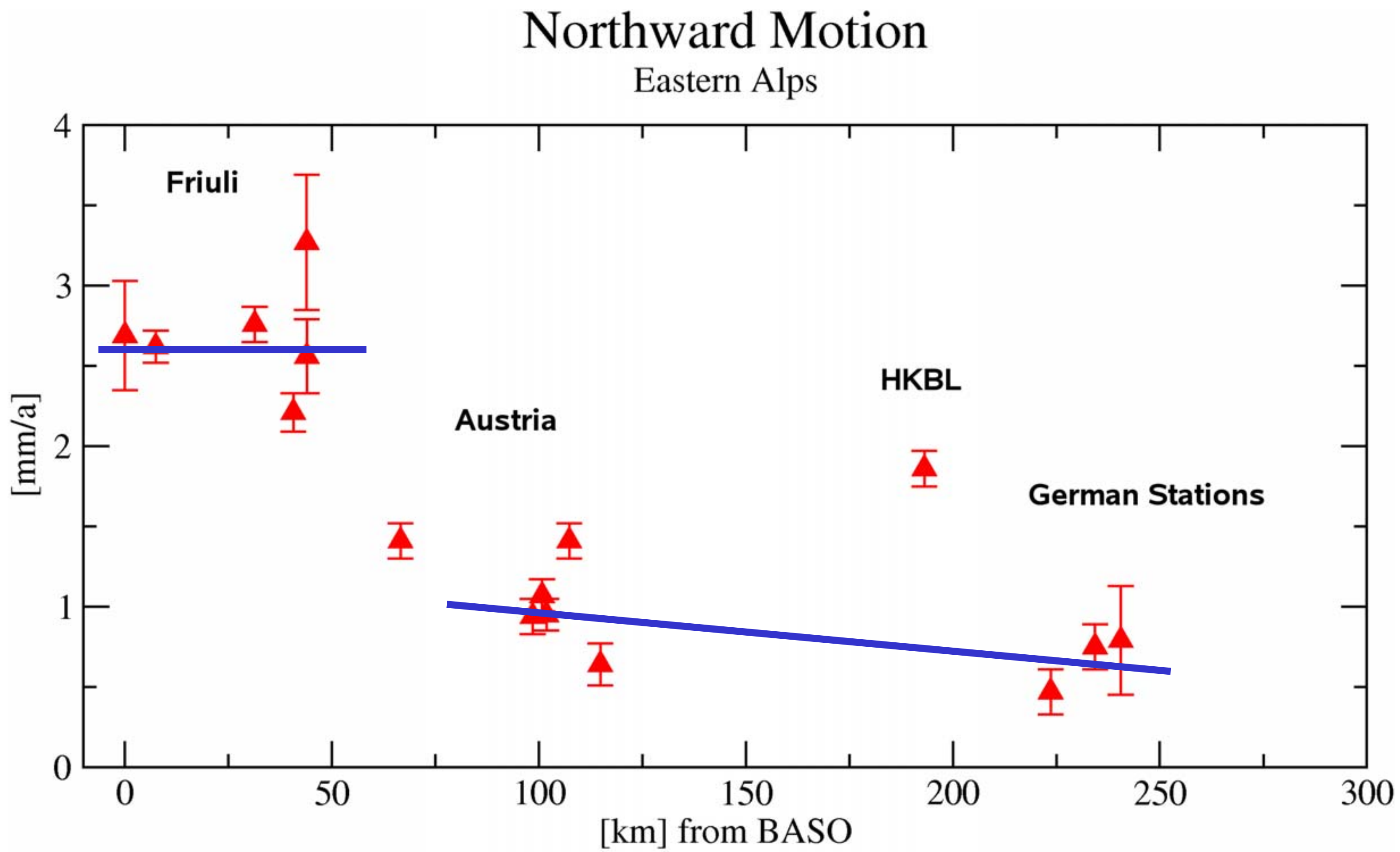
Deformation across the Eastern Alps

Deformation Zone:

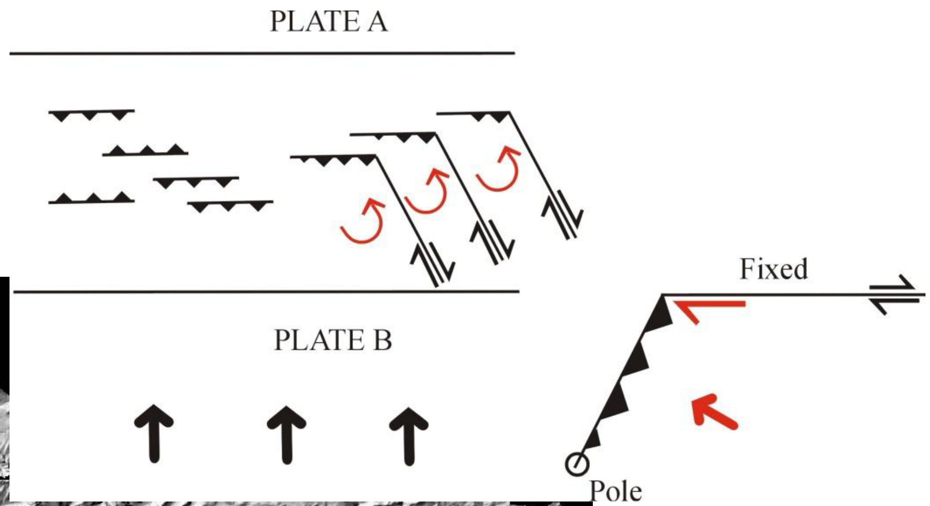
Φ=46.5-48.3° N
Λ=12.0-14.0° E



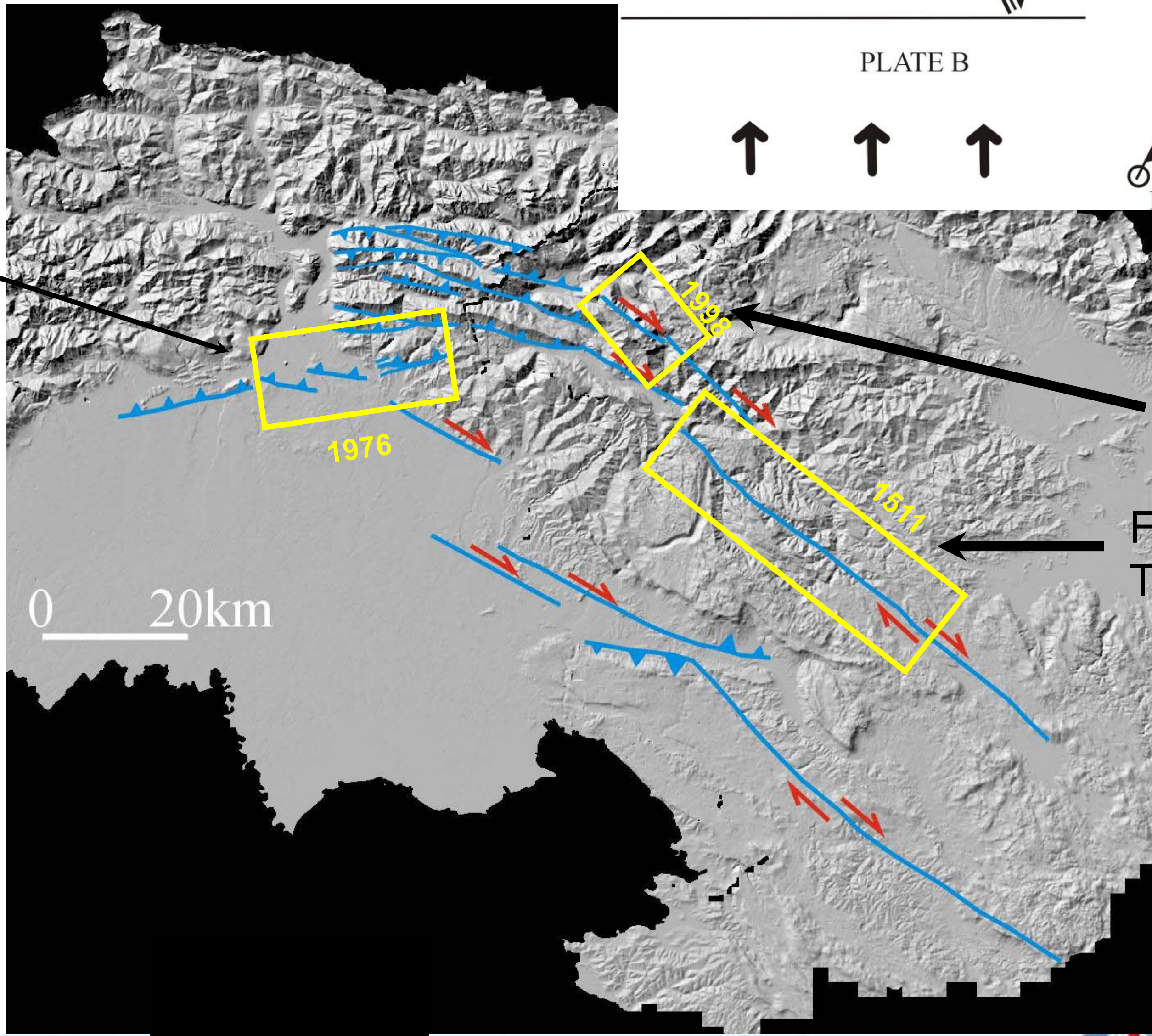
Profile across the Alps



Active faults and earthquakes



Aoudia et al., GRL, 2000

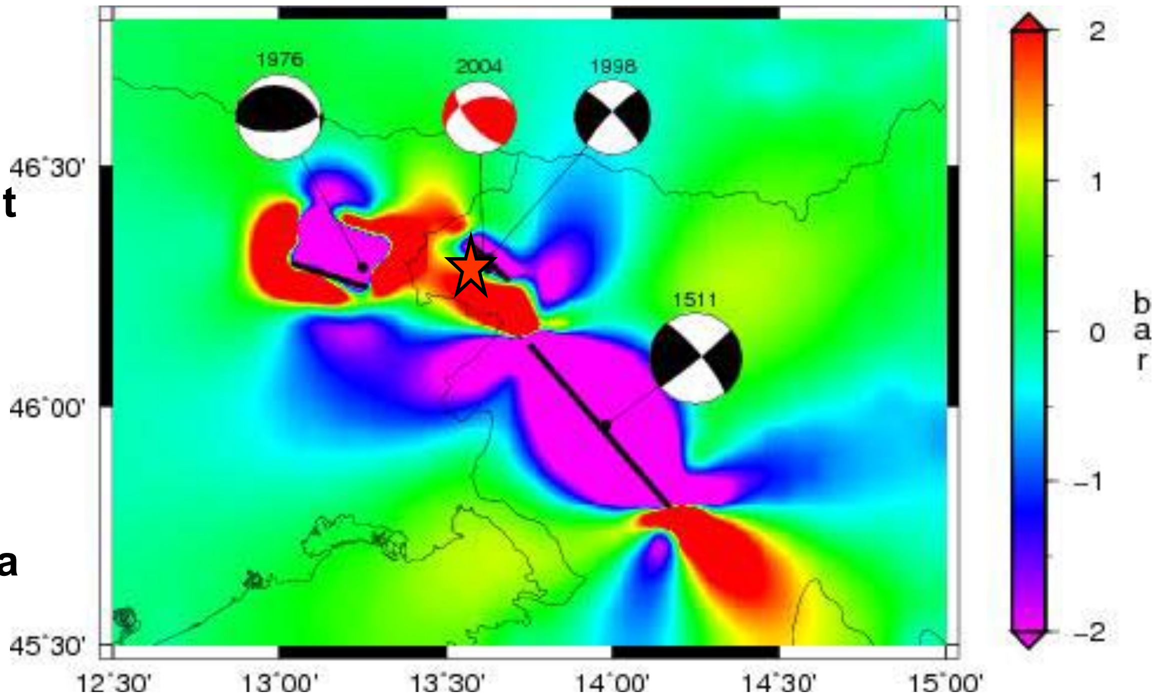


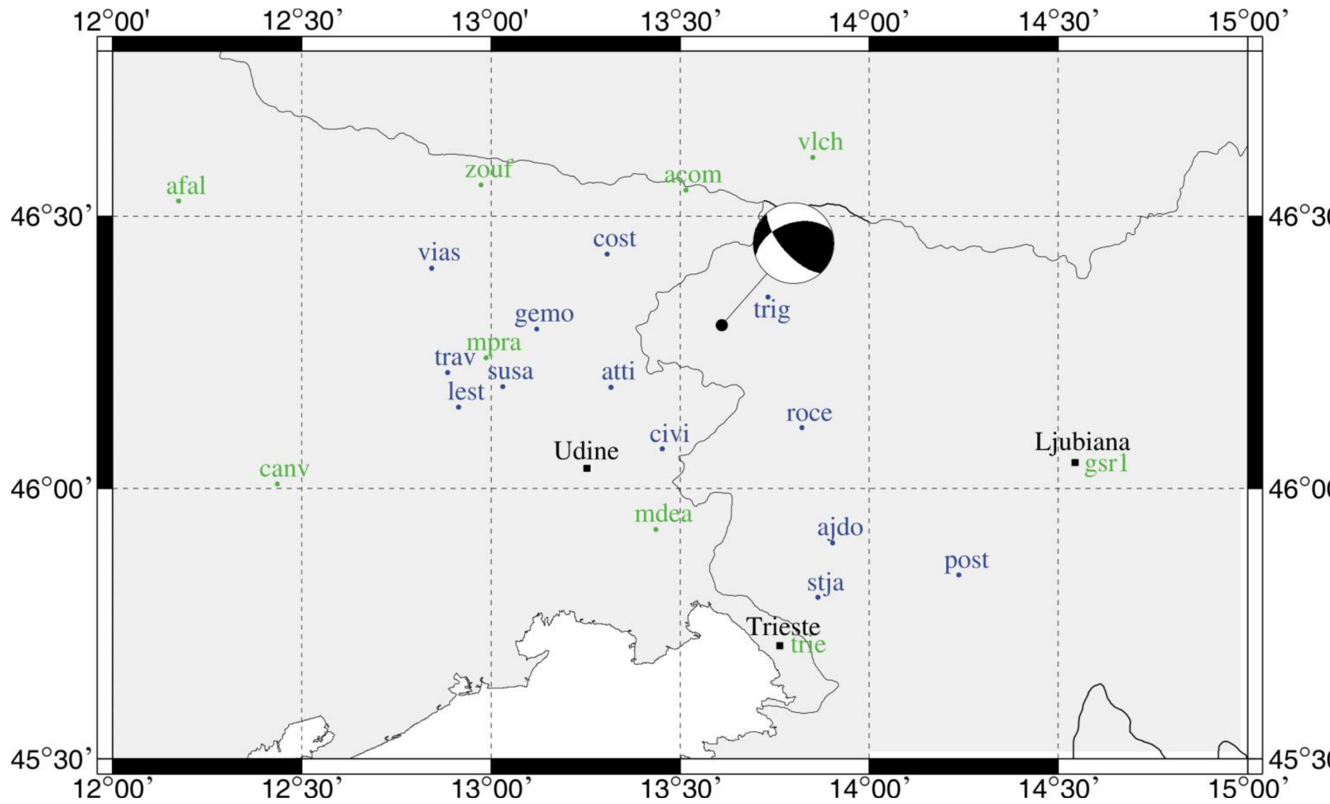
Bajc, Aoudia, GRL, 2001

Fitzko, Aoudia, Tectonics, 2005

Visco-elastic modeling and stress evolution since 1511 up to 2004 accounting for coseismic and postseismic deformation of each past major event.

- **3-D Finite Elements Method approach (Riva & Aoudia, 2008)**
- **domain boundaries extending 100 km away from the most external point of each fault**
- **an earth model comprised by a 16-km-thick elastic upper curst, a viscoelastic lower crust with viscosity 10^{19} Pa s between a depth of 16 km and the Moho at 37 km and a viscoelastic lithospheric mantle with viscosity 10^{21} Pa s.**





12°00'
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acom
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vias
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gemo
mpra
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lest
roce
civi
Udine
Ljubiana
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mdea
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stja
Trieste
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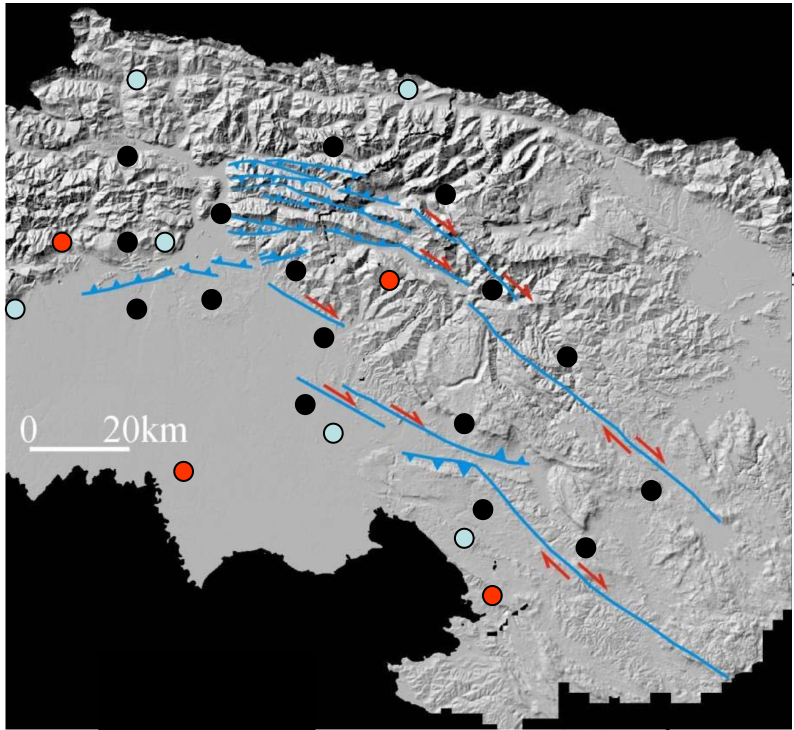
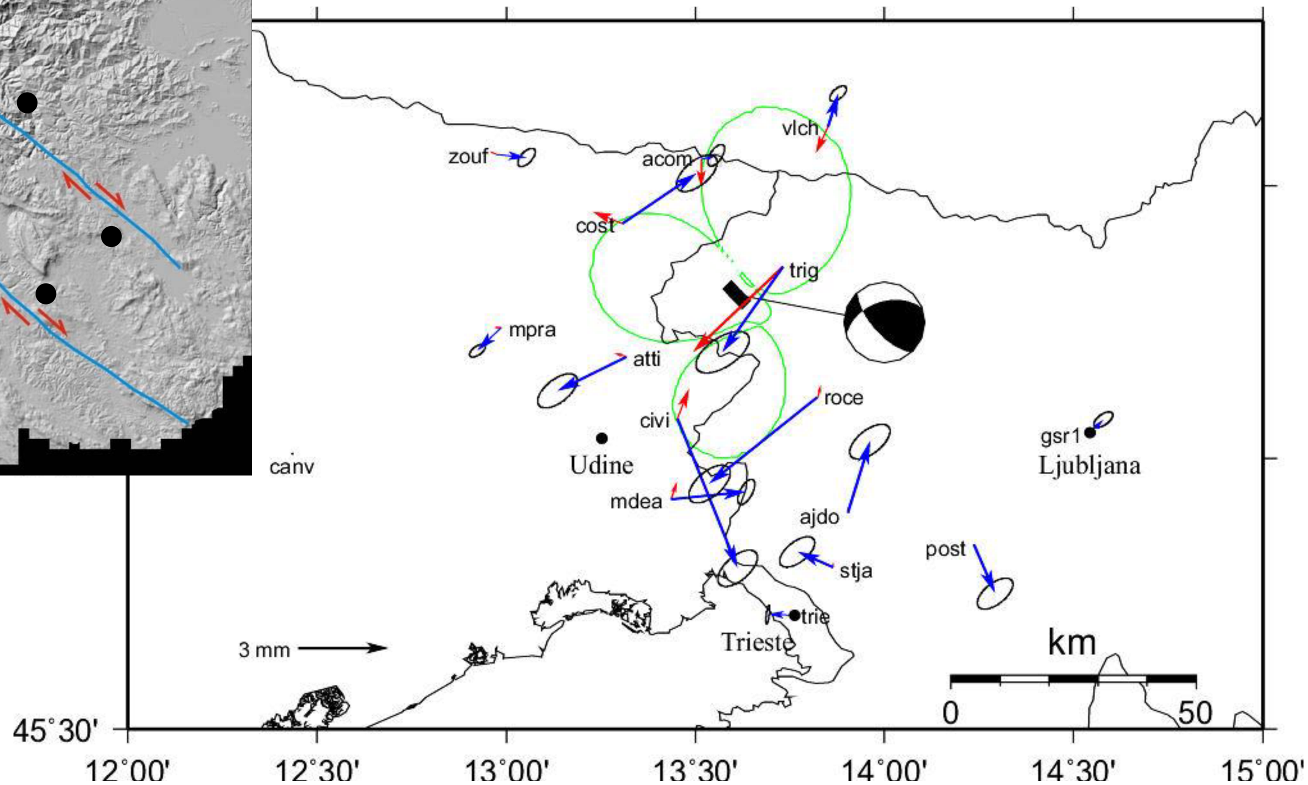
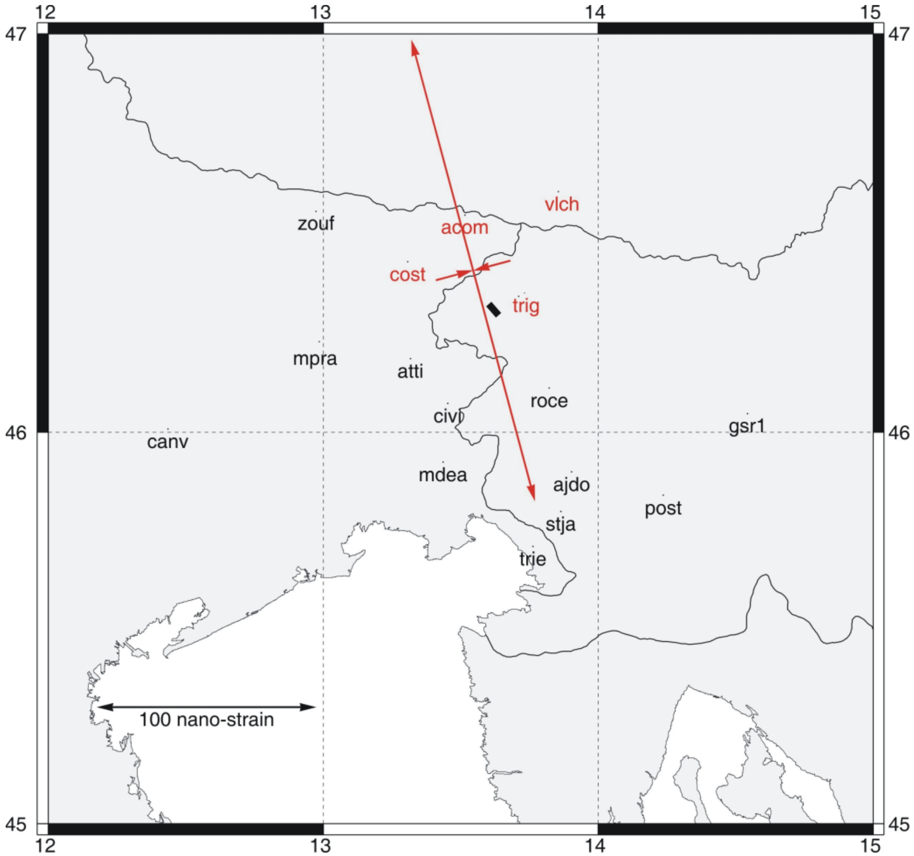
The July 2004 earthquake related deformation

Borghi & Aoudia, Tectonophysics, 2009



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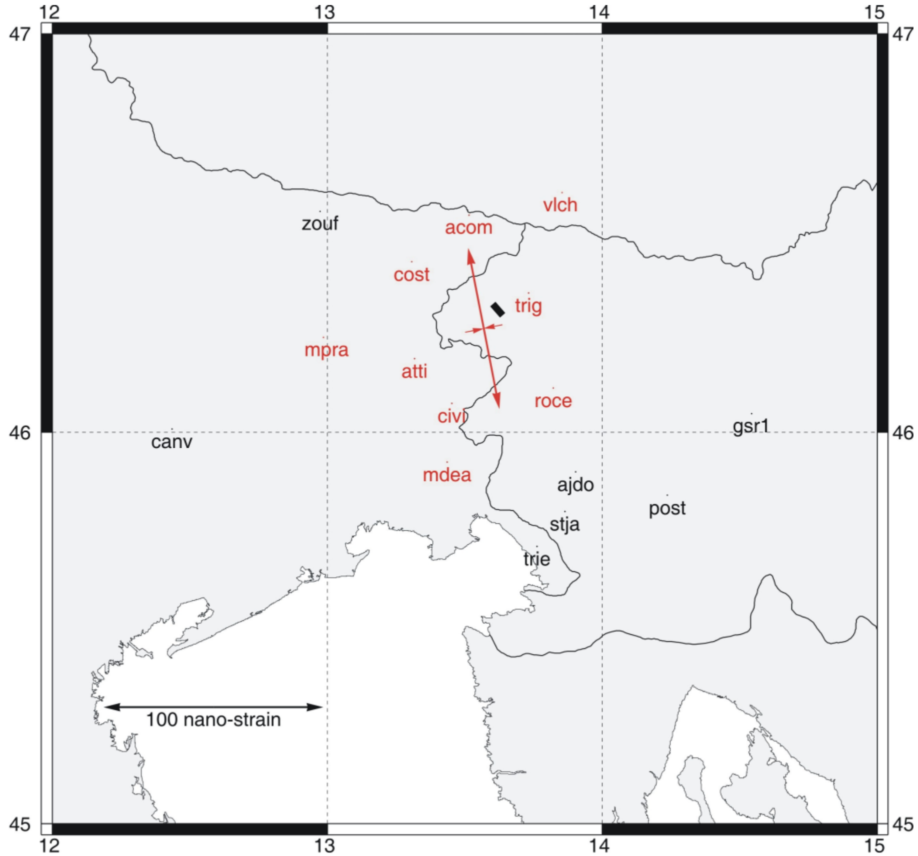
100 nano-strain

(a)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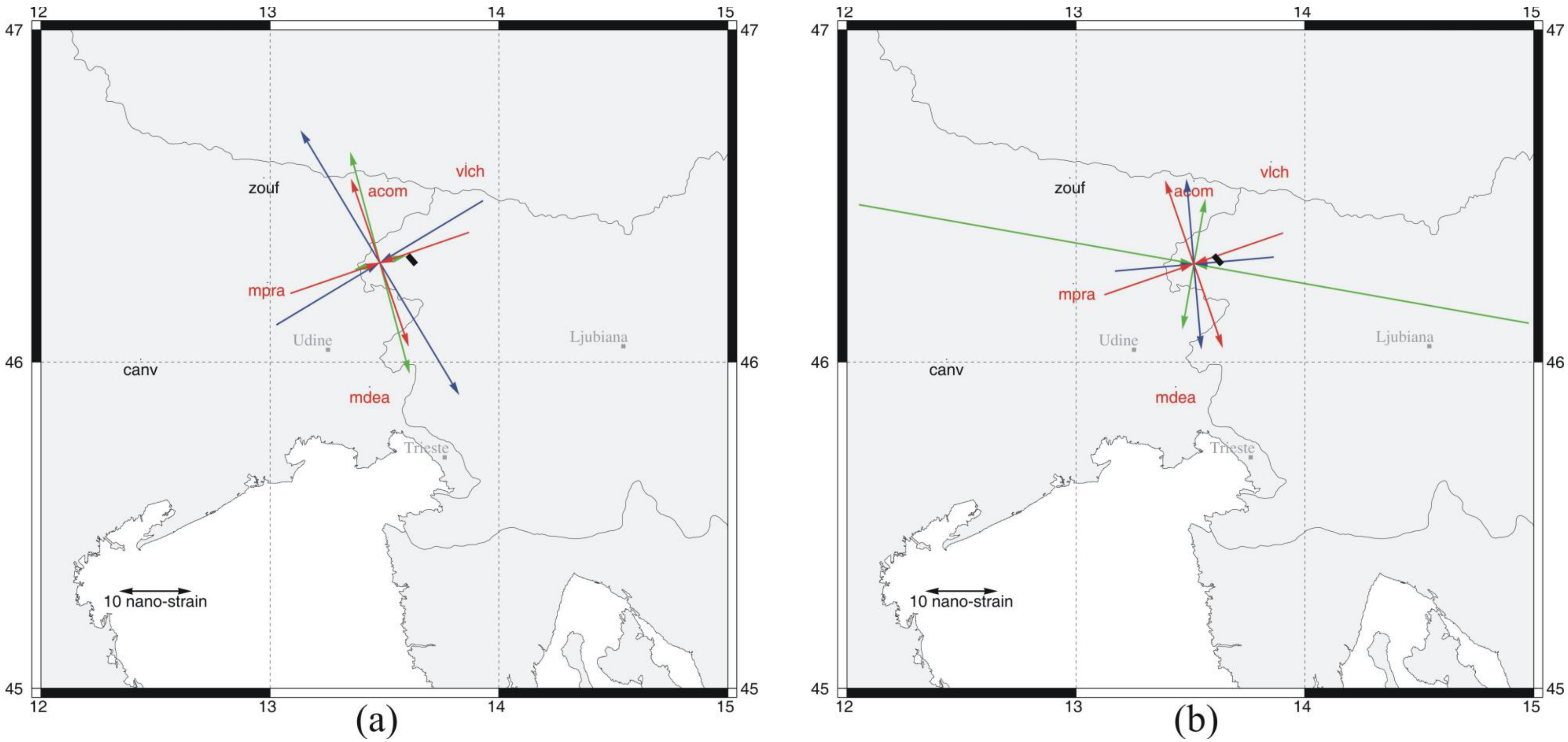
(b)

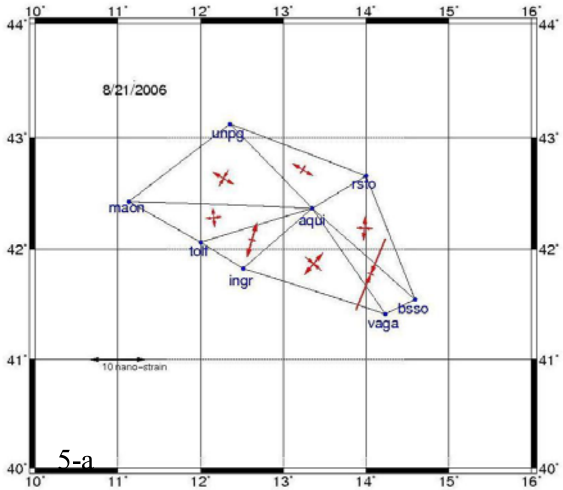
Strain-rate before (a) and after (b) the Krn Mountain 2004 earthquake. Red arrows = strain-rate computed on the whole data set (2002-2008), blue= 6 months before and after.

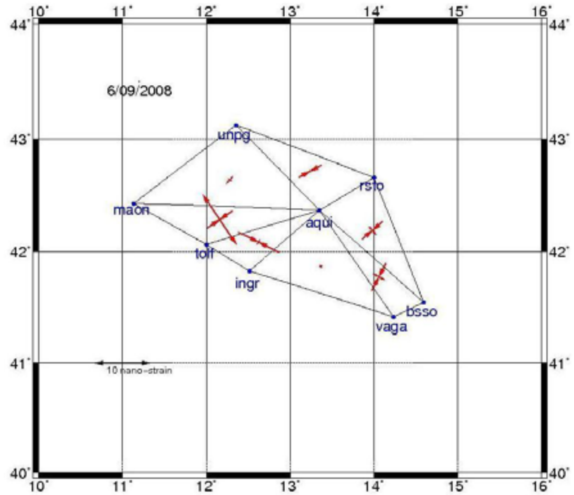


the Mw 6.3April 6, 2009 L'Aquila earthquake

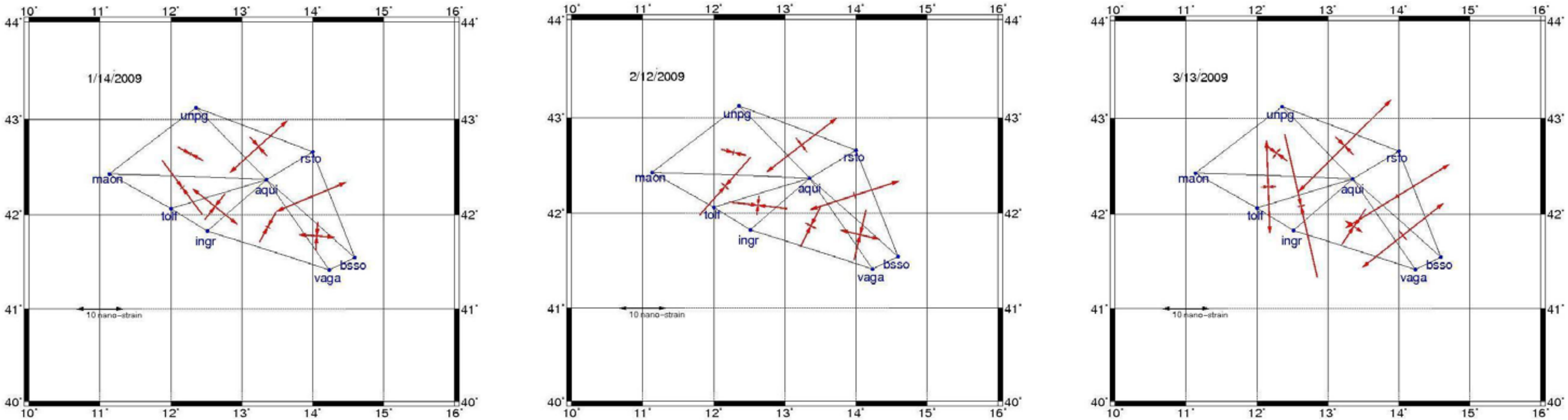
- GPS, InSAR and strong motion data agree on a ~ 16 km SW-dipping shallow normal fault with the city of L'Aquila lying right above the fault hanging-wall.
- A noticeable seismic activity started intensifying 3 months prior to the earthquake and 433 foreshocks with ML <4.1 were recorded and located within a radius of ~20km around the city of L'Aquila: largest foreshocks were recorded on March 30th 2009 with Mw 4.1 and on the 5th of April 2009, ~ 5 hours before the main shock, with Mw 3.9.
- rapid radon changes were reported in the period January – April 2009.
- Extensively discussed in the mass-media (prior the main shock) and led to major concerns both among the local communities as well as within the regional and national authorities.

Mean strain averaged over the six months time interval providing the strain changes with respect to the steady state corresponding to August 2006, June 2008.



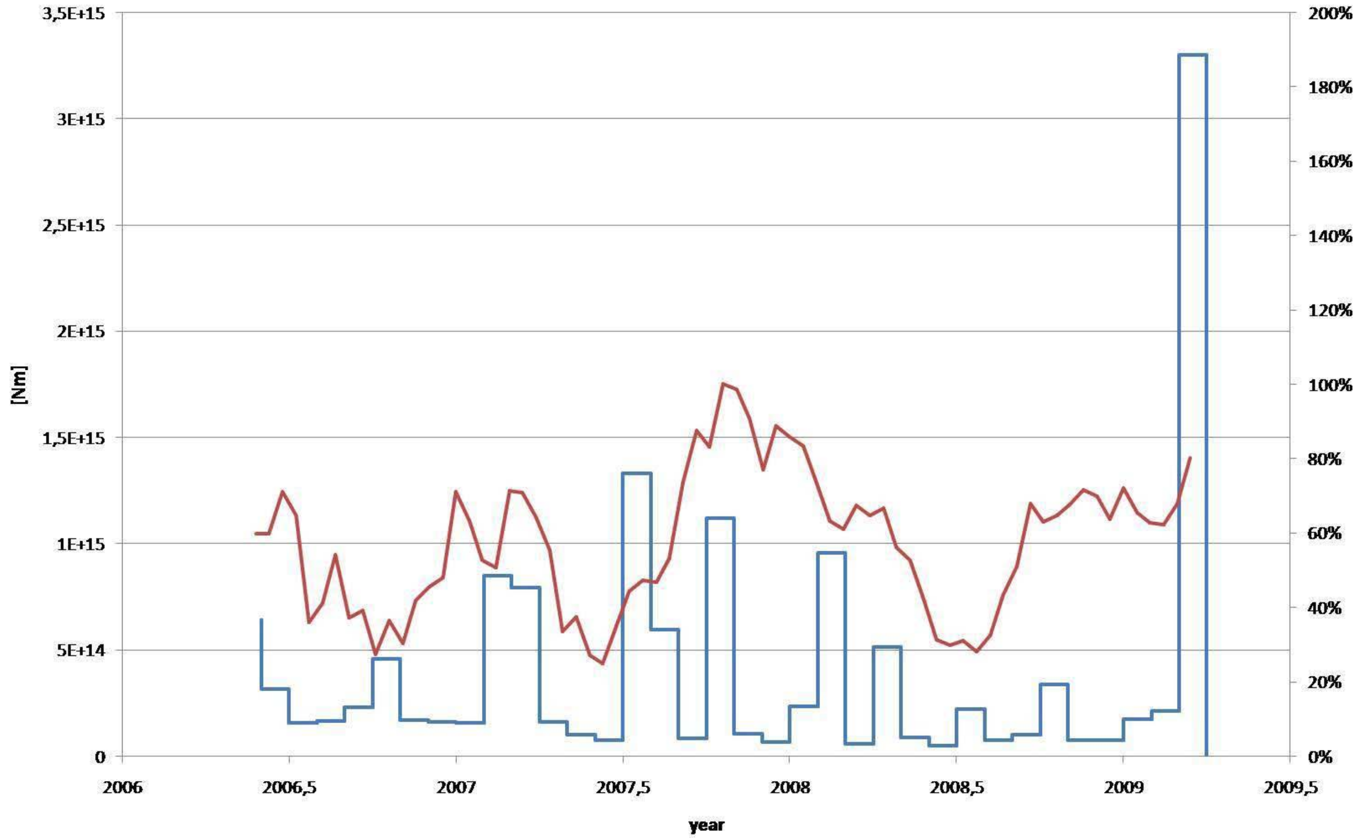


Mean strain averaged over the six months time interval providing the strain changes with respect to the steady state corresponding to January 2009, February 2009, March 2009 (4-h).



4-h

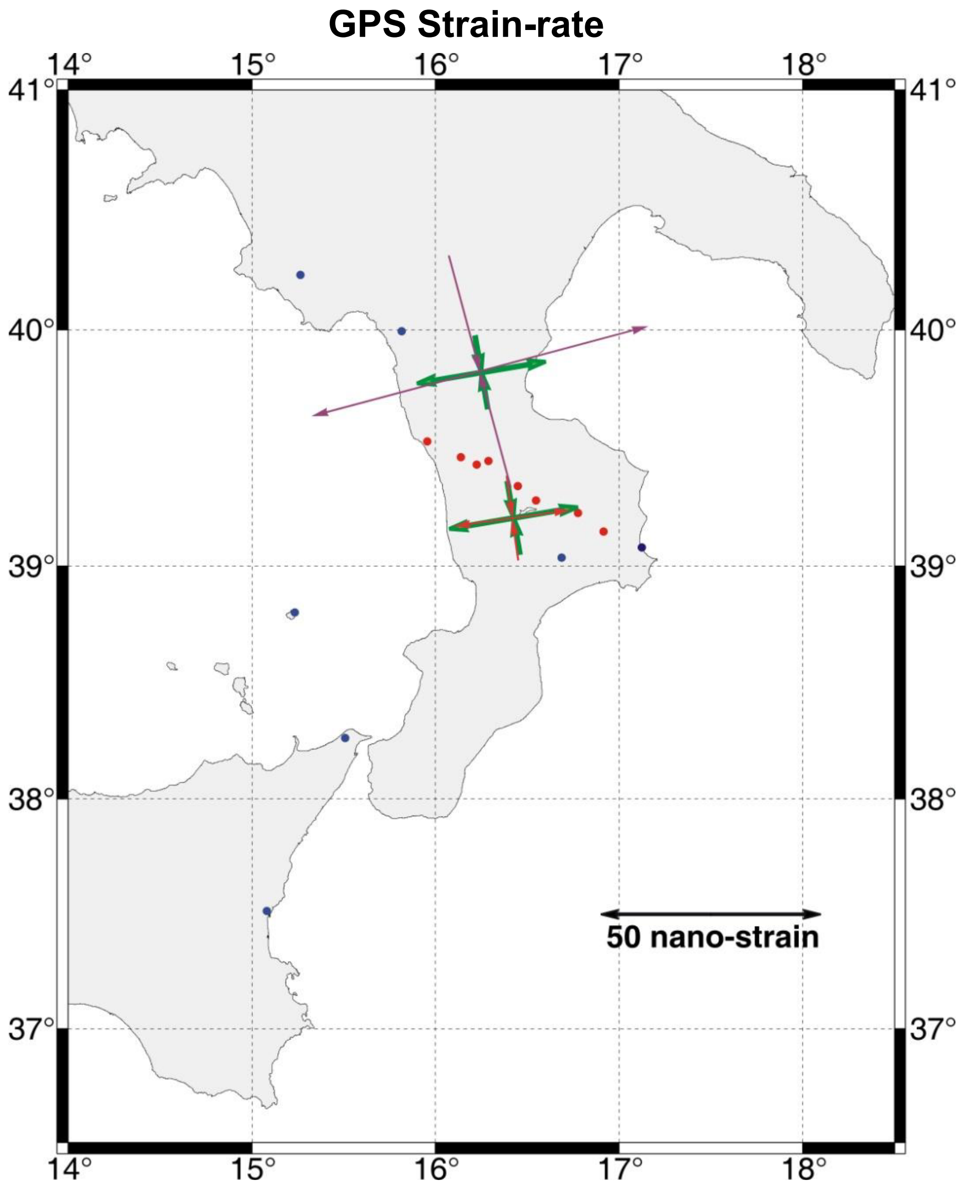
Monthly seismic moment release (blue line) and normalized mean geodetic strain (red line)



Dati Abruzzo

Strain

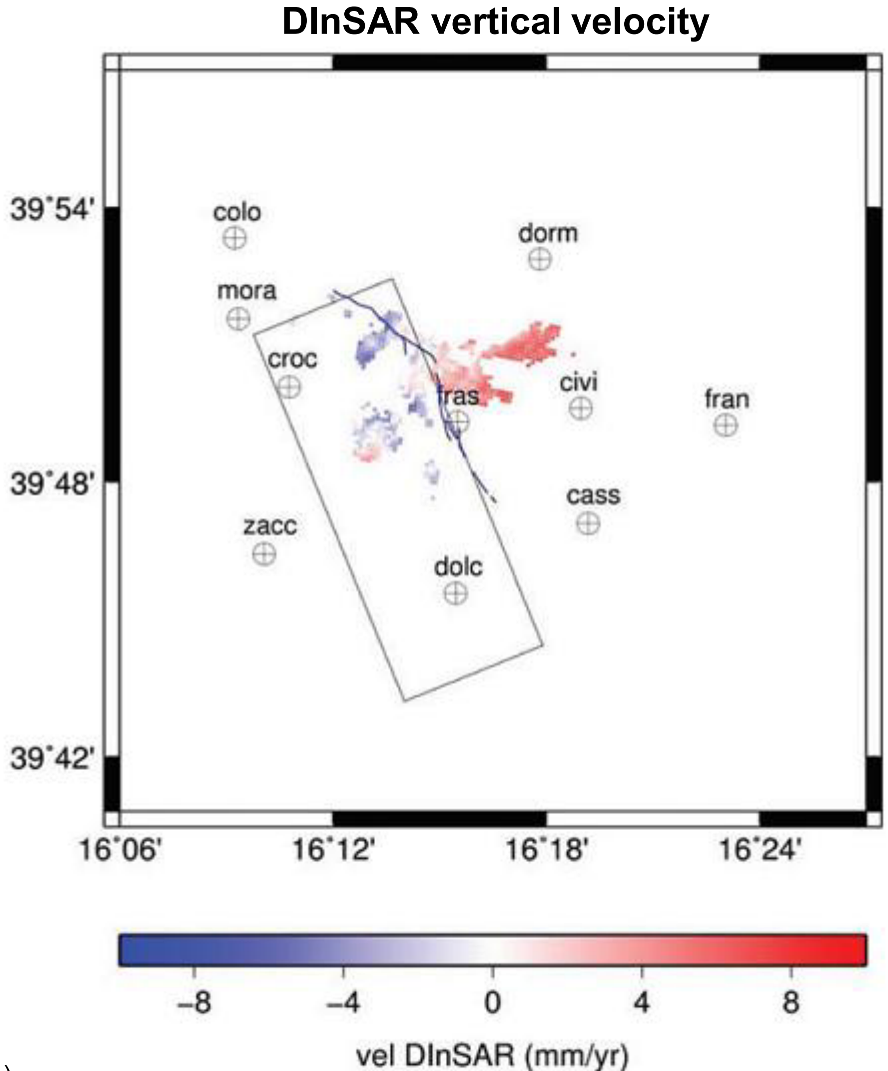
The present-day behaviour of the Castrovillari Fault



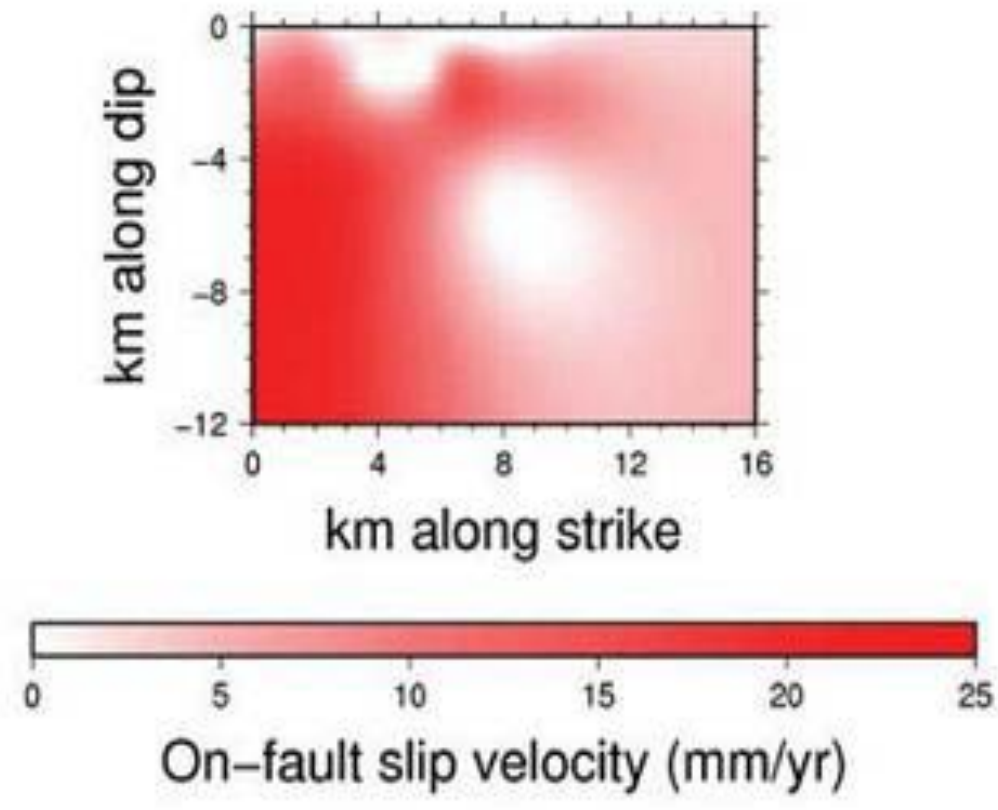
green arrows = mean strain-rate computed with all the CGPS stations;

red arrows = mean strain rate computed with only the UNAVCO stations (red points) except for the KROT station;

violet arrows = mean strain-rate of the campaign GPS station across the Pollino-Castrovillari faults



SAR images covering the period 1995–2000.



Locked central patch (white) surrounded by fast creeping.

Chasing transients in Southern Italy: methodology and preliminary applications

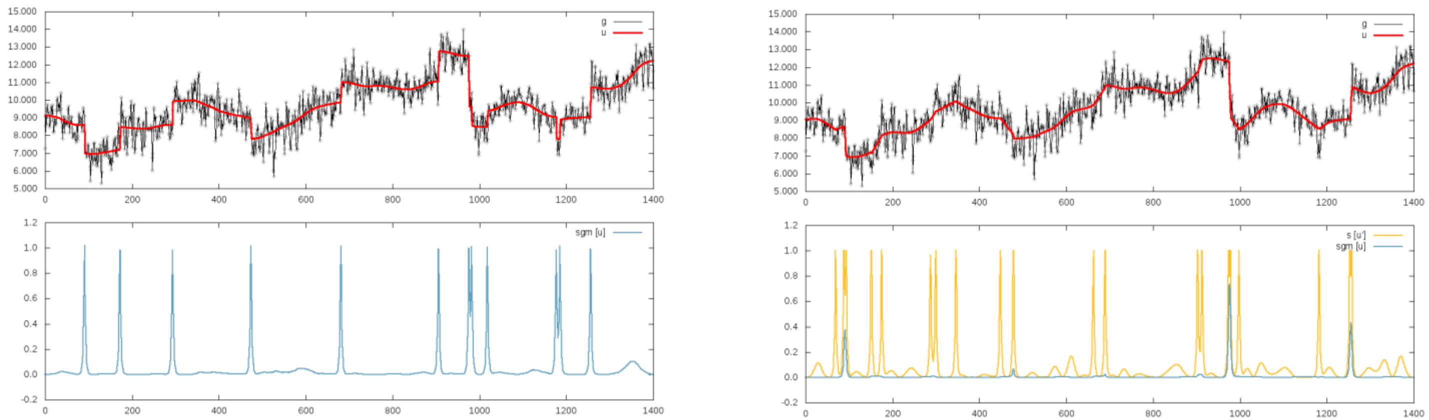
► Methodology

Wavelet transform $\Rightarrow$ discontinuities in the signal

Bayesian approach $\Rightarrow$ discontinuities in the signal

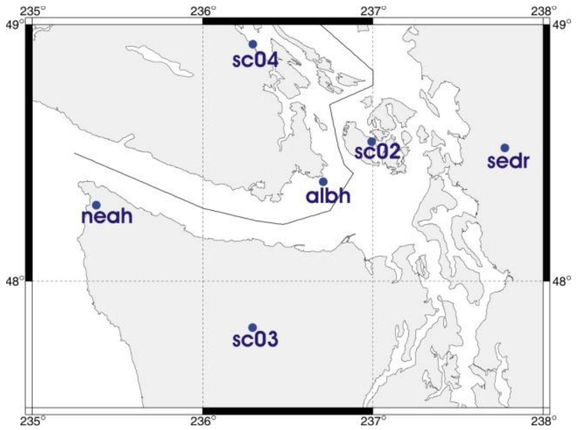
Blake and Zissermann variational model (BZ) $\Rightarrow$ discontinuities in the signal and its derivative

► Testing the methodology in Cascadia

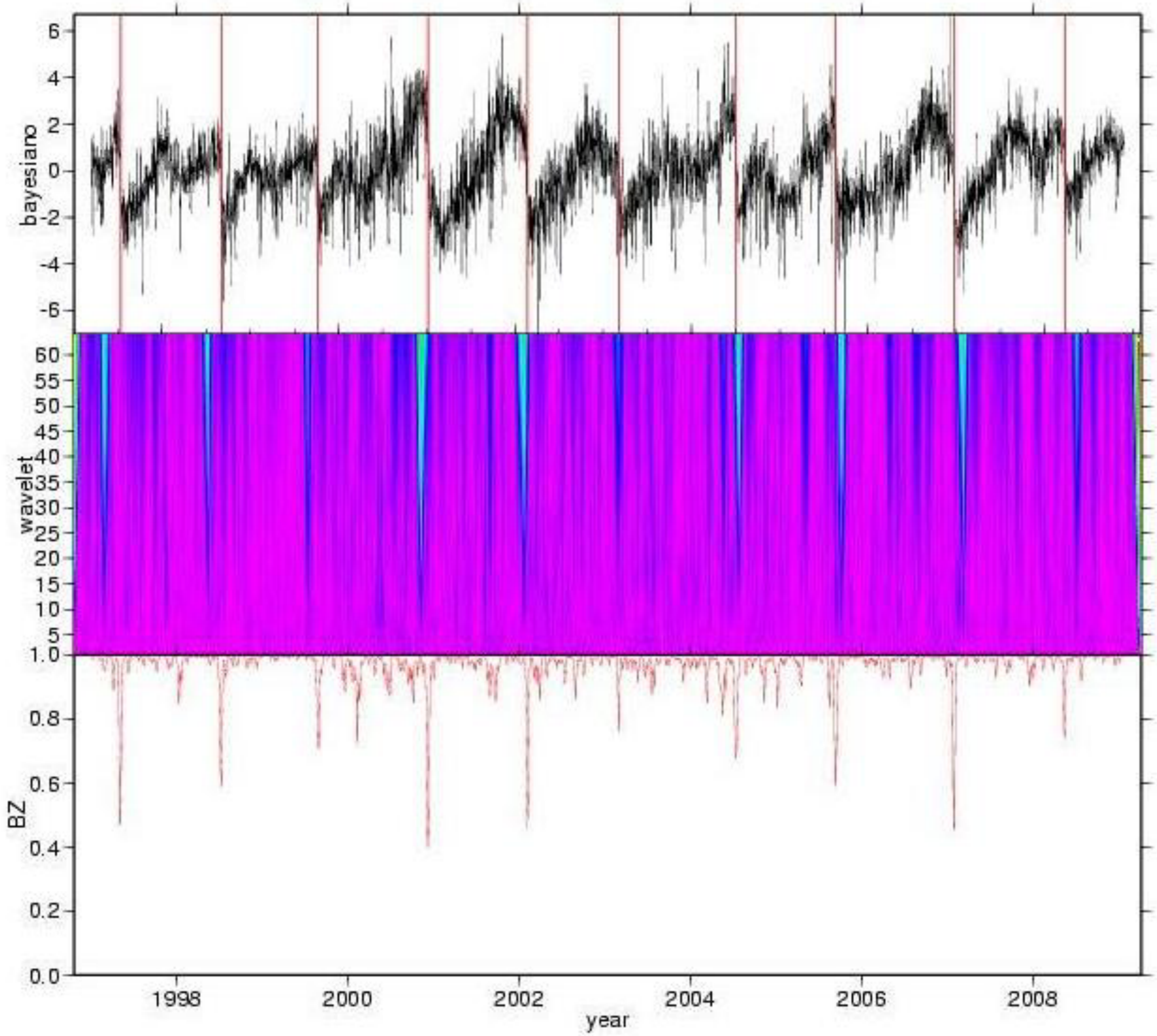


East coordinate residuals of SC02 analysed by BZ method. According to the choice of the BZ parameters, we can focus our analysis on the research of signal discontinuities (blue lines on the left) or signal derivative jumps, i.e. velocity changes (yellow line on the right).

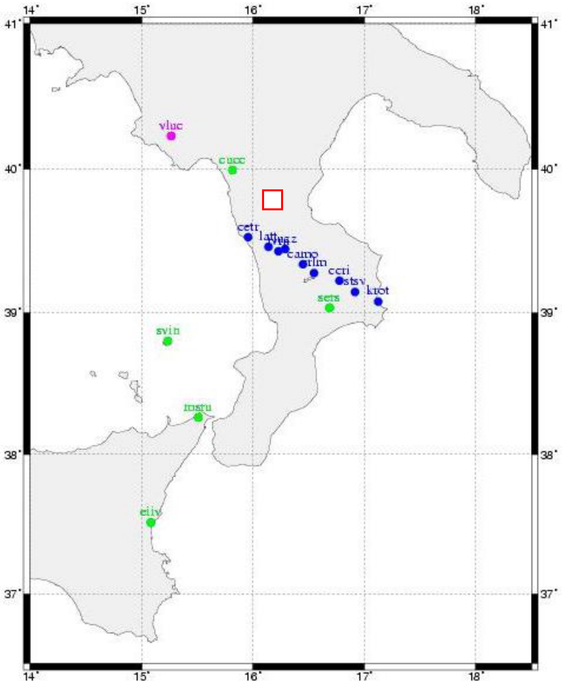
Cascadia



Esempio di individuazione dei salti con I tre metodi utilizzati **ALBH** (coordinata Est)

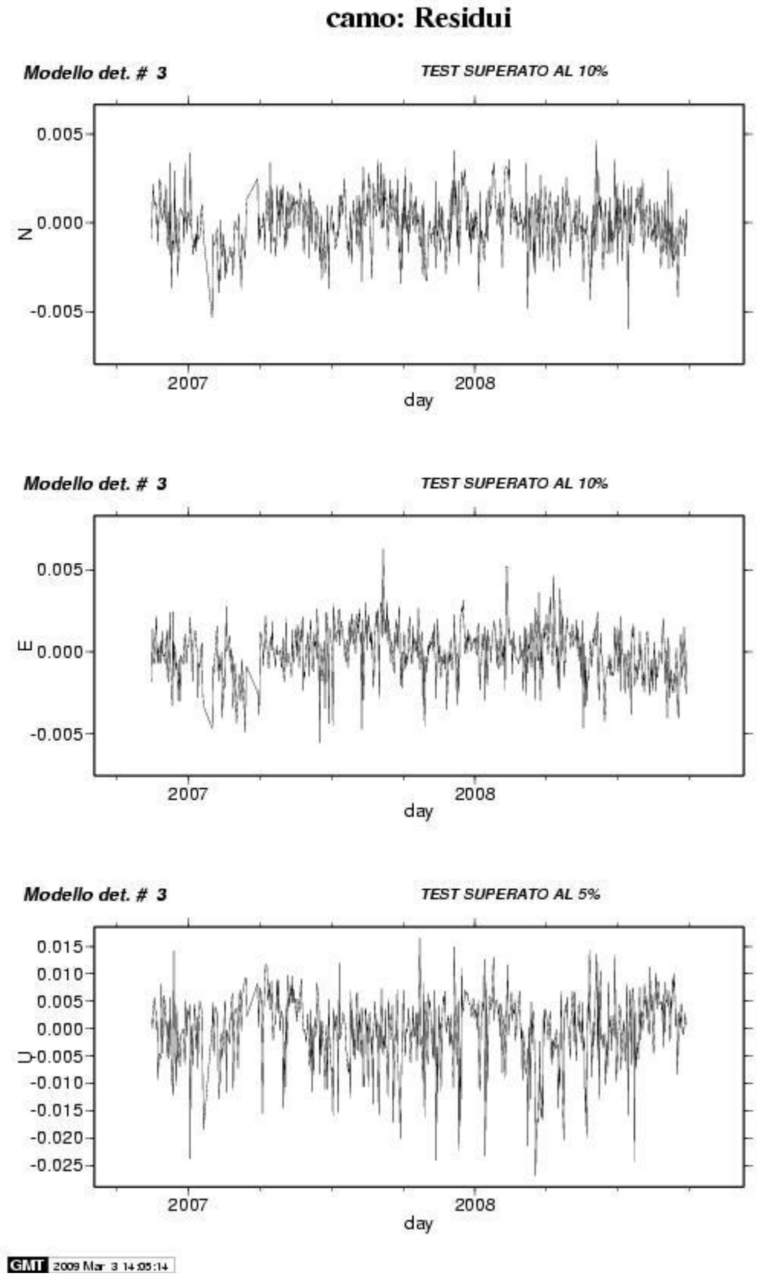


Arco Calabro



- UNAVCO (CatScan)
- RING
- ASI

□ 10 vertici non permanenti
sulla faglia del Pollino-Castrovillari



GPS can help with...

Earthquake response information

- identify fault source, extent and amount of slip
- model finite fault source
- measure and model deformation field
- provide all above to emergency responders

Damage estimation

- provide data for use in shake maps
- support of remote sensing and positioning for accurate and timely collection, reporting and control of other data that require accurate position and/or timing
- monitor large engineered structure

Early warning system

fault slip sensors in real-time to detect fault slip at the surface

GPS is cool...
but there are many layers to the onion...

- *Phase biases*
- *Imperfect clocks*
- *Indices of refraction*
- *Satellite-Earth-GPS geometry*
- *Other effects*
  - *Loading (tidal, hydrological, ...)*
  - *Electrical environment (satellite antennas, receiving antennas)*
  - *Use of different antennas for the same monument*
  - *Dome...*