The Abdus Salam International Centre for Theoretical Physics

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Asi-Sisma Presentations

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ITALY

SISMA Project

The role of GNSS in SISMA project

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Seismic Risk Mitigation & Sustainable Development

The Abdus Salam International Centre for Theoretical Physics

14 May 2010, Miramare - Trieste

Outline

- List of present GNSS products inside SISMA project
- Description of the algorithms of GNSS SISMA Software applied at regional scale
- Example of GNSS product at regional scale
- Description of the algorithms of GNSS SISMA Software applied at local scale
- Example of GNSS product at local scale
- Conclusions

The SISMA products of the GNSS

At <u>Regional</u> scale:

- Maps of crustal strain and strain-rate tensors, which provide a description of the tectonic process over the Italian region

At <u>Local</u> scale:

- Maps of crustal strain and strain-rate tensors, which provide a description of the fault strain accumulation

The SISMA products of the GNSS

All maps are derived by GNSS coordinate time series analysis

At Regional scale:

- Daily data collected by several GPS Permanent Station Networks are analysed. The GPS stations cover the Italian territory

At Local scale:

- Periodical data collected by means of GPS campaigns are analysed. The GPS vertices are located for monitoring fault system purpose

The SISMA software for GNSS time series analysis

At <u>Regional</u> scale:

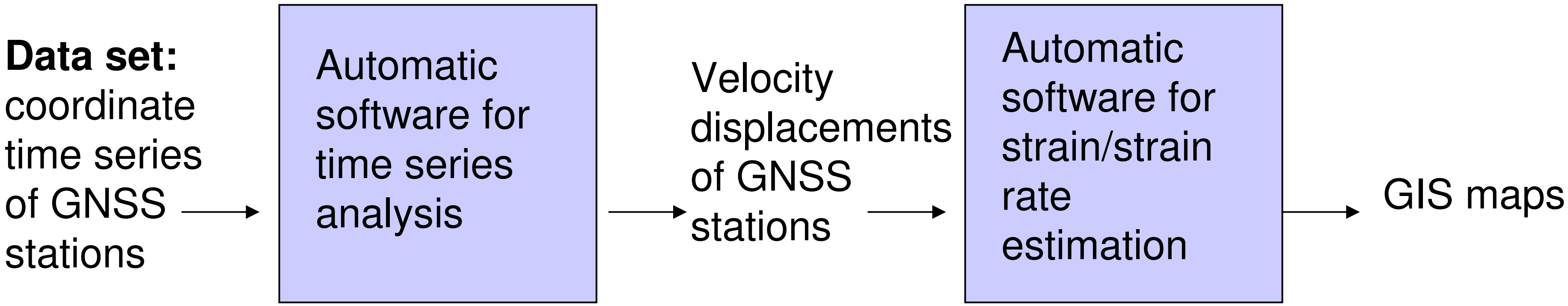
- *gnss_naz* is the developed automatic software for GNSS coordinate time series analysis coming from GPS permanent stations

At <u>Local</u> scale:

- *gnss_loc* is the developed automatic software for GNSS coordinate time series coming from GPS local campaigns.

The SISMA software for GNSS time series analysis

Flow diagram of GNSS data analysis



The algorithms of regional GNSS time series analysis are quite different from those of local GNSS time series. The main characteristics will be briefly described

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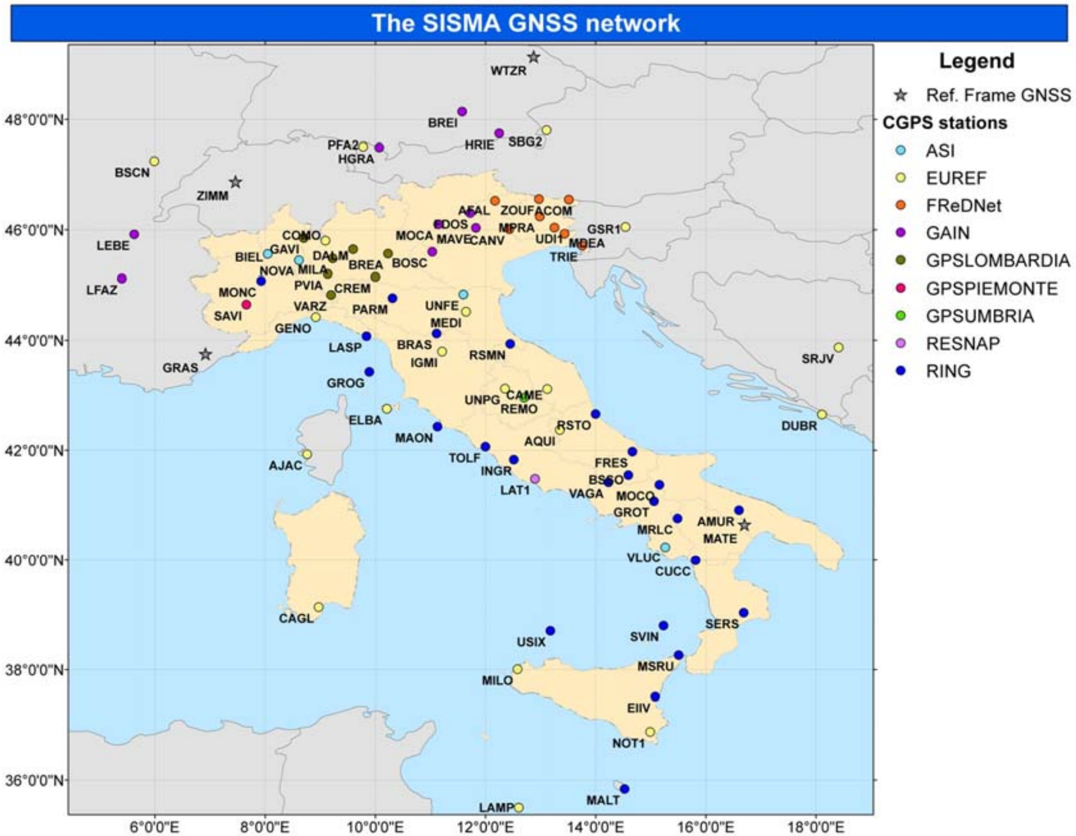
The regional GPS network



- ~ 80 GNSS Permanent Stations belonging to several Networks set up for quite different purposes
- Freely available on ftp sites
- Collected data must be at least three years long: it is simple to add or remove other stations

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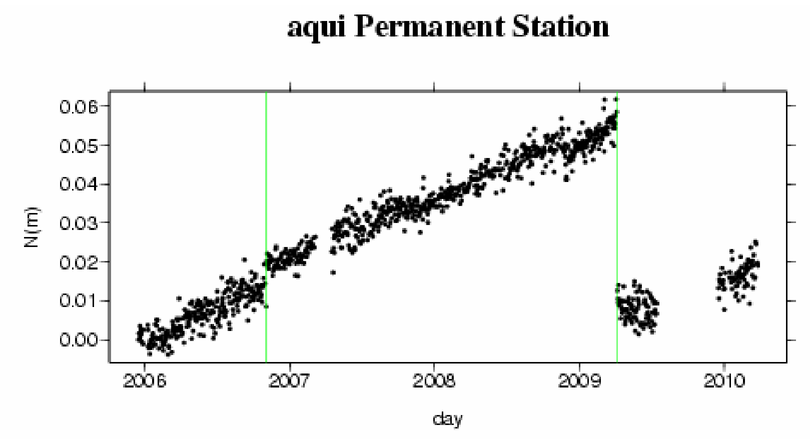
GPS data processing

• Inside SISMA project the GPS data processing software used for regional analysis is NDA Professional, which was developed by Galileian Plus.

• NDA Professional computes automatically coordinates time series for the network stations.

• At the moment the available time span of the GNSS coordinate time series are four years long, starting from 2006

The steps of the automatic *gnss_naz* software



1° Step: removal of outliers and known discontinuities due to:

- technical equipment changes (i.e. GNSS antennas)
- not straight alignment of Reference Frames transformation parameters
- co-seismic effect

2° Step: linear and periodic parameter estimations by least square adjustment

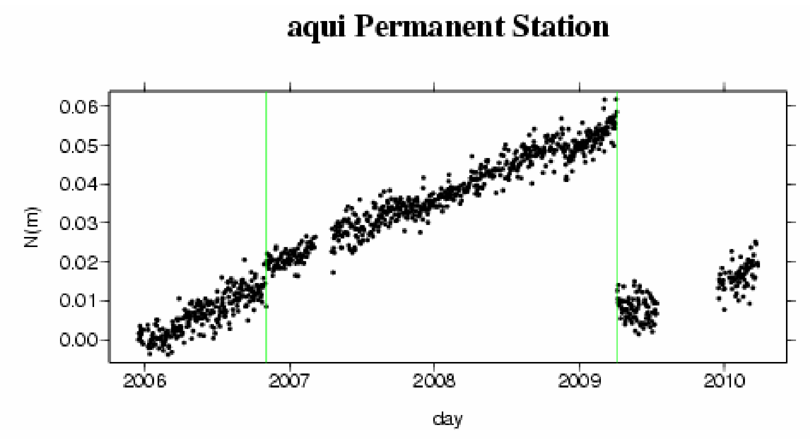
3° Step: generalised KPSS test on residuals for assessment of stationary behaviour

4° Step: account of coordinate time series correlations

- Stationary residuals → Estimate of the Empirical Covariance Function
- Not stationary residuals → simplified White Noise + Flicker Noise model (Williams, S.D.P., 2003)

5° Step: linear and periodic parameter re-estimations by least square adjustment applying the correct stochastic model

The steps of the automatic *gnss_naz* software



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The deterministic model for GPS time series analysis

Functional model

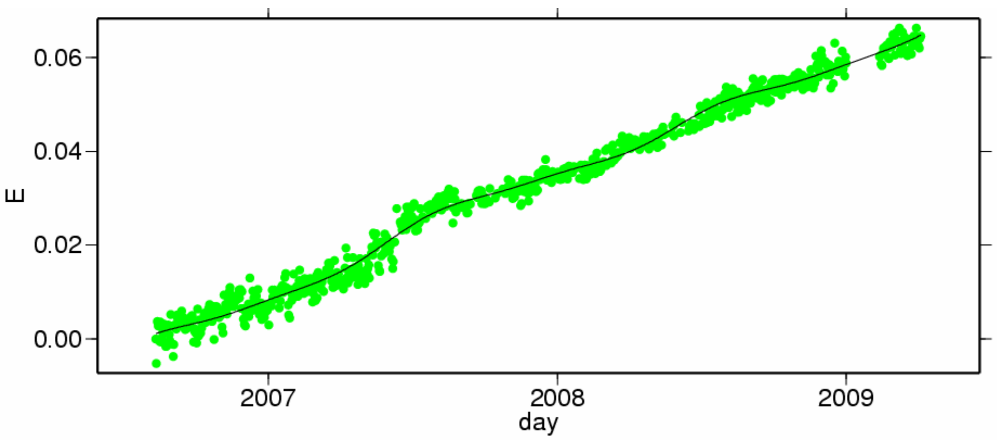
$$y_i = a + bt_i + \sum_{m=0}^{m_0} \left[A_m \cos(\omega_m t_i) + B_m \operatorname{sen}(\omega_m t_i)\right] + \sum_{k=1}^{j} H(t_i - T_k) g_k + \varepsilon_i$$

Stochastic model

$$C_{yy} = \operatorname{diag}(C_{yy})$$

Where:

- a is the intercept
- b is the displacement rate due to plate tectonic motion
- A_m, B_m are cosine and sine amplitudes at frequency $f_m=2\pi\omega_m$.
- $H(t_i-T_k)$ is the Heaviside function, which equals 1 for $t_i > T_k$
- g_k are the amplitude of any offset due to co-seismic events, Reference System or GPS Antenna or Receiver changes
- ε_i is the noise component



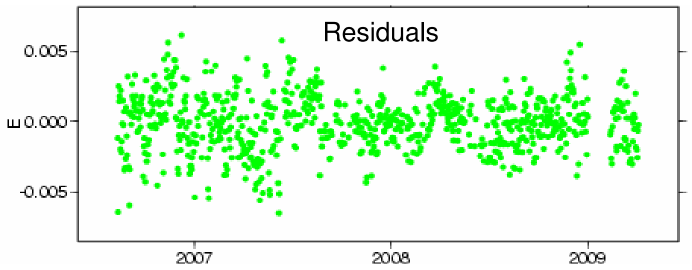
The frequencies f_m and their maximum number m_0 are chosen among the most significant Lomb's periodogram peaks.

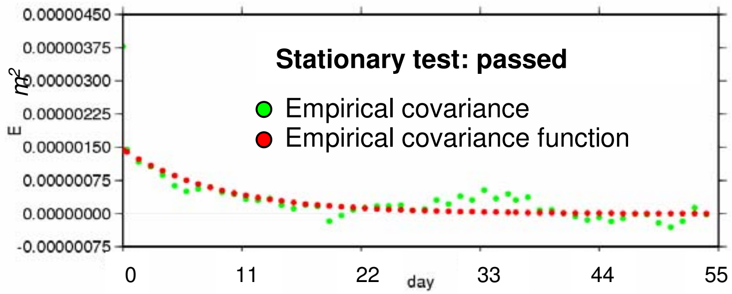
The stochastic model for GPS time series analysis

$$y_i = a + bt_i + \sum_{m=0}^{m_0} \left[A_m \cos(\omega_m t_i) + B_m \operatorname{sen}(\omega_m t_i)\right] + \sum_{k=1}^{j} H(t_i - T_k) g_k \boxed{+ \varepsilon_i}$$

Stationary domain

$$C_{yy} = \operatorname{mod}\left(\hat{C}_{yy}\right)$$





Not Stationary domain

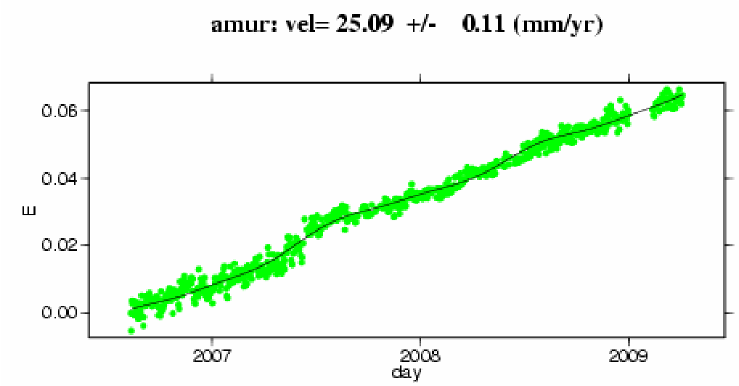
$$C_{yy} = \sigma_w^2 I + \sigma_f^2 Q_f$$

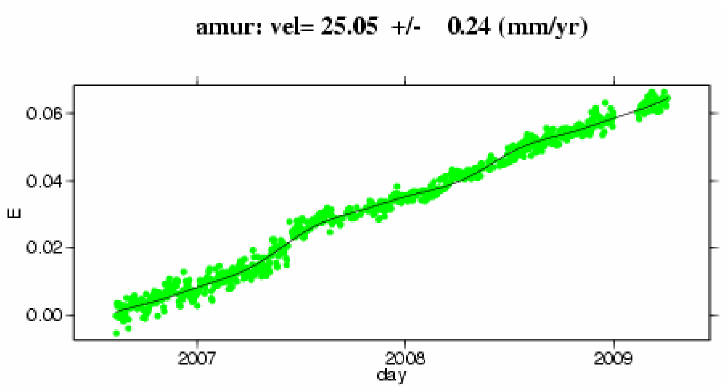
(Williams, S.D.P., 2003)

Final parameter estimates

$$
\begin{cases}
y_i = a + bt_i + \sum_{m=0}^{m_0} \left[A_m \cos(\omega_m t_i) + B_m \operatorname{sen}(\omega_m t_i)\right] + \sum_{k=1}^{j} H(t_i - T_k) g_k \boxed{+ \varepsilon_i} \\
C_{yy} = \operatorname{mod}\left(\hat{C}_{yy}\right) \qquad \text{OR} \qquad C_{yy} = \sigma_w^2 I + \sigma_f^2 Q_f
\end{cases}
$$

Stochastic model **AMUR GPS Permanent station**	**North**	**East**	**Up**
Velocity estimate under in-correlation hypothesis	18.81 +/- 0.10	25.09 +/+ 0.11	3.05 +/- 0.33
Velocity estimate by ECF	18.79 +/- 0.13	25.05 +/- 0.24	3.20 +/- 0.59





Remarks on gnss_naz software

1. The software is automatic and the network can be modified easily

2. The software attempts to combine the present day scientific knowledge on GPS time series analysis coming from different approaches:

   - The software is intended to looking for proper functional model

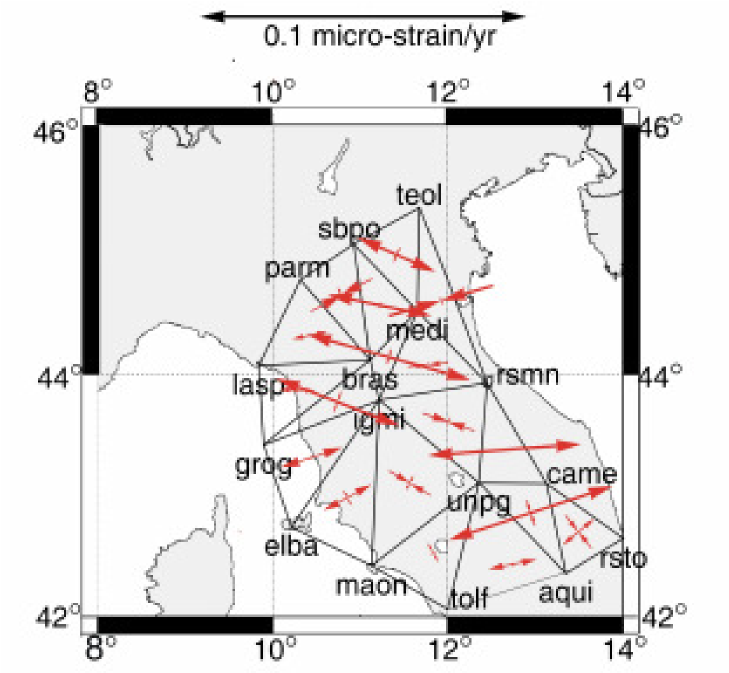
     Nikolaidis, R., 2002. Observation of Geodetic and Seismic Deformation with the Global Positioning System, PhD thesis. University of California, San Diego
     Amiri-Simkooei A.R., Tiberius C.C.J.M., Teunissen P.J.G. (2007), "Assessment of noise in GPS coordinate time series: Methodology and results", Journal of geophysical research, 112, B07413.

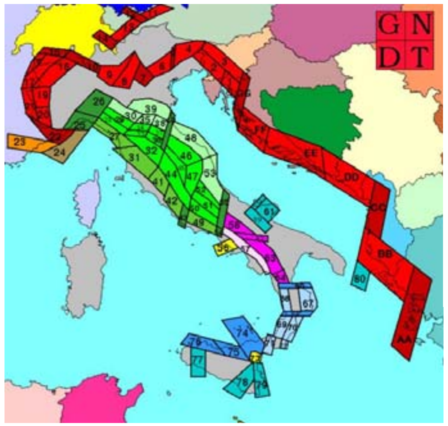
   - The software is intended to looking for proper stochastic model

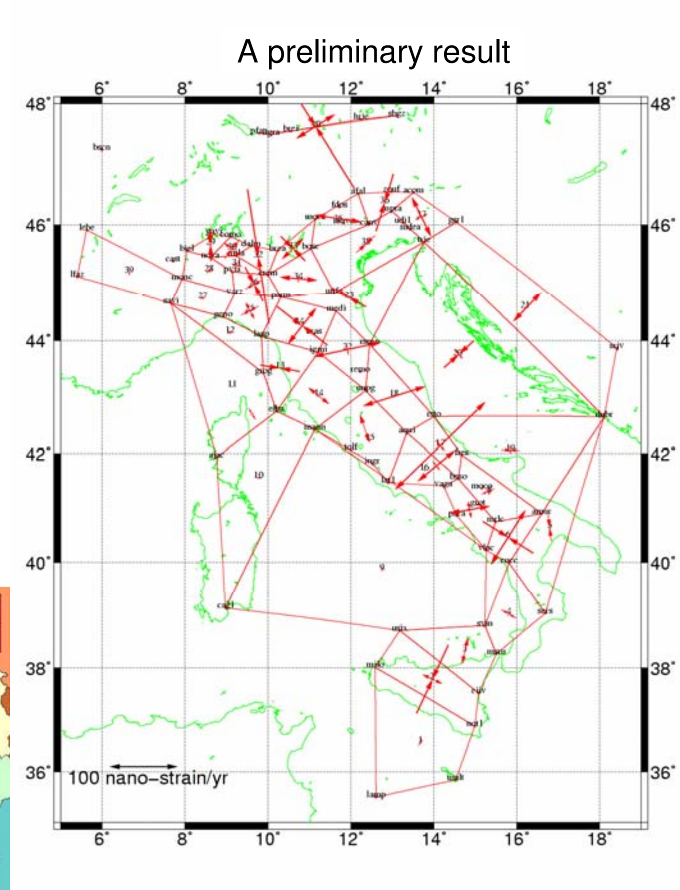
     Williams S.D.P. (2003), "The effect of coloured noise on the uncertainties of rates estimated from geodetic time series", Journal of Geodesy, 76, 483-494.
     Cannizzaro L. (2008), "Analysis of temporal correlations in GPS time series: comparison between different methods at different space scale", PhD Thesis in Geodesy and Geomatics, Politecnico di Milano

3. Further improvements are, of course, necessary: e.g. the post-seismic phase in GNSS time series must be developed and further investigated

The Regional scale: the GNSS final product

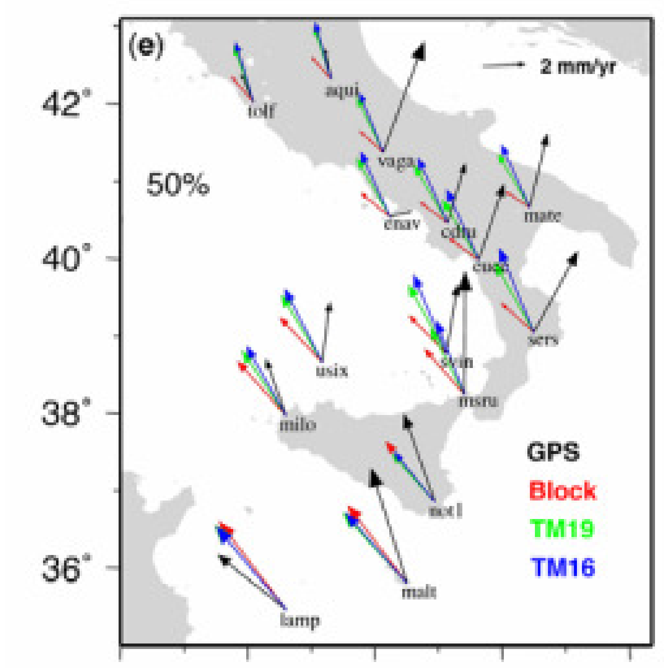




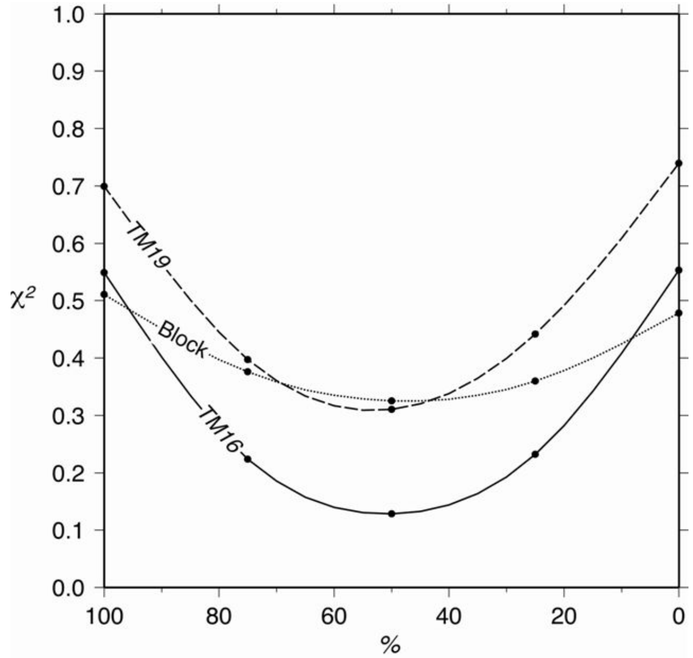


Zonazione sismogenetica ZS9 - App.2 al rapporto conclusivo, C. Meletti, G. Valise et al, marzo 2004. INGV

Other GNSS results



Predicted (coloured arrows) vs GPS velocities (black arrows). The percent represents the amount of Africa–Eurasia convergence transmitted through the Calabrian subduction.



Classification of the geophysical models obtained with the χ^2 analysis. The per cent indicates the percentage of the Africa–Eurasia convergence transmitted to the Eurasian plate through the Calabrian subduction zone.

SPLENDORE, R., MAROTTA, A. M., BARZAGHI, R., BORGHI, A. & CANNIZZARO, L., Block model versus thermo-mechanical model: new insights on the present-day regional deformation in the surroundings of the Calabrian Arc. Geological Society, London, Special Publications, 332, 129–147

The local GNSS scale

The aim of GNSS technique inside the project was also:

- to improve the knowledge of local faults mechanisms by means of local GNSS campaigns
- to provide GNSS data for GFIM partners

An automatic procedure to analyse GNSS local campaign data was developed

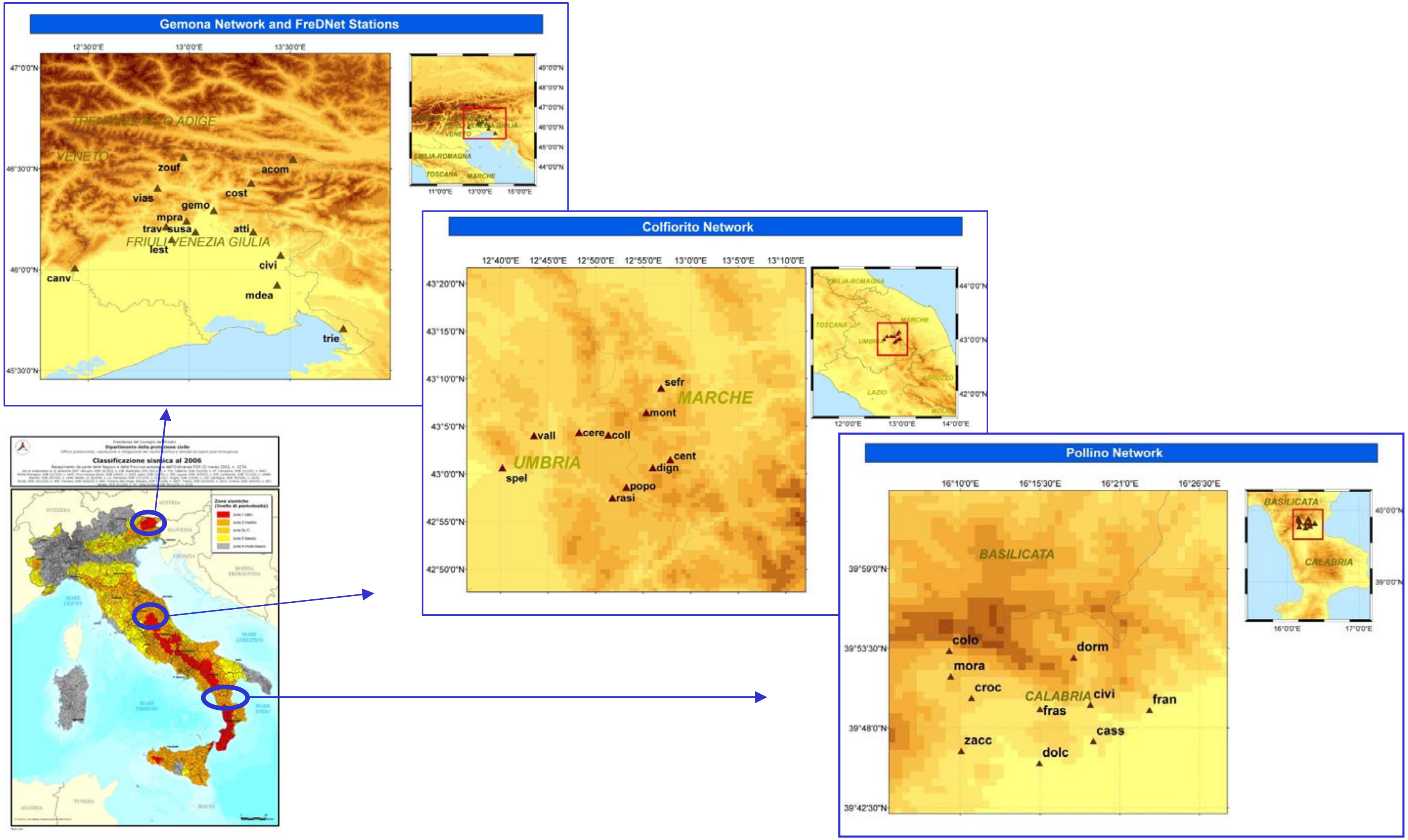
The local campaigns require:

- a dense GPS network in a quite small area
- a careful distribution of the GNSS sites in the studied area
- a solid and expensive monumentation of the GNSS sites
- a significant observation window

Three test areas:

- the GNSS network has been already monumented
- some GNSS campaigns have been already done
- three different earthquake cycle: inter-seismic, pre-seismic and post-seismic phases

The test areas



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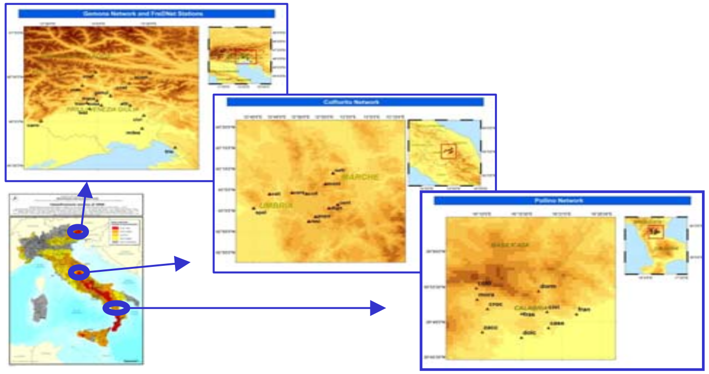
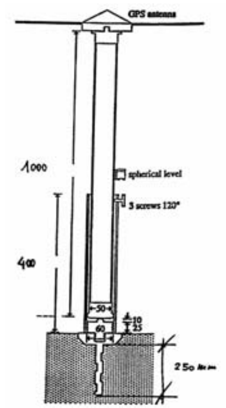
The available campaigns

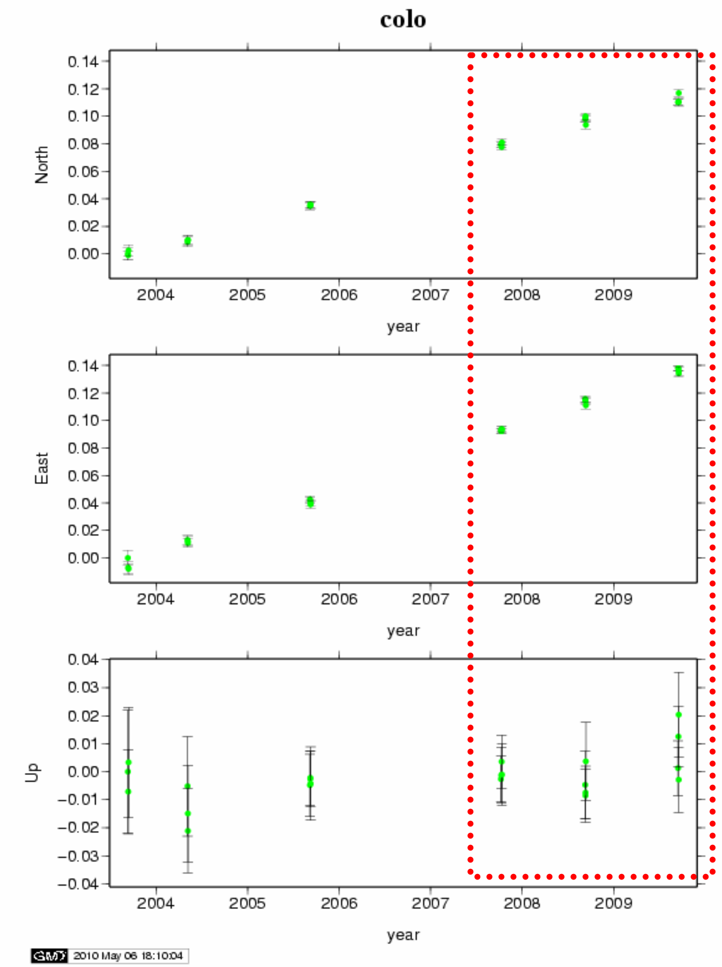




Area	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Tot.
Colfiorito	X	X	X		X					X		**5**
Pollino					X	X	X		X	X	X	**6**
Gemona del Friuli				X		X	X		X		X	**5**

SISMA campaigns

The steps of the automatic *gnss_loc* software



1° Step: estimation of GNSS solutions: GAMIT/GLOBK and NDA professional

2° Step: linear parameter estimations (velocity displacements) by least square adjustment

3° Step: Common Mode Error reduction (Widowinski et al., 1997)

4° Step: unique solution

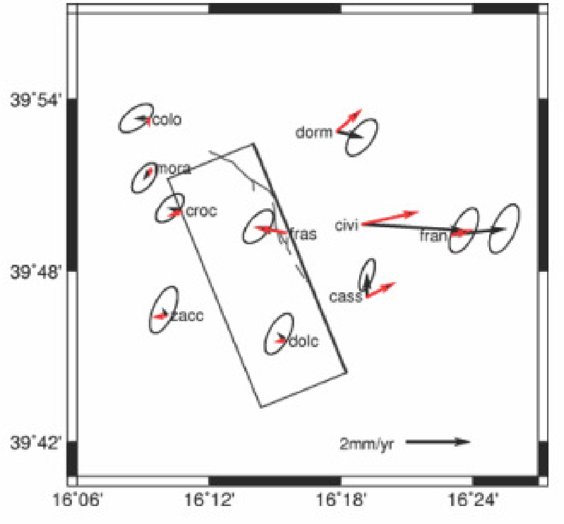
5° Step: velocity re-estimations by least square adjustment

Critical point

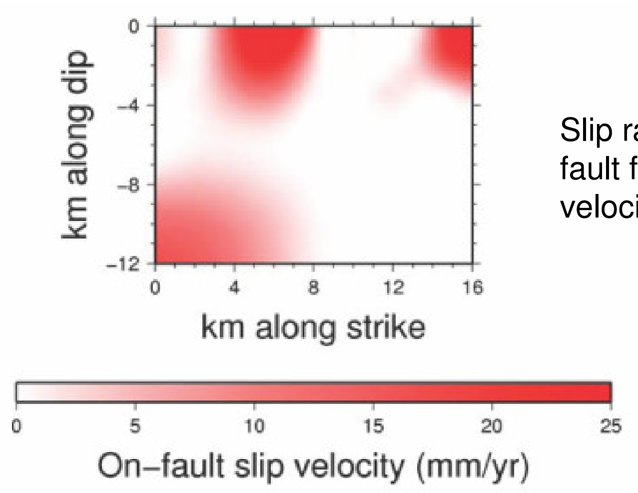
It is difficult to take into account time series discontinuities (e.g. antenna change, Reference Frame residual, co-seismic event)

SISMA campaigns

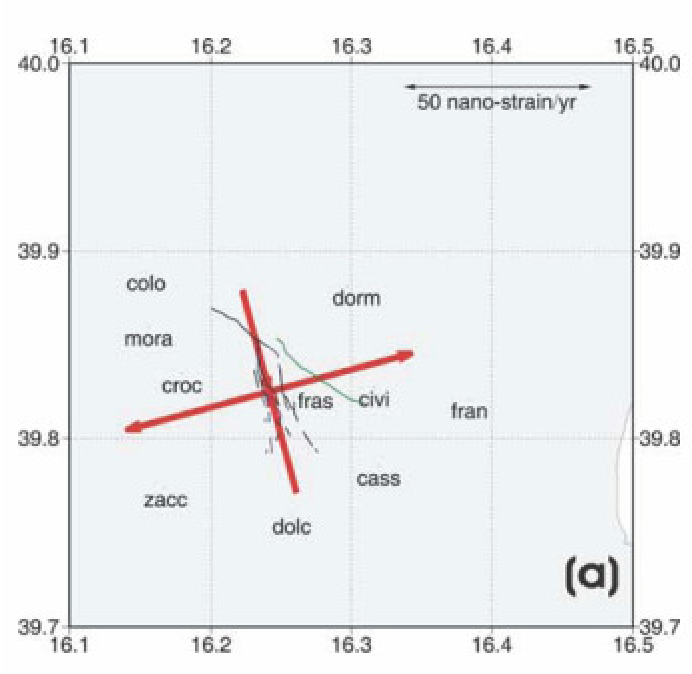
Some results: GPS for GFIM support in Pollino area



GPS velocities (black arrows) in the Eurasian reference frame (defined by the geodetic plate kinematic model APKIM2005) and relative 1σ confidence error ellipses vs. model velocities (red arrows)



Slip rate over the Castrovillari fault from the inversion of GPS velocities.



Mean strain-rates from GPS surveying, at the ten GPS sites in the Pollino Range. The thin grey lines indicate the Castrovillari fault scarps (Cinti et al. 2002)

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Conclusions

The present GNSS contribution inside SISMA project consists in:

• Providing an automatic software that allows a continuous updating of GNSS deformation maps coming from Continuous GPS network analysis.

• Providing an automatic software that allows the analysis of GNSS data for local faults monitoring

V3

At the moment we are studying and looking for geodetic indicators that highlight geodetic anomalous behaviours that could be the used to integrate seismic results and geodesy information.

Thanks for your attention.