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# Stability of the reference frame for structural monitoring

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# Introduction (1/3)

- GNSS technology is nowadays a useful tool for precise positioning applications:
  - Geodynamics
  - Landslide monitoring
  - Structures monitoring
  - Cadastral
  - etc..

… because permits an all-weather and continuous precise positioning (also in real time).

… because is a quite low cost technology, both for instrumentations and for also for monumentation aspects

# Introduction (2/3)

- Nowadays several software packages are availables, both by GNSS manufacturers and by scientific institutions.
  - Scientific software packages: Bernese, Gamit, Gipsy etc..
  - GNSS data-processing software packages: each manufacturer provide a software package both for static and kinematic data processing
  - free and open source software packages: RTKLIB, GoGPS, etc.

- The traditional approach for GNSS monitoring is based on a relative positioning between one (or more) monitoring stations (MS) and one or more reference stations (RS), assumed as stable;

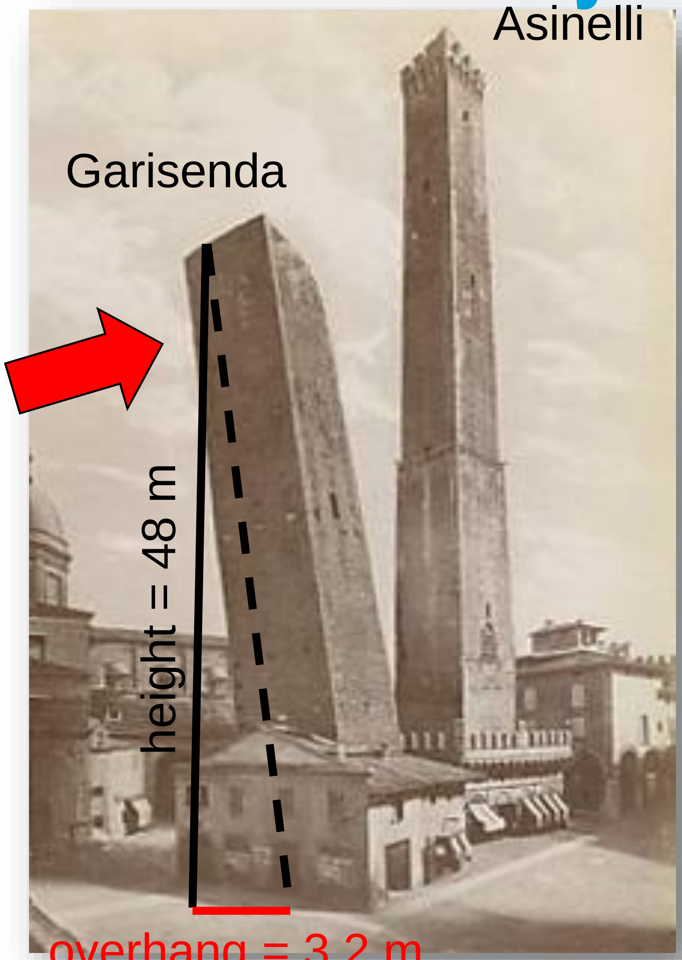
# Introduction (3/3)

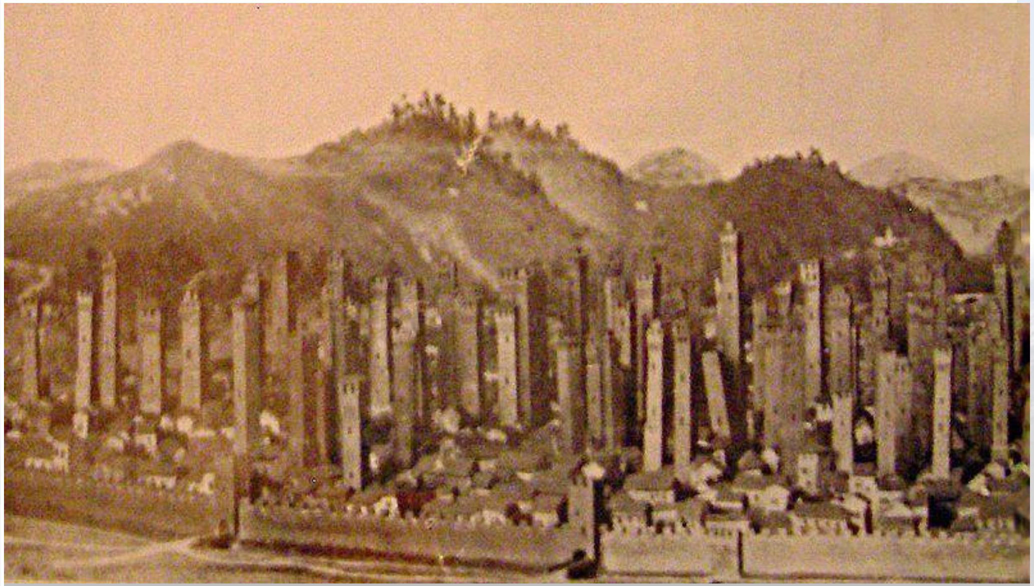
Typically for geodynamics studies (or for example for landslide monitoring) the number of RS is constituted by more than one station but for structures monitoring, considering also the extension of the area and the overall equipment cost, the number of reference stations is almost one (assumed as stable) and closed to the monitoring structure.

**The aim of this work would like to**

**Evaluate the impact of the RS for monitoring applications**

# The case study: Garisenda tower



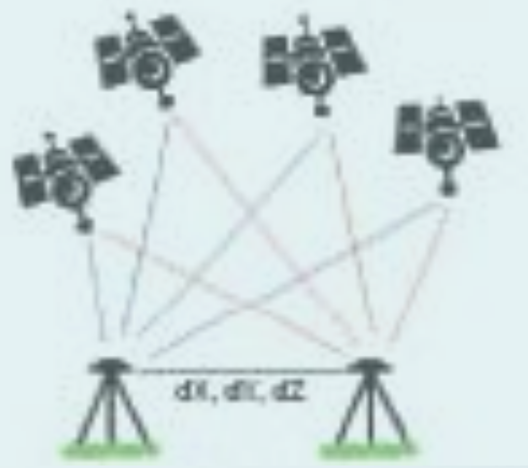
A Landscape of Bologna in the XI Century

One of the most important Bologna’s cultural heritage
Garisenda tower characterized by stability problems

# MS: The Experimentation

- GNSS station - BOGA (dual freq. geodetic receiver)
- Installation: October, 2013
- data continuously sent to the analysis center (School of Engineering of Bologna) using a mobile-phone connection
- Available Dataset: 2 years

# Dataprocessing approach



**Differenced approach**

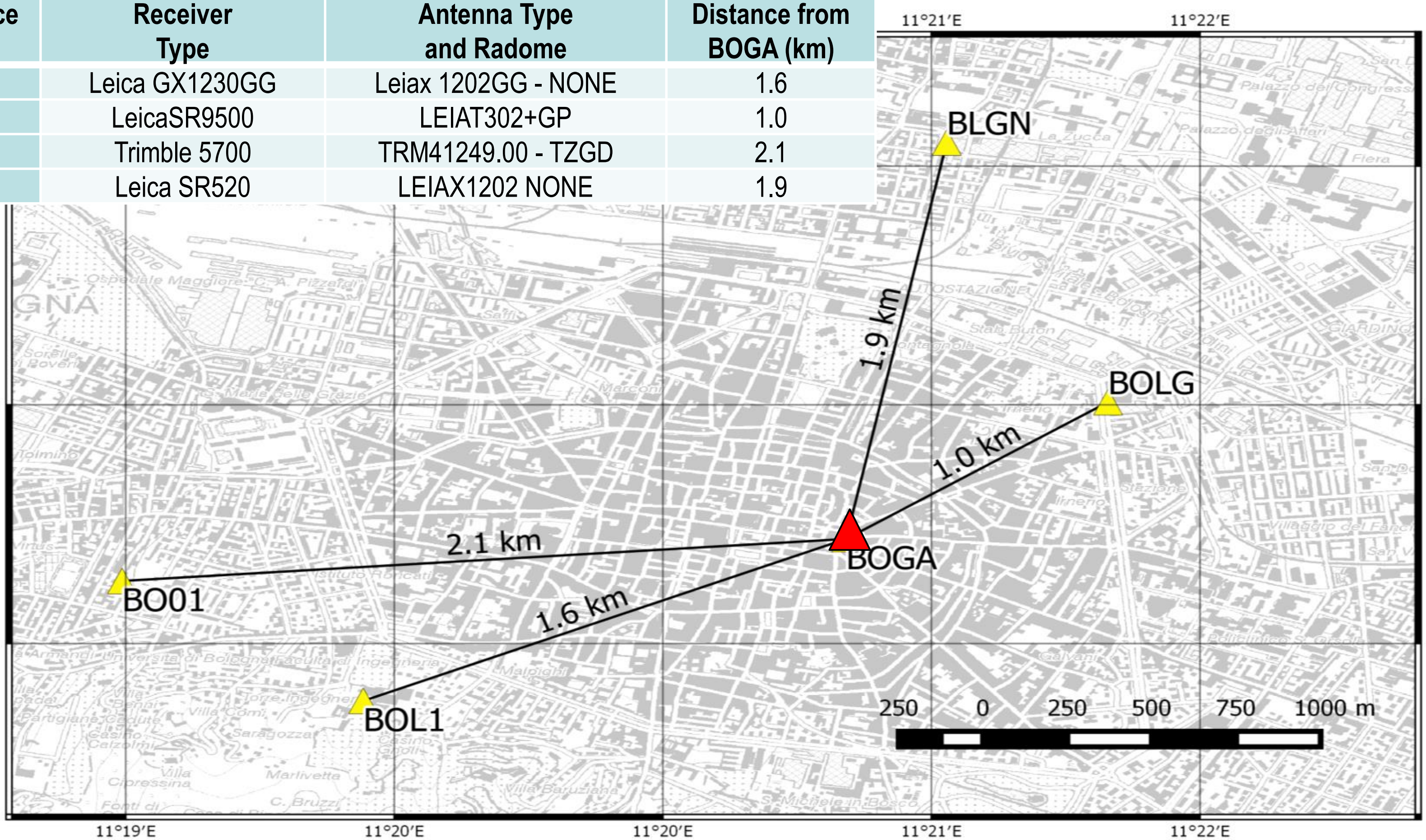
- Relative position estimation
- High repeatability for short baselines
- Any movement of the RS will be transfer into the MS


**Un-differenced approach (PPP)**

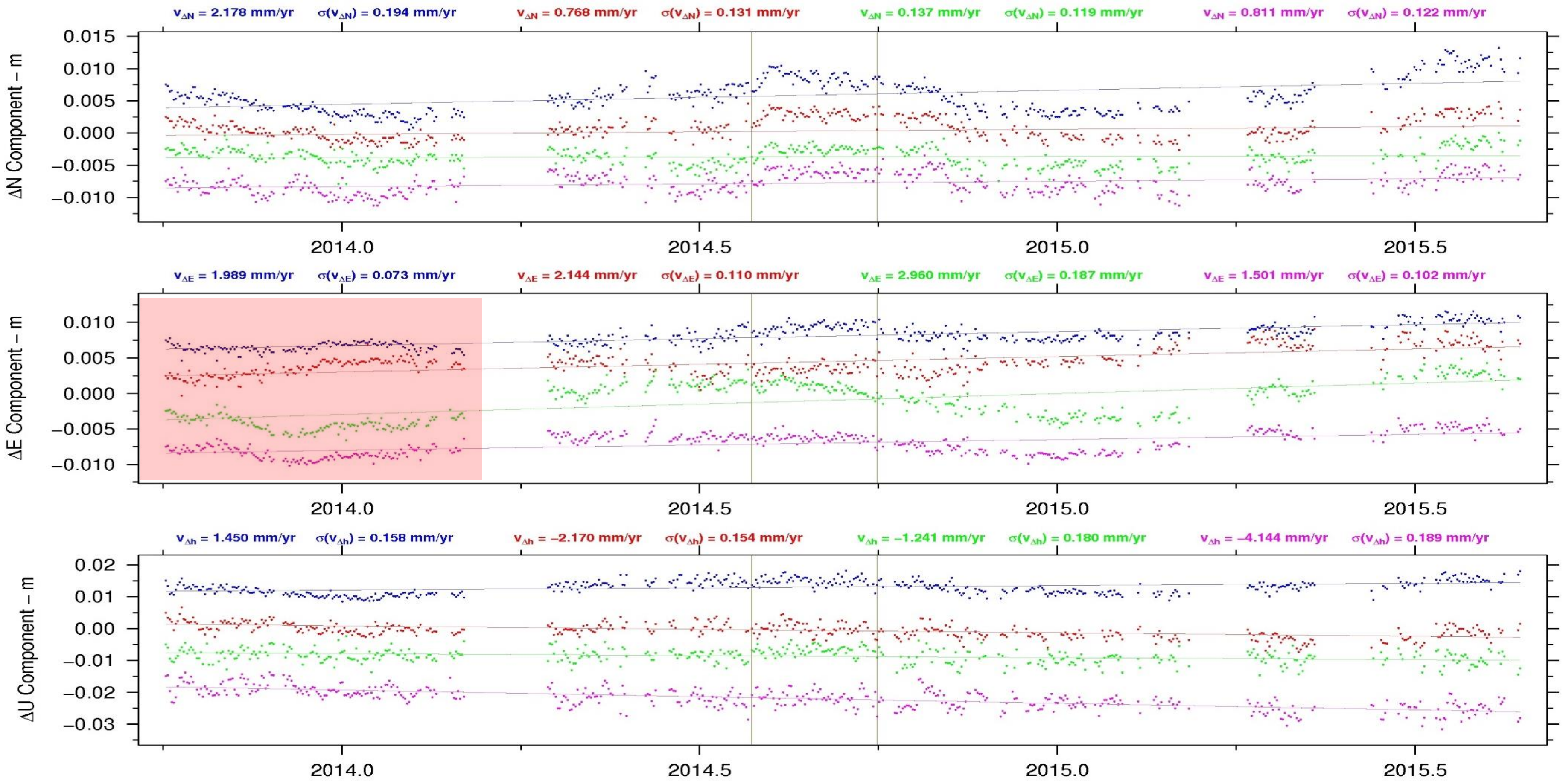
- Absolute position estimation (no direct correlation between two different stations)
- The obtained solutions are expressed in a defined reference frame (ITRF ..ETRF)

# Reference Geodetic Network

| GNSS Reference Station | Receiver Type | Antenna Type and Radome | Distance from BOGA (km) |
|---|---|---|---|
| **BOL1** | Leica GX1230GG | Leiax 1202GG - NONE | 1.6 |
| **BOLG** | LeicaSR9500 | LEIAT302+GP | 1.0 |
| **BO01** | Trimble 5700 | TRM41249.00 - TZGD | 2.1 |
| **BLGN** | Leica SR520 | LEIAX1202 NONE | 1.9 |



# First test: different solution for each RS




NEU Reference System, solution are biased for graphical needs

# First test: preliminary comment

In case of real stability of each RS, and a quite good (stable) location of the RS, we expect that all the four solutions evidence “the same things”.

Defining the Pearson correlation coefficient as $\rho_{XY} = \dfrac{\sigma_{XY}}{\sigma_X \sigma_y}$

we expect for the four time series are characterized by a very high Pearson correlation parameter [E(ρ)=1] because we start from the same data of the MS.

# First test: Result discussion

Results:

Correlation coeff. respect BOL1

| Time Series | $\rho_N$ | $\rho_E$ | $\rho_U$ |
|---|---|---|---|
| $BOGA_{\mathrm{BOLG}}$ | 0.62 | 0.70 | 0.03 |
| $BOGA_{\mathrm{BO01}}$ | 0.90 | 0.65 | 0.29 |
| $BOGA_{\mathrm{BLGN}}$ | 0.59 | 0.64 | -0.28 |
| **Average** | **0.70** | **0.66** | **0.02** |

Mean Vel.

| Time Series | $\overline{\mathrm{V}}_{\mathrm{N}}$ (mm/y) | $\sigma_{\overline{\mathrm{V}}_{\mathrm{N}}}$ (mm/y) | $\overline{\mathrm{V}}_{\mathrm{E}}$ (mm/y) | $\sigma_{\overline{\mathrm{V}}_E}$ (mm/y) | $\overline{\mathrm{V}}_U$ (mm/y) | $\sigma_{\overline{\mathrm{V}}_U}$ (mm/y) |
|---|---|---|---|---|---|---|
| $BOGA_{\mathrm{BLGN}}$ | 0.82 | 0.12 | 1.50 | 0.10 | -4.14 | 0.19 |
| $BOGA_{\mathrm{BO01}}$ | 0.77 | 0.13 | 2.14 | 0.11 | -2.17 | 0.15 |
| $BOGA_{\mathrm{BOL1}}$ | 2.18 | 0.19 | 1.99 | 0.07 | 1.45 | 0.16 |
| $BOGA_{BOLG}$ | 0.14 | 0.12 | 2.96 | 0.19 | -1.24 | 0.18 |
| **Weighted average** | **0.75** | | **1.97** | | **-1.34** | |
| **Rms** | **0.90** | | **0.60** | | **2.33** | |

Probably the initial hypothesis was not so correct..

# Second Test: Consider a model for each RS

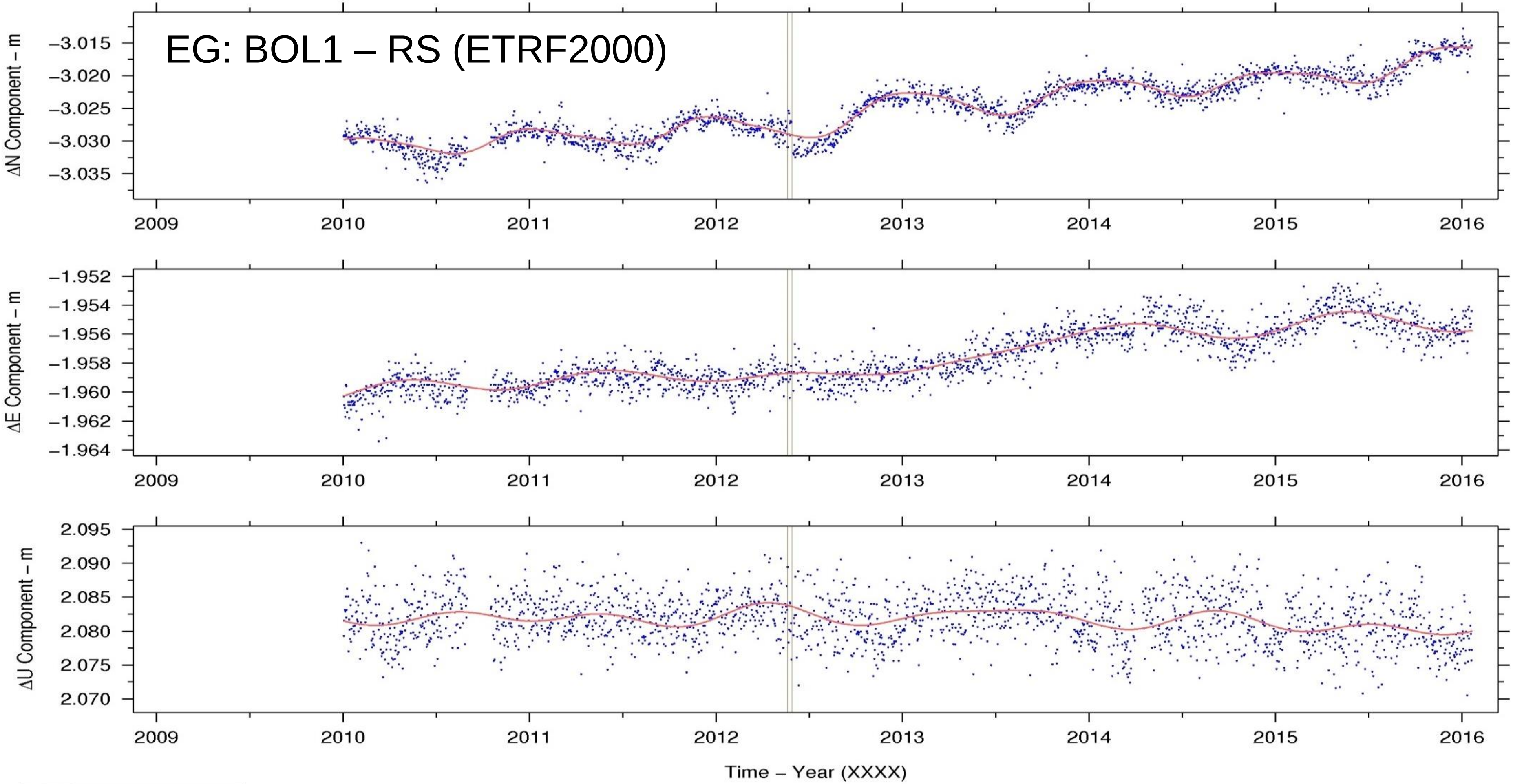
Using PPP (Gipsy OASIS - JPL) we process the 4 time RS and we generate a synthetic model based on this formula

$$x(t) = q + m * t + \sum_{i=1}^{5} \left[ A^{i} \sin\left(2\pi f^{i} * t\right) + B^{i} \cos\left(2\pi f^{i} * t\right) \right] + noise$$

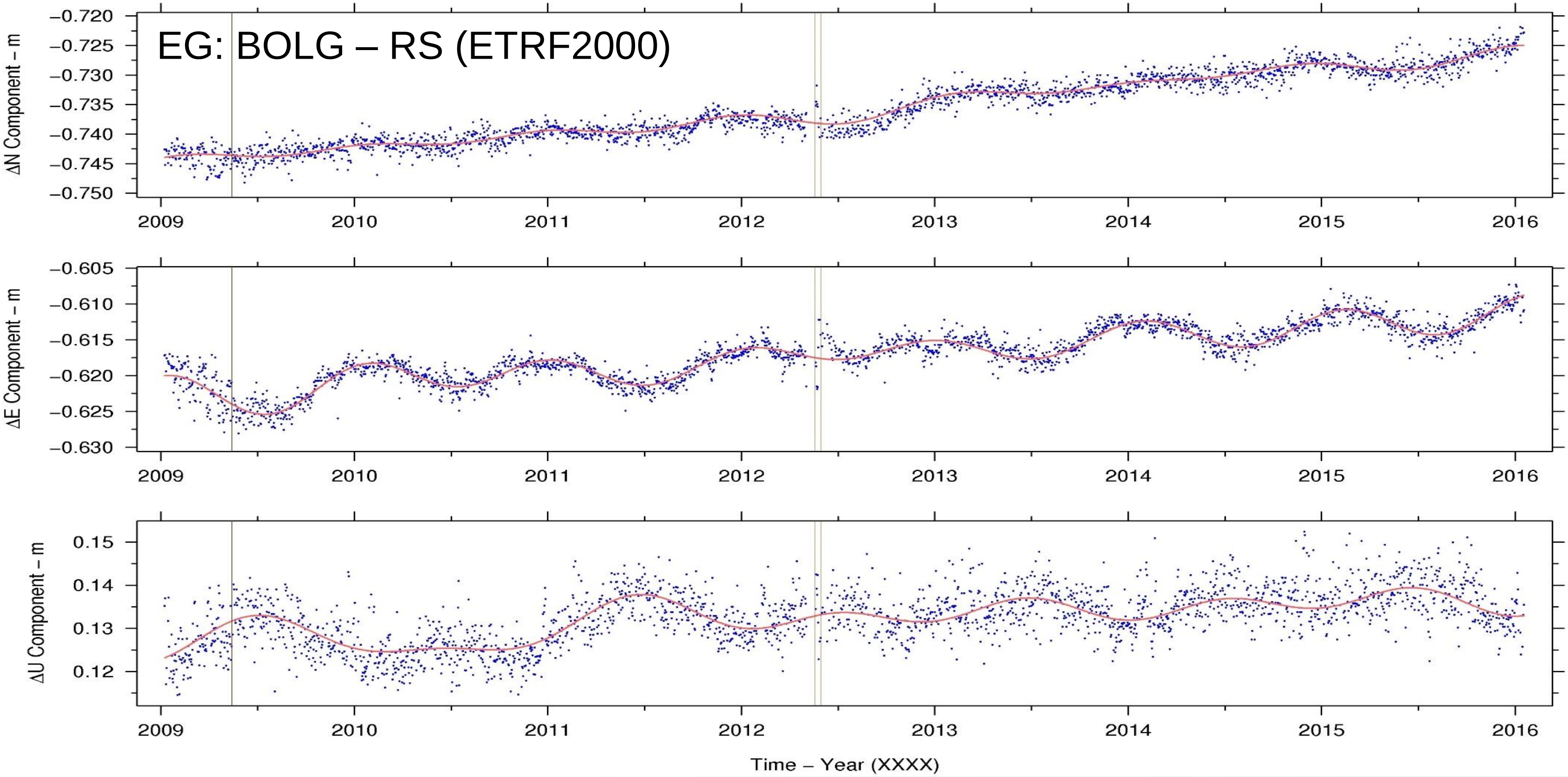
… after an automatic data snooping based on 3*sigma rejection criteria…

NOTE: PPP solution are referred to ETRF2000 RF after a transformation from ITRF08 (Boucher & Altamimi memo v8) and in this RF for the northern part of Italy a intraplate residual velocity of about a few mm/y still present

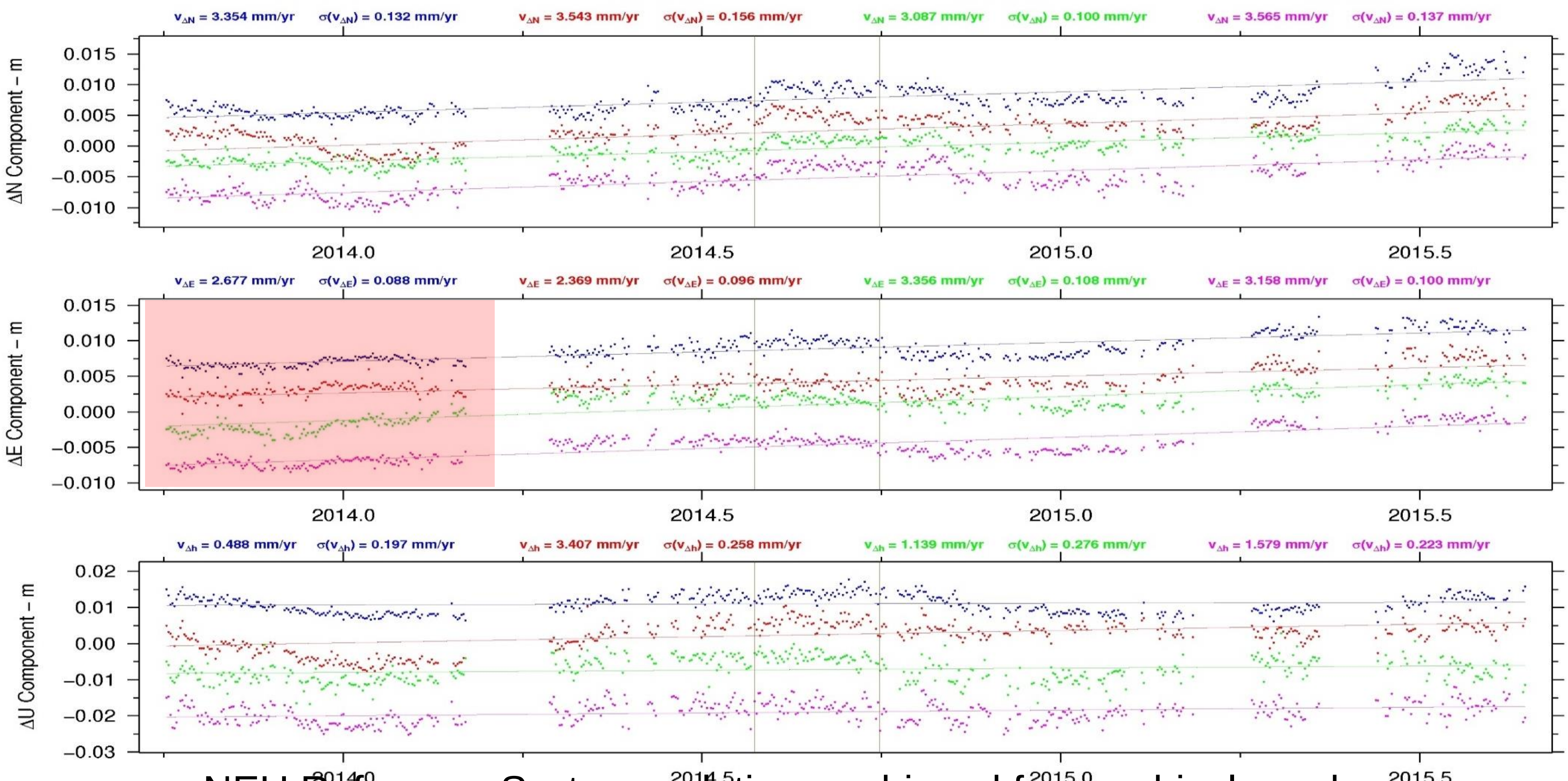
# Second Test: Model Generation for each RS



# Second Test: Model Generation for each RS



# Second Test: obtained results




NEU Reference System, solution are biased for graphical needs

# Second Test: Consider a model for each RS

Results: Correlation coeff. respect BOL1

| Time Series | $\rho_N$ | $\rho_E$ | $\rho_U$ |
|---|---|---|---|
| $BOGA_{BOLG}$ | 0.62 | 0.70 | 0.03 |
| $BOGA_{BO01}$ | 0.90 | 0.65 | 0.29 |
| $BOGA_{BLGN}$ | 0.59 | 0.64 | -0.28 |
| Average | 0.70 | 0.66 | 0.02 |

| Time Series | $\rho_N$ | $\rho_E$ | $\rho_U$ |
|---|---|---|---|
| $BOGA_{BOLG}$ | 0.82 | 0.81 | 0.39 |
| $BOGA_{BO01}$ | 0.88 | 0.90 | 0.68 |
| $BOGA_{BLGN}$ | 0.81 | 0.88 | 0.37 |
| average | 0.84 | 0.86 | 0.48 |

Mean Vel.

| Time Series | $\bar{V}_N$ (mm/y) | $\sigma_{\bar{V}_N}$ (mm/y) | $\bar{V}_E$ (mm/y) | $\sigma_{\bar{V}_E}$ (mm/y) | $\bar{V}_U$ (mm/y) | $\sigma_{\bar{V}_U}$ (mm/y) |
|---|---|---|---|---|---|---|
| $BOGA_{BOL1}$ | 3.35 | 0.13 | 2.68 | 0.09 | 0.49 | 0.20 |
| $BOGA_{BLGN}$ | 3.56 | 0.14 | 3.16 | 0.10 | 1.58 | 0.22 |
| $BOGA_{BO01}$ | 3.54 | 0.16 | 2.37 | 0.10 | 3.41 | 0.26 |
| $BOGA_{BOLG}$ | 3.09 | 0.10 | 3.36 | 0.11 | 1.14 | 0.28 |
| weighted average | 3.32 | | 2.85 | | 1.49 | |
| Rms | 0.23 | | 0.45 | | 1.27 | |

Probably the initial hypothesis was not so correct..

not movements !!

# Second Test: Consider a model for each RS

- If we need to investigate about movements we need to remove the residual plate velocity of the area.
- As first approach we estimate the mean residual velocity starting from the velocity of each RS and we compute that trough a weighted average.

| Time Series | $\overline{V}_N$ (mm/y) | $\sigma_{\overline{V}_N}$ (mm/y) | $\overline{V}_E$ (mm/y) | $\sigma_{\overline{V}_E}$ (mm/y) | $\overline{V}_U$ (mm/y) | $\sigma_{\overline{V}_U}$ (mm/y) |
|---|---|---|---|---|---|---|
| $BOGA_{BOL1}$ | 0.76 | 0.46 | 1.16 | 0.54 | -0.81 | 1.88 |
| $BOGA_{BLGN}$ | 0.97 | 0.47 | 1.64 | 0.54 | 0.28 | 1.89 |
| $BOGA_{BO01}$ | 0.95 | 0.47 | 0.86 | 0.54 | 2.11 | 1.89 |
| $BOGA_{BOLG}$ | 0.49 | 0.46 | 1.84 | 0.54 | -0.16 | 1.89 |
| weighted average | 0.78 | | 1.37 | | 0.36 | |
| Rms | 0.22 | | 0.45 | | 1.25 | |

# Final Consideration

- The Monitoring of structure using GNSS technology is of course possible (the literature is wide in this field of application) and this technique allow us to reach very high levels of repeatability (sub-cm level) specially if we dispose of a continuously monitoring system.
- If the movements are quite large the classical practices, that assume as stable the RS closed to the MS, cannot be a problem.
- Otherwise if the expected movements are very small this hypothesis cannot be accepted as true (this aspect have not to be restricted on the GNSS technology but can be extended to all the geodetic or topographic networks)
- In the presented experience we shows as if we assume as stable each RS the time series of the same data of the MS processed using four different RS located at less than 2km from the MS one evidence significant differences.

# Final Consideration

For that reason we need to consider also the movements of the RS and for that study we use PPP approach to model each RS because this approach permit a single station data processing without any direct correlations with other stations (but for that approach at the moment we require for dual frequency geodetic receiver)

Using this approach the obtained results by 4 different RS are much more closed. At this moment, considering the available time span, the estimated velocity is not statistically significant (at 95% of conf. level).

**Thank you for your attention!**

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