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Detecting natural and anthropic effects on displacements and water level changes: a combined observation from rain gauges, piezometers and CGNSS

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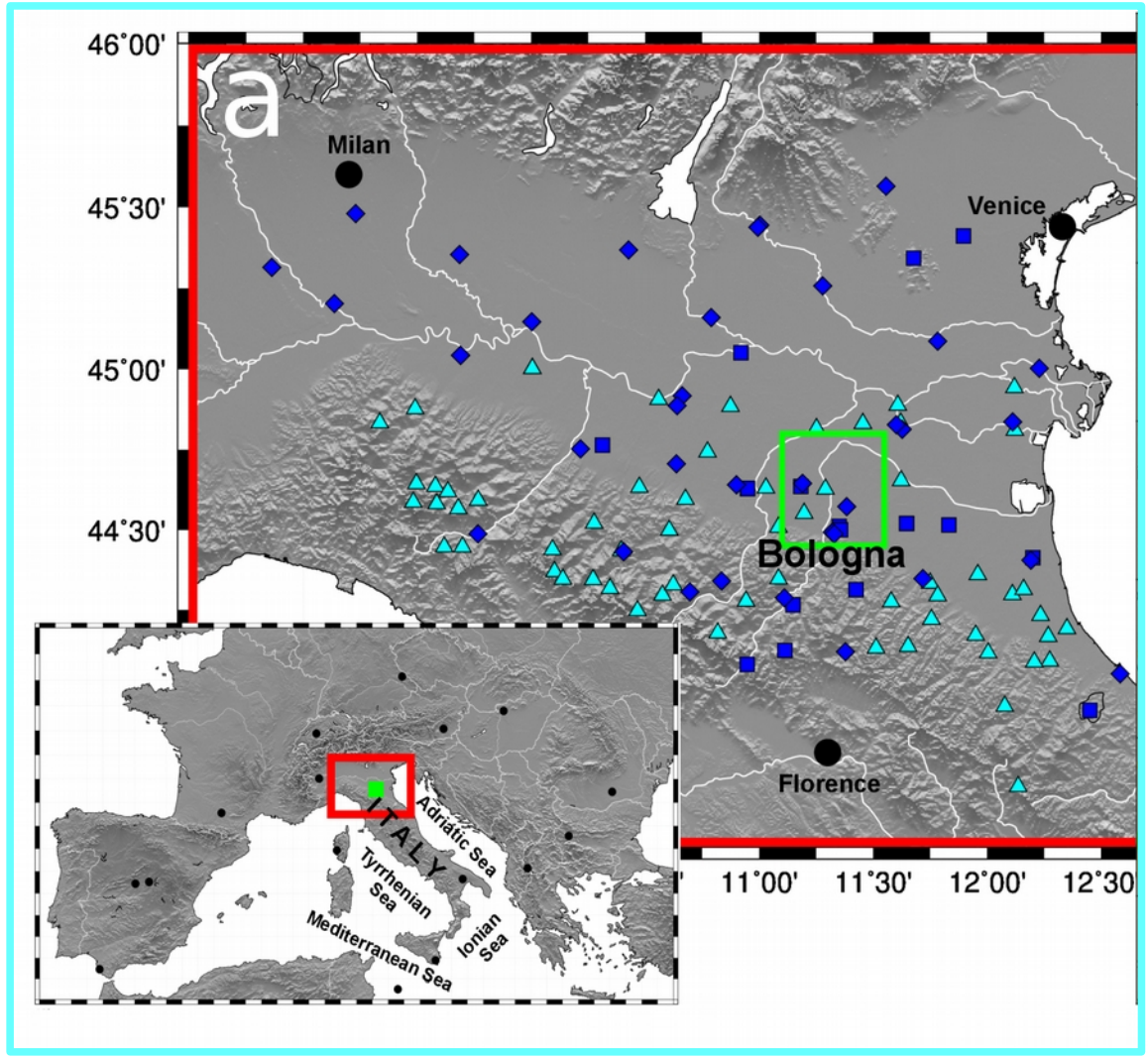
The Po plain (Northern Italy) has largely subsided due to natural processes and human activities.

Such an area is characterized by an excellent **monitoring activity**

with a good **spatial** and **temporal** distribution of data

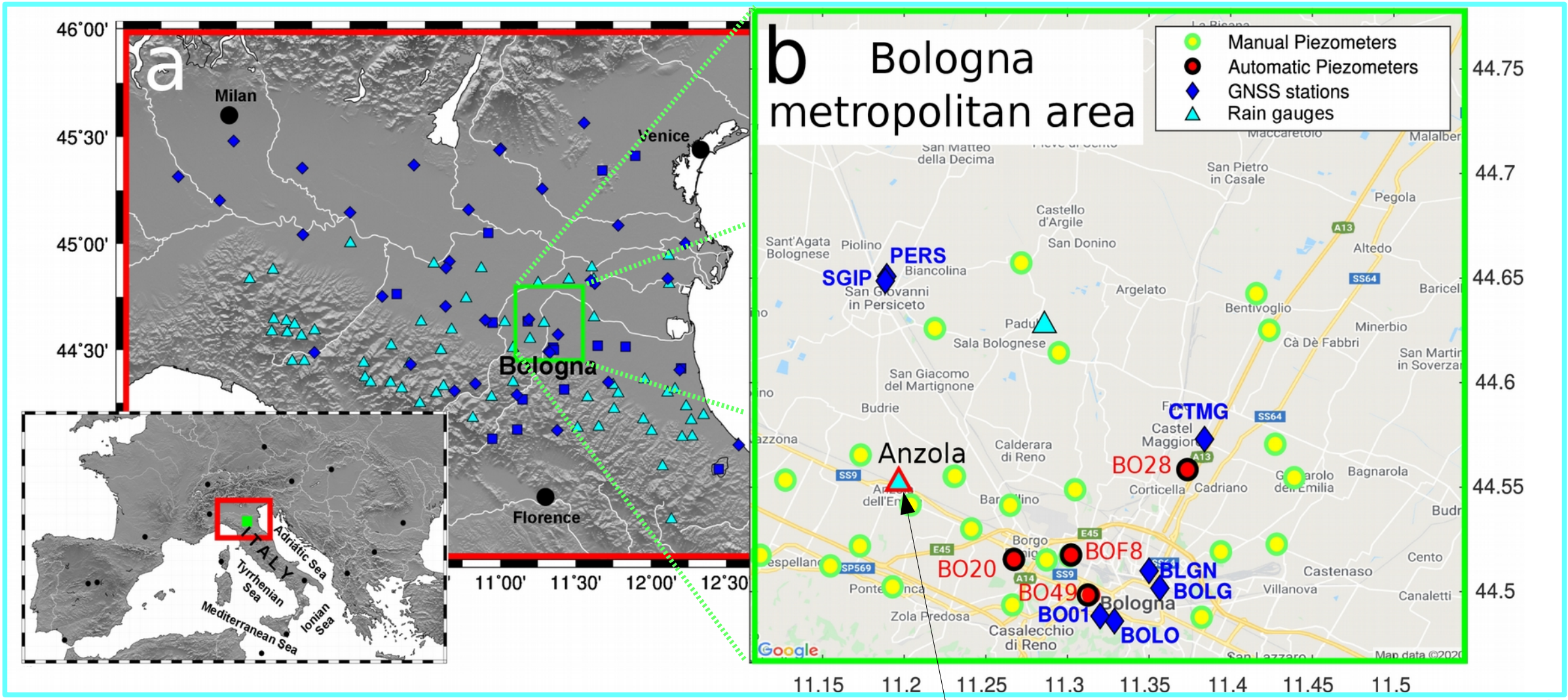
Continuous **GNSS sites** and **rain gauges** are distributed in the whole Po plain

In particular we focus on the **Bologna metropolitan area.**



GNSS sites

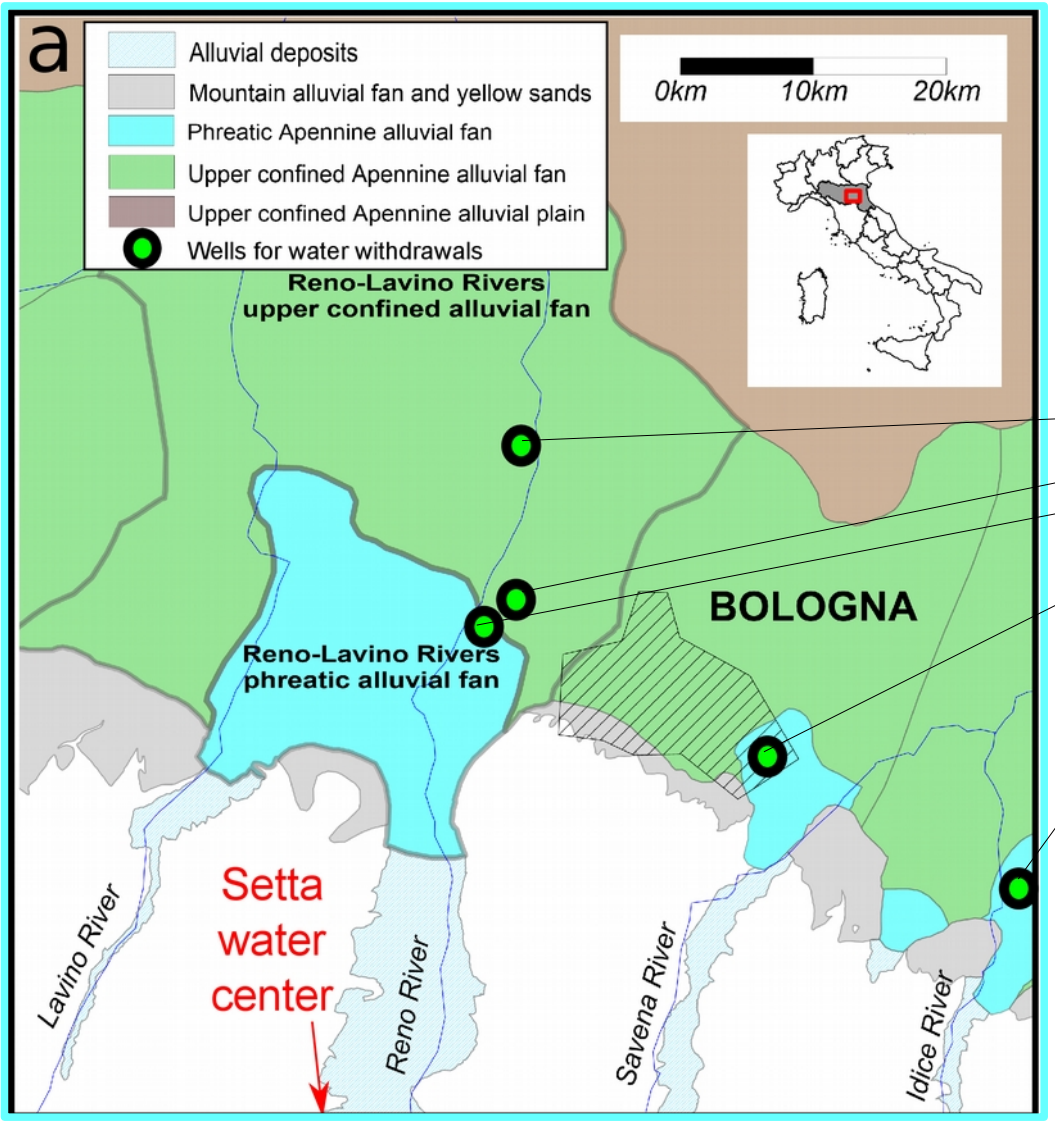
Rain gauges

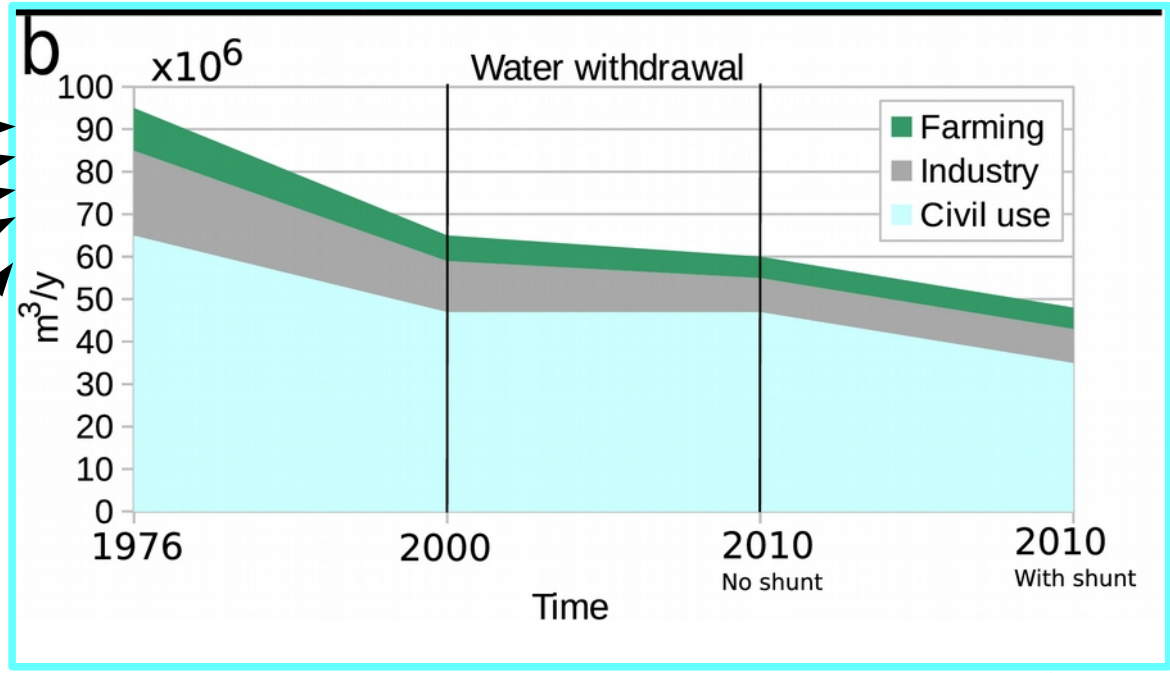


Several **manual** and **automatic** **piezometers** are distributed near Bologna

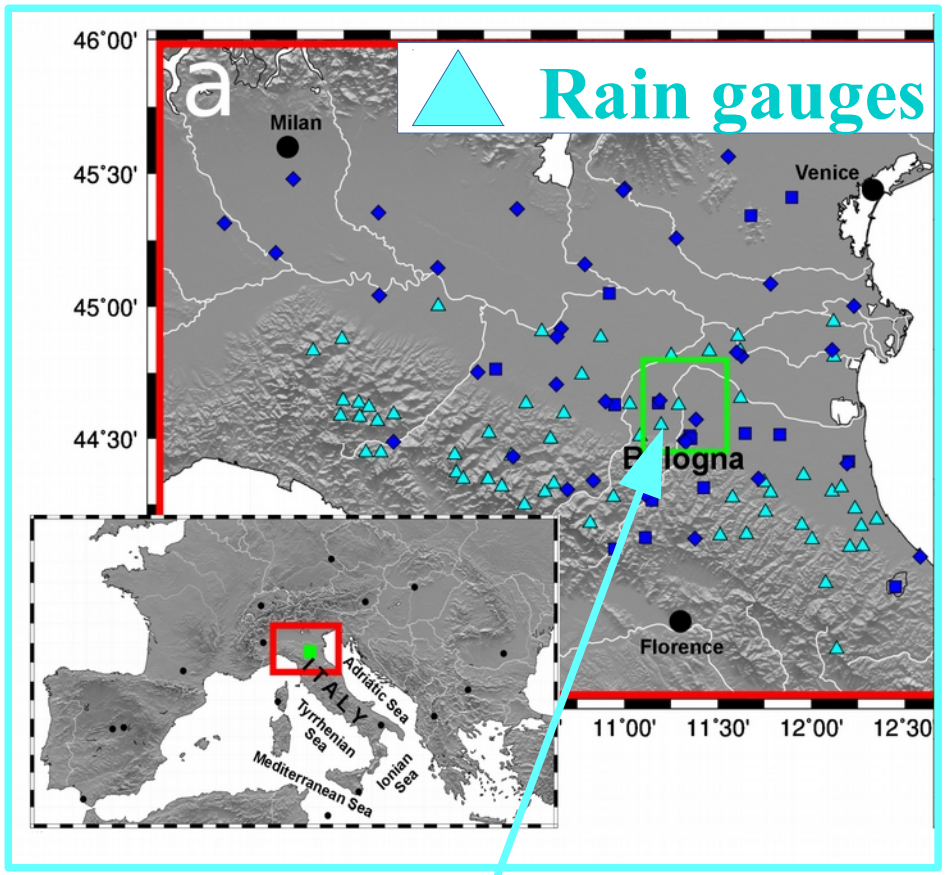
The closest rain gauge (Anzola)

In the Bologna metropolitan area a politic decision in **2010** imposed a significant **reduction of civil water supply** from groundwater withdrawal wells.



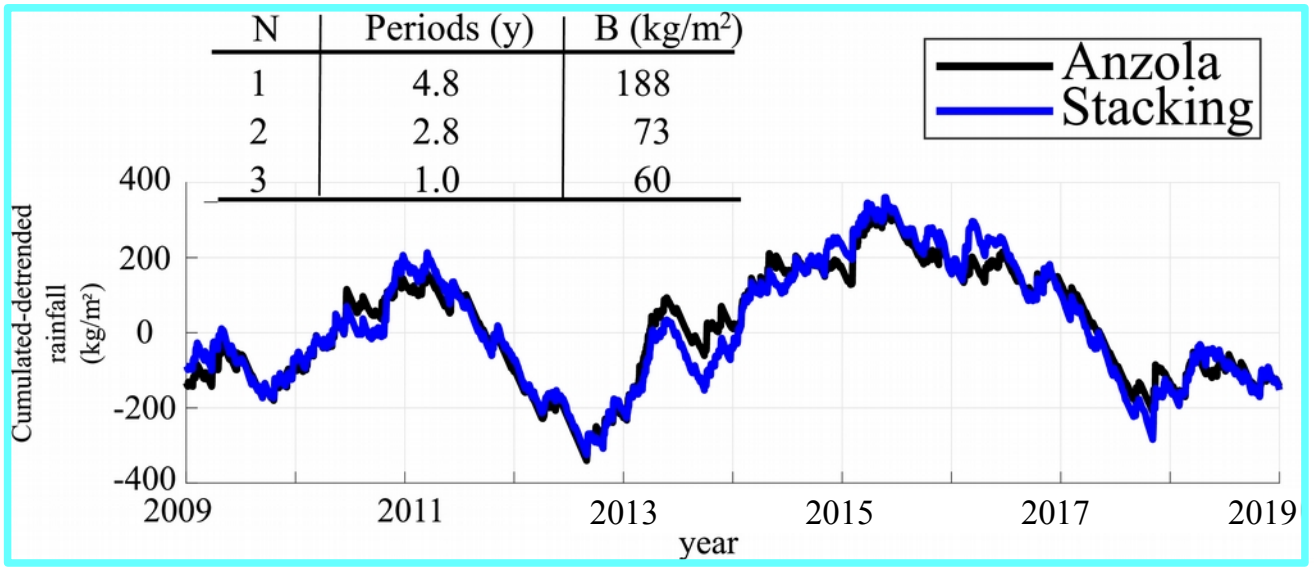


Analyzing the rainfall data



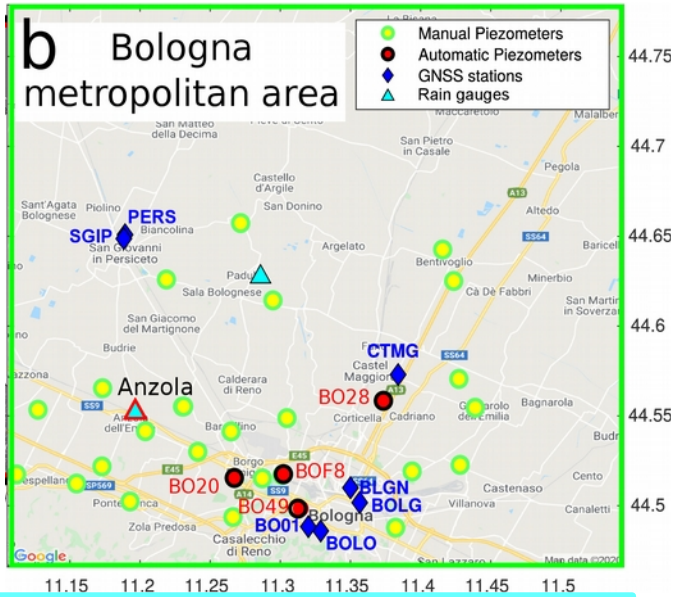
Anzola rain gauge

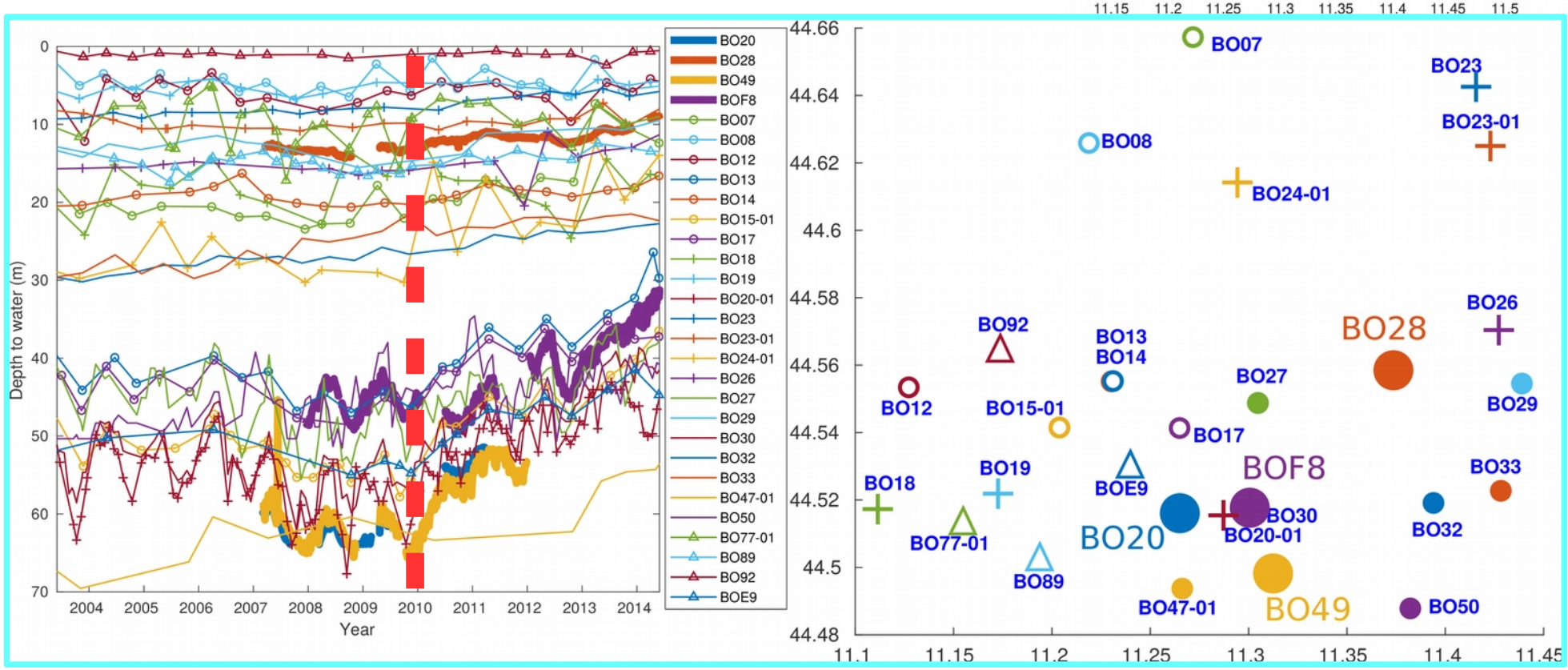
- **Cumulated** rainfall
- Removal of **linear trend**
- **Stacking** of residual time series
- Find 3 meaningful **seasonal signals**



Depth to water time series

- Resampling of raw piezometric data (step of 3 month)



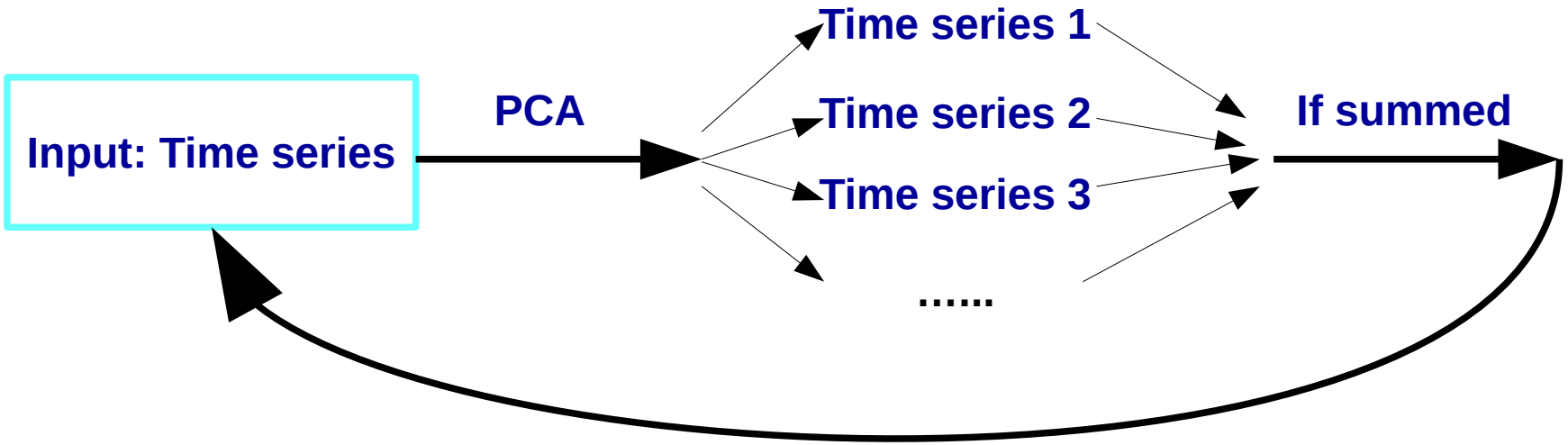


Depth to water time series

- The resampled time series of the piezometers were analyzed with a **Principal Component Analysis** (PCA)

- Spatiotemporal **separation** of the data into a set of **linearly uncorrelated principal components**

- **Each component** is as a signal due to a **source** generating the observed **water level variations**.

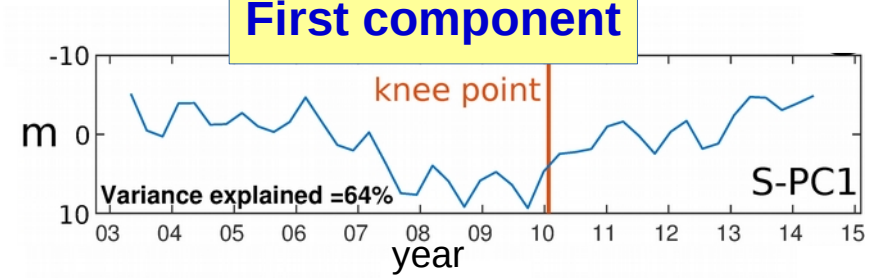


Depth to water time series

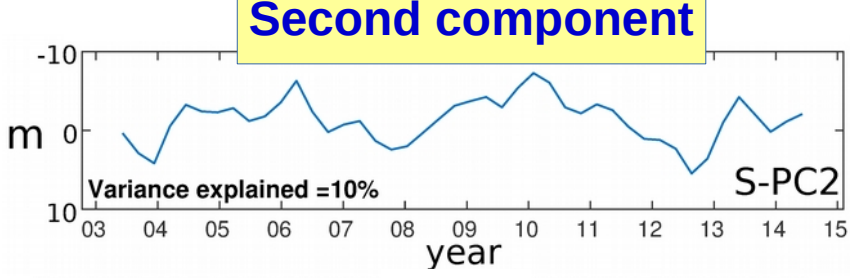
- According to the PCA, the first principal component (PC1) has the largest possible **variance**, so **it explains much of the observation**, and the subsequent components are ordered with decreasing variance values.

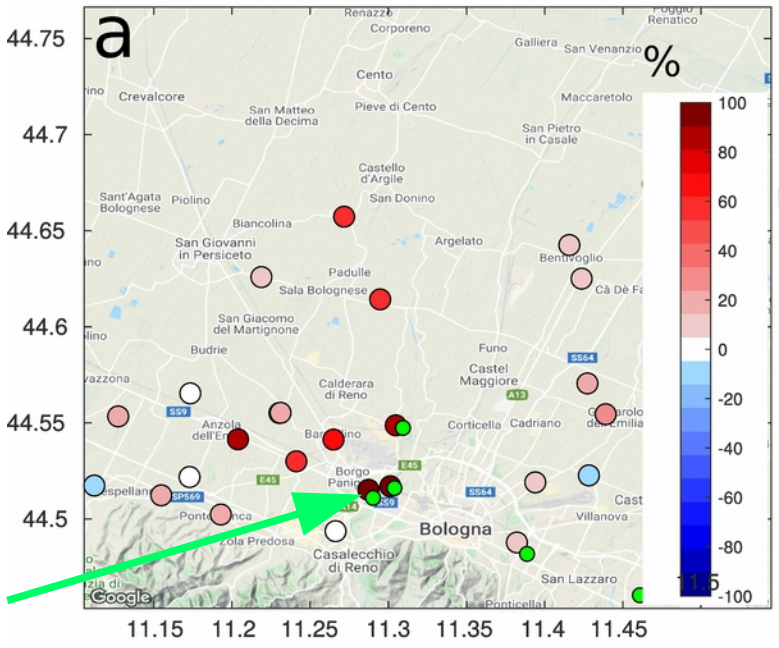
PCA on depth to water time series

First component

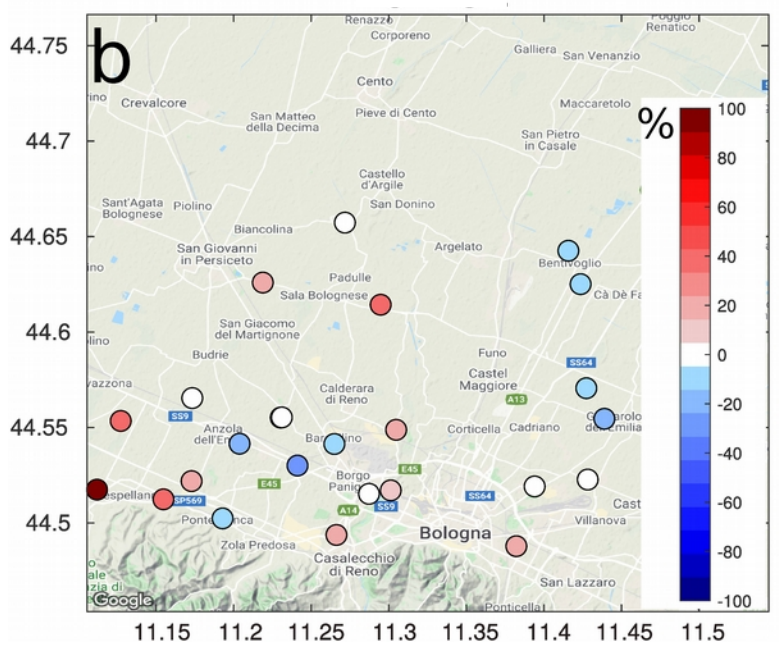


Second component





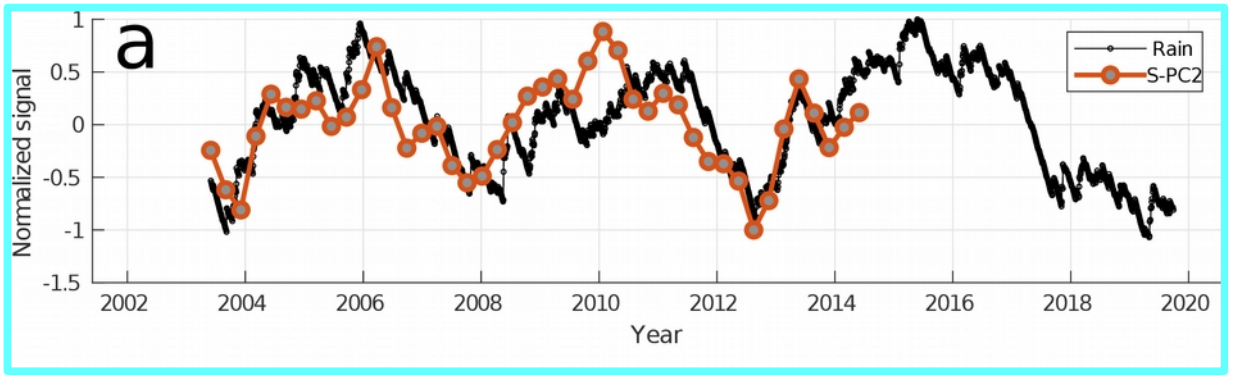
Water wells



Reduction of fluid withdrawal (2010)

Rainfall

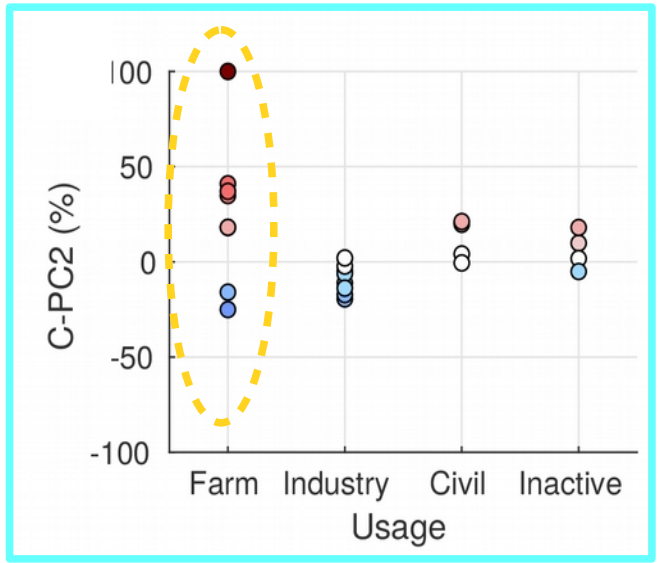
PCA on depth to water time series

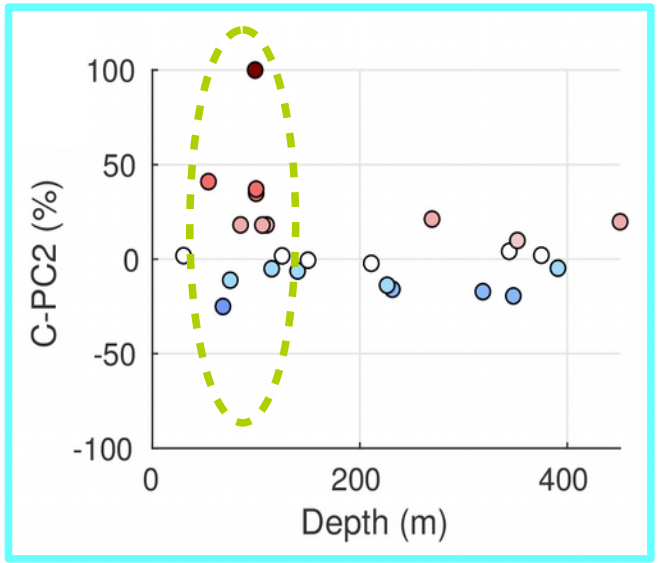


The second PC (**PC2**) **correlates with rainfall**

The magnitude of **PC2** is greater in piezometers:

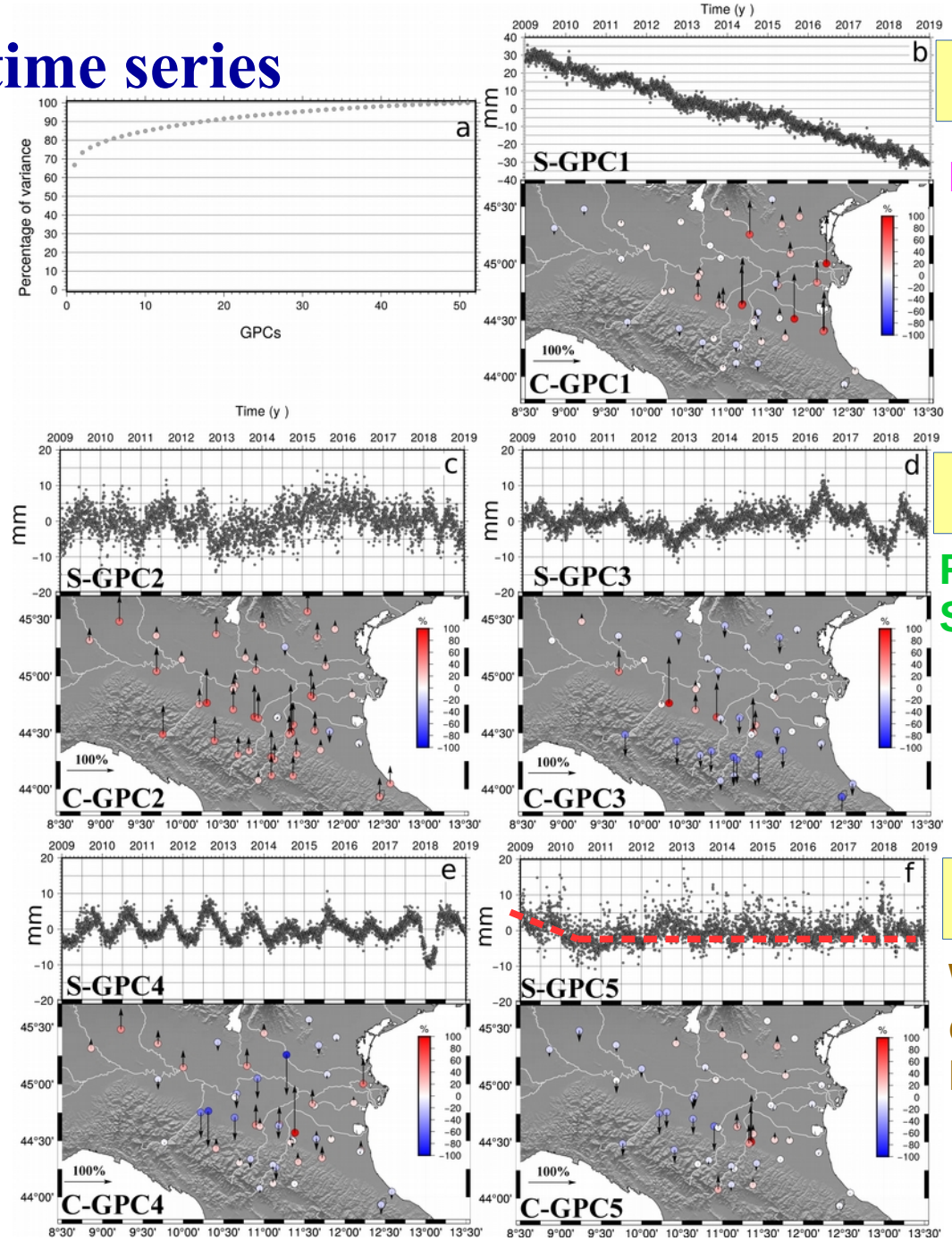
- located in **agricultural** or **farming zones**
- with a **small depth**





Piezometers

PCA on GNSS time series



First component

Kinematic pattern

Second component

Rainfall
Long periods

Third component

Rainfall
Short periods

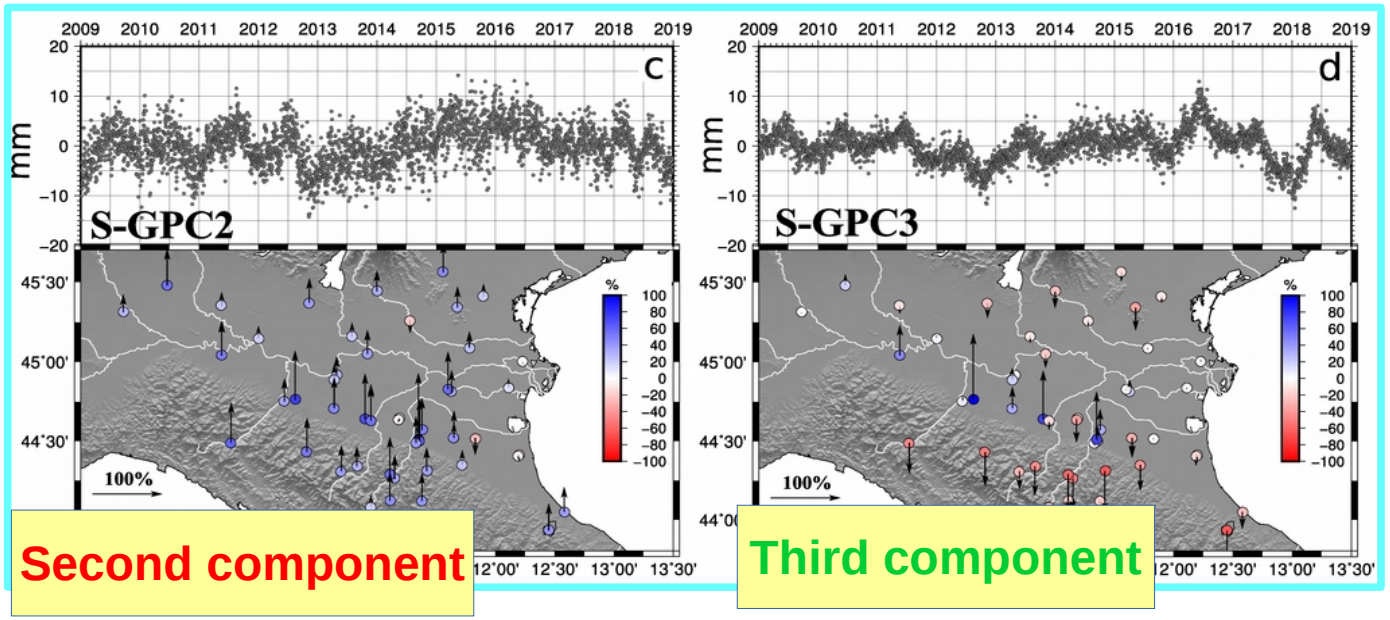
Fourth component

Periodic, local, antrhopic water withdrawal

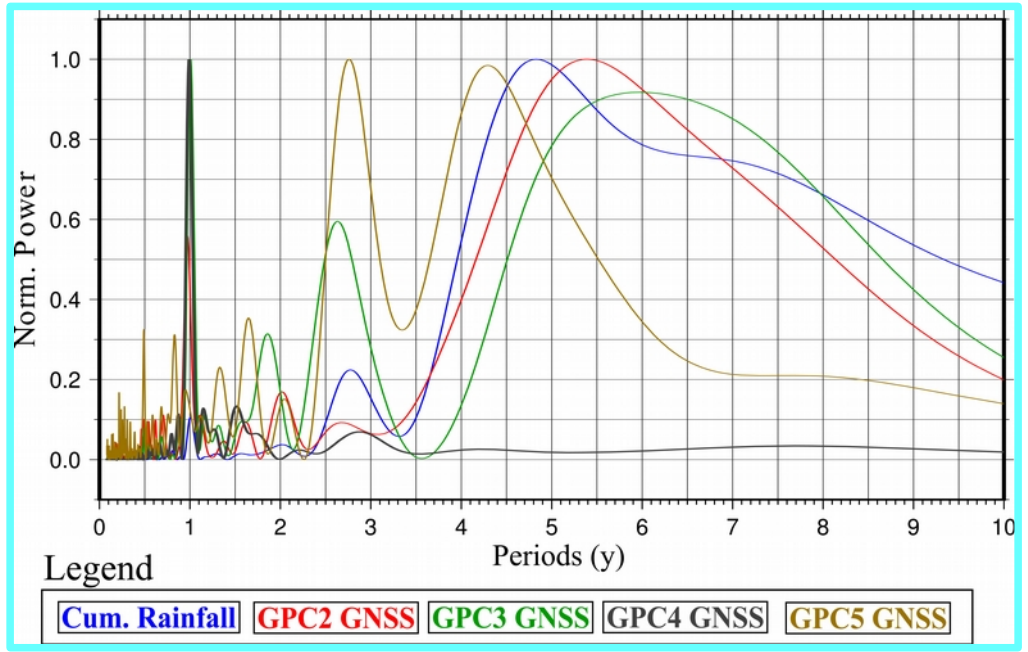
Fifth component

Water withdrawal change in Bologna (2010)

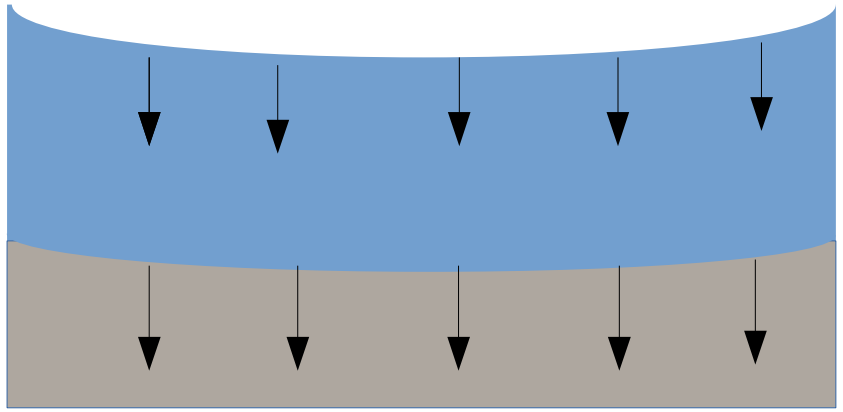
The second and third components: the effects of rainfall



There is an agreement between the spectra of residual cumulative rainfall, S-GPC2 and S-GPC3, in terms of peak periods

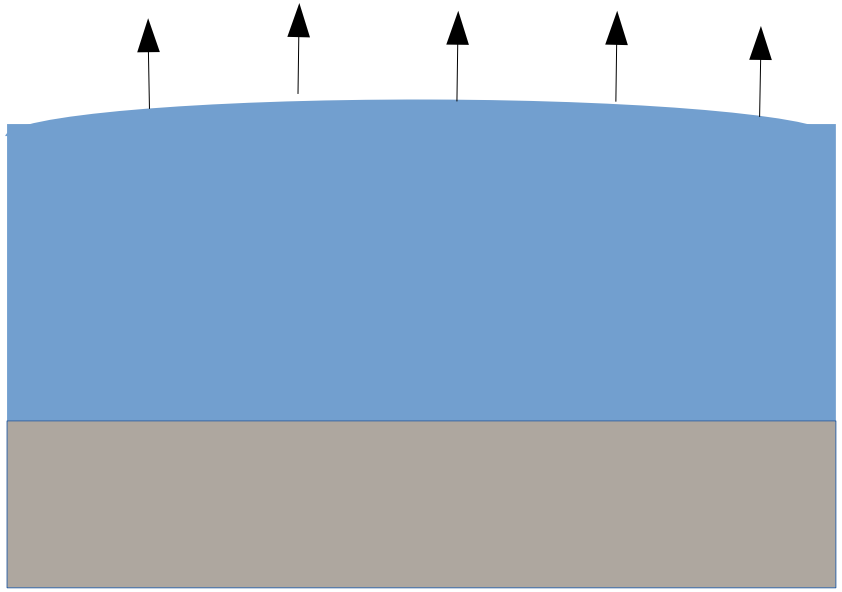


Elastic or poro-elastic response to the rainfall ?



Dominant Elastic loading

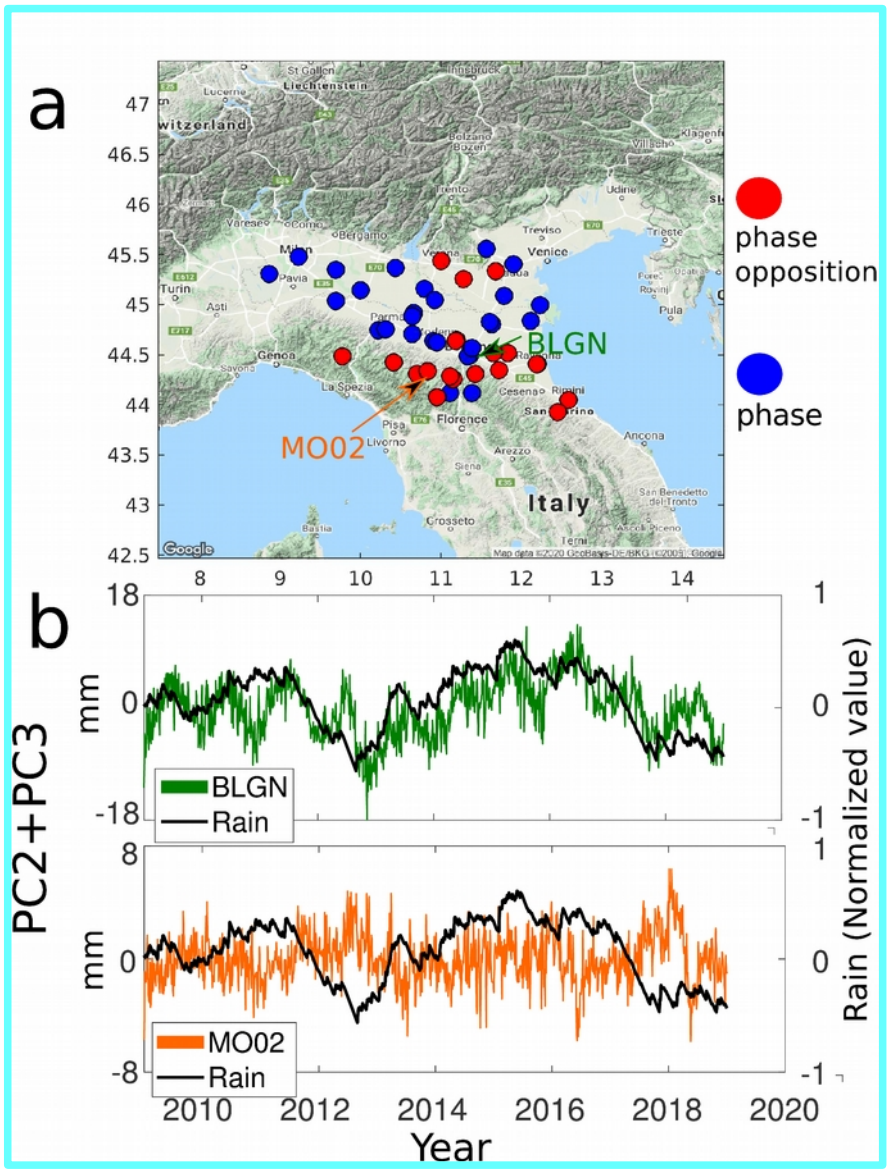
Subsidence



Dominant Poro-elastic expansion

Uplift

Elastic or poro-elastic response to the rainfall ?



In each station we determine if the GPC2 + GPC3 response is

in phase
(Poro-Elastic response)

or

in opposition of phase
(Elastic response)

with rainfall time series

Discussion

The limitations due to the **different sampling rate** (1 day for GNSS and about 3 months for piezometric data) and **discontinuous observation time span** in the available datasets as well as the **spatial heterogeneity** of networks, represent a problem/challenge.

We showed that the **PCA results** represents a possible solution.

Discussion

While the analysis of piezometric data shows a clear increase in the water level following the withdrawal decrease, the **anthropic induced surface displacements** are significantly smaller (about few mm) than the ones locally induced by rainfall (about 10 mm).

Accordingly, **without a multivariate analysis** such effect on vertical displacements would have remained **hidden** in the raw time series.

It is worth to notice that after 2010 the subsidence rate in the Bologna city area is decreased of about **4 mm/y**, this represents an **important contribution** to reducing the long-term subsidence effects.

Conclusions

To correctly model the rainfall contribution to the vertical movement of the surface, it is necessary to consider different prevailing effects: **elastic** in the case of mountains and **poro-elastic** in the case of the sedimentary plain.

The combined observation of **GNSS** and **piezometers**, **rainfall**, **geological setting** and the use of **PCA**, are very important in order to get a complete understanding of the anthropic and natural signals in cases of aquifer over-exploitation.

The study of different observables can provide precious hints to assess the **best practices for the governance of groundwater resources in a climate change scenario.**

Thanks for your attention !

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Research papers

The interaction between displacements and water level changes due to natural and anthropogenic effects in the Po Plain (Italy): The different point of view of GNSS and piezometers

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