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# Cluster analysis applications for ground deformation monitoring due to fluid production/injection in underground geological formations, based on InSAR measurements

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## Why, How and What...

**UGS (Underground Gas Storage)** involves the cyclical injection and withdrawn of gas into subsurface formations in response to the seasonal energy needs (storage during spring-summer months and production during autumn-winter months) producing mainly a seasonal vertical oscillatory behavior (uplift during injection periods and subsidence during withdrawn) (Codegone et al., 2016; Teatini et al., 2011).

Whereas a more continuous behavior in time for extended time-frames (i.e. trend) is typical of other anthropogenic ground deformation (GD) induced by **hydrocarbon production** or **aquifer withdrawn** (Bitelli et al., 2010; Teatini et al., 2006).

**An automatic methodology for InSAR data analysis** has been developed for _quantifying_ and _geolocalizing_ subsidence or uplift effects in areas where operations of fluid production or injection occur.

The developed methodology relies on the **time-series decomposition** (TSD) of the **vertical movements** for each measurement point (MP), extracting its seasonal (S) and trend (T) components. Subsequently, the **cluster analysis**, an unsupervised machine learning technique, groups MPs according to the similarity in S or T components.

Two case study where evaluated: an UGS site near Bologna in an area with strong superposition of GD effects, for which the clustering analysis on the S-component was the decisive factor in isolating the oscillatory effects of the storing cycles; and a coastal area near Ravenna on which mixed factors (like fluid withdrawn) contribute to the subsidence of the area. For this case, the clustering analysis on the T-component depicted the deformative behavior. The results of both case studies were compared with previous findings.

## Methodology

**Example of induced ground deformation by UGS**

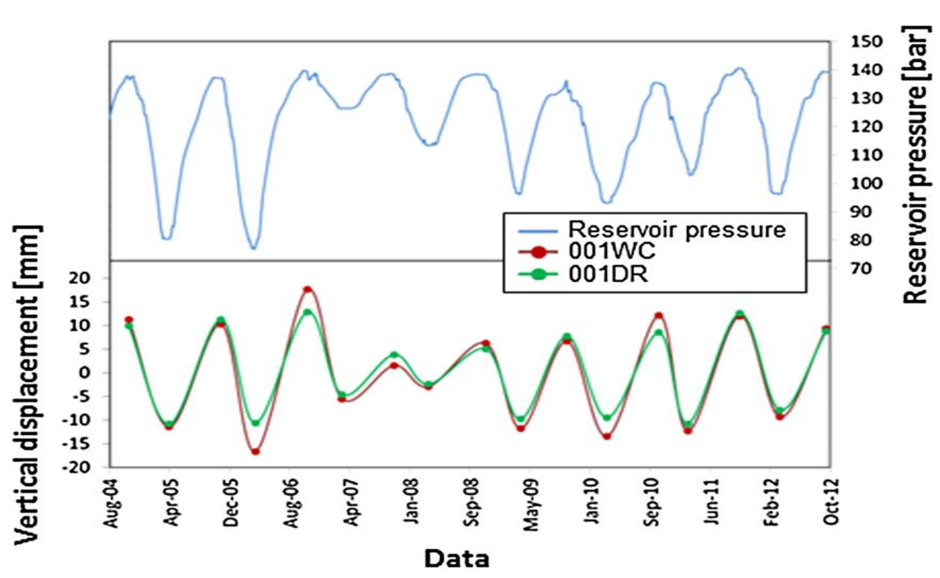
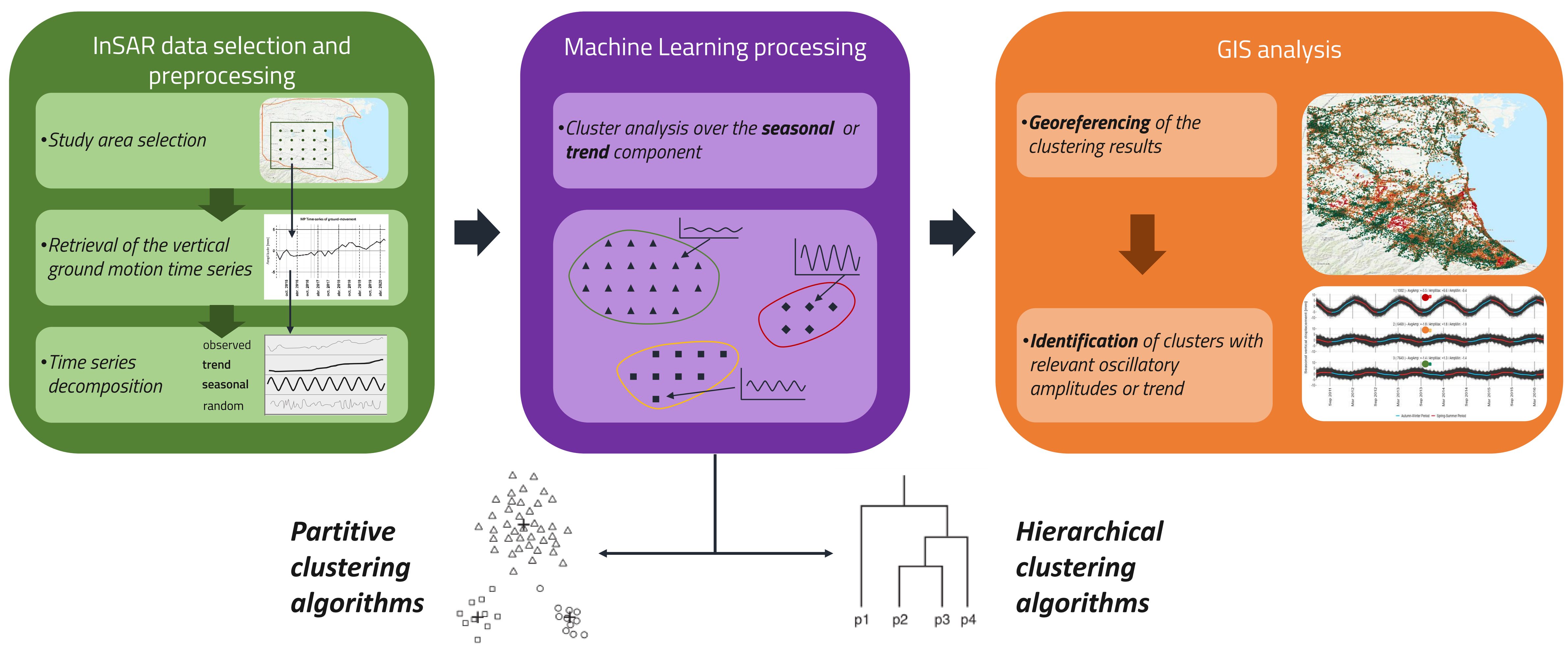



*Fig. 1 - Example of recorded GD and average static reservoir pressure for an **UGS** site (Codegone et al, 2016).*




## Case study A – Seasonal component (S)

***Area:*** UGS site located inside an urban area in northern Italy, near Bologna.

Fig. 2 shows the **yellow cluster (1)** which identifies the UGS effects. Its areal distribution is in agreement with the deformation results modeled by Codegone et al. (2016) for the gas withdrawn period (red isolines): they where obtained with a 3D numerical approach that combined static, and calibrated dynamic and mechanical models of the system.

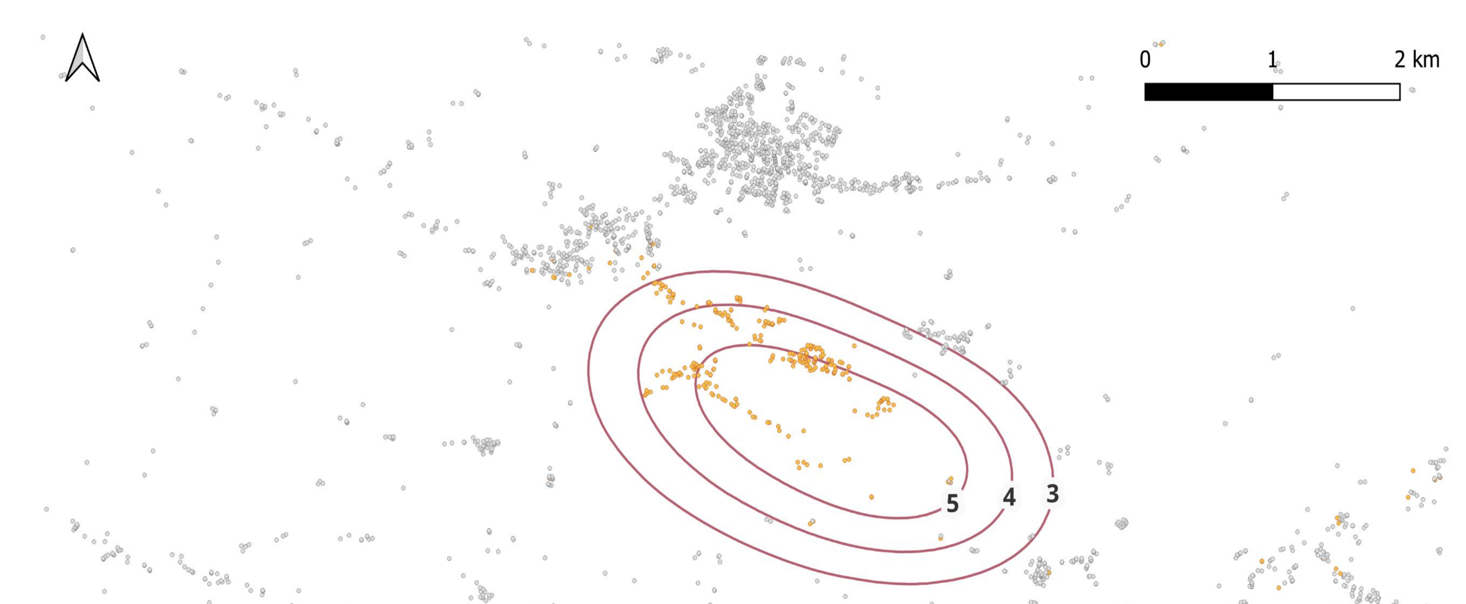



*Fig. 2*

Fig. 3 **Shows the oscillatory behavior of cluster 1 in agreement with the seasonal UGS cycles** (uplift from march to September, subsidence from October to February).

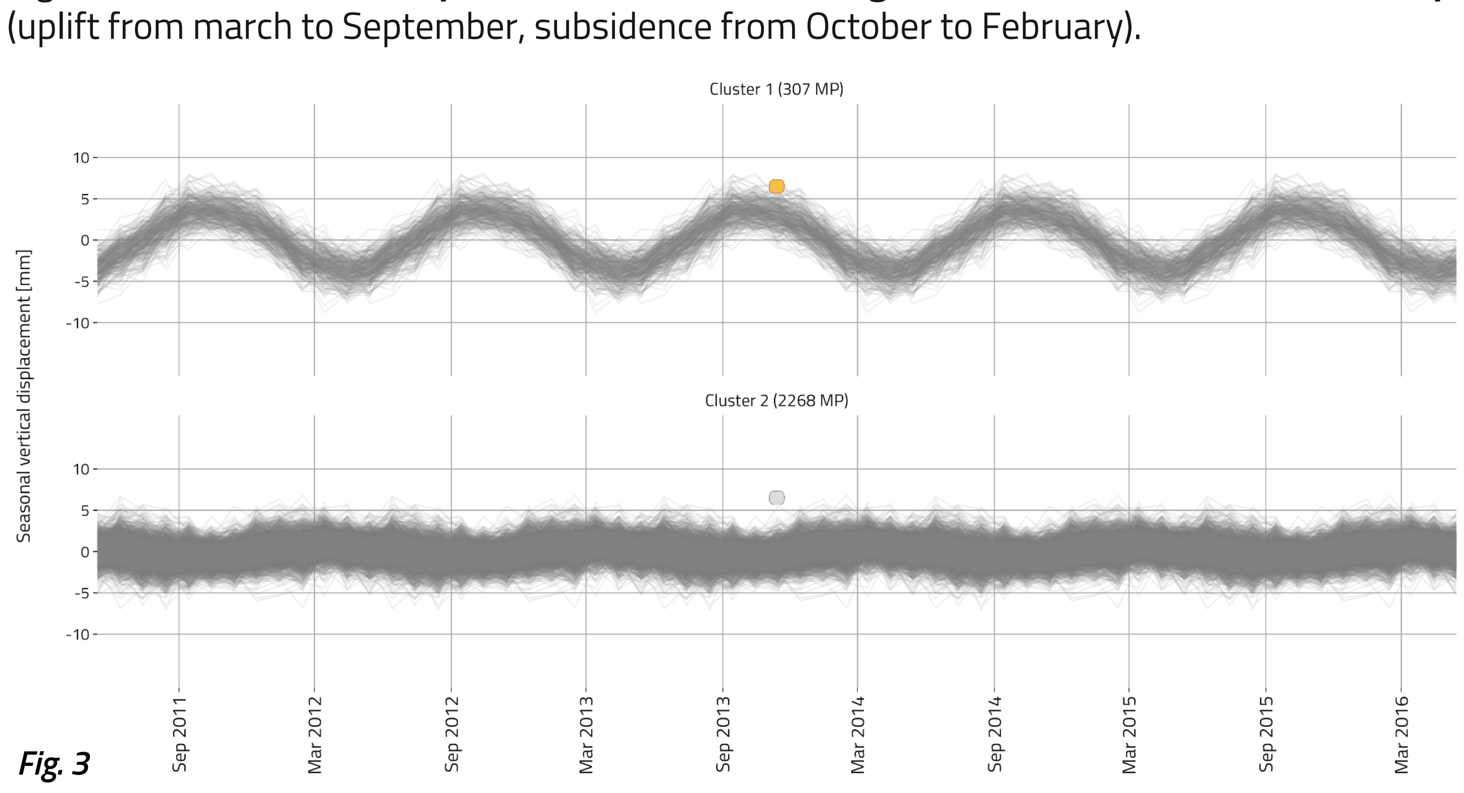



*Fig. 3*

## Case study B – Trend component (T)

***Area:*** Coastal Area Y in northern Italy, near Ravenna.

Fig. 4 depicts a cohesive and well separated cluster configuration showing maximum subsidence. Fig. 6 shows 3 well isolated trend behaviors.
Results are compared with ARPA's (2018) an Bitelli's findings (2010).

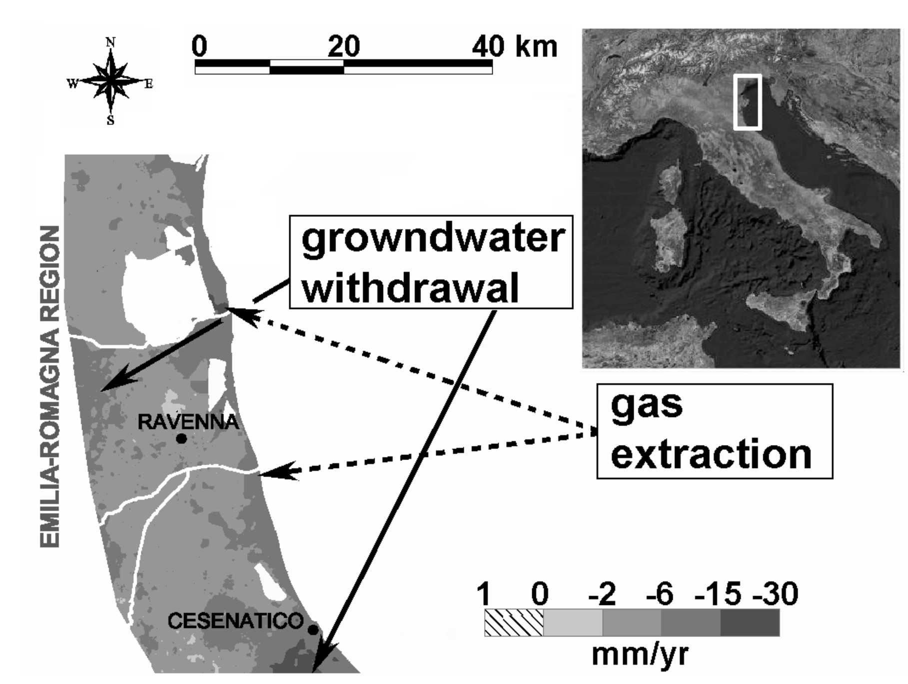
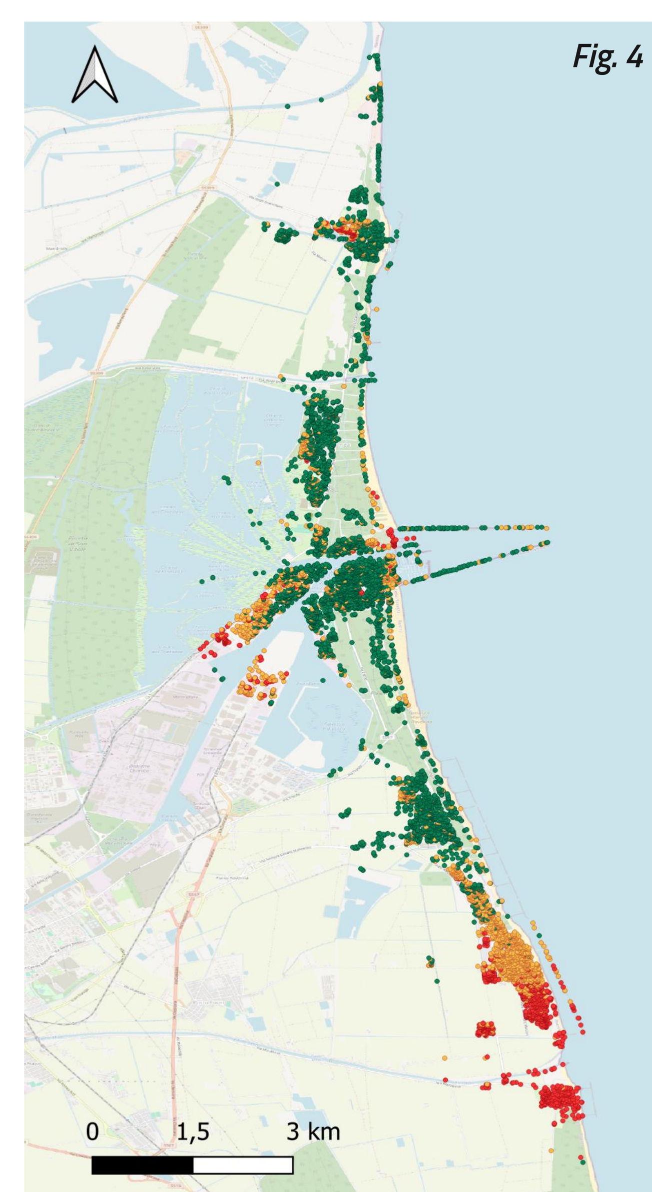



*Fig. 5 - Findings of Bitelli et al. (2010) regarding likely factors for GD over the area for the period 1992-2000.*



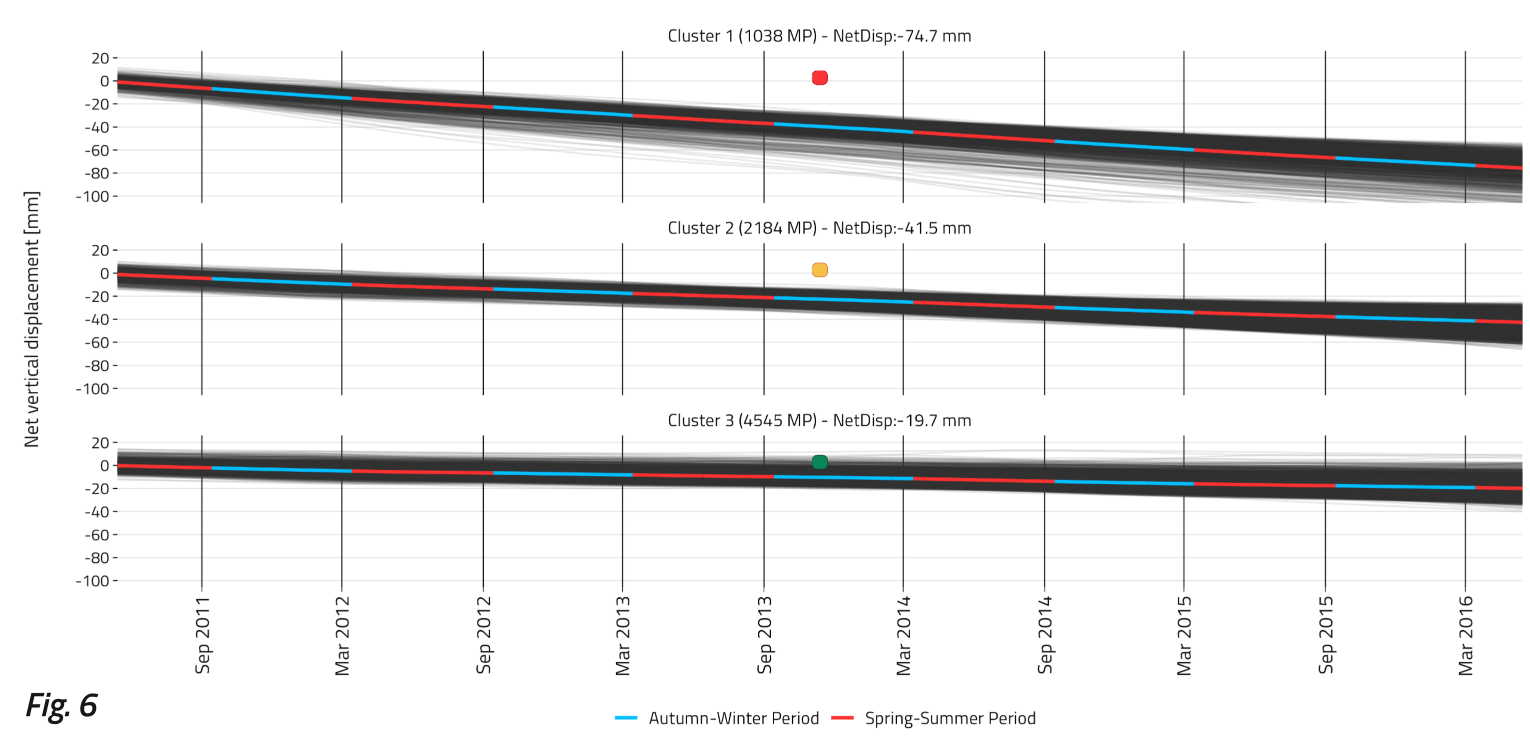




*Fig. 6*

## Highlights

- This study shows that machine learning techniques can exploit InSAR data capabilities and succeed in quantifying the magnitude and extension of areas affected by GD due to production and production/injection of fluids from/into the underground.
- The seasonal component is a key player for isolating oscillatory behaviors due to UGS in areas where superposition of effects is particularly intense.

## Next steps

- A comparison between the clustering results and the GD measured by local GPS stations (GNSS data) where available.
- An evaluation on how different algorithms for obtaining the TS from the SAR images may affect the clustering results.

## References

ARPA – Regional Agency for Prevention and Environment – Emilia-Romagna. (2018). Subsidence measurements of the Emilia-Romagna plain 2017 – Second phase – Final report.

Bitelli, G., Bonsignore, F., Carbognin, L., Ferretti, A., Strozzi, T., Teatini, P., … & Vittuari, L. (2010). Radar interferometry-based mapping of the present land subsidence along the low-lying northern Adriatic coast of Italy. Land Subsidence, Associated Hazards and the Role of Natural Resources Development, Proceedings of EISOLS, 339, 279-286.

Codegone, G., Rocca, V., Verga, F., & Coti, C. (2016). Subsidence Modelling Validation Through Back Analysis for an Italian Gas Storage Field. Geotechnical and Geological Engineering, 34, 1749-1763. https://doi.org/10.1007/s10706- 016-9986-9.

Teatini, P., Ferronato, M., Gambolati, G., & Gonella, M. (2006). Groundwater pumping and land subsidence in the Emilia-Romagna coastland, Italy: Modelling the past occurrence and the future trend. Water Resources Research, 42. https://doi.org/10.1029/2005WR004242.

Teatini, P. et al. (2011). Geomechanical response to seasonal gas storage in depleted reservoirs: A case study in the Po River basin, Italy. Journal of Geophysical Research, 116.583 https://doi.org/10.1029/2010JF001793. 3