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A multivariate time series analysis of underground gas storage deformations using InSAR data

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Underground gas storage (UGS) is of strategic importance both in terms of security of supply and to ensure the operational continuity of primary industrial basins. UGS reservoirs make it possible to guarantee the country a continuous and reliable supply of natural gas. It is well known that UGS activities can induce ground deformations, in response to gas injection and extraction cycles. The Lombardy region (Italy) has a predominant part in the Italian national policy of UGS in depleted reservoirs. In this work, five UGS reservoirs located in Lombardy and three additional ones in Italy, which differ in geometric and geo-lithological features, were considered.

In this context, the InSAR (Interferometric Synthetic Aperture Radar) technique plays a key role in monitoring ground deformations induced by UGS activities, providing precise measurements of ground displacement.

In this contribution, we present (i) an application of a multi-method approach for the analysis of trends and seasonal signals in the EGMS InSAR time series of ground displacements in the proximity of UGS reservoirs to recognise specific footprints and spatial-temporal patterns of ground deformation. For this purpose, large datasets of ground displacements covering the UGS area in Lombardy (25 km^2) from 2015 to 2022 were analysed; and (ii) an interpretation of the possible causal relationship between displacement and gas injection and extraction time series using cross-correlation approach and wavelet tools in the time-frequency domain.

The multi-method approach involves the application and optimization of Principal Component (PCA) and Independent Component Analyses (ICA) in temporal (T-) and spatial (S-) modes on both ascending and descending InSAR time series, as well as on the vertical and horizontal ones, allowing for a spatial-temporal separation of the original data into a set of limited components. Among them, it is possible to isolate those related to the USG deformations, from other signals typical of the region. Subsequently, clustering analysis is performed to group the InSAR time series and identify characteristic ground deformation patterns, which could also be related to differences in grain size properties.

As a result, it was possible to recognize and separate a limited number of signal components, describing long-term displacement and seasonal fluctuations, and the derived maps allowed the characterization of the area of influence relative to each UGS reservoir. Finally, cross-correlation approach and wavelet tools made it possible to identify and interpret the time lag between the

peaks and, consequently to improve the correlation between displacements and anthropogenic triggers.

To validate the deformation patterns resulting from the approach, numerical analyses were performed in which the gas injection and extraction time series were considered as input variables.