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# Disentangling shallow sources of subsidence in an urbanized reclaimed coastal plain, Almere, South Flevopolder the Netherlands

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Reclaimed coastal plains often experience significant subsidence as a result of phreatic water level lowering, which induces oxidation of organic material, shrinkage of clay, and sediment compaction. A primary example in the center of the Netherlands, is the 'South Flevopolder' which was reclaimed in 1968 and transformed into an area for residential, industrial and agricultural use. The area subsided over 1.5 m since its reclamation and its surface is still lowering.

The city of Almere, with roughly 200.000 inhabitants and a surface area of c. 250 km$^2$, is situated in the South Flevopolder. Most buildings in the city are founded in deeper Pleistocene sand, whilst objects such as parking lots, sport fields and playgrounds are often unfounded and are directly situated on the younger Holocene coastal deposits. Currently, the unfounded objects show subsidence rates as high as 5 mm per year for which the different subsidence rates may be related to subsurface heterogeneities. The upper layers in the area are dominated by clay and sand, up to a few meters in thickness, which overly peat and highly organic layers. The lowering of the phreatic surface results in an erratic pattern of subsidence over the area.

We present a workflow to disentangle and parameterize the different contributions of shallow subsidence from Interferometric synthetic-aperture radar (InSAR) measurements. InSAR measurements from founded and unfounded scatterers are separated with a dimensionality reduction technique, t-Distributed Stochastic Neighbor Embedding (t-SNE), followed by an automatic detection of clusters with Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN). We have limited ourselves to structures with a construction date of >10 years with respect to the first InSAR measurement date to reduce the effect of construction-related consolidation and isolate the effect of shallow subsidence related to reclamation and phreatic surface level changes. The filtered dataset represents the surface response of unfounded structures in the urbanized reclaimed coastal area.

The subsidence processes are disentangled and parameterized with an Ensemble Smoother with Multiple Data Assimilation (ES-MDA). Additional input data for this method is provided by a phreatic groundwater level model and a voxelized lithological model from the surface towards the top of the Pleistocene sand layers.

We show that the automated data selection method prevents bias by selecting unfounded objects and the proposed workflow can be of aid when studying shallow subsidence in urbanized areas, where most objects are founded below the level at which shallow subsidence takes place. The results of this study quantify the rate of the different subsidence processes on a spatiotemporal scale and thus provide insights for tailored decision making to mitigate subsidence.