Analysis of Complex Surface Displacements above a Storage Cavern Field in NW-Germany, Observed by InSAR

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The cavern field at Epe has been brined out of a salt deposit belonging to the lower Rhine salt flat, which extends under the surface of the North German lowlands and part of the Netherlands, and is used to store e.g. natural gas, brine and petroleum. Cavern convergence and operational pressure changes cause surface displacements that have been studied for this work with the help of SAR interferometry (InSAR) using distributed and persistent scatterers. Vertical and East-West movements have been determined based on Sentinel-1 data from ascending and descending orbit. Simple geophysical modeling is used to support InSAR processing and helps to interpret the observations. In particular, an approach is presented that allows to relate the deposit pressures with the observed surface displacements. Seasonal movements occurring over a fen situated over the western part of the storage site further complicate the analysis. Findings are validated with ground truth from levelling and groundwater level measurements.

For porous storage sites the geomechanic response can be described as elastic: displacement is almost proportional to reservoir pressure and displays the same pronounced seasonal behavior. At Epe the visco-elastic response of the salt layer has to be considered. The general appearance of the surface displacement is that of a strongly smoothed and shifted version of the cavern pressure curve. To deal with this situation a temporal model for displacement with pressure changes (pressure response) is derived that relates cavern pressure with observed displacement based on the theory for visco-elastic behavior of a Kelvin-Voigt body.

In order to deal successfully with the challenging displacement field at Epe several algorithmic improvements were implemented. To obtain a more complete picture of the displacement field DS pre-processing has been combined with StaMPS. Furthermore, StaMPS was modified in order to support unwrapping with a phase model composed of linear trend, pressure response and a seasonal component (caused by ground water level changes). Finally, refining the iterative estimation scheme of StaMPS helped avoiding leakage of the displacement signal to the spatially correlated noise term.

Determining vertical and east-west displacements from InSAR line-of-sight displacements is fundamental for interpretation and integration with levelling data. In this study, a basic method of orbit combination and another one supported by a simplistic geophysical model were applied in
In order to obtain 2D-displacements. For the basic method the north-south component was handled as if it were zero, while the geophysical model predicts the LOS effect of NS displacements. It assumes that caverns act as spherical pressure/volume sources embedded in an elastic half space ("Mogi" sources). To incorporate the visco-elastic component, each cavern is encompassed by a spherical salt shell that obeys the Kelvin-Voigt differential equations. The model is used here to describe either the parameters of the linear component of the displacement model or of the pressure response. A novelty of the orbit combinations implemented for this study is that the different components of the phase model are combined separately. This allows for a better understanding of the phenomena that contribute to the displacement field.