KEM Research review, evaluation and interpretation (max. 4 pages + annex)
TITLE KEM 49 InSAR subsidence data for salt cavern management in Twente

KEM Quality review

Description of the scientific quality of the results (team, research method, research results, quality of the products, …), if needed external review result

The report reflects two main topics: InSAR data acquisition and processing and geotechnical modelling of salt cavern dynamics. Both use appropriate methods and the research is executed with scientific rigour and with an eye for maintaining scientific quality. Quality control measures were taken and well described in the report. Geotechnical model and investigated scenarios are clearly described and illustrated. Various models and assumptions are well described.
The SENSAR and TNO teams are complementary teams that have well worked together with a good integrated product and clear results.
The project went beyond expectation by including an inverse modelling case study yielding a good match between the observed surface deformation pattern and the modelled salt cavern properties. This demonstrated the potential of developing an early warning system based on InSAR monitoring and when certain thresholds are crossed additional geotechnical modelling can be executed to identify the risk of cavern collapse.

KEM Evaluation of the results

Evaluation whether the research questions are addressed adequately (questions answered, precision and uncertainties on outcomes, potential consequences on current practice addressed, ..)

The project focused on answering the following research questions:

1. What are the quality control procedures of the InSAR data and what levels of accuracy and precision can be expected?
   The project has clearly investigated and quantified the quality control procedures of the InSAR data and what levels of accuracy and precision. The Precision and Accuracy are good enough to do relevant surface change monitoring. The main challenge is that the methodology relies on roads and buildings to do reliable monitoring. The potential addition of monitoring in grasslands areas would improve the methodology.
2. What are the global experiences with salt cavern monitoring using InSAR?
   The project did a good state of the art literature overview, including recent and relevant literature. Time resolved InSAR monitoring of failure processes remains relatively uncommon, and even fewer studies establish a direct link between observed surface deformation and physical modelling of the underlying failure mechanisms. A sound framework of various salt cavern deformation and collapse is proposed. Although inverse modelling approaches have been applied in some cases, these efforts have predominantly focused on gradual, long term deformation signals.
3. Which locations over the last 10 years show subsidence rates which correspond to possible unstable salt caverns in Twente?
   The areas with higher subsidence rates are identified. it is still difficult to make a hard conclusion on cavern instability in the Twenthe-Rijn region. Linear deformation hotspot and spatially correlated deformation pattern that correspond with known borehole locations can be detected. Analysing InSAR data over the last 10 years, a subsidence hotspot is detected at the Boortorenweg. At this location a cavern has collapsed in the past and the signal observed is most likely a continuation of its post-collapse subsidence. As deformation at the surface above the cavern is often slow, spatially correlated deformation patterns are considered relevant for potential cavern instability. Such spatial patterns are present at the Beckumerstraat in the Twente mining area, corresponding to borehole locations. This location may experience stronger deformation in the future and is recommended to be monitored for sudden changes in surface movement.
4. What is the coupling between (known) Twente cavern deformation and subsidence data? Which Twente caverns may be unstable?
   Early detection of developing sinkholes is an important capability. The project has demonstrated that such capability can be developed when applying modelling insights to advanced InSAR monitoring.
   Cavern characterization can be greatly helped with inverting surface movement estimates obtained with InSAR. The temporal behaviour can be analysed to identify changes in the deformation rate, which may be indicative for cavern migration. The shape attributes show the depth and size of the cavern. Their temporal behaviour can be a strong piece of information for the identification of failure.

In this project we have shown that InSAR can be a powerful monitoring tool for early detection of abnormal surface deformations in region of salt caverns. The surface deformations observed with InSAR are in good agreement with geomechanical modelling results, taking into account subsurface characteristics and cavern geometry.

KEM interpretation of the outcome

The interpretation of the results (consequences on methods/data to be used in practice, con risk instrument modules, on inspection procedures and operator procedures, ..) (project evaluation text website)

The results of this approach, being the combination of long term surface subsidence monitoring using InSAR with geotechnical modelling in case of accelerated subsidence rates, is an excellent approach to develop an early warning system for salt mining activities in the Netherlands. It is low cost, pro-active and could be potentially shared with civilians to stimulate transparent sharing of surface ground motion effects due to salt mining. The coupled geotechnical modelling supports the interpretation of what is causing the observed subsidence and helps to qualify and quantify the risks involved.

Closure text for the website

A summary in simple terms of the goal, the outcome and impact on mining policies or toolboxes of the research project.

This project has delivered a feasibility study of using InSAR satellite data to monitor surface elevation changes in Twente related to salt cavern mining. The data is sufficiently precise and accurate to do this monitoring in a reliable and consistent way and to identify stable and potentially unstable caverns. A large part of the investigated salt mining area does not show significant subsidence indicating only stable caverns.
Subsidence hotspots were identified. These are linear deformation hotspot and spatially correlated deformation pattern that correspond with known cavern locations. Analysing InSAR data over the last 10 years, a subsidence hotspot is detected at the Boortorenweg. At this location a cavern has collapsed in the past and the subsidence is most likely a continuation of its post-collapse subsidence. The Boortorenweg subsidence hotspot was also geotechnical modelled to understand the underlying mechanism of how salt cavern evolution reflects on the surface subsidence characteristics. Model inversion allowed a convincingly good match with he observed surface deformation. Allowing insight in salt cavern evolution is key to understand if sinkhole development is likely to happen. For the deformation pattern around the Boortorenweg, it showed that the depth of the converging volume was closer to 250 m than to 350 m, so this cavern had migrated upwards out of the rock salt layers.
For future InSAR monitoring it is recommend to focus as early warning on locations where surface movement is observed of more than 5 mm/year.