On the use of InSAR observations for subsidence estimation: an application to compacting reservoirs

Samantha S.R. Kim[1], Wietske S.Brouwer[2], Ramon F. Hanssen[2], Femke C. Vossepoel[1]

1 Department of Geoscience and Engineering, Delft University of Technology, Delft, The Netherlands
2 Department of Geoscience and Remote sensing, Delft University of Technology, Delft, The Netherlands

s.s.r.kim@tudelft.nl

Abstract

During hydrocarbon production, gas reservoirs can experience compaction. Change of reservoir height at several kilometer depth can lead to land subsidence at the surface. Additionally to reservoir compaction, processes occurring in the shallow subsurface such as compaction, shrinkage and swell in the soil surface layers contribute to the total land displacement. InSAR observations provide a large scale monitoring of the land displacement. Subsidence is measured above the Groningen gas field, in the Netherlands as a result of a compacting reservoir, however it is not sure how sensitive InSAR technique is to the displacement coming from other sources, e.g., land displacements resulting from a shallow compaction. To identify the contribution of different compaction processes in the InSAR observations, we use a data-assimilation method to combine model-predicted subsidence with subsidence observations. We separate drivers of subsidence based on the scale of spatial and temporal correlation in InSAR observations of subsidence. We assume spatially correlated observations over the gas field for subsidence from the compacting reservoir and local influence of subsidence for other processes. We highlight a strong seasonal pattern in the subsidence estimate and identify the effect of data reduction on the sensitivity of InSAR to shallow processes of subsidence above the Groningen gas field.

Introduction

In the area above the Groningen gas field, in the Netherlands, subsidence caused by a depleting gas reservoir has been extensively monitored (Bourne et al. 2014, van Thienen-Visser et al. 2017). Subsidence in the Groningen area is twofold. Soil types in this region are prone to subsidence (Koster et al. 2018) and hydrocarbon production causes a pressure reduction, causing rock compaction at reservoir depth and subsidence at the surface.

InSAR (Interferometric synthetic-aperture radar) observations are used to measure the surface displacements above the reservoir (Ketelaar at al. 2009). InSAR observations exhibit a characteristic bowl-shaped subsidence. However, the observations also show additional subsidence patterns not primarily attributed to the compacting reservoir. These processes arise from the InSAR signal processing (Hanssen 2001) or other driving mechanisms of subsidence. Therefore, monitoring the subsidence caused by the compacting reservoir from InSAR observations, requires to identify the origin of the different drivers of subsidence. We consider *deep* and *shallow* drivers of subsidence, that we define as follow. We refer to reservoir compaction as the *deep* driver of subsidence. Other driving mechanisms causing subsidence are referred to as *shallow*, such as the phreatic groundwater table drop, leading to shrinkage and oxidation of the organic material above the ground water level.

We propose an approach using a data-assimilation method, so-called particle filter. The particle filter has a fast implementation, however its efficiency depends on the system dimension (e.g., number of observations). To assimilate geodetic observations we use the particle filter with an optimal proposal.

Methods

Model of subsidence

We built a conceptual model based on a compaction in the reservoir and in the shallow subsurface. In the gas reservoir, changes in pressure caused by hydrocarbon production can result in reservoir compaction and subsidence of the surface, where compaction is a reduction of thickness of a material layer in the subsurface.

For the subsidence with a shallow origin, we consider a local displacement that is linearly proportional to a compaction. Processes such as peat oxidation (van Asselen et al. 2018), clay shrinkage, interaction with groundwater level (Fokker et al. 2019), usually require models of higher complexity (Koster et al. 2018). We do not include assumptions on the physical processes and keep a generic model, that can later be adapted with the right assumption for any case of interest.

Data

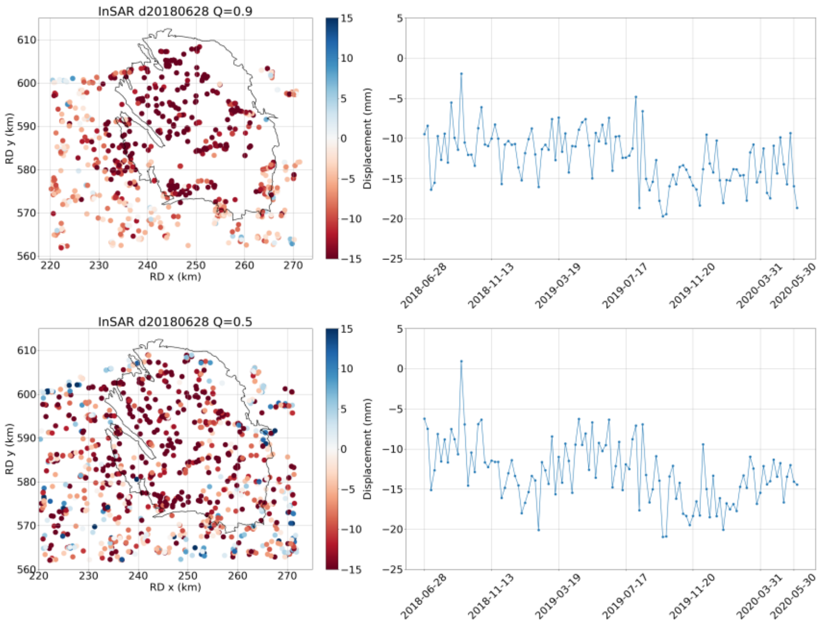

Figure 1 Subsidence observations above the Groningen gas field with InSAR point scatterers selected on their quality from 2015 to 2020. (top) Example for the epoch of 28-06-2018, the scatterers with higher quality shows a typical bowl-shaped subsidence profile but the time series usually show less clear seasonal pattern. (bottom) Point scatterers with lower quality (0.5>Q>0.9) show more spatial variability in the subsidence but show a periodic trend in the times series.

We use InSAR (Interferometric synthetic-aperture radar) observations from the period of 28-06-2018 to 29-06-2020 providing a subsidence measurement over the area of Groningen every 6 days. The dataset is reduced using 1) only point scatterers with quality Q>0.9 and quality 0.5>Q>0.9 and 2) by averaging scatterers in a radius of 250m around parcels in the area of Groningen.

Data-assimilation

In this study we use a data-assimilation method based on importance sampling, the particle filter. Using the particle filter we can estimate unknown model states or parameters. The principle of importance sampling is to sample an ensemble of values for model states or parameters. Each value of state in the ensemble is called an ensemble member or a particle. The forward modeling with a particle gives a model prediction which is compared with observations to give the *best estimate* of the unknown states. In a particle filter with a large number of observations, weights in the posterior distribution collapse unless the ensemble size increases. To solve the problem of weight collapse and assimilate InSAR dataset, we implement the particle filter with an optimal proposal (Doucet et al. 2000).

Results

Results of the assimilation of the two years of InSAR epochs provide estimations of compaction for the reservoir (i.e., deep) and shallow sources of compaction. From the estimated compactions we model the estimate of subsidence caused by *deep* and *shallow*. The estimated reservoir compaction remains quasi constant over the two years period, which is consistent with the decrease of hydrocarbon production.

To identify if the estimate of shallow subsidence comes from soil processes, we use a simplified geology of the area with soils mainly composed of clay in the North and sand in the South and we identify observation points in clay or in sand. We then compare subsidence estimates for observations in clay and in sand at all epochs. We obtain time series of the shallow subsidence estimate for the North and the South of the gas reservoir from 28-06-2018 to 29-06-2020. To see seasonal patterns possibly originated from soil motion, Figure 2 shows the autocorrelation of those time series with high correlation coefficient in red, highlighting a periodicity at each repetition.

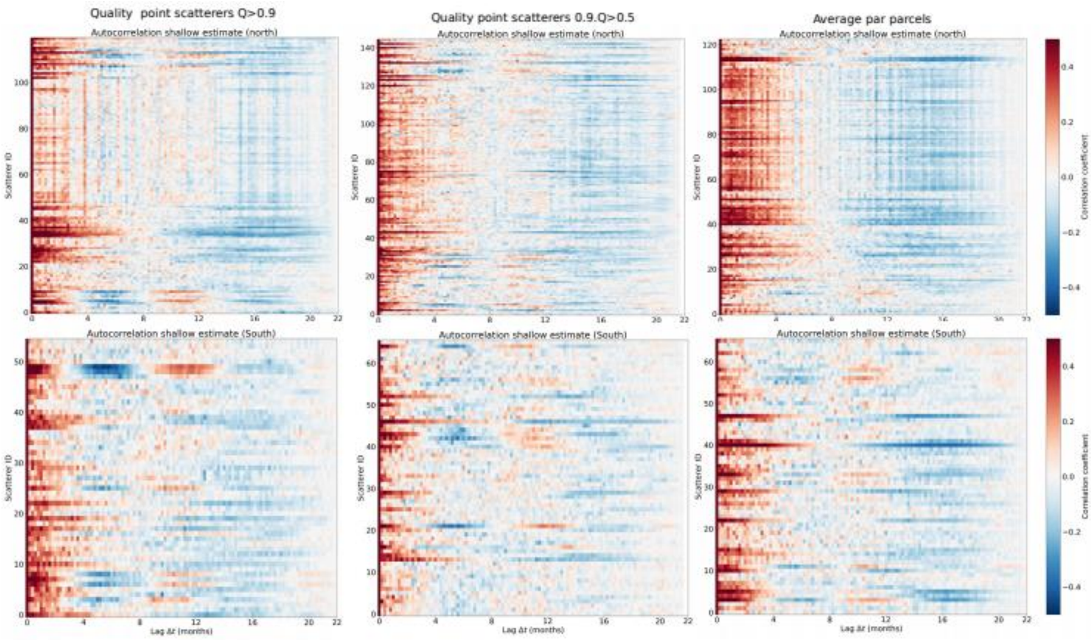

Figure 2   Autocorrelation of estimate of subsidence from shallow drivers from scatterers with different quality and the averaged observations per parcels. Results are plotted for the Northern (first row) and the Southern (second row) parts of the gas field.

We observe a clear difference in the autocorrelation in the North and in the South, suggesting different processes and different information in the assimilated InSAR data from North to South.

Results show a seasonal pattern with a periodicity of 1 year, mainly visible in dataset with high quality points and interestingly in the dataset averaged per parcels in the south of the Groningen gas field. However, comparison of autocorrelation with displacement time series can show a subsidence in winter and an uplift in summer. We know that the InSAR method is sensitive to deep-founded infrastructures, with seasonal expansion due to temperature changes. Nevertheless, scatterers in the North (i.e., clay soil) with lower quality show more consistent seasonal patterns than with high quality points. It is likely that selecting high quality scatterers also removes some shallow components in the dataset. Both the displacement time series and the autocorrelation show a pattern of subsidence with a longer period. This is also visible in the observations averaged per parcels and mostly in the North of the area. Assimilation of longer time series is necessary to conclude on its origin.

Conclusion

To monitor the subsidence above the Groningen gas field we use a data-assimilation method, the particle filter and estimate the origin of subsidence in InSAR observations.

Additionally to the subsidence from the compacting reservoir, we highlight the sensitivity of InSAR point scatterers to non-deep sources of displacement. We show different seasonal patterns in the estimate of subsidence from *shallow* processes. This estimate may contain signals from infrastructure expansion from annual temperature changes. Moreover the comparison with soil type geology suggests that it is possible to observe subsidence related to shallow geology in InSAR point scatterers in the example of the Groningen gas field.

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