

KEM Research Question

TITLE Modelling impact of subsurface heterogeneities on subsidence above a depleting gas reservoir

Objective

In general, in subsidence models the subsurface is schematized as a sequence of laterally continuous, more or less horizontal layers with relatively small variations in thickness. Data from seismic surveys and boreholes show that heterogeneities, such as lateral variations in lithologies, layer thickness and material properties, can exist both at reservoir level and at various depths in the overburden of a gas reservoir, whereas these heterogeneities can have varying length scales. Depending on depth, lateral and vertical dimensions and contrasts in material properties, these heterogeneities may have an impact on the shape of the subsidence bowl at surface level, and may potentially be a (partial) source of small-wavelength fluctuations in subsidence, such as observed at surface level.

The specific objective of this study is to further understand and quantify the contribution of lateral heterogeneities (in terms of laterally varying lithologies & elastic properties) within the reservoir and in the overburden on small-wavelength fluctuations of the subsidence bowl above depleting gas reservoirs. Here we define small-wavelength fluctuations as all fluctuations with a length-scale smaller than the reservoir-scale.

State of the art, background

Subsidence modelling. (Semi-)analytical models such as AESUBS have been frequently used to model the evolution of subsidence above depleting gas reservoirs. These (semi-)analytical approaches are generally computationally efficient, which enables their use in data-assimilation and model calibration against observations of subsidence, and they have been successfully used for modelling the large-scale evolution of the subsidence bowl in time. However, (semi-)analytical approaches can only account for vertical variations in lithologies and properties, but cannot account for lateral variations in lithologies and elastic properties. To model the impact of these lateral subsurface heterogeneities on the occurrence of small / intermediate wave-lengths fluctuations in the subsidence profile, numerical modelling techniques are required.

Subsurface data and subsidence measurements. Information on the various scales of lateral heterogeneities in the subsurface can be obtained from seismic surveys, geological maps and cross sections and borehole data available at www.nlog.nl as well as from the GeoTop model of the shallow subsurface. In general, data on subsurface heterogeneities will be more abundant for the shallow subsurface. Data on characteristic small-wavelengths fluctuations in the subsidence profile above Dutch gas reservoirs, such as the Groningen gasfield can be derived from observations, such as levelling-, GPS- and InSar data.

Research Question

The project will comprise the following main activities, with focus on the northern part of the Netherlands:

- A1. Literature review
- A2. Geodetic analysis of different length-scales of fluctuations in subsidence, based on subsidence data (using e.g. InSar and levelling data).

- A3. Geological analysis of different length-scales of fluctuations in subsurface geology, based on information available from e.g. DTM, GeoTop, interpreted cross sections from www.NLOG.nl
- A4. Forward modelling of subsidence due to reservoir depletion in the analytical software of AESUBS, for various length-scales of subsurface heterogeneities
- A5. Forward modelling of subsidence due to reservoir depletion in the numerical software of DIANA-FEA, for various length-scales of subsurface heterogeneities
- A6. First order estimation of length-scale of fluctuations in subsidence due to shallow groundwater extraction
- A7. Comparison of modelling results from analytical tools to numerical tools and to observations
- A8. Implications for policy and technical assessment of production plans

ed on the above activities the following research questions will be addressed:

1. Main research question: What is the effect of lateral heterogeneities in the subsurface on the shape of the subsidence bowl above a depleting, compacting gas reservoir? Can they explain the occurrence of small wavelength fluctuations in subsidence such as observed above Dutch depleting gas fields?
2. What characteristic length-scales of subsurface heterogeneities can we expect at reservoir level and in the overburden of producing gas fields?
3. What is the magnitude of typical small wavelength fluctuations in subsidence as observed above depleting gas fields?
4. How does the magnitude of the fluctuations observed compare to the measurement error? How does the magnitude of the small wavelength fluctuations compare to the uncertainty of the predictions with common layer-cake analytical solutions?
5. What is the impact of a major lithological heterogeneity in the subsurface, such as 1) a visco-elastic salt-dome on top of an elastic reservoir, 2) deep subglacial valley deposits, on subsidence above a depleting gas field?
6. What is the impact of intra-reservoir heterogeneity and spatial variation in elastic material parameters on fluctuations in subsidence at surface level? What is the effect of heterogeneities in the overburden on fluctuations in subsidence at surface level? In what way do depth and dimension of the heterogeneity (in terms of height and lateral extent) affect the subsidence profile?
7. What is the first order estimate of expected fluctuations in subsidence caused by groundwater lowering? How do wavelengths of fluctuations in subsidence due to the process of reservoir compaction compare to differential surface movements caused by shallow processes like groundwater extraction?
8. How do numerical modelling results compare to layer-cake analytical solutions, in case of subsurface heterogeneity?
9. How do the results impact policy on the Dutch mining activities?
10. How do the results impact TNO's technical assessment of production plans?

Deliverables expected

A single written report covering:

- D1. Literature study into what is already available on the topic
- D2. Analysis and description of the scale of fluctuations observed in subsidence measurements above producing reservoirs in the Netherlands and typical scale of geological heterogeneities in reservoirs and overburden.
- D3. Sensitivity/scenario-based study using numerical models to quantify the effect of heterogeneities of varying dimensions, depth levels and contrast in elastic parameters. This analysis will be based on a geological setting representative for the Rotliegend gas fields in the Northern Netherlands (range of depths, reservoir thickness, dimension and elastic parameters of heterogeneity).

- D4. Numerical modelling study quantifying the effect of a major structure like a 1) salt dome and 2) deep subglacial valley deposits ('Peelo-geulen') on top of a producing reservoir on the subsidence at surface level. The numerical model for the salt-dome will be based on an axisymmetrical geometry, representing a salt dome of varying dimensions (in terms of the ratio height/width) situated on top of a (disk-shaped) reservoir layer of varying thickness and radius. The sub-glacial valley structure will be modelled in 2D-plane-strain.
- D5. Comparison of numerical results versus layer-cake analytical solutions and comparison to observations. Conclusions on the contribution of subsurface heterogeneities to small-scale fluctuations in subsidence caused by reservoir depletion (as compared to shallow groundwater extraction). Recommendations for the use of modelling techniques for future subsidence studies.
- D6. Reflection on the impact of the study on policy and TNO's technical assessment of subsidence due to gas production.

Timeline

3 months for deliverable D1 and D2, which can be performed in parallel. Results of D1 and D2 will be presented to KEM representatives and client in a (skype/teams) meeting. During this meeting the set up and boundary conditions of the numerical modelling studies in D3 and D4 will be discussed and defined. 4 months for deliverable D3 and D4, which will be presented to the client and KEM representatives in a (skype/teams) meeting. 2 months for deliverable D5 and D6, including final end-meeting. Project is aiming to start mid February.

Expected use

The results will be beneficial to understand at what depth and scale subsurface heterogeneities are expected to contribute to irregularities in subsidence at surface level. The outcome of the study can be used to decide which modelling techniques to choose in case significant subsurface heterogeneity is expected. The results will give a scientific base for discriminating between the likely role of deep heterogeneities and processes and shallow heterogeneities and processes to the occurrence of small scale fluctuations in the subsidence profile. This is of particular relevance in communication towards the public, as small-scale fluctuations are generally considered more likely to cause damage than smooth subsidence gradients. Also the results may impact current mining related policy of the Ministry.

Expertise and tools preferred for the team

The TNO team will include specialists on geodetics (Guang Zhai), geology (Kay Koster/Kees Geel), hydromechanical analytical, numerical modelling (Brecht Wassing, Frans Aben, Peter Fokker, Thibault Candela) and policy advice for production plans (Joost Roholl, Maarten Pluymaekers). Access to the Rotliegend gas fields geological, geomechanical and subsidence data (via www.nlog.nl, GeoTop, and publicly available subsidence data).

Quality assurance, Organisational and communication requirements

The TNO-team will consist of a dedicated project leader. Regular meetings will be organized with the client (and a representative of the KEM-panel) to keep the client informed of progress and results and to set and keep the expectations right. Additionally the study will be presented in the half-yearly meeting with the KEM panel. The team will use both benchmarked in-house and commercial modelling software like AESUBS/ESIP and DIANA-FEA.

References

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