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Dynamic reservoir compaction inferred from 4D surface subsidence observations.

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Observations of subsidence can give us a better handle on the subsurface processes like compaction behavior of a reservoir, and can tell us more about the reservoir itself: about undrained compartments or the strength of the aquifer. However, to get the information from subsidence data, you have to carefully follow an inversion procedure. This inversion exercise is a big challenge, in which all the available knowledge has to be used to the fullest possible extent. We introduce a novel, 4D inversion scheme to resolve dynamic reservoir compaction from surface subsidence observations (leveling or GPS data, InSAR, tiltmeter monitoring) in a single procedure. The method uses a prior model, as well as both the prior model covariance matrix and the data covariance matrix. These two covariance matrices incorporate the spatial and temporal correlations between model parameters and data, respectively. Since the time-dependence is implicit in the formulation of the inverse problem, the method can cope with more sites being added in later observation campaigns, and also with the fact that not all sites are necessarily included in each campaign. The method is validated by a synthetic case study based on an existing gas reservoir, adapted to give a sizeable subsidence signal. The available geological information from seismic sections and boreholes (i.e. volume, shape and depth of the reservoir, presence of faults, permeability, porosity, and type of overburden) and the uncertainty in the transmissibility at the gas/water interface were combined with production information in a reservoir simulator. A Monte Carlo approach for simulating the depletion for 50 pseudo-random transmissibilities with a log-normal distribution centered at 0.01 was adopted. This way, a pressure depletion field and a realistic model covariance were generated which were used as prior information in the inversion procedure. The subsidence data were generated using the

"true" geological input. 50 points were randomly sampled to provide a realistic subset of subsidence information. The incorporation of the full prior model covariance implicitly guarantees smoothness of the model estimate, while maintaining specific geological features like sharp boundaries. This characteristic of our method is vital for the timely identification of undrained compartments in gas fields, as well as for studying the behavior of aquifer-driven production of reservoirs and aquifer response. Additionally, through the prior model covariance matrix the spatial and temporal relationships between model parameters enhance the influence of the data on the inverted model estimate. In conjunction with the temporal aspect of the method, this yields a better constrained model estimate. This enables the identification of non-linear acceleration or delay in reservoir compaction.