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Recursive update of channel information for reliable history matching of channel reservoirs using EnKF with DCT

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ABSTRACT

Ensemble Kalman filter (EnKF) is one of the promising reservoir characterization schemes for history matching. It has been widely researched due to its excellence in recursive data processing and dependable uncertainty quantification. However, EnKF has critical limitations for applying to non-Gaussian distribution fields such as channel reservoirs.

In this study, we propose a novel scheme to characterize channel reservoirs reliably. The scheme, recursive update of channel information (RUCI), updates key channel information such as facies ratio and permeabilities of each rock facies as components of the state vector. Since permeabilities assimilated by EnKF follow a Gaussian distribution, EnKF itself is not adequate to preserve channel structure. To overcome this limitation, we use cumulative distribution function mapping to maintain its bimodal distribution. In addition to RUCI, discrete cosine transform (DCT) is utilized to preserve clear channel continuities by figuring out essential channel trend.

The proposed method, RUCI in EnKF with DCT, is applied to three different channel reservoir cases and is compared with typical three methods: EnKF, EnKF with DCT, and EnKF with normal score transform (NST). Both of conventional EnKF and EnKF with DCT show overshooting and fail to present channel details. Furthermore, their permeability distributions have a tendency to follow a Gaussian, not a typical bimodal distribution of sand and shale. Even if EnKF with NST maintains a bimodal distribution after updates, it cannot figure out overall channel trend. The proposed method not only prevents overshooting but also preserves a bimodal distribution of permeability. It can clearly characterize true channel trend even though initial reservoir models are poorly made. In addition, it gives better estimation of future oil and water productions than the other 3 methods by reducing uncertainties and matching true performances.

1. Introduction

Reservoir characterization is a process to make reliable reservoir models. It is imperative for dependable uncertainty quantification and reservoir management. Its procedures typically consist of static data integration and history matching. Since prior reservoir models generated by static data only have large uncertainties, history matching should be accomplished to reduce these uncertainties. A lot of optimization methods have been suggested for history matching in petroleum engineering.

Ensemble Kalman filter (EnKF), proposed by Evensen (1994), is one of the most promising optimization schemes for history matching. Nævdal et al. (2002) applied EnKF for characterizing permeability distribution in an oil reservoir at the very first time. EnKF can integrate observation data in real time and provide reliable uncertainty quantification by using a group of models, called as ensemble. Moreover, EnKF has flexibility for model parameters and is easy to couple with any forward simulator.

In spite of these benefits, EnKF has critical limitations for applying to non-Gaussian distribution fields such as channel reservoirs (Sarma and Chen, 2009; Kang et al., 2016; Lee et al., 2016), because updated parameters by EnKF have a tendency to follow a Gaussian distribution. Since geological properties of channel reservoirs are distributed in a bimodal not a Gaussian, EnKF usually fails to characterize channel structures. In addition, poor characterization results cause two typical problems: overshooting and filter divergence. Overshooting describes the phenomenon that some parameters are adjusted abnormally high. Filter divergence occurs when ensemble members become so similar that they cannot be updated anymore even with additional observed data. To solve these limitations, many attempts have been made to

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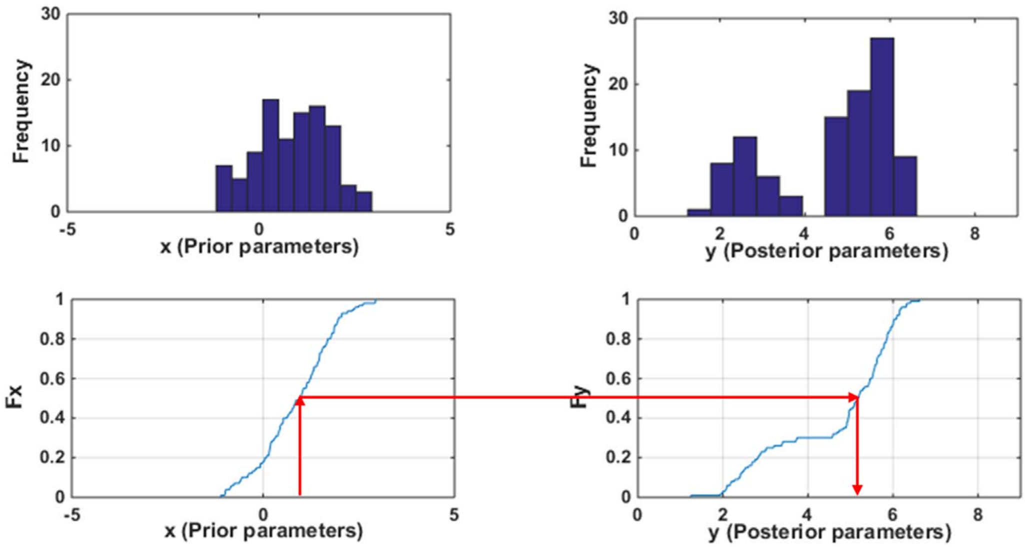
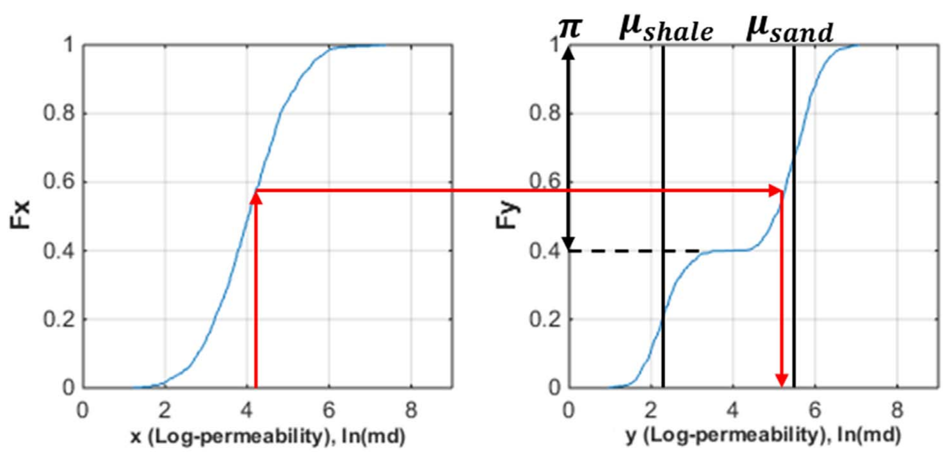


(a) Histogram and CDF of prior parameters
(b) Histogram and CDF of posterior parameters

Fig. 1. An example of CDF mapping. (a) Histogram and CDF of prior parameters. (b) Histogram and CDF of posterior parameters.



(a) CDF of updated permeabilities
(b) Constructed CDF for bimodal distribution

Fig. 2. CDF mapping after assimilation (Gaussian to bimodal distribution). (a) CDF of updated permeabilities. (b) Constructed CDF for bimodal distribution.

characterize non-Gaussian reservoirs using ensemble-based history matching methods (Vabø et al., 2008; Dovera and Della Rossa, 2011; Oliver et al., 2011; Hu et al., 2013; Lee et al., 2013, 2014, 2016; Zhang et al., 2014; Vo and Durlofsky, 2015).

Jafarpour and McLaughlin (2007) introduced discrete cosine transform (DCT) for deriving low dimensional parameterizations. Since DCT selects main components among an original set of unknowns, it can capture main features of channel reservoirs by removing noises. Even if their proposed scheme cannot preserve a bimodal distribution, they demonstrated that DCT can be helpful to figure out overall channel pattern and preserve geological continuity (Jafarpour and McLaughlin, 2008, 2009a, 2009b). However, it showed overshooting and failed to find detail parts of the channel. Jafarpour (2011) also suggested other parameterization method called as discrete wavelet transform (DWT) and integrated the scheme with EnKF to represent geological facies. The author determined important wavelet coefficients using prior information and sensitivity to the flow response. Similar to the previous studies, EnKF with DWT cannot identify small-scale features in ill-posed inverse problems.

Lorentzen et al. (2013) proposed a level set function to parameterize facies fields. They defined a signed distance for each facies type, as minimum Euclidian distance from each grid to the channel border. Grid cells located in the designated facies domain have positive distance values and those located outside have negative distance values. Then the distance parameters are updated as components of EnKF and transformed to facies maps based on a maximization criterion.

Jafarpour and Khodabakhshi (2011) presented a probability conditioning method for constraining training image (TI) based facies simulation. They inverted the flow data using EnKF to get a probability map for facies description and used the resulting facies maps to conduct multipoint statistical facies simulation with TI. Their proposed scheme properly estimated future productions and channel trend by retaining the feature of prior TI. However, if TI is not reliable, the scheme cannot give us suitable characterization results. Lee et al. (2017) suggested a novel concept of the history matched facies-probability data to define channel connectivity. They integrated dynamic data into geostatistics using pseudo-soft data.