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A Hybrid Ensemble Kalman Filter With Coarse Scale Constraint for Nonlinear Dynamics

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Abstract

The recent interest in Ensemble Kalman Filters (EnKF) is driven to a large extent by the need for continuous reservoir model updating and uncertainty assessments based on dynamic data. The EnKF approach relies on sample-based statistics derived from an ensemble of reservoir model realizations. Sampling error in these statistics, particularly with the use of modest ensemble sizes, can severely degrade EnKF performance leading to parameter overshoots and filter divergence. However, for computational efficiency, the ensemble size needs to be kept small resulting in spurious sample correlations and loss of geologic realism during model updating. Moreover, facies-based non-Gaussian geologic models and the non-linearity of multiphase flow problems pose significant additional challenges for the EnKF. The EnKF updates are designed to be optimal only for Gaussian priors and linear model dynamics. For multiphase history matching, the posterior distribution will be non-Gaussian and the ensemble mean is not a good representation of the central tendency. As a result the EnKF can result in a poor match to the data or unrealistic model updates.

The hybrid multiscale EnKF proposed here provides an improved approach to operational data assimilation problems and tends to overcome many of the limitations associated with the classical EnKF implementation. Our approach combines non-linear inversion with the EnKF to account for the inherent non-linearities of multiphase inverse problems. Specifically, we update the ensemble mean in a conventional EnKF through a non-linear inversion at selected time intervals and replace the ensemble mean with the 'posterior mode' from the inversion. This explicitly recognizes the fact that for non-Gaussian distributions, the posterior mode is a better representation of the central tendency compared to the ensemble mean. Furthermore, the inversion results are imposed on the individual ensemble members via a coarse-scale constraint using a sequential second stage updating in the conventional EnKF and a flow-based upscaling. Our approach ensures that the ensemble members in the conventional EnKF will follow the trajectory of the non-linear inversion within a specified degree of tolerance. This not only allows us to account for non-linearities in the model updates but also prevents filter divergence arising from the use of limited ensemble size. We first illustrate the advantage of the hybrid approach using a synthetic example and present a detailed validation of our results. Next, the approach is applied to a west Texas carbonate reservoir to demonstrate its power and utility for practical field problems.

Introduction

One of the primary motivations for history matching is to construct reliable reservoir predictive models and to quantify the uncertainties in the reservoir forecasting. The traditional approach to history matching generally involves applying local and regional changes through multipliers to reservoir properties to calibrate the reservoir model to production data (Williams et al 1998). Although commonly used in practice, this approach very often creates artificial discontinuities leading to a loss of geologic realism in the updated model. Additionally, the considerable manpower and time required to achieve a satisfactory history match renders the manual history matching procedure inefficient for assessing multiple model realizations. Consequently, automated methods that utilize inverse theory or stochastic approaches to minimize appropriately defined misfit functions have received increased attention in recent years (Landa and Horne 1997; Cheng et al 2005; Oliver et al 2008). This has been considerably aided by the development of robust history matching algorithms and enhancements in computational capabilities.

Beginning with a reservoir model conditioned to prior static information, such as geologic data, core- and log-analysis and seismic interpretation studies, automatic history matching algorithms commonly utilize all previously recorded dynamic data in the search for a plausible solution. With the advent of modern field monitoring technology, such as permanent well monitors