Integrating Tracer Data in Simple Geological/Reservoir Models Using the Ensemble Kalman Filter Approach.

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Introduction and Methodology

Tracers are widely used to increase the understanding of fluid flow, they can be used to label injection fluids, hence, well connections and fluid patterns can be established when the tracer appears in production wells. Tracer data contains valuable information that can be used in production planning and help enhance petroleum production, but the information is often under-exploited. Here we use a methodology for assimilation of tracer data for reservoir model updating using the Ensemble Kalman Filter (EnKF). A full presentation of the methodology is found in Valestrand *et al.* (2008).

Tracers are inert chemical or radioactive compounds that are used to label and track fluids. They can be used to monitor wells, production equipment, as well as fluid movement in the reservoir. In the reservoir, tracers can be used in single well operations, e.g., to evaluate remaining oil in the near-well zone, or in inter-well tracer tests (IWTT), to evaluate fluid movement between injectors and producers. A general review of tracers applied in petroleum reservoirs is given by Zemel (1994). A review of inter-well tracer testing is given by Dugstad (2007). IWTT provide an additional source of data, which should be used in combination with production data (well pressure and production rates) and 4D seismic (see e.g., Huseby *et al.*, 2007).

The ensemble Kalman Filter has recently gained popularity as a method for history matching. The EnKF includes online update of parameters and the dynamical states. An ensemble of model representations is used to represent the model uncertainty. This paper addresses reservoir model improvement by integrating injected tracer data in work-flows aimed at conditioning reservoir simulation models to production data. Conditioning of reservoir simulation models to production data (history matching) is a challenging task. Recently, the EnKF, has been shown to be a promising approach for this problem. The EnKF was first introduced in Evensen (1994) motivated by applications in oceanographic and atmospheric sciences. The EnKF was shown to be an efficient tool for data assimilation for large-scale systems, and there is an extensive literature see, e.g., Ehrendorfer (2007); Evensen (2007); Nævdal *et al.* (2005), for more information.

Tracers are present in the reservoirs at miniscule quantities, and do not affect the other fluids in the reservoir. For this reason, modeling of tracers may be performed in a separate module decoupled from the reservoir simulation itself (Sagen *et al.*, 1996). We have used the modular method here, which allows coupling to any black oil or compositional reservoir simulators.

We use the EnKF methodology to update reservoir variables. The variables we update are static fields (e.g., permeability and porosity fields), dynamic fields (e.g., reservoir pressure and fluid saturations), and additional parameters (e.g., permeability multiplier and fault transmissibility multiplier). The essence of the EnKF methodology is to update an ensemble of reservoir models with different values of the variables we want to estimate, by means of the production data (well measurement).

Reservoir Description

A short description of the synthetic reservoir is given here, for more detail see Valestrand *et al.* (2008). The total number of grid cells in the case is 40 x 40 x 1, with 746 active grid cells. The cell dimension is 75m x 75m x 10m. A single producer, PROD1, and two injectors, denoted by INJE2 and INJE5, are defined. Figure 1 (a) shows the location of the wells. A fault is located above the INJE2 injection well; see the white horizontal line in Figure 1 (a). The transmissibility multiplier of the fault has a value of 10^{-5} and hence will significantly reduce the flow across the fault zone. The fault will mainly affect the flow between the two wells INJE2 and PROD1. The true permeability is isotropic. Gas is injected in both injectors INJE2 and INJE5. A constant injection rate, $Q_g = 150000$ Sm^3/day, have been applied, and gas tracers were injected in both injectors. The tracers are labeled according to the injection wells, i.e., in the following, tracer IG2 is injected in well INJE2 and IG5 is injected in well INJE5. The simulation spans a time interval of 1901 days and data is assimilated every 30 days. A one-day injection of tracer pulse of 1.0 per Sm^3 is performed after 300 days. This is done in both injection wells; the tracers injected in the two wells are different. The following measurements are collected for the history matching: Tracer concentrations in the production well for the two tracers and gas-oil-ratio. (Oil production is not used as a measurement as the production well is conditioned by historical oil rate.) To simulate measurement error we have added Gaussian noise with zero mean to the data. The initial ensemble members for the permeability field are generated from Gaussian distributions. The initial ensemble members for the fault transmissibility multiplier are chosen in order to cover the range of values from a closed to an open fault.

We use the EnKF methodology to update five dynamic fields; pressure, water saturation, gas saturation, and concentration of two gas tracers, and to estimate one static field, the permeability of the 2D reservoir, and one static variable, the transmissibility multiplier of the fault. Only the estimated fault transmissibility multiplier will be discussed here, for results on the permeability-estimation see Valestrand *et al.* (2008)

Results

In Figure 1, (b) and (c), the pink dots show the estimated transmissibility multiplier (i.e, the mean of the updated multiplier ensemble members) as a function of time. The maximum and minimum multiplier value, among the ensemble members, at each time, are indicated by the cyan dots, and the red dashed line is the true multiplier value. The result showed in (b) is obtained using information from tracer data in the assimilation, while in the result obtained in (c) tracer data is not used. It is clear that the tracer data is crucial, in (b) the estimated transmissibility multiplier is very close to the true value while in (c) we see that the EnKF updating has no effect on the multiplier value.

Figure 2 shows the gas saturation after 1901 days. Sub-figure (a) shows the true saturation, (b) shows the estimated saturation obtained using tracer data in the assimilation, and (c) shows the estimated saturation obtained when tracer data was not used in the assimilation. The saturation above the fault is important here. We see that in (b) the gas does not move through the fault while in (c) it does. As a consequence, a to large area is swept between INJE2 and PROD1 before breakthrough when the fault is erroneous estimated (c). Building models able to correctly describe the fluid flow is crucial when it comes to enhanced production. Figure 2 clearly shows that tracer data can play an important role in geological/reservoir modelling.

To evaluate how well the two estimations (with and without tracer data) are performed, we compare the following simulated outputs: I) The 100 final ensemble members (updated members at last time step) obtained using tracer data are used as inputs to the simulator and the whole production history is calculated (100 green lines in Figure 3), and; II) The 100 final ensemble members obtained without tracer data are used as inputs to the simulator and the whole production history is calculated (100 blue lines in Figure 3). The match of the data is clearly better using tracer data in the assimilation.

Acknowledgments

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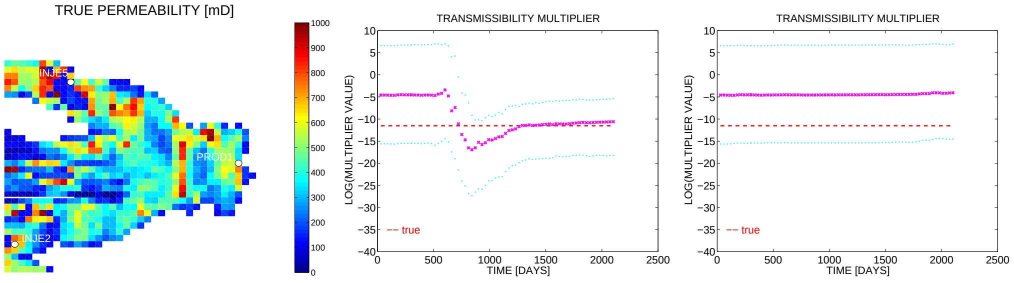
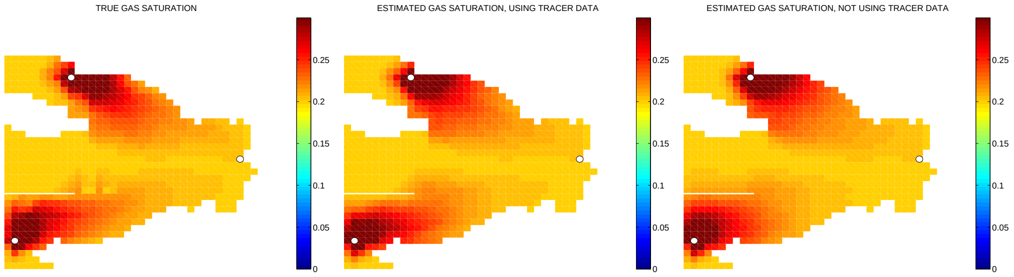
Figures



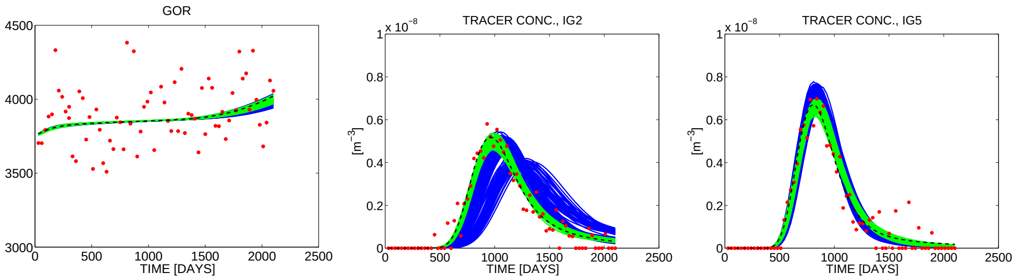
(a) (b) (c)

Figure 1: (a): True permeability. (b) and (c): The pink x-marks show the estimated fault transmissibility as a function of time. The cyan dots show thew maximum and minimum multiplier value, among the ensemble members, at each time step. (b): Using information from tracer data. (c): Not using information from tracer data.



(a) (b) (c)

Figure 2: (a): True gas saturation at 1901 days (b) and (c): Estimated gas saturation at 1901 days. (b): Using information from tracer data. (c): Not using information from tracer data.



(a) (b) (c)

Figure 3: (a): Gas oil ratio. (b): Concentration of tracer IG2. (c): Concentration of tracer IG5. All: The black dashed lines are the true data, the red dots are the measurements, and the 100 blue/green lines are generated by using the 100 estimated ensemble members at the final time step as inputs to the simulator. Blue/green lines from estimate obtained not-using/using tracer data.