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Assisted seismic history matching of the Nelson field: Managing large numbers of unknowns by divide and conquer

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ABSTRACT

Automatic history matching may be used to condition reservoir simulation models with time-lapse seismic data. Stochastic optimization algorithms are used to perform a good search of the parameter space to ensure effective determination of the best models. These approaches can require many thousands of simulations for large dimensional problems. Divide and conquer is an assisted history matching approach that enables deconvolution of the parameters so that they can be searched more efficiently and also leads to better uncertainty analysis.

We present an application of this approach on the Nelson field. Nine years of production history data are used along with baseline and monitor seismic surveys. Localised variations were made to permeability and net-to-gross ratio in the model. The reservoir was divided into separate parameter regions by combining experimental design and proxy model analysis. The former enabled insignificant parameters to be discarded while the latter showed that each region could be treated as a separate history matching sub-problem. Each sub-problem was then solved simultaneously using an adapted stochastic neighbourhood algorithm.

The results show that a forty-two dimensional problem could be reduced to a combination of three 9D problems and a 3D problem due to the spatial deconvolution of parameters and misfits. An improved match was obtained for the production and seismic data. Compared to a full stochastic search of the parameter space, the number of required models was several orders of magnitude smaller. Improved uncertainty analysis was made possible resulting in better understanding of the future behaviour of the reservoir.

An improved match to reservoir models leads to better confidence in their prediction and thus they can be used more effectively in reservoir management. The method presented here to improve the match retains the benefits of stochastic searching without the penalty of requiring an impractical number of simulations.

1. Introduction

Seismic history matching is the process where time-lapse (4D) seismic data are used to condition reservoir simulation models along with more conventional production data. 4D seismic data offers spatial information that is somewhat missing from production data and by integrating this data, history matched models will then give a more accurate representation for forecasting. Numerous studies have been presented previously and despite the success of this approach there are many known difficulties. Some of these arise from the overwhelming number of unknowns. This is often reduced by suitable choice of parameterization. Optimization routines such as gradient based methods (e.g. Lépine et al., 1999, Dong and Oliver, 2005, Gosselin et al., 2003, Mezghani et al., 2004) are not so troubled by the volume of the search space but they often produce a single best model unless combined with stochastic approaches. Probabilistic methods such as EnKF (e.g. Skjervheim et al. 2007; Aanonsen et al. 2009) work around this by finding geostatistical realisations so that the simulations match the data while maximizing probabilities in a Bayesian framework. However the EnKF approach can be problematic with large seismic datasets and a number of specific techniques such as smoothing or localisation must be applied (Aanonsen et al. 2009).

In this paper we consider an approach to separate the problem into manageable sub-problems using an approach which we call Divide and Conquer (Sedighi and Stephen, 2010). The philosophy is similarly applied in other areas such as calculation of Fast Fourier Transforms and the Merge Sort Routine. The aim is to break a problem into smaller problems which can be treated identically or in a similar manner using existing algorithms. This approach has been presented previously in seismic history matching and has been applied to the Schiehallion field with some success (Sedighi and Stephen, 2010). It is based on the estimation of a proxy model which is then analysed to determine

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interactions between parameters and their effect on the misfit. Parameters showing no interaction can be modified independently, albeit as groups. This reduces the volume of the hypercube of the parameter space and makes the search more efficient.

Proxy surfaces have been used in reservoir simulation as a way of generating fast models that capture the majority of reservoir behaviour (e.g. Cullick et al. 2006; Zangl et al. 2006). In history matching they may be used to represent the misfit surface (Christie and Bazargan, 2012) and are an alternative to methods such as gradient based and adjoint methods (Wu et al., 1999) which calculate the response of the misfit to property changes. There are also various options for calculating the proxy function depending on their form. Kriging of the response variable can be carried out (Pan and Horne, 1998; Goodwin, 2015) or machine learning (Zangl et al., 2006) through neural nets have been used. We use a reasonably simple quadratic equation.

We apply a Divide and Conquer approach to the Nelson field for the first time in this paper. The problems are somewhat different compared to the Schiehallion field in that permeability and net-to-gross ratio are the main unknown quantities rather than barrier transmissibility, there are many more wells and the reservoir is generally better connected. However, we have applied seismic history matching previously to this field without Divide and Conquer being fully explored. The approach is attractive for seismic history matching where seismic sensitivities are quite difficult to calculate directly as a numerical form of the analytical solution.

2. Method

History matching consists of an iterative modification of simulation input data during which predictions of equivalent observed data are made followed by an assessment of the match via a misfit function which is used to guide updates (Fig. 1). Model updates are controlled through parameterization using a control vector of parameters, $\underline{\theta}$. Conventionally production data are predicted and may include oil and water rates and possibly reservoir or flowing pressures. Time-lapse seismic data may also be included in the process. This step requires that either seismic data is inverted to obtain reservoir saturation and/or pressure data or some form of seismic modelling is required. In this paper we predict maps of acoustic impedance using a petro-elastic model (for details see Stephen et al., 2009 and Stephen & Kazemi, 2014) and compare to equivalent observed data obtained by inversion.

2.1. Petro-elastic model and seismic data

We first calculate the bulk density along with the saturated bulk and shear moduli for each simulation cell using output from the simulator and a petro-elastic model. The bulk density is then

$$\rho = \rho_{sa} NTG(1-\varphi) + \rho_{sh}(1-NTG) + [\varphi(\rho_w S_w + \rho_o(1-S_w))]NTG \quad (1)$$

where ρ_{sa}, ρ_{sh}, ρ_w, ρ_o, are the densities of sand matrix, shale matrix, water and oil respectively, NTG is the net-to-gross ratio, ϕ is the sand porosity and S_w is the water saturation. In the field studied here, laboratory measurements revealed that dry and shear bulk moduli follow quadratic equations in terms of porosity. The dry bulk modulus for sandstone in each cell is then:

$$\kappa_d = 32(1 - 2.07\varphi + 2.38\varphi^2) \quad (2)$$

and the shear modulus is:

$$\mu = 30.2(1 - 4.67\varphi + 7.16\varphi^2) \quad (3)$$

The saturated bulk modulus was calculated using the Gassmann equation:

$$\kappa_{sat} = \kappa_d + \frac{(1-\kappa_d/\kappa_m)^2}{\frac{\varphi}{\kappa_f} + \frac{1-\varphi}{\kappa_m} - \frac{\kappa_d}{\kappa_m^2}} \quad (4)$$

where κ_m is the bulk modulus of the sand grains and taken to be 37 GPa (Simmons and Wang, 1971) and κ_f is the fluid modulus from

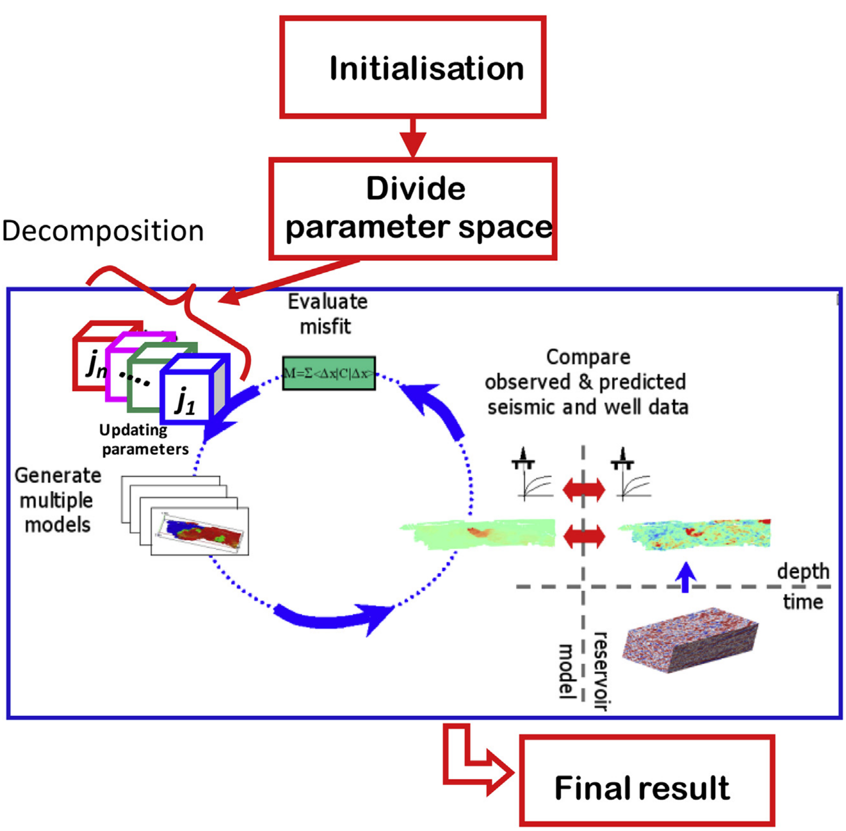

Fig. 1. Divide and Conquer workflow within the history matching process (after Sedighi and Stephen, 2010). A proxy model is fitted to the misfits from the initialization step. Interaction terms in the misfit then identify which parameters combine and these are used then to identify sub-volumes. The parallel history matching loop computes a misfit for each parameter sub-volume and selects new parameter values based on the NA or GA approach. The simulation model is then updated using the whole parameter space and new predictions are made.