CONTINUOUS MODEL UPDATING AND FORECASTING FOR A NATURALLY FRACTURED RESERVOIR

A Thesis

by

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ABSTRACT

Recent developments in instrumentation, communication and software have enabled the integration of real-time data into the decision-making process of hydrocarbon production. Applications of real-time data integration in drilling operations and horizontal-well lateral placement are becoming industry common practice. In reservoir management, the use of real-time data has been shown to be advantageous in tasks such as improving smart-well performance and in pressure-maintenance programs. Such capabilities allow for a paradigm change in which reservoir management can be looked at as a strategy that enables a semi-continuous process of model updates and decision optimizations instead of being periodic or reactive. This is referred to as closed-loop reservoir management (CLRM).

Due to the complexity of the dynamic physical processes, large sizes, and huge uncertainties associated with reservoir description, continuous model updating is a large-scale problem with a highly dimensional parameter space and high computational costs. The need for an algorithm that is both feasible for practical applications and capable of generating reliable estimates of reservoir uncertainty is a key element in CLRM.

This thesis investigates the validity of Markov Chain Monte Carlo (MCMC) sampling used in a Bayesian framework as an uncertainty quantification and model-updating tool suitable for real-time applications. A 3-phase, dual-porosity, dual-permeability reservoir model is used in a synthetic experiment. Continuous probability density functions of cumulative oil production for two cases with different model updating frequencies and reservoir maturity levels are generated and compared to a case with a known geology, i.e., truth case.

Results show continuously narrowing ranges for cumulative oil production, with mean values approaching the truth case as model updating advances and the reservoir becomes more mature. To deal with MCMC sampling sensitivity to increasing numbers of observed measurements, as in the case of real-time applications, a new formulation of the likelihood function is proposed. Changing the likelihood function significantly improved chain convergence, chain mixing and forecast uncertainty quantification. Further, methods to validate the sampling quality and to judge the prior model for the MCMC process in real applications are advised.

DEDICATION

This thesis is dedicated to my parents for their limitless love and endless support.

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1. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Reservoir management is a process that is concerned with determining and implementing an optimal set of decisions to maximize a hierarchy of stated objectives (i.e., rate plateaus, recovery, net present value (NPV), etc.). The quality of reservoir management is determined by how well these objectives are met. To assume that this set of optimal decisions or controls can be determined upfront, is to assume that one has accurate knowledge of the system (i.e., subsurface, wells, facilities and economics), and is able to accurately model it. Clearly, these are the wrong assumptions to make in the case of reservoir management. The amount of uncertainties is huge and the physical processes are only modeled approximately. It has been demonstrated that ignoring or undermining the role of uncertainty when making decisions, can result in suboptimal decisions and huge disappointments (see Sec. 1.2.2)

Reservoir simulation literature indicates that an acceptable level of matching historical reservoir performance is required to establish reliable forecasts. However, this does not guarantee accuracy of forecast results. History matching is an ill-posed problem; multiple models can be found to reproduce historical performance yet have different forecasted outputs. Quality of project value evaluation is dependent on how rigorous one is after finding all these possible models (see Sec. 1.2.3) and how well forecast uncertainty is characterized. Additionally, production optimization and decision-making should be done with recognition of reservoir uncertainties and their impact on the expectations of project value and risk.

This been said, it is clear that reservoir management should not be looked at as an open-loop process, where all system controls can be optimally determined upfront and do not need to be changed. Instead, a closed-loop approach in which: (1) system controls are optimized under uncertainty, (2) optimal set of controls are implemented, and (3) model updating is performed to include new observed measurements. It has been demonstrated that implementing a closed-loop approach in reservoir management yields higher objective function value than open-loop or reactive approaches (Brouwer et al. 2004; Jansen et al. 2009; Sarma et al. 2005; Wang et al. 2009).

Given the huge amount of uncertainties, the large and complex nature of reservoir models, the limitless nature of decisions that can be considered, and the scarcity of data in comparison to model size, the problem of closed-loop reservoir management (CLRM) is not a trivial one. Historically, the industry has either ignored the role of uncertainty in optimizing and forecasting reservoir performance or has implemented simplistic models to handle the problem. In most cases, optimum decisions are based on a single realization of the system. Uncertainties on forecasted outputs are then introduced using a scenario approach (i.e., low and high case scenarios), gradient-based search method, or a stochastic method.

In recent years, a new trend of integrating real-time data into the decision making process is making its way into the petroleum industry. Remote monitoring and control of drilling and well-placement operations in real-time have allowed for improved decisions, safer operations, and better value for the operators that it is widely growing to be an industry common practice. In reservoir management, smart-field technology, in which sensors and subsurface valves are remotely monitored and controlled, has proved its merits in improving well performance and pressure maintenance programs. The realized benefits in adopting a closed-loop approach in the examples mentioned above have, recently, stimulated a growing interest in CLRM.

This research focuses on the continuous model-updating and uncertainty quantification element of the CLRM process. In addition to the tremendous value it adds to the decision-making process, continuous model updating provides a powerful tool to increase reservoir understanding and a mechanism to calibrate uncertainties overtime (Liu and McVay 2010). The behavior of the evolving distributions of forecasted output and uncertain parameters provides information about the quality of the models used and may flag the need for a new study to be performed. Additionally, following the continuous approach allows the execution of more simulation runs than what would normally be the case in conventional one-time model updating.

1.2 Background

1.2.1 Reservoir Management

Reservoir management is a process that involves the utilization of data, mathematical modeling, and expertise, in order to specify a set of decisions and operation controls that optimize reservoir profitability or some other stated objective.

The process, also, includes the implementation of these decisions and the monitoring of reservoir response (Gringarten 1998; Saputelli et al. 2005).

Historically, reservoir management used to be associated with reservoir and production engineering. The need for integration between geoscience and engineering disciplines for improved reservoir management was recognized as early as the 1970s. In 1977 Halbouty stated, “It is the duty and responsibility of industry managers to encourage full coordination of geologists, geophysicists, and petroleum engineers to advance petroleum exploration, development, and production” (Halbouty 1977). The concept of asset teams was introduced in the 1980s. Asset teams did not start to show success until the 1990s when advancements in software and computing power allowed for some level of integration between team members. In the late 1990s, formalized processes were developed to standardize asset teams’ workflow and assure quality (Elrafie et al. 2007).

Recent technology advances have allowed for real-time remote monitoring and control of well and field production. Such capabilities enable continuous and automatic fine-tuning of production controls to optimize project economics and/or some well or reservoir performance stated objective. Remotely activated sub-surface valves on “smart wells” are becoming fairly common technology in the oil industry as they are used to optimize the production and injection of fluids form different pay zones and remotely monitor multiphase flow meters and pressure gauges.

Smart field technology, with all its capabilities, gives rise to a new concept of reservoir management. CLRM or Real Time Asset Management (RTAM) is a reservoir management process that utilizes real-time monitoring capabilities, model updating algorithms, and model-based optimization algorithms in a closed loop, to continuously control production in a semi-automatic manner in order to optimize a field-wide stated objective such as NPV or hydrocarbon recovery. The promise this breakthrough would bring to the oil industry is substantial in terms of higher amount of hydrocarbon recoveries, improved project life-cycle value, and better utilization of human resources. Although such approach is not practically feasible yet, it is receiving rapidly growing attention from both industry and academia.

1.2.2 Value of Assessing Uncertainty

Capen (1976) demonstrated more than 30 years ago that people tend to significantly underestimate uncertainty. He suggested that a better understanding of uncertainty would have a significant effect on risk assessment and profits. In their analysis of financial performance of the oil and gas industry, Brashear et al. (2001) noted that return on net assets by the largest U.S.-based companies in the exploration and production sector is seven percent on average for projects that are selected with a hurdle rate of 15 percent and financed with capital that costs 9 to 12 percent on average. They attributed this under performance of the oil and gas industry at least partially, to the use of deterministic methods to estimate project value. "When compared to the "full" recognition of uncertainties, dependencies, and risk, ranking by deterministic estimates of project value –by far today's widely used approach—was found to overstate expected value by a factor greater than two, to ignore critical risks, and to select a portfolio of projects with a lower return and higher, uncompensated risk than were possible if full uncertainty had been recognized," the authors state, comparing deterministic and probabilistic project evaluation.

McVay and Dossary (2012) performed a quantitative study to measure the value of assessing uncertainty. In this work, the authors performed portfolio optimization simulation where estimates of NPV are calculated with inherent overconfidence (underestimation of uncertainty) and directional bias (optimism or pessimism). Next, they calculate expected disappointment, which is the difference between what a company estimates and a realized case where decisions are made based on estimates but actual values are based on a true distribution (i.e., assuming no overconfidence or bias.) The results of their simulations show that expected disappointment ranges from about 30 percent for moderate amounts of overconfidence and bias to 100 percent for high degrees of bias and overconfidence.

Both references cited above hint to the fact that optimal decision-making in the oil and gas industry is not realized by the transition from conventional deterministic approaches to simplified approximation of uncertainty but rather by full assessment of uncertainty. Brashear et al. (2001) stated that such "short cut" approximations of uncertainty can result in significant over estimation of expected values and underestimation of risk even with the simplest possible projects. It is needless to say that the task of performing full assessment of uncertainty in the oil and gas industry is not a trivial one. Even for a simple project, the amount of uncertainties is substantial, ranging from subsurface uncertainties of reservoir description to uncertainties related to project execution (i.e., cost of material, delays, change of regulations, etc.) and even uncertainties related to the global market of energy as they impact demand, supply, and pricing. Clearly, the problem of quantifying uncertainty is an overwhelming problem that involves a wide range of disciplines such as geology, geophysics, petroleum engineering, project management, statistics and economics. This thesis will only attempt to address the impact of subsurface uncertainty of reservoir description on forecasted reservoir performance.

1.2.3 Uncertainty Quantification

Assessing the impact of model uncertainties on production forecast typically consists of (1) parameterization of the uncertain space, (2) the use of algorithms to search the space for models that reproduce the historical production data within an accepted error margin (i.e., history matching), and (3) the use of these models to forecast reservoir performance and generate distributions for desired output (i.e. cumulative oil production, NPV, etc.). Generating multiple history-matched models, however, does not lead to an accurate assessment of uncertainty if used outside the realm of statistics and probability theory (Emerick and Reynolds 2011).

Different algorithms presented in the petroleum literature are used to explore uncertain parameter space of reservoir models for solutions. These methods can be classified into four categories: (1) deterministic methods, (2) stochastic methods, (3) data assimilation, and (4) Posterior sampling or Estimation of Distribution Algorithms (EDAs).

Classic examples of deterministic methods are gradient-based algorithms. This class of algorithms converts the history match problem into an optimization problem where an objective function is minimized by evaluating the derivative information at different points. Examples of such algorithms are steepest descent, conjugate gradients, Gauss-Newton, Quasi-Newton, Davidon-Fletcher-Powell (DFP), etc. Gradient-based methods are known to be a strong optimization tool for smooth function; however, because it uses derivatives to search for a minimum, there is high possibility of being trapped in a local minimum. When the objective function uses only the sum of squares, the resulting model is called the maximum likelihood (ML) solution and when a prior term is included in the objective function, the resulting model is called maximum a posteriori (MAP) solution (Floris et al. 2001). Sarma et al. (2005) proposed a hybrid procedure where gradient-based optimization is used for history-matching, and then model approximation and uncertainty propagation methods, namely polynomial chaos expansion and probabilistic collocation method, are used to quantify uncertainty.

Stochastic methods also convert the history-matching problem into an optimization problem. However, they include elements of randomness to the searching process that allow the algorithm to escape a local minimum. Stochastic optimization is a class of algorithms that vary widely in complexity and efficiency. Population-based\Evolutionary algorithms are a special group of stochastic methods that have been recently employed in the history-matching problem. This class of algorithms usually operates by balancing two processes; exploration of solution space and exploitation, i.e., local search and refinement in already explored regions (Abdollahzadeh et al. 2011). Although stochastic methods have greater chances than gradient-based methods of finding a global solution, they are usually more complex to implement and require more computations. Examples of such methods are: Genetic Algorithms (GA), Simulated Annealing, Tabu Search, Particle Swarm Optimization, etc. (Abdollahzadeh et al. 2011)

Floris et al. (2001) summarized uncertainty quantification approaches that couple gradient-based optimization and stochastic methods. These methods usually employ deterministic methods to search for one or multiple (ML\MAP) then use stochastic methods starting from the location of the ML\MAP to characterize the uncertainty around one or multiple solutions.

Data assimilation refers to the process of merging information from observation into reservoir models. Ensemble Kalman-Filter (EnKF) is a data-assimilation technique that has been used widely in weather forecasting and has begun to receive rapid attention in reservoir engineering in recent years.

Another approach to uncertainty quantification is employing a Bayesian framework in which a "likelihood" function, which calculates the likelihood of the model to explain the observed data, is combined with a prior knowledge of reservoir uncertain parameters' distributions. Markov Chain Monte Carlo (MCMC) is a promising posterior sampling method that has been recently used in applications of reservoir engineering problems.

1.2.4 EnKF

EnKF is a data assimilation method that has been used extensively in weather forecasting. Kalman Filter (KF) is a method that estimates the states of a linear dynamic system by continuously utilizing noisy measurements of the system. As summarized by (Aanonsen et al. 2009), the algorithm of the KF consists of two major steps. The first is a forward step that uses a model equation, which has the current states of the model with uncertainties expressed in the form of a covariance matrix, and an observation equation, which models a linear relationship between model states and system measurements, to compute a forecast of model states. Measurements are also, considered to have inherent uncertainties. The second step is an analysis step where estimated values of states and covariance matrix are corrected based on most recent measurements.

The first application of continuous model updating in reservoir engineering, to the best of my knowledge, was the work of Naevdal et al. (2002) in which an EnKF was used to update an ensemble of near-well models representing geological uncertainty through continuous data assimilation. Since then, EnKF have been used rapidly in synthesized data assimilation experiments to improve some model parameter estimates, mainly permeability, and to predict reservoir performance. The results of this work show continuously improving parameter estimates and forecast qualities as validated by a case of already known geology, i.e., truth case (Brouwer et al. 2004; Jansen et al. 2008; Lorentzen et al. 2009; Naevdal et al. 2005; Wang et al. 2009).

The attractiveness of EnKF as a data assimilation tool arises from its simplicity of implementation, low computational cost, and data management efficiency. On the contrary, there are many reservations about its application in reservoir model updating. Aanonsen et al. (2009) provided a thorough review of the literature on EnKF in which authors discussed several issues that might hinder the accuracy of its application in reservoir engineering, such as dependency on initial ensemble, deficiency in approximating a covariance matrix, weakness in handling non-Gaussian prior distributions and strongly non-linear physical processes. The particular problem of approximating a covariance matrix in EnKF is that it results in a large underestimation of the uncertainty in the posterior probability density function (pdf) (Emerick and Reynolds 2011). The authors summarize the requirements for EnKF to represent a correct posterior distribution as the following: (1) Gaussian prior model for the state vectors, (2) linear relation between predicted data and the state vector, (3) Gaussian measurement errors which are uncorrelated in time, (4) dynamic systems that represent a first-order Markov process, and (5) ensemble sizes that approach infinity. Clearly, these requirements either do not apply or are not feasible in the case of modeling fluid flow in porous media. Several suggestions to handle such limitation in EnKF were proposed in the literature. Examples are the use of iterative EnKF to handle strong non-linearity and covariance localization to improve covariance matrix approximation (Aanonsen et al. 2009; Chen et al. 2009). The use of EnKF for reservoir model updating is still a subject of ongoing research.

1.2.5 Bayes' Theorem

Bayesian statistics provides a natural and straightforward framework to handle uncertainty in reservoir engineering problems. Bayes' law provides a mean for updating one's subjective belief of a parameter to account for new observations. In Bayesian language, initial knowledge of the parameter distribution is called prior, the updated distribution—conditioned to new evidence – is called posterior, and the likelihood function is to express the relationship between estimated parameter and observation.

$$p(X|Y)=c \cdot p(X) \cdot l(X|Y) \quad (1)$$

Eq. 1 (Draper 2001) is a basic expression of Bayes' law where Y represents a new observation and X represents estimated parameter. The equation basically states that the posterior—distribution of parameter X conditioned to new observation Y—is equal to the prior distribution multiplied by a likelihood function and normalization constant. The prior distribution is an initial distribution of parameter X. The likelihood function is a function of parameter X at a fixed Y expressing the likelihood of the parameter to explain the observation. Using a Bayesian framework, the problem of quantifying uncertainty in reservoir characterization can be reduced to sampling a posterior distribution of model parameters conditioned to a set of historical production data.

1.2.6 MCMC

MCMC is a class of methods that aims to generate samples from a target distribution. As the name suggests, it implies a Markov process, which describes a system under transition, where the next state on the chain (X_{t+1}) depends only on the current one (X_t) (Walsh 2002):

$$P\left(X_{t+1} = s_j \middle| X_0 = s_k, \dots, X_t = s_i\right) = P(X_{t+1} = s_j | X_t = s_i) \quad (2)$$

MCMC has been applied in reservoir engineering to condition reservoir description to production data. In such problems, reservoir simulation is used to generate samples in a Markov chain whose stationary density represents the updated reservoir description.

The following subsequent sections will explain more in detail, the theory and implementation of MCMC with special focus on reservoir engineering type problems.

1.2.6.1 Metropolis-Hasting Algorithm

Metropolis Hasting (M-H) is a sampling algorithm that generates an MCMC chain. The beauty of M-H is that it does not require knowing the normalizing constant of the target distribution. Theoretically, it can be proven that M-H generates a chain whose stationary density correctly represents the target density (see (Chib and Greenberg 1995), unlike approximate sampling methods (i.e., randomized maximum likelihood (RML) and linearization about the maximum a posteriori (LMAP)).

Walsh (2002) summarized the steps in Metropolis-Hasting algorithm as the following: first, the chain starts by drawing a random state (X). Then, a candidate state (X_{t+1}) in the chain is drawn from a proposal distribution (also called jumping distribution). Using the current value (X_t) and the candidate value (X_{t+1}), the probability of the move (α) is calculated as

$$\alpha = \min\left(\frac{f(X_{t+1})}{f(X_t)}, 1\right) \qquad (3)$$

With a probability equal to α, the candidate is either accepted or rejected. When the candidate is accepted, it is retained in the chain and its value is used in determining the next member in the chain. Otherwise, the candidate is discarded. Repeating the previous steps generates a Markov chain which, after a sufficient "burn-in" period, reaches a stationary distribution that represents the target distribution.

1.2.6.2 Proposal Distribution

Proposal distribution is the distribution from which a random candidate is drawn. There are generally two approaches to generate proposals for the Metropolis-Hasting algorithm: (1) random walk chains and (2) independent chains. In random walk chains, the new value is equal to the value from the previous member plus a random variable (z). The density function of the proposal is associated with the random variable distribution.

In independent chains, the new value is independent of the previous member value but instead; it is drawn from a distribution of interest. Draper (2001) stated that higher acceptance rates could be obtained by lowering the variance in the proposal distribution.

For multi-dimensional problems, one can choose to perturb all parameters (global perturbation) or some of the parameters (local perturbation) in the candidate member. It is concluded from previous experiments with MCMC that local perturbation to model parameters are more effective than perturbing all parameters when highly non-linear problems (i.e. reservoir characterization) are considered (Emerick and Reynolds 2011; Liu and Oliver 2003; Oliver et al. 1997).

1.2.6.3 "Burn-in" and Stationarity

In theory, sampling a stationary MCMC chain represents direct draws from the target distribution. However, rate of convergence into stationarity and the size of the initial sample of transitional elements (burn-in) cannot be determined (Chib and Greenberg 1995). Although it cannot be analytically calculated, several empirical approaches to identifying the burn-in period and test for stationarity have been developed.

The most famous and widely-used approach is time-series plots (random values of the members being generated vs. iteration number). When the trace is moved from an initial value to a different value over time where the trace appears to settle down, it could be said that all members preceding this point are burn-in. However, there is no guarantee that the actual burn-in period might be much higher than indicated by the trace (Walsh 2002). It could be said that time-series trace plots are useful in answering the question of what is the minimum number of members that one can consider as burn-in.

Another way, suggested by Gelman and Rubin (1992), is to run multiple chains and compare the variability within and between chains to gain information about convergence and stationarity. The authors argue that one cannot tell for any particular problem if a single chain has converged. It is only through running multiple chains that one can make inferences about sampling variability. In this work, a starting distribution approximating the target distribution was first defined to obtain multiple starting values. Second, multiple sequences are run and inferences from those sequences are obtained to estimate the target distribution. Geyer (1992), on the other hand, argues that inferences should be made based on one long Markov chain. He claims that similarities between multiple shorter chains do not necessarily imply convergence but can be very possibly induced by the experiment design. The only value of multiple chain diagnostics, he concludes, is that it signifies the need for more runs when disagreement between chains is present.

Liu and Oliver (2003) addressed the debate of whether it is better to run one long Markov chain to reduce dependency on initial model or whether to run several independent shorter sequences to reduce the risk of basing conclusions on a slowly mixing chain with variability that is less than actual variability. The results of their experimentation on a small 1D single-phase black-oil model unfortunately did not contribute much to the resolution of this argument. Their results show that running shorter independent chains results on large differences of the means of individual chains suggesting strong dependency on initial model. On the other hand, they show that longer chains results in slow mixing suggesting less than actual variability.

Even after removing burn-in period, adjacent members in the chain are expected to be positively correlated; this correlation can be quantified using an autocorrelation function (Walsh 2002). The correlation between members could introduce some bias in estimating the target distribution when the sample size is not large enough to offset any correlation effect. Walsh (2002) suggests the use of two time series analysis plots: (1) the serial autocorrelation as a function of time lag, and (2) partial autocorrelation as a function of time lag. The author argues that using these plots helps underline correlation structure in the chain that is not as obvious when only looking at the time-series plot.

One simple and effective way to test for stationarity is suggested by Geweke (1992). This test suggests splitting the chain after discarding the burn-in period into two sub samples. If the chain is stationary, both sub samples should have similar means. A modified z-test can be done on both sub-samples. Typically, values greater than two indicate that the mean is still drifting and the distribution has not converged yet. Raftery and Lewis (1992) introduced another method that determines how many initial runs should be discarded, the total chain length, and what thinning ratio (i.e., only retain every k^{th} element in the chain to offset autocorrelation) should be applied on the chain values. In their method, the problem is formulated by calculating a quantile of the posterior function with a certain specified accuracy. The chain is initially run for an initial number of iterations. Then, using those iterations, specified quantile, and required accuracy, the number of burn-in runs and the total number of additional runs can be calculated.

Although Markov chain simulation does not require beforehand knowledge of target distribution, many authors reported that the choice of prior, initial state and proposal distribution can significantly impact the burn-in period and the convergence process (Chib and Greenberg 1995; Geweke 1992; Raftery and Lewis 1992; Walsh 2002). Gelman and Rubin (1992) argue that when target distribution is complex and have multiple peaks, the need for better definition of a starting distribution and running multiple chains with different initial points is greater to minimize the risk of getting trapped in one area of the parameter space. The authors suggest a three-step process for defining a starting distribution. First, the modes of the target distribution are found using optimization algorithms or statistical methods in order to define the high density regions of the target distribution. Second, an over-dispersed approximation distribution is defined to ensure the starting distribution covers the target distribution. Third, importance resampling is used to downweight regions that have relatively low density under the target distribution. Following the steps mentioned above, help start sequences from initial values that are in high-density regions of the target distribution and will, generally, speed the convergence rate of the sequences, the authors argue.

1.2.6.4 Mixing

A chain is said to have well-mixing if it appears to explore more of the parameter space. A good indication of well-mixing is "white noise" behavior on a time-series plot. On the contrary, when the time-series trace is flat and not variable, it is an indication of poor mixing. Flat regions in the time-series trace indicate that more members are being rejected rather than retained in the chain. Naturally, one would desire to have higher acceptance rations and retain as many models in the chain, at least from a computational perspective. However, high acceptance ratio does not necessarily indicate well-mixing. In M-H algorithm, acceptance is influenced by the amount of change in the proposed state relative to the current member. Candidate generating process in Markov chains is controlled by how the proposal distribution is defined. Proposal distributions with large variances generate members that, in general, are more different from the current member in the chain. To the contrary, proposal distributions with small variances generate candidates that are not very different from current state of the model. A large step change on the state value means a large step move inside the explored parameter space, indicating faster exploration of the parameter space. The side effect of this is a lower probability of acceptance (i.e. more flat periods.) To recap, when the generated candidate states are not much different from the current ones, the chain would have high acceptance ratio but would be poorly mixed. On the other hand, when the generated candidates are very different than current states, the chain would have low acceptance ratios and consequently, poor mixing.

Clearly, the variability of the proposal should be chosen in such a way that results in a reasonable acceptance rate without sacrificing the quality of chain mixing. However, it is difficult to determine beforehand how much variability the proposal distribution should have. Liu (2008) and Walsh (2002) suggest an iterative process where the variability of the proposal is changed and the chain is monitored until a predetermined acceptance ratio is achieved. Perturbation size for multi-dimensional chains is a factor that affects chain mixing and acceptance ratio. Increasing the perturbation size introduces more change in the candidate stat, thus, making it possible to be looked at as increasing variability. In this case, the problem becomes more difficult as one need to tune the standard deviation of the proposal distribution as well as the perturbation size.

1.2.6.5 Computation Efficiency

Typical application of MCMC in reservoir engineering problems requires reservoir simulation to be run every time a candidate model is proposed in order to evaluate the likelihood part of the posterior function. Additionally, an initial sample of reservoir simulation models (usually in the hundreds and sometimes in the thousands) is considered burn-in and thus, is discarded. Even after the chain is stabilized, only accepted models are used for analysis; usually less than half of the reservoir simulation models are accepted. Often, only a subset of the accepted models is used due to autocorrelation. For large complex models (i.e., Mega+ grid cell models, dual-porosity dual-permeability (DPDP), compositional etc.), this typical implementation of MCMC is generally not feasible. Running multiple smaller chains in parallel makes the problem more manageable. The argument of running one long chain versus multiple shorter chains has not been resolved yet (see Sec. 1.2.6.4).

Several modifications to the standard MCMC application have been proposed to make the process more efficient. The literature on increasing the computational efficiency of MCMC can be classified into two groups: (1) methods that aim to reduce the dependency on the full reservoir simulation to evaluate the likelihood function and (2) methods that aim to generate "smarter" candidate models that are more likely to be accepted. Examples of the first group include the work of Oliver et al. (1997) and Ma et al. (2008). Both papers introduce an additional step before a candidate model can be either accepted or rejected. Only those models that pass the first stage pass to the second stage where a full simulation model needs to be run. In both cases, cheap and approximate calculation of the sensitivity of the likelihood function to uncertain parameters is performed. Gelman and Rubin (1992) proposed a method in which coarse model approximation is used to determine acceptance in the first stage. Emerick and Reynolds (2011) proposed an algorithm that couples EnKF and MCMC to take advantage of the computational efficiency of the first and the statistical rigorousness of the latter. Their approach consists of running traditional EnKF procedure to update and ensemble of realizations. Simulation is then used to run the entire ensemble from time zero and covariance matrix is calculated. Finally, ensemble mean and covariance matrix are used to propose new models, evaluate likelihood function, and calculate acceptance ratio in MCMC procedure without the need of running the simulation. To eliminate the linear relationship assumption between measurement and grid cell states (i.e. pressures and saturations), they use Peaceman's equation to directly calculate predicted data associated with proposed states. An example of the latter group of methods is adaptive chains. Adaptive chains differ from Markov chains in that the current state in the chain depends on all or a set of previous states, not only that last state as in Markov chains. Holden (1998) claimed that using adaptive chains yields higher convergence rates. Floris et al. (2001) suggested that GA could be used to select parent models for the new proposed model in what they call an "adaptive genetic MCMC."

1.3 Research Objectives

The main objective of this research is to develop and test the validity of a MCMC Metropolis-Hasting algorithm as a continuous model updating procedure that satisfies three main requirements: (1) reliably quantifies the uncertainty of model parameters and outputs at any phase of a project's life, (2) capable of handling complex physical processes (i.e., 3-phase flow and DPDP models), and (3) has practical run times for real-time applications. Additional objectives are to determine the effects of model updating frequencies and reservoir maturity levels on the MCMC modeling process and to determine the impact of likelihood formulation on the convergence of the Markov chain and on the accuracy of uncertainty quantification.

2. METHODOLOGY AND MODEL DESCRIPTION

2.1 Introduction

This section is concerned with presenting the methodology and introducing the various integrated models used to generate results for this work. The following sections will cover in details the simulation model used, the truth case definition, and the definition of observed data. Next, uncertainty parameterization is explained and uncertain parameters along with their ranges are provided. Finally, the code used to run the MCMC model updating experiments is presented.

2.2 Simulation Model Description

The simulation model is built to resemble a carbonate naturally fractured reservoir with an anticline shape and edge-water drive. The general geological trend assumed is marine transgression to shelf depositional environment. To cut run time, only one half of the anticline is modeled. The 3D geological model of an average net thickness of 300 feet is divided into seven vertical layers and it consists of a total of 13,720 grid cells (49 x 40 x 7). The reservoir encompasses an area of about 8,100 acres. Six vertical wells are included in this model—three flank water injectors and six oil producers. All wells are perforated in all seven layers. **Fig. 1** provides a visualization of the 3D grid, well names and locations. A DPDP approach is used to model the natural fractures in the system. The fracture model consists of major fracture fairways that cut through the reservoir in vertical planes and super permeability zones in different layers (**Fig. 2**).

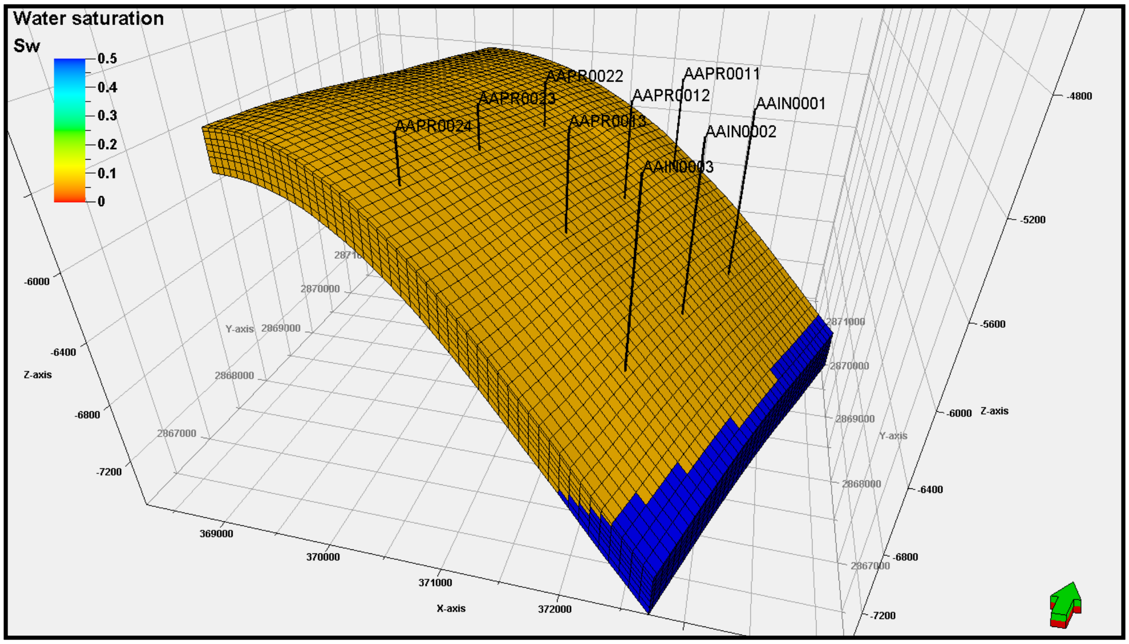

Fig. 1—3D geological model, well locations and initial water saturation

The model is initialized as three-phase model (oil, water, and gas) with initial pressure of 3410 psi at datum depth of 6500 ft TVDSS and a FWL of 7025 ft TVDSS. The fluid is undersaturated with a bubble point pressure of 2533 psi. The fluid densities at standard conditions are 0.83880, 0.00097, and 1.15100 gm/cc for oil, gas, and water, respectively. No capillary forces are assumed. Saturation tables, PVT tables, and other simulation input are provided in Appendix A.

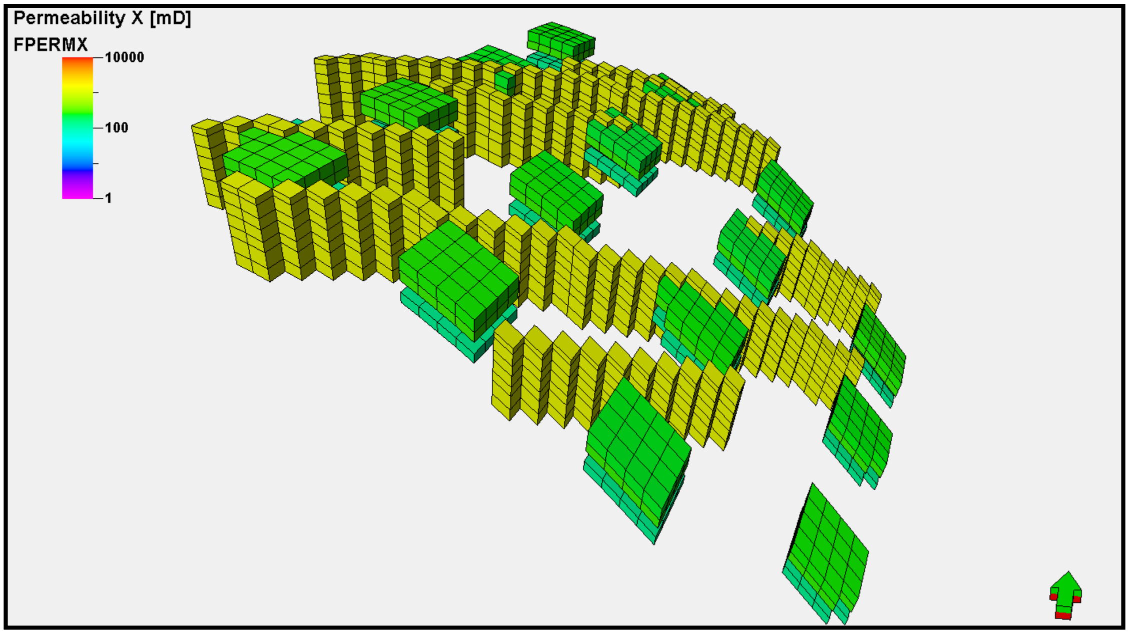

Fig. 2—Fracture model showing major fracture corridors (yellow) and super permeability zones (green)

2.3 Truth Case Definition

The truth case is defined to generate a set of observed data that can be used in history matching and to establish a reference case for comparison with forecasted cumulative oil production distributions and validation of the posterior reservoir description. The truth case is generated using a particular set of reservoir description parameters and production/injection controls. **Table 1** provides a summary of the initialization results of the truth case. The subsequent sections discuss in detail the reservoir description and production/injection controls used to generate the truth case.

Table 1—Initialization of truth case

Parameter	Value
Original Oil in Place (thousand STB)	1,199,890
Original Water in Place (thousand STB)	41,553,201
Original Dissolved Gas in Place (MMscf)	1,019,906

2.3.1 True Reservoir Description

The grid cell values of horizontal permeability are randomly sampled from a lognormal distribution with different means and standard deviations for each layer. Parameters used to generate distributions are summarized in **Table 2**. A histogram showing true horizontal permeability values is shown in **Fig. 3** and a 3D visualization is provided in **Fig. 4**. Vertical permeability is modeled by using a ratio of 0.5 to horizontal permeability.

Table 2—Distributions for true horizontal permeability modeling

Layer	Mean (md)	Standard Deviation (md)
1	20	4
2	1000	160
3	500	100
4	10	2
5	5	1
6	3	1
7	3	1

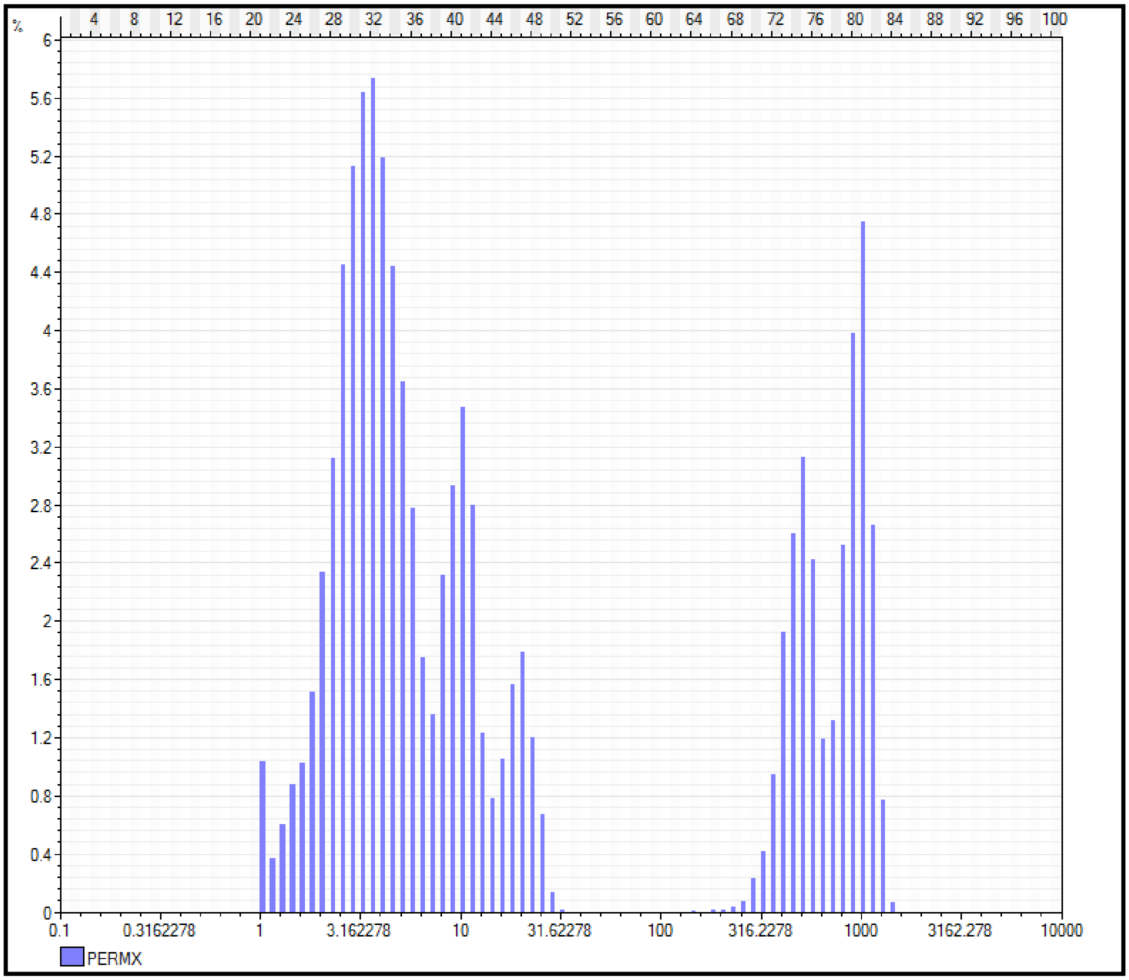

Fig. 3—Histogram of true horizontal permeability (md) values

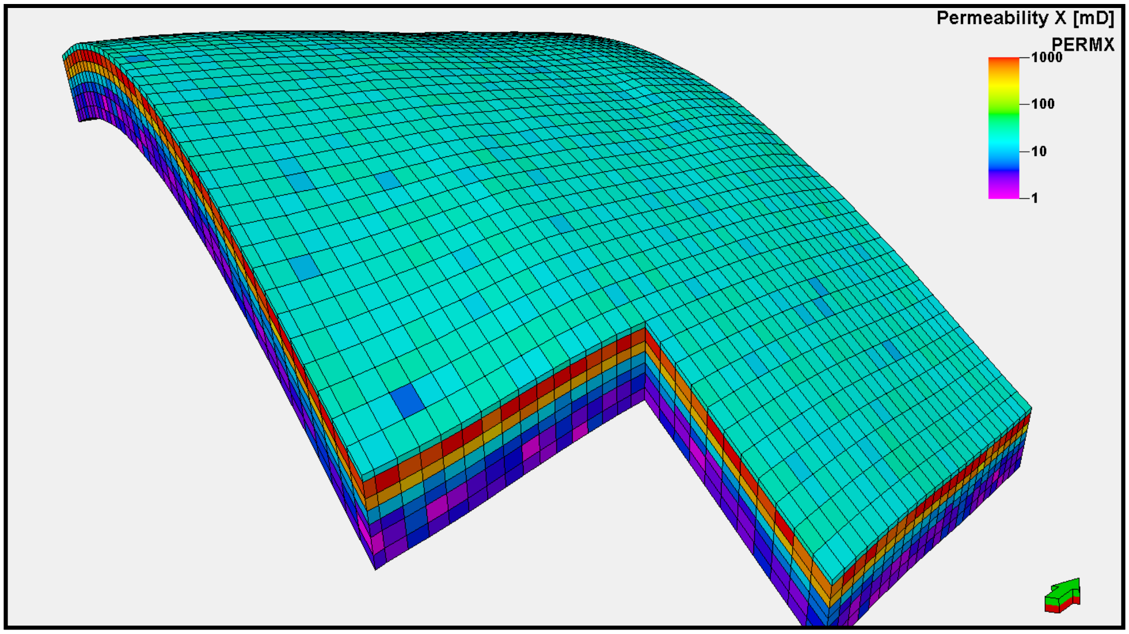

Fig. 4—3D visualization of true horizontal permeability

Porosity is modeled by randomly sampling a normal distribution with a mean of 0.2 and a standard deviation of 0.03. **Fig. 5** shows a histogram of the porosity values of the truth case. To model aquifer extent, the pore volumes of the cells in the first (I=1) cross-section are multiplied by 1000. No permeability multipliers were used to model aquifer strength. Rather the same permeability values (Table 2) were used to model aquifer connectivity to the reservoir. However, both porosity and permeability multipliers are used as uncertain parameters in the experiments conducted for this work (see Sec. 2.4). A 3D visualization of the porosity model is presented in **Fig. 6**.

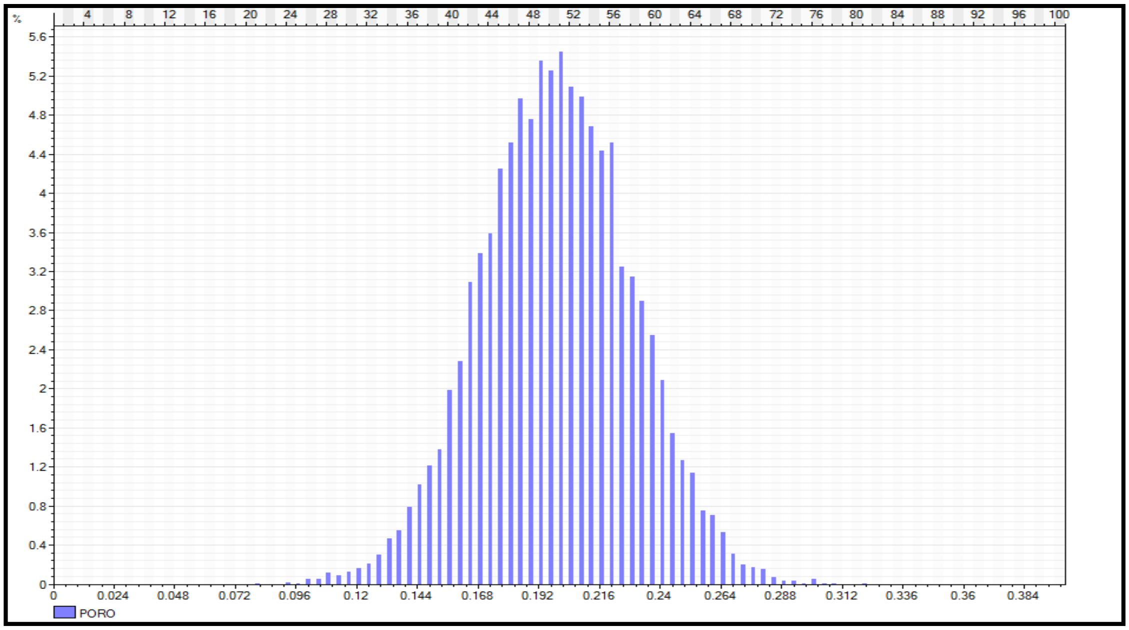

Fig. 5—Histogram of the true porosity values

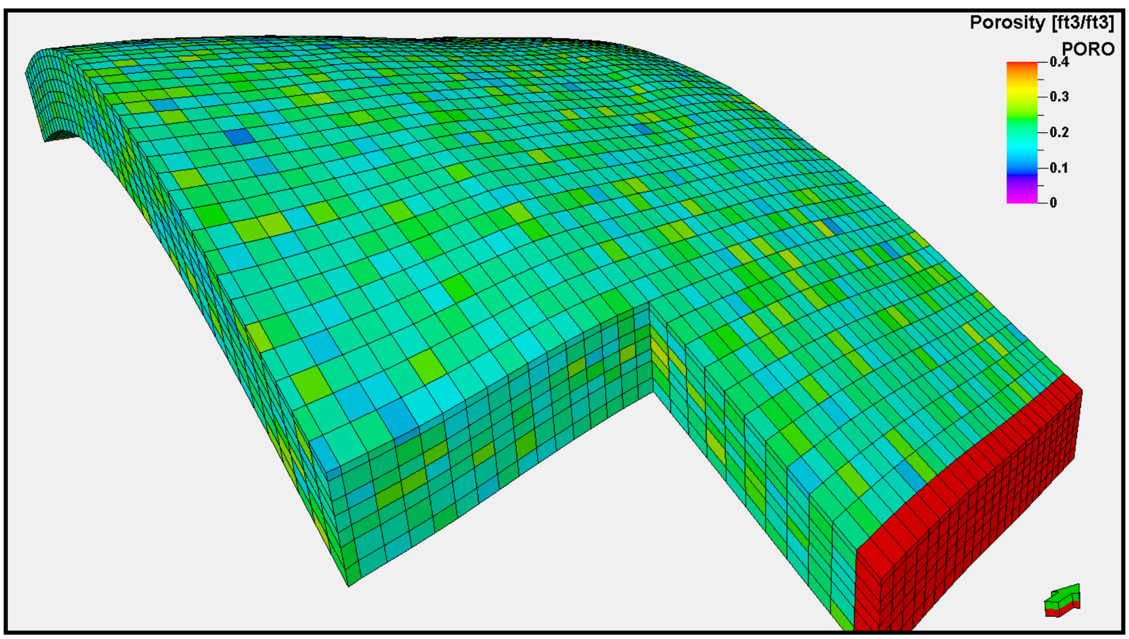

Fig. 6—3D visualization of true porosity values

2.3.2 Observed Data

The field production and injection plan is defined and summarized in **Table 3**. A simulation case that includes the true reservoir description and the tabulated production scenario (i.e., the truth case) is run to generate true reservoir performance profiles. Gaussian noise is then introduced to the true reservoir performance to model uncertainties around observed measured data. **Table 4** provides definitions of the Gaussian distributions used to introduce measurement errors. **Fig. 7** plots the profiles of reservoir performance before and after introducing Gaussian noise. Appendix B includes complete listings of all true reservoir and observed measurements data.

Table 3—True production/injection controls

Control Type	Value	Group	Starting Date
Well bottom-hole pressure control	1,500 psi	All producers	1/1/2000
Maximum well liquid production rate	10,000 bbl/day	All producers	1/1/2000
Well bottom-hole pressure control	4,500 psi	All injectors	1/1/2007
Maximum group injection rate	30,000	All injectors	1/1/2007

Table 4—Definitions for the distributions used to model measurement errors

Data Type	Frequency	Mean	Standard Deviation
Shut-in well pressure	Monthly	True value	10 psi
Well flowing bottom-hole pressure	Annual	True value	10 psi
Well oil production rate (before water breakthrough)	Monthly	True value	1 % of true value
Well oil production rate (after water breakthrough)	Monthly	True value	2.5 % of true value
Well water production rate	Monthly	True value	10 % of true value
Well gas production rate (above bubble point pressure)	Monthly	True value	3% of true value
Well gas production rate (below bubble point pressure)	Monthly	True value	5% of true value

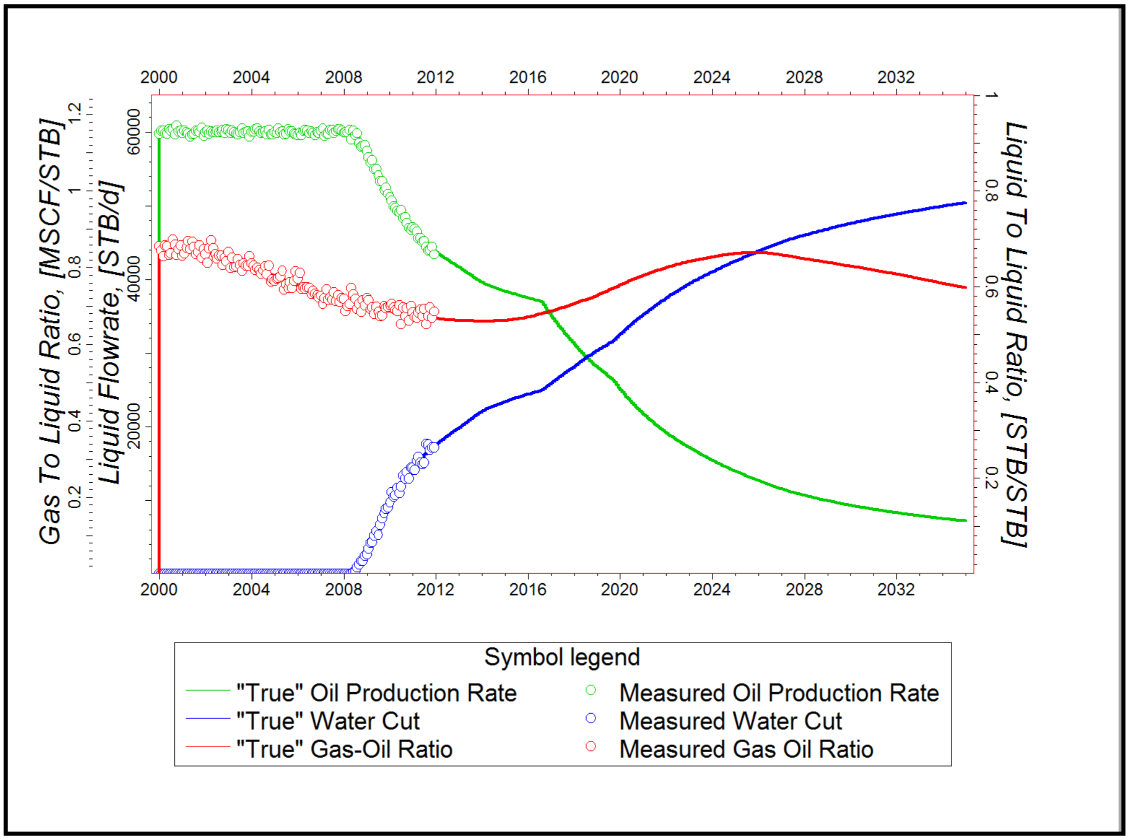

Fig. 7—Comparison between oil production rate (green), water cut (blue), and gas-oil ratio (red) for true reservoir performance (solid line) and noisy reservoir performance (dots)

2.4 Parameterization

Parameterization of uncertainty is performed by dividing the field into six spatial uncertainty regions (**Fig. 8**) with three parameters for each region: porosity, horizontal permeability and vertical-permeability multipliers. All multipliers within one region or across regions are considered independent. Regions are defined based on the locations of aquifer, injectors, and producer wells.

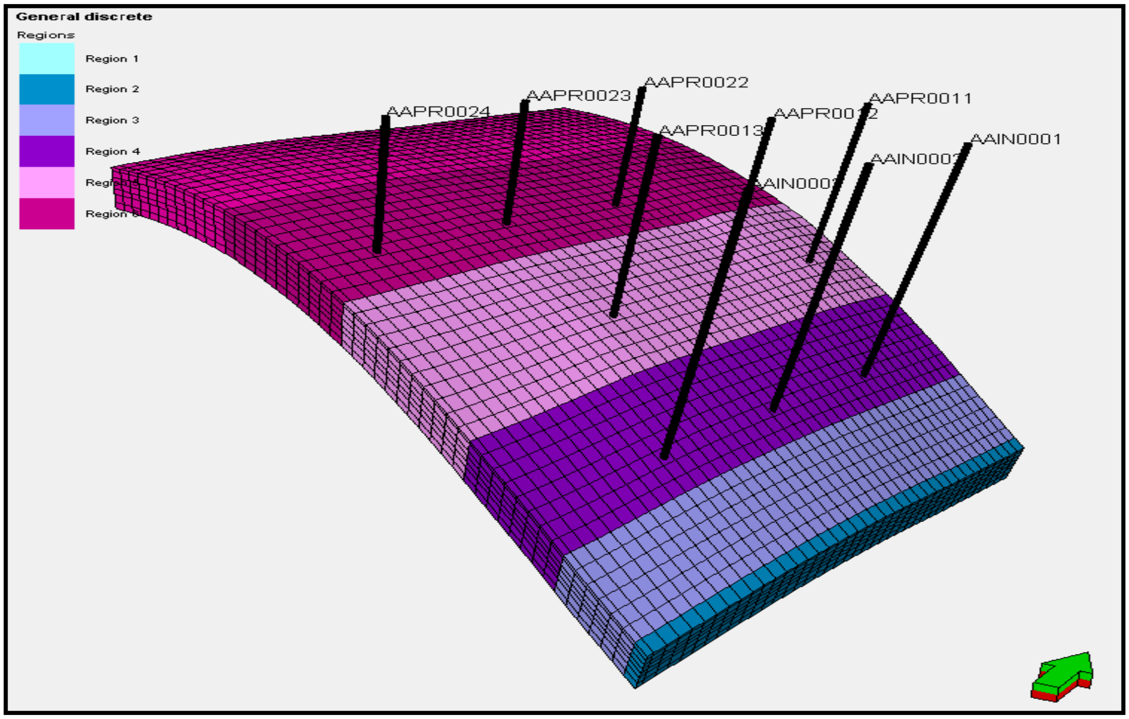

Fig. 8—3D visualization of the six uncertainty regions

2.5 Metropolis-Hasting Algorithm

Metropolis-Hasting algorithm is used to sample the posterior distribution. An existing code, written using Microsoft Visual C# 2010 (see Liu (2008), 13-15), was modified to suit the simulation model and the experiment setup associated with this work. The general steps in this algorithm are summarized below:

1. Randomly draw an initial model from the prior distribution ($M^{t=1}$)
2. Run the simulation model using ECLIPSE black-oil simulation
3. Calculate the posterior term for $M^{t=1}$

4. Draw another model from the proposal distribution ($M^{t=2}$)
5. Run the simulation model using ECLIPSE black-oil simulation
6. Calculate the posterior term for $M^{t=2}$
7. Calculate probability of acceptance (α)
8. If $M^{t=2}$ is rejected, go back to step number 4. If $M^{t=2}$ is accepted, store $M^{t=2}$ as $M^{t=1}$ and go back to step 4.

This process is repeated until the number of simulation models in the chain is sufficient to represent the posterior distribution of model parameters given the current set of observed data. When more observed data are added to the process, the posterior term of the last model in the chain is evaluated using the updated set of observed data. Then, the process continues from step 4 to step 7, again. Each of the time-series chains, when converged, represents a posterior distribution of the model parameters conditioned to the latest production data. The values of cumulative oil production calculated by these models are then used to characterize the uncertainty of the production forecast of this field. The following sections provide detailed description of the definitions of the prior distribution, the proposal distribution, the probability of acceptance, the likelihood function, and the posterior distribution.

2.5.1 Prior Distribution

Each model in the Markov chain is defined by 18 uncertain parameters. These 18 parameters are porosity, horizontal permeability, and vertical permeability multipliers that are spatially spread over six regions (see Sec. 2.4). The 18 parameters are drawn from two main distributions: Gaussian distribution for porosity multipliers and lognormal distribution for both horizontal and vertical permeability multipliers. The lognormal distribution for permeability multipliers is transformed to a Gaussian distribution. No assumptions of spatial correlation between uncertain parameters are made. The prior distribution has the form

$$f(M)=C\ \exp\left[-\frac{1}{2}\left\{\sum_{i=1}^{6}\left(\frac{m_{\emptyset i}-\mu_{\emptyset}}{\sigma_{\emptyset}}\right)^2+\sum_{i=1}^{12}\left(\frac{\log m_{ki}-\mu_{\log k}}{\sigma_{\log k}}\right)^2\right\}\right] \quad (4)$$

where M represents the sampled model or a vector of 18 multipliers, C is a normalization constant, $m_{\emptyset i}$ is a porosity multiplier, $\mu_{\emptyset}$ is the mean of the porosity multipliers prior distribution, $\sigma_{\emptyset}$ is the standard deviation of the porosity multipliers prior distribution, $\log m_{ki}$ is the log-transformed permeability multiplier, $\mu_{\log k}$ is the mean of the log-transformed permeability multiplier prior distribution, and $\sigma_{\log k}$ is the standard deviation of the log-transformed permeability multiplier prior distribution. There are a total of six porosity multipliers and twelve permeability multipliers drawn from two separate distributions. The means and standard deviations for the distributions are being changed in the experiments conducted in this research. The actual values for these parameters will be mentioned and discussed with their associated experiments in Sec. 3 of this thesis.

2.5.2 Proposal Distribution

Random-walk perturbation algorithm is used as the proposal distribution for this work. Reservoir parameters from the current model in the chain are used and a change is introduced to some of the model parameters. The number of parameters changed is controlled by a parameter called the *perturbation size*. The amount of added change is sampled randomly from a normal distribution with a mean of 0 and standard deviation of 0.1. Perturbation size and variability of the change are tuning parameters that affect the convergence and performance of the chain. Perturbation size was chosen through an iterative process by observing the acceptance ratio and the performance of the chain in a time-trace plot for each experiment. More about choice of perturbation size and its effect on convergence will be discussed in Sec. 3.

2.5.3 Likelihood Function

The purpose of the likelihood function is to provide a measure of how likely a particular model is to produce the observed data. Production measurements are assumed to be statistically independent both in space and time and to have Gaussian errors. Based on these assumptions the form of the likelihood function becomes (Floris et al. 2001; Geweke 1992)

$$f(d_{obs}|M)=C\exp\left[-\frac{1}{2}\sum_{i=1}^{n}\left(\frac{d_{obs(i)}-g_{M(i)}}{\sigma_i}\right)^2\right] \qquad (5)$$

In Eq. 5, $d_{obs(i)}$ represents the observed production data, $g_{m(i)}$ represents the corresponding simulation response, σ_i is the error around the measurement, and n is the total number of observed measurements. Please note that this form will change for some of the experiments conducted in this work. The new form of the likelihood along with justifications for change will be discussed later (see Sec. 3.4).

For this particular problem, two types of measurements are considered: (1) shut-in well pressure, and (2) well water production rate. Observed measurements of oil production rate values produced by the truth case are used as oil rate control during the history portion of the simulation, after adding Gaussian noise (see Table 4). Although, typically, all performance data should be considered when history matching is performed, limiting the number of observed measurements in the likelihood function is necessary to achieve better convergence and forecast uncertainty quantification results (see Sec. 3.4.2 and Sec. 4.3.2). A balance should be struck between including all production data to ensure history match quality and including fewer data not to overwhelm the likelihood function. In this work, oil and gas production rates were not included in the likelihood function because they are considered of secondary significance to shut-in pressures and water production. Oil production rates are used as a control parameter by the reservoir simulator and they are expected to be met, in most cases. Matching gas production, on the other hand, are strongly related to shut-in pressures match as amount of gas in reservoir whether free or dissolved are defined in terms of pressure. **Table 5** summarizes the types of observed data used and how they are handled in the likelihood function.

Table 5—Handling of observed data in the likelihood function

Data Type	Frequency	Number of wells	Standard Deviation
Well shut-in pressure	Monthly	6	40 psi
Well water production rate	Monthly	6	50 bbl

Based on the specifications above, each month of production adds 12 measured data points to the likelihood function. The frequency at which models are updated and data points are added to the likelihood function in this research differs between experiments. Section 3 of this thesis highlights how model updating is done for each of the experiments performed in this research. It is also worth noting that standard deviations used in the likelihood function are bigger than those used to model Gaussian errors in data measurements. The standard deviations used in the likelihood function are assumed to include the measurement errors plus model errors. For example, reservoir simulations usually use some block pressure averaging method to calculate well shut-in pressure while measured value is usually calculated using a different model utilizing pressure transient analysis principles. Additionally, standard deviation in the likelihood function reflects how much tolerance the engineer think is acceptable based on knowledge of the model and its application. For some applications, production optimization might be tolerant to small errors in the prediction of pressures, for example, while very sensitive to accuracy of pressure values in others.

2.5.4 Posterior Distribution

As mentioned in Sec. 1.2.5, the proposal distribution represents the distribution of model parameters conditioned to observed data. Based on the specifications of this problem, the posterior distribution will have the form

$$f(M|d_{obs})= C\exp\left[-\frac{1}{2}\left\{\sum_{i=1}^{n}\left(\frac{d_{obs(i)}-g_{M(i)}}{\sigma_i}\right)^2+\sum_{i=1}^{6}\left(\frac{m_{\emptyset i}-\mu_{\emptyset}}{\sigma_{\emptyset}}\right)^2+\sum_{i=1}^{12}\left(\frac{\log m_{ki}-\mu_{\log k}}{\sigma_{\log k}}\right)^2\right\}\right] \quad (6)$$

The posterior equation (Eq. 6) includes both prior and likelihood terms. Information from the prior and information from the observed data play role in the definition of the posterior distribution. The contribution of the prior to the definition of the posterior is constant throughout time since there are always 18 model parameters to change. The contribution of the likelihood, however, is not constant over time but rather increases. Typically, as more observed data are included, one would like to see an increasing contribution of observed measurements in defining the posterior. On the other hand, one needs to be careful with the assumptions made about these data and their relation to model parameters. One major assumption made here is that observed data are spatially and temporally independent. This assumption is not an accurate one. Clearly, some degrees of spatial and temporal correlation exist between measurements that belong to the same or different data types. It is well established in reservoir simulation that pressure and saturation values at a given time and location depend on the spatial distribution of pressures and saturations calculated at previous time steps. Measured responses from the wells, thus, exhibit some degrees of temporal and spatial correlations, as they are functions of those pressures and saturations. Additionally, introducing changes to the model (i.e. infill drilling, injection, changing production controls) may change how measured data are correlated. Due to the complexity of modeling the underlying structure of data correlation and because of the dynamic nature of this correlation, observed production data are usually assumed independent. Eq. 7 (Liu 2008) expresses the likelihood function in vector notation when correlation is assumed.

$$f(d_{obs}|M)=c\ \exp\left[-\frac{1}{2}\left[g_M-d_{obs}\right]^T C_D^{-1}\left[g_M-d_{obs}\right]\right] \qquad (7)$$

Experimenting with Eq. 6 and Eq. 7 shows that the assumption of correlation might significantly change the value of the likelihood function, especially with problems with large observed measurement data sets. Because all measurement errors are considered independent rather than correlated, the impact these errors have on defining the posterior are exaggerated. This leads to poor convergence, strict acceptance criteria and inaccurate forecast uncertainty quantification. This issue will be discussed in more details in Experiments 3 through 5 (see Sec. 3.4 through Sec. 3.6).

Additionally, it is also well known that the problem of changing reservoir parameters to match measured well responses is an ill-posed problem. Given the size and complexity of reservoir models, one should be careful not to exaggerate the role observed production data play on calibrating reservoir models. Considering the problem in this research, 12 uncorrelated production measurements per month are used to update 18 uncertain multipliers. Although the formulation of the posterior equation (Eq. 6) provides equal treatment to both regional multipliers and observed measurements, the amount of information implicit in the measured observations is expected to be small relative to the size of regional multipliers. In this work, only six wells scattered in the reservoir are used to make inference about the uncertainty of model parameters representing the entire volume of the reservoir. In reservoir simulation, one well shut-in pressure measurement, for example, is a non-linear function of the production controls of the well and the states of the grid-cells surrounding the well. Those states are, as well, non-linear functions of uncertain parameters such as porosity and permeability. In this model, having 3-phase flow and dual porosity-dual permeability effects adds to the non-linearity and complicates the relationship between measurements and uncertain parameters. Additionally, as one moves away from the well, the ability of these measurements to make inferences about the states or the uncertain parameters of the grid-cells diminishes. Localization of the measured data and its effects on the posterior of uncertain parameters is not studied in this work. Some of the regions in the model, which inferences are made about, do not include any wells and, on the other hand, some include more than one well (Fig. 8). This simplification of the likelihood function may affect the role it plays in shaping the posterior distribution. More about the handling of the likelihood function as it affects the convergence of the chain and accuracy of results is discussed later (see Sec. 3.4.2).

2.5.5 Probability of Acceptance

The probability of the proposed model being accepted in the chain follows the Metropolis-Hasting criteria (see Sec. 1.2.6.1). For this problem, the acceptance ratio is

$$\alpha = \frac{f(M^{t=2}|d_{obs})}{f(M^{t=1}|d_{obs})} \quad (8)$$

When the terms are expanded the following equation is obtained

$$\alpha = \frac{\exp\left[-\frac{1}{2}\left\{\sum_{i=1}^{n}\left(\frac{d_{obs(i)}-g_{M(i)}{}^{t=2}}{\sigma_i}\right)^2+\sum_{i=1}^{6}\left(\frac{m_{\emptyset i}{}^{t=2}-\mu_{\emptyset}}{\sigma_{\emptyset}}\right)^2+\sum_{i=1}^{12}\left(\frac{\log m_{ki}{}^{t=2}-\mu_{\log k}}{\sigma_{\log k}}\right)^2\right\}\right]}{\exp\left[-\frac{1}{2}\left\{\sum_{i=1}^{n}\left(\frac{d_{obs(i)}-g_{M(i)}{}^{t=1}}{\sigma_i}\right)^2+\sum_{i=1}^{6}\left(\frac{m_{\emptyset i}{}^{t=1}-\mu_{\emptyset}}{\sigma_{\emptyset}}\right)^2+\sum_{i=1}^{12}\left(\frac{\log m_{ki}{}^{t=1}-\mu_{\log k}}{\sigma_{\log k}}\right)^2\right\}\right]} \quad (9)$$

When the probability of acceptance (α) is equal to or greater than one, the new proposal increases the density of the posterior and, thus, is accepted. If the density ratio is less than one, the model is accepted with a probability of α. A random number drawn from a uniform distribution between 0 and 1 is compared to α. The model is only accepted if α is larger than this random number. It is worth noting that although the likelihood term grows as more data are added, the acceptance ratio is always calculated for two models with consistent likelihood definition.

3. UNCERTAINTY QUANTIFICATION AND MODEL UPDATING RESULTS

3.1 Introduction

This section of the thesis presents the results of the model updating work conducted in this research. Five different experiments were performed using the Metropolis-Hasting Markov chain updating algorithm. The first three experiments were conducted to calibrate the tuning parameters of the process and to gather insights that help in designing the other experiments. The latter two experiments were continuous model updating experiments conducted at different updating frequencies. The following subsequent sections provide details about each of the five experiments in terms of experiment setup, results, discussion of results, and conclusions.

3.2 Experiment 1: Reference Case for MCMC Parameters' Sensitivity

3.2.1 Experiment Setup

The objective of this experiment was to explore the MCMC process and to establish a reference case for investigating the sensitivities of certain parameters (i.e., prior and proposal distributions) influencing the performance of the chain. In this experiment, 13,500 runs were performed to history match the first 12 years of production (years 2000 to 2012). No continuous modeling was performed in this experiment. Hence, the likelihood functions contained a constant number of 1728 observed data points for the entirety of the experiment. The prior was defined by constructing two distributions (**Fig. 9**): (1) a truncated normal distribution for porosity multipliers with a mean of one, a standard deviation of 0.3 and truncation limits of zero and three, and (2) a truncated normal distribution for the log of permeability multipliers with a mean of zero, a standard deviation of 0.354 and truncation limits of -2 and 2. The porosity and log of permeability multipliers for the truth case are the means of these distributions. A random walk change with a perturbation size of one was used as the choice for the proposal distribution. The amount of added change is sampled randomly from a normal distribution with a mean of zero standard deviation of 0.1. **Table 6** summarizes the parameters used in this experiment.

Table 6—Experiment 1 setup summary

Parameter	Value	
Total Number of Runs	13,500	
Prior Porosity Multiplier	Mean = 1	S.D. = 0.3
Prior Log-Permeability Multiplier	Mean = 0	S.D. = 0.354
Proposal Distribution	Random-Walk Change	
Perturbation Size	1	
Proposal Change	Mean = 0	S.D. = 0.1
Number of measurements, n	1728	

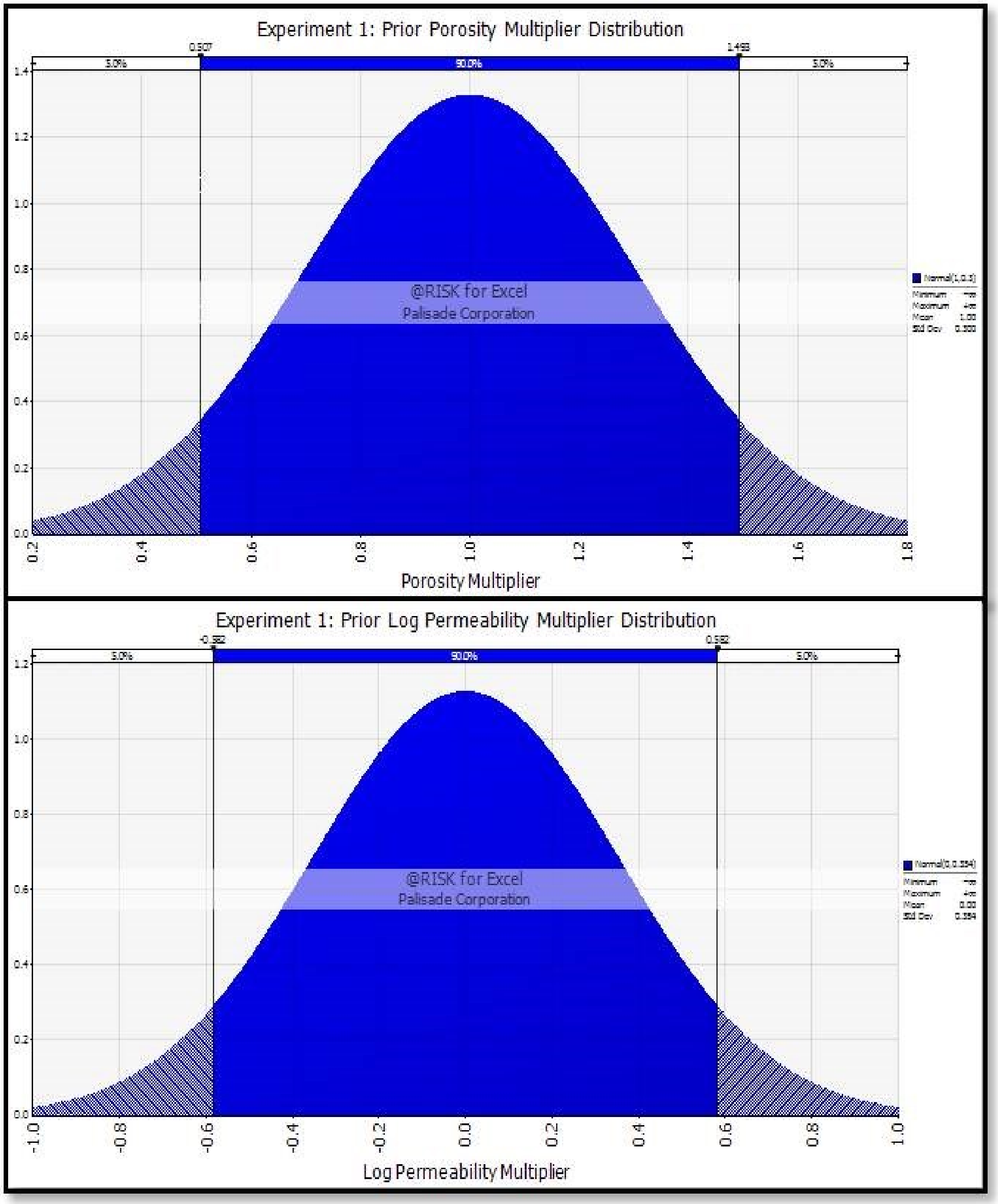

Fig. 9—Experiment 1 prior distribution

3.2.2 Experiment Results

The time-trace plot (**Fig. 10**) shows the trace of the objective function value as more simulation runs are added to the chain. The objective function value plotted is the summation of the prior and the likelihood contributions, as expressed in Eq. 10.

$$O(M) = \sum_{i=1}^{n}\left(\frac{d_{obs(i)} - g_{M(i)}}{\sigma_i}\right)^2 + \sum_{i=1}^{6}\left(\frac{m_{\emptyset i} - \mu_{\emptyset}}{\sigma_{\emptyset}}\right)^2 + \sum_{i=1}^{12}\left(\frac{\log m_{ki} - \mu_{\log k}}{\sigma_{\log k}}\right)^2 \quad \text{.................. (10)}$$

The objective function value is, also, the argument of the exponent in the posterior function (Eq. 6) as shown in Eq. 11.

$$f(M|d_{obs}) = c \exp\left[-\frac{1}{2}\{O(M)\}\right] \quad \text{... (11)}$$

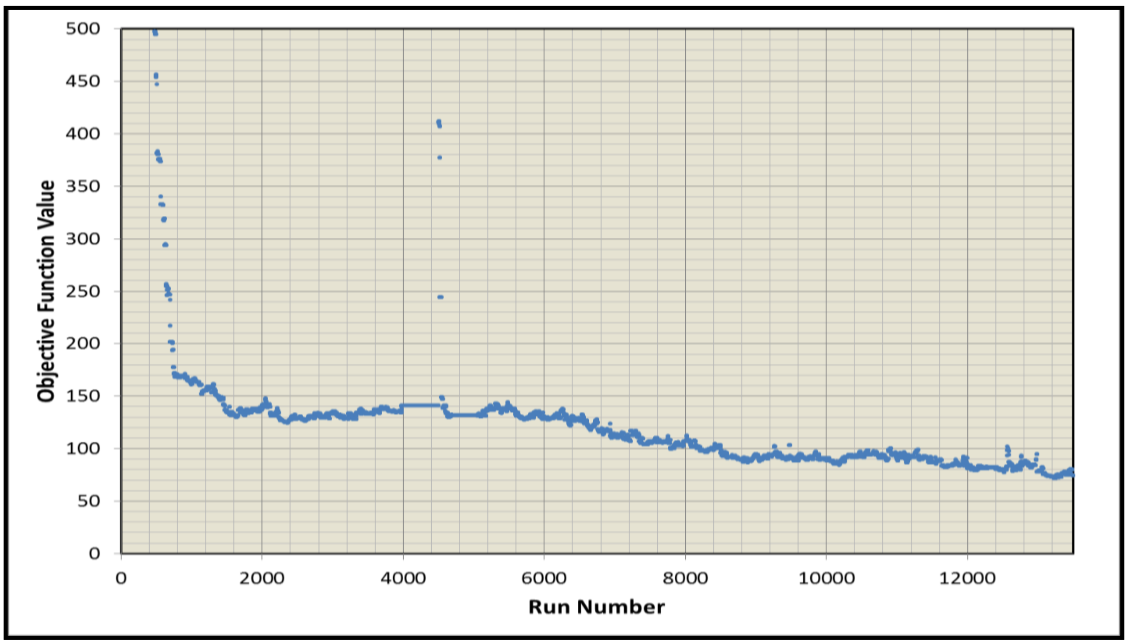

Fig. 10—Time-trace plot for Experiment 1

The plot of objective function value vs. number of runs is a good diagnostic plot for the performance of the chain. As the objective function includes both prior and likelihood contributions, it provides a measure of the ability of the model to reproduce the historical data without violating the geological characterization of the reservoir, as expressed in the prior. The chain typically starts with higher values of objective function (burn-in period). The trace should, then, show a decline behavior until a white-noise behavior around a lower objective function value is observed, indicating convergence (see Sec. 1.2.6.3).

In this experiment, a clear burn-in period of at least 1,500 runs is observed. However, it cannot be said that the chain has converged to a stationary distribution after this burn-in period. To the contrary, a continuing decline behavior in the chain is observed, indicating transience. Thus, the simulation models in the chain after excluding the burn-in period cannot be said to represent the posterior distribution but rather some transient distribution.

The acceptance rate in this experiment is calculated to be 0.255. Although this value represents a reasonably desirable behavior of the chain, it cannot be concluded that the chain has converged or it is well mixing. As mentioned, the lack of white-noise behavior indicates transience. Having a reasonable acceptable rate despite the observed slow convergence of the chain can be explained by how the proposal distribution is defined. In this experiment, the next proposed model in the chain is only one uncertain parameter different from the current one. Having a small amount of change in the proposal increases the chance of the candidate model being accepted. This might also explain the slow convergence rate of the chain, as many more runs are required to perform a thorough exploration of the parameter space.

Fig. 11 shows the distribution of the cumulative oil production at year 2035 forecasted by the simulation models in the chain of Experiment 1, excluding an initial sample of 1,500 runs. The dashed line show the cumulative oil production calculated using the truth case. The truth case is bracketed by the forecasted distribution.

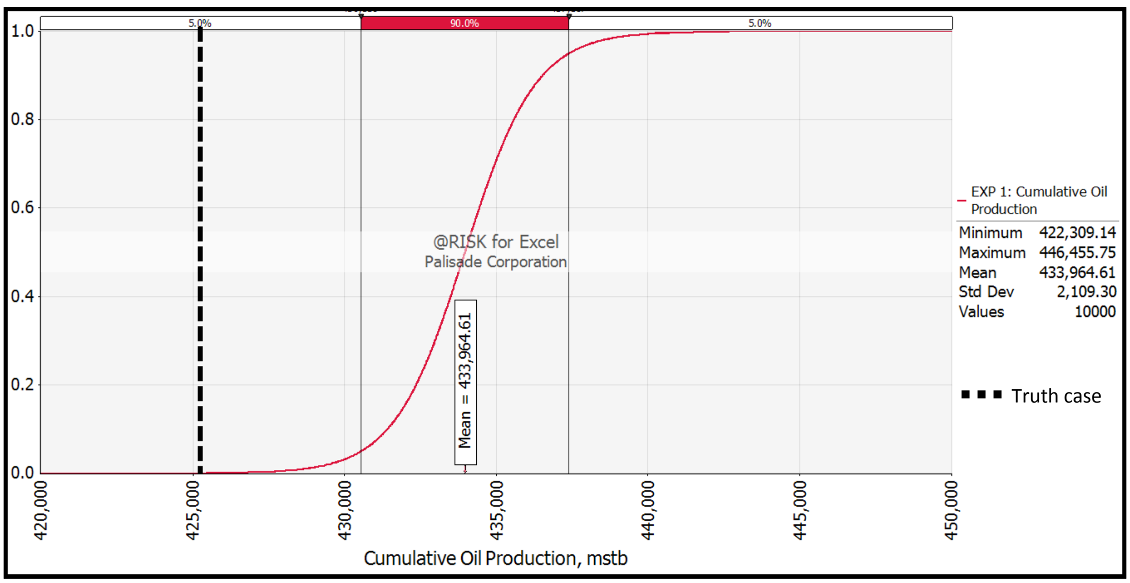

Fig. 11—Cumulative oil production forecast for Experiment 1

Fig. 12 shows summary statistics of the chain divided into sub chains of 2,000 models each, excluding the initial sample of 1,500 models. The plot shows changing values for the means (yellow line) of the first three sub chains. The latter three chains show a steady change of the means toward the truth case value. In fact, only the last sub chain (sub chain 6) includes the truth case (**Table 7**). This continuous decline in the direction of the truth case value could indicate that the chain is slowly converging toward the posterior distribution. Although the change of means and standard deviations is not significant enough to draw clear conclusions of non-stationarity, the poor mixing trend observed in the time-trace plot, the continuous reduction in the objective function value, and the fact that the truth case is being sampled only in the later portion of the chain indicate transience. One cannot conclude based on this if the chain is going to converge or how many more runs are required for convergence. The statistics on the cumulative oil production forecast, then, represents some transient distribution rather than the posterior distribution. However, it is clear that a behavior of poor mixing and slow convergence is experienced. This is due, at least in part, to the small value of perturbation size used in this experiment. Table 7 provides a summary of the statistics on the cumulative oil production forecast.

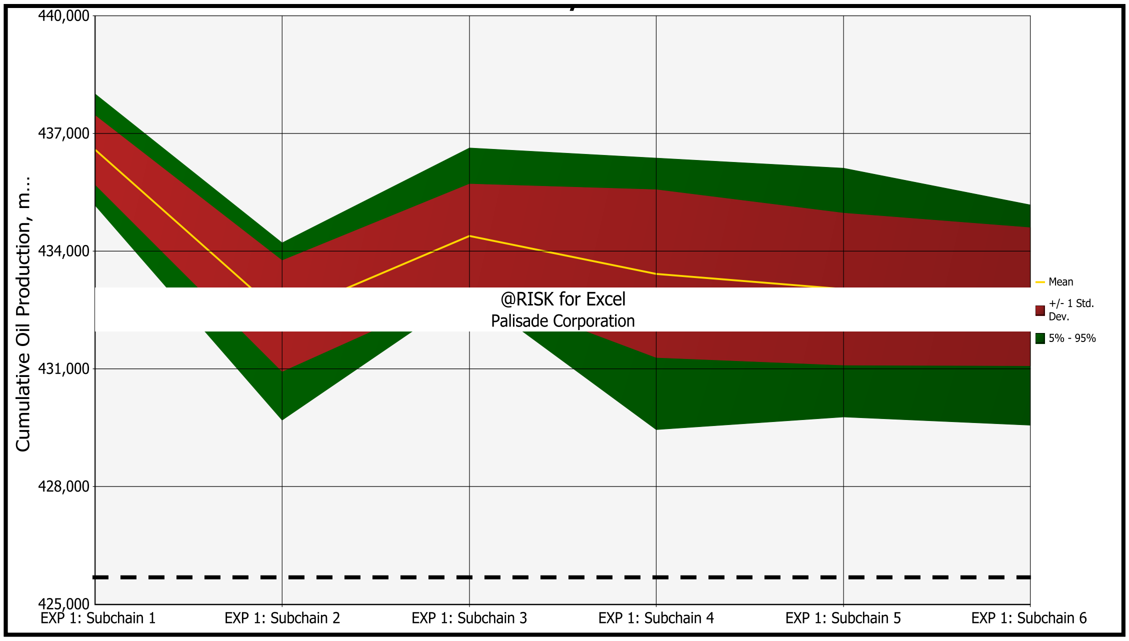

Fig. 12—Summary statistics of the sub chains of Experiment 1: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

Table 7—Cumulative oil production forecast summary statistics for Experiment 1

Chain	Mean (thousand STB)	Min. (thousand STB)	Max. (thousand STB)	S.D. (thousand STB)
Entire Chain	433,964	422,309	446,455	2,109
Sub chain 1	436,574	431,699	441,751	874
Sub chain 2	432,349	428,404	434,624	1,413
Sub chain 3	434,391	432,070	454,869	1,313
Sub chain 4	433,427	427,512	437,289	2,143
Sub chain 5	433,032	428,081	437,347	1,936
Sub chain 6	432,841	420,883	436,934	1,754
Truth Case	425,475	NA	NA	NA

3.3 Experiment 2: Effect of Perturbation Size

3.3.1 Experiment Setup

The objective of this experiment was to investigate the effect of changing the perturbation size on the performance of the chain. In Experiment 1, slow convergence rate was observed, possibly related to how the proposal distribution was defined. Because only a small change is introduced in the proposal, the rate at which the parameter space is investigated is slow. Thus, the chain is converging at a slow rate. In this experiment, the perturbation size is changed to three, compared to one in the previous experiment. The experiment was terminated after 4,500 models were run. All other parameters are kept the same as Experiment 1. **Table 8** presents a summary of the parameters used in Experiment 2.

Table 8—Experiment 2 setup summary

Parameter	**Value**	
Total Number of Runs	4,500	
Prior Porosity Multiplier	Mean = 1	S.D. = 0.3
Prior Log Permeability Multiplier	Mean = 0	S.D. = 0.354
Proposal Distribution	Random-Walk Change	
Perturbation Size	3	
Proposal Change	Mean = 0	S.D. = 0.1
Number of measurements, n	1728	

3.3.2 Experiment Results

When perturbation size was increased to 3, the chain seems to have faster convergence rate than in the previous experiment (**Fig. 13**). The plot shows a shorter clear burn-in period, ~700 models compared to ~1500 models. Additionally, the chain continues to decline in value at a faster rate than in the previous experiment. For the last 900 runs the chain seems to settle at an objective function value of around 100 to 110. A chain of 900 models, however, does not seem long enough to make conclusions about convergence. Another major difference in this experiment is the acceptance rate. Only 5.84 % of the total simulation models run in this experiment were accepted. The decline in acceptance rate is an expected consequence of increasing the perturbation size. As more change is introduced in the model, the probability of this model being accepted drops.

The time-trace values for Experiment 2 show more flat periods reflecting the lower acceptance ratio. Additionally, the jumps in objective function value observed in this experiment were bigger than those in Experiment 1. This is an expected trade-off between bigger change (and, thus, faster exploration of the parameter space) and lower acceptance rates (see Sec. 1.2.6.4).

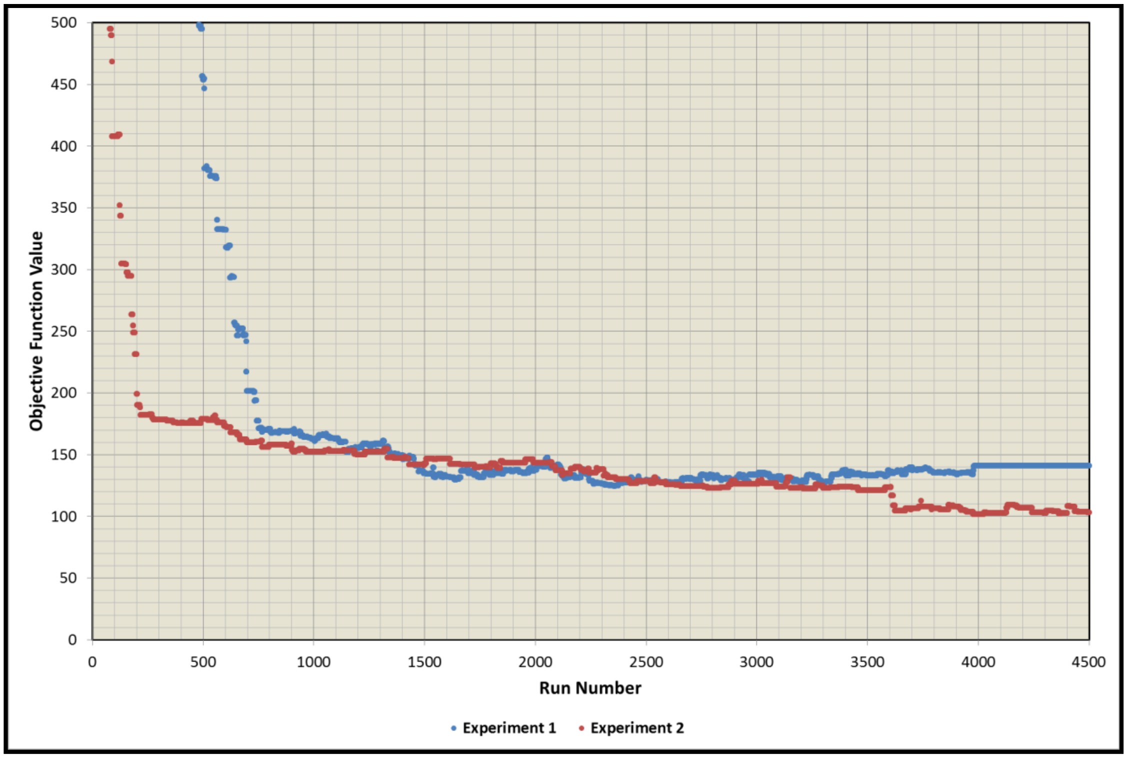

Fig. 13—Comparison between the time-trace of the objective function values for Experiment 1 (blue) and Experiment 2 (red)

Fig. 14 shows a comparison of the cumulative oil production forecasts for Experiments 1 and 2. For consistency, only the first 4,500 runs from Experiment 1 were used in this comparison. The distribution for Experiment 2 is further away from the truth case value. This, again, indicates non-convergent behavior. Additionally, the results for this experiment show a bigger spread than the previous one. This is a result of increasing the perturbation size. This chain includes models that are more different than those in the previous experiment. This, of course, impacts the production forecast. The forecast distribution of this experiment, however, is based on a smaller sample size of models (4,500 vs. 13,500).

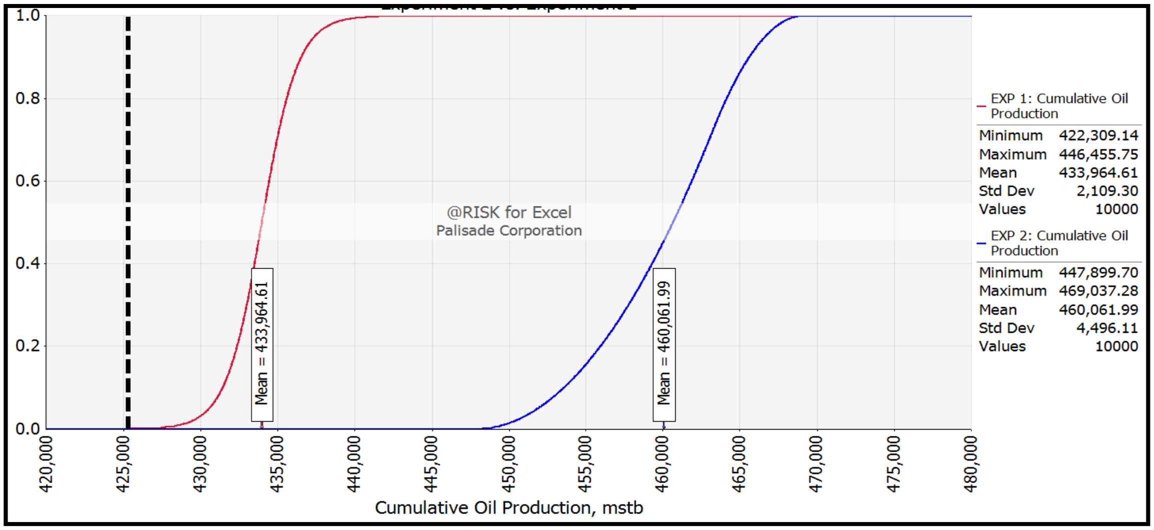

Fig. 14—Comparison between the cumulative oil production forecasts of Experiment 1 (red), Experiment 2 (blue) and truth case (dashed black)

Fig. 15 shows a summary of the statistics on the cumulative oil production forecast calculated by the models in the chain of Experiment 2, after excluding an initial sample of 500 runs. The chain is then divided into four sub chains with 1000 simulation models in each. Although the results of Experiment 2 shows a mean that is further away from the truth case (Fig. 14), increasing the perturbation size seems to cause the chain to converge at a faster rate. The consequence of this, however, is lower acceptance rate. The fact that the range of cumulative oil production in this experiment is further away from the truth case than the range obtained in Experiment 1 could be attributed to the fact that the two chains started from different initial models that were randomly selected. However, mean values (Fig. 15) show a clear trend of decrease in the direction of the truth case. This might indicate that the chain is converging toward the posterior distribution. It is not clear, however, if this is practically feasible given the poor mixing performance shown in the time-trace plot (Fig. 13) and the relatively low acceptance ratio. It is concluded from this experiment that although it is important to use higher values of perturbation size, i.e., three, to speed up the process of parameter space exploration, this could result in lower acceptance ratios that would also attribute to poor mixing and slows convergence.

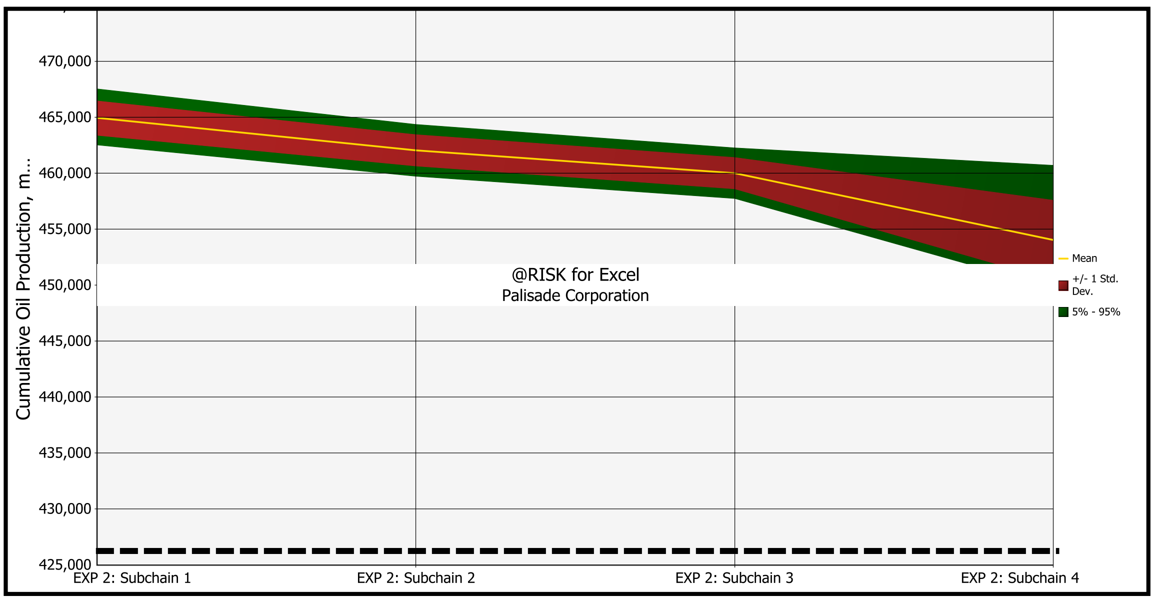

Fig. 15— Summary statistics of the sub chains of Experiment 2: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

Table 9 summarizes the statistics on the cumulative oil production forecast for Experiment 2.

Table 9—Cumulative oil production forecast summary statistics for Experiment 2

Chain Name	Mean (thousand STB)	Min. (thousand STB)	Max. (thousand STB)	S.D. (thousand STB)
Entire Chain	460,062	447,982	469,059	4,496
Sub chain 1	464,932	459,958	472,201	1,525
Sub chain 2	462,045	456,551	467,636	1,420
Sub chain 3	459,986	452,004	467,211	1,391
Sub chain 4	454,014	447,433	489,423	3,584
Truth Case	425,475	NA	NA	NA

3.4 Experiment 3: Impact of Wider Prior

3.4.1 Experiment Setup

The objective of this experiment is to investigate the effect of changing the prior definition on the performance of the chain. The two previous experiments show a need to increase the perturbation size to more than one to speed up convergence. They, also, show the dramatic effect increasing the perturbation size has on the acceptance rate. In this experiment, a perturbation size of 3 is used but the prior definition is changed to the following: (1) normal distribution for porosity multipliers with a mean of 1 and a standard deviation of 0.5, and (2) normal distribution for the log of permeability multipliers with a mean of 0 and a standard deviation of 0.5. The same maxima and minima for porosity and permeability distributions from experiments 1 and 2 are used. This experiment differs from the previous two experiments in the number of observed data points included in the likelihood function. Only 1284 points of observed measurements are included, representing years 2000 to 2009. The experiment was terminated when the total number of simulation models reached 8,500 models. **Table 10** summarizes the parameters used in this experiment.

Table 10—Experiment 3 setup summary

Parameter	Value	
Total Number of Runs	8,500	
Prior Porosity Multiplier	Mean = 1	S.D. = 0.5
Prior Log Permeability Multiplier	Mean = 0	S.D. = 0.5
Proposal Distribution	Random-Walk Change	
Perturbation Size	3	
Proposal Change	Mean = 0	S.D. = 0.1
Number of measurements, n	1284	

3.4.2 Experiment Results

Increasing the size of the prior distribution did not improve the performance of the chain. To the contrary, convergence of the chain seems to be slower than previous experiment. In this experiment, a clear burn-in period of at least 1,500 runs is observed (**Fig. 16**). The acceptance rate for this chain is still low at 0.0562. The low value of the acceptance rate can be explained by the higher value of perturbation size, as in Experiment 2.

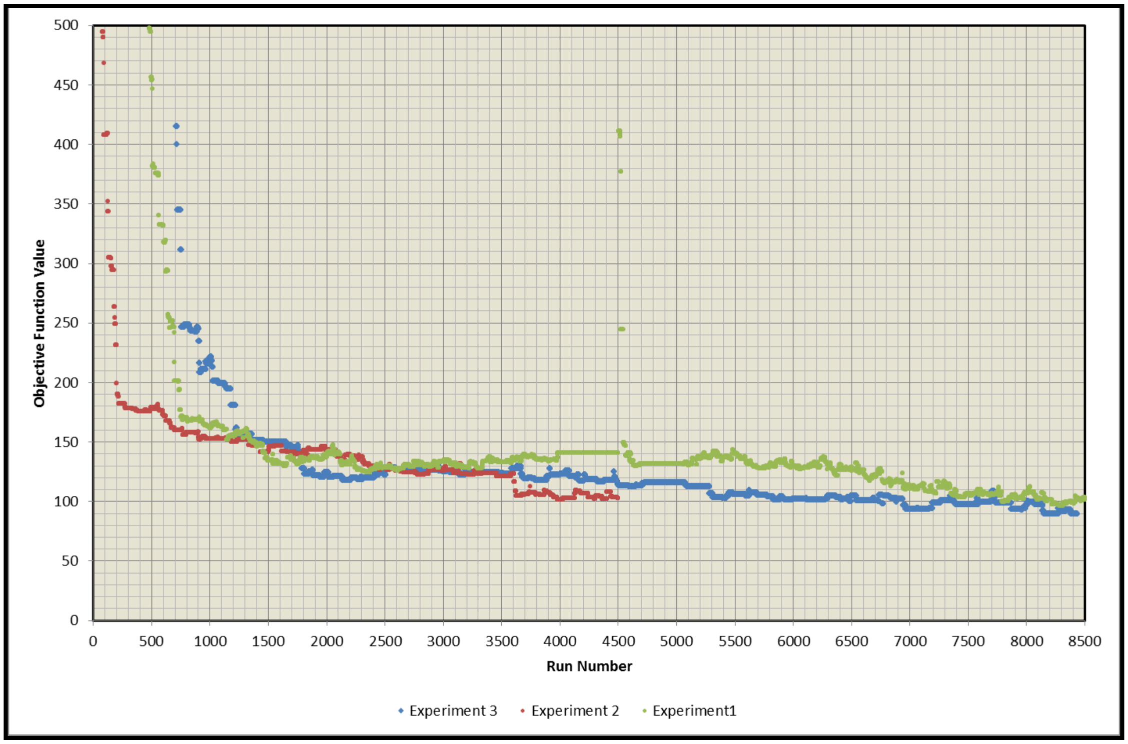

Fig. 16—Comparison between the time-trace of the objective function values for Experiment 1 (green), Experiment 2 (red), and Experiment 3 (blue)

The slower convergence rate observed in this experiment is a consequence of the chain exploring a wider parameter space. **Fig. 17** shows dominant flat periods in the time-trace of objective function value, indicating that the chain is trapped in certain areas of the parameter space, which generate models that are more likely to be rejected (i.e., not likely to produce the observed data). Even when the experiment is repeated, a similar trend of flat periods and big jumps is obtained. This is a behavior that was not observed in the previous experiments. This shows, clearly, that a proper choice of prior speeds up the convergence of the chain into a stationary distribution. Good choice of prior, however, is difficult to define. In these synthetic experiments, the truth case is known and the prior distribution is constructed around the truth case. In practice, a truth case is not known and is not guaranteed to be included in the prior distribution. Choosing prior distributions with big variances might slow down the convergence of the chain. On the other hand, choosing a narrow prior distribution could mess the actual characterization of the reservoir and, consequently, have negative impact on the convergence of the chain, as well. In practice, prior distributions should be wide enough to reflect the current understanding of the reservoir and properly characterize uncertainties, especially at earlier times of reservoir life when knowledge of reservoir is primitive and uncertainties are huge.

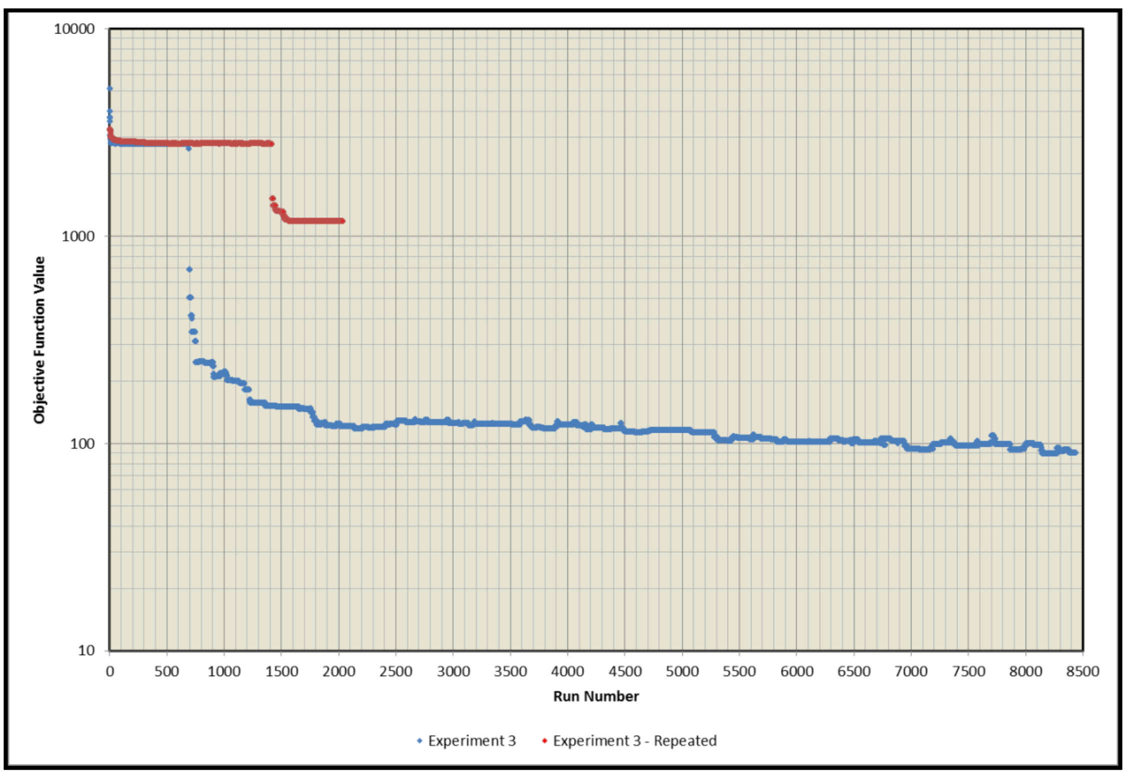

Fig. 17—Time-trace plot for Experiment 3 (blue) and Experiment 3-Repeated (red)

The breakdown of the objective function value (**Fig. 18**) shows dominance of the likelihood contribution over the prior contribution. This is a direct consequence of the number of observed data measurements (1284 data points) being significantly larger than the number of uncertainty multipliers included in the prior term (18 parameters). The consequence of that is having a prior with almost a negligible contribution to the objective function value. Additionally, because the acceptance criterion of the Metropolis-Hasting algorithm is defined in terms of the posterior terms, which include an exponential function, the process becomes extremely sensitive to changes in the likelihood. The acceptance ratio (Eq. 9) can be expressed in terms of the objective function value as the following:

$$\alpha = \exp\left\{-\frac{1}{2}\left[O(M^{t=2})-O(M^{t=1})\right]\right\} \qquad (12)$$

This implies that the calculated acceptance ratio becomes very sensitive to small changes in the magnitude of the objective function values. When this difference is negative, implying improvement to the quality of the history match (i.e., less sum of square errors), the model is accepted ($\alpha > 1$). However, only a small positive change is enough to generate very small values of α (i.e., very low probability of acceptance). For example, if the likelihood term of the proposed model is greater than the likelihood term of the current model by a value of 10, this implies that this proposed model has only a 0.7% probability of being accepted. It is intuitive that when more observed data points are being considered the expectation of sum of square errors should increase. However, in terms of normalized average error and history match quality of the model, this increase is negligible given there are 1284 data points. Given the setup parameters of this experiment, if this difference of 10 in the likelihood term values are assumed to be due to change in pressure values calculated by the two models, this would imply that the pressure values of the second model is deviated from the first model by 0.2 psi, in average. The consequence of that is models with about the same likelihood of generating the observed data are being rejected more often than they should be. This, of course, slows down the convergence of the process. Additionally, even if convergence is reached, the chain has to be run much longer to correctly sample the posterior distribution, as more representative samples are being thrown away. Auto correlation is expected to be high, as more representative models are being rejected and more models that are too similar are being accepted. Thus, additional samples need to be discarded to correct for auto-correlation.

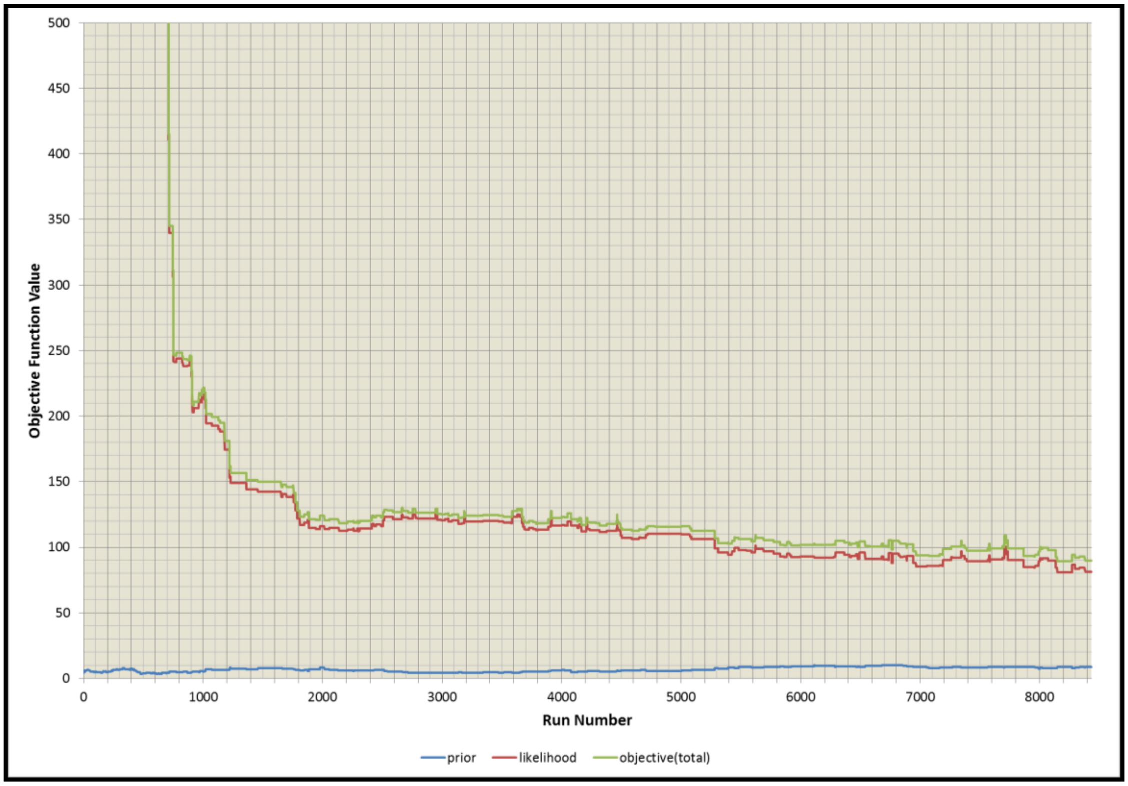

Fig. 18—Time-trace plot of Experiment 3 showing the objective function value (green), the likelihood contribution (red), and the prior contribution (blue)

To summarize, the current formulation of the likelihood function greatly exaggerates the contribution of the likelihood and causes the acceptance criteria of the process to be very sensitive to subtle changes in the likelihood term. This is a major contributor to the slow convergence rate experienced and may affect the accuracy of the characterization of the posterior, even if the chain reached convergence. The current likelihood function needs to be adjusted to reduce this sensitivity and to provide a reasonable measure of the actual likelihood of the model to produce the observed data.

3.5 Experiment 4: High Level of Reservoir Maturity and Six Month Continuous Updating

3.5.1 Experiment Setup

This experiment investigates the performance and analyzes the results obtained from a continuous model update experiment using a different definition of the likelihood function and incorporating the lessons learned from the three previous experiments. The new likelihood formulation (Eq. 13) aims to reduce the sensitivity of acceptance to small changes in likelihood contribution values and proposing a more reasonable way of evaluating the likelihood of models to produce the observed measurements.

$$f(d_{obs}|M)=c\ \exp\left[-\frac{1}{2}\sqrt{\sum_{i=1}^{n}\left(\frac{d_{obs(i)}-g_{M(i)}}{\sigma_i}\right)^2}\ \right] \quad (13)$$

The motivation behind this new formulation is to reduce the sensitivity of changes in the likelihood without undermining the value of information new observations add to the definition of the posterior distribution. In one hand, reducing the "unreasonable" sensitivity to small changes in the likelihood is needed but, in the other hand, the posterior should be updated to reflect the value of additional information obtained from new observations. Using the same example discussed previously (see Sec. 3.4.2), this new formulation implies that the proposed model will have a 52% probability of being accepted.

This experiment keeps a perturbation size of three, as in the previous two experiments, and adopts the same prior distribution defined in Experiment 3. MCMC code was used with the production data of the first 9 years (1284 data points). New production data were, then, included continuously to simulate a case with a model update frequency of 6 months, in average. **Table 11** and **Table 12** summarize the parameters used in the experiment and explain the continuous update process as more production data are being included.

Table 11—Experiment 4 setup summary

Parameter	**Value**	
Prior Porosity Multiplier	Mean = 1	S.D. = 0.5
Prior Log Permeability Multiplier	Mean = 0	S.D. = 0.5
Proposal Distribution	Random-Walk Change	
Perturbation Size	3	
Proposal Change	Mean = 0	S.D. = 0.1

Table 12—Continuous process setup for Experiment 4

Update	**Duration**	**Number of Observed Measurements**	**Number of Simulation Models in the Chain**
Static	9 years	1,284	9,000
1st	6 months	1,344	6,000
2nd	7 months	1,428	8,313
3rd	6 months	1,488	9,836
4th	7 months	1,572	6,754
5th	5 months	1,632	6,504
6th	5 months	1,728	1,803

3.5.2 Experiment Results

The time-trace plot of the objective function value (**Fig. 19**) shows a better performance than what have been observed in the previous experiments, in general. The chain appears to have less burn-in periods, less more flat periods, and more of what look like a white-noise behavior. Moreover, acceptance ratios have been greatly improved, ranging from 0.22 to 0.13 (**Table 13**).

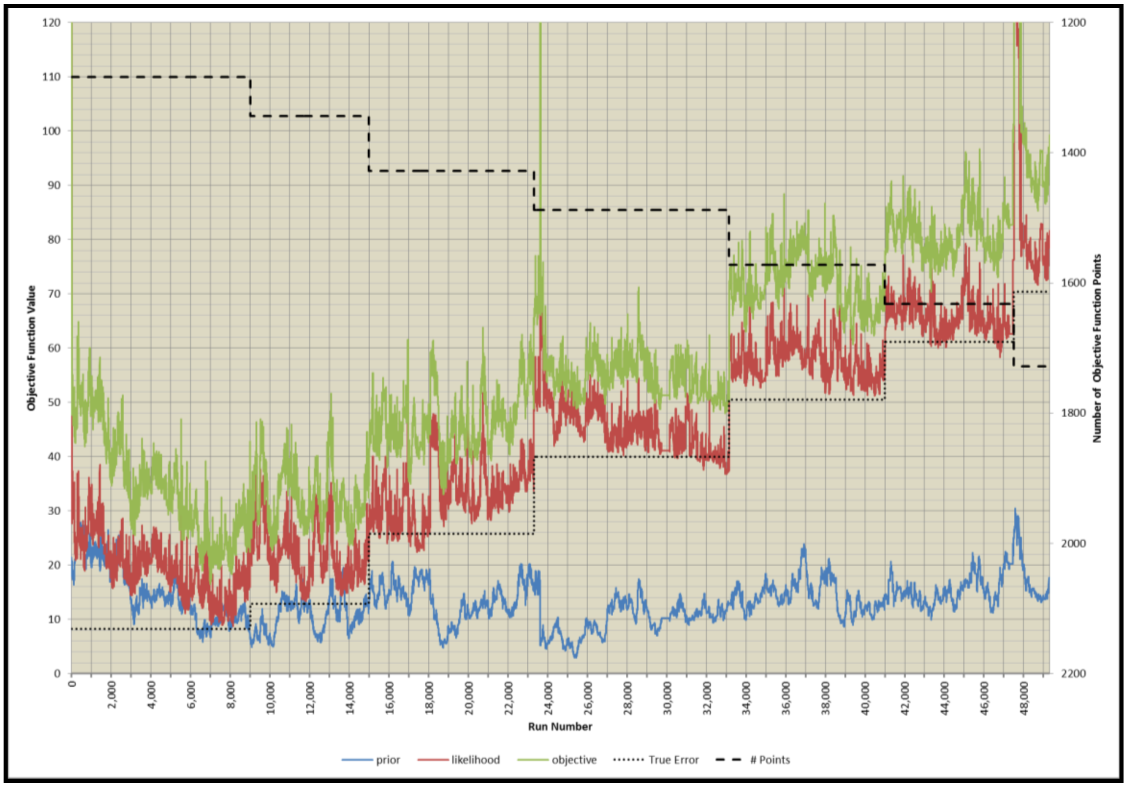

Fig. 19—Time-trace plot of Experiment 4 showing the objective function value (green), the likelihood contribution (red), the prior contribution (blue), the number of observed data points included-reverse scale (bold dashed black), and the objective function value of the noisy measurements (dotted black)

The breakdown of the objective function value (Fig. 19) in this experiment shows different behavior than the previous experiment reflecting the change of likelihood function formulation. During the static part, the contributions of the prior and likelihood terms to the objective function value are equal, for the most part. As more observed data measurements are added in the subsequent updates, the magnitude of the likelihood contribution increases relative to the prior distribution. This reflects the desire of being more driven by data as model updating advances.

The results of this experiment show a relationship between the amount of observed data included and acceptance ratio (Table 13). As more data are included in the likelihood function, the magnitude of the objective function value is expected to increase and acceptance becomes more sensitive to likelihood change. Although the new formulation of the likelihood function has greatly reduced this sensitivity of the acceptance ratio to the number of observed points, it has not completely eliminated it.

Table 13—Acceptance ratio and summary statistics of objective function values for Experiment 4

Update	Acceptance Ratio	Mean Objective Function Value	Minimum Objective Function Value	Maximum Objective Function Value
Static	0.217	34.6	16.4	632.5
1st	0.198	32.2	22.7	51.6
2nd	0.160	45.9	33.0	63.8
3th	0.131	56.2	48.0	758.5
4th	0.140	71.6	60.7	88.4
5th	0.136	80.9	70.4	101.6
6th	0.127	103.1	85.3	202.1

Unlike previous experiments, the curves for forecasted cumulative oil production (**Fig. 20**) are bracketing the truth case (dashed line). This shows some improvement over the previous experiments. The truth case is part of the posterior distribution and having forecasts that include the truth case provides a level of confidence that the algorithm is sampling the posterior distribution, at least partially.

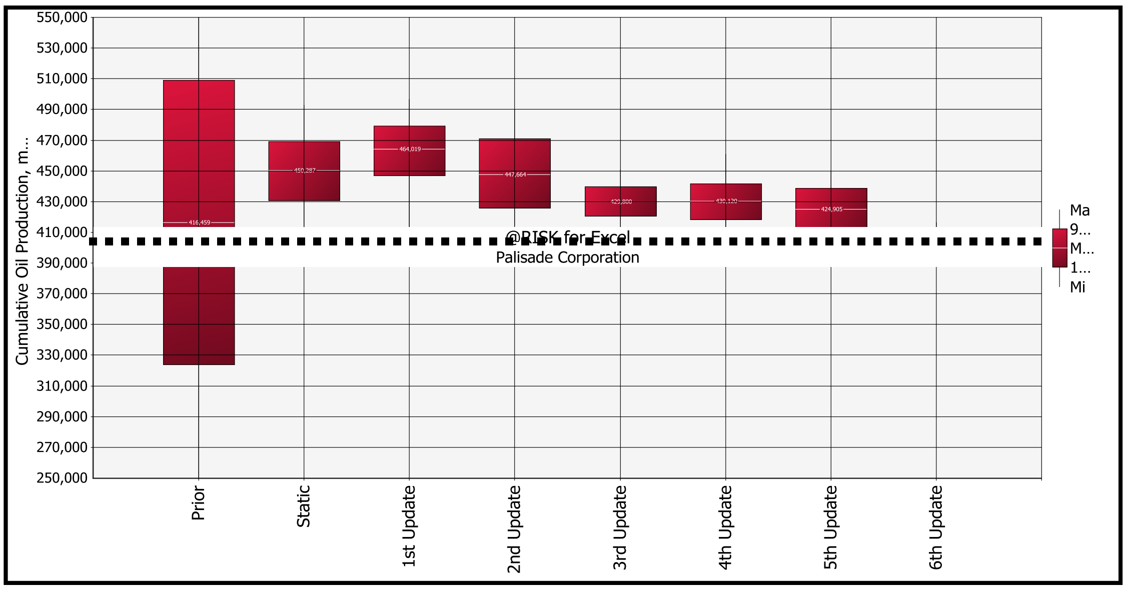

Fig. 20—Box plot for cumulative oil production forecasts for Experiment 4 showing the truth case (dotted black)

To investigate chain convergence and stationarity, each of the seven chains summarized in Table 13 is divided into sub chains of 500 models. Convergence is reached when subsequent sub chains show similar means and standard deviations. **Figs. 21 through 27** provide summary statistical visualization of the cumulative oil production forecasts for these sub chains. **Fig. 28** shows the time-series evolution of the chain through all model updates and **Table 14** provides the same information in tabulated format.

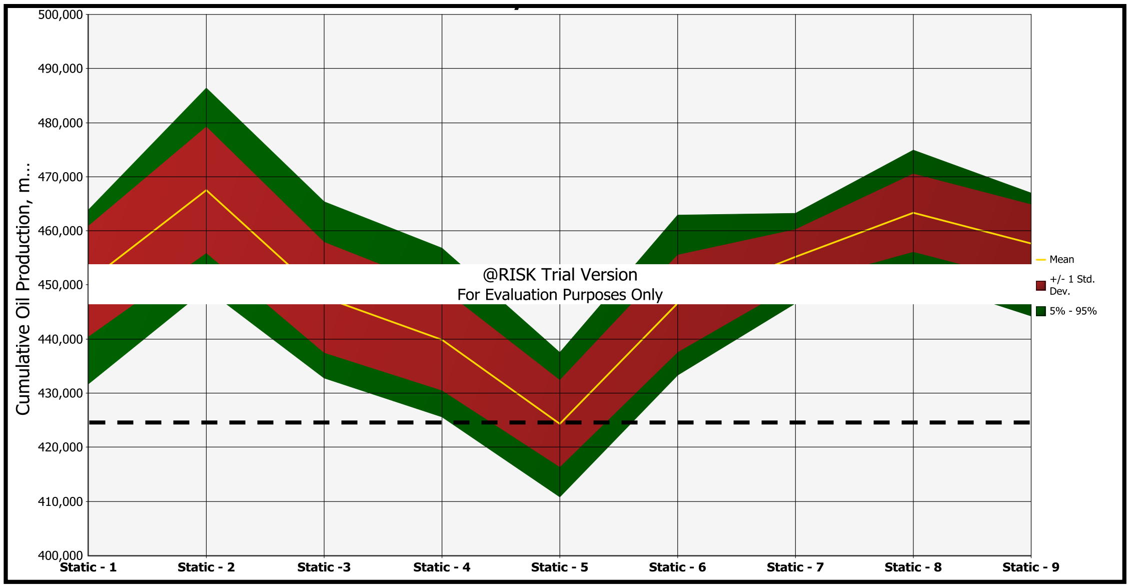

Fig. 21— Summary statistics of the static sub chains of Experiment 4: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

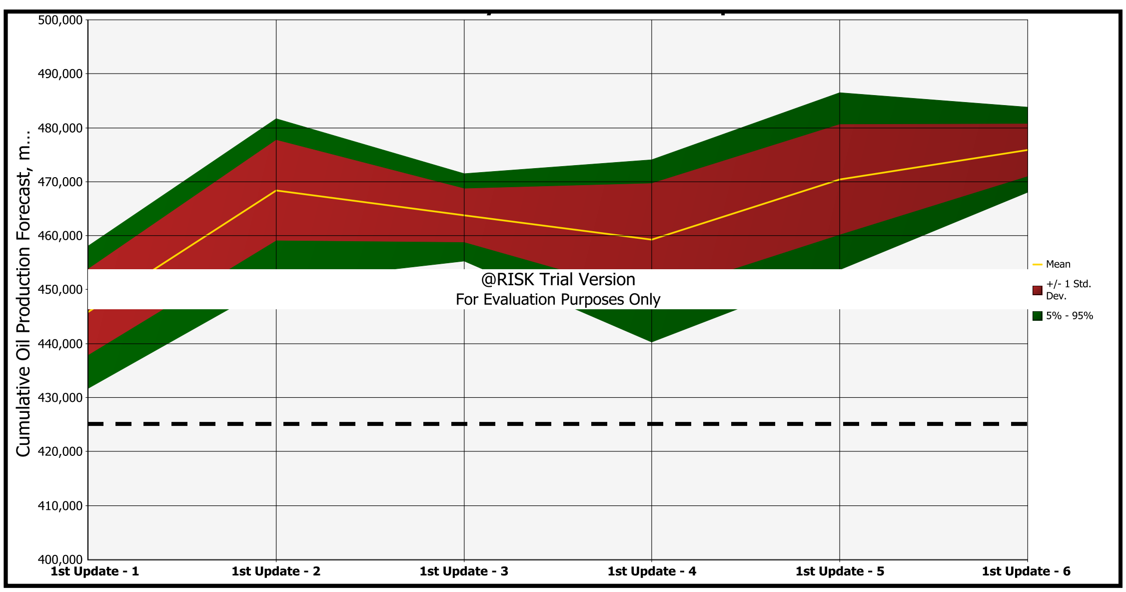

Fig. 22—Summary statistics of the 1st update sub chains of Experiment 4: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

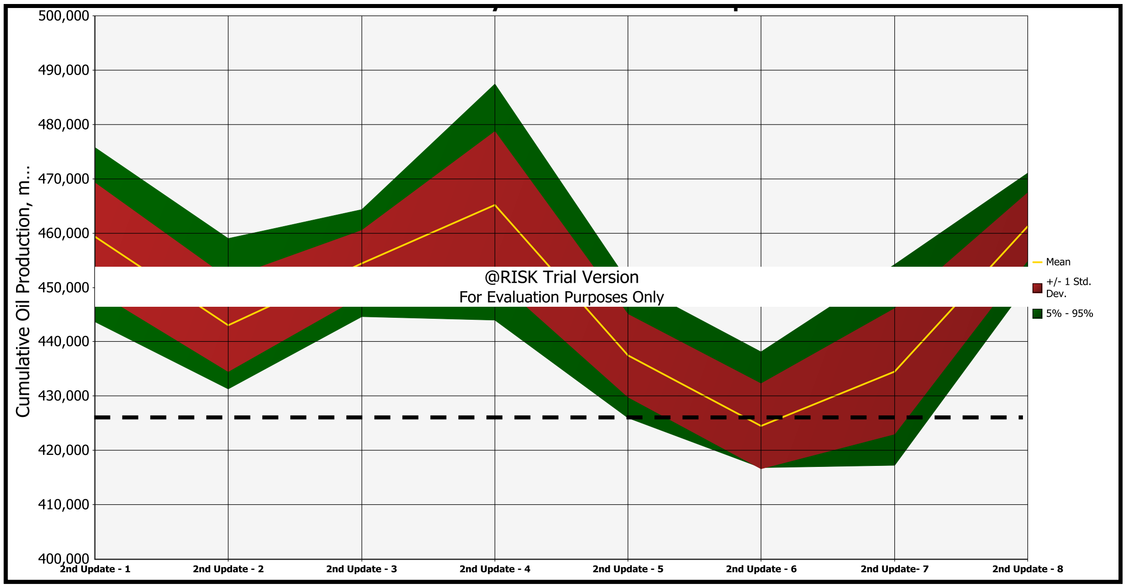

Fig. 23—Summary statistics of the 2nd update sub chains of Experiment 4: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

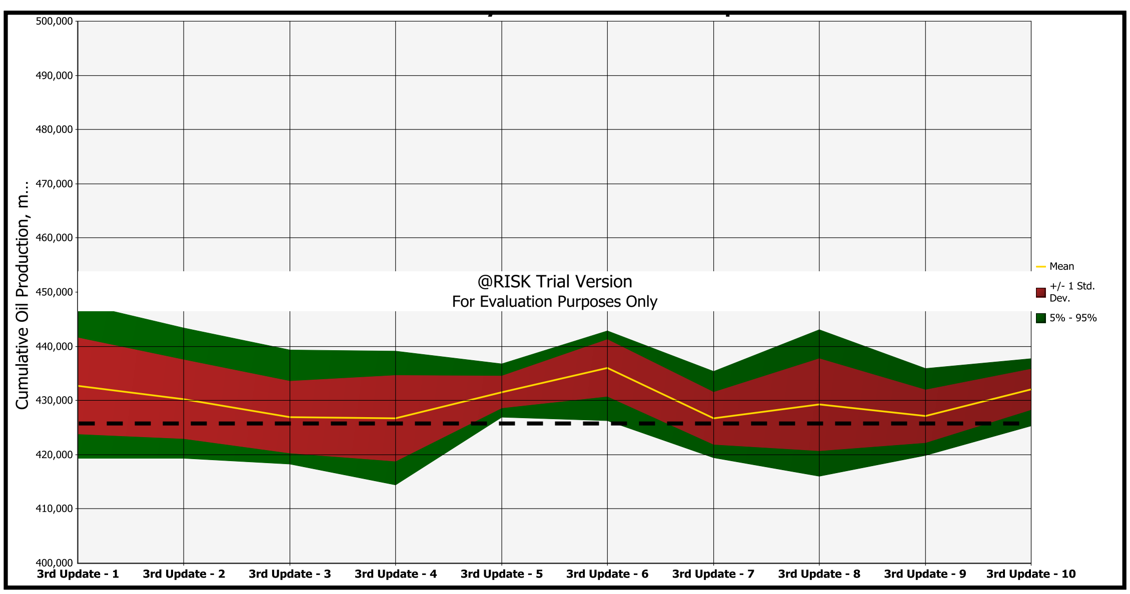

Fig. 24—Summary statistics of the 3rd update sub chains of Experiment 4: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

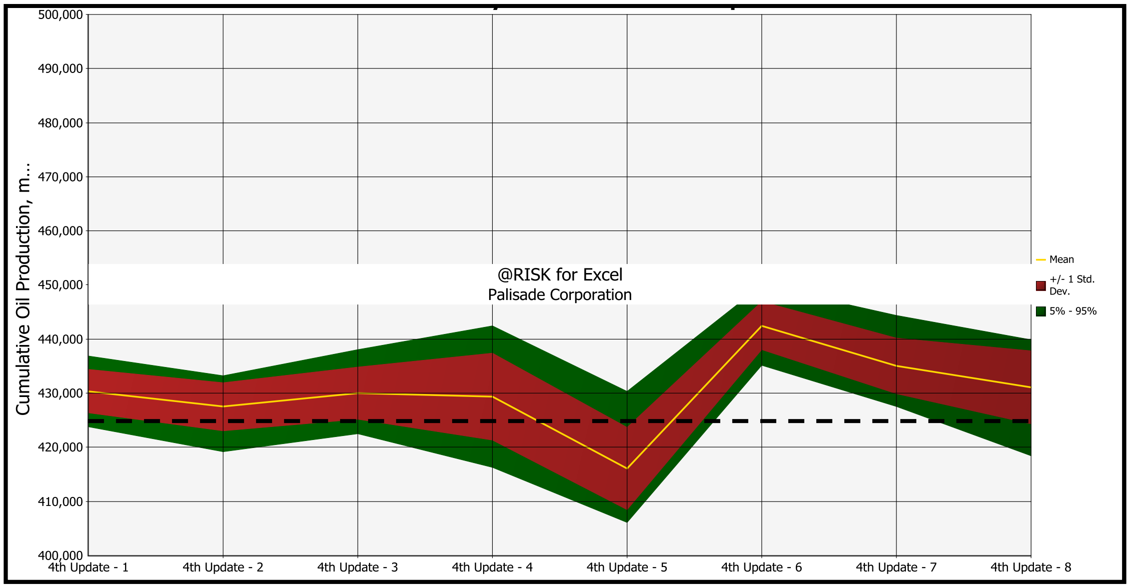

Fig. 25—Summary statistics of the 4th update sub chains of Experiment 4: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

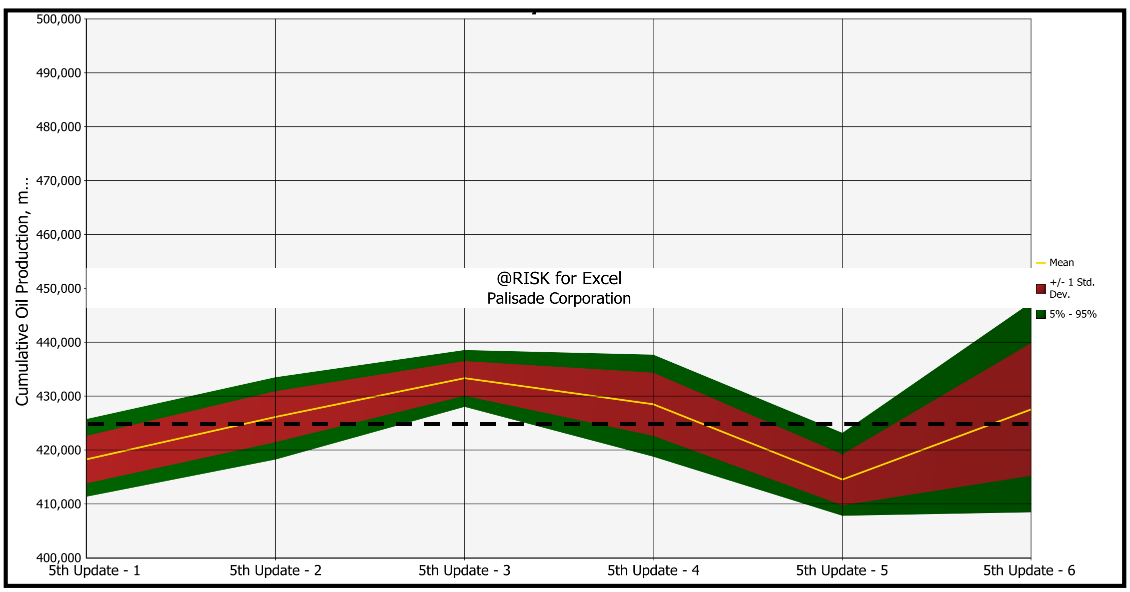

Fig. 26—Summary statistics of the 5th update sub chains of Experiment 4: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

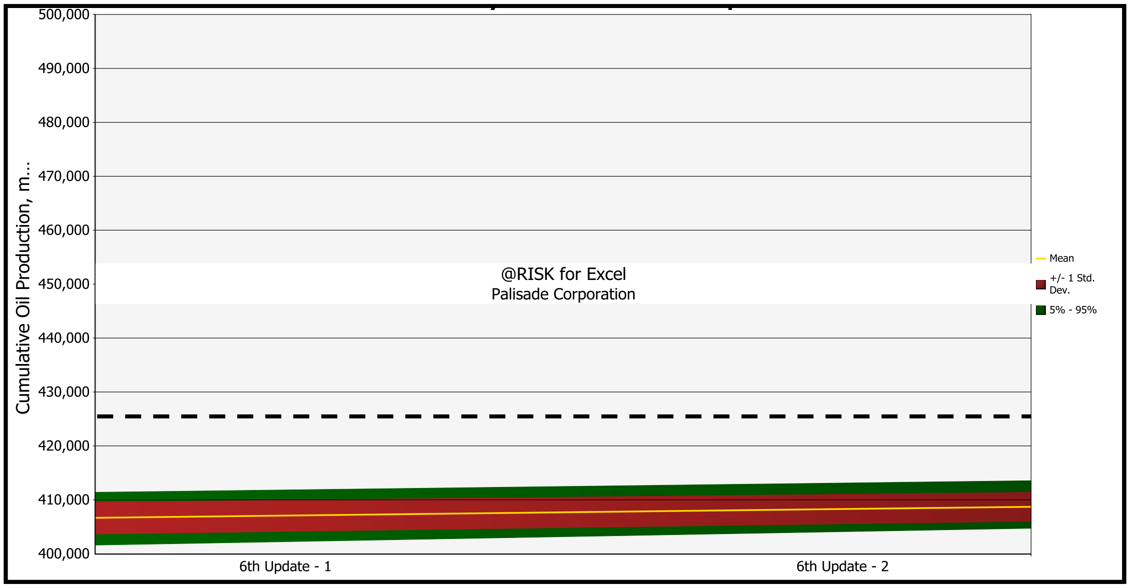

Fig. 27—Summary statistics of the 6th update sub chains of Experiment 4: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

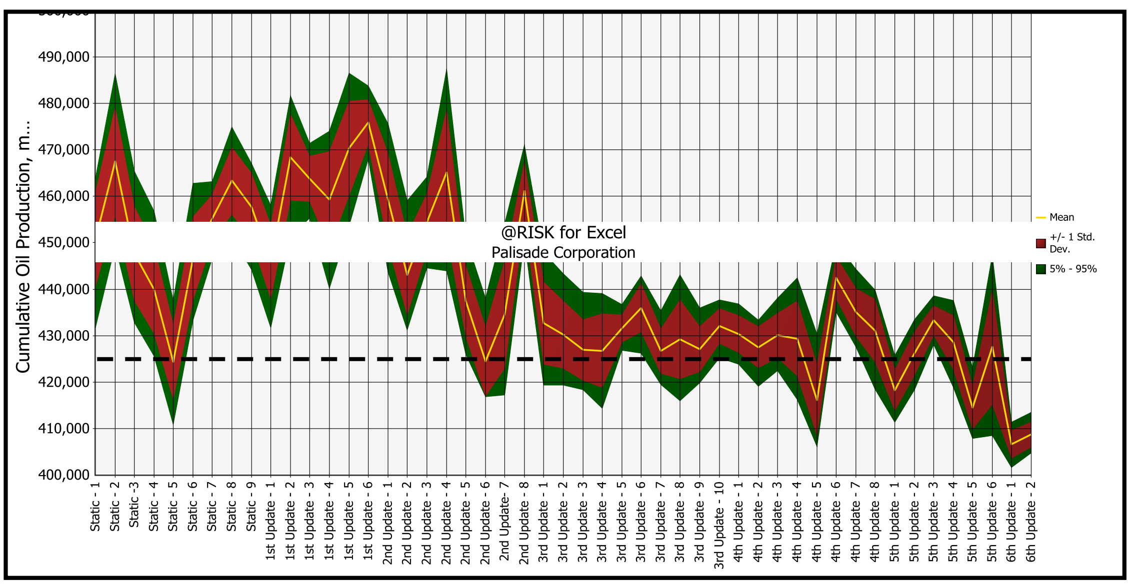

Fig. 28—Summary statistics of the time-series evolution of Experiment 4: mean (yellow), +/- 1 S.D. (red), 5%/95% percentiles (green) and truth case (dashed black)

Table 14—Summary statistics of cumulative oil production for the sub chains in Experiment 4

Chain	Sub Chain	Mean	S.D.	P10	P90
Static	1	450,697	10,138	431,770	461,851
Static	2	467,543	11,642	449,328	483,788
Static	3	447,693	10,135	432,797	462,231
Static	4	439,923	9,420	425,627	453,396
Static	5	424,351	7,969	410,849	435,043
Static	6	446,572	8,979	433,370	459,556
Static	7	455,235	5,027	446,650	461,629
Static	8	463,372	7,162	451,300	472,814
Static	9	457,665	7,173	444,271	465,560
1st Update	1	445,884	7,922	431,773	455,965
1st Update	2	468,409	9,275	451,383	479,686
1st Update	3	463,789	4,895	455,334	469,963
1st Update	4	459,322	10,349	440,277	471,848
1st Update	5	470,368	10,185	453,731	484,241
1st Update	6	475,912	4,825	468,051	481,401
2nd Update	1	459,337	9,928	443,679	473,137
2nd Update	2	443,058	8,602	431,285	455,721
2nd Update	3	454,454	6,044	444,609	461,333
2nd Update	4	465,184	13,490	443,992	483,979
2nd Update	5	437,448	7,595	425,998	448,333
2nd Update	6	424,447	7,874	416,832	433,070
2nd Update	7	434,551	11,529	417,239	450,971
2nd Update	8	461,191	6,205	450,542	469,052
3rd Update	1	432,712	8,876	419,372	445,322
3rd Update	2	430,211	7,279	419,329	440,679
3rd Update	3	426,921	6,594	418,318	436,712

Table 14—Continued

Chain	Sub Chain	Mean	S.D.	P10	P90
3rd Update	4	426,743	7,907	414,416	437,697
3rd Update	5	431,528	2,947	426,905	435,681
3rd Update	6	435,983	5,213	426,250	441,722
3rd Update	7	426,695	4,801	419,462	433,579
3rd Update	8	429,244	8,501	415,984	441,121
3rd Update	9	427,110	4,861	419,913	434,124
3rd Update	10	432,061	3,765	425,282	436,782
4th Update	1	430,361	4,012	423,828	434,925
4th Update	2	427,505	4,428	419,188	432,789
4th Update	3	430,042	4,841	422,512	436,824
4th Update	4	429,369	8,064	416,270	440,382
4th Update	5	416,065	7,611	406,139	427,373
4th Update	6	442,488	4,485	435,140	448,341
4th Update	7	435,032	5,166	427,592	441,905
4th Update	8	431,090	6,621	418,755	439,075
5th Update	1	418,233	4,356	412,540	424,162
5th Update	2	426,164	4,708	419,538	432,473
5th Update	3	433,301	3,181	429,121	437,418
5th Update	4	428,538	5,804	420,450	436,306

Table 14—Continued

Chain	Sub Chain	Mean	S.D.	P10	P90
5th Update	5	414,481	4,678	408,848	421,297
5th Update	6	427,532	12,290	410,754	444,702
6th Update	1	406,632	2,965	402,651	410,477
6th Update	2	408,702	2,654	405,414	412,521

The statistics of within and across time-series chains of Experiment 4 indicate non-stationarity at least for the static, 1st update and 2nd update phases. The trend of the means of the cumulative oil production shows high fluctuations, initially, until they converge and appear to become more stable during the 3rd and 4th update periods (Fig. 28). Although, the time-trace of objective function values shows spikes in magnitude when model updating occurs, reflecting the change of likelihood function definition, this is not reflected in the cumulative oil production forecast results. In fact, the means plotted in Fig. 28 behave like they belong to one continuous chain that go through an initial burn-in period then transition into stationary distribution despite of a changing likelihood function definition. This indicates that the impact burn-in has on the results become less severe and rate of convergence improve as the total number of models in the chain increases. The general direction the means of cumulative oil production is going through from higher values to convergence around the truth case value supports the observation of a one continuous chain behavior sampling from the posterior distribution when a period of transience is passed.

On the other hand, making inferences about convergence and stationarity is trickier and less obvious when one is looking at individual chains or early on in the continuous updating process. One can make the argument that the static chain is exhibiting a stationary behavior at the last four sub chains, for example. Similar arguments can be made about the other chains in this experiment. In reality, a reference truth case value does not exist to be used in validation. It is only when sufficient number of models accumulates in the chain to allow the construction of a number of sub chains of statistical significance, one can draw conclusions about the convergence of the distribution's mean. It is probably better to allow for more models during the early stages of the model updating process to establish more confidence of whether the chain has converged. Depending only on the time-trace plot of the objective function value to evaluate convergence can be misleading. When transient chains are falsely identified as stationary, one would mistake samples drawn from some other transient distribution as representing the posterior distribution, as in the static and the first two updates in this experiment.

The trend of the standard deviations for the sub chains of the cumulative oil production forecasts is more scattered and less clear (**Fig. 29**). However, a general trend of decreasing standard deviation is observed. Although, differences in the standard deviations within one chain signals non-stationarity, one should not expect such complex process to show signs of strong stationarity as the parameter space is large and the relationship between input and output is complex. The results show a drop in the average standard deviation value as the experiment advances from the static chain to the 4th update. This reflects the value of adding observed data in reducing the amount of uncertainty and improving the forecast quality.

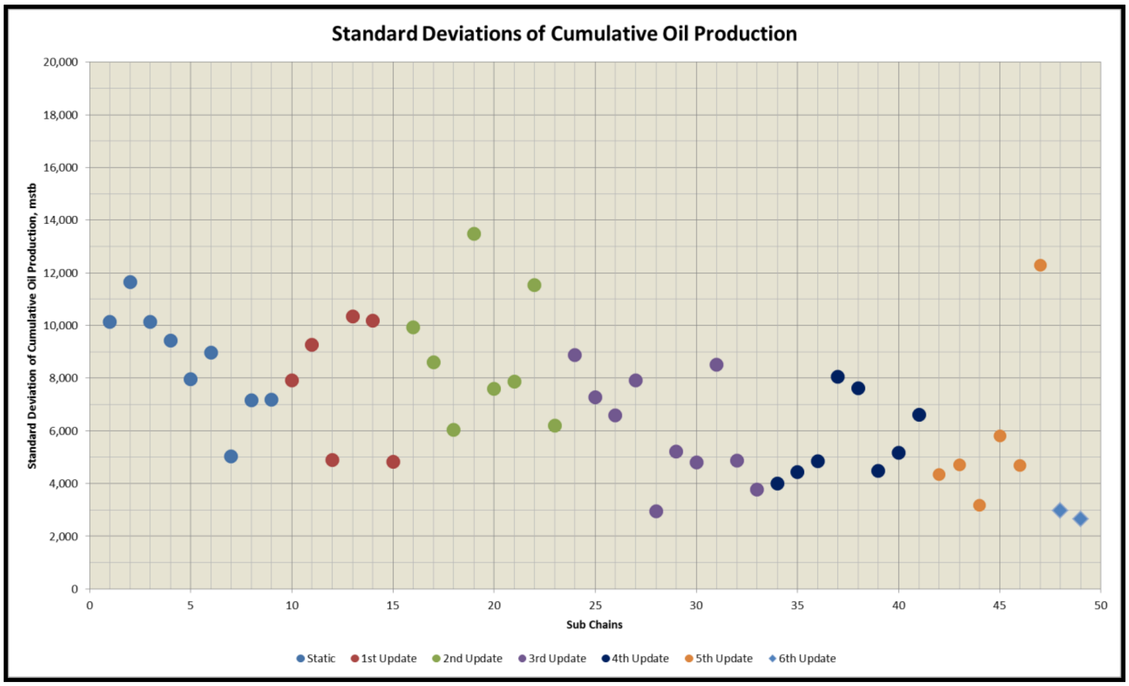

Fig. 29—Standard deviations of cumulative oil production forecast for the sub chains of Experiment 4—static chain (blue), 1st update (red), 2nd update (green), 3rd update (purple), and 4th update (navy)

It is worth noting that although cumulative oil production is more interesting output to study and analyze, it is not the posterior distribution of this experiment. Here, the assumption that when a stationary distribution of models representing the posterior is reached, the resulting cumulative oil production forecasts calculated by these models would be stationary, as well, is made.

Unfortunately, only one sample that belongs to the true distribution of the uncertain parameters is known, In fact, the true distribution consists only of that one sample that is the truth case. The general expectation of a continuous process that properly characterize the uncertainty of the system is to have posterior distributions that include the truth case and have variability that continuously reduce as more information about this system becomes available. In this MCMC continuous approach, the two main drivers that influence the posterior distribution are the definition of prior and likelihood. In general, at early times when less data are available the posterior is more controlled by the prior distribution. If the prior distribution is poorly defined, models that are closer to the prior mean will have more probability of being represented in the posterior than models with high likelihood of explaining the observed data but not necessarily close to the mean of the prior. In such case, the posterior distribution evolves from a state of equilibrium between "stronger" prior force and "weaker" likelihood force, at early times, to a state of equilibrium between "weaker" prior force and "stronger" likelihood force, at later times. The strength of these forces depend on the location of the mean of the prior with regard to the true mean, the variance of the prior distribution, the number of uncertain parameters, the variance of error around measurements, and the number of observed data points.

In this synthetic experiment, the truth case is chosen as the mean of the prior. This eliminates any effect the prior mean may have on biasing the posterior distribution.

This, however, is not to say that definition of prior is perfect and, thus, all any sources of error in the definition of the posterior should be attributed to the handling of likelihood. Although the prior model is simplified with 18 independent Gaussian distributions that all share the same variance, the actual parameter space exhibits degrees of dependence and more complex. Further, the relationship between the parameter space and the observed data are very complex and highly non-linear. Spatial correlation, temporal correlation, and degrees of localization between observed data and parameter space are non-modeled factors that influence this relationship. All the plots of the time-trace contributions of objective function show many episodes of increasing likelihood contribution corresponding to diminishing prior contribution, for example.

The posterior distribution is a hyper-space that consists of 18 dimensions. The truth case is a vector of uncertain parameters that generates a case that would not be penalized by the prior term, as being the mean of the prior, and would be highly rewarded by the likelihood, as being the model that generated the observed data. Theoretically, all posterior distributions should include this point regardless of update stage. Generating posteriors, that do not include this point, flag some level of estimation error. This, also, implies an inadequate parameter space search. In other words, if the entire parameter space has been sampled, the truth case would have been part of the posterior, with no doubt. In practice, one does not have infinite resources enabling full search of the parameter space.

Fig. 30 shows an example of the CDF of the porosity posterior for the six uncertainty regions of the model after the 4th update, along with the prior and the CDF of the porosity multipliers of the six regions combined. The distributions of porosity show wide variation across the six regions. The curves of individual regions indicate that one update cycle is not enough to explore the entire parameter space. Although time-trace plots and cumulative oil production analysis implies that the posterior is being sampled, investigation of parameter space indicates that this posterior has not been fully explored.

To summarize, the results of this experiment show that the new formulation of the likelihood improved the convergence of the chain as it reduced the sensitivity of the acceptance criteria to small and insignificant changes in the likelihood magnitude. Both time-trace of the objective function and cumulative oil production diagnostics show signs of convergence and stationarity, especially from the 3rd update forward. Investigation of the posterior distribution suggests some level of correlation between uncertain parameters and reveals the shortcoming of the random-walk perturbation method in performing a thorough exploration of the parameter space within reasonable amount of runs.

Appendix C provides detailed statistics on both cumulative oil production forecasts and posterior uncertain parameters.

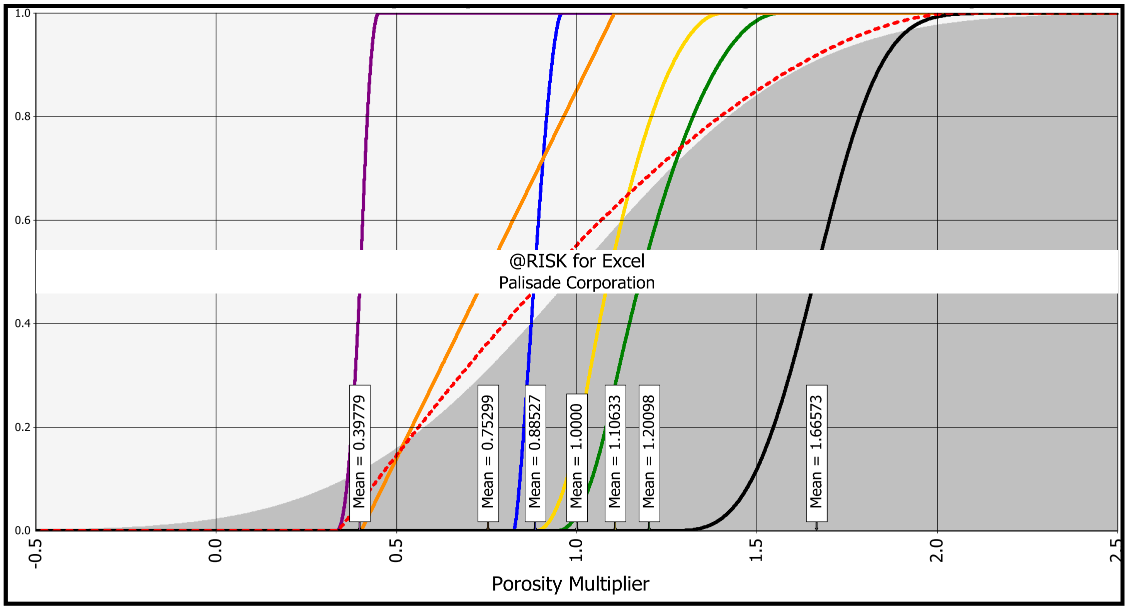

Fig. 30—Porosity multiplier posterior after the 4th update for regions: 1(blue), 2(green), 3(purple), 4(yellow), 5(orange), 6(black); all regions (dashed red) and prior (solid gray)

3.6 Experiment 5: Low Level of Reservoir Maturity and 1 Month Continuous Updating

3.6.1 Experiment Setup

The objective of this experiment is to investigate the effect of changing the update frequency and level of reservoir maturity on the performance of the chain and forecast results. Additionally, the impact of having likelihood with fewer data points on the posterior distribution is studied. The last experiment started with a likelihood function that include 1284 observed data points and was updated in six stages to include 1728 data points at the end of the experiment. In this experiment, the same setup used in Experiment 4 (Table 11) is used. The only difference is that the process is started using the first month of historical production data and then an update frequency of one month is used. The amount of observed production data and corresponding number of models used in the continuous updating process are presented in **Table 15**.

Table 15—Continuous process setup for Experiment 5

Update	Duration	Number of Observed Measurements	Number of Simulation Models in the Chain
1st	1 month	12	1,200
2nd	1 month	24	1,800
3rd	1 month	36	1,400
4th	1 month	48	2,200
5th	1 month	60	1,800
6th	1 month	72	1,600
7th	1 month	84	2,000
8th	1 month	96	2,000
9th	1 month	108	2,000
10th	1 month	120	2,000
11th	1 month	132	363

3.6.2 Experiment Results

A noticeable difference between the time-trace of objective function value of this experiment (**Fig. 31**) and previous experiments is that the prior term has bigger contribution relative to the likelihood term. This reflects the effects of having fewer observed data points, as well as, the new formulation of the likelihood (Eq. 13). In other words, at this early stage of the process, the posterior represents a state of equilibrium between forces that penalize deviation from the prior mean more than they penalize deviation from the observed data. If the formal expression of the likelihood function was used (Eq. 5), the same effect of the posterior having a stronger relationship with the prior than the likelihood would be present but less emphasized.

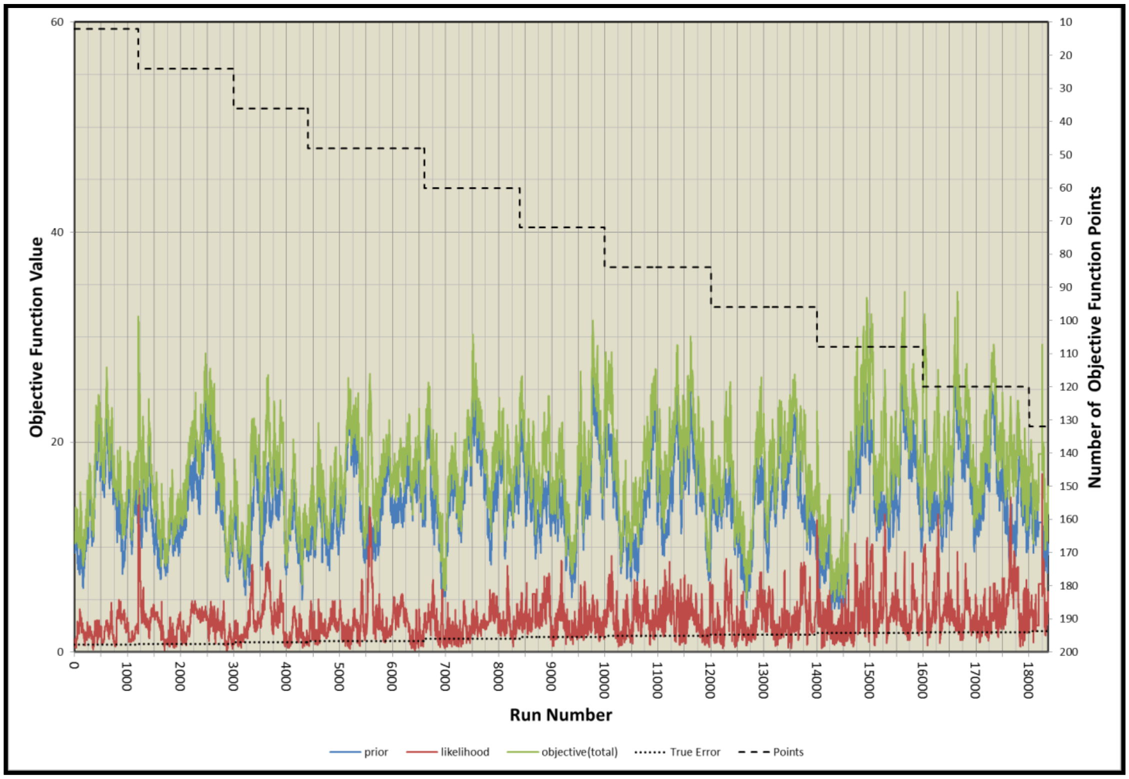

Fig. 31—Time-trace plot of Experiment 5 showing the objective function value (green), the likelihood contribution (red), the prior contribution (blue), the number of observed data points included-reverse scale (bold dashed black), and the objective function value of the noisy measurements (dotted black)

Another difference in this experiment is higher values of acceptance rate. The acceptance rates range from 0.879 to 0.569 (**Table 16**). As the number of observed data points is small and the new formulation the likelihood reduces the sensitivity of acceptance to changes in the likelihood, these high acceptance rates are expected.

The objective function time-trace shows a white noise behavior indicating well mixing across all updates. No noticeable differences in objective function values across all the updates indicating there is less significance attributed to the information provided in the likelihood relative to the prior contribution at these early stages of project life.

Table 16—Acceptance ratio and summary statistics of objective function values for Experiment 5

Update	Acceptance Ratio	Mean Objective Function Value	Minimum Objective Function Value	Maximum Objective Function Value
1st	0.818	16	8	27
2nd	0.863	17	7	32
3th	0.569	15	6	26
4th	0.868	17	10	27
5th	0.879	18	6	30
6th	0.853	18	7	32
7th	0.822	18	8	30
8th	0.823	17	5	26
9th	0.809	18	5	34
10th	0.801	20	12	34
11th	0.658	16	10	29

The cumulative oil production forecasts (**Fig. 32**) do not show a clear trend of shift as in Experiment 4. This could be attributed to the fact that during those early updates, the prior is dominating the posterior and the incremental information added to the process through the observed production data is not sufficient enough. This suggests that the amount of added observed data during the first seven months of production did not have a noticeable impact on the definition of the posterior. Thus, differences in the cumulative oil production forecasts generated during those seven updates might be attributed to estimate errors more than reflecting actual change in the posterior.

Consequently, models from previous updates can be used as samples belonging to the current posterior despite the differences in likelihood function definition. Mixing models from previous updates with models from the current update should reduce estimate errors under the assumption that changes in the likelihood function do not have considerable impact on the posterior. As more observed data are being added, the role the likelihood contribution plays in shaping the posterior will get bigger. The ability to use previous models to estimate posterior diminish with time. Having more frequent updates would, probably, enable the use of more previous models, as the incremental impact on the posterior would be smaller. The question of how many previous models could be included in the current posterior is specific to individual problem. It depends on the relationship between the prior and likelihood, as well as, the assumptions made for uncertain parameters and observed data. One suggestion is to monitor statistics of individual chains and lump samples that belong to distributions with similar statistics.

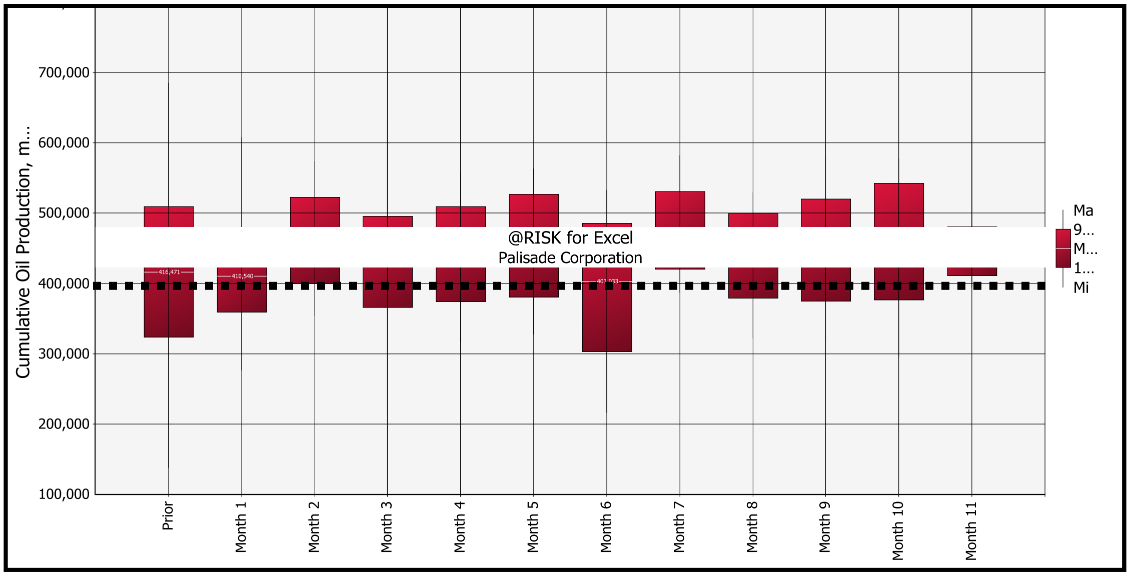

Fig. 32—Box plot for the cumulative oil production forecasts for Experiment 5 showing truth case (dotted black)

Table 17 presents a summarized statistic for the cumulative oil production distributions.

Table 17—Summary statistics of cumulative oil production for the chains in Experiment 5

Chain	Mean	S.D.	P10	P90
Prior	416,471	72,228	323,840	509,022
1st	410,539	41,102	359,110	464,160
2nd	459,056	45,394	399,553	522,253
3rd	430,841	50,493	366,114	495,520
4th	443,669	49,875	374,238	509,057
5th	455,147	53,821	380,252	526,793
6th	403,033	68,178	303,344	485,412
7th	470,902	41,299	419,983	530,664
8th	445,151	44,947	379,243	499,158
9th	447,154	53,617	375,233	520,418
10th	468,462	62,369	376,377	542,406
11th	441,187	36,905	414,677	525,175

Appendix D provides detailed statistics on the results of the cumulative oil production forecasts and posterior uncertain parameters for Experiment 5.

4. DISCUSSION OF RESULTS

4.1 Introduction

Statistics is the natural habitat of uncertainty and probability theory. Bayesian statistics provides an excellent framework to handle uncertainty quantification in reservoir engineering problems as it naturally accommodates the integration of new observations and provides updated characterizations of uncertainty reflecting current levels of understanding. Other methods that base uncertainty quantification on one or multiple history matched models are not guaranteed to produce accurate descriptions of uncertainty. In reservoir engineering application of Bayes' theory, the quality of the estimated production forecast distribution is determined by how well the posterior function is formulated and how well the process is sampling the posterior. Accurate formulation of the posterior includes proper parameterization of the uncertainty, a prior definition that accurately characterizes the uncertainty of these parameters and how they are correlated, and a likelihood function that provides for an accurate evaluation of the likelihood of samples to produce the observation. The sampling quality depends on the ability to perform a thorough exploration of the parameter space and the criteria used for accepting samples.

4.2 Validation of Results

In this work, 18 parameters are chosen to represent the uncertain space and one sample of the posterior distribution is known beforehand, per the synthetic experiment design. Because of the large size of parameter space and the complex relationship between uncertain parameters and observed measurements, it is difficult to evaluate whether posterior estimates are in close agreement with the population posterior. Moreover, in real applications, no truth case values are provided. This makes the problem of validating results even more complicated. Despite the difficulties, there are few metrics that can be used as guidelines for ensuring the quality of production forecasts.

First, one has to continue observing the chain for signs of convergence to ensure that samples represent the posterior distributions rather than some other transient distribution. As discussed, time-trace plots and sub chain statistics provide a good measure of stationarity.

Second, updated forecast distributions that fall within the range of previous distributions provide indication of adequate characterization of uncertainty. Narrowing ranges of distributions is a consequence of reduced uncertainty in the likelihood as more observed data are included. It also implies that a proper job of parameterization and building a prior model was done. Forecast distributions that shift with time indicate either sampling errors or poor definition of prior. Poor definition of the prior could be due to parameterization, distribution means being too far from the true reservoir characterization, narrow variances that underestimate uncertainties, or lack of accurate description of the correlation between parameters.

4.3 Likelihood Function Change

As mentioned before, likelihood formulation has a consequential impact on the posterior distribution. The function of likelihood in the Bayes process is to provide a fair evaluation of the likelihood of a sample to explain the observation. This research shows that when the number of observed data points in the likelihood increases, the acceptance criteria become very sensitive to changes in the likelihood values. Consequently, candidate models with slightly and insignificantly lower average errors will have very little chances of being accepted. This has a great impact on the convergence of the chain as has been demonstrated in Experiment 3 (see Sec. 3.4.2). Additionally, it questions the capability of this formulation of the likelihood (Eq. 5—see Sec. 2.5.3) to provide fair evaluation of the samples when number of observations is large. As per the example mentioned, minor changes as much as 0.2 psi per point of observed pressure measurement can reduce the model chances of acceptance to less than one percent.

The likelihood function as formulated in Eq. 5 assumes no spatial or temporal correlation between observed measurements. It is well established that some level of spatial and temporal correlation exists between observed measurements exist and that it could have significant impact on the likelihood (see Sec. 2.5.4). As the number of observed measurements increases and simulation errors around measurements are assumed independent, small changes in history-match quality would yield extremely larger changes in likelihood function value. Additionally, the formulation of posterior function as in Eq. 6 provides equal treatment to the uncertain parameters and observed measurement points when it comes to calculating the probability of accepting the candidate model. This implicitly implies that one observed measurement exerts the same amount of force on shaping the posterior distribution as a regional porosity or permeability multiplier. Localization of observed measurements is not modeled as well.

The simplistic assumptions made above exaggerate the role the likelihood function plays in shaping the posterior and make the process over sensitive to insignificant changes in measurement errors. As the number of observed measurements increases, the implications of this exaggeration become more severe. The consequence of this is a bias evaluation of simulation models that result in unreasonably strict acceptance criteria. This, in turn, results in a slow convergence and poor mixing.

In this research, the definition of the likelihood function is changed (Eq. 13) to reduce the high sensitivity of likelihood to subtle changes in history-match quality. The goal behind this change is to provide this Bayesian model updating process with a likelihood function that reduce this high sensitivity to measurement errors while retaining the value more observation adds to updating the posterior. The approach followed was empirical. The new form was shown to produce reasonable acceptance probabilities for the range of observed measurements used in this experiment (see Sec. 3.5.1). Additionally, results of experiments four and five show that the proposed formulation produced chains with faster convergence rates, better mixing, and more accurate quantification of the uncertainty.

4.4 Parameter Space Exploration

Analysis of posterior distribution of parameters indicates that the search algorithm does not span the entire parameter space within one update cycle. Models from different update cycles cannot be always mixed to represent the posterior when they have significantly different likelihood functions. Accurate representation of posterior requires efficient exploration of the parameter space given the allocated time and resources. Replacing the random-walk code with more rigorous sampling methods could improve the process. Additionally, methods that provide for cheaper and faster likelihood evaluation could be used to speed up the process.

4.5 Continuous Bayesian Modeling

Typical applications of Bayesian statistics implies that once a posterior distribution is established, it should be used as a prior distribution for subsequent updates. In this research, the initial definition of the prior is retained throughout the updating process. As mentioned above, one update cycle is not sufficient enough to fully investigate the parameter space and sample the posterior distribution. Thus, updating the posterior definition after each cycle might result in underestimation of the uncertainty and produce posteriors distribution that does not accurately characterize the probabilities of forecasted outputs. This problem should be looked at as a continuous chain that samples the posterior distribution. The continuous updating process provides a better environment for further investigation of the parameter space. Additionally, it integrates measurements in the process to generate updated posteriors reflecting the current knowledge of the reservoir. A way of mixing these models, which are evaluated at different likelihood functions, should be investigated to generate more accurate posterior estimates.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Conclusions

- The continuous model updating study yielded results that bracket the truth case with uncertainty ranges that narrow over time, demonstrating the capability of MCMC to handle continuous model updating for reservoirs with complex features (i.e., natural fractures and three-phase flow).
- The definition of the likelihood function and the number of points included has a significant impact on the convergence of the chain and forecast distribution. When a large number of points are included in the likelihood function, the Metropolis-Hasting acceptance criteria becomes extremely sensitive to minor changes in the likelihood function, resulting in low acceptance rates. This leads to limiting the sampling of posterior to a subset of the true distribution as more models are being unfairly rejected.
- Despite the change in the likelihood's definition across updates, chains show signs of faster convergence rates and smaller burn-in periods as the process advances.
- Analysis of the posterior distributions of uncertain parameters suggests that, for the problem studied, the iterations performed during one update

cycle of fixed chain length was not sufficient to explore the entire parameter space. Mixing models from different update periods will likely result in a more accurate posterior, as this will increase the sampling size.

5.2 Recommendations for Future Work

Additional areas for improvement to this work should focus on enhancing the application of MCMC in reservoir model updating and uncertainty quantification for real-time applications. Some of these areas for improvements include:

1. Changing how the prior model is defined to more rigorous definition that honors geostatistics and spatial correlation between parameters rather than a simplistic independent regional property multiplier.
2. Investigate further the effect of likelihood formulation on the quality of posterior distribution. It would be useful to estimate the correlation factors between observed measurements and use a likelihood formulation that honors these dependencies.
3. In this study, only shut-in pressures and water production rates were included in the likelihood function. It would be useful to test how including all performance data could impact the process.
4. The use of more aggressive search algorithm for thorough and faster exploration of the parameter space. Adaptive chains that analyze a set of previous models to propose the next model in the chain is a promising area of improvement. The use of reduced model proxies or other cheap

alternatives for the evaluation of likelihood can speed up the process allowing for better sampling of the parameter space in a shorter time and with lower computational requirements.

5. Investigate ways to utilize models from previous updates for improving the estimate of the posterior either through importance sampling or by investigating a cheap way of re-evaluating existing models using a different likelihood function.

NOMENCLATURE

C	=Normalization constant
C_D	=Covariance matrix
CDF	=Cumulative density function
CLRM	=Closed-loop reservoir management
$d_{obs(i)}$	=Observed value of measurement
DFP	=Davidson-Fletcher-Powell
DPDP	=Dual-porosity dual-permeability
EDA	=Estimation of distribution algorithm
EnKF	=Ensemble Kalman-filter
$f(d_{obs}\|M)$	=Likelihood function for model parameters given the observation
$f(M)$	=Prior distribution for model parameters
$f(M\|d_{obs})$	=Posterior distribution of model parameters
FWL	=Free water level, L, ft
$g_{M(i)}$	=Simulated value of measurement
GA	=Genetic algorithms
log Kh	=Horizontal permeability, L^2, md
log Kv	=Vertical permeability, L^2, md
$l(X\|Y)$	=Likelihood
LMAP	=Linearization about maximum a posteriori

$\log m_{ki}$	=Log of permeability multiplier value
$m_{\emptyset i}$	=Uncertain porosity multiplier value
$M^{t=1}$	=Current reservoir simulation model in the chain
$M^{t=2}$	=Proposed reservoir simulation model
MAP	=Maximum a posteriori
MCMC	=Markov chain Monte Carlo
M-H	=Metropolis-Hasitng algorithm
ML	=Maximum Likelihood
n	=Number of observed measurements
NPV	=Net present value
$O(M)$	=Objective function value of reservoir simulation model
$p(X)$	=Prior
$p(X\|Y)$	=Posterior
pdf	=Probability density function
PVT	=Pressure, volume and temperature relationship
RML	=Randomized maximum likelihood
RTAM	=Real time asset management
SCAL	=Special core analysis laboratory
TVDSS	=Sub-sea true vertical depth, L, ft
X_t	=Current state in the chain
X_{t+1}	=Next state in the chain
α	=Probability of acceptance

$\mu_{\log k}$ =Mean of log permeability multiplier prior distribution

$\mu_{\emptyset}$ =Mean of porosity multiplier prior distribution

$\sigma_{\log k}$ =Standard deviation of log permeability multiplier prior distribution

$\sigma_{\emptyset}$ =Standard deviation of porosity multiplier prior distribution

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APPENDIX A

A.1 ECLIPSE Black-Oil Simulation PVT and Initialization Data

```
PVTW                    -- Generated : Petrel
   3118.3   1.0207   2E-006    0.4     0 /


PVTO                    -- Generated : Petrel
    0.222     400    1.2379   0.7784
   758.33   1.2303   0.81086
   1116.7   1.2228   0.84467
     1475   1.2153   0.87988
   1833.3   1.2078   0.91657
   2191.7   1.2004   0.95479
     2550   1.1931   0.9946
   2908.3   1.1857   1.0361
   3266.7   1.1785   1.0793
     3625   1.1713   1.1243
   3983.3   1.1641   1.1711
   4341.7   1.1569   1.22
     4700   1.1498   1.2708
   5058.3   1.1428   1.3238
   5416.7   1.1358   1.379
     5775   1.1288   1.4365
   6133.3   1.1219   1.4964
   6491.7   1.115    1.5588
     6850   1.1082   1.6238
   7208.3   1.1014   1.6915
   7566.7   1.0947   1.7621
     7925   1.0879   1.8355
```

8283.3	1.0813	1.9121	
8641.7	1.0746	1.9918	
9000	1.0681	2.0748 /	
0.287	600	1.2726	0.6955
950	1.265	0.72381	
1300	1.2574	0.75328	
1650	1.2499	0.78394	
2000	1.2424	0.81585	
2350	1.235	0.84906	
2700	1.2276	0.88362	
3050	1.2202	0.91959	
3400	1.2129	0.95703	
3750	1.2056	0.99598	
4100	1.1984	1.0365	
4450	1.1912	1.0787	
4800	1.1841	1.1226	
5150	1.177	1.1683	
5500	1.17	1.2159	
5850	1.163	1.2654	
6200	1.156	1.3169	
6550	1.1491	1.3705	
6900	1.1422	1.4263	
7250	1.1354	1.4843	
7600	1.1286	1.5448	
7950	1.1218	1.6077	
8300	1.1151	1.6731	
8650	1.1084	1.7412	
9000	1.1018	1.8121 /	
0.347	800	1.3012	0.636
1141.7	1.2936	0.66126	
1483.3	1.286	0.68753	
1825	1.2785	0.71483	
2166.7	1.271	0.74322	

2508.3	1.2636	0.77274	
2850	1.2562	0.80344	
3191.7	1.2489	0.83535	
3533.3	1.2416	0.86853	
3875	1.2343	0.90302	
4216.7	1.2271	0.93889	
4558.3	1.2199	0.97618	
4900	1.2128	1.015	
5241.7	1.2057	1.0553	
5583.3	1.1987	1.0972	
5925	1.1917	1.1408	
6266.7	1.1847	1.1861	
6608.3	1.1778	1.2332	
6950	1.1709	1.2822	
7291.7	1.164	1.3331	
7633.3	1.1572	1.386	
7975	1.1505	1.4411	
8316.7	1.1437	1.4983	
8658.3	1.1371	1.5578	
9000	1.1304	1.6197 /	
0.402	1000	1.3259	0.584
1333.3	1.3183	0.60662	
1666.7	1.3108	0.63011	
2000	1.3033	0.65452	
2333.3	1.2959	0.67987	
2666.7	1.2885	0.7062	
3000	1.2812	0.73355	
3333.3	1.2739	0.76197	
3666.7	1.2666	0.79148	
4000	1.2594	0.82213	
4333.3	1.2522	0.85397	
4666.7	1.245	0.88705	
5000	1.2379	0.92141	

5333.3	1.2309	0.95709	
5666.7	1.2239	0.99416	
6000	1.2169	1.0327	
6333.3	1.2099	1.0727	
6666.7	1.203	1.1142	
7000	1.1962	1.1574	
7333.3	1.1894	1.2022	
7666.7	1.1826	1.2488	
8000	1.1758	1.2971	
8333.3	1.1691	1.3474	
8666.7	1.1625	1.3995	
9000	1.1558	1.4537 /	
0.455	1200	1.3486	0.5356
1525	1.3411	0.55582	
1850	1.3336	0.5768	
2175	1.3262	0.59857	
2500	1.3188	0.62116	
2825	1.3115	0.6446	
3150	1.3042	0.66894	
3475	1.297	0.69418	
3800	1.2898	0.72039	
4125	1.2826	0.74758	
4450	1.2754	0.77579	
4775	1.2684	0.80508	
5100	1.2613	0.83546	
5425	1.2543	0.867	
5750	1.2473	0.89972	
6075	1.2404	0.93368	
6400	1.2335	0.96893	
6725	1.2266	1.0055	
7050	1.2198	1.0434	
7375	1.213	1.0828	
7700	1.2063	1.1237	

8025	1.1996	1.1661	
8350	1.1929	1.2101	
8675	1.1862	1.2558	
9000	1.1797	1.3032 /	
0.507	1400	1.3705	0.4918
1716.7	1.3631	0.50988	
2033.3	1.3557	0.52862	
2350	1.3483	0.54805	
2666.7	1.341	0.5682	
2983.3	1.3338	0.58909	
3300	1.3265	0.61074	
3616.7	1.3193	0.63319	
3933.3	1.3122	0.65647	
4250	1.3051	0.6806	
4566.7	1.298	0.70562	
4883.3	1.291	0.73155	
5200	1.284	0.75845	
5516.7	1.277	0.78633	
5833.3	1.2701	0.81523	
6150	1.2632	0.8452	
6466.7	1.2564	0.87627	
6783.3	1.2496	0.90848	
7100	1.2428	0.94187	
7416.7	1.2361	0.9765	
7733.3	1.2294	1.0124	
8050	1.2227	1.0496	
8366.7	1.2161	1.0882	
8683.3	1.2095	1.1282	
9000	1.2029	1.1697 /	
0.56	1600	1.3927	0.4542
1908.3	1.3854	0.47045	
2216.7	1.378	0.48728	
2525	1.3708	0.50471	

2833.3	1.3635	0.52277	
3141.7	1.3563	0.54147	
3450	1.3492	0.56084	
3758.3	1.3421	0.58091	
4066.7	1.335	0.60169	
4375	1.3279	0.62321	
4683.3	1.3209	0.64551	
4991.7	1.314	0.6686	
5300	1.307	0.69252	
5608.3	1.3001	0.7173	
5916.7	1.2933	0.74296	
6225	1.2864	0.76954	
6533.3	1.2797	0.79707	
6841.7	1.2729	0.82558	
7150	1.2662	0.85512	
7458.3	1.2595	0.88571	
7766.7	1.2529	0.91739	
8075	1.2462	0.95021	
8383.3	1.2397	0.98421	
8691.7	1.2331	1.0194	
9000	1.2266	1.0559 /	
0.615	1800	1.4163	0.4238
2100	1.409	0.43854	
2400	1.4018	0.4538	
2700	1.3946	0.46959	
3000	1.3874	0.48593	
3300	1.3803	0.50283	
3600	1.3732	0.52033	
3900	1.3662	0.53843	
4200	1.3592	0.55717	
4500	1.3522	0.57655	
4800	1.3452	0.59661	
5100	1.3383	0.61737	

5400	1.3315	0.63884	
5700	1.3246	0.66107	
6000	1.3178	0.68407	
6300	1.311	0.70787	
6600	1.3043	0.7325	
6900	1.2976	0.75798	
7200	1.291	0.78435	
7500	1.2843	0.81164	
7800	1.2777	0.83988	
8100	1.2712	0.8691	
8400	1.2646	0.89934	
8700	1.2582	0.93063	
9000	1.2517	0.96301 /	
0.673	2000	1.4422	0.4003
2291.7	1.435	0.41383	
2583.3	1.4278	0.42783	
2875	1.4207	0.44229	
3166.7	1.4136	0.45724	
3458.3	1.4066	0.4727	
3750	1.3995	0.48868	
4041.7	1.3925	0.5052	
4333.3	1.3856	0.52229	
4625	1.3787	0.53994	
4916.7	1.3718	0.5582	
5208.3	1.3649	0.57707	
5500	1.3581	0.59658	
5791.7	1.3514	0.61675	
6083.3	1.3446	0.6376	
6375	1.3379	0.65916	
6666.7	1.3312	0.68144	
6958.3	1.3246	0.70448	
7250	1.318	0.7283	
7541.7	1.3114	0.75292	

7833.3 1.3048 0.77838

8125 1.2983 0.8047

8416.7 1.2918 0.8319

8708.3 1.2854 0.86003

9000 1.279 0.8891 /

0.736 2200 1.4716 0.3825

2483.3 1.4645 0.39506

2766.7 1.4574 0.40803

3050 1.4503 0.42142

3333.3 1.4433 0.43525

3616.7 1.4363 0.44954

3900 1.4293 0.4643

4183.3 1.4224 0.47954

4466.7 1.4155 0.49528

4750 1.4086 0.51154

5033.3 1.4018 0.52833

5316.7 1.395 0.54568

5600 1.3882 0.56359

5883.3 1.3815 0.58209

6166.7 1.3748 0.6012

6450 1.3681 0.62094

6733.3 1.3615 0.64132

7016.7 1.3549 0.66237

7300 1.3483 0.68412

7583.3 1.3417 0.70657

7866.7 1.3352 0.72977

8150 1.3288 0.75373

8433.3 1.3223 0.77847

8716.7 1.3159 0.80402

9000 1.3095 0.83042 /

0.804 2400 1.5058 0.3682

2675 1.4987 0.37993

2950 1.4917 0.39203

3225	1.4846	0.40451	
3500	1.4776	0.41739	
3775	1.4707	0.43068	
4050	1.4638	0.4444	
4325	1.4569	0.45855	
4600	1.45	0.47316	
4875	1.4432	0.48822	
5150	1.4364	0.50377	
5425	1.4296	0.51982	
5700	1.4229	0.53637	
5975	1.4162	0.55345	
6250	1.4095	0.57108	
6525	1.4029	0.58927	
6800	1.3963	0.60803	
7075	1.3897	0.62739	
7350	1.3832	0.64738	
7625	1.3767	0.66799	
7900	1.3702	0.68927	
8175	1.3637	0.71122	
8450	1.3573	0.73387	
8725	1.3509	0.75724	
9000	1.3446	0.78135 /	
0.841	2500	1.5251	0.3612
2770.8	1.518	0.37253	
3041.7	1.511	0.38421	
3312.5	1.504	0.39625	
3583.3	1.497	0.40868	
3854.2	1.4901	0.42149	
4125	1.4832	0.43471	
4395.8	1.4763	0.44834	
4666.7	1.4694	0.4624	
4937.5	1.4626	0.4769	
5208.3	1.4558	0.49185	

5479.2	1.4491	0.50728	
5750	1.4424	0.52318	
6020.8	1.4357	0.53959	
6291.7	1.429	0.55651	
6562.5	1.4224	0.57396	
6833.3	1.4158	0.59196	
7104.2	1.4092	0.61052	
7375	1.4027	0.62966	
7645.8	1.3962	0.64941	
7916.7	1.3897	0.66977	
8187.5	1.3833	0.69077	
8458.3	1.3769	0.71243	
8729.2	1.3705	0.73477	
9000	1.3641	0.75781 /	
0.85	2523.5	1.5299	0.3595
2793.4	1.5228	0.37073	
3063.2	1.5158	0.38231	
3333.1	1.5088	0.39426	
3602.9	1.5018	0.40657	
3872.8	1.4949	0.41928	
4142.6	1.488	0.43238	
4412.5	1.4811	0.44588	
4682.3	1.4743	0.45981	
4952.2	1.4674	0.47418	
5222	1.4607	0.48899	
5491.9	1.4539	0.50427	
5761.8	1.4472	0.52002	
6031.6	1.4405	0.53627	
6301.5	1.4339	0.55302	
6571.3	1.4272	0.5703	
6841.2	1.4206	0.58812	
7111	1.4141	0.60649	
7380.9	1.4075	0.62544	

7650.7 1.401 0.64498

7920.6 1.3946 0.66513

8190.4 1.3881 0.68591

8460.3 1.3817 0.70734

8730.1 1.3753 0.72944

9000 1.369 0.75222 /

0.88 2600 1.5462 0.3435

2866.7 1.5391 0.3541

3133.3 1.5321 0.36503

3400 1.5251 0.3763

3666.7 1.5182 0.38792

3933.3 1.5112 0.39989

4200 1.5043 0.41223

4466.7 1.4975 0.42496

4733.3 1.4906 0.43807

5000 1.4838 0.4516

5266.7 1.477 0.46553

5533.3 1.4703 0.4799

5800 1.4636 0.49472

6066.7 1.4569 0.50999

6333.3 1.4503 0.52573

6600 1.4436 0.54196

6866.7 1.437 0.55869

7133.3 1.4305 0.57593

7400 1.4239 0.59371

7666.7 1.4174 0.61203

7933.3 1.411 0.63093

8200 1.4045 0.6504

8466.7 1.3981 0.67048

8733.3 1.3917 0.69117

9000 1.3854 0.71251 /

0.963 2800 1.5947 0.3224

3058.3 1.5876 0.33204

3316.7	1.5806	0.34196	
3575	1.5736	0.35218	
3833.3	1.5667	0.36271	
4091.7	1.5597	0.37355	
4350	1.5528	0.38471	
4608.3	1.546	0.39621	
4866.7	1.5391	0.40805	
5125	1.5323	0.42025	
5383.3	1.5256	0.43281	
5641.7	1.5188	0.44574	
5900	1.5121	0.45907	
6158.3	1.5054	0.47279	
6416.7	1.4987	0.48692	
6675	1.4921	0.50147	
6933.3	1.4855	0.51646	
7191.7	1.4789	0.53189	
7450	1.4724	0.54779	
7708.3	1.4659	0.56416	
7966.7	1.4594	0.58102	
8225	1.4529	0.59839	
8483.3	1.4465	0.61627	
8741.7	1.4401	0.63469	
9000	1.4338	0.65366 /	
1.056	3000	1.6531	0.302
3250	1.646	0.31073	
3500	1.639	0.31971	
3750	1.632	0.32896	
4000	1.625	0.33847	
4250	1.618	0.34825	
4500	1.6111	0.35832	
4750	1.6042	0.36868	
5000	1.5973	0.37934	
5250	1.5905	0.3903	

5500	1.5837	0.40159	
5750	1.5769	0.4132	
6000	1.5702	0.42514	
6250	1.5634	0.43743	
6500	1.5567	0.45008	
6750	1.5501	0.46309	
7000	1.5434	0.47648	
7250	1.5368	0.49026	
7500	1.5303	0.50443	
7750	1.5237	0.51901	
8000	1.5172	0.53402	
8250	1.5107	0.54946	
8500	1.5042	0.56534	
8750	1.4978	0.58168	
9000	1.4914	0.5985 /	
1.16	3200	1.723	0.2822
3441.7	1.7159	0.29008	
3683.3	1.7088	0.29819	
3925	1.7017	0.30651	
4166.7	1.6947	0.31508	
4408.3	1.6876	0.32388	
4650	1.6807	0.33292	
4891.7	1.6737	0.34222	
5133.3	1.6668	0.35178	
5375	1.6599	0.36161	
5616.7	1.653	0.37171	
5858.3	1.6462	0.38209	
6100	1.6394	0.39277	
6341.7	1.6326	0.40374	
6583.3	1.6258	0.41502	
6825	1.6191	0.42661	
7066.7	1.6124	0.43852	
7308.3	1.6057	0.45077	

7550	1.5991	0.46337	
7791.7	1.5925	0.47631	
8033.3	1.5859	0.48961	
8275	1.5793	0.50329	
8516.7	1.5728	0.51735	
8758.3	1.5663	0.5318	
9000	1.5598	0.54665 /	
1.277	3400	1.8051	0.2631
3633.3	1.7979	0.27019	
3866.7	1.7907	0.27748	
4100	1.7835	0.28496	
4333.3	1.7764	0.29264	
4566.7	1.7693	0.30053	
4800	1.7623	0.30863	
5033.3	1.7552	0.31695	
5266.7	1.7482	0.32549	
5500	1.7412	0.33427	
5733.3	1.7343	0.34328	
5966.7	1.7273	0.35253	
6200	1.7204	0.36203	
6433.3	1.7135	0.37179	
6666.7	1.7067	0.38181	
6900	1.6999	0.39211	
7133.3	1.6931	0.40268	
7366.7	1.6863	0.41353	
7600	1.6796	0.42468	
7833.3	1.6729	0.43613	
8066.7	1.6662	0.44788	
8300	1.6595	0.45996	
8533.3	1.6529	0.47236	
8766.7	1.6463	0.48509	
9000	1.6397	0.49817 /	
1.407	3600	1.8974	0.2447

3825	1.8901	0.25106	
4050	1.8828	0.25758	
4275	1.8755	0.26427	
4500	1.8683	0.27114	
4725	1.8611	0.27818	
4950	1.854	0.28541	
5175	1.8468	0.29283	
5400	1.8397	0.30044	
5625	1.8326	0.30824	
5850	1.8255	0.31625	
6075	1.8185	0.32447	
6300	1.8115	0.3329	
6525	1.8045	0.34155	
6750	1.7976	0.35042	
6975	1.7906	0.35952	
7200	1.7837	0.36887	
7425	1.7769	0.37845	
7650	1.77	0.38828	
7875	1.7632	0.39837	
8100	1.7564	0.40872	
8325	1.7496	0.41934	
8550	1.7429	0.43024	
8775	1.7362	0.44141	
9000	1.7295	0.45288 /	
1.554	3800	1.9926	0.2269
4016.7	1.9852	0.23257	
4233.3	1.9778	0.23839	
4450	1.9705	0.24435	
4666.7	1.9632	0.25046	
4883.3	1.9559	0.25673	
5100	1.9486	0.26315	
5316.7	1.9414	0.26973	
5533.3	1.9342	0.27647	

5750	1.927	0.28339	
5966.7	1.9199	0.29047	
6183.3	1.9128	0.29774	
6400	1.9057	0.30518	
6616.7	1.8986	0.31281	
6833.3	1.8915	0.32064	
7050	1.8845	0.32866	
7266.7	1.8775	0.33687	
7483.3	1.8706	0.3453	
7700	1.8636	0.35393	
7916.7	1.8567	0.36278	
8133.3	1.8498	0.37186	
8350	1.8429	0.38116	
8566.7	1.8361	0.39069	
8783.3	1.8293	0.40046	
9000	1.8225	0.41047 /	
1.72	4000	2.0722	0.2099
4208.3	2.0648	0.21494	
4416.7	2.0574	0.22011	
4625	2.0501	0.2254	
4833.3	2.0428	0.23082	
5041.7	2.0355	0.23637	
5250	2.0282	0.24205	
5458.3	2.021	0.24786	
5666.7	2.0138	0.25382	
5875	2.0066	0.25992	
6083.3	1.9994	0.26617	
6291.7	1.9923	0.27257	
6500	1.9852	0.27912	
6708.3	1.9781	0.28583	
6916.7	1.971	0.2927	
7125	1.964	0.29973	
7333.3	1.957	0.30693	

7541.7 1.95 0.31431

7750 1.9431 0.32186

7958.3 1.9361 0.3296

8166.7 1.9292 0.33752

8375 1.9223 0.34563

8583.3 1.9155 0.35394

8791.7 1.9086 0.36245

9000 1.9018 0.37116 /

2.5 5000 2.43 0.18

5166.7 2.4231 0.18345

5333.3 2.4161 0.18697

5500 2.4092 0.19056

5666.7 2.4024 0.19421

5833.3 2.3955 0.19794

6000 2.3887 0.20174

6166.7 2.3818 0.2056

6333.3 2.375 0.20955

6500 2.3682 0.21357

6666.7 2.3615 0.21766

6833.3 2.3547 0.22184

7000 2.348 0.2261

7166.7 2.3413 0.23043

7333.3 2.3346 0.23485

7500 2.328 0.23936

7666.7 2.3213 0.24395

7833.3 2.3147 0.24863

8000 2.3081 0.2534

8166.7 2.3015 0.25826

8333.3 2.2949 0.26321

8500 2.2884 0.26826

8666.7 2.2818 0.27341

8833.3 2.2753 0.27865

9000 2.2688 0.284 /

3.28	6000	2.8	0.16
6125	2.794	0.1623	
6250	2.788	0.16463	
6375	2.782	0.16699	
6500	2.7761	0.16938	
6625	2.7701	0.17182	
6750	2.7642	0.17428	
6875	2.7583	0.17678	
7000	2.7524	0.17932	
7125	2.7465	0.18189	
7250	2.7406	0.1845	
7375	2.7347	0.18715	
7500	2.7288	0.18984	
7625	2.723	0.19256	
7750	2.7172	0.19533	
7875	2.7113	0.19813	
8000	2.7055	0.20097	
8125	2.6997	0.20386	
8250	2.694	0.20678	
8375	2.6882	0.20975	
8500	2.6824	0.21276	
8625	2.6767	0.21582	
8750	2.6709	0.21891	
8875	2.6652	0.22205	
9000	2.6595	0.22524 /	
4	7000	3.1	0.14
7083.3	3.0956	0.14134	
7166.7	3.0911	0.14269	
7250	3.0867	0.14405	
7333.3	3.0823	0.14542	
7416.7	3.0779	0.14681	
7500	3.0735	0.14821	
7583.3	3.0691	0.14963	

7666.7	3.0647	0.15105	
7750	3.0604	0.1525	
7833.3	3.056	0.15395	
7916.7	3.0516	0.15542	
8000	3.0473	0.15691	
8083.3	3.0429	0.1584	
8166.7	3.0386	0.15991	
8250	3.0342	0.16144	
8333.3	3.0299	0.16298	
8416.7	3.0255	0.16454	
8500	3.0212	0.16611	
8583.3	3.0169	0.16769	
8666.7	3.0126	0.16929	
8750	3.0083	0.17091	
8833.3	3.004	0.17254	
8916.7	2.9997	0.17419	
9000	2.9954	0.17585 /	
5.5	9000	3.61	0.12
9010	3.6094	0.12014	
9020	3.6088	0.12027	
9030	3.6081	0.12041	
9040	3.6075	0.12055	
9050	3.6069	0.12069	
9060	3.6063	0.12082	
9070	3.6057	0.12096	
9080	3.605	0.1211	
9090	3.6044	0.12124	
9100	3.6038	0.12138	
9110	3.6032	0.12151	
9120	3.6026	0.12165	
9130	3.602	0.12179	
9140	3.6013	0.12193	
9150	3.6007	0.12207	

```
        9160     3.6001     0.12221
        9170     3.5995     0.12235
        9180     3.5989     0.12249
        9190     3.5982     0.12263
        9200     3.5976     0.12277
        9210      3.597     0.12291
        9220     3.5964     0.12305
        9230     3.5958     0.12319
        9240     3.5952     0.12333 /
 /

PVDG                          -- Generated : Petrel
        14.7       230     0.0112
         730       4.1     0.0127
         930       3.1     0.0134
        1130      2.52     0.0141
        1330       2.1     0.0148
        1530       1.8     0.0155
        1730     1.583     0.0162
        1930     1.406     0.0169
        2130     1.268     0.0177
        2330     1.158     0.0184
        2530     1.069     0.0191
        2730     0.995     0.0199
        2930     0.935     0.0206
        3130     0.884     0.0213
        3330      0.84     0.0221
        3530     0.802     0.0228
        3730      0.77     0.0236
        3930     0.741     0.0243
        4130     0.716      0.025
        4330     0.693     0.0258
        4530     0.673     0.0265
```

```
        4730      0.655     0.0272
        4930      0.638      0.028
        5930       0.58     0.0283
        6930      0.534      0.0285
        7930        0.5     0.029
        8930       0.47     0.0295
        9930       0.45     0.0297
 /

DENSITY                        -- Generated : Petrel
      52.341     71.822    0.060943 /

FILEUNIT                       -- Generated : Petrel
 FIELD /
```

A.2 ECLIPSE Black-Oil Simulation SCAL Data for Matrix

```
SWOF                          -- Generated : Petrel
      0.0675          0          1          0
       0.177      9E-005      0.975          0
         0.2   0.003859    0.80361          0
       0.208    0.00517      0.744          0
       0.242     0.0163      0.545          0
       0.276      0.032      0.393          0
        0.31     0.0516      0.277          0
       0.343     0.0748      0.191          0
       0.377      0.101      0.128          0
       0.411      0.131     0.0832          0
       0.445      0.163     0.0529          0
       0.478      0.198     0.0321          0
       0.512      0.236     0.0185          0
```

0.546	0.277	0.0101	0
0.58	0.32	0.00514	0
0.6	0.34647	0.0035165	0
0.614	0.365	0.00238	0
0.647	0.413	0.00098	0
0.681	0.463	0.00034	0
0.715	0.516	0.0001	0
0.749	0.57	2E-005	0
0.782	0.627	0	0
0.816	0.686	0	0
0.85	0.747	0	0
1	1	0	0

/

SGOF -- Generated : Petrel

0	0	1	0
0.03	0	1	0
0.0588	0	0.87462	0
0.0882	0	0.75922	0
0.118	1E-005	0.65563	0
0.147	4E-005	0.56303	0
0.196	0.00025	0.43093	0
0.245	0.0009	0.32354	0
0.294	0.0025	0.23762	0
0.343	0.00587	0.17004	0
0.392	0.01214	0.11802	0
0.4	0.013898	0.11164	0
0.441	0.02291	0.07897	0
0.49	0.04023	0.05052	0
0.539	0.06673	0.03055	0
0.588	0.10566	0.01718	0
0.637	0.16095	0.00877	0
0.686	0.23727	0.00391	0

```
     0.711     0.28501     0.00243          0
     0.735     0.34015     0.00142          0
     0.745     0.36445     0.00112          0
     0.755     0.39015     0.00087          0
     0.765     0.41725     0.00066          0
       0.8     0.61425  0.00032029          0
     0.833         0.8           0          0
     0.933           1           0          0
 /

FILEUNIT                          -- Generated : Petrel
 FIELD /
```

A.3 ECLIPSE Black-Oil Simulation SCAL Data for Fracture

```
SWOF                             -- Generated : Petrel
         0         0         1          0
       0.5       0.5       0.5          0
         1         1         0          0
 /

SGOF                             -- Generated : Petrel
         0         0         1          0
       0.5       0.5       0.5          0
         1         1         0          0
 /

FILEUNIT                          -- Generated : Petrel
 FIELD /
```

APPENDIX B

B.1 True Reservoir Performance Data in Eclipse Black-Oil Simulation Format

```
*FIELD
*DAILY
*IGNORE_MISSING
*UPTIME_FRACTIONS
*UUCRATES
*DAY *MONTH *YEAR *HOUR *MINUTE *SECOND *BHP *WINJ *PRESS *GAS *OIL *WATER *UPTIME
*NAME AAIN0001
1 1 2000 0 0 0    0    0    0    0    0    0    1
1 2 2000 0 0 0    0    0    0    0    0    0    1
1 3 2000 0 0 0    0    0    0    0    0    0    1
1 4 2000 0 0 0    0    0    0    0    0    0    1
1 5 2000 0 0 0    0    0    0    0    0    0    1
1 6 2000 0 0 0    0    0    0    0    0    0    1
1 7 2000 0 0 0    0    0    0    0    0    0    1
1 8 2000 0 0 0    0    0    0    0    0    0    1
1 9 2000 0 0 0    0    0    0    0    0    0    1
1 10 2000 0 0 0   0    0    0    0    0    0    1
1 11 2000 0 0 0   0    0    0    0    0    0    1
1 12 2000 0 0 0   0    0    0    0    0    0    1
1 1 2001 0 0 0    0    0    0    0    0    0    1
1 2 2001 0 0 0    0    0    0    0    0    0    1
1 3 2001 0 0 0    0    0    0    0    0    0    1
1 4 2001 0 0 0    0    0    0    0    0    0    1
1 5 2001 0 0 0    0    0    0    0    0    0    1
1 6 2001 0 0 0    0    0    0    0    0    0    1
1 7 2001 0 0 0    0    0    0    0    0    0    1
```

1 8 2001 0 0 0	0	0	0	0	0	0	1
1 9 2001 0 0 0	0	0	0	0	0	0	1
1 10 2001 0 0 0	0	0	0	0	0	0	1
1 11 2001 0 0 0	0	0	0	0	0	0	1
1 12 2001 0 0 0	0	0	0	0	0	0	1
1 1 2002 0 0 0	0	0	0	0	0	0	1
1 2 2002 0 0 0	0	0	0	0	0	0	1
1 3 2002 0 0 0	0	0	0	0	0	0	1
1 4 2002 0 0 0	0	0	0	0	0	0	1
1 5 2002 0 0 0	0	0	0	0	0	0	1
1 6 2002 0 0 0	0	0	0	0	0	0	1
1 7 2002 0 0 0	0	0	0	0	0	0	1
1 8 2002 0 0 0	0	0	0	0	0	0	1
1 9 2002 0 0 0	0	0	0	0	0	0	1
1 10 2002 0 0 0	0	0	0	0	0	0	1
1 11 2002 0 0 0	0	0	0	0	0	0	1
1 12 2002 0 0 0	0	0	0	0	0	0	1
1 1 2003 0 0 0	0	0	0	0	0	0	1
1 2 2003 0 0 0	0	0	0	0	0	0	1
1 3 2003 0 0 0	0	0	0	0	0	0	1
1 4 2003 0 0 0	0	0	0	0	0	0	1
1 5 2003 0 0 0	0	0	0	0	0	0	1
1 6 2003 0 0 0	0	0	0	0	0	0	1
1 7 2003 0 0 0	0	0	0	0	0	0	1
1 8 2003 0 0 0	0	0	0	0	0	0	1
1 9 2003 0 0 0	0	0	0	0	0	0	1
1 10 2003 0 0 0	0	0	0	0	0	0	1
1 11 2003 0 0 0	0	0	0	0	0	0	1
1 12 2003 0 0 0	0	0	0	0	0	0	1
1 1 2004 0 0 0	0	0	0	0	0	0	1
1 2 2004 0 0 0	0	0	0	0	0	0	1
1 3 2004 0 0 0	0	0	0	0	0	0	1
1 4 2004 0 0 0	0	0	0	0	0	0	1

1 5 2004 0 0 0	0	0	0	0	0	0	1
1 6 2004 0 0 0	0	0	0	0	0	0	1
1 7 2004 0 0 0	0	0	0	0	0	0	1
1 8 2004 0 0 0	0	0	0	0	0	0	1
1 9 2004 0 0 0	0	0	0	0	0	0	1
1 10 2004 0 0 0	0	0	0	0	0	0	1
1 11 2004 0 0 0	0	0	0	0	0	0	1
1 12 2004 0 0 0	0	0	0	0	0	0	1
1 1 2005 0 0 0	0	0	0	0	0	0	1
1 2 2005 0 0 0	0	0	0	0	0	0	1
1 3 2005 0 0 0	0	0	0	0	0	0	1
1 4 2005 0 0 0	0	0	0	0	0	0	1
1 5 2005 0 0 0	0	0	0	0	0	0	1
1 6 2005 0 0 0	0	0	0	0	0	0	1
1 7 2005 0 0 0	0	0	0	0	0	0	1
1 8 2005 0 0 0	0	0	0	0	0	0	1
1 9 2005 0 0 0	0	0	0	0	0	0	1
1 10 2005 0 0 0	0	0	0	0	0	0	1
1 11 2005 0 0 0	0	0	0	0	0	0	1
1 12 2005 0 0 0	0	0	0	0	0	0	1
1 1 2006 0 0 0	0	0	0	0	0	0	1
1 2 2006 0 0 0	0	0	0	0	0	0	1
1 3 2006 0 0 0	0	0	0	0	0	0	1
1 4 2006 0 0 0	0	0	0	0	0	0	1
1 5 2006 0 0 0	0	0	0	0	0	0	1
1 6 2006 0 0 0	0	0	0	0	0	0	1
1 7 2006 0 0 0	0	0	0	0	0	0	1
1 8 2006 0 0 0	0	0	0	0	0	0	1
1 9 2006 0 0 0	0	0	0	0	0	0	1
1 10 2006 0 0 0	0	0	0	0	0	0	1
1 11 2006 0 0 0	0	0	0	0	0	0	1
1 12 2006 0 0 0	0	0	0	0	0	0	1
1 1 2007 0 0 0	2660	9590	2590	0	0	0	1

1 2 2007 0 0 0	2660	9560	2590	0	0	0	1
1 3 2007 0 0 0	2660	9560	2590	0	0	0	1
1 4 2007 0 0 0	2660	9530	2590	0	0	0	1
1 5 2007 0 0 0	2660	9510	2590	0	0	0	1
1 6 2007 0 0 0	2660	9490	2590	0	0	0	1
1 7 2007 0 0 0	2660	9480	2590	0	0	0	1
1 8 2007 0 0 0	2650	9460	2580	0	0	0	1
1 9 2007 0 0 0	2650	9450	2580	0	0	0	1
1 10 2007 0 0 0	2650	9440	2580	0	0	0	1
1 11 2007 0 0 0	2650	9430	2580	0	0	0	1
1 12 2007 0 0 0	2650	9420	2580	0	0	0	1
1 1 2008 0 0 0	2650	9410	2580	0	0	0	1
1 2 2008 0 0 0	2640	9410	2570	0	0	0	1
1 3 2008 0 0 0	2640	9410	2570	0	0	0	1
1 4 2008 0 0 0	2640	9410	2570	0	0	0	1
1 5 2008 0 0 0	2640	9400	2570	0	0	0	1
1 6 2008 0 0 0	2640	9400	2570	0	0	0	1
1 7 2008 0 0 0	2630	9400	2570	0	0	0	1
1 8 2008 0 0 0	2630	9400	2560	0	0	0	1
1 9 2008 0 0 0	2630	9400	2560	0	0	0	1
1 10 2008 0 0 0	2630	9400	2560	0	0	0	1
1 11 2008 0 0 0	2620	9400	2560	0	0	0	1
1 12 2008 0 0 0	2620	9410	2550	0	0	0	1
1 1 2009 0 0 0	2620	9410	2550	0	0	0	1
1 2 2009 0 0 0	2620	9410	2550	0	0	0	1
1 3 2009 0 0 0	2620	9410	2550	0	0	0	1
1 4 2009 0 0 0	2610	9410	2550	0	0	0	1
1 5 2009 0 0 0	2610	9410	2540	0	0	0	1
1 6 2009 0 0 0	2610	9410	2540	0	0	0	1
1 7 2009 0 0 0	2610	9410	2540	0	0	0	1
1 8 2009 0 0 0	2600	9410	2540	0	0	0	1
1 9 2009 0 0 0	2600	9410	2530	0	0	0	1
1 10 2009 0 0 0	2600	9410	2530	0	0	0	1

1 11 2009 0 0 0	2600	9410	2530	0	0	0	1
1 12 2009 0 0 0	2590	9410	2530	0	0	0	1
1 1 2010 0 0 0	2590	9410	2520	0	0	0	1
1 2 2010 0 0 0	2590	9410	2520	0	0	0	1
1 3 2010 0 0 0	2590	9410	2520	0	0	0	1
1 4 2010 0 0 0	2590	9410	2520	0	0	0	1
1 5 2010 0 0 0	2580	9410	2520	0	0	0	1
1 6 2010 0 0 0	2580	9410	2510	0	0	0	1
1 7 2010 0 0 0	2580	9410	2510	0	0	0	1
1 8 2010 0 0 0	2580	9410	2510	0	0	0	1
1 9 2010 0 0 0	2570	9410	2510	0	0	0	1
1 10 2010 0 0 0	2570	9410	2500	0	0	0	1
1 11 2010 0 0 0	2570	9410	2500	0	0	0	1
1 12 2010 0 0 0	2570	9410	2500	0	0	0	1
1 1 2011 0 0 0	2560	9410	2500	0	0	0	1
1 2 2011 0 0 0	2560	9410	2500	0	0	0	1
1 3 2011 0 0 0	2560	9420	2490	0	0	0	1
1 4 2011 0 0 0	2560	9420	2490	0	0	0	1
1 5 2011 0 0 0	2550	9420	2490	0	0	0	1
1 6 2011 0 0 0	2550	9420	2490	0	0	0	1
1 7 2011 0 0 0	2550	9420	2480	0	0	0	1
1 8 2011 0 0 0	2550	9420	2480	0	0	0	1
1 9 2011 0 0 0	2550	9420	2480	0	0	0	1
1 10 2011 0 0 0	2540	9420	2480	0	0	0	1
1 11 2011 0 0 0	2540	9420	2480	0	0	0	1
1 12 2011 0 0 0	2540	9420	2470	0	0	0	1
*NAME AAIN0002							
1 1 2000 0 0 0	0	0	0	0	0	0	1
1 2 2000 0 0 0	0	0	0	0	0	0	1
1 3 2000 0 0 0	0	0	0	0	0	0	1
1 4 2000 0 0 0	0	0	0	0	0	0	1
1 5 2000 0 0 0	0	0	0	0	0	0	1
1 6 2000 0 0 0	0	0	0	0	0	0	1

1 7 2000 0 0 0	0	0	0	0	0	0	1
1 8 2000 0 0 0	0	0	0	0	0	0	1
1 9 2000 0 0 0	0	0	0	0	0	0	1
1 10 2000 0 0 0	0	0	0	0	0	0	1
1 11 2000 0 0 0	0	0	0	0	0	0	1
1 12 2000 0 0 0	0	0	0	0	0	0	1
1 1 2001 0 0 0	0	0	0	0	0	0	1
1 2 2001 0 0 0	0	0	0	0	0	0	1
1 3 2001 0 0 0	0	0	0	0	0	0	1
1 4 2001 0 0 0	0	0	0	0	0	0	1
1 5 2001 0 0 0	0	0	0	0	0	0	1
1 6 2001 0 0 0	0	0	0	0	0	0	1
1 7 2001 0 0 0	0	0	0	0	0	0	1
1 8 2001 0 0 0	0	0	0	0	0	0	1
1 9 2001 0 0 0	0	0	0	0	0	0	1
1 10 2001 0 0 0	0	0	0	0	0	0	1
1 11 2001 0 0 0	0	0	0	0	0	0	1
1 12 2001 0 0 0	0	0	0	0	0	0	1
1 1 2002 0 0 0	0	0	0	0	0	0	1
1 2 2002 0 0 0	0	0	0	0	0	0	1
1 3 2002 0 0 0	0	0	0	0	0	0	1
1 4 2002 0 0 0	0	0	0	0	0	0	1
1 5 2002 0 0 0	0	0	0	0	0	0	1
1 6 2002 0 0 0	0	0	0	0	0	0	1
1 7 2002 0 0 0	0	0	0	0	0	0	1
1 8 2002 0 0 0	0	0	0	0	0	0	1
1 9 2002 0 0 0	0	0	0	0	0	0	1
1 10 2002 0 0 0	0	0	0	0	0	0	1
1 11 2002 0 0 0	0	0	0	0	0	0	1
1 12 2002 0 0 0	0	0	0	0	0	0	1
1 1 2003 0 0 0	0	0	0	0	0	0	1
1 2 2003 0 0 0	0	0	0	0	0	0	1
1 3 2003 0 0 0	0	0	0	0	0	0	1

1 4 2003 0 0 0	0	0	0	0	0	0	1
1 5 2003 0 0 0	0	0	0	0	0	0	1
1 6 2003 0 0 0	0	0	0	0	0	0	1
1 7 2003 0 0 0	0	0	0	0	0	0	1
1 8 2003 0 0 0	0	0	0	0	0	0	1
1 9 2003 0 0 0	0	0	0	0	0	0	1
1 10 2003 0 0 0	0	0	0	0	0	0	1
1 11 2003 0 0 0	0	0	0	0	0	0	1
1 12 2003 0 0 0	0	0	0	0	0	0	1
1 1 2004 0 0 0	0	0	0	0	0	0	1
1 2 2004 0 0 0	0	0	0	0	0	0	1
1 3 2004 0 0 0	0	0	0	0	0	0	1
1 4 2004 0 0 0	0	0	0	0	0	0	1
1 5 2004 0 0 0	0	0	0	0	0	0	1
1 6 2004 0 0 0	0	0	0	0	0	0	1
1 7 2004 0 0 0	0	0	0	0	0	0	1
1 8 2004 0 0 0	0	0	0	0	0	0	1
1 9 2004 0 0 0	0	0	0	0	0	0	1
1 10 2004 0 0 0	0	0	0	0	0	0	1
1 11 2004 0 0 0	0	0	0	0	0	0	1
1 12 2004 0 0 0	0	0	0	0	0	0	1
1 1 2005 0 0 0	0	0	0	0	0	0	1
1 2 2005 0 0 0	0	0	0	0	0	0	1
1 3 2005 0 0 0	0	0	0	0	0	0	1
1 4 2005 0 0 0	0	0	0	0	0	0	1
1 5 2005 0 0 0	0	0	0	0	0	0	1
1 6 2005 0 0 0	0	0	0	0	0	0	1
1 7 2005 0 0 0	0	0	0	0	0	0	1
1 8 2005 0 0 0	0	0	0	0	0	0	1
1 9 2005 0 0 0	0	0	0	0	0	0	1
1 10 2005 0 0 0	0	0	0	0	0	0	1
1 11 2005 0 0 0	0	0	0	0	0	0	1
1 12 2005 0 0 0	0	0	0	0	0	0	1

1 1 2006 0 0 0	0	0	0	0	0	0	1
1 2 2006 0 0 0	0	0	0	0	0	0	1
1 3 2006 0 0 0	0	0	0	0	0	0	1
1 4 2006 0 0 0	0	0	0	0	0	0	1
1 5 2006 0 0 0	0	0	0	0	0	0	1
1 6 2006 0 0 0	0	0	0	0	0	0	1
1 7 2006 0 0 0	0	0	0	0	0	0	1
1 8 2006 0 0 0	0	0	0	0	0	0	1
1 9 2006 0 0 0	0	0	0	0	0	0	1
1 10 2006 0 0 0	0	0	0	0	0	0	1
1 11 2006 0 0 0	0	0	0	0	0	0	1
1 12 2006 0 0 0	0	0	0	0	0	0	1
1 1 2007 0 0 0	2660	10200	2590	0	0	0	1
1 2 2007 0 0 0	2660	10200	2590	0	0	0	1
1 3 2007 0 0 0	2660	10200	2590	0	0	0	1
1 4 2007 0 0 0	2660	10200	2590	0	0	0	1
1 5 2007 0 0 0	2660	10200	2590	0	0	0	1
1 6 2007 0 0 0	2660	10300	2590	0	0	0	1
1 7 2007 0 0 0	2660	10300	2590	0	0	0	1
1 8 2007 0 0 0	2660	10300	2590	0	0	0	1
1 9 2007 0 0 0	2660	10300	2590	0	0	0	1
1 10 2007 0 0 0	2660	10300	2590	0	0	0	1
1 11 2007 0 0 0	2660	10300	2590	0	0	0	1
1 12 2007 0 0 0	2660	10300	2590	0	0	0	1
1 1 2008 0 0 0	2650	10300	2590	0	0	0	1
1 2 2008 0 0 0	2650	10300	2580	0	0	0	1
1 3 2008 0 0 0	2650	10300	2580	0	0	0	1
1 4 2008 0 0 0	2650	10300	2580	0	0	0	1
1 5 2008 0 0 0	2650	10300	2580	0	0	0	1
1 6 2008 0 0 0	2640	10300	2580	0	0	0	1
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1 7 2011 0 0 0	1840	0	1960	3660	5220	4780	1
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1 10 2011 0 0 0	1840	0	1960	3490	4990	5010	1
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*NAME AAPR0012

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1 4 2000 0 0 0	3020	0	3080	8500	10000	0.000541	1
1 5 2000 0 0 0	2990	0	3050	8500	10000	0.000615	1
1 6 2000 0 0 0	2960	0	3020	8500	10000	0.000682	1
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1 6 2001 0 0 0	2680	0	2730	8500	10000	0.00137	1
1 7 2001 0 0 0	2660	0	2710	8500	10000	0.00142	1
1 8 2001 0 0 0	2640	0	2690	8500	10000	0.00148	1
1 9 2001 0 0 0	2620	0	2670	8500	10000	0.00153	1
1 10 2001 0 0 0	2600	0	2650	8500	10000	0.00157	1
1 11 2001 0 0 0	2580	0	2640	8500	10000	0.00161	1
1 12 2001 0 0 0	2570	0	2620	8500	10000	0.00164	1
1 1 2002 0 0 0	2560	0	2610	8500	10000	0.00167	1
1 2 2002 0 0 0	2550	0	2600	8500	10000	0.0017	1
1 3 2002 0 0 0	2540	0	2590	8500	10000	0.00172	1
1 4 2002 0 0 0	2530	0	2580	8500	10000	0.00174	1
1 5 2002 0 0 0	2520	0	2570	8500	10000	0.00176	1
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1 7 2002 0 0 0	2500	0	2560	8500	10000	0.00179	1
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1 12 2005 0 0 0	2190	0	2270	7730	10000	0.00406	1
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1 3 2006 0 0 0	2160	0	2250	7670	10000	0.00425	1
1 4 2006 0 0 0	2160	0	2240	7650	10000	0.00432	1
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1 6 2006 0 0 0	2140	0	2230	7600	10000	0.00445	1
1 7 2006 0 0 0	2140	0	2220	7580	10000	0.00451	1
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1 3 2008 0 0 0	2030	0	2120	7200	9910	93.9	1

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1 6 2008 0 0 0	2020	0	2100	6970	9650	354	1
1 7 2008 0 0 0	2010	0	2100	6900	9560	437	1
1 8 2008 0 0 0	2010	0	2090	6830	9490	514	1
1 9 2008 0 0 0	2000	0	2090	6770	9410	586	1
1 10 2008 0 0 0	2000	0	2080	6710	9330	666	1
1 11 2008 0 0 0	1990	0	2080	6640	9250	753	1
1 12 2008 0 0 0	1980	0	2080	6560	9150	853	1
1 1 2009 0 0 0	1980	0	2070	6460	9020	979	1
1 2 2009 0 0 0	1970	0	2070	6350	8870	1130	1
1 3 2009 0 0 0	1970	0	2060	6210	8680	1320	1
1 4 2009 0 0 0	1960	0	2060	6090	8520	1480	1
1 5 2009 0 0 0	1960	0	2050	5950	8340	1660	1
1 6 2009 0 0 0	1950	0	2050	5830	8170	1830	1
1 7 2009 0 0 0	1950	0	2050	5700	8000	2000	1
1 8 2009 0 0 0	1940	0	2040	5500	7730	2270	1
1 9 2009 0 0 0	1940	0	2040	5320	7470	2530	1
1 10 2009 0 0 0	1930	0	2030	5130	7210	2790	1
1 11 2009 0 0 0	1930	0	2030	4950	6950	3050	1
1 12 2009 0 0 0	1920	0	2030	4770	6700	3300	1
1 1 2010 0 0 0	1920	0	2020	4610	6480	3520	1
1 2 2010 0 0 0	1910	0	2020	4490	6300	3700	1
1 3 2010 0 0 0	1900	0	2020	4360	6110	3890	1
1 4 2010 0 0 0	1900	0	2020	4240	5960	4040	1
1 5 2010 0 0 0	1890	0	2010	4130	5810	4190	1
1 6 2010 0 0 0	1890	0	2010	4040	5680	4320	1
1 7 2010 0 0 0	1890	0	2010	3940	5550	4450	1
1 8 2010 0 0 0	1880	0	2000	3840	5420	4580	1
1 9 2010 0 0 0	1880	0	2000	3760	5300	4700	1
1 10 2010 0 0 0	1880	0	2000	3670	5170	4830	1
1 11 2010 0 0 0	1880	0	1990	3590	5060	4940	1
1 12 2010 0 0 0	1870	0	1990	3500	4940	5060	1

1 1 2011 0 0 0	1870	0	1990	3420	4820	5180	1
1 2 2011 0 0 0	1870	0	1980	3350	4720	5280	1
1 3 2011 0 0 0	1860	0	1980	3270	4610	5390	1
1 4 2011 0 0 0	1860	0	1980	3190	4500	5500	1
1 5 2011 0 0 0	1860	0	1980	3110	4390	5610	1
1 6 2011 0 0 0	1860	0	1970	3040	4290	5710	1
1 7 2011 0 0 0	1850	0	1970	2970	4190	5810	1
1 8 2011 0 0 0	1850	0	1970	2910	4100	5900	1
1 9 2011 0 0 0	1850	0	1970	2850	4020	5980	1
1 10 2011 0 0 0	1840	0	1960	2790	3940	6060	1
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1 4 2000 0 0 0	3030	0	3080	8500	10000	0.00054	1
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1 6 2000 0 0 0	2970	0	3020	8500	10000	0.000686	1
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1 4 2001 0 0 0	2730	0	2780	8500	10000	0.00131	1
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1 7 2001 0 0 0	2670	0	2720	8500	10000	0.00148	1
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1 9 2001 0 0 0	2630	0	2680	8500	10000	0.00159	1
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1 12 2001 0 0 0	2580	0	2630	8500	10000	0.00171	1
1 1 2002 0 0 0	2570	0	2620	8500	10000	0.00174	1
1 2 2002 0 0 0	2560	0	2610	8500	10000	0.00177	1
1 3 2002 0 0 0	2550	0	2600	8500	10000	0.00179	1
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1 5 2002 0 0 0	2530	0	2580	8500	10000	0.00183	1
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1 7 2003 0 0 0	2420	0	2470	8370	10000	0.00208	1
1 8 2003 0 0 0	2410	0	2460	8350	10000	0.00213	1
1 9 2003 0 0 0	2400	0	2450	8330	10000	0.00218	1
1 10 2003 0 0 0	2400	0	2450	8310	10000	0.00225	1
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1 9 2004 0 0 0	2310	0	2370	8040	10000	0.00326	1
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1 9 2005 0 0 0	2220	0	2290	7800	10000	0.00426	1
1 10 2005 0 0 0	2210	0	2280	7780	10000	0.00433	1
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1 12 2005 0 0 0	2200	0	2270	7740	10000	0.00445	1
1 1 2006 0 0 0	2190	0	2260	7710	10000	0.0045	1
1 2 2006 0 0 0	2180	0	2260	7690	10000	0.00456	1
1 3 2006 0 0 0	2180	0	2250	7670	10000	0.00461	1
1 4 2006 0 0 0	2170	0	2240	7650	10000	0.00466	1
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1 6 2006 0 0 0	2160	0	2230	7610	10000	0.00476	1
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1 1 2007 0 0 0	2110	0	2190	7450	10000	0.00511	1
1 2 2007 0 0 0	2110	0	2180	7450	10000	0.00521	1

1 3 2007 0 0 0	2110	0	2180	7440	10000	0.00531	1
1 4 2007 0 0 0	2100	0	2180	7430	10000	0.00536	1
1 5 2007 0 0 0	2100	0	2170	7420	10000	0.0054	1
1 6 2007 0 0 0	2090	0	2170	7410	10000	0.00546	1
1 7 2007 0 0 0	2090	0	2170	7390	10000	0.00563	1
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1 9 2007 0 0 0	2080	0	2160	7370	10000	0.0296	1
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1 2 2008 0 0 0	2050	0	2130	7220	9900	95.4	1
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1 7 2008 0 0 0	2030	0	2110	6850	9470	535	1
1 8 2008 0 0 0	2020	0	2100	6770	9380	624	1
1 9 2008 0 0 0	2010	0	2100	6710	9300	697	1
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1 11 2008 0 0 0	2000	0	2090	6530	9080	925	1
1 12 2008 0 0 0	1990	0	2080	6410	8910	1090	1
1 1 2009 0 0 0	1990	0	2080	6290	8760	1240	1
1 2 2009 0 0 0	1980	0	2070	6200	8640	1360	1
1 3 2009 0 0 0	1980	0	2070	6090	8510	1490	1
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1 5 2009 0 0 0	1970	0	2060	5880	8230	1770	1
1 6 2009 0 0 0	1970	0	2060	5770	8080	1920	1
1 7 2009 0 0 0	1960	0	2050	5650	7930	2070	1
1 8 2009 0 0 0	1960	0	2050	5530	7770	2230	1
1 9 2009 0 0 0	1950	0	2050	5420	7620	2380	1
1 10 2009 0 0 0	1950	0	2040	5300	7460	2540	1
1 11 2009 0 0 0	1950	0	2040	5070	7140	2860	1

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1 1 2010 0 0 0	1940	0	2030	4650	6560	3440	1
1 2 2010 0 0 0	1930	0	2030	4510	6360	3640	1
1 3 2010 0 0 0	1930	0	2030	4390	6190	3810	1
1 4 2010 0 0 0	1920	0	2020	4290	6050	3950	1
1 5 2010 0 0 0	1920	0	2020	4180	5900	4100	1
1 6 2010 0 0 0	1910	0	2020	4080	5760	4240	1
1 7 2010 0 0 0	1900	0	2010	3960	5590	4410	1
1 8 2010 0 0 0	1900	0	2010	3840	5430	4570	1
1 9 2010 0 0 0	1900	0	2010	3740	5300	4700	1
1 10 2010 0 0 0	1890	0	2000	3650	5180	4820	1
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1 5 2011 0 0 0	1870	0	1980	3070	4380	5620	1
1 6 2011 0 0 0	1870	0	1980	3000	4270	5730	1
1 7 2011 0 0 0	1870	0	1980	2930	4170	5830	1
1 8 2011 0 0 0	1870	0	1970	2860	4070	5930	1
1 9 2011 0 0 0	1860	0	1970	2790	3980	6020	1
1 10 2011 0 0 0	1860	0	1970	2720	3880	6120	1
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1 12 2011 0 0 0	1860	0	1960	2590	3690	6310	1
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1 2 2000 0 0 0	3030	0	3050	8500	10000	0.000197	1
1 3 2000 0 0 0	2990	0	3000	8500	10000	0.000253	1
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1 7 2000 0 0 0	2850	0	2870	8500	10000	0.000415	1

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1 2 2002 0 0 0	2470	0	2480	8450	10000	0.000852	1
1 3 2002 0 0 0	2460	0	2480	8430	10000	0.000862	1
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1 5 2002 0 0 0	2440	0	2460	8390	10000	0.000883	1
1 6 2002 0 0 0	2440	0	2450	8360	10000	0.0009	1
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1 9 2002 0 0 0	2420	0	2430	8290	10000	0.000953	1
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1 3 2006 0 0 0	2130	0	2150	7350	10000	0.00184	1
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1 5 2006 0 0 0	2110	0	2130	7310	10000	0.00187	1
1 6 2006 0 0 0	2110	0	2130	7290	10000	0.00188	1
1 7 2006 0 0 0	2100	0	2120	7270	10000	0.0019	1
1 8 2006 0 0 0	2090	0	2110	7250	10000	0.00192	1
1 9 2006 0 0 0	2090	0	2110	7230	10000	0.00193	1
1 10 2006 0 0 0	2080	0	2100	7210	10000	0.00195	1
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1 12 2006 0 0 0	2070	0	2090	7170	10000	0.00199	1
1 1 2007 0 0 0	2060	0	2080	7150	10000	0.00202	1
1 2 2007 0 0 0	2060	0	2080	7130	10000	0.00204	1
1 3 2007 0 0 0	2050	0	2070	7110	10000	0.00207	1
1 4 2007 0 0 0	2050	0	2070	7100	10000	0.0021	1
1 5 2007 0 0 0	2040	0	2060	7080	10000	0.00212	1
1 6 2007 0 0 0	2040	0	2060	7070	10000	0.00215	1
1 7 2007 0 0 0	2030	0	2050	7050	10000	0.00217	1
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1 10 2007 0 0 0	2020	0	2040	7010	10000	0.00224	1
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1 10 2008 0 0 0	1960	0	1980	6850	10000	0.00245	1

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1 12 2008 0 0 0	1950	0	1970	6830	10000	0.00247	1
1 1 2009 0 0 0	1940	0	1960	6820	10000	0.00249	1
1 2 2009 0 0 0	1940	0	1960	6810	10000	0.0025	1
1 3 2009 0 0 0	1940	0	1950	6790	10000	0.00251	1
1 4 2009 0 0 0	1930	0	1950	6780	10000	0.00252	1
1 5 2009 0 0 0	1930	0	1950	6770	10000	0.00254	1
1 6 2009 0 0 0	1920	0	1940	6760	10000	0.00255	1
1 7 2009 0 0 0	1920	0	1940	6750	10000	0.00256	1
1 8 2009 0 0 0	1910	0	1930	6740	10000	0.00258	1
1 9 2009 0 0 0	1910	0	1930	6730	10000	0.00259	1
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1 11 2009 0 0 0	1900	0	1920	6710	10000	0.00261	1
1 12 2009 0 0 0	1900	0	1920	6700	10000	0.00262	1
1 1 2010 0 0 0	1890	0	1910	6690	10000	0.00264	1
1 2 2010 0 0 0	1890	0	1910	6680	10000	0.00265	1
1 3 2010 0 0 0	1890	0	1910	6670	10000	0.00266	1
1 4 2010 0 0 0	1880	0	1900	6660	10000	0.00267	1
1 5 2010 0 0 0	1880	0	1900	6650	10000	0.00268	1
1 6 2010 0 0 0	1880	0	1900	6640	10000	0.00269	1
1 7 2010 0 0 0	1870	0	1890	6640	10000	0.0027	1
1 8 2010 0 0 0	1870	0	1890	6630	10000	0.00272	1
1 9 2010 0 0 0	1870	0	1880	6620	10000	0.00273	1
1 10 2010 0 0 0	1860	0	1880	6610	10000	0.00274	1
1 11 2010 0 0 0	1860	0	1880	6600	10000	0.00275	1
1 12 2010 0 0 0	1850	0	1870	6590	10000	0.00276	1
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1 3 2011 0 0 0	1850	0	1860	6570	10000	0.00279	1
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1 5 2011 0 0 0	1840	0	1860	6560	10000	0.00281	1
1 6 2011 0 0 0	1840	0	1850	6550	10000	0.00282	1
1 7 2011 0 0 0	1830	0	1850	6540	10000	0.00283	1

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1 3 2000 0 0 0	2940	0	2990	8500	10000	0.00055	1
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1 6 2000 0 0 0	2840	0	2890	8500	10000	0.000827	1
1 7 2000 0 0 0	2810	0	2860	8500	10000	0.000908	1
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1 9 2000 0 0 0	2760	0	2800	8500	10000	0.00105	1
1 10 2000 0 0 0	2730	0	2780	8500	10000	0.00112	1
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1 6 2001 0 0 0	2550	0	2600	8500	10000	0.00161	1
1 7 2001 0 0 0	2530	0	2580	8500	10000	0.00166	1
1 8 2001 0 0 0	2510	0	2550	8500	10000	0.00172	1
1 9 2001 0 0 0	2490	0	2530	8500	10000	0.00177	1
1 10 2001 0 0 0	2470	0	2520	8500	10000	0.00182	1
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1 12 2001 0 0 0	2450	0	2490	8460	10000	0.00189	1
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1 2 2002 0 0 0	2430	0	2470	8410	10000	0.00195	1
1 3 2002 0 0 0	2420	0	2460	8390	10000	0.00201	1

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1 9 2002 0 0 0	2370	0	2420	8230	10000	0.00246	1
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1 4 2004 0 0 0	2210	0	2280	7800	10000	0.00424	1
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1 3 2005 0 0 0	2140	0	2210	7550	10000	0.00486	1
1 4 2005 0 0 0	2130	0	2200	7530	10000	0.00491	1
1 5 2005 0 0 0	2120	0	2200	7510	10000	0.00497	1
1 6 2005 0 0 0	2120	0	2190	7490	10000	0.00502	1
1 7 2005 0 0 0	2110	0	2180	7470	10000	0.00507	1
1 8 2005 0 0 0	2100	0	2180	7450	10000	0.00512	1
1 9 2005 0 0 0	2100	0	2170	7420	10000	0.00517	1
1 10 2005 0 0 0	2090	0	2160	7400	10000	0.00522	1
1 11 2005 0 0 0	2080	0	2160	7380	10000	0.00527	1
1 12 2005 0 0 0	2080	0	2150	7360	10000	0.00533	1
1 1 2006 0 0 0	2070	0	2140	7340	10000	0.00538	1
1 2 2006 0 0 0	2060	0	2140	7320	10000	0.00543	1
1 3 2006 0 0 0	2060	0	2130	7300	10000	0.00549	1
1 4 2006 0 0 0	2050	0	2120	7280	10000	0.00555	1
1 5 2006 0 0 0	2040	0	2120	7260	10000	0.00561	1
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1 7 2006 0 0 0	2030	0	2100	7220	10000	0.00574	1
1 8 2006 0 0 0	2020	0	2100	7200	10000	0.0058	1
1 9 2006 0 0 0	2020	0	2090	7180	10000	0.00587	1
1 10 2006 0 0 0	2010	0	2080	7160	10000	0.00594	1
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1 6 2007 0 0 0	1960	0	2040	7030	10000	0.00657	1
1 7 2007 0 0 0	1960	0	2030	7020	10000	0.00664	1
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1 11 2007 0 0 0	1940	0	2010	6970	10000	0.00685	1
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1 8 2010 0 0 0	1790	0	1870	6610	10000	0.00848	1
1 9 2010 0 0 0	1780	0	1870	6600	10000	0.00852	1
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1 6 2000 0 0 0	2850	0	2900	8500	10000	0.000786	1
1 7 2000 0 0 0	2820	0	2870	8500	10000	0.000862	1
1 8 2000 0 0 0	2790	0	2840	8500	10000	0.000934	1
1 9 2000 0 0 0	2770	0	2810	8500	10000	0.001	1
1 10 2000 0 0 0	2740	0	2790	8500	10000	0.00107	1
1 11 2000 0 0 0	2720	0	2760	8500	10000	0.00113	1
1 12 2000 0 0 0	2690	0	2740	8500	10000	0.00119	1
1 1 2001 0 0 0	2670	0	2720	8500	10000	0.00125	1
1 2 2001 0 0 0	2650	0	2690	8500	10000	0.0013	1

1 3 2001 0 0 0	2620	0	2670	8500	10000	0.00136	1
1 4 2001 0 0 0	2600	0	2650	8500	10000	0.00142	1
1 5 2001 0 0 0	2580	0	2630	8500	10000	0.00147	1
1 6 2001 0 0 0	2560	0	2610	8500	10000	0.00153	1
1 7 2001 0 0 0	2540	0	2580	8500	10000	0.00158	1
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1 9 2001 0 0 0	2500	0	2540	8500	10000	0.00169	1
1 10 2001 0 0 0	2480	0	2530	8500	10000	0.00173	1
1 11 2001 0 0 0	2470	0	2510	8500	10000	0.00176	1
1 12 2001 0 0 0	2460	0	2500	8480	10000	0.00179	1
1 1 2002 0 0 0	2450	0	2490	8460	10000	0.00182	1
1 2 2002 0 0 0	2440	0	2480	8440	10000	0.00184	1
1 3 2002 0 0 0	2430	0	2470	8410	10000	0.00186	1
1 4 2002 0 0 0	2420	0	2470	8390	10000	0.00191	1
1 5 2002 0 0 0	2410	0	2460	8370	10000	0.00197	1
1 6 2002 0 0 0	2400	0	2450	8340	10000	0.00203	1
1 7 2002 0 0 0	2390	0	2440	8320	10000	0.0021	1
1 8 2002 0 0 0	2390	0	2440	8290	10000	0.00217	1
1 9 2002 0 0 0	2380	0	2430	8270	10000	0.00224	1
1 10 2002 0 0 0	2370	0	2420	8240	10000	0.00232	1
1 11 2002 0 0 0	2360	0	2420	8210	10000	0.0024	1
1 12 2002 0 0 0	2350	0	2410	8190	10000	0.00249	1
1 1 2003 0 0 0	2340	0	2400	8160	10000	0.00257	1
1 2 2003 0 0 0	2340	0	2400	8140	10000	0.00265	1
1 3 2003 0 0 0	2330	0	2390	8110	10000	0.00275	1
1 4 2003 0 0 0	2320	0	2380	8090	10000	0.00284	1
1 5 2003 0 0 0	2310	0	2370	8060	10000	0.00293	1
1 6 2003 0 0 0	2300	0	2370	8040	10000	0.00303	1
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1 9 2003 0 0 0	2280	0	2350	7970	10000	0.00333	1
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1 3 2005 0 0 0	2150	0	2220	7590	10000	0.00457	1
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1 7 2005 0 0 0	2120	0	2200	7500	10000	0.00477	1
1 8 2005 0 0 0	2110	0	2190	7480	10000	0.00482	1
1 9 2005 0 0 0	2110	0	2180	7460	10000	0.00487	1
1 10 2005 0 0 0	2100	0	2180	7440	10000	0.00491	1
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1 12 2005 0 0 0	2090	0	2160	7400	10000	0.005	1
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1 2 2006 0 0 0	2070	0	2150	7360	10000	0.00509	1
1 3 2006 0 0 0	2070	0	2140	7340	10000	0.00514	1
1 4 2006 0 0 0	2060	0	2140	7320	10000	0.00519	1
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1 7 2006 0 0 0	2040	0	2120	7260	10000	0.00534	1
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1 10 2006 0 0 0	2020	0	2100	7200	10000	0.0055	1
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1 9 2007 0 0 0	1960	0	2040	7030	10000	0.00619	1
1 10 2007 0 0 0	1950	0	2030	7020	10000	0.00625	1
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1 12 2007 0 0 0	1940	0	2020	6990	10000	0.00635	1
1 1 2008 0 0 0	1940	0	2020	6980	10000	0.0064	1
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1 3 2008 0 0 0	1930	0	2010	6960	10000	0.00649	1
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1 5 2008 0 0 0	1920	0	2000	6930	10000	0.00659	1
1 6 2008 0 0 0	1910	0	2000	6920	10000	0.00664	1
1 7 2008 0 0 0	1910	0	1990	6910	10000	0.00668	1
1 8 2008 0 0 0	1900	0	1990	6900	10000	0.00673	1
1 9 2008 0 0 0	1900	0	1980	6890	10000	0.00677	1
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1 12 2008 0 0 0	1890	0	1970	6850	10000	0.0069	1
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1 2 2009 0 0 0	1880	0	1960	6830	10000	0.00698	1
1 3 2009 0 0 0	1870	0	1960	6820	10000	0.00702	1
1 4 2009 0 0 0	1870	0	1950	6810	10000	0.00706	1
1 5 2009 0 0 0	1860	0	1950	6800	10000	0.0071	1

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1 5 2010 0 0 0	1810	0	1900	6680	10000	0.00756	1
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1 7 2010 0 0 0	1810	0	1890	6670	10000	0.00763	1
1 8 2010 0 0 0	1800	0	1890	6660	10000	0.00767	1
1 9 2010 0 0 0	1800	0	1880	6650	10000	0.0077	1
1 10 2010 0 0 0	1790	0	1880	6640	10000	0.00773	1
1 11 2010 0 0 0	1790	0	1880	6630	10000	0.00777	1
1 12 2010 0 0 0	1790	0	1870	6620	10000	0.0078	1
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B.2 Observed Measurements Data in Eclipse Black-Oil Simulation Format

```
*FIELD
*DAILY
*IGNORE_MISSING
*UPTIME_FRACTIONS
*UUCRATES
*DAY *MONTH *YEAR *HOUR *MINUTE *SECOND *BHP *WINJ *PRESS *GAS *OIL *WATER *UPTIME
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1 7 2008 0 0 0	2033	0	2099	6875	8679	340	1
1 8 2008 0 0 0	2033	0	2103	6931	7569	477	1
1 9 2008 0 0 0	2033	0	2092	7421	10414	578	1
1 10 2008 0 0 0	2033	0	2084	6420	10281	576	1
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1 2 2009 0 0 0	1975	0	2065	6625	7457	1108	1
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1 6 2010 0 0 0	1929	0	1989	4364	6263	3985	1
1 7 2010 0 0 0	1929	0	1993	4188	5263	3836	1
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1 2 2009 0 0 0	1947	0	2067	6760	8834	1016	1
1 3 2009 0 0 0	1947	0	2062	6090	8417	1527	1
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1 6 2009 0 0 0	1947	0	2049	5567	7831	2111	1
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1 8 2009 0 0 0	1947	0	2042	5660	7589	2129	1
1 9 2009 0 0 0	1947	0	2038	5666	7597	2859	1
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1 1 2008 0 0 0	2110	0	2128	7740	10060	51	1
1 2 2008 0 0 0	2110	0	2126	7099	9971	94	1
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1 4 2009 0 0 0	1972	0	2053	5871	8239	1613	1
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1 9 2011 0 0 0	1761	0	1824	6324	10020	0	1
1 10 2011 0 0 0	1761	0	1805	6010	10087	0	1
1 11 2011 0 0 0	1761	0	1828	6464	9880	0	1
1 12 2011 0 0 0	1761	0	1833	6839	9891	0	1
*NAME AAPR0024							
1 1 2000 0 0 0	0	0	3108	8459	10104	0	1
1 2 2000 0 0 0	0	0	3041	8440	9973	0	1
1 3 2000 0 0 0	0	0	3004	8748	9810	0	1
1 4 2000 0 0 0	0	0	2941	8463	10013	0	1
1 5 2000 0 0 0	0	0	2940	8477	10067	0	1
1 6 2000 0 0 0	2864	0	2901	8343	9970	0	1
1 7 2000 0 0 0	2864	0	2870	8678	9963	0	1
1 8 2000 0 0 0	2864	0	2850	8476	9991	0	1
1 9 2000 0 0 0	2864	0	2804	8600	10012	0	1
1 10 2000 0 0 0	2864	0	2793	9186	9974	0	1
1 11 2000 0 0 0	2864	0	2747	8751	9975	0	1
1 12 2000 0 0 0	2864	0	2740	8006	10008	0	1
1 1 2001 0 0 0	2864	0	2690	8533	9834	0	1
1 2 2001 0 0 0	2864	0	2710	8323	9955	0	1
1 3 2001 0 0 0	2864	0	2667	8634	10091	0	1
1 4 2001 0 0 0	2864	0	2648	8742	10054	0	1

1 5 2001 0 0 0	2864	0	2629	8463	9898	0	1
1 6 2001 0 0 0	2573	0	2605	8255	9942	0	1
1 7 2001 0 0 0	2573	0	2571	8176	10058	0	1
1 8 2001 0 0 0	2573	0	2561	8355	9924	0	1
1 9 2001 0 0 0	2573	0	2547	8549	10032	0	1
1 10 2001 0 0 0	2573	0	2534	8280	9800	0	1
1 11 2001 0 0 0	2573	0	2509	7972	9869	0	1
1 12 2001 0 0 0	2573	0	2503	8195	10033	0	1
1 1 2002 0 0 0	2573	0	2467	8436	10096	0	1
1 2 2002 0 0 0	2573	0	2490	8128	10035	0	1
1 3 2002 0 0 0	2573	0	2468	8362	9889	0	1
1 4 2002 0 0 0	2573	0	2470	8708	10099	0	1
1 5 2002 0 0 0	2573	0	2452	8229	10062	0	1
1 6 2002 0 0 0	2409	0	2448	8191	9954	0	1
1 7 2002 0 0 0	2409	0	2435	8795	10102	0	1
1 8 2002 0 0 0	2409	0	2431	8088	10174	0	1
1 9 2002 0 0 0	2409	0	2429	8200	10032	0	1
1 10 2002 0 0 0	2409	0	2423	9284	10043	0	1
1 11 2002 0 0 0	2409	0	2410	8450	9960	0	1
1 12 2002 0 0 0	2409	0	2413	7964	10051	0	1
1 1 2003 0 0 0	2409	0	2382	7875	10070	0	1
1 2 2003 0 0 0	2409	0	2385	7745	10081	0	1
1 3 2003 0 0 0	2409	0	2394	7953	10069	0	1
1 4 2003 0 0 0	2409	0	2375	7487	10032	0	1
1 5 2003 0 0 0	2409	0	2368	8449	9886	0	1
1 6 2003 0 0 0	2323	0	2369	8735	9832	0	1
1 7 2003 0 0 0	2323	0	2351	7856	9958	0	1
1 8 2003 0 0 0	2323	0	2348	7546	9931	0	1
1 9 2003 0 0 0	2323	0	2353	7265	9778	0	1
1 10 2003 0 0 0	2323	0	2332	7555	9913	0	1
1 11 2003 0 0 0	2323	0	2325	8371	10097	0	1
1 12 2003 0 0 0	2323	0	2342	8058	9939	0	1
1 1 2004 0 0 0	2323	0	2306	7536	9992	0	1

1 2 2004 0 0 0	2323	0	2317	8110	10263	0	1
1 3 2004 0 0 0	2323	0	2292	7592	10058	0	1
1 4 2004 0 0 0	2323	0	2286	7112	10248	0	1
1 5 2004 0 0 0	2323	0	2300	7581	9965	0	1
1 6 2004 0 0 0	2206	0	2277	7254	10294	0	1
1 7 2004 0 0 0	2206	0	2280	7672	9996	0	1
1 8 2004 0 0 0	2206	0	2279	7777	10009	0	1
1 9 2004 0 0 0	2206	0	2270	8028	9906	0	1
1 10 2004 0 0 0	2206	0	2239	7803	10161	0	1
1 11 2004 0 0 0	2206	0	2259	7528	9942	0	1
1 12 2004 0 0 0	2206	0	2243	7395	9931	0	1
1 1 2005 0 0 0	2206	0	2221	7909	10033	0	1
1 2 2005 0 0 0	2206	0	2243	7402	9936	0	1
1 3 2005 0 0 0	2206	0	2235	7857	9957	0	1
1 4 2005 0 0 0	2206	0	2203	7220	9926	0	1
1 5 2005 0 0 0	2206	0	2215	7077	9896	0	1
1 6 2005 0 0 0	2137	0	2216	7933	10055	0	1
1 7 2005 0 0 0	2137	0	2205	7987	10100	0	1
1 8 2005 0 0 0	2137	0	2191	6756	10077	0	1
1 9 2005 0 0 0	2137	0	2189	7787	9992	0	1
1 10 2005 0 0 0	2137	0	2166	7700	10078	0	1
1 11 2005 0 0 0	2137	0	2157	7261	10230	0	1
1 12 2005 0 0 0	2137	0	2175	7150	10068	0	1
1 1 2006 0 0 0	2137	0	2165	7490	10018	0	1
1 2 2006 0 0 0	2137	0	2145	6980	9879	0	1
1 3 2006 0 0 0	2137	0	2133	7323	10177	0	1
1 4 2006 0 0 0	2137	0	2140	6880	9945	0	1
1 5 2006 0 0 0	2137	0	2127	7308	10049	0	1
1 6 2006 0 0 0	2061	0	2112	7351	10070	0	1
1 7 2006 0 0 0	2061	0	2136	6875	10023	0	1
1 8 2006 0 0 0	2061	0	2100	7597	10037	0	1
1 9 2006 0 0 0	2061	0	2123	7281	9874	0	1
1 10 2006 0 0 0	2061	0	2079	7509	9799	0	1

1 11 2006 0 0 0	2061	0	2092	7248	10001	0	1
1 12 2006 0 0 0	2061	0	2092	6955	10221	0	1
1 1 2007 0 0 0	2061	0	2076	6635	10052	0	1
1 2 2007 0 0 0	2061	0	2065	7039	9948	0	1
1 3 2007 0 0 0	2061	0	2064	7139	10158	0	1
1 4 2007 0 0 0	2061	0	2066	7061	10066	0	1
1 5 2007 0 0 0	2061	0	2063	6785	10062	0	1
1 6 2007 0 0 0	1986	0	2058	7406	9943	0	1
1 7 2007 0 0 0	1986	0	2039	7530	10050	0	1
1 8 2007 0 0 0	1986	0	2032	7326	9991	0	1
1 9 2007 0 0 0	1986	0	2018	7541	9938	0	1
1 10 2007 0 0 0	1986	0	2038	6525	9903	0	1
1 11 2007 0 0 0	1986	0	2051	7397	10089	0	1
1 12 2007 0 0 0	1986	0	2035	7353	9922	0	1
1 1 2008 0 0 0	1986	0	2031	7567	10143	0	1
1 2 2008 0 0 0	1986	0	2014	7217	10137	0	1
1 3 2008 0 0 0	1986	0	2011	6963	9921	0	1
1 4 2008 0 0 0	1986	0	2011	7359	10107	0	1
1 5 2008 0 0 0	1986	0	2009	6577	9981	0	1
1 6 2008 0 0 0	1912	0	2001	6405	10019	0	1
1 7 2008 0 0 0	1912	0	2002	7234	9892	0	1
1 8 2008 0 0 0	1912	0	1976	7193	10072	0	1
1 9 2008 0 0 0	1912	0	1969	6669	10059	0	1
1 10 2008 0 0 0	1912	0	1983	6515	10148	0	1
1 11 2008 0 0 0	1912	0	1953	6518	10064	0	1
1 12 2008 0 0 0	1912	0	1989	7150	9973	0	1
1 1 2009 0 0 0	1912	0	1967	6435	9882	0	1
1 2 2009 0 0 0	1912	0	1946	6879	10078	0	1
1 3 2009 0 0 0	1912	0	1966	7287	10109	0	1
1 4 2009 0 0 0	1912	0	1960	7264	10144	0	1
1 5 2009 0 0 0	1912	0	1957	7245	9997	0	1
1 6 2009 0 0 0	1861	0	1950	6781	10081	0	1
1 7 2009 0 0 0	1861	0	1936	6860	10020	0	1

1 8 2009 0 0 0	1861	0	1948	6860	10006	0	1
1 9 2009 0 0 0	1861	0	1929	6137	9940	0	1
1 10 2009 0 0 0	1861	0	1927	6385	10018	0	1
1 11 2009 0 0 0	1861	0	1911	6975	9993	0	1
1 12 2009 0 0 0	1861	0	1913	7729	10025	0	1
1 1 2010 0 0 0	1861	0	1908	6824	9832	0	1
1 2 2010 0 0 0	1861	0	1906	7390	10038	0	1
1 3 2010 0 0 0	1861	0	1903	6625	10213	0	1
1 4 2010 0 0 0	1861	0	1890	7299	9989	0	1
1 5 2010 0 0 0	1861	0	1892	6497	10093	0	1
1 6 2010 0 0 0	1806	0	1886	6619	9764	0	1
1 7 2010 0 0 0	1806	0	1893	6699	9894	0	1
1 8 2010 0 0 0	1806	0	1892	6660	9887	0	1
1 9 2010 0 0 0	1806	0	1893	6620	9878	0	1
1 10 2010 0 0 0	1806	0	1881	6382	9950	0	1
1 11 2010 0 0 0	1806	0	1877	6382	9836	0	1
1 12 2010 0 0 0	1806	0	1865	5774	10033	0	1
1 1 2011 0 0 0	1806	0	1850	6705	9993	0	1
1 2 2011 0 0 0	1806	0	1877	6271	9937	0	1
1 3 2011 0 0 0	1806	0	1856	6613	9968	0	1
1 4 2011 0 0 0	1806	0	1864	6726	10090	0	1
1 5 2011 0 0 0	1806	0	1855	6617	10139	0	1
1 6 2011 0 0 0	1761	0	1850	6891	10093	0	1
1 7 2011 0 0 0	1761	0	1842	6602	10020	0	1
1 8 2011 0 0 0	1761	0	1840	6117	9999	0	1
1 9 2011 0 0 0	1761	0	1831	6639	9804	0	1
1 10 2011 0 0 0	1761	0	1829	6235	10061	0	1
1 11 2011 0 0 0	1761	0	1836	6902	9958	0	1
1 12 2011 0 0 0	1761	0	1808	6505	10088	0	1

APPENDIX C

C.1 Cumulative Oil Production Distributions for Experiment 3

Chain	Sub Chain	Minimum (mstb)	Maximum (mstb)	Mean (mstb)	S.D. (mstb)	Mode (mstb)	P10 (mstb)	P90 (mstb)
*Prior	N.A.	133,068	716,302	416,471	72,264	422,814	323,840	509,022
Static	All	404,145	502,617	450,288	14,790	451,583	430,714	469,211
1st Update	All	401,399	497,279	464,018	12,833	468,029	446,857	479,246
2nd Update	All	413,681	492,445	447,665	16,785	442,659	425,711	470,999
3rd Update	All	413,015	451,999	429,801	7,263	427,564	420,403	439,693
4th Update	All	402,563	463,032	430,119	9,044	430,397	418,167	441,729
5th Update	All	405,757	450,577	424,904	9,704	423,042	412,261	438,483
6th Update	All	381,645	430,727	407,474	4,366	407,619	402,188	412,756
Static	1	385,884	472,898	450,699	10,129	455,322	437,465	461,852
Static	2	446,315	490,167	467,543	11,643	466,010	451,653	483,789
Static	3	430,418	471,930	447,693	10,136	440,631	434,574	462,233
Static	4	420,095	464,706	439,923	9,420	435,155	428,050	453,394
Static	5	404,913	443,512	424,351	7,970	424,984	413,459	435,040
Static	6	428,540	470,774	446,572	8,980	440,673	435,482	459,552
Static	7	438,883	471,104	455,235	5,027	455,850	448,559	461,627
Static	8	442,996	481,069	463,372	7,163	463,238	453,679	472,813
Static	9	406,316	474,040	457,664	7,181	460,786	448,302	465,557
1st Update	1	425,324	463,028	445,884	7,922	449,575	434,621	455,968
1st Update	2	443,168	486,277	468,409	9,276	475,146	454,884	479,681
1st Update	3	446,663	478,715	463,789	4,895	464,442	457,266	469,960
1st Update	4	430,990	479,035	459,322	10,350	467,640	444,204	471,848
1st Update	5	449,616	489,976	470,368	10,186	470,997	456,238	484,237
1st Update	6	445,025	505,119	475,911	4,827	475,946	470,416	481,399
2nd Update	1	440,134	480,391	459,337	9,929	457,731	445,898	473,137
2nd Update	2	427,654	466,906	443,058	8,603	434,513	432,819	455,720
2nd Update	3	420,980	492,121	454,455	6,043	454,411	447,564	461,332
2nd Update	4	439,647	493,269	465,184	13,491	461,273	446,906	483,984
2nd Update	5	421,456	457,466	437,448	7,595	433,005	427,919	448,335
2nd Update	6	413,891	538,842	424,436	7,600	420,107	417,711	433,066
2nd Update	7	414,480	460,018	434,551	11,529	427,243	419,339	450,970
2nd Update	8	440,184	480,750	461,191	6,205	461,822	452,935	469,049
3rd Update	1	416,876	453,469	432,712	8,877	429,032	421,073	445,319
3rd Update	2	415,217	449,557	430,211	7,280	425,890	421,126	440,676
3rd Update	3	416,771	445,239	426,921	6,594	418,695	419,057	436,709
3rd Update	4	413,049	440,434	426,743	7,907	416,746	415,783	437,693
3rd Update	5	425,015	439,080	431,528	2,947	430,505	427,728	435,680
3rd Update	6	403,123	447,260	435,984	5,210	438,583	429,174	441,720
3rd Update	7	416,658	439,345	426,695	4,801	424,114	420,672	433,576
3rd Update	8	413,873	445,726	429,244	8,501	427,831	417,654	441,124
3rd Update	9	417,216	440,007	427,110	4,861	423,948	421,081	434,124
3rd Update	0	422,151	439,982	432,061	3,765	434,176	426,658	436,782
4th Update	1	405,485	455,525	430,361	4,010	430,389	425,790	434,921
4th Update	2	415,146	434,241	427,505	4,428	433,133	420,924	432,790
4th Update	3	421,125	440,030	430,042	4,841	429,208	423,503	436,821
4th Update	4	412,160	446,555	429,369	8,064	429,243	418,358	440,383
4th Update	5	404,597	437,184	416,065	7,611	406,222	406,976	427,367
4th Update	6	429,730	459,759	442,488	4,486	442,161	436,620	448,337
4th Update	7	422,161	460,599	435,031	5,165	433,290	428,874	441,901

Chain	Sub Chain	Minimum (mstb)	Maximum (mstb)	Mean (mstb)	S.D. (mstb)	Mode (mstb)	P10 (mstb)	P90 (mstb)
4th Update	8	412,525	441,452	431,090	6,713	439,464	421,119	439,092
5th Update	1	408,272	431,035	418,233	4,355	418,119	412,539	424,182
5th Update	2	416,169	434,748	426,164	4,707	427,603	419,541	432,472
5th Update	3	423,901	444,008	433,301	3,181	433,014	429,123	437,429
5th Update	4	415,605	439,916	428,538	5,802	429,688	420,463	436,319
5th Update	5	405,732	427,165	414,480	4,676	410,685	408,849	421,320
5th Update	6	405,795	450,741	427,532	12,285	420,187	410,753	444,721
6th Update	1	397,311	414,419	406,632	2,965	406,917	402,661	410,476
6th Update	2	403,346	415,837	408,702	2,653	406,903	405,421	412,533
6th Update	3	393,532	417,079	405,305	6,799	395,060	395,880	414,721

*Prior was sampled using Monte Carlo sampling with 3000 iterations

C.2 Regional Multipliers' Distributions for Experiment 3

Multiplier	Region	Update	Minimum	Maximum	Mean	S. D.	Mode	P10	P90
Ø	1	Static	0.629	0.766	0.703	0.034	0.713	0.655	0.749
log Kh	1	Static	-0.422	0.903	0.241	0.383	-0.270	-0.290	0.771
log Kv	1	Static	-0.426	0.916	0.406	0.302	0.730	-0.041	0.763
Ø	2	Static	-0.394	0.421	0.242	0.075	0.269	0.144	0.324
log Kh	2	Static	-0.329	1.115	0.145	0.246	0.024	-0.158	0.487
log Kv	2	Static	-0.503	0.790	0.079	0.322	-0.072	-0.349	0.534
Ø	3	Static	0.548	1.105	0.796	0.144	0.712	0.605	1.001
log Kh	3	Static	-0.252	0.627	0.141	0.184	0.063	-0.093	0.403
log Kv	3	Static	-0.484	0.868	0.400	0.319	0.826	-0.074	0.780
Ø	4	Static	0.232	1.201	0.645	0.238	0.523	0.335	0.984
log Kh	4	Static	-0.146	0.740	0.100	0.081	0.079	0.008	0.198
log Kv	4	Static	-0.543	0.634	0.126	0.228	0.166	-0.187	0.422
Ø	5	Static	0.745	2.342	1.397	0.253	1.393	1.069	1.730
log Kh	5	Static	-0.349	1.449	0.106	0.207	0.016	-0.122	0.376
log Kv	5	Static	-1.373	0.903	0.136	0.543	0.897	-0.672	0.785
Ø	6	Static	1.062	2.829	1.846	0.410	1.807	1.306	2.422
log Kh	6	Static	-0.838	1.000	0.160	0.409	0.229	-0.407	0.701
log Kv	6	Static	-1.115	0.927	-0.035	0.384	-0.054	-0.551	0.470
Ø	All	Static	0.034	3.330	0.940	0.568	0.585	0.283	1.740
Ø	1	1	0.704	0.781	0.739	0.016	0.734	0.719	0.762
log Kh	1	1	-0.816	0.551	0.012	0.301	0.302	-0.431	0.370
log Kv	1	1	-0.520	0.674	-0.002	0.254	-0.175	-0.317	0.365
Ø	2	1	0.210	0.639	0.399	0.113	0.329	0.250	0.560
log Kh	2	1	-0.448	1.058	0.078	0.149	0.062	-0.095	0.261
log Kv	2	1	-0.680	1.018	-0.006	0.374	-0.349	-0.452	0.544
Ø	3	1	0.758	1.130	0.909	0.081	0.837	0.811	1.028
log Kh	3	1	-0.206	0.364	0.096	0.157	0.227	-0.126	0.307
log Kv	3	1	-0.492	0.074	-0.176	0.120	-0.109	-0.348	-0.026
Ø	4	1	0.820	1.250	0.965	0.091	0.899	0.854	1.096
log Kh	4	1	-0.157	0.399	0.018	0.096	-0.028	-0.098	0.153
log Kv	4	1	-0.415	0.359	-0.017	0.160	0.001	-0.237	0.196
Ø	5	1	0.640	2.404	1.945	0.293	2.148	1.532	2.280
log Kh	5	1	-0.314	1.872	0.050	0.242	-0.102	-0.190	0.362
log Kv	5	1	-0.911	1.402	0.013	0.300	-0.058	-0.354	0.409
Ø	6	1	0.665	3.007	1.190	0.265	1.073	0.900	1.537
log Kh	6	1	-1.363	0.940	-0.208	0.476	-0.213	-0.853	0.436
log Kv	6	1	-0.830	0.903	0.324	0.410	0.899	-0.285	0.814
Ø	All	1	0.111	2.453	1.107	0.501	0.737	0.493	1.833
Ø	1	2	0.705	1.250	0.978	0.157	0.828	0.760	1.195
log Kh	1	2	-0.934	0.656	-0.343	0.306	-0.468	-0.729	0.086
log Kv	1	2	-0.600	0.324	-0.125	0.208	-0.126	-0.409	0.156
Ø	2	2	0.502	1.623	1.062	0.324	0.788	0.614	1.511
log Kh	2	2	-0.592	1.065	0.193	0.345	0.107	-0.259	0.674
log Kv	2	2	-0.724	0.399	-0.132	0.235	-0.074	-0.460	0.175

Multiplier	Region	Update	Minimum	Maximum	Mean	S. D.	Mode	P10	P90
Ø	3	2	0.315	1.169	0.853	0.192	1.074	0.568	1.081
log Kh	3	2	-0.858	0.833	0.016	0.143	0.015	-0.147	0.179
log Kv	3	2	-1.078	-0.111	-0.604	0.177	-0.598	-0.837	-0.368
Ø	4	2	0.627	1.691	1.159	0.295	1.085	0.750	1.568
log Kh	4	2	-0.080	0.571	0.212	0.137	0.139	0.039	0.407
log Kv	4	2	0.163	0.903	0.654	0.176	0.897	0.391	0.865
Ø	5	2	0.644	2.199	1.421	0.449	1.336	0.799	2.043
log Kh	5	2	-0.234	1.004	0.376	0.255	0.362	0.034	0.724
log Kv	5	2	-1.341	0.721	-0.080	0.459	0.378	-0.757	0.464
Ø	6	2	0.421	0.926	0.629	0.109	0.539	0.497	0.788
log Kh	6	2	-0.775	0.988	0.079	0.350	0.069	-0.388	0.552
log Kv	6	2	-1.498	1.543	-0.419	0.371	-0.504	-0.876	0.069
Ø	All	2	0.395	2.209	1.060	0.415	0.563	0.568	1.675
Ø	1	3	0.882	1.133	0.967	0.060	0.883	0.895	1.055
log Kh	1	3	0.011	0.838	0.366	0.193	0.299	0.113	0.640
log Kv	1	3	-1.245	0.390	-0.427	0.472	-1.155	-1.082	0.227
Ø	2	3	1.194	1.793	1.393	0.092	1.375	1.277	1.517
log Kh	2	3	-0.285	1.779	0.012	0.146	-0.038	-0.134	0.179
log Kv	2	3	-0.486	0.693	0.177	0.270	0.221	-0.202	0.532
Ø	3	3	0.276	0.724	0.511	0.070	0.517	0.418	0.600
log Kh	3	3	-0.309	0.584	0.199	0.190	0.328	-0.075	0.434
log Kv	3	3	-0.398	0.713	0.385	0.196	0.516	0.108	0.617
Ø	4	3	1.076	1.497	1.260	0.094	1.240	1.137	1.391
log Kh	4	3	-0.088	0.904	0.161	0.084	0.143	0.068	0.262
log Kv	4	3	-0.558	1.298	0.114	0.185	0.096	-0.103	0.339
Ø	5	3	0.553	1.427	1.071	0.144	1.088	0.877	1.255
log Kh	5	3	-0.327	0.749	0.055	0.158	0.012	-0.149	0.265
log Kv	5	3	-0.826	0.701	-0.031	0.339	-0.021	-0.496	0.424
Ø	6	3	0.446	1.362	0.823	0.199	0.652	0.583	1.114
log Kh	6	3	-1.142	1.025	0.315	0.324	0.468	-0.125	0.707
log Kv	6	3	-1.340	0.649	-0.076	0.455	0.469	-0.750	0.464
Ø	All	3	0.300	1.670	0.995	0.307	1.038	0.576	1.411
Ø	1	4	0.825	0.957	0.884	0.031	0.871	0.843	0.929
log Kh	1	4	0.355	0.932	0.670	0.129	0.692	0.492	0.841
log Kv	1	4	-1.198	-0.093	-0.624	0.287	-0.522	-1.024	-0.235
Ø	2	4	0.947	1.543	1.206	0.127	1.127	1.048	1.389
log Kh	2	4	-0.189	0.783	0.302	0.226	0.314	-0.007	0.610
log Kv	2	4	-0.608	0.775	0.004	0.219	0.011	-0.283	0.289
Ø	3	4	0.335	0.446	0.399	0.024	0.417	0.364	0.428
log Kh	3	4	-0.243	0.247	-0.072	0.114	-0.222	-0.208	0.098
log Kv	3	4	0.525	0.903	0.714	0.109	0.761	0.563	0.865
Ø	4	4	0.882	1.746	1.096	0.100	1.044	0.986	1.227
log Kh	4	4	0.005	0.420	0.165	0.087	0.129	0.055	0.288
log Kv	4	4	-1.544	0.585	0.085	0.235	0.177	-0.222	0.344
Ø	5	4	0.402	1.104	0.753	0.203	0.532	0.472	1.034
log Kh	5	4	-0.359	0.862	0.048	0.180	-0.003	-0.180	0.289
log Kv	5	4	-1.192	0.903	-0.145	0.605	-0.826	-0.983	0.694
Ø	6	4	1.276	2.153	1.666	0.138	1.656	1.485	1.847
log Kh	6	4	-0.921	1.034	-0.104	0.418	-0.415	-0.614	0.504
log Kv	6	4	-0.959	0.869	-0.111	0.283	-0.066	-0.484	0.253
Ø	i	4	0.338	2.032	0.983	0.430	0.442	0.447	1.616
Ø	1	5	0.691	0.874	0.809	0.024	0.818	0.777	0.837
log Kh	1	5	-0.048	0.755	0.353	0.232	0.173	0.032	0.674
log Kv	1	5	-1.453	-0.134	-0.882	0.281	-1.052	-1.230	-0.476
Ø	2	5	0.906	1.395	1.087	0.079	1.073	0.987	1.193
log Kh	2	5	-0.020	0.921	0.398	0.178	0.369	0.166	0.639
log Kv	2	5	-1.003	0.156	-0.393	0.241	-0.327	-0.729	-0.077
Ø	3	5	0.378	0.504	0.401	0.014	0.395	0.386	0.420
log Kh	3	5	-0.450	0.270	-0.083	0.063	-0.083	-0.155	-0.011
log Kv	3	5	0.426	0.903	0.742	0.114	0.902	0.573	0.878
Ø	4	5	0.630	1.267	1.110	0.073	1.142	1.015	1.190

Multiplier	Region	Update	Minimum	Maximum	Mean	S. D.	Mode	P10	P90
log Kh	4	5	-0.055	0.648	0.268	0.091	0.265	0.151	0.385
log Kv	4	5	-0.422	0.275	0.042	0.165	0.266	-0.203	0.239
Ø	5	5	0.214	1.099	0.760	0.199	0.974	0.466	0.996
log Kh	5	5	-0.179	0.509	0.137	0.156	0.106	-0.070	0.353
log Kv	5	5	-1.168	0.908	-0.006	0.546	0.365	-0.789	0.713
Ø	6	5	1.255	3.455	1.606	0.163	1.544	1.441	1.793
log Kh	6	5	-1.135	1.049	-0.048	0.452	-0.042	-0.660	0.563
log Kv	6	5	-1.151	1.074	-0.155	0.466	-0.376	-0.746	0.509
Ø	All	5	0.260	2.107	0.925	0.426	0.422	0.418	1.558
Ø	1	6	0.629	0.727	0.641	0.008	0.637	0.634	0.651
log Kh	1	6	-0.023	0.286	0.110	0.066	0.069	0.029	0.206
log Kv	1	6	-1.237	-0.730	-0.941	0.108	-0.854	-1.099	-0.809
Ø	2	6	1.209	1.656	1.385	0.098	1.289	1.268	1.530
log Kh	2	6	0.311	0.903	0.705	0.140	0.896	0.496	0.873
log Kv	2	6	-1.166	-0.016	-0.482	0.252	-0.271	-0.852	-0.180
Ø	3	6	0.384	0.457	0.421	0.021	0.409	0.391	0.450
log Kh	3	6	0.046	0.371	0.208	0.094	0.282	0.078	0.338
log Kv	3	6	0.330	0.473	0.402	0.041	0.350	0.345	0.459
Ø	4	6	0.690	0.855	0.773	0.047	0.740	0.707	0.838
log Kh	4	6	0.231	1.673	0.334	0.062	0.309	0.279	0.398
log Kv	4	6	-0.518	0.102	-0.106	0.147	0.094	-0.325	0.070
Ø	5	6	-0.769	1.233	0.779	0.212	0.866	0.503	1.012
log Kh	5	6	-0.281	1.265	0.017	0.207	-0.102	-0.210	0.300
log Kv	5	6	-0.045	0.903	0.429	0.274	0.889	0.050	0.809
Ø	6	6	1.573	1.953	1.736	0.081	1.681	1.637	1.853
log Kh	6	6	-0.395	0.926	0.463	0.274	0.614	0.071	0.801
log Kv	6	6	-0.933	0.259	-0.328	0.301	-0.302	-0.744	0.083
Ø	All	6	0.231	2.141	0.933	0.437	0.409	0.414	1.580
Ø	1	All	0.628	1.252	0.840	0.147	0.639	0.664	1.058
log Kh	1	All	-1.066	0.929	0.231	0.403	0.494	-0.343	0.728
log Kv	1	All	-1.423	0.929	-0.302	0.537	-0.320	-1.024	0.437
Ø	2	All	-0.178	1.668	0.965	0.415	1.401	0.352	1.456
log Kh	2	All	-0.541	1.881	0.210	0.286	0.145	-0.133	0.587
log Kv	2	All	-1.432	1.350	-0.051	0.344	-0.081	-0.492	0.389
Ø	3	All	0.310	1.203	0.635	0.204	0.390	0.392	0.938
log Kh	3	All	-0.309	0.602	0.079	0.194	-0.048	-0.160	0.360
log Kv	3	All	-1.060	0.903	0.240	0.469	0.898	-0.457	0.801
Ø	4	All	0.160	1.714	0.923	0.320	0.896	0.495	1.362
log Kh	4	All	-0.156	0.696	0.165	0.126	0.166	0.002	0.331
log Kv	4	All	-0.606	2.650	0.158	0.298	0.059	-0.193	0.550
Ø	5	All	0.229	2.467	1.199	0.472	0.918	0.610	1.878
log Kh	5	All	-0.372	1.523	0.127	0.235	0.013	-0.137	0.439
log Kv	5	All	-1.291	0.941	0.019	0.505	0.257	-0.696	0.672
Ø	6	All	0.433	2.786	1.293	0.532	0.878	0.632	2.063
log Kh	6	All	-1.295	1.002	0.084	0.444	0.307	-0.534	0.650
log Kv	6	All	-1.379	1.051	-0.102	0.438	-0.101	-0.688	0.474
Ø	All	All	0.034	3.005	0.986	0.445	0.785	0.452	1.591
log Kh	All	All	-1.689	1.574	0.035	0.277	0.033	-0.281	0.350
log Kv	All	All	-0.755	2.011	0.011	0.314	-0.106	-0.349	0.422
log Kh	All	All	-1.898	1.795	0.106	0.355	0.103	-0.324	0.536
log Kv	All	All	-1.322	1.211	-0.112	0.487	-0.070	-0.758	0.543
log Kh	All	All	-0.748	2.043	0.184	0.243	0.155	-0.098	0.481
log Kv	All	All	-2.643	0.980	0.023	0.426	0.218	-0.534	0.492
log Kh	All	All	-0.976	1.274	0.166	0.346	0.209	-0.287	0.614
log Kv	All	All	-1.382	0.903	0.131	0.546	0.897	-0.680	0.784
log Kh	All	All	-1.103	1.001	0.180	0.303	0.263	-0.226	0.545
log Kv	All	All	-1.683	0.903	0.039	0.611	0.897	-0.870	0.770
log Kh	All	All	-0.292	1.053	0.305	0.283	0.162	-0.052	0.709
log Kv	All	All	-1.210	0.938	-0.170	0.532	-0.153	-0.893	0.566

APPENDIX D

D.1 Cumulative Oil Production Distributions for Experiment 4

Chain	Minimum (mstb)	Maximum (mstb)	Mean (mstb)	S.D. (mstb)	Mode (mstb)	P10 (mstb)	P90 (mstb)
*Prior	133,068	716,302	416,471	72,264	422,814	323,840	509,022
Month 1	270,842	589,071	410,539	41,115	404,180	359,110	464,160
Month 2	355,157	573,250	459,056	45,395	447,895	399,553	522,253
Month 3	237,315	627,887	430,842	50,490	432,742	366,114	495,520
Month 4	317,341	558,297	443,669	49,878	455,843	374,238	509,057
Month 5	327,672	562,495	455,147	53,825	459,537	380,252	526,793
Month 6	217,936	533,147	403,033	68,181	459,594	303,344	485,412
Month 7	388,048	581,931	470,902	41,301	442,694	419,983	530,664
Month 8	321,560	528,561	445,151	44,950	484,898	379,243	499,158
Month 9	320,266	578,332	447,154	53,618	444,125	375,233	520,418
Month 10	295,199	576,685	468,462	62,372	532,291	376,377	542,406
Month 11	394,037	578,081	463,794	41,509	418,162	414,677	525,175

*Prior was sampled using Monte Carlo sampling with 3000 iterations

D.2 Regional Multiplier's Distributions for Experiment 4

Multiplier	Region	Update	Minimum	Maximum	Mean	S.D.	Mode	P10	P90
Ø	1	1	-0.036	1.883	0.740	0.421	0.367	0.235	1.356
log Kv	1	1	-0.672	0.232	-0.235	0.206	-0.266	-0.513	0.048
log Kh	1	1	-0.849	0.246	-0.248	0.266	-0.182	-0.621	0.105
Ø	2	1	-0.103	1.981	0.776	0.444	0.459	0.232	1.420
log Kv	2	1	-2.481	0.887	0.023	0.397	0.170	-0.496	0.460
log Kh	2	1	-0.722	0.904	0.091	0.470	-0.584	-0.560	0.742
Ø	3	1	0.615	1.792	1.108	0.252	0.920	0.799	1.474
log Kv	3	1	-0.906	0.700	0.069	0.326	0.227	-0.388	0.482
log Kh	3	1	-0.338	1.097	0.287	0.302	0.108	-0.090	0.720
Ø	4	1	0.008	1.465	0.495	0.345	0.019	0.083	1.008
log Kv	4	1	-1.573	2.125	0.221	0.260	0.222	-0.074	0.515
log Kh	4	1	-0.653	0.728	0.043	0.285	0.072	-0.345	0.426
Ø	5	1	-0.305	4.450	0.982	0.405	0.871	0.540	1.468
log Kv	5	1	-1.266	0.914	-0.049	0.558	0.221	-0.844	0.687
log Kh	5	1	-0.493	1.000	0.080	0.335	-0.279	-0.316	0.575
Ø	6	1	0.766	2.426	1.486	0.448	0.987	0.900	2.133
log Kv	6	1	-0.992	0.505	-0.280	0.311	-0.355	-0.688	0.152
log Kh	6	1	-0.534	1.086	0.108	0.356	-0.228	-0.317	0.630
Ø	ALL	1	-0.070	3.409	0.912	0.502	0.698	0.297	1.594
log Kv	ALL	1	-1.421	1.055	-0.046	0.391	0.031	-0.565	0.460
log Kh	ALL	1	-0.819	1.089	0.060	0.398	-0.078	-0.454	0.620
Ø	1	2	0.002	2.021	1.012	0.583	0.416	0.204	1.819
log Kv	1	2	-0.412	0.977	0.167	0.249	0.103	-0.154	0.506

Multiplier	Region	Update	Minimum	Maximum	Mean	S.D.	Mode	P10	P90
log Kh	1	2	-0.907	0.524	-0.148	0.310	-0.064	-0.574	0.266
Ø	2	2	-0.020	1.629	0.748	0.391	0.646	0.224	1.292
log Kv	2	2	-0.819	1.060	0.183	0.392	0.317	-0.368	0.689
log Kh	2	2	-0.978	0.958	0.112	0.289	0.162	-0.275	0.472
Ø	3	2	0.445	2.265	1.574	0.411	2.026	0.967	2.060
log Kv	3	2	-1.178	0.724	-0.300	0.503	-0.394	-0.975	0.412
log Kh	3	2	-0.624	0.903	0.388	0.364	0.891	-0.154	0.824
Ø	4	2	0.428	1.858	1.129	0.210	1.138	0.850	1.396
log Kv	4	2	-1.052	0.969	0.152	0.440	0.542	-0.493	0.680
log Kh	4	2	-0.353	0.904	0.276	0.363	0.169	-0.227	0.778
Ø	5	2	0.100	2.053	1.168	0.409	1.359	0.586	1.689
log Kv	5	2	-2.349	1.045	0.171	0.375	0.318	-0.320	0.584
log Kh	5	2	-1.433	1.283	0.025	0.259	0.028	-0.288	0.338
Ø	6	2	0.213	2.003	1.012	0.448	0.882	0.418	1.647
log Kv	6	2	-1.011	0.588	-0.117	0.233	-0.068	-0.428	0.171
log Kh	6	2	-0.900	0.698	-0.061	0.395	0.041	-0.612	0.472
Ø	ALL	2	-0.104	2.258	1.103	0.487	1.172	0.433	1.753
log Kv	ALL	2	-1.482	1.046	0.034	0.425	0.102	-0.543	0.571
log Kh	ALL	2	-0.927	1.054	0.090	0.379	0.057	-0.419	0.593
Ø	1	3	-0.062	1.674	0.871	0.379	0.898	0.348	1.376
log Kv	1	3	-0.930	0.904	-0.013	0.530	0.675	-0.747	0.721
log Kh	1	3	-0.561	0.904	0.171	0.423	0.530	-0.415	0.757
Ø	2	3	0.460	1.861	1.032	0.225	0.993	0.742	1.330
log Kv	2	3	-0.590	0.833	0.039	0.301	-0.131	-0.337	0.471
log Kh	2	3	-0.659	0.969	0.054	0.344	-0.131	-0.376	0.547
Ø	3	3	0.143	1.972	1.088	0.508	1.209	0.377	1.781
log Kv	3	3	-1.061	0.690	-0.138	0.463	-0.056	-0.789	0.488
log Kh	3	3	-0.459	0.810	0.105	0.267	-0.017	-0.233	0.487
Ø	4	3	-0.152	1.735	0.969	0.410	1.311	0.369	1.462
log Kv	4	3	-2.988	1.825	-0.450	0.352	-0.453	-0.851	-0.050
log Kh	4	3	-0.733	0.925	0.070	0.343	0.020	-0.387	0.541
Ø	5	3	0.097	1.667	0.891	0.328	0.934	0.447	1.332
log Kv	5	3	-0.752	0.417	-0.182	0.292	-0.237	-0.580	0.222
log Kh	5	3	-0.266	0.904	0.319	0.338	0.535	-0.150	0.787
Ø	6	3	0.375	2.393	1.378	0.278	1.375	1.022	1.734
log Kv	6	3	-0.877	1.082	0.129	0.304	0.191	-0.274	0.515
log Kh	6	3	-0.904	0.524	-0.236	0.281	-0.262	-0.608	0.146
Ø	ALL	3	-0.015	2.007	1.032	0.419	1.108	0.453	1.587
log Kv	ALL	3	-1.187	0.968	-0.093	0.446	-0.057	-0.702	0.505
log Kh	ALL	3	-0.876	1.103	0.092	0.374	0.072	-0.404	0.593
Ø	1	4	0.329	3.429	1.272	0.372	1.173	0.834	1.763
log Kv	1	4	-0.400	0.938	0.289	0.329	0.350	-0.167	0.736
log Kh	1	4	-1.550	0.408	-0.363	0.455	-0.035	-1.017	0.215
Ø	2	4	-0.314	1.783	0.759	0.294	0.823	0.367	1.126
log Kv	2	4	-0.763	0.911	0.188	0.417	0.313	-0.407	0.734
log Kh	2	4	-0.980	0.489	-0.208	0.268	-0.188	-0.566	0.147
Ø	3	4	0.083	1.807	0.925	0.355	0.896	0.450	1.410
log Kv	3	4	-1.371	0.774	0.122	0.325	0.289	-0.325	0.510
log Kh	3	4	-0.667	0.903	0.375	0.374	0.883	-0.181	0.822
Ø	4	4	0.260	2.644	1.144	0.541	0.522	0.504	1.945
log Kv	4	4	-0.810	0.814	0.111	0.343	0.325	-0.383	0.538
log Kh	4	4	-0.287	0.974	0.212	0.278	-0.057	-0.120	0.620
Ø	5	4	0.007	2.279	1.015	0.505	0.850	0.349	1.720
log Kv	5	4	-1.272	0.912	-0.233	0.574	-0.350	-1.012	0.572
log Kh	5	4	-0.536	0.932	0.290	0.339	0.396	-0.187	0.736
Ø	6	4	0.296	1.735	0.980	0.225	1.003	0.683	1.271
log Kv	6	4	-0.310	0.904	0.297	0.351	0.813	-0.189	0.782
log Kh	6	4	-0.879	0.984	-0.036	0.387	-0.216	-0.530	0.513
Ø	ALL	4	-0.159	2.989	1.018	0.434	0.871	0.488	1.592
log Kv	ALL	4	-1.437	0.961	0.124	0.446	0.334	-0.501	0.677
log Kh	ALL	4	-1.590	1.450	0.027	0.435	0.146	-0.554	0.568

Multiplier	Region	Update	Minimum	Maximum	Mean	S.D.	Mode	P10	P90
Ø	1	5	-1.133	2.335	1.532	0.378	1.688	1.039	1.947
log Kv	1	5	-0.509	0.930	0.238	0.350	0.228	-0.247	0.711
log Kh	1	5	-1.277	0.904	-0.186	0.630	-0.023	-1.059	0.686
Ø	2	5	-0.065	2.168	0.988	0.465	0.873	0.379	1.637
log Kv	2	5	-0.912	0.842	0.103	0.254	0.148	-0.236	0.418
log Kh	2	5	-1.070	1.127	0.096	0.315	0.180	-0.324	0.492
Ø	3	5	0.574	2.261	1.237	0.372	0.876	0.794	1.785
Ø	3	5	0.573	2.254	1.237	0.372	0.885	0.794	1.784
log Kv	3	5	-1.574	1.841	0.018	0.302	0.035	-0.347	0.383
log Kh	3	5	-0.594	0.904	0.155	0.433	0.896	-0.445	0.754
Ø	4	5	-0.364	1.666	1.042	0.367	1.241	0.523	1.481
log Kv	4	5	-0.869	0.903	0.310	0.419	0.899	-0.313	0.812
log Kh	4	5	-0.330	0.926	0.185	0.260	0.089	-0.149	0.548
Ø	5	5	-0.015	1.527	0.678	0.354	0.636	0.209	1.173
log Kv	5	5	-0.531	0.904	0.205	0.397	0.350	-0.349	0.748
log Kh	5	5	-0.103	0.904	0.400	0.291	0.446	-0.002	0.803
Ø	6	5	0.080	2.043	1.030	0.443	0.992	0.432	1.638
log Kv	6	5	-1.107	0.467	-0.211	0.367	-0.063	-0.730	0.269
log Kh	6	5	-0.765	0.916	0.207	0.414	0.446	-0.387	0.745
Ø	ALL	5	-0.060	2.190	1.098	0.482	1.111	0.440	1.744
log Kv	ALL	5	-1.123	1.012	0.117	0.399	0.244	-0.431	0.629
log Kh	ALL	5	-1.397	0.946	0.144	0.459	0.429	-0.508	0.709
Ø	1	6	-0.023	2.156	1.197	0.318	1.245	0.772	1.591
log Kv	1	6	-0.361	0.903	0.477	0.301	0.900	0.028	0.837
log Kh	1	6	-1.095	0.761	-0.012	0.400	0.308	-0.596	0.474
Ø	2	6	0.656	2.372	1.351	0.355	1.219	0.895	1.848
log Kv	2	6	-1.215	0.650	-0.090	0.405	0.271	-0.685	0.394
log Kh	2	6	-0.745	1.629	0.273	0.215	0.247	0.014	0.533
Ø	3	6	0.167	2.442	1.198	0.581	0.869	0.424	2.019
log Kv	3	6	-1.381	0.377	-0.331	0.386	0.021	-0.897	0.132
log Kh	3	6	-0.415	2.131	0.108	0.287	-0.048	-0.214	0.492
Ø	4	6	0.228	1.453	0.883	0.296	0.979	0.469	1.280
log Kv	4	6	-0.880	0.951	-0.035	0.433	-0.110	-0.614	0.569
log Kh	4	6	-0.433	0.907	0.126	0.288	-0.097	-0.225	0.546
Ø	5	6	0.001	1.386	0.469	0.331	0.005	0.073	0.960
log Kv	5	6	-0.712	0.934	0.322	0.373	0.751	-0.232	0.764
log Kh	5	6	-0.458	1.020	0.202	0.310	0.048	-0.190	0.643
Ø	6	6	0.336	2.286	1.132	0.423	0.781	0.621	1.750
log Kv	6	6	-0.675	0.904	0.115	0.456	-0.130	-0.517	0.746
log Kh	6	6	-0.961	0.923	0.097	0.401	0.335	-0.479	0.597
Ø	ALL	6	-0.101	2.431	1.036	0.502	0.952	0.379	1.722
log Kv	ALL	6	-1.343	0.939	0.070	0.482	0.314	-0.613	0.681
log Kh	ALL	6	-1.173	1.221	0.123	0.345	0.193	-0.338	0.551
Ø	1	7	0.127	2.308	1.194	0.606	1.095	0.363	2.040
log Kv	1	7	-0.484	1.005	0.135	0.322	-0.122	-0.256	0.604
log Kh	1	7	-0.540	0.904	0.182	0.417	0.074	-0.396	0.759
Ø	2	7	-1.427	4.719	1.412	0.472	1.409	0.876	1.948
log Kv	2	7	-0.428	0.666	0.031	0.235	-0.133	-0.257	0.372
log Kh	2	7	-0.512	0.715	-0.118	0.177	-0.156	-0.341	0.119
Ø	3	7	0.400	1.682	1.096	0.291	1.155	0.691	1.484
log Kv	3	7	-1.382	0.688	-0.268	0.431	-0.105	-0.877	0.286
log Kh	3	7	-0.549	1.415	0.111	0.244	0.037	-0.183	0.434
Ø	4	7	0.434	2.188	1.273	0.364	1.185	0.795	1.778
log Kv	4	7	-1.554	2.807	-0.469	0.384	-0.557	-0.891	-0.006
log Kh	4	7	-1.044	0.903	0.247	0.464	0.898	-0.443	0.802
Ø	5	7	0.754	2.404	1.477	0.399	1.374	0.951	2.042
log Kv	5	7	-0.791	0.852	0.195	0.362	0.534	-0.337	0.627
log Kh	5	7	-1.106	0.334	-0.236	0.316	0.062	-0.701	0.141
Ø	6	7	-0.101	1.442	0.729	0.320	0.839	0.280	1.142
log Kv	6	7	0.213	10.701	1.177	0.875	0.536	0.444	2.232
log Kh	6	7	-1.255	0.978	0.022	0.475	0.359	-0.666	0.608

Multiplier	Region	Update	Minimum	Maximum	Mean	S.D.	Mode	P10	P90
Ø	ALL	7	-0.099	2.802	1.195	0.492	1.160	0.557	1.854
log Kv	ALL	7	-1.811	7.575	0.135	0.668	-0.062	-0.589	0.933
log Kh	ALL	7	-1.072	1.001	0.000	0.430	0.064	-0.593	0.572
Ø	1	8	0.291	2.192	1.227	0.393	1.193	0.700	1.764
log Kv	1	8	-0.596	0.810	0.057	0.295	0.001	-0.334	0.461
log Kh	1	8	-1.364	0.904	-0.230	0.655	-1.331	-1.138	0.677
Ø	2	8	0.254	1.926	0.981	0.357	0.767	0.538	1.495
log Kv	2	8	-0.232	1.771	0.236	0.243	0.110	-0.029	0.557
log Kh	2	8	-0.544	0.904	0.180	0.418	-0.102	-0.399	0.759
Ø	3	8	-0.017	1.667	0.725	0.356	0.525	0.280	1.235
log Kv	3	8	-1.373	0.823	-0.313	0.457	-0.406	-0.918	0.317
log Kh	3	8	-0.576	0.889	0.101	0.232	0.123	-0.204	0.400
Ø	4	8	0.074	2.162	1.295	0.451	1.656	0.636	1.842
log Kv	4	8	-0.724	0.928	0.143	0.379	0.145	-0.380	0.651
log Kh	4	8	-0.846	1.071	0.057	0.335	0.068	-0.385	0.503
Ø	5	8	0.627	4.539	1.281	0.293	1.187	0.985	1.619
log Kv	5	8	-0.305	0.957	0.366	0.277	0.361	-0.016	0.736
log Kh	5	8	-1.167	0.799	0.062	0.446	0.543	-0.598	0.589
Ø	6	8	-0.037	1.743	0.749	0.384	0.704	0.244	1.281
log Kv	6	8	0.375	18.513	3.125	1.936	1.948	1.108	5.708
log Kh	6	8	-0.855	0.346	-0.229	0.249	-0.182	-0.576	0.098
Ø	ALL	8	-0.074	2.203	1.034	0.447	0.971	0.440	1.638
log Kv	ALL	8	-1.252	17.895	0.471	1.088	0.035	-0.496	1.606
log Kh	ALL	8	-1.717	1.249	0.000	0.432	0.132	-0.578	0.533
Ø	1	9	0.004	1.954	1.070	0.408	1.272	0.489	1.588
log Kv	1	9	-0.835	0.512	-0.177	0.280	-0.208	-0.551	0.208
log Kh	1	9	-0.881	1.152	-0.109	0.403	-0.297	-0.618	0.456
Ø	2	9	0.761	2.093	1.360	0.281	1.220	1.004	1.760
log Kv	2	9	-0.413	0.604	0.104	0.235	0.109	-0.218	0.422
log Kh	2	9	-0.533	1.476	0.176	0.278	0.149	-0.183	0.543
Ø	3	9	-0.798	1.821	1.116	0.295	1.250	0.731	1.440
log Kv	3	9	-0.987	0.680	-0.060	0.350	0.116	-0.559	0.382
log Kh	3	9	-0.543	0.696	0.031	0.245	0.007	-0.292	0.364
Ø	4	9	0.320	1.738	0.950	0.249	0.910	0.627	1.286
log Kv	4	9	-0.460	0.909	0.337	0.341	0.536	-0.154	0.779
log Kh	4	9	-1.119	0.828	-0.319	0.423	-0.669	-0.830	0.298
Ø	5	9	0.233	2.006	1.263	0.383	1.568	0.705	1.728
log Kv	5	9	-1.893	0.506	-0.482	0.518	-0.078	-1.238	0.145
log Kh	5	9	-1.707	0.763	-0.357	0.521	-0.114	-1.098	0.307
Ø	6	9	0.297	2.861	1.291	0.567	0.713	0.618	2.127
log Kv	6	9	0.274	7.130	1.880	0.969	1.338	0.755	3.208
log Kh	6	9	-0.948	0.877	-0.028	0.395	0.025	-0.564	0.504
Ø	ALL	9	-0.630	3.428	1.171	0.407	1.134	0.685	1.668
log Kv	ALL	9	-1.840	11.013	0.220	0.840	-0.054	-0.663	1.206
log Kh	ALL	9	-1.995	1.162	-0.099	0.432	0.014	-0.677	0.430
Ø	1	10	0.672	2.202	1.486	0.320	1.578	1.038	1.901
log Kv	1	10	-0.721	1.119	-0.029	0.413	-0.473	-0.517	0.581
log Kh	1	10	-0.925	0.848	0.163	0.394	0.556	-0.419	0.630
Ø	2	10	0.093	1.841	1.252	0.417	1.819	0.631	1.751
log Kv	2	10	-0.462	0.726	0.094	0.247	0.030	-0.228	0.439
log Kh	2	10	-0.437	0.904	0.234	0.387	-0.162	-0.303	0.770
Ø	3	10	0.001	1.739	0.870	0.502	0.879	0.174	1.565
log Kv	3	10	-1.305	0.396	-0.455	0.491	0.047	-1.135	0.226
log Kh	3	10	-0.361	0.491	-0.074	0.163	-0.166	-0.273	0.156
Ø	4	10	0.054	1.763	1.006	0.363	1.208	0.486	1.461
log Kv	4	10	-0.782	0.588	-0.198	0.333	-0.307	-0.632	0.276
log Kh	4	10	-0.420	0.848	0.341	0.279	0.611	-0.070	0.674
Ø	5	10	0.343	2.187	1.265	0.520	1.256	0.545	1.985
log Kv	5	10	-0.626	0.853	0.114	0.427	0.225	-0.478	0.705
log Kh	5	10	-0.499	0.911	0.302	0.301	0.499	-0.133	0.673
Ø	6	10	0.198	2.044	1.007	0.391	0.776	0.517	1.569

Multiplier	Region	Update	Minimum	Maximum	Mean	S.D.	Mode	P10	P90
log Kv	6	10	-0.579	0.907	0.137	0.412	-0.045	-0.425	0.715
log Kh	6	10	-0.937	0.562	-0.347	0.332	-0.686	-0.742	0.142
Ø	ALL	10	-0.095	2.185	1.177	0.483	1.450	0.483	1.782
log Kv	ALL	10	-1.539	1.066	-0.038	0.444	0.036	-0.639	0.535
log Kh	ALL	10	-0.976	0.974	0.097	0.396	0.173	-0.447	0.619
Ø	1	11	0.363	2.030	1.196	0.481	1.005	0.529	1.863
log Kv	1	11	-1.130	0.441	0.057	0.179	0.131	-0.176	0.254
log Kh	1	11	-0.983	0.657	-0.288	0.259	-0.331	-0.624	0.053
Ø	2	11	0.399	1.493	0.867	0.213	0.823	0.592	1.160
log Kv	2	11	-0.195	0.954	0.446	0.241	0.574	0.100	0.749
log Kh	2	11	-0.548	0.696	-0.133	0.294	-0.545	-0.485	0.304
Ø	3	11	0.997	1.761	1.376	0.179	1.383	1.131	1.620
log Kv	3	11	-0.335	0.652	0.216	0.175	0.262	-0.021	0.443
log Kh	3	11	-0.685	0.424	-0.112	0.229	-0.078	-0.428	0.191
Ø	4	11	0.581	2.211	1.277	0.349	1.029	0.847	1.783
log Kv	4	11	-0.919	0.020	-0.558	0.207	-0.770	-0.804	-0.252
log Kh	4	11	-0.519	0.848	0.213	0.277	0.207	-0.165	0.581
Ø	5	11	0.009	1.661	0.835	0.477	1.504	0.173	1.495
log Kv	5	11	-0.864	0.335	-0.128	0.267	0.152	-0.522	0.189
log Kh	5	11	-0.540	1.043	0.237	0.328	0.201	-0.202	0.686
Ø	6	11	0.433	3.435	1.124	0.320	1.012	0.771	1.542
log Kv	6	11	-1.152	0.766	-0.287	0.527	-0.979	-0.987	0.469
log Kh	6	11	-0.331	0.739	0.184	0.221	0.150	-0.108	0.490
Ø	ALL	11	-0.441	2.271	1.126	0.419	1.229	0.567	1.657
log Kv	ALL	11	-1.184	0.926	-0.030	0.438	0.162	-0.652	0.530
log Kh	ALL	11	-0.972	1.264	0.024	0.337	-0.015	-0.411	0.470
Ø	1	ALL	-0.141	2.376	1.151	0.494	1.121	0.486	1.810
log Kv	1	ALL	-0.923	1.133	0.099	0.377	0.072	-0.402	0.601
log Kh	1	ALL	-1.522	1.028	-0.089	0.489	-0.034	-0.758	0.548
Ø	2	ALL	-0.120	3.128	1.061	0.456	1.055	0.470	1.661
log Kv	2	ALL	-1.205	1.443	0.122	0.338	0.126	-0.310	0.555
log Kh	2	ALL	-0.869	1.369	0.057	0.349	-0.011	-0.384	0.523
Ø	3	ALL	-0.182	2.502	1.107	0.451	1.117	0.518	1.706
log Kv	3	ALL	-1.322	0.739	-0.143	0.441	0.158	-0.782	0.400
log Kh	3	ALL	-0.599	0.998	0.130	0.334	-0.014	-0.297	0.602
Ø	4	ALL	-0.108	2.601	1.054	0.430	1.043	0.493	1.616
log Kv	4	ALL	-1.245	0.953	-0.005	0.476	0.069	-0.668	0.619
log Kh	4	ALL	-1.215	1.029	0.120	0.388	0.236	-0.411	0.610
Ø	5	ALL	-0.130	2.379	1.047	0.502	1.015	0.382	1.728
log Kv	5	ALL	-1.837	0.937	0.026	0.510	0.273	-0.692	0.644
log Kh	5	ALL	-3.005	1.177	0.088	0.490	0.301	-0.553	0.628
Ø	6	ALL	-0.334	3.069	1.053	0.455	0.914	0.494	1.652
log Kv	6	ALL	-1.142	47.153	0.683	1.634	-0.019	-0.492	2.089
log Kh	6	ALL	-1.108	1.136	-0.030	0.405	-0.085	-0.567	0.513
Ø	ALL	ALL	-0.190	2.827	1.080	0.465	1.064	0.476	1.690
log Kv	ALL	ALL	-1.608	5.869	0.119	0.591	-0.013	-0.535	0.831
log Kh	ALL	ALL	-1.500	1.276	0.049	0.412	0.137	-0.498	0.570