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Local Update of Object-Based Geomodels

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Abstract

A method for local updating of object-based facies models by further development of already existing software is presented. An existing facies realization is adjusted to match new well observations by changing objects locally or adding/removing objects if required. Parts of the realization which is not influenced by the new wells are not changed. Local update of a specified region of the reservoir can be performed, leaving the rest of the reservoir unchanged or with minimum change due to new wells.

The main focus in the method is on the algorithm implemented to fulfill well conditioning. The effect of this algorithm on different object models is presented through several case studies. These studies show how the local update consistently includes new information while leaving the rest of the realization unperturbed and thereby preserves the good history match.

Introduction

Rapid updating of static and dynamic reservoir models is important for reservoir management. Continual maintenance of history matched models allows for right time decisions to optimize the reservoir performance. The process from drilling a new well through to update of the static model and history matching of the new model is often a time consuming process. Static reservoir models and history matches are only updated intermittently and there is typically a one to two year delay between the drilling of a new well and the generation of a reliable history matched model which incorporates the new information.

This paper presents new algorithms which allow rapid updating of static reservoir models when new wells are drilled. The static model update is designed to keep as much of the existing history match by locally adjusting the existing static model to the new well data. For many reservoir types, stochastic object models provide the best reservoir description for understanding reservoir connectivity and for history matching purposes. The algorithms presented in this paper are designed for local updating of such models.

As the name implies, object models use a set of facies objects to generate a facies realization. The model gives control of the geometry of these objects and the interaction between them, so geological input is important. In addition to the geometrical control, the main advantage of object models is the ability to create petrophysical trends inside objects and to correlate facies objects between observations in different wells.

Two main groups of objects are treated by the algorithm for local update. The first is fluvial channels. These typically run through the reservoir along a main direction line. Holden et al. (1998) describes how the modeling and simulation of such objects is performed. The other group consists of general objects characterized as axial or backbone. These are generally of limited size. Hauge et al. (2006) and Lia et al. (1996) give a description of these models. In the next section the object models are briefly presented.

An algorithm is developed to make the updated model condition all well observations correctly. Where there is conflict between well observations and an object, a local change in the object is attempted. For complex well patterns, such changes may not be sufficient to solve the problem; in these cases, the conflicting object is removed. Similarly, for observations that are not conditioned by objects, a local change in a nearby object is attempted in order to match the observation. If this fails for all nearby objects, a new object is generated to cover the observation.

For the objects of general shape and limited extension it is possible to define a region of the reservoir where a local update is performed. Then all objects with reference point inside the region can be changed or removed, and new objects can be added. Model parameters can be changed within the region, such that for example object size and intensity is different inside and outside. Outside the region objects are kept unchanged, except necessary changes due to well conditioning.

Object models

The main parameterization of the object models used here is the same, so a common algorithm can do local updating in all of them. The objects are defined relative to a main axis. Along this axis, the width and relative horizontal location of the object centre are given as 1D Gaussian fields. Similarly, the thickness and relative vertical location of the object centre are given as 2D Gaussian fields, with one axis along the main axis and one in the local width direction.

The difference between the models lies in how the main axis is defined. For the fluvial channel model, the main axis is an infinite straight line, so the object never starts or ends inside the modeling area. The axial objects in the general model are very similar, except that the line here is finite, so most objects start and end inside the modeling area. The backbone object is a more generalized version, as the main axis here is a set of connected line segments. The orientation of these segments can be specified by azimuth maps. An example of a backbone object is shown in Figure 1.

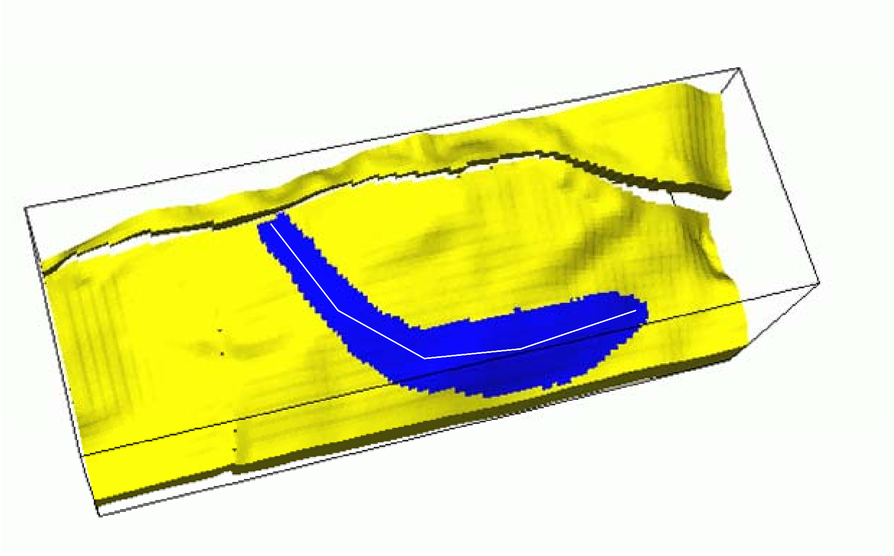

Figure 1: Example of a backbone lobe with main axis in white.

The shape of the object is defined by the global location of the main axis, and the expectation and variance structure of the Gaussian fields. Each object has a width parameter and a thickness parameter, which are drawn from a user-defined distribution. These are used to scale the expectation and variance of the corresponding Gaussian fields. The correlation structure in the Gaussian fields is also important for the object shape, as illustrated in Figure 2.

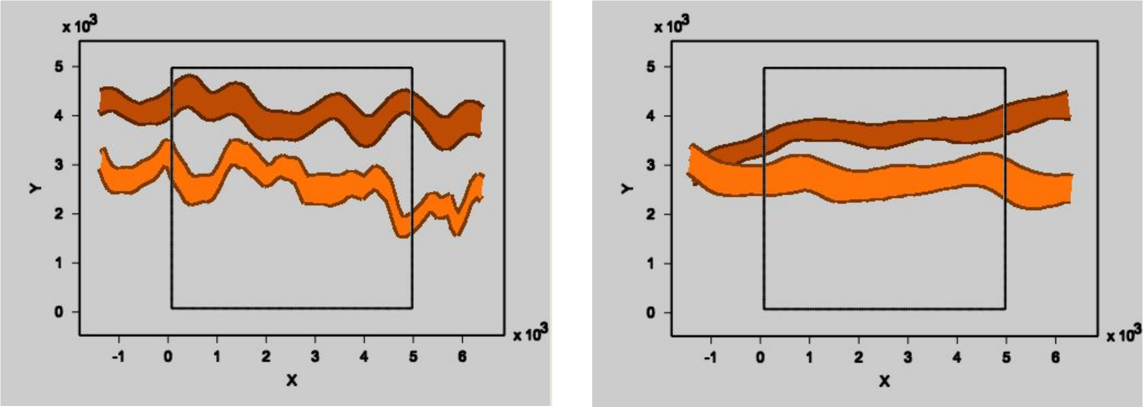

Figure 2: Examples of channels with short (left) and long (right) correlation length for the Gaussian fields.

Conditioning algorithm

For the update algorithm it is an overall principle to keep the changes in the realization as small as possible within the specified model and to condition all well observations correctly. This means that much attention is given to make existing objects incorporate unconditioned observations. Only in case this is impossible or nearly impossible new objects are generated. This will also ensure that the volume fraction is as close as possible to the original.

In the following, objects present in the original realization are called existing objects. The conditioning is divided in five main steps.

(i) Identify observations that are in conflict with existing objects.
(ii) Identify observations that are not conditioned by existing objects.
(iii) Assign all unconditioned observations to existing objects, if possible.
(iv) For each object with conflicts or newly assigned observations:
    a. Simulate local changes in existing objects such that well conditionings are fulfilled, if possible.
    b. If the object fails to cover an assigned unconditioned observation, this observation is reassigned if possible.
    c. If the object does not manage to avoid a conflicting observation, it is removed, and all its observations reassigned to other objects if possible.
(v) Simulate new objects to condition observations that are still unconditioned.

Identify observations. When the update model is initiated all observations are classified as conditioned or unconditioned. Some of the unconditioned observations might be in conflict with existing objects. These have to be identified. The types of possible conflicts are background facies seen inside an object, observation of wrong facies type inside an object or discrepancy between the size of the object and the size of the observation. For each such identified conflict, the object is changed in a region around the location of the conflicting observation.

Assign unconditioned observations to objects. All unconditioned observations are tentatively assigned to condition an existing object. To do that, the distance from the observation to each object is calculated according to some defined distance function. This distance is not well defined for all pairs of observations and objects, in case it is set to infinity. For all observations where the distance to at least one object is less than a maximum limit, the observation is assigned to the closest object.

Simulate local changes. When all the unconditioned observations are identified and assigned to objects as far as possible, the objects are perturbed one by one. The assigned conditioning observations and those in conflict with the object, together define which parts of the object that is changed. The objects are changed one correlation length to each side of these observations. This gives one or more intervals where new Gaussian fields for the object position must be drawn. The object position outside the change intervals define conditioning points for the simulations inside the interval to ensure that the merging between changed and unchanged parts of the objects is done smoothly. If it is impossible to change an object so that the conditioning and the constraints defined by the conflicts is fulfilled, the object is removed, and all belonging observations become unconditioned. Figure 3 shows the original channel from an unconditional simulation (left) updated to include well01 and to avoid well05 (right).

Simulate new objects. When the local changes are completed on existing objects, the remaining unconditioned observations are used to simulate new objects.

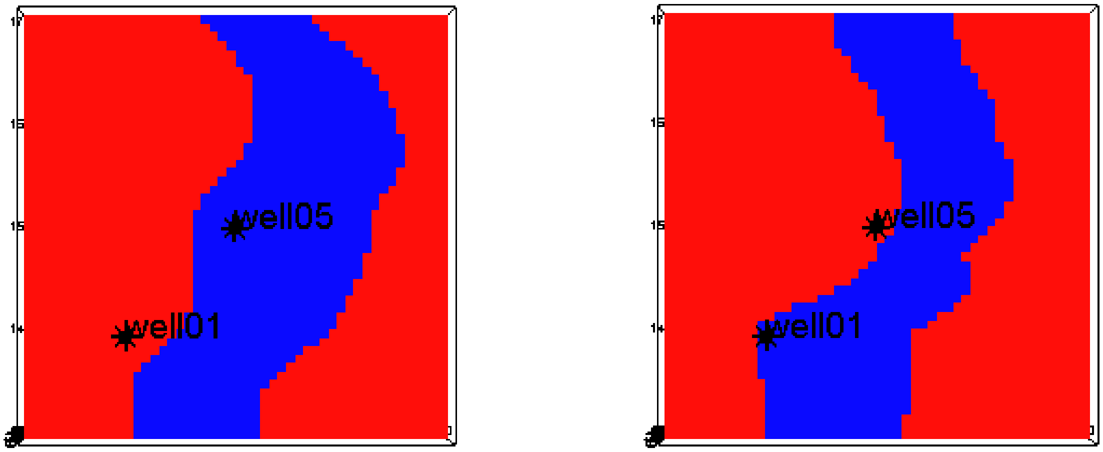

Figure 3: Left: Single channel object that has not been conditioned to well01 and well05. Right: Local update conditioned to observations in the same wells. The channel was penetrated by well01, but not well05.

Examples

The algorithm presented above is used on three different stochastic object models to illustrate how the concept of local update improves the reservoir management including history matching. The first two examples show the update after a new well is drilled in a fluvial channel model and a turbidite object model respectively. The last example illustrates a regional local update.

Local update of fluvial channel model

An oilfield has been produced under pure depletion. Most wells are located along the structural high of the rotated fault block. A number of infill wells have been planned due to declining oil rates. Well prod_34 was targeted to tap into an area of high net oil volume between wells that have been producing at high rates. Figure 4 (left) shows the average sand distribution map based on the existing reservoir model before prod_34 was drilled. Figure 5 (left) shows the net oil column map of the field. Figure 4 (centre) and Figure 5 (centre) shows the average sand distributions and net oil column map of the updated model. As can be seen the differences from the pre-update model (left) is localized to the area around prod_34.

The existing static reservoir model predicted that the infill well would penetrate thick channel sand. The facies prognosis in prod_34 is seen in Figure 6 (lower right, left). When drilled, prod_34 penetrated the sand interval of expected sand with minor deviations from the predicted thickness. The well also penetrated three additional sand intervals not predicted from the original model. The observed facies in prod_34 is seen in Figure 6 (lower right, right).

A local update simulation incorporating the new well data in prod_34 was run. The algorithm locally adjusted the channels which were encountered in the well to match exactly the correct thicknesses and depths by adjusting already existing channels sand objects. Figure 6 shows the channels involved in the local model update. To the left are the channels before the local update. In the centre are the same channels updated to condition the observations in prod_34. The upper right figure shows details of the changing geometry of one of the channels to fit the uppermost sand observation in the well. The updated object (without gridlines) is wider than the original near the well in order to include the observation.

To illustrate the flow properties of the model before and after the local update, streamlines have been simulated between wells to the north and south of the field. Figure 7 (left) shows the streamlines from the pre-update model. There is no connection between the wells in the southern area of the field, and no connection between the wells to the north and south. Figure 7 (centre) shows that the flow pattern has not changed after the local update has been performed.

For comparison between the effect of performing a local update and a new simulation, a conventional full update by re-simulation with the new well was executed. Adding just a new well to the stochastic simulation resulted in significant changes in the sand distribution (Figure 4, right), net oil column map (Figure 5, right) and flow pattern (Figure 7, right). This is a long way off from the existing history matched model and a poor starting point for the history match.

In contrast the locally updated model is already matched throughout the field and only small adjustments in the region of the new well will be necessary to achieve a history matched model which can be used to optimize the reservoir performance.

Local update of turbidite object model

The updating of a history matched turbidite reservoir model is illustrated. The reservoir has been modeled using a backbone object model. This type of model is ideal for modeling of turbidite reservoirs where the local orientation is strongly controlled by paleotopography of the seafloor. The overall location and distribution of the turbidites can be identified from seismic attributes. A number of wells have been drilled and a model conditioned to the well observations has been built. Average sand distribution can be seen in Figure 8 (left) and the net oil column map in Figure 9 (left). Production data have been history matched. Seismic information indicates a lobe system separated from the lobes on the main area of the field. This system had not been penetrated and it was decided to drill a well to verify the existence of these lobes and optionally to convert the well to a producer.

Sampling the model from the proposed location of well South_1 indicated the existence of one single lobe. The well however revealed the existence of two separate lobes, as illustrated in Figure 8 (right).

The model was locally updated. The existing lobe was modified to match the new well observation, and a new lobe was inserted and conditioned to the well. Figure 8 (centre) and 9 (right) show that the update had only local influence on the model, restricted to the area south of the main field.

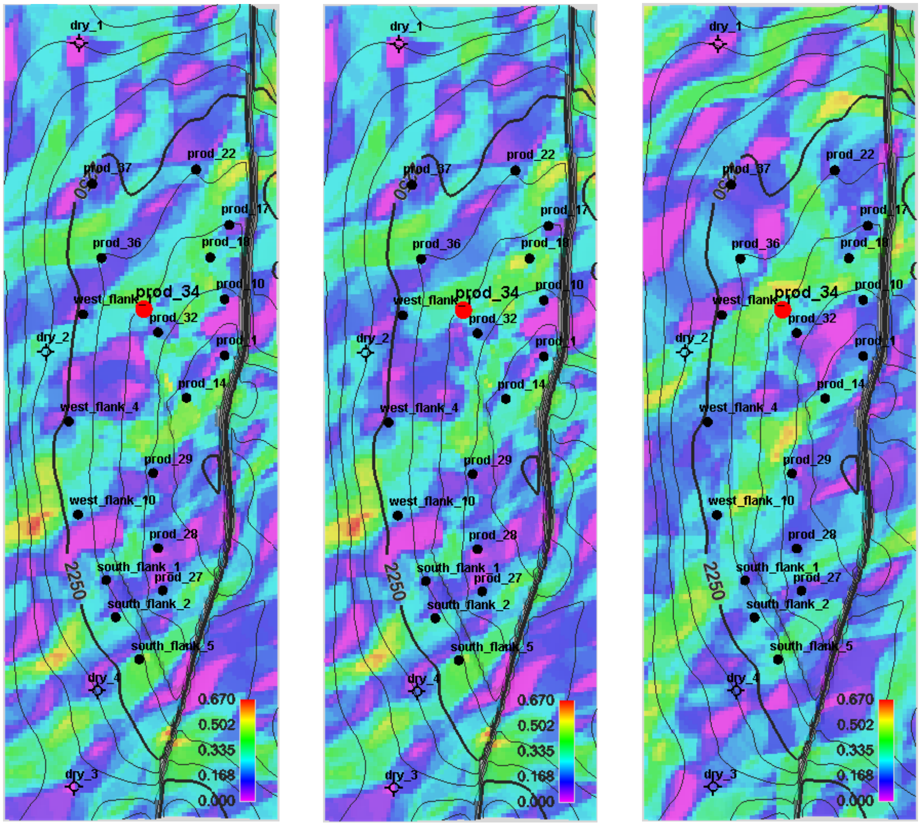

Figure 4: Average sand distribution (fraction) maps. Left: Original model. Centre: Model locally updated to match observations in well prod_34. Right: New model simulated and conditioned to all wells including prod_34.

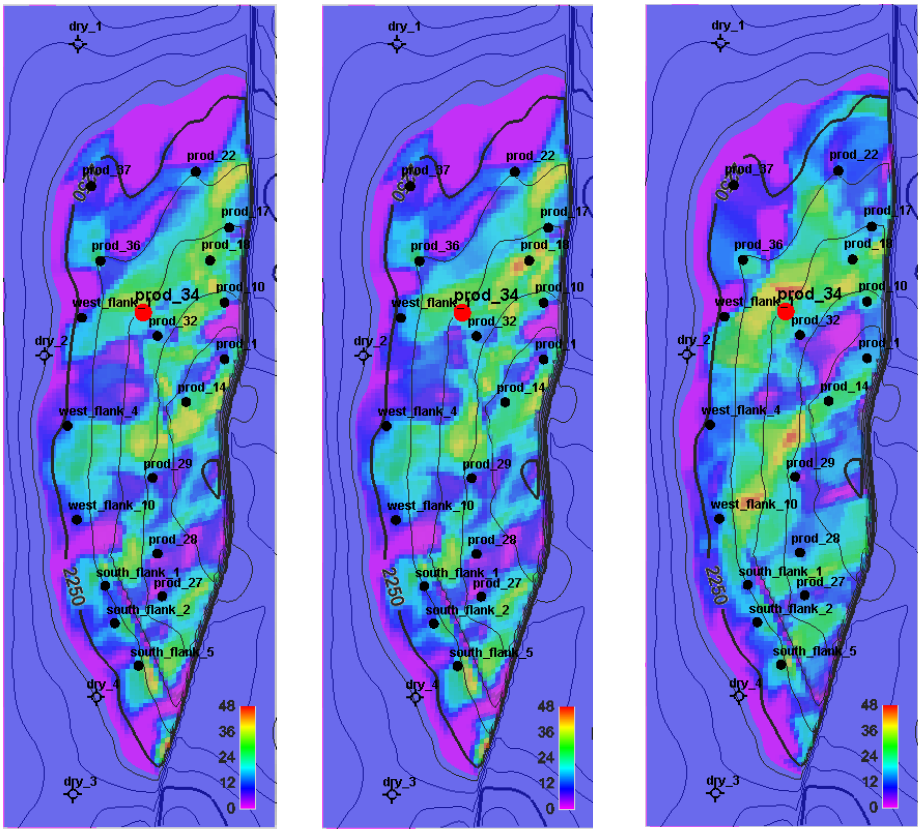

Figure 5: Net oil column maps. Left: Original model. Centre: Model locally updated to match observations in well prod_34. Right: New model simulated and conditioned to all wells including prod_34.

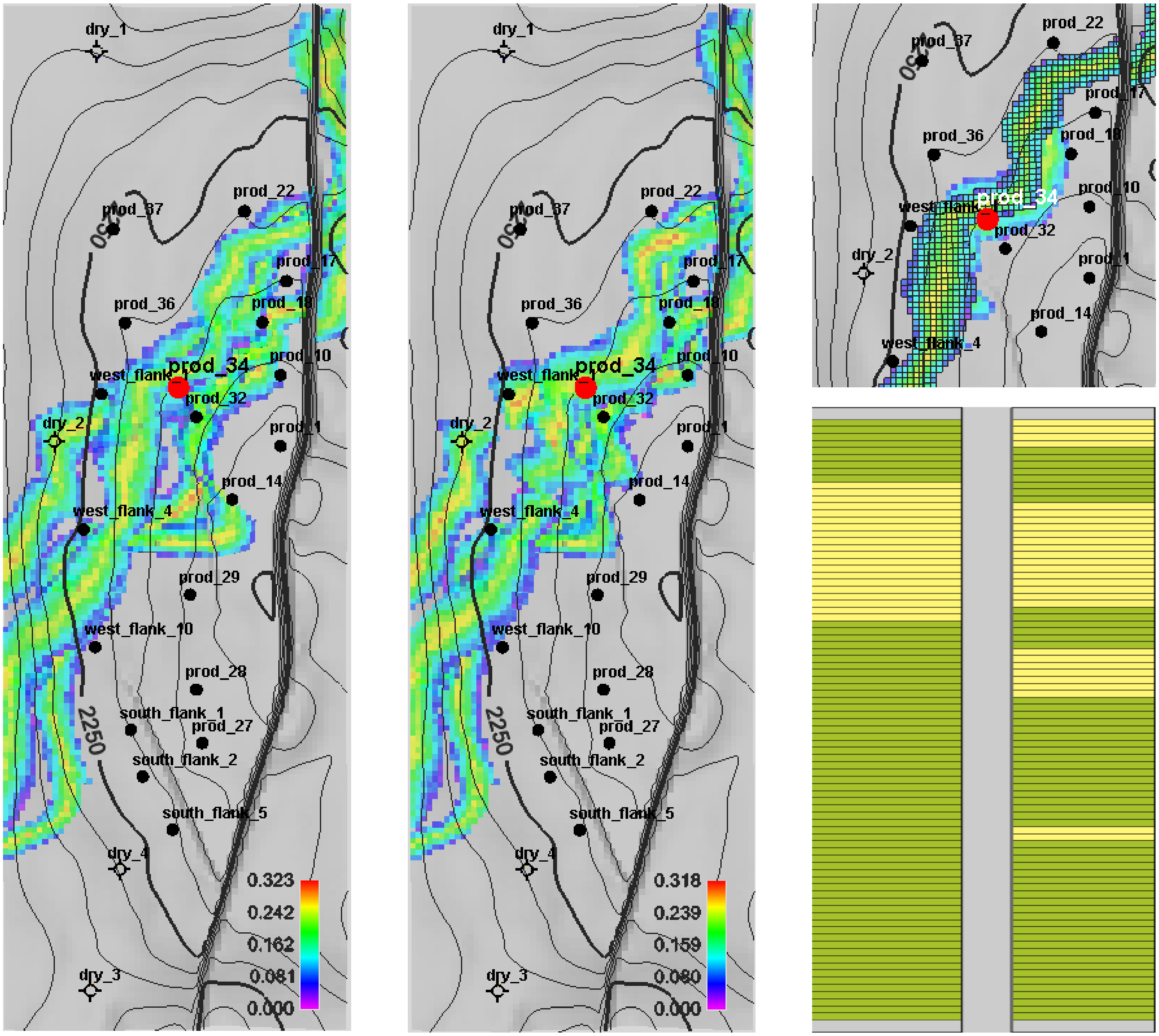

Figure 6: Channel sand objects involved in the local update: Left: Original model. Centre: Model locally updated to match observations in well prod_34. Upper right: Changes in geometry of the object representing the upper observation in prod_34. Original object with gridlines. Colors represent porosity distribution. Lower right: Well prod_34: Yellow: Channel sand. Green: Overbank facies. Left: Sampled from original model in position of prod_34. Right: Channel sands observed in well prod_34.

Segment locking during history match

The last example illustrates the use of the local update approach within the actual history matching process. It is based on a reservoir model comprising elongate reservoir objects representing coast parallel sand bars deposited in a wave dominated shallow marine environment. The coast parallel sand bars are interpreted to be oriented NE-SW in the southern part of the field and N-S in the central and northern parts of the field. Figure 10 shows the simulated objects in the original model (left) and the average sand distribution (second right). The early production data supports the general anisotropy in the southern and central segments. In the northern segment however the production history was very different from the simulation results.

One possible explanation was that the anisotropy in the north is wrong. A re-interpretation by the geologist suggested that a NE-SW orientation was also plausible for the sand bodies in the north. The local update algorithm was then used to lock the geometries in the southern and central parts of the field and generate new geometries in the northern segment with a predominantly NE-SW orientation. This immediately produced a much better match with the observed production data. Figure 10 shows the simulated objects (second left) and average sand distribution (right) of the updated model. Black frame shows the local update region. Red lines show the azimuth fields used in the simulations.

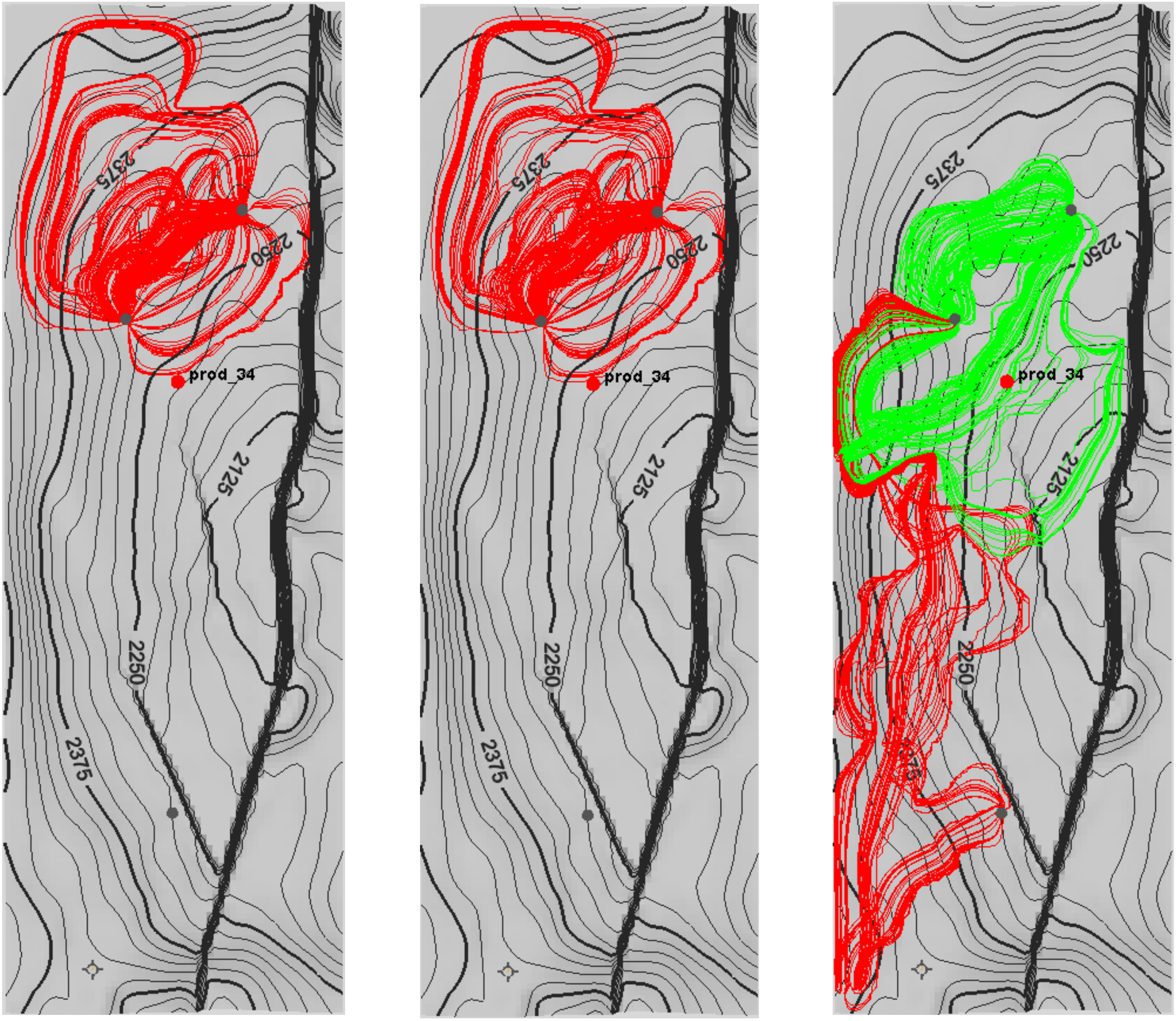

Figure 7: Streamlines simulated between wells in the northern and southern part of the field. Left: Original model. Centre: Model locally updated to match observations in well prod_34. Right: New model simulated and conditioned to all wells including prod_34.

Conclusions

An algorithm for local updating of object models has been presented. This algorithm allows minimal changes to fit an object model realization to new well data, or to resimulate a part of the realization while keeping the rest intact. This is particularly useful in a history matching setting, where the match is good in other parts of the reservoir.

The usefulness of this method is illustrated in three realistic examples. The first example shows how the overall flow pattern is preserved when doing a local update, while creating a completely new realization gives a very different flow pattern. The second example is similar, and shows how a surprising well observation still only results in a local volume change, leaving the rest of the volume unperturbed when doing local updating. The final example illustrates how local updating in a region can be used to change properties in that area, in this case the azimuth.

Acknowledgments

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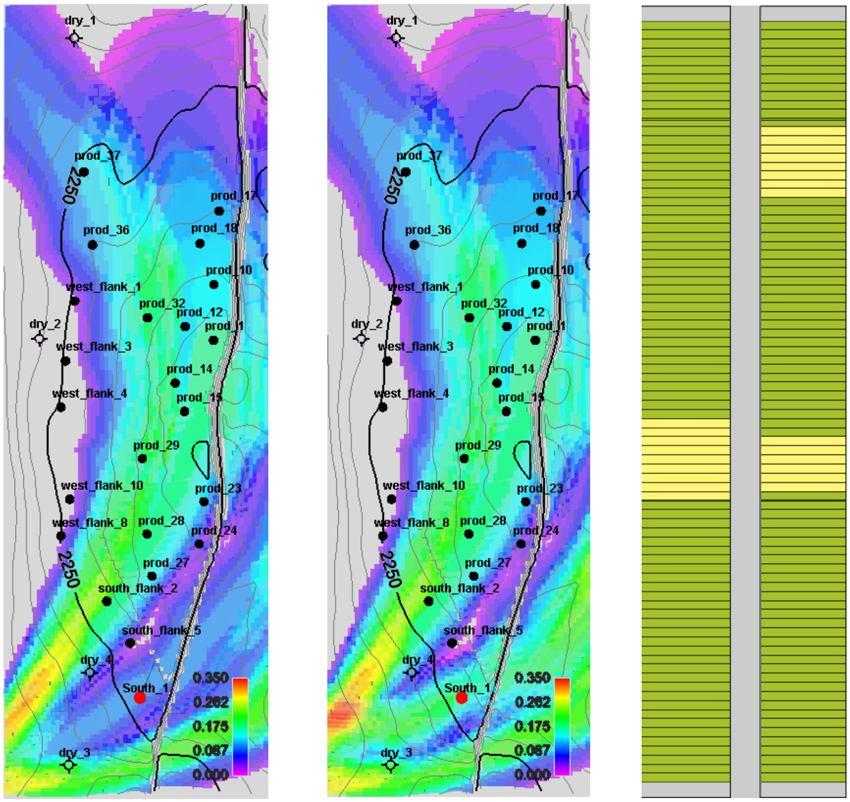

Figure 8: Average sand distribution (fraction) of turbidite lobe systems. Left: Original model. Centre: Model locally updated to match observations in well South_1 (red dot). Right: Well South_1: Yellow: Turbidite lobes. Green: Shales. Left: Facies sampled from original model. Right: Turbidites observed in well.

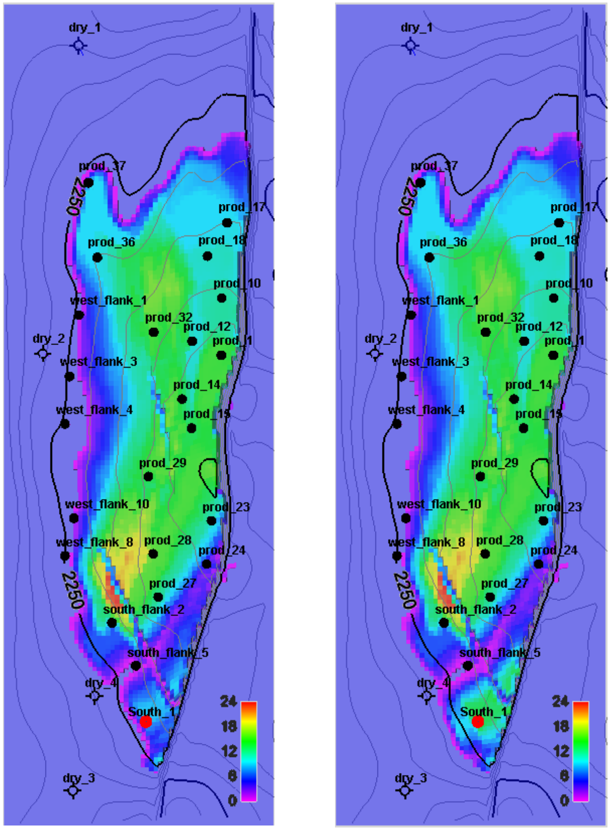

Figure 9: Net oil column map of turbidite lobe systems. Left: Original model. Right: Model locally updated to match observations in well South_1 (red dot).

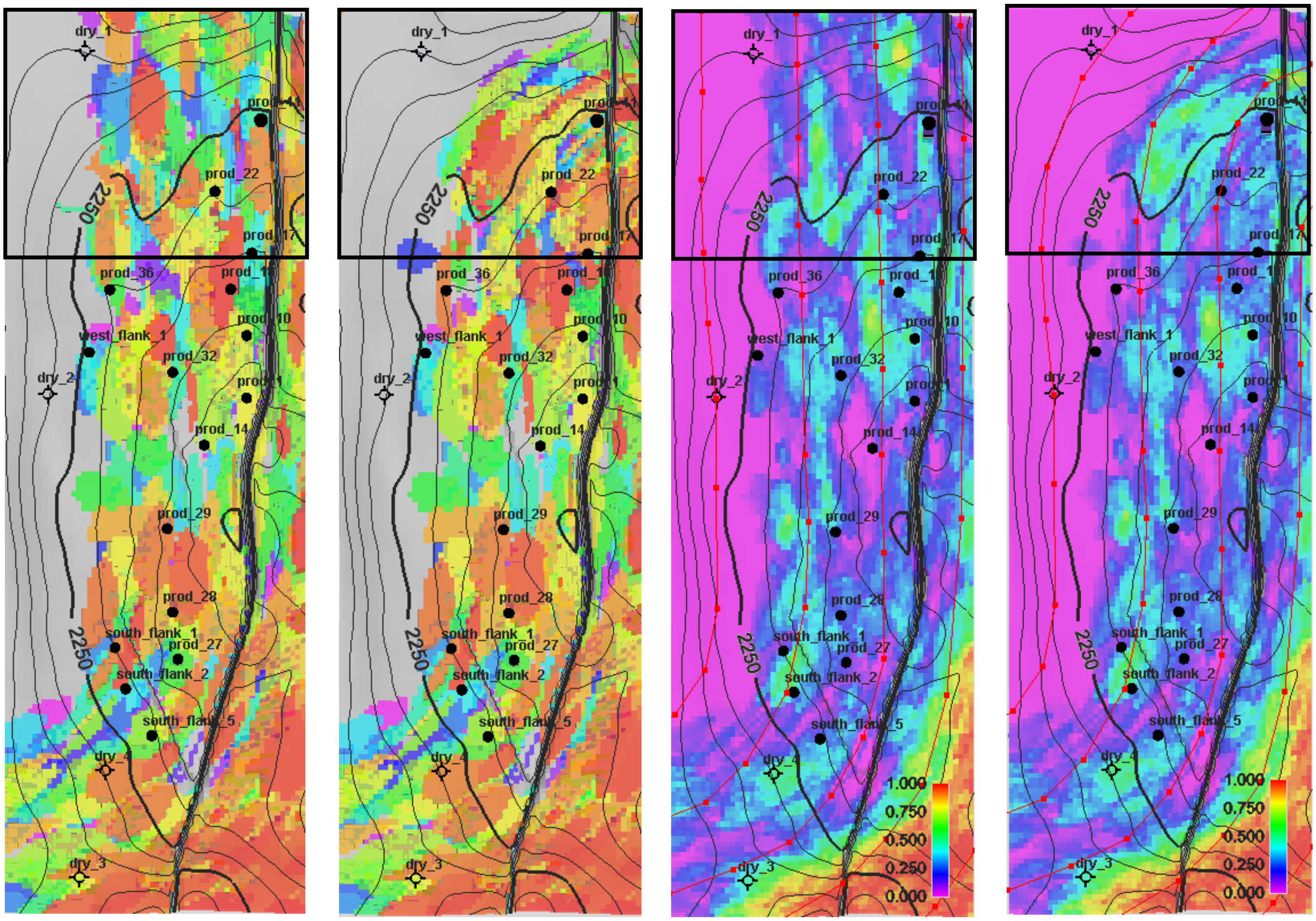

Figure 10: Object model representing coast parallel sand bars deposited in a wave dominated shallow marine environment. Left: Original model. Second left: Model updated within the region represented by the black frame. Colors represent object index. Second right: Average sand distribution (fraction) in original model. Right: Average sand distribution in model updated within the region represented by the black frame. Red lines represent azimuth trend of objects.

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