A MARKED POINT PROCESS MODEL CONDITIONED ON INVERTED SEISMIC DATA

O. Lia and J. Gjerde

Norwegian Computing Center
P.O. Box 114 Blindern
N-0314 Oslo,
Norway

SUMMARY.This paper describes a method to condition a marked point process model on invertible seismic data. The model is used for modeling facies bodies or objects of finite size which is distributed within a reservoir zone. The method is implemented and demonstrated in an example with several facies objects.

1. INTRODUCTION

Flexible models are important in stochastic reservoir description in order to be able to model different depositional enviroments. Geological knowledge about the sedimentary enviroment can give information about the building blocks or individual facies objects. Information about morphology or shapes, size distributions, orientation, spatial distributions, stacking patterns of facies objects etc. can be used to specify a prior model. This paper will present a flexible marked point process model for facies modelling. The model is able to condition both on complex well data and inverted seismic impedances. The focus on this paper will be on the latest extensions of this model emphasizing the seismic conditioning.

2. DESCRIPTION OF THE MODEL

The main features of the model are roughly summarized in the following list:

- Many different facies types can be simulated at once.
- For each facies type the following properties can be specified:
  - A characteristic shape or shape type. There are several possible choices available.
  - An intensity distribution describing partly the probability distribution for location of the facies objects and the number of them. The intensity distribution is a function of position such that spatial trends are possible.
  - A size distribution for length, width and thickness. The distribution is a truncated multinormal distribution with spatially dependent expectations and standard deviations.
  - Orientation angles are multinormally distributed with spatially depended expectations and standard deviations.
  - A local coordinate system is defined individually for each facies object and makes it easier to model a top and bottom surface for each facies object.
  - The top and bottom surfaces of each individual facies object is modeled as a trend surface defined by the shape type and size parameters plus Gaussian residual

fields. This makes the shape very flexible such that it is possible to condition one facies object on more than one well if necessary or probable.
  - It is possible to give a global constraint on volume fraction such that the total volume fraction of the facies type is within certain limits of a target volume fraction in the realizations from the model.
- Spatial interaction or repulsion is possible between facies objects of the same type or different types. Individual pairwise interaction functions can be specified for each pair of facies types.
- The model can condition on both vertical wells, deviating wells and even rather general wells which can move up and down (horizontal wells).
- Well condition can take care of the erosion rule. This means that well observations of facies intervals often can be from a thicker facies objects than seen in wells due to erosion.
- Seismic conditioning on impedances defined on a 3D grid is possible.

To simulate from the model, we use the Metropolis-Hasting algorithm, see [2]. Other documentation and papers related to this model is found in [3]. For a related model, conditioned on seismic data, see [4].

3. MODEL CONDITIONED ON SEISMIC OBSERVATIONS

The available information is seismic impedances $s_{i,j,k}$ within a 3D grid covering at least the volume occupied by the reservoir zone to be modeled. In addition we assume that probability distributions $g(f|s)$ for facies type given seismic impedances for a grid block has been estimated. This probability distribution relates the seismic impedance to facies within one arbitrary grid block of the seismic grid without taking into account any spatial dependency.

The seismic data is introduced by using a Bayesian approach.

$$\pi(\boldsymbol{u}|\boldsymbol{s}) = C \cdot \pi(\boldsymbol{u}) \cdot \pi(\boldsymbol{s}|\boldsymbol{u}) \tag{1}$$

where $\pi(\boldsymbol{u})$ is the prior model(without seismic conditioning). Here $\pi(\boldsymbol{s}|\boldsymbol{u})$ is the likelihood for the input seismic given the facies realization $\boldsymbol{u}$. This density is modeled by introducing a *'seismic weight factor'* a such that

$$\pi(\boldsymbol{s}|\mathbf{u}) = \left(\prod_{i=1}^{n_x} \prod_{j=1}^{n_y} \prod_{k=1}^{n_z} h(s_{i,j,k}|f_{i,j,k}) \right)^a \tag{2}$$

The seismic factor a can be interpreted in at least two different ways:

1. It is a weight factor telling us about the contribution of the seismic term relative to the other terms in the model.
2. It can indirectly be regarded as a measure for the spatial correlation of the original seismic.

When we look closer to the probability density $h(s|f)$, it is possible to express this by a probability of facies given seismic $g(f|s)$ by using

$$h(s|f) = \frac{g(f|s)p(s)}{v(f)}$$

The different terms are:

- $h(s|f)$ - probability for seismic given facies in a grid block. We assume that this is the same for all blocks (i, j, k).

- $p(s)$ - probability for seismic in a grid block. We assume that this also is the same for all blocks (i, j, k). This can be estimated by calculating an empiric distribution of s based on the values of s for all grid blocks in the seismic grid. The assumption is then that these grid blocks is a representative sample of the frequency of the seismic values.
- $v(f) = \int_0^\infty g(f|s)p(s)ds$ is a normalization constant which can be interpreted as a volume fraction for the facies type f if only the seismic terms have been used in the model.

In the case that we want to use a weight factor for seismic quality, the probability for seismic given facies $h(s|f)$ is then defined by

$$h(s|f) = w \cdot h_0(s|f) + (1 - w) \cdot p(s)$$

where the weight factor $w = 1$ if the original distribution $h_0(s|f)$ of seismic given facies is to be used and 0 if the unconditioned distribution of seismic is to be used. Intermediate cases will also be possible.

4. EXAMPLE

We have looked at a model with different facies types, consisting of sand, calcite and a background facies. The sand is given top priority when it comes to the erosion rule. The reservoir size is 4000m (length), 4000m (width) and 100m(height) with an sample size og 40m in each direction. There is not specified any interaction or well observations. The facies sand has an ellipsoid shape with expected length of 400m, width of 200m and height 8m. The facies calcite has an conical shape with the same size as sand. The input probabilities for facies given seismic, is given in figure 1, the seismic quality is put to be qual one and the seismic factor is set to 0.1. The probability of seismic given facies, is seen in 3. We have simulated from this model using volume restrictions, where the global volume factors is given from the seismic information. The resulting volume fractions are seen in figure 2.

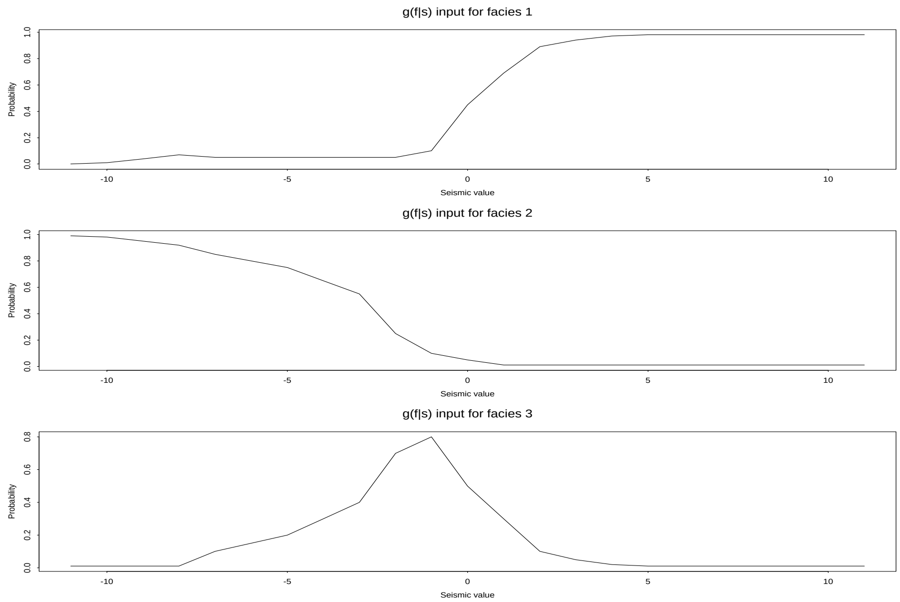

FIGURE 1. Specified input probabilities for facies given seismic for facies 1,2 and background which corresponds to the same in figure 2.

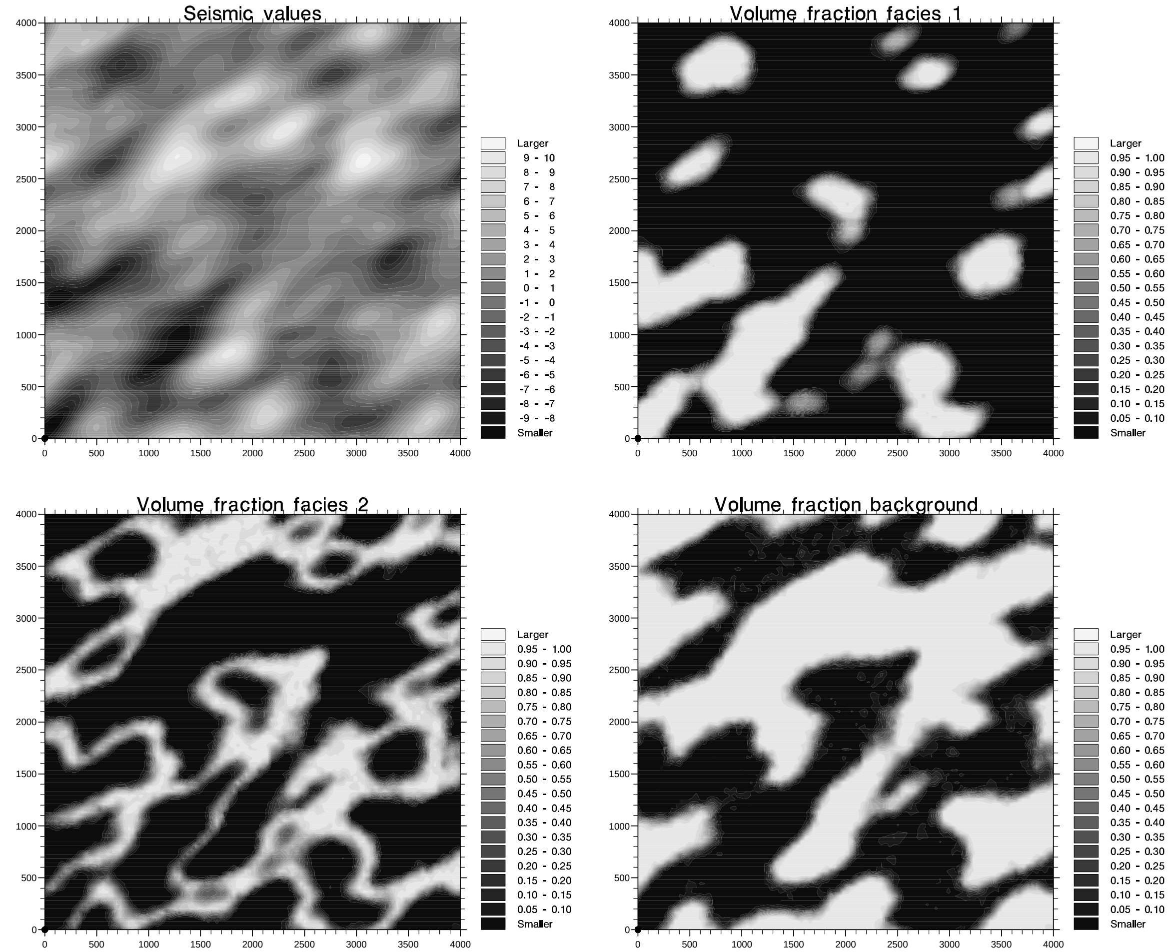

FIGURE 2. An example from seismic conditioning. The map in upper left corner show a synthetic input seismic value. The other maps show result volume fractio n maps for two foreground facies and the background facies.

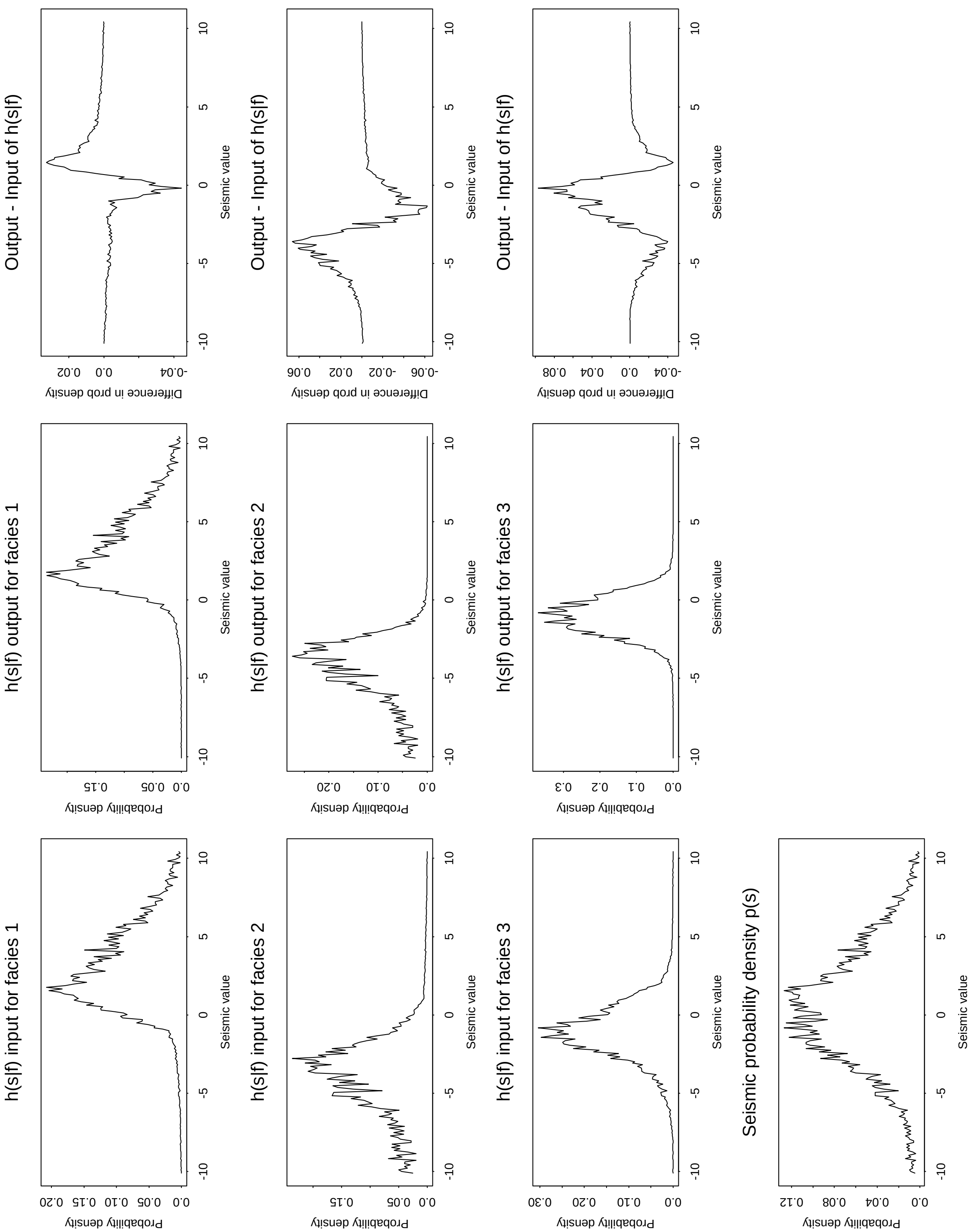

FIGURE 3. The left column of figures (after rotating the plot correctly) show the input distributions for probability density for seismic given facies. The middle column shows the probability for seismic given facies in the simulated realization while the rightmost column show the difference. The lower most plot show the unconditi oned probability density for seismic. The facies type 1,2 and background corresponds to the same in figure 2 and 1.

5. CONCLUSION

Using the seismic model described in this paper, we are able to condition on inverted seismic data. This has been demonstraded using a example with several different facies types. It is possible to run the model in a loop, varying the seismic factor in each iteration, until a best fit is found.

References

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