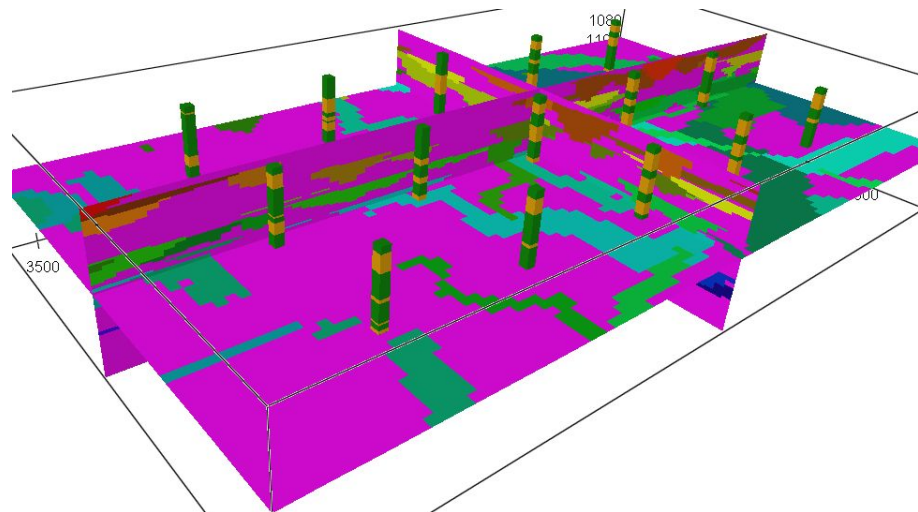


# Simulating 2D Gaussian fields for top and thickness of channels



Note no  
Author  
Date

**SAND/13/07**  
**Frode Georgsen and Ragnar Hauge**  
**13th December 2007**

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### **Abstract**

In order to increase flexibility in the vertical position and shape of channels in the fluvial reservoir model used in Irap:RMS, two-dimensional Gaussian fields are introduced for top and thickness of channels. Alternative trend functions for the thickness are also presented, and a detailed description is given on how well conditioning is performed. Examples from realistic case studies are presented.

Keywords	Object modelling, Well conditioning, Sim2D
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# 1 Introduction

In the original version of the fluvial object model implemented as Facies:Channels in Irap RMS, the position and shape of the channels are modelled as several correlated 1D Gaussian fields. This means that in a vertical cross section perpendicular on a channels main axis, the vertical position and thickness of the channel is constant. When the distance between the wells is small compared to the width of the channel, two or several wells might penetrate a channel on almost the same position along the main axis, but with different positions for top and bottom intersection. In such a case conditioning in the model described above might be difficult, or impossible, and a more flexible approach is needed. A solution is to let the top and thickness, and thereby also the bottom, of the channel across the main axis be modelled as random functions. A model for this introducing 2D Gaussian fields is presented along with a description on how to simulate from this model. The conditioning on well observations is described in detail. Examples from a realistic case is presented.

## 2 Model description

Numerous references give a description on how the channels and crevasses within the concept of channel belts are modelled as 1D Gaussian fields within a reservoir simulation box, for instance Holden et. al. (1998). Each channel has a main direction axis. The channel, with crevasses, is modelled within a local 3D coordinate system with this main axis as the x-axis. The other coordinate axis are orthogonal on this in the horizontal and vertical plane respectively. For each x-value the channel position and size is described by four random functions: Horizontal deviation of the center point from the main axis,  $Z_H$ , vertical deviation of center point from the main axis,  $Z_V$ , horizontal width,  $Z_W$  and vertical thickness,  $Z_T$ . This means that in a vertical cross section perpendicular on the main axis, the channel has a rectangular shape. This is shown by the thin solid lines in Figure 1.

In order to increase the flexibility in vertical position and thickness of the channel, the rectangular shape of the channel cross section is modified through the introduction of 2D Gaussian fields for the top and thickness of the channel. The deviation from the original top position of the channel is given by a stationary residual field,  $\varepsilon_V(x, y)$ , with zero expectation everywhere. This means that the top position of the channel for a fixed x-value,  $x_0$ , is  $(Z_V(x_0) + 0.5Z_T(x_0) + \varepsilon_V(x_0, y))$ . The thickness of the channel is given by a trend function  $\mu_T(x, y)$  plus a stationary residual field  $\varepsilon_T(x, y)$  with zero expectation. Section 2.1 describes different trend functions. The standard deviations and correlation functions for the residual fields are specified by the user as described in Appendix A.

Figure 1 shows a schematic vertical cross section of a channel for a fixed x-value ( $x_0$ ). The result of the 1D simulation is given by the rectangle. Along the y-axis the channel is discretized by 9 gridnodes. The variation of the top position of the channel along the y-axis is shown by thick solid lines. The bottom position appears as the thickness field

added to the top position. In this example the thickness trend  $\mu_T(x_0, y)$  equals  $Z_T$ .

Note that the side edges and the width of the channel are not influenced by the 2D-fields.

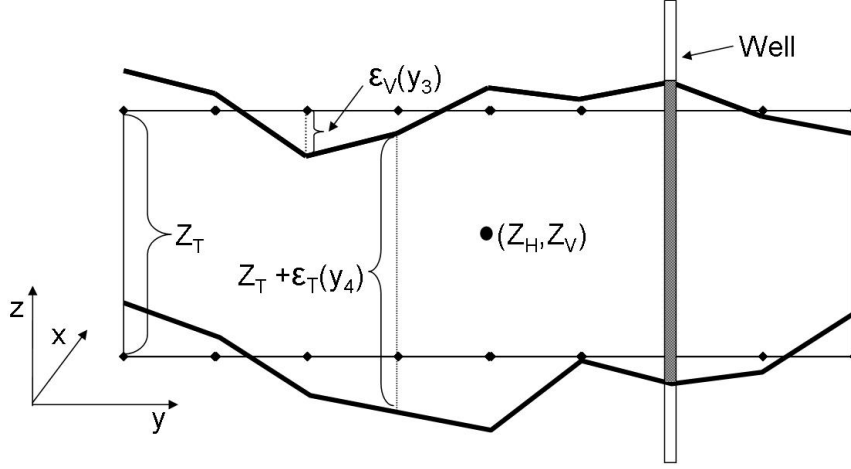


Figure 1. Schematic vertical cross section of channel. The original rectangular channel position is shown with random fields for top and bottom.

## 2.1 Thickness trend functions

The default thickness trend for the channel is constant for a given  $x$ -value, i.e.  $\mu_T(y) = Z_T$ . This represents a rectangle in the vertical cross section as in Figure 1. However, two additional trend functions are available when 2D simulations are invoked. These are given by the parameter [profile] in the model file.

Let  $y_{min} = Z_H - \frac{1}{2}Z_W$  and  $y_{max} = Z_H + \frac{1}{2}Z_W$  define the edges of the channel in the vertical cross section. A parable shape is chosen when the keyword 'quadratic' is used. In this case the thickness trend,  $\mu_T(x_0, y)$  for some  $x_0$ , is given by

$$\mu_T(y) = -\frac{6Z_V}{Z_W^2}(y - y_{max})(y - y_{min}), \quad (1)$$

for  $y \in (y_{min}, y_{max})$  and zero elsewhere.

A more rectangular shape that is rounded towards the edges is chosen when the keyword 'rounded' is chosen. In this case the thickness trend is constant for  $y$ -values that are more than  $\frac{1}{10}Z_W$  away from  $y_{min}$  or  $y_{max}$  towards the center. Closer to the edges the shape follows a third degree curve. Formally the thickness trend is given by

$$\mu_T(y) = \begin{cases} \frac{20Z_T}{19} Z_W \left(1 - \left(\frac{Z_W - 10y}{Z_W}\right)^3\right) & \text{for } y \in (y_{min}, y_{min} + \frac{1}{10}Z_W) \\ \frac{20Z_T}{19} & \text{for } y \in (y_{min} + \frac{1}{10}Z_W, y_{max} - \frac{1}{10}Z_W) \\ \frac{20Z_T}{19} Z_W \left(1 - \left(\frac{9Z_W - 10y}{Z_W}\right)^3\right) & \text{for } y \in (y_{max} - \frac{1}{10}Z_W, y_{max}) \end{cases} \quad (2)$$

and zero elsewhere. The constants in the expressions 1 and 2 are chosen so that the area of the cross section in these cases is equal to the area in the rectangular case. Note that



for both the alternative trend functions, the thickness of the channel converges to zero towards the side edges of the channel.

Note that in the implemented algorithm the location of the side edges is not conditioned on the thickness of the observation. A more correct approach would be to have a tendency to let thin observations penetrate the channel close to one of the sides and thick observations nearer the center.

## 2.2 Crevasses

One or more crevasses can be attached to the channel. The modelling of 2D-fields for channel top and thickness do only affect the crevasse modelling through the choice of thickness trend function described above. The crevasses are modelled as attached to the channels on one of the sides. If the chosen trend function of the channel gives that the thickness at the edge is zero this might give that the crevasse ends up being disconnected from the channel as shown in Figure 2. In order to avoid this, the crevasse is prolonged until it is attached to the actual side edge of the channel. In the case that the top of the crevasse is above the top of the channel or the bottom of the crevasse is below the bottom of the channel, the crevasse is prolonged to the center of the channel. Since channel always erodes crevasse, the visible, and contributing, part of the crevasse will only be the part outside the channel.

An unfortunate effect of this is that bias is introduced with respect to the crevasse-sand fraction in the reservoir. This fraction will systematically be increased since the crevasse objects are made larger. Further experience is needed in order to decide if this bias is crucial.

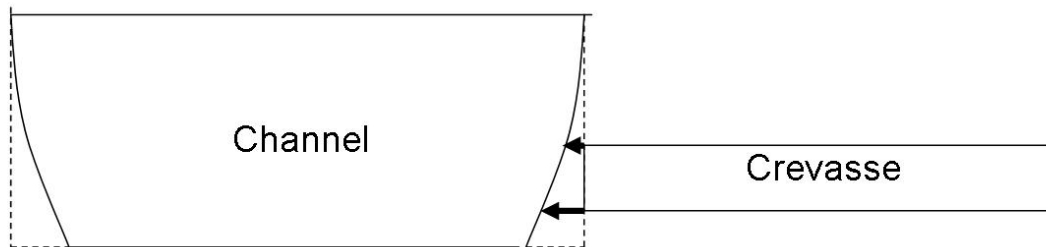


Figure 2. Schematic vertical cross section of channel with rounded thickness trend and crevasse.

## 3 Simulation algorithm

The simulation of the objects from the model described in the previous section is performed in two stages. In the first stage, the 1D-fields giving the rectangular shaped channels with constant vertical position and thickness are simulated by the Metropolis-Hastings algorithm combined with simulated annealing. The crevasses are also simulated in this

stage. This algorithm is explained in details in Holden et.al. (1998). The behaviour of the simulations is constrained to different convergence criterias, including how well the realization conditions the well data. The conditioning is performed as described in Skorstad et. al. (1999), except that some tolerance is given on the conditioning on well observations when 2D simulations are invoked. This is due to the fact that the residual fields are supposed to perform the exact conditioning. Section 4 describes the conditioning algorithm. Since the convergence of the Metropolis-Hastings algorithm is ensured in this first stage, the target volume fraction will be reached at this stage. This might cause that the final volume fraction might differ from the target since it is not accounted for in the next stage.

The second stage, giving the variability in vertical position and thickness across the channel, is a post-process performed on one channel at the time. Due to the memory demands in storing 2D-grids for each channel, the realization is written to file, and the memory deallocated before the next channel is simulated. For each channel the following procedure is performed:

1. Simulate unconditioned 2D Gaussian random functions for the residual fields
2. Add the thickness trend to the residual thickness field
3. Compute the differences between the observed values and the residual values in the observation points
4. Perform simple kriging on the differences
5. Add the kriged values to the residual values to get conditioned 2D Gaussian fields

The next section describes how the conditioning points are found.

## 4 Conditioning on well observations

Figure 1 shows a well containing a channel observation. As the figure shows, the 1D fields do not condition this observation exactly at the top and bottom. This is due to the fact that since the vertical position and thickness of the channel is simulated in the post-process some tolerance is given in the 1D simulations. The tolerance for the top observations is twice the standard deviation for the top residual field. Since the bottom position is the sum of the top and the thickness, the variance for the bottom position is the sum of the variances for top and thickness. The tolerance for the bottom observations is twice the square root of this variance.

The well conditioning is fulfilled by identifying and drawing conditioning points for the channel. First, the exact top and bottom observations are identified. They give hard conditioning points. For each hard top conditioning point ( $P^T = (x_i, y_i, z_i)$ ) it must be checked if there is a hard conditioning point that is highly correlated with a potential bottom conditioning point for position  $(x_i, y_i)$ . If not, a bottom conditioning point is drawn at  $(x_i, y_i)$  from a conditional multinormal distribution given all the other bottom conditioning point and  $P^T$  and truncated according to the channels minimum and maximal thickness. Then the same procedure is performed for the hard bottom conditioning

points. These steps gives an initial list of top and bottom conditioning points on which the simulation in the previous section is performed. Highly correlated does in this setting mean that two points have a correlation coefficient larger than 0.99.

In order to make sure that the channel does not only condition correctly the observations of the channel, but also avoids the part of the wellpaths that it should avoid, the following procedure is performed:

1. Step through the wells and identify all points containing background observations or observations of other objects that intersects the channel.
2. For all such points identify if they should be above or below the channel.
3. If above, the point defines an upper bound for the channel at that  $(x, y)$ -location, if below it defines a lower bound.
4. Clean up the collection of points so that no two points are highly correlated with other points in the list or with conditioning points identified in the initial list above.
5. For each of the points above the channel, draw a top conditioning point from a multinormal distribution conditioned on all the other top conditioning points and truncated on the upper bound found in 3, and the minimum and maximum thickness of the channel. If a potential bottom conditioning point at the same  $(x, y)$ -location is not highly correlated with other conditioning points, such one is drawn from a multinormal distribution conditioned on all the other bottom conditioning points and the opposite top conditioning point and truncated on the minimum and maximum thickness of the channel.
6. Perform the same as in the previous step for all the points below the channel.

If the procedure above gives new conditioning points, the steps 3-5 in the simulation algorithm described in the previous section is repeated on the new extended set of conditioning points. This iterative process is performed until the simulated channel does not generate any conflict in wells.

This method does not generate more conditioning points than necessary in order to fulfill the well observations. This is on average time-saving compared to first identifying all possible conditioning points and truncation limits.

## 5 Examples

The following figures are taken from simulations performed with 2D-fields on a test case from the Escanilla formation. This is a synthetic case based on a real fluvial analog outcrop from the Ainsa Basin, Spanish Pyrenees. The parameters given for 2D simulations to the model file are given in section 5.1.

An unconditioned realization based on realistic geological input is generated. The 15 regularly distributed wells are drilled through the simulation box. The well logs from

this sample is the used as conditioning data for further studies. Figure 3 shows the wells in the simulation box for the case with only channel facies (yellow) and background.

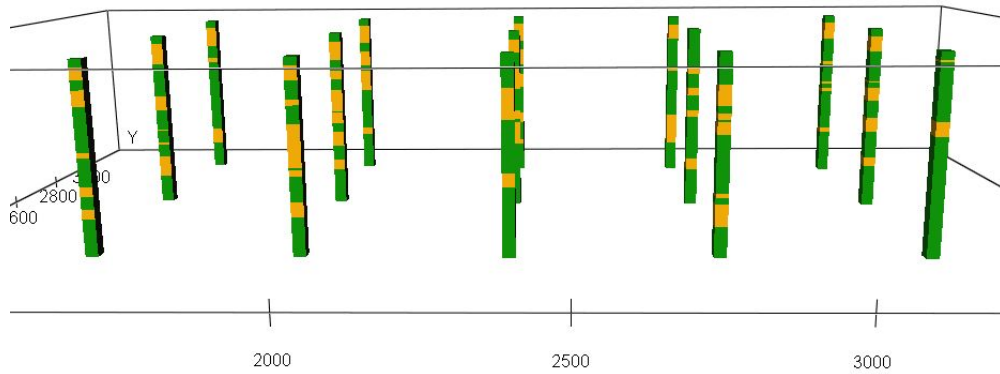


Figure 3. 15 regularly distributed wells with channel observations.

Figures 4 - 7 show the result from one random simulation based on the same prior input as the unconditional simulation and conditioned on the synthetic drilled wells. Figure 4 shows an example of a log from one of the wells. The solid (light-blue) line indicates the body log used for conditioning, while the different colours show the simulated channel bodies and the background facies (purple). This shows that the conditioning is fulfilled. The result of the conditioning is also shown in Figure 5 where a vertical cross section is taken along a plane going through 5 wells. Here it is also possible to see the parabolic thickness trend. The picture in different cross sections is shown in Figure 6.

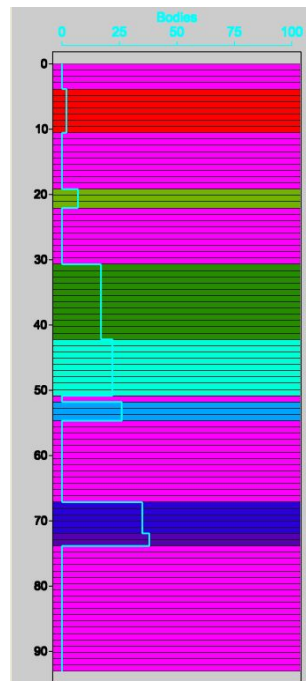


Figure 4. Well log showing observed bodies together with realisation from conditioned simulation.

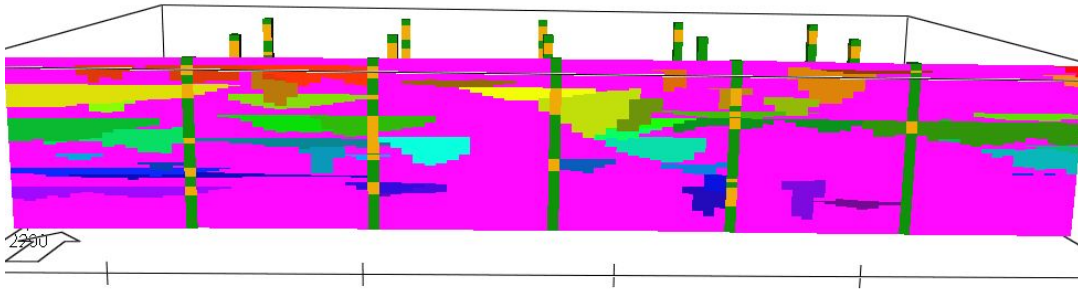


Figure 5. Cross section showing parabolic shaped channel and well logs.

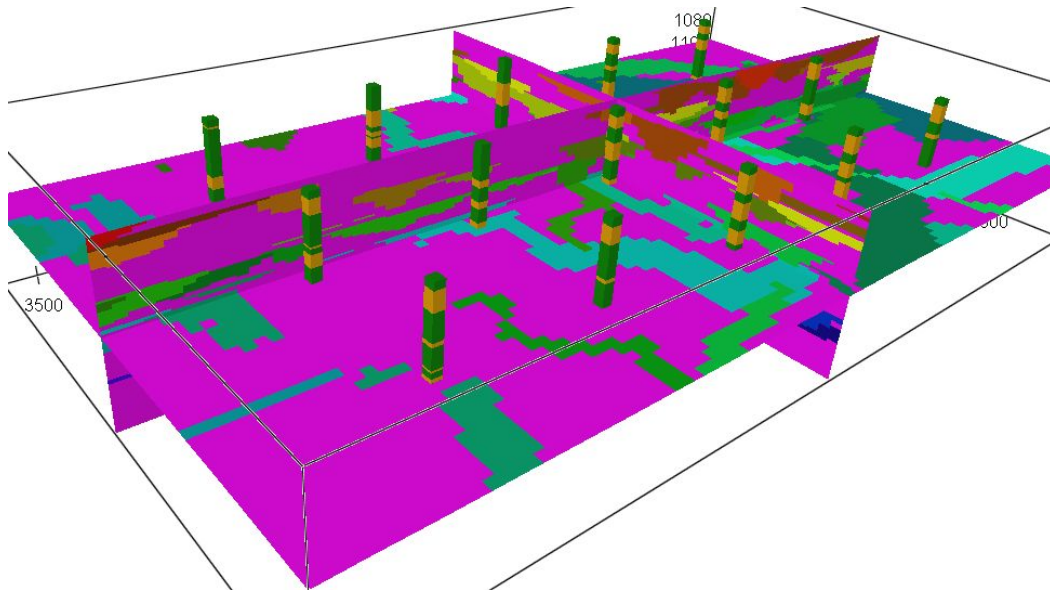


Figure 6. Vertical and horizontal cross sections from realisation with parabolic thickness trend.

Figure 7 is taken from a simulation with rectangular thickness trend function. Only a selection of the channels is shown to indicate the vertical variability. Note that the variability of the top surface is much smaller than the variability of the bottom surface. This is fully in accordance with the input parameters. The apparently isolated parts of bodies are caused by erosion by objects filtered away in the figure.

Figure 8 shows a realisation from a conditioned simulation with channels (green) and crevasses (blue). The thickness trend in the channels is parabolic and it is clearly shown how the crevasses are attached to the channel edges.

## 5.1 Model parameters

```
SIM2D <corrtype-thick(string)> spherical
      <range1-thick(real)> 500
      <range2-thick(real)> 250
      <relative-sd-thick(real)> 0.4
      <corrtype-depth(string)> spherical
```

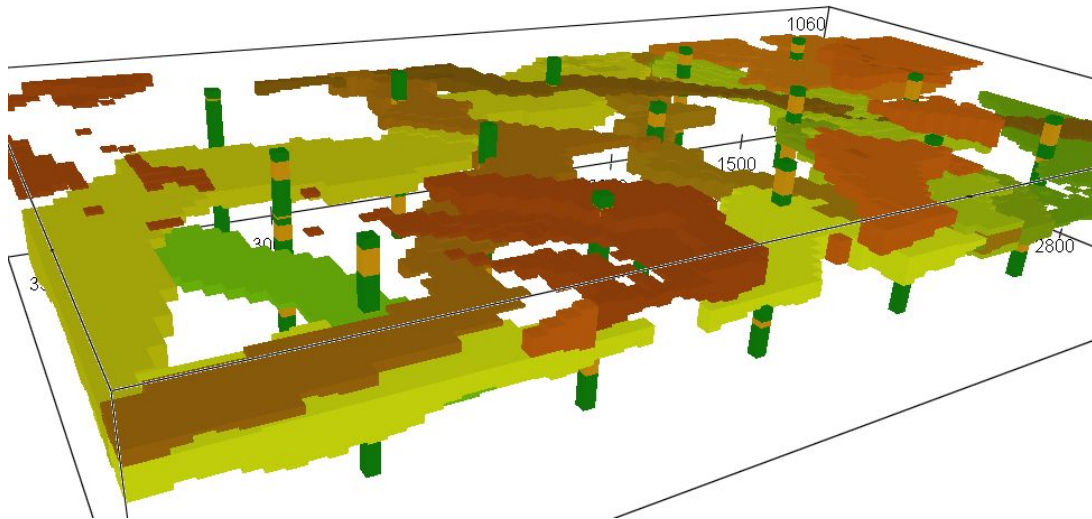


Figure 7. A selection of channels with rectangular trend shape.

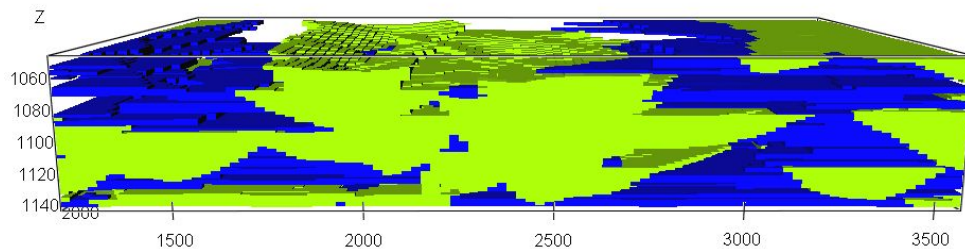


Figure 8. Parabolic shaped channels (green) with crevasses (blue).

```

<range1-depth(real)> 500
<range2-depth(real)> 250
<relative-sd-depth(real)> 0.2
[profile(string)] quadratic
[simulate(string)] simulate
[rel-gridblock-size(real)] 0.5
[corr-angle-thick(real)] 0
[corr-angle-depth(real)] 0
;

```

## 6 Conclusions

The model and algorithm for increasing flexibility in vertical position and shape of channels in a fluvial reservoir model by introducing 2D Gaussian fields are presented. Preliminary tests on realistic, but synthetic case studies show that well conditioning is taken care of in a consistent manner. Crevasses are also kept attached to the channel edges to

ensure realism in the final realisation. The problem concerning final volume fractions deviating from the target is not solved. To give a full evaluation of the method, including difficult conditioning schemes, a real field study with deviating and horizontal wells is recommended.

## 7 Acknowledgments

The project and the development of the methodology described above has benefited significantly on valuable discussions with key personnel in Roxar. The research has been financially supported by Roxar.

## References

- Skorstad, A., Hauge, R. and Holden, L. [1999]: Well conditioning in a fluvial reservoir model, *Mathematical Geology*, 31 No 7, p. 857-872
- Holden, L., Hauge, R., Skare, Ø. and Skorstad, A. [1998]: Modeling of fluvial reservoirs with object models, *Mathematical geology*, 30, p. 473-496

## A Model parameters

The model parameters for the simulation of 2D fields are given through the model file. The command SIM2D is given, followed by 8 compulsory (in <angle brackets>) and 5 optional (in [square brackets]) parameters. The format of the model file follows below. The compulsory parameters defines the standard deviations and correlation function for the two residual fields for top and thickness respectively. Note that the standard deviation of the thickness residual field is the given parameter times the mean thickness of the channel. The standard deviation for the top residual field is the given parameter times the standard deviation of  $Z_V$ .

SIM2D

<corrtype-thick(string)>

Description: Type of correlation function for simulation of the two dimensional residual field for thickness that is added to the thickness of channels.

Legal values: The text strings: 'gaussian', 'exponential' or 'spherical'

<range1-thick(real)>

Description: Correlation length along the channels for the residual field added to the thickness of channels.

Legal values: Positive numbers.

<range2-thick(real)>

Description: Correlation length across the channels for the residual field added to thickness of channels.

Legal values: Positive numbers.

<relative-sd-thick(real)>

Description: Relative standard deviation of the residual field added to the thickness of the channels. The standard deviation for the residual field is calculated as the product of the number specified here and the mean thickness of the channel.

Legal values: Positive numbers, but should usually be less than 1.0.

<corrtype-depth(string)>

Description: Type of correlation function for the residual field added to the vertical position of the top of the channels.

Legal values: The text strings: 'gaussian', 'exponential' or 'spherical'.

<range1-depth(real)>



Description: Correlation length along the channels for the residual field added to the depth to the top of the channels.

Legal values: Positive number.

<range2-depth(real)>

Description: Correlation length across the channels for the residual field added to the depth of the top of the channels.

Legal values: Positive numbers.

<relative-sd-depth(real)>

Description: Relative standard deviation of the residual field added to the depth to the top of the channels. The standard deviation for the residual field is calculated as the product of the number specified here and the standard deviation for the one dimensional field for vertical displacement of the channel.

Legal values: Positive numbers, but should usually be less than 1.0.

[profile(string)]

Description: The shape type of the channel as seen in a vertical cross section orthogonal to the channel axis. The three choices are rectangular, parable and semi-parable shape. They are specified by 'quadratic' for parable shape, 'rounded' for semi-parable shape and 'constant' for rectangular shape. The trend value for the thickness of the channels is defined to be equal to the one dimensional thickness field if 'constant' is specified. If 'quadratic' or 'rounded' is specified, the thickness from the one dimensional field of the channel is multiplied by a parable or semi-parable with 0 value at the edges of the channel.

Legal values: Text string 'quadratic', 'rounded' or 'constant'.

Default value: The text string 'constant'.

[simulate(string)]

Description: Here the user can specify whether the two dimensional residual grids for top and thickness of the channels should be simulated according to the specified variogram and conditioned or only conditioned by kriging.

Legal values: Text string 'simulate' or 'kriging'

Default value: The text string 'simulate'

[rel-gridblock-size(real)]

Description: The size of the grid blocks of the two dimensional grids representing the top and thickness of channels can be modified by this command. The grid block size along the channels is not possible to modify here, but the grid block size across the channel can be modified. The specified number is a relative number and the grid block size across the channel is this relative number times the internally defined grid block size along the channels. Usually this number should be equal to 1.0 or slightly less than 1.0. If the grid resolution across the channels should be 10 times as fine as along the channels, this number must be specified to be 0.1. The grid block size along the channels is determined internally by the program and depends on the correlation length of the one dimensional fields specified for the channels in command CHANNEL.

Legal values: Values in the interval between 0.01 and 10.0.

Default value: 1.0

[corr-angle-thick(real)]

Description: The variogram for the thickness field can have anisotropy not along the channels and orthogonal to the channel axis, but in an angle relative to this. An ellipse will in general define all the points with the same correlation relative to the centre of the ellipse. If the correlation along and across the channels are equal, this ellipse is a circle, but for the case that there are larger correlation length along than across the channels, we get an ellipse. If the user would like that the 'correlation ellipse' should be rotated relative to the channel direction, an angle must be specified here.

Legal values: Angle between  $-\pi$  and  $\pi$  .

Default value: 0.0.

[corr-angle-depth(real)]

Description: The same description as for the parameter above, but valid for the correlation for the two dimensional field for depth of the channels.

Legal values: Angle between  $-\pi$  and  $\pi$ .

Default value: 0.0.