Assessing paleo-channel distribution for probabilistic offshore windfarm ground modelling using Multiple-Point Statistics

Introduction

In offshore windfarm development commonly a dense grid of seismic lines is acquired to investigate and characterize the subsurface for ground modelling purposes. While full 3D data acquisition becomes more frequent, still the majority is based on 2D data acquisition. For the provision of 3D ground models this leads to higher uncertainties of the interpreted geology apart from the investigated lines. Its uncertainty is seldom quantified and only a best estimate location of geological structures is provided. Specifically, paleo-channel structures can obtain unforeseen directional changes. A precise location of those features is important since they can pose challenges in foundation design e.g. due to their heterogeneous nature on the scale of offshore windfarm development (e.g. Velenturf et al., 2021).

In this study the probability of paleo-channel structures off 2D seismic grids is quantified using the direct sampling Multiple-Point statistics (MPS) approach based on the geological interpretation as conditional information and training images (TIs). Numerical results are compared to known locations of paleo-channels. Thereby, different geophysical line spacings and TIs are tested to investigate the effect of line spacing density and selection of TIs on the results and their accordance with the true channel distribution.

Multiple-Point Statistics (MPS)

For the MPS simulation, the algorithm DeeSee is used, which is based on the direct sampling (DS) approach originally proposed by Marietholz et al. (2010). It is implemented in the Isatis.neo software which was used for this study.

The general concept of the DS method is illustrated in Figure 1. It allows for the modelling of the spatial variability of categorical and continuous variables using a TI as reference. Following a random path to generate the results, several realizations can be created which can be used for probabilistic assessment.

Compared to other MPS techniques, in DS the TI is directly sampled without the use of a database. For a more precise description of the MPS and DS concepts, the reader is referred to Marietholz et al. (2010) and Marietholz and Caers (2014). Figure 1 illustrates that aside from the actual TI and conditional data (CD), there are several parameters that have a direct influence on the quality of the results. These include the acceptance threshold (t), the maximum scan fraction of the TI (f) and the maximum number of closest informed nodes (N). Based on controlled tests, we choose $t = 0.05$, $f = 50$ and $N = 50$ for this study. A more complete framework for testing and a detailed description of the parameters and their influence on the output can be found in Meerschman et al. (2013) and Juda et al (2022).

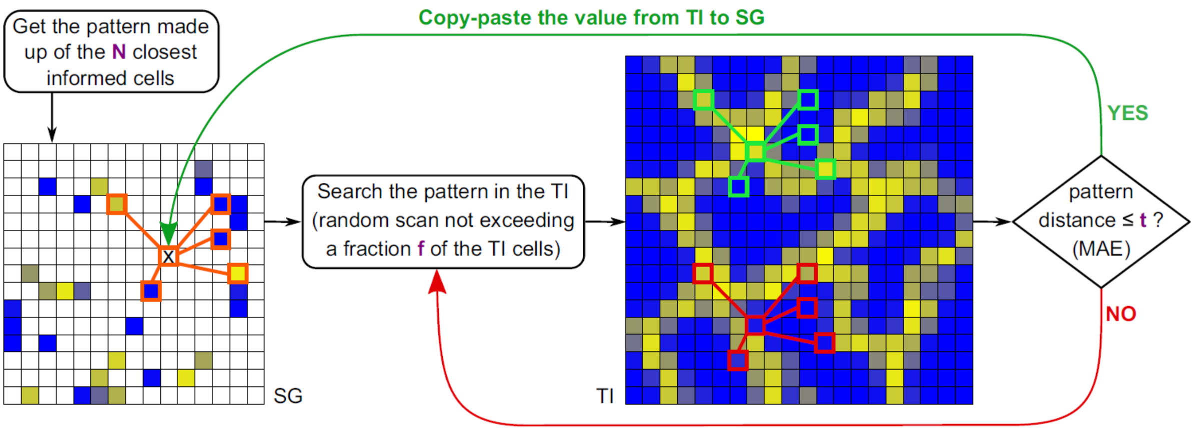

Figure 1 *Visualisation of the direct sampling approach showing the simulation grid (SG) on the left and the training image (TI) on the right (from Straubhaar, 2020).*

Training Images and Conditioning Data

Based on the available subsurface interpretation, two different TIs (Figure 2) are created which are based on interpretation of an offshore windfarm area. The exact location withheld due to confidentiality constraints. The images are divided in the two categorical variables "channel" and "non-channel". Although the TIs are based on true data, the channels' structure is slightly simplified to streamline the analysis in this feasibility study. Different channel widths are preserved.

Two CD sets are created based on the TIs. Using the initial drawings of the TIs as a georeferenced raster, an evenly spaced grid of points with 10-meter spacing across its extent, comprising approximately 3 million cells, is overlaid. Different line spacings are being introduced by keeping the categorical information only along the lines and ignoring the rest of the data. Three different line spacings are tested to investigate its influence on the paleo-channel probability encountered apart from the 2D seismic grid: 150 m, 500 m and 1000 m. Points that intersect with channels or floodplains are assigned the corresponding categorical value. Tests are performed using the TI and CD from the same area as well as using the TI to simulate paleo-channel probability in another area (differing TI and CD).

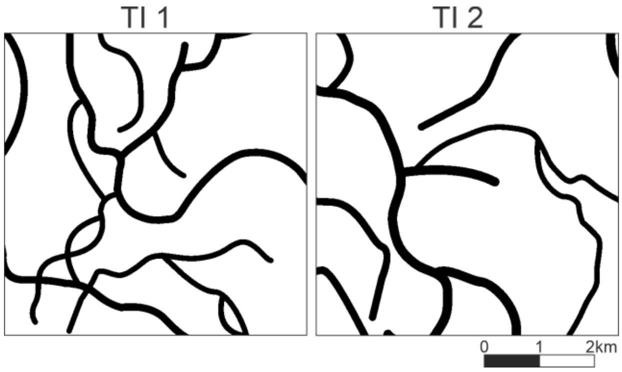

Figure 2 *TIs used in this study. From both TIs conditional data has been extracted along the seismic lines for the given line density.*

Results and Discussion

Figure 3 shows the results for the channel probabilities from the MPS simulation for the different TI and CD configurations (TI1-CD1 and TI2-CD2: Test TI on CD from the same area; TI1 – CD2 and TI2 – CD1: Test TI on CD from different areas) and line spacings. The number of realizations was set to 200 to avoid unnecessary computational overhead since prior tests showed that no significant changes in the results were encountered for an increased number of runs. For comparison, dashed lines indicate the location of the channel distribution as it is known from interpretation. White lines indicate the line spacing on which the conditional data is available.

The results suggest that, for a line spacing of 150 m all considered TI and CD configurations replicate the channel distribution to a high degree of accuracy and with high probability. The line spacing is dense enough so that sufficient conditional data is available and distances between unknown points are small enough, leading to reliable prediction results.

For TI and CD from the same areas (Figure 3A-B), a wider line spacing of 500 m does not result in a major loss in accuracy indicating reliable results with wider line spacing. With 1000 m between the lines, probability drops significantly in some branches of the expected channels, especially close to the borders of the simulation grid. Still the overall channel system is maintained widely with high probabilities.

Looking at the examples where TI and CD are from different areas (Figure 3B-C), with 500 m line spacing channels are far less accurately predicted in large parts of the simulation grid, compared to the denser line spacing and the results from Figure 3A-B. Potential channels still maintain the shape of the original pattern. The connectivity of some channels is lost, which is critical in the way, that the results suggest low to zero probability where a channel is encountered in the true data. More artifacts become visible, with channels are being suggested, where one would not expect them from the original input data. This is introduced by statistical patterns from the other TI which might not be representative for the other area.

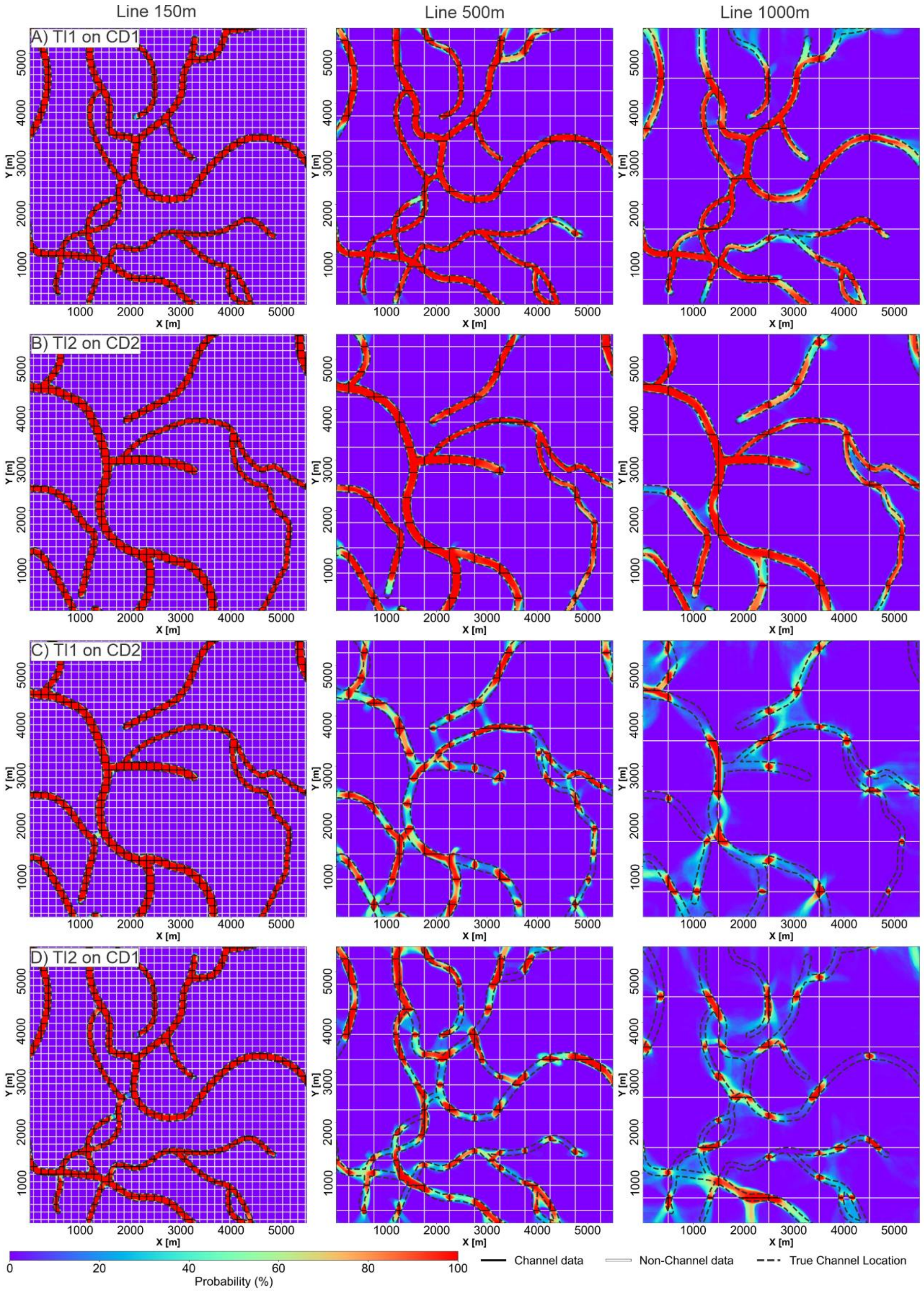

Figure 3 *Results of the MPS simulation for different line spacings (left: 150 m; centre:500 m, right 1000 m) and TI and CD constellation. Above TI and CD is from the same area and below from different areas with A) TI1 and CD1, B) TI2 and CD2, C) TI1 and CD2, D) TI2 and CD1.*

For the 1000 m line spacing, the predicted channels increasingly lose connectivity and channels cannot be reliably predicted. Only close to conditional data points predictions become reliable, whereas confidence rapidly declines off the observational grid. This makes the results for TI and CD from different areas with such high line spacing insufficient for a precise assessment of paleo-channel distribution. In conclusion, for a reliable transfer of predictability to other areas a sufficiently small 2D seismic line spacing needs to be ensured. 150 m and 500 m are in the range of common line spacings found in offshore windfarm site investigation.

Conclusions

Multiple-Point Statistics is used to calculate probabilities of paleo-channel distribution apart from interpreted 2D seismic lines considering different line spacings and training images for offshore windfarm ground modelling.

Findings indicate that independent of the TIs a very good match of the channel positions can be reached with a line spacing of 150 m, while it diminishes with wider line spacings because of less CD and therefore known fixed points. This is specifically true for TIs from different areas than the CD, which show different statistical patterns. Nevertheless, they can be helpful for denser line spacing, showcasing the transferability of known information from one area to support the assessment of another. Care should be taken with the selection of TIs, which have a strong influence on the outcome.

Future work will focus on investigating more generalized and statistically diverse TIs for a better transferability on other areas, adding also multiple TIs to the process. Also, the potential of 3D unit simulation and the use of MPS for continuous variables (geotechnical and geophysical) for offshore windfarm ground models will be investigated.

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