

## ***Interactive comment on “A new methodology to train fracture network simulation using Multiple Point Statistic” by Pierre-Olivier Bruna et al.***

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Dear Reviewer

First let us thank you very much for your comments and for the interest you found in our paper.

In the first paragraph of your review you stated: “this manuscript is designed for a journal like GMD rather than Solid Earth”.

As you also mentioned earlier in the review, we believe that the topic is relevant for Solid Earth as it presents an innovative method to build DFN models considering more geology than the existing (exclusively statistical or almost) methods. As stated in the manuscript, we are using an existing algorithm from Mariethoz et al., 2010 that we

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simply tuned and applied to fracture network geometry predictions. We also think that the paper is quite long and developing the MPS method and the training image further will probably not be really helpful for the reader. We also cited a series of reference papers explaining more in detail how the DS algorithm was written (Mariethoz et al., 2010), how could be used the DS algorithm (Meersmann et al., 2013) and presenting a series of application of MPS to generate fracture networks (Chugunova et al., 2017, Karimpouli et al., 2017, Jung et al., 2013). We believe that these references will greatly help readers to go deeper into the MPS method.

In the manuscript no changes are required

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Specific comments Line 22-33, remove from the abstract, this is material for the intro.

We agree with the reviewer comment and we believe that the initial part of the abstract need to be rephrased . As the same material is stated (differently) into the introduction we did not reintegrated this paragraph there.

In the manuscript, we rewrote line 22 to line 30 from the abstract as following: Natural fractures have a strong impact on flow and storage properties of reservoirs. Their distribution in the subsurface is largely unknown mainly due to their sub-seismic scale and to the scarcity of available data sampling them (borehole). Outcrop can be considered as analogues where natural fracture characteristics can be extracted from high-resolution images acquired from drone and photogrammetry. Outcrops thus become a digital laboratory where the interpreted fracture network can be tested mechanically (fracture aperture, distribution of strain/stress) and dynamically (fluid flow simulations).

Line 30 Avoid citations in the Abstract:

We agree with the reviewer comment

As this line is part of the previously removed paragraph, this comment is already taken into account

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Line 34 The abstract should be self-supporting. Define training images:

A training image is a sketch drawn by the user and containing patterns (series of pixels) representing a geological object (e.g. a fluvial channel or a fracture network). In this case, all the statistics generated during the simulation process are not dependent on the simulation algorithm but come from the user-designed training image (Journal., 2003). Consequently, the realisations should represent a geological concept the user has in mind. The concept of training image has been fairly well defined in previous studies and we are not sure that this definition will be beneficial to our article.

In the manuscript, we did not extended further the definition of the training image as we thought that the concept is familiar to the major part of the audience of this paper

Line 35 Which process?:

we agree that a process cannot be reproduced by an image. In fact it is a sketch of a network supposed to be representative of the network.

In the manuscript, the term was removed from the manuscript.

Line 38 Same basic concepts of statistic should be expanded:

we understand there that you would like us to define the non-stationarity. As stated in line 93-94: “the local stationarity hypothesis suggests the invariance of all of the generated statistics by translation in the simulated domain”. This means for instance that if the user decide that the spacing of fracture family X is 1 m, then each X fracture will be spaced accordingly in the simulation domain. In our case we want to create sub domains, intrinsically stationary but overall inducing variability in the simulation grid. In our case Family X in domain Y (elementary zone) will have a spacing of 1m but family X in domain Z (elementary zone) will have a spacing of 2m. \_\_\_\_\_

\_\_\_\_\_ In the Manuscript the abstract was entirely revised as following Natural fractures have a strong impact on flow and storage properties of reservoirs. Their distribution in the subsurface is

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largely unknown mainly due to their sub-seismic scale and to the scarcity of available data sampling them (borehole). Outcrop can be considered as analogues where natural fracture characteristics can be extracted from high-resolution images acquired from drone and photogrammetry. Outcrops thus become a digital laboratory where the interpreted fracture network can be tested mechanically (fracture aperture, distribution of strain/stress) and dynamically (fluid flow simulations). One of those outcrop, a flat pavement from the Apodi area in Brazil, was used as a benchmark to evaluate how good are the Multiple Point Statistics (MPS) to replicate the complex arrangement of a reference manually-interpreted fracture network. The MPS method presented in this article is innovative as it is based on the creation of small and synthetic training images representing the variability of the distribution of fracture parameters observed in the field. These images are flexible as they can be simply sketched by the user. We proposed to use simultaneously a set of training images in specific elementary zones defined in a probability map in order to best represent the non-stationarity of the reference network. A sensitivity analysis emphasizing the influence of the conditioning data, the simulation parameters and the used training images was conducted on the obtained simulations. Fracturing density computations and stress-induced fracture aperture calculations were performed on the best realisations and compared the reference outcrop fracture interpretation to qualitatively evaluate the accuracy of our simulations. The method proposed here is adaptable in term of training images and probability map) and introduces geology since the initial part of the simulation process. It can be used on any type of rocks containing natural fractures in any kind of tectonic context. This workflow can also be applied to the subsurface to predict the fracture arrangement and its fluid flow efficiency in water, heat or hydrocarbon reservoirs.

Line 58 determined (instead of inherited):

modification taken into account in the manuscript

Line 97 Explain why fracture connectivity are poorly constrained in these representations:

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The fracture network connectivity implies crosscutting or abutting relationship. While scanning the training image, the MPS algorithm is looking for patterns. In this case abutments are easily found, as it is a singular combination of pixel color. However a crosscutting relationship implies that one fracture is above another. Pixel-wise there will be one fracture continuous and another one discontinuous as the crossing locus cannot be the two colors at the same time. Then without considering a particular facies at the crosscutting locus the fact that two fractures are crossing each other is not taken into account and consequently the connectivity is (partially) lost.

In the manuscript we did not explained more as this problem is detailed in line 325-347 and associated with a figure (6)

Section II.1 (The direct sampling methods). This section is extremely difficult to follow

We are aware that this section is difficult to understand as it implies some terms that are very specific to MPS method. However we tried to make a resume of Mariethoz et al., 2010 and others authors that used the same method before us. This part is also very short and we think that it is not mandatory to understand the rest of the paper. We believe however that it is necessary to present this part to audience that is more aware of MPS technique for them to understand on which method we base our calculations.

In the manuscript we decided to not change this part as it is already simplified and must be included into the paper in our sense. However we added in supplementary material a pseudocode of the DS algorithm to help people to better understand how DS is working.

Line 144. Grid in the X&Y axis; what a node does represent? A node represents a pixel of the grid. A node in the simulation grid is called x, whereas a node in the training image grid is called y. Here “x” and “y” are not related to an axis of the grid.

No change seems to be required in the manuscript

Line 166. Check “Reference” We apologize for this error into the manuscript. It should

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have been removed. Indeed it will not appear in the revised manuscript

In the manuscript we removed this error

Section II.3; sub-sub-section “Training images”: this text requires a figure. It is hard to follow it. We do not believe that a figure of what is a training image should be required. The training image is nothing complex but a simple sketch drawn by the geologist. In the case of fracture network it could also be a photograph with an interpretation on it (representative element area for instance) used to populate one part of the simulation domain. In the manuscript we will cite figures 5, 6, 9 and 10 where the training images appear to make them more explicit to the reader.

Line 199. This does not make sense. How can an image represent a phenomenon? It is a sketch?

See above the reply concerning line 35

Line 295. How?

We agree that this sentence is out of place

We removed this sentence from the manuscript

Line 312. I suppose that EZ are determined according to their fracture pattern

Yes they are. This is what we meant by visual inspection of the pavement.

We do not think that action is required in the manuscript for this issue

Section IV.2. Is this section really necessary for this work?

The reviewer is probably not fully aware of reservoir simulation grid resolutions and the need for an upscaled value of permeability. One of the purposes of our MPS technique is to generate DFN realizations of which the local response is later upscaled to a field scale reservoir model. For small-scale fracture networks as ours, the fracture aperture is an unknown quantity, which greatly affects the local pressure response. The matter in

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Section IV.2 discusses a method to calculate this unknown and compare the aperture variability between various MPS realizations. The results of such a geomechanical approach highlight the robustness of the MPS method as it is able to recreate networks that have similar regions where apertures are open / closed and hence the implications are that they would have a similar fluid flow pressure response.

However following similar comments from the other reviewer we decided to remove this part from the manuscript

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