3D Multiple-point Statistics Simulations of the Roussillon Continental Pliocene Aquifer using DeeSse (Valentin Dall'alba et al)

Hydrol. Earth Syst. Sci. Discuss.,https://doi.org/10.5194/hess-2020-96-RC1, 2020

Anonymous Referee #3 (17 June 2020) :

General comments :	
This manuscript presents a method for large-scale 3D MPS simulations in areas without the necessity of creating a 3D Training Image, which can be a cumbersome and tedious task. Especially, the presented method focuses on areas with few geological observations and little to no geophysical data (soft conditioning data). Overall, a well written paper, albeit with some technical errors, which can easily be corrected. I recommend the paper for publication. Moderate review.	We are thankful to the reviewer for his/her overall evaluation and its detailed comments on the paper. The specific and technical comments will help to improve the manuscript. Below we discuss more precisely the different issues raised by the reviewer and how we plan to adjust the paper in consequence.
Specific comments :	
1- Line 21-22: Explain why we want to skip this step. There are researchers who spend a large portion of their time building handheld 3D geological models and would not understand why it is an advantage to bypass the 3D TI.	This is an important point that was not sufficiently well explained in the introduction. We propose to add a paragraph explaining why we think that this is an important aspect of the methodology : "When using MPS, an important question is the construction of the training image. We first want to note that the conceptual sedimentological models are usually represented in 2D map views or block diagrams and geologists are used to express their understanding of a system by drawing such maps and cross sections. Furthermore, remote sensing data or geological maps are widely available and can be used to refine these 2D conceptual models. Accessing 2D training images is therefore easy and simple. However, the standard MPS workflow requires a 3D training image to generate 3D simulations. Getting the 3D training image from 2D concepts is not a simple task. It may require a significant

	amount of tedious work to construct manually a 3D training image from the 2D concepts. Therefore, previous research was devoted to the design of MPS algorithms able to use 2D training images directly as input for 3D simulations (Comunian et al., 2012; Cordua et al., 2016). Here, we propose a simple approach that allows the user to avoid the step of the 3D training image construction. This is not mandatory. If a 3D training image is available, it can easily be used in the workflow, but if it is not available it should not be a limitation as we will illustrate in the paper."
2- Line 51-61: A good overview, perhaps also mention Image Quilting Simulation (IQSIM) (Hoffimann 2017 - Stochastic simulation by image quilting of process-based geological models) and other more recent methods if any.	We will add this reference in the revised version of the manuscript, we also add more recent advances made on the DeeSse algorithm : "In other algorithms, such as FILTERSIM (Zhang et al., 2006), CCSIM (Tahmasebi et al., 2012) or IQSIM (Hoffimann et al., 2017), the simulation grid is filled by directly pasting or quilting patches, i.e. several pixels at a time. FILTERSIM uses a set of filters to reduce the dimension of the problem, whereas CCISM is based on cross-correlation between patches. The image quilting simulation (IQSIM) proposes a new approach that bypasses traditional ad-hoc weighting of auxiliary variables."
3- Line 68-69: Slightly elaborate "many options", so that the reader can grasp the advantages/disadvantages of DeeSse better.	We proposed to add recent publication on the code DeeSse but would prefer to no explain/list in details all of the DeeSse options and parameters : "More details about the features of the DeeSse code are provided in Meerschman et al. (2013); Straubhaar et al. (2016, 2020). "
4- Line 124-125: I think you mean two-point statistics. A variogram is not a geostatistical method, but a mathematical/statistical construct that is used in different geostatistical methods.	We agree on this point and will replace "variogram" with "two-points statistics" in line 124-125 of the manuscript.

5- Line 180-181: Making 3D Tis is not "too complex". In fact, in the literature, many studies are presented where handheld 3D geological models are created, which are essentially 3D TIs. Rephrase it to emphasize that it is a difficult, time consuming and subjective way of modeling, but NOT "too complex"	The reviewer is right on the subjective use of "too complex" and that some other studies lead to the creation of 3D geological models, which could be used as TI. We propose to review the manuscript with this new version : "As discussed in the introduction, this approach allows avoiding the construction of a 3D TI that could be cumbersome."
6- Line 201: What geological map? You should show it or cite it. If it is the one in Figure 1, then include a reference to figure 1 here.	We will add the reference to the cited geological map.
7- Line 204-205: If it is essential to condition the model to the geological map, then you should describe how you do this.	We agree on this point and proposed to add some information on the process : "The hard conditioning data set also incorporates geological information from the geological map of the Roussillon (Genna,2009). These data correspond to the mapped Pliocene alluvial fan outcrops. We transformed the polygons from the geological map toward conditioning data set for the simulation. The facies assigned to these outcrops corresponds to the alluvial fan facies."
8- Figure 3 caption: What is c) referring to? And b) is not mentioned. Needs to be fixed. Also, the grey model makes sense, but you should still describe it in the figure caption.	It was a typo in the caption. We propose this new caption for the figure 3 : "a) 3D grid of the Pliocene, dark green (the grey volume representing the transformed space). b) transformed grid (flattened space) of the Pliocene layer inside which the 2D simulations are simulated, dark orange (the grey volume representing the original space). The vertical scale is exaggerated for this representation. View from the South of the area toward the North."
9- Figure 4: In the b) and c) it would be a lot better if you added a thin black line to mark the outline of the layers, especially in relation to the stacked trend map in c). As for the current state of the figure I do not really get a lot of information from the stacked trend maps since all the colors of the different layers are identical by design.	The stacked trend map only shows the progradation of the trend as we move upward in the layers, the dark blue color is moving gradually towards the sea as the system evolves. Black contour lines will be added to the figure for a better presentation of the 3D view.

10- Line 256-257: What do the diffusivity equations look like? And what is considered "proper boundary conditions"?	To answer this comment, we propose to rewrite the text as follows : "In the flattened space grid, the auxiliary variables are computed by solving numerically a diffusivity equation in steady-state ($\Delta h=0$, with Δ representing the Laplacian operator) for each of the 2D layers composing the 3D grid. The problem is solved using a finite element mesh following the exact geometry of the domain. The boundary conditions are: prescribed values $h(x)=h_0$ on some parts of the boundary; and $\nabla h(x)\cdot n_x=0$ on the rest, meaning that the gradient of $h(x)$ should be perpendicular to the vector n_x that is normal to the boundary at that location, i.e. the maximum variation of the trend must be parallel to the boundary."
11- Line 274: Insert a reference to Figure 5b) here	Agree, this will be corrected.
12- Line 276-277: Since river system are highly dynamic in nature, and since the reader has no idea about the sedimentation rates over the last 6 My in the given sedimentary basin, you should probably state why we can safely assume that the variation of the paleo orientations are encompassed by +/- 10 degrees of the values observed at the surface currently.	It is true that river systems are highly dynamic and that their bed orientations can vary through time. However, since our TI encompasses the whole river bed, as shown in figure 2d, we do not expect to see strong orientation changes. The rotation map is derived from interpretation and thus cannot be taken as true fixed values of the paleo orientations. The +/- 10 degrees of tolerance is fixed to take into account this uncertainty. This tolerance also helps to not overconstrain the model and to accommodate the location of the patterns to the hard data during simulations. We think that the sentence "The orientation map is based on interpretation and therefore uncertain. DeeSse allows to account for this uncertainty. A tolerance of +/- 10° is considered and added/subtracted to the kriged map to obtain two rotation maps..." gives enough information on the reader on the fact that the kriged value is not the true orientation of the paleo river and that some flexibility must be left to the algorithm to simulate the orientation of the patterns.

13- Line 285-287: Seems a bit discerning, can you elaborate as to why the vertical continuity was not as good when all 6 facies were included for sampling?	This question has already been raised by the reviewer#1. We propose to copy the answer of this comment : Since the "floodplain facies" is the most frequent, sampling the facies at random location leads to an over-representation of the flood plain and tends to bias the MPS simulations. After some tests, it appeared that the easiest way to control the connectivity of the objects of interest was to sample only those facies (alluvial fan, braided and meandering river). We also decided to not sample the levee and crevasse splay facies in order to avoid constraining the whole structure of the fluvial objects too heavily. We propose to add these explanations in the revised version of the manuscript.
14- Figure 7: You should always introduce each sub figure in order a) -> b) -> c), not a) -> c) -> b). Also, a very important detail is that nowhere in the paper do you present a vertical slice, or profile, of the simulated models, so the reader cannot see how bad/well the vertical constraints worked in comparison to a full 3D TI. It would be easy to add a cross section view in this figure.	The caption for figure 7 has been corrected, the b) and c) were simply swapped. We understand the need of cross section view in order to visually inspect the effect of the vertical sampling approach on the simulation outputs. We propose a new figure 11 including these elements. The figure is presented at the end of this document. We also add a small description in section 4.4 : "The impact of the sampling approach can also be easily observed when studying vertical cross-sections along the x and y axis in the transformed grid space (Fig. 11). In Fig. 11a the channels created by the stacking of the braided/meandering facies are vertically disconnected from each other. The impact of the sampling approach that leads to the creation of vertically connected objects can be observed in Fig. 11b. By opposition to the simulation that not using the sampling strategy, it is now possible to observe "channels like" cross-sections in the simulation output."

15- Line 346-348: How do the maps explain that the model is not over constrained? It might be obvious to you, but not necessarily the reader.	We agree with the reviewer that more information needs to be included for the reader. We propose a revised version of this sentence for the manuscript : "These maps also highlight the fact that the model is not over-constrained by neither the TI nor the HD. Focusing on the meandering and braided river facies. We can observe that in some locations the probability maps show high probability values due to the presence of conditioning data. However, this probability decreases proportionally to the distance to the hard data, which demonstrates that the model is not over-constrained by the conditioning data. Moreover, even when a river bed location is constrained with a hard data, the associated spacing with other river bed is not fixed and can fluctuate through the simulation set, which indicates that the TI does not lock the locations of the pattern during a simulation."
16- Lines 385-387: I think you are going need to touch on the strengths/weaknesses when making a comparison like that. The so-called classical MPS studies simply have a lot of geophysical/conditioning data available to them, and will, in large, be better conditioned to the actual subsurface. On the other hand, your method is clearly advantageous when you do not have a lot of geophysical/conditioning data available, but of course will not be as nicely conditioned to the actual subsurface. There are many places in the world where they need methods like this, since they do not have elaborate geophysical data sets available to them.	We think that the presented method should not be viewed in opposition to other methods where geophysical data are available. There is no strength in lacking soft information, the objects are not well described neither in their size nor their location and validation approach cannot be performed when lacking conditioning data. The proposed workflow is only an alternative that tries to take into account most of the available conceptual knowledge.
17- Line 408-409: How are they satisfactorily reproduced? Based on what? Is it solely based on the boreholes being conditioned correctly and the simulations resembling the TI? Then, it would be nice to show some statistics regarding how well the boreholes and simulations agree.	The facies proportions are satisfactorily reproduced base on the fact that they are similar to the borehole facies proportion distributions, excepted for the alluvial fan proportion that is under-represented in the hard data but compensated with the influence of the TI. We believe that this is shown in figure 10 a and fully explain in the sub-section 4.4.

Technical comments :	
1- In general, it is not called a "meander river", but a "meandering river". This needs to be fixed.	Agree. We will correct this point.
2- Line 28: The abbreviations for Marine Pliocene aquifer is PMS. Perhaps this is an abbreviation that makes sense in relation to the French name for the unit, but in order to make the paper more readable I recommend using MPA, which makes more sense. 3- Line 28: Similarly, the abbreviation for Continental Pliocene is PC. It would be more fitting to use CP.	This comment was already mentioned by the reviewer#1. Here is the proposed answer : We understand the possible confusion for the reader, however, this acronym is used by all of the persons that are working in the area. We prefer to keep it for consistency. But we will replace the acronym as much as possible in the revised version of the paper and propose to use the term "Pliocene" when referring to the "Continental Pliocene layer". We will introduce the terminology at the end of the Geology subsection 2.1 : "In the following, and because we do not consider the deeper Marine Pliocene formations in this paper, we refer to the Continental Pliocene layer and aquifer (usually denoted PC in the area) as Pliocene."
4- Line 68: Change "It" to "it", i.e. no capital letters after comma.	Agree. We will correct this point.
5- Line 76-77: Add ":" after "The paper is structured as follows", followed by changing "The" to "the"	Agree. We will correct this point.
6- Line 78: Missing comma after DeeSse algorithm, and "Section 3" should not have a capital letter	Agree. We will correct this point.
7- Line 95: You mean the "extent" and not "extend".	Agree. We will correct this point.
8- Line 238: change "express" to "expressed"	Agree. We will correct this point.
9- Line 360: Change "the alluvial fan dominate" to "the alluvial fan dominates"	Agree. We will correct this point.

New figure 11 :