Response to Reviewer Comments 1

We thank the reviewer for their supportive comments about our work. Note that we use the abbreviation **RC1** for reviewer comments 1 and **AR** for our authors' response in the following. Removed text is shown in red, e.g., ~~this text has been removed.~~. New text is shown in blue, e.g., this text has been added.

RC1: This is a good description of what sounds like an elegant and useful numerical tool for modelling coupled hydro-geomechanical processes in heterogeneous subsurface environments. I like the model. I think other researchers in the field will find great value in it as well. The modelling results are impressive.

> **AR:** We thank the reviewer for the time and effort in evaluating the manuscript and providing such positive feedback. Please find a detailed response to every comment below. We revised our manuscript as explained by our response.

RC1: My point of concern is that the authors, in justifying the raison d'etre of this publication, seem to imply that the list modelling platforms they discuss in the build-up is exhaustive. I know this is not stated explicitly. It is implicit though. In fact, the authors list is, I presume, simply based on their experience. My point is that the list does not have to be exhaustive (in my opinion), but I would advise the authors to state this more clearly.

> **AR:** We agree on that the list of modelling platforms does not have to be exhaustive. Hence, a short disclaimer was added.
>
> Line 38: In the following section, well-known subsurface simulation libraries are briefly reviewed. Since the number of subsurface simulation codes is vast, we only included platforms that are relevant to modelling heterogeneity, for an exhaustive list see White et al. (2018). Current subsurface hydro-geomechanical simulation codes can be classified (...)

RC1: I cannot seem to find any statement regarding the computational effort of this code. I would consider this important information.

AR: We have added this information to the manuscript as well as the caption of each figure containing simulation results.

Line 171: The four verification scenarios are described in the following subsections. The numerical solution were simulated in a 8 core Intel i7-3770 CPU @ 3.40GHz with 32 GB DDR4 RAM memory and the results were stored on a hard disk drive.

Figure 2. Comparison of analytical and numerical solution of the one dimensional consolidation problem obtained in a sample of 100 m. The lines represent the analytical solution whereas the dots represent the RHEA solution. (a) Homogeneous case. For this simulation, a total of 100 nodes and 99 elements were set. The total time for computing 101 time steps was 1.92 s (b) Heterogeneous case For this simulation, a total of 100 nodes and 99 elements were set. The total time for computing 701 time steps was 13.8 s. ~~The lines represent the analytical solution whereas the dots represent the RHEA solution.~~

Figure 3. (...) solution which is not feasible to replicate the latter with RHEA. The total simulation time was 312.6 s for 101 time steps and 10.000 elements with 20.502 nodes.

Figure 5. (...) colour range to highlight the small variations in pore pressure. The total simulation time was 0.49 hours for 70 time steps and 44.341 elements with 44.800 nodes.

RC1: The examples are in 2D. What is the practical feasibility – both in terms of availability of information/data and in terms of computational effort – of such simulations in 3D?

AR: A three-dimensional setup would not add much complexity to the proposed workflow. The user just needs to add an extra dimensional variable (z-dimension in this case) during the data formatting in the python script. From there, RHEA only needs minor adjustments in the simulation control file. For example, set gravity to the right direction as well as include a third dimension in the mesh. Unfortunately, we cannot say how much the computational efforts would increase, since that would depend not only on the number of elements of the mesh but also the hydro-geomechanical properties of the setup since the mesh will automatically be refined in those nodes where gradients are sharp. For this contribution, only a two-dimensional example was considered for the sake of simplicity as the authors believe this demonstrates RHEA's potential.

If the reader is interested in further insights into RHEA's computational performance, Permann et al. (2020) tested MOOSE under challenging conditions with meshes consisting of more than 78 million nodes. Moreover, the same authors tested the parallel capabilities of MOOSE in thousands of processor cores. Since RHEA is based on MOOSE, it should theoretically be possible to perform any RHEA simulation with at least that number of cores in parallel. We add to the discussion
Line 349: (...) meshing capabilities with implicit time stepping. In this work RHEA capabilities has been studied in two dimensions, but three dimensional simulations are also possible. In that case, a three dimensional mesh according to the data set has to be generated, from this point the data formatting workflow and simulation control are applied as described in section 3.

RC1: Line 74: " However, a more robust implementation is Porous Flow, . . . " I cannot say whether this statement is true or not, but I suggest that the authors buttress such statements with facts. Why is PorousFlow the more robust implementation and where has this been shown?

AR: The term "robust" was utilized in this context because up to now (17/05/2021) GOLEM neither supports multi-phase flow nor chemical coupling, whereas PorousFlow does. It is true, however, that GOLEM has been used more extensively than PorousFlow judging by scientific publications, for example (Freymark et al., 2019; Blöcher et al., 2018; Jacquey et al., 2018; Peters et al., 2018). We agree that the sentence may be misleading people who are not familiar with the MOOSE environment.

Line 74 - 75: ~~However, a more robust implementation is Porous Flow, an embedded MOOSE library to simulate multi-phase flow and THMC processes in porous media (Wilkins et al., 2020)~~

Line 74 - 75: Another cutting-edge implementation is PorousFlow, an embedded MOOSE library to simulate multi-phase flow and Thermal-Hydraulic-Mechanical-Chemical (THMC) processes in porous media (Wilkins et al., 2020)

RC1: Line 82: I cannot see why the MOOSE naming convention or which kind of bird Rhea is should be relevant to the reader.

AR: Agree. The following line has been removed

Line 81 - 82: ~~This name is motivated by the MOOSE tradition of using animal names: Rhea is a flightless bird that is native to the South American continent.~~
Line 81 - 82: The name Rhea depicts a flightless bird that is native to the South American continent.

References

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