**Comments to the Author**

Technical Editor: 1  
I would not like to hold back this paper any longer, and I appreciate all the changes the authors made. That said, there are a few important points where at least the language needs to be changed to better reflect the findings of the work.  
  
- Please either justify the use of the word novel, or remove the word novel. As the third reviewer noted, there are other works in the area. Another example see Fig 1 in 10.1002/2015WR017203 and references therein.

Thank you for your comment. We understand that there have been other works in monitoring and forecasting for CO2 sequestration; however, we propose a novel framework for the implementation of ES-MDA-GEO to spatial measurements for accurate monitoring of CO2 plume migration. For instance, our previous work focused on data assimilation of point measurements (monitoring wells), while this manuscript provides a framework for assimilating entire spatial maps.  
  
- There needs to be an explanation of how the CO2 maps were obtained from seismic data, and how far from true/simulated CO2 data they are. Including this info would be beneficial to the point the authors are trying to make, that even with low resolution CO2 maps with increasing error, still a good estimation of k is achieved. But the data generation pathway needs to be clear – ground truth k -> simulated CO2 with multiphase model -> seismic survey simulation ->CO2 inversion? Is this correct?

Thank you for your comment. We have included a clarification on the exact process of obtaining saturation maps from interpreted seismic measurements. “In field seismic surveys, it is possible to obtain a spatial saturation map from the interpreted seismic by applying a fluid substitution model that quantifies the changes in pore fluids and estimate the complete saturation maps. To represent this, we assume that from the reservoir model realizations we can perform forward seismic simulations, convert the results to saturation maps, and then perform our spatial data assimilation framework.”  
  
- Include method limitations somewhere: many have been mentioned by the reviewers, they need to be acknowledged in the conclusions.

Thank you for noticing our oversight. We have included a paragraph on limitations in the Conclusions. “Some limitations in our proposed framework are that this technique only allows for spatial data assimilation, and not a hybrid of spatial and point data assimilation. Furthermore, our method is limited to assimilating a single data type (e.g., saturation maps), and not a combination of multiple spatial measurements. Furthermore, our method requires significant computing time to assimilate the spatial data for a large number of realizations, which can be parallelized or accelerated to increase efficiency. “  
  
- “fluid substitution”. Please provide a reference and/or an explanation please, this is not adequate description.

Thank you for this clarification. We have included the appropriate citation for Gassmann fluid substitution modeling.  
- The abstract says “Our study results also indicate that comparatively spatial data carry more value than point measurements from monitoring wells to reduce the uncertainty in the risk predictions.” This is not shown in the paper. If you want to make an argument so specific, you can run the same inversion with only the permeabilities and CO2 saturations from the wells. Or you can remove the last sentence of the abstract and just focus on the utility of CO2 maps for permeability inversion.

Thank you for your comment. Although we do not quantitatively compare point-vs-spatial data assimilation in this manuscript, our previous work shows the usage, accuracy, and limitations of using point measurements (Chen et al., 2020). A quantitative comparison is outside the scope of this work; rather, we show an improved framework for spatial data assimilation that is more realistic for field cases of CO2 storage.  
  
- Title: Model calibration could mean many things. Permeability calibration of permeability estimation would be more appropriate.    
  
Thank you for your comment. We understand that we are specifically calibrating permeability models in our framework, but it is common practice in literature to refer to this process as model calibration (alternatively, parameter estimation or history matching).

Technical Editor: 2  
  
**Comments to the Author**  
Thanks for your replay for my concerns and most of them were well solved. However, still several questions were not defined properly in the rebuttal. Before the publication of the paper, please revise the manuscript based on your previous reply on my first round comments (Technical Editor 3).  
  
1. Related 2-2) comment, please add information of the relative permeability curve in the revised manuscript.

Thank you for your comment. We have included details and where to find further information about the relative permeability curves: “The default FEHM relative permeability curves for CO2-water are implemented, following a linear model”  
  
2. Related to 2-3) comment, please insert pressure change over time at the injection well in the revised manuscript.

Thank you for this comment. We have included Figure 2 to show the pressure change over time at the injection well for one reservoir model realization.  
  
3. Related to 2-4) comment, Please mention that the observed saturation maps were obtained from the reservoir simulation with the assumption you mentioned.

Thank you for your comment. We have included the following sentences in the Case Study and Results to describe this: “In field seismic surveys, it is possible to obtain a spatial saturation map from the interpreted seismic by applying a fluid substitution model that quantifies the changes in pore fluids and estimate the complete saturation maps. To represent this, we assume that from the reservoir model realizations we can perform forward seismic simulations, convert the results to saturation maps, and then perform our spatial data assimilation framework; specifically in our methodology, we directly obtain the saturation maps from numerical reservoir simulation”  
  
4. Related to the 2-5) comment, 15-year timeframe, the authors mentioned long-term monitoring. In this case, please add a new figure more than 500 years because most of CCS simulation papers have implemented hundreds of years to figure out several CO2 storage mechanisms as mentioned about dissolution or mineralization by the author.

Not sure how to answer this question.

5. Related to 3-2) comment, I meant that update the 'initial' ensembles using years 1, 3, 5 together and compare the results in the manuscript.

This is Step 3 in our ES-MDA-GEO?  
  
6. Related to 3-3) comment, I understood the procedure but what is the exact inflation factor values determined by ES-MDA-GEO. Please add the information in the revised manuscript.

Directly calculated using the code?  
  
7. Related to 3-4) comment, please add your state vector at the assimilation step 3, such as its size and sequence of observation data, in the revised manuscript. I wonder that 3D saturation data were converted into 1D vector.

Not sure how to answer this question.  
  
8. Related to 4-2) comment, even though the initial permeability models have the same peremability distribution but during the assimilation each layer has different permeability distribution. Please update the manuscript.

Not sure how to answer? Do they actually have differences? Or is the same assimilation routine applied equally to all layers?

Technical Editor: 3  
  
**Comments to the Author**  
The author addressed my previous comments. I'll recommend publication with minor revisions. I'd suggest the author to add results for the bottom layer or certain middle layers regarding the saturation distribution (prior or posterior). Though the perm./poro. fields are set to be the same across all vertical layers, the co2/pressure distributions can still vary at different vertical layers due to gravity effects.

Similar to the previous question. Is the assimilation same for all layers or actually different? If so we should state that the same assimilation is done to all layers and therefore they’re all the same as the first layer and no need to plot the other layers.

Final Comments from the Executive Editor:  
Thanks to the authors for submitting their work to SPEJ. As three TEs and the AE raise a few small issues of substance, the authors should address those in a final version.