



EGUsphere, author comment AC1
<https://doi.org/10.5194/egusphere-2022-766-AC1>, 2023
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Reply on RC1

Arundhuti Banerjee et al.

Author comment on "On Parameter Bias in Earthquake Sequence Models using Data Assimilation" by Arundhuti Banerjee et al., EGU sphere,
<https://doi.org/10.5194/egusphere-2022-766-AC1>, 2023

Response to the editorial comments for the Manuscript entitled "**On Parameter Bias in Earthquake Sequence Models using Data Assimilation**"

The authors are thankful to the editor for his insightful guidance in making us improve the quality of the manuscript and for considering us for possible publication in the esteemed journal of 'Nonlinear Processes in Geophysics'. The authors are thankful to the reviewers for their helpful comments. Following the comments of the reviewers, the necessary changes are made in the revised manuscript.

Comments from Reviewer 1

Comment 1:

Synthetic observations are produced by sampling from the synthetic truth and adding an observational error from a Gaussian distribution with standard deviation. However, the real observations could be affected by instrumental noise, missing data, spikes, etc, and a short time step of four time units may no longer be applicable. I understand that the authors lack real observations. But they should at least discuss this limitation in Section 5.

Response:

The authors thank the reviewer for the comment. Indeed, the assumption of data availability (once every four time units) and the assumptions on the standard deviation and distribution of the observational error may not be valid when assimilating real data. We have mentioned this as a limitation in our discussion (page 21, line 348-356).

Comment No. 2:

In introduction, please review some previous studies where either the frictional parameters have been estimated as part of the data assimilation or assumed to be perfectly known.

Response:

The authors have included some references which estimates frictional parameters using data assimilation and are mentioned in the manuscript as (page 2, line 35-37).

Comment No. 3:

Section 2.1: Please specify how to quantitatively determine the observation noise error. Please review some data assimilation frameworks and explain the reason why this framework is selected.

Response:

Observational errors can be determined by comparing observations of velocity or displacement with independent observations of these variables. This text is added to the manuscript. In the introduction, we motivate the choice for using ensemble-based data assimilation methods especially particle filters (page 2, line 38-44). For a further review of data assimilation frameworks, we refer the reader to the recent book by Evensen et al (2022). This reference has been added to the respective text in the introduction as (line 40-41, page 2).

Comment No. 4:

Equation 4: What does j mean? Is it a typo?

Response:

The authors appreciate the reviewer's comments. It is a typo and it should be i which is the number of realization. It has been corrected in the manuscript.

Comment No. 5:

Line 89: In the presence of filter degeneracy, how to guarantee that one or few particles with high weight are sufficiently representative as the input?

Response:

In degeneracy, the weight of one particle is close to one while the weight of all the other particles is close to zero. In this case, a single particle represents the filtered distribution, which results in an extremely poor approximation. Hence it is important to avoid filter degeneracy by (i) adding jitter in the prior distribution and (ii) using resampling step in particle filter. In the present work, we have included both to avoid filter degeneracy.

Comment No. 6:

Line 96: The sequential importance resampling process duplicates particles with high weight. Please explain its physical meaning in data assimilation.

Response:

The authors appreciate the reviewers' comments. In this implementation of the particle filter, the sequential importance resampling attributes higher weight to particles that are closer to the observations. This is done by multiplying the prior by the likelihood, which can be considered a weight function (in this study, a Lorentz function). Then, in the resampling step, the importance resampling process removes those particles which have low weight in the distribution and thereby retains only those particles which have a higher weight. These are then duplicated according to their weight, in such a way that the number of particles remains constant. This ensures an approximation of the prior

distribution that is less sensitive to particle degeneracy. We have mentioned this in text from line 102-105 in page 4.

Comment No. 7:

Section 2.2: The model of forwarding simulation is important to data assimilation. In this study, a zero-dimensional (0D) model is considered. However, 1D, 2/3D models are also available. Please specify the reason why 0D model is selected. More details of its pros and cons are expected.

Response:

The authors appreciate the comment of the reviewer. We have explained the reason of choosing a simplified model for this study in detail from line 357-366 (page 21) in the discussion of the manuscript.

Comment No. 8:

Line 149: What if in the region $a-b > 0$?

Response:

The parameter combination $(a - b) < 0$ corresponds to steady state slip rate-weakening properties causing an unstable rapid slip (frictionally unstable), while $(a - b) > 0$ corresponds to the steady state velocity-strengthening behaviour, causing a stable slip (frictionally stable). Since we are primarily interested in frictionally unstable earthquake cycles, we have focused on parameter combination for $(a - b) < 0$. According to Ruina (1983), if a velocity-strengthening system experiences a slip instability, the motion will be rapidly dampened down to a state of stability. A velocity-weakening system, on the other hand, will no matter how carefully driven, always exhibit growing oscillations and reach a state of regular stick slip (Scholz (2019)). The velocity-strengthening behaviour is thus intrinsically stable. For this reason, we have not investigated the case of $(a-b) > 0$ in this study.

Comment No. 9:

Section 3.2: The assimilation step may have an important effect on the results. In this study a very short time step is adopted. Please provide more discussions on its effect. If a longer time step is used, can a small parameter bias still be compensated?

Response:

Having large assimilation steps can also have a detrimental effect on the data assimilation process as it can miss characteristic variations of the earthquake cycle. A parameter bias can have a substantial effect on the evolution of the state variables, which may be difficult to correct if the assimilation step is large. Hence a short time step is to be chosen that allows the assimilation to capture the important characteristics of the earthquake cycle.

Comment 10:

Discussion: I appreciate the authors' efforts in stating the limitations of this study, but here I expect more discussion on their results and comparison with previous studies (without data assimilation).

Response:

We extended the discussion with a section that discusses our results in relation to previous studies without data assimilation (line 330-339, page 21).

References:

Evensen, G., Vossepoel, F. C., & van Leeuwen, P. J. (2022). Data Assimilation Fundamentals: A Unified Formulation of the State and Parameter Estimation Problem.

References:

Hsu, Y. J., Simons, M., Avouac, J. P., Galetzka, J., Sieh, K., Chlieh, M., ... & Bock, Y. (2006). Frictional afterslip following the 2005 Nias-Simeulue earthquake, Sumatra. *Science*, 312(5782), 1921-1926.

Li, M., Pranger, C., & van Dinther, Y. (2022). Characteristics of Earthquake Cycles: A Cross-Dimensional Comparison of 0D to 3D Numerical Models. *Journal of Geophysical Research: Solid Earth*, 127(8), e2021JB023726.

Miyazaki, S. I., Segall, P., Fukuda, J., & Kato, T. (2004). Space time distribution of afterslip following the 2003 Tokachi-oki earthquake: Implications for variations in fault zone frictional properties. *Geophysical Research Letters*, 31(6).

Ruina, A. (1983). Slip instability and state variable friction laws. *Journal of Geophysical Research: Solid Earth*, 88(B12), 10359-10370.

Scholz, C. H. (2019). *The mechanics of earthquakes and faulting*. Cambridge university press.

van Dinther, Y., Künsch, H. R., & Fichtner, A. (2019). Ensemble data assimilation for earthquake sequences: probabilistic estimation and forecasting of fault stresses. *Geophysical Journal International*, 217(3), 1453-1478.

Please also note the supplement to this comment:

<https://egusphere.copernicus.org/preprints/2022/egusphere-2022-766/egusphere-2022-7>

[66-AC1-supplement.pdf](#)