

Reply to anonymous referee #2

October 3, 2026

The authors thank the Anonymous Referee #2 for their constructive feedback on our work. We have the following answers to the reviewer’s comments (“RC2:” stand for the reviewer comment, “AC:” stand for author’s response comment).

1 General comment

RC: *The manuscript titled "A data assimilation scheme to improve groundwater state estimation in the Aqui-FR modelling platform" presents a method for model prediction correction using techniques adopted from optimal control theory. Specifically, the work invokes a Kalman filtering approach to adjust model predictions based on available data (hence, producing a mean behavior in accordance with data considering expected system/measured variance). While it seems that their updated models outperform standard openloop models, I do find that certain elements of the manuscript are challenging to follow.*

AC: We thank the reviewer for acknowledging the technical approach and performance improvements. We agree that some sections require clarification, particularly regarding the model description and localization methods. We will revise the manuscript to address these concerns by adding more details about the open-loop model (Sections 2.1 and 2.2) and by expanding the explanation of the localization methodology (Section 2.4.1) with mathematical details and visual examples. More details are provided below.

2 Detailed comments

RC: *One point of contention is that it is unclear exactly which type of hydrological model is being used in the study (i.e. can the reader assume unsaturated soil conditions or is that neglected due to scale?). Some specificity regarding the open loop model would help the reader to understand the parameter space used for the fitting as well. This leads into further details that could help the readers to understand the process.*

AC: The model used is a distributed saturated groundwater model (MARTHE), which is an equivalent to Modflow, is used and coupled to a Land Surface Model (ISBA). Marthe uses a 3D finite difference scheme (with volume control) to solve the groundwater flow equation (the

diffusivity equation, combining the Darcy equation, and continuity equation, cf. L150). The ISBA model version used in Aquifer-FR solves the water and energy balance at the land surface (i.e. unsaturated soil). The modelling chain is described in details in Vergnes et al. (2020) as cited in the manuscript. The infiltration and run-off fluxes from ISBA, computed for the infiltration at the bottom of the root zone, are converted into groundwater recharge using a conceptual reservoir approach (Gardénia part, as stated L189 - this part will also be revised in line with RC#1 comments), used as a transfer function (see L189).

These details will be added to sections 2.1 and 2.2.

RC: *Ground water is specified as a state variable here in L199, but more examples would help for different parameters (what are observations used for forecasting etc.?).*

AC: We added a description of the observations in Section 2.5.1, but we agree that a more detailed description of the observation vector or operator could help the reader. We propose to add informations about the observation vector as follows: (L199) "... p the dimension of observations (i.e. the number of observation stations, piezometric stations here, see 2.5.1 for the dataset description)". The full sentence may be rewritten/split for a clearer syntax.

RC: *There are some notations that come out of nowhere that are unclear for readers (e.g. what is the Marthe model in L212?). Specificity would help the reader, so a subsection on the open loop model would be really good.*

AC: As mentioned above, the revised manuscript will include more details about the open loop model to clarify this point. These details will be included in sections 2.1 for the kind of model (Aquifer-FR framework and Marthe code) and 2.2 (for the regional model of the Somme basin used). However, we believe that these two sections should contain all the necessary information about the open loop model and that a dedicated subsection would be redundant.

Additionally, the Marthe notation in line 212 does not add any information to the text and clearly causes confusion. It will therefore be removed.

We will also ensure that all notations are explained in the revised manuscript.

RC: *The introduction of the local weights is also difficult to follow. Do the weights in eq5 integrate to 1? There is little to no explanation on eq 7. I understand that there are two localization methods being used, but their differences remain unclear to me. Explicitly showing some differences and the form of the weight matrices would be good here too. For example, what should the reader understand about L_{xy} if we do not really know what L looks like?*

AC: We do agree that the part about the localization weights needs to be clarified. We will add more explanations of all the equations, especially ensuring that all notations are explained. Equation 5 provides the computation of weights between two cells in order to construct matrices, such as the cross state-observation space matrix, denoted by $\mathbf{L}_{xy}$, and the observation space matrix, denoted by $\mathbf{L}_{yy}$. These matrices are integrated into equation 1, as shown by equation 8, which is equation 1 rewritten to combine equation 2 and add the localization matrices (see L253). As stated line 236, the $\mathbf{L}$ matrices are composed of the weights between cells. These are computed using either with a distance varying method, or a correlation (variogram) method. As shown in figure 2, the distance method produces circular influence zones, whereas the correlation method produces anisotropic patterns that better reflect the physics of the system. We do agree that the link between the weight computation and the construction of the $\mathbf{L}$ matrices could be

clearer. We will revise the explanations and include matrices examples in the manuscript.

RC: *Coming to the results, they mostly show improved performance in most regions. There is Figure 4 f that looks odd, but that just needs some elaborating. The organization of some of the results are hard to follow. Figure 5 needs sub labels (a-l) along with more legible axis labels. I do not know what we are supposed to take from this. Lastly, I do not understand why increasing the lead time increases the error in Figure 6. I see that in figure 7 it reduces the median of the RMSE monthly, but is that even significant reduction between 3 and 6 months?*

AC: We will address each concern:

- Figure 4f shows a verification site near an assimilated site. The odd appearance is due to differing biases in the model at these two nearby locations. This relates to the discussion in section 4.2, from L478 to 488, and we do agree that this link should be made more explicit. We will add a reference to figure 4f in the discussion and more detailed explanations.
- Figure 5: We will add sub-labels and increase the axis font size. The key takeaway is that both methods performed quite similarly (which was not expected) but still correlation-based localization (svg) still shows more robust performance at validation sites across all observation as performance degradation is limited with lower observation densities.
- Figure 6: The error increases with lead time because the evaluation is performed with reanalysis forcings. After “forecast” initial conditions correction, in free mode, the model slowly returns to the open loop state (due to uncorrected structural uncertainties and parameters). The key point is that even with a simple state data assimilation the correction can be expected to last for a seasonal forecast range.
- Figure 7 shows that the distributions shift towards lower normalized information criteria (NIC) from 3 to 6 months. After 6 months, the distributions are more spread, with more NIC negatives (i.e. worse performance). This adds nuance to the previous figure (figure 6) and the discussion. Despite average good results, degradation of forecasting performance is still expected.

RC: *I guess my final concluding statement would be for the authors to spell out the novelty a bit more explicitly. I trust that its technical and state of the art, but is not this being used already? Really hammer in and make it clear what is different and what we should take home from this work. There are few references to particular results in the discussion (none that I can see actually). Please specify figures or tables that can help the reader to navigate the discussion in a manner that is supported by your findings. I would recommend the manuscript be revised in accordance with my comments.*

AC: This is actually a challenging point. We do agree that previous works in the literature have used similar techniques of data assimilation for hydrological modelling. However, we believe that there is still a gap for operational use of data assimilation in groundwater modelling.

Many studies use data assimilation to optimize parameters and analyse uncertainty in the context of history matching. However, the added value of state data assimilation with a distributed regional groundwater model has not yet been fully explored in the literature, particularly in the context of seasonal forecasts. To our knowledge, few studies have explored the persistence of DA correction, which of course depends on the hydrogeological context (as discussed). However, this

remains an important consideration from an operational perspective, where parameter updates are not always relevant at each forecast initialization.

The configuration of such data assimilation remains challenging, with localization being one of the most important parameters. Recently, Li et al. (2023, cited in the manuscript) used distance-based localization, which was originally used in meteorological applications. For groundwater, a different localization method could be used. We believe that the methodology developed for large-scale surface hydrology (Revel et al., 2019) could be adopted for groundwater. However, this has not yet been done in the literature. The results are not perfect, but they also pave the way for further research and development dedicated to regional or national scale groundwater data assimilation problems.

The manuscript will be revised to better reflect these challenges. We will also revise the discussion to explicitly reference all the figures and tables that support the findings.