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Geoscientific Model Development Discussions

Interactive comment on "TerrSysMP-PDAF (version 1.0): a modular high-performance data assimilation framework for an integrated land surface–subsurface model" *by* W. Kurtz et al.

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General comments
This paper by Kurtz et al. introduces a modular high performance data assimilation framework for a coupled land surface groundwater model (part of the TerrSysMP model). This paper introduces the technical implementation in great detail, analyzed the computational efficiency of the parallel framework, and provides an illustrative example. The paper is generally well written. Both data assimilation and coupled modeling systems have become increasingly popular in the hydrometeorology community in recent years. The coupling technique and the implementation of data assimilation

technique introduced in this paper could be expanded to other data assimilation method and other coupled modeling systems.

Reply: We thank the reviewer for pointing out the relevance of our work.

Specific comments
1. P9622, L12 "However, while such integrated modelling approaches provide a better description of model physics which effectively reduces model structural errors that often occur in single compartment models through the parameterization of lower or upper boundary conditions. . ." I don't quite agree. Sometimes coupled models could introduce model structural errors. However, this is minor.

Reply: We believe that one of the main purposes for coupling different geoscientific compartment models is the better physical description of processes at the compartment interfaces. Therefore, we think that our statement is generally valid. Of course, if the coupling is not done in a consistent way or if the coupling violates some underlying assumptions in the parameterization of the forward models, one could easily introduce model structural errors. However, if the coupling is done in a physically consistent manner, the model error should decrease.

2. P9627, L24 "For example, local filter variants like LETKF need special routines to infer the position of each element of the state vector in the model domain in order to perform the localization which is not needed by global filter algorithms like EnKF." I understand that localization is not needed by EnKF. However, covariance localization could be important for a large-scale multi- watershed application. Is there a way to account for localization in the data assimilation system?

Reply: Sorry, our formulation was a bit misleading here. We wanted to express

that this special routine (determination of distances between state vector elements) is not used by the EnKF formulation in PDAF. The reason is that localization for EnKF is currently not implemented in the release version of PDAF.
We certainly agree that localization could be a very important factor for the data assimilation results. However, this is currently not possible with EnKF in PDAF. Alternatively, PDAF provides local variants of several other filters (e.g., ETKF/LETKF). This functionality is not yet available in TerrSysMP-PDAF but will be provided in the near future.
In order to avoid confusion, we will rephrase this sentence and remove the misleading formulation *"...which is not needed by global filter algorithms like EnKF."*.

3. P9633, L6 "In this case, pressure values in ParFlow are indirectly corrected with the incoming soil moisture measurements through the correlations between soil moisture and pressure. This is necessary, because the prognostic variable in ParFlow is pressure and soil moisture (or saturation) is a derived quantity which is not directly used as a state variable for the next time step." I understand that soil moisture is a derived variable but not a prognostic variable in ParFlow. But the pressure values could easily be converted into soil moisture using the van Genuchten equation. So why not convert the pressure values into soil moisture values, update the soil moisture values, and convert them back into pressure values?

Reply: You are certainly right. There are basically two ways how pressure can be updated with soil moisture data in ParFlow: (1) The one we described in the manuscript is to use an augmented state vector composed of soil moisture and pressure. Pressure is then indirectly updated through the correlations with soil moisture. (2) Alternatively, as you mentioned, one can also use saturation/ soil moisture as the solely state variable in the filtering step and then transfer the updated saturation/ soil moisture values back to pressure via the 'inverse' van

Genuchten function. In fact, this second variant of updating soil moisture/ pressure is also included in TerrSysMP-PDAF for testing purposes. As we are using the first method in the verification example, we did not mention that there are two options in TerrSysMP-PDAF for assimilating soil moisture data, in order to avoid confusion. Nevertheless, we will clearly mention in the revised manuscript that there are two options in TerrSysMP-PDAF to assimilate soil moisture contents in ParFlow.

4. The system can be used to estimate parameter values. Is there a way to constrain the parameter values (and state variables) in their physically plausible ranges? This could be important as some "bad" parameter values could break the model.

Reply: Currently, TerrSysMP-PDAF does not include a plausibility check for updated state or parameter values. We agree that an update towards implausible state/parameter values could pose a problem to model performance. However, an update towards implausible parameter values can also hint to some problems in the overall model/ data assimilation configuration. Restricting the updated values to predefined bounds will possibly not solve these problems but will just mask them from the user. From our perspective, a better solution is to identify the reasons for too extreme state/parameter updates (e.g., spurious correlations due to limited ensemble size) and then try to take actions that reduce this problem (e.g, increasing ensemble size, localization).

5. P9643, L18 "The improvements made by assimilating soil moisture content are relatively limited for land surface fluxes which is related to the shallow ground water table in the simulations guaranteeing that actual evapotranspiration is equal to potential evapotranspiration." I don't think the actual evapotranspiration is equal to potential evapotranspiration in this case. The plant stomatal conductance is affected by visible solar radiation (S), air temperature (Tair), air humidity (RH), and soil moisture (Θ). In *this case, although soil moisture is close to saturation, S, Tair and RH still limit the actual ET which may not reach the potential ET. The reason that the AAE is small for H and LE is because (1) S, Tair , and RH are the same in the ensemble as in the reference run; (2) in both the ensemble and the reference run, soil moisture is close to saturation, and (3) the other parameters affecting ET are not perturbed (e.g., the minimum stomatal conductance).*

Reply: We agree with the reviewers' point. Concerning the land surface fluxes, we only focused on the hydrological aspects but did not take into account plant physiology and the meteorological forcings. We will add an additional paragraph in Sect. 5.3 that addresses the reasons for the relatively low errors and improvements of land surface fluxes. We will also remove the statement that actual ET is identical to potential ET.

Technical corrections

1. P9619 L1 "20 Mio. Unknows" Should be "unknowns".

Reply: Will be changed.

2. P9619 L10 "precipitation, hydraulic properties" Could be more clear if change this to "soil hydraulic properties".

Reply: Will be changed.

3. P9620, L4 ". . . and to a lesser extend also concentration" Not clear concentration of what.

Reply: *Liu et al. (2008)* and *Li et al. (2012)* used solute concentrations in a groundwater model and *Gharamti et al. (2014)* used molar fractions in a reservoir model. We will specify this more clearly in the revised manuscript.

4. L9622, L7 "like, e.g., . . ." "Like" is redundant.

Reply: We will remove *'like'*.

5. P9623, L22 "Finally, 6 provides. . ." Change this to "Section 6".

Reply: We will change *'Finally, 6 provides ...'* to *'Finally, Sect. 6 provides ...'*.

6. P9624, L10 "i.e., the is no lateral exchange. . ." Change this to "there is no lateral exchange".

Reply: Will be changed.

7. P9625, L21 "recharge values" Do you mean infiltration values? Are they the same?

Reply: The recharge values q_{inf} are composed of the infiltration values at the top soil layer and the transpiration losses from the root zone (first ten soil layers).

8. P9627, L21 "for e.g." "For" is redundant.

Reply: We will remove *'for'*.

9. P9635, L6 "The poroity is set to a value of 0.4 and . . ." Unit is missing for porosity.

Reply: **Will be changed to: *"The porosity is set to a value of 0.4* $\mathrm{m^3 m^{-3}}$ *and ..."*.**

10. P9641, L11 "A more detailed information . . ." "A" is redundant.

Reply: **Will be changed to: *"More detailed information..."*.**

11. P9642, L13 ". . . stays above > 0.8" The greater than symbol is redundant.

Reply: **We will remove the greater than symbol.**

12. P9644, L15 "Therefore, it was also tested whether the . . . framework is also applicable . . ." "Also" appear twice in this sentence.

Reply: **We will remove the second *'also'* from the sentence.**

13. Figure 9 Legend is missing. The ensemble mean is not shown in the figure.

Reply: **A line for the ensemble mean and a legend will be included in Fig. 9.**

14. Figure 10 There is a phantom line at y = 1500 m. Not sure if this is a pdf rendering problem.

Reply: **Unfortunately, we found that there was a problem in the calculation of the AAE fields (time shift between the reference and the ensemble mean of soil moisture). Based on the new calculations, the discontinuity at y=1500m vanished and the background AAE value of 0.03 was decreased to zero (see Fig. 1 below). Other results were not affected by this calculation error.**

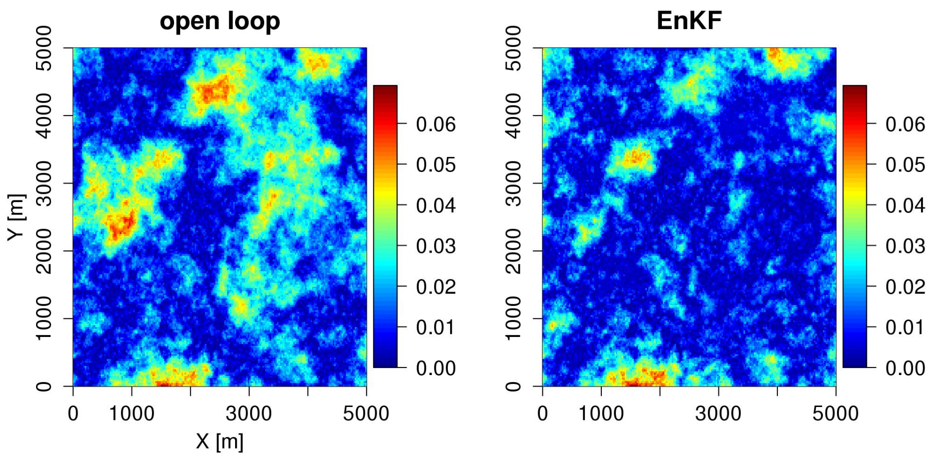

Fig. 1. Absolute average error of soil water content for open-loop (left) and assimilation (right) at a depth of −65 cm from April–June 2013.