Brief description of the modifications of the manuscript

The major modifications of our manuscript are

- More relevant literatures and explanations are added in the introduction to highlight the enhancement of our study.
- An additional scene with a series of wide prior parameter distribution cases are added in the revised manuscript. And more detailed discussions are added in section 4 to test the effects of prior distribution of parameters on the performance of estimation.
- Dual-parameter estimation cases are added to give more detailed discussions about multi-parameter estimation analyses.

Detailed responses

Anonymous Referee #3

The stated contribution is in demonstrating that constraining the parameters to be estimated in a simultaneous parameter estimation/data assimilation scheme will improve the otherwise poor performance. The authors tie the parameters together via constraints based on pedotransfer functions (relationships linking soil sand and clay fractions to soil hydraulic parameter values). I think of this as a relatively mild contribution for the reasons stated below. I would not recommend publishing unless the five points can adequately be addressed:

1) Rather than introduce the constraints, why not simply use sand and clay fractions as the parameters to be estimated? Sand and clay, via the pedotransfer functions used (those of Cosby et al.), fully define the four hydraulic parameters. The authors instead stick with the four parameters and constrain them with the relationships developed from the pedotransfer function relationships. Had they simply used sand and clay as the two variables included in their framework, the same outcomes would be achieved by my read of their paper. If so, the conclusion would be that the simultaneous parameter estimation/data assimilation is more likely to be successful with two parameters than four, which is not a significant contribution to parameter estimation/data assimilation methodology. The authors should address this point.

A: We used soil hydraulic parameters but not sand and clay fractions as estimated parameters in our study, because the sand and clay fractions were not explicit parameters in the AVIM model. There were six soil texture classes which derived from Zobler (1986) in the AVIM model: sand, sandy loam, loam, clay loam, clay, organic soil. Each soil texture had a set of hydraulic parameters, such as three estimated parameters (saturated hydraulic conductivity, saturated soil moisture suction, and soil texture empirical parameter *b*) in this study. These soil hydraulic parameters were explicit in the model. So they were chosen to be estimated.

Since the AVIM model do not have sand and clay fractions, we can not perform experiments to test whether the same outcomes would be achieved if sand and clay are used as estimated parameters. In the future study, we can try this idea using other land surface model (e.g. SiB2, (Sellers et al. 1996)), in which sand and clay are two explicit parameters.

2) Pedotranfer functions also have errors and such errors are not incorporated in the analysis. In this sense, the parameter values are overconstrained. They could have incorporated such errors into the framework. This would address in part the concerns from my first point.

A: This comment is generally correct. However, any scientific paper must have a major point. The objectives of this paper are: (i) to investigate the capability of the EnKF in state-parameter estimation in soil moisture assimilation, and (ii) to discuss if the performance of estimation can be improved further when constraints between these parameters are considered in assimilation process.

In the AVIM model (and also in most of other LSMs), there is often only one kind of pedotranfer function been used to estimate soil hydraulic parameters according to soil texture class because it is easy to implement. If errors in pedotranfer function need to be considered, more different LSMs beside the AVIM model need to be used in this study. Therefore, despite pedotranfer functions have errors, it is still very difficult, and beyond the scope of this study, to consider these errors in our assimilation framework.

3) The problems with the batch methods are overstated. P. 1436, ln 6: "(ii) it only addresses parameter error while errors from initial conditions and atmospheric forcing data are ignored." This is not the case. It may be true that "as commonly practiced, errors from initial conditions and forcing data are ignored." But it is not an inherent limitation of batch methods. Vrugt et al. (2005) is such an example of a batch method that does consider such errors. This is important because the parameter estimation procedure in batch methods is infinitely more robust than that inherent in the simultaneous parameter estimation/data assimilation approach, which relies essentially on a random walk-like search (which is why it scales poorly with the number of parameters to be estimated.) The only real reason to use a simultaneous approach, it seems to me, then is their point (i), that observations can be incorporated continually. This may have some benefit in operational systems in which it may be burdensome to routinely carry out a batch analysis.

A: We agree with this comment. We changed the statement according to this comment. The new sentence is “There exist two main weaknesses in these calibration approaches: (i) it can not include information from new observations, and (ii) as commonly practiced, errors from initial conditions and forcing data are ignored.”.

4) In the next paragraph (p. 1436), Vrugt et al. (2005) is erroneously cited as an example of a simultaneous state-parameter estimation approach. In a paper claiming a methodological contribution, this is a significant misread of the literature. Vrugt et al. (2005) is a batch procedure.

A: We agree with this comment. There is our mistake in the manuscript to cite Vrugt et al. (2005) as an example of simultaneous state and parameter estimation approach. We removed this literature in our revised manuscript.

5) The constraint formulation in this case is relatively straightforward due to the *simplicity of the Cosby relationships, all of which have a linear function in one variable (conductivity as linear function of sand fraction). It would not be as easy given more complex pedotransfer function relationships. And it still seems far easier to define the parameters, in this case, sand and clay fraction, as the parameters to be estimated rather than back out the constraints.*

A: We understand this comment as two points, and respond them item by item:

5.1 As the constraint formulation in this study is relatively straightforward, it may be hard to get corresponding constraint formulation for more complex pedotransfer function relationships.

A: In our study, the constraint formulation is obtained by linear regression analyses on the means of these parameters according to Cosby et al. (1984). These statistical relationships are the first order approximation to the actual statistical relationships between these parameters. Because the purpose of this study is to test whether these statistical constraint relationships can improve the performance of state-parameter estimation, these first order approximations were used. Results from our manuscript showed that these first order approximations were proved to be effective for state-parameter estimation in soil moisture assimilation.

If more complex pedotransfer function relationships will be used in similar studies, these relationships can be expanded by multi-order approximations (e.g. using power function or Fourier function) firstly. Then, the constraint formulations can be constructed by the first few order approximations of these complex pedotransfer function relationships according to the number of estimated parameters.

5.2 It seems far easier to use sand and clay fraction as the parameters to be estimated.

A: Similar to the answer of comment 1, the sand and clay fractions are not explicit parameters in the AVIM model, therefore, we use soil hydraulic parameters but not sand and clay fractions as estimated parameters in this study.

Since the AVIM model do not has sand and clay fractions, we can not perform experiments to test whether easier outcomes would be achieved when sand and clay are used as estimated parameters.

References:

Vrugt, J. A., Diks, C. G. H., Gupta, H. V., Bouten, W., and Verstraten, J. M.: Improved treatment of uncertainty in hydrologic modeling: Combining the strengths of global optimization and data assimilation, Water Resour. Res., 41, W01017, doi:10.1029/2004WR003059, 2005.

Sellers, P. J., et al.: A revised land surface parameterization (SiB2) for atmospheric GCMS: Part I. Model formulation, J. Clim., 9, 676– 705, 1996.

Zobler, L.: A world soil file for global climate modeling. NASA Tech. Memo. 87802, 33 pp, 1986.