

Response to Reviewer #2 Comments

Yunhao Fu, et al.

April 27, 2026

General Comments. Reviewing of the manuscript ‘Effectively Assimilate Satellite Land Surface Temperature into Offline Land Surface Models within Ensemble-based Assimilation Frameworks’ by Y. Fu et al. submitted to Geoscientific Model Development (Manuscript Number: egusphere-2025-6159). This work aims to improve the offline Land Surface Model by data assimilation techniques to assimilate land surface temperature, updates the soil temperature and soil moisture simultaneously. This process influences significantly the land-atmosphere interactions and the soil temperature in different layers. The following is my comments in details:

Response:

We thank you for the review. Below is our point-by-point response to each concern.

Comment 1

1. The manuscript uses a lot of abbreviations, which is not necessary and influence the readability of this work. For example, the Data Assimilation (DA), Common Land Model (CoLM), Extended Kalman Filter (EKF). There are a lot of more examples than these, and I will not list them all. The authors please reduce some unnecessary abbreviations to improve the fluency and readability of this manuscript.

Response:

We have carefully reviewed the manuscript and removed several unnecessary abbreviations that appeared infrequently, including GCOS (L21), ECV (L21), EKF (L71), EnSRF (L121), EAKF (L121), LEKF (L123, L179), WFD (L192), CHTESSEL (L228), and EH (Fig. 1, L301, L303). Meanwhile, abbreviations such as CoLM (Common Land Model), DA (data assimilation), LST, and LSM have been retained to maintain conciseness throughout the manuscript.

Comment 2

2. The subtitles are overly simple. For example, Section 2.1 CoLM, 2.2 Observation operator, 2.3 LETKF. Again, there are more examples than these, and it is the responsibility of the authors to read through the entire manuscript to improve them.

Response:

We have carefully reviewed the entire manuscript and revised all overly simple subtitles to provide clearer context for each section. Specifically, we have made the following updates:

Section 2.1 "CoLM" is now "CoLM Configuration and Ensemble Generation" (L85).

Section 2.2 "Observation operator" is now "Land Surface Temperature Observation Operator" (L107).

Section 2.3 "LETKF" is now "The Local Ensemble Transform Kalman Filter Scheme" (L117).

Section 4.3.1 "Temperature" is now "Impacts on Soil and Snow Temperature" (L309).

Section 4.3.2 "Water content" is now "Improvements in Snow Properties and Soil Moisture Content" (L362).

Section 4.3.3 "Evaporation and heat flux" is now "Modulations of Evaporation and Surface Heat Fluxes" (L447).

Comment 3

3. Error or mistakes in writing. For example, Page 1 Line 22, delete the comma in '..... (, GCOS)'. Page 5 Lines 9-12, add 'is' in each expression following the variables. BTW, it is a little bit awkward to use down arrow following LW, please consider revising it.

Response:

Thank you for your careful reading. We have addressed all of your comments in the revised manuscript, as detailed below:

1. We have corrected the citation formatting by removing the misplaced comma in "... (, GCOS)" (Lines 22–23). 2. We have added the verb "is" after each variable in the definitions (Lines 110–113). 3. We have replaced the downward arrow following "LW" with "DLW" (Equation 2 and Line 113).

Comment 4

4. Add a full flowchart of this model coupling work including the data assimilation processes. It is not necessary to list the detailed equations but show the concepts of this entire process.

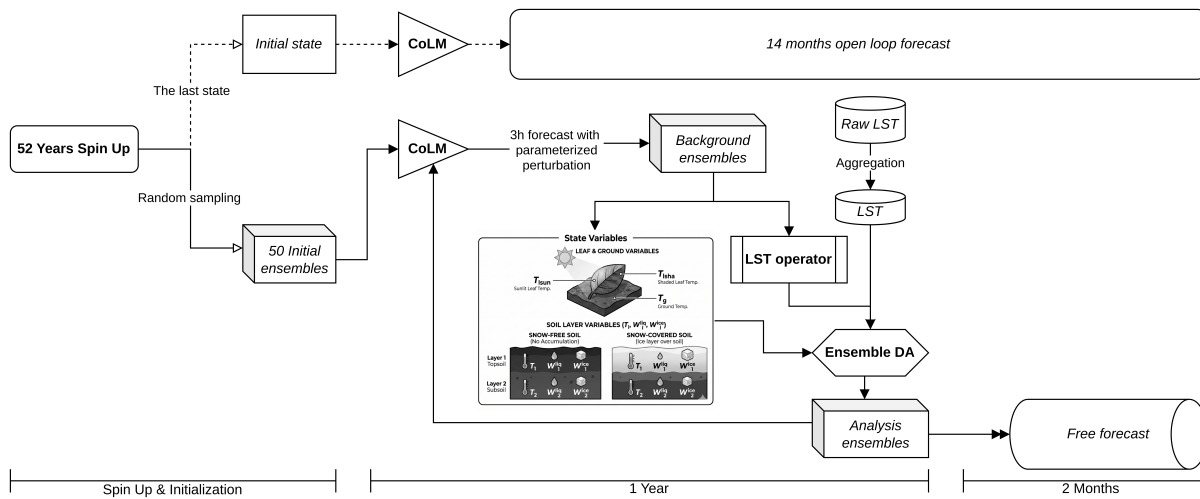


Figure 1: Schematic workflow of the coupling architecture and DA experiments. The process comprises a 52-year spin-up for initialization, a 1-year period comparing the assimilation group (solid lines, continuous 3-hour cycles updating leaf, ground, and soil variables) against the open-loop baseline (dashed lines), and a subsequent 2-month free forecast.

Response:

We have added a comprehensive flowchart (Fig. 1) illustrating the CoLM-LETKF land data assimilation workflow, which includes a 52-year spin-up, ensemble initialization, and 3-hour forecast cycles with parameterized perturbations. Alongside the DA experiment, an open-loop experiment (without data assimilation) was conducted to serve as a baseline. For the sake of completeness, the equations are retained in the text. Modifications have been added in L254-255.

Comment 5

5. 1.3 Evaluation datasets. The writing style of this Section reads a little bit like AI-generated. For example, the point ‘-ERA5-Land’ or ‘-GLDS’ or ‘-MERRA2’ followed by a paragraph’. Please consider revising and re-writing for fluency.

Response:

We have rewritten Section 3.1.3 to improve its narrative fluency (L225-241).

Comment 6

6. The format of this work should be consistent throughout the whole manuscript. For example, leave space when starting a new paragraph in the front.

Response:

We appreciate the reviewer's attention to the formatting details of the manuscript. We have thoroughly checked the text to ensure consistency. The absence of indentation at the beginning of sections is due to the default settings of the official GMD LaTeX template (https://www.geoscientific-model-development.net/Copernicus_LaTeX_Package.zip), which we used for this submission. In this template, the first paragraph of each section is not indented, whereas all subsequent paragraphs are properly indented. We have strictly adhered to this official formatting standard throughout the revision.

Comment 7

7. Section 4.1 for Equation (19), this is the skill metrics and should be removed to the Method Section. Please double check the definitions of RMSD and unbiased RMSD, if the mathematical formulae are correct or not.

Response:

Regarding the placement of the "Evaluation Metrics" subsection (including Equation 19), we have moved it to a position between the "Setup of the Assimilation and Open-Loop Experiments" and "Results" sections. We chose this specific location because the application of these metrics—and the subsequently presented Table 3—logically builds upon the experimental setup and the validation datasets introduced immediately prior (Lines 271–285).

We have also double-checked the formulations for both RMSD and unbiased RMSD. The equations presented are fully consistent with the calculation methods defined in Appendix B of [2].

Comment 8

8. The Table 2 is not necessary, please delete it.

Response:

Table 2 has been removed from the revised manuscript, as the experimental configurations are already fully described in the text.

Comment 9

9. When comparison for AEXP or OEXP driven by ERA5 or GLDAS or MERRA2, what the observational data are used or is there any in-situ data to evaluate the model performance? This is an important issue, since the comparison and validation are throughout the whole manuscript.

AEXP - OEXP

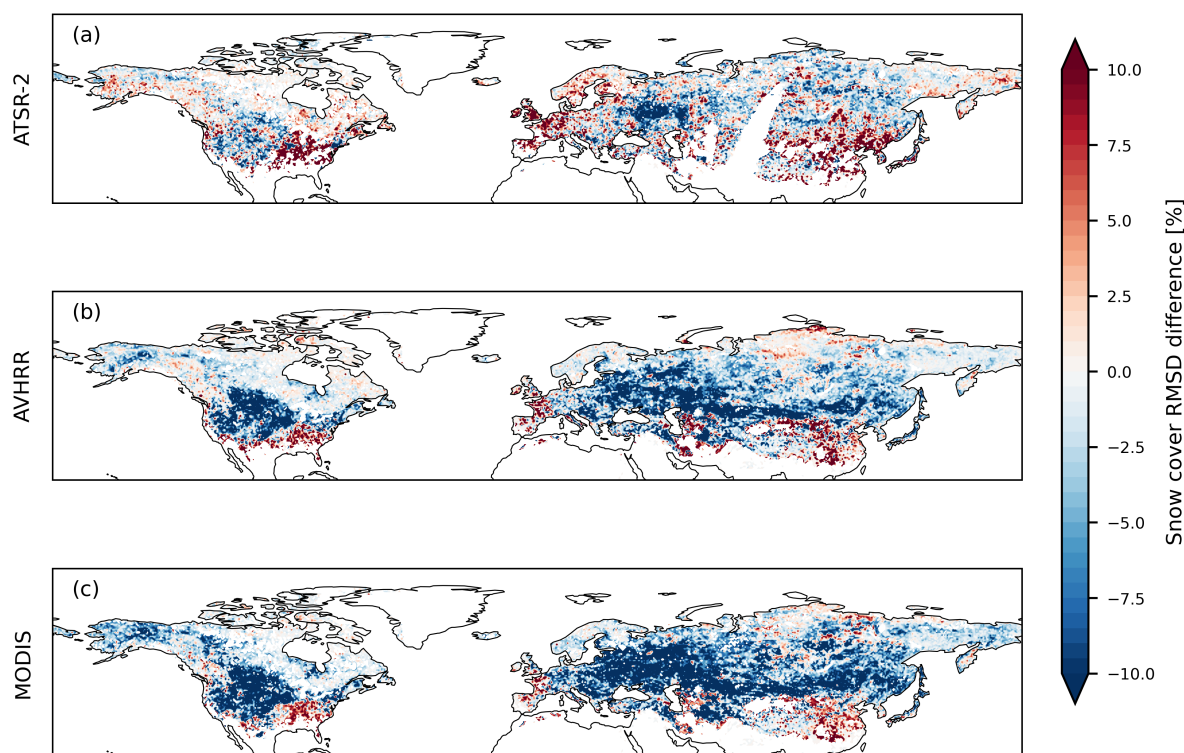


Figure 2: Snow cover [%] yearly (31 January 2001 to 31 December 2001) RMSD_d evaluated based on different satellite products: (a) ATSR-2, (b) AVHRR, and (c) MODIS.

Response:

We have introduced independent satellite and in-situ observations into the revised manuscript to robustly evaluate the assimilation performance. Using datasets retrieved from multiple satellites, including ATSR-2 [8], AVHRR [4], and MODIS [5], significant improvement in snow cover across the Northern Hemisphere is seen in Fig. 2. With in-situ observations from the FLUXNET2015 [7] and AmeriFlux [6] networks, improvements in both sensible and latent heat fluxes are evident in Fig. 3. Descriptions of these added observations are provided in L247-251 and L285-L286. We've added the corresponding evaluation in L386-393 for snow cover, L478-485 for surface heat fluxes.

Comment 10

10. Figure 4: The use of 'MAM' and 'SON'. What do these abbreviations mean? Please be clear.

Response:

We have clarified these abbreviations in the revised manuscript. 'MAM' and 'SON' stand for the months March-April-May and September-October-November, respectively. The captions for Figure 4 and Figure 7 have been updated to explicitly define these terms.

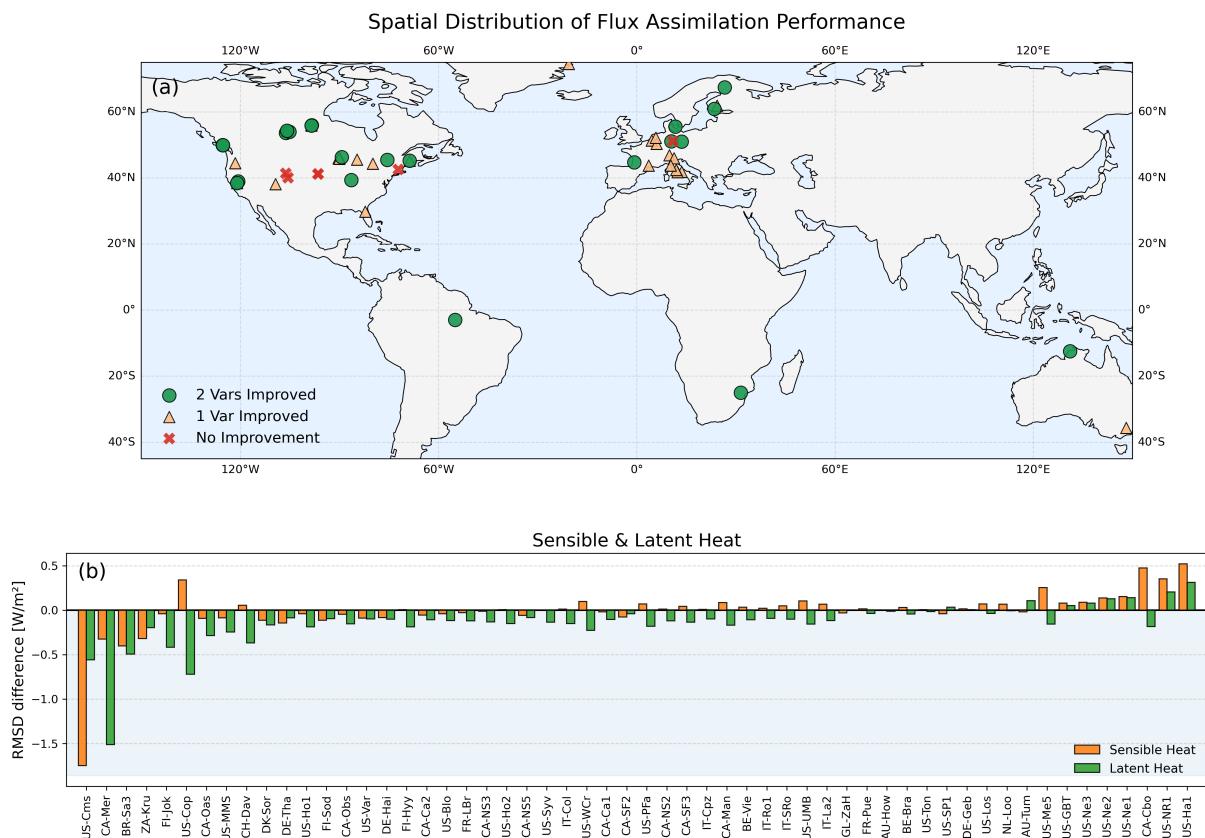


Figure 3: Spatial and quantitative evaluation of the impact of assimilation on surface heat fluxes across global sites. (a) Distribution of assimilation performance based on sensible heat and latent heat. Markers categorize sites by the number of improved flux variables: green circles indicate improvement in both heat fluxes, orange triangles represent improvement in a single variable, and red crosses denote no improvement. (b) Site-specific $RMSD_d$ for sensible heat (orange bars) and latent heat (green bars) across the year (31 January 2001 to 31 December 2001).

Comment 11

11. Figure 10: why the evaporation from the bare soil is missing for AEXP-OEXP vs. GLDAS?

Response:

The evaporation from bare soil compared based on GLDAS is presented in Fig. 10(c) of the original manuscript.

Comment 12

12. This work needs substantial improvements for the Discussion, e.g., 1. Compare the work/accuracy of land surface temperature, soil moisture, water content, soil humidity simulated by model compared with previous or similar studies? The physical mechanisms behind the parameter tuning strategy needs to substantially improve.

Response:

Regarding the first point, we have expanded the Discussion section to compare our assimilation performance with relevant previous studies. In general, the degree of improvement observed in these previous studies is very similar to what we achieved in our current work. For instance, Huang, Li, and Lu [3] assimilated LST solely to update soil temperature; thus, their analysis concentrated primarily on soil temperature improvements, reporting an error reduction of approximately 1 K for the soil profile at specific sites. Their findings are highly consistent with our results, where the bias in soil temperature over Northeast Asia is reduced by approximately 1.0 K, 1.5 K, and 2.0 K with increasing depth (Fig. 2). Furthermore, Chen et al. [1] assimilated LST to update soil temperature alongside brightness temperature to update soil moisture, focusing mainly on the Tibetan Plateau. They reported a reduction in the RMSD for shallow-layer soil moisture ranging from 19% to 71% across various sites. In our study, the proposed LST assimilation achieves a comparable impact on soil moisture, reducing the unbiased RMSD for the upper soil layer by approximately 40% across Northern Asia (Fig. 8). We've added this discussion in L501-507.

For the second issue, the tuning parameters encompass six key physical processes, which are distinguished by different colors in Table 1: surface turbulent exchange (**blue**); canopy hydrology (**cyan**); runoff generation (**orange**); soil thermal dynamics (**red**); snow hydrology (**purple**); and soil water dynamics (**magenta**). The Crank-Nicholson factor is explicitly excluded ($\Delta = 0$) as it is a numerical scheme parameter rather than a physical one. The modification is in L516-521. Please note that aside from the added color coding, the content of Table 1 is identical to the original manuscript, provided here to facilitate your review.

Table 1: Tunable parameters, their default values, and maximum perturbed magnitudes in CoLM. The parameters are color-coded based on the six key physical processes they regulate: [surface turbulent exchange](#), [canopy hydrology](#), [runoff generation](#), [soil thermal dynamics](#), [snow hydrology](#), and [soil water dynamics](#). The numerical parameter (black) is excluded from perturbation.

Tunable parameter	Default (λ)	Max Perturb. (Δ)
Roughness length for soil [m]	0.01	0.0015
Roughness length for snow [m]	0.0024	0.00036
Drag coefficient for soil under a canopy [-]	0.004	0.0006
Maximum dew [mm]	0.1	0.015
Fraction of model area with high water table	0.3	0.045
Tuning factor (turn first layer T into surface T)	0.34	0.051
Crank-Nicolson factor (between 0 and 1)	0.5	0.0
Irreducible water saturation of snow	0.033	0.00495
Water impermeable if porosity less than wimp	0.05	0.0075
Pond depth [mm]	10.0	1.5
Wilting point potential [mm]	-1.5E5	2.25E4
Restriction for minimum of soil potential [mm]	-1.0E8	1.5E7
Maximum transpiration for moist soil+100% veg [mm/s]	0.0002	0.00003
Critical temperature [K] (to determine rain or snow)	0.0	0.15

References

- [1] Weijing Chen et al. “Retrieving Accurate Soil Moisture over the Tibetan Plateau Using Multisource Remote Sensing Data Assimilation with Simultaneous State and Parameter Estimations”. In: *Journal of Hydrometeorology* 22.10 (Oct. 1, 2021), pp. 2751–2766. DOI: 10.1175/JHM-D-20-0298.1.
- [2] Andreas Colliander et al. “Validation of Soil Moisture Data Products From the NASA SMAP Mission”. In: *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 15 (2022), pp. 364–392. DOI: 10.1109/JSTARS.2021.3124743.
- [3] C Huang, X Li, and L Lu. “Retrieving Soil Temperature Profile by Assimilating MODIS LST Products with Ensemble Kalman Filter”. In: *Remote Sensing of Environment* 112.4 (Apr. 15, 2008), pp. 1320–1336. DOI: 10.1016/j.rse.2007.03.028.
- [4] Kathrin Naegeli et al. *ESA Snow Climate Change Initiative (Snow_cci): Daily Global Snow Cover Fraction - Snow on Ground (SCFG) from AVHRR (1982 - 2018), Version 2.0*. application/xml. NERC EDS Centre for Environmental Data Analysis, 2022. DOI: 10.5285/3F034F4A08854EB59D58E1FA92D207B6.
- [5] Thomas Nagler et al. *ESA Snow Climate Change Initiative (Snow_cci): Daily Global Snow Cover Fraction - Snow on Ground (SCFG) from MODIS (2000-2020), Version 2.0*. application/xml. NERC EDS Centre for Environmental Data Analysis, 2022. DOI: 10.5285/8847A05EEDA646A29DA58B42BDF2A87C.
- [6] K.A. Novick et al. “The AmeriFlux Network: A Coalition of the Willing”. In: *Agricultural and Forest Meteorology* 249 (Feb. 2018), pp. 444–456. DOI: 10.1016/j.agrformet.2017.10.009.
- [7] Gilberto Pastorello et al. “The FLUXNET2015 Dataset and the ONEFlux Processing Pipeline for Eddy Covariance Data”. In: *Scientific Data* 7.1 (July 9, 2020), p. 225. DOI: 10.1038/s41597-020-0534-3.
- [8] Rune Solberg et al. *ESA Snow Climate Change Initiative (Snow_cci): Daily Global Snow Cover Fraction - Snow on Ground (SCFG) from ATSR-2 (1995 - 2003), Version 1.0*. application/xml. NERC EDS Centre for Environmental Data Analysis, 2023. DOI: 10.5285/0AEBA0C203C2447B9553A78F99D3A276.