

General response:

We sincerely thank the Editor and the referees for their careful review and insightful comments. We have provided detailed, point-by-point responses to the comments and suggestions from the referees. Each response addresses the specific feedback received, with detailed explanations and corresponding modifications to the manuscript where necessary.

Our responses are structured for clarity: Referee comments in black, our responses in blue, and manuscript modifications highlighted in red.

In general, our revisions primarily include the following points:

- (1) Expanded the explanation of how measurement, ancillary-variable, model-structure, and support-matching uncertainties propagate into the inversion-derived τ calibration targets, and clarified the conditional scope of the reported posterior uncertainty.
- (2) Quantified the magnitude and land-cover dependence of footprint-representation sensitivity, added cautious explanations for bare soil, rice, and wheat, and revised causal wording throughout the manuscript.
- (3) Reorganized the Results and Discussion by moving Figure 7, Table 2, Figure 8, and their quantitative descriptions into new Results subsections, while retaining interpretation and limitations in the Discussion.

Referee #1 comments:

#1: The revised manuscript has been substantially improved and addresses most of the concerns raised in the previous review round. The retrieval evaluation is considerably stronger than in the previous version. The addition of 219 independent validation points, crop-specific uncertainty estimates, footprint-sensitivity tests, and posterior uncertainty diagnostics provides a more robust assessment of model performance. The revised discussion appropriately avoids overstating causal attribution and now acknowledges limitations related to calibration dependence, footprint assumptions, parameter interactions, and transferability.

However, a few minor issues remain. Please address following minor issues and submit revised manuscript.:

Response: Thank you for the positive assessment. We have carefully addressed the remaining minor issues as detailed below.

#2 First, the discussion of uncertainty propagation into the τ calibration targets remains

largely qualitative, while the authors acknowledge that inversion-derived τ inherits uncertainties from soil moisture, temperature, roughness, and brightness temperature, a clearer explanation of the propagation pathway would further strengthen the methodology section. A brief discussion of the propagation pathway and the expected relative importance of the different error sources would strengthen the manuscript. A full formal uncertainty analysis may not be necessary, but the current response does not completely address the original concern.

Response: Thank you for this important suggestion. We expanded Sect. 2.4 to describe the propagation pathways from TDR soil moisture, TBH/TBV, effective temperature, roughness, co-registration, and footprint support into the inversion-derived τ targets. We also provided a cautious qualitative assessment of their expected relative importance and clarified that the fitted prior width and final posterior intervals do not constitute formal error propagation or variance decomposition. Corresponding clarifications were added in Sects. 2.5 and 4.3 (see manuscript lines 262–283, 312–314, and 542–546).

#3 Second, revised Methods state that the square-footprint experiment was introduced to assess footprint-shape uncertainty. However, the Results and Discussion primarily compare statistical performance between footprints rather than explicitly discussing the magnitude of footprint-shape uncertainty and its implications for retrieval robustness. The manuscript could more explicitly discuss the magnitude of footprint-shape uncertainty and why certain classes (e.g., bare soil and rice) showed limited sensitivity.

Response: Thank you for this suggestion. We moved the footprint comparison to the new Results Sect. 3.4 and now explicitly report the magnitude of the differences (ΔRMSE and ΔMAE : -0.002 to $0.007 \text{ m}^3 \text{ m}^{-3}$; ΔBias : -0.001 to $0.004 \text{ m}^3 \text{ m}^{-3}$). We interpret the small overall differences as evidence of robustness to the two tested footprint representations, while retaining the class-dependent effects. The Discussion now provides cautious explanations for the limited sensitivity of bare soil and rice and notes that wheat slightly favored the square footprint (see manuscript lines 437–444 and 485–496).

#4 Third, some interpretations linking performance gains to specific physical mechanisms (e.g., vegetation attenuation effects) should continue to be framed as evidence consistent with the observations rather than definitive attribution.

Response: We agree and conducted a manuscript-wide language review. Statements in the Abstract, Introduction, Results, Discussion, and Conclusion were revised to

describe statistical associations and evidence consistent with physical interpretations rather than definitive causal attribution. We also state explicitly that the ablation and texture analyses do not isolate a unique physical mechanism (see manuscript lines 356–358, 369–370 and 563–566).

Referee #2 comments:

#1 I appreciate the authors' effort in addressing all the comments received.

In the discussion, section 4.1 some paragraphs focuses on the results, so it seems to fit better in the 'Results' section than in the 'Discussion' section itself (e.g. lines 402–420).

Furthermore, the figures/tables presented in this section (Discussion) refer to the results, so I suggest moving them to supplementary material or an appendix, or including them in the 'Results' section.

Response: Thank you for this helpful organizational suggestion. We reorganized the manuscript more broadly by moving all quantitative descriptions, Figure 7, Table 2, and Figure 8 from the Discussion into three new Results subsections (Sects. 3.3–3.5). The revised Discussion now focuses on physical interpretation, retrieval implications, parameter coupling, and limitations, without presenting figures or tables.