Response to Referee Comments

Manuscript: egusphere-2026-858
Conditioning-controlled retrieval of broadband land surface temperature and emissivity from paired ground-based longwave irradiance measurements
Collins Mito

General response

I thank both referees for their careful and constructive assessments. The manuscript has been substantially revised. The principal changes include expansion of the field validation to 637 source datasets from nine SURFRAD/BSRN stations, including Desert Rock and Gobabeb; explicit workflow-stage sample accounting; a complementary 6000-scene physics-based known-truth experiment spanning broadband emissivity 0.85–0.99; clearer separation of structural underdetermination, irradiance identifiability, and numerical conditioning; and qualification of conclusions so that they apply only to the screened retrieval population.

The revised field workflow contains 632 usable datasets after five initial-irradiance exclusions. All 632 yield final finite retrievals; 628 use the stable-centre pathway and four use the prescribed fallback. The workflow accounting records 88,154 geometry-valid candidate pairs, 88,135 finite-irradiance pairs, 81,682 quasi-steady/denominator-valid pairs, 68,525 physically admissible linear-emissivity pairs, and 63,190 irradiance-identifiable pairs.

Location in revised manuscript: Abstract, p. 1, lines 5–25; Sect. 1, pp. 2–3, lines 40–120; Sect. 4.1–4.5, pp. 12–14, lines 275–330; Sect. 5.7–5.8, pp. 22–23, lines 410–440; Appendix A, pp. 24–26, lines 485–495.

Referee 1 (RC1)

Reviewer comment: The validation is insufficient and should include bare-soil cases, including simulated data and suitable in-situ data such as Desert Rock and bare-soil BSRN stations.

Response: I agree and have substantially expanded the validation. The field experiment now contains nine stations and explicitly includes Desert Rock (DRA) and Gobabeb (GOB), providing bare/desert representation. The revised field population contains 637 source datasets and 632 usable cases. I also added a separate 6000-scene physics-based known-truth experiment in which emissivity is independently prescribed over 0.85–0.99, with 2000 scenes in each of three emissivity regimes. The same truth scenes are evaluated under noiseless (G1) and production-noise (G2) conditions.

Location in revised manuscript: Sect. 4.1, pp. 12–13, lines 275–290 and Table 1; Sect. 4.4–4.5, p. 14, lines 315–330; Sect. 5.7, p. 22, lines 410–425 and Table 3; Appendix B, pp. 27–28, lines 495–505.

Reviewer comment: Line 19: 'broadband' should be moved from in front of LST to emissivity products.

Response: Revised. The wording now uses "broadband" to qualify the emissivity and longwave measurements, rather than land-surface temperature.

Location in revised manuscript: Abstract, p. 1, lines 5–15; Sect. 1, p. 3, lines 100–105; Sect. 2.1, pp. 3–4, lines 125–135.

Reviewer comment: Line 86: apparent temperature is always $\leq$ LST; revise the statement about a physically meaningful lower bound.

Response: Revised. The manuscript no longer treats apparent radiometric temperature as a universal lower or upper bound. It is now described as an emissivity-weighted radiometric state and used only as an observable quasi-steady diagnostic.

Location in revised manuscript: Sect. 2.2, p. 4, lines 135–145, especially the final paragraph of Sect. 2.2.

Reviewer comment: Line 210: Eq. (14) limits the strength of the signal from which LST and emissivity are retrieved; convincing validation is essential.

Response: Agreed. The revised manuscript interprets the irradiance-identifiability condition as a surface-sensitive contrast requirement rather than as proof of retrieval validity. Its performance is tested independently through the expanded field experiment and the prescribed-truth experiment.

Location in revised manuscript: Sect. 3.3, p. 6, lines 180–195, especially Eq. (14) and the paragraph immediately following it; Sect. 4.1–4.5, pp. 12–14, lines 275–330; Sect. 5.7, p. 22, lines 410–425.

Reviewer comment: Many occurrences: check 'radiance' versus 'irradiance'.

Response: I reviewed the terminology throughout and retained "irradiance" for L and l because these are hemispheric broadband longwave flux quantities ($\mathrm{W\,m^{-2}}$), not directional radiances ($\mathrm{W\,m^{-2}\,sr^{-1}}$). The terms "radiometric" and "radiative" are retained only where they refer to measurement or physical-state concepts.

Location in revised manuscript: Representative examples: Sect. 2.1, pp. 3–4, lines 125–135; Sect. 3.2–3.3, pp. 5–6, lines 165–195; Table 1, p. 13; Fig. 6 and Sect. 5.4, pp. 18–19, lines 375–390.

Reviewer comment: Line 629: typo 'SURFRAD'.

Response: Corrected.

Location in revised manuscript: Representative current usage: Sect. 4.1, pp. 12–13, lines 275–285; Acknowledgements, p. 30, lines 515–525.

Reviewer comment: Table 1/Fig. 6: clarify case index; Table 2: add case index; Fig. 6 should preferably use station abbreviations.

Response: The validation presentation has been redesigned rather than retaining the former case-index structure. Table 1 now reports the station names and codes directly, while station-wise workflow accounting is given in Appendix A. The former case-index figures/tables have been replaced by population-level and station-wise summaries, eliminating the ambiguous mapping between case index and filename.

Location in revised manuscript: Table 1, p. 13, lines 280–290; Fig. 7 and Sect. 5.5, p. 20, lines 390–400; Table A2, p. 26.

Reviewer comment: Figures 4 and 5 and elsewhere: 'dt' or 't'?

Response: The temporal notation has been standardized. Candidate times are written explicitly as t_i, t_j, and t_m, while selected-pair separation is reported as Δt where a time difference is intended. The former ambiguous 'dt' wording has been removed.

Location in revised manuscript: Sect. 3.2, p. 5, lines 165–180 and Eqs. (5)–(6); Sect. 5.1 and Fig. 3, p. 15, lines 335–350.

Reviewer comment: The same-site emissivity variation over only a few days appears unrealistic over grass.

Response: I agree that the former case-wise presentation could be overinterpreted as physical day-to-day emissivity change. The revised analysis no longer uses that plot as evidence of true short-term emissivity variability. Field emissivity distributions are now presented descriptively, and direct emissivity accuracy is assessed only against independently prescribed synthetic truth.

Location in revised manuscript: Sect. 5.5 and Fig. 7, p. 20, lines 390–400; Sect. 5.7, p. 22, lines 410–425; Sect. 5.8, p. 23, lines 425–440; Conclusions, pp. 23–24, lines 440–485.

Reviewer comment: Table 4: the columns with the absolute bias / error values can be deleted.

Response: The results tables have been redesigned. The revised known-truth table reports signed bias together with MAE and RMSE and does not retain redundant absolute-bias columns.

Location in revised manuscript: Table 3, p. 22, lines 410–425; Table B1, p. 28.

Referee 2 (RC2)

Reviewer comment: Clarify structural underdetermination (N observations, $N + 1$ unknowns) separately from deterioration of numerical conditioning under low irradiance contrast.

Response: Agreed. The revised Introduction now explicitly states the N-equation/$N + 1$-unknown structure and distinguishes it from the additional loss of conditioning caused by weak irradiance contrast. Section 2.3 then separates temporal admissibility, irradiance identifiability, and numerical conditioning.

Location in revised manuscript: Sect. 1, p. 2, lines 40–50; Sect. 2.3, p. 4, lines 145–160.

Reviewer comment: Title: 'Conditioning-controlled retrieval' may sound non-standard; consider 'conditioning-aware' or 'stability-aware'.

Response: I considered the suggested alternatives but retained 'conditioning-controlled' because the framework does more than diagnose conditioning: physical-state, irradiance-identifiability, and information-sufficiency controls determine which observation geometry reaches nonlinear inversion. The term is now explicitly defined to avoid implying that it refers only to a numerical condition-number threshold.

Location in revised manuscript: Sect. 1, p. 3, lines 100–110, especially the paragraph defining "conditioning-controlled".

Reviewer comment: Introduction: qualify the novelty claim concerning emissivity uncertainty propagation.

Response: Revised. The broad claim that emissivity uncertainty is generally not propagated has been removed. The manuscript now focuses on what is done in this framework—correlated uncertainty propagation and decomposition—and explicitly cautions that propagated uncertainties are not automatically calibrated confidence intervals.

Location in revised manuscript: Sect. 1, p. 3, lines 85–100; Sect. 3.7, pp. 10–11, lines 255–270; Sect. 5.8, p. 23, lines 425–440.

Reviewer comment: Section 3 is detailed; streamline or move standard inverse-problem material if appropriate.

Response: Section 3 has been reorganized around the retrieval workflow and streamlined for readability. The governing equations, screening criteria, fixed eight-update Newton-Raphson formulation, and uncertainty expressions are retained, while the accompanying prose has been shortened and clarified. Figure 1 provides the workflow overview, and detailed sample accounting and synthetic diagnostics are presented in Appendices A–C.

Location in revised manuscript: Sect. 3, pp. 4–11, lines 160–270; Fig. 1, p. 8, around line 220; Appendices A–C, pp. 24–29, lines 485–510.

Reviewer comment: Use Newton-Raphson consistently; 'optimizes numerical conditioning' should be 'improves/screens conditioning'; 'well-posed data pairs' should be rephrased.

Response: Corrected. 'Newton-Raphson' is used consistently for nonlinear refinement. Candidate filtering is described as physical/numerical screening and irradiance-identifiability testing rather than as direct optimization of the Jacobian, and the former 'well-posed data pairs' wording has been removed.

Location in revised manuscript: Sect. 3.3, pp. 5–6, lines 180–195; Sect. 3.6, pp. 9–10, lines 240–255.

Reviewer comment: 'Local curvature' and Pk interpretation should be changed to local sensitivity/rate of convergence; avoid calling a Jacobian 'flat'.

Response: Corrected. The revised manuscript uses residual magnitude and derivative magnitude as numerical diagnostics and refers to local sensitivity rather than curvature. The former 'flat Jacobian' and curvature wording has been removed from the interpretation.

Location in revised manuscript: Sect. 3.7, pp. 10–11, lines 255–270; Sect. 5.3, p. 17, lines 360–375.

Reviewer comment: 'High-frequency' is unclear.

Response: Rephrased throughout as 'high-temporal-resolution' observations or as selected temporal-pair separation, depending on context.

Location in revised manuscript: Abstract, p. 1, lines 5–15; Sect. 1, p. 2, lines 55–65; Conclusions, p. 24, lines 480–485.

Reviewer comment: The field reference is not fully independent because it shares upwelling longwave irradiance with the retrieval.

Response: Agreed and now stated explicitly when the field reference is introduced. It is described as a realistic ground-based validation benchmark for combined emissivity-temperature retrieval behaviour, not as independent broadband-emissivity truth. Direct emissivity accuracy is evaluated only in the prescribed-truth experiment.

Location in revised manuscript: Sect. 4.2, p. 13, lines 290–305; Sect. 5.6, pp. 20–21, lines 395–410; Sect. 5.8, p. 23, lines 425–440.

Reviewer comment: Report the effective validation sample size after pairing, filtering, and screening.

Response: Added in detail. Five of 637 source datasets lack the required finite initial irradiances, leaving 632 usable cases. The audit reports 88,154 geometry-valid pairs, 88,135 finite-irradiance pairs, 81,682 quasi-steady/denominator-valid pairs, 68,525 physically admissible linear-emissivity pairs, and 63,190 irradiance-identifiable pairs. All 632 usable scenes enter Newton-Raphson refinement and complete eight valid updates.

Location in revised manuscript: Sect. 4.1, pp. 12–13, lines 275–290 and Table 1; Sect. 4.3, p. 14, lines 305–315; Appendix A, pp. 24–26, especially Tables A1–A2.

Reviewer comment: Discuss uncertainty/assumptions in externally specified emissivity used to construct field reference temperatures.

Response: Added. The manuscript now states explicitly that the externally specified reference emissivities are subject to spectral, spatial, temporal, and representativeness uncertainty, and this is used to justify interpreting the field comparison as a realistic benchmark rather than independent emissivity truth.

Location in revised manuscript: Sect. 4.2, p. 13, lines 295–305, especially the final paragraph of Sect. 4.2.

Reviewer comment: Residual/Jacobian plots characterize retained cases only; avoid broad claims of robustness.

Response: Agreed. The revised Results explicitly state that Fig. 5 characterizes only accepted retrievals and should not be taken as evidence that arbitrary temporal pairs are well conditioned. The limitations section reiterates that conditioning and Newton diagnostics apply to the screened retrieval population.

Location in revised manuscript: Sect. 5.3, p. 17, lines 360–375; Sect. 5.8, p. 23, lines 425–440.

Reviewer comment: Fig. 2/Table 1: near-linear convergence for retained cases; clarify whether weakly conditioned cases were screened out.

Response: The workflow has been redesigned to make this ordering explicit. Physical/numerical admissibility, irradiance identifiability, and information sufficiency are evaluated before the final Newton-Raphson analysis. Figure 5 therefore describes the numerical state of the accepted retrieval population, not the unscreened candidate population.

Location in revised manuscript: Sect. 3.3–3.4, pp. 5–7, lines 180–220; Fig. 1, p. 8; Sect. 5.3, p. 17, lines 360–375; Appendix A, pp. 24–26.

Reviewer comment: Fig. 5: do not conclude that temporal pairing is a 'neutral conditioning mechanism' solely from the plot.

Response: Agreed. The broad neutrality claim has been removed. The revised discussion reports the selected-pair distribution and uses the separation-versus-emissivity relationship only as an empirical check for systematic displacement within the retained population.

Location in revised manuscript: Sect. 5.1 and Fig. 3, p. 15, lines 335–350.

Reviewer comment: Fig. 6: clarify how many candidate and retained retrievals were analyzed and whether stability holds outside the screened cases.

Response: Added. The main Methods now reports candidate-pair and scene-level accounting, Appendix A provides detailed overall and station-wise counts, and the Results explicitly restrict numerical-stability interpretations to the screened population.

Location in revised manuscript: Sect. 4.3, p. 14, lines 305–315; Sect. 5.3, p. 17, lines 360–375; Sect. 5.8, p. 23, lines 425–440; Appendix A, pp. 24–26.

Reviewer comment: Report candidate pairs, rejected pairs, retained pairs, and successful Newton-Raphson retrievals for each site/file before making broad claims about robustness.

Response: Added through the workflow-stage accounting. The overall stage counts are reported in Table A1, and station-wise source, admissible, identifiable, stable/fallback, production-pair, Newton-update, and final counts are reported in Table A2.

Location in revised manuscript: Appendix A, pp. 24–26, lines 485–495; Table A1, pp. 25–26; Table A2, p. 26.

Reviewer comment: Line 735: local curvature -> local sensitivity?

Response: Corrected throughout. The current manuscript uses local sensitivity for the derivative-based diagnostic.

Location in revised manuscript: Sect. 3.7, pp. 10–11, lines 255–270; Sect. 5.3, p. 17, lines 360–375.

Reviewer comment: Contrast/SNR discussion: clarify whether interpretations are supported by the dataset or represent expected general behaviour.

Response: Revised. The present Results restrict the quantitative contrast-sensitivity relationships to the 632 retained retrievals, while Sect. 5.8 separates the evidence from broader limitations and expected behaviour. Low-emissivity/weak-information regimes are explicitly identified as remaining challenges rather than as universally resolved conditions.

Location in revised manuscript: Sect. 5.4, pp. 18–19, lines 375–390; Sect. 5.7, p. 22, lines 415–425; Sect. 5.8, p. 23, lines 425–440; Conclusions, pp. 23–24, lines 440–485.