

Response to RC2

Soil slope monitoring with Distributed Acoustic Sensing under wetting and drying cycles

Discussion: <https://doi.org/10.5194/egusphere-2025-1725>

Comments from the reviewers are given in black.

Our responses are given in blue. *The revisions to be made in the manuscript are given in italic style.*

Overall Assessment

The revision addresses several structural and figure requests. However, three technical areas remain insufficiently justified or documented: (i) the choice and implications of a 10 m gauge length (GL) for low-frequency DAS; (ii) the documentation and alignment of in-situ soil-moisture observations with DAS metrics; and (iii) limits of daily dv/v stacks and depth sensitivity. Addressing these items would materially improve reproducibility and interpretation.

We thank you for your careful second review and for your constructive comments. We have carefully re-read our revised manuscript in light of your report.

We believe that most of the concerns raised have already been addressed in our revised manuscript and also want to note that some technical comments (e.g., with references to line numbers) appear to correspond to the original submission rather than the revised version. In the responses below, we indicate where the requested clarifications have been incorporated into the current version, and we have bolded the new additions compared to the first revision. We are happy to make additional edits to further highlight them.

Major Comments

1) Gauge-length choice and effective spatial resolution

The methods state a 10 m gauge length (GL) and channel-averaging over ~10 m prior to integrating strain-rate. Please justify this choice and quantify how it affects both sensitivity to meter-scale variability and comparisons with point sensors.

Requested actions:

- Provide a rationale for selecting 10 m GL (SNR/stability vs spatial resolution).

- Quantify the effective along-fiber spatial response (e.g., GL convolution kernel and its width/FWHM).
- Include a short re-processing test with a smaller GL (e.g., 2.5–5 m) or a forward model, to illustrate amplitude/phase biases for localized signals.
- Revise any language claiming sub-meter resolution; with 1 m spacing and 10 m GL, the smallest resolvable feature is on the order of 10 m along fiber.
- Clarify implications for comparing DAS (spatial average along GL) against point soil-moisture sensors.

The gauge length of the iDAS interrogator is an acquisition parameter (not a post-processing setting). In our deployment it was set to the default of 10 m, which represents a common trade-off between improved signal-to-noise stability and reduced sensitivity to sub-meter heterogeneity. We have already removed all “sub-meter” resolution claims in the first-round revision. The role of gauge length is discussed explicitly as well in L451:

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The 10 m gauge length, a fixed parameter of the iDAS interrogator we used, functions as a spatial moving average over a 10 m segment of soil. It filters out localized, small-scale heterogeneities and improves the signal quality for observing the bulk soil response but inherently limits the spatial resolution of the strain measurement. This averaging effect is a crucial factor when integrating DAS with traditional point-based instruments. Future near-surface studies targeting more localized phenomena would benefit from deployments using interrogators with a configurable and shorter gauge length.

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2) Soil-moisture observations and integration with DAS

The interpretation relies on moisture-driven mechanisms, but the sensor documentation and the coupling to DAS can be made crisper.

Requested actions:

- Explicitly list sensor types/models, measured variables (VWC, SWP), depths, sampling cadence, and distance to the cable.
- Describe calibration/QA and any screening of out-of-range values.
- State how soil-moisture series are aligned with DAS metrics: daily medians for dv/v vs sub-daily series for low-frequency strain/strain-rate; interpolation and gap handling.

- Justify the depths used in comparisons (e.g., shallow composite 0.15–0.40 m vs multi-depth 0.15–1.0 m).
- Summarize simple correlations/lag analyses between moisture indices (and effective stress) and DAS metrics, noting spatial variability.
- If one sensor cluster failed at some point, note reliance on the remaining cluster and any implications.

Thanks for your suggestion. Sensor models, depths and calibration details are already in Section 3.2 L146:

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Since April 2019, point-measurements of soil moisture have been conducted at a 10 min interval near the top of the slope, close to the malfunctioning cable section (EMM_1), and in a flat area adjacent to the loafing shed at the slope toe (EMM_2) (Fig. 2b) (Wicki et al., 2024). VWC was derived from dielectric permittivity measurements following Topo et al. (1980), using capacitance-based sensors (ECH2O 5TE, METER Group). SWP was recorded with tensiometers (T8 Tensiometer, METER Group), which measure pressure differences in the soil with a piezoelectric sensor embedded in a water-filled porous ceramic cup. At EMM_1, two sensors of each type (2 × VWC and 2 × SWP) were installed at depths of 0.15 m, 0.30 m, 0.50 m, and 1.00 m. At EMM_2, two sensors of each type were installed at 0.15 m, 0.50 m, and 0.95 m, with an additional sensor pair (1 × VWC and 1 × SWP) installed at 0.20 m and 0.70 m. No site-specific calibration of the sensors was conducted, as the original study by Wicki et al., (2024) focused primarily on relative changes in VWC. While this study used absolute values to estimate effective stress, only relative changes in effective stress were analyzed for comparison with the strain rates derived from the DAS measurements.

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The depths were selected to match the sensitivity of each DAS product: 0.15 m soil moisture corresponds to the fiber burial depth and was used for quasi-static strain (L330), while dv/v is sensitive to the whole soil profile and was therefore compared with a two-layer model (0–0.15 m and 0.15–1.53 m), with the deeper layer represented by 0.95 m data (L264). To avoid confusion, we added a clarifying sentence after L330.

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We focus on 0.15 m depth because it matches the cable burial depth and thus best represents quasi-static strain, which is different from the dv/v analysis. This is because dv/v is sensitive to seismic velocity changes integrated over

several meters depth, whereas the low-frequency strain reflects direct near-surface deformation at the fiber depth.

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The spatial correlation between DAS and soil moisture metrics is shown in Fig.10f with discussion starting L440. During the monitoring period, the sensors at the depths used remained operational.

3) dv/v temporal resolution and depth sensitivity

dv/v is computed from daily noise stacks; such products cannot substantiate intraday variability. Also, depth sensitivity of the 8–16 Hz band should be explicitly related to the moisture sensors used.

Requested actions:

- State explicitly that dv/v is daily and avoid intraday claims unless sub-daily processing is added.
- Provide a concise depth-sensitivity summary for the analyzed band and reconcile with the chosen moisture depths.

The previously revised version has rephrased the sub-daily statement at L453 to: 'The long-term soil consolidation is further supported...'. The summary of depth sensitivity and the rationale for the chosen moisture depth are provided in the paragraph starting at L370.

4) Instrument/cable low-frequency response and temperature/drift

Thermal strain is estimated to be small and no correction is applied. Please also describe potential interrogator/cable LF response and drift controls when integrating strain-rate.

Requested actions:

- Specify cable construction (tight-buffer vs loose-tube, jacket, burial details) and discuss implications for LF response.
- Include a brief check comparing strain-rate with the temporal derivative of temperature over selected windows to assess instrument-related contributions.
- Summarize detrending/high-pass choices used to mitigate integration drift and how robustness was verified.

Please find an entire new section added in the manuscript 6.1.1 Instrumental drift quantification at around L280. In short summarize, we calculated the instrumental drift from the apt of the cable in the garage and also applied

thermal correction. The cable construction and discussion is presented at L410.

Minor / Editorial

- Appendix: correct “Index of fraction” → “Index of refraction.”

We appreciate the comment. This issue was already modified in the earlier version.

- After Figure 3 caption: ensure the next paragraph begins with a capitalized “Hourly ...”.

Thanks for your suggestion. This concerns a figure placement issue. It fits within the paragraph and breaks across a single sentence. In the last version, the starting word is ‘heterogeneity,’ which belongs to the last sentence and is therefore not capitalized.

- Consider adding cable specs (make/type) in Methods §3.2 for completeness.

Thanks. This was added as well in the last version “*fiber-optic gel-filled non-metallic loose...*”

- Ensure all instances of resolution claims are consistent with the stated GL and spacing.

Thank you. We have ensured that all sub-meter phrasing has been removed and that the text now corresponds to the gauge length.

Minor language/clarity – around L180 (soil-moisture paragraph after Fig. 3)

The current wording is understandable but could be tighter and more precise (e.g., SWP “decreases” → “becomes more negative”), and the historical citation after “Pearson” isn’t needed here.

Thank you very much for your suggestion. We have revised the paragraph accordingly

Consider rephrasing the following sections for clarity and consistency:

- A) Results — Soil-moisture paragraph (after Fig. 3, ~L175–L186).

Suggested replacement:

Soil moisture closely tracked rainfall: volumetric water content (VWC) rose during infiltration, while soil-water potential (SWP) became more negative. Measurements from EMM_1 and EMM_2 were highly correlated for both

variables (Pearson's $r > 0.9$), indicating that either site can serve as a representative indicator of regional soil-moisture dynamics.

Thank you very much for your suggestion. We have revised the paragraphs accordingly.

- B) Methods — Soil moisture (Section 4.2 “In situ Soil Moisture Measurements”, ~L170–L176 starter lines; drop-in fits immediately after).

Suggested replacement:

Volumetric water content (VWC) and soil-water potential (SWP) were measured at 0.15–1.0 m depth (10-min cadence) near the buried cable. We screened outliers, computed daily medians to match dv/v stacks, and used both a shallow composite (0.15–0.40 m) and a multi-depth composite (0.15–1.0 m) to assess sensitivity to depth selection.

Thank you. Please see above the detail depths, model type and correction on the soil moisture measurements. We value your suggestion and also add this sentence at the end at L156:

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We computed daily medians to match the dv/v analysis. For low-frequency strain analysis, we used the 0.15 m depth, while the dv/v models were built using a multi-depth composite at 0.15 m and 0.95 m. Further details are provided in the following sections.

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- C) Conclusion — resolution claim (the “In conclusion...” sentence, ~L403–L407; the number 405 appears at line end).

Suggested replacement:

We integrate traditional seismic wave analysis with continuous monitoring of quasi-static deformation using DAS to track moisture-driven hydromechanical changes, achieving meter-scale along-cable resolution with a 10 m gauge length.

Thank you very much for your suggestion. We have revised the paragraphs accordingly.