

Author Response Letter to Editor and Referees

Soil moisture monitoring with cosmogenic neutrons: an asset for the development and assessment of soil moisture products in the state of Brandenburg (Germany)

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EC/RC: *Editor/referee comment*, **AR:** *Author Response*, **Manuscript text**

Dear Dr Somogyvári, dear referees,

we would like to thank you once more for the review of the manuscript. Based on the editorial decision and the referee comments, we have revised the manuscript once more in order to clarify the uncertainty of the CRNS-based soil moisture estimates. Please find below the corresponding comments and a more detailed response.

We would also like to use the opportunity to mention that we updated some information in the manuscript with regard to the new monitoring locations that were meanwhile instrumented (as announced in the manuscript, see ll. 112 of the previous version). The corresponding changes are the following: (1) the monitoring location "Schönhagen" (in the north-east of Brandenburg) had been replaced by the location "Dubrau" (in the south). We changed the corresponding line in table 1 in which we also specify the location attributes, updated Fig. 1 accordingly, and revised all occurrences in the text that referred to "planned" locations; (2) furthermore, the product name of the four new CRNS systems that were deployed by end of 2025 is not "CRS-2000-B" (as previously stated in the four bottom rows of table 1), but "CRS-2000-DE" (according to the manufacturer).

As these new locations were not part of our analysis, we would like to underline that none of these changes affects the scientific results of the paper. They just allow the readers to obtain the latest information about the configuration of the monitoring network.

We hope that the paper can now be accepted for publication.

Thanks again to the editor and the referees for the patience and scrutiny they have invested in this process.

Kind regards,
Maik Heistermann
(on behalf of the author team)

1. Reply to comments of the editor

EC: *There were still some concerns from reviewers whether the manuscript fits to the scope of NHESS. After some discussion with NHESS editors, we agreed that your contribution is relevant especially for the scope of the special issue.*

AR: Thanks for the balanced decision. For us, it was always important to maintain that the manuscript fits well to the scope of the special issue, not necessarily to the overall scope of NHESS (see also our response to referee #5). We are glad that the editorial team agrees.

EC: *There are still some outstanding questions regarding the confidence in the results. We would appreciate if you could provide a statement about this in the final submission (please see reviewer report #1).*

AR: We have revised the manuscript accordingly. Please see our response to referee #3 below.

2. Reply to the comments of referee #3

RC: *[...] The reviewer thanks the authors for their extensive work and their well organized answers for the questions brought up during the review. The reviewer specifically thanks the authors for including more/improved context into their manuscript which significantly increased its scientific value and the understanding of the contribution of this network. There is, however, a final remark on the evaluation of the CRNS data, which is central to the methodology of this manuscript. The authors seem to be surprisingly confident about the results of the soil moisture assessment. The reviewer is thankful for the transparency the authors show with respect to their analysis, it, however, delivers a message of mediocre performance comparing the estimated soil moisture date with the evaluated soil moisture data. Originally, the title of the manuscript referred to a drought monitor and the precision the authors show one can raise questions whether this is an approach which would be suitable for such. The CRNS footprint is large and there may be many unknowns of influence (for example the rail tracks or other infrastructure), given the systematic deviation of soil moisture values it may rather required to address the methodology. The Heistermann 2024 et al. approach seems to offer an elegant way to overcome a local calibration, but the manuscript rather seems to confirm that a local calibration as shown by other authors yields better results. At the given stage the reviewer is not having the relevant details to go more deep into the analysis chain of the authors. In good faith the authors may one last time recheck some basic assumptions like the compared count rate or whether the devices would be supplied with a different soil moisture calibration relation in order to potentially get a better alignment with the sample evaluation. Regardless of that technical detail the reviewer is confident about the improvements and congratulates the authors for their article.*

AR: We thank the referee for the positive feedback on the revision, as well as for the critical comments. Based on the referee's comment as well as on the editor's suggestion, we revised the manuscript by emphasizing the uncertainties that come along with the CRNS-based soil moisture estimates, in order to avoid the impression of overconfidence in these estimates.

Having said that, we do not fully agree with the impression of being "surprisingly confident about the results of the soil moisture assessment". As the referee stated himself or herself, we spent, in section 3.1, quite an effort to assess the performance of the CRNS-based soil moisture estimation, and also to put it in context with other validation results. On that basis, we referred to the RMSE of $0.037 \text{ m}^3 \text{ m}^{-3}$ as a "satisfactory agreement" and extensively discussed the role of systematic errors, clearly stating the need to explore the potential of a new conversion function to address this issue. In that section, we also discussed other relevant

sources of uncertainty, and have now, based on the referee's comment, also mentioned (after l. 320 of the previous manuscript version) the potential uncertainty introduced by the proximity to railway tracks (only affects the locations Golm and Paulinenaue).

In order to further address the referee's comment and the editor's suggestion, we have added a statement at the end of section 3.2 (before l. 404 of the previous manuscript version) that the usefulness of the CRNS-based soil moisture estimates as a soil moisture benchmark is of course limited by their own uncertainty (as discussed in section 3.1). We have also put more emphasis on this issue in the conclusions section (after l. 561 of the previous manuscript version).

The referee's question whether the precision of the CRNS-based soil moisture estimates is sufficient for applications in drought monitoring is, in our view, highly dependent on the specific application context and also on the availability of alternative solutions.

Finally, and for the record, we would like to briefly respond to the referee's statement that "[...] the manuscript rather seems to confirm that a local calibration as shown by other authors yields better results". We do not quite agree. In comparison to other studies, our performance metrics are not substantially worse. However, we are aware that a comparison with results from other environments is problematic. The only way to actually confirm such a statement in the context of our study would be the availability of additional groundtruth measurements. That way, we could apply a local calibration on, e.g., the first ground truth measurement, use a second for validation, and compare the performance to the general calibration variant. We do not yet have the data for such a comparison, but hope to obtain them in future research projects. Our honest opinion, however, with regard to the major source of bias, is not the general calibration approach as such, but the use of the conversion function, as repeatedly pointed out in the manuscript. In our opinion, the integration of the conversion function from Koehli et al. (2021) into the general calibration framework should be the way to go in the future.

3. Reply to the comments of referee #5

RC: *The paper presents an interesting new effort to monitor soil moisture in the state of Brandenburg by developing a network of CRNS stations. It addresses the issue of obtaining reliable, precise soil moisture measurements. The authors describe the design, implementation and evaluation of the new CRNS-network and how these measurements can be useful to improve soil moisture products. The manuscript is well written and has no methodological or major technical flaws. I want to praise the authors and reviewers for the excellent work and great effort put into the manuscript. I agree with the other reviewers that the Brief Communication was not a proper format and that the expanded version better aligns with the authors' intent to publish their technical work. The added analysis and comparison of different datasets also broaden the scope of the papers. Although the paper does not introduce fundamentally new ideas, the authors give meaningful contributions through the documentation of developing a CRNS-network in the state of Brandenburg and how the measurements can be used to improve indirectly-assessed soil moisture. I do believe it is of interest to the scientific community, being particularly useful for other groups interested in developing similar monitoring systems. Notwithstanding, it is important to address the limitation of the manuscript's scope. Although the authors consider the context of water-related risks in Brandenburg, the manuscript remains focused on soil-moisture monitoring and technical evaluation of the product, adding limited value to natural hazard discussions. The authors do not directly address natural hazards such as droughts and floods, nor impacts, risks, and policy contexts in the region. Although the paper's focus is on soil moisture monitoring in the State of Brandenburg (Germany), its results and general scope do not tackle*

natural hazards such as drought and flood risks. It is my opinion that the manuscript should be submitted to a different journal. Recommendation: The manuscript is well-executed and well-written, and deals with the issue of regional monitoring of soil moisture. Readers working on soil moisture measurement, hydrological modelling, and water resources planning/management will have great interest in the text. Given the scope and emphasis of the manuscript, I recommend rejection and advise the authors to consider submitting to a more specialised journal, rather than one focused on natural hazards.

AR: We appreciate both the positive feedback and the critical appraisal of whether the manuscript fits the journal's scope. With regard to the latter, we fully understand the referee's reservations. However, we are convinced that the specific scope of the special issue would not only include contributions that explicitly address natural hazards research with regard to the federal state of Brandenburg, but which could contribute to any such endeavour. Throughout the manuscript, specifically in section 4, we attempted to outline perspectives for such contributions.