Interactive Discussion: Author Response to Referee #1

Soil moisture observation in a forested headwater catchment: combining a dense cosmic-ray neutron sensor network with roving and hydrogravimetry at the TERENO site Wüstebach

Maik Heistermann et al.
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RC: ***Reviewer Comment***, AR: *Author Response*, □ Manuscript text

Dear Referee,

we would like to thank you very much for your willingness to review this paper, and for your very swift - and positive - response to the manuscript.

Please find our responses to your comments below. These should be considered as preliminary (part of the interactive discussion). The final implementation of changes also depends on another referee report that is still pending.

Thanks again for your efforts!

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

1.1. CRNS Calibration

RC: ***[...] The only really major criticism I have concerns the calibration of the stationary cosmic ray neutron sensors (CRNS). It has been shown that highly variable systems like temperate forests require calibration for at least two points in time (one dry state and one wet state of the system, preferably), (see, e.g., Heidbüchel et al., 2016; Tan et al., 2020). Having the SoilNet sensors with continuous monitoring available, this can be done – however, the SoilNet does not cover the entire footprint of all the CRNS. Instead, one manual soil core sampling campaign was conducted to 'fill in the gaps' and get additional data on bulk density, lattice water content, etc. This allows for the proper calibration of the CRNS at (only) one point in time. I would expect a discussion of this deliberate choice to only use one point in time for calibration – in particular noticing the fact that in your case the calibrated CRNS seems to consistently overestimate soil moisture during the dry periods.***

AR: We thank you for pointing out this important issue. In the original manuscript, we had decided not to address it in depth since the prime focus of the paper is on the presentation of the data set and some of its fundamental properties. Based on your comment, though, we agree that it makes sense to discuss the different calibration

options and the resulting implications for different use cases.

As you correctly pointed out, the calibration setup was a deliberate choice which was motivated particularly by enhancing the comparability to the SoilNet observations. You also already laid out the trade-offs we have to confront in this context:

- Using only the SoilNet for calibration reduces the number of data points per footprint, particularly for outward CRNS sensors. In turn, the resulting CRNS-based soil moisture estimates are more representative for the SoilNet area (i.e., north of the main road). That increases the comparability to the SoilNet observations, and hence the evaluation of the CRNS-based soil moisture estimates over space and time. That way, we could also introduce another calibration time for drier conditions, as you have pointed out.
- However, if we intend to estimate the mean soil moisture of the entire catchment (including the area south of the main road), we need to include the manual samples from the campaign on October 19, 2020. This would be advisable e.g. for hydrological applications that aim at closing the catchment's water balance. The downside is, as you pointed out, that these measurements are only available for one point in time, and that the comparability to the SoilNet pattern might be biased when additional points from outside the SoilNet area are included in the calibration.

One possible perspective to resolve this apparent conflict is to calibrate N_0 not individually for each sensor, but to estimate one single N_0 value for all sensor locations as demonstrated by [Heistermann et al., 2021]. This requires to carefully homogenize neutron intensities across sensors by accounting for the effects of sensor sensitivity, vegetation, soil carbon and lattice water, and would be possible for multiple calibration points in time, too. Such an approach would also allow to combine SoilNet observations and manual measurements. The validity of any single N_0 estimate could then be evaluated in a set of calibration/validation experiments, in order to demonstrate transferability in space and time (within the campaign period and within the study area).

There is ample room for experimenting with these options and their combinations in future studies. While this exceeds the scope of this data paper, we agree that the audience should be aware of these options and their implications. Hence, we will extend the paragraph on "Soil moisture estimation from stationary CRNS" (ll. 440-460) accordingly, and will also emphasize the benefit of calibrating at two (or more) points in time, as outlined above.

1.2. Other specific comments

RC: ***Abstract, Line 7: Do you mean 'watershed boundary'? 'Watershed' alone can also mean the catchment.***

AR: In fact, we have used the term watershed, in this context, in the sense of the "watershed boundary". As this is obviously ambiguous, we will replace "watershed" by "catchment boundary".

RC: ***Line 283-284, 307: In order to calibrate a CRNS properly it is recommended to independently measure soil moisture twice (preferably under wet and under dry conditions, see, e.g. Heidbüchel et al., 2016; Tan et al., 2020). Also, it is recommended to have 18 different sampling locations within the footprint of a CRNS (see Franz et al., 2012). For many of the CRNS this requirement is not fulfilled. How do you justify this? At least it would be added value to provide a two-point calibration.***

AR: Please see our response to your first comment 1.1.

RC: ***Line 311: What are these 18 locations? In Figure 2 there are more than 18 locations marked with 'manual sampling'.***

AR: Thank you for pointing out this possible misunderstanding. As you stated correctly in the next comment, there were 68 manual measurements of soil moisture profiles: 18 measurements with soil cores (gravimetric determination in the lab, see ll. 311-316), and 50 in-situ measurements with handheld FDR-sensors (see ll. 317-324). We had decided not to distinguish the two approaches in Fig. 2 for the sake of clarity. However, as the you explicitly requested the positions of the soil core sampling (next comment), we will distinguish the two approaches in Fig. 2, and also clarify, in the first paragraph of Sect. 3.8.2, the total number of manual samples.

RC: ***Line 317: I guess that is where the extra 'manual samples' derive from. I would mark them differently in Figure 2. (I really want to know where you did the soil core sampling).***

AR: Please see our response to the previous comment.

RC: ***Line 357: Why won't you tell us the exact number of plots in the grassland and in the shrubland areas?***

AR: We will. Originally, we had intended to distinguish only two land cover types: forest and open land - which is why we assigned 15 plots to each type. However, during vegetation mapping and biomass sampling, it turned out that a few parts of the "open land" were already dominated by shrubs which is why we differentiated into grassland (with 11 sample plots) and shrubland (with four sample plots). We will add these numbers to the manuscript in the line which you referred to.

RC: ***Line 409: What do you mean by 'complemented'?***

AR: By "complemented", we meant that we also contributed our improved land cover maps to the OSM community land use data. As this is not really relevant to the paper, we will just drop "and complemented" from the revised version of the manuscript.

RC: ***Line 445-448: You only used one date (and one condition) to calibrate N0, although you have SoilNet values for all kinds of soil moisture conditions. That is dangerous and potentially weakens the measurement performance of the CRNS. You can see in Fig. 4b that the CRNS overestimates soil moisture in dry conditions – this could have been avoided with another calibration performed when it's dry.***

AR: Please see our response to your first comment.

RC: ***Also, what about the manual samples from the soil cores, did you use them at all for calibration? If so, how did you incorporate them? If not, why not? After all, SoilNet does not cover the entire footprint of all of the sensors. At least, I would like to see this discussed.***

AR: In our exemplary data analysis in section 5, we did not use the manual sample for calibration, but focused on the SoilNet observations. We will explicitly discuss this choice as already elaborated in our response to comment 1.1.

1.3. Technical corrections

RC: ***Abstract, Line 15: 'hillslope' instead of 'hill-slope'.***

AR: Will be corrected.

RC: ***Abstract, Line 16: '...the retrieval OF soil water...'.***

AR: Will be corrected.

RC: ***Line 39: 'Soon enough…'?***

AR: We will replace "Soon enough [...]" by "Soon after the feasibility of soil moisture observation with stationary CRNS had been demonstrated, a mobile CRNS sensor [...]"

RC: ***Line 41: Schrön et al., which year?***

Thanks for spotting the broken reference. We will fix it:

Schrön, M. et al. (2021). Neutrons on rails: Transregional monitoring of soil moisture and snow water equivalent. Geophysical Research Letters, 48, e2021GL093924. doi:10.1029/2021GL093924

RC: ***Line 350: '…of the forest IS rather homogeneous...'***

AR: Will be corrected.

RC: ***Line 363: raspBerry.***

AR: Will be corrected.

RC: ***Line 402: '…groundwater depth…' (no space between ground and water).***

AR: Will be corrected.

RC: ***Line 403: North Rhine-Westphalia is the English word.***

AR: Will be corrected.

RC: ***Line 438: 'Thenceforth' is quite archaic and literary. I have never seen it used in a scientific paper.***

We will replace "thenceforth" by "thereafter".

References

[Heistermann et al., 2021] Heistermann, M., Francke, T., Schrön, M., and Oswald, S. E. (2021). Spatio-temporal soil moisture retrieval at the catchment scale using a dense network of cosmic-ray neutron sensors. *Hydrology and Earth System Sciences*, 25(9):4807–4824.