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Comment on hess-2021-25

Anonymous Referee #1

Referee comment on "Spatio-temporal soil moisture retrieval at the catchment scale using a dense network of cosmic-ray neutron sensors" by Maik Heistermann et al., Hydrol. Earth Syst. Sci. Discuss., <https://doi.org/10.5194/hess-2021-25-RC1>, 2021

HESS Review on "Spatio-temporal soil moisture retrieval at the catchment-scale using a dense network of cosmic-ray neutron sensors" (<https://doi.org/10.5194/hess-2021-25>)

- General comments:

The paper "Spatio-temporal soil moisture retrieval at the catchment-scale using a dense network of cosmic-ray neutron sensors" by Heistermann et al., 2021 presents the first published analyses of comprehensive dataset of a dense network on Cosmic ray neutron sensors (CRNS) data and adjacent measurements, which were featured in the publication by Fersch et al., 2020 (<https://doi.org/10.5194/essd-2020-48>). The present paper is a contribution of high scientific significance as it presents a novel method for spatial interpolation of CRNS data from a network of closely positioned CRNS sensors. The study brings significant insights into the potential (and limitations) of CRNS technology to characterise spatiotemporal variability of soil water content (SWC) (i) at relatively high resolution (10m grid) and (ii) full small catchment scale (1km²) coverage.

Together with Fersch et al., 2020 this paper is a valuable scientific contribution to the way we look at SWC spatiotemporal variability with CRNS sensors. The methodological framework of the study includes the standardization of sensitivity of multiple (and diverse) CRNS sensors; it addresses thoroughly the correction of the signal for static effects and dynamic factors on the sensors' signals; the calibration for obtaining a single N_0 for all sensors is especially valuable for further CRNS studies. Moreover, the assessment of uncertainties is thorough and openly assessed. The spatial interpolation (using unconstrained and constrained model) is one of the most important assets of the paper, as a contribution to the CRNS community.

Nevertheless, my main concerns are with the presentation quality of the paper: the length

and structure of the manuscript could be substantially improved (see specific comments). Therefore, I would like to suggest major revisions.

- Specific comments:
 - While this is a discussion paper, I would encourage the authors to be more concise and structured when presenting their findings (examples are given below). There are sections which seem to be excessively long. That would hopefully help address another issue, which is the often “downplaying” of the study findings (examples also given). Moreover, during the discussion the implications of the findings and potential benefit of the application of these novel analyses are shown/discussed but in a scattered manner throughout “Results and discussion” section. I would recommend condensing them in a subsection within “Summary and conclusions”. Below I outline specific examples:

In **Section 1.2**. Aims and objectives: research questions and specific objectives of the study are presented between lines 65-95 and surely could be condensed. If you would wish to keep all the text, separate clearly in “aims and objectives” and “justification”. That would help structuring further the manuscript.

Section 4.4. has effectively three subsections “Unconstrained model”, “Constrained model” and “Forward operator”. Please give these index numbers 4.4.1. , 4.4.2 and 4.4.3. (similar to what you have done in section 4.1.). Also, lines 319-340 from subsection Unconstrained model: please try to shorten and restructure. Only in line 327 you say what you have actually done in the study and before that you give several examples (319-327). I would encourage you to first say what you did and then give the examples.

Section 5.2. between lines 473-484. – text can be shortened, and arguments presented more concisely. For example, line 472 “Clearly, the agreement is less than perfect. Still, the general pattern suggests”, can be rephrased to “While the agreement is not perfect, the general pattern suggests...”.

In general, in **Section 5**: try to restructure main discussion points (5.1. to 5.5.) in a way that it follows the flow of your aims and objectives.

Section 6 Summary and conclusions (which are then called “main lessons learned along these steps”) needs to be more concise. Shortly introduce the “main lessons” and then expand on them in 6.1. and 6.2.

2.1. Section 4.3. is particularly good, as uncertainties have been very well acknowledged and explained. Moreover, the limitations of the study are thoroughly and openly discussed. However, I encourage the authors to include a short comment in discussion on

the applicability and reproducibility of the set-up (of dense CRNS networks) and perhaps provide examples of what would be the minimum number of CRNS probes to be included in a similar set-up in order to assess CRNS SWC spatiotemporal variability in a reliable way at the catchment (in this case 1 km²) scale.

- Technical corrections:
 - Figures: Improvements suggested on the following figures

Figure 1: In the legend you refer to "Climate gauge" and in caption to "Climate station" and in the text (line 169) you use the term meteorological station. Please choose one term only. Besides, from the figure it does not become apparent where are the peaty soils within this catchment are located. From the text we understand that location 23 is on peaty soils, but what is the extend of these? Would it be possible to include the soils on this map too? May be in a separate panel? Finally, the manual samples locations: they seem to be very close to the CRNS sensors, which is ok, but visually it is impossible to distinguish how many you had around each CRNS probe. Could you include information on their number (e.g. in Table 1)?

Figure 3: Is it correct that the rover can sense neutron intensity between 7000 and 11000 cph? (this is just a question, rather than an improvement suggestion)

Figure 5: great figure. Could you include the legend also on the right panel for consistency? Also, optionally name the panels as a),b) and c), this will help you shorten the text related to that figure.

Figure 6: another very clear figure. However, I wonder why precipitation is presented as mm/6h and the SWC at the panel below in daily values? I guess it is ok if the width of the cell representing a day on the bottom panel is matched with the width 4 bars of rain.

- Tables:

Table 1: to address my comment on Figure 1, perhaps you can include an extra column to this table "Dominant soil type" or give percentage of the soil types present within each footprint.

Table 2: Under each header add the units, if applicable. That might avoid having a lengthy caption and faster to understand to readers.

- Others:

Line 9-11: Do you need to enumerate all the static effects and temporally dynamic factors in the abstract? Shorten sentence if possible.

Line 14: you mention already here "constrained interpolation", which is great. Could you also please mention what you will refer later on as "unconstrained" to improve clarity and keep consistent?

Line 44: on "isolated" sensor footprints only. Change "only" for "mainly", as there are already several key studies published using CRNS rovers.

Line 51-57: Am I correct that here you present the main aim of the study? If so, please restructure this paragraph first stating the main aim and then then the justification. (the content is good, but the flow can be improved).

Lines 67 – 78: The first question or specific objective has been given more space compared to questions 2 and 3. Could you please make this section more concise? In that way the "weight" of the three specific objectives seems equally distributed.

Line 94: Abbreviation FDR is not defined previously. Could you please include "Frequency domain reflectometry" here?

Line 102: change to "We then present and discuss the corresponding results (section 5)..."
– as Results and Discussion are presented simultaneously.

Line 109: please provide information on what portion of the catchment is covered with grassland (in %) and forest (in %) to give a better idea of the heterogeneity in land use to which you refer in Line 60.

Line 113: Section 3.1. Overview does not add anything to point 3. Data. In fact, you state "as already pointed out". Thus, I would remove the current Section 3.1.

Line 138-142: Section 3.3. is unnecessarily long and can be shortened to two sentences. Alternatively fuse current sections 3.3. and 3.6. as one, giving it an appropriate name. The measurements described in these two sections are used to do the continuous correction of the signal.

Line 144: "As we mention in section 1.1. we require local measurements of the soil water content and the soil bulk density" – you don't actually mention soil bulk density in current section 1.1. Either include it there or rephrase this sentence.

Line 146: Do "several measurement techniques" refer to the techniques outlines in sections 3.4.1., 3.4.2. and 3.4.3.? If so, please change to "the following measurement techniques".

Line 168: Current section 3.6 should be moved after current section 3.1., as the meteorological data is relevant to all the CRNS analysis. Also, see my comment on using "climatic gauge", "climate station" or "meteorological station".

Line 172: Section 3.7 does not really present data (since you do not use it for analysis and merely to create figure 1). I would remove this section as the information is already provided in the caption of Figure 1. Optionally, add the hyperlink from the current section 3.7 to the caption of Fig.1 .

Line 173: replace "incl." with "including".

Line 411: SMT100 cluster (SoilNet) should be defined/mentioned earlier, as for example in line 90. In line 431 you refer to the same as "FDR-cluster". Choose one term and stick to it.

Line 484: "... Fig.5 is both encouraging and disappointing" – put first disappointing and then encouraging, as this is the order in which you present them afterwards. Also, why would you say disappointing about a Figure you include in a publication? Choose a different less negative word. There are several places in the manuscript where you downplay the results of your research (see my comment about line 611 for example).

Line 486: "The vertical shades in the left panel indicate that the theta (Ni) is highly uncertain." You refer here to the percentiles, but which ones/which grey shades? The 5-95% or the 25-75% ones? Be more specific. Also you can see from this left panel that the uncertainty is larger in the wetter range and smaller in the drier range. Acknowledge that instead of saying that they all are highly uncertain. See my comments about downplaying your results.

Line 605-607: While limitations are honestly acknowledged the paragraph ends on a negative note, which does not reflect the main outcome. I would recommend rephrasing along the lines "While both the unconstrained and the constrained approaches failed to fully simulate the dry are in the southwest of the SoilNet area, the constrained captured it relatively better."

Line 611: "largely" outperform seems like an overstatement (downplaying the overall good results of your study). I would remove "largely". If you mean that the unconstrained model outperforms during a prolonged period of time, modify text accordingly.

Line 622: typo. Change "reliably" to "reliability".

Line 629: I understand the willingness to emphasize the "heterogeneous" in here, as it is a key word in this study. However, not entire convinced about "heterogeneous hydro-meteorological conditions". Are you not considering that precipitation, temperature and barometric pressure measured at the climate station are all the same for all sensors? I would recommend saying "dynamic" or rephrase.

Line 725: typo. Change "August 2910" to the corresponding year.

Supplementary material is clear and neatly presented.