



EGUsphere, author comment AC1
<https://doi.org/10.5194/egusphere-2022-219-AC1>, 2022
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Reply on RC1

Martin Schrön et al.

Author comment on "Signal contribution of distant areas to cosmic-ray neutron sensors – implications for footprint and sensitivity" by Martin Schrön et al., EGU sphere,
<https://doi.org/10.5194/egusphere-2022-219-AC1>, 2022

Dear Reviewer 1,

thank you very much for your positive review. We will briefly comment on your concerns in the spirit of the interactive discussion. (RC=reviewer comment, AR=author response)

Main comments

> *RC1.1: "In my opinion, one of the strongest assumption that might be warranted is that neutron contribution of each sub-domain can be assessed individually (L149). As far as I have understood, this is also actually not challenged by the MonteCarlo simulations because also in these analyses the distance of the first contact with the land is used for the calculation (L179 and L212). In contrast, assuming a more diffuse transport process I expect more interactions and mixing. This might change significantly the results. I would say that for addressing this question, a different definition of detected distance in the MonteCarlo simulation should be tested. If this will not the case within the present study, I suggest at least to extend the discussion around that."*

AR: This is indeed a fundamental assumption and has been discussed in lines 138-149. In fact, the question of the importance of secondary interactions beyond the individual area and the implication for the detector signal was one to which we paid particular attention in this context. That's why we challenged this hypothesis in section 3.1 with very heterogeneous soil moisture patterns. It turned out that the prediction of the contributions is still very close to Monte-Carlo simulations, so the assumption, that these secondary interactions are of minor importance seems to hold. We believe this is one of the major findings of the study, so we will better clarify this the text in the revision.

Regarding the definition of origin in the simulations: Previous studies dedicated to the CRNS footprint were based on the same definition that we use in our study, i.e., on the distance between first soil contact (=origin) and detection. Ofcourse there are further interactions on the way (on average two to three land-atmosphere interface crossings). However, simulations from Köhli et al. (2015) have shown that the first contact is the most important for the neutron, i.e., the soil moisture at the first-contact location is the most dominant in the detected neutron signal.

> *RC1.2: "I like the practical question that has been formulated, i.e., "At what distance are soil moisture changes still visible to the CRNS" (L325). This could help better*

understanding neutron signal and supporting agro-hydrological applications. However, I'm not convinced that this should be posted as an alternative definition of footprint size R86 (L324). As far as I understood, on the one hand, R86 refers to the average radius over all the directions from the sensor (as stated at L365) and it does not assume that no neutrons are coming from more remote areas (on the contrary to the statement at L367). On the other hand, the Authors nicely show how soil moisture changes at a field nearby can be detected only at different distance than R86 in case soil moisture where the sensor is placed remains constant. But this does not contradict R86, i.e., on average over all direction R86 is different then the new R.

AR: The statement in L367 says that the definition of R86 suggests that extreme changes of soil moisture might not be "...sensible much beyond the conventional footprint radius". We are not saying that "no" neutrons are coming from beyond that radius, in fact it is implicit that 14% of neutrons are coming from there. But the definition does not take strong soil moisture contrasts and asymmetric geometries into account. Thus, it will fail in extreme situations (as shown in Fig. 8b). Depending on the field geometry, in some directions the 86% limit might hold, but in some it might be completely off. That is why we believe that for many applications, R has a higher practical relevance than the "on average" quantity R86.

We would like to point out that the original formulation of the footprint definition as R86 has already sparked discussions in the community regarding its practical applicability. The exponential shape of the radial weighting function with its very long tails and its strong near-field sensitivity is not very intuitive. Therefore providing one number for the radius led to misunderstandings regarding the actual sensitivity of a CRNS instrument. Nevertheless, R86 has its qualities, too, but it is only a radially symmetric approximation. It is certainly useful for many applications, but it is less useful in highly asymmetric cases, such as adjacent fields. On the other hand, the new R is a good alternative definition for some specific cases, but certainly it might be less useful in other situations. In the revised manuscript we will make more clear that R is not a general alternative to R86, but rather more practical in certain scenarios. In general, however, the concept of defining the footprint in this, spatially more explicit way, and to include the sensor sensitivity, is applicable to any thinkable scenario.

> RC1.2 cnt.: "Moreover, I do not have anything against these showcases but I think these support the conclusion that CRNS is not suitable for supporting irrigation management at relative small farms. But this I think was already clear from first CRNS publications. In contrast, it should be acknowledged that in any other conditions we soil experiences wetting or drying soil moisture profiles even if at different degrees that is still detected (even if in a non-linear way) by the sensor. So overall, I see the new R as an additional indicator rather than an alternative footprint size, i.e., I would still like having an indicator that accounts for neutron intensity changes in all directions (L365)."

AR: The reviewer is correct, that for irrigated patches much smaller than the footprint the corresponding signal strength might be weak. In general, we fully agree that the new R should not replace the conventional R86 characteristics, it wasn't meant to. The new R should rather be an additional quantity to be more useful for some practical questions. We will adapt the nuances of the text to make that more clear.

> RC1.3: "my final main comment is related to the fact that all the discussion is based on a forward operator $N(\theta)$ (eq. 11). I agree that the results of this contribution will support some practical questions, e.g., where to install the sensor or modelling applications, e.g., data assimilation. However, I believe that in several applications soil moisture is the targeted variable, i.e., we do not know soil moisture within the footprint. Thus, I think one could conclude that 1) it remains an ill-posed problem to try to resolve soil moisture variability within the footprint and 2) CRNS sensor should be strategically

located to avoid difficulties with signal interpretation. I would encourage the Authors to extend on these."

AR: We agree that we cannot directly derive soil moisture patterns from the neutron signal alone, and ideally and in the sense of a good interpretability of the signals, one should always aim at operating the sensor in areas that are as homogeneous as possible. However, this requirement is often -- if not in the majority of cases -- not met, mainly for practical reasons. The presented method can help, firstly, to better assess the potential influence of spatial heterogeneity on the sensor signal, e.g. by forward modeling different variations of soil moisture, see how it influences the signal theoretically, and improve the uncertainty assessment of the signal. It has also the potential to support better understanding of certain features in the signal and thereby "detect" non-reported irrigation, for instance. Secondly, to drive inversion experiments (L413), i.e., to test the known variations of soil moisture patterns and find the best match to the actual soil moisture signal. This way, the subfootprint-patterns could be derived indirectly (see also Franz et al. 2015, 10.1002/2015gl063963). We will better clarify this in the revised manuscript.

Specific comments

> "L2: Through the manuscript, the Authors use the term "concept" to refer to what they have developed and tested. A concept is in my opinion an abstraction or perception. So, more than a concept, the Authors have developed an "approach" or a "method". I suggest using one of these terms instead of using "concept"."

AR: Thank you, we will adapt the terms where necessary. In general, we believe that the "generation times transport" formula is still a theoretical concept, but the way how it is applied to CRNS might indeed better be described by "method".

> "L3. I understand that similar concept (or approach, see comment before) can be developed for snow. But the study focuses on soil moisture and the snow application is not addressed. I would remove from abstract and methods the snow applications and only refer to that as a possible extension of the study in the conclusions section."

AR: Besides irrigation, patchy snow cover is one of the most relevant fields where this method has a good potential for application. The reason is that the average descriptions of R86 and N(theta) mainly fail at the very extremes of soil moisture heterogeneity, which is one of the main take home messages of this paper. Patchy snow cover (=pure water) on rocks (=purely dry soil) hits this sweet spot, where new methods are necessary to describe the CRNS signal (see e.g., Franz et al. 2013, or Schattan et al. 2017, 2019).

> "L86. Why only humid?"

AR: This word was misleading and will be removed.

> "L88. Vegetation height might be not a good proxy for biomass effect to the neutron signal. I guess it was selected for simplicity but would be nice to extend the discussion on the consequences of this approximation."

AR: The influence of vegetation height to the footprint has been discussed in Köhli et al. 2015. It will be interesting to better understand its influence on signal contributions in general, but this is out of scope of this study.

> "L172. What is "drf"?"

AR: It refers to the detector response function as explained in the end of this sentence.

We will make that more clear in the revision.

> "*L193. I lost from where these ranges come from.*"

AR: Sorry for the confusion. This is the Euklidian distance to the corners of a 500x500 or 200x200 square, respectively. We will make that more clear in the revision.