Review of Towards disentangling heterogeneous soil moisture patterns in Cosmic-Ray Neutron Sensor footprints by Rasche et al.

Summary

The Authors explored the use of thermal and epithermal neutrons to detect soil moisture spatial variability within a CRNS sensor footprint. The study is based on several simulations performed with URANOS model and long term experimental data collected at one location in Germany. The manuscript is well structured and written, results are clearly explained and discussed. In my opinion the manuscript is suitable for the journal but should be strengthen in several parts. Below I provide my general concerns followed by specific comments in order of appearance in the manuscript. I hope these comments could help for further improvements.

General comments

[1]. The more complex response of the thermal neutrons rise my main concern of the present study. The potential use of thermal and epithermal neutrons has been pointed since the first CRNS publications (Desilets et al., 2010; Rivera Villarreyes et al., 2011). Further attempts have also been performed later by dedicated studies (Bogena et al., 2020; Jakobi et al., 2018; Tian et al., 2016). As far as I understood, difficulties to handle these two signals are related to the non-unique response of the thermal neutrons, i.e., in contrast to epithermal, they depend on chemistry and the thermal intensity also increases during the wetting of initially dry soils (Desilets et al., 2010; Zweck et al., 2013). The present study quantifies the different footprint of thermal and epithermal neutrons. As such, it sheds lights on the understanding on the processes. However, few is discussed on the possibility to generalize the correlation found in the present study between epithermal and thermal in other conditions. As such I see the high risk of this study to be very limited. In addition, if the Authors are really interested on disentangling footprint variability, I rather believe that the use of side-shielded detector (Zreda et al., 2021) could be easier and more promising than the use of the thermal detector.

[2]. As far as I have understood, the comparison between neutrons simulations and neutron measurements is not consistent. Simulations are based on theoretical detectors sensitive only to thermal or epithermal ranges. In contrast, measurements have been collected with bare and moderated detectors that are contaminated by epithermal and thermal neutrons, respectively, as highlighted by the Authors. Previous studies showed clear discrepancy between simulations and measurements when this contamination effect was not properly account for (Andreasen et al., 2016; McJannet et al., 2014). As such, I'm surprised about this setting. Either the detectors should be improved to remove the contamination from thermal and epithermal. If this is not possible within the present study, why not repeating the simulations with the real detectors? Despite more rigorous understanding of thermal and epithermal, you are allowed to compare the simulations and the experimental data.

[3]. Point scale soil moisture observations are very limited and they represent only short distance. This has been pointed as main limitation of the present study but very late in the manuscript and without explaining the consequences of that. Please note that the use of limited number of soil moisture locations have been highly criticized in former studies (see discussion for (Rivera Villarreyes et al., 2013). Despite I'm personally do not against comparisons with relative few points sensors, it should be noted that the present study concluded that the use of thermal signal improved the performance. However, I see a strong bias if we consider that thermal has a smaller footprint and point scale soil moisture used for the comparisons are located in the near field. As such, I would rather presume to have worst results in case the point soil moisture sensors would have been distributed also at larger distance.

Specific comments

L2: I suggest the term estimations instead of measurements, i.e., the sensors measures neutrons and, based on that, estimate soil moisture.

L4-5: I think it should better phrased. 1) soil homogeneous conditions are unlikely and from my understanding 2) the added value of CRNS emerges exactly in case of heterogeneous conditions. The key assumption is in my opinion to sense a representative volume where soil moisture shows a relative short correlation length. In this case neutrons well mix within the footprint. In case of longer correlation length and spatial patterns, empirical data deviates from theoretical functions and hysteresis behavior could also emerge. Similar consideration has been detected in snow patches conditions (Schattan et al., 2019)

L39. If I'm not wrong, some papers refer to the threshold 0.5 for thermal neutrons. Could you provide reasoning for this value?

L43. The more complex response of the thermal neutrons rise my main concern of the present study, i.e., the results are very site specific (see general comment above)

L65. I'm very surprised if most studies with stationary CRNS assume homogeneous site conditions. Please rephrased as previously discussed.

L105. Please add if possible the 21 random locations on figure 1.

L125. but why to simulate something that it does not represent the real detector? See general comment above

L131. point scale soil moisture observations are very limited, they represent only short distance and they are not evenly distributed. The CRNS calibration is strongly biased

L166-183. This text refers to all simulations and not only to simulation set 1. It should be moved up in section 2.2.

L180. As far I understood from previous studies, D86 is not spatially constant. Please specify if you refers here to the maximum (or average) depth over the footprint

Figure 2. ground water level should be reported as depth from soil surface to ground water instead of ground water level above sea level to facilitate the interpretation on the discussion on shallow water table influencing soil moisture detected by CRNS.

Equation 6: you merge thermal and epithermal with different footprints. But you compare the scaled sum with point scale soil moisture weighted based on epithermal footprint. Are you not mixing up the signals? Additionally, what about using only thermal? I expect good or even better results when calibrating with these near field point locations.

Figure 3b. If you calculate the maximum D86, it should be expected to not changing much the depth by increasing far-field soil moisture. Please clarify

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