

Interactive comment on “Use of cosmic ray neutron sensors for soil moisture monitoring in forests” by I. Heidbüchel et al.

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Résumé

This study concerns the application of the cosmic-ray neutron method to monitor soil moisture in a mixed forest in the lowlands of north-eastern Germany. The authors tested several calibration procedures using soil samples taken 10 times within one year inside the footprint of the sensor. A two-point calibration is assumed to be adequate to correctly define the shape of the NO-calibration function with adjusted parameters when calibration points were taken during both dry and wet conditions covering at least 50% of the total range of soil moisture.

This paper is an interesting presentation of a forest application of the cosmic-ray neu-
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tron method giving some new insights into the calibration process. It is also very well written and fits well to the scope of HESS. However, some methodological improvements need to be undertaken as outlined in my comments. In addition, the results should be better discussed in the light of existing publications on the calibration of the cosmic-ray neutron probe.

General comments

The calibration results might have been affected by the unfavourable locations of the sampling locations. As demonstrated by Köhli et al. (2015), the highest contribution comes from the first 10 m radius, whereas the nearest sampling locations are still 25 m away from the CRNS probe. Please add a discussion on how thus soil moisture differences between the close-up area and the sampling locations might have affected the calibration results.

The vegetation within the footprint of the CRS probe is quite heterogeneous (please add a table of the landuse contributions), which complicates the spatial averaging of soil moisture. For instance, as shown by the authors, the coniferous sites are consistently dryer compared to the areas covered by beech. Thus, the limited number of sampling locations could be an additional reason for the differences in the CRS calibrations.

Iwema et al. (2015) already showed that using only one calibration data can lead to large uncertainties especially in humid regions with large hydrogen pools. They showed that the best trade-off between number of calibration dates and calibration accuracy can be achieved by using 6 calibration dates. Please discuss your results in the light of the results of this recent publication.

This study also considers the vegetation correction developed by Baatz et al. (2015). However, since the method considers only linear scaling of the neutron counts, its application should not alter the calibration accuracy in case of temporally stable above ground biomass (as in this study). Therefore the application makes only sense where temporal biomass dynamics are expected and temporal information on biomass

changes are available or in case of cosmic rover applications.

Specific comments

L143-145: On the web-site of the sensor manufacturer no specification of the measurement technique is given. I suspect that these sensors are actually based on an oscillator-ring as described in Qu et al. (2014) and not on the time-domain transmission technique. In addition, a problem of these sensors could be the top shielding, influencing the soil water content below. Since these kind of sensors only measure soil moisture at a very small volume (only very few centimeters around the sensor blade) this might lead to systematic underestimations of soil moisture.

L147-148: Is the sensor blade actually 15 cm long (at the web site there is no information on the seize and the pictures suggest that the sensor blade to be much shorter)

L149: Why didn't you use all data for the calibration?

L205-208: No scaling needed since this correction considers the relative changes in incoming neutron flux. However, the cutoff rigidity of the Jungfraujoch Station is somewhat different from the study site given is lower latitude. An good choice for the neutron monitor is be the Lomnický station, Slovakia (LMKS).

L206: The correct unit for incoming neutrons is "counts/sec"

L224: The methods to determine soil organic carbon and root biomass water equivalents are not presented.

L230: This statement is too vague. I think what you meant here is that the objective performance measure is minimized, right?

L315: What about the other tree species?

L317: On which grounds did you assume these values?

L359: The correct unit for incoming neutrons is "counts/sec"

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L380: Change to "the same value for the N0 calibration parameter"

L381: The correct unit for the CRS measured neutron intensity is "counts/h"

L382-387: According to Zreda et al. (2012) the presence of other hydrogen pools than soil moisture increases the stopping power of the soil, which leads to a change in the slope of the calibration function. Thus, calibration has to be performed using the total hydrogen pool, and soil moisture is then computed by subtracting other hydrogen pools than soil moisture from the measured neutron-derived soil moisture. It is unclear whether this procedure was applied in this study. If not, this would partly explain the differences in soil moisture estimates.

L388: The term "new calibration function" is misleading. Changing the "a" parameters of the N0 calibration function is not new and was already presented by Iwema et al. (2015). They called this more adequately "modified N0 method". However, they only calibrated 3 parameters (the N0 parameter was omitted), because of strong correlations between the parameters leading to ambiguous calibration results (equifinality problem). Did you check for this calibration issue?

L400-402: Do you have any idea why?

L407: See comment L388

L414-416: Please provide a figure showing the comparison.

L422-424: Shouldn't the relationships vary with soil moisture content due changing sensor penetration depths?

L429-430: This finding is quite obvious given the insignificant changes in above biomass. Generally, the application of the vegetation correction makes only sense, when temporal biomass dynamics are expected and temporal information on biomass changes are available.

L441: This investigation is very similar to Iwema et al. (2015). Please discuss your

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results in the light of this study.

L450-457: The results plotted in Fig. 12 show clearly, that only the most extreme dry and wet samplings result in an acceptable calibration result, whereas sampling at intermediate soil moisture will lead to very uncertain calibration of the modified N0-method. On the other hand, this illustrates the value of the standard N0-method that will also produce stable results in case only one sampling date is available. Please add this to the discussion.

L458: This chapter belongs to discussion.

L471-474: This is only true when assuming that the CRS footprint is completely covered by beech, which is however not the case.

L484-485: So the whole discussion of this chapter is unimportant and should be reduced to 1-2 sentences.

L488-518: This section is a summary, not a discussion and thus should be omitted.

L520-528: Please discuss your results in the light of the results found by Iwema et al. (2015).

L558-560: This statement is not clear to me. Please explain in more detail.

L564-569: This part is somewhat misleading. Corrections of the neutron count rate (Eqs. 1-3) are essential for any application of the CRS (e.g. Zreda et al., 2012). Vegetation correction is only needed for sites with significant biomass changes. On the other hand, the characterization of the temporal stable hydrogen pools is important for the application of the N0-method. However, the abundance of different pools and the uncertainties in the sensing depth estimation will always lead to uncertainties in the calibration process. As shown by Iwema et al. (2015) and by the results found in this study, this issue can be partly circumvented by the using site specific calibration parameters estimated at using in-situ samples taken during dry and wet conditions. Please reformulate in this sense.

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L583-584: Actually, the seasonal changes of the hydrogen pools in this forest site are negligible. Thus vegetation correction can be omitted.

L594-600: This statement is based on Köhli et al. (2015), but not on results of this study and thus should be omitted.

L606-608: This step is obvious and should be omitted.

L614: The sampling locations should be adapted to the footprint estimates after Köhli et al. (2015).

Figures

Figure 1: This map should be integrated in figure 2.

Figure 2: According to recent results of Köhli et al. (2015) the footprint is considerably smaller than 300 m. Please adapt the figure. In addition, it would be helpful to color the aerial photograph according to the different tree species.

Figure 3: This figure can be omitted (see comment L205-208)

Figure 4: This schematic figure is wrong in presenting the cosmic-ray neutron intensities as actual rays that are reflected by the soil. The actual processes leading to neutron intensity are far more complex (see e.g. Köhli et al., 2015) and should not be presented in this way in a scientific paper. Also the above ground and below ground footprints are not connected in the simple way as suggested by the schematic drawing. Thus, the figure should be omitted.

Figure 12: The Pareto front needs to be discussed in the text as well.

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