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Supplement of

Spatio-temporal soil moisture retrieval at the catchment scale using a dense network of cosmic-ray neutron sensors

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Supplement

S1 Fitting vertical profiles for soil variables

As pointed out in the main manuscript, we decided to generalize the vertical distribution of soil variables v_i (i.e. θ, ρ_b, SOM, LW) across the study area. To that end, we fitted a piecewise linear function with two parameters to each profile and variable: from the soil surface (0 cm) down to a depth of 13 cm, the function assumes a linear change of any variable value from $v_i(0cm)$ to $v_i(13cm)$. Below 13 cm depth, the variable is assumed to remain constant at a value $v_i(13cm)$. This approach has been found to reflect the typical vertical distribution pattern for all soil variables fairly well, while reducing spurious effects of outliers when the variables are horizontally interpolated.

The following figures illustrate the results for profiles that were manually sampled using soil cores.

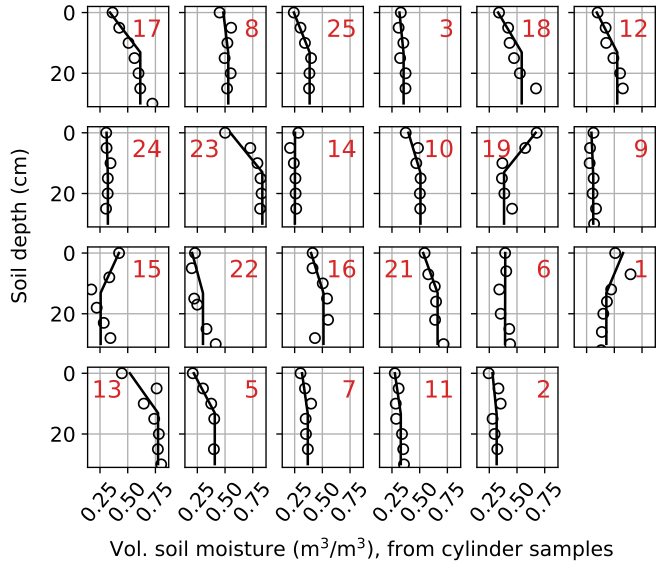

Figure S1. Measured profiles of volumetric soil moisture and corresponding function fits. The circles denote volumetric soil moisture as sampled by soil cores (from 0 to 30 cm in increments of 5 cm). These profiles were sampled in the direct vicinity of the CRNS sensors. The sensor ID is shown in red text. The solid black lines show the function fits.

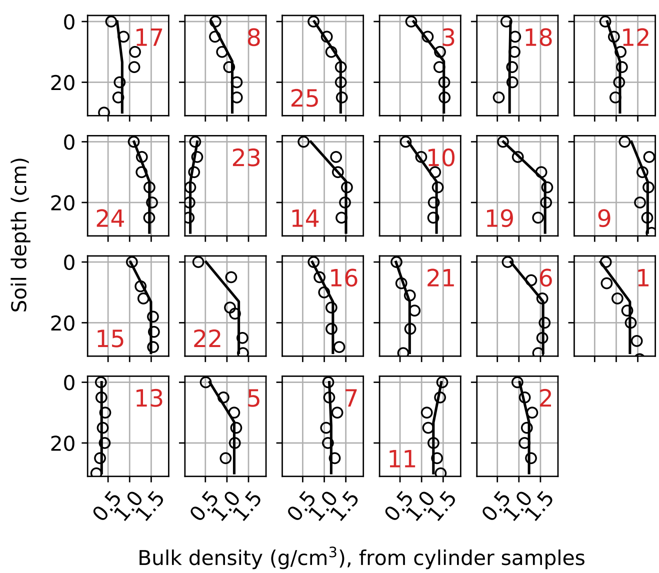

Figure S2. Measured profiles of soil bulk density and corresponding function fits. The circles denote soil bulk density as sampled by soil cores (from 0 to 30 cm in increments of 5 cm). These profiles were sampled in the direct vicinity of the CRNS sensors. The sensor ID is shown in red text. The solid black lines show the function fits.

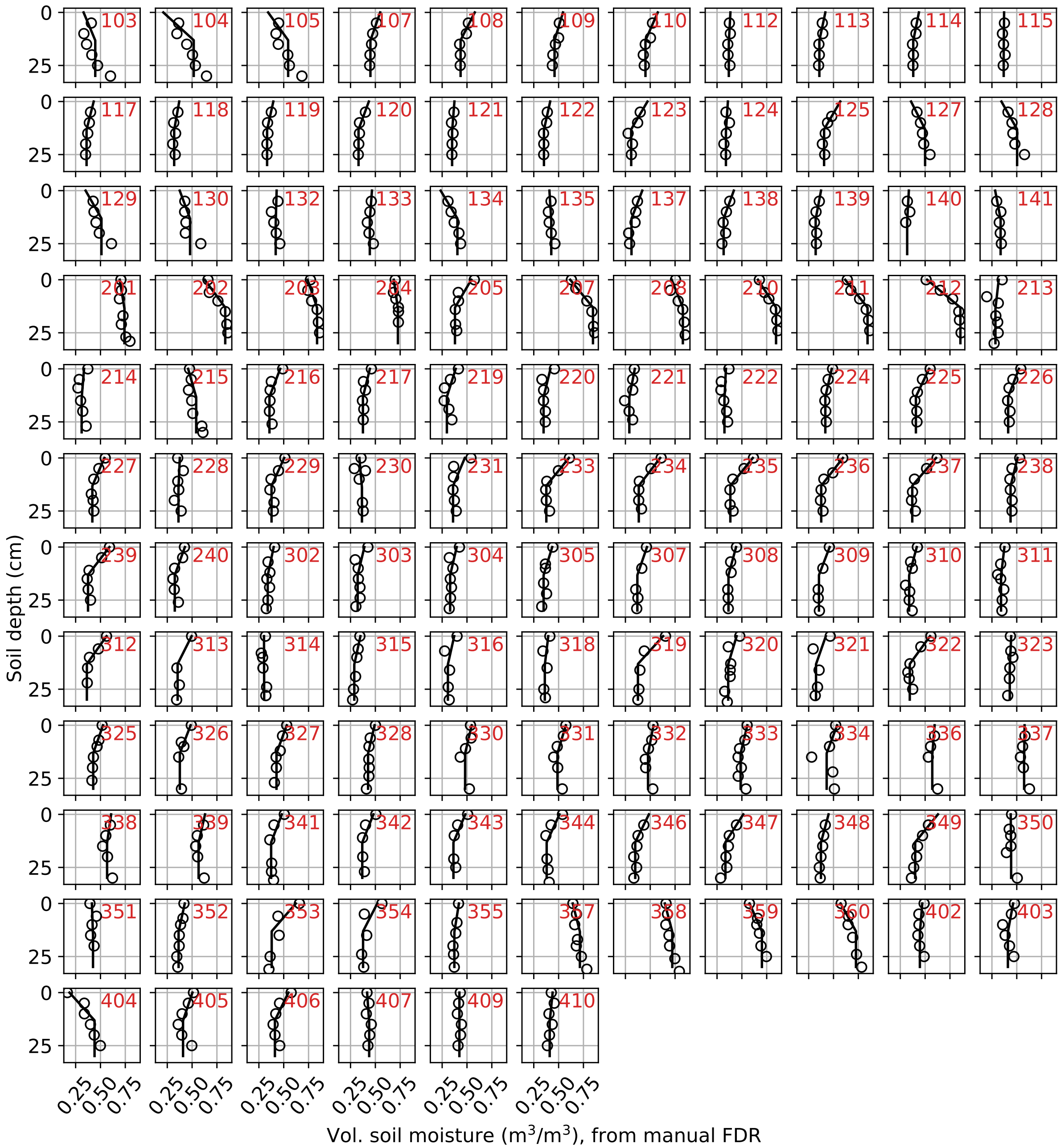

Figure S3. Measured profiles of volumetric soil moisture and corresponding function fits. The circles denote volumetric soil moisture as sampled by manual FDR measurements (from 0 to 30 cm in increments of 5 cm). The sample ID is shown in red text. The solid black lines show the function fits

S2 How robust is the standardization of the sensitivity?

One important requirement to identify a uniform N_0 was to scale the neutron count rates of the different sensors to a uniform sensitivity level. To that end, a mobile calibrator probe and concomitant measurements with the rover unit were used.

However, the comparison between the rover and the stationary CRNS is not entirely straightforward: while the rover is sensitive enough to obtain sufficiently robust statistics in a period of 30 minutes, the same does not apply to the stationary sensors. Hence, the neutron counts from the stationary sensors had to be averaged over a longer period for which we chose a window of 12 hours around the time of sensor collocation. Fig. S4 shows the corresponding results.

For each sensor, it shows the standardized count rates versus those of the rover unit during collocation. The bars indicate the standard errors of the mean neutron count rate (within 12 h and 30 min for stationary and rover units, respectively). A line was fitted through the average values, the slope of which represents the sensitivity ratio between rover and the stationary CRNS sensors standardized to calibrator sensitivity. Or, in other words, the slope of the fit should correspond to the ratio between the sensitivities of the rover and the calibrator, and amounts to a value of 5.58. The ratio between rover and calibrator count rates, as obtained from the actual collocation of both sensors (shown in blue), amounts to 5.43 - that is about 2.7 % less, which we consider a good agreement. Furthermore, most of the stationary CRNS sensors are very consistent with the rover, particularly given the range of standard errors. However, three sensors - 2, 18, and 19 - do not exhibit any overlap of the error bars with the 95 % confidence interval of the fitted line which might raise some concern with regard to the integrity of their scaling. Still, a variety of causes could be behind the disagreement. For sensor 19, e.g., the rover had to be placed, due to difficult terrain, at a distance of approx. 5 meters from the sensor which could have a substantial effect given the high sensitivity of the sensors to the near range field. The same applies to sensor 18, which was located close to the rivulet (see Fig. 1 in the main paper) where we can expect very high local soil moisture gradients. In such a setting, a distance of one meter could already have an effect, and the fact that sensor 19 was located between the rover and the rivulet is consistent with the higher neutron intensity observed by the rover (as it might have been placed on drier terrain). Finally, sensor 2 was affected by a series of erratic count rates just during the time of the roving campaign. The removal of these erratic count rates produced some data gaps, and could have caused some bias. Given these circumstances, it appears that the homogenisation of sensitivity was rather successful. Still, attention should be paid for those sensors which fall out of line, when we evaluate the results of the N_0 calibration.

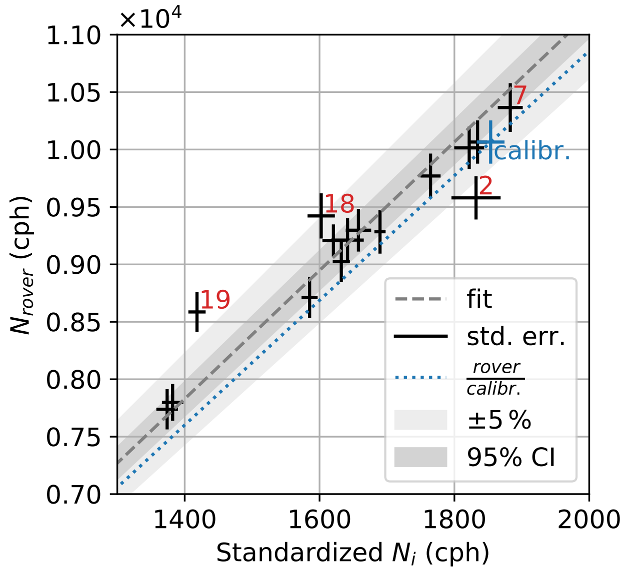

Figure S4. Comparison between standardized neutron intensities of the stationary CRNS sensors (N_i) and the mobile calibrator (x-axis), and the roving CRNS (N_{rover}, y-axis). The solid black lines indicate the standard error of the mean neutron intensities within 30 minutes (N_{rover}) and 12 hours (N_i, calibrator), respectively; the dashed line represents a linear fit between N_{rover} and N_i, the dark shade is the corresponding 95 % confidence interval of that fit; the light shade indicates a deviation of $\pm$ 5% in N_{rover}, the slope of the blue dashed line shows the ratio between N_{rover} and $N_{\text{calibrator}}$ when both were collocated; the red numbers highlight the IDs of selected stationary CRNS sensors.