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Discussions

Interactive comment on "Closing the water balance with cosmic-ray soil moisture measurements and assessing their spatial variability within two semiarid watersheds" *by* A. P. Schreiner-McGraw et al.

Anonymous Referee #1

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In this study, soil moisture dynamics of two semiarid watersheds in Arizona and New Mexico were analysed through a comparison of the CRS method with a distributed sensor network as well as estimates from water balance closure. In addition, relationships between the spatially-averaged CRS estimates and the spatial variability of soil moisture in the measurement footprint as well as with the spatially-averaged ET obtained from the EC method are analysed and an analytical relation between evapotranspiration the spatial variability of soil moisture is proposed.

The study presents some interesting results using extensive sensor network data from two semiarid test sites. Also the topic fits well to the scope of HESS. However, the authors are mixing too many different topics and aspects making the manuscript hard to follow. Also many statements are inconsistent and contradicting. In addition, there are several inaccuracies that need to be improved (see my specific comments).

I therefore recommend a major revision of the manuscript.

General comments:

1. The paper deals with many different topics (e.g. CRNS validation, water balance closing, soil moisture variability, comparison of two test sites). In consequence each of these topics is only dealt with in a rather superficially way and the reader is lost in too much and inconsistent information. In order to focus the paper, I suggest removing the sections on soil moisture variability.

2. There already exists a long list of papers dealing with the validation of the CRNS method for soil moisture determination and it was already shown that the methods works very well in arid systems due to the relatively low hydrogen content. Therefore, the good agreement with the in-situ measurements is of no surprise. However, also deviations were shown, e.g. during soil recessions. For the growing community it would be more interesting to learn more about reasons for such deviations.

3. There are several contradictions in the manuscript. For instance, on the one hand it is stated that percolation at both site is mainly restricted to the first 40 cm and on the other hand it is stated that substantial amounts of precipitation percolated to deeper layers. In addition there are many ambiguities in the methods (e.g. assumptions concerning z*, z_m, and leakage).

4. The methods section should be better structured. For instance, the soil water balance based on the CRS and the water balance closing should be presented together.

5. Chapter “summary and results” is quite extensive. It should be shortened and

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focussed on the main results of the paper

Specific comments:

Title: As mentioned above, the soil moisture variability part should be removed.

P3L18: Since the probe presented in this paper measures secondary fast neutron intensity above ground (and not cosmic-rays in general), it should called cosmic-ray neutron probe or in short CRNS.

P4L7: This equation is not correct since it assumes that all storage changes are taking place within the effective sensing depth of the CRNS. Instead z should represent the depth of the root zone.

P4L18: Be more specific. Which spatial properties are you referring to?

P5L1-4: Recently Qu et al. (2015) demonstrated that variability of soil moisture can be explained by mean soil hydraulic parameters and their standard deviations in different ecosystems and climates. In addition this study showed that dry environments can also experience a decrease of SM variability in the wetter range.

P5L8-10: The sensor network can provides both catchment scale average and spatial variability of soil moisture. Please explain why a combination of both techniques is still necessary for this kind of studies.

P5L14: Actually there are three watersheds investigated in this study (two at SRER)

P5L17: This study does not present a validation of CRNS in a strict sense, but rather a comparison with other methods. First, the soil moisture sensor network of both test sites is not well distributed within the CRNS footprint (the sensor networks do not cover well the CRNS foot and also do not consider the decreasing sensitivity of the CRNS with distance). Second, the water balance approach makes strong assumptions (e.g. CRNS measurement depth is assumed to be 40 cm). However, the actual sensing depth will strongly vary and given the variety in plant species of these ecosystems,

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the root zone is very heterogeneous and is not restricted to 40 cm everywhere. In addition, large parts of both test sites are not vegetated and which are only subject to evaporation. Here the soil depth that contributes to evaporation will be highly variable in time depending on SM content and soil properties.

P5L22: “evapotranspiration” instead of “root water uptake”

P5L22: The term “leakage” typically not used in vadose zone hydrology in this respect. The correct term would be “deep drainage” or “deep percolation”.

P6L8: Soil properties and topographic features of both sites need to be presented as well.

P7L15: The watersheds are much smaller than the footprints of CRNS and EC. Please comment on why you believe that measurement still can be compared, especially in the light of soil heterogeneity.

P7L21: How many rain gauges were used in each site?

P8L20-21: Statements in Campbell (1990) are not related to the measurement volume of the Hydra Probes used in this study.

P9L6-9: It is unclear why you are using different methods for each site. Please describe in more detail the reasoning behind the method selection. In addition, comment on why you are not accounting for the decreasing sensitivity of the CRNS with radial distance, like e.g. Bogena et al. (2013).

P9L13: I thought the CRS-1000 was used in SRER.

P9L21: The recent paper of Köhli et al. (2015) found different estimates for the CRNS footprint.

P10L4: Eq. 2 gives gravimetric water content (see Bogena et al., 2013)

P10L13-17: Please give more information on the soil sampling (e.g. disturbed or undis-

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turbed samples, dates etc.) as well as on the properties (e.g. mean values, standard deviations etc.).

P10L21: Please give more information on this method (e.g. how exactly rainfall periods have been ignored).

P11L6: According to Templeton et al. (2014), the clay content at JER is 20.8 %. Thus, lattice water needs to be accounted for at the JER site. Deviations between CRNS and in-situ SM at JER might be partly due to the false assumption of lattice water content.

P11L10-11: This is a very rough procedure. The horizontal weighing scheme of Bogena et al., 2013, should be applied instead.

P11L14-17: Please comment on possible influences of soil heterogeneity.

P11L17: According to Köhli et al. (2015) the CRNS shows considerable variations in horizontal footprint size.

P11L21: According to Templeton et al. (2014), the bulk soil density at JER is 1.37 g/cm^3

P11L22: There are large differences in clay contents indicating differences in lattice water contents.

P12L5 and L17-18: Please present the temporal variations in z* for both sites and discuss implications for the soil water storage change estimations.

P12L20-22: According to results shown in Fig. 8 there is a considerable amount of deep drainage taking place at JER for several weeks during winter. What are the consequences of this violation of the “no-leakage” assumption?

P13L5: Eq. 6 is not from Franz et al. (2012). Why are you using the minimum z*-value? Elsewhere you assume that z* equals z_m.

P13L7: I think it would be better to speak of “net” inflow and “net” outflow into/from the

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representative volume.

P13L11: Change into ". . .between soil domains above and below z*."

P13L16: The results of the soil sample analysis should to be presented in a Table (e.g. mean and std of grav. soil water content (SWC), soil density etc.). How did grav. SWC compare to sensor network SWC at both sites? How did grav. SWC compare to calibrated CRNS SWC at both sites?

P14L11-12: Please describe in more detail how you derived these analytical relationships.

P15L5-7: Differences of 3 to 6 Vol.% SWC are not large.

P15L11: Channels or linear structures are not visible in Fig. 1. What was the distance to a channel? Typically, water in channels shows very low effect on CRNS given their large measurement footprint.

P15L21: There is a huge scatter and even bias shown in Fig. 5. Therefore the term "excellent" is not appropriate.

P16L9-11: Is it really realistic that the soil completely dries out? Looking at Fig. 4 it becomes apparent that during very dry periods the statistical noise in the CRNS data (which is in the range of the SWC) produces values near zero which are clearly artefacts. In addition, the N0-method is not valid for SWC <0.2 (Desilets et al., 2010).

P16L11: What kind of limitations?

P17L9: Why should more homogenous soil lead to a shallower infiltration front? This should only influence the variability of the infiltration front. To support any discussion on influences of soil properties on hydrological processes, more detailed soil information of both catchments need to be provided.

P17L11: Undulated terrain typically promotes lateral water flow and not vertical water flow. Please explain why vertical flow is increased in JER by topography.

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P17L16-18: Obviously the comparison between both sites is hampered by the non-average precipitation amounts in both. For an unbiased comparison longer time series would be needed to balance out any climatic anomalies.

P18L1: “more soil water” instead of “more ET”

P18L7-9: Earlier you have stated that deep percolation at SRER is very limited (ony few days).

P20L12: The term “excellent” is not appropriate here given the large differences

P20L14-16: See earlier comment on P16L9-11. Also it was stated earlier that CRNS does not integrate over the complete root zone.

P20L17-18: How do you come to this conclusion?

P20L21-22: But you stated earlier that the mesquite trees are extracting water below z*.

Figures and Tables

Fig. 1: Should be combined with Fig. 2

Fig. 2: Why do you present the 50 % contributing areas of CRNS and EC?

Fig. 4: Please add the calibration points.

Table 2: Not important. Consider deletion.

Table 3: Remove equations from the caption.

Table 4: Precipitation and ET were measured and should be listed separately.

References:

Köhli M., M. Schrön, M. Zreda, U. Schmidt, P. Dietrich, S. Zacharias (2015): Footprint characteristics revised for field-scale soil moisture monitoring with cosmic-ray neutrons. Water Resources Research, DOI: 10.1002/2015WR017169

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Qu, W., H.R. Bogena., J.A. Huisman, J. Vanderborght, M. Schuh, E. Priesack and H. Vereecken (2015): Predicting sub-grid variability of soil water content from basic soil information. Geophys. Res.Lett. 42: 789–796, doi:10.1002/2014GL062496.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 5343, 2015.