Geoscientific
Instrumentation
Methods and
Data Systems
Discussions

Interactive comment on "Intercomparison of Cosmic-Ray Neutron Sensors andWater Balance Monitoring in an Urban Environment" *by* Martin Schrön et al.

Anonymous Referee #2

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General comments:

The manuscript addresses relevant scientific questions suitable for GI. The manuscript covers two topics; 1) sensor inter-comparability, and 2) cosmic-ray neutron detection in an urban area. The study involves neutron transport modeling and field measurements using multiple stationary detectors as well as a cosmic-ray rover. In addition, soil moisture is estimated using frequency domain reflectometry sensors in various depths, and measured from soil sampling and oven drying.

Many aspects and applications are included in the manuscript, and it is obvious that a lot of work has gone into the making of the manuscript. Still, there is room for improve-

ment. As a reader I felt a little lost on what are the actual outcomes of the study. The authors touch upon a lot of different aspects, but the storyline is unclear. For example, I'm missing reasoning for: 1) why it is important to use multiple detectors for examining soil moisture in an urban area, 2) why it is important that detectors measure the exact same neutron intensity, and 3) why we would use CRNS detection to estimate area average soil moisture in an urban area with a lot of paved ground.

In order to avoid that the reader is left back with these unanswered questions, I suggest the authors to work on the storyline and the structure of the manuscript. At this point the introduction is a bit confusing and should be rearranged. Please introduce the manuscript by explaining why urban hydrology is important, what the problem is, and then in the end, how CRNS detection can be used to solve some of these problems. In the introduction, make sure to include an explanation to better link the part on inter-comparability and the part on soil moisture estimation in an urban area. In Section 2 the different equipment and modeling is described, however, some of the field experiments and modeling in also described in Section 3. I suggest the authors to collect all this in Section 2. Finally, I suggest that Section 3 is divided into two sections (one on "results", and another on "discussion").

The placement and numbering of figures should be changed. The figures should be placed at the point where they the first time are described. Furthermore, you should number the figures according to the order you are referring to them: Fig. 1, Fig. 2, Fig. 3..., and not like it is now: Fig. 1, Fig. 5, Fig. 4, Fig. 9... For these reasons I think the authors should put some more effort into improving the manuscript before publication.

Specific comments:

p1, l2-3: Please explain why consistency among sensors is more important when a larger volume is measured, and when a complex urban area is considered.

p1, l4: How large is "large-scale"? Please specify the CRNS response area.

p1, l9-10: Consider reformulating the sentence.

p2, l5: Because Köhli et al. (2015) report 83 cm, I suggest you to write "...of approximately 80 cm".

p2, l6: Desilets and Zreda, 2013 is an import paper on the examination of the neutron detector footprint, and must be included.

p2, l8-10: Include the studies of Franz et al., 2013 (WRR) and Franz et al., 2016.

p2, l9: "...in a forest (Bogena et al., 2015)".

p2, l10-11: This statement is out of place. Instead, the statement could be included it in the paragraph where you are listing the objectives of the paper (p. 3, l. 17-24).

p2, l12-15: Many more studies have used more neutron detectors at once. I suggest you to extent this part. This will also emphasize the importance of a sensor comparability study.

p2, l22: Explain "magnetospheric event".

p2, l30: Write "moderated cosmic-ray neutrons" instead of "epithermal cosmic-ray neutrons" as not only epithermal neutrons are detected.

p2, l33: But are we interested in the soil moisture underneath the buildings/roads? Please explain this.

p3, l1-2: The sentence should be rephrased, as it is hard to read.

p3, l1-6: The explanation of the problem of urbanization on hydrology should be improved. For example, why is urbanization challenging the functionality and sustainability, how is urbanization affecting the micro-climate, biodiversity and soil stability and why is a reduced infiltration and increased evaporation (because of sealed surfaces) a threat to urban environments and urban micro-climates?

p3, l6-7: Please explain why evapotranspiration (ET) is important. I would think that

infiltration is important because low infiltration at extreme rain events may result in flooding, which is harming the infrastructure and the buildings.

p3, l7-11: Eddy covariance measurements both represent a large area (similar to CRNS), and have a high temporal resolution. I would say that the disadvantage of Eddy is the price (equipment and maintenance). Furthermore, I don't understand the disadvantages of penetration depth in terms of ET measurements. Please revise the paragraph.

p3, l11-12: What is the normal practice in urban hydrology in terms of field work and modeling? Is it similar to what is done in rural areas? Are urban-hydrological models used? Please elaborate.

p3, l18-19: Too specific. Move this to "Methods".

p3, l12: Why is CRNS measurements useful in urban hydrology? Why do you want to know area-average soil moisture including the soil moisture below buildings and roads? Please explain.

p3, l18-19: For here, this sentence is too specific. Explain your objectives using more general terms, and consider moving the sentence to the section describing the method.

p3, l19-20: Please rephrase the sentence.

p3, l27-29: Not "while" as both Zreda et al. (2012) and Köhli et al. (2015) provided details of the underlying physics and the detector footprint. Zreda et al. (2008), Desilets and Zreda (2013) and Franz et al. (2012) are important papers and should be included.

p3, l32: You could consider shorten this sentence because you in Section 2.1.1 explain the energies measured by the detectors. For example: "Each system comprises a bare and a moderated neutron detector, an advanced NPM…"

p4, l4: Remove this sentence if you are not using this option in this study.

p4, l5: Please remove this sentence.

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p4, l6-7: How is a larger tube increasing the counting rate? Please explain. Please describe the rover with greater detail, e.g., how many detectors (or the count rate compared to the stationary detectors), a map of the rout you are driving/walking, the speed you are collecting neutron intensity data and the dates of measurements. Some of this is described in Section 3.5. I suggest that the part from section 3.5 is moved up to the "method" section. The setup of the 9 stationary detectors is explained in Section 2.2.1. Please consider restructuring the section in a way so the setup and the field experiments conducted using the stationary detectors and the rover is explained concurrently.

p4, l12: Add a reference (Andreasen et al., 2016).

p5, l4-5: Revise the sentence - "puls" is mentioned five times.

p5, l8: Here the second reference to a figure is provided. Therefore it should be "Fig. 2b", not "Fig. 5b". Please fix the numbering of the figures throughout the whole manuscript.

p5, l12: Is this the geometry of the neutron detector? Please specify.

p5, l8-12: Is this a part of what sometimes make a PHS irregular (p5, l13-16)? If so, move this part down to there you are describing the sources for irregularity.

p5, l23: Please explain "bins". "Bins" of what?

p5, l24-25: Please provide a reference.

p5, l29: Are the NPMs of your systems from before or after 2013?

p5, l30-31: Can CRNS users themselves adjust the detector parameters, or is it something you need Quaesta/Hydroinnova to do for you? Later in the manuscript, I get the impression that you need the manufacture to adjust the detector parameters. However, please specify this a bit more clearly in the manuscript.

p6, l7: Consider to explain why neutron count rates are corrected for barometric pres-

sure, atmospheric water vapor and incoming cosmic radiation. You should remove the abbreviations for air pressure (pi) and air temperature (Ti) as you are not using them later in the manuscript.

p6, l9: The equation is difficult to grasp. For the reader, it would be nice if you explained the different correction models one-by-one. In addition, numbering of this equation is missing.

p6, l11: What is "cps"?

p6, l17-20: This paragraph seems a little bit out of place. Either remove/move it, or better link it to the previous text, e.g., explain the calibration procedure (for the determination of N0).

p6, l22: Please explain what a super-detector is.

p6, l25 and p7, l1: Numbering of the equations is missing. This applies for most of the equations in the manuscript.

p7, l4 and l6: Is "a" the number of neutron detector? Please explain.

p7, l10: Consider to remove "(not to confuse with air pressure p)". Please extend the explanation of the performance measures using vector p-norms.

p8, Figure 3: You have a Figure 3a and a Figure 3b, and should therefore include "a" and "b" in the figure caption.

p8, l13: Please explain "cross-sections".

p9, l1: "(Schrön et al., 2015; 2017)". Note, not all journals accept a conference paper as a reference (Schrön et al., 2015).

p9, l2: What is meant by "advance research in detector characterization"?

p9, l6: The title should be changed as the section also describes volumetric soil sampling for soil moisture measurements.

p9, l9: What is meant by "continuous"? Are the sensors installed permanently at the two locations providing time-series of soil moisture? Or is soil moisture obtained on certain days of measurements? What time-period or what days did you measure?

p9, l9: What depths? Was the dry bulk density and the porosity calculated from the soil samples?

p9, l11-15: This paragraph could be taken out.

p9, l20-21: Please add a reference.

p9, l21-23: "device-specific" – is this for the Truebner SMT100 sensor? Please add a reference.

p9, l24: How many?

p9, l25: Please divide the section into two (one section on results, and another on discussion).

p9, l27-29: This should be described in the method-section.

p9, l28-29: Was the measured neutron intensity corrected for changes in atmospheric water vapor, pressure and incoming cosmic ray before performing the procedure obtaining the same count rate from all detectors? What is your reasoning for correcting before performing the comparability-procedure?

p9, l30: Should it say "In the first phase, from Feb 22nd. . ."? On page 11 line 1 you begin the sentence with "in the second phase,. . .", but at this point it is not clear what the first phase is. Furthermore, the different phases of the experiment should be described in the method section. In the results section, you merely provide the results of the experiment.

p11, l1-2: This should be moved to the method section.

p11, l12-15: Please remove this sentence as this is explained in section 2.1.2.

p11, l17-25: Please move this paragraph to the methods section.

p11, l23-24: How did you adjust these settings? Please explain this in the manuscript.

p11, l25: Could you quantify how much the procedure increased the count rate? I think many CRNS people will apply the detector parameter correction if the approach is shown to increase the neutron count rate significantly.

p12, Figure 5b: Please show the result of the calibration for all nine detectors (not only for sensor #3). In addition, the effect of correction could be quantified in counts and in percent (see comment above) and presented in a table.

p12, l2-5: This paragraph should be revised, and possible be moved to the section on methods.

p13, l11: What does cmp mean? Is that a standard abbreviation?

p14, l1: Consider to include a "field site" section in the beginning of the manuscript and include following details in the section: "humid conditions, in complex terrain, and at sea level".

p14, l2: Explain why a higher correlation is expected at homogeneous terrain. This should be included in the discussion-section.

p14, l13: Could this also be due to other reasons? E.g., the wetting occurs during short time periods (with similar weather conditions), while the drying occurs for multiple days (maybe) with changing weather, hence the variability is due to varying rates of evaporation and dewfall.

p14, l8: Most hydrologists will not know what a Bonners sphere is. Please include a description.

p15, l6-10: This belongs in the section describing the methods. In addition, what is the chemical composition of the material used for the paved ground (in terms of hydrogen content, is concrete "wet" or "dry" in comparison to the non-paved area of soil moisture

0.30)?

p15, l17: In order to give the reader a better insight to the modeling, please provide a detailed description of the model setup and the modeling procedure. On page 15 line 9-10 I got the impression that all non-sealed areas are defined as grassland, while it at page 15 line 16-17 sounds like vegetation is included (here "uniform biomass density" is mentioned as a modeling assumption). If vegetation was not included in the model, then the marks representing vegetation in Figure 8c should be taken out. If vegetation was included, then please provide some details on how vegetation was included in the model setup. E.g., amount of biomass (the hydrogen content) per tree, the chemical composition of the vegetation, vegetation height. . .

p15, l18: I suggest you to soften the sentence, as measurements and modeling were not directly compared, e.g., ". . .the model results can be assessed visually using measurements from a CRNS rover."

p15, l19-20: Move this to the "method" section. Furthermore, did you use the same equipment measuring from the car and the wagon, and were the detectors directed in the same way (horizontally or vertically) and installed in the same height? A map showing the CRNS roving route would be valuable (e.g., add the route in Figure 8). Please explain the field experiment in the "method" section.

p15, l21-22: The interpolation procedure for the measurements obtained using the CRNS rover should be explained in the "method" section.

p15, l20-23: Could the model results be scaled to match the CRNS roving measurements?

p15, l31: What is environmental soil moisture?

P16, Figure 8: What is the outline of the measured area in Figures 8D and 8E representing? Is it the driven route (I guess not, since the line crosses through building) or is it some meters away from where you drove/walked the rover (e.g., the footprint

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radius)? Furthermore, what is the uncertainty of the measurements and modeling? Please provide these number in the figure or in the text.

p17, l1-2: Please revise the sentence, and remove the hyphens and the italic format.

p17, l4: This belongs to the "method" section.

p17, l26 – p18 l2: Please revise this paragraph. Interception, as an important variable for urban hydrology, should be mentioned when explaining urban hydrology in the introduction. The authors conclude that the difference between CRNS and WSN soil moisture is due to interception. Evidence is missing that the additional water seen by the CRNS detector is interception, and the difference could just as well be a result of other effects, e.g., different measurement scale (point scale and hectometer scale) and measurement depth. Either add some supporting modeling and measurement results or exclude the part of interception from the manuscript. A third option could be to include "interception" in the discussion of the results provided in Figure 9b. The discussion should also include other possible reasons for the different soil moisture of CRNS and WSN.

p18, l4-6: This belongs to the section describing the method.

p18, l3-9: Either, explain the purpose of the field experiment with greater detail as well as show and discuss the results, or take this part out.

p19, l4: See comment for "p17, l26 – p18 l2".

p19, l8: Please quantify (e.g., in %).

p19, l23-24: See comment for "p17, l26 – p18 l2".

p20, l1: If you use data retrieved from NMDB, NMDB ask you to: "acknowledge the origin by a sentence like "We acknowledge the NMDB database (www.nmdb.eu), founded under the European Union's FP7 programme (contract no. 213007) for providing data. ", and acknowledge individual monitors following the information given on the respec-

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Interactive comment

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tive station information page."

p22, l10-19: The work by Köhli is not ordered alphabetically.

Technical corrections:

p2, l13: Should this be "...to calibrate the CRNS..."?

p2, l32: Should this be "..., could also be..."?

p3, l6: "and" instead of "und"

p3, l12: "groundwater"

p3, l33: Erase "robust".

p4, Figure 1 caption: Include the abbreviation PE for polyethylene in the figure caption. Remove the dot after "environment". Add primarily before "detects epithermal neutrons...".

p4, l2: Should it be "include a" instead of "samples"?

p5, l12: A dot is missing in the end of the sentence.

p6, l13: Should it be "soil moisture" instead of "(soil) water equivalent"?

p9, l7: I would say "calibrate and validate". Furthermore, I think you should remove "real" as soil moisture from the WSN is estimated from measures of permittivity. Only soil sampling and oven drying provides direct measures of soil moisture, and still this method has some uncertainties.

p10, Table 1: Should it be "soil moisture" instead of "evaporated water content"?

p11, l12: The abbreviation for PHS was already provided at page 5.

p14, Figure 7: "Influence of integration time, in hours (h),..."

p15, l7: "500m x 500m"

p17, l3: The abbreviation WSN was already introduced in section 2.4.

p17, l6: Erase "robust".

p17, l22: Remove "areal correction" (as it is also stated on line 21).

I hope you find the review useful.

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