Interactive comment on “Quantifying mesoscale soil moisture with the cosmic-ray rover” by B. Chrisman and M. Zreda

H. Bogena (Referee)

h.bogena@fz-juelich.de

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Review of “Quantifying mesoscale soil moisture with the cosmic-ray rover“ by Chrisman and Zreda

Dr. Bogena’s comments are in black font.
Our responses are in blue font.

General comments

The cosmic-ray rover is a promising instrument to close the gap between point and remote sensing measurements of soil moisture. This paper describes a feasibility study in which the cosmic-ray rover is used for the first time to generate soil moisture maps. Challenges as well as possible hydrological applications are presented.

The manuscript is well written and the data are of good quality. The results are interesting and useful. Scientists interested in using the cosmic-ray rover for hydrology applications will find the paper useful. It is a good paper and it deserves publication in HESS.

However, some assumptions which have been made to upscale soil moisture information are problematic and need attention (see specific comments).

Specific comments

L27 “soil moisture data products” instead of “campaigns”

Changed as suggested.

L34 “At the...”

Changed as suggested.

L64 “The study area is situated: : :”

Changed as suggested.

L64 What do you mean with “extended basin”?

Our mistake. It should be “extensional basin”. The change was made in text.

L67 Provide the mean annual precipitation amount

Added as suggested. The average annual precipitation in Tucson is 300 mm/yr. Year 2012 was lower than normal, with the total of 225 mm.

L76 delete “a Sonoran”

Changed as suggested.

L96-112 Since this paper is kind of a feasibility study these aspects (e.g. uncertainty, footprint, resolution) should be discussed in detail in the results section.

Agreed. Section 3.1 was simplified to outline the methodological approach. The other aspects that are new to in this study were added to the results section. The first part of the result section format was changed as follows:

Section 4 Results: Overview

Section 4.1 Tucson Basin Survey

Section 4.1.1 Survey Scheme: resolution, footprint, and uncertainty

Section 4.1.2 Calibration: site specific calibration results

Section 4.1.3 Soil Moisture Maps: interpolated results

L159 Please, do not write theta as a function of N

We can see why this looks strange; the equation says that soil water is a function of neutron intensity, which is not true in the physical sense. But it is true in the mathematical sense, and we use this equation in the inverse mode: given neutron intensity, (back) calculate water content. Therefore, we decided to keep the notation in its original form.

L161-163 This is not true for vegetation due to its temporal dynamic content of hydrogen.

That is correct. N_o may be changing in time if there is a significant hydrogen content in the vegetation and if this hydrogen varies in time, for example with seasons. However, for the desert that vegetation effect is minimal. We've added a clarifying statement at the end of the paragraph:

"N_o may be variable in time if there are significant temporal variations in biomass, but this is likely negligible in the Tucson Basin due to the arid climate and limited vegetation"

L167 "Gravimetric sampling" is an improper formulation; better: "soil sampling with subsequent gravimetric soil water content determination"

Changed as suggested.

L175 Could you also indicate the vegetation influence in terms of neutron counts or soil eater content (e.g. <5% N/h for average wetness conditions)

To do this you compute the amount of water (or hydrogen) in vegetation and add to (or subtract from) soil water, then compute N values. At Santa Rita the vegetation amounts to roughly 1 mm of water equivalent; 20% of the neutron signal when the soil is driest at 0.02 $m^3 m^{-3}$ and 0.5% of the neutron signal when the soil is wet at 0.20 $m^3 m^{-3}$. The vegetation is sparse within the basin and relatively homogenous, we do not expect much deviation from these percentages.

L178 explain "wt. %"

Wt. % is mass of lattice water, determined at Actlabs, Inc., per unit mass of soil previously dried at 100 deg C.

L191-192 Could you also indicate the soil organic carbon influence in terms of neutron counts or soil eater content (e.g. <5% N/h for average wetness conditions)

In the same way as in two comments above, we compute the amount of water (or hydrogen) in soil organic matter and add to (or subtract from) soil water, then compute N values. Soil organic carbon has a negligible influence to the neutron counts in this survey area.

L200 Wouldn't it be better to use the in-situ soil water content measurements of the TDT sensor network to calibrate the cosmic-ray rover?

We consider the gravimetric method superior to anything else. The oven drying method measures soil water content directly, whereas the TDT method measures dielectric properties and computes soil water content. Plus, all COSMOS probes have been calibrated on water content determined by the oven drying method, so it is important to use the same methodology to calibrate the COSMOS rover. TDT data would not produce a significantly different calibration for the rover because of the good agreement, to within 2% most of the time, between oven drying data and TDT data.

L241 Please provide also the experimental variogram as well as the variogram model.

We have added an example experimental variogram and the variogram model to the supplemental section for the one-minute and seven-minute data.

L252-257 I do not understand these statements. From Fig. 2 only a seasonal change of soil water content can be seen. Please explain in more detail and provide statistics of the SWC maps (e.g. mean, variance) in a table.

A statistical summary table was added to the supplemental table. We have also added a clarifying sentence:

"This seasonal moisture effect is seen in the survey maps from as a relative shift in soil moisture (Fig. 3) with a corresponding increase in regional variance and similarly, an increase in the standard deviation (Table. S1)"

L258 For a better understanding of the soil moisture pattern it would be helpful if you could include the landuse of the area in the left map of Fig. 1.

Agreed. Fig.1 is already a very large figure so we have added the landuse map to the supplemental section (Fig. S1).

L263 "Agricultural wetness" is an improper formulation. How large is the influence of vegetation on neutron counts in these areas?

Agreed. We have changed the sentence to:

"Increased soil wetness is apparent in two areas of irrigated agriculture in the survey area,…".

The true vegetation influence would be no more than the footprint of the instrument, 660 m in diameter. In our maps, we did not capture the edges of the agricultural area well due to the absence of perpendicular roads. That is why the area of influence looks larger on the soil moisture maps than on the landuse map. For future work, co-krigring interpolation techniques should be investigated to constrain the area of influence.

L285-304 This section discusses which temporal resolution is best suited to derive SWC maps from the data. Since you come to the conclusion that the 7 min data is the best compromise, it would be more logic to present this section before you are presenting the SWC maps.

Agreed. This section was moved to the beginning of section 4.1.3 before the SWC maps were discussed. The intention of these paragraphs is to outline the inherent biases with the mobile measurement.

L315 It would be helpful for the reader if you would include a short motivation for the temporal interpolation.

Agreed. We have added included a brief motivation in the section 4 Results:

"Twenty two snap shots of the soil moisture field (within one year) give insight to the climatic pattern, but they cannot be solely used to calculate the surface water fluxes that happen at a much finer time scale. Therefore, we attempt to link these patterns to daily observations in order to predict the behavior between surveys".

L324 It would be better if you would always refer to "study area" which is actually a rectangular box and not a true basin.

Agreed. This was adjusted throughout the paper.

L335 The soil moisture range of the data set is not large enough to guaranty that the function of Famiglietti et al. (2008) is actually representing the standard deviation /mean soil moisture relationship. Numerous studies on soil moisture variability have shown different functional relationships.

This I correct. Addressing this issue requires more surveys when the soil is wetter and we look to investigate this in future rover work. We decided to use this formulation to illustrate our data's similarity to Famiglietti et al. (2008) since there seems to be a promising initial correlation. We do not have justification for it over other formulations at this time, but our modelling approach (Section 4.2 Time Interpolation) required an estimation of the standard deviation from the mean.

L339-340 Please provide also the absolute difference to mean soil moisture maps of Fig. 2.

The absolute difference maps between the surveys and the modelled results were added to the supplemental section (Fig. S2).

L350-351 Which natural processes could that be? How will the water management and irrigation in the urban areas influence the correlation?

We hypothesize that the difference in elevation and soil texture accentuate the difference in soil moisture behavior with increased precipitation. Water in the coarser fluvial soils at Santa Rita may leave the near surface through percolation or evaporation quicker than that from the soils in the rest of the survey area which lay closer to the basin center.

We have noticed a low correlation between the agricultural areas and Santa Rita COSMOS and higher correlation between Santa Rita COSMOS and the desert areas indicating that the correlation decreases with water management activities, notably irrigation.

L367 Actually the cosmic-ray rover integrates between 0 and 76 cm. Is that considered correctly in the soil moisture profile calculation?

Not quite so. It would be 0-76 cm if there were no other hydrogen present. But because there is lattice water and water in soil organic matter, the measurement depth decreases to ~50 cm in Tucson when dry, and much less than that when wet.

L368-370 What is the grid resolution of the used SMOS data? It would be helpful if you would also present the SMOS data (e.g. one representing low soil moisture and one representing high soil moisture).

The SMOS L3 data is ~40 x 40 km. The closest SMOS measurement to each rover survey has been added in a Table in the supplemental section.

L384-386 This a very strong assumption and can only be justified in case of homogeneous soil properties within the study area. Therefore you should provide some information on the soil properties (e.g. soil texture) within the study area and discuss possible uncertainties in upscaling.

We agree that this is a very strong assumption and a weakness of the approach. However, the point of this is to provide an example of how to integrate the two observations as mentioned in the introduction to results. The water dynamics (mass flux) near the surface in the study area dominates that below 40 cm, so for the case of measuring mass flux, we assumed no recharge and isolate the dominant process. This may result in an overestimation of the total ET leaving the system.

The soils are not homogenous in the survey area. A few sentences on uncertainties have been added…"In addition, the TDT network is a point measurement and carries the uncertainty that the deep soil moisture behavior at the point may not be representative of the rest of the survey area."

L387 Change "leakage" into "percolation"

We agree that "leakage" is not the best choice here, but we would prefer to use the term "recharge" in replacement.

L393 Here you are correlating 0-5 cm data with 0-76 cm data. How is this justified?

Our soil moisture data based on thousands of samples (not shown in this paper; under preparation for submission later this year) show a strong correlation between integrated moisture in 0-5 cm and integrated moisture in 0-30 cm. However, it is essentially an ad hoc solution to deal with the significant amount of noise in the SMOS data. This is a major assumption in the method and future work should look to improve this component.

L411-413 In hydrology the term "surface storage" denotes water that is stored on the surface (puddles, ponds, streams etc.). You should refer to "soil moisture storage" instead. In the equation the water Storage change of the unsaturated zone between soil and groundwater is missing.

Agreed. This was changed to "soil moisture storage" and $\Delta S_{soil}(t)$.

L419-429 Since the catchment area does not correspond to the study area and runoff is a negligible term of the water balance in this area this section should be omitted.

Agreed. This section was mostly cut, but still includes a short rationale for why we assume that the runoff is negligible.

L465-466 In your data temporal stability of soil moisture is also a result of water management activities.

Yes, this was added.

L480-481 I know that at least one Fluxnet-station is located in the study area. The data is freely available and should be used to validate the ET estimates.

The nearest fluxnet-station is outside of our survey area and represents a scale of tens to hundreds of meters, much smaller than the 40 x 25 km estimates we are computing. We do not think that isolated fluxnet sites could serve as validation sites.

Tables and Figures

Figure 1: Obviously the study area is arbitrary rectangular box and only covers part of the actual basin. Thus it should be called simply study area throughout.

Changed as suggested.

Figure 2: To what kind of smoothing are you referring to?

The capture was changed to:

“Figure 3. Twenty interpolated soil moisture maps from seven-minute data in 2012. The urban area and agricultural fields have anomalously high soil moisture values that persist throughout the duration of the survey.”