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

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Received and published: 10 July 2013

This paper describes an extension of previous work on a soil moisture sensor based on neutron intensity originating from cosmic rays. In this paper, the authors deploy a portable neutron detector (the “cosmic-ray rover”), to measure soil moisture temporal and spatial variation at the meso-scale. The paper presents data from multiple surveys of neutron counts, and the authors analyse this data to produce soil moisture maps of the study area, to test methods for synthesising these maps based on a stationary probe, and to attempt a water balance of the area. This is an interesting study exploring the potential of a new method for mesoscale soil moisture estimation, and would be of interest to HESS readers.

I have two main, and a few minor comments that I recommend the authors to address before publication.

Main comments.

(1) The authors brush relatively lightly over some of the assumptions and uncertainties inherent in the method. Given that the method is new, it would help to convince the reader of its potential if these assumptions were discussed in some more detail. The authors should not be hesitant to state the assumptions/uncertainties as these are to be expected and will presumably be addressed during research in the coming years. I suggest the following additions:

- In Section 3.1, add a summary of the main assumptions of the method

Agreed. A summary of assumptions has been added.

- In Section 3.2, add a description of the assumptions that lie behind each correction factor, and whether there are particular situations when they might be more or less accurate. E.g. Equation (1): Is this ratio constant over the Earth’s surface? Equation (3) This is presumably calculated from humidity at the ground surface – but is the neutron intensity affected by humidity in the high atmosphere? Equation (5) Is then that the rover ultimately calibrated on (and hence reliant on) interpolation of point measurements, which as discussed may not represent actual soil moisture heterogeneity?

We have added text on the assumptions of each correction factor.

(2) It would be helpful to add at the start of the paper, a description of the mechanism by which the COSMOS probe/rover work. I.e. what causes neutron intensity to be related to total hydrogen? A diagram may be useful.

We included a short description of the principle on which the method is based. Detailed information is given in the recent paper by Zreda et al. (2012) and we did not want to repeat it here. Instead, we referenced Zreda et al (2012).

The added text reads:

“COSMOS probes take advantage of the remarkable ability of hydrogen to scatter and eventually remove neutrons created by cosmic rays at and near the land surface (Zreda et al., 2008, 2012). In absence of surface water bodies, the main reservoir of hydrogen is soil moisture. Hydrogen in soil moisture removes a fraction of neutrons from the soil and the atmosphere, and the neutron intensity above the land surface is inversely correlated with soil moisture content. The cosmic-ray method and stationary COSMOS probes are described in detail in in Zreda et al. (2012)."

Minor comments.

P7129 L20 Need to say what a COSMOS probe is.

We added a sentence:

"A detailed description of the stationary COSMOS probes was given in Zreda et al. (2012)." The paper goes into detail about our current understanding of soil moisture monitoring using stationary cosmic-ray probes.

P7131 L14 Is the temperature affected by the immediate road environment?

It might be, under certain circumstances. Our observations (unpublished) show that iButtons perform well in moving vehicles (other sensors may or may not do so). The best location is under the front bumper, which is counterintuitive because of the proximity of the engine and the road. The worst places are back window and side doors. However, the water vapor correction is small, and any uncertainties on the measured temperature and relative humidity have negligible effects on the computed water vapor correction factor.

P7131 L21 Not clear how the value of 5% uncertainty was calculated.

The 5% was obtained as the standard deviation of count rate in the Poisson statistics, which is standard in particle counting (Knoll, G. F.: Radiation detection and measurement, Wiley, New York, 802 pp., 2000). The standard deviation is equal to square root of the number of counts (Zreda et al., 2012). In the Tucson Basin, 1-minute count rates, with our rover, are roughly 400 counts per minute (cpm), so the standard deviation is 20 cpm, or 5%. To decrease the standard deviation to 2%, we must integrate (5%/2%)^2 minutes, which gives 6.25 minutes, rounded to the next full minute to give 7 minutes.

A shorter version of the above calculation is included in the paper.

P7135 Perhaps not necessary to provide so much detail on lattice water estimation and measurement in urban environments, given that it is then ignored (L15).

This section has been shortened.

P7136 L22 Not sure convoluting is the correct word here.

We changed to "combining".

P7139 L2 It seems a bit of a stretch to associate the points and the curved relationship in Figure 3.

This is correct, The dry climate of the Tucson Basin limits the range of soil moisture values, which made it impossible fully to define functions similar to those in Famiglietti et al. (2008). Our modelling approach required an estimation of the standard deviation from the mean and we decided to utilize previous work that showed correlation. Specifically, we wanted to show two things here: (1) that our data follow the general patterns shown in Famiglietti et al. (2008), as they should; and (2) that 7-minute averages produce data points falling below the 1-minute averages, as they should.

P7139 L6 Was the Famiglietti study in the same location as this study? If not, I don't see why the scaling should be the same.

Good point. The Famiglietti study was not in the same location. We have deleted that sentence.

P7139 L23 - P7140 L11 This is a nice discussion of possible biases associated with vehicle speeds and interpolations.

No response necessary.

P7143 L18 – 22 It was not clear to me what calculation you were using here. Do you mean that you used a linear transform of the cosmic ray measurement to estimate the SMOS value? If so, does this work during/after rainfall events when relative magnitudes of nearsurface/subsurface moisture content would change?

This sentence was changed to:

”In order to limit noise propagating through the storage terms and also to fill the time gaps, the surface value was re-calculated based on the linear function with a given cosmic-ray measurement. The re-calculated surface value was then used as the surface input in the profile calculation.”

This is an ad hoc solution to a problem we do not know how to handle yet. It is likely not very reliable during a rainfall and immediately afterwards.

P7143 L29 – P7144 L2 I am unclear why these values do not match exactly if they are all back-calculated from the same measurement.

This analysis adds little to the paper and has been removed.