

## ***Interactive comment on “Integral quantification of seasonal soil moisture changes in farmland by cosmic-ray neutrons” by C. A. Rivera Villarreyes et al.***

**Anonymous Referee #2**

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The paper describes a field monitoring experiment in which the cosmic-ray sensor was used to measure area-average soil moisture content over several months starting in August 2010 and ending in March 2011. Other soil moisture measuring devices were installed at the site, soil samples were collected for soil moisture determination in the laboratory, and meteorological data were obtained from nearby stations. The experimental work was well designed and executed, the conclusions are sound and supported by data, and the paper is well written. The main conclusions are that the cosmic-ray method gives reasonable soil moisture data, that the probe can be calibrated using field data from other methods, that vegetation has negligible effect on neutron inten-

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sity, and that snow greatly affects neutron intensity. The authors proposed new ways of plotting and analyzing the data, which is highly commendable. I particularly liked the multi-point calibration approach (although I am not sure it is right), and the plotting of the difference between fast and thermal (although I am almost sure it is wrong). But only through trials like these progress can be made. The paper is good enough to be published as is.

I have a few minor criticisms; they are described in the next section entitled MAIN CRITICISMS. None of them is disqualifying the paper. However, I urge the authors to consider them to improve the paper.

I did make numerous suggestions how to improve the writing. They are listed below in section DETAILS. These are just suggestions, so the authors can disagree and ignore them.

### **MINOR CRITICISMS**

I have one comment on the calibration. Multiple soil moisture levels were used in calibration, giving different sets of calibration constants  $a_0$ ,  $a_1$  and  $a_2$ . With these different constants the shape of the calibration function changes. Instead of one calibration function, you have more than one. This seems incorrect. The shape of the calibration function for a given site should be constant. Perhaps what you mean is that the constant shape of the calibration function is approximated more than once?

Plotting the difference between thermal and epithermal measurements is a standard approach in neutron physics. But when one detector is moderated by plastic, as it is the case here, the difference method will not work as well as in the case of epithermal neutrons (which are measured without artificial moderator). So I am not sure what the difference can tell us, or even if it has meaning. Perhaps you can consider looking at the ratio of fast to thermal? This said, I do like the fact that you try to link the two energy levels and interpret the difference in terms of field conditions.

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## DETAILS

Page 6868: -----

line 2: Change to "Soil moisture at..." (delete "The measurement of")

line 6: delete "so called" (it is irrelevant)

line 21: scattering cross section for H is not 82.02 barns; total cross section, which may be 82.02, includes thermal neutrons, and is irrelevant here because the probe measures fast neutrons.

line 7: change "Central European lowland" to "Germany"

line 11: in evaluation (not into)

line 17: explain the "two variants of cosmic ray counters"

line 17-20: delete the last sentence of the abstract - doesn't say anything important

line 24: delete "in its own right"

line 26: change "vegetative life on the planet", for example to "vegetation"

Page 6869: -----

line 6: delete "several"

line 7: delete "to interpolate and extrapolate values" (it is obvious what geostatistical techniques do)

line 10: delete "significant misinterpretation of hydrological scenarios and"

line 18: change "Although the great promising of these techniques for practical applications" to "Although these techniques are promising"

line 22: delete "gap"

line 23: TDR, GPR and ERT are not new techniques; perhaps the sentence should

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start with "New measurement methodologies" which will mean the new use of these existing methods

Page 6870: -----

line 5: delete "so called"

lines 6-11: if gravity is not discussed in the paper then there is no point to write about it; please delete the gravity parts of this section

line 11: change "former novel method performed via an above ground cosmic ray sensor (CRS)" to "cosmic-ray method"

line 12: delete "effectively"

line 14: change to "Using neutron transport simulations, Zreda et al. (2008) and Desilets et al. (2010) showed that..."

line 16: "correlated with"

line 16:

"over an integration area"

line 17: "diameter of ca. 600 m"

line 18: delete "relevant" and give a value (86%, or two e-folds)

line 19: it is less than 1.0 m; if you are unsure how deep, say "a few decimeters"

lines 20-21: total scattering cross sections of 82.02 barns is irrelevant it includes thermal neutrons); fast neutrons measured by the probe range from ca 100 eV to 10 MeV or so; in this range the scattering cross section is ca 20 barns

line 24: delete "water" after snow

line 25: "intercepted water"

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line 25: delete "water" after biomass

line 25: delete "also"

line 27" change "environmental compartments" to "different reservoirs"

line 28: I don't know what "cold neutron" is. will others know?

Page 6871: -----

lines 1-10: The entire paragraph (which started on page 6870) is irrelevant and should be deleted.

line 13: change "in a summer period" to "during summer"; change "during a fall-winter period" to "during winter"

lines 14-15: delete the sentence that starts with "This is" - the claim of priority is unnecessary

line 21: "at the ground/air"

Page 6872: -----

line 3: Not true. Reword as "Primary cosmic rays that enter the Earth consist mostly of ..."

lines 3-4: I don't understand the sentence that starts with "The major". Please rewrite.

line 5: change "Since there is a" to "Because of"

line 5: delete "along the globe"

line 6: change "incoming high energy cosmic rays vary for different locations" to the intensity of high-energy cosmic rays varies in space"

line 7: change the sentence that begins with "Besides" to "The incoming cosmic-ray intensity also varies with the solar cycle"

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line 14: "the intensity of"

line 16: delete "as a much denser medium" - irrelevant as neutron transport depends on total mass not medium density (10 g of air is nearly the same as 10 g of rock)

line 18: delete "so called"

line 19: change "and thus free air" to "and thus enter the atmosphere"

line 19: delete "after scattering in the soil"

line 20: delete "several"

line 21: delete "surrounding"

line 21: delete the end of the sentence starting with "others are"

line 23: change "this neutron attenuation of thermal to fast neutrons" to "moderation of neutrons"

line 24: "requires only"

lines 27-28: change "water molecules, namely  $1\text{H}$  and  $16\text{O}$ , are a key factor to moderate these" to "hydrogen in water molecules is the key factor in moderating these"

Page 6873: -----

line 1: change "above strongly" to "above the ground surface strongly"

line 7: how is equation 1 different from that in Desilets et al.? your NR is Desilets'  $N/N_0$  - the same thing; and your equation does not lend itself to simple calibration that produces  $N_0$

line 9: "without the need of modeling" came out of nowhere - either explain what you meant or delete

line 23: delete "mainly"

C3902

Page 6874: \_\_\_\_\_

line 1: "equal to the square root of the total counts"

line 4: change "in the direct proximity" to "nearby"

line 5: change "in altitudes near to sea level compared to mountain altitudes" to "at sea level than at mountain altitudes"

line s 7-8: change "longer integration periods of neutron counts" to "longer integration time"

lines 18-26: Very good idea to use multiple neutron detectors to get temporal variations. But then you did not use these corrections. Please remove this section as irrelevant.

Page 6875: \_\_\_\_\_

line 8: delete "so called"

lines 9-10: The sentence starting with "Probability" is not necessarily true; on the basis of total mass the two probabilities are comparable; when you factor in density AND express probability on the basis of length, then your sentence is true. Please clarify.

lines 10-11: the reason is that there is more water in soil than in air; please clarify

lines 11-12: change sentence to "Therefore, neutron counting rate above the ground surface is a measure of neutron intensity in soil"

line 15: change "the vertical coverage" to "the vertical footprint" or "the depth of measurement"

line 18: change "typical rock chemical constituents" to "common elements in rocks"

lines 21-24 and equation 5: give the reference for the equation in equation 5, I bet the last term in the denominator is negligible and can be omitted (the medium density plays a role here)

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Page 6876: \_\_\_\_\_

line 9: delete "but only to minor degree on soil composition" - it is redundant

lines 9-15: This is useful information, but it is not clearly written. Please rewrite.

line 20: "during the last ice age"

line 20: "Soil consist of 75% sand, 17.2% silt and 7.8% clay."

lines 22-23: delete "from this field site in Bornim" - obvious that the samples are from this site

line 27: delete "In terms of climate conditions"

line 28: "in the last 50 years"

Page 6877: \_\_\_\_\_

line 1: "in November through January"

line 2: replace "Historical data of air temperature shows minimum and maximum values of" with "Temperature ranges from... to...."

line 5: delete "At the field site"

line 7: delete "was again"

line 10: delete "winter to even"

lines 13-14: replace "East of the site" with "to the east"

line 16: The first sentence is unnecessary.

line 23: that paper considers high-energy neutrons

Page 6878: \_\_\_\_\_

line 9: replace "moderated" with "surrounded"

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line 10: delete "surrounding"  
line 10: delete "without moderator"  
lines 11-12: delete "but was identical to the first otherwise"  
line 13: replace "more" with "predominantly"  
lines 19-20: delete "in order to collect neutrons from a footprint"  
line 21: replace "with a distance of about 6 m" with "6 m apart"

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line 9:

"used only 5"

line 14: delete "here"

line 14: specify which depths were used

Page 6880: \_\_\_\_\_

lines 10-16: your dry condition determined in the field is NOT the dry condition that goes into the calibration function; please clarify that this is just an intermediate moisture level

Page 6881: \_\_\_\_\_

line 13:

change "presences" to "sources"

line 14: change "method" to "flux"

Page 6882: \_\_\_\_\_

line 4: "data not shown"

C3905

line 14: delete "By that,"

line 13: change "maximally" to "at most"

line 24: 8 cm of snow or 8 cm of snow-water equivalent? if snow, which seems likely, then also specify its density to give an idea how much water there was

Page 6884: \_\_\_\_\_

line 27-29 and the next page: the different calibration coefficients are probably fine, given that Desilets' coefficients are for SiO<sub>2</sub>; however there may be some variations in the shape of the real calibration functions; it is plausible that a polynomial can provide better fit to the calibration data than the equation in Desilets et al. I would not worry about your coefficients being different. However, please write a succinct paragraph about this, and do not invoke locations, different counters or counter settings, neutron attenuation, soil matrix etc to explain the difference. All these explanations are ad-hoc and most are probably rubbish.

Page 6886: \_\_\_\_\_

lines 1-5: Don't speculate wildly about the observed inconsistency; it is sufficient to say that the reasons are unknown and require further research. Temporal failure of pressure correction is nonsense; reduced voltage supply - is there evidence in the data file? reduced solar activity - would result in lower computed soil moisture, and you would see the evidence in the neutron monitor data at Kiel or Jungfraujoch (did you?). It is best to drop such speculations.

Page 6887: \_\_\_\_\_

line 15: delete ",thus soil temperature"

Page 6889: \_\_\_\_\_

line 3: "greater depth"

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lines 8-11: Sentence starting with "Nevertheless" is unnecessary - the information is not revealing any known facts, and, to the contrary, you suggest that the footprint could change with soil moisture distribution which is not true (the footprint depends on the air, not soil). Please, delete this misleading sentence.

line 17: "not to lead to"

line 18: change "this may not need to be accounted for" to "this does not have to be accounted for"

line 19: delete the sentence starting with "However" - there is no evidence that this is the case, except the paper that concentrated on high-energy neutrons in the context of surface-exposure dating.

Page 6890: \_\_\_\_\_

line 17: "Time series of precipitation"

Page 6891: \_\_\_\_\_

line 2: "simple"

Page 6894: \_\_\_\_\_

Table 1 - check the values of cross sections (H is wrong); the important parameter - stopping power - is missing; see Zreda et al., 2008 - supplement. Either cite it or reproduce here.

Page 6899: \_\_\_\_\_

Fig. 3 - not very useful; data not usable in any interpretable way because the cosmic-ray probe integrates over the entire area.

Page 6900: \_\_\_\_\_

Fig. 4 - not sure if plotting the difference makes physical sense; please explain what the meaning is or delete. Look in Desilets et al., 2010 for a similar plot, but using a ratio

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of fast to thermal.

Page 6902: \_\_\_\_\_

Fig. 6 - unnecessary - does not bring anything useful. It is obvious that two identical probes correlate well. And it is obvious that neutron count rate correlates with inverse of pressure. Please delete this figure.

Page 6903: \_\_\_\_\_

Fig. 7 - shows data similar to fig. 5; should be compared with figure 5, or perhaps figs 5 and 7 should be combined into one figure (with multiple panels). The right panel shows very impressive data.

Page 6905: \_\_\_\_\_

Fig. 9 - lower panel does not show soil moisture but combined soil moisture and snow - please label the vertical axis appropriately (eg, "total" moisture)

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