Review of the manuscript entitled:
Integral quantification of seasonal soil moisture changes in farmland by cosmic ray neutrons
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General comments (scientific arguments)

This manuscript reports methodological details about using neutron density aboveground to extract soil moisture information. It is a timely and needed contribution. Introducing a “new“ method always stimulates expectations of uncritical users. Therefore, it is utmost important to better understand the system properties, which control the measured signal. This method is highly suitable to fill the scale-gap between traditional local and newer large scale soil moisture monitoring, The authors compare the signal with a footprint of roughly 600m diameter with the contributing factors on this areal scale.

The ‘cosmic neutron rays’ method has been tested in a cropped field on sandy soils located at low altitude. The count rates measured with the two differently shielded Count Rate Sensors (CRS) are compared with soil moisture data obtained by soil coring and gravimetric water content determination and by multiple FDR sensors. In addition, the authors determined the biomass of the corn crop. The time series of these point-scale soil water contents extend over a summer, fall, and winter season. Hence, they produced a quite rigorous set of calibration data.

The major interpretation problems are identified at the very end of the manuscript (p.6889 l.8-11 and l.14-20). They argue that only the hydrogen (H) present in environmental compartments that vary in time on a seasonal scale need to be taken into account for monitoring changes of soil water storage below- and aboveground. However, to extrapolate the calibration parameters from gauged to ungauged sites, one apparently needs to include all significant H-pools. The soil organic matter (incl. wet leaf litter and raw humus in forests), the presence of organic matter and water in the canopy, and the ice in the soil and snow pack affect the site-specific parameterisation. This partly explains the massive discrepancy between the parameters obtained in this study and those reported by Zreda et al. (2208). Soil freezing and the role of snow is recognized as being a significant factor. In this context the reasoning in this paper is quite superficial. The Theta-probes do not produce outliers during frost periods (with bare soils) that mess up the calibration but they measure the liquid water content only (the dielectric constant of ice is less than half of that of water). Also, the snow height is a poor characteristic for calibration purposes. It is the snow water equivalent which affects the thermalization of neutrons more directly (as already noted by Kodama et al. 1983)

Snow melt apparently leads to a higher count rate of the shielded CRS is possibly due to the extremely high volumetric water content in wet snow. I asked myself whether this is also the case above a free water surface where I

expect a higher density of weakly attenuated neutrons than above a soil body where the water is distributed over greater depths … This could be possibly simulated with the code used by Zreda et al. (2008). ?

The added information about the factors contributing to the neutron count rate sensors makes the paper worthwhile to be published.

There are some "buts" in terms of the manuscripts editorial quality. Below, I detail some of the editorial deficiencies and raise open question.

Editorial comments

On p.1. l.6 and p.6970 l.4 & l.11 the authors refer to this method as being "*very recently introduced the first time".* The work of Kodama et al (references below) show that this method has only recently been re-discovered and has been referred to by Zreda et al. (2008). In cases when the message of a publication is of a methodological nature the authors should dig deeper in the literature. A short search in the Web of Science with the key word *'cosmic neutron rays'* AND '*soil'* produces information in addition to what I refer at the end of the review. Hence, phrase it more precisely, because not the method of cosmic neutron rays per se is novel, but may be the mode of its application.

p.6870 l.14/15. Again, Kodama's early work was related to snow water equivalent whether this has been done outside of US or not is not relevant.

p. 6870 l.13. I do have a problem with the notion 'cosmic ray sensor'. The Geiger-Müller counter counts the thermalized neutrons (or faster neutrons when shielded) that means, the density of thermalized and only partly attenuated neutron density aboveground and not the cosmic rays per se. If the acronym is already sort of a 'terminus technicus' then not much can be done with this terminological imprecision.

p. 6871 l.24 ff. The basic problem in the published studies is, to my knowledge, the fact, that the importance of soil moisture at various depths for the CRS signal is not known because it is an integral of near-surface soil moisture storage whereas the areal footprint of the 'CRS' signal has been modeled and experimentally identified. One of the merits of this publication is the information on how water in the various compartments affects the signal.

p. 6872 l.17. Not only 'soil' but maybe 'interactions with soil, snow and plant canopies' …

p.6872 l.19-21. Suggestion: … 'penetrate the soil, being scattered and randomly distributed below- and above-ground loosing kinetic energy in the course of several successive collisions with light nuclei in the soil and near-surface atmosphere'

p.6875 l. 10/11. Lingual precision: The H in the soil water and atmospheric water vapor are the collision partners of the fast neutrons and not soil moisture and air humidity which are terms referring to the water status.

p.6875 l. 15 … depends on soil moisture and organic matter distribution …

p.6876 l. 20/21. Are these percentages the values obtained from composite samples taken at various depths ?

p.6876 l. 20/21. The most frequently used SI unit of years is y not yr

p.6877 l. 10. You mean either winter or spring but not both … and 'data' is the plural of datum.

p.6877 l. 21. The volumetric content of H in organic matter (let us say 2-3 % by weight) is not negligible compared with an average (volumetric) water content of 0.15

p.6878 l. 21. I hesitate on picking at such editorial details but one meter is not written as 1-m but 1m (tis applies through all texts you write. … or p.6881 l.15 small numbers are being spelled out: three not 3 (in-text).

p.68781 l. 16. meaning of *'to begin with'* is unclear. Is this analysis a preliminary data interpretation that will be followd up by a more in depth interpretation. If yes , then do it and submit it to HESS when done.

p.6881 l. 13. presence is only used in singular form

p.6882 l. 16. I found many many many "Germanisms", which you should avoid. Lingual precision is a virtue also for those whose mother tongue is not English.

We can infer … better we infer …

An approach considered … an approach never considers anything

We decided to do = we did

A five weeks period _ a five-week period

Had a similar response = responded similarly etc etc etc

Homogeneous classification does not mean that the object has been classified as being homogeneous.

p. 6883 l.4 ff. You can do a better job in assessing the distributional properties of the soil properties (spatial variability, error propagation etc.)

p. 6884 l.13/14. Report only the two to three significant digits (and not a mix)

p. 6884 l.19 – 26. I just do not understand what you mean.

p. 6885 l. 9 – 13. Similar shortcomings as in case of the classical neutron probe (bare, unshielded CRS)

p. 6886 l. 4/5. Sentence had an accident, did it ?

p. 6890 l. 27. This is a courageous extrapolation : sandy soil of Northern Germany are not really "the majority" of Europe's soils … be careful with such statements.

p. xy l… there are many more possibilities to eliminate editorial problems. My notes are just examples.

Figures and Figure Captions

Fig. 1 I read it differently in the text. The distance between the two CRS was mentioned several times as being 6m … here at the upper left they are next to each other.

Fig 4 It is obvious that all “treatments “ show an exponential relationship between Nf and A-B. Graphically the curves of the bare field and snow are indistinguishable, because the symbols of the single values are too large

References referred to above

Application of atmospheric neutrons to soil moisture measurement
M KODAMA, S KUDO... - Soil science, 1985 - journals.lww.com
This paper describes the possibility of continuous remote sensing of the moisture content of soil using atmospheric neutrons produced by cosmic radiations near the ground surface. Using polyethylene-moderated BF3 neutron counters at several different underground depths, ...
Cited by 1 - Related articles - All 4 versions

Cold Regions Science and Technology
Volume 3, Issue 4, August 1980, Pages 295-303

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Continuous monitoring of snow water equivalent using cosmic ray neutrons

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Abstract

During the period from December 1977 to May 1978, continuous observations of water equivalent of snow were carried out at four different sites distributed between sea level and 1440 m elevation, using the attenuation of cosmic-ray-produced neutrons through snow cover. Day-to-day variations of the snow water equivalent, thus determined, demonstrate an excellent agreement with those obtained by snow core sampler and other methods. For this cosmic-ray snow gauge, the counting statistics are the predominant source of experimental error, which is found to be a few percent of the total value of snow water equivalent. It is emphasized that the cosmic-ray snow gauge is very useful to determine the absolute value of snow water equivalent in place of the existing snow sampler or other methods. Some uncertainties in determination due to primary cosmic-ray modulations and soil moisture content are discussed.

An introduction to applied cosmic ray physics
M Kodama - Japanese Journal of Applied Physics, 1984 - jpsj.ipap.jp
Japanese Journal of Applied Physics Vol. 23, No. 6, June, 1984 pp. 726 728 An Introduction to Applied Cosmic Ray Physics Masahiro Kodama Department of Physics, Yamanashi Medical College, Tamaho, Nakakoma, Yamanashi 409-38 (Received December 27, 1983; ...
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