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The mobile monitoring of cosmic-ray neutrons using cosmic rovers is a promising way to non-invasively measure soil moisture at larger scales. However, for the processing of cosmic rover data ancillary information is needed (e.g. soil and vegetation properties). This paper describes and tests methods to provide this information using commonly available data sets. The manuscript is well written, however it contains some unclear or incomplete scientific reasoning that need to be amended (see comments below).

General comments:
This study investigates relationships between vegetation indices from optical remote sensing and above ground biomass. However, there is already a vast amount of literature on this topic, see e.g. Kumar et al. (2015) and Duncan et al. (2016) for recent reviews on this topic. Thus, the findings of this study should be discussed also in the light of results from existing literature. For instance, already established relationships could be compared with those from this study or could be used to extend the presented method to other vegetation types.

We thank the reviewer for the updated literature and will investigate the relationships suggested. The field of remote sensing and available indices on vegetation characteristics is growing at an enormous rate given the interest in precision agriculture, food and water security, by both public and private industry.

The usefulness of the derived soil properties from the GSDE data for CNRP rover applications needs to be better documented. At the moment, I am not fully convinced that the GSDE data is actually useful for CNRP rover applications.

We anticipate this is a first guess for a study or useful for rover applications in novel or austere environments. For example, the US government is interested in the rover technology and has supported research for assessing things like battlefield condition, which include information on soil strength and stability. The ability to make realtime soil moisture maps in hostile environments is of practical application to governments. In addition the monitoring of long transects, say a rover mounted on a train or commercial vehicle would be labor intensive for detailed sampling efforts.

First, it is recommended to determine these parameters from in-situ soil samples anyway (L503-505).

Yes, for the highest quality datasets it would still be advisable to collect local samples. I am not sure that will ever change for use of available soil datasets.

For instance, Franz et al. (2015) simply used the average values of these parameters derived from in-situ soil samples to successfully determine soil moisture for an area of 12 *12 km using the

CNRP rover. A 12 *12 km area already seems to be the maximum area achievable by CNRP rover applications due to the speed limitation dictated by the CNRP sensitivity.

This scale and driving speed was selected in order to provide a soil moisture map at the critical agricultural 0.8 km resolution. For coarser spatial resolutions higher driving speeds and larger sampling areas would be appropriate. For example, this coming summer the UNL and USACE rovers will be used in tandem in the SMAPVEX16 Iowa campaign. The dual rovers will cover a 36x36 km for validation against SMAP. It is estimated that the pixel can be driven in 6 hours to collect a 1 km product. Sampling a 36x36 km grid is going to be challenging requiring a team of 25+ individuals. The Chrisman 2013 paper also covered a large pixel.

Secondly, given the very low spatial resolution of the GSDE soil data, it will most likely not provide any useful spatial information for such a small area.

Agreed, we are currently using SSURGO for Nebraska based work. We would only recommend the GSDE for long transects, larger watershed sampling campaigns, or use in austere environments where SSURGO type data is not available.

Thirdly, the substantial uncertainties of relationships between the GSDE data and CNRP calibration parameters may lead to very uncertain calibration results (see also my specific comment L329). Thus, regional soil data bases like SSURGO in the USA or the soil information system FISBo in Germany would be more promising for CNRP rover applications.

Note that the GSDE data is derived from SSURGO following Shangguan et al. (2014). For hi-resolution surveys we would also suggest use of SSURGO. In fact Co-author Finkenbiner will be presenting some results of SSURGO data from Nebraska rover surveys at EGU later this month.

The error propagation method is useful to derive first guess estimates of the uncertainties involved in the proposed method. However, a stronger test would be the application of the method using data from existing CRNP rover applications (e.g. Christman et al. (2013), Dong et al. (2014), Franz et al. (2015).

Yes, this is a first approximation as suggested. Not totally sure what the reviewer is suggesting. In fact, the lattice water and soil bulk densities used in Chrisman, Dong and Franz are part of the dataset presented here. Seems having new independent samples to compare against would be most useful and avoid some circularity.

This study excludes below ground biomass, which can be a significant hydrogen pool depending on vegetation type (e.g. Bogena et al., 2013, Franz et al., 2013). Thus, the presented method should be extended by this factor. For instance, the plant specific root-shoot ratio could be used to calculate below ground biomass from above ground biomass (see e.g. Peichl et al., 2012).

Correct. However, we note that the above ground biomass estimates used to compute N0 slope and intercept corrections implicitly include below ground biomass in the N0 estimate. This means the method depends on the repeatability of below ground biomass development with above ground biomass that is measured. This is essentially what the reviewer is suggesting by *using a plant specific root-shoot ratio. We will note this as an alternative procedure to encourage future directions and independent validations of the N0 biomass correction factors for above and below ground biomass.*

Specific comments:

L60-61: This is not entirely true. In fact in-situ measurements of soil moisture have certain correlation lengths that can be used to infer larger scale information (e.g. Korres et al., 2015).

Thank you for the suggested paper, we will investigate further. Variogram analysis by the corresponding author in Arizona and Nebraska with TDR probes often revealed correlation lengths less than 50 m, which would limit the spatial representativity of point sensors.

L70: A more recent review on non-invasive sensing of soil moisture dynamics from field to catchment scale is given by Bogena et al. (2015).

Thank you for the suggested paper.

L78: According to Köhli et al. (2015) the footprint diameter ranges between 160 and 210 m.

Yes, we will be more specific with language. Conversations with Darin Desilets of HydroInnova indicate that this is still an open issue. We hope the next COSMOS workshop in August 2016 in Denmark will provide some fruitful discussion here and perhaps put this important issue to rest within the community.

L91: Baatz et al. (2014) is more appropriate here. This paper deals with CRNP calibration, whereas Baatz et al. (2015) describes a method for biomass correction of CRNP count rates.

Thank you, we will change.

L94: Add a citation, e.g. Baatz et al. (2015)

Thank you, we will change.

L96: “exploit” instead of “harness”

Thank you, we will change.

L103: “instead” instead of “in lieu”

Thank you, we will change.

L109: CONUS was explained in the abstract, but it would be good to explain it here again because of readers ignoring the abstract.

Thank you, we will change.

L133: “Köhli”

Thank you, we will change.

L144: see comment L78

Thank you.

L147: “Köhli”

Thank you.

L147-148: Köhli et al. also investigated effects of vegetation and SWC.

Thank you.

L152: Change into “Baatz et al. (2014)”

Thank you.

L170: The geomagnetic latitude is not a factor for the neutron counts correction. It is only used for the scaling of neutron counts to a specific location.

From rover calibration across Nebraska we have found that the estimate of p0 (reference pressure) and scaling factor must be consistent for a single rover calibration function at different locations. In order to estimate a site’s p0 and scale factor we use latitude, longitude, and elevation in the COSMOS scaling calculator (http://cosmos.hwr.arizona.edu/Util/calculator.php). This ensures that each new site or rover survey point has the same values and neutrons are corrected in the same way.

L212-213: To solve the calibration function, information on depth-weighted average soil water content is needed as well. In addition, the depth-weighted average of mentioned parameters should be used to account for the decreasing sensitivity of the CRNP with depth (see e.g. Köhli et al., 2015). Furthermore, below ground biomass can be an important hydrogen pool for certain vegetation types especially during dry conditions, e.g. sugar beet, spruce forest etc. (see Bogena et al., 2013).

Perhaps it is unclear but we only trying to solve for the average soil water content from neutron counts. The issue of depth sensitivity may indeed be important, particularly during infiltration events where a step function of water content may exist. In addition, these step functions may also be present in soil horizons or root development, making vertical integration challenging for a nonlinear sensitivity function. We will mention these issues but prefer to deal with the challenge of horizontal measurements only in this paper instead of the more complex issue of horizontal and vertical variability of parameter data. We believe this will keep the focus of the *paper on global datasets clearer. In addition, we note the collected in-situ datasets did not always vertically resolve the calibration datasets. Finally we not that the GSDE and SSURGO datasets do allow for depth information to be extracted and we recommend future research using this and more complete and vertically resolved calibration datasets.*

L217: "Köhli"

Thank you.

L237: "Global Soil Dataset"

Thank you.

L249: This step needs a better explanation.

This involves expert knowledge by a soil pedologist, here Prof. Mark Kuzila. The method follows expert knowledge and the NRCS soil taxonomy handbook. We will add reference to the handbook here.

L258-259: In which cases "taking mean values" were preferred over "taking linear relationships"?

We only used the linear relationships were a significant p value was found for slope. We will add distinction.

L268: Actually, only one vegetation index is presented here.

Thank you.

L271 "...65 ha large."

Thank you.

L288-289: This information is not needed.

Thank you.

L329: This is not the point. The problem actually is that the slope of the correlation strongly deviates from the 1:1 line in both cases. The error for soil organic carbon is larger than the organic carbon content of most of the samples. This questions the reliability of the GSDE data set for local applications like the cosmic-ray rover.

We agree the SOC data is very poor from the GSDE and in situ samples. Better estimates of SOC are needed. However the influence of SOC seems to be fairly minor.

L348: add an adjective like e.g. reasonably

Thank you.

L362: “the” instead of “these”

Thank you.

L428-430: Better data sets are not only needed for higher resolution applications, but also to increase the reliability of the calibration function.

Thank you.

L434-435: The impact of soil organic carbon (SOC) on the calibration strongly depends on the total SOC amount and on the vertical distribution. For arable land SOC are relatively low and homogeneously distributed in the A-horizon due to land management activities. However, in grassland and forest sites, high SOC amounts and strong SOC gradients typically exist in the top soil (e.g. Bogena et al., 2013).

Thank you. We will add discussion here.

L463-465: Actually, this is an argument for adding more vegetation types in the analysis to increase the relevance of the paper.

Thank you.

L501-517: This section is not a conclusion and thus should be moved to the discussion section.

Thank you, will you it to the discussion section.

Literature

Baatz, R., H. Bogena, H.-J. Hendricks Franssen, J.A. Huisman, Q. Wei, C. Montzka and H. Vereecken (2014): Calibration of a catchment scale cosmic-ray soil moisture network: A comparison of three different methods. J. Hydrol. 516: 231-244, doi: 10.1016/j.jhydrol.2014.02.026.

Bogena, H.R., J.A. Huisman, C. Hübner, J. Kusche, F. Jonard, S.Vey, A. Güntner and H. Vereecken (2015): Emerging methods for non-invasive sensing of soil moisture dynamics from field to catchment scale: A review. WIREs Water 2(6): 635–647, doi: 10.1002/wat2.1097.

Duncan J.M.A. et al. (2016): The potential of satellite-observed crop phenology to enhance yield gap assessments in smallholder landscapes. Front. Environ. Sci., http://dx.doi.org/10.3389/fenvs.2015.00056

Korres, W., T.G. Reichenau, P. Fiener, C.N. Koyama, H.R. Bogena, T. Cornelissen, R. Baatz, M. Herbst, B. Diekkrüger, H. Vereecken, and K. Schneider (2015): Spatio-temporal soil moisture patterns - a meta-analysis using plot to catchment scale data. J. Hydrol. 520: 934-946, doi:10.1016/j.jhydrol.2014.11.042.

Kumar, L, Sinha, P. Taylor S. et al. (2015): Review of the use of remote sensing for biomass estimation to support renewable energy generation. J. Appl. Remote Sens. 9(1), doi:10.1117/1.JRS.9.097696
Peichl, M., Leava, N. A. and Kiely, G. (2012): Above- and belowground ecosystem biomass, carbon and nitrogen allocation in recently afforested grassland and adjacent intensively managed grassland. Plant and Soil, 350, 281-296.

Anonymous Referee #2
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General comments
The manuscript focuses on the mobile application of cosmic-ray neutron soil moisture probes (CRNP) and tests the reliability and accuracy of globally/continentally available data sets to provide information to support the calibration procedure. The relationship between CRNP measured low-energy neutron concentration and soil moisture can be strongly affected by changes in soil texture/soil type, surrounding vegetation, organic carbon content in the upper soil layer. Therefore, an operational procedure to provide information about CRNP calibration parameters for larger scales is of critical importance and relevance for the mobile application of CRNP. The paper is generally well written and easy to follow. However, especially the overview of CRNP and its calibration in the method section (chapter 2.1 - 2.3.) require a deeper revision. In 2015, Köhli et al. revised the footprint characteristics for soil moisture monitoring with cosmic-ray neutrons substantially. Although the authors cite Köhli et al. (2015) several times, key insights of the Köhli paper are omitted or reported incorrectly. By improving the physical representativeness of the underlying neutron transport model, Köhli et al. (Ibid.) revealed the highly dynamic nature of the CRNP footprint (horizontal and vertical) and redefined the footprint radius to range from 130 to 240 m. Furthermore, Köhli et al. revealed the high sensitivity of the CRNP to soil moisture (and other affecting properties) in the first tens of meters around the probe resulting in the need for a dynamically weighted average of CRNP-affecting properties within the probe's footprint (very recently applied and successfully tested by Heidbüchel et al. (2016)). While the manuscript mentions results of "recent neutron transport modeling" (l 145-146), the only given number for the CRNP support volume is the outdated "circle of ~ 300 m radius" (l 144). Although the authors mention the need for an adjustment of the sampling pattern for in-situ calibration ("in the light of recent modelling", 217-219), the sampling scheme presented in detail in the paper is based on results from 2012. Also here it would be desirable to provide a more detailed discussion of the importance of a weighted sampling scheme. All these aspects impact the interpretation of the CRNP signal and are of critical relevance for mobile CRNP applications. Even though the aspects mentioned above did not affect directly the interpretation of the manuscript's main topic (evaluation of accuracy of globally available data sets for CRNP calibration), the reviewer recommends a more intense discussion of the current state of knowledge about the CRNP theory and its importance for the mobile CRNP application. More comments on this topic can be found in the "Specific comments" section of this review. Despite these critical remarks, the manuscript is of high interest for the CRNP community and the manuscript's topic is well suited for the journal and the

journal readers. I recommend a moderate revision before the article is considered for publication.

We thank the reviewer for their comments and concerns. Per the issue of the footprint characteristics we have had detailed discussions with Darin Desilets of HydroInnova about its refinement following Köhli et al 2015. It seems there is some on going discussion within the community that should be a central topic for the upcoming COSMOS workshop in August 2016 in Denmark. We hope that this issue and others with the calibration function, sampling method, sampling frequency etc. will be resolved at that time. We will add more exact language to the introduction and summarize conclusions from the Köhli et al. 2015 paper.

Specific comments

1. L 50-52: Delete "(~36 km)" and "(e.g.~2-5 cm ... Entekhabi et al., 2010)" since this is repeated and described again with the same citations in the following paragraph.

Thank you.

2. L 66: I assume that the footprint is given square kilometers.

Thank you.

3. L78-79: The authors mention here the footprint radius of "~300 m" and underpin this by a citation of Köhli et al (2015). Since Köhli et al. revealed a reduced footprint radius (see also comments above) this is a wrong citation and should be corrected using the correct numbers.

We will provide more exact language.

4. L109: Since it is introduced for the first time (except from the abstract), "CONUS" should be written out here.

Thank you.

5. L132: The use of the term "energy levels" is unusual in unbound particle systems. Energies of free atmospheric neutrons can be approximated as a continuum throughout the elastic scattering spectrum. Better use "well-known energy spectrum" or "continuous energy spectrum".

Thank you.

6. L135-136: "(i.e., the neutrons which are primarily measured by the moderated detector)" repeated information, compare line 130.

We will remove repetition.

7. L 145-148: The authors mention new findings regarding the CRNP footprint and

its dependency upon vegetation, soil moisture, atmospheric water vapor, elevation, surface heterogeneity. Since Köhli et al. (2015) investigated all of these aspects the citation should be placed at the end of the sentence. Furthermore, it would be highly desirable to discuss the impact of the dynamic nature of the CRNP footprint on the applicability for mobile surveys.

We will provide more exact language and discussion here.

8. L173: The term "correction factor" has been used four times in the last 5 lines, please rephrase.

We will remove repetition.

9. L217-L219: "In light of recent modelling ... reduced footprint area". How does this recent finding affect the mobile application of CRNP?

I am not really sure it does for simplistic applications. Currently, the corresponding author assumes the centroid of measurement location (middle point after driving 1 minute) is a point and then performs spatial interpolation on those series of survey points. However, the elliptical shape and weighting function could be considered in the geostatistical analysis more explicitly. This would require advanced spatial interpolation techniques not provided by standard software. Certainly this is an open area of research for a skilled scientist in computational and statistical methods. Unclear how important this will be in light of other errors in the calibration method.

10. L260: Delete ",and lattice water" since the test for lattice water relationships is described above.

We will remove repetition.

11. L302-308: Excessive of the verb "use" - used six times within five consecutive sentences.

We will remove repetition.

12. L323-324: I recommend to delete the sentence "Other than 1 outlier..." here, since this is repeated and discussed in section 4.1.

We will remove repetition.

13. L330-333: Repetition of L 241-244

We will remove repetition.

14: L350: Change to "Figure 4a and 4b".

Thank you.

15: L365: Instead of "MODIS product and derived equation" it might be better to write "MODIS product in combination with the derived equations".

Thank you.

16: L381: Change the title since it is the same like the title for chapter 2.6

Thank you.

17: L393-394: Why is this sentence given in italic letters? Furthermore, I find the formulation misleading. "Future sampling efforts" probably won't "minimize the range of bulk densities". But it can certainly increase the accuracy of bulk density estimation. Bulk density itself is affected by the land use and can be a very dynamic parameter (e.g. due to agricultural cultivation measures) and this dynamic nature it a further challenge for the mobile CRNP application. This issue should be mentioned. The incorporation of land use information can increase the accuracy of bulk density estimation.

This is a key point and area that the users of the cosmic-ray probe should be aware of. The impact of land use on bulk density or soil organic carbon will be better highlighted. Perhaps a better definition is identifying the 5 and 95% quantiles of bulk density at a survey location. Therefore, more samples may indeed resolve these quantile estimates by eliminating the influence of outliers.

18: L405-407: "This strong correlation is significant because large portions or the ... regions are made up of mollisol soils". I did not understand this sentence. A "large portion" isn't an explanation for the significance, is it?

We mean that a majority of the collected samples came from the mollisol group. Therefore the correlation for all samples with clay percent will be more heavily weighted to the mollisol soil group, which is highly correlated to clay percent. Clearly more samples are needed to resolve this issue amongst soil groups.

19: L477-479: "...given the relatively small change in BWE... in forests, we would expect small change in N0 through time". CRNP measurements in forest can be challenging for several other reasons. Bogena et al. (2013) revealed the importance of the litter layer and its dynamic water content for CRNP calibration. Heidbüchel et al. (2016) found strong deviations in N0 calibrations for different times of the year and recommend a two-time calibration to catch seasonal variations in aboveground biomass. Furthermore, they found a considerable influence of root biomass on the CRNP signal.

The additional citation and discussion will be added for forest areas. Reviewer 1 also points out that the vertical distribution of SOC or bulk density may be more important there.

20. L503: "minimum of 7" is a strong recommendation for a value which should be dependent on the individual site heterogeneity. Since there is no statistical proof for this statement, I suggest to avoid a concrete number.

This is more of a rule of thumb found as good practice used by the authors. We will soften the language here.

21. L505: Why is N0 a correction factor? Please clarify to which function and which parameters you are referring to.

N0 is not a correction factor but calibration parameter dependent on vegetation conditions that may change through time. Thank you.

22. L507: The influence of road type has not been discussed in this work. Please explain the reasons for this recommendation.

This is briefly discussed in Chrisman 2013 and Franz 2015. The asphalt will be much drier than say a dirt road and influence the neutron counts.

23. L507: replace "in missing areas" by "data gaps".

Thank you.

References: Bogena H.R., Huisman J.A., Baatz R., Franssen H.J.H., Vereecken H. (2013) Accuracy of the cosmic-ray soil water content probe in humid forest ecosystems: The worst case scenario. Water Resources Research 49:5778-5791. DOI:10.1002/wrcr.20463. Heidbüchel I., Güntner A., Blume T. (2016) Use of cosmic-ray neutron sensors for soil moisture monitoring in forests. Hydrol. Earth Syst. Sci. 20:1269-1288. Köhli M., Schrön M., Zreda M., Schmidt U., Dietrich P., Zacharias S. (2015) Footprint characteristics revised for field-scale soil moisture monitoring with cosmic-ray neutrons. Water Resour. Res. 51:5772-5790.