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Interactive comment on "Calibration of a non-invasive cosmic-ray probe for wide area snow water equivalent measurement" *by* M. J. P. Sigouin and B. C. Si

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Dear Authors,

I take the chance of the open discussion provided by the Journal for adding a short comment. I hope this could help for further improving of the manuscript. We have experienced the use of Cosmic-Ray neutron sensing (CRNS) since 2010. Our studies focused mainly on soil moisture measurements. However the role of snow was also detected and a preliminary concept for possible quantification was provided (see fig. 9 in Rivera Villarreyes et al., 2011). After that experience, we realized that CRNS has several opportunities to estimate not only soil moisture. For this reason we put some efforts to show the possibility to identify additional hydrogen pools (Baroni and Oswald,

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2015). Similarly, I believe that also your contribution for snow estimation is a valuable and important study to explore new applications.

Author reply: Thank you for mentioning the study by Rivera Villarreyes et al. (2011). We included a reference to the relationship found in fig. 9 of Rivera Villarreyes et al. (2011).

Changed in manuscript: "Additionally, Rivera Villarreyes et al. (2011) observed the possibility to measure snow with neutron counts from a CRP (model CRS-1000), but only explored the relationship between neutron counting rates and snow cover instead of SWE."

Independently from the target of the study (soil moisture, snow etc.), I think one of the main challenge that we are facing now for the applicability of the method is the characteristics of the footprint. The temporal variability of the penetration depth of the CRNS as a function of hydrogen pools was already underlined in the earlier publication (Zreda et al., 2008). The need of a vertical weighting function was developed later (Franz et al., 2012). Recently, Köhli et al. (2015) showed that also the spatial footprint shrinks in space and a spatial weighting function is also needed. Overall we have to take into account that the water estimate by CRNS is a weighting value within a footprint that changes in time. So far the studies focused on soil moisture but we could expect that the same happens in snow conditions. One could even speculate that the role of snow could be even stronger i.e., smaller footprint and stronger time variability. Exactly for this reason I would suggest the Authors to include in the analysis a spatial and vertical weighting function for the point snow measurements. The same comment was underlined by the Reviewers (e.g., Reviewer 1: the author should then recalculate the regression using only the nearest points, and see if the regression improves) but I write to emphasis that a time dependent weighting function (horizontal and vertical) might also be necessary i.e., the weights might change in each campaign.

Author Response: We agree that the CRP reading is a weighted horizontal measurement. Similar to the depth weighting function provided by Franz et al. (2012), a horizontal weighting function might also be necessary in environments where snow distribution is distinctly heterogeneous (i.e. rolling landscape with more snow accumulation closer to the CRP). We did redo the regression with only using the sampling points along the 25 and 75 m radials, and found that the regression slope and intercept was similar to the previous regression including all radials (25, 75, 200 m). Also, the RMSE of the CRP-predicted SWE did not improve when using the new 25 and 75 m radial regression. The reason that we did not see an improvement from using only the nearest points to the CRP is most likely because our site is a flat, bare (except for short crop stubble) agriculture field causing the SWE distribution to be relatively homogenous. We included a short discussion of the possible need for a weighted horizontal function in sites that are more heterogeneous in terms of landscape and vegetation.

Changed in manuscript: Line 490 – 511 “3.5 Footprint for CRP-estimated SWE In this study, the footprint of the CRP was assumed to be ~300 m based on original studies using the CRP for soil water content measurements (Desilets and Zreda, 2013). Recent evidence displays that the CRP footprint might range from 130 – 240 m depending on soil water content and that a horizontal weighting function is needed to compare CRP measurements to other point measurements (Köhli et al., 2015). With an assumed footprint of ~300 m, snow samples along 25, 75, and 200 m radials around the CRP were included in our calibration and validation of CRP-estimated SWE. Despite including the 200 m radial, the calibration provided acceptable estimates of SWE with the CRP when compared to snow surveys, which also included samples from the 200 m radial. The linear regression and calibration was redone using only the snow samples from the 25 and 75 m radials, but the regression slope and intercept was similar to the original regression (SWE samples from 25, 75, and 200 m radials). Furthermore, the RMSE of the CRP-estimated SWE did not improve when using the 25 and 75 m radial calibration. The characteristics of the study site is most likely the reason why including the 200 m radial for calibration and assuming a larger footprint (300 m) provided similar results as the calibration without the samples from the 200 m radial. The study site is flat and relatively bare of vegetation (short crop stubble evenly throughout field) causing the variability of SWE to be similar throughout the entire site. Using radials closer to the CRP when calibrating for SWE measurements would likely be necessary in other sites where vegetation or topography causes SWE distribution to be distinctly heterogeneous. For example, if the CRP was located in a depression where greater amounts of snow accumulated around versus further away from the probe."

A small final remark is also that I did not find information about the altitude of the experimental site. Since this effects the dimension of the footprint (more precisely by the relation between altitude and air pressure) I would suggest the Authors to provide additional information and in case to extend the discussion. For an estimation of the footprint as a function of pressure see eq. 21 on (Desilets and Zreda, 2013).

Author reply: We added a short discussion regarding the footprint size based on altitude/air pressure at our site.

Changed in manuscript: Line 174 "The altitude and average air pressure of Saskatoon are 482 m and 955 hPa, respectively. According to Desilets and Zreda (2013) the measurement footprint of the CRP changes slightly based on air pressure of the site. Air pressure affects the neutron moderation length, which controls the footprint of the CRP. Using Eq. 21 from Desilets and Zreda (2013) and sea level as a reference (moderation length = 150 m, air pressure = 1013 hPa), the moderation length for Saskatoon was found to be 141 m. The radius of the CRP footprint is 2 times the moderation length. Therefore, the site-specific CRP footprint for Saskatoon has a radius of 283 m."

In conclusion, I would suggest the Authors putting more effort on the analysis of the data and to extend the discussion accordingly. With these, the manuscript could represent more than an additional proof of concept on the use of CRNS for snow measurements but it could show some new insight on how to use the method for this application.

Author reply: Thank you very much for your valuable comments.

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