

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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General Comments

This work discusses the use of a non-invasive cosmic-ray sensor for measuring snow water equivalent (SWE) and provides a calibration function that applies to shallow snow packs. The technology is relatively new. The same type of sensor has been used for monitoring soil moisture in a number of countries, starting with the COSMOS network in the US, since around 2006. To my knowledge this is the first SWE calibration that has been submitted for publication. These results will enable the use of COSMOS data (and data from other networks) for monitoring winter SWE in addition to summer soil moisture. I believe this work to be highly valuable through its demonstration and

advancement of new technology that will benefit snow hydrologists.

Author reply: We appreciate the excellent comments.

Specific Comments Line 319-322: I am fairly sure that there is no density or porosity effect based on my knowledge of physical principles (and also modeling and empirical results). It's really the number of collisions that matter—i.e. the number of collisions that a neutron will experience as it passes through the snow pack. The distance between collisions will increase as density decreases, but the total effect is exactly the same. However, if you want to stick with this explanation I would suggest starting the sentence with "We speculate that..."

Author reply: We do not have neutron transport simulations to back up our statement regarding the penetration of neutrons in snow so we will remove our speculation.

Line 591: (Figure 3) I don't see any value in the combined regression as it is done here, given the evidence for an offset. Hence in order to "combine" the two seasons of data, one season should be normalized to the other, and then the linear regression performed. Or the regression coefficients (slopes and intercepts) might simply be averaged between the two seasons. I am not sure which is better; but should not matter anyhow since the slopes are nearly the same.

Author reply: We agree that the combined regression in Figure 3 does not give significant value. With the offset applied to the 2014/15 data, the slope is similar to the 2013/14 regression thus the combined regression really does not add much value. We will remove the combined regression since we used the regression from 2013/14 (not the combined regression) for estimating SWE for 2014/15.

Line 352-364: The first half of this paragraph is a bit awkward. I think the most relevant part is the last two sentences of the paragraph; before that the author seems caught in a circle. I think it can be explained like this: the author collected two seasons of calibration data, and the RMSE for each season was ____.

Author reply: We edited the mentioned paragraph to be more concise and focus on the RMSE of the 2014/15 CRP-estimated SWE.

Changed in manuscript: Line 434 – 440 “For both winters, the CRP-estimated SWE match the manually measured SWE well. Of course for 2013/14 the manually measured SWE corresponds nicely to the CRP-estimated SWE since the regression equation from 2013/14 was used for SWE prediction. The CRP-estimated SWE for 2014/15 also agrees with manually measured SWE. The root-mean-squared error (RMSE) and mean absolute error for the 2014/15 CRP-estimated SWE is 8.8 and 7.5 mm, respectively. These error results are comparable to Rasmussen et al. (2012), who found an RMSE of 5.1 mm between SWE estimated from snow depth and from a CRP.”

Technical Comments

Line 52: replace "measurement scale" with "spatial scale" (word measurement is redundant in this sentence)

Change in manuscript: Line 51-53 “We explored the potential of using the cosmic-ray soil moisture probe (CRP) to measure average SWE at a spatial scale between those provided by snow tubes and remote sensing.”

Line 65: delete "very"

Change in manuscript: Line 65 “...measured SWE and moderated neutron counts were similar, thus differences in antecedent...”

Line 86: insert "field survey" between "common" and "method" (I am not sure what is the most common method overall, but it seems uncontroversial that the snow tube is the most common method for campaign style surveys.)

Changed in manuscript: Line 89 “...most common field survey method for determining SWE and although it provides a point...”

Line 88: importantly, snow tubes are prone to systematic errors, the magnitude and

direction of which depends on snow conditions. At least that is what this reviewer has observed; I wish I had a better reference than that handy.

Changed in manuscript: Line 91-92 "...However, snow surveys with snow tubes are labour intensive, can be difficult to perform in remote locations, and are prone to over- and underestimation of SWE depending on snowpack conditions (Goodison, 1978)."

Line 110: cite Desilets et al. (2010) with regard to the potential to measure SWE.

Changed in manuscript: Line 116 "...but also has the potential to be a useful tool for measuring SWE (Desilets et al., 2010)."

Line 114: delete "the" at end of line.

Changed in manuscript: line 126 "...capable of measuring neutrons moderated by hydrogen in snow, i.e. frozen water."

Line 128: add "and the Pyrenees of Spain" after the word "France".

Changed in manuscript: Line 135 "...probes in France and the Pyrenees of Spain (Paquet et al., 2008)."

Line 141: delete everything after word "site". (These extra words are superfluous.)

Changed in manuscript: Line 150 "...from multiple locations around the study site."

Line 154: "increased accumulation of snow along the line" for clarity

Changed in manuscript: Line 163 "...causing increased snow accumulation along the line, but the irrigation line was removed..."

Line 163: this is a good place to explain why you only analyze data from the mod tube. You could end the first sentence by saying something like "...following the practice established for soil moisture observations (Zreda et al., 2012)." Relationships between the bare tube counting rate and SWE are thought to be less straightforward.

Changed in manuscript: Line 173 – 178 "Slow neutrons are affected by more than just

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H, including other neutron absorbing elements in soil such as B, Cl, and K (Desilets et al., 2010). Also, the relationship between the bare tube counting rate and SWE are thought to be less straightforward than the moderated neutron and SWE relationship. Thus, only the moderated neutron count was used in this study following the practice established for soil moisture observations (Zreda et al., 2012)."

Line 187: start sentence with "The raw neutron..." (i.e. delete everything before that)

Changed in manuscript: Line 208 "The raw neutron counts must be corrected for differences in air pressure, atmospheric water vapor, and the temporal variation of incoming cosmic ray flux."

Line 205: (1) For consistency in units, convert g cm^{-2} to hPa ($130.24 * 0.9807 = 127.5$ hPa). (2) Round to one decimal place or less (higher precision is not justified or needed).

Changed in manuscript: Line 226 – 228 "L represents the mass attenuation length (hPa), which is a function of latitude and atmospheric depth (Desilets and Zreda, 2003). The mass attenuation length for Saskatoon was found to be 127.5 hPa."

Line 247: insert words "a first order" (or something with similar meaning) between "for" and "comparison".

Changed in manuscript: Line 272 "Snow depth data from two reference sites were used for a first order comparison to the snow surveys and CRP data."

Line 301: delete word "regression" which is redundant.

Changed in manuscript: Line 326 "Initial regressions showed that both 2013/14 and 2014/15 had similar slopes but quite different intercepts."

Lines 305-306: please clarify by saying that the intercepts of the regression lines match up more closely. (at least I think you mean the intercepts).

Changed in manuscript: Line 331 – 332 "The added soil water storage caused the

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intercept of the 2014/15 regression line to match more closely with the intercept for 2013/14.”

Line 324: instead of saying "and simple regression was completed" say something like "and fitted with a linear regression model"

Author reply: This sentence was removed from the manuscript because we removed the combined regression.

Line 332: delete "simple" (superfluous)

Changed in manuscript: Line 361 “...thus linear regression was used for modeling SWE from moderated neutrons.”

Line 337: no need to show this equation both here and on Line 348.

Changed in manuscript: Line 366 – 367 “The best-fit linear regression equation for the 2013/14 data produced an r^2 of 0.84.”

Line 394: replace "fully" with "quantitatively"

Changed in manuscript: Line 425 – 426 “It is difficult to quantitatively compare the snow depth results to the CRP-modeled SWE since...”

Line 422: replace "regards" with "regard"

Changed in manuscript: Line 454 – 456 “Overall, the presented equation performed favourable with regard to providing an estimate of average field SWE at this agricultural study site.”

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