Hydrol. Earth Syst. Sci. Discuss., 12, C5128–C5134, 2015
www.hydrol-earth-syst-sci-discuss.net/12/C5128/2015/

Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Uncertainty analysis for evaluating the accuracy of snow depth measurements" *by* J.-E. Lee et al.

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Received and published: 26 November 2015

This study estimates errors in snow depth measurements by comparing manual, ultrasonic and laser sensors over a winter season. This is an important topic since errors in snow depth measurements remain large and poorly understood. The measurement system seems to have been carefully prepared for a proper comparison between the different sensors. The data set is quite short, but seems comprehensive and was carefully quality-controlled. The uncertainty analysis appears to be sound, based on classical statistical methods. However, the interpretation of the results is quite disappointing and the authors do not reach very substantial conclusions (see the main comments below). The text and figures must be improved (see specific comments). The text should be shorter and more concise.

Main comments

- A comparison between different sensors is used to estimate the measurement uncertainties. However, the errors are not related to the sensor specifications nor to the climatic conditions (snowfall, strong wind, and so on. . .). Then, the discussion remains quite vague and the numerous results obtained in this study are not very useful for other studies. For instance, Section 5.1 concludes that the snow depth is higher on the west than on the east of the study site, but this result is not discussed in relation with the site characteristics nor with the wind conditions during the snowfall events. At the beginning of the paper, Section 3 mentions that the prevailing wind direction is west to east and that the surface of the site has a slight slope east to west (P4164), but this information is not used to interpret the results of the error analysis. The analysis of the measurement errors of each sensor should be expanded (Section 5.2.1). The second paragraph of the section is not clear (P4170-4171). Different kinds of errors are expected for laser or sonic sensors; they have different resolutions, beam angles, sensitivities to climatic conditions (wind, humidity. . .) and so on. . . These points should be discussed. ⇒ We discussed the results found in the paper with other studies below as: - We added: "Neumann et al. 2006 demon12strated spatial variability of snow depth within several sites and concluded that snow distribution was related to climate, topography, and local vegetation. We can conclude that the spatial variability of snow depth within CARE site caused by prevailing wind and slope of CARE site resulted in bias between manual observations". - We added: "These results also emphasize the necessity of several manual observations within the experimental site and support that single point measurements could not represent snow depth of surrounding area as mentioned in Grünewald and Lehning 2014". - We added: "Lopez-Moreno et al. 2011 mentioned that the increase of sample size reduces snow depth estimation error. In this study, the uncertainty of 36 samples located on different bases and snow depth target were calculated". - We added: "These results could show that established observation system can affect the uncertainty of snow depth measurements". ⇒ Section 5.2.1 have been expanded below as: - We added: "Snow depth data was all almost zero before snow season, but deviated from manual snow depth during snow season in both ultrasonic and laser snow depth measurements". - We added: "When comparing the biases and NBRRMSEs of snow depth sensor sharing same snow target, NBRRMSE of snow depth sensors that was deviated much from manual observation was higher than the other: SR50A > JEN, JEN > SOM, JEN > FEL". ⇒ The second paragraph of the section is not clear (P4170-4171) - Diamonds and circles are the BE between snow depth sensors of same type as explained in manuscript when we considered the snow depth sensors on base 12A reference. Diamonds are calculated from dataset of each sensor. Moreover, the BE between snow depth sensors can be determined from snow variability in manual measurements and the BE between snow depth sensor and manual measurements. Thus, circles in Fig. 11a was calculated by adding the BEs in Figs. 7a and 9a. - Revised: We clarified the differences between diamonds and circles as below: The diamonds and circles are calculated by considering the snow depth sensors on base 12A as reference from snow depth senor dataset and from snow variability in manual measurements and the BE between snow depth sensor and manual measurements. ⇒ Revised: we added: "Different kinds of errors expected for laser or ultrasonic sensors in that they have different resolution, beam angles, sensitivities to climatic conditions and so on. The instrumental uncertainty of SOM having smallest beam angle is largest, and this could be due to the fact that the SOM reported the data in one centimeter resolution. The laser snow depth sensor (JEN) showed larger uncertainty than SR50A and FEL although they have high resolution. The instrumental uncertainty of FEL having 15ãĂň beam angles was larger than SR50A having 22ãĂň."

- In relation with the previous comments, there is often confusion between measurement errors and spatial variability. For instance, Section 5.1 concludes that 'the uncertainty for manual snow depth measurements should be lower bound of the range of 1.33 to 1.81cm'. This uncertainty appears quite large considering a resolution of 0.5 m. In fact, part of this variability may reflect actual spatial variability of the snow depth. Lines 3-5, P4166: mention that the spatial variations of manual snow depth measurements may also be due to measurement errors. The text mentions that the

negative BEs of snow depth sensors on bases 20 and 11A may result from 'the spatial distribution of snow depth' (Section 5.2.1). However, Figure 8a shows that the manual observations give the largest snow depths on bases 20 and 11A. Please clarify. ⇒ Actually, the uncertainty for manual snow depth measurements did not reflect actual spatial variability of the snow depth in that the bias caused by this was removed in calculation of uncertainty. However, we mentioned that quite large uncertainty is due to the temporal vacation of snow depth during manual observation, which was not taken into account by the long-term BE remove. Thus, the uncertainty for manual snow depth measurements should be lower bound of the range of 1.33 cm to 1.81 cm. ⇒ According to bias in manual observation, the largest snow depths was on bases 20 and 11A. However, the bias between manual observation and snow depth sensor was positive on base 12A and 20 and was negative on 11A. Therefore, the negative BEs of snow depth sensors on bases 20 and 11A was shown. These are mentioned in detail as below: The snow depths measured at bases 12A and 20 are lower than that measured at base 11A, based on the result from comparison of manual observations (Fig. 8a). Meanwhile, the snow depth sensors on bases 12A and 20 (11A) overestimate (underestimate) snow depth relative to the manual observations (Fig. 10a). Thus, the BEs of bases 20 and 11A are negative, as snow depths measured by the snow depth sensors on base 12A are larger than those measured by snow depth sensors on bases 20 and 11A.

- The measurement time step is set to 1 minute, which is quite short (P4167). As the depth variations should be measured over a time interval long enough to detect true depth changes, the time step should be defined in relation with sensor resolution (and accuracy). ⇒ In this study, we aim to calculate the uncertainty of snow depth measurement during entire snow season, not newly fallen snow. Thus, the snow depth measured with 1 minute resolution is useful to show the measurement uncertainty although resolution is quite short to detect depth changes. The same time step for different sensors is also relevant to quantify their uncertainty in the same condition.

Specific comments

- The abstract is not clear and should be rewritten ⇒ We have rewritten abstract to express our purpose and method for analyzing uncertainty in snow depth measurements more clearly. The revised abstract have attached as supplement to this comment.

- Explain better Equation (7) ⇒ Revised: We explain that the variance can be expressed as the mean of square minus square of mean.

- P4164: what does 'well-exposed' mean? ⇒ 'well-exposed' means that there is no obstacle that could affect snow measurements around this site.

- P4165: give the beam angle and size of the target on the ground for each sensor, FEL resolution is missing, the resolution of the laser sensor is probably less than 1 mm (0.1 mm?). ⇒ We could not find the FEL resolution anywhere, including user manual and website. ⇒ Revised: We added a column showing beam angle and modified the resolution of the laser sensor to 0.1 mm.

- P4168: automatic measurements above snow free ground can be used to estimate the random errors (Figure 7 is useless: change the Y-scale or remove the figure e). This estimation should be compared to the errors derived from Figure 12b, even if the snow signal may be different from the bare ground signal. ⇒ Revised: We removed Figure 7. ⇒ We agree that it would be interesting to analyze separately the data outside of snowfall events. Analysis of these periods, while interesting, is outside the scope of this paper.

- Section 4.2 is too long. Only give the percentages of outliers in each data set. What are the causes of the numerous FEL errors at the end of the study period (Figure 5a)? ⇒ Revised: We have rewritten Section 4.2. ⇒ Revised: We have given the percentages of outliers as bellows: Some of the data from FEL (12A: 0.09 %, 20: 35.0 %, 11A: 30.1 %), SOM (12A: 0.11 %, 20: 0.13 %, 11A: 0.18 %), and JEN (12A: 0.96 %, 20:0.61 %, 11A: 0.56 %) fall outside the reasonable range for a given site

and observation period ⇒ The deviation of FEL 11A in Fig. 5a results from the loss of communication between the sensor and datalogger. When no response from the sensor is received by the datalogger within a specified time interval, a 'null' value of 6998 is recorded, which is subsequently filtered out by the quality control procedure.

- P4168: justify the choice of the average snow depth of stakes 1 to 4 on base 12A as a reference. It must be noted that this base has the highest random errors (P4169). ⇒ We selected the average snow depth of stakes 1 to 4 on base 12A as reference because they are located at the easternmost snow depth target though they has the highest random errors. Four snow stakes at one snow depth target were needed to show spatial variability of snow depth. ⇒ We mentioned that when comparing the uncertainty for each snow depth target, the uncertainty for stakes 1 to 4 on base 20 (1.58 cm) is the largest.

- P4170: the text mentions that snowfalls may perturb the ultrasonic measurements. However, it is not clear if the data during snowfall events were removed from the analysis. ⇒ We would like to mention that the uncertainty of snow depth measured from snow depth sensors may be affected by limitation of sensor. Meanwhile, we used the quality-controlled data to calculate the uncertainty for the whole period from 20 December 2013 to 26 March 2014, including snowfall events. However, some of unrealistic data were removed by quality controlled.

- Equations 1-3: only introduce the variables that are used in the results (MAE?) ⇒ Revised: We removed equations of MAE and RMSE that were not used in the results.

- Tables 2 and 3: the unities of BE and 'uncertainty' are missing ⇒ Revised: We added units in Tables 2 and 3.

- Figure 1: mention the color of each automatic sensor. ⇒ Revised: We mentioned the color of each automatic sensor as below: The orange rectangles and small circles indicate snow stakes and snow depth sensors (blue: FELIX, purple: SR50A, red: JENOPTIK, green: SOMMER).

- Figure 5 is not very useful and could be removed. ⇒ Revised: We removed Fig. 5 from the manuscript.

- Figures 9 and 11: the text is too small. ⇒ Revised: We have enlarged the text in Figs. 9 and 11.

- Figure 12A: clarify the differences between diamonds and circles. ⇒ We already answered with respect to main comment 1 (above).

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/12/C5128/2015/hessd-12-C5128-2015-supplement.pdf

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 4157, 2015.