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Hydrology and Earth System Sciences Discussions

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Interactive Comment

Interactive comment on "Applying a time-lapse camera network to observe snow processes in mountainous catchments" *by* J. Garvelmann et al.

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Authors Reply to the Referee Comment on "Applying a time-lapse camera network to observe snow processes in mountainous catchments" by J. Garvelmann et al.

Review Comment: This paper presents an interesting monitoring experiment in three catchments of the Black Forest in Germany. The authors investigate the potential of time lapse photography to derive information on snow depth, snow canopy interception, precipitation phase and snow albedo. They employ an impressive array of 45 cameras and an undisclosed number of meteorological stations. The potential for acquiring useful distributed data at the catchment scale is very good and the continuation of this type of work should be encouraged. However, the data analysis is very poor, there are too many unnecessary simplifications of complex processes, information is lacking and replicability nearly impossible. In the evaluation criteria of papers submitted to HESS, point number six states: 6- Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? The answer is no.

Authors Reply: We thank the referee Dr. Javier Corripio for his thoughtful comments and his helpful suggestions on our manuscript. The intention of the paper was to give an overview of the potential of a distributed camera network for snow hydrological applications at various scales. Therefore, we did not provide all the technical details regarding the image analysis as suggested by the reviewer. However, we will gladly provide these in the revised manuscript (as detailed below) to allow a better reproducibility for other scientists.

Section Image analysis says: "We used IDL image processing software to extract information about snow depth, albedo and the interception of snow in the forest canopy from the digital images." Yet no further information is given on which tools, techniques or procedures are used. IDL has hundreds of image processing routines, all of them well documented and in many cases with clear code provided. If the reader is going to trust this study and benefit from its application, the algorithms used should be clearly stated.

Authors Reply: The sentence referred to by the reviewer is indeed misleading since we actually used self-written codes that were only embedded in IDL. The sentence will be rewritten in the revised manuscript and a more detailed description of the codes and the procedure to derive information from the digital images will be included at the respective sections in the text.

Equation 1 for albedo derivation comes from an online secondary school exercise. The "Albedo project" is a very commendable enterprise, but it is not a rigorous study and therefore that equation should be tested carefully. Even more when the source re-

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ferred indicates that “this is approximate; final analysis is not yet complete”. According to Equation 1 the albedo of a section of the image (ROI) is directly proportional to the ratio of reflectance between the ROI and a reference target. How do you know that the response of the camera sensor is directly proportional to illumination intensity? We have used many different types of cameras to derive snow albedo (35 mm slides, CCDs, CMOS) and found that in most cases the response of the digital sensor to illuminance is nearly logarithmic. It is affected not only by the sensor but also by the lens and the camera internal image processing. The final result is better approximated by a polynomial function, a 3rd order is usually sufficient, as shown in Figure 1, below. It is clear from this figure that the linear fit is the least appropriate, while the polynomial fit is a much better representation of the relationship between DN (digital number, your RGB) values in the photographic image and actual reflectance values in the real photographed scene. Figure 1 is for a different camera, but deriving the relationship for the cameras used in this work should be straightforward. Using a reference board on the photographic scene is perfectly valid, but we need to know the actual albedo of the reference and its illumination conditions. Unless you have used a Spectralon panel as a reference, it can not be called a “perfect white” (10691, 27). What is the albedo of this reference board and how was it calculated? If you don’t have this value, the result of Equation 1 cannot be called albedo. Even if we know the exact albedo of the reference board, the RGB pixel values collected by the camera will depend on the intensity of the illumination of the panel. If the relationship between ground surface and reference board illumination changes, then Equation 1 is not valid anymore. As the board has a different orientation than the ground, their ratio of illumination intensity will change over the season. Equation 1 needs to be corrected for this variation. If not corrected the errors can be very large, as appreciated on Figures 1 and 2. There is also need to correct for the ratio of direct to diffuse insolation in cloudy days. These corrections can be implemented using any solar radiation software, I used the R package insol (http://cran.r-project.org/web/packages/insol/).

Authors Reply: We are very thankful to the author for this comment, which will definitely improve the study. We were thinking about a similar approach. However, we would like to point out that we are mostly interested in applying our approach to an albedo (reflectance) in the range between 50-100% and when looking at Figure 1 provided by the referee it seems that the relationship in in this range is in fact almost linear. Nevertheless, we will follow the reviewers suggestion and use a Kodak greycard Q13 to get a calibration relationship for the reflectance values of our camera type. We will also use this relationship to retrieve reflectance values for our reference white board for differing illumination conditions to test the sensitivity of the approach. Generally, we are aware that albedo calculation is a very complex process. The angle of incoming solar radiation has a diurnal signal and the angle of the camera to the reference board is constantly changing due to slight movements of the camera. Most importantly, the angle of the snow surface is permanently changing due to accumulation, redistribution, and melt processes. Under the forest canopy the situation is even more complex. We assume that, for our approach, all these changing conditions cannot be taken care of since we cannot apply a complex approach as proposed, for example, by the reviewer in his recent paper for the huge amount of pictures we used in this study (ca. 65000). To minimize the sources of errors for the calculation of the snow surface albedo we use average values for each day. Furthermore, we will develop and apply separate calibration curves for clear and cloudy days with more direct and diffuse insolation, respectively. With this, we will be able to improve our albedo calculations and eventually recalculate the results we got from equation1 with an adjusted equation. It should be noted again, that the goal of the study was not to present a perfect model for the calculation of absolute values of the snow surface albedo from digital images. We are more interested in relative differences at individual locations and a comparison of the relative temporal evolution of the albedo between different locations (open vs. forest at different altitudes and exposures).

We are told that the albedo derivation is supported by a high correlation between the photography-derived albedo and that measured by an AWS. Yet, out of a very impressive set of images from 45 cameras during two winter seasons, we are presented with

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the correlation values for a mere seven days. Why such a short series? That single week of albedo correlation includes a strong melt event, and there is a synchronous large drop of albedo values both from the camera and at the AWS to reach low values that do not correspond to snow. This results in a high correlation that does not necessarily represents that of the whole season. Please provide longer time series that are representative of the full study.

Authors Reply: We will present a time series of daily averages of surface albedo for the whole winter season 2011/2012 of a camera station located close to a meteorological weather station (figure 1). We did not do this in the original paper since we wanted to relate this time series to the derived relationship between observed albedo and albedo from image analysis.

The digital image analysis was also applied to: snow depth, state of precipitation and snow canopy interception

The procedure was executed in a batch mode, but there is no further information on how this was done, what precise analysis was performed, how was it automated, what problems did you encounter and how did you solve them? For example, for snow depth, how were the pixels in the scale bar counted? How did you correct for the viewing angle and distance to the camera? Did image distortion alter the readings?

Authors Reply: As already mentioned above there will be given more information about the batch mode and the image analysis approach in the revised manuscript. We would also like to mention that batch mode is not necessarily a fully automated process.

For state of precipitation, how did you identified separately snow and rain? Which shutter speed did you used (they are fast moving targets)? Did low light affected the measurements?

Authors Reply: Here the original paper might have been misleading. No image analysis software was applied to derive the state of precipitation. The images were analyzed vi-

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sually for the different events to identify the state of precipitation at different elevations. This will be clarified in the revised version.

And for snow canopy interception, what thresholds for vegetation and snow did you use? What error analysis was applied? What was the difference between low branches and high branches estimated (surely the viewing angle of the camera has an important effect)? Without this additional information the technique described is of little use to other researchers.

Authors Reply: The fraction of white pixels within three polygon masks was only calculated for pictures taken from outside of the forest but with a view of the forest canopy (as shown in Figure 2 of the submitted paper with one ROI as an example in the canopy). Therefore, the ROIs used for canopy snow interception calculations cover a large section of the canopy. The polygon masks were applied for areas in the canopy covering low braches as well as high branches to get an overall estimate of the fraction of snow within the canopy. The threshold was derived by looking at the RGB color space for snow versus non-snow pixels, where one can see a clear difference between snow and non-snow pixels. We used a threshold of 50 which seemed to be the most appropriate threshold for differing illumination conditions. An error analysis (e.g. threshold $\pm$10% and standard deviation of hourly values compared to daily values to check the differences in illumination under constant interception conditions) can be included in the revised manuscript. But since the correct values of snow interception are not known, it will always be an analysis without knowing the true values.

Additional comments

Page 10689, lines 10, 11. It looks to me that Jost et. al (2009) evaluated one single model, it is not possible to generalize from here that all albedo models respond in the same manner. I will suggest checking the output of the SNOWMIP inter-comparison exercise or the albedo simulations in models such as CROCUS or SNOWPACK. Other simpler implementations may perform better than the model studied by Jost et al. See

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for example: Brock et al. (2000); Brun et al. (1989); Etchevers et al. (2004); Lehning et al. (2002); Oerlemans and Knapp (1998).

AR: We will have a more detailed look into the literature and will be more specific in this paragraph.

P. 10690, l. 7. What is a “vegetational situation”?

AR: This refers to the type of vegetation (deciduous, conifer). Will be more specific in the revised manuscript.

P. 10690, l. 12. I doubt that there is such a thing as a “typical mid latitude mountain range”. Please provide some broad description of the forest, such as composition (deciduous, conifer, mixed,...), size, density, etc.

AR: A more detailed description about the forest characteristics in the Black Forest will be provided in the revised manuscript.

P.10692, l. 2. The term white balance and white/black balance is confusing, as in photography it refers to an adjustment of the temperature of the light to get realistic colours. It is not used in the same sense here, please be more specific.

AR: This will be explained more specific in the revised manuscript.

P. 10693, l. 4. CCDs and CMOS are actually sensitive to NIR radiation, which is an advantage for albedo estimation. In fact, this property is used by many digital camera applications in astronomy and vegetation studies. Usually manufacturers filter the NIR component and do not provide full information of the sensitivity range due commercial confidentiality, but the sensor can measure beyond the visible spectrum.

AR: Thanks for the suggestion which will be included

P. 10695. Spatial SWE distribution was derived from a linear regression model. How does the model compares with measured values of SWE? P. 10699, l. 10 “A high density meteorological observation network”. How many stations were installed? Please

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provide a list or table with the instrumentation, sensor type and measuring range and precision.

AR: The project uses, in addition to the time-lapse camera network, a network of measurement stations (LOCUS) for snow depth as well as air temperature and relative humidity. A comprehensive description of the LOCUS sensor system used in this study can be found in Varhola et al. (2010). Nine pairs of LOCUS stations (with one station in the forest and another one in an adjacent open field site) could be used to validate the analysis in this paper. Again, our intention was more to show the potential of a network of digital cameras to receive useful spatial distributed data on snow depth and SWE, rather than presenting a sophisticated approach to interpolate the snow depth data derived from the cameras to the catchment area. Therefore we used a simple linear regression dependent only on elevation and two land use types (open and forest) and did not further specify relations between snow depth and different forest types, aspect or other topographic influences. The table below shows a comparison (mean SWE, R^2) of SWE values derived from the cameras and the simple linear regression model with SWE values observed with the 18 LOCUS stations. This or a similar Table (table 1) will appear in the revised version.

A detailed description of the LOCUS network and more sophisticated analysis of the spatial and temporal snow cover variability based on the field measurements will follow in another paper.

P. 10699, l. 23. Some snow models calculate the snow/rain threshold from atmospheric profiles, dew point or other parameters, and it is not unusual to set the threshold at a positive temperature, see for example Lundquist et al. (2008) and references therein.

AR: This sentence will be written more specific in the revised manuscript. Of course there are sophisticated models that can calculate the threshold. However, many hydrological model, in particular operational models, only use temprature values (sometimes also variable) to differentiate between rain and snow. Our observed values are rela-

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tively high compared to frequently used threshold temperatures in these models.

Figure 1. The color scale makes no sense, as different colors indicate overlapping altitude ranges. Please provide coordinates and which way is north.

AR: Revised figure (figure 2):

Figure 11. On day 2012-01-05 measured albedo drops to zero. That is rather unusual for a partially snow covered grass surface. Do you have any explanation?

AR: Figure will be changed with the new albedo calculation approach. A time-series of a whole winter season will be provided (see authors reply above).

Figure 12. Is there any direct measurement of albedo with an albedometer to validate these results under the canopy?

AR: No, there are no direct measurements of the albedo under the forest canopy, which is very time consuming and complicated since a large spatial extend needs to be measured to get useful results (Stähli et al., 2009).

References

Stähli, M., Jonas, T., and Gustafsson, D. (2009): The role of snow interception in winter-time radiation processes of a coniferous sub-alpine forest, Hydrological Processes, 23, 2498–2512 (DOI: 10.1002/hyp.7180).

Varhola, A., Wawerla, J., Weiler, M., Coops, N.C., Bewley, D. and Alila, Y. (2010): A New Low-Cost, Stand-Alone Sensor System for Snow Monitoring, Journal of Atmospheric and Oceanic Technology, Vol. 27 Issue 12, 1973-1978.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 10687, 2012.

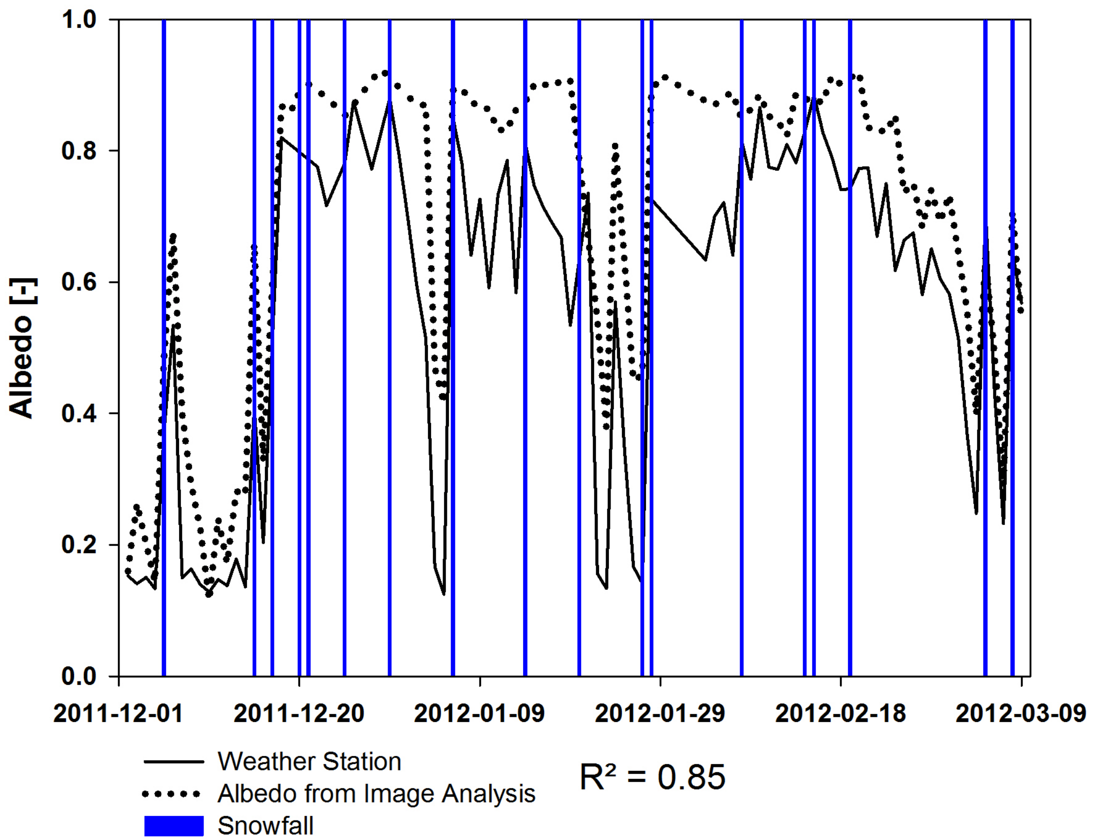

Fig. 1.

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	2011-12-30 mean SWE [mm] observed	**2011-12-30** mean SWE [mm] modelled	**2011-12-30** R^2 observed vs. modelled	**2012-01-03** mean SWE [mm] observed	**2012-01-03** mean SWE [mm] modelled	**2012-01-03** R^2 observed vs. modelled
Open	mean=73.1	mean=76.5	R^2=0.92	mean=30.4	mean=18.5	R^2=0.53
Forest	mean=55.1	mean=58.2	R^2=0.75	mean=26.0	mean=15.0	R^2=0.13

Fig. 2.

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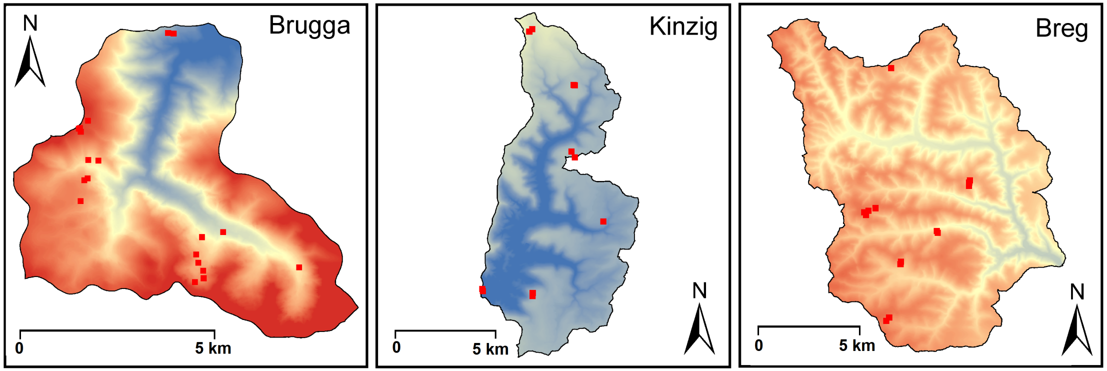

Catchment	Size [km²]	Elevation [m.a.s.l.]	Forest [%]	Cameras
Brugga	40	433-1493	79	19
Kinzig	76	354-842	63	11
Breg	158	738-1142	70	15

Fig. 3.

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