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Hydrology and Earth System Sciences Discussions

Interactive comment on "MODIS snow cover mapping accuracy in small mountain catchment – comparison between open and forest sites" *by* J. Parajka et al.

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Author response to review 2

We would like to thank the reviewer for her/his positive, constructive and very helpful comments on the manuscript. We have addressed the comments as follows (our response is in italics): General comments:

1. Additional information on the MODIS snow map pre-processing might be useful, particularly for geolocation error interpretation. Please provide some more details on the MODIS data processing in Section 2.2: were the images reprojected? Are these

images orthorectified? *We used MRT tool for reprojection of original MODIS images into state planar system used in Slovakia. We have added this information to Section 2.2.*

2. The title term "mountain catchment" implies more than just the difference between open and forested sites. The reader may expects also some statements on the snow mapping accuracy depending on topography (i.e. slope/aspect/elevation), which is also of major interest in this field of research as snow in mid-latitudes is predominatly bound to mountain regions. Even though the number of snow courses and sites is limited, such kind of analysis extention might substiantially rise the contribution of this study. (From the naming of the profiling sites in Table 1 it seems that you have different aspects available for such analysis). *The results of our study did not indicate any relationship between snow mapping accuracy and topographical characteristics (slope,aspect,elevation,curvature, etc). There are some differences between open and forest sites, but no clear difference with respect to elevation, etc within the forest. We note that because of the accessibility of sites and safety (avalanche danger) it was not possible to measure snow characteristics at the whole range of available slopes and aspects. In response to this comment we have added following text to the Discussion section: " The accuracy at individual sites varies between 87.5 and 100, but there is no clear dependence between mapping accuracy and topography. More clear difference is found between open and forested sites. The accuracy at sites in forest, open and mixed conditions at the Červenec site is ..."*

3. Likewise, the SI could be analyzed seasonally. How doe the MODIS snow detection performance vary over time? How good is the accuracy in the accumulation vs. the ablation phase? *The profile measurements do not allow a robust comparison between accumulation and ablation phase, as they are biased towards periods of maximum snow storage in the catchment and subsequent snowmelt. In response to this comment, we have extended Results section and added the seasonal performance for forested sites. Indeed, we believe that existing Figures already clearly indicate the*

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mapping performance during snowmelt period.

Specific comments:

- Title: change to "MODIS snow cover mapping accuracy in "a“ small mountain catchment – comparison between open and forest sites“ *Corrected.*

- 4074, 20-26 and p. 4075, 1-10: All the listed general statements on the importance of snow and other studies conducted (like "Numerous studies...“, "A range of MODIS snow cover products have been used“) in this field require references! *In response to this comments, we have added following references to this section: Kaufmann et al., 2002, Poon and Valeo, 2006, Pu et al., 2007, Sirguey et al., 2009, Tong et al. 2009, Wang and Xie, 2009, Parajka and Blöschl, 2012.*

- 4075, 6-7: What about Klein et. al. (2003)? This validation was also based on snow courses in a mountain catchment (see below for exact reference). *In response to this comment, we have added some of the findings of Klein and Barnett (2003) into the discussion section. This study, however, does not refer to MODIS validation by snow courses measurements. We are not sure if this study is meant in the comment, but are happy to further revise this section, if more details will be provided.*

- 4075, 10: Climate station bias: this is generally true, but the study area covered here does not exceed this critical altitude (i.e. in ParajkaBlöschl 2006: station altitudes up to 2290m a.s.l. were used). So, this is not quite a reason for the study at hand. *This sentence refers to the idea that for more robust validation of satellite products in alpine regions, climate stations observations tend to be biased. In Slovakia, there are only a few stations located at altitudes above 1000 m a.s.l., so experimental observation at altitudes as referred in this study are very helpful. We would thus prefer to retain the sentence as it is.*

- 4076, 5: Please also refer to Klein et al. (1998), where a snow reflectance model was used in conjunction with a canopy reflectance model to model the reflectance of

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a snow-covered forest stand and the MODIS snow detection scheme was extended with the inclusion of the NDVI. Are these model assumptions,outputs maybe not valid globally leading to over-underestimation of snow cover? This could be included this in your discussion as well. *In response to this comment we have added a reference to Klein et al. (1998). A detailed dataset on reflectance, vegetation and snow pack characteristics (i.e. grain size, LAI, etc) is not available, so we are not able to verify and discuss these assumptions.*

- 4076, 12: What difference in the results between mountain forested areas and other forested areas can be assumed? And what are the reasons for such different validation results concerning forested areas, can you speculate? *The specifics of mountain forests include the plant species (predominantly spruce and dwarf pine, in our case) and also different seasonality and snow cover characteristics (snow depth, snowpack duration). This is the reason for specifically stating the mountain forest in the objectives of the paper.*

- 4076, 19: add "The“ lower part. *Corrected.*

- 4076,20: forest line = tree line, add "the“ forest "is“. *Corrected.*

- 4076,21: add "and“ covers. *Corrected.*

- 4076, 25: add "the“ Forest Management Plan. *Corrected.*

- 4076, 25: briefly introduce "stand density“ here. *In response to this comment, we have revised the sentence as follows: "The stand density (i.e. a measure of the degree of stem crowding within a stand) varies between 0.05 and 15.21 (Kostka and Holko, 1997)."*

- 4077, 5: specify "in the middle“ is this every 25 m, starting at 12.5m? *Yes, it is approximately at 12.5m, but the exact location always varies according to the specific terrain, vegetation and snow conditions.*

- 4078, 11: NDVI, NDSI: abbreviations need to be introduced at their first mention,

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without the explanation of NDSI, the follow-up sentence in unclear. *Corrected.*

- 4078, 16-18: Does the fact, that only MODIS Terra images can be accounted for NDVI influence your results? How can you consistently combine the products when snow detection algrithms (i.e. thresholds) slightly differ between the sensors? *We thank for this comment. In our assessment, we used Terra images as the main source of information for combining Terra and Aqua (not Aqua as it was in the manuscript). So pixels classified as clouds in Terra images were updated by the Aqua pixel value. We have revised text accordingly. Our results for forest sites showed that the pixels misclassifying snow as land were always in the primary Terra product. However, for days of misclassification, Aqua product shows the same results and/or classifies the pixels as clouds.*

- 4078, 18: "false snow detection“ = "false alarms“? *We are not sure about the meaning of this comment. This part of the text refers to an explanation provided by MODIS dataset provider.*

- 4083, 13-14: This is not quite correct: Higher SI values in the 2-day composites does not mean a better MODIS algorithm performance. The 2-day compositing basically rises the number of clear-sky days which finally results in a increased SI (which, in turn, says that the 2-day compositing is accurate, but it does not say anything about the SI of the MODIS snow algorithm). *It was not our intention to indicate that 2-day filter improves MODIS algorithm performance. In order to clarify this, we have revised the sentence as follows: "... In total, 2-day temporal filter decreases the number of cloudy days in the Jalovecky creek catchment to 26 and increases the snow cover mapping index to 94."*

Figures and Tables:

- Be consisten with Tab./Table and Fig./Figure in the text. *Corrected.*

- Fig.2 : it would be helpful to add the lat/long information (Some of the "open“ areas

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(H1400,B1500W) might be locally open, but it seems that a MODIS pixel covers a large part of the surrounding forest? Or what season is represented in the Google image?) *In response to this comment, we have revised Fig.2 and added the lat/lon coordinates to the caption of Fig2 and cardinal direction to show map orientation. The exact date of Google Earth image is not known, our guess would be the end of summer season (August).*

- Figure 3 is not necessary or could be included in Figure 2. *We would prefer to retain Figure 3 in the manuscript as it displays in a detail the within pixel variability of land cover.*

- Figure 4,6,8: please add a legend. *For the clarity of presentation we would prefer to describe the color of symbols in Figure caption.*

- Figure 4/Table 3: Are there no open site measurements in 2009? Or no MODIS data? *There were no snow course campaigns at open sites in 2009.*

- Figure 5: May indicate that this figure refers to Fig.4 (the same holds for the following figures, that refer to each other). *Corrected.*

- Table 3: what does "OK“ mean in the row name? *We have revised the Tables and changed SNOW OK to Snow True.*

- Figure 9: For consistency, display the missclassification in red as in the other figures. The snowmelt in the MODIS product from March 24 to the 25 in 2010 seems kind of unrealistic. Are there any explanations for this? *We have revised Fig.9 as suggested by the reviewer. The snowmelt season 2010 was rather specific, because of shorter snow cover duration an, lower snow pack mainly at altitudes below 1000m a.s.l. However it is not clear to what extent it is reflected in snow cover pattern of such relatively small catchment.*

Proper citation for the MODIS data: Hall, Dorothy K., George A. Riggs, and Vincent V. Salomonson. 2006, updated daily. MODIS/Terra Snow Cover Daily L3 Global 500m

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Grid V005. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.
We have revised this reference as suggested by the reviewer.

References: Kaufman, Y. J., Kleidman, R. G., Hall, D. K., and Martins, J. V. (2002). Remote sensing of subpixel snow cover using 0.66 and 2.1 μm channels. Geophysical Research Letters, 29(16), 10.1029/2001GL01358.

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