

Interactive comment on “Interrelationships between MODIS/Terra remotely sensed snow cover and the hydrometeorology of the Quesnel River Basin, British Columbia, Canada” by J. Tong et al.

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Received and published: 7 July 2009

1) Please define more clearly the SCF and SCE. Are they relating the number of pixels classified as snow to the total number of pixels in the region, or to the total number of snow and land classified pixels? In my opinion the latter would be more robust, but the definition is not clear.

Response: For consideration of cloud cover, we define the SCF as the ratio of the

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number of pixels classified as snow to the total number of pixels in the region. See the revised wording on lines 133-136 where this is made clearer: “Snow cover extent (SCE) and snow cover fraction (SCF) in this paper denote respectively the total area of the pixels classified as snow and the ratio of number of the pixels classified as snow to the total number of pixels in the entire QRB or some of its smaller subbasins.”

2) What is the area of Horsefly River subbasin? And how are estimated the precipitation and air temperature averages?

Response: The Horsefly River subbasin is about 2,760 km². See the revised wording at line 181: “the Horsefly River subbasin (~2,760 km²) upstream of Quesnel Lake. ...” The basin precipitation and air temperature are estimated by averaging the measured daily precipitation and air temperature at all nine in-situ stations.

3) What is the OA for removed stations? I disagree that 5-10% occurrence of snow coverage will bias the accuracy assessment (especially in this case, where only a few stations are available).

Response: The OA for the removed stations are all under 60%, which is not consistent with the general OA for MOD10A2 snow maps. Since the observed snow occurs only 5-10% of the time, the observed 8-day snow cover are totally at most 15-20 times for the eight years. Therefore, a single error in classifying snow as no snow will lead to more than a 5% UE, which lacks statistical meaning. In other words, the sample sizes are insufficiently large to conduct a robust statistical analysis of the accuracy of the MODIS snow products at the removed stations. Hence, these stations with sporadic snow cover are removed from the accuracy assessments.

4) Figs. 4, 5, 7. Please use the same units for SCF. (e.g. %)

Response: In Fig. 5, the range for the y-axis SCF is 0-1, therefore 0-100% is used as the range of the SCF. In Fig. 7, we do not use SCF.

5) Table 5 caption. It is not clear what the numbers in parentheses are?

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Response: See the revised caption on lines 781-783: “The numbers in parentheses are the times that the stations observed as snow or land, respectively.”

6) I would suggest to move the 5.1 and 5.2 subsections into the Results section.

Response: Following the referee’s recommendation, we have moved subsections 5.1 and 5.2 into the results section.

7) p.3699. Authors state: “...complex topography is a main factor to UE...”. What is the mean snow depth for underestimation cases? Are the UE errors caused by topographical shading or due to some specific local conditions of snow depth measurement? Please provide more discussion.

Response: The mean SD for underestimation cases is around 50 cm for all the 4 in-situ stations. However, the SD for underestimation cases ranges from 0 to over 150 cm. Therefore, the UE errors may be caused not only by the SD but also the specific atmospheric conditions such as fog and thin clouds when the satellite over passes the in-situ stations. Normally, complex topography leads to more variable atmospheric conditions to prevent the satellite from obtaining the signals from the earth’s surface. See the revised text at lines: 354-358: “This phenomenon suggests that the complex topography in the sub-boreal forest is a dominant factor leading to the UE of snow from MODIS (Tong et al., 2009). This may be due to the more variable atmospheric conditions and topographical shading that prevent the remote sensing instrument in obtaining clear signals from the earth’s surface.”

8) In the discussion, there are some imprecise statements. Please consider to formulate more precisely the final findings. E.g.

“There are limited evaluations of MODIS snow products in sub-boreal mountainous forests...”. Are the snow depth measurements (used for validation) carried out in the forest or on a grassy site? Are then the results relevant for subboreal forest or for a general grassy site (usually used for snow depth measurements)?

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Response: In all cases, the snow depth is not measured under a forest canopy, but rather on a grassy site. However, in the 5 km² area around the in-situ stations, the forest land cover counts for from 80% - 95% according to the 1 km resolution land cover classification. Therefore, the statistical results should represent the OA in the sub-boreal forest area.

"The OA of MODIS snow products in sub-boreal mountainous forests provides a better understanding...". I'm not sure if OA provides a better understanding. . . The recent study of Gafurov (HESSD, 2009) focuses on the full elimination of the clouds from MODIS images. Please consider to cite this study.

Response: See the revised text at lines: 501-503: "The spatial filtered MODIS snow products in sub-boreal mountainous forests provide a better understanding and prediction of the snow cover distribution and the resulting streamflow in these regions." The SF method is a more feasible, straightforward method to deal with the cloud coverage in the MODIS snow products. See the revised text at lines: 495-501: "Gafurov and Bardossy (2009) eliminate all of the cloud cover in MODIS snow products in the Kokcha catchment of Afghanistan; however, the approaches are based on different assumptions of the temporal and spatial distribution of snow cover, some of which are not well understood in the complex topography of the sub-boreal forest. The results of this study demonstrate that the SF is a feasible, straightforward method that reduces the cloud coverage to improve the snow mapping from the original MOD10A2 product."

There are several studies focusing on the interrelation between snowmelt runoff and snow cover extent. Please consider to discuss more your interrelation findings with results in existing literature.

Response: In response to this comment, more discussion is added to the Concluding Discussion. See lines: 471-485: "Many studies have examined the contribution of snow ablation to the spring freshet in high-latitude or alpine watersheds such as the Mackenzie River Basin of northern Canada (Dyer, 2008), the Upper Rio Grande River Basin

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of Colorado (Zhou et al., 2005), and the large Siberian watersheds (Yang et al., 2003). Compared to these basins, however, the relationships between streamflow and SCE in the QRB exhibits higher and more significant correlation coefficients. The hydrological cycle is complex, involving processes such as precipitation, surface water runoff, surface infiltration and groundwater storage, and evaporation. Although the terrain of the QRB is not highly permeable, groundwater may have an impact on streamflow of the Quesnel River, particularly during the low flow season (winter). However, the majority of the annual discharge occurs during the spring freshet when the groundwater has much less impacts on overall streamflow (Burford et al., 2009). This paper focuses only on the relationships between surface water storage such as snow and streamflow. Therefore, it is beyond the scope of this study to truly evaluate the groundwater contribution to the overall streamflow.” See also lines: 488-501: “In general, climate change will have multiple, nonlinear impacts on snow accumulation and snowmelt runoff. Since the QRB is located in the sub-boreal forest where snowmelt forms the majority of spring runoff, its timing is highly sensitive to air temperature. However, the results should be combined with other climate change scenarios for precipitation, evaporation, and earlier onset of photosynthesis in other areas.” “Gafurov and Bardossy (2009) eliminate all of the cloud cover in MODIS snow products in the Kokcha Catchment, Afghanistan; however, the approaches are based on different assumptions of the temporal and spatial distribution of snow cover, some of which are not well understood in the complex topography of the sub-boreal forest. The results of this study demonstrate that the SF is a feasible, straightforward method that reduces the cloud coverage to improve the snow mapping from the original MOD10A2 product.”

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 6, 3687, 2009.

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