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Hydrology and Earth System Sciences Discussions

Interactive comment on "Simulation of the snowmelt runoff contributing area in a small alpine basin" *by* C. M. DeBeer and J. W. Pomeroy

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We would like to thank both of the reviewers for their insightful and constructive comments on this manuscript. We have carefully considered the points made by each reviewer, and find these to be fair and relevant. In general, the comments highlight two key aspects of the manuscript that need to be improved: 1) more detail is required on the model parameterization and model testing, and 2) there should be more emphasis on how the results are improved and/or the significance of including the effects of inhomogeneous melt across the SWE distributions. We have addressed these two issues in our revised manuscript, along with the remaining points made by each reviewer. Our responses below describe in detail how we have incorporated these changes into the revised manuscript.

Reviewer 1: “Please be consistent whether to write numbers under 10 in words or numbers”, and “p. 980 line 24 “Mt Allan cirque” is missing a “.” after Mt.”

We have changed the numbers under 10 to be consistently expressed in numerical format, and we have corrected the term Mt. Allan.

Reviewer 2: “Fig 2 is supposed to show simulated and measured SWE. But according to chapter 2 there has not been continuous measurements of SWE, only continuous measurements of snow depth.”

We have added the following statement in the section Study Area and Field Methods of the revised ms to clarify how the SWE series were derived: “Bulk snowpack density measured in the pits near the stations (on a semi-weekly basis in spring) were interpolated over time and used to convert SR-50 snow depth measurements into continuous SWE series (Fig. 2). New snowfall depths were assigned a density of 150 kg/m3.”

Reviewer 2: “One of the key results, Fig. 3, is difficult to understand. . .I think you need to explain more in detail how this simulation was done.”

We have added the following statement in the section Simulated Melt Rate – SWE Associations to clarify how the simulations were performed: “In each case, the model was run from initial conditions beginning on 1-Mar and the simulation ended once the snow disappeared. Thus, melt rates associated with shallow SWE later in the melt period were based on the remaining snowpack from simulations with greater initial SWE values, rather than initializing the model with shallow SWE at later times in the melt period.”

Reviewer 1: “p. 979 line 19: The next two paragraphs explain the model calibration. A more detailed explanation of this process would certainly enhance the clarity and transparency of this process to the reader.” Reviewer 2: “I claim that the selection of the "maximum active layer thickness" (which is a parameter in the model) is quite critical for what we see in Fig. 3 at the beginning of the spring melt (the early melting for shallow snowpacks). Did you investigate that?"

We have addressed these issues by adding more detail in our explanation of the modelling procedures, parameter selection, and model evaluation in the revised manuscript. We have added the following statement in the section Snowmelt Modelling and Validation: "The performance of the model was assessed through visual comparison of the results and the corresponding observations at each site; root mean square (RMS) errors between the results and observations provided a quantitative measure of the model performance." Also, we have provided more detailed descriptions of the choice of value for each parameter in the model in this section. Specifically, with respect to the selection of the maximum active layer thickness, we have added the following statements: "The maximum active layer thickness was assigned the default value of 0.25 m used in Snobal. The results were sensitive to this parameter (discussed in the following section), but this value produced the optimum results in combination with the other chosen parameter values". In the next section (Simulated Melt Rate – SWE Associations) we discuss how the results were sensitive to this parameter. The following statements were included here: "The simulated melt rates during this early phase were sensitive to the maximum active layer thickness parameter in the model. Other factors equal, smaller values of maxz,s0 produced higher melt rates. Differences of up to 10 mm/d over the range of 0.01 m > maxz,s0 >1.0 m were observed for various SWE depths. However, the value of 0.25 m was found to give results that corresponded well with observed melt rates in the validation process at all sites. Further, the overall patterns of variable melt rates over the range of SWE depths were not significantly affected when this parameter was held fixed while initial SWE was varied."

Reviewer 1: "Unless I've missed it this is the first time that the authors mention that their approach is limited to basically non-vegetated surfaces. A clear statement of this fact earlier in the paper (i.e. Method Section) would be helpful in my opinion."

The following statement now appears in the final paragraph of the Introduction section: "The approach we develop and use in this study is meant to be applied over open,

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sparsely vegetated alpine slopes."

Reviewer 2: "It is a particular problem of this manuscript that only results from one single winter (except Fig. 2, which is not a key-result of the addressed issue) are shown. This leaves the question unanswered how general the shown effect is. We don't know too much about the weather conditions of this particular spring. So it's hard to know if this spring was typical or special in some way. Consequently, we are not sure whether the observed effect of an inhomogeneous melt is typical or maybe an exception." It would be difficult to show how general this effect is by including results from a variety of seasons with different conditions. However, we have tried to more clearly elucidate the effect of the melt rate variability in the context of this particular spring by including a new figure (Fig. 3) showing the daily average air temperature and daily precipitation throughout the later winter and spring. We have included the following discussion in the section Simulated Melt Rate – SWE Associations to provide insight on the particular conditions during this season and how representative they are of the general conditions: "Figure 3 shows the observed air temperature and precipitation series at Fisera Ridge for the spring of 2008. There were some early, but short-duration melting events in the month of April, when average air temperatures were above freezing for several days. The main melt period was during May and June, but was frequently interrupted by heavy snowfall events and periods of cooler weather. This pattern during the melt period is characteristic of most springs in the alpine zone of Marmot Creek and common in the Rocky Mountain Front Ranges."

Reviewer 1: "Figures 4 and 5: These are in my opinion two key figures of the paper as they show the improvements made in the prediction of the SCD when using the inhomogeneous melt approach developed by the authors. While a qualitative improvement is clearly visible and discussed in the paper, it would certainly be nice to have an objective statistical comparison (e. g. regression coefficient, average errors between the two predicted and the observed area fraction) that would allow the quantification of the improvements. A short mention and discussion of this analysis should then also be included in the text." Reviewer 2: "There are only few results presented demonstrating that a simulation with inhomogeneous melt yields a better correspondence with observations than a simulation with uniform melt. We see that on the south-facing slope for the period 26 April to 6 May (Fig. 4b and 5b), but for all other events and for the North-facing slope it is not clear to me. So in conclusion, there is not a strong evidence in the presented results that we improve the snowmelt simulation with the inhomogeneous melt."

We have addressed these comments thoroughly in the revised manuscript. First we have included a new table (Table 3) to provide the RMS errors between the simulated and observed depletion curves (early melt period and entire spring) for the north and south-facing slopes, as well as the aggregated basin. We have revised the previous Figures 4 and 5 to show slightly adjusted results that were obtained from applying the modelling framework after 13-May, 2008 based on SWE distributions at this time (peak accumulation). We have also revised the previous Figure 6 to include aggregated simulations from both uniform and inhomogeneous melt, as well as the observed basin scale SCD curve. The revised manuscript now provides an improved qualitative measure, and a quantitative measure of the improvements at different times and spatial scales. We have added the following discussion in the text: "Both approaches (uniform applied melt and melt computed for different SWE depths) yielded similar SCD curves that corresponded reasonably well with the observations, except for problems with the simulated snowcover decline at the end of May. The similarity in these curves between the two approaches was due to the fact that the variation in melt rates across the distributions of SWE were less pronounced later in the snowmelt period. However, at several times this variation following cooler periods and new snowfall events did have a minor effect on the rescaled depletion curves by initially accelerating the areal SCD. Despite this, only slight improvements resulted from including simulations of inhomogeneous melt over the entire snowmelt period in the spring (Table 3)." Further, in describing the aggregated results representing the basin scale simulation, we have added: "Comparison of the aggregated results based on uniform and inhomogeneous melt with the observed basin scale SCD curve shows an improvement when accounting for melt rate variability over SWE distributions and individual slopes, particularly in the early melt period (Fig. 7; Table 3)." The Discussion and Conclusions section of the manuscript highlights how consideration of the melt rate differences amongst different classes of SWE depth at different times is important to realistically derive an estimate of the snowmelt runoff contributing area. Thus, although the simulated SCD curve may not be significantly improved at later times in the melt period by including inhomogeneous melt, it is still important to consider the effect that this variation has over a cold and redistributed snowcover in terms of the evolution of the SRCA. This is one of the main points we are attempting to show through these simulations.

Reviewer 2: "The authors' awareness of related work that has been done is confined to studies in North America. There is actually also recent and ongoing work in other parts of the world dealing with the spatial simulation of the snowcover in alpine terrain. This should be referred to as well."

We have included additional references to related work done outside of North America in our revised manuscript. These include: Anderton et al. (2002), Anderton et al. (2004), Fierz et al. (1997), and Fierz et al. (2003). These studies are indeed relevant to the current work with respect to spatial simulation of snowcover, parameterization of internal snowpack energetics and spatial distribution, and findings on the importance of representing internal processes to obtain best results (and the time scale over which such consideration is important).

Anderton, S.P, White, S.M., and Alvera, B.: Micro-scale spatial variability and the timing of snow melt runoff in a high mountain catchment, J. Hydrol., 268, 158–176, 2002. Anderton, S.P, White, S.M., and Alvera, B.: Evaluation of spatial variability in snow water equivalent for a high mountain catchment, Hydrol. Process., 18, 435–453, 2004. Fierz, C., Plüss, C, and Martin, E..: Modelling the snow cover in a complex alpine topography, Ann. Glaciol., 25, 312–316, 1997. Fierz, C., Riber, P., Adams, E.E., Curran, A.R., Föhn, P.M.B, Lehning, M., and Plüss, C.: Evaluation of snow-surface energy balance models in alpine terrain, J. Hydrol., 282, 76–94, 2003.

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Interactive Comment