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Hydrology and Earth System Sciences Discussions

Interactive comment on "A simple model for local scale sensible and latent heat advection contributions to snowmelt" *by* P. Harder et al.

Anonymous Referee #1

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General comments:

This work presents a simple model for the advection of sensible and latent heat, which is very welcome in hydro-meteorological studies. A certain strength of this study is the availability of experimental data presented by Harder et al., (2017). Generally, the manuscript is well written and presents interesting results on the effect of heat advection, especially the relative contribution of latent heat versus sensible heat considering different upwind surfaces. I encourage the authors, however, to improve the structure of the paper, which is confusing at some parts – especially in the results section. In its current form the manuscript provides information dropwise and some is missing (mainly in the methodology part). Also, the authors miss to introduce the process of heat advection and the complex nature of resulting heat exchange over snow. Although the

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Discussion paper

model is a simplified approach not accounting for some of the processes, the interaction between heat advection and boundary layer development over patchy snow covers should be shortly explained in the introduction part. The presentation of the model results is a bit vague, especially when the authors explain the non-existing difference in the energy balance when using heat advection and without using it. The explanation is not very convincing to me. This part certainly needs improvement. Furthermore, the effect of heat advection is based on one certain model input. A kind of sensitivity analysis with at least varying relative humidity, air temperature and wind speed would provide a better estimate of the range of relative contribution of heat advection to total melt energy.

Detailed comments

1. Introduction:

The references are very limited and only refer to model approach of heat advection. The process itself and how it affects the heat exchange over snow is very complex and should be introduced here. Already published experimental studies on the influence of heat advection on the boundary layer and heat exchange over patchy snow covers are not referenced at all (Mott et al., 2016 and Mott et al., 2017) or are not discussed in the introduction (Harder et al., 2017). The number of recent scientific studies on local heat advection are very limited. To highlight these efforts in the last few years these results should be discussed and referenced here to motivate the study presented here and the need for a new/extended model approach! There is also one new approach, a temperature footprint approach, presented by Schlögl et al., (under review, but close to acceptance). If the work is accepted earlier, it would be interesting for this study to give a comparison of model estimations of the effect of heat advection to total snow melt.

Please add Sauter and Galos, 2016 to the references as they also applied LES to simulate local heat advection, but over glacierized area.

2. Methodology

P3: In addition to the reference to Harder et al. (2017) I would like to see a very brief description of the SSAM model, especially in comparison with the EBSM model. This will be important for later comparisons and interpretations of model results. Although references are given, the paper should stand on its own and should provide all information necessary to understand the methodology.

EBSM: here it would be worth to already mention the indirect consideration of the patchy snow cover in the model by the mixed albedo approach and how this is implemented in the model (briefly).

2.1: an information on the development of SCA in the model area would be very interesting as in many areas the patchy snow cover duration is very short, compared to the continuous snow cover situation. This means that the effect to total snow melt can be rather small and strongly depends on the spatial snow cover distribution. Snow covers with a high spatial variability will show a longer period of patchiness, thus stronger influence of heat advection to total snow melt. Also, this should be discussed in the results part.

P4: how do you determine the atmospheric stability, you use for coefficient b? Does this refer to the upwind stability only or also to stability over snow? Even if this information is provided in Granger et al., 2002, such information is critical for understanding the methodology.

You are using fixed atmospheric conditions to test the effect of heat advection: Of course, chosen relative humidity, air temperature and wind velocity have a large effect on the results and a sensitivity analysis would be very important at this point. At least cases with low and high humidity should be added to this analysis – the same for wind speed and temperature. This is especially important when showing the differential behavior between dry and wet upwind surfaces, as the atmospheric stability and the boundary conditions of air temperature are very important for the results.

3. Results: Section: 3.1.:

Especially the neutral stratification approach is very problematic as very high stabilities and instabilities can develop due to advection processes. Strong atmospheric stability, for example, will lead to a decoupling effect (see Fujita et al., 2010; Mott et al., 2016; Mott et al., 2017), preventing heat advection to be transported towards the snow cover. Of course, such processes cannot be accounted for by such a simple model, but these limitations need to be discussed somewhere in the results section.

Also note that this approach is highly sensitive to an accurate estimation of atmospheric conditions (stability). This should be clearly stated in the text.

P10, L7: please write boundary layer depth instead of simply saying boundary layer.

P11, L8-10: this sentence should be reformulated – I do not really understand the meaning of this because it is still an average and not a total rate. Advection is only active over a certain fetch distance over snow. This means that a decreasing snow cover fraction not necessarily means that the areal average melt rate/energy decreases. I would even say that the opposite is the case because the percentage of snow pixels affected by heat advection increases resulting in an increase of the mean average melt.

Figure 7: I really like this figure as it nicely shows the fluxes depending on SCA and for the different setups. This figure is, however, not really discussed in the text. Interestingly, not only the net advection flux changes when considering wet or dry upwind source areas, but also the peak of the flux is shifted to later stages in the melting period. Please also discuss this point in this section here, because this has a very strong implication for the effective duration of the melting period and thus snow hydrology.

P12: section 3.3.: This section on the implication of process representation is not clear to me. Please explain more clearly why an implementation of advection processes to the energy balance term does not really change the SWE depletion curve. Is this explained by low frequency of clear days favoring energy advection? How do you explain lower areal averages of snow melt for the earlier year when considering the advection process?

P12: L 12-15: SSAM and SLHAM-SSAM simulations do not only show very small differences in SWE depletion but also in the calculated fluxes – which is not explained here.

P12/L20: what do you mean with vertical snow-atmosphere fluxes – turbulent fluxes of sensible and latent heat? Also, this explanation is very vague.

P12/13: section 3.4.: yes, the energy fluxes will compensate each other in case of dry upwind surfaces, but the sensible heat fluxes are therefore larger leading to larger net fluxes. Reading the text at is presented now, it appears as the compensation leads to lower net fluxes for dry surfaces than for wet surfaces. This is also shown in Figure 7. Table 6 shows that including advection does not really change the turbulent fluxes above snow? Can you explain that more in detail?

Section 3.6.:

The authors already provide a limitations section. Within this section I would like to see a short discussion on processes that are not covered by the presented approach but are shown to be important for situation with strong heat advection. Such processes are mainly induced by the increase of local stratification close to the ground leading to a suppression of the advection effect or even decoupling effects (these results are discussed in Fujita et al., 2010; Mott et al., 2016 and Mott et al., 2017). As mentioned earlier, I strongly miss the connection to experimental findings (apart from Harder et al., 2017) achieved in the last years. This also means a discussion on the complex nature of boundary layer development during advection situations, which of course is difficult to include in a simple advection model. The reader should, however, be aware of this.

Also, heat advection is strongly reduced in the downwind distance over the snow patch. This strong dependency of heat advection on fetch distance has strong implications of the spatial snow melt dynamics and the duration of the melt season. I would like to see a discussion on limitations that are connected to areal average advection.

Conclusions:

Model results indicate that advection constitutes an important portion of melt energy: 11% of the melt observed in the 2016 snowmelt season. I am bit confused because Table 6 (also Figure 9) shows almost no difference in turbulent heat fluxes when using the advection model???? The authors try to explain this in section 3.3.2, but this explanation is still not very convincing.

Additional information on the mean snow patch size and duration of patchy snow cover is important for your model estimation of 11%. Furthermore, an upper limit of the contribution of heat advection to the total melt energy, depending on snow patch size distribution and duration of patchy snow cover would be highly interesting.

Although not published yet (but very close to acceptance) the paper of Schlögl et al., 2018, presents estimates on the effect of heat advection of total melt rates of a catchment (increase of melt rates of approximately 3- 5%). As these are the first studies really estimating a contribution of advection to melt energy for the whole melting season, these results should be compared.

P 15, L11: a "to" is missing here ntroduction:

Table 6: what is the unit here?

These references need to be added:

Sauter and Galos, 2016: Effects of heat advection on the spatial sensible heat flux variation on a mountain glacier, The Cryosphere, 10, 2887-2905,2016.

Fujita et al. (2010): Fujita,ÂăK.,ÂăK. Hiyama,ÂăH. Iida, andÂăY. Ageta (2010),ÂăSelfâĂŘregulated fluctuations in the ablation of a snow patch over four decades,ÂăWater Resour. Res.,Âă46, W11541, doi:10.1029/2009WR008383.

Mott et al., 2016: Mott, R., Paterna, E., Horender S., Crivelli, P., and Lehning, M.: Wind tunnel experiments: Cold-air pooling and atmospheric decoupling above a melting snow patch, Cryopshere,10, 445-458, 10.5194/tc-10-445-2016

Mott et al., 2017: Impact of Extreme Land Surface Heterogeneity on Micrometeorology over Spring Snow Cover. J. of Hydromet. , DOI:Âă10.1175/JHM-D-17-0074.1.

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