The Cryosphere Discussions

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Comment on tc-2021-171

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Referee comment on "Understanding wind-driven melt of patchy snow cover" by Luuk D. van der Valk et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-171-RC2, 2021

The paper presents a very interesting study discussing wind-driven processes that affect the energy balance of a melting patchy snow pack. Recent studies have demonstrated that heat advection processes significantly contribute to total snow melt. However, the implementation of the advection process in snow-hydrological studies is very challenging and several approaches have been suggested by other studies. None of these approaches are currently used in larger-scale snow-hydrological models. Thus, the topic of the study is highly relevant and the study is an important contribution to the snow-hydrological community. The paper provides an interesting approach using DNS to calculate turbulent heat fluxes affected by heat advection processes over a patchy snow cover situation. They further present a scaling approach to relate the sensible heat flux to the patch size and conducted snow melt observations at a snow patch. There are several questions regarding the methodology and process description and representation which need clarification and revision. Please consider revising the manuscript considering major and more specific comments below.

General comment:

- The authors describe a process they term *advection of turbulent heat flux* and reference studies discussing local advection of sensible heat as described in Mott et al. (2018) and also Harder et al., (2017). It is not clear to me to which term the authors are really relating to as it seems to me that they mix up advection of sensible heat with the vertical turbulent sensible heat flux. The ambiguity becomes particularly clear when the authors compare modelled sensible heat fluxes with estimated advected sensible heat as presented in Harder et al (2017). I recommend to include equations where they clearly state at which terms they are looking at and how these are calculated. Equations for advection of sensible heat are presented in Harder et al. (2017) and Mott et al. (2020).

- The Introduction of the process and its relevance could be extended to allow the readers an easier access to the very complex interplay of near-surface boundary layer processes that become important over patchy snow covers. I think that the manuscript would particularly benefit from a more detailed background (also including "older" studies) on wind-driven heat exchange processes, the development of internal boundary layers (.e.g. Granger et al., 2002; Essery et al., 2006) and the local advection of sensible heat (e.g. Marsh et al., 1999).
- The connection between the experimental and the numerical part of the manuscript is not totally clear to me. For the experimental part, the study would particularly benefit from a more detailed analysis on the spatial aspect of the process, i.e. analysis of fetch distance related snow melt and advection estimates. What is the added values of the experimental part?
- Why are such extreme boundary conditions used for the DNS leading to unrealistically high calculated turbulent heat fluxes? In my view, more representative meteorological boundary conditions (i.e. matching up with the conditions at the observed snow path) would provide more meaningful conclusions. Also, Schlögl et al. (2018a) did a similar modeling study using ARPS. Please set your results more in context of this recent study. What are the benefits of using DNS? How do the results compare? What do we learn? How can we represent the process in larger-scale models?

Specific comments:

- L 39: Warm air advection is AN important source for the energy balance but not generally the main cause of snow melt. Please change the sentence accordingly.
- L 46-50: While the introduction to the process is correct, the sentence in L46/47 does not describe the process that is typically described as local advection of sensible heat (as by Mott et., 2018; Harder et al., 2017): Local heat advection is generally understood as a process where the mean wind that transports the warm air from snow-free towards snow-covered area. It is NOT the horizontal gradient in air temperature which initiates this process like sea breezes. The process is defined in Mott et al. (2020) as "Horizontal transport of sensible (and latent) heat with the mean flow" and can be written as wind speed*dT/dx (For further details also see Mott, R., Stiperski, I., and Nicholson, L.: Spatio-temporal flow variations driving heat exchange processes at a mountain glacier, The Cryosphere, 14, 4699–4718, https://doi.org/10.5194/tc-14-4699-2020, 2020.). The process as described in studies of Mott el. (2015,2018, 2020) and Harder et al. (2017) not refer to the advection of turbulent heat fluxes which would be defined as: U * d/dx(w'T') + U*d/dx(w'q'). As you refer to advection of turbulent heat fluxes throughout the manuscript, it is very important that you include equations on the terms you are analysing.
- The process of advection of heat was found to be not only an important process over snow patches but also for ice fields (Mott et al., 2019) and glaciers (Sauter and Galos, 2016; Mott et al., 2020) potentially affecting snow melt processes there. Please include this in your intro to provide a more complete picture of the process and the importance for glaciers mass balance studies as well.
- L 59: Please also mention rain on snow events as situations where TI models drastically fail.
- L 76; as you reference both Schlögl et al (2018) paper you should introduce 2018a and

2018b.

- L79: this is not entirely correct as Schlögl et al. (2018b) did snow ablation and turbulence measurements over three entire ablation periods.
- L 83: "This advocates the use of spatial field observations, however, most methods for estimates
- on small spatial scales are relatively expensive or come with low precision and accuracy" here you should reference studies using TLS to measure high-resolution snow ablation rates (Grünewald et al., 2010; Egli et al., 2012; Schlögl et al., 2018b).
- L110: Although not being an expert on photogrammetry, I think it is not fully correct that you state that you are using SfM – you are actually using stereophotogrammetry as structure from motion implies that the 3D structure was created using camera movement.
- L114: can you shortly explain how those measurements serve as a basis?
- L129: Please elaborate on how you used the meteorological data in 2.5 km distance from the actual field site. Have you applied any spatial interpolation to data to account for elevation difference or local terrain effects (e.g. wind, radiation)?
- L134: Why did you not measure the spatial distribution of snow ablation over the entire snow patch? How did you determine the local wind direction? Also, was the wind fetch always constant through the measurement time period?
- L139: why did you not measure SWE for the entire snowpack? Doing so at different sites with different snow depths would allow a more precise information on SWE of the snowpack at the snow patch. Was the snow pack already isothermal at the start of the measurement campaign?
- L159: would be nice to show the resulting snow ablation map of the snow patch retrieved from SfM.
- Figure 1: the small figure is not clear to me. Are white areas still snow-covered? Is this an orthofoto? How did you determine the local wind direction?
- L 161: what do you mean by assuming a snow albedo between 0.6 and 0.8? changed the value in time? Can you provide a reference for choosing those numbers? The albedo value has an extreme effect on your energy balance calculation and your estimated contribution from turbulent heat fluxes.
- L174: the relative humidity was measured at the large-distance test site?
- L 187: local scale advection of what? Also, it is not clear how measurements of Harder have been used for the idealised system. What did you use for what exactly?
- Figure 2: Please insert the meaning of the parameters in the figure caption. It is not easy to understand what the figure is showing.
- L 195: if theta_atm is the temperature of the atmosphere – what is theta then? The surface temperature of snow/bare ground? Please define.
- L 318: how do you define up-wind and downwind edge? is it the first grid cell? How do you deal with grid cells which become snow-free during the observation day? The daily-melt rate will be underestimated if you also consider pixels which become snow-free during a measurement day. Would be interesting to see a snow ablation rate curve depending on fetch distance.
- L336 and table 4: Please provide more precise explanation on your estimate ranges. Please also state whether any spatial interpolation is done to the meteorological variables or not.
- L337: is that the length of the sow patch?
- L343: I assume that you are taking the difference of snow melt due to radiation (equation2) and the actual snow melt to estimate the contribution of the turbulent heat flux. Please add more information how you exactly calculate the turbulent heat flux (latent and sensible turbulent heat flux?)
- L353/354: and how does this compare to the contribution at the downwind edge? As mentioned earlier it would be extremely interesting to have a fetch distance related estimate of the contribution of turbulent heat fluxes (sensible and latent). Also, if you provide a number of 60-80% contribution at the upwind edge – what does this exactly mean? Over which area? As known from other studies, the contribution strongly

changes with fetch distance. These high numbers of 60-80% might be very misleading looking at the relevance for the catchment scale snow melt. It would be very interesting to see an analysis on the contribution of heat advection to total snow melt for varying snow patch sizes and snow cover fractions. Furthermore, the relative contrition of heat advection to total snow melt strongly depends on the spatial variability of snow depths as snowpacks with a high spatial variability of end of season snow depths are typically characterized by a longer time period of the patchy snow cover stage and therefore a higher importance of the heat advection process. A more detailed discussion would allow a better comparison to the study of Schlögl et al., 2018a. Please relate to results of Schlögl et al. (2018), who tried to put the local scale estimations into the catchment scale context to draw conclusions for its relevance.

- Section 4.1: These estimations include many uncertainties (snow density differences depending on snow height, differences in shortwave radiation between snow patch and actualmeasurement location due to terrain shading, albedo). The high number of turbulent heat fluxes at the surface do not tell us how much of this turbulent heat flux originates from the higher air temperatures at the upwind edge caused by the local advection of sensible heat. Regarding the uncertainty in the net shortwave radiation the authors should consider doing radiation modelling for the area for the respective time period including high-resolution terrain information.
- Figure 5: the authors are quite lazy with terms – please clearly state sensible turbulent heat flux as it has to be clear that this is the turbulent exchange of sensible heat.
- L366: if I understand it correctly you describe here the turbulent sensible heat flux per grid cell and not the heat advection. These values are extremely high. You compare these with estimates of Harder et al (2017) (L273) but they are providing estimates on the advected sensible and latent heat between two points and not the advected turbulent heat flux (paper Harder et al., 2017; equation 2 and 3).
- L405: I do not fully understand the sentence here. For the local advection of sensible heat not the difference between snow surface temperature and air temperature is important but the horizontal air temperature difference (and mean horizontal wind speed).
- L406: the reduction in the turbulent sensible heat flux of 20% in downwind distance is most probably the result of a decreasing contribution of the advection of sensible heat with increasing fetch distance over snow.
- L409: yes, exactly, the difference arises as you compare the simulated turbulent sensible heat flux at the surface (by your model) to an estimation of the advected sensible heat calculated by Harder et al. (2017).

Reference suggestions:

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