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The Cryosphere Discussions

Interactive comment on "Effects of local advection on the spatial sensible heat flux variation on a mountain glacier" *by* Tobias Sauter and Stephan P. Galos

Anonymous Referee #1

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General comments

The authors Sauter and Galos present a pseudo-reality case study of meteorological conditions over glaciers in the Bozen Province of Northern Italy. Their work demonstrates, using detailed Large Eddy Simulations (LES), that surplus energy associated with local wind systems produces significant increases in sensible heat fluxes above the glaciers. The study presents comparative results from LES simulations and the commonly adopted bulk approach based on Monin-Obukhov theory as well as highlighting a key problem of site 'representativeness' for forcing data in distributed models. Overall, the work is well written and presented. The approach is novel and emphasises a key problem in the literature which is so often dealt with using over-simplified ex-

trapolation techniques. Recent works have indeed demonstrated how inadequate the extrapolations of temperature from a few sites can be and which often do not account for boundary layer effects or local wind conditions. Although I suggest some minor revisions to the discussions manuscript, I would recommend this work for publication in The Cryosphere due to its scientific quality and significance.

Due to the computationally intensive nature of the LES, it is understandable that a small timeframe is most suitable to demonstrate the expected variation of sensible heat fluxes over the glaciers. However, I think the paper would benefit from having more detail on the conditions of the hour for which statistics are presented. The authors describe a blue sky condition which is known to be favourable for the development of a katabatic boundary layer, however the strength of the boundary layer can also be affected by the ambient air temperature (data from the off-glacier sites seen in Figure 1 could aid this). Furthermore, could the LES be compared with a cooler/cloudier hour? Though adding some extra work, I think this would benefit the scientific community and be informative for when (under which conditions) sensible heat fluxes are most likely to be inadequately modelled.

As the work details, the LES is not required to be an observed real-world case, as the realistic simulation of processes and their spatial variation is key. However the authors indicate several weather stations in Figure 1 (which are not used). It would be interesting to present what the actual lapse rate on glacier would be and also compare the calculation of sensible heat fluxes using this measured data. If no AWS measurements are to be utilised in this study, please remove them from the figure.

The authors also outline several sub-regions and 'virtual' sites of interest on Zufallferner though with no clear justification for why. I think it is important to demonstrate the spatial variation of wind fields along a glacier centreline and focus on specific sites (i.e. Z1-Z4), particularly when attempting to simulate and understand interactions of the glacier boundary layer with synoptic scale winds. Furthermore, the selection of temperature extrapolation locations is important although often somewhat arbitrary in many studies.

However, the presentation of several different sites between figures (Figures 7,8,9 for example) and their naming conventions (Z3 changes to Za then to Zc) is misleading. The authors should add some additional reasoning to their choices of virtual sites. The authors should also guide the reader to aspects of figure subplots by labelling them (i.e. a-d). Misleading information for Figure 3 is particularly noteworthy.

Finally, while it is clear from section 1 what the problems of the literature are (and it is very well written), I think it is important to stress in a little more detail what the aim of the paper is and add some more discussion regarding the applicability of an LES approach at the end.

Specific comments

1 7: Add the temporal scale for which of the flux over- and under-estimates are found (i.e. 1 hour of statistics).

1 18: Re-word “loss of information”.

2 10: I think it is important to stress that this “over 50%” contribution from turbulent heat fluxes is typical for overcast conditions or for maritime glaciers (as is given by the studies you cite –e.g. Cullen and Conway, 2015) as otherwise the dominance is typically from shortwave radiation. For your study you assess a clear sky condition and a continental glacier.

2 13: Replace “peculiar” with “particular”.

2 25-26: Though I agree that there is still much to be understood about the impact of these assumptions on glacier melt rates, citing some of the work which has made attempts to use distributed temperature for this purpose would be suitable here. For example, Immerzeel et al. (2014) investigate this for a catchment/valley scale and Shaw et al. (2016) investigate this for a debris-covered glacier.

3 19: I assume here that you refer to the surface boundary layer for “SBL”? Write out in full before using the acronym.

3 20: What does SGS refer to? Write out in full as well.

4 4: A minor point, but you are missing an equation number for eddy viscosity (this should be eqn 7).

4 9-11: This sentence needs re-writing. It is unclear what it is trying to say and the sentence has syntax errors.

5 2: Changes in temperature and phase from radiative forcing would be relevant if the LES approach was adopted over a longer time-frame. This may be worth adding to the discussion?

5 16-17: How is the topography representative of many in the European Alps? Can you also add the mean slope of the glacier to this section?

5 21: What grid size do you use for the ERA-Interim reanalysis data? Is this re-sampled from the 6 hourly temporal scale of ERA-Interim? Additional detail would be useful here.

5 28: Specify if the 100 m temperature is that from the ERA-Interim.

6 2: Why 8 m/s-1? Is this the mean value from the given six hour period of the reanalysis data?

6 8: It is unclear what you mean by this - “some sort of model”. Please re-word this sentence.

6 23: How did you derive these values of z0? While your z0 fits within the range of published values (as you discuss later in section 3.4), a reference here would be useful. Do you have different values for snow and ice or is the spatial variation for all on-glacier surfaces constant? It would be interesting to plot the snowline for this day on to Figure 1 if it is known. Are the effects of different on-glacier surfaces (snow/ice) important here, considering a constant 273.16K surface temperature?

6 28: What is the hour of the 12th August that is being reported in this paper? I think

this may be relevant for the time of day on the glacier and the expected temperature outside the glacier boundary layer and possible shading effects etc.

7 8-9: Has the size of computational domain been altered to test the resultant differences in turbulent energy generation?

7 9: What is meant by opposite DEM boundaries? I think that a new figure providing a schematic of the layers/grids used for the LES would be very useful, albeit selective of the key things to include. The description of the LES model is detailed well, though considering it comprises a large proportion of the paper, the addition of a figure could be beneficial to aid the reader.

7 15: Remove “very”

7 18: Remove “it turns out that” and add a supporting reference for M-O application.

8 14: Why these sites? Please add some brief justification/description.

8 15-16: Remove “Apparently” – Spelling mistake “luv” – Assumed to be “lee”?

8 25: Replace with “Generally, katabatic winds. . ..”

9 7: “for mountain glaciers during CLEAR sky conditions”.

9 12: “Similarly, ...”

9 12-14: The downslope winds at Z4 would also be weaker due to a minimal fetch of the boundary layer too.

9 16: Please add the wind direction cases to Figure 3 as they are currently just interpreted from the same positioning as Figure 2. Also, it would be beneficial to add letters a-d to all subplots to more easily direct the reader to the appropriate information from the text.

9 16-17: This doesn’t appear to be the case for the bottom left figure, which I assume to be the Northerly wind case. Are the authors only referring to the westerly (upper left)

case here?

6 15-20: I think this paragraph could do with greater clarification about which cases are being described. Again, some detail about conditions during the considered time period would be interesting. Does the free-air meteorology represent the typical cycle of the region?

10 2: Change “shapening” to “ ,shaping”.

10 15: Rewrite as “More importantly, the distortion. . ...”

11 1: Rewrite as “On the one hand, distributed mass. . ..”

11 5-6: spelling correction “of course”.

11 18: I think adding Brock et al. (2006) here would be suitable.

11 31: remove “used”.

13 1: Again, I think some justification for these two ‘virtual’ points is needed.

13 2: Change the acronyms here and elsewhere in the manuscript as Z0 and z0 (roughness) are too similar.

13 20: It is not clear where in Table 2 that 7 Wm -2 is derived from. Please clarify. Is this underestimated relative to the LES for just the west case, 6.9 Wm-2?

13 26-28: To my understanding, Figure 9 shows the differences in sensible heat fluxes between the LES and bulk method when data are extrapolated using lapse rates (Table 3) between different site combinations. It is not clear however whether a particular wind case (of the LES) is presented in the figure. As mentioned earlier, the naming convention and the way in which it changes between subsections of the paper is confusing and needs changing. Furthermore, although the test of lateral sites is interesting and an important aspect of glacier micro-meteorology to consider, why was site Zb selected in its current position? Was this randomised?

13 29-30: Re-word “lack to reflect”

13 30: You mention variability in time. However, this paper is only demonstrating statistics for one hour (p6, l27-28). Although it is likely that the bulk approach would poorly represent this temporal variability, Figure 9 does not show it.

13 32: Refer to Table 3 here.

14 1: “Similarly, ...”

14 1: I think it is better to refer to a “shallow” temperature gradient/lapse rate rather than “small”, however, the scientific community does not always agree on this and it is a minor point.

14 4-5: This is a crucial point, though it could perhaps be supported with measured data as well, which will still represent relative temperature differences at two on-glacier locations (through use of lapse rates) even if the LES isn’t designed here to represent the observed absolute values.

14 7: replace “what generates” with “that generates”.

14 12: Perhaps re-word this as we are talking about a much small period of time than just a summer.

14 16: Check the consistency of spelling using British/American English – here referring to “Parametrised” - (http://www.the-cryosphere.net/for_authors/manuscript_preparation.html). (See p11, l15 / p12 l9 etc)

14 24-25: The difference in lapse rate between Z0-Za and Z0-Zc is strong, presumably due to the heat advection from the south west ridge of Zufallferner (Box R1). I think it would be useful to refer explicitly to this potentially large difference over a small (200 m?) distance on the glacier.

Cited literature

Brock BW, Willis IC and Sharp MJ (2006) Measurement and parameterization of aerodynamic roughness length variations at Haut Glacier d’Arolla , Switzerland. J. Glaciol. 52(177), 281-297

Immerzeel WW, Petersen L, Ragettli S and Pellicciotti F (2014) The importance of observed gradients of air temperature and precipitation for modeling runoff from a glacierized watershed. Water Resour. Res. 50, 2212–2226 (doi:10.1002/2013WR014506)

Shaw T, Brock B, Fyffe C, Pellicciotti F, Rutter N and Diotri F (2016) Air temperature distribution and energy balance modelling of a debris-covered glacier. J. Glaciol. 62 (231) 185-198 (doi:10.1017//jog.2016.31)

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