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The Cryosphere Discussions

Interactive comment on "Insights into the effect of spatial and temporal flow variations on turbulent heat exchange at a mountain glacier" *by* Rebecca Mott et al.

Anonymous Referee #1

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This paper sets out to examine the interaction between katabatic and across-glacier glacier flows, and how this contributes to turbulent heat exchange. To my knowledge, this is one of the largest and best quality datasets exploring this complex interaction.

I found the writing compelling, but I'm not certain I would have reached all the same conclusions by looking at the data. Apart from computing fluxes, the quantitative analysis contained in this work did not extend much beyond correlation coefficients. Given the volume and complexity of the data and day-to-day variability, almost all figures presented could benefit greatly from more quantitative analyses. Because of this, it is not clear which conclusions are truly substantiated by their data and which are a product

of statistical outliers influencing qualitative analysis. This work could also benefit from more robust analysis of magnitudes and sources of possible uncertainties.

Specific comments:

-"Sensitivity analysis, however, shows that this increase is no considerable even when reducing the surface roughness by an order of magnitude." A number for what they deem "not considerable" would be helpful.

-The authors delineate wind regimes as "katabatic situations" and "disturbed situations". Although grammatically correct, I don't feel that "situation" is the best choice of words here. In the caption of Figure 3, the authors use "katabatic conditions" and "disturbed conditions", which feels more appropriate. As an alternate, I suggest "katabatic flows" and "disturbed flows".

-The authors state, "Following these observations, the position of the jet-speed maximum can be estimated by linear interpolation between two heights where momentum fluxes are measured (Grachev et al., 2016). This estimate assumes that the momentum flux decreases linearly, and can be applied confidently only if the jet maximum height happens to be between the two measurement levels." I understand that it won't work if the jet maximum height occurs outside of the two measurement levels, but this reads that they are confident that linear interpolation is appropriate (which they later state provides a crude estimate).

-"Flux footprints tend to be smaller during disturbed situations", although I don't see this from Figure 3. To my eyes, the areas enclosed (b) are larger than those enclosed in (a). My guess is that these are envelopes of the superposition of all footprints over the day, but I'm uncertain. Additionally, are these footprints of 80% flux contribution? More clarity here would be appreciated.

-"This extreme increase of wind speed with height is confirmed by preliminary numerical simulations (not shown)." It is unclear to me what these numerical simulations are

confirming. Two hypotheses are listed previously – is the numerical simulation confirming either of those? Or are the simulations simply confirming that this is possible (that the measurements are not faulty)? Wind shearing in excess of 15 m/s over only 55 cm is very significant for a mountain glacier. In either case, this is an opportunity to provide more detail and build a clearer physical picture of the dynamics at play.

-The authors should be more explicit with what they consider a strong correlation. "Sensible heat fluxes, however, show a strong correlation with the low-level wind speed during disturbed situations". Although not weak, I would argue that -0.42 and -0.47 aren't particularly strong correlations.

I'm not sure I follow the justification nor the implications for the analysis at the end of page 16.

-"During disturbed situations turbulence data showed small spatial difference of turbulent heat exchange at the across-glacier transect". The resulting scatters look similar, but is there any structure in plots of w'T' at TT3 vs w'T' at TT1?

âĂĺ-"Fluxes are particularly similar at TT1 and TT3 despite significantly higher air temperatures observed at TT1" How similar is "particularly similar"? Again, a scatter and more site-to-site analysis would aid this discussion.âĂĺ

-"In contrast to the margin station TT1 which shows similar correlations between air temperature and turbulent heat fluxes for both situations, the central station TT3 shows no correlation between air temperatures and heat fluxes". Although -0.2 and -0.21 are similar numbers, neither are strong correlations. One could also argue that 0.06 and 0.12 are similar numbers.âĂĺ

-"Figure 8 illustrates the advection of heat as a function of the deviation of the flow from the dominant katabatic flow direction" – this statement is backwards.

-Figure 8 and some of the following analyses are misleading. When wind direction isn't parallel with the station alignment, heat is no longer being advected between sta-

tions. Even if HA is calculated only using wind component V, U must be considered to determine the source of the heat advection. For example: if considering stations TT2 and TT1, if V = 1 m/s and U = 0 m/s, then it reasonable to assume heat is being advected from TT1 to TT2. If V= 1 m/s and U = 0.1 m/s, the source of the advection is slightly further up-glacier than TT1, so the measurement of HA is more inaccurate, as it assumes the up-glacier conditions are the same as those at TT1. This becomes a far more uncertain if V = 1 m/s and U = 5 m/s, for example. A clearer analysis of uncertainties and error here (and in figure 9) would be helpful. Currently, much of the information in Figure 8, along with the statement "Horizontal heat advection HA increased with temperature differences and V-component along the transect line" are guaranteed results considering that is how HA is defined. I wonder if factoring in these uncertainties would improve correlation coefficients between HA and w'T', as although 0.31 is a higher correlation than 0.19, I wouldn't call either of them a strong correlation.

The discussion could benefit from a rewrite with far more quantitative analysis to justify the interpretation of results, as it currently reads as purely qualitative. Some examples:

-"Second, the transect stations reveal a trend for both situations from more frequently measured positive and small momentum fluxes at the margin to larger and more frequently measured negative momentum fluxes at the central station." Distributions would be helpful in justifying this. I don't see this trend in the katabatic situation.

-". . . higher flux divergence of turbulent heat fluxes during disturbed situations." If all of the scatter in y is projected onto a single line across the x-axis, do (a vs. d), (b vs. e), and (c vs. f) really look so different? How much higher are the flux divergences?

-"During westerly flow situations turbulence data at the centerline of the glacier (TT3) show a strong increase of downward vertical sensible heat fluxes with increasing downward momentum fluxes (negative values) (Fig. 10c)." This relationship is not apparent. I don't visually see any correlation between the colourbar (vertical sensible heat fluxes) with the y-axis (momentum fluxes).

-“While the mid-transect station TT2 evidences predominantly negative momentum fluxes with a considerably smaller flux divergence and smaller turbulent heat fluxes than observed at the centerline. . .” Certainly the maximum flux divergence is smaller, but how do the distributions/means compare? Is there any structure to the scatter plots? A similar analysis would be helpful in arguing that the turbulent heat fluxes are larger at the centerline. Is this comparison being done quantitatively or by eye?

Along a similar vein, some of the conclusions do not seem to fall from the work done in the paper.

-“Local turbulence profiles of momentum and heat revealed a strong contribution of heat advection to the local heat budget”. Where was this done explicitly? The advective term is higher, but how strong is its contribution to the local heat budget (as a percentage, say)? What are the other components in the budget?

-“Strongest horizontal advection of heat was promoted by large horizontal gradients of air temperature along the transect, coinciding with maximum heat exchange towards the glacier surface.” I’m not sure this is the conclusion that Figure 9 leads me to. At least in the case of TT2 & TT3, R(w’T’,V)=0.56, but R(w’T’,HA)=0.31. This implies to me that maximum heat exchange is more dependent on wind speed, but since HA = HA(V), elevated HA is somewhat correlated to elevated w’T’, although is not the cause. âĂÍAgain, performing an uncertainty analysis on HA given wind direction/speed could help make this distinction clearer.

-“Furthermore, the steepness of the surrounding terrain plays a decisive role for the sheltering of peripheral areas from heat advection from the surrounding terrain.” Where does this conclusion come from?

Other aspects to tidy up:

-Occasionally, variables are not written in math mode/italicized (for example: w’T’ on line 164, labels in all figures/tables).

- x’y’ and \overline{x’y’} are used interchangeably, but should all be changed to the latter as they do not mean the same thing.

-Inconsistent labels on figures throughout (for example: “Height z (m)” & “Z (m)” are both used to denote height – Figure 5 even has both. Likewise with “wind speed U (m/s)” and “U (m/s)”. Other labels such as (Fig 2 c,f) “Momentum, flux u‘w‘ (K m s^{-1})” Contain all of these inconsistencies, an extra comma, and the wrong units).

-A comma instead of a period in “6,3 km” in line 86

-Throughout this paper, the figures are neither colourblind-friendly, nor are they B&W printer-friendly. They are also not saved in a .pdf format, so are low resolution. Figures 2, 4, and 5 are challenging to interpret as the colours appear very similar. Brown and grey, for example, are difficult to distinguish between. I would suggest a different colour palette and to make it consistent with Figure 3. -The dates of Figure 3 are not listed in chronological order.

-When appropriate, I would suggest making axis limits self-consistent. For example, Figure 4 (a&b), (c), (d), and (e) all have different x-axis limits. The same applies for Figure 4 (a/c) and (b/d) and Figure 9.

-I don’t feel that diverging colourmaps are appropriate for the data presented in Figure 6, 9, or 10.

-Units need to be reviewed in all figures. To mention a couple: In Figure 6, T_a/T_mean does not have units of C. Perhaps (C/C) is what is intended here. In Figure 8, (b) has incorrect units on the y-axis, and the x-axis has no units. Figure 10 has incorrect units on the y-axis and no units on the x-axis. Table 1 has units for RH but no other variables.

-The citations are not consistent with the journal’s citation guide. Some journal names are cited in italic, and abbreviated journal names should have periods following them, i.e. “J Atmos Ocean Technol”. The citations should be checked for consistency throughout. This journal is cited as both “Cryosphere” and other times “The

Cryosphere", not all journal titles are abbreviated appropriately, etc.

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