Response to Reviewer 2

Below we provide our responses **(in red text)** point-by-point to each comment from the reviewer **(in black text)**. ***Italic texts*** are used to highlight specific changes in the updated manuscript.

The authors present a very clear study on multiple winters worth of energy balance data from a site in the Western Himalaya. They show the consistent importance of sublimation during snow cover times and find results that generally match well with previous studies in the field. The work is very timely and the numbers found here will guide research conducted on the larger scale that is not able to include the process on a distributed scale. The paper is very clearly written, well supported with data and clear Figures that leave only very few general comments from my side which I detail below and which I hope you can address. I have a number of minor comments at the end. I applaud the authors for the field work that this work is based on as well as the clear way of presenting the results. It is important work and I think this should be an important paper in the TC library in future.

We sincerely thank Reviewer 2 for evaluating our manuscript, suggestions, and the positive feedback on our study. We have responded to your specific comments and outlined the changes that we have made in the revised manuscript. If the reviewers and the editor are satisfied with our responses, we will submit our revised manuscript. Below, we have highlighted (point-wise) the major revisions that we have made in the revised manuscript in response to your main comments:

- Included a detailed discussion on the influence of cloud cover on sublimation, based on correlation analysis and comparison of existing cloud and sublimation studies from the Himalaya/Tibet region,
- Included a future perspective on sublimation sensitivities to meteorological variables, which may be useful to readers in getting an idea of future sublimation and subsequent changes in terms of SEB of snow/glacier surfaces,
- In addition, the result and discussion sections have been significantly revised, with new text and restructuring in response to Reviewer 1's suggestions.

General:

In the Discussion I would expect more discussion of the role of cloud cover, which as you note is important but to me has a surprisingly low correlation and obviously wind plays a very different role in these regimes (your Figure 12). Could you compare the relative cloud cover to the other sites, or at least the ones from (Guo et al., 2021; Stigter et al., 2018). Not to cite here as still in review but (Conway et al., 2022) also provides some new great insights in this direction. I would hope to learn here how different I can expect my sublimation rates to be when I work in a different regime of overcast conditions.

We thank Reviewer 2 for the suggestions. We have considered the suggested studies to compare with our results and expanded the discussion section (Sect. 5.1). Some of the newly incorporated texts discussing the respective aspect are mentioned below.

Conway et al. (2022) focused on the melt seasons SEB and associated meteorological characteristics, but they also discussed the complex interaction between cloud cover and overall SEB of the glaciers across various sites, including four glacier sites in the Himalaya. The findings of Conway et al. (2022) are consistent with our findings in general. They also point out that at most of their study sites, increased cloud cover decreases the magnitude of *LE* and $F_{surface}$. At very high altitude sites (e.g., Mera, Zongo) they found that *LE* is still negative (that means sublimation) in overcast conditions (at *CF* > 0.7 mean melt-season's *LE* was ~-60 W m^{-2}; Fig. A5 in Conway et al., 2022). Overall, their findings show that in overcast conditions, near-surface meteorology (particularly near-surface vapour pressure and relative humidity) is significantly altered which limits higher magnitude of radiation and turbulent heat fluxes. Cloud cover, on the other hand, has little impact on wind speed and T_{air} at most sites, including the Chhota Shigri Glacier (Fig. 8 in Conway et al. 2022). Although the climatic setting varies greatly across the Himalayan region, and cloud cover's influence is complex, we highlight that overcast conditions lower the magnitude of sublimation, as shown by our study and Conway et al. (2022). Following your suggestion as Conway et al. (2022) is still in review we did not cite it in this study.

Line No. 653-663:

'We note the importance of cloud cover in modulating the surface atmosphere at the AWS-M site which favours sublimation, however, the correlation coefficient between CF and LE was poor (r = -0.09 and -0.16 in clear-sky and overcast conditions, respectively; Fig. 10). This is most likely due to the complex influence of cloud cover on meteorological variables, particularly S_{in} and L_{in}. Cloud cover reduces S_{in}, which impedes sublimation, but at the same time it also increases L_{in}, which promotes sublimation partly by raising T_s. This is well-supported by the higher correlations between sublimation and S_{in} and L_{in}, particularly in overcast conditions (Fig. 10). Although Stigter et al. (2018) did not discuss the correlation between sublimation and cloud cover/factor at the Yala Glacier, they did indicate that sublimation was negligible or about zero on overcast days when humidity was higher. This is supported by the poor correlation of determination (r^2 = 0.08) between sublimation and RH at the Yala Glacier. Guo et al. (2021) also did not obtain a statistical relationship between sublimation and cloud cover, but they also noted a weak sublimation rate during cloudy months due to high moisture and warm conditions.'

Table 2: In text you say max T_a is 0.1, in Table 0.0

Thanks for pointing this out. We have revised Table 2 (original manuscript) with maximum T_{air} as 0.1°C. Following Reviewer 1's suggestion, we have shifted Table 2 (original manuscript) to supplementary material (as Table S3).

Table 4: R2 for u is 0? I am also surprised that CF seems to be more correlated to sublimation in the transition phase than in overcast or clear sky condition. Can that be explained? I would have expected a higher correlation under overcast condition.

In the previous version of the manuscript, we showed Pearson's correlation coefficient (*r*) as well as the coefficient of determination (r^2) through linear regression analysis. Since we already have a dedicated analysis and figure showing *r* (Figure 10; revised manuscript; Sect. 4.5), we planned to remove r^2/linear regression between sublimation and meteorological variables from Table 3 (revised manuscript; note: Table 3 was Table 4 in original manuscript). We only kept the multiple linear regression analysis in Table 3 (revised manuscript) to show the readers how a combined effect of meteorological variables influences sublimation. This way we still have the correlation analysis between sublimation and meteorological variation and discussion (Fig. 10; Sect. 4.5 dedicatedly) while skipping the discussion of r^2 for the same relationships. Using *r* and r^2 for the same relationship is a little confusing and difficult to follow for the readers.

Indeed, the relationship between *u* and sublimation is weak in both clear-sky and cloudy conditions (*r* = 0.37 and 0.33 in clear-sky and overcast, respectively; Fig. 10 in revised manuscript). The absence of strong correlation between sublimation and *u* is expected because a supportable condition for an enhanced sublimation was created by a combination of meteorological variables, primarily the vertical moisture and temperature gradient, wind speed and the state of the surface boundary layer (stability) (please refer to Sect. 5.1 in revised manuscript). The weak correlation between *u* and sublimation can be partly explained by the very heterogeneous wind speed at the AWS-M. For example, available observation from various studies showed that *u* generally decreased in overcast conditions (e.g., Stigter et al., 2018; also in Conway et al., 2022 in several glacier sites). However, in overcast conditions we often had higher *u* (Fig. 9 and Fig. 11; revised manuscript) due to westerly activities (discussed in Sect. 4.5 and 4.6; revised manuscript). This heterogeneity was the cause of weak correlation between *u* and sublimation in part. In this regards, new study by Fugger et al. (2022) also reported that the relationship between *LE* and meteorological variables was highly unpredictable, and *u* failed to explain the variability of *LE*/sublimation at five on-site glacier studies in the central and eastern Himalaya (see their Fig. 9A).

Correlation between sublimation and *CF* was also weak (*r* = -0.09 and -0.16 in clear-sky and overcast conditions, respectively; Fig. 10 in revised manuscript). This is likely due to the complex influence of cloud cover on meteorological variables, particularly S_{in} and L_{in}. For instance, cloud cover reduces S_{in}, which impedes sublimation, but at the same time it also increases L_{in}, which promotes sublimation partly by raising T_s.

We do observe a slightly higher correlation between sublimation and *CF* in overcast conditions (r = -0.16) than clear-sky (r = -0.09), but not that significant.

To give a thought to your concern (based on our observation in the original manuscript) that *CF* was more correlated in the transition phase, we analysed this relationship a bit further. We analysed the sublimation correlations for three more cloud conditions by binning *CF* for three more categories within the transition phase (i.e., *CF* > 0.2 <= 0.4; *CF* > 0.4 <= 0.6; *CF* > 0.6 <= 0.8). In those categories, we also did not find any strong correlation between sublimation rates and CF. The *r* values were similar as in clear-sky and overcast conditions (not shown here). This is partially reflected in Fig. 13 (revised manuscript; a copy shown below).

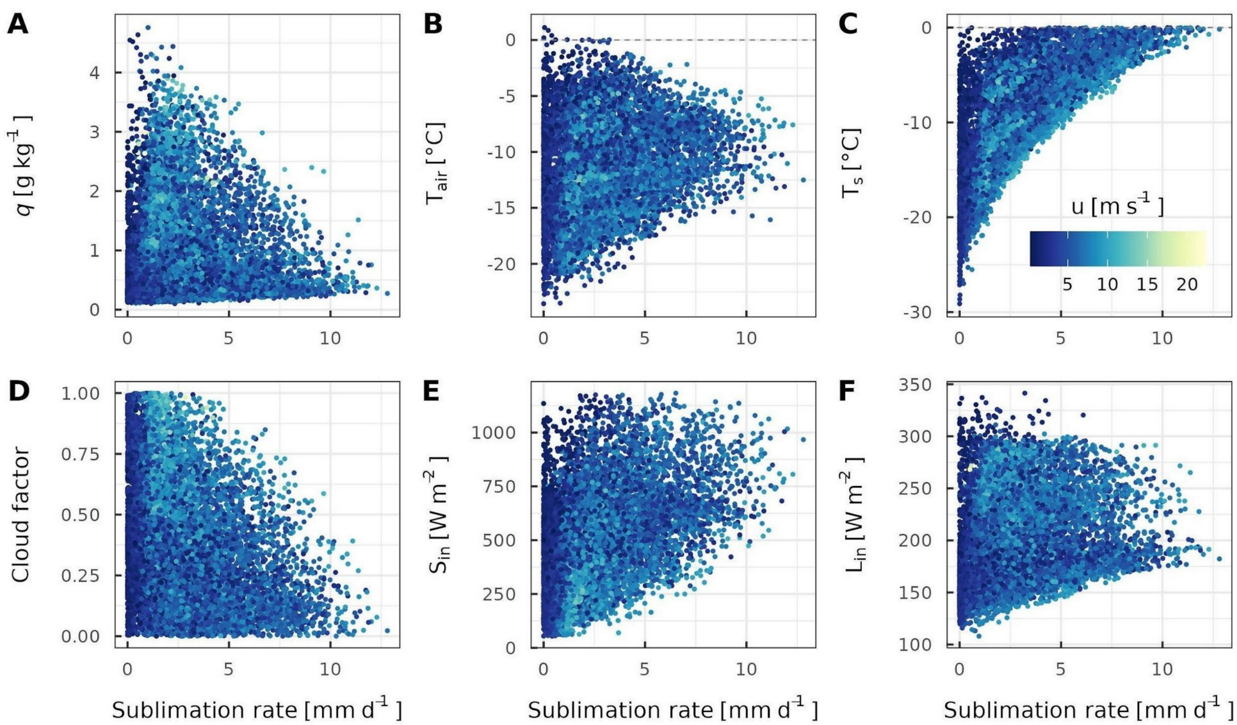

Figure 13 (in revised manuscript). Scatter plot of *u*, *q*, T_{air}, T_s, *CF*, S_{in} and L_{in} against sublimation rate at the AWS-M. The colour of the data points refers to the measured wind speed (*u*). Total n = 14088 half-hourly data points between 09:00 and 16:00 IST for DJFMA (2009-2020).

Based on the above argument on the weak relationship of *u* and *CF* with sublimation, we revised our discussion. We would like to invite the reviewer to go through the revised manuscript (Sect. 5.1; revised manuscript). The newly incorporated texts are highlighted below:

Line No. 644-653 (Sect. 5.1):

'Stigter et al. (2018) and Guo et al. (2021) noted a stronger direct relationship between LE and u, which does not agree with the present study. This could be partly explained by the very heterogeneous wind speed at the AWS-M (Fig. 13). For example, the available observations from different sites showed that u generally decreases in overcast conditions (e.g., Stigter et al., 2018; Guo et al., 2021). However, at the AWS-M, u was often higher in overcast conditions (Fig. 9; Fig. S5) due to westerly activities (discussed in Sect. 4.5 and 4.6). Very high u maintains a neutral stratification of the boundary layer resulting in a lower LE magnitude. This heterogeneity is likely the cause of weak correlation between u and sublimation in part. However, the highest multiple regression variance in combination with u (~90%; Table 3) in clear-sky and overcast conditions emphasise the importance of u in driving LE/sublimation. Fugger et al. (2022) also noted that the relationship between LE and meteorological variables is highly unpredictable, and u fails to explain the variability of LE at five on-glacier sites in the central and eastern Himalaya (see their Fig. 9A).'

Line No. 653-659 (Sect. 5.1):

'We note the importance of cloud cover in modulating the surface atmosphere at the AWS-M site which favours sublimation, however, the correlation between CF and LE was poor (r = -0.09 and -0.16 in clear-sky and overcast conditions, respectively; Fig. 10). This is most likely due to the complex influence of cloud cover on meteorological variables, particularly S_{in} *and* L_{in}*. Cloud cover reduces* S_{in}*, which impedes sublimation, but at the same time it also increases* L_{in}*, which promotes sublimation partly by raising* T_s*. This is well-supported by the higher correlations between sublimation and* S_{in} *and* L_{in}*, particularly in overcast conditions (Fig. 10).'*

L505ff/Figure 15: This is interesting – could you expand here what that means for a potential future change especially of T_air? Also in the text you mention the big sensitivity to T_s, but that under melting condition won't change much. It seems to be equally (or just slightly less) sensitive to T_air though, which likely will change. That seems important to me for future consideration.

Thank you for the suggestion. The future perspective of the sensitivities is interesting and worth expanding. Following your suggestion, we have expanded the discussion. The newly incorporated texts are presented below. We invite you to go through the revised respective section (Sect. 5.2; revised manuscript).

Line No. 686-696 (Sect. 5.2):

'Another important aspect of sensitivity to meteorological variables is related to the future atmospheric warming and its consequences to sublimation. T_s *exhibited a higher sublimation sensitivity than* T_{air} *(Fig. 14), but under melting conditions it will not change much because the temperature of snow/ice surface cannot rise above the melting point (*T_s *= 0°C). However, relative potential changes in* T_{air} *are likely to be higher across the globe including in the*

Himalayan region (Hock et al., 2019; Krishnan et al., 2019). Therefore, sublimation sensitivity with respect to T_{air} could be a major concern in the future, due to the expected warming. Considering a future T_{air} increase of ~0.3 ± 0.2°C decade^{-1} for the Himalayan region (Ren et al., 2017; Krishnan et al., 2019), a crude estimate suggests a ~5% decrease in sublimation per decade from snow/glacier surfaces. This could probably be attributed to a lower energy sink through LE, which will boost the efficiency of S_{in}/R_{net} resulting in a more surface melt. However, since sublimation is a process driven by the combined effect of multiple meteorological variables, it remains to be seen how the sensitivity of a single variable influences the overall sublimation and associated processes.'

Minor comments:

L20: replace 'consequently' with 'resulting in'

Done.

L21: 'largest fraction' or 'proportion'

We think 'proportion' would be a better choice. Thanks for the suggestion. Done.

L24: 'to the region'

Done.

L26: sublimation is a variable, not a parameter; remove the two 'the' articles

Done, thanks.

L40: 'more abundant'

Done.

L53: 'The contribution …is …'

Done.

L:57: 'poorly understood'

Done.

L71: Technically it has been applied (Sakai et al., 2004) although they did not term it sublimation and on this debris cover (as in (Steiner et al., 2018)) it is more an evaporative process. But this is a grey area, and at least our attempt to measure sublimation over snow with a pan lysimeter have simply been unsuccessful because they freeze and can't measure properly. You also later mention the PhD thesis by Yang (2010).

Thanks for the information.

L101: 'radiation', no need for a plural here

Done.

Table1: The superscript a at the bottom is missing. Also again I would use 'radiation' in singular

We will make sure the superscript is there, thanks. Changed it to 'radiation'.

L134: 'single-Alter-shielded'

Done.

L164: you use 'net radiation' here but earlier used net all-wave radiation'. I would go throughout for the shorter version.

We choose net radiation across the manuscript following your suggestion.

L166: The two sentences should be conjoined with comma or you need to restructure syntax

We have revised it following your suggestion.

L189f and in general: no need to include [in …] with the units

Done, we remove [in ...] here and elsewhere.

L229: remove 'equation by' or 'the equation by'

Done.

L292: I would leave 'snow cover' in singular

Done.

L299: does not

We removed this sentence from the revised manuscript considering Reviewer 1's suggestion to shorten the respective section.

L310: maybe rather ‘down to’

Done, thanks.

L322: ‘such a high contribution’

Done.

L336: remove ‘thin’

Done.

Figure 11: Nice figure and just a pedantic comment – can you make Tair-Ts instead of Tair_Ts in the axis label? Also you introduce D here but only introduce it much later in the text (L447). Make sure to somehow introduce it earlier, otherwise as a reader I need to go looking forward in the text, which is awkward. The question is though why you show it at all here as it is just the reverse from q-qs – you could consider to just remove the column/row in both subfigures.

Thanks for pointing this out and the suggestion. We have revised the figure (Figure 10; revised manuscript; a copy shown below) as suggested and removed *D* from the figure (Figure 10). Also, considering *D* is already included in *LE* equation, we have decided not to use *D* at all, across the manuscript and therefore, revised the respective sections accordingly.

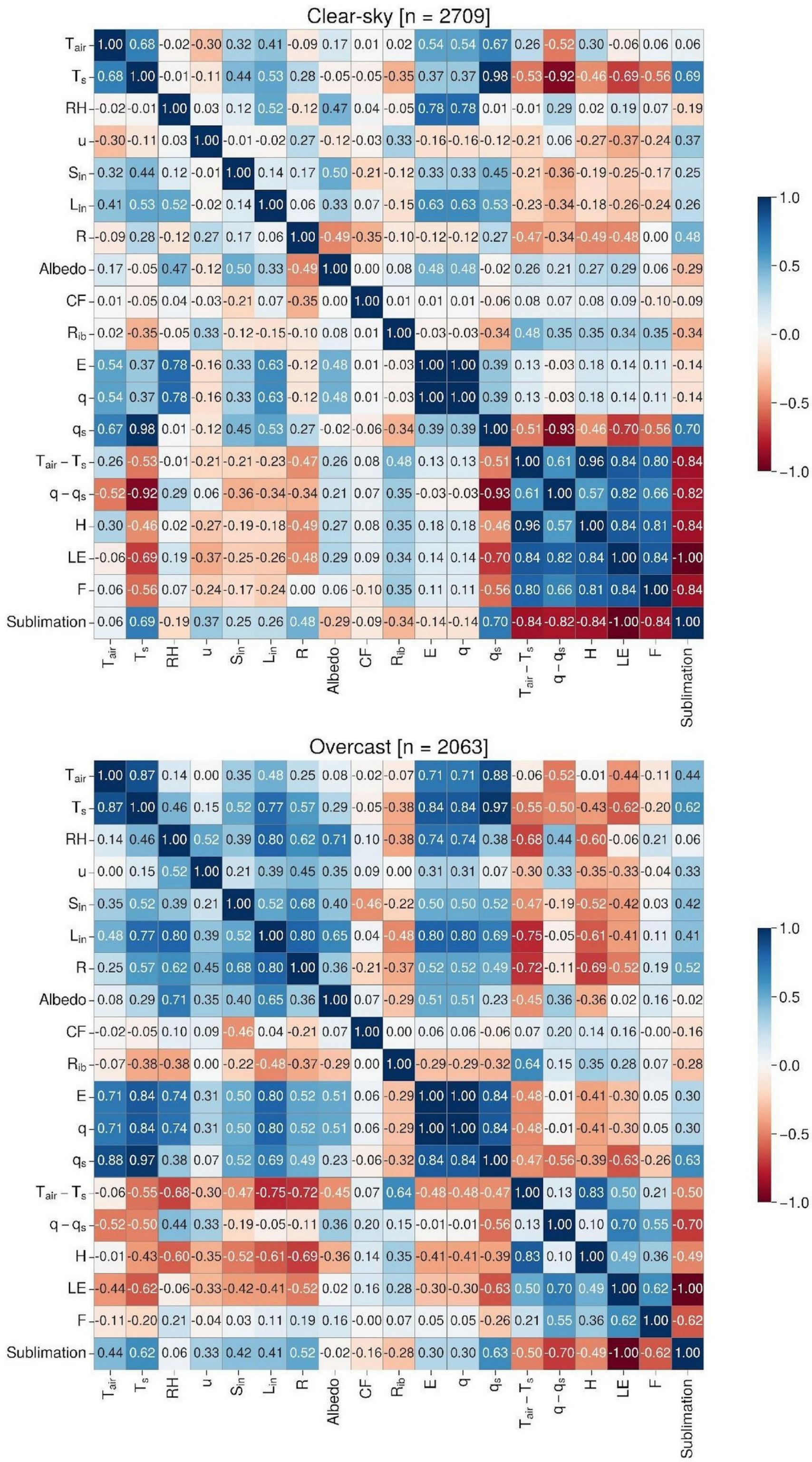

Figure 10 (in revised manuscript). Pearson's correlation coefficient (*r*) matrix of various meteorological and SEB components at the AWS-M in clear-sky and overcast conditions between 09:00 and 16:00 IST, 2009-2020. Number (n) of half-hourly data points are shown on top of the panels.

L433: ‘restrict’

We removed this sentence from the revised manuscript.

L453: It is quite clear that D is directly positively related to LE as it is the main part of the equation/definition, so it can’t really be any other way. I would remove this sentence.

We have removed this as suggested.

L523: remove one ‘in this study’

Done.

L525/L540: maybe ‘similar’ or ‘comparable’ instead of ‘identical’

Done. We choose ‘similar’.

L577: ‘with the major part’

Done.

L581: ‘This supports …’

Done.

L600: ‘impediment’

Done, thanks.

L603: maybe ‘reducing by 70%’ and ‘raising by 25%’

Done, thanks.

L604: Bit confusing – restraining to what? Also ‘50% cloud fraction’ to be clear.

We revised the respective sentences for clarity. Now the sentence reads as:

Line No.: 798-799
‘The cloud cover also restrains the meteorological condition favourable for turbulent heat fluxes and reduces their magnitude by more than 50%.’

L607: remove ‘were’

Done.

L608: ‘suggesting it is crucial for …’

Done.

L612f: remove ‘significantly’ – that is a hard term and you don’t really show that here. I would also remove the part behind the semi-colon. That is always a given and a bit redundant. And you say the same in the following sentences already.

Done, we have revised it as suggested.

L620: Please provide this for the final version. It is a pity if such a statement remains without a link in a final publication.

We have uploaded AWS-M data used in this study in Zenodo along with the codes used in SEB calculation and generating the figures. The citable open-access link (https://doi.org/10.5281/zenodo.6609605; Mandal et al., 2022) is now provided in the revised manuscript.

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