Review of Conway et al. Cloud forcing of surface energy balance from in-situ measurements in diverse mountain glacier environments

Conway et al. use a global selection of on-glacier AWS data to determine the effect of clouds on the surface energy balance. They investigate the influence of clouds on the near-surface meteorology, individual energy fluxes and the frequency and magnitude of melt. They found an increase in the frequency of melt during cloudy conditions but the effect of clouds on the energy available for melt varied spatially.

Overall, I think the purpose of the paper is a very good one, and it is certainly an interesting approach to look at the impacts of clouds across a range of sites, since often energy balance studies are confined to one site or a region, so the global aspect is appealing. The paper is also clearly written throughout, and the methodology followed is sensible. However, I do have a couple more significant concerns which I highlight in the major comments below:

Major comments

1. Depth of analysis and understanding of global trends

In the main results section the variation in the results (in terms of the cloud effect on the meteorology, surface fluxes and melt) caused by the different location, climate and elevation of the sites is mentioned (certainly when the effect is quite clear). However, I don't think the authors really make the best use of their dataset to fully interrogate the spatial variation in the results. The relationship between the cloud effect and station and energy balance characteristics is not investigated fully (with scatter graphs) until section 4.2 (which anyway should be a result section). Although the figures earlier in the results section are clear as they are they are not well suited to investigating the spatial differences and improving these figures to make the station characteristics clearer and including scatter graphs earlier in the results would be a good idea. Furthermore, the analysis in section 4.2 is not robust, the authors need to calculate the correlation and regression (if appropriate) coefficients and report them in the paper. Currently assessments are made only on a visual assessment. In general, I think the paper needs an extra stage of analysis yet to give its findings more credibility, and this may also allow clearer findings on why the effect of clouds on melt energy varies in sign spatially.

2. Discussion

The first two sections of the discussion are really still results, and then there are only the limitations and implications sections, with the latter section really missing references. I miss here a proper in-depth discussion which brings together the understanding alongside other studies. Consider answering some questions, e.g. Why do clouds influence the near surface meteorology in the ways you found? (explain the physical mechanisms) What factors cause changes in the impact of clouds on melt? You touch on this in sections 4.1 and 4.2 and also in your limitations, but I feel you need to set this out more as a clear discussion with each of the factors and their influence. There is also a need to bring in other energy balance studies which have looked at the cloud effect (or even seasonal differences where cloud cover likely varies markedly), especially in regions not covered by your analysis.

Minor comments

L56: To me the subsurface is more the material under the glacier, I think Qc is the conductive heat flux into the surface.

L57: Are all the fluxes in W m^{-2} (they usually are but just state this)?

L86-88: It might be worth expanding on some of these methods to derive cloudiness and their main assumptions/difficulties.

L99: Define AWS here.

In methods: Maybe it would be useful to have a simple idea of the climate type/seasonality of each site? It seems that the overall broader climatology will drive the differences in the cloudiness patterns and how they relate to the melt seasons, so having this context early on would be useful.

L110: Due to the different methods of the calculation of the turbulent fluxes consider including a table with how the non-radiative fluxes were calculated for each site (in the appendix/SI would be fine).

Figure 1: Maybe include insets where you have several sites relatively close by in a region. Also use a different symbol to label colour for readability.

Sections 2.3, 2.4 and 2.5 – if these are all within 'data processing' then it might make sense for these sections to be 2.2.1, 2.2.2, 2.2.3 (so sub-sections of 2.2)

Figure 3 caption: 'Steps'

L149-162: Honestly, I think this could go into an appendix or SI. But I am wondering, if you had to do these quality checks then how do you know that the SEB fluxes were also calculated post these quality checks - I thought you were using the published data (which hopefully would already be checked?) Can you clarify this please. Calculating Ts from LWout works quite well but not always, give the reference for how you did this.

L172: Also define sigma as the Stefan Boltzmann constant, and give a reference for this equation.

Section 2.4 could probably be shortened.

Figure A2, A4: Please add a legend so the reader knows that the colours are used to define the melt season.

L224: Why only look at the cloud effects versus the radiative fluxes? You do look in Figure 11 at the importance the turbulent fluxes for melt and how that varies with cloudiness, but why not also include them as for the radiative fluxes in Figure 7. Furthermore, is there not some circularity in looking at the LWnet differences given that LWin is used to calculate the cloudiness?

Figure 4 caption: It would be useful to have a legend, or at least to explain what the darker via lighter colours represent. From the text it seems like darker colours = greater frequency of conditions, but this should also be clear from the figure/legend on its own. Consider outer boxes (or other methods) showing the splits between regions.

L258: 'between monsoon and arid regions *although it still shows an increase in partially cloudy conditions in the melt season*' Or something similar, just for clarity.

Figure 5: This is nice way to show the cloudiness at the sites, but it might be useful to have some overall metrics so its slightly quicker to compare sites, e.g. the mean and range of melt season monthly cloudiness? It might also be useful to group by region (Himalayan, European etc.) Even though I know most of these sites and where they are its not so easy to see trends, and I imagine it would be harder if you didn't know inherently the site locations.

Figure 6: Maybe it would be helpful to take this a step further, for instance can you relate the gradients of these lines to the site lat/long/elevation, e.g. in a scatter graph? It's easy to see that KERS, MERA and ZONG are different but harder to know what is causing the variation in the other sites. You do attempt this in the discussion but I think this analysis could be more thorough and come earlier in the paper.

L289: 'cloud effect is small and negative' It would be useful also to scatter this overall change in Rnet against the sites to see if there are regional clusters.

L293: 'more positive response to' - do you mean in terms of an increase in Rnet here?

L307: 'relationship is weak and non-linear' - Quantifying the strengths of these relationships and their gradients (for all the variables in Figure 8) would be a good idea.

L323: 'at all study sites' - this doesn't appear to be the case for GUAN.

L329 – 331 'While…..day and night' – Add a reference to this effect if you don't show the analysis yourself.

L331- 334: This sentence might be better earlier in the paragraph.

Figure 9: Here and in other similar figures, it might be a good idea to use different line styles as well as colours to indicate different regions? It might also allow you to use fewer colours, and have a palette which is more colour blind friendly. The strength of this paper is the wide range of sites and yet you need to show better the regional/climate/elevation differences in your plots.

L337: 'indicating *sublimation*' Since we are going from ice to vapour.

Section 4.1 In this section in general you could do with better links (references to) your results section, so for instance refer back to the figures or sections where these results which you are bringing together are first mentioned. I also think this section could also be rather in the results section still.

L388: 'At all *of these* sites,'

L392: 'and QL' Usually increased QL (sublimation) would decrease melt? Or do you mean increased in terms of less negative? But I would expect the opposite if its windier.

Section 4.2: Again, to me this section is still results. You need to do the statistics here and show them - are these relationships significant at a given p-value? What are the R^2 values? Just showing the scatters on their own in Fig 12 is not enough. Also consider looking at only the sites in the ablation zone or those in different regions separately.

L403: 'with latitude or altitude' - There does look to be a relationship with latitude, perhaps with an outlier? Do the stats to check.

L404: 'Neither average near-surface air temperature' - Again, Ta does look to relate to the cloud effect, but you need to do the stats to know!

Figure 12: Here it would really help (similar to in the line graphs above) to somehow differentiate (maybe using symbols) the different regions. You should also include a legend for this figure so the reader can understand it on its own. Also why not include also the influence of the turbulent fluxes and wind speed?

L435: Zongo's large seasonal variations in climate. Perhaps make it clear that the precipitation and cloudiness are the key variables which change seasonally here, rather than Ta.

L441-442: Is this reference to Chen et al. (2021) also referring to the site at BREW?

L458: 'in *the* first partial'

L470-473: You need to cite the studies you refer to here. Are you sure there are no studies that include changes in cloud in future glacier change?

L474-475: Reference here to your results figures/sections.

L476: 'during marginal melt seasons *and especially at high elevations*.'

L483 and 484 'metadata'

L488-489: 'As many…' You need to cite studies here, also I'm less sure what you mean, usually Swin is influenced strongly by topography whereas Lwin is less so (aside from cloud forming processes but they are not related to Swin). There are parameterisations of Lwin from Swin (e.g. Juszak and Pellicciotti, 2013), if that is what you mean?

L506: When mentioning the turbulent heat fluxes be clear about how the latent heat flux changes, since it is often negative.

L509-511: 'The association….' I think you could have pulled this apart in more detail, it feels like you have the data to understand this, but it needs more in-depth analysis than you have shown.

Data availability: Given your point in the limitations it would be much better if these data were made available together (with your analysis code) in a repository. Of course, it depends on the agreement of individual data providers, but you should aim for this.

Figure A1: Tidy up the labels here to use correct notation, also add units for the left hand variables.

Figure A2: Tidy up the labels and legend to use superscript (for units) and proper notation for the fluxes.

Figure A4/A6: Missing a legend, its not clear what the colours represent.

References

Juszak, I. and Pellicciotti, F. (2013) A comparison of parameterizations of incoming longwave radiation over melting glaciers: Model robustness and seasonal variability, *Journal of Geophysical Research: Atmospheres*, 118, 3066-3084, doi:10.1002/jgrd.50277