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Interactive comment on "Processes governing the mass balance of Chhota Shigri Glacier (Western Himalaya, India) assessed by point-scale surface energy balance measurements" *by* M. F. Azam et al.

Anonymous Referee #2

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General comments

This paper describes automatic weather station measurements at Chhota Shigri Glacier in the Western Himalaya and an analysis of the surface energy balance with a model. Given the sparse observations on glaciers in this region, this paper provides very valuable information on meteorological conditions and surface energy balance characteristics for the Himalayan glaciers. The paper is well-written and generally uses good English. However, in many sentences, there is a lack of usage of 'the' and 'a/an'. I give a few examples in the Technical Comments below, but there were too many to

list them all. I recommend to have the text proof-read by a native English speaker.

The methods used are mostly sound, but two points need attention, as described below.

In the given SEB equation, the conductive heat flux G is given, but the text mentions that this flux is small enough to be ignored. First of all, I wonder whether this is a valid assumption, since the surface temperature is well below zero outside the summer season indicating considerable heat loss from the subsurface layers. As noted in the text, without G the SEB is a balance between the radiative and turbulent fluxes. Only when melt is allowed, Q is positive. However, in later parts of the manuscript, Q also has non-zero values for periods without melt. The authors explain these non-zero values with conductive heat transfer and change of the surface temperature, which is not consistent with the neglectance of G. In fact, the non-zero values are a measure for the inaccuracies in the model assumptions, which is not a problem as long as the values are small. The authors either need to present the non-zero values for non-melting conditions as the model error, or use a model including G. The latter is preferred, because the assumption that $G = 0$ does not seem to hold outside the summer season.

The model validation presented in the paper is rather weak and should be improved. The authors compare computed ablation with a number of stake measurements in the direct vicinity of the AWS. They however also have the continuous height change detected by the sonic ranger, which should also be used for the model validation. Even though the record seems to have data gaps, a significant part of the ablation season with ice at the surface remains. If the authors would include a subsurface model in their SEB calculations, they can also calculate T_{surf} with the model and compare it to T_{surf} derived from LWO.

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Detailed comments

2869,13-16: I do not agree with this statement. There was clearly an error in the IPCC AR4, but as suggested by Cogley et al. (2010), this is likely a typing error. Although this points out the inadequate checking of references by the IPCC, this particular error does not show the poor understanding of Himalayan glacier changes.

2872,29-20: Just a remark, perhaps useful for the future: I would recommended to use half-hourly averaged wind directions instead of instantaneous measurements. This however requires a more complicated data logger program, since the instantaneously measured wind speeds and directions should be added vectorially. Especially at low wind speeds, the wind vane is moving a lot and this introduces unwanted noise if only one measurement per half hour is taken. In addition, wind speed is a half-hourly average, so wind direction and wind speed represent different periods.

2873,18-22: What is the range of values this cloud factor can have, is it between 0 and 1? So for clear-sky days, 93% of the STOA reaches the glacier surface and for cloudy days, this is 21%? It would be good to add at least the range, for clarity.

2874,7-8: I assume this is a result of the temperature effect on the sonic ranger signal? Perhaps the authors can slightly rewrite to make clear that this sentence follows up on the previous one.

2875,11-14: Perhaps the authors can include all monthly values alongside the monthly means in the figure, for example as dots. This will then nicely demonstrate that the seasonal cycle is larger than the interannual variability in the monthly values.

2876,1-4: I do not think the measured RH gives much information about moisture received at the glacier. If the authors are speaking of precipitation, then the next section shows that winter precipitation is higher than summer precipitation, while RH values are lower in winter than in summer. If the authors are speaking of sublimation/resublimation, the SEB analysis shows that the glacier only receives moisture in

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summer, in winter it looses mass. I suggest to remove this speculation about moisture sources.

2876,8-10: Does the 33 $W\,m^{-2}$ come from the difference between the pre-monsoon and the summer-monsoon SWI? Then better write something like 'The summer-monsoonal mean is 33 $W\,m^{-2}$ lower than the pre-monsoonal average'. By writing 'is reduced', readers might think that the loss of radiation on its path through the atmosphere is 33 $W\,m^{-2}$. Furthermore, I do not think that RH is a good indicator for cloud conditions, better use the cloud factor. Especially, a mean RH of 68% is not particularly high and does not necessarily indicate overcast conditions.

2880,11-12: What is meant with 'in these conditions'? Why is the sensor mainly receiving isotropic radiation, is this because of overcast conditions? In case the cloud factor has values between 0 and 1, the reported mean value does indicate that cloudy conditions prevailed most of the time.

2884,5: I assume that the z_{0m} values cannot be negative, which the STD values suggest?

2885,27: This is a bit confusing, because in Sect. 2.4.1 it is said that the highest SWI values are measured in the pre-monsoon season. This season is not included in the comparison for the glacier values, but perhaps it can be mentioned that the pre-monsoon values are presumably larger with a reference to Sect. 2.4.1.

2886,20-24: What are the dominant wind directions of the large-scale circulation in the summer and winter seasons? Even though the glacier may be surrounded by high valley walls, the authors cannot conclude that the observed winds are mostly katabatic winds without mentioning the large-scale circulation winds. A first-order analysis can for instance be made from meteorological reanalysis products.

2888,8-10: The latent heat values of condensation and sublimation are different (2.50 and $2.83 \cdot 10^6$ J/kg, hence gained mass estimates will also vary. Please specify which

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processes are considered, it seems that (re)sublimation is assumed under all conditions.

2888,25-28: I would be interested to see the relative amounts of mass loss/gain by melt and (re)sublimation, to illustrate whether (re)sublimation is important in the surface mass balance of Chhota Shigri. Please include total numbers here.

2889,17-18: There is a very prominent minimum wind speed in the morning in the post-monsoon season, any idea what causes this?

2891,15-21: Was a gradient in precipitation with elevation included here? It is probably not correct to assume that precipitation amounts at AWS1 and AWS2 are equal. If no information is available, the authors should be more careful with mentioning snow amounts on the glacier.

2892,1-24: It would be interesting to assess the effect of the summer snowfall by running the SEB model for the 2012 period without the increased surface albedo, so constantly kept at 0.19. This gives more quantitive information than the comparison with 2013, when meteorological conditions were also different. However, this requires the computation of T_{surf} (and LWO) in the model, which is currently not the case.

2892,25-2893,24: This is a brave attempt to transfer the point-scale results to glacier-average mass balance. However, I do not think the input data used are good enough to give reliable results. For example, the authors show in Sect. 2.4.2 that the precipitation regime of Bhuntar and AWS1 is noticeably different, not only regarding the amounts, but also the seasonality. Do they have any indication, for instance for the 2012/2013 season, that precipitation events on the glacier correspond to the Bhuntar record? In addition, the effects of summer snowfalls cannot be separated from the effect of simultaneous low air temperatures on the mass balance. I therefore think that the authors should leave out this analysis and stick to the point-scale analysis.

2908,Table 4: The percentages of the fluxes in this table do not seem correct for the

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locations with negative fluxes. I would think Q should always be 100% and that fluxes with negative values have a negative contribution. For example, for Laohugou No 12 the percentages should be 108% for R, 9% for H, -17% for LE and 100% for Q. This method is at least common to compute the contribution of the different fluxes to melt, which should ideally only include those periods when the surface was actually melting. All studies in Table 4 are conducted over the summer season, so this seems a reasonable assumption. But perhaps the authors used a different definition of the flux contribution, it would be good to explain this.

Technical comments

2868,11: 'During the summer-monsoon'

2868,14: 'of the energy balance'

2868,17: 'and an almost permanently melting surface'

2869,6: I would suggest to replace 'with the fact that' by 'in line with the observation'

2869,10: 'on the long term'

2869,15: 'Himalayan glaciers'

2869,25: 'in detail by studying the glacier'

2869,27-28: 'has improved'

2869,28-2870,8: The first sentence suggests that SEB studies have not yet been conducted in High Mountain Asia, while the second sentence lists several studies. To avoid confusion, I would suggest to rewrite: '... Nicholson et al, 2013). In High Mountain Asia, only a few studies have...'. I also suggest to write 'High Mountain Asia' instead of 'High Asia Mountains' throughout the manuscript.

2870,9-11: In my opinion, the authors push it a bit too far here to make clear that SEB

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studies in the Himalaya's would be very welcome. I suggest to rewrite as: 'Glacier SEB studies... are not yet available. Such SEB studies are of crucial...'

2870,16-19: Chhota Shigri is highlighted here, but it is not yet made clear in the introduction that this glacier is the topic of the current paper. I would suggest to include this at the beginning of the paragraph about Chhota Shigri, for example: 'In this paper, we present a SEB analysis for Chhota Shigri Glacier, one of the best...'. The explicit reference to Chhota Shigri in the previous paragraph should then be removed: '... Wagnon et al., 2013). Glaciers in Western...'

2871,13: 'Automatic Weather Stations'

2872,1: 'of the Indus river'

2873,1-2: The specifications are for the sensors, not the variables, hence write 'with the sensor specifications'

2873,9: 'complete data sets'

2873,25: 'following Iqbal (1983)'

2874,2-3: It is the height of the surface that changes, not the height of the sensors, so it would be better to for instance speak of 'decreasing/increasing distance to the surface'

2874,5: 'to correct for'

2874,10: 'During the summer-monsoon season on Chhota Shigri Glacier, sporadic'

2874,11-12: 'the surface height variations'

2875,23-27: Remove 'annual' from all notifications of seasonal mean values, this is very confusing.

2876,6-7: 'Although the solar angle is at its annual maximum during the summer-monsoon season, SWI...'

2876,10: Has 'STD' been used before? If not, please give both the full description and

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the abbreviation the first time.

2877,11-12: 'et al., 2005). It therefore provides high precipitation on the windward'

2877,13: 'precipitation on its leeward side'

2878,21-22: I would not say that temperature is really average, perhaps write: '1969-2013. Especially concerning precipitation, the 2012/2013 hydrological year can be'

2879,25: 'is melting when'

2880,23: 'radiate and influence'

2880,25: 'Figure 6a'

2884,14-15: 'smooth snow surfaces' and 'rough icy surfaces'

2885,28: 'Most SWI (81%) is'

2886,2-3: This sentence seems a bit out of place here, regarding the subjects in the surrounding sentences. Is it perhaps intended to say something about LWI? Then please include this link.

2886,7: 'might have occurred'

2886,9: 'the other two seasons', to indicate that not all seasons are covered

2886,10: 'high wind speeds'

2887,17: why 'very high', compared to what is it 'very high'?

2887,22-23: A mean value of -0.1 ^{o}C for T_{surf} is not 'relatively high' but the maximum possible, as T_{surf} cannot be higher than 0 ^{o}C.

2888,4: 'the surface lost mass'

2888,11-12: 'same seasonal oscillation as'

2888,25: If meltwater is present on the surface, evaporation is also possible. Perhaps

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it is better to write 'sublimation/evaporation or re-sublimation/condensation' such that the pairs indicate processes in the same direction.

2890,1: 'show similar daily cycles in'

2890,27: 'is melting permanently'

2892,2-3: 'melting, which was continuous before the snowfall event, is reduced'

2895,23: suggestion to rewrite: 'In the Indian Himalaya, where .. scarce, the meteorological dataset at 4863 m a.s.l. .... (AWS2) since August 2009 is one ....'

2897,13: 'energy source and'

2907, Table 3, caption: The variable symbols are not all described in the text, please also refer to Table 1.

2915,Figure 7: Can you include horizontal lines for Albedo=0 and CF=1, perhaps the panels are too close together?

References not included in the manuscript J. Graham Cogley, Jeffrey S. Kargel, G. Kaser, and C. J. van der Veen: Tracking the Source of Glacier Misinformation, Science 29 January 2010: 522. [DOI:10.1126/science.327.5965.522-a]

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