Response to Anonymous Referee #2
We acknowledge the constructive comments of both reviewers and have responded to each comment point by point. Our responses are italicized.

Anonymous Referee #2 Comments

Summary:
This article details the findings of 3 field seasons of ablation measurements on debris covered portions of glaciers in 2 basins to the north and south side of the Caucasus divide. Glacier extent and debris cover extent evolution through time is presented for the last 35 years, and then the field measurements are used to constrain a model experiment to compare the ablation and influence of debris cover on ablation in the 2 catchments.

General comments:
The comparison exercise undertaken is an interesting idea, as the north and south side of the range appear to differ in the occurrence of debris cover, if the 2 basins chosen are representative. It would be an interesting topic to explore the climatological and possible geomorphological reasons for this. The modelling approach is a good idea and although simple, seems appropriate for the limited dataset available. However this paper does not give sufficient details of either measurements, or analysis undertaken to be acceptable as a useful addition to the scientific literature on debris covered glaciers. The discussion lacks direction, in the form of a clear aim, and critical assessment of the findings – there is no real conclusion regarding why the incidence of debris covered ice differs in the north and the south. In addition, the whole article needs to be read by a native English speaker before being acceptable for publication, as the text contains repetition of many minor errors which are too numerous to list here, and the language used tends to be imprecise. Consequently, I recommend that the paper in its current form is not suitable for publication in TC, although the field data and modelling work could be publishable in the context of a paper with a stronger aim and glacioclimatological interpretation of the analysis.

As a conclusion of the "general comments" we accept that the discussion and conclusions of our study does neither reach far enough, nor present the achieved results satisfactorily in the general context. We recognise that there are weaknesses in the paper, but we are convinced that we can provide enough improvements in a revised version, so that the manuscript will meet the high standards of "The Cryosphere". Most of the issues criticised in this review can be solved by improving explanations in the text, or by providing new analysis based on our existing data. Also the English will be improved by a native English speaking person.

Specific comments:
Section 1
Specify the aims more clearly. Is the goal to understand why there are fewer debris covered glaciers in the south, or to specify the effect of debris cover on runoff in the north and south of the divide? It is not clear enough why it is of interest to compare these basins.

The main aim of the study is the comparison of two basins North and South of the divide in respect to their ablation conditions. A comparison of other Caucasus glaciers shows that many glaciers are at least partially debris covered. Our analysis also shows that the supra-glacial debris cover increased during the last decades. This trend will also continue if the climate evolves according to the usual scenarios. Therefore any reasonable investigation of the current ablation conditions needs to take debris cover on glaciers into account. The Caucasus is strongly divided by its main ridge, with different climatic conditions in the North and in the South. This is also reflected by the distribution and the size of the glaciers. In our opinion this is a good reason for investigating differences between these two regions. Unfortunately there are not many glacier related data available in the Caucasus. This is also one reason why we demonstrate the applicability of a simple method with a limited amount of required input data for the assessment of local conditions.
It appears that our motivation is not presented in a convincing way in the current paper, therefore we will add a section explaining the situation and the motivation in more detail in the revised version.

Section 2
Back up this section with improved maps. Also the descriptions of the area and glaciogeomorphological features in it need to be made more precise and quantified where possible. Some of the glaciers appear to have only very marginal debris cover. In maps 1 and 2 it appears to me that there is only 1 glacier in each image that have truly debris covered tongues, the remainder have some debris cover but only on the margines. What is the local geology difference that explains the difference in R mentioned in the conclusion? Provide details of the 3 AWS's used in a table (location (x,y,z), types of sensors, height of each sensor, logger, logging interval, duration). Debris temperatures were only measured in one glacier for 4 days. How many thermistors in Djankuat glacier? Where? How deep? What type of sensor?

Improved maps can be produced, including a better representation of debris cover on the glaciers. In the Zopkhito basin there are basically two glaciers with debris cover. Laboda glacier shows a more extensive debris cover than Zopkhito glacier, but is not suitable for any monitoring work. In the Adylsu basin most glaciers have at least some debris cover. Djankuat glacier is covered completely across its lower tongue and shows distributed debris cover in higher areas of the glacier tongue. This is a typical distribution of supra-glacial debris cover on glaciers in this valley. Only Schelda glacier shows a much higher concentration of debris on its tongue. A general description of the geological settings will be included in the revised manuscript.
At the two sample glaciers, Djankuat glacier in the North and Zopkhito glacier in the South identical weather stations were installed. Moreover, at Djankuat glacier there were two automatic weather stations, one on debris cover and one on clean ice for the season of our debris investigations. We will include a table with the sensors and detailed information about the setup. Debris temperature measurements were carried out on both glaciers as a basis for the calculation of the thermal resistance of the debris cover. We will provide a more detailed description of the debris temperature measurements including the determination of the thermal resistance. This will be also in accordance with a similar request of reviewer one.

Section 3
Provide more details of images and maps used. Resolution and sources of previous maps? Error estimates of previously mapped areas? Error assessment of manually delimited glaciers from the SPOT images? Clarify reasons for using additional images in the southern catchment – I understand it to be due to cloud cover? Paragraph starting line 11 p 437 does not belong here – reported observations of debris cover type should be in section 5 alongside the ablation observations.

Most of the information is given in the manuscript. In order to make it more legible, we will condense the information in a separate section, including the missing details. The errors assessment was done and the results will also be provided. The additional image was used for areas with cloud cover in the original image. This also will be explained more clearly in the manuscript.

Section 4
The quality of the ablation measurements is not clearly explained. How often were the stakes measured, and how? Were the stakes in the naturally occurring debris thickness or were the plots prepared to a specified debris thickness? Is 4 days of debris temperature monitoring sufficient to stabilise the profile after installation of thermistors?

A section about the details of field measurements will be included and the already existing description will be improved. Stake measurements have been made manually by measuring the distance between the stake tip and the debris surface. These measurements are usually better than 1 cm in accuracy. On both glaciers measurements were carried out twice a day in the first period (1 week to 10 days). Afterwards the measurement frequency was not constant, but was dependent on the field program of our local partners. All the stakes were place in natural debris cover. After installation of the stake, the small excavation of natural debris was re-installed as close to the natural conditions as possible. The

natural temperature profile is already reached again after a several hours. In general, temperature measurements show that for debris thicknesses of less than 40 cm the daily temperature cycle is fully compensated during the night. The accuracy of the thermistors used in the debris cover is good enough to identify the established temperature gradient (~0.2 °C). We will also provide more information about the sensors used and the measurement procedure in the text.

Section 5
The higher melt rates found at longer time scales may be due to the progressive warming of the debris as the melt season progresses –justify attributing this to washout of fines and resettling alone.
What was the quality control criteria of ablation measurements used? Were any points/measurements discarded and, if so, why? I would expect degree day factors for different debris thicknesses to conform to the shape of previously published curves of the melt dependence on debris thickness i.e. an increase at thin debris thicknesses followed by an asymptotic decline, but it does not. This needs discussion and explanation.

See also explanation for section 4. The heat capacity of the debris cover is usually (for the thicknesses measured here) not high enough to store extra heat over a period of time. The temperature profile is only determined by the daily temperature cycle and thus the daily radiation intensity and air temperature. In Fig. 7 we show all available measurements. But for the derivation of the ablation relation we only used the measurements, where we are convinced about their validity. For the long term measurements it is likely that the debris thickness was not constant over time, but was not checked at all stakes.
Our measurements also represent the general findings about an increase in melt rates for very thin debris layers. This is also discussed in the text. However, especially for very thin debris covers the measurements are not easy, due to rather variable and highly dynamic debris covers. Still the high melt rates compared to thicker debris covers and clean ice can be seen, even though this effect is restricted to rather thin debris layers. We will try and visualise these conditions in an improved figure.

Section 6
As climatological parameters are used as explanation of the differences in ELA, a table characterising the climate conditions in each basin should be included (section 2). Also, drawing on meteorological explanations of differences needs to be somehow linked to the DDF's – which cannot take cloudiness etc. into account. Explain acronyms of hydrological models listed as examples

We will provide information about the general meteorological conditions for the two glaciers. We also provided some explanation about our arguments for e.g. cloudiness in the answer to reviewer one. But we will also include a more thorough discussion about the linkages between meteorological parameters and the DDF used for the ablation model. The model acronyms will be explained in the text.

Section 7
How was the debris thickness surveyed? At how many points? Just at the 11 stakes It is interesting that the critical debris thickness is quite thick, while the thickness of 50% reduction is lower than previously published estimates.

Debris thickness was surveyed at the stakes and for low debris thicknesses also at other locations. Ice ablation shows only a rather low sensitivity for debris thicknesses of more than 20 cm. Therefore we did no high resolution survey of thicker debris. Even with a certain spatial variability the effect on the total melt amount will be not significant. For Djankuat glacier also rather detailed maps of debris distribution and thickness exist for earlier years, providing information on the thickness variability which agrees well with our point measurements during our observation period. On Zopkhito glacier most of the glacier shows rather thin debris layers which could be mapped while installing the stake network. In 2009 dedicated debris thickness measurements were performed for regions where we did not have information from the previous field season. Therefore, also at Zopkhito glacier we have a rather good idea about debris thickness distribution.

The critical debris thickness usually is found to be only somecentimeters. But also larger values are found which fit with our observations (Brock, 2010.). In order to provide our data in this context we will add a part with a short review of these data.

Figures:
Need a general orientation map of the station locations relative to the 2 glacier study valleys, with frequently named glaciers indicated by letter. Need to include station and stake locations one of the map options within the paper. It's a personal preference but I suggest improving the quality of the graphs, excel does not produce especially elegant graphs and it would be a simple task to make the layout and appearance of the graphs much better.

We will include the suggestions in the revised version of the figures and also use a different graph program for a more elegant style.

Fig 1: show where the site is on the inset map; add stake locations as points on the studied glacier
Fig 2: show where the site is on the inset map; add stake locations as points on the studied glacier

Inset maps are probably to small to show the stake positions on the glacier. We will include another figure with a detailed view of the investigated glaciers and the measurement positions

Fig 3: what is the purpose of this graph? If it is to convince the reader of the theory of precipitation events lowering the temperature on the glacier, then known precipitation events should be marked on the graph

This figure shows the generally good correlation between the low lying climate station and our meteorological data at the glacier. This is important for the applicability of the ablation model und thus we will leave the figure in the manuscript.

Fig 4 and 5: scale should stop at 4500; better as 2 panels(a and b) alongside the current figure 5; give area units as square kms; a line without markers would look cleaner in my opinion; do you even need to show the catchment hypsometry?; excluding the clean ice glaciers from the southern catchment may have skewed the elevation of maximum ice cover

We will change the figures accordingly. In our opinion the catchment hypsometry provides valuable information for comparing the two catchments. Therefore we will keep the figures in the manuscript.

Fig 6: not really needed, as numbers are so few, these can simple be listed in the text

The graphical impression will explain the temporal evolution of the debris cover much more easily. Also it demonstrates well the situation of only two debris cover maps in the southern test region in contrast to the improved information content for the northern test site. Therefore in our opinion this figure illustrates the situation better than just some numbers in the text.

Fig 7: not a clear figure – I am surprised a the irregularity of the values obtained; need
inset blow-up of thin debris cover portion of graph; I suggest linking some of the points with lines to improve legibility.

We are aware about the confusing appearance of the figure. We wanted to show all measurements taken over the two seasons, including measurements which might not be of the required quality. One of the main problems is the temporal dynamics of the debris cover. Unfortunately debris thickness was not determined at the end of the ablation season again. Therefore, temporal changes of the debris cover might have obscured the true ablation relation. On the other hand we know that the debris conditions were stable over the first period in each season. These measurements have been used to determine the debris thickness- ablation relation. We suggest to remove all doubtful values from the graph to show only the values where we are sure about the quality.

Fig 8: label the data collected in this study as ‘this study’; need inset blow-up of thin debris cover portion of graph; I suggest linking some of the points with lines to improve legibility

The data will be labelled accordingly and the thin debris cover part will be changed. We will also include the derived degree-day functions used in the model accordingly to review 1.

Fig 9: label the data collected in this study as ‘this study’

Will be done.

Fig 10: end the x axes at 3300m to eliminate unused space

Will be changed.

References:

Brock, B.W., Mihalcea, C., Kirkbride, M.P., Diolaiuti, G., Cutler, M.E.J., and Smiraglia, C.: Meteorology and surface energy fluxes in the 2005–2007 ablation seasons at the Miage debris‐covered glacier, Mont Blanc Massif, Italian Alps, J. Geophysical Research, 115, d09106, doi:10.1029/2009JD013224, 2010