We thank the reviewer for his valuable comments and suggestions. As the reviewer said, he/she with the group members did very nice studies on the typical debris-covered glaciers, on which abundant and detailed observations of meteorology and debris properties are available (e.g., Brock et al., 2010; Foster et al., 2012; Reid et al., 2012; Lejeune et al., 2013). As we all know, poor knowledge of the large-scale spatial distribution of debris thickness and properties with the scarce glacio-meteorological observations is the main challenge in the Tibetan Plateau for better understanding the debris-cover effects at a regional scale. Therefore, the main aim of our study is to present a simple, physically-based approach that can require as less input data as possible to well understand the potential influences of debris cover and its spatial distribution on the average status of the glaciers at a regional scale. This, in turn, allows us to apply such approach to other debris-covered glaciers of the Tibetan Plateau. Suggestions and comments are indicated by *blue colored italic*, and our replies are denoted by a header [Reply].

1. *Turbulent fluxes can be ignored in the energy-balance calculation*

[Reply] The 5.1 section of this study discussed one of the limitations of our approach for calculating the thermal resistance, which is the assumption of neglecting the turbulent heat fluxes in the surface energy-balance calculation. This assumption is based on the fact that the net radiation is usually the dominant heat source in the Tibetan Plateau and the contribution of the turbulent heat fluxes to the total energy balance is normally small on debris-covered glaciers of the Tibetan Plateau and surroundings (Mattson and Gardner, 1991; Kayastha et al., 2000; Shi et al., 2000; Takeuchi et al., 2000; Suzuki et al., 2007; Zhang et al., 2011). In particular, Shi et al. (2000; Table 4-2) analyzed the characteristics of the components of the surface energy budget for different type glaciers located in different mountain ranges of the Tibetan Plateau and surroundings. They found most of glaciers where the net radiation is the dominant heat source, and the maximum is up to 100%. On the other hand, on some debris-covered glaciers, with the exception of the net radiation, the turbulent heat fluxes play an important role in the debris surface energy budget (e.g. Brock et al., 2010; Foster et al., 2012; Reid et al., 2012; Lejeune et al., 2013). Therefore, to evaluate the uncertainty caused by this assumption, Suzuki et al. (2007) calculated the thermal resistances from observed meteorological data on debris-covered glaciers of Bhutan using two methods: one considers all components of the debris surface energy budget, and the other only considers the net radiation. Their results suggested that this uncertainty is unlikely to affect the spatial pattern of the thermal resistance of the debris layer. Although differences in the contribution of turbulent heat fluxes are apparent from region to region (Shi et al., 2000; Brock et al., 2010), leading to uncertainties in the calculation of thermal resistance, our study attempted to present a simple, physically-based approach that requires as less input data as possible to assess the debris-cover effect at a large scale, not on a glacier scale. Hence, based on the observed conditions in the glacierized regions of the Tibetan Plateau and the characteristics of the components of the surface energy budget, this assumption can be acceptable at a regional scale. We inserted the new discussions above mentioned and suggested by the reviewer in the 5.1 section.

2. *The description of how NCEP/NCAR reanalysis data are used to derive downwardly directed radiation fluxes is unclear (p. 2422, paragraph 1). As far as I am aware, the highest temporal resolution of the reanalysis is 6-hours and hence there is a significant mismatch between the instantaneous incoming shortwave radiation flux at the surface at the time of image acquisition and the 6-hour average provided by the reanalysis. The imagery were acquired close to midday local time (5, 2418) and during the middle hours of the day the incoming shortwave radiation flux can vary by 100 W m-2 per hour. Hence, using the reanalysis data ": : :which corresponding to the nearest time: : : of ASTER acquisition" (6, 2422) introduces a very large uncertainty to the energy balance and R calculations, which is not acknowledged or evaluated. There is also likely to be a large uncertainty in the incoming longwave radiation estimated in thisway. A radiative model for incoming radiation would provide a better solution.*

[Reply] The average radiation fluxes from the NCEP/NCAR reanalysis data maybe introduce the uncertainty to the calculation of the thermal resistance of the debris layer, but earlier investigations on different glaciers indicated that the spatial patterns of thermal resistances estimated using the same approach and dataset corresponded well with the spatial patterns of debris thicknesses (Suzuki et al., 2007; Zhang et al., 2011), reflecting large-scale variations in the extent and thickness of the debris cover. And a comparison between high-resolution in situ measurements of debris thickness and estimated thermal resistance data confirmed that the estimated thermal resistances correlated reasonably well with ground-surveyed debris thicknesses (Zhang et al., 2011). In addition, we calculated the thermal resistance of the debris layer in thickness of 10 cm based on the empirical equation derived from the relationship between ground-surveyed debris thicknesses and ASTER-derived thermal resistances (Zhang et al., 2011; Figure 5(a)). The thermal resistance for debris layer in thickness of 10cm is 0.0192 m^2 K W^{-1}, and the thermal conductivity (ratio of debris thickness and thermal resistance) is 5.19 W^{-1} m K^{-1}. These results are the similar order with those of Lambrecht et al. (2011), who calculated the thermal resistance in a 10 cm thick layer for different rock types and thermal conductivity of the respective material. This can partly assess the reliability of the NCEP/NCAR reanalysis data as input data. Furthermore, data limitation and the aim of this approach and its applicability at a large scale in the Tibetan Plateau are the other reasons for using this dataset. As the reviewer said, a radiative model for incoming radiation would provide a better solution, rather than using NCEP/NCAR reanalysis data. If studying a typical debris-covered glacier where detailed meteorological observations are available, the radiative model will be the best choice. However, for the glacierized regions in the Tibetan Plateau where few glaciological and meteorological observations are available, it is difficult to use the radiate model to calculate the incoming radiation. Overall, the reasons discussed above combined with our research scale let us choose the NCEP/NCAR reanalysis data in Mount Gongga of the southeastern Tibetan Plateau.

We inserted the discussion about the uncertainty caused by NCEP/NCAR reanalysis data in the 5.1 section as discussed above in the revised manuscript, which is '*In addition, the surface downward radiation* *fluxes from NCEP/NCAR reanalysis 1 that correspond to the nearest time and location of ASTER acquisition can cause the uncertainty for the calculation of the thermal resistance of the debris layer. Earlier investigations, estimated the thermal resistance on different glaciers using the same approach and dataset (Suzuki et al., 2007; Zhang et al., 2011), indicated that the spatial patterns of estimated thermal resistances of debris layers correspond well with the spatial patterns of debris thickness, reflecting large-scale variations in the extent and thickness of the debris cover. Meanwhile, the estimated thermal resistances correlated reasonably well with ground-surveyed debris thicknesses (Zhang et al., 2011). We calculated the thermal resistance of the debris layer in thickness of 0.1m based on the relationship between ground-surveyed debris thicknesses and ASTER-derived thermal resistances (Zhang et al., 2011). The thermal resistance for the debris layer in thickness of 0.1m is about 0.0192* m^2 *K* W^{-1}*, and its thermal conductivity (the ratio of debris thickness and thermal resistance) is about 5.19* W^{-1} *m* K^{-1}*. These results are the similar order with those of Lambrecht et al. (2011), who calculated the thermal resistance in a 10 cm thick layer for different rock types and thermal conductivity of the respective material.*'.

3. *At the time of ASTER acquisition the debris layer will be warming (under the conditions described) and there will consequently be a significant flux due to the change in heat stored in the debris layer, which is ignored in the methodology (based on Zhang et al. 2011). The magnitude of the heat store flux will be spatially variable, i.e. larger on thicker debris with greater volume, with direct consequences for any interpretation of spatial patterns in R and model calculations of spatially-variable debris effects. While only limited information is provided on meteorological conditions at the time of acquisition (13, 2432), given the presence of cloud-free skies and "high temperatures" in winter it must be a strong possibility that the debris is affected by night-time freezing and daytime thawing of melt water, representing another important, neglected and spatially-variable heat flux. This would also lead to a violation of the assumption of a linear temperature profile with depth, as layers with frozen water will remain at or below zero degrees Celsius until thawed. Note, that there is also the possibility that the debris may remain below zero throughout the day in some areas and depths, violating the assumption that the base of the debris is at zero degrees. Evidence, i.e. ASTER surface temperature maps, should have been presented so that all of these issues could be assessed.*

[Reply] We added the discussions about the meteorological conditions at, before and after the image acquisition date in details, which is '*According to the observations at AWS and at the precipitation gauge (Fig. 1), we analyzed the meteorological conditions at the time of ASTER acquisition, and found that the air temperatures are 1.8 and 5.7 °C on 17 December 2008 and 18 January 2009, respectively, with low relative humidity (< 30%), low wind speed (< 0.75 m s-1), almost no clouds and no precipitation. Furthermore, the meteorological conditions before and after the image acquisition date were analyzed based on the meteorological observations, which were characterized by high temperatures, cloud-free skies, and prolonged lack of precipitation*'. According to the analysis of the meteorological conditions at, before and after the image acquisition date, it is little possibility for the fact that the debris is affected by night-time freezing and daytime thawing of melt water at the time of image acquisition.

In addition, field observations confirmed that daily and seasonal variations in temperature profiles of debris layers are well approximated by a linear gradient (Han et al., 2006; Nicholson and Benn, 2006, 2013). More importantly, according to the observations of debris temperature and its profile in debris of different grain size on a Himalaya glacier, Nicholson and Benn (2013) found that the bottom temperature of all profiles is close to 0 ºC. Similarly, Lejeune et al. (2013) measured and simulated diurnal cycles of temperatures in the debris layers in different thicknesses under different meteorological conditions, and found that the temperature at the bottom of the debris layer in different thicknesses varies from -1.65 to 0.05 °C. It can be seen that although there is the possibility that the debris may remain below zero throughout the day in some areas and depths, the bottom temperature of the debris is approximately 0 ºC on average. On the other hand, the glaciers in Mount Gongga are the maritime glaciers, on which the ice surface temperature reaches the melting point (Li and Su, 1996; Shi and Liu, 2000). Hence, the assumption that the base of the debris is at zero degrees is appropriate in this study.

4. *The findings of Nicholson and Benn (2006) are misrepresented (22-3, 2431).*

[Reply] We removed it from the cited list.

5. *Summarising assumptions 1 and 3 (the sign and magnitude of assumption 2 is difficult to determine although certainly not negligible) several large heat 'sinks' in the debris surface energy balance at the time of satellite acquisition have been ignored. The net effect is to overestimate the conductive heat flux in debris, i.e. the residual from which R is derived (following Zhang et al., 2011). Overestimation of the conductive heat flux leads to an underestimate of R which is manifest in the results shown in Figure 3. Reading from the graph, it can be seen that where debris thickness, h, is 0.8 m, R is approximately 0.08 m2 K W-1, where h is 0.3, R is approximately 0.03 and so on. In other words, the ratio of h to R is roughly 10 to 1. If we substitute these numbers into Equation 1 (R = h/thermal conductivity,) and rearrange to find thermal conductivity we obtain a value of 10 W m^{-1} K^{-1}. This is far higher than is physically possible from typical rock types which, in solid form, have thermal conductivities in the range of about 1 to 4 W m-1 K-1, but reduce to values around 1 when void spaces filled with much lower-conductivity air and water in debris layers are considered (Nicholson and Benn, 2013). In other words, neglecting these important fluxes in the method generates R values which are around an order of magnitude too small over a wide range of debris thicknesses. In fact, R values calculated in this paper are not the same as thermal resistances in any physically meaningful way and their units are not m^2 K W^{-1}.*

[Reply] We calculated the thermal resistance of debris layer in thickness of 10 cm based on the empirical equation derived from the relationship between surveyed debris thickness and ASTER-derived thermal resistance (Zhang et al., 2011; Figure 5(a)). The thermal resistance for debris layer in thickness of 10cm is

0.0192 m^2 K W^{-1}, and the thermal conductivity (ratio of debris thickness and thermal resistance) is 5.19 W^{-1} m K^{-1}. These results are the similar order with those of Lambrecht et al. (2011), who calculated the thermal resistance in a 10 cm thick layer for different rock types and thermal conductivity of the respective material. Note that thermal resistance of a debris layer is a combination of properties of the rock, the air filling void space and water situated especially in the lower parts of the debris layer (Brock et al., 2007). Consequently, the difference in thermal resistance is apparent from region to region. In addition, Figure 3 of the manuscript shows the comparison of the ground-surveyed debris thickness and ASTER-derived thermal resistance, the aim of which is to verify their spatial patterns. Note that thermal resistance is the value of each grid cell, rather than the point values. Although the approach used in this study has some limitations, the estimated thermal resistances can be acceptable compared to another similar study (Lambrecht et al., 2011). We inserted the discussion mentioned above in the 5.1 section.

6. *A compounding problem is that the effects of these neglected fluxes are spatially variable, for example, turbulent fluxes are likely to be higher over thicker, (warmer) debris than cooler (thinner) debris, and similarly for the energy used in thawing frozen layers in the debris. Consequently, it isn't possible to simply scale the results in an attempt to get some physically-meaningful values for R. This fundamentally undermines the main purpose of the paper, which is to assess regional differences in debris cover effect between glaciers. It isn't possible to interpret the spatial patterns in debris-cover influence on mass balance in any significant way. In this respect, an empirical method which simply relates R to ASTER-derived surface temperature, (e.g. Mihalcea et al., 2008) with carefully calibration and testing, would be better than the overly-simplistic energy-balance approach used here. The large number of data presented in Figure 3 suggests that there might be enough data to calibrate such relationships.*

[Reply] In the study of Mihalcea et al. (2008), they compared high resolution in situ surface temperature measurements of supraglacial debris cover to ASTER-derived surface temperature data. For our study region, the debris surface temperature observations are not available, so we cannot do such comparison, but we compared high resolution in situ measurements of debris thickness to ASTER-derived thermal resistance, and found that ASTER-derived thermal resistances correlated reasonably well with ground-surveyed debris thicknesses, and across- and along-glacier patterns of thermal resistances correspond well with spatial patterns of ground-surveyed debris thickness. Meanwhile, such spatial distribution is verified on other two glaciers of Mount Gongga, which is shown in Figure 3 of this study. In this study we used such empirical relationship to analyze the spatial features of debris thickness and the effects.

7. *However, the best approach would be to do things properly and perform a complete energy-balance calculation forced with ASTER surface-temperature values to derive values of R, including a sensitivity analysis. In fact, such a method has already been demonstrated by Foster et al. (2012) – another important recent study which has been ignored. A much more valuable exercise would have been to look at how the methodology of Foster et al., previously demonstrated on a European Alpine glacier, could be applied in*

the context of south-eastern Tibetan glaciers. This is a key first step. Only when a scientifically-sound method of extracting R from satellite data has been demonstrated for the glaciers in question, can spatially-variable debris effects be reliably modelled.

[Reply] Foster et al. (2012) developed a physically based model that utilizes ASTER imagery and is based on a solution of the energy balance at the debris surface. Their model has the potential to be used for regional-scale supraglacial debris-thickness mapping and monitoring for debris up to at least 0.50 m thickness, but improved understanding of the spatial patterns of air temperature, aerodynamic roughness length and thermal properties across debris-covered glaciers is needed (Foster et al., 2012). As the reviewer said, the methodology of Foster et al. (2012), previously demonstrated on a European Alpine glacier, could be applied in the context of the south-eastern Tibetan glaciers. This is a key first step. For the future work, we hope that we can use the model developed by Foster et al. (2012) to map debris thickness on a typical debris-covered glacier of the southeastern Tibetan Plateau, this may be an important step to verify the applicability of their methods and evaluate the uncertainties of the approach used in this study.

8. *References*

[Reply] We cited references as the reviewer suggested, which include Brock et al. (2010), Reid et al. (2012), Foster et al. (2012) and Leejeune et al. (2013).

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