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Interactive comment on "Thermal remote sensing of ice-debris landforms using ASTER" *by* A. Brenning et al.

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AC: Both referees find the proposed approach novel and interesting, but have some critical comments concerning the transferability of the presented results to other areas and the uncertainties present in our analysis and discussion. To emphasize the exemplary character of this study and its limited spatial scope – which is, however, supported by a substantial sample size in terms of number of ice-debris landforms and in-situ measurement sites – we decided to indicate the study region in the title of the revised article. In addition, we have made amendments to the article that will put stronger emphasis on the discussion of uncertainties, and physical aspects of the present research such as links between apparent thermal inertia and surface energy balance are now discussed in more detail.

We would like to thank the anonymous referees for their thoughtful comments, which helped to improve the manuscript.

Point-by-point reply to the referee's comments

RC: This manuscript presents an empirical study about the application of ASTER thermal imagery to characterize debris-covered glaciers and rock glaciers in Punta Negra Valley (Central Andes). A statistical evaluation is performed to analyze the spatial patterns of Aster surface temperature and near surface in-situ temperature measurements. The purpose is to distinguish rock glaciers and debris-covered glaciers from other debris landforms by using the apparent thermal inertia derived from Aster surface temperature estimates. The approach is novel and interesting. The authors reference well most of the recent literature and the paper is well presented and structured. However, the study area is rather small, the data and the results are not sufficient to support the utility of using apparent thermal inertia as a proxy for mapping ice-debris landforms and also the transfer to other mountain regions.

AC: We appreciate the referee's comment regarding the novelty and interestingness of the proposed approach. The exemplary character of our study, which, naturally, uses one study area to demonstrate the application of this approach, is now emphasized by changing the title to indicate the study region. The size of the study region is determined by the availability of high-quality ground truth information on the distribution of ice-debris landforms and instrumentation with ground temperature data loggers in an area with difficult logistics. This being said, there are more than 50 ice-debris landforms in this study region, and data from 37 data loggers was available for this analysis. Many similar glacier remote sensing studies in mountain regions lack this degree of replication (see also response to a similar comment by referee #1).

RC: The utility of this approach is limited and I would suggest major revisions or rejection.

AC: While we agree that the utility of ATI mapping for discriminating ice-debris landforms appears to be limited – contrary to earlier findings of Piatek (2009) – we would like to remind the referee and the editor that the non-significance of results or a smaller than expected effect size cannot constitute a criterion for rejecting manuscripts. There is overwhelming evidence from other research areas that shows that this introduces a publication bias (e.g., Fanelli, 2012). In this particular case not reporting the limitations of ATI for mapping ice-debris landforms would possibly lead other researchers to rely on more encouraging findings of Piatek (2009), which can, however, be explained with confounding with vegetation effects in a more humid environment (Alaska).

RC: The apparent thermal inertia calculation should be discussed in more detail, especially in-pixel distribution of surface temperature and the influence of topography (aspect and slope). Sensible and latent heat fluxes should be included in the analysis to support the application in a complex terrain and transfer to other areas.

AC: The two scales mentioned by the referee, pixel-level analysis and within-pixel (sub-pixel) analysis, are present in our analysis in the form of separate analyses of remotely-sensed and in-situ temperature (and inertia/amplitude) variables. We did not intend to analyze the within-pixel distribution of surface temperatures in its strict sense; neither do we have the data that would be necessary to accomplish this (sufficient replication of in-situ measurements within pixels, i.e. hundreds of measurements instead of 37), nor do we think this is strictly necessary to accomplish the goals of our study.

While slope angles were already accounted for in our analysis, decided to consider slope aspect related influences in a post-hoc analysis that we added to the revised paper. Especially possible influences of anisotropic relfection can be eliminated by adding aspect variables (sine and cosine of aspect) to our models. While general coefficient estimates and in particular the ones for rock glacier effects remained unchanged (within the confidence limits), greater thermal and ATI anomalies were observed in this post-hoc analysis for debris-covered glaciers. These post-hoc results are mentioned in the revised Results section (Sect. 4.2) and in the Methods (Sect. 3.6).

We did not measure sensible and latent heat fluxes in this study. While such measurements would provide additional insights into the processes controlling LST and ultimately influencing calculated ATI, it is evident that it would not be possible to achieve the level of replication desired to control for confounders in our empirical-statistical approach, which without doubt is a valid research approach in cryospheric and geomorphological research. We furthermore refer the referee to changes made in response to comments of referee #1 concerning the control for different energy balance components and the possibility of confounding with turbulent heat flux effects.

RC: Some information about the lithology in this area should be presented.

AC: The following text was added to Sect. 3.1: "The study area presents mainly dark volcanic rocks of the Tertiary Abanico Formation. A granodioritic intrusive unit is present in the northwestern corner of the study area, and volcanic and sedimentary sequences of the Late Cretassic Colimapu Formation occupy the eastern margin of the study area (Fock et al., 2005; Farías et al., 2008). All data logger locations are in the dark volcanic area, while a small percentage (<10%) of the matched samples introduced in Sect. 3.6 are located in the other geological units."

RC: What is the area (km2) covered by rock and debris covered glaciers in Punta Negra Valley?

AC: The following text was added to the revised manuscript to provide the requested information (Sect. 3.5): "The study area covers 48 km2 between 3000 and 3900 m a.s.l., of which 4.9 km2 correspond to ice-debris landforms (rock glaciers: 3.3 km2). The area of interest is reduced to 21 km2 after removing irrelevant areas such as exposed ice and bedrock. More than 50 rock glaciers are present in the study area, the exact number depending on how multi-part rock glaciers are counted."

RC: If available, ground albedo measurements (also literature) should be compared to remote sensing data.

AC: ASTER-derived albedo values have been compared to values reported in the literature, yielding a good correspondence, as already mentioned in the discussion paper (p. 2903, l.23-27). A new table that summarizes albedo values obtained for a variety of surfaces from glacier accumulation areas to water bodies and different rock types has been now added in response to the referee comment in order to support our claim (Table 1).

RC: What is the distance between EEY and the analyzed area?

AC: EEY is 9 km south of the core part of the study area with the data logger sites. This information was added to the revised manuscript.

RC: Are debris thickness measurements available at the near surface temperature sites?

AC: Debris thicknesses were not measured; however, near-vertical profiles are exposed at the margins of the numerous melt-out depressions of the debris-covered glaciers of Punta Negra and Casa de Piedra, which have both been visited in numerous occasions. Based on this, we estimate debris thicknesses to be typically up to 1-1.5 m in the lower half of the debris-covered glaciers (Bodin et al., 2010). Similar thicknesses have been observed by us and other authors at similar altitudes and latitudes in the Andes, but of course variation within a debris-covered glacier is large. In the upper part in the transition to the uncovered glacier portions debris-thicknesses evidently become thinner. Rock glacier active layer thicknesses have not been measured on the numerous rock glaciers in this study area; however, observations by Trombotto and Borzotta (2009) and unpublished data from our own active-layer boreholes in the semi-arid Andes are consistent with active-layer depths between 2.5 at higher elevations and 7 m at lower elevations on active or at least intact rock glaciers. General information on this is already included in Sect. 2.3. No changes made.

RC: Correlation between debris thickness and in–situ temperature measurements?

AC: Such measurements are not available in our study area, and this would likely constitute a study of its own, which would require multiple data sources (geophysical measurements, boreholes) in order to achieve sufficient replication even on a single ice-debris landform (let alone the >50 landforms studied here). However, such correlations have been studied in much detail in other regions empirically as well as using physically-based models (e.g., references in the manuscript to Mattson et al., 1993; Nicholson and Benn, 2006), and similar relationships can be expected to hold in our study area.

RC: Errors both involved in estimating surface temperature, albedo, apparent thermal inertia from the Aster imagery and in-situ temperature measurements should be presented and discussed in more detail.

AC: Model and accuracy of the data loggers used for in-situ measurements are included in the revised manuscript (Sect. 3.5). The following sentence is added to Sect. 4.1 to reflect the offset between remotely-sensed LST and NSGT during the reference period: "Median nighttime and daytime NSGT during the reference period were, however, 6-7°C higher than LST at the logger sites (Table 1). This can be partly explained by 3°C higher air temperatures during the reference period, and it may also reflect differences in turbulent heat fluxes or a bias in LST measurements relative to NSGT, which was measured at about 5 cm depth and at a point scale." Discrepancies between point-scale NSGT and pixel-scale LST in one important aspect are also pointed out very clearly in Sect. 5.1, and it was found that another study targeting specifically scale-dependent patterns found a similar discrepancy (Gubler et al., 2011). Patterns in LST and NSGT, however, correlate reasonably well, which supports our view that LST and derived ATI can be useful for thermal imaging in mountain environments. The plausibility of albedo estimates, for which no in-situ measurements are available for comparison, is discussed above in response to an earlier comment.

RC: Pag. 2917 Lines 19-21: Physically based modeling and geophysical investigations would indeed provide valuable insights for this study.

AC: We obviously agree with this statement from our manuscript. Our approach is to make one step at a time, conducting a thoroughly designed remotely-sensed and field based study of thermal properties at this point. We do think that we have accomplished our goal of assessing the utility of ATI for discriminating ice-debris landforms, which was one of our objectives. We showed that even in a completely vegetation-free environment (as opposed to earlier studies in which confounding with vegetation induced more striking contrasts) ATI is the result of multiple external influences as well as complex relationships with the structure of an ice-debris landform. In addition, we effectively demonstrated that remotely-sensed LST and ATI are in many aspects consistent with in situ observations, which is an important prerequisite for future studies of this kind in complex topography. As a next step, we hope that physically-based modeling and geophysical investigations can provide additional insights, and one member of the author team (A. Soliman) is currently engaged in such activities. We have furthermore already conducted simple model simulations of the surface temperature variations of two-layer structures with assumed thermophysical and structural properties similar to those of rock glaciers and debris-covered glaciers, but evidently these simulation experiments are clearly beyond the scope and reasonable page limit of this contribution.

References

Bodin, X., Rojas, F., and Brenning, A.: Status and evolution of the cryosphere in the Andes of Santiago (Chile, 33.5°S.), Geomorphology, 118, 453-464. doi: 10.1016/j.geomorph.2010.02.016, 2010a.

Fanelli, D.: Negative results are disappearing from most disciplines and countries, Scientometrics, 90: 891-904, 2012.

Farías, M., Charrier, R., Carretier, S., Martinod, J., Fock, A., Campbell, A., Cáceres, J., and Comte, D.: Late Miocene high and rapid surface uplift and its erosional response in the Andes of central Chile (33°–35°S), Tectonics, 27, TC1005, doi:10.1029/2006TC002046, 2008.

Fock, A., Charrier, R., Farías, R., Maksaev, V., Fanning, M., Álvarez, P.: Exhumation and uplift of the western Main Cordillera between 33° and 34°S, in: Extended Abstracts, 6th International Symposium on Andean Geodynamics, ISAG 2005, Barcelona, 273-276. Geiger, R., Aron, R. H., and Todhunter, P.: The climate near the ground, sixth edition, Rowman and Littlefield Publ., Lanham, MD, USA, 2003.

Knap, W. H., Reijmer, C. H., and Oerlemans, J.: Narrowband to broadband conversion of Landsat TM glacier albedos, International Journal of Remote Sensing, 20(10), 2091-2110, 1999.

Lillesand, T. M., Kiefer, R. W., Chipman, J. W.: Remote sensing and image interpretation, fifth edition, John Wiley & Sons, New York, 2004. Piatek, J. L., Hardgrove, C., and Moersch, J. E.: Potential rock glaciers on Mars: comparison with terrestrial analogs, in: Seventh International Conference on Mars, held July 9-13, 2007 in Pasadena, California, LPI Contribution No. 1353, 3353, 2007.

Piatek, J. L.: Thermophysical properties of terrestrial rock and debris-covered glaciers as analogs for Martian lobate debris aprons, 40th Lunar and Planetary Science Conference, Lunar and Planetary Science XL, held March 23-27, 2009 in The Woodlands, Texas, id. 2127, 2009.

Trombotto, D., and Borzotta, E.: Indicators of present global warming through changes in active layer-thickness, estimation of thermal diffusivity and geomorphological observations in the Morenas Coloradas rockglacier, Central Andes of Mendoza, Argentina, Cold Regions Science and Technology 55, 321-330, 2009.

Interactive comment on The Cryosphere Discuss., 5, 2895, 2011.