Response to comments from C. S. Zender (Referee)

We thank the C. S. Zender for the reading of and comments to our manuscript. The comments of C. S. Zender are repeated below in italic font. Our responses to the comments are shown in roman font.

General comments and responses

- *However, the manuscript unintentionally exaggerates the role of tilt-bias by considering only clear sky (not cloudy sky) conditions.*

  The manuscript has been updated to also discuss cloud sky conditions. However, we do consider this analysis to demonstrate the significance this error may have, particularly when one considers the importance of clear sky observations for the validation of satellite retirievals.

Specific comments and responses

- *The manuscript quotes Stroeve et al. (2006) that leveling errors dominate snow albedo measurement errors. On this basis the manuscript restricts itself to a theoretical quantification of that error, especially at the large zenith angles appropriate to polar environments. However, the Stroeve et al. claim is unverified until/unless someone examines actual AWS albedo measurements and show that removing the tilt-induced bias consistently eliminates at least half the error (e.g., versus a known good calibrated measurement like BSRN or some other metric). Has this been done? This manuscript would be more interesting if it showed readers how much better a tilt-adjusted albedo looks than a raw albedo from actual measurements. The inclusion of measurements would also add balance to this model study.*

  Measurements are the acid test of any theory. Our investigation is purely theoretical as indicated in the title. However, our model has been validated against measurements numerous times, albeit not for the specific conditions studied here. Paragraphs describing the model validation have been added to the revised manuscript. Please also see our response to the second comment by D. van As.

  We are not aware that anyone has examined "actual AWS albedo measurements" against "known good calibrated measurement like BSRN " and showed "that removing the tilt-induced bias consistently eliminates at least half the error". However, the recent paper by Wang et al. (2015) clearly shows that tilt-correction reduces errors. We were unaware of this paper while submitting our manuscript. The Wang et al. (2015) manuscript is discussed in our revised manuscript.

- *p. 4364: The manuscript mentions some effects of cloud cover, but the authors chose not to include more results because the values are entirely dependent on the definition of many separate parameters controlling the properties of the cloud cover. I disagree with this decision and think the manuscript would be more interesting if it presented*

results for homogeneous cloud cover. The manuscript is a sensitivity study that already makes numerous assumptions (flat snow, Lambertian albedo, no aerosols). Snow-covered surfaces in the arctic are often cloud-covered, and ignoring that aspect inflates the AWS tilt-errors relative to their all-sky values. It takes instrument teams months of planning, days of installation, and sometimes years of maintenance to collect their measurements. They (an TC readers) deserve a model-sensitivity study that attempts to replicate the field conditions to greatest extent possible. I suggest you expand the study to include tilt-sensitivity to some arguably representative plane-parallel 100% cloudy conditions. Apparently you have already done the calculations, so it would be a matter of incorporating them into the manuscript. Then you will have more carefully bounded the tilt problem for your readers.

The tilt-error under cloudy conditions have been addressed in the revised manuscript. The "Discussion" and "Conclusions" sections have been re-arranged and partly re-written to include the cloudy results. Furthermore, results for cloudy situations have been added to Figs. 1 and 2.

- *p. 4366: Sensors for monitoring orientation (like inclinometers) are helpful though not required to ascertain (and thus adjust for) tilt. Our manuscript currently in review in The Cryosphere demonstrates how to estimate tilt angles from tilt-biased broad-band radiometer measurements (with adequate temporal resolution) in clear-sky conditions. The method is called RIGB (Retrospective, Iterative, Geometry-Based). It is retrospective because it works with (sub-daily clear-sky) timeseries measurements already taken, and its tilt-adjusted values have lower biases than measurements from AWS without and with (!) inclinometers (that can have their own problems). Please include in the Discussion non-invasive methods such as RIGB which can adjust for tilt without (and with!) the added expense and complication of additional instrumentation.*

  A discussion of the tilt-correction method by Wang et al. (2015) has been included in the revised manuscript.

Bibliography

Wang, W., Zender, C. S., van As, D., Smeets, P. C. J. P., and van den Broeke, M. R.: A Retrospective, Iterative, Geometry-Based (RIGB) tilt correction method for radiation observed by Automatic Weather Stations on snow-covered surfaces: application to Greenland, The Cryosphere Discussions, 9, 6025–6060, doi:10.5194/tcd-9-6025-2015, URL `http://www.the-cryosphere-discuss.net/9/6025/2015/`, 2015.