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Interactive comment on "From Doktor Kurowski's Schneegrenze to our modern glacier equilibrium line altitude (ELA)" *by* R. J. Braithwaite

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Title: From Doktor Kurowski's Schneegrenze to our modern glacier equilibrium line altitude (ELA)

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General comments:

Roger Braithwaite presents an interesting and valuable study, revisiting an "old" ap-

proach proposed by Ludwig Kurowski in the late 19th century to retrieve the elevation of the balance-budget equilibrium line from the area-altitude distribution of a glacier.

The methods are well-described including their uncertainties, the writing is clear as well as the figures; even if I have a list of edits about the main text and few suggestions about the figures that need to be considered (see "Specific comments").

However, I would appreciate that the following points would be further discussed in the manuscript, most probably in the discussion section:

(1) Applicability of the method at global scale, particularly for glaciers outside of the mid-latitudes (e.g. in the tropical and sub-tropical regions or in the polar environment).

Most of the glaciers in your sample apparently belong to the mid-latitudes. I recognize that this results from the availability of mass balance data. However do you think that Kurowski's method is reliable for glaciers all over the world, whatever the climate conditions and so the climate-glacier relationship are?

You mention in the introduction that for polar regions superimposed ice can be found on the glacier resulting in a difference between the snow line and the ELA. Shall we have to conclude that in that case, the area-weighted mean elevation of the glacier cannot be used as a proxy of the ELA0?

The only glacier in your dataset belonging to the tropical region seems to be Zongo Glacier in Bolivia. You clearly stated that mass balance data have been reanalyzed in the study by Soruco et al. (2009), but I cannot see any discussion about the case of tropical glaciers. Zongo Glacier clearly has a high AABR and appears as an outlier on your Figure 10. However, Zongo Glacier is quite typical for tropical glaciers with a very high balance gradient in the ablation zone and a quite low gradient in the accumulation zone leading to the typical high AABR of tropical glaciers. This has been mentioned in several studies (e.g. Kaser, 2001) and the high mass balance gradient in the ablation area is attributed to ablation conditions lasting almost year round and to

the high variability of the surface-state with frequent changes in snow cover throughout the long ablation season (e.g., Kuhn, 1984; Sicart et al., 2011; Rabatel et al., 2012). In addition, mass balance data are also available for several glaciers in the tropical region (e.g. in Ecuador on Antisana 15 Glacier, in Peru on Artesonraju, Yanamarey or Shallap glaciers, in Bolivia on the vanished Chacaltaya Glacier) and you can refer to Rabatel et al. (2013a) and the literature cited therein for an overview of available data in the tropical Andes. If the Kurowski method cannot be used for tropical glaciers, it has to be stated and discussed.

Note that this is also the case for glaciers in the sub-tropics, located well above the 0°C isotherm, for which sublimation is an important part of the annual ablation, and where no mass balance gradient can be clearly seen. You can refer to the study of Rabatel et al. (2011, and the Figure 6 therein) on Chilean glaciers of the sub-tropical region. Again, is the Kurowski's method applicable there?

Finally, mass balance data have been recently published for Himalayan glaciers (e.g., Azam et al., 2014; Wagnon et al., 2013). One of these glaciers, Mera Glacier in Nepal being a "monsoon-type" glacier. Are these data included in your dataset? Is the Kurowski's method reliable for these glaciers?

References:

- Azam, F.M., P. Wagnon, C. Vincent, A. Ramanathan, A. Linda, V.B. Singh. 2014. Reconstruction of the annual mass balance of Chhota Shigri Glacier (Western Himalaya, India) since 1969. Annals Glaciol., 55(66), doi: 10.3189/2014AoG66A104.

- Kaser, G. 2001. Glacier–climate interaction at low latitudes. J. Glaciol., 47(157), 195–204. doi: 10.3189/172756501781832296

- Kuhn, M. 1984. Mass budget imbalances as criterion for a climatic classification of glaciers. Geogr. Ann., 66A(3), 229–238

- Rabatel, A., H. Castebrunet, V. Favier, L. Nicholson, C. Kinnard. 2011. Glacier

changes in the Pascua-Lama region, Chilean Andes (29°S): recent mass-balance and 50-year surface area variations. The Cryosphere, 5, 1029–1041. doi:10.5194/tc-5-1029-2011.

- Rabatel, A., A. Bermejo, E. Loarte, A. Soruco, J. Gomez, G. Leonardini, C. Vincent, J.-E. Sicart. 2012. Can the snowline be used as an indicator of the equilibrium line and mass balance for glaciers in the outer tropics? Journal of Glaciology, 58 (212), 1027-1036. doi: 10.3189/2012JoG12J027.

- Rabatel, A., B. Francou, A. Soruco, J. Gomez, B. Caceres, J.L. Ceballos, R. Basantes, M. Vuille, J.-E. Sicart, C. Huggel, M. Scheel, Y. Lejeune, Y. Arnaud, M. Collet, T. Condom, G. Consoli, V. Favier, V. Jomelli, R. Galarraga, P. Ginot, L. Maisincho, M. Ménégoz, J. Mendoza, E. Ramirez, P. Ribstein, W. Suarez, M. Villacis, P. Wagnon. 2013a. Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change. The Cryosphere, 7, 81-102. doi: 10.5194/tc-7-81-2013.

- Sicart, J.E., Hock, R., Ribstein, P., Litt, M. and Ramirez, E. 2011. Analysis of seasonal variations in mass balance and meltwater discharge of the tropical Zongo Glacier by application of a distributed energy balance model. J. Geophys. Res., 116(D13), D13105. doi: 10.1029/2010JD015105

- Wagnon, P., Vincent, C., Arnaud, Y., Berthier, E., Vuillermoz, E., Gruber, S., et al. 2013. Seasonal and annual mass balances of Mera and Pokalde glaciers (Nepal Himalaya) since 2007. The Cryosphere, 7(6), 1769–1786.

(2) An expansion of the discussion about the climatic and morpho-topographic control of the ELA.

The last paragraph of the discussion section mentions the influence of local topography on the balance-budget ELA. This is an interesting point and deserves to be thoroughly discussed. On the basis on ELA time series for 43 glaciers reconstructed over the

period 1984-2010 from the end-of summer snow line identified on satellite images. Rabatel et al. (2013b) discussed on the climate and morpho-topographic control on the ELA mean location, long-term changes, and spatial/temporal variability. These authors concluded that the average ELA over the study period of each glacier is strongly controlled by its morpho-topographic variables, namely its average altitude, surface area, latitude and aspect; and that the interannual variability of the average ELA of the glaciers studied is strongly controlled by climate variables, with the observed increasing trend in the average ELA truly mainly driven by increasingly warm temperatures, even if nonlinear low frequency fluctuations in the average ELA time series appear to be significantly related to winter precipitation anomalies.

These statements are in close agreement with your assersion in the last paragraph of the discussion section, and the results you present for Hintereisferner agree well with the time series presented by the authors.

- Rabatel, A., A. Letréguilly, J.-P. Dedieu, N. Eckert. 2013b. Changes in glacier equilibrium-line altitude in the western Alps over the 1984-2010 period: evaluation by remote sensing and modeling of the morpho-topographical and climate controls. The Cryosphere, 7, 1455-1471. doi:10.5194/tc-7-1455-2013.

Specific comments:

P3166-L8: “modern glacier” is not explicit for me!

P3167-L9: I suggest replacing ‘but’ by ‘and’ in the sentence “[. . .] or snow-free but a mass balance concept [. . .]”

P3167-L20: Here and in other places in the paper (e.g. P3172-L13), you should better quote Cogley et al. [2011] mass balance glossary than Anonymous [1969]

P3168-L24: You could also quote here

Rabatel et al., 2005. Using remote-sensing data to determine equilibrium-line altitude and mass-balance time series: validation on three French glaciers, 1994-2002. Journal

of Glaciology, 51 (175), 539-546. doi: 10.3189/172756505781829106

Rabatel et al., 2013b. Changes in glacier equilibrium-line altitude in the western Alps over the 1984-2010 period: evaluation by remote sensing and modeling of the morpho-topographical and climate controls. The Cryosphere, 7, 1455-1471. doi:10.5194/tc-7-1455-2013.

P3170-L28: Replace ‘this’ by ‘Hintereisferner’ in the sentence “the area-altitude distribution of this glacier [. . .]”

P3171-L7: Replace ‘snowline’ by ‘snow line’ to be consistent with the rest of the paper.

P3171-L9 and L21: Heim, 1885 is referenced as 1884 in the bibliography.

P3171-L25: Gafurov et al., 2014 is referenced as 2015 in the bibliography.

P3172-L23 to 25: A clear distinction is made in Cogley et al. (2011) between steady-state AAR and balanced-budget AAR. This could be quoted here.

P3173-L17 to 19: you should mention here Rabatel et al. (2005) cited above in this review and the Fig. 5 herein where mass-balance gradients values are plotted for glaciers in the French Alps. These values are in agreement with the one suggested by Kurowski.

P3174-L20: the reference by Abermann et al. is not about Swiss glaciers (mentioned in this paragraph) but glaciers in Austria. It appears useless here.

P3174-L23 to 29: Such a standard-deviation and large range of variability in the elevation of the snow line is in agreement with the values presented by Rabatel et al. 2013b (cited above) on 43 glaciers on the Franco-Italian-Swiss Alps over an almost 30-yr period (1984-2010). This study could be cited here.

P3175-L1 to 5: The importance of aspect on the location of the end of summer snow line (ELA) is also reported in Rabatel et al. (2013b), see the Figure 6D therein. This paper should also be reported here.

P3175-L15: Instead of Haeberli et al., 2007. You should better refer to WGMS, 2012. WGMS (2012) Fluctuations of Glaciers 2005–2010, Volume X. Edited by: Zemp M, Frey H, Gärtner-Roer I, Nussbaumer SU, Hoelzle M, Paul F and Haeberli W, ICSU(WDS)/IUGG(IACS)/UNEP/UNESCO/WMO, World Glacier Monitoring Service, Zurich, Switzerland, 336 p (doi: 10.5904/wgms-fog-2012-11)

P3175-L20: Jania and Hagen (1995) is referenced as 1996 in the list. Please check.

P3177-L3: I suggest changing 'secular' by 'multi-decadal'.

P3177-L6 and 7: "[. . .] is therefore too high for the first three decades and too low [. . .]". Too high or too low referring to what?

P3177-L1 to 12. The multi-decadal trend and patterns of ELA location in the late 1970s-early 1980s and in the 2000s for Hintereisferner is in clear agreement with the data presented in Rabatel et al. (2013) on 43 glaciers. This study could strengthen the argumentation here.

P3177-L18: '$\pm$35' seems to be '$\pm$17.5' when looking at Fig. 4. Please check.

P3177-L18: 'From Fig. 4' has to be replaced by 'From figures 3 and 4', because what you mention after cannot be seen from Figure 4 only.

P3178-L9 to 10: are the mentioned "good correlations" are statistically significant? Please prefer mentioning a P-value.

P3179-L15 to 18. When area-altitude distribution data are missing for "your" glaciers, it could quite easily be computed from a DEM (SRTM or ASTERGDEM) and an outline of the glacier found on the GLIMS database.

P3180-L28: Should it be ELA0 instead of E0 in "(E0-Hmean)"?

P3182-L9: Should be ELA0 instead of ELA.

P3182-L15 to 19. A reference to Lliboutry (1974) would be welcome here. Lliboutry

L (1974) Multivariate statistical analysis of glacier annual balances. J. Glaciol., 13, 371–392

P3183-L6: It seems to me that the '/' sign is missing in Eq. 10.

P3183-L10: is it ELA or ELA0? Please check.

P3183-L21: "Soruco" instead of "Suroco". This reference is missing in the list as mentioned by R. Pellitero.

P3185-L22 to 25. I would change "There is a high correlation between balanced-budget ELA and Kurowski mean altitude for the 103 glaciers for which the necessary data are available. There is a relatively small difference between balanced-budget ELA and Kurowski mean altitude for the 103 glaciers, with a mean difference of $-$36m with standard deviation $\pm$56m." by "There is a high correlation between balanced-budget ELA and Kurowski mean altitude for the 103 glaciers for which the necessary data are available, and a small difference of $-$36 m in average with standard deviation $\pm$56 m."

Figures

Figures 1 and 2: As mentioned by the scientific Editor, putting Fig. 1 and Fig 2 into a single figure with A and B parts would facilitate their reading.

Figure 3: To my point of view, it could be good to mention in the caption that the missing data in the 2000s match years for which the ELA was above the maximum elevation of the glacier. Figure 10: The X-axis needs to be extended till 250 to get Goldbergkees Glacier on the graph.

Interactive comment on The Cryosphere Discuss., 9, 3165, 2015.