tcd-9-3165-2015 2015 From Doktor Kurowski's Schneegrenze…. Response to A. Rabatel by Roger Braithwaite

Roger J. Braithwaite

I should thank the two referees for all their efforts, especially in providing their reviews so early. I don't think there is any serious discrepancy between what the two referees want, and I am sure that I can revise my discussion paper to satisfy the points they each raise.

It was more convenient for me to respond to Cogley first as I needed to read some journal articles before responding to Rabatel (here).

I plan to make a further comment on balance ratios as a response to both G. Cogley and A. Rabatel. I am also trying to explain the apparent "anomaly" represented by results from Goldbergkees, and I will post a comment if I make any progress.

In his referee comments, Rabatel refers to several recent studies and asks if they are included in my study. I therefore had to read these references to check if I had overlooked some data that I could have used to increase my present sample size from the 103 glaciers.

For my study, I require (1) a series of annual mass balance and ELA data for at least 5 years, and (2) a table of glacier areas for regular altitude intervals for at least one year. I need these data in numeric form so I can code them. I do not explicitly state the fact in my paper but I implicitly follow WGMS's old rule to only consider "observed data" and not "modelled data" (indeed I helped formulate this policy for Fluctuations of Glaciers Vol. III (1970-75).

In his Referee Comment, Rabatel describes my study as "interesting" and "valuable" and he makes kind remarks about methodology and writing. He raises minor points about the text and figures that are listed at the end of this response. I am rather ashamed that there are so many! He also raises two substantive points that he suggests could be covered in the discussion section, and I discuss these below.

1) APPLICABILITY OF THE METHOD AT GLOBAL SCALE

Rabatel asks if Kurowski's method is reliable for glaciers all over the world. To understand this point you have to follow the logic of my paper very carefully. Glaciologists were in trouble with their determination of snow line altitude towards the end of the 19th century. Kurowski (1891) neatly sidestepped this problem by associating the snow line with the zero balance line and then modelling snow line altitude as the mean altitude of the glacier. I argue that the altitude of "Doktor Kurowski's Schneegrenze" is our modern ELA, and I can compare Kurowski's mean altitude with modern ELA data. The point is that Kurowski did not treat his snow line as anything to do with snow-covered landscape, or apparent boundary between snow and bare ice, which modern glaciologists can now measure with remote sensing techniques. However, having measured snow lines in a way that Kurowski could not, modern glaciologists have the problem of relating their snow line altitudes to the ELA. This can be difficult for glaciers with extensive zones of superimposed ice (at high latitudes) or for glaciers with weak seasonal variations (in tropical regions). However, if an ELA can be deduced from a satellite measurement of snow line altitude it should be reasonably close to Kurowski's mean altitude.

Results for high latitude and tropical glaciers are summarized in Table AC 1, which is based on the data for the 103 glaciers in the supplement at doi:10.5194/tcd-9-3165-2015-supplement. Means and standard deviations of the differences (ELA_0 - H_{mean}) are given in Table AC 2 for the two sub-samples and for the full dataset of 103 glaciers.

There are eight high latitude glaciers in the present study (Table AC 1) that probably have extensive zones of superimposed ice, especially White Glacier (Axel Heibery Island) and Devon Islance ice cap (NW sector) which have large negative errors for the Kurowski mean. However the average differences between ELA_0 and H_{mean} for this sub-sample (AC 2) are not greatly out of line with statistics for the whole 103-glacier sample. Likewise, differences for the five tropical glaciers in the present study (Table AC 1) are similar. Obviously, we would like lots more data for all kinds

of glaciers but present results do not show a systematically poorer performance for Kurowski's mean altitude as a proxy for balanced-budget ELA for either high latitude or tropical glaciers compared with other glaciers. From the graph in Fig. 10, I still believe that the main source of error is Rea's balance ratio. If we accept that the balance ratio actually shown in Fig. 10 for Zongo is anomalously high, the regression line still suggests a true high balance ratio for Zongo. The key here is balance ratio and I will certainly quote Kuhn (1984) and Kaser (2001) in a revised discussion section. I might also quote Lliboutry (1974) here if I can better understand the paper!

Rabatel hints that I may have overlooked data from a number of glaciers. There are mass balance measurements from a further eight tropical glaciers (Ventorillo, Loc Ritacubas, Meren, Carstensz, Artesonraju, Yanamarey, Quelccaya and Chacaltaya) in the dataset for 371 glaciers but combined mass balance and ELA records for all these glaciers are shorter than the five years that I adopted for my criteria to calculate balanced-budget ELA. I hope that further data may arise in the future from these glaciers (except for Chacaltaya that has sadly disappeared) but I cannot do anything further at present.

Rabatel et al. (2011) presents mass balance data for six years on four glaciers in the Chilean Andes but I can nowhere find ELA data for these glaciers. The comment in the paper that "… concepts of accumulation/ablation zone and equilibrium line altitude cannot be easily applied" suggests there might be good reasons for the lack of measured ELA. I will cite Rabatel et al. (2011) in my revised discussion section.

Although it is not immediately relevant for my study, I can mention here that the small seasonal variation in monthly temperatures that exists in tropical South America (as one would expect) also extend south of the Tropic of Capricorn, without a northern hemisphere counterpart.

Rabatel raises a point about available mass balance measurements on Himalayan glaciers (Azam et al., 2014 and Wagnon et al., 2013). Currently, there are no Himalayan glaciers in my dataset of 103 glaciers. In the case of Chhota Shigri Glacier, also discussed by Wagnon et al. (2007), I cannot find the five years of mass balance and ELA data that I would need to include Chhota Shigri in my study. Wagnon et. (2007) quotes a balanced-budget ELA_0 for Chhota Shigri of 4880 m a.s.l. but does not explain how it is estimated. The Kurowski mean altitude for this glacier is 5053 m a.sl., which means the error $ELA_0 - H_{mean}$ would be -173 m, which is high but still within the range in Fig. 8, if I could accept the ELA_0 value of unknown provenance. There are five years of mass balance and ELA data from Mera Glacier (Wagnon et al., 2013) but I cannot find the area-altitude data to calculate the Kurowski mean altitude. I will certainly keep an eye out for new data for tropical and Himalayan Glaciers, possibly in the next volume of Fluctuations of Glaciers (2010-2015) from the WGMS.

2) CLIMATIC AND TOPOGRAPHIC CONTROL OF ELA

Rabatel wants me to thoroughly discuss the influence of local topography on the balance-budget ELA_0. I already quote Evans (1977 and 2006) for the importance of aspect for glacier ELAs and further discussion is beyond the scope of my paper. The best treatment of this topic is by Rabatel et al. (2013). On reading their paper, I was amused to note that one of their main topographic variables is "glacier mean altitude" which they show is highly correlated with mean ELAs for 43 glaciers, e.g. see Fig. 6b in Rabatel et al. (2013). Their definition of this variable is "the arithmetic mean of the elevation of each pixel of the DEM included within the glacier outline". This is Kurowski's mean altitude! Rabatel et al. (2013) were therefore using my proxy for balanced-budget ELA_0 as their main topographic variable. In English we say that "great minds think alike".

The above example is interesting as it illustrates that glacier mean altitude is easily calculated using GIS software once one has an outline of the glacier superimposed onto a DEM (digital elevation model) of geo-referenced pixel altitudes. This is a good justification for my concern for proper statistical terminology: users of GIS software would be surprised if they found glaciologists using their own special definitions for simple terms like mean and median.

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Table AC 1. High latitude and tropical glaciers in the present study

Glacier Name	Sub-sample	Lat	ELA_0	NNN	H_{mean}	ELA_0 - H_{mean}
		(° N)	(m asl)	(a)	(m asl)	(m)
White Glacier	High lat.	79.5	992	47	1097	-105
Austre Broeggerbreen	High lat.	78.9	286	40	313	-27
Midtre Lovenbreen	High lat.	78.9	301	42	328	-27
Kongsvegen	High lat.	78.8	538	24	625	-87
Hansbreen	High lat.	77.1	304	19	306	-2
Devon Ice Cap NW	High lat.	75.4	1000	48	1105	-105
Langfjordjoekelen	High lat.	70.1	749	20	786	-37
McCall	High lat.	69.3	1991	12	2014	-23
La Conejera	Tropical	4.5	4816	5	4773	43
Lewis	Tropical	-0.2	4769	5	4798	-29
Antizana 15 Alpha	Tropical	-0.5	5067	16	5216	-149
Charquini sur	Tropical	-16.2	5127	7	5123	4
Zongo	Tropical	-16.3	5245	19	5383	-138

Table AC 2. Summary statistics for high latitude and tropical glaciers in the present study

	Glaciers	Mean	S.D.
		(m asl)	(m asl)
High latitude glaciers	8	-52	±41
Tropical glaciers	5	-54	±86
Full dataset	103	-36	±56

Specific comments by Rabatel

Line	*Page*	*Referee*	*Comment*	*Response*
8	*3166*	*Rabatel*		*Will write "present day"*
9	*3167*	*Rabatel*		*OK*
20	*3167*	*Rabatel*		*Will insert Cogley et al (2011) in addition to Anonymous (1969)*
13	*3172*	*Rabatel*		*Will insert Cogley et al (2011) in addition to Anonymous (1969)*
24	*3168*	*Rabatel*		*Will cite*
28	*3170*	*Rabatel*		*Yes*
7	*3171*	*Rabatel*		*Yes*
9 and 21	*3171*	*Rabatel*		*I'm sorry! It is 1885.*
25	*3171*	*Rabatel*		*2015 is correct*
23 to 25	*3172*	*Rabatel*		*Yes*
17-19	*3173*	*Rabatel*		*I am sorry that I overlooked this reference. It is a good source of information. Also Lliboutry*
20	*3174*	*Rabatel*		*Will insert "… for Alpine glaciers …"*
23 to 29	*3174*	*Rabatel*		*Will cite*
15	*3175*	*Rabatel*		*Prefer Haeberli et al (2007) for "political reasons".*
20	*3175*	*Rabatel*		*1996 is correct*
3	*3177*	*Rabatel*		*OK*
6 and 7	*3177*	*Rabatel*		*Will rephrase. I myself do not understand what I was trying to say.*
1 to 12	*3177*	*Rabatel*		*The point of this graph is to demonstrate ELA terminology. I would expect a broad similarity of ELA variations across the whole Alps but did not want to use space to justify it as this is not my present concern.*
18	*3177*	*Rabatel*		*Good eyesight! It is ±17.5 m. The figure 35 would refer to the total width*
18	*3177*	*Rabatel*		*You are correct!*

Line	*Page*	*Referee*	*Comment*	*Response*
9 to 10	*3178*	*Rabatel*		*The problem is that the correlations have different sample sizes with a minimum of N = 5. A "good" correlation here is one that explains more than 50% of unexplained variance, i.e. r = 0.707. I do not argue that the correlations are (or are not) significant at some preset P-value. If I only had one correlation, I would need to state if it is statistically significant but with 150 correlations this not so important. For a sample size of N = 5, a correlation would need to be greater than r =0.81 to be statistically significant at less than 5% probability.*
15 to 18 *3 to 5*	*3179* *3180*	*Rabatel*		*Good point! Since retirement, I have been slowly learning to use ArcGis so I should soon be able to make these measurements myself. There might be some issues of differing coordinate systems, especially glacier mass balance and ELA determinations using old maps. The ideal solution is still to persuade the field observers to provide this information. My paper will be (further) confirmation that such data are useful.*
28	*3180*	*Rabatel*		*Yes*
15 to 19	*3182*	*Rabatel*		*Yes*
6	*3183*	*Rabatel*		*Yes. I'm sorry*
10	*3183*	*Rabatel*		*I think it should be* ELA_0
21	*3183*	*Rabatel*		*Yes but I get it correct in my response to Pellitero*
22 to 25	*3185*	*Rabatel*		*Thanks. I will take your suggestion.*
Figs 1 and 2	*3194 and 3195*	*Rabatel*		*I will put the figures together as Fig. 1a and Fig. 1b as you suggest. I hope I won't make too much of a mess of re-numbering all the other figures!*
Fig. 3	*3196*	*Rabatel*		*I thought it was obvious from the text but I will put this information into the caption*
Fig. 10	*3203*	*Rabatel*		*There is no balance ratio data for Goldbergkees (at present) so the x-axis was chosen to accommodate the data actually present. The graph would look very strange if the x-axis was extended to 250 with the present distribution of points. I am presently re-checking my data to try to explain the anomaly with Goldbergkees.*