tcd-9-3165-2015 From Doktor Kurowski's Schneegrenze….

Response to G. Cogley and A. Rabatel by Roger Braithwaite

Although offering many comments and suggestions, neither Rabatel or Cogley have any serious criticism of the basic philosophy and structure of the paper. Aside from correcting mistakes throughout the paper, I propose to strengthen the discussion session of the paper as this appears to be what both referees want. Both find the repetition of (ELA_0 - H_{mean}) a bit tedious. I will therefore define an error E_{mean} as follows:

$$E_{mean} = ELA_0 - H_{mean}$$

E_{mean} represents the "error in ELA_0 caused by assuming that $ELA_0 = H_{mean}$". This definition uses a different sign convention to Braithwaite and Müller (1980) but I think it is more logical. The above equation will be inserted earlier in the paper and Equation (8) (line 22 page page 3182) will be redundant.

On line 17 of page 3182, I refer to workers who have questioned the assumption of linear balance gradients in the context of estimating ELA, but I will add further references to other works on linear/nonlinear balance gradients. These will include Lliboutry (1974), Braithwaite and Müller (1980), Kuhn (1984) and Kaser (2001).

From line 1 on p. 3186 I will expand the discussion along the lines:

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The most likely physical explanation for different balance gradients in ablation and accumulation areas is the vertical variation in precipitation and/or accumulation across glaciers (Jarosch et al. 2012). Aside from the possible expansion of the balance ratio dataset (Rea, 2009) to include small glaciers, some further insights into balance ratios could be gained from glacier-climate modelling. For example, my group have in the past tuned mass-balance models in two different ways. Method 1 (Braithwaite and Zhang, 1999; Braithwaite et al., 2002) involved varying precipitation to fit the model mass balance to observed mass balance over the whole altitude range of the glacier. Method 2 (Raper and Braithwaite, 2006; Braithwaite and Raper, 2007), involved varying precipitation at the assumed ELA to make the model mass balance at the ELA equal to zero. In method 1 the model gives precipitation across the whole altitude range of the glacier while method 2 only gives model precipitation at the ELA.

For method 1, model precipitation increases with elevation for some glaciers, e.g. see Fig. 2 in Braithwaite et al. (2002), but not for others. For method 2 modelled balance gradients are consistently lower in the accumulation zone compared with the ablation zone (Raper and Braithwaite, 2006, Fig. 2; Braithwaite and Raper, 2007, Fig. 5). Results from method 1 are consistent with a range of values for balance ratio while method 2 indicates higher values of balance ratio, presumably reflecting the fact that our mass balance model uses a higher degree-day factor for melting ice than for melting snow.

On real-world glaciers, precipitation may increase due to orographic or topographic channelling effects, or the 'effective' precipitation at the glacier surface may be augmented by snow drifting or avalanching from surrounding topography. These effects are probably more likely to be important for mountain glaciers that are more constrained by topography than for outlet and valley glaciers. For example, two mountain glaciers in the Polar Ural (IGAN and Obrucheva) have excellent agreement between balanced-budget ELA and Kurowski mean altitude and are known to depend upon topographic augmentation of precipitation (Voloshina, 1988).

The discussion of modelling results cannot be definitive but it suggests that earlier degree-day modelling work with method 1 (Braithwaite et al., 2002) ought be repeated and expanded with more explicit emphasis on precipitation variations and balance ratios. Without further progress and insights, we must be satisfied with present results that balanced-budget ELA can be approximated by Kurowski mean altitude with a mean error of only a few decametres.

Kurowski (1891) is a good example of a glacier-centred approach to snow line avoiding problematic discussions of climatic and orographic snowlines as proposed by Ratzel (1886). Hess (1904, p. 68) suggests that glacier-based snow line refers to climatic snow line but most glaciers are influenced to some degree by local topography so balanced-budget ELA's generally have the nature of orographic rather than climatic snow line. Some glaciers, e.g. many of the mountain glaciers in the present study, may be more affected by local precipitation variations than most of the outlet and valley glaciers in the present study. The distinction between two types of ELA, i.e. TP-ELA and TPW-ELA, by Bakke and Nesje (2011) might be relevant here as the latter type is more influenced by wind-transported snow than the former.

END OF INSERTION

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