The Cryosphere Discussions

The Cryosphere Discuss., referee comment RC3
https://doi.org/10.5194/tc-2021-96-RC3, 2021

Comment on tc-2021-96

Douglas Benn (Referee)

Referee comment on "Surge dynamics of Shisper Glacier revealed by time-series correlation of optical satellite images and their utility to substantiate a generalized sliding law" by Flavien Beaud et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-96-RC3, 2021

This is an intriguing paper that is rich in both data and ideas. Among other things, it represents a bold and innovative attempt to use remote sensing observations to calibrate a proposed 'generalized sliding law'. There are some shortcomings in the implementation of this idea and the discussion of the results, but with some additional work the paper should become a very original, worthwhile and thought-provoking addition to the literature.

Following a well-written introduction, the paper provides an admirably clear exposition of recent sliding law literature, which culminates in the proposal of a 'generalized sliding law'. The proposed solution is elegant, and neatly highlights the fundamental similarity of existing hard-bed and soft-bed sliding laws. However, the proposed law subsumes effective pressure *N* into both the threshold sliding velocity U_t and maximum resistive stress σ_{max}, meaning that these two main components of the U_b - T_b relationship are inherently subject to large variations, particularly on glaciers that exhibit large and rapid velocity variations (e.g. surging glaciers). This is reflected in the very large spread of values in Figure 8, which the authors interpret more or less entirely as the result of variations in *N*. Therefore, I feel that in its present form, the generalized law is not particularly useful.

It would be better to retain *N* as an explicit variable in the sliding law by replacing U_t with something like a.*N* and σ_{max} with b.*N*, where a and b are 'constants' largely determined by bed properties (C, A_s, tanφ etc.). Although a and b will be spatially variable, this approach might allow temporal variations in *N* to be approximated if τ_b and U_b are known, potentially extracting considerably more structure from the data gathered by the authors.

The data on the surge of Shisper glacier are excellent and very interesting. The combination of Sentinel and Landsat data provides a dense and high-quality velocity series, allowing the evolution of the surge to be interrogated in detail. The description of the processing work flow should prove useful to other workers in the field. Given the quality of the data, however, the discussion of the underlying processes is disappointing. The discussion of surge mechanisms presents an out-dated binary choice between thermal and hydraulic switch mechanisms, and by dismissing the thermal mechanism, the authors conclude that the hydraulic mechanism as the only other option. In its widely accepted form, however, the hydraulic switch idea is problematical. First, no convincing mechanism has ever been proposed for why drainage systems should spontaneously switch from channelised to distributed forms (the detailed analysis of Kamb 1987 focuses on the opposite switch, which satisfactorily explains surge termination but not onset; and Fowler's model of the hydraulic switch simply incorporates an heuristic function designed to have the desired effect). Second, the hydraulic switch idea ignores the crucial issue of where the water comes from: i.e. the influence of surface-to-bed drainage and basal melting over surge cycles. Enthalpy balance theory (Benn et al. 2019) addresses these problems and unites surge mechanisms in a single framework, which potentially provides a more complete explanation of the sequence of events observed on Shisper Glacier. In particular, the exponential speed-up of Shisper in 2018 is consistent with frictional heating - velocity feedbacks, and the subsequent peaks and troughs in velocity appear to reflect competition between surface water inputs and drainage against a background of high frictional heating, all of these being associated with fluctuations in *N*. Overall, the pattern of surge evolution is remarkably similar to that observed during a recent surge of Morsnevbreen, Svalbard (paper cited below), and possibly for the same reasons. I suggest the authors investigate this possibility and weave it into their discussion of the Shisper Glacier surge.

Figure 7 shows a conceptual representation of σ_{max} alongside the observed velocity fluctuations of Shisper Glacier. If the general sliding law is reframed with *N* as an explicit variable, it should be possible to replace this conceptual curve with estimates of *N* - potentially a much more interesting and valuable outcome. Figure 8 shows that the relationship between driving stress and velocity is extremely noisy, and this noise is attributed in the Discussion largely in terms of variations in *N*. If this is true, we should expect to see some structure in calculated values of *N* in time and space. Uncertainties will of course persist (e.g. variation in a and b as defined above; errors in the ice thickness derived from the Farinotti models), but if the authors' arguments are correct, some structure should be apparent. I urge the authors to explore this possibility in detail.

The existing discussion of the importance of *N* in surging is not new. *N* is an integral component of the hard-bed and soft-bed sliding laws from which the 'generalised law' is derived, so it cannot be claimed that the generalised law 'highlights the importance of effective pressure'. However, if the authors can pull estimates of *N* from their excellent dataset and show how it varies during quiescence and surge, that would give the paper something really unique and valuable.

Benn, D.I., Jones, R.L., Luckman, A., Fürst, J.J., Hewitt, I. and Sommer, C., 2019. Mass and enthalpy budget evolution during the surge of a polythermal glacier: a test of theory.*Journal of Glaciology*, *65*(253), pp.717-731.