Review of “Time forecast of a break-off event from a hanging glacier”

by J. Faillettaz, M. Funk and M. Vagliasindi

This paper present a successful prediction 10 days in advance of a cold hanging glacier break-off that occurred in the south face of the Grande Jorasse (Mt Blanc area, Italy) on September 2014. The prediction is based on the high precision monitoring of glacier surface displacement on four different stakes over almost 3 years and until up to few hours prior to the break-off. The paper use the fact that the critical behaviours of the rupture processes can generally be described by a power law function of the time of failure for which an additional log-periodic signal is superimposed [Sornette and Sammis, 1995]. This behaviour have been observed in various domains [Sornette, 2002] and was first used in glaciology as way to describe hanging glacier rupture by Rothlisberger [1977] (power law) and by Luthi [2003] (log-periodic). Surface displacement measurement prior to rupture has been successfully reproduced using these relations in Pralong et al. [2005] and Failletaz et al. [2008]. The determination of the best fit parameters calibrated on surface velocities prior to rupture offer a way to predict the break off [Pralong et al. 2005; Failletaz et al., 2008]. This paper is another application of the same method to new data on another glacier.

Although the paper does not bring new insight about hanging glacier rupture, it shows the robustness of the failure prediction using surface displacement monitoring method [Failletaz et al., 2008] and confirms nicely the existence of the log-periodic oscillations before rupture. It also shows that using a threshold surface velocity for which the failure occur rather than using the critical time parameter lead to more precise prediction. The extrapolation of the surface velocity based on the best log periodic fit to the threshold velocity seems to give a very precise time estimation of the glacier rupture. The authors propose a value of this threshold velocity to define a highly probable time zone of break-off occurrence that can be determined about 10 days in advance.

I think the paper provide nice results and successful natural hazard prediction in Geo-science is something uncommon. The paper deserve therefore publication in The Cryosphere after substantial revision following the points addressed in general comments.

General Comments

• It remains unclear in the current paper how uncertainty on the data affect the inferred rupture time. I think the final result, which is the date of rupture, could be better defined by using a probabilistic approach. Here is what I suggest:

1. Define a probability density function for the threshold velocity, could be Gaussian, for example:

$$P(V_T) \propto \exp(-0.5(V_T - V_{ref})^2/\sigma_{V_T}^2)$$

where V_T is the threshold velocity, V_{ref} is the most likely threshold velocity and σ_{V_T} the confidence interval (or standard deviation). P(VT) could be also set to 1 if there is no preferential threshold velocity.

2. For a range of possible fixed threshold velocity (VT), calculate a density function of the rupture time

for each VT from the misfit between measurement and model: each parameter set M=(tc, θ, s0, us a, C, D) is associated to one rupture time (TR) for a given VT and each parameter set (M) can be associated to one probability:

P(TR(M),VT)∝exp(−0.5 (sdata−smodel)Cm−1(sdata−smodel))

where sdata and smodel are respectively the measured and modelled surface displacement, Cm is the covariance matrix that describe data uncertainty.

3. A final probability density function for the rupture time can be estimated by:

P(TR)∝∫V Tmin V Tmax P(TR(M),VT)Ã—P(VT)dV T

The calculation in real time of this probability density function could be a more nicer and rigorous way to estimate the rupture time by taking into account uncertainty on the data. This paper could be the opportunity of calculate the evolution of this function during time (as the measurement are getting closer to the break-off).

We agree that this paper should better address how uncertainty on the data affect the inferred rupture time, although this dataset is very accurate (1cm). However errors resulting from the fitting procedure are predominant. To illustrate this, we artificially added uniformly distributed random noise of different amplitude to our initial dataset, and performed the same fitting procedure. It appears that the error associated with fitting procedure is about one order of magnitude higher than those associated with data accuracy. (see new section 5.1)

As we are expecting to predict in near real time the occurrence of the break-off at a daily precision, such sophisticate analysis might not be relevant for our purpose.

• Because the paper do not really bring new insight about hanging glacier failure, I recommend to the authors to give, at least, a precise and clear methodology for predicting failure based on their expertise: Stakes emplacement ? How much stakes ? monitoring method ? Minimal resolution (time and space) for the displacement measurement ? Fit procedure ? Define a probability density function of the rupture time as the final result (see first general comment) ?

See new section 5.5

• I think the paper need some clarification about the choice of λ. Indeed, the logarithmic frequency can only be determined if the critical time is known (after the rupture occur) but the prediction of the failure need to fix a value for λ. I assume that it is possible to infer a value for λ without doing the Lomb periogram. λ seems also to be a universal value (set to 2d) [Failletaz et al., 2008], which is, by the way, confirmed in this paper. However, the authors show that the value of λ can be affected the geometrical change due to the first break-off (from λ=2 to λ=7.4, stake 2 and 13). So a discussion about the value of λ (constant for every glacier ?) and the sensitivity of the prediction to this parameter is needed.

Faillettaz et al. 2008 and the present study show that λ=2 for Weisshorn and Grandes Jorasses. Such a value has a physical explanation related to the dynamic interactions between newly developed micro-cracks. The appearance of other subharmonic frequencies before the last break-off is also discussed and possible physical explanation related to sudden geometry change was also found.

• As the authors claim their method as universal (P4938, lines 5-9), the transferability of the method to another glacier should be more discussed. Is the similar value of the threshold velocity (0.5 to 1 m/d) or λ (=2d) in several different studies could be link to the fact that all the three studied glaciers (Jorasse, Weisshorn, Monch) have similar geometry ? What could happen with totally different geometry ? Is the prediction method still valid ?

Cold hanging glaciers have alwaysa very similar geometry. This method was first developed and applied on Weisshorn and Monch and was shown to be a valuable tool for prediction purpose. For the first time, measurements could be performed up to the final break-off. Results confirm the appearance of logperiodic oscillations superimposed on the powerlaw acceleration, validating this prediction method.

Specific Comments

Abstract, line 5: this event was successfully ….

OK

P4927, lines 5 to 16 : Distinction between the two types of instabilities is not clear. I would speak first about temperate ice/bed interface (remove polythermal) and then about 'transition from cold to temperate ice/bed interface' rather than speak about 'partly temperate' ice/bed interface.

Fixed, see line 30-35

P4928, lines 16 to 23: Give more information about the glacier: accumulation rate, dimensions, temperature …

OK, see section 2.1

Figure 1 : Add a map that show the configuration of the valley bellow the glacier (topography, habitation, road, infrastructure ...), it would help to understand the context of this hazard. The limit where previous avalanches stopped could be also shown on this figure.

OK, see now Fig 1.

P4930, lines 3 to 14: What happen to the GPS measurement ?

See section 5.5

P4930, lines 23-24: Remove. (already say in next section).

OK

P4931, line 2: Which correction ? Maybe here a short description of the correction that have been done, even if already described in Faillettaz et al. [2008].

Ok see line 164-166

P4931, line 3: associated

OK

P4931: Point no 2: Be more precise about the geometry, which kind of geometry are the authors refer to ?

OK

P4931, line 20: replace fig 3 by fig 1 ?

OK, now Fig . 2

P4934, lines 5 to 7, the sentence sounds really unclear to me. Please reformulate.

OK see now lines 217-224

Figure 4 and 5: Unit is missing in the residual

Fixed

Figure 7: A grid would help to read the graph

OK

References

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