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Interactive comment

Interactive comment on "Comment on: Dynamics of the Askja caldera July 2014 landslide, Iceland, from seismic signal analysis: precursor, motion and aftermath" *by* Tómas Jóhannesson et al.

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We thank the authors for their comment on our paper. Unfortunately, the comment was not submitted during the review process of our manuscript. We would like to take up the points mentioned by Jóhannesson et al. by explaining our inversion modelling and its results in the following paragraphs in detail.

We acknowledge the results of Gylfadóttir et al. (2017) that the horizontal displacement of the mobilised landslide mass at the bottom of the lake was about 2000 m with a deposit volume of 10 million m^3. However, these parameters were not required for our inversion. The landslide seismic inversion adopted in Schöpa et al. (2018) was conducted with the assumptions (i) of a block model with time-independent landslide mass and (ii) that the long-period (LP: 12.5-50 seconds) seismic signals were mainly induced by landsliding along a planar failure surface on land. To satisfy the assumption of a constant block mass, Schöpa et al. (2018) only interpreted the landslide dynamics inferred from the LP seismic records when the mass was sliding on land. After a landslide mass enters a lake, it disintegrates and hence the seismic energy generated by a moving mass underwater is dissipated rapidly. Previous studies have demonstrated that seismic signals caused by sediment transport underwater exhibit relatively higher frequencies (> 1 Hz, Hsu et al., 2011; Chao et al., 2015). The seismic stations far away from the source could not capture these short-period signals induced by the movement of the submerged mass.

Landslide volume and trajectory: Once the landslide force-time history (LFH) is derived from the LP seismic waveform inversion, the acceleration of the center of the block mass can be computed by dividing the LFH by a constant mass. The displacement is found by a double integration of the acceleration. We used three frequency bands (0.02-0.05 Hz, 0.02-0.08 Hz, 0.04-0.08 Hz) for the source inversion (Schöpa et al., 2018). The computed LFH gave a sliding mass in the range of 7-16$\times 10^{10}$ kg by fitting the runout distance on land (1200 m, from the center of mass of the source area to the lakeshore, from satellite images and field observations). Assuming an average density of 2000 $\mathrm{kg/m}^3$, 35-80 million m^3 of landslide volume was obtained. This value overestimated the landslide volume compared to the 20 million m^3 reported by Gylfadóttir et al. (2017). We attribute this discrepancy to (i) the underestimation of the runout distance used in the seismological determination of the landslide mass. In other words, the initially submerged sliding material may have contributed to the LP seismic signals; thus the mass derived from the trajectory needs to be updated. Longer runout path results in smaller mass of the sliding block. However, we note that seismic analysis can provide a constraint on the upper limit of a landslide mass. We further attribute the discrepancy of the landslide volumes to (ii) the limitation of applying a constant mass assumption in the waveform inversion, (iii) the effects of a rotational block slide, and (iv) uncertainties in the volume computation resulted from the poor constraint of the sliding surface. Nevertheless, we apologise for unintentionally not having quoted Gylfadóttir et al. (2017)'s estimation of the landslide mass correctly.

Sliding velocity: Schöpa et al. (2018) stated the fact that the waveform inversion gives the spatially and temporally averaged velocity of the whole sliding block on land, whereas the tsunami modelling is adopting the velocity (U_0 in Gylfadóttir et al., 2017) of the front of the slide entering the lake. Therefore, a comparison between these two velocity values is difficult to make. In our work, we listed possible reasons for the discrepancy of the velocities (Schöpa et al., 2018). We have observed a late-arriving seismic phase (Fig. 5d in Schöpa et al., 2018) in the high-frequency envelope waveform recorded by the closest station, which might be induced by parts of the sliding material hitting the shoreline and moving into the lake. A similar observation of seismic signals has been reported by Chao et al. (2016). A possible solution would be to obtain the front velocity of the submerged mass by using the seismic radiation energy of the late-arriving signals.

We also noticed that the U_0 value derived from the tsunami modelling of Gylfadóttir et al. (2017) is very sensitive to the friction coefficient (μ), which ranges from 0.15 to 0.30 for the majority of rockslide configurations. With the fixed input parameters, such as μ, total deposit volume, drag coefficient (C_d), and add mass coefficient (C_m), U0 and the block thickness (d) are obtained through a grid-search scheme by fitting the observed water level of the lake. The reliability of this optimisation procedure is mainly controlled by the uncertainties in the fixed parameters. Before having a detailed comparison between seismologically-determined and tsunami-based impact velocities, sensitivity tests for these fixed parameters in the tsunami modelling are required.

Landslides occurring in coastal and lakeside regions can generate destructive tsunami waves when the mass slides into the water, which can pose a series of hazards to the coastal or lakeside population. The volume of the sliding mass that enters the water is the crucial parameter for tsunami-wave simulations. Our recent study (Chao et al., 2018) showed how seismic techniques using real-time seismic records can provide estimates of essential physical parameters (i.e., sliding volume) of landslides, which can be utilised for near-real-time tsunami wave simulations. A combined analysis of the real-time seismic waveform inversion and of forward tsunami-wave modelling could enable timely operational warnings before the arrival of the destructive tsunami waves.

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