



## Comment on “Dynamics of the Askja caldera July 2014 landslide, Iceland, from seismic signal analysis: precursor, motion and aftermath” by Schöpa et al. (2018)

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Schöpa et al. (2018) report on an analysis of seismic signals released by the Askja July 2014 rockslide, central Iceland, and conclude from their analysis that the volume of material displaced by the slide was  $35\text{--}80 \times 10^6 \text{ m}^3$  and that the centre of mass was displaced horizontally by  $1260 \pm 250 \text{ m}$  and vertically by  $430 \pm 300 \text{ m}$ . Referring to Gylfadóttir et al. (2017) as a source, they state that the volume of the slide was  $12\text{--}50 \times 10^6 \text{ m}^3$  according to geodetic surveys. We note that the volume of the rockslide according to Gylfadóttir et al. (2017) was actually reported as  $20 \times 10^6 \text{ m}^3$  based on field measurements that include multi-beam surveys of the bottom of Lake Askja, measurements of the lake level, and photogrammetric digital elevation models (DEMs) of the rockslide area on land, from before and after the slide. Larger, preliminary estimates for the volume of the rockslide ( $30\text{--}50 \times 10^6 \text{ m}^3$ , Helgason et al., 2014;  $> 12 \times 10^6 \text{ m}^3$  for the tongue that entered Lake Askja, Höskuldsson et al., 2015;  $20\text{--}50 \times 10^6 \text{ m}^3$ , Sæmundsson et al., 2015; and  $15\text{--}30 \times 10^6 \text{ m}^3$ , Gylfadóttir et al., 2016) were given in a memo with preliminary results and in conference presentations. They were based on initial estimates of the rise of the water level in the lake due to the slide and inaccurate estimates of the rockslide volume on land. These were revised after the processing of multi-beam and lake level data and photogrammetric DEMs was completed (Grímsdóttir et al., 2016), and the revised results were used in the tsunami modelling of Gylfadóttir et al. (2017). Some of these earlier reports and conference presentations are also referenced by Schöpa et al. (2018).

Our estimate for the volume of material mobilized by the rockslide is based on a reconstruction of the geometry of the sliding plane from the available field evidence. It

is, however, hard to exclude the possibility that some rotational movement took place at a deeper level, leaving little evidence in the surface geometry of the rockslide after the event. The volume of the debris tongue in the lake, approximately  $10 \times 10^6 \text{ m}^3$ , is rather well determined. The average horizontal displacement of this mass at the bottom of the lake is  $\sim 2000 \text{ m}$ . If the horizontal displacement of the centre of mass of the mobilized material was as great as estimated by Schöpa et al. (2018), most of the debris mass that terminated on land must have moved from the starting area down to the run-out zone near the shore of the lake, which has an area of  $\sim 330\,000 \text{ m}^2$ . This area is estimated as the part of the run-out area farther than  $600 \text{ m}$  from the highest part of the source area of the rockslide since material that travelled a shorter distance does not contribute much to the horizontal displacement of the centre of mass. The volume and centre-of-mass displacement estimated by Schöpa et al. (2018) correspond to an average debris thickness of  $75\text{--}210 \text{ m}$  in this part of the run-out zone of rockslide on land. This thickness is difficult to reconcile with the available field measurements, in particular the thickness values near the higher end of this range. The field measurements indicate that the thickness of the debris tongue in most of this area is more than an order of magnitude smaller. In combination, the volume and centre-of-mass displacement estimated by Schöpa et al. (2018) are therefore inconsistent with our field observations.

From their seismic analysis, Schöpa et al. (2018) also report an averaged maximum sliding velocity for the rockslide of  $7 \pm 0.7 \text{ m s}^{-1}$  at the shoreline when the rockslide enters the lake, which is much lower than the impact velocity  $U_0 = 31 \text{ m s}^{-1}$  used in the tsunami simulations of Gylfadóttir et al. (2017). Gylfadóttir et al. (2017) estimated their impact

velocity by calibrating the tsunami model against measurements of the run-up of the tsunami wave around the lake, so their velocity estimate is also an indirect estimate based on modelling. Higher up the slope, Schöpa et al. (2018) estimate a slide velocity of up to ca.  $18 \text{ m s}^{-1}$  well before the rockslide entered the lake (this can be derived from their Fig. 5b). Both these velocities estimated from the seismic analysis are surprisingly low in the middle of the path of a large rockslide released from an elevation of hundreds of metres. This needs to be discussed in a paper suggesting such remarkably low velocities. Both because a much higher velocity at the shoreline had been inferred by the tsunami modelling of Gylfadóttir et al. (2017), but perhaps more importantly because it is unreasonable from a physical standpoint for a rockslide that will propagate 2100 m farther into the lake and deposit half of its volume beyond the shoreline. Schöpa et al. (2018) discuss the discrepancy between the velocity obtained from their analysis and the frontal velocity when the rockslide enters the lake as estimated by Gylfadóttir et al. (2017). They suggest three possible explanations for this: “(i) the limited applicability of a constant mass assumption in the waveform inversion, (ii) the fact that the inversion gives the velocity of the total landslide mass, whereas the tsunami is calculating the velocity of the front of the slide, (iii) uncertainties in the volume of the material sliding into the lake used for the modelling”. These explanations may all matter but do not properly reflect the possibility that there is something fundamentally or seriously wrong with the analysis that causes this discrepancy. In this context, the uncertainty of the velocity of  $\pm 0.7 \text{ m s}^{-1}$  presented by Schöpa et al. (2018) seems remarkable. It is also difficult, if not impossible, to account for the observed run-up of tsunami waves in the lake with a slide velocity as low as that deduced by Schöpa et al. (2018) from their seismic analysis.

We note that the rockslide may be expected to have been retarded somewhat at the shoreline from the maximum velocity farther up the path because it has propagated  $\sim 600 \text{ m}$  over relatively flat terrain from the location where it reached its highest velocity before it comes to the shoreline. Therefore, the velocity estimate of  $31 \text{ m s}^{-1}$  at the shoreline by Gylfadóttir et al. (2017) corresponds to considerably higher velocity higher up in the path where the analysis of Schöpa indicates an averaged maximum velocity of ca.  $18 \text{ m s}^{-1}$ . The maximum velocity of ca.  $18 \text{ m s}^{-1}$ , which may be inferred from Fig. 5b in Schöpa et al. (2018), corresponds to the foot of the slope before the rockslide enters the run-out zone and where there has presumably been comparatively little retardation of the rockslide mass. The kinetic energy corresponding to this velocity is  $\sim 160 \text{ J kg}^{-1}$ . For comparison, the average potential energy released in the descent of the rockslide mass down ca. 250 m vertically may be estimated to be on the order of  $2500 \text{ J kg}^{-1}$ . A velocity of ca.  $18 \text{ m s}^{-1}$  at the foot of the slope, therefore, implies that more than 90 % of the original potential energy of the rockslide is already dissipated by friction when the rockslide enters the run-out

zone and has 2700 m farther to go into the run-out zone and the lake. Of course the centre of mass of the moving material does not propagate this far into the lake. It nevertheless seems dynamically implausible that the rockslide propagates at ca.  $18 \text{ m s}^{-1}$  at the foot of the slope after falling down ca. 250 m, as well as propagating at ca.  $7 \text{ m s}^{-1}$  at the shoreline with 2100 m farther to go. The estimated velocity of  $7 \text{ m s}^{-1}$  at the shoreline corresponds to the potential energy of  $25 \text{ J kg}^{-1}$ , which is equivalent to the potential energy of an object raised vertically by only 2–3 m. We further note that both  $7 \text{ m s}^{-1}$  (in the middle of or somewhat above the middle of the run-out zone) and  $18 \text{ m s}^{-1}$  (maximum velocity at the start of the run-out zone) are quite low velocities for large rockslides with volumes of tens of millions of cubic metres; see, e.g., the inferred velocities of several large landslides quoted by Evans et al. (2006).

There are few direct measurements of the velocity of large rockslides, and volumes are often uncertain because of a difficulty locating the sliding surface. Interpretation of seismic data to estimate volumes and velocities of landslides are, therefore, interesting and could be useful in the context of hazard management and, of course, for a general understanding of rockslides as a geophysical phenomenon. The disagreement between the results of Schöpa et al. (2018) and available field measurements for the Askja 2014 rockslide indicates that further development is needed to obtain quantitative information about rockslide dynamics from the seismic signal analysis that they employ.

**Data availability.** This comment is based on data and analysis in previously published papers and does not independently present new data or computational analysis.

**Author contributions.** TJ drafted the initial version of the comment with contributions about tsunami modelling by SSG and field observations by JKH. All three authors contributed to paper revision and read and approved the submitted version.

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## References

- Evans, S. G., Scarascia Mugnozza, G., Strom, A. L., Hermanns, R. L., Ischuk, A., and Vinnichenko, S.: Landslides from massive rock slope failure and associated phenomena, in: *Landslides from Massive Rock Slope Failure*, edited by: Evans, S. G., Scarascia Mugnozza, G., Strom, A. L., and Hermanns, R. L., NATO Science series IV. Earth and Environmental Sciences, Springer, Dordrecht, the Netherlands, 49, 3–52, 2006.
- Grímsdóttir, H., Helgason, J. K., Brynjólfsson, S., Gíslason, E., Jóhannesson, T., Vogfjörð, K. S., Hensch, M., Jónsdóttir, K., Pfeiffer, M. A., Höskuldsson, Á., Sigmundsson, F., Hjartardóttir, Á. R., Sæmundsson, T., and Guðmundsson, Á.: Berghlaup í Öskju 21. júlí 2014. Yfirlit um mælingar og könnun á vettvangi (Rockslide in Askja on 21st July 2014. Overview of measurements and field work), Icel. Meteorol. Office, Techn. rep. HG/ofl/2016-01, Reykjavík, Iceland, 2016.
- Gylfadóttir, S. S., Kim, J., Helgason, J. K., Brynjólfsson, S., Höskuldsson, Á., Jóhannesson, T., Harbitz, C. B., and Løvholt, F.: The 2014 Lake Askja rockslide tsunami – Optimization of landslide parameters comparing numerical simulations with observed run-up, EGU General Assembly Conference Abstracts, 17–22 April 2016, Vienna, Austria, 18, 8927, 2016.
- Gylfadóttir, S. S., Kim, J., Helgason, J. K., Brynjólfsson, S., Höskuldsson, Á., Jóhannesson, T., Harbitz, C. B., and Løvholt, F.: The 2014 Lake Askja rockslide-induced tsunami: Optimization of numerical tsunami model using observed data, *J. Geophys. Res.-Oceans*, 122, 4110–4122, <https://doi.org/10.1002/2016JC012496>, 2017.
- Helgason, J. K., Brynjólfsson, S., Jóhannesson, T., Vogfjörð, K. S., Grímsdóttir, H., Hjartardóttir, Á. R., Sæmundsson, T., Höskuldsson, Á., Sigmundsson, F., and Reynolds, H.: Rockslide in Askja, 21 July 2014 – Preliminary results of observations, Icel. Meteorol. Office, Techn. Memo dated 5.8.2014, Reykjavík, Iceland, 12 pp., 2014.
- Höskuldsson, Á., Gans, P., Burbank, D., and Wiss, A.: Avalanche induced tsunami in Askja caldera lake Iceland, 21 June 2014. EGU General Assembly Conference Abstracts, 12–17 April 2015, Vienna, Austria, 17, 9762, 2015.
- Schöpa, A., Chao, W.-A., Lipovsky, B. P., Hovius, N., White, R. S., Green, R. G., and Turowski, J. M.: Dynamics of the Askja caldera July 2014 landslide, Iceland, from seismic signal analysis: precursor, motion and aftermath, *Earth Surf. Dynam.*, 6, 467–485, <https://doi.org/10.5194/esurf-6-467-2018>, 2018.
- Sæmundsson, T., Helgason, J. K., Brynjólfsson, S., Höskuldsson, Á., Hjartardóttir, Á. R., and Sigmundsson, F.: The rockslide in the Askja caldera on the 21st of July 2014. EGU General Assembly Conference Abstracts, 12–17 April 2015, Vienna, Austria, 17, 11734, 2015.