Hydro- and morpho-dynamic modelling of a lacustrine tsunami and its deposits

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Background and Study Goals

Lake tsunamis are long-wavelength lacustrine waves, mostly triggered by subaqueous landslides, subaerial rockfall impacts, and subaerial landslides [1, 2, 3]. On 18 September 1601 CE, multiple lacustrine tsunamis occurred on Lake Lucerne with maximum amplitudes of several meters. These tsunamis were triggered by subaqueous landslides, which in turn had been triggered by a concurrent Mw 5.9 earthquake [1, 2, 4, 5, 6]. However, the deposits found from this tsunami remain sparse [1].

- Using BASEMENT to find lake tsunami deposits in the Bay of Lucerne could allow for a better understanding of the hazard
- Groundtruthing BASEMENT results with sediment cores would show how accurate the model is at finding tsunami deposits
- This has implications for event recurrence intervals and risk assessments

Methods

BASEMENT is a modelling software developed by VAW at ETH Zürich to model hydrodynamics and morphodynamics in rivers. This tool is applicable to lacustrine tsunamis because of its use of shallow-water equations (in tsunamis, water is shallow in relation to the ~100+ m wavelength). BASEMENT allows the user to create a hydrodynamic model of the tsunami along with its sedimentation (morphodynamic change in the lakebed) [1]. We use BASEMENT to create a sedimentation simulation of the 1601 CE Lake Lucerne tsunami event, focusing on the Bay of Lucerne.

- As a first step while creating the sedimentation simulation, we use tracers (marked water) to follow the water from certain regions of high dimensionless bed shear stress (Shields Parameter $\theta>0.05$) during the tsunami [1]
- The simulation results will be groundtruthed with sediment cores in Spring 2023

Study Site: Lake Lucerne

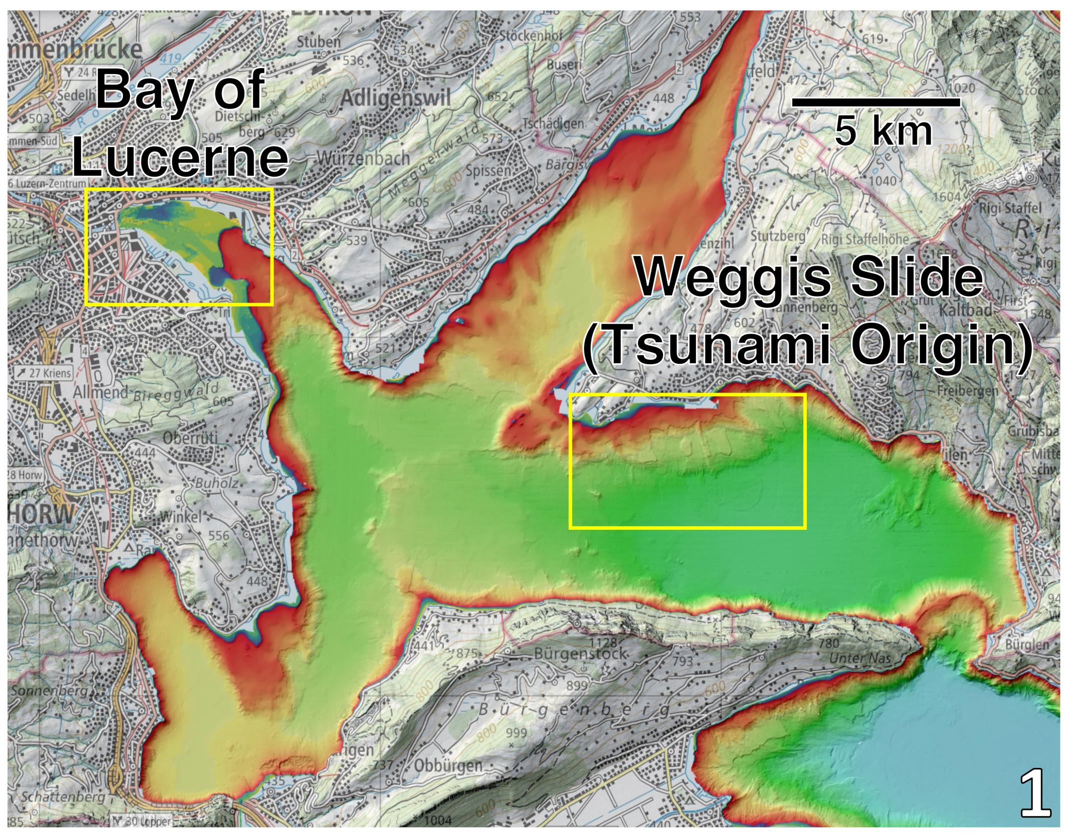
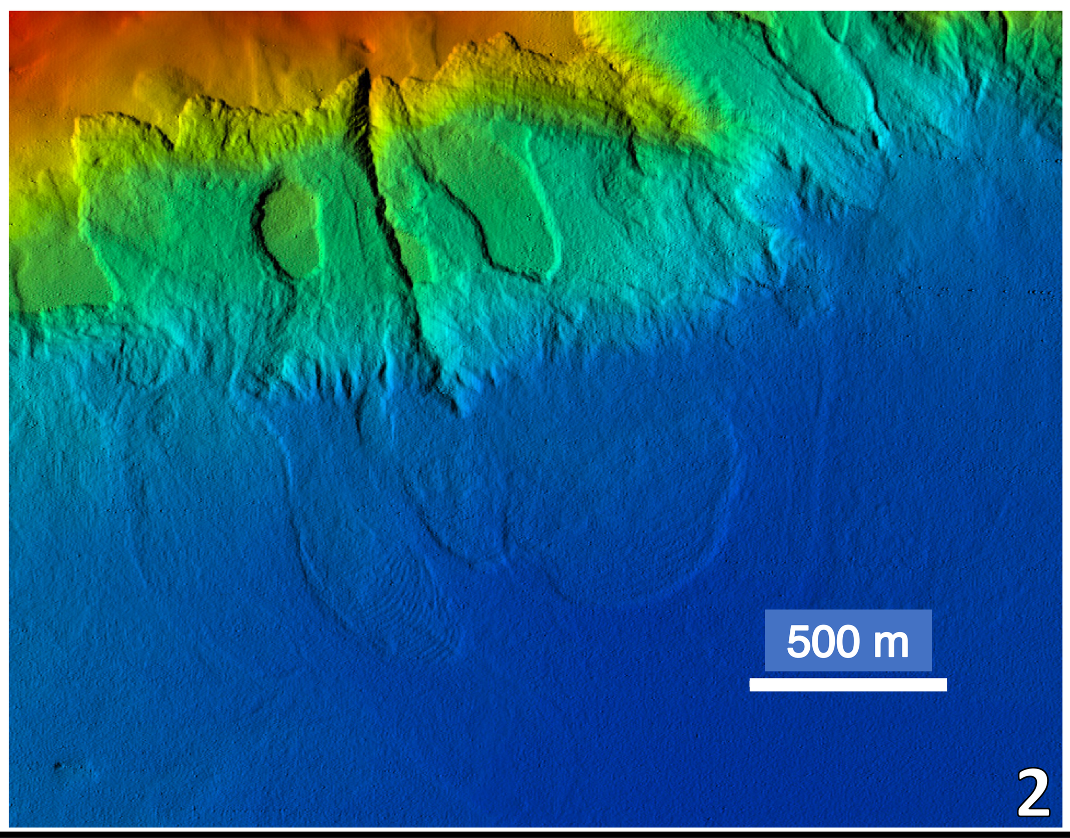


Figure 1. Map of Lake Lucerne, modified from publicly available SwissTopo data. Marked on the map in a yellow box on the left is the Bay of Lucerne, the focus of the search for lacustrine tsunami deposits. The Weggis Slide, the event which caused the tsunami [6], is marked in another yellow box on the right.

Figure 2. The Weggis Slide in more detail, modified from [6]. The escarpment starkly contrasts with the sliding surface, and the runout is also contrasted with a smooth lakebed. Scale of moved mass is in the 10s of millions m^3.



First Results

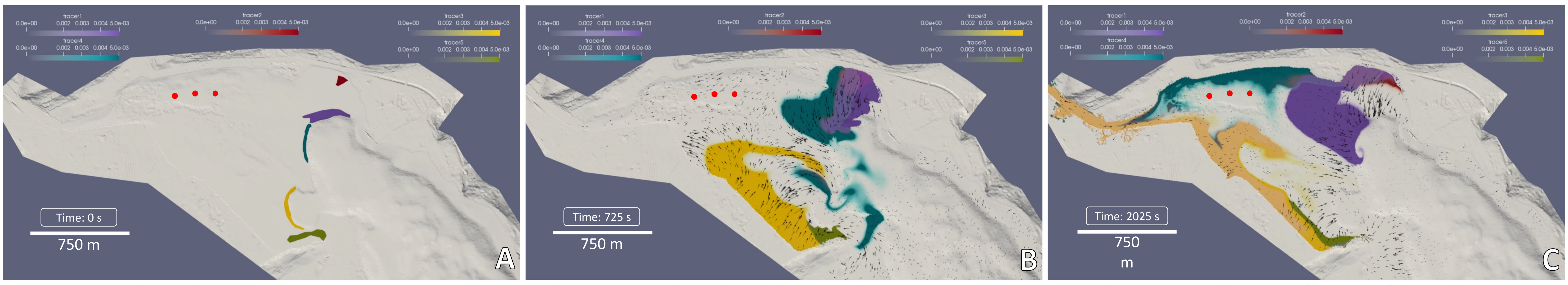


Figure 3. Snapshots of simulation at various times with tracers beginning on the edge of the Bay of Lucerne, at various times. These starting locations (figure 3A) have the highest θ in Bay simulated by BASEMENT [1]. Tracers tend to collect around the shores and other regions around the Bay, but interestingly they seem to avoid the location which Nigg et al. (2021) interpreted as a deposit from the 1601 CE event (core locations by Nigg et al. (2021) marked by 3 red dots). The full animation of this simulation can be seen in QR code to the right of this description.

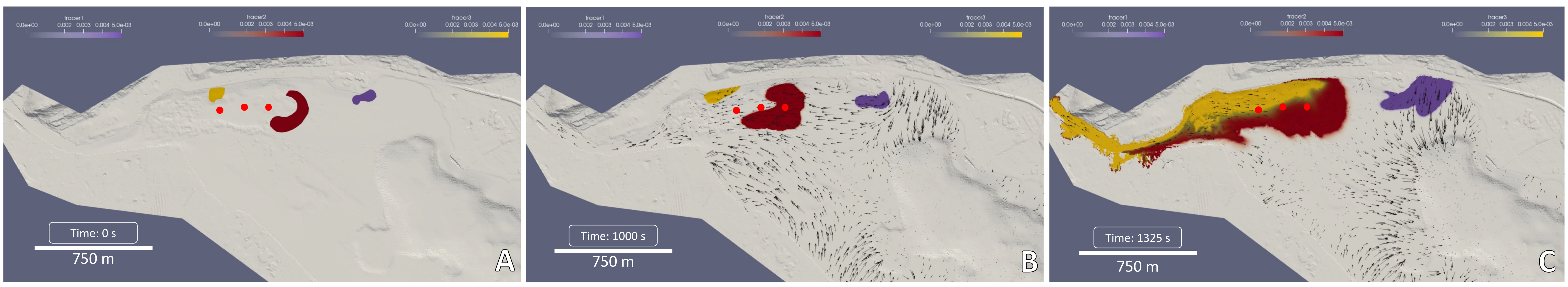


Figure 4. Snapshots of simulation at various times with tracers beginning near coring location described by Nigg et al. (2021) (figure 4A), marked with red dots. The highest θ near this location was at the lake shore (tracers 1, 3). The tracers don't begin to move until 970 s, so the water where tracer 2 begins is assumed to have suspended particles, perhaps some mobilized larger particles as well. Unlike what is shown in Figure 1, these tracers do collect in the area described by Nigg et al. (2021). The full animation of this simulation can be seen in QR code to the right of this description.

Preliminary conclusions and outlook

- Tracers collect in areas consistent with Nigg et al. (2021), along with other areas in the Bay of Lucerne
- Next step is to simulate the sedimentation of the tsunami (morphodynamic simulation)
- Based on the results of the sedimentation simulation, we will take sediment cores in the Lucerne Bay in Spring 2023
- We will then compare cores with results of simulation to see if BASEMENT is a valid tool for sedimentation simulations for lacustrine tsunamis

Sources

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