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Numerical modeling of landslide-generated tsunami using adaptive unstructured meshes

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Landslides impacting into or occurring under water generate waves, which can have devastating environmental consequences. Depending on the characteristics of the landslide the waves can have significant amplitude and potentially propagate over large distances. Linear models of classical earthquake-generated tsunamis cannot reproduce the highly nonlinear generation mechanisms required to accurately predict the consequences of landslide-generated tsunamis. Also, laboratory-scale experimental investigation is limited to simple geometries and short time-scales before wave reflections contaminate the data.

Computational fluid dynamics models based on the nonlinear Navier-Stokes equations can simulate landslide-tsunami generation at realistic scales. However, traditional chessboard-like structured meshes introduce superfluous resolution and hence the computing power required for such a simulation can be prohibitively high, especially in three dimensions. Unstructured meshes allow the grid spacing to vary rapidly from high resolution in the vicinity of small scale features to much coarser, lower resolution in other areas. Combining this variable resolution with dynamic mesh adaptivity allows such high resolution zones to follow features like the interface between the landslide and the water whilst minimising the computational costs. Unstructured meshes are also better suited to representing complex geometries and bathymetries allowing more realistic domains to be simulated.

Modelling multiple materials, like water, air and a landslide, on an unstructured adaptive mesh poses significant numerical challenges. Novel methods of interface preservation must be considered and coupled to a flow model in such a way that ensures conservation of the different materials. Furthermore this conservation property must be maintained during successive stages of mesh optimisation and interpolation. In this paper we validate a new multi-material adaptive unstructured fluid dynamics model against the well-known Lituya Bay landslide-generated wave experiment and case study [1]. In addition, we explore the effect of physical parameters, such as the shape, velocity and viscosity of the landslide, on wave amplitude and run-up, to quantify their influence on the landslide-tsunami hazard.

As well as reproducing the experimental results, the model is shown to have excellent conservation and bounding properties. It also requires fewer nodes than an equivalent resolution fixed mesh simulation, therefore minimising at least one aspect of the computational cost. These computational savings are directly transferable to higher dimensions and some initial three dimensional results are also presented. These reproduce the experiments of DiRisio *et al.* [2], where an $80cm$ long landslide analogue was released from the side of an $8.9m$ diameter conical island in a $50 \times 30m$ tank of water. The resulting impact between the landslide and the water generated waves with an amplitude of $1cm$ at wave gauges around the island. The range of scales that must be considered in any attempt to numerically reproduce this experiment makes it an ideal case study for our multi-material adaptive unstructured fluid dynamics model.

[1] FRITZ, H. M., MOHAMMED, F., & YOO, J. 2009. Lituya Bay Landslide Impact Generated Mega-Tsunami 50th Anniversary. *Pure and Applied Geophysics*, **166**(1), 153–175.

[2] DIRISIO, M., DEGIROLAMO, P., BELLOTTI, G., PANIZZO, A., ARISTODEMO, F., MOLFETTA, M. G., & PETRILLO, A. F. 2009. Landslide-generated tsunamis runup at the coast of a conical island: New physical model experiments. *Journal of Geophysical Research*, **114**.