Simulation of water-induced seismic waveforms in glaciers through hydrodynamic modelling

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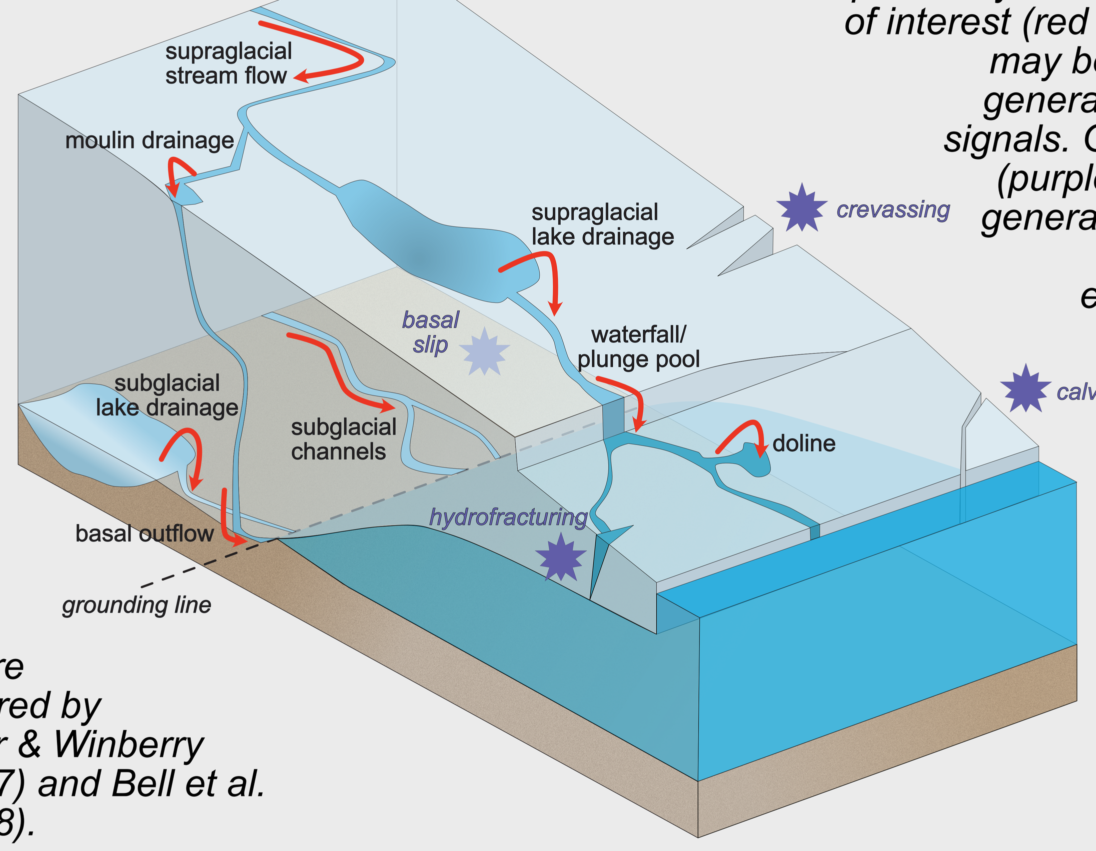
Glacier Monitoring Using Seismic Waveforms

Glaciers are a noisy environment with a broad range of processes capable of generating a seismic response (Winberry & Aster, 2017).



Examples of hydrological events of interest (red arrows) that may be capable of generating seismic signals. Other events (purple stars) also generate signals in the glacier environment.

Figure inspired by Aster & Winberry (2017) and Bell et al. (2018).

Movement of water through the glacier system accounts for several seismogenic mechanisms, so seismic networks provide an opportunity to **monitor hidden and transient hydrological events.**

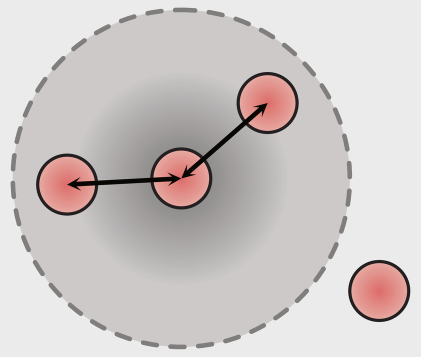
Model Purpose

Goal: Aid in the interpretation of seismic signals associated with glacier hydrology for increased monitoring capability of hidden and transient processes.

Approach: Develop a model that couples three-dimensional hydrodynamic simulations with wave propagation techniques to characterise the expected seismic signals from a range of hydrological events of interest for glacier dynamics.

Smoothed Particle Hydrodynamics

We choose to use **smoothed particle hydrodynamics** (SPH) to model water flow as it allows complex fluid dynamics to be modelled within a simple mesh-free framework (Gingold & Monaghan, 1977; Monaghan, 2011).

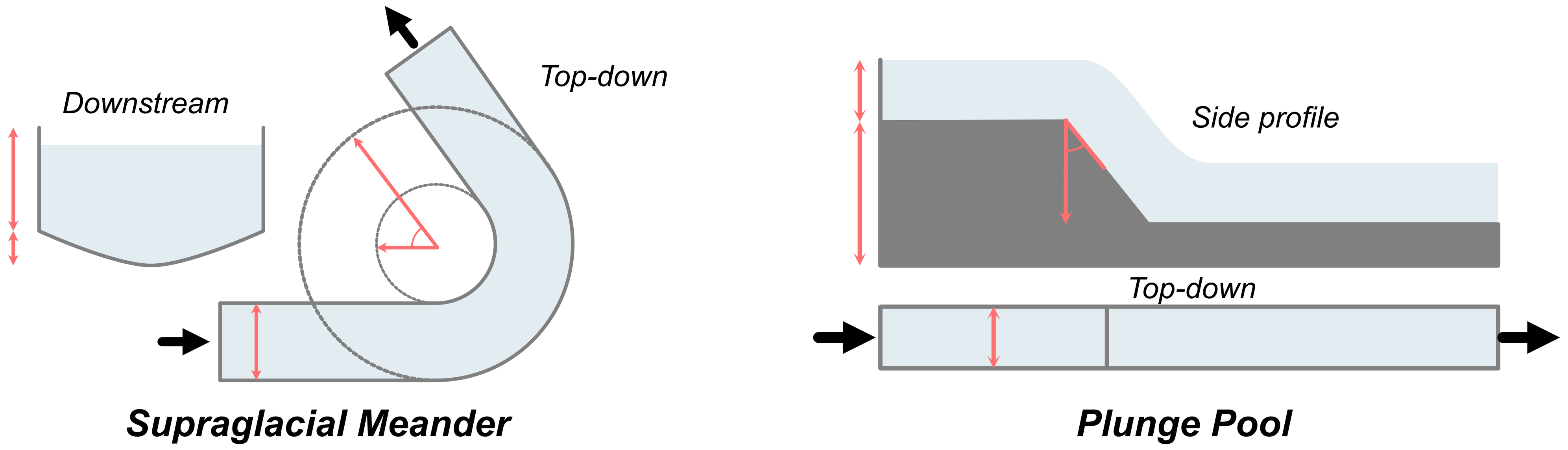


$$\mathbf{F}_i = \sum_j \underbrace{V_i V_j \left(P_{ij} + \Pi_{ij} + T_{ij}\right) \nabla W_{ij}}_{\mathbf{F}_{ij}}$$

The water and surrounding solid conduit are represented by moving particles (red circles) which exert forces upon each other (black arrows, equation above) up to a given radius (dashed line) which is defined by a kernel function *W*. We use these forces to model the seismic response to flowing glacier water.

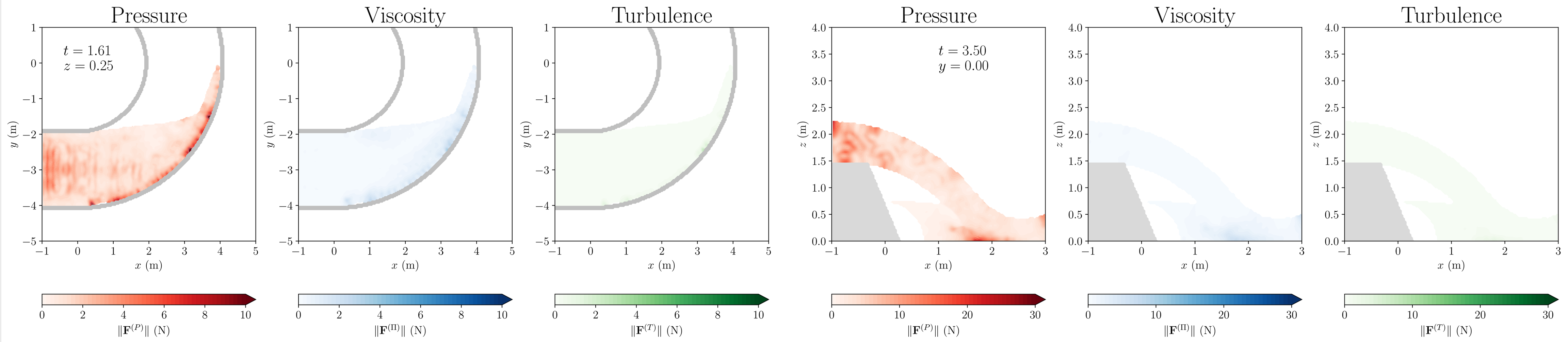
1 Glacier Conduit Design

We select solid walls and boundary conditions to suit the hydrological system of interest. Here, we consider two examples: a curve in a supraglacial stream, and a plunge pool.



2 Hydrodynamic Modelling

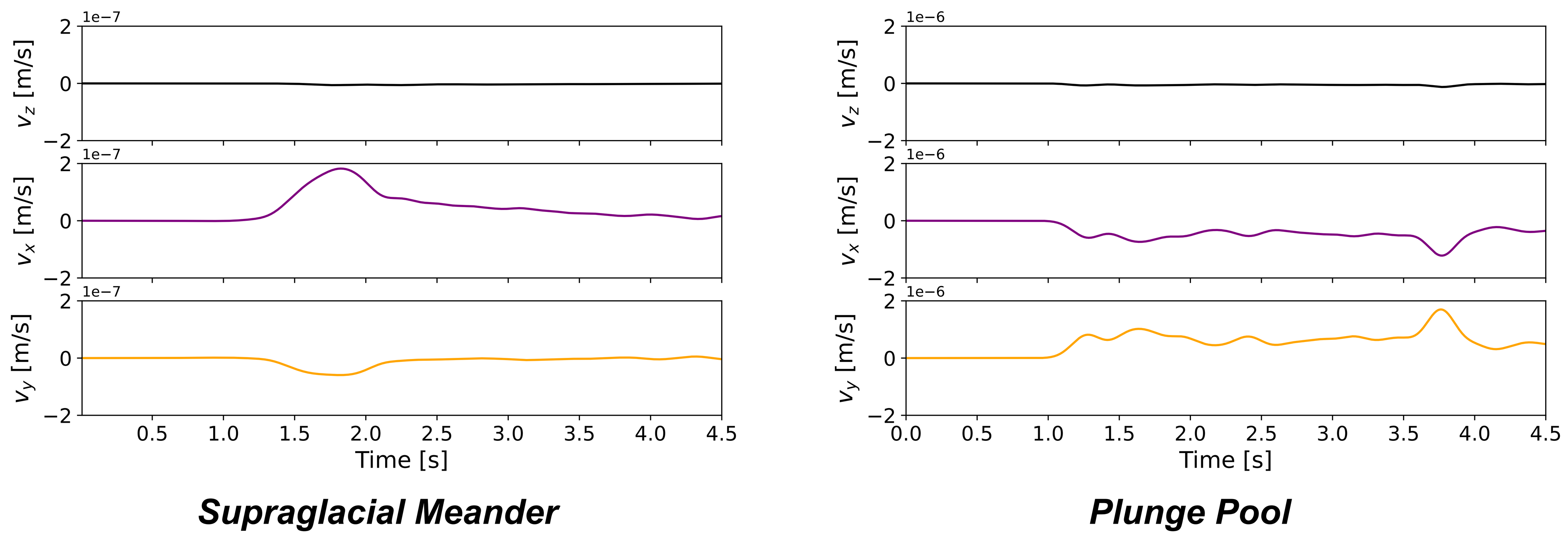
An SPH simulation is run using the chosen geometry and flow conditions. The resulting forces between fluid and solid particles are used to generate synthetic waveforms, and the interactions between fluid particles can inform us on properties of the flow (e.g. turbulent structures).



The magnitude of force contributions (pressure, red; viscous, blue; turbulent, green). Corresponding terms are indicated in the SPH equation (left panel, lower section, coloured boxes).

3 Seismic Wave Propagation

The forces of the water upon the surrounding conduit are used to model the seismic response at chosen seismic receiver locations (seismic velocities derived from Kohnen, 1974).



3-component velocities at a seismometer due to seismic body waves. Using the Cartesian coordinate system from **2** (above), the seismometer is located at (*x*,*y*,*z*) = (20,30,2). Events with different flow characteristics generate waveforms with distinct differences (see poster led by **Ross Turner**).

Conclusions

Coupling a hydrodynamic model of choice with wave propagation methods allows simulation of expected seismic waveforms for a range of glacier hydrology events.

Smoothed particle hydrodynamics (SPH) yields a flexible modelling framework where many different flow types can be generated without altering the model significantly. This allows consistency and easier comparison between event types.

Fluid-solid interface forces can easily be extracted from SPH simulations to act as the seismic source, with filtering of these time series necessary for stable waveform computation.

Current Limitations

We currently exclusively model **body waves**, but expect **surface waves** to be important for sustained tremor-like signals (Gimbert et al., 2014).

Assumptions made in the SPH model mean that the water is artificially compressible, and thus not suitable for modelling **resonant frequencies** (Roeosli et al., 2016).

We assume that the seismometer is located on the ice, and do not account for wave propagation across an ice-rock interface.

Ongoing Work

This model currently only considers body wave propagation. For sustained signals, we expect significant contribution from surface waves.

A range of filtering methods (e.g. wavelets) are being considered for removing numerical noise from interface forces.

We aim to explore a greater range of glacier hydrology geometries relevant to ice sheet dynamics than those considered here.

This modelling framework as the potential to be used in conjunction with machine learning techniques for signal classification and interpretation.

References

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