# Numerical modelling of volcanic tsunamis

Lily Battershill and Matthew Hayward

Climate, Freshwater & Ocean Science

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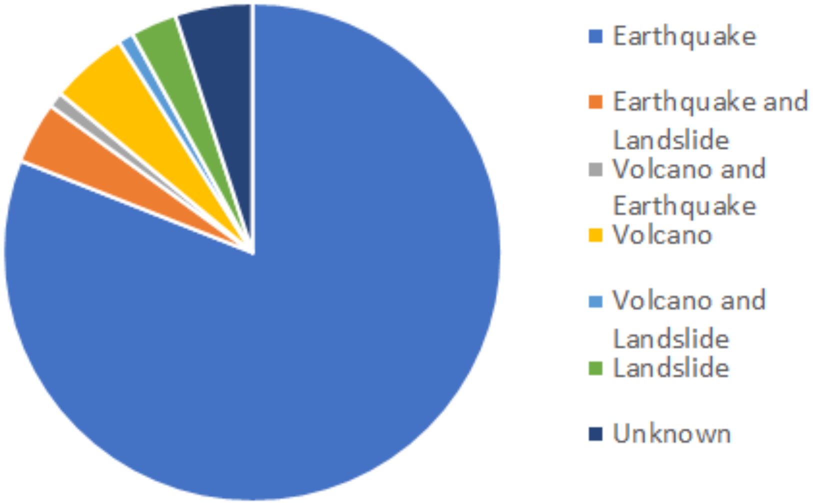
# A bit of background...

Tsunami sources (Harbitx et al Nat Hazards 2013)




- Most tsunamis are generated by submarine earthquakes on subduction zones.
- But earthquakes are not the only way to generate tsunamis!
- At least 10% of historical tsunamis are not associated with an earthquake…
- And another 5% of tsunamis occurred after an earthquake, but that was not the primary trigger

Cas & Wright 1991, Watts & Waythomas 2003, Maeno & Imamura 2011, Sulpizo et. al. 2014, Dufek 2016, Bread & Lube 2017,

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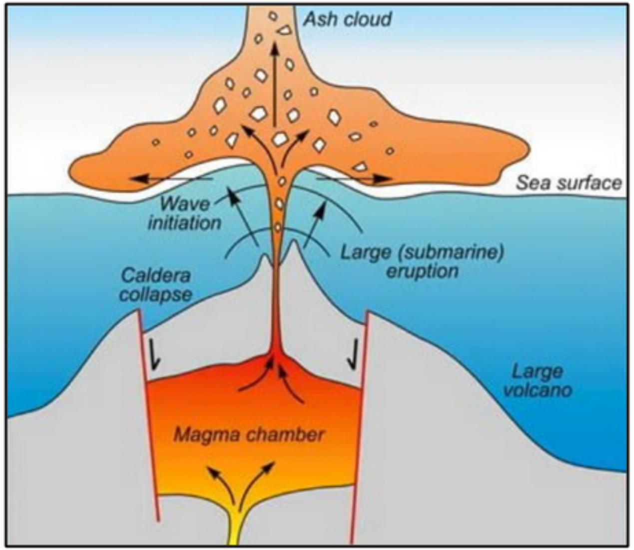
# So what else causes tsunamis?

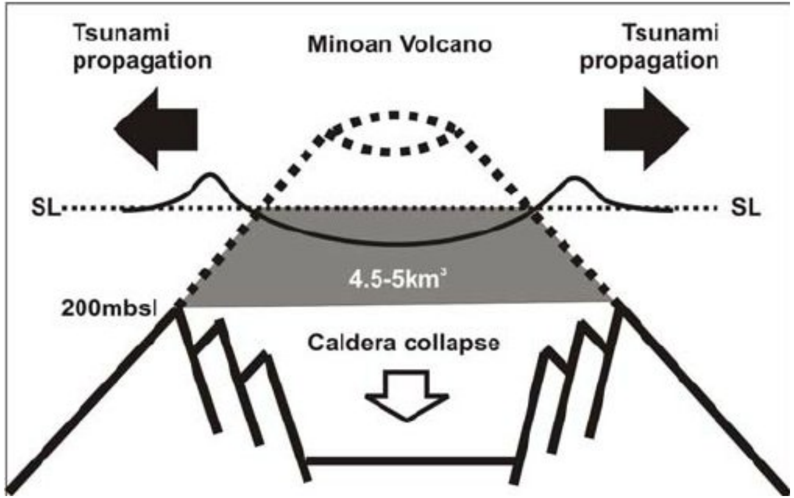



https://www.shtfplan.com/headline-news/frightening-methane-explosion-steam-volcano-may-cause-massive-tsunami_07082010

## Tsunamis of volcanic origin

- Underwater eruption
- Caldera collapse
- Pyroclastic flows
- Flank failure
- Shock waves

# So what else causes tsunamis?

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Sakellariou, D., Rousakis, G., Nomikou, P., Bell, K.C., Carey, S., Sigurdsson, H., 2012. Tsunami triggering mechanisms associated with the 17th cent. BC Minoan eruption of Thera volcano, Greece. Int. Soc. Offshore Polar Eng Online.

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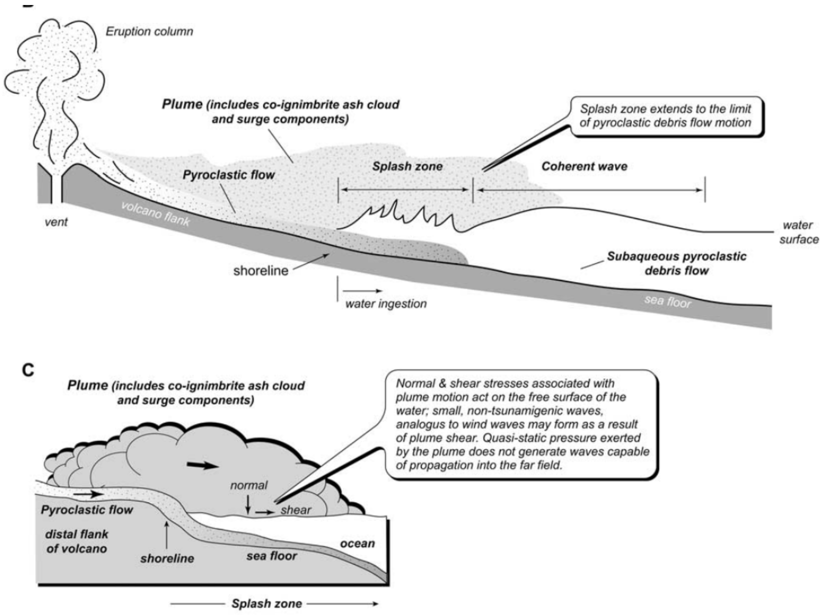


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https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2002JB002265

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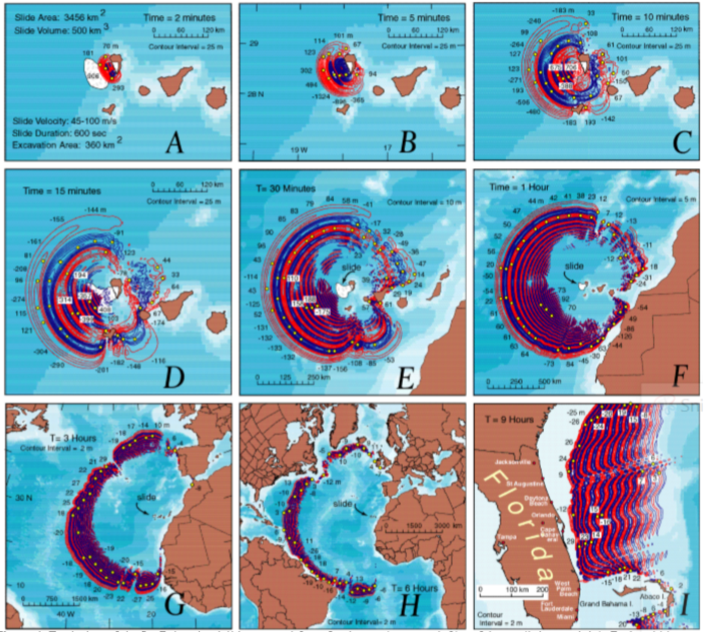


## Tsunamis of volcanic origin

- Underwater eruption
- Caldera collapse
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- **Flank failure**
- Shock waves

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# So what else causes tsunamis?


https://www.youtube.com/watch?v=BUREX8aFbMs

## Tsunamis of volcanic origin

- Underwater eruption
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- Shock waves

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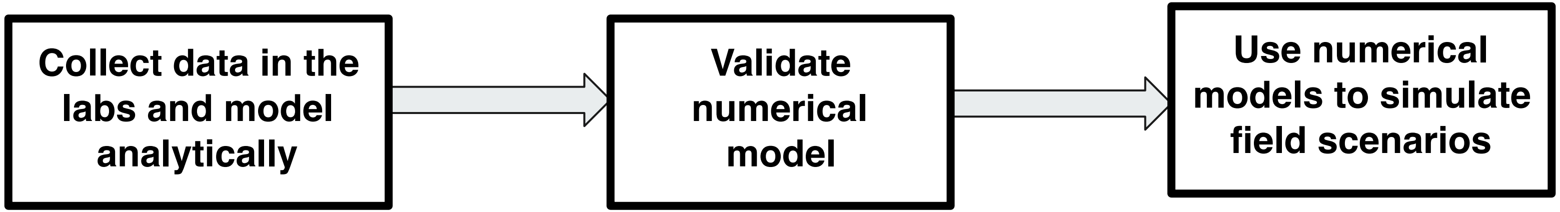
# Volcanic Tsunamis Project

- Funding for 4 PhDs (Marsden and UoA Doctoral Scholarships)
- 2 x experimental PhDs and 2 x numerical (Matty and I!)
- **Underwater eruptions and pyroclastic flows**
- Integrated physical-numerical approach



# Lily Battershill

Investigating the **tsunami generation potential** of **pyroclastic flows** with **numerical modelling**

# What do we know?

- Two key **end members** to a pyroclastic flow: dense-type & light type
- A number of **historical examples** of PDCs
- **Experimental & numerical models** of entrance of PDCs into water, gravity currents, landslides, experiments on PDC deposits → simplified initialisation models
- **Theoretical work:** how PDCs can generate waves. Plume shear, plume pressure, debris flow, explosions
- Recent advances in numerical modelling: can understand phenomena involved. I.e. fluidisation of granular phases.

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# Current limitations

- Most current numerical modelling of pyroclastic flows simplifies the problem to a ‘fast moving (in come cases mobile) landslide’
- Assumption that all wave propagation is controlled by the dense part of the flow
- Depth averaged → cannot model turbulent mixing
- Heat transfer & flow water interactions not accounted for
- Computational expense vs. understanding the sensitivity

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# My work so far

- Familiarising myself with the problem & mechanisms involved (theoretical work).
- Main area of focus = tsunami wave generation potential of dilute pyroclastic flows.
- Identifying how I am going to simplify the scenario: ‘Jet of fast gas’ vs. cavity collapse
- Simple Basilisk simulations (see next page)
- Basic comparison study: how well does a cavity collapse model the waves generated by a jet. How much does injection of momentum affect the wave profile?

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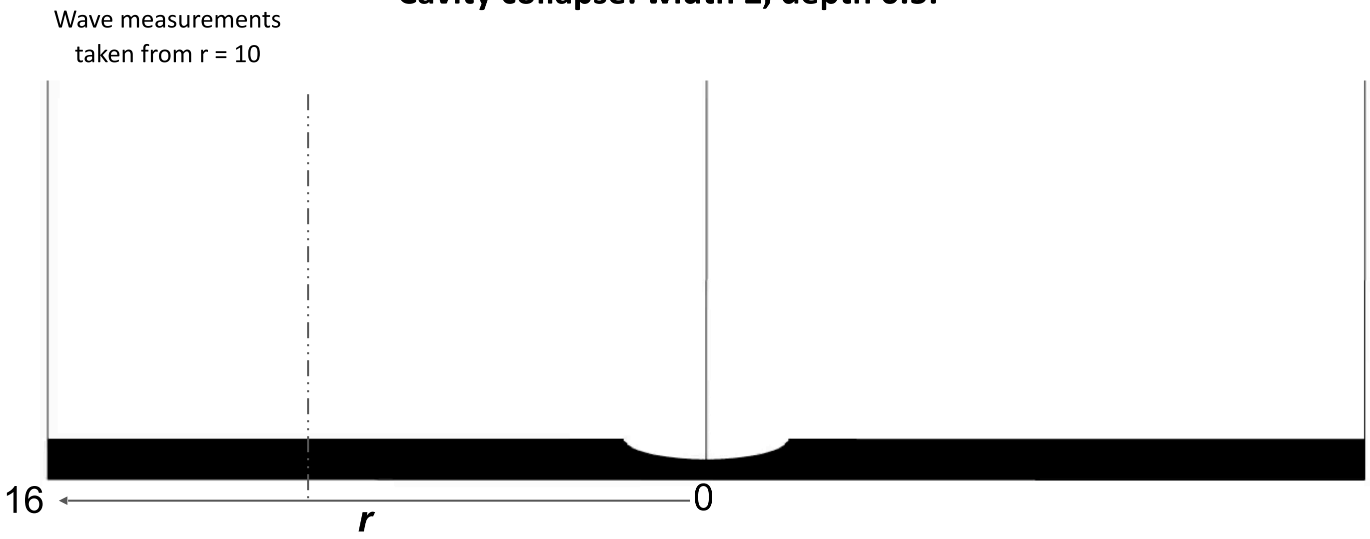
# Jet of gas vs. cavity collapse simulations

**Cavity collapse: width 2, depth 0.5.**

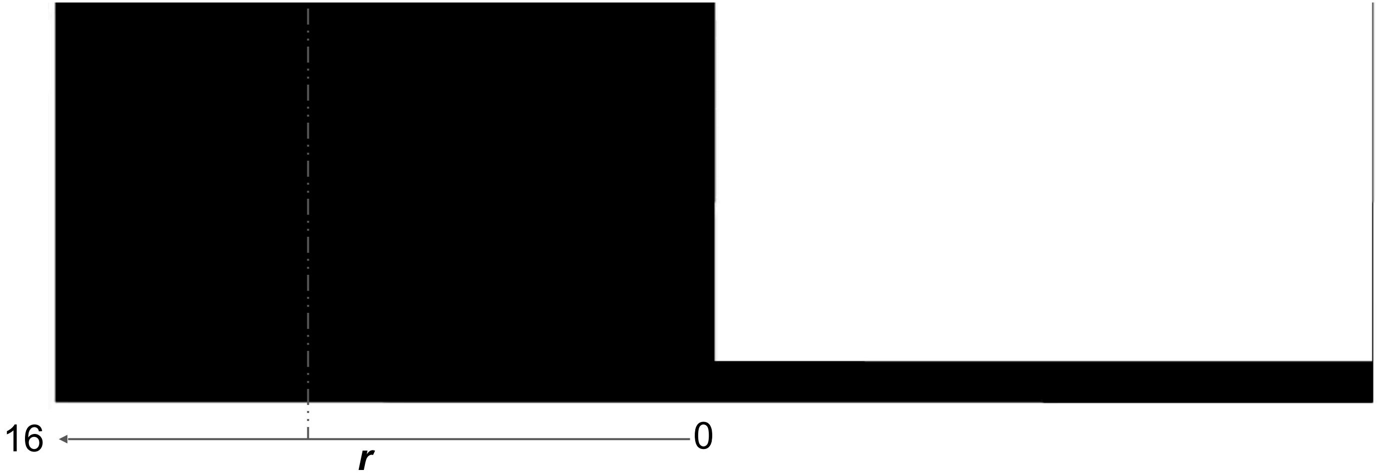



- Non dimensionalised by water depth h and shallow water wave speed.
- Domain size 16 x 16
- 0 axis is axis of symmetry
- Left is vertical velocity, right is horizontal

# Jet of gas vs. cavity collapse simulations

**Jet of fast gas: width 0.5, duration on 2, speed 50**

Wave measurements taken from r = 10



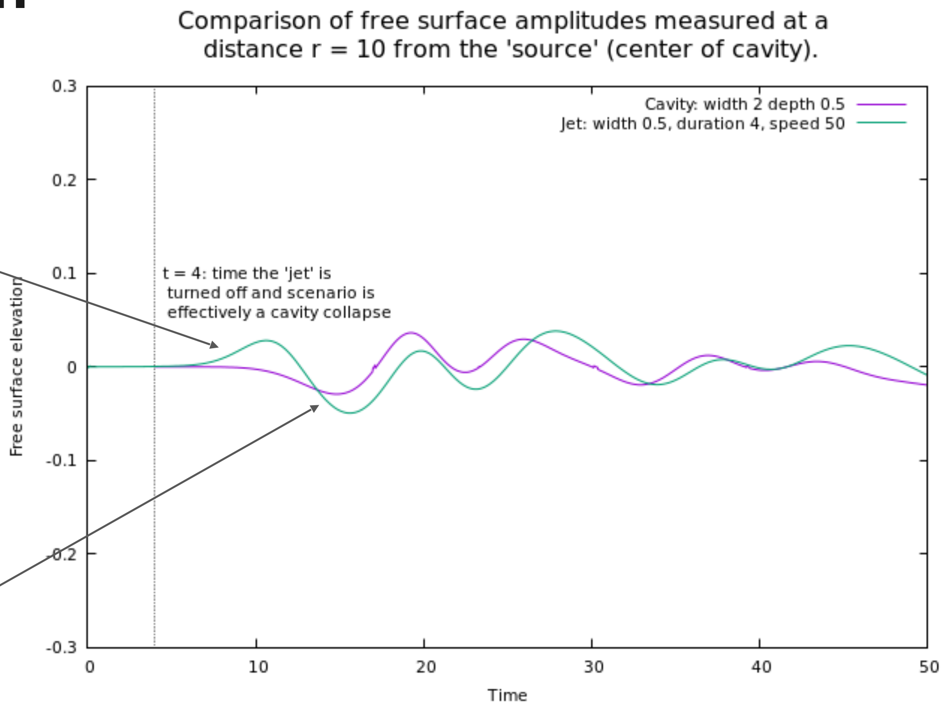

- Non dimensionalised by water depth h and shallow water wave speed.
- Domain size 16 x 16
- 0 axis is axis of symmetry
- Left is vertical velocity, right is horizontal

# Time series comparison

**Key difference:** initial waveform is a peak not a trough.

Can I create a cavity with a leading 'lip' then compare?

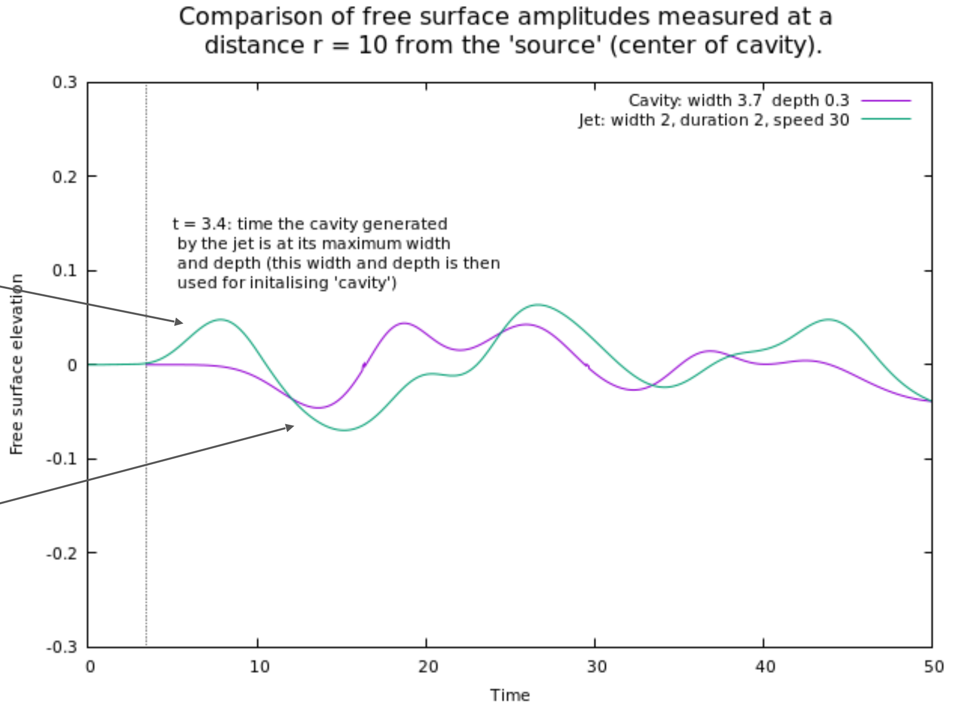
Shape of waveform correlates reasonably well after initial peak. How much discrepancy is down to pre 'injection' of momentum? How much is due to the slight difference in initialised cavity vs. generated cavity? *How well does a simple cavity collapse model a 'jet' generated cavity collapse?*



# Time series comparison

**Key difference:** again, initial waveform is a peak not a trough.

Shape of waveform correlates less well than in the previous comparison. Why is this? What is controlling the correlation.



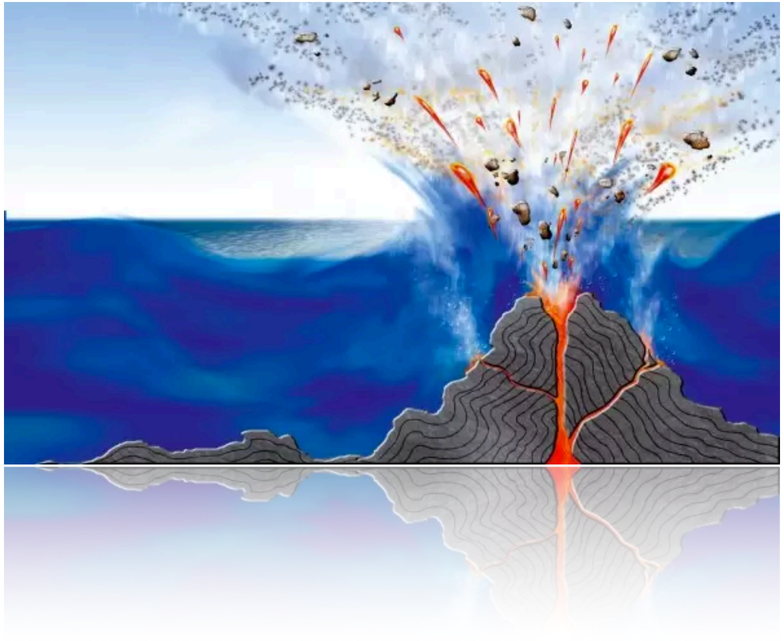
# Next steps and questions (Lily)

- Investigate the correlation of the cavity and blow scenarios
- Explore the parameter space further.
- Mimic a column collapse/entry at an angle, thus extending the parameter space.
- Run in 3D and explore directionality: a key factor in pyroclastic flow generated tsunamis
- Dispersion?
- Dry granular flows → fluidised granular flows

# Matty Hayward

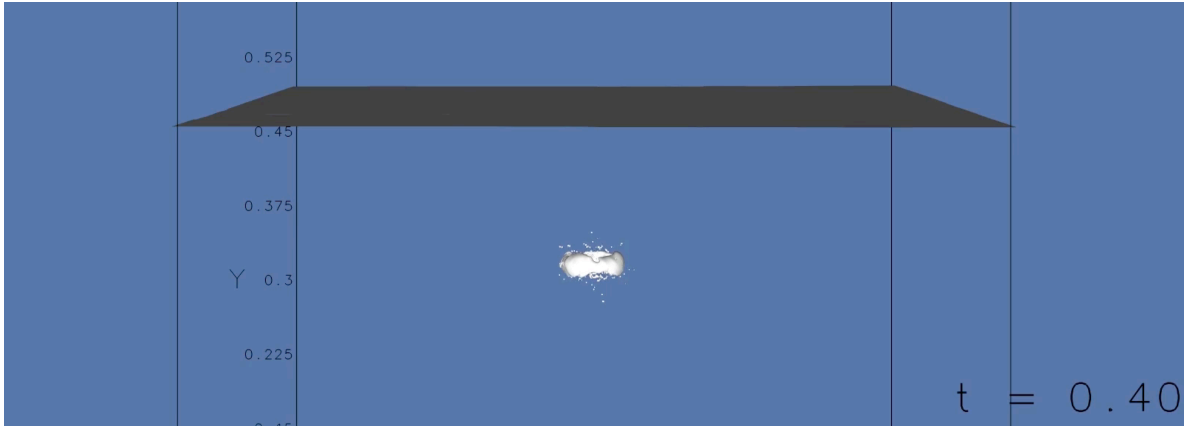
## Underwater Triggers

- Plumes
- Jets
- (Steam) Explosions
- Bathymetric (e.g. caldera collapse)



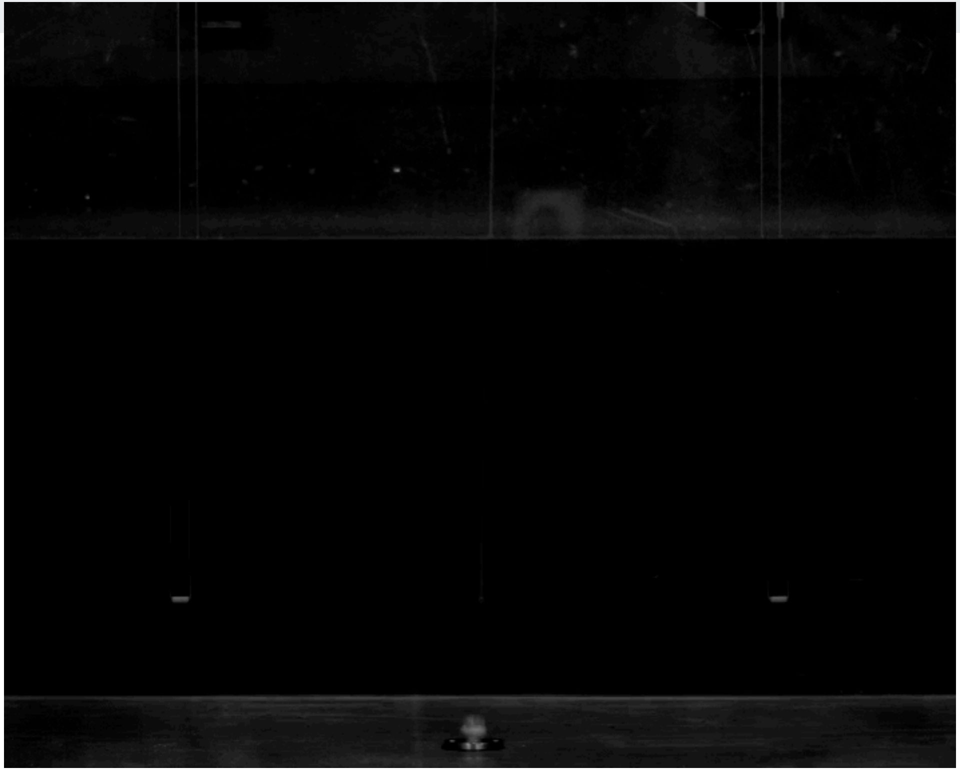
# Work so far

- Crash course in Basilisk!
- Start with simple cases:



# Work so far

- Crash course in Basilisk!
- ...and a simplified replication model of physical experiment:



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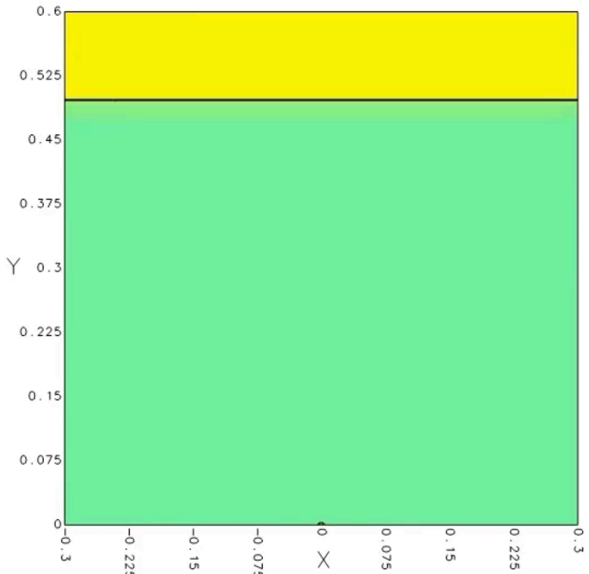
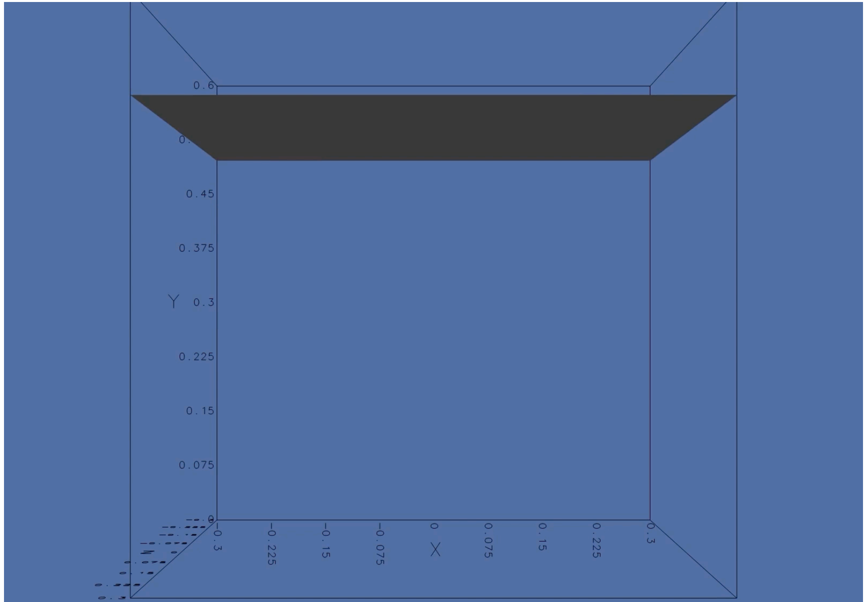



Going from 2D…

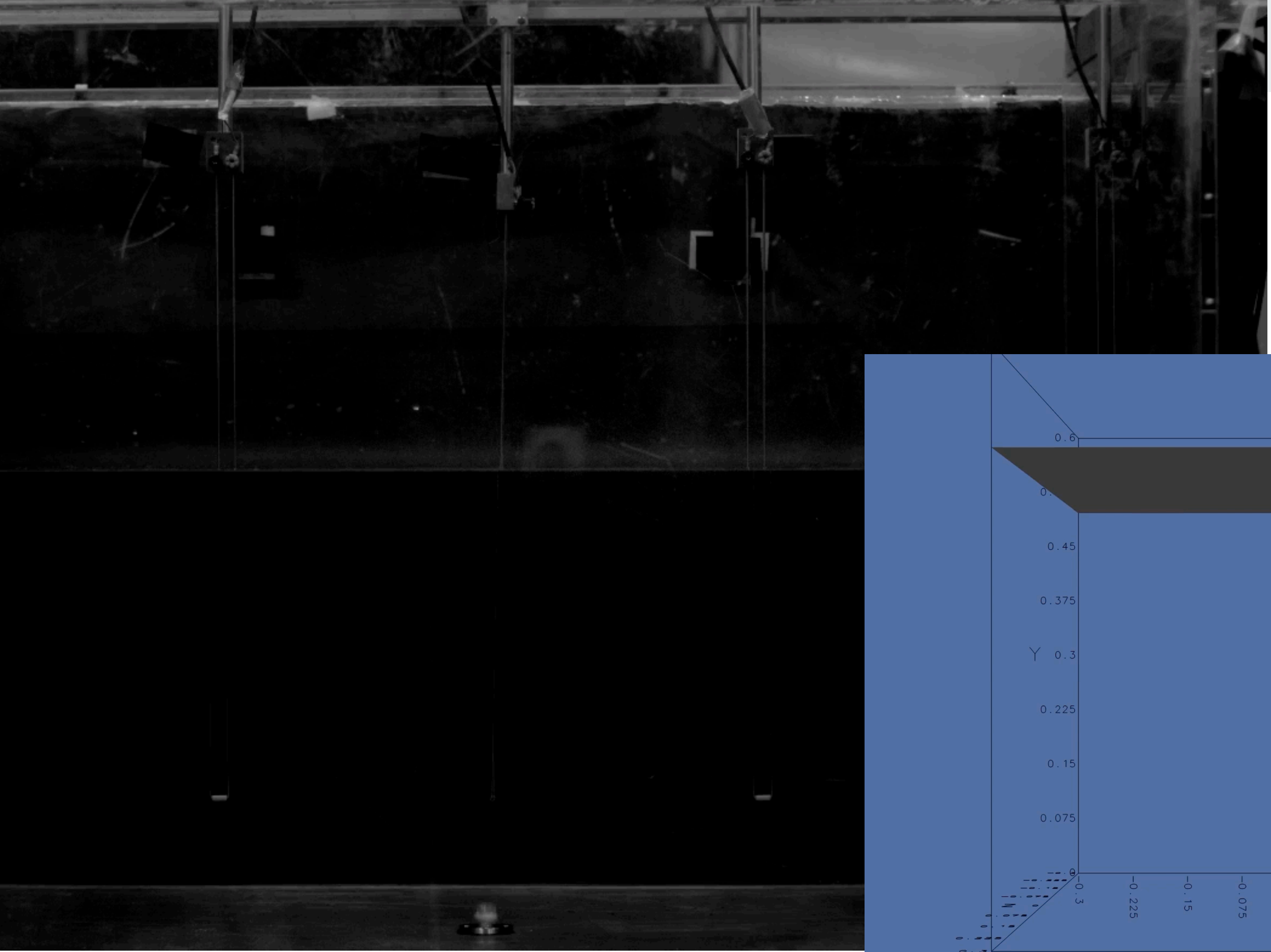
# Work so far

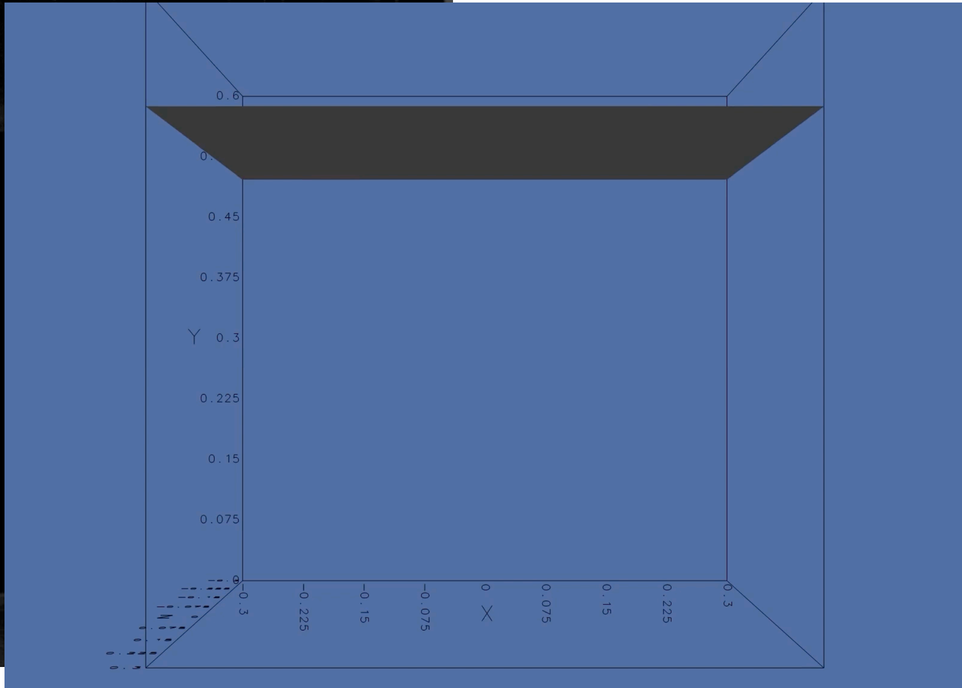
- Crash course in Basilisk!
- …and a simplified replication model of physical experiment:




Going from 2D…

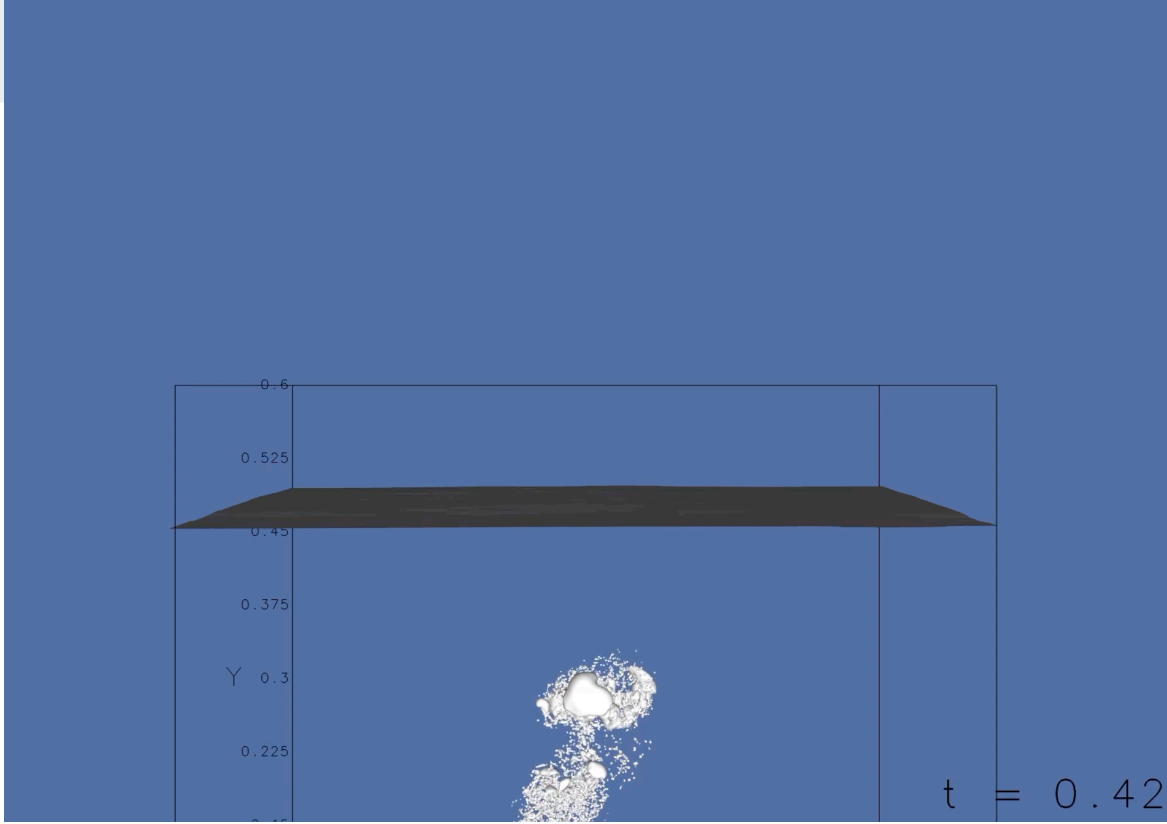
…into 3D!

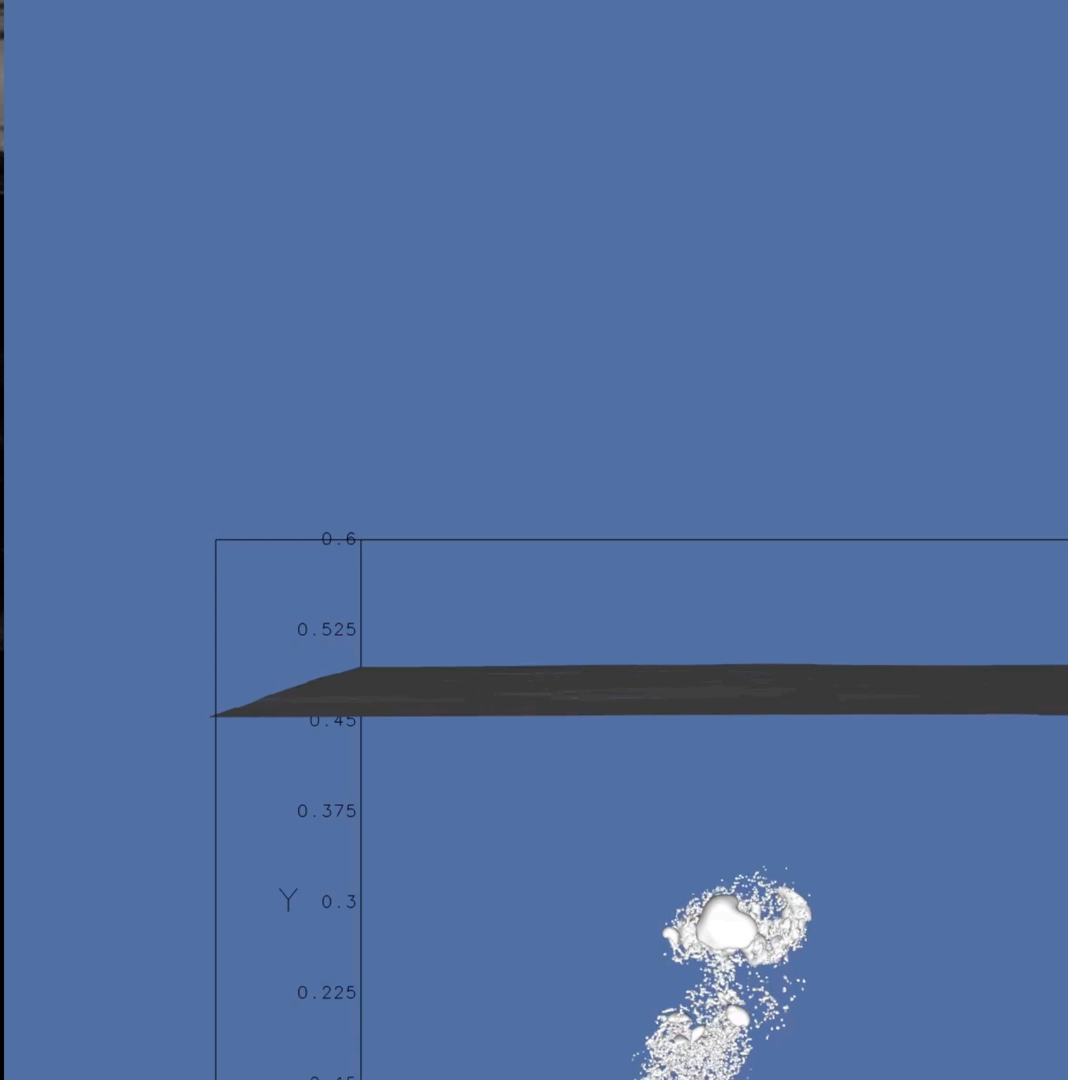



0.6
0.45
0.375
Y
0.3
0.225
0.15
0.075
0
-0.3
-0.225
-0.15
-0.075
0
X
0.075
0.15
0.225
0.3

# Work so far

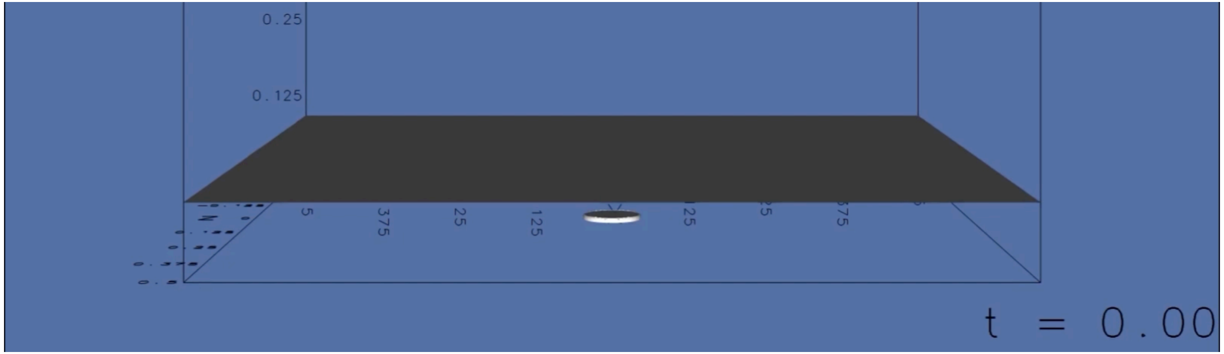
- Crash course in Basilisk!
- …and a simplified replication model of physical experiment:




0.6
0.525
0.45
0.375
Y
0.3
0.225

# Work so far

- Crash course in Basilisk!
- …also try adapt to a given other scenario:



# Work so far

- Crash course in Basilisk!
- Usage of HPC
- In our case, the New Zealand eScience Infrastructure
- From a ‘newbie’ perspective, very easy to work in parallel.

## Next Steps

- Develop way to extract generated wave data for use in other solvers.
- Expand scale to be more relevant and realistic.

## Early Questions Raised

- Potential of three-phase solver?
- Compressibility?