On the forces at play during kilometer-scale iceberg capsize: insight from numerical simulations

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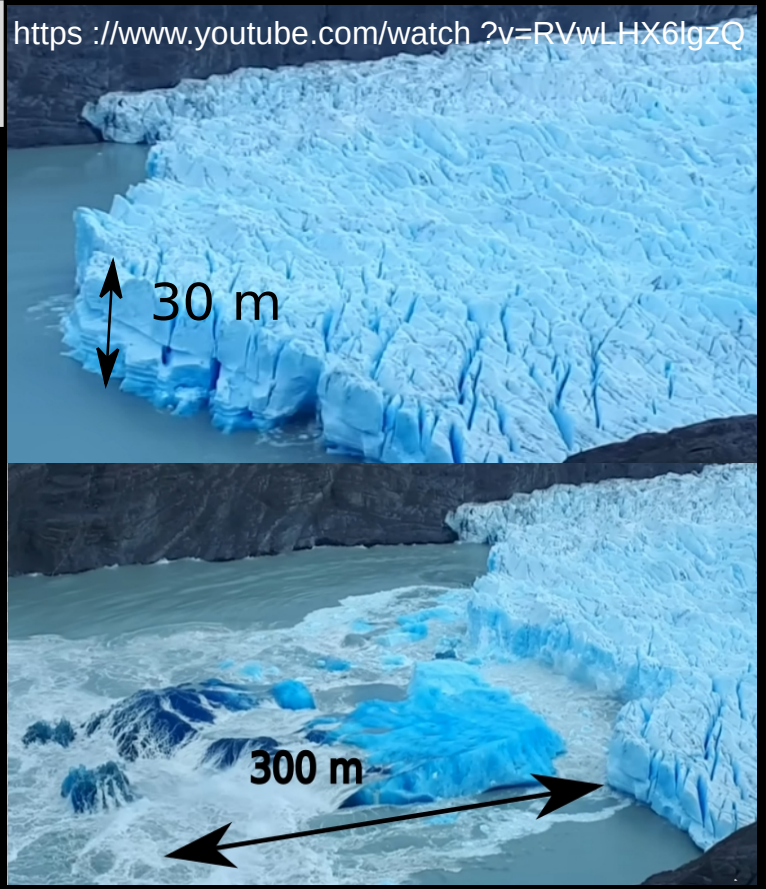
Iceberg Calving & Capsize

66% of Greenland ice mass loss = dynamic processes
[Mouginot et al. 2019]



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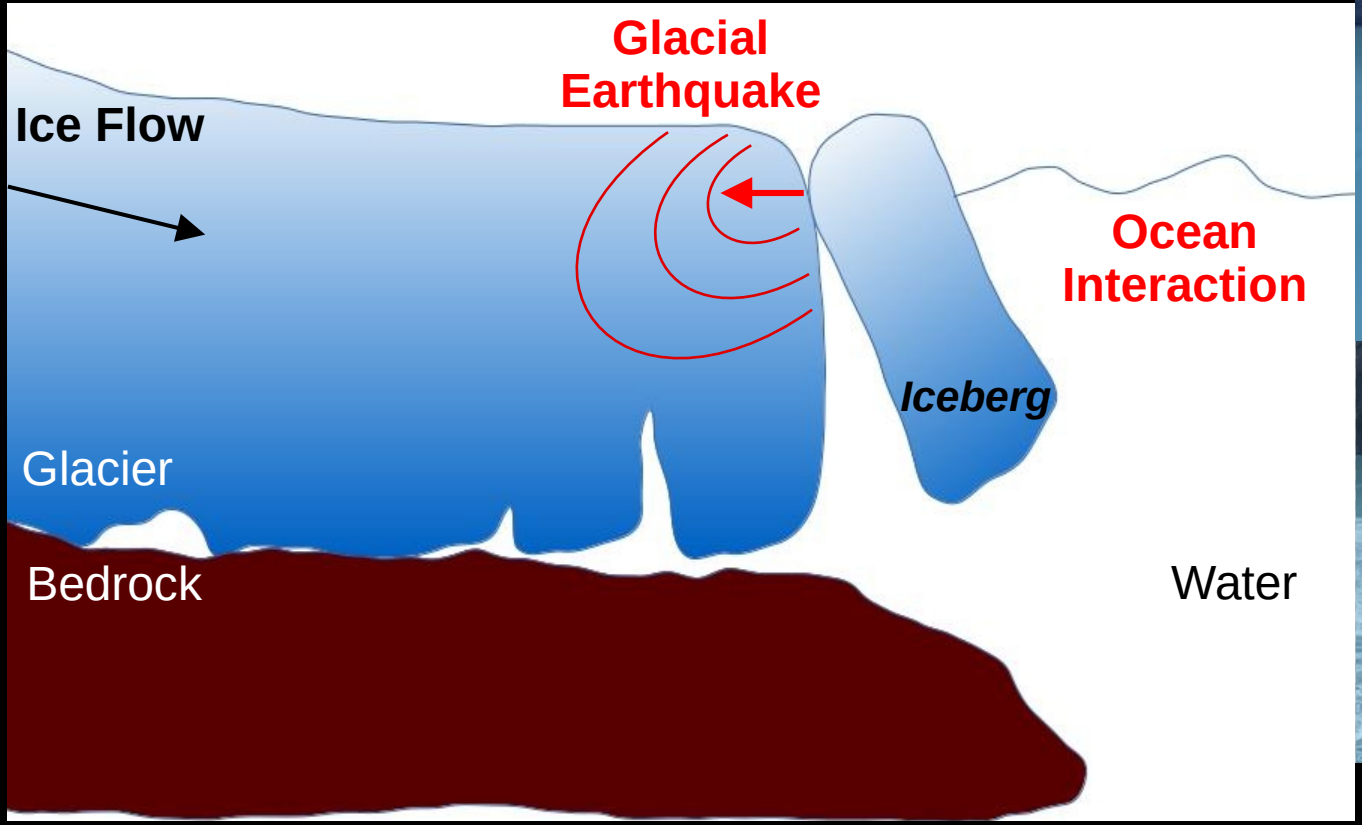

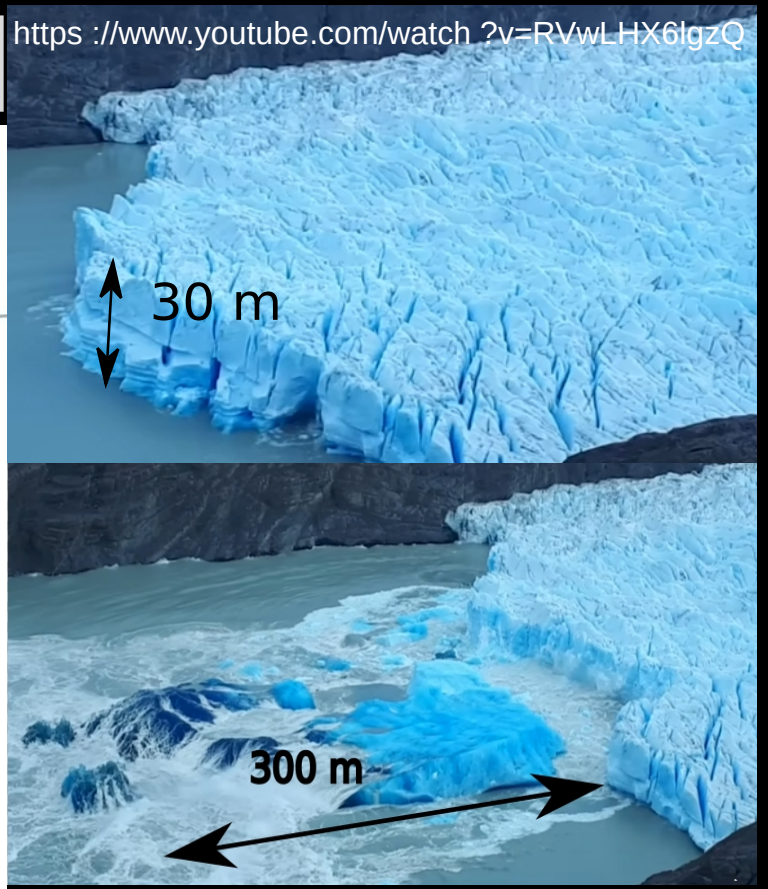

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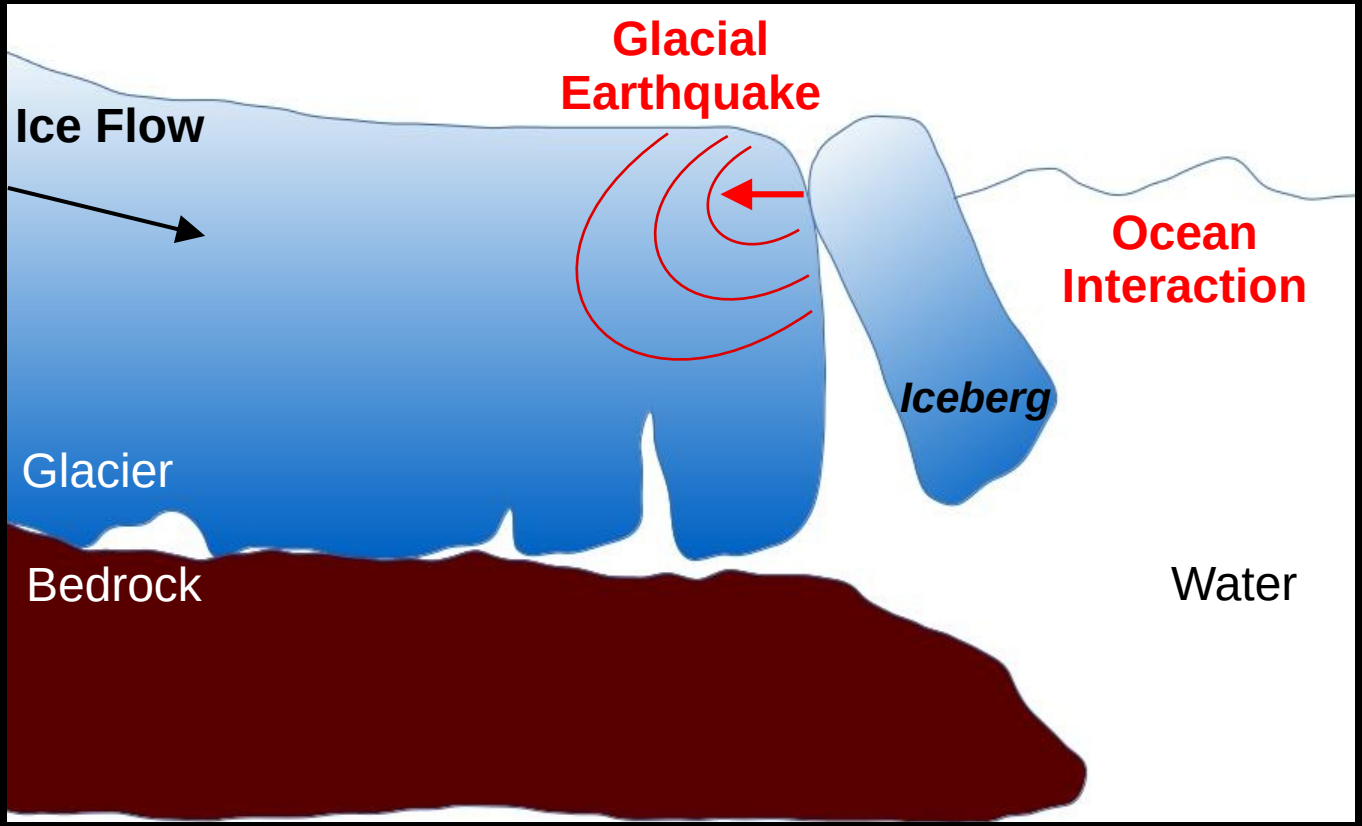


Objectives:

- Find a relationship between seismic signal and iceberg volume
- Evolution of Greenland ice loss through calving
- Glacier response to capsize

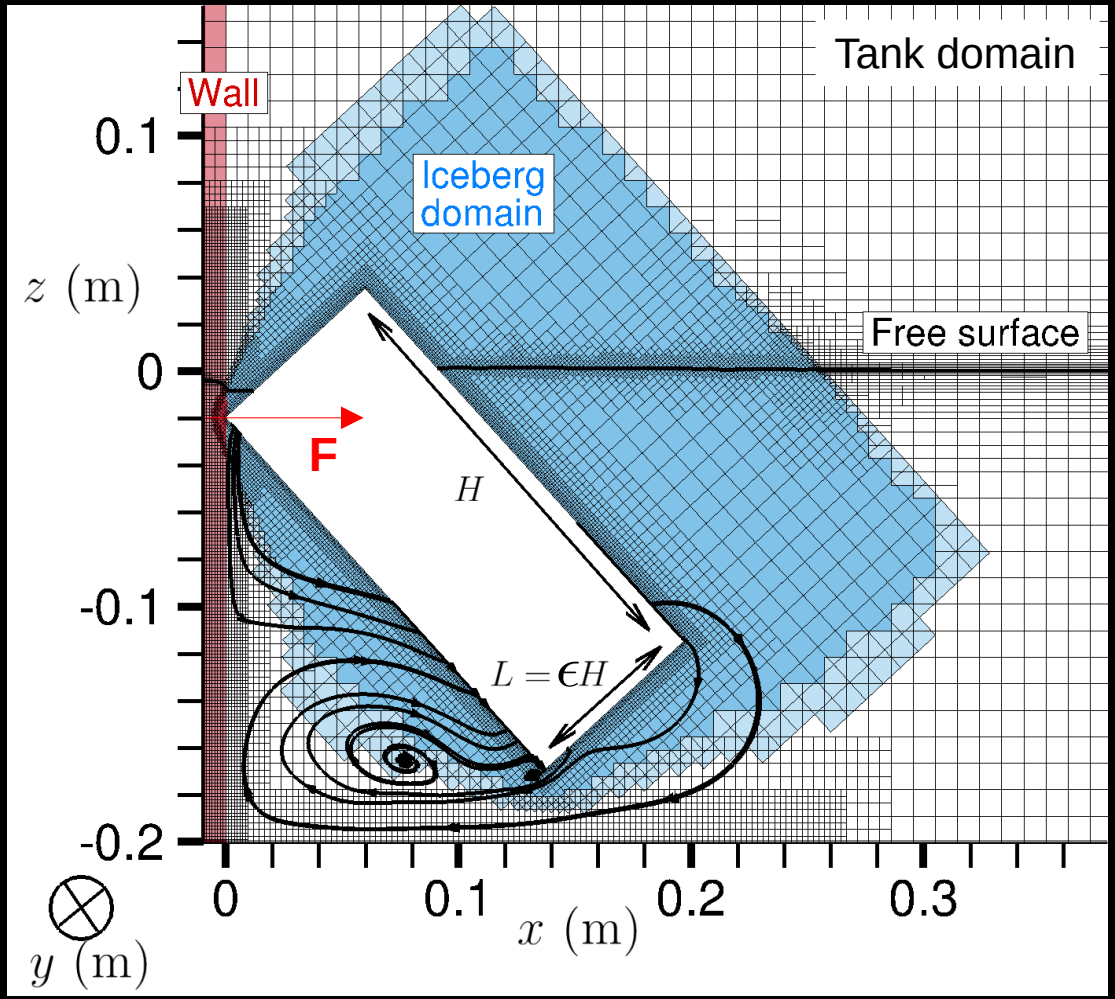
Numerical model for capsize

ISIS-CFD solver developed at LHEEA lab & distributed by Cadense Design
for **Fluid-Structure interactions**

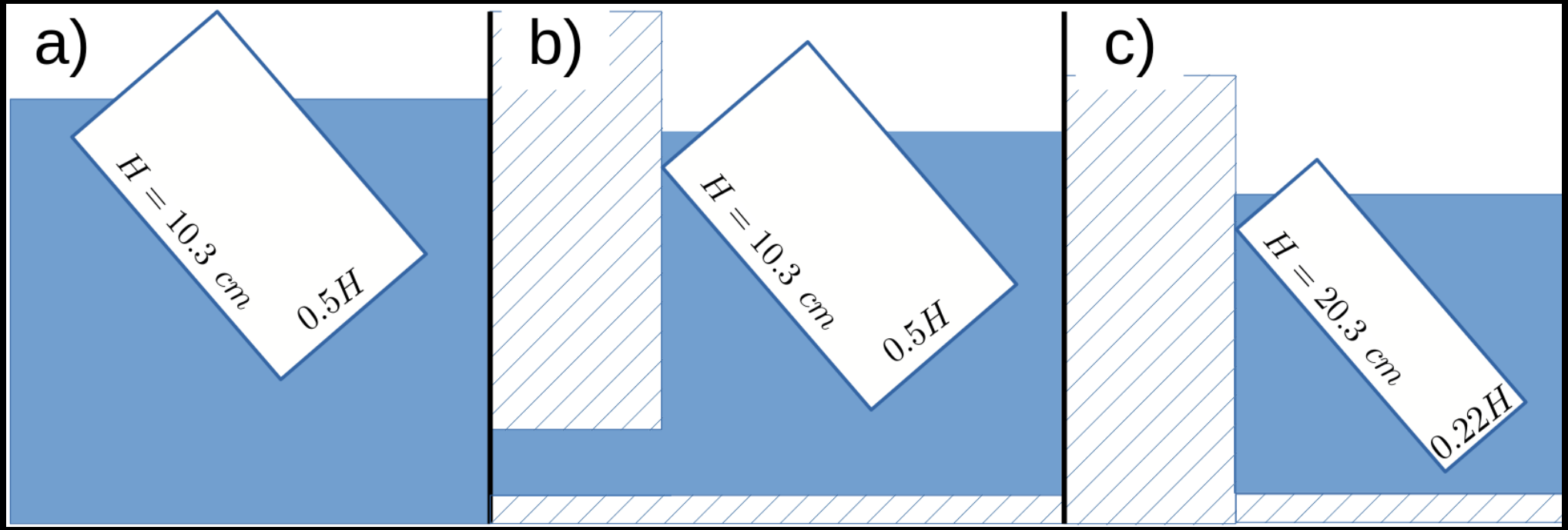
- Reynolds Average Navier-Stokes Equations
- Two fluids (air / water)
- Overlapping grids
- Automatic Grid refinement

Iceberg-Wall Contact

- **Volume penalisation method**
[Engels et al. 2015, Hester et al. 2021]
- **Spring-damper contact force model (F)**
[Rengifo et al. 2009]



Experimental Data Base



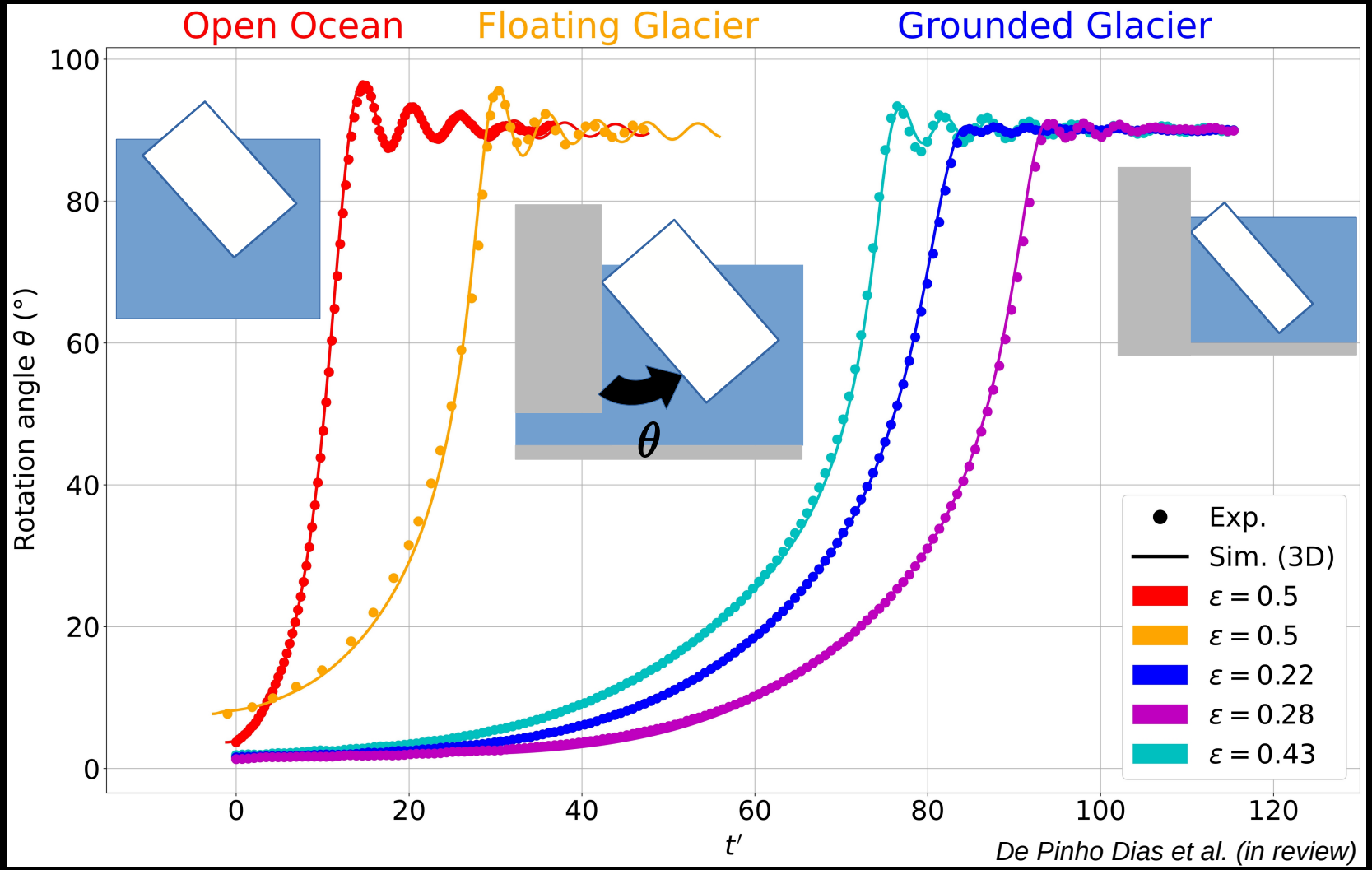
(a) “Open Ocean”
[Burton et al. 2012]

(b) “Floating Glacier”
[Amundson et al. 2012]

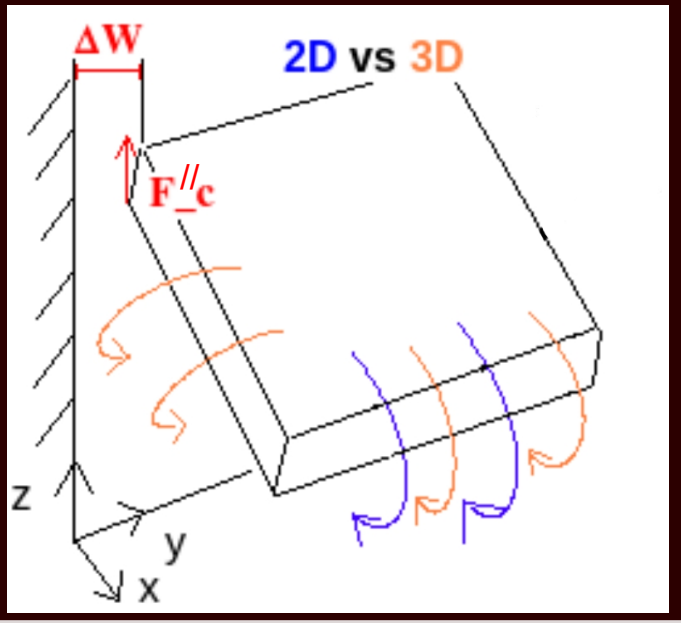
(c) “Grounded Glacier”
[Murray et al. 2015]

Aspect ratio, height, water depth

Lab-scale Validation : Bottom-out



Lateral flow importance

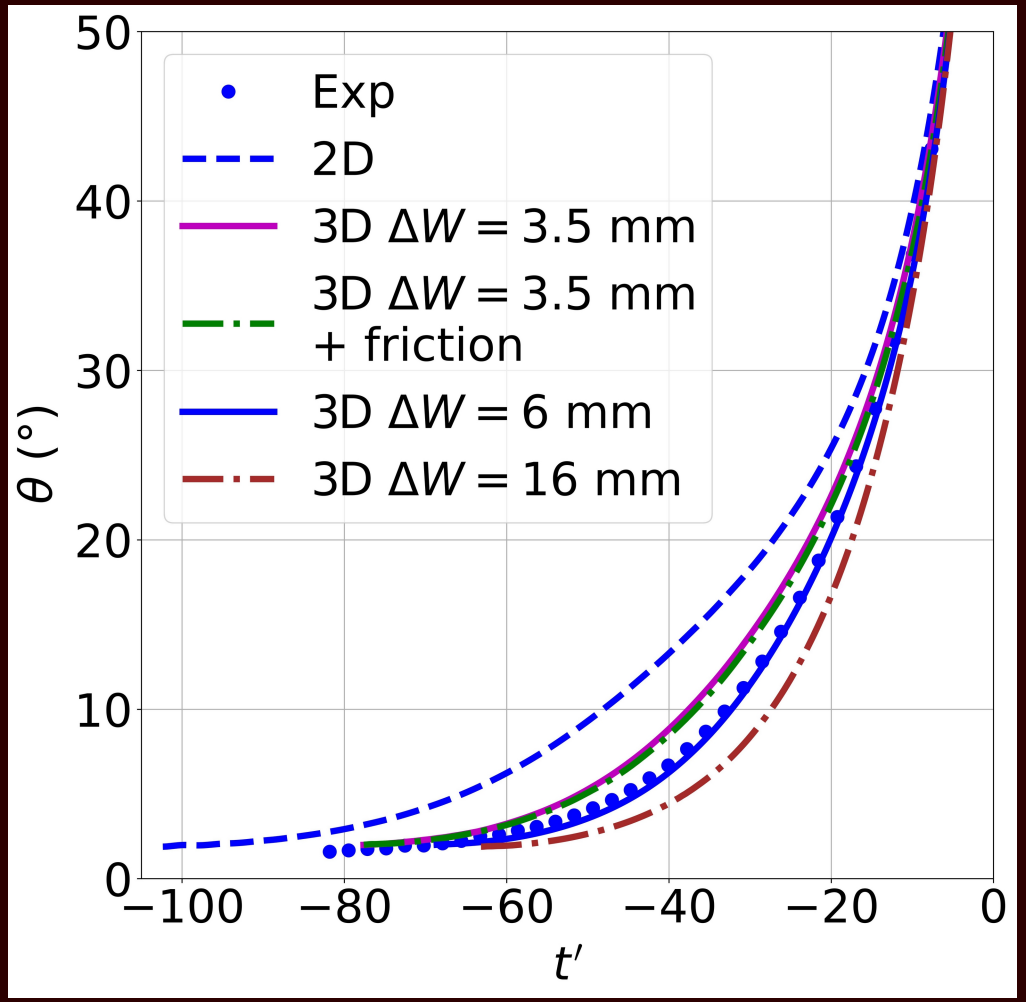


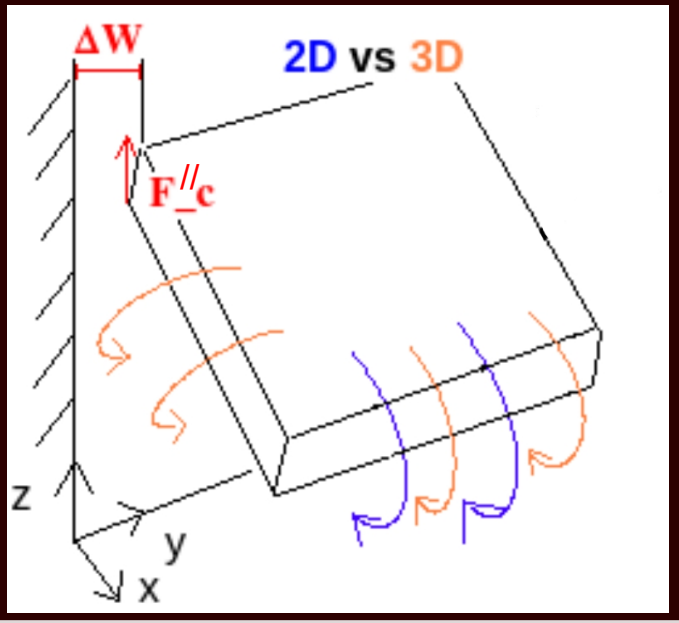
+ Changing the gap ΔW

+ Adding Coulomb-type friction $F_{\_c}^{//}$

$\rightarrow \Delta W$ controls the dynamics

Lateral flow importance





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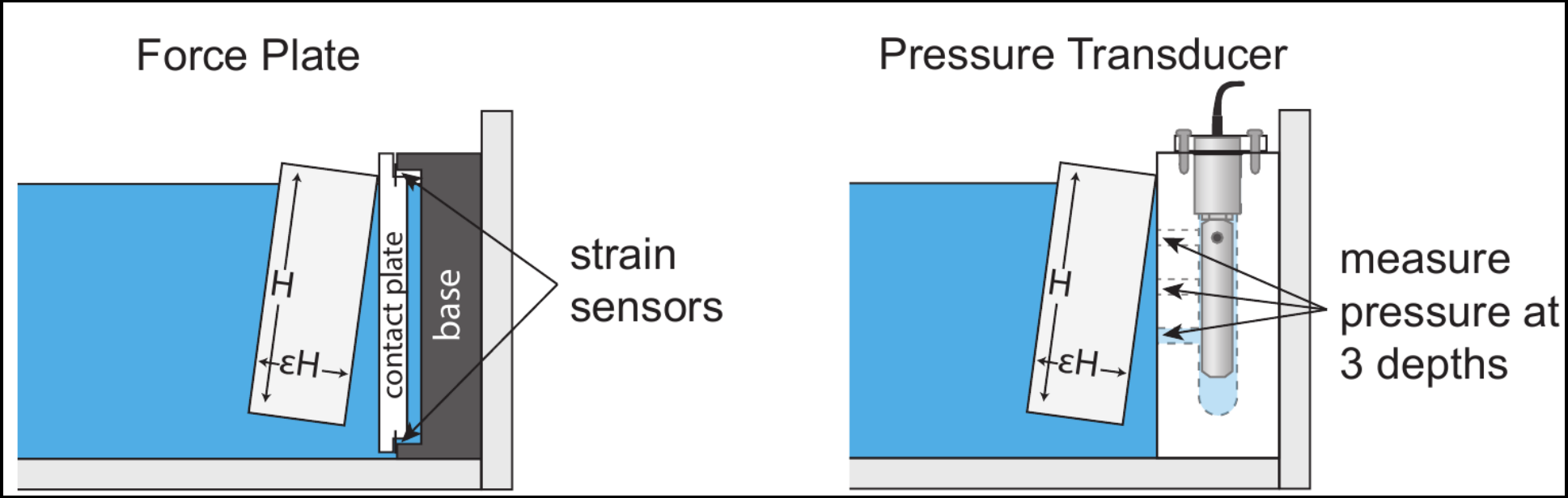
Force experiments and simulations



Force Configuration “FC”

Pressure Configuration “PC”

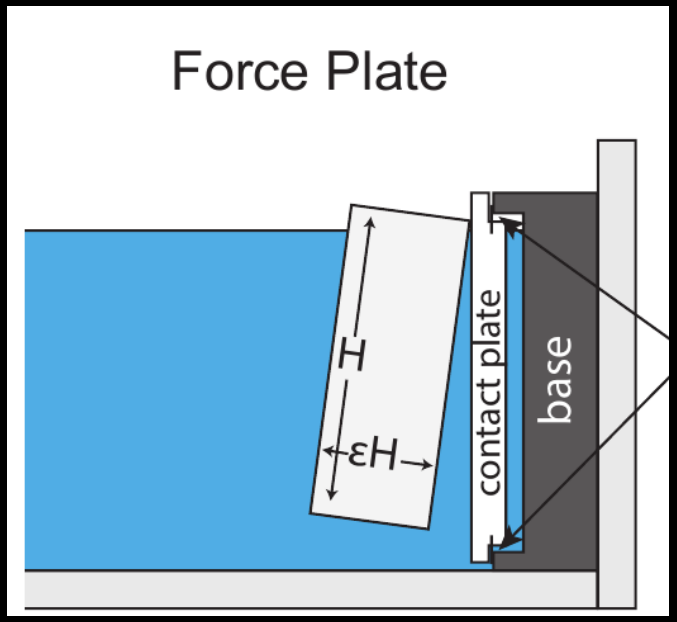
Simulation output :

contact force F_c

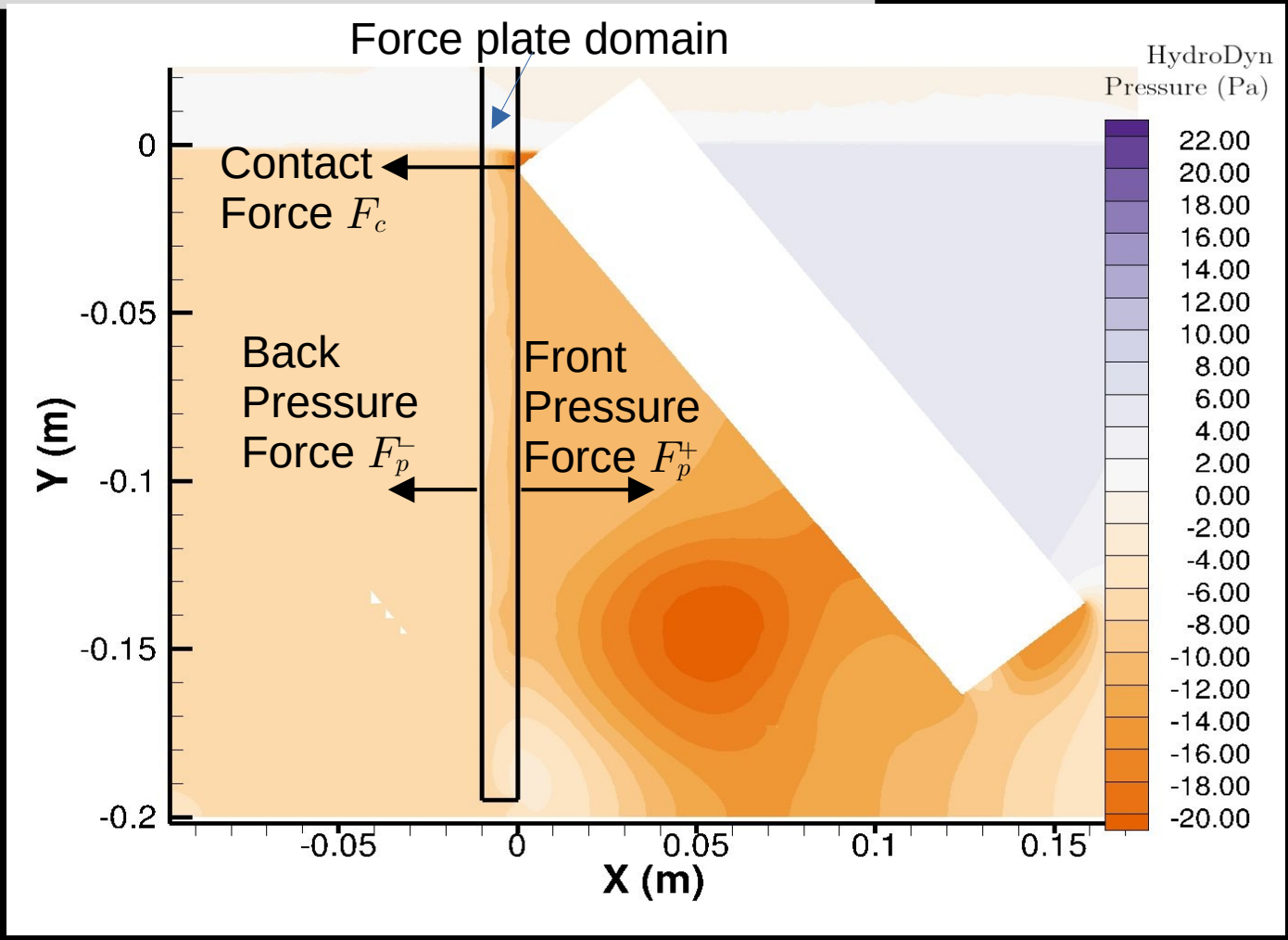
pressure at probes

pressure field on the glacier wall(s)

Force experiments and simulations

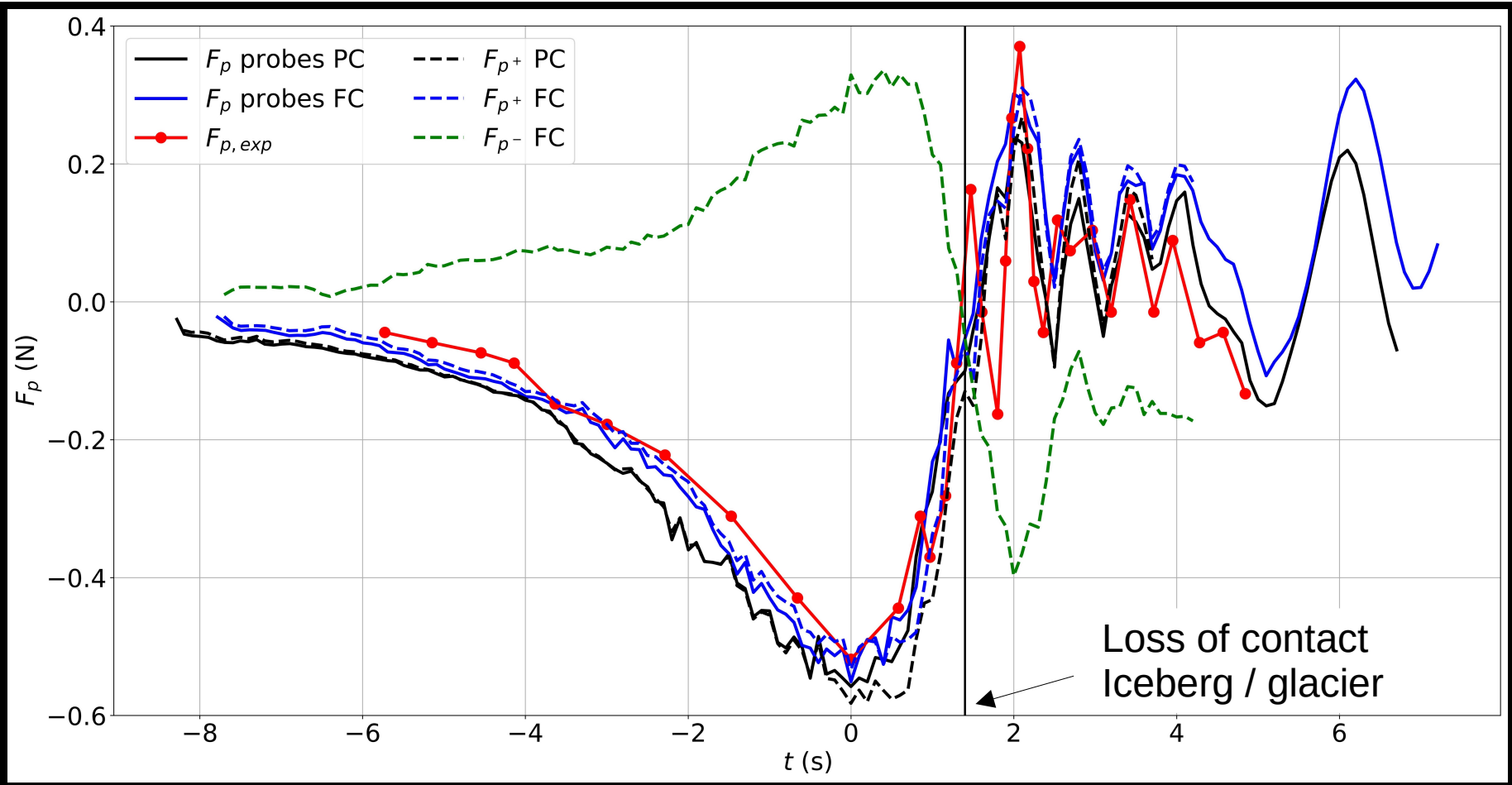


“Base” and plate deformation
Not implemented

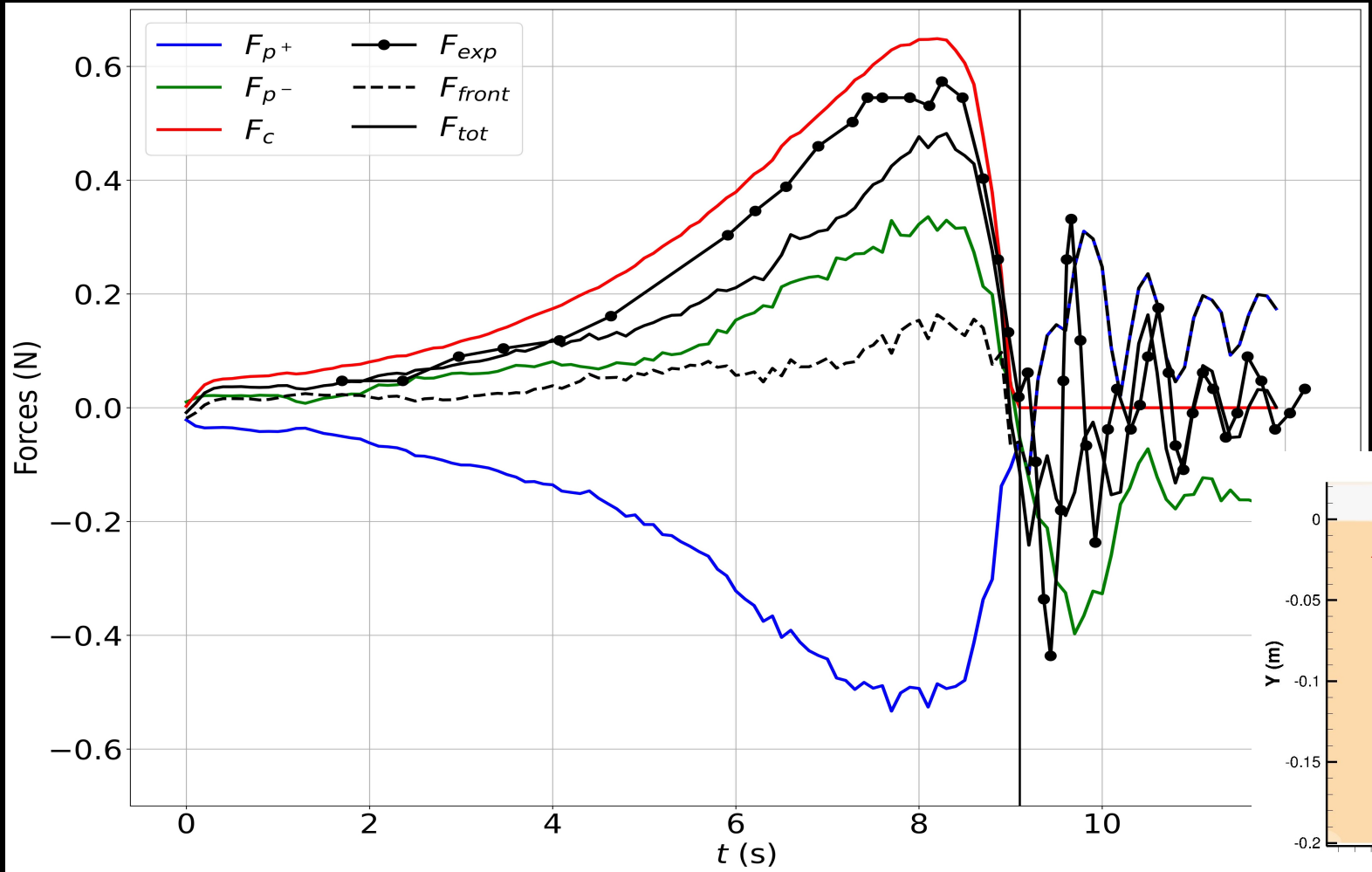


Pressure force comparisons, $\epsilon = 0.22$

Configuration: Force vs Pressure | **Computation:** Average of probe points vs Integration

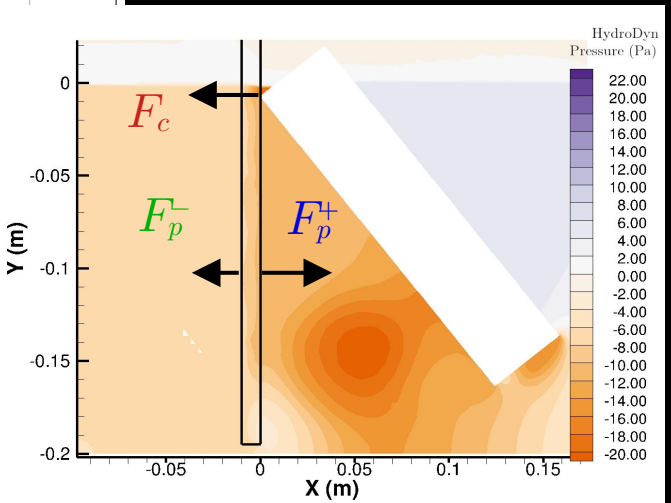


Total force comparisons, $\epsilon = 0.22$

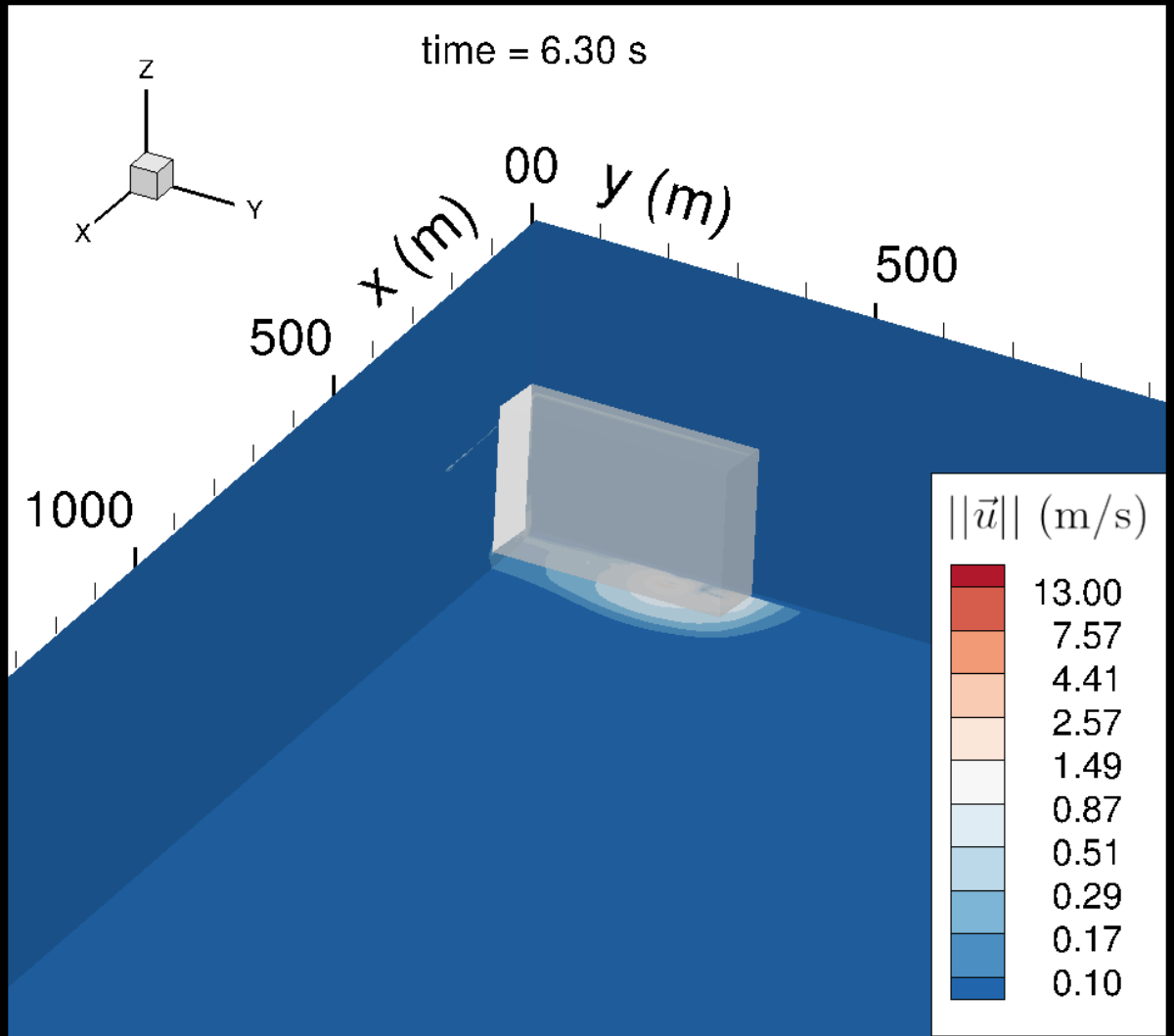


$$F_{front} = F_c + F_p^+$$
$$F_{tot} = F_c + F_p^+ + F_p^-$$

The misfit F_{tot} - F_{exp} might come from the plate deformation



Field-scale “animation”



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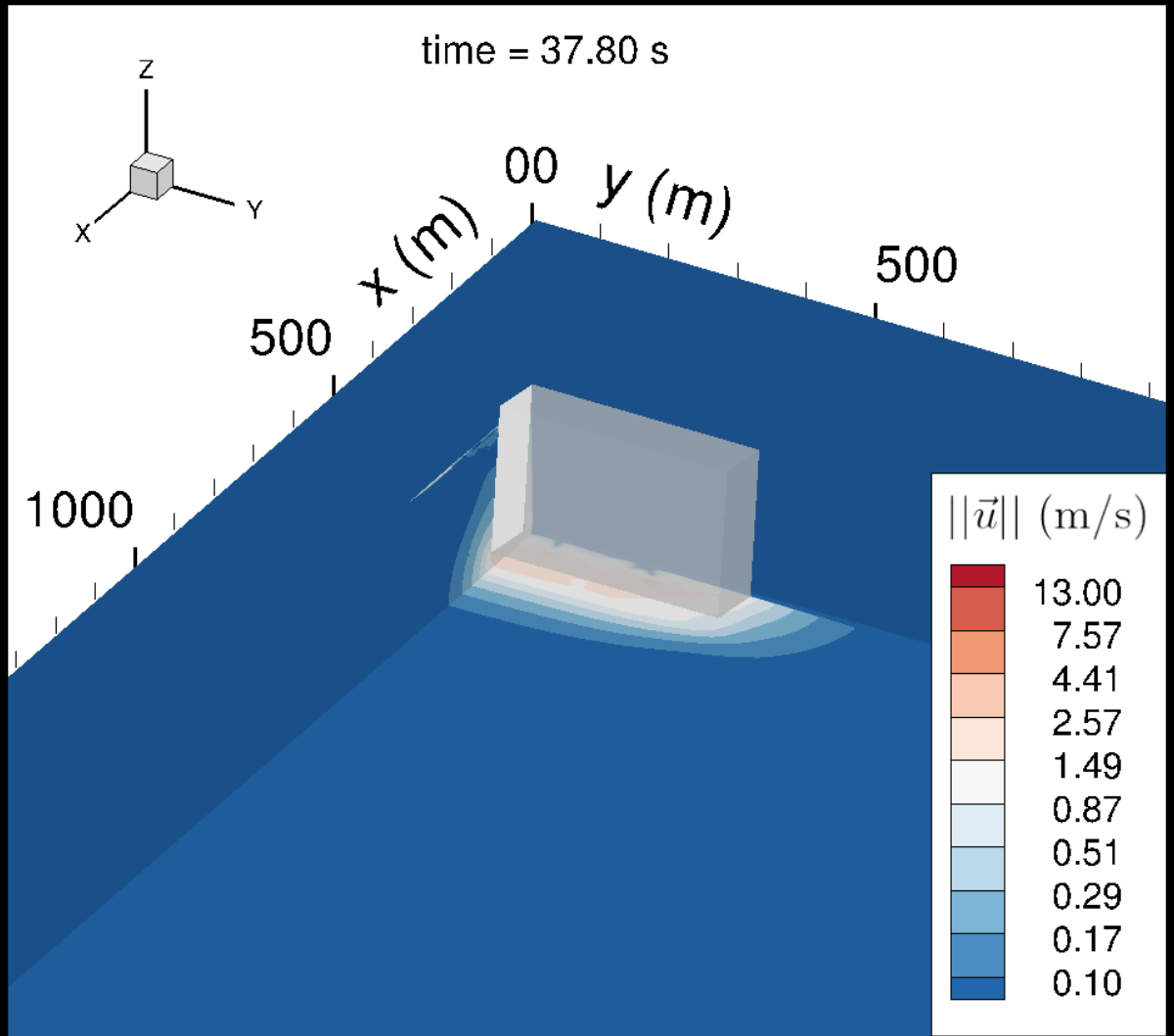

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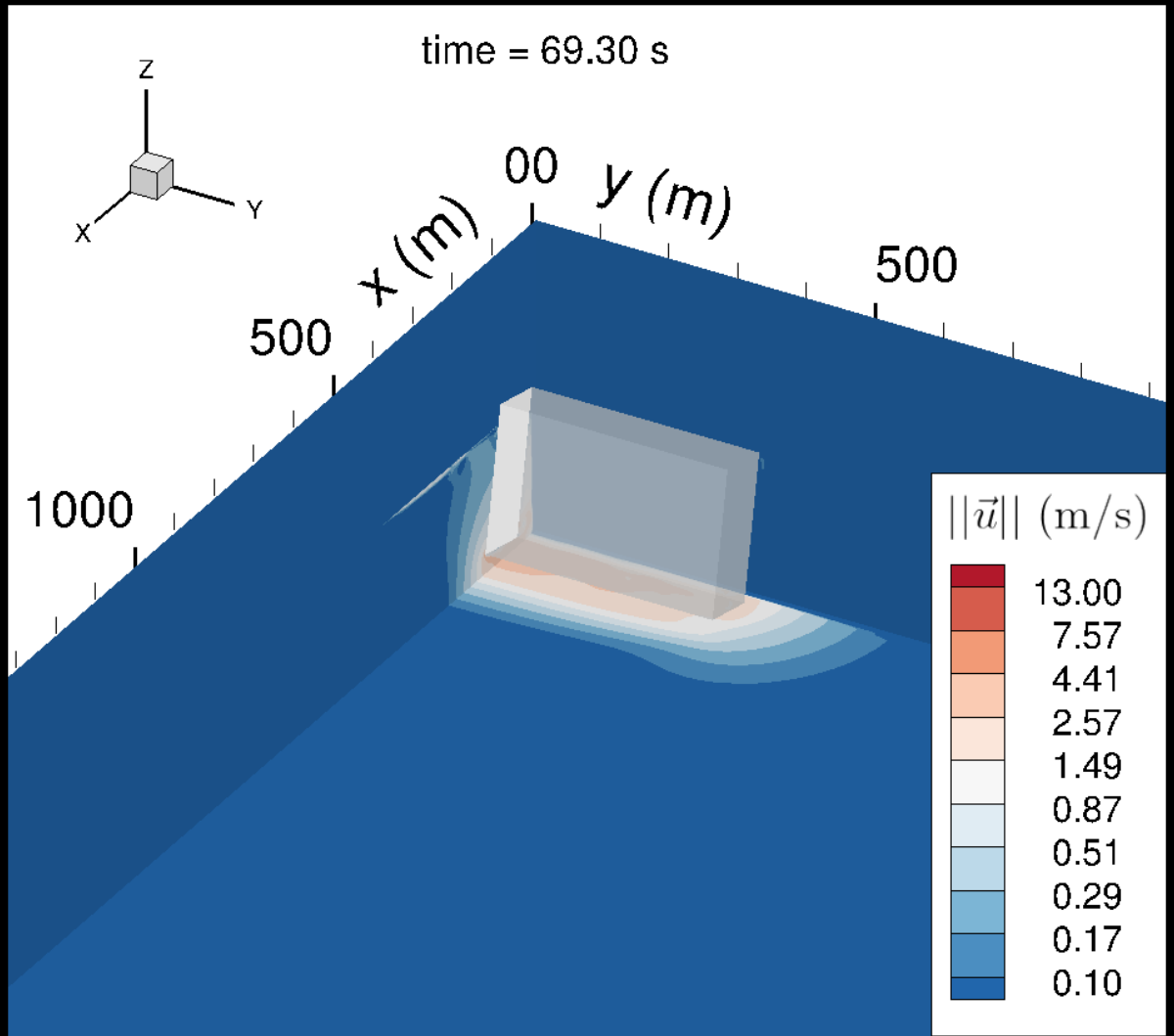

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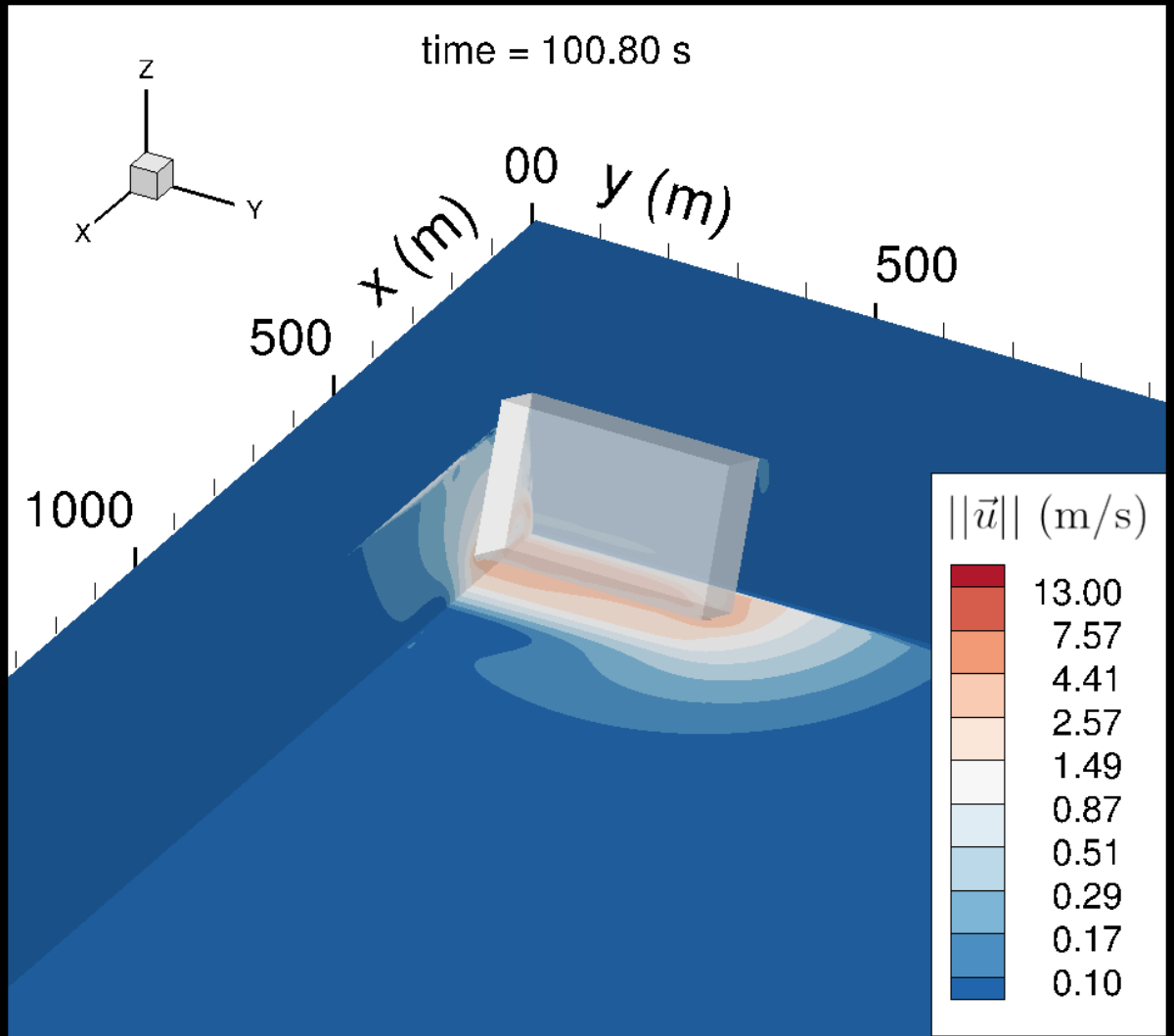

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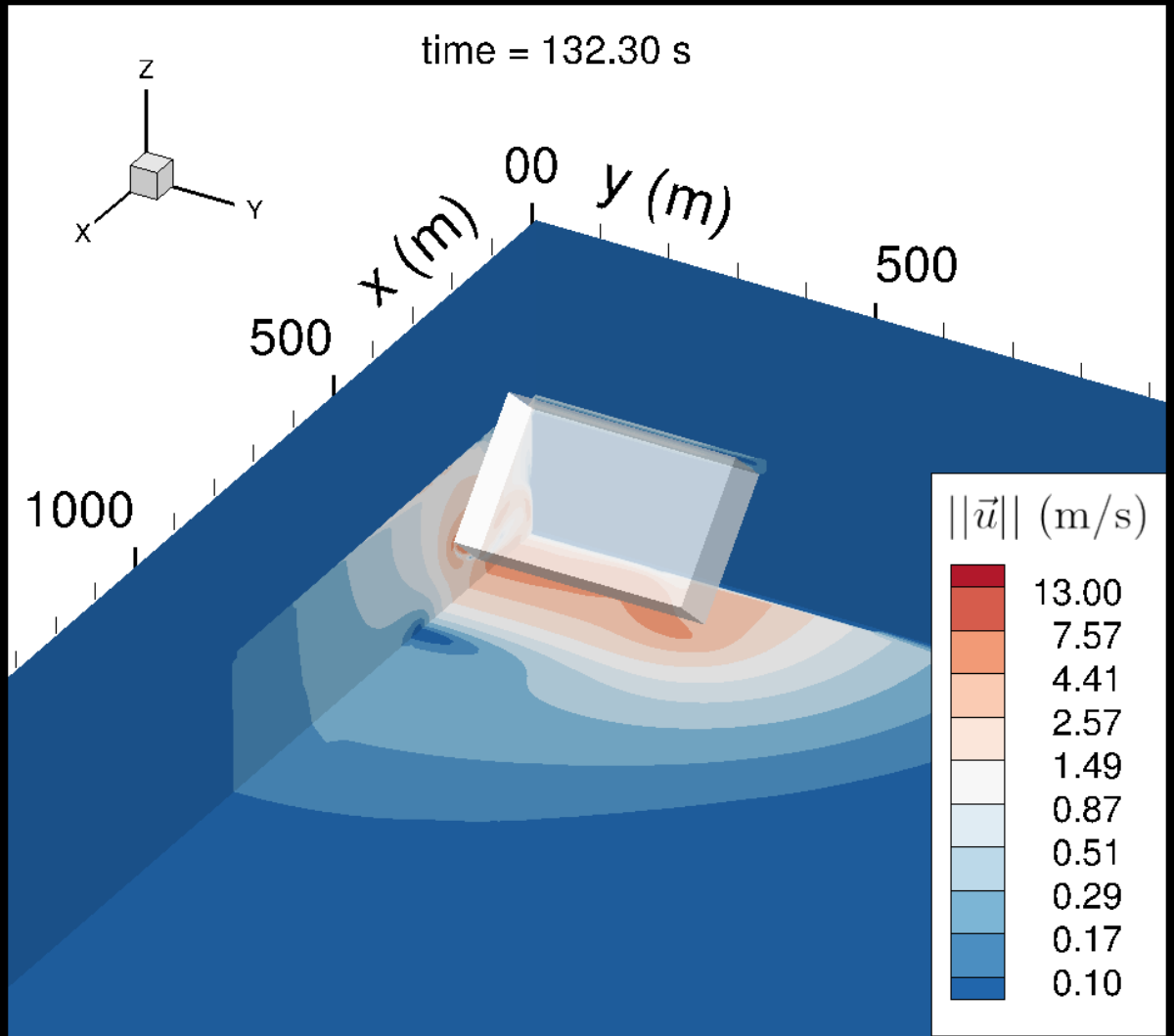

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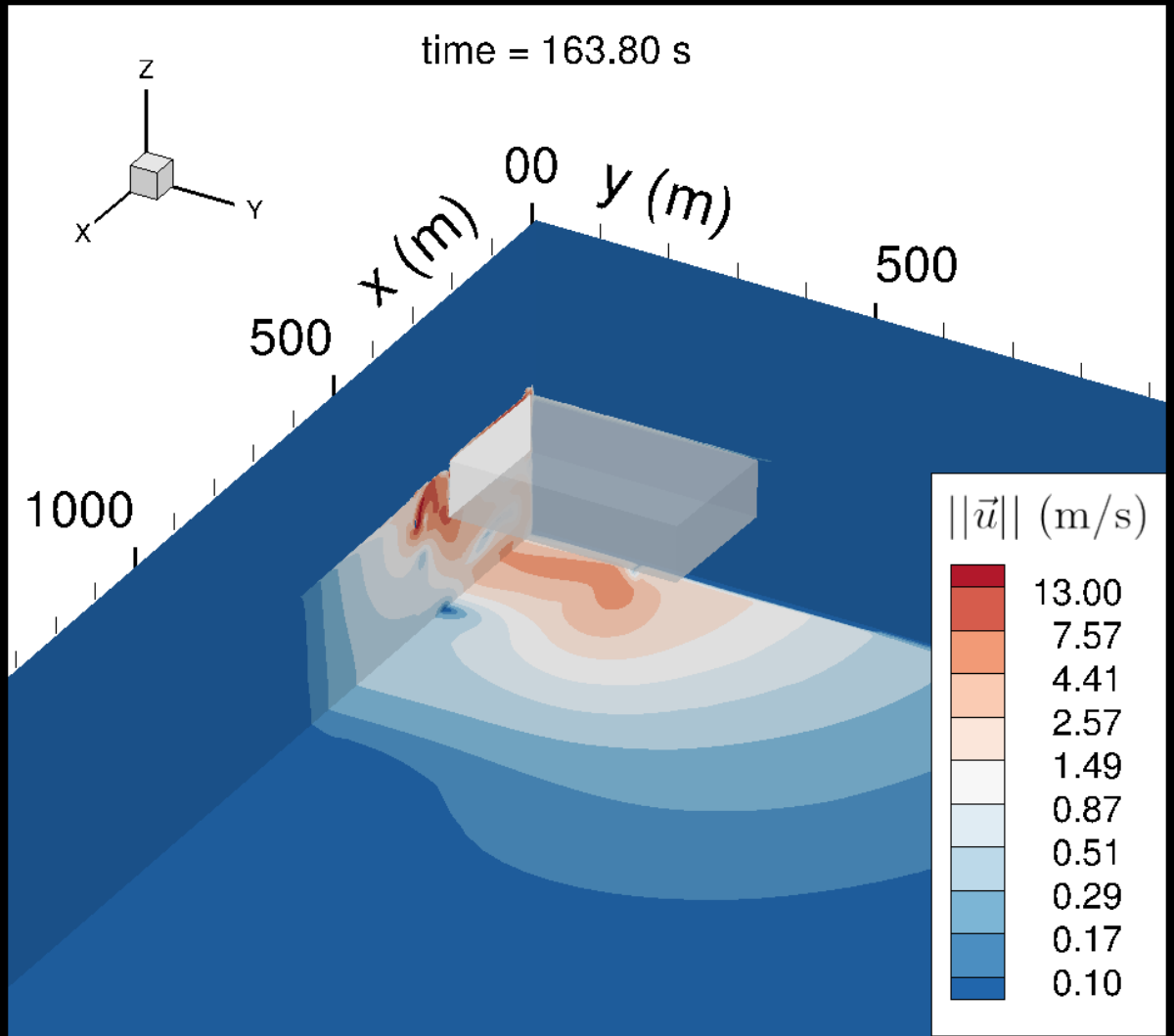

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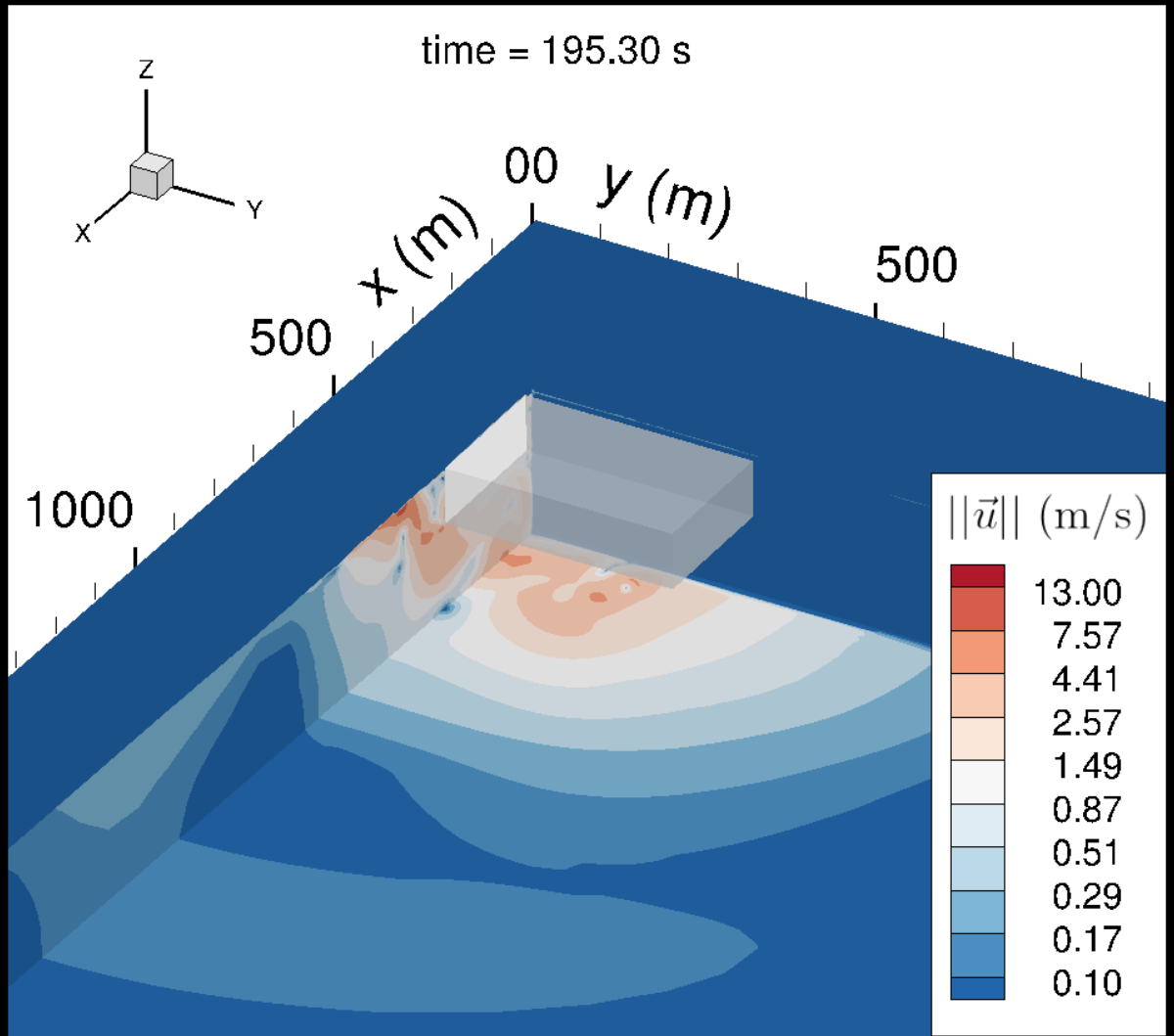
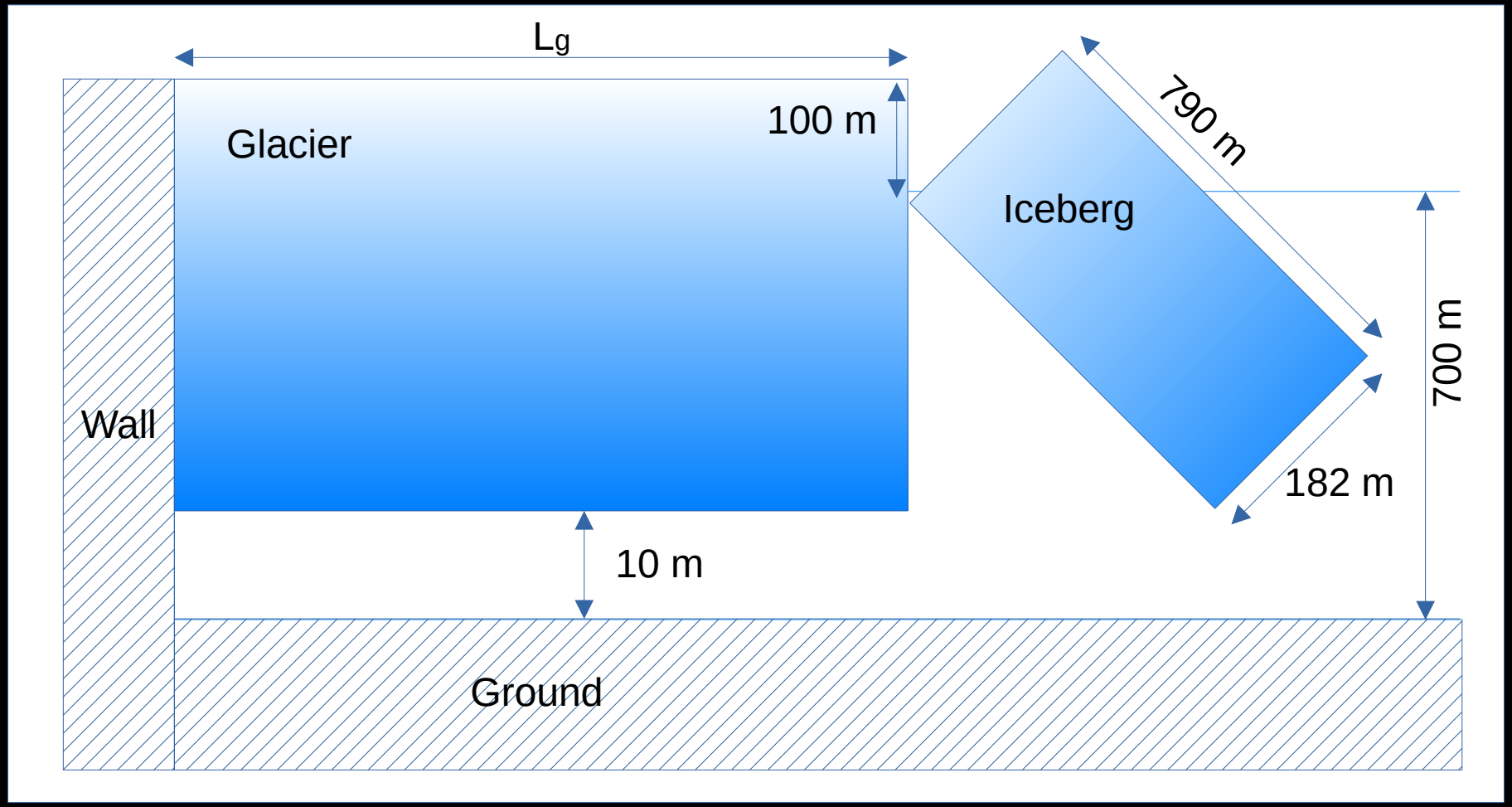


Coupling and Glacier response

Helheim calving simulations
cf *[Murray et al. 2015]*



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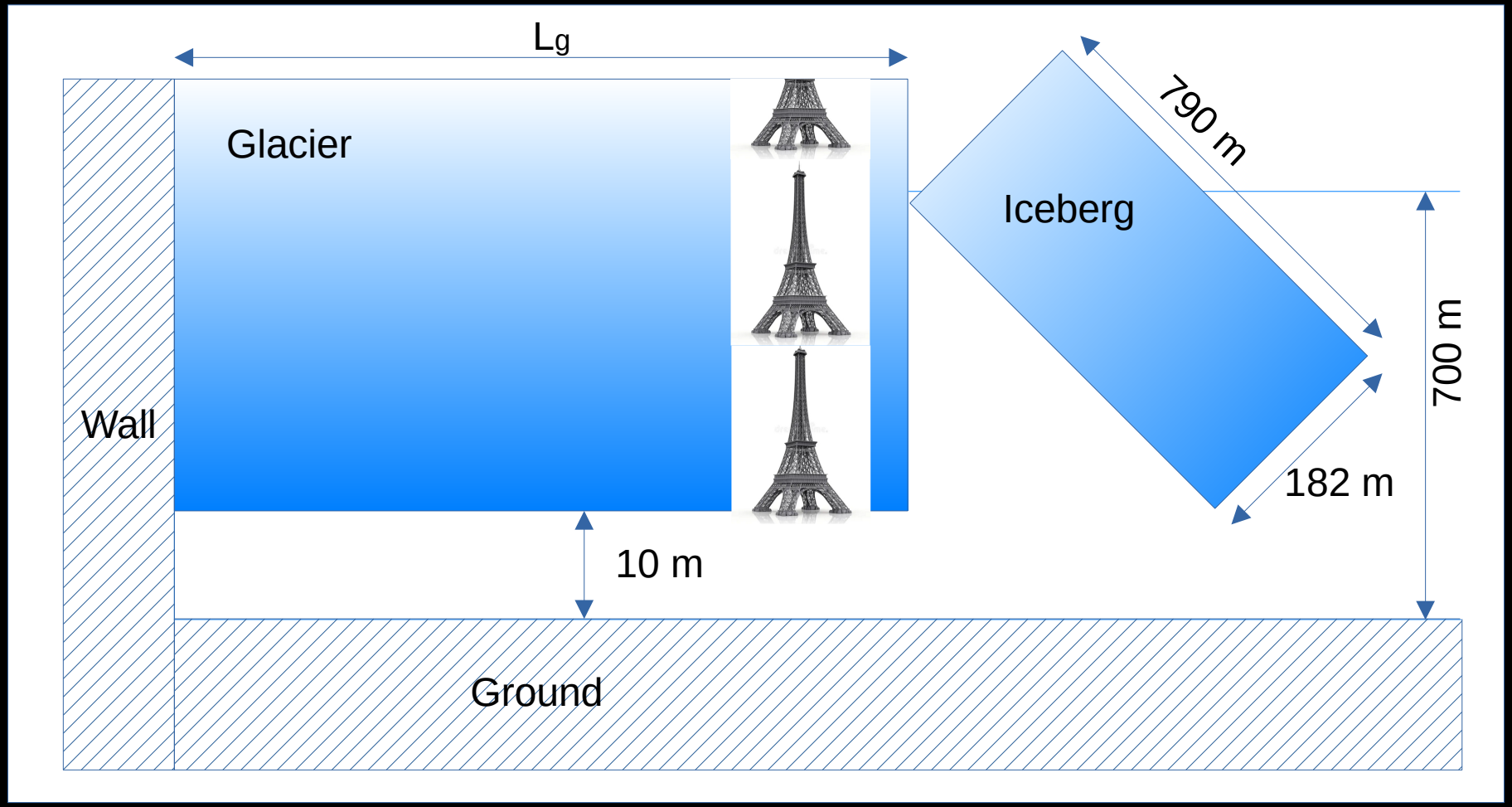

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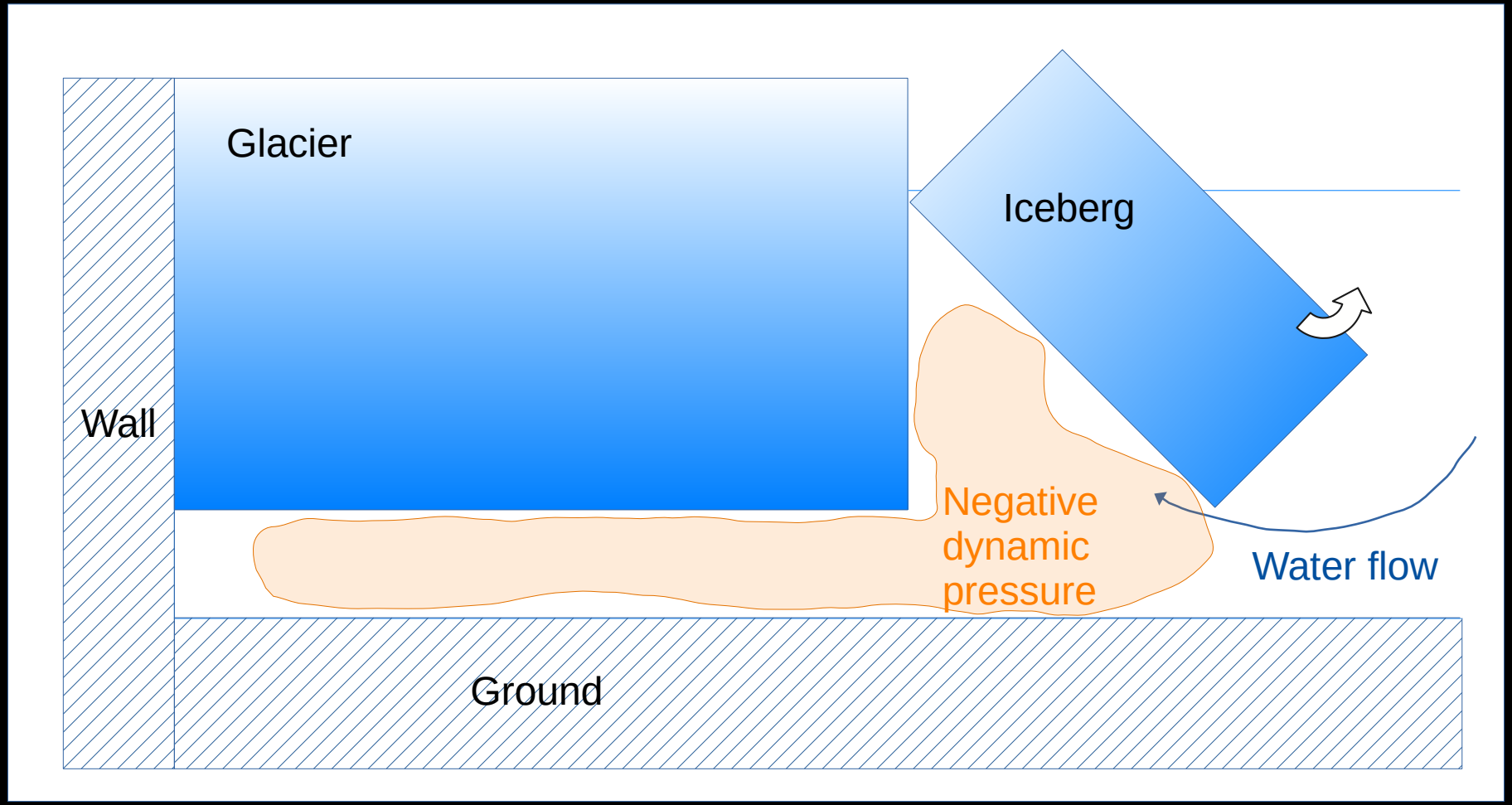

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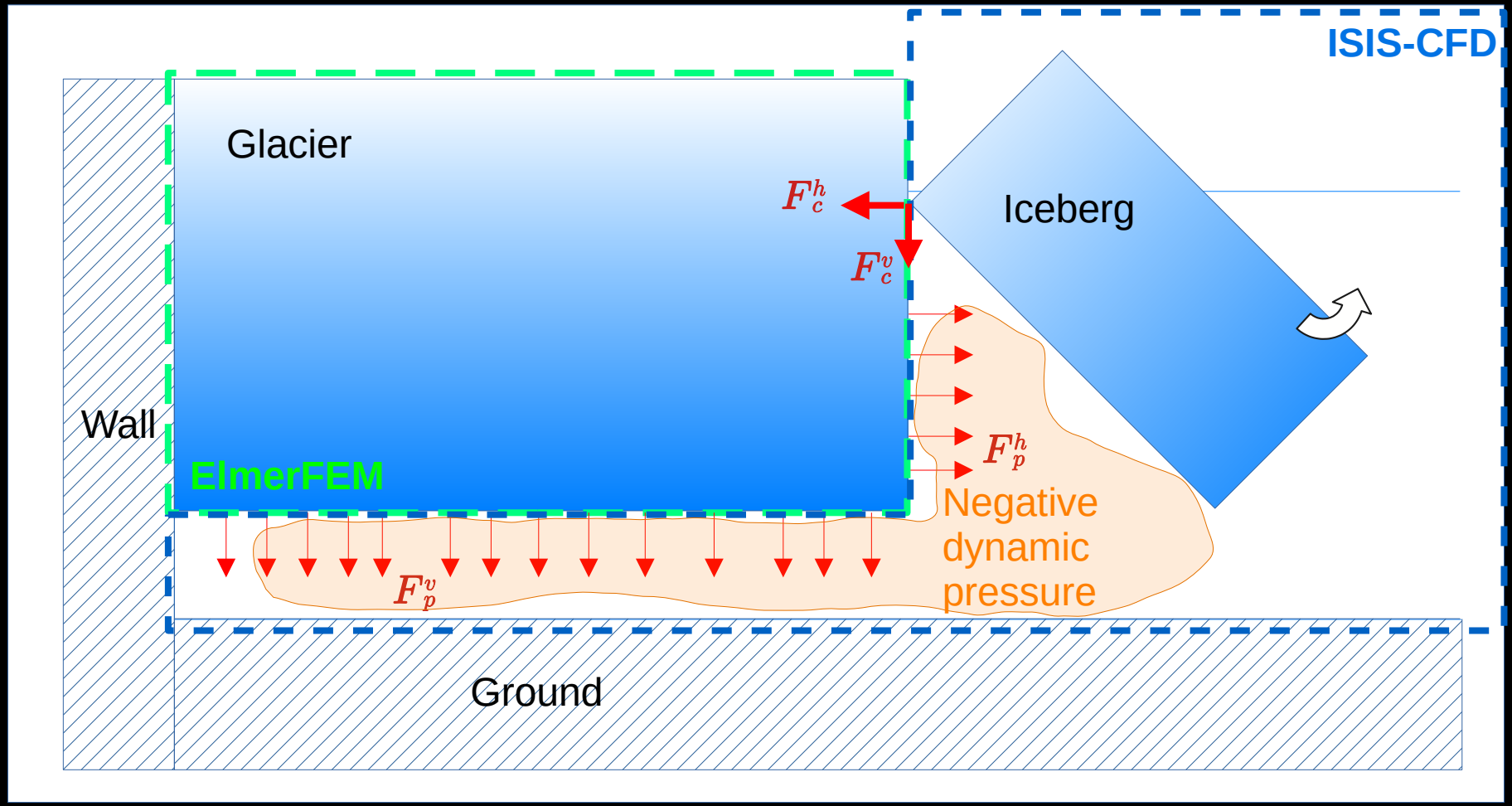
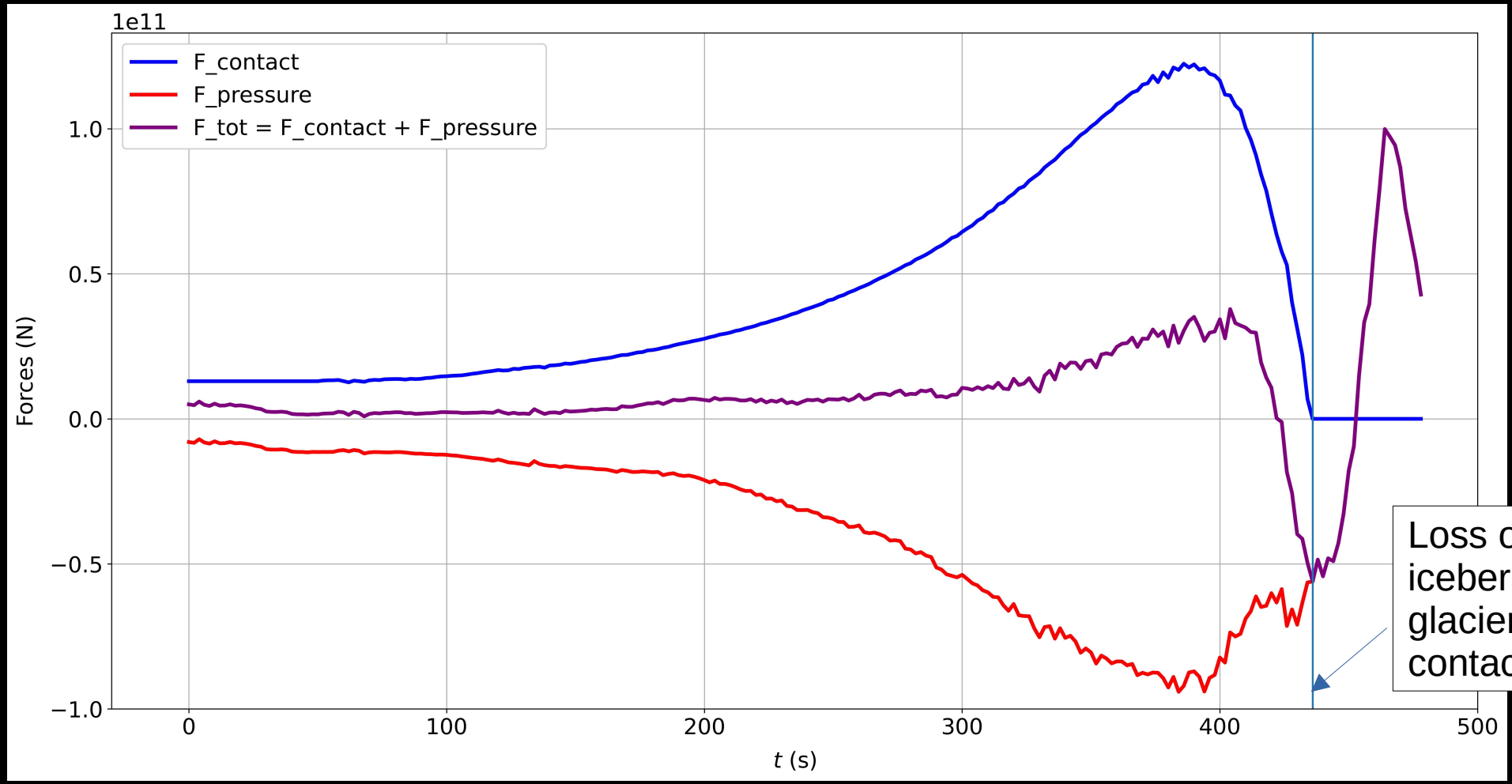
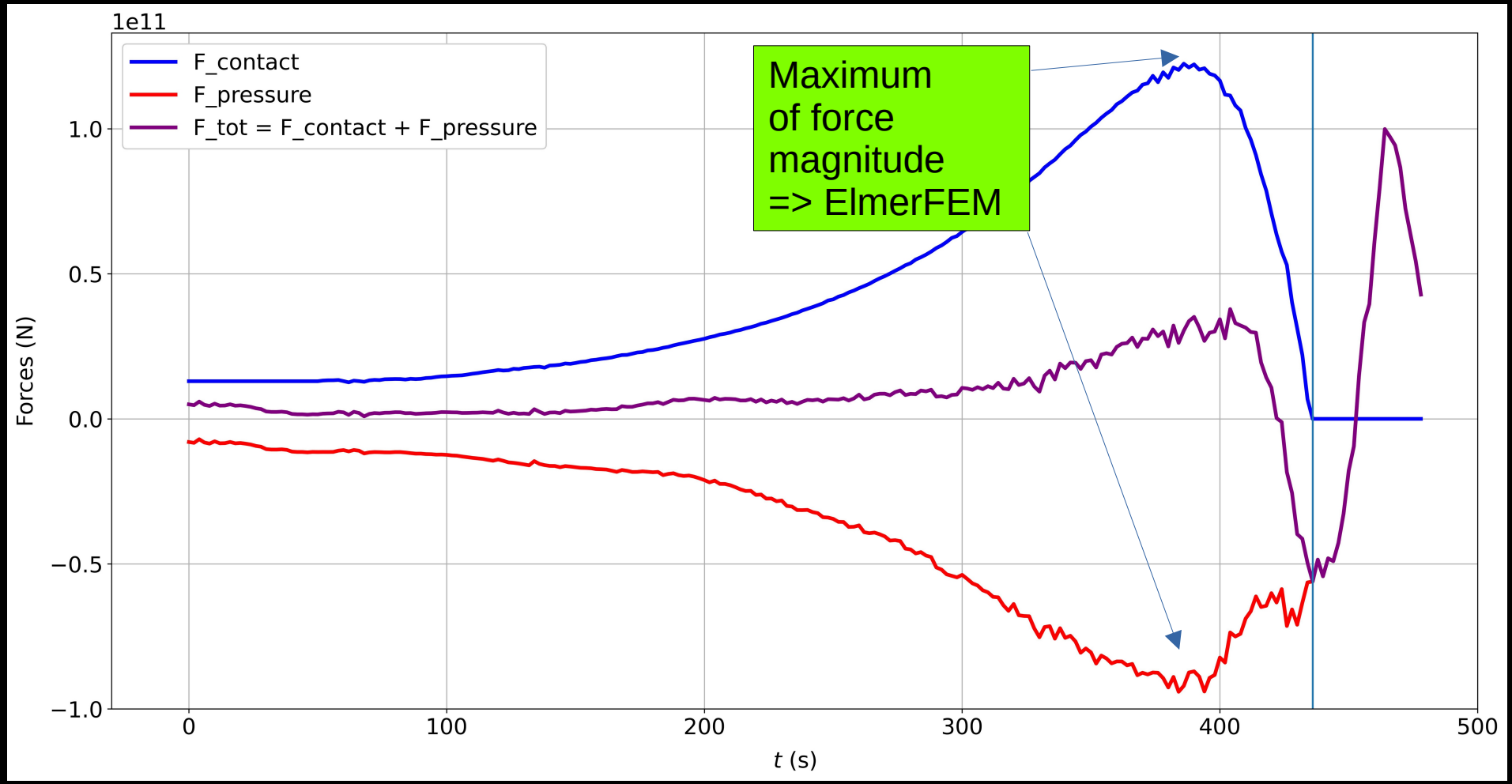


Horizontal Forces from the Fluid-structure simulation



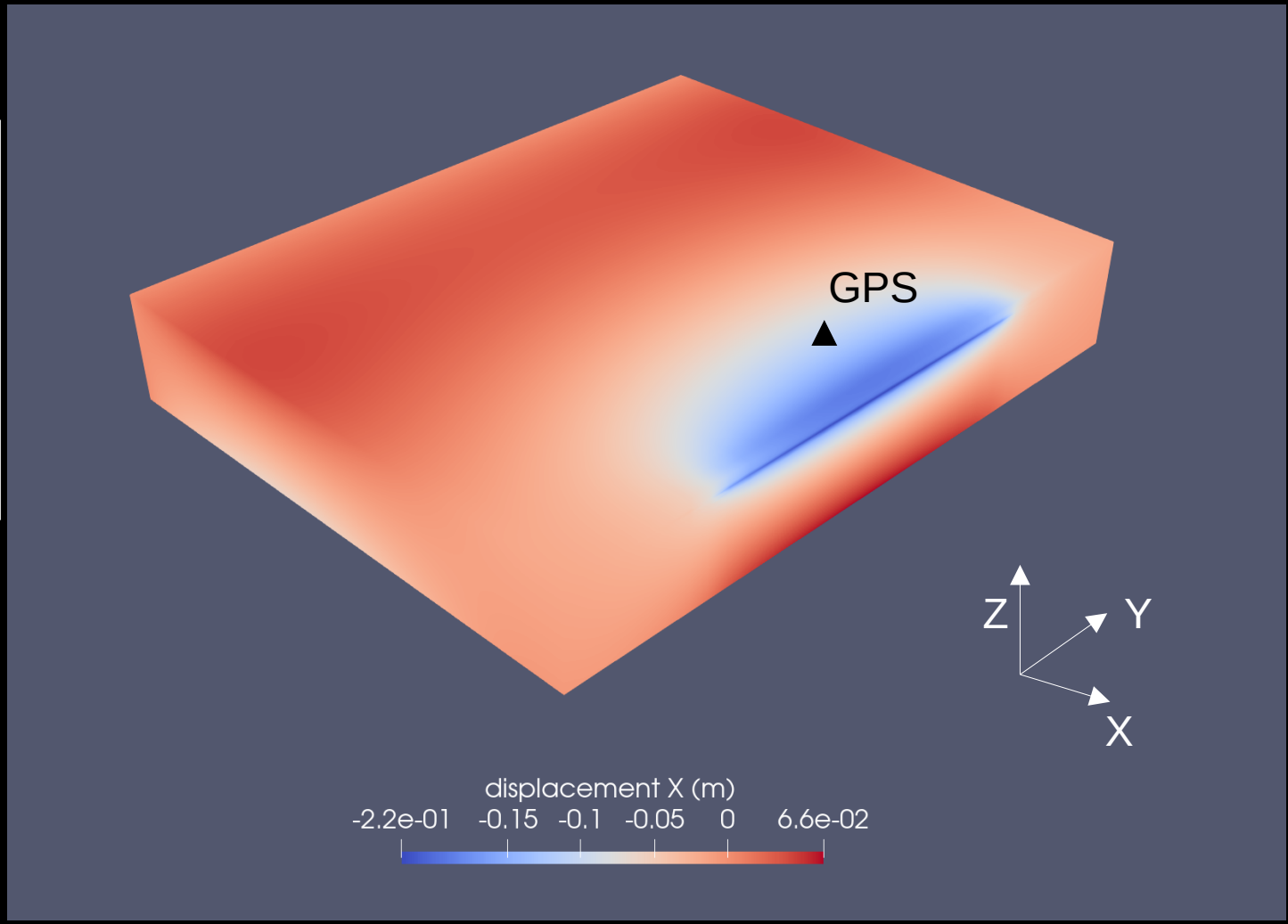
Forces from Fluid-structure simulation



Helheim maximum horizontal deformation

Featuring:

- ElmerFEM
- Static linear elastic case at maximum force magnitude
- Clamped at the back
- Free elsewhere
- L_g = 4 km



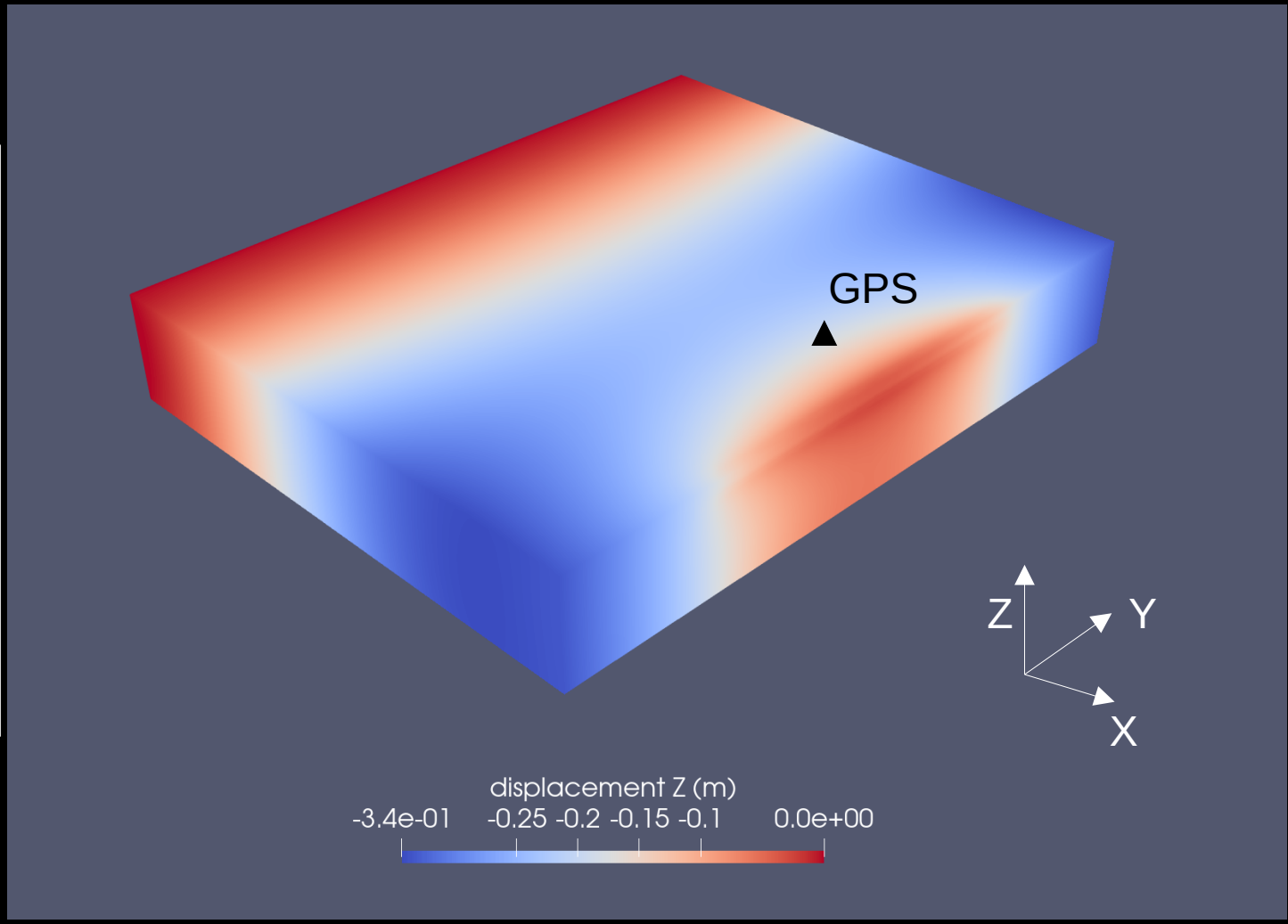
Helheim maximum vertical deformation

Compared to Murray et al. 2015:

- Good order of magnitude at GPS location (0.15 m)

But <u>many uncertainties</u>:

- Boundary conditions
- Friction coefficient
- Glacier length
- Vertical pressure force



Conclusion

Summary:

- CFD model robust enough to retrieve experimental data in details
- Hydrodynamic pressure forces are not negligible
- First Helheim response modeling gives promising results

Next steps:

- Quantify the response of the whole glacier (ElmerIce)
- Create a simulation database of forces
- Invert recorded seismic signal to infer calved-iceberg mass loss

The End

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Feel free to contact me at:

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Numerical model for capsize

Fine/Marine,
ISIS-CFD solver developed at LHEEA lab & distributed by Cadense Design
for Naval applications + Fluid-Structure interactions

Reynolds Average Navier-Stokes Equations

+ Incompressible, k-ω SST

+ Unstructured finite-volume method

+ Interface capturing method *[Queutey & Visonneau, 2007]*

+ Arbitrary Lagrangian Eulerian formulation *[Leroyer et al., 2008]*

+ Automatic Grid Refinement *[Wackers et al, 2012]*

+ Overlapping grids