R-channel laboratory experiment

Data evaluation and numerical simulations

Stefanie Börsig[1,2], Mauro A. Werder[1,2], Alexander Jarosch[3], Yuri Prohaska[1,2], Daniel Farinotti[1,2]

[1]Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich; [2]Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf; [3]ThetaFrame Solutions, Kufstein, Austria

Want to know more?

Send an email to sboersig@ethz.ch

Sharing is encouraged

Motivation

- The glacial drainage system influences the flow of ice, gives insight into glacier outburst floods, is linked to ice dynamics by affecting the basal sliding and thus having an impact on the rise of sea level (e. g. Clarke, 2003; Werder et al., 2013).
- Glaciological theories, such as waterflow in R-channels, often adopt empirical relations from other research fields or use arguments on a theoretical basis (Clarke, 2003; Werder et al., 2013; Spring and Hutter, 1982).
- **Direct observations and experimental measurements of the drainage system are rare, but necessary to validate and tune physical models (Pohle et al., 2022).**

Method Overview

Laboratory experiment

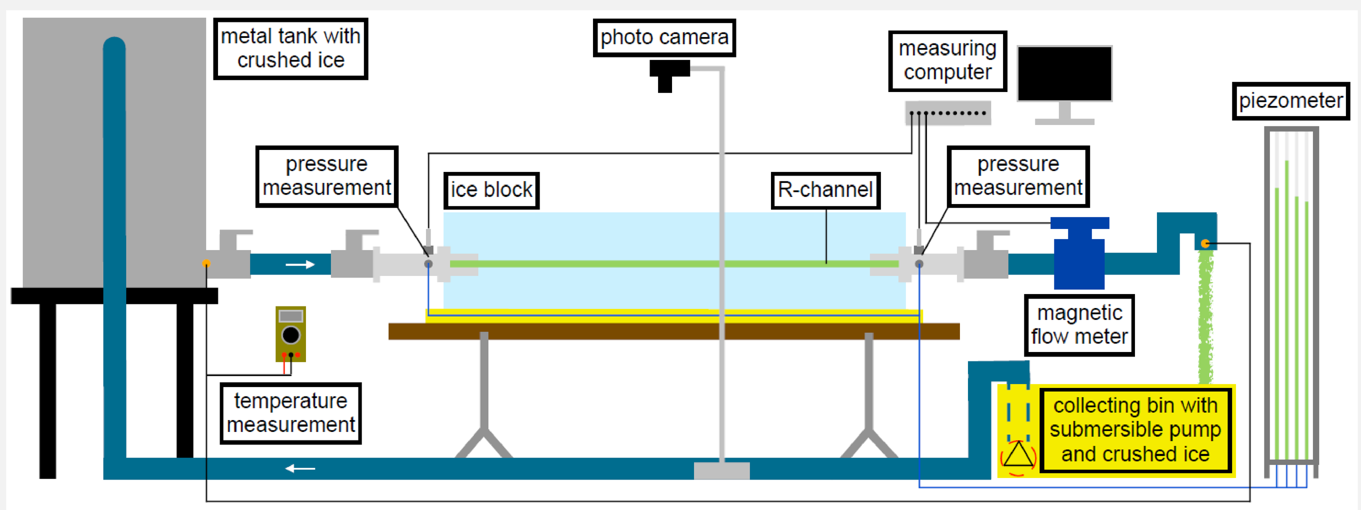


Fig. 1: Sketch of the set up of the laboratory experiment

- 4 experiments with self-produced, transparent ice blocks
- initially small and flat channel widens and develops scallops

Numerical simulations

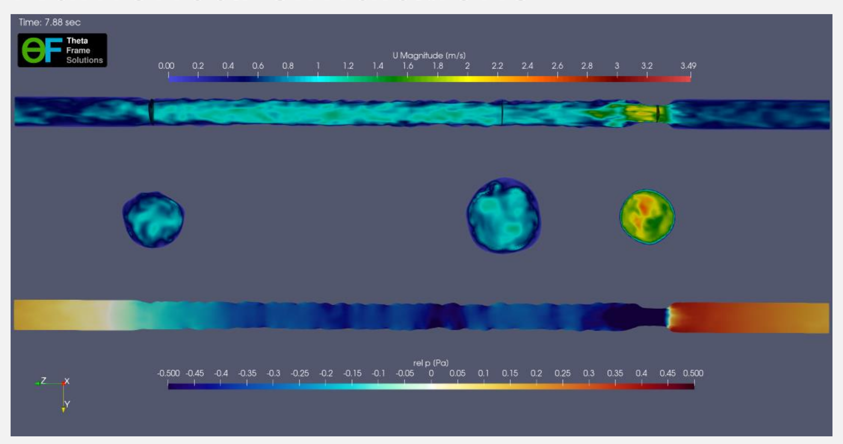


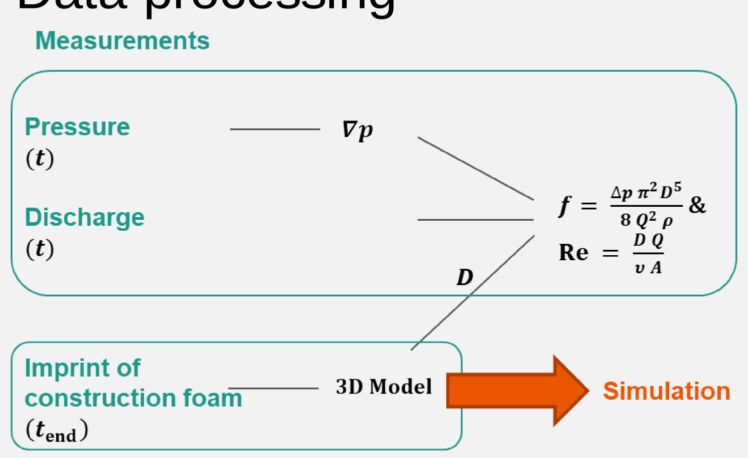
Fig. 2: Snapshot of the simulation animation.

- Large eddy simulation conducted with the software OpenFOAM

Snapshot of the animation:

- flow oriented from right to left
- velocity in the channel (top)
- kinematic pressure in the channel (bottom)
- velocity at exemplary cross sections (middle circles, positions marked above)

Data processing

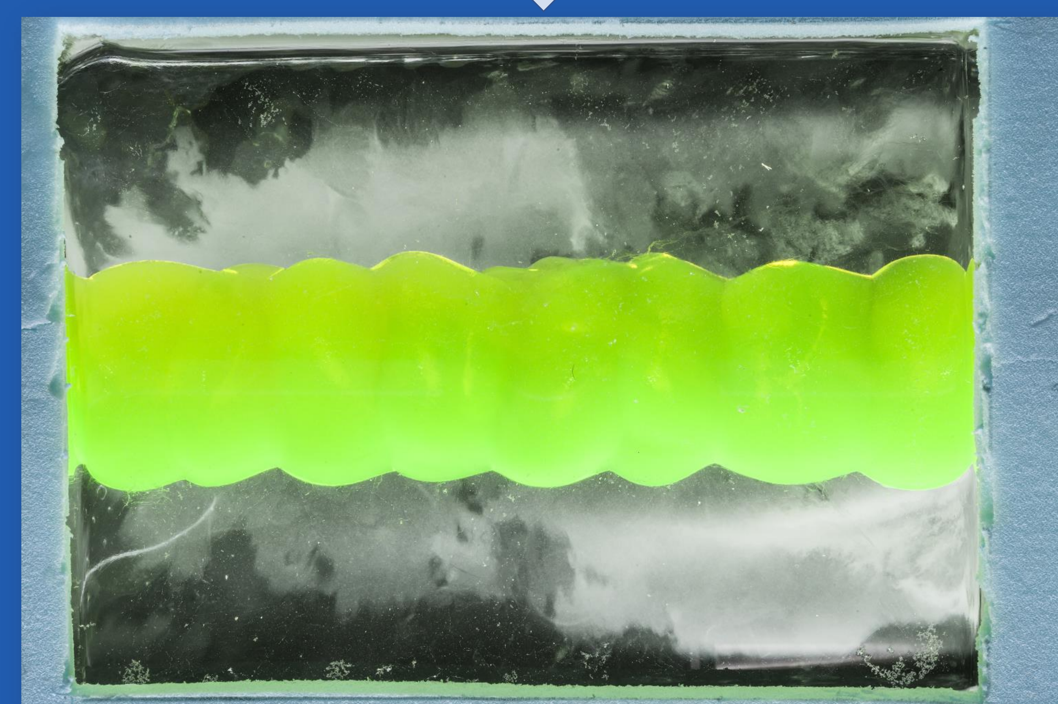


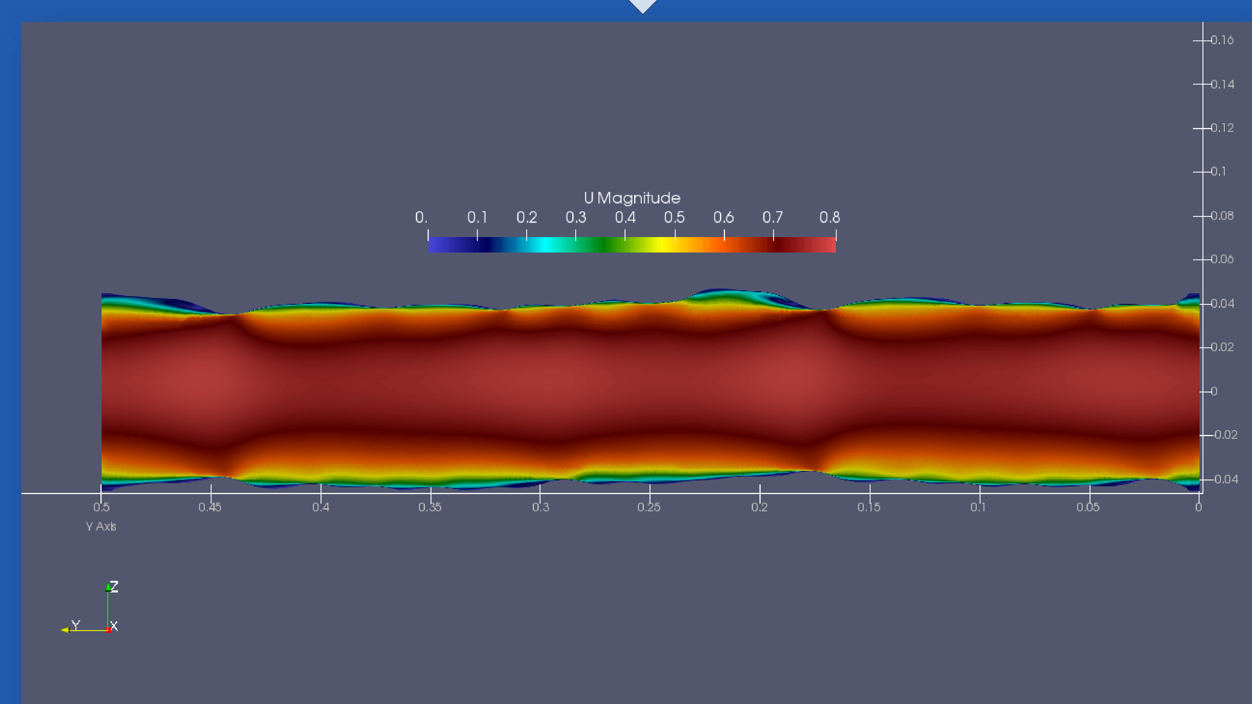
Data flow:

- quantities obtained from measurements (left column)
- calculated and related quantities (middle section)
- quantities the analysis aims at (right hand side)

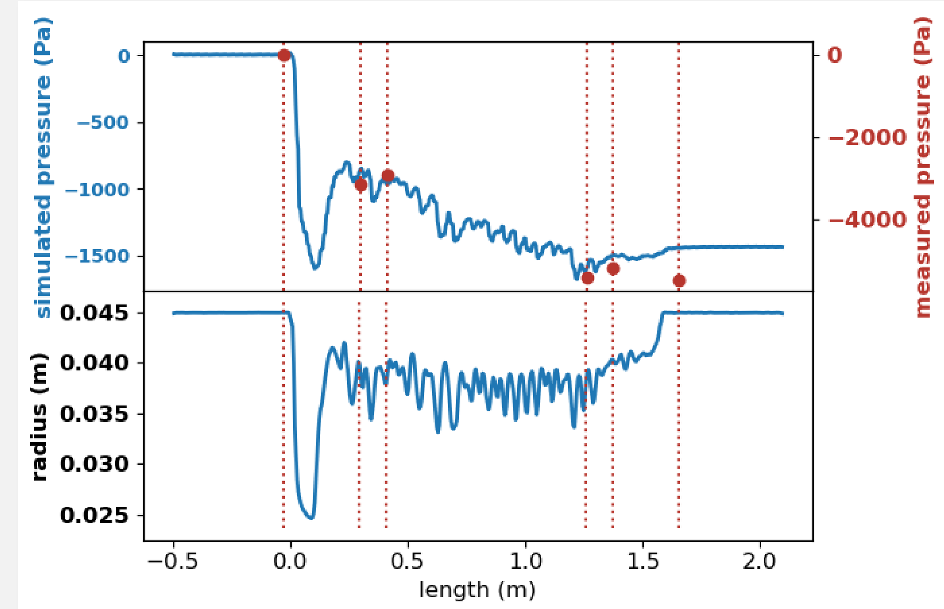
Fig. 3: Visualization of the data flow. Upper green frame emphasizes the analysis of the laboratory experiment while the lower one is framing the process leading to the numerical simulation.

Englacial R-channels are represented by a laboratory experiment and complementary numerical simulations.
The derived flow properties agree with recent publications.





Results and Discussion



Pressure

- overall pressure loss along the channel
- simulated pressure (blue line in upper panel) different scale than measured pressure (red dots)
- in middle of ice channel ("test track"): pressure reduces with roughly linear trend, fluctuations connected to radius (lower panel)

exp.	pressure gradient ∇p_{simu}	∇p_{lab}	friction coefficient f_{simu}	f_{lab}	Reynolds number Re
1	−239	−422	0.143	0.253	$32 \cdot 10^3$
2	−1020	−2950	0.134	0.386	$40 \cdot 10^3$
3	−744	−2940	0.137	0.541	$38 \cdot 10^3$
4	−55	−111	0.031	0.062	$34 \cdot 10^3$

Results of test tracks of all experiments

- laboratory pressure gradient significantly higher than simulation pressure gradient
- trend of pressure gradients continues on friction coefficients
- all Reynolds numbers very high and confirm turbulent flow properties

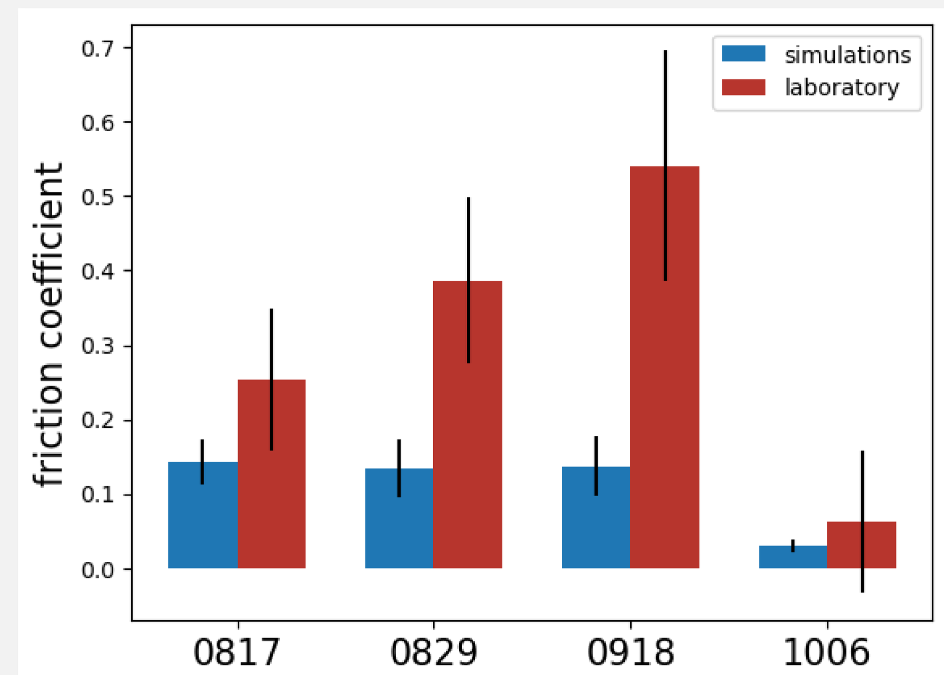


Fig. 4, 5 and Tab. 1: top) simulated and measured pressure; radius of the channel; middle table) overview of the test track properties of all experiments; bottom) overview of friction coefficients of all experiments.

Conclusion

- most important section of the channel is in the middle part of the ice channel, "test track" with clearest R-channel behavior
- simulation and measurements only partially agree on pressure gradients and the resulting hydraulic friction factor. However, the individual results are within the published range of variability.

The derived friction coefficients suggest that the laboratory experiment is a representation of the flow properties of an actual R-channel in glaciers. The experimental set up appears to be a functional analogy of R-channels.

References

Clarke, G. K. C. (2003). Hydraulics of subglacial outburst floods: New insights from the Spring-Hutter formulation. Journal of Glaciology, 49 (165), 299-313. https://doi.org/10.3189/172756503781830728

Fowler, A., Ng, F. (2021). Sliding, Drainage and Subglacial Geomorphology. In: Fowler, A., Ng, F. (eds) Glaciers and Ice Sheets in the Climate System. Springer Textbooks in Earth Sciences, Geography and Environment. Springer, Cham. https://doi.org/10.1007/978-3-030-42584-5_3

Pohle, A., Werder, M. A., Gräff, D. & Farinotti, D. (2022). Characterising englacial R-channels using artificial moulins. https://doi.org/10.1017/jog.2022.4

Spring, U. & Hutter, K. (1982). Conduit flow of a fluid through its solid phase and its application to intraglacial channel flow. International Journal of Engineering Sciences, 20 (2), 327-363. https://doi.org/10.1016/0020-7225(82)90029-5

Werder, M. A., Hewitt, I. J., Schoof, C. & Flowers, G. E. (2013). Modeling channelized and distributed subglacial drainage in two dimensions. Journal of Geophysical Research. https://doi.org/10.1002/jgrf.20146