Particle-resolved simulation of antidunes in free-surface flows

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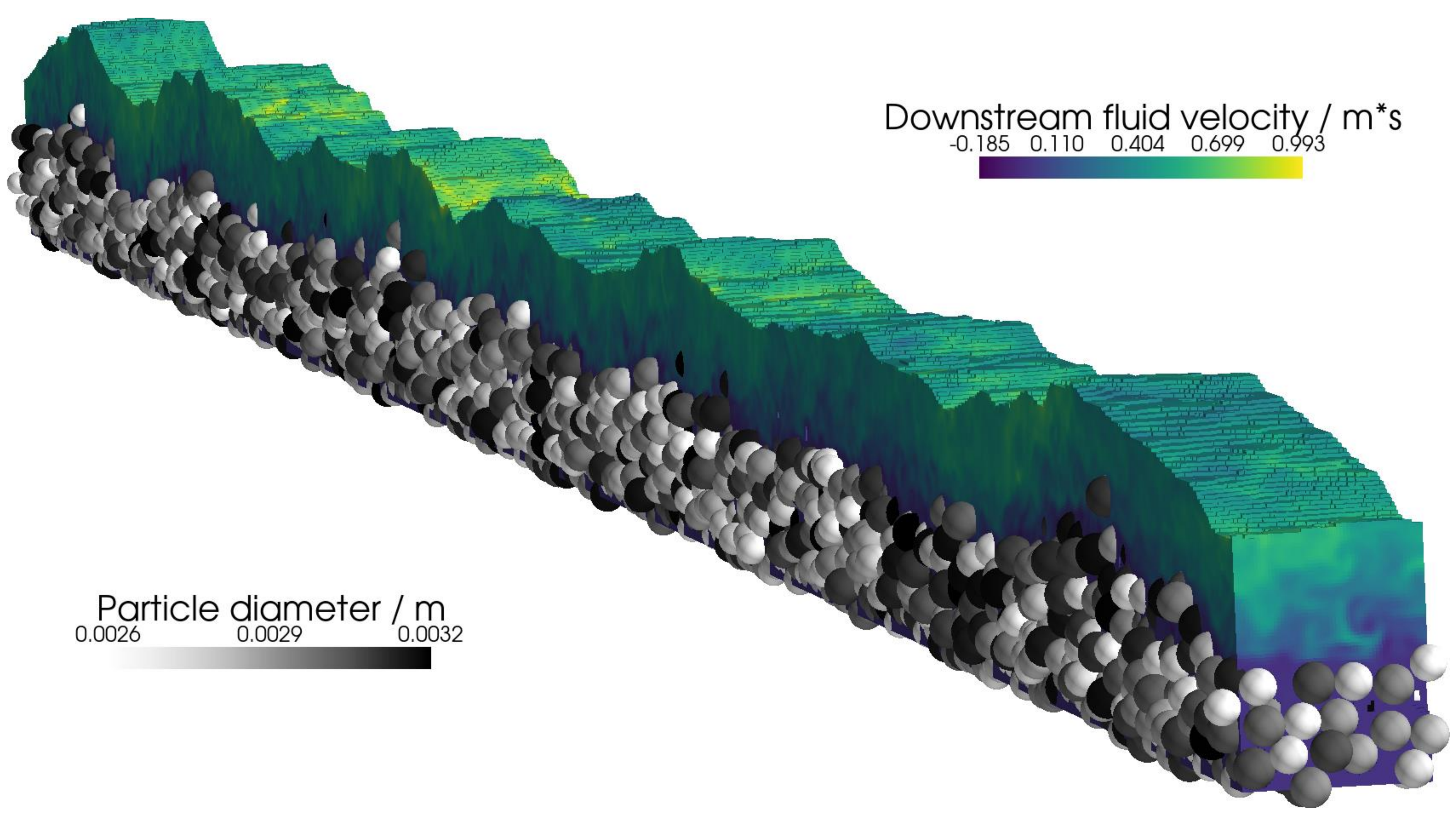
Simulation scenario: Supercritical turbulent flow over an erodible granular bed

Setup

- Qualitative reproduction of two experiments by Pascal et al.[4]
- Polydisperse bed: 6.528 spherical particles
- Supercritical flow over sediment bed
- Density ratio $\rho_p/\rho_f = 2.55$
- Domain size $3200 \times 60 \times 160$ cells
- 10 cells per particle diameter
- Starting from a flat sediment bed
- PID controller regulates force in flow direction to maintain constant fluid flow rate
- Simulated for 192h on 768 processes on SuperMUC-NG, LRZ



Direct Numerical Simulation

- Lattice Boltzmann method for fluid flow above and through sediment bed
- Discrete element method to account for particle collisions[2]
- Fluid-particle coupling via momentum-exchange method
- Deformable free surface using a volume of fluid scheme[3]
- Integrated in open-source simulation framework WALBERLA[1] (www.walberla.net)

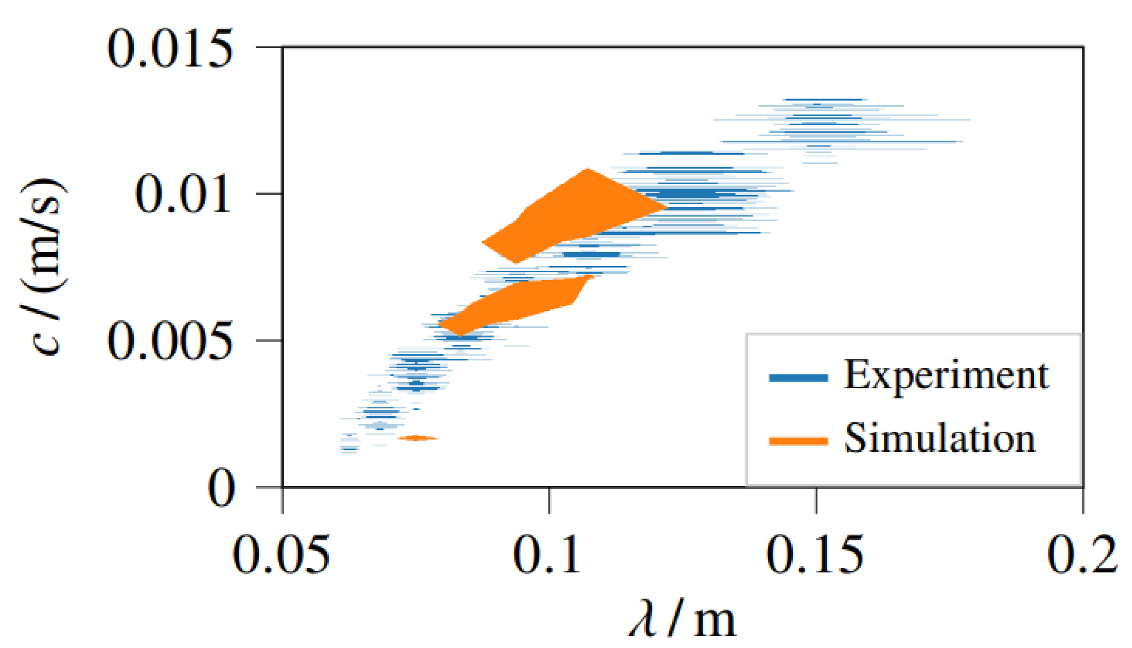
Scenarios

- Two experiments by Pascal et al. (E1 and E4)
- $\rho_p = 2550 \frac{kg}{m^3}$
- Median particle diameter d_p: 2.9 mm
- Different Reynolds number Re, Froude number Fr, Weber number We and liquid height h

	E1	E4
Re	3100	4800
Fr	1.31	1.45
We	15.62	30.25
h/d_p	2.97	3.59

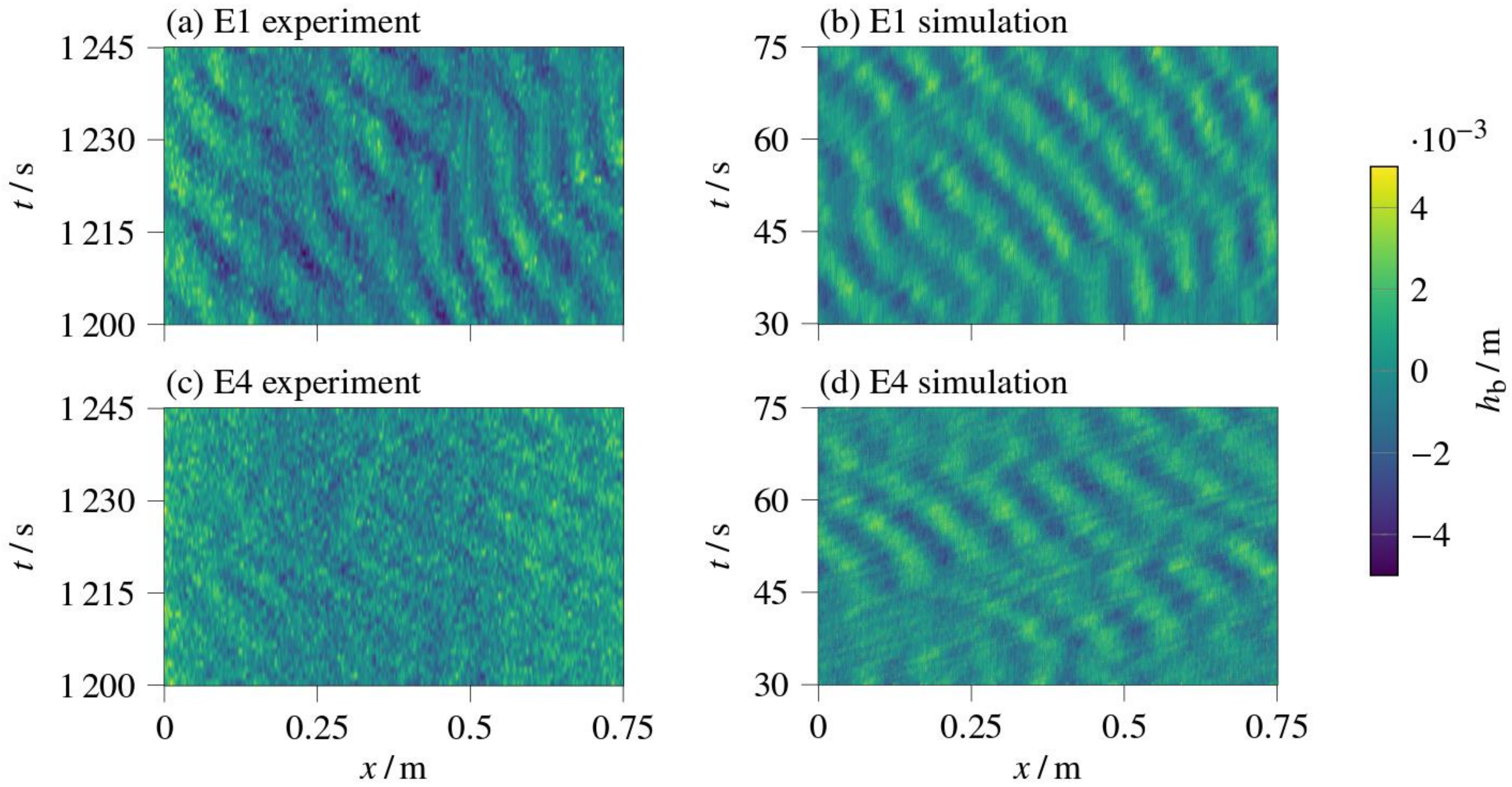
Validation of the celerity

Power spectral density contour of celerity c and wavelength λ for experiment E1

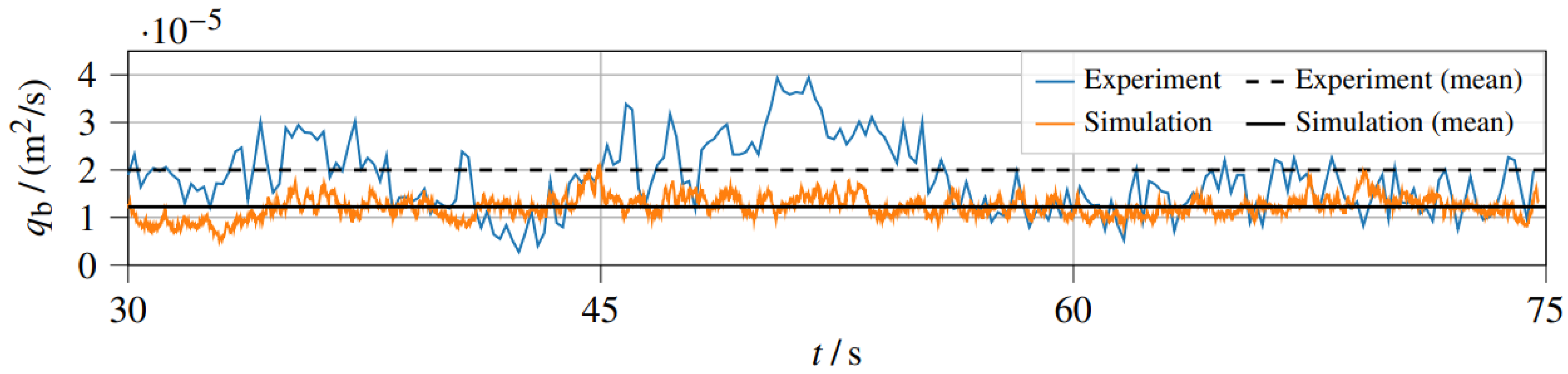


Validation of the bed elevation and transport rate

Evaluation of the **sediment bed elevation** h_b



Validation of the **bedload transport rate** $q_b(t)$ as measured in E1



→ Successful simulation of upstream migrating antidunes, good agreement with experiments
→ Enables campaigns with high-resolution simulations to study antidune dynamics

1. Bauer, M., Eibl, S., Godenschwager, C., Kohl, N., Kuron, M., Rettinger, C., Schornbaum, F., Schwarzmeier, C., Thönnes, D. Köstler, H. & Rüde, U. (2021). waLBerla: A block-structured high-performance framework for multiphysics simulations. *Computers & Mathematics with Applications*, *81*, 478-501.
2. Rettinger, C., & Rüde, U. (2022). An efficient four-way coupled lattice Boltzmann–discrete element method for fully resolved simulations of particle-laden flows. *Journal of Computational Physics*, *453*, 110942
3. Schwarzmeier, C., Holzer, M., Mitchell, T., Lehmann, M., Häusl, F., & Rüde, U. (2023). Comparison of free-surface and conservative Allen–Cahn phase-field lattice Boltzmann method. *Journal of Computational Physics*, *473*, 111753.
4. Pascal, I., Ancey, C., & Bohorquez, P. (2021). The variability of antidune morphodynamics on steep slopes. *Earth Surface Processes and Landforms*, *46*(9), 1750-1765.

Recent work on **antidunes** published in **JFM-Rapids**
https://doi.org/10.1017/jfm.2023.262
Corresponding simulation **videos** in supplementary materials